Quantifying the Benefit of an Active CO2 Mission Concept in a Carbon Cycle Data Assimilation System

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Problem statement

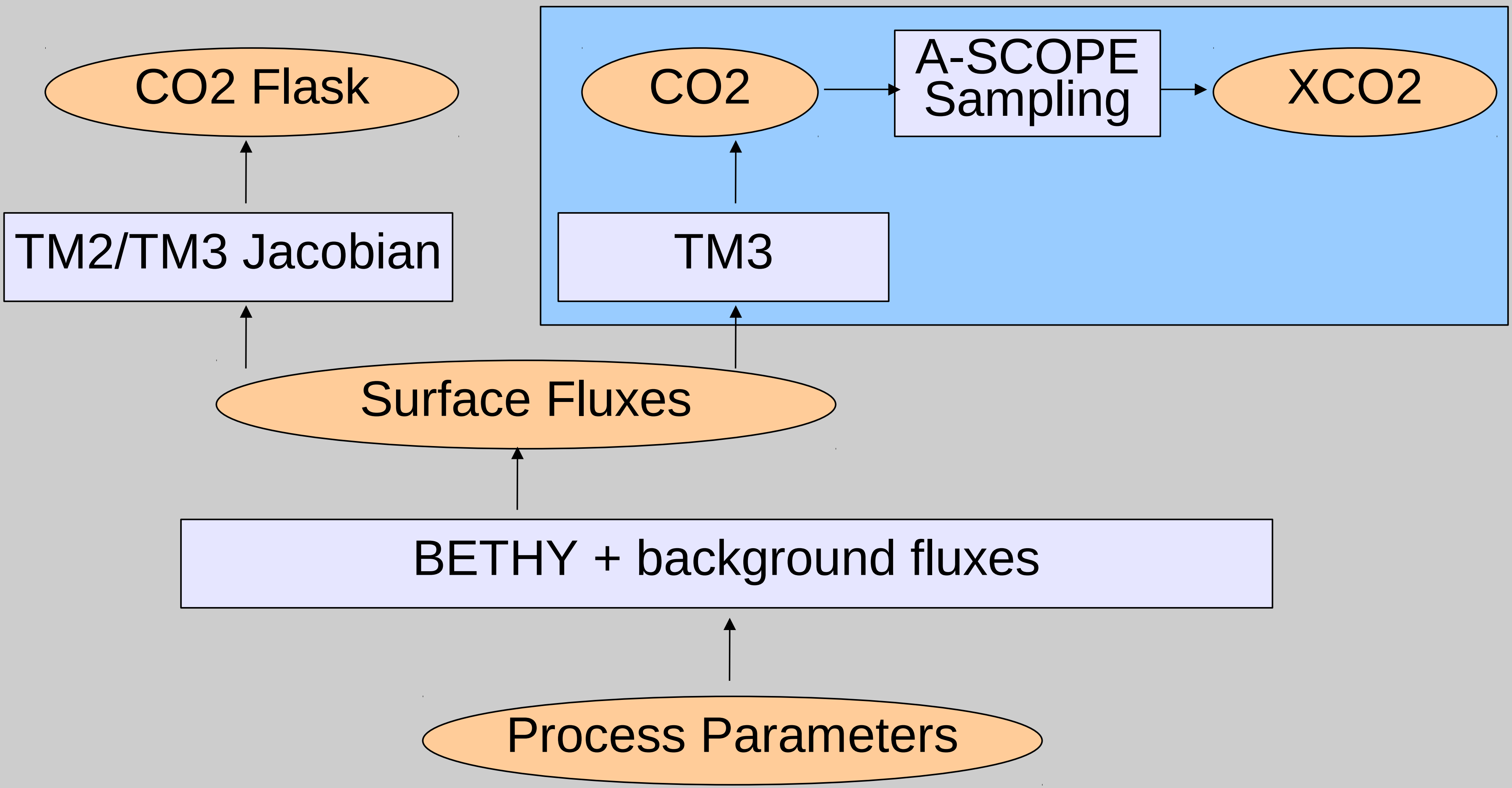
Question:

What is the benefit of XCO2 from an active LIDAR as quantified by the posterior uncertainty for surface fluxes in a CCDAS?

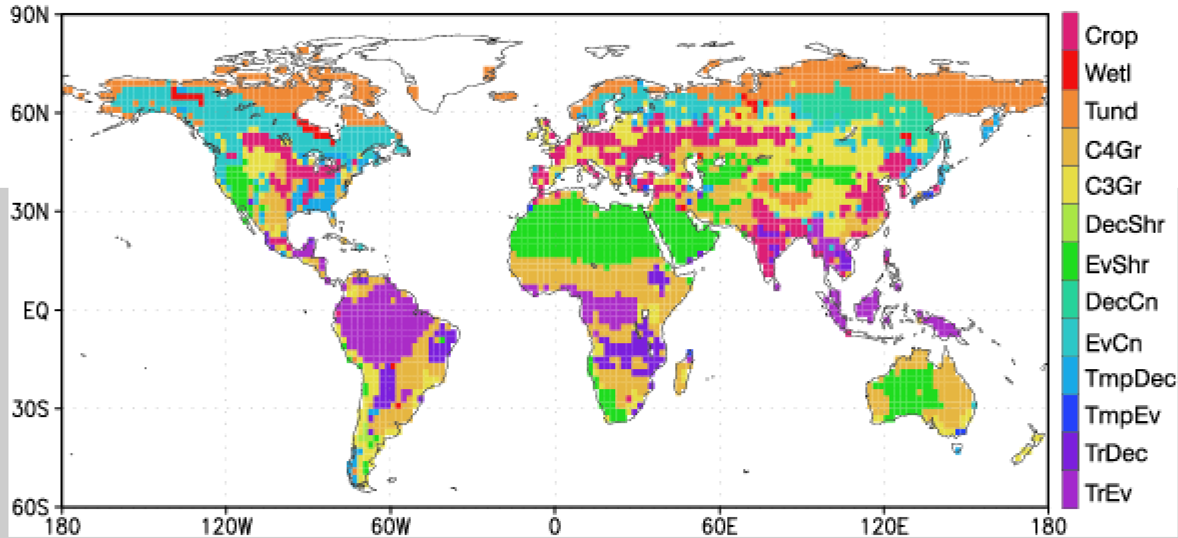
Uncertainty in a terrestrial model simulation:

- Driving data
- Relevant processes and their implementation (structural)
- Process parameters (parametric)
- Initial state

CCDAS


CO2 Flask
CO2
A-SCOPE Sampling
XCO2
TM2/TM3 Jacobian
TM3
Surface Fluxes
BETHY + background fluxes
Process Parameters

BETHY setup



- 2 by 2 degrees, global
- 13 Plant Functional Types
- 57 Process Parameters (Initial Conditions)
  - 3 PFT specific
  - 17 not PFT specific
  - 1 atmospheric
- Parameter values taken from Scholze et al. (2007)
- Prior parameter uncertainties taken from Scholze et al. (2007), in the order of 25%

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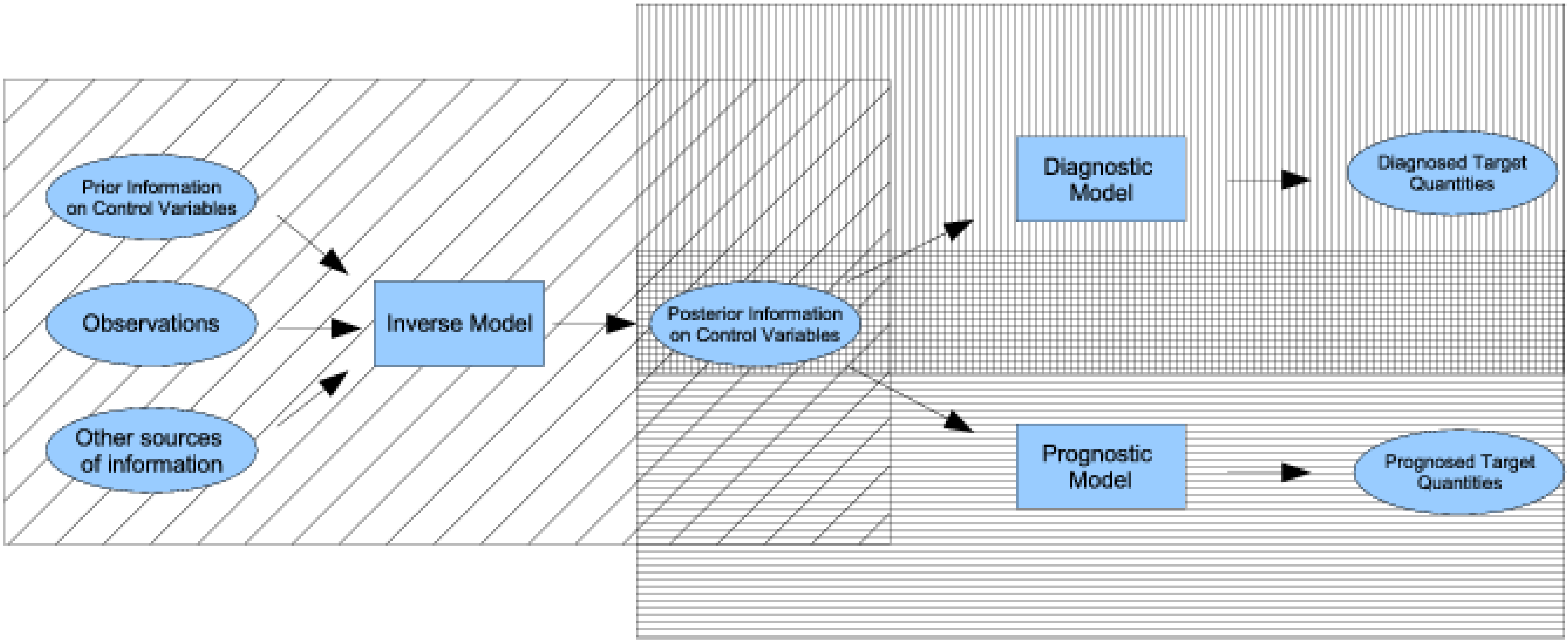
CCDAS scheme



Rayner et al. (2005); Scholze et al. (2007)

Uncertainty calculation in 2 steps

x: Parameters

x_{pr}: Priors

C_{pr}: Uncertainties

$M(x)$: Model

d: Observations

C_d: 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

All derivative code generated from model code by automatic differentiation tool TAF

Inverse step:

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

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

uncertainty in observations AND model

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

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

Propagation step:

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

Data Uncertainty

$$C(d) = C(d_{\mathrm{obs}}) + C(d_{\mathrm{rep}}) + C(d_{\mathrm{mod}})$$

$$\sigma_{\mathrm{rep}}^2 = \frac{\sigma_{\mathrm{het}}^2}{n}$$

For default setup (monthly sampling, 1.6 micron) in ppm:

- σ_{obs} = 0.5 (land)/1.5 (ocean)
- n = 30, σ_{het} = 3
- σ_{mod} = 0.5
- all uncorrelated

Setup

Target quantities:

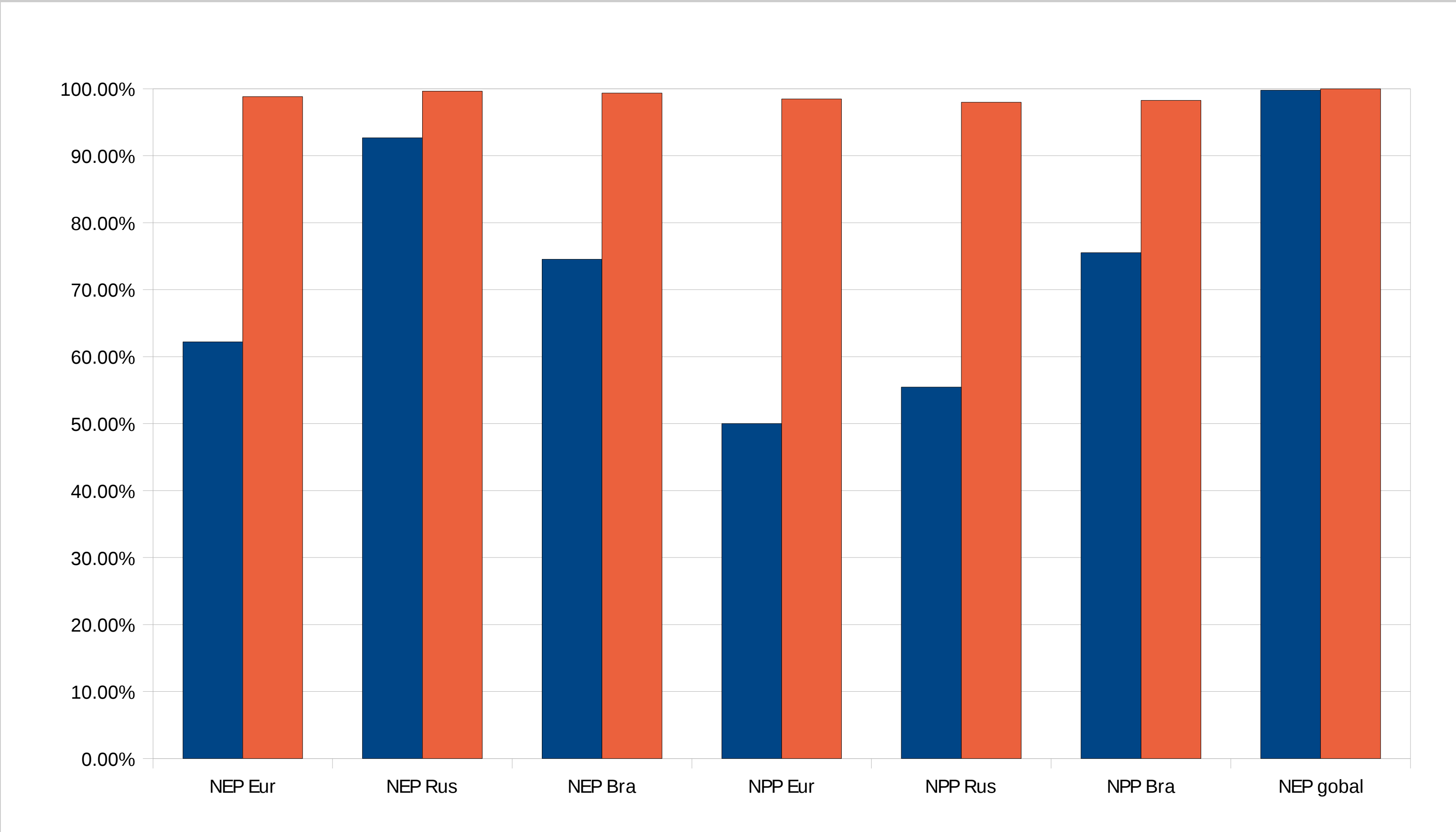
- NEP
- NPP
- regionally integrated
- averaged over 20 years

Assimilation window:

- A-SCOPE: 1 years
- Flask: 20 years

Flask assessment with 41 GLOBALVIEW sites taken from Scholze et al. (2007)

A-SCOPE + flask (red) vs flask (blue)



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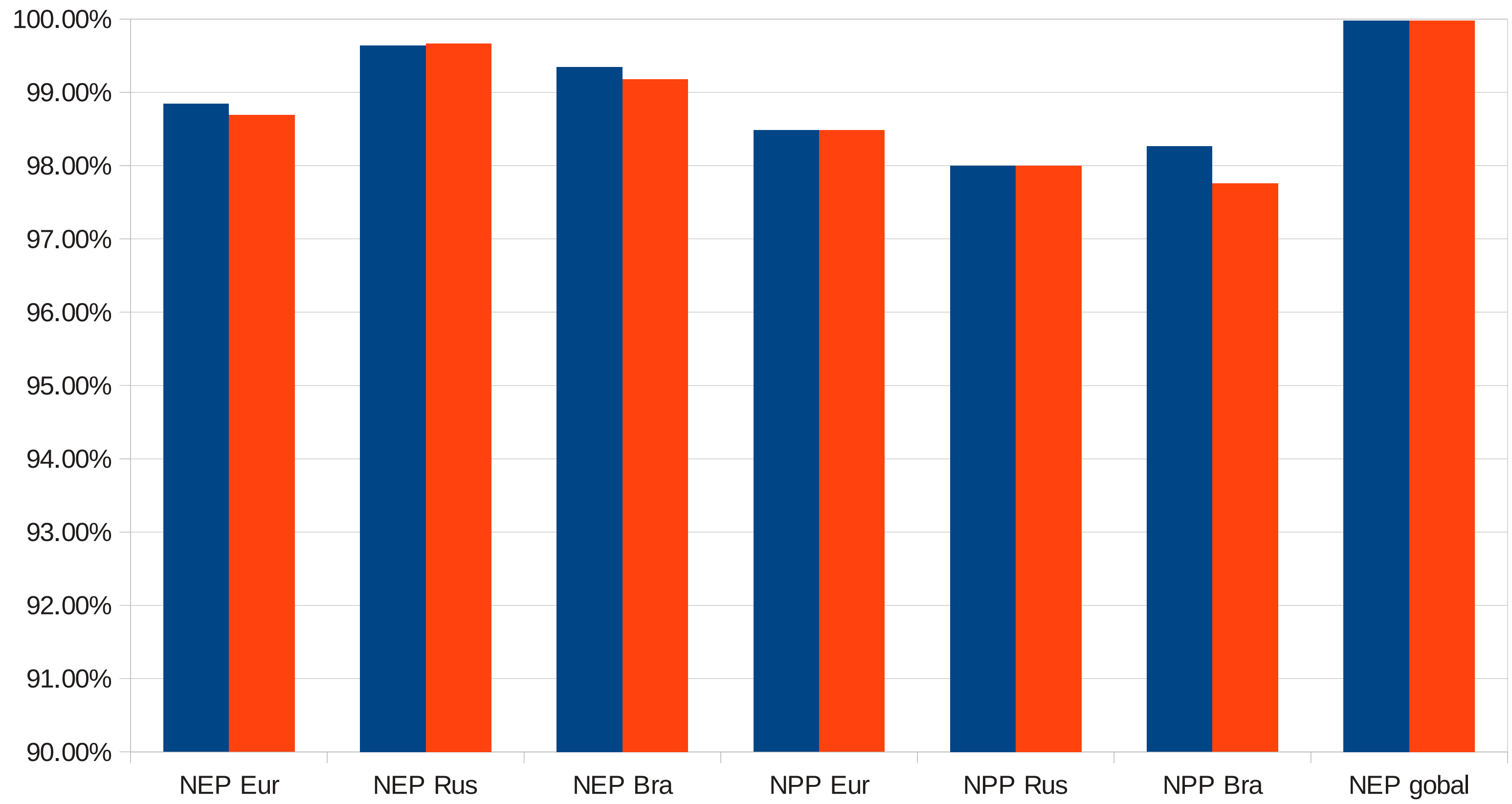
A-SCOPE + GLOBALVIEW
monthly (red) vs inst. sampling (blue)



inst. sampling: $3\sigma_{mod}$

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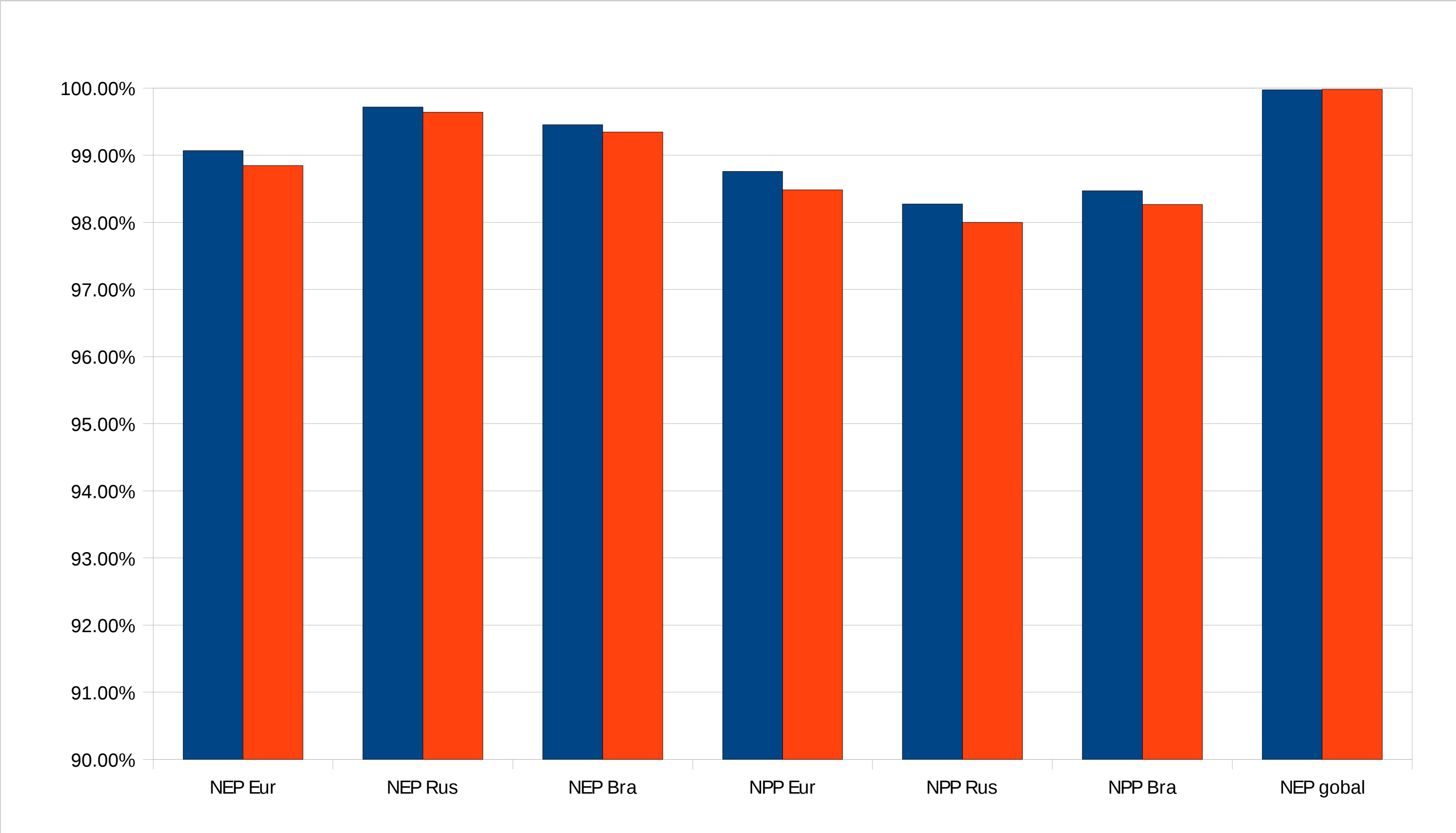
1.6 micron (red) vs 2.0 micron (blue)



2.0 micron: $2\sigma_{obs}$

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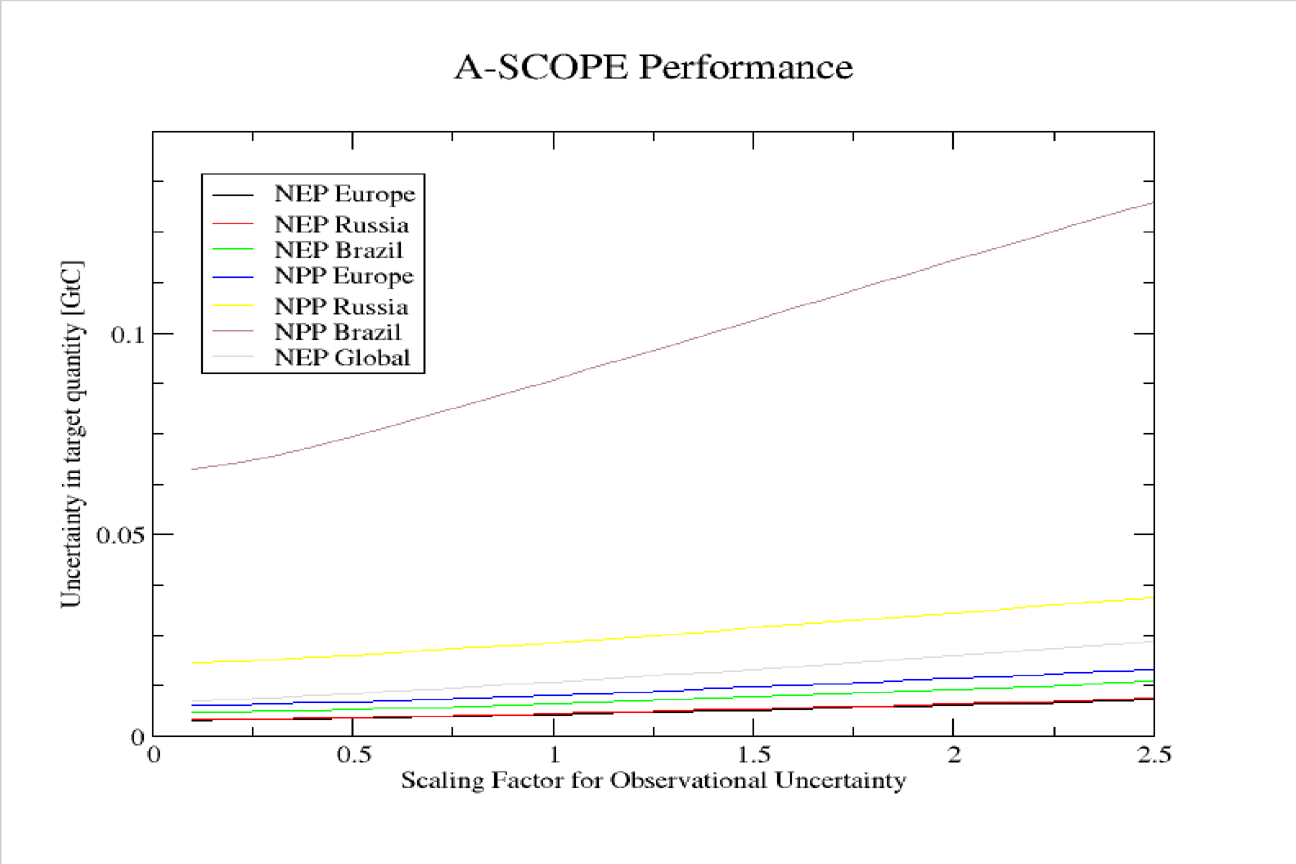
Impact of observational uncertainty



$\sigma(y_{mod})=0$

$$\sigma(y)^2 = \mathbf{D}(\mathbf{N})\left(\frac{1}{k\sigma_{\mathrm{obs}}^2 + \sigma_{\mathrm{rep}}^2 + \sigma_{\mathrm{mod}}^2} H_A + H_0\right)^{-1} \mathbf{D}(\mathbf{N})^T + \sigma^2(y_{mod})$$

Conclusions

- Evaluated A-SCOPE performance for calibration of a terrestrial biosphere model
- Assumed uncorrelated data uncertainty
- A-SCOPE performs better than ground-based flask sampling network
- Better performance regardless of weighting function and sampling in the model
- Holds for a range of observational uncertainties
- CCDAS approach shows potential for higher level RS products: carbon stocks and fluxes (beyond net and beyond assimilation period)