Global estimates of CO sources with high resolution by adjoint inversion of multiple satellite datasets (MOPITT, **AIRS**, SCIAMACHY, TES)

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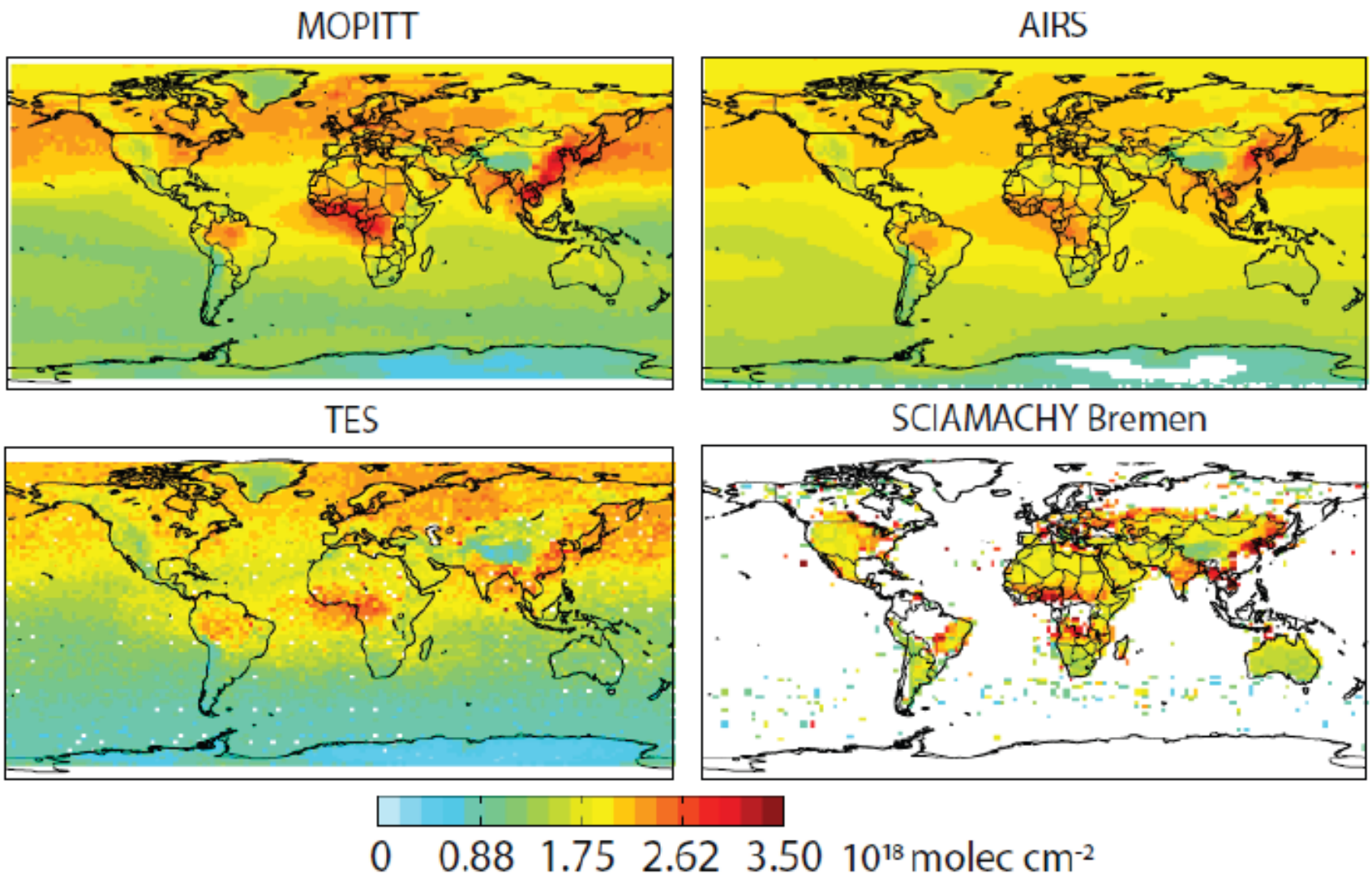
NOAA, Climate Program Office

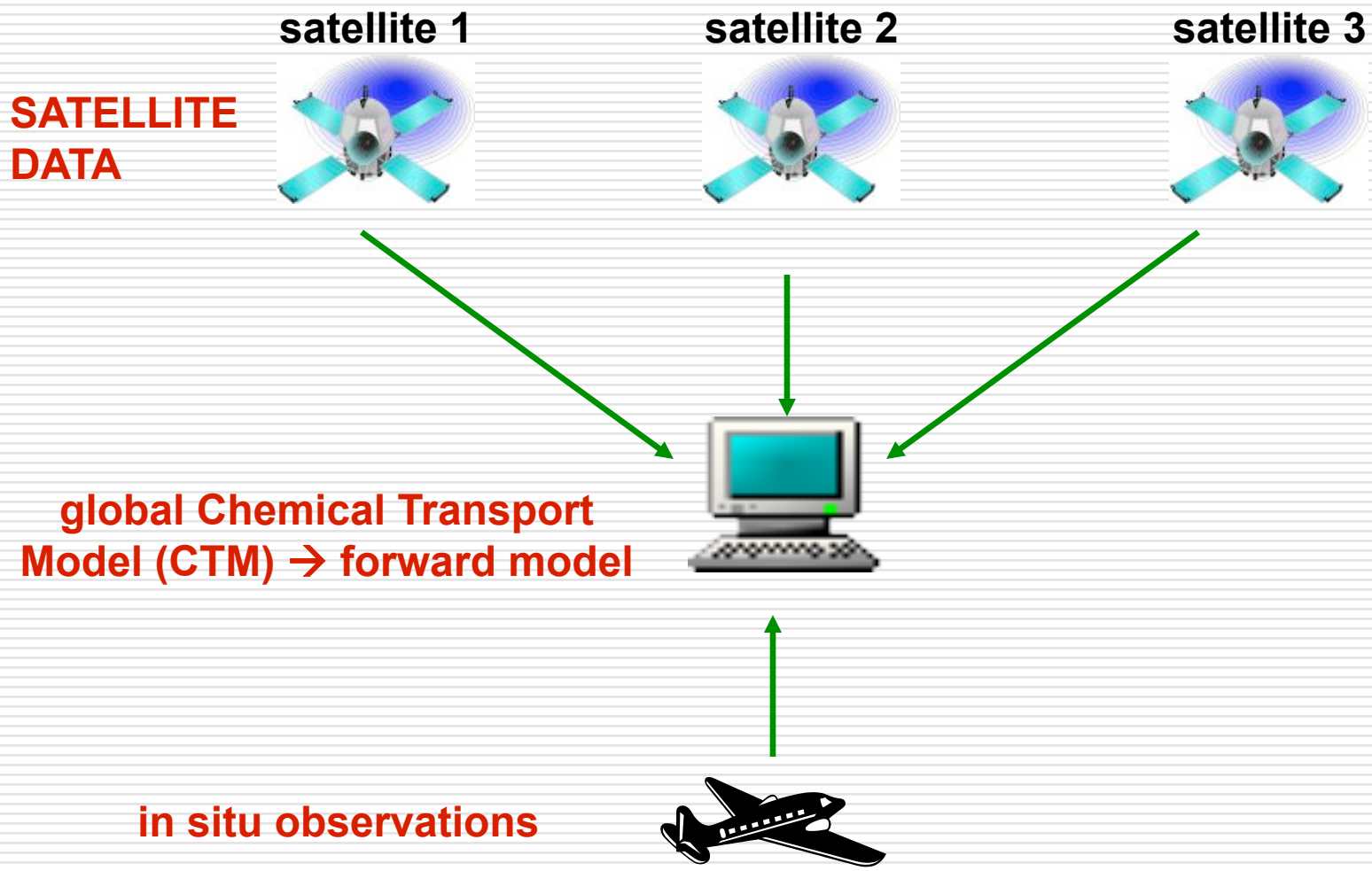
November 3, 2010

Satellite data available for constraining CO sources



CO columns expected to be different due to different vertical sensitivity, but are they consistent?

Data consistency: Chemical Transport Model (CTM) as a comparison platform



TRUTH

but very sparse in time and space

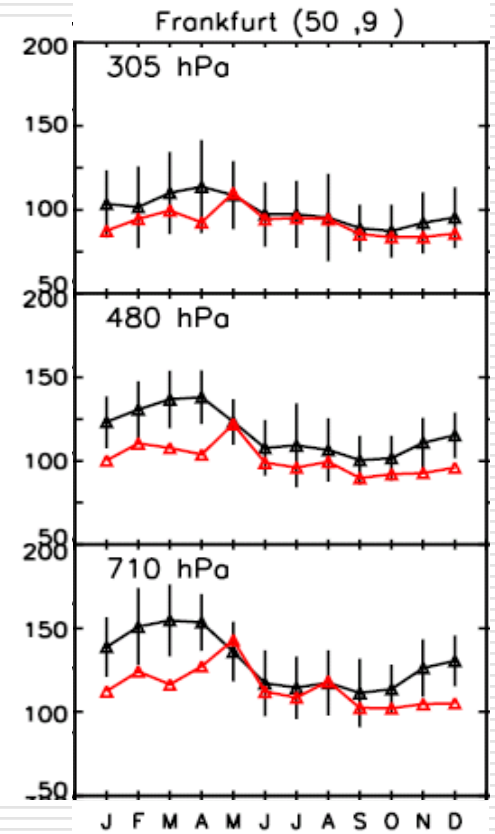
GEOS-Chem Chemical Transport Model (CTM): the comparison platform

EMISSIONS → **CTM** → **CONCENTRATIONS**

Compare with in situ data

aircraft

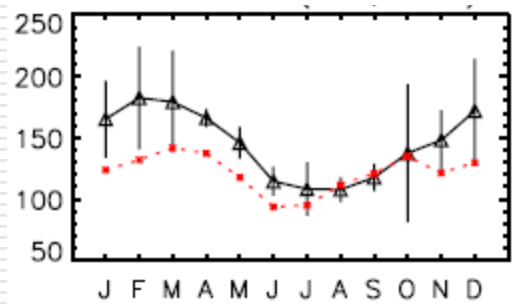
MOZAIC



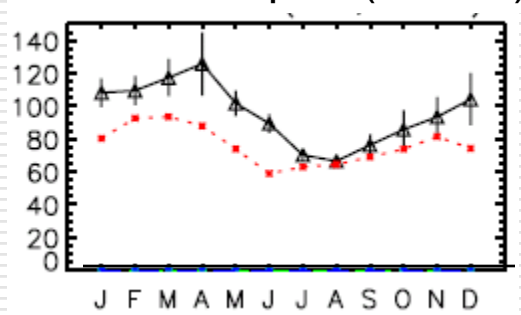
surface

GMD

Northern midlatitudes (Ireland)



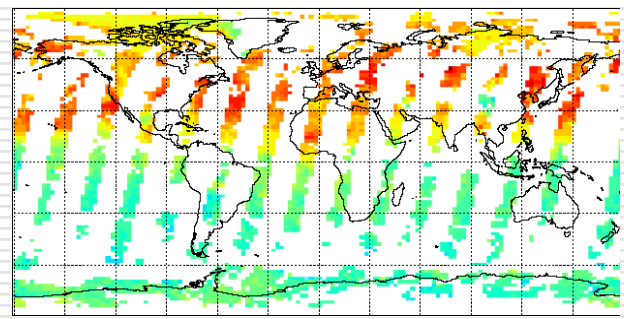
Northern tropics (Hawaii)



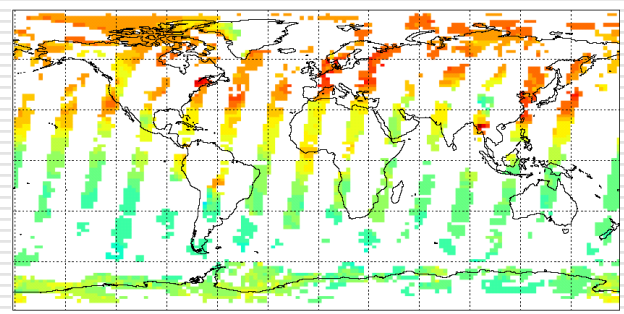
Compare with satellite data

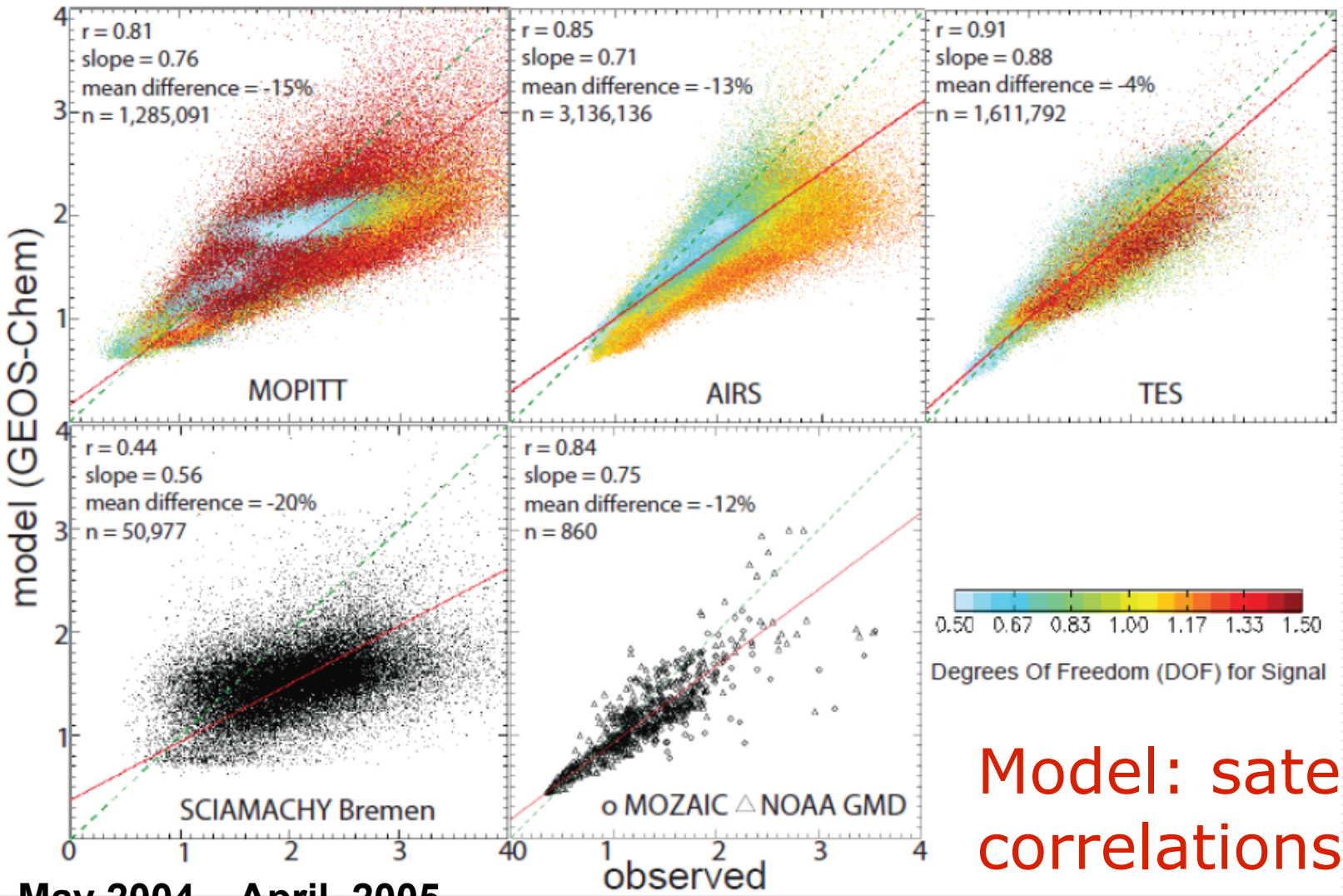
$$\hat{\mathbf{y}} = \mathbf{y}_a + \mathbf{A}(\mathbf{y} - \mathbf{y}_a)$$

MOPITT CO columns



GEOS-Chem+ MOPITT AK





Model: satellite correlations

May 2004 – April 2005 global daytime columns (averaged on 2°x2.5° resolution of GEOS-Chem)

**TES data for 2005-2006*

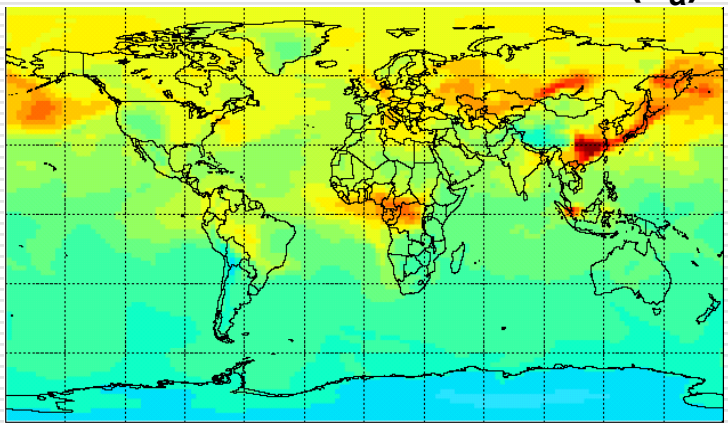
Measure of information content: degrees of freedom (DOFs) ← color dimension

Unit: 10^{18} molec/cm^2

Kopacz et al. *2010*

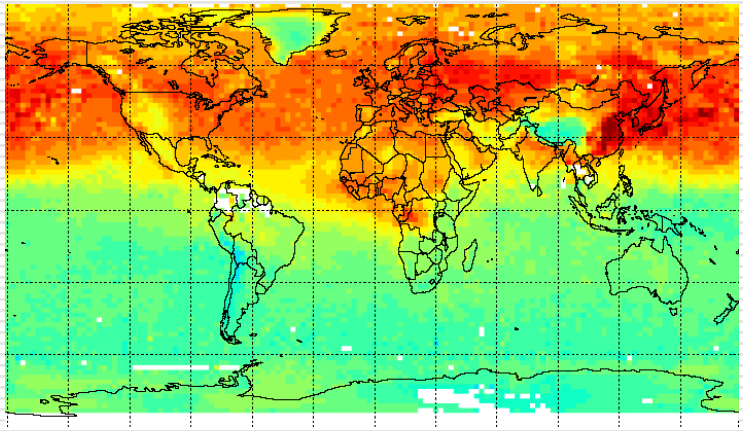
Inverse estimates of CO sources

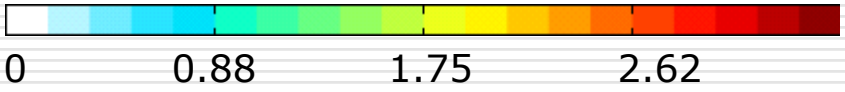
GEOS-Chem CO column: $F(x_a)$



$\neq$

satellite CO column: y





***a priori* sources:** $\mathbf{x_a} + \boldsymbol{\varepsilon_a}$

satellite data (MOPITT, AIRS, SCIAMACHY Bremen) : $\mathbf{y} + \boldsymbol{\varepsilon_o}$

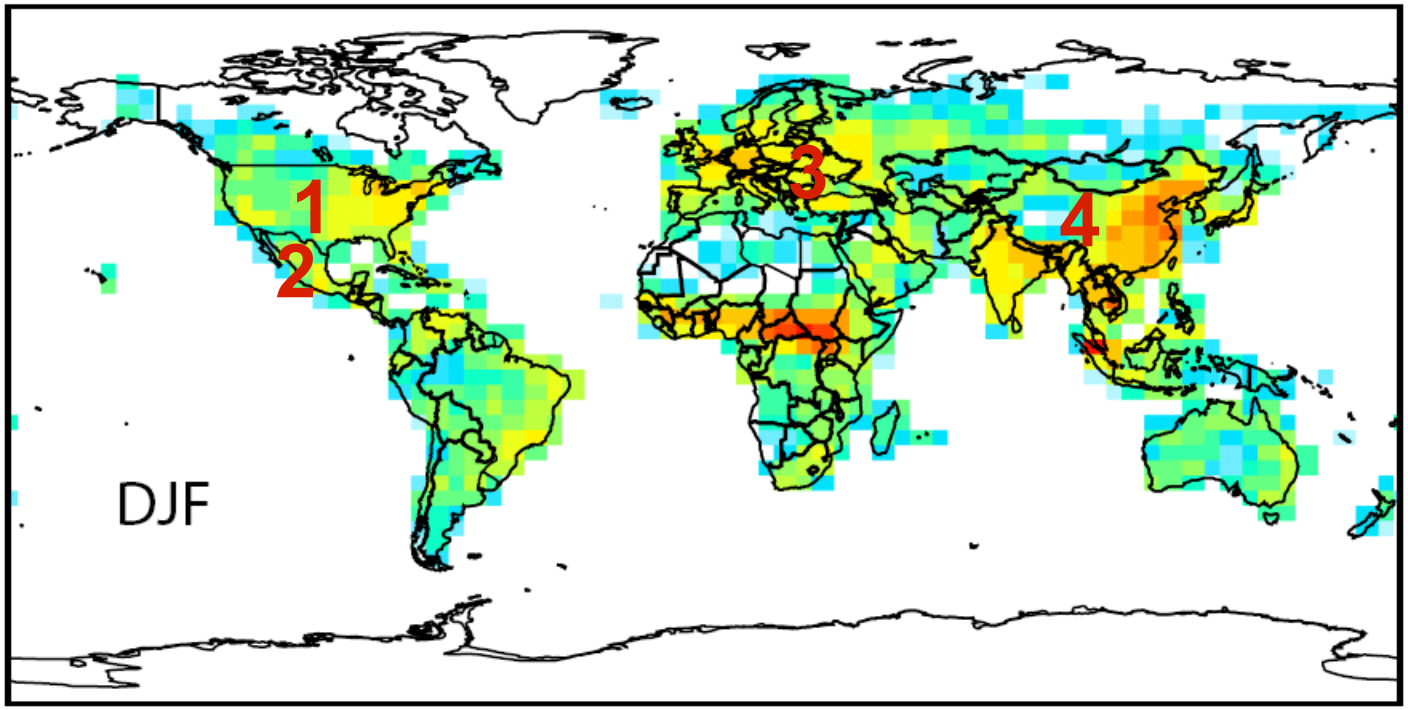
model concentrations: $\mathbf{F(x)} + \boldsymbol{\varepsilon_m}$

observation error: $\boldsymbol{\varepsilon_e} = \boldsymbol{\varepsilon_o} + \boldsymbol{\varepsilon_m} + \boldsymbol{\varepsilon_r}$

$$\min J(\mathbf{x}) = (\mathbf{F}(\mathbf{x}) - \mathbf{y})^{\mathrm{T}} \mathbf{S}_{\varepsilon}^{-1} (\mathbf{F}(\mathbf{x}) - \mathbf{y}) + (\mathbf{x} - \mathbf{x}_a)^{\mathrm{T}} \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a)$$

RESULT: monthly CO source estimates at 4º x 5º resolution

A priori emissions ($\mathbf{x_a}$): fossil fuel, biofuel and biomass burning



Global inventories:

Fossil fuel EDGAR 3.2 (global)

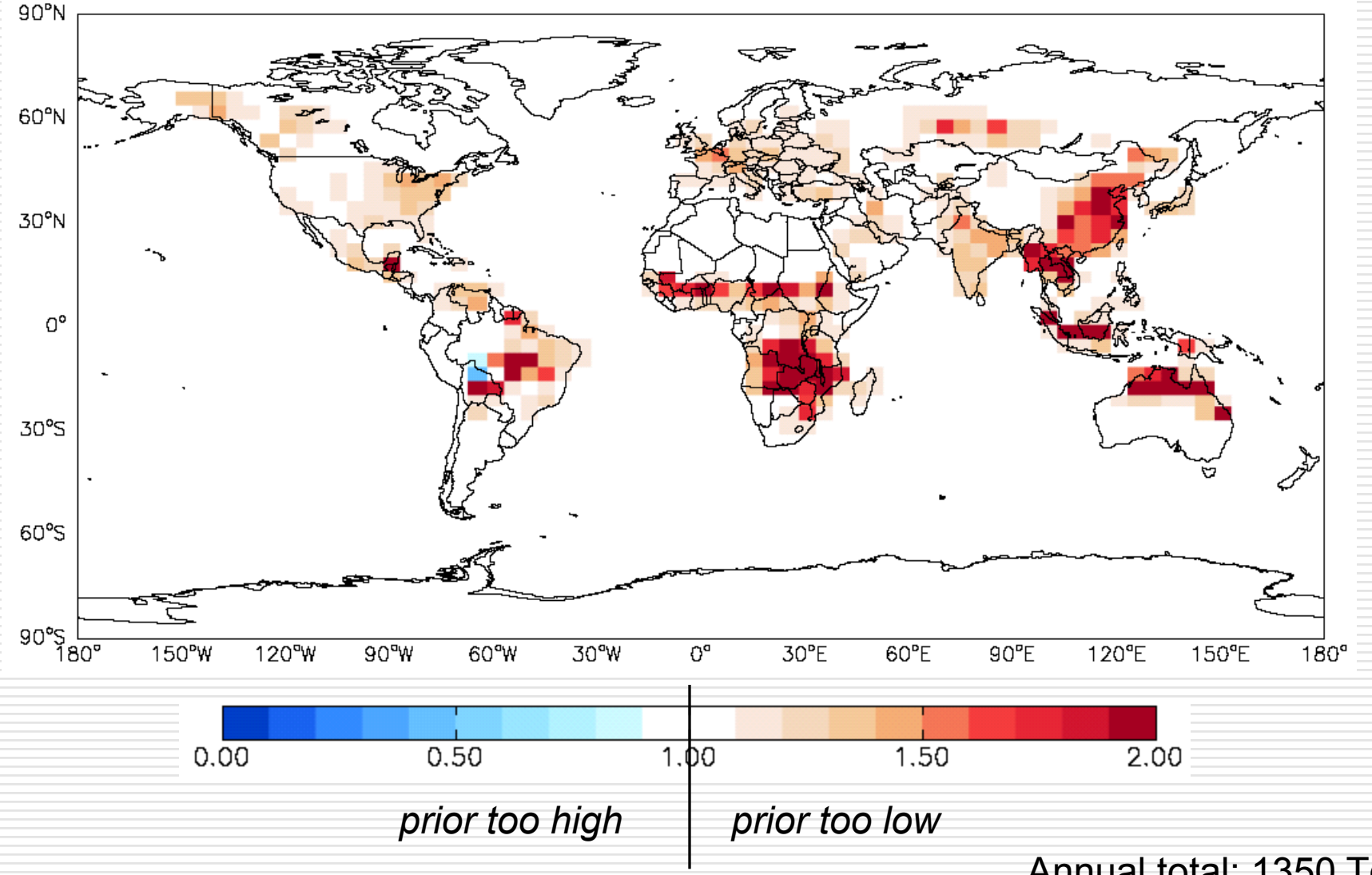
Biomass burning GFED2 (global)

Regional inventories:

1. US fossil fuel: NEI99 – 60%
2. Mexico fossil fuel: BRAVO
3. Europe fossil fuel: EMEP
4. Asia fossil fuel: *Streets et al.* 2006 for China and *Streets et al.* 2003 elsewhere

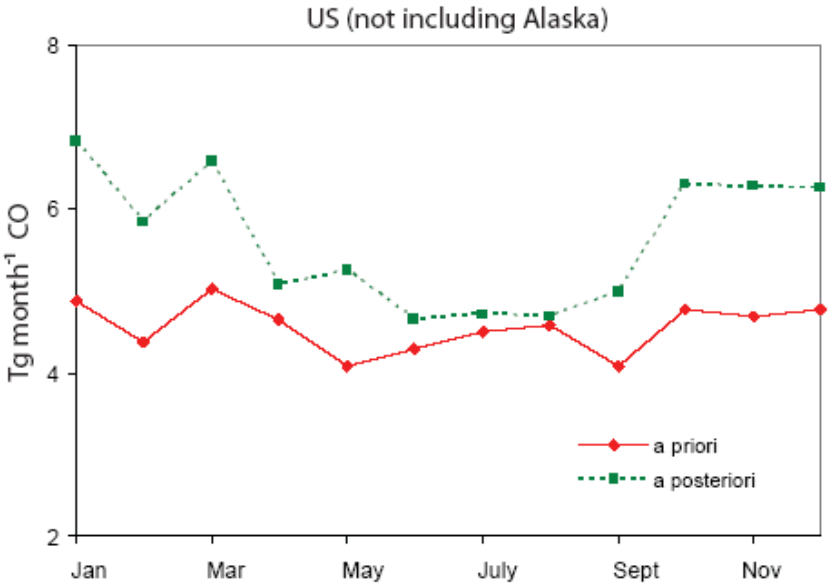
A posteriori estimates of CO sources: emissions too low

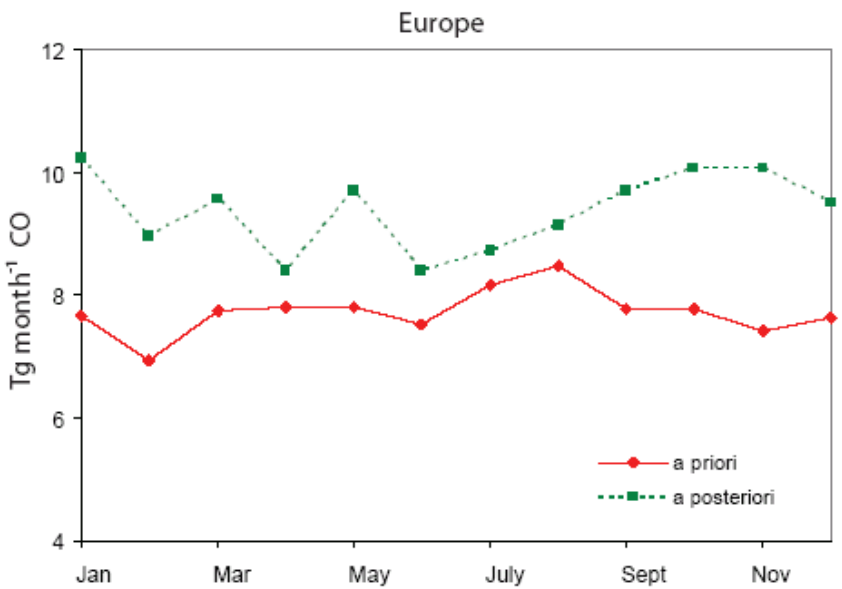
Annual mean *a posteriori/a priori* emission ratio

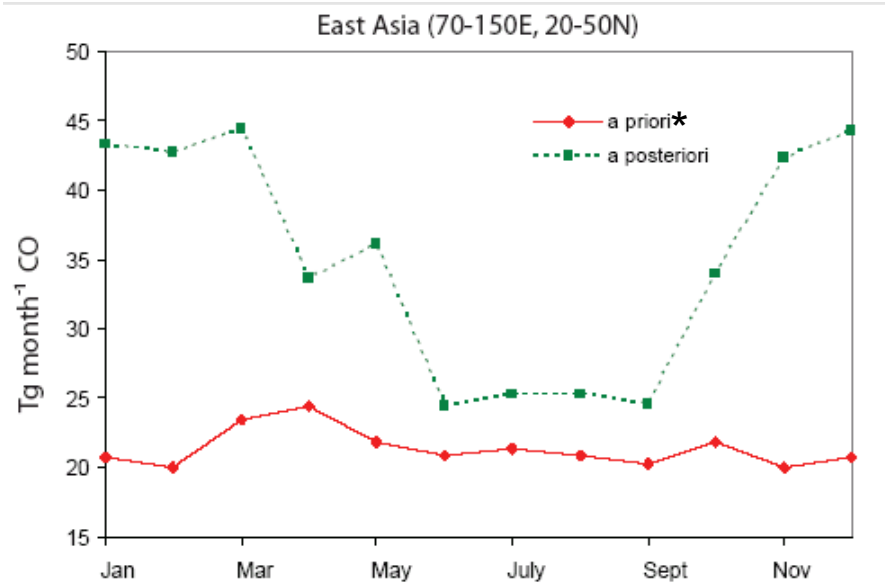


Annual total: 1350 Tg

Seasonal variability of emissions: largely missing in *a priori* estimates







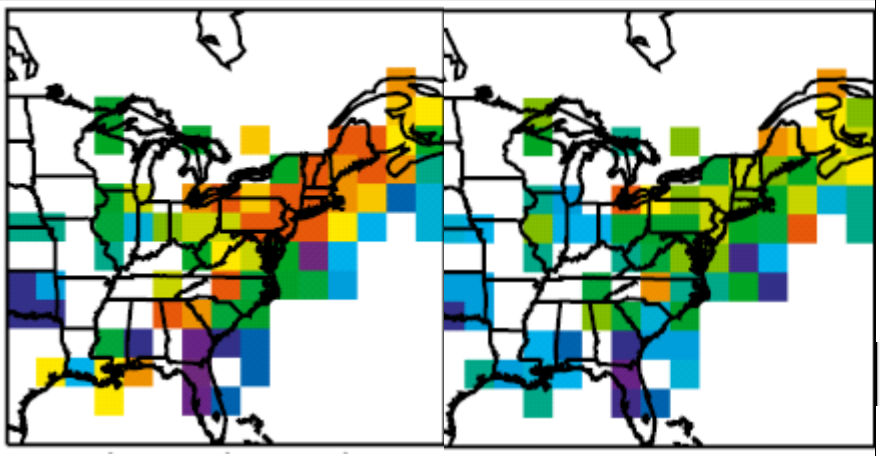
Includes regional inhomogeneity

* *Streets et al.* [2006] did not include *Streets et al.* [2003] seasonality

Regional CO source estimates: N. America

Previous study

GEOS-Chem w/ NEI99 emission inventory > INTEX-A observations

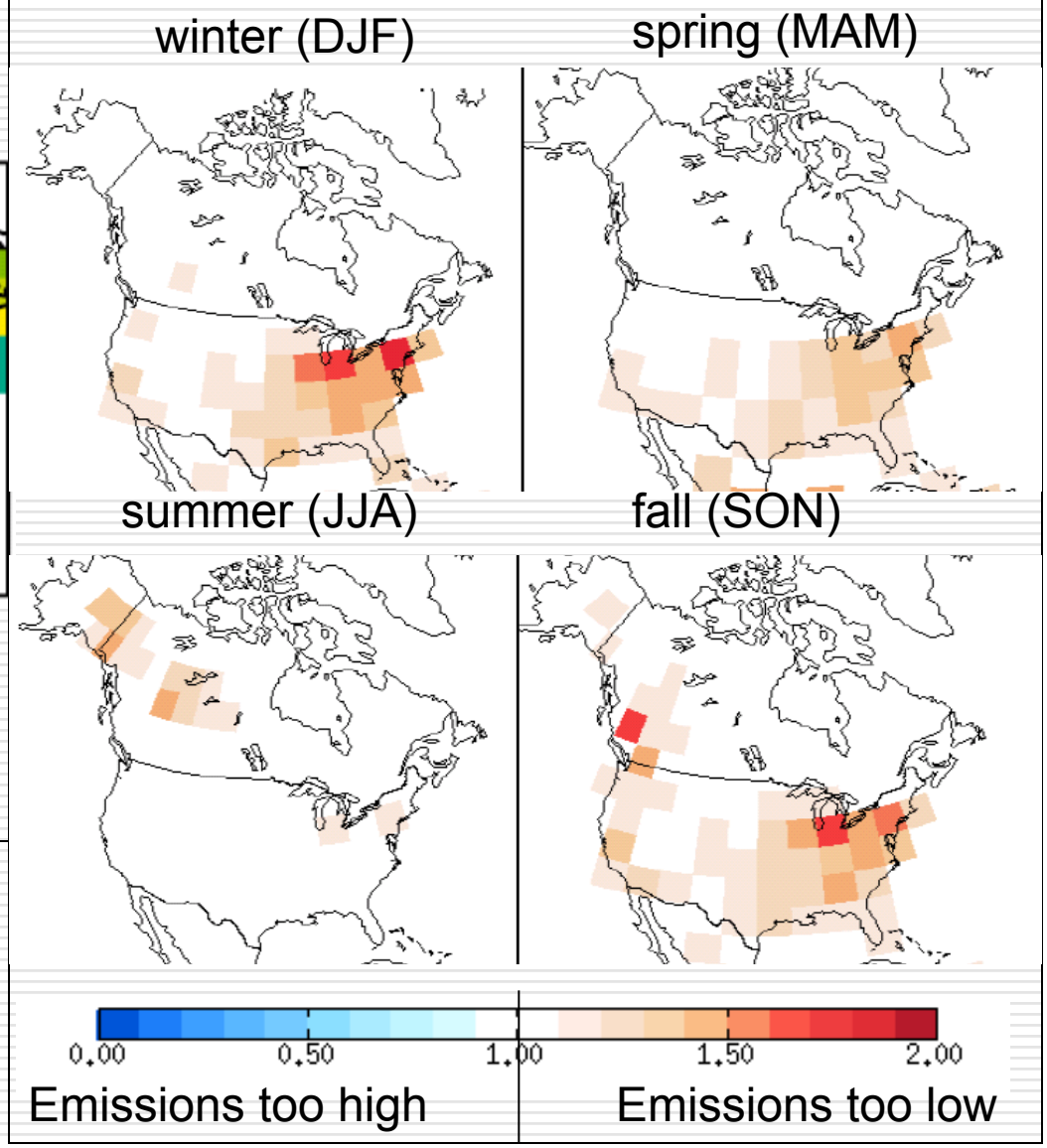


Hudman et al. [2008]

NEI99 60% too high (in the summer)

Conclusion: *Hudman et al.* [2007] correction to NEI99 inventory ok in the summer, not in fall-winter

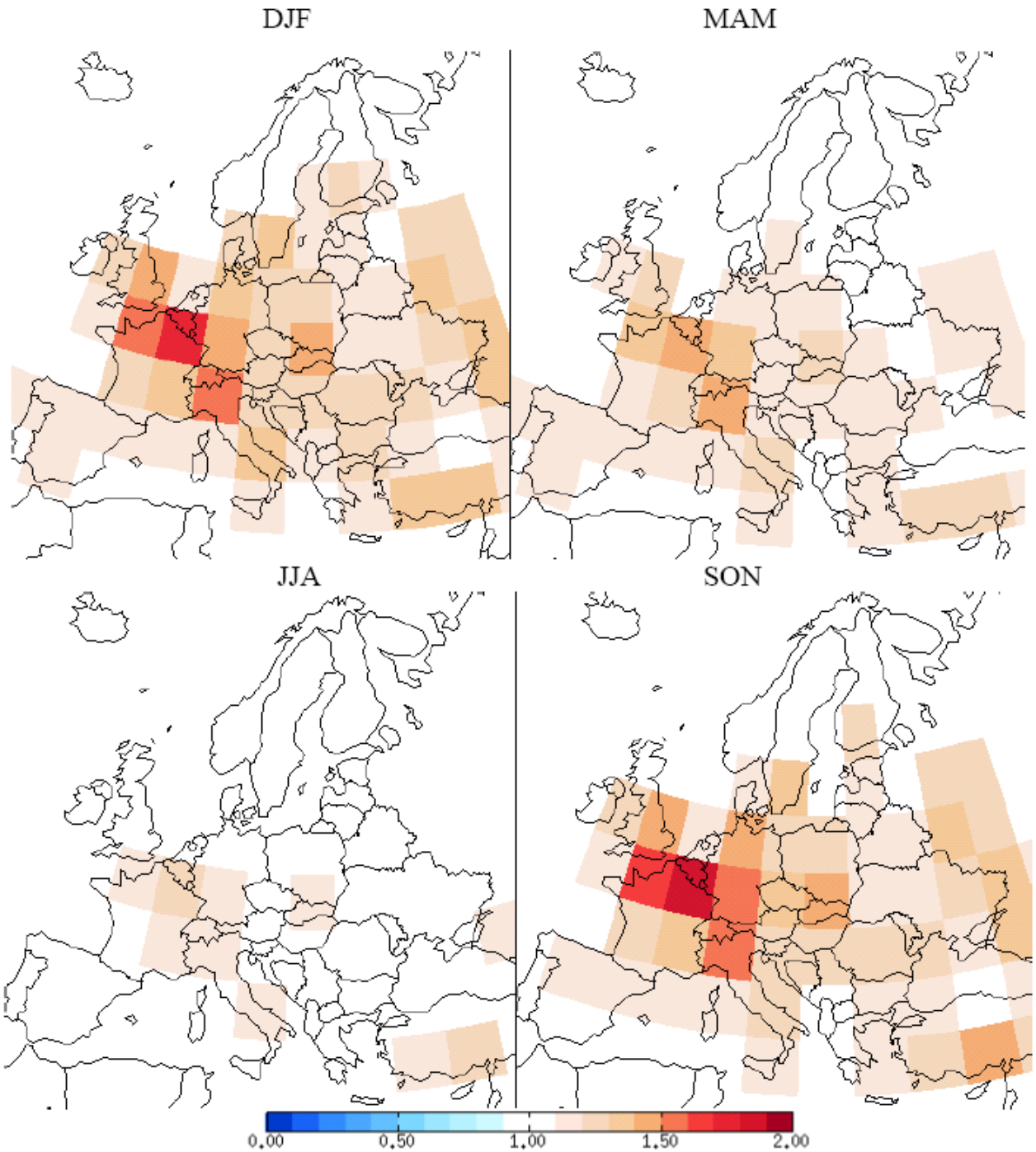
Current study w/ 60% correction



Regional CO source estimates: Europe

<u>Findings:</u> Similar seasonality and spatial inhomogeneity as in N. America

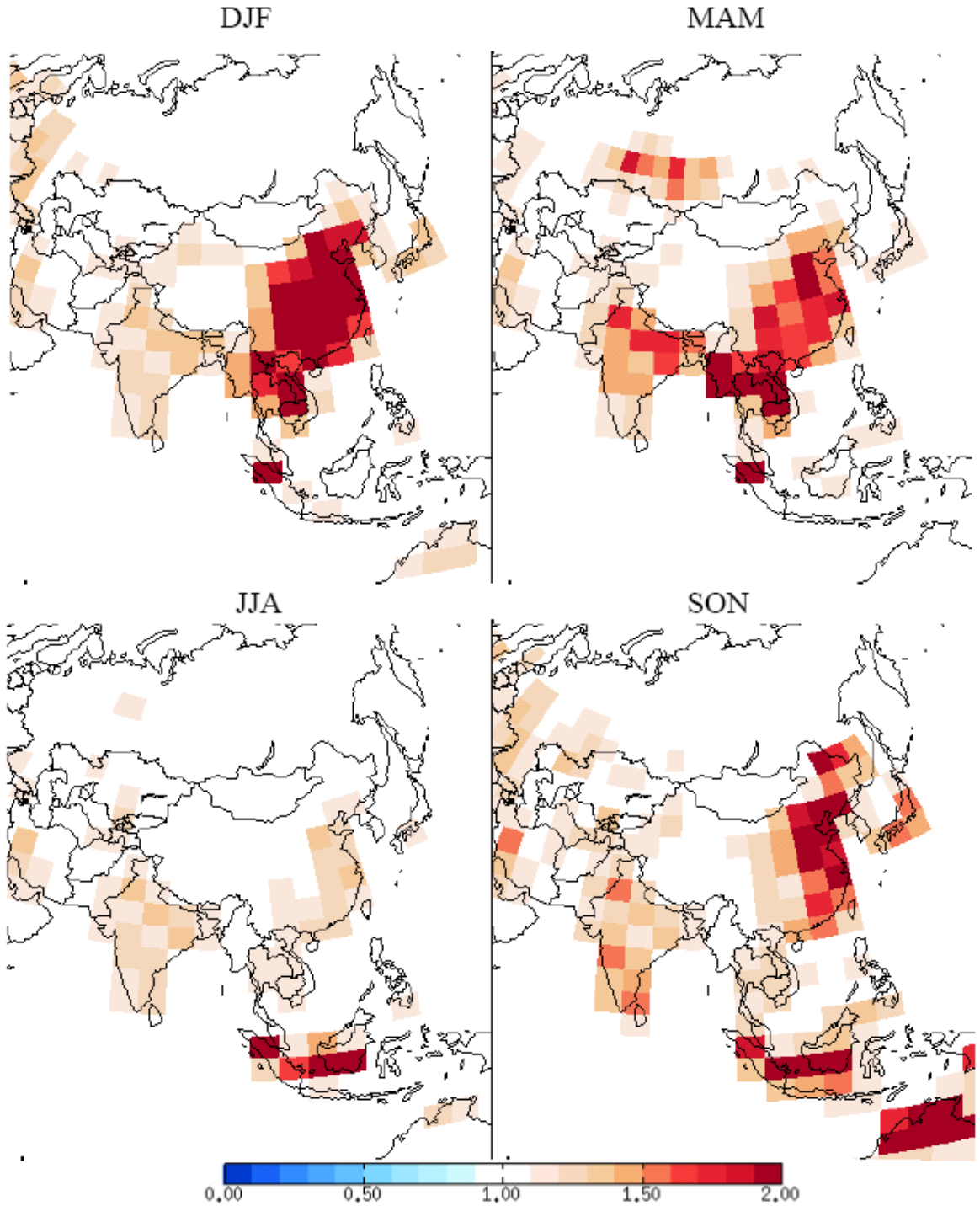
Possible **<u>reasons</u>** for underestimate: residential heating, “cold starts”



Regional CO source estimates: Asia

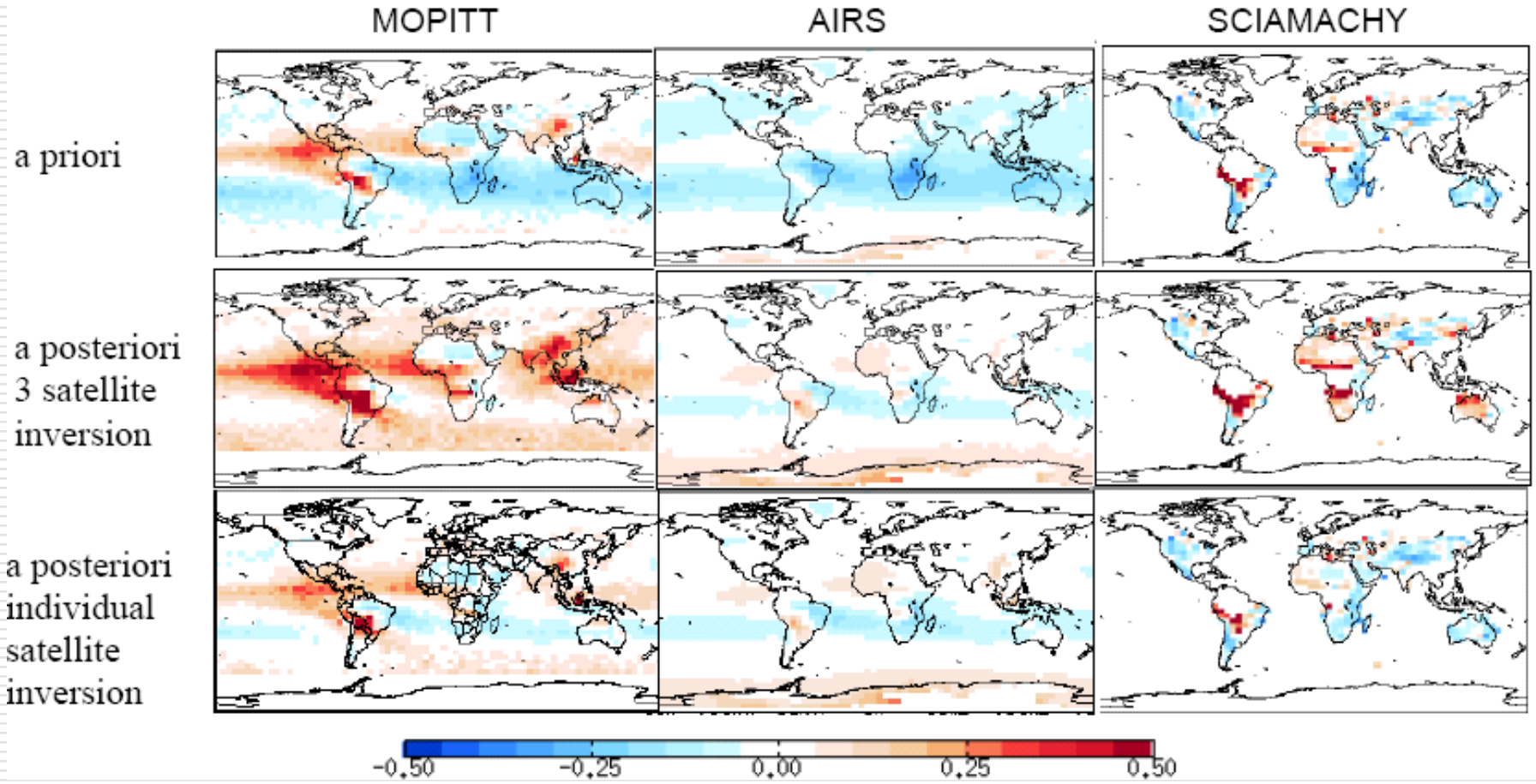
Findings:
Stronger seasonality in China than in N. America, no considerable seasonality in India

Possible **reasons** for underestimate: residential heating, “cold starts”



Improvement in model-data agreement from source inversion

Fractional model bias: **(model-data)/data** during sample period: Sept-Oct-Nov 2004

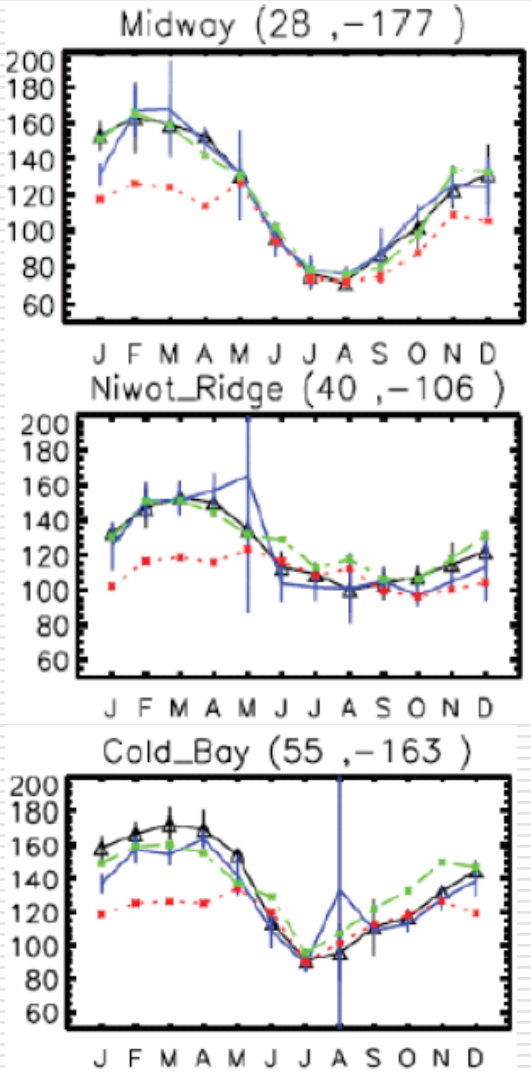


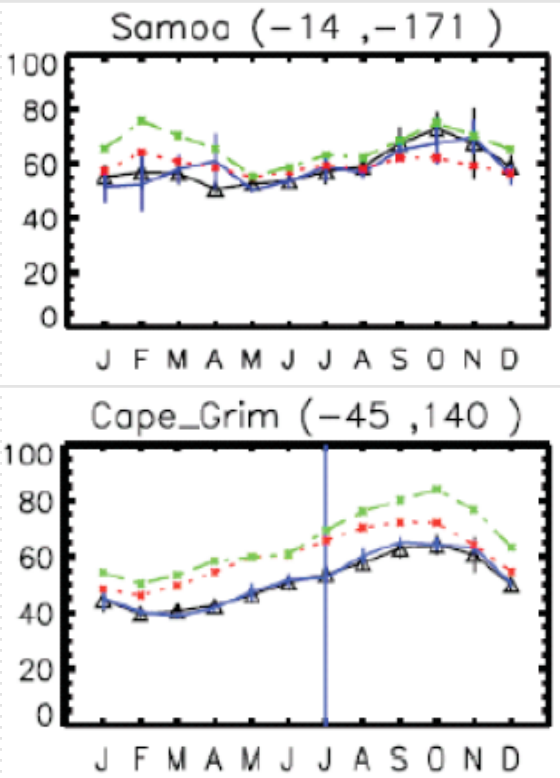
<u>Conclusion:</u> a balance of information, but AIRS dominates due to data density AND regional instrument inconsistencies

Comparison with independent surface measurements (GMD network)

Northern Hemisphere:
great improvement

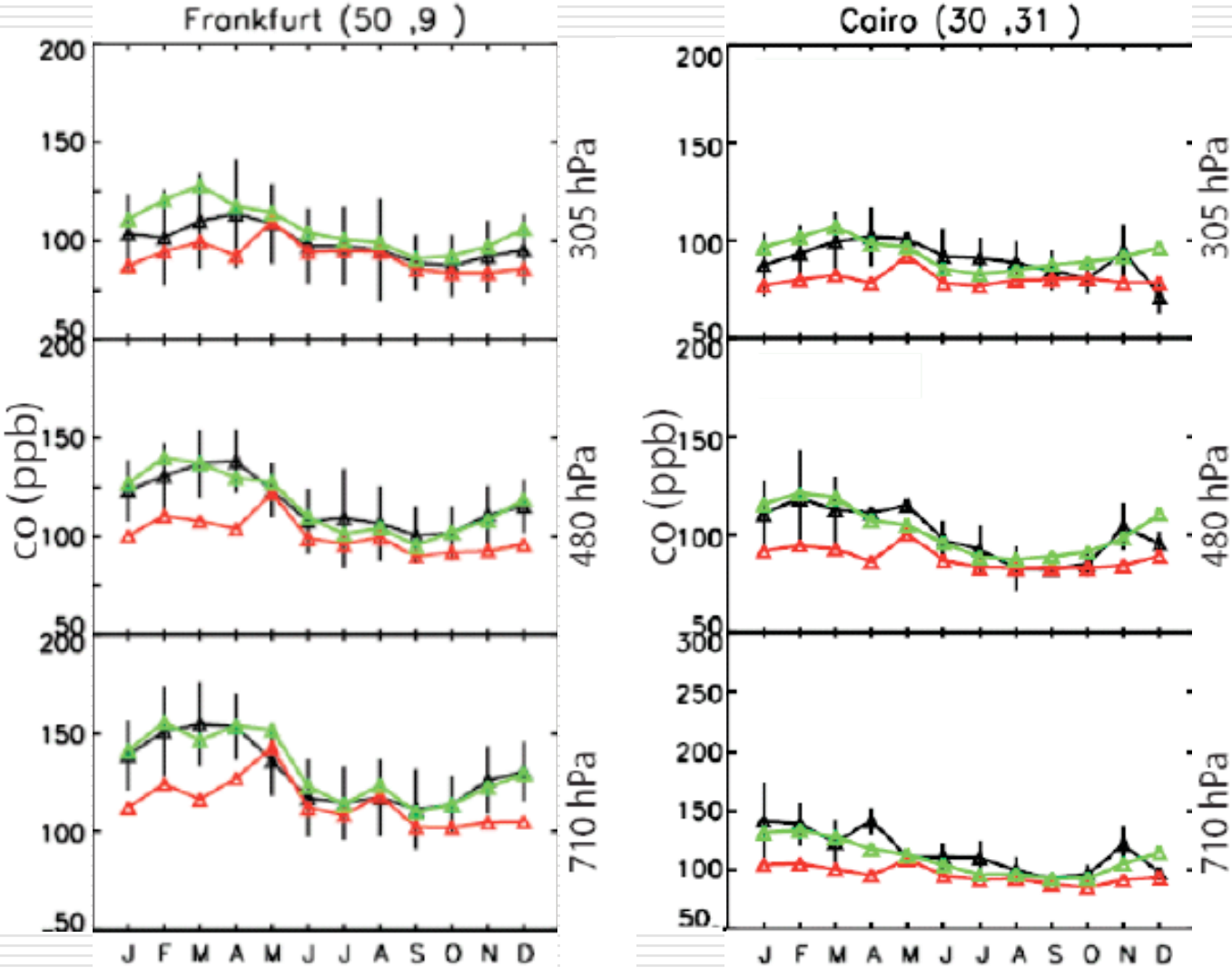
Southern Hemisphere:
still a challenge to match obs.





Model *a priori*	Model *a posteriori*
Obs (2004-2005)	Obs (climatology)

Comparison with independent aircraft measurements (MOZAIC)



Model *a priori* Model *a posteriori* Obs (climatology)

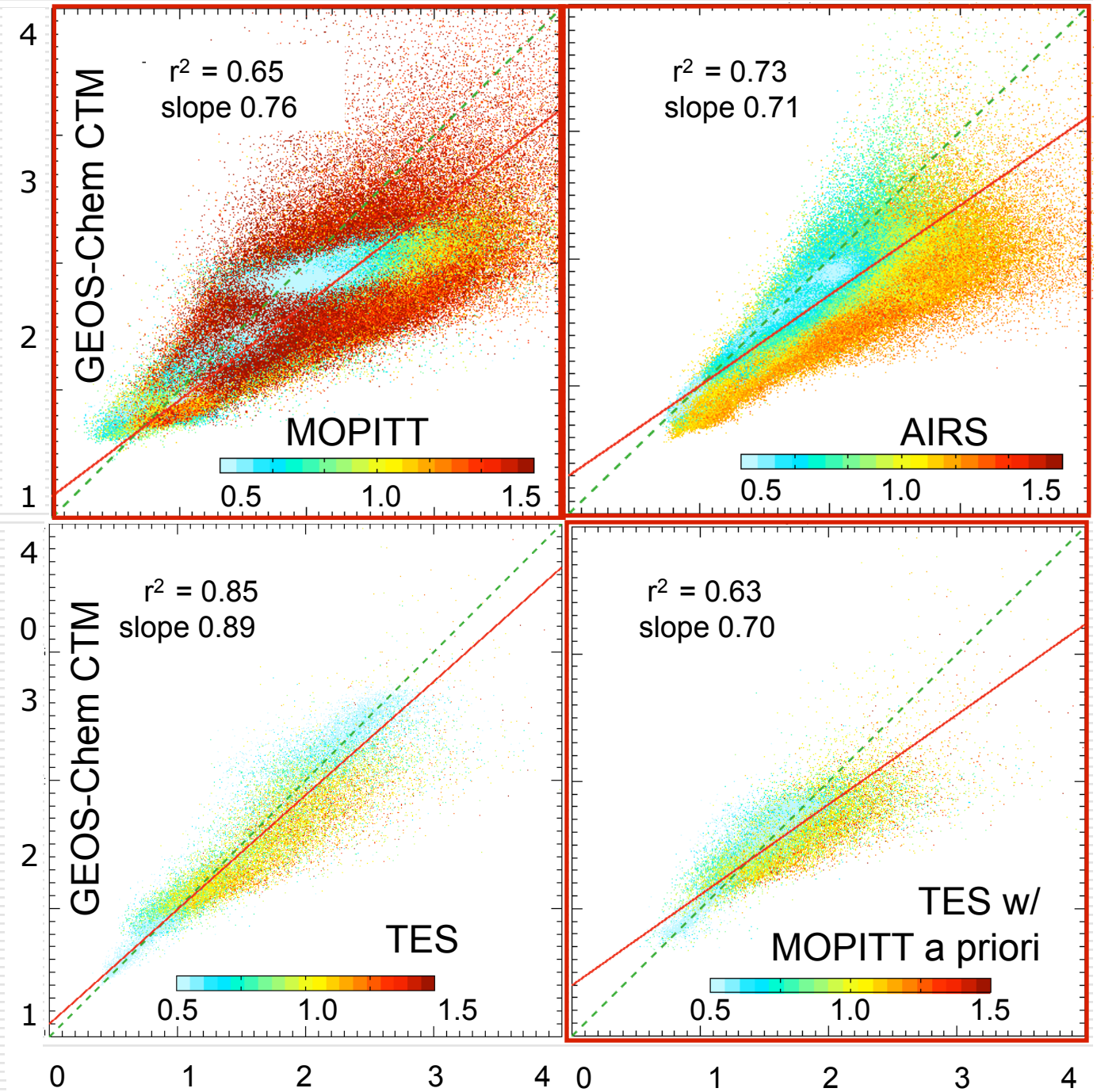
Major conclusions

1. GEOS-Chem CTM is a useful intercomparison platform for analyzing satellite data consistency
2. MOPITT, AIRS, TES and SCIAMACHY CO concentrations are generally consistent, especially in the northern hemisphere
3. Global annual CO emissions are found to be 1350 Tg
4. CO emissions in N. America, Europe and China exhibit strong seasonality, consistent with surface and aircraft observations
5. Tropical (mostly biomass burning) sources in S. America and Africa are estimated to be 183 and 343 Tg, mostly driven by AIRS data (larger than MOPITT or SCIAMACHY in southern hemisphere)
6. Regional satellite inconsistencies in southern hemisphere result in overestimated sources → motivation for more accurate data

Acknowledgement: Funding provided by NASA graduate fellowship

THANK YOU!!!

Amount of *a priori* information in model-satellite correlations

Measure of information content: degrees of freedom (DOFs)

Note: DOFs not available for SCIA; reprocessing with MOPITT a priori does not change SCIA correlations