



User's Guide Version 1.3

- Compatible with GSI community release v3.7

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Foreword

This User's Guide for the community ensemble Kalman filter (EnKF) data analysis system is particularly geared for beginners. It describes the fundamentals of using EnKF, including basic skills of installing, running, diagnosing, and tuning EnKF. EnKF version (v) 1.3 was released in November 2018. This version of code is compatible with the Gridpoint Statistical Interpolation (GSI) analysis system community release v3.7.

This User's Guide includes six chapters and one appendix:

Chapter 1 provides a background introduction of the operational and community EnKF system, Data Assimilation review committee, and data types that can be used in this version.

Chapter 2 contains basic information about how to get started with EnKF, including system requirements; required software; how to download EnKF; and information about compilers, libraries, and how to build the code.

Chapter 3 focuses on the input files needed to run EnKF and how to configure and run GSI observer and EnKF through a sample run script. This chapter also provides an example of a successful EnKF run.

Chapter 4 includes information about diagnostics and tuning of the EnKF system through EnKF standard output and namelist variables.

Chapter 5 illustrates how to setup and run the GSI observer and EnKF for a regional configuration and a global configuration, as well as how to diagnose the results.

Chapter 6 introduces EnKF theory and the main structure of the code.

Appendix A describes the contents of the EnKF namelist.

This document is updated annually. For the EnKF documentation and annual release code, please visit the EnKF User's Website:

<https://dtcenter.org/EnKF/users>

Please send questions and comments to the EnKF help desk:

enkf-help@ucar.edu

This document and the annual EnKF releases are made available through a community EnKF effort led by the Developmental Testbed Center (DTC), in collaboration with EnKF developers. To help sustain this effort, we encourage for those who use the community released EnKF, the EnKF helpdesk, the EnKF User's Guide, and the other DTC EnKF services, please refer to this user's guide in their work and publications.

Citation:

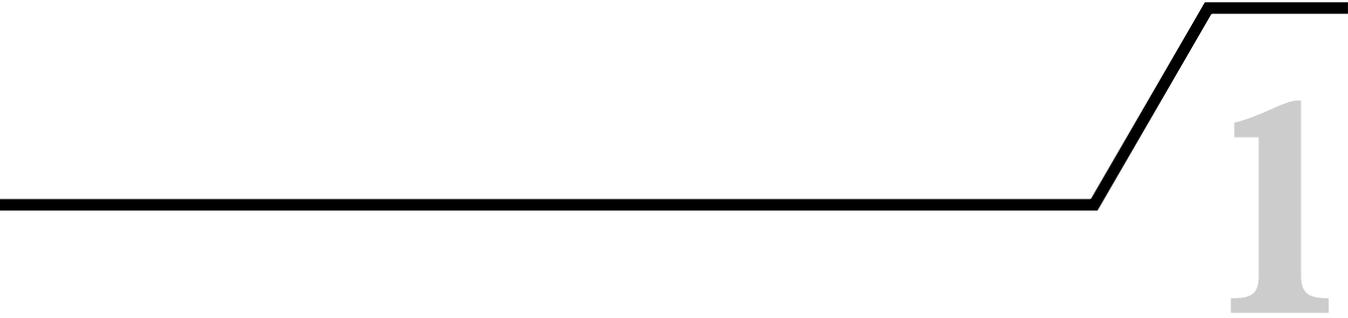
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1

Overview

1.1 EnKF History and Background

The ensemble Kalman filter (EnKF) is a Monte-Carlo algorithm for data assimilation that uses an ensemble of short-term forecasts to estimate the background-error covariance in the Kalman filter. Each ensemble member is cycled through the data assimilation system and updated by EnKF. The EnKF code was developed by the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Lab (ESRL) in collaboration with the research community. It contains two separate algorithms for calculating an analysis increment, a serial Ensemble Square Root Filter (EnSRF) algorithm described by [6] and a Local Ensemble Kalman Filter (LETKF) algorithm described by [4]. The parallelization scheme used by the EnSRF algorithm is based on that used in the Data Assimilation Research Testbed (DART) toolkit developed at the National Center for Atmospheric Research (NCAR) and described by [1]. The LETKF code was contributed by Yoichiro Ota of the Japanese Meteorological Agency (JMA) while he was a visitor at the National Centers for Environmental Prediction (NCEP).

The EnKF code became an operational data assimilation system at NCEP in May 2012, providing ensemble update to the Global Forecast System (GFS) hybrid Ensemble-Variational (EnVar) data assimilation system. It can work with both global forecast models (e.g., GFS) and regional forecast models (e.g., the Hurricane Weather Research and Forecasting (WRF) (HWRF) model, the North American Mesoscale (NAM) system, the Advanced Research WRF (ARW) system).

1.2 EnKF Becomes Community Code

The Developmental Testbed Center (DTC), in collaboration with major development groups, began transforming the EnKF operational system into a community system in 2014, following the same protocol as the GSI community effort ([5], <http://www.dtcenter.org/com-GSI/users/>). Consequently, the EnKF code and its user support are managed by the DTC, along with the GSI community system.

The DTC complements the development groups in providing EnKF documentation, porting EnKF to multiple platforms, and testing EnKF in an independent and objective environment, while still maintaining functionally equivalent to operational centers. Working with code developers, the DTC is maintaining a unified community GSI/EnKF repository to facilitate community users to develop EnKF. Based on the repository, the DTC releases EnKF code annually with GSI. The first community version of the EnKF system was released on July 31, 2015. This user's guide describes the third release of EnKF (v1.3) in November 2018. The DTC provides user support through the EnKF Helpdesk (enkf-help@ucar.edu), tutorials, and workshops. More information about the EnKF community services can be found at the DTC EnKF webpage (<http://www.dtcenter.org/EnKF/users/>).

1.2.1 EnKF Code Management and Review Committee

The EnKF code development and maintenance are administrated by the Data Assimilation Review Committee (DARC). DARC was originally formed as the GSI Review Committee in 2010. The committee was reformed in 2014 to include members representing the EnKF development and applications. Such a combination enhanced collaboration of development groups in both variational and ensemble data assimilation communities. Currently, DARC contains members from NCEP's Environmental Modeling Center (EMC), the National Aeronautics and Space Administration (NASA) Goddard Global Modeling and Assimilation Office (GMAO), NOAA/ESRL, the National Center for Atmospheric Research (NCAR) Mesoscale & Microscale Meteorology Laboratory (MMM), the National Environmental Satellite, Data, and Information Service (NESDIS), the United States Air Force (USAF), the University of Maryland, Joint Center for Satellite Data Assimilation (JCSDA), and the DTC.

DARC primarily steers distributed GSI/EnKF development and community code management and support. The responsibilities of the committee are divided into two major aspects: coordination and code review. The purpose and guiding principles of the review committee are described in the Chapter 1 of the GSI User's Guide.

1.2.2 Community Code Contributions

EnKF is a community data assimilation system, open to contributions from scientists and software engineers from both the operational and research communities. DARC oversees the

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code transition from prospective contributors. This committee reviews proposals for code commits to the GSI/EnKF repository and monitors that coding standards and tests are being fulfilled. Once the committee reaches approval, the contributed code will be committed to the GSI/EnKF code repository and available for operational implementation and public release.

To facilitate this process, the DTC is providing code transition assistance to the general research community. Prospective contributors should contact the DTC EnKF helpdesk (enkf-help@ucar.edu) as early as possible. It is the contributor's responsibility to ensure that a proposed code change is correct, meeting the EnKF coding standards, and well-documented. The DTC will help the contributors run the regression tests and merge the code with the top of the repository. Prospective contributors can also apply to the DTC visitor program for their EnKF research and code transition. The visitor program is open to applications year-round. Please check the visitor program webpage (<https://dtcenter.org/visitor-program>) for the latest announcement of opportunity and application procedures.

1.3 About This EnKF Release

This user's guide was composed for the EnKF community release version(v) 1.3, which is compatible with the GSI community release v3.7. Please note the major focuses of the DTC are currently on testing and evaluation of EnKF for regional numerical weather prediction (NWP) applications though the instructions and cases for EnKF global applications are available with this release.

Running this EnKF system requires running GSI as a prior for its observation operators. Therefore, the GSI User's Guide is referred throughout this documentation. This GSI user's guide can be obtained at the GSI user's webpage (<http://www.dtcenter.org/com-GSI/users/docs/index.php>).

1.3.1 What Is New in This Release Version

The following lists some of the new functions and changes included in the v1.3 release of the EnKF versus v1.2:

- Added the capability to perform model-space vertical localization using modulated ensembles
- Added option for GSI to write out diag files in NetCDF format as well as binary format
- Added option for EnKF to read NetCDF format diag files
- Added option of running GSI in the observer mode once for the ensemble mean and saving the observation operator jacobian in diag files. The jacobian is then used in EnKF for computing linearized observation operator for ensemble perturbations
- Added option for EnKF to save ensemble spread in diag files

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- Bug fixes

1.3.2 Observations Used by This Version

EnKF is using the GSI system as the observation operator to generate observation innovations. Therefore, the observation types assimilated by EnKF are the same as GSI. This version of EnKF has been tested to work with the community GSI release v3.7. It can assimilate, but is not limited to, the following types of observations:

Conventional observations (including satellite retrievals):

- Radiosondes
- Pilot balloon (PIBAL) winds
- Synthetic tropical cyclone winds
- Wind profilers: USA, Jan Meteorological Agency (JMA)
- Conventional aircraft reports
- Aircraft to Satellite Data Relay (ASDAR) aircraft reports
- Meteorological Data Collection and Reporting System (MDCRS) aircraft reports
- Dropsondes
- Moderate Resolution Imaging Spectroradiometer (MODIS) IR and water vapor winds
- Geostationary Meteorological Satellite (GMS), JMA, and Meteosat cloud drift IR and visible winds
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and GOES water vapor cloud top winds
- GEOS hourly IR and cloud top wind
- Surface land observations
- Surface ship and buoy observation
- Special Sensor Microwave Imager (SSM/I) wind speeds
- Quick Scatterometer (QuikSCAT), the Advanced Scatterometer (ASCAT) and Oceansat-2 Scatterometer (OSCAT) wind speed and direction
- RapidScat observations
- SSM/I and Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) precipitation estimates
- Velocity-Azimuth Display (VAD) Next Generation Weather Radar ((NEXRAD) winds
- Global Positioning System (GPS) precipitable water estimates
- Sea surface temperature (SST)
- Doppler wind Lidar
- Aviation routine weather report (METAR) cloud coverage
- Flight level and Stepped Frequency Microwave Radiometer (SFMR) High Density Observation (HDOB) from reconnaissance aircraft
- Tall tower wind

Satellite radiance/brightness temperature observations (instrument/satellite ID):

- SBUV: *NOAA-17, NOAA-18, NOAA-19*

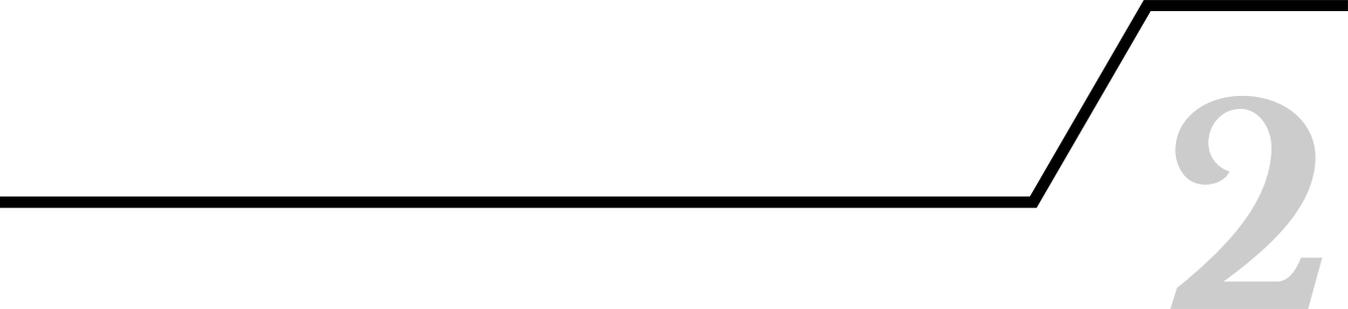
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- High Resolution Infrared Radiation Sounder (HIRS): *Meteorological Operational-A (MetOp-A), MetOp-B, NOAA-17, NOAA-19*
- GOES imager: *GOES-11, GOES-12*
- Atmospheric IR Sounder (AIRS): *aqua*
- AMSU-A: *MetOp-A, MetOp-B, NOAA-15, NOAA-18, NOAA-19, aqua*
- AMSU-B: *MetOp-B, NOAA-17*
- Microwave Humidity Sounder (MHS): *MetOp-A, MetOp-B, NOAA-18, NOAA-19*
- SSMI: *DMSP F14, F15, F19*
- SSMI/S: *DMSP F16*
- Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E): *aqua*
- GOES Sounder (SNDR): *GOES-11, GOES-12, GOES-13*
- Infrared Atmospheric Sounding Interferometer (IASI): *MetOp-A, MetOp-B*
- Global Ozone Monitoring Experiment (GOME): *MetOp-A, MetOp-B*
- Ozone Monitoring Instrument (OMI): *aura*
- Spinning Enhanced Visible and Infrared Imager (SEVIRI): *Meteosat-8, Meteosat-9, Meteosat-10*
- Advanced Technology Microwave Sounder (ATMS): *Suomi NPP*
- Cross-track Infrared Sounder (CrIS): *Suomi NPP*
- GCOM-W1 AMSR2
- GPM GMI
- Megha-Tropiques SAPHIR
- Himawari AHI

Others:

- GPS Radio occultation (RO) refractivity and bending angle profiles
- Solar Backscatter Ultraviolet (SBUV) ozone profiles, Microwave Limb Sounder (MLS) (including NRT) ozone, and Ozone Monitoring Instrument (OMI) total ozone
- Doppler radar radial velocities
- Radar reflectivity Mosaic
- Tail Doppler Radar (TDR) radial velocity and super-observation
- Tropical Cyclone Vitals Database (TCVital)
- Particulate matter (PM) of 10-um diameter, 2.5-um diameter or less
- MODIS AOD (when using GSI-chem package)

Please note some of these above mentioned data are not yet fully tested and/or implemented for operations. Therefore, the current GSI code might not have the optimal setup for these data.



2

Software Installation

2.1 Introduction

The DTC community EnKF is a community distribution of NOAA's operational ensemble Kalman filter. The community EnKF expands the portability of the operational code by adding a flexible build system and providing example run scripts that allow the system to run on many common platforms. The current version of the community EnKF builds and runs on most standard Linux platforms using the Intel, PGI, and GNU compilers.

This chapter describes how to build and install the DTC community EnKF on your local Linux computing resources. By default EnKF is built as part of the GSI build. The only difference between the steps necessary to build GSI and EnKF are that for EnKF one of three IO configurations must be chosen prior to enacting the build.

The EnKF build process consists of the three steps:

- Obtaining the source code for EnKF/GSI.
- Setting the appropriate environment variables for the build.
- Configuring and compiling the source code using CMake.

Section 2.2 describes how to obtain the source code from the DTC website. Section 2.2.1 describes the three different IO options that can be selected prior to building the code. Section 2.3 presents an outline of the build process. Section 2.3.1 illustrates an Intel build in detail, and discusses optional arguments. Section 2.3.2 describes all of the current optional settings for the build. Sections 2.4 and 2.5 cover the system requirements (tools, libraries, and environment variable settings) and currently supported platforms in detail. Section 2.6 discusses what to do if you have problems with the build and where to get help.

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2.2 Obtaining the Source Code

The community EnKF code and the GSI code are released as a combined source code package. The current EnKF release is v1.3 and is paired with the community GSI release version 3.7. The community EnKF release is available from the DTC community EnKF users website;

<http://www.dtcenter.org/EnKF/users/index.php>

The community GSI/EnKF release includes the source code for both the EnKF v1.3 and the GSI v3.7 models, as well as an integrated build system, utilities, and documentation necessary to build and run the EnKF.

To download the source code from either the GSI or the EnKF website, select the Download tab along with the GSI/EnKF System sub-tab on the vertical menu located on the left side of the main page. New users must first register before downloading the source code. Returning users only need to enter their registration email address to log in. After accessing the download page, select the link to the `comGSIv3.7_EnKFv1.3` tarball. Please only use the source code provided with the `comGSIv3.7_EnKFv1.3` tarball. Do not mix and match this tarball with other versions of the community GSI code or supplemental libraries, as this will lead to unpredictable results.

The community EnKF version 1.3 comes in a tar file named `comGSIv3.7_EnKFv1.3.tar`. The tar file may be unpacked by using the standard UNIX commands:

```
gunzip comGSIv3.7_EnKFv1.3.tar.gz
tar -xvf comGSIv3.7-EnKFv1.3.tar
```

This creates the top level GSI directory `comGSIv3.7_EnKFv1.3/`. After downloading the source code, and prior to building, the user should check the known issues link on the download page of DTC website to determine if any bug fixes or platform specific customizations are needed.

Specifics on the source code directory structure can be found in the GSI User's Guides section 2.3, at the DTC community GSI users website:

<http://www.dtcenter.org/com-GSI/users/index.php>

2.2.1 Versions of EnKF

The EnKF code has three build time configurations for the I/O; WRF regional, GFS global, and NMMB. The EnKF analysis is identical in each case, only the capability to digest model input differs. The regional version can only digest WRF formatted I/O files. The global

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version can only digest spectral input from the NCEP global model, and lastly, the NMMB version can only digest NMMB files.

The default build constructs the regional configuration of EnKF. To get global EnKF, it is necessary to add optional build arguments to the cmake command.

- `-DENKF_MODE=GFS` to get the GFS version EnKF

Similar arguments control the enacting the NMMB bindings. This will be explained in detail in section 2.3.1 and 2.3.2.

2.3 Compiling EnKF

A new unified build system based on CMake has been added to the EnKF/GSI code. While the new build system is a significant departure from the previous DTC build system, CMake is a very powerful cross-platform open-source build system that has many capabilities to make building easier.

The CMake build infrastructure consists of a top level directory with the name `cmake/` and configuration files in each directory named (`CMakeLists.txt`). This replaces the old `arch/` directory. CMake relies on a two step command line process, similar to the old UNIX "configure" and "compile." Command line arguments are used to specify paths and compilers. By default CMake is configured to build the source code "out-of-place," meaning that it does not populate the source code directory with the build. The location for the build must be specified by the user.

Once a compiler has been chosen, CMake generates local makefiles by invoking the `cmake` command with the proper arguments. One of those arguments selects that a local build of the NCEP libraries needed by EnKF/GSI will be conducted prior to the source code being built. The final step is to invoke a parallel build (`make`) of the code.

A significant advantage with using CMake to build the code, is that CMake automatically generates code dependencies each time a build is invoked, allowing the use of a parallel make as the final step of the build. This greatly reduces the time it take to complete the build. Because of the parallel compiling, the time to complete the CMake build is typically a quarter of the time needed for the serial DTC "configure" and "compile" to complete.

Once the build is complete, the EnKF executable is placed in the `bin` directory of the build directory. Note that the name of the executables and their location differs from the traditional DTC build.

Summary of CMake build steps:

1. Set up the build environment
 - Select a specific compiler by loading modules or setting paths as needed
 - Set the environment path for the NetCDF library (The HDF5 library is also needed if your NetCDF version is 4+).

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- Set the LAPACK/MKL mathematics libraries as needed.
2. Create a directory for your build and change into it.
 3. Run the cmake command with the appropriate arguments.
 4. Run make
 5. The executables are located in the build directory within the bin directory.

2.3.1 Example build using the Intel Fortran Compiler

This section details how to build EnKF on the NCAR supercomputer Cheyenne, using the Intel V18.0.1 fortran compiler, the 2018 MKL libraries, NetCDF v4.6.1, and the 2018 Intel MPI libraries.

- Set up your build environment

```
module purge
module load cmake/3.9.1
module load intel/18.0.1 ncarenv/1.2 ncarcompilers/0.4.1 mkl/2018.0.1
module load netcdf/4.6.1
module load impi/2018.1.163
```

- Next, create a build directory and move into it.

```
mkdir ./build
cd build
```

- From within the build directory, invoke the cmake command to build the global GFS version of EnKF.

```
cmake -DENKF_MODE=GFS path_to_comGSI_directory
```

The makefiles customized to your platform and the environment, are now created.

- Run make (parallel compile) on eight cores

```
make -j8
```

Because CMake has already figured out the dependencies, the make can run in parallel.

Lets look at relevant arguments for cmake when building EnKF. The first is `-DBUILD_CORELIBS=ON`. This argument directs CMake to look in the `libsrc/` directory to build the NCEP libraries needed for EnKF and GSI.

The argument `CMAKE_C_COMPILER` specifies the C compiler to use with the build. For the Intel compiler, use `icc`. The argument `CMAKE_CXX_COMPILER` specifies the C++ compiler to use with the build. For the Intel compiler, use `icpc`. The argument `CMAKE_Fortran_COMPILER` specifies the Fortran compiler to use with the build. Because this is an parallel MPI code, on Cheyenne use `mpif90` instead of `ifort`. Typically, the only time one would explicitly specify the compilers on the command line is when you wish to override a default choice set in your dot files or if you were to create a batch script to conduct the build.

To run the cmake command with a compiler other than Intel only requires replacing the values for `CMAKE_C_COMPILER`, `CMAKE_CXX_COMPILER`, and `CMAKE_Fortran_COMPILER` that correspond to the new compiler. Table 2.1 lists these values.

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Table 2.1: The compiler specific values for the cmake compiler argument

Compiler	C	C++	FC
Intel	icc	icpc	mpif90
PGI	pgcc	pgcc++	mpif90
GNU	gcc	g++	mpif90

2.3.2 Default Options

The CMake build has a number of options to when building. These are enacted by adding the option with the prefix `-D` to the command line call to `cmake`. For instance, in the example above, the `BUILD_CORELIBS` option is enacted by adding `-DBUILD_CORELIBS=ON` to the `cmake` call. The currently available command line build options are:

- `BUILD_ENKF`: builds the `enkf` executable (default is ON)
- `BUILD_CORELIBS`: Attempts to build the core libraries from source
- `USE_WRF`: Builds GSI with WRF dependencies (default is ON)
- `BUILD_GFS`: Builds ENKF using GFS (default is ON)
- `BUILD_WRF`: Builds ENKF using WRF (default is OFF)
- `BUILD_NMMB`: Builds ENKF using NMMB (default is OFF)

Note that by default EnKF built is global with GFS. See the readme file *README.cmake* in the top directory for a current list of options; or look in the `CMakeLists.txt` in the top directory and search for options.

2.4 System Requirements and Compiler Specific Notes

The EnKF source code is written in FORTRAN, FORTRAN 90, and C. In addition, the parallel executables require some flavor of MPI and OpenMP for the distributed memory parallelism. The I/O relies on the NetCDF I/O libraries. And CMake is needed to build the code.

The basic requirements for building and running the GSI system are the following:

- CMake V2.8+
- A FORTRAN compiler that supports the 2003 or newer standard
- C compiler
- MPI v1.2+
- OpenMP
- NetCDF V4.2+ and HDF5
- LAPACK and BLAS mathematics libraries, or equivalent

In addition, GSI and EnKF require linear algebra libraries such as LAPACK and BLAS. The Intel compiler usually comes with a vendor provided mathematics library known as the *Mathematics Kernel Libraries* or MKL for short. While *most* installations of the Intel compiler

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come with the MKL libraries installed not all do. In addition, if it is not installed correctly, the ifort compiler does not automatically load the library. It is therefore necessary to set the LAPACK_PATH variable to the location of the MKL libraries when using the Intel compiler. You may need to ask your system administrator for the correct path to these libraries.

IBM systems typically come installed with the LAPACK equivalent ESSL library that links automatically. Likewise, the PGI compiler often comes with a vendor provided version of LAPACK that links automatically with the compiler. The Gnu compiler is the only one that does not come with any installed version of the LAPACK and BLAS libraries.

Because all but the last of these tools and libraries are typically the purview of system administrators to install and maintain, they are lumped together here as part of the basic system requirements.

2.5 Compilers Tested for Release

Version 1.3 of the DTC community EnKF system has been extensively tested with a variety of compilers and versions of those compilers, on standard Linux platforms. To summarize, Intel compiler versions 16-18 should build and run without issue. Early version 15 has some known issues, but 15.1, 15.3, and 15.6 should work. For the Portland Group compiler, versions 16-18 should work without issue, and Gnu version 6.3, 7.1, and 7.3 are known to work. Version 18 of Gnu has issues and is not currently supported. See table ?? for the complete list compilers and versions tested. See release notes (https://dtcenter.org/com-GSI/users/support/release_notes/index_GSIv3.7.php) for the complete list compilers and versions tested.

Unforeseen build issues may occur when using older compiler and library versions. As always, the best results will be achieved by using the most recent compiler versions.

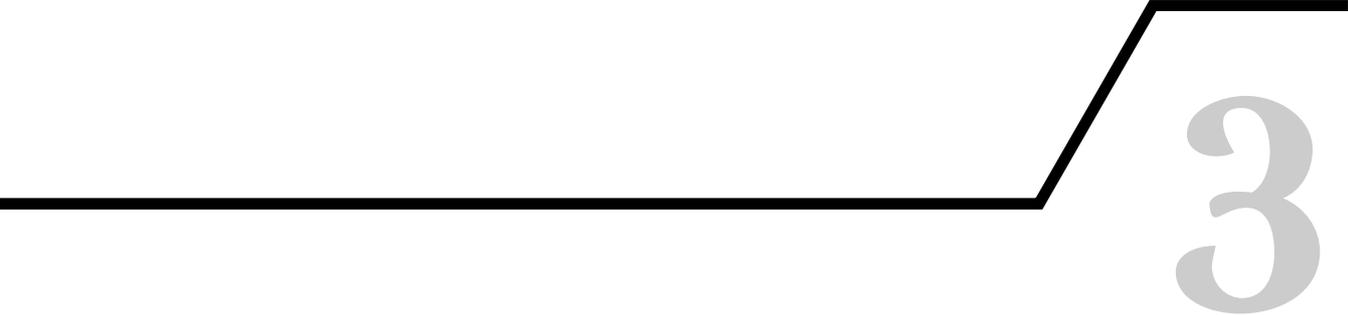
2.6 Getting Help and Reporting Problems

Should the user experience any difficulty building EnKF on their system, please first confirm that GSI has successfully built. Feel free to contact the community EnKF support at

enkf-help@ucar.edu

for assistance.

At a minimum, when reporting issues building the code, please include a copy of the EnKF build log.



3

Running EnKF

3.1 Input Data Required to Run EnKF

This chapter discusses the process of running EnKF cases. It includes:

1. Discussions of the input data required to run EnKF.
2. A detailed explanation of how to run both a regional and global EnKF with the released run scripts.
3. Introduction to the files in a successful regional and global EnKF run directory

3.1.1 Input Data Required to Run EnKF

In most cases, three types of input data, including ensemble mean and members, observations, and fixed files, must be available before running EnKF.

1. Ensemble mean and members

The ensemble members and ensemble mean of certain regional and global ensemble forecast systems are used as the background for the EnKF analysis. When this EnKF system is used for regional analysis with WRF ensembles, the ensemble members and ensemble mean follow the naming convention:

```
firstguess.mem001  
firstguess.mem002  
... ..
```

3. Running EnKF

`firstguess.ensmean`

Please note that the number of allocated computer cores to run EnKF must be larger than the ensemble size. The ensemble members can be generated using various methods, such as:

- Using global/regional ensemble forecasts.
- Ensemble forecasts generated using multi-physics, multi-models, or adding random perturbations drawn from climatology.
- In cycling assimilation, using ensemble forecasts initialized from previous ensemble analyses generated by EnKF.

This version EnKF can use any of the following ensemble files as the background:

- ARW NetCDF forecast
- NMM or NMMB forecast (not tested and supported by DTC)
- GFS forecast files

2. Prepare observation ensemble priors (observation innovation)

In addition to the ensemble backgrounds on model grids, the ensemble priors of all observations (observation innovation for all ensemble members) are also needed to run EnKF. The observation ensemble priors are generated by running GSI observation forward operators with the ensemble members as backgrounds (without doing actual GSI analyses). In this release, the GSI v3.7 run script includes options for generating the observation ensemble priors (details in section 3.2). The observation ensemble priors files should follow the following naming conventions:

- For conventional observations:

```
diag_conv_ges.mem001
diag_conv_ges.mem002
... ..
diag_conv_ges.ensmean
```

- For radiance observations:

```
diag_instrument_Satellite.mem001 (e.g. diag_hirs4_n19.mem001)
diag_instrument_Satellite.mem002 (e.g. diag_hirs4_n19.mem002)
... ..
diag_instrument_Satellite.ensmean (e.g. diag_hirs4_n19.ensmean)
```

These diag files contain a lot of information about each observation. For more details on the content of diag files, please refer to the GSI User's Guide Appendix A.2. The preparation of observations for EnKF assimilation is done within GSI, including quality control of observations, selection of observation types for assimilation, and observation error tuning. In the default namelist situation, NO additional online quality control of observations is performed in the EnKF analysis step (although there is an option to do the similar quality control of observations as the GSI variational scheme.)

3. Fixed files

EnKF uses the the same fixed files as GSI to setup the analysis configurations. Detailed

3. Running EnKF

explanation of all fixed files provided in the community GSI system is in the GSI user's Guide, Chapter 3. The following is a list of fixed files needed for EnKF analyses:

- for observation control:

```
convinfo - conventional data (prepufr) info file
ozinfo - ozone retrieval info file
satinfo - satellite channel info file
```

- when satellite radiance data are assimilated, the following files are needed to do the adaptive radiance bias correction:

```
satbias_in - satellite bias correction coefficient file
satbias_pc - satellite bias correction coefficient file for passive channels
```

Note that this version EnKF uses adaptive bias correction. The bias correction coefficients are in a single file that combined satellite angle dependent and mass bias correction coefficients. See GSI User's Guide for more detail. When the namelist parameter *readin_localization* is set to true, file *hybens_locinfo* is needed, in which customized localization values varying by model level are contained.

3.2 EnKF and GSI Observer Run Scripts

In this release version, four sample run scripts for EnKF applications are under directory `comGSIv3.7_EnKFv1.3/ush`:

- *ush/comgsi_run_regional.ksh* for running regional GSI to generate the observation ensemble priors. Referred to as the GSI observer run scripts.
- *ush/comgsi_run_global.ksh* is GSI observer run script for global applications (to generate the observation ensemble priors).
- *ush/comenkf_run_regional.ksh* for running regional EnKF
- *ush/comenkf_run_global.ksh* for running global EnKF

These run scripts are introduced in detail in the following sections. Also provided are three scripts for generating the GSI and EnKF namelist:

- *ush/comgsi_namelist.sh* generates GSI namelist on the fly (called by GSI observer run scripts).
- *ush/comgsi_namelist_gfs.sh* generates GSI namelist on the fly (called by GSI observer run scripts) for global GSI applications.
- *ush/comenkf_namelist.sh* generates EnKF namelist on the fly (called by EnKF run script) for regional EnKF applications.

3.2.1 General Introduction to the Run Scripts

These run scripts provide the run time environment necessary for running the GSI and EnKF executables. They all have similar steps, as follows:

3. Running EnKF

1. Request computer resources to run GSI/EnKF.
2. Set environmental variables for the machine architecture.
3. Set experimental variables (such as experiment name, analysis time, background, and observation).
4. Check the definitions of required variables. Generate a run directory for GSI/EnKF
5. Copy the GSI/EnKF executable to the run directory.
6. Copy/Link the background file/ensemble files to the run directory.
7. Link observations to the run directory.
8. Link fixed files (statistic, control, and coefficient files) to the run directory.
9. Generate namelist for GSI/EnKF.
10. Run the GSI/EnKF executable.
11. Post-process: save analysis results, generate diagnostic files, clean run directory.

In the GSI User's Guide, three sections explain the first three steps in detail:

- Section 3.2.2.1: Setting up the machine environment (step 1)
- Section 3.2.2.2: Setting up the running environment (step 2)
- Section 3.2.2.3: Setting up an analysis case (step 3)

For this documentation, the first 2 steps will be skipped and the 3rd step in the GSI observer and EnKF run scripts will be discussed. The community GSI analysis run script and the GSI observer run script are the same, with the GSI observer capability controlled by flags that turn off the minimization, select appropriate namelist options and enable looping through all the ensemble members to generate the ensemble observation priors for each member, including the ensemble mean.

3.2.2 GSI Observer Run Scripts

Setting up a case

This section discusses variables specific to the user's case, such as analysis time, working directory, background and observation files, location of fixed files and CRTM coefficients, and the GSI executable file. The script looks like:

```
#####  
# case set up (users should change this part)  
#####  
#  
# ANAL_TIME= analysis time (YYYYMMDDHH)  
# WORK_ROOT= working directory, where GSI runs  
# PREPBURF = path of PreBUFR conventional obs  
# BK_FILE = path and name of background file  
# OBS_ROOT = path of observations files  
# FIX_ROOT = path of fix files  
# GSI_EXE = path and name of the gsi executable  
# ENS_ROOT = path where ensemble background files exist  
ANAL_TIME=2017051318  
JOB_DIR=the_job_directory  
#normally you put run scripts here and submit jobs form here, require a copy of gsi.x at this directory  
RUN_NAME=a_descriptive_run_name_such_as_case05_3denvar_etc  
OBS_ROOT=the_directory_where_observation_files_are_located  
BK_ROOT=the_directory_where_background_files_are_located
```

3. Running EnKF

```
GSI_ROOT=the_comgsi_main_directory_where_src/ ush/ fix/ etc_are_located
CRTM_ROOT=the_CRTM_directory
ENS_ROOT=the_directory_where_ensemble_backgrounds_are_located
#ENS_ROOT is not required if not running hybrid EnVAR
HH='echo $ANAL_TIME | cut -c9-10'
GSI_EXE=${JOB_DIR}/gsi.x #assume you have a copy of gsi.x here
WORK_ROOT=${JOB_DIR}/${RUN_NAME}
FIX_ROOT=${GSI_ROOT}/fix
GSI_NAMELIST=${GSI_ROOT}/ush/comgsi_namelist.sh
PREPBUFR=${OBS_ROOT}/nam.t${HH}z.prepbuf.r.tm00
BK_FILE=${BK_ROOT}/wrfinput_d01.${ANAL_TIME}
```

The options `ANAL_TIME`, `WORK_ROOT`, `PREPBUFR`, `BK_FILE`, `OBS_ROOT`, `FIX_ROOT`, `GSI_EXE` are all the same settings as the GSI analysis configuration. Two options: `BK_ROOT`, `GSI_ROOT`, are the root directories for ensemble members and the GSI system. These exist to make links to the background and GSI system easy and shorter. The new option: `GSI_NAMELIST` is needed because the namelist section was taken out of the run scripts in this release as a separate file to improve the structure and readability of the run scripts. Users can find the namelist files for both GSI and EnKF in the same directory as the run scripts. Please note the option `BK_FILE` is pointing to the ensemble mean. The next part of this block has additional options to specify other important aspects of the GSI observer.

```
#-----
# bk_core= which WRF core is used as background (NMM or ARW or NMMB)
# bkcv_option= which background error covariance and parameter will be used
#              (GLOBAL or NAM)
# if_clean = clean : delete temperal files in working directory (default)
#              no  : leave running directory as is (this is for debug only)
# if_observer = Yes : only used as observation operator for enkf
# if_hybrid   = Yes : Run GSI as 3D/4D EnVar
# if_4DEnVar  = Yes : Run GSI as 4D EnVar
# if_nemsio   = Yes : The GFS background files are in NEMSIO format
# if_oneob    = Yes : Do single observation test
# if_hybrid=No # Yes, or, No -- case sensitive !
# if_4DEnVar=No # Yes, or, No -- case sensitive (set if_hybrid=Yes first)!
# if_observer=No # Yes, or, No -- case sensitive !
# if_nemsio=No # Yes, or, No -- case sensitive !
# if_oneob=No # Yes, or, No -- case sensitive !

bk_core=ARW
bkcv_option=NAM
if_clean=clean
...
# The following two only apply when if_observer = Yes, i.e. run observation operator for EnKF
# no_member number of ensemble members
# BK_FILE_mem path and base for ensemble members
no_member=20
BK_FILE_mem=${BK_ROOT}/wrfarw.mem
```

The options *bk_core*, *bkcv_option*, and, *if_clean* are the same as in the GSI analysis run scripts. The new option `if_observer` indicates if this GSI run is for the generation of the observation ensemble priors or for a regular GSI run. The new option *no_member* specifies the number of ensemble members that are need to be calculated for the observation ensemble priors. This should also be the ensemble number in the EnKF analysis. Option *BK_FILE_mem* is the path and the name of the ensembles without the ensemble member ID appended. The scripts will add the ensemble member ID as a three digital number, such as 000, 001,...

Loop through ensemble members

As mentioned previously, the GSI ensemble observer run scripts are the same as the GSI analysis run scripts released with the community GSI. Since the observer only generates diag files, which includes useful information on the observation innovation, the GSI outer loop number for the observer should be set to 0 to skip all minimization iterations.

The contents of the run scripts can be divided into two parts, those before the following comments and those after:

```
#####  
# start to calculate diag files for each member  
#####
```

Before this comment, the scripts have the same functionality as when running a GSI analysis, except that the background options in the scripts for the observer functionality are set for the ensemble mean. Additionally, the namelist is built with the two following options set, which skips the minimization and saves all observation processing from the ensemble mean:

```
if [ ${if_observer} = Yes ] ; then  
  nummiter=0  
  if_read_obs_save='.true.'  
  if_read_obs_skip='.false.'  
else
```

Please refer to the GSI user's guide for detailed explanation of the remainder of this portion of the run scripts. The second portion of the script loops through each member to calculate the observation ensemble priors based on the GSI run environments setup by the first portion.

Listed below is an annotated version of the 2nd part of the GSI observer run script with explanations on each function block.

```
if [ ${if_observer} = Yes ] ; then
```

This 2nd part of the script only runs if option *if_observer* is set to "Yes". The diag files from the ensemble mean need to be saved first with the following commands:

```
string=ges  
for type in $listall; do  
  count=0  
  if [[ -f diag_${type}_${string}.${ANAL_TIME} ]]; then  
    mv diag_${type}_${string}.${ANAL_TIME} diag_${type}_${string}.ensmean  
  fi  
done  
mv wrf_inout wrf_inout_ensmean
```

The following section builds the namelist for ensemble members. Please note two options need to be set different between mean and members:

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```
# Build the GSI namelist on-the-fly for each member
nummiter=0
if_read_obs_save='.false.'
if_read_obs_skip='.true.'
. $GSI_NAMELIST
```

The option *if_read_obs_save* and *if_read_obs_skip* switch from "True" and "False", respectively for the mean to "False" and "True", respectively for the ensemble members.

This saves all observation processing information (including bias correction, thinning, etc) from the ensemble mean and save the same information for the ensemble members to keep observations constant.

The script loops through each ensemble member (from member 001 to *no_member*) to create the diag files for each member:

```
# Loop through each member
loop="01"
ensmem=1
while [[ $ensmem -le $no_member ]];do

    rm pe0*

    print "\$ensmem is $ensmem"
    ensmemid='printf %3.3i $ensmem'
```

After a member is processed, the script removes the old ensemble member and links to the new member before rerunning the calculation:

```
# get new background for each member
if [[ -f wrf_inout ]]; then
    rm wrf_inout
fi

BK_FILE=${BK_FILE_mem}${ensmemid}
echo $BK_FILE
ln -s $BK_FILE wrf_inout
```

Run the GSI observer for this member:

```
# run GSI
echo ' Run GSI with' ${bk_core} 'for member ', ${ensmemid}

case $ARCH in
    'IBM_LSF')
        ${RUN_COMMAND} ./gsi.exe < gsiparm.anl > stdout_mem${ensmemid} 2>&1 ;;
    * )
        ${RUN_COMMAND} ./gsi.exe > stdout_mem${ensmemid} 2>&1 ;;
esac

# run time error check and save run time file status
error=$?

if [ ${error} -ne 0 ]; then
    echo "ERROR: ${GSI} crashed for member ${ensmemid} Exit status=${error}"
    exit ${error}
fi

ls -l * > list_run_directory_mem${ensmemid}
```

3. Running EnKF

Generate diag files for this member:

```
# generate diag files

for type in $listall; do
    count='ls pe*${type}_${loop}* | wc -l'
    if [[ $count -gt 0 ]]; then
        cat pe*${type}_${loop}* > diag_${type}_${string}.mem${ensmemid}
    fi
done

# next member
(( ensmem += 1 ))

done

fi
```

Since all members are using the same run directory, the run status of each member is overwritten by the following member. The stdout file and the file list in run directory are preserved with the ensemble member ID for debug.

3.2.3 Sample Regional EnKF Run Scripts

As described in section 3.2.1, the regional EnKF run scripts have been designed to have a similar structure to the GSI analysis and observer run scripts. Again, please refer to the GSI User's Guide section 3.2.2.1 and 3.2.2.2 for the first two steps.

The 3rd step is to setup the variables specific to the user's case, such as analysis time, working directory, background and observation files, location of fixed files and CRTM coefficients, and the EnKF executable. Most of the options in this portion are the same as the 3rd step in the GSI observer run scripts, which is discussed in section 3.2.2 of this User's Guide. Users should setup most of the variables in this portion based on the options in the GSI observer run scripts as they are the variables to setup the same things for the GSI and EnKF. The following is a sample script with explanations:

```
#####
# case set up (users should change this part)
#####
#
# ANAL_TIME= analysis time (YYYYMMDDHH)
# WORK_ROOT= working directory, where GSI runs
# PREPBURF = path of PreBUFR conventional obs
# OBS_ROOT = path of observations files
# FIX_ROOT = path of fix files
# ENKF_EXE = path and name of the EnKF executable
ANAL_TIME=2014021300 #used by comenkf_namelist.sh
JOB_DIR=the_job_directory
#normally you put run scripts here and submit jobs form here, require a copy of enkf_wrf.x at this directory
RUN_NAME=a_descriptive_run_name_such_as_case05_3denvar_etc
OBS_ROOT=the_directory_where_observation_files_are_located
BK_ROOT=the_directory_where_background_files_are_located
GSI_ROOT=the_comgsi_main_directory_where_src/ ush/ fix/ etc are located
CRTM_ROOT=the_CRTM_directory
diag_ROOT=the_observer_directory_where_diag_files_exist
ENKF_EXE=${JOB_DIR}/enkf_wrf.x
WORK_ROOT=${JOB_DIR}/${RUN_NAME}
FIX_ROOT=${GSI_ROOT}/fix
ENKF_NAMELIST=${GSI_ROOT}/ush/comenkf_namelist.sh
```

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Options *ANAL_TIME*, *BK_ROOT*, *BK_FILE*, *GSI_ROOT*, *FIX_ROOT*, *CRTM_ROOT* have the same meanings as the ensemble GSI observer run scripts and should be set to the same values as the ensemble GSI observer run scripts. The option *WORK_ROOT* is the working directory which should have enough space to hold the ensemble members and EnKF analysis results. The option *diag_ROOT* is pointing to the run directory of the GSI observer, where the diag files are generated as data input for the EnKF. The option *ENKF_EXE* points to the EnKF executable, which is under the GSI source code directory in this release. The option *ENKF_NAMELIST* is the path and the EnKF namelist file, which sits outside of the run script as a separate file like the GSI namelist. Users can find the namelist files for both GSI and the EnKF in the same directory as the run scripts.

The next part of this block includes several additional options that specify several aspects of the ensemble members.

```
# ensemble parameters
#
NMEM_ENKF=20
BK_FILE_mem=${BK_ROOT}/wrfarw
NLONS=129
NLATS=70
NLEVS=50
IF_ARW=.true.
IF_NMM=.false.
list="conv"
# list="conv amsua_n18 mhs_n18 hirs4_n19"
```

Options *NMEM_ENKF*, *BK_FILE_mem* are also in the GSI observer run script and should be set to the same values as the GSI observer run script. Options *NLONS*, *NLATS*, and *NLEVS* specify 3 dimensions (XYZ) of the ensemble grid. Options *IF_ARW* and *IF_NMM* indicates which background, ARW NetCDF ensemble or the NMM NetCDF ensemble, is used in this EnKF run. Option *list* is a list of the observation types that the EnKF will use in the analysis. This list should be based on the diag files generated by the ensemble GSI observer.

At this point, users should be able to run the EnKF for simple cases without changing the rest of the script. However, some advanced users may need to change some of the following blocks for special applications.

```
#####
# Users should NOT change script after this point
#####
```

The next block sets the run command to run EnKF on multiple platforms. The *ARCH* is set at the beginning of the script.

```
case $ARCH in
  'IBM_LSF')
    ##### IBM LSF (Load Sharing Facility)
    RUN_COMMAND="mpirun.lsf " ;;
  'LINUX')
    if [ $GSIPROC = 1 ]; then
      ### Linux workstation - single processor
      RUN_COMMAND=""
    else
      ##### Linux workstation - mpi run
```

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```
    RUN_COMMAND="mpirun -np ${GSIPROC} -machinefile ~/mach "
fi ;;

'LINUX_LSF')
##### LINUX LSF (Load Sharing Facility)
RUN_COMMAND="mpirun.lsf " ;;

'LINUX_PBS')
### Linux cluster PBS (Portable Batch System)
#   RUN_COMMAND="mpirun -np ${GSIPROC} " ;;
   RUN_COMMAND="mpiexec_mpt -n ${GSIPROC} " ;;

'DARWIN_PGI')
### Mac - mpi run
if [ $GSIPROC = 1 ]; then
##### Mac workstation - single processor
   RUN_COMMAND=""
else
##### Mac workstation - mpi run
   RUN_COMMAND="mpirun -np ${GSIPROC} -machinefile ~/mach "
fi ;;

* )
print "error: $ARCH is not a supported platform configuration."
exit 1 ;;
esac
```

The following block sets up fixed files and some analysis-time related values:

```
# Given the analysis date, compute the date from which the
# first guess comes. Extract cycle and set prefix and suffix
# for guess and observation data files
# gdate='$ndate -06 $adate'
gdate=$ANAL_TIME
YYYYMMDD='echo $adate | cut -c1-8'
HH='echo $adate | cut -c9-10'

# Fixed files
# CONVINFO=${FIX_ROOT}/global_convinfo.txt
# SATINFO=${FIX_ROOT}/global_satinfo.txt
# SCANINFO=${FIX_ROOT}/global_scaninfo.txt
# OZINFO=${FIX_ROOT}/global_ozinfo.txt
CONVINFO=${diag_ROOT}/convinfo
SATINFO=${diag_ROOT}/satinfo
SCANINFO=${diag_ROOT}/scaninfo
OZINFO=${diag_ROOT}/ozinfo
# LOCINFO=${FIX_ROOT}/global_hybens_locinfo.164.txt
```

The next block creates a working directory (`workdir`) in which EnKF will run. The directory should have enough disk space to hold all the files needed for this run. This directory is cleaned before each run, therefore, save all the files needed from the previous run before rerunning EnKF.

```
# Set up workdir
rm -rf $WORK_ROOT
mkdir -p $WORK_ROOT
cd $WORK_ROOT
```

After creating a working directory, copy or link the EnKF executable, ensembles, diag files (observations), bias correction coefficients, and fixed files into the working directory.

```
cp $ENKF_EXE      ./enkf.x
cp $CONVINFO      ./convinfo
```

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```
cp $SATINFO          ./satinfo
cp $SCANINFO         ./scaninfo
cp $OZINFO           ./ozinfo
# cp $LOCINFO         ./hybens_locinfo

cp $diag_ROOT/satbias_in ./satbias_in
cp $diag_ROOT/satbias_pc ./satbias_pc

# get mean
ln -s ${BK_FILE_mem}.ensmean ./firstguess.ensmean
for type in $list; do
  ln -s $diag_ROOT/diag_${type}_ges.ensmean .
done

# get each member
imem=1
while [[ $imem -le $NMEM_ENKF ]]; do
  member="mem"$(printf %03i $imem)
  ln -s ${BK_FILE_mem}.${member} ./firstguess.${member}
  for type in $list; do
    ln -s $diag_ROOT/diag_${type}_ges.${member} .
  done
  (( imem = $imem + 1 ))
done
```

The following script is used to generate the EnKF namelist called `enkf.nml` in the working directory. Some namelist variables are explained in detail in Section 4.3. Appendix A gives a full list of namelist options.

```
# Build the GSI namelist on-the-fly
. $ENKF_NAMELIST
cat << EOF > enkf.nml

$enkf_namelist

EOF
```

Copy the ensemble background files to the working directory and rename them as `"analysis.${member}"`. The EnKF will update those files as the analysis results.

```
# make analysis files
cp firstguess.ensmean analysis.ensmean
# get each member
imem=1
while [[ $imem -le $NMEM_ENKF ]]; do
  member="mem"$(printf %03i $imem)
  cp firstguess.${member} analysis.${member}
  (( imem = $imem + 1 ))
done
```

The following block runs EnKF and checks if the EnKF has successfully completed.

```
#####
# run EnKF
#####
echo ' Run EnKF'

${RUN_COMMAND} ./enkf.x < enkf.nml > stdout 2>&1

#####
# run time error check
#####
error=?
```

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```
if [ ${error} -ne 0 ]; then
  echo "ERROR: ${ENKF_EXE} crashed Exit status=${error}"
  exit ${error}
fi
```

If this point is reached, the EnKF successfully finishes and exits with 0:

```
exit
```

3.3 Understanding Resulting Files in GSI Observer and EnKF Run Directory

To check if the GSI observer and EnKF runs have been successfully finished, it is important to understand the meaning of each file in the run directory.

3.3.1 The GSI Observer Run Directory

After customizing the GSI observer run script to your personal environment, it may be submitted to the batch system just as any other job. Following a successful run, the majority of the files in the GSI observer run directory will be the same as those in a successful GSI analysis run directory. The difference for the observer run is that the GSI observer generates more diag and stdout files related to each ensemble member. Below is an example of the files generated in the run directory from a GSI observer run:

amsuabuf	diag_amsua_n18_ges.mem010	fit_t1.2014021300	mhsbuf
amsubbuf	diag_amsua_n18_ges.mem011	fit_w1.2014021300	obs_input.0001
anavinfo	diag_amsua_n18_ges.mem012	fort.201	obs_input.0002
berror_stats	diag_amsua_n18_ges.mem013	fort.202	obs_input.0003
convinfo	diag_amsua_n18_ges.mem014	fort.203	obs_input.0004
diag_amsua_metop-a_ges.ensmean	diag_amsua_n18_ges.mem015	fort.204	obs_input.0006
diag_amsua_metop-a_ges.mem001	diag_amsua_n18_ges.mem016	fort.205	obs_input.0010
diag_amsua_metop-a_ges.mem002	diag_amsua_n18_ges.mem017	fort.206	obs_input.0019
diag_amsua_metop-a_ges.mem003	diag_amsua_n18_ges.mem018	fort.207	obs_input.0021
diag_amsua_metop-a_ges.mem004	diag_amsua_n18_ges.mem019	fort.208	obs_input.0022
diag_amsua_metop-a_ges.mem005	diag_amsua_n18_ges.mem020	fort.209	obs_input.0026
diag_amsua_metop-a_ges.mem006	diag_conv_ges.ensmean	fort.210	obs_input.0027
diag_amsua_metop-a_ges.mem007	diag_conv_ges.mem001	fort.211	obs_input.0028
diag_amsua_metop-a_ges.mem008	diag_conv_ges.mem002	fort.212	obs_input.0029
diag_amsua_metop-a_ges.mem009	diag_conv_ges.mem003	fort.213	obs_input.0030
diag_amsua_metop-a_ges.mem010	diag_conv_ges.mem004	fort.214	obs_input.common
diag_amsua_metop-a_ges.mem011	diag_conv_ges.mem005	fort.215	ozinfo
diag_amsua_metop-a_ges.mem012	diag_conv_ges.mem006	fort.217	pcpbias_out
diag_amsua_metop-a_ges.mem013	diag_conv_ges.mem007	fort.218	pcpinfo
diag_amsua_metop-a_ges.mem014	diag_conv_ges.mem008	fort.219	prepbufr
diag_amsua_metop-a_ges.mem015	diag_conv_ges.mem009	fort.220	prepobs_prep.bufhtable
diag_amsua_metop-a_ges.mem016	diag_conv_ges.mem010	fort.221	satbias_ang.out
diag_amsua_metop-a_ges.mem017	diag_conv_ges.mem011	fort.223	satbias_in
diag_amsua_metop-a_ges.mem018	diag_conv_ges.mem012	fort.224	satbias_out
diag_amsua_metop-a_ges.mem019	diag_conv_ges.mem013	fort.225	satbias_out.int
diag_amsua_metop-a_ges.mem020	diag_conv_ges.mem014	fort.226	satbias_pc
diag_amsua_n15_ges.ensmean	diag_conv_ges.mem015	fort.227	satbias_pc.out
diag_amsua_n15_ges.mem001	diag_conv_ges.mem016	fort.228	satinfo
diag_amsua_n15_ges.mem002	diag_conv_ges.mem017	fort.229	sigf03
diag_amsua_n15_ges.mem003	diag_conv_ges.mem018	fort.230	stdout

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diag_amsua_n15_ges.mem004	diag_conv_ges.mem019	gpsrobufr	stdout.anl.2014021300
diag_amsua_n15_ges.mem005	diag_conv_ges.mem020	gsi.exe	stdout_mem001
diag_amsua_n15_ges.mem006	diag_hirs4_metop-a_ges.ensmean	gsiparm.anl	stdout_mem002
diag_amsua_n15_ges.mem007	diag_hirs4_metop-a_ges.mem001	hirs3bufr	stdout_mem003
diag_amsua_n15_ges.mem008	diag_hirs4_metop-a_ges.mem002	hirs4bufr	stdout_mem004
diag_amsua_n15_ges.mem009	diag_hirs4_metop-a_ges.mem003	l2rwbufr	stdout_mem005
diag_amsua_n15_ges.mem010	diag_hirs4_metop-a_ges.mem004	list_run_directory	stdout_mem006
diag_amsua_n15_ges.mem011	diag_hirs4_metop-a_ges.mem005	list_run_directory_mem001	stdout_mem007
diag_amsua_n15_ges.mem012	diag_hirs4_metop-a_ges.mem006	list_run_directory_mem002	stdout_mem008
diag_amsua_n15_ges.mem013	diag_hirs4_metop-a_ges.mem007	list_run_directory_mem003	stdout_mem009
diag_amsua_n15_ges.mem014	diag_hirs4_metop-a_ges.mem008	list_run_directory_mem004	stdout_mem010
diag_amsua_n15_ges.mem015	diag_hirs4_metop-a_ges.mem009	list_run_directory_mem005	stdout_mem011
diag_amsua_n15_ges.mem016	diag_hirs4_metop-a_ges.mem010	list_run_directory_mem006	stdout_mem012
diag_amsua_n15_ges.mem017	diag_hirs4_metop-a_ges.mem011	list_run_directory_mem007	stdout_mem013
diag_amsua_n15_ges.mem018	diag_hirs4_metop-a_ges.mem012	list_run_directory_mem008	stdout_mem014
diag_amsua_n15_ges.mem019	diag_hirs4_metop-a_ges.mem013	list_run_directory_mem009	stdout_mem015
diag_amsua_n15_ges.mem020	diag_hirs4_metop-a_ges.mem014	list_run_directory_mem010	stdout_mem016
diag_amsua_n18_ges.ensmean	diag_hirs4_metop-a_ges.mem015	list_run_directory_mem011	stdout_mem017
diag_amsua_n18_ges.mem001	diag_hirs4_metop-a_ges.mem016	list_run_directory_mem012	stdout_mem018
diag_amsua_n18_ges.mem002	diag_hirs4_metop-a_ges.mem017	list_run_directory_mem013	stdout_mem019
diag_amsua_n18_ges.mem003	diag_hirs4_metop-a_ges.mem018	list_run_directory_mem014	stdout_mem020
diag_amsua_n18_ges.mem004	diag_hirs4_metop-a_ges.mem019	list_run_directory_mem015	wrfanl.2014021300
diag_amsua_n18_ges.mem005	diag_hirs4_metop-a_ges.mem020	list_run_directory_mem016	wrf_inout
diag_amsua_n18_ges.mem006	errtable	list_run_directory_mem017	wrf_inout_ensmean
diag_amsua_n18_ges.mem007	fit_p1.2014021300	list_run_directory_mem018	
diag_amsua_n18_ges.mem008	fit_q1.2014021300	list_run_directory_mem019	
diag_amsua_n18_ges.mem009	fit_rad1.2014021300	list_run_directory_mem020	

This case was a regional analysis with WRF/ARW NetCDF backgrounds. In this case, 20 ensemble members are used to generate the diag files. A brief introduction of the additional files in the GSI observer runs is given below:

- *diag_conv_ges.mem.???* - Diag files of conventional observations for ensemble member ???.
- *diag_conv_ges.ensmean* - Diag files of satellite radiance observation for ensemble mean.
- *stdout_mem.???* - Standard output from GSI observer run for ensemble member ???.
- *list_run_directory_mem.???* - The list of the files in the run directory after the GSI observer is finished for ensemble member ???.

3.3.2 Files in the EnKF Run Directory

After customizing the EnKF run script to your personal environment, it may be submitted to the batch system just as any other job. Upon successful assimilation, the ensemble analyses (both members and ensemble mean), covariance inflation factor to the ensemble analyses, and updated satellite bias correction coefficients (if requested) are output in the run directory. Below is an example of the files generated in the run directory from one of the EnKF regional test cases:

analysis.ensmean	diag_amsua_n18_ges.mem003	diag_conv_ges.mem008	firstguess.mem002
analysis.mem001	diag_amsua_n18_ges.mem004	diag_conv_ges.mem009	firstguess.mem003
analysis.mem002	diag_amsua_n18_ges.mem005	diag_conv_ges.mem010	firstguess.mem004
analysis.mem003	diag_amsua_n18_ges.mem006	diag_conv_ges.mem011	firstguess.mem005
analysis.mem004	diag_amsua_n18_ges.mem007	diag_conv_ges.mem012	firstguess.mem006
analysis.mem005	diag_amsua_n18_ges.mem008	diag_conv_ges.mem013	firstguess.mem007
analysis.mem006	diag_amsua_n18_ges.mem009	diag_conv_ges.mem014	firstguess.mem008
analysis.mem007	diag_amsua_n18_ges.mem010	diag_conv_ges.mem015	firstguess.mem009
analysis.mem008	diag_amsua_n18_ges.mem011	diag_conv_ges.mem016	firstguess.mem010
analysis.mem009	diag_amsua_n18_ges.mem012	diag_conv_ges.mem017	firstguess.mem011
analysis.mem010	diag_amsua_n18_ges.mem013	diag_conv_ges.mem018	firstguess.mem012
analysis.mem011	diag_amsua_n18_ges.mem014	diag_conv_ges.mem019	firstguess.mem013
analysis.mem012	diag_amsua_n18_ges.mem015	diag_conv_ges.mem020	firstguess.mem014

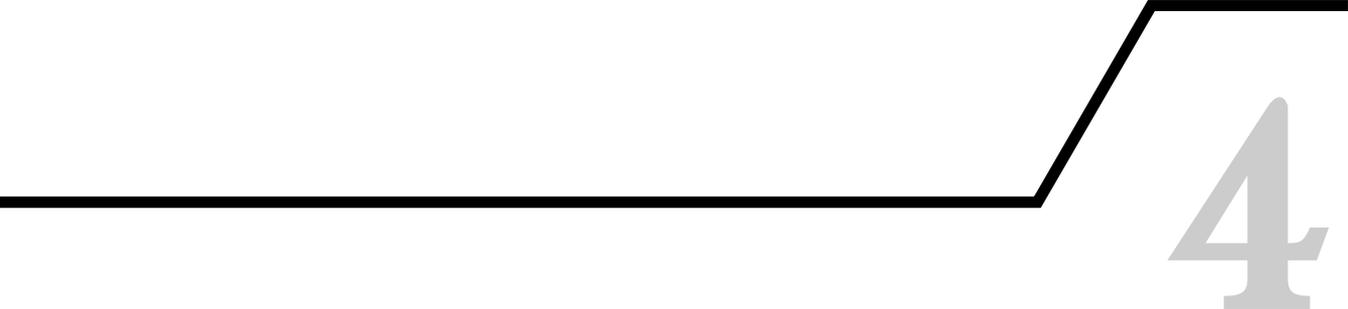
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analysis.mem013	diag_amsua_n18_ges.mem016	diag_gome_metop-a_ges.ensmean	firstguess.mem015
analysis.mem014	diag_amsua_n18_ges.mem017	diag_gome_metop-b_ges.ensmean	firstguess.mem016
analysis.mem015	diag_amsua_n18_ges.mem018	diag_omi_aura_ges.ensmean	firstguess.mem017
analysis.mem016	diag_amsua_n18_ges.mem019	diag_sbu2v2_n16_ges.ensmean	firstguess.mem018
analysis.mem017	diag_amsua_n18_ges.mem020	diag_sbu2v2_n17_ges.ensmean	firstguess.mem019
analysis.mem018	diag_conv_ges.ensmean	diag_sbu2v2_n18_ges.ensmean	firstguess.mem020
analysis.mem019	diag_conv_ges.mem001	diag_sbu2v2_n19_ges.ensmean	ozinfo
analysis.mem020	diag_conv_ges.mem002	diff.nc	satbias_ang.out
anavinfo	diag_conv_ges.mem003	enkf.log	satbias_in
convinfo	diag_conv_ges.mem004	enkf.nml	satbias_out.int
diag_amsua_n18_ges.ensmean	diag_conv_ges.mem005	enkf.x	satbias_pc
diag_amsua_n18_ges.mem001	diag_conv_ges.mem006	firstguess.ensmean	satinfo
diag_amsua_n18_ges.mem002	diag_conv_ges.mem007	firstguess.mem001	stdout

This case was a regional analysis with WRF/ARW NetCDF backgrounds. In this case, 20 ensemble members are used to estimate ensemble covariance, and both conventional observations (prepbufr) and radiance observations (AMSU-A) are assimilated.

A brief introduction of the files is given in the table below:

stdout	A text output file. This is the most commonly used file to check the analysis processes as well as basic and important information about the analyses. The contents of stdout are explained in detail in Chapter 4 and users are encouraged to read this file to become familiar with the order of EnKF analysis processing.
firstguess. mem001-0??	ensemble members of WRF background, in NetCDF format. This is in the same format as the WRF forecast. The ensemble background of the analysis variables are extracted from the files.
firstguess.ensmean	ensemble mean of WRF background, in NetCDF format.
analysis. mem001-0??:	ensemble analysis if EnKF completes successfully. The format is the same as the background file.
analysis.ensmean	ensemble mean of analyses, in NetCDF format.
diag_conv_ges. mem001-0??:	diag files in binary for conventional and GPS RO observations, which contain the observations and their priors.
covinflate.dat	Three-dimensional multiplicative inflation factor fields (from function inflate_ens in module inflation). These inflation fields can be visualized using plotting software.
*info (convinfo, satinfo, . . .):	info files that control data usage. Please see GSI User guide Chapter 4 for details.
satbias_in	the input coefficients of bias correction for satellite radiance observations.
satbias_pc	the input coefficients of satellite radiance bias correction for passive channels.



4

EnKF Diagnostics and Tuning

This chapter will discuss how to assess whether an EnKF was successful based on the contents of the standard output (stdout). Properly checking the EnKF output will also provide useful information to diagnose potential errors in the system. The chapter begins with an introduction to the content and structure of the EnKF stdout, followed by detailed discussion of tuning options in the namelist. This chapter follows a case at 00z on February 13th, 2014 (case 2014021300). This case uses WRF-ARW NetCDF ensemble files as the background and analyzes several observations typical for operations, including most conventional observation data and select radiance data (AMSU-A , HIRS4). The case was run on a Linux cluster supercomputer, using 32 cores. Users can follow this test to reproduce the following results by visiting:

<http://www.dtcenter.org/EnKF/users/tutorial/index.php>

4.1 Understanding the Standard Output from EnKF (stdout)

Upon completion of an EnKF run, it is always useful to do a quick check of the standard output (stdout), to assess the performance of the EnKF. The stdout file has information about whether the EnKF analysis has successfully completed, if the ensemble spread inflation looks good, and if the background and analysis fields are reasonable. Understanding the contents of this file can also be very helpful for users to find clues in the event of a crash.

The EnKF stdout has following information:

- a. namelist configuration
- b. background ensemble members of observations and analysis variables

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The actual analysis variables and the background type are printed, as well as the maximum and minimum of the surface pressure as a sanity check:

```
Updating U, V, T, QVAPOR, PH, and MU for WRF-ARW...
Surface pressure (spressmn) min/max range: 678.673339843750
1032.22473144531
```

Next, the contents of convinfo are displayed:

```
READ_CONVINFO: tcp      112  0  1  3.000    0  0  0  75.00    5.000    1.000    75.00    0.000    0  0.000    0.000    0  0.000    0.000    2
READ_CONVINFO: ps      120  0  1  3.000    0  0  0  4.000    3.000    1.000    4.000    0.3000E-03    0  0.000    0.000    0  0.000    0.000    2
line ignored in convinfo due to use flag ps
-1
.....
line ignored in convinfo due to use flag gps
-1
```

The next 272 lines show the content of ozinfo:

```
OZINFO_READ:  jpch_oz= 272
 1 sbuv6_n14    lev = 1 use = -1 pob = 0.240 gross = 1.000 error = 1.000 b_oz = 10.000 pg_oz = 0.000
 2 sbuv6_n14    lev = 2 use = -1 pob = 0.490 gross = 1.000 error = 1.000 b_oz = 10.000 pg_oz = 0.000
 3 sbuv6_n14    lev = 3 use = -1 pob = 0.980 gross = 1.000 error = 1.000 b_oz = 10.000 pg_oz = 0.000
... ..
271 mls30_aura  lev = 54 use = -1 pob = 999.999 gross = 9.999 error = 9.999 b_oz = 10.000 pg_oz = 0.000
272 mls30_aura  lev = 55 use = -1 pob = 999.999 gross = 9.999 error = 9.999 b_oz = 10.000 pg_oz = 0.000
```

The next 2723 lines show the content of satinfo and starts reading in the radiance bias correction coefficients:

```
RADINFO_READ:  jpch_rad= 2723
 1 amsua_n15    chan= 1 var= 3.000 varch_cld= 20.000 use= 1 ermax= 4.500 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
 2 amsua_n15    chan= 2 var= 2.200 varch_cld= 18.000 use= 1 ermax= 4.500 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
 3 amsua_n15    chan= 3 var= 2.000 varch_cld= 12.000 use= 1 ermax= 4.500 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
 4 amsua_n15    chan= 4 var= 0.600 varch_cld= 3.000 use= 1 ermax= 2.500 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
... ..
2722 ahi_himawari8 chan=15 var= 2.200 varch_cld= 0.000 use= -1 ermax= 2.000 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
2723 ahi_himawari8 chan=16 var= 2.200 varch_cld= 0.000 use= -1 ermax= 2.000 b_rad= 10.00 pg_rad= 0.00 icld_det=-2
```

The majority of next near 3000 lines show the content of radiance bias correction coefficients:

```
RADINFO_READ:  guess air mass bias correction coefficients below
 1 amsua_n15    -1.96518  0.00000  39.06817 -0.92319  0.40846  0.00000  0.00000  0.00173  3.68970  2.36747  8.86294 -1.84829
 2 amsua_n15    -7.41540  0.00000  80.13801 -0.81847 -1.01321  0.00000  0.00000  0.01427  2.63880  8.31509  22.04145 -1.56477
... ..
2679 avhrr3_metop-b 0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
2680 avhrr3_metop-b 0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
```

Among the lines describing the radiance bias correction coefficients, the EnKF also starts to inventory the observation number and types for both conventional and radiance data. Observations of various types are read in (from the diag** files) and the number of the observations and time spent reading in the observations are shown:

Start to check the radiance and ozone observations:

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```

1      sbuv2_n16  nread=      0  nkeep=      0  num_obs_tot=      0
1      amsua_n15  nkeep=      0  num_obs_tot=      0
2      sbuv2_n17  nread=      0  nkeep=      0  num_obs_tot=      0
3      sbuv2_n18  nread=      0  nkeep=      0  num_obs_tot=      0
4      sbuv2_n19  nread=      0  nkeep=      0  num_obs_tot=      0
5      omi_aura   nread=      0  nkeep=      0  num_obs_tot=      0
6      gome_metop-a nread=      0  nkeep=      0  num_obs_tot=      0
7      gome_metop-b nread=      0  nkeep=      0  num_obs_tot=      0
0      ozone obs
2      amsua_n18  nkeep=    6284  num_obs_tot=    6284
3      amsua_n19  nkeep=      0  num_obs_tot=    6284
6      amsua_aqua nkeep=      0  num_obs_tot=    6284
7      amsua_metop-a nkeep=      0  num_obs_tot=    6284
8      airs_aqua  nkeep=      0  num_obs_tot=    6284
11     hirs4_metop-a nkeep=    154  num_obs_tot=    6438
12     mhs_n18    nkeep=      0  num_obs_tot=    6438
13     mhs_n19    nkeep=      0  num_obs_tot=    6438
14     mhs_metop-a nkeep=      0  num_obs_tot=    6438
15     goes_img_g11 nkeep=      0  num_obs_tot=    6438
25     ssmis_f17  nkeep=      0  num_obs_tot=    6438
45     sndrd1_g15 nkeep=      0  num_obs_tot=    6438
46     sndrd2_g15 nkeep=      0  num_obs_tot=    6438
47     sndrd3_g15 nkeep=      0  num_obs_tot=    6438
48     sndrd4_g15 nkeep=      0  num_obs_tot=    6438
49     iasi_metop-a nkeep=      0  num_obs_tot=    6438
52     seviri_m10 nkeep=      0  num_obs_tot=    6438
53     amsua_metop-b nkeep=      0  num_obs_tot=    6438

```

Start to check the conventional observations:

```

columns below obtype,nread, nkeep
t      8043      7904
q      2625      2621
ps     14133     14133
uv     21982     21982
sst      0        0
gps      0        0
pw      0        0
dw      0        0
srw     0        0
rw      0        0
tcp     0        0

```

A summary of the total number of conventional (1st number 46640), ozone (2nd number 0), and radiance observations (3rd number 6438) in diag files is given:

```
nobs_conv, nobs_oz, nobs_sat =      46640      0      6438
```

Also, the following normalization factors for the radiance bias predictors could be inside the bias correction coefficient lines:

```

npred =      12
      1 biasprednorm =      1.000000
      2 biasprednorm =      1.000000
... ..
     11 biasprednorm =      1.000000
     12 biasprednorm =      1.000000

```

Then, the time spent reading in the observations and the total number of observations kept and rejected are shown:

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```

max time in mpireadobs = 0.6105460
total number of obs      53078
  53078 obs kept
    0 total obs rejected
time in read_obs = 1.25072427513078    on proc      0

```

In the stdout, regional averaged (northern hemisphere - NH, southern hemisphere - SH, and tropics - TR) statistics of the ensemble 'priors' fit to all observations are provided, partly for checking if the inflation is appropriate. The details of this part are discussed in next Section 4.2.

```

innovation statistics for prior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH  all ps  14083 -0.591E-02  0.860E+00  0.814E+00  0.601E+00  0.550E+00
TR  all ps   50 -0.629E-01  0.422E+00  0.661E+00  0.367E+00  0.550E+00
NH  all t   7766 -0.228E+00  0.163E+01  0.128E+01  0.480E+00  0.119E+01
TR  all t   138 -0.130E+00  0.118E+01  0.119E+01  0.234E+00  0.117E+01
NH  all uv  21680  0.136E-01  0.295E+01  0.276E+01  0.140E+01  0.237E+01
TR  all uv   302 -0.379E+00  0.251E+01  0.268E+01  0.124E+01  0.238E+01
NH  all q   2553 -0.323E-01  0.146E+00  0.157E+00  0.868E-01  0.131E+00
TR  all q    68 -0.721E-01  0.202E+00  0.164E+00  0.582E-01  0.154E+00
satellite brightness temp
instrument, channel #, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
  amsua_n18  1  241 -0.199E+00  0.194E+01  0.306E+01  0.176E+01  0.250E+01
  amsua_n18  2  248 -0.194E+00  0.145E+01  0.234E+01  0.806E+00  0.220E+01
  amsua_n18  3  248 -0.620E+00  0.119E+01  0.206E+01  0.497E+00  0.200E+01
  amsua_n18  4  248 -0.189E+00  0.398E+00  0.568E+00  0.140E+00  0.550E+00
  amsua_n18  5  248  0.188E-01  0.337E+00  0.315E+00  0.966E-01  0.300E+00
  amsua_n18  6 1203 -0.396E-01  0.198E+00  0.238E+00  0.610E-01  0.230E+00
  amsua_n18  7 1225 -0.215E+00  0.324E+00  0.235E+00  0.480E-01  0.230E+00
  amsua_n18  8 1155 -0.235E+00  0.369E+00  0.259E+00  0.675E-01  0.250E+00
  amsua_n18 10 1211  0.408E+00  0.491E+00  0.353E+00  0.429E-01  0.350E+00
  amsua_n18 11  12  0.720E+00  0.723E+00  0.404E+00  0.567E-01  0.400E+00
  amsua_n18 15  245 -0.311E+00  0.198E+01  0.380E+01  0.148E+01  0.350E+01
  hirs4_metop-a  3  1  0.115E+01  0.115E+01  0.534E+00  0.631E-01  0.530E+00
  hirs4_metop-a  4  42  0.260E+00  0.521E+00  0.403E+00  0.488E-01  0.400E+00
  hirs4_metop-a  5  7 -0.534E+00  0.558E+00  0.367E+00  0.696E-01  0.360E+00
  hirs4_metop-a  6  7 -0.748E+00  0.782E+00  0.473E+00  0.109E+00  0.460E+00
  hirs4_metop-a  7  9 -0.557E+00  0.815E+00  0.580E+00  0.108E+00  0.570E+00
  hirs4_metop-a  8  9  0.374E+00  0.675E+00  0.100E+01  0.208E-01  0.100E+01
  hirs4_metop-a 10  9  0.199E+00  0.581E+00  0.612E+00  0.120E+00  0.600E+00
  hirs4_metop-a 11  9 -0.380E-01  0.718E+00  0.143E+01  0.770E+00  0.120E+01
  hirs4_metop-a 12  34 -0.988E+00  0.179E+01  0.213E+01  0.141E+01  0.160E+01
  hirs4_metop-a 13  9  0.694E-01  0.330E+00  0.382E+00  0.116E+00  0.364E+00
  hirs4_metop-a 14  9 -0.369E-01  0.257E+00  0.294E+00  0.137E+00  0.260E+00
  hirs4_metop-a 15  9  0.352E-01  0.289E+00  0.281E+00  0.107E+00  0.260E+00
time in estimate_work_enkf1 = 5.723375361412764E-002 secs

```

Next, the analysis variable fields and the observations are distributed to the different processors. The following lines show the maximum and minimum number of observations and grid on subdomain and the time used to setup those decompositions:

```

time in estimate_work_enkf1 = 5.723375361412764E-002 secs
min/max numobs      32      7663
min/max estimated work  637809    638478
npts = 9030
min/max number of points per proc = 243      317
time to do model space decomp = 1.529277069494128E-003
nobstot = 53078
min/max number of obs per proc = 1658      1659
time to do ob space decomp = 3.935033455491066E-004
sending out observation prior ensemble perts from root ...
nobstot*nanals      1061560
npts*ndim           2266530
... took 1.730861375108361E-002 secs
time in load_balance = 7.929413160309196E-002 on proc      0

```

4. EnKF Diagnostics and Tuning

Then, the ensemble background members of the analysis variables are read in and the maximum and minimum values of the fields at each vertical level are displayed. The maximum and minimum values are useful for a quick confirmation that the background fields have been read successfully. The size of the real array of ensemble perturbations updated on each processor and the time spent to read in and distribute the background ensemble are also shown:

```
anal_chunk size =      1591340
READGRIDDATA_ARW: U          1 -20.55222      20.72632
...
READGRIDDATA_ARW: U          50 -12.60845      52.03727
READGRIDDATA_ARW: V          51 -11.67894      21.03603
...
READGRIDDATA_ARW: V
...
READGRIDDATA_ARW: V          100 -17.20951      21.87867
READGRIDDATA_ARW: T          101 -62.00526      13.33912
...
READGRIDDATA_ARW: T          150  469.5381      509.8757
READGRIDDATA_ARW: QVAPOR      151  8.4173851E-05  1.7215064E-02
...
READGRIDDATA_ARW: QVAPOR      200  1.5460877E-06  1.0506745E-05
READGRIDDATA_ARW: PH          201 -14.64355      4.688477
...
READGRIDDATA_ARW: PH          250  7195.078      14206.67
READGRIDDATA_ARW: MU          251 -1326.610      3290.569
time in readgriddata on root  0.326851664343849      secs
time to scatter state on root  0.163762195268646      secs
time in read_ensemble = 0.494254242163152      on proc      0
```

In EnSRF, observations can be skipped/not assimilated due to the adaptive observation thinning. The following lines show how many observations are skipped or not assimilated by this thinning.

```
assimilate obs in order they were read in
1 timing on proc 0 = 0.51 0.24 0.01 0.10 0.00 0.15 0
    22152 out of 53078 obs skipped, 30926 used
    22736 out of 30926 same lat/long
time to broadcast obfit_post = 5.432746838778257E-004 secs, niter =
1
```

Next, the update to the analysis variables is performed and the time for the updating is shown:

```
time in enfk_update = 4.79503449611366      on proc      0
```

The regional averaged statistics of the inflation values are shown for surface pressure:

```
global ps prior std. dev min/max = 21.52301      172.3270
NH mean ps prior standard deviation = 57.82042
NH mean ps posterior standard deviation (before inflation)= 29.20955
NH mean ps posterior standard deviation (after inflation) = 54.58403
NH mean ps inflation = 2.421974
TR mean ps prior standard deviation = 31.09247
TR mean ps posterior standard deviation (before inflation)= 28.31872
TR mean ps posterior standard deviation (after inflation) = 30.79383
TR mean ps inflation = 1.106122
time in inflate_ens = 1.366839744150639E-002 on proc      0
```

After the EnKF analysis, innovation statistics of the ensemble analyses are shown, similar to the ensemble prior's fit to all observations:

4. EnKF Diagnostics and Tuning

```
*****RESOURCE STATISTICS*****
The total amount of wall time           = 7.431095
The total amount of time in user mode   = 6.480014
The total amount of time in sys mode    = 0.713891
The maximum resident set size (KB)      = 122848
Number of page faults without I/O activity = 46688
Number of page faults with I/O activity = 0
Number of times filesystem performed INPUT = 0
Number of times filesystem performed OUTPUT = 0
Number of Voluntary Context Switches    = 24121
Number of InVoluntary Context Switches  = 138
*****END OF RESOURCE STATISTICS*****
```

all done!

4.2 Tuning of Inflation and Localization

Proper inflation and localization values need to be determined by experimenting with different inflation values. The goal is to make the total ensemble spreads of priors match the innovations as much as possible. In the tuning process, the vertical and horizontal structure of the match should be carefully examined. The 3D distribution of the inflation values can be plotted offline from the output file "covinflate.dat".

The tuning processes can vary for different resolutions and physics of the models as well as the observation types assimilated. The performance of the tuning may be better examined after multiple assimilation cycles allowing their effects to be accumulated and converged in cycling assimilation. Please also note that proper settings of observation error estimations are also critical for the inflation tuning.

Next, the test case is taken as an example to check if the inflation is appropriate. In the following lines of the standard output (stdout), the number (column nobs), mean (column bias), and standard deviation (column innov stdev) of the ensemble background fits to Ps, wind, temperature, and water vapor observations in the NH and TR are shown:

```
innovation statistics for prior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH all ps 14083 -0.591E-02 0.860E+00 0.814E+00 0.601E+00 0.550E+00
TR all ps 50 -0.629E-01 0.422E+00 0.661E+00 0.367E+00 0.550E+00
NH all t 7766 -0.228E+00 0.163E+01 0.128E+01 0.480E+00 0.119E+01
TR all t 138 -0.130E+00 0.118E+01 0.119E+01 0.234E+00 0.117E+01
NH all uv 21680 0.136E-01 0.295E+01 0.276E+01 0.140E+01 0.237E+01
TR all uv 302 -0.379E+00 0.251E+01 0.268E+01 0.124E+01 0.238E+01
NH all q 2553 -0.323E-01 0.146E+00 0.157E+00 0.868E-01 0.131E+00
TR all q 68 -0.721E-01 0.202E+00 0.164E+00 0.582E-01 0.154E+00
```

It would be desirable that the total ensemble spreads of prior/background match the innovation standard deviations as close as possible (Equation 15). In practice, one should check if there is any substantial ensemble spread deficiency. In the above sample standard output lines, the ensemble prior spreads are shown in the column \sqrt{S} , and the total spreads in the column $\sqrt{S+R}$. Here, \sqrt{R} is the observation error.

The above sample statistics shows that in NH, the total spread of temperature observation priors (0.128E+01) is close to the innovation standard deviation (0.163E+01) of the priors fit to the observations.

4.3 Tuning EnKF through Key Namelist Options

The namelist parameters controlling the EnSRF analysis are set in the namelist sections: /enkf_nml/, /satobs_enkf/, and /nam_wrf/ (all in the file `enkf.nml`). To obtain a successful analysis, it is very important to setup/tune properly the namelist variables, particularly those related to inflation and localization, for each specific application configuration of various models and observation types.

4.3.1 Set Up the Analyses Time and Data Location

The analysis time and working location are setup by the following parameters:

datein: analysis time (YYYYMMDDHH)
datapath: path to data directory (include trailing slash). In most cases, this should point to the current directory because the run scripts have setup the run environment in the working directory including copying the EnKF executable and data into the working directory.

4.3.2 Set Up Analysis Algorithm

In the current implementation, a few variations/flavors of the EnKF are available, including the ensemble square root Kalman filter (EnSRF, *Whitaker et al.*, 2010, etc), the perturbed observations EnKF, and the local transformed Kalman filter (LETKF). These options are set in the namelists below:

deterministic = true, use EnSRF without perturbed observations;
= false, use perturbed observations version of EnKF.
sortinc if deterministic = false, re-order observations to minimize regression errors as described in Anderson (2003).
letkf_flag if true, use the LETKF scheme.
boxsize observation box size for LETKF (deg)
iassim_order = 0, assimilation of observations in the order they are read in;
= 1 in random order;
= 2 in order of predicted posterior variance reduction.

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paoverpb_thresh the threshold of the ratio of observation space posterior variance divided by prior variance (≤ 1.0), that is, the expected reduction of prior variance by the observations.

Smaller values mean only those observations with stronger impact will be assimilated.

If =1, no thinning of observations is done. Typical values: 0.99 or 0.98.

4.3.3 Set Up the Analyses Variables

The analyses variables for both global and regional models are hardcoded in the EnSRF. There are several options using the following parameters:

```
nvars: number of 3d model variables to update.
```

For hydrostatic global models, there are typically 5, including U, V, T, QVAPOR, Ozone. For non-hydrostatic regional models, like WRF, different combinations of the 3D and 2D analyses variables are set as below:

```
For ARW          (arw =true)
  nvars          =3: U, V, T, and MU
                 =4: U, V, T, QVAPOR, and MU
                 =5: U, V, T, QVAPOR, PH, and MU
                 =6: U, V, W, T, QVAPOR, PH, and MU

For NMM          (nmm =true)
  nvars          =3: U, V, T, and PD
                 =4: U, V, T, QVAPOR, and PD
                 =5: U, V, T, QVAPOR, CWM, and PD
```

The analyses variable list can be adjusted or additional variables, such as moisture related variables, can be added to the list by modifying the subroutines "gridinfo.F90" and "gridio.F90" accordingly.

pseudo_rh: use or not 'pseudo-rh' analysis variable, as in GSI.
cliptracers: if true, tracers are clipped to zero when read in, and just before they are written out.

4.3.4 Set Up the Ensemble Backgrounds

The following parameters define which background fields will be used in the analyses and their dimensions:

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<i>regional</i>	= true, perform regional EnSRF analyses using either ARW or NMM inputs as the background. =false, perform a global analysis. If either the parameter nmm or wrf is set to true, it will be set to true.
<i>nmm</i>	if true, background comes from WRF NMM. When using other background fields, set it to false.
<i>wrf</i>	if true, background comes from WRF ARW. When using other background fields, set it to false.
<i>nlons</i>	number of grid points in longitude of the model background
<i>nlats</i>	number of grid points in latitude of the model background
<i>nlevs</i>	number of vertical levels of the model background
<i>nanls</i>	number of ensemble members

4.3.5 Set Up Localization Distances

In the current EnKF implementation, distances for localization can be set separately in the northern hemisphere, tropics and southern hemisphere, and in the horizontal, vertical and time dimensions, and for different observation types using namelist parameters. The length scales should be given in km for the horizontal, hours for time, and scale heights (units of $-\log(P/P_{ref})$) in the vertical.

There are two options to setup the localization distances in horizontal and vertical. These are decided by the namelist variable "readin_localization" :

<i>readin_localization:</i>	=.true., customized horizontal and vertical localization values varying with model levels are read in from the external text file "hybens_locinfo". =.false., the horizontal and vertical localization distances are set by the following parameters
<i>corrlengthnh:</i>	length for horizontal localization in km in the northern hemisphere (25N-90N, NH)
<i>corrlengthtr:</i>	length for horizontal localization in km in the tropics (25S-25N, TR)
<i>corrlengthsh:</i>	length for horizontal localization in km in the southern hemisphere (25S-90S, SH)
<i>linsigcutoffnh:</i>	scale height for vertical localization in $-\log(P/P_{ref})$ in NH.
<i>linsigcutofftr:</i>	scale height for vertical localization in $-\log(P/P_{ref})$ in TR.
<i>linsigcutoffsh:</i>	scale height for vertical localization in $-\log(P/P_{ref})$ in SH.

The text file "hybens_locinfo" contains vertical profile of horizontal and vertical localization length scales (in e-folding scale). These scales are converted to the full distance width ($*1/0.388$ in km) of Gaspari-Cohn function, where it goes to zero. The horizontal and vertical scales can be adjusted for each observation types easily in the subroutine "read_locinfo.f90" .

For satellite radiance and surface pressure observations, the vertical localization distances are set separately using the following parameters:

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l_{nsigcutoffsatnh}, l_{nsigcutoffsattr}, l_{nsigcutoffsatsh}; and
l_{nsigcutoffpsnh}, l_{nsigcutoffpstr}, l_{nsigcutoffpssh}

There is also one option to setup the time localization window, which is the time away from the analyses time. This is decided by the following namelist variables:

obtimelnh: time in hours away from the analyses time to move 2800
km at 30 ms-1 in the northern hemisphere
obtimeltr: same as *obtimelnh* but for the tropics
obtimelsh: same as *obtimelnh* but for the southern hemisphere

The empirical determination/tuning of proper localization distances is important for successful analyses with ensemble data assimilation. In general, large horizontal scale observations, like GPS radio occultation and radiosonde observations, require larger horizontal localization distances to fully take advantage of the observations. On the other hand, high horizontal resolution observations, like radar observations, may need shorter horizontal localization distances. The same is true for the localization distance in vertical.

4.3.6 Set Up Adaptive Posterior Inflation Parameters

The inflation can be set up by the following parameters:

anapertwtnh: inflation parameter in NH.
anapertwttr: inflation parameter in TR.
anapertwtsh: inflation parameter in SH.
The parameters = 0 means no inflation.
= 1 means inflation all the way back to prior spread.

These are the key tuning parameters for the performance of EnSRF. Typical values: 0.95.

The inflation factor fields can be smoothed out using the following parameter:

smoothparm: parameter for smoothing inflation factor,
= -1 for no smoothing.
> 0, the estimated inflation factor is smoothed using a
Gaussian spectral filter with an e-folding scale of the parameter
latbound: where the transition latitude starts (=25N or 25S)
delat: latitude width of transition zone where the inflation
parameter is smoothed.

The minimum and maximum inflation values allowed can be controlled by the following parameters:

covinflatemin: minimum inflation factor
covinflatemax: maximum inflation factor

4.3.7 Satellite Observations Related Parameters

The following parameters are used to setup the adaptive satellite bias correction:

<i>lupd_satbias:</i>	= .true., update the satellite bias correction coefficients using the adaptive bias correction scheme (when the iterations of <i>numiter</i> > 1).
	= .false., the bias correction coefficients are not updated.
<i>numiter:</i>	number of iterations for state/bias correction coefficients update. (only relevant when satellite radiances assimilated, i.e. <i>nobs_sat</i> >0)
<i>biasvar:</i>	background error variance for radiance bias coefficients (used in <i>radbias.f90</i>). The default is GSI value.
<i>saterrfact:</i>	factor to multiply satellite radiance errors.
<i>sattypes_rad:</i>	list of satellite observation types to be assimilated.
<i>sattypes_oz:</i>	list of ozone observation types to be assimilated.

4.3.8 Observation QC Parameters

In addition to the observation quality flags decided in the GSI observer, the EnSRF itself also conducts a gross check on the observations.

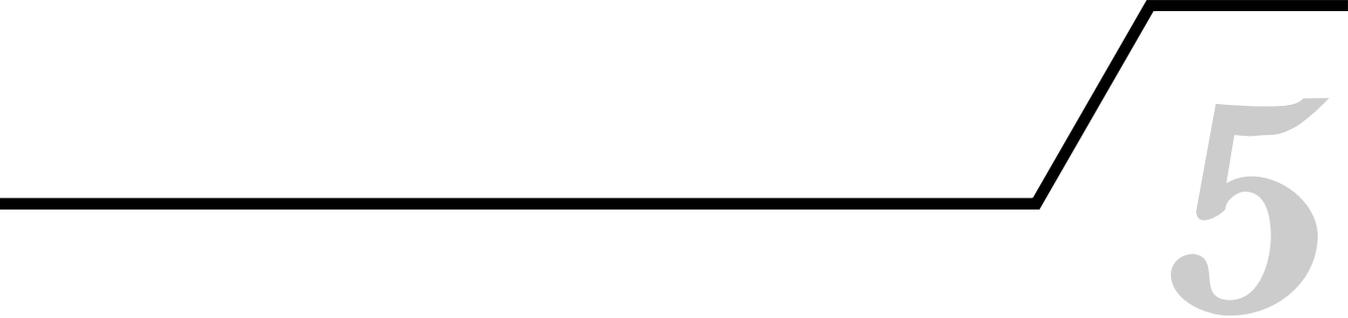
The outlier test computes the difference between the observation value and the prior ensemble mean. It then computes a standard deviation by taking the square root of the sum of the observation error variance and the prior ensemble variance for the observation. If the difference between the ensemble mean and the observation value is more than the specified number of standard deviations, then the observation is tossed. The threshold of the check is set as following:

sprd_tol: tolerance for gross check of observations.

Reject a observation if the prior mean is more than this many $\sqrt{(S + R)}$ from the observation, where S is ensemble prior variance and R is observation error variance. Typical value: 3.0

The following parameters are used to control if the GSI quality control procedure is performed in EnSRF:

<i>varqc:</i>	= .false., no variational quality control performed (default).
<i>huber:</i>	= .true., use huber norm instead of "flat-tail" (default: .false.).
<i>zhuberleft:</i>	departure parameter of huber norm.
<i>zhuberright:</i>	departure parameter of huber norm.



5

Applications for Regional and Global EnKF

In this chapter, the elements from the previous chapters will be applied to demonstrate how to run a regional and global case using the GSI observer and EnKF. These examples are intended to give users a clear idea of how to set up the GSI observer and EnKF for a particular application and properly check the run status and analysis results in order to determine if the run was successful. Note that the regional example focuses on WRF ARW, however WRF NMM and NMMB runs are similar, but require different background ensemble and namelist options. Similarly, the global example features a single global configuration (T254), however users may wish to use a different configuration, again requiring different background ensemble and namelist options.

It is assumed that the reader has successfully compiled GSI and EnKF on a local machine. For **regional case studies**, users should have the following data available:

1. Ensemble for background
 - Ensemble files from WRF-ARW, WRF-NMM, NMM-B forecast files may be used. For this case, WRF-ARW ensemble members will be used, which are generated from the GFS ensemble, following the naming convention: `wrfarw.mem00nn`. Where `nn` corresponds to each ensemble member ("ensmean" appended for ensemble mean).
2. Conventional, GPSRO and radiance data
 - Real time GDAS and NAM PrepBUFR data can be obtained from the server: `ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/`

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<ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/nam/prod/>

3. Fixed files

- Fixed files are located in the `comGSIv3.7_EnKFv1.3/fix` directory

For **global case studies**, users should have the following data available:

1. Ensemble for background

- Ensemble files from GFS forecast files may be used. GFS ensemble members corresponding to various spectral resolutions may be used, following the naming convention: `sfg_yyyymmddhh_fhrff_mem0nn`. The "yyyymmddhh" corresponds to the initialization date, "ff" corresponds to the forecast hour, and "nn" corresponds to each ensemble member (ensmean appended for ensemble mean).

2. Conventional data

- Real time GDAS PrepBUFR (and BUFR) data can be obtained from the server:
<ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/>

3. Fixed files

- Fixed files are located in the `comGSIv3.7_EnKFv1.3/fix` directory

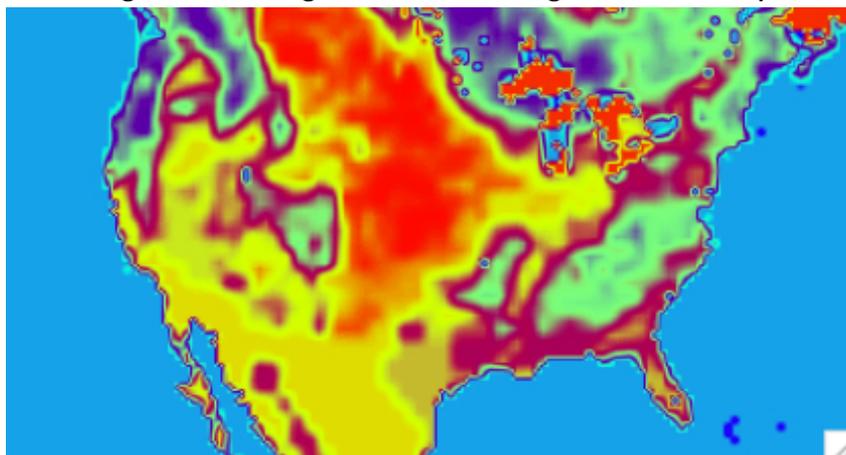
The following cases will give users an example of how to run the EnKF for a regional case with various data sources, as well as a simple global application case. Users are welcome to download these examples from the EnKF User's webpage (online case for release v1.1) or create a new background ensemble and obtain observation data from the above server.

The background ensemble files and observations used in the regional case studies are as follows:

1. Background files: `wrfarw.mem0001 - wrfarw.mem0020`, `wrfarw.ensmean`

- The horizontal grid spacing is 45-km with 51 vertical sigma levels.

Figure 5.1: Background used for regional case study



2. Conventional, GPSRO and radiance data from 00 UTC 13 February 2014

- Conventional file:
 - `gdas1.t00z.prepbufr.nr`
- GPSRO file:
 - `gdas1.t00z.gpsro.tm00.bufr_d`

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- Radiance files:
 - gdas1.t00z.1bamua.tm00.bufr_d
 - gdas1.t00z.1bhrs4.tm00.bufr_d
 - gdas1.t00z.1bmhs.tm00.bufr_d
3. Fixed files:
- Fixed files are located in the GSI/EnKF community code package, under /comGSIv3.7_EnKFv1.3/fix
 - For observation control:
 - convinfo: conventional data (PrepBUFR, GPSRO) info file
 - ozinfo: ozone retrieval info file
 - satinfo: satellite radiance info file
 - Adaptive radiance bias correction. Although example files are provided in the /fix directory, it is better to obtain bias correction files valid for the proper date. For this case, GFS bias correction coefficients are provided with the case data:
 - comgsi_satbias_in: satellite bias correction coefficient file
 - comgsi_satbias_pc_in: satellite bias correction coefficient file for passive channels.

This case study was run on a linux cluster. GSI no longer (from GSI v3.2) requires byte-swapping to little endian format. BUFRlib can automatically handle byte order issues.

For the **regional ARW case**, assume the following locations:

Path to the background ensemble files:

```
/scratch/casedata/enkf_arw_2014021300/bk/
```

the path to the observations:

```
/scratch/casedata/enkf_arw_2014021300/obs
```

and the GSI release version 3.7/EnKF version 1.3 is located at:

```
/scratch/comGSIv3.7_EnKFv1.3
```

For the global GFS case, assume locations as follows: Path to background ensemble files:

```
/scratch/casedata/enkf_glb_t62/bkg
```

the path to the observations:

```
/scratch/casedata/enkf_glb_t62/obs
```

and the GSI release version 3.7/EnKF version 1.3 is located at:

```
/scratch/comGSIv3.7_EnKFv1.3
```

5.1 Running GSI Observer for Regional Applications

5.1.1 Run Script

With both GSI and EnKF compiled and the background ensemble files and observations acquired, the next step is to work with the `gsi` observer run script, `comgsi_run_regional.ksh`. The location of this script is under `comGSIv3.7_EnKFv1.3/ush`. This run script is the same as the one used for a GSI analysis run, with a few specific options selected in order to loop through all the ensemble members and generate the ensemble observation priors for each member and the ensemble mean. In addition to the GSI observer specific options, other user-specific modifications need to be made:

- **Set up batch queuing system**

To run GSI with multiple processors, a job queuing head must be added to the `comgsi_run_regional.ksh` script. The set up of the job queue is dependent on the machine and the job control system. Refer to the GSI User's Guide, section 3.2.2, for more examples of the setup section of this script. The following example is setup to run on a Linux cluster with PBS:

```
#PBS -A P????????
#PBS -l walltime=00:20:00
#PBS -N observer-allobs
#PBS -l select=1:ncpus=4:mpiprocs=4
#PBS -q regular
#PBS -o out.observer-allobs
#PBS -j oe
```

- **Set up number of processors and the job queue system used** For this example, LINUX_PBS and 4 processors are used:

```
GSIPROC=4
ARCH='LINUX_PBS'
```

- **Set up the case data, analysis time, fix files, GSI executable, and CRTM coefficients:**

Set up analysis time:

```
ANAL_TIME=2014021300
```

Set up working directory, which will hold the analysis results (all ensemble members will be run in this directory). This directory must have the proper write permissions as well as enough space to hold the output.

```
JOB_DIR=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/gsideag_2014021300
```

Set path to the observation directory and the PrepBUFR file within the observation directory. All observations to be assimilated should reside in this directory.

```
WORK_ROOT=/scratch/${user}/casedata/enkf_arw_2014021300/obs
PREPBUFR=${OBS_ROOT}/gdas1.t00z.prepbuf.r.nr
```

Set path to background ensemble files:

```
BK_ROOT=/scratch/${user}/casedata/enkf_arw_2014021300/bkg
```

Set file for background ensemble mean:

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```
BK_FILE=${BK_ROOT}/wrfarw.ensmean
```

Set the GSI system used for this case, including the paths of the fix files and the CRTM coefficients as well as the location of the GSI executable:

```
CRTM_ROOT=/scratch/${user}/CRTM_v2.3.0
GSI_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/
FIX_ROOT=${GSI_ROOT}/fix
GSI_EXE=${GSI_ROOT}/build/bin/gsi.exe
GSI_NAMELIST=${GSI_ROOT}/ush/comgsi_namelist.sh
```

- **Set which background and background error file to use**

```
bk_core=ARW
bkcv_option=NAM
if_clean=clean
```

This example uses the ARW NetCDF background; therefore `bk_core` is set to ARW. The regional background error covariance file is used in this case, as set by `bkcv_option=NAM`. Finally, the run scripts are set to clean the run directory to delete all temporary intermediate files.

- **Choose to run GSI observer, set up background ensemble information**

```
if_observer=Yes
no_member=20
BK_FILE_mem=${BK_ROOT}/wrfarw.mem
```

The option `if_observer=Yes` is the switch that enables `run_gsi_regional.ksh` to run the GSI observer (rather than GSI analysis). In this example, 20 ensemble members are selected with the naming convention: `wrfarw.memnnnn`. Note that `memnnnn` which is associated with each ensemble member (`nnnn`), is not included and will be appended later in the script.

- **Link observations**

```
# Link to the prepbuf data
ln -s ${PREPBUFR} ./prepbuf
# Link to the radiance data
... ..
ln -s ${srcobsfile[$ii]} ${gsiobsfile[$ii]}
... ..
```

Past the arch selection, environment variable checks, and creation of working directory, users will find the location where the observations are linked. For this case, the conventional PrepBUFR observations have been linked, as well as three different satellite radiance BUFR files (AMSU-A, HIRS4, and MHS) and a GPS RO BUFR file. These files will be linked to the working directory and observation innovations (`diag`) files will be generated for each observation.

In the run script, the proper `anavinfo` file is selected based on the core and background error covariance used for the case:

```
echo ' Use NAM background error covariance'
BERROR=${FIX_ROOT}/${BYTE_ORDER}/nam_nmmstat_na.gcv
OBERROR=${FIX_ROOT}/nam_errtable.r3dv
```

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```
if [ ${bk_core} = NMM ] ; then
    ANAVINFO=${FIX_ROOT}/anavinfo_ndas_netcdf
fi
if [ ${bk_core} = ARW ] ; then
    ANAVINFO=${FIX_ROOT}/anavinfo_arw_netcdf
fi
if [ ${bk_core} = NMMB ] ; then
    ANAVINFO=${FIX_ROOT}/anavinfo_nems_nmmb
fi
```

The anavinfo file used for this case is `anavinfo_arw_netcdf`, because the background is NetCDF ARW and the regional background error covariance has been selected. It is important to make sure the number of vertical levels in `anavinfo_arw_netcdf` must match those for the background. The example run script provided with the release code, `comgsi_run_regional.ksh`, takes care of this automatically for the regional ARW case.

5.1.2 Run GSI Observer and Check Run Status

Once the run script is set up properly for the case data and the machine environment, GSI can be run through the run script. The following command will submit the job, for LINUX PBS:

```
$ qsub comgsi_run_regional.ksh
```

While the job is running, move to the working directory and check the details. Given the following working directory setup:

```
WORK_ROOT=/scratch/${user}/comGSIV3.7_EnKFv1.3/run/gsideag_2014021300
```

Go to directory `WORK_ROOT=/scratch/${user}/comGSIV3.7_EnKFv1.3/` and check the run directory. A directory named `gsideag_2014021300` should have been created. This is the directory for this GSI observer run. The directory will be populated with many files such as:

```
amsua_n18.TauCoeff.bin
ssmi_f15.SpcCoeff.bin
amsua_n18.SpcCoeff.bin
ssmi_f15.TauCoeff.bin
imgr_g11.SpcCoeff.bin
imgr_g11.TauCoeff.bin
... ..
```

These files are CRTM coefficients that have been linked to this run directory through the GSI run script. Similar to running the GSI analysis, many other files are linked or copied to this run directory, such as:

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<i>gsiparm.anl:</i>	GSI namelist
<i>prepbuf:</i>	PrepBUFR file for conventional observation
<i>convinfo:</i>	data usage control for conventional data
<i>satbias_in:</i>	satellite bias correction coefficient file
<i>satinfo:</i>	data usage and channel control for satellite radiance data
<i>berror_stats:</i>	background error file
<i>errtable:</i>	observation error file

Additionally, for the GSI observer many files are generated as a result of the `read_obs_save` and `read_obs_skip` options in the namelist for writing/reading collective observation selection information:

<i>obs_input.nnnn:</i>	During ensemble mean (<code>save=True</code> , <code>skip=False</code>), save all observation preprocessing to this file. Each file (nnnn) is for a different variable type
<i>pennnn.obs_setup:</i>	When looping through ensemble members (<code>save=False</code> , <code>skip=True</code>), all observation preprocessing is skipped, <i>obs_input.nnnn</i> files are read and <i>pennnn.obs_setup</i> is written for each processor (nnnn) for all observations.

As the GSI observer is running for the ensemble mean as well as looping through each member, files are generated for each ensemble member, as well as the ensemble mean.

<i>pennnn.conv_01:</i>	Files generated after O-B, generated for conventional observations as well as one file per sensor (e.g. AMSU-A n18). These files are trimmed for resulting diag files and cleaned.
<i>list_run_directory:</i>	Directory listing after ensemble mean is run, before directory is cleaned for running the ensemble members.
<i>list_run_directory_memnnn:</i>	As as above, for each ensemble member (nnn).
<i>stdout:</i>	Standard output file for ensemble mean.
<i>stdout_memnnn:</i>	Standard output file for each ensemble member (nnn).

The presence of the standard output files in the directory suggest the GSI observer run scripts have successfully set up a run environment for the GSI observer, properly looping through the ensemble members, and the GSI executable is running on each ensemble member.

Once GSI has finished running, diag files should be generated for each observation type for each member as well as the ensemble mean:

<code>diag_conv_ges.ensmean</code>	<code>diag_conv_ges.mem001</code>
<code>diag_conv_ges.mem002</code>	<code>diag_conv_ges.mem003</code>
<code>diag_conv_ges.mem004</code>	<code>diag_conv_ges.mem005</code>
<code>... ..</code>	<code>diag_conv_ges.mem020</code>
<code>diag_amsua_metop-a_ges.ensmean</code>	<code>diag_amsua_metop-a_ges.mem001</code>
<code>diag_amsua_metop-a_ges.mem002</code>	<code>diag_amsua_metop-a_ges.mem003</code>
<code>diag_amsua_metop-a_ges.mem004</code>	<code>diag_amsua_metop-a_ges.mem005</code>
<code>... ..</code>	<code>diag_amsua_metop-a_ges.mem020</code>

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```
diag_amsua_n18_ges.ensmean      diag_amsua_n18_ges.mem001
diag_amsua_n18_ges.mem002      diag_amsua_n18_ges.mem003
diag_amsua_n18_ges.mem004      diag_amsua_n18_ges.mem005
.....
diag_amsua_n15_ges.ensmean      diag_amsua_n15_ges.mem001
diag_amsua_n15_ges.mem002      diag_amsua_n15_ges.mem003
diag_amsua_n15_ges.mem004      diag_amsua_n15_ges.mem005
... ..                          diag_amsua_n15_ges.mem020
```

5.1.3 Check for Successful GSI Completion

The presence of the diag files and standard out files for the ensemble mean and each member indicates that the GSI observer has run without crashing, but does not necessarily indicate a successful analysis. It is important to check the stdout files in the run directory to make sure the GSI observer completed each step without any obvious problems. The following are several important areas of the standard out file to check:

1. Read in the anavinfo and namelist

```
gsi_metguess_mod*init_: 2D-MET STATE VARIABLES:
ps
z
gsi_metguess_mod*init_: 3D-MET STATE VARIABLES:
u
v
div
vor
tv
q
oz
cw
.....

&SETUP
GENCODE = 78.00000000000000 ,
FACTQMIN = 0.000000000000000E+000,
FACTQMAX = 0.000000000000000E+000,
.....
```

2. Read in the background field

The following lines in stdout immediately following the namelist section, indicate that GSI is reading the background fields. For regional GSI observer run, background file wrf_inout is used and therefore users will see some information about problems with files wrf_inou1, ..., wrf_inou9, which is normal.

```
NetCDF error: No such file or directory
NetCDF error: No such file or directory
NetCDF error in wrf_io.F90, line      1078
NetCDF error in wrf_io.F90, line      1078
CONVERT_NETCDF_MASS: problem with flnm1 = wrf_inou1, Status =      -1021
iy,m,d,h,m,s=      2014      2      13      0      0      0
... ..
READ_wrf_mass_FILES: analysis date,minutes 2014  2  13  0  0  18996480
```

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```

READ_wrf_mass_FILES:  sigma guess file, nming2  0.0000000000000000  2014  2  13  0  0  18
READ_wrf_mass_FILES:  sigma fcst files used in analysis :      2  1.0000000000000000
READ_wrf_mass_FILES:  surface fcst files used in analysis:    2  1.0000000000000000
... ..

```

3. Read in observational data

The `stdout` (ensemble mean) and `stdout_memnnn` (ensemble members) contains distinct differences for the reading in the observational data controlled by the `lread_obs_save` and `lread_obs_skip` options in the namelist

a. Ensemble mean

```

read_obs_check: bufr file date is 2014021300 prepbufr q
read_obs_check: bufr file date is 2014021300 prepbufr ps
read_obs_check: bufr file uv      not available satwndbufr
read_obs_check: bufr file rw      not available radarbufr
read_obs_check: bufr file pcp_tmi trmm not available tmirrbufr
read_obs_check: bufr file hirs3   n17  not available hirs3bufr
... ..
  number of extra processors          1
READ_OBS: read 33 mhs      mhs_n18      using ntasks= 2 0 1796 999999
READ_OBS: read 34 mhs      mhs_n19      using ntasks= 2 2 585 999999
READ_OBS: read 35 mhs      mhs_metop-a   using ntasks= 2 0 175 999999
READ_OBS: read 36 mhs      mhs_metop-b   using ntasks= 2 2 3 999999
... ..
READ_BUFRTOVS      : file=mhsbufr      type=mhs      sis=mhs_n18      nread=      70080
ithin= 2 rmesh= 60.000000 isfcalc= 0 nkeep= 7665 ntask= 2
... ..
READ_PREPBUFR      : file=prepbufr     type=ps      sis=ps      nread=      22486
ithin= 0 rmesh= 120.000000 isfcalc= 0 nkeep= 16005 ntask= 1
... ..
READ_OBS: write collective obs selection info to obs_input.common

```

For the ensemble mean, the same procedure for observation processing as the GSI analysis is followed (`read_obs_check`, `READ_OBS`, `READ_BUFRTOVS`, `READ_GPS`, `READ_PREPBUFR` ..). Finally, it is indicated that the collective observations selection information is written out for use with the ensemble members.

b. Ensemble members

For the `stdout_memnnn`, the observation processing steps are skipped and observation information is read in from the ensemble mean:

```
OBSERVER_SET: read collective obs selection info from obs_input.common
```

4. Indication that the GSI has successfully run:

```

glbsoi: complete
[000]gsisub(): : complete.

      ENDING DATE-TIME   OCT 29,2018  22:51:51.865  302  MON   2458421
      PROGRAM GSI_ANL HAS ENDED.
* . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * .

```

After looking over each section of the standard output files, it can be concluded that the GSI observer ran without issues. Note that because the outer loop was set to 0 (`miter=0`) for the GSI observer, no minimization occurred and therefore no analysis results were produced.

5.2 Running EnKF for Regional Applications

5.2.1 Run Script

Once the GSI observer has been run successfully, the next step is to setup the EnKF run script, `comenkf_run_regional.ksh`. This script is located under `comGSIv3.7_EnKFv1.3/ush`. This run script uses the diag files generated by the GSI observer script as observation input, and generates the EnKF analysis. Similar to the GSI observer script, several user-specific modifications need to be made:

- Set up batch queueing system

```
#PBS -A P????????
#PBS -l walltime=00:20:00
#PBS -N cg02-case24-enkf-allobs
#PBS -l select=2:ncpus=36:mpiprocs=36
#PBS -q premium
#PBS -o out.case24-enkf-allobs
#PBS -j oe
```

- Set up number of processors and the job queue system used:

```
GSIPROC=36
ARCH='LINUX_PBS'
```

One difference from the GSI observer script is that the number of processors used should be greater than at least the number of ensemble members for running the EnKF. In this case we have 20 ensemble members and have requested 32 cores.

- Set up the analysis time, fixed files, EnKF executable

```
ANAL_TIME=2014021300
WORK_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/enkf_2014021300
diag_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/gsideag_2014021300
BK_ROOT=/scratch/${user}/casedata/enkf_arw_2014021300/bk
BK_FILE=${BK_ROOT}/wrfarw.ensmean
GSI_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3
FIX_ROOT=${GSI_ROOT}/fix
ENKF_EXE=${GSI_ROOT}/build/bin/enkf_wrf.x
CRTM_ROOT=/scratch/${user}/CRTM_v2.3.0/
ENKF_NAMELIST=${GSI_ROOT}/ush/comenkf_namelist.sh
```

- Set background file and location of the diag files (from GSI observer)

```
diag_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/gsideag_2014021300
BK_FILE=${BK_ROOT}/wrfarw.ensmean
```

Two modifications to note for the EnKF are the `diag_ROOT` and `BK_FILE`. The `diag_ROOT` points to the working directory where the GSI observer was run. This directory contains `diag*` files which will be linked to the EnKF working directory. `BK_FILE` points to the background ensemble mean.

- Select ensemble parameters

```
NMEM_ENKF=20
BK_FILE_mem=${BK_ROOT}/wrfarw
NLONS=129
```

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```
NLATS=70
NLEVS=50
IF_ARW=.true.
IF_NMM=.false.
```

This section sets information about the ensemble, including the number of members, background ensemble members, domain specifications, dynamical core, and list of observations to be used in the EnKF. Note that the ensemble members (BK_FILE_mem) do not include the 3-digit member number. This will be appended to the name specified for this field later in the script.

- Select observations

```
list="conv amsua_n18 mhs_n18 hirs4_n19"
```

This list is contained with the ensemble parameter section. This list of observations/platforms to be assimilated can be different from the list that run through the GSI observer but be aware that only observations/platforms that have been run through the GSI observer (and therefore a diag* file exists) are valid.

5.2.2 Run EnKF and Check Run Status

Once the run script is set up properly for the case and the machine, EnKF can be run through the run script. The following command will submit the job:

```
$ qsub comenkf_run_regional.ksh
```

While the job is running, move to the working directory and check the details. Given the following working directory setup:

```
WORK_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/enkf_2014021300
```

Go to directory `/scratch/${user}/comGSIv3.7_EnKFv1.3/run` and check the run directory. A directory named `enkf_2014021300` should have been created. This directory is the run directory for this EnKF case study. The directory will be populated with many links:

```
diag_conv_ges.ensmean  diag_conv_ges.mem007  diag_conv_ges.mem014
diag_conv_ges.mem001  diag_conv_ges.mem008  diag_conv_ges.mem015
diag_conv_ges.mem002  diag_conv_ges.mem009  diag_conv_ges.mem016
diag_conv_ges.mem003  diag_conv_ges.mem010  diag_conv_ges.mem017
diag_conv_ges.mem004  diag_conv_ges.mem011  diag_conv_ges.mem018
diag_conv_ges.mem005  diag_conv_ges.mem012  diag_conv_ges.mem019
diag_conv_ges.mem006  diag_conv_ges.mem013  diag_conv_ges.mem020
```

```
diag_amsua_n18_ges.ensmean  diag_amsua_n18_ges.mem007  diag_amsua_n18_ges.mem014
diag_amsua_n18_ges.mem001  diag_amsua_n18_ges.mem008  diag_amsua_n18_ges.mem015
diag_amsua_n18_ges.mem002  diag_amsua_n18_ges.mem009  diag_amsua_n18_ges.mem016
diag_amsua_n18_ges.mem003  diag_amsua_n18_ges.mem010  diag_amsua_n18_ges.mem017
diag_amsua_n18_ges.mem004  diag_amsua_n18_ges.mem011  diag_amsua_n18_ges.mem018
```

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```
diag_amsua_n18_ges.mem005  diag_amsua_n18_ges.mem012  diag_amsua_n18_ges.mem019
diag_amsua_n18_ges.mem006  diag_amsua_n18_ges.mem013  diag_amsua_n18_ges.mem020
```

```
diag_mhs_n18_ges.ensmean  diag_mhs_n18_ges.mem007  diag_mhs_n18_ges.mem014
diag_mhs_n18_ges.mem001  diag_mhs_n18_ges.mem008  diag_mhs_n18_ges.mem015
diag_mhs_n18_ges.mem002  diag_mhs_n18_ges.mem009  diag_mhs_n18_ges.mem016
diag_mhs_n18_ges.mem003  diag_mhs_n18_ges.mem010  diag_mhs_n18_ges.mem017
diag_mhs_n18_ges.mem004  diag_mhs_n18_ges.mem011  diag_mhs_n18_ges.mem018
diag_mhs_n18_ges.mem005  diag_mhs_n18_ges.mem012  diag_mhs_n18_ges.mem019
diag_mhs_n18_ges.mem006  diag_mhs_n18_ges.mem013  diag_mhs_n18_ges.mem020
```

The diag files are linked from the GSI observer working directory. These links are specified in the run script. Note that there are broken links to `diag_hirs4_n19_ges.*` because `hirs4_n19` is not the one that run through the GSI observer.

The first guess files are also linked into the directory from the run script, pointing to the path of the ensemble mean and ensemble members designated in the setup section.

```
firstguess.ensmean  firstguess.mem007  firstguess.mem014
firstguess.mem001  firstguess.mem008  firstguess.mem015
firstguess.mem002  firstguess.mem009  firstguess.mem016
firstguess.mem003  firstguess.mem010  firstguess.mem017
firstguess.mem004  firstguess.mem011  firstguess.mem018
firstguess.mem005  firstguess.mem012  firstguess.mem019
firstguess.mem006  firstguess.mem013  firstguess.mem020
```

Similar to running the GSI observer, many other static files are linked or copied to this run directory, such as:

enkf.nml: EnKF namelist
convinfo: data usage control for conventional data
satbias_in: satellite bias correction coefficient file
satbias_pc: satellite bias correction file for passive channels
satinfo: data usage and channel control for satellite radiance data
ozinfo: data usage control from ozone data
stdout: EnKF standard output file

The presence of the standard output file in the directory suggest the EnKF run script has successfully set up a run environment for the EnKF, properly linking the first guess and diag files from the GSI observer, and the EnKF executable is running. Once EnKF has finished running, analysis files should be generated for each member as well as the ensemble mean:

```
analysis.ensmean  analysis.mem006  analysis.mem012  analysis.mem018
analysis.mem001  analysis.mem007  analysis.mem013  analysis.mem019
analysis.mem002  analysis.mem008  analysis.mem014  analysis.mem020
analysis.mem003  analysis.mem009  analysis.mem015
analysis.mem004  analysis.mem010  analysis.mem016
analysis.mem005  analysis.mem011  analysis.mem017
```


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```

RADINFO_READ:  guess air mass bias correction coefficients below
 1             amsua_n15    2.499241    0.000000    0.000000    0.461710    0.046909
   0.000000    0.000000   -0.009783    3.994601    3.216754   -4.797873   -2.041783
 2             amsua_n15    1.679784    0.000000    0.000000   10.938589   -4.478499
   0.000000    0.000000   -0.007970    3.716146    9.172844   -4.571728   -1.761180
... ..

```

4. Statistics of the ensemble prior

Following many lines describing the bias correction coefficients, the inventory of the observation number, observation types from the input diag* files, and the time spent reading in each observation type, statistics of the ensemble priors fit to all observations are provided for each region (NH, TR), depending on the analysis domain:

```

innovation statistics for prior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH  all ps  14083 -0.591E-02  0.860E+00  0.813E+00  0.601E+00  0.547E+00
TR  all ps    50 -0.629E-01  0.422E+00  0.641E+00  0.367E+00  0.526E+00
NH  all t   7766 -0.228E+00  0.163E+01  0.128E+01  0.480E+00  0.119E+01
TR  all t    138 -0.130E+00  0.118E+01  0.119E+01  0.234E+00  0.117E+01
NH  all uv  21680 0.136E-01  0.295E+01  0.276E+01  0.140E+01  0.237E+01
TR  all uv   302 -0.379E+00  0.251E+01  0.268E+01  0.124E+01  0.238E+01
NH  all q   2553 -0.323E-01  0.146E+00  0.157E+00  0.868E-01  0.131E+00
TR  all q    68 -0.721E-01  0.202E+00  0.164E+00  0.582E-01  0.154E+00
NH  all gps  1232 -0.262E-04  0.879E+00  0.117E+01  0.683E+00  0.950E+00
satellite brightness temp
instrument, channel #, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
amsua_n18  1  219 -0.210E+00  0.193E+01  0.299E+01  0.164E+01  0.250E+01
amsua_n18  2  222 -0.342E+00  0.178E+01  0.232E+01  0.746E+00  0.220E+01
amsua_n18  3  222 -0.431E+00  0.118E+01  0.205E+01  0.464E+00  0.200E+01
amsua_n18  4  222 -0.198E+00  0.433E+00  0.567E+00  0.139E+00  0.550E+00
amsua_n18  6 1190 -0.755E-01  0.224E+00  0.238E+00  0.611E-01  0.230E+00
amsua_n18  7 1174 -0.288E+00  0.373E+00  0.235E+00  0.481E-01  0.230E+00
amsua_n18 10 1172  0.458E+00  0.529E+00  0.353E+00  0.429E-01  0.350E+00
amsua_n18 11   8  0.765E+00  0.767E+00  0.404E+00  0.550E-01  0.400E+00
amsua_n18 15  221 -0.541E+00  0.205E+01  0.377E+01  0.141E+01  0.350E+01
mhs_n18   1  479  0.813E+00  0.240E+01  0.271E+01  0.105E+01  0.250E+01
mhs_n18   2  497  0.149E+01  0.309E+01  0.280E+01  0.127E+01  0.250E+01
mhs_n18   3  497  0.241E+00  0.101E+01  0.329E+01  0.213E+01  0.250E+01
mhs_n18   4  497 -0.306E+00  0.886E+00  0.249E+01  0.148E+01  0.200E+01
mhs_n18   5  497 -0.109E+00  0.963E+00  0.220E+01  0.909E+00  0.200E+01

```

This table should be checked in order to determine if the inflation is appropriate. The goal is to make the total ensemble spreads of priors ($\sqrt{S + R}$) match the innovations (innov std) as much as possible. We can see in certain regions, the differences are notable. These differences are associated with higher observation error (\sqrt{R}). Users should consider tuning of inflation and localization, which is typically determined using cases with multiple assimilation cycles. Refer to section 4.2 of this User's Guide for more information on tuning.

5. Check the minimum and maximum values of the fields at each vertical level as a quick sanity check

```

Surface pressure (spressmn) min/max range:  678.67333984375000    1032.2247314453125
READGRIDDATA_ARW: u             1 -20.5522194             20.7263222
READGRIDDATA_ARW: u             2 -20.8787842             21.2031631
READGRIDDATA_ARW: u             3 -21.6104603             22.3617668

```

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```
READGRIDDATA_ARW: u      4 -22.6256084      24.0846481
READGRIDDATA_ARW: u      5 -24.0716515      26.4782734
READGRIDDATA_ARW: u      6 -25.8923721      32.8184052
... ..
```

6. Domain and observation partition:

```
npts =          9030
min/max number of points per proc =          222          283
time to do model space decomp =    1.2303239927859977E-003
nobstot =          54989
min/max number of obs per proc =          1527          1528
time to do ob space decomp =    3.6349199945107102E-004
sending out observation prior ensemble perts from root ...
nobstot*nanals          1099780
... took    3.9184329943964258E-003  secs
time in load_balance =  0.13166810100665316      on proc          0
```

The analysis variables and the observations are distributed to different processors. We can see in this case that the min/max number of points per processor are 222 and 283, respectively. Similarly, we can see that the min/max number of observations per processor are 1527 and 1528, respectively, indicating that the observations are well dispersed among the processors.

5.2.4 Diagnose EnKF Analysis Results

At the bottom of the standard output file, there are several output statistics and tables that are helpful for users to diagnose the quality of the EnKF analysis.

1. Spread inflation of the analysis ensemble

```
global ps prior std. dev min/max =    0.215956211      1.72586155
NH mean ps prior standard deviation =    0.578957915
NH mean ps posterior standard deviation (before inflation)=    0.287781417
NH mean ps posterior standard deviation (after inflation) =    0.546174467
NH mean ps inflation =    2.43589163
TR mean ps prior standard deviation =    0.311811596
TR mean ps posterior standard deviation (before inflation)=    0.280985802
TR mean ps posterior standard deviation (after inflation) =    0.308485359
TR mean ps inflation =    1.12325037
time in inflate_ens =    5.9949199930997565E-003 on proc          0
```

This section is important for checking whether the values of the inflation are reasonable by looking at a summary of the maximum and minimum values. Also, viewing the regional averaged statistics before and after inflation. For this case we can see both the NH and TR show larger standard deviation after the inflation, which is more consistent with the prior standard deviation.

2. Spread inflation of the analysis ensemble

```
innovation statistics for posterior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH all ps 14083 0.818E-02 0.756E+00 0.566E+00 0.143E+00 0.547E+00
```

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TR	all ps	50	-0.530E-01	0.398E+00	0.558E+00	0.188E+00	0.526E+00	
NH	all t	7766	-0.835E-01	0.145E+01	0.122E+01	0.261E+00	0.119E+01	
TR	all t	138	-0.107E+00	0.115E+01	0.118E+01	0.199E+00	0.117E+01	
NH	all uv	21680	0.375E-01	0.267E+01	0.246E+01	0.656E+00	0.237E+01	
TR	all uv	302	-0.260E+00	0.236E+01	0.246E+01	0.636E+00	0.238E+01	
NH	all q	2553	-0.174E-01	0.114E+00	0.138E+00	0.443E-01	0.131E+00	
TR	all q	68	-0.280E-01	0.168E+00	0.159E+00	0.413E-01	0.154E+00	
NH	all gps	1232	-0.142E-04	0.489E+00	0.101E+01	0.350E+00	0.950E+00	
satellite brightness temp								
instrument, channel #, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):								
	amsua_n18	1	219	0.333E-01	0.177E+01	0.260E+01	0.704E+00	0.250E+01
	amsua_n18	2	222	-0.204E+00	0.177E+01	0.223E+01	0.338E+00	0.220E+01
	amsua_n18	3	222	-0.339E+00	0.112E+01	0.201E+01	0.222E+00	0.200E+01
	amsua_n18	4	222	-0.141E+00	0.386E+00	0.557E+00	0.853E-01	0.550E+00
	amsua_n18	6	1190	-0.200E-01	0.179E+00	0.234E+00	0.439E-01	0.230E+00
	amsua_n18	7	1174	-0.234E+00	0.320E+00	0.233E+00	0.356E-01	0.230E+00
	amsua_n18	10	1172	0.426E+00	0.499E+00	0.352E+00	0.371E-01	0.350E+00
	amsua_n18	11	8	0.734E+00	0.736E+00	0.403E+00	0.525E-01	0.400E+00
	amsua_n18	15	221	-0.279E+00	0.189E+01	0.355E+01	0.610E+00	0.350E+01
	mhs_n18	1	479	0.907E+00	0.228E+01	0.254E+01	0.472E+00	0.250E+01
	mhs_n18	2	497	0.159E+01	0.292E+01	0.258E+01	0.653E+00	0.250E+01
	mhs_n18	3	497	0.240E+00	0.105E+01	0.279E+01	0.124E+01	0.250E+01
	mhs_n18	4	497	-0.281E+00	0.904E+00	0.218E+01	0.863E+00	0.200E+01
	mhs_n18	5	497	-0.112E+00	0.963E+00	0.208E+01	0.576E+00	0.200E+01

After the EnKF analysis, it is important to check the innovation statistics, much like the prior fit to all observation.

5.3 Running GSI Observer for Global Applications

5.3.1 Run Script

With both GSI and EnKF compiled (note that a separate global executable must be generated for EnKF: `enkf_gfs.x`) and the background ensemble files and observations acquired, the next step is to work with the gsi observer run script, `comgsi_run_gfs.ksh`. The location of this script is under `comGSIv3.7_EnKFv1.3/ush`. This run script is the same as the one used for a GSI global analysis run, with a few specific options selected in order to loop through all the ensemble members and generate the ensemble observation priors for each member and the ensemble mean. For the global examples, users must choose a case that corresponds to the spectral resolution of the background ensemble. For this example, we will be using T62. In addition to the GSI observer specific options, other user-specific modifications need to be made:

- Set up batch queueing system

To run GSI with multiple processors, a job queuing head must be added to the `comgsi_run_gfs.ksh` script. The set up of the job queue is dependent on the machine and the job control system. Refer to the GSI User's Guide, section 3.2.2, for more examples of the setup section of this script. The following example is setup to run on a Linux cluster with PBS:

```
#PBS -A P???????
```

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```
#PBS -l walltime=00:20:00
#PBS -N cg02-case25-observer-gfs
#PBS -l select=1:ncpus=4:mpiprocs=4
#PBS -q premium
#PBS -o out.case25-observer-gfs
#PBS -j oe
```

- Set up number of processors and the job queue system used. For this example, LINUX_PBS and 36 processors are used:

```
GSIPROC=36
ARCH='LINUX_PBS'
```

- Set up the case data, analysis time, fix files, GSI executable, and CRTM coefficients:

Set up analysis time and select global case:

```
ANAL_TIME=2014092918
GFSCASE=enkf_glb_t62
```

Set up working directory, which will hold the analysis results (all ensemble members will be run in this directory). This directory must have the proper write permissions as well as enough space to hold the output.

```
WORK_ROOT=/scratch/${user}/comGSIv3.7-EnKFv1.3/run/gsi diag_${GFS_CASE}
```

Set path to background ensemble files:

```
BK_ROOT=/scratch/${user}/casedata/enkf_glb_t62/bkg
```

Set path to the observation directory and the PrepBUFR file within the observation directory. All observations to be assimilated should reside in this directory.

```
OBS_ROOT=/scratch/${user}/casedata/enkf_glb_t62/obs
PREPBUFR=${OBS_ROOT}/gdas1.t18z.prepbufr.nr
```

Set the GSI system used for this case, including the paths of the fix files and the CRTM coefficients as well as the location of the GSI executable:

```
CRTM_ROOT=/scratch/${user}/CRTM_v2.3.0
GSI_ROOT=/scratch/${user}/comGSIv3.7-EnKFv1.3/
FIX_ROOT=${GSI_ROOT}/fix
GSI_EXE=${GSI_ROOT}/build/bin/gsi.x
GSI_NAMELIST=${GSI_ROOT}/ush/comgsi_namelist_gfs.sh
```

Note that the GSI namelist generation script used for the global case (comgsi_namelist_gfs.sh) is different from the one used for the regional example.

- Choose to run GSI observer, set up background ensemble information

```
if_observer=Yes # Yes ,or, No -- case sensitive!!!
no_member=10
PDYa='echo $ANAL_TIME | cut -c1-8'
cyca='echo $ANAL_TIME | cut -c9-10'
gdate='date -u -d "$PDYa $cyca -6 hour" +%Y%m%d%H' #guess date is 6hr ago
BK_FILE_mem=${BK_ROOT}/sfg_${gdate}
```

The option if_observer=Yes is the switch that enables comgsi_run_gfs.ksh to run the GSI observer (rather than GSI analysis). In this example, 10 ensemble members are selected with the naming convention: sfg_\${GUESS_DATE}_memnnnn . Note that

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_memnnnn which is associated with each ensemble member (nnnn), is not included and will be appended later in the script.

- Set the JCAP resolution for the case:

```
if [[ "$GFSCASE" = "T62" ]]; then
    JCAP=62
    JCAP_B=62
elif [[ "$GFSCASE" = "T126" ]]; then
    JCAP=126
    JCAP_B=126
elif [[ "$GFSCASE" = "enkf_glb_t62" ]]; then
    JCAP=62
    JCAP_B=62
elif [[ "$GFSCASE" = "T254" ]]; then
    JCAP=254
    JCAP_B=574
elif [[ "$GFSCASE" = "T574" ]]; then
    JCAP=574
    JCAP_B=1534
else
    echo "INVALID case = $GFSCASE"
    exit
fi
LEVS=64
```

Note that this selection is filled based on selection of the GFSCASE. This example used the `enkf_glb_t62` case. All cases use 64 levels.

Further in the run script `comgsi_run_gfs.ksh`, the resolution parameters are set based on the requested case (resolution). For this case, we are using `JCAP=62`:

```
elif [[ "$JCAP" = "62" ]]; then
    LONA=192
    LATA=128
    DELTIM=1200
    resol=2
```

- Link satellite bias correction coefficients, background ensemble files, and observations:

```
if [[ "$GFSCASE" = "enkf_glb_t62" ]]; then
    cp $BK_ROOT/bfg_${gdate}_fhr03_ensmean ./sfcf03
    cp $BK_ROOT/bfg_${gdate}_fhr06_ensmean ./sfcf06
    cp $BK_ROOT/bfg_${gdate}_fhr09_ensmean ./sfcf09

    cp $BK_ROOT/sfg_${gdate}_fhr03_mem001 ./sigf03
    cp $BK_ROOT/sfg_${gdate}_fhr06_mem001 ./sigf06
    cp $BK_ROOT/sfg_${gdate}_fhr09_mem001 ./sigf09
else
    ... ..
fi

cp ${GSI_ROOT}/fix/comgsi_satbias_in ./satbias_in
cp ${GSI_ROOT}/fix/comgsi_satbias_pc_in ./satbias_pc_in
... ..
# Link to the prepbuf data
ln -s ${PREPBUFR} ./prepbuf

# Link to the other observation data
if [ -r "${OBS_ROOT}/satwnd" ]; then
```

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```
ln -s ${OBS_ROOT}/satwnd .
fi
if [ -r "${OBS_ROOT}/gpsrobufr" ]; then
  ln -s ${OBS_ROOT}/gpsrobufr .
fi
... ..
```

Past the arch selection, environment variable checks, and creation of working directory, users will find the location where the observations are linked. For this case, we can see that the conventional PrepBUFR observations have been linked, as well as AMSU-A, HIRS4 and MHS satellite radiance BUFR files. These files will be linked to the working directory and separate observation innovation (diag) files will be generated for each observation.

5.3.2 Run GSI Observer and Check Run Status

Once the run script is set up properly for the case and the machine, GSI can be run through the run script. The following command will submit the job:

```
$ qsub comgsi_run_gfs.ksh
```

While the job is running, move to the working directory and check the details. Given the following working directory setup:

```
WORK_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/gsidiag_${GFSCASE}
```

Go to directory `/scratch/${user}/comGSIv3.7_EnKFv1.3/` and check the run directory. A directory named `gsidiag_enkf_glb_t62` should have been created. This directory is the run directory for this GSI observer case study. The directory will be populated with many files such as:

```
AerosolCoeff.bin          hirs4_n19.TauCoeff.bin      sndrD1_g14.TauCoeff.bin
ahi_himawari8.SpcCoeff.bin  iasi616_metop-a.SpcCoeff.bin  sndrD1_g15.SpcCoeff.bin
ahi_himawari8.TauCoeff.bin  iasi616_metop-a.TauCoeff.bin  sndrD1_g15.TauCoeff.bin
airs281SUBSET_aqua.SpcCoeff.bin  iasi616_metop-b.SpcCoeff.bin  sndrD2_g11.SpcCoeff.bin
... ..
```

These files are CRTM coefficients that have been linked to this run directory through the GSI run script. Similar to running the GSI analysis, many other files are linked or copied to this run directory, such as:

Additionally, for the GSI observer many files are generated as a result of the `lread_obs_save` and `lread_obs_skip` options in the namelist for writing/reading collective observation selection information:

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gsiparm.anl : GSI namelist
prepbuf : PrepBUFR file for conventional observation
convinfo : data usage control for conventional data
satbias_in : satellite bias correction coefficient file
satinfo : data usage and channel control for satellite radiance data
berror_stats : background error file
errtable : observation error file

obs_input.nnnn: During ensemble mean (save=True, skip=False), save all observation preprocessing to this file. Each file (nnnn) is for a different variable type

pennnn.obs_setup: When looping through ensemble members (save=False, skip=True), all observation preprocessing is skipped, obs_input.nnnn files are read and pennnn.obs_setup is written for each processor (nnnn) for all observations.

As the GSI observer is running for the ensemble mean as well as looping through each member, files are for each ensemble member, as well as the ensemble mean:

The presence of the standard output files in the directory suggest the GSI observer run scripts have successfully set up a run environment for the GSI observer, properly looping through the ensemble members, and the GSI executable is running on each ensemble member. Once GSI has finished running, diag files should be generated for each observation type for each member as well as the ensemble mean:

```
diag_conv_ges.ensmean  diag_conv_ges.mem004  diag_conv_ges.mem008
diag_conv_ges.mem001  diag_conv_ges.mem005  diag_conv_ges.mem009
diag_conv_ges.mem002  diag_conv_ges.mem006  diag_conv_ges.mem010
diag_conv_ges.mem003  diag_conv_ges.mem007
diag_amsua_metop-a_ges.ensmean  diag_amsua_metop-a_ges.mem006
diag_amsua_metop-a_ges.mem001  diag_amsua_metop-a_ges.mem007
diag_amsua_metop-a_ges.mem002  diag_amsua_metop-a_ges.mem008
diag_amsua_metop-a_ges.mem003  diag_amsua_metop-a_ges.mem009
diag_amsua_metop-a_ges.mem004  diag_amsua_metop-a_ges.mem010
diag_amsua_metop-a_ges.mem005
diag_amsua_metop-b_ges.ensmean  diag_amsua_metop-b_ges.mem006
diag_amsua_metop-b_ges.mem001  diag_amsua_metop-b_ges.mem007
diag_amsua_metop-b_ges.mem002  diag_amsua_metop-b_ges.mem008
diag_amsua_metop-b_ges.mem003  diag_amsua_metop-b_ges.mem009
diag_amsua_metop-b_ges.mem004  diag_amsua_metop-b_ges.mem010
diag_amsua_metop-b_ges.mem005
```

pennnn.conv_01 : Files generated after O-B, generated for conventional observations as well as one file per sensor (e.g. AMSU-A n18). These files are trimmed for resulting diag files and cleaned.

list_run_directory : Directory listing after ensemble mean is run, before directory is cleaned for running the ensemble members.

list_run_directory_memnnn: As as above, for each ensemble member (nnn).

stdout : Standard output file for ensemble mean.

stdout_memnnn : Standard output file for each ensemble member (nnn).

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3. Read in observational data

The `stdout` (ensemble mean) and `stdout_memnnn` (ensemble members) contains distinct differences for the reading in the observational data controlled by the `lread_obs_save` and `lread_obs_skip` options in the namelist.

a. Ensemble mean

```
read_obs_check: bufr file date is 2014092918 prepbuf q
read_obs_check: bufr file date is 2014092918 prepbuf ps
read_obs_check: bufr file uv          not available satwndbuf
... ..
number of extra processors          2
READ_OBS: read 28 mhs             mhs_n18             using ntasks= 2 0 780 999999 999999
READ_OBS: read 29 mhs             mhs_metop-a         using ntasks= 2 2 514 999999 999999
... ..
READ_OBS: write collective obs selection info to obs_input.common
```

For the ensemble mean, the same procedure for observation processing as the GSI analysis is followed (`read_obs_check`, `READ_OBS`, `READ_BUFRTOVS`, `READ_GPS`, `READ_PREPBUFR`, ...). Finally, it is indicated that the collective observations selection information is written out for use with the ensemble members.

b. Ensemble members

For the `stdout_memnnn`, the observation processing sets are skipped and observation information is read in from the ensemble mean:

```
OBSERVER_SET: read collective obs selection info from obs_input.common
```

4. Indication that the GSI observer has successfully run:

```
glbsoi: complete
[000]gsisub(): : complete.
```

```
ENDING DATE-TIME    JUL 15,2016 15:48:52.880 197 FRI 2457585
PROGRAM GSI_ANL HAS ENDED.
* . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * . * .
```

After looking over each section of the standard output files, it can be concluded that the GSI global observer ran without issues. Note that because the outer loop was set to 0 (`miter=0`) for the GSI observer, no minimization occurred and therefore no analysis results were produced.

5.4 Running EnKF for Global Applications

5.4.1 Run Script

Once the GSI global observer has been run successfully, the next step is to setup the EnKF run script, `comenkf_run_gfs.ksh`. This script is located under `comGSIv3.7_EnKFv1.3/ush`. This run script uses the diag files generated by the GSI global

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observer script as observation input, and generates the global EnKF analysis. Similar to the GSI observer script, several user-specific modifications need to be made:

- Set up batch queueing system

```
#PBS -A P??????
#PBS -l walltime=00:20:00
#PBS -N cg02-case26-enkf-gfs
#PBS -l select=2:ncpus=36:mpiprocs=36
#PBS -q premium
#PBS -o out.case26-enkf-gfs
#PBS -j oe
```

One difference from the GSI observer script is that the number of processors used should be greater than at least the number of ensemble members for running the EnKF. In this case we have 10 ensemble members and have requested 36 cores due to the large global domain.

- Set up the analysis time, global case, fixed files, EnKF executable

```
ANAL_TIME=2014092918
GFSCASE=enkf_glb_t62
WORK_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/enkf_${GFSCASE}
BK_ROOT=/scratch/${user}/casedata/enkf_glb_t62/bkg
GSI_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3
FIX_ROOT=${GSI_ROOT}/fix
ENKF_EXE=${GSI_ROOT}/build/bin/enkf_gfs.x
CRTM_ROOT=/scratch/${user}/CRTM_v2..3.0
ENKF_NAMELIST=${GSI_ROOT}/ush/comenkf_namelist_gfs.sh
```

- Set location of the diag files (from GSI observer)

```
DIAG_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/gsi diag_${GFSCASE}
```

One modification to note for the EnKF is the DIAG_ROOT. The DIAG_ROOT points to the working directory where the GSI observer runs. This directory contains diag* files which will be linked to the EnKF working directory.

- Select ensemble and case parameters

```
NMEM_ENKF=10
LEVS=64
NVAR=5
... ..
elif [[ "$GFSCASE" = "enkf_glb_t254" ]]; then
    JCAP=254
    JCAP_B=254
... ..
elif [[ "$JCAP" = "254" ]]; then
    LONA=512
    LATA=256
    DELTIM=1200
    resol=2
```

This section sets information about the number of background ensemble members, domain specifications. This information mirrors that of the run_gsi_global.ksh script.

- Read in namelist

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```
#Build EnKF namelist on-the-fly
. $ENKF_NAMELIST
```

Similar to the regional enkf (`comenkf_run_regional.ksh`), the global EnKF builds the namelist from an outside script for namelist generation (`enkf_namelist_gfs.sh`).

- Select observations

```
list="conv amsua_metop-a amsua_n18 amsua_n15"
```

The above line is contained within the ensemble looping section. For the observations to be assimilated, be aware that only observations/platforms that have been run through the GSI observer (and therefore a `diag*` file exists) are valid. For this example case, we will run EnKF for conventional observations and satellite radiance from AMSU-A.

5.4.2 Run EnKF and Check Run Status

Once the run script is set up properly for the case and the machine, EnKF can be run through the run script. The following command will submit the job:

```
$ qsub comenkf_run_gfs.ksh
```

While the job is running, move to the working directory and check the details. Given the following working directory setup:

```
WORK_ROOT=/scratch/${user}/comGSIv3.7_EnKFv1.3/run/enkf_${GFSCASE}
```

Go to directory `/scratch/${user}/comGSIv3.7_EnKFv1.3/` and check the run directory. A directory named `enkf_enkf_glb_t62` should have been created. This directory is the run directory for this EnKF case study. The directory will be populated with many links:

```
diag_conv_ges.ensmean  diag_conv_ges.mem004  diag_conv_ges.mem008
diag_conv_ges.mem001  diag_conv_ges.mem005  diag_conv_ges.mem009
diag_conv_ges.mem002  diag_conv_ges.mem006  diag_conv_ges.mem010
diag_conv_ges.mem003  diag_conv_ges.mem007
diag_amsua_metop-a_ges.ensmean  diag_amsua_metop-a_ges.mem006
diag_amsua_metop-a_ges.mem001  diag_amsua_metop-a_ges.mem007
diag_amsua_metop-a_ges.mem002  diag_amsua_metop-a_ges.mem008
diag_amsua_metop-a_ges.mem003  diag_amsua_metop-a_ges.mem009
diag_amsua_metop-a_ges.mem004  diag_amsua_metop-a_ges.mem010
diag_amsua_metop-a_ges.mem005
diag_amsua_n18_ges.ensmean  diag_amsua_n18_ges.mem004  diag_amsua_n18_ges.mem008
diag_amsua_n18_ges.mem001  diag_amsua_n18_ges.mem005  diag_amsua_n18_ges.mem009
diag_amsua_n18_ges.mem002  diag_amsua_n18_ges.mem006  diag_amsua_n18_ges.mem010
diag_amsua_n18_ges.mem003  diag_amsua_n18_ges.mem007
diag_amsua_n15_ges.ensmean  diag_amsua_n15_ges.mem004  diag_amsua_n15_ges.mem008
diag_amsua_n15_ges.mem001  diag_amsua_n15_ges.mem005  diag_amsua_n15_ges.mem009
diag_amsua_n15_ges.mem002  diag_amsua_n15_ges.mem006  diag_amsua_n15_ges.mem010
diag_amsua_n15_ges.mem003  diag_amsua_n15_ges.mem007
```

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The diag files are linked from the GSI global observer working directory. These links are specified in the run script. Note that ozone diag files (gome, omi, sbuv) will appear in the directory without links (zero length files) if ozone diags are not present from the GSI observer.

```
sfg_2014092918_fhr06_ensmean  sfg_2014092918_fhr06_mem004  sfg_2014092918_fhr06_mem008
sfg_2014092918_fhr06_mem001  sfg_2014092918_fhr06_mem005  sfg_2014092918_fhr06_mem009
sfg_2014092918_fhr06_mem002  sfg_2014092918_fhr06_mem006  sfg_2014092918_fhr06_mem010
sfg_2014092918_fhr06_mem003  sfg_2014092918_fhr06_mem007
```

The first guess files are also linked into the directory from the run script, pointing to the path of the ensemble mean and ensemble members designated in the setup section.

Similar to running the GSI observer, many other static files are linked or copied to this run directory, such as:

```
enkf.nml:      EnKF namelist
convinfo:     data usage control for conventional data
satbias_in:   satellite bias correction coefficient file
satbias_angle: satellite bias correction angle file
satinfo:     data usage and channel control for satellite radiance data
ozinfo:      data usage control from ozone data
stdout:      EnKF standard output file
```

The presence of the standard output file in the directory suggests the EnKF run script has successfully set up a run environment for the EnKF, properly linking the first guess and diag files from the GSI observer, and the EnKF executable is running. Once EnKF has finished running, analysis files should be generated for each member:

```
sanl_2014092918_mem001  sanl_2014092918_mem005  sanl_2014092918_mem009
sanl_2014092918_mem002  sanl_2014092918_mem006  sanl_2014092918_mem010
sanl_2014092918_mem003  sanl_2014092918_mem007
sanl_2014092918_mem004  sanl_2014092918_mem008
```

5.4.3 Check for Successful EnKF Completion

The presence of the EnKF analysis files for each member as well as the standard out file indicates that the EnKF has run without crashing, but does not necessary indicate a successful analysis. It is important to check the stdout file in the run directory to make sure the EnKF completed each step without any obvious problems. The following are several important areas of the standard out file to check:

1. Check namelist has been properly read in and configuration is correct:

```
namelist parameters:
-----
&NAM_ENKF
DATEIN = 2014092918,
```

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```

DATAPATH      = ./
IASSIM_ORDER=      0,
NVAR=         5,
COVINFLATEMAX= 100.000000    ,
COVINFLATEMIN= 1.00000000    ,
DETERMINISTIC=T,
SORTINC=T,
CORRLENGTHNH= 2000.00000    ,
CORRLENGTHTR= 2000.00000    ,
CORRLENGTHSH= 2000.00000    ,
... ..

```

2. Check analysis time, number of ensemble members, as well as the actual analysis variables and the background type.

```

analysis time 2014092918
          10 members
WARNING: nvars and massbal_adjust are no longer used!
They are inferred from the anavinfo file instead.
number of background forecast times to be used for H(x) =          1
first-guess forecast hours for observation operator = 06
number of background forecast times to be updated =          1
first-guess forecast hours for analysis = 06
using multiplicative inflation based on Pa/Pb

```

3. Statistics of the ensemble prior

After many lines describing the bias correction coefficients, the inventory of the observation number, observation types from the input diag* files, and the time spent reading in each observation type, statistics of the ensemble priors fit to all observations are provided:

```

innovation statistics for prior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH  all ps  11905  0.184E+00  0.107E+01  0.148E+01  0.462E+00  0.141E+01
TR  all ps   2078  0.310E+00  0.122E+01  0.131E+01  0.273E+00  0.128E+01
SH  all ps   895  -0.235E+00  0.135E+01  0.141E+01  0.752E+00  0.119E+01
NH  all t   1798  0.690E-01  0.143E+01  0.208E+01  0.451E+00  0.203E+01
TR  all t    275  0.390E+00  0.148E+01  0.212E+01  0.257E+00  0.211E+01
SH  all t    70  0.155E+00  0.130E+01  0.185E+01  0.503E+00  0.178E+01
NH  all uv  9776  0.552E-01  0.268E+01  0.238E+01  0.866E+00  0.221E+01
TR  all uv  2508  -0.396E-01  0.208E+01  0.307E+01  0.697E+00  0.299E+01
SH  all uv  1120  0.845E-01  0.205E+01  0.358E+01  0.114E+01  0.340E+01
NH  all q   641  0.285E-01  0.137E+00  0.206E+00  0.506E-01  0.200E+00
TR  all q    88  0.442E-01  0.108E+00  0.202E+00  0.246E-01  0.200E+00
SH  all q    37  0.108E-01  0.117E+00  0.204E+00  0.409E-01  0.200E+00
satellite brightness temp
instrument, channel #, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
amsua_n15  1  27 -0.122E+00  0.387E+01  0.348E+01  0.176E+01  0.300E+01
amsua_n15  2  26 -0.341E+00  0.375E+01  0.257E+01  0.132E+01  0.220E+01
amsua_n15  3  27 -0.227E+00  0.240E+01  0.220E+01  0.918E+00  0.200E+01
amsua_n15  4  27 -0.127E+00  0.570E+00  0.627E+00  0.181E+00  0.600E+00
amsua_n15  5  27 -0.190E+00  0.271E+00  0.317E+00  0.103E+00  0.300E+00
amsua_n15  7  41 -0.877E-01  0.213E+00  0.278E+00  0.121E+00  0.250E+00
amsua_n15  8  41 -0.768E-01  0.211E+00  0.317E+00  0.158E+00  0.275E+00
amsua_n15  9  41  0.128E+00  0.275E+00  0.381E+00  0.172E+00  0.340E+00
amsua_n15 10  41  0.152E+00  0.320E+00  0.431E+00  0.159E+00  0.400E+00
amsua_n15 12  41  0.735E+00  0.881E+00  0.103E+01  0.234E+00  0.100E+01
amsua_n15 13  41  0.151E+01  0.160E+01  0.155E+01  0.400E+00  0.150E+01
amsua_n15 15  26 -0.129E+01  0.476E+01  0.420E+01  0.231E+01  0.350E+01

```

5. Applications for Regional and Global EnKF

```

amsua_n18 1 24 -0.176E+00 0.395E+01 0.301E+01 0.167E+01 0.250E+01
amsua_n18 2 24 -0.104E+01 0.452E+01 0.259E+01 0.136E+01 0.220E+01
amsua_n18 3 24 -0.132E+01 0.304E+01 0.218E+01 0.877E+00 0.200E+01
amsua_n18 4 24 -0.298E+00 0.704E+00 0.578E+00 0.178E+00 0.550E+00
amsua_n18 6 29 -0.129E+00 0.201E+00 0.249E+00 0.947E-01 0.230E+00
amsua_n18 7 35 -0.103E+00 0.226E+00 0.260E+00 0.120E+00 0.230E+00
amsua_n18 10 36 0.666E-01 0.273E+00 0.373E+00 0.128E+00 0.350E+00
amsua_n18 11 36 0.239E+00 0.323E+00 0.425E+00 0.144E+00 0.400E+00
amsua_n18 12 35 0.464E+00 0.599E+00 0.598E+00 0.234E+00 0.550E+00
amsua_n18 13 33 0.131E+01 0.138E+01 0.896E+00 0.404E+00 0.800E+00
amsua_n18 15 24 -0.331E+01 0.587E+01 0.409E+01 0.211E+01 0.350E+01
amsua_metop-a 1 21 -0.254E+00 0.353E+01 0.285E+01 0.137E+01 0.250E+01
amsua_metop-a 2 22 0.500E-01 0.427E+01 0.249E+01 0.116E+01 0.220E+01
amsua_metop-a 3 23 -0.415E+00 0.319E+01 0.219E+01 0.883E+00 0.200E+01
amsua_metop-a 4 23 -0.346E-01 0.871E+00 0.586E+00 0.203E+00 0.550E+00
amsua_metop-a 5 23 -0.128E+00 0.245E+00 0.323E+00 0.119E+00 0.300E+00
... ..

```

This table should be checked in order to determine if the inflation is appropriate. As mentioned in the regional EnKF example, the goal is to make the total ensemble spreads of priors ($\sqrt{(S + R)}$) match the innovations (innov std) as much as possible. This is a global run using both conventional observation and satellite radiance data, we can see that all regions (NH,TR,SH) are listed for the conventional observations but not for radiances. We can see certain obtypes have fairly close values. On the other hand, there are still regions/obtypes that have notable differences, mainly associated with larger observation errors ($\sqrt{(R)}$). Users should consider tuning of inflation and localization, which is typically determined using cases with multiple assimilation cycles. Refer to section 4.2 of this User's Guide for more information on tuning.

4. Check the minimum and maximum values of the firstguess fields at each vertical level as a quick sanity check.:

```

ensemble mean first guess surface pressure:
  504.57253229632835      1096.3372866780792
time level          1
-----
sigio, min/max pressi      1  504.922180      1097.21021
sigio, min/max pressi      2  502.231506      1091.36328
sigio, min/max pressi      3  499.185242      1084.73694
... ..

```

5.4.4 Diagnose EnKF Analysis Results

At the bottom of the standard output file, there are several output statistics and tables that are helpful for users to diagnose the quality of the EnKF analysis.

5. Statistics of the ensemble analysis

```

global ps prior std. dev min/max = 4.96712141E-02 2.97986627
NH mean ps prior standard deviation = 0.594350934
NH mean ps posterior standard deviation (before inflation)= 0.422546178
NH mean ps posterior standard deviation (after inflation) = 0.566656113

```

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```

NH mean ps inflation =      1.39436281
SH mean ps prior standard deviation =      1.02483916
SH mean ps posterior standard deviation (before inflation)=      0.905294895
SH mean ps posterior standard deviation (after inflation) =      1.00432444
SH mean ps inflation =      1.15615737
TR mean ps prior standard deviation =      0.285711318
TR mean ps posterior standard deviation (before inflation)=      0.271452606
TR mean ps posterior standard deviation (after inflation) =      0.283461034
TR mean ps inflation =      1.03808999
time in inflate_ens =      8.0578343942761421E-002 on proc          0

```

This section is important for checking whether the values of the inflation are reasonable by looking at a summary of the maximum and minimum values. Also, viewing the regional averaged statistics before and after inflation. For this case we can see for all regions, larger standard deviation after the inflation are reported, which is more consistent with the prior standard deviation.

6. Spread inflation of the analysis ensemble

```

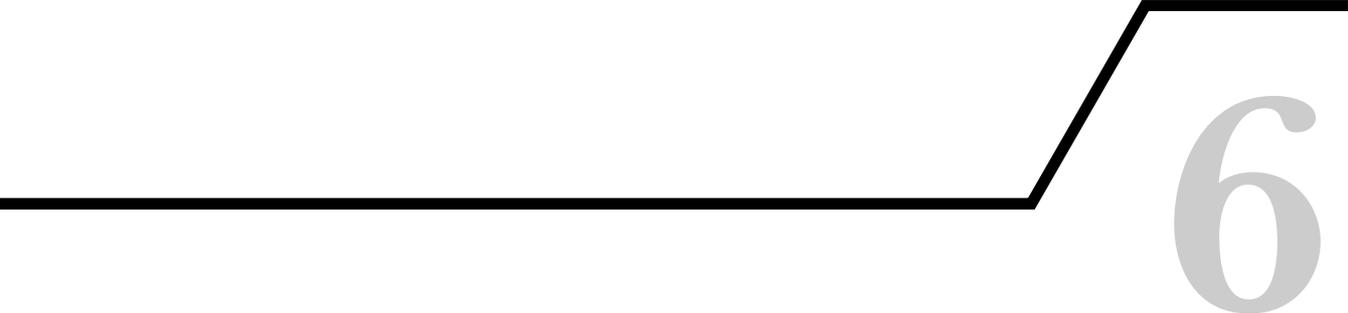
innovation statistics for posterior:
conventional obs
region, obtype, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
NH  all ps  11905  0.422E-01  0.903E+00  0.143E+01  0.230E+00  0.141E+01
TR  all ps   2078  0.235E+00  0.113E+01  0.130E+01  0.228E+00  0.128E+01
SH  all ps    895 -0.183E+00  0.102E+01  0.126E+01  0.426E+00  0.119E+01
NH  all t   1798  0.569E-01  0.130E+01  0.205E+01  0.287E+00  0.203E+01
TR  all t    275  0.354E+00  0.143E+01  0.212E+01  0.206E+00  0.211E+01
SH  all t    70  0.149E+00  0.116E+01  0.181E+01  0.367E+00  0.178E+01
NH  all uv  9776  0.334E-01  0.226E+01  0.227E+01  0.489E+00  0.221E+01
TR  all uv  2508 -0.578E-02  0.175E+01  0.303E+01  0.532E+00  0.299E+01
SH  all uv  1120  0.145E-01  0.166E+01  0.347E+01  0.690E+00  0.340E+01
NH  all q   641  0.334E-01  0.127E+00  0.203E+00  0.318E-01  0.200E+00
TR  all q    88  0.385E-01  0.921E-01  0.201E+00  0.178E-01  0.200E+00
SH  all q    37  0.149E-01  0.112E+00  0.202E+00  0.286E-01  0.200E+00
satellite brightness temp
instrument, channel #, nobs, bias, innov stdev, sqrt(S+R), sqrt(S), sqrt(R):
amsua_n15  1  27  0.767E-01  0.349E+01  0.334E+01  0.146E+01  0.300E+01
amsua_n15  2  26 -0.242E+00  0.349E+01  0.247E+01  0.113E+01  0.220E+01
amsua_n15  3  27 -0.145E+00  0.213E+01  0.215E+01  0.796E+00  0.200E+01
amsua_n15  4  27 -0.990E-01  0.507E+00  0.621E+00  0.160E+00  0.600E+00
amsua_n15  5  27 -0.177E+00  0.255E+00  0.314E+00  0.915E-01  0.300E+00
amsua_n15  7  41 -0.683E-01  0.177E+00  0.264E+00  0.852E-01  0.250E+00
amsua_n15  8  41 -0.634E-01  0.161E+00  0.295E+00  0.106E+00  0.275E+00
amsua_n15  9  41  0.114E+00  0.219E+00  0.362E+00  0.123E+00  0.340E+00
amsua_n15 10  41  0.126E+00  0.262E+00  0.418E+00  0.122E+00  0.400E+00
amsua_n15 12  41  0.639E+00  0.802E+00  0.102E+01  0.202E+00  0.100E+01
amsua_n15 13  41  0.135E+01  0.144E+01  0.154E+01  0.343E+00  0.150E+01
amsua_n15 15  26 -0.108E+01  0.431E+01  0.401E+01  0.196E+01  0.350E+01
amsua_n18  1  24  0.323E-01  0.373E+01  0.286E+01  0.139E+01  0.250E+01
amsua_n18  2  24 -0.923E+00  0.440E+01  0.245E+01  0.108E+01  0.220E+01
amsua_n18  3  24 -0.124E+01  0.294E+01  0.212E+01  0.713E+00  0.200E+01
amsua_n18  4  24 -0.294E+00  0.683E+00  0.573E+00  0.161E+00  0.550E+00
amsua_n18  6  29 -0.102E+00  0.165E+00  0.242E+00  0.759E-01  0.230E+00
amsua_n18  7  35 -0.653E-01  0.167E+00  0.247E+00  0.897E-01  0.230E+00
amsua_n18 10  36  0.513E-01  0.235E+00  0.365E+00  0.103E+00  0.350E+00
amsua_n18 11  36  0.186E+00  0.276E+00  0.417E+00  0.118E+00  0.400E+00
amsua_n18 12  35  0.307E+00  0.458E+00  0.579E+00  0.182E+00  0.550E+00
amsua_n18 13  33  0.104E+01  0.111E+01  0.858E+00  0.310E+00  0.800E+00

```

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amsua_n18	15	24	-0.304E+01	0.553E+01	0.392E+01	0.176E+01	0.350E+01
amsua_metop-a	1	21	-0.523E-01	0.320E+01	0.277E+01	0.119E+01	0.250E+01
amsua_metop-a	2	22	0.169E+00	0.392E+01	0.243E+01	0.104E+01	0.220E+01
amsua_metop-a	3	23	-0.324E+00	0.284E+01	0.215E+01	0.789E+00	0.200E+01
amsua_metop-a	4	23	0.379E-03	0.805E+00	0.579E+00	0.180E+00	0.550E+00
amsua_metop-a	5	23	-0.969E-01	0.227E+00	0.317E+00	0.103E+00	0.300E+00
...

After the EnKF analysis, it is important to check the innovation statistics, as previously discussed in the regional test case.



6

EnKF Basic Concepts and Code

Structure

This chapter briefly describes basic concepts and the main code structure used in the current implementation of the NOAA EnKF in the form of EnSRF. Please note there are also other EnKF algorithms provided in this EnKF system. We are working on documenting the other algorithms and will complete the User's Guide in the future.

6.1 Basic Concepts (in the Form of EnSRF)

6.1.1 Analysis Variables

In theory, EnKF can use any of the model prognostic variables as analysis variables as long as there exist meaningful/clear correlations between the variables and observations. Typically, for hydrostatic global models, horizontal wind components, temperature, water vapor, surface pressure, and ozone are used as analysis variables. For non-hydrostatic meso-scale models, like WRF, the vertical component of wind, rain/cloud related water content variables, and surface variables could be used as additional analysis variables.

6.1.2 Update of Analysis Variables

The minimum error-variance estimate of the analyzed variables X^a is given by the traditional Kalman filter update equation,

$$\begin{aligned} X^a &= X^b + K(y^o - HX^b) & (6.1) \\ K &= P^b H^T (HP^b H^T + R)^{-1} & (6.2) \end{aligned}$$

Where

X^b an m-dimensional background model forecast (i.e., prior)

X^a an m-dimensional analyses at model grids (i.e., posterior)

y^o a p-dimensional set of observations

H the operators that convert the model state to the observation space

P^b the mm -dimensional background-error covariance matrix

R the pp -dimensional observation-error covariance matrix

K the Kalman gain

Here, the Kalman gain is a function of the multivariate covariances of the model state variables and observations and the operator matrix that relates the model state to the observations. This update process is basically similar to a simple optimal interpolation (OI) scheme, where the Kalman gain is set to static.

The update equations (6.1) and (6.2) can be solved using ensemble technique. The Kalman gain can be estimated and propagated using a set of ensemble forecasts. Expressing the model state vector of the analysis variables as an ensemble mean (denoted by an overbar) and a deviation from the mean (denoted by a prime), the update equations for EnSRF ([6]) are written as:

$$\bar{X}^a = \bar{X}^b + K(y^o - H\bar{X}^b) \quad (6.3)$$

$$X'^a = X'^b - \tilde{K} H X'^b \quad (6.4)$$

$$\tilde{K} = \alpha K \quad (6.5)$$

$$\alpha = \left[1 + \sqrt{R / (HP^b H^T + R)} \right]^{-1} \quad (6.6)$$

Where K is the Kalman gain defined by (6.2) and estimated using the ensemble method described in the following section. \tilde{K} is the gain used to update ensemble deviations from the ensemble mean. Here, the observational error covariance is assumed uncorrelated, that is, R is diagonal. Then observations can be assimilated serially, one at a time, so that the analysis after assimilation of the Nth observation becomes the background estimate for assimilating the (N+1)th observation. For an individual observation, R and $HP^b H^T$ are scalars, K and \tilde{K} are vectors of the same dimension as the model state vector (before applying localization). Both K and \tilde{K} are calculated from the prior ensemble of the observation being assimilated and each of the analyses variables on the model grids individually.

Please note EnSRF is a revised EnKF that eliminates the necessity to perturb the observations. Therefore, the equation (6.4) does not contain the equivalent observation term to the one in the equation (6.3). However, this EnKF system itself provides an option to perturb the observations as well. In the future, we will add the description of the EnKF algorithm using perturbed observations into this user's guide.

6. EnKF Basic Concepts and Code Structure

In the EnKF framework, there is no need to compute and store the full matrix P^b . Instead, $P^b H^T$ and $H P^b H^T$ are estimated statistically from an ensemble of model forecasts/background. Specifically, these two quantities are obtained as:

$$P^b H^T = \overline{X^{ib} (H X^{ib})^T} = \sum_{i=1}^n X_i^{ib} (H X_i^{ib})^T / (n - 1) \quad (6.7)$$

$$H P^b H^T = \overline{H X^{ib} (H X^{ib})^T} = \sum_{i=1}^n H X_i^{ib} (H X_i^{ib})^T / (n - 1) \quad (6.8)$$

where n is the ensemble size of model forecasts; i is the index of each individual ensemble member. The expected analyses error covariance at the model grids after assimilation is given by

$$P^a = (I - KH) P^b (I - KH)^T \quad (6.9)$$

6.1.3 Updates of Observation Priors

In a serial assimilation of observations, the model first-guess or backgrounds at model grids are updated by one single observation at a time. For the assimilation of next observation, the first-guess of the next observation (observation priors) needs to be re-computed using the updated model background and a forward observation operator. This process is straightforward while running on a single processor computer, but is not efficient in a parallel computing environment, particularly when the first-guess of the observations are all pre-calculated.

Alternatively, the first-guess of the next observation can also be updated by the observation being assimilated, similar to the update to the model variables, so that re-computing the first-guess using the observational operators is not needed (see [1]). After the update of the first guess of model variables, the Nth observation being assimilated is also used to update the first-guess of the (N+1)th and next observations within the localization distance. This process can be expressed in the following update equations, similar to the equations (6.3)-(6.6):

$$\bar{Z}^a = \bar{Z}^b + K_z (y^o - H \bar{X}^b) \quad (6.10)$$

$$Z'^a = Z'^b - \alpha K_z H X'^b \quad (6.11)$$

$$K_z = Z'^b (H X'^b)^T (H P^b H^T + R)^{-1} \quad (6.12)$$

Where

y^o is the observation being assimilated.

Z^b is the first-guess of the next unassimilated observation

Z^a is the updated first-guess of the next unassimilated observation

K_z is the Kalman gain between the first-guess of the observation being assimilated and next unassimilated observation

6.1.4 Assimilation Order and Adaptive Thinning of Observations

In realistic assimilation systems, observations may have a non-linear relationship with the analysis variables. In addition, sampling errors are common due to the limited ensemble sizes. As a result, the achieved analysis can depend on the order of the observations assimilated. There are three options for choosing the orders of the observations for assimilation:

1. Assimilate observations in the order they are read in (default). This seems a reasonable choice for assimilating “BEST” observation types first (like radiosonde winds)
2. Shuffle the observations randomly before assimilating
3. Assimilate in order of increasing predicted observation analysis variance relative to the prior

For the third option, the predicted observational analysis variance against the first-guess in the observational space is defined as (for details, see [8] and [7]):

$$\mathbf{HP}^a\mathbf{H}^T/\mathbf{HP}^b\mathbf{H}^T = \mathbf{R}/(\mathbf{HP}^b\mathbf{H}^T + \mathbf{R}) \quad (6.13)$$

Note that the predicted variance is based on the observation priors' variance as if the observation is assimilated alone, and does not include the effect of the assimilation of other observations.

The observations can be further thinned adaptively. It is done via the updated estimation of the predicted analysis variance of next observation. If the predicted analysis variance for one observation is very close to the prior of this observation, the impact of this observation is expected to be very small and, therefore, it can be skipped. The threshold is set by the namelist parameter *paoverpb_thresh*.

6.1.5 Ensemble Spread Inflation

EnSRF uses a multiplicative inflation to inflate analyses/posterior ensemble spread back to the one of first-guess. The amount of inflation is given at each analysis grid point by:

$$\begin{aligned} \sigma^b &= \sqrt{\sum_{i=1}^n (\mathbf{X}'_i^b)^2 / (n-1)} \\ \sigma^a &= \sqrt{\sum_{i=1}^n (\mathbf{X}'_i^a)^2 / (n-1)} \\ r &= \left(\beta \frac{\sigma^b - \sigma^a}{\sigma^a} + 1 \right) \\ r\mathbf{X}'_i^a &\rightarrow \mathbf{X}'_i^a(\text{inflated}) \end{aligned} \quad (6.14)$$

where σ^b is the prior/first-guess ensemble standard deviation; σ^a is posterior/analyses ensemble standard deviation (before inflation); r is the inflation factor applied to each ensemble member deviation from the ensemble mean; β is a tunable namelist parameter (*analpertwt*)

defined in module `params`: If $\beta = 1$, ensemble is inflated so posterior standard deviation becomes the same as prior; If $\beta = 0$, there is no inflation.

For a given value of β , the inflation factor is proportional to the amount of ensemble spread reduction by assimilation of observations, normalized by the analyses ensemble spread. As a result, the inflation is in general larger where observations are denser or have larger impact. The actual inflation factor can be quite different for each variable and cross vertical and horizontal grids. If the smoothing namelist parameter (`smoothparm`) > 0 , the estimated inflation factor is smoothed using a Gaussian spectral filter with an e-folding scale of `smoothparm`. The minimum and maximum values allowed can be controlled by namelist parameters. In additions, extra inflation can be obtained by adding random noise from a climatology distribution of the model errors ([7]). The amount of the random noises to be added can be controlled through namelist parameters as well.

The total amount of inflation from these two inflation schemes should meet the following relationship ([3]), as close as possible:

$$\langle (\mathbf{y}^o - \mathbf{H}\bar{\mathbf{X}}^b)(\mathbf{y}^o - \mathbf{H}\bar{\mathbf{X}}^b) \rangle = (\mathbf{H}\mathbf{P}^b\mathbf{H}^T + \mathbf{R}) \quad (6.15)$$

Satisfaction of this equation ensures that the total ensemble spreads (ensemble spreads plus observational error covariance, right side of the equation) is a reasonable estimation of the RMS errors of observation priors against observations (left side of the equation). This relationship justifies that the ensemble system works reasonably well. Moreover, the ensemble spreads should be tuned appropriately relative to observation errors (assuming these errors are correctly set). Substantially smaller ensemble spreads could lead to underweight of observations. As a result, EnKF may ignore the observations for assimilation and/or lead to an over-divergent ensemble.

6.1.6 Covariance Localization

To reduce the impact of spurious ensemble covariance on the update of both analyses variables at model grids and the first-guess of observations (observation priors), localization is applied to the covariance (Kalman gains) in the equations (6.7) and (6.12) in both horizontal and vertical. The function of [2] is used in horizontal localization. It uses a 5th order compact polynomial and the impact of observations is gradually reduced to zero at the specified cutoff distance. The scale height $-\log(P/P_{ref})$ is used in vertical localization.

The localization distance is an important tunable parameter for a successful analysis of EnSRF. Tuning the localization distance depends on several factors, including the ensemble size used, model grid resolutions, weather scenario, etc. In general, a larger ensemble size allow a longer localization distance. But assimilation with a smaller ensemble size may benefit from a reduced localization distance to reduce the impact of spurious covariance. In addition, assimilation of higher-resolution observations (e.g., radar data) may require a much shorter localization distance.

6.1.7 Adaptive Radiance Bias Correction with EnSRF

An adaptive radiance bias correction procedure is used for the satellite radiance data assimilation in EnSRF. The first-guess of the radiance observations are updated by the radiance observations using the assimilation procedure outlined in the section (6.2.2). The updated innovations (O-B) are then used to update the coefficients of the radiance bias correction scheme. The first-guess of the radiance observations are updated again using the updated bias correction coefficients. This process may be repeated/iterated multiple times until the updated first-guess of the radiance observations and bias correction coefficients converge.

6.2 EnSRF Code Structure and Key Functions

6.2.1 Main Code Tree

The code structure for main code *enkf_main.f90*:

Step	Code	Explanation
initialize	call <code>mpi_initialize</code>	initialize MPI
	call <code>init_rad</code>	Initial radinfo variables
	call <code>read_namelist</code>	read namelist (enkf.nml)
	call <code>mpi_initialize_io</code>	initialize MPI communicator for IO tasks
	call <code>init_rad_vars</code>	Initialize derived radinfo variables
prepare data	call <code>getgridinfo</code>	read horizontal grid information and pressure fields from forecast ensemble mean file
	call <code>readobs</code>	Read observations, observation priors for each ensemble member (from <code>diag**</code> files generated by GSI forward operators). initial screening.
	call <code>print_innovstats</code>	print innovation statistics for prior
	<i>if</i> (<code>readin_localization</code>) call <code>read_locinfo</code>	read in vertical profile of horizontal and vertical localization length scales, set values for each obs
	call <code>load_balance</code>	do load balancing (partitioning of grid points, observations among processors)
	call <code>read_ensemble</code>	read in prior ensemble members, distribute pieces to each task
analysis	<i>if</i> (<code>letkf_flag</code>) <i>then</i> call <code>letkf_update</code> <i>else</i> call <code>enkf_update</code>	Update state variables, observation priors, and radiance bias correction coefficients with EnSRF or the EnKF with perturbed observations
write results	call <code>inflate_ens</code>	Inflate posterior ensemble using the multiplicative inflation scheme
	call <code>print_innovstats</code>	print innovation statistics for posterior
	call <code>radinfo_write</code>	write out bias coeffs on root
	call <code>write_ensemble</code>	write out analysis ensemble
clean up	call <code>obsmod_cleanup</code> call <code>gridinfo_cleanup</code> call <code>statevec_cleanup</code> call <code>loadbal_cleanup</code> call <code>mpi_cleanup</code>	

Please note additive inflation may be added to the posterior ensemble offline.

6.2.2 Driver of Serial Ensemble Square Root Filter

If using the EnKF algorithm (if *letkf_flag = .false.*), the priors of model analyses variables, observation priors, and bias correction coefficients are updated by subroutine *enkf_update* in *enkf.f90*. The code structure of *enkf_update* is:

Step	Code
1: Determine the order of all observations for assimilation according to the namelist choice	<pre> if (iassim_order == 1) then ! create random index array so obs are assimilated ! in random order. else if (iassim_order .eq. 2) then ! assimilate obs in order of increasing HPaHT/HPbHT else ! assimilate obs in order they were read in end if </pre>
2 begin outer loop	<i>do niter=1,numiter</i>
2.1 reset ob error to account for gross errors	<pre> if (niter > 1 .and. varqc) then if (huber) then ! "huber norm" QC else ! "flat-tail" QC. endif else oberrvaruse(nob) = oberrvar(nob) end if </pre>
2.2: assimilation loop over all observations, one observation at a time	<pre> obsloop: do nobx=1,nobstot end do obsloop ! loop over obs to assimilate </pre>
2.3	<pre> ! make sure posterior perturbations still have ! zero mean ! distribute the O-A stats to all processors ! satellite bias correction update </pre>
2: end outer loop	<i>enddo ! niter loop</i>

The details of the step 2.2 is listed below:

6. EnKF Basic Concepts and Code Structure

Step	Code in Step 2.2
1: which observation to assimilate next	<pre> if (iassim_order == 2) then else nob = indxassim(nobx) endif </pre>
2. calculate : $\frac{HP^bH^T}{(HP^bH^T + R)^{-1}}$ $R/(HP^bH^T + R)$	<pre> hpfht = sum(anal_obchunk(:,nob1)**2)*r_nanalsm1 hpfhtoberrinv=one/(hpfht+oberrvaruse(nob)) paoverpb = oberrvar(nob)/(hpfht + oberrvar(nob)) </pre>
3. calculate Equation 6.6	<pre> if (deterministic) then ! EnSRF. obganl = -anal_obtmp/(one+sqrt(oberrvaruse(nob)*hpfhtoberrinv)) else ! perturbed obs EnKF. end if </pre>
4. Calculate Kalman gain (<i>kfgain</i>) (K, Equation (6.5)) and add the analyses increments of the observation being assimilated to the ensemble mean (<i>ensmean_chunk</i> and perturbations of analyses variables at model grids (<i>anal_chunk</i>) (Equations (6.3) and (6.4))	<pre> if (nf2 > 0) then do ii=1,nf2 ! loop over nearby horiz grid points do nb=1,nbackgrounds ! loop over background time levels do nn=nn1,nn2 nnn=index_pres(nn) if (taperv(nnn) > zero) then ! gain includes covariance localization update all time levels kfgain=taperv(nnn)*sum(anal_chunk(:,i,nn,nb)*anal_obtmp) ! update mean. ensmean_chunk(i,nn,nb) = ensmean_chunk(i,nn,nb) + kfgain*obinc_tmp ! update perturbations. anal_chunk(:,i,nn,nb) = anal_chunk(:,i,nn,nb) + kfgain*obganl(:) end if end do end do ! end loop over background time levels. end do ! end loop over nearby horiz grid points end if ! if .not. lastiter or no close grid points </pre>
5. Calculate the Kalman gain <i>kfgain</i> (Kz: Equation (6.12)) and add the analyses increments of the observation being assimilated to the nearby observation priors <i>ensmean_obchunk</i> , and <i>anal_obchunk</i> (Equations (6.10) and (6.11)).	<pre> if (nf > 0) then do nob1=1,nf ! gain includes covariance localization. kfgain = taper_disob(nob1)* & taper(lnsig*lnsiglinv)*taper(obt*obtimelinv)* & sum(anal_obchunk(:,nob2)*anal_obtmp)*hpfhtcon ! update mean. ensmean_obchunk(nob2) = ensmean_obchunk(nob2) + kfgain*obinc_tmp ! update perturbations. anal_obchunk(:,nob2) = anal_obchunk(:,nob2) + kfgain*obganl end do </pre>



Content of Namelist

The following are lists and explanations of the EnKF namelist variables. Users can also check file *params.f90* for the details.

Section **nam_enkf**

Variable Name	Description	Data Type	Default
datein	Analysis date in YYYYMMDDHH	integer	0
datapath	path to data directory (include trailing slash)	Character (len=500)	""
iassim_order	= 0 for the order they are read in, =1 for random order = 2 for order of predicted posterior variance reduction (based on prior)	integer	0
covinflatemax	maximum inflation	real(r_single)	1.e30
covinflatemin	minimum inflation	real(r_single)	1.0
deterministic	if true, use EnSRF w/o perturbed obs. if false, use perturbed obs EnKF.	logical	true
sortinc	if false, re-order obs to minimize regression errors as described in Anderson (2003).	logical	true
corrlengthnh	length for horizontal localization (in km) in north hemisphere	real(r_single)	2800
corrlengthtr	length for horizontal localization (in km) in tropic	real(r_single)	2800
corrlengthsh	length for horizontal localization (in km) in south hemisphere	real(r_single)	2800

A. Content of Namelist

Variable Name	Description	Data Type	Default
varqc	Turn on varqc	logical	false
huber	use huber norm instead of "flat-tail"	logical	fales
nlons	number of lons	integer	0
nlats	Number of lats	integer	0
smoothparm	smoothing parameter for inflation (-1 for no smoothing)	real(r_single)	-1
readin_localization	If true, read in localization length scales from an external file	logical	false
zhuberleft	Parameter for "huber norm" QC	real(r_single)	1.e30
zhuberright	Parameter for "huber norm" QC	real(r_single)	1.e30
obtimelnh	observation time localization in hours over north hemisphere	real(r_single)	25.925
obtimeltr	observation time localization in hours over tropic	real(r_single)	25.925
obtimelsh	observation time localization in hours over south hemisphere	real(r_single)	25.925
reducedgrid	Do smooth in a reduced grid with a variable number on longitudes per latitude. The number of longitudes is chosen so that the zonal grid spacing is approximately the same as at the equator	logical	false
lnsigcutoffnh	length for vertical localization in ln(p) over north hemisphere for conventional observation	real(r_single)	2.0
lnsigcutofftr	length for vertical localization in ln(p) over tropic conventional observation	real(r_single)	2.0
lnsigcutoffsh	length for vertical localization in ln(p) over south hemisphere for conventional observation	real(r_single)	2.0
lnsigcutoffsatnh	length for vertical localization in ln(p) over north hemisphere for satellite radiance observation	real(r_single)	-999.0
lnsigcutoffsattr	length for vertical localization in ln(p) over tropic satellite radiance observation	real(r_single)	-999.0
lnsigcutoffsatsh	length for vertical localization in ln(p) over south hemisphere for satellite radiance observation	real(r_single)	-999.0
lnsigcutoffpsnh	length for vertical localization in ln(p) over north hemisphere for surface pressure observation	real(r_single)	-999.0
lnsigcutoffpstr	length for vertical localization in ln(p) over tropic surface pressure observation	real(r_single)	-999.0
lnsigcutoffpssh	length for vertical localization in ln(p) over south hemisphere for surface pressure observation	real(r_single)	-999.0

A. Content of Namelist

Variable Name	Description	Data Type	Default
analpertwtnh	adaptive posterior inflation parameter over north hemisphere: 1 means inflate all the way back to prior spread	real(r_single)	0.0
analpertwtsh	adaptive posterior inflation parameter over tropic: 1 means inflate all the way back to prior spread	real(r_single)	0.0
analpertwttr	adaptive posterior inflation parameter over south hemisphere: 1 means inflate all the way back to prior spread	real(r_single)	0.0
sprd_tol	tolerance for background check: observations are not used if they are more than $\sqrt{S+R}$ from mean, where S is ensemble variance and R is observation error variance.	real(r_single)	9.9e31
nlevs	total number of levels	integer	0
nanals	number of ensemble members	integer	0
nvars	number of 3d variables to update. For hydrostatic models, typically 5 (u,v,T,q,ozone).	integer	5
saterrfact	factor to multiply sat radiance errors	real(r_single)	1.0
univaroz	If true, ozone observations only affect ozone	logical	true
regional	If true, analysis is for regional	logical	false
use_gfs_nemsio	If true, GFS background is in NEMS format	logical	false
paoverpb_thresh	if observation space posterior variance divided by prior variance less than this value, observation is skipped during serial processing. 1.0 = don't skip any obs	(r_single)	1.0
latbound	definition of tropics and mid-latitudes (for inflation).	real(r_single)	25.0
delat	width of transition zone	real(r_single)	10.0
pseudo_rh	use 'pseudo-rh' analysis variable, as in GSI	logical	false
numiter	number of times to iterate state/bias correction update. (only relevant when satellite radiances assimilated, i.e. nobs_sat>0)	integer	1.0

A. Content of Namelist

Variable Name	Description	Data Type	Default
biasvar	background error variance for rad bias coeffs (used in radbias.f90). Default is (old) GSI value. if negative, bias coeff error variace is set to - biasvar/N, where N is number of obs per instrument/channel. if newpc4pred is .true., biasvar is not used - the estimated analysis error variance from the previous cycle is used instead (same as in the GSI).	real(r_single)	0.1
lupd_satbiasc	if performing satellite bias correction update	logical	true
cliptracers	if true, tracers are clipped to zero when read in, and just before they are written out.	logical	true
simple_partition	partition obs for enkf using Graham's rule	logical	true
adp_anglebc	turn off or on the variational radiance angle bias correction	logical	false
angord	order of polynomial for angle bias correction	Integer	0
newpc4pred	controls preconditioning due to sat-bias correction term	logical	
nmmb	If true, ensemble forecast is NMMB	logical	false
iau		logical	false
nhr_anal	background forecast time for analysis	integer	6
letkf_flag	If true, do LETKF	logical	false
boxsize	Observation box size for LETKF (deg)	real(r_single)	90.0
massbal_adjust	mass balance adjustment for GFS	logical	false
use_edges	logical to use data on scan edges (.true.=to use)	logical	true
emiss_bc	If true, turn on emissivity bias correction	logical	false

Section **nam_wrf**

Variable Name	Description	Data Type	Default
arw	regional dynamical core ARW	logical	false
nmm	regional dynamical core NMM	logical	true
doubly_periodic		logical	true

A. Content of Namelist

Section **satobs_enkf**

Variable Name	Description	Data Type	Default
sattypes_rad	strings describing the satellite data type (which form part of the diag* filename).	character(len=20) array (nsat- max_rad)	''''
dsis	strings corresponding to sattypes_rad which correspond to the names in the NCEP global_satinfo file.	character(len=20) array (nsat- max_rad)	''''

Section **ozobs_enkf**

Variable Name	Description	Data Type	Default
sattypes_oz	strings describing the ozone satellite data type (which form part of the diag* filename)	character(len=20) array (nsat- max_oz)	''''

Bibliography

- [1] J. Anderson and N. Collins. Scalable implementations of ensemble filter algorithms for data assimilation. *Journal of Atmospheric and Oceanic Technology*, 24:1452–1463, 2007.
- [2] G. Gaspari and S. E. Cohn. Construction of correlation functions in two and three dimensions. *Quarterly Journal of the Royal Meteorological Society*, 125:723–757, 1999.
- [3] P. L. Houtekamer and H. L. Mitchell. Ensemble kalman filtering. *Quarterly Journal of the Royal Meteorological Society*, 131(613):3269–3289, 2005.
- [4] B. R. Hunt, E. J. Kostelich, and I. Szunyogh. Efficient data assimilation for a spatiotemporal has: a local ensemble transform kalman filter. *Physica D*, 230:112–126, 2007.
- [5] H. Shao, J. Derber, X.-Y. Huang, M. Hu, K. Newman, D. Stark, M. Lueken, C. Zhou, L. Nance, Y.-H. Kuo, and B. Brown. Bridging research to operations transitions: Status and plans of community gsi. *Bulletin of the American Meteorological Society*, 2016.
- [6] J. Whitaker and T. Hamill. Ensemble data assimilation without perturbed observations. *Mon. Wea. Rev.*, 130:1913–1924, 2002.
- [7] J. Whitaker and T. Hamill. Evaluating methods to account for system errors in ensemble data assimilation. *Mon. Wea. Rev.*, 140:3078–3089, 2012.
- [8] J. Whitaker, T. Hamill, X. Wei, Y. Song, and Z. Toth. Ensemble data assimilation with the ncep global forecast system. *Mon. Wea. Rev.*, 436:463–482, 2008.