Aspects of Resolution-Dependent Analysis:
Vertical Mapping from Data Space

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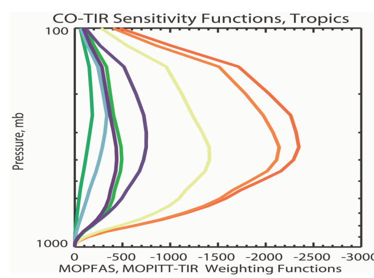
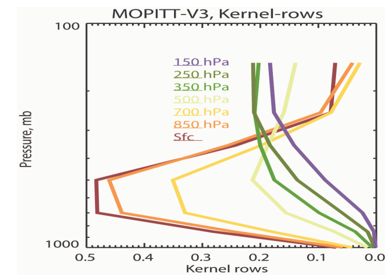
- **Topic:** analysis of space-borne observations when the sensitivity (weighting) functions of sensors spread over deep layers, 5 km or more.





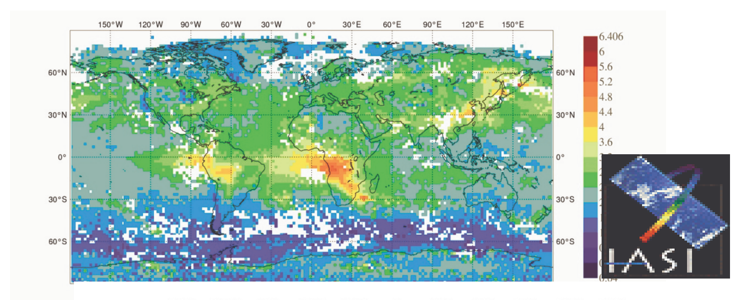
- **Motivation -** interpret the recently reported systematic differences in carbon monoxide (CO) nadir products by reexamining the vertical mapping of CO from measured radiances.

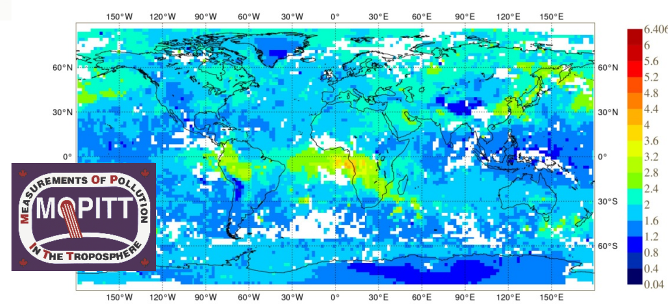
- Three questions:

1) *Why retrieved CO profiles is extremely sensitive to background errors ?*

2) *How the principle of the Resolution-Dependent Analysis,* ***"Constrain only scales observed by instruments"*** *is acknowledged by constituents retrievals ?*

3) *What would be consequence for the chemical DA, in particular for observation-operator, when the scale-inconsistent mapping is performed for estimation of* **CO.**





Multi-sensor CO retrievals in the troposphere: TIR (sm. prof.), NIR (columns), Limb (profiles)

- Carbon monoxide is a greenhouse gas with lifetime ~2 months, it is a good tracer to study chemistry, transport and emissions of pollution on the global and regional scales.

- Magnificent 7 (sensors) monitor CO distribution from the space:

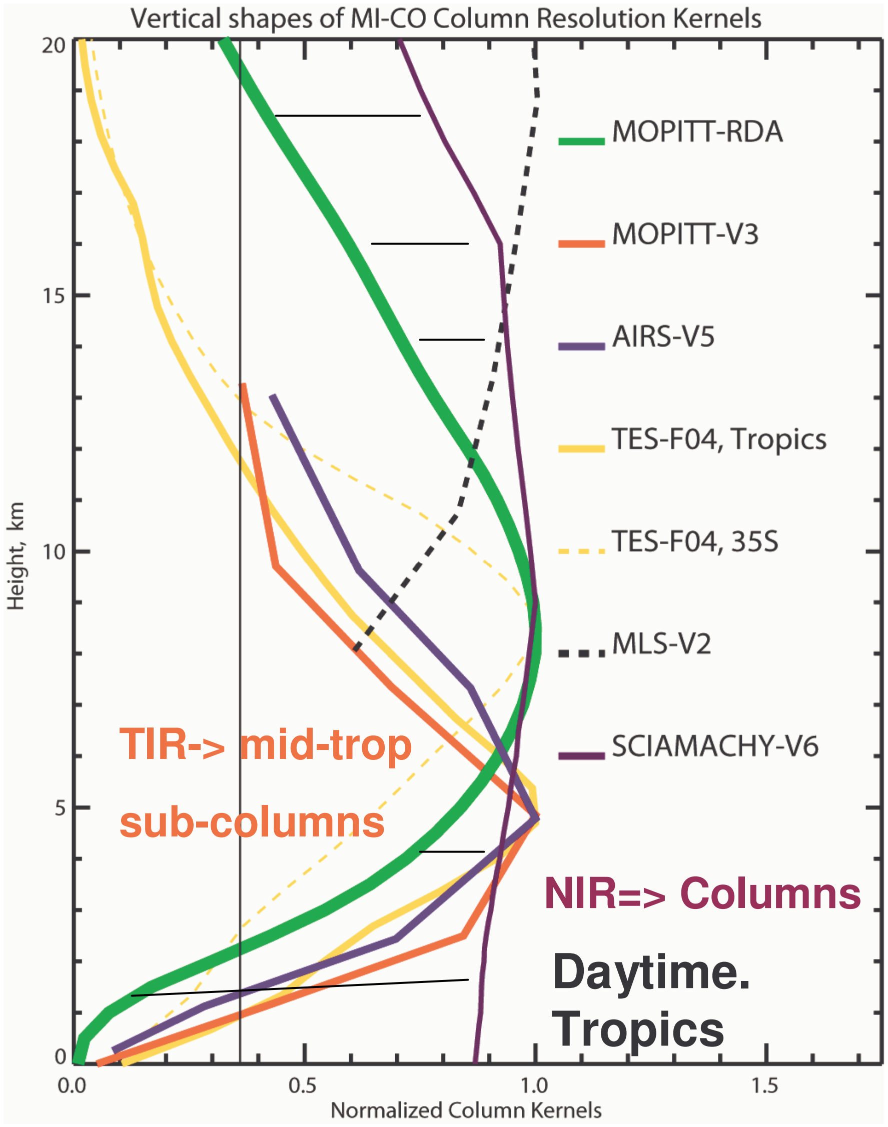
Nadir daytime and nighttime **TIR from AIRS, TES, MOPITT, IASI –>** smoothed CO profiles with AK;

Nadir daytime **NIR from SCIAMACHY, MOPITT** (mainly over the land) –> column-based data with AK.

Limb sensors, **MLS; ACE => CO profiles** in the UT+MA.

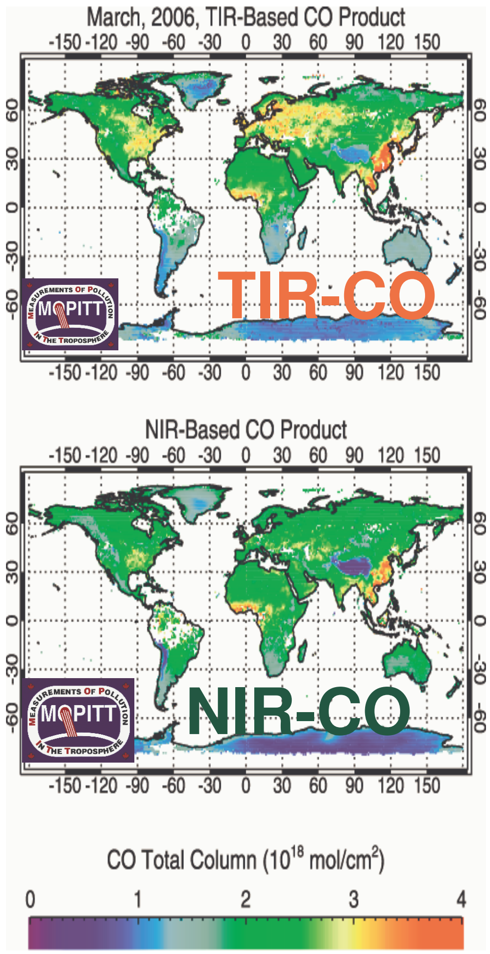
- Current goals: 1) Combine/unify nadir data; 2) Add vertical information from limb profiles (MLS) in the UT.
- Current related issues and needs for CDA: adequate Resolution Kernels and unbiased CO data.

For example, at polluted scenes with similar a priori , good SNR it is expected that **Col-NIR** > **Col-TIR**, but in reality….

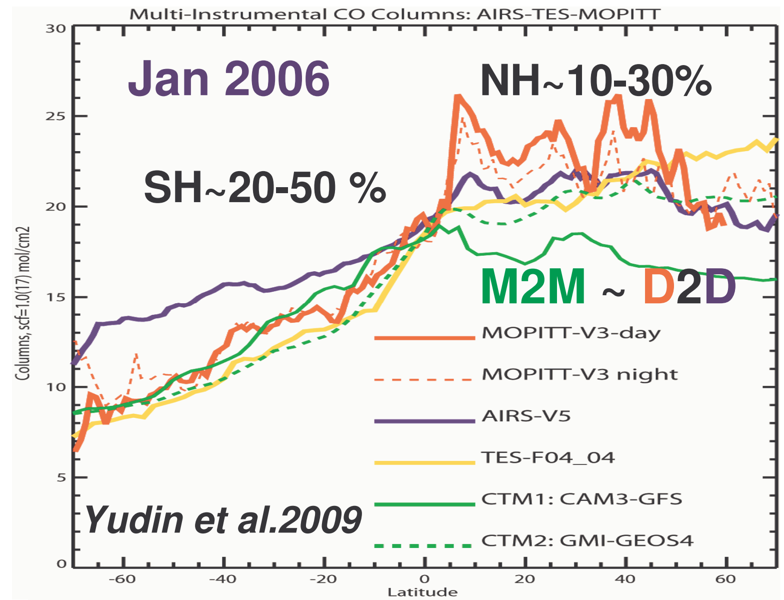


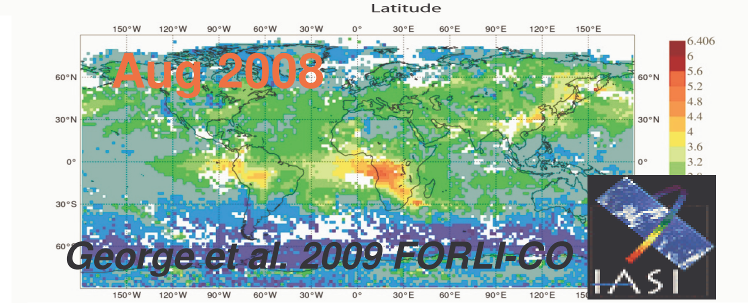
Estimation of CO columns =>
multiple choice for the chemical DA

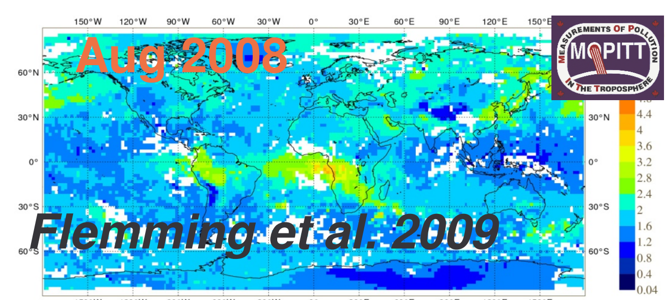
- Columns of **TIR-CO** exceed columns of **NIR-CO** (MOPITT-V3)~20-30%.
- TIR-CO (**AIRS, IASI, TES, MOPITT**) - similar patterns, but systematic differences misleading optimization of CO budget.
- *Fortems-Chalney et al.:* IASI-CO-based est-n of total **Jul-Nov of 2008** CO emissions is ~**790 Tg,** while emissions based on the MOPITT-V3 ~**560 Tg**.
- Why V2V and D2D differences in CO products?
- *Radiances; Jacobians; Priors; or Algorithm errors.*



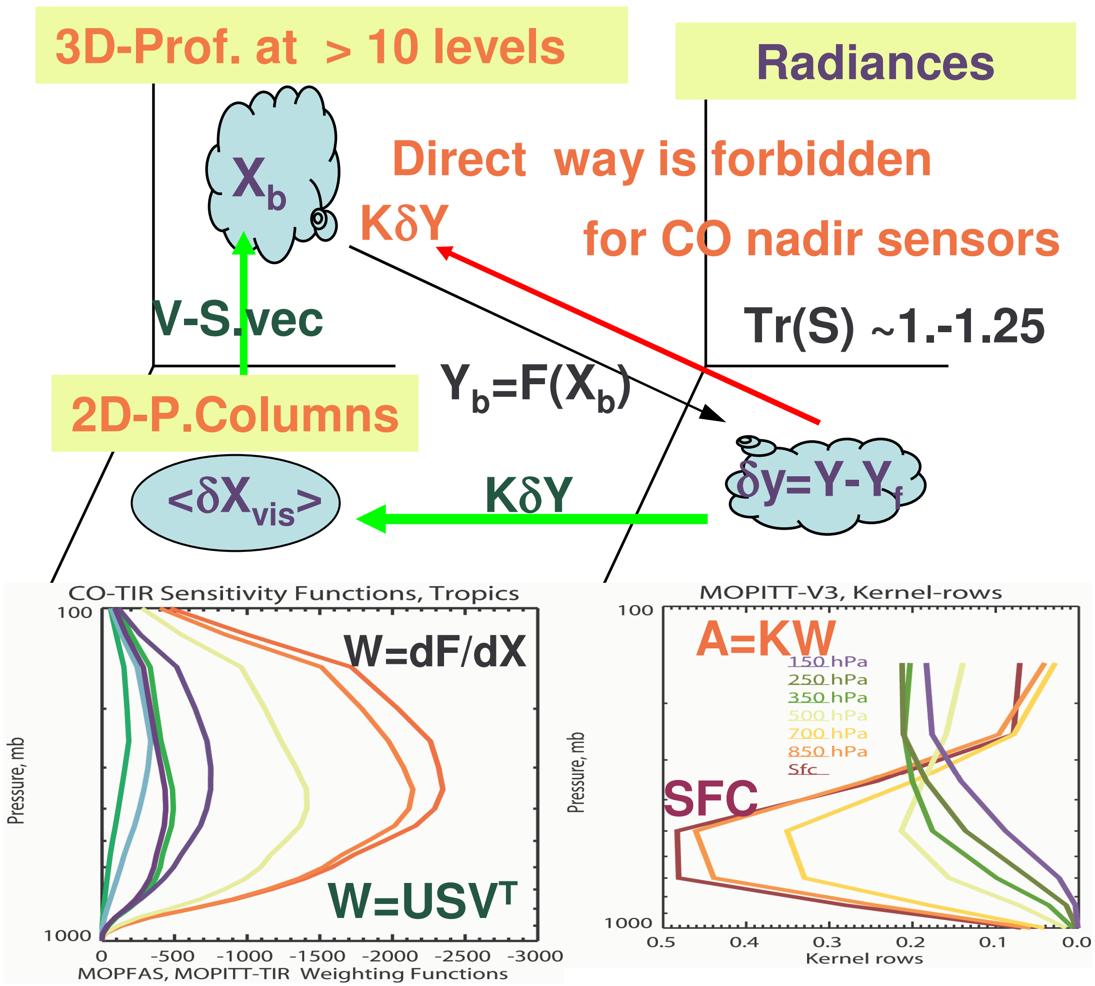
Deeter et al. 2009







Model and Data Spaces: Forward and Inverse Transforms, Jacobians and Kernels, Observables and Non-observables



$X_a=(I-A)X_b + AX_t = \delta X_{inv} + AX_t$ Sm.Profiles

$T_a=T_b - A_tX_f+A_tX_t=\delta T_{inv} + A_tX_t$ Columns

Forward: $Y = F(X)$

- $W= dF/dX$, at $X=X_b$,

$$\delta Y = W\delta X$$

- Inverse: $\delta X_a = K\delta Y$

$\delta X_a = A\delta X_t$ $\delta Y_a = D\delta Y$

- **Post-Inverse Diagnostics:**

  $A= KW$ $D = WK$

- **Ranks:** dim(δY) =/= dim(δX)
- **RDA-SVD:** $W=USV^T$

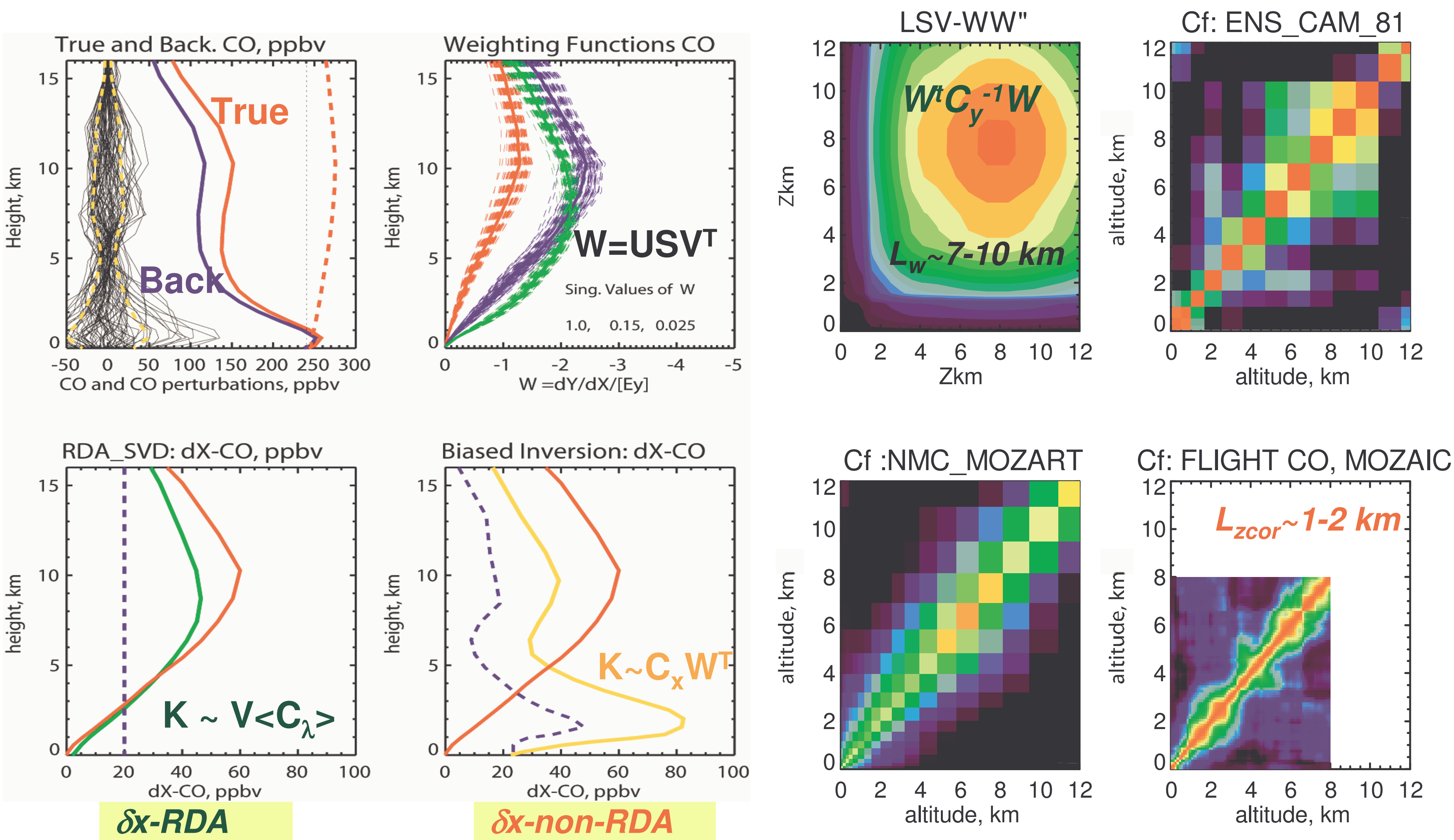
  $\dim(U^T\delta Y>) \Leftrightarrow \dim(<V^T\delta X>)$

$<\delta X_{vis}>=V<\delta\lambda_{vis}>$, $\delta X_{inv}= X_b - V^TX_b$

- $X_a= <X_b> + <\delta X_{vis}> + \delta X_{inv}$

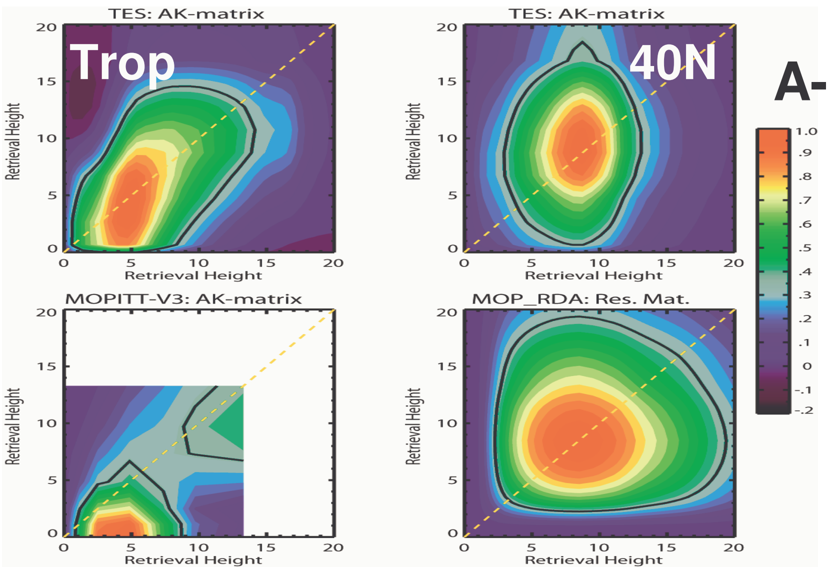
Scale-dependent error analysis

$$\langle C_x^{-1}\rangle =/= C_x^{-1} + W^T C_y^{-1} W \Rightarrow \langle C_p^{-1}\rangle = C_p^{-1} + W^T C_y^{-1} W$$



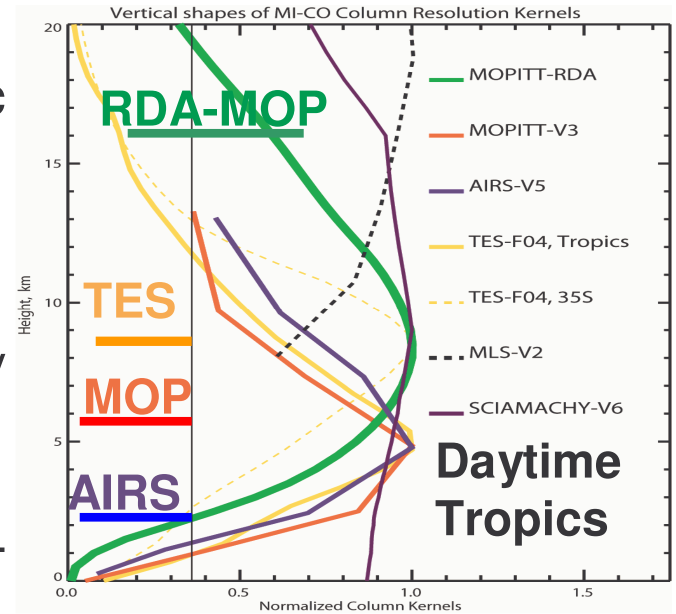
CO Kernels (A=KW) is part of the H-operator,

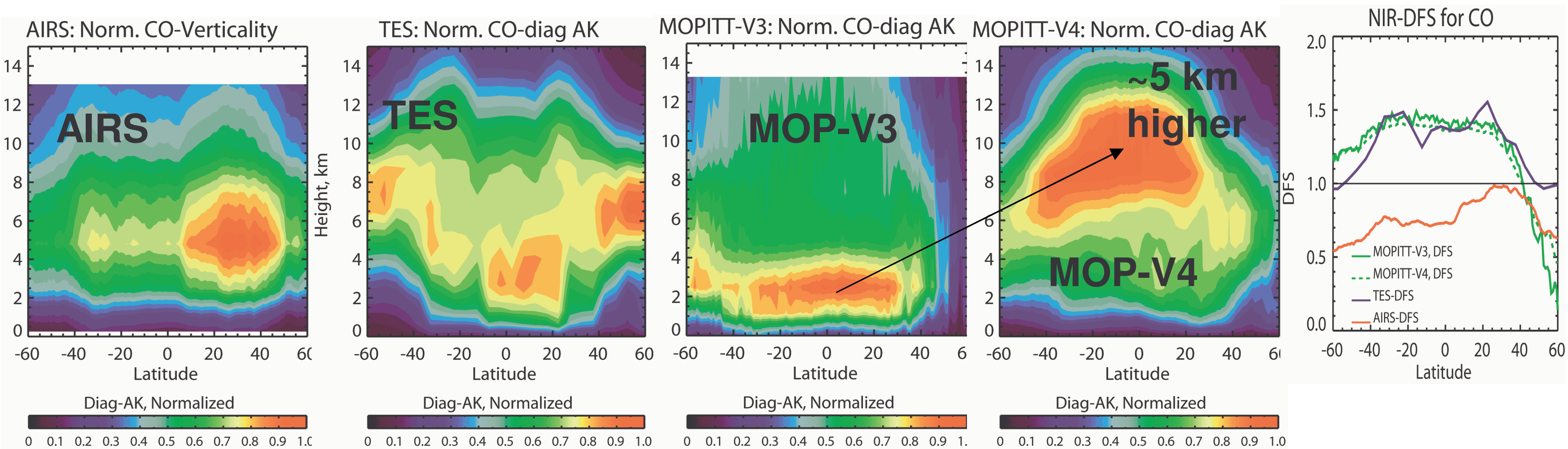
$H=AH_{int}$: $A=VK_{\lambda}V^T$ vs $A=C_xW^T(HC_xH^T+C_y)^{-1}W$



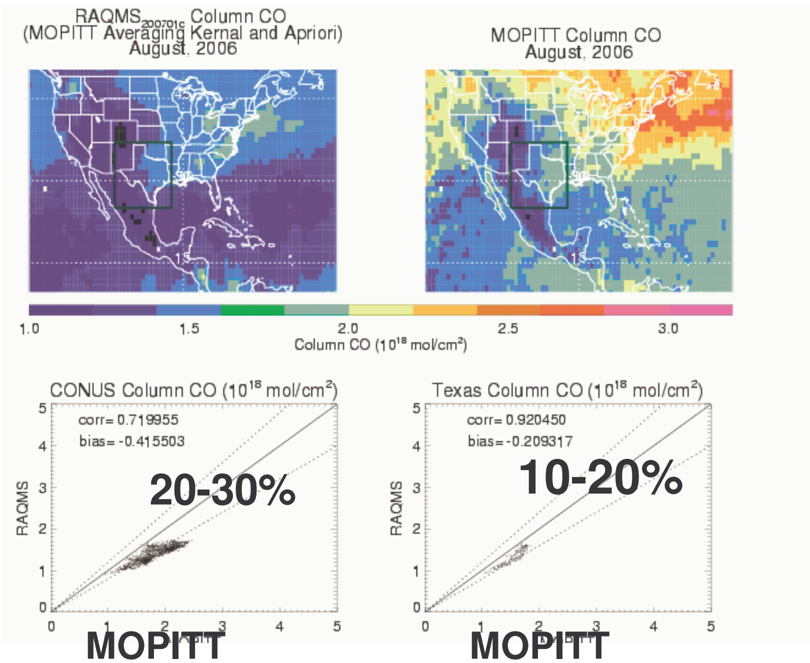
A-mat => A-vec

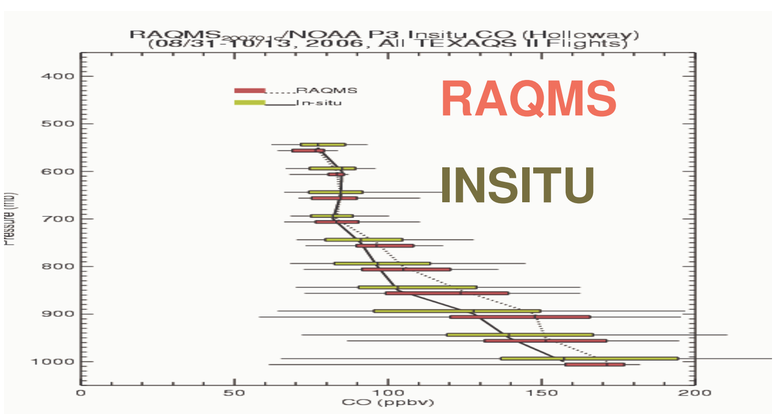
Analysis of CO columns is a compromise to unify sensitivity of 3 sensors, but biases still exist (V3 vs V4).



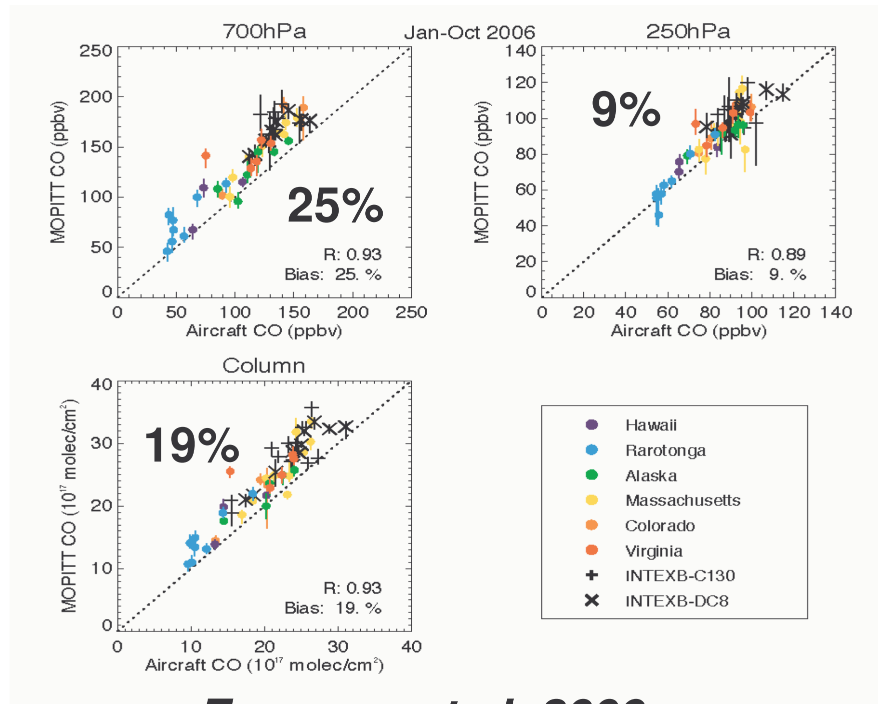


Evaluating MOPITT-V3 CO in the retrieval space: 20-30% positive bias below 500 mb





Pierce et al. 2008

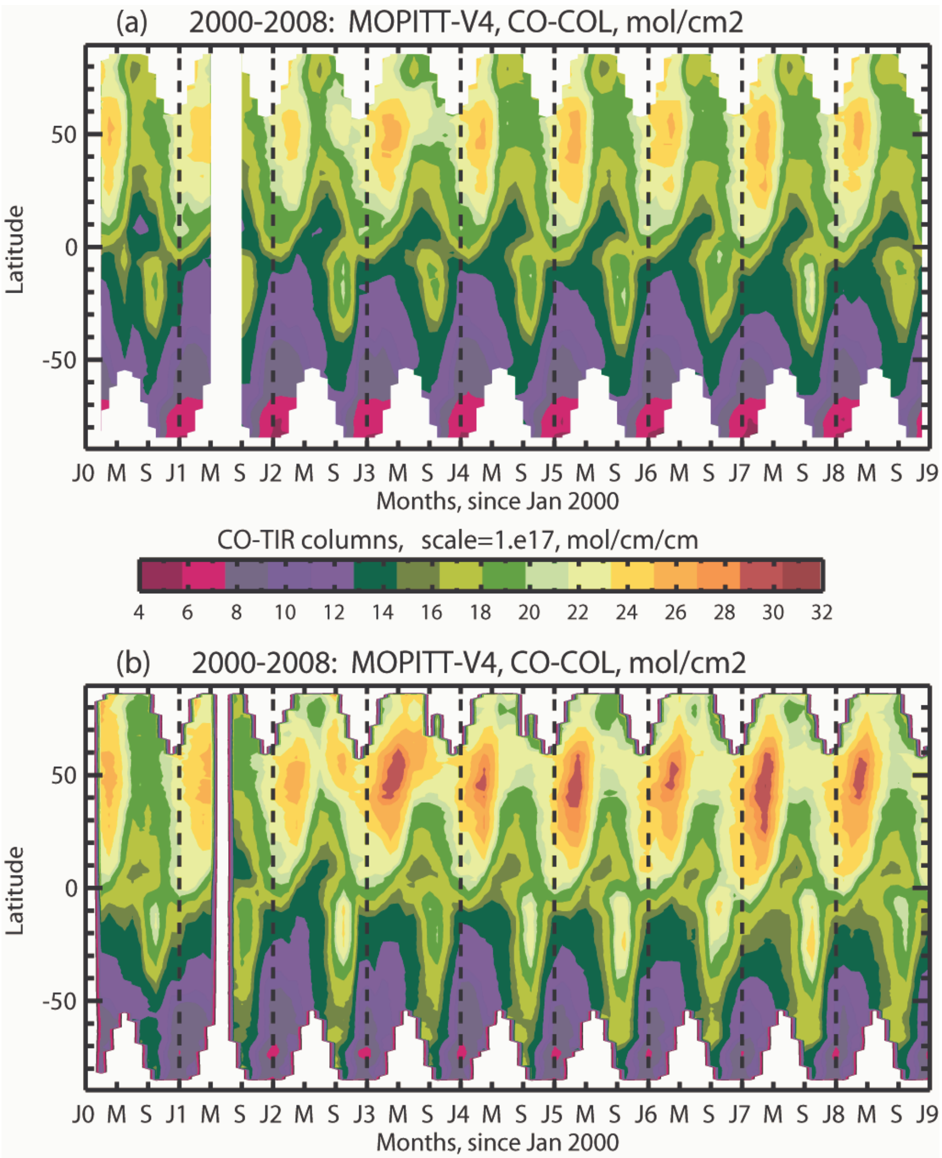


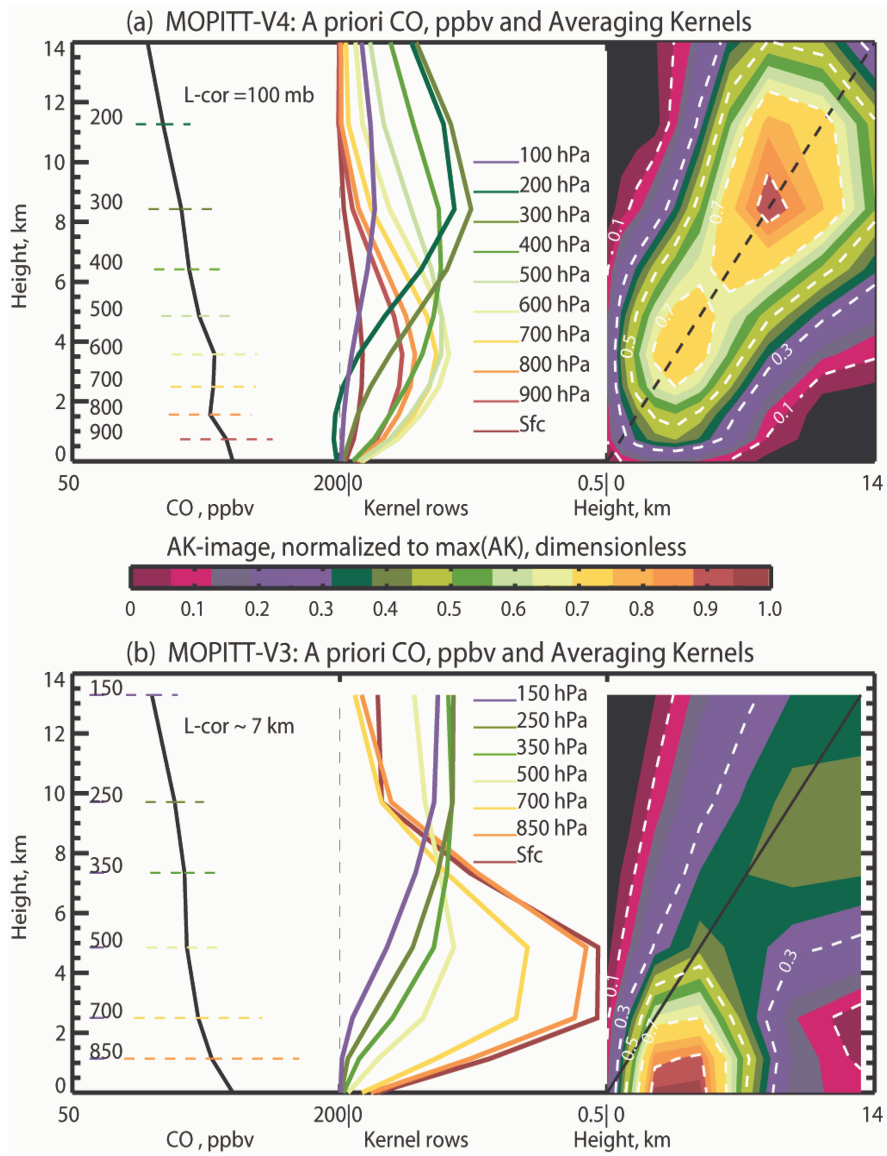
Emmons et al. 2009

$$X_{d\text{->}MV3} = (I-A)X_b + A(HX_d),$$

MOPITT-V3 CO biases are initiated by algorithmic errors, the "near-surface" kernels erroneously take the largest amount of information from measured radiances.

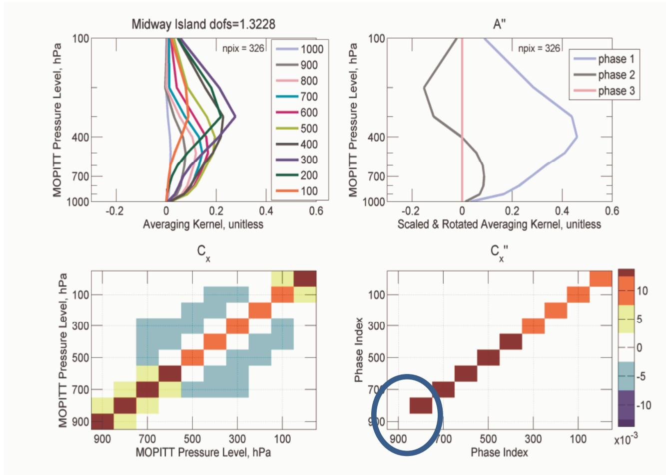
Summary: MOPITT V3 vs V4

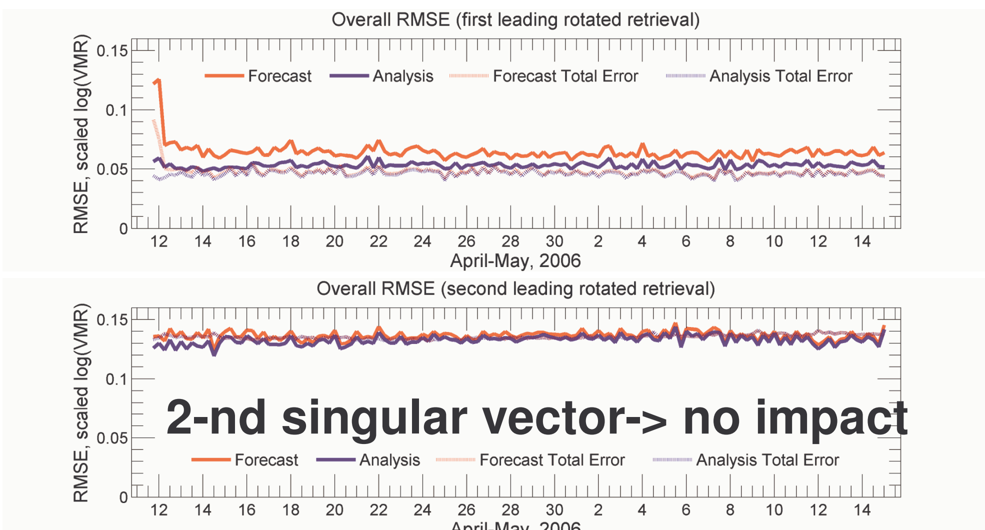


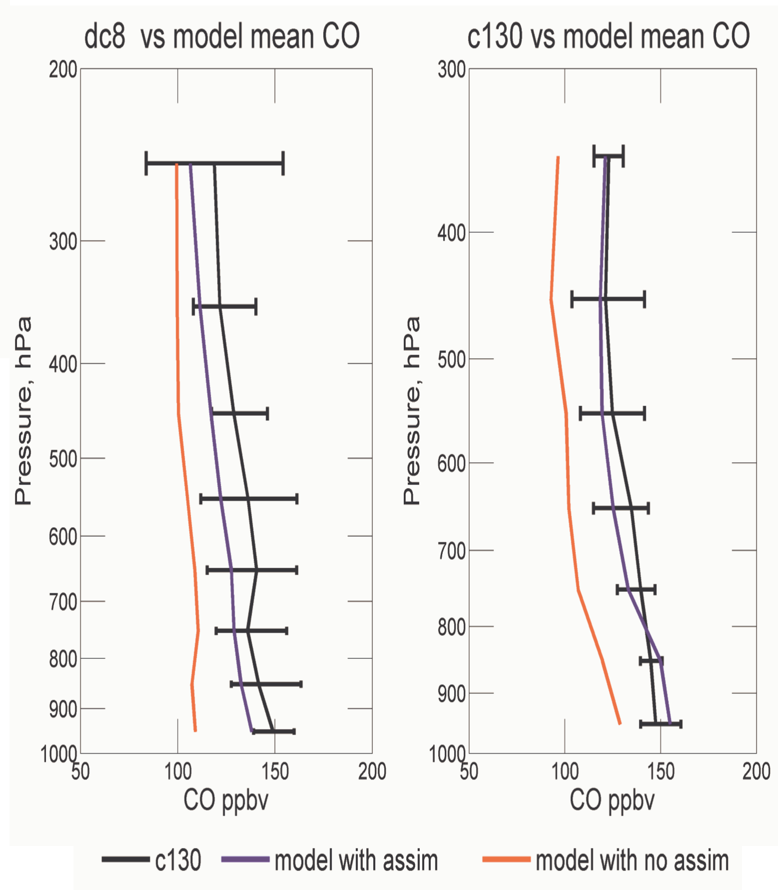


Analysis CO with tuning of observation errors, verification with INTEX-B flight data (2006)

1. **SVD – AK**
2. **2-first vectors**
3. **Correct CO retrieval errors.**



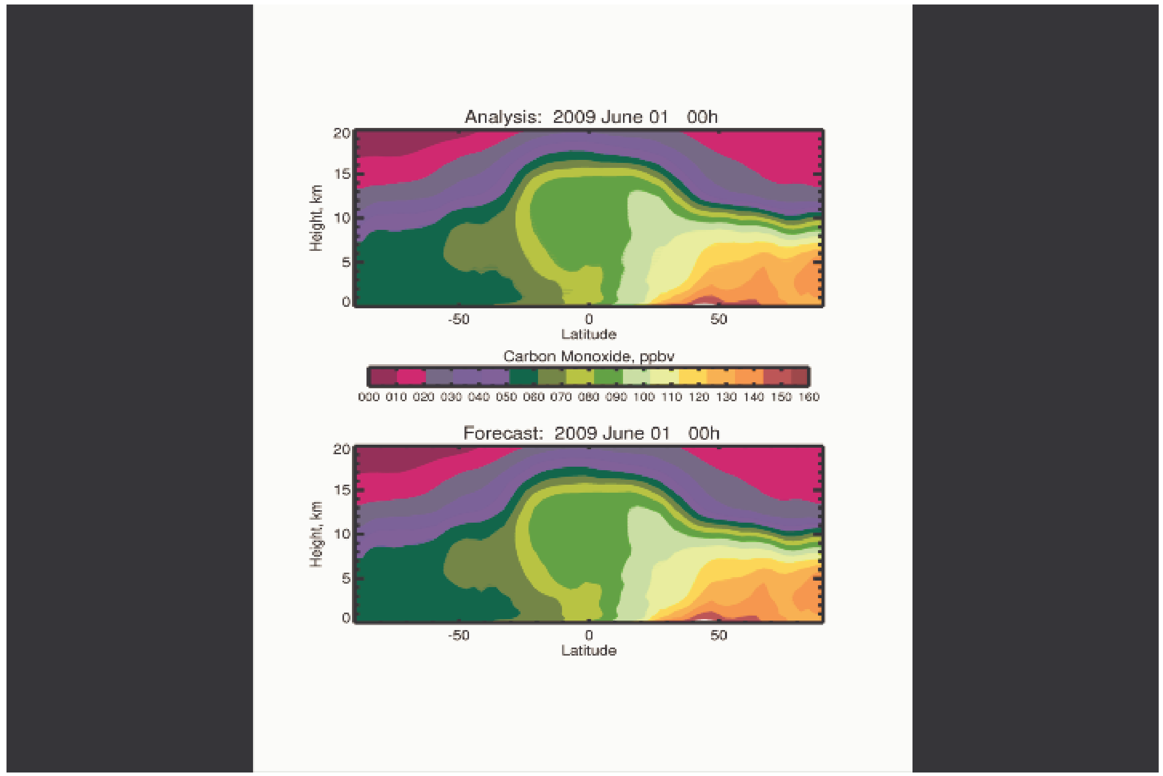


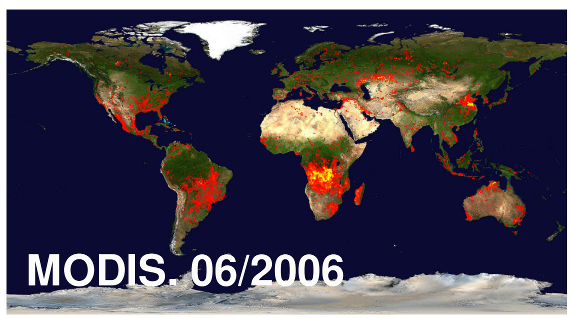


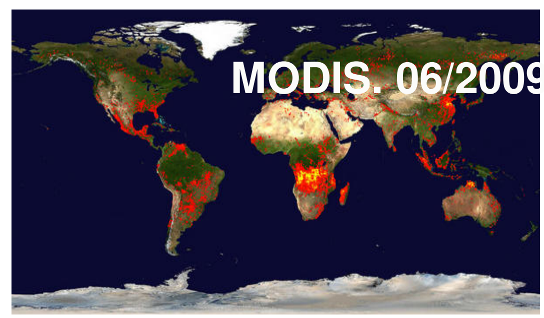
- Measurements from G. Sachse (DC-8) and T. Campos (C-130)
- Error bars are 10th -90th per-tile of median CO across different flights

Assimilating MOPITT-V4 columns with quality controls employing kernels: June 2009

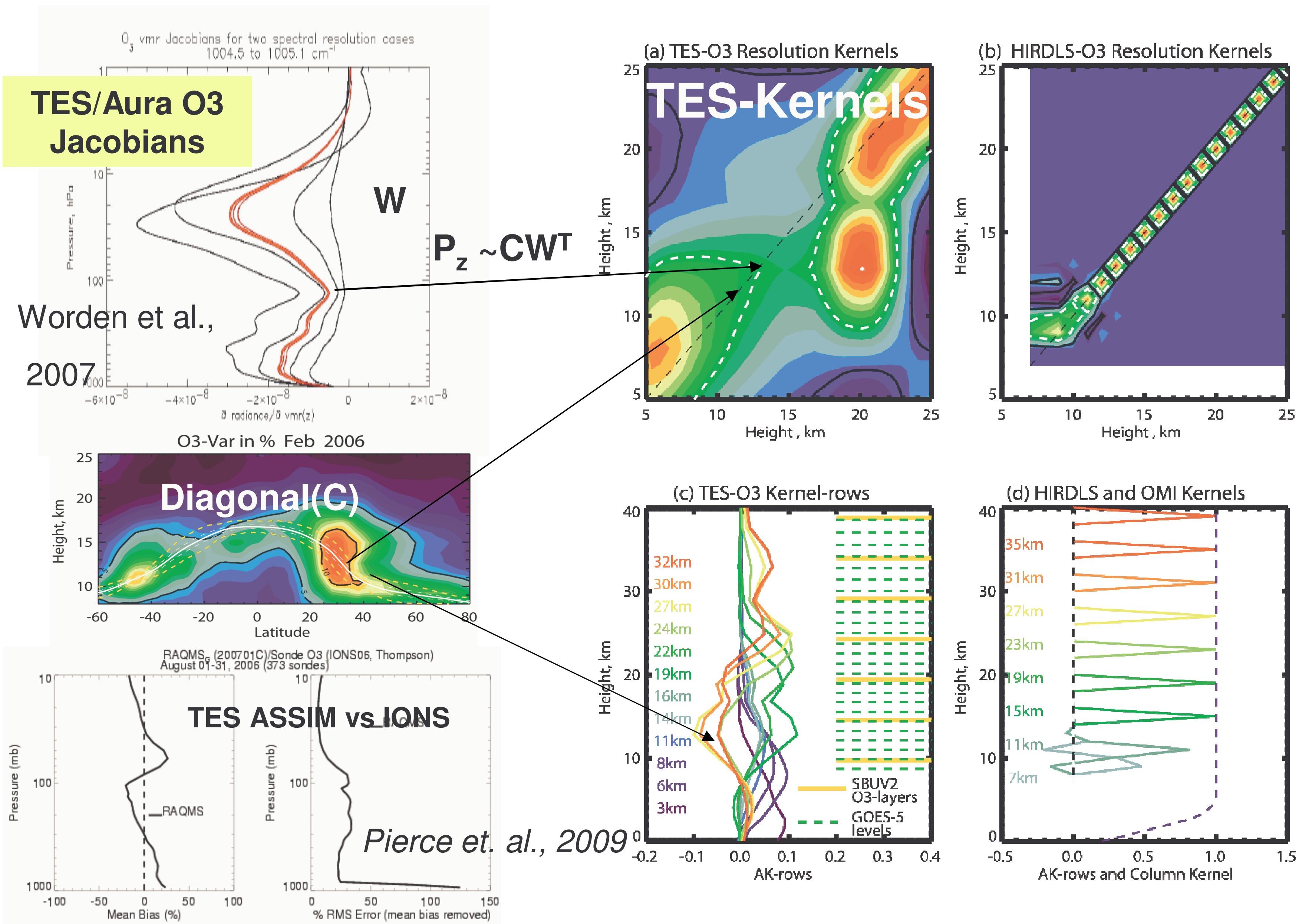
- MOZART-4 CTM, Emmons et al. (2009), NOAA/GFS forecast.
- Simple QC: Pixels with dominant near-surface element in the kernel vectors are rejected.
- Analysis of columns is an intermediate step to demonstrate that the resolution dependent mapping without correcting PBL-layers (where MOPITT is blind) provide adequate results.
- After 15 days, QC scheme is turned off, and “bad” data spread out in the SH-PBL => attention to the quality of data in the SH high latitudes.
- In the tropics and in the NH, decrease of mid-trop. CO is consistent quantitatively with TES-CO retrievals.







Ozone Jacobians and Kernels



Concluding remarks

- Resolution kernels highlight observable and “data-null” scales (layers), they are key part of H-operator for DA of retrieved species.

- Images of kernels distinguish Resolution-Dependent analysis from scale-inconsistent algorithms. Properties of kernels can flag biases and perform data quality control.

- Main aspect of Resolution-Dependent Analysis:

Constrain observable scales (variables), preventing explicit spread of information to non-observable scales (layers).

Errors are scale-dependent, partial columns or layer averaged data cannot reduce grid-wise variance, but can reduce errors of corresponding model variables observable by sensors.

Outcome of RDA in general:

a) scale-dependent treatment of errors prevents smearing of non-observable forecast scales;

b) optimal vertical mapping and observation operators that adequately reflect physics of observations.

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