

Quantifying the benefit of actively measured XCO₂ data in a CCDAS

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Objectives

- Demonstrate the benefit of total column CO₂ data from a potential active satellite mission in a Carbon Cycle Data Assimilation System
- Assess the reduction in uncertainty of carbon fluxes
- Explore carbon flux uncertainty reduction as a function of instrument uncertainty

Results

- A-SCOPE performs better than ground-based flask sampling network
- Better performance regardless of weighting function and sampling in the model
- Performance holds for a range of observational uncertainties

Outlook

- Low and constant measurement bias in time and space necessary to maximise information content in observations
- Accurate quantification of representation error
- Take uncertainty in background fluxes (ocean, fossil, land use change) into account, in order not to be over-confident
- More information in Kaminski et al., 2010³

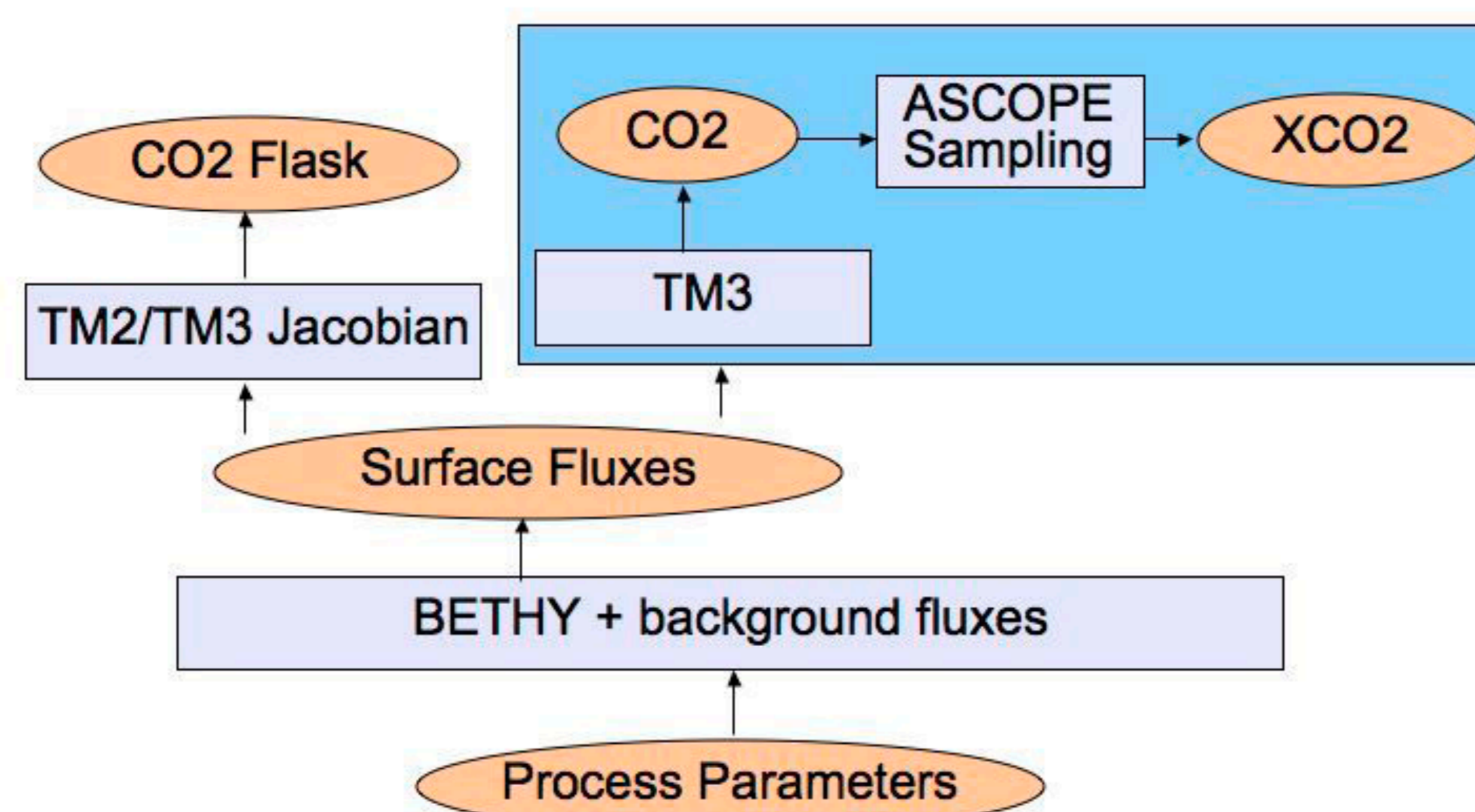


Figure 1: Revised CCDAS scheme.

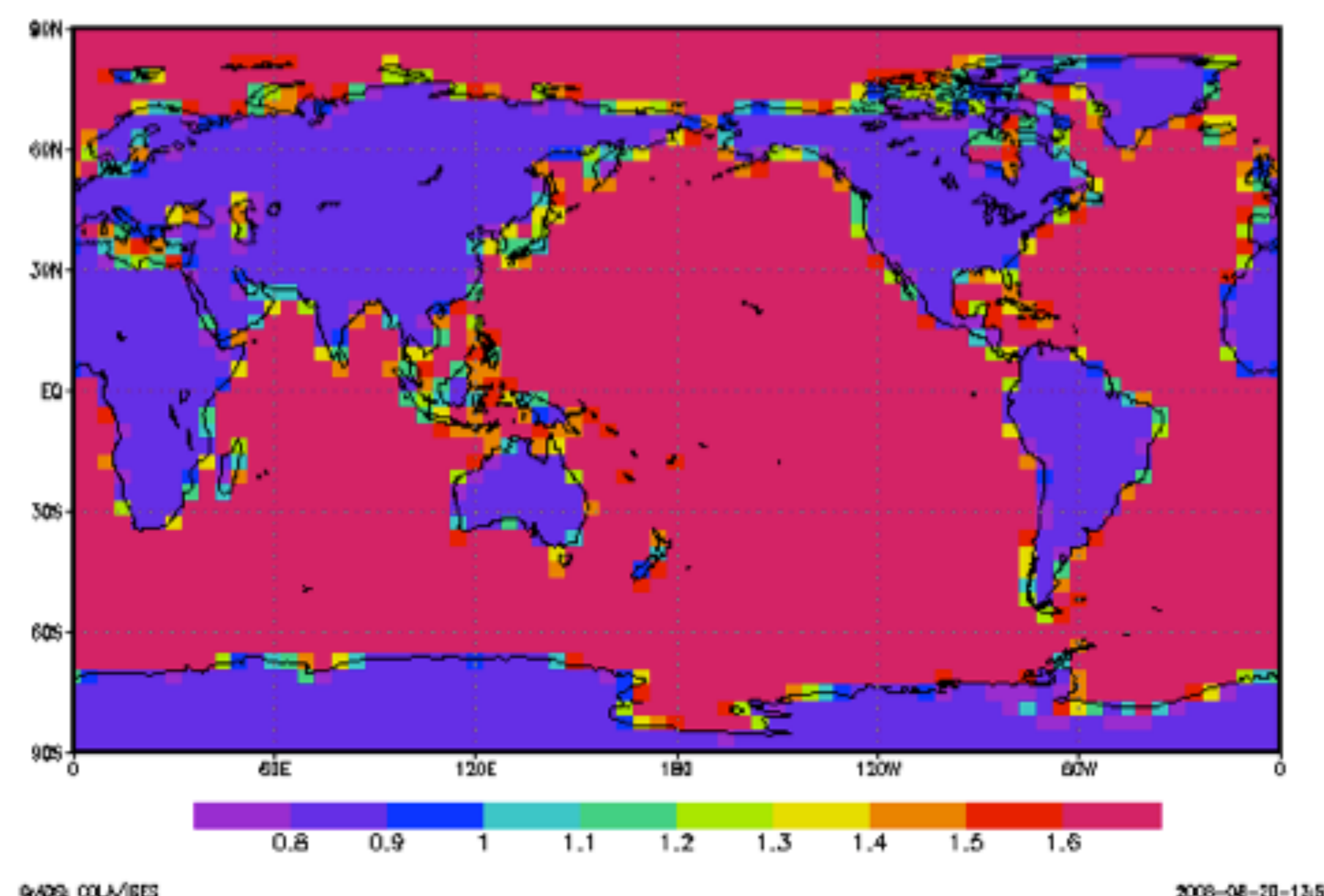


Figure 2: Total data uncertainties for monthly Jacobians.

A-SCOPE Performance

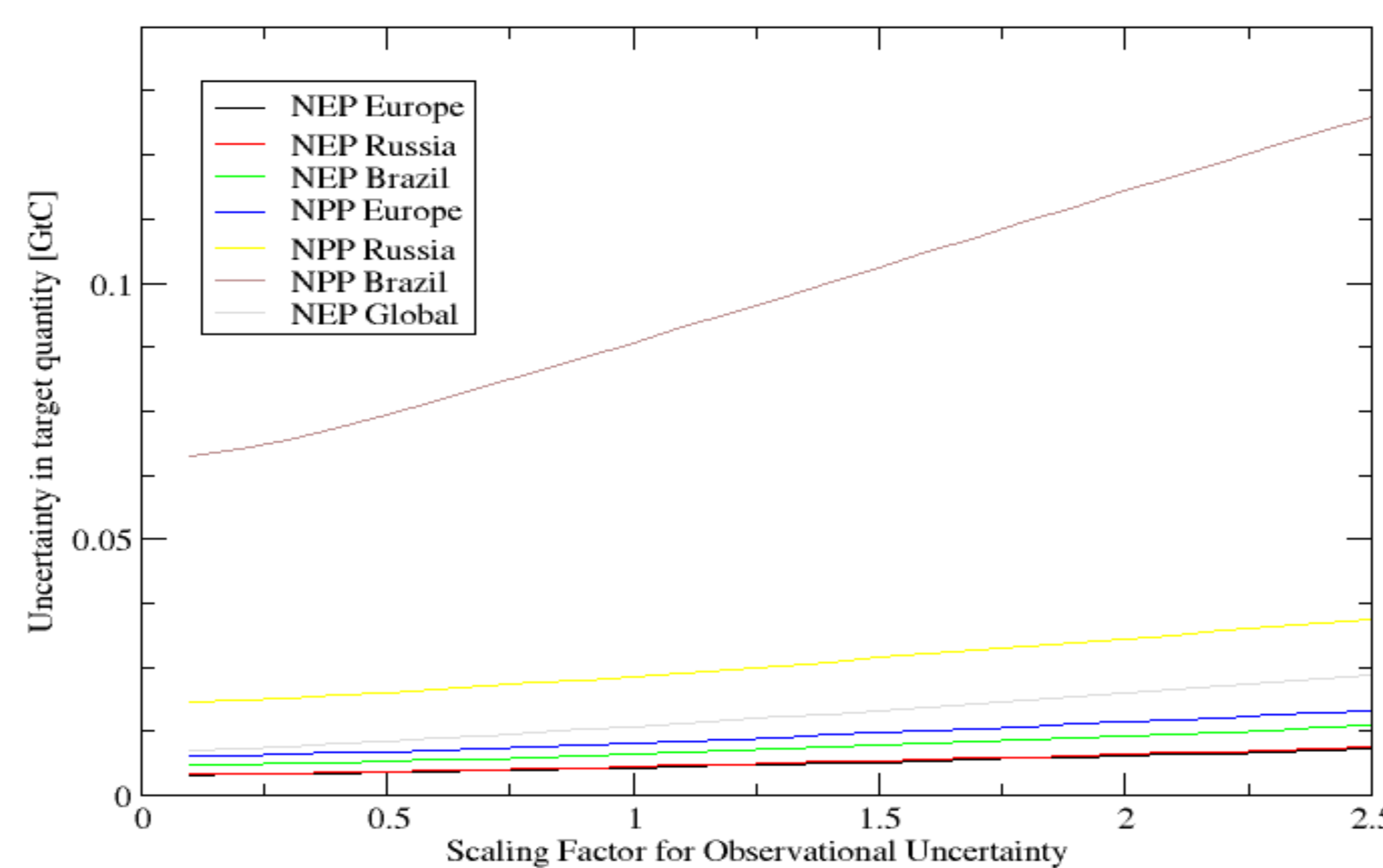


Figure 3: Posterior uncertainty for ASCOPE only as a function of observational uncertainty σ_{obs} .

Methods

- Extend the Carbon Cycle Data Assimilation System (CCDAS)¹ to include observation operator for XCO₂ from ASCOPE (Fig 1)
- Fixed fluxes from sources other than terrestrial biosphere
- Quantify potential uncertainty of satellite total column CO₂ data based on ASCOPE mission requirement document²: (Fig 2): $C(d) = C(d_{\text{obs}}) + C(d_{\text{rep}}) + C(d_{\text{mod}})$ with diagonal elements:
 σ_{obs} : land 0.5 ppmv, ocean 1.5 ppmv
 σ_{mod} : monthly 0.5 ppmv, inst. 1.5 ppmv
 $\sigma_{\text{rep}}^2 = \sigma_{\text{het}}^2 / n$ (monthly: n=30; inst.: n=1)
 σ_{het} : 3.0 ppmv
- Test two different sampling strategies (monthly vs instantaneous) and two wavelengths (1.6 and 2.0 micron)
- Only measurement uncertainties are needed for Observing System Simulation Experiment (OSSE) (see Algorithm box)
- Use Hessian (2nd derivative) information to infer *a posteriori* uncertainties of parameters
- Project *a posteriori* uncertainties from parameters to carbon fluxes (see Algorithm box): net flux (NEP) and biomass growth (NPP) over Europe, Russia and Brasil (Fig 4)

Algorithm for uncertainty propagation

$$J(x) = \frac{1}{2} (x - x_{pr})^T C_{pr}^{-1} (x - x_{pr}) + \frac{1}{2} \sum_{i=1,nd} \left(\frac{M_i(x) - d_i}{\sigma_{d_i}} \right)^2$$

$$\frac{d^2 J(x)}{dx^2} = C_{pr}^{-1} + \sum_{i=1,nd} \frac{1}{\sigma_{d_i}^2} \frac{d^2}{dx^2} (M_i(x) - d_i)^2$$

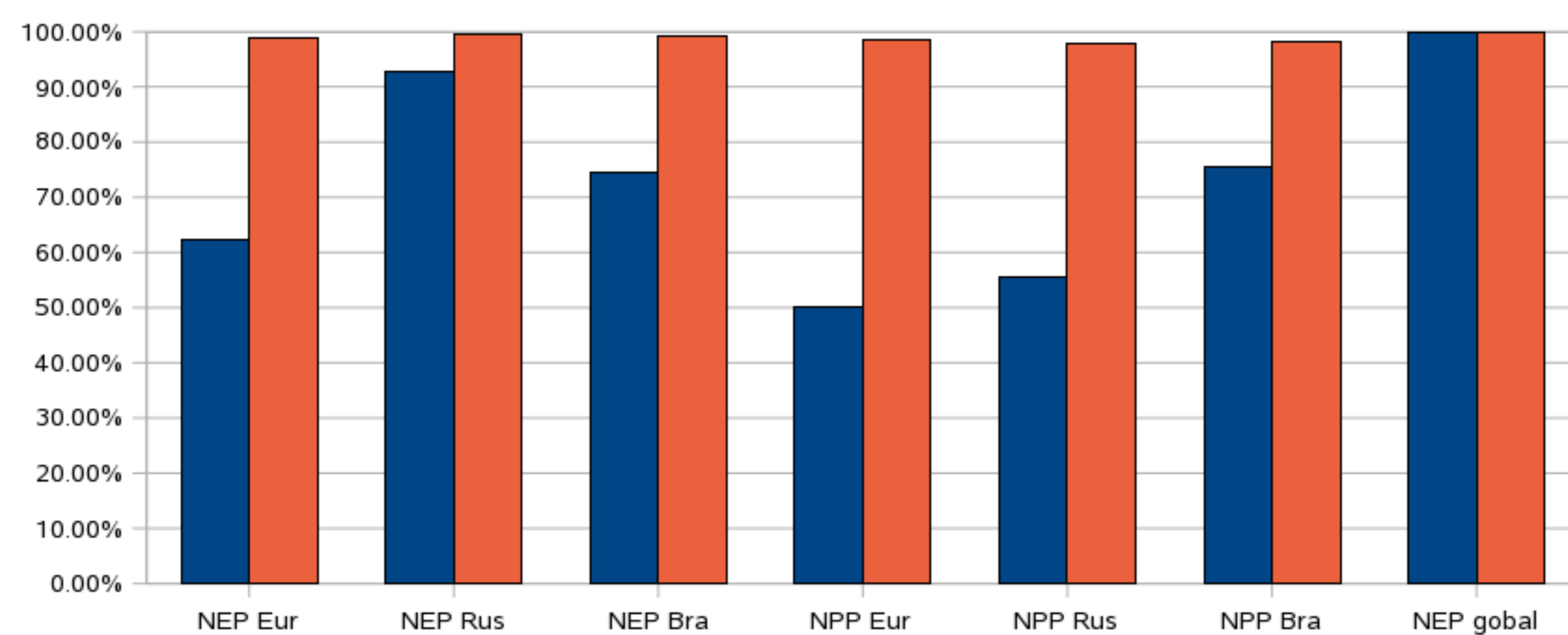
- Hessian independent of x for linear model
- For synthetic data use $d = M(x)$
- Decomposes nicely, can precompute model contribution

$$C_{po} \approx \frac{d^2 J(x_{po})}{dx^2}^{-1}$$

$$\sigma_y \approx \frac{dy(x_{po})}{dx} C_{po} \frac{dy(x_{po})}{dx}^T \approx \frac{dy(x_{po})}{dx} \frac{d^2 J(x_{po})}{dx^2}^{-1} \frac{dy(x_{po})}{dx}^T$$

x : Parameters
 x_{pr} : Priors
 C_{pr} : Uncertainties
 $M(x)$: Model
 d : Observations
 d_i : Their uncertainties
 σ_{d_i} : Uncorrelated!
 $J(x)$: Cost function
 $\frac{d^2 J(x)}{dx^2}$: Hessian
 x_{po} : Posterior parameters
 C_{po} : Posterior uncertainties
 $y(x)$: Target quantity
 σ_y : Its uncertainty

Figure 4: Relative uncertainty reduction (monthly sampling and 1.6 micron wavelength) for target quantities (NEP and NPP over Europe, Russia and Brasil), blue bars: ground-based station network only (GLOBALVIEW); red bars: GLOBALVIEW + ASCOPE.



References

- 1-Rayner, P. J., M. Scholze, W. Knorr, T. Kaminski, R. Giering and H. Widmann (2005), Two decades of terrestrial carbon fluxes from a Carbon Cycle Data Assimilation System (CCDAS), *Global Biogeochemical Cycles*, 19, doi: 10.1029/2004GB002254.
- 2-ESA (2008) A-SCOPE - Advanced Space Carbon And Climate Observation of Planet Earth, Technical Report SP-1313/1, European Space Agency, Noordwijk, The Netherlands.
- 3-Kaminski T., M. Scholze and S. Houweling (2010), Quantifying the benefit of ASCOPE data for reducing uncertainties in terrestrial carbon fluxes in CCDAS, *Tellus*, doi: 10.1111/j.1600-0889.2010.00483.x