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Providing Operational GSI and EnKF to the Research Community: 2017 Update

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Data Assimilation Software

- **Gridpoint Statistical Interpolation (GSI)** analysis system:
  - Originally developed by NCEP/EMC
  - Community system since 2009
    - Active developers from various operational and research institutes and agencies
    - Centralized support through the Developmental Testbed Center (DTC)
  - Operational applications:
    - NCEP: Global Forecasting System (GFS), North American Mesoscale system (NAM), Hurricane WRF (HWRF), Real-Time Mesoscale Analysis (RTMA)
    - NOAA: Rapid Refresh (RAP), High-Resolution Rapid Refresh (HRRR)
    - NASA: Goddard Earth Observing System (GEOS)
    - Air Force: Mesoscale forecast analysis system
- **Ensemble Kalman Filter (EnKF)** based analysis system:
  - Originally developed by NOAA/ESRL
  - Community system since 2015
  - Applications:
    - Operational as part of the GFS data assimilation (GDAS) system (GSI-EnKF hybrid)
    - Can be used for regional models and systems, e.g., HWRF, NAM, ARW

Supported DA Techniques

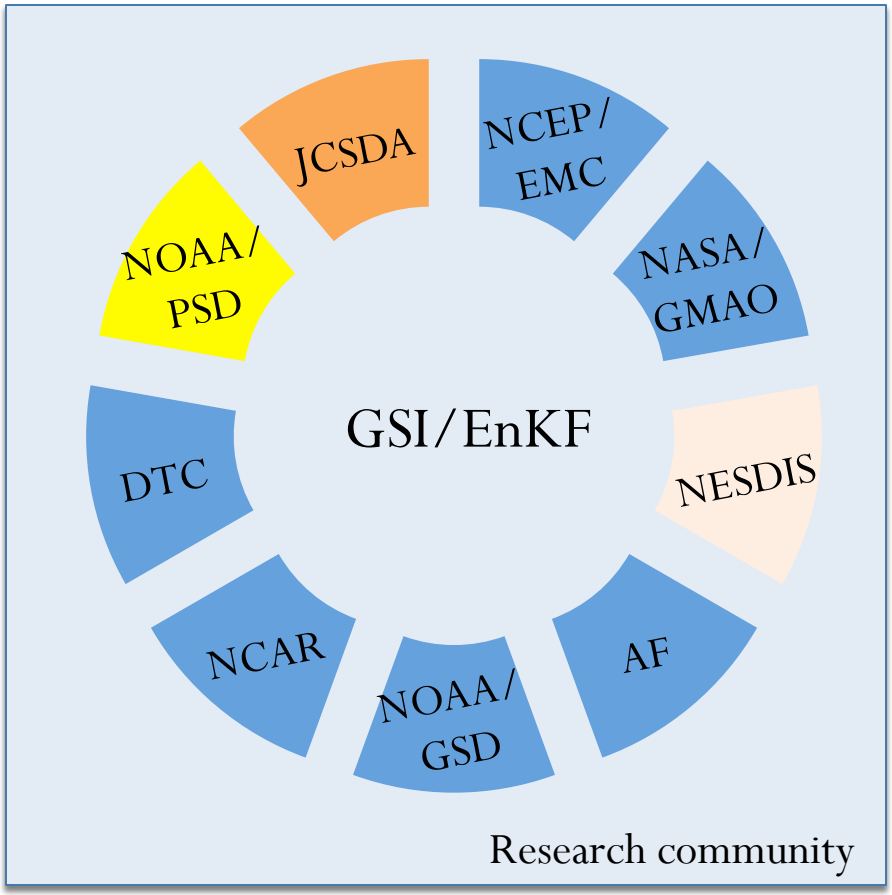
- GSI:
  - 2DVar
  - 3DVar
  - 3D (hybrid) EnVar
  - 4D (hybrid) EnVar

EnVar : Variational (Var) DA using ensemble background covariances
Hybrid: Variational DA using a combination of climatological and ensemble covariances
- Nomenclature adopted from Lorenc (2013)

- EnKF: using GSI as the observation operators (assimilating same observation types as GSI)
  - Ensemble Square Root Filter (EnSRF)
    - Parallelization scheme based on NCAR Data Assimilation Research Testbed (DART) toolkit
  - Local Ensemble Transform Kalman Filter (LETKF)

Code Management and Support

- Code is managed by the Data Assimilation Review Committee, formed in 2010
  - Include major code development teams
  - Coordinate code development
  - Review code changes
- All committee members are aware of latest code changes and responsible for their specific operational applications
- The DTC provides centralized code support to the general research community



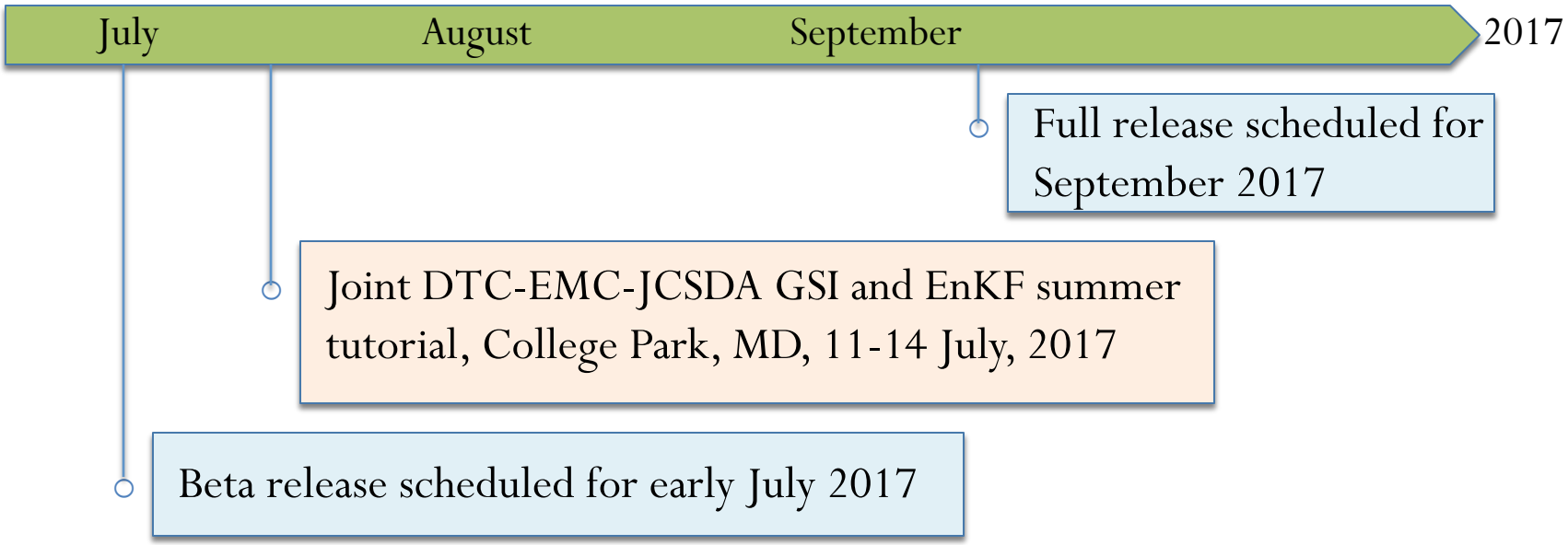
Members since 2010

Member added in 2011

Members added in 2015

Member added in 2016

GSI v3.6/EnKF v1.2



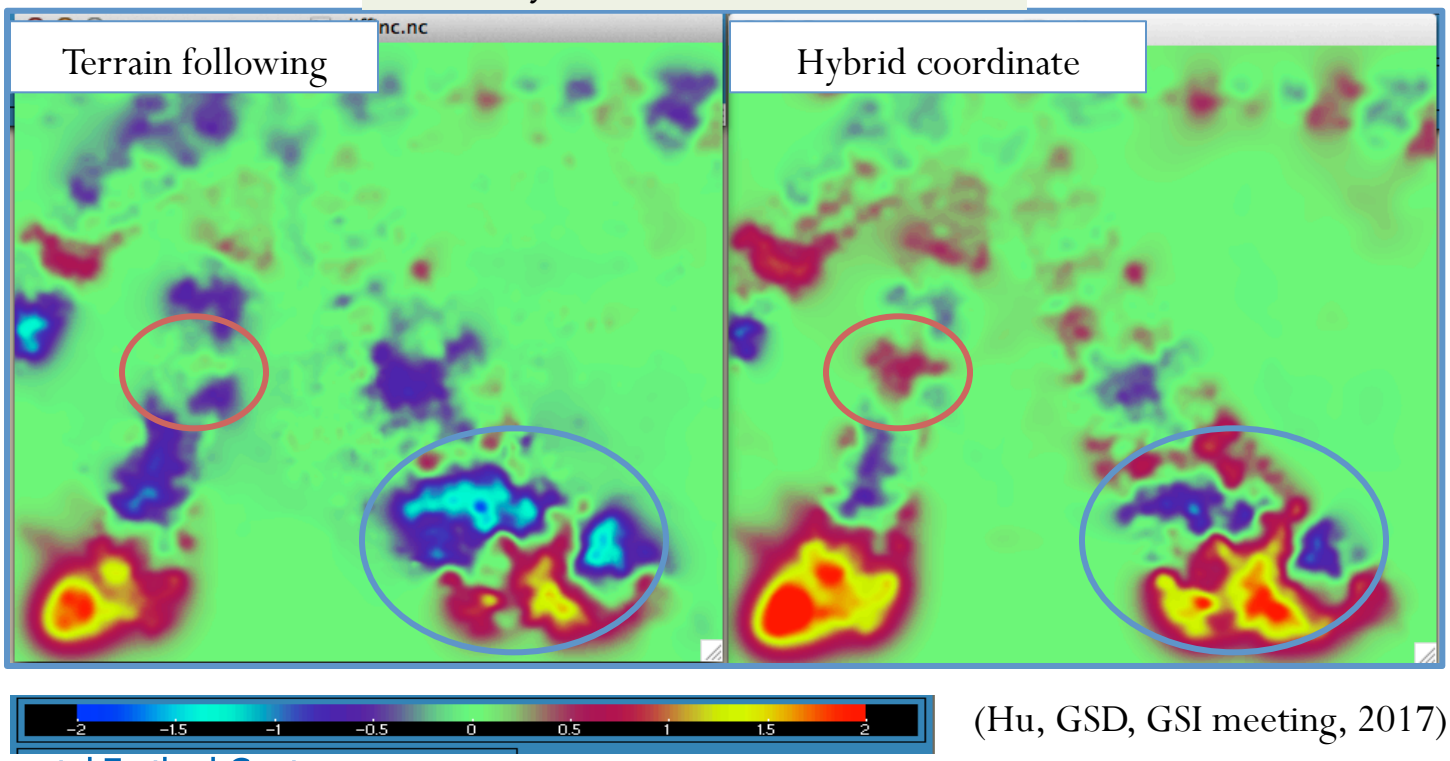
Major changes:

- Enhanced and updated capabilities
- Code refactoring and optimization

Adding ARW Hybrid Vertical Coordinate Background to GSI

- GSI is updated to run with ARW background using hybrid vertical coordinate
- Resulting differences for analysis increments were found mostly at upper levels

T analysis increment at level 46



(Hu, GSD, GSI meeting, 2017)

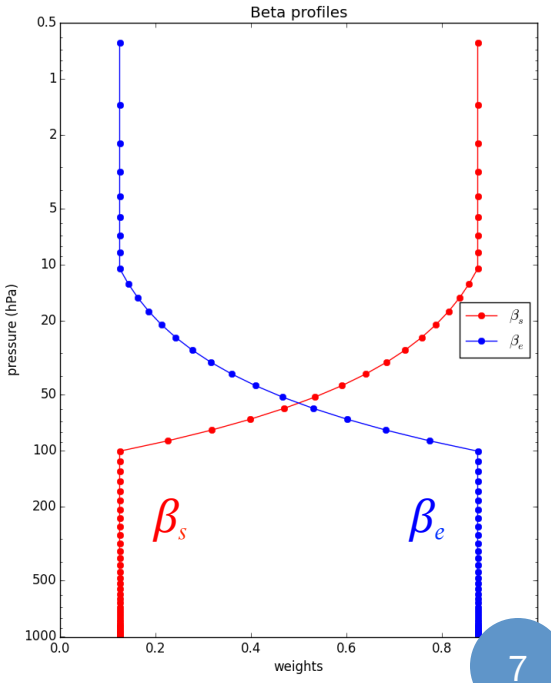
Update to Use of Hybrid Background Error Weighting Profiles in GSI

$$J(\mathbf{x}_1,\alpha)=(\beta_s)^{-1}\mathbf{x}_1^T\mathbf{B}^{-1}\mathbf{x}_1+(\beta_e)^{-1}\alpha^T A^{-1}\alpha+(\mathbf{Hx}-\delta\mathbf{y}_0)^T R^{-1}(\mathbf{Hx}-\delta\mathbf{y}_0)$$

Static background error covariance

Incorporating ensemble background-error information through extended control variable α

- β_s and β_e are weighting factors for static and ensemble background error contributions. In last GSI release,
  - $\beta_s + \beta_e = 1$
  - β_s and β_e were scalar constants
- Currently, GSI loosens up $\beta_s + \beta_e = 1$ and uses vertical profiles of weighting functions
  - Use diagonal matrix of β_s and β_e
  - Fixed code bugs for implementation of diagonal matrices in GSI cost function preconditions



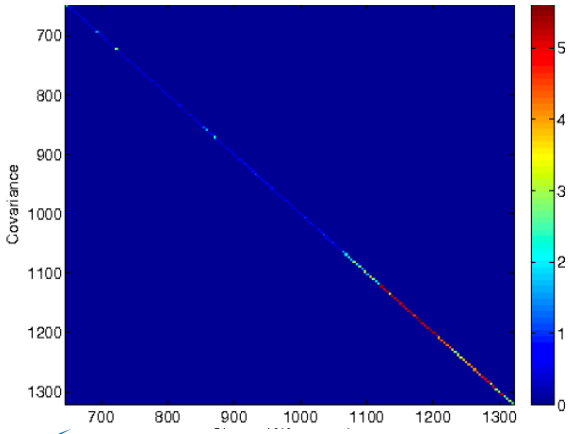
(Parrish, EMC, GSI meeting, 2016)

Correlated Radiance Observation Errors

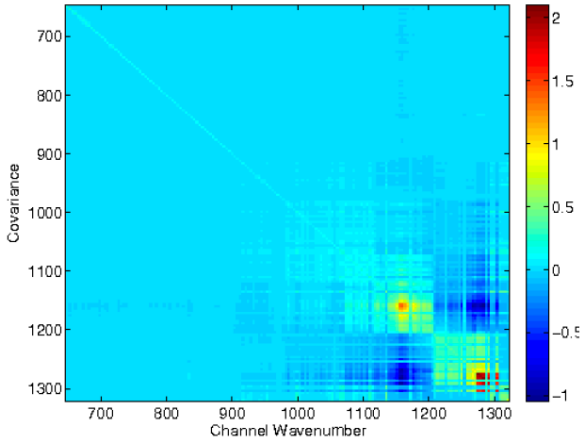
$$J(\mathbf{x}_1,\alpha)=(\beta_s)^{-1}\mathbf{x}_1^T\mathbf{B}^{-1}\mathbf{x}_1+(\beta_e)^{-1}\alpha^T A^{-1}\alpha\ +(\mathbf{Hx}-\delta\mathbf{y}_0)^T R^{-1}(\mathbf{Hx}-\delta\mathbf{y}_0)$$

- For satellite observations, observation error covariance matrix (**R**), specified in the satinfo file, was originally a diagonal matrix => uncorrelated observation errors
- GSI is now updated to use a full **R** as part of options
- A utility cov_calc is added to util/Correlated_obs to compute a non-diagonal **R** and recondition

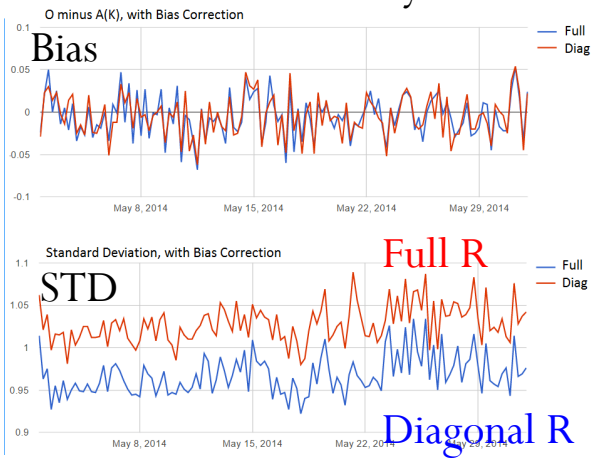
Diagonal R



Full R



Observation-Analysis



Bathmann, et al, EMC, GSI meeting, 2016

Application Specific Updates and Enhancements

Non-variational cloud analysis:

- Added number concentration for cloud water, cloud ice and rain to match cloudy analysis with the Thompson Microphysical scheme
- Visibility/fog observation namelist options for lowest two levels
- Added capability to use NASA global LaRC cloud products

RTMA:

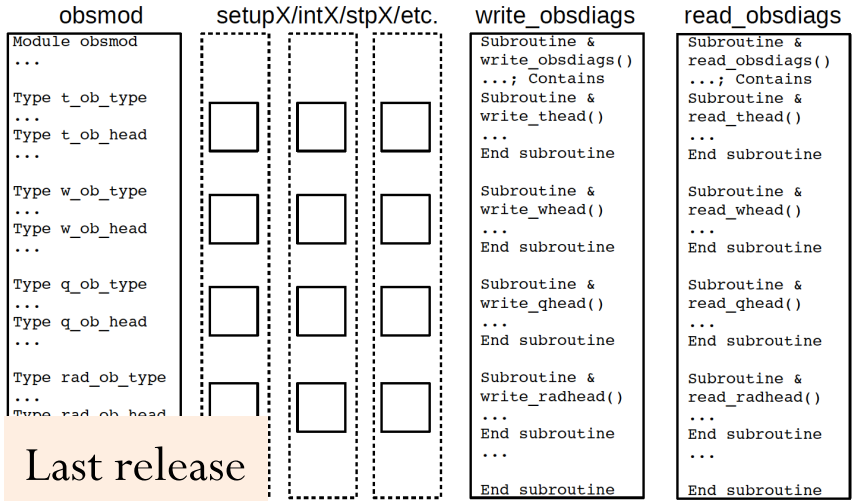
- Variational QC algorithm using super-logistic distribution function.
- Added cloud ceiling height and scalar wind as analysis variables

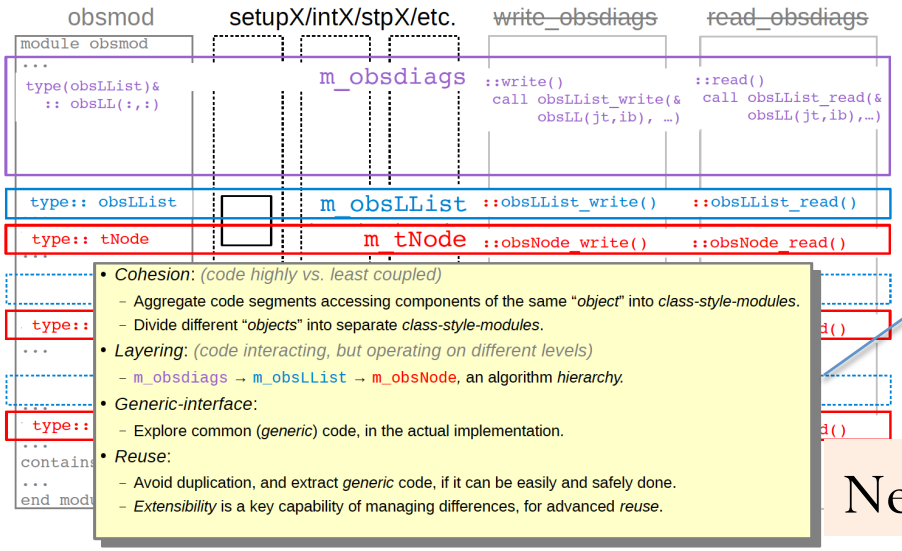
Other:

- Now using full spectral resolution CrIS radiance observations
- Using NCEP nemio interface
- Unified RAP and NMM-B cloud analysis libraries
- Near surface temperature (NST)
- Utility updates
- Bug fixes

Polymorphic Observations:
from Procedural to Object-Oriented

- Changes are related to steps for adding a new observation type
- Bottom-up development through refactoring to improve overall modularity, extensibility and maintainability





- Aggregate code segments
- Layer code in an algorithm hierarchy
- Provide generic interface
- Reuse and extend generic code for adding new observations

(Guo and Todling, GMAO, GSI meeting, 2017)

Other Code Refactoring and Optimization Efforts

- Generalized all radiance assimilation across different sensors/ instruments for cloud and aerosol usages in GSI (Zhu, NCEP/EMC, GSI meeting, 2015)
  - Centralized cloud and aerosol usage information
  - Simplified code
  - Enhanced code flexibility to expand current capabilities to additional instruments
- Removed the First-Order Time extrapolation to the Observation (FOTO) from GSI
- Removed other unused modules/variables in GSI
- Updated to netCDF v4.0 functionality

Toward Unified Operational and Research Build System

Community release build: Perl, shell , & make

- Two-step build with user-friendly interface
  - configure: WRF-like menu
  - compile
- Created for general computer platforms
- User support for general usage
- Include compilation of NCEP I/O library code

EMC build: make

- Command line
- Tailored for NOAA computers
- Operational compilation

Unified build: Perl, shell, & cmake

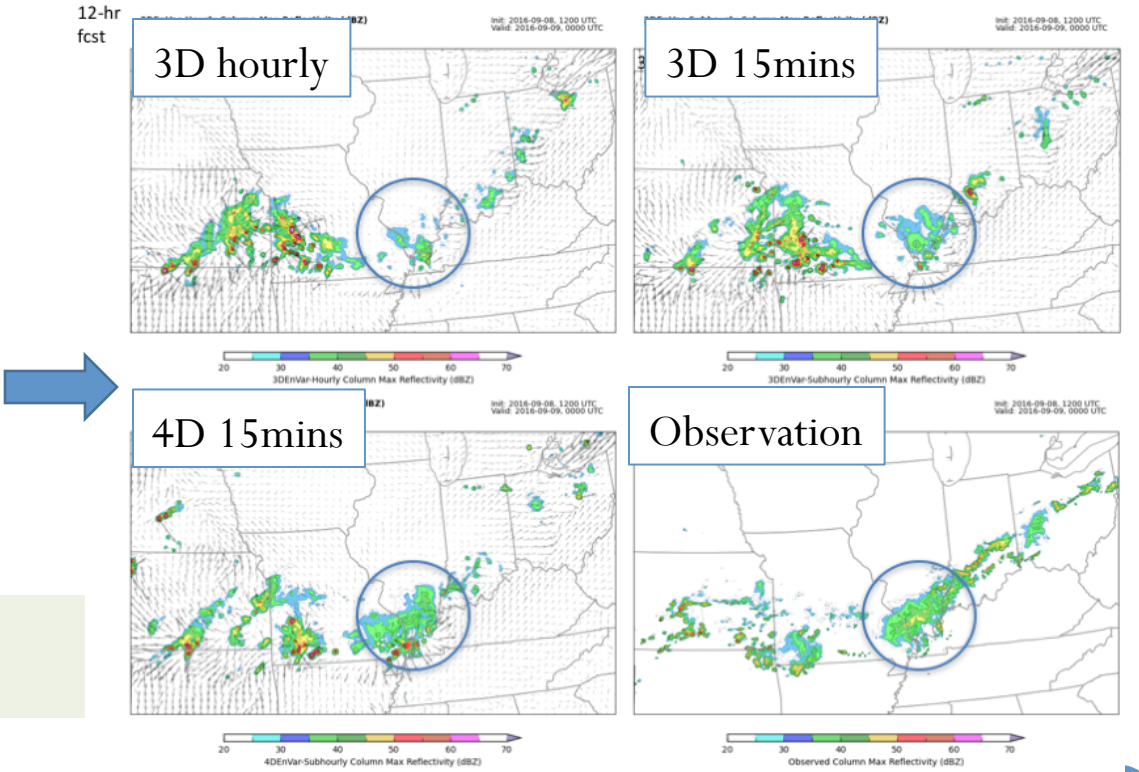
- User interface
  - configure
  - compile
- Can be run from command line
- Include both general platforms and NOAA-specific platforms
- Support operational compilation flags
- Include compilation of NCEP I/O library code
- User support for both general usage and operational usage (NOAA)
- May consider extension to other applications

Last release

New

DTC Code Tests: Using 4D EnVar for Convective Weather Forecasts

- Evaluate 4D EnVar hourly cycling for a convective scale case
  - 7B.3: Zhou, Chunhua, et. al, Testing and evaluation of the hybrid 4D EnVar GSI for 3-km High-resolution regional applications
- Evaluate 3D/4D EnVar for sub-hourly cycling
  - P12: Beck, Jeff, et. al, An evaluation of 3D- and 4D-EnVar sub-hourly data assimilation in the HRRR



Radar Reflectivity Comparison: 1200 UTC 8 September 2016

Call for Research Contributions

- Repository
  - To apply for access, contact the helpdesk (gsi-help@ucar.edu)
  - Code transition support
- DTC visitor program:
  - Proposals to work directly with the GSI system and/or the NOAA EnKF system are strongly encouraged.
  - Year-around applications
  - Apply via the DTC visitor program website: http://www.dtcenter.org/visitors/

DTC DA webpage:

GSI: http://www.dtcenter.org/com-GSI/users/

EnKF: http://www.dtcenter.org/EnKF/users/

(shared helpdesk and contact)

Future Plans

- Joint DTC-EMC-JCSDA GSI and EnKF community tutorial:
  - 11-14 July, 2017, College Park, MD
- Annual code release for GSI v3.6, EnKF v1.2
  - by end of September 2017
- The community code repository will be transitioned from svn to Git
- Continue to perform code tests and evaluation
- Coordinate with the Joint Effort for Data assimilation Integration (JEDI) led by JCSDA, in collaboration with major development teams
- Encourage community contributions and collaborations

Observations Types (I)

- Radiosondes
- Pibal winds
- Synthetic tropical cyclone winds
- Conventional aircraft reports
- ASDAR aircraft reports
- MDCARS aircraft reports
- Dropsondes
- Surface land observations
- Surface ship and buoy observation
- Wind profilers: US, JMA
- Tall tower winds
- SSM/I wind speeds
- MODIS IR and water vapor winds
- GMS, JMA, METEOSAT, and GOES cloud drift IR and visible winds
- GOES hourly IR and cloud top winds
- QuikSCAT, ASCAT, and OSCAT wind speed and direction
- ISS-RapidScat winds
- GOES CAWV AMV
- AVHRR winds

Conventional

Satellite wind & retrievals

- EUMETSAT and GOES water vapor cloud top winds
- METAR cloud observations
- SSM/I and TRMM TMI precipitation estimates
- Doppler radial velocities
- VAD (NEXRAD) winds
- Radar Reflectivity Mosaic
- Tail Doppler Radar (TDR) radial velocity and super-observation
- Flight level and Stepped Frequency Microwave Radiometer (SFMR) High Density Observation (HDOB) from reconnaissance aircraft
- GPS precipitable water estimates
- GPS Radio occultation (RO) refractivity bending angle profiles
- Doppler wind Lidar data
- SBUV ozone profiles, MLS (including NRT) ozone, and OMI total ozone
- SST
- Tropical cyclone VITAL (TCVital)
- PM2.5, PM10
- AOD: MODIS

Radar

GPS

Others

Observations Types (II)

- SBUV: n17, n18, n19
- HIRS: metop-a, metop-b, n17, n19
- GOES_IMG: g11, g12
- AIRS:aqua
- AMSU-A: metop-a, metop-b, n15, n18, n19, aqua
- AMSU-B: metop-b, n17
- MHS: metop-a, metop-b, n18, n19
- SSMI: f14, f15
- SSMIS: f16, f18, f19
- AMSRE: aqua
- SNDR: g11,g12, g13
- IASI: metop-a, metop-b
- GOME: metop-a, metop-b
- OMI: aura
- SEVIRI: m08, m09, m10
- ATMS: Suomi NPP
- CRIS: Suomi NPP

Satellite Radiance

- GCOMW1 AMSR2
- GPM GMI
- Megha-Tropiques SAPHIR
- Himawari AHI

Acronyms should be found from GSI and EnKF's user's guide