Using correlations between atmospheric CO_2 and CO to improve inverse analyses of carbon fluxes

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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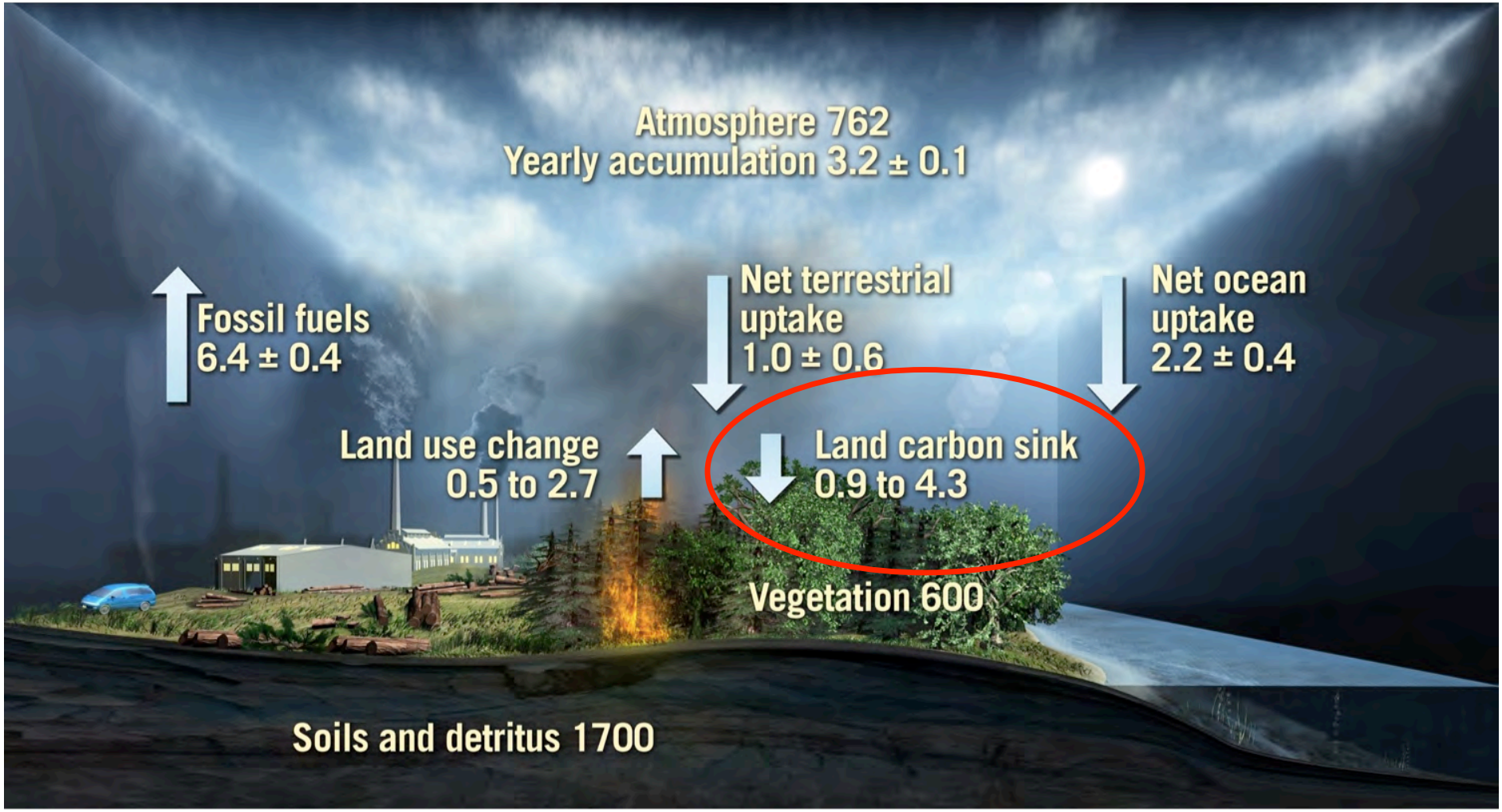
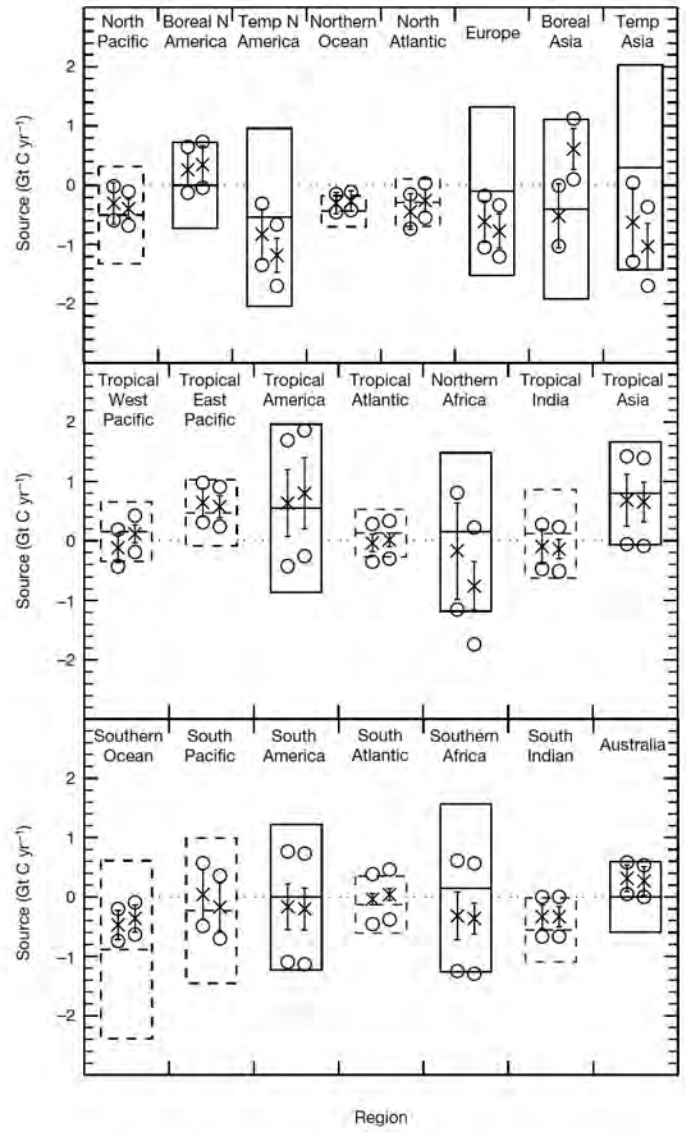
Uncertainty in CO_2 fluxes

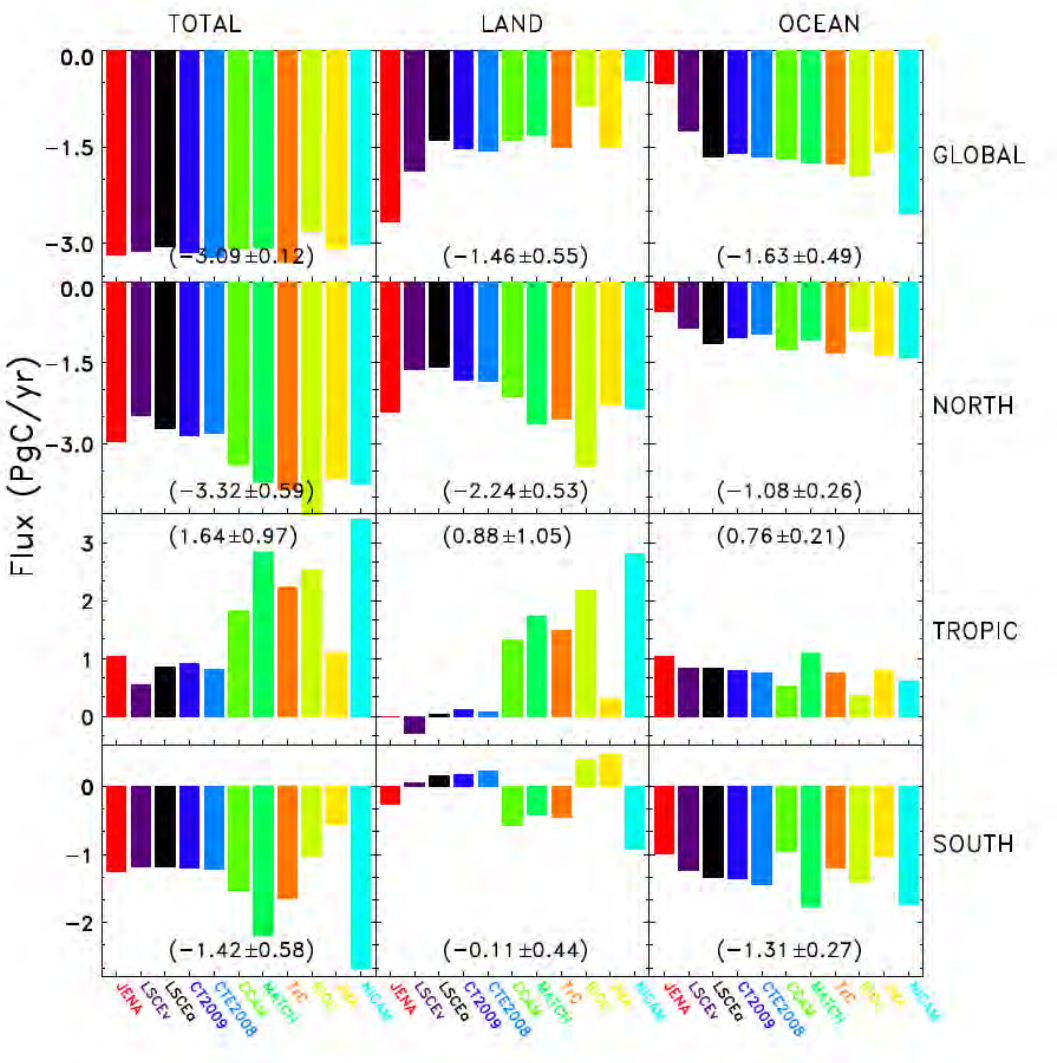


S. Quegan, BIOMASS: ESA User Consultation Meeting, Lisbon, Portugal, 20-21 Jan 2009

Previous CO_2 inversion studies

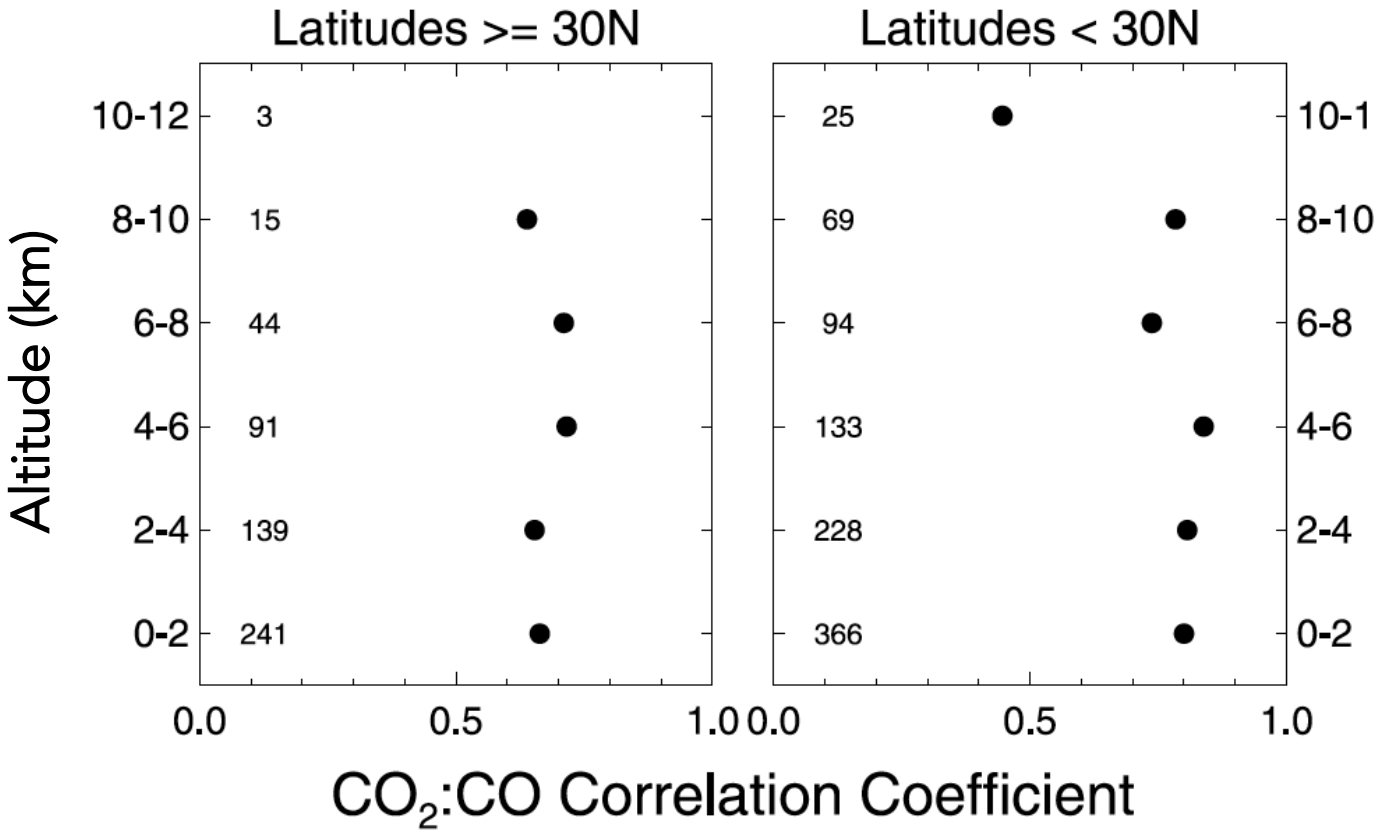


Gurney et al., 2002



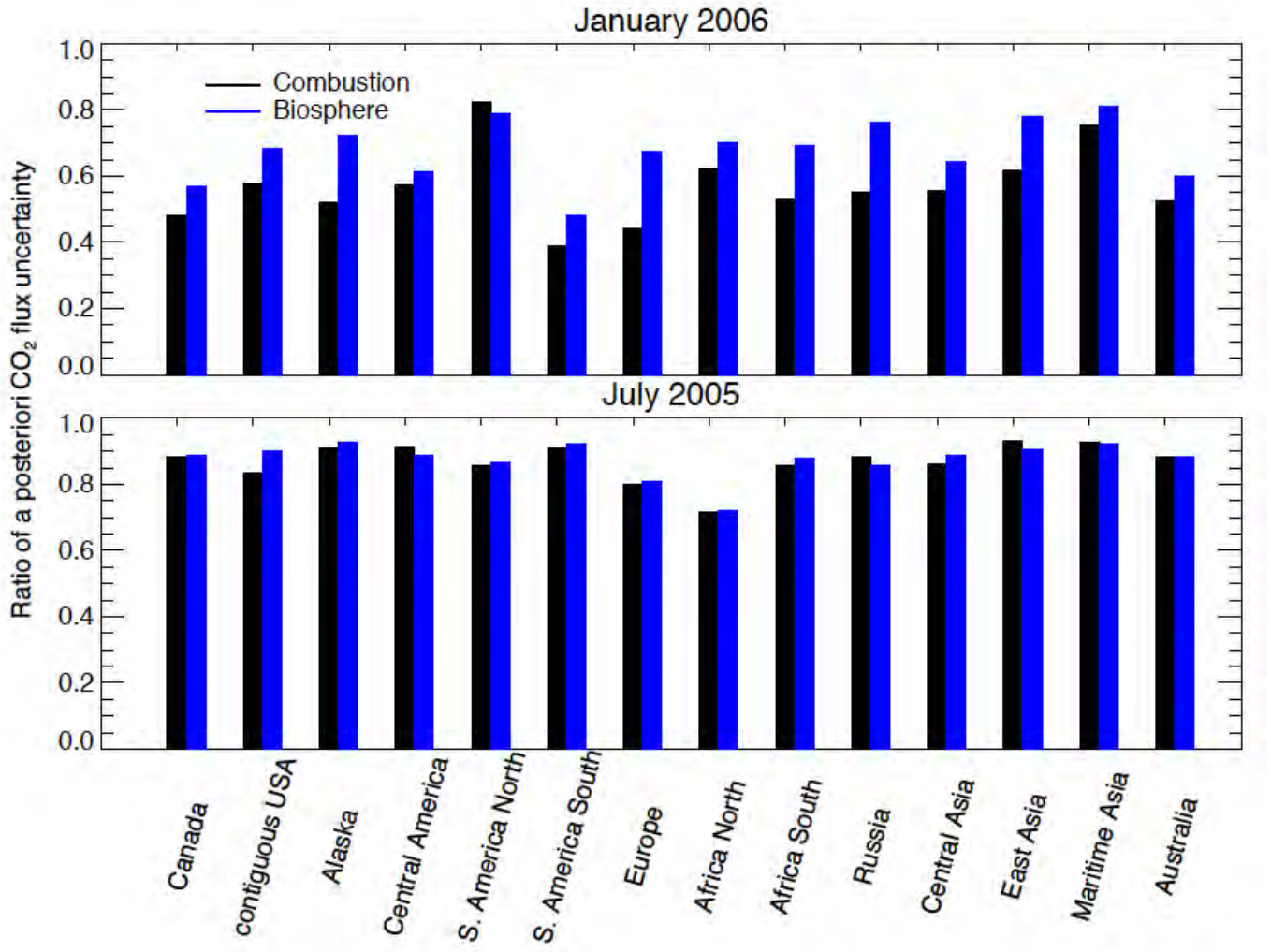
Peylin et al., 2013

CO_2:CO correlations



Correlation coefficients (r) between CO and CO_2 mixing ratios measured during TRACE-P campaign in East Asia (from Palmer et al., 2006).

CO_2:CO correlations



Ratio of a posteriori CO_2 surface flux error between a joint CO_2-CO inversion and a CO_2-only inversion in January 2006 (top) and July 2005 (bottom) (from Wang et al., 2009).

Inverse Modelling

AIM: "to minimise atmospheric model-observation differences of a species whilst remaining close to prior knowledge of fluxes"

$$J(\underline{x}) = \tfrac{1}{2}(\underline{x}-\underline{x}_a)^T B^{-1}(\underline{x}-\underline{x}_a) + \tfrac{1}{2}(T\underline{x}-\underline{y'})^T R^{-1}(T\underline{x}-\underline{y'})$$

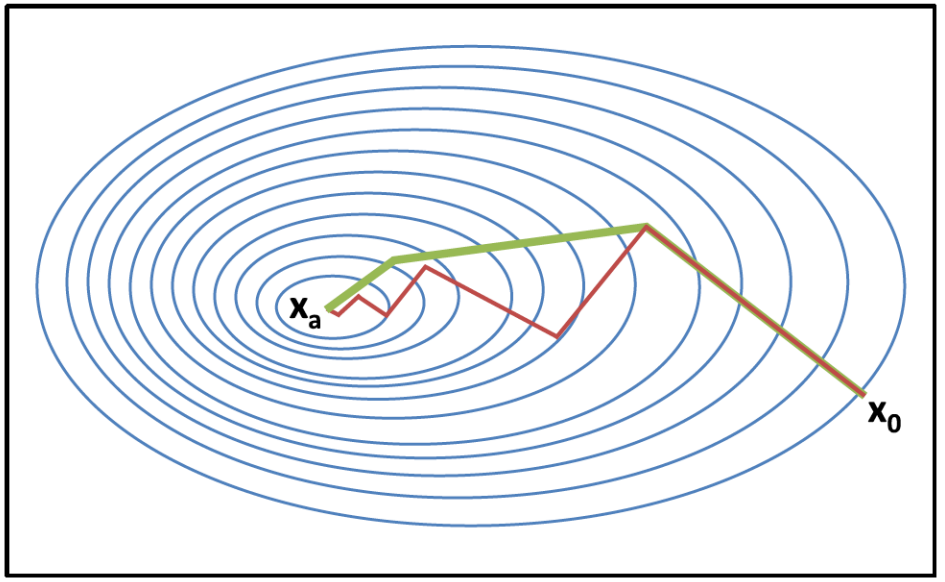
Different methods of solving this:

1) Bayesian synthesis inversion
2) Kalman filter (e.g. Ensemble KF)
3) Variational inversion (4D-Var)

4D-Var:

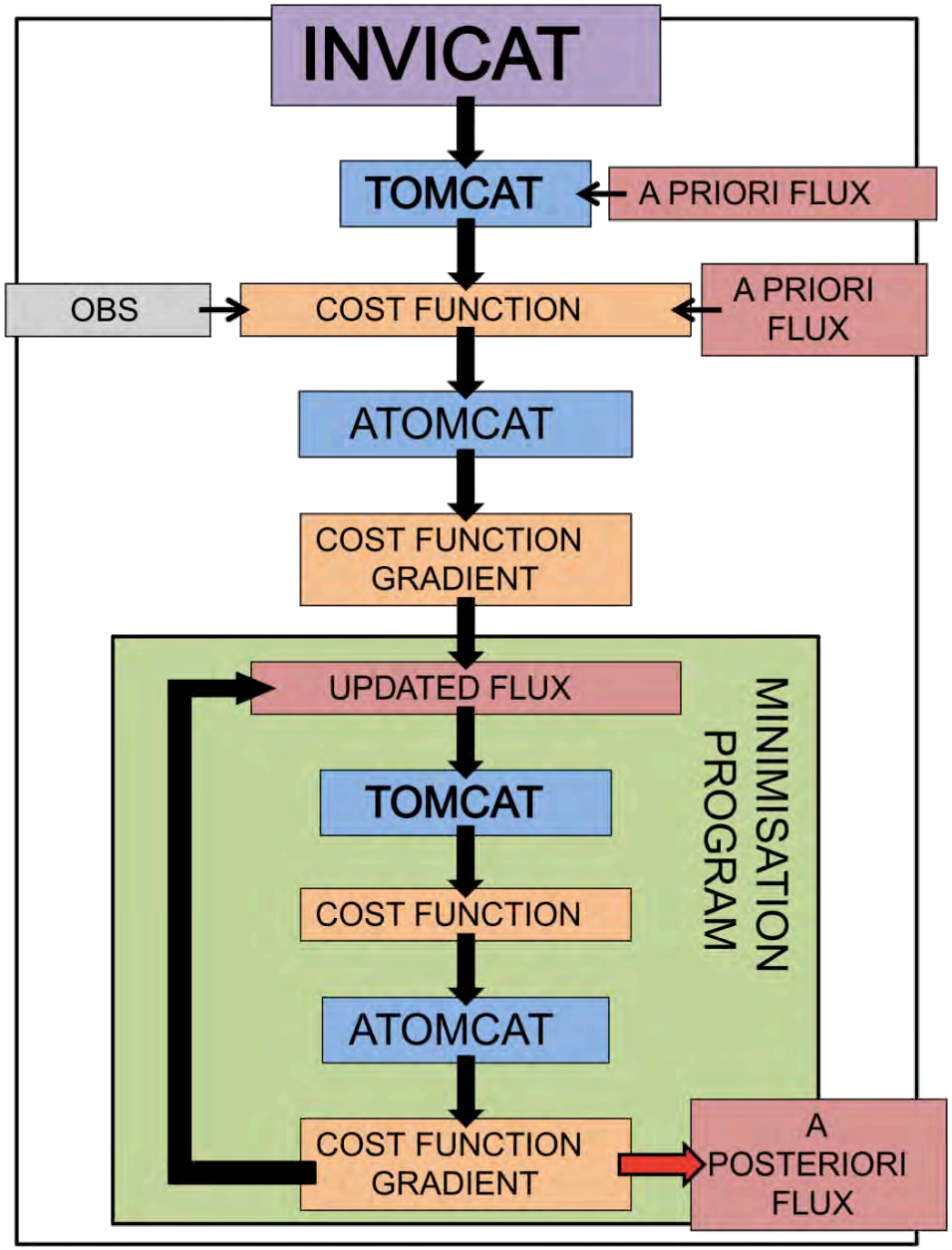
- retrieves fluxes on model grid scale, reduces aggregation error
- reduces J(x) iteratively (see right), rather than directly, as in other methods
- requires an adjoint model

Below: 2D example of iterative reduction of J(x) in 4D-var

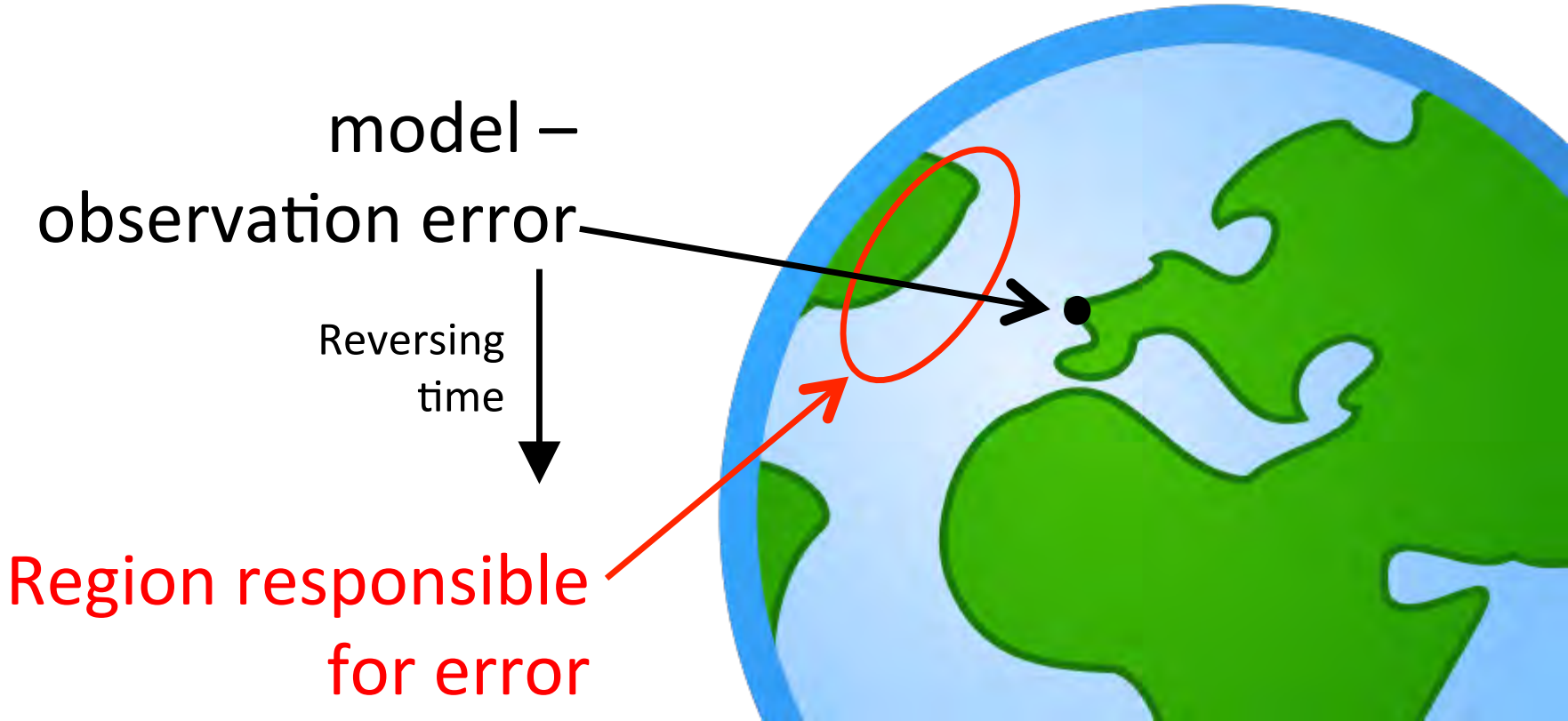


INVICAT

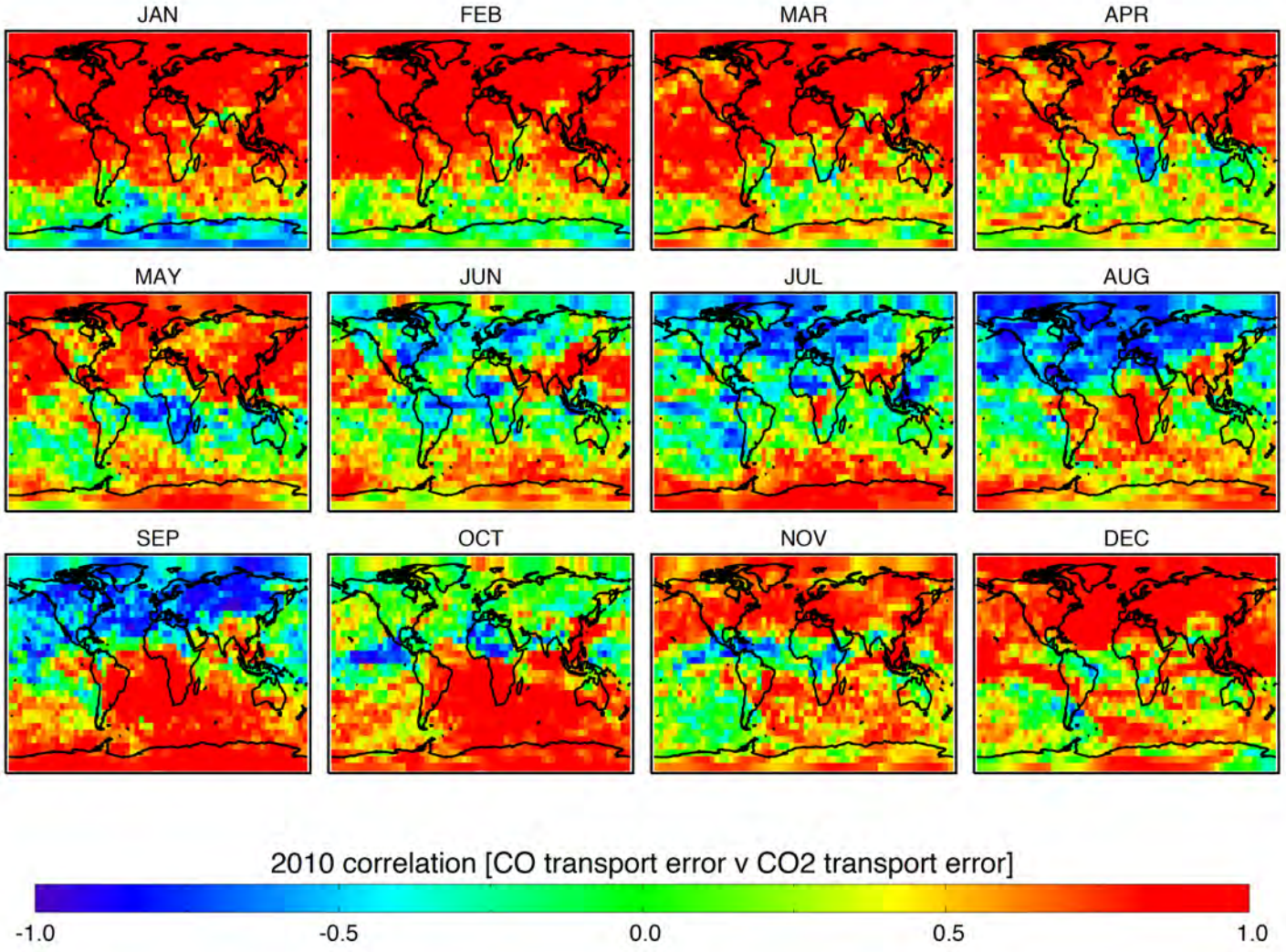
- A 4D-Var inverse model based on the CTM TOMCAT
- Includes TOMCAT and ATOMCAT (the adjoint version of TOMCAT)
- ATOMCAT finds the gradient of the cost function J(x)
- Technical paper in GMDD describing deveopment & performance of INVICAT (Wilson et al., 2013)
- Has been used in the past for methane inversions with in-situ and satellite data (from GOSAT)



ATOMCAT propagates model/obs differences backwards through time to find sensitivities…

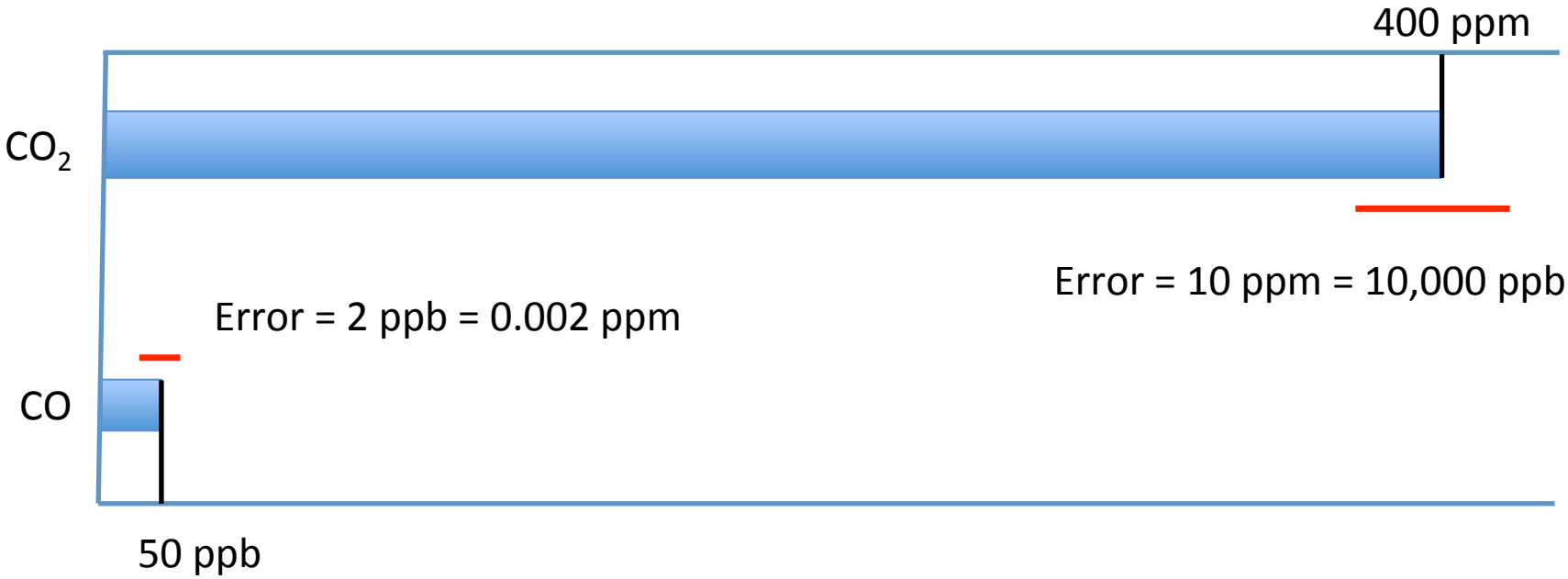


CO_2:CO error correlations in TOMCAT



$$R = \begin{pmatrix} R_{CO2} & E(e_{CO}e_{CO2}^{T}) \\ E(e_{CO}e_{CO2}^{T}) & R_{CO} \end{pmatrix}$$

Scale mismatch of CO and CO_2



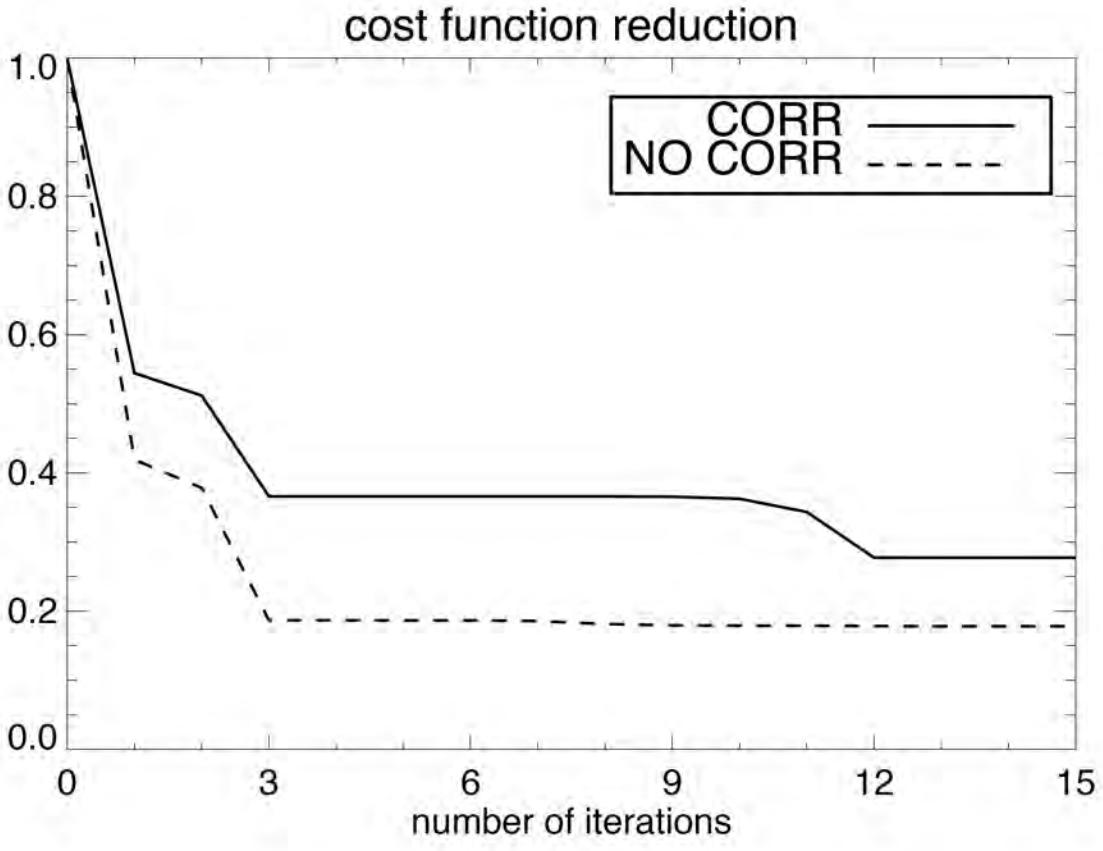
AIM: to improve the rate of minimisation by scaling $\underline{x}$:

Ideally, we'd use: $\underline{z}=(J''\underline{x})^{-1/2}\underline{x}$

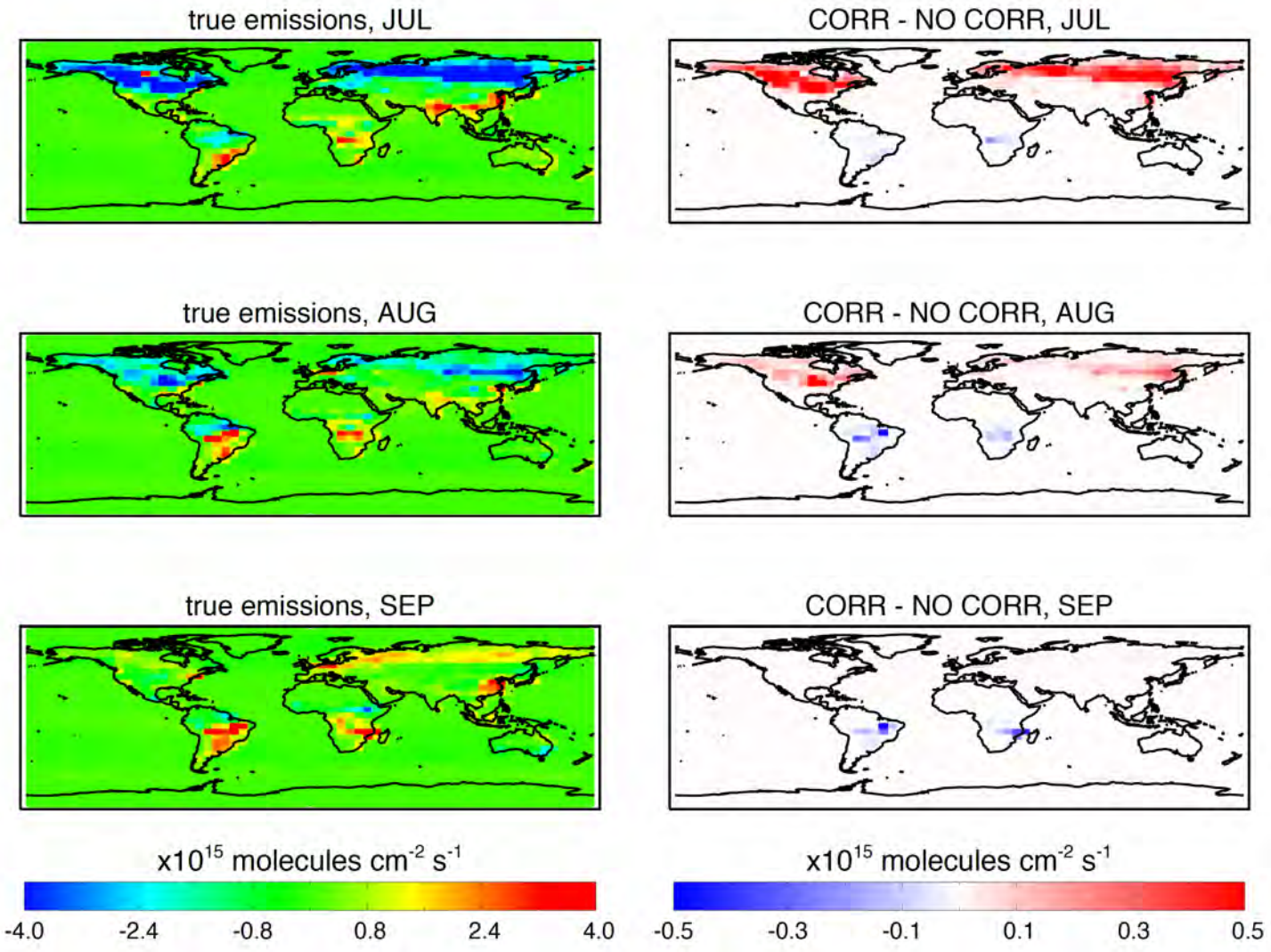
But, in practice: $\underline{z}=\mathbf{B}^{-1/2}(\underline{x}-\underline{x}_b)$

Results

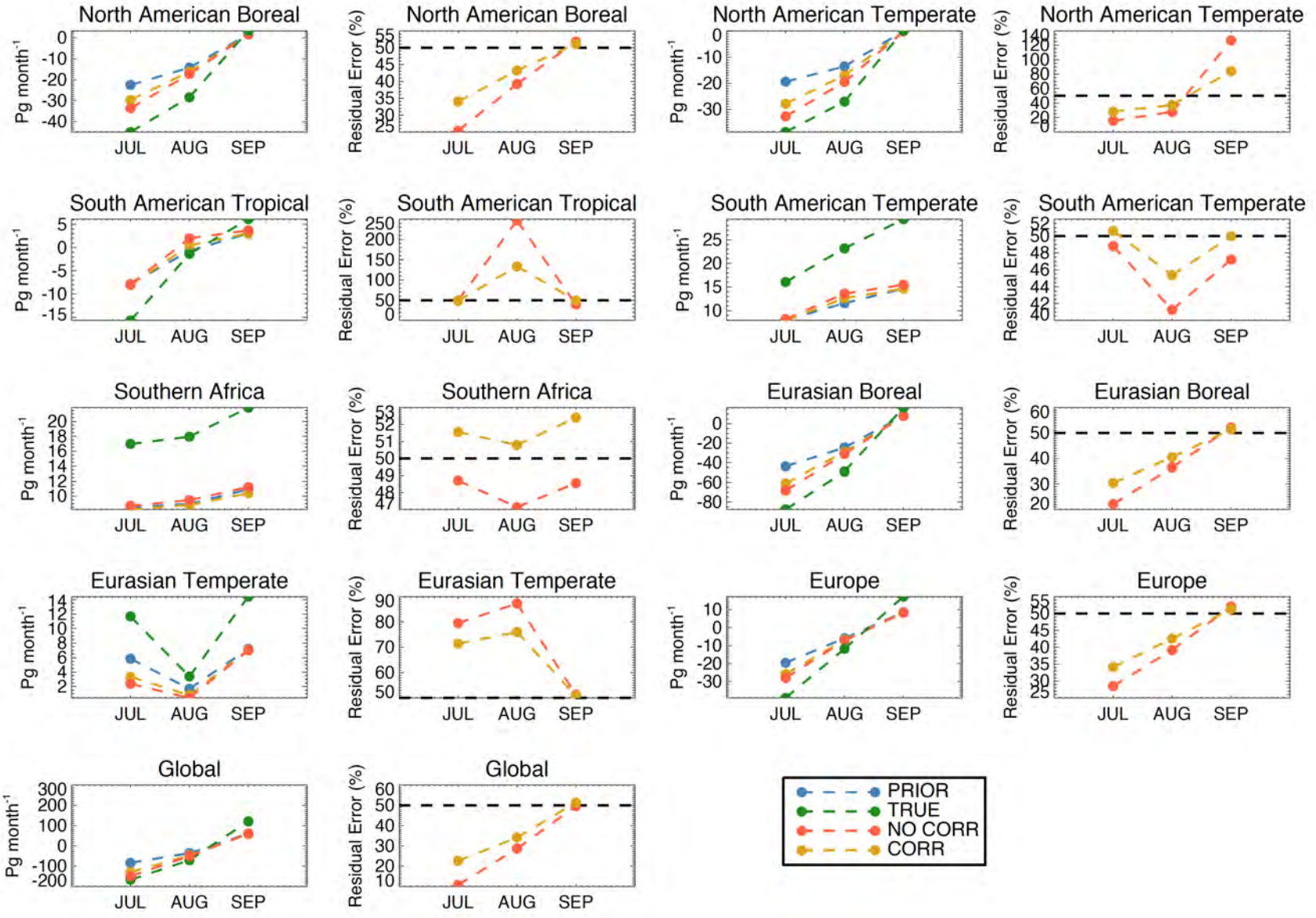
- Performed two 3-month inversions (starting in July 2010), with and without error correlations included
- All CO_2 emissions are multiplied by 10 initially
- Sampled standard model output as per the TES satellite, and added random noise
- Cut CO emissions by 20% and CO_2 emissions by 50% for use as a priori
- Tried to retrieve 'true' surface fluxes



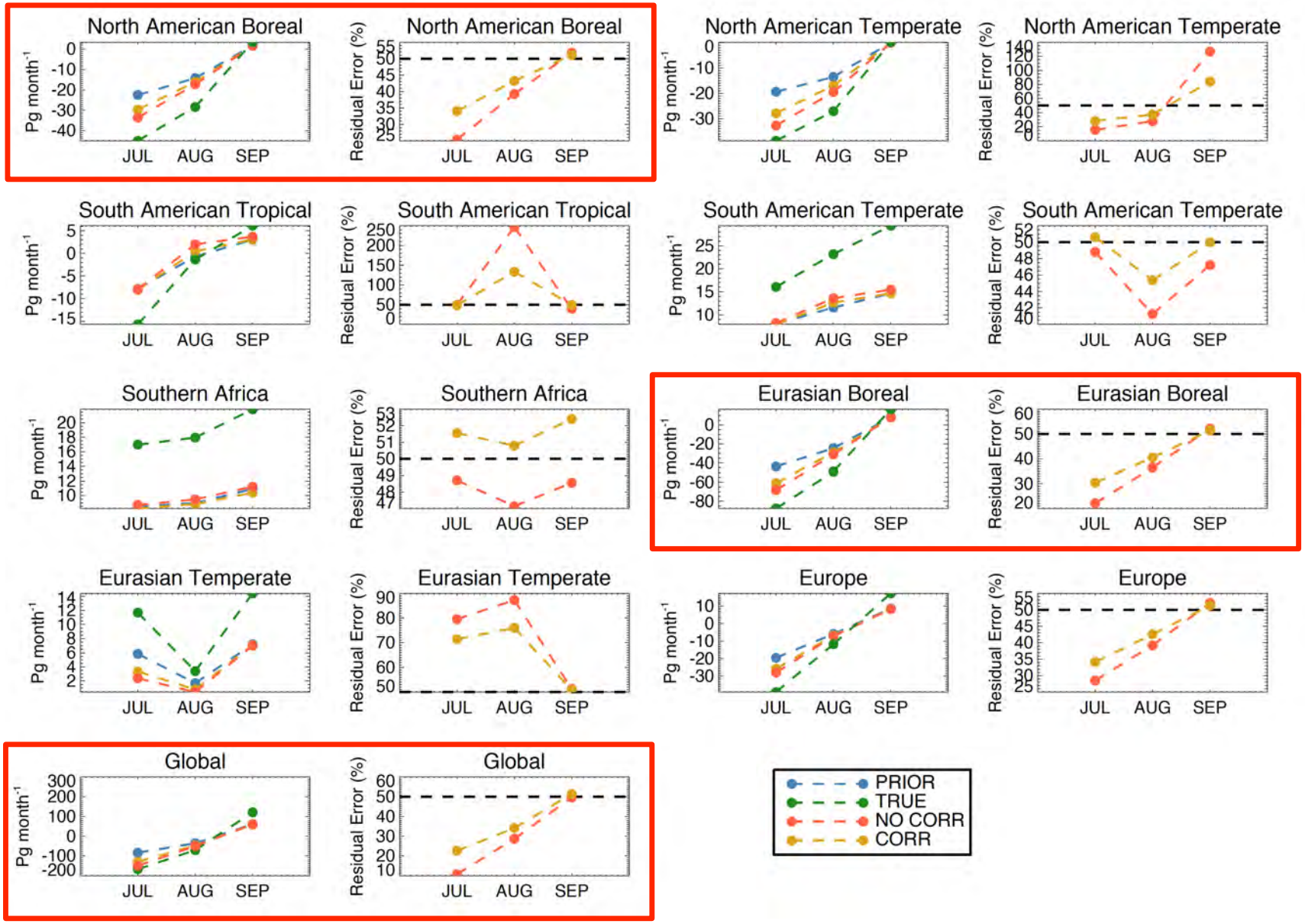
Results


true emissions, JUL
CORR - NO CORR, JUL
true emissions, AUG
CORR - NO CORR, AUG
true emissions, SEP
CORR - NO CORR, SEP
x10^15 molecules cm^-2 s^-1
-4.0
-2.4
-0.8
0.8
2.4
4.0
x10^15 molecules cm^-2 s^-1
-0.5
-0.3
-0.1
0.1
0.3
0.5

Results


North American Boreal
Pg month-1
Residual Error (%)
North American Temperate
South American Tropical
South American Temperate
Southern Africa
Eurasian Boreal
Eurasian Temperate
Europe
Global
JUL
AUG
SEP
PRIOR
TRUE
NO CORR
CORR

Results


North American Boreal
Pg month-1
Residual Error (%)
North American Temperate
South American Tropical
South American Temperate
Southern Africa
Eurasian Boreal
Eurasian Temperate
Europe
Global
JUL
AUG
SEP
PRIOR
TRUE
NO CORR
CORR

Conclusions

- Inverse modelling of CO_2 emissions is difficult due to large observation errors and small concentration gradients
- CO_2:CO error correlations should help to constrain CO_2 emission inventories using inverse modelling
- The INVICAT 4D-Var system was adapted in order to perform simultaneous inversions of the two species
- However, scale mismatch between the two causes problems for iterative solver in 4D-Var
- Preconditioning helps a little, but 'background only' preconditioner is not enough
- Test inversions performed with 10x CO_2 emissions, but inclusion of correlations currently seems to slow down convergence globally
- More work is required – probably in finding appropriate preconditioner – in order to allow 4D-Var method make use of CO_2:CO correlations