Data Assimilation for Tropospheric CO

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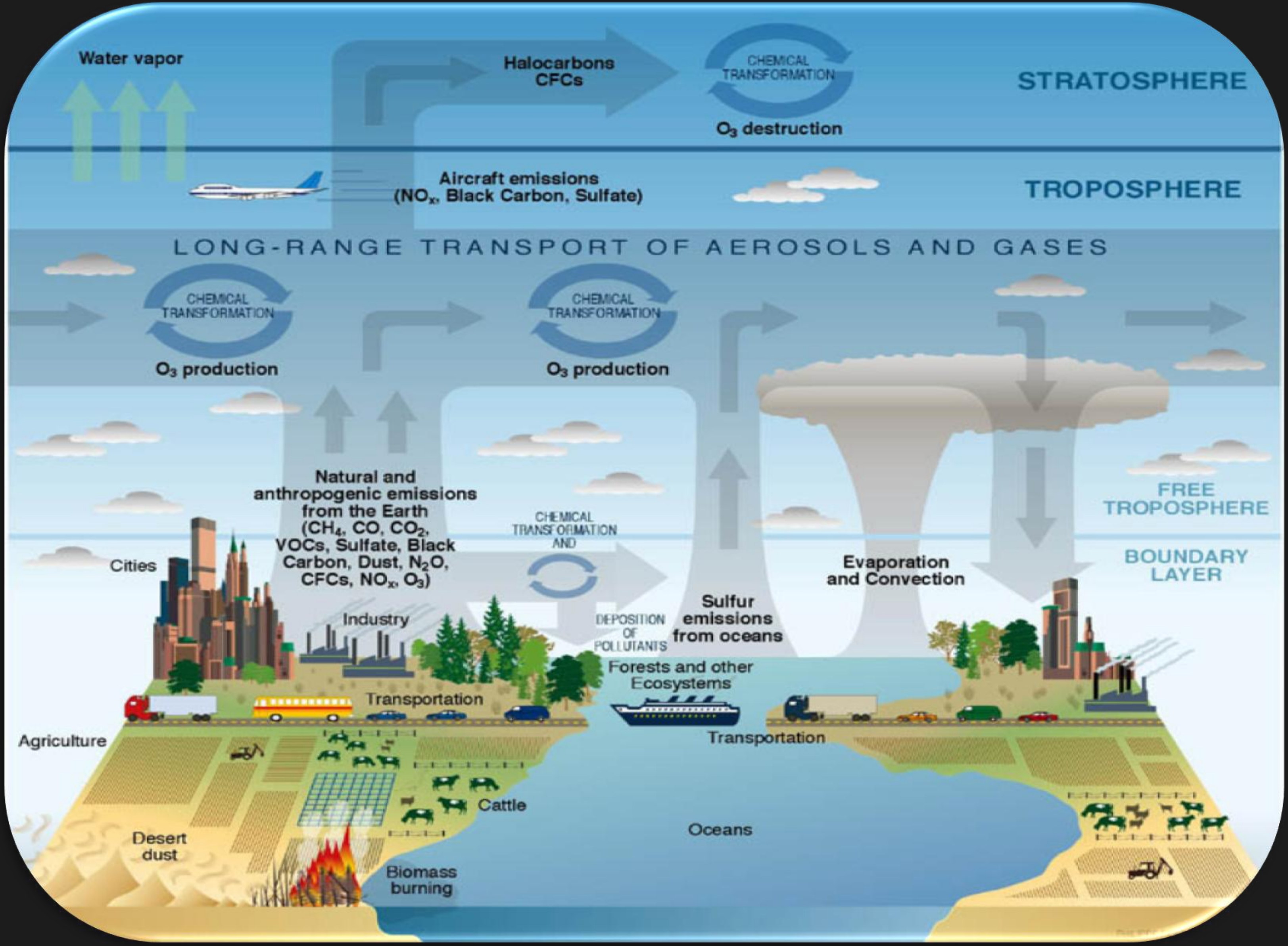
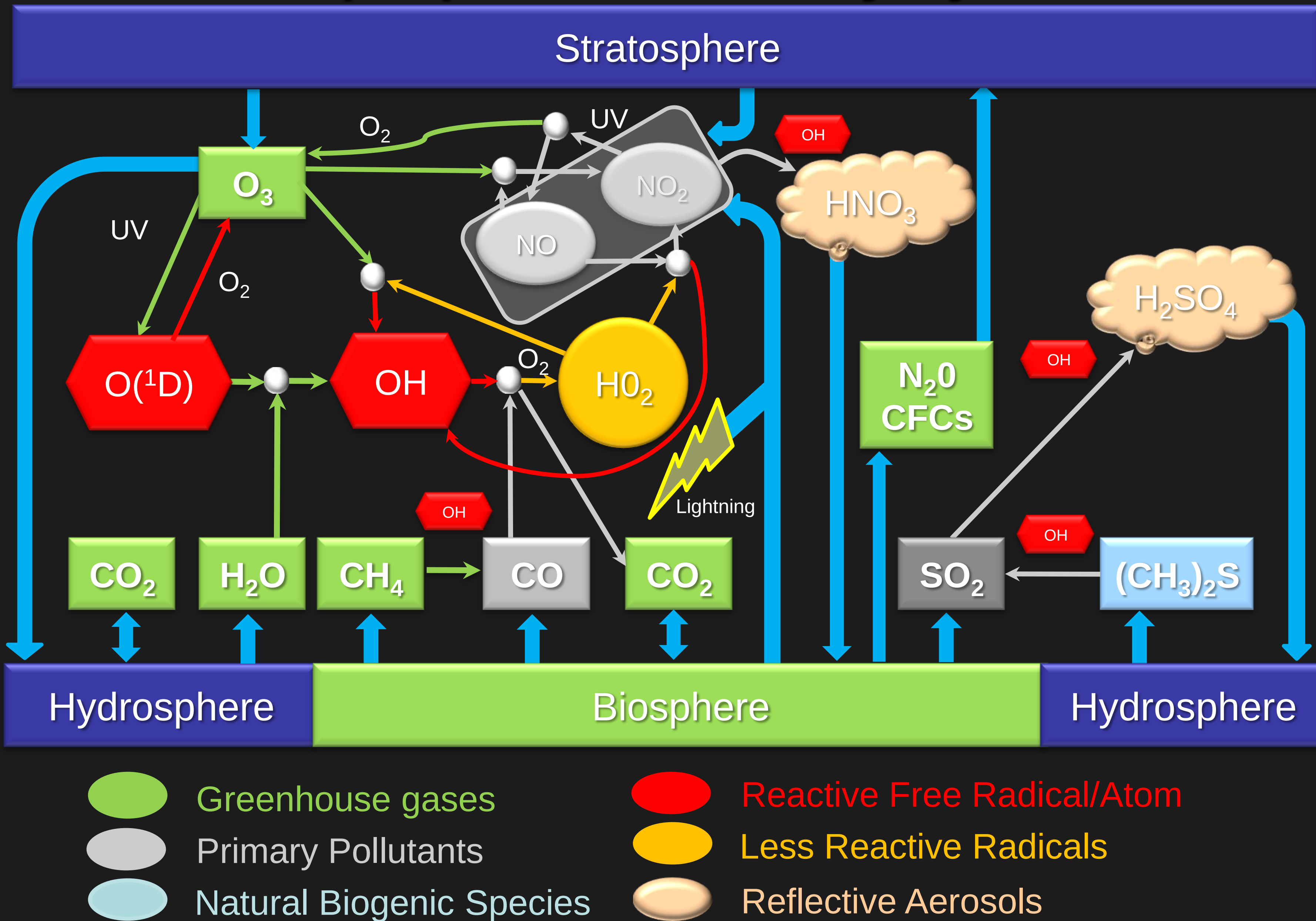
Caveat: Illustrative rather than quantitative, applied rather than theoretical

Based on Arellano and Hess, GRL, 2006 and Arellano et al., ACPD, 2007

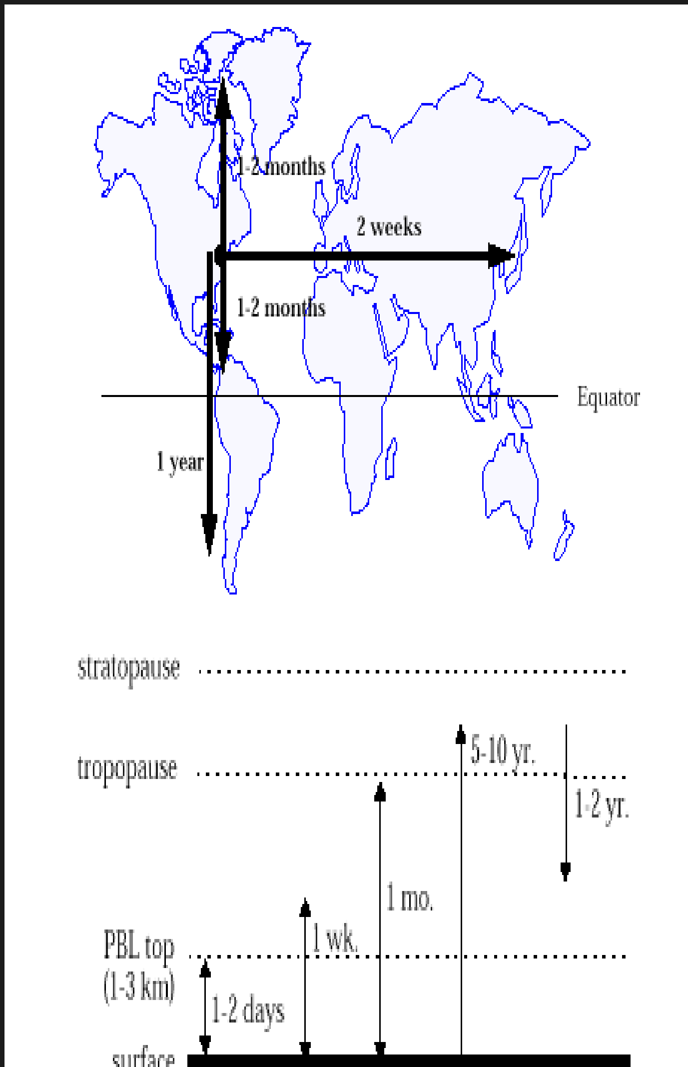


From: Strategic Plan for the Climate Change Science Program, Final Report, July 2003

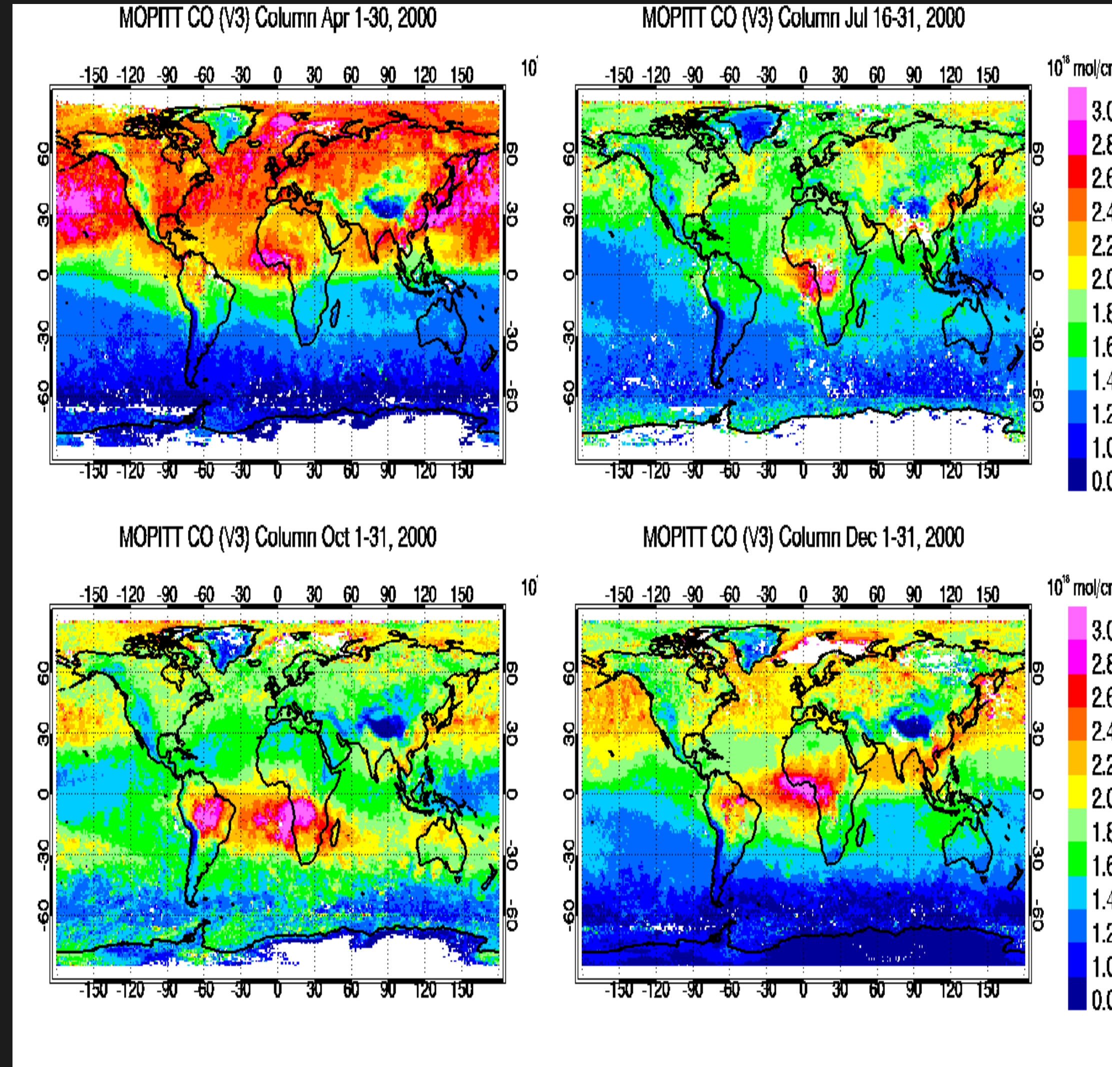
Tropospheric Chemistry Cycles



CO Distribution (τ_{co} ~ 1-2 months)



Introduction to Atmospheric Chemistry, Jacob, D. J., 1999



http://www.eos.ucar.edu/mopitt/data

Modeling the evolution of CO concentration

For each model grid, the change in the concentration of CO is determined by a) emissions, b) transport, c) chemical loss/production, and d) deposition.

$$\frac{d[CO]}{dt} = \left(\frac{\partial [CO]}{\partial t}\right)_{emission} + \left(\frac{\partial [CO]}{\partial t}\right)_{transport} + \left(\frac{\partial [CO]}{\partial t}\right)_{chemistry} + \left(\frac{\partial [CO]}{\partial t}\right)_{deposition}$$

e.g. (transport): $-\vec{v} \cdot \nabla[CO]$ Advection

e.g. (chemistry):

$-k_{CO-OH}[CO][OH]$ Loss

$k_{CH_4-OH}[CH_4][OH]$ Production

Letting x be CO concentration, u emission, and θ other variables in the model:

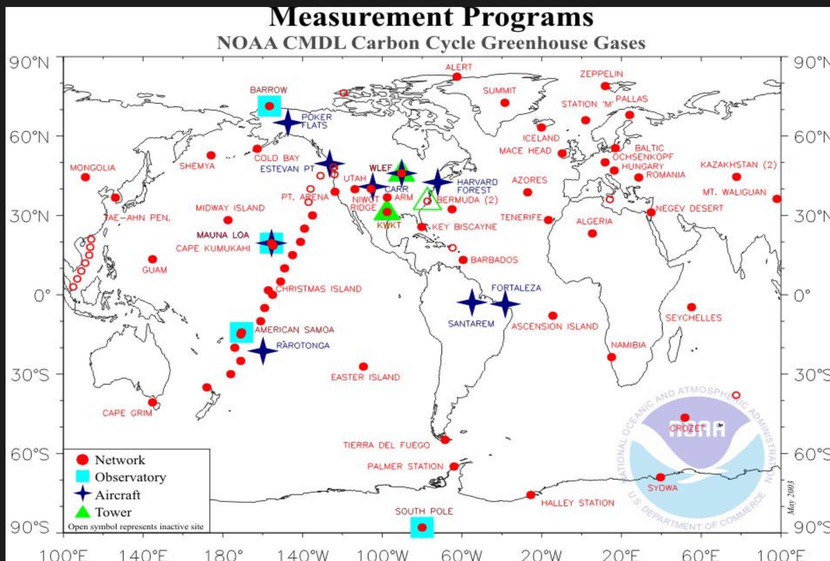
$$\mathrm{x}_{i+1} = \Phi(\mathrm{x}_i, \mathrm{u}, \theta)$$

For faster model integration, [OH] is typically prescribed. The model can also be driven by assimilated meteorology or reanalysis (offline-CTMs).

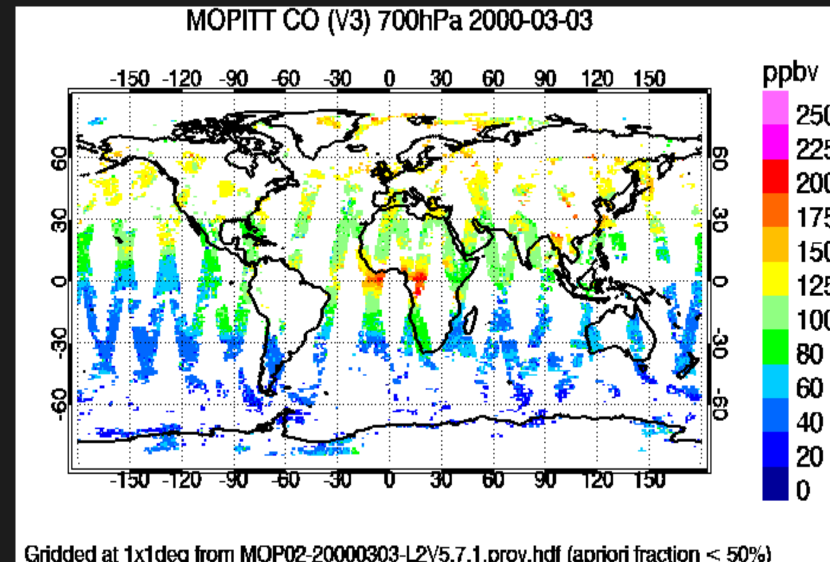
Problem: *Uncertainties exist in modeling the emission, parameterizing convection and boundary layer processes …*

Observations of CO $Z_j = h_j(x_i) + \varepsilon_j$

In-Situ Measurements

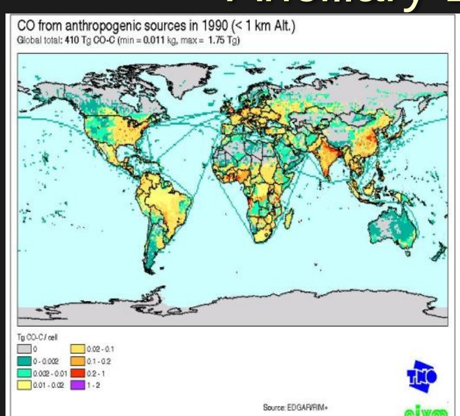


Remote-sensed Measurements



e.g. MOPITT, TES, SCIAMACHY, AIRS, MLS

Ancillary Data



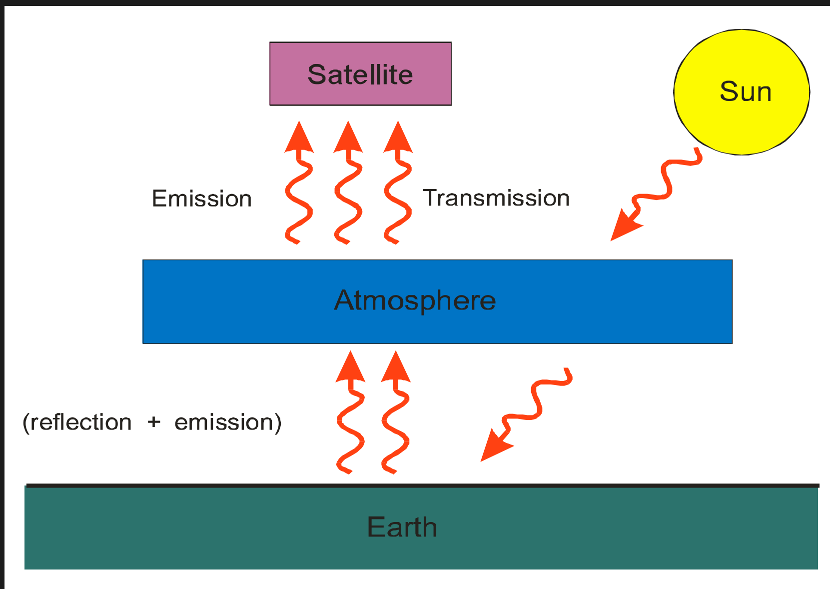
Source Inventories

Fire Data

Aircraft Measurements

MOPITT CO Retrievals $Z_j = x_{ret}$ (instead of radiance)

Level 2 CO product → Retrieved CO profiles with 7 levels (surface, 850, 700, 500, 350, 250, 150 hPa)

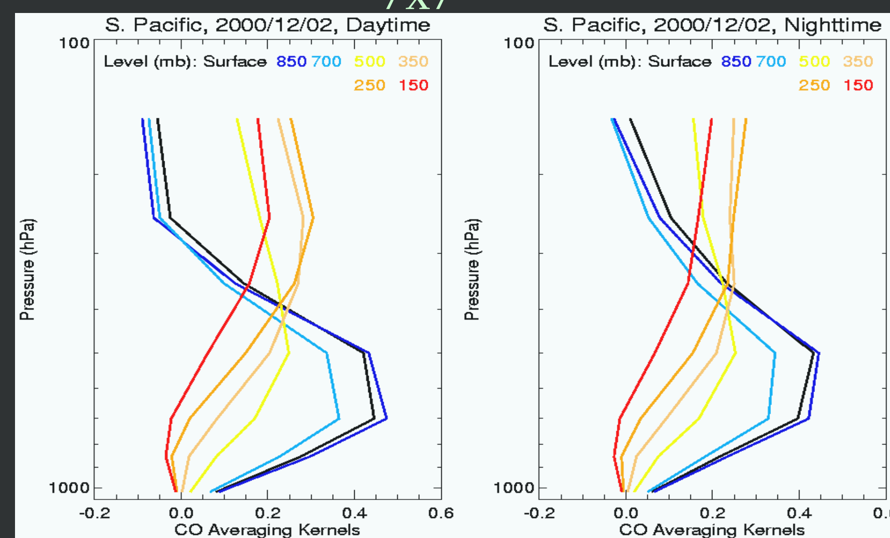


$$x_{ret} = x_a + K(y_o - Hx_a)$$

- x_{ret} → CO profile
- y_o → radiances
- H → $\delta h / \delta CO$ (from radiative transfer model)
- x_a → prior CO profile

Posterior diagnostic (averaging kernel)

$$A_{7x7} = KH$$



For our application:

$$Z_j = h_j(x_i) + \varepsilon_j$$

$$h_j(x_i) = Ax_i + (I-A)x_a$$

ε_j = retrieval error

Science Applications (global scale):

1) Inverse modeling of CO sources

2) Ensemble-based CO assimilation (using DART/CAM-Chem chemical data assimilation system)

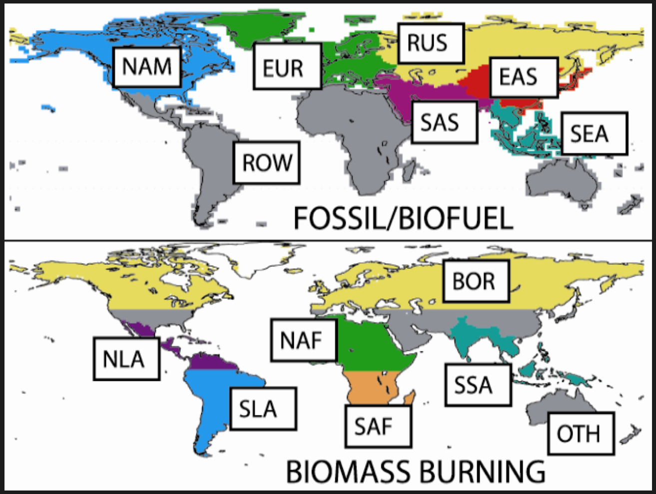
1) Inverse Modeling of CO Sources (method)

e.g. [emission | MOPITT] ~ [MOPITT | emission] [emission]

$N(\hat{\mu}, \hat{P}_u)$ $N(Hx, R)$ $N(\mu_u, P_u)$

We solve for regional source scaling factors

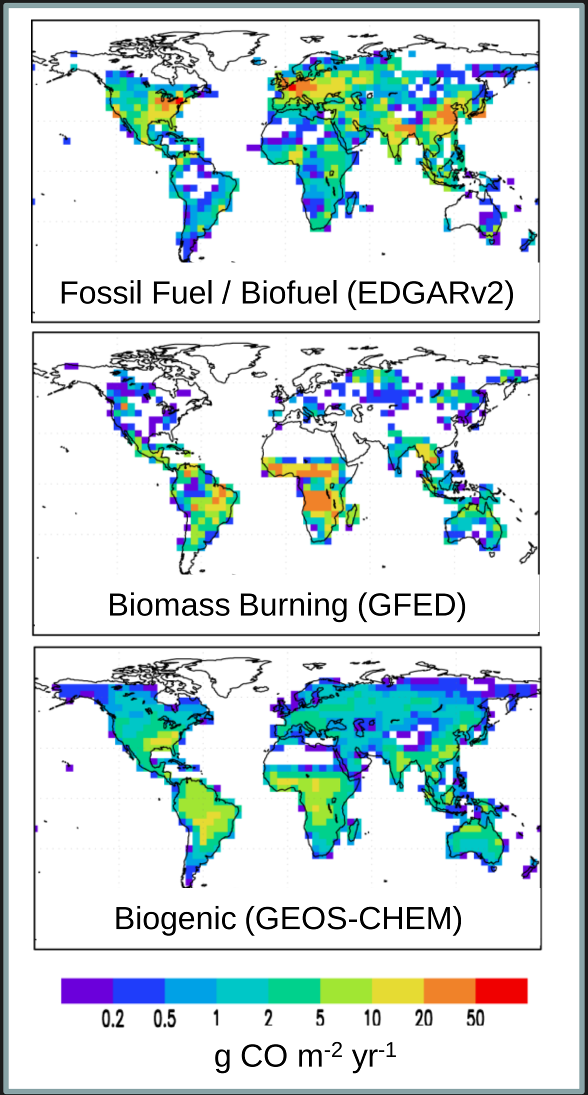
e.g.



Scaling factors can be time-dependent or time-independent (based on Enting, 2002)

Note that the posterior mean is sensitive to data, prior estimates, error specification and model leading to persistent discrepancies in source estimates

(No TransCom framework for CO)



Sensitivity of source estimates to treatment of GCTM transport

→ Use 3 ‘different’ models with the same prior source distribution

1) MOZART with NCEP reanalysis

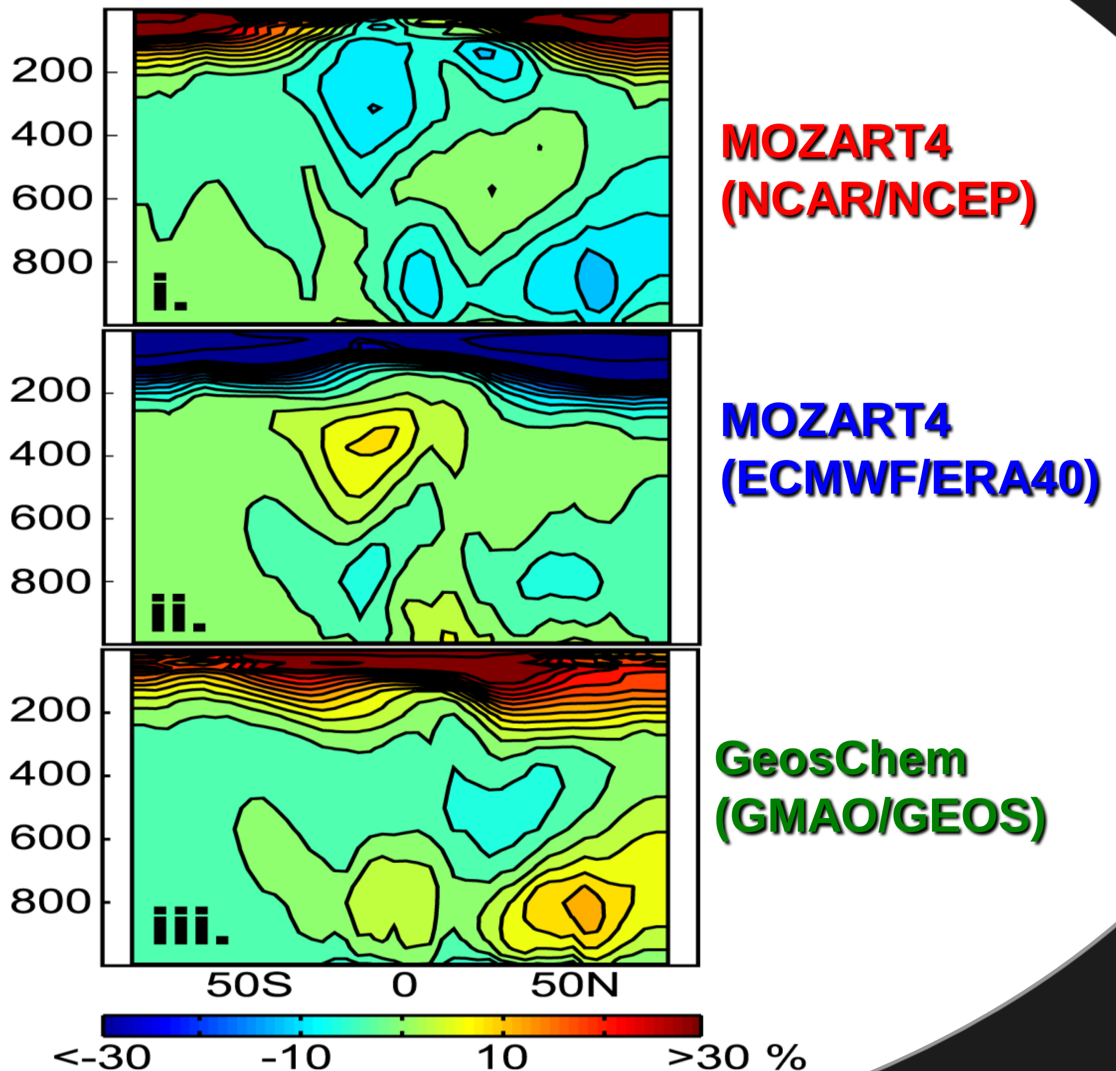
2) MOZART with ECMWF reanalysis

3) GEOSChem with GMAO assimilated meteorology

MOZART and GEOSChem have different parameterization for convection and boundary layer. Similar advection scheme.

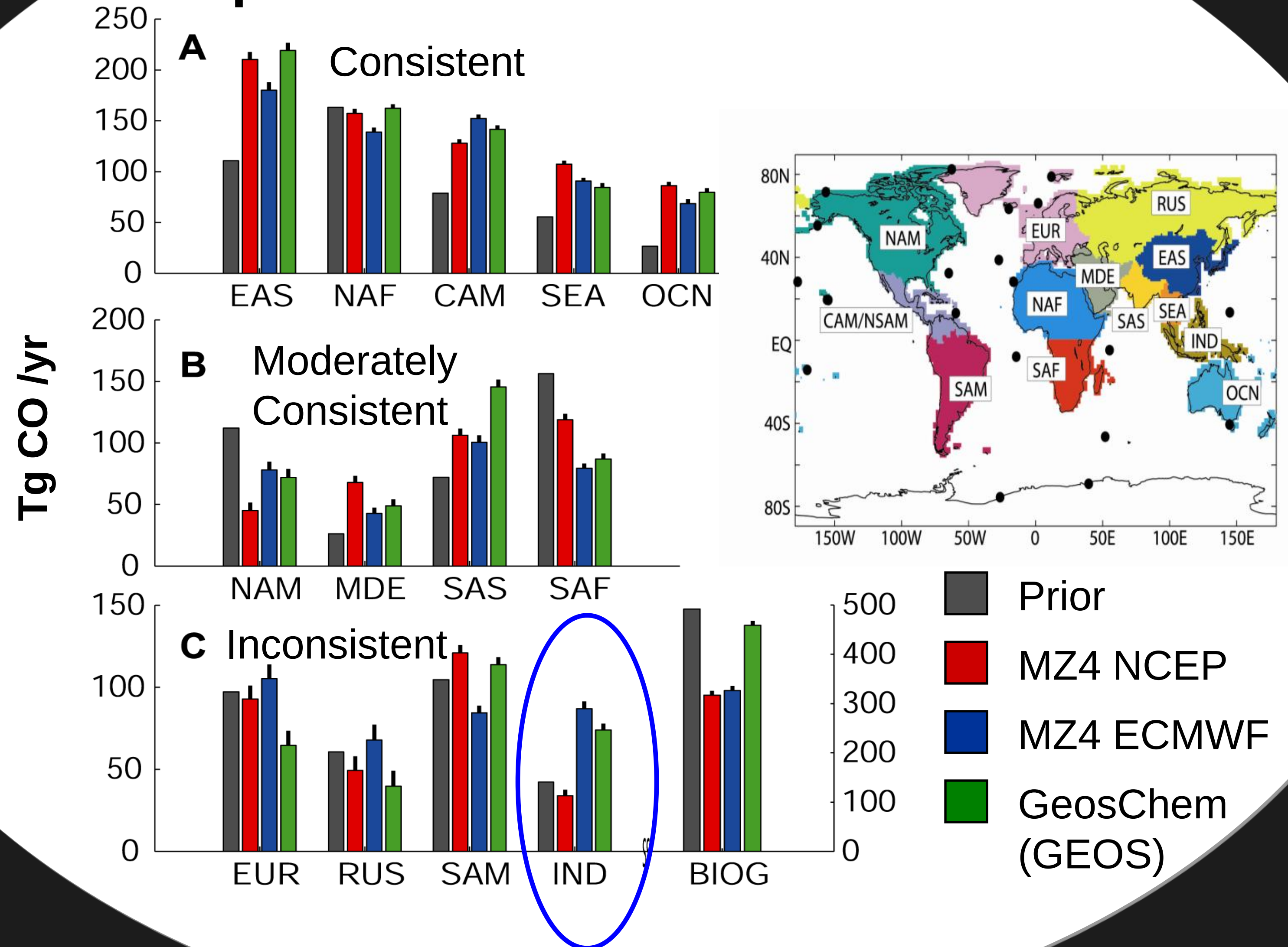
→ Conduct 3 sets of inversions for 14 time-independent source scaling factors.

Relative % Difference in Zonal Mean CO Concentration



Arellano and Hess (2006)

Top-down CO Emission Estimates



Arellano and Hess (2006)

2) 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°x2.5° 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)

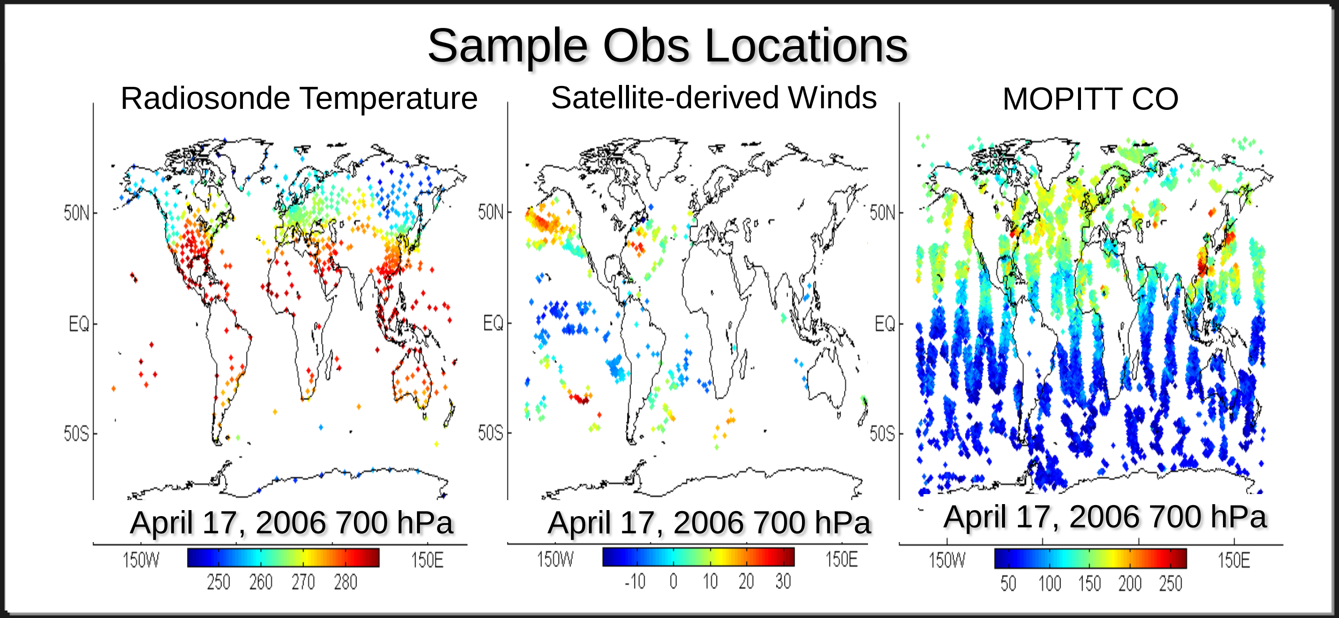
EnKF Package (DART)

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

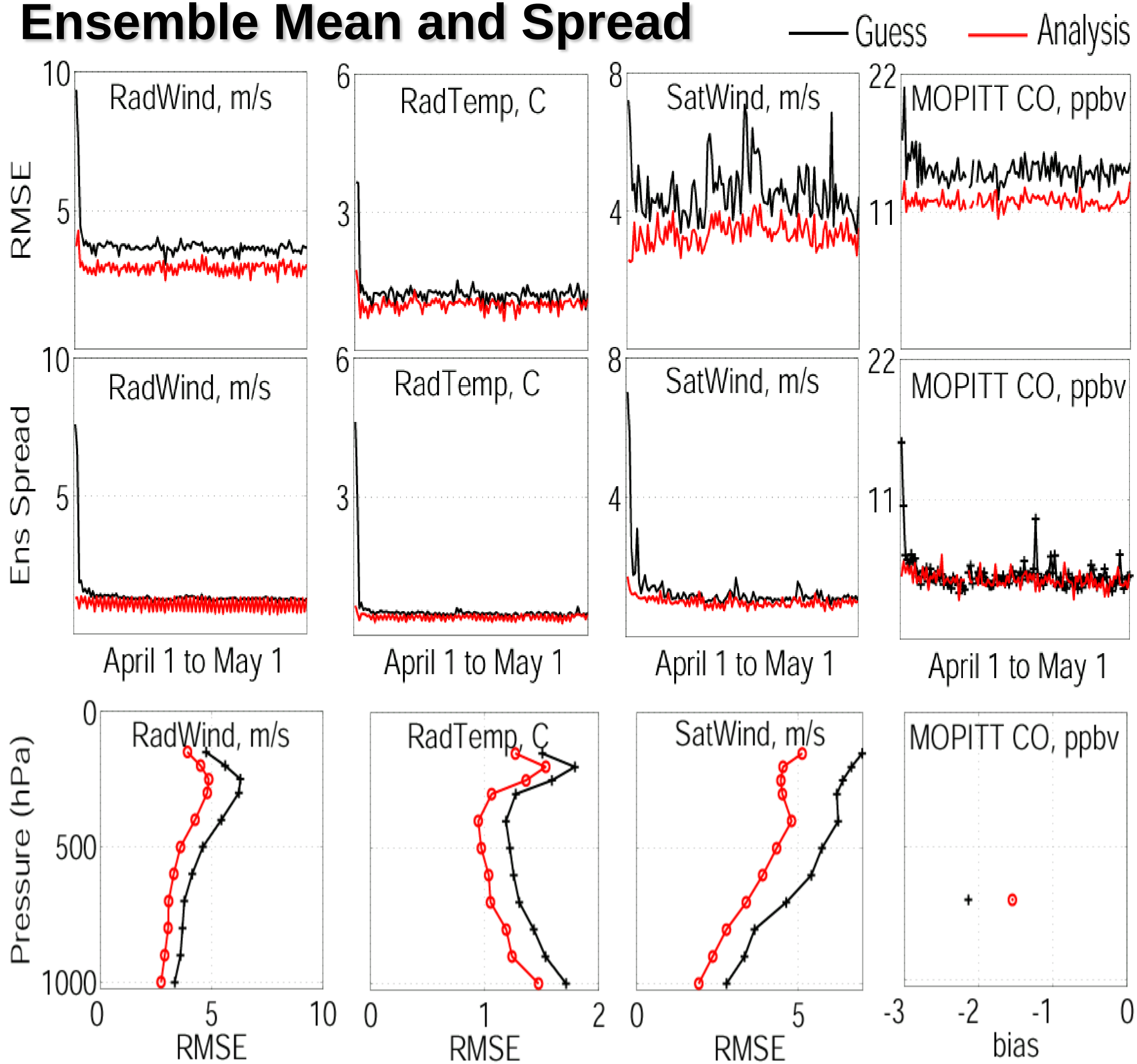
Observations

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

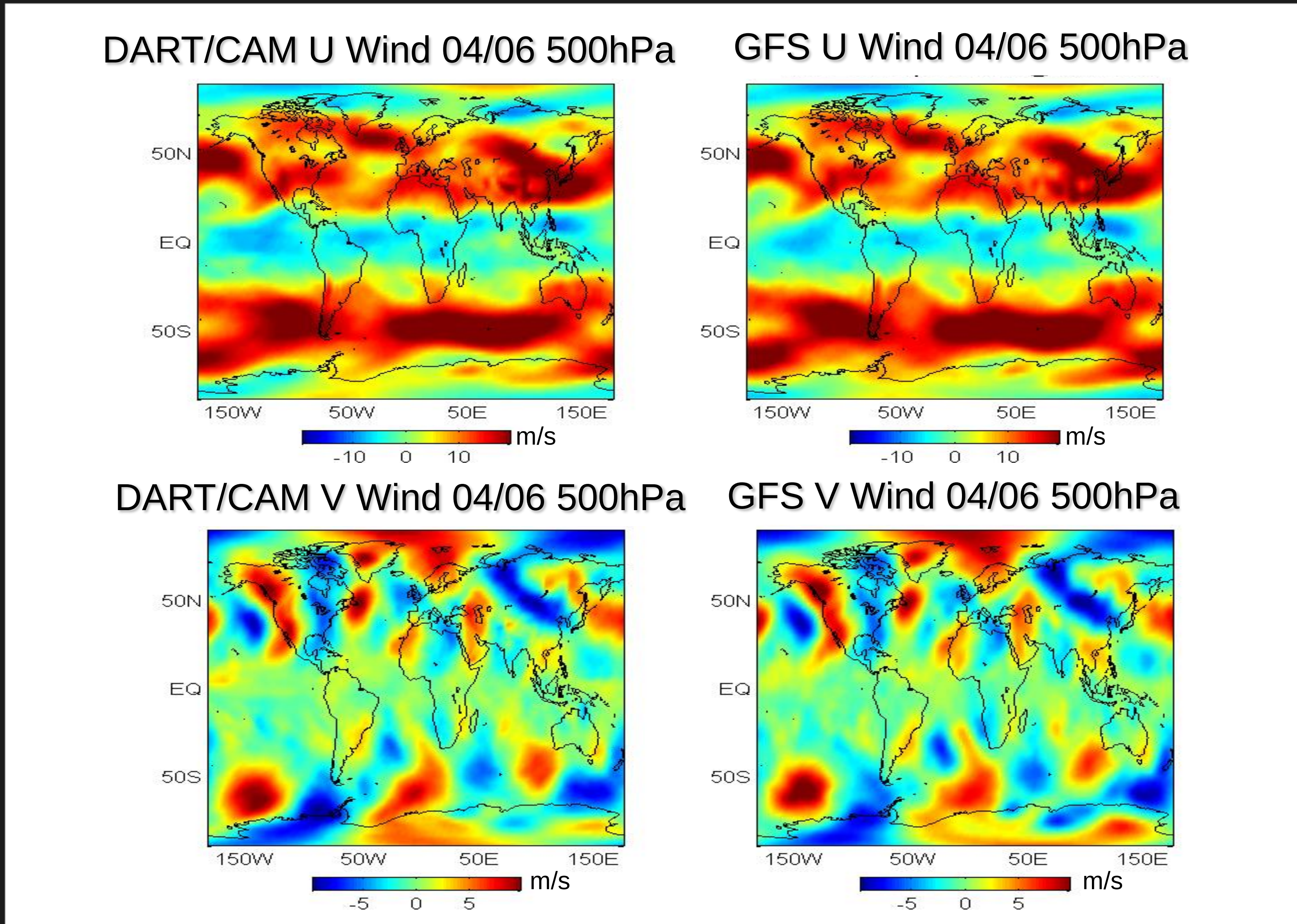
MOPITT CO retrievals (used 700 hPa for now)



Ensemble Mean and Spread



DART/CAM vs GFS Winds



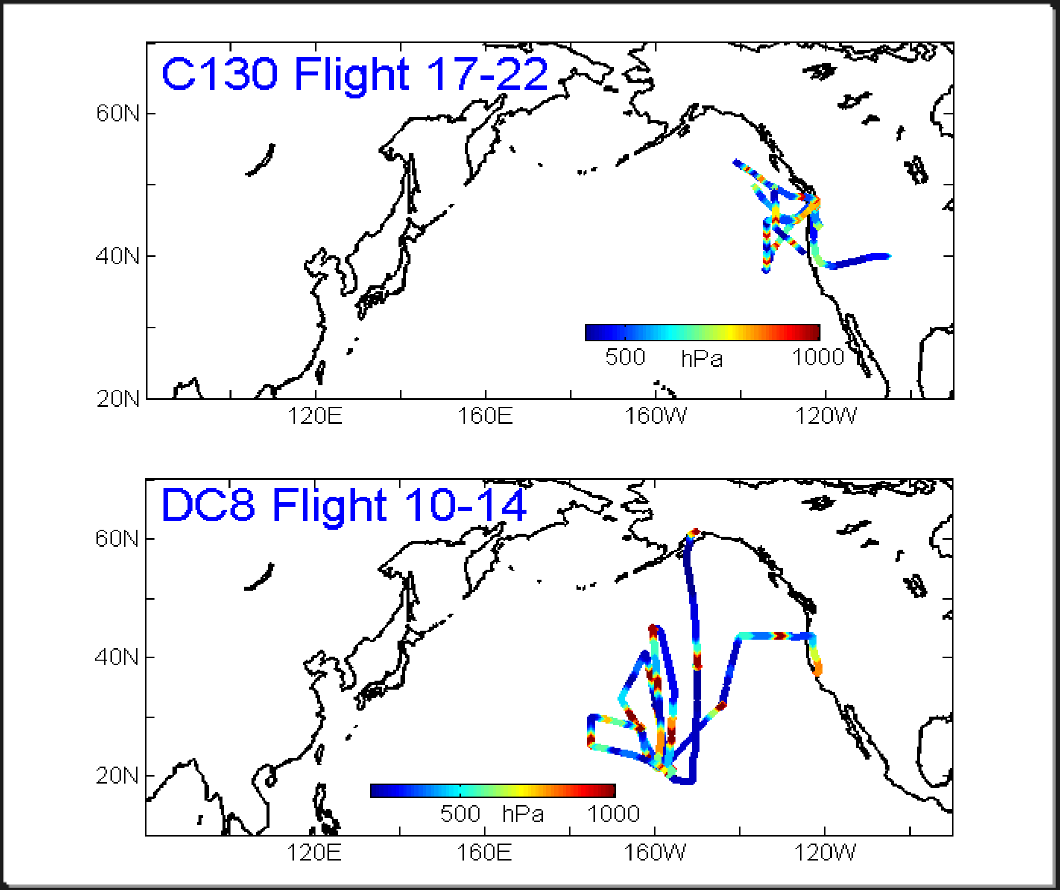
INTEX-B Field Campaign

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.

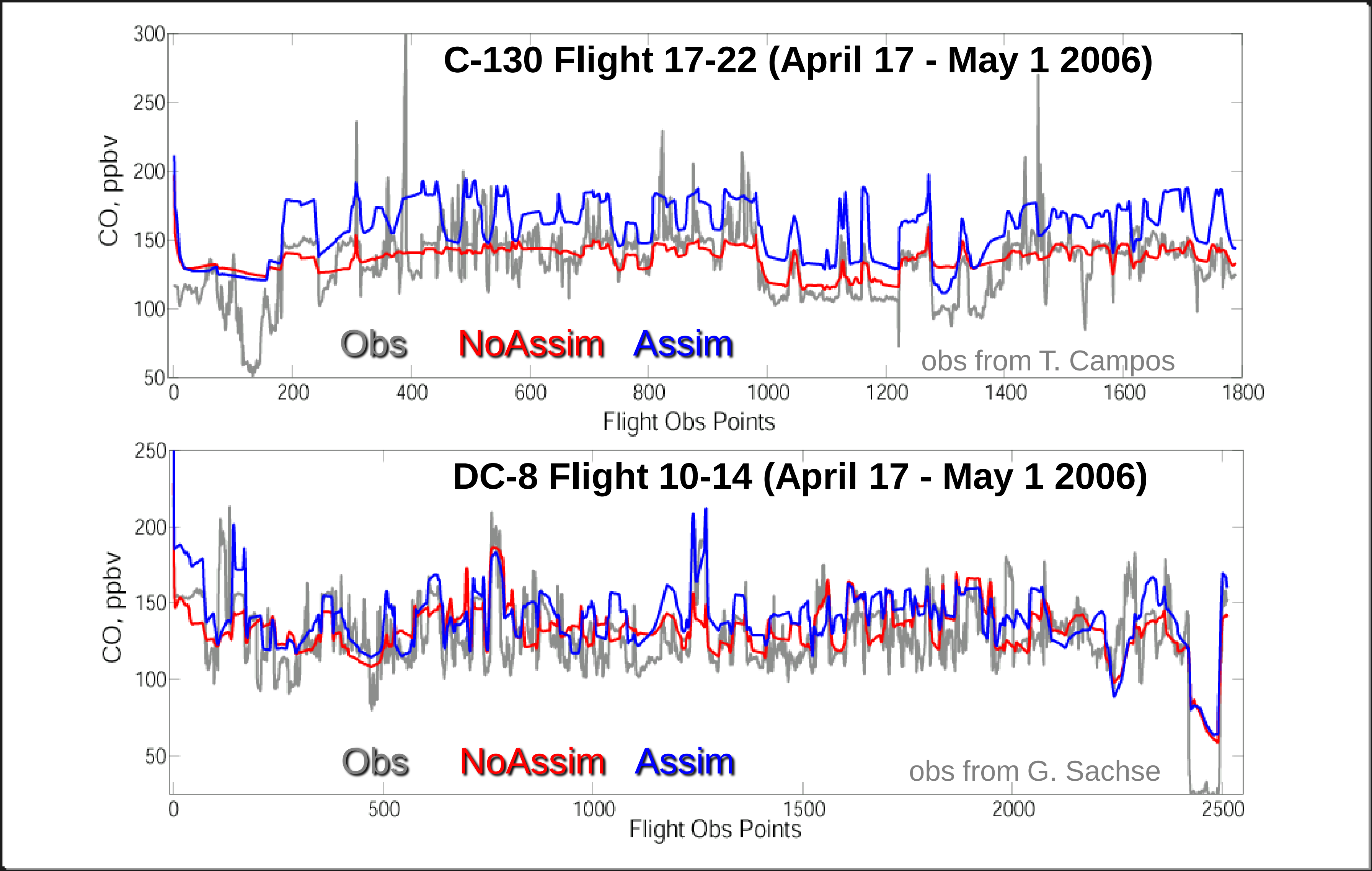
→ Regional to global chemical transport models (GCTMs) were used extensively to aid in flight planning (i.e. chemical forecasts).

→ Opportunity to verify model performance and assimilation system.

Flight tracks during the first half of INTEX-B



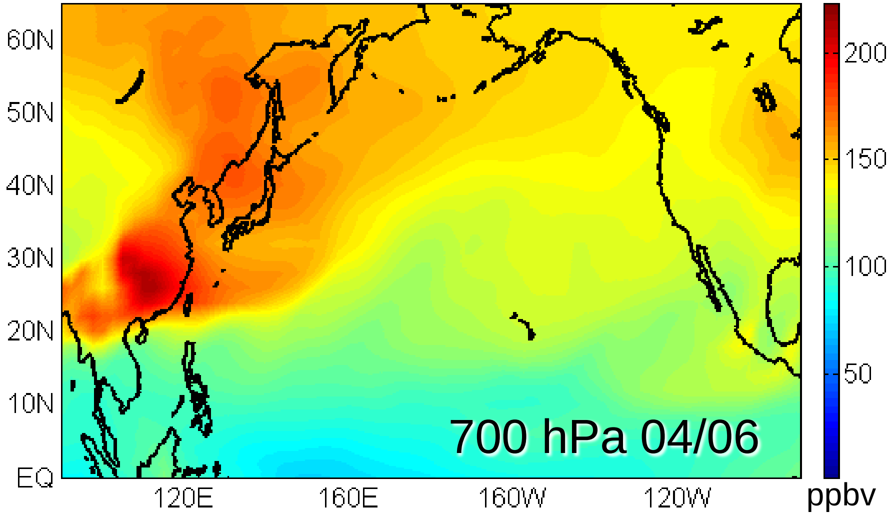
DART/CAM CO vs INTEX-B CO



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

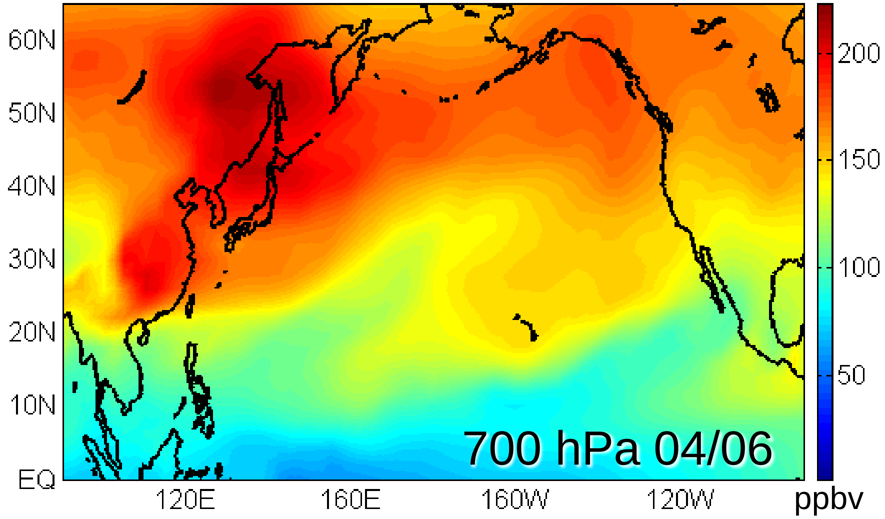
Impact of Assimilation in Modeled CO

Ensemble Mean CO w/o MOPITT Assim



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

Ensemble Mean CO with MOPITT Assim



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

Present and Future Directions

1) Joint state-parameter estimation using DART/CAM
2) Assimilation of multi-sensor observations
3) Assimilation of multi-species observations incl. aerosols
4) Observation System Simulation Experiments (OSSEs) for current and future chemical observing systems