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 behaviour of the terrestrial **carbon cycle** has 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 evaluate candidates of networks that better constrain the process parameters of a biospheric model. The impact of various atmospheric and terrestrial measurements 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) (Knorr, 2000), 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.

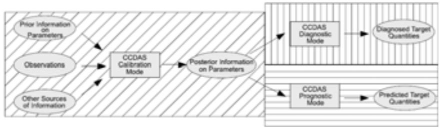


Figure 1: The two-steps procedure for inferring diagnostic and prognostic target quantities from CCDAS.

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

$$J(x) = \frac{1}{2}\left[\sum_{i=1}^{n} \frac{1}{(\sigma_{di})^2}(M_i(x) - d_i)^2 + (x - x_0)^T . C(x_0)^{-1} . (x - x_0)\right]$$

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

d : the observations (1)

σ_{d_i} : the uncertainty in observations and model

$M(x)$: 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). 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).

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

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

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

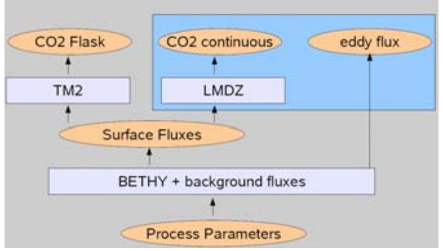


Figure 2: Carbon Cycle Assimilation System (CCDAS). Forward modelling chain together with the modules for full network design tool.

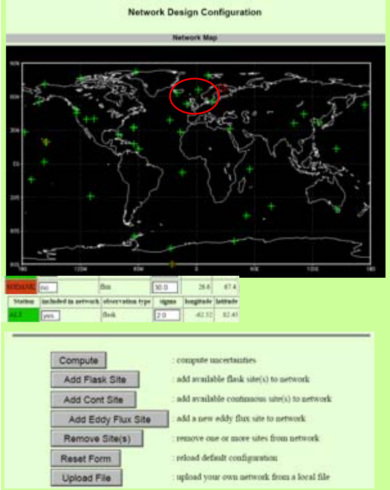
Set up

The network designer allows to handle (Figure 2):

- Flask sampling of atmospheric CO_2, using the transport model TM2 as observational operator.
- Continuous samples for atmospheric $C0_2$, using the atmospheric transport model LMD_Z as observational operator.
- Direct flux observations.

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

Network Design Tool and First Applications



Station	included in network	observation type	sigma	longitude	latitude
[illegible]	no	flux	30.0	28.6	67.4
ALT	yes	flask	2.0	-62.52	82.45

: compute uncertainties
: add available flask site(s) to network
: add available continuous site(s) to network
: add a new eddy flux site to network
: remove one or more sites from network
: reload default configuration
: upload your own network from a local file

Figure 3:

The CO_2 network consists of 41 Global View (GV) flask sites (**+**), 2 continuous measurement sites (**x**) and an Eddy flux measurement site (**O**).

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:

Network 1 consists of 41 GV stations

Network 2 consists of 37 GV stations, excluding 4 sites over Europe (○)

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

or consult http://imecc.ccdas.org

Application to CO_2 fluxes

The tool has been used to evaluate candidate networks for the carbon cycle study, using only flask samples of atmospheric CO_2 as observations. We focused on the CO_2 fluxes. The uncertainty on the CO_2 data [σ_{di}] that reflects the combined effect of observational and model error was set to 2 ppm_v for each flask.

The Uncertainties on the Net Ecosystem Production NEP (net CO_2 flux between the atmosphere and the biosphere) and the Net Primary Production NPP of the biosphere are calculated for the **two networks of Figure 3**.

Table 1: Uncertainties on NPP and NEP evaluated from Network 1 (41 stations, green) and Network 2 (37 stations, blue). The prior uncertainties of these quantities are also reported (black).

Sigma (Gt C/yr)	parameter	Europe	Russia	Brazil
Prior uncertainties	**NPP**	**0.66**	**1.08**	**4.86**
	NEP	**0.45**	**1.45**	**1.13**
With inverse modelling	**NPP**	**0.08** **0.10**	**0.14** **0.15**	**0.50** **0.52**
	NEP	**0.05** **0.06**	**0.06** **0.07**	**0.13** **0.13**

Uncertainties on NPP and NEP decrease by more than 87% and 89% respectively, when using all the GV sites (Table 1). For the case under study, the exclusion of 4 stations does not significantly alters this reduction (i.e. less than 1%).

References

Kaminski T. and P. J. Rayner (2008), 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
Knorr W. (2000), Annual and interannual CO_2 exchanges of the terrestrial biosphere: process based simulations and uncertainties, *Glob. Ecol. And Biogeogr*., 9:225-252
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