PROJECTING TERRESTRIAL CARBON CYCLING WITH UNCERTAINTIES: RESULTS FROM A CARBON CYCLE DATA ASSIMILATION SYSTEM (CCDAS)

M. Scholze[1], T. Kaminski[2], P. Rayner[3], W. Knorr[1], and R. Giering[2]
[1]*University of Bristol, Department of Earth Sciences, Queens Road, Bristol, BS8 1RJ, UK; marko.scholze@bristol.ac.uk*
[2]*FastOpt GmbH, Schanzenstraße 36, 20357 Hamburg, Germany*
[3]*Laboratoire des Sciences du Climat et l'Environnement, Bat. 701 LSCE - CEA de Saclay Orme des Merisiers, 91191Gif-sur-Yvette, France*

ABSTRACT
We present results from a CO_2 hindcasting experiment using the Carbon Cycle Data Assimilation System (CCDAS). In its optimization mode CCDAS has been run to calibrate some 57 model parameters using atmospheric CO_2 concentrations from 1979 to 1999 as observational constraints. These calibrated parameters and their posterior uncertainties have subsequently been used in CCDAS' prognostic mode to project terrestrial carbon cycling and atmospheric CO_2 concentrations for the years 2000 to 2003. Projected uncertainties for annual net carbon fluxes remain in the same range as over the diagnostic period, however, projected uncertainties in prognostic concentrations increase from year to year.

INTRODUCTION
Atmospheric inversion studies have become an important tool for identifying terrestrial sources and sinks of CO_2 at the interannual time scale. Such traditional top-down studies have so far delivered important insights into the atmosphere-biosphere and atmosphere-ocean CO_2 exchanges fluxes. However, they suffer from the inverse problem being seriously under determined and they do not have any prognostic power, i.e. they cannot predict the evolution of future CO_2 fluxes.

These inverse methods are usually contrasted with bottom-up approaches using process-based terrestrial or oceanic models capable of predicting CO_2 fluxes. These models, however, cannot take into account the information contained in CO_2 measurements from the extensive flask-sampling network. Here, we present results from a Carbon Cycle Data Assimilation System (CCDAS, Rayner et al., 2005) that combines the two approaches. We present results from a hindcasting experiment for prognostically calculated net CO_2 fluxes plus uncertainties as well as atmospheric CO_2 concentrations plus uncertainties and compare them with recent atmospheric measurements for the years 2000 to 2003.

METHODS
CCDAS is built around the process-based terrestrial ecosystem model BETHY (Biosphere Energy Transfer Hydrology Scheme, Knorr, 2000) coupled to the atmospheric tracer transport model TM2 (Heimann, 1995). It consists of a two-stage assimilation system assimilating in the first stage remotely sensed vegetation activity and in the second stage atmospheric CO_2 concentration data into the terrestrial biosphere model BETHY.

CCDAS infers values of the parameters controlling the function of a process model of the terrestrial biosphere using various observations. The controlling parameters for the second stage in this model are inferred by nonlinear optimization based on the model's adjoint. We predict the model evolution using these optimized parameters and calculate quantities of interest such as the net carbon flux. This can be done in a diagnostic mode, calculating fluxes for the same period as the assimilation consistent both with observations and model dynamics. If, however, the model is prognostic one can run it for other periods, either the future or the past.

Here, we use an optimized parameter set within the CCDAS framework to infer prognostic carbon fluxes that are consistent with observations for the assimilation period and model dynamics. We assimilate atmospheric CO_2 data from 41 observing sites for the years 1979 to 1999 (GLOBALVIEW-CO2, 2004). The assimilation procedure also allows to calculate uncertainties on the parameters via

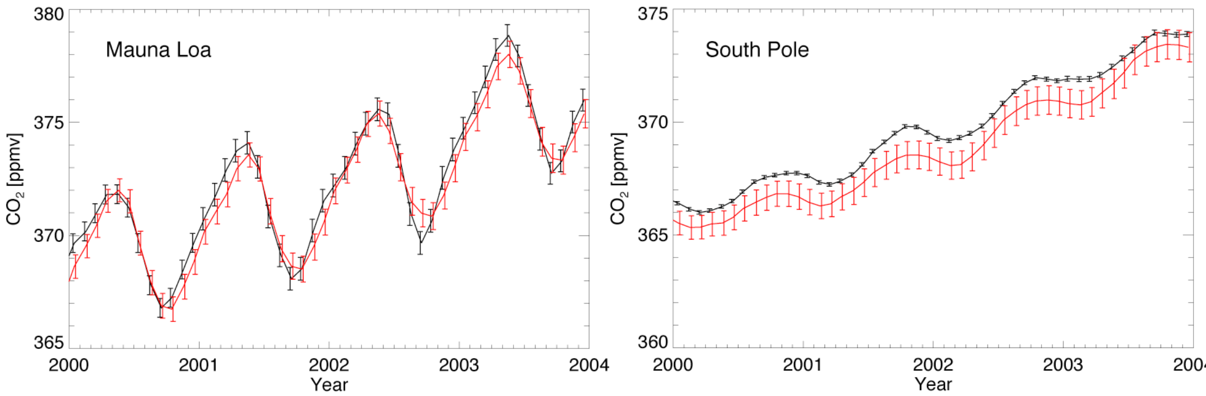

Fig. 1: Measured atmospheric CO_2 concentrations (black line) with uncertainties (vertical bars) and simulated CO_2 concentrations (red line) by CCDAS in for two stations.

the model's Hessian (second derivatives). These uncertainties are then mapped forward on predicted quantities such as net CO_2 fluxes to the atmosphere via the model's Jacobian. The adjoint, Hessian, and Jacobian are generated by automatic differentiation of the model's source code (Giering and Kaminski, 1998).

RESULTS

Predicted and measured CO_2 concentrations lie well within their uncertainty bounds at Mauna Loa, whereas at South Pole simulated CO_2 concentrations are consistently underestimated (see also Table 1, in particular the bias corrected RMS value) and lie mostly outside the uncertainty bounds as shown in Fig. 1. The large magnitude of the bias (Table 1), especially for South Pole, is not surprising given that we ran our prognostic simulations with climatological ocean-atmosphere CO_2 exchange background fluxes. Over the prognostic period, our demonstration yields posterior uncertainties on global annual net fluxes that are approximately of the same size as over the diagnostic period; posterior uncertainties in prognostic concentrations increase from year to year (not shown here, more details are given in Scholze et al., 2007).

Table 1: Comparison of predicted and observed concentrations for the prognostic time period (2000-2003, a total of 48 data points; RMS: root mean square difference between model prediction and observation; Bias: mean of the model-observation difference), unit for columns 3-5 is ppmv.

Station Code	Descriptive Name	RMS	Bias	Bias corrected RMS
MLO	Mauna Loa, Hawaii	0.6	-0.32	0.51
SPO	South Pole	0.9	-0.87	0.21

REFERENCES

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.

Knorr, W. (2000), Annual and interannual CO2 exchange of the terrestrial biosphere: Process-based simulations and uncertainties, *Global Ecol. Biogeogr.,* 9, 225-252.

Heimann, M. (1995), The global atmospheric tracer model TM2, *Tech. Rep.,* 10, Dtsch. Klimarechenzentrum, Hamburg, Germany.

GLOBALVIEW-CO2 (2004), Cooperative Atmospheric Data Integration Project - Carbon Dioxide, CD-ROM, NOAA CMDL, Boulder, Colorado, [Also available on Internet via anonymous FTP to ftp.cmdl.noaa.gov, Path: ccg/co2/GLOBALVIEW].

Giering, R. and T. Kaminski (1998) Recipes for Adjoint Code Construction. *ACM Trans. Math. Software*, 24, 437-474.

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.