FastOpt University of BRISTOL SRON Netherlands Institute for Space Research IMECC INFRASTRUCTURE FOR MEASUREMENT OF THE EUROPEAN CARBON CYCLE

Supporting the improvement of the carbon observing system by quantitative network design

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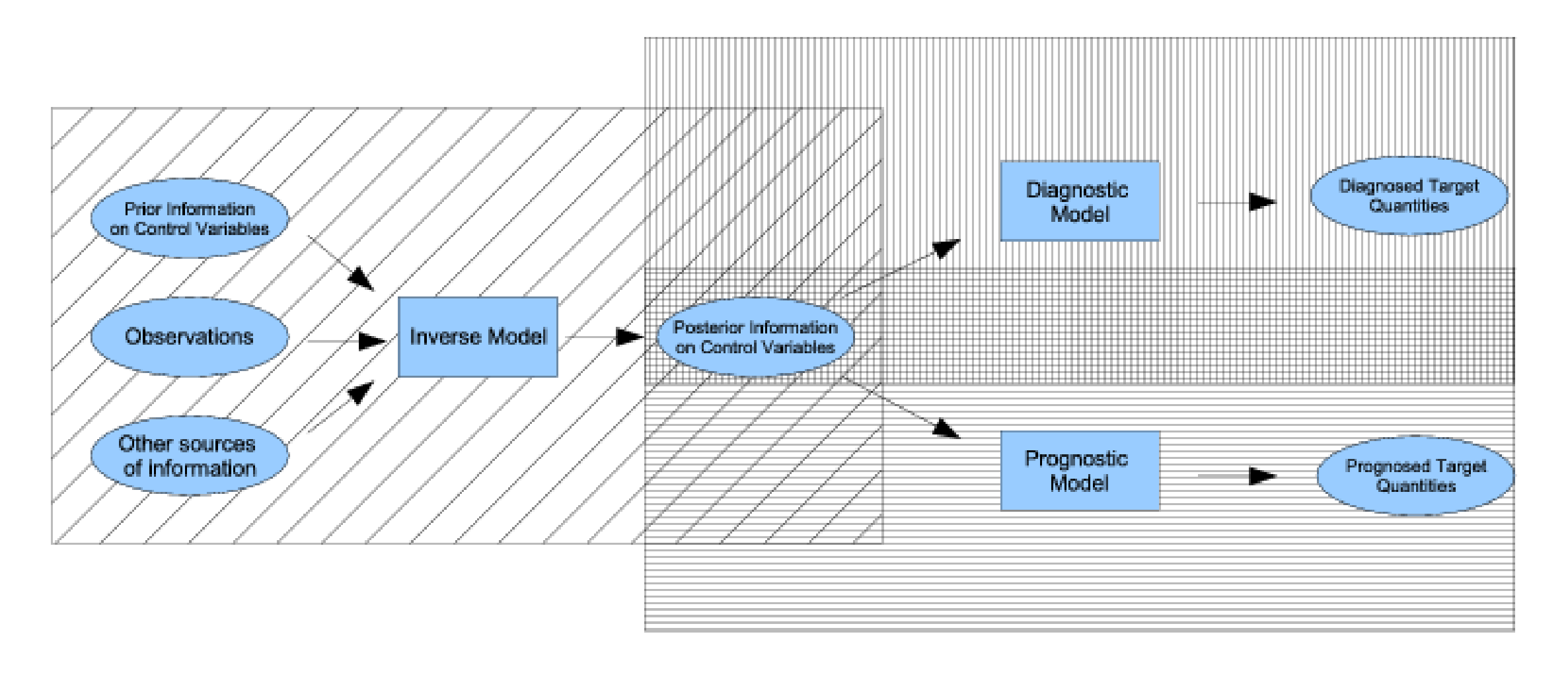
Objectives

- Demonstrate the rigorous quantitative evaluation of observational networks for the carbon cycle in a Carbon Cycle Data Assimilation System (CCDAS)
- Demonstrate the simultaenous use of multiple data streams
- Demonstrate the evaluation of a mission concept for remotely sensed CO_2 in a CCDAS

CCDAS

CCDAS works in a 2-step procedure:

- In an inversion step it estimates process parameters plus their uncertainties from observations and their uncertainties
- In a diagnostic/prognostic step it maps these uncertainties forward to target quantities of interest



Quantitative Network Design

- Evaluates prescribed networks in terms of their constraint on target quantities of interest
- Can handle potential networks, only the combined observational and model uncertainty has to be prescibed

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
$\frac{d^2J(x)}{dx^2}$: 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:

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

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

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

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

Propagation step:

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

References

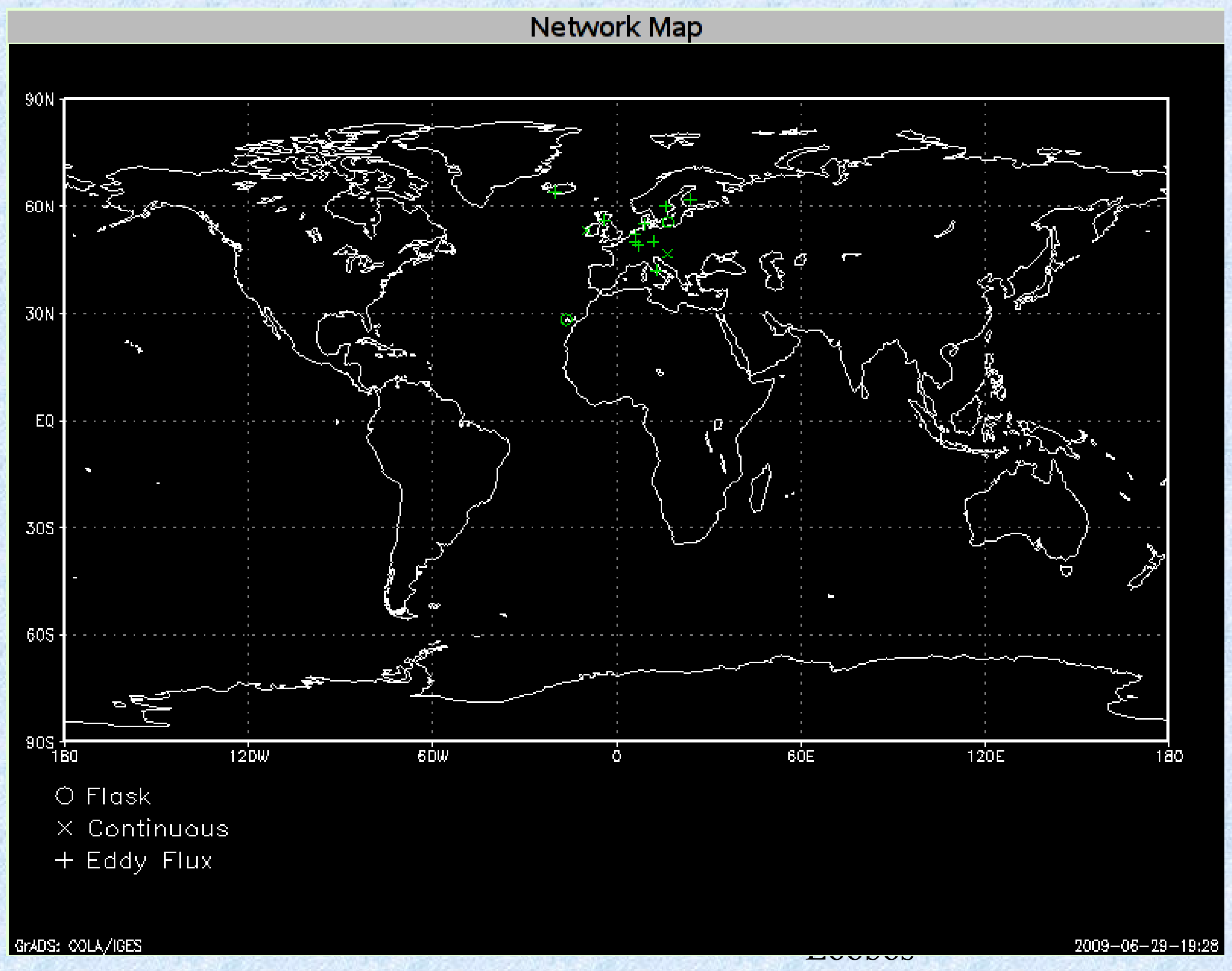
Giering, R. and T. Kaminski (1998), Recipes of Adjoint Code Construction, ACM Trans. Math. Software 24, 437-474.
GLOBALVIEW-CO2 (2004), Cooperative Atmospheric Data Integration Project - Carbon Dioxide, CD-ROM, NOAA CMDL, Boulder, Colorado.
Heimann, M. (1995), The global atmospheric tracer model TM2, *Tech. Rep.,* 10, Dtsch. Klimarechenzentrum, Hamburg, Germany.
Heimann, M. and S. Körner (2003), The global atmospheric tracer model TM3, *Tech. Rep., 5*, Max Planck Institut für Bieogeochemie, Jena, Germany.
Kaminski, T. and P. J. Rayner (2008), Assimilation and network design. In H. Dolman, A. Freibauer, and R. Valentini, editors, *Observing the continental scale Greenhouse Gas Balance of Europe*, Ecological Studies, chapter 3, pages 33-52.
Kaminski, T., M. Scholze, and S. Houweling (2009), Quantifying the Benefit of A-SCOPE Data for Reducing Uncertainties in Terrestrial Carbon Fluxes in CCDAS. *J. Geopphys. Res, in revision*
Knorr, W. (2000), Annual and interannual CO2 exchange of the terrestrial biosphere: Process-based simulations and uncertainties, *Global Ecol. Biogeogr.,* 9, 225-252.
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 Biogeochem. Cycles,* 19, GB2026.
Scholze, M., T. Kaminski, P. Rayner, W. Knorr and R. Giering (2007), Propagating uncertainty through prognostic carbon cycle data assimilation system simulations, *J. Geopphys. Res.,* 112, D17305.

Network Designer

- Interactive online tool (http://imecc.ccdas.org)
- Evaluates three observational data types: flask and continuous observations of atmospheric CO_2, direct flux measurements
- Provides as target quantities NPP and NEP over three regions
- Constructed with European Commission project I3 project IMECC (http://imecc.org)

Network Designer in support of ICOS

- Evaluated five networks for ICOS
- All observational constraints active over twenty years



Configuration	Flux	Flask	Continuous
prior	0	0	0
base	10	2	2
noflux	0	2	2
noflask	10	0	2
nocont	10	2	0

Network	NEP Eur	NEP Rus	NEP Bra	NPP Eur	NPP Rus	NPP Bra
prior	0.45	1.45	1.13	0.66	1.08	4.86
base	0.01	0.09	0.08	0.01	0.06	0.19
noflux	0.08	0.19	0.12	0.12	0.24	0.82
noflask	0.02	0.14	0.11	0.01	0.06	0.22
nocont	0.03	0.16	0.28	0.01	0.06	0.29

Table 1: Posterior uncertainties in GtC/yr

A-SCOPE: CO_2 from space

- Active lidar instrument, can sample day and night
- Evaluated two horizonatl weighting functions, two transport Jacobians based on TM3 in fine resolution, and a range of observational uncertainties
- Significantly better performance than 41 stations from GLOBALVIEW network
- Reduction in Uncertainty with respect to prior for 1.6 micron band horizontal weighting (red bars) and, for comparison, with GLOBALVIEW network only: