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

David Edwards, Avelino Arellano,
Dallas Masters, Merritt Deeter & Debbie Mao
ACRESP, NCAR, Boulder, Colorado USA

Cathy Clerbaux & Maya George
Service d'Aéronomie /CNRS, IPSL, Paris, France

Pierre Coheur & Daniel Hurtmans
Université Libre de Bruxelles, Belgium

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**

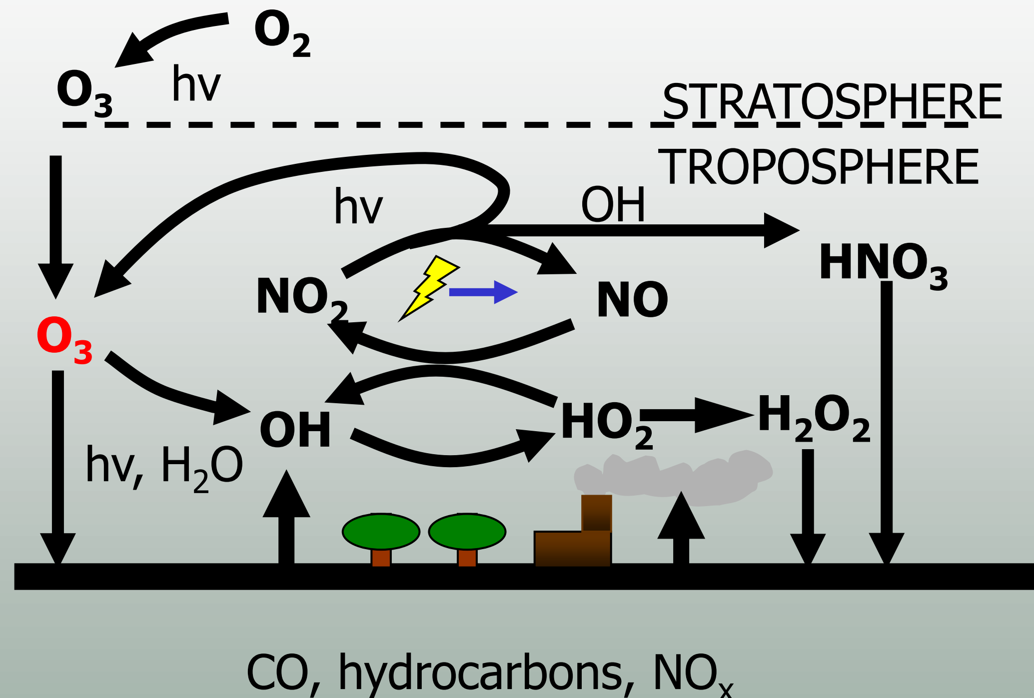
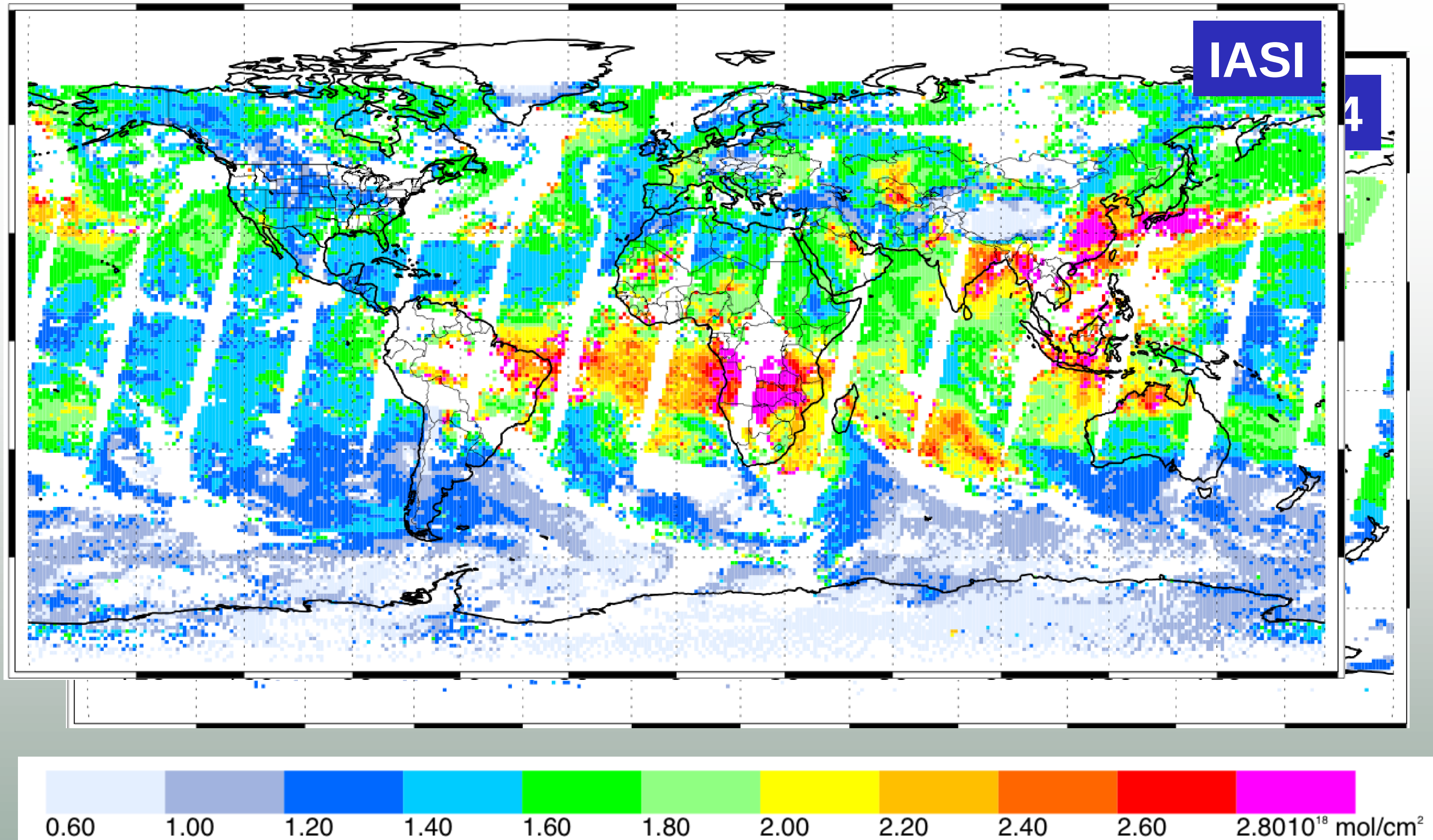


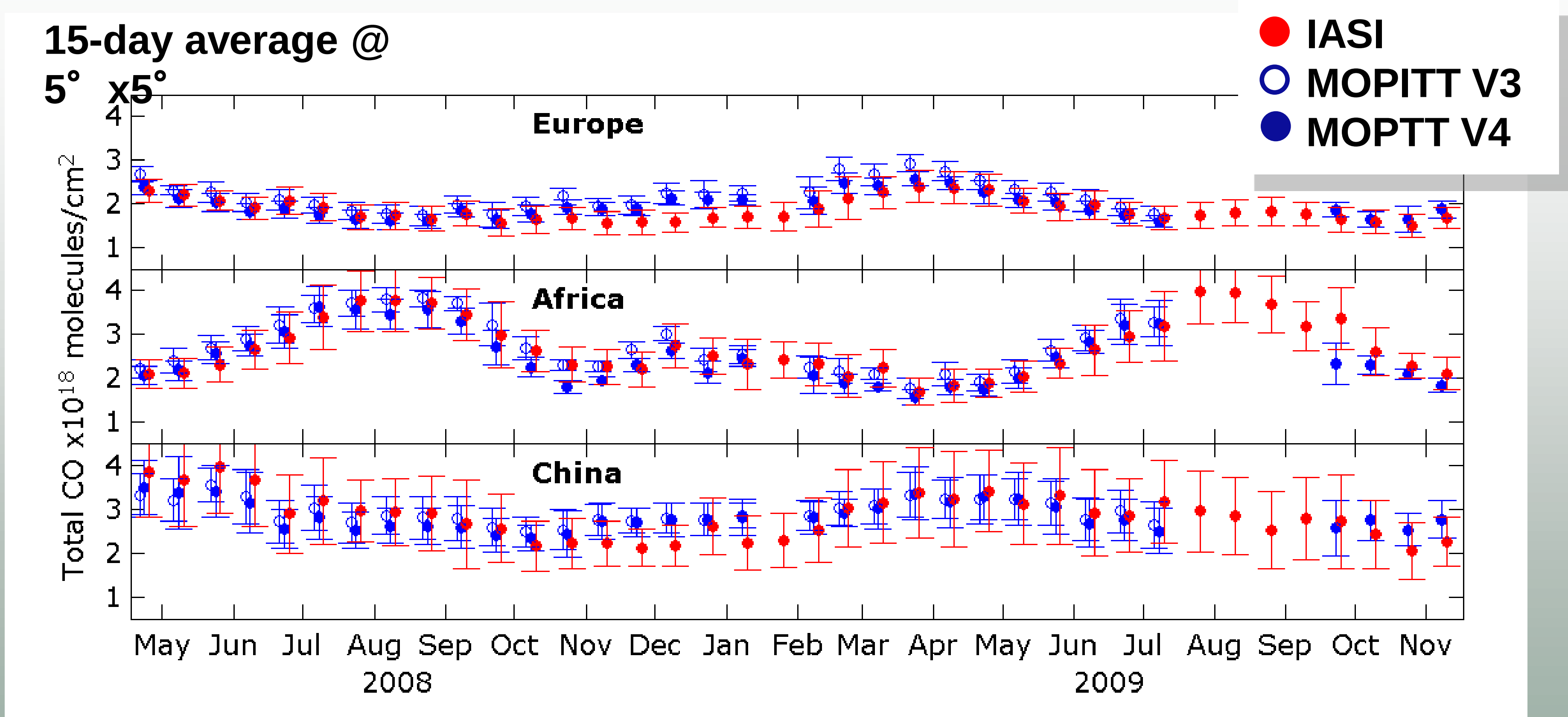
Fig: Daniel Jacob, University of Harvard

CO total column 15 Sept. 2009



IASI & MOPITT Trends in CO Column

- **Good general agreement!**
- **In clean regions, MOPITT V3 columns are usually higher than V4 and IASI because of a higher assumed *a priori* profile**
- **The much better sampling of IASI captures more plume variability**
- ***A priori* assumptions account for some of the other differences**

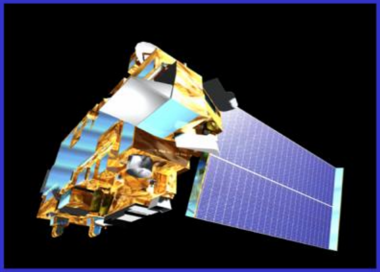


The Retrieval

What we want:

For required atmospheric state $\mathbf{x}$

New Observations $\mathbf{y}, \mathbf{S}_{\varepsilon}$



Auxiliary observations will probably also be needed

What we think we already know :

The Physics of the Measurement:

Forward Model $\mathbf{y} = \mathbf{F}(\mathbf{x}) + \varepsilon$

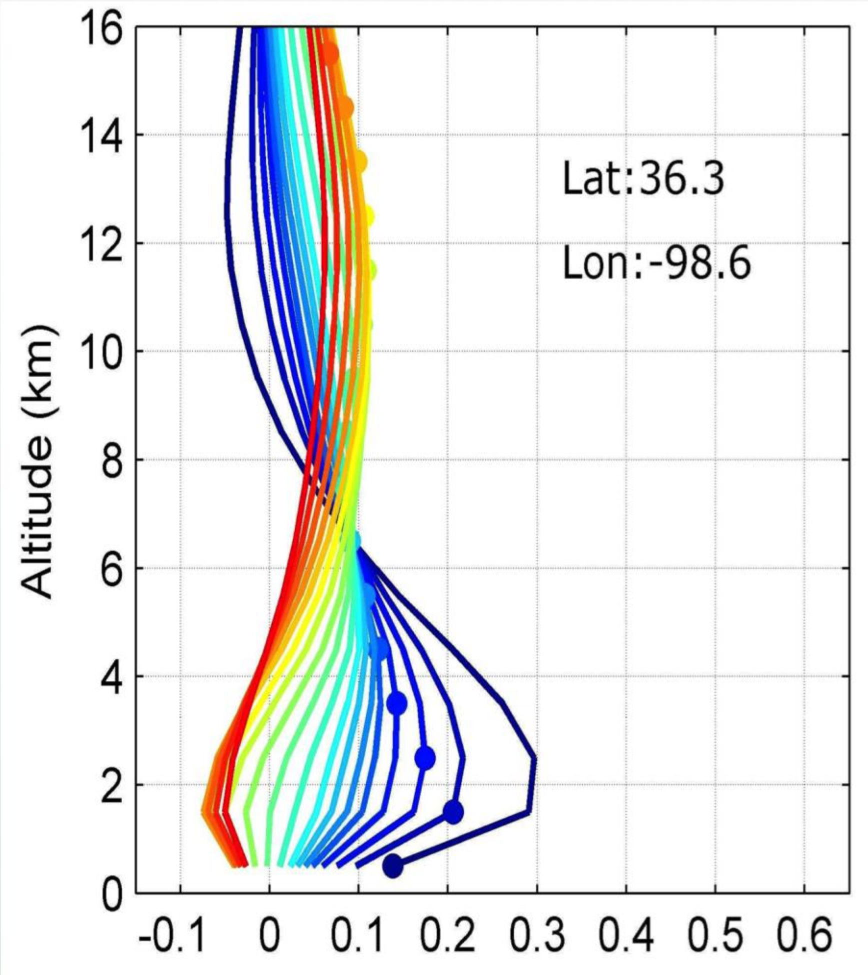
Measurement sensitivity $\mathbf{K} = \dfrac{\partial \mathbf{F}}{\partial \mathbf{x}}$

a priori constraint data $\mathbf{x}_a , \mathbf{S}_a$

A cost function is minimized to obtain an "optimal estimate" of $\mathbf{x}$ given the new observation & our prior knowledge of the atmosphere

$$\hat{\mathbf{x}}, \ \hat{\mathbf{S}}, \ \mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

The Averaging Kernel



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

$$\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

represents the retrieved profile sensitivity to the true profile

$$\hat{\mathbf{x}} - \mathbf{x}_a = \underbrace{\mathbf{A}\left(\mathbf{x} - \mathbf{x}_a\right)}_{\text{smooth err.}} + \underbrace{\varepsilon \ldots}_{\text{ret. err.}}$$

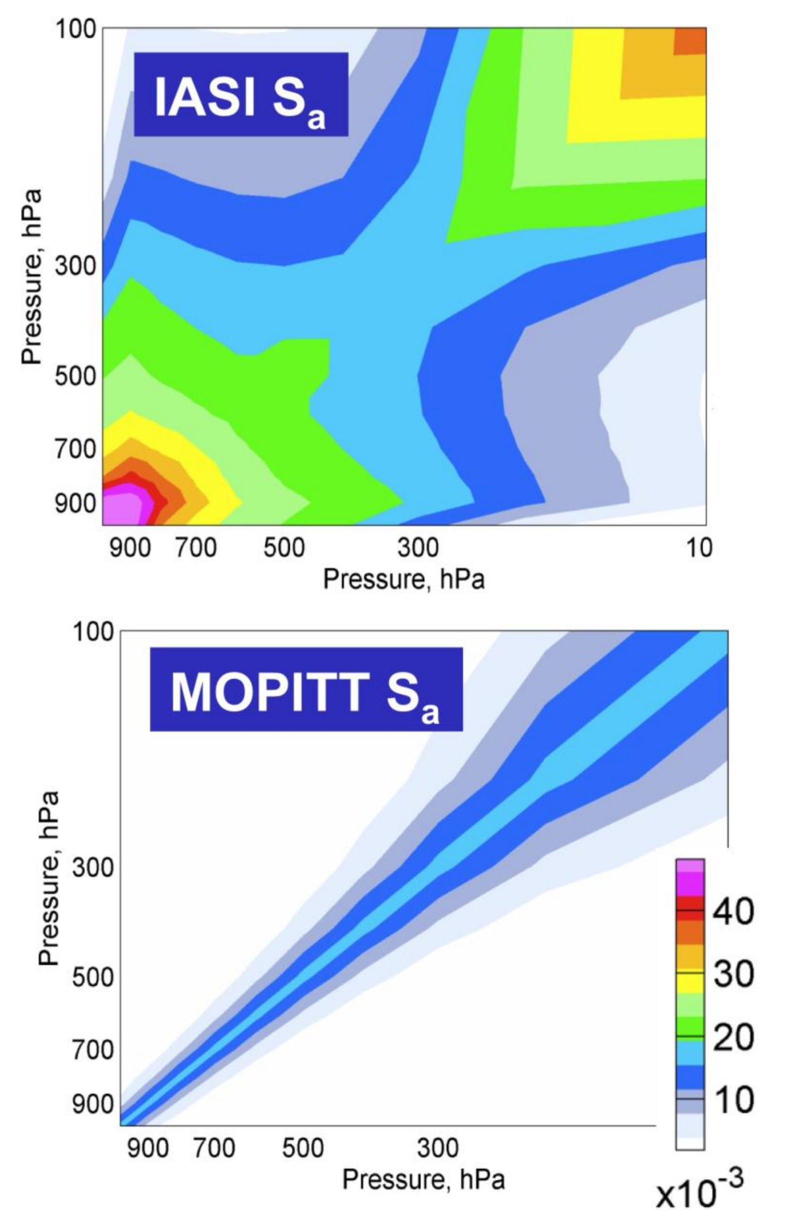
IASI averaging kernels for 19 retrieval layers, DFS = 1.99
George et al., ACP, 2009

$$trace\,(\mathbf{A}) =$$ ***degrees of freedom of signal (DFS)***

A closer look at the *a priori* assumptions….

- **IASI uses fixed *a priori* $\mathbf{x}_a$ & $\mathbf{S}_a$: Based on MOZAIC aircraft, ACE-FTS satellite and LMDx-INCA model data**
- **Profile surface value ~ 100 ppbv and $\mathbf{S}_a$ assumes relatively large fractional variability of 62% near the surface decreasing with altitude and a relatively long correlation length**
- **MOPITT uses variable *a priori* $\mathbf{x}_a$ and fixed $\mathbf{S}_a$: Based on monthly 1° x 1° MOZART model data and NOAA aircraft validation for MOPITT**
- **$\mathbf{S}_a$ assumes constant 30% fractional variability with altitude and a short correlation length**
  ➔ $\mathbf{A}$ looks more like $\mathbf{K}$

$$\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}} = \mathbf{I} - \hat{\mathbf{S}}\mathbf{S}_a^{-1} = (\mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1}\ \mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K}$$



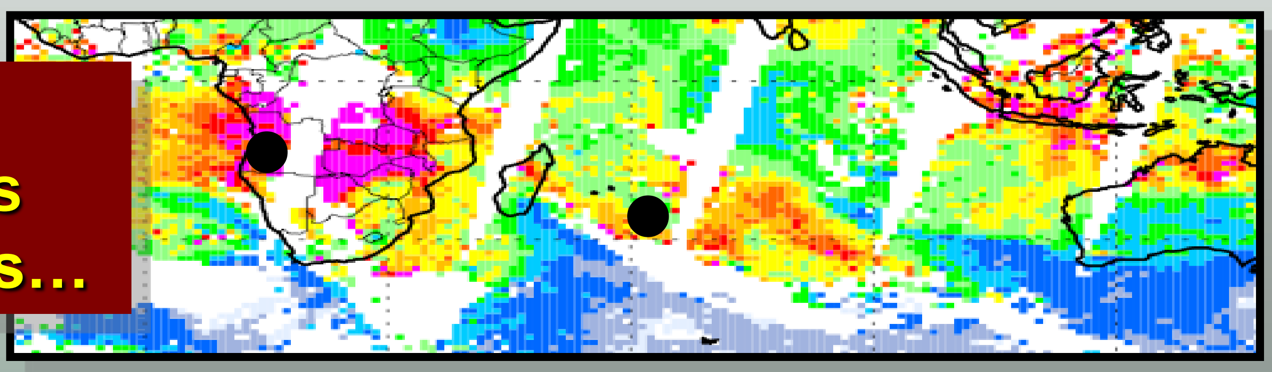
Explaining Profile Differences

- **A validation exercise comparing retrievals from two instruments must first quantify the expected difference due to:**

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

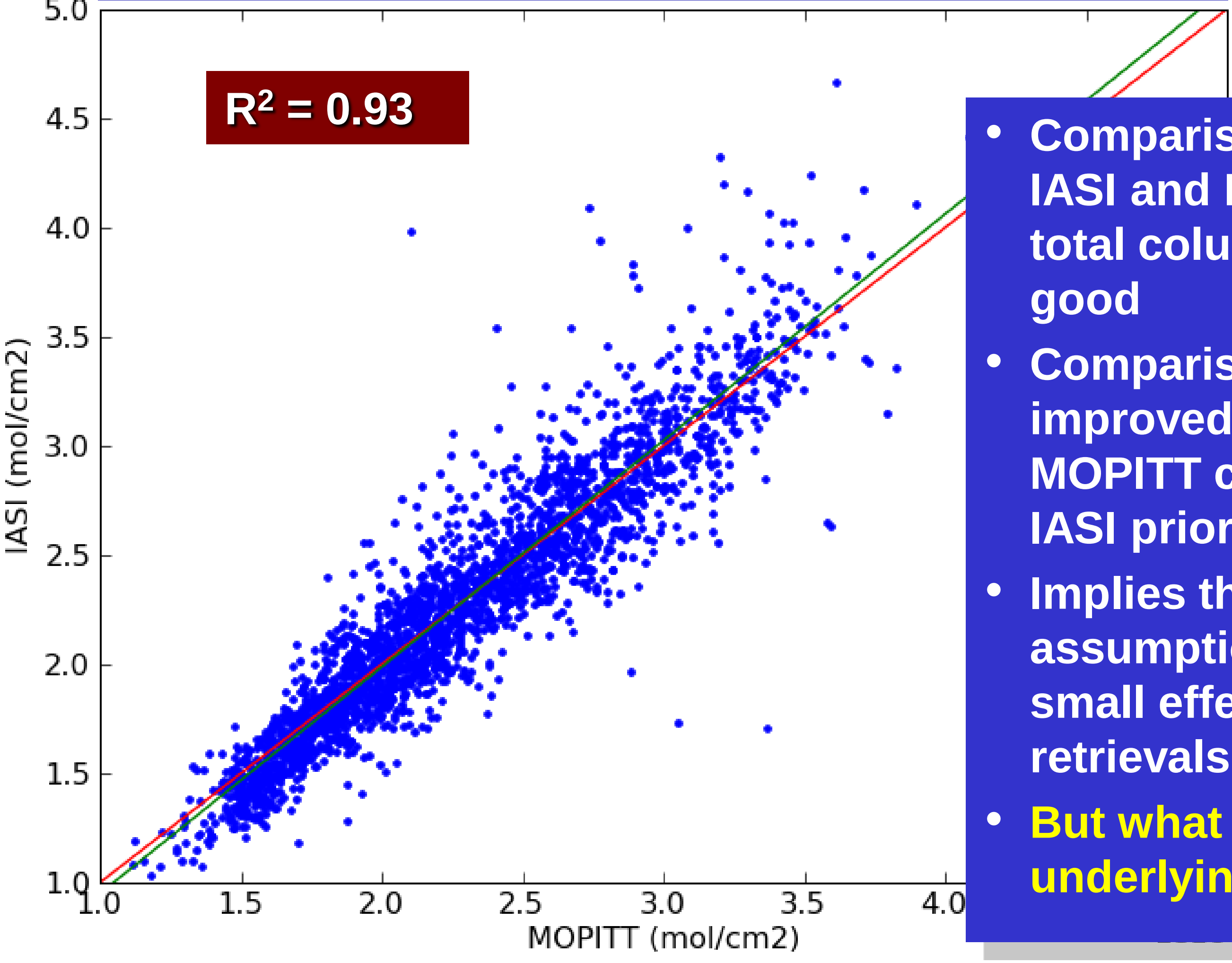
- **Any remaining ‘problem’ differences are due to inaccurate characterization of the above**
- **An ideal comparison would use the same retrieval algorithm**
- **Here we use a common OE methodology and *a priori* to pin down 1) and look for consistency between retrievals based on what we know about 2)**

Compare coincidences at 2 locations…



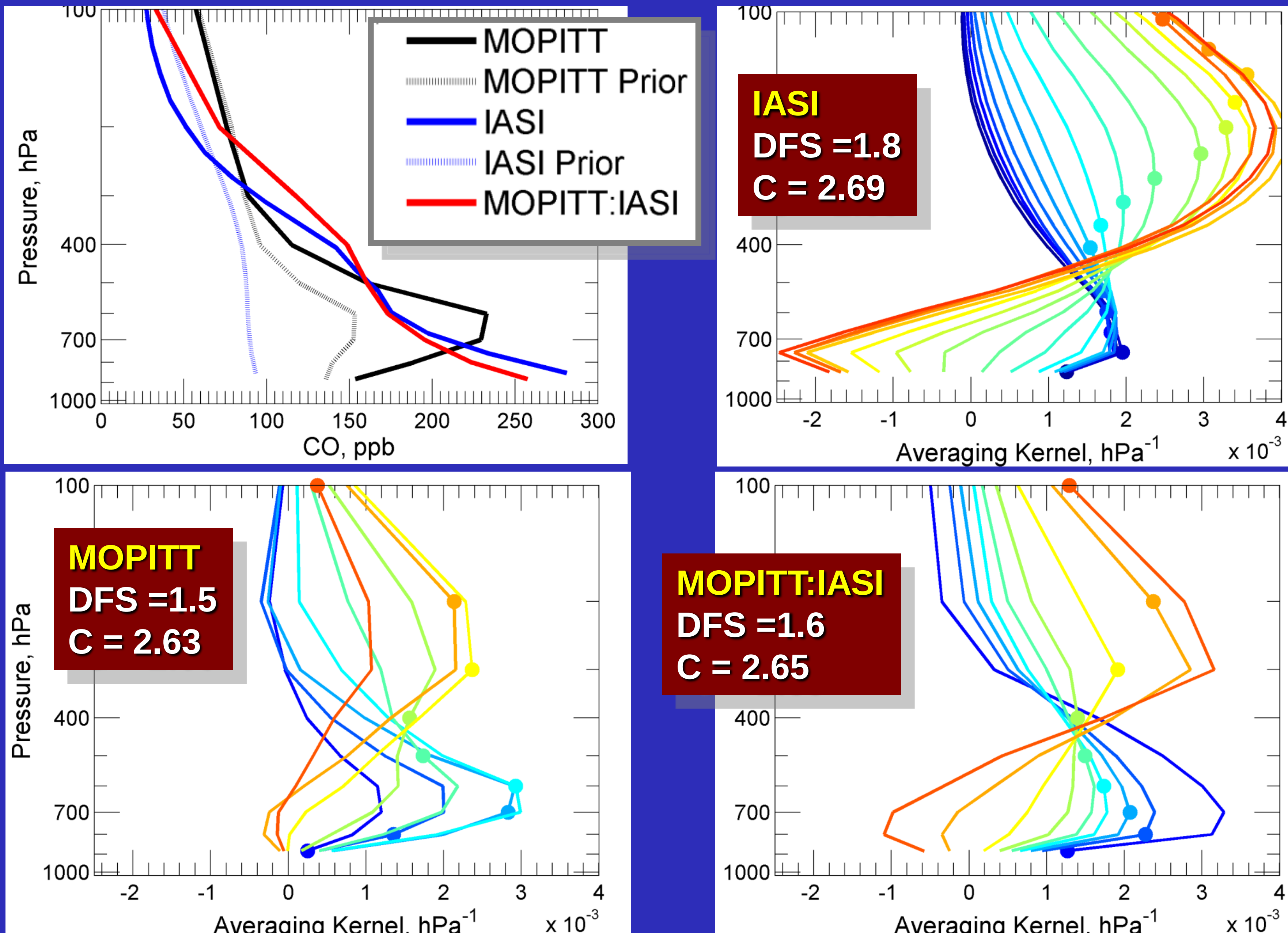
Comparison of Column Data, Oct. 2009

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



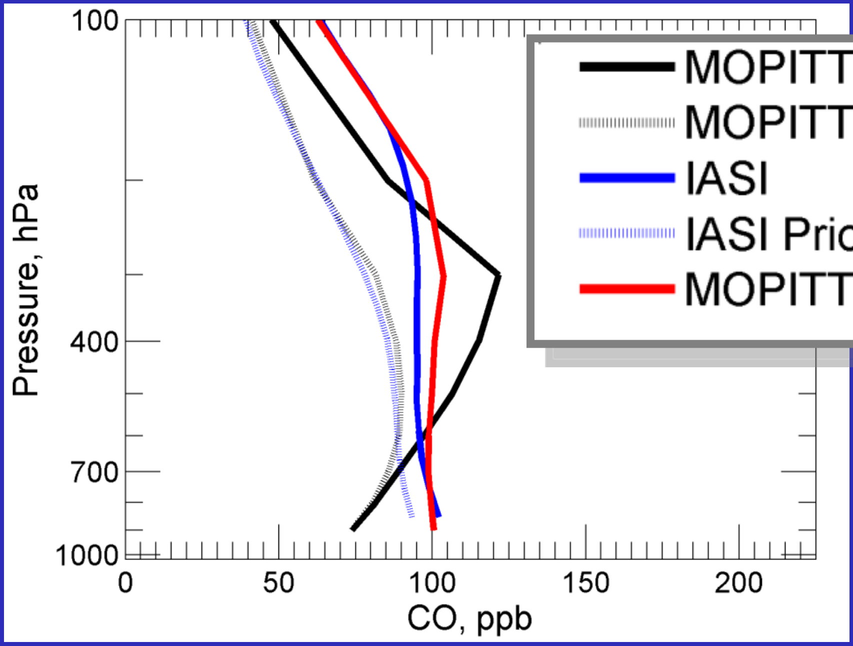
- **Comparison of co-located IASI and MOPITT (V4) CO total columns is generally good**
- **Comparison is not much improved by processing MOPITT column data using IASI prior constraints**
- **Implies that *a priori* assumptions have only a small effect on total column retrievals**
- **But what about the underlying profile shapes?**

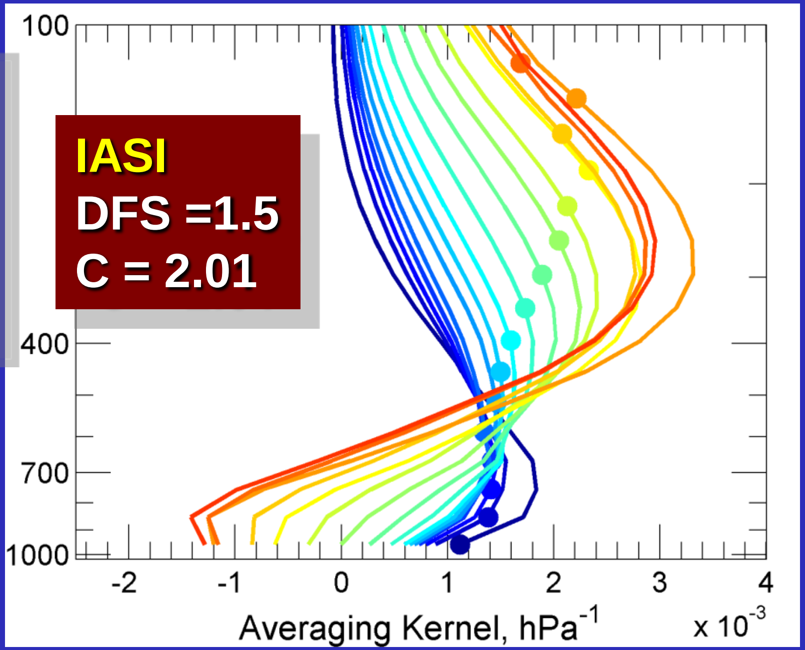
Over Angola: 14E,14S, Oct. 15, 2009

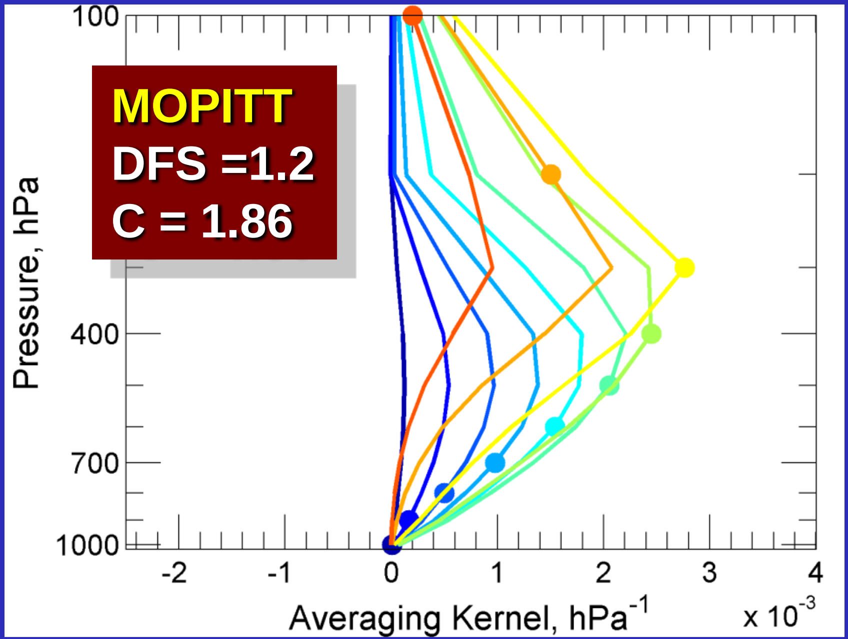


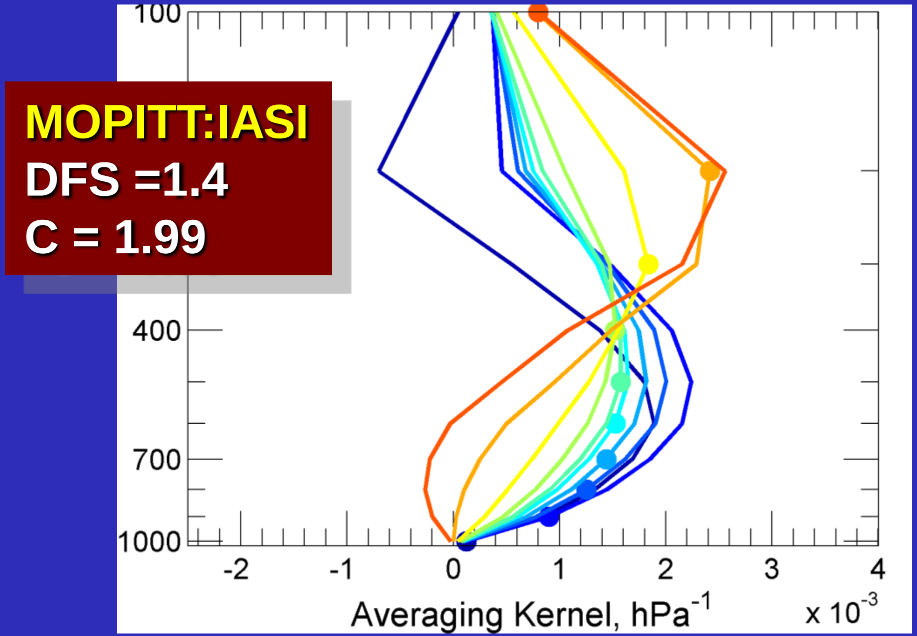
Units of C are (x10^{18}) molecules/cm^2

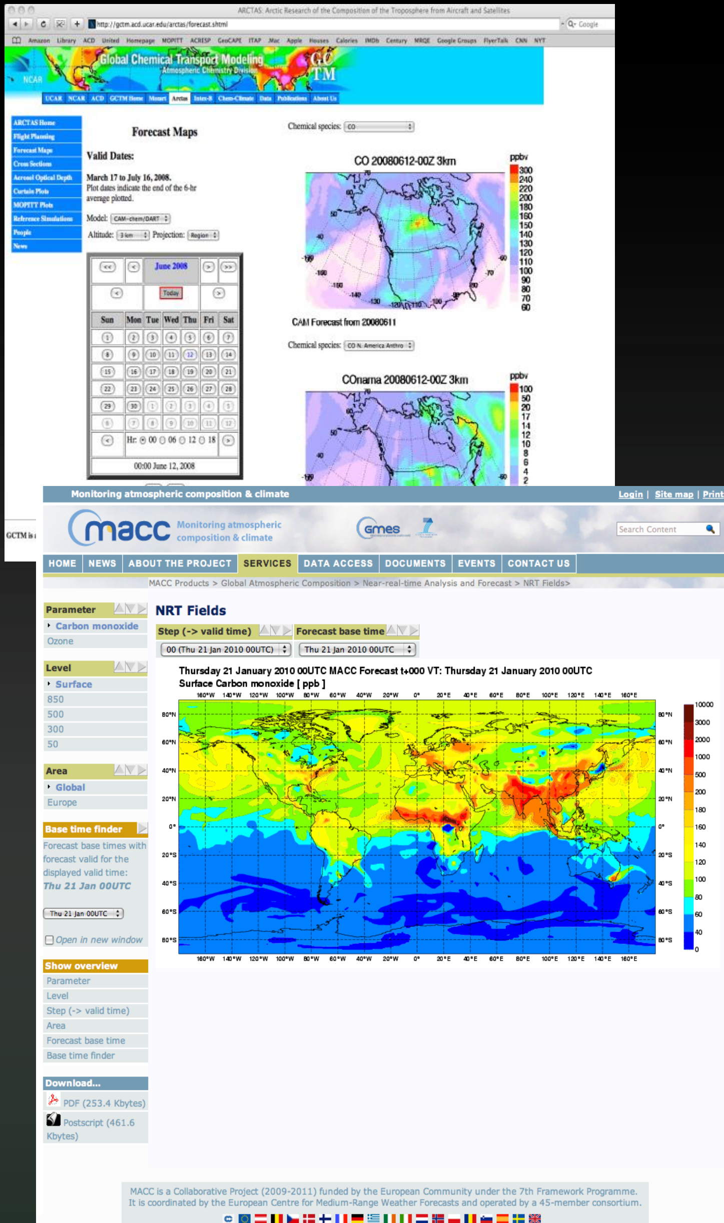
Over Indian Ocean: 60E, 40S, Oct. 15, 2009



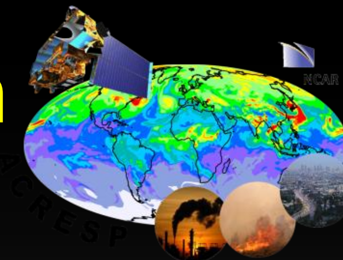








Data Assimilation



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

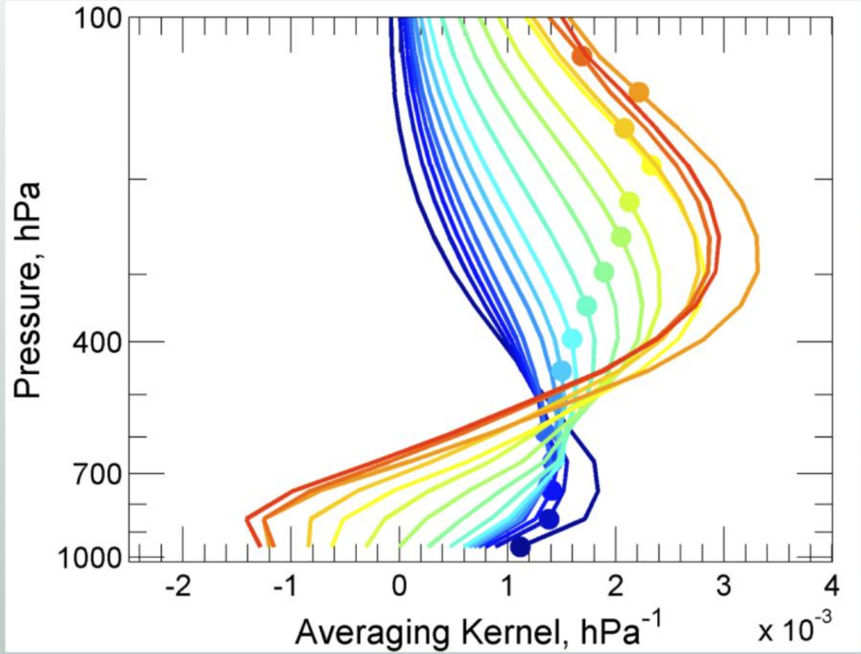
Retrieved Profile Assimilation Options

- Assimilation of $\hat{\mathbf{x}}$ with covariance $\hat{\mathbf{S}}$ is inappropriate because of the contribution from $\mathbf{x}_a$
- Assimilation of $\hat{\mathbf{x}} - \mathbf{x}_a = \mathbf{A}(\mathbf{x} - \mathbf{x}_a) + \varepsilon$ 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:

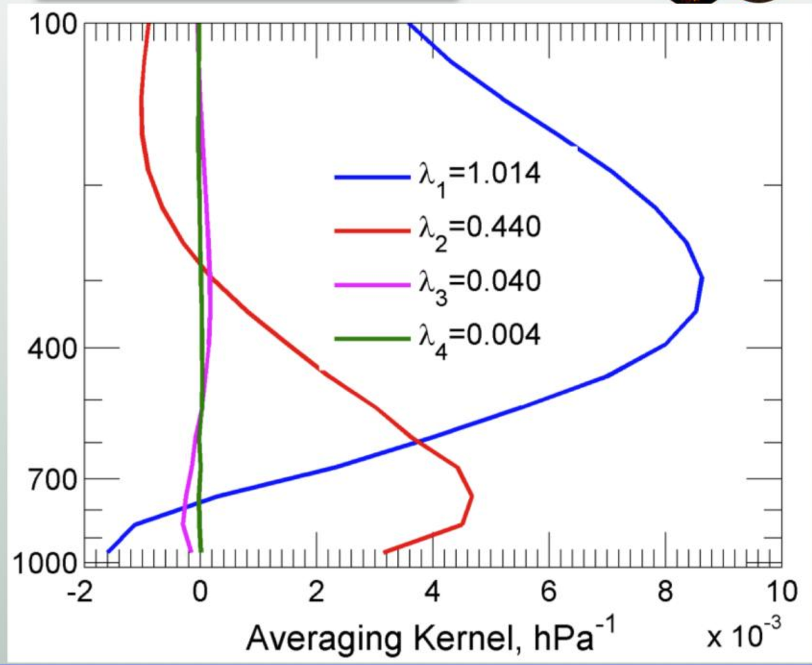
> - Reducing the number of 'measurements' to ≈ DFS which eliminates the correlated errors inherent in assimilation of profile points
> - Improving efficiency for processing the large amount of IASI profile data

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 *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:

$$\mathbf{y} - \mathbf{F}(\mathbf{x}_0) = \mathbf{K}(\mathbf{x} - \mathbf{x}_0) + \varepsilon, \quad \mathbf{S}_\varepsilon$$

- Eliminates explicit impact of retrieval *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!