Data Assimilation in WACCM

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**Motivation:** Even in perfect model experiments, nudging dynamical fields leads to error growth in the MLT, and does not capture wave dynamics.

Results courtesy of Anne Smith
Motivation: Large differences occur in the MLT despite constraint at lower altitudes.
Motivation: Differences in modeled MLT dynamics influence nitric oxide descent

Direct assimilation of lower, middle, and upper atmosphere observations in WACCM is one approach to improving simulations of MLT dynamics

(Siskind et al., 2015)
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.

The ensemble approach eliminates the need to specify background covariance, since it is obtained directly from the ensemble of model simulations.
WACCM+DART provides an atmospheric reanalysis from the surface to the lower thermosphere (~145 km).

Lower Atmosphere Observations:
   Aircraft temperature and wind
   Radiosonde temperature and wind
   Satellite drift winds
   COSMIC GPS refractivity

Middle/Upper Atmosphere Observations:
   TIMED/SABER Temperature
   Aura MLS Temperature

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.

Bias Removal in the MLT

Bias relative to SABER

Bias relative to Aura MLS

Results for $5 \times 10^{-3}$ hPa
Bias Removal in the MLT

5 x 10^{-3} hPa, Sept. 29 2011, 0000 UT

WACCM Climatology

WACCM+DART

TIMED/SABER Obs.

Aura MLS Obs.

WACCM+DART
Implementation of data assimilation in the Whole Atmosphere Community Climate Model better captures the dynamic variability in the high latitude wintertime stratosphere and mesosphere.

The figure shows the zonal mean temperature averaged from 70 to 90°N for January and February 2009 from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) reanalysis. It compares observations and model simulations, specifically WACCM+DART, SD-WACCM, and SABER, with Aura MLS observations. The comparison highlights how assimilation techniques improve model performance in simulating stratospheric temperature changes during sudden stratospheric warmings (SSWs).

Key points from the figure:
- **WACCM+DART** simulations reproduce the stratopause descent and subsequent warming of the stratosphere, beginning around days 18–20.
- **SD-WACCM** simulations also show similar features, indicating the effectiveness of assimilation methods.
- **SABER** did not sample high latitudes in the Northern Hemisphere prior to day 11, limiting its utility for comparison.
- **Aura MLS observations** are averaged between 70 and 90°N, providing a data set for validation against model results.

The figure underscores the importance of data assimilation in improving model simulations of stratospheric dynamics, particularly in capturing the rapid changes and variability associated with SSWs.
WACCM+DART captures the variability in chemical species during SSWs.

Figure 11. Zonal mean ozone at 2 hPa for the WACCM+DART (a) LA, (b) LA+S experiments, and (c) SABER observations. (d) Difference between SABER observations and WACCM+DART LA experiment. (e) Same as Figure 11d except for the LA+S experiment. Note that SABER did not observe high latitudes in the Northern Hemisphere prior to day 11 and did not observe high latitudes in the Southern Hemisphere after day 11.

Limited local time sampling of the SABER observations from influencing the comparison, the WACCM+DART ozone was sampled based on the locations of the SABER observations. Ozone variability may contribute to the SW2 variability during the SSW, and it is considered to be potentially important for coupling stratospheric and ionospheric variability [e.g., Goncharenko et al., 2012]. It is therefore important to accurately simulate the ozone variability during the SSW. The results in Figure 11 show an overall agreement between both WACCM+DART experiments and the SABER observations in terms of the ozone temporal variability.

We attribute the similarity of the two WACCM+DART experiments to the fact that 2 hPa is not significantly above the maximum altitude of the lower atmosphere observations (≈1 hPa). Around the time of the SSW, an equatorial ozone enhancement of ≈1 ppm and a significant ozone depletion at high latitudes in the Northern Hemisphere can be seen in both the SABER observations and WACCM+DART. Both also show a narrow region of enhanced ozone near 60°N beginning on day 30. Since we do not directly assimilate ozone in WACCM+DART, the agreement between the WACCM+DART and SABER ozone provides an indirect validation of the WACCM+DART data assimilation system during the 2009 SSW. Though the WACCM+DART ozone agrees with the SABER observations in terms of the temporal and latitudinal variability, the SABER observations are consistently larger than the WACCM+DART values (Figures 11d and 11e). At low and mid-latitudes, the WACCM+DART ozone bias is roughly 0.8–1.0 ppm for the LA experiment and 0.5–0.75 ppm for the LA+S+A experiment. Ozone variability in the upper stratosphere during SSWs is dominated by PEDATELLA ET AL. ©2014. American Geophysical Union. All Rights Reserved.
Short-term tidal variability is captured by WACCM+DART

Results based on 10-day average
Short-term tidal variability is captured by WACCM+DART

Results based on 10-day average
Summary

The capability to perform data assimilation in WACCM has been implemented using the DART ensemble Kalman filter.

By assimilating lower, middle, and upper atmosphere observations WACCM+DART reduces the model bias in the MLT, and can be used to study chemical and dynamical variability associated with sudden stratosphere warmings as well as short-term tidal variability.

A draft document is in preparation that will guide any interested users through setting up and running WACCM+DART.

Potential future directions:

- Scientific investigations using WACCM+DART reanalysis
- SD-WACCMX using WACCM+DART to constrain WACCMX up to the lower thermosphere
- Whole atmosphere data assimilation with WACCMX+DART
Data assimilation using DART ensemble Kalman filter