Development in Cloud Analyses within NGGPS-FV3GFS

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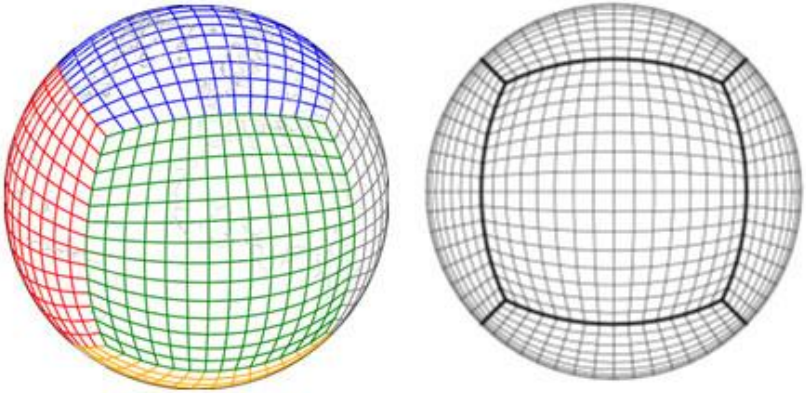
Acknowledgements:
Russ Treadon, John Derber, Andrew Collard (IMSG/NCEP)
Jeff Whitaker and Phil Pegion (NOAA/ESRL)
The GFDL FV3 Team

6 March 2018
International Symposium on Data Assimilation

NGGPS-FV3GFS

- Next Generation Global Prediction System

- FV3 selected for dynamic core component for the Global Forecast System (GFS)
  - Cubed-sphere grid
  - Using non-hydrostatic option
  - C768 (~13km) L64 (55km top)
  - **Upgraded microphysics**
  - Target implementation 2019



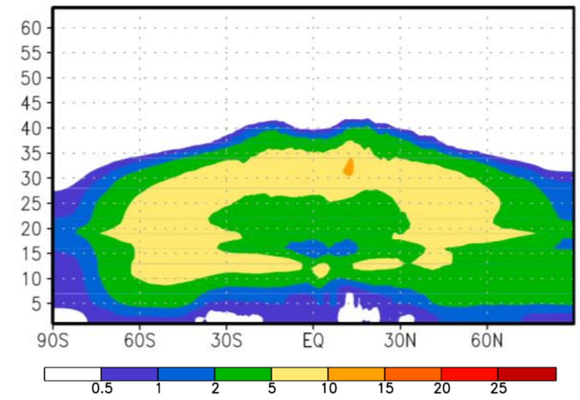
Courtesy: GFDL

- Other presentations
  - Daryl Kleist (Talk, Monday at 5:00 pm): The use of stochastic physics in operational global data assimilation with NGGPS-FV3GFS
  - Rahul Mahajan (Poster, Wed/Thurs) : 10.2 – Adopting NCEP's Hybrid 4DEnVar Data Assimilation System to the FV3GFS

Clouds in 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
- 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

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



Zhu et al. (2016)

GFDL Microphysics (MP)

Lin et al., 1983

↓

Lord et al., 1984

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Krueger et al., 1995

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Chen and Lin, 2011 Chen and Lin, 2013

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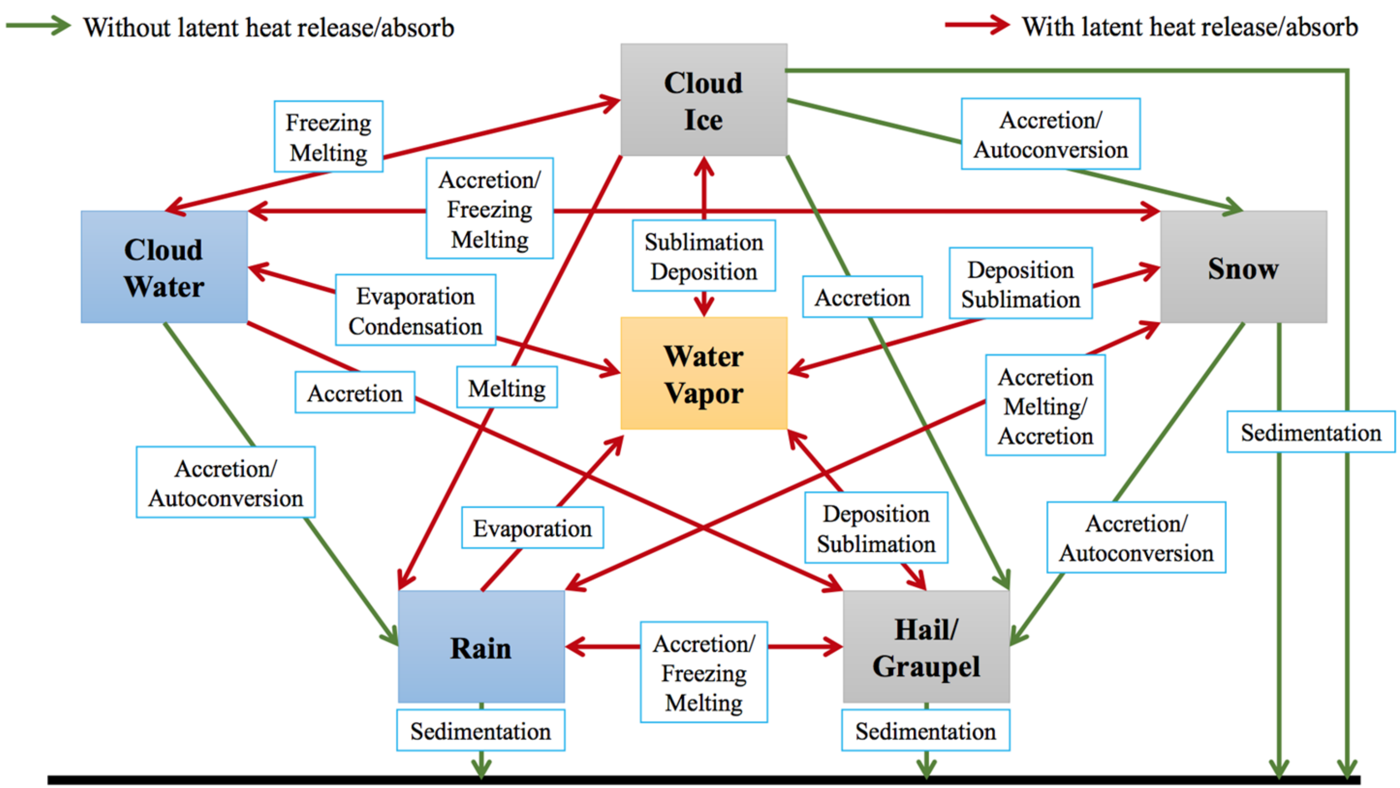
Zhou et al., 2017



Courtesy SJ Lin GFDL

GFDL MP moves the GFS from a total cloud water variable to five predicted hydrometeors.

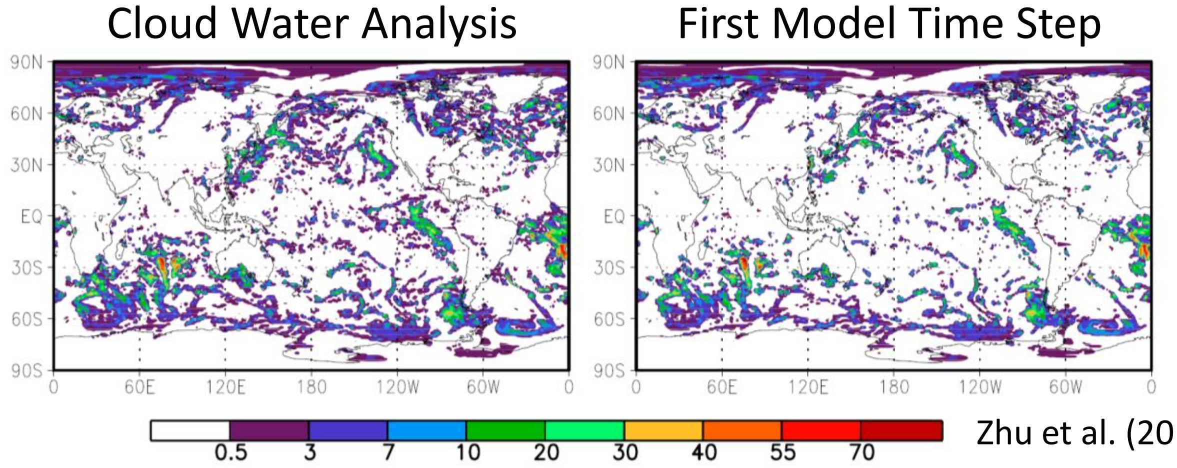
Cloudy DA with GFDL MP

- The model outputs individual hydrometeors, but the DA currently expects total cloud water.

- Possible approaches:
  - Combine cloud liquid water and cloud ice into one control variable, allowing the DA to remain unchanged. Partition the total cloud water analysis into cloud liquid water and ice analyses.
  - Send the cloud liquid water and cloud ice to the CRTM.
  - Send all hydrometeors to the CRTM.
  - Create analyses for each individual hydrometeor.
  - Create analyses that do not feed back to the model.

Cloudy DA in FV3GFS

- Current solution:
  - Combine cloud liquid water and cloud ice into one control variable upon read in the DA.
  - Partition cloud analysis increments into cloud liquid water and cloud ice based on temperature during the analysis write and add the increments to their original backgrounds.
  - Use current operational background error.
  - Do not feed back the cloud increments to the model.



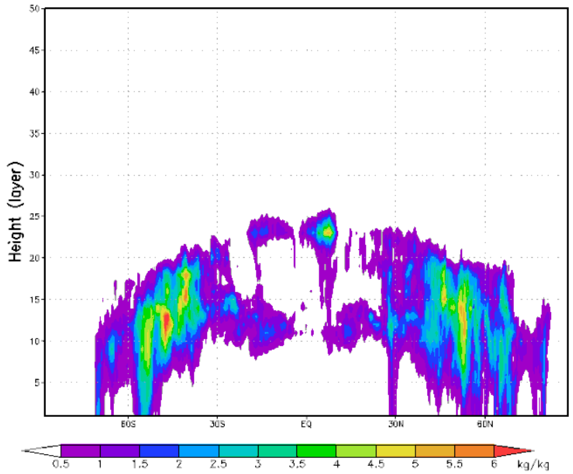
Zhu et al. (2016)

Low Resolution Experiment Setup

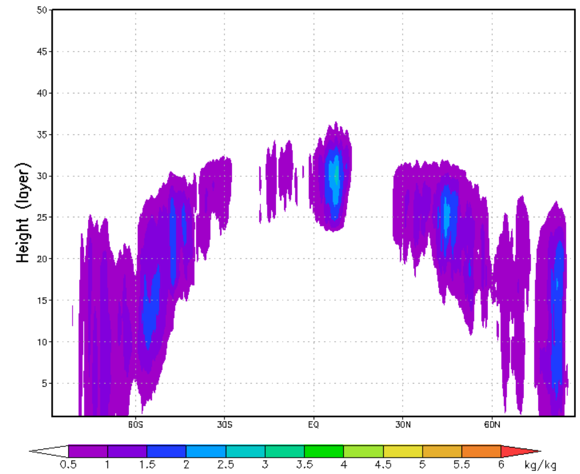
- Dual low resolution C384/C192 (25 km/50 km)
- Experimental FV3GFS as of early February 2018
- Hybrid 4DEnVar (12.5% static/87.5% ensemble) with 80 members
- Four experiments:
  - Operational GFS spectral model with Zhao Carr MP
  - FV3GFS with Zhao Carr MP
  - FV3GFS with Zhao Carr MP with zero cloud increments
  - FV3GFS with GFDL MP with zero cloud increments
- Variational bias correction coefficients spun up from zero for each experiment.

GFDL Hydrometeors, 6 Hour Forecast

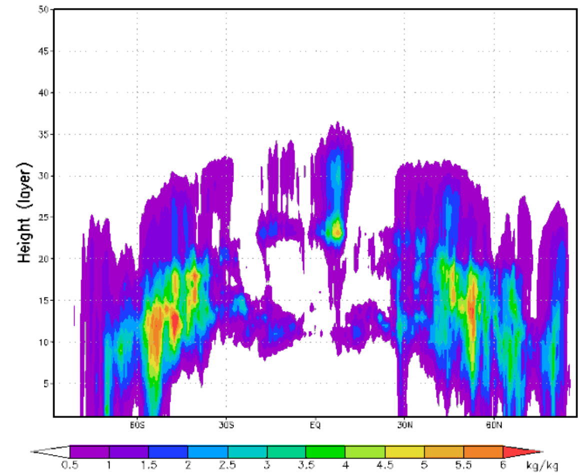
Cloud Liquid Water



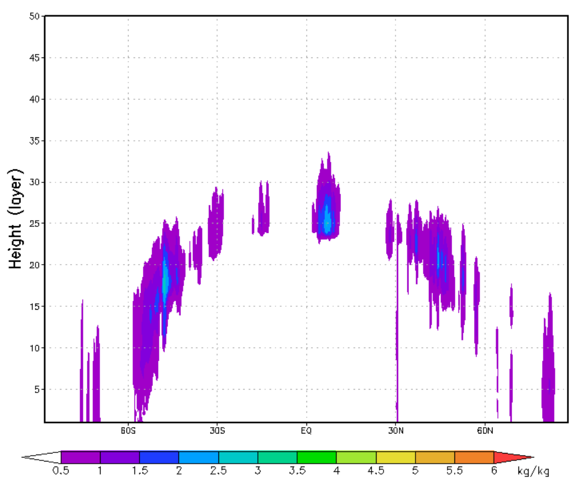
Cloud Ice



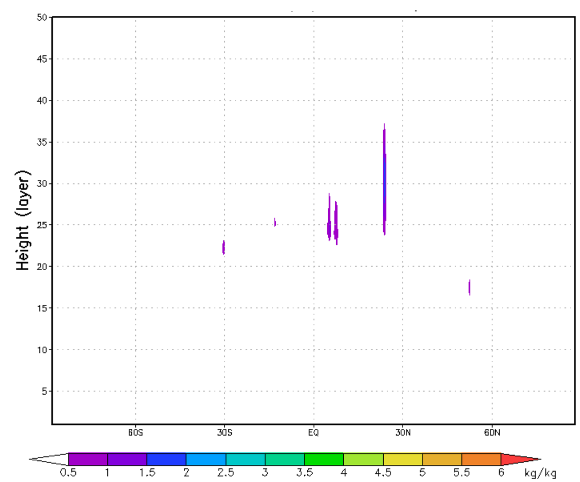
Total Cloud Water (Liq + Ice)



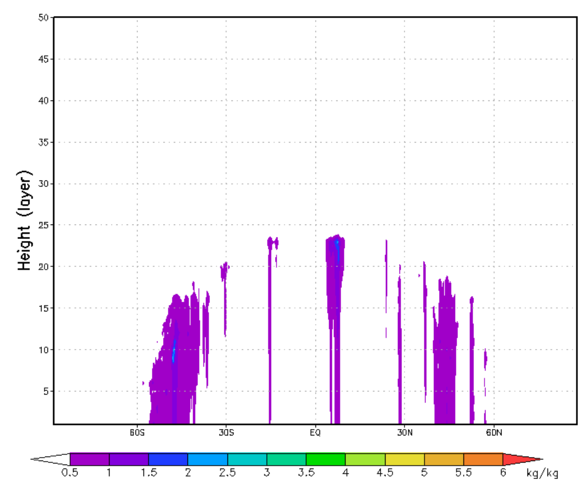
Snow



Graupel

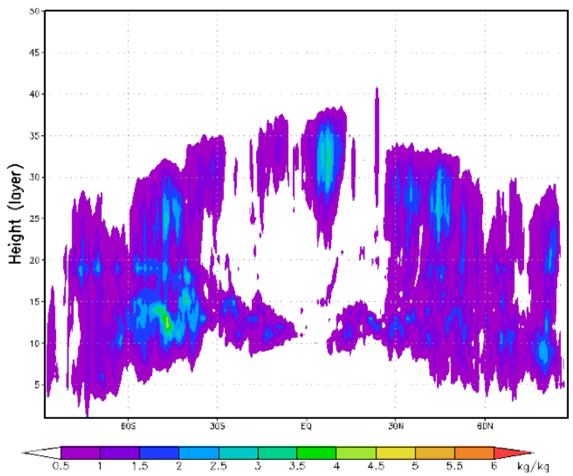


Rain

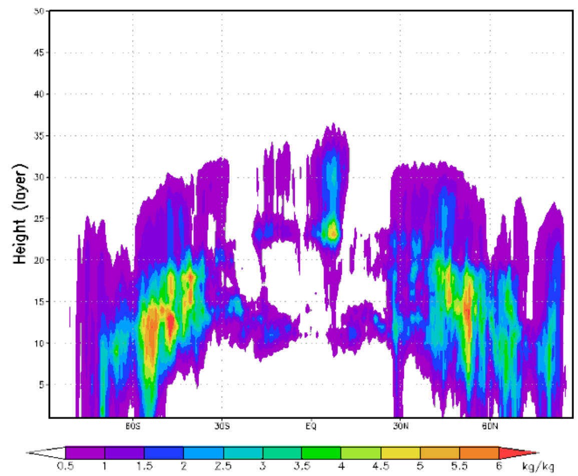


Total Cloud Water Comparison

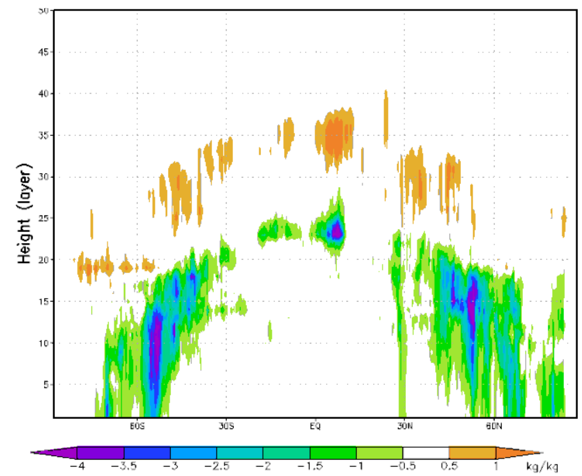
Zhao Carr Total Cloud Water



GFDL Total Cloud Water

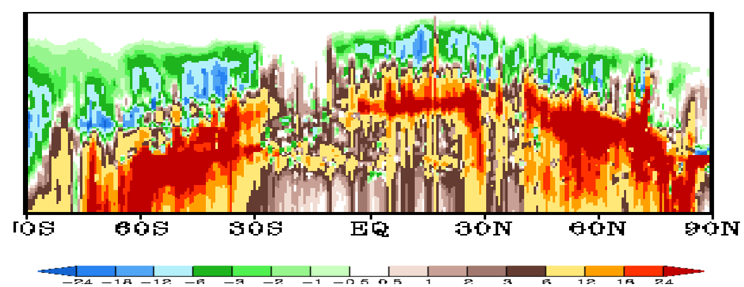


Zhao Carr - GFDL Total Cloud Water



- GFDL MP produces more middle and low level cloud than the Zhao Carr MP.
- It also produces less high cloud than Zhao Carr MP.
- This comparison is consistent with a previously run free forecast experiment at full resolution initialized from operational initial conditions.

Previous Free Forecast Comparison
GFDL – Zhao Carr Total Cloud Water



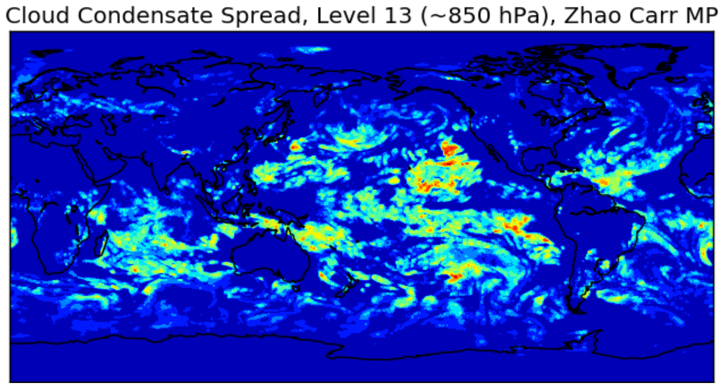
Courtesy Fanglin Yang

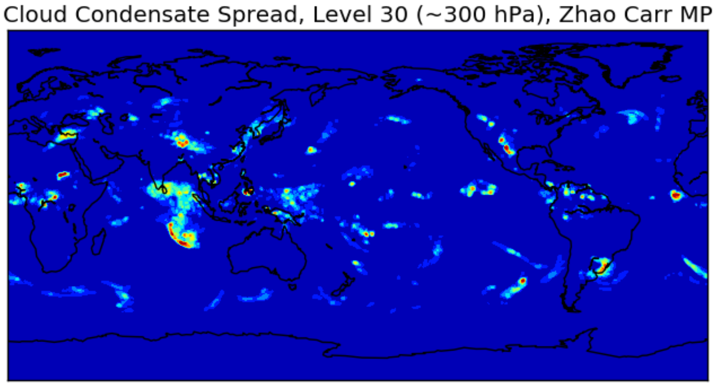
Total Cloud Water Spread

~ 850 hPa

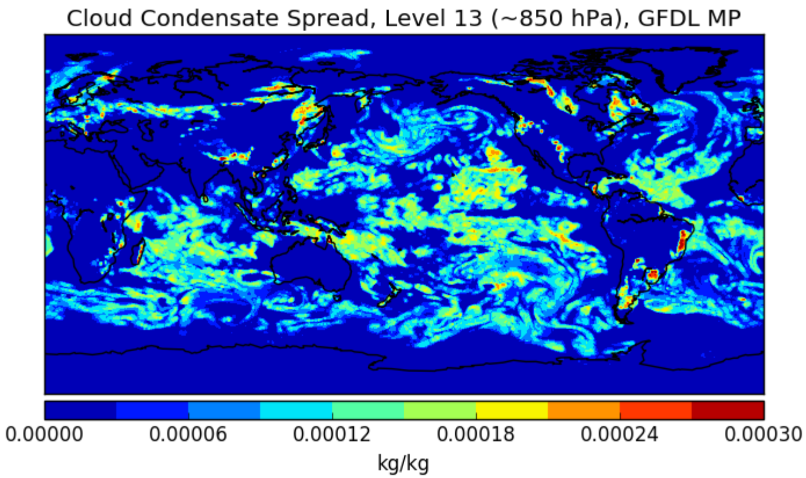
~ 300 hPa

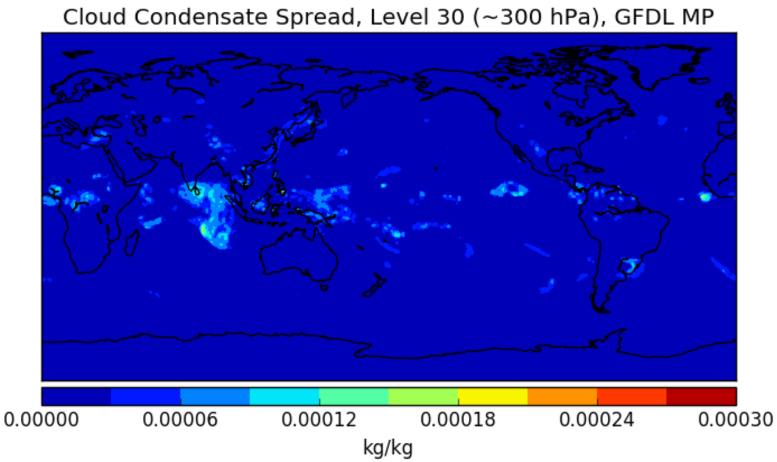
Zhao Carr MP





GFDL MP

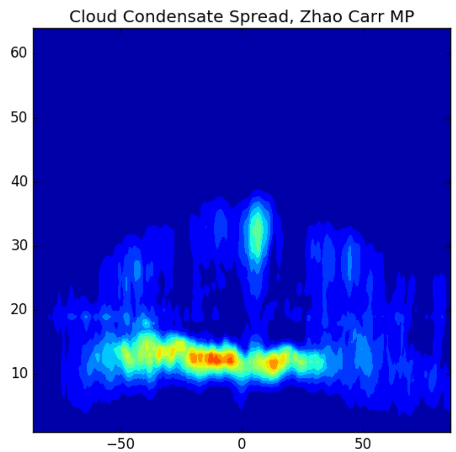


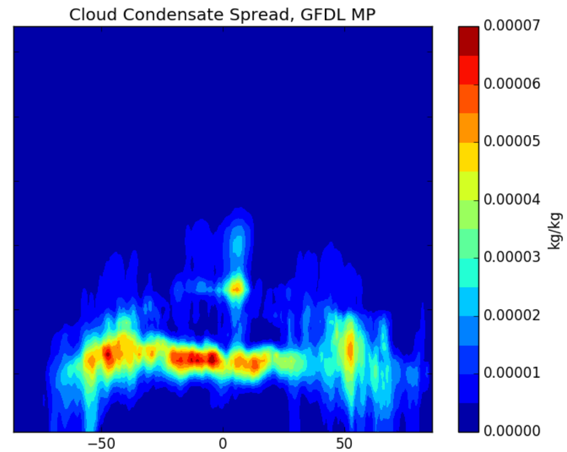


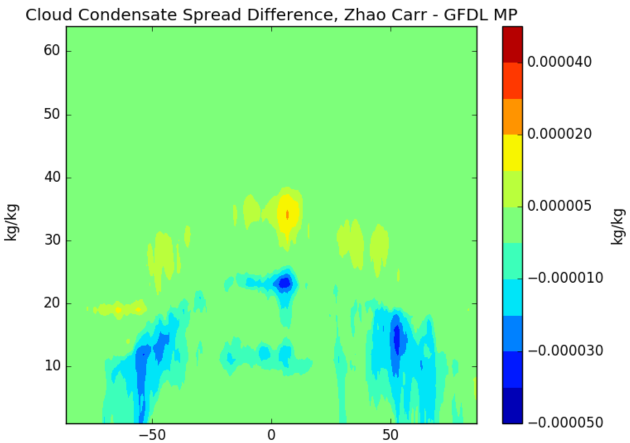
Total Cloud Water

Zhao Carr | **GFDL** | **Zhao Carr - GFDL**

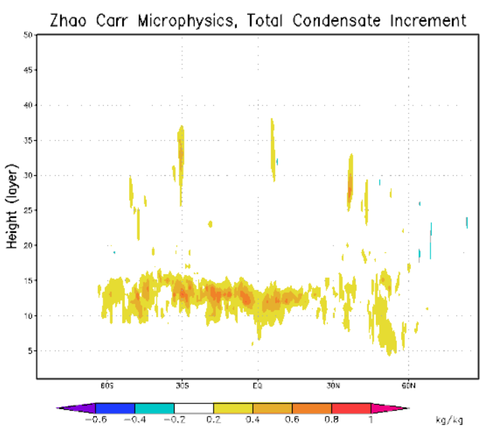
Ensemble Spread

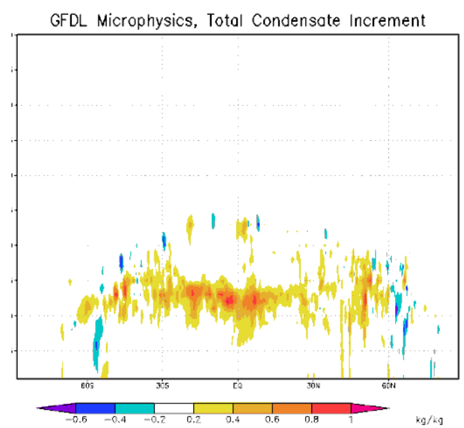


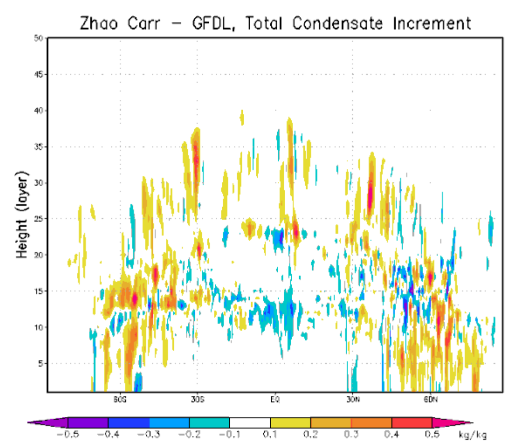




Analysis Increment







The cloud amount differences seen in the forecast are also seen in the ensemble spread.

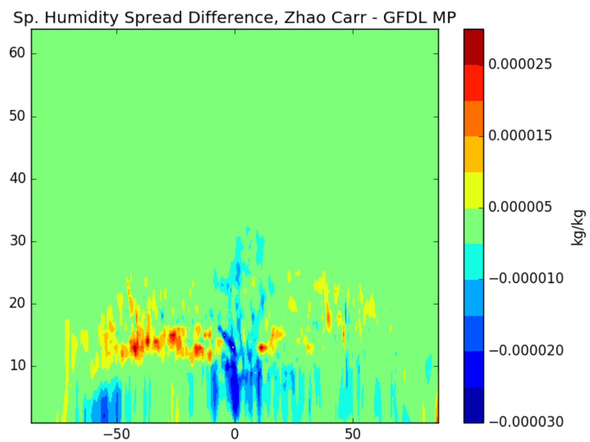
Specific Humidity and Temperature

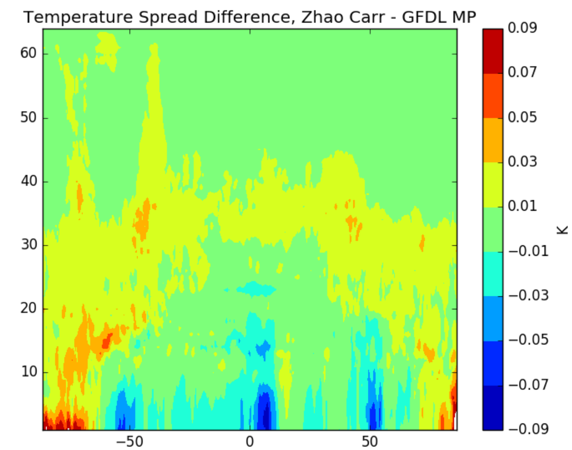
Zhao Carr – GFDL MP

Specific Humidity

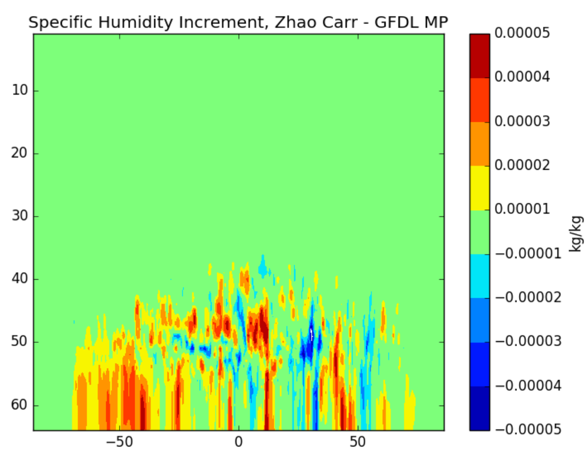
Temperature

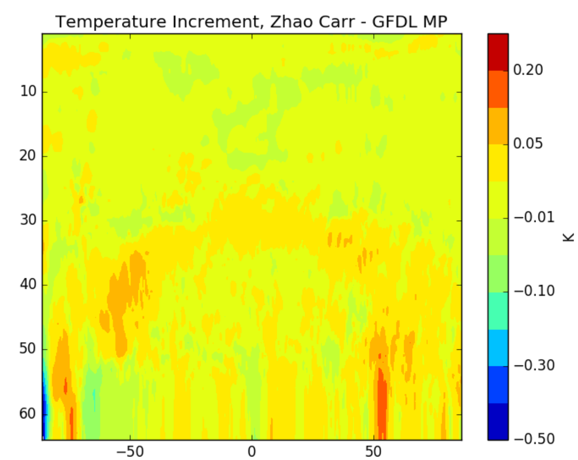
Ensemble Spread





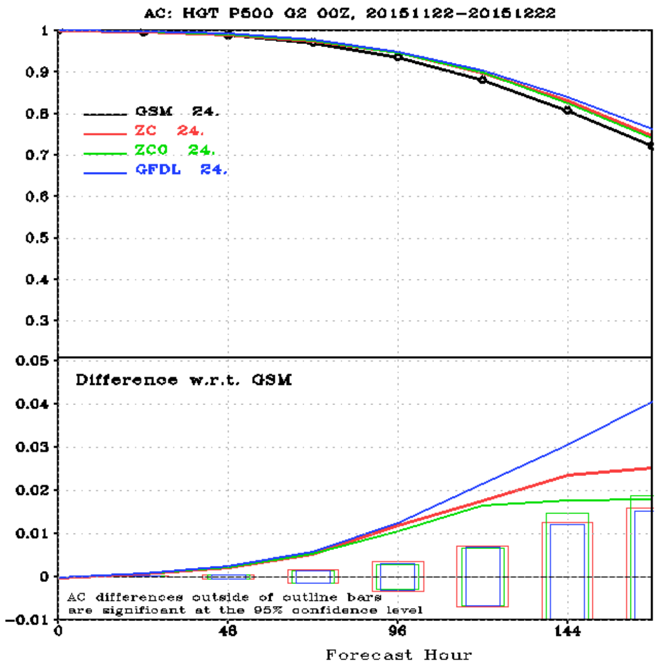
Analysis Increment

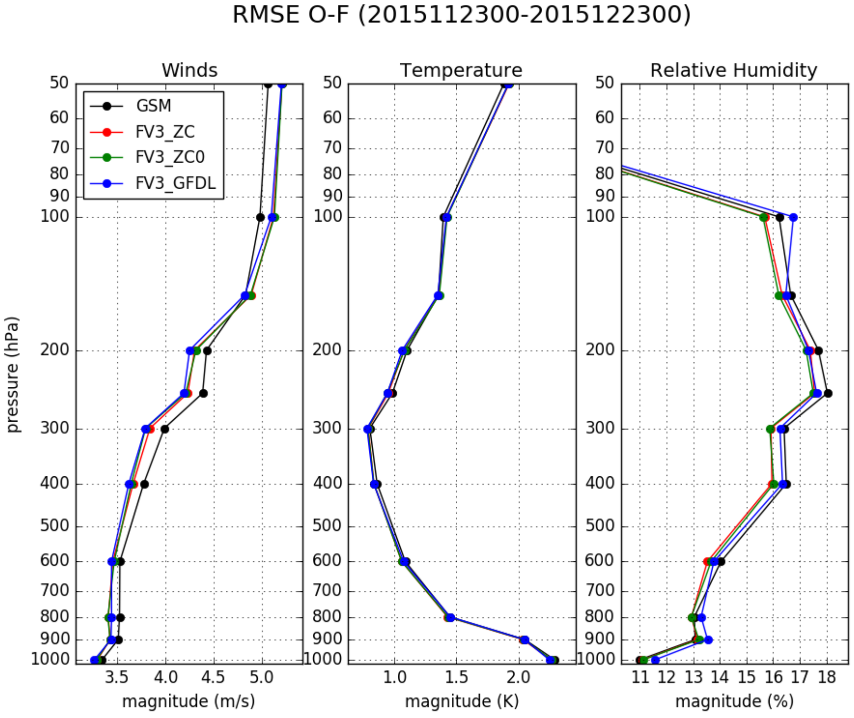




Experiment Results

- 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 at this point. GFDL MP performs slightly better in the troposphere for winds/heights, but slightly worse for humidity.
- Any improvement of GFDL MP does not appear related to the zeroing of the cloud increments.





Future Investigation

- Hydrometeor analysis
  - The cloud liquid water and cloud ice analyses are not currently being ingested in the forecast model.
  - The analyses for the two hydrometeors can be ingested in the forecast model.
  - Analyses for all hydrometeors can be calculated.
- Background errors
  - A new static background error will be calculated for the proposed increase in model top. This would be an ideal time to explore a new static background error for the hydrometeors.
  - Ensemble spread for each hydrometeor needs to be examined in detail.
- Community Radiative Transfer Model (CRTM)
  - Currently, cloud liquid water and cloud ice are sent to the CRTM by partitioning the total cloud water.
  - The cloud liquid water and cloud ice from the model can be sent to the CRTM.
  - All individual hydrometeors can be sent to the CRTM. For this to occur, an effective radius needs to be calculated for each hydrometeor.

Summary

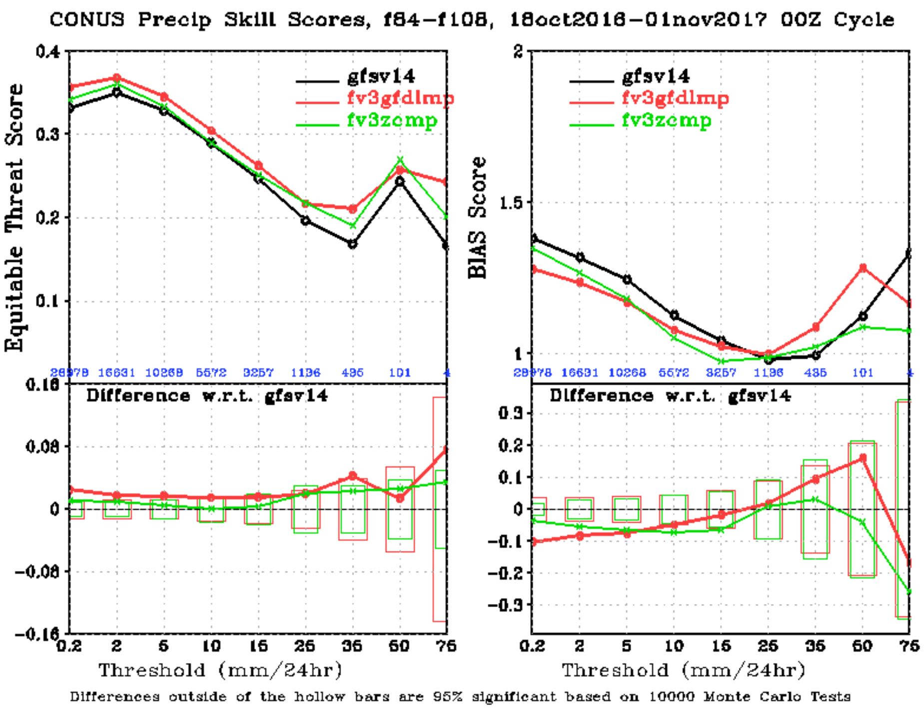
- The FV3 will replace the current dynamical core in the GFS. The experimental beta configuration testing is underway.
- The operational MP that predicted total cloud water has been replaced with GFDL MP which predicts five hydrometeors.
- Modifications were made to the DA to minimize the impact. The cloud liquid water and cloud ice were combined within the DA to mimic the operational total cloud water. The cloud analysis increments were not fed back to the model to reduce spin down.
- GFDL MP produces more mid- and low-level cloud and less high cloud. The ensemble spread for the GFDL MP is also higher for the mid- and low-level clouds and lower for the high cloud.
- GFDL MP performs slightly better in the troposphere for standard global metrics in our low resolution experiment.

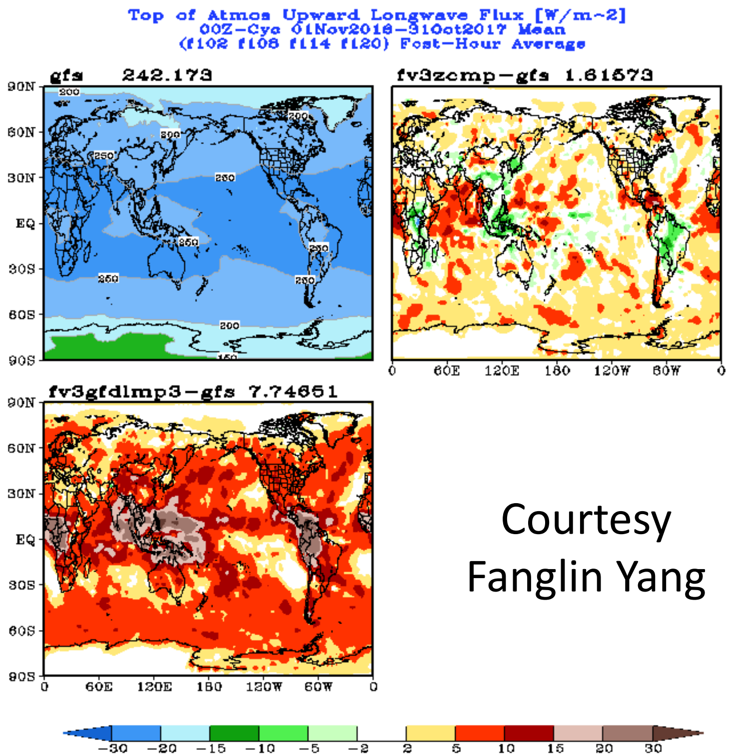
Thank You

Back Up Slides

Free Forecasts with GFDL MP

- Initialized from operational GFS at 00z every 5 days for one year.
- GFDL MP is colder than Zhao Carr MP near the tropopause.
- After 5 days of forecast, GFDL MP has less high clouds but much more mid- and low-layer clouds than Zhao Carr MP, resulting in larger outgoing longwave radiation.

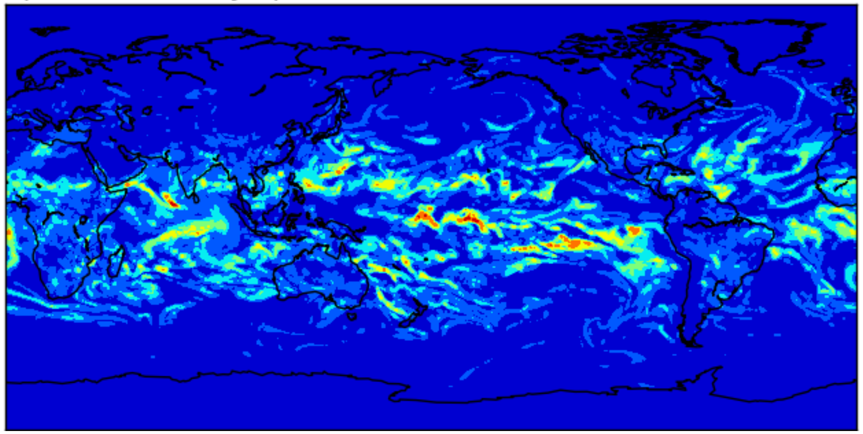




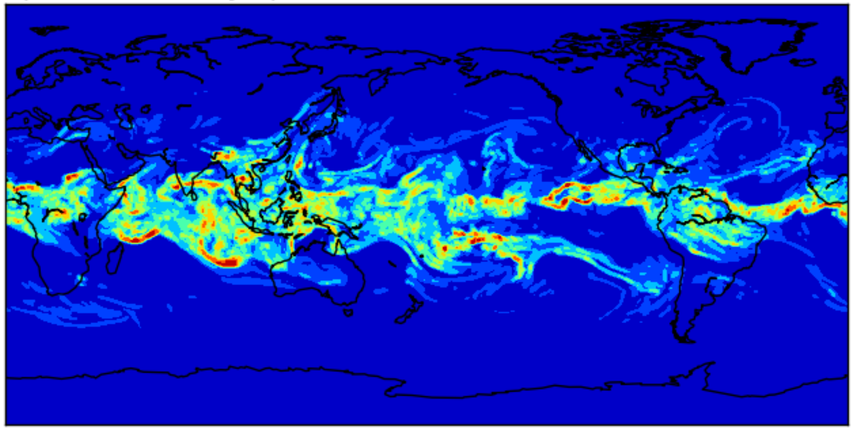
Courtesy Fanglin Yang

Specific Humidity Spread

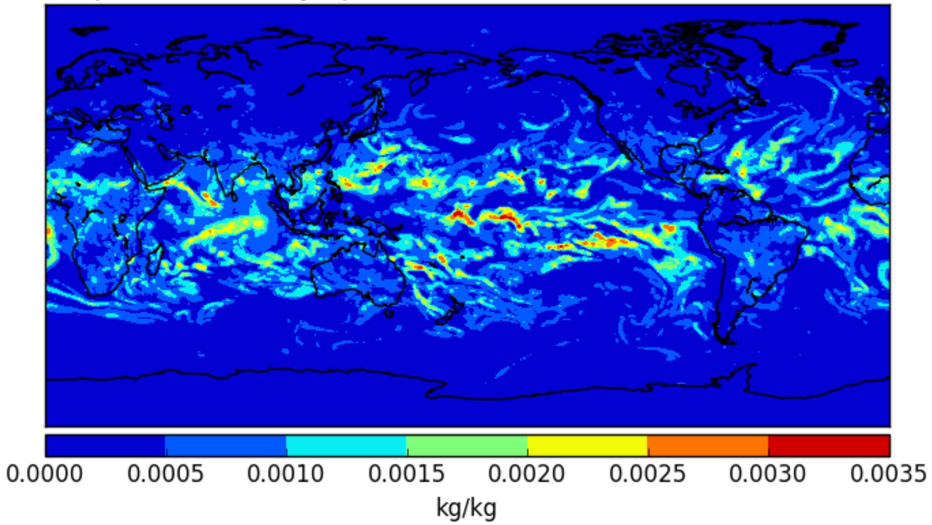
Specific Humidity Spread, Level 13 (~850 hPa), Zhao Carr MP



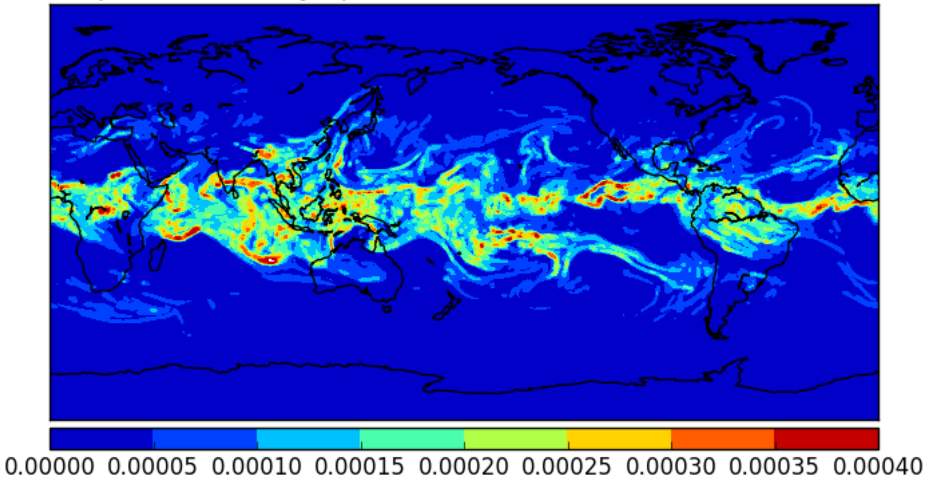
Specific Humidity Spread, Level 30 (~300 hPa), Zhao Carr MP



Specific Humidity Spread, Level 13 (~850 hPa), GFDL MP

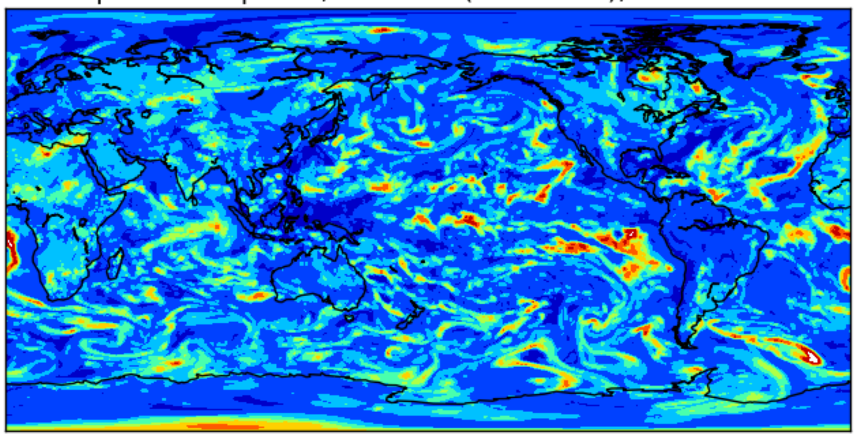


Specific Humidity Spread, Level 30 (~300 hPa), GFDL MP

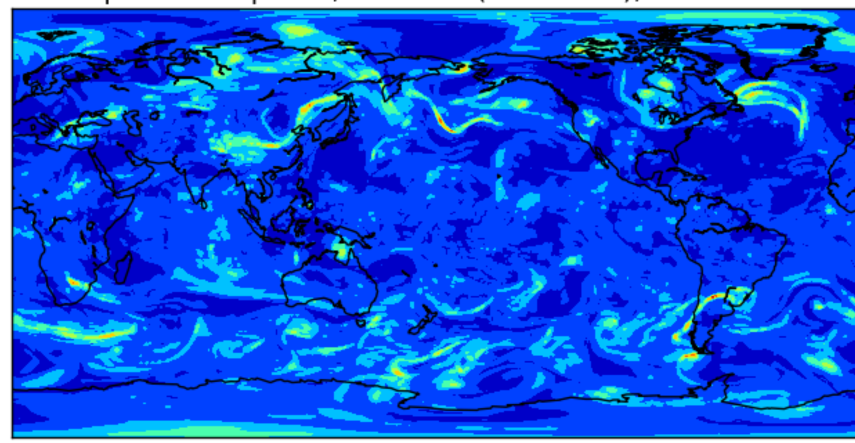


Temperature Spread

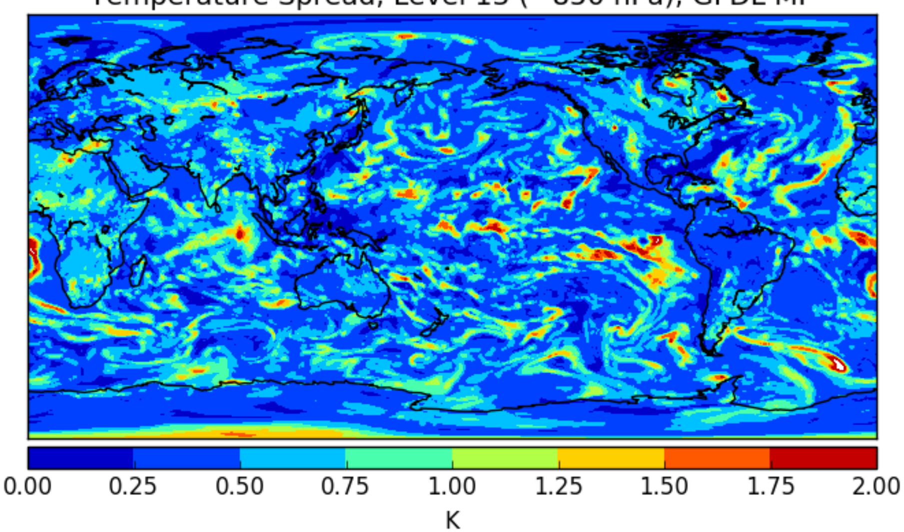
Temperature Spread, Level 13 (~850 hPa), Zhao Carr MP



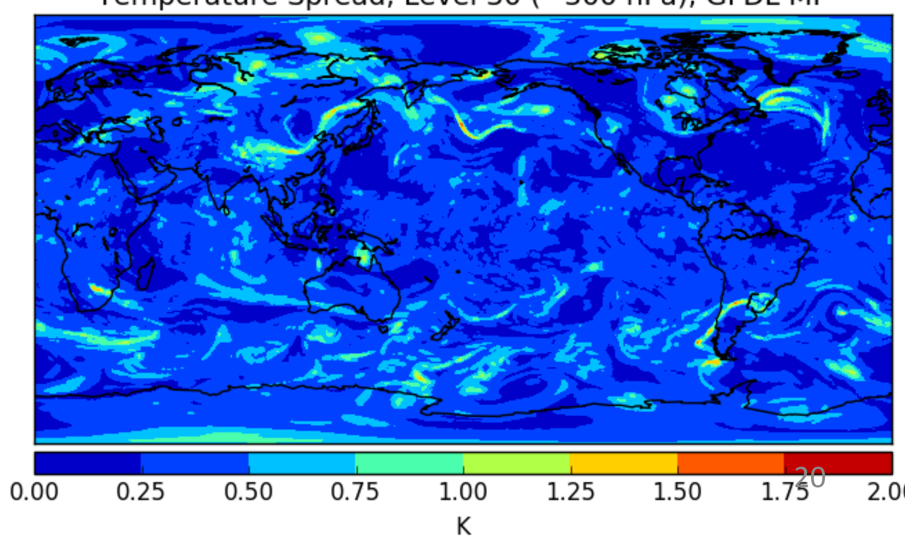
Temperature Spread, Level 30 (~300 hPa), Zhao Carr MP



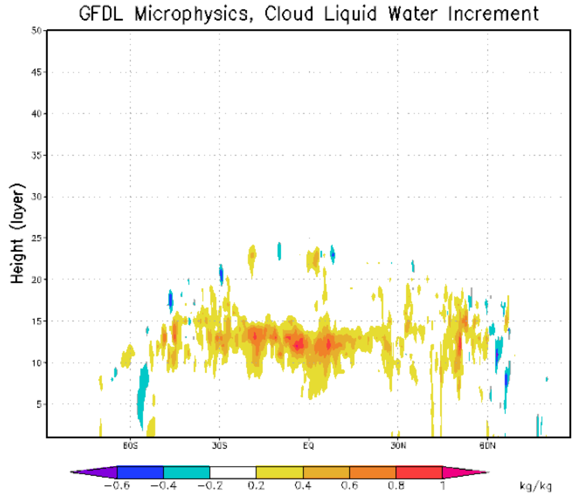
Temperature Spread, Level 13 (~850 hPa), GFDL MP

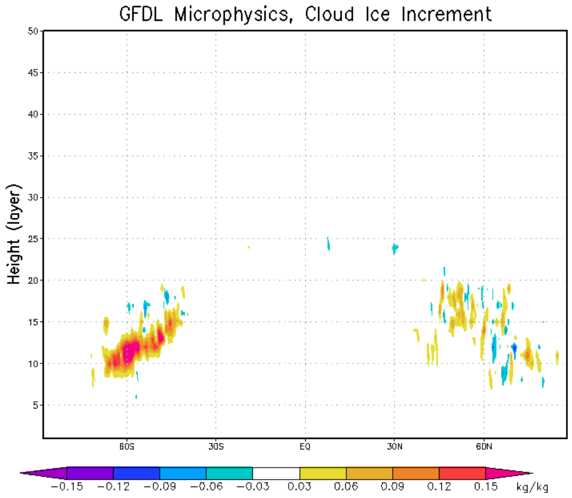


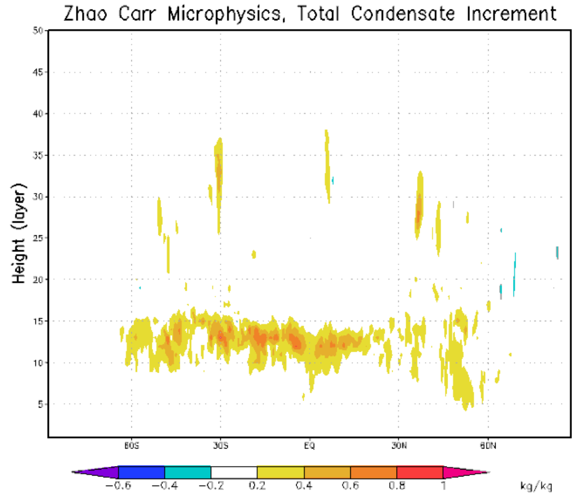
Temperature Spread, Level 30 (~300 hPa), GFDL MP

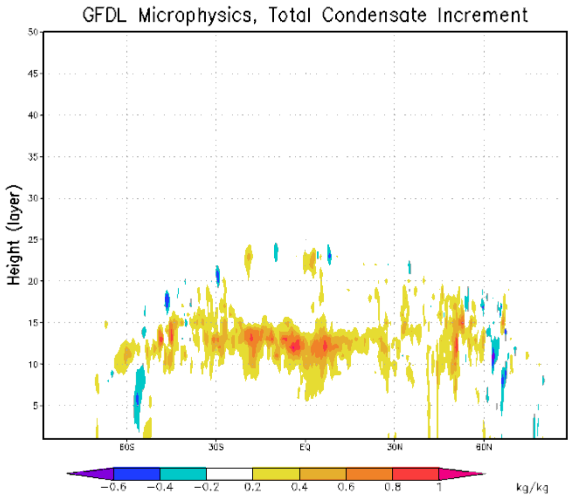


Cloud Analysis Increments

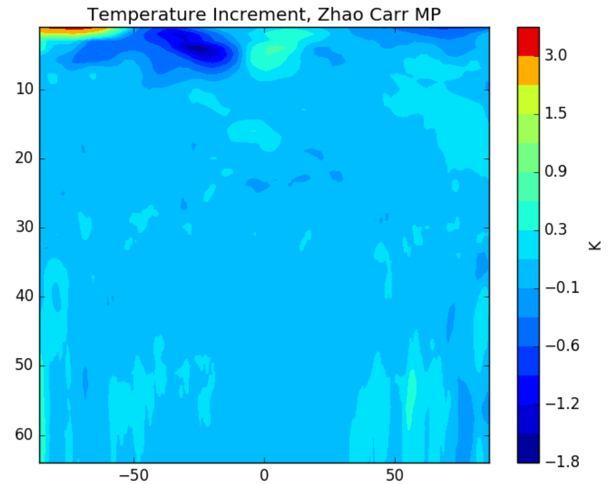


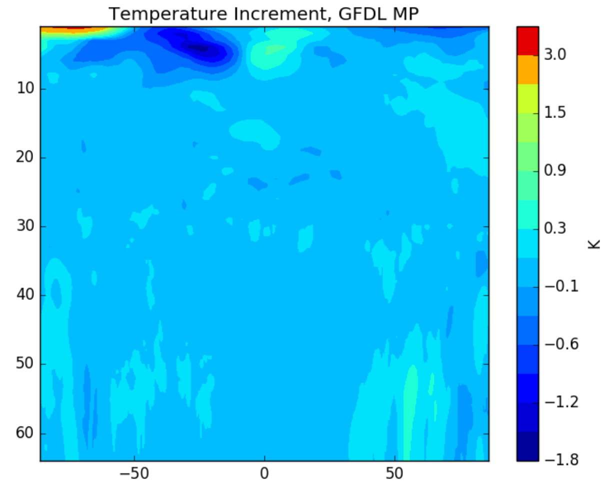


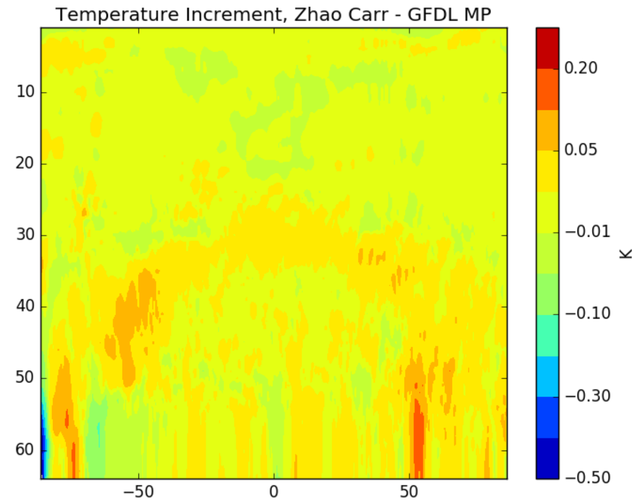




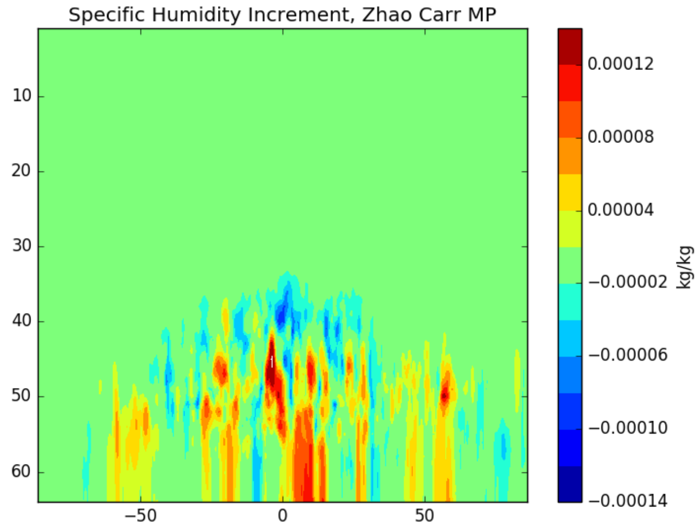
Temperature Increments

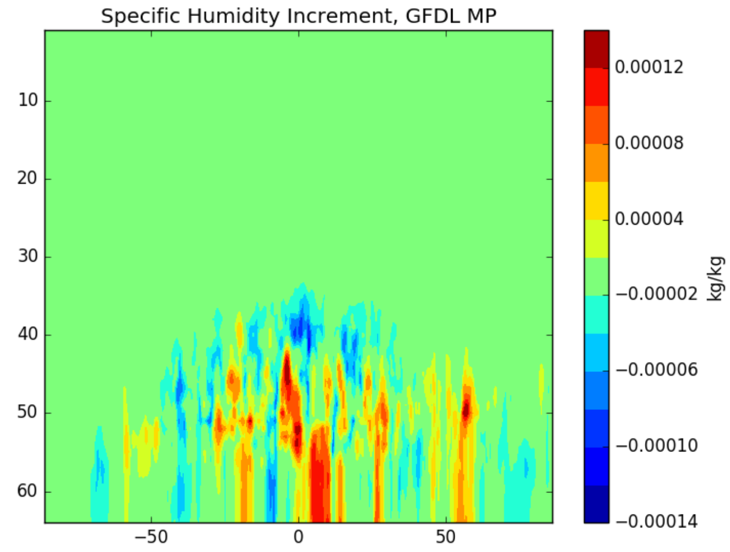


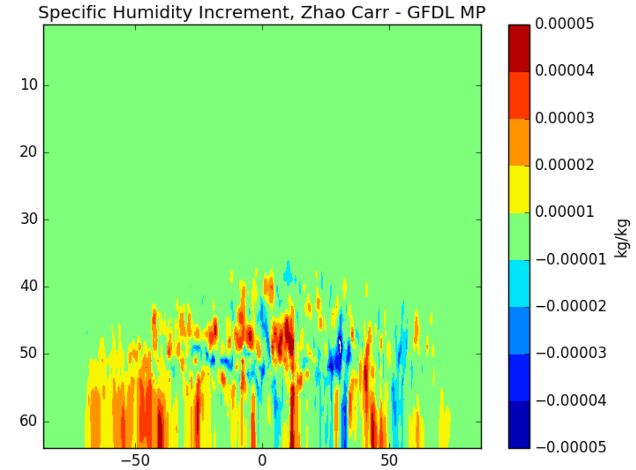




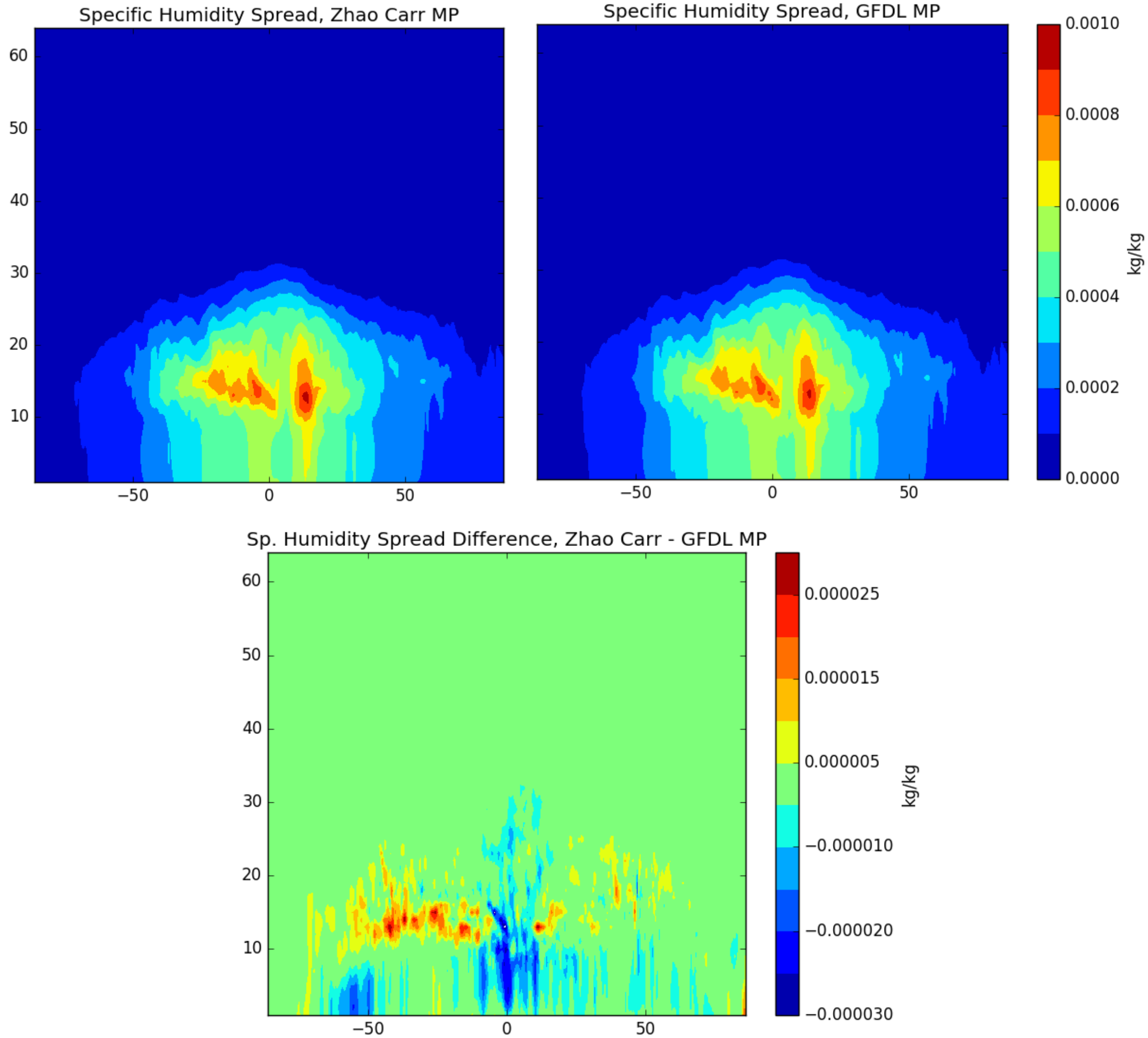
Humidity Increments



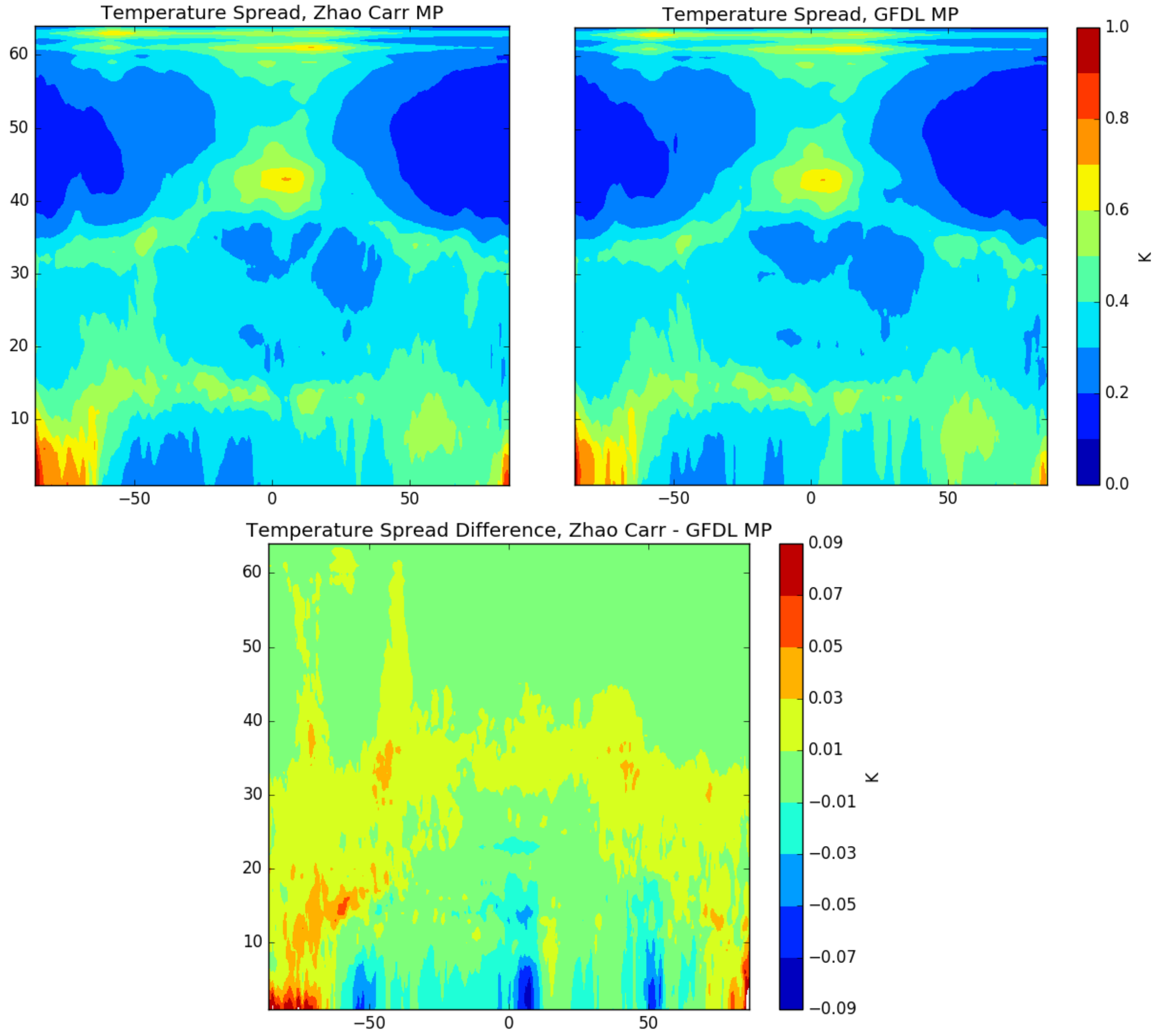




Specific Humidity Spread

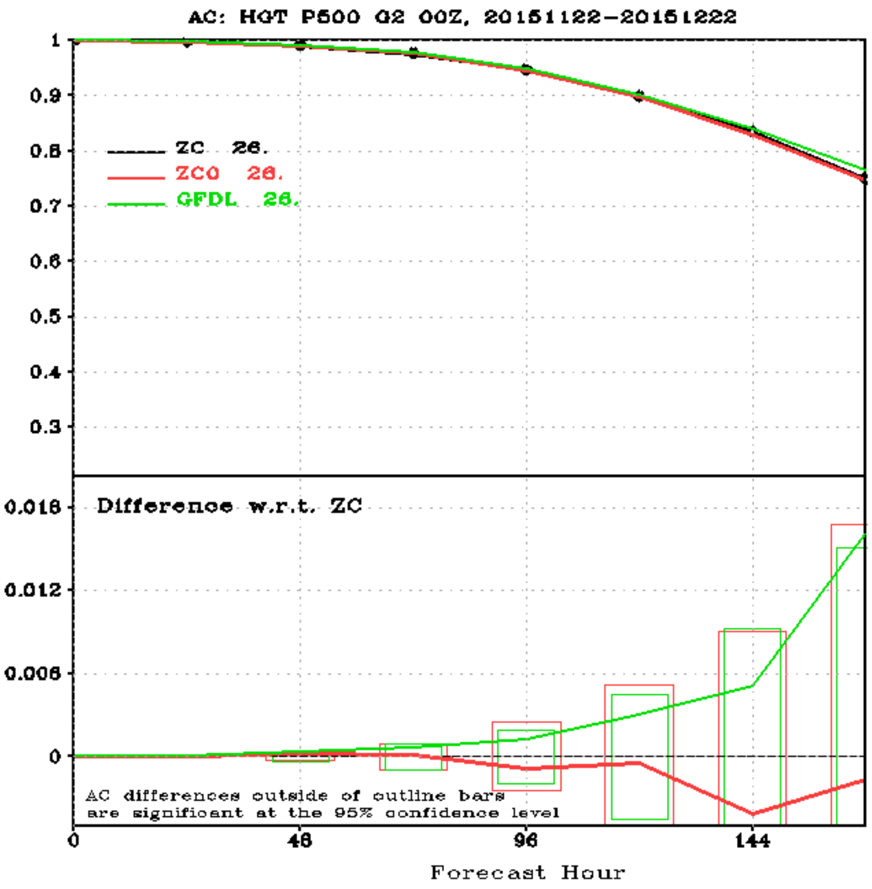


Temperature Spread

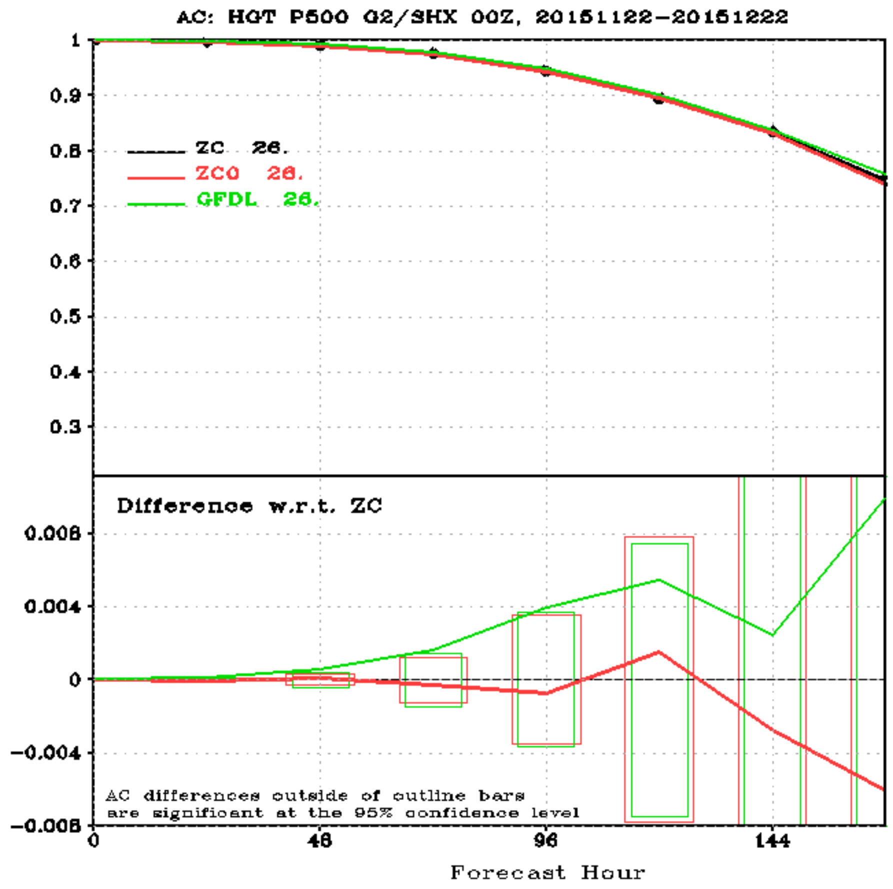


GFDL and ZC Direct Comparison

Global



Southern Hemisphere



Temperature and Water Vapor Anl