Data Assimilation in WACCM-X: Technical Developments and Science Applications

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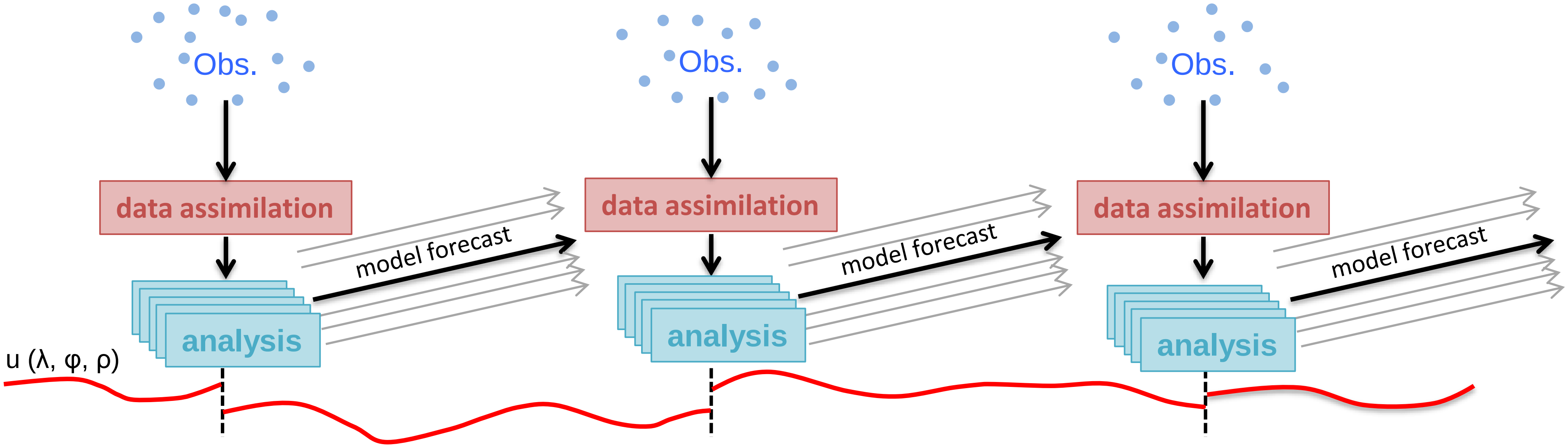
Data assimilation using DART ensemble Kalman filter



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.

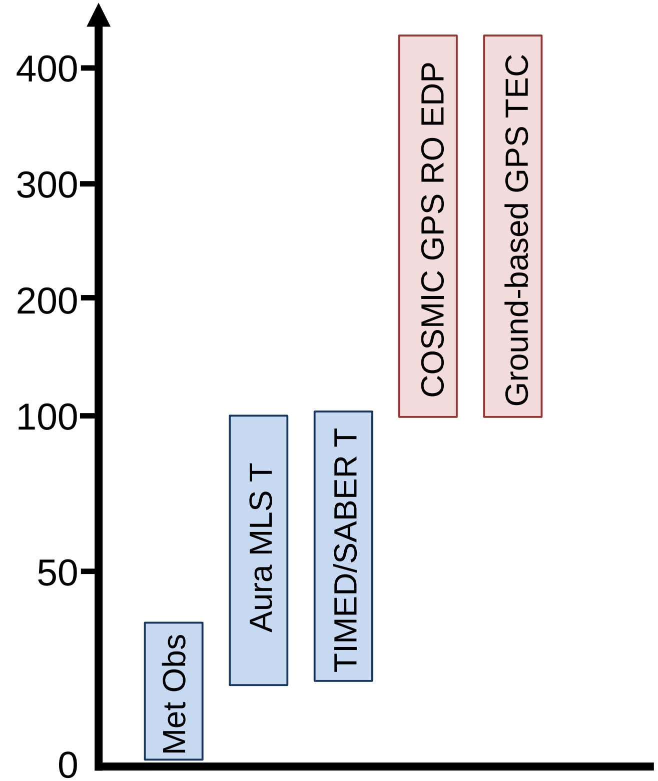
The ensemble approach eliminates the need to specify background covariance, since it is obtained directly from the ensemble of model simulations.

Assimilated Observations

The assimilation of neutral atmosphere observations up to ~100 km was previously implemented in WACCMX+DART.

The forward operators to assimilate ionosphere observations from COSMIC electron density profiles (EDP) and ground-based GPS total electron content (TEC) have recently been implemented.

Assimilation of ionosphere observations recently tested using an OSSE.



WACCMX+DART OSSE Experiment

- Truth was generated using a single instance of WACCMX, and with F107 = F107 + 10

- Synthetic observations are generated by sampling the truth WACCMX simulation

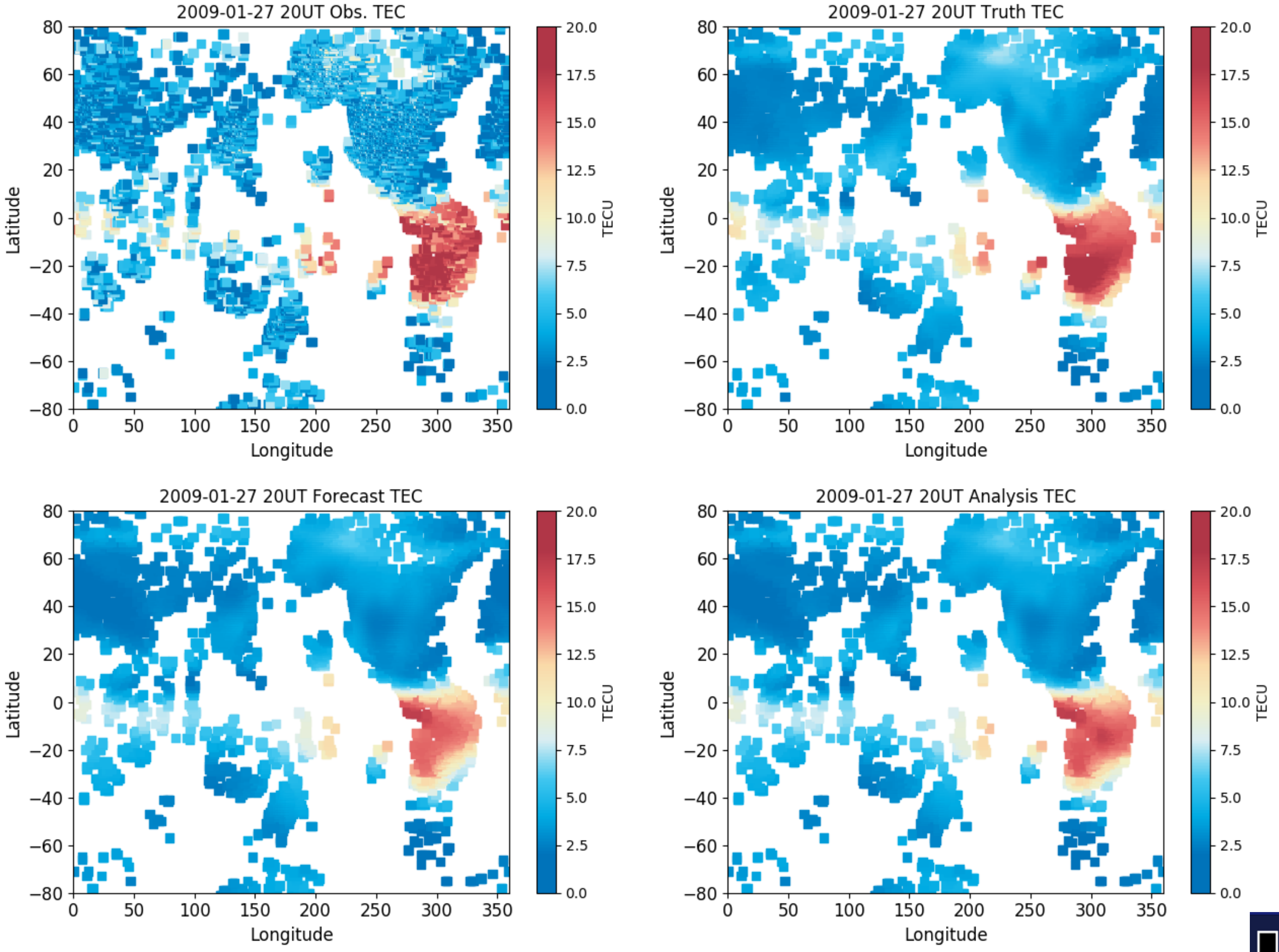
- Ensemble is 40 members and assimilation is performed every 1 hr

- From January 2 – 27 only lower-middle atmosphere data are assimilated

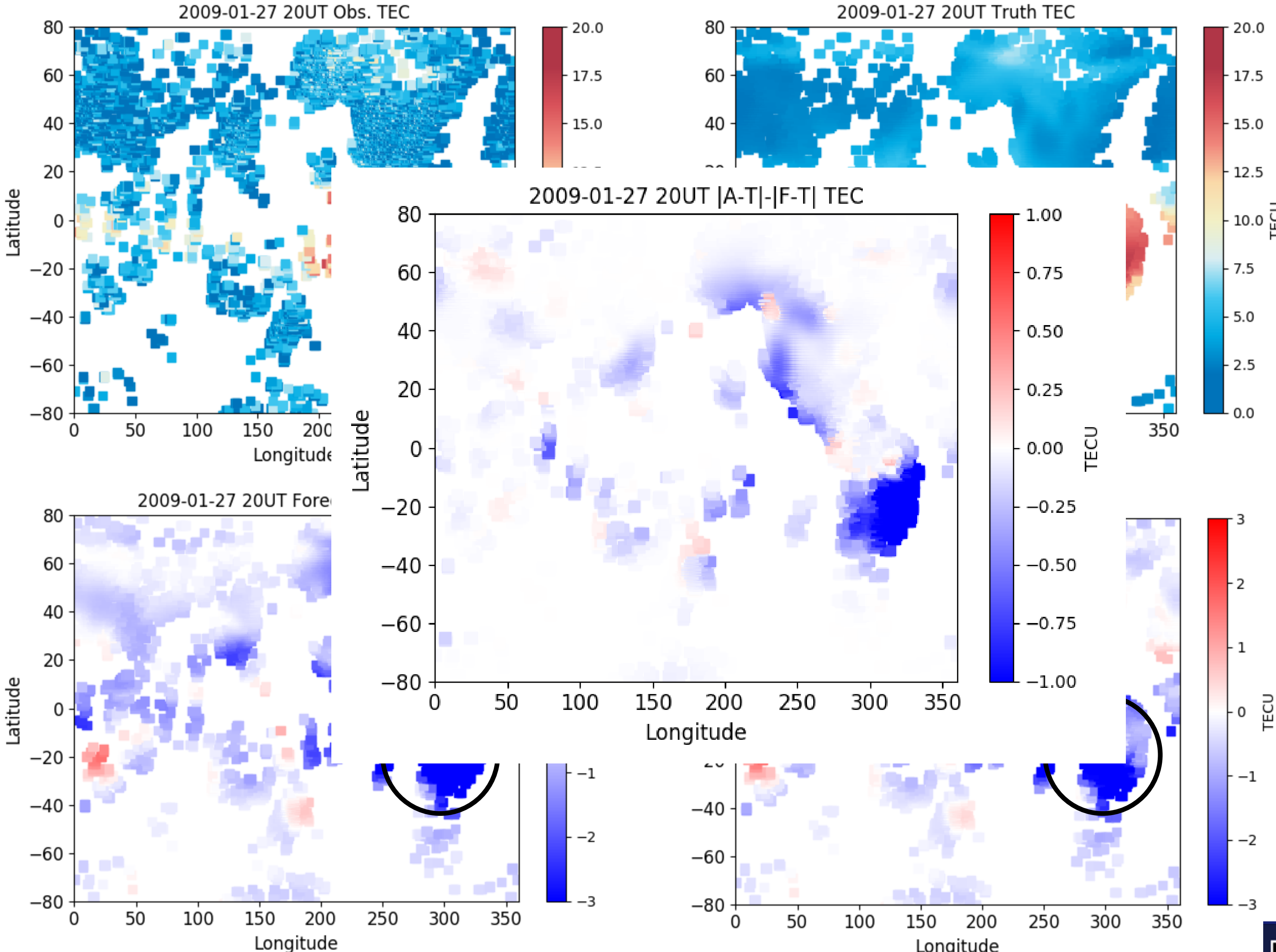
- Beginning on January 27, there are two cases:
    1. Assimilate only lower-middle atmosphere observations
    2. Assimilated lower-middle atmosphere observations plus ionosphere observations

- GPS TEC observations are localized to F-region altitude (10^{-7} hPa)

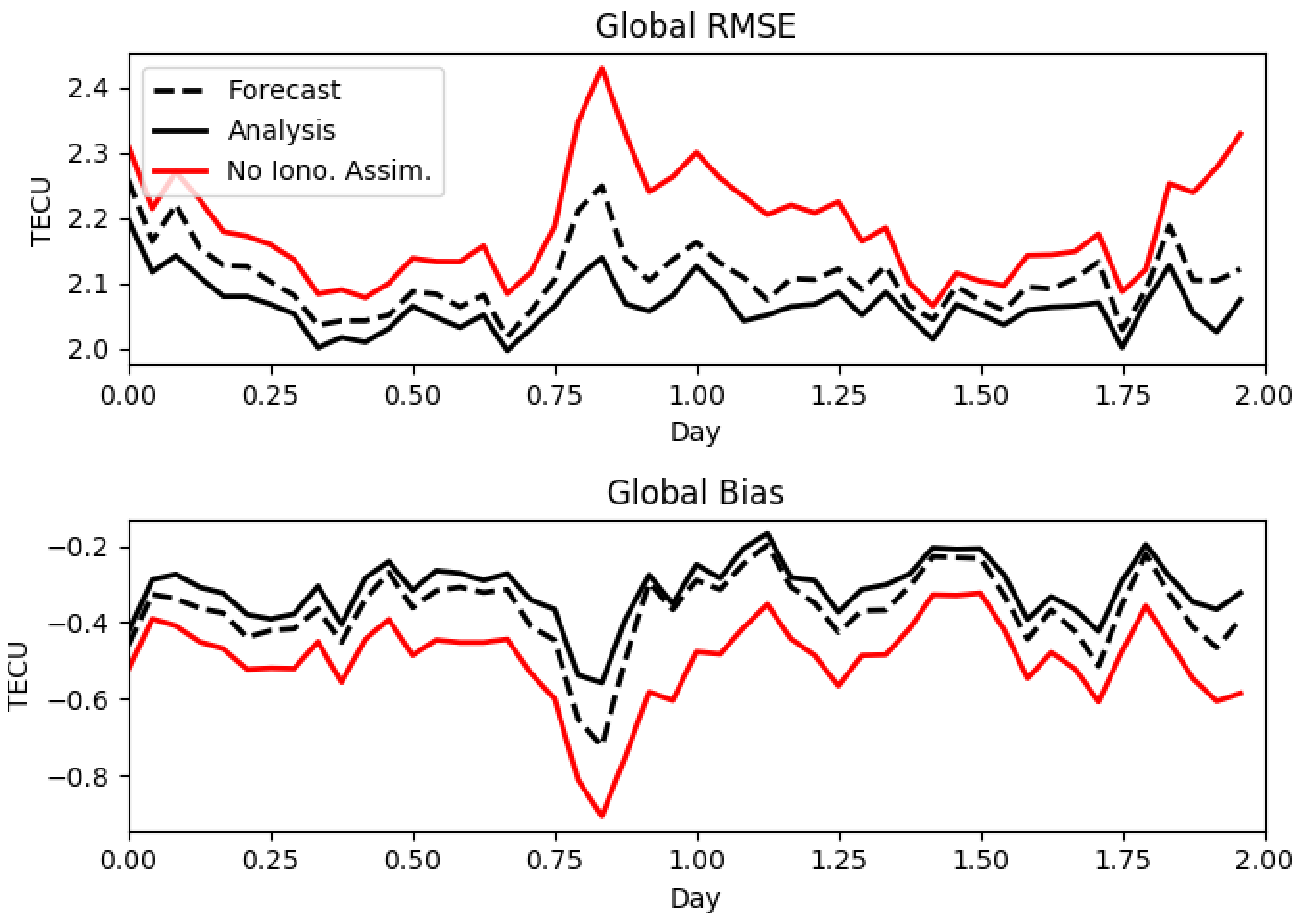
Assimilation of ground-based GPS TEC



Assimilation of ground-based GPS TEC

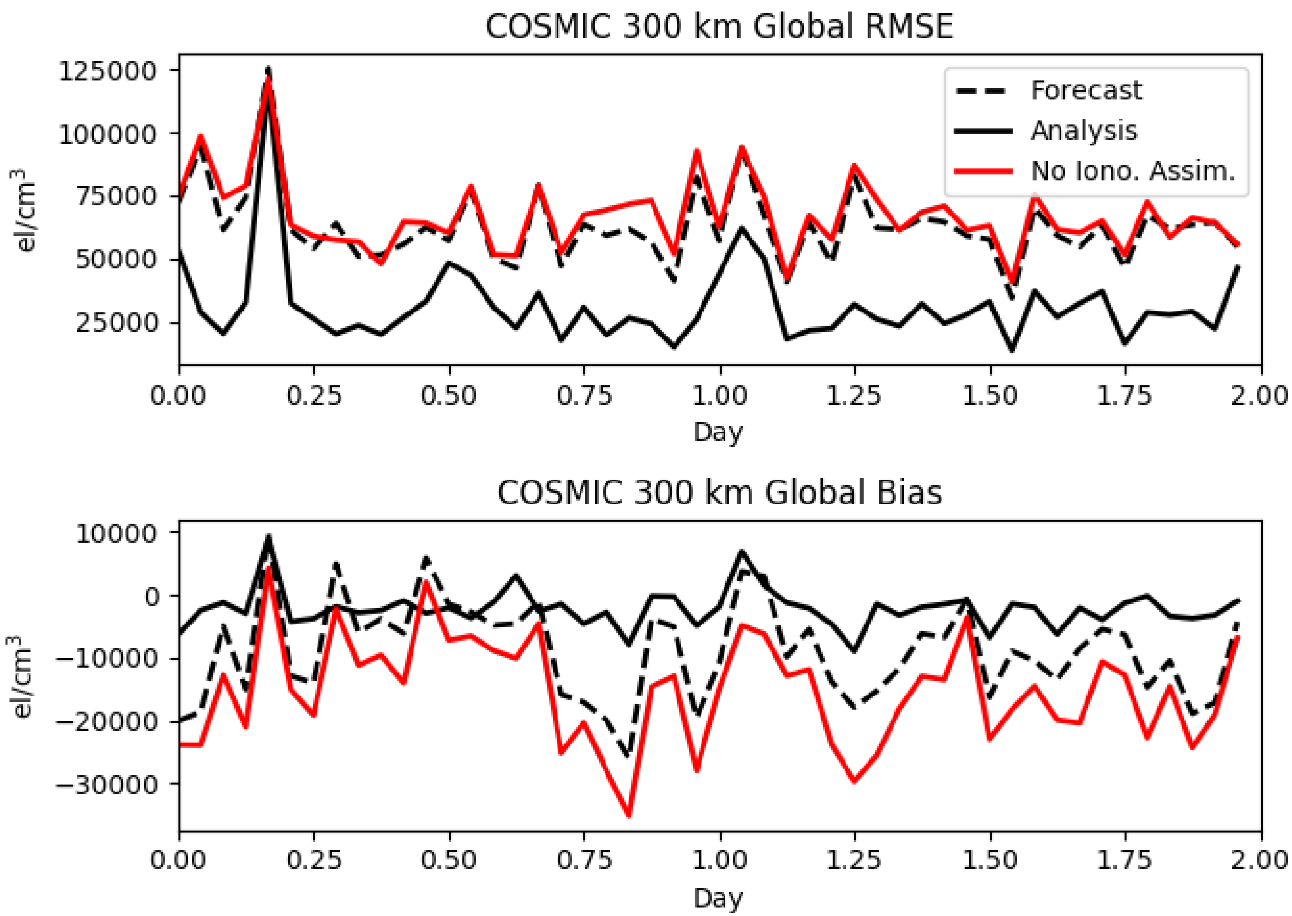


RMSE and Bias for GPS TEC



RMSE (no assim): 2.19
RMSE (forecast): 2.11 (-3.7%)
RMSE (analysis): 2.07 (-5.8%)

RMSE and Bias for COSMIC Electron Density (300 km)



RMSE (no assim
RMSE (forecast)
RMSE (analysis)

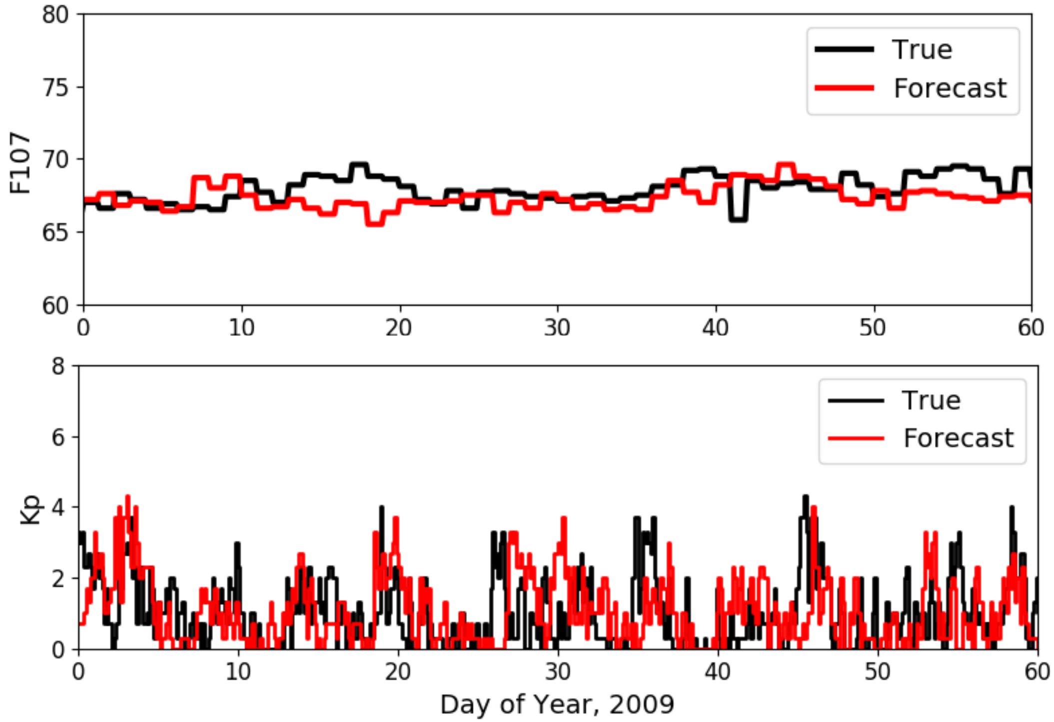
Assimilation of ionospheric observations currently has only a limited impact on the short-term (1 hr) forecasts in WACCMX+DART

Science Applications:

(1) Hindcast experiments to investigate MLT forecast capabilities.
(2) NO and Lagrangian Coherent Structures (LCS) during 2009 SSW.

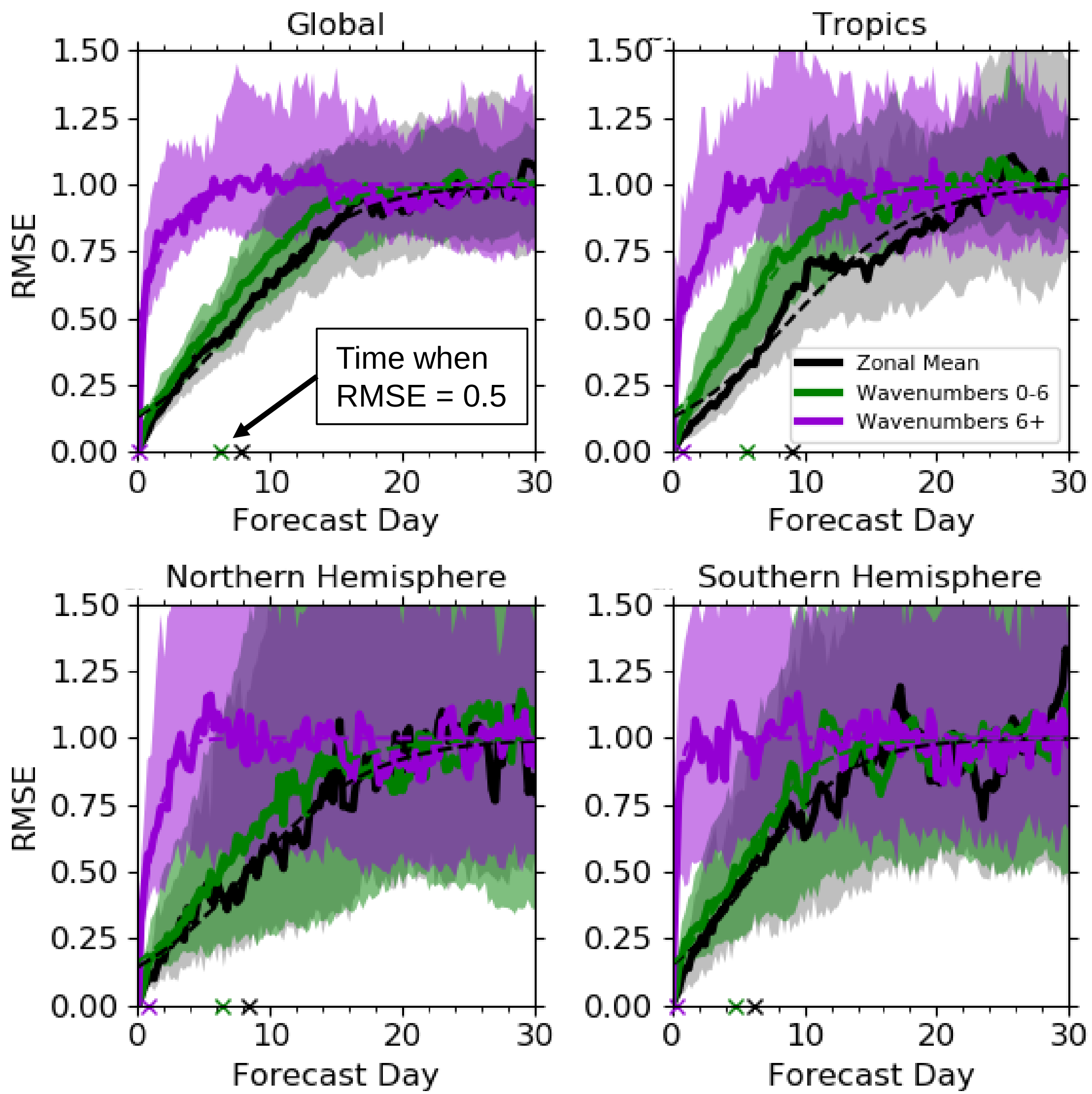
WACCMX+DART Hindcast Experiments

- Generate WACCMX+DART analysis fields for Jan. 2009-Dec. 2010.
- Hindcasts are initialized on the 1st and 15th of each month during 2009 and 2010 from the WACCMX+DART analysis fields.
- Ocean SSTs are specified as the true values (i.e., not forecasted)
- Solar activity is specified by using 27-days prior solar activity (persistence “forecast”)
- Due to insufficient global observations in the MLT, we verify the WACCMX+DART hindcasts using the analysis fields, which are considered our best estimate of the true state of the MLT.



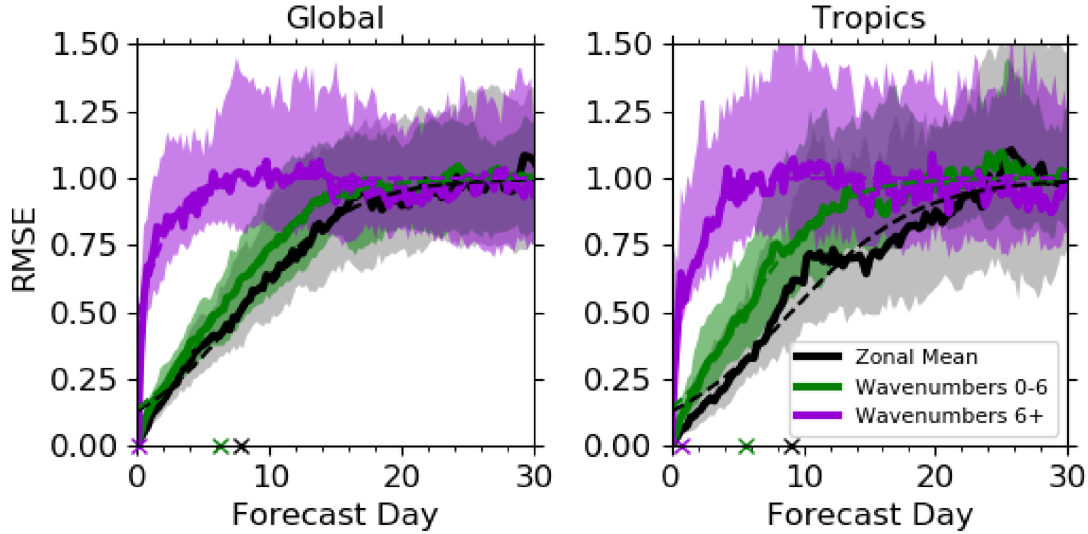
The normalized RMSE shows a clear dependence on spatial-scale, with faster error growth, and shorter-forecast skill for small-scale waves compared to large-scale waves and the zonal mean.

Normalized RMSE at 0.1 hPa

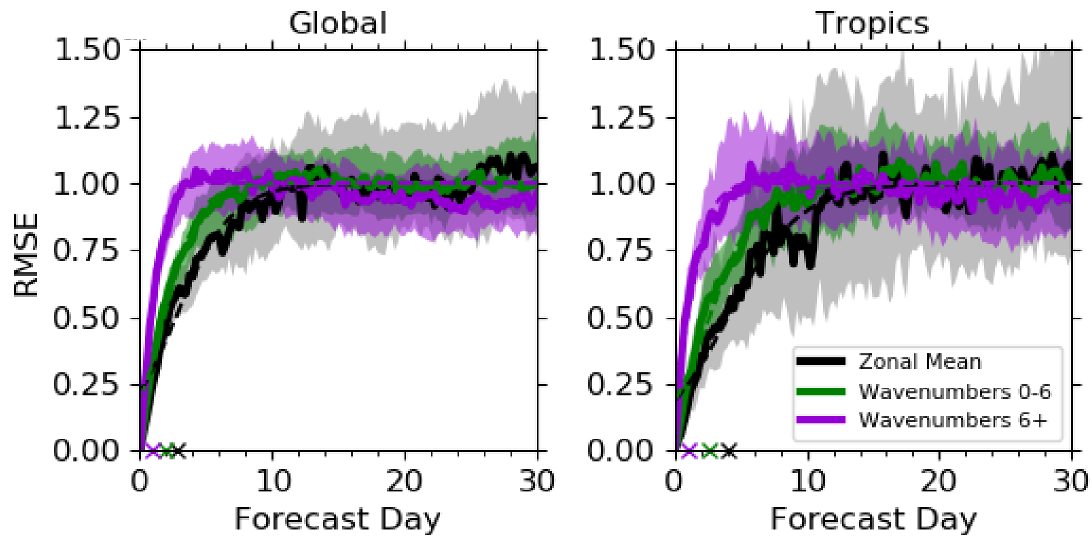


The error growth rate is significantly faster at higher altitudes.

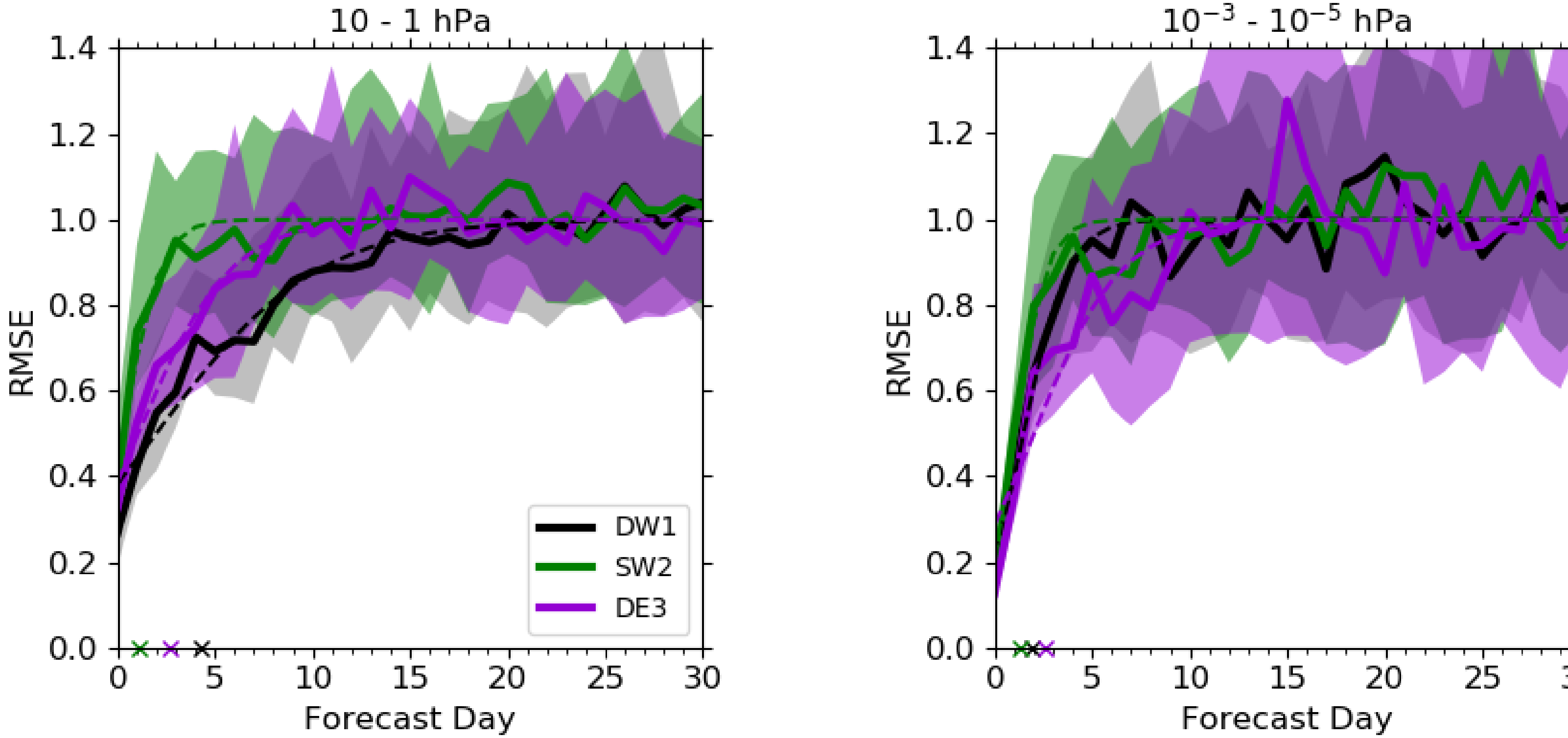
Normalized RMSE at 0.1 hPa



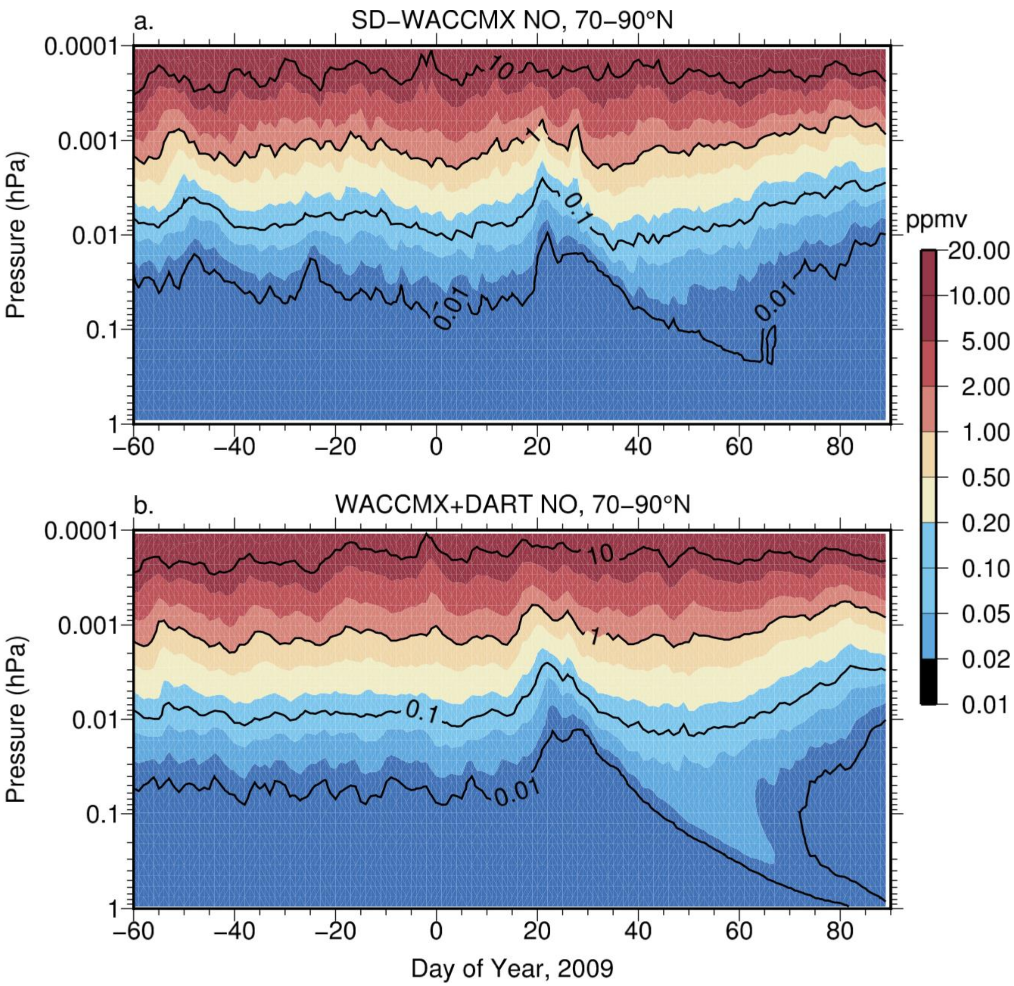
Normalized RMSE at 0.01 hPa

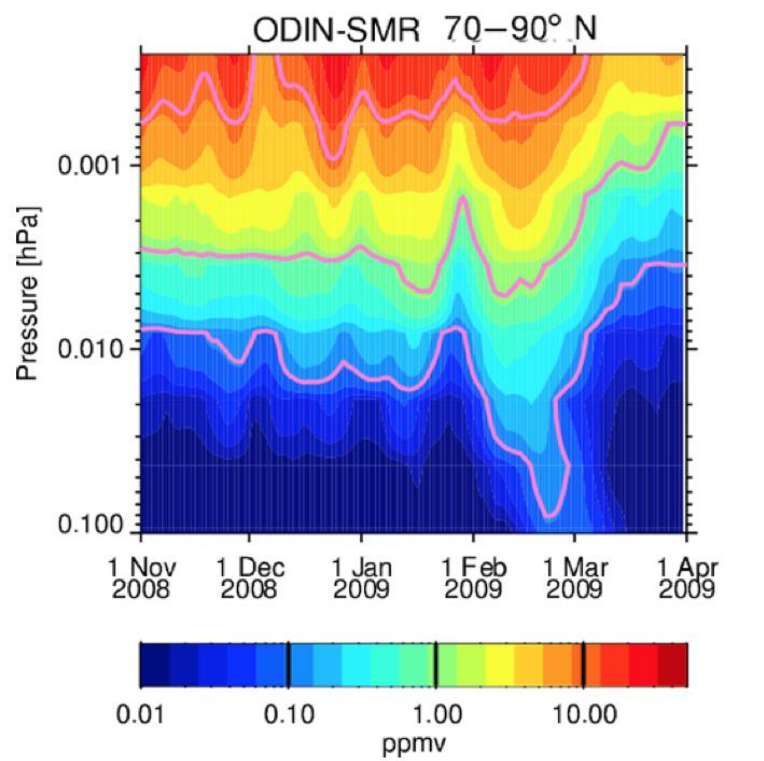


Errors in migrating and nonmigrating tides grow quickly, and only have forecast skill of a few days at altitudes where they are relevant for driving ionospheric variability.



By better representing the dynamics of the MLT, WACCMX+DART captures the descent of NO following the 2009 SSW better than SD-WACCMX.



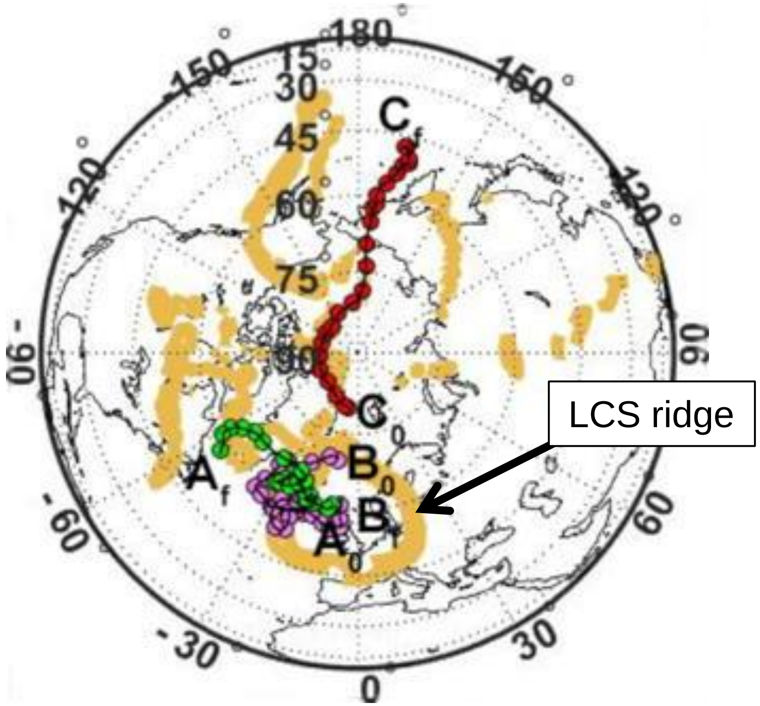


(Funke et al., 2017)

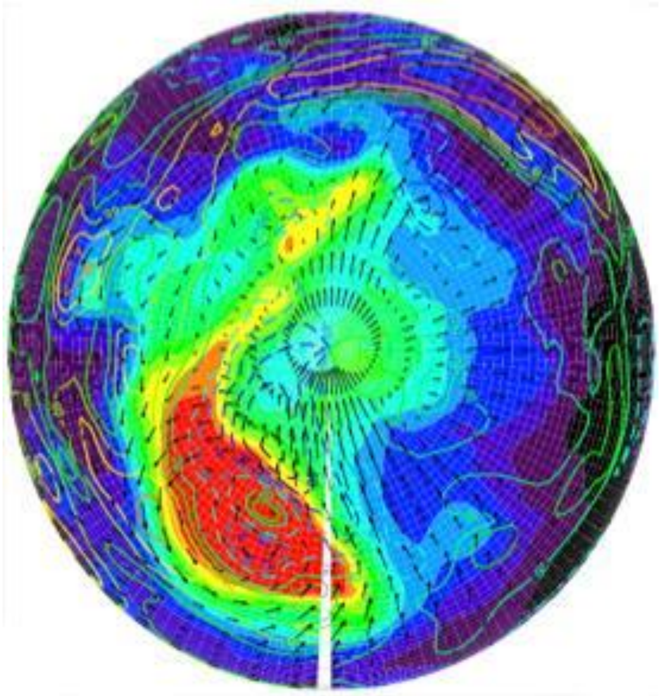
(Pedatella et al., 2018)

WACCMX+DART chemical and dynamical fields can provide insight into factors controlling the MLT chemistry

LCS at 90 km



NO at 90 km



Lagrangian Coherent Structures (LCS) in the lower mesosphere are related to enhanced NO.

- LCS ridges indicate barriers in (horizontal) transport.

Credit: Lynn Harvey

Summary

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

Recent developments include the assimilation of ionospheric observations from COSMIC GPS radio occultation and ground-based GPS total electron content.

Ionospheric data assimilation is nominally working, though there are aspects that could still be improved in order to enhance the impact of the ionospheric observations.

An extensive set of hindcast experiments in WACCMX+DART provides insight into current capabilities for forecasting the lower atmospheric drivers of ionosphere-thermosphere variability.

Results demonstrate that the forecast skill depends on spatial scale and altitude, and is generally on the order of a few days at MLT altitudes in WACCMX+DART.

The WACCMX+DART analysis fields are currently being used for scientific investigations into the transport of NO (Harvey HSR; Bardeen HGI)