# Regional distinctions in the global mean pattern of terrestrial $CO_2$ fluxes due to missing observational constraints


Quantifying and Understanding the Earth System

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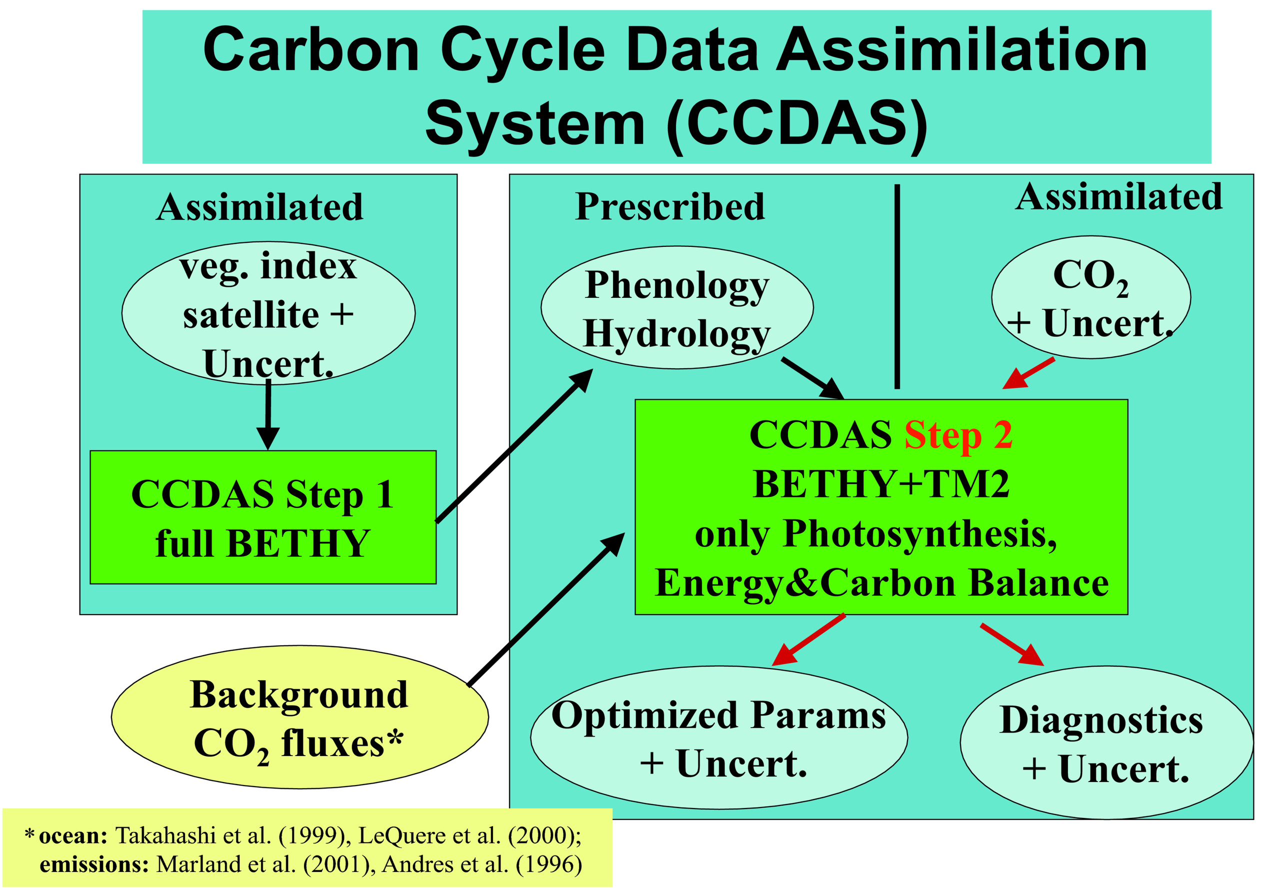


**Figure 1:** Schematic representing information flow in CCDAS. In each of the steps, parameters of the Biosphere Energy-Transfer Hydrology scheme (BETHY) are optimally adjusted to match observations. Ocean and anthropogenic $CO_2$ fluxes are represented as background fields.

## INTRODUCTION

The Carbon Cycle Data Assimilation System (CCDAS) [1,2] allows the assimilation of atmospheric $CO_2$ concentrations into the terrestrial biosphere model BETHY [3], constraining its process parameters via an adjoint approach. Current approaches do not use any regionalization, but rely on globally applicable, universal parameters. That means, the parameters are not regionally differentiated, and if they are differentiated at all, then only by plant functional type (PFT). Due to the fact that carbon fluxes might be determined by regional differences, a geographical representation is inevitably. Therefore, the subject of the present study is the regionalization of the key carbon storage parameter $\beta$, which determines the characteristics of the slowly decomposing soil carbon pool and represents processes that are difficult to model explicitly.

## METHODOLOGY

The CCDAS used here is an estimator algorithm for a set of terrestrial biosphere model parameters, which uses automatically generated adjoint code for parameter optimization and Hessian model code for estimating posterior parameter uncertainties. Calculated fluxes are then mapped to atmospheric concentrations using the atmospheric transport model TM2 [4]. The data assimilation is performed in two steps as illustrated in Fig. 1 over a period of 25 years from 1979 to 2003. In contrast to the set up used in [1,2] we only optimize the soil carbon part of BETHY in the second step, keeping all parameters controlling net primary production (NPP) fixed. This study investigates two cases:

(1) Base case: one $\beta$ parameter for each of the 13 PFTs, resulting in a set of 19 control parameters,

(2) Regionalization: separate $\beta$ for each PFT within each of the 8 distinct land regions, resulting in a set of 91 control parameters.

| | PFT | Land regions | | | | | | | | | Standard inversion |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | North American boreal (1) | North American temperate (2) | South American tropical (3) | South American temperate (4) | Africa (5) | Eurasia (6) | Asia (7) | Australia (8) | Σ | Σ |
| 1 | Tropical broadleaved evergreen tree | ---- | 5 | -549 | 359 | -884 | ---- | 1920 | 7 | **860** | **2881** |
| 2 | Tropical broadleaved deciduous tree | ---- | 50 | 660 | -926 | 3076 | ---- | 737 | 1 | **2123** | **-8** |
| 3 | Temperate broadleaved evergreen tree | ---- | 3 | ---- | ---- | 7 | 0 | 44 | 48 | **102** | **180** |
| 4 | Temperate broadleaved deciduous tree | 12 | 895 | 0 | -62 | 0 | 38 | 234 | -24 | **1093** | **1990** |
| 5 | Evergreen coniferous tree | -1803 | -415 | -8 | -26 | ---- | 446 | 242 | -14 | **-1079** | **-1329** |
| 6 | Deciduous coniferous tree | ---- | ---- | ---- | ----- | ---- | -429 | ---- | ---- | **-429** | **439** |
| 7 | Evergreen shrub | -17 | 50 | -3 | -129 | 192 | 144 | 425 | 489 | **1151** | **1435** |
| 8 | Deciduous shrub | -8 | 18 | -4 | -230 | -77 | 141 | -58 | 13 | **-204** | **-853** |
| 9 | C3 gras | 203 | -34 | -330 | -1704 | -16 | -1833 | 600 | 277 | **-2837** | **-5155** |
| 10 | C4 gras | 0 | -417 | 901 | 369 | -1176 | 408 | 1863 | -862 | **1086** | **-1623** |
| 11 | Tundra vegetation | -9 | 0 | ---- | -1 | ---- | 449 | 2 | 0 | **441** | **172** |
| 12 | Swamp vegetation | -24 | ---- | 0 | -27 | -6 | 23 | 0 | ---- | **-33** | **-236** |
| 13 | Crops | 1 | 795 | -5 | -60 | -60 | 916 | -1656 | 15 | **-53** | **4325** |
| | Σ | **-1145 (81)** | **949 (64)** | **661 (143)** | **-2436 (108)** | **1057 (135)** | **303 (119)** | **2880 (137)** | **-48 (91)** | **2221 (5)** | |
| | Standard inversion Σ | **-615 (34)** | **1114 (28)** | **1183 (95)** | **-1058 (36)** | **-507 (62)** | **184 (46)** | **1818 (32)** | **97 (43)** | | **2218 (5)** |

**Table 1:** NEP (TgC/yr) for each PFT and land region using the extended set of 91 parameters. The last column to the right and the bottom row present the results using the standard set of 19 parameters (base case). Sources are highlighted in red and sinks are highlighted in blue. Uncertainties (+1 σ) are given in brackets for each land region.

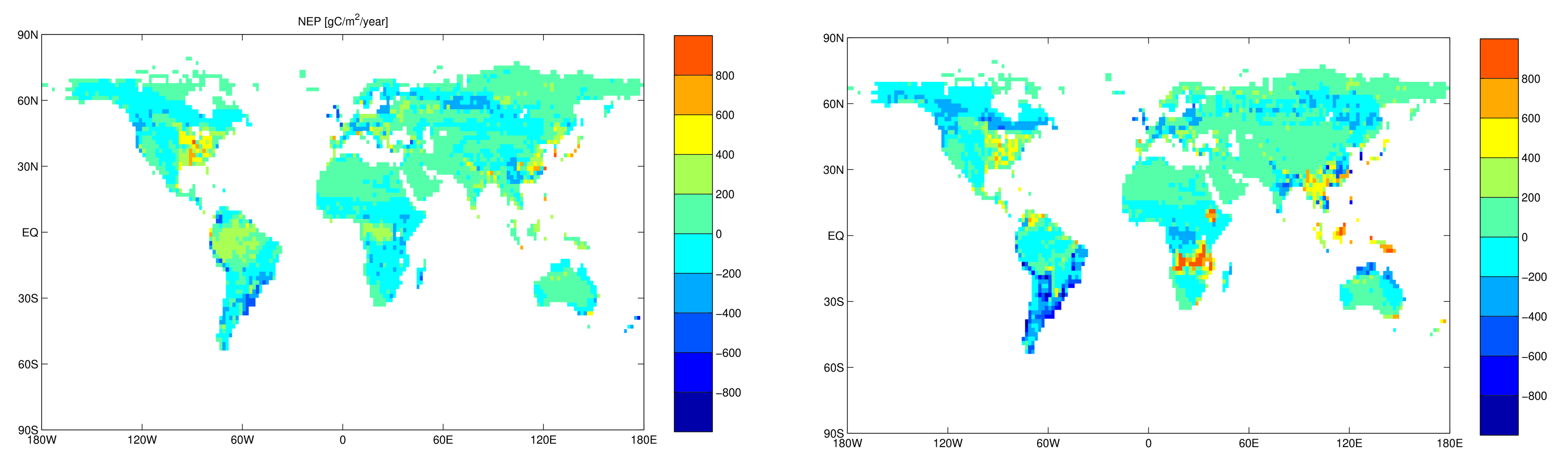


**Figure 2:** Mean annual net $CO_2$ flux to the atmosphere for the period 1979-2003 (gC/m$^2$/yr) for the base case using the standard set of 19 parameters (left) and the regionalization case using the extended set of 91 parameters (right).

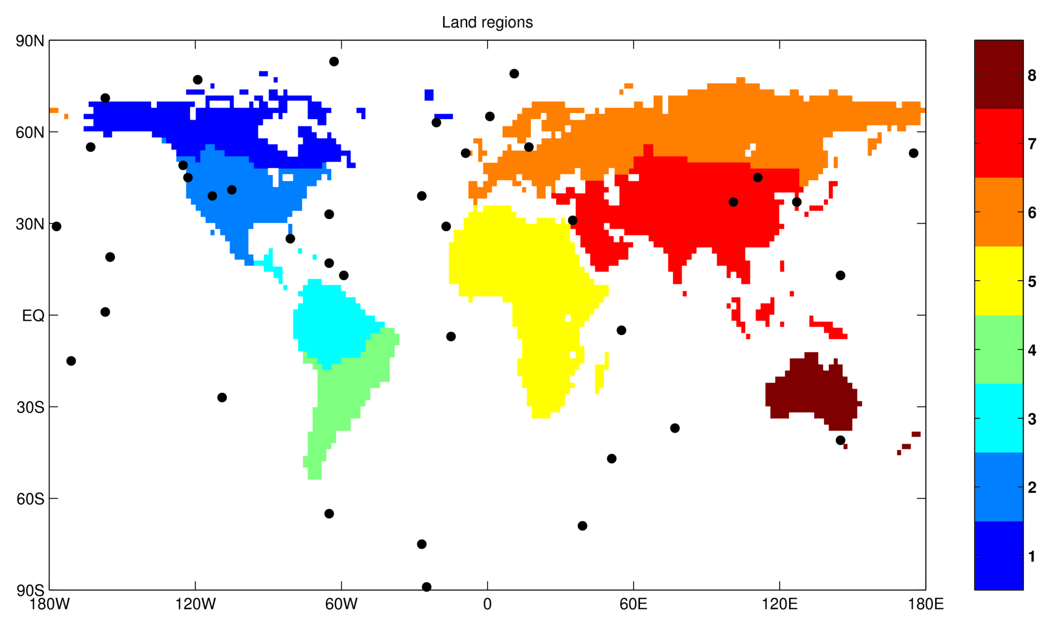


**Figure 3:** Land regions and the location of the 41 observational sites as used in CCDAS. Land region labels are given in Table 1.

## RESULTS

The regionalization leads to a smaller cost function value (c=8232) in comparison to the case where $\beta$ was only allowed to vary with PFT (c=9682), which indicates a better fit to the observations. This is not surprising since we have a larger number of parameters in case of the regionalization which increases the degree of freedom for the optimization. The flux pattern as presented in Fig. 2 shows distinct differences between the two cases, particularly in the tropics and subtropics. Disagreement in the direction of the net fluxes exist for region 5 (Africa) and region 8 (Australia) as shown in Table 1. The largest difference in the mean flux between the two cases exists for region 4 (South American temperate). A very large source is identified for the regionalization with about 2400 TgC/yr and a much smaller source with about 1000 TgC/yr for the base case.

Although the regional differentiation of the key carbon storage parameter $\beta$ led to a significantly improved fit to the observations, the analysis of the net $CO_2$ fluxes revealed widely diverged patterns between the two cases. To assure that the net carbon flux does not exceed NPP on a grid cell level, we used a log transformation to constrain the $\beta$ parameter to values smaller than two in both cases. This additional constraint is necessary, because the observational network (in particular in the tropics) is not dense enough to guarantee realistic net fluxes on a grid cell level. The results also suggest that $\beta$ is not a universal parameter and that it is sensitive to the regionalization process. In future work we will investigate other criteria for a geographical representation of $\beta$, for example by including information about the history of a site.

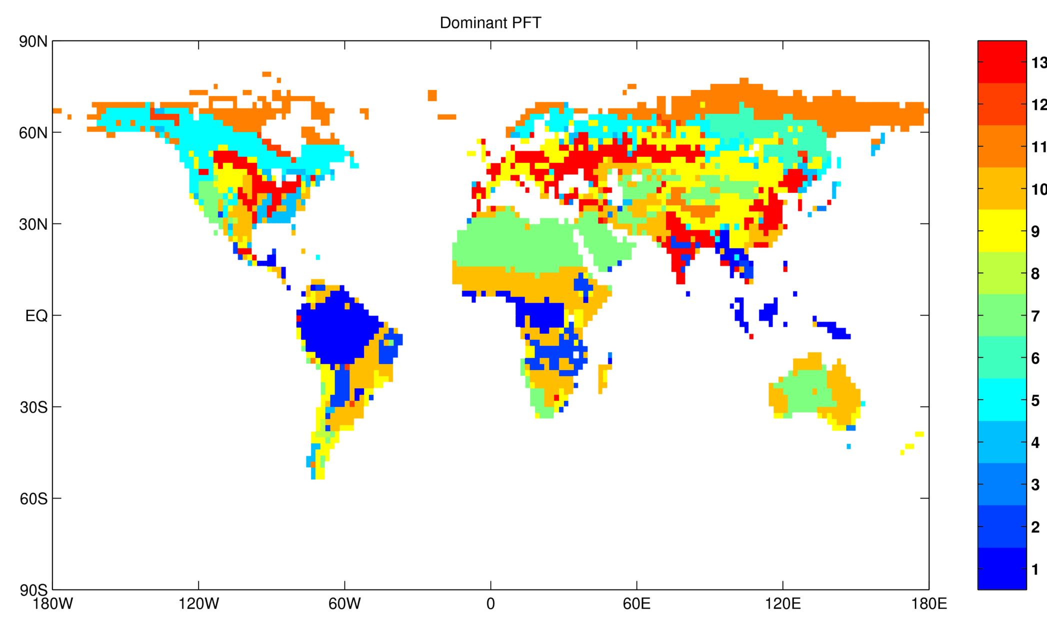


**Figure 4:** Distribution of the dominant PFT per grid cell. PFT labels are given in Table 1.


[1] Rayner, P.J., M. Scholze, W. Knorr, T. Kaminski, R. Gieing and H. Widmann (2005). Two decades of terrestrial carbon fluxes from a carbon cycle data assimilation system (CCDAS). *Global Biogeochem. Cycles*, 19, GB2026.

[2] 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.

[3] Knorr, W. (2000), Annual and interannual $CO_2$ exchanges of the terrestrial biosphere: Process-based simulations and uncertainties, *Global Ecol. Biogeogr.*, 9, 225-252.

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



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