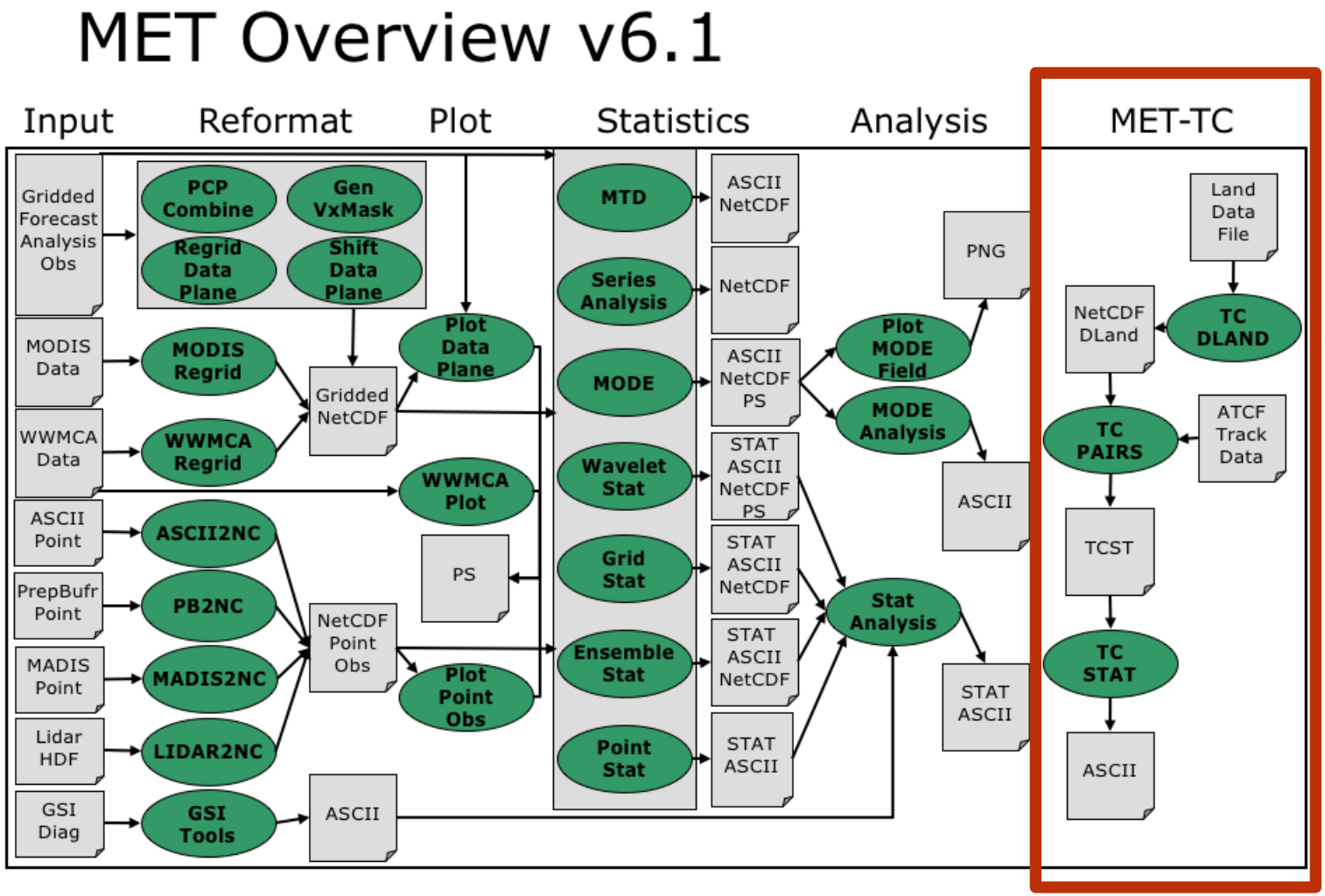
2018 MET tutorial
February 2, 2018
Boulder, CO

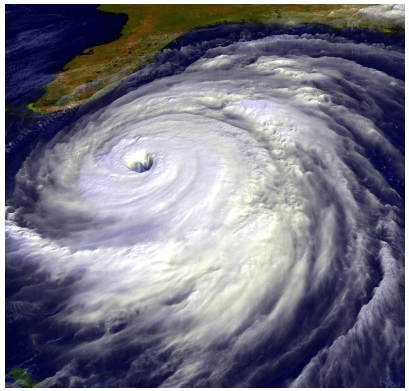
Model Evaluation Tools – Tropical Cyclone (MET-TC)

Kathryn M. Newman

Introduction



Introduction



- WHAT is MET-TC?
  - A set of tools to aid in TC forecast evaluation and verification
  - Developed to replicate (and add to) the functionality of the National Hurricane Center (NHC) verification software
  - Modular set of tools which utilize the MET software framework
    - Allows for additional capabilities and features to be added to future releases
- WHY use MET-TC?
  - Provides Tropical Cyclone (TC) verification statistics consistent with operational centers
  - Easily parse and subset TC datasets

Compile & build

- Must use METv4.1 or newer for MET-TC
- MET-TC specific code and tools:
  - **bin/** : executables for each MET-TC module (**tc_dland**, **tc_pairs**, **tc_stat**)
  - **share/met/config/** : configuration files (TCPairsConfig_default, TCStatConfig_default)
  - **share/met/tc_data/** : static files used in MET-TC (*land.dat, wwpts_us.txt)
  - **doc/** : contains the MET User's Guide (MET-TC: chapters 17-20)
  - **src/tools/tc_utils/** : source code for three MET-TC modules
  - **scripts/Rscripts/** : contains R scripts (plot_tcmpr.R & plot_probri.R) which provides graphics tools for MET-TC

Getting Started…

- The **best track analysis** is used primarily used as the observational dataset in MET-TC.
  - May use any reference dataset in ATCF format
- The input files must be in Automated Tropical Cyclone Forecasting System (**ATCF**) **format**.
- Model output must be run through an internal/external **vortex tracking algorithm**

Observations

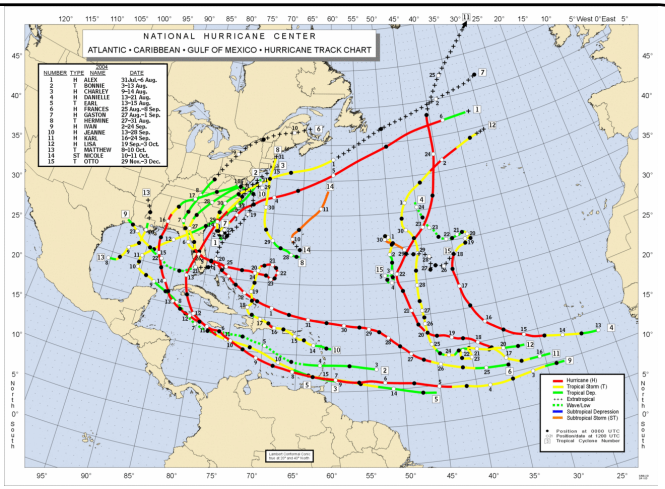
- Observations are an important consideration for TC verification
  - Quality and quantity of observations available
    - Typically sparse or intermittent

- The **best track analysis** is used primarily used as the observational dataset in MET-TC.

All operational model aids and best track analysis can be found on the NHC ftp server: `ftp://ftp.nhc.noaa.gov/atcf/archive/`

The Best Track is a subjective dataset – not consistent across basins!!

Observations



- **Best track analysis**
  - Subjective assessment of TC's center location and intensity (6 hr) using all observations available
  - Includes center position, maximum sfc winds, minimum center pressure, quadrant radii of 34/50/64 kt winds
  - Subjectively smoothed representation of storm's location and intensity over its lifetime

```
AL, 02, 2008070318,  , BEST,  0, 132N, 252W,  35, 1006, TS, 34, NEQ,  30,  30,  0,  30, 1012, 170,  30,  45,  0,  L,  0,  ,  0,  0,  BERTHA, M, 12, NEQ,  30,  30,  0,  30
AL, 02, 2008070400,  , BEST,  0, 134N, 265W,  40, 1006, TS, 34, NEQ,  60,  30,  0,  60, 1012, 170,  30,  50,  0,  L,  0,  ,  0,  0,  BERTHA, M, 12, NEQ,  30,  30,  30,  30
AL, 02, 2008070406,  , BEST,  0, 140N, 278W,  40, 1003, TS, 34, NEQ,  60,  30,  0,  60, 1012, 180,  30,  50,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ,  30,  30,  30,  30
AL, 02, 2008070412,  , BEST,  0, 148N, 292W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ,  60,  30,  30,  60
AL, 02, 2008070418,  , BEST,  0, 154N, 308W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ, 120, 120,  60,  90
AL, 02, 2008070500,  , BEST,  0, 158N, 326W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ, 120, 120,  60,  90
AL, 02, 2008070506,  , BEST,  0, 163N, 344W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ, 120, 120,  60,  90
AL, 02, 2008070512,  , BEST,  0, 164N, 364W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ, 240,  90,  60, 180
AL, 02, 2008070518,  , BEST,  0, 166N, 384W,  45, 1000, TS, 34, NEQ,  75,  30,  0,  75, 1012, 180,  30,  55,  0,  L,  0,  ,  0,  0,  BERTHA, D, 12, NEQ, 300, 150,  75, 240
```

Getting Started…

- Automated Tropical Cyclone Forecasting System (**ATCF**) **format**
  - First developed at Naval Oceanographic and Atmospheric Research Laboratory (NRL)
  - Currently used for NHC operations

- Must adhere to for MET-TC tools to properly parse the input data (first 17 columns must exist - missing values ok)
  - To ensure proper matching input data must contain:
    - Basin, cyclone number, initialization time, forecast hour, model name

```
AL, 18, 2011102200, 03, AVNO,  48, 152N,  812W,  25, 1006, XX,  34, NEQ,    0,    0,    0,    0,
```

✓ MET-TC User's Guide outlines these 17 columns and necessary fields

✓ For detailed information on ATCF format:
http://www.nrlmry.navy.mil/atcf_web/docs/database/new/abdeck.txt

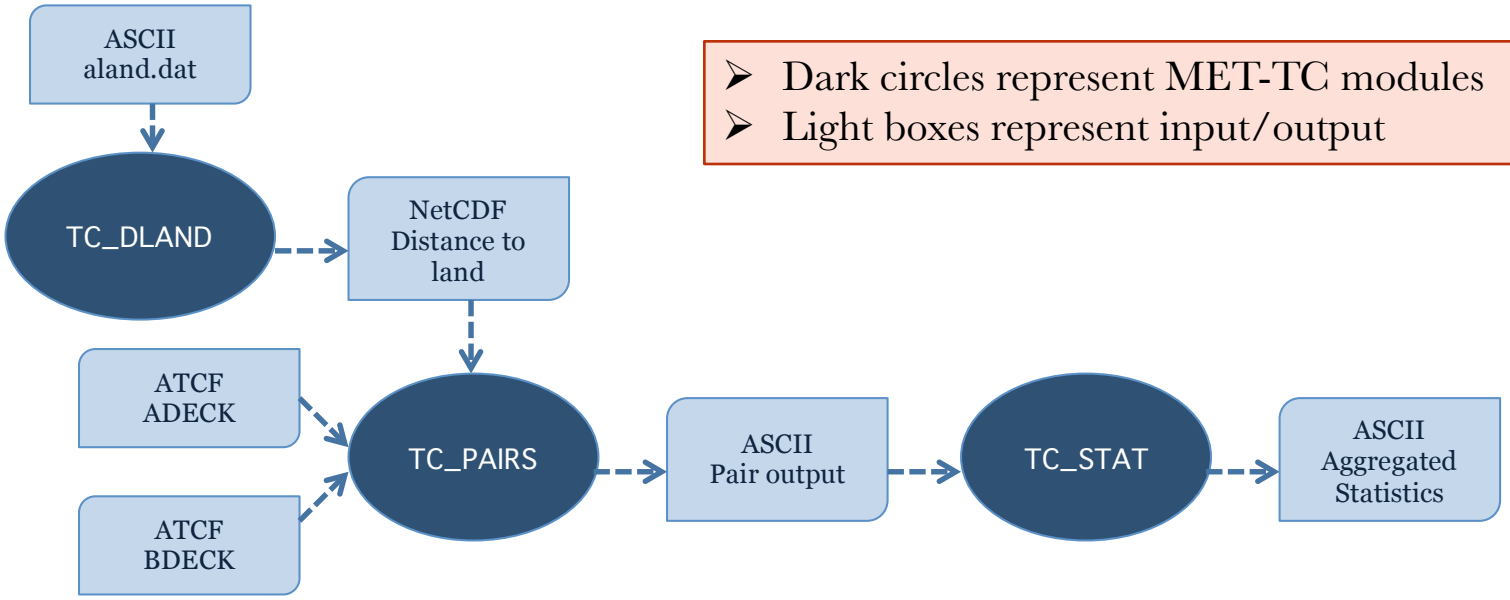
Getting Started…

- Model output must be run through an internal/external **vortex tracking algorithm**
- Any algorithm that obtains basic position, maximum wind, minimum sea level pressure information from model forecasts (in ATCF format) may be used
- Fully supported and freely available: GFDL Vortex Tracker

For more information (includes code and documentation):

http://www.dtcenter.org/HurrWRF/users/downloads/index.php

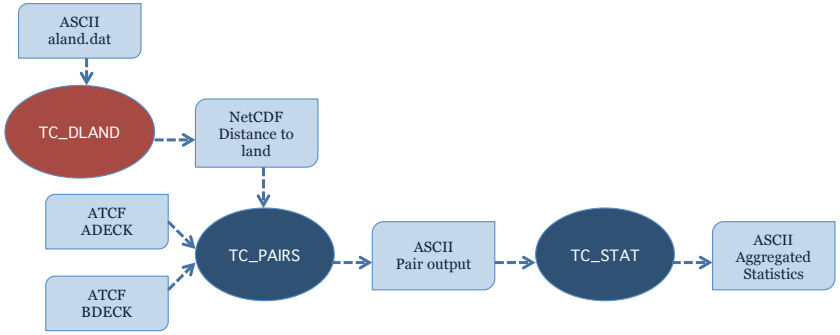
MET-TC components



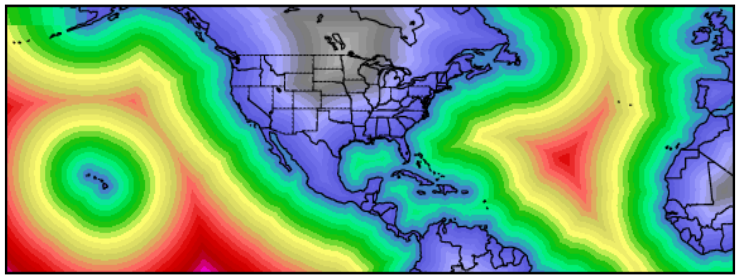
- Dark circles represent MET-TC modules
- Light boxes represent input/output

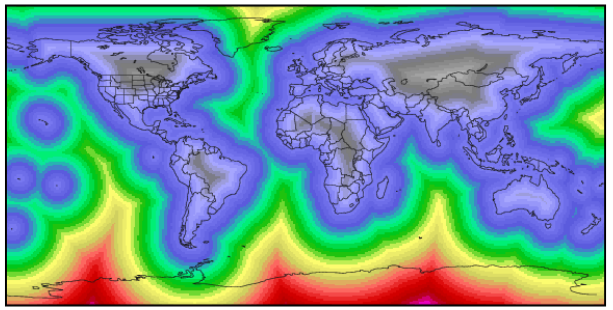
- Primary functions of the code are:
  - Compute pair statistics from ATCF input files
  - Filter pair statistics based on user specifications
  - Compute summary statistics

TC-dland



- Aids in quickly parsing data for filter jobs:
  - Only verify over water
  - Threshold verification based on distance to land
  - Exclusion/inclusion of forecasts within a specified window of landfall
- Input: ASCII file containing Lon/Lat coordinates of all coastlines/islands considered to be a significant landmass. (aland.dat, shland.dat, wland.dat)
- Output: gridded field representing distance to nearest coastline/island in NetCDF format





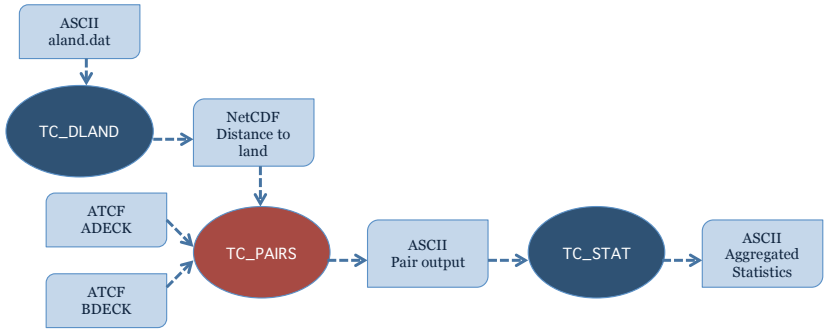
TC-dland

- Usage: **`tc_dland`**
  `out_file`
  `[-grid_spec]`
  `[-noll]`
  `[-land file]`
  `[-log file]`
  `[-v level]`

- This exe only needs to be run once to establish the NetCDF file!
- If running over the AL/EP and desire NHC land/water determination OR 1/10th degree grid global coverage: **NetCDF file provided in build**

out_file	Indicates NetCDF output file containing the computed distances to land
-grid_spec	Overrides the default 1/10th grid
-noll	Skips writing to reduce size of NetCDF file
-land file	Overwrites the default land data file
-log file	Outputs log messages to the specified file
-v level	Overrides the default level of verbosity (2)
-compress level	Specifies the desired level of compression for NetCDF variables (0-9)

TC-pairs



- Produces pair statistics on independent model input, user-specified consensus forecasts, or probabilistic forecasts
- Matches forecast with reference TC dataset (most commonly Best Track Analysis)
- Pair generation can be subset based on user-defined filtering criteria
- ASCII pair output allows for new or additional analyses to be completed without performing full verification process

This tool is similar to **point_stat**: matched pair information!

Tc_pairs

- Input: NetCDF gridded distance file, forecast/reference in ATCF format
- Output: TCSTAT format
  - Header, column-based ASCII output
- Usage: **tc_pairs**

```
-adeck source
-edeck source
-bdeck source
-config file
[-out base]
[-log file]
[-v level]
```

At least one –adeck or –edeck option must be specified.

-adeck source	ATCF format file containing TC model forecast
-edeck source	ATCF format file containing probabilistic track data
-bdeck source	ATCF format file containing TC reference dataset
-config file	Name of configuration file to be used
-out base	Indicates path of output file base
-log file	Name of log file associated with pairs output
-v level	Indicates desired level of verbosity

METv6.1 only supports the rapid intensification edeck probability type

Tc_pairs

- Configuration file determines filtering criteria

MODEL	VALID_MASK
STORM_ID	CHECK_DUP
BASIN	INTERP_12
CYCLONE	CONSENSUS
STORM_NAME	LAG_TIME
INIT_BEG/INIT_END	BEST_BASELINE
INIT_INC/INIT_EXC	OPER_BASELINE
VALID_BEG/VALID_END	MATCH_POINTS
INIT_HR	DLAND_FILE
INIT_MASK	WATCH_WARN
LEAD_REQ	VERSION

➢ Take care not to over-subset!
Can perform additional filters with tc_stat tool

```
// Model initialization time windows to
include or exclude
//
init_beg = "";
init_end = "";
init_inc = [];
init_exc = [];
//
// Valid model time window
//
valid_beg = "";
valid_end = "";
//
// Model initialization hours
//
init_hour = [];
//
// Required lead time in hours
//
lead_req = [];
//
// lat/lon polylines defining masking
regions
//
init_mask  = "";
valid_mask = "";
//
// Specify if the code should check for
duplicate ATCF lines when building tracks
//
check_dup = FALSE;
//
// Specify whether special processing
should be performed for interpolated
models.
//
interp12 = REPLACE;
//
// Specify how consensus forecasts should
be defined:
//e.g.
// consensus = [
// {
//   name = "CON1";
//   members = ["MOD1", "MOD2", "MOD3"];
//   required = [TRUE, FALSE, FALSE];
//   min_req = 2;
//  }
//
consensus = [];
//
```

Tc_pairs

- Output in ASCII space delimited columns with header information

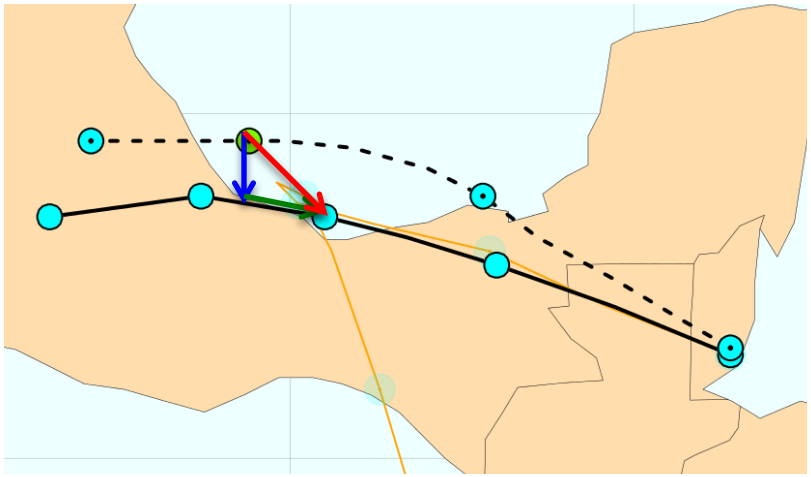
TCMPR OUTPUT FORMAT		
Column Number	**Header Column Name**	**Description**
13	TCMPR	Tropical Cyclone Matched Pair line type
14	TOTAL	Total number of pairs in track
15	INDEX	Index of the current track pair
16	LEVEL	Level of storm classification
17	WATCH_WARN	HU or TS watch or warning in effect
18	INITIALS	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)
28	ADLAND	adeck distance to land (nm)
29	BDLAND	bdeck distance to land (nm)
30	AMSLP	adeck mean sea level pressure
31	BMSLP	bdeck mean sea level pressure
32	AMAX_WIND	adeck maximum wind speed
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

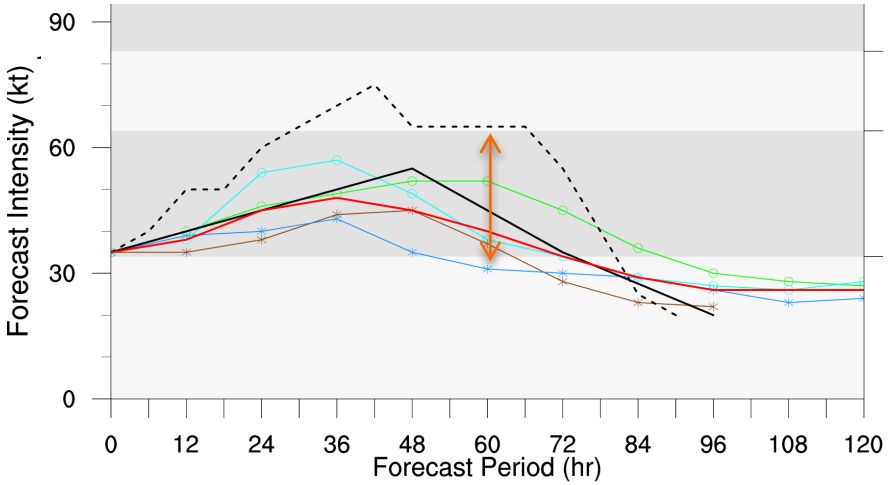
LEAD	VALID	INIT_MASK	VALID_MASK	LINE_TYPE	TOTAL	INDEX	LEVEL	WATCH_WARN	INITIALS	ALAT	ALON	BLAT	BLON	TK_ERR	X_ERR	Y_ERR	ALTK_ERR	CRTK_ERR
000000	20091104_060000	NA	NA	TCMPR	11	1	TD	NA	NA	10.60000	-81.00000	11.00000	-81.30000	29.80988	17.68135	-23.99998	-28.86526	-7.42332
120000	20091104_180000	NA	NA	TCMPR	11	2	TS	NA	NA	11.10000	-81.80000	11.80000	-82.30000	51.26922	29.40295	-41.99999	-49.33109	-13.92946
240000	20091105_060000	NA	NA	TCMPR	11	3	HU	NA	NA	11.30000	-82.50000	12.60000	-83.00000	91.04526	46.95995	-78.00001	-80.83007	-41.86590
360000	20091105_180000	NA	NA	TCMPR	11	4	TS	NA	NA	11.30000	-82.90000	13.20000	-83.00000	125.62137	52.77057	-113.99998	-124.32610	-17.83440
480000	20091106_060000	NA	NA	TCMPR	11	5	TD	NA	NA	11.40000	-83.10000	14.10000	-84.00000	170.34669	52.66857	-162.00005	-169.03902	20.81721
600000	20091106_180000	NA	NA	TCMPR	11	6	TD	NA	NA	11.70000	-83.00000	15.40000	-83.90000	228.12263	52.49704	-221.99999	-221.96036	52.48623
720000	20091107_060000	NA	NA	TCMPR	11	7	TS	NA	NA	11.70000	-82.70000	16.80000	-84.00000	315.20052	75.60019	-305.99997	-305.94534	75.58471
840000	20091107_180000	NA	NA	TCMPR	11	8	TS	NA	NA	11.60000	-82.00000	18.70000	-84.00000	443.02103	121.62077	-426.00002	-435.51454	80.77160
960000	20091108_060000	NA	NA	TCMPR	11	9	HU	NA	NA	11.60000	-81.10000	20.10000	-85.00000	564.68317	242.41923	-510.00000	-507.36406	-247.65705
1080000	20091108_180000	NA	NA	TCMPR	11	10	HU	HUWATCH	NA	11.80000	-80.70000	21.90000	-86.00000	683.36364	315.83208	-605.99997	-678.00027	84.45908
1200000	20091109_060000	NA	NA	TCMPR	11	11	HU	HUWARN	NA	11.80000	-81.20000	24.40000	-87.00000	837.03580	359.29512	-755.99997	-829.20702	-113.10325
000000	20091104_180000	NA	NA	TCMPR	11	1	TS	NA	NA	11.80000	-82.30000	11.80000	-82.30000	0.00000	0.00000	0.00000	0.00000	0.00000
120000	20091105_060000	NA	NA	TCMPR	11	2	HU	NA	NA	12.30000	-83.10000	12.60000	-83.00000	21.47822	11.71808	-18.00001	-19.40374	-9.20015
240000	20091105_180000	NA	NA	TCMPR	11	3	TS	NA	NA	12.40000	-83.50000	13.20000	-83.00000	51.10875	17.55287	-48.00001	-49.80666	-11.42192
360000	20091106_060000	NA	NA	TCMPR	11	4	TD	NA	NA	12.30000	-83.20000	14.10000	-84.00000	117.67701	46.73197	-108.00001	-114.90728	25.28261
480000	20091106_180000	NA	NA	TCMPR	11	5	TD	NA	NA	12.40000	-82.30000	15.40000	-83.90000	202.69221	93.18869	-180.00000	-179.96817	93.17082
600000	20091107_060000	NA	NA	TCMPR	11	6	TS	NA	NA	12.90000	-81.50000	16.80000	-84.00000	275.27821	144.99002	-233.99998	-233.95874	144.96248
720000	20091107_180000	NA	NA	TCMPR	11	7	TS	NA	NA	13.50000	-80.70000	18.70000	-84.00000	368.45576	195.99904	-312.00005	-329.07915	165.58289
840000	20091108_060000	NA	NA	TCMPR	11	8	HU	NA	NA	13.80000	-80.20000	20.10000	-85.00000	478.08130	292.70757	-378.00001	-464.41822	-113.11568
960000	20091108_180000	NA	NA	TCMPR	11	9	HU	HUWATCH	NA	14.60000	-80.70000	21.90000	-86.00000	538.57587	313.40071	-437.99995	-519.74405	140.80364
1080000	20091109_060000	NA	NA	TCMPR	11	10	HU	HUWARN	NA	15.90000	-82.40000	24.40000	-87.00000	585.34140	287.27088	-510.00000	-583.95241	-38.73931
1200000	20091109_180000	NA	NA	TCMPR	11	11	HU	TSWARN	NA	18.00000	-84.70000	27.90000	-88.00000	631.87555	215.47793	-593.99998	-621.25866	114.71981
000000	20091105_060000	NA	NA	TCMPR	11	1	HU	NA	NA	12.60000	-83.30000	12.60000	-83.00000	0.00000	0.00000	0.00000	0.00000	0.00000
120000	20091105_180000	NA	NA	TCMPR	11	2	TS	NA	NA	13.10000	-83.50000	13.20000	-83.00000	18.52665	17.52818	-5.99997	-14.57644	11.42980
240000	20091106_060000	NA	NA	TCMPR	11	3	TD	NA	NA	13.60000	-83.40000	14.10000	-84.00000	46.06223	34.95324	-30.00000	-36.10644	28.58828
360000	20091106_180000	NA	NA	TCMPR	11	4	TD	NA	NA	14.30000	-83.20000	15.40000	-83.90000	77.48645	40.59747	-65.99997	-65.98833	40.58976
480000	20091107_060000	NA	NA	TCMPR	11	5	TS	NA	NA	15.20000	-83.10000	16.80000	-84.00000	109.13504	51.90822	-95.99997	-95.98301	51.89828

TCMPR line type (PROBRI also available)

TC Metrics

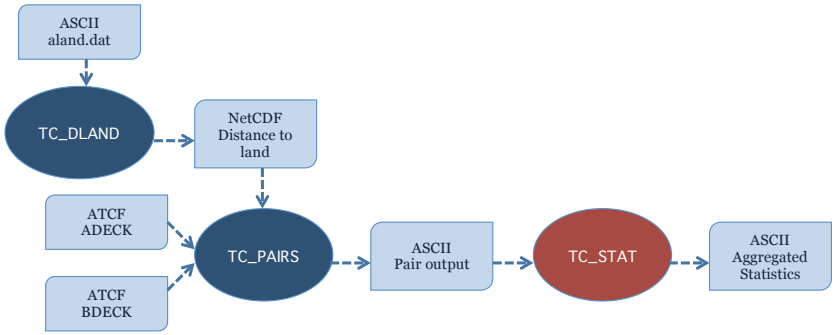
- **Track Error**: great-circle distance between the forecast location and the actual location of the storm center (nmi)
- **Along-track Error**: indicator of whether a forecasting system is moving a storm too slowly/quickly
- **Cross-track Error**: indicates displacement to the right/left of the observed track
- **Intensity Error**: Difference between forecast and actual intensity (kts)
  - Raw intensity errors (bias) vs. absolute intensity errors (magnitude of error)





Graphics courtesy of NCAR TCMT

Tc_stat



- Provides summary statistics and filtering jobs on TCST output
- ✓ Filter job:
  - Stratifies pair output by various conditions and thresholds
- ✓ Summary job:
  - Produces summary statistics on specific column of interest
- ✓ rirw job:
  - Identifies rapid intensification/weakening events, populates a 2x2 contingency table, and derives contingency table statistics
- ✓ probrirw job:
  - Processes PROBRIRW lines, populates at Nx2 contingency table, and derives probabilistic statistics
- Input: TCST output from tc_pairs
- Output: TCST output file from a job listed above

This tool is similar to **stat_analysis**: summarizes pairs (filter/summary jobs)!

Tc_stat

- Usage: **tc_stat**
  -lookin source
  [-out file]
  [-log file]
  [-v level]
  [-config file] | [JOB COMMAND LINE]

> ➢ Jobs may be specified either on the command line or within the configuration file. If jobs are specified in both, the configuration file will override

-lookin source	Location of TCST files generated from tc_pairs
-out file	Desired name of output file
-log file	Name of log file associated with tc_stat output
-v level	Verbosity level
-config file	Configuration file to be used
Job command line	specify joblist on command line

Tc_stat

- Configuration file will filter TCST output from tc_pairs to desired subset over which statistics will be computed

AMODEL/BMODEL	INIT_MASK/VALID_MASK	LANDFALL
STORM_ID	LINE_TYPE	LANDFALL_BEG (END)
BASIN	TRACK_WATCH_WARN	MATCH_POINTS
CYCLONE	COLUMN_THRESH_NAME (VAL)	EVENT_EQUAL
STORM_NAME	COLUMN_STR_NAME (VAL)	EVENT_EQUAL_LEAD
INIT_BEG/INIT_END	INIT_THRESH_NAME (VAL)	OUT_INIT_MASK
INIT_INC/INIT_EXC	INIT_STR_NAME (VAL)	OUT_VALID_MASK
VALID_BEG/VALID_END	WATER_ONLY	JOBS [ ]
VALID_INC/VALID_EXC	RIRW	VERSION
INIT_HR/VALID_HR/LEAD		

```
// Stratify by the ADECK and BDECK
distances to land.
//
water_only = FALSE;
//
// Specify whether only those track
points for which rapid
intensification/weakening of the maximum
wind speed occurred in the previous time
step should be retained.
//
rirw = {
   track = NONE;(NONE, ADECK, BDECK, BOTH)
   adeck = {
      time = 24;
      exact = TRUE; (exact, max int. diff)
      thresh = >=30.0;
   }
   bdeck = adeck;
}
//
// Specify whether only those track
points occurring near landfall should be
// retained, and define the landfall
retention window in HH[MMSS] format.
//
landfall     = FALSE;
landfall_beg = -86400;
landfall_end = 0;
//
// Specify whether only those track
points common to both the ADECK and
BDECK tracks should be retained.
//
match_points = TRUE;
//
// Specify whether only those cases
common to all models in the dataset
should be retained.
//
event_equal = TRUE;
//
// Specify lead times that must be
present for a track to be included in
the event equalization logic
event_equal_lead = ["12","24","36"];
```

Tc_stat

- The user may specify one or more analysis jobs to be performed on the lines that remain after applying filtering parameters
- Format for an analysis job:

```
-job job_name REQUIRED and OPTIONAL ARGUMENTS

-job filter –line_type TCMPR –amodel HWFI –dump_row ./tc_filter_job.tcst
-job summary –line_type TCMPR –column TK_ERR –dump_row ./tc_summary_job.tcst
-job rirw –line_type TCMPR –rirw_time 24 –rirw_exact false –rirw_thresh ge20
-job probrirw –line_type PROBRIRW –column_thresh RI_WINDOW==24 –probrirw_thresh 30
```

Tc_stat

- Filter job output: TC_stat output similar to TC_pairs
- Summary job output
  - "-column" option produces summary statistics for the specified column
  - "-by" option can be run once for each unique combination of the entries found in the column(s)

When operating on columns:

- A specific column
- Difference of two columns
- Absolute value of column(s)

Shortcuts:

- TRACK: all track error
- WIND: all wind radii errors
- TI: tracker and abs intensity error
- AC: along- and cross-track errors
- XY: x- and y- component track errors

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	Interqurtile range (75th - 25th percentile)
18	Range (Maximum - Minimum)
19	Sum
20-21	Independence time
22-25	Frequency of superior performance

Tc_stat

- RIRW job: produces contingency table counts and statistics defined by identifying rapid intensification or weakening events in the adeck and bdeck
- Configuration options:

`-rirw_time`	defines time window of interest
`-rirw_thresh`	defines intensity change event threshold
`-rirw_window`	define how close adeck and bdeck events must be to be considered hits or correct negatives
`-out_line_type`	defines output data – CTC, CTS, MPR
`-out_alpha`	option to define alpha value for CIs
`–by`	option to run the same job across multiple stratifications of the data

		Observation		
		RI	***No RI***	***Total***
Model Forecast	***RI***	128 (0.3%)	253 (0.6%)	381 (0.9%)
	No RI	1623 (4.1%)	37654 (94.9%)	39277 (99%)
	Total	1751 (4.4%)	37907 (95.6%)	39658 (100%)

Tc_stat

- PROBRIRW job: produces probabilistic contingency table counts and statistics defined by placing forecast probabilities and BEST track rapid intensification events into a Nx2 contingency table
- Configuration options:

-prob_thresh	Defines which probability threshold should be evaluated (default: 30kt increase)
-prob_exact	Defines whether exact or maximum BEST track intensity change over the window should be used (default: true)
-probri_delta_thresh	define how close adeck and bdeck events must be to be considered hits or correct negatives
-probri_prob_thresh	Defines the probability thresholds used to create the output N2x contingency table.
-out_line_type	Defines output data - PCT, PSTD, PJC, PRC
–out_alpha	option to define the alpha value for the confidence intervals in the PSTD line type

PROBRIRW is the only capability from e-decks in v6.1. Capabilities may be expanded in future releases

Graphics tools

MET-TC includes supported graphics tools

- Graphical capabilities are included in the MET-TC release
  - `plot_tcmpr.R, plot_probri.R`
- Input: TCSTAT tc_pairs output
- Output: R graphics, tc_stat logs/filter job TCSTAT (optional)
- Usage: `Rscript plot_tcmpr.R –lookin`
  - -filter (specify filter job)
  - -config (run filter job w/ configuration file)
    - Default Rscript configuration file included in release

Graphics tools-examples