Whole Atmosphere Data Assimilation in WACCMX+DART

Nick Pedatella[1,2], Hanli Liu[1], Daniel Marsh[1,3], J. Liu[1], Jeffrey Anderson[4], and Kevin Raeder[4]

[1]High Altitude Observatory, NCAR
[2]COSMIC Program Office, UCAR
[3]Atmosphere Chemistry Observations and Modeling, NCAR
[4]Computational Information Systems Laboratory, NCAR

Outline

- WACCM+DART and WACCMX+DART
- 2009 SSW Analysis and Hindcasts
- Challenges in Whole Atmosphere DA
- Summary

Data Assimilation Research Testbed

DART is an open source, community, software package for performing ensemble data assimilation

Data assimilation tools are independent of the model, and meant to be easily adaptable to different types of numerical models

Adding new observations only requires writing a forward operator

Efficiently scales to thousands of processors for large geophysical systems

Adaptive spatially and temporally varying inflation to prevent ensemble collapse

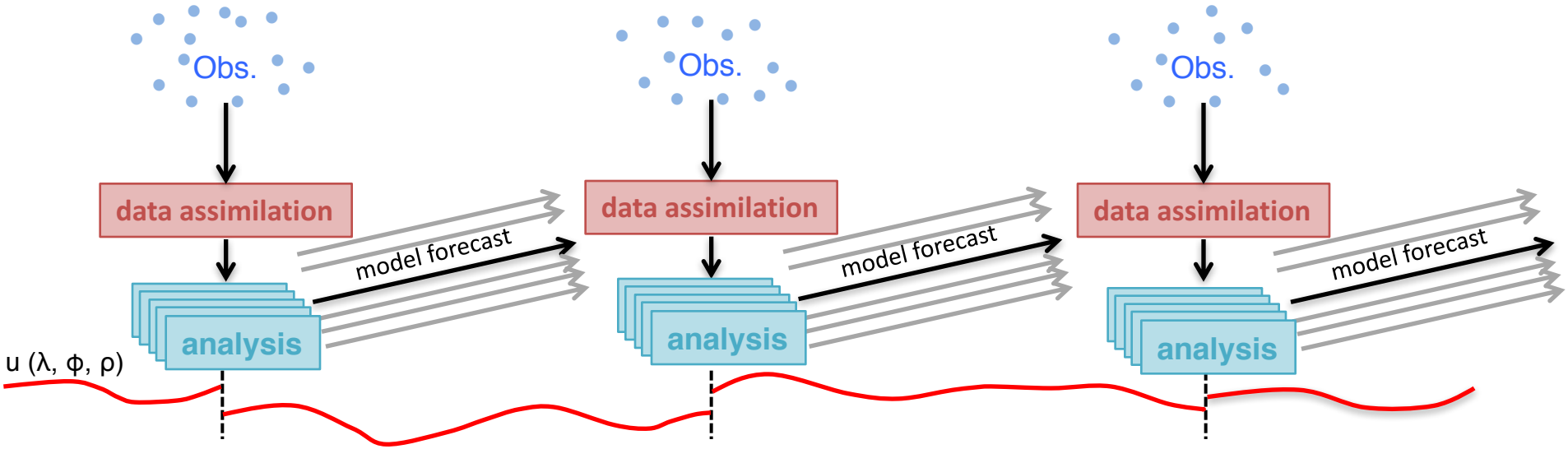
Used in a wide number of different applications

- Ocean assimilation
- Mesoscale NWP (i.e., WRF)
- Global climate models
- Upper atmosphere GCMs
- Chemical assimilation
- Observing System Simulation Experiments
- Parameter estimation
- Quantifying impact of new observation types

Source code available at http://www.image.ucar.edu/DAReS/DART/

Anderson, J. L., T. Hoar, K Raeder, H. Liu, N. Collins, R. Torn, and A. F. Arellano (2009), The Data Assimilation Research Testbed: A Community data assimilation facility, *BAMS*

Data assimilation using DART ensemble Kalman filter



Data assimilation constrains the model directly based on observations providing a more realistic representation of the true state of the atmosphere at a specific time

We use the DART ensemble Kalman filter to implement data assimilation in WACCM/WACCMX

The ensemble approach eliminates the need to specify background covariance, since it is obtained directly from the ensemble of model simulations

WACCM+DART

WACCM+DART provides an atmospheric reanalysis from the surface to the lower thermosphere (~145 km).

Conventional Lower Atmosphere Observations:

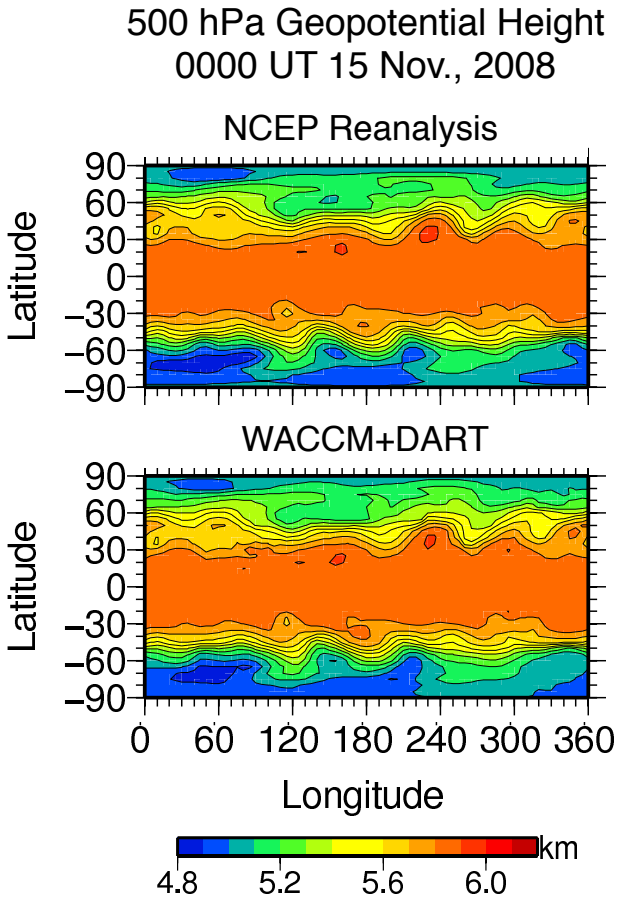
- Aircraft temperature and wind
- Radiosonde temperature and wind
- Satellite drift winds
- COSMIC GPS refractivity

Sparse Middle/Upper Atmosphere Observations:

- TIMED/SABER Temperature (100 - 5×10^{-4} hPa)
- Aura MLS Temperature (260 - 1×10^{-3} hPa)

Typically use a 40-member ensemble, which is a tradeoff between computational expense and having a sufficiently large ensemble to capture a variety of atmospheric states.

WACCM+DART is useful for correcting model biases, studying dynamical variability due to sudden stratosphere warmings, and short-term tidal variability



Pedatella, N. M., K. Raeder, J. L. Anderson, and H.-L. Liu (2014), Ensemble data assimilation in the Whole Atmosphere Community Climate Model, *J. Geophys. Res., 119*, doi: 10.1002/2014JD021776.

WACCMX+DART

Framework for WACCMX+DART is identical to WACCM+DART

Same observations are assimilated in the troposphere, stratosphere, and mesosphere.

Main change between WACCMX+DART and WACCM+DART is increased damping in WACCMX. This was necessary for model stability, and to ensure that mixing from small scale waves introduced by the data assimilation do not excessively reduce thermosphere O/N_2 and electron density.

Changes made for model stability tend to damp tidal amplitudes, and have a slight negative impact on performance of the data assimilation in the troposphere-stratosphere.

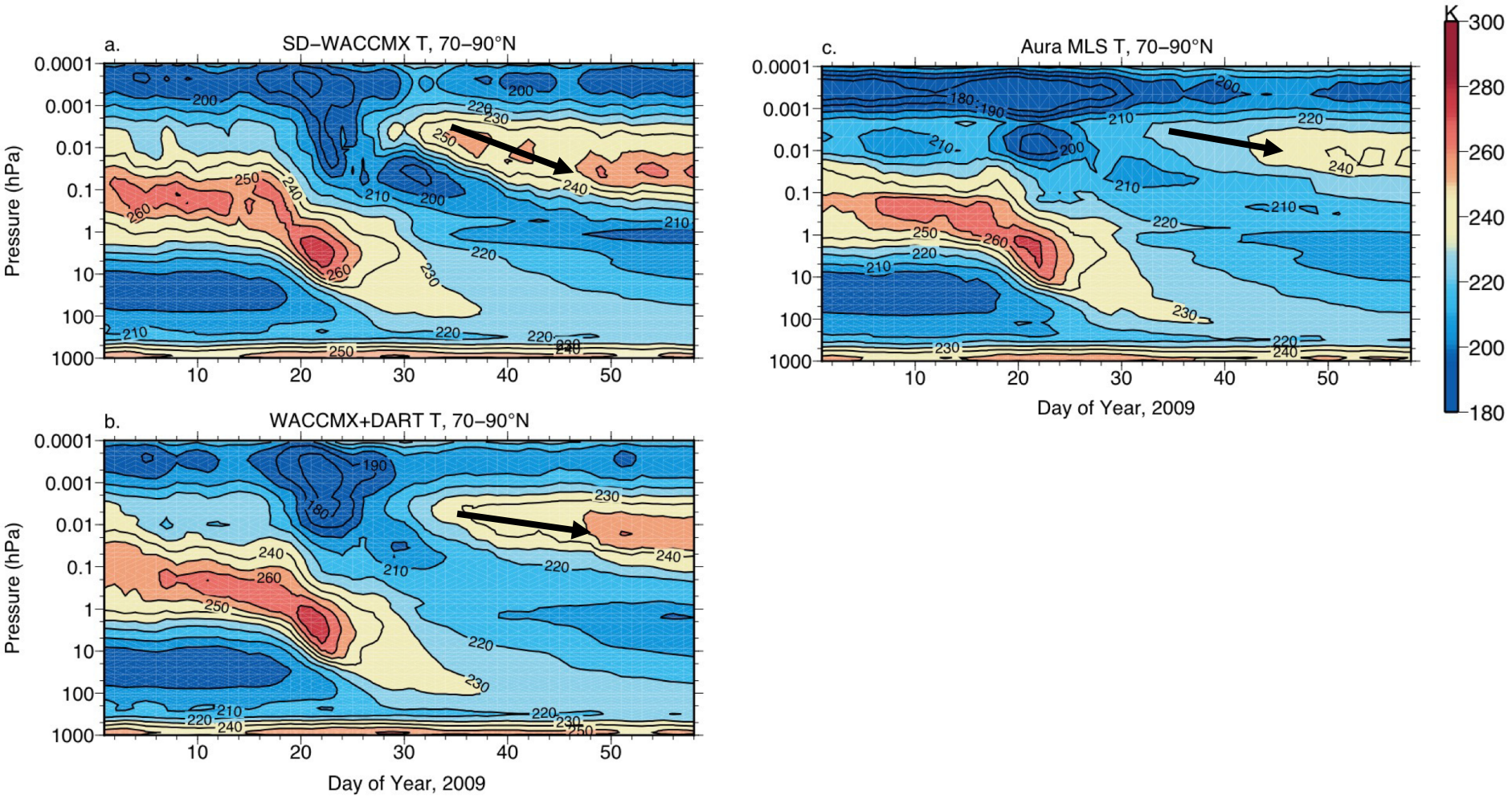
Troposphere humidity is biased by ~20-30% due to model physics issue when using a 5 min time-step.

We have performed initial WACCMX+DART analysis and hindcast simulations for the 2009 SSW time period.

Outline

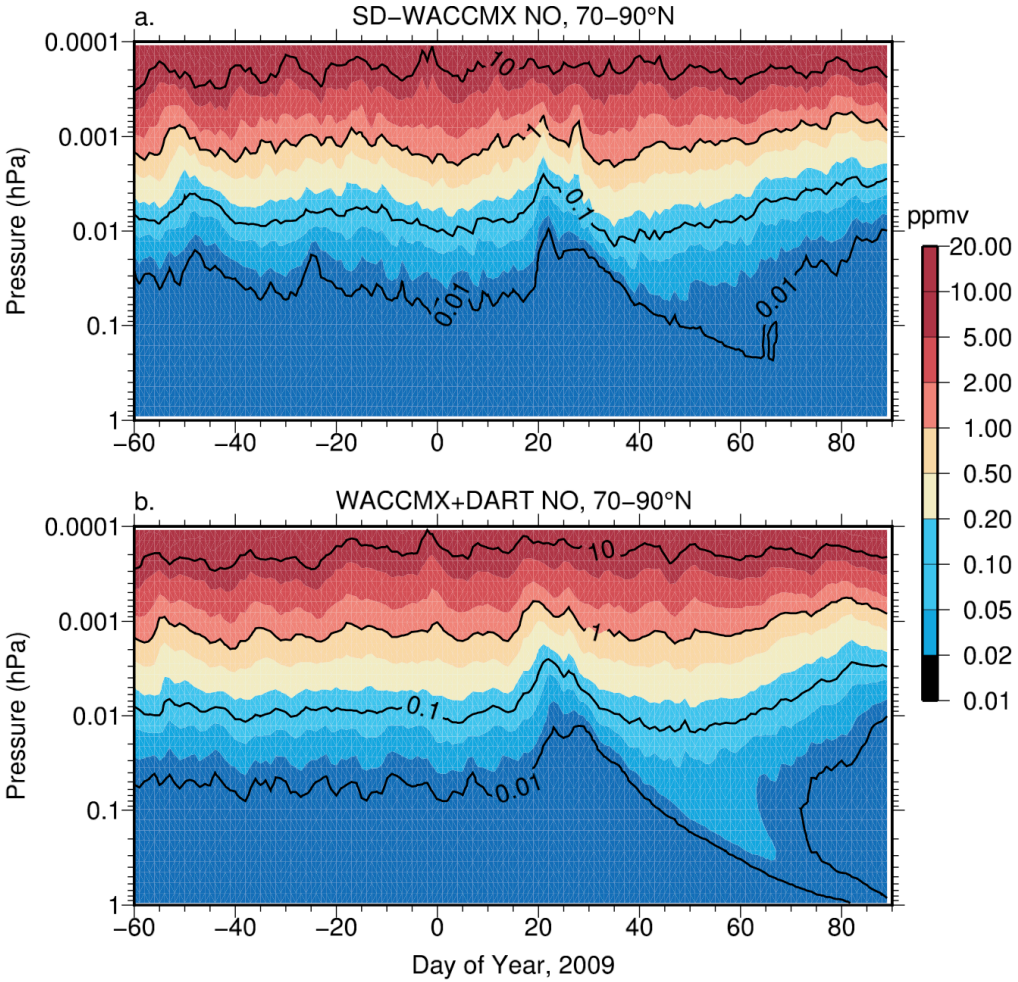
- WACCM+DART and WACCMX+DART
- 2009 SSW Analysis and Hindcasts
- Challenges in Whole Atmosphere DA
- Summary

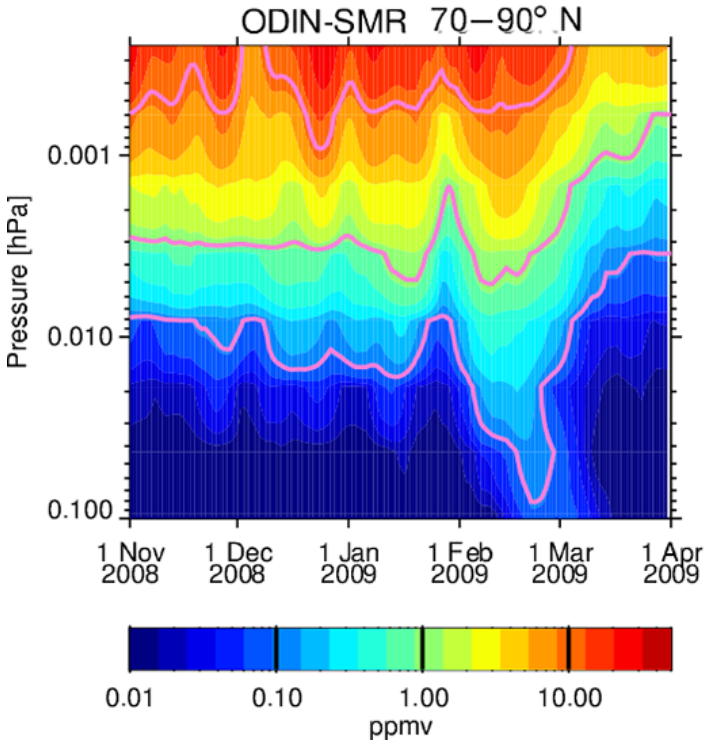
Middle Atmosphere Variability in WACCMX+DART and SD-WACCMX



SD-WACCMX: Specified Dynamics WACCMX constrained to MERRA meteorology up to 50km

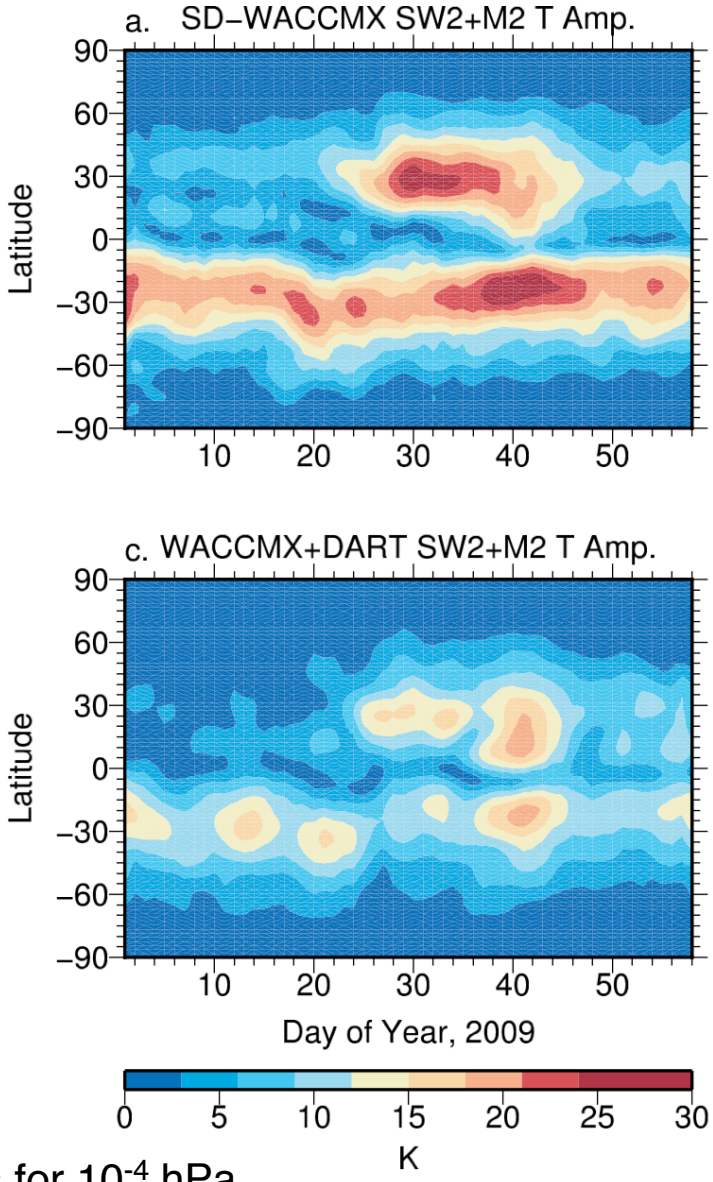
NO descent following the SSW

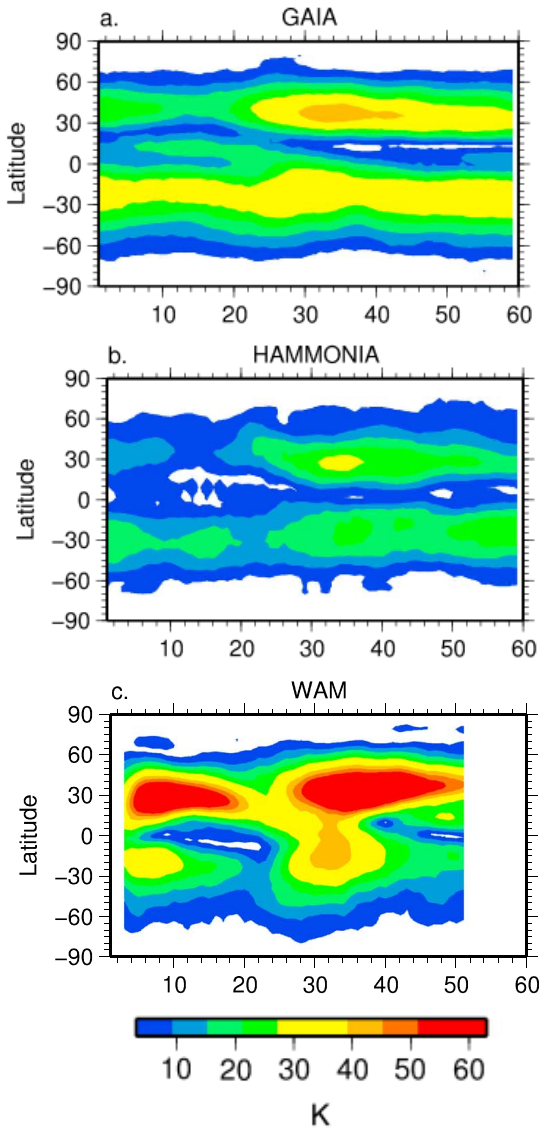




(Funke et al., 2017)

Temporal tidal variability is reproduced in WACCMX+DART, but tidal amplitudes are too weak.

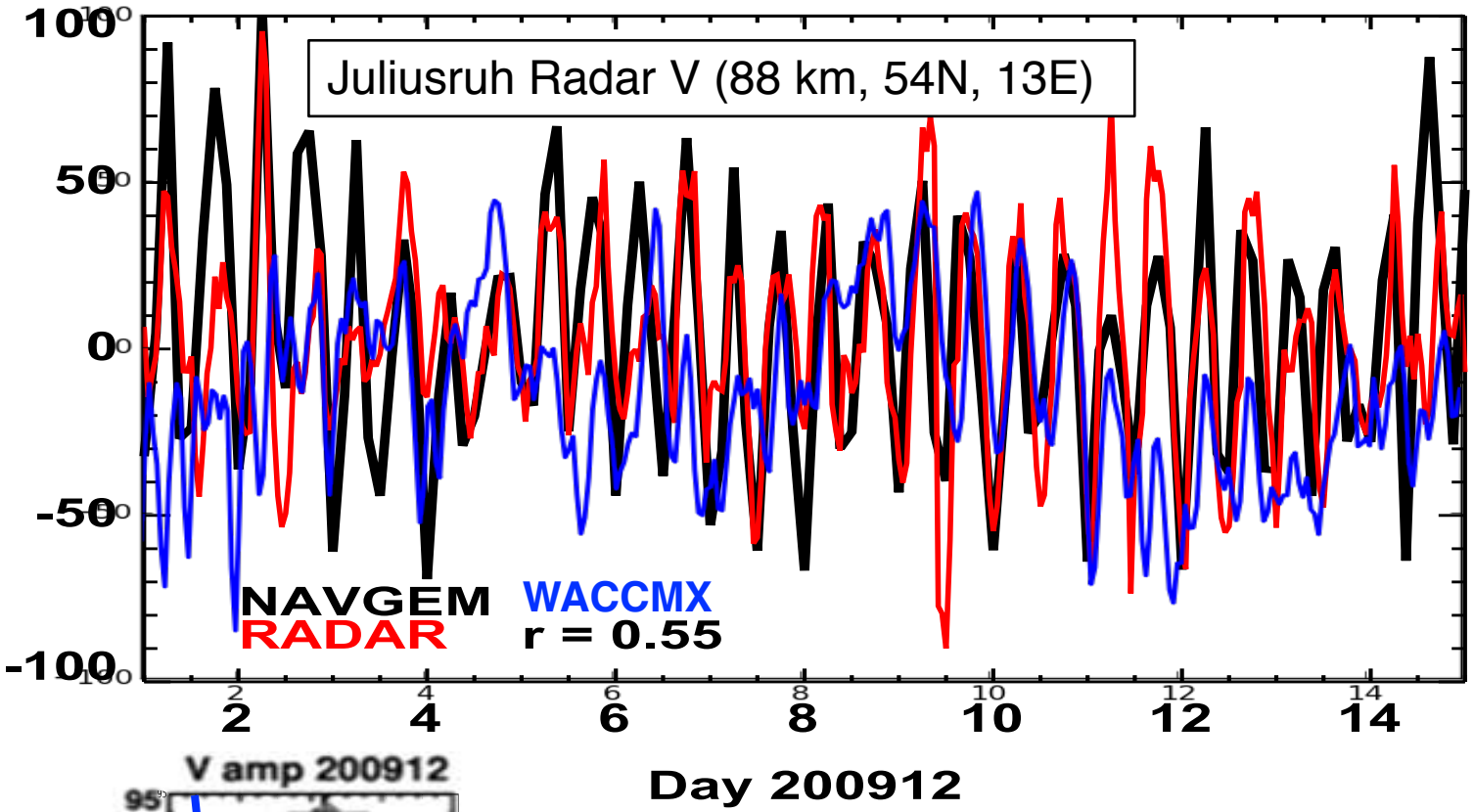


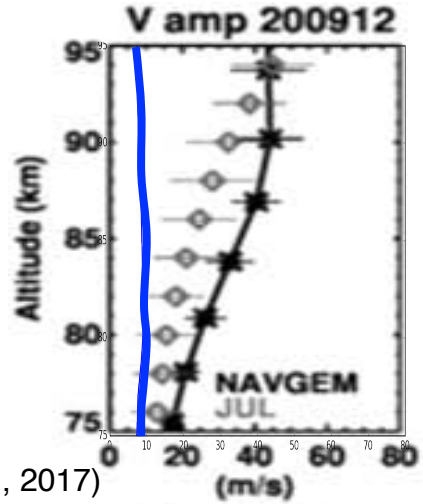


Results for 10^{-4} hPa

(Pedatella et al., 2014)

Comparison with Juliusruh MF Radar

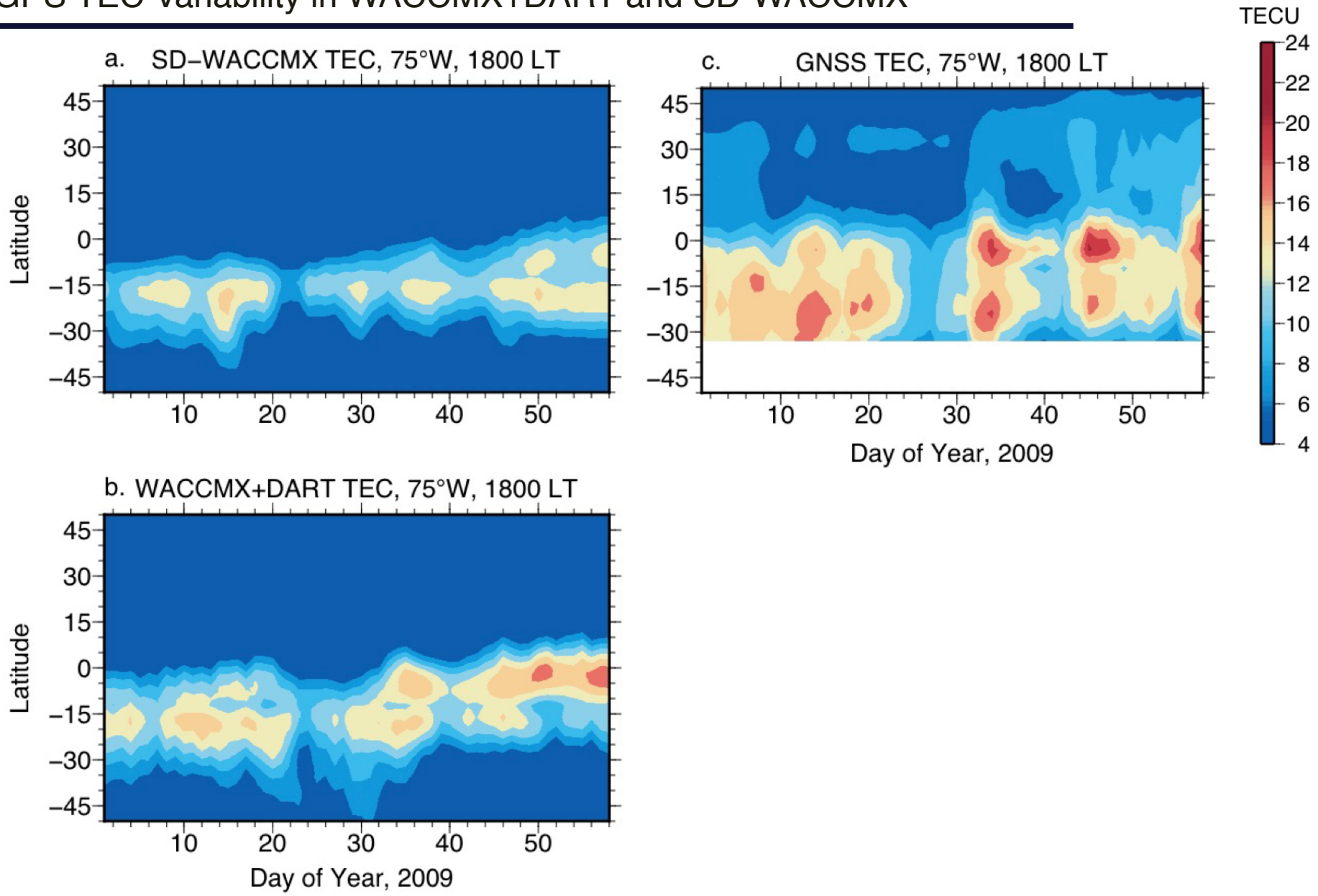




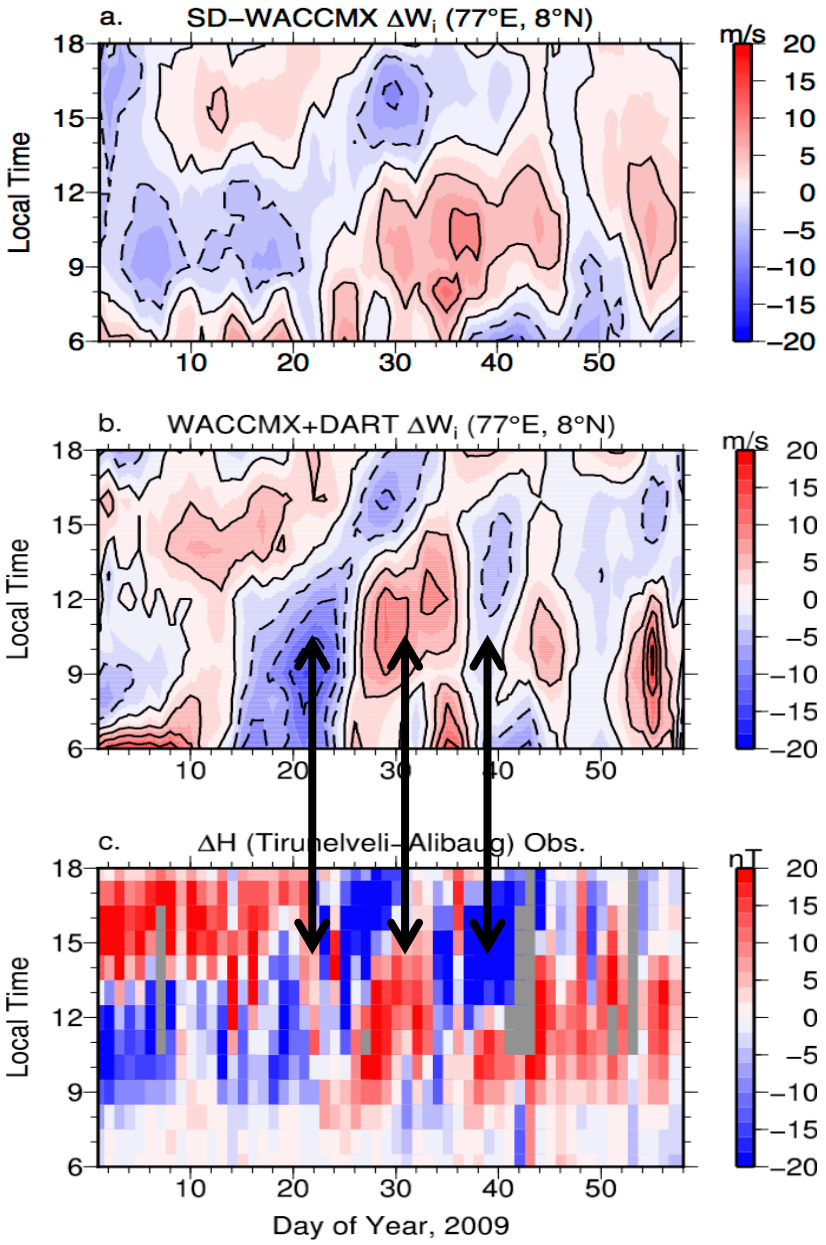
(McCormack et al., 2017)

Tides are too weak in WACCMX+DART due to damping

GPS TEC Variability in WACCMX+DART and SD-WACCMX



Equatorial Vertical Drift Variability in WACCMX+DART and SD-WACCMX

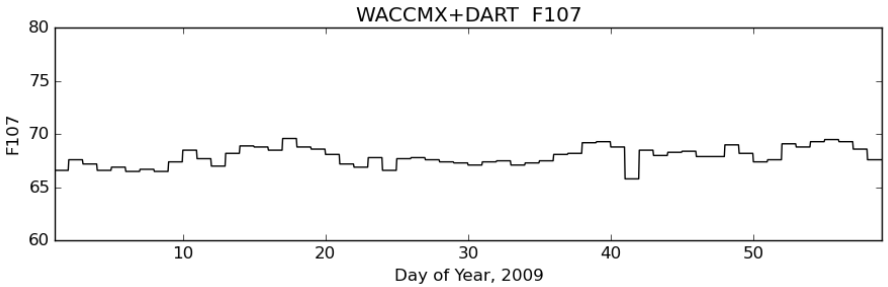


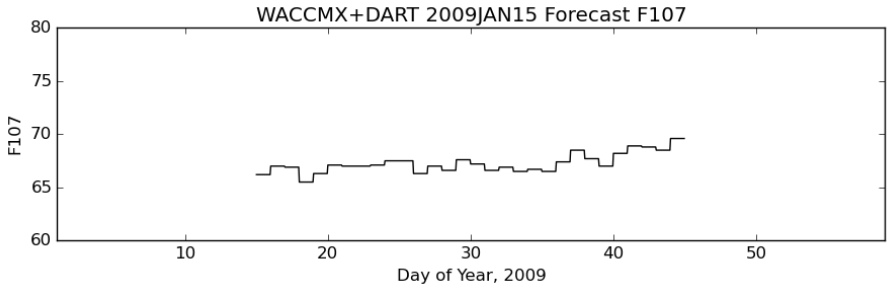
2009 SSW Hindcast Experiments

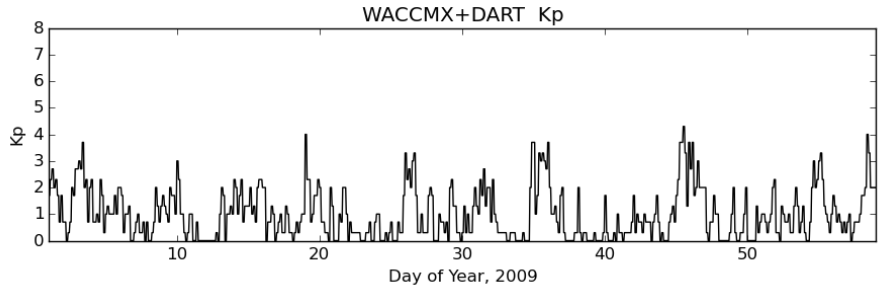
- Initialize 40-member ensemble forecasts (hindcasts) of the 2009 SSW on January 5, 10, 15, 20, and 25.

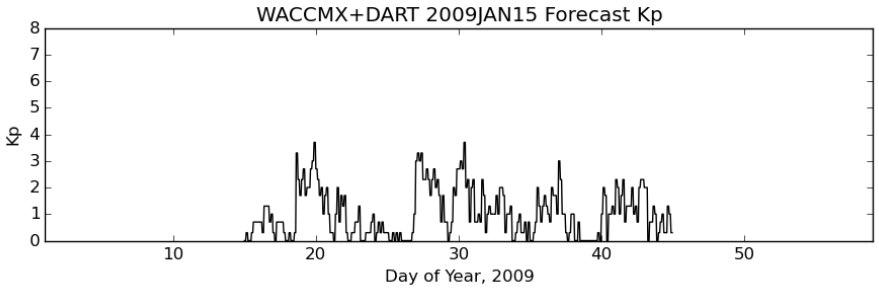
- Ocean SSTs are specified as the true values (i.e., not forecasted)

- Solar activity is specified by using 27-days prior solar activity

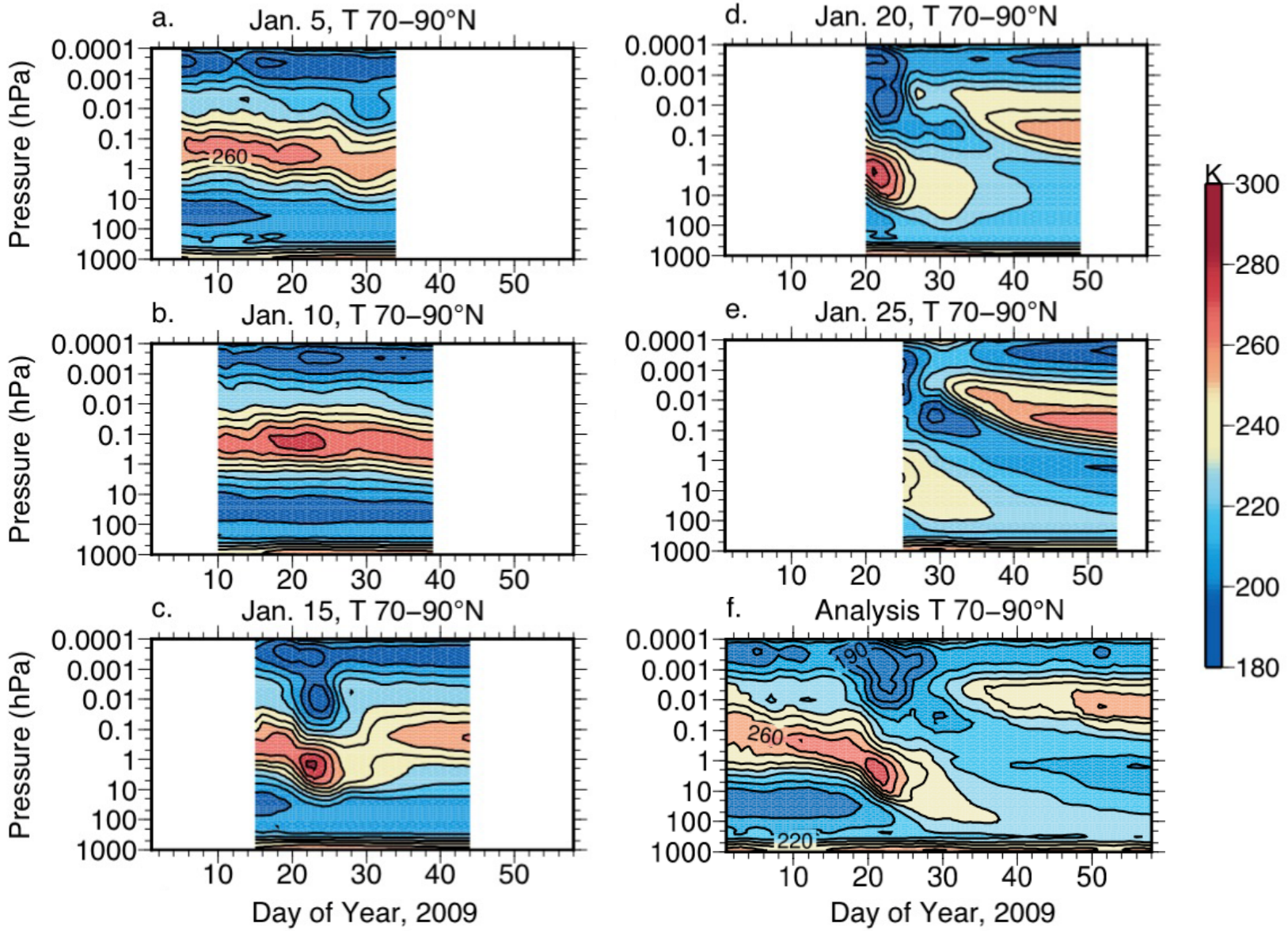




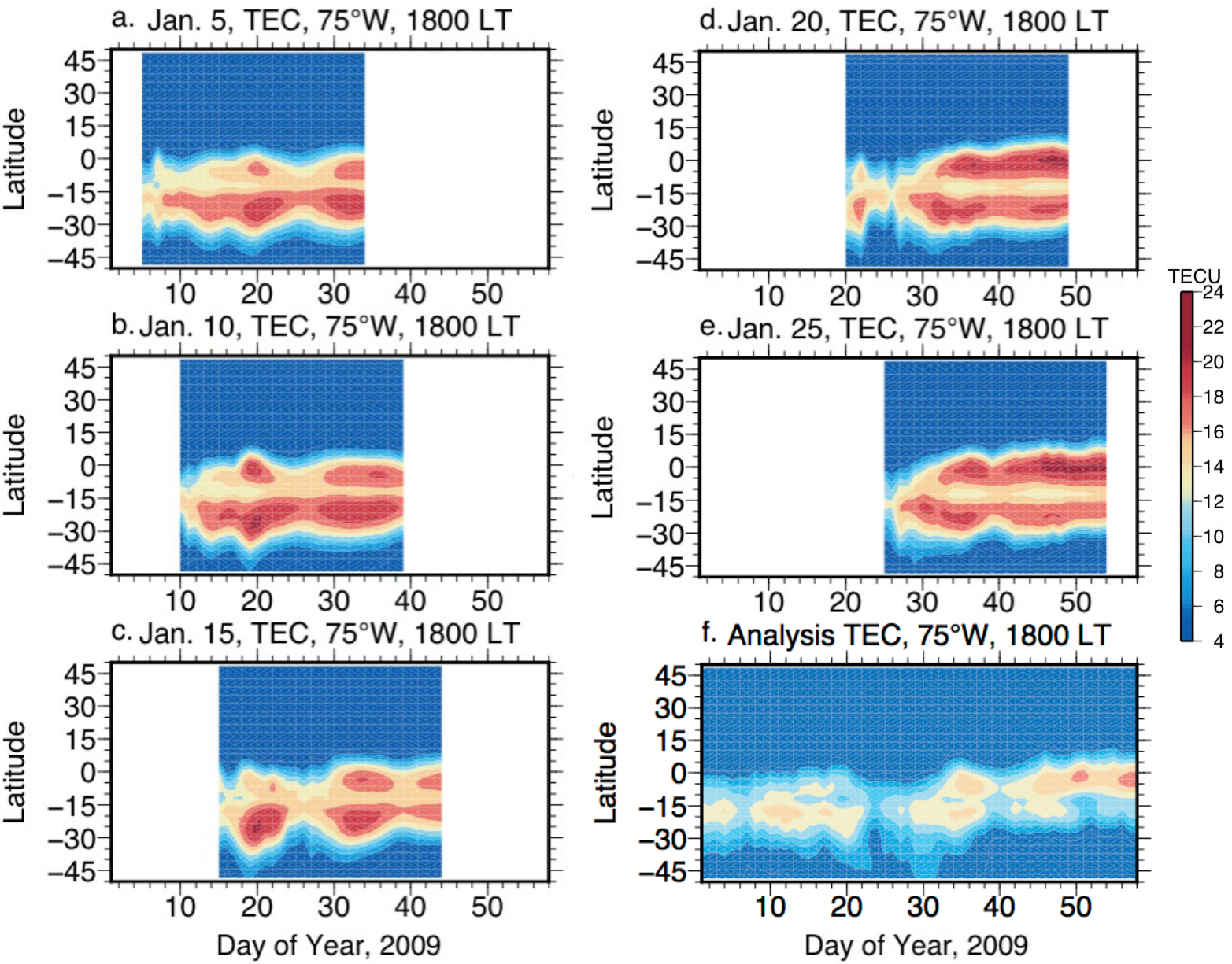




2009 SSW Hindcasts: 70-90° N Temperature



2009 SSW Forecasts: TEC at 75W



Outline

- WACCM+DART and WACCMX+DART
- 2009 SSW Analysis and Hindcasts
- Challenges in Whole Atmosphere DA
- Summary

Challenges in Whole Atmosphere Data Assimilation

The data assimilation increments can lead to unbalanced flows, resulting in spurious waves which pose additional challenges for whole atmosphere DA:

1) The large wave growth with altitude can lead to model instabilities

2) Wave dissipation in the MLT has consequences for IT composition

Filtering can be applied, but this can unintentionally remove real waves as well as potentially damp larger scale waves (i.e., tides)

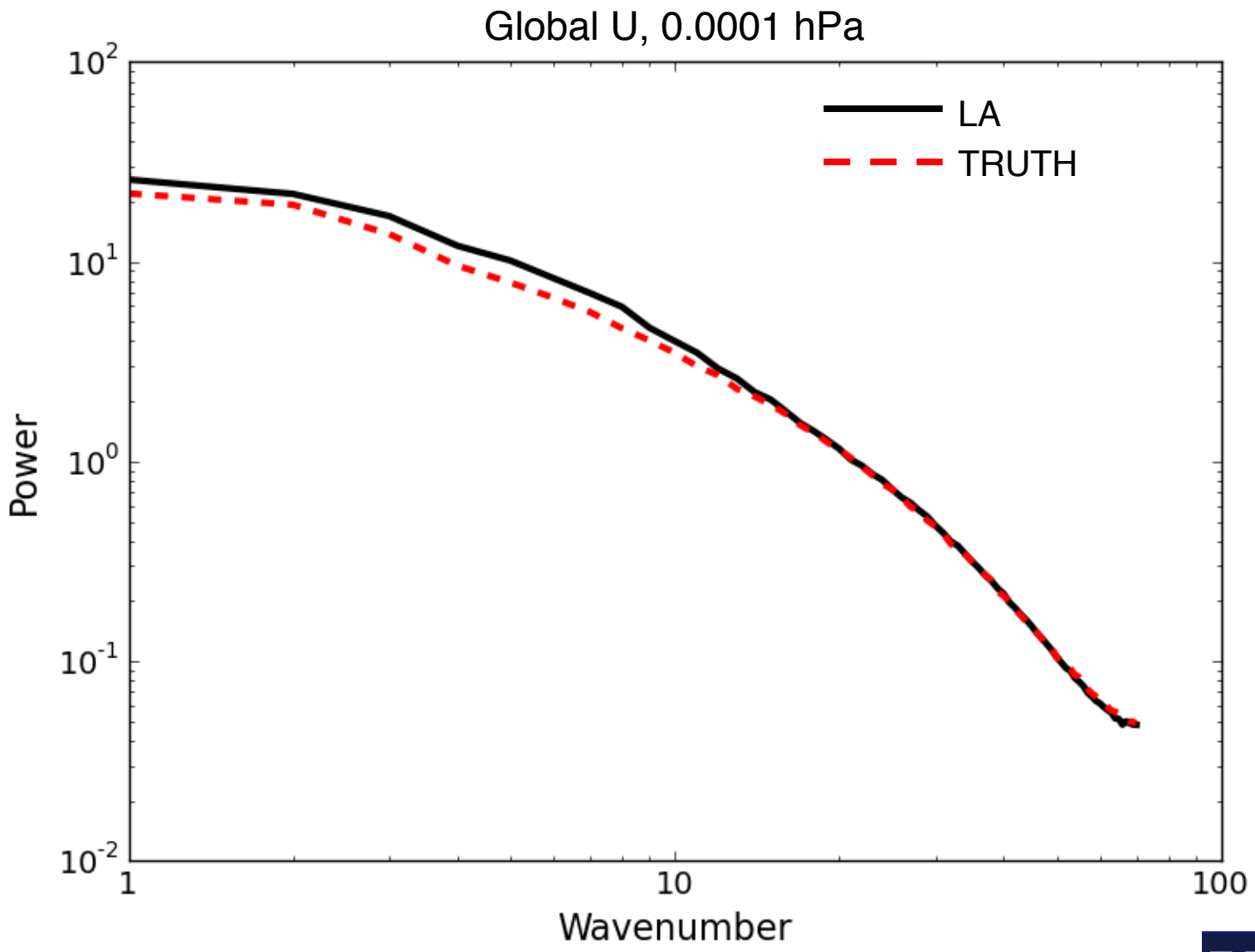
There are additional challenges specific to ionosphere-thermosphere DA:

1) Time scales tend to be shorter compared to lower atmosphere

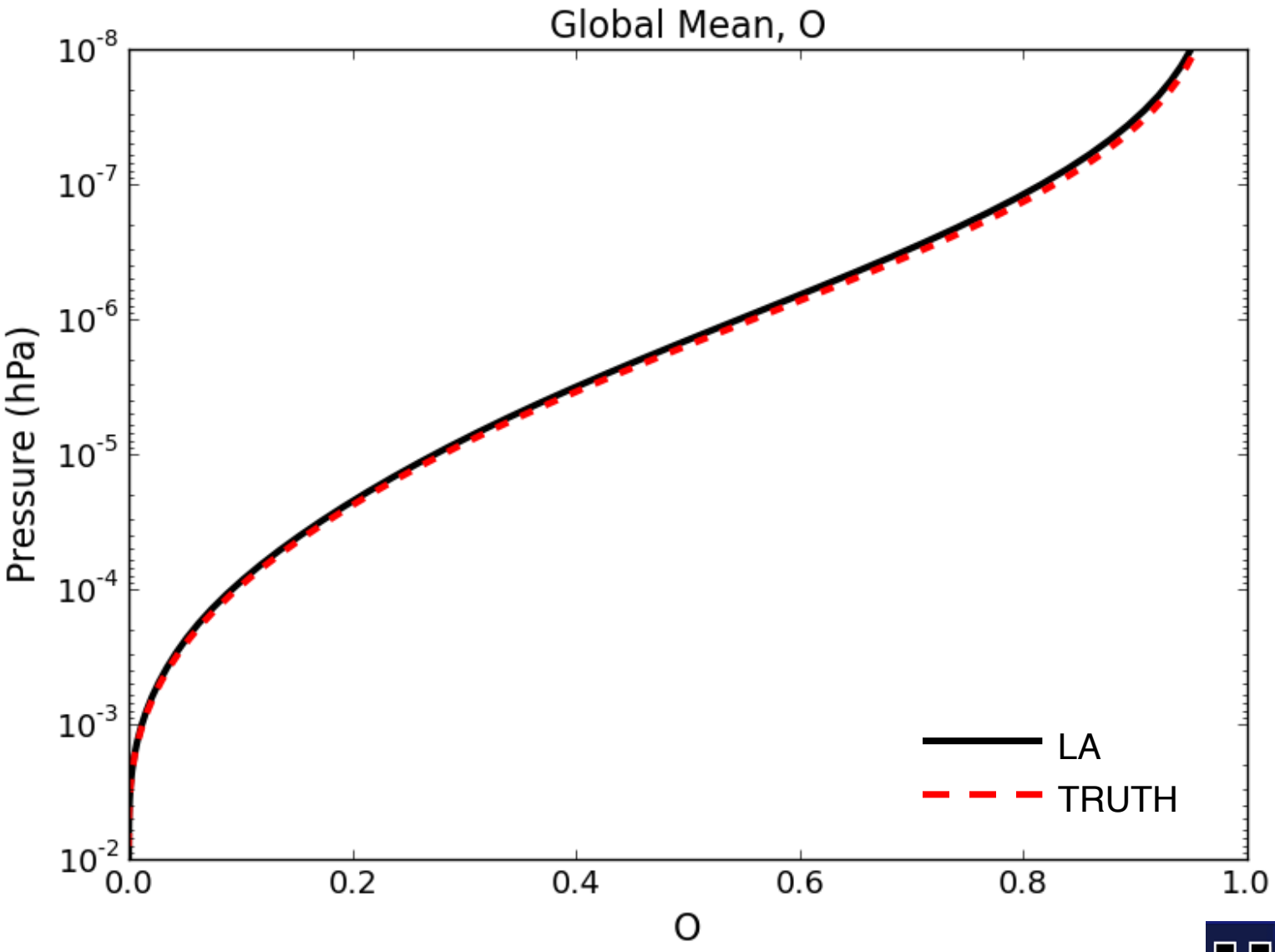
2) The IT is strongly driven by external forcing, making it more difficult to overcome model biases

3) Data are sparser, though this may be less of a challenge in the near future.

Wave variability in the mesosphere is larger when assimilating lower atmosphere observations, increasing the mixing in the MLT.

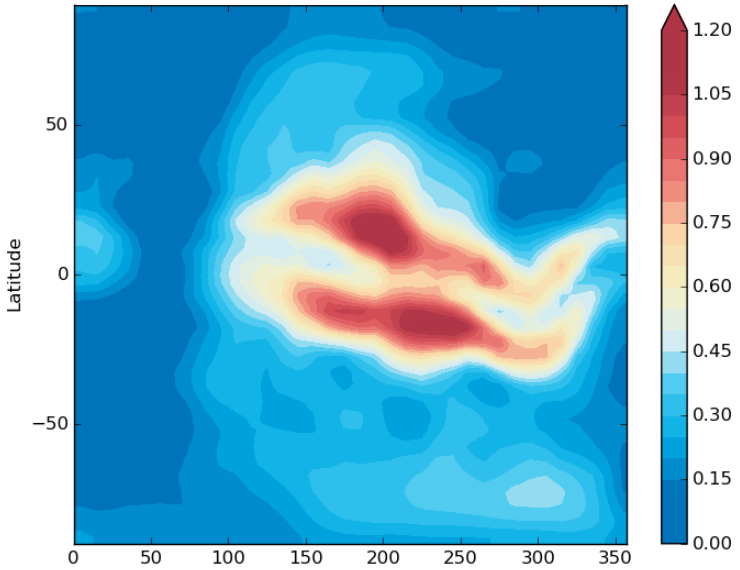


Impact of enhanced wave variability is a decrease in atomic oxygen, in-turn decreasing the electron density.

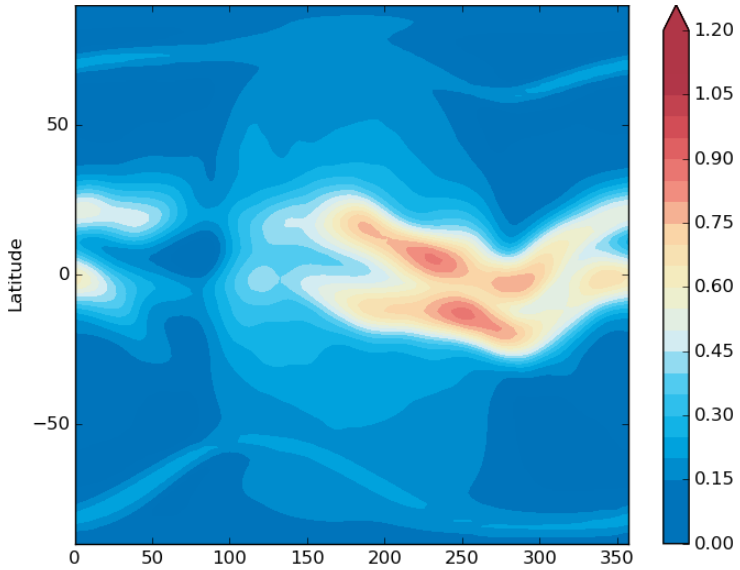


Impact on ionosphere electron density

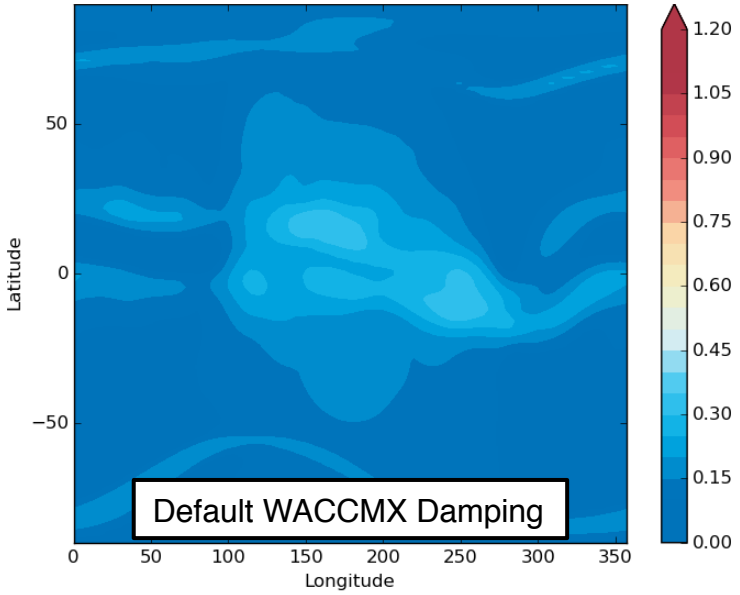
COSMIC NmF2 Oct. 2008, 0000UT



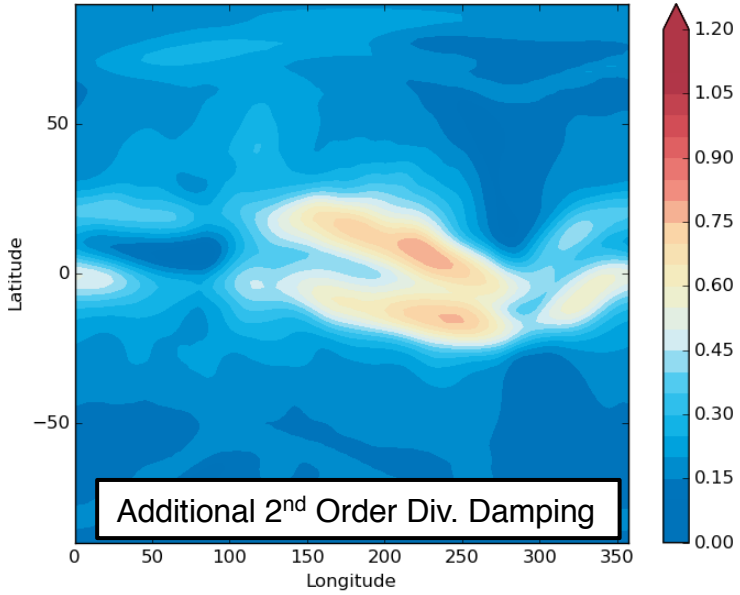
WACCMX No DA NmF2 Oct. 2008, 0000UT



WACCMX+DART NmF2 Oct. 2008, 0000UT

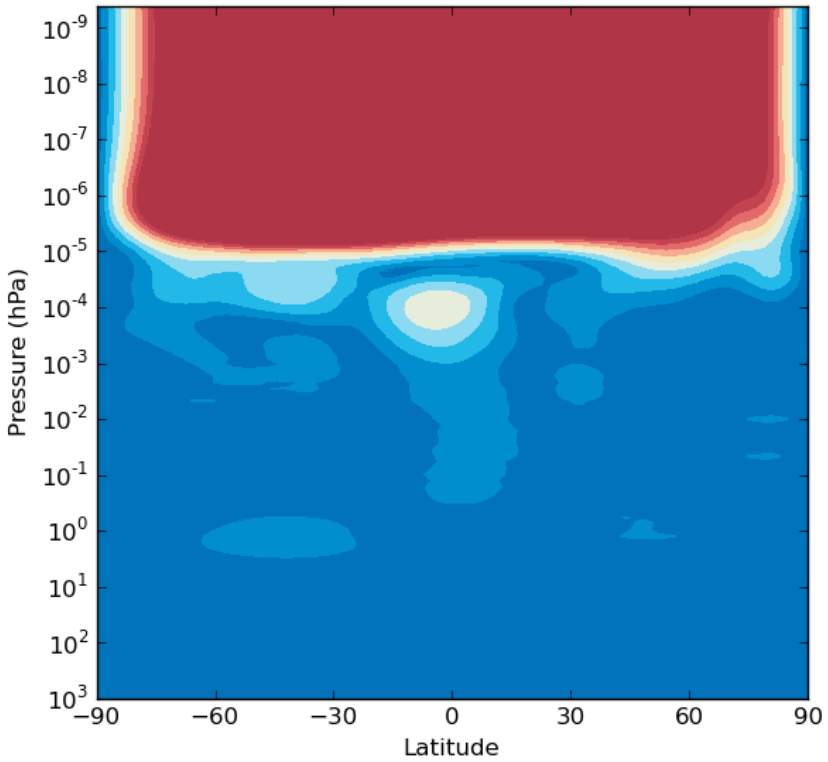


WACCMX+DART NmF2 Oct. 2008, 0000UT

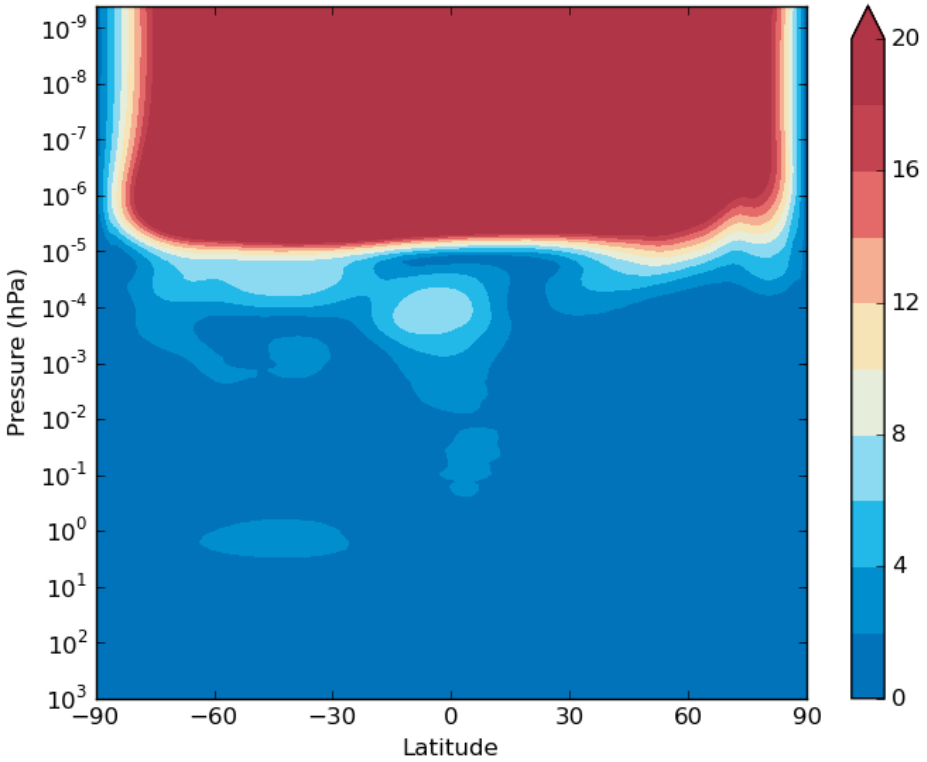


Influence of filtering on tidal amplitudes

WACCMX+DART DW1
no additional damping

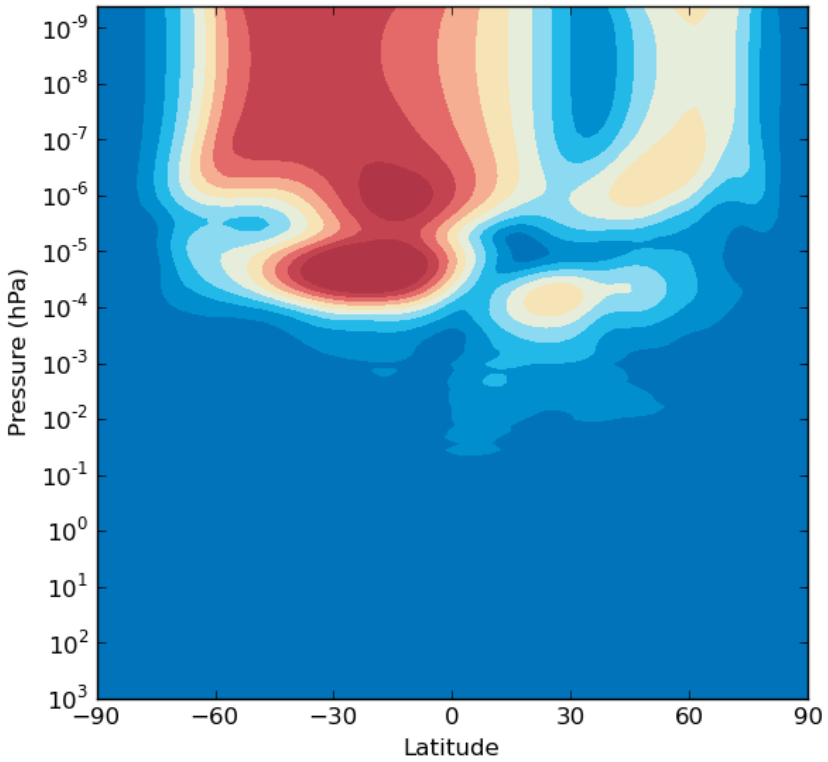


WACCMX+DART DW1
additional 2nd order div. damping

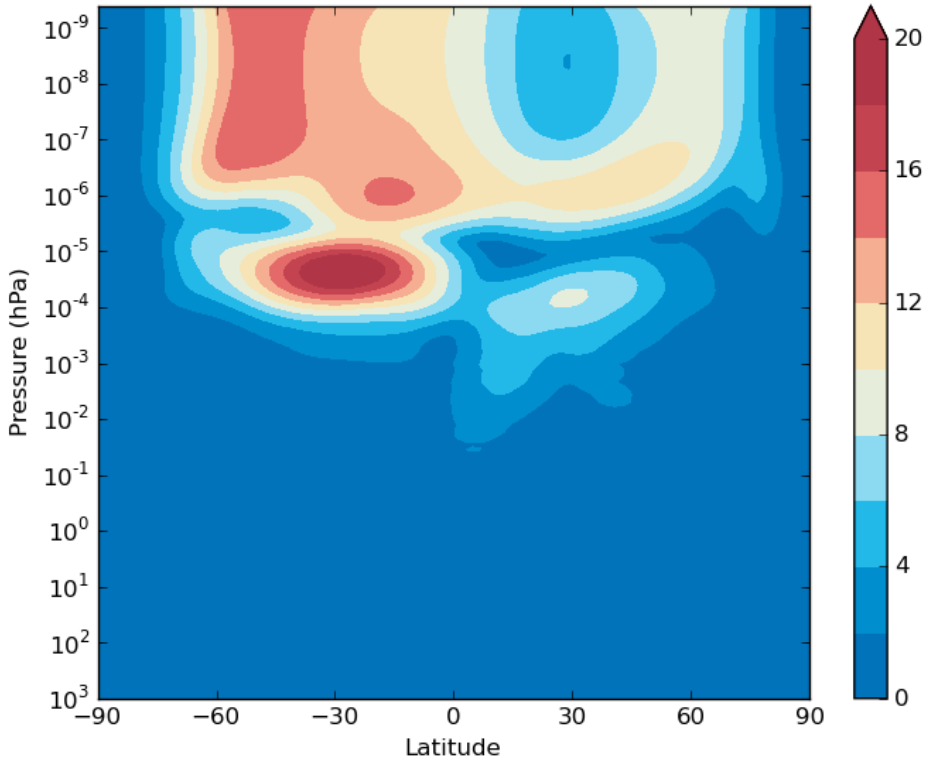


Influence of filtering on tidal amplitudes

WACCMX+DART SW2
no additional damping



WACCMX+DART SW2
additional 2nd order div. damping



Summary

Recent developments in WACCMX support whole atmosphere data assimilation, providing a global view of the troposphere, stratosphere, mesosphere, thermosphere, and ionosphere state

Middle atmosphere chemical and dynamical variability are generally well reproduced in WACCMX+DART.

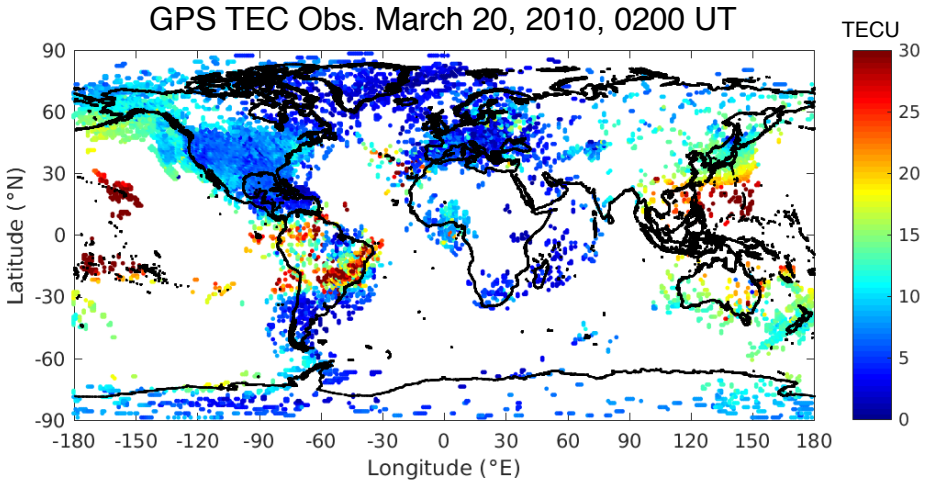
Tidal amplitudes are generally too weak in WACCMX+DART, indicating the need to determine a better method for filtering small-scale waves introduced by DA.

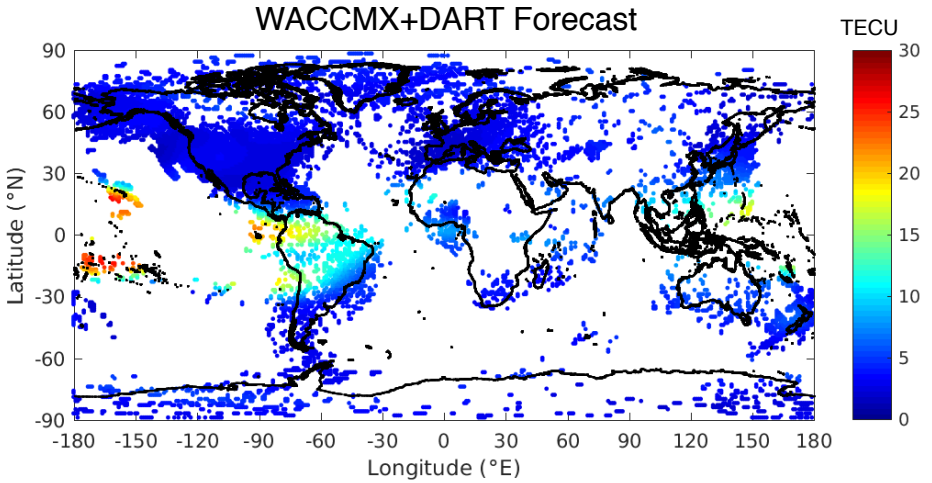
Ionosphere variability during the 2009 SSW is reproduced in WACCMX+DART.

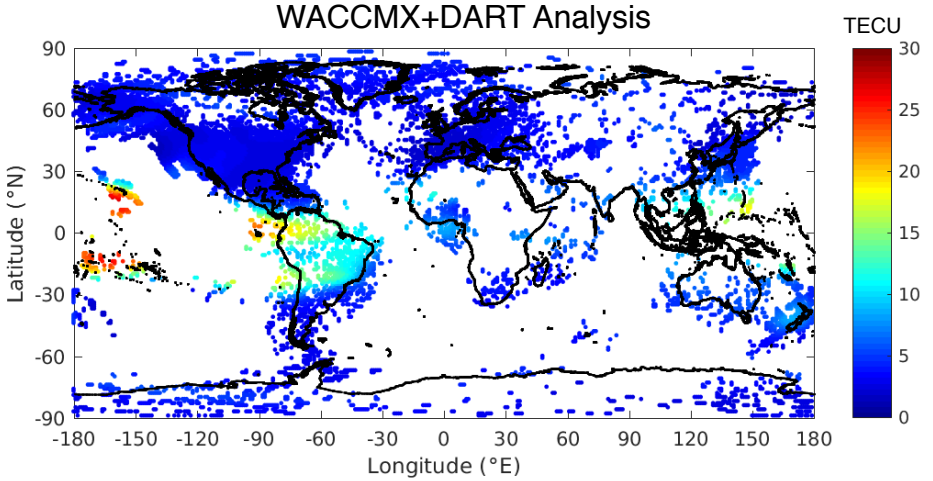
Forecast experiments for 2009 SSW show that middle-upper atmosphere variability can be qualitatively predicted ~5-10 days in advance of the SSW.

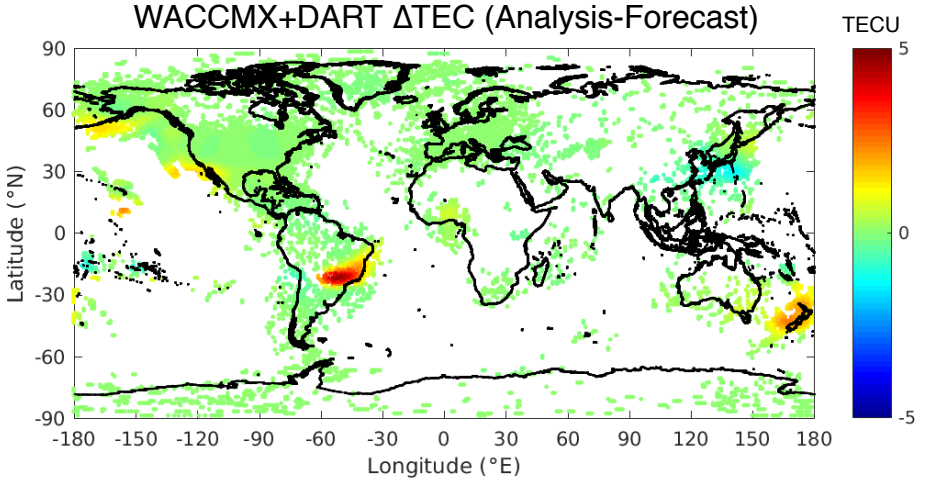
Work is ongoing to improve ionosphere-thermosphere analysis fields through assimilation of ionospheric observations

TEC Assimilation in WACCMX+DART









(Results courtesy of Koichi Chen, NCKU)

Agreement with radar observations is better in WACCM+DART