LOCAL-SCALE CARBON CYCLE DATA ASSIMILATION USING SATELLITE-DERIVED FAPAR WITH A GENERIC PHENOLOGY MODEL

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ABSTRACT

We present a new approach for linking FAPAR and vegetation-to-atmosphere carbon fluxes through variational data assimilation. The scheme extends the Carbon Cycle Data Assimilation System (CCDAS) by a newly developed, globally applicable and generic leaf phenology model, which includes both temperature and water-driven leaf development. A parameter optimization is carried out simultaneously for six sites against 20 months of daily FAPAR from the Medium Resolution Imaging Spectrometer (MERIS). Assimilation of FAPAR leads to reduced uncertainty margins of 12 of the 38 control parameters, including 3 parameters related to photosynthesis. The approach can easily be extended to regional or global studies and to the assimilation of further remotely sensed data sources.

INTRODUCTION

FAPAR products have been related to large-scale changes in land-atmosphere CO_2 fluxes via algorithms for net primary productivity (NPP) (Cao et al. 2004) or by validation with results from vegetation modelling (Knorr et al. 2007). This study reports on progress of the Carbon Cycle Data Assimilation System (CCDAS), where FAPAR data is used in the context of vegetation modelling through data assimilation. This approach allows computing prior (before assimilation) and posterior (after assimilation) process parameters and carbon fluxes with uncertainty ranges.

METHODS

Assimilating FAPAR information into the full functionality of CCDAS requires that the phenology and hydrology be integrated into the variational step (Step 2) of the previous setup (Rayner et al. 2005). However, the existing phenology scheme, as most other published models, proved to be non-differentiable with respect to the control parameters of CCDAS at certain points in parameter space. This prevents efficient optimization within the variational data assimilation framework used with CCDAS. For that reason, a new phenology scheme has been developed. It uses temperature and day length thresholds for leaf development in boreal and temperate climates with parameters that are statistically distributed at the sub-pixel scale. Apart from being more realistic, this results in “smooth” transitions if the threshold parameters a varied and thus achieves the desired differentiability.
Leaf development is described by one generic equation covering all functional types:

$$\frac{d\Lambda(t)}{dt} = \xi[\Lambda_{\max} - \Lambda(t)]f - \frac{\Lambda(t)}{\tau_L}(1-f) \qquad (1)$$

where Λ is leaf area index, t time, ξ a parameter describing how quickly leaves develop, f the fraction of plants in growth or active phase within a grid cell, and τ_L leaf longevity after senescence (to control deciduous or evergreen behaviour in cold climates). Water and other limitations on LAI are implemented via Λ_{max}. Water limitation is controlled by the potential rate of transpiration per LAI, plant available soil water and a parameter describing the expected length dry spells, τ_W.

This new phenology scheme has a total of seven parameters, which are typically specific to groups of PFTs. They are added to the existing parameters of CCDAS (Scholze et al., 2007). The data assimilation follows the method already discussed by Rayner et al. (2005), but assimilating the FAPAR product by Gobron et al. (2005) at the operational resolution 1.2~km for the period June 2002 to September 2003.

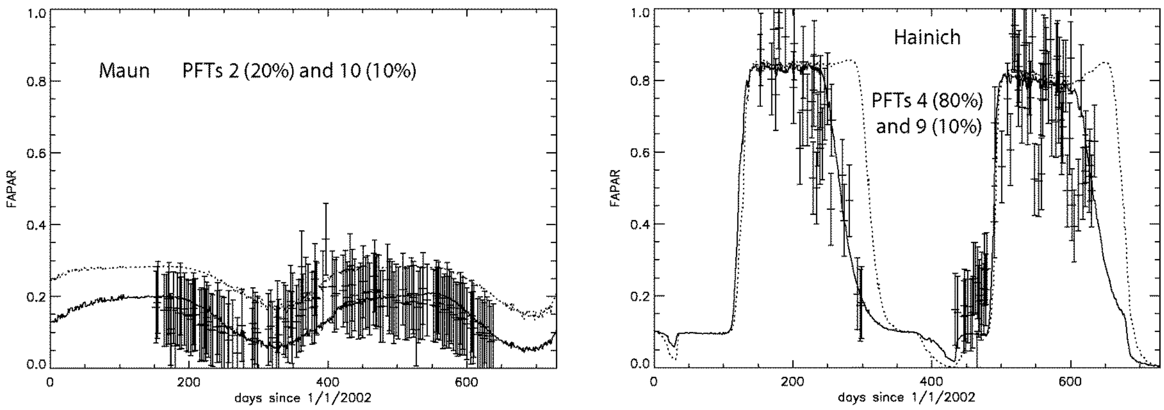

Fig. 1: satellite-derived FAPAR with uncertainties (vertical bars) and simulated FAPAR for two sites. Prior simulations are dotted. For PFTs, see note under Table 1.

RESULTS AND CONCLUSIONS

The assimilation results in a marked improvement of the simulated FAPAR, as shown for two of the six sites in Fig. 1. There is a reduction of uncertainty mainly for the parameters of the phenology model, as shown in Table 1. The assimilation of 20 months of FAPAR data across six sites has lead to an improvement of more than 10% in 7 of the 36 parameters. We conclude that FAPAR data are well suited for constraining global models of vegetation phenology.

Table 1: The 14 parameters for the new phenology scheme as optimised in CCDAS. An additional 24 Parameters were optimised from the original CCDAS, with uncertainty reductions of up to 7%.

Parameter	PFTs[1]	Prior value	Posterior value	Uncert. reduction [%]
$\tilde{\Lambda}$ maximum LAI	all	5.00±0.25	4.36±0.23	6
T_φ temperature threshold	4, 5	10.00±0.50	9.34±0.27	46
T_φ "	8	6.00±0.50	8.11±0.50	0
T_φ "	9, 10	2.00±0.50	1.53±0.41	18
T_r spatial variability of T_φ	1, 2, 4, 5, 8	2.00±0.10	2.04±0.10	1
T_r "	9, 10	0.50±0.10	0.52±0.10	0
t_c day length threshold	4, 5, 8	10.50±0.50	13.73±0.43	14
t_r spatial variability of t_c	4, 5, 8	0.50±0.10	0.46±0.10	0
ξ see Equ. (1)	all	0.50±0.10	0.52±0.10	0
k_L=1/τ_L see Equ. (1)	all exc. 5	0.100±0.050	0.058±0.012	76
k_L=1/τ_L see Equ. (1)	5	$3.0\pm1.5\times10^{-3}$	$3.3\pm8.9\times10^{-4}$	40
τ_W water-limited leaf longevity	1	360±180	1114±192	61
τ_W "	2	50±25	112±19	62
τ_W "	9, 10	50±25	28±12	9

[1]1: tropical evergreen trees, 2: tropical drought-deciduous trees; 4: temperate cold-deciduous trees; 5: evergreen conifers; 8: deciduous understorey shrub; 9: C3 grass; 10: C4 grass. The PFTs exist at the following sites: Sodankylä (5, 4), Zotino (5, 4), Loobos (5, 8, 9), Hainich (4, 9), Manaus (1, 10) and Maun, Botswana (2, 10).

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