

Model Evaluation Tools Version 5.1 (METv5.1)
User's Guide

Developmental Testbed Center
Boulder, Colorado

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Foreword: A note to MET users

This user's guide is provided as an aid to users of the Model Evaluation Tools (MET). MET is a set of verification tools developed by the Developmental Testbed Center (DTC) for use by the numerical weather prediction community - and especially users and developers of the Weather Research and Forecasting (WRF) model - to help them assess and evaluate the performance of numerical weather predictions.

It is important to note here that MET is an evolving software package. Previous releases of MET have occurred each year since 2008. This documentation describes the 5.1 release from 2015. Intermediate releases may include bug fixes. MET is also be able to accept new modules contributed by the community. If you have code you would like to contribute, we will gladly consider your contribution. Please send email to: met_help@ucar.edu. We will then determine the maturity of new verification method and coordinate the inclusion of the new module in a future version.

This User's Guide was prepared by the developers of the MET, including Tressa Fowler, John Halley Gotway, Randy Bullock, Kathryn Newman, Julie Prestopnik, Lisa Goodrich, Tara Jensen, Barbara Brown, Nancy Rehak, Paul Oldenburg, Anne Holmes, Lacey Holland, David Ahijevych, Eric Gilleland and Bonny Strong.

New for MET v5.1

METv5.1 includes several new tools and enhancements. The six new tools are MODE Time Domain (mtd), `regrid_data_plane`, `shift_data_plane`, `gen_vx_mask`, `gsid2mpr`, and `gsidens2mpr`. Major enhancements for this release include automated regridding of data, generalized definition of thresholds, conditional continuous statistics, and the expanded use of climatology data. Additional details on these changes are listed below.

Major Upgrades:

New tools:

1. The mtd (MODE Time Domain) tool runs on time-series of gridded data fields to define 3-dimensional space-time objects.

2. The `regrid_data_plane` tool regrids one or more gridded data fields to the user-defined output grid.
3. The `shift_data_plane` tool reads a single gridded data field and applies a rigid shift defined by source and destination lat/lon values.
4. The `gen_vx_mask` tool replaces the `gen_poly_mask` and `gen_circle_mask` tools and adds support for track masking and accumulating multiple masks together.
5. The `gsid2mpr` tool reads one or more binary GSI diagnostic files and reformats them into the MPR line type for further analysis by the Stat-Analysis tool.
6. The `gsidens2orank` tool reads an ensemble of binary GSI diagnostic files and reformats them into the ORANK line type for further analysis by the Stat-Analysis tool.

Enhancements to Existing Tools:

- Distribute the latest set of bugfixes, details not listed here.
- ASCII2NC
 - Add support for Western Wind and Solar Integration Study (WWSIS) data.
 - Add support for AOT AERONET observations.
- MADIS2NC
 - Add support for `acarsProfiles` data, as provided to MET by AER.
- TC-Pairs
 - Reduce the minimum number of required input ATCF columns from 18 to 8.
 - Add 16 columns to the TCST output line type for the ADECK and BDECK values for RADP, RRP, MRD, GUSTS, EYE, DIR, SPEED, and DEPTH.
- TC-Stat
 - Add rapid intensification and weakening (RIRW) event category job type.
 - Replace references to `"rapid_inten"` with `"rirw"` to shorten command line and config file options.
 - Redefine config file options `landfall_beg` and `landfall_end` as timestring in HH[MMSS] format rather than an integer number of seconds, but make it backward compatible. Interpret integers as seconds and strings as timestrings.
 - Add support for reading and filtering extra columns of data at the end of the input ASCII files.
- Stat-Analysis
 - When passed a directory, search for `.stat` files. When passed a file name, read it regardless of the extension.
 - Add support for reading and filtering extra columns of data at the end of the input ASCII files.

- Add new ramp job type based on DYDT logic or the swinging door algorithm.
- Add swinging door algorithm to the new vx_time_series library.
- Add -out_stat output to write aggregated actual STAT lines. Including -set_hdr option.
- Add support for ORANK to SSVAR aggregate_stat job type.
- Add -out_cnt_logic and -out_wind_logic job command options to handle conditional continuous verification.
- Add -out_thresh job command option as a shortcut for -out_fcst_thresh and -out_obs_thresh.
- Add -out_wind_thresh job command option as a shortcut for -out_fcst_wind_thresh and -out_obs_wind_thresh.
- Add -column_thresh job command option to be consistent with other tools, but retain -column_min, -column_max, and -column_eq for backward compatibility.
- PCP-Combine
 - Rename -varname command line option to -name to be consistent with other MET tools.
 - Rename -config command line option to -field to be consistent with other MET tools. Silently support -config for backward compatibility.
- Grid-Stat
 - Add SAL1L2 and VAL1L2 output line types.
- Series-Analysis
 - Add SAL1L2 output statistics types.
- Automated regridding
 - Add automated regridding support to the MET statistics tools to regrid to verify on the forecast grid, observation grid, or an independent, user-defined grid.
 - Add regrid dictionary to the config files to define how regridding should be performed.
 - Add vx_regrid library to support automated regridding.
- Generalized thresholding
 - Generalized definition of thresholds across all the MET tools. Use && or || to string together event definition logic.
- Conditional continuous verification
 - Add support for conditional continuous verification to Point-Stat, Grid-Stat, Series-Analysis.
 - Add cnt_thresh and cnt_logic config file options to specify what filtering thresholds should be applied.
- Climatology Data

- Add support for reading climatology data to Point-Stat, Grid-Stat, Ensemble-Stat, and Series-Analysis.
 - Add `climo_mean` dictionary to the config files for these tools to specify the climatology data to be read.
 - Remove the `-climo` command line option from Point-Stat since the new functionality replaces the old.
 - Add anomaly correlation (`ANOM_CORR`) to the CNT line type.
 - Add the climatology value (`CLIMO`) to ORANK line type.
 - Add the climatology-based Brier score (`BRIERCL`) and the Brier Skill Score (`BSS`) to the PSTD line type.
 - Add the Continuous Ranked Probability Skill Score (`CRPSS`) to the RHIST line type.
- ConfigConstants
 - Add `exit_on_warning` option. If true, any warning message results in an error and returning of bad status.
 - Add `output_precision` option to specify the number of non-zero decimal places to be written to ASCII output files.
- File I/O Changes
 - Improved logic when writing large unixtime values to NetCDF files. Write them as strings rather than integers, which caused integer overflow.
 - Better handling of timing information and lat/lon dimensions from CF-compliant NetCDF files.
 - When writing gridded NetCDF output, write lat/lon variables for lat/lon grids as 1-dimensional. For all other projection types, continue writing 2-dimensional lat/lon variables.
 - Add `obtype` configuration entry to Grid-Stat, Ensemble-Stat, Wavelet-Stat, MODE, and Series-Analysis. It's string value is written to the output files.
 - Add `Rscript` to scripts directory named `gpspairs2mpr.R` to read Grid-Stat NetCDF matches pairs and write MPR output lines.
 - Update the `vx_data2d_pinterp` library to also read the output of the `wrf_interp` utility.
- Summary of changes to existing line types
 - CNT: Add columns for anomaly correlation (`ANOM_CORR`), mean error squared (`ME2`), and the mean squared error skill score (`MSESS`) plus confidence limits.
 - PSTD: Add columns for climatological brier score (`BRIERCL`) and brier skill score (`BSS`).
 - ORANK: Add columns for ensemble mean (`ENS_MEAN`) and climatology (`CLIMO`) columns.
 - RHIST: Add column continuous ranked probability skill score (`CRPSS`).
 - TCMPR: Add 16 columns for the ADECK and BDECK values for RADP, RRP, MRD, GUSTS, EYE, DIR, SPEED, and DEPTH.

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Chapter 1

Overview of MET

1.1 Purpose and organization of the User's Guide

The goal of this User's Guide is to provide basic information for users of the Model Evaluation Tools (MET) to enable users to apply MET to their datasets and evaluation studies. MET has been specifically designed for application to the Weather Research and Forecasting (WRF) model (see <http://www.wrf-model.org/index.php> for more information about the WRF). However, MET may also be used for the evaluation of forecasts from other models or applications if certain file format definitions (described in this document) are followed.

The MET User's Guide is organized as follows. Chapter 1 provides an overview of MET and its components. Chapter 2 contains basic information about how to get started with MET - including system requirements, required software (and how to obtain it), how to download MET, and information about compilers, libraries, and how to build the code. Chapter 3 - 6 focuses on the data needed to run MET, including formats for forecasts, observations, and output. These chapters also document the reformatting and masking tools available in MET. Chapters 7 - 11 focus on the main statistics modules contained in MET, including the Point-Stat, Grid-Stat, Ensemble-Stat, Wavelet-Stat and GSI Diagnostic Tools. These chapters include an introduction to the statistical verification methodologies utilized by the tools, followed by a section containing practical information, such as how to set up configuration files and the format of the output. Chapters 12 and 13 focus on the analysis modules, Stat-Analysis and Series-Analysis, which aggregate the output statistics from the other tools across multiple cases. Chapters 14 - 16 describe a suite of object-based tools, including MODE, MODE-Analysis, and MODE-TD. Chapters 17 - ?? describe tools focused on tropical cyclones, including MET-TC Overview, TC-Dland, TC-Pairs and TC-Stat. Finally, Chapter 21 includes plotting tools included in the MET release for checking and visualizing data, as well as some additional tools and information for plotting MET results. The appendices provide further useful information, including answers to some typical questions (Appendix A: How do I... ?); and links and information about map projections, grids, and polylines (Appendix B). Appendices C and D provide more information about the verification measures and confidence intervals that are provided by MET. Sample code that can be used to perform analyses on the output of MET and create particular types of plots of verification results is posted on

the MET website (<http://www.dtcenter.org/met/users/>). Note that the MET development group also accepts contributed analysis and plotting scripts which may be posted on the MET website for use by the community. It should be noted there are References plus a List of Tables and Figures between Chapter 21 and Appendices.

The remainder of this chapter includes information about the context for MET development, as well as information on the design principles used in developing MET. In addition, this chapter includes an overview of the MET package and its specific modules.

1.2 The Developmental Testbed Center (DTC)

MET has been developed, and will be maintained and enhanced, by the Developmental Testbed Center (DTC; <http://www.dtcenter.org/>). The main goal of the DTC is to serve as a bridge between operations and research, to facilitate the activities of these two important components of the numerical weather prediction (NWP) community. The DTC provides an environment that is functionally equivalent to the operational environment in which the research community can test model enhancements; the operational community benefits from DTC testing and evaluation of models before new models are implemented operationally. MET serves both the research and operational communities in this way - offering capabilities for researchers to test their own enhancements to models and providing a capability for the DTC to evaluate the strengths and weaknesses of advances in NWP prior to operational implementation.

The MET package will also be available to DTC visitors and to the WRF modeling community for testing and evaluation of new model capabilities, applications in new environments, and so on.

1.3 MET goals and design philosophy

The primary goal of MET development is to provide a state-of-the-art verification package to the NWP community. By "state-of-the-art" we mean that MET will incorporate newly developed and advanced verification methodologies, including new methods for diagnostic and spatial verification and new techniques provided by the verification and modeling communities. MET also utilizes and replicates the capabilities of existing systems for verification of NWP forecasts. For example, the MET package replicates existing National Center for Environmental Prediction (NCEP) operational verification capabilities (e.g., I/O, methods, statistics, data types). MET development will take into account the needs of the NWP community - including operational centers and the research and development community. Some of the MET capabilities include traditional verification approaches for standard surface and upper air variables (e.g., Equitable Threat Score, Mean Squared Error), confidence intervals for verification measures, and spatial forecast verification methods. In the future, MET will include additional state-of-the-art and new methodologies.

The MET package has been designed to be modular and adaptable. For example, individual modules can be applied without running the entire set of tools. New tools can easily be added to the MET package due to this modular design. In addition, the tools can readily be incorporated into a larger "system" that

may include a database as well as more sophisticated input/output and user interfaces. Currently, the MET package is a set of tools that can easily be applied by any user on their own computer platform.

The MET code and documentation is maintained by the DTC in Boulder, Colorado. The MET package is freely available to the modeling, verification, and operational communities, including universities, governments, the private sector, and operational modeling and prediction centers.

1.4 MET components

The major components of the MET package are represented in Figure 1.1. The main stages represented are input, reformatting, plotting, intermediate output, statistical analyses, and output and aggregation/analysis. The MET-TC package functions independently of the other MET modules, as indicated in the Figure. Each of these stages is described further in later chapters. For example, the input and output formats are discussed in Chapter 2 as well as in the chapters associated with each of the statistics modules. MET input files are represented on the far left.

The reformatting stage of MET consists of the Gen-Vx-Mask, PB2NC, ASCII2NC, Pcp-Combine, MADIS2NC, MODIS regrid, WWMCA Regrid, and Ensemble Stat tools. The PB2NC tool is used to create NetCDF files from input PrepBuf files containing point observations. Likewise, the ASCII2NC tool is used to create NetCDF files from input ASCII point observations. Many types of data from the MADIS network can be formatted for use in MET by the MADIS2NC tool. MODIS and WWMCA files are regridded and formatted into NetCDF files by their respective tools. These NetCDF files are then used in the statistical analysis step. The Gen-Vx-Mask and Pcp-Combine are optional. The Gen-Vx-Mask tool will create a bitmapped masking area in one of two ways. The first is from a user specified polygon, i.e. a text file containing a series of latitudes / longitudes. This mask can then be used to efficiently limit verification to the interior of a user specified region. Similarly, the Gen-Vx-Mask tool can create a circular masking region, frequently used with radar observations. The Pcp-Combine tool accumulates precipitation amounts into the time interval selected by the user - if a user would like to verify over a different time interval than is included in their forecast or observational dataset. The Ensemble-Stat tool will combine many forecasts into an ensemble mean or probability forecast. Additionally, if observations are included ensemble rank histogram and probability integral transform information is produced.

Several optional plotting utilities are provided to assist users in checking their output from the data preprocessing step. Plot point obs will create a postscript plot showing the locations of point observations. This can be quite useful for assessing whether the latitude and longitude of observation stations was specified correctly. Plot data plane produces a similar plot for gridded data. For users of the MODE object based verification methods, the plot_mode_field utility will create graphics of the MODE object output. Finally, WWMCA plot produces a plot of the raw WWMCA data file.

The main statistical analysis components of the current version of MET are: Point-Stat, Grid-Stat, Series-Analysis, Ensemble-Stat, MODE, MODE-TD (MTD), and Wavelet-Stat. The Point-Stat tool is used for grid-to-point verification, or verification of a gridded forecast field against a point-based observation (i.e., surface observing stations, ACARS, rawinsondes, and other observation types that could be described as a

MET Overview v5.1

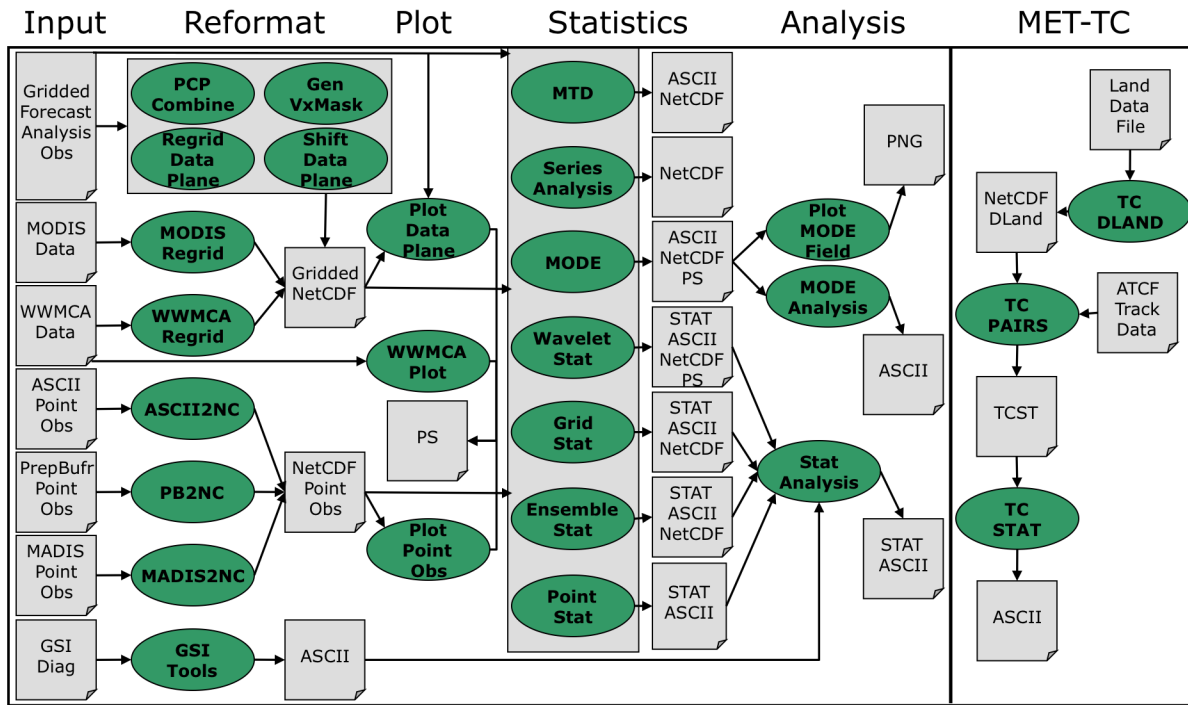


Figure 1.1: Basic representation of current MET structure and modules. Colored areas represent software and modules included in MET, and gray areas represent input and output files.

point observation). In addition to providing traditional forecast verification scores for both continuous and categorical variables, confidence intervals are also produced using parametric and non-parametric methods. Confidence intervals take into account the uncertainty associated with verification statistics due to sampling variability and limitations in sample size. These intervals provide more meaningful information about forecast performance. For example, confidence intervals allow credible comparisons of performance between two models when a limited number of model runs is available.

Sometimes it may be useful to verify a forecast against gridded fields (e.g., Stage IV precipitation analyses). The Grid-Stat tool produces traditional verification statistics when a gridded field is used as the observational dataset. Like the Point-Stat tool, the Grid-Stat tool also produces confidence intervals. The Grid-Stat tool also includes "neighborhood" spatial methods, such as the Fractional Skill Score (Roberts and Lean 2008). These methods are discussed in Ebert (2008). The Grid-Stat tool accumulates statistics over the entire domain.

Users wishing to accumulate statistics over a time, height, or other series separately for each grid location should use the Series-Analysis tool. Series-Analysis can read any gridded matched pair data produced by the other MET tools and accumulate them, keeping each spatial location separate. Maps of these statistics can be useful for diagnosing spatial differences in forecast quality.

The MODE (Method for Object-based Diagnostic Evaluation) tool also uses gridded fields as observational datasets. However, unlike the Grid-Stat tool, which applies traditional forecast verification techniques, MODE applies the object-based spatial verification technique described in Davis et al. (2006a,b) and Brown et al. (2007). This technique was developed in response to the "double penalty" problem in forecast verification. A forecast missed by even a small distance is effectively penalized twice by standard categorical verification scores: once for missing the event and a second time for producing a false alarm of the event elsewhere. As an alternative, MODE defines objects in both the forecast and observation fields. The objects in the forecast and observation fields are then matched and compared to one another. Applying this technique also provides diagnostic verification information that is difficult or even impossible to obtain using traditional verification measures. For example, the MODE tool can provide information about errors in location, size, and intensity.

The MODE-TD tool extends object-based analysis from two-dimensional forecasts and observations to include the time dimension. In addition to the two dimensional information provided by MODE, MODE-TD can be used to examine even more features including displacement in time, and duration and speed of moving areas of interest.

The Wavelet-Stat tool decomposes two-dimensional forecasts and observations according to the Intensity-Scale verification technique described by Casati et al. (2004). There are many types of spatial verification approaches and the Intensity-Scale technique belongs to the scale-decomposition (or scale-separation) verification approaches. The spatial scale components are obtained by applying a wavelet transformation to the forecast and observation fields. The resulting scale-decomposition measures error, bias and skill of the forecast on each spatial scale. Information is provided on the scale dependency of the error and skill, on the no-skill to skill transition scale, and on the ability of the forecast to reproduce the observed scale structure. The Wavelet-Stat tool is primarily used for precipitation fields. However, the tool can be applied to other variables, such as cloud fraction.

Though Ensemble-Stat is a preprocessing tool for creation of ensemble forecasts from a group of files, it also produces several types of ensemble statistics. Thus, it is included as a statistics tool in the flowchart.

Results from the statistical analysis stage are output in ASCII, NetCDF and Postscript formats. The Point-Stat, Grid-Stat, and Wavelet-Stat tools create STAT (statistics) files which are tabular ASCII files ending with a ".stat" suffix. In earlier versions of MET, this output format was called VSDB (Verification System DataBase). VSDB, which was developed by the NCEP, is a specialized ASCII format that can be easily read and used by graphics and analysis software. The STAT output format of the Point-Stat, Grid-Stat, and Wavelet-Stat tools is an extension of the VSDB format developed by NCEP. Additional columns of data and output line types have been added to store statistics not produced by the NCEP version.

The Stat-Analysis and MODE-Analysis tools aggregate the output statistics from the previous steps across multiple cases. The Stat-Analysis tool reads the STAT output of Point-Stat, Grid-Stat, Ensemble-Stat, and Wavelet-Stat and can be used to filter the STAT data and produce aggregated continuous and categorical statistics. The MODE-Analysis tool reads the ASCII output of the MODE tool and can be used to produce summary information about object location, size, and intensity (as well as other object characteristics) across one or more cases.

Tropical cyclone forecasts and observations are quite different than numerical model forecasts, and thus they have their own set of tools. The MET-TC package includes three modules: TC-DLAND, TC-PAIRS, and TC-STAT. The TC-DLAND module calculates the distance to land from all locations on a specified grid. This information can be used in later modules to eliminate tropical cyclones that are over land from being included in the statistics. TC-PAIRS matches up tropical cyclone forecasts and observations and writes all output to a file. In TC-STAT, these forecast / observation pairs are analyzed according to user preference to produce statistics.

1.5 Future development plans

MET is an evolving verification software package. New capabilities are planned in controlled, successive version releases. Bug fixes and user-identified problems will be addressed as they are found and posted to the known issues section of the MET Users web page (www.dtcenter.org/met/users/support). Plans are also in place to incorporate many new capabilities and options in future releases of MET. Some of the planned additions are listed below.

Additional statistical capabilities

- Additional spatial forecast verification methods
- Additional hurricane verification fields and methods
- Enhanced support for time series verification
- Additional methods for verification of climate and seasonal forecasts

Support for other input formats

- Support for NetCDF 4.

Additional analysis capabilities and plotting routines

- Post to the MET website sample analysis and plotting routines that may include
 - Boxplots
 - Discrimination plots
 - Reliability diagrams
 - Scatter/density plots
 - Color-fill/contour maps of statistics
 - Height series
 - Histograms

- Taylor diagrams
- Performance diagrams

Other capabilities

- Database and display system for the statistical output of MET

1.6 Code support

MET support is provided through a MET-help e-mail address: `met_help@ucar.edu`. We will endeavor to respond to requests for help in a timely fashion. In addition, information about MET and tools that can be used with MET are provided on the MET Users web page (<http://www.dtcenter.org/met/users/>).

We welcome comments and suggestions for improvements to MET, especially information regarding errors. Comments may be submitted using the MET Feedback form available on the MET website. In addition, comments on this document would be greatly appreciated. While we cannot promise to incorporate all suggested changes, we will certainly take all suggestions into consideration.

The MET package is a "living" set of tools. Our goal is to continually enhance it and add to its capabilities. Because our time, resources, and talents are limited, we welcome contributed code for future versions of MET. These contributions may represent new verification methodologies, new analysis tools, or new plotting functions. For more information on contributing code to MET, please contact `met_help@ucar.edu`.

Chapter 2

Software Installation/Getting Started

2.1 Introduction

This chapter describes how to install the MET package. MET has been developed and tested on Linux operating systems. Support for additional platforms and compilers may be added in future releases. The MET package requires many external libraries to be available on the user's computer prior to installation. Required and recommended libraries, how to install MET, the MET directory structure, and sample cases are described in the following sections.

2.2 Supported architectures

The MET package was developed on Debian Linux using the GNU compilers and the Portland Group (PGI) compilers. The MET package has also been built on several other Linux distributions using the GNU, PGI, and Intel compilers. Past versions of MET have also been ported to IBM machines using the IBM compilers, but we are currently unable to support this option as the development team lacks access to an IBM machine for testing. Other machines may be added to this list in future releases as they are tested. In particular, the goal is to support those architectures supported by the WRF model itself.

The MET tools run on a single processor. Therefore, none of the utilities necessary for running WRF on multiple processors are necessary for running MET. Individual calls to the MET tools have relatively low computing and memory requirements. However users will likely be making many calls to the tools and passing those individual calls to several processors will accomplish the verification task more efficiently.

2.3 Programming languages

The MET package, including MET-TC, is written primarily in C/C++ in order to be compatible with an extensive verification code base in C/C++ already in existence. In addition, the object-based MODE and

MODE-TD verification tools relies heavily on the object-oriented aspects of C++. Knowledge of C/C++ is not necessary to use the MET package. The MET package has been designed to be highly configurable through the use of ASCII configuration files, enabling a great deal of flexibility without the need for source code modifications.

NCEP's BUFRLIB is written entirely in Fortran. The portion of MET that handles the interface to the BUFRLIB for reading PrepBufr point observation files is also written in Fortran.

The MET package is intended to be a tool for the modeling community to use and adapt. As users make upgrades and improvements to the tools, they are encouraged to offer those upgrades to the broader community by offering feedback to the developers.

2.4 Required compilers and scripting languages

The MET package was developed and tested using the GNU `g++/gfortran` compilers, the Portland Group (PGI) `pgCC/pgf90` compilers, and the Intel `icc/fort` compilers. As additional compilers are successfully tested, they will be added to the list of supported platforms/compilers.

The GNU `make` utility is used in building all executables and is therefore required.

The MET package consists of a group of command line utilities that are compiled separately. The user may choose to run any subset of these utilities to employ the type of verification methods desired. New tools developed and added to the toolkit will be included as command line utilities.

In order to control the desired flow through MET, users are encouraged to run the tools via a script. Some sample scripts are provided in the distribution; these examples are written in the Bourne shell. However, users are free to adapt these sample scripts to any scripting language desired.

2.5 Required libraries and optional utilities

Three external libraries are required for compiling/building MET and should be downloaded and installed before attempting to install MET. Additional external libraries required for building advanced features in MET are discussed in Section 2.6 :

1. NCEP's BUFRLIB is used by MET to decode point-based observation datasets in PrepBufr format. BUFRLIB is distributed and supported by NCEP and is freely available for download from NCEP's website at <http://www.nco.ncep.noaa.gov/sib/decoders/BUFRLIB>. BUFRLIB requires C and Fortran-90 compilers that should be from the same family of compilers used when building MET.
2. Several tools within MET use Unidata's NetCDF libraries for writing output NetCDF files. NetCDF libraries are distributed and supported by Unidata and are freely available for download from Unidata's

website at <http://www.unidata.ucar.edu/software/netcdf>. The same family of compilers used to build NetCDF should be used when building MET. MET is compatible with most NetCDF version 3 releases, but it is not yet compatible with the enhanced data model provide in NetCDF version 4.

3. The GNU Scientific Library (GSL) is used by MET when computing confidence intervals. GSL is distributed and supported by the GNU Software Foundation and is freely available for download from the GNU website at <http://www.gnu.org/software/gsl>.
4. The Zlib is used by MET for compression when writing postscript image files from tools (e.g. MODE, Wavelet-Stat, Plot-Data-Plane, and Plot-Point-Obs). Zlib is distributed and supported Zlib.org and is freely available for download from the Zlib website at <http://www.zlib.net>.

Two additional utilities are strongly recommended for use with MET:

1. The Unified Post-Processor is recommended for post-processing the raw WRF model output prior to verifying the model forecasts with MET. The Unified Post-Processor is freely available for download from the "downloads" section of the WRF-NMM user's website at <http://www.dtcenter.org/wrf-nmm/users>. MET can read data on a standard, de-staggered grid and on pressure or regular levels in the vertical. The Unified Post-Processor outputs model data in this format from both WRF cores, the NMM and the ARW. However, the Unified Post-Processor is not strictly required as long as the user can produce gridded model output on a standard de-staggered grid on pressure or regular levels in the vertical. Two-dimensional fields (e.g., precipitation amount) are also accepted for some modules.
2. The copygb utility is recommended for re-gridding model and observation datasets in GRIB version 1 format to a common verification grid. The copygb utility is distributed as part of the Unified Post-Processor and is available from other sources as well. While earlier versions of MET required that all gridded data be placed on a common grid, MET version 5.1 added support for automated re-gridding on the fly. After version 5.1, users have the option of running copygb to regrid their GRIB1 data ahead of time or leveraging the automated regridding capability within MET.

2.6 Installation of required libraries

As described in Section 2.5, some external libraries are required for building the MET:

1. NCEP's BUFRLIB is used by the MET to decode point-based observation datasets in PrepBuf format. Once you have downloaded and unpacked the BUFRLIB tarball, refer to the README_BUFRLIB file. When compiling the library using the GNU C and Fortran compilers, users are strongly encouraged to use the `-DUNDERSCORE` and `-fno-second-underscore` options. Also, MET expects the BUFRLIB archive file to be named "libbuf.a". Therefore, compiling the BUFRLIB using the GNU compilers consists of the following 3 steps:

```
* gcc -c -DUNDERSCORE *.c
* gfortran -c -DUNDERSCORE -fno-second-underscore *.f *.F
* ar crv libbuf.a *.o
```

Compiling the BUFRLIB using the PGI C and Fortran-90 compilers consists of the following 3 steps:

```
* pgcc -c -DUNDERSCORE *.c
* pgf90 -c -DUNDERSCORE -Mnosecond_underscore *.f *.F
* ar crv libbufr.a *.o
```

Compiling the BUFRLIB using the Intel icc and ifort compilers consists of the following 3 steps:

```
* icc -c -DUNDERSCORE *.c
* ifort -c DUNDERSCORE *.f *.F
* ar crv libbufr.a *.o
```

2. Unidata's NetCDF libraries are used by several tools within MET for writing output NetCDF files. The same family of compilers used to build NetCDF should be used when building MET. Users may also find some utilities built for NetCDF such as `ncdump` and `ncview` useful for viewing the contents of NetCDF files. Detailed installation instructions are available from Unidata at <http://www.unidata.ucar.edu/software/netcdf/docs/netcdf-install/>
3. The GNU Scientific Library (GSL) is used by MET for random sampling and normal and binomial distribution computations when estimating confidence intervals. Precompiled binary packages are available for most GNU/Linux distributions and may be installed with root access. When installing GSL from a precompiled package on Debian Linux, the developer's version of GSL must be used; otherwise, use the GSL version available from the GNU website (<http://www.gnu.org/software/gsl/>). MET requires access to the GSL source headers and library archive file at build time.
4. For users wishing to compile MET with GRIB2 file support, NCEP's GRIB2 Library in C (`g2clib`) must be installed, along with `jasperlib`, `libpng`, and `zlib`. (<http://www.nco.ncep.noaa.gov/pmb/codes/GRIB2>).
5. Users wishing to compile MODIS-regrid will need to install both the HDF4 and HDF-EOS2 libraries available from the HDF group websites (<http://www.hdfgroup.org/products/hdf4>) and (<http://www.hdfgroup.org/hdfeos.html>).
6. The MODE-Graphics utility requires Cairo and FreeType. Thus, users who wish to compile this utility must install both libraries, available from (<http://cairographics.org/releases>) and (<http://www.freetype.org/download.html>). In addition, users will need to download Ghostscript font data required at runtime (<http://sourceforge.net/projects/gs-fonts>).

2.7 Installation of optional utilities

As described in the introduction to this chapter, two additional utilities are strongly recommended for use with MET.

1. The Unified Post-Processor is recommended for post-processing the raw WRF model output prior to verifying the data with MET. The Unified Post-Processor may be used on output from both the ARW

and NMM cores. Please refer to online documentation for instructions on how to install and use the Unified Post-Processor. Installation instructions for the Unified Post-Processor can be found in Chapter 7 of the WRF-NMM User's Guide or online at http://www.dtcenter.org/wrf-nmm/users/docs/user_guide/V3/users_guide_nmm_chap7.pdf.

2. The copygb utility is recommended for re-gridding model and observation datasets in GRIB format to a common verification grid. The copygb utility is distributed as part of the Unified Post-Processor and is available from other sources as well. Please refer to the "Unified Post-processor" utility mentioned above for information on availability and installation.

2.8 MET directory structure

Once you have downloaded the MET tarball and unzipped and unpacked its contents, the top-level MET directory structure follows this outline:

```
met-5.1/  
  
  aclocal.m4  
  config.guess  
  config.h.in  
  config.sub  
  configure  
  configure.ac  
  data/  
  depcomp  
  doc/  
  install-sh  
  internal_tests/  
  Makefile.am  
  Makefile.in  
  Make-include  
  missing  
  out/  
  README  
  run_tests  
  scripts/  
  src/
```

The top-level MET directory consists of a README file, Makefiles, configuration files, and several subdirectories. The top-level Makefile and configuration files control how the entire toolkit is built. Instructions for using these files to build MET can be found in Section 2.9.

When MET has been successfully built and installed, the installation directory contains two subdirectories. The `bin/` directory contains executables for each module of MET as well as several plotting utilities. The `share/met/` directory contains many subdirectories with data required at runtime. The `colortables/`, `map/`, and `ps/` subdirectories contain data used in creating PostScript plots for several MET tools. The `poly/` subdirectory contains predefined lat/lon polyline regions for use in selecting regions over which to verify. The polylines defined correspond to verification regions used by NCEP as described in Appendix B. The `config/` directory contains default configuration files for the MET tools. The `table_files/` and `tc_data/` subdirectories contain GRIB table definitions and tropical cyclone data, respectively.

The `data/` directory contains several configuration and static data files used by MET. The `sample_fcst/` and `sample_obs/` subdirectories contain sample data used by the test scripts provided in the `scripts/` directory.

The `doc/` directory contains documentation for MET, including the MET User's Guide.

The `out/` directory will be populated with sample output from the test cases described in the next section.

The `src/` directory contains the source code for each of the tools in MET.

The `scripts/` directory contains test scripts that are run by `make test` after MET has been successfully built, and a directory of sample configuration files used in those tests located in the `scripts/config/` subdirectory. The output from the test scripts in this directory will be written to the `out/` directory. Users are encouraged to copy sample configuration files to another location and modify them for their own use.

The `scripts/Rscripts` directory contains a handful of sample R scripts, include **plot_tcmpr.R**, which provides graphic utilities for MET-TC. For more information on the graphics capabilities, see Section 21.2.3 of this User's Guide.

2.9 Building the MET package

Building the MET package consists of three main steps: (1) install the required libraries, (2) configure the environment variables, and (3) configure and execute the build.

Install the required libraries.

- Please refer to Section 2.6 and 2.7 on how to install the required and optional libraries.

Set Environment Variables

The MET build uses environment variables to specify the locations of the needed external libraries. For each library, there is a set of three environment variables to describe the locations: `$MET_<lib>`, `$MET_<lib>INC` and `$MET_<lib>LIB`.

The `$MET_<lib>` environment variable can be used if the external library is installed such that there is a main directory which has a subdirectory called "lib" containing the library files and another subdirectory

called "include" containing the include files. For example, if the NetCDF library files are installed in `/opt/netcdf/lib` and the include files are in `/opt/netcdf/include`, you can just define the `$MET_NETCDF` environment variable to be `"/opt/netcdf"`.

The `$MET_<lib>INC` and `$MET_<lib>LIB` environment variables are used if the library and include files for an external library are installed in separate locations. In this case, both environment variables must be specified and the associated `$MET_<lib>` variable will be ignored. For example, if the NetCDF include files are installed in `/opt/include/netcdf` and the library files are in `/opt/lib/netcdf`, then you would set `$MET_NETCDFINC` to `"/opt/include/netcdf"` and `$MET_NETCDFLIB` to `"/opt/lib/netcdf"`.

The following environment variables should also be set:

- Set `$MET_NETCDF` to point to the main NetCDF directory, or set `$MET_NETCDFINC` to point to the directory with the NetCDF include files and set `$MET_NETCDFLIB` to point to the directory with the NetCDF library files.
- Set `$MET_BUFR` to point to the main BUFR directory, or set `$MET_BUFRLIB` to point to the directory with the BUFR library files. Because we don't use any BUFR library include files, you don't need to specify `$MET_BUFRINC`.
- Set `$MET_GSL` to point to the main GSL directory, or set `$MET_GSLINC` to point to the directory with the GSL include files and set `$MET_GSLLIB` to point to the directory with the GSL library files.
- If compiling support for GRIB2, set `$MET_GRIB2CINC` and `$MET_GRIB2CLIB` to point to the main GRIB2C directory which contains both the include and library files. These are used instead of `$MET_GRIB2C` since the main GRIB2C directory does not contain include and lib subdirectories.
- If compiling MODIS-Regrid, set `$MET_HDF` to point to the main HDF directory, or set `$MET_HDFINC` to point to the directory with the HDF include files and set `$MET_HDFLIB` to point to the directory with the HDF library files. Also, set `$MET_HDFEOS` to point to the main HDF EOS directory, or set `$MET_HDFEOSINC` to point to the directory with the HDF EOS include files and set `$MET_HDFEOSLIB` to point to the directory with the HDF EOS library files.
- If compiling MODE Graphics, set `$MET_CAIRO` to point to the main Cairo directory, or set `$MET_CAIROINC` to point to the directory with the Cairo include files and set `$MET_CAIROLIB` to point to the directory with the Cairo library files. Also, set `$MET_FREETYPE` to point to the main FreeType directory, or set `$MET_FREETYPEINC` to point to the directory with the FreeType include files and set `$MET_FREETYPELIB` to point to the directory with the FreeType library files.
- When running MODE Graphics, set `$MET_FONT_DIR` to the directory containing font data required at runtime. A link to the tarball containing this font data can be found on the MET website.

For ease of use, you should define these in your `.cshrc` or equivalent file.

Configure and execute the build

Example: To configure MET to install all of the available tools in the "bin" subdirectory of your current directory, you would use the following commands:

1. `./configure --prefix='pwd' --enable-grib2 --enable-modis --enable-mode_graphics`
2. Type `'make install >& make_install.log &'`
3. Type `'tail -f make_install.log'` to view the execution of the make.
4. When make is finished, type `'CNTRL-C'` to quit the tail.

If all tools are enabled and the build is successful, the "`<prefix>/bin`" directory (where `<prefix>` is the prefix you specified on your configure command line) will contain 27 executables:

- `ascii2nc`
- `ensemble_stat`
- `gen_vx_mask`
- `grid_stat`
- `gsid2mpr`
- `gsidens2orank`
- `madis2nc`
- `mode`
- `mode_analysis`
- `modis_regrid`
- `mtd`
- `pb2nc`
- `pcp_combine`
- `plot_data_plane`
- `plot_mode_field`
- `plot_point_obs`
- `point_stat`
- `regrid_data_plane`
- `series_analysis`
- `shift_data_plane`
- `stat_analysis`
- `tc_dland`
- `tc_pairs`
- `tc_stat`
- `wavelet_stat`
- `wmca_plot`
- `wmca_regrid`

NOTE: Several compilation warnings may occur which are expected. If any errors occur, please refer to the appendix on troubleshooting for common problems.

The configure script has command line options to specify where to install MET and which MET utilities to install. Include any of the following options that apply to your system:

-prefix=PREFIX

By default, MET will install all the files in `"/usr/local/bin"`. You can specify an installation prefix other than `"/usr/local"` using `"-prefix"`, for instance `"-prefix=$HOME"` or `"-prefix='pwd'"`.

-enable-grib2

Enable compilation of utilities using GRIB2

-disable-block4

Disable use of BLOCK4 in the compilation. Use this if you have trouble using PrepBuf files.

-disable-ascii2nc

Disable compilation of `ascii2nc`

-disable-ensemble_stat

Disable compilation of `ensemble_stat`

-disable-gen_vx_mask

Disable compilation of `gen_vx_mask`

-disable-grid_stat

Disable compilation of `grid_stat`

-disable-madis2nc

Disable compilation of `madis2nc`

-disable-mode

Disable compilation of `mode`

-disable-mode_analysis

Disable compilation of `mode_analysis`

-disable-pb2nc

Disable compilation of `pb2nc`

-disable-pcp_combine

Disable compilation of `pcp_combine`

-disable-plot_data_plane

Disable compilation of plot_data_plane

-disable-plot_data_plane

Disable compilation of plot_data_plane

-disable-regrid_data_plane

Disable compilation of regrid_data_plane

-disable-shift_data_plane

Disable compilation of shift_data_plane

-disable-plot_point_obs

Disable compilation of plot_point_obs

-disable-point_stat

Disable compilation of point_stat

-disable-stat_analysis

Disable compilation of stat_analysis

-disable-wavelet_stat

Disable compilation of wavelet_stat

-disable-series_analysis

Disable compilation of series_analysis

-disable-wwmca

Disable compilation of wwmca

-enable-modis

Enable compilation of modis

-enable-mode_graphics

Enable compilation of mode_graphics

-disable-mode_time_domain

Disable compilation of mode_time_domain

-disable-tc_utils

Disable compilation of tc_utils

-disable-gsi_tools

Disable compilation of gsi_tools

Make Targets

The autoconf utility provides some standard make targets for the users. In MET, the following standard targets have been implemented and tested:

1. **all** - compile all of the components in the package, but don't install them.
2. **install** - install the components (where is described below). Will also compile if "make all" hasn't been done yet.
3. **clean** - remove all of the temporary files created during the compilation.
4. **uninstall** - remove the installed files. For us, these are the executables and the files in \$MET_BASE.

MET also has the following non-standard targets:

5. **test** - runs the scripts/test_all.sh script. You must run "make install" before using this target.

2.10 Sample test cases

Once the MET package has been built successfully, the user is encouraged to run the sample test scripts provided. They are run using make test in the top-level directory. Execute the following commands:

1. Type 'make test >& make_test.log &' to run all of the test scripts in the directory. These test scripts use test data supplied with the tarball. For instructions on running your own data, please refer to the MET User's Guide.
2. Type 'tail -f make_test.log' to view the execution of the test script.
3. When the test script is finished, type 'CNTRL-C' to quit the tail. Look in "out" to find the output files for these tests. Each tool has a separate, appropriately named subdirectory for its output files.
4. In particular, check that the PB2NC tool ran without error. If there was an error, run "make clean" then rerun your configure command adding "-disable-block4" to your configure command line and rebuild MET.

Chapter 3

MET Data I/O

Data must be preprocessed prior to using for verification. Several MET tools exist for this purpose. In addition to preprocessing observations, some plotting utilities for data checking are also provided and described at the end of this chapter. Both the input and output file formats are described in this chapter. Sections 3.1 and 3.2 are primarily concerned with re-formatting input files into the intermediate files required by some MET modules. These steps are represented by the first three columns in the MET flowchart depicted in Figure 1.1. Output data formats are described in later Section 3.3. Common configuration files options are described in Section 3.5. Description of software modules used to reformat the data may now be found in Chapters 4 and 5.

3.1 Input data formats

The MET package can handle gridded input data in one of three formats: GRIB version 1, GRIB version 2, or netCDF classic format. Point observation files may be supplied in either PrepBufr, ASCII, or MADIS format. Note that MET does not require the Unified Post-Processor to be used, but does require that the input GRIB data be on a standard, de-staggered grid on pressure or regular levels in the vertical. While the Grid-Stat, Wavelet-Stat, and MODE tools can be run on a gridded field at virtually any level, the Point-Stat tool can only be used to verify forecasts at the surface or on pressure levels.

When comparing two gridded fields with the Grid-Stat, Wavelet-Stat, Ensemble-Stat, MODE, or MODE-TD tools, the input model and observation datasets must be on the same grid. MET will regrid files according to user specified options. Alternately, outside of MET, the copygb utility is recommended for re-gridding GRIB files. To preserve characteristics of the observations, it is generally preferred to re-grid the model data to the observation grid, rather than vice versa.

Input point observation files in PrepBufr format are available through NCEP. The PrepBufr observation files contain a wide variety of point-based observation types in a single file in a standard format. However, some users may wish to use observations not included in the standard PrepBufr files. For this reason, prior

to performing the verification step in the Point-Stat tool, the PrepBuf file is reformatted with the PB2NC tool. In this step, the user can select various ways of stratifying the observation data spatially, temporally, and by type. The remaining observations are reformatted into an intermediate NetCDF file. The ASCII2NC tool may be used to convert ASCII point observations that are not available in the PrepBuf files into this NetCDF format for use by the Point-Stat verification tool. Users with METAR or RAOB data from MADIS can convert these observations into NetCDF format with the MADIS2NC tool, then use them with the Point-Stat verification tool.

Tropical cyclone forecasts and observations are typically provided in a specific ASCII format, in A Deck and B Deck files.

3.2 Intermediate data formats

MET uses NetCDF as an intermediate file format. The Ensemble-Stat, WWMCA-Tool, Pcp-Combine, Gen-Vx-Mask, PB2NC, MADIS2NC, and ASCII2NC tools write intermediate files in NetCDF format.

The Pcp-Combine tool operates in three different modes. It may be used to sum accumulated precipitation from several GRIB files into a single NetCDF file containing the desired accumulation period. It may also be used to add or subtract the accumulated precipitation in two gridded data files directly. The command line arguments for the Pcp-Combine tool vary depending on the mode in which it is run.

The user may choose to: (1) combine the model accumulations to match the observation accumulation period, (2) combine the observation accumulations to match the model accumulation period, or (3) combine both the model and observation accumulations to some new period desired for verification. In performing this summation, the user may not specify an accumulation interval smaller than the accumulation period in the input files. However, if the input model and observation files already contain accumulated precipitation with the same desired accumulation period, then **pcp_combine** need not be run. Each time the Pcp-Combine tool is called, a NetCDF file is written containing the requested accumulation period.

The **Gen-Vx-Mask** tool is used to define a bitmapped masking region that can be used by the statistics tools as a verification subdomain. It is generally more efficient to use the NetCDF output of this tool to define a masking region than using a complex polyline directly in the other MET tools. However, the NetCDF output can only be applied to datasets on a common domain. It must be regenerated for each domain used.

The **PB2NC** tool is used to reformat the input PrepBuf files containing point observations. This tool stratifies the observations as requested in a configuration file and writes out the remaining observations in a NetCDF format. The NetCDF output of the PB2NC tool is used as input to the verification step performed in the Point-Stat tool.

The **ASCII2NC** tool simply reformats ASCII point observations into the NetCDF format needed by the Point-Stat tool. The output NetCDF file from the ASCII2NC tool has a format that is identical to the format of the output from the PB2NC tool.

3.3 Output data formats

The MET package currently produces output in the following basic file formats: STAT files, ASCII files, NetCDF files, PostScript plots, and png plots from the Plot-Mode-Field utility.

The STAT format consists of tabular ASCII data that can be easily read by many analysis tools and software packages. MET produces STAT output for the **Grid-Stat**, **Point-Stat**, **Ensemble-Stat** and **Wavelet-Stat** tools. STAT is a specialized ASCII format containing one record on each line. However, a single STAT file may contain multiple line types. Several header columns at the beginning of each line remain the same for each line type. However, the remaining columns after the header change for each line type. STAT files can be difficult for a human to read as the quantities represented for many columns of data change from line to line.

For this reason, ASCII output is also available as an alternative for the Grid-Stat, Point-Stat, and Wavelet-Stat tools. The ASCII files contain exactly the same output as the STAT files but each STAT line type is grouped into a single ASCII file with a column header row making the output more human-readable. The configuration files control which line types are output and whether or not the optional ASCII files are generated.

The **MODE** tool creates two ASCII output files as well (although they are not in a STAT format). It generates an ASCII file containing contingency table counts and statistics comparing the model and observation fields being compared. The MODE tool also generates a second ASCII file containing all of the attributes for the single objects and pairs of objects. Each line in this file contains the same number of columns, and those columns not applicable to a given line type contain fill data.

The **TC-Pairs** and **TC-Stat** modules produce ASCII output, similar in style to the STAT files, but with TC relevant fields.

Many of the tools generate gridded NetCDF output. Generally, this output acts as input to other MET tools or plotting programs. The point observation preprocessing tools produce NetCDF output as input to the statistics tools. Full details of the contents of the NetCDF files is found in the Section below. 3.4

The MODE, Wavelet-Stat and plotting tools produce PostScript plots summarizing the spatial approach used in the verification. The PostScript plots are generated using internal libraries and do not depend on an external plotting package. The MODE plots contain several summary pages at the beginning, but the total number of pages will depend on the merging options chosen. Additional pages will be created if merging is performed using the double thresholding or fuzzy engine merging techniques for the forecast and observation fields. The number of pages in the Wavelet-Stat plots depend on the number of masking tiles used and the dimension of those tiles. The first summary page is followed by plots for the wavelet decomposition of the forecast and observation fields. The generation of these PostScript output files can be disabled using command line options.

Users can use the optional plotting utilities Plot-Data-Plane, Plot-Point-Obs, and Plot-Mode-Field to produce graphics showing forecast, observation, and MODE object files.

3.4 Data format summary

The following is a summary of the input and output formats for each of the tools currently in MET. The output listed is the maximum number of possible output files. Generally, the type of output files generated can be controlled by the configuration files and/or the command line options:

1. PB2NC Tool

- * **Input:** One PrepBufr point observation file and one configuration file.
- * **Output:** One NetCDF file containing the observations that have been retained.

2. ASCII2NC Tool

- * **Input:** One or more ASCII point observation file(s) that has (have) been formatted as expected, and optional configuration file.
- * **Output:** One NetCDF file containing the reformatted observations.

3. MADIS2NC Tool

- * **Input:** One MADIS point observation file.
- * **Output:** One NetCDF file containing the reformatted observations.

4. Pcp-Combine Tool

- * **Input:** Two or more gridded model or observation files (in GRIB format for “sum” command, or any gridded file for “add” or “subtract” commands) containing accumulated precipitation to be combined to create a new accumulation interval.
- * **Output:** One NetCDF file containing the summed accumulation interval.

5. Regrid-Data-Plane Tool

- * **Input:** One gridded model or observation field and one gridded field to provide grid specification if desired.
- * **Output:** One NetCDF file containing the regridded data field.

6. Shift-Data-Plane Tool

- * **Input:** One gridded model or observation field.
- * **Output:** One NetCDF file containing the shifted data field.

7. MODIS-Regrid Tool

- * **Input:** One gridded model or observation field and one gridded field to provide grid specification.
- * **Output:** One NetCDF file containing the regridded data field.

8. Gen-VX-Mask Tool

- * **Input:** One gridded model or observation file and one ASCII file defining a Lat/Lon masking polyline.
- * **Output:** One NetCDF file containing a bit map for the masking region defined by the polyline over the domain of the gridded input file.

9. Point-Stat Tool

- * **Input:** One gridded model file, at least one point observation file in NetCDF format (as the output of the PB2NC, MADIS2NC, or ASCII2NC tool), and one configuration file.
- * **Output:** One STAT file containing all of the requested line types, and several ASCII files for each line type requested.

10. Grid-Stat Tool

- * **Input:** One gridded model file and one gridded observation file, and one configuration file.
- * **Output:** One STAT file containing all of the requested line types, several ASCII files for each line type requested, and one NetCDF file containing the matched pair data and difference field for each verification region and variable type/level being verified.

11. Ensemble Stat Tool

- * **Input:** An arbitrary number of gridded model files and one or more optional files containing observations. Point and gridded observations are both accepted.
- * **Output:** One NetCDF file containing requested ensemble forecast information. If observations are provided, one STAT file containing all requested line types, and several ASCII files for each line type requested.

12. Wavelet-Stat Tool

- * **Input:** One gridded model file, one gridded observation file and one configuration file.
- * **Output:** One STAT file containing the “ISC” line type, one ASCII file containing intensity-scale information and statistics, one NetCDF file containing information about the wavelet decomposition of forecast and observed fields and their differences, and one PostScript file containing plots and summaries of the intensity-scale verification.

13. GSID2MPR Tool

- * **Input:** One or more binary GSI diagnostic files (conventional or radiance) to be reformatted.
- * **Output:** One ASCII file in matched pair format.

14. GSID2ORANK Tool

- * **Input:** One or more binary GSI diagnostic files (conventional or radiance) to be reformatted.
- * **Output:** One ASCII file in orank format.

15. Stat-Analysis Tool

- * **Input:** One or more STAT files output from the Point-Stat, Grid-Stat, or Ensemble Stat, or Wavelet-Stat tools and, optionally, one configuration file containing specifications for the analysis job(s) to be run on the STAT data.
- * **Output:** ASCII output of the analysis jobs will be printed to the screen unless redirected to a file using the “-out” option.

16. Series Analysis Tool

- * **Input:** An arbitrary number of gridded model files and gridded observation files and one or more optional files containing observations.
- * **Output:** One NetCDF file containing requested output statistics on the same grid as the input files.

17. MODE Tool

- * **Input:** One gridded model file and one gridded observation file and one or two configuration files.
- * **Output:** One ASCII file containing contingency table counts and statistics, one ASCII file containing single and pair object attribute values, one NetCDF file containing object indices for the gridded simple and cluster object fields, and one PostScript plot containing a summary of the features-based verification performed.

18. MODE-Analysis Tool

- * **Input:** One or more MODE object statistics files from the MODE tool and, optionally, one configuration file containing specification for the analysis job(s) to be run on the object data.
- * **Output:** ASCII output of the analysis jobs will be printed to the screen unless redirected to a file using the “-out” option.

19. MODE-TD Tool

- * **Input:** Two or more gridded model file and two or more gridded observation file and one or two configuration files.
- * **Output:** Three ASCII files containing 2D single object and 3D single and pair object attribute values and one NetCDF file containing object indices for the gridded simple and cluster object fields.

20. TC-Dland Tool

- * **Input:** One file containing the longitude (degrees W negative) and latitude (degrees N positive) of all the coastlines and islands considered to be a significant landmass.
- * **Output:** One NetCDF format file containing a gridded field representing the distance to the nearest coastline or island, as specified in the input file

21. TC-Pair Tool

- * **Input:** Two ATCF format files containing output from a tropical cyclone tracker and one configuration file. One file would be for the forecast, or “A”-deck. The other is expected to be the NHC Best Track Analysis, but could also be any ATCF format reference.

- * **Output:** ASCII output with the suffix `.tcstat`

22. TC-Stat Tool

- * **Input:** One or more TCSTAT files output from the Point-Stat, Grid-Stat, or Ensemble Stat, or Wavelet-Stat tools and, optionally, one configuration file containing specifications for the analysis job(s) to be run on the TCSTAT data.
- * **Output:** ASCII output of the analysis jobs will be printed to the screen unless redirected to a file using the “-out” option.

23. Plot-Point-Obs Tool

- * **Input:** One NetCDF file with point observations in it. Most likely the output from `ascii2nc`, `pb2nc`, `madis2nc`.
- * **Output:** One postscript file containing a plot of the requested field.

24. Plot-Data-Plane Tool

- * **Input:** One gridded data file to be plotted.
- * **Output:** One postscript file containing a plot of the requested field.

25. Plot-MODE-Field Tool

- * **Input:** One or more MODE output files to be used for plotting and one configuration file.
- * **Output:** One NetCDF file with the requested MODE objects plotted. Options for objects include `raw`, `simple` or `cluster` and `forecast` or `observed` objects.

3.5 Configuration File Details

Part of the strength of MET is the leveraging of capability across tools. There are several config options that are common to many of the tools. They are described in this section.

Many of the MET tools use a configuration file to set parameters. This prevents the command line from becoming too long and cumbersome and makes the output easier to duplicate.

Settings common to multiple tools are described in the following sections while those specific to individual tools are explained in the chapters for those tools. In addition, these configuration settings are described in the `share/met/config/README` file and the `share/met/config/README-TC` file for the MET-Tropical Cyclone tools.

3.5.1 General MET Config Options - Common to many tools

This information may also be found, along with detailed information regarding configuration of individual tools, in the data/config/README file.

```

////////////////////////////////////
//
// Configuration file overview.
//
////////////////////////////////////

```

The configuration files that control many of the MET tools contain formatted ASCII text. This format has been updated for METv4.0 and continues to be used in subsequent releases.

Settings common to multiple tools are described in the top part of this README file and settings specific to individual tools are described beneath the common settings. Please refer to the MET User's Guide in the "doc" directory for more details about the settings if necessary.

A configuration file entry is an entry name, followed by an equal sign (=), followed by an entry value, and is terminated by a semicolon (;). The configuration file itself is one large dictionary consisting of entries, some of which are dictionaries themselves.

The configuration file language supports the following data types:

- Dictionary:
 - Grouping of one or more entries enclosed by curly braces {}.
- Array:
 - List of one or more entries enclosed by square braces [].
 - Array elements are separated by commas.
- String:
 - A character string enclosed by double quotation marks "".
- Integer:
 - A numeric integer value.
- Float:
 - A numeric float value.
- Boolean:
 - A boolean value (TRUE or FALSE).
- Threshold:
 - A threshold type (<, <=, ==, !-, >=, or >) followed by a numeric value.
 - The threshold type may also be specified using two letter abbreviations (lt, le, eq, ne, ge, gt).

- Multiple thresholds may be combined by specifying the logic type of AND (&&) or OR (||). For example, ">=5&&<=10" defines the numbers between 5 and 10 and "==1||==2" defines numbers exactly equal to 1 or 2.
- Piecewise-Linear Function (currently used only by MODE):
 - A list of (x, y) points enclosed in parenthesis ().
 - The (x, y) points are *NOT* separated by commas.

The context of a configuration entry matters. If an entry cannot be found in the expected dictionary, the MET tools recursively search for that entry in the parent dictionaries, all the way up to the top-level configuration file dictionary. If you'd like to apply the same setting across all cases, you can simply specify it once at the top-level. Alternatively, you can specify a setting at the appropriate dictionary level to have finer control over the behavior.

In order to make the configuration files more readable, several descriptive integer types have been defined in the ConfigConstants file. These integer names may be used on the right-hand side for many configuration file entries.

Each of the configurable MET tools expects a certain set of configuration entries. Examples of the MET configuration files can be found in data/config and scripts/config.

When you pass a configuration file to a MET tool, the tool actually parses up to four different configuration files in the following order:

- (1) Reads share/met/config/ConfigConstants to define constants.
- (2) If the tool produces PostScript output, it reads share/met/config/ConfigMapData to define the map data to be plotted.
- (3) Reads the default configuration file for the tool from share/met/config.
- (4) Reads the user-specified configuration file from the command line.

Many of the entries from step (3) are overwritten by the user-specified entries from step (4). Therefore, the configuration file you pass in on the command line really only needs to contain entries that differ from the defaults.

Any of the configuration entries may be overwritten by the user-specified configuration file. For example, the map data to be plotted may be included in the user-specified configuration file and override the default settings defined in the share/met/config/ConfigMapData file.

The configuration file language supports the use of environment variables. They are specified as `${ENV_VAR}`, where ENV_VAR is the name of the environment variable. When scripting up many calls to the MET tools, you may find it

convenient to use them. For example, when applying the same configuration to the output from multiple models, consider defining the model name as an environment variable which the controlling script sets prior to verifying the output of each model. Setting MODEL to that environment variable enables you to use one configuration file rather than maintaining many very similar ones.

The MET_BASE variable is defined in the code at compilation time as the path to the MET shared data. These are things like the default configuration files, common polygons and color scales. MET_BASE may be used in the MET configuration files when specifying paths and the appropriate path will be substituted in. If MET_BASE is defined as an environment variable, its value will be used instead of the one defined at compilation time.

An error in the syntax of a configuration file will result in an error from the MET tool stating the location of the parsing error.

```

////////////////////////////////////
//
// Configuration settings used by the MET tools.
//
////////////////////////////////////

////////////////////////////////////
//
// Settings common to multiple tools
//
////////////////////////////////////

//
// The "exit_on_warning" entry in ConfigConstants may be set to true or false.
// If set to true and a MET tool encounters a warning, it will immediately exit
// with bad status after writing the warning message.
//
exit_on_warning = FALSE;

//
// The "output_precision" entry in ConfigConstants defines the precision
// (number of significant decimal places) to be written to the ASCII output
// files. Setting this option in the config file of one of the tools will
// override the default value set in ConfigConstants.
//
output_precision = 5;

```

```

//
// The "model" entry specifies a name for the model being verified. This name
// is written to the MODEL column of the ASCII output generated. If you're
// verifying multiple models, you should choose descriptive model names (no
// whitespace) to distinguish between their output.
// e.g. model = "GFS";
//
model = "WRF";

//
// The "obtype" entry specifies a name to describe the type of verifying gridded
// observation used. This name is written to the OBTYP column in the ASCII
// output generated. If you're using multiple types of verifying observations,
// you should choose a descriptive name (no whitespace) to distinguish between
// their output. When verifying against point observations the point
// observation message type value is written to the OBTYP column. Otherwise,
// the configuration file obtype value is written.
//
obtype = "ANALYS";

//
// The "regrid" entry is a dictionary containing information about how to handle
// input gridded data files. The "regrid" entry specifies regridding logic
// using the following entries:
//
// - The "to_grid" entry may be set to NONE, FCST, OBS, a named grid, the path
//   to a gridded data file defining the grid, or an explicit grid specification
//   string.
//   - to_grid = NONE;   To disable regridding.
//   - to_grid = FCST;   To regrid observations to the forecast grid.
//   - to_grid = OBS;    To regrid forecasts to the observation grid.
//   - to_grid = "G218"; To regrid both to a named grid.
//   - to_grid = "path"; To regrid both to a grid defined by a file.
//   - to_grid = "spec"; To define a grid specified as follows:
//     - lambert Nx Ny lat_ll lon_ll lon_orient D_km R_km standard_parallel_1
//       [standard_parallel_2]
//     - stereo Nx Ny lat_ll lon_ll lon_orient D_km R_km lat_scale N|S
//     - latlon Nx Ny lat_ll lon_ll delta_lat delta_lon
//     - mercator Nx Ny lat_ll lon_ll lat_ur lon_ur
//
// - The "vld_thresh" entry specifies a proportion between 0 and 1 to define
//   the required ratio of valid data points. When regridding, compute
//   a ratio of the number of valid data points to the total number of

```

```

//      points in the neighborhood.  If that ratio is less than this threshold,
//      write bad data for the current point.
//
// - The "method" entry defines the regridding method to be used.
//   - Valid regridding methods:
//     MIN, MAX, MEDIAN, UW_MEAN, DW_MEAN, LS_FIT, BILIN, NEAREST, BUDGET
//
// - The "width" entry specifies a regridding width, when applicable.
//   - width = 4;           To regrid using a 4x4 box.
//
regrid = {
  to_grid    = NONE;
  vld_thresh = 0.5;
  method     = NEAREST;
  width      = 1;
}

//
// The "fcst" entry is a dictionary containing information about the field(s)
// to be verified.  This dictionary may include the following entries:
//
// - The "field" entry is an array of dictionaries, each specifying a
//   verification task.  Each of these dictionaries may include:
//
//   - The "name" entry specifies a name for the field.
//
//   - The "level" entry specifies level information for the field.
//
//   - Setting "name" and "level" is file-format specific.  See below.
//
// - The "prob" entry is a boolean defined in the forecast dictionary.
//   When set to TRUE, it indicates that the data should be treated as
//   probabilities.  Probability fields should contain values in the range
//   [0, 1] or [0, 100].  However, when MET encounters a probability field
//   with a range [0, 100], it will automatically rescale it to be [0, 1]
//   before applying the probabilistic verification methods.
//
// - The "cat_thresh" entry is an array of thresholds to be used when
//   computing categorical statistics.
//
// - The "cnt_thresh" entry is an array of thresholds for filtering
//   data prior to computing continuous statistics and partial sums.
//

```



```
// - The "cnt_logic" entry may be set to UNION, INTERSECTION, or SYMDIFF
// and controls the logic for how the forecast and observed cnt_thresh
// settings are combined when filtering matched pairs of forecast and
// observed values.
//
// - The "file_type" entry specifies the input file type rather than letting
// the code determine it itself. For valid file_type values, see "File types"
// in the data/config/ConfigConstants file.
//
// - The "wind_thresh" entry is an array of thresholds used to filter wind
// speed values when computing VL1L2 vector partial sums. Only those U/V
// pairs that meet this wind speed criteria will be included in the sums.
// Setting this threshold to NA will result in all U/V pairs being used.
//
// - The "wind_logic" entry may be set to UNION, INTERSECTION, or SYMDIFF
// and controls the logic for how the forecast and observed wind_thresh
// settings are combined when filtering matched pairs of forecast and
// observed wind speeds.
//
// - The "init_time" entry specifies the initialization time in YYYYMMDD[_HH[MMSS]]
// format. This entry can be included in the "fcst" entry as shown below or
// included in the "field" entry if the user would like to use different
// initialization times for different fields.
//
// - The "valid_time" entry specifies the valid time in YYYYMMDD[_HH[MMSS]]
// format. This entry can be included in the "fcst" entry as shown below or
// included in the "field" entry if the user would like to use different
// valid times for different fields.
//
// - The "lead_time" entry specifies the lead time in HH[MMSS]
// format. This entry can be included in the "fcst" entry as shown below or
// included in the "field" entry if the user would like to use different
// lead times for different fields.
//
// It is only necessary to use the "init_time", "valid_time", and/or "lead_time"
// settings when verifying a file containing data for multiple output times.
// For example, to verify a GRIB file containing data for many lead times, you
// could use "lead_time" to specify the record to be verified.
//
// File-format specific settings for the "field" entry:
//
// - GRIB1 and GRIB2:
//   - The "name" entry specifies a GRIB code number or abbreviation.
```

```

//      http://www.nco.ncep.noaa.gov/pmb/docs/on388/table2.html
//      - The "level" entry specifies a level type and value:
//          - ANNN for accumulation interval NNN
//          - ZNNN for vertical level NNN
//          - ZNNN-NNN for a range of vertical levels
//          - PNNN for pressure level NNN in hPa
//          - PNNN-NNN for a range of pressure levels in hPa
//          - LNNN for a generic level type
//          - RNNN for a specific GRIB record number
//      - The "GRIB_lvl_typ" entry specifies the level type.
//      - The "GRIB_lvl_val1" and "GRIB_lvl_val2" entries specify the first
//        and second level values.
//      - The "GRIB1_ptv" entry specifies the GRIB1 parameter table version
//        number.
//      - The "GRIB1_rec" entry specifies the GRIB1 record number.
//      - The "GRIB2_disc" entry specifies the GRIB2 discipline code.
//      - The "GRIB2_parm_cat" entry specifies the parameter category code.
//      - The "GRIB2_parm" entry specifies the parameter code.
//
//      - NetCDF (from MET tools, CF-compliant, p_interp, and wrf_interp):
//      - The "name" entry specifies the NetCDF variable name.
//      - The "level" entry specifies the dimensions to be used:
//          - (i,...,j,*,*) for a single field, where i,...,j specifies fixed
//            dimension values and *,* specifies the two dimensions for the
//            gridded field.
//      e.g.
//          field = [
//              {
//                  name      = "QVAPOR";
//                  level     = "(0,5,*,*)";
//              },
//              {
//                  name      = "TMP_P850_ENS_MEAN";
//                  level     = [ "(*,*)" ];
//              }
//          ];
//
//
//
fcst = {
    cnt_thresh  = [ NA ];
    cnt_logic   = UNION;
    wind_thresh = [ NA ];

```

```
wind_logic = UNION;
message_type = [ "ADPSFC" ];
init_time = "20120619_12";
valid_time = "20120620_00";
lead_time = "12";

field = [
  {
    name = "APCP";
    level = [ "A03" ];
    cat_thresh = [ >0.0, >=5.0 ];
  }
];
}

//
// The "obs" entry specifies the same type of information as "fcst", but for
// the observation data. It will often be set to the same things as "fcst",
// as shown in the example below. However, when comparing forecast and
// observation files of different format types, this entry will need to be set
// in a non-trivial way. The length of the "obs.field" array must match the
// length of the "fcst.field" array.
// e.g.
//     obs = fcst;
//
// or
//
//     fcst = {
//       cnt_thresh = [ NA ];
//       cnt_logic = UNION;
//       wind_thresh = [ NA ];
//       wind_logic = UNION;
//
//       field = [
//         {
//           name = "PWAT";
//           level = [ "L0" ];
//           cat_thresh = [ >2.5 ];
//         }
//       ];
//     }
//
//
```

```

//      obs = {
//          cnt_thresh = [ NA ];
//          cnt_logic  = UNION;
//          wind_thresh = [ NA ];
//          wind_logic  = UNION;
//
//          field = [
//              {
//                  name      = "IWV";
//                  level     = [ "L0" ];
//                  cat_thresh = [ >25.0 ];
//              }
//          ];
//      }
//
//
// - The "message_type" entry is an array of point observation message types
//   to be used.  This only applies to the tools that verify against point
//   observations.  This may be specified once at the top-level "obs"
//   dictionary or separately for each "field" array element.  In the example
//   shown above, this is specified in the "fcst" dictionary and copied to "obs".
// - The "message_type" would be placed in the "field" array element if more
//   than one "message_type" entry is desired within the config file.
// e.g.
// fcst = {
//     cnt_thresh = [ NA ];
//     cnt_logic  = UNION;
//     wind_thresh = [ NA ];
//     wind_logic  = UNION;
//
//     field = [
//         {
//             message_type = [ "ADPUPA" ];
//             sid_exc      = [ ];
//             name         = "TMP";
//             level        = [ "P250", "P500", "P700", "P850", "P1000" ];
//             cat_thresh   = [ <=273.0 ];
//         },
//         {
//             message_type = [ "ADPSFC" ];
//             sid_exc      = [ "KDEN", "KDET" ];
//             name         = "TMP";
//             level        = [ "Z2" ];

```

```
//          cat_thresh = [ <=273.0 ];
//      }
//  ];
//  }

//  - The "sid_exc" entry is an array of station ID groups indicating which
//    station ID's should be excluded from the verification tasks. Each element
//    is either the name of a single station ID or a station ID group file name.
//    A station ID group file consists of a name for the group followed by a
//    list of station ID's. All of the station ID's indicated will be placed
//    into one long list of station ID's to be excluded.
//  - As with "message_type" above, the "sid_exc" setting can be placed in the
//    in the "field" array element to control which station ID's are excluded
//    for each verification task.
//
obs = fcst;

//
// The "climo_mean" dictionary specifies climatology data to read by the
// Grid-Stat, Point-Stat, and Ensemble-Stat tools. It consists of several
// entires defining the climatology file names and fields to be used.
//
//  - The "file_names" entry specifies one or more file names containing
//    the gridded climatology data to be used.
//
//  - The "field" entry is an array of dictionaries, specified the same
//    way as those in the "fcst" and "obs" dictionaries. If the array has
//    length zero, not climatology data will be read and all climatology
//    statistics will be written as missing data. Otherwise, the array
//    length must match the length of "field" in the "fcst" and "obs"
//    dictionaries.
//
//  - The "regrid" dictionary defines how the climatology data should be
//    regridded to the verification domain.
//
//  - The "time_interp_method" entry specifies how the climatology data should
//    be interpolated in time to the forecast valid time:
//    - NEAREST for data closest in time
//    - UW_MEAN for average of data before and after
//    - DW_MEAN for linear interpolation in time of data before and after
//
//  - The "match_day" entry may be set to TRUE or FALSE. When searching
//    climatology data, only consider times where the month matches the
```

```

// forecast valid month. Set match_day to TRUE or FALSE to define whether
// the climatology day must also match.
// - match_day = FALSE for monthly climatology
// - match_day = TRUE for daily climatology
//
// - The "time_step" entry specifies the spacing of climatology data in
// seconds. Set to 60*60*6 = 21600 for 6-hourly data or 60*60 = 3600
// for hourly data.
//
climo_mean = {

    file_name = [];
    field      = [];

    regrid = {
        vld_thresh = 0.5;
        method      = NEAREST;
        width       = 1;
    }

    time_interp_method = DW_MEAN;
    match_day          = FALSE;
    time_step          = 21600;
}

//
// The "mask_missing_flag" entry specifies how missing data should be handled
// in the Wavelet-Stat and MODE tools:
// - "NONE" to perform no masking of missing data
// - "FCST" to mask the forecast field with missing observation data
// - "OBS" to mask the observation field with missing forecast data
// - "BOTH" to mask both fields with missing data from the other
//
mask_missing_flag = BOTH;

//
// The "obs_window" entry is a dictionary specifying a beginning ("beg"
// entry) and ending ("end" entry) time offset values in seconds. It defines
// the time window over which observations are retained for scoring. These time
// offsets are defined relative to a reference time t, as [t+beg, t+end].
// In PB2NC, the reference time is the PrepBufr files center time. In
// Point-Stat and Ensemble-Stat, the reference time is the forecast valid time.
//

```

```
obs_window = {
    beg = -5400;
    end = 5400;
}

//
// The "mask" entry is a dictionary that specifies the verification masking
// regions to be used when computing statistics. Each mask defines a
// geographic extent, and any matched pairs falling inside that area will be
// used in the computation of statistics. Masking regions may be specified
// in the following ways:
//
// - The "grid" entry is an array of named grids. It contains a
// comma-separated list of pre-defined NCEP grids over which to perform
// verification. An empty list indicates that no masking grids should be
// used. The standard NCEP grids are named "GNNN" where NNN indicates the
// three digit grid number. Supplying a value of "FULL" indicates that the
// verification should be performed over the entire grid on which the data
// resides.
// http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html
//
// - The "poly" entry contains a comma-separated list of files that define
// verification masking regions. These masking regions may be specified in
// two ways: as a lat/lon polygon or using a gridded data file such as the
// NetCDF output of the Gen-Vx-Mask tool.
//
// - An ASCII file containing a lat/lon polygon.
// Latitude in degrees north and longitude in degrees east.
// The first and last polygon points are connected.
// e.g. "MET_BASE/poly/EAST.poly" which consists of n points:
// "poly_name lat1 lon1 lat2 lon2... latn lonn"
//
// Several masking polygons used by NCEP are predefined in the
// installed share/met/poly directory. Creating a new polygon is as
// simple as creating a text file with a name for the polygon followed
// by the lat/lon points which define its boundary. Adding a new masking
// polygon requires no code changes and no recompiling. Internally, the
// lat/lon polygon points are converted into x/y values in the grid. The
// lat/lon values for the observation points are also converted into x/y
// grid coordinates. The computations performed to check whether the
// observation point falls within the polygon defined is done in x/y
// grid space.
//
```

```

//      - The NetCDF output of the gen_vx_mask tool.
//
//      - Any gridded data file that MET can read may be used to define a
//      verification masking region. Users must specify a description of the
//      field to be used from the input file and, optionally, may specify a
//      threshold to be applied to that field. Once this threshold is applied,
//      any grid point where the resulting field is 0, the mask is turned off.
//      Any grid point where it is non-zero, the mask is turned on.
//      e.g. "sample.grib {name = \"TMP\"; level = \"Z2\";} >273"
//
//      - The "sid" entry is an array of strings. Each entry in that array is
//      either the name of a single station id or a filename. If it is a single
//      station id name, that station will be treated as its own masking region.
//      If it is a filename, that file should contain a "name" for the station
//      id group followed by a space-separated list of station id's to be used.
//      That group "name" entry is what MET puts in the VX_MASK output column.
//      This provides a way to define one or more groups of individual stations
//      over which to compute statistics. This is an alternative to defining a
//      masking region using a polyline or grid and is more convenient if you
//      have a specific list of station id's you'd like to use.
//
mask = {
  grid   = [ "FULL" ];
  poly   = [ "MET_BASE/poly/LMV.poly",
             "MET_BASE/out/gen_vx_mask/CONUS_poly.nc",
             "MET_BASE/sample_fcst/2005080700/wrfprs_ruc13_12.tm00_G212 \
             {name = \"TMP\"; level = \"Z2\";} >273"
             ];
  sid    = [ "CONUS.stations" ];
}

//
// The "ci_alpha" entry is an array of floats specifying the values for alpha
// to be used when computing confidence intervals. Values of alpha must be
// between 0 and 1. The confidence interval computed is 1 minus the alpha value.
// Therefore, an alpha value of 0.05 corresponds to a 95% confidence interval.
//
ci_alpha = [ 0.05, 0.10 ];

//
// The "boot" entry defines the parameters to be used in calculation of
// bootstrap confidence intervals. The interval variable indicates what method
// should be used for computing bootstrap confidence intervals:

```



```
//
// - The "interval" entry specifies the confidence interval method:
//   - "BCA" for the BCa (bias-corrected percentile) interval method is
//     highly accurate but computationally intensive.
//   - "PCTILE" uses the percentile method which is somewhat less accurate
//     but more efficient.
//
// - The "rep_prop" entry specifies a proportion between 0 and 1 to define
// the replicate sample size to be used when computing percentile
// intervals. The replicate sample size is set to boot_rep_prop * n,
// where n is the number of raw data points.
//
// When computing bootstrap confidence intervals over n sets of matched
// pairs, the size of the subsample, m, may be chosen less than or equal to
// the size of the sample, n. This variable defines the size of m as a
// proportion relative to the size of n. A value of 1 indicates that the
// size of the subsample, m, should be equal to the size of the sample, n.
//
// - The "n_rep" entry defines the number of subsamples that should be taken
// when computing bootstrap confidence intervals. This variable should be
// set large enough so that when confidence intervals are computed multiple
// times for the same set of data, the intervals do not change much.
// Setting this variable to zero disables the computation of bootstrap
// confidence intervals, which may be necessary to run MET in realtime or
// near-realtime over large domains since bootstrapping is computationally
// expensive. Setting this variable to 1000 indicates that bootstrap
// confidence interval should be computed over 1000 subsamples of the
// matched pairs.
//
// - The "rng" entry defines the random number generator to be used in the
// computation of bootstrap confidence intervals. Subsamples are chosen at
// random from the full set of matched pairs. The randomness is determined
// by the random number generator specified. Users should refer to detailed
// documentation of the GNU Scientific Library for a listing of the random
// number generators available for use.
// http://www.gnu.org/software/gsl/manual/html\_node/Random-Number-Generator-Performance.html
//
// - The "seed" entry may be set to a specific value to make the computation
// of bootstrap confidence intervals fully repeatable. When left empty
// the random number generator seed is chosen automatically which will lead
// to slightly different bootstrap confidence intervals being computed each
// time the data is run. Specifying a value here ensures that the bootstrap
// confidence intervals will be reproducible over multiple runs on the same
```

```
//      computing platform.
//
boot = {
  interval = PCTILE;
  rep_prop = 1.0;
  n_rep    = 0;
  rng      = "mt19937";
  seed     = "";
}

//
// The "interp" entry is a dictionary that specifies what interpolation or
// smoothing (for the Grid-Stat tools) methods should be applied.
// This dictionary may include the following entries:
//
// - The "field" entry specifies to which field(s) the interpolation method
//   should be applied. This does not apply when doing point verification
//   with the Point-Stat or Ensemble-Stat tools:
//   - "FCST" to interpolate/smooth the forecast field.
//   - "OBS" to interpolate/smooth the observation field.
//   - "BOTH" to interpolate/smooth both the forecast and the observation.
//
// - The "vld_thresh" entry specifies a number between 0 and 1. When
//   performing interpolation over some neighborhood of points the ratio of
//   the number of valid data points to the total number of points in the
//   neighborhood is computed. If that ratio is less than this threshold,
//   the matched pair is discarded. Setting this threshold to 1, which is the
//   default, requires that the entire neighborhood must contain valid data.
//   This variable will typically come into play only along the boundaries of
//   the verification region chosen.
//
// - The "type" entry is an array of dictionaries, each specifying an
//   interpolation method. Interpolation is performed over a N by N box
//   centered on each point, where N is the width specified. Each of these
//   dictionaries must include:
//
// - The "width" entry is an integer which specifies the dimension of the
//   interpolation box. The neighborhood is simply a square containing the
//   observation point. The width value specifies the width of that square.
//   A width value of 1 is interpreted as the nearest neighbor model grid
//   point to the observation point. A width of 2 defines a 2 x 2 square of
//   grid points around the observation point (the 4 closest model grid
//   points), while a width of 3 defines a 3 x 3 square of grid points
```

```
//      around the observation point, and so on.  For grid-to-grid comparisons,
//      the width must be odd.
//
//      - The "method" entry specifies the interpolation procedure to be
//      applied to the points in the box:
//      - "MIN" for the minimum value
//      - "MAX" for the maximum value
//      - "MEDIAN" for the median value
//      - "UW_MEAN" for the unweighted average value
//      - "DW_MEAN" for the distance-weighted average value
//      - "LS_FIT" for a least-squares fit
//      - "BILIN" for bilinear interpolation
//      - For grid-to-grid comparisons, only valid options are MIN, MAX,
//      MEDIAN, and UW_MEAN are options.
//
interp = {
  field      = BOTH;
  vld_thresh = 1.0;

  type = [
    {
      method = UW_MEAN;
      width  = 1;
    }
  ];
}

//
// The "nbrhd" entry is a dictionary that is very similar to the "interp"
// entry.  It specifies information for computing neighborhood statistics in
// Grid-Stat.  This dictionary may include the following entries:
//
//      - The "vld_thresh" entry is described above.
//
//      - The "width" entry is as described above, and must be odd.
//
//      - The "cov_thresh" entry is an array of thresholds to be used when
//      computing categorical statistics for the neighborhood fractional
//      coverage field.
//
nbrhd = {
  vld_thresh = 1.0;
  width      = [ 1 ];
```

```

    cov_thresh = [ >=0.5 ];
}

//
// The "output_flag" entry is a dictionary that specifies what verification
// methods should be applied to the input data.  Options exist for each
// output line type from the MET tools.  Each line type may be set to one of:
//   - "NONE" to skip the corresponding verification method
//   - "STAT" to write the verification output only to the ".stat" output file
//   - "BOTH" to write to the ".stat" output file as well the optional
//       "_type.txt" file, a more readable ASCII file sorted by line type.
//
output_flag = {
    fho    = BOTH; // Forecast, Hit, Observation Rates
    ctc    = BOTH; // Contingency Table Counts
    cts    = BOTH; // Contingency Table Statistics
    mctc   = BOTH; // Multi-category Contingency Table Counts
    mcts   = BOTH; // Multi-category Contingency Table Statistics
    cnt    = BOTH; // Continuous Statistics
    sl1l2  = BOTH; // Scalar L1L2 Partial Sums
    sal1l2 = BOTH; // Scalar Anomaly L1L2 Partial Sums when climatological data is supplied
    vl1l2  = BOTH; // Vector L1L2 Partial Sums
    val1l2 = BOTH; // Vector Anomaly L1L2 Partial Sums when climatological data is supplied
    pct    = BOTH; // Contingency Table Counts for Probabilistic Forecasts
    pstd   = BOTH; // Contingency Table Statistics for Probabilistic Forecasts with Dichotomous outcomes
    pjc    = BOTH; // Joint and Conditional Factorization for Probabilistic Forecasts
    prc    = BOTH; // Receiver Operating Characteristic for Probabilistic Forecasts
    mpr    = BOTH; // Matched Pair Data
    nbrctc = BOTH; // Neighborhood Contingency Table Counts
    nbrcts = BOTH; // Neighborhood Contingency Table Statistics
    nbrcnt = BOTH; // Neighborhood Continuous Statistics
    isc    = BOTH; // Intensity-Scale
    rhist  = BOTH; // Rank Histogram
    phist  = BOTH; // Probability Integral Transform Histogram
    orank  = BOTH; // Observation Rank
    ssvar  = BOTH; // Spread Skill Variance
}

//
// The "nc_pairs_flag" can be set either to a boolean value or a dictionary
// in either Grid-Stat, Wavelet-Stat or MODE. The dictionary (with slightly
// different entries for the various tools ... see the default config files)
// has individual boolean settings turning on or off the writing out of the

```

```
// various fields in the netcdf output file for the tool. Setting all
// dictionary entries to false means the netcdf file will not be generated.
//
// "nc_pairs_flag" can also be set to a boolean value. In this case, a value
// of true means to just accept the default settings (which will turn on
// the output of all the different fields). A value of false means no
// netcdf output will be generated.
//
nc_pairs_flag = TRUE;

//
// The "ps_plot_flag" entry is a boolean value for Wavelet-Stat and MODE
// indicating whether a PostScript plot should be generated summarizing
// the verification.
ps_plot_flag = TRUE;

//
// The "rank_corr_flag" entry is a boolean to indicate whether Kendall's Tau
// and Spearman's Rank Correlation Coefficients (in the CNT line type) should
// be computed. Computing them over large datasets is computationally
// intensive and slows down the runtime significantly.
rank_corr_flag = FALSE;

//
// The "duplicate_flag" entry specifies how to handle duplicate point
// observations in Point-Stat and Ensemble-Stat. Three techniques are
// currently supported:
//
// - "NONE" to use all point observations (legacy behavior)
// - "UNIQUE" if two or more observations match identically except in the
//   station ID field, only use a single observation
// - "SINGLE" if two or more observations appear at a single location
//   (lat, lon, level, elv), use only the observation that has the valid
//   time closest to the forecast valid time
//
// The reporting mechanism for this feature can be activated by specifying
// a verbosity level of three or higher. The report will show information
// about where duplicates were detected and which observations were used
// in those cases.
//
duplicate_flag = NONE;

//
```

```
// The "obs_quality" entry specifies the quality flag values that are to be
// retained and used for verification. An empty list signifies that all
// point observations should be used, regardless of their quality flag value.
// The quality flag values will vary depending on the original source of the
// observations. The quality flag values to retain should be specified as
// an array of strings, even if the values themselves are numeric.
//
obs_quality = [ "1", "2", "3", "9" ];

//
// The "met_data_dir" entry specifies the location of the internal MET data
// sub-directory which contains data files used when generating plots. It
// should be set to the installed share/met directory so the MET tools can
// locate the static data files they need at run time.
//
met_data_dir = "MET_BASE";

//
// The "fcst_raw_plot" entry is a dictionary used by Wavelet-Stat and MODE
// containing colortable plotting information for the plotting of the raw
// forecast field:
//
// - The "color_table" entry specifies the location and name of the
//   colortable file to be used.
//
// - The "plot_min" and "plot_max" entries specify the range of data values.
//   If they are both set to 0, the MET tools will automatically rescale
//   the colortable to the range of values present in the data. If they
//   are not both set to 0, the MET tools will rescale the colortable using
//   their values.
//
fcst_raw_plot = {
    color_table = "MET_BASE/colortables/met_default.etable";
    plot_min = 0.0;
    plot_max = 0.0;
}

//
// The "obs_raw_plot", "wvlt_plot", and "object_plot" entries are dictionaries
// similar to the "fcst_raw_plot" described above.
//
//
```

```
// The "tmp_dir" entry is a string specifying the location where temporary
// files should be written.
//
tmp_dir = "/tmp";

//
// The "output_prefix" entry specifies a string to be included in the output
// file name. The MET statistics tools construct output file names that
// include the tool name and timing information. You can use this setting
// to modify the output file name and avoid naming conflicts for multiple runs
// of the same tool.
//
output_prefix = "";

//
// The "version" entry specifies the version number of the configuration file.
// The configuration file version number should match the version number of
// the MET code being run. This value should generally not be modified.
//
version = "V5.1";
```

3.5.2 MET-TC Config Options - Common to all TC tools

This information may also be found, along with detailed information regarding configuration of individual tools, in the data/config/README_TC file.

```
////////////////////////////////////
//
// Configuration file overview.
//
////////////////////////////////////

See General MET Readme for overview

////////////////////////////////////
//
// Configuration settings common to multiple tools
//
////////////////////////////////////
//
// Specify a comma-separated list of storm id's to be used:
// 2-letter basin, 2-digit cyclone number, 4-digit year
```

```
// An empty list indicates that all should be used.
//
// e.g. storm_id = [ "AL092011" ];
//
// This may also be set using basin, cyclone, and timing information below.
//
storm_id = [];

//
// Specify a comma-separated list of basins to be used.
// Expected format is 2-letter basin identifier.
// An empty list indicates that all should be used.
// Valid basins: WP, IO, SH, CP, EP, AL, SL
//
// e.g. basin = [ "AL", "EP" ];
//
basin = [];

//
// Specify a comma-separated list of cyclone numbers (01-99) to be used.
// An empty list indicates that all should be used.
//
// e.g. cyclone = [ "01", "02", "03" ];
//
cyclone = [];

//
// Specify a comma-separated list of storm names to be used.
// An empty list indicates that all should be used.
//
// e.g. storm_name = [ "KATRINA" ];
//
storm_name = [];

//
// Specify a model initialization time window in YYYYMMDD[_HH[MMSS]] format
// or provide a list of specific initialization times to include (inc)
// or exclude (exc). Tracks whose initial time meets the specified
// criteria will be used. An empty string indicates that all times
// should be used.
//
// e.g. init_beg = "20100101";
```



```
//      init_end = "20101231";
//      init_inc = [ "20101231_06" ];
//      init_exc = [ "20101231_00" ];
//
init_beg = "";
init_end = "";
init_inc = [];
init_exc = [];

//
// Specify a model valid time window in YYYYMMDD[_HH[MMSS]] format.
// Tracks for which all valid times fall within the time window will be used.
// An empty string indicates that all times should be used.
//
// e.g. valid_beg = "20100101";
//      valid_end = "20101231";
//
valid_beg = "";
valid_end = "";

//
// Specify a comma-separated list of model initialization hours to be used
// in HH[MMSS] format. An empty list indicates that all hours should be used.
//
// e.g. init_hour = [ "00", "06", "12", "18" ];
//
init_hour = [];

//
// Specify lat/lon polylines defining masking regions to be applied.
// Tracks whose initial location falls within init_mask will be used.
// Tracks for which all locations fall within valid_mask will be used.
//
// e.g. init_mask = "MET_BASE/poly/EAST.poly";
//
init_mask = "";
valid_mask = "";

//
// Indicate the version number for the contents of this configuration file.
// The value should generally not be modified.
//
version = "V5.1";
```

Chapter 4

Re-Formatting of Point Observations

There are several formats of point observations that may be preprocessed using the suite of reformatting tools in MET. These include PrepBufr data from NCEP, SURFRAD data from NOAA, AERONET data from NASA, MADIS data from NOAA, little_r from WRF simulations, and user defined data in a generic ASCII format. These steps are represented by the first columns in the MET flowchart depicted in Figure 1.1. Output data formats and the software modules used to reformat point data are described in later sections.

4.1 PB2NC tool

This section describes how to configure and run the PB2NC tool. The PB2NC tool is used to stratify the contents of an input PrepBufr point observation file and reformat it into NetCDF format for use by the Point-Stat tool. The PB2NC tool must be run on the input PrepBufr point observation file prior to performing verification with the MET statistics tools.

4.1.1 pb2nc usage

The usage statement for the PB2NC tool is shown below:

```
Usage: pb2nc
      prepbuf_file
      netcdf_file
      config_file
      [-pbfile prepbuf_file]
      [-valid_beg time]
      [-valid_end time]
      [-nmsg n]
```

```
[-dump path]
[-log file]
[-v level]
```

pb2nc has both required and optional arguments.

Required arguments for pb2nc

1. The **prepbufr_file** argument indicates the name of the PrepBufr file to be processed.
2. The **netcdf_file** argument indicates the name given to the output NetCDF file.
3. The **config_file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for pb2nc

1. The **-pbfile prepbufr_file** option may be used to pass additional PrepBufr files to the PB2NC tool.
2. The **-valid_beg time** option in YYYYMMDD[_HH[MMSS]] format sets the beginning of the retention time window.
3. The **-valid_end time** option in YYYYMMDD[_HH[MMSS]] format sets the end of the retention time window.
4. The **-nmsg num_messages** option may be used for testing purposes. This argument indicates that only the first “num_messages” PrepBufr messages should be processed rather than the whole file. This option is provided to speed up testing because running the PB2NC tool can take a few minutes for each file. Most users will not need this option.
5. The **-dump path** option may be used to dump the entire contents of the PrepBufr file to several ASCII files written to the directory specified by “path”. The user may use this option to view a human-readable version of the input PrepBufr file, although writing the contents to ASCII files can be slow.
6. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
7. The **-v level** option indicates the desired level of verbosity. The value of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

An example of the pb2nc calling sequence is shown below:

```
pb2nc sample_pb.blk \
sample_pb.nc \
PB2NCConfig
```

In this example, the PB2NC tool will process the input **sample_pb.blk** file applying the configuration specified in the **PB2NCConfig** file and write the output to a file named **sample_pb.nc**.

4.1.2 pb2nc configuration file

The default configuration file for the PB2NC tool named **PB2NCConfig_default** can be found in the installed `share/met/config` directory. The version used for the example run in Section 2.10 is available in `scripts/config`. It is recommended that users make a copy of configuration files prior to modifying their contents.

When editing configuration files, environment variables may be used for setting the configurable parameters if convenient. The configuration file parser expands any environment variables to their full value before proceeding. Within the configuration file, environment variables must be specified in the form: `${VAR_NAME}`.

For example, using an environment variable to set the `message_type` (see below) parameter to use ADPUPA and ADPSFC message types might consist of the following:

* In a C-Shell: `setenv MSG_TYP 'ADPUPA,ADPSFC'`

* In the configuration file: `message_type[] = [${MSG_TYP}];`

The contents of the default pb2nc configuration file are described below.

```
obs_window = { beg = -5400; end = 5400; }
mask       = { grid = ""; poly = ""; }
tmp_dir    = "/tmp";
version    = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```
message_type = [];
```

Each PrepBufr message is tagged with one of eighteen message types as listed in the `share/met/config/README` file. The 'message_type' refers to the type of observation from which the observation value (or 'report') was derived. The user may specify a comma-separated list of message types to be retained. Providing an empty list indicates that all message types should be retained.

```
station_id = [];
```

Each PrepBufr message has a station identification string associated with it. The user may specify a comma-separated list of station IDs to be retained. Providing an empty list indicates that messages from all station IDs will be retained.

```
elevation_range = { beg = -1000; end = 100000; }
```

The **beg** and **end** variables are used to stratify the elevation (in meters) of the observations to be retained. The range shown above is set to -1000 to 100000 meters, which essentially retains every observation.

```
pb_report_type = [];  
in_report_type = [];  
instrument_type = [];
```

The **pb_report_type**, **in_report_type**, and **instrument_type** variables are used to specify comma-separated lists of PrepBufr report types, input report types, and instrument types to be retained, respectively. If left empty, all PrepBufr report types, input report types, and instrument types will be retained. See the following for more details:

http://www.emc.ncep.noaa.gov/mmb/data_processing/prepbufr.doc/table_4.htm

http://www.emc.ncep.noaa.gov/mmb/data_processing/prepbufr.doc/table_6.htm

```
level_range     = { beg = 1; end = 255; }  
level_category = [];
```

The **beg** and **end** variables are used to stratify the model level of observations to be retained. The range shown above is 1 to 255, which is the current maximum possible level.

The **level_category** variable is used to specify a comma-separated list of Prepbuf data level categories to retain. An empty string indicates that all level categories should be retained. Accepted values and their meanings are described in Table 4.1. See the following for more details:

http://www.emc.ncep.noaa.gov/mmb/data_processing/prepbufr.doc/table_1.htm

Table 4.1: Values for the level_category option.

Level category value	Description
0	Surface level
1	Mandatory level
2	Significant temperature level
3	Winds-by-pressure level
4	Winds-by-height level
5	Tropopause level
6	Reports on a single level
7	Auxiliary levels generated via interpolation from spanning levels

```
obs_grib_code = [ 'SPFH', 'TMP', 'HGT', 'UGRD', 'VGRD' ];
```

Each PrepBuf message will likely contain multiple observation variables. The `obs_grib_code` variable is used to specify which observation variables should be retained or derived. The value from GRIB parameter table version 2 or the corresponding abbreviation may be used to specify which observation variables are to be retained or derived. The following GRIB codes may be retained: SPFH, TMP, HGT, UGRD, and VGRD for specific humidity, temperature, height, and the u and v components of winds. The following GRIB codes may be derived: DPT, WIND, RH, MIXR, and PRMSL for dewpoint, wind speed, relative humidity, mixing ratio, and pressure reduced to MSL.

```
quality_mark_thresh = 2;
```

Each observation has a quality mark value associated with it. The `quality_mark_thresh` is used to stratify out which quality marks will be retained. The value shown above indicates that only observations with quality marks less than or equal to 2 will be retained.

```
event_stack_flag = TOP;
```

A PrepBuf message may contain duplicate observations with different quality mark values. The `event_stack_flag` indicates whether to use the observations at the top of the event stack (observation values have had more quality control processing applied) or the bottom of the event stack (observation values have had no quality control processing applied). The flag value of **TOP** listed above indicates the observations with the most amount of quality control processing should be used, the **BOTTOM** option uses the data closest to raw values.

4.1.3 pb2nc output

Each NetCDF file generated by the PB2NC tool contains the dimensions and variables shown in Tables 4.2 and 4.3.

Table 4.2: NetCDF file dimensions for pb2nc output.

pb2nc NetCDF DIMENSIONS	
NetCDF Dimension	Description
mxstr	Maximum string length (16)
hdr_arr_len	Number of entries in each PrepBuf message header array (3)
obs_arr_len	Number of entries in each PrepBuf observation array (5)
nobs	Number of PrepBuf observations in the file (UNLIMITED)
nhdr	Number of PrepBuf messages in the file (variable)

Table 4.3: NetCDF variables in pb2nc output.

pb2nc NetCDF VARIABLES		
NetCDF Variable	Dimension	Description
obs_arr	nobs, obs_arr_len	Array of floats containing values for each observation including: * Reference to the entry in the hdr_arr with which this observation is associated * GRIB code corresponding to this observation type * Pressure level in hPa or accumulation interval * Height in meters above sea level * Observation value
obs_qty	nobs, mxstr	Text string containing quality control value for each observation.
hdr_typ	nmsg, mxstr	Text string containing the message type for each PrepBuf message
hdr_sid	nmsg, mxstr	Text string containing the station id for each PrepBuf message
hdr_vld	nmsg, mxstr	Text string containing the observation valid time for each PrepBuf message in YYYYMMDD_HHMMSS format
hdr_arr	nhdr, hdr_arr_len	Array of floats containing values for each PrepBuf message including: * Latitude in degrees north * Longitude in degrees east * Elevation in meters above sea level

4.2 ASCII2NC tool

This section describes how to run the ASCII2NC tool. The ASCII2NC tool is used to reformat ASCII point observations into the NetCDF format expected by the Point-Stat tool. For those users wishing to verify

against point observations that are not available in PrepBuf format, the ASCII2NC tool provides a way of incorporating those observations into MET. If the ASCII2NC tool is used to perform a reformatting step, no configuration file is needed. However, for more complex processing, such as summarizing time series observations, a configuration file may be specified. For details on the configuration file options, see the `share/met/config/README` file and example configuration files distributed with the MET code.

Initial versions of the ASCII2NC tool supported only a simple 11 column ASCII point observation format. It currently supports point observation data in the following formats: the default 11 column format, `little_r` format, SURFace RADiation (SURFRAD) and Integrated Surface Irradiance Study (ISIS) formats (found at <http://www.esrl.noaa.gov/gmd/grad/surfrad/>), the Western Wind and Solar Integration Study (WWSIS) format, and the AErosol RObotic NETwork (AERONET) format (found at <http://aeronet.gsfc.nasa.gov/>). WWSIS data are available by request from National Renewable Energy Laboratory (NREL) in Boulder, CO.

The default ASCII point observation format consists of one row of data per observation value. Each row of data consists of 11 columns as shown in Table 4.4.

Table 4.4: Input MET `ascii2nc` point observation format
`ascii2nc` ASCII Point Observation Format

Column	Name	Description
1	Message_Type	Text string containing the observation message type as described in the previous section on the PB2NC tool.
2	Station_ID	Text string containing the station id.
3	Valid_Time	Text string containing the observation valid time in YYYYMMDD_HHMMSS format.
4	Lat	Latitude in degrees north of the observing location.
5	Lon	Longitude in degrees east of the observation location.
6	Elevation	Elevation in msl of the observing location.
7	Grib_Code	Integer GRIB code value corresponding to this observation type.
8	Level	Pressure level in hPa or accumulation interval in hours for the observation value.
9	Height	Height in msl or agl of the observation value.
10	QC_String	Quality control value.
11	Observation_Value	Observation value in units consistent with the GRIB code definition.

4.2.1 `ascii2nc` usage

Once the ASCII point observations have been formatted as expected, the ASCII file is ready to be processed by the ASCII2NC tool. The usage statement for ASCII2NC tool is shown below:

```
Usage: ascii2nc
      ascii_file [ascii_file2 ... ascii_filen]
```



```

netcdf_file
[-format ASCII_format]
[-config file]
[-mask_grid string]
[-mask_poly file]
[-log file]
[-v level]

```

ascii2nc has two required arguments and can take several optional ones.

Required arguments for ascii2nc

1. The **ascii_file** argument indicates the name of the ASCII point observation file to be processed.
2. The **netcdf_file** argument indicates the name given to the output NetCDF file.

Optional arguments for ascii2nc

3. The **-format ASCII_format** option may be set to "met_point", "little_r", "surfrad", "wvswis", or "aeronet". If passing in ISIS data, use the "surfrad" format flag.
4. The **-config file** option specifies the configuration file to generate summaries of the fields in the ASCII files.
5. The **-mask_grid string** option specifies a named grid or a gridded data file for filtering the point observations spatially.
6. The **-mask_poly file** option defines a polyline masking file for filtering the point observations spatially.
7. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
8. The **-v level** option indicates the desired level of verbosity. The value of 'level' will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

An example of the **ascii2nc** calling sequence is shown below:

```

ascii2nc sample_ascii_obs.txt \
sample_ascii_obs.nc

```

In this example, the ASCII2NC tool will reformat the input **sample_ascii_obs.txt** file into NetCDF format and write the output to a file named **sample_ascii_obs.nc**.

4.2.2 ascii2nc configuration file

The default configuration file for the ASCII2NC tool named **Ascii2NcConfig_default** can be found in the installed `share/met/config` directory. It is recommended that users make a copy of this file prior to modifying its contents.

The ASCII2NC configuration file is optional and only necessary when defining time summaries or message type mapping for `litte_r` data. The contents of the default ASCII2NC configuration file are described below.

```
version = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```
time_summary = {
    flag      = FALSE;
    beg       = "000000";
    end       = "235959";
    step      = 300;
    width     = 600;
    grib_code = [ 11, 204, 211 ];
    type      = [ "min", "max", "range", "mean", "stdev", "median", "p80" ];
}
```

The time summary feature was implemented to allow additional processing of observations with high temporal resolution, such as SURFRAD data every 5 minutes. The "flag" entry toggles the "time_summary" on (TRUE) and off (FALSE). Observations may be summarized across the user specified time period defined by the "beg" and "end" entries in HHMMSS format. The "step" entry defines the time between intervals in seconds. The "width" entry specifies the width of the summary interval in seconds.

This example listed above does a 10-minute time summary (width = 600;) every 5 minutes (step = 300;) throughout the day (beg = "000000"; end = "235959;"). The first interval will be from 23:55:00 the previous day through 00:04:59 of the current day. The second interval will be from 0:00:00 through 00:09:59. And so on.

The summaries will only be calculated for the specified GRIB codes. The supported summaries are "min" (minimum), "max" (maximum), "range", "mean", "stdev" (standard deviation), "median" and "p##" (percentile, with the desired percentile value specified in place of ##). If multiple summaries are selected in a single run, a string indicating the summary method applied will be appended to the output message type.

```
message_type_map = [  
    { key = "FM-12 SYNOP"; val = "ADPSFC"; },  
    { key = "FM-13 SHIP"; val = "SFCSHP"; },  
    { key = "FM-15 METAR"; val = "ADPSFC"; },  
    { key = "FM-18 BUOY"; val = "SFCSHP"; },  
    { key = "FM-281 QSCAT"; val = "ASCATW"; },  
    { key = "FM-32 PILOT"; val = "ADPUPA"; },  
    { key = "FM-35 TEMP"; val = "ADPUPA"; },  
    { key = "FM-88 SATOB"; val = "SATWND"; },  
    { key = "FM-97 ACARS"; val = "AIRCFT"; }  
];
```

This entry is an array of dictionaries, each containing a "key" string and "val" string which define a mapping of input strings to output message types. This mapping is currently only applied when converting input `little_r` report types to output message types.

4.2.3 `ascii2nc` output

The NetCDF output of the ASCII2NC tool is structured in the same way as the output of the PB2NC tool described in Section 4.1.3.

4.3 MADIS2NC tool

This section describes how to run the MADIS2NC tool. The MADIS2NC tool is used to reformat Meteorological Assimilation Data Ingest System (MADIS) point observations into the NetCDF format expected by the MET statistics tools. More information about MADIS data and formatting is available at <http://madis.noaa.gov>. Since the MADIS2NC tool simply performs a reformatting step, no configuration file is needed. The MADIS2NC tool supports many of the MADIS data types, as listed in the usage statement below. Support for additional MADIS data types may be added in the future based on user feedback.

4.3.1 `madis2nc` usage

The usage statement for MADIS2NC tool is shown below:

```
Usage: madis2nc  
      madis_file  
      out_file  
      -type str  
      [-qc_dd list]
```

```

[-lvl_dim list]
[-rec_beg n]
[-rec_end n]
[-mask_grid string]
[-mask_poly file]
[-log file]
[-v level]

```

madis2nc has required arguments and can also take optional ones.

Required arguments for madis2nc

1. The **madis_file** argument indicates the name of the point observation file to be processed.
2. The **netcdf_file** argument indicates the name given to the output NetCDF file.
3. The argument **-type str** specifies the type of MADIS observations (metar, raob, profiler, maritime, mesonet or acarsProfiles).

Optional arguments for madis2nc

4. The **-qc_dd list** option specifies a comma-separated list of QC flag values to be accepted (Z,C,S,V,X,Q,K,G,B).
5. The **-lvl_dim list option** specifies a comma-separated list of vertical level dimensions to be processed.
6. To specify the exact records to be processed, the **-rec_beg n** specifies the index of the first MADIS record to process and **-rec_end n** specifies the index of the last MADIS record to process. Both are zero-based.
7. The **-mask_grid string** option specifies a named grid or a gridded data file for filtering the point observations spatially.
8. The **-mask_poly file** option defines a polyline masking file for filtering the point observations spatially.
9. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
10. The **-v level** option indicates the desired level of verbosity. The value of 'level' will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the madis2nc calling sequence is shown below:

```

madis2nc sample_madis_obs.nc \
sample_madis_obs_met.nc -log madislog -v 3

```

In this example, the MADIS2NC tool will reformat the input `sample_madis_obs.nc` file into NetCDF format and write the output to a file named `sample_madis_obs_met.nc`. Warnings and error messages will be written to the `madislog` file, and the verbosity will be level three.

4.3.2 **madis2nc output**

The NetCDF output of the MADIS2NC tool is structured in the same way as the output of the PB2NC tool described in Section 4.1.3.

Chapter 5

Re-Formatting of Gridded Fields

Several MET tools exist for the purpose of reformatting gridded fields. MET offers a suite of reformatting tools to put data in a common format. Both the input and output file formats of these reformatting tools are described in this chapter. These tools are represented by the reformatting column of MET flowchart depicted in Figure 1.1.

5.1 Pcp-Combine tool

This section contains a description of running the Pcp-Combine tool. The Pcp-Combine tool is used (if needed) to modify the precipitation accumulation intervals from two or more gridded files into a single NetCDF file containing the desired accumulation interval. This tool enables users to define identical forecast and observation or analysis precipitation accumulation intervals prior to running the MET statistics tools. The "sum" command can only be run on GRIB1 or GRIB2 files while the "add" and "subtract" commands can be run on any gridded file. Use of Pcp-Combine on a single file will result in that file being written out in NetCDF format, with no changes to the data values. The files being combined must all be on a common grid. The Pcp-Combine tool does not support automated regridding. When running the "subtract" or "sum" command, the input files must have the same initialization time unless the user has indicated that it should ignore the initialization time for the "sum" command.

5.1.1 pcp_combine usage

The usage statement for the Pcp-Combine tool is shown below:

```
Usage: pcp_combine
      [[-sum] sum_args] | [-add add_args] | [-subtract subtract_args]
      [-field string]
```

```

[-name variable_name]
[-log file]
[-v level]

```

The arguments to `pcp_combine` vary depending on the mode in which it is run. Listed below are the arguments for the `sum` command:

```

SUM_ARGS:
  init_time
  in_accum
  valid_time
  out_accum
  out_file
  [-pcpdir path]
  [-pcprx reg_exp]

```

Listed below are the arguments for the `add` command:

```

ADD_ARGS:
  in_file1 accum1 [in_file2 accum2 ... in_fileN accumN]
  out_file

```

Listed below are the arguments for the `subtract` command:

```

SUBTRACT_ARGS:
  in_file1 accum1
  in_file2 accum2
  out_file

```

Required arguments for the `pcp_combine`

1. The `Pcp-Combine` tool must be run with exactly one of the `-sum`, `-add`, or `-subtract` command line arguments with the corresponding additional arguments.

Optional arguments for `pcp_combine`

2. The `-field string` option defines the data to be extracted from the input files.
3. The `-name variable_name` gives the name of the combined variable in output NetCDF file.

4. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
5. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

Required arguments for the **pcp combine sum** command

1. The **init_time** argument, provided in YYYYMMDD[_HH[MMSS]] format, indicates the initialization time for model data to be summed. Only files found with this initialization time will be processed. If combining observation files, Stage II or Stage IV data for example, the initialization time is not applicable. Providing a string of all zeros (00000000_000000) indicates that all files, regardless of initialization time should be processed.
2. The **in_accum** argument, provided in HH[MMSS] format, indicates the accumulation interval of the model or observation gridded files to be processed. This value must be specified, since a model output file may contain multiple accumulation periods for precipitation in a single file. The argument indicates which accumulation period to extract.
3. The **valid_time** argument, in YYYYMMDD[_HH[MMSS]] format, indicates the desired valid time to which the accumulated precipitation is to be summed.
4. The **out_accum** argument, in HH[MMSS] format, indicates the desired total accumulation period to be summed.
5. The **out_file** argument indicates the name for the NetCDF file to be written.

Optional arguments for **pcp combine sum** command

6. The **-pcpdir path** option indicates the directories in which the input files reside. The contents of “**path**” will override the default setting.
7. The **-pcprx reg_exp** option indicates the regular expression to be used in matching files in the precipitation directory specified. The contents of “**reg_exp**” will override the default setting that matches all file names. If the precipitation directory contains a large number of files, the user may specify that only a subset of those files be processed using a regular expression which will speed up the run time.

Required arguments for the **pcp combine add** command

1. The **in_file1** argument indicates the first file to be processed, and can be any gridded file.
2. The **in_accum1** argument, provided in HH[MMSS] format, indicates the accumulation interval to be extracted from the first file. For non-precipitation fields, this argument can be replaced by a configuration string, e.g. 'name="TMP"; level="P500";'.

An arbitrary number of additional files and accumulations can be provided. All of them will be added and the total will be placed in the output file.

Required arguments for the pcp_combine subtract command

3. The `in_file1` argument indicates the first file to be processed, and can be any gridded file.
4. The `in_accum1` argument, provided in HH[MMSS] format, indicates the accumulation interval to be extracted from the first gridded file. For non-precipitation fields, this argument can be replaced by a configuration string, e.g. `'name="TMP"; level="P500";'`.
5. The `in_file2` argument indicates the second file to be processed.
6. The `in_accum2` argument, provided in HH[MMSS] format, indicates the accumulation interval to be extracted from the second file. This accumulation will be subtracted from the first. For non-precipitation fields, this argument can be replaced by a configuration string, e.g. `'name="TMP"; level="P500";'`.

An example of the `pcp_combine` calling sequence is presented below:

Example 1:

```
pcp_combine -sum \  
20050807_000000 3 \  
20050808_000000 24 \  
sample_fcst.nc \  
-pcpdir ../data/sample_fcst/2005080700
```

In Example 1, the Pcp-Combine tool will sum the values in model files initialized at 2005/08/07 00Z and containing 3-hourly accumulation intervals of precipitation. The requested valid time is 2005/08/08 00Z with a requested total accumulation interval of 24 hours. The output file is to be named `sample_fcst.nc`, and the Pcp-Combine tool is to search the directory indicated for the input files.

The Pcp-Combine tool will search for 8 files containing 3-hourly accumulation intervals which meet the criteria specified. It will write out a single NetCDF file containing that 24 hours of accumulation.

A second example of the `pcp_combine` calling sequence is presented below:

Example 2:

```
pcp_combine -sum \  
00000000_000000 1 \  
20050808_000000 24 \  
sample_obs.nc \  
-pcpdir ../data/sample_obs/ST2m1
```

Example 2 shows an example of using the Pcp-Combine tool to sum observation data. The "init_time" has been set to all zeros to indicate that when searching through the files in precipitation directory, the initialization time should be ignored. The "in_accum" has been changed from 3 to 1 to indicate that the input observation files contain 1-hourly accumulations of precipitation. Lastly, -pcpdir provides a different directory to be searched for the input files.

The Pcp-Combine tool will search for 24 files containing 1-hourly accumulation intervals which meet the criteria specified. It will write out a single NetCDF file containing that 24 hours of accumulation.

Example 3:

```
pcp_combine -add input_pinterp.nc 'name="TT"; level="(0,*,*)";' tt_10.nc
```

This command would grab the first level of the TT variable from a pinterp NetCDF file and write it to the output tt_10.nc file.

5.1.2 pcp_combine output

The output NetCDF files contain the requested accumulation intervals as well as information about the grid on which the data lie. That grid projection information will be parsed out and used by the MET statistics tools in subsequent steps. One may use NetCDF utilities such as ncdump or ncview to view the contents of the output file. Alternatively, the MET Plot-Data-Plane tool described in Section 21.1.2 may be run to create a PostScript image of the data.

Each NetCDF file generated by the Pcp-Combine tool contains the dimensions and variables shown in the following two tables.

Table 5.1: NetCDF file dimensions for pcp_combine output.

Pcp_combine NetCDF dimensions	
NetCDF dimension	Description
lat	Dimension of the latitude (i.e. Number of grid points in the North-South direction)
lon	Dimension of the longitude (i.e. Number of grid points in the East-West direction)

Table 5.2: NetCDF variables for `pcp_combine` output.

Pcp_combine NetCDF variables		
NetCDF variable	Dimension	Description
lat	lat, lon	Latitude value for each point in the grid
lon	lat, lon	Longitude value for each point in the grid
GRIB Code Abbreviation or -name option	lat, lon	Data value (i.e. accumulated precipitation) for each point in the grid. The name of the variable describes the name and level.

5.2 Regrid_data_plane tool

This section contains a description of running the `regrid_data_plane` tool. This tool may be run to read data from any gridded file MET supports (i.e. GRIB1, GRIB2, and a variety of NetCDF formats), interpolate to a user-specified grid, and write the field(s) out in NetCDF format. The user may specify the method of interpolation used for regridding as well as which fields to regrid. This tool is particularly useful when dealing with GRIB2 and NetCDF input files that need to be regridded. For GRIB1 files, it has also been tested for compatibility with the `copygb` regridding utility mentioned in Section 2.7.

5.2.1 regrid_data_plane usage

The usage statement for the `regrid_data_plane` utility is shown below:

```
Usage: regrid_data_plane
      input_filename
      to_grid
      output_filename
      -field string
      [-method type]
      [-width n]
      [-vld_thresh n]
      [-name str]
      [-log file]
      [-v level]
```

Required arguments for regrid_data_plane

1. The `input_filename` is the gridded data file to be read.
2. The `to_grid` defines the output grid as a named grid, the path to a gridded data file, or an explicit grid specification string.

3. The **output_filename** is the output NetCDF file to be written.
4. The **-field string** may be used multiple times to define the field(s) to be regridded.

Optional arguments for regrid_data_plane

5. The **-method type** option overrides the default regridding method. Default is NEAREST.
6. The **-width n** option overrides the default regridding width. Default is 1.
7. The **-vld_thresh n** option overrides the default required ratio of valid data for regridding. Default is 0.5.
8. The **-name str** option specifies the output variable name
9. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
10. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

For more details on setting the **-method**, **-width**, and **-vld_thresh** options, see the **regrid** entry in Section 3.5.1. An example of the `regrid_data_plane` calling sequence is shown below:

```
regrid_data_plane \
input.grb \
togrid.grb \
regridded.nc \
-field 'name="APCP"; level="A6";' \
-field 'name="TMP"; level="Z2";' \
-field 'name="UGRD"; level="Z10";' \
-field 'name="VGRD"; level="Z10";' \
-field 'name="HGT"; level="P500";' \
-method BILIN -width 2 -v 1
```

In this example, the `regrid_data_plane` tool will regrid data from the **input.grb** file to the grid on which the first record of the **togrid.grb** file resides using Bilinear Interpolation with a width of 2 and write the output in NetCDF format to a file named **regridded.nc**. The variables in **regridded.nc** will include 6-hour accumulated precipitation, 2m temperature, 10m U and V components of the wind, and the 500mb geopotential height.

5.2.2 Automated regridding within tools

While the `regrid_data_plane` tool is useful as a stand-alone tool, the capability is also included to automatically regrid one or both fields in most of the MET tools that handle gridded data. See the **regrid** entry in Section 3.5 for a description of the configuration file entries that control automated regridding.

5.3 Shift_data_plane tool

This section contains a description of running the `shift_data_plane` tool. This tool may be run to perform a rigged shift of the entire grid based on user-defined specifications and write the field(s) out in NetCDF format. This tool was originally designed to account for track error when comparing fields associated with tropical cyclones. The user specifies the latitude and longitude of the source and destination points to define the shift. Both points must fall within the domain and are used to define the X and Y direction grid unit shift. The rigid is then applied to all grid points. The user may specify the method of interpolation and the field to be shifted. The effects of topography and land/water masks are ignored.

5.3.1 shift_data_plane usage

The usage statement for the `shift_data_plane` utility is shown below:

```
Usage: shift_data_plane
       input_filename
       output_filename
       field_string
       -from lat lon
       -to   lat lon
       [-method type]
       [-width n]
       [-log file]
       [-v level]
```

`shift_data_plane` has five required arguments and can also take optional ones.

Required arguments for shift_data_plane

1. The **input_filename** is the gridded data file to be read.
2. The **output_filename** is the output NetCDF file to be written.
3. The **field_string** defines the data to be shifted from the input file.

4. The **-from lat lon** specifies the starting location to define the shift (location must be in the file). Lat is deg N, Lon is deg E.
5. The **-to lat lon** specifies the ending location to define the shift (location may or may not be in the file). Lat is deg N, Lon is deg E.

Optional arguments for shift_data_plane

6. The **-method type** overrides the default regridding method. Default is NEAREST.
7. The **-width n** overrides the default regridding width. Default is 1.
8. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
9. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

For more details on setting the **-method** and **-width** options, see the **regrid** entry in Section 3.5.1. An example of the `shift_data_plane` calling sequence is shown below:

```
shift_data_plane \
nam.grib \
nam_shift_APCP_12.nc \
'name = "APCP"; level = "A12";' \
-from 38.6272 -90.1978 \
-to 40.1717 -105.1092 \
-v 2
```

In this example, the `shift_data_plane` tool reads 12-hour accumulated precipitation from the **nam.grib** file, applies a rigid shift defined by (38.6272, -90.1978) to (40.1717, -105.1092) and writes the output in NetCDF format to a file named **nam_shift_APCP_12.nc**. These **-from** and **-to** locations result in a grid shift of -108.30 units in the x-direction and 16.67 units in the y-direction.

5.4 MODIS regrid tool

This section contains a description of running the MODIS regrid tool. This tool may be run to create a NetCDF file for use in other MET tools from MODIS level 2 cloud product from NASA. The data browser for these files is: <http://ladsweb.nascom.nasa.gov/>.

5.4.1 modis_regrid usage

The usage statement for the modis_regrid utility is shown below:

```
Usage: modis_regrid
       -data_file path
       -field name
       -out path
       -scale value
       -offset value
       -fill value
       [-units text]
       modis_file
```

modis_regrid tool has some required arguments and can also take optional ones.

Required arguments for modis_regrid

1. The **-data_file path** argument specifies the data files used to get the grid information.
2. The **-field name** argument specifies the name of the field to use in the MODIS data file.
3. The **-out path** argument specifies the name of the output NetCDF file.
4. The **-scale value** argument specifies the scale factor to be used on the raw MODIS values.
5. The **-offset value** argument specifies the offset value to be used on the raw MODIS values.
6. The **-fill value** argument specifies the bad data value in the MODIS data.
7. The **-modis_file** argument is the name of the MODIS input file.

Optional arguments for modis_regrid

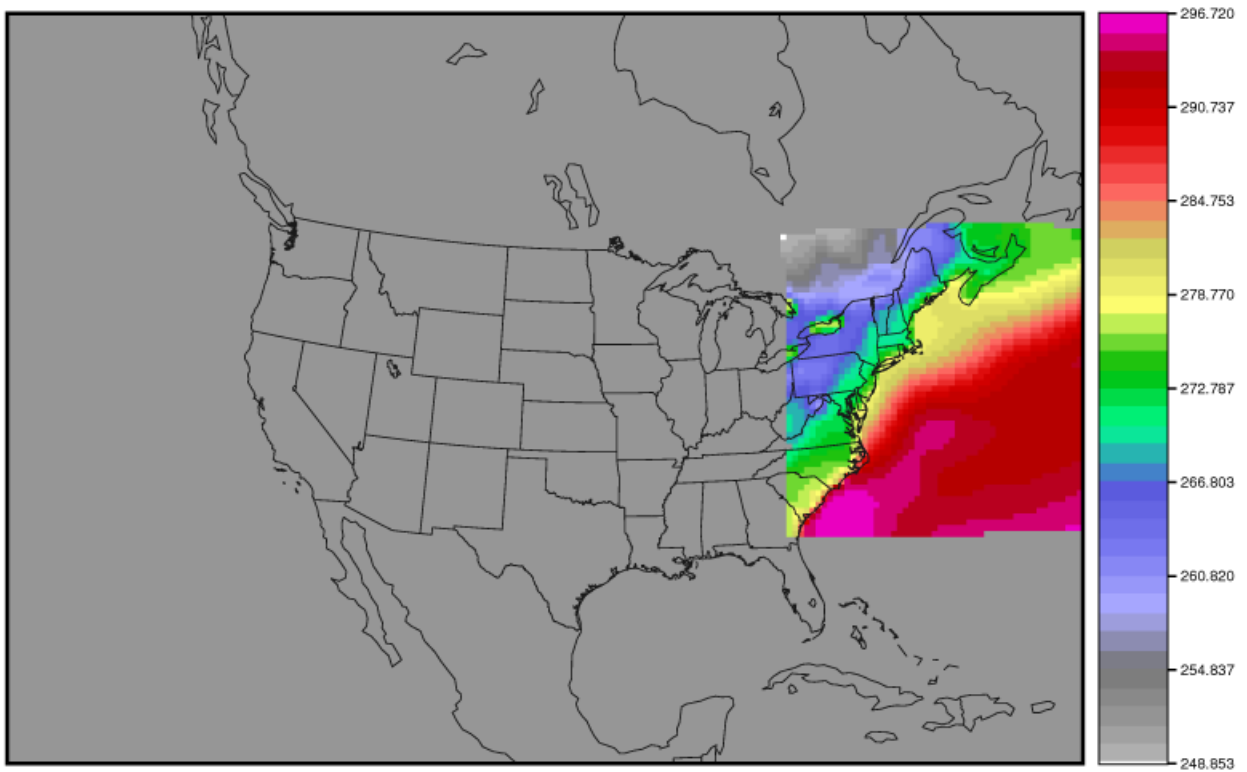
8. The **-units text** option specifies the units string in the global attributes section of the output file.

An example of the modis_regrid calling sequence is shown below:

```
modis_regrid -field Cloud_Fraction \  
-data_file grid_file \  
-out t2.nc \  
-units percent \  
-scale 0.01 \  
-offset 0 \  
-fill 127 \  
modisfile
```

In this example, the `modis_regrid` tool will process the `Cloud_Fraction` field from `modisfile` and write it out to the output NetCDF file `t2.nc` on the grid specified in `grid_file` using the appropriate scale, offset and fill values.

MYD06_L2.A2013032.0630.051.2013032185634.hdf



t1.nc

Figure 5.1: Example plot showing surface temperature from a MODIS file.

Chapter 6

Regional Verification using Masking

Verification over a particular region or area of interest may be performed using “masking”. Defining a masking region is simply selecting the desired set of grid points to be used. The Gen-Vx-Mask tool automates this process and replaces the Gen-Poly-Mask and Gen-Circle-Mask tools in previous releases. It may be run to create a bitmap verification masking region to be used by many of the statistical tools. This tool enables the user to generate a masking region once for a domain and apply it to many cases. It has been enhanced to support additional types of masking region definition (e.g. tropical-cyclone track over water only). An iterative approach may be used to define complex areas by combining multiple masking regions together.

6.1 Gen-Vx-Mask tool

This section contains a description of running the Gen-Vx-Mask tool. The Gen-Vx-Mask tool may be run to create a bitmap verification masking region to be used by the the MET statistics tools. This tool enables the user to generate a masking region once for a domain and apply it to many cases. While the MET statistics tools can define some masking regions on the fly, doing so can be slow especially for complex polylines containing hundreds of vertices. Using the Gen-Poly-Mask tool to create a bitmap masking region before running the other MET tools will make them run more efficiently.

6.1.1 `gen_vx_mask` usage

The usage statement for the Gen-Vx-Mask tool is shown below:

```
Usage: gen_vx_mask
       input_file
       mask_file
       out_file
```

```

[-type str]
[-input_field string]
[-mask_field string]
[-complement]
[-union|-intersection|-symdiff]
[-thresh string]
[-value n]
[-name string]
[-log file]
[-v level]

```

gen_vx_mask has three required arguments and can take optional ones.

Required arguments for gen_vx_mask

1. The **input_file** argument indicates the name of a gridded data file that defines the domain over which the masking bitmap is to be defined.
2. The **mask_file** argument indicates the name of the file data file that defines the masking region - ASCII Lat/Lon polyline file for “poly”, “circle”, and “track” masking; Gridded data file for “grid” and “data” masking.
3. The **out_file** argument indicates the name given to the output NetCDF mask file.

Optional arguments for gen_vx_mask

4. The **-type string** option can be used to override the default masking type (poly).
5. The **-input_field string** option can be used to read existing mask data from "input_file".
6. The **-mask_field string** option can be used to define the field from "mask_file" to be used for "data" masking.
7. The **-complement** option can be used to compute the complement of the area defined in "mask_file".
8. The **-union | -intersection | -symdiff** option can be used to specify how to combine the masks from "input_file" and "mask_file".
9. The **-thresh string** option can be used to define the threshold to be applied - Distance (km) for "circle" and "track" masking; Raw input values for "data" masking.
10. The **-value n** option can be used to override the default output mask data value (1).
11. The **-name string** option can be used to specify the output variable name for the mask.
12. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.

13. The **-v level** option indicates the desired level of verbosity. The value of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

The Gen-Vx-Mask tool supports the following types of masking region definition selected using the **-type** command line option:

1. Polyline (**poly**) masking reads an input ASCII file containing Lat/Lon locations, connects the first and last points, and selects grid points falling inside that polyline. This option is useful when defining geographic sub-regions of a domain.
2. Circle (**circle**) masking reads an input ASCII file containing Lat/Lon locations and for each grid point, computes the minimum great-circle arc distance in kilometers to those points. If the **-thresh** command line option is not used, the minimum distance value for each grid point will be written to the output. If it is used, only those grid points whose minimum distance meets the threshold criteria will be selected. This option is useful when defining areas within a certain radius of radar locations.
3. Track (**track**) masking reads an input ASCII file containing Lat/Lon locations and for each grid point, computes the minimum great-circle arc distance in kilometers to the track defined by those points. The first and last track points are not connected. As with **circle** masking the output for each grid points depends on the use of the **-thresh** command line option. This option is useful when defining the area within a certain distance of a hurricane track.
4. Grid (**grid**) masking reads an input gridded data file, extracts the field specified using the its grid definition, and selects grid points falling inside that grid. This option is useful when using a model nest to define the corresponding area of the parent domain.
5. Data (**data**) masking reads an input gridded data file, extracts the field specified using the **-mask_field** command line option, thresholds the data using the **-thresh** command line option, and selects grid points which meet that threshold criteria. The option is useful when thresholding topography to define a mask based on elevation or when threshold land use to extract a particular category.

The polyline, circle, and track masking methods all read an ASCII file containing Lat/Lon locations. Those files must contain a string, which defines the name of the masking region, followed by a series of whitespace-separated latitude (degrees north) and longitude (degree east) values.

The Gen-Vx-Mask tool read the **input_file** file and extracts the grid definition from the file. If the **-input_field** command line option is used, it will read the specified field of data and initialize each grid point to the value of that field. If that option is not used, the tool will check to see if the **input_file** file was generated by the Gen-Vx-Mask tool. If so, it will read the previously defined mask data and initialize each grid point to the value of that mask. If not, it will simply initialize each grid point to a value of zero.

This feature enables the Gen-Vx-Mask tool to be run iteratively on its own output to generate complex masking areas. Additionally, the **-union**, **-intersection**, and **-symdiff** options control the logic for combining the input data value and current mask value at each grid point. For example, one could define a complex masking region by selecting grid points with an elevation greater than 1000 meters within a specified geographic region by doing the following:

- Run the Gen-Vx-Mask tool to apply data masking by thresholding a field of topography greater than 1000 meters.
- Rerun the Gen-Vx-Mask tool passing in the output of the first call and applying polyline masking to define the geographic area of interest.
 - Use the **-intersection** option to only select grid points whose value is non-zero in both the input field and the current mask.

An example of the `gen_vx_mask` calling sequence is shown below:

```
gen_vx_mask sample_fcst.grb \  
CONUS.poly CONUS_poly.nc
```

In this example, the Gen-Vx-Mask tool will read the ASCII Lat/Lon file named **CONUS.poly** and apply the default polyline masking method to the domain on which the data in the file **sample_fcst.grib** resides. It will create a NetCDF file containing a bitmap for the domain with a value of 1 for all grid points inside the CONUS polyline and a value of 0 for all grid points outside. It will write an output NetCDF file named **CONUS_poly.nc**.

Chapter 7

Point-Stat Tool

7.1 Introduction

The Point-Stat tool provides verification statistics for forecasts at observation points (as opposed to over gridded analyses). The Point-Stat tool matches gridded forecasts to point observation locations and supports several different interpolation options. The tool then computes continuous, categorical, and probabilistic verification statistics. The categorical and probabilistic statistics generally are derived by applying a threshold to the forecast and observation values. Confidence intervals - representing the uncertainty in the verification measures - are computed for the verification statistics.

Scientific and statistical aspects of the Point-Stat tool are discussed in the following section. Practical aspects of the Point-Stat tool are described in Section 7.3.

7.2 Scientific and statistical aspects

The statistical methods and measures computed by the Point-Stat tool are described briefly in this section. In addition, Section 7.2.1 discusses the various interpolation options available for matching the forecast grid point values to the observation points. The statistical measures computed by the Point-Stat tool are described briefly in Section 7.2.2 and in more detail in Appendix C. Section 7.2.3 describes the methods for computing confidence intervals that are applied to some of the measures computed by the Point-Stat tool; more detail on confidence intervals is provided in Appendix D.

7.2.1 Interpolation/matching methods

This section provides information about the various methods available in MET to match gridded model output to point observations. Matching in the vertical and horizontal are completed separately using different methods.

In the vertical, if forecasts and observations are at the same vertical level, then they are paired as is. If any discrepancy exists between the vertical levels, then the forecasts are interpolated to the level of the observation. The vertical interpolation is done in natural log of pressure coordinates, except for specific humidity, which is interpolated using the natural log of specific humidity in natural log of pressure coordinates. Vertical interpolation for heights above ground are done linear in height coordinates. When forecasts are for the surface, no interpolation is done. They are matched to observations with message type ADPSFC or SFCSHP.

To match forecasts and observations in the horizontal plane, the user can select from a number of methods described below. Many of these methods require the user to define the width of the forecast grid W , around each observation point P , that should be considered. For example, a width of 2 defines a 2 x 2 square of grid points enclosing P , or simply the 4 grid points closest to P . A width of 3 defines a 3 x 3 square consisting of 9 grid points centered on the grid point closest to P . Figure 7.1 provides illustration. The point P denotes the observation location where the interpolated value is calculated. The interpolation width W , shown is five.

This section describes the options for interpolation in the horizontal.

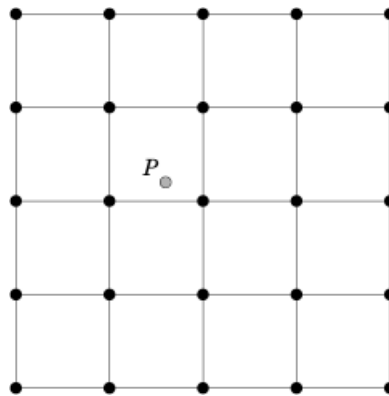


Figure 7.1: Diagram illustrating matching and interpolation methods used in MET. See text for explanation.

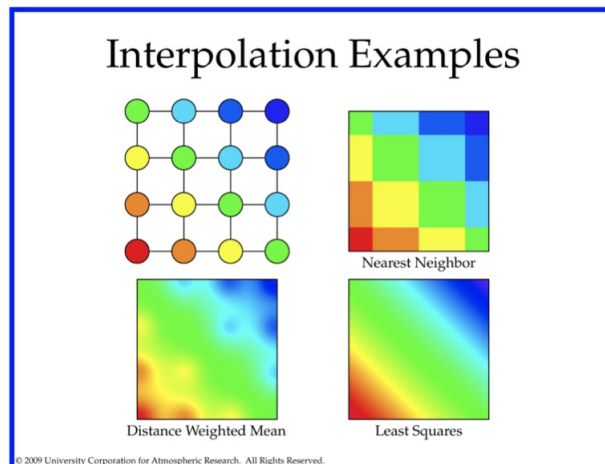


Figure 7.2: Illustration of some matching and interpolation methods used in MET. See text for explanation.

Nearest Neighbor

The forecast value at P is assigned the value at the nearest grid point. No interpolation is performed. Here, "nearest" means spatially closest in horizontal grid coordinates. This method is used by default when the interpolation width, W, is set to 1.

Minimum value

The forecast value at P is the minimum of the values in the W x W square.

Maximum value

The forecast value at P is the maximum of the values in the W x W square.

Distance-weighted mean

The forecast value at P is a weighted sum of the values in the W x W square. The weight given to each forecast point is the reciprocal of the square of the distance (in grid coordinates) from P. The weighted sum of forecast values is normalized by dividing by the sum of the weights.

Unweighted mean

This method is similar to the distance-weighted mean, except all the weights are equal to 1. The distance of any point from P is not considered.

Median

The forecast value at P is the median of the forecast values in the W x W square.

Least-Squares Fit

To perform least squares interpolation of a gridded field at a location P, MET uses an $\mathbf{W}\mathbf{x}\mathbf{W}$ subgrid centered (as closely as possible) at P. Figure 7.1 shows the case where $N = 5$.

If we denote the horizontal coordinate in this subgrid by x , and vertical coordinate by y , then we can assign coordinates to the point P relative to this subgrid. These coordinates are chosen so that the center of the grid is. For example, in Figure 7.2, P has coordinates $(-0.4, 0.2)$. Since the grid is centered near P, the coordinates of P should always be at most 0.5 in absolute value. At each of the vertices of the grid (indicated by black dots in the figure), we have data values. We would like to use these values to interpolate a value at P. We do this using least squares. If we denote the interpolated value by z , then we fit an expression of the form $z = \alpha(x) + \beta(y) + \gamma$ over the subgrid. The values of α, β, γ are calculated from the data values at the vertices. Finally, the coordinates (\mathbf{x}, \mathbf{y}) of P are substituted into this expression to give z , our least squares interpolated data value at P.

Bilinear Interpolation

This method is performed using the four closest grid squares. The forecast values are interpolated linearly first in one dimension and then the other to the location of the observation.

7.2.2 Statistical measures

The Point-Stat tool computes a wide variety of verification statistics. Broadly speaking, these statistics can be subdivided into statistics for categorical variables and statistics for continuous variables. The categories of measures are briefly described here; specific descriptions of the measures are provided in Appendix C. Additional information can be found in Wilks (2011) and Jolliffe and Stephenson (2003), and on the world-wide web at

http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html.

In addition to these verification measures, the Point-Stat tool also computes partial sums and other FHO statistics that are produced by the NCEP verification system. These statistics are also described in Appendix C.

Measures for categorical variables

Categorical verification statistics are used to evaluate forecasts that are in the form of a discrete set of categories rather than on a continuous scale. If the original forecast is continuous, the user may specify one or more thresholds in the configuration file to divide the continuous measure into categories. Currently, Point-Stat computes categorical statistics for variables in two or more categories. The special case of dichotomous

(i.e., 2-category) variables has several types of statistics calculated from the resulting contingency table and are available in the CTS output line type. For multi-category variables, fewer statistics can be calculated so these are available separately, in line type MCTS. Categorical variables can be intrinsic (e.g., rain/no-rain) or they may be formed by applying one or more thresholds to a continuous variable (e.g., temperature < 273.15 K or cloud coverage percentages in 10% bins). See Appendix C for more information.

Measures for continuous variables

For continuous variables, many verification measures are based on the forecast error (i.e., $f - o$). However, it also is of interest to investigate characteristics of the forecasts, and the observations, as well as their relationship. These concepts are consistent with the general framework for verification outlined by Murphy and Winkler (1987). The statistics produced by MET for continuous forecasts represent this philosophy of verification, which focuses on a variety of aspects of performance rather than a single measure. See Appendix C for specific information.

A user may wish to eliminate certain values of the forecasts from the calculation of statistics, a process referred to here as “conditional verification”. For example, a user may eliminate all temperatures above freezing and then calculate the error statistics only for those forecasts of below freezing temperatures. Another common example involves verification of wind forecasts. Since wind direction is indeterminate at very low wind speeds, the user may wish to set a minimum wind speed threshold prior to calculating error statistics for wind direction. The user may specify these thresholds in the configuration file to specify the conditional verification. Thresholds can be specified using the usual Fortran conventions ($<$, $<=$, $=$, $!$, $>=$, or $>$) followed by a numeric value. The threshold type may also be specified using two letter abbreviations (lt, le, eq, ne, ge, gt). Further, more complex thresholds can be achieved by defining multiple thresholds and using $\&\&$ or $||$ to string together event definition logic. The forecast and observation threshold can be used together according to user preference by specifying one of: UNION, INTERSECTION, or SYMDIFF (symmetric difference).

Measures for probabilistic forecasts and dichotomous outcomes

For probabilistic forecasts, many verification measures are based on reliability, accuracy and bias. However, it also is of interest to investigate joint and conditional distributions of the forecasts and the observations, as in Wilks (2011). See Appendix C for specific information.

Probabilistic forecast values are assumed to have a range of either 0 to 1 or 0 to 100. If the max data value is > 1 , we assume the data range is 0 to 100, and divide all the values by 100. If the max data value is $<= 1$, then we use the values as is. Further, thresholds are applied to the probabilities with equality on the lower end. For example, with a forecast probability p , and thresholds $t1$ and $t2$, the range is defined as: $t1 <= p < t2$. The exception is for the highest set of thresholds, when the range includes 1: $t1 <= p <= 1$.

Measures for comparison against climatology

For each of the types of statistics mentioned above (categorical, continuous, and probabilistic), it is possible to calculate measures of skill relative to climatology. MET will accept a climatology file provided by the user, and will evaluate it as a reference forecast. Further, anomalies, i.e. departures from average conditions, can be calculated. As with all other statistics, the available measures will depend on the nature of the forecast. Common statistics that use a climatological reference include: the mean squared error skill score (MSESS), the Anomaly Correlation (ANOM_CORR), scalar and vector anomalies (SAL1L2 and VAL1L2), continuous ranked probability skill score (CRPSS), Brier Skill Score (BSS) (Wilks, 2011; Mason, 2004).

Often, the sample climatology is used as a reference by a skill score. The sample climatology is the average over all included observations and may be transparent to the user. This is the case in most categorical skill scores. The sample climatology will probably prove more difficult to improve upon than a long term climatology, since it will be from the same locations and time periods as the forecasts. This may mask legitimate forecast skill. However, a more general climatology, perhaps covering many years, is often easier to improve upon and is less likely to mask real forecast skill.

7.2.3 Statistical confidence intervals

A single summary score gives an indication of the forecast performance, but it is a single realization from a random process that neglects uncertainty in the score's estimate. That is, it is possible to obtain a good score, but it may be that the "good" score was achieved by chance and does not reflect the "true" score. Therefore, when interpreting results from a verification analysis, it is imperative to analyze the uncertainty in the realized scores. One good way to do this is to utilize confidence intervals. A confidence interval indicates that if the process were repeated many times, say 100, then the true score would fall within the interval $100(1 - \alpha)\%$ of the time. Typical values of α are 0.01, 0.05, and 0.10. The Point-Stat tool allows the user to select one or more specific α -values to use.

For continuous fields (e.g., temperature), it is possible to estimate confidence intervals for some measures of forecast performance based on the assumption that the data, or their errors, are normally distributed. The Point-Stat tool computes confidence intervals for the following summary measures: forecast mean and standard deviation, observation mean and standard deviation, correlation, mean error, and the standard deviation of the error. In the case of the respective means, the central limit theorem suggests that the means are normally distributed, and this assumption leads to the usual $100(1 - \alpha)\%$ confidence intervals for the mean. For the standard deviations of each field, one must be careful to check that the field of interest is normally distributed, as this assumption is necessary for the interpretation of the resulting confidence intervals.

For the measures relating the two fields (i.e., mean error, correlation and standard deviation of the errors), confidence intervals are based on either the joint distributions of the two fields (e.g., with correlation) or on a function of the two fields. For the correlation, the underlying assumption is that the two fields follow a bivariate normal distribution. In the case of the mean error and the standard deviation of the mean

error, the assumption is that the errors are normally distributed, which for continuous variables, is usually a reasonable assumption, even for the standard deviation of the errors.

Bootstrap confidence intervals for any verification statistic are available in MET. Bootstrapping is a non-parametric statistical method for estimating parameters and uncertainty information. The idea is to obtain a sample of the verification statistic(s) of interest (e.g., bias, ETS, etc.) so that inferences can be made from this sample. The assumption is that the original sample of matched forecast-observation pairs is representative of the population. Several replicated samples are taken with replacement from this set of forecast-observation pairs of variables (e.g., precipitation, temperature, etc.), and the statistic(s) are calculated for each replicate. That is, given a set of n forecast-observation pairs, we draw values at random from these pairs, allowing the same pair to be drawn more than once, and the statistic(s) is (are) calculated for each replicated sample. This yields a sample of the statistic(s) based solely on the data without making any assumptions about the underlying distribution of the sample. It should be noted, however, that if the observed sample of matched pairs is dependent, then this dependence should be taken into account somehow. Currently, in the confidence interval methods in MET do not take into account dependence, but future releases will support a robust method allowing for dependence in the original sample. More detailed information about the bootstrap algorithm is found in the appendix.

Confidence intervals can be calculated from the sample of verification statistics obtained through the bootstrap algorithm. The most intuitive method is to simply take the appropriate quantiles of the sample of statistic(s). For example, if one wants a 95% CI, then one would take the 2.5 and 97.5 percentiles of the resulting sample. This method is called the percentile method, and has some nice properties. However, if the original sample is biased and/or has non-constant variance, then it is well known that this interval is too optimistic. The most robust, accurate, and well-behaved way to obtain accurate CIs from bootstrapping is to use the bias corrected and adjusted percentile method (or BCa). If there is no bias, and the variance is constant, then this method will yield the usual percentile interval. The only drawback to the approach is that it is computationally intensive. Therefore, both the percentile and BCa methods are available in MET, with the considerably more efficient percentile method being the default.

The only other option associated with bootstrapping currently available in MET is to obtain replicated samples smaller than the original sample (i.e., to sample $m < n$ points at each replicate). Ordinarily, one should use $m = n$, and this is the default. However, there are cases where it is more appropriate to use a smaller value of m (e.g., when making inference about high percentiles of the original sample). See Gilleland (2008) for more information and references about this topic.

MET provides parametric confidence intervals based on assumptions of normality for the following categorical statistics:

- Base Rate
- Forecast Mean
- Accuracy
- Probability of Detection

- Probability of Detection of the non-event
- Probability of False Detection
- False Alarm Ratio
- Critical Success Index
- Hanssen-Kuipers Discriminant
- Odds Ratio
- Log Odds Ratio
- Odds Ratio Skill Score
- Extreme Dependency Score
- Symmetric Extreme Dependency Score
- Extreme Dependency Index
- Symmetric Extremal Dependency Index

MET provides parametric confidence intervals based on assumptions of normality for the following continuous statistics:

- Forecast and Observation Means
- Forecast, Observation, and Error Standard Deviations
- Pearson Correlation Coefficient
- Mean Error

MET provides parametric confidence intervals based on assumptions of normality for the following probabilistic statistics:

- Brier Score
- Base Rate

MET provides non-parametric bootstrap confidence intervals for many categorical and continuous statistics. Kendall's Tau and Spearman's Rank correlation coefficients are the only exceptions. Computing bootstrap confidence intervals for these statistics would be computationally unrealistic.

For more information on confidence intervals pertaining to verification measures, see Wilks (2011), Jolliffe and Stephenson (2003), and Bradley (2008).

7.3 Practical information

This section contains a description of how to configure and run the Point-Stat tool. The Point-Stat tool is used to perform verification of a gridded model field using point observations. The gridded model field to be verified must be in one of the supported file formats. The point observations must be formatted as the NetCDF output of the point reformatting tools described in Chapter 4. The Point-Stat tool provides the capability of interpolating the gridded forecast data to the observation points using a variety of methods as described in Section 7.2.1. The Point-Stat tool computes a number of continuous statistics on the matched pair data as well as discrete statistics once the matched pair data have been thresholded.

7.3.1 `point_stat` usage

The usage statement for the Point-Stat tool is shown below:

```
Usage: point_stat
       fcst_file
       obs_file
       config_file
       [-point_obs file]
       [-obs_valid_beg time]
       [-obs_valid_end time]
       [-outdir path]
       [-log file]
       [-v level]
```

`point_stat` has three required arguments and can take many optional ones.

Required arguments for `point_stat`

1. The **`fcst_file`** argument names the gridded file in either GRIB or NetCDF containing the model data to be verified.
2. The **`obs_file`** argument indicates the NetCDF file (output of PB2NC or ASCII2NC) containing the point observations to be used for verifying the model.
3. The **`config_file`** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for `point_stat`

4. The **`-point_obs file`** may be used to pass additional NetCDF point observation files to be used in the verification.

5. The `-obs_valid_beg time` option in `YYYYMMDD[_HH[MMSS]]` format sets the beginning of the observation matching time window, overriding the configuration file setting.
6. The `-obs_valid_end time` option in `YYYYMMDD[_HH[MMSS]]` format sets the end of the observation matching time window, overriding the configuration file setting.
7. The `-outdir path` indicates the directory where output files should be written.
8. The `-log file` option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
9. The `-v level` option indicates the desired level of verbosity. The value of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `point_stat` calling sequence is shown below:

```
point_stat sample_fcst.grb \
sample_pb.nc \
PointStatConfig
```

In this example, the Point-Stat tool evaluates the model data in the `sample_fcst.grb` GRIB file using the observations in the NetCDF output of PB2NC, `sample_pb.nc`, applying the configuration options specified in the `PointStatConfig` file.

7.3.2 point_stat configuration file

The default configuration file for the Point-Stat tool named `PointStatConfig_default` can be found in the installed `share/met/config` directory. Another version is located in `scripts/config`. We encourage users to make a copy of these files prior to modifying their contents. The contents of the configuration file are described in the subsections below.

Note that environment variables may be used when editing configuration files, as described in Section 4.1.2 for the PB2NC tool.

```
model          = "WRF";
regrid         = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }
climo_mean     = {}
obs_window     = { beg = -5400; end = 5400; }
mask          = { grid = [ "FULL" ]; poly = []; sid = []; }
```

```

ci_alpha      = [ 0.05 ];
boot          = { interval = PCTILE; rep_prop = 1.0; n_rep = 1000;
                  rng = "mt19937"; seed = ""; };
interp        = { vld_thresh = 1.0; type = [ { method = NEAREST; width = 1; } ]; };
obs_quality   = [];
rank_corr_flag = TRUE;
duplicate_flag = NONE;
tmp_dir       = "/tmp";
output_prefix = "";
version       = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

Setting up the **fcst** and **obs** dictionaries of the configuration file is described in Section 3.5.1. The following are some special consideration for the Point-Stat tool.

The **obs** dictionary looks very similar to the **fcst** dictionary. However since point observation are assigned GRIB1 codes, the observation section must be defined following GRIB1 conventions. When verifying GRIB1 forecast data, one can easily copy over the forecast settings to the observation dictionary using **obs = fcst;**. However, when verifying non-GRIB1 forecast data, users will need to specify the **fcst** and **obs** sections separately.

The **sid_exc** entry, defined in the **obs** dictionary, contains a comma-separated list of the station id's to be excluded from verification. This option is typically used when an observation file contains some stations known to have bad or unreliable data.

The **message_type** entry, defined in the **obs** dictionary, contains a comma-separated list of the message types to use for verification. At least one entry must be provided. The Point-Stat tool performs verification using observations for one message type at a time. See http://www.emc.ncep.noaa.gov/mmb/data_processing/prepbufr.doc/table_1.htm for a list of the possible types. If verifying GRIB1 forecast data, it may be defined in the forecast dictionary and the copied into the observation dictionary using **obs = fcst;**

```

output_flag = {
  fho    = BOTH;
  ctc    = BOTH;
  cts    = BOTH;
  mctc   = BOTH;
  mcts   = BOTH;
  cnt    = BOTH;

```

```
    sl112 = BOTH;
    sal112 = BOTH;
    vl112 = BOTH;
    val112 = BOTH;
    pct = BOTH;
    pstd = BOTH;
    pjc = BOTH;
    prc = BOTH;
    mpr = BOTH;
}
```

The **output_flag** array controls the type of output that the Point-Stat tool generates. Each flag corresponds to an output line type in the STAT file. Setting the flag to **NONE** indicates that the line type should not be generated. Setting the flag to **STAT** indicates that the line type should be written to the STAT file only. Setting the flag to **BOTH** indicates that the line type should be written to the STAT file as well as a separate ASCII file where the data is grouped by line type. The output flags correspond to the following output line types:

1. **FHO** for Forecast, Hit, Observation Rates
2. **CTC** for Contingency Table Counts
3. **CTS** for Contingency Table Statistics
4. **MCTC** for Multi-category Contingency Table Counts
5. **MCTS** for Multi-category Contingency Table Statistics
6. **CNT** for Continuous Statistics
7. **SL1L2** for Scalar L1L2 Partial Sums
8. **SAL1L2** for Scalar Anomaly L1L2 Partial Sums when climatological data is supplied
9. **VL1L2** for Vector L1L2 Partial Sums
10. **VAL1L2** for Vector Anomaly L1L2 Partial Sums when climatological data is supplied
11. **PCT** for Contingency Table counts for Probabilistic forecasts
12. **PSTD** for contingency table Statistics for Probabilistic forecasts with Dichotomous outcomes
13. **PJC** for Joint and Conditional factorization for Probabilistic forecasts
14. **PRC** for Receiver Operating Characteristic for Probabilistic forecasts
15. **MPR** for Matched Pair data

Note that the first two line types are easily derived from each other. Users are free to choose which measures are most desired. The output line types are described in more detail in Section 7.3.3.

Note that writing out matched pair data (MPR lines) for a large number of cases is generally not recommended. The MPR lines create very large output files and are only intended for use on a small set of cases.

If all line types corresponding to a particular verification method are set to NONE, the computation of those statistics will be skipped in the code and thus make the Point-Stat tool run more efficiently. For example, if FHO, CTC, and CTS are all set to NONE, the Point-Stat tool will skip the categorical verification step.

7.3.3 point_stat output

point_stat produces output in STAT and, optionally, ASCII format. The ASCII output duplicates the STAT output but has the data organized by line type. The output files will be written to the default output directory or the directory specified using the "-outdir" command line option.

The output STAT file will be named using the following naming convention:

point_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV.stat where **PREFIX** indicates the user-defined output prefix, **HHMMSSL** indicates the forecast lead time and **YYYYMMDD_HHMMSS** indicates the forecast valid time.

The output ASCII files are named similarly:

point_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV_TYPE.txt where **TYPE** is one of **mpr**, **fho**, **ctc**, **cts**, **cnt**, **mctc**, **mcts**, **pct**, **pstd**, **pjc**, **prc**, **sl12**, **sal12**, **vl12**, or **val12** to indicate the line type it contains.

The first set of header columns are common to all of the output files generated by the Point-Stat tool. Tables describing the contents of the header columns and the contents of the additional columns for each line type are listed in the following tables.

Table 7.1: Header information for each file point-stat outputs.

HEADER		
Column Number	Header Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID_BEG	Forecast valid start time in YYYYMMDDHH format
5	FCST_VALID_END	Forecast valid end time in YYYYMMDDHH format
6	OBS_LEAD	Observation lead time in HHMMSS format
7	OBS_VALID_BEG	Observation valid start time in YYYYMMDDHH format
8	OBS_VALID_END	Observation valid end time in YYYYMMDDHH format
9	FCST_VAR	Model variable
10	FCST_LEV	Selected Vertical level for forecast
11	OBS_VAR	Observation variable
12	OBS_LEV	Selected Vertical level for observations
13	OBTYP	Observation message type selected
14	VX_MASK	Verifying masking region indicating the masking grid or polyline region applied
15	INTERP_MTHD	Interpolation method applied to forecasts
16	INTERP_PNTS	Number of points used in interpolation method
17	FCST_THRESH	The threshold applied to the forecast
18	OBS_THRESH	The threshold applied to the observations
19	COV_THRESH	NA in Point-Stat
20	ALPHA	Error percent value used in confidence intervals
21	LINE_TYPE	Output line types are listed in tables 7.2 through 7.18.

Table 7.2: Format information for FHO (Forecast, Hit rate, Observation rate) output line type.

FHO OUTPUT FORMAT		
Column Number	FHO Column Name	Description
21	FHO	Forecast, Hit, Observation line type
22	TOTAL	Total number of matched pairs
23	F_RATE	Forecast rate
24	H_RATE	Hit rate
25	O_RATE	Observation rate

Table 7.3: Format information for CTC (Contingency Table Counts) output line type.

CTC OUTPUT FORMAT		
Column Number	CTC Column Name	Description
21	CTC	Contingency Table Counts line type
22	TOTAL	Total number of matched pairs
23	FY_OY	Number of forecast yes and observation yes
24	FY_ON	Number of forecast yes and observation no
25	FN_OY	Number of forecast no and observation yes
26	FN_ON	Number of forecast no and observation no

Table 7.4: Format information for CTS (Contingency Table Statistics) output line type.

CTS OUTPUT FORMAT		
Column Number	CTS Column Name	Description
21	CTS	Contingency Table Statistics line type
22	TOTAL	Total number of matched pairs
23-27	BASER, BASER_NCL, BASER_NCU, BASER_BCL, BASER_BCU	Base rate including normal and bootstrap upper and lower confidence limits
28-32	FMEAN, FMEAN_NCL, FMEAN_NCU, FMEAN_BCL, FMEAN_BCU	Forecast mean including normal and bootstrap upper and lower confidence limits
33-37	ACC, ACC_NCL, ACC_NCU, ACC_BCL, ACC_BCU	Accuracy including normal and bootstrap upper and lower confidence limits
38-40	FBIAS, FBIAS_BCL, FBIAS_BCU	Frequency Bias including bootstrap upper and lower confidence limits
41-45	PODY, PODY_NCL, PODY_NCU, PODY_BCL, PODY_BCU	Probability of detecting yes including normal and bootstrap upper and lower confidence limits
46-50	PODN, PODN_NCL, PODN_NCU, PODN_BCL, PODN_BCU	Probability of detecting no including normal and bootstrap upper and lower confidence limits
51-55	POFD, POFD_NCL, POFD_NCU, POFD_BCL, POFD_BCU	Probability of false detection including normal and bootstrap upper and lower confidence limits
56-60	FAR, FAR_NCL, FAR_NCU, FAR_BCL, FAR_BCU	False alarm ratio including normal and bootstrap upper and lower confidence limits
61-65	CSI, CSI_NCL, CSI_NCU, CSI_BCL, CSI_BCU	Critical Success Index including normal and bootstrap upper and lower confidence limits
66-68	GSS, GSS_BCL, GSS_BCU	Gilbert Skill Score including bootstrap upper and lower confidence limits

Table 7.5: Format information for CTS (Contingency Table Statistics) output line type, continued from above

CTS OUTPUT FORMAT		
Column Number	CTS Column Name	Description
69-73	HK, HK_NCL, HK_NCU, HK_BCL, HK_BCU	Hanssen-Kuipers Discriminant including normal and bootstrap upper and lower confidence limits
74-76	HSS, HSS_BCL, HSS_BCU	Heidke Skill Score including bootstrap upper and lower confidence limits
77-81	ODDS, ODDS_NCL, ODDS_NCU, ODDS_BCL, ODDS_BCU	Odds Ratio including normal and bootstrap upper and lower confidence limits
82-86	LODDS, LODDS_NCL, LODDS_NCU, LODDS_BCL, LODDS_BCU	Logarithm of the Odds Ratio including normal and bootstrap upper and lower confidence limits
87-91	ORSS, ORSS_NCL, ORSS_NCU, ORSS_BCL, ORSS_BCU	Odds Ratio Skill Score including normal and bootstrap upper and lower confidence limits
92-96	EDS, EDS_NCL, EDS_NCU, EDS_BCL, EDS_BCU	Extreme Dependency Score including normal and bootstrap upper and lower confidence limits
97-101	SEDS, SEDS_NCL, SEDS_NCU, SEDS_BCL, SEDS_BCU	Symmetric Extreme Dependency Score including normal and bootstrap upper and lower confidence limits
102-106	EDI, EDI_NCL, EDI_NCU, EDI_BCL, EDI_BCU	Extreme Dependency Index including normal and bootstrap upper and lower confidence limits
107-111	SEDI, SEDI_NCL, SEDI_NCU, SEDI_BCL, SEDI_BCU	Symmetric Extremal Dependency Index including normal and bootstrap upper and lower confidence limits
112-114	BAGSS, BAGSS_BCL, BAGSS_BCU	Bias Adjusted Gilbert Skill Score including bootstrap upper and lower confidence limits

Table 7.6: Format information for CNT(Continuous Statistics) output line type.

CNT OUTPUT FORMAT		
Column Number	CNT Column Name	Description
21	CNT	Continuous statistics line type
22	TOTAL	Total number of matched pairs
23-27	FBAR, FBAR_NCL, FBAR_NCU, FBAR_BCL, FBAR_BCU	Forecast mean including normal and bootstrap upper and lower confidence limits
28-32	FSTDEV, FSTDEV_NCL, FSTDEV_NCU, FSTDEV_BCL, FSTDEV_BCU	Standard deviation of the forecasts including normal and bootstrap upper and lower confidence limits
33-37	OBAR, OBAR_NCL, OBAR_NCU, OBAR_BCL, OBAR_BCU	Observation mean including normal and bootstrap upper and lower confidence limits
38-42	OSTDEV, OSTDEV_NCL, OSTDEV_NCU, OSTDEV_BCL, OSTDEV_BCU	Standard deviation of the observations including normal and bootstrap upper and lower confidence limits
43-47	PR_CORR, PR_CORR_NCL, PR_CORR_NCU, PR_CORR_BCL, PR_CORR_BCU	Pearson correlation coefficient including normal and bootstrap upper and lower confidence limits
48	SP_CORR	Spearman's rank correlation coefficient
49	KT_CORR	Kendall's tau statistic
50	RANKS	Number of ranks used in computing Kendall's tau statistic
51	FRANK_TIES	Number of tied forecast ranks used in computing Kendall's tau statistic
52	ORANK_TIES	Number of tied observation ranks used in computing Kendall's tau statistic
53-57	ME, ME_NCL, ME_NCU, ME_BCL, ME_BCU	Mean error (F-O) including normal and bootstrap upper and lower confidence limits
58-62	ESTDEV, ESTDEV_NCL, ESTDEV_NCU, ESTDEV_BCL, ESTDEV_BCU	Standard deviation of the error including normal and bootstrap upper and lower confidence limits

Table 7.7: Format information for CNT(Continuous Statistics) output line type continued from above table

CNT OUTPUT FORMAT		
Column Number	CNT Column Name	Description
63-65	MBIAS, MBIAS_BCL, MBIAS_BCU	Multiplicative bias including bootstrap upper and lower confidence limits
66-68	MAE, MAE_BCL, MAE_BCU	Mean absolute error including bootstrap upper and lower confidence limits
68-71	MSE, MSE_BCL, MSE_BCU	Mean squared error including bootstrap upper and lower confidence limits
72-74	BCMSE, BCMSE_BCL, BCMSE_BCU	Bias-corrected mean squared error including bootstrap upper and lower confidence limits
75-77	RMSE, RMSE_BCL, RMSE_BCU	Root mean squared error including bootstrap upper and lower confidence limits
78-92	E10, E10_BCL, E10_BCU, E25, E25_BCL, E25_BCU, E50, E50_BCL, E50_BCU, E75, E75_BCL, E75_BCU, E90, E90_BCL, E90_BCU	10th, 25th, 50th, 75th, and 90th percentiles of the error including bootstrap upper and lower confidence limits
93-95	IQR, IQR_BCL, IQR_BCU	The Interquartile Range including bootstrap upper and lower confidence limits
96-98	MAD, MAD_BCL, MAD_BCU	The Median Absolute Deviation including bootstrap upper and lower confidence limits
99-103	ANOM_CORR, ANOM_CORR_NCL, ANOM_CORR_NCU, ANOM_CORR_BCL, ANOM_CORR_BCU	The Anomaly Correlation including normal and bootstrap upper and lower confidence limits.
104-106	ME2, ME2_BCL, ME2_BCU	The square of the mean error (bias) including bootstrap upper and lower confidence limits.
107-109	MSESS, MSESS_BCL, MSESS_BCU	The mean squared error skill score including bootstrap upper and lower confidence limits.

Table 7.8: Format information for MCTC (Multi-category Contingency Table Count) output line type.

MCTC OUTPUT FORMAT		
Column Number	MCTC Column Name	Description
21	MCTC	Multi-category Contingency Table Counts line type
22	TOTAL	Total number of matched pairs
23	N_CAT	Dimension of the contingency table.
24-??	Fi_Oj	Count of events in forecast category i and observation category j, with the observations incrementing first.

Table 7.9: Format information for MCTS (Multi- category Contingency Table Statistics) output line type.

MCTS OUTPUT FORMAT		
Column Number	MCTS Column Name	Description
21	MCTS	Multi-category Contingency Table Statistics line type
22	TOTAL	Total number of matched pairs
23	N_CAT	The total number of categories in each of dimension of the contingency table. So the total number of cells is N_CAT*N_CAT.
24-28	ACC, ACC_NCL, ACC_NCU, ACC_BCL, ACC_BCU	Accuracy, normal confidence limits and bootstrap confidence limits
29-31	HK, HK_BCL, HK_BCU	Hanssen and Kuipers Discriminant and bootstrap confidence limits
32-34	HSS, HSS_BCL, HSS_BCU	Heidke Skill Score and bootstrap confidence limits
35-37	GER, GER_BCL, GER_BCU	Gerrity Score and bootstrap confidence limits

Table 7.10: Format information for PCT (Contingency Table Counts for Probabilistic forecasts) output line type.

PCT OUTPUT FORMAT		
Column Number	PCT Column Name	Description
21	PCT	Probability contingency table count line type
22	TOTAL	Total number of matched pairs
23	N_THRESH	Number of probability thresholds
24	THRESH_i	The ith probability threshold value (repeated)
25	OY_i	Number of observation yes when forecast is between the ith and i+1th probability thresholds (repeated)
26	ON_i	Number of observation no when forecast is between the ith and i+1th probability thresholds (repeated)
*	THRESH_n	Last probability threshold value

Table 7.11: Format information for PSTD (Contingency Table Statistics for Probabilistic forecasts) output line type.

PSTD OUTPUT FORMAT		
Column Number	PSTD Column Name	Description
21	PSTD	Probabilistic statistics for dichotomous outcome line type
22	TOTAL	Total number of matched pairs
23	N_THRESH	Number of probability thresholds
24-26	BASER, BASER_NCL, BASER_NCU	The Base Rate, including normal upper and lower confidence limits
27	RELIABILITY	Reliability
28	RESOLUTION	Resolution
29	UNCERTAINTY	Uncertainty
30	ROC_AUC	Area under the receiver operating characteristic curve
31-33	BRIER, BRIER_NCL, BRIER_NCU	Brier Score including normal upper and lower confidence limits
34-36	BRIERCL, BRIERCL_NCL, BRIERCL_NCU	Climatological Brier Score including upper and lower normal confidence limits
37	BSS	Brier Skill Score
38	THRESH_i	The ith probability threshold value (repeated)

Table 7.12: Format information for PJC (Joint and Conditional factorization for Probabilistic forecasts) output line type.

PJC OUTPUT FORMAT		
Column Number	PJC Column Name	Description
21	PJC	Probabilistic Joint/Continuous line type
22	TOTAL	Total number of matched pairs
23	N_THRESH	Number of probability thresholds
24	THRESH_i	The ith probability threshold value (repeated)
25	OY_TP_i	Number of observation yes when forecast is between the ith and i+1th probability thresholds as a proportion of the total OY (repeated)
26	ON_TP_i	Number of observation no when forecast is between the ith and i+1th probability thresholds as a proportion of the total ON (repeated)
27	CALIBRATION_i	Calibration when forecast is between the ith and i+1th probability thresholds (repeated)
28	REFINEMENT_i	Refinement when forecast is between the ith and i+1th probability thresholds (repeated)
29	LIKELIHOOD_i	Likelihood when forecast is between the ith and i+1th probability thresholds (repeated)
30	BASER_i	Base rate when forecast is between the ith and i+1th probability thresholds (repeated)
*	THRESH_n	Last probability threshold value

Table 7.13: Format information for PRC (PRC for Receiver Operating Characteristic for Probabilistic forecasts) output line type.

PRC OUTPUT FORMAT		
Column Number	PRC Column Name	Description
21	PRC	Probability ROC points line type
22	TOTAL	Total number of matched pairs
23	N_THRESH	Number of probability thresholds
24	THRESH_i	The ith probability threshold value (repeated)
25	PODY_i	Probability of detecting yes when forecast is between the ith and i+1th probability thresholds (repeated)
26	POFD_i	Probability of false detection when forecast is between the ith and i+1th probability thresholds (repeated)
*	THRESH_n	Last probability threshold value

Table 7.14: Format information for SL1L2 (Scalar Partial Sums) output line type.

SL1L2 OUTPUT FORMAT		
Column Number	SL1L2 Column Name	Description
21	SL1L2	Scalar L1L2 line type
22	TOTAL	Total number of matched pairs of forecast (f) and observation (o)
23	FBAR	Mean(f)
24	OBAR	Mean(o)
25	FOBAR	Mean(f*o)
26	FFBAR	Mean(f ²)
27	OOBAR	Mean(o ²)
28	MAE	Mean Absolute Error

Table 7.15: Format information for SAL1L2 (Scalar Anomaly Partial Sums) output line type.

SAL1L2 OUTPUT FORMAT		
Column Number	SAL1L2 Column Name	Description
21	SAL1L2	Scalar Anomaly L1L2 line type
22	TOTAL	Total number of matched triplets of forecast (f), observation (o), and climatological value (c)
23	FABAR	Mean(f-c)
24	OABAR	Mean(o-c)
25	FOABAR	Mean((f-c)*(o-c))
26	FFABAR	Mean((f-c) ²)
27	OOABAR	Mean((o-c) ²)
28	MAE	Mean Absolute Error

Table 7.16: Format information for VL1L2 (Vector Partial Sums) output line type.

VL1L2 OUTPUT FORMAT		
Column Number	VL1L2 Column Name	Description
21	VL1L2	Vector L1L2 line type
22	TOTAL	Total number of matched pairs of forecast winds (uf, vf) and observation winds (uo, vo)
23	UFBAR	Mean(uf) ²
24	VFBAR	Mean(vf) ²
25	UOBAR	Mean(uo) ²
26	VOBAR	Mean(vo) ²
27	UVFOBAR	Mean(uf*uo+vf*vo)
28	UVFFBAR	Mean(uf ² +vf ²)
29	UVOOBAR	Mean(uo ² +vo ²)

Table 7.17: Format information for VAL1L2 (Vector Anomaly Partial Sums) output line type.

VAL1L2 OUTPUT FILE		
Column Number	VAL1L2 Column Name	Description
21	VAL1L2	Vector Anomaly L1L2 line type
22	TOTAL	Total number of matched triplets of forecast winds (uf, vf), observation winds (uo, vo), and climatological winds (uc, vc)
23	UFABAR	Mean(uf-uc) ²
24	VFABAR	Mean(vf-vc) ²
25	UOABAR	Mean(uo-uc) ²
26	VOABAR	Mean(vo-vc) ²
27	UVFOABAR	Mean((uf-uc)*(uo-uc)+(vf-vc)*(vo-vc))
28	UVFFABAR	Mean((uf-uc) ² +(vf-vc) ²)
29	UVOOABAR	Mean((uo-uc) ² +(vo-vc) ²)

Table 7.18: Format information for MPR (Matched Pair) output line type.

MPR OUTPUT FORMAT		
Column Number	MPR Column Name	Description
21	MPR	Matched Pair line type
22	TOTAL	Total number of matched pairs
23	INDEX	Index for the current matched pair
24	OBS_SID	Station Identifier of observation
25	OBS_LAT	Latitude of the observation in degrees north
26	OBS_LON	Longitude of the observation in degrees east
27	OBS_LVL	pressure level of the observation in hPa or accumulation interval in hours
28	OBS_ELV	Elevation of the observation in meters above sea level
29	FCST	Forecast value interpolated to the observation location
30	OBS	Observation value
31	CLIMO	Climatological value
32	OBS_QC	Quality control flag for observation

The STAT output files described for `point_stat` may be used as inputs to the Stat-Analysis tool. For more information on using the Stat-Analysis tool to create stratifications and aggregations of the STAT files produced by `point_stat`, please see Chapter 12.

Chapter 8

Grid-Stat Tool

8.1 Introduction

The Grid-Stat tool provides verification statistics for a matched forecast and observation grid. All of the forecast grid points in the region of interest are matched to observation grid points on the same grid. All the matched grid points are used to compute the verification statistics. The Grid-Stat tool functions in much the same way as the Point-Stat tool, except that no interpolation is required because the forecasts and observations are on the same grid. However, the interpolation parameters may be used to perform a smoothing operation on the forecast and observation fields prior to verification. In addition to traditional verification approaches, the Grid-Stat tool includes neighborhood methods, designed to examine forecast performance as a function of spatial scale.

Scientific and statistical aspects of the Grid-Stat tool are briefly described in this chapter, followed by practical details regarding usage and output from the tool.

8.2 Scientific and statistical aspects

8.2.1 Statistical measures

The Grid-Stat tool computes a wide variety of verification statistics. Broadly speaking, these statistics can be subdivided into three types of statistics: measures for categorical variables, measures for continuous variables, and measures for probabilistic forecasts. Further, when a climatology file is included, reference statistics for the forecasts compared to the climatology can be calculated. These categories of measures are briefly described here; specific descriptions of all measures are provided in Appendix C. Additional information can be found in Wilks (2011) and Jolliffe and Stephenson (2012), and on the world-wide web at

http://www.cawcr.gov.au/projects/verification/verif_web_page.html.

In addition to these verification measures, the Grid-Stat tool also computes partial sums and other FHO statistics that are produced by the NCEP verification system. These statistics are also described in Appendix C.

Measures for categorical variables

Categorical verification statistics are used to evaluate forecasts that are in the form of a discrete set of categories rather than on a continuous scale. Grid-Stat computes both 2x2 and multi-category contingency tables and their associated statistics, similar to Point-Stat. See Appendix C for more information.

Measures for continuous variables

For continuous variables, many verification measures are based on the forecast error (i.e., $f - o$). However, it also is of interest to investigate characteristics of the forecasts, and the observations, as well as their relationship. These concepts are consistent with the general framework for verification outlined by Murphy and Winkler (1987). The statistics produced by MET for continuous forecasts represent this philosophy of verification, which focuses on a variety of aspects of performance rather than a single measure. See Appendix C for specific information.

A user may wish to eliminate certain values of the forecasts from the calculation of statistics, a process referred to here as “conditional verification”. For example, a user may eliminate all temperatures above freezing and then calculate the error statistics only for those forecasts of below freezing temperatures. Another common example involves verification of wind forecasts. Since wind direction is indeterminate at very low wind speeds, the user may wish to set a minimum wind speed threshold prior to calculating error statistics for wind direction. The user may specify these thresholds in the configuration file to specify the conditional verification. Thresholds can be specified using the usual Fortran conventions ($<$, $<=$, $=$, $!$, $>=$, or $>$) followed by a numeric value. The threshold type may also be specified using two letter abbreviations (lt, le, eq, ne, ge, gt). Further, more complex thresholds can be achieved by defining multiple thresholds and using $\&\&$ or $||$ to string together event definition logic. The forecast and observation threshold can be used together according to user preference by specifying one of: UNION, INTERSECTION, or SYMDIFF (symmetric difference).

Measures for probabilistic forecasts and dichotomous outcomes

For probabilistic forecasts, many verification measures are based on reliability, accuracy and bias. However, it also is of interest to investigate joint and conditional distributions of the forecasts and the observations, as in Wilks (2011). See Appendix C for specific information.

Probabilistic forecast values are assumed to have a range of either 0 to 1 or 0 to 100. If the max data value is > 1 , we assume the data range is 0 to 100, and divide all the values by 100. If the max data value is $<= 1$, then we use the values as is. Further, thresholds are applied to the probabilities with equality on the lower end. For example, with a forecast probability p , and thresholds $t1$ and $t2$, the range is defined as: $t1 <= p < t2$. The exception is for the highest set of thresholds, when the range includes 1: $t1 <= p <= 1$.

Use of a climatology field for comparative verification

The Grid-Stat tool allows evaluation of model forecasts compared with a user-supplied climatology. Prior to calculation of statistics, the climatology must be put on the same grid as the forecasts and observations. In particular, the anomaly correlation and mean squared error skill score provide a measure of the forecast skill versus the climatology. For more details about climatological comparisons and reference forecasts, see the relevant section in the Point-Stat Chapter, Section 7.2.2

Use of analysis fields for verification

The Grid-Stat tool allows evaluation of model forecasts using model analysis fields. However, users are cautioned that an analysis field is not independent of its parent model; for this reason verification of model output using an analysis field from the same model is generally not recommended and is not likely to yield meaningful information about model performance.

8.2.2 Statistical confidence intervals

The confidence intervals for the Grid-Stat tool are the same as those provided for the Point-Stat tool except that the scores are based on pairing grid points with grid points so that there are likely more values for each field making any assumptions based on the central limit theorem more likely to be valid. However, it should be noted that spatial (and temporal) correlations are not presently taken into account in the confidence interval calculations. Therefore, confidence intervals reported may be somewhat too narrow (e.g., Efron 2007). See Appendix D for details regarding confidence intervals provided by MET.

8.2.3 Neighborhood methods

MET also incorporates several neighborhood methods to give credit to forecasts that are close to the observations, but not necessarily exactly matched up in space. Also referred to as “fuzzy” verification methods, these methods do not just compare a single forecast at each grid point to a single observation at each grid point; they compare the forecasts and observations in a neighborhood surrounding the point of interest. With the neighborhood method, the user chooses a distance within which the forecast event can fall from the observed event and still be considered a hit. In MET this is implemented by defining a square search window around each grid point. Within the search window, the number of observed events is compared to the number of forecast events. In this way, credit is given to forecasts that are close to the observations without requiring a strict match between forecasted events and observed events at any particular grid point. The neighborhood methods allow the user to see how forecast skill varies with neighborhood size and can help determine the smallest neighborhood size that can be used to give sufficiently accurate forecasts.

There are several ways to present the results of the neighborhood approaches, such as the Fractions Skill Score (FSS) or the Fractions Brier Score (FBS). These scores are presented in Appendix C. One can also simply

up-scale the information on the forecast verification grid by smoothing or resampling within a specified neighborhood around each grid point and recalculate the traditional verification metrics on the coarser grid. The MET output includes traditional contingency table statistics for each threshold and neighborhood window size.

The user must specify several parameters in the `grid_stat` configuration file to utilize the neighborhood approach, such as the interpolation method, size of the smoothing window, and required fraction of valid data points within the smoothing window. For FSS-specific results, the user must specify the size of the neighborhood window, the required fraction of valid data points within the window, and the fractional coverage threshold from which the contingency tables are defined. These parameters are described further in the practical information section below.

8.3 Practical information

This section contains information about configuring and running the Grid-Stat tool. The Grid-Stat tool verifies gridded model data using gridded observations. The input gridded model and observation datasets must be in one of the MET supported file formats. The requirement of having all gridded fields using the same grid specification has been removed with METv5.1. There is a `regrid` option in the configuration file that allows the user to define the grid upon which the scores will be computed. The gridded observation data may be a gridded analysis based on observations such as Stage II or Stage IV data for verifying accumulated precipitation, or a model analysis field may be used.

The Grid-Stat tool provides the capability of verifying one or more model variables/levels using multiple thresholds for each model variable/level. The Grid-Stat tool performs no interpolation when the input model, observation, and climatology datasets must be on a common grid. MET will interpolate these files to a common grid if one is specified. The interpolation parameters may be used to perform a smoothing operation on the forecast field prior to verifying it to investigate how the scale of the forecast affects the verification statistics. The Grid-Stat tool computes a number of continuous statistics for the forecast minus observation differences, discrete statistics once the data have been thresholded, or statistics for probabilistic forecasts. All types of statistics can incorporate a climatological reference.

8.3.1 `grid_stat` usage

The usage statement for the Grid-Stat tool is listed below:

```
Usage: grid_stat
       fcst_file
       obs_file
       config_file
       [-outdir path]
       [-log file]
       [-v level]
```

grid_stat has three required arguments and accepts several optional ones.

Required arguments for grid_stat

1. The **fcst_file** argument indicates the gridded file containing the model data to be verified.
2. The **obs_file** argument indicates the gridded file containing the gridded observations to be used for the verification of the model.
3. The **config_file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for grid_stat

4. The **-outdir path** indicates the directory where output files should be written.
5. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
6. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

An example of the grid_stat calling sequence is listed below:

Example 1:

```
grid_stat sample_fcst.grb \  
sample_obs.grb \  
GridStatConfig
```

In Example 1, the Grid-Stat tool will verify the model data in the sample_fcst.grb GRIB file using the observations in the sample_obs.grb GRIB file applying the configuration options specified in the GridStatConfig file.

A second example of the grid_stat calling sequence is listed below:

Example 2:

```
grid_stat sample_fcst.nc  
sample_obs.nc  
GridStatConfig
```

In the second example, the Grid-Stat tool will verify the model data in the sample_fcst.nc NetCDF output of **pcp_combine**, using the observations in the sample_obs.nc NetCDF output of **pcp_combine**, and applying the configuration options specified in the GridStatConfig file. Because the model and observation files contain only a single field of accumulated precipitation, the GridStatConfig file should be configured to specify that only accumulated precipitation be verified.

8.3.2 grid_stat configuration file

The default configuration file for the Grid-Stat tool, named `GridStatConfig_default`, can be found in the installed `share/met/config` directory. Other versions of the configuration file are included in `scripts/config`. We recommend that users make a copy of the default (or other) configuration file prior to modifying it. The contents are described in more detail below.

Note that environment variables may be used when editing configuration files, as described in Section 4.1.2 for the PB2NC tool.

```

model          = "WRF";
obtype         = "ANALYS";
regrid         = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }
climo_mean     = {}
mask           = { grid = [ "FULL" ]; poly = []; }
ci_alpha       = [ 0.05 ];
boot           = { interval = PCTILE; rep_prop = 1.0; n_rep = 1000;
                  rng = "mt19937"; seed = ""; }
interp         = { field = BOTH; vld_thresh = 1.0;
                  type = [ { method = NEAREST; width = 1; } ]; }
rank_corr_flag = TRUE;
tmp_dir        = "/tmp";
output_prefix  = "";
version        = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```

nbrhd = {
  vld_thresh = 1.0;
  width      = [ 1 ];
  cov_thresh = [ >=0.5 ];
}

```

The `nbrhd` dictionary contains a list of values to be used in defining the neighborhood to be used when computing neighborhood verification statistics. The neighborhood is simply a square centered on the current point and the `width` value specifies the width of that square as an odd integer.

The `vld_thresh` entry contains a number between 0 and 1. When performing neighborhood verification over some neighborhood of points the ratio of the number of valid data points to the total number of points

in the neighborhood is computed. If that ratio is greater than this threshold, that value is included in the neighborhood verification. Setting this threshold to 1, which is the default, requires that the entire neighborhood must contain valid data. This variable will typically come into play only along the boundaries of the verification region chosen.

The `cov_thresh` entry contains a comma separated list of thresholds to be applied to the neighborhood coverage field. The coverage is the proportion of forecast points in the neighborhood that exceed the forecast threshold. For example, if 10 of the 25 forecast grid points contain values larger than a threshold of 2, then the coverage is $10/25 = 0.4$. If the coverage threshold is set to 0.5, then this neighborhood is considered to be a “No” forecast.

```
output_flag = {
    fho    = BOTH;
    ctc    = BOTH;
    cts    = BOTH;
    mctc   = BOTH;
    mcts   = BOTH;
    cnt    = BOTH;
    sl112  = BOTH;
    sal112 = NONE;
    vl112  = BOTH;
    val112 = NONE;
    pct    = BOTH;
    pstd   = BOTH;
    pjc    = BOTH;
    prc    = BOTH;
    nbrctc = BOTH;
    nbrcts = BOTH;
    nbrcnt = BOTH;
}
```

The `output_flag` array controls the type of output that the Grid-Stat tool generates. Each flag corresponds to an output line type in the STAT file. Setting the flag to `NONE` indicates that the line type should not be generated. Setting the flag to `STAT` indicates that the line type should be written to the STAT file only. Setting the flag to `BOTH` indicates that the line type should be written to the STAT file as well as a separate ASCII file where the data are grouped by line type. These output flags correspond to the following types of output line types:

1. **FHO** for Forecast, Hit, Observation Rates
2. **CTC** for Contingency Table Counts

3. **CTS** for Contingency Table Statistics
4. **MCTC** for Multi-Category Contingency Table Counts
5. **MCTS** for Multi-Category Contingency Table Statistics
6. **CNT** for Continuous Statistics
7. **SL1L2** for Scalar L1L2 Partial Sums
8. **SAL1L2** for Scalar Anomaly L1L2 Partial Sums when climatological data is supplied
9. **VL1L2** for Vector L1L2 Partial Sums
10. **VAL1L2** for Vector Anomaly L1L2 Partial Sums when climatological data is supplied
11. **PCT** for Contingency Table Counts for Probabilistic forecasts
12. **PSTD** for Contingency Table Statistics for Probabilistic forecasts
13. **PJC** for Joint and Conditional factorization for Probabilistic forecasts
14. **PRC** for Receiver Operating Characteristic for Probabilistic forecasts
15. **NBRCTC** for Neighborhood Contingency Table Counts
16. **NBRCTS** for Neighborhood Contingency Table Statistics
17. **NBRCNT** for Neighborhood Continuous Statistics

Note that the first two line types are easily derived from one another. The user is free to choose which measure is most desired. The output line types are described in more detail in Section 8.3.3.

```
nc_pairs_flag = {  
    latlon = TRUE;  
    raw    = TRUE;  
    diff   = TRUE;  
}
```

The `nc_pairs_flag` entry may either be set to a boolean value or a dictionary specifying which fields should be written. Setting it to `TRUE` indicates the output NetCDF matched pairs file should be created with all available output fields, while setting all to `FALSE` disables its creation. The `latlon`, `raw`, and `diff` entries control the creation of output variables for the latitude and longitude, the raw forecast and observed fields, and the forecast minus observation difference fields. Setting these entries to `TRUE` indicates that they should be written, while setting them to `FALSE` disables their creation.

8.3.3 grid_stat output

grid_stat produces output in STAT and, optionally, ASCII and NetCDF formats. The ASCII output duplicates the STAT output but has the data organized by line type. The output files are written to the default output directory or the directory specified by the `-outdir` command-line option.

The output STAT file is named using the following naming convention:

`grid_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV.stat` where PREFIX indicates the user-defined output prefix, HHMMSSL indicates the forecast lead time and YYYYMMDD_HHMMSSV indicates the forecast valid time.

The output ASCII files are named similarly:

`grid_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV_TYPE.txt` where TYPE is one of fho, etc, cts, mctc, mcts, cnt, sl1l2, vl1l2, pct, pstd, pjc, prc, nbrctc, nbrcs, and nbrcnt to indicate the line type it contains.

The format of the STAT and ASCII output of the Grid-Stat tool are the same as the format of the STAT and ASCII output of the Point-Stat tool with the exception of the three additional neighborhood line types. Please refer to the tables in Section 7.3.3 (**point_stat** output) for a description of the common output STAT and optional ASCII file line types. The formats of the three additional neighborhood line types for `grid_stat` are explained in the following tables.

Table 8.1: Header information for each file grid-stat outputs.

HEADER		
Column Number	Header Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID_BEG	Forecast valid start time in YYYYMMDDHH format
5	FCST_VALID_END	Forecast valid end time in YYYYMMDDHH format
6	OBS_LEAD	Observation lead time in HHMMSS format
7	OBS_VALID_BEG	Observation valid start time in YYYYMMDDHH format
8	OBS_VALID_END	Observation valid end time in YYYYMMDDHH format
9	FCST_VAR	Model variable
10	FCST_LEV	Selected Vertical level for forecast
11	OBS_VAR	Observation variable
12	OBS_LEV	Selected Vertical level for observations
13	OBTYPE	User provided text string designating the observation type
14	VX_MASK	Verifying masking region indicating the masking grid or polyline region applied
15	INTERP_MTHD	Interpolation method applied to forecast field
16	INTERP_PNTS	Number of points used by interpolation method
17	FCST_THRESH	The threshold applied to the forecast
18	OBS_THRESH	The threshold applied to the observations
19	COV_THRESH	Proportion of observations in specified neighborhood which must exceed obs_thresh
20	ALPHA	Error percent value used in confidence intervals
21	LINE_TYPE	Various line type options, refer to Section 7.3.3 and the tables below.

Table 8.2: Format information for NBRCTC (Neighborhood Contingency Table Counts) output line type.

NBRCTC OUTPUT FORMAT		
Column Number	NBRCTC Column Name	Description
21	NBRCTC	Neighborhood Contingency Table Counts line type
22	TOTAL	Total number of matched pairs
23	FY_OY	Number of forecast yes and observation yes
24	FY_ON	Number of forecast yes and observation no
25	FN_OY	Number of forecast no and observation yes
26	FN_ON	Number of forecast no and observation no

Table 8.3: Format information for NBRCTS (Neighborhood Contingency Table Statistics) output line type.

NBRCTS OUTPUT FORMAT		
Column Number	NBRCTS Column Name	Description
21	NBRCTS	Neighborhood Contingency Table Statistics line type
22	TOTAL	Total number of matched pairs
23-27	BASER, BASER_NCL, BASER_NCU, BASER_BCL, BASER_BCU	Base rate including normal and bootstrap upper and lower confidence limits
28-32	FMEAN, FMEAN_NCL, FMEAN_NCU, FMEAN_BCL, FMEAN_BCU	Forecast mean including normal and bootstrap upper and lower confidence limits
33-37	ACC, ACC_NCL, ACC_NCU, ACC_BCL, ACC_BCU	Accuracy including normal and bootstrap upper and lower confidence limits
38-40	FBIAS, FBIAS_BCL, FBIAS_BCU	Frequency Bias including bootstrap upper and lower confidence limits
41-45	PODY, PODY_NCL, PODY_NCU, PODY_BCL, PODY_BCU	Probability of detecting yes including normal and bootstrap upper and lower confidence limits
46-50	PODN, PODN_NCL, PODN_NCU, PODN_BCL, PODN_BCU	Probability of detecting no including normal and bootstrap upper and lower confidence limits
51-55	POFD, POFD_NCL, POFD_NCU, POFD_BCL, POFD_BCU	Probability of false detection including normal and bootstrap upper and lower confidence limits
56-60	FAR, FAR_NCL, FAR_NCU, FAR_BCL, FAR_BCU	False alarm ratio including normal and bootstrap upper and lower confidence limits
61-65	CSI, CSI_NCL, CSI_NCU, CSI_BCL, CSI_BCU	Critical Success Index including normal and bootstrap upper and lower confidence limits
66-68	GSS, GSS_BCL, GSS_BCU	Gilbert Skill Score including bootstrap upper and lower confidence limits

Table 8.4: Format information for NBRCTS (Neighborhood Contingency Table Statistics) output line type, continued from above.

Column Number	NBRCTS Column Name	Description
69-73	HK, HK_NCL, HK_NCU, HK_BCL, HK_BCU	Hanssen-Kuipers Discriminant including normal and bootstrap upper and lower confidence limits
74-76	HSS, HSS_BCL, HSS_BCU	Heidke Skill Score including bootstrap upper and lower confidence limits
77-81	ODDS, ODDS_NCL, ODDS_NCU, ODDS_BCL, ODDS_BCU	Odds Ratio including normal and bootstrap upper and lower confidence limits
82-86	LODDS, LODDS_NCL, LODDS_NCU, LODDS_BCL, LODDS_BCU	Logarithm of the Odds Ratio including normal and bootstrap upper and lower confidence limits
87-91	ORSS, ORSS_NCL, ORSS_NCU, ORSS_BCL, ORSS_BCU	Odds Ratio Skill Score including normal and bootstrap upper and lower confidence limits
92-96	EDS, EDS_NCL, EDS_NCU, EDS_BCL, EDS_BCU	Extreme Dependency Score including normal and bootstrap upper and lower confidence limits
97-101	SEDS, SEDS_NCL, SEDS_NCU, SEDS_BCL, SEDS_BCU	Symmetric Extreme Dependency Score including normal and bootstrap upper and lower confidence limits
102-106	EDI, EDI_NCL, EDI_NCU, EDI_BCL, EDI_BCU	Extreme Dependency Index including normal and bootstrap upper and lower confidence limits
107-111	SEDI, SEDI_NCL, SEDI_NCU, SEDI_BCL, SEDI_BCU	Symmetric Extremal Dependency Index including normal and bootstrap upper and lower confidence limits
112-114	BAGSS, BAGSS_BCL, BAGSS_BCU	Bias Adjusted Gilbert Skill Score including bootstrap upper and lower confidence limits

Table 8.5: Format information for NBRCNT(Neighborhood Continuous Statistics) output line type.

NBRCNT OUTPUT FORMAT		
Column Number	NBRCNT Column Name	Description
21	NBRCNT	Neighborhood Continuous statistics line type
22	TOTAL	Total number of matched pairs
23-25	FBS, FBS_BCL, FBS_BCU	Fractions Brier Score including bootstrap upper and lower confidence limits
26-28	FSS, FSS_BCL, FSS_BCU	Fractions Skill Score including bootstrap upper and lower confidence limits
29-31	AFSS, AFSS_BCL, AFSS_BCU	Asymptotic Fractions Skill Score including bootstrap upper and lower confidence limits
32-34	UFSS, UFSS_BCL, UFSS_BCU	Uniform Fractions Skill Score including bootstrap upper and lower confidence limits
35-37	F_RATE, F_RATE_BCL, F_RATE_BCU	Forecast event frequency including bootstrap upper and lower confidence limits
38-40	O_RATE, O_RATE_BCL, O_RATE_BCU	Observed event frequency including bootstrap upper and lower confidence limits

If requested in the `output_flag` array, a NetCDF file containing the matched pair and forecast minus observation difference fields for each combination of variable type/level and masking region applied will be generated. The output NetCDF file is named similarly to the other output files: `grid_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV_pairs.nc`. Commonly available NetCDF utilities such as `ncdump` or `ncview` may be used to view the contents of the output file.

The output NetCDF file contains the dimensions and variables shown in the following Tables 8.6 and 8.7.

Table 8.6: Dimensions defined in NetCDF matched pair output.

grid_stat NETCDF DIMENSIONS	
NetCDF Dimension	Description
Lat	Dimension of the latitude (i.e. Number of grid points in the North-South direction)
Lon	Dimension of the longitude (i.e. Number of grid points in the East-West direction)

Table 8.7: Variables defined in NetCDF matched pair output.

grid_stat NETCDF VARIABLES		
NetCDF Variable	Dimension	Description
FCST_VAR_LVL_MASK _INTERP_MTHD _INTERP_PNTS	lat, lon	For each model variable (VAR), vertical level (LVL), masking region (MASK), and, if applicable, smoothing operation (INTERP_MTHD and INTERP_PNTS), the forecast value is listed for each point in the mask
OBS_VAR_LVL_MASK	lat, lon	For each model variable (VAR), vertical level (LVL), and masking region (MASK), the observation value is listed for each point in the mask
DIFF_FCSTVAR _FCSTLVL _OBSVAR _OBSLVL_MASK _INTERP_MTHD _INTERP_PNTS	lat, lon	For each model variable (VAR), vertical level (LVL), masking region (MASK), and, if applicable, smoothing operation (INTERP_MTHD and INTERP_PNTS), the difference (forecast - observation) is computed for each point in the mask

The STAT output files described for **grid_stat** may be used as inputs to the Stat-Analysis tool. For more information on using the Stat-Analysis tool to create stratifications and aggregations of the STAT files produced by **grid_stat**, please see Chapter 12.

Chapter 9

Ensemble Stat Tool

9.1 Introduction

This chapter contains a description of the Ensemble-Stat tool. This tool may be run to create simple ensemble forecasts (mean, probability, spread, etc) from a set of several forecast model files to be used by the MET statistics tools. If observations are also included, ensemble statistics such as rank histograms, probability integral transform histograms, spread/skill variance, and continuous ranked probability score are produced. A climatology file may also be provided, and will be used as a reference forecast in several of the output statistics. Details about and equations for the statistics produced for ensembles are given in Appendix C C.4.

9.2 Practical Information

This section contains information about configuring and running the Ensemble-Stat tool. The Ensemble-Stat tool creates or verifies gridded model data. For verification, this tool can accept either gridded or point observations. If provided, the climatology file must be gridded. The input gridded model, observation, and climatology datasets must be on the same grid prior to calculation of any statistics, and in one of the MET supported gridded file formats. If gridded files are not on the same grid, MET will do the regridding for you if you specify the desired output grid. The point observations must be formatted as the NetCDF output of the point reformatting tools described in Chapter 4.

9.2.1 ensemble_stat usage

The usage statement for the Ensemble Stat tool is shown below:

```
Usage: ensemble_stat
      n_ens ens_file_1 ... ens_file_n | ens_file_list
      config_file
      [-grid_obs file]
      [-point_obs file]
      [-ssvar_mean file]
      [-obs_valid_beg time]
      [-obs_valid_end time]
      [-outdir path]
      [-log file]
      [-v level]
```

`ensemble_stat` has three required arguments and accepts several optional ones.

Required arguments `ensemble_stat`

1. The `n_ens ens_file_1 ... ens_file_n` is the number of ensemble members followed by a list of ensemble member file names. This argument is not required when ensemble files are specified in the `ens_file_list`, detailed below.
2. The `ens_file_list` is an ASCII file containing a list of ensemble member file names. This is not required when a file list is included on the command line, as described above.
3. The `config_file` is an EnsembleStatConfig file containing the desired configuration settings.

Optional arguments for `ensemble_stat`

4. To produce ensemble statistics using gridded observations, use the `-grid_obs file` option to specify a gridded observation file. This option may be used multiple times if your observations are in several files.
5. To produce ensemble statistics using point observations, use the `-point_obs file` to specify a NetCDF point observation file. This option may be used multiple times if your observations are in several files.
6. Used in conjunction with the SSVAR output line type, the `-ssvar_mean file` specifies an ensemble mean model data file. If not provided, the mean value of the input ensemble members will be used.
7. To filter point observations by time, use `-obs_valid_beg time` in YYYYMMDD[_HH[MMSS]] format to set the beginning of the matching observation time window.
8. As above, use `-obs_valid_end time` in YYYYMMDD[_HH[MMSS]] format to set the end of the matching observation time window.
9. Specify the `-outdir path` option to override the default output directory (`./`).
10. The `-log` file outputs log messages to the specified file.

11. The **-v level** option indicates the desired level of verbosity. The value of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `ensemble_stat` calling sequence is shown below:

```
ensemble_stat \  
6 sample_fcst/2009123112/*gep*/d01_2009123112_02400.grib \  
config/EnsembleStatConfig \  
-grid_obs sample_obs/ST4/ST4.2010010112.24h \  
-point_obs out/ascii2nc/precip24_2010010112.nc \  
-outdir out/ensemble_stat -v 2
```

In this example, the Ensemble-Stat tool will process six forecast files specified in the file list into an ensemble forecast. Observations in both point and grid format will be included, and used to ensemble statistics separately. Ensemble Stat will create a NetCDF file containing requested ensemble fields and an output STAT file.

9.2.2 ensemble_stat configuration file

The default configuration file for the Ensemble-Stat tool named **EnsembleStatConfig_default** can be found in the installed `share/met/config` directory. Another version is located in `scripts/config`. We encourage users to make a copy of these files prior to modifying their contents. Each configuration file (both the default and sample) contains many comments describing its contents. The contents of the configuration file are also described in the subsections below.

Note that environment variables may be used when editing configuration files, as described in the Section 4.1.2 for the PB2NC tool.

```
model          = "WRF";  
obtype        = "ANALYS";  
regrid        = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }  
climo_mean    = {}  
obs_window    = { beg = -5400; end = 5400; }  
mask          = { grid = [ "FULL" ]; poly = []; sid = []; }  
ci_alpha      = [ 0.05 ];  
interp        = { field = BOTH; vld_thresh = 1.0;  
                  type = [ { method = NEAREST; width = 1; } ]; }  
duplicate_flag = NONE;  
obs_quality    = [];  
output_prefix = "";  
version        = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```

ens = {
  ens_thresh = 1.0;
  vld_thresh = 1.0;
  field = [
    {
      name = "APCP";
      level = "A03";
      cat_thresh = [ >0.0, >=5.0 ];
    }
  ];
}

```

The **ens** dictionary defines which ensemble fields should be processed.

When summarizing the ensemble, compute a ratio of the number of valid ensemble fields to the total number of ensemble members. If this ratio is less than the **ens_thresh**, then quit with an error. This threshold must be between 0 and 1. Setting this threshold to 1 will require that all ensemble members be present to be processed.

When summarizing the ensemble, for each grid point compute a ratio of the number of valid data values to the number of ensemble members. If that ratio is less than **vld_thresh**, write out bad data. This threshold must be between 0 and 1. Setting this threshold to 1 will require each grid point to contain valid data for all ensemble members.

For each **field** listed in the forecast field, give the name and vertical or accumulation level, plus one or more categorical thresholds. The thresholds are specified using symbols, as shown above. It is the user's responsibility to know the units for each model variable and to choose appropriate threshold values. The thresholds are used to define ensemble relative frequencies, e.g. a threshold of ≥ 5 can be used to compute the proportion of ensemble members predicting precipitation of at least 5mm at each grid point.

```

sid_exc          = [];
ens_ssvar_bin_size = 1.0;
ens_phist_bin_size = 0.05;

```

Setting up the **fcst** and **obs** dictionaries of the configuration file is described in Section 3.5.1. The following are some special consideration for the Ensemble-Stat tool.

The **ens** and **fcst** dictionaries do not need to include the same fields. Users may specify any number of ensemble fields to be summarized, but generally there are many fewer fields with verifying observations available. The **ens** dictionary specifies the fields to be summarized while the **fcst** dictionary specifies the fields to be verified.

The **obs** dictionary looks very similar to the **fcst** dictionary. If verifying against point observations which are assigned GRIB1 codes, the observation section must be defined following GRIB1 conventions. When verifying GRIB1 forecast data, one can easily copy over the forecast settings to the observation dictionary using **obs = fcst;**. However, when verifying non-GRIB1 forecast data, users will need to specify the **fcst** and **obs** sections separately.

The **sid_exc** entry, defined in the **obs** dictionary, contains a comma-separated list of the station id's to be excluded from verification. This option is typically used when an observation file contains some stations known to have bad or unreliable data.

The **ens_ssvr_bin_size** and **ens_phist_bin_size** specify the width of the categorical bins used to accumulate frequencies for spread-skill-variance or probability integral transform statistics, respectively.

```
output_flag = {
    rhist = BOTH;
    phist = BOTH;
    orank = BOTH;
    ssvr = BOTH;
}
```

The **output_flag** array controls the type of output that is generated. Each flag corresponds to an output line type in the STAT file. Setting the flag to NONE indicates that the line type should not be generated. Setting the flag to STAT indicates that the line type should be written to the STAT file only. Setting the flag to BOTH indicates that the line type should be written to the STAT file as well as a separate ASCII file where the data is grouped by line type. The output flags correspond to the following output line types:

1. **RHIST** for Rankd Histogram Counts
 2. **PHIST** for Probability Integral Transform Histogram Counts
 3. **ORANK** for Ensemble Matched Pair Information when point observations are supplied
 4. **SSVAR** for Binned Spread/Skill Variance Information
-

```
ensemble_flag = {  
    mean      = TRUE;  
    stdev     = TRUE;  
    minus    = TRUE;  
    plus     = TRUE;  
    min      = TRUE;  
    max      = TRUE;  
    range    = TRUE;  
    vld_count = TRUE;  
    frequency = TRUE;  
    rank     = TRUE;  
}
```

The **ensemble_flag** specifies which derived ensemble fields should be calculated and output. Setting the flag to TRUE produces output of the specified field, while FALSE produces no output for that field type. The flags correspond to the following output line types:

1. Ensemble Mean Field
2. Ensemble Standard Deviation Field
3. Ensemble Mean - One Standard Deviation Field
4. Ensemble Mean + One Standard Deviation Field
5. Ensemble Minimum Field
6. Ensemble Maximum Field
7. Ensemble Range Field
8. Ensemble Valid Data Count
9. Ensemble Relative Frequency for each categorical threshold (**cat_thresh**) specified. This is an uncalibrated probability forecast.
10. Observation Ranks for Input Gridded Observations

```
rng = {  
    type = "mt19937";  
    seed = "";  
}
```

The **rng** group defines the random number generator **type** and **seed** to be used. In the case of a tie when determining the rank of an observation, the rank is randomly chosen from all available possibilities. The randomness is determined by the random number generator specified.

The **seed** variable may be set to a specific value to make the assignment of ranks fully repeatable. When left empty, as shown above, the random number generator seed is chosen automatically which will lead to slightly different bootstrap confidence intervals being computed each time the data is run.

Refer to the description of the **boot** entry in Section 3.5.1 for more details on the random number generator.

9.2.3 ensemble_stat output

The Ensemble-Stat tool can calculate any of the following fields from the input ensemble members:

Ensemble Mean fields

Ensemble Standard Deviation fields

Ensemble Mean - 1 Standard Deviation fields

Ensemble Mean + 1 Standard Deviation fields

Ensemble Minimum fields

Ensemble Maximum fields

Ensemble Range fields

Ensemble Valid Data Count fields

Ensemble Relative Frequency by threshold fields

Ranked Histograms (if Observation Field Provided)

Probability Integral Transform (PIT) Histograms (if Observation Field Provided)

Spread/Skill variance (if Observation Field Provided)

The Ensemble-Stat tool then writes:

Gridded fields of Ensemble forecast values to a NetCDF file

Gridded field of Observation Ranks to a NetCDF file (if Gridded Observations Provided)

STAT file and optional ASCII files with Ranked Histograms, Probability Integral Transform (PIT) Histogram, Spread/Skill Information, and Ensemble Matched Pair Information (if Point Observations Provided)

Table 9.1: Header information for each file ensemble-stat outputs

HEADER		
Column Number	Header Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID_BEG	Forecast valid start time in YYYYMMDDHH format
5	FCST_VALID_END	Forecast valid end time in YYYYMMDDHH format
6	OBS_LEAD	Observation lead time in HHMMSS format
7	OBS_VALID_BEG	Observation valid start time in YYYYMMDDHH format
8	OBS_VALID_END	Observation valid end time in YYYYMMDDHH format
9	FCST_VAR	Model variable
10	FCST_LEV	Selected Vertical level for forecast
11	OBS_VAR	Observation variable
12	OBS_LEV	Selected Vertical level for observations
13	OBTYPE	Type of observation selected
14	VX_MASK	Verifying masking region indicating the masking grid or polyline region applied
15	INTERP_MTHD	Interpolation method applied to forecasts
16	INTERP_PNTS	Number of points used in interpolation method
17	FCST_THRESH	The threshold applied to the forecast
18	OBS_THRESH	The threshold applied to the observations
19	COV_THRESH	The minimum fraction of valid ensemble members required to calculate statistics.
20	ALPHA	Error percent value used in confidence intervals
21	LINE_TYPE	Output line types are listed in tables 9.2 through 9.5.

Table 9.2: Format information for RHIST (Ranked Histogram) output line type.

RHIST OUTPUT FORMAT		
Column Number	RHIST Column Name	Description
21	RHIST	Ranked Histogram line type
22	TOTAL	Count of observations
23	CRPS	Continuous Ranked Probability Score
24	IGN	Ignorance score
25	N_RANK	Number of possible ranks for observation
26	CRPSS	Continuous Ranked Probability Skill Score
27-?	RANK_?	# of instances that observation has this rank

Table 9.3: Format information for PHIST (Probability Integral Transform Histogram) output line type.

PHIST OUTPUT FORMAT		
Column Number	PHIST Column Name	Description
21	PHIST	Probability Integral Transform line type
22	TOTAL	Count of observations
23	BIN_SIZE	Probability interval width
24	N_BIN	Total number of probability intervals
25-?	BIN_i	Count of observations within each probability interval

Table 9.4: Format information for ORANK (Observation Rank) output line type.

ORANK OUTPUT FORMAT		
Column Number	ORANK Column Name	Description
21	ORANK	Observation Rank line type
22	TOTAL	Count of observations
23	INDEX	Line number in ORANK file
24	OBS_SID	Station Identifier
25	OBS_LAT	Latitude of the observation
26	OBS_LON	Longitude of the observation
27	OBS_LVL	Level of the observation
28	OBS_ELV	Elevation of the observation
29	OBS	Value of the observation
30	PIT	Probability Integral Transform
31	RANK	Rank of the observation
32	N_ENS_VLD	Number of valid ensemble values
33	N_ENS	Number of ensemble values
34-?	ENS_?	Value of each ensemble member
Last-2	OBS_QC	Quality control string for the observation
Last-1	ENS_MEAN	The ensemble mean value
Last	CLIMO	The value of the included climatology

Table 9.5: Format information for SSVAR (Spread/Skill Variance) output line type.

SSVAR OUTPUT FORMAT		
Column Number	SSVAR Column Name	Description
21	SSVAR	Spread/Skill Variance line type
22	TOTAL	Count of observations
23	N_BIN	Number of bins for current forecast run
24	BIN_i	Index of the current bin
25	BIN_N	Number of points in bin i
26	VAR_MIN	Minimum variance
27	VAR_MAX	Maximum variance
28	VAR_MEAN	Average variance
29	FBAR	Average forecast value
30	OBAR	Average observed value
31	FOBAR	Average product of forecast and observation
32	FFBAR	Average of forecast squared
33	OOBAR	Average of observation squared
34	FBAR_NCL	Normal confidence lower bound of mean forecast
35	FBAR_NCU	Normal confidence upper bound of mean forecast
36	FSTDEV	Standard deviation of the error
37	FSTDEV_NCL	Normal confidence lower bound on error std dev
38	FSTDEV_NCU	Normal confidence upper bound on error std dev
39	OBAR_NCL	Normal confidence lower bound of mean observation
40	BAR_NCU	Normal confidence upper bound of mean observation
41	OSTDEV	Standard deviation of the error
42	OSTDEV_NCL	Normal confidence lower bound on error std dev
43	OSTDEV_NCU	Normal confidence upper bound on error std dev
44	PR_CORR	Pearson correlation coefficient
45	PR_CORR_NCL	Normal confidence lower bound on PR_CORR
46	PR_CORR_NCU	Normal confidence upper bound on PR_CORR
47	ME	Mean error
48	ME_NCL	Normal confidence lower bound on mean error
49	ME_NCU	Normal confidence upper bound on mean error
50	ESTDEV	Standard deviation of the error
51	ESTDEV_NCL	Normal confidence lower bound on error std dev
52	ESTDEV_NCU	Normal confidence upper bound on error std dev
53	MBIAS	Mangitude bias
54	MSE	Mean squared error
55	BCMSE	Bias corrected root mean squared error
56	RMSE	Root mean squared error

Chapter 10

Wavelet-Stat Tool

10.1 Introduction

The Wavelet-Stat tool decomposes two-dimensional forecasts and observations according to intensity and scale. This chapter provides a description of the Wavelet-Stat tool, which enables users to apply the Intensity-Scale verification technique described by Casati et al. (2004).

The Intensity-Scale technique is one of the recently developed verification approaches that focus on verification of forecasts defined over spatial domains. Spatial verification approaches, as opposed to point-by-point verification approaches, aim to account for the presence of features and for the coherent spatial structure characterizing meteorological fields. Since these approaches account for the intrinsic spatial correlation existing between nearby grid-points, they do not suffer from point-by-point comparison related verification issues, such as double penalties. Spatial verification approaches aim to account for the observation and forecast time-space uncertainties, and aim to provide feedback on the forecast error in physical terms.

The Intensity-Scale verification technique, as most of the spatial verification approaches, compares a forecast field to an observation field. To apply the Intensity-Scale verification approach, observations need to be defined over the same spatial domain of the forecast to be verified.

Within the spatial verification approaches, the Intensity-Scale technique belongs to the scale-decomposition (or scale-separation) verification approaches. The scale-decomposition approaches enable users to perform the verification on different spatial scales. Weather phenomena on different scales (e.g. frontal systems versus convective showers) are often driven by different physical processes. Verification on different spatial scales can therefore provide deeper insights into model performance at simulating these different processes.

The spatial scale components are obtained usually by applying a single band spatial filter to the forecast and observation fields (e.g. Fourier, Wavelets). The scale-decomposition approaches measure error, bias and skill of the forecast on each different scale component. The scale-decomposition approaches therefore provide feedback on the scale dependency of the error and skill, on the no-skill to skill transition scale, and on the capability of the forecast of reproducing the observed scale structure.

The Intensity-Scale technique evaluates the forecast skill as a function of the intensity values and of the spatial scale of the error. The scale components are obtained by applying a two dimensional Haar wavelet filter. Note that wavelets, because of their locality, are suitable for representing discontinuous fields characterized by few sparse non-zero features, such as precipitation. Moreover, the technique is based on a categorical approach, which is a robust and resistant approach, suitable for non-normally distributed variables, such as precipitation. The intensity-scale technique was specifically designed to cope with the difficult characteristics of precipitation fields, and for the verification of spatial precipitation forecasts. However, the intensity-scale technique can also be applied to verify other variables, such as cloud fraction.

10.2 Scientific and statistical aspects

10.2.1 The method

Casati et al (2004) applied the Intensity-Scale verification to preprocessed and re-calibrated (unbiased) data. The preprocessing was aimed to mainly normalize the data, and defined categorical thresholds so that each categorical bin had a similar sample size. The recalibration was performed to eliminate the forecast bias. Preprocessing and recalibration are not strictly necessary for the application of the Intensity-Scale technique. The MET Intensity-Scale Tool does not perform either, and applies the Intensity-Scale approach to biased forecasts, for categorical thresholds defined by the user.

The Intensity Scale approach can be summarized in the following 5 steps:

1. For each threshold, the forecast and observation fields are transformed into binary fields: where the grid-point precipitation value meets the threshold criteria it is assigned 1, where the threshold criteria are not met it is assigned 0. Figure 10.1 illustrates an example of a forecast and observation fields, and their corresponding binary fields for a threshold of 1mm/h. This case shows an intense storm of the scale of 160 km displaced almost its entire length. The displacement error is clearly visible from the binary field difference and the contingency table image obtained for the same threshold (Table 10.1).
2. The binary forecast and observation fields obtained from the thresholding are then decomposed into the sum of components on different scales, by using a 2D Haar wavelet filter (Figure 10.2). Note that the scale components are fields, and their sum adds up to the original binary field. For a forecast defined over square domain of $2^n \times 2^n$ grid-points, the scale components are $n+1$: n mother wavelet components + the largest father wavelet (or scale-function) component. The n mother wavelet components have resolution equal to $1, 2, 4, \dots, 2^{n-1}$ grid-points. The largest father wavelet component is a constant field over the $2^n \times 2^n$ grid-point domain with value equal to the field mean.

Note that the wavelet transform is a linear operator: this implies that the difference of the spatial scale components of the binary forecast and observation fields (Figure 10.2) are equal to the spatial scale components of the difference of the binary forecast and observation fields (Figure 10.3), and these scale components also add up to the original binary field difference (Figure 10.11). The intensity-scale technique considers

thus the spatial scale of the error. For the case illustrated (Figure 10.1 and Figure 10.3) note the large error associated at the scale of 160 km, due the storm, 160km displaced almost its entire length.

Note also that the means of the binary forecast and observation fields (i.e. their largest father wavelet components) are equal to the proportion of forecast and observed events above the threshold, $(\mathbf{a}+\mathbf{b})/\mathbf{n}$ and $(\mathbf{a}+\mathbf{c})/\mathbf{n}$, evaluated from the contingency table counts (Table 10.1) obtained from the original forecast and observation fields by thresholding with the same threshold used to obtain the binary forecast and observation fields. This relation is intuitive when observing forecast and observation binary fields and their corresponding contingency table image (Figure 10.1). The comparison of the largest father wavelet component of binary forecast and observation fields therefore provides feedback on the whole field bias.

3. For each threshold (\mathbf{t}) and for each scale component (\mathbf{j}) of the binary forecast and observation, the Mean Squared Error (MSE) is then evaluated (Figure 10.4). The error is usually large for small thresholds, and decreases as the threshold increases. This behavior is partially artificial, and occurs because the smaller the threshold the more events will exceed it, and therefore the larger would be the error, since the error tends to be proportional to the amount of events in the binary fields. The artificial effect can be diminished by normalization: because of the wavelet orthogonal properties, the sum of the MSE of the scale components is equal to the MSE of the original binary fields: $MSE(t) = \sum_j MSE(t, j)$. Therefore, the percentage that the MSE for each scale contributes to the total MSE may be computed: for a given threshold, \mathbf{t} , $MSE\%(t, j) = MSE(t, j)/MSE(t)$. The MSE% does not exhibit the threshold dependency, and usually shows small errors on large scales and large errors on small scales, with the largest error associated to the smallest scale and highest threshold. For the NIMROD case illustrated, note the large error at 160 km and between the thresholds of and 4 mm/h, due to the storm, 160km displaced almost its entire length.

Note that the MSE of the original binary fields is equal to the proportion of the counts of misses (\mathbf{c}/\mathbf{n}) and false alarms (\mathbf{b}/\mathbf{n}) for the contingency table (Table 10.1) obtained from the original forecast and observation fields by thresholding with the same threshold used to obtain the binary forecast and observation fields: $MSE(t) = (b + c)/n$. This relation is intuitive when comparing the forecast and observation binary field difference and their corresponding contingency table image (Figure 14.1).

4. The MSE for the random binary forecast and observation fields is estimated by $MSE(t)_{random} = FBI * Br * (1 - Br) + Br * (1 - FBI * Br)$, where $FBI = (a+b)/(a+c)$ is the frequency bias index and $Br = (a+c)/n$ is the sample climatology from the contingency table (Table 10.1) obtained from the original forecast and observation fields by thresholding with the same threshold used to obtain the binary forecast and observation fields. This formula follows by considering the Murphy and Winkler (1987) framework, applying the Bayes' theorem to express the joint probabilities \mathbf{b}/\mathbf{n} and \mathbf{c}/\mathbf{n} as product of the marginal and conditional probability (e.g. Jolliffe and Stephenson, 2003; Wilks, 2006), and then noticing that for a random forecast the conditional probability is equal to the unconditional one, so that \mathbf{b}/\mathbf{n} and \mathbf{c}/\mathbf{n} are equal to the product of the corresponding marginal probabilities solely.
5. For each threshold (\mathbf{t}) and scale component (\mathbf{j}), the skill score based on the MSE of binary forecast and observation scale components is evaluated (Figure 10.5). The standard skill score definition as in

Jolliffe and Stephenson (2003) or Wilks (2006) is used, and random chance is used as reference forecast. The MSE for the random binary forecast is equipartitioned on the $n+1$ scales to evaluate the skill score: $SS(t, j) = 1 - \text{MSE}(t, j) * (n + 1) / \text{MSE}(t)_{\text{random}}$

The Intensity-Scale (IS) skill score evaluates the forecast skill as a function of the precipitation intensity and of the spatial scale of the error. Positive values of the IS skill score are associated to a skillful forecast, whereas negative values are associated to no skill. Usually large scales exhibit positive skill (large scale events, such as fronts, are well predicted), whereas small scales exhibit negative skill (small scale events, such as convective showers, are less predictable), and the smallest scale and highest thresholds exhibit the worst skill. For the NIMROD case illustrated note the negative skill associated to the 160 km scale, for the thresholds to 4 mm/h, due to the 160 km storm displaced almost its entire length.

Table 10.1: **2x2** contingency table in terms of counts. The n_{ij} values in the table represent the counts in each forecast-observation category, where i represents the forecast and j represents the observations.

Forecast	Observation		Total
	$o = 1$ (e.g., "Yes")	$o = 0$ (e.g., "No")	
$f = 1$ (e.g., "Yes")	Hits= \mathbf{a}	False Alarms = \mathbf{b}	$\mathbf{a+b}$
$f = 0$ (e.g., "No")	Misses= \mathbf{c}	Correct rejections = \mathbf{d}	$\mathbf{c+d}$
Total	$\mathbf{a+c}$	$\mathbf{b+d}$	$\mathbf{a+b+c+d}$

In addition to the MSE and the SS, the energy squared is also evaluated, for each threshold and scale (Figure 10.6). The energy squared of a field X is the average of the squared values: $\text{En2}(X) = \sum_i x_i^2$. The energy squared provides feedback on the amount of events present in the forecast and observation fields for each scale, for a given threshold. Usually, small thresholds are associated to a large energy, since many events exceed the threshold. Large thresholds are associated to a small energy, since few events exceed the threshold. Comparison of the forecast and observed squared energy provide feedback on the bias on different scales, for each threshold.

The En2 bias for each threshold and scale is assessed by the En2 relative difference, equal to the difference between forecast and observed squared energies normalized by their sum: $[\text{En2}(F) - \text{En2}(O)] / [\text{En2}(F) + \text{En2}(O)]$. Since defined in such a fashion, the En2 relative difference accounts for the difference between forecast and observation squared energies relative to their magnitude, and it is sensitive therefore to the ratio of the forecast and observed squared energies. The En2 relative difference ranges between -1 and 1, positive values indicate over-forecast and negative values indicate under-forecast. For the NIMROD case illustrated the forecast exhibits over-forecast for small thresholds, quite pronounced on the large scales, and under-forecast for high thresholds.

As for the MSE, the sum of the energy of the scale components is equal to the energy of the original binary field: $\text{En2}(t) = \sum_j \text{En2}(t, j)$. Therefore, the percentage that the En2 for each scale contributes the total En2 may be computed: for a given threshold, \mathbf{t} , $\text{En2}\%(t, j) = \text{En2}(t, j) / \text{En2}(t)$. Usually, for precipitation fields, low thresholds exhibit most of the energy percentage on large scales (and less percentage on the small scales), since low thresholds are associated to large scale features, such as fronts. On the other hand, for higher thresholds the energy percentage is usually larger on small scales, since intense events are associated to small scales features, such as convective cells or showers. The comparison of the forecast and observation

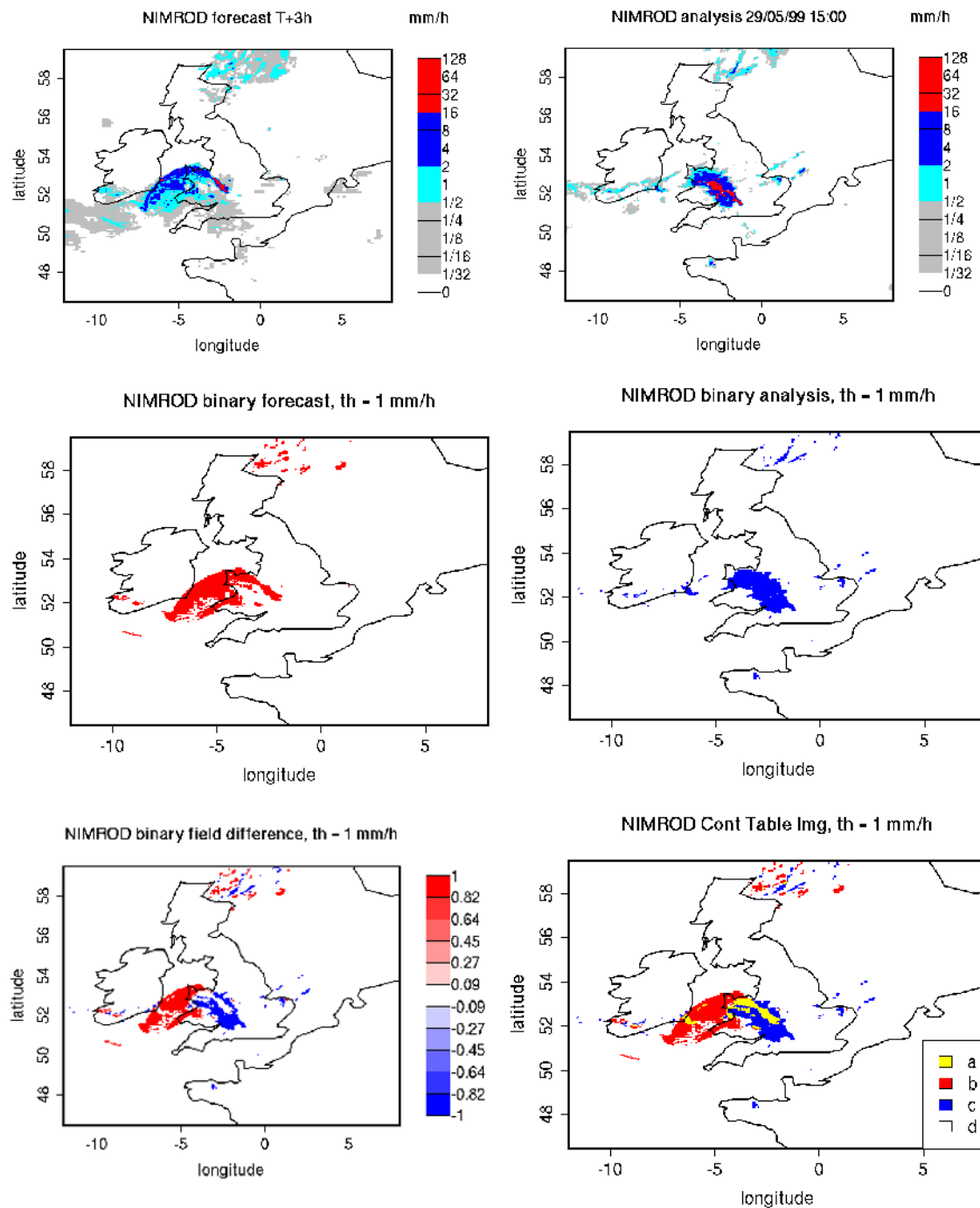


Figure 10.1: NIMROD 3h lead-time forecast and corresponding verifying analysis field (precipitation rate in mm/h, valid the 05/29/99 at 15:00 UTC); forecast and analysis binary fields obtained for a threshold of 1mm/h, the binary field difference has their corresponding Contingency Table Image (see Table 10.1). The forecast shows a storm of 160 km displaced almost its entire length.

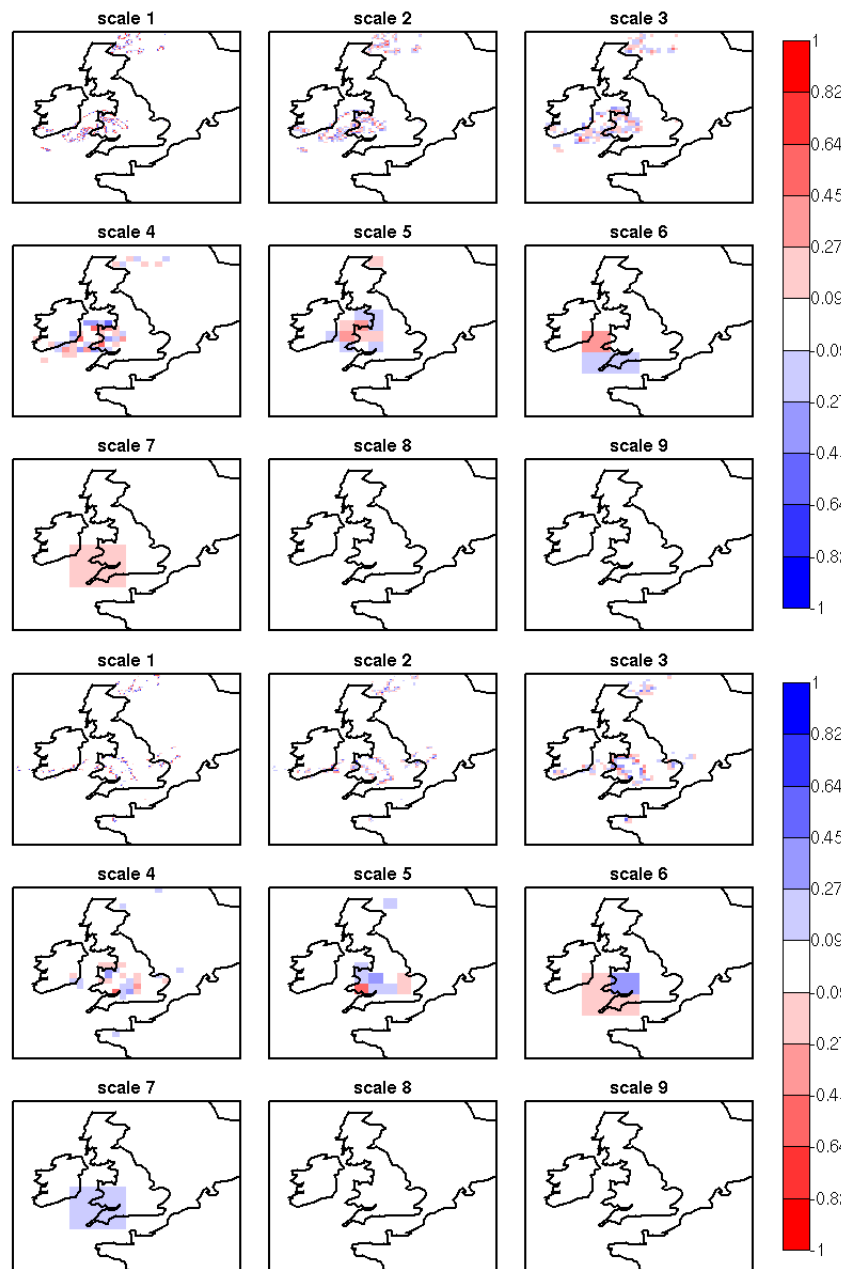


Figure 10.2: NIMROD binary forecast (top) and binary analysis (bottom) spatial scale components obtained by a 2D Haar wavelet transform ($th=1$ mm/h). Scale 1 to 8 refer to mother wavelet components (5, 10, 20, 40, 80, 160, 320, 640 km resolution); scale 9 refer to the largest father wavelet component (1280 km resolution).

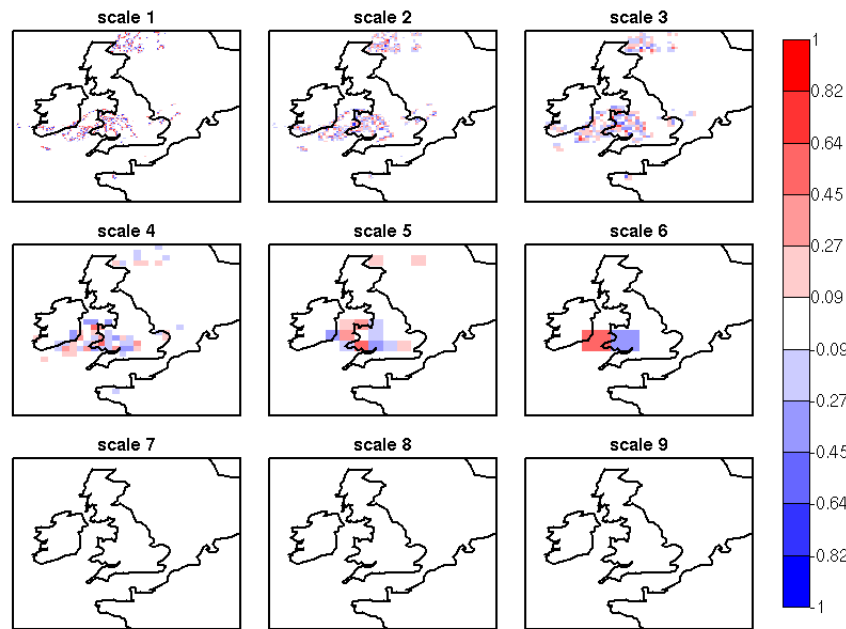


Figure 10.3: NIMROD binary field difference spatial scale components obtained by a 2D Haar wavelet transform ($th=1$ mm/h). Scales 1 to 8 refer to mother wavelet components (5, 10, 20, 40, 80, 160, 320, 640 km resolution); scale 9 refers to the largest father wavelet component (1280 km resolution). Note the large error at the scale 6 = 160 km, due to the storm, 160 km displaced almost of its entire length.

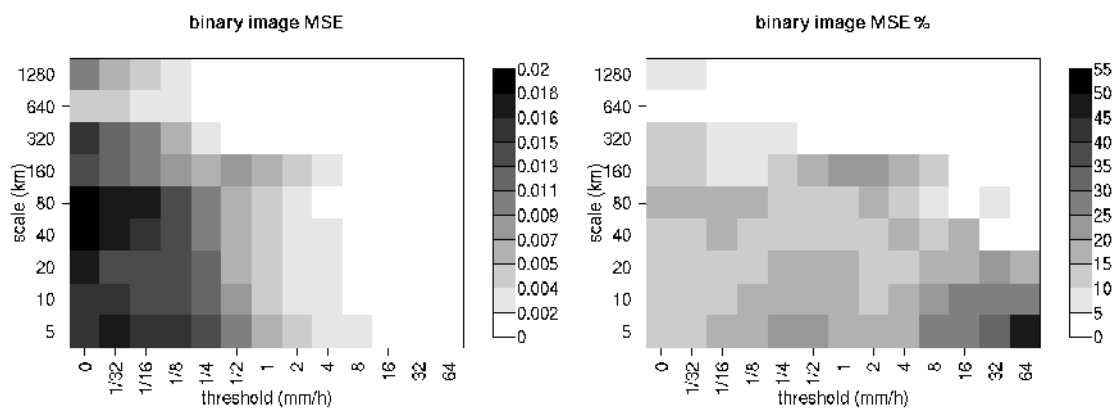


Figure 10.4: MSE and MSE % for the NIMROD binary forecast and analysis spatial scale components. In the MSE%, note the large error associated to the scale 6 = 160 km, for the thresholds $\frac{1}{2}$ to 4 mm/h, associated to the displaced storm.

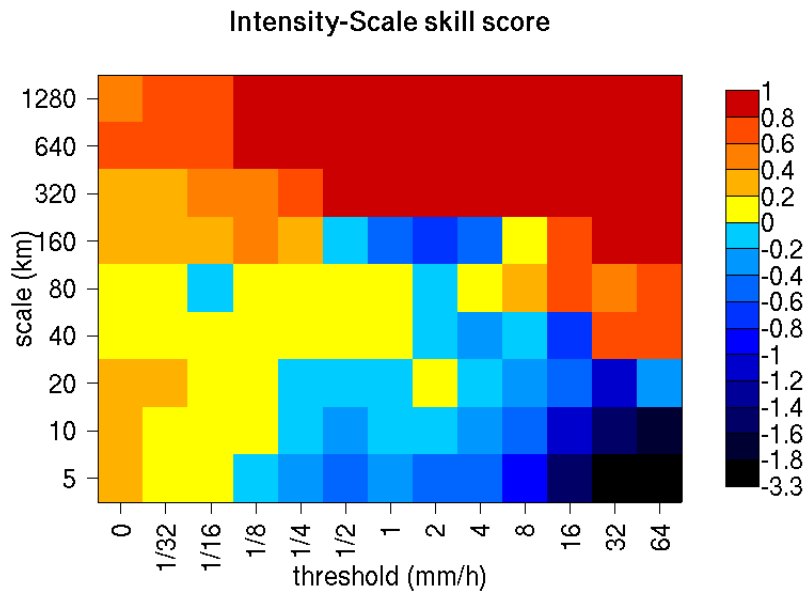


Figure 10.5: Intensity-Scale skill score for the NIMROD forecast and analysis shown in Figure 10.1. The skill score is a function of the intensity of the precipitation rate and spatial scale of the error. Note the negative skill associated to the scale 6 = 160 km, for the thresholds to 4 mm/h, associated to the displaced storm.

squared energy percentages provides feedback on how the events are distributed across the scales, and enable the comparison of forecast and observation scale structure.

For the NIMROD case illustrated, the scale structure is assessed again by the relative difference, but calculated of the squared energy percentages. For small thresholds the forecast over-estimates the number of large scale events and under-estimates the number of small scale events, in proportion to the total number of events. On the other hand, for larger thresholds the forecast under-estimates the number of large scale events and over-estimates the number of small scale events, again in proportion to the total number of events. Overall it appears that the forecast over-estimates the percentage of events associated to high occurrence, and under-estimate the percentage of events associated to low occurrence. The $En2\%$ for the 64 mm/h thresholds is homogeneously under-estimated for all the scales, since the forecast does not have any event exceeding this threshold.

Note that the energy squared of the observation binary field is identical to the sample climatology $Br = (a + c)/n$. Similarly, the energy squared of the forecast binary field is equal to $(a + b)/n$. The ratio of the squared energies of the forecast and observation binary fields is equal to the FBI $= (a+b)/(a+c)$ $FBI=(a+b)/(a+c)$, for the contingency table (Table 10.1) obtained from the original forecast and observation fields by thresholding with the same threshold used to obtained the binary forecast and observation fields.

10.2.2 The spatial domain constraints

The Intensity-Scale technique is constrained by the fact that orthogonal wavelets (discrete wavelet transforms) are usually performed dyadic domains, square domains of $2^n \times 2^n$ grid-points. The Wavelet-Stat

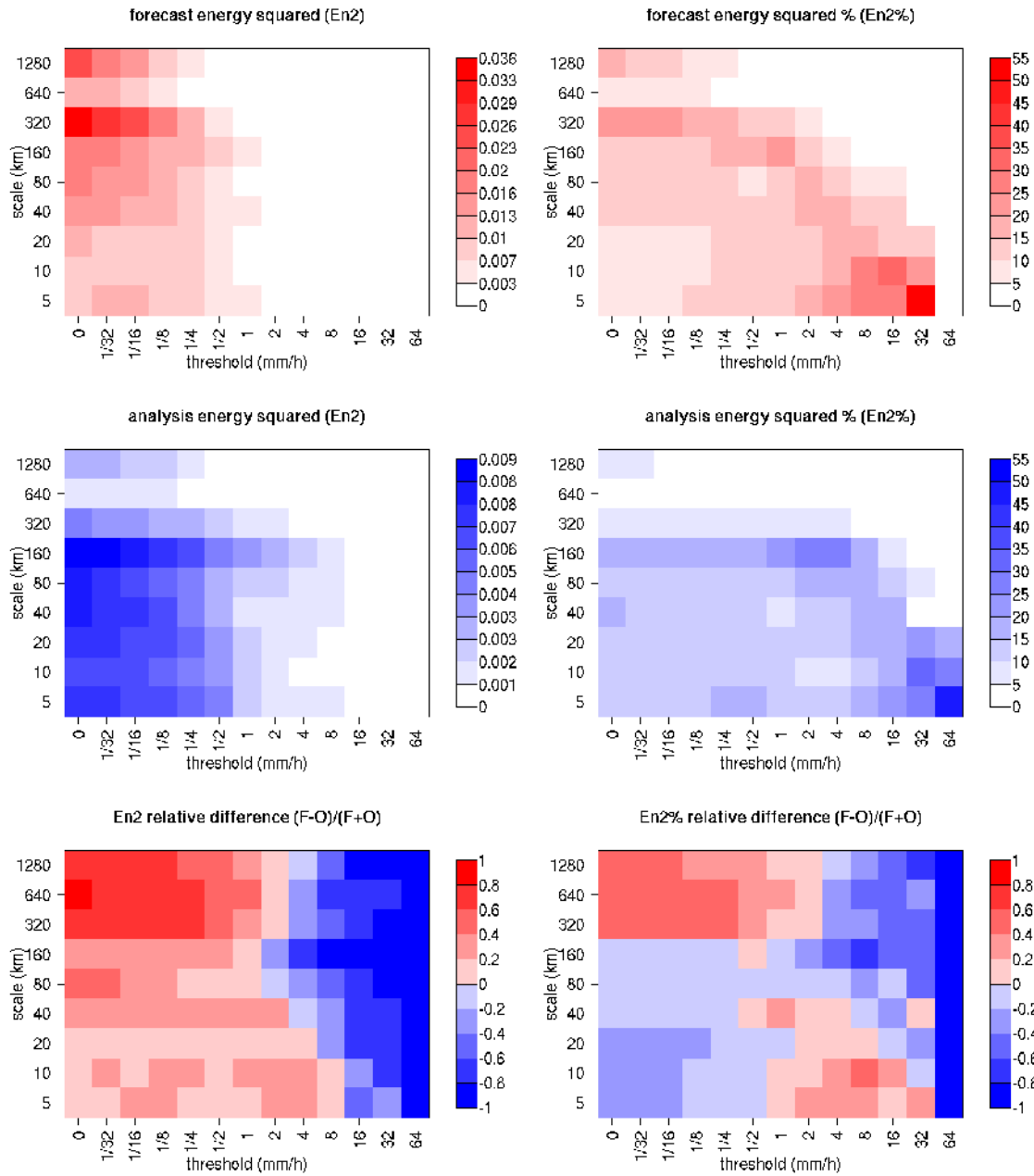


Figure 10.6: Energy squared and energy squared percentages, for each threshold and scale, for the NIMROD forecast and analysis, and forecast and analysis En2 and En2% relative differences.

tool handles this issue based on settings in the configuration file by defining tiles of dimensions $2^n \times 2^n$ over the input domain in the following ways:

1. **User-Defined Tiling:** The user may define one or more tiles of size $2^n \times 2^n$ over their domain to be applied. This is done by selecting the grid coordinates for the lower-left corner of the tile(s) and the tile dimension to be used. If the user specifies more than one tile, the Intensity-Scale method will be applied to each tile separately. At the end, the results will automatically be aggregated across all the tiles and written out with the results for each of the individual tiles. Users are encouraged to select tiles which consist entirely of valid data.
2. **Automated Tiling:** This tiling method is essentially the same as the user-defined tiling method listed above except that the tool automatically selects the location and size of the tile(s) to be applied. It figures out the maximum tile of dimension $2^n \times 2^n$ that fits within the domain and places the tile at the center of the domain. For domains that are very elongated in one direction, it defines as many of these tiles as possible that fit within the domain.
3. **Padding:** If the domain size is only slightly smaller than $2^n \times 2^n$, for certain variables (e.g. precipitation), it is advisable to expand the domain out to $2^n \times 2^n$ grid-points by adding extra rows and/or columns of fill data. For precipitation variables, a fill value of zero is used. For continuous variables, such as temperature, the fill value is defined as the mean of the valid data in the rest of the field. A drawback to the padding method is the introduction of artificial data into the original field. Padding should only be used when a very small number of rows and/or columns need to be added.

10.2.3 Aggregation of statistics on multiple cases

The Stat-Analysis tool aggregates the intensity scale technique results. Since the results are scale-dependent, it is sensible to aggregate results from multiple model runs (e.g. daily runs for a season) on the same spatial domain, so that the scale components for each singular case will be the same number, and the domain, if not a square domain of $2^n \times 2^n$ grid-points, will be treated in the same fashion. Similarly, the intensity thresholds for each run should all be the same.

The MSE and forecast and observation squared energy for each scale and thresholds are aggregated simply with a weighted average, where weights are proportional to the number of grid-points used in each single run to evaluate the statistics. If the same domain is always used (and it should) the weights result all the same, and the weighted averaging is a simple mean. For each threshold, the aggregated Br is equal to the aggregated squared energy of the binary observation field, and the aggregated FBI is obtained as the ratio of the aggregated squared energies of the forecast and observation binary fields. From aggregated Br and FBI, the MSE_{random} for the aggregated runs can be evaluated using the same formula as for the single run. Finally, the Intensity-Scale Skill Score is evaluated by using the aggregated statistics within the same formula used for the single case.

10.3 Practical information

The following sections describe the usage statement, required arguments and optional arguments for the Stat-Analysis tool.

10.3.1 wavelet_stat usage

The usage statement for the Wavelet-Stat tool is shown below:

```
Usage: wavelet_stat
      fcst_file
      obs_file
      config_file
      [-outdir path]
      [-log file]
      [-v level]
```

wavelet_stat has three required arguments and accepts several optional ones.

Required arguments for wavelet_stat

1. The **fcst_file** argument indicates the gridded file containing the model data to be verified.
2. The **obs_file** argument indicates the gridded file containing the gridded observations to be used for the verification of the model.
3. The **config_file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for wavelet_stat

4. The **-outdir path** indicates the directory where output files should be written.
5. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as cout and cerr. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
6. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the wavelet_stat calling sequence is listed below:

```

wavelet_stat \
sample_fcst.grb \
sample_obs.grb \
WaveletStatConfig

```

In the example, the Wavelet-Stat tool will verify the model data in the **sample_fcst.grb** GRIB file using the observations in the **sample_obs.grb** GRIB file applying the configuration options specified in the **WaveletStatConfig** file.

10.3.2 wavelet_stat configuration file

The default configuration file for the Wavelet-Stat tool, **WaveletStatConfig_default**, can be found in the installed **share/met/config** directory. Another version of the configuration file is provided in **scripts/config**. We recommend that users make a copy of the default (or other) configuration file prior to modifying it. The contents are described in more detail below. Note that environment variables may be used when editing configuration files, as described in the Section 4.1.2 for the PB2NC tool.

```

model          = "WRF";
obtype         = "ANALYS";
fcst           = {};
obs            = {};
regrid         = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; };
mask_missing_flag = NONE;
met_data_dir   = "MET_BASE";
ps_plot_flag   = TRUE;
fcst_raw_plot  = { color_table = "MET_BASE/colortables/met_default.ctable";
                  plot_min = 0.0; plot_max = 0.0; };
obs_raw_plot   = {};
wvlt_plot      = {};
output_prefix  = "";
version        = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```

grid_decomp_flag = AUTO;
tile = {
    width      = 0;
    location = [ { x_ll = 0; y_ll = 0; } ];
}

```

The `grid_decomp_flag` variable specifies how tiling should be performed:

- **AUTO** indicates that the automated-tiling should be done.
- **TILE** indicates that the user-defined tiles should be applied.
- **PAD** indicated that the data should be padded out to the nearest dimension of $2^n \times 2^n$

The `width` and `location` variables allow users to manually define the tiles of dimension they would like to apply. The `x_ll` and `y_ll` variables specify the location of one or more lower-left tile grid (x, y) points.

```

wavelet = {
    type    = HAAR;
    member  = 2;
}

```

The `wavelet_flag` and `wavelet_k` variables specify the type and shape of the wavelet to be used for the scale decomposition. The Casati et al. (2004) method uses a Haar wavelet which is a good choice for discontinuous fields like precipitation. However, users may choose to apply any wavelet family/shape that is available in the GNU Scientific Library. Values for the `wavelet_flag` variable, and associated choices for k, are described below:

- **HAAR** for the Haar wavelet (member = 2).
- **HAAR_CNTR** for the Centered-Haar wavelet (member = 2).
- **DAUB** for the Daubechies wavelet (member = 4, 6, 8, 10, 12, 14, 16, 18, 20).
- **DAUB_CNTR** for the Centered-Daubechies wavelet (member = 4, 6, 8, 10, 12, 14, 16, 18, 20).
- **BSPLINE** for the Bspline wavelet (member = 103, 105, 202, 204, 206, 208, 301, 303, 305, 307, 309).
- **BSPLINE_CNTR** for the Centered-Bspline wavelet (member = 103, 105, 202, 204, 206, 208, 301, 303, 305, 307, 309).

```

output_flag = {
    isc = BOTH;
}

```


The **output_flag** array controls the type of output that the Wavelet-Stat tool generates. This flag is set similarly to the output flags of the other MET tools, with possible values of NONE, STAT, and BOTH. The ISC line type is the only one available for Intensity-Scale STAT lines.

```
nc_pairs_flag = {
    latlon = TRUE;
    raw    = TRUE;
}
```

The `nc_pairs_flag` is described in Section 8.3.2

10.3.3 wavelet_stat output

wavelet_stat produces output in STAT and, optionally, ASCII and NetCDF and PostScript formats. The ASCII output duplicates the STAT output but has the data organized by line type. While the Wavelet-Stat tool currently only outputs one STAT line type, additional line types may be added in future releases. The output files are written to the default output directory or the directory specified by the **-outdir** command-line option.

The output STAT file is named using the following naming convention:

wavelet_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV.stat where **PREFIX** indicates the user-defined output prefix, **HHMMSS** indicates the forecast lead time, and **YYYYMMDD_HHMMSS** indicates the forecast valid time.

The output ASCII files are named similarly:

wavelet_stat_PREFIX_HHMMSSL_YYYYMMDD_HHMMSSV_TYPE.txt where **TYPE** is **isc** to indicate that this is an intensity-scale line type.

The format of the STAT and ASCII output of the Wavelet-Stat tool is similar to the format of the STAT and ASCII output of the Point-Stat tool. Please refer to the tables in Section 7.3.3(**point_stat output**) for a description of the common output for STAT files types. The information contained in the STAT and isc files are identical. However, for consistency with the STAT files produced by other tools, the STAT file will only have column headers for the first 21 fields. The isc file contains all headers. The format of the **ISC** line type is explained in the following table.

The **Wavelet-Stat** tool creates a NetCDF output file containing the raw and decomposed values for the forecast, observation, and difference fields for each combination of variable and threshold value.

The dimensions and variables included in the `wavelet_stat` NetCDF files are described in Tables 10.4 and 10.5.

Table 10.2: Header information for each file wavelet-stat outputs.

HEADER		
Column Number	Header Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID_BEG	Forecast valid start time in YYYYMMDDHH format
5	FCST_VALID_END	Forecast valid end time in YYYYMMDDHH format
6	OBS_LEAD	Observation lead time in HHMMSS format
7	OBS_VALID_BEG	Observation valid start time in YYYYMMDDHH format
8	OBS_VALID_END	Observation valid end time in YYYYMMDDHH format
9	FCST_VAR	Model variable
10	FCST_LEV	Selected Vertical level for forecast
11	OBS_VAR	Observation variable
12	OBS_LEV	Selected Vertical level for observations
13	OBTYPE	User provided text string designating the observation type
14	VX_MASK	Verifying masking region indicating the masking grid or polyline region applied
15	INTERP_MTHD	NA in Wavelet-Stat
16	INTERP_PNTS	NA in Wavelet-Stat
17	FCST_THRESH	The threshold applied to the forecast
18	OBS_THRESH	The threshold applied to the observations
19	COV_THRESH	NA in Wavelet-Stat
20	ALPHA	NA in Wavelet-Stat
21	LINE_TYPE	See table below.

Table 10.3: Format information for the ISC (Intensity-Scale) output line type.

ISC OUTPUT FORMAT		
Column Number	ISC Column Name	Description
21	ISC	Intensity-Scale line type
22	TOTAL	The number of grid points (forecast locations) used
23	TILE_DIM	The dimensions of the tile
24	TILE_XLL	Horizontal coordinate of the lower left corner of the tile
25	TILE_YLL	Vertical coordinate of the lower left corner of the tile
26	NSCALE	Total number of scales used in decomposition
27	ISCALE	The scale at which all information following applies
28	MSE	Mean squared error for this scale
29	ISC	The intensity scale skill score
30	FENERGY	Forecast energy squared for this scale
31	OENERGY	Observed energy squared for this scale
32	BASER	The base rate (not scale dependent)
33	FBIAS	The frequency bias

Table 10.4: Dimensions defined in NetCDF output.

wavelet_stat NetCDF DIMENSIONS	
NetCDF Dimension	Description
x	Dimension of the tile which equals 2^n
y	Dimension of the tile which equals 2^n
scale	Dimension for the number of scales. This is set to $n+2$, where 2^n is the tile dimension. The 2 extra scales are for the binary image and the wavelet averaged over the whole tile.
tile	Dimension for the number of tiles used

Table 10.5: Variables defined in NetCDF output.

wavelet-stat NetCDF VARIABLES		
NetCDF Variable	Dimension	Description
FCST_FIELD_LEVEL_RAW	tile, x, y	Raw values for the forecast field specified by "FIELD_LEVEL"
OBS_FIELD_LEVEL_RAW	tile, x, y	Raw values for the observation field specified by "FIELD_LEVEL"
DIFF_FIELD_LEVEL_RAW	tile, x, y	Raw values for the difference field ($\mathbf{f-o}$) specified by "FIELD_LEVEL"
FCST_FIELD_LEVEL_THRESH	tile, scale, x, y	Wavelet scale-decomposition of the forecast field specified by "FIELD_LEVEL_THRESH"
OBS_FIELD_LEVEL_THRESH	tile, scale, x, y	Wavelet scale-decomposition of the observation field specified by "FIELD_LEVEL_THRESH"

Lastly, the Wavelet-Stat tool creates a PostScript plot summarizing the scale-decomposition approach used in the verification. The PostScript plot is generated using internal libraries and does not depend on an external plotting package. The generation of this PostScript output can be disabled using the **ps_plot_flag** configuration file option.

The PostScript plot begins with one summary page illustrating the tiling method that was applied to the domain. The remaining pages depict the Intensity-Scale method that was applied. For each combination of field, tile, and threshold, the binary difference field ($\mathbf{f-o}$) is plotted followed by the difference field for each decomposed scale. Underneath each difference plot, the statistics applicable to that scale are listed. Examples of the PostScript plots can be obtained by running the example cases provided with the MET tarball.

Chapter 11

GSI Tools

Gridpoint Statistical Interpolation (GSI) diagnostic files are binary files written out from the data assimilation code before the first and after each outer loop. The files contain useful information about how a single observation was used in the analysis by providing details such as the innovation (O-B), observation values, observation error, adjusted observation error, and quality control information.

For more detail on generating GSI diagnostic files and their contents, see the GSI User's Guide: <http://www.dtcenter.org/com-GSI/users/docs/index.php>

When MET reads GSI diagnostic files, the innovation (O-B; generated prior to the first outer loop) or analysis increment (O-A; generated after the final outer loop) is split into separate values for the observation (OBS) and the forecast (FCST), where the forecast value corresponds to the background (O-B) or analysis (O-A).

MET includes two tools for processing GSI diagnostic files. The `gsid2mpr` tool reformats individual GSI diagnostic files into the MET matched pair (MPR) format, similar to the output of the Point-Stat tool. The `gsidens2orank` tool processes an ensemble of GSI diagnostic files and reformats them into the MET observation rank (ORANK) line type, similar to the output of the Ensemble-Stat tool. The output of both tools may be passed to the Stat-Analysis tool to compute a wide variety of continuous, categorical, and ensemble statistics.

11.1 GSID2MPR tool

This section describes how to run the tool `gsid2mpr` tool. The `gsid2mpr` tool reformats one or more GSI diagnostic files into an ASCII matched pair (MPR) format, similar to the MPR output of the Point-Stat tool. The output MPR data may be passed to the Stat-Analysis tool to compute a wide variety of continuous or categorical statistics.

11.1.1 gsid2mpr usage

The usage statement for the gsid2mpr tool is shown below:

```
Usage: gsid2mpr
      gsi_file_1 [gsi_file_2 ... gsi_file_n]
      [-swap]
      [-channel n]
      [-set_hdr col_name value]
      [-suffix string]
      [-outdir path]
      [-log file]
      [-v level]
```

gsid2mpr has one required argument and and accepts several optional ones.

Required arguments for gsid2mpr

1. The `gsi_file_1 [gsi_file2 ... gsi_file_n]` argument indicates the GSI diagnostic files (conventional or radiance) to be reformatted.

Optional arguments for gsid2mpr

2. The `-swap` option switches the endianness when reading the input binary files.
3. The `-channel n` option overrides the default processing of all radiance channels with the values of a comma-separated list.
4. The `-set_hdr col_name value` option specifies what should be written to the output header columns.
5. The `-suffix string` option overrides the default output filename suffix (.stat).
5. The `-outdir path` option overrides the default output directory (./).
6. The `-log file` option outputs log messages to the specified file.
7. The `-v level` option overrides the default level of logging (2).

An example of the gsid2mpr calling sequence is shown below:

```
gsid2mpr diag_conv_ges.mem001 \
-set_hdr MODEL GSI_MEM001 \
-outdir out
```

In this example, the gsid2mpr tool will process a single input file named `diag_conv_ges.mem001` file, set the output `MODEL` header column to `GSI_MEM001`, and write output to the `out` directory. The output file is named the same as the input file but a `.stat` suffix is added to indicate its format.

11.1.2 gsid2mpr output

The gsid2mpr tool performs a simple reformatting step and thus requires no configuration file. It can read both conventional and radiance binary GSI diagnostic files. Support for additional GSI diagnostic file type may be added in future releases. Conventional files are determined by the presence of the string **conv** in the filename. Files that are not conventional are assumed to contain radiance data. Multiple files of either type may be passed in a single call to the gsid2mpr tool. For each input file, an output file will be generated containing the corresponding matched pair data.

The gsid2mpr tool writes the same set of MPR output columns for the conventional and radiance data types. However, it also writes additional columns at the end of the MPR line which depend on the input file type. Those additional columns are described in the following tables.

Table 11.1: Format information for GSI Diagnostic Conventional MPR (Matched Pair) output line type.

GSI DIAGNOSTIC CONVENTIONAL MPR OUTPUT FILE		
Column Number	Column Name	Description
1-32		Standard MPR columns described in Table 7.18.
33	OBS_PRS	Model pressure value at the observation height (hPa)
34	OBS_ERR_IN	PrepBufr inverse observation error
35	OBS_ERR_ADJ	read_prepbufr inverse observation error
36	OBS_ERR_FIN	Final inverse observation error
37	PREP_USE	read_prepbufr usage
38	ANLY_USE	Analysis usage (1 for yes, -1 for no)
39	SETUP_QC	Setup quality control
40	QC_WGHT	Non-linear quality control relative weight

Table 11.2: Format information for GSI Diagnostic Radiance MPR (Matched Pair) output line type.

GSI DIAGNOSTIC RADIANCE MPR OUTPUT FILE		
Column Number	Column Name	Description
1-32		Standard MPR columns described in Table 7.18.
33	CHAN_USE	Channel used (1 for yes, -1 for no)
34	SCAN_POS	Sensor scan position
35	SAT_ZNTH	Satellite zenith angle (degrees)
36	SAT_AZMTH	Satellite azimuth angle (degrees)
37	SUN_ZNTH	Solar zenith angle (degrees)
38	SUN_AZMTH	Solar azimuth angle (degrees)
39	SUN_GLNT	Sun glint angle (degrees)
40	FRAC_WTR	Fractional coverage by water
41	FRAC_LND	Fractional coverage by land
42	FRAC_ICE	Fractional coverage by ice
43	FRAC_SNW	Fractional coverage by snow
44	SFC_TWTR	Surface temperature over water (K)
45	SFC_TLND	Surface temperature over land (K)
46	SFC_TICE	Surface temperature over ice (K)
47	SFC_TSNW	Surface temperature over snow (K)
48	TSOIL	Soil temperature (K)
49	SOILM	Soil moisture
50	LAND_TYPE	Surface land type
51	FRAC_VEG	Vegetation fraction
52	SNW_DPTH	Snow depth
53	SFC_WIND	Surface wind speed (m/s)
54	FRAC_CLD CLD_LWC	Cloud fraction (%) Cloud liquid water (kg/m**2) (microwave only)
55	CTOP_PRS TC_PWAT	Cloud top pressure (hPa) Total column precip. water (km/m**2) (microwave only)
56	TFND	Foundation temperature: Tr
57	TWARM	Diurnal warming: d(Tw) at depth zob
58	TCOOL	Sub-layer cooling: d(Tc) at depth zob
59	TZFND	d(Tz)/d(Tr)
60	OBS_ERR	Inverse observation error
61	FCST_NOBC	Brightness temperature with no bias correction (K)
62	SFC_EMIS	Surface emissivity
63	STABILITY	Stability index
64	PRS_MAX_WGT	Pressure of the maximum weighing function

The `gsid2mpr` output may be passed to the Stat-Analysis tool to derive additional statistics. In particular, users should consider running the `aggregate_stat` job type to read MPR lines and compute partial sums (SL1L2), continuous statistics (CNT), contingency table counts (CTC), or contingency table statistics (CTS). Stat-Analysis has been enhanced to parse any extra columns found at the end of the input lines. Users can filter the values in those extra columns using the `-column_thresh` and `-column_str` job command options.

An example of the Stat-Analysis calling sequence is shown below:

```
stat_analysis -lookin diag_conv_ges.mem001.stat \
```

```
-job aggregate_stat -line_type MPR -out_line_type CNT \
-fcst_var t -column_thresh ANLY_USE eq1
```

In this example, the Stat-Analysis tool will read MPR lines from the input file named **diag_conv_ges.mem001.stat**, retain only those lines where the **FCST_VAR** column indicates temperature (**t**) and where the **ANLY_USE** column has a value of 1.0, and derive continuous statistics.

11.2 GSIDENS2ORANK tool

This section describes how to run the tool `gsidens2orank` tool. The `gsidens2orank` tool processes an ensemble of GSI diagnostic files and reformats them into the MET observation rank (ORANK) line type, similar to the output of the Ensemble-Stat tool. The ORANK line type contains ensemble matched pair information and is analogous to the MPR line type for a deterministic model. The output ORANK data may be passed to the Stat-Analysis tool to compute ensemble statistics.

11.2.1 gsidens2orank usage

The usage statement for the `gsidens2orank` tool is shown below:

```
Usage: gsidens2orank
      ens_file_1 ... ens_file_n | ens_file_list
      -out path
      [-ens_mean path]
      [-swap]
      [-rng_name str]
      [-rng_seed str]
      [-set_hdr col_name value]
      [-log file]
      [-v level]
```

`gsidens2orank` has three required arguments and accept several optional ones.

Required arguments for `gsidens2orank`

1. The **ens_file_1 ... ens_file_n** argument is a list of ensemble binary GSI diagnostic files to be reformatted.
2. The **ens_file_list** argument is an ASCII file containing a list of ensemble GSI diagnostic files.
3. The **-out path** argument specifies the name of the output **.stat** file.

Optional arguments for gsidens2orank

4. The **-ens_mean path** option is the ensemble mean binary GSI diagnostic file.
5. The **-swap** option switches the endianness when reading the input binary files.
6. The **-channel n** option overrides the default processing of all radiance channels with a comma-separated list.
7. The **-rng_name str** option overrides the default random number generator name (mt19937).
8. The **-rng_seed str** option overrides the default random number generator seed.
9. The **-set_hdr col_name value** option specifies what should be written to the output header columns.
10. The **-log file** option outputs log messages to the specified file.
11. The **-v level** option overrides the default level of logging (2).

An example of the gsidens2orank calling sequence is shown below:

```
gsidens2orank diag_conv_ges.mem* \  
-ens_mean diag_conv_ges.ensmean \  
-out diag_conv_ges_ens_mean_orank.txt
```

In this example, the gsidens2orank tool will process all of the ensemble members whose file name matches **diag_conv_ges.mem***, write output to the file named **diag_conv_ges_ens_mean_orank.txt**, and populate the output **ENS_MEAN** column with the values found in the **diag_conv_ges.ensmean** file rather than computing the ensemble mean values from the ensemble members on the fly.

11.2.2 gsidens2orank output

The gsidens2orank tool performs a simple reformatting step and thus requires no configuration file. The multiple files passed to it are interpreted as members of the same ensemble. Therefore, each call to the tool processes exactly one ensemble. All input ensemble GSI diagnostic files must be of the same type. Mixing conventional and radiance files together will result in a runtime error. The gsidens2orank tool processes each ensemble member and keeps track of the observations it encounters. It constructs a list of the ensemble values corresponding to each observation and writes an output ORANK line listing the observation value, its rank, and all the ensemble values. The random number generator is used by the gsidens2orank tool to randomly assign a rank value in the case of ties.

The gsid2mpr tool writes the same set of ORANK output columns for the conventional and radiance data types. However, it also writes additional columns at the end of the ORANK line which depend on the input file type. The extra columns are limited to quantities which remain constant over all the ensemble members

and are therefore largely a subset of the extra columns written by the gsid2mpr tool. Those additional columns are described in the following tables.

Table 11.3: Format information for GSI Diagnostic Conventional ORANK (Observation Rank) output line type.

GSI DIAGNOSTIC CONVENTIONAL ORANK OUTPUT FILE		
Column Number	Column Name	Description
1-?		Standard ORANK columns described in Table 9.4.
Last-2	N_USE	Number of members with ANLY_USE = 1
Last-1	PREP_USE	read_prepbufr usage
Last	SETUP_QC	Setup quality control

Table 11.4: Format information for GSI Diagnostic Radiance ORANK (Observation Rank) output line type.

GSI DIAGNOSTIC RADIANCE MPR OUTPUT FILE		
Column Number	Column Name	Description
1-?		Standard ORANK columns described in Table 9.4.
Last-24	N_USE	Number of members with OBS_QC = 0
Last-23	CHAN_USE	Channel used (1 for yes, -1 for no)
Last-22	SCAN_POS	Sensor scan position
Last-21	SAT_ZNTH	Satellite zenith angle (degrees)
Last-20	SAT_AZMTH	Satellite azimuth angle (degrees)
Last-19	SUN_ZNTH	Solar zenith angle (degrees)
Last-18	SUN_AZMTH	Solar azimuth angle (degrees)
Last-17	SUN_GLNT	Sun glint angle (degrees)
Last-16	FRAC_WTR	Fractional coverage by water
Last-15	FRAC_LND	Fractional coverage by land
Last-14	FRAC_ICE	Fractional coverage by ice
Last-13	FRAC_SNW	Fractional coverage by snow
Last-12	SFC_TWTR	Surface temperature over water (K)
Last-11	SFC_TLND	Surface temperature over land (K)
Last-10	SFC_TICE	Surface temperature over ice (K)
Last-9	SFC_TSNW	Surface temperature over snow (K)
Last-8	TSOIL	Soil temperature (K)
Last-7	SOILM	Soil moisture
Last-6	LAND_TYPE	Surface land type
Last-5	FRAC_VEG	Vegetation fraction
Last-4	SNW_DPTH	Snow depth
Last-3	TFND	Foundation temperature: Tr
Last-2	TWARM	Diurnal warming: d(Tw) at depth zob
Last-1	TCOOL	Sub-layer cooling: d(Tc) at depth zob
Last	TZFND	d(Tz)/d(Tr)

The gsidens2orank output may be passed to the Stat-Analysis tool to derive additional statistics. In particular, users should consider running the **aggregate_stat** job type to read ORANK lines and ranked histograms (RHIST), probability integral transform histograms (PHIST), and spread-skill variance output (SSVAR). Stat-Analysis has been enhanced to parse any extra columns found at the end of the input

lines. Users can filter the values in those extra columns using the `-column_thresh` and `-column_str` job command options.

An example of the Stat-Analysis calling sequence is shown below:

```
stat_analysis -lookin diag_conv_ges_ens_mean_orank.txt \  
-job aggregate_stat -line_type ORANK -out_line_type RHIST \  
-by fcst_var -column_thresh N_USE eq20
```

In this example, the Stat-Analysis tool will read ORANK lines from the input file named `diag_conv_ges_ens_mean_orank.txt`, retain only those lines where the `N_USE` column indicates that all 20 ensemble members were used, and write ranked histogram (RHIST) output lines for each unique value of encountered in the `FCST_VAR` column.

Chapter 12

Stat-Analysis Tool

12.1 Introduction

The Stat-Analysis tool ties together results from the Point-Stat, Grid-Stat, Ensemble-Stat and Wavelet-Stat tools by providing summary statistical information and a way to filter their STAT output files.

The Stat-Analysis tool requires STAT output from Point-Stat, Grid-Stat, and/or Wavelet-Stat. See Sections 7.3.3, 8.3.3, 9.2.3, or 10.3.3 respectively, for information on the STAT output format of the Point-Stat, Grid-Stat, Ensemble-Stat, and Wavelet-Stat tools.

12.2 Scientific and statistical aspects

The Stat-Analysis tool (i) aggregates results over a user-specified time; (ii) stratifies statistics based on time of day, model initialization time, lead-time, model run identifier, output filename, or wavelet decomposition scale; and (iii) computes specific verification indices such as the GO Index¹ and wind direction statistics. Future functionality may include information about time-trends and/or calculations based on climatology (e.g., anomaly correlation). This section summarizes the capabilities of the Stat-Analysis tool and describes how the GO Index, wind direction, summary statistics, and aggregated statistics are computed.

12.2.1 Filter STAT lines

The Stat-Analysis tool can be used to simply filter out specific STAT lines based on user-specified search criteria. All of the STAT lines that are retained from one or many files are written to a single output file. The output file for filtered STAT lines must be specified using the **-dump_row** job command option.

¹The GO Index is a summary measure for NWP models that is used by the Air Force Weather Agency. It combines verification statistics for several forecast variables and lead times.

12.2.2 Summary statistics for columns

The Stat-Analysis tool can be used to produce summary information for a single column of data. After the user specifies the line type, column of interest, and any other relevant search criteria, summary information is produced from values in that column of data. The summary statistics produced are: mean, standard deviation, minimum, maximum, and the 10th, 25th, 50th, 75th, and 90th percentiles.

Confidence intervals are computed for the mean and standard deviation of the column of data. For the mean, the confidence interval is computed two ways - based on an assumption of normality and also using the bootstrap method. For the standard deviation, the confidence interval is computed using the bootstrap method. In this application of the bootstrap method, the values in the column of data being summarized are resampled, and for each replicated sample, the mean and standard deviation are computed.

12.2.3 Aggregated values from multiple STAT lines

The Stat-Analysis tool can be used to create aggregated values from multiple STAT lines of the same type. The user may specify the specific line type of interest and any other relevant search criteria. The Stat-Analysis tool then creates sums of each of the values in all lines matching the search criteria. The aggregated data are output as the same line type as the user specified. The STAT line types which may be aggregated in this way are the contingency table (FHO, CTC, PCT, MCTC, NBRCTC), partial sums (SL1L2, SAL1L2, VL1L2, and VAL1L2), and other (ISC, RHIST, PHIST, NBRCNT, SSVAR) line types.

12.2.4 Aggregate STAT lines and produce aggregated statistics

The Stat-Analysis tool can be used to aggregate multiple STAT lines of the same type together and produce relevant statistics from the aggregated line. This may be done in the same manner listed above in 8.2.3. However, rather than writing out the aggregated STAT line itself, the relevant statistics generated from that aggregated line are provided in the output. Specifically, if a contingency table line type (FHO, CTC, PCT, MCTC, or NBRCTC) has been aggregated, a contingency table statistics (CTS, PSTD, MCTS, or NBRCTS) line type will be written out. If a partial sums line type (SL1L2 or SAL1L2) has been aggregated, a continuous statistics (CNT) line type will be written out. For ensembles, the ORANK line type can be accumulated into RHIST or PHIST output. If the matched pair line type (MPR) has been aggregated, the user may choose the line type to be output (FHO, CTC, CTS, CNT, MCTC, MCTS, WDIR, SL1L2, SAL1L2, PCT, PSTD, PJC, or PRC). Only wind vector statistics are produced from the vector partial sums line types (VL1L2 or VAL1L2).

When aggregating the matched pair line type (MPR) and computing an output contingency table statistics (CTS) or continuous statistics (CNT) line type, the bootstrapping method is applied for computing confidence intervals. The bootstrapping method is applied here in the same way that it is applied in the statistics tools. For a set of n matched forecast-observation pairs, the matched pairs are resampled with replacement many times. For each replicated sample, the corresponding statistics are computed. The confidence intervals are derived from the statistics computed for each replicated sample.

12.2.5 Skill Score Index, including GO Index

The Stat-Analysis tool can be used to calculate the skill score indices by weighting scores for different meteorological fields at different pressure levels and for different lead times. Specifically, the GO Index can be computed. The GO index is a weighted average of the RMSE values for wind speed, dewpoint temperature, temperature, height, and pressure at several levels in the atmosphere. The variables, levels, and lead times included in the index are shown in Table 12.1. The partial sums (SL1L2 lines in the STAT output) for each of these variables at each level and lead time must have been computed in a previous step. The Stat-Analysis tool then uses the weights in Table 12.1 to compute values for the GO Index. For a general skill score index, the user can specify the weights and variables to use in the calculations.

Table 12.1: Variables, levels, and weights used to compute the GO Index.

Variable	Level	Weights by Lead time			
		12 h	24 h	36 h	48 h
Wind speed	250 hPa	4	3	2	1
	400 hPa	4	3	2	1
	850 hPa	4	3	2	1
	Surface	8	6	4	2
Dewpoint temperature	400 hPa	8	6	4	2
	700 hPa	8	6	4	2
	850 hPa	8	6	4	2
	Surface	8	6	4	2
Temperature	400 hPa	4	3	2	1
	Surface	8	6	4	2
Height	400 hPa	4	3	2	1
Pressure	Mean sea level	8	6	4	2

12.2.6 Wind Direction Statistics

The Stat-Analysis tool can be used to calculate the error statistics for the wind direction. The vector partial sums (VL1L2) or matched pairs (MPR) for the UGRD and VGRD must have been computed in a previous step, i.e. by Point-Stat or Grid-Stat tools. This job computes an average forecast wind direction and an average observed wind direction along with their difference. The output is in degrees. In Point-Stat and Grid-Stat, the UGRD and VGRD can be verified using thresholds on their values or on the calculated wind speed. If thresholds have been applied, the wind direction statistics are calculated for each threshold.

The first step in verifying wind direction is running the Grid-Stat and/or Point-Stat tools to verify each forecast of interest and generate the VL1L2 or MPR line(s). When running these tools, please note:

1. To generate VL1L2 or MPR lines, the user must request the verification of the U-component of the wind followed by the V-component, both at the same vertical level.
2. To generate VL1L2 or MPR lines, the user must set the "output_flag" to indicate that the VL1L2 or MPR line should be computed and written out.
3. The user may select one or more spatial verification regions over which to accumulate the statistics.

4. The user may select one or more wind speed thresholds to be applied to the U and V wind components when computing the VL1L2 lines. It may be useful to investigate the performance of wind forecasts using multiple wind speed thresholds. For MPR line types, the wind speed threshold can be applied when computing the MPR lines, or the MPR output may be filtered afterwards by the Stat-Analysis tool.

Once the appropriate lines have been generated for each verification time of interest, the user may run the Stat-Analysis tool to analyze them. The Stat-Analysis job "aggregate_stat", along with the "-output_line_type WDIR" option, reads all of the input lines and computes statistics about the wind direction. When running this job the user is encouraged to use the many Stat-Analysis options to filter the input lines down to the set of lines of interest. The output of the wind direction analysis job consists of two lines with wind direction statistics computed in two slightly different ways. The two output lines begin with "ROW_MEAN_WDIR" and "AGGR_WDIR", and the computations are described below:

1. For the "ROW_MEAN_WDIR" line, each of the input VL1L2 lines is treated separately and given equal weight. The mean forecast wind direction, mean observation wind direction, and the associated error are computed for each of these lines. Then the means are computed across all of these forecast wind directions, observation wind directions, and their errors.
2. For the "AGGR_WDIR" line, the input VL1L2 lines are first aggregated into a single line of partial sums where the weight for each line is determined by the number of points it represents. From this aggregated line, the mean forecast wind direction, observation wind direction, and the associated error are computed and written out.

12.3 Practical information

The following sections describe the usage statement, required arguments and optional arguments for the Stat-Analysis tool.

12.3.1 stat_analysis usage

The usage statement for the Stat-Analysis tool is shown below:

```
Usage: stat_analysis
      -lookin path
      [-out file]
      [-tmp_dir path]
      [-log file]
      [-v level]
      [-config config_file] | [JOB COMMAND LINE]
```

`stat_analysis` has two required arguments and accepts several optional ones.

In the usage statement for the Stat-Analysis tool, some additional terminology is introduced. In the Stat-Analysis tool, the term "job" refers to a set of tasks to be performed after applying user-specified options (i.e., "filters"). The filters are used to pare down a collection of output from the MET statistics tools to only those lines that are desired for the analysis. The job and its filters together comprise the "job command line". The "job command line" may be specified either on the command line to run a single analysis job or within the configuration file to run multiple analysis jobs at the same time. If jobs are specified in both the configuration file and the command line, only the jobs indicated in the configuration file will be run. The various jobs types are described in Table 10.3 and the filtering options are described in Section 10.3.2.

Required arguments for `stat_analysis`

1. The **-lookin path** specifies the name of a specific STAT file (any file ending in `.stat`) or the name of a directory where the Stat-Analysis tool will search for STAT files. This option may be used multiple times to specify multiple locations.
2. Either a configuration file must be specified with the **-config** option, or a **JOB COMMAND LINE** must be denoted. The **JOB COMMAND LINE** is described in Section 14.3.2

Optional arguments for `stat_analysis`

3. The **-config config_file** specifies the configuration file to be used. The contents of the configuration file are discussed below.
4. The **-out file** option indicates the file to which output data should be written. If this option is not used, the output is directed to standard output.
5. The **-tmp_dir path** option selects the directory for writing out temporary files.
6. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
7. The **-v level** indicates the desired level of verbosity. The contents of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `stat_analysis` calling sequence is shown below.

```
stat_analysis -lookin ../out/point_stat \  
-config STATAnalysisConfig
```

In this example, the Stat-Analysis tool will search for valid STAT lines located in the `../out/point_stat` directory that meet the options specified in the configuration file, `config/STATAnalysisConfig`.

12.3.2 stat_analysis configuration file

The default configuration file for the Stat-Analysis tool named **STATAnalysisConfig_default** can be found in the installed **share/met/config** directory. The version used for the example run in Chapter 2 is also available in **scripts/config**. Like the other configuration files described in this document, it is recommended that users make a copy of these files prior to modifying their contents.

The configuration file for the Stat-Analysis tool is optional. Users may find it more convenient initially to run Stat-Analysis jobs on the command line specifying job command options directly. Once the user has a set of or more jobs they would like to run routinely on the output of the MET statistics tools, they may find grouping those jobs together into a configuration file to be more convenient.

Most of the user-specified parameters listed in the Stat-Analysis configuration file are used to filter the ASCII statistical output from the MET statistics tools down to a desired subset of lines over which statistics are to be computed. Only output that meet all of the parameters specified in the Stat-Analysis configuration file will be retained.

The Stat-Analysis tool actually performs a two step process when reading input data. First, it stores the filtering information defined top section of the configuration file. It applies that filtering criteria when reading the input STAT data and writes the filtered data out to a temporary file. Second, each job defined in the **jobs** entry reads data from that temporary file and performs the task defined for the job. After all jobs have run, the Stat-Analysis tool deletes the temporary file.

This two step process enables the Stat-Analysis tool to run more efficiently when many jobs are defined in the configuration file. If only operating on a small subset of the input data, the common filtering criteria can be applied once rather than re-applying it for each job. In general, filtering criteria common to all tasks defined in the **jobs** entry should be moved to the top section of the configuration file.

As described above, filtering options specified in the first section of the configuration file will be applied to every task in the **jobs** entry. However, if an individual job specifies a particular option that was specified above, it will be applied for that job. For example, if the **model[]** option is set at the top to ["Run 1", "Run2"], but a job in the joblist sets the **-model** option as "Run1", that job will be performed only on "Run1" data. Also note that environment variables may be used when editing configuration files, as described in the Section4.1.2 for the PB2NC tool.

```

boot          = { interval = PCTILE; rep_prop = 1.0; n_rep = 1000;
                  rng = "mt19937"; seed = ""; }
rank_corr_flag = TRUE;
tmp_dir       = "/tmp";
version      = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```
model = [];
```

The user may specify a comma-separated list of model names to be used for all analyses performed. The names must be in double quotation marks. If multiple models are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-model**" option within the job command lines.

```
fcst_lead = [];
obs_lead = [];
```

The user may specify a comma-separated list of forecast and observation lead times in HH[MMSS] format to be used for any analyses to be performed. If multiple times are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-fcst_lead**" and "**-obs_lead**" options within the job command lines.

```
fcst_valid_beg = "";
fcst_valid_end = "";
fcst_valid_hour = "";
obs_valid_beg = "";
obs_valid_end = "";
obs_valid_hour = "";
```

The user may specify the beginning, ending, and instantaneous valid times in YYYYMMDD[_HH[MMSS]] format to be used for all analyses performed. If multiple valid times fall within the valid time window, the analyses will be performed on their union. These selections may be further refined by using the "**-fcst_valid_beg**", "**-fcst_valid_end**", "**-obs_valid_beg**", "**-obs_valid_end**", "**-fcst_valid_hour**" and "**-obs_valid_hour**" options within the job command line.

```
fcst_init_beg = "";
fcst_init_end = "";
fcst_init_hour = "";
obs_init_beg = "";
obs_init_end = "";
obs_init_hour = "";
```

The user may specify the beginning, ending, or exact model initialization times in YYYYMMDD[_HH[MMSS]] format to be used for all analyses performed. If multiple init times fall within the init time window, the analyses will be performed on their union. These selections may be further refined by using the "**fcst_init_beg**", "**fcst_init_end**", "**obs_init_beg**", "**obs_init_end**", **fcst_init_hour**" and "**obs_init_hour**" options within the job command line.

```
fcst_var = [];  
obs_var  = [];
```

The user may specify a comma-separated list of forecast and observation variable types to be used for any analyses to be performed. If multiple variable types are listed, the analyses will be performed on their union. These selections may be further refined by using the "**fcst_var**" and "**obs_var**" options within the job command lines.

```
fcst_lev = [];  
obs_lev  = [];
```

The user may specify a comma-separated list of forecast and observation level types to be used for any analyses to be performed. If multiple level types are listed, the analyses will be performed on their union. These selections may be further refined by using the "**fcst_lev**" and "**obs_lev**" options within the job command lines.

```
obtype = [];
```

The user may specify a comma-separated list of observation types to be used for all analyses. If multiple observation types are listed, the analyses will be performed on their union. These selections may be further refined by using the "**obtype**" option within the job command line.

```
vx_mask = [];
```

The user may specify a comma-separated list of verification masking regions to be used for all analyses. If multiple verification masking regions are listed, the analyses will be performed on their union. These selections may be further refined by using the "**vx_mask**" option within the job command line.

```
interp_mthd = [];
```

The user may specify a comma-separated list of interpolation methods to be used for all analyses. If multiple interpolation methods are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-interp_mthd**" option within the job command line.

```
interp_pnts = [];
```

The user may specify a comma-separated list of interpolation points to be used for all analyses. If multiple interpolation points are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-interp_pnts**" option within the job command line.

```
fcst_thresh = [];  
obs_thresh  = [];  
cov_thresh  = [];
```

The user may specify comma-separated lists of forecast, observation, and coverage thresholds to be used for any analyses to be performed. If multiple thresholds are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-fcst_thresh**", "**-obs_thresh**", and "**-cov_thresh**" options within the job command lines.

```
alpha = [];
```

The user may specify a comma-separated list alpha confidence values to be used for all analyses. If alpha values are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-alpha**" option within the job command line.

```
line_type = [];
```

The user may specify a comma-separated list of line types to be used for all analyses. If multiple line types are listed, the analyses will be performed on their union. These selections may be further refined by using the "**-line_type**" option within the job command line.

```
column = [];
weight = [];
```

The column and weight fields are used to define a skill score index. The computation of a single value will be computed from each column and weight value specified. The GO Index is a specific example of a skill score index.

```
jobs = [
  "-job filter -dump_row ./filter_job.stat"
];
```

The user may specify one or more analysis jobs to be performed on the STAT lines that remain after applying the filtering parameters listed above. Each entry in the joblist contains the task and additional filtering options for a single analysis to be performed. The format for an analysis job is as follows:

-job job_name REQUIRED and OPTIONAL ARGUMENTS

All possible tasks for **job_name** are listed in Table 12.2.

Table 12.2: Description of components of the job command lines for the Stat-Analysis tool.

Job Name	Job commandDescription	Required Arguments
filter	Filters out the statistics lines based on applying options* (See note below table)	-dump_row
summary	Computes the mean, standard deviation, and percentiles (min, 10th, 25th, 50th, 75th, 90th, and max)	-line_type -column
aggregate	Aggregates the statistics output, computing the statistic specified for the entire collection of valid lines	-line_type
aggregate_stat	Aggregates the statistics output, and converts the input line type to the output line type specified	-line_type -out_line_type
go_index	Calculates the GO Index as described in section 12.2.5.	-fcst_init_begin -fcst_init_end
ramp	Defines a ramp event on a time-series of forecast and observed values. The amount of change from one time to the next is computed for forecast and observed values. Those changes are thresholded to define events which are used to populate a 2x2 contingency table.	-ramp_type -ramp_thresh -out_line_type -column -ramp_time -ramp_exact -ramp_window

```
out_alpha = 0.05;
```

This entry specifies the alpha value to be used when computing confidence intervals for output statistics. It is similar to the `ci_alpha` entry describe in Section 3.5.1.

```
vif_flag = FALSE;
```

The variance inflation factor (VIF) flag indicates whether to apply a first order variance inflation when calculating normal confidence intervals for an aggregated time series of contingency table counts or partial sums. The VIF adjusts the variance estimate for the lower effective sample size caused by autocorrelation of the statistics through time. A value of **FALSE** will not compute confidence intervals using the VIF. A value of **TRUE** will include the VIF, resulting in a slightly wider normal confidence interval.

The Stat-Analysis tool support several additional job command options which may be specified either on the command line when running a single job or within the **jobs** entry within the configuration file. These additional options are described below:

```
-by col_name
```

This job command option is extremely useful. It can used multiple times to specify a list of STAT header column names. When reading each input line, the Stat-Analysis tool concatnates together the entries in the specified columns and keeps track of the unique cases. It applies the logic defined for that job to each unique subset of data. For example, if your output was run over many different model names and masking regions, specify **-by MODEL, VX_MASK** to get output for each unique combination rather than having to run many very similar jobs.

```
-column_min    col_name value
-column_max    col_name value
-column_eq     col_name value
-column_thresh col_name thresh
-column_str    col_name string
```

The column filtering options may be used when the **-line_type** has been set to a single value. These options take two arguments, the name of the data column to be used followed by a value, string, or threshold to be applied. If multiple `column_min/max/eq/thresh/str` options are listed, the job will be performed on their intersection. Each input line is only retained if its value meets the numeric filtering criteria defined or matches one of the strings defined by the **-column_str** option. Multiple filtering strings may be listed using commas. Defining thresholds in MET is described in Section 3.5.1.

```
-dump_row file
```

Each analysis job is performed over a subset of the input data. Filtering the input data down to a desired subset is often an iterative process. The **-dump_row** option may be used for each job to specify the name of an output file to which the exact subset of data used for that job will be written. When initially constructing Stat-Analysis jobs, users are strongly encouraged to use the option and check its contents to ensure that the analysis was actually done over the intended subset.

```
-out_line_type name
```

This option specifies the desired output line type for the **aggregate_stat** job type.

```
-out_stat file
-set_hdr col_name string
```

The Stat-Analysis tool writes its output to either standard out or the file specified using the **-out** command line option. However that output lacks the standard STAT header columns. The **-out_stat** job command option may be used for each job to specify the name of an output file to which full STAT output lines should be written. Jobs will often combine output with multiple entries in the header columns. For example, a job may aggregate output with three different values in the **VX_MASK** column, such as “mask1”, “mask2”, and “mask3”. The output **VX_MASK** column will contain the unique values encountered concatenated together with commas: “mask1,mask2,mask3”. Alternatively, the **-set_hdr** option may be used to specify what should be written to the output header columns, such as “-set_hdr VX_MASK all_three_masks”.

```
-mask_grid name
-mask_poly file
```

When processing input MPR lines, these options may be used to define a masking grid or polyline to filter the matched pair data geographically prior to computing statistics.

```
-out_fcst_thresh thresh
-out_obs_thresh thresh
-out_thresh thresh
-out_cnt_logic string
```

When processing input MPR lines, these options are used to define the forecast, observation, or both thresholds to be applied when computing statistics. For categorical output line types (FHO, CTC, CTS, MCTC, MCTS) these define the categorical thresholds. For continuous output line types (SL1L2, SAL1L2, CNT), these define the continuous filtering thresholds and **-out_cnt_logic** defines how the forecast and observed logic should be combined.

```

-out_fcst_wind_thresh thresh
-out_obs_wind_thresh  thresh
-out_wind_thresh      thresh
-out_wind_logic       string

```

These job command options are analogous to the options listed above but apply when processing input MPR lines and deriving wind direction statistics.

```

-out_bin_size value

```

When processing input ORANK lines and writing output RHIST or PHIST lines, this option defines the output histogram bin width to be used.

12.3.3 stat-analysis tool output

The output generated by the Stat-Analysis tool contains statistics produced by the analysis. It also records information about the analysis job that produced the output for each line. Generally, the output is printed to the screen. However, it can be redirected to an output file using the **"-out"** option. The format of output from each STAT job command is described below.

The **"-by column"** job command option may be used to run the same job multiple times on unique subsets of data. Specify the **"-by column"** option one or more times to define a search

key, and that job will be run once for each unique search key found. For example, use **"-by VX_MASK"** to run the same job for multiple masking regions, and output will be generated for each unique masking region found. Use **"-by VX_MASK -by FCST_LEAD"** to generate output for each unique combination of masking region and lead time.

Job: filter

This job command finds and filters STAT lines down to those meeting criteria specified by the filter's options. The filtered STAT lines are written to a file specified by the **"-dump_row"** option.

The output of this job is the same STAT format described in sections 7.3.3, 8.3.3, and 10.3.3.

Job: summary

This job produces summary statistics for the column name and line type specified by the **"-column"** and **"-line_type"** options. The output of this job type consists of three lines. The first line contains **"JOB_LIST"**, followed by a colon, then the filtering and job definition parameters used for this job. The second line contains **"COL_NAME"**, followed by a colon, then the column names for the data in the next line. The third line contains the word **"SUMMARY"**, followed by a colon, then the total, mean with

confidence intervals, standard deviation with confidence intervals, minimum value, percentiles (10th, 25th, 50th, 75th, and 90th) and the maximum value. The output columns are shown in Table 12.3 below.

Table 12.3: Columnar output of "summary" job output from the Stat-Analysis tool.

Column Number	Description
1	SUMMARY: (job type)
2	Total
3-7	Mean including normal and bootstrap upper and lower confidence limits
8-10	Standard deviation including bootstrap upper and lower confidence limits
11	Minimum value
12	10th percentile
13	25th percentile
14	Median (50th percentile)
15	75th percentile
16	90th percentile
17	Maximum value

Job: aggregate

This job aggregates output from the STAT line type specified using the "**-line_type**" argument. The output of this job type is in the same format as the line type specified (see Sections 7.3.3, 8.3.3, and 10.3.3). Again the output consists of three lines. The first line contains "**JOB_LIST**", as described above. The second line contains "**COL_NAME**", followed by a colon, then the column names for the line type selected. The third line contains the name of the line type selected followed by the statistics for that line type.

Job: aggregate stat

This job is similar to the "**aggregate**" job listed above, however the format of its output is determined by the "**-out_line_type**" argument. Again the output consists of three lines for "**JOB_LIST**", "**COL_NAME**", and the name of the output STAT line, as described above. Valid combinations of the "**-line_type**" and "**-out_line_type**" arguments are listed in Table 12.4 below.

Table 12.4: Valid combinations of "-line_type" and "-out_line_type" arguments for the "aggregate_stat" job.

Input Line Type	Output Line Type
FHO or CTC	CTS
MCTC	MCTS
SL1L2 or SAL1L2	CNT
VL1L2 or VAL1L2	WDIR (wind direction)
PCT	PSTD, PJC, PRC
NBRCTC	NBRCTS
ORANK	RHIST, PHIST
MPR	CNT, SL1L2, SAL1L2, WDIR
MPR	FHO, CTC, CTS, MCTC, MCTS, PCT, PSTD, PJC, or PRC (must specify " -out_fcst_thresh " and " -out_obs_thresh " arguments)

Job: go_index

The output from this job consists of three lines, the first two of which contain "JOB_LIST" and "COL_NAME", as described above. The third line contains "GO_INDEX" followed by a colon and then the value computed for the GO Index.

Job: ramp

The ramp job operates on a time-series of forecast and observed values and is analogous to the RIRW (Rapid Intensification and Weakening) job described in Section 20.3.3. The amount of change from one time to the next is computed for forecast and observed values. Those changes are thresholded to define events which are used to populate a 2x2 contingency table.

See the README file in the installed share/met/config directory for a detailed description of the job command options available for ramp job type.

The default output for this job is contingency table counts and statistics (-out_line_type CTC,CTS). Matched pair information may also be output by requesting MPR output (-out_line_type CTC,CTS,MPR).

Chapter 13

Series-Analysis Tool

13.1 Introduction

The Series-Analysis Tool accumulates statistics separately for each horizontal grid location over a series. Often, this series is over time or height, though any type of series is possible. This differs from the Grid-Stat tool in that Grid-Stat verifies all grid locations together as a group. Thus, the Series-Analysis Tool can be used to find verification information specific to certain locations or to identify differences.

13.2 Practical Information

This section contains a description of how to configure and run the Series-Analysis tool. This tool performs verification of gridded model fields using matching gridded observation fields. The Series-Analysis tool will produce a variety of user-selected statistics. These statistics are a subset of those produced by the Grid-Stat tool, with options for statistic types, thresholds, and conditional verification options as discussed in the Chapter 8. However, these statistics will be produced separately for each grid location and accumulated over some series such as time or height, rather than accumulated over the whole domain for a single time or height as is done by Grid-Stat.

This tool computes statistics for exactly one series each time it is run. Multiple series may be processed by running the tool multiple times. The length of the series to be processed is determined by the first of the following that is greater than one: the number of forecast fields in the configuration file, the number of observation fields in the configuration file, the number of input forecast files, the number of input observation files. Several examples of defining series are described below.

To define a time series of forecasts where the valid time changes for each time step, set the forecast and observation fields in the configuration file to single values and pass the tool multiple forecast and observation

files. The tool will loop over the forecast files, extract the specified field from each, and then search the observation files for a matching record with the same valid time.

To define a time series of forecasts that all have the same valid time, set the forecast and observation fields in the configuration file to single values. Pass the tool multiple forecast files and a single observation file containing the verifying observations. The tool will loop over the forecast files, extract the specified field from each, and then retrieve the verifying observations.

To define a series of vertical levels all contained in a single input file, set the forecast and observation fields to a list of the vertical levels to be used. Pass the tool single forecast and observation files containing the vertical level data. The tool will loop over the forecast field entries, extract that field from the input forecast file, and then search the observation file for a matching record.

13.2.1 series_analysis usage

The usage statement for the Series-Analysis tool is shown below:

```
Usage: series_analysis
      -fcst file_1 ... file_n | fcst_file_list
      -obs  file_1 ... file_n | obs_file_list
      [-both file_1 ... file_n | both_file_list ]
      -out file
      -config file
      [-log file]
      [-v level]
```

series_analysis has four required arguments and accepts several optional ones.

Required arguments series_stat

1. The **-fcst file_1 ... file_n | fcst_file_list** options specify the gridded forecast files or ASCII files containing lists of file names to be used.
2. The **-obs file_1 ... file_n | obs_file_list** are the gridded observation files or ASCII files containing lists of file names to be used.
3. The **-out file** is the NetCDF output file containing computed statistics.
4. The **-config file** is a Series-Analysis Configuration file containing the desired settings.

Optional arguments for series_analysis

5. To set both the forecast and observations to the same set of files, use the optional **-both file_1 ... file_n | both_file_list** option to the same set of files. This is useful when reading the NetCDF matched pair output of the Grid-Stat tool which contains both forecast and observation data.
6. The **-log file** outputs log messages to the specified file.
7. The **-v level** overrides the default level of logging (2).

An example of the `series_analysis` calling sequence is shown below:

```
series_analysis \  
-fcst  myfcstfilelist.txt \  
-obs   myobsfilelist.txt \  
-config SeriesAnalysisConfig \  
-out   out/my_series_statistics.nc
```

In this example, the Series-Analysis tool will process the list of forecast and observation files specified in the text file lists into statistics for each grid location using settings specified in the configuration file. Series-Analysis will create an output NetCDF file containing requested statistics.

13.2.2 series_analysis output

The Series-Analysis tool produces NetCDF files containing output statistics for each grid location from the input files. The details about the output statistics available from each output line type are detailed in Chapter 5 since they are also produced by the Grid-Stat Tool. A subset of these can be produced by this tool, with the most notable exceptions being the wind vector and neighborhood statistics. Users can inventory the contents of the Series-Analysis output files using the `ncdump -h` command to view header information. Additionally, `ncview` or the `plot_data_plane` tool can be used to visualize the output. An example of Series-Analysis output is shown in Figure 13.1 below.

13.2.3 series_analysis configuration file

The default configuration file for the Series-Analysis tool named *SeriesAnalysisConfig_default* can be found in the installed `share/met/config` directory. The contents of the configuration file are described in the subsections below.

Note that environment variables may be used when editing configuration files, as described in the Section 4.1.2 for the PB2NC tool.

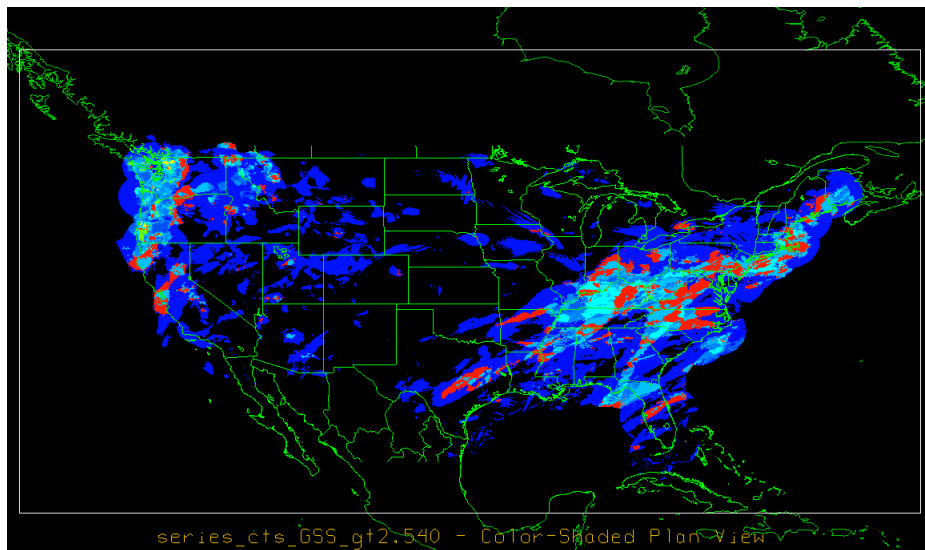


Figure 13.1: An example of the Gilbert Skill Score for precipitation forecasts at each grid location for a month of files.

```

model      = "WRF";
obtype     = "ANALYS";
regrid     = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }
fcst      = {};
obs       = {};
climo_mean = {};
ci_alpha  = [ 0.05 ];
boot      = { interval = PCTILE; rep_prop = 1.0; n_rep = 1000;
              rng = "mt19937"; seed = ""; };
mask      = { grid = [ "FULL" ]; poly = []; };
rank_corr_flag = TRUE;
tmp_dir   = "/tmp";
version   = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```
block_size = 1024;
```

Number of grid points to be processed concurrently. Set smaller to use less memory but increase the number of passes through the data. The amount of memory the Series-Analysis tool consumes is determined by the size of the grid, the length of the series, and the `block_size` entry defined above. The larger this entry is set the faster the tool will run, subject to the amount of memory available on the machine.

```
vld_thresh = 1.0;
```

Ratio of valid matched pairs for the series of values at each grid point required to compute statistics. Set to a lower proportion to allow some missing values. Setting it to 1.0 requires that every data point be valid over the series to compute statistics.

```
output_stats = {
    fho    = [];
    ctc    = [];
    cts    = [];
    mctc   = [];
    mcts   = [];
    cnt    = ["RMSE", "FBAR", "OBAR"];
    sl1l2  = [];
    sal1l2 = [];
    pct    = [];
    pstd   = [];
    pjc    = [];
    prc    = [];
}
```

The `output_stats` array controls the type of output that the Series-Analysis tool generates. Each flag corresponds to an output line type in the STAT file and is used to specify the comma-separated list of statistics to be computed. Use the column names from the tables listed below to specify the statistics. The output flags correspond to the following types of output line types:

1. **FHO** for Forecast, Hit, Observation Rates (See Table 7.2)
2. **CTC** for Contingency Table Counts (See Table 7.3)
3. **CTS** for Contingency Table Statistics (See Table 7.4)
4. **MCTC** for Multi-Category Contingency Table Counts (See Table 7.8)
5. **MCTS** for Multi-Category Contingency Table Statistics (See Table 7.9)
6. **CNT** for Continuous Statistics (See Table 7.6)
7. **SL1L2** for Scalar L1L2 Partial Sums (See Table 7.14)
8. **SAL1L2** for Scalar Anomaly L1L2 Partial Sums climatological data is supplied (See Table 7.15)
9. **PCT** for Contingency Table Counts for Probabilistic forecasts (See Table 7.10)
10. **PSTD** for Contingency Table Statistics for Probabilistic forecasts (See Table 7.11)

11. **PJC** for Joint and Conditional factorization for Probabilistic forecasts (See Table 7.12)
12. **PRC** for Receiver Operating Characteristic for Probabilistic forecasts (See Table 7.13)

Chapter 14

MODE Tool

14.1 Introduction

This chapter provides a description of the Method for Object-Based Diagnostic Evaluation (MODE) tool, which was developed at the Research Applications Laboratory, NCAR/Boulder, USA. More information about MODE can be found in Davis **et al.** (2006a, b) and Brown **et al.** (2007).

MODE was developed in response to a need for verification methods that can provide diagnostic information that is more directly useful and meaningful than the information that can be obtained from traditional verification approaches, especially in application to high-resolution NWP output. The MODE approach was originally developed for application to spatial precipitation forecasts, but it can also be applied to other fields with coherent spatial structures (*e.g.*, clouds, convection).

MODE is only one of a number of different approaches that have been developed in recent years to meet these needs. In the future, we expect that the MET package will include additional methods. References for many of these methods are provided at <http://www.rap.ucar.edu/projects/icp/index.html>.

MODE may be used in a generalized way to compare any two fields. For simplicity, field1 may be thought of in this chapter as “the forecast,” while field2 may be thought of as “the observation”, which is usually a gridded analysis of some sort. The convention of field1/field2 is also used in Table 14.2. MODE resolves objects in both the forecast and observed fields. These objects mimic what humans would call “regions of interest.” Object attributes are calculated and compared, and are used to associate (“merge”) objects within a single field, as well as to “match” objects between the forecast and observed fields. Finally, summary statistics describing the objects and object pairs are produced. These statistics can be used to identify correlations and differences among the objects, leading to insights concerning forecast strengths and weaknesses.

14.2 Scientific and statistical aspects

The methods used by the MODE tool to identify and match forecast and observed objects are briefly described in this section.

14.2.1 Resolving objects

The process used for resolving objects in a raw data field is called *convolution thresholding*. The raw data field is first convolved with a simple filter function as follows:

$$C(x, y) = \sum_{u, v} \phi(u, v) f(x - u)(y - v).$$

In this formula, \mathbf{f} is the raw data field, ϕ is the filter function, and \mathbf{C} is the resulting convolved field. The variables (\mathbf{x}, \mathbf{y}) and (\mathbf{u}, \mathbf{v}) are grid coordinates. The filter function ϕ is a simple circular filter determined by a radius of influence \mathbf{R} , and a height \mathbf{H} :

$$\phi(x, y) = \begin{cases} H & \text{if } x^2 + y^2 \leq R^2 \\ 0 & \text{otherwise.} \end{cases}$$

The parameters \mathbf{R} and \mathbf{H} are not independent. They are related by the requirement that the integral of ϕ over the grid be unity:

$$\pi R^2 H = 1.$$

Thus, the radius of influence \mathbf{R} is the only tunable parameter in the convolution process. Once \mathbf{R} is chosen, \mathbf{H} is determined by the above equation.

Once the convolved field \mathbf{C} is in hand, it is thresholded to create a mask field \mathbf{M} :

$$M(x, y) = \begin{cases} 1 & \text{if } C(x, y) \geq T \\ 0 & \text{otherwise.} \end{cases}$$

where T is the threshold. The objects are the connected regions where $\mathbf{M} = \mathbf{1}$. Finally, the raw data are restored to object interiors to obtain the object field \mathbf{F} :

$$F(x, y) = M(x, y)f(x, y).$$

Thus, two parameters — the radius of influence \mathbf{R} , and the threshold \mathbf{T} — control the entire process of resolving objects in the raw data field.

An example of the steps involved in resolving objects is shown in Figure 14.1. Figure 14.1a shows a "raw" precipitation field, where the vertical coordinate represents the precipitation amount. Part b shows the convolved field, and part c shows the masked field obtained after the threshold is applied. Finally, Figure 14.1d shows the objects once the original precipitation values have been restored to the interiors of the objects.

14.2.2 Attributes

Object attributes are defined both for single objects and for object pairs. One of the objects in a pair is from the forecast field and the other is taken from the observed field.

Area is simply a count of the number of grid squares an object occupies. If desired, a true area (say, in km^2) can be obtained by adding up the true areas of all the grid squares inside an object, but in practice this is seldom necessary.

Moments are used in the calculation of several object attributes. If we define $\xi(x, y)$ to be 1 for points (x, y) inside our object, and zero for points outside, then the first-order moments, S_x and S_y , are defined as

$$S_x = \sum_{x,y} x \xi(x, y) \quad \text{and} \quad S_y = \sum_{x,y} y \xi(x, y).$$

Higher order moments are similarly defined and are used in the calculation of some of the other attributes. For example, the **centroid** is a kind of geometric center of an object, and can be calculated from first moments. It allows one to assign a single point location to what may be a large, extended object.

Axis Angle, denoted by θ , is calculated from the second-order moments. It gives information on the orientation or "tilt" of an object. **Curvature** is another attribute that uses moments in its calculation, specifically, third-order moments.

Aspect Ratio is computed by fitting a rectangle around an object. The rectangle is aligned so that it has the same axis angle as the object, and the length and width are chosen so as to just enclose the object. We make no claim that the rectangle so obtained is the smallest possible rectangle enclosing the given object. However, this rectangle is much easier to calculate than a smallest enclosing rectangle and serves our purposes just as well. Once the rectangle is determined, the aspect ratio of the object is defined to be the width of the fitted rectangle divided by its length.

Another object attribute defined by MODE is **complexity**. Complexity is defined by comparing the area of an object to the area of its convex hull.

All the attributes discussed so far are defined for single objects. Once these are determined, they can be used to calculate attributes for pairs of objects. One example is **centroid difference**. This measure is simply the (vector) difference between the centroids of the two objects. Another example is **angle difference**, the difference between the axis angles.

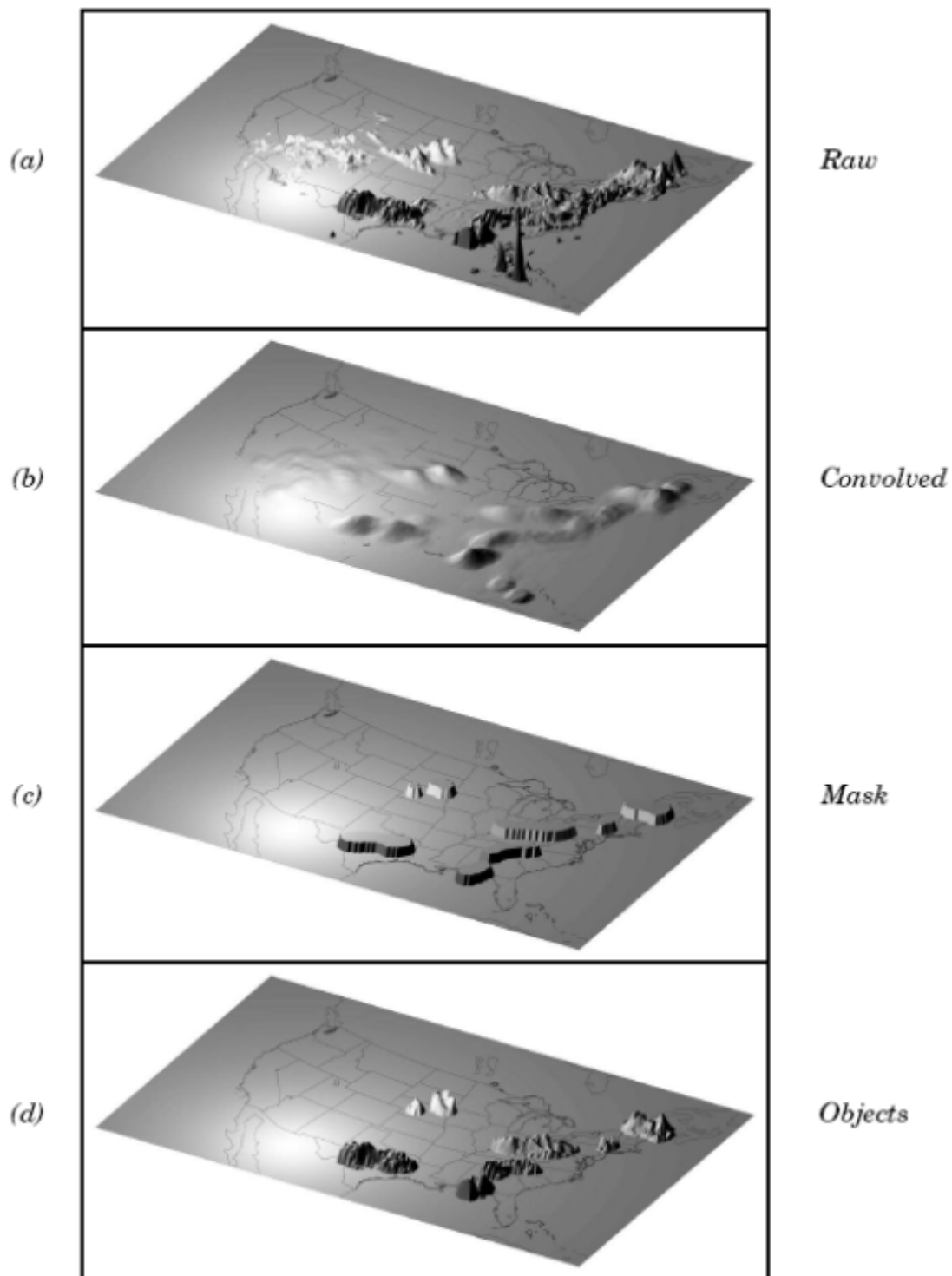


Figure 14.1: Example of an application of the MODE object identification process to a model precipitation field.

Several area measures are also used for pair attributes. **Union Area** is the total area that is in either one (or both) of the two objects. **Intersection Area** is the area that is inside both objects simultaneously. **Symmetric Difference** is the area inside at least one object, but not inside both.

14.2.3 Fuzzy logic

Once object attributes $\alpha_1, \alpha_2, \dots, \alpha_n$ are estimated, some of them are used as input to a fuzzy logic engine that performs the matching and merging steps. **Merging** refers to grouping together objects in a single field, while **matching** refers to grouping together objects in different fields, typically the forecast and observed fields. Interest maps I_i are applied to the individual attributes α_i to convert them into interest values, which range from zero (representing no interest) to one (high interest). For example, the default interest map for centroid difference is one for small distances, and falls to zero as the distance increases. For other attributes (*e.g.*, intersection area), low values indicate low interest, and high values indicate more interest.

The next step is to define confidence maps C_i for each attribute. These maps (again with values ranging from zero to one) reflect how confident we are in the calculated value of an attribute. The confidence maps generally are functions of the entire attribute vector $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n)$, in contrast to the interest maps, where each I_i is a function only of α_i . To see why this is necessary, imagine an electronic anemometer that outputs a stream of numerical values of wind speed and direction. It is typically the case for such devices that when the wind speed becomes small enough, the wind direction is poorly resolved. The wind must be at least strong enough to overcome friction and turn the anemometer. Thus, in this case, our confidence in one attribute (wind direction) is dependent on the value of another attribute (wind speed). In MODE, all of the confidence maps except the map for axis angle are set to a constant value of 1. The axis angle confidence map is a function of aspect ratio, with values near one having low confidence, and values far from one having high confidence.

Next, scalar weights w_i are assigned to each attribute, representing an empirical judgment regarding the relative importance of the various attributes. As an example, the initial development of MODE, centroid distance was weighted more heavily than other attributes, because the location of storm systems close to each other in space seemed to be a strong indication (stronger than that given by any other attribute) that they were related.

Finally, all these ingredients are collected into a single number called the total interest, \mathbf{T} , given by:

$$T(\alpha) = \frac{\sum_i w_i C_i(\alpha) I_i(\alpha_i)}{\sum_i w_i C_i(\alpha)}.$$

This total interest value is then thresholded, and pairs of objects that have total interest values above the threshold are merged (if they are in the same field) or matched (if they are in different fields).

Another merging method is available in MODE, which can be used instead of, or along with, the fuzzy logic based merging just described. Recall that the convolved field is thresholded to produce the mask field. A second (lower) threshold can be specified so that objects that are separated at the higher threshold but joined at the lower threshold are merged.

14.2.4 Summary statistics

Once MODE has been run, summary statistics are written to an output file. These files contain information about all single and cluster objects and their attributes. Total interest for object pairs is also output, as are percentiles of intensity inside the objects. The output file is in a simple flat ASCII tabular format (with one header line) and thus should be easily readable by just about any programming language, scripting language, or statistics package. Refer to Section 14.3.3 for lists of the statistics included in the MODE output files. Example scripts will be posted on the MET website in the future.

14.3 Practical information

This section contains a description of how MODE can be configured and run. The MODE tool is used to perform a features-based verification of gridded model data using gridded observations. The input gridded model and observation datasets must be in one of the MET supported gridded file formats. The requirement of having all gridded fields using the same grid specification has been removed with METv5.1. The Grid-Stat tool performs no interpolation when the input model, observation, and climatology datasets must be on a common grid. MET will interpolate these files to a common grid if one is specified. There is a regrid option in the configuration file that allows the user to define the grid upon which the scores will be computed. The gridded analysis data may be based on observations, such as Stage II or Stage IV data for verifying accumulated precipitation, or a model analysis field may be used. However, users are cautioned that it is generally unwise to verify model output using an analysis field produced by the same model.

MODE provides the capability to select a single model variable/level from which to derive objects to be analyzed. MODE was developed and tested using accumulated precipitation. However, the code has been generalized to allow the use of any gridded model and observation field. Based on the options specified in the configuration file, MODE will define a set of simple objects in the model and observation fields. It will then compute an interest value for each pair of objects across the fields using a fuzzy engine approach. Those interest values are thresholded, and any pairs of objects above the threshold will be matched/merged. Through the configuration file, MODE offers a wide range of flexibility in how the objects are defined, processed, matched, and merged.

14.3.1 mode usage

The usage statement for the MODE tool is listed below:

```
Usage: mode
      fcst_file
      obs_file
      config_file
      [-config_merge merge_config_file]
```

```
[-outdir path]
[-log file]
[-v level]
```

The MODE tool has three required arguments and can accept several optional arguments.

Required arguments for mode

1. The **fcst_file** argument indicates the gridded file containing the model field to be verified.
2. The **obs_file** argument indicates the gridded file containing the gridded observations to be used for the verification of the model.
3. The **config_file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for mode

4. The **-config_merge merge_config_file** option indicates the name of a second configuration file to be used when performing fuzzy engine merging by comparing the model or observation field to itself. The MODE tool provides the capability of performing merging within a single field by comparing the field to itself. Interest values are computed for each object and all of its neighbors. If an object and its neighbor have an interest value above some threshold, they are merged. The **merge_config_file** controls the settings of the fuzzy engine used to perform this merging step. If a **merge_config_file** is not provided, the configuration specified by the **config_file** in the previous argument will be used.
5. The **-outdir path** option indicates the directory where output files should be written.
6. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
7. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

An example of the MODE calling sequence is listed below:

Example 1:

```
mode sample_fcst.grb \  
sample_obs.grb \  
MODEConfig_grb
```

In Example 1, the MODE tool will verify the model data in the `sample_fcst.grb` GRIB file using the observations in the `sample_obs.grb` GRIB file applying the configuration options specified in the `MODEConfig_grb` file.

A second example of the MODE calling sequence is presented below:

Example 2:

```
mode sample_fcst.nc \
sample_obs.nc \
MODEConfig_nc
```

In Example 2, the MODE tool will verify the model data in the `sample_fcst.nc` NetCDF output of `pcp_combine` using the observations in the `sample_obs.nc` NetCDF output of `pcp_combine`, using the configuration options specified in the `MODEConfig_nc` file. Since the model and observation files contain only a single field of accumulated precipitation, the `MODEConfig_nc` file should specify that accumulated precipitation be verified.

14.3.2 mode configuration file

The default configuration file for the MODE tool, `MODEConfig_default`, can be found in the installed `share/met/config` directory. Another version of the configuration file is provided in `scripts/config`. We encourage users to make a copy of the configuration files prior to modifying their contents. Descriptions of `MODEConfig_default` and the required variables for any MODE configuration file are also provided below. While the configuration file contains many entries, most users will only need to change a few for their use. Specific options are described in the following subsections.

Note that environment variables may be used when editing configuration files, as described in Section 4.1.2 for the `PB2NC` tool.

```
model          = "WRF";
obtype         = "ANALYS";
regrid         = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }
met_data_dir   = "MET_BASE";
output_prefix  = "";
version        = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```
grid_res = 4;
```

The `grid_res` entry is the nominal spacing for each grid square in kilometers. This entry is not used directly in the code, but subsequent entries in the configuration file are defined in terms of it. Therefore, setting this appropriately will help ensure that appropriate default values are used for these entries.

```
fcst = {
  field = {
    name = "APCP";
    level = "A03";
  }
  raw_thresh      = NA;
  conv_radius     = 60.0/grid_res; // in grid squares
  conv_thresh     = >=5.0;
  vld_thresh     = 0.5;
  area_thresh     = NA;
  inten_perc_value = 100;
  inten_perc_thresh = NA;
  merge_thresh    = >=1.25;
  merge_flag      = THRESH;
}
obs = fcst;
```

The **field** entries in the forecast and observation dictionaries specify the model and observation variables and level to be compared. See a more complete description of them in Section 3.5.1. In the above example, the forecast settings are copied into the observation dictionary using `obs = fcst`;

The **raw_thresh** entry is used to threshold the raw forecast and/or observation fields. Prior to defining objects, it is recommended that the raw fields should be made to look similar to each other. For example, if the model only predicts values for a variable above some threshold, the observations should be thresholded at that same level. The thresholds can be specified using symbols. By default, no raw field thresholded is applied.

The **conv_radius** entry defines the radius of the circular convolution applied to smooth the raw fields. The radii are specified in terms of grid units. The default convolution radii are defined in terms of the previously defined `grid_res` entry.

The **conv_thresh** entry specifies the threshold values to be applied to the convolved field to define objects. By default, objects are defined using a convolution threshold of 5.0.

The **vld_thresh** entry must be set between 0 and 1. When performing the circular convolution step if the proportion of bad data values in the convolution area is greater than or equal to this threshold, the

resulting convolved value will be bad data. If the proportion is less than this threshold, the convolution will be performed on only the valid data. By default, the `vld_thresh` is set to 0.5.

The `area_thresh` entry specifies the area threshold values to be applied to the defined objects. The area of an object is simply a count of the number of grid squares that comprise it. A user may, for example, want to only consider objects that meet some minimum size criteria. By default, all objects are retained since no area threshold is applied.

The `inten_perc_value` and `inten_perc_thresh` entries specify the intensity threshold values to be applied to the defined objects. For each object defined, the intensity values within the object are sorted, and the requested intensity percentile value is computed. By default, the maximum value is computed since the intensity percentiles are set to 100. Any objects with an intensity percentile that does not meet the corresponding intensity percentile threshold specified will be discarded. A user may, for example, want to only consider objects that meet some maximum intensity criteria. By default, no intensity percentile threshold is applied.

The `merge_thresh` entry is used to define larger objects for use in merging the original objects. It defines the threshold value used in the double thresholding merging technique. Note that in order to use this merging technique, it must be requested for both the forecast and observation fields. These thresholds should be chosen to define larger objects that fully contain the originally defined objects. For example, for objects defined as ≥ 5.0 , a merge threshold of ≥ 2.5 will define larger objects that fully contain the original objects. Any two original objects contained within the same larger object will be merged. By default, the merge thresholds are set to be greater than or equal to 1.25.

The `merge_flag` entry controls what type of merging techniques will be applied to the objects defined in each field.

- **NONE** indicates that no merging should be applied.
- **THRESH** indicates that the double thresholding merging technique should be applied.
- **ENGINE** indicates that objects in each field should be merged by comparing the objects to themselves using a fuzzy engine approach.
- **BOTH** indicates that both techniques should be used.

By default, the double thresholding merging technique is applied.

```
mask_missing_flag = NONE;
```

The `mask_missing_flag` entry specifies how missing data in the raw model and observation fields will be treated.

- **NONE** indicates no additional processing is to be done.
- **FCST** indicates missing data in the observation field should be used to mask the forecast field.
- **OBS** indicates missing data in the forecast field should be used to mask the observation field.
- **BOTH** indicates masking should be performed in both directions (*i.e.*, mask the forecast field with the observation field and vice-versa).

Prior to defining objects, it is recommended that the raw fields be made to look similar to each other by assigning a value of **BOTH** to this parameter. However, by default no masking is performed.

```
match_flag = MERGE_BOTH;
```

The **match_flag** entry controls how matching will be performed when comparing objects from the forecast field to objects from the observation field. An interest value is computed for each possible pair of forecast/observation objects. The interest values are then thresholded to define which objects match. If two objects in one field happen to match the same object in the other field, then those two objects could be merged. The **match_flag** entry controls what type of merging is allowed in this context.

- **NONE** indicates that no matching should be performed between the fields at all.
- **MERGE_BOTH** indicates that additional merging is allowed in both fields.
- **MERGE_FCST** indicates that additional merging is allowed only in the forecast field.
- **NO_MERGE** indicates that no additional merging is allowed in either field, meaning that each object will match at most one object in the other field.

By default, additional merging is allowed in both fields.

```
max_centroid_dist = 800/grid_res;
```

Computing the attributes for all possible pairs of objects can take some time depending on the numbers of objects. The **max_centroid_dist** entry is used to specify how far apart objects should be in order to conclude that they have no chance of matching. No pairwise attributes are computed for pairs of objects whose centroids are farther away than this distance, defined in terms of grid units. Setting this entry to a reasonable value will improve the execution time of the MODE tool. By default, the maximum centroid distance is defined in terms of the previously defined **grid_res** entry.

```

mask = {
  grid = "";
  grid_flag = NONE; // Apply to NONE, FCST, OBS, or BOTH
  poly = "";
  poly_flag = NONE; // Apply to NONE, FCST, OBS, or BOTH
}

```

Defining a **grid** and **poly** masking region is described in Section 3.5.1. Applying a masking region when running MODE sets all grid points falling outside of that region to missing data, effectively limiting the area of which objects should be defined.

The **grid_flag** and **poly_flag** entries specify how the grid and polyline masking should be applied:

- **NONE** indicates that the masking grid should not be applied.
- **FCST** indicates that the masking grid should be applied to the forecast field.
- **OBS** indicates that the masking grid should be applied to the observation field.
- **BOTH** indicates that the masking grid should be applied to both fields.

By default, no masking grid or polyline is applied.

```

weight = {
  centroid_dist    = 2.0;
  boundary_dist    = 4.0;
  convex_hull_dist = 0.0;
  angle_diff       = 1.0;
  area_ratio       = 1.0;
  int_area_ratio   = 2.0;
  complexity_ratio = 0.0;
  inten_perc_ratio = 0.0;
  inten_perc_value = 50;
}

```

The **weight** entries listed above control how much weight is assigned to each pairwise attribute when computing a total interest value for object pairs. The weights listed above correspond to the **centroid distance** between the objects, the **boundary distance** (or minimum distance), the **convex hull distance** (or minimum distance between the convex hulls of the objects), the **orientation angle difference**, the **object area ratio**, the **intersection divided by the minimum object area ratio**, the **complexity ratio**, and the **intensity ratio**. The weights need not sum to any particular value. When the total interest value is computed, the weighted sum is normalized by the sum of the weights listed above.

The **inten_perc_value** entry corresponds to the **inten_perc_ratio**. The **inten_perc_value** should be set between 0 and 100 to define which percentile of intensity should be compared for pairs of objects. By default, the 50th percentile, or median value, is chosen.

```

interest_function = {
    centroid_dist    = (...);
    boundary_dist   = (...);
    convex_hull_dist = (...);
    angle_diff      = (...);
    corner          = 0.8;
    ratio_if        = ( ( 0.0, 0.0 ) ( corner, 1.0 ) ( 1.0, 1.0 ) );
    area_ratio      = ratio_if;
    int_area_ratio  = (...);
    complexity_ratio = ratio_if;
    inten_perc_ratio = ratio_if;
}

```

The set of interest function entries listed above define which values are of interest for each pairwise attribute measured. The interest functions may be defined as a piecewise linear function or as an algebraic expression. A piecewise linear function is defined by specifying the corner points of its graph. An algebraic function may be defined in terms of several built-in mathematical functions. See Section 15.2 for how interest values are used by the fuzzy logic engine. By default, many of these functions are defined in terms of the previously defined **grid_res** entry.

```
total_interest_thresh = 0.7;
```

The **total_interest_thresh** entry should be set between **0** and **1**. This threshold is applied to the total interest values computed for each pair of objects. Object pairs that have an interest value that is above this threshold will be matched, while those with an interest value that is below this threshold will remain unmatched. Increasing the threshold will decrease the number of matches while decreasing the threshold will increase the number of matches. By default, the total interest threshold is set to 0.7.

```
print_interest_thresh = 0.0;
```

The **print_interest_thresh** entry determines which pairs of object attributes will be written to the output object attribute ASCII file. The user may choose to set the **print_interest_thresh** to the same value as

the **total_interest_thresh**, meaning that only object pairs that actually match are written to the output file. By default, the print interest threshold is set to zero, meaning that all object pair attributes will be written as long as the distance between the object centroids is less than the **max_centroid_dist** entry.

```

fcst_raw_plot = {
    color_table = "MET_BASE/colortables/met_default.ctable";
    plot_min = 0.0;
    plot_max = 0.0;
    colorbar_spacing = 1;
}
obs_raw_plot = {
    color_table = "MET_BASE/colortables/met_default.ctable";
    plot_min = 0.0;
    plot_max = 0.0;
    colorbar_spacing = 1;
}
object_plot = {
    color_table = "MET_BASE/colortables/mode_obj.ctable";
}

```

Specifying dictionaries to define the **color_table**, **plot_min**, and **plot_max** entries are described in Section 3.5.1.

The MODE tool generates a color bar to represent the contents of the colortable that was used to plot a field of data. The number of entries in the color bar matches the number of entries in the color table. The values defined for each color in the color table are also plotted next to the color bar. The **colorbar_spacing** entry is used to define the frequency with which the color table values should be plotted. Setting this entry to 1, as shown above, indicates that every color table value should be plotted. Setting it to an integer, $n > 1$, indicates that only every n -th color table value should be plotted.

```

zero_border_size = 1;

```

The MODE tool is not able to define objects that touch the edge of the grid. After the convolution step is performed the outer columns and rows of data are zeroed out to enable MODE to identify objects. The **zero_border_size** entry specifies how many outer columns and rows of data should be set to bad data.

```

plot_valid_flag = FALSE;

```

When applied, the **plot_valid_flag** entry indicates that only the region containing valid data after masking is applied should be plotted.

- **FALSE** indicates the entire domain should be plotted.
- **TRUE** indicates only the region containing valid data after masking should be plotted.

The default value of this flag is **FALSE**.

```
plot_gcArc_flag = FALSE;
```

When applied, the **plot_gcArc_flag** entry indicates that the edges of polylines should be plotted using great circle arcs as opposed to straight lines in the grid. The default value of this flag is **FALSE**.

```
ps_plot_flag = TRUE;
ct_stats_flag = TRUE;
```

These flags can be set to **TRUE** or **FALSE** to produce additional output, in the form of PostScript plots and contingency table counts and statistics, respectively.

```
nc_pairs_flag = {
  latlon      = TRUE;
  raw         = TRUE;
  object_raw  = TRUE;
  object_id   = TRUE;
  cluster_id  = TRUE;
  polylines   = TRUE;
}
```

Each component of the pairs information in the NetCDF file can be turned on or off. The old syntax is still supported: **TRUE** means accept the defaults, **FALSE** means no NetCDF output is generated. NetCDF output can also be turned off by setting all the individual dictionary flags to false.

```
shift_right = 0;
```

When **MODE** is run on global grids, this parameter specifies how many grid squares to shift the grid to the right. **MODE** does not currently connect objects from one side of a global grid to the other, potentially causing objects straddling the “cut” longitude to be separated into two objects. Shifting the grid by integer number of grid units enables the user to control where that longitude cut line occurs.

14.3.3 mode output

MODE produces output in ASCII, NetCDF, and PostScript formats.

ASCII output

The MODE tool creates two ASCII output files. The first ASCII file contains contingency table counts and statistics for comparing the forecast and observation fields. This file consists of 4 lines. The first is a header line containing column names. The second line contains data comparing the two raw fields after any masking of bad data or based on a grid or lat/lon polygon has been applied. The third contains data comparing the two fields after any raw thresholds have been applied. The fourth, and last, line contains data comparing the derived object fields scored using traditional measures.

Table 14.1: Format of MODE CTS output file.

MODE ASCII CONTINGENCY TABLE OUTPUT FORMAT		
Column Number	MODE CTS Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID	Forecast valid start time in YYYYMMDDHH format
5	FCST_ACCUM	Forecast accumulation time in HHMMSS format
6	OBS_LEAD	Observation lead time in HHMMSS format; when field2 is actually an observation, this should be "000000"
7	OBS_VALID	Observation valid start time in YYYYMMDDHH format
8	OBS_ACCUM	Observation accumulation time in HHMMSS format
9	FCST_RAD	Forecast convolution radius in grid squares
10	FCST_THR	Forecast convolution threshold
11	OBS_RAD	Observation convolution radius in grid squares
12	OBS_THR	Observation convolution threshold
13	FCST_VAR	Forecast variable
14	FCST_LEV	Forecast vertical level
15	OBS_VAR	Observation variable
16	OBS_LEV	Observation vertical level
17	FIELD	Field type for this line:* RAW for the raw input fields* FILTER for the raw fields after applying the raw thresholds* OBJECT for the resolved object fields
18	TOTAL	Total number of matched pairs
19	FY_OY	Number of forecast yes and observation yes
20	FY_ON	Number of forecast yes and observation no
21	FN_OY	Number of forecast no and observation yes
22	FN_ON	Number of forecast no and observation no
23	BASER	Base rate
24	FMEAN	Forecast mean
25	ACC	Accuracy
26	FBIAS	Frequency Bias
27	PODY	Probability of detecting yes
28	PODN	Probability of detecting no
29	POFD	Probability of false detection
30	FAR	False alarm ratio
31	CSI	Critical Success Index
32	GSS	Gilbert Skill Score
33	HK	Hanssen-Kuipers Discriminant
34	HSS	Heidke Skill Score
35	ODDS	Odds Ratio

This first file uses the following naming convention:

```
mode_PREFIX_FCST_VAR_LVL_vs_OBS_VAR_LVL_HHMMSSL_YYYYMMDD_HHMMSSV_HHMMSSA_cts.txt
```

where `PREFIX` indicates the user-defined output prefix, `FCST_VAR_LVL` is the forecast variable and vertical level being used, `OBS_VAR_LVL` is the observation variable and vertical level being used, `HHMSSL` indicates the forecast lead time, `YYYYMMDD_HHMSSV` indicates the forecast valid time, and `HHMSSA` indicates the accumulation period. The `cts` string stands for contingency table statistics. The generation of this file can be disabled using the `ct_stats_flag` option in the configuration file. This CTS output file differs somewhat from the CTS output of the Point-Stat and Grid-Stat tools. The columns of this output file are summarized in Table 14.1.

The second ASCII file the MODE tool generates contains all of the attributes for simple objects, the merged cluster objects, and pairs of objects. Each line in this file contains the same number of columns, though those columns not applicable to a given line contain fill data. The first row of every MODE object attribute file is a header containing the column names. The number of lines in this file depends on the number of objects defined. This file contains lines of 6 types that are indicated by the contents of the `OBJECT_ID` column. The `OBJECT_ID` can take the following 6 forms: `FNN`, `ONN`, `FNNN_ONNN`, `CFNNN`, `CONNN`, `CFNNN_CONNN`. In each case, `NNN` is a three-digit number indicating the object index. While all lines have the first 18 header columns in common, these 6 forms for `OBJECT_ID` can be divided into two types - one for single objects and one for pairs of objects. The single object lines (`FNN`, `ONN`, `CFNNN`, and `CONNN`) contain valid data in columns 19–39 and fill data in columns 40–51. The object pair lines (`FNNN_ONNN` and `CFNNN_CONNN`) contain valid data in columns 40–51 and fill data in columns 19–39. These object identifiers are described in Table 14.2.

Table 14.2: Object identifier descriptions for MODE object attribute output files.

mode ASCII OBJECT IDENTIFIER DESCRIPTIONS		
Object identifier (object_id)	Valid Data Columns	Description of valid data
FNNN, ONNN	1-18,19-39	Attributes for simple forecast, observation objects
FNNN_ONNN	1-18, 40-51	Attributes for pairs of simple forecast and observation objects
CFNNN, CONNN	1-18,19-39	Attributes for merged cluster objects in forecast, observation fields
CFNNN_CONNN	1-18, 40-51	Attributes for pairs of forecast and observation cluster objects

A note on terminology: a cluster (referred to as "composite" in earlier versions) object need not necessarily consist of more than one simple object. A cluster object is by definition any set of one or more objects in one field which match a set of one or more objects in the other field. When a single simple forecast object matches a single simple observation object, they are each considered to be cluster objects as well.

The contents of the columns in this ASCII file are summarized in Table 14.3 and 14.4.

Table 14.3: Format of MODE object attribute output files.

mode ASCII OBJECT ATTRIBUTE OUTPUT FORMAT		
Column	MODE Column Name	Description
1	VERSION	Version number
2	MODEL	User provided text string designating model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID	Forecast valid start time in YYYYMMDDHH format
5	FCST_ACCUM	Forecast accumulation time in HHMMSS format
6	OBS_LEAD	Observation lead time in HHMMSS format; when field2 is actually an observation, this should be "000000"
7	OBS_VALID	Observation valid start time in YYYYMMDDHH format
8	OBS_ACCUM	Observation accumulation time in HHMMSS format
9	FCST_RAD	Forecast convolution radius in grid squares
10	FCST_THR	Forecast convolution threshold
11	OBS_RAD	Observation convolution radius in grid squares
12	OBS_THR	Observation convolution threshold
13	FCST_VAR	Forecast variable
14	FCST_LEV	Forecast vertical level
15	OBS_VAR	Observation variable
16	OBS_LEV	Observation vertical level
17	OBJECT_ID	Object numbered from 1 to the number of objects in each field
18	OBJECT_CAT	Object category indicating to which cluster object it belongs
19-20	CENTROID_X, _Y	Location of the centroid (in grid units)
21-22	CENTROID_LAT, _LON	Location of the centroid (in lat/lon degrees)
23	AXIS_ANG	Object axis angle (in degrees)
24	LENGTH	Length of the enclosing rectangle (in grid units)
25	WIDTH	Width of the enclosing rectangle (in grid units)
26	AREA	Object area (in grid squares)
27	AREA_FILTER	Area of the object containing non-zero data in the filtered field (in grid squares)
28	AREA_THRESH	Area of the object containing data values in the filtered field that meet the object definition threshold criteria (in grid squares)
29	CURVATURE	Radius of curvature of the object defined in terms of third order moments (in grid units)
30-31	CURVATURE_X, _Y	Center of curvature (in grid coordinates)
32	COMPLEXITY	Ratio of the difference between the area of an object and the area of its convex hull divided by the area of the complex hull (unitless)
33-37	INTENSITY_10, _25, _50, _75, _90	10th, 25th, 50th, 75th, and 90th percentiles of intensity of the filtered field within the object (various units)
38	INTENSITY_NN	The percentile of intensity chosen for use in the percentile intensity ratio (column 50; variable units)

Table 14.4: Format of MODE object attribute output files, continued.

mode ASCII OBJECT ATTRIBUTE OUTPUT FORMAT		
Column	MODE Column Name	Description
39	INTENSITY_SUM	Sum of the intensities of the filtered field within the object (variable units)
40	CENTROID_DIST	Distance between two objects centroids (in grid units)
41	BOUNDARY_DIST	Minimum distance between the boundaries of two objects (in grid units)
42	CONVEX_HULL_DIST	Minimum distance between the convex hulls of two objects (in grid units)
43	ANGLE_DIFF	Difference between the axis angles of two objects (in degrees)
44	AREA_RATIO	Ratio of the areas of two objects defined as the lesser of the forecast area divided by the observation area or its reciprocal (unitless)
45	INTERSECTION_AREA	Intersection area of two objects (in grid squares)
46	UNION_AREA	Union area of two objects (in grid squares)
47	SYMMETRIC_DIFF	Symmetric difference of two objects (in grid squares)
48	INTERSECTION_OVER_AREA	Ratio of intersection area to the lesser of the forecast and observation object areas (unitless)
49	COMPLEXITY_RATIO	Ratio of complexities of two objects defined as the lesser of the forecast complexity divided by the observation complexity or its reciprocal (unitless)
50	PERCENTILE_INTENSITY_RATIO	Ratio of the nth percentile (column 37) of intensity of the two objects defined as the lesser of the forecast intensity divided by the observation intensity or its reciprocal (unitless)
51	INTEREST	Total interest value computed for a pair of simple objects (unitless)

NetCDF Output

The MODE tool creates a NetCDF output file containing the object fields that are defined. The NetCDF file contains gridded fields including indices for the simple forecast objects, indices for the simple observation objects, indices for the matched cluster forecast objects, and indices for the matched cluster observation objects. The NetCDF file also contains lat/lon and x/y data for the vertices of the polygons for the boundaries of the simple forecast and observation objects. The generation of this file can be disabled using the `nc_pairs_flag` configuration file option.

The dimensions and variables included in the mode NetCDF files are described in Tables 14.5, 14.6 and 14.7.

Table 14.5: NetCDF dimensions for MODE output.

mode NETCDF DIMENSIONS	
NetCDF Dimension	Description
lat	Dimension of the latitude (i.e. Number of grid points in the North-South direction)
lon	Dimension of the longitude (i.e. Number of grid points in the East-West direction)
fcst_thresh_length	Number of thresholds applied to the forecast
obs_thresh_length	Number of thresholds applied to the observations
fcst_simp	Number of simple forecast objects
fcst_simp_bdy	Number of points used to define the boundaries of all of the simple forecast objects
fcst_simp_hull	Number of points used to define the hull of all of the simple forecast objects
obs_simp	Number of simple observation objects
obs_simp_bdy	Number of points used to define the boundaries of all of the simple observation objects
obs_simp_hull	Number of points used to define the hull of all of the simple observation objects
fcst_clus	Number of forecast clusters
fcst_clus_hull	Number of points used to define the hull of all of the cluster forecast objects
obs_clus	Number of observed clusters
obs_clus_hull	Number of points used to define the hull of all of the cluster observation objects

Table 14.6: Variables contained in MODE NetCDF output.

mode NETCDF VARIABLES		
NetCDF Variable	Dimension	Description
lat	lat, lon	Latitude
lon	lat, lon	Longitude
fcst_raw	lat, lon	Forecast raw values
fcst_obj_raw	lat, lon	Forecast Object Raw Values
fcst_obj_id	lat, lon	Simple forecast object id number for each grid point
fcst_clus_id	lat, lon	Cluster forecast object id number for each grid point
obs_raw	lat, lon	Observation Raw Values
obs_obj_raw	lat, lon	Observation Object Raw Values
obs_obj_id	-	Simple observation object id number for each grid point
obs_clus_id	-	Cluster observation object id number for each grid point
fcst_conv_radius	-	Forecast convolution radius
obs_conv_radius	-	Observation convolution radius
fcst_conv_threshold	-	Forecast convolution threshold
obs_conv_threshold	-	Observation convolution threshold
n_fcst_simp	-	Number of simple forecast objects
n_obs_simp	-	Number of simple observation objects
n_clus		Number of cluster objects

Table 14.7: Variables contained in MODE NetCDF output - Simple Objects, continued from Table 14.6

mode NETCDF VARIABLES		
NetCDF Variable	Dimension	Description
fcst_simp_bdy_start	fcst_simp	Forecast Simple Boundary Starting Index
fcst_simp_bdy_npts	fcst_simp	Number of Forecast Simple Boundary Points
fcst_simp_bdy_lat	fcst_simp_bdy	Forecast Simple Boundary PoLatitude
fcst_simp_bdy_lon	fcst_simp_bdy	Forecast Simple Boundary PoLongitude
fcst_simp_bdy_x	fcst_simp_bdy	Forecast Simple Boundary PoX-Coordinate
fcst_simp_bdy_y	fcst_simp_bdy	Forecast Simple Boundary PoY-Coordinate
fcst_simp_hull_start	fcst_simp	Forecast Simple Convex Hull Starting Index
fcst_simp_hull_npts	fcst_simp	Number of Forecast Simple Convex Hull Points
fcst_simp_hull_lat	fcst_simp_hull	Forecast Simple Convex Hull Point Latitude
fcst_simp_hull_lon	fcst_simp_hull	Forecast Simple Convex Hull Point Longitude
fcst_simp_hull_x	fcst_simp_hull	Forecast Simple Convex Hull Point X-Coordinate
fcst_simp_hull_y	fcst_simp_hull	Forecast Simple Convex Hull Point Y-Coordinate
obs_simp_bdy_start	obs_simp	Observation Simple Boundary Starting Index
obs_simp_bdy_npts	obs_simp	Number of Observation Simple Boundary Points
obs_simp_bdy_lat	obs_simp_bdy	Observation Simple Boundary Point Latitude
obs_simp_bdy_lon	obs_simp_bdy	Observation Simple Boundary Point Longitude
obs_simp_bdy_x	obs_simp_bdy	Observation Simple Boundary Point X-Coordinate
obs_simp_bdy_y	obs_simp_bdy	Observation Simple Boundary Point Y-Coordinate
obs_simp_hull_start	obs_simp	Observation Simple Convex Hull Starting Index
obs_simp_hull_npts	obs_simp	Number of Observation Simple Convex Hull Points
obs_simp_hull_lat	obs_simp_hull	Observation Simple Convex Hull Point Latitude
obs_simp_hull_lon	obs_simp_hull	Observation Simple Convex Hull Point Longitude
obs_simp_hull_x	obs_simp_hull	Observation Simple Convex Hull Point X-Coordinate
obs_simp_hull_y	obs_simp_hull	Observation Simple Convex Hull Point Y-Coordinate

Table 14.8: Variables contained in MODE NetCDF output - Clustered Objects, continued from Table 14.7

mode NETCDF VARIABLES		
NetCDF Variable	Dimension	Description
fcst_clus_hull_start	fcst_clus	Forecast Cluster Convex Hull Starting Index
fcst_clus_hull_npts	fcst_clus	Number of Forecast Cluster Convex Hull Points
fcst_clus_hull_lat	fcst_clus_hull	Forecast Cluster Convex Hull Point Latitude
fcst_clus_hull_lon	fcst_clus_hull	Forecast Cluster Convex Hull Point Longitude
fcst_clus_hull_x	fcst_clus_hull	Forecast Cluster Convex Hull Point X-Coordinate
fcst_clus_hull_y	fcst_clus_hull	Forecast Cluster Convex Hull Point Y-Coordinate
obs_clus_hull_start	obs_clus	Observation Cluster Convex Hull Starting Index
obs_clus_hull_npts	obs_clus	Number of Observation Cluster Convex Hull Points
obs_clus_hull_lat	obs_clus_hull	Observation Cluster Convex Hull Point Latitude
obs_clus_hull_lon	obs_clus_hull	Observation Cluster Convex Hull Point Longitude
obs_clus_hull_x	obs_clus_hull	Observation Cluster Convex Hull Point X-Coordinate
obs_clus_hull_y	obs_clus_hull	Observation Cluster Convex Hull Point Y-Coordinate

Postscript File

Lastly, the MODE tool creates a PostScript plot summarizing the features-based approach used in the verification. The PostScript plot is generated using internal libraries and does not depend on an external plotting package. The generation of this PostScript output can be disabled using the **ps_plot_flag** configuration file option.

The PostScript plot will contain 5 summary pages at a minimum, but the number of pages will depend on the merging options chosen. Additional pages will be created if merging is performed using the double thresholding or fuzzy engine merging techniques for the forecast and/or observation fields. Examples of the PostScript plots can be obtained by running the example cases provided with the MET tarball.

The first page of PostScript output contains a great deal of summary information. Six tiles of images provide thumbnail images of the raw fields, matched/merged object fields, and object index fields for the forecast and observation grids. In the matched/merged object fields, matching colors of objects across fields indicate that the corresponding objects match, while within a single field, black outlines indicate merging. Note that objects that are colored royal blue are unmatched. Along the bottom of the page, the criteria used for object definition and matching/merging are listed. Along the right side of the page, total interest values for pairs of simple objects are listed in sorted order. The numbers in this list correspond to the object indices shown in the object index plots.

The second and third pages of the PostScript output file display enlargements of the forecast and observation raw and object fields, respectively. The fourth page displays the forecast object with the outlines of the

observation objects overlaid, and vice versa. The fifth page contains summary information about the pairs of matched cluster objects.

If the double threshold merging or the fuzzy engine merging techniques have been applied, the output from those steps is summarized on additional pages.

Chapter 15

MODE-Analysis Tool

15.1 Introduction

Users may wish to summarize multiple ASCII files produced by MODE across many cases. The MODE output files contain many output columns making it very difficult to interpret the results by simply browsing the files. Furthermore, for particular applications some data fields in the MODE output files may not be of interest. The MODE-Analysis tool provide a simple way to compute basic summary statistics and filtering capabilities for these files. Users who are not proficient at writing scripts can use the tool directly, and even those using their own scripts can use this tool as a filter, to extract only the MODE output lines that are relevant for their application.

15.2 Scientific and statistical aspects

The MODE-Analysis tool operates in two modes, called “summary” and “by case.” In summary mode, the user specifies on the command line the MODE output columns of interest as well as filtering criteria that determine which input lines should be used. For example, a user may be interested in forecast object areas, but only if the object was matched, and only if the object centroid is inside a particular region. The summary statistics generated for each specified column of data are the minimum, maximum, mean, standard deviation, and the 10th, 25th, 50th, 75th and 90th percentiles. In addition, the user may specify a “dump” file: the individual MODE lines used to produce the statistics will be written to this file. This option provides the user with a filtering capability. The dump file will consist only of lines that match the specified criteria.

The other option for operating the analysis tool is “by case.” Given initial and final values for forecast lead time, the tool will output, for each valid time in the interval, the matched area, unmatched area, and the number of forecast and observed objects that were matched or unmatched. For the areas, the user can specify forecast or observed objects, and also simple or cluster objects. A dump file may also be specified in this mode.

15.3 Practical information

The MODE-Analysis tool reads lines from MODE ASCII output files and applies filtering and computes basic statistics on the object attribute values. For each job type, filter parameters can be set to determine which MODE output lines are used. The following sections describe the `mode_analysis` usage statement, required arguments, and optional arguments.

15.3.1 mode_analysis usage

The usage statement for the MODE-Analysis tool is shown below:

```
Usage: mode_analysis
      -lookin path
      -summary | -bycase
      [-column name]
      [-dump_row filename]
      [-out filename]
      [-log file]
      [-v level]
      [-help]
      [MODE FILE LIST]
      [-config config_file] | [MODE LINE OPTIONS]
```

The MODE-Analysis tool has two required arguments and can accept several optional arguments.

Required arguments for mode_analysis:

1. The **-lookin path** specifies the name of a specific STAT file (any file ending in .stat) or the name of a directory where the Stat-Analysis tool will search for STAT files. This option may be used multiple times to specify multiple locations.
2. The MODE-Analysis tool can perform two basic types of jobs -summary or -bycase. Exactly one of these job types must be specified.

Specifying **-summary** will produce summary statistics for the MODE output column specified. For this job type, a column name (or column number) must be specified using the **-column** option. Column names are not case sensitive. The column names are the same as described in Section 14.3.3. More information about this option is provided in subsequent sections.

Specifying **-bycase** will produce a table of metrics for each case undergoing analysis. Any columns specified are ignored for this option.

Optional arguments for mode analysis

3. The `mode_analysis` options are described in the following section. These are divided into sub-sections describing the analysis options and mode line options.

Analysis options

The general analysis options described below provide a way for the user to indicate configuration files to be used, where to write lines used to perform the analysis, and over which fields to generate statistics.

`-config filename`

This option gives the name of a configuration file to be read. The contents of the configuration file are described in Section 15.3.2.

`-dump_row filename`

Any MODE lines kept from the input files are written to `filename`.

`-column column`

Specifies which columns in the MODE output files to generate statistics for. Fields may be indicated by name (case insensitive) or column number (beginning at one). This option can be repeated to specify multiple columns.

MODE Command Line Options

MODE command line options are used to create filters that determine which of the MODE output lines that are read in, are kept. The MODE line options are numerous. They fall into seven categories: toggles, multiple set string options, multiple set integer options, integer max/min options, date/time max/min options, floating-point max/min options, and miscellaneous options. These options are described here.

Toggles

The MODE line options described in this section are shown in pairs. These toggles represent parameters that can have only one (or none) of two values. Any of these toggles may be left unspecified. However, if

neither option for each toggle is indicated, the analysis will produce results that combine data from both toggles. This may produce unintended results.

`-fcst | -obs`

This toggle indicates whether forecast or observed lines should be used for analysis.

`-single | -pair`

This toggle indicates whether single object or object pair lines should be used.

`-simple | -cluster`

This toggle indicates whether simple object or cluster object lines should be used.

`-matched | -unmatched`

This toggle indicates whether matched or unmatched object lines should be used.

Multiple-set string options

The following options set various string attributes. They can be set multiple times on the command line but must be separated by spaces. Each of these options must be indicated as a string. String values that include spaces may be used by enclosing the string in quotation marks.

`-model value`

This option specifies which model to use; value must be a string.

```
-fcst_thr value  
-obs_thr  value
```

These two options specify thresholds for forecast and observation objects to be used in the analysis, respectively.

```
-fcst_var value  
-obs_var  value
```

These options indicate the names of variables to be used in the analysis for forecast and observed fields.

```
-fcst_lev value  
-obs_lev  value
```

These options indicate vertical levels for forecast and observed fields to be used in the analysis.

Multiple-set integer options

The following options set various integer attributes. They can be set multiple times on the command line but must be separated by spaces. Each of the following options may only be indicated as an integer.

```
-fcst_lead value  
-obs_lead  value
```

These options are integers of the form HH[MMSS] specifying an (hour-minute-second) lead time.

```
-fcst_init value  
-obs_init  value
```

These options are integers of the form HH[MMSS] specifying an (hour-minute-second) model initialization time of day.

```
-fcst_accum value  
-obs_accum value
```

These options are integers of the form HHMMSS specifying an (hour-minute-second) accumulation time.

```
-fcst_rad value  
-obs_rad value
```

These options indicate the convolution radius used for forecast or observed objects, respectively.

Integer max/min options

These options set limits on various integer attributes. Leaving a maximum value unset means no upper limit is imposed on the value of the attribute. The option works similarly for minimum values.

```
-area_min value  
-area_max value
```

These options are used to indicate minimum/maximum values for the area attribute to be used in the analysis.

```
-area_filter_min value  
-area_filter_max value
```

These options are used to indicate minimum/maximum values accepted for the area filter. The area filter refers to the number of non-zero values of the raw data found within the object.

```
-area_thresh_min value  
-area_thresh_max value
```

These options are used to indicate minimum/maximum values accepted for the area thresh. The area thresh refers to the number of values of the raw data found within the object that meet the object definition threshold criteria used.

```
-intersection_area_min value  
-intersection_area_max value
```

These options refer to the minimum/maximum values accepted for the intersection area attribute.

```
-union_area_min value  
-union_area_max value
```

These options refer to the minimum/maximum union area values accepted for analysis.

```
-symmetric_diff_min value  
-symmetric_diff_max value
```

These options refer to the minimum/maximum values for symmetric difference for objects to be used in the analysis.

Date/time max/min options

These options set limits on various date/time attributes. The values can be specified in one of three ways:

First, the options may be indicated by a string of the form YYYYMMDD_HHMMSS. This specifies a complete calendar date and time.

Second, they may be indicated by a string of the form YYYYMMDD_HH. Here, the minutes and seconds are assumed to be zero.

The third way of indicating date/time attributes is by a string of the form YYYYMMDD. Here, hours, minutes and seconds are assumed to be zero.

```
-fcst_valid_min YYYYMMDD[_HH[MMSS]]  
-fcst_valid_max YYYYMMDD[_HH[MMSS]]
```

These options indicate minimum/maximum values for the forecast valid time.

```
-obs_valid_min YYYYMMDD[_HH[MMSS]]  
-obs_valid_max YYYYMMDD[_HH[MMSS]]
```

These two options indicate minimum/maximum values for observation valid time.

Floating-point max/min options

Setting limits on various floating-point attributes. One may specify these as integers (i.e., without a decimal point), if desired. The following pairs of options indicate minimum and maximum values for each MODE attribute that can be described as a floating-point number. Please refer to Chapter 14.3.3 for a description of these attributes as needed.

```
-centroid_x_min value  
-centroid_x_max value
```

```
-centroid_y_min value  
-centroid_y_max value
```

```
-centroid_lat_min value  
-centroid_lat_max value
```

```
-centroid_lon_min value  
-centroid_lon_max value
```

-axis_ang_min value
-axis_ang_max value

-length_min value
-length_max value

-width_min value
-width_max value

-curvature_min value
-curvature_max value

-curvature_x_min value
-curvature_x_max value

-curvature_y_min value
-curvature_y_max value

-complexity_min value
-complexity_max value

-intensity_10_min value
-intensity_10_max value

-intensity_25_min value
-intensity_25_max value

-intensity_50_min value
-intensity_50_max value

-intensity_75_min value
-intensity_75_max value

-intensity_90_min value
-intensity_90_max value

-intensity_user_min value
-intensity_user_max value

-intensity_sum_min value
-intensity_sum_max value

-centroid_dist_min value
-centroid_dist_max value

-boundary_dist_min value
-boundary_dist_max value

-convex_hull_dist_min value
-convex_hull_dist_max value

-angle_diff_min value
-angle_diff_max value

-area_ratio_min value
-area_ratio_max value

-intersection_over_area_min value
-intersection_over_area_max value

-complexity_ratio_min value
-complexity_ratio_max value

-percentile_intensity_ratio_min value
-percentile_intensity_ratio_max value

```
-interest_min value  
-interest_max value
```

Miscellaneous options

These options are used to indicate parameters that did not fall into any of the previous categories.

```
-mask_poly filename
```

This option indicates the name of a polygon mask file to be used for filtering. The format for these files is the same as that of the polyline files for the other MET tools.

```
-help
```

This option prints the usage message.

15.3.2 mode_analysis configuration file

To use the MODE-Analysis tool, the user must un-comment the options in the configuration file to apply them and comment out unwanted options. The options in the configuration file for the MODE-Analysis tools are the same as the MODE command line options described in Section 15.3.1.

The parameters that are set in the configuration file either add to or override parameters that are set on the command line. For the “set string” and “set integer type” options enclosed in brackets, the values specified in the configuration file are added to any values set on the command line. For the “toggle” and “min/max type” options, the values specified in the configuration file override those set on the command line.

15.3.3 mode_analysis output

The output of the MODE-Analysis tool is a self-describing tabular format written to standard output. The length and contents of the table vary depending on whether **-summary** or **-bycase** is selected. The contents also change for **-summary** depending on the number of columns specified by the user.

Chapter 16

MODE Time Domain Tool

16.1 Introduction

16.1.1 Motivation

MODE Time Domain (MTD) is an extension of the MODE object-based approach to verification. In addition to incorporating spatial information, MTD utilizes the time dimension to get at temporal aspects of forecast verification. Since the two spatial dimensions of traditional meteorological forecasts are retained in addition to the time dimension, the method is inherently three dimensional. Given that, however, the overall methodology has deliberately been kept as similar as possible to that of traditional MODE.

A plot of some MTD precipitation objects is shown over the United States in Figure 16.1. The colors indicate longitude, with red in the east moving through the spectrum to blue in the west. Time increases vertically in this plot (and in most of the spacetime diagrams in this users' guide). A few things are worthy of note in this figure. First, the tendency of storm systems to move from west to east over time shows up clearly. Second, tracking of storm objects over time is easily done: if we want to know if a storm at one time is a later version of a storm at an earlier time, we need only see if they are part of the same 3D spacetime object. Lastly, storms splitting up or merging over time are handled easily by this method.

The 2D (or traditional) MODE approach to object-based verification enabled users to analyze forecasts in terms of location errors, intensity errors and shape, size and orientation errors. MTD retains all of that capability, and adds new classes of forecast errors involving time information: speed and direction errors, buildup and decay errors, and timing and duration errors. This opens up new ways of analyzing forecast quality.

In the past, many MET users have performed separate MODE runs at a series of forecast valid times and analyzed the resulting object attributes, matches and merges as functions of time in an effort to incorporate temporal information in assessments of forecast quality. MTD was developed as a way to address this need

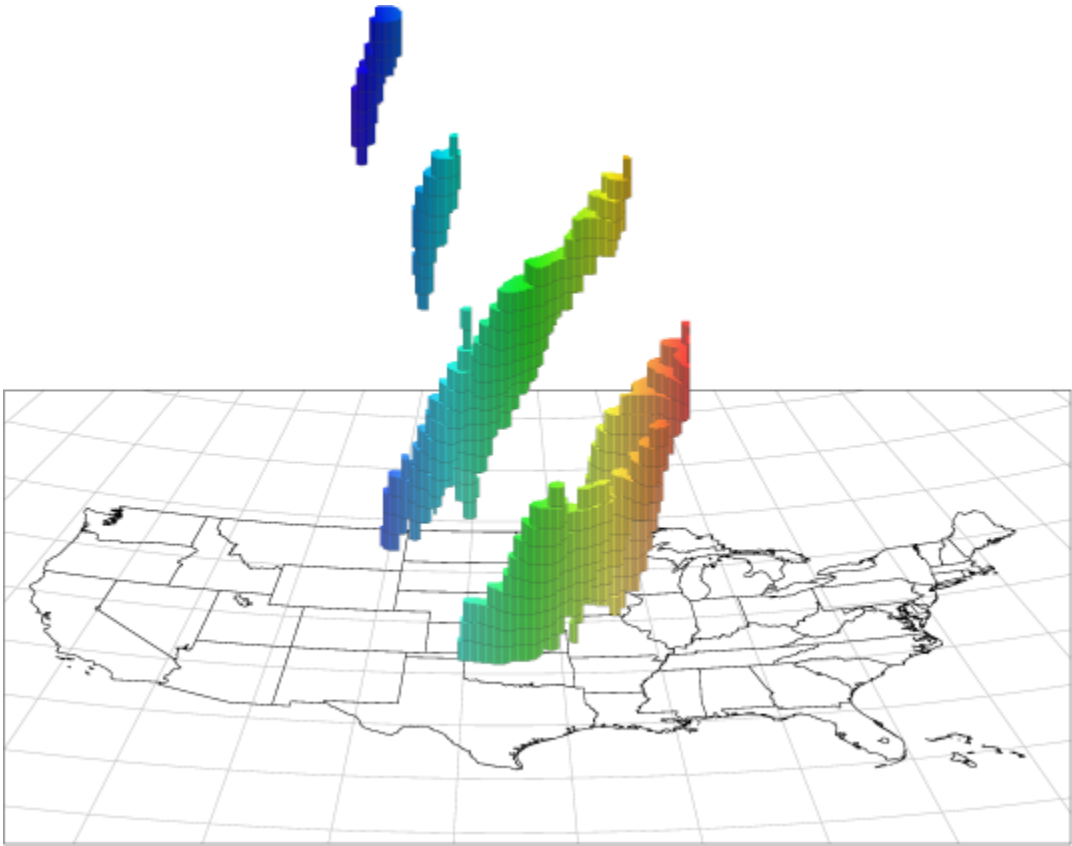


Figure 16.1: MTD Spacetime Objects

in a more systematic way. Most of the information obtained from such multiple coordinated MODE runs can be obtained more simply from MTD.

At first glance, the addition of a third dimension would seem to entail no difficulties other than increased memory and processing requirements to handle the three-dimensional datasets and objects, and that would indeed be largely true of an extension of MODE that used three spatial dimensions. In fact, the implementation of MTD entailed both conceptual difficulties (mostly due to the fact that there is no distance function in spacetime, so some MODE attributes, such as centroid distance, no longer even made sense), and engineering difficulties brought on by the need to redesign several core MODE algorithms for speed. It is planned that in the future some of these improved algorithms will be incorporated into MODE.

In this users' guide, we will assume that the reader has a basic familiarity with traditional MODE, its internal operation, (convolution thresholding, fuzzy logic matching and merging) and its output. We will not review these things here. Instead, we will point out differences in MTD from the way traditional MODE does things when they come up. This release is a beta version of MTD, intended mostly to encourage users to experiment with it and give us feedback and suggestions to be used in a more robust MTD release in the future.

16.2 Scientific and statistical aspects

16.2.1 Attributes

Object attributes are, for the most part, calculated in much the same way in MTD as they are in MODE, although the fact that one of the dimensions is non-spatial introduces a few quirks. Several of the object attributes that traditional MODE calculates assume that distances, angles and areas can be calculated in grid coordinates via the usual Euclidian/Cartesian methods. That is no longer the case in spacetime, since there is no distance function (more precisely, no *metric*) there. Given two points in this spacetime, say (x_1, y_1, t_1) and (x_2, y_2, t_2) , there is no way to measure their separation with a single nonnegative number in a physically meaningful way. If all three of our dimensions were spatial, there would be no difficulties.

This means that some care must be taken both in determining how to generalize the calculation of a geometric attribute to three-dimensional spacetime, and also in interpreting the attributes even in the case where the generalization is straightforward.

16.2.2 Convolution

As in MODE, MTD applies a convolution filter to the raw data as a preliminary step in resolving the field into objects. The convolution step in MTD differs in several respects from that performed in MODE, however.

First, MTD typically reads in several planes of data for each data field—one plane for each time step, and there is really no limit to the number of time steps. So MTD is convolving much more data than it would

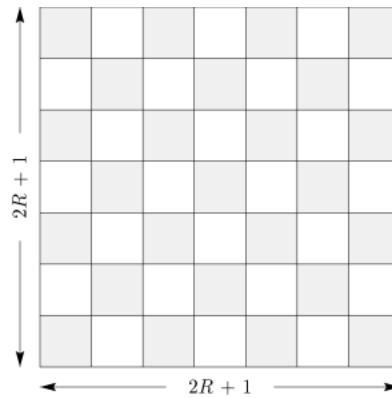


Figure 16.2: Convolution Region

be if it were simply analyzing a 2D data field. Secondly, MTD convolves in time as well as space, which again increases the amount of data needing to be processed. The net effect of all this is to greatly increase the time needed to perform the convolution step.

Because of this, the developers decided to make several changes in the way convolution was performed in MTD. Most of the differences come from the need to make the convolution step as fast as possible.

The most basic change is to use a square convolution filter rather than the circular one that MODE uses. The overall “size” of the filter is still determined by one parameter (denoted R , as in MODE), but this should not be thought of as a *radius*. Instead, the size of the square is $(2R + 1) \times (2R + 1)$, as shown in Figure 16.2.

Another change is that we do not allow any bad data in the convolution square. In MODE, the user may specify what percentage of bad data in the convolution region is permissible, and MODE will rescale the value of the filter accordingly for each data point. For the sake of speed, MTD requires that there be no bad data in the convolution region. If any bad data exists in the region, the convolved value there is set to a bad data flag.

16.2.3 3D Single Attributes

MTD calculates several 3D attributes for single objects. The object could come from either the forecast field or the observed field.

A 3D spacetime **centroid** $(\bar{x}, \bar{y}, \bar{t})$ is calculated. There are no statistical overtones here. The number \bar{x} , for example, is just the average value of the x coordinate over the object.

The vector **velocity** (v_x, v_y) is obtained by fitting a line to an 3D object. The requirement for fitting the line is to minimize the sum of the squares of the *spatial* distances from each point of the object to the line be minimized. (We can’t measure distances in spacetime but at each fixed time t we can measure purely spatial distances.) See Figure 16.3 for an illustration, where the solid line is the fitted axis, and the inclination of the axis from the vertical is a measure of object speed. Thus, from this velocity we get the **speed** and **direction** of movement of the object.

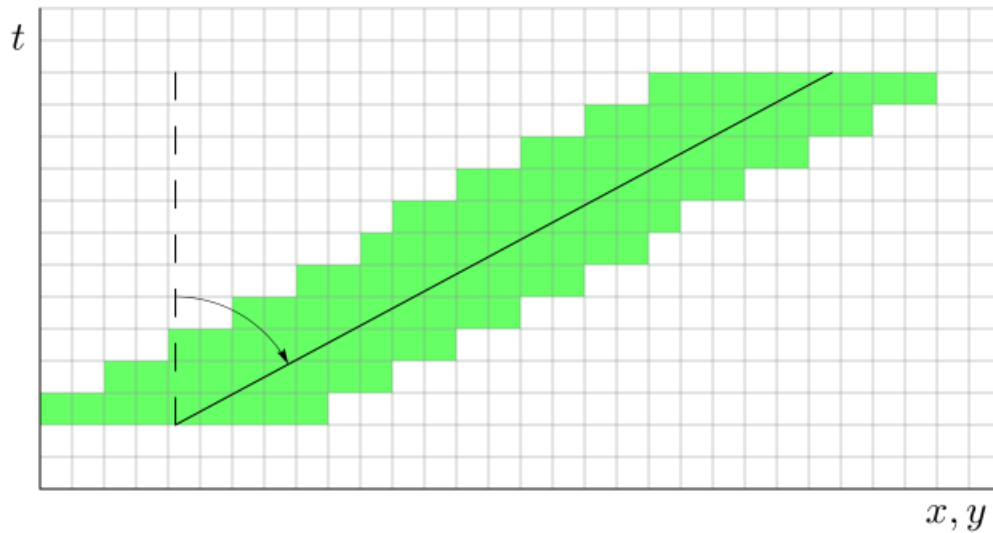


Figure 16.3: Velocity

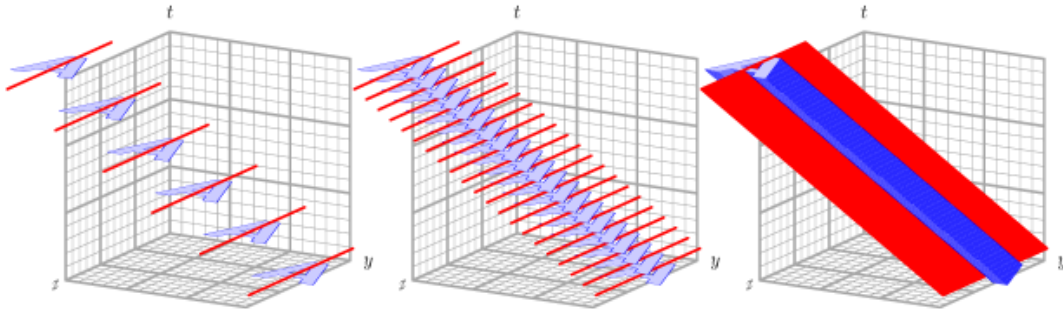


Figure 16.4: 3D axis

The spatial orientation of a object (what traditional MODE calls the **axis angle** of an object) is gotten by fitting a plane to an object. As with the case of velocity, our optimization criterion is that the sum of the squares of the spatial distances from each point of the object to the plane be minimized.

Figure 16.4 gives some idea of the reason for fitting a plane, rather than a line, as MODE does. On the left in the figure, we see an object (in blue shaped like an “A”) at several time steps moving through the grid. For simplicity, the object is not rotating as it moves (though of course real objects can certainly do this). At each time step, the 2D MODE spatial axis of the object is indicated by the red line. In the center of the figure, we see the same thing, just with more time steps. And on the right, even more time steps. We see that the axis lines at each time step sweep out a plane in three dimensions, shown in red on the right. This plane is the same one that MTD would calculate for this 3D object to determine its spatial orientation, *i.e.*, axis angle. Indeed, for the special case of an object that is not moving at all, the MTD calculation of axis angle reduces to the same one that traditional MODE uses, as it should.

A simple integer count of the number of grid squares in an object for all of it’s lifetime gives the **volume** of the object. Remember that while we’re working in three dimensions, one of the dimensions is non-spatial, so one should not attempt to convert this to a volume in, *e.g.*, km^3 .

The **start time** and **end time** of an object are attributes as well. This is an integer telling which time step an object starts and ends at. These values are zero-based, so for example, if an object comes into existence at the 3rd time step and lasts until the 9th time step, then the start time and end time will be listed as 2 and 8, respectively. Note that this object has a lifetime of 7 time steps, not 6.

Finally, MTD calculates several **intensity percentiles** of the raw data values inside each object. Not all of the the attributes are purely geometrical.

16.2.4 3D Pair Attributes

The next category of spatial attributes is for pairs of objects — one of the pair coming from the collection of forecast objects, the other coming from the observation objects.

Note: whenever a pair attribute is described below as a *delta*, that means it's a simple difference of two single-object attributes. The difference is always taken as “forecast minus observed.”

The **spatial centroid distance** is the purely spatial part of the centroid separation of two objects. If one centroid is at $(\bar{x}_1, \bar{y}_1, \bar{t}_1)$ and the other is at $(\bar{x}_2, \bar{y}_2, \bar{t}_2)$ then the distance is calculated as

$$\sqrt{(\bar{x}_1 - \bar{x}_2)^2 + (\bar{y}_1 - \bar{y}_2)^2}$$

The **time centroid delta** is the difference between the time coordinates of the centroid. Since this is a simple difference, it can be either positive or negative.

The **axis difference** is smaller of the two angles that the two spatial axis planes make with each other. Figure 16.5 shows the idea. In the figure, the axis angle would be reported as angle α , not angle β .

Speed delta and **direction difference** are obtained from the velocity vectors of the two objects. Speed delta is the difference in the lengths of the vectors, and direction difference is the angle that the two vectors make with each other.

Volume ratio is volume of the forecast object divided by the volume of the observed object. Note that any 3D object must necessarily have a nonzero volume, so there's no chance of zeros in the denominator.

Start time delta and end time delta are the differences in the corresponding times associated with the two objects.

Intersection volume measures the overlap of two objects. If the two objects do not overlap, then this will be zero.

Finally, the **total interest** gives the result of the fuzzy-logic matching and merging calculation for this pair of objects. Note that this is provided only for simple objects, not for composites.

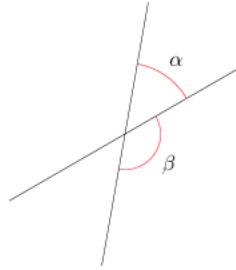


Figure 16.5: Axis Angle Difference

16.2.5 2D Constant-Time Attributes

The final category of object attributes calculated by MTD are two-dimensional spatial attributes for horizontal (*i.e.*, constant-time) slices of a spacetime object. This is so that the behavior of these attributes over time can be examined.

For example, in our earlier discussion relating to Figure 16.4, we mentioned that for simplicity, the object in the figure was not allowed to rotate as it moved. But what if the object (a hurricane, for example) *is* rotating over time? In that case, it's probably not meaningful to assign a single spatial orientation to the object over its entire lifetime. If we had a spatial axis angle at each time, however, then we could fit a model such as $\theta = \theta_0 + \omega t$ to the angles and test the goodness of fit.

For such reasons, having 2D spatial attributes (as in MODE) for each object at each time step can be useful. The list of the 2D attributes calculated is:

- Centroid (x, y)
- Centroid latitude and longitude
- Area
- Axis Angle

16.2.6 Matching and Merging

Matching and merging operations in MTD are done in a simpler fashion than in MODE. In order to understand this operation, it is necessary to discuss some very basic notions of graph theory.

A **graph** is a finite set of **vertices** (also called **nodes**) and **edges**, with each edge connecting two vertices. Conceptually, it is enough for our purposes to think of vertices as points and edges as lines connecting them. See Figure 16.6 for an illustration. In the figure we see a collection of 11 nodes, indicated by the small circles, together with some edges indicated by straight line segments. A **path** is a sequence of vertices (v_1, v_2, \dots, v_n) such that for each $1 \leq i < n$ there is an edge connecting v_i to v_{i+1} . For example, in Figure 16.6, there is no edge connecting vertices #6 and #7, but there is a path connecting them. In illustrations, graph vertices are often labelled with identifying information, such as the numbers in Figure 16.6.

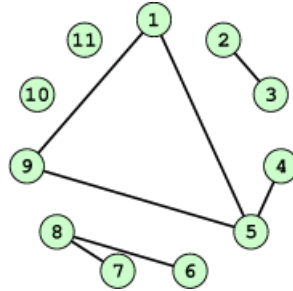


Figure 16.6: Basic Graph Example

If we consider two distinct nodes in a graph to be related if there is a path connecting them, then it's easy to see that this defines an equivalence relation on the set of nodes, partitioning the graph into equivalence classes. Any node, such as #10 in Figure 16.6, that has no edges emanating from it is in a class by itself.

We have barely scratched the surface of the enormous subject of graph theory, but this will suffice for our purposes. How does MTD use graphs? Essentially the simple forecast and observed objects become nodes in a graph. Each pair of objects that have sufficiently high total interest (as determined by the fuzzy logic engine) generates an edge connecting the two corresponding nodes in the graph. The graph is then partitioned into equivalence classes using path connectivity (as explained above), and the resulting equivalence classes determine the matches and merges.

An example will hopefully make this clear. In parts (a) and (b) of Figure 16.7 we indicate the objects in the forecast and observed field for this simple example. We have used 2D rather than 3D objects in this example for simplicity. Also, to help distinguish the objects in each field, the forecast objects are labelled by numbers and the observed object by letters. Each forecast and each observed object become nodes in a graph as indicated in part (c) of the figure.

For the purposes of this example, suppose that the MTD fuzzy engine reports that observed simple object B and forecast simple object 4 together have a total interest higher than the total interest threshold specified in the config file. Also, observed simple object C and forecast simple object 4 have high enough interest to pass the threshold. Furthermore, forecast simple objects 2 and 3 both have sufficiently high interest when paired with observed simple object A.

These four pairings result in the 4 edges in the graph shown by the solid lines in part (c) of the figure. Partitioning this graph into equivalence classes results in the three sets indicated in part (d) of the figure. These three sets are the cluster objects determined by MTD. In this example, forecast objects 2 and 3 are merged into forecast cluster object #1 which is matched to observed cluster object #1, consisting of observed object A. (As in MODE, a cluster object may contain multiple simple objects, but may also consist of a single simple object.) Essentially, forecast simple objects 2 and 3 are merged because there is a path connecting them in the graph. This is indicated by the dashed line in the graph.

Continuing this example, forecast cluster object #2 (consisting only of forecast simple object 4) is matched to observed cluster object #2 (consisting of observed simple objects B and C). Again, the merging of observed simple objects is indicated by the dashed line in the graph.

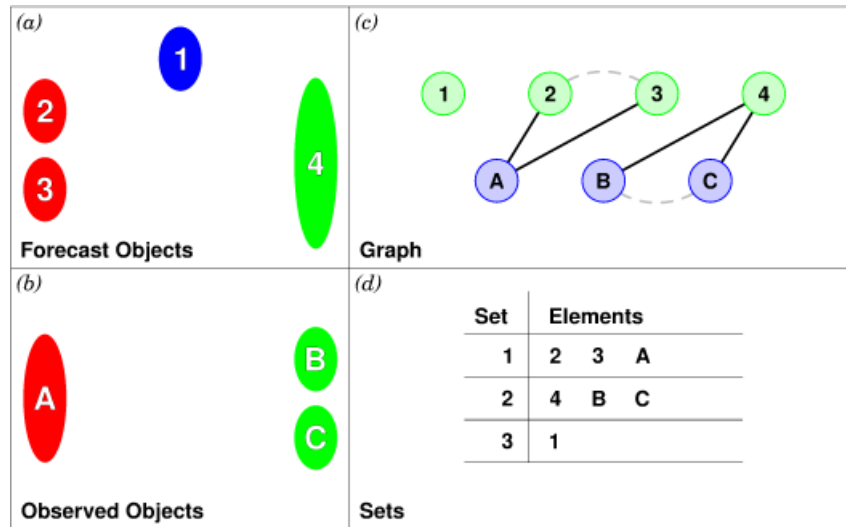


Figure 16.7: Match & Merge Example

Forecast cluster object #3 consists solely of forecast simple object 1. It is not matched to any observed cluster object. Alternatively, one may take the viewpoint that forecast simple object 1 ended up not participating in the matching and merging process; it is not merged with anything, it is not matched with anything. Essentially it represents a false alarm.

To summarize: Any forecast simple objects that find themselves in the same equivalence class are merged. Similarly, any observed objects in the same class are merged. Any forecast and observed objects in the same class are matched.

16.3 Practical information

16.3.1 mtd input

The formats for two-dimensional data files used as input to MTD are the same ones supported by most of the MET tools. Generally speaking, if MODE can use a forecast or observation data file as input, then that file can also be used by MTD. The only difference is that while MODE takes only one forecast and one observed data file as input, MTD takes a series of files.

As shown in the next section, filenames for each time used must be given. Thus, for example, if MTD is being used for verification over a period of 24 hours, and the data file valid times are separated by one hour, then a total of 48 filenames must be specified on the MTD command line — 24 filenames for the forecast files, and 24 for the observation files. Further, the filenames must be given in order of increasing valid time. Many users will prefer to write scripts to automate this, rather than type in a lengthy command line by hand.

16.3.2 mtd usage

The usage statement for the MODE-TD tool is listed below: The command-line switches may be given in any order.

```
Usage: mtd
      -fcst   file_1 ... file_n | file_list
      -obs    file_1 ... file_n | file_list
      -single file_1 ... file_n | file_list
      -config config_file
      [-outdir path]
      [-log   file]
      [-v    level]
```

The MODE-TD tool has three required arguments and can accept several optional arguments.

Required arguments for mtd

1. `-fcst file_list` gives a list of forecast 2D data files to be processed by MTD. The files should have equally-spaced intervals of valid time.
2. `-obs file_list` gives a list of observation 2D data files to be processed by MTD. As with the `{\cb -fcst}` option, the files should have equally-spaced intervals of valid time. This valid time spacing should be the same as for the forecast files.
3. `-config config_file` gives the path to a local configuration file that is specific to this particular run of MTD. The default MTD configuration file will be read first, followed by this one. Thus, only configuration options that are different from the default settings need be specified. Options set in this file will override any corresponding options set in the default configuration file.

Optional arguments for mtd

4. `-log file` gives the name of a file where a log of this MTD run will be written. All output that appears on the screen during a MTD run will be duplicated in the log file.
5. `-v level` gives the verbosity level. As with the `-log` option described above, this option is present in most of the MET tools. Increasing this value causes more diagnostic output to be written to the screen (and also to the log file, if one has been specified).
6. `-outdir path` gives the name of the directory into which MTD will write its output files. If not specified, then MTD will write its output into the current directory.

An example of the mtd calling sequence is listed below:

```

mtd -fcst fcst_files/*.grb \
    -obs obs_files/*.grb \
    -config MTDCconfig_default \
    -outdir out_dir/mtd \
    -v 1

```

In this example, the MODE-TD tool will read in a list of forecast GRIB file in the fcst_files directory and a similarly spaced observation GRIB files in the obs_files director. It uses a configuration file called MTDCconfig_default and writes the output to out_dir/mtd directory.

16.3.3 mtd configuration file

The default configuration file for the MODE tool, MODEConfig_default, can be found in the installed share/met/config directory. Another version of the configuration file is provided in scripts/config. We encourage users to make a copy of the configuration files prior to modifying their contents. Most of the entries in the MTD configuration file should be familiar from the corresponding file for MODE. This initial beta release of MTD does not offer all the tunable options that MODE has accumulated over the years, however. In this section, we will not bother to repeat explanations of config file details that are exactly the same as those in MODE; we will only explain those elements that are different from MODE, and those that are unique to MTD.

```

model          = "WRF";
obtype         = "ANALYS";
regrid         = { to_grid = NONE; vld_thresh = 0.5; method = NEAREST; width = 1; }
met_data_dir   = "MET_BASE";
output_prefix  = "";
version        = "VN.N";

```

The configuration options listed above are common to many MET tools and are described in Section 3.5.1.

```

grid_res = 4;
fcst = {
    field = {
        name = "APCP";
        level = "A03";
    }
    conv_radius = 60.0/grid_res; // in grid squares

```



```

    conv_thresh      = >=5.0;
}
obs = fcst;
total_interest_thresh = 0.7;

```

The configuration options listed above are common to many MODE and are described in Section 14.3.2.

```

min_volume = 2000;

```

The **min_volume** entry tell MTD to throw away objects whose “volume” (as described elsewhere in this chapter) is smaller than the given value. Spacetime objects whose volume is less than this will not participate in the matching and merging process, and no attribute information will be written to the ASCII output files. The default value is 10,000. If this seems rather large, consider the following example: Suppose the user is running MTD on a 600×400 grid, using 24 time steps. Then the volume of the whole data field is $600 \times 400 \times 24 = 5,760,000$ cells. An object of volume 10,000 represents only $10,000/5,760,000 = 1/576$ of the total data field. Setting **min_volume** too small will typically produce a very large number of small objects, slowing down the MTD run and increasing the size of the output files. The configuration options listed above are common to many MODE and are described in Section 14.3.2.

```

weight = {
    space_centroid_dist = 1.0;
    time_centroid_delta = 1.0;
    speed_delta         = 1.0;
    direction_diff      = 1.0;
    volume_ratio        = 1.0;
    axis_angle_diff     = 1.0;
    start_time_delta    = 1.0;
    end_time_delta      = 1.0;
}

```

The **weight** entries listed above control how much weight is assigned to each pairwise attribute when computing a total interest value for object pairs. See Table 16.4 for a description of each weight option. When the total interest value is computed, the weighted sum is normalized by the sum of the weights listed above.

```

interest_function = {
    space_centroid_dist = (...);
    time_centroid_delta = (...);
    speed_delta         = (...);
    direction_diff      = (...);
    volume_ratio        = (...);
    axis_angle_diff     = (...);
    start_time_delta    = (...);
    end_time_delta      = (...);
};

```

The **interest_function** entries listed above control how much weight is assigned to each pairwise attribute when computing a total interest value for object pairs. See Table 16.4 for a description of each weight option. The interest functions may be defined as a piecewise linear function or as an algebraic expression. A piecewise linear function is defined by specifying the corner points of its graph. An algebraic function may be defined in terms of several built-in mathematical functions. See Section 14.2 for how interest values are used by the fuzzy logic engine. By default, many of these functions are defined in terms of the previously defined **grid_res** entry.

```

nc_output = {
    latlon = true;
    raw = true;
    object_id = true;
    cluster_id = true;
};

```

The **nc_output** dictionary contains a collection of boolean flags controlling which fields are written to the NetCDF output file. **latlon** controls the output of a pair of 2D fields giving the latitude and longitude of each grid point. The **raw** entry controls the output of the raw input data for the MTD run. These will be 3D fields, one for the forecast data and one for the observation data. Finally, the **object_id** and **cluster_id** flags control the output of the object numbers and cluster numbers for the objects. This is similar to MODE.

```

txt_output = {
    attributes_2d = true;
    attributes_3d = true;
};

```

The **txt_output** dictionary also contains a collection of boolean flags, in this case controlling the output of ASCII attribute files. The **attributes_2d** flag controls the output of the 2D object attributes for constant-time slices of 3D objects, while the **attributes_3d** flag controls the output of single and pair 3D spacetime object attributes.

16.3.4 mtd output

MTD creates several output files after each run in ASCII and NetCDF formats. There are text files giving 2D and 3D attributes of spacetime objects and information on matches and merges, as well as a NetCDF file giving the objects themselves, in case any further or specialized analysis of the objects needs to be done.

MODE, along with several other of the MET tools (`wavelet_stat` for example, and a few others), provides PostScript-based graphics output to help visualize the output. Unfortunately, no similar graphics capabilities are provided with MTD, mainly because of the complexity of producing 3D plots. This should not discourage the user from making their own plots, however. There is enough information in the various output files created by MTD to make a wide variety of plots. Highly motivated users who write their own plotting scripts are encouraged to submit them to the user-contributed code area of the MET website. Due credit will be given, and others will benefit from their creations.

ASCII output

Five ASCII output files are created:

- Single attributes for 3D simple objects
- Single attributes for 3D composite objects
- Pair attributes for 3D simple objects
- Pair attributes for 3D composite objects
- 2D spatial attributes for single simple objects for each time index of their existence.

Each ASCII file is laid out in tabular format, with the first line consisting of text strings giving names for each column. The first 15 columns of each file are identical, and give information on timestamps, model names, and the convolution radius and threshold used for the forecast and observation input data.

These columns are explained in Table 16.1. Each file contains additional columns that come after these. Columns for 2D constant-time attributes are shown in Table 16.2. Columns for 3D single and pair attributes are shown in Tables 16.3 and 16.4 respectively.

One thing that is slightly different in the ASCII output files from the way MODE does things is the way in which object numbers (both simple and composite) are indicated. For example, in the ASCII attribute files that MODE produces, forecast simple object number #1 is indicated as F001, while in MTD is indicated as F_1. Similarly, for cluster forecast object #1 is indicated in MODE as CF001, while in MTD it is indicated by CF_1. MODE indicates that a simple object is not part of a cluster by giving it a cluster number of zero, as in CF000. In MTD, the corresponding notation is simply CF.

NetCDF File

MTD writes a NetCDF file containing various types of information as specified in the configuration file. The possible output data are:

Table 16.1: Text Header Columns

HEADER		
Column	Name	Description
1	VERSION	Version number
2	MODEL	User provided text string giving model name
3	FCST_LEAD	Forecast lead time in HHMMSS format
4	FCST_VALID	Forecast valid time in YYYYMMDDHH format
5	OBS_LEAD	Observation lead time in HHMMSS format
6	OBS_VALID	Observation valid time in YYYYMMDDHH format
7	T_DELTA	Time separation between input data files in HHMMSS format
8	FCST_RAD	Forecast convolution radius in grid units
9	FCST_THR	Forecast convolution threshold
10	OBS_RAD	Observation convolution radius in grid units
11	OBS_THR	Observation convolution threshold
12	FCST_VAR	Forecast variable
13	FCST_LEV	Forecast vertical level
14	OBS_VAR	Observation variable
15	OBS_LEV	Observation vertical level

Table 16.2: 2D Attribute
2D Attribute Columns

Column	Name	Description
16	OBJ_ID	Object number
17	CLUSTER_ID	Cluster number
18	TIME_INDEX	Time index of slice
19	AREA	2D cross-sectional area
20	CENTROID_X	x coordinate of centroid
21	CENTROID_Y	y coordinate of centroid
22	CENTROID_LAT	Latitude of centroid
23	CENTROID_LON	Longitude of centroid
24	AXIS_ANG	Angle that the axis makes with the grid x direction

Table 16.3: 3D Single Attribute

3D Single Attribute Columns		
Column	Name	Description
16	OBJ_ID	Object number
17	CLUSTER_ID	Cluster number
18	CENTROID_X	x coordinate of centroid
19	CENTROID_Y	y coordinate of centroid
20	CENTROID_T	t coordinate of centroid
21	CENTROID_LAT	Latitude of centroid
22	CENTROID_LON	Longitude of centroid
23	X_DOT	x component of object velocity
24	Y_DOT	y component of object velocity
25	AXIS_ANG	Angle that the axis plane of an object makes with the grid x direction
26	VOLUME	Integer count of the number of 3D “cells” in an object
27	START_TIME	Object start time
28	END_TIME	Object end time
29	INTENSITY_10	10 th percentile intensity inside object
30	INTENSITY_25	25 th percentile intensity inside object
31	INTENSITY_50	50 th percentile intensity inside object
32	INTENSITY_75	75 th percentile intensity inside object
33	INTENSITY_90	90 th percentile intensity inside object

Table 16.4: 3D Pair Attribute

3D Pair Attribute Columns		
Column	Name	Description
16	OBJ_ID	Object number
17	CLUSTER_ID	Cluster number
18	SPACE_CENTROID_DIST	Spatial distance between (x, y) coordinates of object spacetime centroid
19	TIME_CENTROID_DELTA	Difference in t index of object spacetime centroid
20	AXIS_DIFF	Difference in spatial axis plane angles
21	SPEED_DELTA	Difference in object speeds
22	DIRECTION_DIFF	Difference in object direction of movement
23	VOLUME_RATIO	Ratio of object volumes
24	START_TIME_DELTA	Difference in object start times
25	END_TIME_DELTA	Difference in object end times
26	INTERSECTION_VOLUME	“Volume” of object intersection
27	INTEREST	Total interest for this object pair

- **Latitude** and **longitude** of all the points in the 2D grid. Useful for geolocating points or regions given by grid coordinates.
- **Raw data** from the input data files. This can be useful if the input data were grib format, since NetCDF is often easier to read.
- **Object ID** numbers, giving for each grid point the number of the simple object (if any) that covers that point. These numbers are one-based. A value of zero means that this point is not part of any object.
- **Cluster ID** numbers. As above, only for cluster objects rather than simple objects.

Chapter 17

MET-TC Overview

17.1 Introduction

The purpose of this User's Guide is to provide basic information to the users of the Model Evaluation Tools - Tropical Cyclone (MET-TC) to enable users to apply MET-TC to their tropical cyclone datasets and evaluation studies. MET-TC is intended for use with model forecasts run through a vortex tracking software or with operational model forecasts in Automated Tropical Cyclone Forecast (ATCF) file format.

The following chapters provide an overview of MET-TC and its components, as well as basic information on the software build. The required input, including file format and the MET-TC are discussed followed by a description of the TC-dland tool, TC-Pairs, and TC-Stat tools. Each chapter cover the input and output, and practical usage including a description of the configuration files. This is followed by a short overview of graphical utilities available within the MET-TC release.

17.2 MET-TC components

The MET-TC software is included as a module within the full Model Evaluation Tools (MET) v5.1. Figure 17.1 shows the basic stages of the MET-TC module. The required input and output, as well as each separate tool are described in more detail in later chapters.

The TC-dland tool is used to generate a gridded file that determines the location of coastlines and islands, and is used as input to the TC-Pairs tool to determine the distance from land of a particular track point. The TC-Pairs tool matches pairs of input model data and best track (or any reference forecast) and calculates position errors. The TC-Stat tool uses the TC-Pairs output to perform filter and summary jobs over the matched pair dataset.

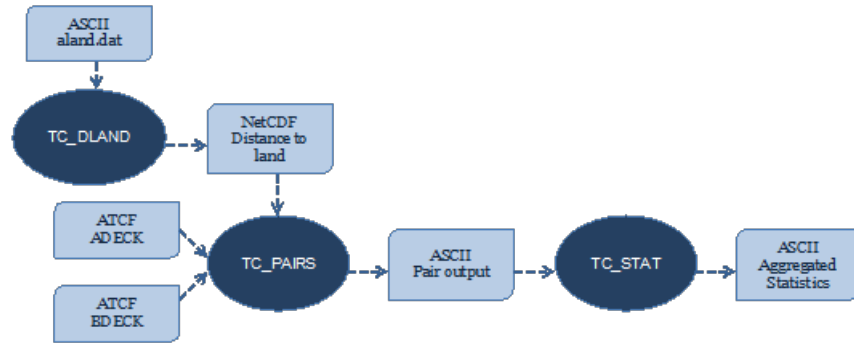


Figure 17.1: Basic representation of the structure of the MET-TC module. Dark blue areas represent each executable and light blue areas represent required input and output to MET-TC.

17.3 Input data format

This chapter discusses the input and output file formats expected and produced by MET-TC. When discussing the input data, it is expected that users have run model output through vortex tracking software in order to obtain position and intensity information in Automated Tropical Cyclone Forecasting System (ATCF) file format. Best track and aids files in Automated Tropical Cyclone Forecasting System (ATCF) format (hereafter referred to as ATCF format) are necessary for model data input into the TC-Pairs tool. The ATCF format was first developed at the Naval Oceanographic and Atmospheric Research Laboratory (NRL), and is currently used for the National Hurricane Center (NHC) operations. ATCF format must be adhered to in order for the MET-TC tools to properly parse the input data.

The ATCF file format includes a section with common fields:

BASIN, CY, YYYYMMDDHH, TECHNUM/MIN, TECH, TAU, LatN/S, LonE/W, VMAX, MSLP, TY, RAD, WINDCODE, RAD1, RAD2, RAD3, RAD4, POUTER, ROUTER, RMW, GUSTS, EYE, SUB-REGION, MAXSEAS, INITIALS, DIR, SPEED, STORMNAME, DEPTH, SEAS, SEASCODE, SEAS1, SEAS2, SEAS3, SEAS4

BASIN: basin

CY: annual cyclone number: 1 - 99

YYYYMMDDHH: Warning Date-Time-Group.

TECHNUM/MIN: objective technique sorting number, minutes for best track: 00 - 99

TECH: acronym for each objective technique or CARQ or WRNG, BEST for best track

TAU: forecast period: -24 through 240 hours, 0 for best-track

LatN/S: Latitude for the date time group (DTG)

LonE/W: Longitude for the DTG

VMAX: Maximum sustained wind speed in knots

MSLP: Minimum sea level pressure, 850 - 1050 mb.

TY: Highest level of tropical cyclone development

RAD: Wind intensity for the radii defined in this record: 34, 50 or 64 kt.

WINDCODE: Radius code

RAD1: If full circle, radius of specified wind intensity, or radius of first quadrant wind intensity

RAD2: If full circle this field not used, or radius of 2nd quadrant wind intensity

RAD3: If full circle this field not used, or radius of 3rd quadrant wind intensity

RAD4: If full circle this field not used, or radius of 4th quadrant wind intensity

POUTER: pressure in millibars of the last closed isobar

ROUTER: radius of the last closed isobar

RMW: radius of max winds

GUSTS: gusts

EYE: eye diameter

SUBREGION: subregion

MAXSEAS: max seas

INITIALS: Forecaster's initials

DIR: storm direction

SPEED: storm speed

STORMNAME: literal storm name, number, NONAME or INVEST, or TCcyx

DEPTH: system depth

SEAS: Wave height for radii defined in SEAS1 - SEAS4

SEASCODE - Radius code

SEAS1: first quadrant seas radius as defined by SEASCODE

SEAS2: second quadrant seas radius as defined by SEASCODE

SEAS3: third quadrant seas radius as defined by SEASCODE

SEAS4: fourth quadrant seas radius as defined by SEASCODE

Of the above common fields in the ATCF file format, MET-TC requires the input file has the first 8 comma-separated columns present. Although all 8 columns must exist, valid data in each field is not required. In order to ensure proper matching, unique data in the BASIN, CY, YYYYMMDDHH, and TAU fields should be present.

The TC-Pairs tool expects two input data sources in order to generate matched pairs and subsequent error statistics. The expected input for MET-TC is an ATCF format file from model output, or the operational aids files with the operational model output for the 'adeck' and the NHC best track analysis (BEST) for the 'bdeck'. The BEST is a subjectively smoothed representation of the storm's location and intensity over its lifetime. The track and intensity values are based on a retrospective assessment of all available observations of the storm.

The BEST is in ATCF file format and contains all the above listed common fields. Given the reference dataset is expected in ATCF file format, any second ATCF format file from model output or operational model output from the NHC aids files can be supplied as well. The expected use of the TC-Pairs tool is to generate matched pairs between model output and the BEST. Note that some of the columns in the TC-Pairs output are populated based on the BEST information (e.g. storm category), therefore use of a different baseline may reduce the available filtering options.

All operational model aids and the BEST can be obtained from the NHC ftp server: <ftp://ftp.nhc.noaa.gov/atcf/archive/>

For more detailed information on the ATCF format description and specifications see: http://www.nrlmry.navy.mil/atcf_web/docs/database/new/abdeck.txt

In order to adhere to ATCF file format, model data must be run through a vortex tracking algorithm prior to becoming input for MET-TC. Many vortex tracking algorithms have been developed in order to obtain basic position, maximum wind, and minimum sea level pressure information from a model forecasts. One vortex tracking algorithm that is supported and freely available is the GFDL vortex tracker. Refer to <http://www.dtcenter.org/HurrWRF/users/downloads/index.php> for more information on the GFDL vortex tracker package.

17.4 Output data format

The MET package produces output in four basic file formats: STAT files, ASCII files, NetCDF files, and Postscript plots. The MET-TC tool produces output in TCSTAT, which stands for Tropical Cyclone - STAT. This output format consists of tabular ASCII data that can be easily read by many analysis tools and software packages, making the output from MET-TC very versatile. Like STAT, TCSTAT is a specialized ASCII format containing one record on each line. Currently, the only line type available in MET-TC is

TCMPR (Tropical Cyclone Matched Pairs). As more line types are included in future releases, all line types will be included in a single TCSTAT file. MET-TC also outputs a NetCDF format file in the TC-dland tool, as input to the TC-Pairs tool.

Chapter 18

TC-Dland Tool

18.1 Introduction

Many filtering criteria within the MET-TC tools depend on the distinction between when a storm is over land or water. The TC-dland tool was developed to aid in quickly parsing data for filter jobs that only verify over water, threshold verification based on distance to land, and exclusion of forecasts outside a specified time window of landfall.

The TC-dland tool underwent a major overhaul for MET v5.1, switching from running legacy FORTRAN code over one quarter of the earth to computing more sophisticated great circle arc distances over the entire globe. The resulting distances are more accurate but take considerably longer to compute. Existing users of MET-TC may notice TC-dland running more slowly and slight differences in the computed distances compared with the previous version.

While the TC-dland tool is available to be run, most users will find the pre-computed distance to land files distributed with the release sufficient. Therefore, the typical user will not actually need to run this tool.

18.2 Input/output format

The input for the TC-dland tool is a file containing the longitude (degrees W negative) and latitude (degrees N positive) of all the coastlines and islands considered to be a significant landmass. The default input is to use all three land data files (aland.dat, shland.dat, wland.dat) found in the installed **share/met/tc_data/** directory. The use of all three files produces a global land data file. The aland.dat file contains the longitude and latitude distinctions used by NHC for the Atlantic and eastern North Pacific basins, the shland.dat contains longitude and latitude distinctions for the Southern Hemisphere (south Pacific and South Indian Ocean), and the wland.dat contains the remainder of the Northern Hemisphere (western North Pacific and

North Indian Ocean). Users may supply their own input file in order to refine the definition of coastlines and a significant landmass.

The output file from TC-dland is a NetCDF format file containing a gridded field representing the distance to the nearest coastline or island, as specified in the input file. This file is used in the TC-Pairs tool to compute the distance from land for each track point in the adeck and bdeck. As noted in chapter 1.3, pre-computed distance to land (NetCDF output from TC-dland) files are available in the release. In the installed `share/met/tc_data` directory:

`dland_nw_hem_tenth_degree.nc`: TC-dland output from `aland.dat` using a 1/10th degree grid

`dland_global_tenth_degree.nc`: TC-dland output from all three land data files (global coverage) using a 1/10th degree grid.

18.3 Practical information

This section briefly describes how to run `tc_dland`. The default grid is set to 1/10th degree NW hemisphere grid.

18.3.1 `tc_dland` usage

```
Usage: tc_dland
       out_file
       [-grid spec]
       [-noll]
       [-land file]
       [-log file]
       [-v level]
```

`tc_dland` has one required arguments and accepts several optional ones.

Required arguments for `tc_dland`

1. The `out_file` argument indicates indicates the NetCDF output file containing the computed distances to land.

Optional arguments for `tc_dland`

2. The `-grid spec` argument overrides the default grid (1/10th NH grid). Spec = `lat_ll lon_ll delta_lat delta_lon n_lat n_lon`
3. The `-noll` argument skips writing the lon/lat variables in the output NetCDF file to reduce the file size.

4. The **-land file** argument overwrites the default land data files (aland.dat, shland.dat, and wland.dat).
5. The **-log file** argument outputs log messages to the specified file.
6. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

Chapter 19

TC-Pairs Tool

19.1 Introduction

The TC-Pairs tool provides position and intensity verification for tropical cyclone forecasts in ATCF file format. The TC-Pairs tool matches an ATCF format tropical cyclone (TC) forecast with a second ATCF format reference TC dataset (most commonly the Best Track analysis). The matched pairs produce position errors, as well as wind, sea level pressure, and distance to land values for each TC dataset. The pair generation can be subset based on user-defined filtering criteria. Practical aspects of the TC-Pairs tool are described in Section 19.2.

19.2 Practical information

This section describes how to configure and run the TC-Pairs tool. The TC-Pairs tool is used to match a tropical cyclone model forecast to a corresponding reference dataset. Both tropical cyclone forecast/reference data must be in ATCF format. Output from the TC-dland tool (NetCDF gridded distance file) is also a required input for the TC-Pairs tool. It is recommended to run **tc_pairs** on a storm-by-storm basis, rather than over multiple storms or seasons to avoid memory issues.

19.2.1 tc_pairs usage

The usage statement for `tc_pairs` is shown below:

```
Usage: tc_pairs
       -adeck source
       -bdeck source
```

```
-config file  
[-out base]  
[-log file]  
[-v level]
```

`tc_pairs` has three required arguments and can accept several optional arguments.

Required arguments for `tc_pairs`

1. The **-adeck source** argument indicates the ATCF format data source containing tropical cyclone model forecast (output from tracker) data to be verified. It specifies the name of an ATCF format file or top-level directory containing ATCF format files ending in “.dat” to be processed.
2. The **-bdeck source** argument indicates the ATCF format data source containing the tropical cyclone reference dataset to be used for verifying the adeck source. It specifies the name of an ATCF format file or top-level directory containing ATCF format files ending in “.dat” to be processed. This source is expected to be the NHC Best Track Analysis, but could also be any ATCF format reference.
3. The **-config file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

Optional arguments for `tc_pairs`

4. The **-out base** argument indicates the path of the output file base. This argument overrides the default output file base (`./out_tcmpr`)
5. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
6. The **-v level** option indicates the desired level of verbosity. The contents of “level” will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.

An example of the `tc_pairs` calling sequence is shown below:

```
tc_pairs -adeck aal092010.dat -bdeck bal092010.dat -config TCPairsConfig
```

In this example, the TC-Pairs tool matches the model track (`aal092010.dat`) and the best track analysis (`bal092010.dat`) for the 9th Atlantic Basin storm in 2010. The track matching and subsequent error information is generated with configuration options specified in the **TCPairsConfig** file.

The TC-Pairs tool implements the following logic:

- Parse the adeck and bdeck data files and store them as track objects.
- Apply configuration file settings to filter the adeck and bdeck track data down to a subset of interest.
- Apply configuration file settings to derive additional adeck track data, such as interpolated tracks, consensus tracks, time-lagged tracks, and statistical track and intensity models.
- For each adeck track that was parsed or derived, search for a matching bdeck track with the same basin and cyclone number and overlapping valid times. If not matching against the BEST track, also ensure that the model initialization times match.
- For each adeck/bdeck track pair, match up their track points in time, lookup distances to land, compute track location errors, and write an output TCMPR line for each track point.

19.2.2 tc_pairs configuration file

The default configuration file for the TC-Pairs tool named 'TCPairsConfig_default' can be found in the installed `share/met/config/` directory. It is encouraged for users to copy these default files before modifying their contents. The contents of the configuration file are described in the subsections below.

The contents of the `tc_pairs` configuration file are described below.

```
storm_id      = [];  
basin         = [];  
cyclone      = [];  
storm_name   = [];  
init_beg     = "";  
init_eng     = "";  
init_inc     = [];  
init_exc     = [];  
valid_beg    = "";  
valid_eng    = "";  
init_hour    = [];  
init_mask    = [];  
valid_mask   = [];  
match_points = TRUE;  
version      = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.2.

```
model = [ "DSHP", "LGEM", "HWRWF" ];
```

The **model** variable contains a list of comma-separated models to be used. The models are identified with an ATCF ID (normally four unique characters). This model identifier should match the model column in the ATCF format input file. An empty list indicates that all models in the input file(s) will be processed.

```
check_dup = FALSE;
```

The **check_dup** flag expects either TRUE and FALSE, indicating whether the code should check for duplicate ATCF lines when building tracks. Setting **check_dup** to TRUE will check for duplicated lines, and produce output information regarding the duplicate. The duplicated ATCF line will not be processed in the `tc_pairs` output. Setting **check_dup** to FALSE, will still exclude tracks that decrease with time, and will overwrite repeated lines, but specific duplicate log information will not be output. Setting **check_dup** to FALSE will make parsing the track quicker.

```
interp12 = NONE;
```

The **interp12** flag expects the entry NONE, FILL, or REPLACE, indicating whether special processing should be performed for interpolated forecasts. The NONE option indicates no changes are made to the interpolated forecasts. The FILL and REPLACE (default) options determine when the 12-hour interpolated forecast (normally indicated with a "2" at the end of the ATCF ID) will be renamed with the 6-hour interpolated ATCF ID (normally indicated with the letter "I" at the end of the ATCF ID). The FILL option renames the 12-hour interpolated forecasts with the 6-hour interpolated forecast ATCF ID only when the 6-hour interpolated forecasts is missing (in the case of a 6-hour interpolated forecast which only occurs every 12-hours (e.g. EMXI, EGRI), the 6-hour interpolated forecasts will be "filled in" with the 12-hour interpolated forecasts in order to provide a record every 6-hours). The REPLACE option renames all 12-hour interpolated forecasts with the 6-hour interpolated forecasts ATCF ID regardless of whether the 6-hour interpolated forecast exists. The original 12-hour ATCF ID will also be retained in the output file (all modified ATCF entries will appear at the end of the TC-Pairs output file). This functionality expects both the 12-hour and 6-hour early (interpolated) ATCF IDs are listed in the model field.

```
consensus = [
  {
    name      = "CON1";
    members  = [ "MOD1", "MOD2", "MOD3" ];
    required = [ true, false, false ];
    min_req  = 2;
  }
];
```

The **consensus** field allows the user to generate a user-defined consensus forecasts from any number of models. All models used in the consensus forecast need to be included in the **model** field (1st entry in TCPairsConfig_default). The name field is the desired consensus model name. The **members** field is a comma-separated list of model IDs that make up the members of the consensus. The **required** field is a comma-separated list of true/false values associated with each consensus member. If a member is designated as true, the member is required to be present in order for the consensus to be generated. If a member is false, the consensus will be generated regardless of whether the member is present. The length of the required array must be the same length as the members array. The **min_req** field is the number of members required in order for the consensus to be computed. The required and min_req field options are applied at each forecast lead time. If any member of the consensus has a non-valid position or intensity value, the consensus for that valid time will not be generated.

```
lag_time = [ "06", "12" ];
```

The **lag_time** field is a comma-separated list of forecast lag times to be used in HH[MMSS] format. For each adeck track identified, a lagged track will be derived for each entry. In the tc_pairs output, the original adeck record will be retained, with the lagged entry listed as the adeck name with "_LAG_HH" appended.

```
best_baseline = [ "BCLP", "BCD5", "BCLA" ];
```

The **best_baseline** field specifies a comma-separated list of CLIPER/SHIFOR baseline forecasts to be derived from the best tracks.

The following are valid baselines for the **best_baseline** field:

BTCLIP: Neumann original 3-day CLIPER in best track mode. Used for the Atlantic basin only. Specify model as BCLP.

BTCLIP5: 5-day CLIPER (Aberson, 1998)/SHIFOR (DeMaria and Knaff, 2001) in best track mode for either Atlantic or eastern North Pacific basins. Specify model as BCS5.

BTCLIPA: Sim Aberson's recreation of Neumann original 3-day CLIPER in best-track mode. Used for Atlantic basin only. Specify model as BCLA.

```
oper_baseline = [ "0CLP", "0CS5", "0CD5" ];
```

The **oper_baseline** field specifies a comma-separated list of CLIPER/SHIFOR baseline forecasts to be derived from the operational (CARQ) tracks.

The following are valid baselines for the **oper_baseline** field:

OCLIP: Merrill modified (operational) 3-day CLIPER run in operational mode. Used for Atlantic basin only. Specify model as OCLP.

OCLIP5: 5-day CLIPER (**Aberson, 1998**)/ SHIFOR (**DeMaria and Knaff, 2001**) in operational mode, rerun using CARQ data. Specify model as OCS5.

OCLIPD5: 5-day CLIPER (**Aberson, 1998**)/ DECAY-SHIFOR (**DeMaria and Knaff, 2001**). Specify model as OCD5.

```
match_points = TRUE;
```

The **match_points** field specifies whether only those track points common to both the adeck and bdeck tracks should be written out. If **match_points** is selected as **FALSE**, the union of the adeck and bdeck tracks will be written out, with "NA" listed for unmatched data.

```
dland_file = "MET_BASE/tc_data/dland_global_tenth_degree.nc";
```

The **dland_file** string specifies the path of the NetCDF format file (default file: `dland_global_tenth_degree.nc`) to be used for the distance to land check in the **tc_pairs** code. This file is generated using `tc_dland` (default file provided in installed **share/met/tc_data** directory).

```
watch_warn = {
    file_name = "MET_BASE/tc_data/wwpts_us.txt";
    time_offset = -14400;
}
```

The **watch_warn** field specifies the file name and time applied offset to the **watch_warn** flag. The **file_name** string specifies the path of the watch/warning file to be used to determine when a watch or warning is in affect during the forecast initialization and verification times. The default file is named **wwpts_us.txt**, which is found in the installed **share/met/tc_data/** directory within the MET build.

The `time_offset` string is the time window (in seconds) assigned to the watch/warning. Due to the non-uniform time watches and warnings are issued, a time window is assigned for which watch/warnings are included in the verification for each valid time. The default watch/warn file is static, and therefore may not include warned storms beyond the current MET code release date; therefore users may wish to contact `met_help@ucar.edu` to obtain the most recent watch/warning file if the static file does not contain storms of interest.

19.2.3 `tc_pairs` output

TC-Pairs produces output in TCSTAT format. The default output file name can be overwritten using the `-out` file argument in the usage statement. The TCSTAT file output from TC-Pairs may be used as input into the TC-Stat tool. The header column in the TC-Pairs output is described in Table 19.1 and 19.2.

Table 19.1: Header information for TC-Pairs TCST output

HEADER		
Column Number	Header Column Name	Description
1	VERSION	Version number
2	AMODEL	User provided text string designating model name
3	BMODEL	User provided text string designating model name
4	STORM_ID	BBCCYYY designation of storm
5	BASIN	Basin
6	CYCLONE	Cyclone number
7	STORM_NAME	Name of Storm
8	INIT	Initialization time of forecast
9	LEAD	Forecast lead time in HH format
10	VALID	Forecast valid time in YYYYMMDD_HH
11	INIT_MASK	Initialization time masking grid applied
12	VALID_MASK	Valid time masking grid applied
13	LINE_TYPE	Output line type (TCMPR currently only line type)
14	TOTAL	Total number of matched pairs
15	INDEX	Index associated with init time
16	LEVEL	Level of storm classification
17	WATCH_WARN	HU or TS watch or warning in effect
18	INITIALS	Forecaster initials
19	ALAT	Latitude position of adeck model
20	ALON	Longitude position of adeck model
21	BLAT	Latitude position of bdeck model
22	BLON	Longitude position of bdeck model
23	TK_ERR	Track error of adeck relative to bdeck (nm)
24	X_ERR	X component position error (nm)
25	Y_ERR	Y component position error (nm)
26	ALTK_ERR	Along track error (nm)
27	CRTK_ERR	Cross track error (nm)

Table continued in Table 19.2

Table 19.2: Header information for TC-Pairs TCST output (cont.)

HEADER		
Column Number	Header Column Name	Description
28	ADLAND	a/deck distance to land (nm)
29	BDLAND	b/deck distance to land (nm)
30	AMSLP	a/deck mean sea level pressure
31	BMSLP	b/deck mean sea level pressure
32	AMAX_WIND	a/deck maximum wind speed
33	BMAX_WIND	b/deck maximum wind speed
34, 35	A/BAL_WIND_34	a/bdeck 34-knot radius winds in full circle
36, 37	A/BNE_WIND_34	a/bdeck 34-knot radius winds in NE quadrant
38, 39	A/BSE_WIND_34	a/bdeck 34-knot radius winds in SE quadrant
40, 41	A/BSW_WIND_34	a/bdeck 34-knot radius winds in SW quadrant
42, 43	A/BNW_WIND_34	a/bdeck 34-knot radius winds in NW quadrant
44, 45	A/BAL_WIND_50	a/bdeck 50-knot radius winds in full circle
46, 47	A/BNE_WIND_50	a/bdeck 50-knot radius winds in NE quadrant
48, 49	A/BSE_WIND_50	a/bdeck 50-knot radius winds in SE quadrant
50, 51	A/BSW_WIND_50	a/bdeck 50-knot radius winds in SW quadrant
52, 53	A/BNW_WIND_50	a/bdeck 50-knot radius winds in NW quadrant
54, 55	A/BAL_WIND_64	a/bdeck 64-knot radius winds in full circle
56, 57	A/BNE_WIND_64	a/bdeck 64-knot radius winds in NE quadrant
58, 59	A/BSE_WIND_64	a/bdeck 64-knot radius winds in SE quadrant
60, 61	A/BSW_WIND_64	a/bdeck 64-knot radius winds in SW quadrant
62, 63	A/BNW_WIND_64	a/bdeck 64-knot radius winds in NW quadrant
64, 65	A/BRADP	pressure in millibars of the last closed isobar, 900 - 1050 mb
66, 67	A/BRRP	radius of the last closed isobar in nm, 0 - 9999 nm
68, 69	A/BMRD	radius of max winds, 0 - 999 nm
70, 71	A/BGUSTS	gusts, 0 through 995 kts
72, 73	A/BEYE	eye diameter, 0 through 999 nm
74, 75	A/BDIR	storm direction in compass coordinates, 0 - 359 degrees
76, 77	A/BSPEED	storm speed, 0 - 999 kts
78, 79	A/BDEPTH	system depth, D-deep, M-medium, S-shallow, X-unknown

Chapter 20

TC-Stat Tool

20.1 Introduction

The TC-Stat tool ties together results from the TC-Pairs tool by providing summary statistics and filtering jobs on TCST output files. The TC-Stat tool requires TCST output from the TC-Pairs tool. See Section 19.2.3 of this users guide for information on the TCST output format of the TC-Pairs tool. A filtering job using TC-Stat provides the ability to filter the input data by various conditions and thresholds described in Section 20.3.2. A summary job produces summary statistics including frequency of superior performance, time-series independence calculations, and confidence intervals on the mean. These statistical aspects are described in Section 20.2, and practical use information for the TC-Stat tool is described in Section 20.3.

20.2 Statistical aspects

20.2.1 Filter TCST lines

The TC-Stat tool can be used to simply filter specific lines of the TCST file based on user-defined filtering criteria. All of the TCST lines that are retained from one or more files are written out to a single output file. The output file is also in TCST format.

Filtering options are outlined below in Section 20.3.2 (configuration file). If multiple filtering options are listed, the job will be performed on their intersection.

20.2.2 Summary statistics for columns

The TC-Stat tool can be used to produce summary information for a single column of data. After the user specifies the specific column of interest, and any other relevant search criteria, summary information

is produced from values in that column of data. The summary statistics produced are: mean, standard deviation, minimum, 10th, 25th, 50th, 75th, and 90th percentiles, and maximum.

Confidence intervals are computed for the mean of the column of data. Confidence intervals are computed using the assumption of normality for the mean. For further information on computing confidence intervals, refer to Appendix D of the MET user's guide.

When operating on columns, a specific column name can be listed (e.g. TK_ERR), as well as the differences of two columns (e.g. AMAX_WIND-BMAX_WIND), and the absolute difference of the column(s) (e.g. abs(AMAX_WIND-BMAX_WIND)). Additionally, several shortcuts can be applied to choose multiple columns with a single entry. Shortcut options for the -column entry are as follows:

TRACK: track error (TK_ERR), along-track error (ALTK_ERR), and cross-track error (CRTK_ERR)

WIND: all wind radii errors (34-, 50-, and 64-kt) for each quadrant

TI: track error (TK_ERR) and absolute intensity error (abs(AMAX_WIND-BMAX_WIND))

AC: along- and cross-track errors (ALTK_ERR, CRTK_ERR)

XY: X- and Y-component track errors (X_ERR, Y_ERR)

The TC-Stat tool can also be used to generate frequency of superior performance and the time to independence calculations when using the TC-Stat summary job.

Frequency of Superior Performance

The frequency of superior performance (FSP) looks at multiple model forecasts (adecks), and ranks each model relative to other model performance for the column specified in the summary job. The summary job output lists the total number of cases included in the FSP, the number of cases where the model of interest is the best (e.g.: lowest track error), the number of ties between the models, and the FSP (percent). Ties are not included in the FSP percentage; therefore the percentage may not equal 100%.

Time-Series Independence

The time-series independence evaluates effective forecast separation time using the Siegel method, by comparing the number of runs above and below the mean error to an expected value. This calculation expects the columns in the summary job to be a time series. The output includes the forecast hour interval and the number of hours to independence.

20.3 Practical information

The following sections describe the usage statement, required arguments, and optional arguments for **tc_stat**.

20.3.1 tc_stat usage

The usage statement for `tc_stat` is shown below:

```
Usage: tc_stat
      -lookin source
      [-out file]
      [-log file]
      [-v level]
      [-config file] | [JOB COMMAND LINE]
```

TC-Stat has one required argument and accepts optional ones.

The usage statement for the TC-Stat tool includes the "job" term, which refers to the set of tasks to be performed after applying user-specified filtering options. The filtering options are used to pare down the TC-Pairs output to only those lines that are desired for the analysis. The job and its filters together comprise a "job command line". The "job command line" may be specified either on the command line to run a single analysis job or within the configuration file to run multiple analysis jobs at the same time. If jobs are specified in both the configuration file and the command line, only the jobs indicated in the configuration file will be run. The various jobs are described in Table 20.1 and the filtering options are described in Section 20.3.2.

Required arguments for tc_stat

1. The **-lookin source** argument indicates the location of the input TCST files generated from `tc_pairs`. This argument can be used one or more times to specify the name of a TCST file or top-level directory containing TCST files to be processed. Multiple tcst files may be specified by using a wild card (*).
2. Either a configuration file must be specified with the **-config** option, or a **JOB COMMAND LINE** must be denoted. The **JOB COMMAND LINE** options are described in Section 20.3.2,

Optional arguments for tc_stat

2. The **-out file** argument indicates the desired name of the TCST format output file.
3. The **-log file** option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
4. The **-v level** option indicates the desired level of verbosity. The contents of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity above 1 will increase the amount of logging.
5. The **-config file** argument indicates the name of the configuration file to be used. The contents of the configuration file are discussed below.

An example of the `tc_stat` calling sequence is shown below:

```
tc_stat -lookin /home/tc_pairs/*al092010.tcst -config TCStatConfig
```

In this example, the TC-Stat tool uses any TCST file (output from `tc_pairs`) in the listed directory for the 9th Atlantic Basin storm in 2010. Filtering options and aggregated statistics are generated following configuration options specified in the `TCStatConfig` file. Further, using flags (e.g. "`-basin`", "`-column`", "`-storm_name`", etc...) option within the job command lines may further refine these selections. See Section 20.3.2 for options available for job command line and 3.5.2 for how to use them.

20.3.2 `tc_stat` configuration file

The default configuration file for the `TC-Stat` tool named `TCStatConfig_default` can be found in the installed `share/met/config` directory. Like the other configuration files described in this document, it is recommended that users make a copy of these files prior to modifying their contents.

The contents of the `tc_stat` configuration file are described below.

```
storm_id      = [];
basin         = [];
cyclone       = [];
storm_name    = [];
init_beg      = "";
init_eng      = "";
init_inc      = [];
init_exc      = [];
valid_beg     = "";
valid_eng     = "";
init_hour     = [];
init_mask     = [];
valid_mask    = [];
match_points  = TRUE;
version       = "VN.N";
```

The configuration options listed above are common to many MET tools and are described in Section 3.5.2.

Note that the options specified in the first section of the configuration file, prior to the job list, will be applied to every job specified in the joblist. However, if an individual job specifies an option listed above, it will be applied to that job. For example, if `model = ["GFSI", "LGEM", "DSHP"]`; is set at the top, but the job in the joblist sets the `-model` option to `"LGEM"`, that job will only run using the LGEM model data.

```
amodel = [];  
bmodel = [];
```

The **amodel** and **bmodel** fields stratify by the `amodel` and `bmodel` columns based on a comma-separated list of model names used for all analysis performed. The names must be in double quotation marks (e.g.: "HWFI"). The **amodel** list specifies the model to be verified against the listed `bmodel`. The **bmodel** specifies the reference dataset, generally the best track analysis. Using the **"-amodel"** and **"-bmodel"** options within the job command lines may further refine these selections.

```
valid_inc = [];  
valid_exc = [];
```

The **valid_inc** and **valid_exc** fields stratify by valid times, based on a comma-separated list of specific valid times to include (`inc`) or exclude (`exc`). Time strings are defined by `YYYYMMDD[_HH[MMSS]]`. Using the **"-valid_inc"**, **"-valid_exc"** options within the job command lines may further refine these selections.

```
valid_hour = [];  
lead       = [];
```

The **valid_hour**, and **lead** fields stratify by the initialization time, valid time, and lead time, respectively. This field specifies a comma-separated list of initialization times, valid times, and lead times in `HH[MMSS]` format. Using the **"-valid_hour"**, and **"-lead"** options within the job command lines may further refine these selections.

```
line_type = [];
```

The **line_type** field stratifies by the `line_type` column. Currently `TCMPR` is the only `line_type` option used in MET-TC.

```
track_watch_warn = [];
```

The **track_watch_warn** flag stratifies over the `watch_warn` column in the TCST files. If any of the watch/warning statuses are present in a forecast track, the entire track is verified. The value "ALL" matches HUWARN, HUWATCH, TSWARN, TSWATCH. Using the "**-track_watch_warn**" option within the job command lines may further refine these selections.

Other uses of the `WATCH_WARN` column include filtering when:

1. A forecast is issued when a watch/warn is in effect
2. A forecast is verifying when a watch/warn is in effect
3. A forecast is issued when a watch/warn is NOT in effect
4. A forecast is verified when a watch/warn is NOT in effect

The following filtering options can be achieved by the following:

1. `init_str_name = ["WATCH_WARN"];`
`init_str_val = ["ALL"];`
2. `column_str_name = ["WATCH_WARN"];`
`column_str_val = ["ALL"];`
3. `init_str_name = ["WATCH_WARN"];`
`init_str_val = ["NA"];`
4. `column_str_name = ["WATCH_WARN"];`
`column_str_val = ["NA"];`

Further information on the `column_str` and `init_str` fields is described below. Listing a comma-separated list of watch/warning types in the `column_str_val` field will stratify by a single or multiple types of warnings.

-
- ```
column_thresh_name = [];
column_thresh_val = [];
```

The `column_thresh_name` and `column_thresh_val` fields stratify by applying thresholds to numeric data columns. Specify a comma-separated list of column names and thresholds to be applied. The length of `column_thresh_val` should match that of `column_thresh_name`. Using the "**-column\_thresh\_name thresh**" option within the job command lines may further refine these selections.

---

```
column_str_name = [];
column_str_val = [];
```

The `column_str_name` and `column_str_val` fields stratify by performing string matching on non-numeric data columns. Specify a comma-separated list of columns names and values to be checked. The length of the `column_str_val` should match that of the `column_str_name`. Using the "`-column_str name val`" option within the job command lines may further refine these selections.

---

```
init_thresh_name = [];
init_thresh_val = [];
```

The `init_thresh_name` and `init_thresh_val` fields stratify by applying thresholds to numeric data columns only when `lead = 0`. If `lead = 0`, but the value does not meet the threshold, discard the entire track. The length of the `init_thresh_val` should match that of the `init_thresh_name`. Using the "`-init_thresh name val`" option within the job command lines may further refine these selections.

---

```
init_str_name = [];
init_str_val = [];
```

The `init_str_name` and `init_str_val` fields stratify by performing string matching on non-numeric data columns only when `lead = 0`. If `lead = 0`, but the string does not match, discard the entire track. The length of the `init_str_val` should match that of the `init_str_name`. Using the "`-init_str name val`" option within the job command lines may further refine these selections.

---

```
water_only = FALSE;
```

The `water_only` flag stratifies by only using points where both the `amodel` and `bmodel` tracks are over water. When `water_only = TRUE`; once land is encountered the remainder of the forecast track is not used for the verification, even if the track moves back over water.

---

```
rirw = {
 track = NONE;
 time = "24";
 exact = TRUE;
 thresh = >=30.0;
}
```

The **rirw** field specifies those track points for which rapid intensification (RI) or rapid weakening (RW) occurred, based on user defined RI/RW thresholds. The **track** entry specifies that RI/RW is not turned on (**NONE**), is computed based on the bmodel only (**BDECK**), is computed based on the amodel only (**ADECK**), or computed when both the amodel and bmodel (the union of the two) indicate RI/RW (**BOTH**). If **track** is set to **ADECK**, **BDECK**, or **BOTH**, only tracks exhibiting rapid intensification will be retained. Rapid intensification is officially defined as when the change in the maximum wind speed over a 24-hour period is greater than or equal to 30 kts. This is the default setting, however flexibility in this definition is provided through the use of the **time**, **exact** and **thresh** options. The **time** field specifies the time window (HH[MMSS] format) for which the RI/RW occurred. The **exact** field specifies whether to only count RI/RW when the intensity change is over the exact time window (TRUE), which follows the official RI definition, or if the intensity threshold is met anytime during the time window (FALSE). Finally, the **thresh** field specifies the user defined intensity threshold (where ">=" indicates RI, and "<=" indicates RW).

Using the `"-rirw_track"`, `"-rirw_time_adeck"`, `"-rirw_time_bdeck"`, `"-rirw_exact_adeck"`, `"-rirw_exact_bdeck"`, `"-rirw_thresh_adeck"`, `"-rirw_thresh_bdeck"` options within the job command lines may further refine these selections. See `README_TC` in `data/config` for how to use these options.

---

```
landfall = FALSE;
landfall_beg = "-24";
landfall_end = "00";
```

The **landfall**, **landfall\_beg**, and **landfall\_end** fields specify whether only those track points occurring near landfall should be retained. The landfall retention window is defined as the hours offset from the time of landfall. Landfall is defined as the last bmodel track point before the distance to land switches from water to land. When **landfall\_end** is set to 0, the track is retained from the **landfall\_beg** to the time of landfall. Using the `"-landfall_window"` option with the job command lines may further refine these selections. The `"-landfall_window"` job command option takes 1 or 2 arguments in HH[MMSS] format. Use 1 argument to define a symmetric time window. For example, `"-landfall_window 06"` defines the time window +/- 6 hours around the landfall time. Use 2 arguments to define an asymmetric time window. For example, `"-landfall_window 00 12"` defines the time window from the landfall event to 12 hours after.

---

```
event_equal = FALSE;
```

The **event\_equal** flag specifies whether only those track points common to all models in the dataset should be retained. The event equalization is performed only using cases common to all listed amodel entries. A case is defined by comparing the following columns in the TCST files: BMODEL, BASIN, CYCLONE, INIT, LEAD, VALID. This option may be modified using the `"-event_equal"` option within the job command lines.

---

```
event_equal_lead = [];
```

The **event\_equal\_lead** flag specifies lead times that must be present for a track to be included in the event equalization logic. The event equalization is performed only using cases common to all lead times listed, enabling the verification at each lead time to be performed on a consistent dataset. This option may be modified using the "**-event\_equal\_lead**" option within the job command lines.

---

```
out_init_mask = "";
```

The **out\_init\_mask** field applies polyline masking logic to the location of the amodel track at the initialization time. If the track point falls outside the mask, discard the entire track. This option may be modified using the "**-out\_init\_mask**" option within the job command lines.

---

```
out_valid_mask = "";
```

The **out\_valid\_mask** field applies polyline masking logic to the location of the amodel track at the valid time. If the track point falls outside the mask, discard the entire track. This option may be modified using the "**-out\_valid\_mask**" option within the job command lines.

---

```
jobs = [];
```

The user may specify one or more analysis jobs to be performed on the TCST lines that remain after applying the filtering parameters listed above. Each entry in the joblist contains the task and additional filtering options for a single analysis to be performed. There are three types of jobs available including *filter*, *summary*, and *rirw*. Please refer to the README\_TC in data/config for details on how to call each job. The format for an analysis job is as follows:

```
-job job_name REQUIRED and OPTIONAL ARGUMENTS
e.g.: -job filter -amodel HWFI -dump_row ./tc_filter_job.tcst
 -job summary -line_type TCMPR -column TK_ERR -dump_row ./tc_summary_job.tcst
```

---

### 20.3.3 tc\_stat output

The output generated from the TC-Stat tool contains statistics produced by the analysis. Additionally, it includes information about the analysis job that produced the output for each line. The output can be redirected to an output file using the **"-out"** option. The format of output from each **tc\_stat** job command is listed below.

#### Job: Filter

This job command finds and filters TCST lines down to those meeting the criteria selected by the filter's options. The filtered TCST lines are written to a file specified by the **"-dump\_row"** option. The TCST output from this job follows the TCST output description in Chapters 18 and 19.

#### Job: Summary

This job produces summary statistics for the column name specified by the **"-column"** option. The output of the summary job consists of three rows: **"JOB\_LIST"**, which shows the job definition parameters used for this job. **"COL\_NAME"**, followed by the summary statistics that are applied. **"SUMMARY"**, which is followed by the total, mean (with confidence intervals), standard deviation, minimum value, percentiles (10th, 25th, 50th, 75th, 90th), maximum value, sum, time to independence, and frequency of superior performance. The output columns are shown below in Table 20.1 The **"-by"** option can also be used one or more times to make this job more powerful. Rather than running the specified job once, it will be run once for each unique combination of the entries found in the column(s) specified with the **"-by"** option.

Table 20.1: Columnar output of "summary" job output from the TC-Stat tool.

| tc_stat Summary Job Output Options |                                                         |
|------------------------------------|---------------------------------------------------------|
| Column number                      | Description                                             |
| 1                                  | SUMMARY: (job type)                                     |
| 2                                  | Column (dependent parameter)                            |
| 3                                  | Case (storm + valid time)                               |
| 4                                  | Total                                                   |
| 5                                  | Vaild                                                   |
| 6-8                                | Mean including normal upper and lower confidence limits |
| 9                                  | Standard deviation                                      |
| 10                                 | Minimum value                                           |
| 11-15                              | Percentiles (10th, 25th, 50th, 75th, 90th)              |
| 16                                 | Maximum Value                                           |
| 17                                 | Sum                                                     |
| 18-19                              | Independence time                                       |
| 20-23                              | Frequency of superior performance                       |



# Chapter 21

## Plotting and Graphics Support

### 21.1 Plotting Utilities

This section describes how to check your data files using plotting utilities. Point observations can be plotted using the `plot_point_obs` utility. A single model level can be plotted using the `plot_data_plane` utility. For object based evaluations, the MODE objects can be plotted using `plot_mode_field`. Occasionally, a postprocessing or timing error can lead to errors in MET. These tools can assist the user by showing the data to be verified to ensure that times and locations match up as expected.

#### 21.1.1 `plot_point_obs` usage

The usage statement for the `plot_point_obs` utility is shown below:

```
Usage: plot_point_obs
 nc_file
 ps_file
 [-gc code]
 [-msg_typ name]
 [-data_file name]
 [-dotsize val]
 [-log file]
 [-v level]
```

`plot_point_obs` has two required arguments and can take optional ones.

#### Required arguments for `plot_point_obs`

1. The `nc_file` argument indicates the name of the file to be plotted.
2. The `ps_file` argument indicates the name given to the output file containing the plot.

### Optional arguments for `plot_point_obs`

3. The `-gc code` is the GRIB code(s) to be plotted.
4. The `-msg_type name` is the message type(s) to be plotted.
5. The `-data_file name` is a data file whose grid should be used for the plot.
6. The `-dotsize val` option overrides the default dotsize value (1).
7. The `-log file` option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
8. The `-v level` option indicates the desired level of verbosity. The value of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `plot_point_obs` calling sequence is shown below:

```
plot_point_obs sample_pb.nc sample_data.ps
```

In this example, the `plot_point_obs` tool will process the input `sample_pb.nc` file write a postscript file containing a plot to a file named `sample_pb.ps`.

### 21.1.2 `plot_data_plane` usage

The usage statement for the `plot_data_plane` utility is shown below:

```
Usage: plot_data_plane
 input_filename
 output_filename
 field_string
 [-color_table color_table_name]
 [-plot_range min max]
 [-title title_string]
 [-log file]
 [-v level]
```

`plot_data_plane` has two required arguments and can take optional ones.

### Required arguments for `plot_data_plane`

1. The `input_filename` argument indicates the name of the gridded data file to be plotted.
2. The `output_filename` argument indicates the name given to the output PostScript file containing the plot.
3. The `field_string` argument contains information about the field and level to be plotted.

### Optional arguments for `plot_data_plane`

4. The `-color_table color_table_name` overrides the default color table ("MET\_BASE/colortables/met\_default.ctable")
5. The `-plot_range min max` sets the minimum and maximum values to plot.
6. The `-title title_string` sets the title text for the plot.
7. The `-log file` option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
8. The `-v level` option indicates the desired level of verbosity. The value of "level" will override the default setting of 2. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `plot_data_plane` calling sequence is shown below:

```
plot_data_plane test.grb test.ps 'name="TMP"; level="Z2";'
```

A second example of the `plot_data_plane` calling sequence is shown below:

```
plot_data_plane test.grb2 test.ps 'name="DSWRF"; level="L0";' -v 4
```

In the first example, the `plot_data_plane` tool will process the input `test.grb` file and write a PostScript image to a file named `test.ps` showing temperature at 2 meters. The second example plots downward shortwave radiation flux at the surface. The second example is run at verbosity level 4 so that user can inspect the output and make sure its plotting the intended record.

### 21.1.3 `plot_mode_field` usage

The usage statement for the `plot_mode_field` utility is shown below:

```
Usage: plot_mode_field
 mode_nc_file_list
 -raw | -simple | -cluster
 -obs | -fcst
 -config file
 [-log file]
 [-v level]
```

`plot_mode_field` has four required arguments and can take optional ones.

#### Required arguments for `plot_mode_field`

1. The `mode_nc_file_list` specifies the MODE output files to be used for plotting.
2. The `-raw` | `-simple` | `-cluster` argument indicates the types of field to be plotted. Exactly one must be specified. For details about the types of objects, see the chapter in this document on MODE.
3. The `-obs` | `-fcst` option specifies whether to plot the observed or forecast field from the MODE output files. Exactly one must be specified.
4. The `-config file` specifies the configuration file to use for specification of plotting options.

#### Optional arguments for `plot_mode_field`

5. The `-log file` option directs output and errors to the specified log file. All messages will be written to that file as well as `cout` and `cerr`. Thus, users can save the messages without having to redirect the output on the command line. The default behavior is no logfile.
6. The `-v level` option indicates the desired level of verbosity. The value of "level" will override the default. Setting the verbosity to 0 will make the tool run with no log messages, while increasing the verbosity will increase the amount of logging.

An example of the `plot_mode_field` calling sequence is shown below:

```
plot_mode_field -simple -obs -config \
plotMODEconfig mode_120000L_20050807_120000V_000000A_obj.nc
```

In this example, the `plot_mode_field` tool will plot simple objects from an observed precipitation field using parameters from the configuration file `plotMODEconfig` and objects from the MODE output file `mode_120000L_20050807_120000V_000000A_obj.nc`. An example plot showing twelve simple observed precipitation objects is shown below.

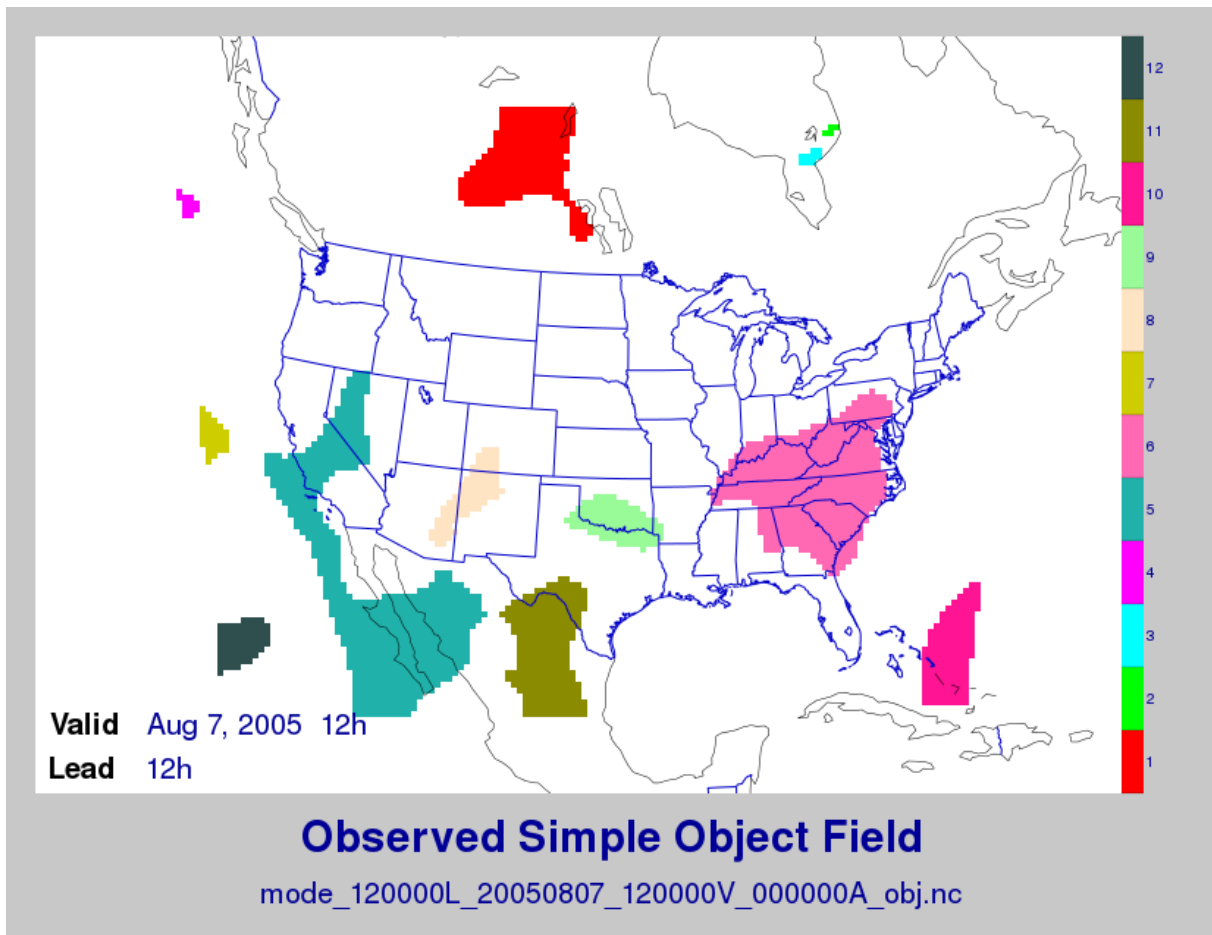


Figure 21.1: Simple observed precipitation objects

Once MET has been applied to forecast and observed fields (or observing locations), and the output has been sorted through the Analysis Tool, numerous graphical and summary analyses can be performed depending on a specific user's needs. Here we give some examples of graphics and summary scores that one might wish to compute with the given output of MET and MET-TC. Any computing language could be used for this stage; some scripts will be provided on the MET users web page (<http://www.dtcenter.org/met/users/>) as examples to assist users.

## 21.2 Examples of plotting MET output

### 21.2.1 Grid-Stat tool examples

The plots in Figure 21.2 show time series of frequency bias and Gilbert Skill Score, stratified according to time of day. This type of figure is particularly useful for diagnosing problems that are tied to the diurnal cycle. In this case, two of the models (green dash-dotted and black dotted lines) show an especially high Bias (near 3) during the afternoon (15-21 UTC; left panel), while the skill (GSS; right panel) appears to be

best for the models represented by the solid black line and green dashed lines in the morning (09-15 UTC). Note that any judgment of skill based on GSS should be restricted to times when the Bias is close to one.

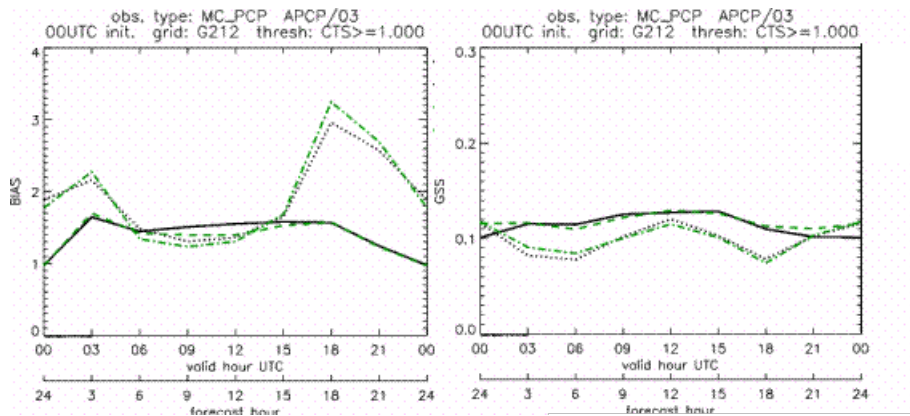


Figure 21.2: Time series of forecast area bias and Gilbert Skill Score for four model configurations (different lines) stratified by time-of-day.

### 21.2.2 MODE tool examples

When using the MODE tool, it is possible to think of matched objects as hits and unmatched objects as false alarms or misses depending on whether the unmatched object is from the forecast or observed field, respectively. Because the objects can have greatly differing sizes, it is useful to weight the statistics by the areas, which are given in the output as numbers of grid squares. When doing this, it is possible to have different matched observed object areas from matched forecast object areas so that the number of hits will be different depending on which is chosen to be a hit. When comparing multiple forecasts to the same observed field, it is perhaps wise to always use the observed field for the hits so that there is consistency for subsequent comparisons. Defining hits, misses and false alarms in this way allows one to compute many traditional verification scores without the problem of small-scale discrepancies; the matched objects are defined as being matched because they are "close" by the fuzzy logic criteria. Note that scores involving the number of correct negatives may be more difficult to interpret as it is not clear how to define a correct negative in this context. It is also important to evaluate the number and area attributes for these objects in order to provide a more complete picture of how the forecast is performing.

Figure 21.3 gives an example of two traditional verification scores (Bias and CSI) along with bar plots showing the total numbers of objects for the forecast and observed fields, as well as bar plots showing their total areas. These data are from the same set of 13-km WRF model runs analyzed in Figure 21.3. The model runs were initialized at 0 UTC and cover the period 15 July to 15 August 2005. For the forecast evaluation, we compared 3-hour accumulated precipitation for lead times of 3-24 hours to Stage II radar-gauge precipitation. Note that for the 3-hr lead time, indicated as the 0300 UTC valid time in Figure 21.2, the Bias is significantly larger than the other lead times. This is evidenced by the fact that there are both a larger number of forecast objects, and a larger area of forecast objects for this lead time, and only for this lead time. Dashed lines show about 2 bootstrap standard deviations from the estimate.

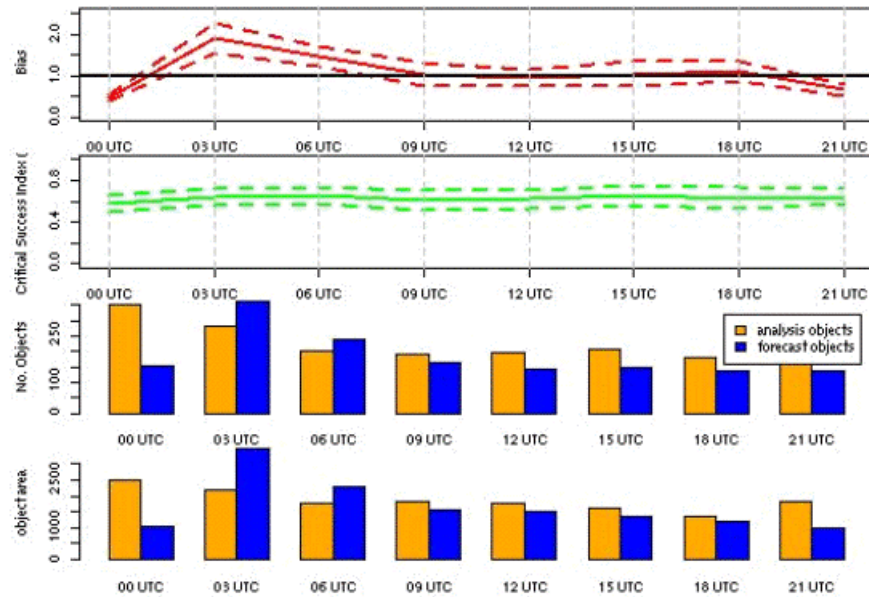


Figure 21.3: Traditional verification scores applied to output of the MODE tool, computed by defining matched observed objects to be hits, unmatched observed objects to be misses, and unmatched forecast objects to be false alarms; weighted by object area. Bar plots show numbers (penultimate row) and areas (bottom row) of observed and forecast objects, respectively.

In addition to the traditional scores, MODE output allows more information to be gleaned about forecast performance. It is even useful when computing the traditional scores to understand how much the forecasts are displaced in terms of both distance and direction. Figure 21.4, for example, shows circle histograms for matched objects. The petals show the percentage of times the forecast object centroids are at a given angle from the observed object centroids. In Figure 21.4 (top diagram) about 25% of the time the forecast object centroids are west of the observed object centroids, whereas in Figure 21.4 (bottom diagram) there is less bias in terms of the forecast objects' centroid locations compared to those of the observed objects, as evidenced by the petals' relatively similar lengths, and their relatively even dispersion around the circle. The colors on the petals represent the proportion of centroid distances within each colored bin along each direction. For example, Figure 21.4 (top row) shows that among the forecast object centroids that are located to the West of the observed object centroids, the greatest proportion of the separation distances (between the observed and forecast object centroids) is greater than 20 grid squares.

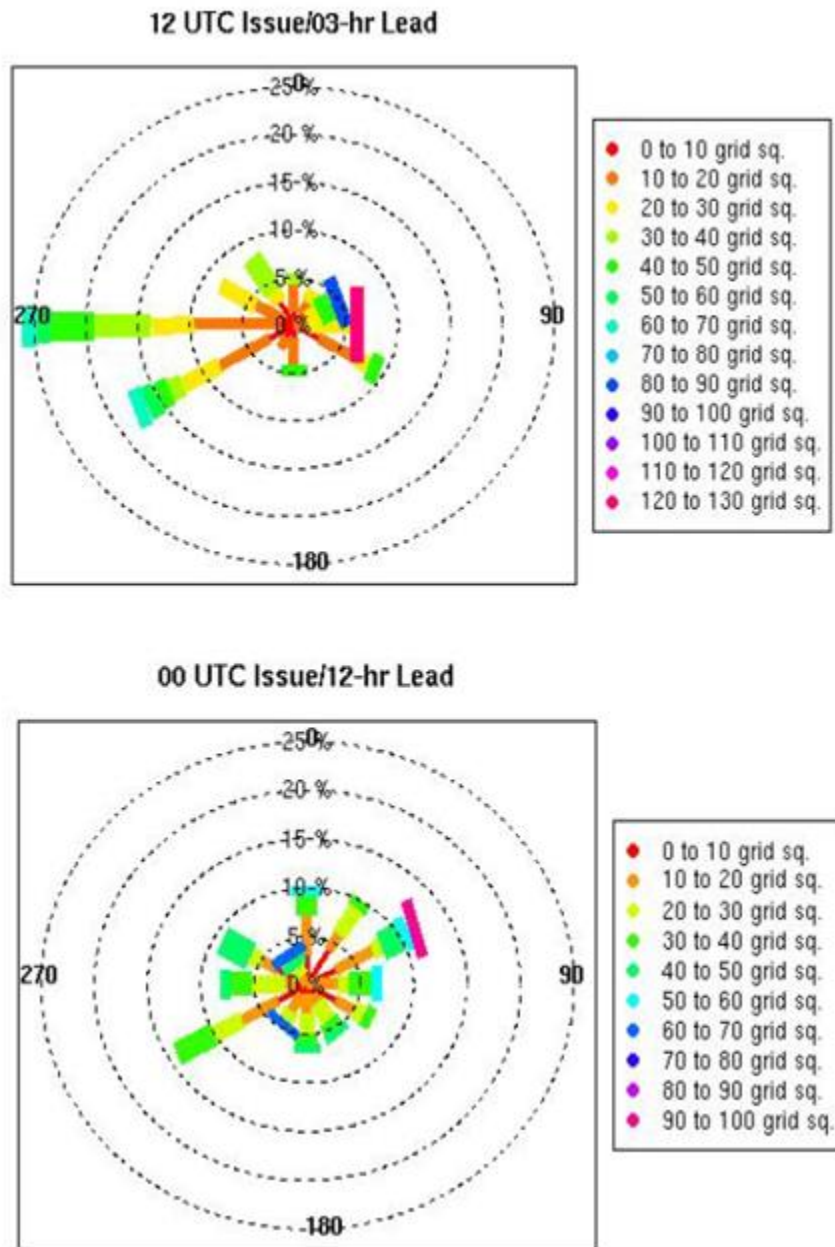


Figure 21.4: Circle histograms showing object centroid angles and distances (see text for explanation).

### 21.2.3 TC-Stat tool example

There is a basic R script located in the MET build in `scripts/Rscripts/plot_tmpr.R`. The usage statement with a short description of the options for `plot_tmpr.R` can be obtained by typing: `Rscript plot_tmpr.R` with no additional arguments. The only required argument is the `-lookin` source, which is the path to the TC-Pairs TCST output files. The R script reads directly from the TC-Pairs output, and calls TC-Stat directly for filter jobs specified in the `"-filter options"` argument.



In order to run this script, the `MET_BUILD_DIR` environment variable must be set to the top-level MET build directory. In addition, the `tc_stat` tool must be in your path.

The supplied R script can generate a number of different plot types including boxplots, mean, median, rank, and relative performance. Pairwise differences can be plotted for the boxplots, mean, and median. Normal confidence intervals are applied to all figures unless the `no_ci` option is set to `TRUE`. Below are two example plots generated from the tools.

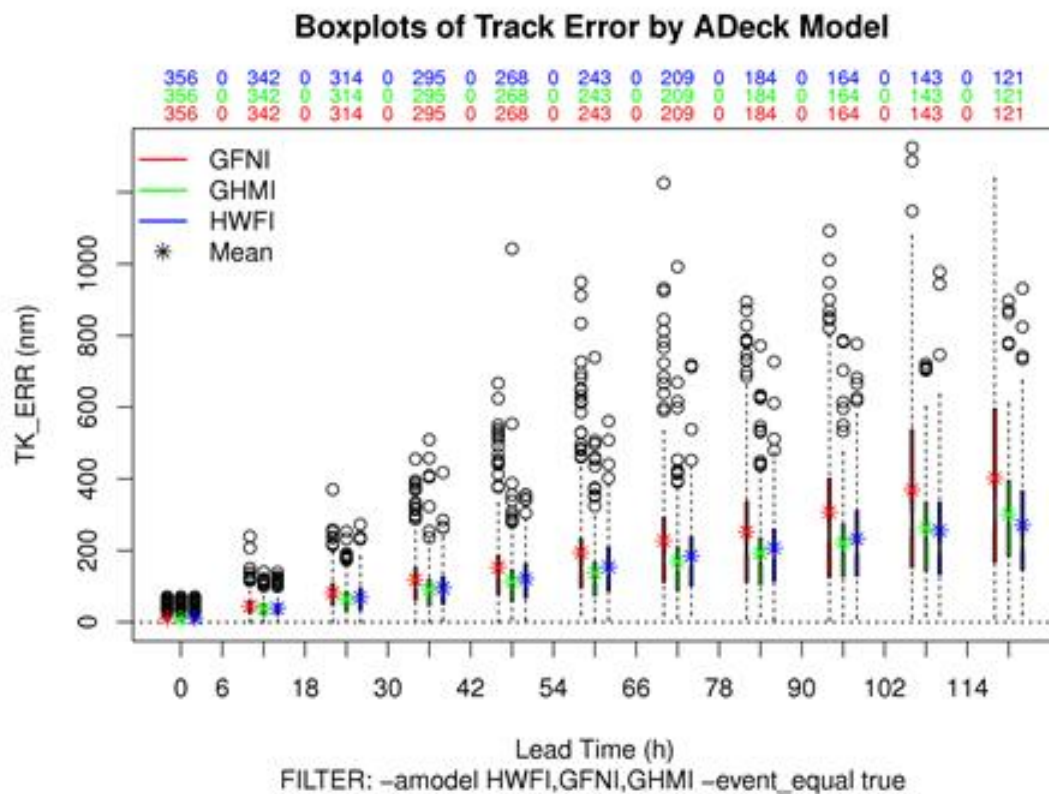


Figure 21.5: Example boxplot from `plot_tcmpr.R`. Track error distributions by lead time for three operational models GFNI, GHMI, HWFI.

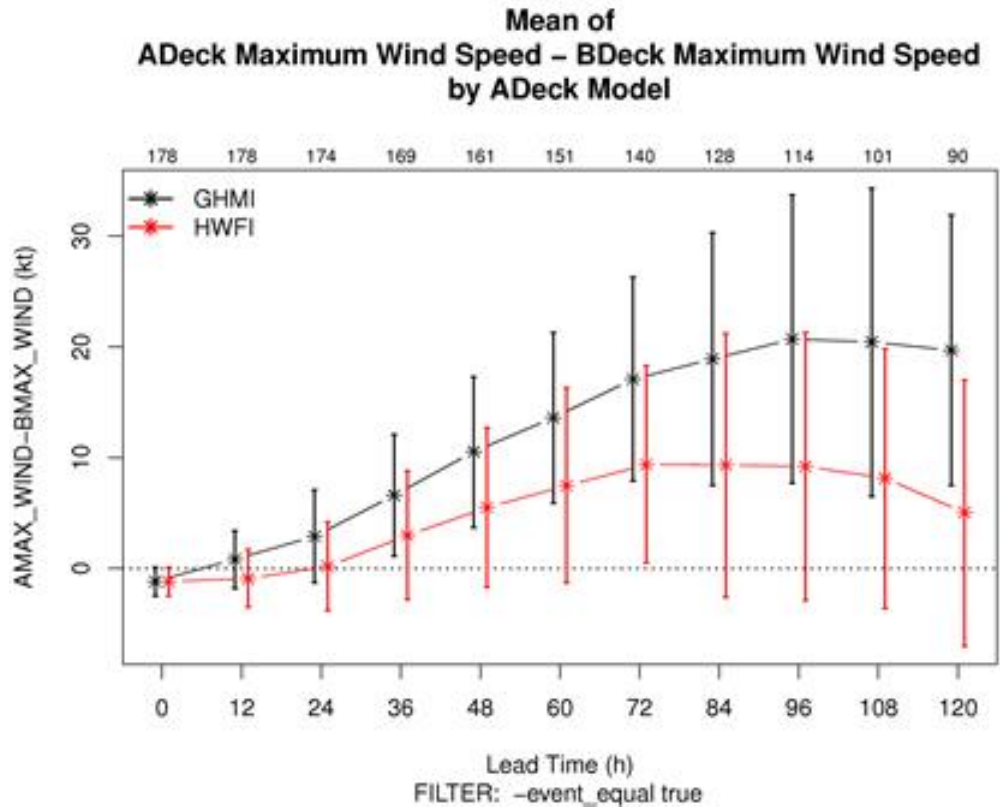


Figure 21.6: Example mean intensity error with confidence intervals at 95% from plot\_tmpr.R. Raw intensity error by lead time for a homogeneous comparison of two operational models GHMI, HWFI.

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# Appendix A

## FAQs & How do I ... ?

### A.1 Frequently Asked Questions

**Q. Why was the MET written largely in C++ instead of FORTRAN?**

A. MET relies upon the object-oriented aspects of C++, particularly in using the MODE tool. Due to time and budget constraints, it also makes use of a pre-existing forecast verification library that was developed at NCAR.

**Q. Why is PrepBufr used?**

A. The first goal of MET was to replicate the capabilities of existing verification packages and make these capabilities available to both the DTC and the public.

**Q. Why is GRIB used?**

A. Forecast data from both WRF cores can be processed into GRIB format, and it is a commonly accepted output format for many NWP models.

**Q. Is GRIB2 supported?**

A. Yes, forecast output in GRIB2 format can be read by MET. Be sure to compile the GRIB2 code by setting the appropriate configuration file options (see Chapter 2).

**Q. How does MET differ from the previously mentioned existing verification packages?**

A. MET is an actively maintained, evolving software package that is being made freely available to the public through controlled version releases.

**Q. How does the MODE tool differ from the Grid-Stat tool?**

A. They offer different ways of viewing verification. The Grid-Stat tool provides traditional verification statistics, while MODE provides specialized spatial statistics.

**Q. Will the MET work on data in native model coordinates?**

A. No - it will not. In the future, we may add options to allow additional model grid coordinate systems.

**Q. How do I get help if my questions are not answered in the User's Guide?**

A. First, look on our website <http://www.dtcenter.org/met/users>. If that doesn't answer your question, then email: [met\\_help@ucar.edu](mailto:met_help@ucar.edu).

**Q. Where are the graphics?**

A. Currently, very few graphics are included. The plotting tools (`plot_point_obs`, `plot_data_plane`, and `plot_mode_field`) can help you visualize your raw data. Also, `ncview` can be used with the NetCDF output from MET tools to visualize results. Further graphics support will be made available in the future on the MET website.

## A.2 Troubleshooting

The first place to look for help with individual commands is this user's guide or the usage statements that are provided with the tools. Usage statements for the individual MET tools are available by simply typing the name of the executable in MET's `bin/` directory. Example scripts available in the MET's `scripts/` directory show examples of how one might use these commands on example datasets. Here are suggestions on other things to check if you are having problems installing or running MET.

### MET won't compile

- \* Have you specified the locations of NetCDF, GNU Scientific Library, and BUFRLIB, and optional additional libraries using corresponding MET\_ environment variables prior to running `configure`?
- \* Have these libraries been compiled and installed using the same set of compilers used to build MET?
- \* Are you using NetCDF version 3.4 or version 4? Currently, only NetCDF version 3.6 can be used with MET.

### Grid\_stat won't run

- \* Are both the observational and forecast datasets on the same grid?

### MODE won't run

- \* If using precipitation, do you have the same accumulation periods for both the forecast and observations? (If you aren't sure, run `pcp_combine`.)
- \* Are both the observation and forecast datasets on the same grid?

### **Point-Stat won't run**

- \* Have you run `pb2nc` first on your `PrepBuf` observation data?

### **General troubleshooting**

- \* For configuration files used, make certain to use empty square brackets (e.g. `[]`) to indicate no stratification is desired. Do NOT use empty double quotation marks inside square brackets (e.g. `[""]`).
- \* Have you designated all the required command line arguments?
- \* Try rerunning with a higher verbosity level. Increasing the verbosity level to 4 or 5 prints much more diagnostic information to the screen.

## **A.3 Where to get help**

If none of the above suggestions have helped solve your problem, help is available through: `met_help@ucar.edu`

## **A.4 How to contribute code**

If you have code you would like to contribute, we will gladly consider your contribution. Please send email to: `met_help@ucar.edu`

# Appendix B

## Map Projections, Grids, and Polylines

### B.1 Map Projections

The following map projections are currently supported in MET:

- \* Lambert Conformal Projection
- \* Polar Stereographic Projection (Northern)
- \* Polar Stereographic Projection (Southern)
- \* Mercator Projection
- \* Lat/Lon Projection

### B.2 Grids

All of NCEP's pre-defined grids that reside on one of the projections listed above are implemented in MET. The user may specify one of these NCEP grids in the configuration files as "GNNN" where NNN is the 3-digit NCEP grid number. Defining a new masking grid in MET would involve modifying the `vx_data_grids` library and recompiling.

Please see NCEP's website for a description and plot of these pre-defined grids:

<http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html>.

The NCEP grids that are pre-defined in MET are listed below by projection type:

- \* Lambert Conformal Projection

- o G145, G146, G163, G206, G209, G211, G212, G215, G218, G221
- o G222, G226, G227, G236, G237, G241, G245, G246, G247, G252
- \* Polar Stereographic Projection (Northern)
  - o G005, G006, G027, G028, G055, G056, G087, G088, G100, G101
  - o G103, G104, G105, G106, G107, G201, G202, G203, G205, G207
  - o G213, G214, G216, G217, G223, G224, G240, G242, G249
- \* Lat/Lon Projection
  - o G002, G003, G004, G029, G030, G033, G034, G045, G085, G086
  - o G110, G175, G228, G229, G230, G231, G232, G233, G234, G243
  - o G248, G250, G251

### B.3 Polylines for NCEP Regions

Many of NCEP's pre-defined verification regions are implemented in MET as lat/lon polyline files. The user may specify one of these NCEP verification regions in the configuration files by pointing to the lat/lon polyline file in the installed share/met/poly directory. Users may also easily define their own lat/lon polyline files.

See NCEP's website for a description and plot of these pre-defined verification regions: <http://www.emc.ncep.noaa.gov/mmb/research/nearsfc/nearsfc.verf.html>

The NCEP verification regions that are implemented in MET as lat/lon polylines are listed below:

- \* APL.poly for the Appalachians
- \* ATC.poly for the Arctic Region
- \* CAM.poly for Central America
- \* CAR.poly for the Caribbean Sea
- \* ECA.poly for Eastern Canada
- \* GLF.poly for the Gulf of Mexico
- \* GMC.poly for the Gulf of Mexico Coast



- \* GRB.poly for the Great Basin
- \* HWI.poly for Hawaii
- \* LMV.poly for the Lower Mississippi Valley
- \* MDW.poly for the Midwest
- \* MEX.poly for Mexico
- \* NAK.poly for Northern Alaska
- \* NAO.poly for Northern Atlantic Ocean
- \* NEC.poly for the Northern East Coast
- \* NMT.poly for the Northern Mountain Region
- \* NPL.poly for the Northern Plains
- \* NPO.poly for the Northern Pacific Ocean
- \* NSA.poly for Northern South America
- \* NWC.poly for Northern West Coast
- \* PRI.poly for Puerto Rico and Islands
- \* SAK.poly for Southern Alaska
- \* SAO.poly for the Southern Atlantic Ocean
- \* SEC.poly for the Southern East Coast
- \* SMT.poly for the Southern Mountain Region
- \* SPL.poly for the Southern Plains
- \* SPO.poly for the Southern Pacific Ocean
- \* SWC.poly for the Southern West Coast
- \* SWD.poly for the Southwest Desert
- \* WCA.poly for Western Canada
- \* EAST.poly for the Eastern United States (consisting of APL, GMC, LMV, MDW, NEC, and SEC)
- \* WEST.poly for the Western United States (consisting of GRB, NMT, NPL, NWC, SMT, SPL, SWC, and SWD)
- \* CONUS.poly for the Continental United States (consisting of EAST and WEST)

# Appendix C

## Verification Measures

This appendix provides specific information about the many verification statistics and measures that are computed by MET. These measures are categorized into measures for categorical (dichotomous) variables; measures for continuous variables; measures for probabilistic forecasts and measures for neighborhood methods. While the continuous, categorical, and probabilistic statistics are computed by both the Point-Stat and Grid-Stat tools, the neighborhood verification measures are only provided by the Grid-Stat tool.

### C.1 MET verification measures for categorical (dichotomous) variables

The verification statistics for dichotomous variables are formulated using a contingency table such as the one shown in Table C-1. In this table  $f$  represents the forecasts and  $o$  represents the observations; the two possible forecast and observation values are represented by the values 0 and 1. The values in Table C-1 are counts of the number of occurrences of the four possible combinations of forecasts and observations.

Table C.1: 2x2 contingency table in terms of counts. The  $n_{ij}$  values in the table represent the counts in each forecast-observation category, where  $i$  represents the forecast and  $j$  represents the observations. The "." symbols in the total cells represent sums across categories.

| Forecast              | Observation                |                            | Total                                   |
|-----------------------|----------------------------|----------------------------|-----------------------------------------|
|                       | $o = 1$ (e.g., "Yes")      | $o = 0$ (e.g., "No")       |                                         |
| $f = 1$ (e.g., "Yes") | $n_{11}$                   | $n_{10}$                   | $n_{1.} = n_{11} + n_{10}$              |
| $f = 0$ (e.g., "No")  | $n_{01}$                   | $n_{00}$                   | $n_{0.} = n_{01} + n_{00}$              |
| Total                 | $n_{.1} = n_{11} + n_{01}$ | $n_{.0} = n_{10} + n_{00}$ | $T = n_{11} + n_{10} + n_{01} + n_{00}$ |

The counts,  $n_{11}$ ,  $n_{10}$ ,  $n_{01}$ , and  $n_{00}$ , are sometimes called the "Hits", "False alarms", "Misses", and "Correct rejections", respectively.

By dividing the counts in the cells by the overall total,  $T$ , the joint proportions,  $p_{11}$ ,  $p_{10}$ ,  $p_{01}$ , and  $p_{00}$  can be computed. Note that  $p_{11} + p_{10} + p_{01} + p_{00} = 1$ . Similarly, if the counts are divided by the

row (column) totals, conditional proportions, based on the forecasts (observations) can be computed. All of these combinations and the basic counts can be produced by the Point-Stat tool.

The values in Table C-1 can also be used to compute the F, O, and H relative frequencies that are produced by the NCEP Verification System, and the Point-Stat tool provides an option to produce the statistics in this form. In terms of the other statistics computed by the Point-Stat tool, F is equivalent to the Mean Forecast; H is equivalent to POD; and O is equivalent to the Base Rate. All of these statistics are defined in the subsections below. The Point-Stat tool also provides the total number of observations, **T**.

The categorical verification measures produced by the Point-Stat and Grid-Stat tools are described in the following subsections. They are presented in the order shown in Tables 4-3 through 4-8.

### **TOTAL**

The total number of forecast-observation pairs, **T**.

### **Base rate**

Called "O\_RATE" in FHO output (Table 4-3)

Called "BASER" in CTS output (Table 4-5)

The base rate is defined as  $\bar{o} = \frac{n_{11} + n_{01}}{T} = \frac{n_{\cdot 1}}{T}$ . This value is also known as the sample climatology, and is the relative frequency of occurrence of the event (i.e., **o** = **1**). The base rate is equivalent to the "O" value produced by the NCEP Verification System.

### **Mean forecast**

Called "F\_RATE" in FHO output (Table 4-3);

Called "FMEAN" in CTS output (Table 4-5)

The mean forecast value is defined as  $\bar{f} = \frac{n_{11} + n_{10}}{T} = \frac{n_{1\cdot}}{T}$ .

This statistic is comparable to the base rate and is the relative frequency of occurrence of a forecast of the event (i.e., **f** = **1**). The mean forecast is equivalent to the "F" value computed by the NCEP Verification System.

**Accuracy**

Called "ACC" in CTS output (Table 4-5)

Accuracy for a 2x2 contingency table is defined as

$$\text{ACC} = \frac{n_{11} + n_{00}}{T}.$$

That is, it is the proportion of forecasts that were either hits or correct rejections - the fraction that were correct. Accuracy ranges from 0 to 1; a perfect forecast would have an accuracy value of 1. Accuracy should be used with caution, especially for rare events, because it can be strongly influenced by large values of  $n_{00}$ .

**Frequency Bias**

Called "FBIAS" in CTS output (Table 4-5)

Frequency Bias is the ratio of the total number of forecasts of an event to the total number of observations of the event. It is defined as

$$\text{Bias} = \frac{n_{11} + n_{10}}{n_{11} + n_{01}} = \frac{n_1}{n_1}.$$

A "good" value of Frequency Bias is close to 1; a value greater than 1 indicates the event was forecasted too frequently and a value less than 1 indicates the event was not forecasted frequently enough.

**Probability of Detection (POD)**

Called "H\_RATE" in FHO output (Table 4-3);

Called "PODY" in CTS output (Table 4-5)

POD is defined as

$$\text{POD} = \frac{n_{11}}{n_{11} + n_{01}} = \frac{n_{11}}{n_1}.$$

It is the fraction of events that were correctly forecasted to occur. POD is equivalent to the H value computed by the NCEP verification system and is also known as the hit rate. POD ranges from 0 to 1; a perfect forecast would have  $\text{POD} = 1$ .

**Probability of False Detection (POFD)**

Called "POFD" in CTS output (Table 4-5)

POFD is defined as

$$\text{POFD} = \frac{n_{10}}{n_{10} + n_{00}} = \frac{n_{10}}{n_{\cdot 0}}$$

It is the proportion of non-events that were forecast to be events. POFD is also often called the False Alarm Rate<sup>2</sup>. POFD ranges from 0 to 1; a perfect forecast would have POFD = 0.

**Probability of Detection of the non-event (PODn)**

Called "PODN" in CTS output (Table 4-5)

PODn is defined as

$$\text{PODN} = \frac{n_{00}}{n_{10} + n_{00}} = \frac{n_{00}}{n_{\cdot 0}}$$

It is the proportion of non-events that were correctly forecasted to be non-events. Note that PODn = 1 - POFD. PODn ranges from 0 to 1. Like POD, a perfect forecast would have PODn = 1.

**False Alarm Ratio (FAR)**

Called "FAR" in CTS output (Table 4-5)

FAR is defined as

$$\text{FAR} = \frac{n_{10}}{n_{10} + n_{11}} = \frac{n_{10}}{n_{1\cdot}}$$

It is the proportion of forecasts of the event occurring for which the event did not occur. FAR ranges from 0 to 1; a perfect forecast would have FAR = 0.

**Critical Success Index (CSI)**

Called "CSI" in CTS output (Table 4-5)

CSI is defined as

$$\text{CSI} = \frac{n_{11}}{n_{11} + n_{10} + n_{01}}$$

It is the ratio of the number of times the event was correctly forecasted to occur to the number of times it was either forecasted or occurred. CSI ignores the "correct rejections" category (i.e.,  $n_{00}$ ). CSI is also known as the Threat Score (TS). CSI can also be written as a nonlinear combination of POD and FAR, and is strongly related to Frequency Bias and the Base Rate.

**Gilbert Skill Score (GSS)**

Called "GSS" in CTS output (Table 4-5)

GSS is based on the CSI, corrected for the number of hits that would be expected by chance. In particular,

$$\text{GSS} = \frac{n_{11} - C_1}{n_{11} + n_{10} + n_{01} - C_1},$$

where

$$C = \frac{(n_{11} + n_{10})(n_{11} + n_{01})}{T}.$$

GSS is also known as the Equitable Threat Score (ETS). GSS values range from  $-1/3$  to 1. A no-skill forecast would have  $\text{GSS} = 0$ ; a perfect forecast would have  $\text{GSS} = 1$ .

**Hanssen-Kuipers Discriminant (H-K)**

Called "HK" in CTS output (Table 4-5)

H-K is defined as

$$\text{H-K} = \frac{n_{11}n_{00} - n_{10}n_{01}}{(n_{11} + n_{01})(n_{10} + n_{00})}.$$

More simply,  $\text{H-K} = \text{POD} - \text{POFD}$ .

H-K is also known as the True Skill Statistic (TSS) and less commonly (although perhaps more properly) as the Peirce Skill Score. H-K measures the ability of the forecast to discriminate between (or correctly classify) events and non-events. H-K values range between  $-1$  and  $1$ . A value of  $0$  indicates no skill; a perfect forecast would have  $\text{H-K} = 1$ .

**Heidke Skill Score (HSS)**

Called "HSS" in CTS output (Table 4-5)

HSS is a skill score based on Accuracy, where the Accuracy is corrected by the number of correct forecasts that would be expected by chance. In particular,

$$\text{HSS} = \frac{n_{11} + n_{00} - C_2}{T - C_2},$$

where

$$C_2 = \frac{(n_{11} + n_{10})(n_{11} + n_{01}) + (n_{01} + n_{00})(n_{10} + n_{00})}{T}.$$

HSS can range from minus infinity to 1. A perfect forecast would have  $\text{HSS} = 1$ .

**Odds Ratio (OR)**

Called "ODDS" in CTS output (Table 4-5)

OR measures the ratio of the odds of a forecast of the event being correct to the odds of a forecast of the event being wrong. OR is defined as

$$OR = \frac{n_{11} \times n_{00}}{n_{10} \times n_{01}} = \frac{\left( \frac{POD}{1-POD} \right)}{\left( \frac{POFD}{1-POFD} \right)}.$$

OR can range from 0 to  $\infty$ . A perfect forecast would have a value of  $OR = \text{infinity}$ . OR is often expressed as the log Odds Ratio or as the Odds Ratio Skill Score (Stephenson 2000).

**Logarithm of the Odds Ratio (LODDS)**

Called "LODDS" in CTS output (Table 4-5)

LODDS transforms the odds ratio via the logarithm, which tends to normalize the statistic for rare events (Stephenson 2000). However, it can take values of  $\pm\infty$  when any of the contingency table counts is 0. LODDS is defined as  $LODDS = \ln(OR)$ .

**Odds Ratio Skill Score (ORSS)**

Called "ORSS" in CTS output (Table 4-5)

ORSS is a skill score based on the odds ratio. ORSS is defined as

$$ORSS = \frac{OR - 1}{OR + 1}.$$

ORSS is sometime also referred to as Yule's Q. (Stephenson 2000).

**Extreme Dependency Score (EDS)**

Called "EDS" in CTS output (Table 4-5)

The extreme dependency score measures the association between forecast and observed rare events. EDS is defined as

$$EDS = \frac{2 \ln \left( \frac{n_{11} + n_{01}}{T} \right)}{\ln \left( \frac{n_{11}}{T} \right)} - 1.$$

EDS can range from -1 to 1, with 0 representing no skill. A perfect forecast would have a value of EDS = 1. EDS is independent of bias, so should be presented along with the frequency bias statistic (Stephenson et al, 2008).

### Extreme Dependency Index (EDI)

Called "EDI" in CTS output (Table 4-5)

The extreme dependency index measures the association between forecast and observed rare events. EDI is defined as  $\frac{H - F}{1 - F}$ , where  $H$  and  $F$  are the Hit Rate and False Alarm Rate, respectively.

EDI can range from  $-\infty$  to 1, with 0 representing no skill. A perfect forecast would have a value of EDI = 1 (Ferro and Stephenson, 2011).

### Symmetric Extreme Dependency Score (SEDS)

Called "SEDS" in CTS output (Table 4-5)

The symmetric extreme dependency score measures the association between forecast and observed rare events. SEDS is defined as

$$\text{SEDS} = \frac{2 \ln \left[ \frac{(n_{11} + n_{01})(n_{11} + n_{10})}{T^2} \right]}{\ln \left( \frac{n_{11}}{T} \right)} - 1.$$

SEDS can range from  $-\infty$  to 1, with 0 representing no skill. A perfect forecast would have a value of SEDS = 1 (Ferro and Stephenson, 2011).

### Symmetric Extremal Dependency Index (SEDI)

Called "SEDI" in CTS output (Table 4-5)

The symmetric extremal dependency index measures the association between forecast and observed rare events. SEDI is defined as

$$\text{SEDI} = \frac{\ln F - \ln H + \ln(1 - H) - \ln(1 - F)}{\ln F + \ln H + \ln(1 - H) + \ln(1 - F)},$$

where  $H = \frac{n_{11}}{n_{11} + n_{01}}$  and  $F = \frac{n_{10}}{n_{00} + n_{10}}$  are the Hit Rate and False Alarm Rate, respectively.

SEDI can range from  $-\infty$  to 1, with 0 representing no skill. A perfect forecast would have a value of SEDI = 1. SEDI approaches 1 only as the forecast approaches perfection (Ferro and Stephenson, 2011).



**Bias Adjusted Gilbert Skill Score (GSS)**

Called "BAGSS" in CTS output (Table 4-5)

BAGSS is based on the GSS, but is corrected as much as possible for forecast bias (Brill and Mesinger, 2009).

**C.2 MET verification measures for continuous variables**

For continuous variables, many verification measures are based on the forecast error (i.e.,  $\mathbf{f} - \mathbf{o}$ ). However, it also is of interest to investigate characteristics of the forecasts, and the observations, as well as their relationship. These concepts are consistent with the general framework for verification outlined by Murphy and Winkler (1987). The statistics produced by MET for continuous forecasts represent this philosophy of verification, which focuses on a variety of aspects of performance rather than a single measure.

The verification measures currently evaluated by the Point-Stat tool are defined and described in the subsections below. In these definitions,  $\mathbf{f}$  represents the forecasts,  $\mathbf{o}$  represents the observation, and  $\mathbf{n}$  is the number of forecast-observation pairs.

**Mean forecast**

Called "FBAR" in CNT output (Table 4-6)

Called "FBAR" in SL1L2 output (Table 4-11)

The sample mean forecast, FBAR, is defined as  $\bar{f} = \frac{1}{n} \sum_{i=1}^n f_i$ .

**Mean observation**

Called "OBAR" in CNT output (Table 4-6)

Called "OBAR" in SL1L2 output (Table 4-11)

The sample mean observation is defined as  $\bar{o} = \frac{1}{n} \sum_{i=1}^n o_i$ .

**Forecast standard deviation**

Called "FSTDEV" in CNT output (Table 4-6)

The sample variance of the forecasts is defined as

$$s_f^2 = \frac{1}{T-1} \sum_{i=1}^T (f_i - \bar{f})^2.$$

The forecast standard deviation is defined as  $s_f = \sqrt{s_f^2}$ .

**Observation standard deviation**

Called "OSTDEV" in CNT output (Table 4-6)

The sample variance of the observations is defined as

$$s_o^2 = \frac{1}{T-1} \sum_{i=1}^T (o_i - \bar{o})^2.$$

The observed standard deviation is defined as  $s_o = \sqrt{s_o^2}$ .

**Pearson Correlation Coefficient**

Called "PR\_CORR" in CNT output (Table 4-6)

The Pearson correlation coefficient,  $r$ , measures the strength of linear association between the forecasts and observations. The Pearson correlation coefficient is defined as:

$$r = \frac{\sum_{i=1}^T (f_i - \bar{f})(o_i - \bar{o})}{\sqrt{\sum (f_i - \bar{f})^2} \sqrt{\sum (o_i - \bar{o})^2}}$$

$r$  can range between -1 and 1; a value of 1 indicates perfect correlation and a value of -1 indicates perfect negative correlation. A value of 0 indicates that the forecasts and observations are not correlated.

**Spearman rank correlation coefficient ( $\rho_s$ )**

Called "SP\_CORR" in CNT (Table 4-6)

The Spearman rank correlation coefficient ( $\rho_s$ ) is a robust measure of association that is based on the ranks of the forecast and observed values rather than the actual values. That is, the forecast and observed samples are ordered from smallest to largest and rank values (from 1 to  $n$ , where  $n$  is the total number of pairs) are assigned. The pairs of forecast-observed ranks are then used to compute a correlation coefficient, analogous to the Pearson correlation coefficient,  $r$ .

A simpler formulation of the Spearman-rank correlation is based on differences between the each of the pairs of ranks (denoted as  $d_i$ ):

$$\rho_s = \frac{6}{n(n^2 - 1)} \sum_{i=1}^n d_i^2$$

Like  $r$ , the Spearman rank correlation coefficient ranges between -1 and 1; a value of 1 indicates perfect correlation and a value of -1 indicates perfect negative correlation. A value of 0 indicates that the forecasts and observations are not correlated.

**Kendall's Tau statistic ( $\tau$ )**

Called "KT\_CORR" in CNT output (Table 4-6)

Kendall's Tau statistic ( $\tau$ ) is a robust measure of the level of association between the forecast and observation pairs. It is defined as

$$\tau = \frac{N_c - N_p}{n(n-1)/2}$$

where NC is the number of "concordant" pairs and ND is the number of "discordant" pairs. Concordant pairs are identified by comparing each pair with all other pairs in the sample; this can be done most easily by ordering all of the  $(f_i, o_i)$  pairs according to  $f_i$ , in which case the  $o_i$  values won't necessarily be in order. The number of concordant matches of a particular pair with other pairs is computed by counting the number of pairs (with larger values) for which the value of  $o_i$  for the current pair is exceeded (that is, pairs for which the values of  $\mathbf{f}$  and  $\mathbf{o}$  are both larger than the value for the current pair). Once this is done,  $N_c$  is computed by summing the counts for all pairs. The total number of possible pairs is  $n(n-1)/2$ ; thus, the number of discordant pairs is  $n(n-1)/2 - N_c$ .

Like  $\mathbf{r}$  and  $\rho_s$ , Kendall's Tau ( $\tau$ ) ranges between -1 and 1; a value of 1 indicates perfect association (concordance) and a value of -1 indicates perfect negative association. A value of 0 indicates that the forecasts and observations are not associated.

**Mean Error (ME)**

Called "ME" in CNT output (Table 4-6)

The Mean Error, ME, is a measure of overall bias for continuous variables; in particular  $ME = \text{Bias}$ . It is defined as

$$ME = \frac{1}{n} \sum_{i=1}^n (f_i - o_i) = \bar{f} - \bar{o}$$

A perfect forecast has  $ME = 0$ .

**Mean Error Squared (ME2)**

Called "ME2" in CNT output (Table 4-6)

The Mean Error Squared, ME2, is provided to give a complete breakdown of MSE in terms of squared Bias plus estimated variance of the error, as detailed below in the section on BCMSE. It is defined as  $ME2 = ME^2 + \text{var}(e)$ .

A perfect forecast has  $ME2 = 0$ .

**Multiplicative Bias**

Called "MBIAS" in CNT output (Table 4-6)

Multiplicative bias is simply the ratio of the means of the forecasts and the observations:  $MBIAS = \bar{f}/\bar{o}$

**Mean-squared error (MSE)**

Called "MSE" in CNT output (Table 4-6)

MSE measures the average squared error of the forecasts. Specifically,  $MSE = \frac{1}{n} \sum (f_i - o_i)^2$ .

**Root-mean-squared error (RMSE)**

Called "RMSE" in CNT output (Table 4-6)

RMSE is simply the square root of the MSE,  $RMSE = \sqrt{MSE}$ .

**Standard deviation of the error**

Called "ESTDEV" in CNT output (Table 4-6)

**Bias-Corrected MSE**

Called "BCMSE" in CNT output (Table 4-6)

MSE and RMSE are strongly impacted by large errors. They also are strongly impacted by large bias (ME) values. MSE and RMSE can range from 0 to infinity. A perfect forecast would have  $MSE = RMSE = 0$ .

MSE can be re-written as  $MSE = (\bar{f} - \bar{o})^2 + s_f^2 + s_o^2 - 2s_f s_o r_{fo}$ , where  $\bar{f} - \bar{o} = ME$  and  $s_f^2 + s_o^2 - 2s_f s_o r_{fo}$  is the estimated variance of the error,  $s_{f-o}^2$ . Thus,  $MSE = ME^2 + s_{f-o}^2$ . To understand the behavior of MSE, it is important to examine both of the terms of MSE, rather than examining MSE alone. Moreover, MSE can be strongly influenced by ME, as shown by this decomposition.

The standard deviation of the error,  $s_{f-o}$ , is  $s_{f-o} = \sqrt{s_{f-o}^2} = \sqrt{s_f^2 + s_o^2 - 2s_f s_o r_{fo}}$ .

Note that the square of the standard deviation of the error (ESTDEV2) is sometimes called the "Bias-corrected MSE" (BCMSE) because it removes the effect of overall bias from the forecast-observation squared differences.

**Mean Absolute Error (MAE)**

Called "MAE" in CNT output (Table 4-6)

The Mean Absolute Error (MAE) is defined as  $MAE = \frac{1}{n} \sum |f_i - o_i|$ .

MAE is less influenced by large errors and also does not depend on the mean error. A perfect forecast would have  $MAE = 0$ .

**Inter Quartile Range of the Errors (IQR)**

Called "IQR" in CNT output (Table 4-6)

The Inter Quartile Range of the Errors (IQR) is the difference between the 75th and 25th percentiles of the errors. It is defined as  $IQR = p_{75}(f_i - o_i) - p_{25}(f_i - o_i)$ .

IQR is another estimate of spread, similar to standard error, but is less influenced by large errors and also does not depend on the mean error. A perfect forecast would have  $IQR = 0$ .

**Median Absolute Deviation (MAD)**

Called "MAD" in CNT output (Table 4-6)

The Median Absolute Deviation (MAD) is defined as  $MAD = \text{median}|f_i - o_i|$ .

MAD is an estimate of spread, similar to standard error, but is less influenced by large errors and also does not depend on the mean error. A perfect forecast would have  $MAD = 0$ .

**Bias Adjusted Gilbert Skill Score**

Called "BAGSS" in CNT output (Table 4-6)

The Bias Adjusted Gilbert Skill Score (BAGSS) is the Gilbert Skill Score, but with the contingency table counts adjusted to eliminate as much bias in the forecast as possible. For details, see Brill and Messinger, 2009.

**Percentiles of the errors**

Called "E10", "E25", "E50", "E75", "E90" in CNT output (Table 4-6)

Percentiles of the errors provide more information about the distribution of errors than can be obtained from the mean and standard deviations of the errors. Percentiles are computed by ordering the errors from smallest to largest and computing the rank location of each percentile in the ordering, and matching the rank to the actual value. Percentiles can also be used to create box plots of the errors. In MET, the 0.10th, 0.25th, 0.50th, 0.75th, and 0.90th quantile values of the errors are computed.

### Anomaly Correlation Coefficient

Called "ANOM\_CORR" in CNT output (Table 4-6)

The Anomaly correlation coefficient is equivalent to the Pearson correlation coefficient, except that both the forecasts and observations are first adjusted according to a climatology value. The anomaly is the difference between the individual forecast or observation and the typical situation, as measured by a climatology ( $c$ ) of some variety. It measures the strength of linear association between the forecast anomalies and observed anomalies. The Anomaly correlation coefficient is defined as:

$$\text{Anomaly Correlation} = \frac{\sum(f_i - c)(o_i - c)}{\sqrt{\sum(f_i - c)^2} \sqrt{\sum(o_i - c)^2}}.$$

Anomaly correlation can range between -1 and 1; a value of 1 indicates perfect correlation and a value of -1 indicates perfect negative correlation. A value of 0 indicates that the forecast and observed anomalies are not correlated.

### Scalar L1 and L2 values

Called "FBAR", "OBAR", "FOBAR", "FFBAR", and "OOBAR" in SL1L2 output (Table 4-11)

These statistics are simply the 1st and 2nd moments of the forecasts, observations and errors:

$$\text{FBAR} = \text{Mean}(f) = \bar{f} = \frac{1}{n} \sum_{i=1}^n f_i$$

$$\text{OBAR} = \text{Mean}(o) = \bar{o} = \frac{1}{n} \sum_{i=1}^n o_i$$

$$\text{FOBAR} = \text{Mean}(fo) = \bar{fo} = \frac{1}{n} \sum_{i=1}^n f_i o_i$$

$$\text{FFBAR} = \text{Mean}(f^2) = \bar{f}^2 = \frac{1}{n} \sum_{i=1}^n f_i^2$$

$$\text{OOBAR} = \text{Mean}(o^2) = \bar{o}^2 = \frac{1}{n} \sum_{i=1}^n o_i^2$$

Some of the other statistics for continuous forecasts (e.g., RMSE) can be derived from these moments.

Scalar anomaly L1L2 values

Called "FABAR", "OABAR", "FOABAR", "FFABAR", "OOABAR" in SAL1L2 output (Table 4-12)

Computation of these statistics requires a climatological value,  $c$ . These statistics are the 1st and 2nd moments of the scalar anomalies. The moments are defined as:

and

### Vector L1 and L2 values

Called "UFBAR", "VFBAR", "UOBAR", "VOBAR", "UVFOBAR", "UVFFBAR", "UVOOBAR" in VL1L2 output (Table 4-13)

These statistics are the moments for wind vector values, where  $\mathbf{u}$  is the E-W wind component and  $\mathbf{v}$  is the N-S wind component ( $\mathbf{u}_f$  is the forecast E-W wind component;  $\mathbf{u}_o$  is the observed E-W wind component;  $\mathbf{v}_f$  is the forecast N-S wind component; and  $\mathbf{v}_o$  is the observed N-S wind component). The following measures are computed:

$$\text{UFBAR} = \text{Mean}(u_f) = \bar{u}_f = \frac{1}{n} \sum_{i=1}^n u_{fi}$$

$$\text{VFBAR} = \text{Mean}(v_f) = \bar{v}_f = \frac{1}{n} \sum_{i=1}^n v_{fi}$$

$$\text{UOBAR} = \text{Mean}(u_o) = \bar{u}_o = \frac{1}{n} \sum_{i=1}^n u_{oi}$$

$$\text{VOBAR} = \text{Mean}(v_o) = \bar{v}_o = \frac{1}{n} \sum_{i=1}^n v_{oi}$$

$$\text{UVFOBAR} = \text{Mean}(u_f u_o + v_f v_o) = \frac{1}{n} \sum_{i=1}^n (u_{fi} u_{oi} + v_{fi} v_{oi})$$

$$\text{UVFFBAR} = \text{Mean}(u_f^2 + v_f^2) = \frac{1}{n} \sum_{i=1}^n (u_{fi}^2 + v_{fi}^2)$$

$$\text{UVOOBAR} = \text{Mean}(u_o^2 + v_o^2) = \frac{1}{n} \sum_{i=1}^n (u_{oi}^2 + v_{oi}^2)$$

**Vector anomaly L1 and L2 values**

Called "UFABAR", "VFABAR", "UOABAR", "VOABAR", "UVFOABAR", "UVFFABAR", "UVOOABAR" in VAL1L2 output (Table 4-14)

These statistics require climatological values for the wind vector components,  $\mathbf{u}_c$  and  $\mathbf{v}_c$ . The measures are defined below:

$$\text{UFABAR} = \text{Mean}(u_f - u_c) = \frac{1}{n} \sum_{i=1}^n (u_{fi} - u_c)$$

$$\text{VFBAR} = \text{Mean}(v_f - v_c) = \frac{1}{n} \sum_{i=1}^n (v_{fi} - v_c)$$

$$\text{UOABAR} = \text{Mean}(u_o - u_c) = \frac{1}{n} \sum_{i=1}^n (u_{oi} - u_c)$$

$$\text{VOABAR} = \text{Mean}(v_o - v_c) = \frac{1}{n} \sum_{i=1}^n (v_{oi} - v_c)$$

$$\text{UVFOABAR} = \text{Mean}[(u_f - u_c)(u_o - u_c) + (v_f - v_c)(v_o - v_c)] = \frac{1}{n} \sum_{i=1}^n ((u_{fi} - u_c)(u_{oi} - u_c) + (v_{fi} - v_c)(v_{oi} - v_c))$$

$$\text{UVFFABAR} = \text{Mean}[(u_f - u_c)^2 + (v_f - v_c)^2] = \frac{1}{n} \sum_{i=1}^n ((u_{fi} - u_c)^2 + (v_{fi} - v_c)^2)$$

$$\text{UVOOABAR} = \text{Mean}[(u_o - u_c)^2 + (v_o - v_c)^2] = \frac{1}{n} \sum_{i=1}^n ((u_{oi} - u_c)^2 + (v_{oi} - v_c)^2)$$

**C.3 MET verification measures for probabilistic forecasts**

The results of the probabilistic verification methods that are included in the Point-Stat, Grid-Stat, and Stat-Analysis tools are summarized using a variety of measures. MET treats probabilistic forecasts as categorical, divided into bins by user-defined thresholds between zero and one. For the categorical measures, if a forecast probability is specified in a formula, the mid-point value of the bin is used. These measures include the Brier Score (BS) with confidence bounds (Bradley 2008); the joint distribution, calibration-refinement, likelihood-base rate (Wilks 2011); and receiver operating characteristic information. Using these statistics, reliability and discrimination diagrams can be produced.



The verification statistics for probabilistic forecasts of dichotomous variables are formulated using a contingency table such as the one shown in Table C-2. In this table *f* represents the forecasts and *o* represents the observations; the two possible forecast and observation values are represented by the values 0 and 1. The values in Table C-2 are counts of the number of occurrences of all possible combinations of forecasts and observations.

Table C.2:  $n \times 2$  contingency table in terms of counts. The  $n_{ij}$  values in the table represent the counts in each forecast-observation category, where  $i$  represents the forecast and  $j$  represents the observations. The "." symbols in the total cells represent sums across categories.

| Forecast                                                 | Observation                             |                                        | Total                                                 |
|----------------------------------------------------------|-----------------------------------------|----------------------------------------|-------------------------------------------------------|
|                                                          | $\mathbf{o} = \mathbf{1}$ (e.g., "Yes") | $\mathbf{o} = \mathbf{0}$ (e.g., "No") |                                                       |
| $\mathbf{p}_1 =$ midpoint of (0 and threshold1)          | $\mathbf{n}_{11}$                       | $\mathbf{n}_{10}$                      | $\mathbf{n}_{1.} = \mathbf{n}_{11} + \mathbf{n}_{10}$ |
| $\mathbf{p}_2 =$ midpoint of (threshold1 and threshold2) | $\mathbf{n}_{21}$                       | $\mathbf{n}_{20}$                      | $\mathbf{n}_{2.} = \mathbf{n}_{21} + \mathbf{n}_{20}$ |
| ...                                                      | ...                                     | ...                                    | ...                                                   |
| $\mathbf{p}_j =$ midpoint of (threshold <i>i</i> and 1)  | $\mathbf{n}$                            | $\mathbf{n}_{j0}$                      | $\mathbf{n}_j = \mathbf{n}_{j1} + \mathbf{n}_{j0}$    |
| Total                                                    | $n_{.1} = \sum n_{i1}$                  | $n_{.0} = \sum n_{i0}$                 | $\mathbf{T} = \sum n_i$                               |

**Reliability**

A component of the Brier score. Reliability measures the average difference between forecast probability and average observed frequency. Ideally, this measure should be zero as larger numbers indicate larger differences. For example, on occasions when rain is forecast with 50% probability, it should actually rain half the time.

$$\text{Reliability} = \frac{1}{T} \sum n_i (p_i - \bar{o}_i)^2$$

**Resolution**

A component of the Brier score that measures how well forecasts divide events into subsets with different outcomes. Larger values of resolution are best since it is desirable for event frequencies in the subsets to be different than the overall event frequency.

$$\text{Resolution} = \frac{1}{T} n_i (\bar{o}_i - \bar{o})^2$$

**Uncertainty**

A component of the Brier score. For probabilistic forecasts, uncertainty is a function only of the frequency of the event. It does not depend on the forecasts, thus there is no ideal or better value. Note that uncertainty is equivalent to the variance of the event occurrence.

$$\text{Uncertainty} = \frac{n_{.1}}{T} \left(1 - \frac{n_{.1}}{T}\right)$$

**Brier score**

The Brier score is the mean squared probability error. In MET, the Brier Score (BS) is calculated from the **nx2** contingency table via the following equation:

$$BS = \frac{1}{T}[n_{.1}(p_1 - 1)^2 + n_{.0}p_0]$$

The equation you will most often see in references uses the individual probability forecasts ( $\rho_i$ ) and the corresponding observations ( $\mathbf{o}_i$ ), and is given as  $BS = \frac{1}{T} \sum (p_i - o_i)^2$ . This equation is equivalent when the midpoints of the binned probability values are used as the  $\mathbf{p}_i$ .

BS can be partitioned into three terms: (1) reliability, (2) resolution, and (3) uncertainty (Murphy, 1973).

$$BS = \frac{1}{T} \sum_i (p_i - o_i)^2 = \frac{1}{T} \sum n_i (p_i - \bar{o}_i)^2 - \frac{1}{T} \sum n_i (\bar{o}_i - \bar{o})^2 + \bar{o}(1 - \bar{o})$$

This score is sensitive to the base rate or climatological frequency of the event. Forecasts of rare events can have a good BS without having any actual skill. Since Brier score is a measure of error, smaller values are better.

**Brier Skill Score (BSS)**

BSS is a skill score based on the Brier Scores of the forecast and a reference forecast, such as climatology. BSS is defined as

$$BSS = 1 - \frac{BS_{fcst}}{BS_{ref}}$$

**OY\_TP - Observed Yes Total Proportion.**

This is the cell probability for row  $\mathbf{i}$ , column  $\mathbf{j}=1$  (observed event), a part of the joint distribution (Wilks, 2011). Along with ON\_TP, this set of measures provides information about the joint distribution of forecasts and events. There are no ideal or better values.

$$OYTP(i) = \frac{n_{i1}}{T} = \text{probability}(o_{i1})$$

**ON\_TP - Observed No Total Proportion.**

This is the cell probability for row  $\mathbf{i}$ , column  $\mathbf{j}=0$  (observed non-event), a part of the joint distribution (Wilks, 2011). Along with OY\_TP, this set of measures provides information about the joint distribution of forecasts and events. There are no ideal or better values.

$$ONTP(i) = \frac{n_{i0}}{T} = \text{probability}(o_{i0})$$

### Calibration

Calibration is the conditional probability of an event given each probability forecast category (i.e. each row in the  $\mathbf{nx2}$  contingency table). This set of measures is paired with refinement in the calibration-refinement factorization discussed in Wilks (2011). A well-calibrated forecast will have calibration values that are near the forecast probability. For example, a 50% probability of precipitation should ideally have a calibration value of 0.5. If the calibration value is higher, then the probability has been underestimated, and vice versa.

$$\text{Calibration}(i) = \frac{n_{i1}}{n_{.1}} = \text{probability}(o_1|p_i)$$

### Refinement

The relative frequency associated with each forecast probability, sometimes called the marginal distribution or row probability. This measure ignores the event outcome, and simply provides information about the frequency of forecasts for each probability category. This set of measures is paired with the calibration measures in the calibration-refinement factorization discussed by Wilks (2011).

$$\text{Refinement}(i) = \frac{n_{i.}}{T} = \text{probability}(p_i)$$

### Likelihood

Likelihood is the conditional probability for each forecast category (row) given an event and a component of the likelihood-base rate factorization; see Wilks (2011) for details. This set of measures considers the distribution of forecasts for only the cases when events occur. Thus, as the forecast probability increases, so should the likelihood. For example, 10% probability of precipitation forecasts should have a much smaller likelihood value than 90% probability of precipitation forecasts.

$$\text{Likelihood}(i) = \frac{n_{i1}}{n_{.1}} = \text{probability}(p_i|o_1)$$

Likelihood values are also used to create "discrimination" plots that compare the distribution of forecast values for events to the distribution of forecast values for non-events. These plots show how well the forecasts categorize events and non-events. The distribution of forecast values for non-events can be derived from the POFD values computed by MET for the user-specified thresholds.

### Base Rate

This is the probability of an event for each forecast category  $\mathbf{p}_i$  (row), i.e. the conditional base rate. This set of measures if paired with likelihood in the likelihood-base rate factorization, see Wilks (2011) for further

information. This measure is calculated for each row of the contingency table. Ideally, the event should become more frequent as the probability forecast increases.

$$\text{Base Rate}(i) = \frac{n_{i1}}{n_i} = \text{probability}(o_{i1})$$

### Reliability diagram

The reliability diagram is a plot of the observed frequency of events versus the forecast probability of those events, with the range of forecast probabilities divided into categories.

The ideal forecast (i.e., one with perfect reliability) has conditional observed probabilities that are equivalent to the forecast probability, on average. On a reliability plot, this equivalence is represented by the one-to-one line (the solid line in the figure below). So, better forecasts are closer to the diagonal line and worse ones are farther away. The distance of each point from the diagonal gives the conditional bias. Points that lie below the diagonal line indicate over-forecasting; in other words, the forecast probabilities are too large. The forecast probabilities are too low when the points lie above the line. The reliability diagram is conditioned on the forecasts so it is often used in combination with the ROC, which is conditioned on the observations, to provide a "complete" representation of the performance of probabilistic forecasts.

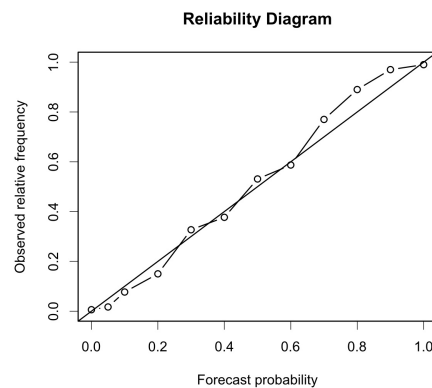


Figure C.1: Example of Reliability Diagram

### Receiver operating characteristic

MET produces hit rate (POD) and false alarm rate (POFD) values for each user-specified threshold. This information can be used to create a scatter plot of POFD vs. POD. When the points are connected, the plot is generally referred to as the receiver operating characteristic (ROC) curve (also called the "relative operating characteristic" curve). See the area under the ROC curve (AUC) entry for related information.

An ROC plot is shown for an example set of forecasts, with a solid line connecting the points for six user-specified thresholds (0.25, 0.35, 0.55, 0.65, 0.75, 0.85). The diagonal dashed line indicates no skill while the dash-dot line shows the ROC for a perfect forecast.

An ROC curve shows how well the forecast discriminates between two outcomes, so it is a measure of resolution. The ROC is invariant to linear transformations of the forecast, and is thus unaffected by bias. An unbiased (i.e., well-calibrated) forecast can have the same ROC as a biased forecast, though most would agree that an unbiased forecast is "better". Since the ROC is conditioned on the observations, it is often paired with the reliability diagram, which is conditioned on the forecasts.

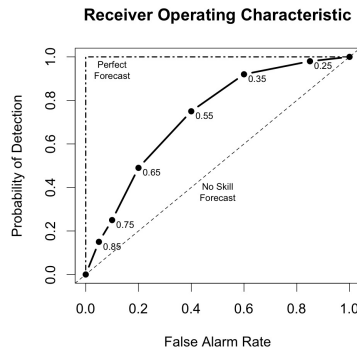


Figure C.2: Example of ROC Curve

### Area Under the ROC curve (AUC)

The area under the receiver operating characteristic (ROC) curve is often used as a single summary measure. A larger AUC is better. A perfect forecast has AUC=1. Though the minimum value is 0, an AUC of 0.5 indicates no skill.

The area under the curve can be estimated in a variety of ways. In MET, the simplest trapezoid method is used to calculate the area. AUC is calculated from the series of hit rate (POD) and false alarm rate (POFD) values (see the ROC entry below) for each user-specified threshold.

$$AUC = \frac{1}{2} \sum_{i=1}^{N_{thresh}} (POD_{i+1} + POD_i)(POFD_{i+1} + POFD_i)$$

## C.4 MET verification measures for ensemble forecasts

### CRPS

The continuous ranked probability score (CRPS) is the integral, over all possible thresholds, of the Brier scores (Gneiting et al, 2004). In MET, the CRPS calculation uses a normal distribution fit to the ensemble forecasts. In many cases, use of other distributions would be better.

**WARNING:** The normal distribution is probably a good fit for temperature and pressure, and possibly a not horrible fit for winds. However, the normal approximation will not work on most precipitation forecasts and may fail for many other atmospheric variables.

Closed form expressions for the CRPS are difficult to define when using data rather than distribution functions. However, if a normal distribution can be assumed, then the following equation gives the CRPS for each individual observation (denoted by a lowercase *crps*) and the corresponding distribution of forecasts.

$$crps_i(N(\mu, \sigma^2), y) = \sigma \left( \frac{y - \mu}{\sigma} \left( 2\Phi \left( \frac{y - \mu}{\sigma} \right) - 1 \right) + 2\phi \left( \frac{y - \mu}{\sigma} \right) - \frac{1}{\sqrt{\pi}} \right)$$

In this equation, the *y* represents the event threshold. The estimated mean and standard deviation of the ensemble forecasts ( $\mu$  and  $\sigma$ ) are used as the parameters of the normal distribution. The values of the normal distribution are represented by the probability density function (PDF) denoted by  $\phi$  and the cumulative distribution function (CDF), denoted in the above equation by  $\Phi$ .

The overall CRPS is calculated as the average of the individual measures. In equation form:  $CRPS = \text{average}(crps) = \frac{1}{N} \sum_i^N crps_i$ .

The score can be interpreted as a continuous version of the mean absolute error (MAE). Thus, the score is negatively oriented, so smaller is better. Further, similar to MAE, bias will inflate the CRPS. Thus, bias should also be calculated and considered when judging forecast quality using CRPS.

### CRPS Skill Score

The continuous ranked probability skill score (CRPSS) is similar to the MESS and the BSS, in that it compares its namesake score to that of a reference forecast to produce a positively oriented score between 0 and 1.

$$CRPSS = 1 - \frac{CRPS_{fcst}}{CRPS_{ref}}$$

### IGN

The ignorance score (IGN) is the negative logarithm of a predictive probability density function (Gneiting et al, 2004). In MET, the IGN is calculated based on a normal approximation to the forecast distribution (i.e. a normal pdf is fit to the forecast values). This approximation may not be valid, especially for discontinuous forecasts like precipitation, and also for very skewed forecasts. For a single normal distribution  $N$  with parameters  $\mu$  and  $\sigma$ , the ignorance score is

$$\text{ign}(N(\mu, \sigma), y) = \frac{1}{2} \ln(2\pi\sigma^2) + \frac{(y - \mu)^2}{\sigma^2}.$$

Accumulation of the ignorance score for many forecasts is via the average of individual ignorance scores. This average ignorance score is the value output by the MET software. Like many error statistics, the IGN is negatively oriented, so smaller numbers indicate better forecasts.

## PIT

The probability integral transform (PIT) is the analog of the rank histogram for a probability distribution forecast (Dawid, 1984). Its interpretation is the same as that of the verification rank histogram: Calibrated probabilistic forecasts yield PIT histograms that are flat, or uniform. Underdispersed (not enough spread in the ensemble) forecasts have U-shaped PIT histograms while overdispersed forecasts have bell-shaped histograms. In MET, the PIT calculation uses a normal distribution fit to the ensemble forecasts. In many cases, use of other distributions would be better.

## RANK

The rank of an observation, compared to all members of an ensemble forecast, is a measure of dispersion of the forecasts (Hamill, 2001). When ensemble forecasts possesses the same amount of variability as the corresponding observations, then the rank of the observation will follow a discrete uniform distribution. Thus, a rank histogram will be approximately flat.

The rank histogram does not provide information about the accuracy of ensemble forecasts. Further, examination of "rank" only makes sense for ensembles of a fixed size. Thus, if ensemble members are occasionally unavailable, the rank histogram should not be used. The PIT may be used instead.

## C.5 MET verification measures for neighborhood methods

The results of the neighborhood verification approaches that are included in the Grid-Stat tool are summarized using a variety of measures. These measures include the Fractions Skill Score (FSS) and the Fractions Brier Score (FBS). MET also computes traditional contingency table statistics for each combination of threshold and neighborhood window size.

The traditional contingency table statistics computed by the Grid-Stat neighborhood tool, and included in the NBRCTS output, are listed below:

- \* Base Rate (called "BASER" in Table 5-3)
- \* Mean Forecast (called "FMEAN" in Table 5-3)
- \* Accuracy (called "ACC" in Table 5-3)
- \* Frequency Bias (called "FBIAS" in Table 5-3)
- \* Probability of Detection (called "PODY" in Table 5-3)
- \* Probability of Detection of the non-event (called "PODN" in Table 5-3)
- \* Probability of False Detection (called "POFD" in Table 5-3)

- \* False Alarm Ratio (called "FAR" in Table 5-3)
- \* Critical Success Index (called "CSI" in Table 5-3)
- \* Gilbert Skill Score (called "GSS" in Table 5-3)
- \* Hanssen-Kuipers Discriminant (called "H-K" in Table 5-3)
- \* Heidke Skill Score (called "HSS" in Table 5-3)
- \* Odds Ratio (called "ODDS" in Table 5-3)

All of these measures are defined in Section C.1 of Appendix C.

In addition to these standard statistics, the neighborhood analysis provides additional continuous measures, the Fractions Brier Score and the Fractions Skill Score. For reference, the Asymptotic Fractions Skill Score and Uniform Fractions Skill Score are also calculated. These measures are defined here, but are explained in much greater detail in Ebert (2008) and Roberts and Lean (2008). Roberts and Lean (2008) also present an application of the methodology.

### Fractions Brier Score

Called "FBS" in NBRCNT output (Table 5-4)

The Fractions Brier Score (FBS) is defined as  $FBS = \frac{1}{N} \sum_N [\langle P_f \rangle_s - \langle P_o \rangle_s]^2$ , where N is the number of neighborhoods;  $\langle P_f \rangle_s$  is the proportion of grid boxes within a forecast neighborhood where the prescribed threshold was exceeded (i.e., the proportion of grid boxes that have forecast events); and  $\langle P_o \rangle_s$  is the proportion of grid boxes within an observed neighborhood where the prescribed threshold was exceeded (i.e., the proportion of grid boxes that have observed events).

### Fractions Skill Score

Called "FSS" in NBRCNT output (Table 5-4)

The Fractions Skill Score (FSS) is defined as

$$FSS = 1 - \frac{FBS}{\frac{1}{N} \left[ \sum_N \langle P_f \rangle_s^2 - \sum_N \langle P_o \rangle_s^2 \right]}$$

, where the denominator represents the worst possible forecast (i.e., with no overlap between forecast and observed events). FSS ranges between 0 and 1, with 0 representing no overlap and 1 representing complete overlap between forecast and observed events, respectively.



**Asymptotic Fractions Skill Score**

Called "AFSS" in NBRCNT output (Table 5-4)

The Asymptotic Fractions Brier Score (AFBS) is a special case of the Fractions Skill score where the entire domain is used as the single neighborhood. This provides the user with information about the overall frequency bias of forecasts versus observations. The formula is the same as for FSS above, but with  $N=1$  and the neighborhood size equal to the domain.

**Uniform Fractions Skill Score**

Called "UFSS" in NBRCNT output (Table 5-4)

The Uniform Fractions Skill Score (AFBS) is a reference statistic for the Fractions Skill score based on a uniform distribution of the total forecast events across the grid. This no-skill forecast defines the UFSS, and thus a skilled forecast must have a higher value of FSS than the UFSS. Again, the formula is the same as for FSS as above, the forecast proportion in each neighborhood is the same, and is equivalent to the overall forecast event proportion.

**Forecast Rate**

Called "F\_rate" in NBRCNT output (Table 5-4)

The overall proportion of grid points with forecast events to total grid points in the domain. The forecast rate will match the observation rate in unbiased forecasts.

**Observation Rate**

Called "O\_rate" in NBRCNT output (Table 5-4)

The overall proportion of grid points with observed events to total grid points in the domain. The forecast rate will match the observation rate in unbiased forecasts. This quantity is sometimes referred to as the base rate.

## Appendix D

# Confidence Intervals

A single verification statistic is statistically meaningless without associated uncertainty information in accompaniment. There can be numerous sources of uncertainty associated with such a statistic including observational, physical uncertainties about the underlying processes governing the equation, sample uncertainty, etc. Although all of the sources of uncertainty can be important, the most heavily researched, and easiest to calculate, is that of sampling uncertainty. It is this source of uncertainty that can presently be obtained with MET, and the techniques for deriving these estimates are described here. Sampling uncertainty through MET is gleaned by way of confidence intervals (CIs) as these are generally most informative. A  $(1 - \alpha) \cdot 100\%$  confidence interval is interpreted, somewhat awkwardly, in the following way. If the test were repeated 100 times (so that we have 100 such intervals), then we expect the true value of the statistics to fall inside  $(1 - \alpha) \cdot 100$  of these intervals. For example, if  $\alpha = 0.05$  then we expect the true value to fall within 95 of the intervals.

There are two main types of CIs available with MET: parametric and non-parametric. All of the parametric intervals used with MET rely on the underlying sample (or the errors,  $F - O$ ) to be at least approximately independent and normally distributed. Future releases will allow for some types of dependency in the sample. The non-parametric techniques utilize what is known in the statistical literature as bootstrap resampling, which does not rely on any distributional assumptions for the sample; the assumption is that the sample is representative of the population. Bootstrap CIs can be inaccurate if the sample is not independent, but there are ways of accounting for dependence with the bootstrap, some of which will be added to MET in future releases. Details about which verification statistics have parametric CIs in MET are described next, and it should be noted that the bootstrap can be used for any statistic, though care should be taken in how it is carried out, and this is described subsequently.

The most commonly used confidence interval about an estimate for a statistic (or parameter),  $\theta$ , is given by the normal approximation

$$\theta \pm z_{\alpha/2} \cdot V(\theta), \tag{D.1}$$

where  $z_{\alpha/2}$  is the  $\alpha - \text{th}$  quantile of the standard normal distribution, and  $V(\theta)$  is the standard error of the statistic (or parameter),  $\theta$ . For example, the most common example is for the mean of a sample,  $X_1, \dots, X_n$ ,

Table D.1: Verification statistics with normal approximation CIs given by (D.1) provided in MET along with their associated standard error estimate.

|                                        |                                                                                                                                                                                                                                                                                              |
|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\hat{\theta}$                         | $V(\theta)$                                                                                                                                                                                                                                                                                  |
| Forecast /<br>Observation<br>Mean      | $V(\bar{X}) = \frac{\sigma_x}{\sqrt{n}}$ where $\sigma_x$ emphasizes that this is the estimated standard deviation of the underlying sample.                                                                                                                                                 |
| Mean error                             | $V(\bar{F} - \bar{O}) = \frac{\sigma_{F-O}}{\sqrt{n}}$ , where $\sigma_{F-O}$ emphasizes that this is the estimated standard deviation of the errors, $F - O$ .                                                                                                                              |
| Brier Score<br>(BS)                    | $V(\text{BS}) = \frac{1}{T} [\Sigma F^4 + \bar{O} (1 - 4\Sigma F_{F O=1}^3 + 6\Sigma F_{F O=1}^2 - 4\Sigma F_{F O=1}) - \text{BS}^2]$ where $\mathbf{F}$ is the <b>probability</b> forecast and $\mathbf{O}$ is the observation. See Bradley <b>et al</b> (2008) for derivation and details. |
| Peirce Skill<br>Score (PSS)            | $V(\text{PSS}) = \sqrt{\frac{H(1-H)}{n_H} + \frac{F(1-F)}{n_F}}$ , where $\mathbf{H}$ is the hit rate, $\mathbf{F}$ the false alarm rate, $n_H$ the number of hits and misses, and $n_F$ the number of false alarms and correct negatives.                                                   |
| Logarithm of<br>the odds ratio<br>(OR) | $V(\ln(\text{OR})) = \sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}}$ , where the values in the denominators are the usual contingency table counts.                                                                                                                            |

of independent and identically distributed (iid) normal random variables with mean  $\mu$  and variance  $\sigma$ . Here, the mean is estimated by  $\bar{X}$ , and the standard error is just the standard deviation of the random variables divided by the square root of the sample size. That is,  $V(\theta) = V(\bar{X}) = \frac{\sigma}{\sqrt{n}}$ , and this must be estimated by  $\frac{1}{n} \sum_{i=1}^n X_i = \bar{X}$ , which is obtained here by replacing  $\sigma$  by its estimate,  $\hat{\sigma}$ , where  $\hat{\sigma} = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$ .

Mostly, the normal approximation is used as an asymptotic approximation. That is, the interval (D.1) may only be appropriate for large  $\mathbf{n}$ . For small  $\mathbf{n}$ , the mean has an interval based on the Student's  $\mathbf{t}$  distribution with  $\mathbf{n}-1$  degrees of freedom. Essentially,  $z_{\alpha/2}$  of (D.1) is replaced with the quantile of this  $\mathbf{t}$  distribution. That is, the interval is given by

$$\mu \pm t_{\alpha/2, \nu-1} \cdot \frac{\sigma}{\sqrt{n}}, \tag{D.2}$$

where again,  $\sigma$  is replaced by its estimate,  $\hat{\sigma}$ , as described above.

Table D.1 summarizes the verification statistics in MET that have normal approximation CIs given by (D.1) along with their corresponding standard error estimates, . It should be noted that for the first two rows of this table (i.e., Forecast/Observation Mean and Mean error) MET also calculates the interval (D.2) for small sample sizes.

Other statistics in MET having parametric CIs that rely on the underlying sample to be at least approximately iid normal, but have a different form derived from the normality assumption on the sample include the variance, standard deviation, and the linear correlation coefficient. These are addressed subsequently.

Generally, the normal interval (D.1) is appropriate for statistics of continuous variables, but a limit law for the binomial distribution allows for use of this interval with proportions. The most intuitive estimate for  $V(\theta)$  in this case is given by  $V(p) = \sqrt{\hat{p}(1-\hat{p})/n}$ . However, this only applies when the sample size is large.

A better approximation to the CI for proportions is given by Wilson's interval, which is

$$\frac{\hat{p} + z_{\alpha/2}^2 + z_{\alpha/2}\sqrt{\hat{p}(1-\hat{p})/4n}}{1 + z_{\alpha/2}^2/n}, \quad (D.3)$$

where  $\hat{p}$  is the estimated proportion (e.g., hit rate, false alarm rate, PODY, PODn, etc.). Because this interval (D.3) generally works better than the more intuitive normal approximation interval for both large and small sample sizes, this is the interval employed by MET.

The forecast/observation variance has CIs derived from the underlying sample being approximately iid normal with mean  $\mu$  and variance  $\sigma$ . The lower and upper limits for the interval are given by

$$l(\sigma^2) = \frac{(n-1)s^2}{\chi_{\alpha/2, n-1}^2} \text{ and } u(\sigma^2) = \frac{(n-1)s^2}{\chi_{1-\alpha/2, n-1}^2}, \quad (D.4)$$

respectively, where  $\chi_{\alpha, \nu}^2$  is the  $\alpha$ -th quantile of the chi-square distribution with  $\mathbf{n-1}$  degrees of freedom. Taking the square roots of the limits in (D.4) yields the CI for the forecast/observation standard deviation.

Finally, the linear correlation coefficient has limits given by

$$\left( \frac{e^{2c_l} - 1}{e^{2c_l} + 1}, \frac{e^{2c_u} - 1}{e^{2c_u} + 1} \right), \quad (D.5)$$

where  $c_l = v - \frac{z_{\alpha/2}}{\sqrt{n-3}}$  and  $c_u = v + \frac{z_{\alpha/2}}{\sqrt{n-3}}$ .

All other verification scores with CIs in MET must be obtained through bootstrap resampling. However, it is also possible to obtain bootstrap CIs for any of the statistics given above, and indeed it has been proven that the bootstrap intervals have better accuracy for the mean than the normal approximation. The bootstrap algorithm is described below.

1. Assume the sample is representative of the population.
2. Resample with replacement from the sample (see text below).
3. Estimate the parameter(s) of interest for the current replicated sample.
4. Repeat steps 2 and 3 numerous times, say  $B$  times, so that you now have a sample of size  $B$  of the parameter(s).
5. Calculate CIs for the parameters directly from the sample (see text below for more details)

Typically, a simple random sample is taken for step 2, and that is how it is done in MET. As an example of what happens in this step, suppose our sample is  $X_1, X_2, X_3, X_4$ . Then, one possible replicate might be  $X_2, X_2, X_2, X_4$ . Usually one samples  $m = n$  points in this step, but there are cases where one should use  $m < n$ . For example, when the underlying distribution is heavy-tailed, one should use a smaller size  $m$  than  $n$  (e.g., the closest integer value to the square root of the original sample size).

There are numerous ways to construct CIs from the sample obtained in step 4. MET allows for two of these procedures: the percentile and the BCa. The percentile is the most commonly known method, and the simplest to understand. It is merely the  $\alpha/2$  and  $1 - \alpha/2$  percentiles from the sample of statistics. Unfortunately, however, it has been shown that this interval is too optimistic in practice (i.e., it doesn't have accurate coverage). One solution is to use the BCa method, which is very accurate, but it is also computationally intensive. This method adjusts for bias and non-constant variance, and yields the percentile interval in the event that the sample is unbiased with constant variance.

If there is dependency in the sample, then it is prudent to account for this dependency in some way. One method that does not make a lot of assumptions is circular block bootstrapping. This is not currently implemented in MET, but will be available in a future release. At that time, the method will be explained more fully here, but until then consult Gilleland (2010) for more details.