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)

Chemical, Aerosol, Removal modules

Met model

CTM

Predicted Quantity: e.g., ozone AQ violation

Emissions

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
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

Example 4dVar:

Cost function

$$\min_y \psi(y) = \left\| y - y^b \right\|_B^{-1} + \left\| H \cdot M(y) - q \right\|_R^{-1}$$

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

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

\[ E = \sqrt{E_B^2 + E_O^2} = \sqrt{10^2 + 8^2} \approx 12.8 \text{ppbv} \]
Observational error

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

Observational Error:
- Representative error
- Measurement error

Observation Inputs
- Averaging inside 4-D grid cells
- Uniform error (8 ppbv)
Information content of various observations evaluated by different combinations of data sets assimilated – the importance of measurements above the surface.

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<th>Time</th>
<th>Number</th>
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<td>All above</td>
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Assimilating multiple species

Measurement uncertainties:

- O₃: 8%
- NO: 20%
- NO₂: 20%
- HNO₃: 100%
- PAN: 100%
- RNO₃: 100%
Aerosol Issues

1) How well do 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?