Potential of TES to constrain estimates of continental sources of carbon monoxide

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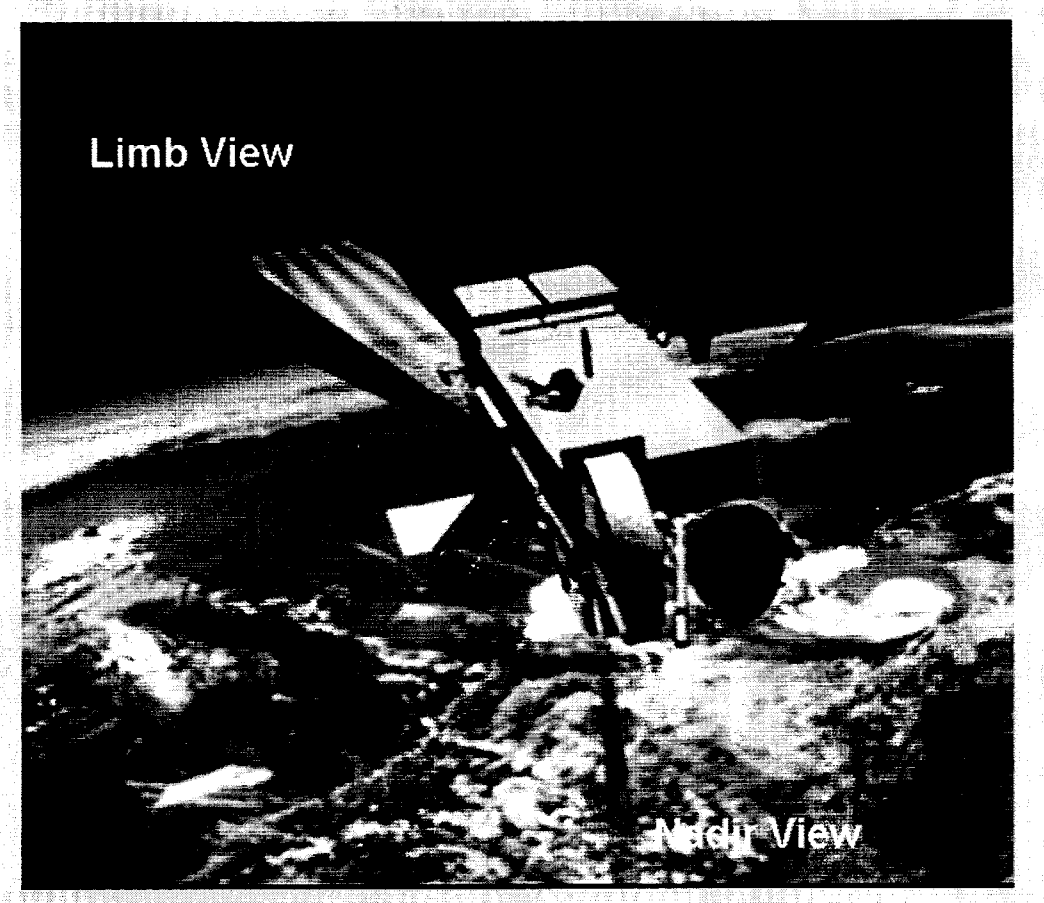
The Next Generation: Tropospheric Emission Spectrometer

- Will be launched in 2004
- Infrared, high resolution Fourier spectrometer (3.3 - 15.4 μm)
- Polar, sun-synchronous orbit
- Makes 14.56 orbits per day and repeats its orbit every 16 days
- Has 2 viewing modes: a nadir view and a limb view
- Spatial resolution of nadir measurement is 8 x 5 km



OBJECTIVE: Determine whether nadir observations of CO from TES will have enough information to reduce uncertainties in our estimates of continental sources of CO

APPROACH:

Assume thatw eknow the true sources of CO

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UseGEO S-CHEM3 -Dmodel to simulate "true" pseudo-atmosphere

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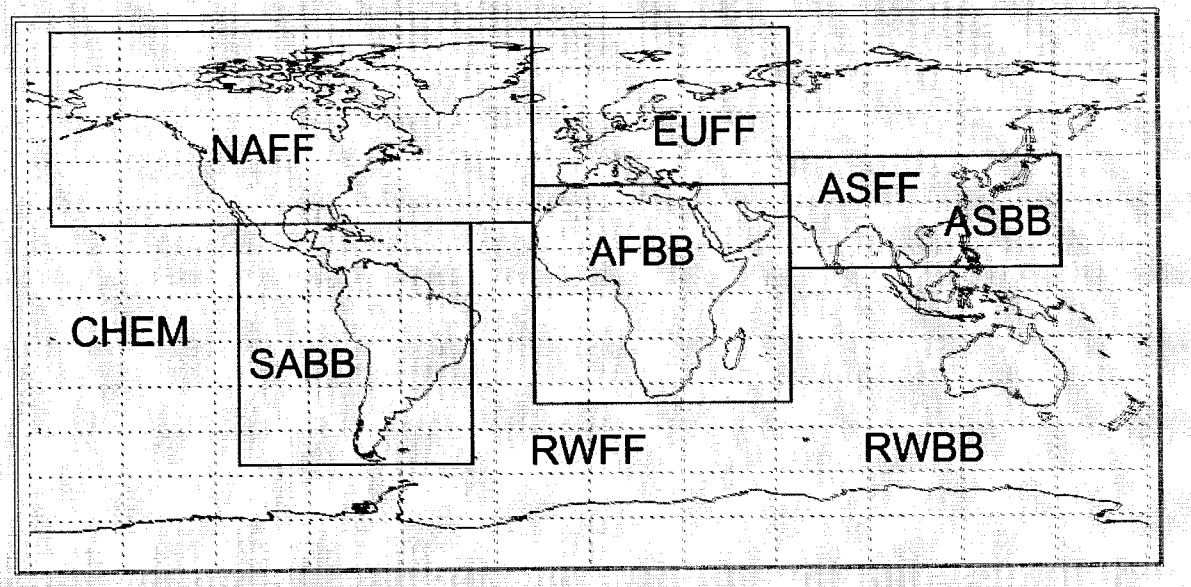
Samplepseud o-atmospherealong orbit of TES and simulate retrievals of CO

↓

Make *a priori* distribution ofCO sources byp erturbing the "true" source → Use optimal estimation → Obtain *a posteriori* estimates anderrors; How successful are we at reducing the error?

CO Source State Vector



"True" Emissions (Tg/yr)

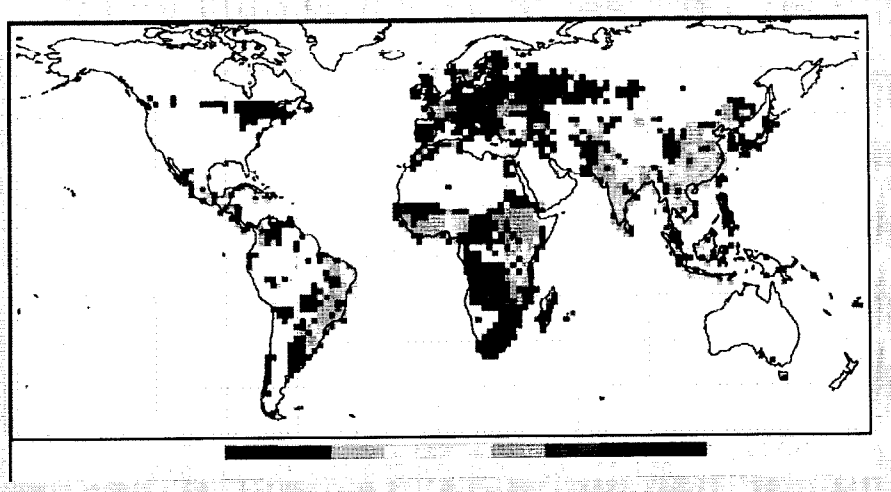
NAFF: 121.3	SABB: 96.5
EUFF: 131.1	RWBB: 98.0
ASFF: 258.3	RWFF: 149.8
ASBB: 96.0	CHEM: 1125.0
AFBB: 193.9	

Total = 2270 Tg/yr

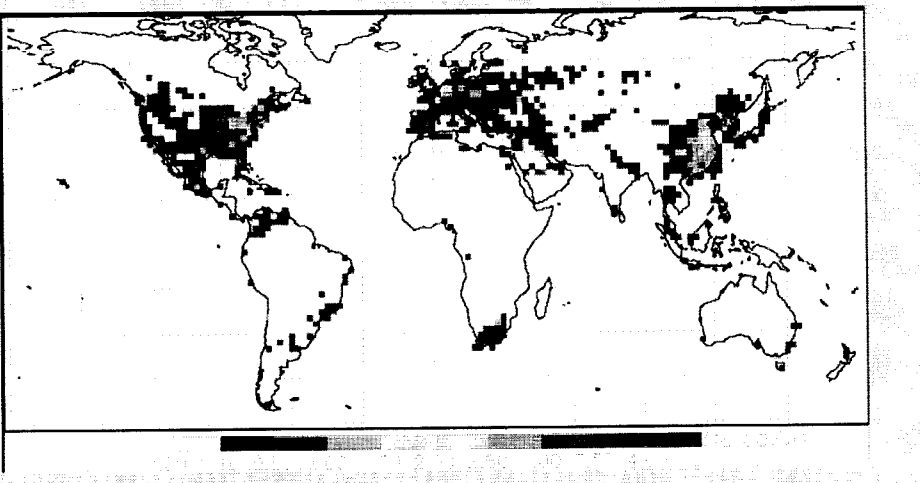
- FF = Fossil Fuel + Biofuel
- All sources include contributions from oxidation of VOCs
- OH is specified
- Use a "tagged CO" method to estimate contribution from each source
- Temporal evolution of emissions is known.

CO Source Distribution in GEOS-CHEM

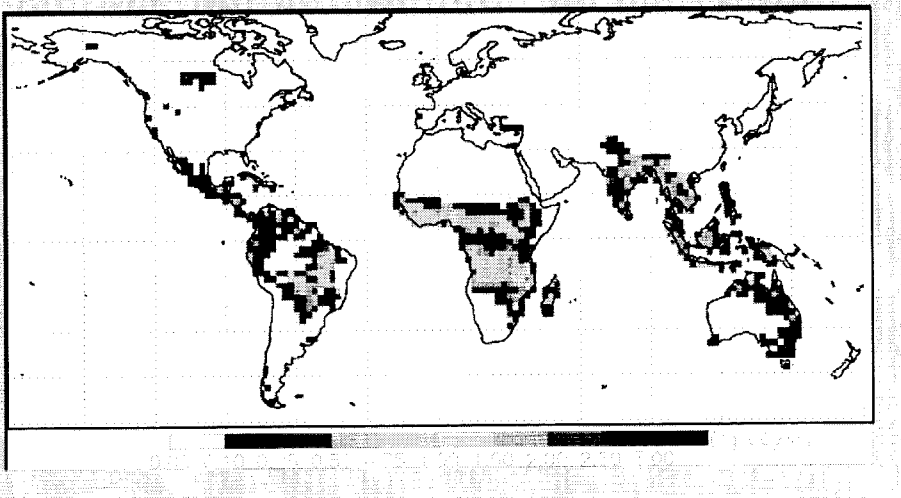
Fossil Fuels



Biofuels

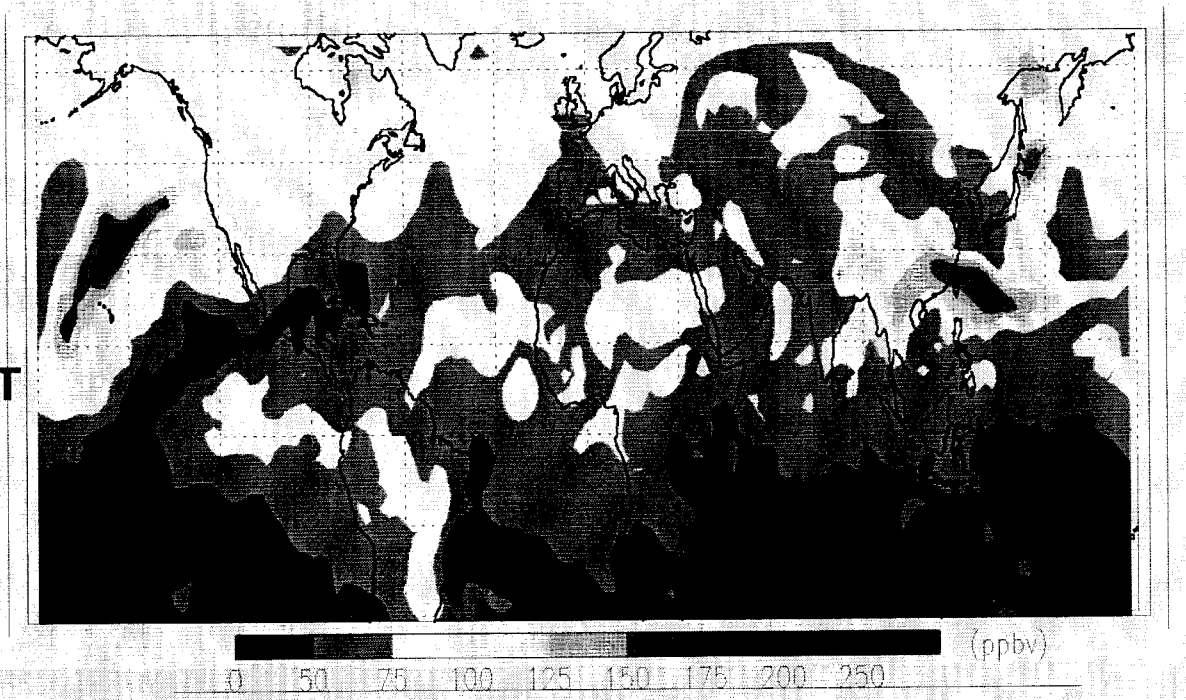


Biomass Burning

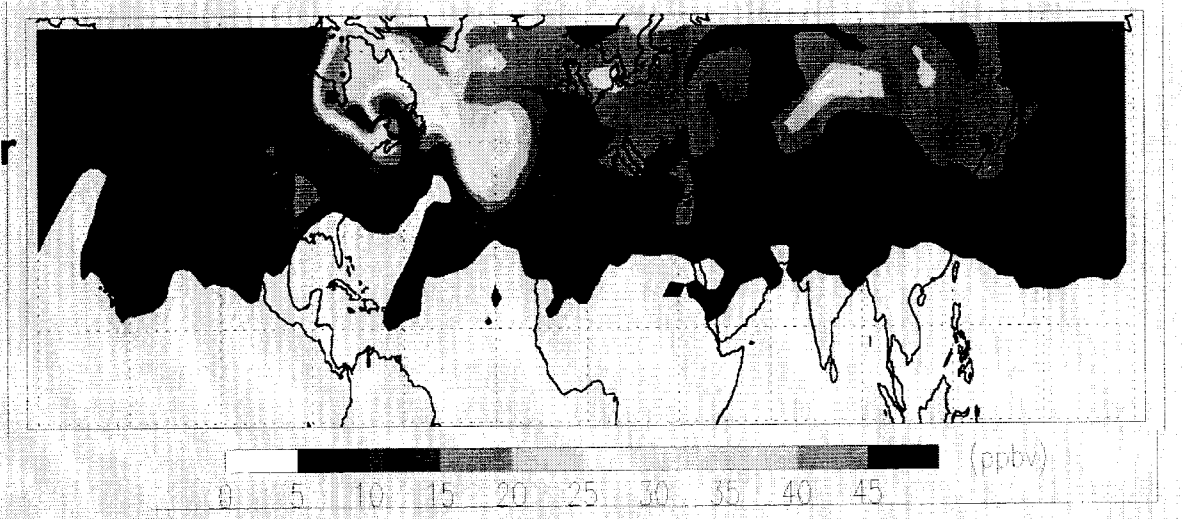


- Other Sources: oxidation of methane and other VOCs
- Main sink: reaction with atmospheric OH
- Relative spatial distribution of each region, e.g. NAFF, is fixed

Modeled CO
Level 13 (6 km)
15 Mar. 2001, 0 GMT



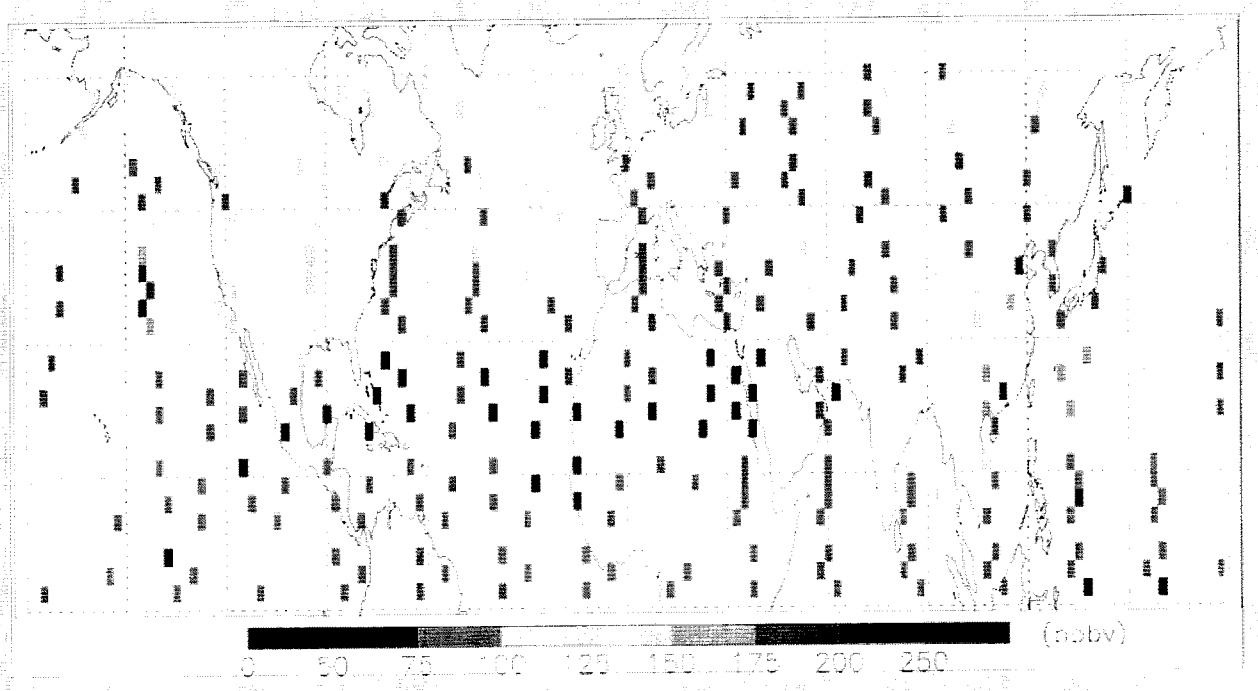
North American
fossil fuel CO tracer



Simulating TES observations

- Sample the synthetic atmosphere along the orbit of TES
- Assume that the TES nadir footprint of 8 x 5 km is representative of the entire GEOS-CHEM 2° x 2.5° grid box
- We consider data only between the equator and 60°N, ~364 profiles/day
- Use cloud fraction from GEOS-3, 60% loss of retrievals
- One averaging kernel used for all pseudo-retrievals

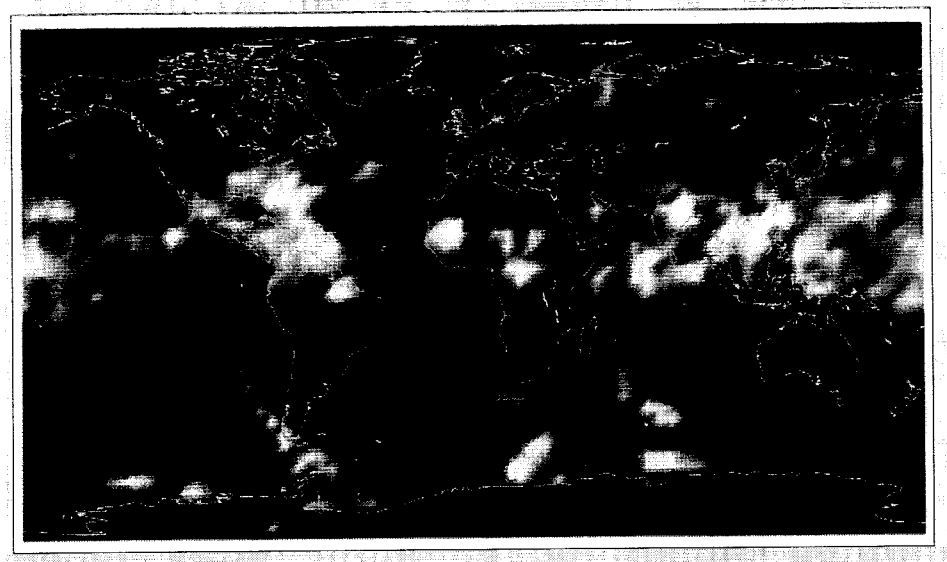
CO at 510.9 hPa for March 15, 2001



Cloud Conditions

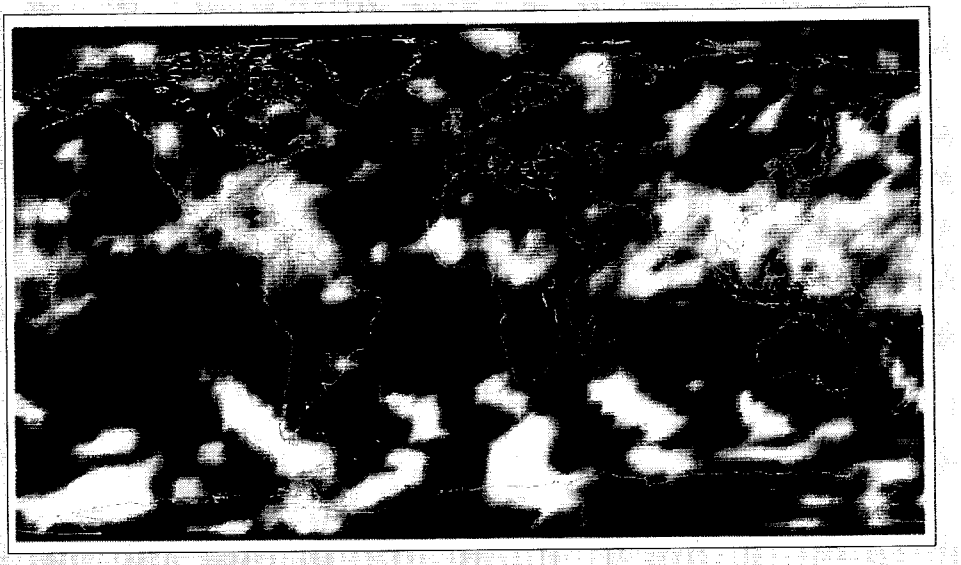
(a) GEOS-CHEM Model: Cloud Probability σ =0.22, ~230 hPa

Month: Aug Day: 15 Hr: 0



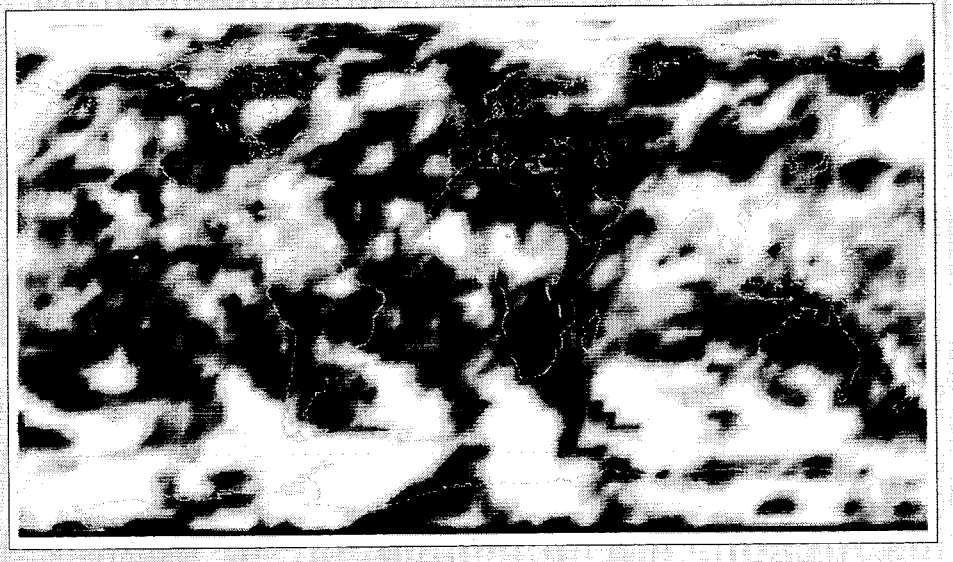
(b) GEOS-CHEM Model: Cloud Probability σ =0.66, ~670 hPa

Month: Aug Day: 15 Hr: 0



(c) GEOS-CHEM Model: Cloud Probability σ =1.0, Surface

Month: Aug Day: 15 Hr: 0



0.0 1.0

Generating the Pseudo-Retrievals of CO

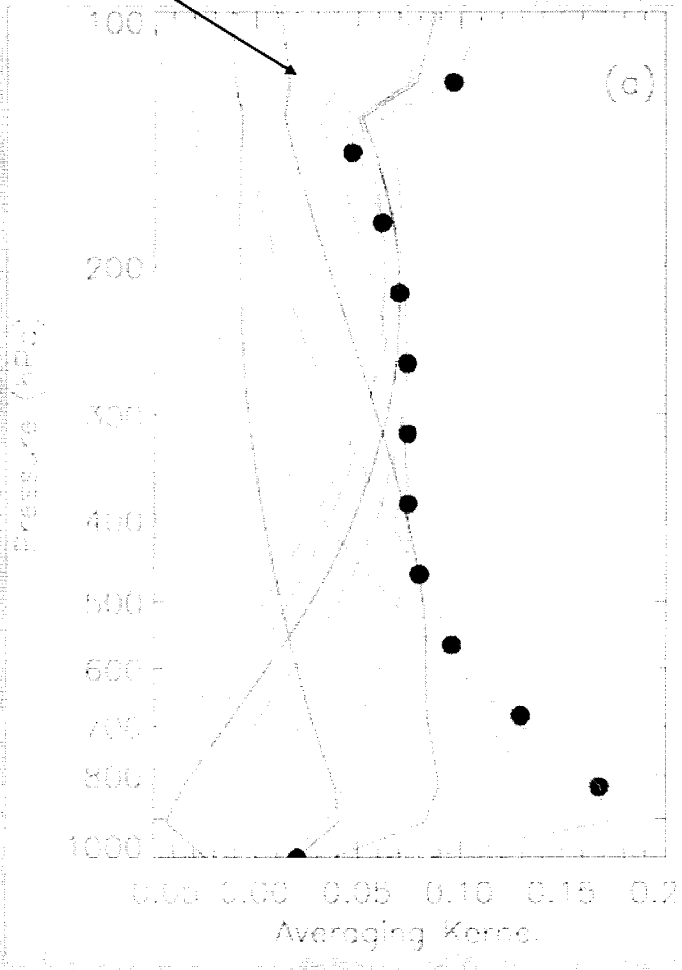
The retrieved profile is: $\hat{y} = y_a + A(y^t - y_a)$

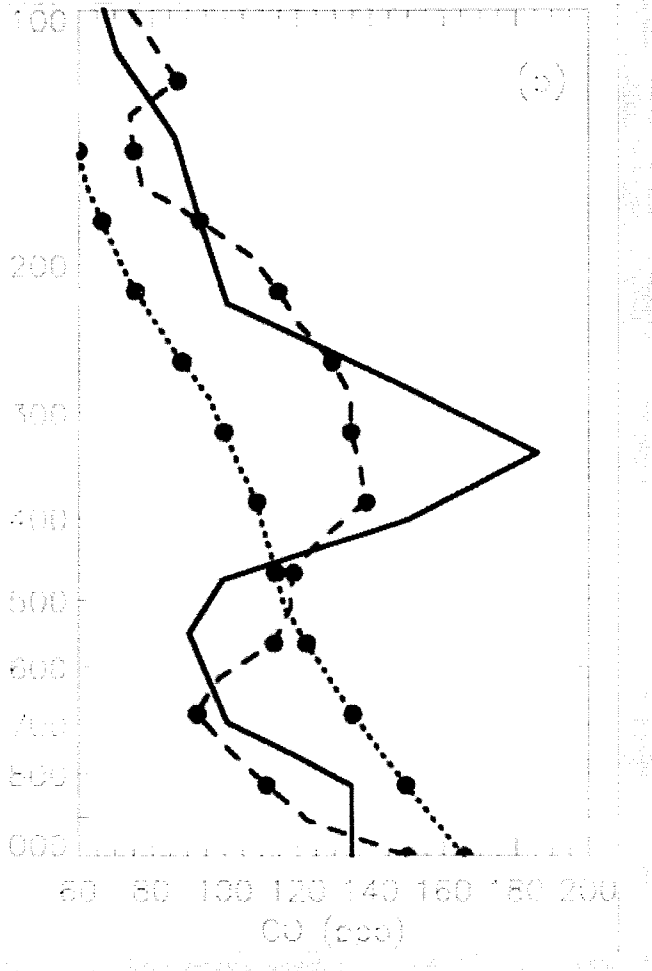
y_a = ***a priori*** **profile**

y^t **= true profile from GEOS-CHEM**

A = averaging kernels

Dofs = 2.1 and NESR= 3.8 x 10^{-9} W cm^{-2} sr^{-1}/cm^{-1}





Inversion Methodology

- Minimize the following maximum a posteriori (MAP) cost function:

$$||\hat{\mathbf{y}} - \mathbf{F}(\mathbf{x})||^2_{\mathbf{S}_\epsilon^{-1}} + ||\mathbf{x} - \mathbf{x_a}||^2_{\mathbf{S_a}^{-1}}$$

$\hat{y}$ = retrieved profile

x = the CO source state vector

x_a = a priori CO source state vector
(generated by perturbing true state)

S_a = a priori error covariance
(assume *a priori* error of 50%)

$F(x)$ = forward model simulation of x

S_ϵ = error covariance of observations
= instrument error + model error + representativeness error

The MAP cost function is minimized using the sequential update method. Assume retrieval errors are spatially uncorrelated.

The Forward Model

The forward model must account for the vertical sensitivity of TES and the *a priori* information used in the retrievals

$$\hat{\mathbf{y}} = \mathbf{F}(\mathbf{x}) + \epsilon$$

$$\mathbf{F}(\mathbf{x}) = \mathbf{y_a} + \mathbf{A}(\ln \mathbf{H}(\mathbf{x}) - \mathbf{y_a})$$

$\mathbf{H}(\mathbf{x})$ = GEOS-CHEM model

$\epsilon = \epsilon_i + \mathbf{A}\epsilon_r + \mathbf{A}\epsilon_m$

ϵ_i = Retrieval noise (< 10%, based on spectral noise of instrument)

Forward model errors of CO are characterized as white Gaussian noise as a function of latitude and longitude.

ϵ_r = representativeness error

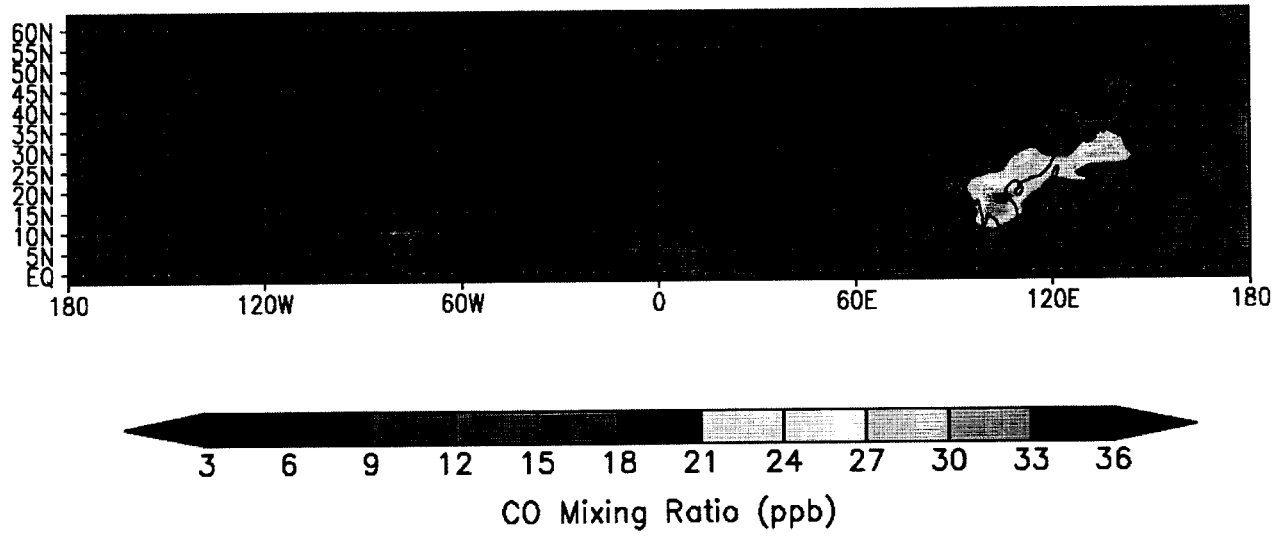
ϵ_m = model error

Constructing the Covariance Matrix for the Model Error

The "NMC method"

- assume that the difference between successive forecasts, which are valid at the same time, is representative of the forecast error structure

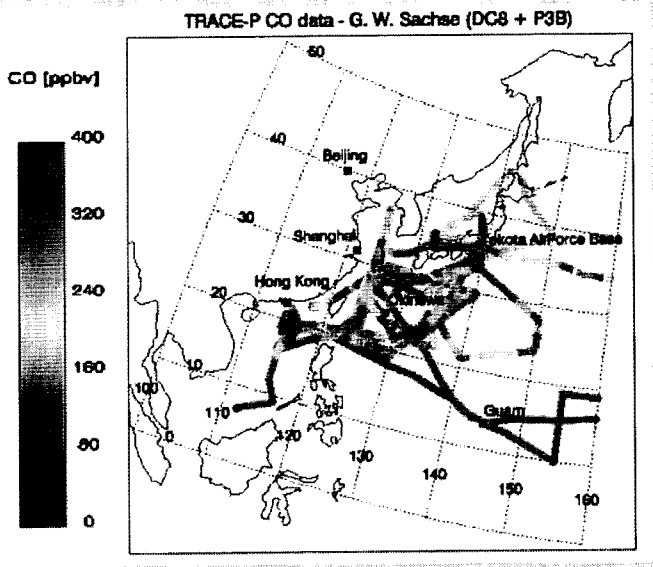
Model Level 16 (8 km)

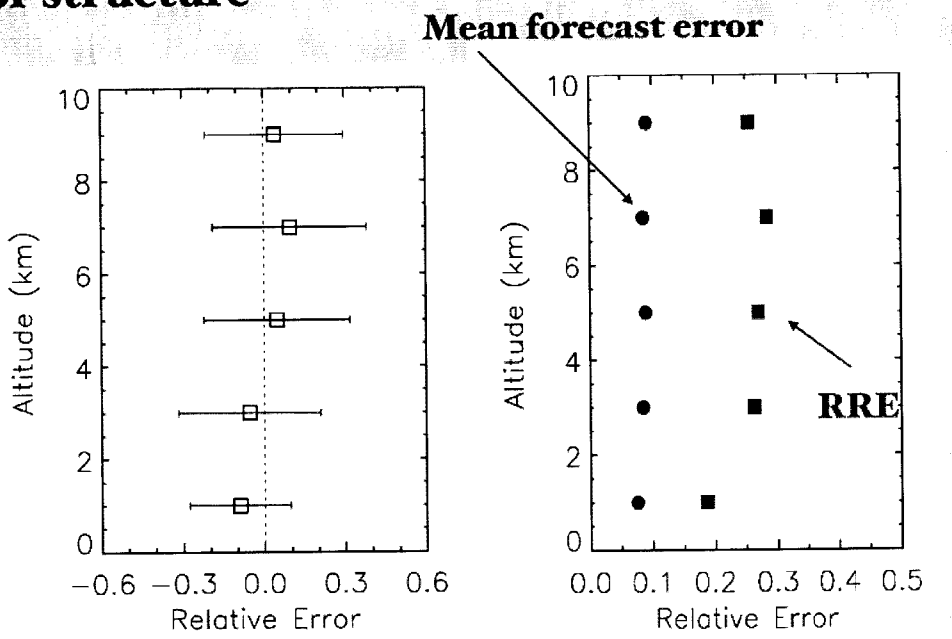


- root mean square error based on the difference of 89 pairs of 48-hr and 24-hr forecasts of CO during Feb-April 2001

Characterizing the Model Error

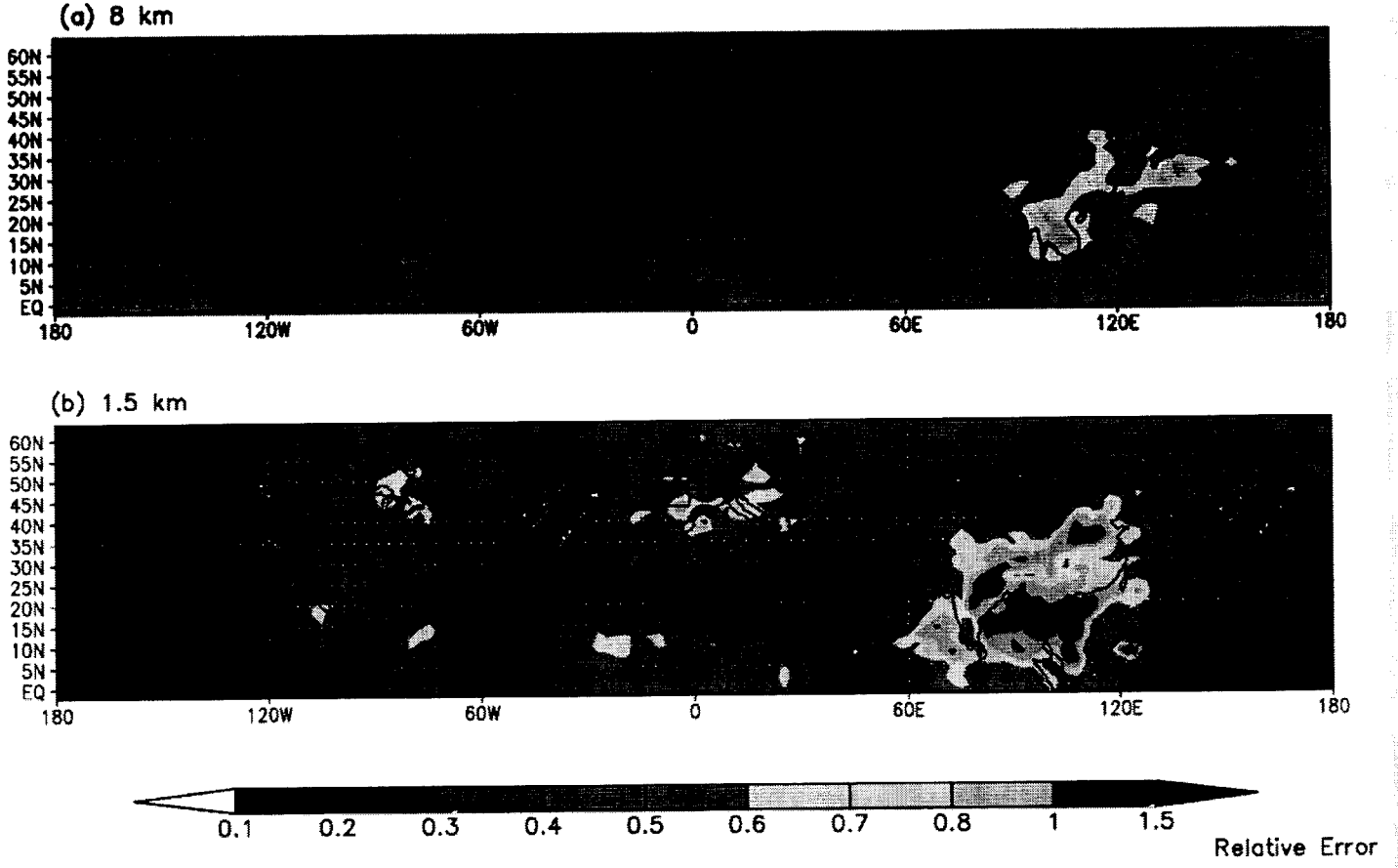
- Compare model with observations of CO from TRACE-P and estimate the relative error
- Assume mean bias in relative error is due to emission errors
- Remove mean bias and assume the residual relative error (RRE) is due to transport
- Use RRE to scale forecast error structure



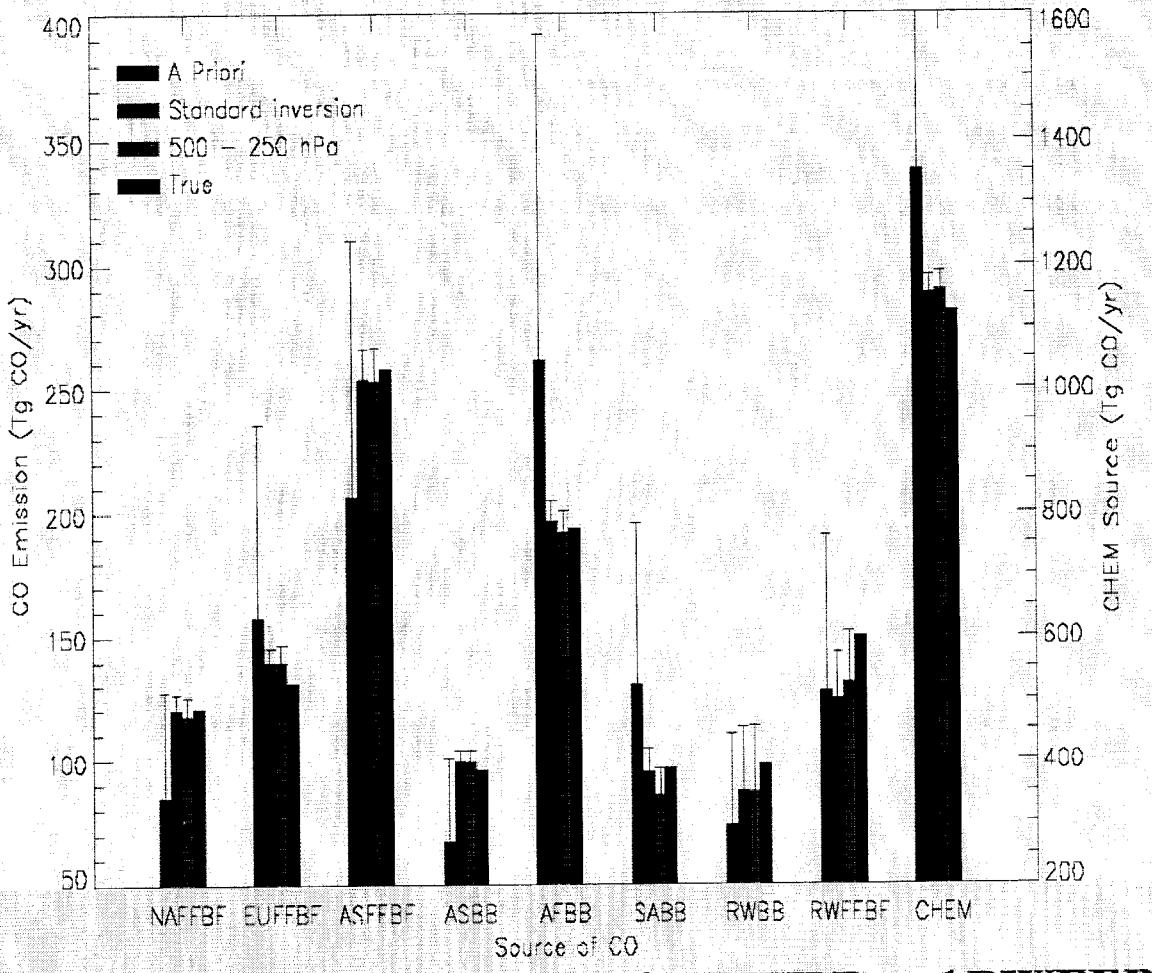


- Representativeness error = 5%, based on sub-grid variability of TRACE-P data

Model Error (Feb-April, 2001)

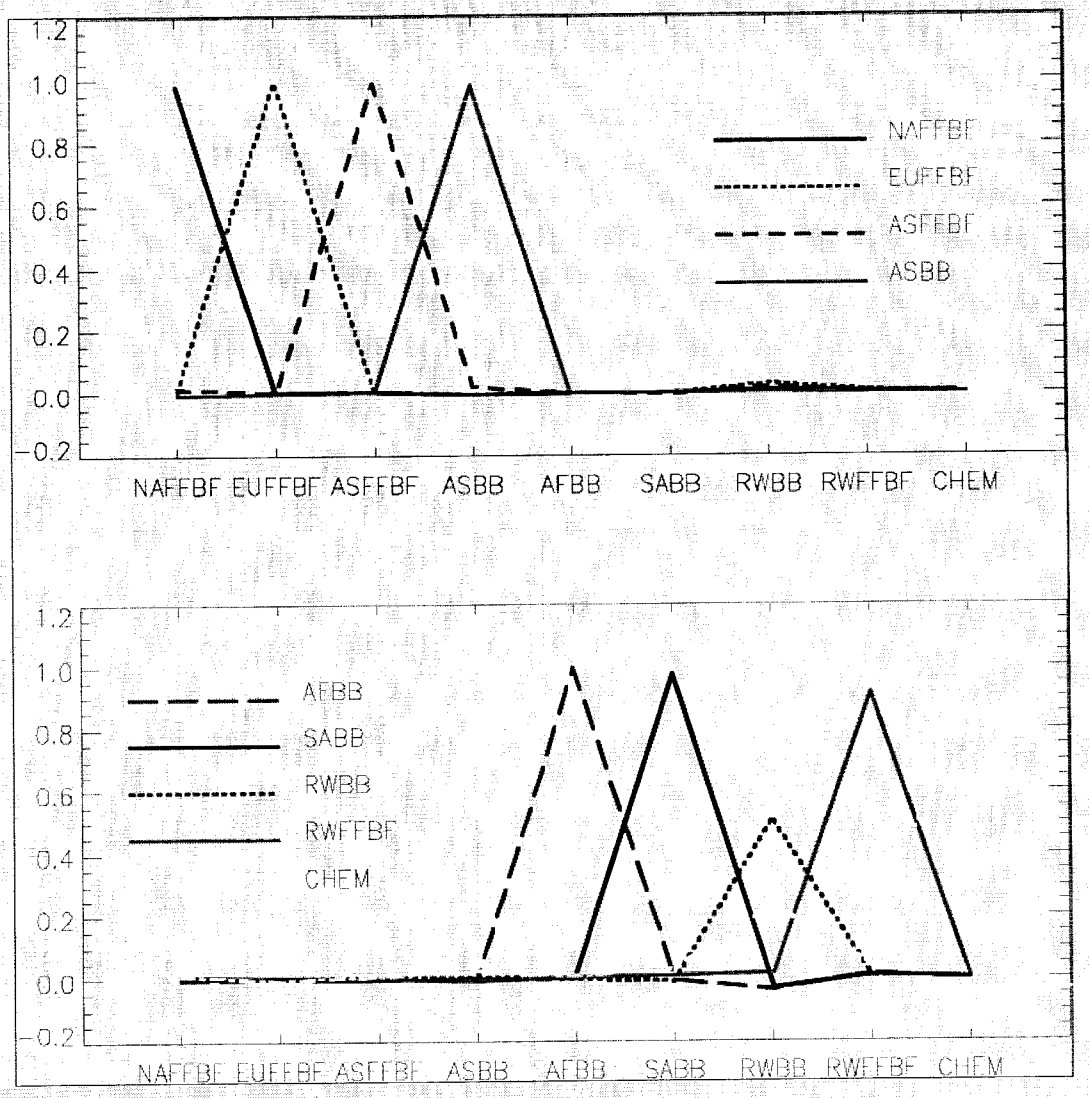


CO Source Estimate: 4 Days of TES Pseudo-Data



- The *a posteriori* errors are ~10% except for RWBB and RWFFBF, which is 15-25% (compare to *a priori* errors of 50%)

CO Source Averaging Kernel



- **Dofs=tr(A) = 8.6 for 9 elements**
- **Suggests that the CO source representation is too coarse.**

Conclusions

- We have presented a formal method for estimating CO sources using the GEOS-CHEM model with TES pseudo-observations

- This approach explicitly accounts for the vertical resolution via the TES averaging kernel and errors in TES retrievals.

- The diagonal of the a posteriori error is between a factor of 2 and 5 less than the a priori error for CO sources.

- This approach shows the potential of TES to significantly constrain the estimates of CO sources.

- Proper error characterization is critical, e.g., model transport error, satellite retrieval errors, chemistry, model representation errors, state vector representation, etc.

- Dofs from CO source averaging kernel suggests that TES could resolve a finer source distribution.