Inversion for carbon source/sink attribution

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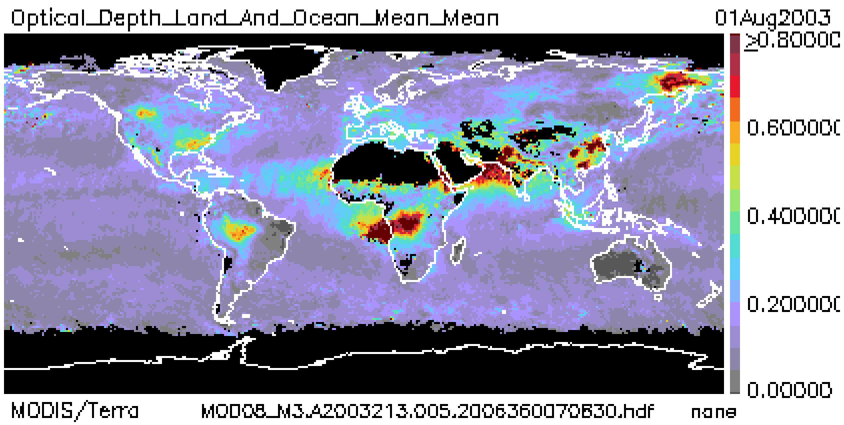
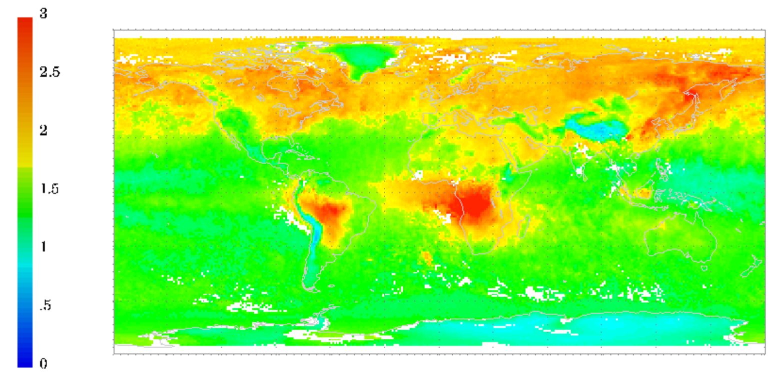
Outline

- Introduction
- Inversion of CO_2 and CO surface fluxes
- Evaluation strategies
- Conclusions

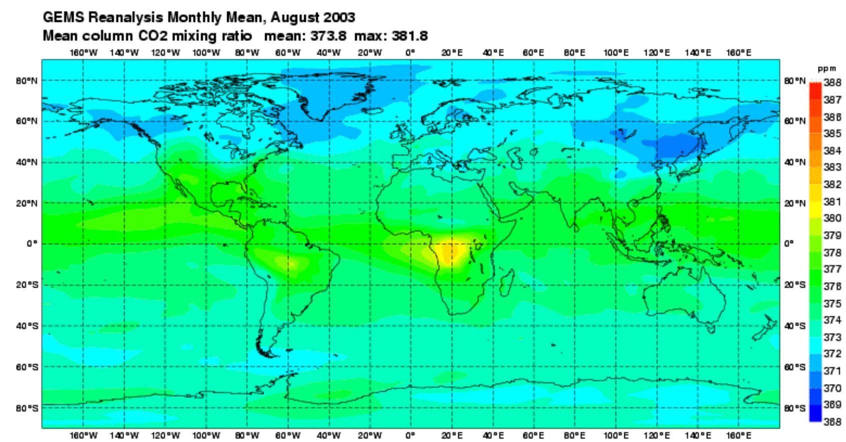
Biomass burning in satellite products

- AIRS, MODIS, MOPITT
  - August 2003



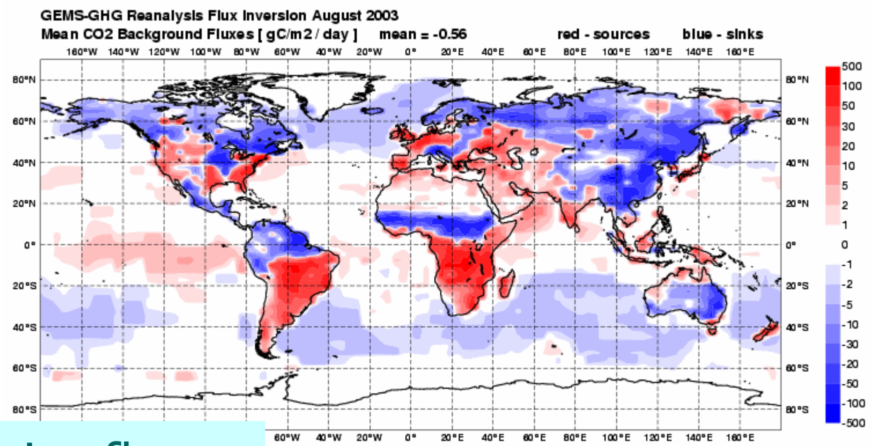


MOPITT CO Total Column (10^18 mol/cm^2)

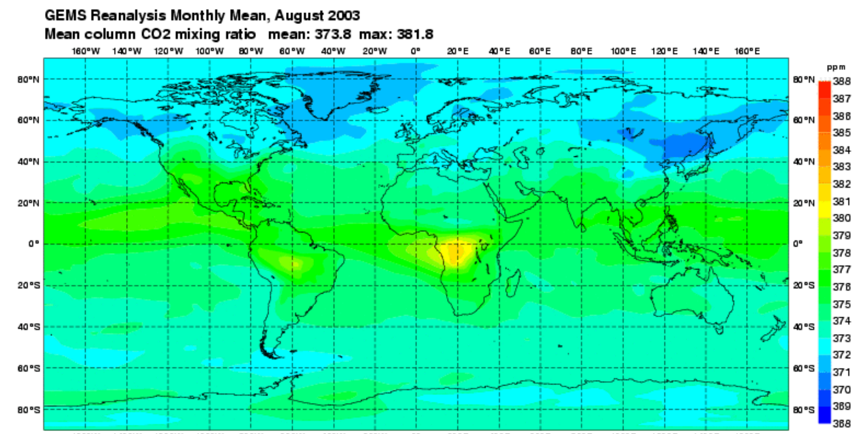


http://gems.ecmwf.int/d/products/ghg/reanalysis/tcco2_mean
http://modis-atmos.gsfc.nasa.gov/IMAGES/
http://www.acd.ucar.edu/mopitt/MOPITT/data/

The GEMS CO_2 flux inversion system

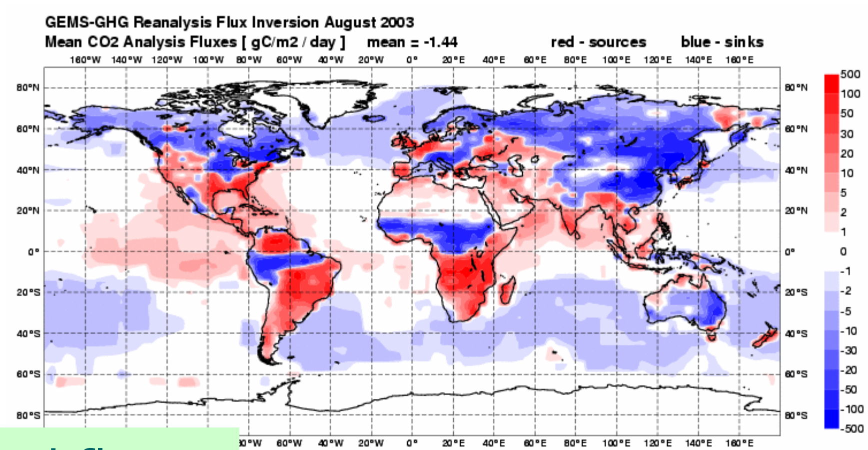


Prior fluxes



Observed concentrations

$$p(\mathbf{x}|\mathbf{y}) \propto p(\mathbf{x}).p(\mathbf{y}|\mathbf{x})$$

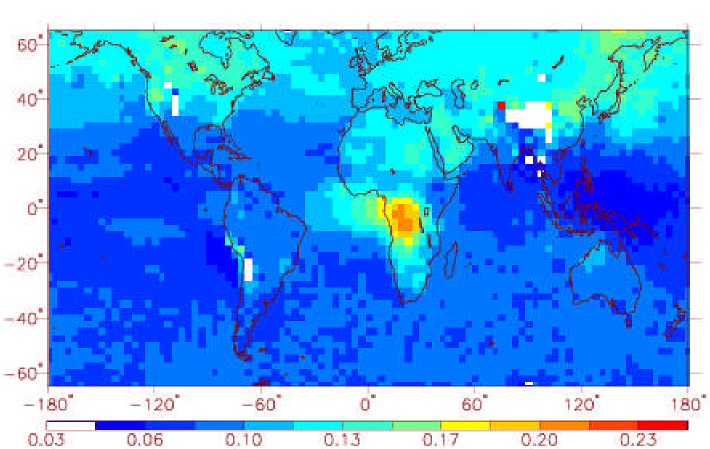


Analysed fluxes

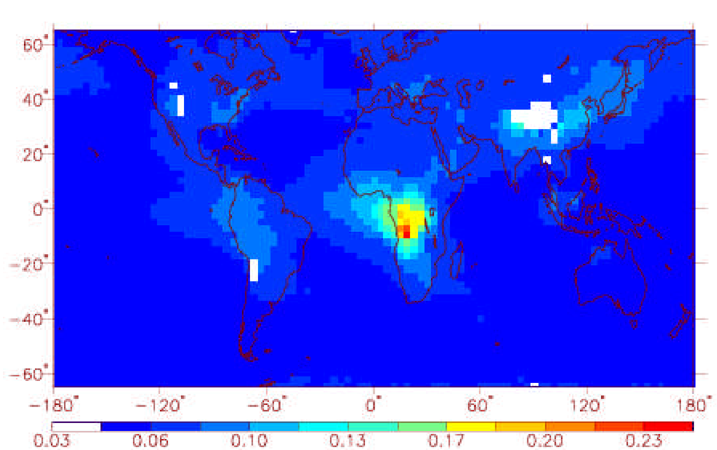
http://gems.ecmwf.int/

Inversion of carbon monoxide fluxes

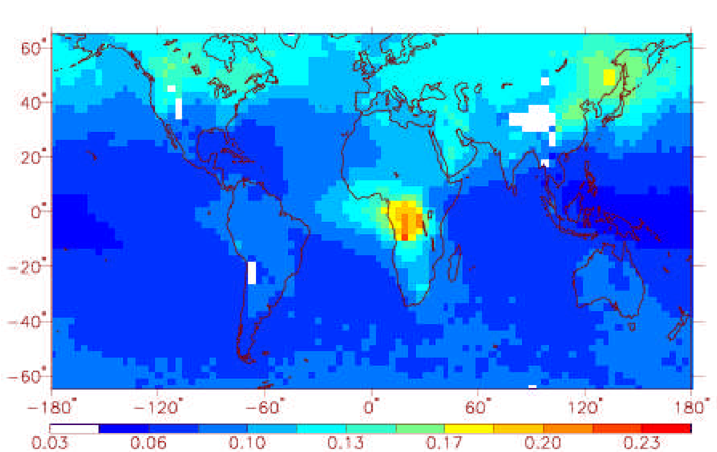
- Mean CO concentrations (ppm) for July 2008
  - 700hPa



MOPITT v3L2 (NASA)



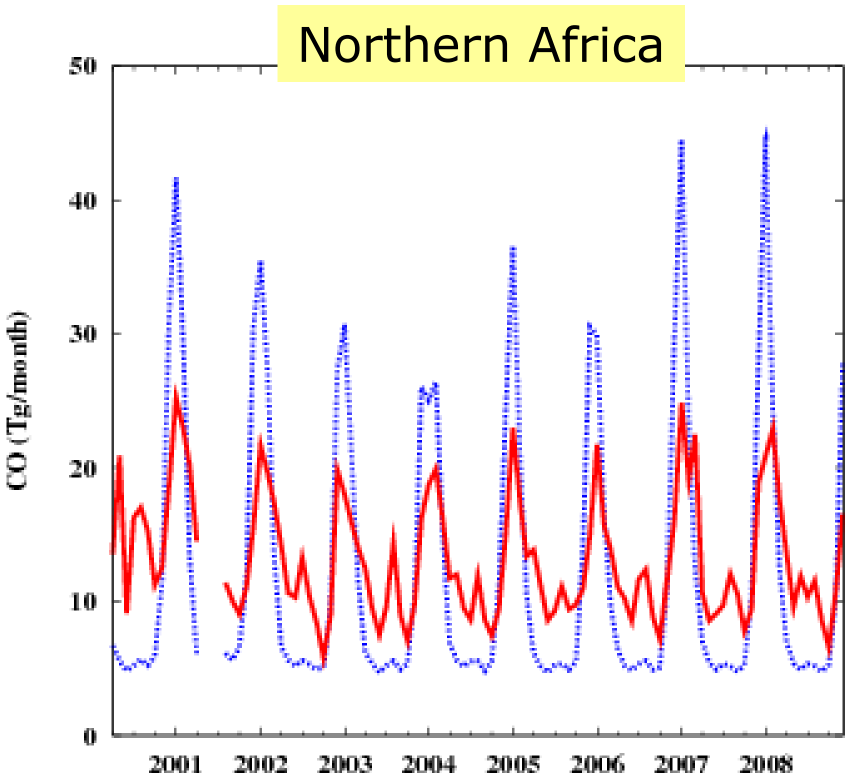
Prior

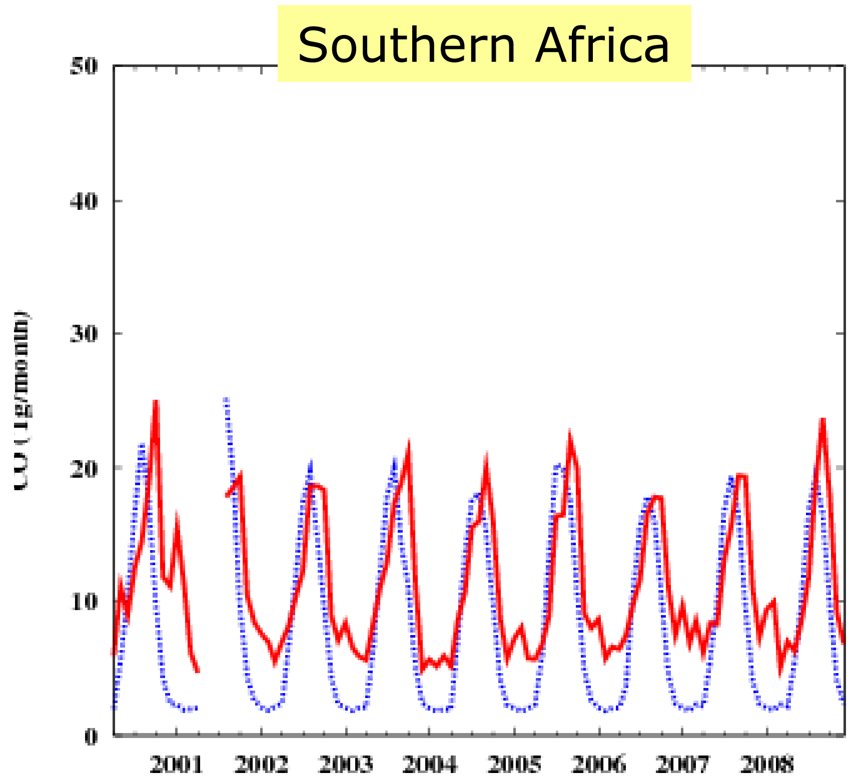


Posterior

Example of Africa

- **Prior** and **posterior** CO fluxes
  - Preliminary update of Chevallier et al. (2009) with MOPITT v4L2

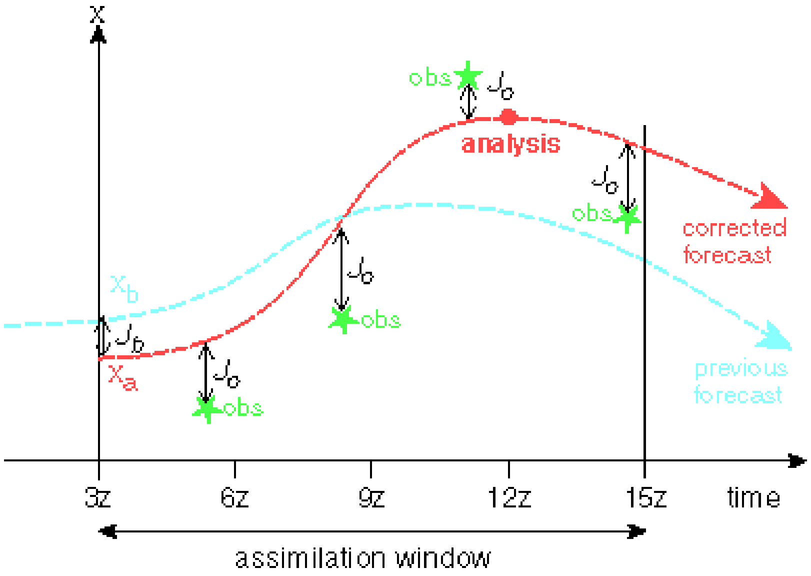




Inside the system

- Adaptation of the 4D-Var concept
  - High-resolution state vector
  - High-resolution observation vector

- Chevallier et al. (2005a, 2007)
- Stavrakou and Müller (2006)
- Elbern et al. (2007)
- Bergamaschi et al. (2007)
- Hakami et al. (2005)
- …



$$p(\mathbf{x}|\mathbf{y}) \propto p(\mathbf{x}).p(\mathbf{y}|\mathbf{x})$$

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathcal{H}(\mathbf{x})-\mathbf{y})^{\mathrm{T}}\mathbf{R}^{-1}(\mathcal{H}(\mathbf{x})-\mathbf{y}))$$

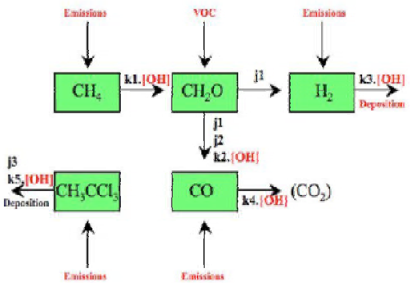
$$\nabla J(\mathbf{x}) = 2\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + 2\mathbf{H}^T\mathbf{R}^{-1}(\mathcal{H}(\mathbf{x})-\mathbf{y})$$

Chemistry-transport modelling (*H*)

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathcal{H}(\mathbf{x})-\mathbf{y})^{\mathrm{T}}\mathbf{R}^{-1}(\mathcal{H}(\mathbf{x})-\mathbf{y}))$$

$$\nabla J(\mathbf{x}) = 2\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + 2\mathbf{H}^{T}\mathbf{R}^{-1}(\mathcal{H}(\mathbf{x})-\mathbf{y})$$

- Tracer transport from LMDZ model (Hourdin et al. 2006)
  - 3.75^{o}x2.5^{o}x19
  - nudged to ECMWF winds
  - Sufficient for CO_2

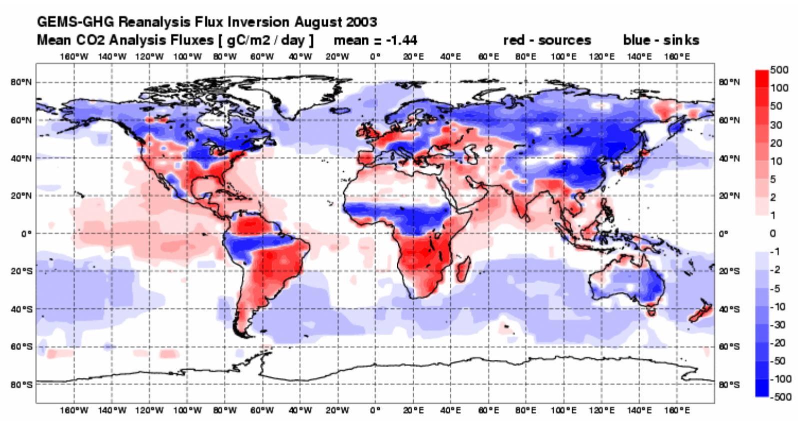


- Hydrocarbon oxidation chain (Pison et al. 2009)
  - Variable CH_4, HCHO, CO, H_2, OH, $C_2H_3Cl_3$
- Four aerosol tracers (Huneeus et al. 2009)
  - Aerosol precursors**:** DMS, SO_2, H_2S
  - Accumulation mode aerosol: SO_4, black carbon, organic matter, dust & sea salt
  - Coarse mode aerosol: sea salt
  - Coarse mode aerosol: dust
- With associated tangent-linear (**H**) and adjoint (**H**^{T}) operators

Evaluation strategy

1. Expert judgment
2. Ground truth measurements
3. Validate fluxes indirectly, based on independent concentration measurements
4. Theoretical error estimation
5. Compare with other flux products
   - http://www.carboscope.eu

Flux inversion (3.75°x2.5°)



Ground truth

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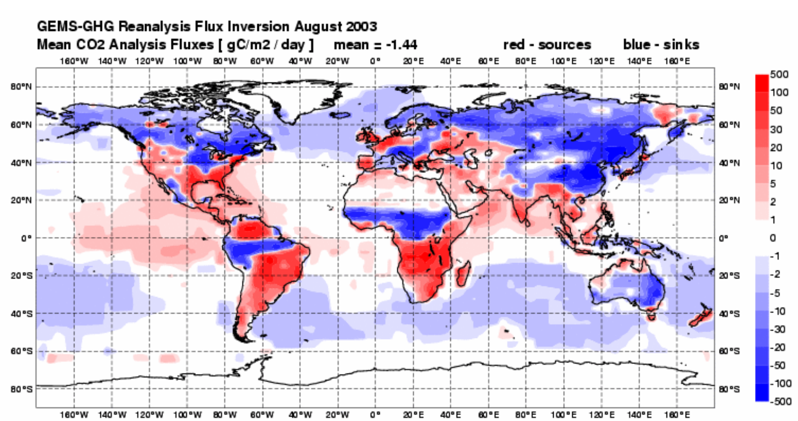
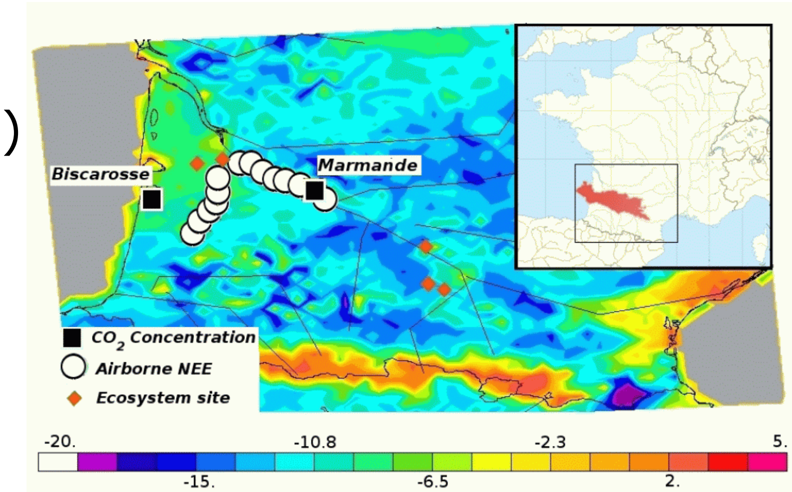
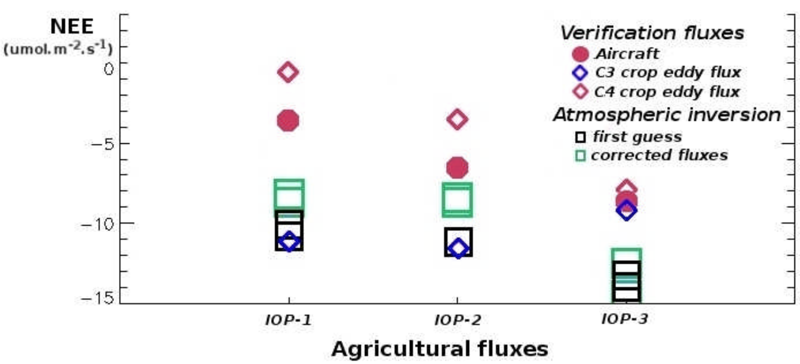


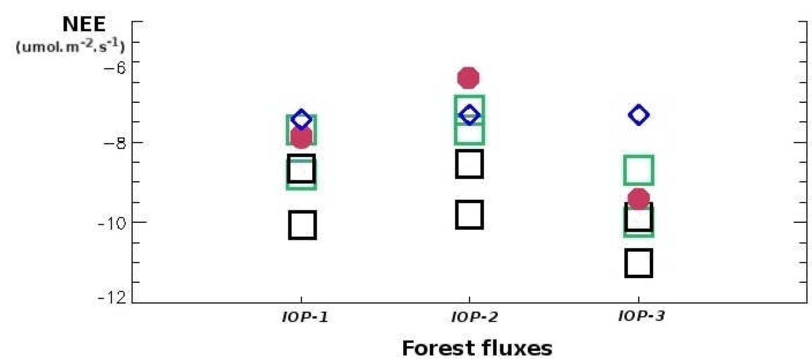
Ground truth

Mesoscale CO_2 flux inversion vs. ground truth

- LPDM/MesoNH transport model @8km
  - CERES campaign (May-June 2005)
  - Prior fluxes from ISBA model
  - Concentration measurements
    - 2 towers
  - Flux measurements
    - aircrafts and 5 towers
  - Lauvaux et al. (2009)



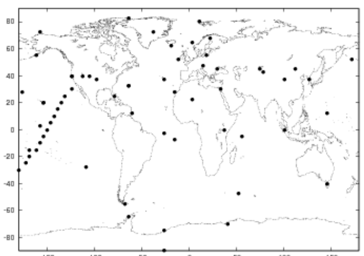




The GEMS CO_2 flux inversion system (cont'ed)

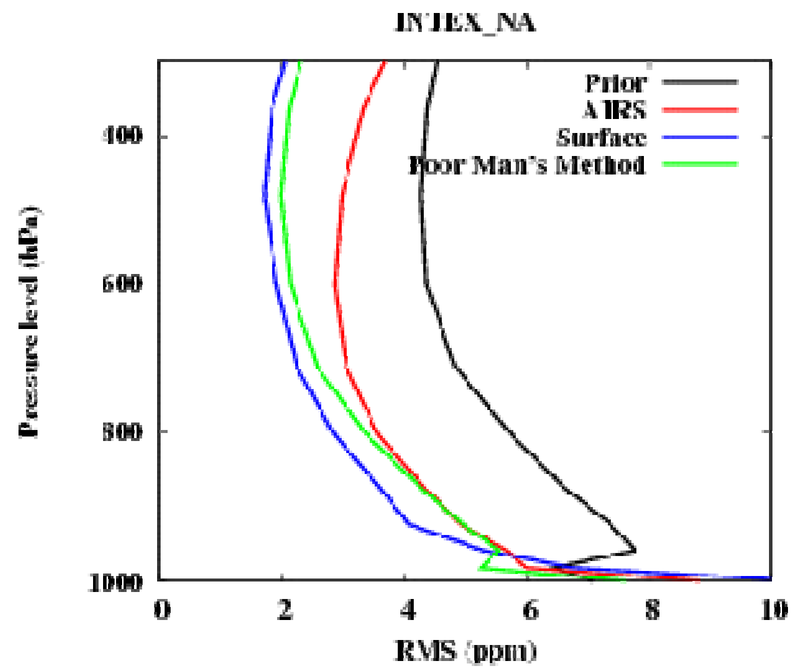
- From AIRS radiances to CO_2 surface fluxes
  - Engelen et al. (2009), Chevallier et al. (2009a)

- Validation with aircraft concentration measurements
  - Inversion from NOAA/ESRL flask data (T. Conway) as a benchmark



Validation with INTEX-NA campaign (S. Vay)

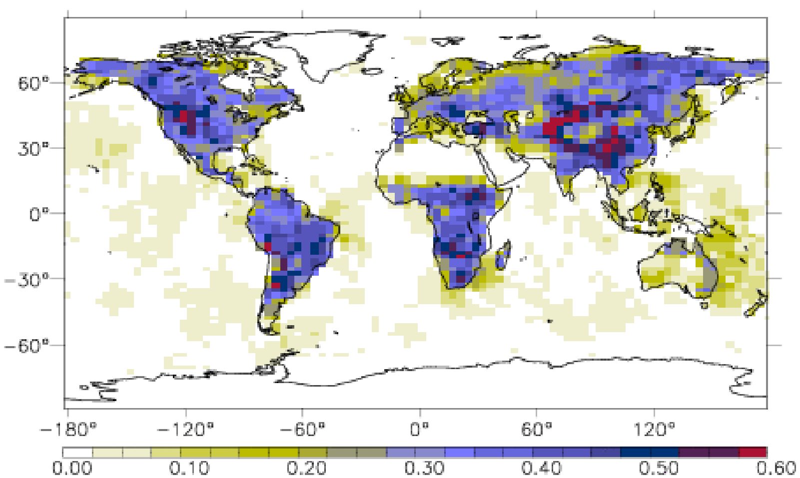
Global Earth Observation and Monitoring



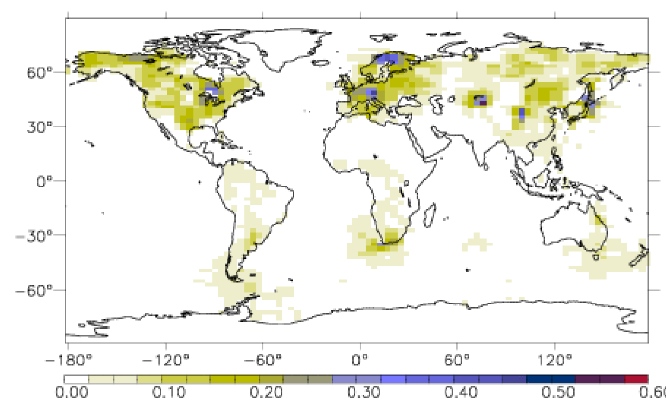
Expected capability of GOSAT

- NIES/JAXA/MoE
- GOSAT launched on 23 Jan 2009
- LSCE-NIES assessment of GOSAT capability
  - Chevallier et al. (2009b)
- Expected uncertainty reduction for the estimation of weekly CO_2 fluxes 1-sig(post)/sig(prior)

GOSAT



Current surface network



Final remarks

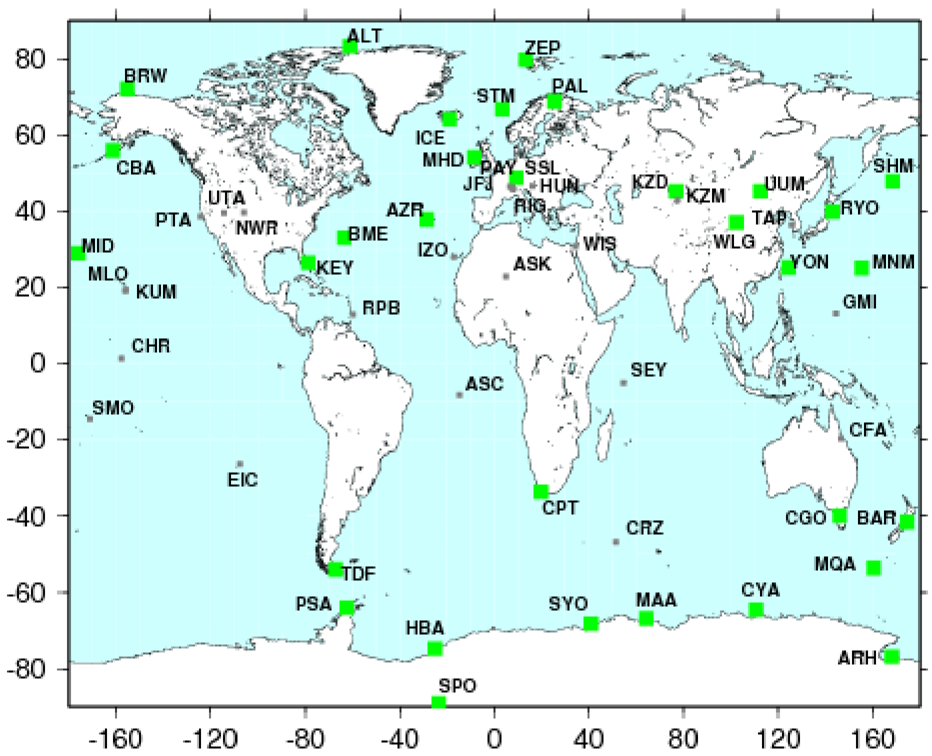
- Estimation of surface fluxes of atmospheric compounds based on concentration measurements is emerging
  - CO_2, CO, CH_4, aerosols, …
  - Extension of the satellite network
  - Variational formulation of Bayes' theorem
- Also able to ingest any other type of information (inventories, process models, …)
  - Ultimate approach?

Final remarks

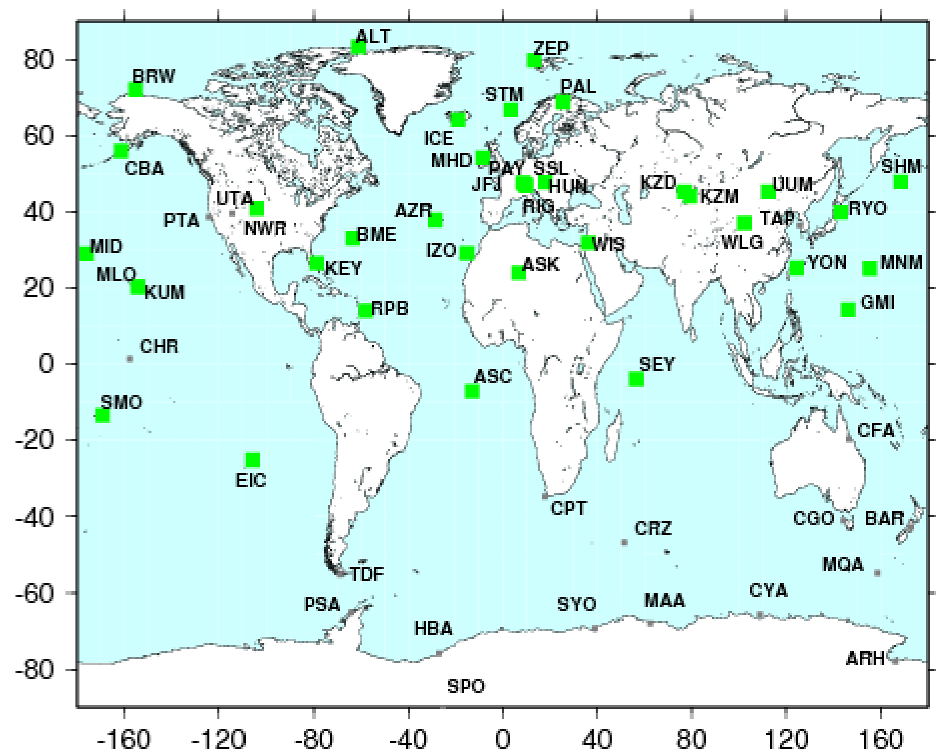
- Estimation of surface fluxes of atmospheric compounds based on concentration measurements is emerging
  - CO_2, CO, CH_4, aerosols, …
  - Extension of satellite capabilities
  - Variational formulation of Bayes' theorem
- Also able to ingest any other type of information (inventories, process models, …)
  - Ultimate approach?
- Statistical approach
  - Relies on statistical models that describe the uncertainty of each information source (bias, variance, correlations, …)
    - Biomass burning make the statistics non-Gaussian
  - Uncertainty in chemistry-transport models reduces the available information content of the observations

Indirect validation

- 42 stations of the NOAA/ESRL network
  - Improved fits (bias) in green



MOPITT phase I (2000-2001)



MOPITT phase II (2001-2007)