The impact of a priori assumptions on CO retrievals from IASI and MOPITT

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This Talk

- Tropospheric carbon monoxide
- Comparison of IASI and MOPITT
- The impact of *a priori* assumptions
- Implications for data assimilation

Also see Maya George’s Poster, *Carbon monoxide distributions from the IASI/Metop mission: Evaluation with other space-borne sensors*
Why Measure Carbon Monoxide?

- CO is created by chemical oxidation and incomplete combustion processes including industry, transport, and biomass burning.
- The main sink of CO is oxidation by OH, so high CO levels can potentially affect the oxidizing capacity of the atmosphere.
- Reaction of CO with OH in the presence of NO$_x$ leads to the formation of tropospheric O$_3$.
- CO lifetime is between a week and two months depending on location.
- This is long enough to be transported without becoming evenly mixed so making it a useful tracer.

Fig: Daniel Jacob, University of Harvard
CO total column 15 Sept. 2009

MOPITT V4

IASI
Good general agreement!

In clean regions, MOPITT V3 columns are usually higher than V4 and IASI because of a higher assumed \textit{a priori} profile

The much better sampling of IASI captures more plume variability

\textit{A priori} assumptions account for some of the other differences

<table>
<thead>
<tr>
<th>IASI</th>
<th>MOPITT V3</th>
<th>MOPITT V4</th>
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<tbody>
<tr>
<td>15-day average @ 5° x5°</td>
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Europe

Africa

China

May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov 2008 2009
What we want:
For required atmospheric state $X$ New Observations $y, S_\varepsilon$
Auxiliary observations will probably also be needed

The Retrieval
A cost function is minimized to obtain an “optimal estimate” of $X$ given the new observation & our prior knowledge of the atmosphere

What we think we already know:

The Physics of the Measurement:
Forward Model

Measurement sensitivity

$a priori$ constraint data $x_a, S_a$

$\hat{x}, \hat{S}, A = \frac{\partial \hat{x}}{\partial x}$
The Averaging Kernel

After the retrieval process we need to know how much information came from the observation relative to the *a priori*

\[
A = \frac{\partial \hat{x}}{\partial x}
\]

represents the retrieved profile sensitivity to the true profile

\[
\hat{x} - x_a = A \left( x - x_a \right) + \varepsilon \ldots
\]

smooth err.

ret. err.

IAASI averaging kernels for 19 retrieval layers, DFS = 1.99
George et al., ACP, 2009

death of freedom of signal (DFS)
A closer look at the *a priori* assumptions....

- IASI uses fixed *a priori* $x_a$ & $S_a$: Based on MOZAIC aircraft, ACE-FTS satellite and LMDx-INCA model data.
- Profile surface value ~ 100 ppbv and $S_a$ assumes relatively large fractional variability of 62% near the surface decreasing with altitude and a relatively long correlation length.
- MOPITT uses variable *a priori* $x_a$ and fixed $S_a$: Based on monthly $1^\circ \times 1^\circ$ MOZART model data and NOAA aircraft validation for MOPITT.
- $S_a$ assumes constant 30% fractional variability with altitude and a short correlation length.

$A = \frac{\partial \hat{X}}{\partial X} = I - \hat{S}S_a^{-1} = (K^T S_{\epsilon}^{-1}K + S_a^{-1})^{-1} K^T S_{\epsilon}^{-1}K$
A validation exercise comparing retrievals from two instruments must first quantify the expected difference due to:

1) Retrieval assumptions: methodology, \textit{a priori}
2) Measurement and instrument characteristics: weighting functions, measurement errors, auxiliary observation

Any remaining ‘problem’ differences are due to inaccurate characterization of the above.

An ideal comparison would use the same retrieval algorithm.

Here we use a common OE methodology and \textit{a priori} to pin down 1) and look for consistency between retrievals based on what we know about 2)

Compare coincidences at 2 locations...
Comparison of Column Data, Oct. 2009

IASI vs. MOPITT over Africa (30 S – Equ, 10-40 E)

$R^2 = 0.93$

- Comparison of co-located IASI and MOPITT (V4) CO total columns is generally good
- Comparison is not much improved by processing MOPITT column data using IASI prior constraints
- Implies that a priori assumptions have only a small effect on total column retrievals
- But what about the underlying profile shapes?
Over Angola: 14E, 14S, Oct. 15, 2009

\[
\text{Units of } C = (x10^{18}) \text{ molecules/cm}^2
\]
Over Indian Ocean: 60E, 40S, Oct. 15, 2009

**MOPITT**
- DFS = 1.2
- C = 1.86

**IASI**
- DFS = 1.5
- C = 2.01

**MOPITT** vs **IASI**
- DFS = 1.4
- C = 1.99
There’s significant activity exploring the assimilation of satellite trace gas data in chemical transport models:

- Chemical weather forecasts
- Flight support for chemistry field campaigns
- Improving emissions estimates
- Improving model physics
- Examining correlations between different pollutant fields including those that are not measured
- Performing OSSEs to quantify the impact of future satellite measurements

For these applications, the impact of retrieval *a priori* assumptions on the DA system must be quantified.
Retrieved Profile Assimilation Options

- Assimilation of $\hat{\mathbf{x}}$ with covariance $\hat{\mathbf{S}}$ is inappropriate because of the contribution from $\mathbf{x}_a$

- Assimilation of
  $$\hat{\mathbf{x}} - \mathbf{x}_a = \mathbf{A} (\mathbf{x} - \mathbf{x}_a) + \mathbf{e}$$
  with $\mathbf{A}$ as the observation operator eliminates the bias due to $\mathbf{x}_a$ (but still leaves a dependence on $\mathbf{S}_a$)

- Retrieved profile values and their $\mathbf{A}$ are correlated because of limited vertical information: Precludes independent sequential DA of each retrieval level

- With DFS $< 2$, there usually exists a null-space in $\mathbf{A}$ and redundant information that may lead to numerical errors

- Application of SVD to $\mathbf{A}$ (Joiner & daSilva, 1998) has the advantages of:
  - Reducing the number of ‘measurements’ to $\approx$ DFS which eliminates the correlated errors inherent in assimilation of profile points
  - Improving efficiency for processing the large amount of IASI profile data
Example IASI Rotated Averaging Kernel

IASI AK over Indian Ocean: DFS = 1.5

Rotated AK

SVD of retrievals prior to data assimilation:

- Transform the retrieval equation for $\hat{X}$ so that the error covariance is a unit matrix
- Rotate the scaled AK matrix using its associated singular vectors
- Truncate the resulting rotated AK matrix at eigenvalues $<< 1$
- The retrieved profile has been transformed into uncorrelated scalar observations while maintaining the information content
Summary

- Agreement of IASI and MOPITT CO retrievals is good and consistent
- Impact of \textit{a priori} assumptions on retrieved total column is small
- Impact on retrieved profile shape is significant
- Performing an SVD of retrievals prior to assimilation has advantages for efficiency

Next Steps

- Instead of assimilating retrievals, use the intermediate linearized radiances:
  \[ y - F(x_0) = K(x - x_0) + \epsilon, \quad S_\epsilon \]
- Eliminates explicit impact of retrieval \textit{a priori}
- User does not have to understand the full forward model or instrument
- Application of SVD is again an option to concentrate on significant measurement information
- Based on this approach we may provide new products for DA application
Thank You!