Quantitative network design for biosphere model process parameters

E. Koffi[1], P. Rayner[1], T. Kaminski[2], M. Scholze[3], M. Voßbeck[2], and R. Giering[2]

[1]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif-sur-Yvette, France (ernest.koffi@lsce.ipsl.fr)
[2]FastOpt , Hamburg, Germany
[3]Quantifying and Understanding the Earth System, Department of Earth Sciences, University of Bristol, United Kingdom

Background and Motivation

Current uncertainty about the present and future behaviours of the terrestrial **carbon cycle** stimulated the research community to build appropriate observing networks. **Quantitative network design**, based on **inverse modelling** systems aims to optimize such networks.

This approach is used, in the framework of the **European project IMECC** (Infrastructure for Measurement of the European Carbon Cycle), to design candidates of networks that better constrain the process parameters of a biospheric model. The impact of various atmospheric and terrestrial measurement locations on the uncertainty of process parameters and concomitant uncertainty of calculated fluxes is demonstrated, along with a tool for assessing networks.

Methodology

Carbon Cycle Data Assimilation System

The network design tool is based on the CCDAS (Carbon Cycle Data Assimilation System) (Figure 1). The system consists of the terrestrial biosphere model BETHY (Biosphere Energy Transfer Hydrology), which can couple with several atmospheric transport models (e.g., Scholze, 2003, Rayner et al., 2005).

CCDAS allows the calculation of diagnostic (Rayner at al., 2005) and prognostic (Scholze et al., 2007) quantities.

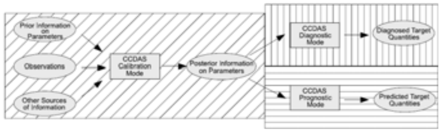

Figure 1: The two-steps procedure for inferring diagnostic and prognostic target quantities from CCDAS.

- Rectangular boxes: processes.
- Oval boxes: data
- Diagonally hatched box: inversion or calibration step.
- Vertical hatched box: diagnostic step.
- Horizonaly hatched box: prognostic step.

Formalism of the network design tool

The method is based on the assessment of candidate networks of carbon cycle measurements through the computation of the uncertainty on a target quantity (Kaminski and Rayner, 2008). The method solves an inverse problem, which is formulated as a minimization of a cost function J(x):

$$J(x) = \frac{1}{2}[\,(M(x)-d)^T.C(d)^{-1}.(M(x)-d) + (x-x_0)^T.C(x_0)^{-1}.(x-x_0)\,] \quad (1)$$

x : parameters to be optimized with prior values x_0 and uncertainty $C(x_0)$

d : the observations with uncertainty $C(d)$

$M(x)$: the model M result corresponding to the observations d

$(.)^T$ denotes the transposed

Uncertainty on a target quantity

If the model M is linear, the data d and the priors of the parameters x have a Gaussian Probability Density Function (PDF), then the posterior (i.e., optimized) values of x also have a Gaussian PDF (Tarantola, 1987). Thus, the posterior uncertainty $C(x_{op})$ is given by the inverse of the Hessian H (i.e., the second derivative) of the cost function J(x) (equation 1). Following Rayner et al., 2005, the uncertainty C(y) of a target quantity y(x) is approximated to first order by the equation (2).

$$C(y) \approx \frac{dy}{dx}(x_{op}).C(x_{op}).\frac{dy}{dx}(x_{op})^T$$

$$C(x_{op}) = H^{-1} \text{ . H is the Hessian of the cost function defined by} \quad (2)$$

$$H = \frac{d^2J(x_{op})}{dx^2} = C(x_0)^{-1} + \frac{1}{2}\sum_{i=1}^{n}\frac{1}{C(d_i)}\frac{d^2}{dx^2}(M_i(x)-d_i)^2$$

Network Design Tool and First Applications

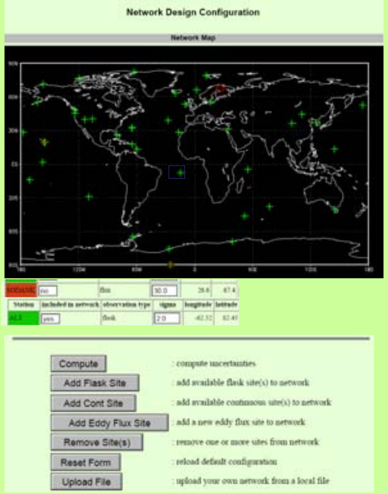

Figure 2:
The CO_2 measurement networks given by 41 Global View (GV) flask sites (+), and two continuous measurement sites (X).

Green color stands for the sites used for the network evaluation

Red color stands for sites that are not used.

Two candidate networks are evaluated: The first one uses all the 41 GV stations and the second one uses 40 sites, excluding one site over the Atlantic Ocean (□)

For further details on the Network Design Tool, contact Thomas kaminski (Thomas.Kaminski@FastOpt.com)

Consult http://imecc.ccdas.org

Table 1: Results for Network 1 (black) and Network 2 (blue)

Targets	sigma[GtC]	
Global Uptake	5.4/	4.8
European Uptake	3.4/	3.4

Preliminary investigations

Evaluation of candidate networks for the study of the carbon cycle and the processes of the biosphere. Two first applications:

1.Candidate networks for BETHY process parameters

Impact of various measurements locations on the uncertainty of the 57 BETHY process parameters: the results (not shown) indicate that a best network can be designed for an ensemble of parameters, which might be physically linked.

2.Candidate networks for CO_2 uptake

Uncertainty of the calculated CO_2 fluxes for various networks: Results for the two networks of Figure 2 are discussed: The first network consists of 41 Global View (GV) sites and the second network excludes one of them, located over the Atlantic Ocean. The results (Table 1) clearly show the impact of the excluded site: the uncertainty on the global uptake of CO_2, which stands for 4.8 GtC when using the 41 GV sites, is enhanced by about 13%. The european CO_2 uptake remains unchanged for the two studied networks.

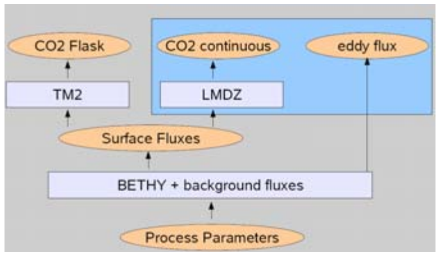

Figure 3: Carbon Cycle Assimilation System (CCDAS). Forward modelling chain together with the modules for full network design tool

Outlook

- This first version of the network designer is restricted to flask sampling of atmospheric CO_2, using the transport model TM2 as observational operator.
- The next data types to be included are continuous samples for atmospheric CO_2, using the atmospheric transport model LMD_Z as observational operator.
- A further data type to be included is direct flux observations.

This work was supported in part by the European Commission under contract numbers FP6-511176-2 (CarboOcean) and FP6-026188 (IMECC)

References

Kaminski T. and P. J. Rayner (2007), Assimilation and network design. In H. Dolman, A. Freibauer, and R. Valentini, editors, *to appear in Observing the continental scale Greenhouse Gas Balance of Europe*, Ecological Studies, chapter 3. Springer-Verlag, New York, 2007
Tarantola, A. (1987), Inverse problem theory – Methods for data fitting and model parameter estimation. *Elsevier Science*, New York, USA, 1987
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 Biogechen. Cycles*, 19, GB2026, Doi:10..1029/2004GB002254
Scholze, M, (2003), Model studies on the response of the terrestrial carbon cycle on climate change and variability, *Examensarbeit, Max-Planck-Inst. Für Meterol.*, Hamburg, Germany
Scholze, M., T. Kaminski, P. Rayner, W. Knorr, and R. Giering (2007), Propagating uncertainty through prognostic carbon cycle data assimilation system simulations. *J. Geophys. Res.*, 112, D17305, doi:10.1029/2007JD008642