

Constraining tropospheric CO using ensemble-based data assimilation

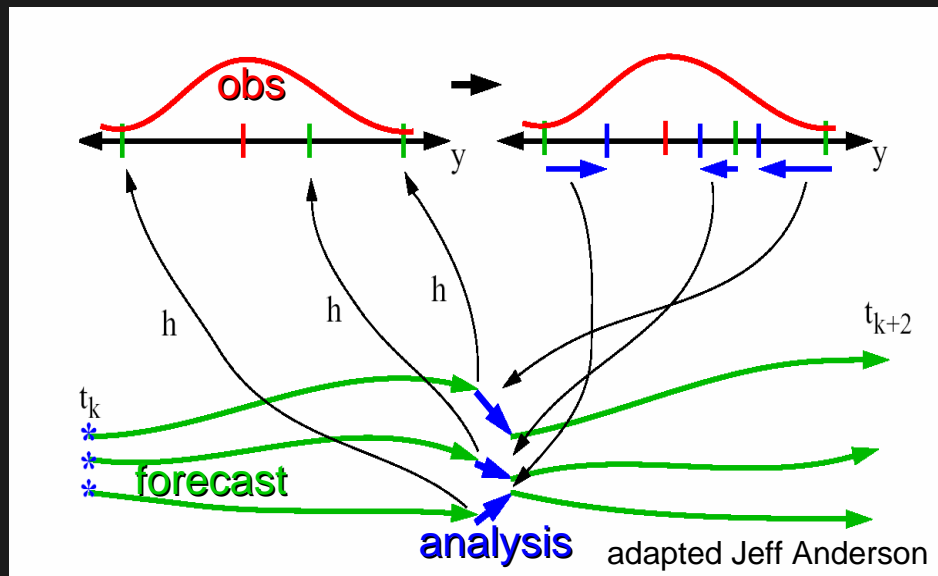
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NCAR Data Assimilation Research Testbed (NCAR DART)

DART is an ensemble Kalman filter software package being developed at NCAR/DARes (<http://www.image.ucar.edu/DARes>).



EnKF Scheme

Supports **low order models** (L63, L84, L96, L2004...), **global models** like NOAA/CDC PE model, CAM 2.0, 3.0, 3.1, GFDL FMS/AM/MOM3, MIT GCM, NCEP GFS, **regional models** like WRF, EPA CMAQ, **intermediate models** like ROSE and Cane-Zebiak 5

Global Chemical Data Assimilation System (DART/CAM)

GCTM (CAM)

Community Atmosphere Model (CAM3.1) with simplified CO chemistry
(used the finite-volume dynamical core at $2^\circ \times 2.5^\circ$ horizontal & 26 vertical levels)

→ ensembles of CO total emissions (based on MOZARTv4 standard emission)

→ ensembles of CAM initial conditions (based on previous CAM climatological runs)

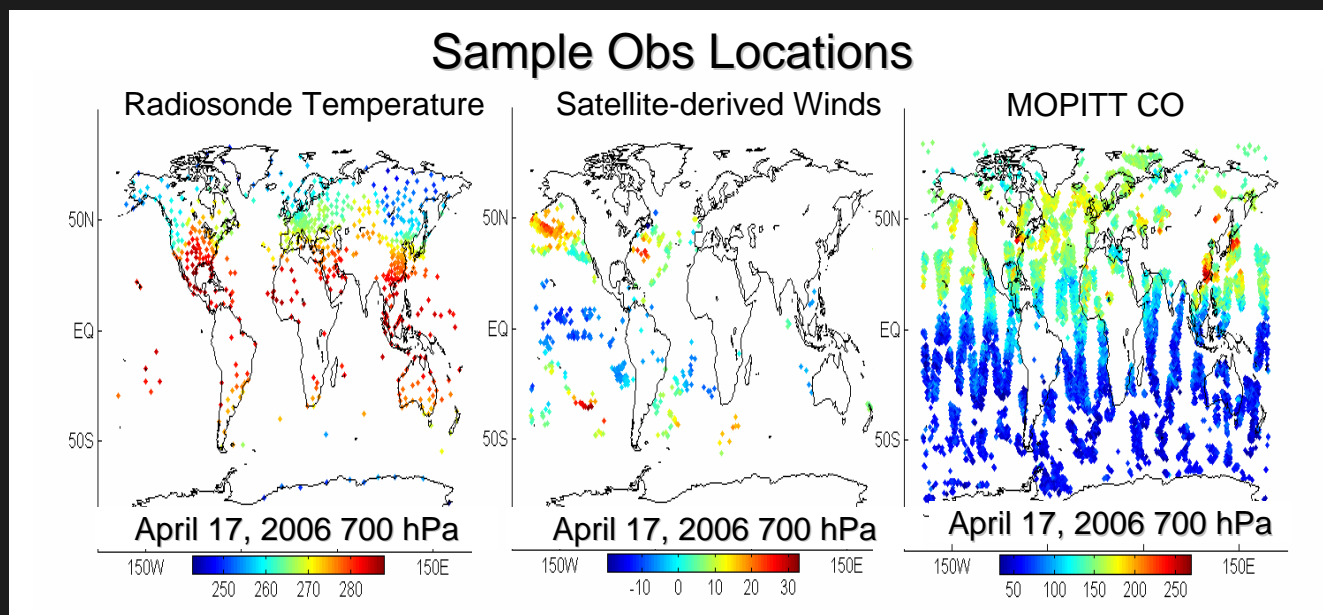
EnKF Package (DART)

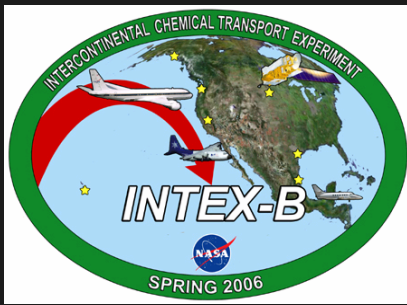
DART with temperature (T), horizontal winds (U,V), specific humidity (Q), cloud ice, cloud water, and CO as state variables

Observations

NCEP BUFR (used a subset that includes radiosonde T, U,V and satellite U,V)

MOPITT CO retrievals (used 700 hPa for now)



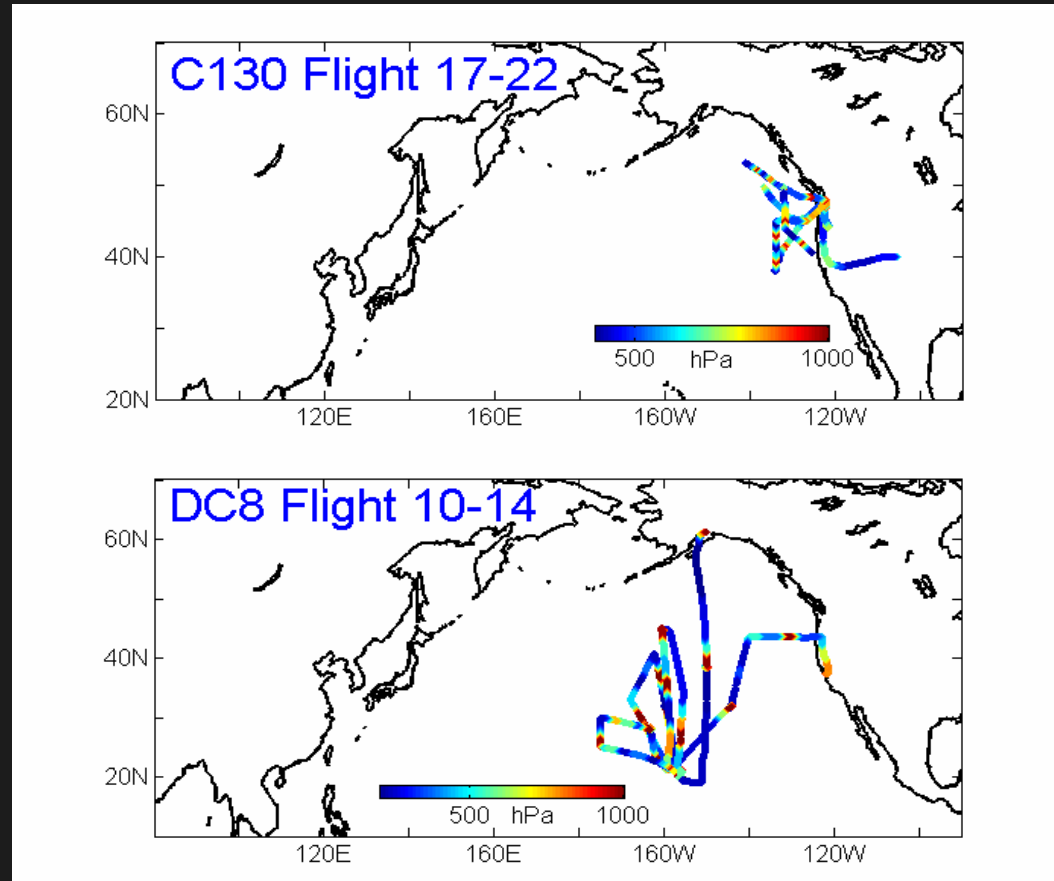


INTEX-B Field Campaign

The NASA Intercontinental Chemical Transport Experiment B 2nd phase (INTEX-B) was aimed at sampling the Asian pollution outflow over Hawaii, Alaska and Seattle during April and May 2006.

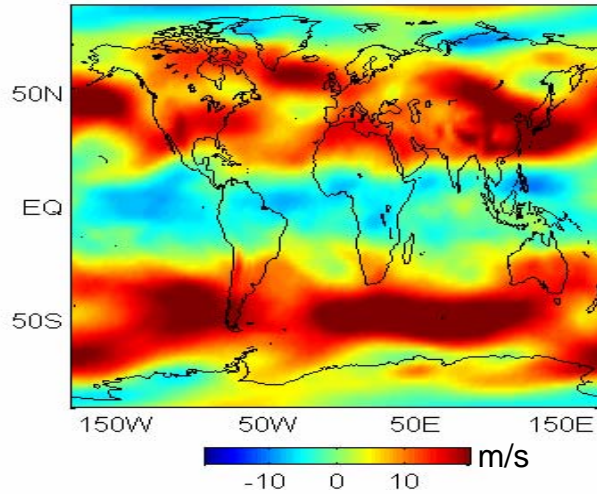
- Regional to global chemical transport models (GCTMs) were used extensively to aid in flight planning (i.e. **chemical forecasts**).
- Opportunity to verify model performance and assimilation system.

Flight tracks during the first half of INTEX-B

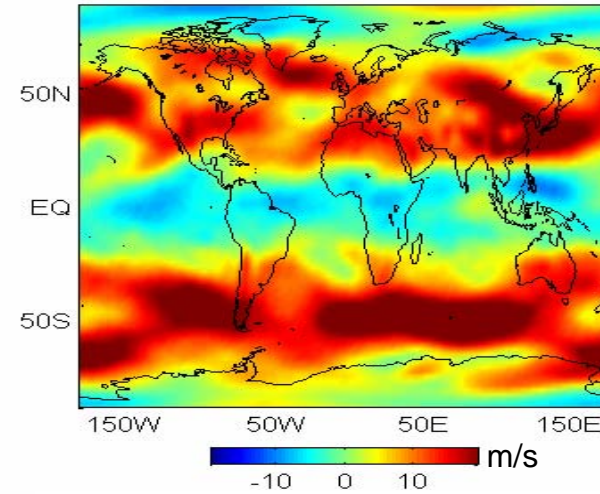


DART/CAM vs GFS Winds

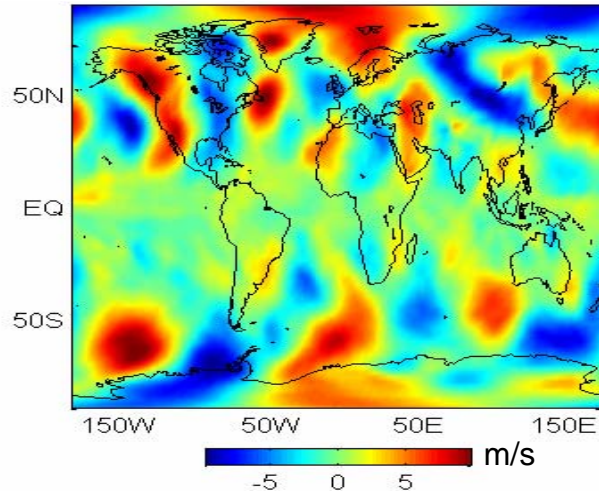
DART/CAM U Wind 04/06 500hPa



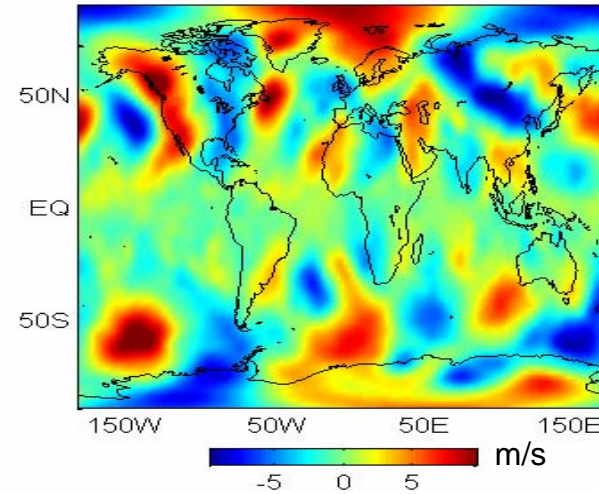
GFS U Wind 04/06 500hPa



DART/CAM V Wind 04/06 500hPa

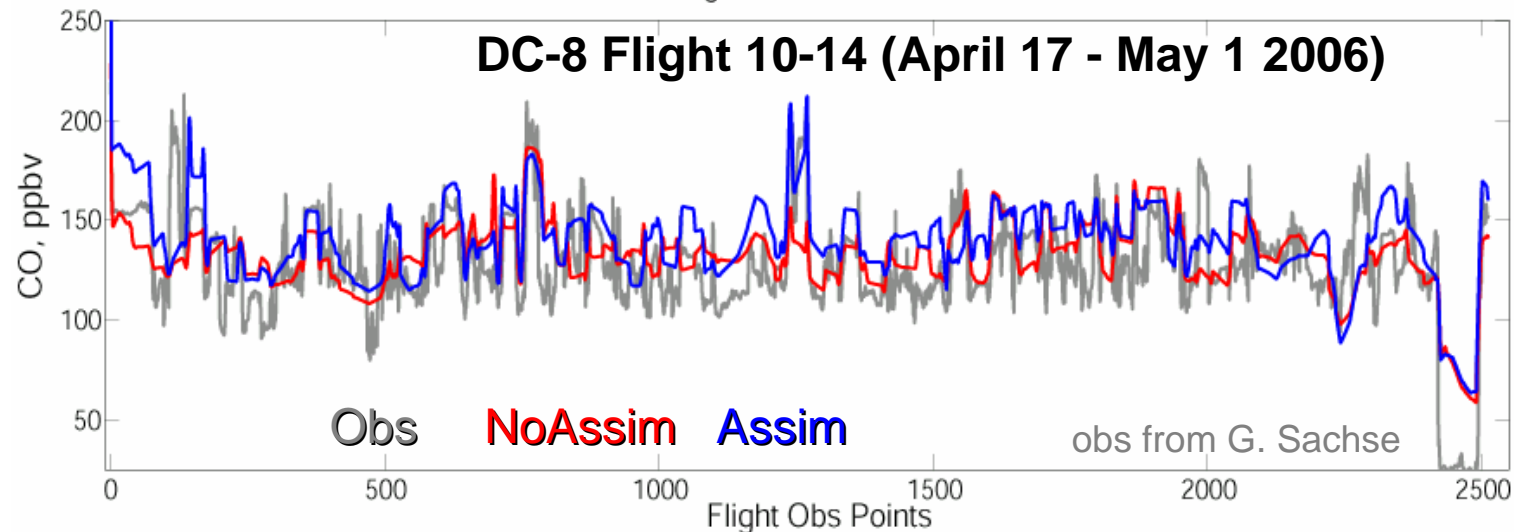
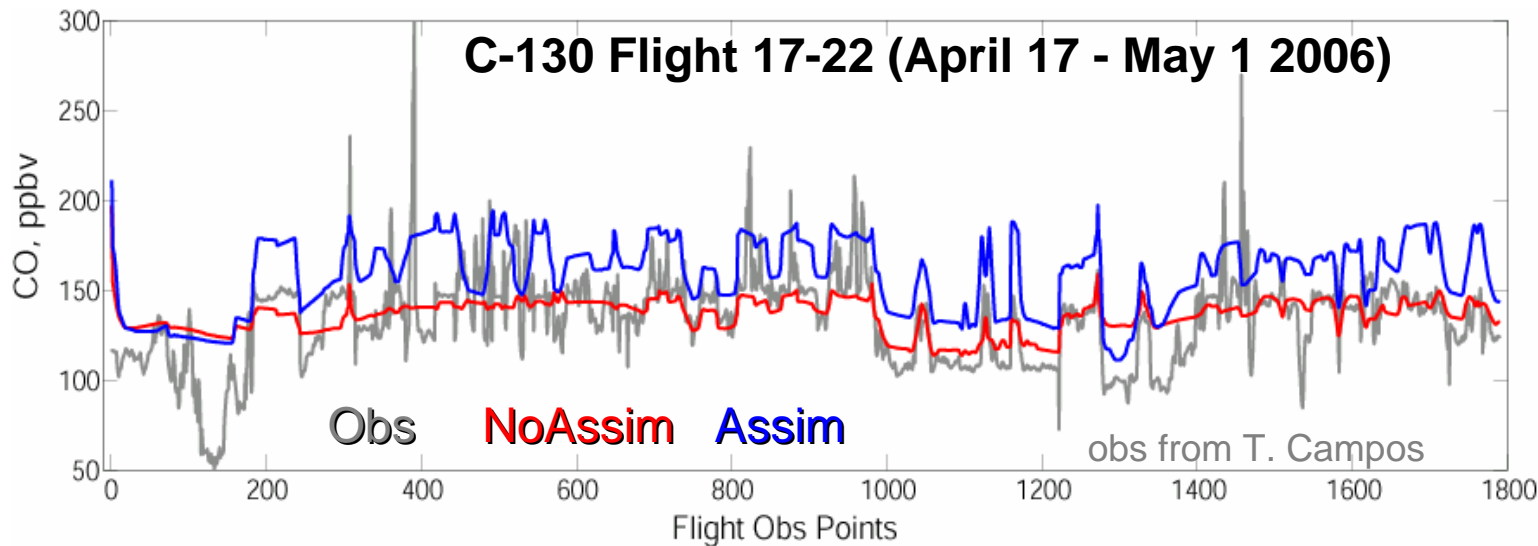


GFS V Wind 04/06 500hPa



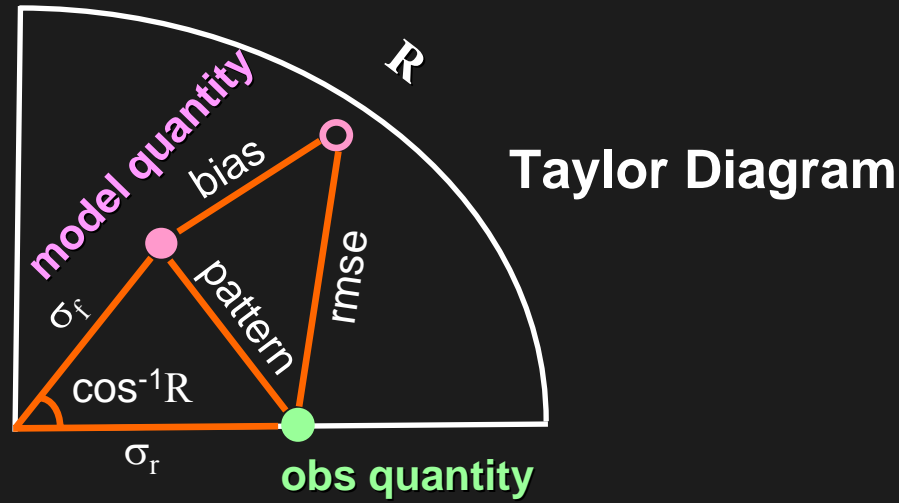
Similarity offers confidence on DART/CAM representing realistic tracer transport.

DART/CAM CO vs INTEX-B CO



Observed CO variability and gradients during INTEX-B are better captured by the model using MOPITT CO assimilation.

Alternative Approach to Illustrate Model Skill



A measure of skill is typically plotted as contours.
Here, skill is defined as:

$$S = \frac{4(1 + R)^4}{(\hat{\sigma}_f + 1/\hat{\sigma}_f)^2 (1 + R_0)^4}$$

$R \sim$ correlation, $R_0 \sim 0.9$

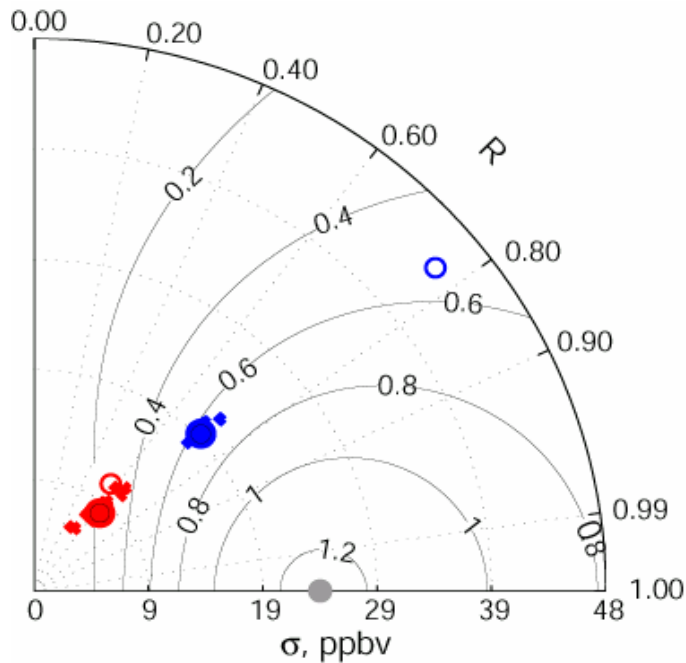
$\sigma_f \sim$ model sigma

$\sigma_r \sim$ obs sigma

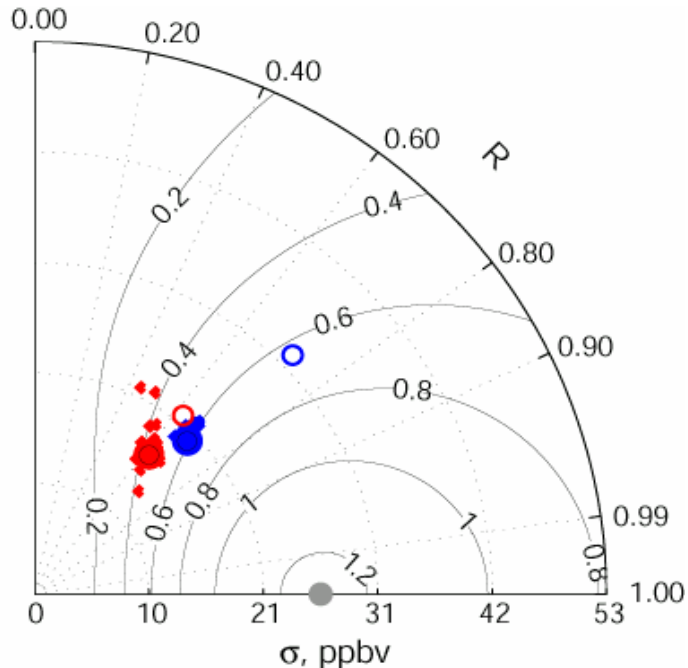
$\hat{\sigma}_f = \sigma_f/\sigma_r$

Assimilation vs No Assimilation

C-130 Flight 17-22 CO
(obs from Teresa Campos)



DC-8 Flight 10-14 CO
(obs from Glen Sachse)

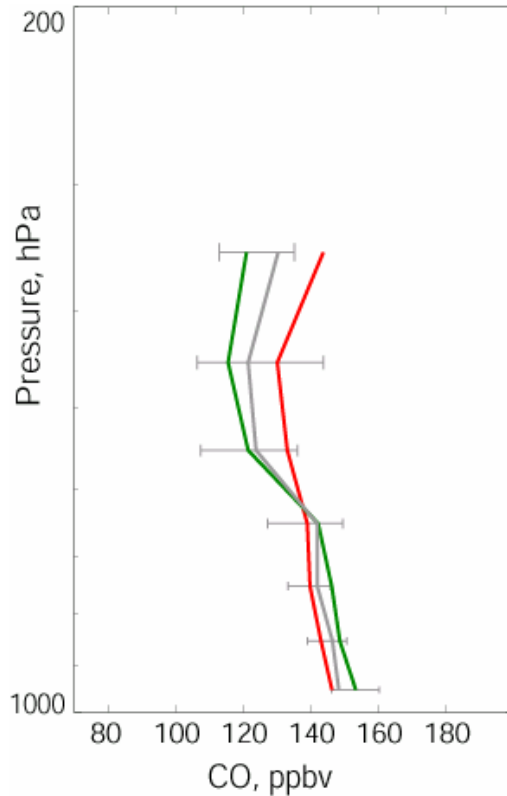


Obs NoAssim Assim

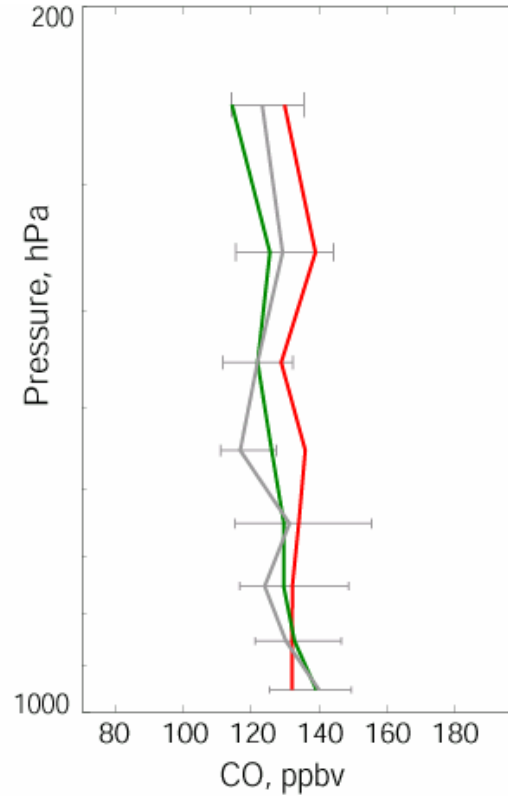
- Assimilation improves the pattern statistics (from skill of ~0.2 to a skill of ~0.6)
- Clear indication of increased bias in assimilated CO relative to no assimilation, indicating that MOPITT is positively biased (~18%±12% for C130, 10%±15% for DC8), consistent with Emmons et al, 2004.

Median Vertical Profiles For All Flights

C-130 Flight 17-22



DC-8 Flight 10-14



Obs

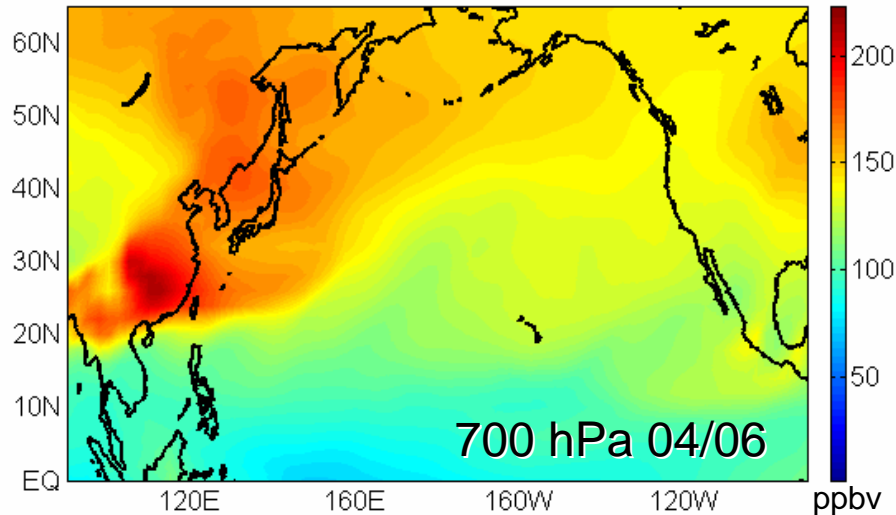
NoAssim

BiasCorrectedAssim

Assimilation also improves the modeled vertical structure of CO.

Impact of Assimilation in Modeled CO

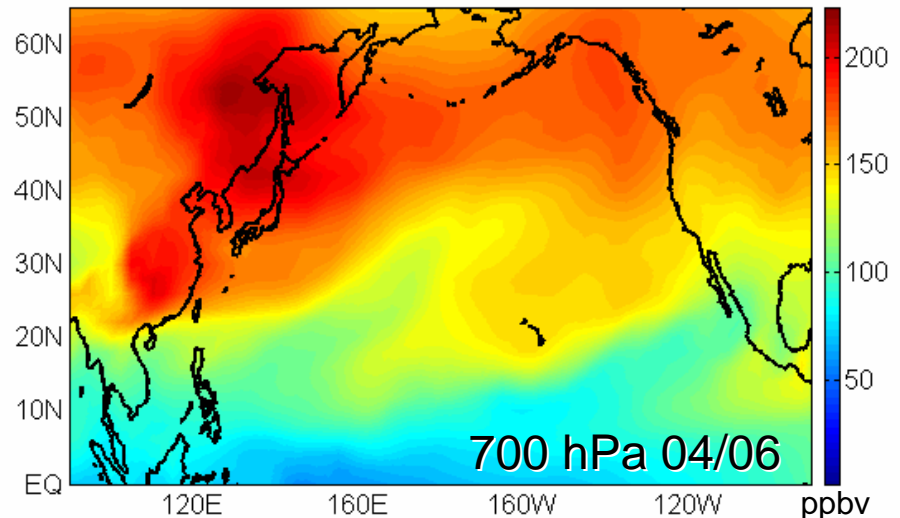
Ensemble Mean CO w/o MOPITT Assim



Assimilating MOPITT CO provides important constraints to regional CO distribution in the troposphere...

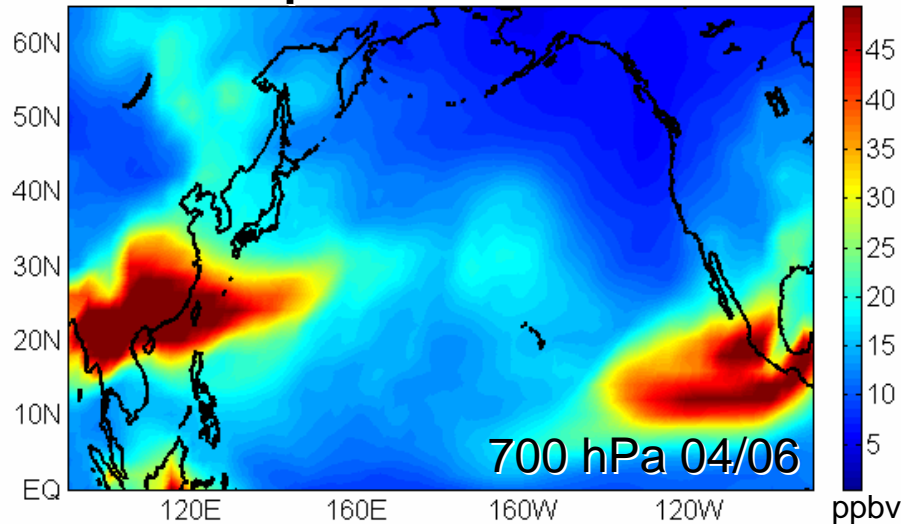
and provides insights on the fidelity of the model to represent CO transport and emissions

Ensemble Mean CO with MOPITT Assim



Estimates of Uncertainties in Modeled CO

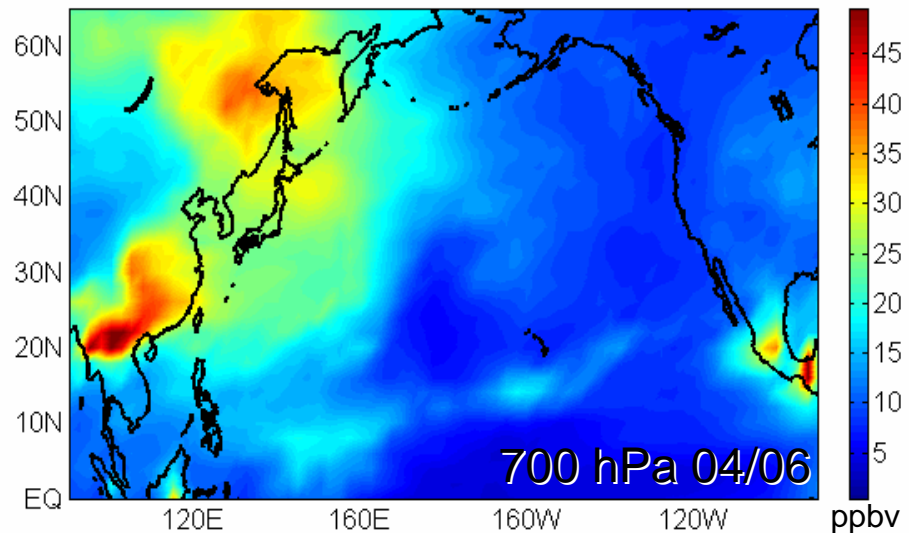
Ensemble Spread CO w/o MOPITT Assim



mainly influenced by our probabilistic estimates of emissions...

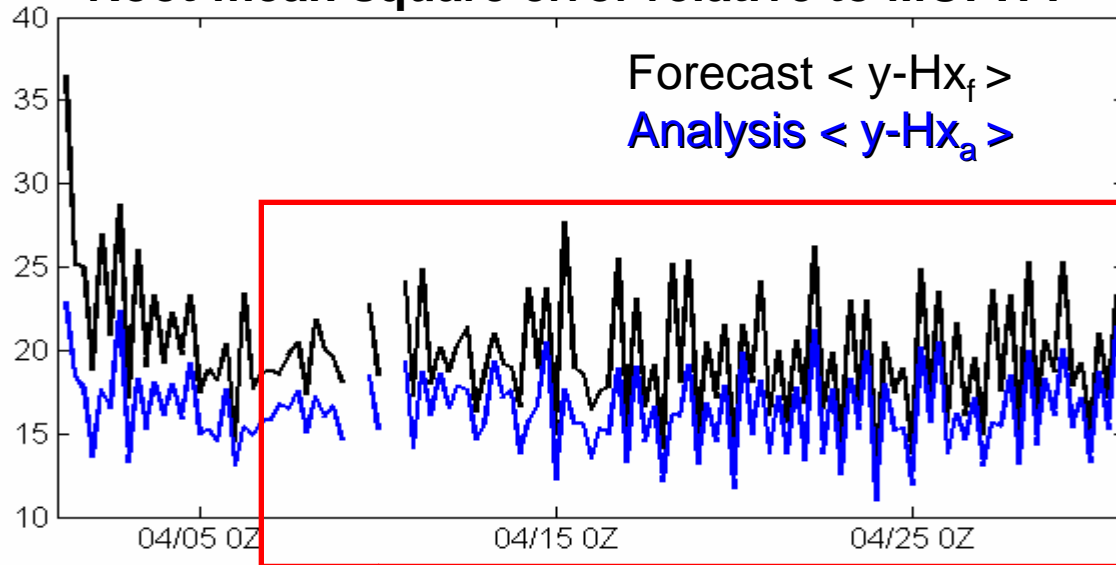
while still appears to be underestimated, MOPITT-constrained estimates show a different structure ...

Ensemble Spread CO with MOPITT Assim



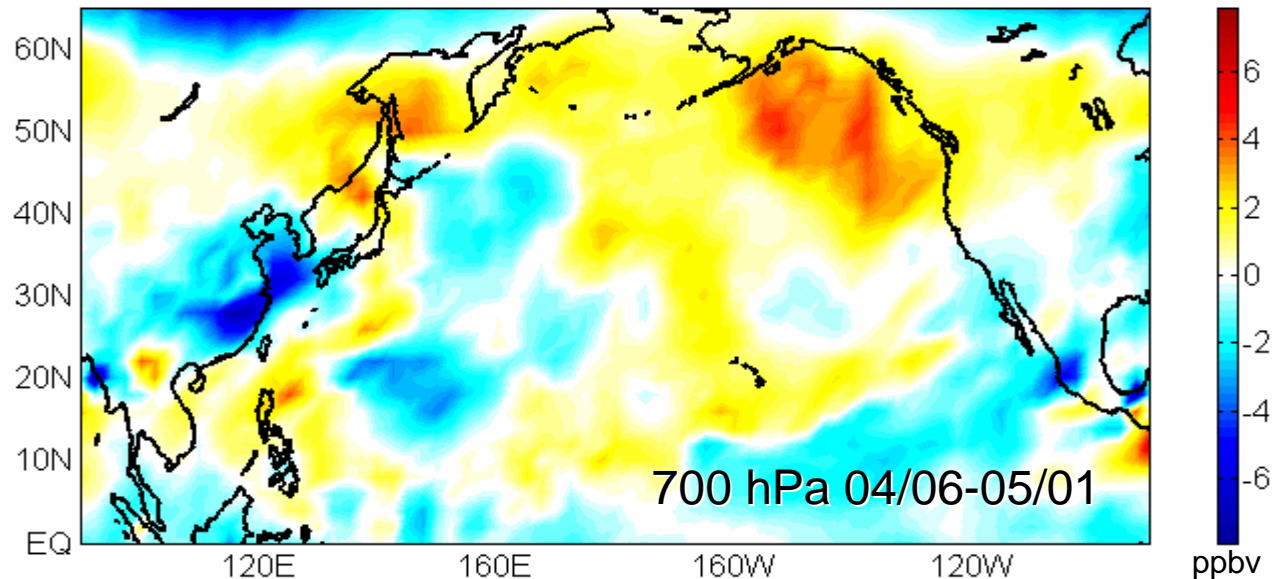
More on Model Uncertainty

Root-mean square error relative to MOPITT



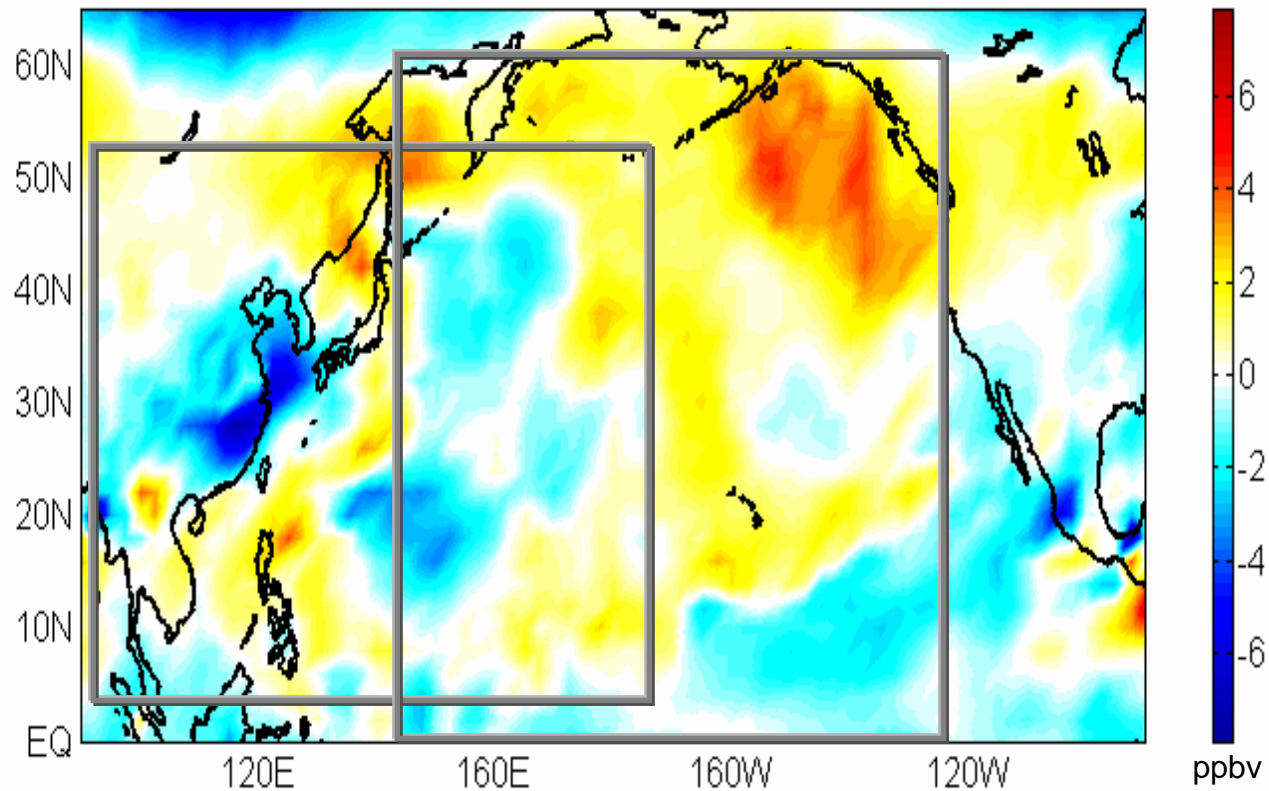
system diagnostic for short-term (6-hourly) forecast errors

Analysis - Forecast $\langle x_a - x_f \rangle$



model overpredicts in source region while underpredicts in downwind region

Implication to Constituent Source Inversions



- inversions are sensitive to the use of different observation domain
- information on model error allows for consistent analysis
- are errors due to transport or emissions or chemistry?

Summary

- A global chemical data assimilation system has been implemented at NCAR using CAM (chem) and DART.
- Such system is verified using INTEX-B CO data and shows significant improvements in CO model skill.
- Constraining tropospheric CO using the assimilation system potentially provides important information not only for chemical forecasting but also for model improvement studies
- Future directions: joint-state-source estimation, multi-species assimilation, studies on feedback mechanisms