Progress Report

Personnel:

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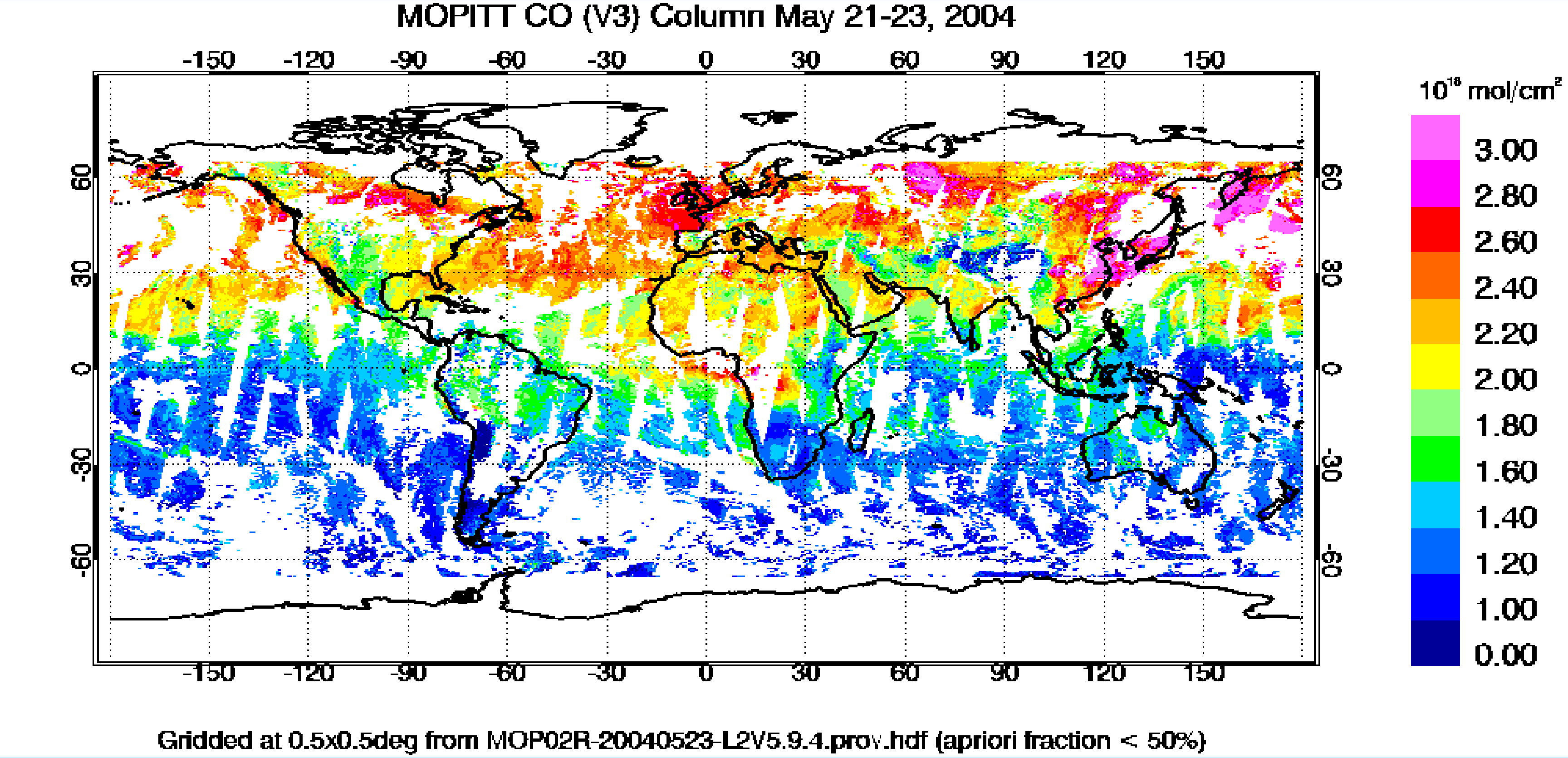
Motivation: How to best utilize satellite data?



Some Current Instruments: MODIS, TOMS, AVHRR, GOME, SCHIAMACHY
Some Planned Future Instruments: TES, OCO, OMI, HIRDLS

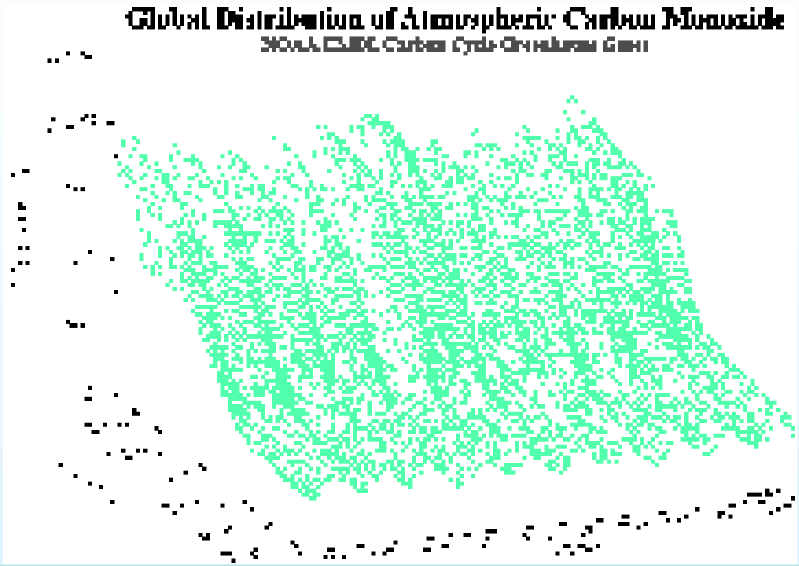
Scientific Foci

- Inverse Modeling of Emissions
  - CO -> Aerosols -> Multiple Species
  - Biomass burning
- Assimilation methodologies
  - Kalman Filter, 4D-Var, Ensemble Kalman Filter
- Sensitivity Studies (i.e., which processes are important to model correctly)

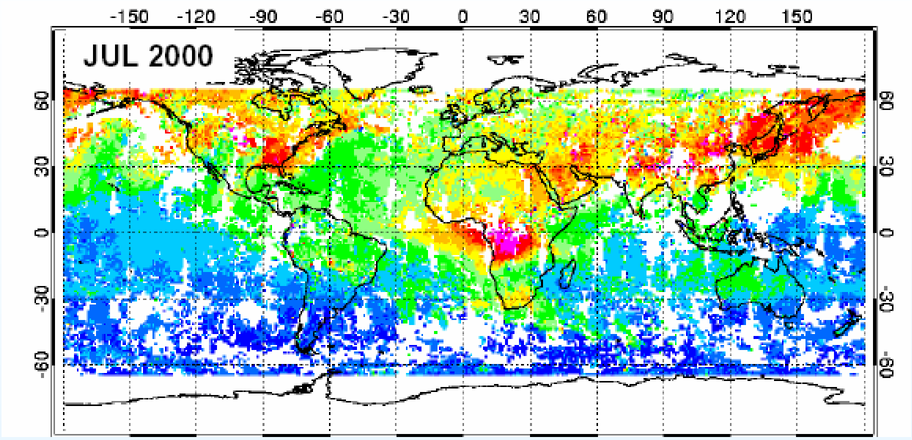
What we have done

- Optimization of CO surface sources using MOZART CTM and MOPITT data
  - recursive synthesis inversion
  - inversion set-up
    - phase1
  - hypotheses
  - results
- MOZART adjoint development

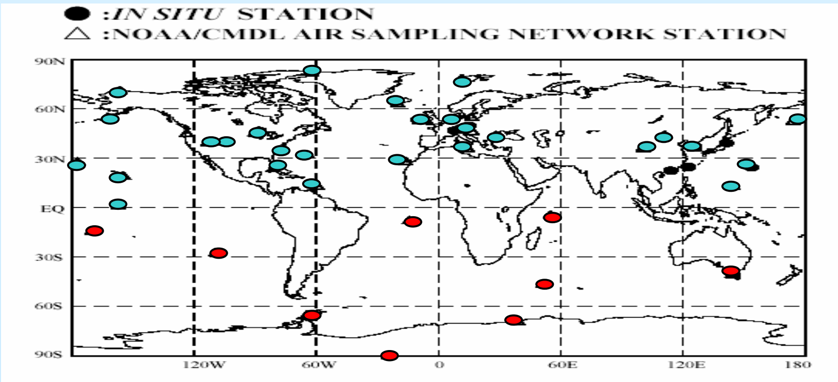
Monitoring of CO



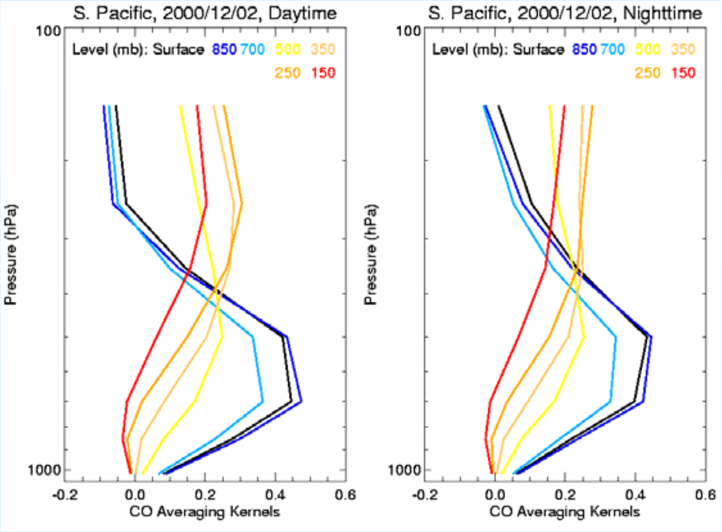
CMDL network of surface stations



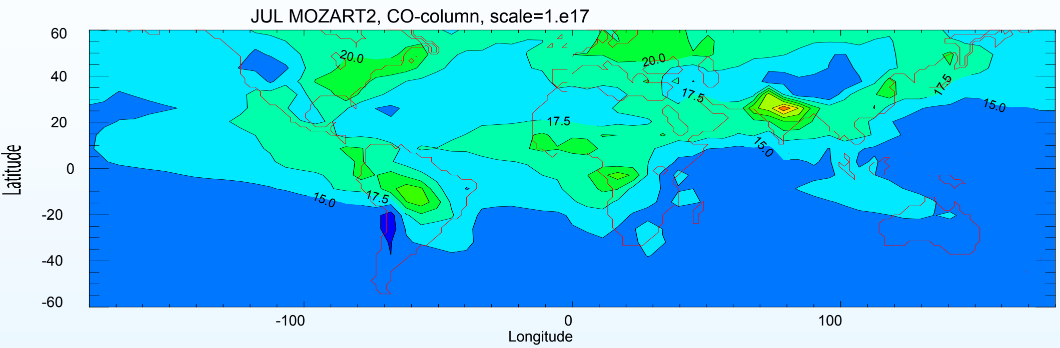
MOPITT CO retrievals (top:500 hPa)

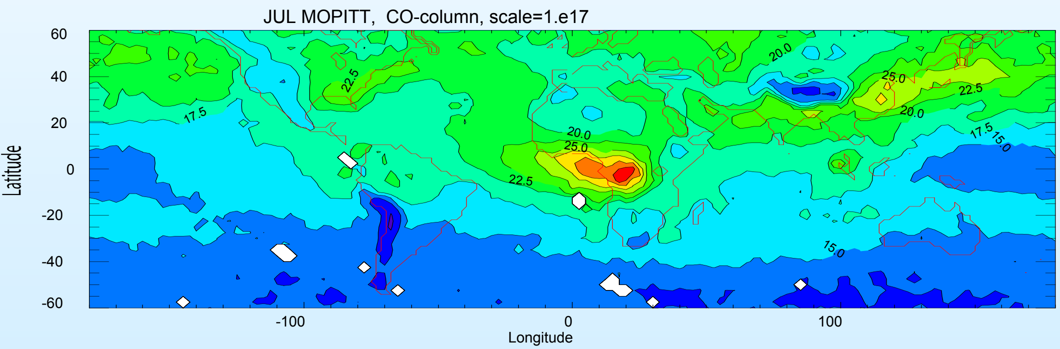


example of averaging kernel A (7,7)



MOZART (top)/MOPITT (bottom) CO column





- **Characteristics** :
  - Global coverage in 3 days
  - 20km x 20km pixel
  - 7 levels
  - **"Lower Precision/*in situ*"**
  - Filtered for clouds
  - Single a priori profile $\mathbf{y_a}$
- CO mixing ratios are Level3 data
- We need to know the averaging Kernel = what MOPITT sees!!

$$\mathbf{y_{comp} = y_a + A(y_{mod} - y_a)}$$

- MOPITT / MOZART :
  - binning of retrieved CO profiles onto MOZART grid
  - use of monthly averages
  - convolution of modeled profile, $\mathbf{y_{mod}}$, with averaging kernel, **A,** derived from the retrieval of MOPITT radiances, use of a priori profile $\mathbf{y_a}$

Sources & Sinks of CO

- Fossil fuel : 300-600
- Biomass burning: 300-900
- (forests, savannas, agric. waste burning, fuel wood use)
- Vegetation :)-200
- 30
- 1000
- 1000

LARGE UNCERTAINTIES

TOT 3700 TgCO/yr

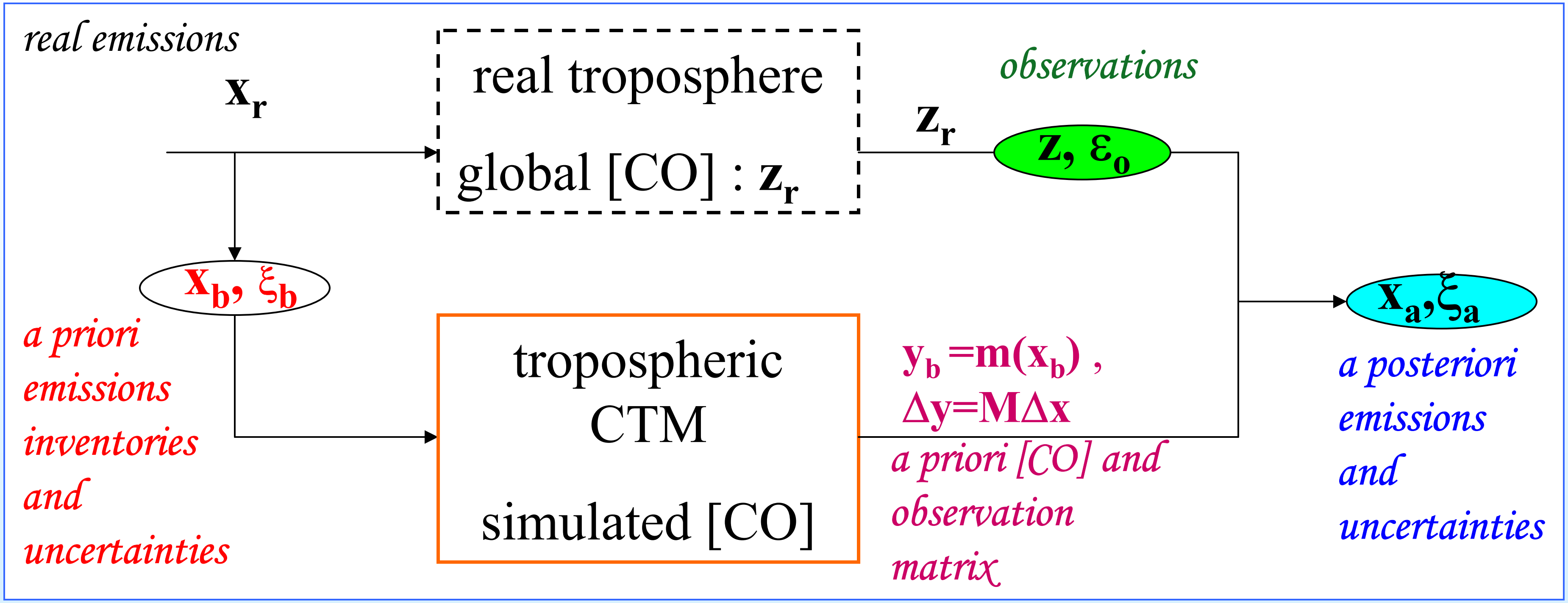
- Photochemical sink : 1400-2600
- Surface deposition: 150-500

TOTAL Sink = 1550 – 3100 TgCO/yr

Question....

Can observations of CO distribution in the troposphere help better constrain CO monthly surface sources?

Inverse problem : combination of information



System to be solved :

$$x_r = x_b + \xi_b$$

unknown : x_r

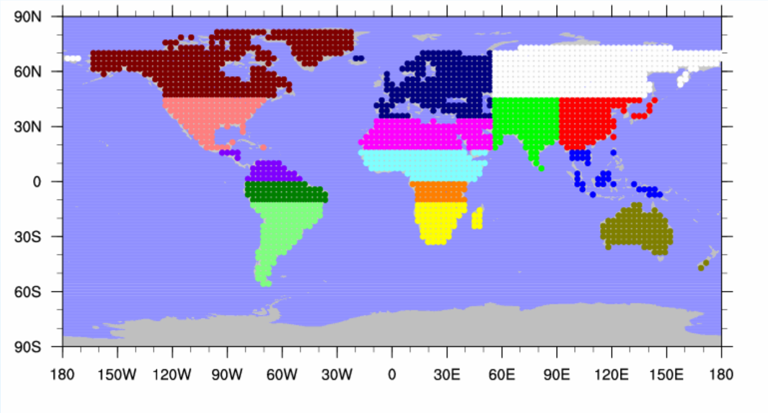
$$z - y_b = M(x_r - x_b) + \varepsilon$$

ε =measurement error and model error = $\varepsilon_o + \varepsilon_m$

hyp: **$E(\xi_b)=E(\varepsilon)=E(\varepsilon.\xi_b^T)=0$; $E(\xi_b \xi_b^T)=B$; $E(\varepsilon.\varepsilon^T)=R$**

Recursive synthesis Bayesian inversion

- Prior information: a priori emissions
- Aggregation of the emissions over large regions
  - monthly source processes : vector **x** (dim=Ne)



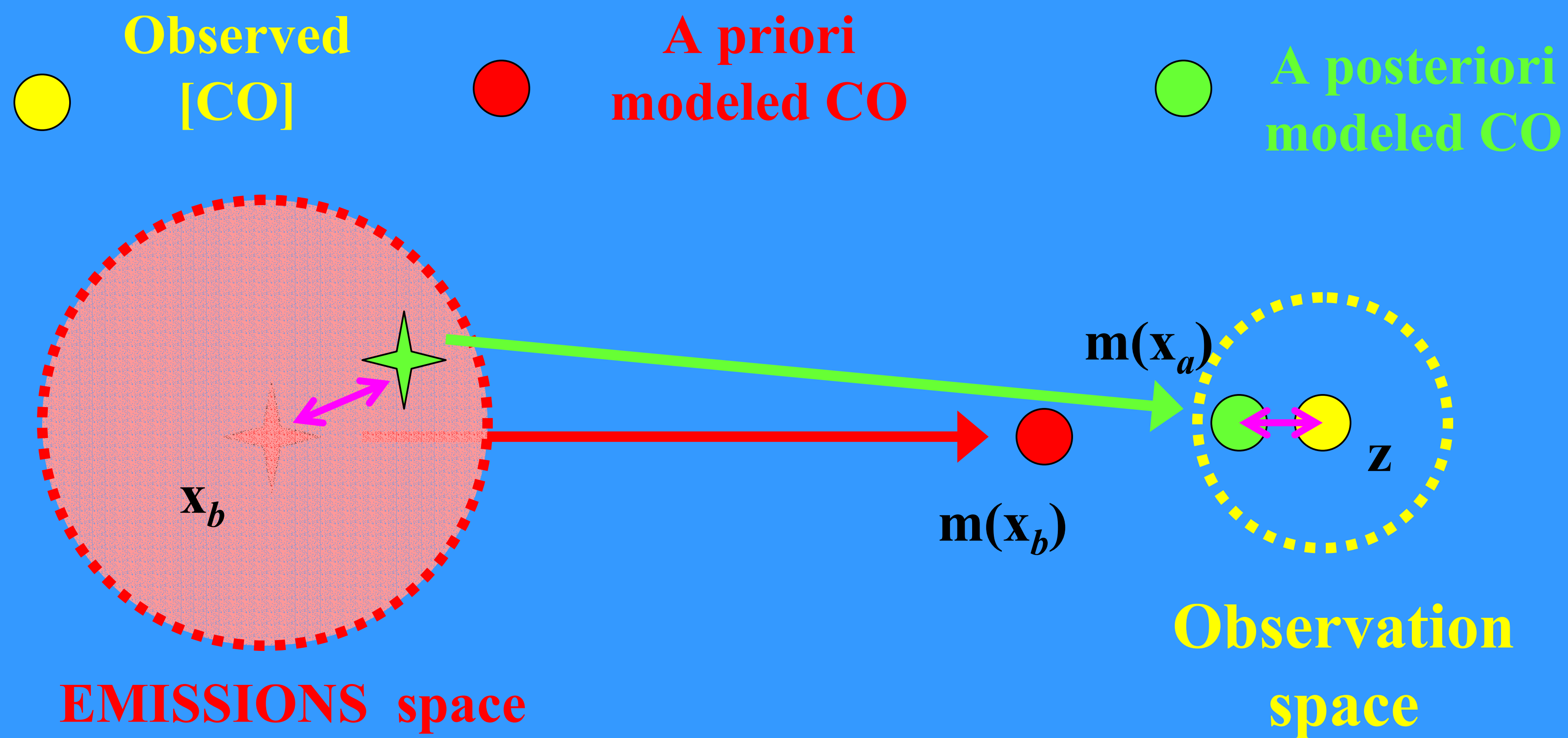
15 continental regions for anthropogenic emissions

4 latitudinal bands for oceanic & biogenic emissions

- Monthly averaged observations @ 700hPa level: vector **z** (dim=No)
  - MOPITT binned on MOZART grid
  - MOPITT CO at 700 hPa

CTM
➔ relationship between emissions and observations

- MOZART: 3D-global
  - Surface to 2hPa
  - 28 vertical levels
  - Horizontal resolution : 2.8º x 2.8º
  - 63 chemical species
  - Dynamical Fields NCEP
  - Time-step : 20 min
  - Monthly emissions
    - EDGAR3 (2000)
    - biomass burning (ATSR)



$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + (\mathbf{m}(\mathbf{x}) - \mathbf{z})^T \mathbf{O}^{-1} (\mathbf{m}(\mathbf{x}) - \mathbf{z})$$

weighted least squares

Hypotheses

- Statistics of errors:
  - All errors are gaussian and independent
  - Statistics of the observations known (first and second moments), ➔ R is diagonal (no correlation)
  - Statistics of the *a priori* sources known (first and second moments), ➔B is diagonal (no correlation)

➔ relative errors
= 100% for a priori emissions and for observations
➔ no biases

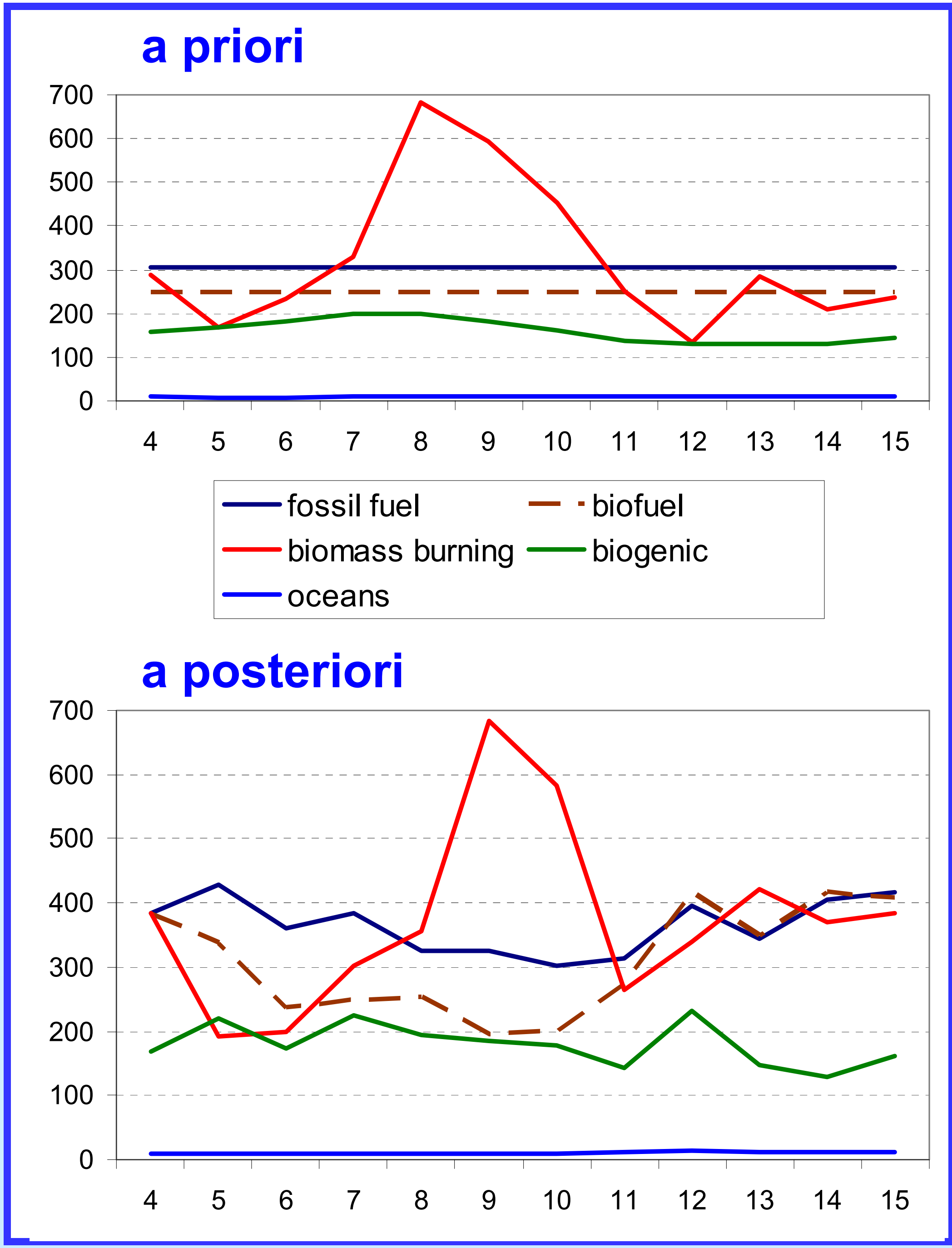
- CO sink and chemical production are not optimized.
- Transport model is perfect

Some results

- global budget (strength, seasonality)
- iterations
- ➔ biomass burning
  - changes (iteration #)
  - comparison with Randerson's inventory
- non-independent sources:
  - cannot distinguish ff/bf in Asia

Monthly global CO surface sources April 2000- March 2001

- shift in biomass burning maximum (august➔ sept)
- biofuel use emissions: maximum in winter (x 2 / summer time)
- fossil fuel emissions: maximum in winter (+30 % / summer time)

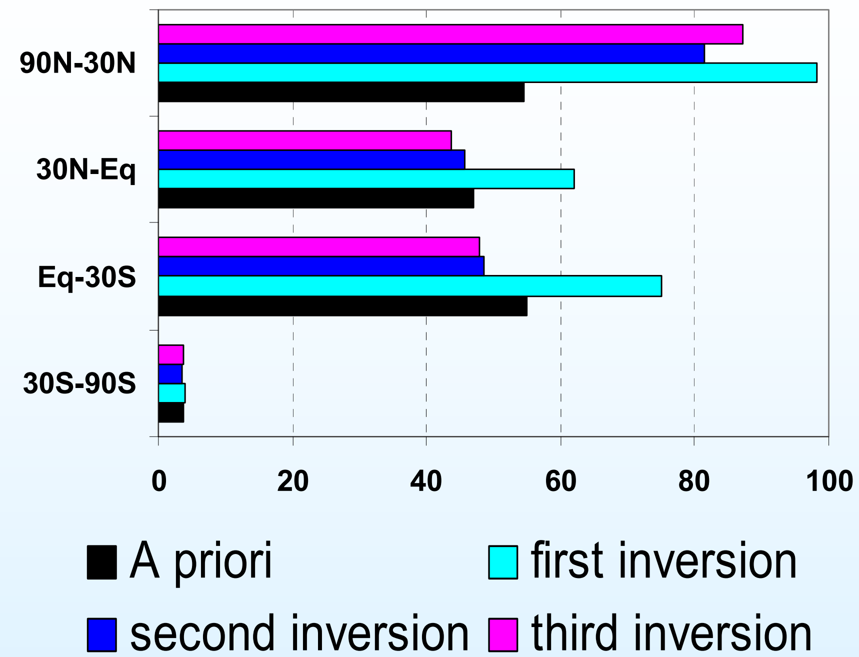


Annual CO emissions for various regions (TgCO/yr)

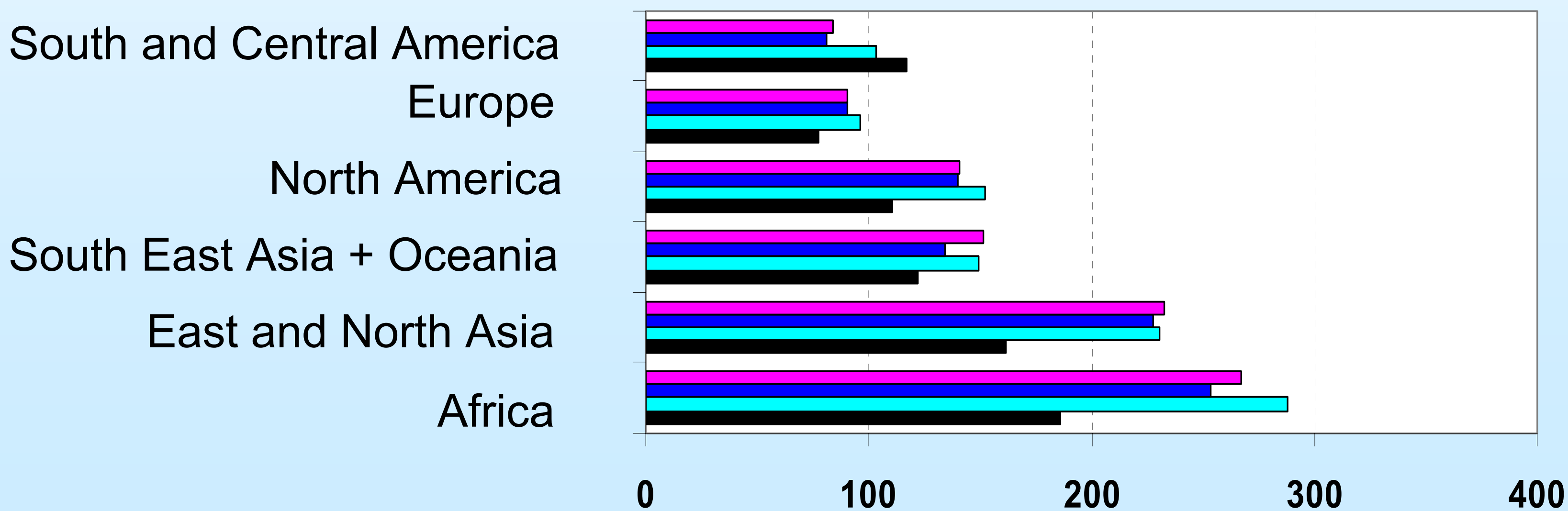
Region	A priori	A posteriori	Change %
Africa	186	254	**37**
East and North Asia	162	227	**40**
SE Asia and Oceania	122	134	**10**
North America	111	140	**27**
Europe	78	90	**16**
Central and South America	117	81	**-30**

Iteration of the inversion

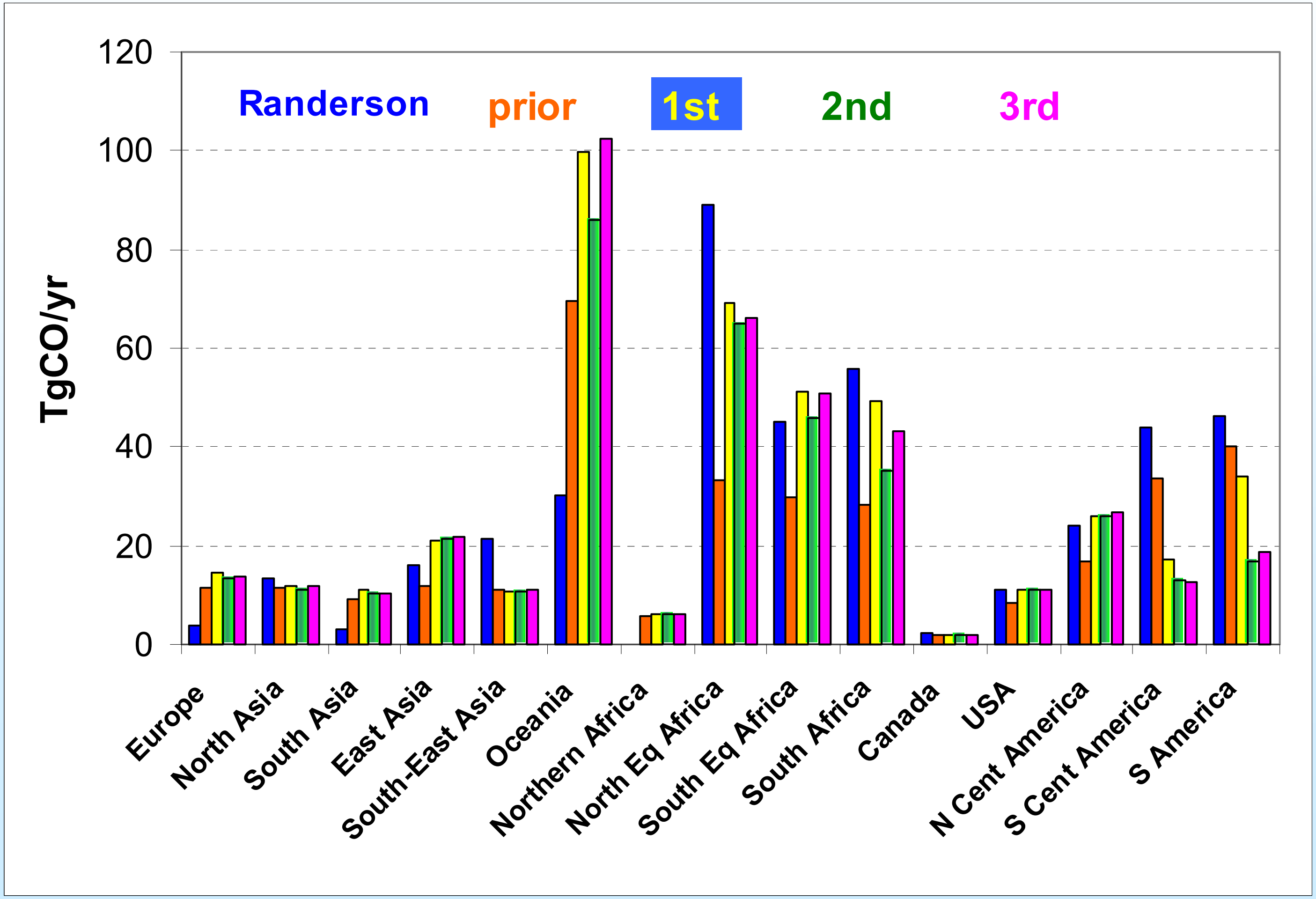
biogenic direct sources (TgCO/yr)



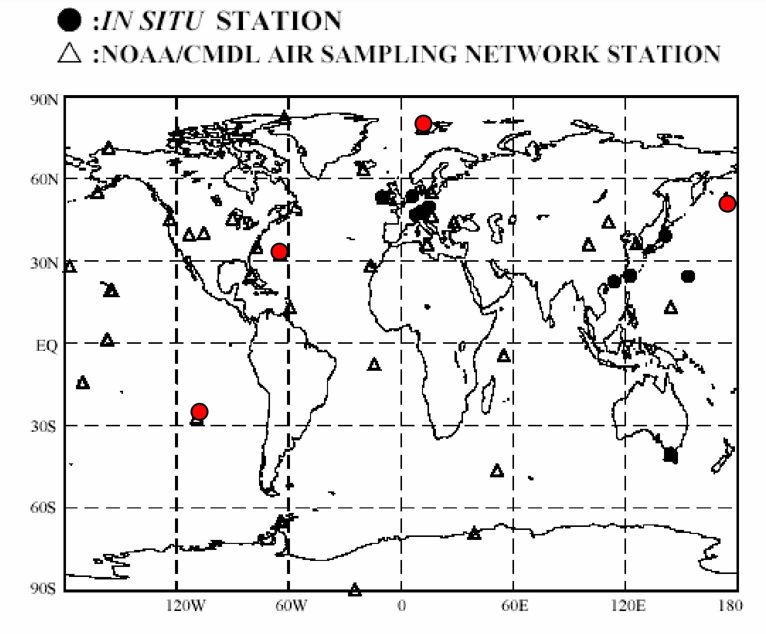
anthropogenic direct sources (TgCO/yr)

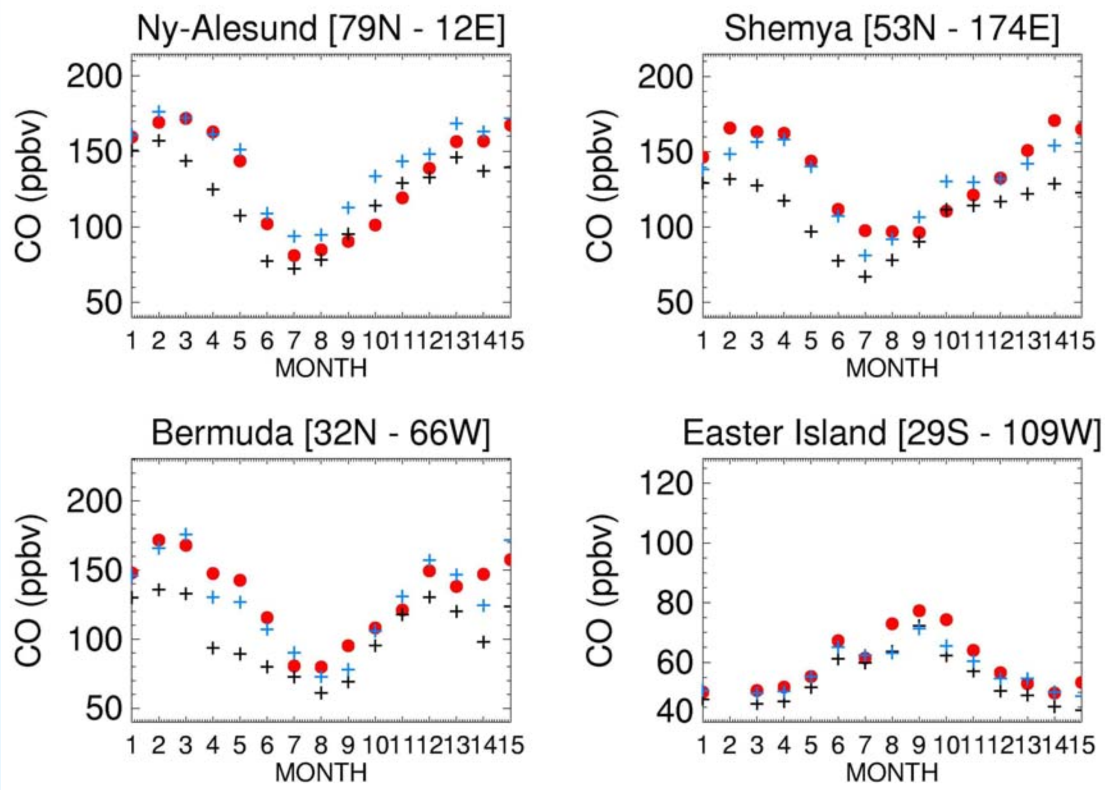


Impact of the iteration # on biomass burning and comparison with Randerson's inventory



Validation using independent observations



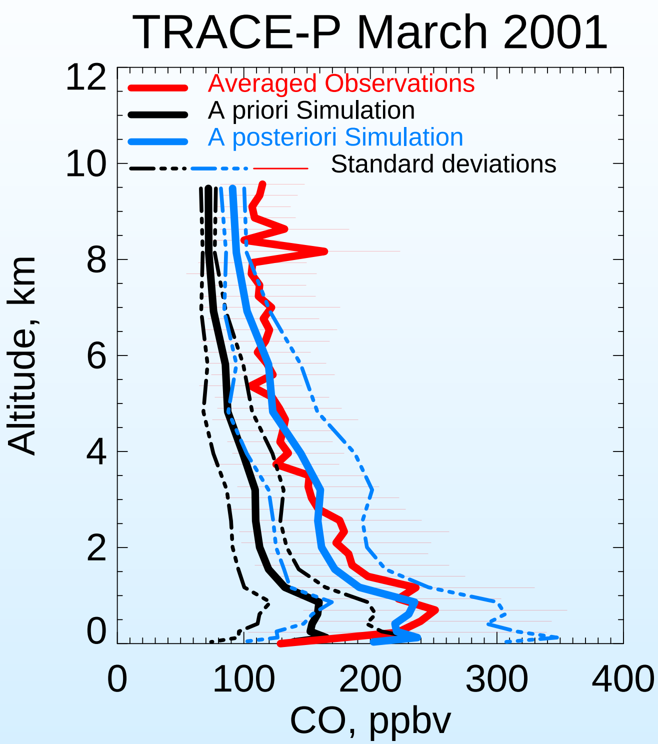


The agreement between the modeled CO and the observations improves at 26 stations (out of 33) when using the optimized sources.

CMDL (www.cmdl.noaa.gov)

TRACE-P March 2001

Asian outflow



observed

a priori

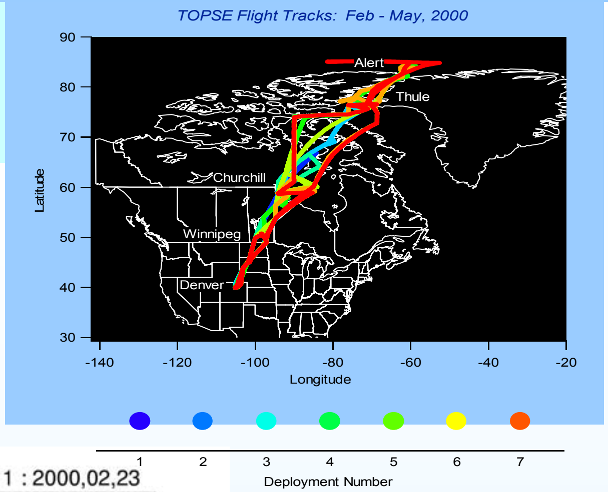
a posteriori

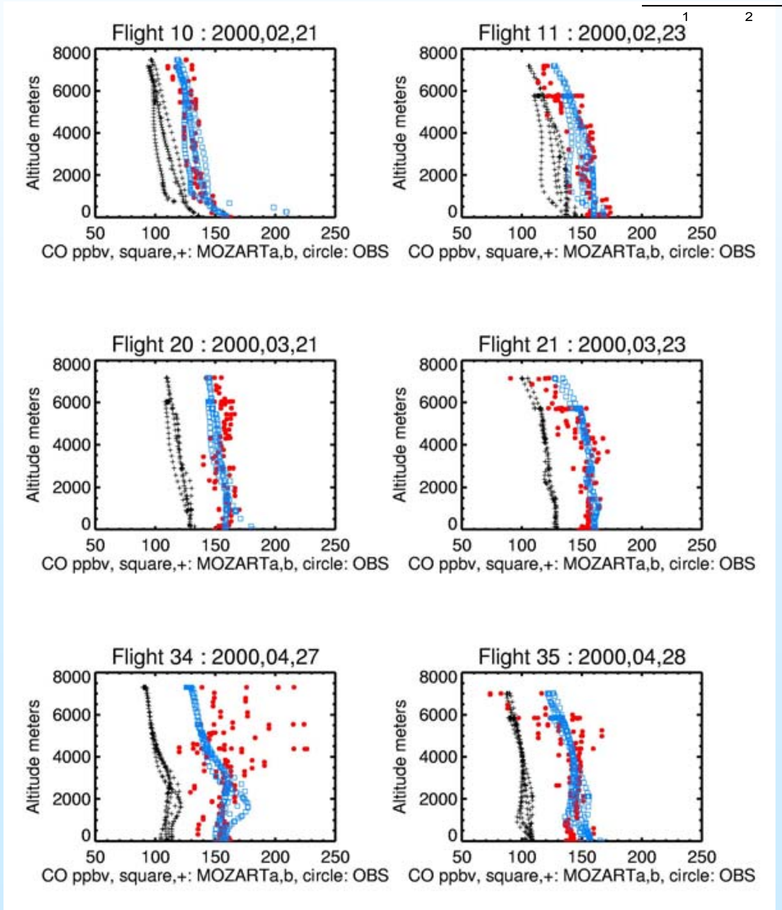
TOPSE Spring 2000

Spring Ozone Maximum

rmsd(prior)=34 ppbv

rmsd(post)=19 ppbv





in BL:

rmsd(prior)=29 ppbv

rmsd(post)=17 ppbv

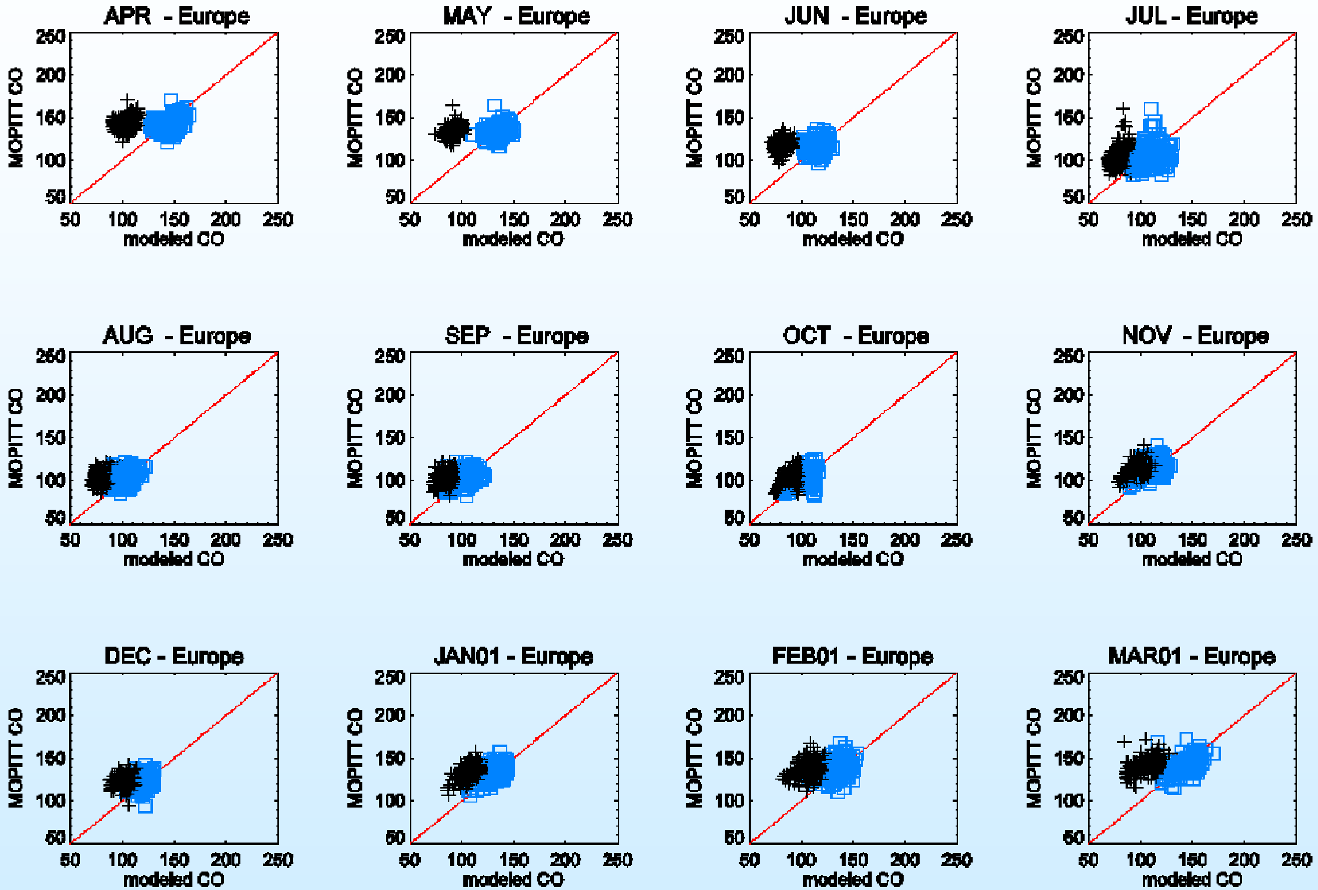
What we are doing

- extending the recursive inversion to 4 years
  - 2000-2003
  - new yearly-dependent biomass burning emissions based on MODIS fire counts
- improving the model and observations errors statistics
  - derive better errors statistics from the comparison of the modelled and the observed CO for the 15 regions

Observations vs Forecast or Analysis

Europe - April 2000 to March 2001

MOPITT CO (700hPa)

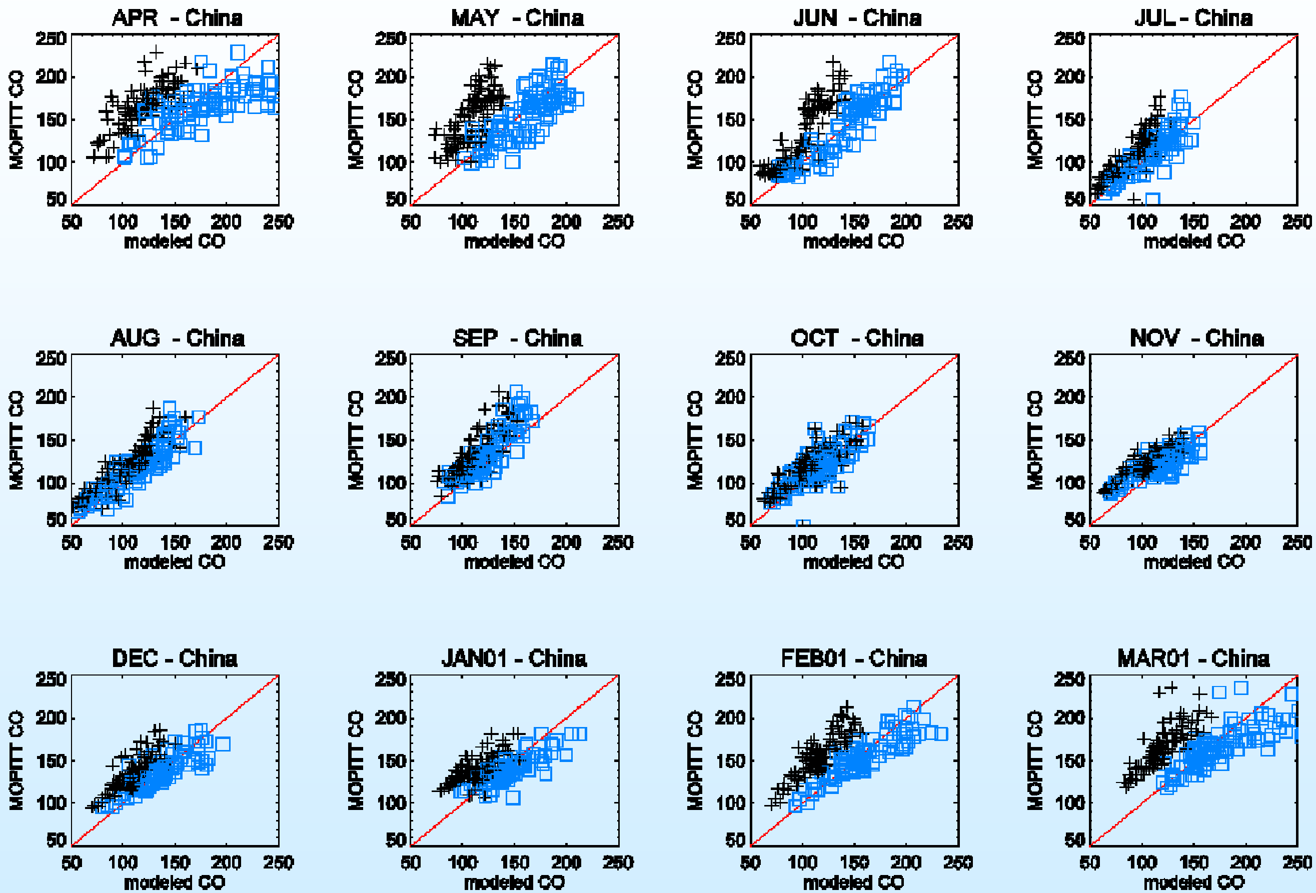


modelled CO : with a priori (black) and a posteriori (blue) emissions

Observations vs Forecast or Analysis

China - April 2000 to March 2001

MOPITT CO (700hPa)

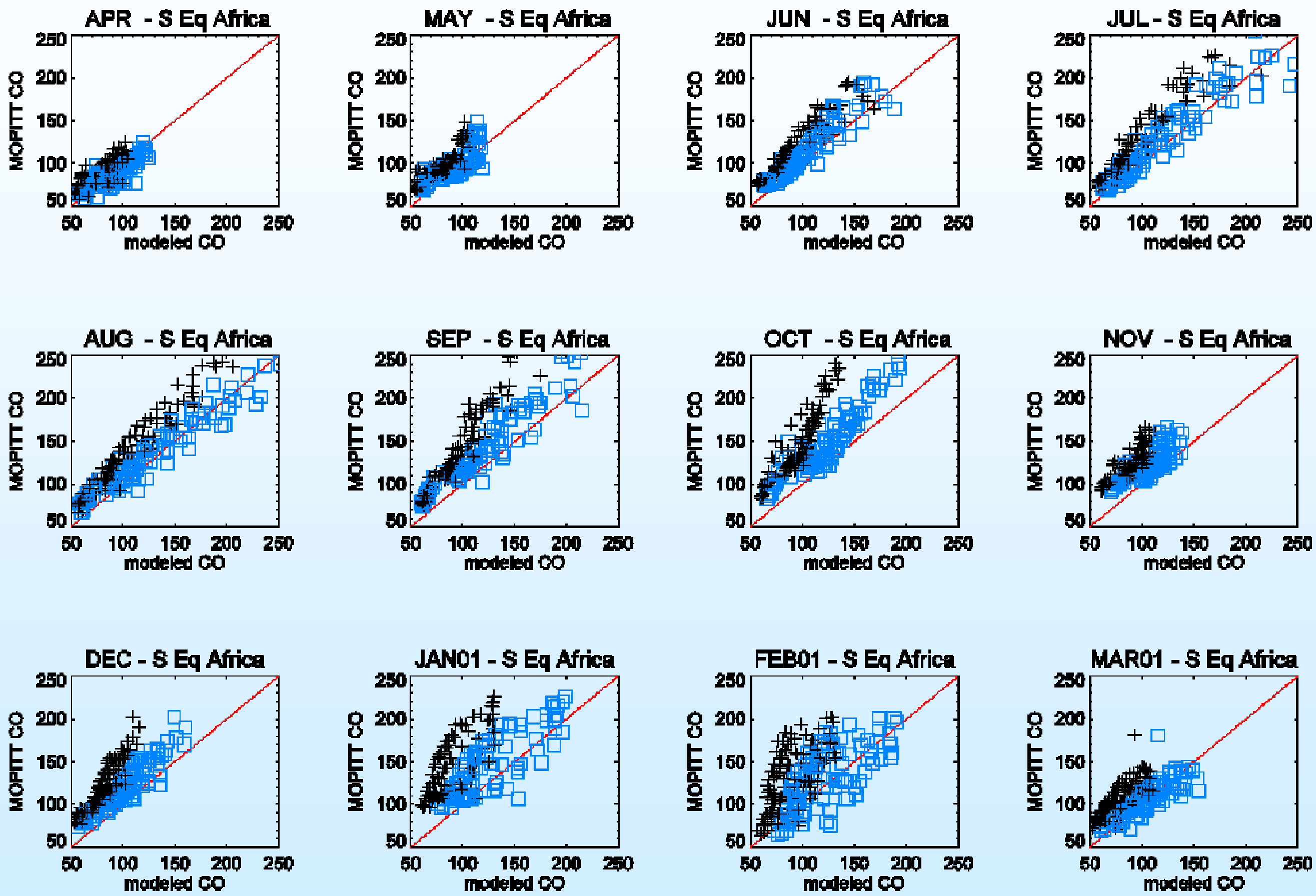


modelled CO : with a priori (black) and a posteriori (blue) emissions

Observations vs Forecast or Analysis

Africa 0-15^{o}S - April 2000 to March 2001

MOPITT CO (700hPa)



modelled CO : with a priori (black) and a posteriori (blue) emissions

Adjoint model development

- Checkpoint and adjoint framework developed
- transport :
  - Diffusion (done)
    - 1D to 3D : perfect results
  - Advection (in progress)
    - Lin and Rood
    - **u→ -u (reverse winds)**
  - Convection (in progress)

Where we are going

technically

- complete adjoint code (chemistry, aerosols)
- transfer to online/offline CCSM w/ Chemistry (long-term)

scientific questions to be addressed

- assimilation of CO / aerosols : comparison of different techniques (LKF, EKF, 4Dvar)
- inversion of CO / aerosols sources : esp. biomass burning emissions
  - observations:
    - CO: MOPITT + in situ
    - aerosols: MODIS, TOMS,
  - global and regional studies with global model and DA
    - first exercise: inversion of CO and black carbon emissions during the SAFARI 2000 campaign (or ACE-Asia...)

Problems/Concerns….

- Adjoint for Lin-Rood
- Aerosol model – Is a simple aerosol model with set size distributions adequate for inverse modeling (aerosols: H_2SO_4, $(NH_4)_2SO_4$, NH_4NO_3, OC, BC, SOA, Dust (4 size bins), Sea-Salt (4 size bins))?
- Integration with the rest of the ITR group.