Data Assimilation Development for the FV3GFS: Higher Vertical Resolution, Cloud Analysis, and Plans for 2020

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Proposed 2020 Operational FV3GFS Implementation

- The 2019 upgrade focuses on adapting the existing data assimilation system (GSI, EnKF, and related utilities) to the new FV3 dynamical core.
- The following implementation aims to make more advances in the forecast model, including:
  - Increasing the vertical resolution
  - Moving the model top to 80 km
  - Incorporating advanced physics
- Similarly, the data assimilation system looks to include several changes:
  - Accommodations for the extended model top
  - Upgrade to the CRTM
  - Hydrometeor analysis
  - Early run EnKF
  - Many more…

Increased Vertical Resolution

- The FV3GFS will move from 64 layers to 127 layers, moving the model top to 80 km.

- This provides a challenge for the data assimilation system. Several components need to be evaluated or modified:
  - Static background error variance
  - Variable transformation regression coefficients
  - Tangent linear normal mode constraint
  - Covariance localization length scales
  - Hybrid covariance weights
  - Ensemble spread and stochastic physics
  - Channel selection for satellite radiances

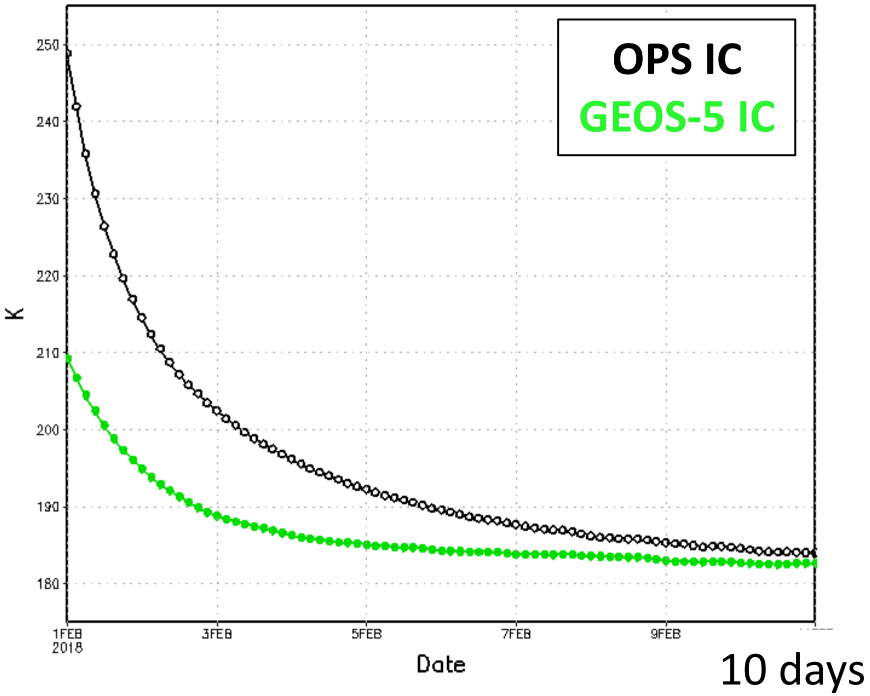
New Static Background Error for 127 Layers

- The pre-operational FV3GFS uses the same static background error as the spectral model.

- NMC method (Parrish and Derber 1992):
  - Traditional method for calculating the static background error.
  - Uses a database of lagged forecast pairs of 24 and 48 hours valid at the same time.

- Pre-operational FV3GFS:
  - When cold-started from 64-layer initial conditions, a uniform temperature profile is inserted in the missing layers.
  - Significant spin up is observed.

Top Layer Global Mean Temperature



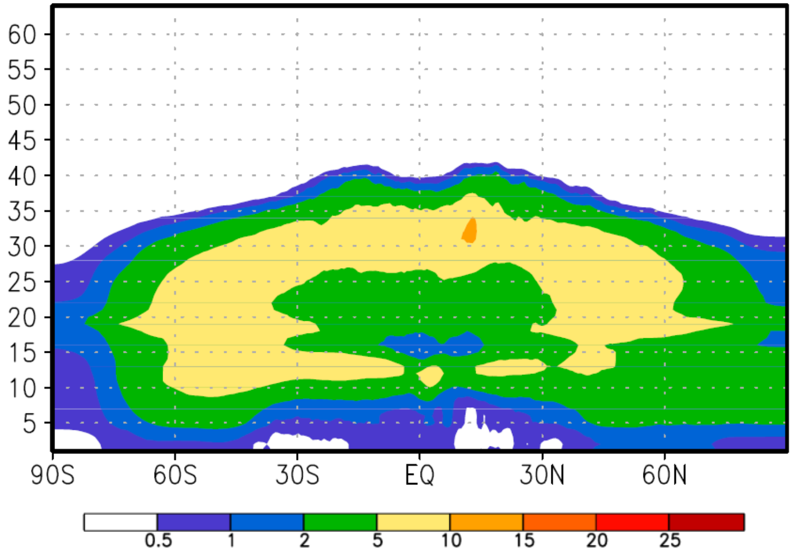
- GEOS-5:
  - Contains FV3 dynamical core and has a similar model top to the 127-layer configuration. Valery Yudin (CU/CIRES) provided EMC with a program to convert GEOS-5 initial conditions to cubed-sphere tiles.
  - Using the GEOS-5 initial conditions reduces the spin up, but does not remove it entirely.

- EMC is exploring the traditional NMC method with the GEOS-5 initial conditions as well as a cycled EnKF only system to provide the perturbations for calculating the new static background error.

Clouds in the Operational GFS

- Forecast Model
  - Cloud microphysics parameterization of Zhao and Carr (1997), Sundqvist et al. (1989), Moorthi et al. (2001)
  - Total cloud water (cloud liquid water + cloud ice) is a prognostic variable

Clear Sky Static **B**
Standard Deviation, Cloud Water

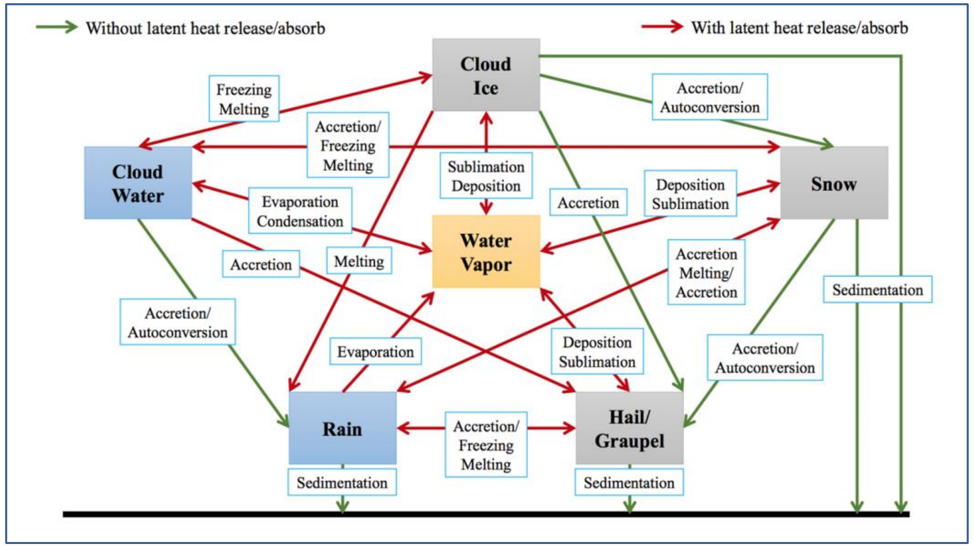


Zhu et al. (2016)

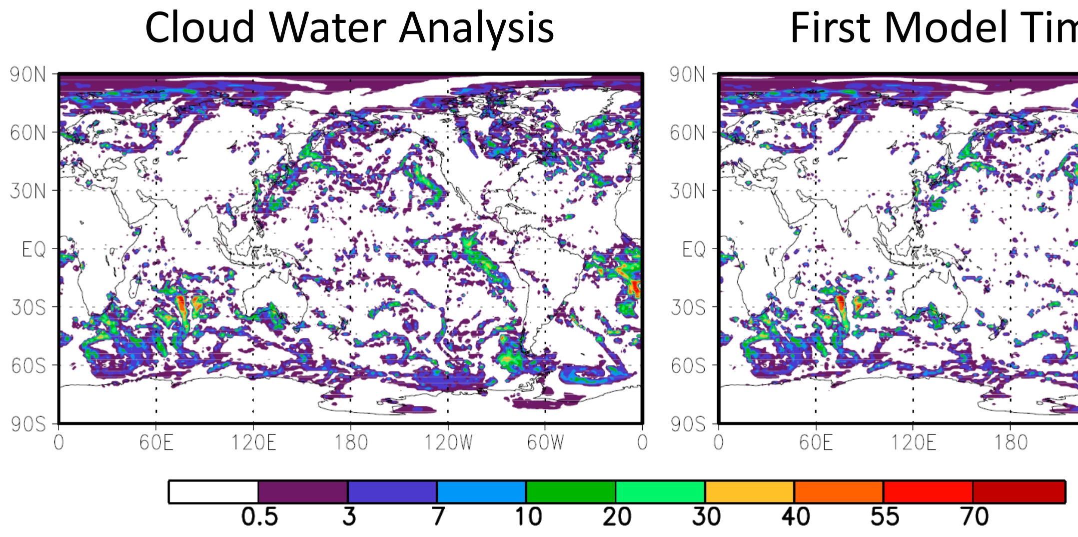
- Data Assimilation
  - Zhu et al. (2016): All-Sky Microwave Radiance Assimilation in NCEP's GSI Analysis System
  - Total cloud water control variable normalized by its background error standard deviation
  - Partitioning of total cloud water based on temperature. Cloud liquid water and cloud ice state variables sent to radiative transfer model
  - Modified static background error
    - Previous clear sky: zonal mean and produces spurious increments
    - Current all sky: 5% of cloud water deterministic first guess and 5.0×10^{-12} kg/kg for locations with cloud water less than 1.0×10^{-10} kg/kg

Clouds in FV3GFSv1

- FV3GFSv1 is moving to GFDL microphysics with five prognostic hydrometeors.
- To reduce the changes to the GSI and EnKF for the initial implementation, the hydrometeors were manipulated to mimic the previous microphysics:
  - Cloud liquid water and cloud ice are added together upon read in the GSI and EnKF to create a total cloud condensate.
  - Total cloud analysis increments are partitioned into cloud liquid water and cloud ice based on temperature during the analysis write and the increments are added to their original backgrounds.
  - The static background error for the total cloud condensate remains unchanged.
  - The cloud analysis is not fed back to the model.



Courtesy SJ Lin GFDL



Zhu et al. (2016)

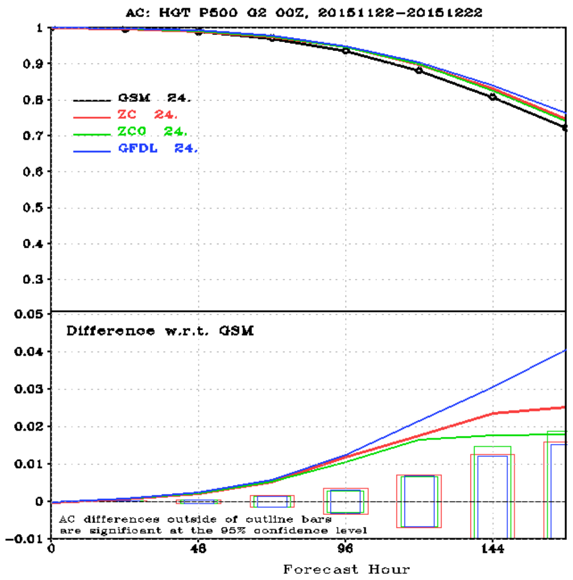
Clouds in FV3GFSv1

Dual low resolution test C384/C192 (25 km/50 km)

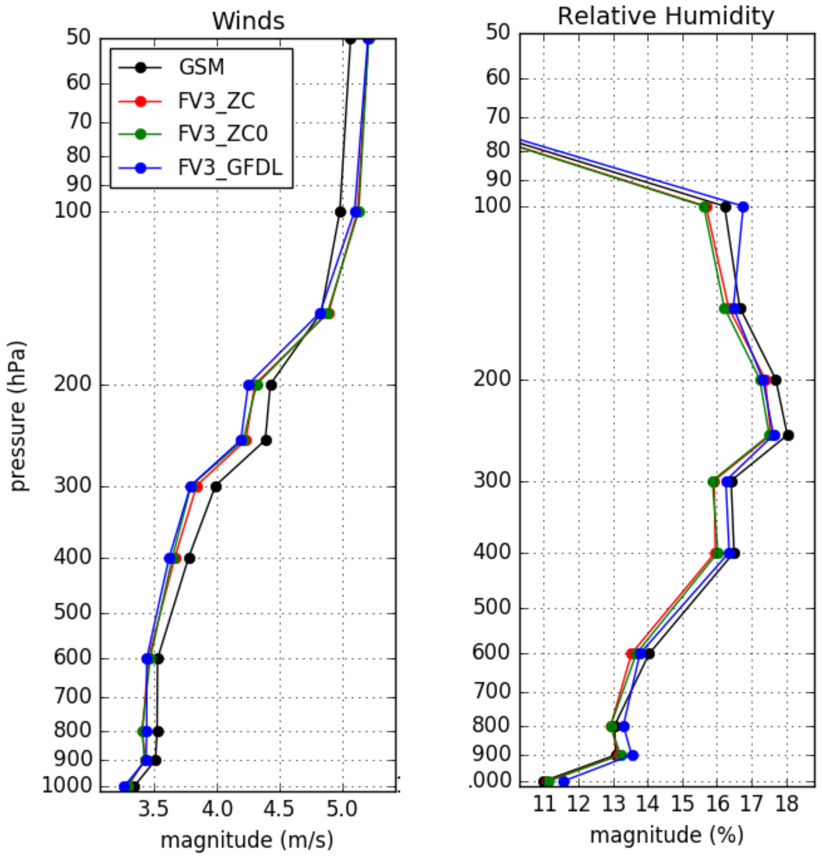
Four experiments:

- Operational GFS with Zhao Carr MP
- FV3GFS with Zhao Carr MP
- FV3GFS with Zhao Carr MP with zero cloud increments
- FV3GFS with GFDL MP with zero cloud increments

500 hPa Height Anomaly Correlation



RMS Fit to Conventional Obs



- All FV3 experiments perform better in the troposphere than the spectral model, but worse in the stratosphere.
- Results between MP schemes are mostly statistically neutral for standard global measures. GFDL MP performs slightly better in the troposphere for winds/heights, but slightly worse for humidity.
- Any improvement from the GFDL MP experiment does not appear related to the zeroing of the cloud increments.

Community Radiative Transfer Model (CRTM)

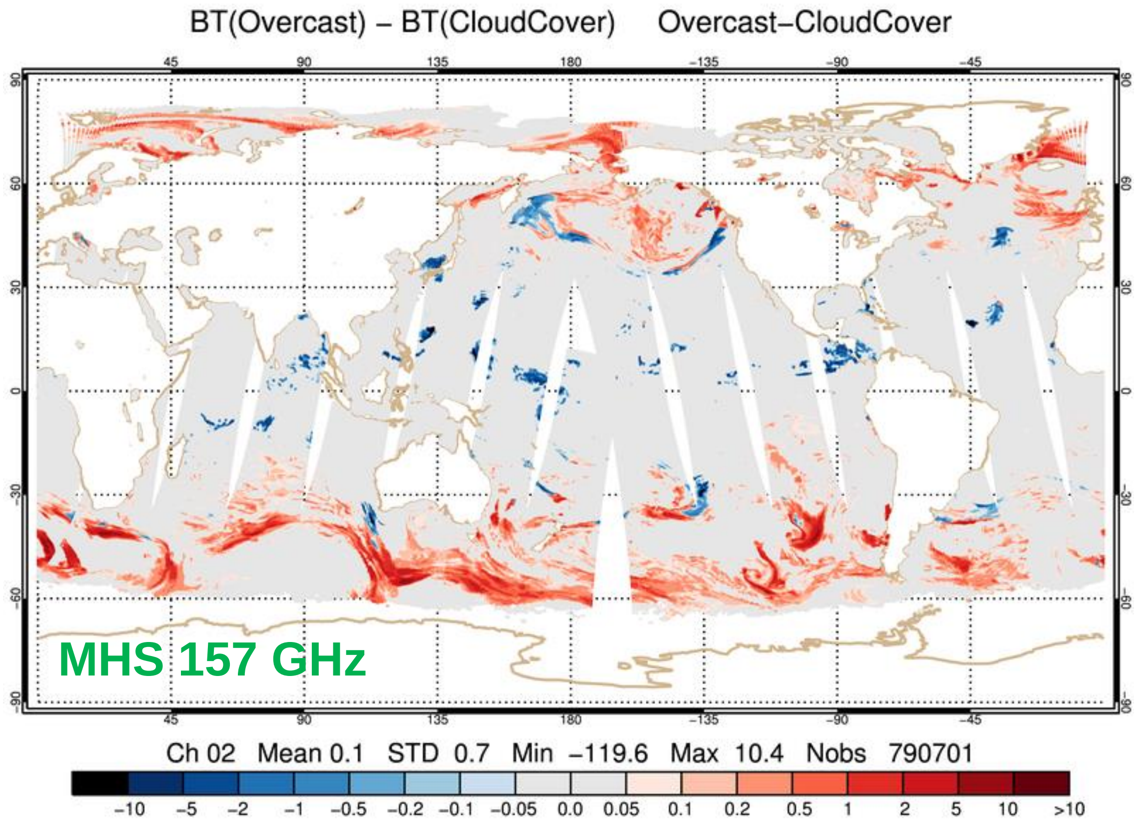
- The CRTM is used within the GSI to compare the radiance observations with the model forecast and analysis control variables.
- Improvements to the CRTM allow for better use of satellite radiances.

Fractional Cloud Cover

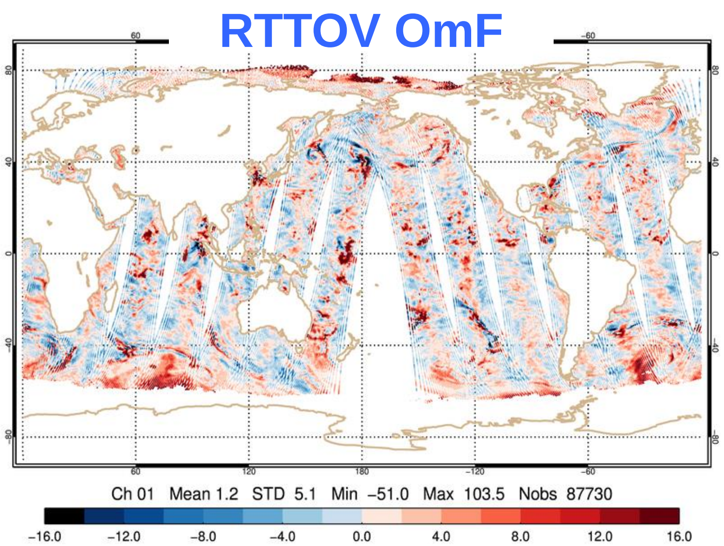
- In current operational CRTM, clouds are simulated as overcast: the total cloud cover (TCC) = 1.
- To better handle fractional cloudiness condition, a two-column radiance calculation has been developed in CRTM:

$$R_\nu = (1 - \boldsymbol{TCC}) \times R_{\nu,clear} + \boldsymbol{TCC} \times R_{\nu,cloudy}$$

- The impact of fractional cloud coverage on BT can be significant when precipitation is involved.
- For high frequency channels, the impact could be over 100 K.

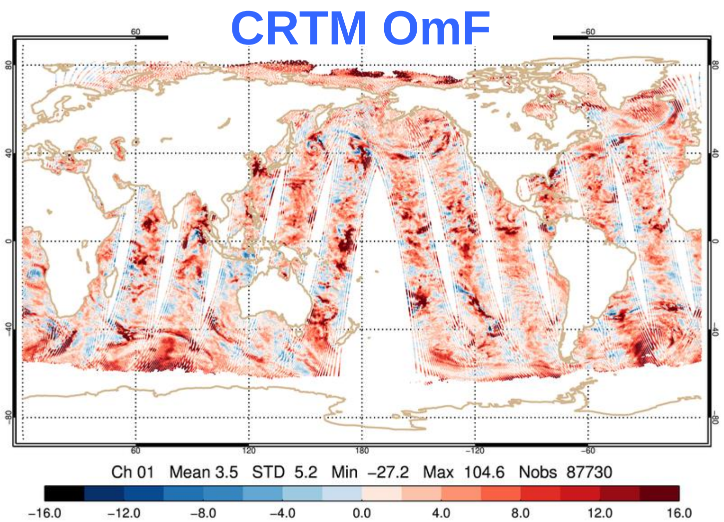


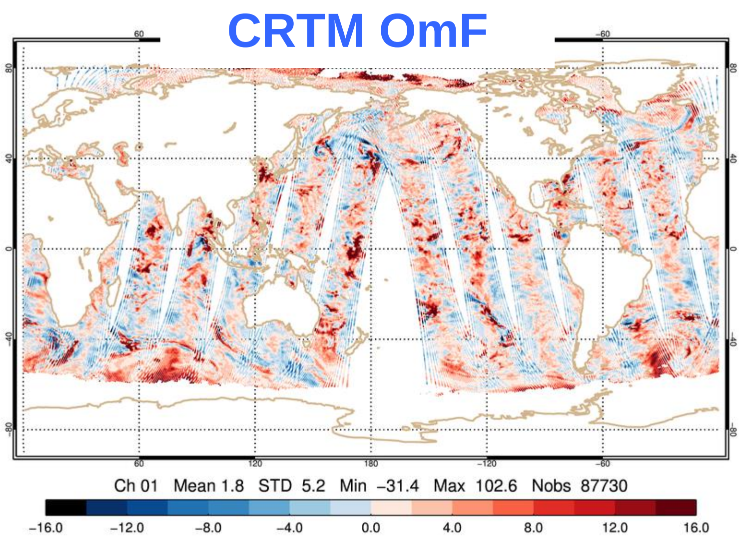
Community Radiative Transfer Model (CRTM)



Another radiative transfer model, RTTOV, was incorporated into the GSI:

- to have a more consistent and flexible way in comparing radiative transfer models (RTMs) by using the same model input
- to better understand differences in optical properties, radiances and Jacobians between the two
- to help in spotting errors by cross validating each other
- to establish symbiotic relationship between the two RTMs by exploring new features in each one





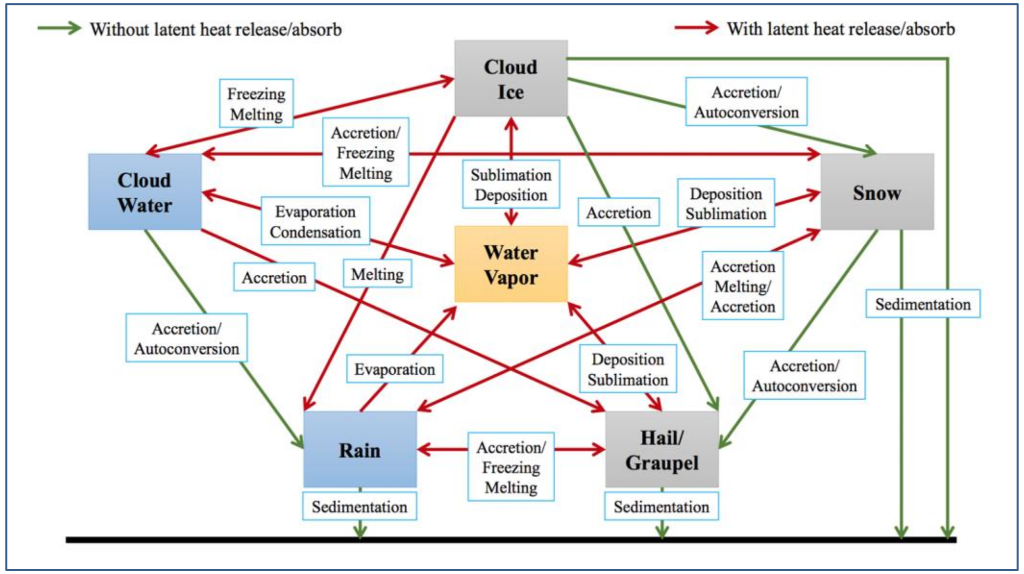
Discovered biases in CRTM:

Under scattering conditions, it was found that there was no diffuse radiation being reflected towards the viewing direction, resulting in a bias. A reflection correction was added to address this bias.

Hydrometeors in the GFS

- Initial FV3GFS implementation:
  - Cloud liquid water and cloud ice are combined to create a total cloud condensate in the GSI.
  - A total cloud condensate analysis is created and partitioned into cloud liquid water and cloud ice according to the analysis temperature.
  - The cloud analysis variables are not fed back to the model.
- Looking ahead:
  - With the recent upgrades to the CRTM, we can create analyses for the individual hydrometeors. These analyses can then be fed back to the model once their utility is confirmed in testing.

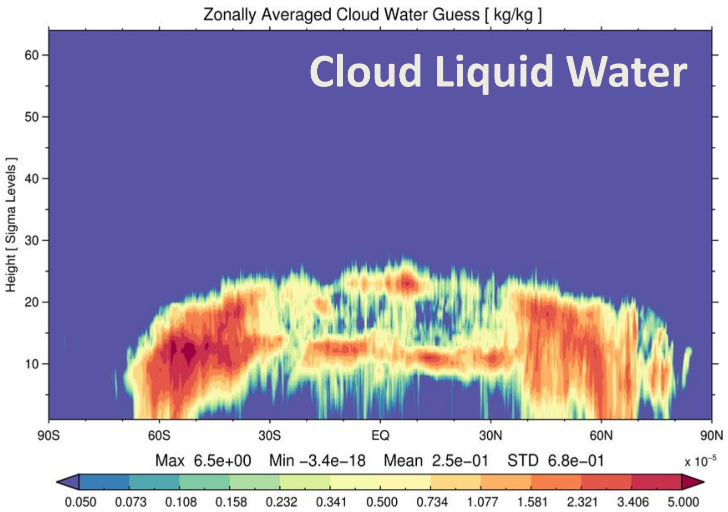
Courtesy SJ Lin GFDL

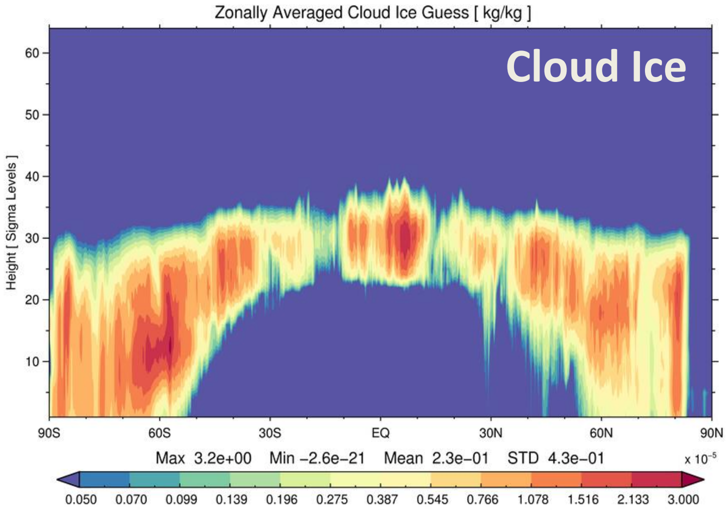


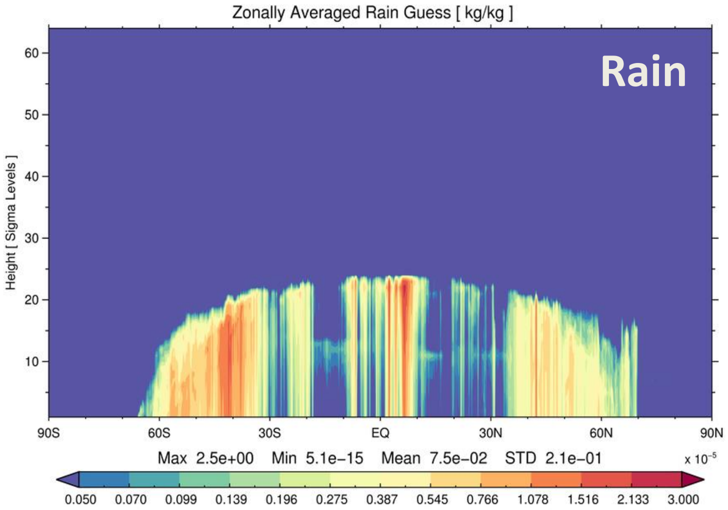
	Operations	FV3GFSv1	Proposed FV3GFSv2
Model Forecast Variables	Total Cloud Condensate	Cloud Liquid Water, Cloud Ice, Graupel, Rain, Snow	Cloud Liquid Water, Cloud Ice, Graupel, Rain, Snow
Analysis Control Variables	Total Cloud Condensate	Total Cloud Condensate	Cloud Liquid Water, Cloud Ice, Graupel, Rain, Snow

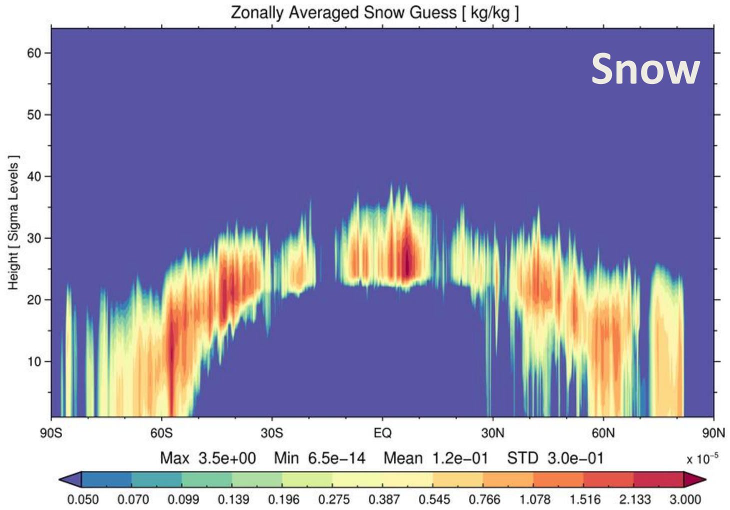
Preliminary Results: Hydrometeors, First Guess

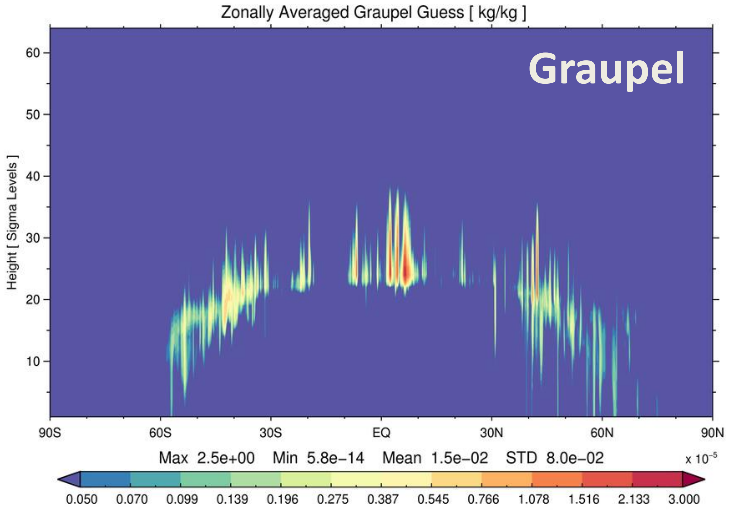
- Modifications to the GSI were made to include all five individual hydrometeors in the analysis control variable.
- The static background error variance was formulated similarly to the total cloud condensate: 5% of the deterministic value.











Preliminary Results: Hydrometeors, Ensemble Spread

- Modifications to the GSI were made to include all five individual hydrometeors in the analysis control variable.
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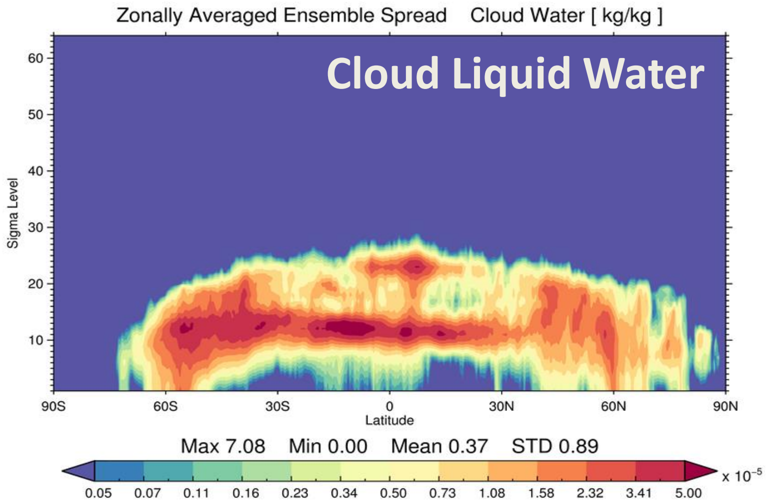
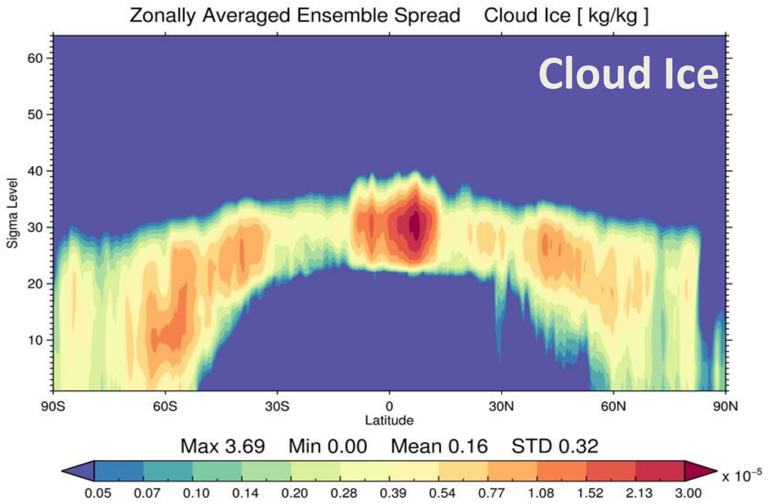
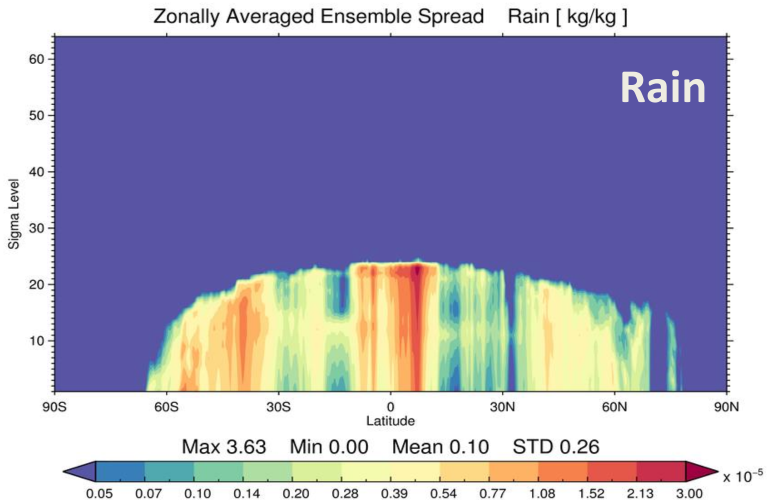
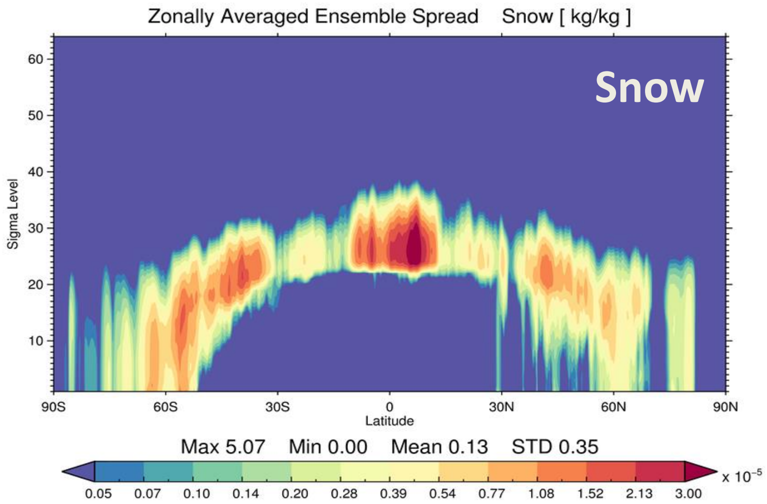
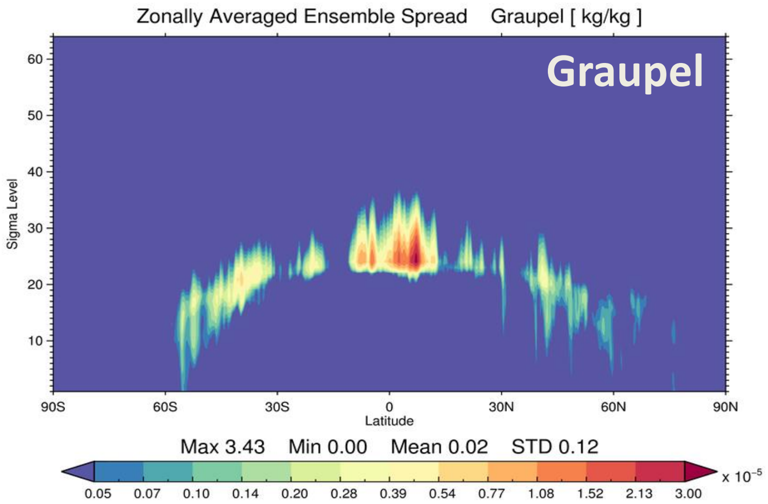




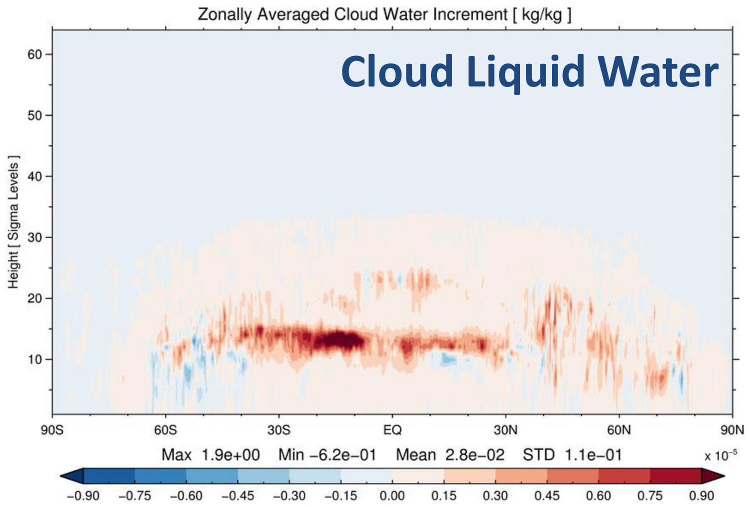


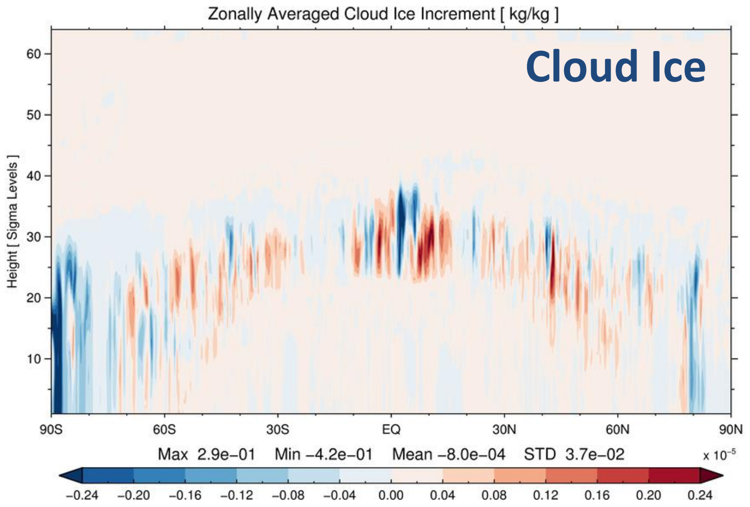


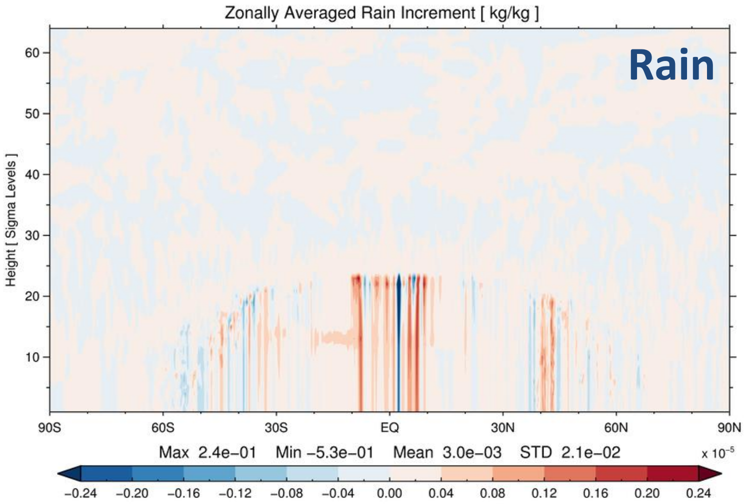


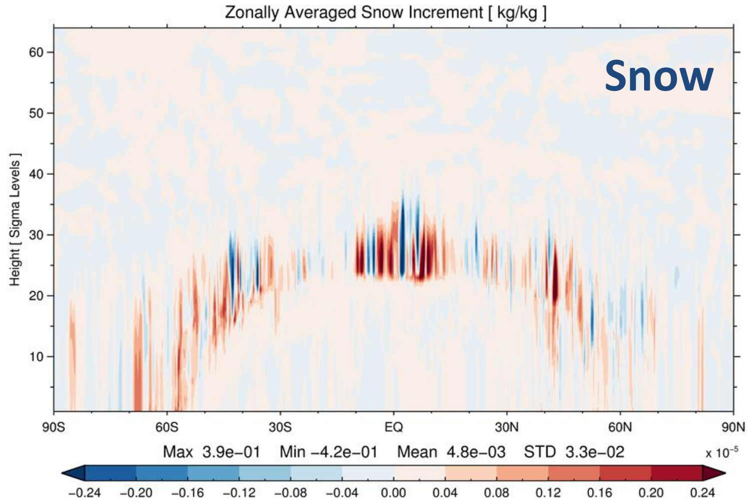
Preliminary Results: Hydrometeors, Analysis Increments

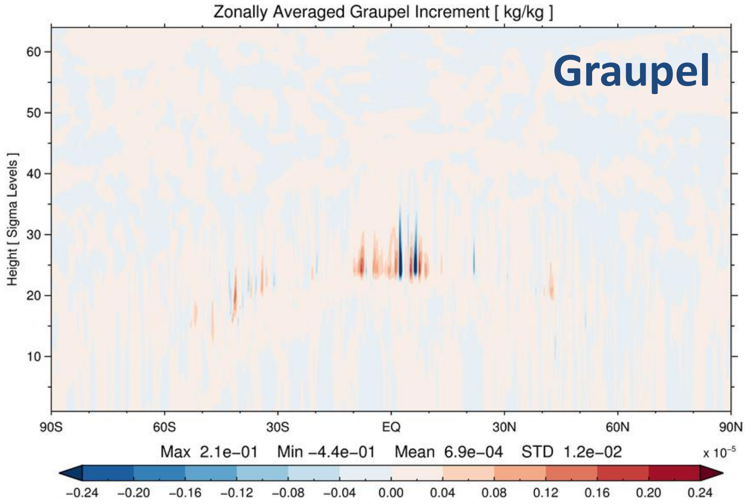
- Modifications to the GSI were made to include all five individual hydrometeors in the analysis control variable.
- The static background error variance was formulated similarly to the total cloud condensate: 5% of the deterministic value.







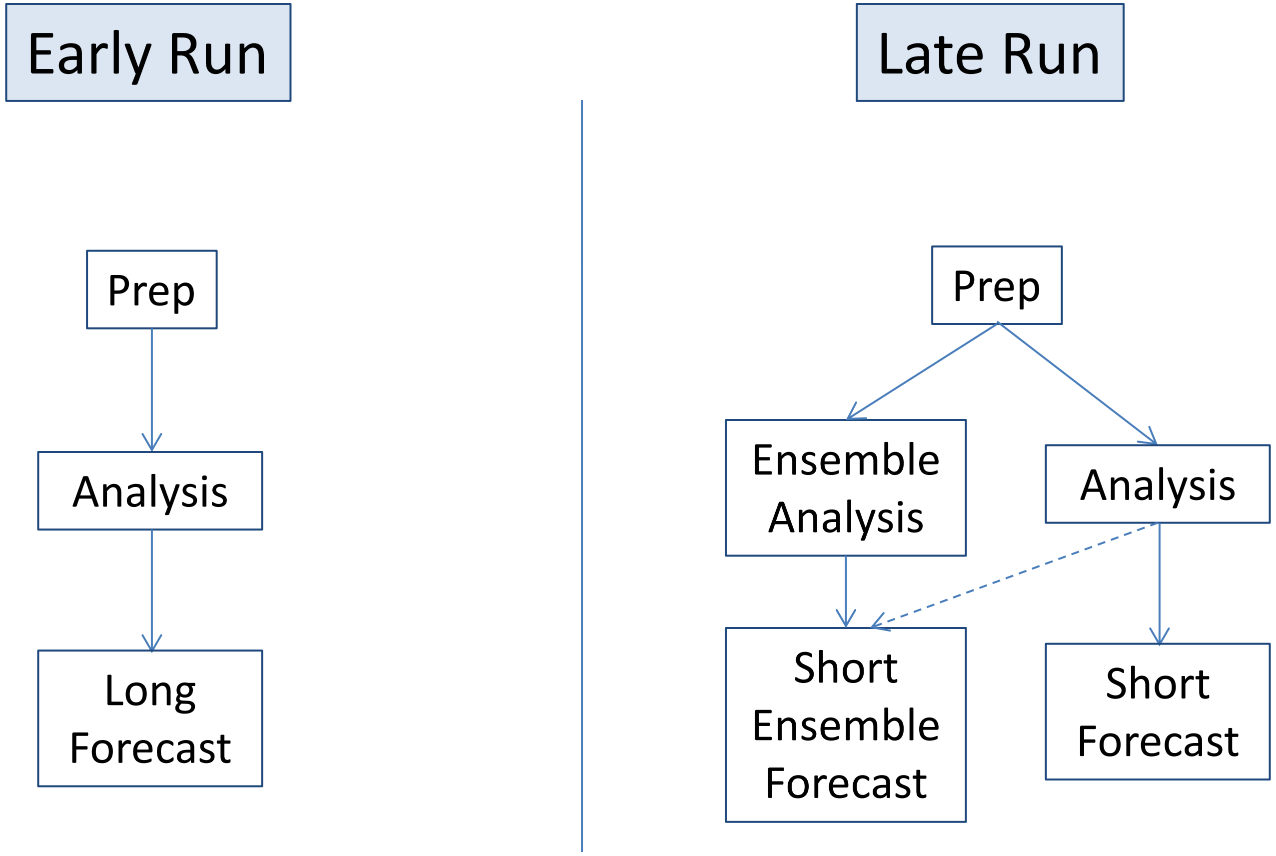




Early Run Ensemble Kalman Filter (EnKF)

The GFS consists of two runs each 6 hour cycle: an early run (GFS) and a late run (GDAS).

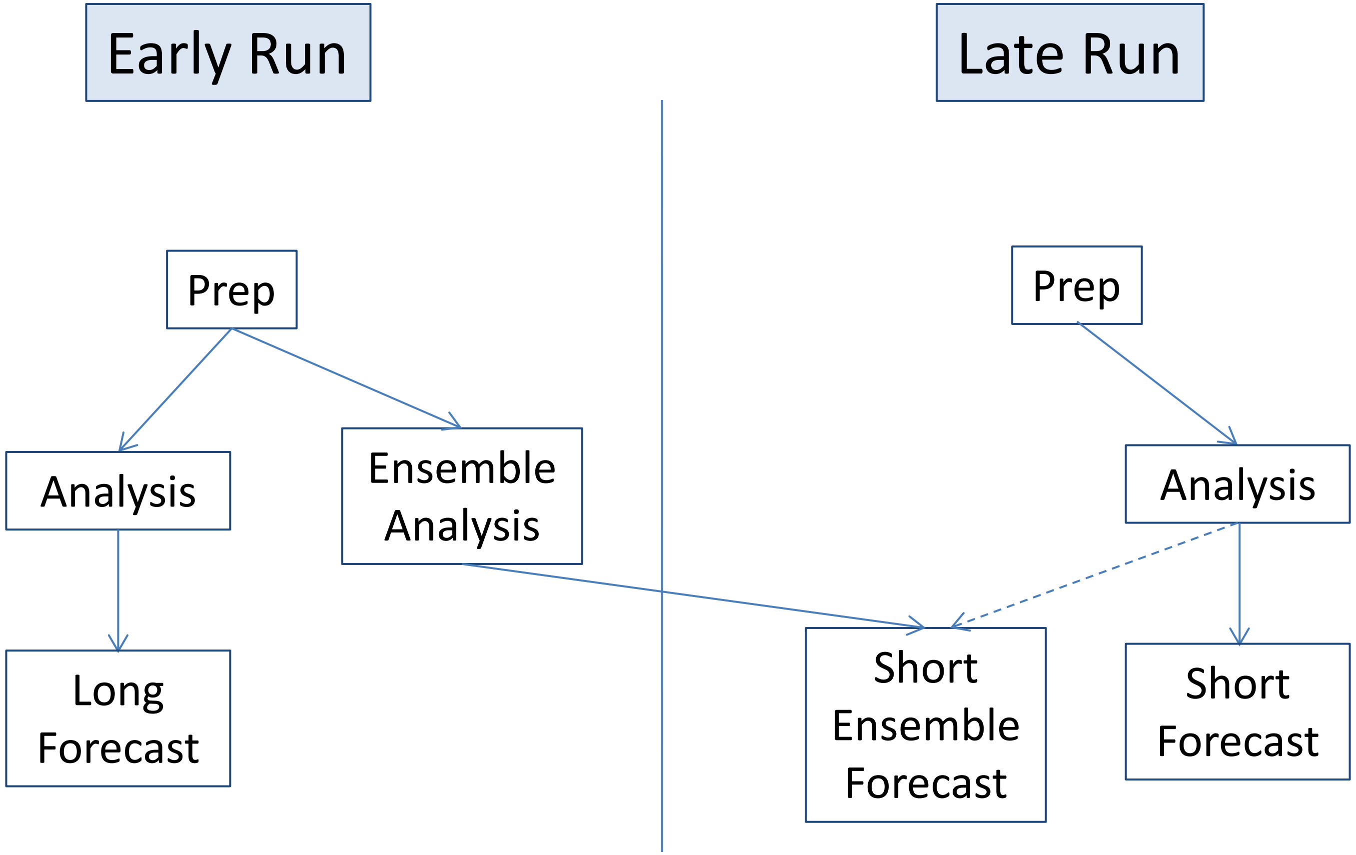
- Early run:
  - Begins approximately 2 hours and 45 minutes after the initialization time.
  - Performs a deterministic analysis with the observations that are available at the time.
  - Produces the long forecast.
- Late run:
  - Begins approximately 6 hours after the initialization time.
  - Performs the deterministic and ensemble analyses with additional observations.
  - Produces the short deterministic and ensemble forecasts that initialize the next cycle.



Early Run Ensemble Kalman Filter (EnKF)

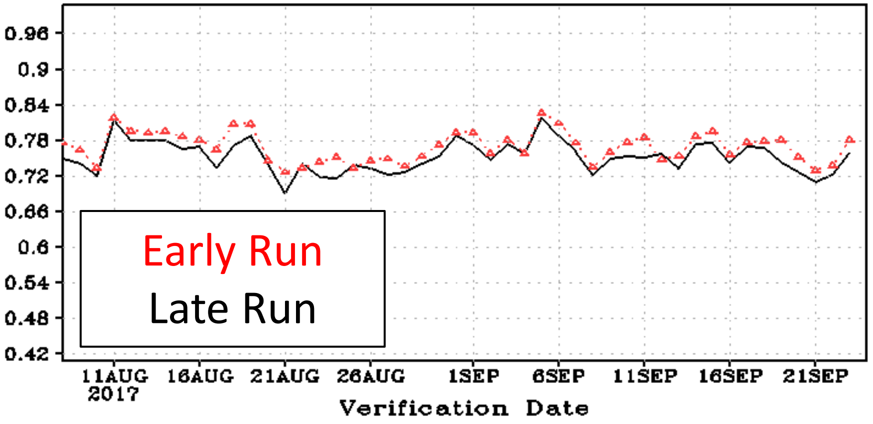
The GFS consists of two runs each 6 hour cycle: an early run (GFS) and a late run (GDAS).

- Since the ensemble analysis is produced in the late run, the Global Ensemble Forecast System (GEFS) must use the previous 6 hour forecast to initialize their ensemble.
- If the ensemble analysis is produced in the early run, the GEFS could use the ensemble analysis directly.
- The ensemble can still be recentered about the late run analysis before generating the short ensemble forecasts.



Early Run Ensemble Kalman Filter (EnKF)

850 hPa Temperature RMSE, 24 Hr Forecast

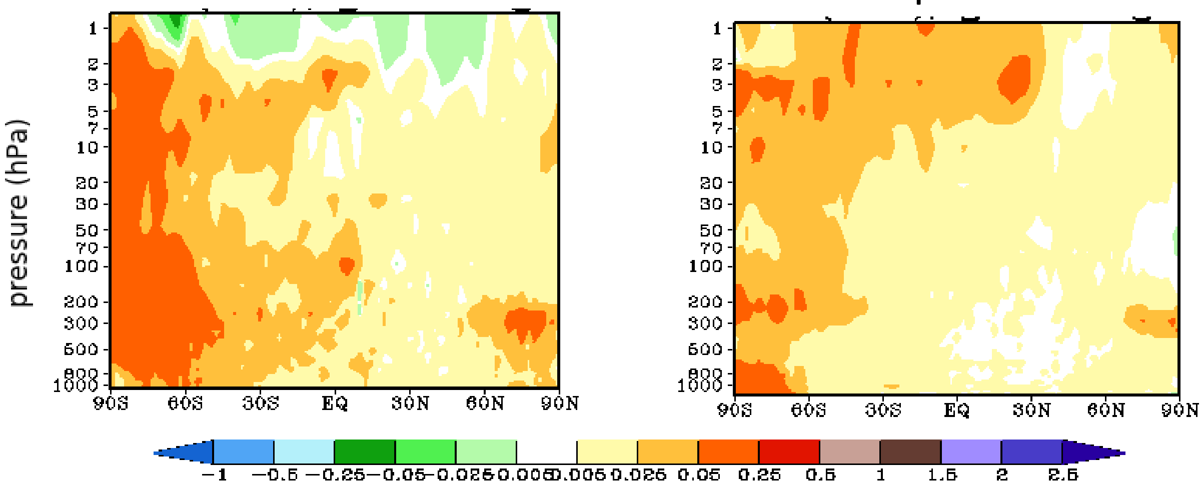


- Lower resolution test (25 km/50 km)
- Early run test showed significant forecast degradation at 24 hours for most variables.
- With reduced observation counts, the ensemble background spread was increased, resulting in a larger analysis increment.
- To use the early run EnKF, we must retune the ensemble spread.

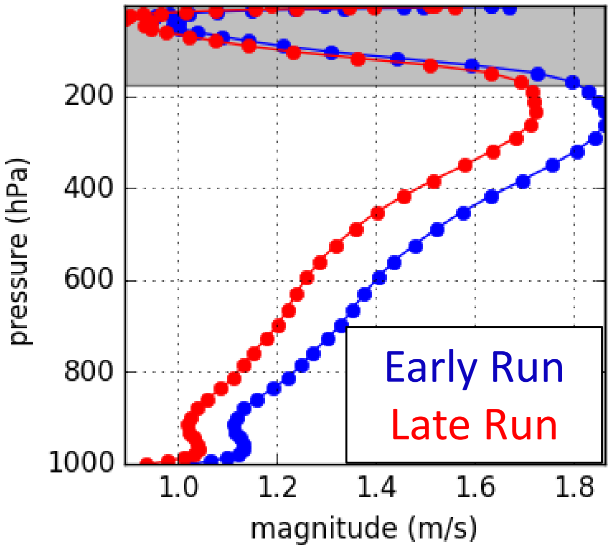
RMS (Early – Late) of Analysis Increment

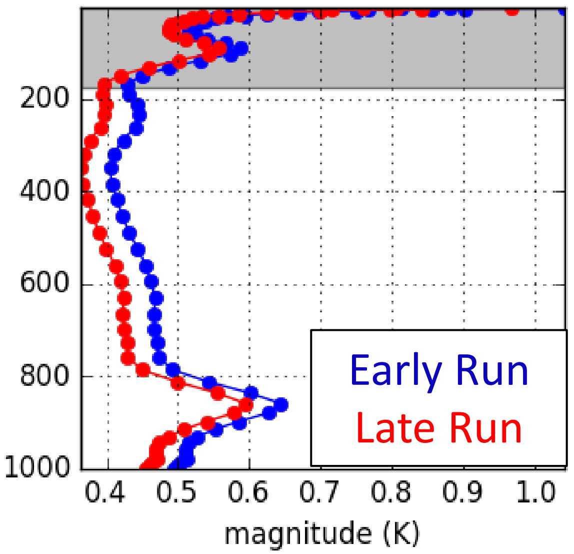
Zonal Wind

Temperature



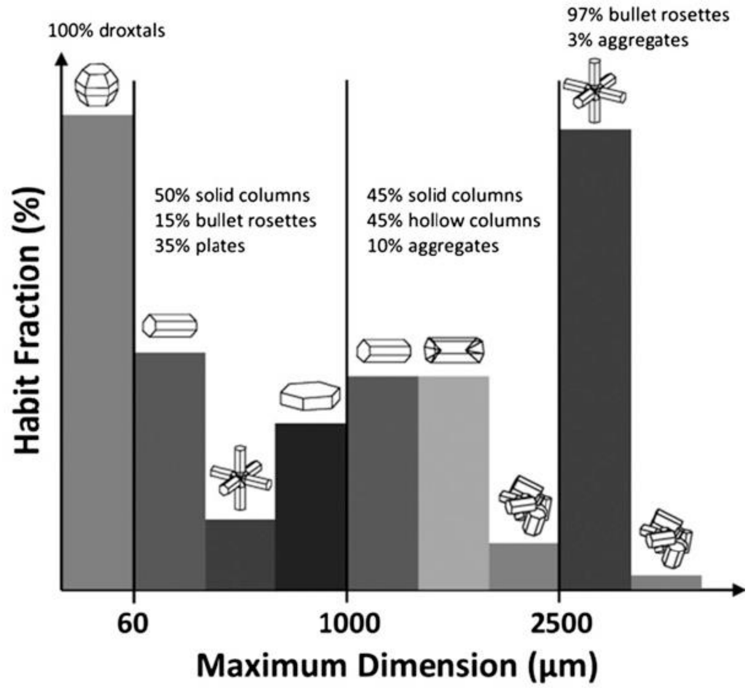
6 Hour Forecast Ensemble Spread





Other Proposed Upgrades

- Change the EnKF analysis update algorithm from the Ensemble Square Root Filter (EnSRF) to the Local Ensemble Transform Kalman Filter (LETKF)
- Incorporate the 4D-Incremental Analysis Update
- Introduce correlated observation errors
- Scale dependent localization
- Lagging/shifting ensembles
- Upgrade CRTM with cloud optical table using particle size dependent mixture of ice crystals
- JEDI and native grid data assimilation
- Many observational changes



Credit : Brian Baum @ SSEC / UW-Madison
Ping Yang @ TAMU

Summary

- The spectral GFS is being replaced with the FV3GFS in January 2019.

- The data assimilation changes for that upgrade were focused on adaptation of the existing system.

- The following FV3GFS implementation (proposed for early 2020) will include many changes to the data assimilation system, including accommodations to the increase in model top and individual hydrometeors.