WRF-Chem/DART - A Regional Chemical Transport/ Ensemble Kalman Filter Data Assimilation System

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1. WRF-Chem/DART: An Introduction

The Weather Research and Forecasting (WRF) model coupled with Chemistry (WRF-Chem) is a community model that simulates the emission, transport, mixing, and transformation of trace gases and aerosols simultaneously with meteorology. It is used for investigation of regional air-quality, field program analysis, and cloud scale chemical interactions. WRF-Chem development is a collaborative effort between: NOAA/ESRL, DOE/PNNL, NCAR/ACOM, and various universities. WRF-Chem is a state-of-the-art chemical weather forecast model that is well documented and contains an educational platform for researchers and academics.

The Data Assimilation Research Testbed (DART) is a community software environment for ensemble data assimilation research developed at NCAR. DART's backbone is the Ensemble Adjustment Kalman Filter (EAKF) of Anderson (2001, 2003). DART also contains other forms of ensemble Kalman filters (EnKFs) as well as adaptive inflation, localization, and many other data assimilation research tools. DART works with geophysical models, ranging from the Lorenz 3-variable model to coupled climate models. DART assimilates dozens of observation types from a variety of sources. DART is a state-of-the-art ensemble data assmilation system that is well documented and contains an interactive educational platform.

WRF-Chem/DART includes the ability to assimilate the following atmospheric chemistry observation types: (i) MOPITT total and partial column CO, (ii) IASI total and partial column CO and O3, (iii) OMI total column NO, and (iv) MODIS AOD retrievals. We are developing the ability to assimilate AirNow in situ observations and to include emissions in forecast model state vector.

2. Retrieval Assimilation Research

The assimilation of trace gas retrievals has been shown to improve air quality initial conditions and forecasts. Retrieval data sets contain: (i) large amounts of data with limited information content, (ii) error covariance cross-correlations, and (iii) contributions from the retrieval prior the should be removed before assimilation. Those properties present challenges to the assimilation retievals. The use of 'Compact Phase Space Retrievals' (CPSRs) addresses/resolves those challenges.

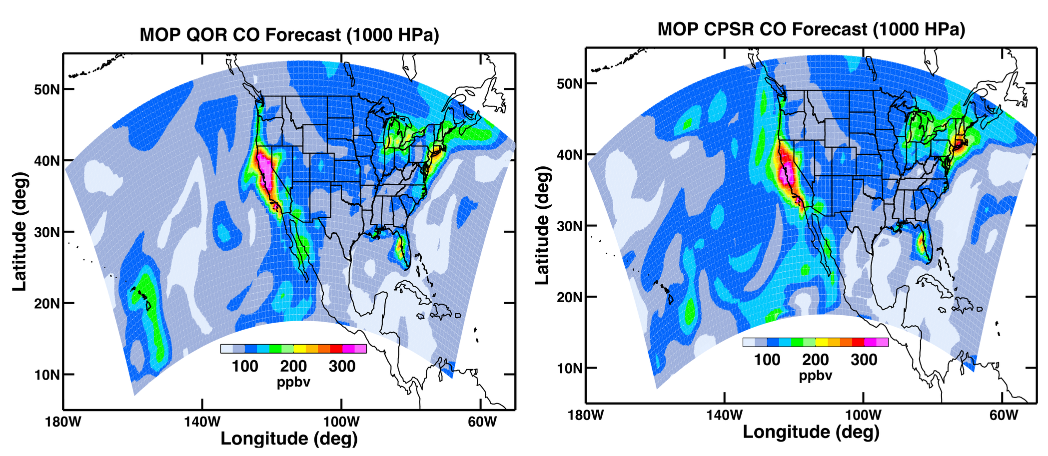

Figure 1: *CO Forecasts from CPSRs and QORs.*

Figure 1 shows the cumulative effect of assimilating CPSRs on the 6-hr CO forecast.

CPSRs advance the work of Joiner and Da Silva (1998) and Migliorini et al. (2008) by compressing the independent information measured by the satellite into a number of observations equal to the number of non-zero singular values in a Singular Value Decomposition (SVD) of the averaging kernel. The associated reduction in the number of retrieval observations is substantial and depends on the differnce between the number of rows and the rank of the averaging kernel. For MOPITT CO reduction is ˜66%. For IASI CO and O3 it is ˜80%,

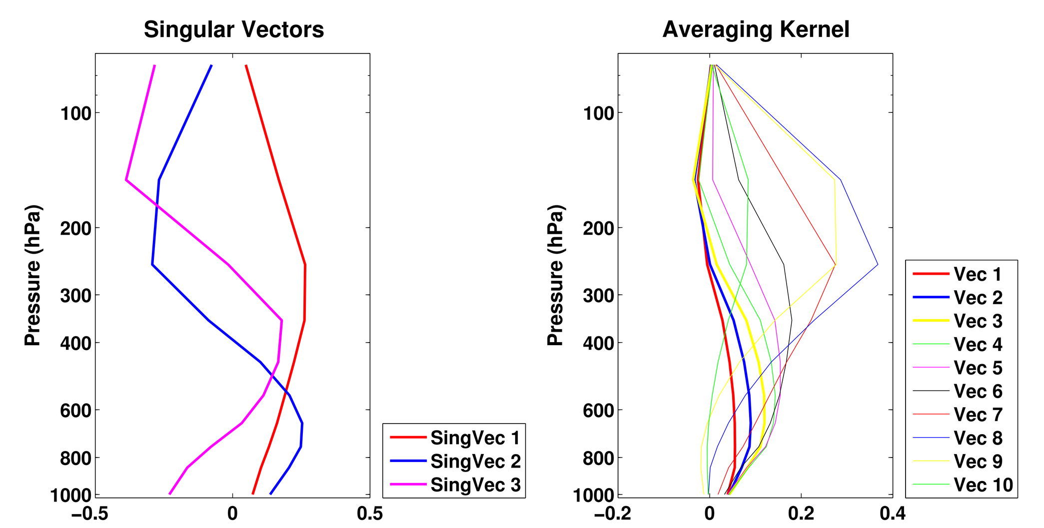

Figure 2: *MOPITT Leading singular vectors and averaging kernel.*

Figure 2 shows the vertical sensitivity of the CPSRs which resembles that of the averaging kernel. Assimilation of CPSRs should yield results similar to that for retrievals, but there differences due to inflation, localization, and observation error truncation.

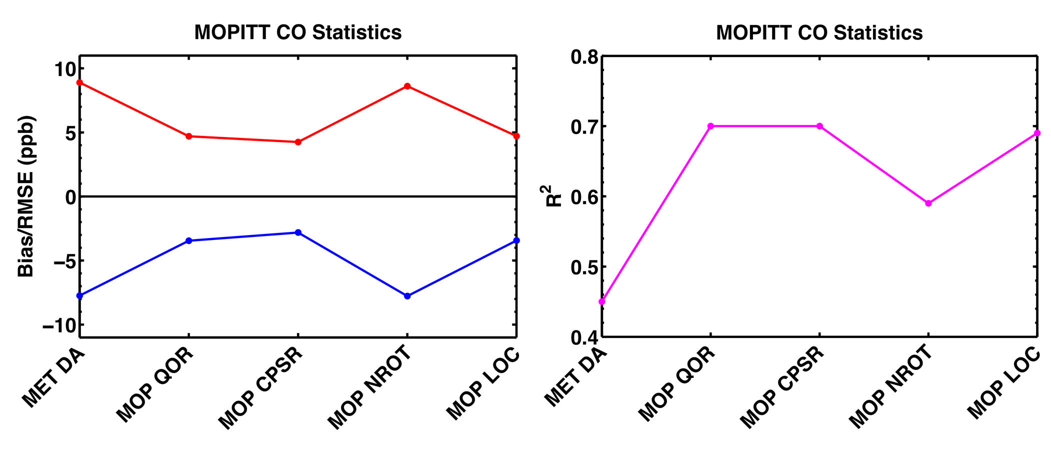

Figure 3: *CO Forecasts from CPSRs and QORs.*

Figure 3 shows that assimilation of CPSRs performs as well or better than the assimilation of retrievals.

3. Application to FRAPPE/Discover-AQ

During the summer of 2014, the Front Range Air Pollution and Photochemistry Experiment (FRAPPE) occurred in conjunction with NASA's Discover-AQ project. FRAPPE measured the chemical composition and reactions associated with air pollution along Front Range of Colorado. One aspect of FRAPPE was to study the NOx chemistry.

NOx is a highly reactive, short-lived air pollutant.. Its primary sources are transportation and power production, but its emissions are uncertain. Prof. Ron Cohen and his student Xueling Liu at the University of California, Berkeley are using WRF-Chem/DART to study NOx chemistry and to better estimate its emissions.

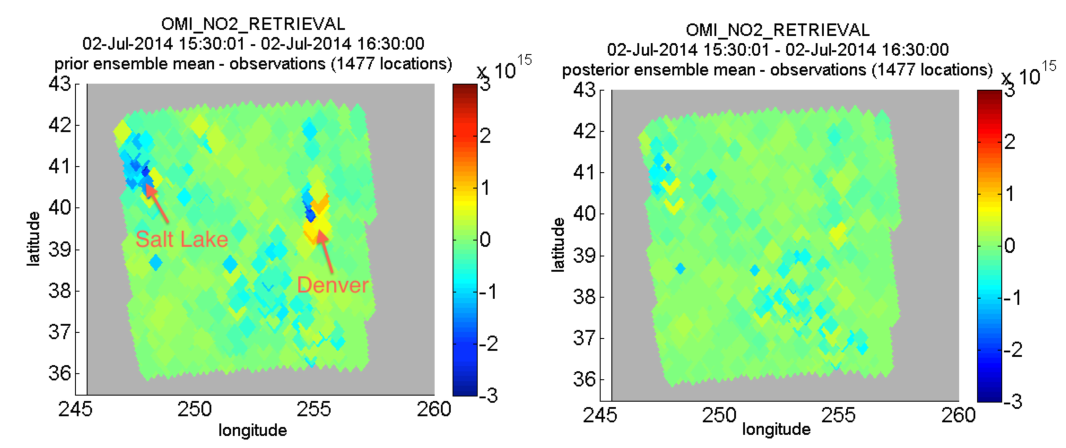

Figure 4: *The FmO and AmO fields for assimilation of OMI NO2 in FRAPPE.*

Figure 4 shows the impact of assimilating OMI NO2 on the FRAPPE domain. The related emission adjustments are shown in the following figure.

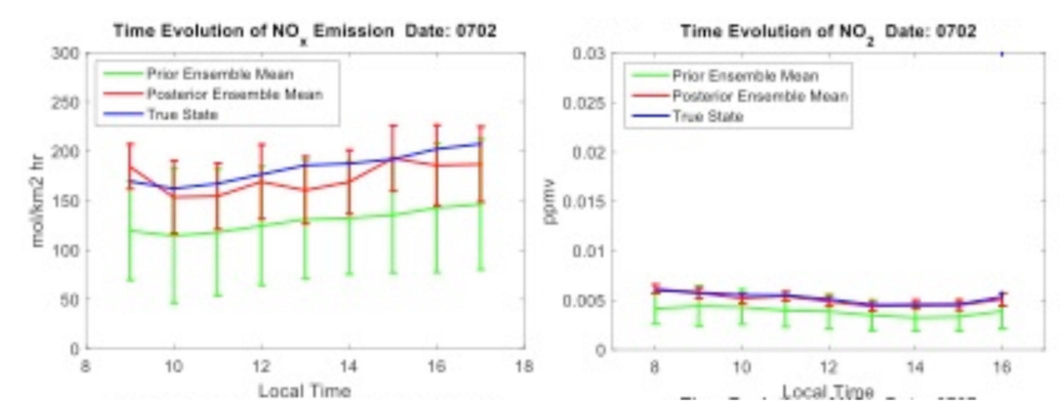

Figure 5: *Time series of emission adjustments from assimilating OMI NO2.*

Gabriele Pfister, one of the FRAPPE PIs, and Arthur Mizzi of NCAR/ACOM are using WRF-Chem/DART to study FRAPPE air chemistry and the impact of assimilating trace gas retrievals on the FRAPPE analyses. The following figure shows the beneficial impact of assimilating chemistry observations.

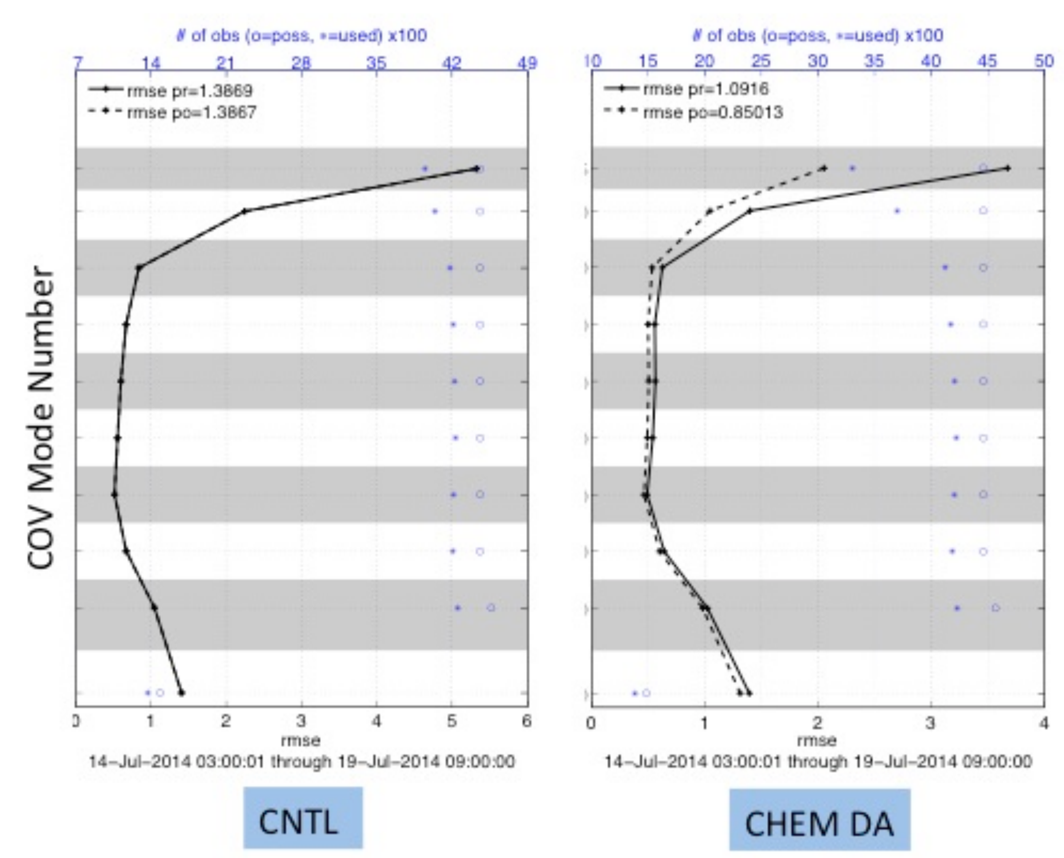

Figure 6: *RMSE scores for the CNTL and CHEM DA experiments as a function of the COV mode and unit observation error.*

4. Assimilation of CO, O3, and AOD

Atmospheric dust impacts our climate, air quality, and health. Aerosol Optical Depth (AOD) is a dust property that can be measured by satellites and assimilated to improve the dust analyses and forecasts. Prof. Yongsheng Chen and his student Jianyu Liang at York University in Toronto are using WRF-Chem/DART to study atmospheric dust..

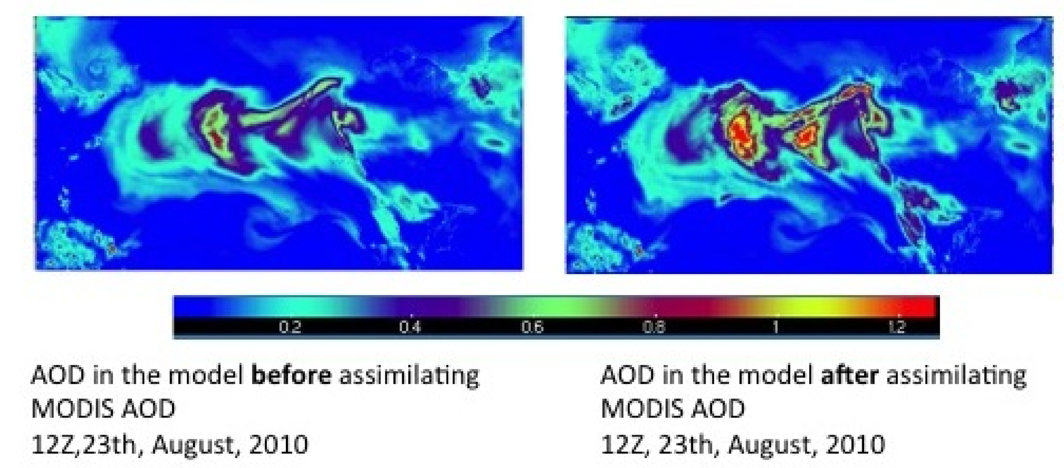

Figure 7: *Comparison of maps showing the impact of assimilating MODIS AOD with WRF-Chem/DART.*

Prof. Chen and a former student Nan Miao collaborated with NCAR/ACOM to add the assimilation of MOPITT total column CO to WRF-Chem/DART and study the associated impacts. Their work showed improvement to the CO analyses and forecasts.

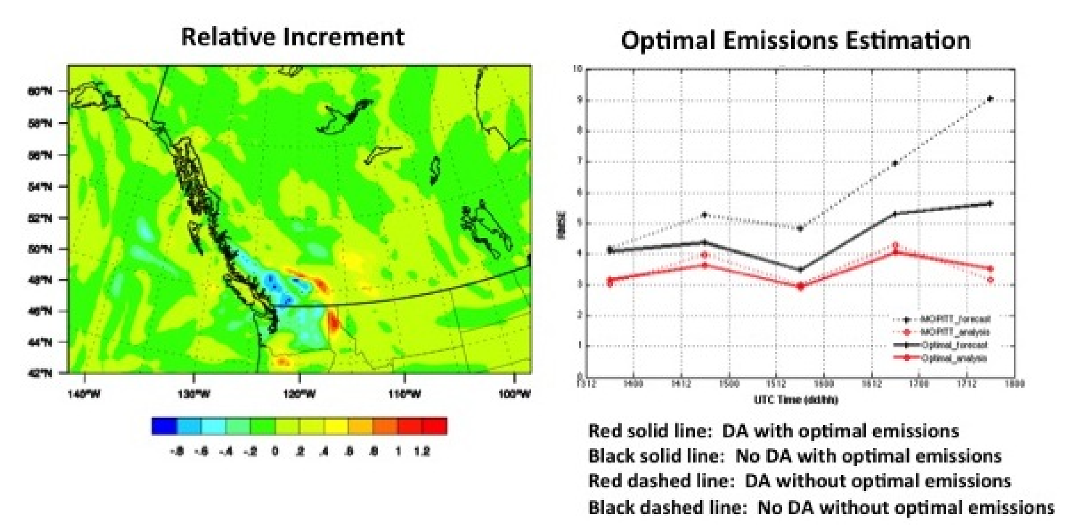

Figure 8: *Left panel shows relative increment from assimilating MOPITT total column CO. Right panel shows impact of estimating the CO emissions from assimilating MOPITT total column CO.*

The left panel of Fig. 8 shows their CO adjustments and transport error corrections. They also investigated the impact of adjusting the CO emissions with assimilation of MOPITT total column CO. Their results are shown in the right panel of Fig. 8 and indicate additional RMSE reductions.

5. More Information

For more information on CPRSs, see Mizzi et al. (2015) *Geosci. Model Dev.* To use WRF-Chem/DART or for information on chemical data assimilation contact Arthur P. Mizzi by e-mail at mizzi@ucar.edu or by phone at 303-497-8987.