Assessing Model Performance Using Aircraft Data

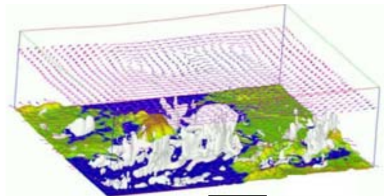
- Overview of the uses of observations by models.
- Using observations to evaluate models.
- Combining observations with models

How are observations used by models

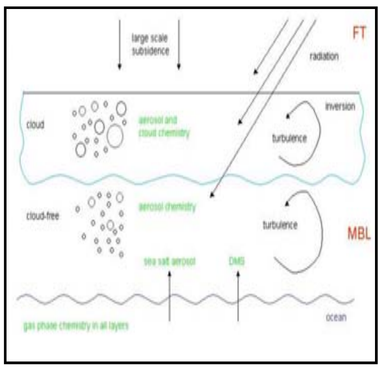
- "Direct" use in models
  - Boundary conditions (in limited area models)
  - Initial conditions (e.g., trajectory fill methods, and observation-based models)
  - As parameters (e.g., size distributions, optical properties)
- Evaluation
  - Point comparisons
  - Profiles
  - Different types of air masses, processes, etc.
- Data assimilation (formally combining observations and models)

Air Quality Modeling: Improving Predictions of Air Quality (analysis and forecasting perspectives)

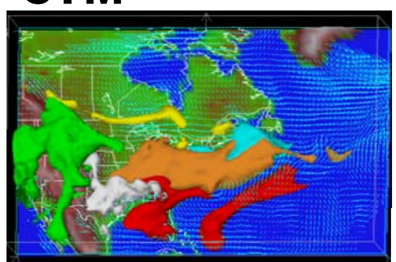
Met model



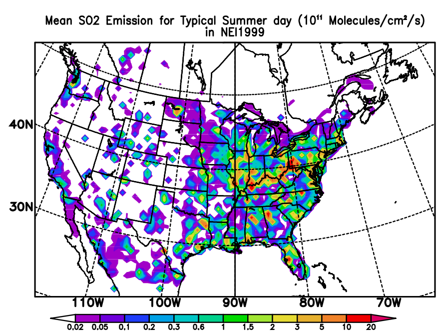
Chemical, Aerosol, Removal modules



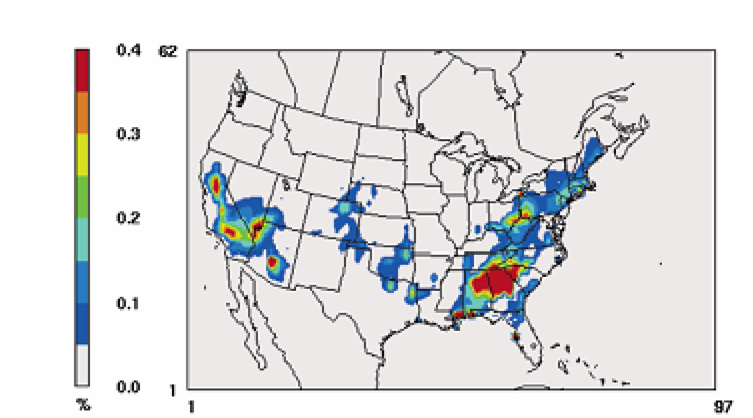
CTM



Emissions

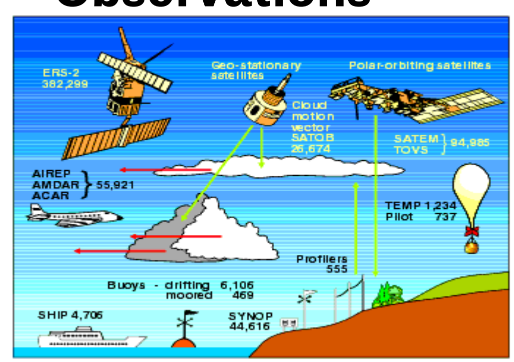


Predicted Quantity: e.g., *ozone AQ violation*

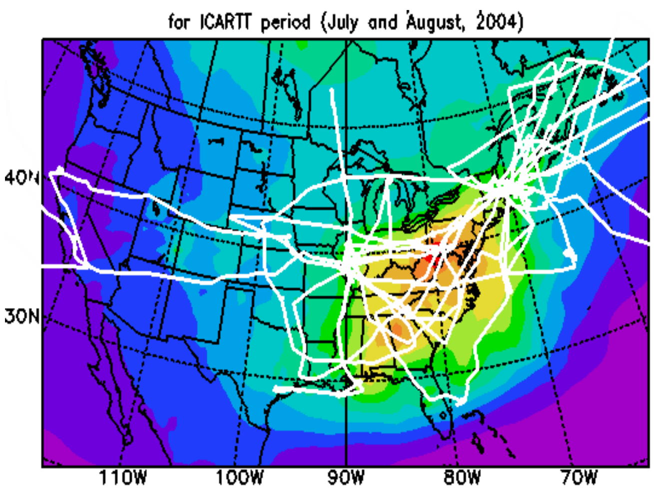


How confident are we in the models & predictions? What do the observations tell us about the quality of the calculation?

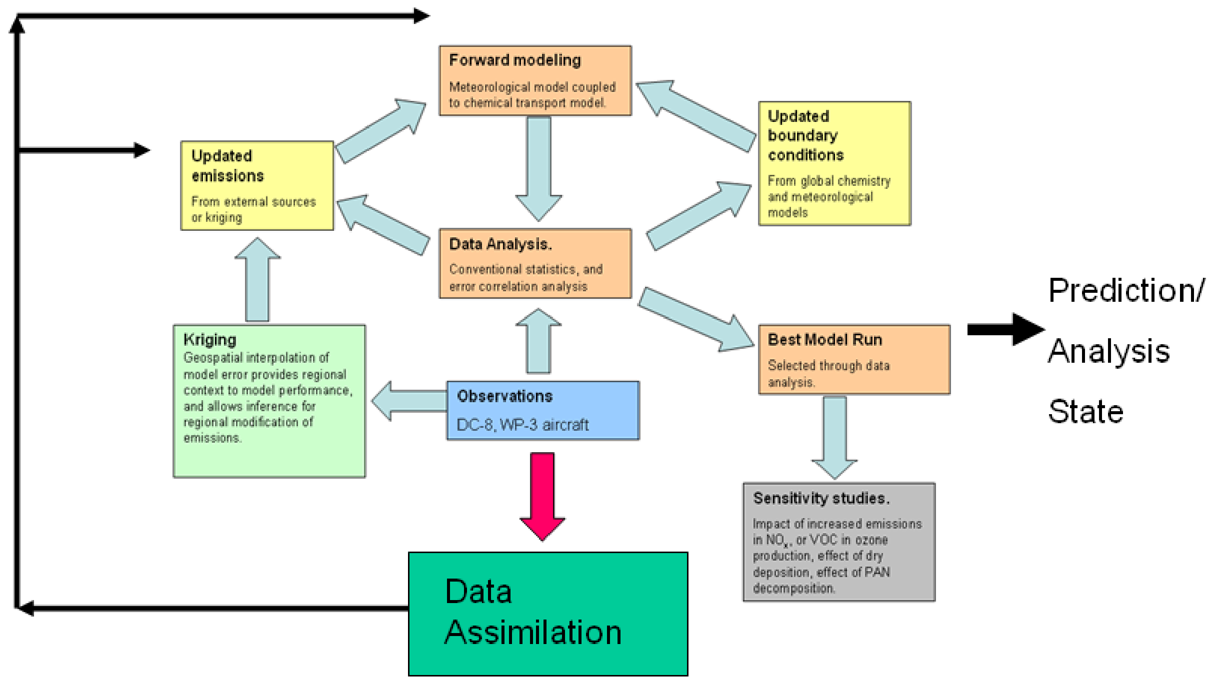
Observations



Experiments such as ICARTT employ mobile "Super-Sites" and Provide a Comprehensive Set of Observations



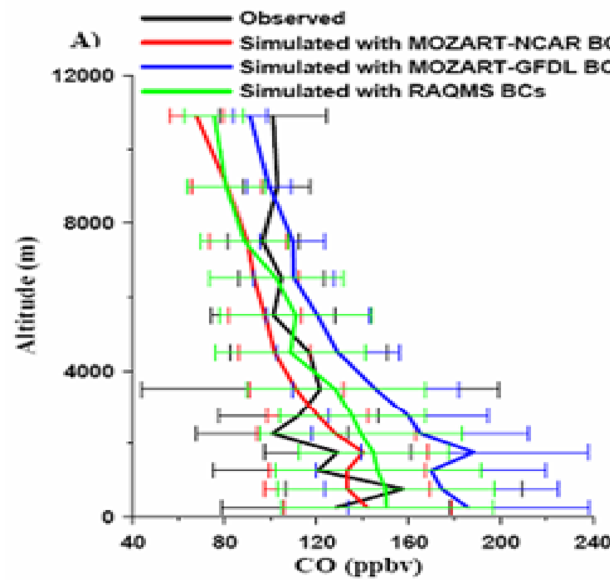
Analysis Approach



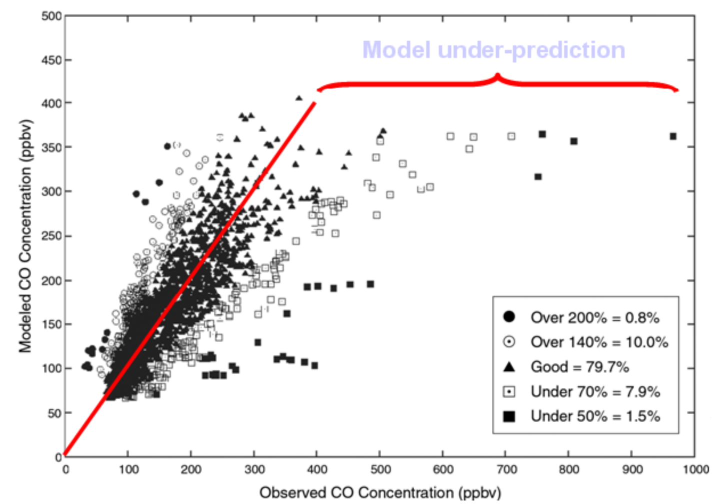
What do the agreements and disagreements with observations tell us?

Possible Reasons for Discrepancies:

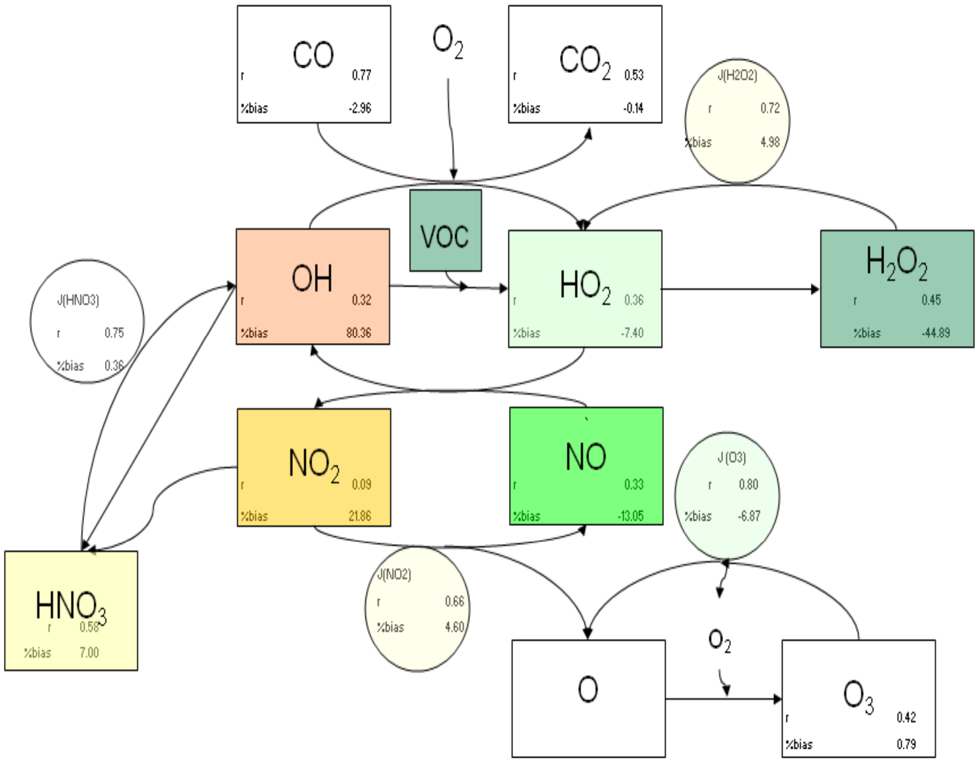
- **Emissions**
- **Meteorology**
- **Chemical processes**
- **Inaccuracy of measurements and representativeness**



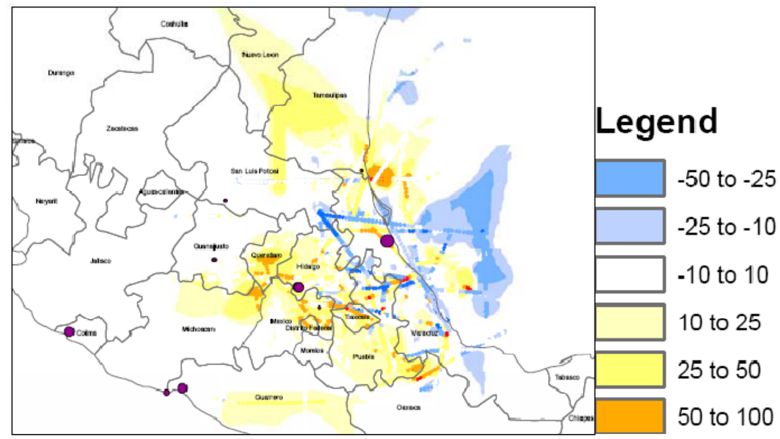
Post-mission analysis has shown that the inventory seems good for most species, except for high CO and BC observations in the Yellow Sea



Characterization of Errors

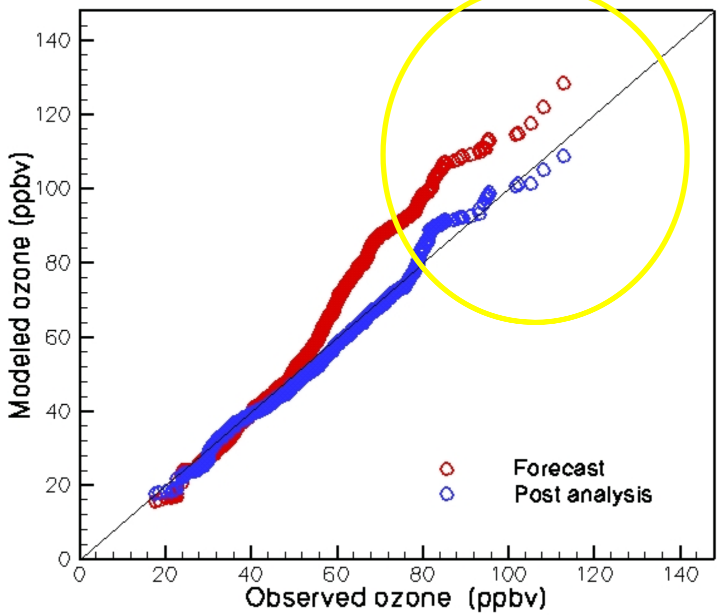


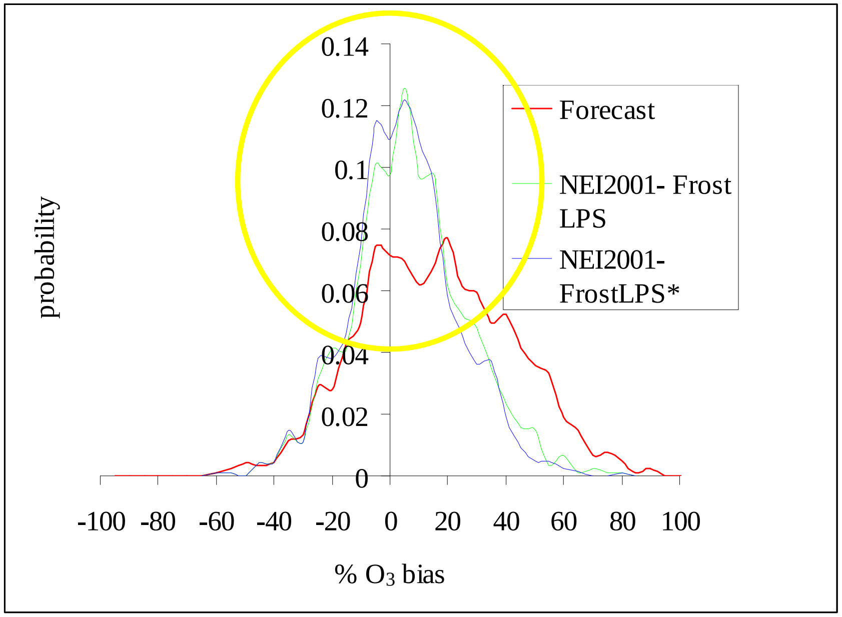
The comprehensive set of observations allows analysis of cycles



Spatial errors of JNO2

Documenting improvement (ICARTT)





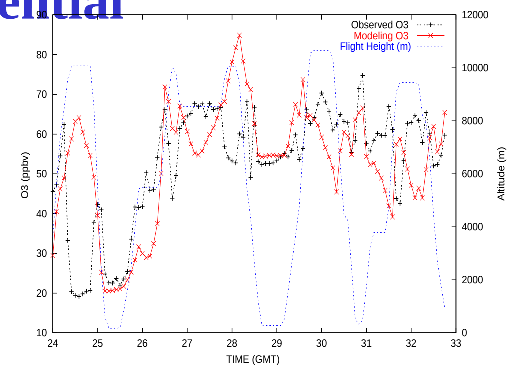
Left: Quantile-quantile plot of modeled ozone with observed ozone for DC-8 platform, data points collected at altitude less than 4000m, STEM-2K3, Forecast: NEI 1999, Post Analysis: NEI2001-Frost LPS*. MOZART-NCAR boundary conditions Right: Probability distribution of % ozone bias for Forecast (NEI 1999) and post analysis runs (NEI2001-FrostLPS and NEI2001-FrostLPS*) for DC-8 measurements under 4000m.

Mena et al., JGR, 2007

Advanced Data Assimilation Techniques Provide Data Fusion and Optimal Analysis Frameworks

-- Treatment of Error is Essential

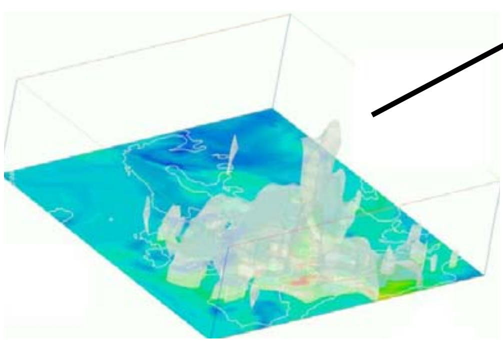
Model ~~vs.~~ + Observations

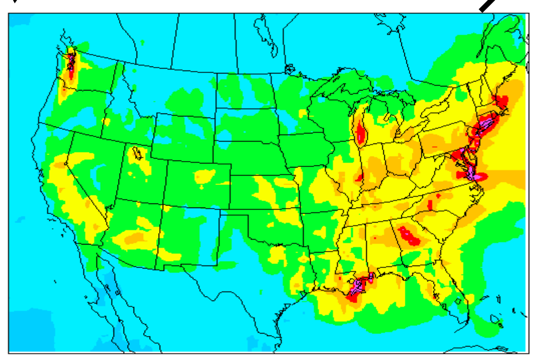


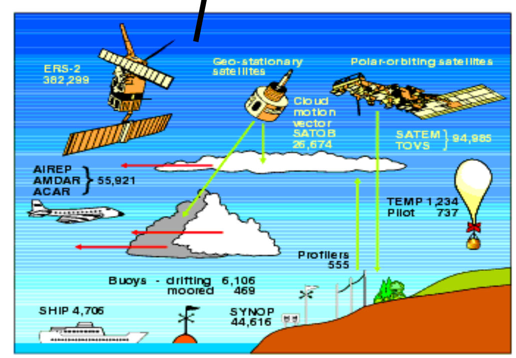
Example 4dVar:

Cost function

$$\min_{\mathbf{y}} \psi(\mathbf{y}) = \left\| \mathbf{y} - \mathbf{y}^{\mathbf{b}} \right\|^2_{\mathbf{B}^{-1}} + \left\| \mathbf{H} \cdot M(\mathbf{y}) - \mathbf{o} \right\|^2_{\mathbf{R}^{-1}}$$







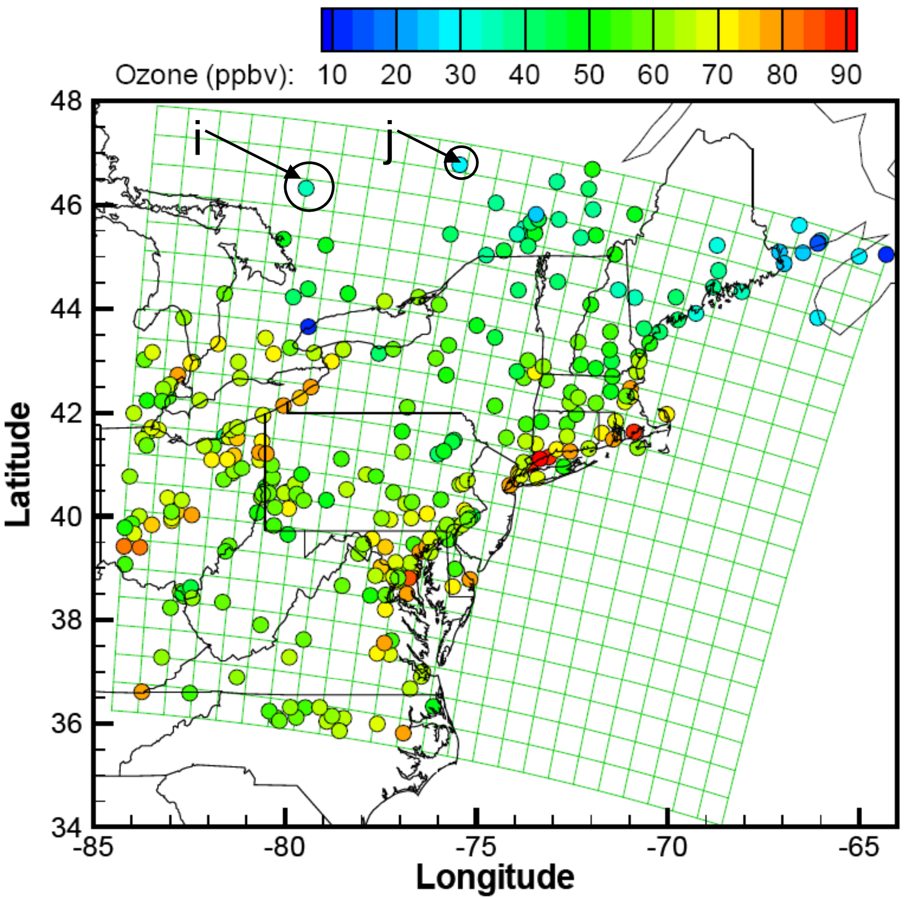
Current knowledge of the state

Model information consistent with physics/chemistry

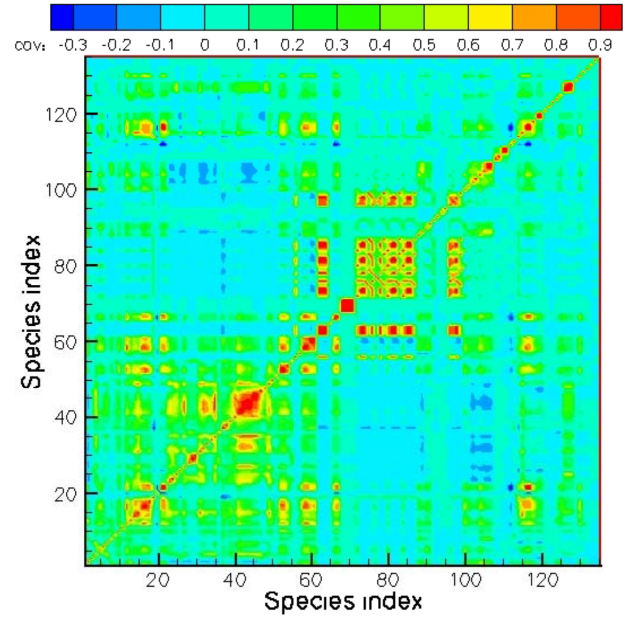
Observations information consistent with reality

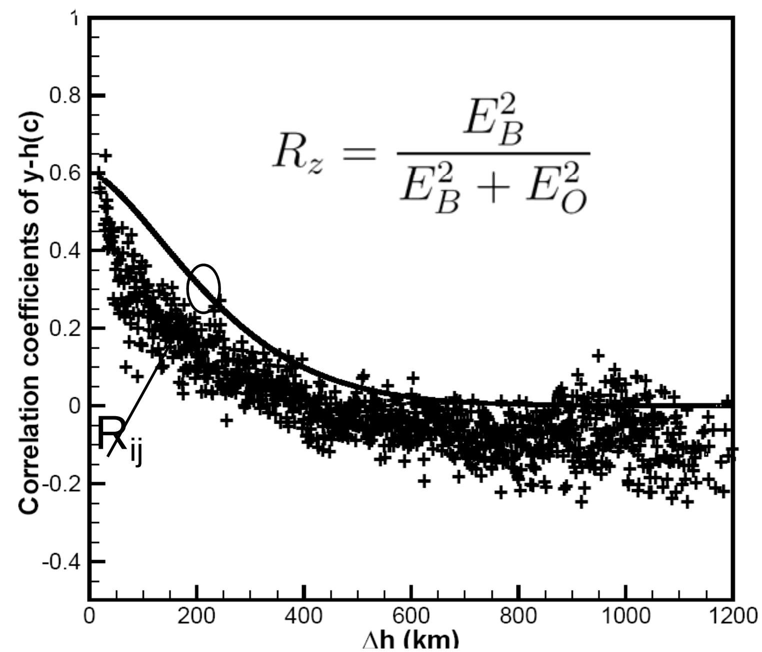
The system is very under-determined – need to combine heterogeneous data sources with limited spatial/temporal information

Observational Method (Hollingsworth-Lönnberg) for Background Errors



$$R_{ij} = \frac{\overline{(y^i - h^i(c))(y^j - h^j(c))}}{\sqrt{\overline{(y^i - h^i(c))} \cdot \overline{(y^j - h^j(c))}}}$$

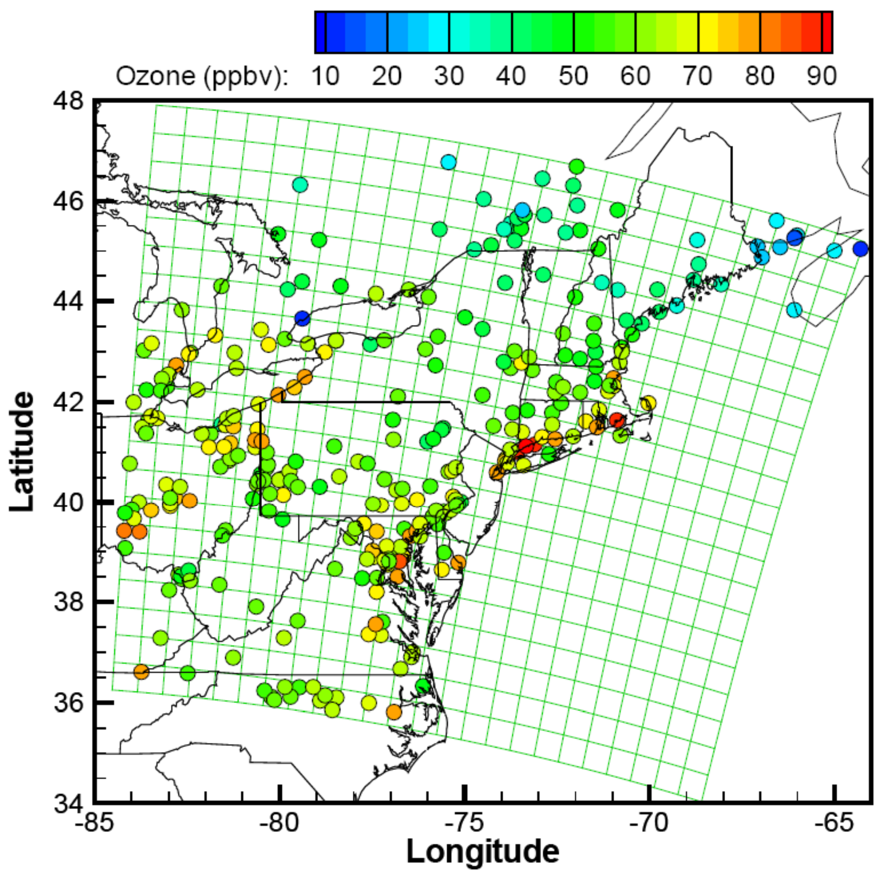




$$E = \sqrt{E_B^2 + E_O^2} = \sqrt{10^2 + 8^2} \approx 12.8 ppbv$$

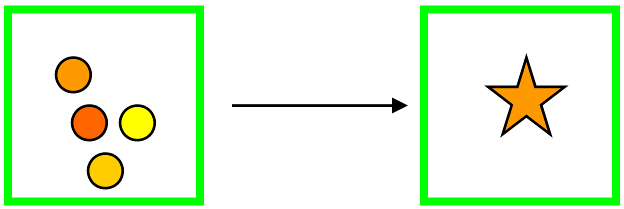
Observational error

$$J = \frac{1}{2}\left[c_0 - c_b\right]^T B^{-1}\left[c_0 - c_b\right] + \frac{1}{2}\left[y - h(c)\right]^T O^{-1}\left[y - h(c)\right]$$



Observational Error:

- Representative error
- Measurement error



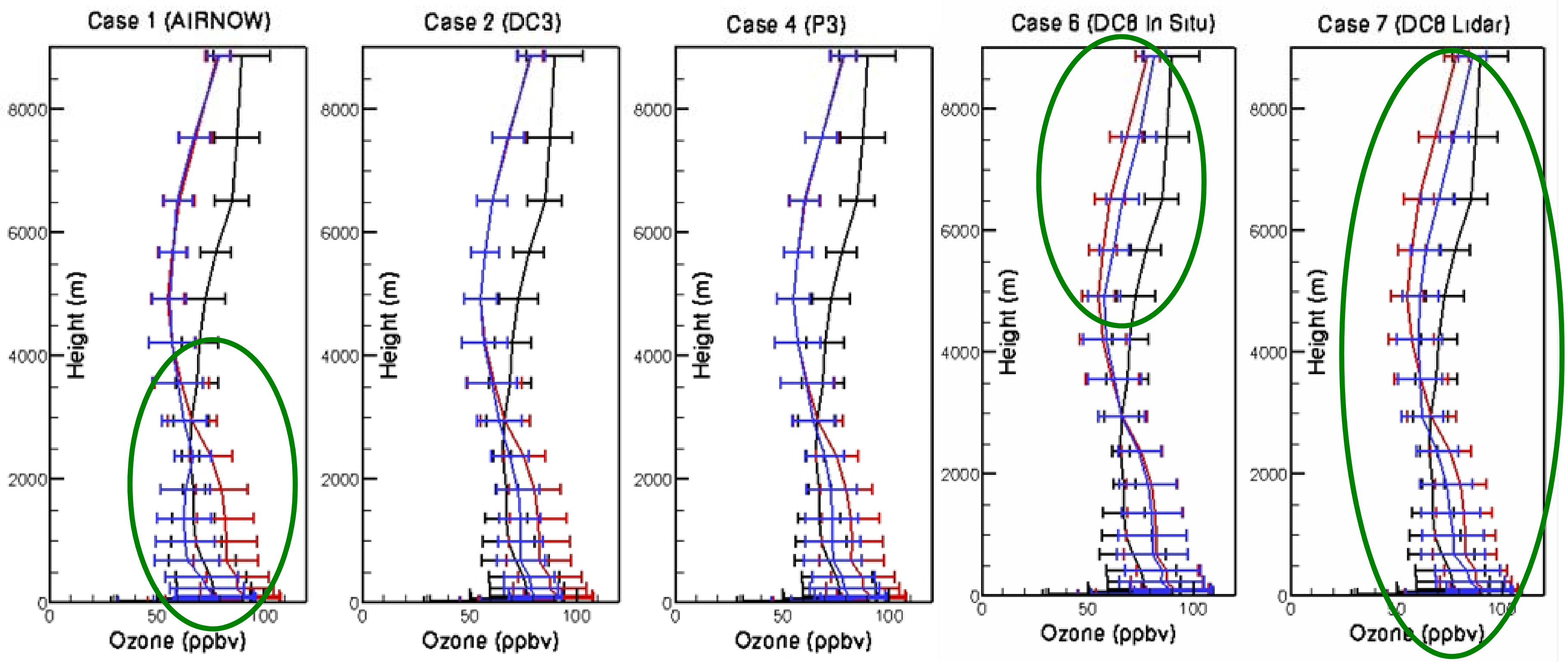
Observation Inputs

- Averaging inside 4-D grid cells
- Uniform error (8 ppbv)

Case	Assimilated Observations	Time	Number
1	AIRNOW	1300–2400 UT, hourly	2075
2	DC3	1852–2356 UT	412
3	MOZ-FN, MOZ-NF	1947–2007 UT, 2238–2252 UT	38
4	P3	1412–2207 UT	208
5	AIRMAP	1215–2400 UT	192
6	DC8-In	1416–2207 UT	138
7	DC8-Li	1429–2137 UT	465
8	RHODE, RONBR	1810–1822 UT, 1900–1921 UT	35
9	All above	1200–2400 UT	3563

Information content of various observations evaluated by different combinations of data sets assimilated –

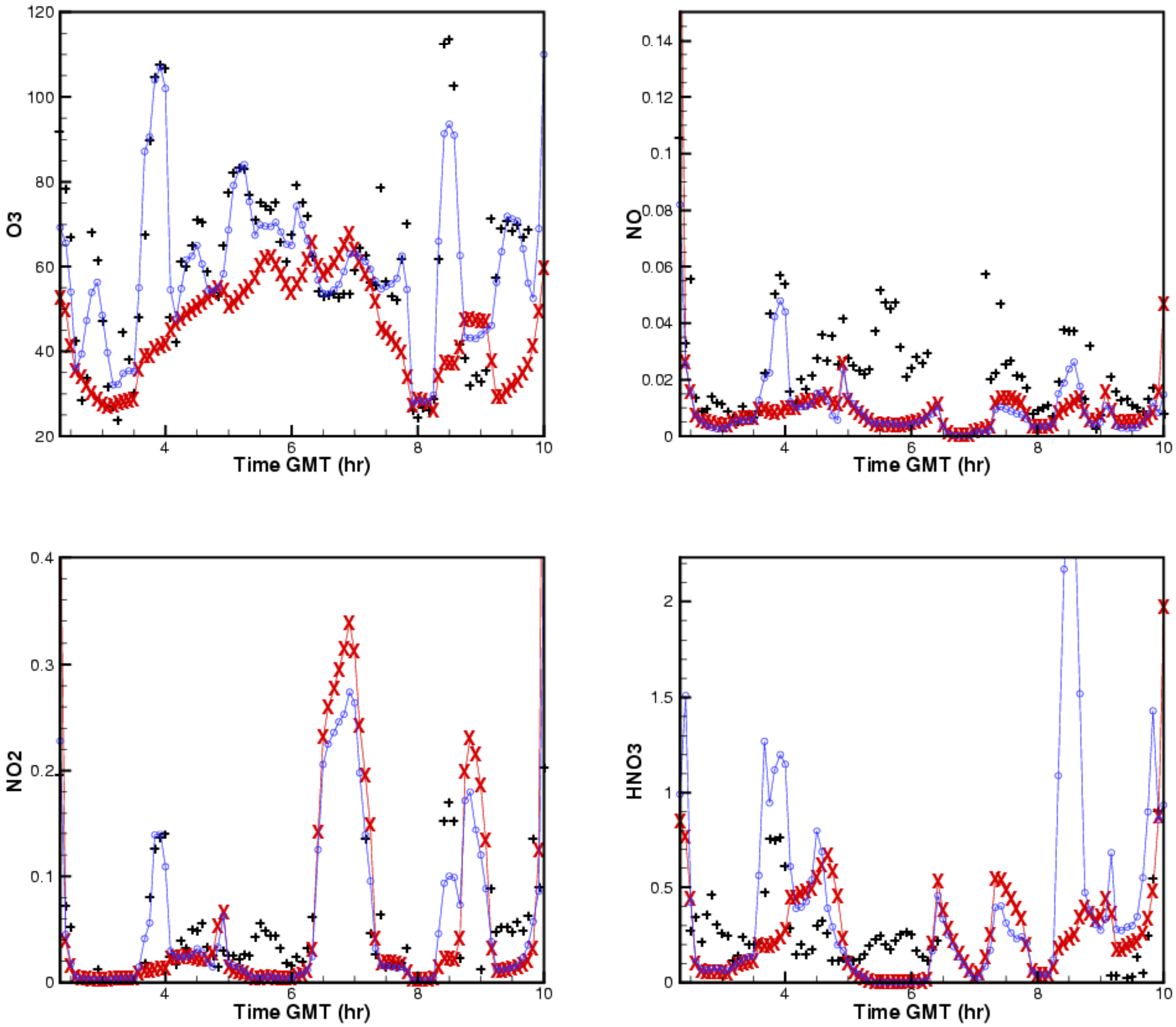
the importance of measurements above the surface.



Surface-only

Lidar-DC8

Assimilating multiple species



Measurement uncertainties:

O3:	8%
NO:	20%
NO2:	20%
HNO3:	100%
PAN:	100%
RNO3:	100%

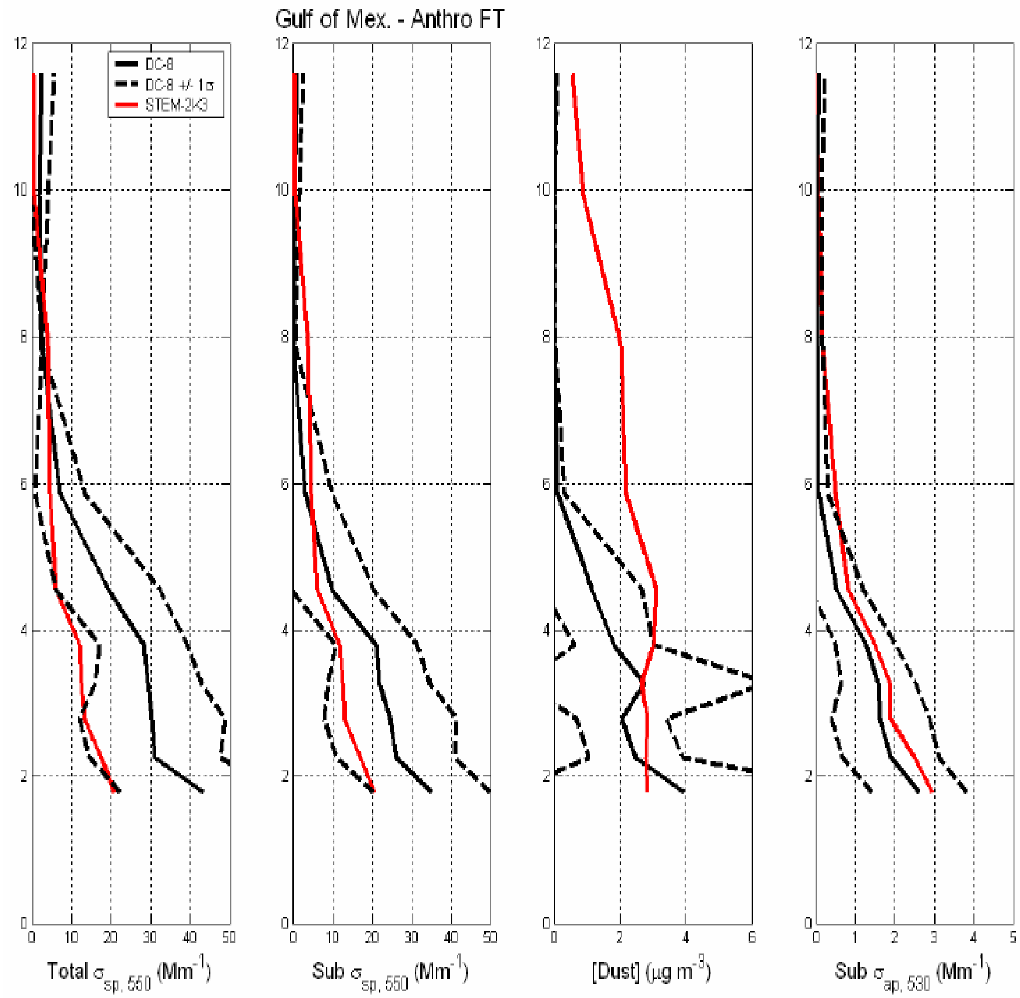
Aerosol Issues

1) **How well to models replicate vertical structure of anthropogenic aerosols?**

2) **How well do models predict column integrated aerosol optical properties?**

Approach: Observations compared to size distributions and optical properties prescribed and/or generated by chemical transport models in order to evaluate the fidelity of the model's representation of the atmospheric aerosol.

There are many challenges: matching size distributions, partitioning, number distributions, etc.



Cam's Thesis (2008)

Models can Also Add Value to the Observations:
e.g., 4-d context, trajectory analysis, observation "filling" using trajectories, etc.

How Representative are the Aircraft Observations?