Modelling of the Carbon Cycle in the Geoland Project

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1. Overview of geoland/ONC

Geoland is an integrated project on land-cover and vegetation, co-funded by the European Commission within the GMES initiative in FP-6.

The geoland services addressing Natural Carbon Fluxes (geoland/ONC) establish a pre-operational global accounting system, dealing with the impact that weather and climate variability have on soil and vegetation carbon fluxes and stocks.

Due to anthropogenic emissions, the atmospheric CO_2 concentration has increased significantly since the 18th century. Furthermore, the average global surface temperature has increased by 0.6 degrees Celsius during the 20th century, and a further increase of 1.4 to 5.8 degrees Celsius is expected for the next century. Since the CO_2 concentration is modulated by the exchange of carbon fluxes between the terrestrial biosphere and the atmosphere, these fluxes have to be monitored in order to support the implementation of the Kyoto protocol.

Information is extracted from a portfolio of ground-based meteorological measurements and different sources of satellite data by using assimilation techniques in global land surface models.

The soil-vegetation-atmosphere CO_2 exchange depends on many biophysical factors. In particular, the leaf area index, the above-ground biomass, the soil carbon storage, the soil water content and the surface water flux. All these quantities will be produced at the same time by the same physically-based model. Constraining the vegetation biomass and the soil water content by using remote sensing products, permit a consolidation of the estimation of the CO_2 flux.

Geoland/ONC is supported by 3 research partners (KNMI, LSCE, ALTERRA) and 2 service providers (ECMWF, Météo-France). A number of national and international organisations and programs are involved in the development and evaluation of the geoland natural carbon fluxes services. The monitoring system will be operated by ECMWF. Geoland/ONC will produce elaborate products by using process models. It is foreseen that the research and development activities will focus on the synergy between water and carbon products in order to contribute to the implementation of a European Core Service dedicated to the global and continental monitoring of land surface processes.

2. Models used in geoland/ONC

Soil-vegetation-atmosphere transfer (SVAT) schemes are designed to simulate exchanges of energy, matter and momentum between the land surface and the atmosphere. From simple bulk parameterizations in the 1970's, they have evolved into sophisticated land surface models (LSMs), including numerous geophysical and biogeochemical processes [*Sellers et al.*, 1996]. The new generation LSMs include interactive vegetation and allow simulating the exchanges of carbon at the canopy level and the vegetation growth (e.g. *Krinner et al.* [2005]; *Calvet et al.* [1998]; *Cox et al.* [1998]; *Dickinson et al.* [1998]; *Foley et al*. [1996], *Kucharick et al*. [2000]; *Sellers et al.* [1996]; see also a review by *Arora* [2002] of the processes of the vegetation dynamics and of the different types of model in which they are implemented.

Two main vegetation properties pilot the exchanges between vegetation and the atmosphere in LSMs: the leaf stomatal conductance (g_s) and the Leaf Area Index (LAI). Both g_s and LAI depend on environmental factors, principally climate and atmospheric CO_2 concentration.

2.1. ISBA-A-gs / C-TESSEL (Météo-France / ECMWF)

The idea is to start from existing operational SVAT schemes used in meteorology and increase the number of processes they can simulate while following the constrains of operational SVAT modelling: a small number of parameters, high computer time efficiency.

ISBA-A-gs (*Calvet et al.* [1998-2004], *Gibelin et al.* [2005]) is a new version of the operational SVAT of Météo-France, ISBA. C-TESSEL is a new version of the operational SVAT of ECMWF, TESSEL. C-TESSEL is being developed in the framework of geoland, based on ISBA-A-gs (Fig. 1).

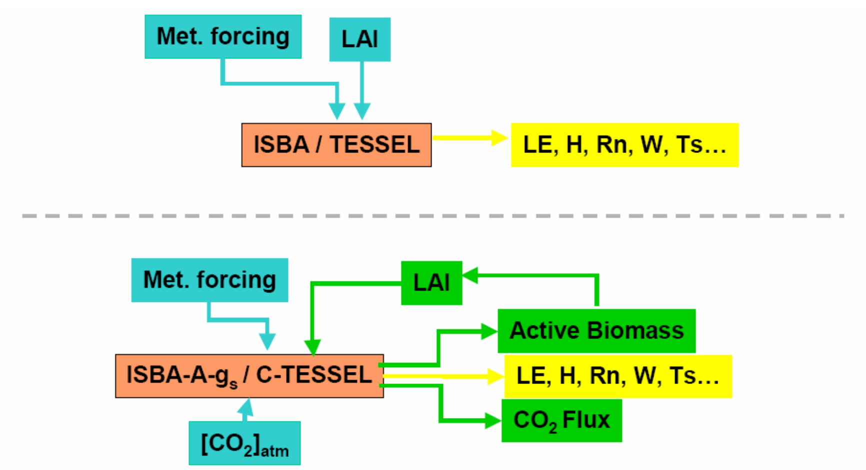


Figure 1 Enhanced models ISBA-A-gs and C-TESSEL, are able to simulate the CO2 fluxes at the soil-vegetation-atmosphere interface, and the vegetation biomass. The Leaf Area Index (LAI) is produced by the model, whereas it had to be prescribed in the original versions. All the versions are able to simulate evapotranspiration (LE), heat flux (H), net radiation (Rn), soil moisture (W), and surface temperature (Ts).

The net ecosystem exchange of CO_2 is the balance between photosynthesis and the ecosystem respiration. The photosynthesis is calculated explicitly by using a biochemical (*Jacobs et al.* [1996]) model and a SVAT approach (time step of a few minutes). Other global models use a biochemical approach: SiB2 (*Sellers et al.* [1996]), IBIS (*Foley et al.* [1996]), BATS (*Dickinson et al.* [1998]), MOSES (*Cox et al.* [1998-2001]), BETHY (*Knorr* [2000]), ORCHIDEE (*Krinner et al.* [2005])…

A specificity of ISBA-A-gs/C-TESSEL is the ability to distinguish 2 different plant responses to drought. In the drought-avoiding strategy, the plant tends to improve the water use efficiency (WUE, i.e. the ratio of photosynthesis to water loss in transpiration) in response to a moderate stress. In the drought-tolerant strategy, WUE varies little or even decreases in response to stress.

In the current version of the two models, the ecosystem respiration (*Gifford* [2003]) is calculated by using a simple Q_{10} function depending on soil temperature. Autotrophic respiration is calculated for the above-ground biomass only and heterotrophic respiration is not explicitly calculated. The allocation of carbon concerns the above-ground biomass, only. The active biomass (= leaves) is a reservoir fed by the net CO_2 uptake by leaves (i.e. An = Photosynthesis – Leaf respiration). It looses carbon following an exponential law whose e-folding time depends on the daily maximum An (*parameter = max leaf span time*). The structural biomass (non-woody) is derived from the active biomass. During the growing period, a logarithmic nitrogen dilution equation is used. During the senescence, respiration losses and an exponential decline reduce the above-ground biomass to a minimum value.

The LAI is linearly related to the active biomass (*parameters = leaf nitrogen concentration and 2 plasticity parameters*). A minimum value of LAI is prescribed (e.g. 0.3 for annual vegetation), permitting a self restart of the vegetation when photosynthesis becomes active. Leaf onset and offset dates do not have to be prescribed (permitting to simulate the interannual variability and climate change effects) and empirical degree-day sums are not used (all the factors are accounted for, not only temperature). For agricultural applications, the possibility exists to cut the vegetation or to maintain LAI at its minimum value (before a given sowing date).

Other models use a similar approach: AVIM (*Ji* [1995], *Dan et al.* [2005]), STEP (*Mougin et al.* [1995], *Lo Seen et al.* [1995]).

Only eight parameters need to be prescribed for each class of vegetation type (Fig. 2).

	Photosynthesis			Allocation/Phenology				
Vegetation type	g_m (mm s^{-1})	g_c (mm s^{-1})	θ_c	τ_m (d)	LAI_{min} (m^{2}m^{-2})	e (m^{2}kg^{-1} %$^{-1}$)	f (m^{2}kg^{-1})	N_L (%)
C3 Crops	1	0.25	0.3	150	0.3	3.79	9.84	1.3
C4 crops	9	0.15	0.3	150	0.3	7.68	-4.33	1.9
C3 grasslands	1	0.25	0.3	150	0.3	5.56	6.73	1.3
C4 grasslands	6	0.15	0.3	150	0.3	7.68	-4.33	1.3
Coniferous forests	2	0	0.3	365	1	4.85	-0.24	2.8
Evergreen forests	2	0.15	0.3	365	1	4.83	2.53	2.5
Deciduous forests	3	0.15	0.3	230	0.3	4.83	2.53	2

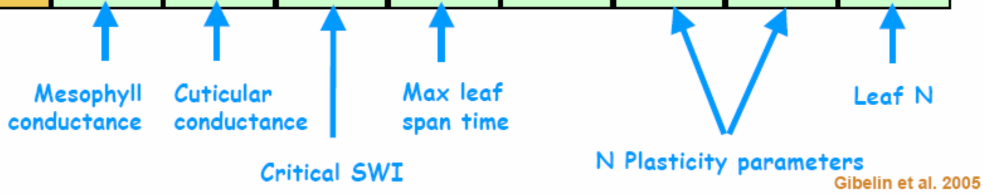


Figure 2 The 8 parameters of ISBA-A-gs and C-TESSEL for 7 global vegetation classes.

2.2. ORCHIDEE (LSCE)

The ORCHIDEE model (*Krinner et al*. [2005]) of LSCE, is a new dynamic global vegetation model designed as an extension of an existing SVAT scheme which is included in a coupled ocean-atmosphere general circulation model:

The new dynamic global vegetation model simulates the principal processes of the continental biosphere influencing the global carbon cycle (photosynthesis, autotrophic and heterotrophic respiration of plants and in soils, fire, etc.) as well as latent, sensible, and kinetic energy exchanges at the surface of soils and plants.

The formulation of stomatal conductance follows *Ball et al*. [1987]. C3 and C4 photosynthesis is calculated following *Farquhar et al*. [1980] and *Collatz et al*. [1991, 1992], respectively. Vertical variations in photosynthetic capacity are conditioned by leaf nitrogen content.

The whole seasonal phenological cycle is prognostically calculated without any prescribed dates or use of satellite data. As ORCHIDEE is designed to be included in an atmospheric general circulation model, leaf onset and leaf senescence have to be treated in a completely prognostic way. For every dormant deciduous PFT, the model has to decide regularly (at least once per week or so) whether leaf onset has to occur. This is done by applying warmth and/or moisture stress criteria to the meteorological conditions of the last days or weeks.

Carbon allocation is treated following *Friedlingstein et al*. [1998]. The basic hypothesis is that the plant will allocate carbon to its different tissues essentially in response to external limitations: water, light, and nitrogen availability.

The autotrophic respiration is calculated for both above- and below-ground biomass and heterotrophic respiration is calculated explicitly.

Carbon dynamics is described through eight biomass pools: leaves, roots, sapwood above and below ground, heartwood above and below ground, ‘‘fruits’’ (plant parts with reproductive functions: flowers, fruits, etc.), and a plant carbohydrate reserve; four litter pools: structural and metabolic litter, above and below the surface; and three soil carbon pools: active, slow, and passive soil carbon. Turnover time for each of the soil carbon and litter pools depends on temperature, humidity, and quality.

The parameterizations of vegetation dynamics have been taken from the model LPJ [*Sitch et al.*, 2003]. As a dynamic vegetation model, it explicitly represents competitive processes such as light competition, sapling establishment, etc. It can thus be used in simulations for the study of feedbacks between transient climate and vegetation cover changes, but it can also be used with a prescribed vegetation distribution.

3. Validation

3.1. LAI

Global simulations of LAI by ISBA-A-gs were compared with satellite-derived LAI estimates (Figs. 3-4) by *Gibelin et al*. [2005].

3.2. FaPAR

The fraction of absorbed photosynthetically active radiation is a common satellite product. The ORCHIDEE model is able to simulate this quantity and Fig. 5 shows the comparison of the simulated and observed 2003 anomaly (particularly large over Europe, consistent with the 2003 heat wave).

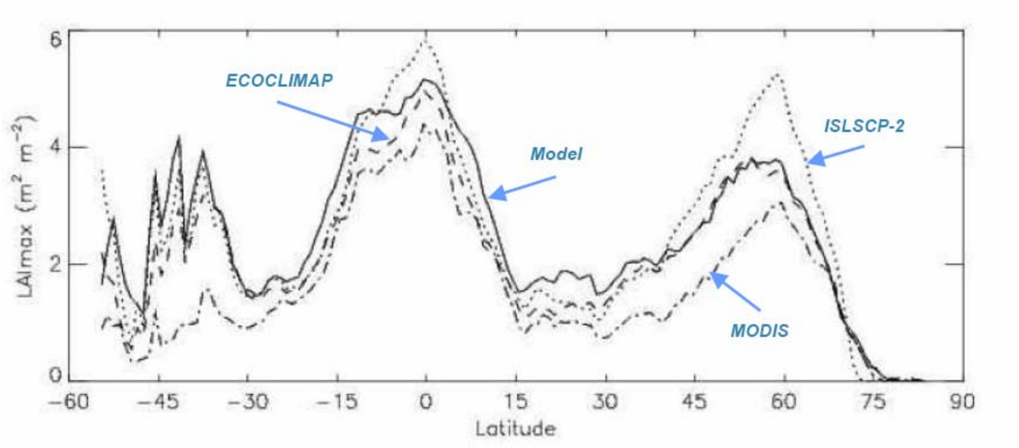


Figure 3 Zonal mean of the maximum of LAI simulated by ISBA-A-gs (mean 1986-1995), or derived from the ISLSCP-II data set (mean 1986-1995), MODIS data set (mean 2001-2004), ECOCLIMAP data set (climatology).

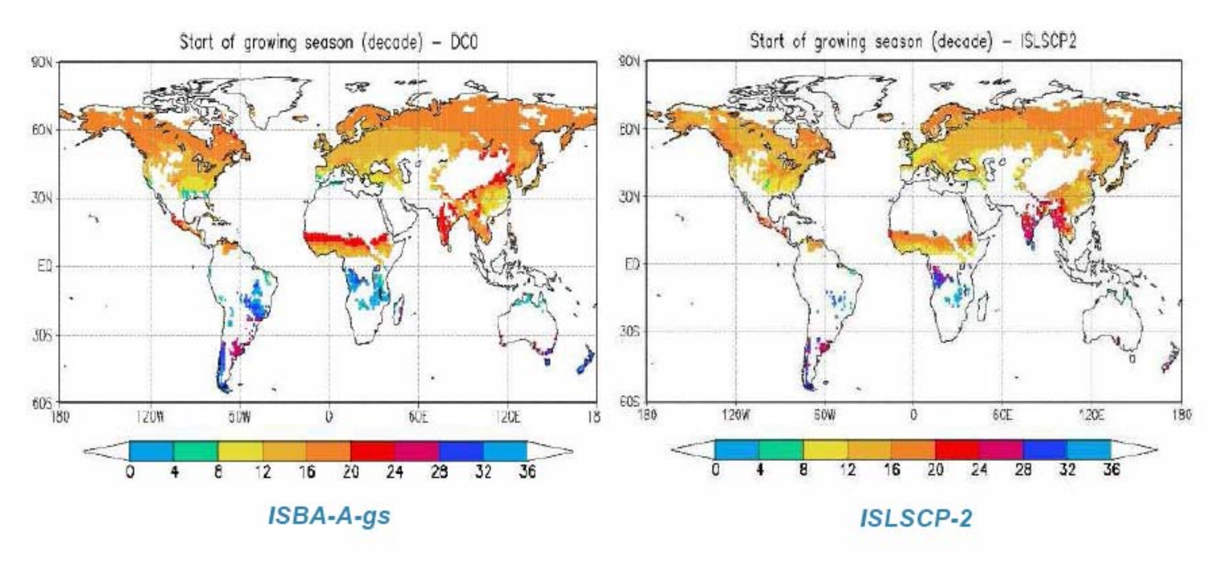


Figure 4 Start of the growing season decade (mean 1986-1995) simulated by ISBA-A-gs and observed in ISLSCP-II. This quantity is derived from monthly LAI series.

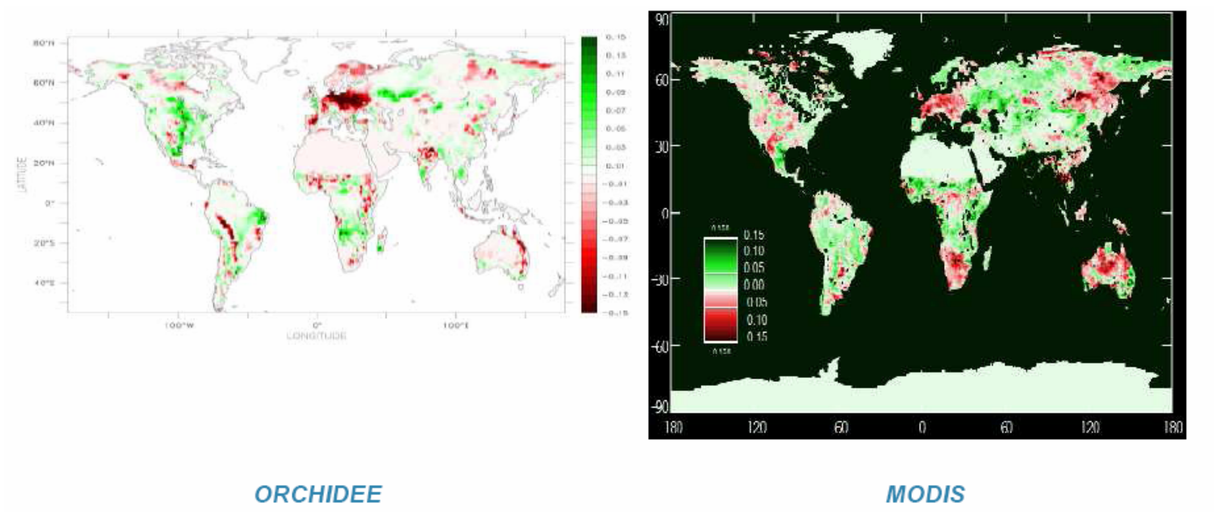


Figure 5 FaPAR anomaly in 2003: simulated by ORCHIDEE (2003-1972/2002), observed by MODIS (2003-2000/2002) – Reinstein.Ground based flux measurements

The international effort of coordination, data dissemination, and harmonization of the experimental protocol of the ground flux measurements (FLUXNET, CarboEurope) now permits to test global models over contrasting biomes. Fig. 6 shows a comparison of ORCHIDEE flux simulations (the in situ atmospheric forcing is used, the LAI is simulated by the model) with the FLUXNET observations.

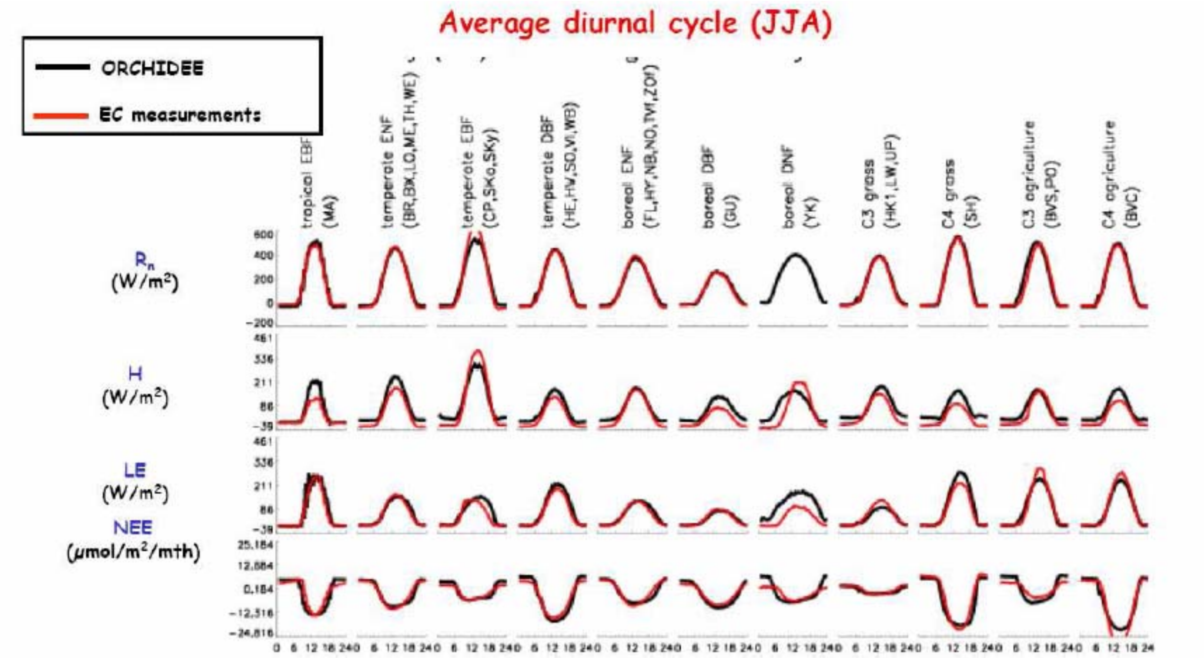


Figure 6 Validation of the ORCHIDEE fluxes by using more than 30 FLUXNET sites: Average diurnal cycle.

3.3. Crop production

In ISBA-A-gs, the fruit biomass is not explicitly calculated. However, the concept of harvest index, i.e. the proportion of above-ground biomass converted into grain by a crop, permits to provide yield estimates from ISBA-A-gs (Fig. 7).

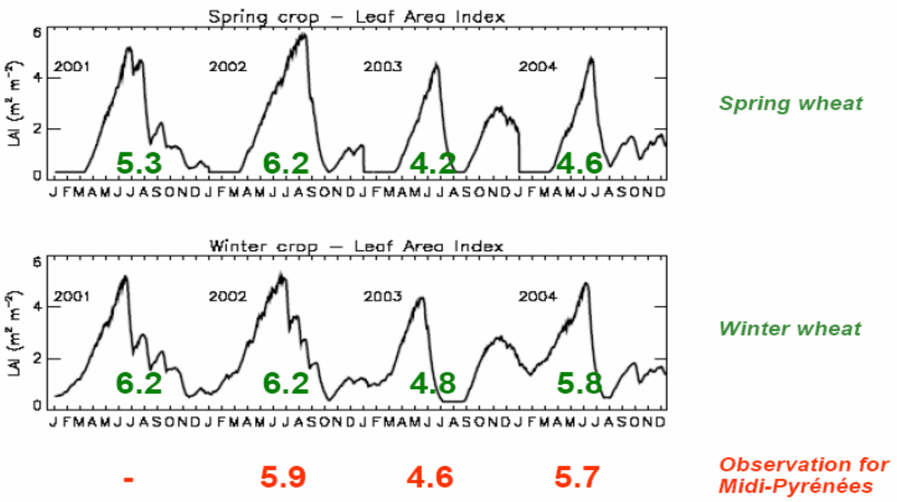
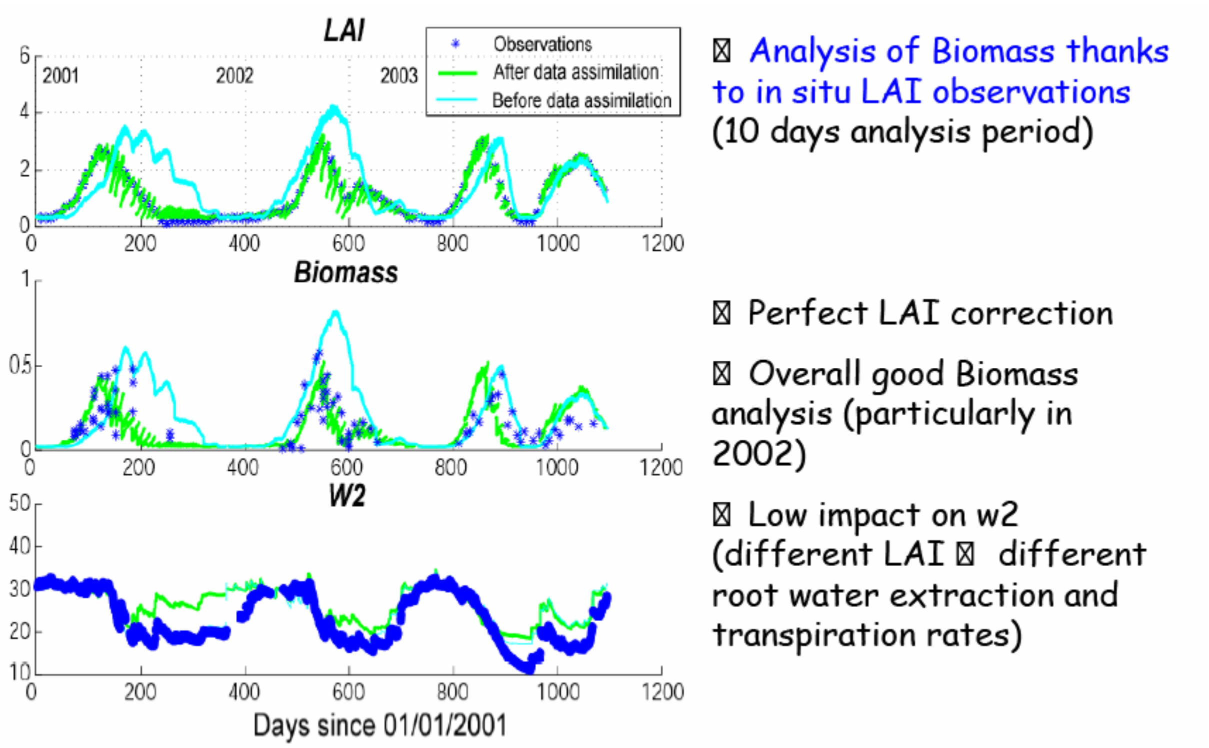


Figure 7 Wheat LAI and yield (t ha-1) estimated by ISBA-A-gs for the area of Toulouse from 2001 to 2004, by assuming a Harvest Index of 0.5

4. Data Assimilation



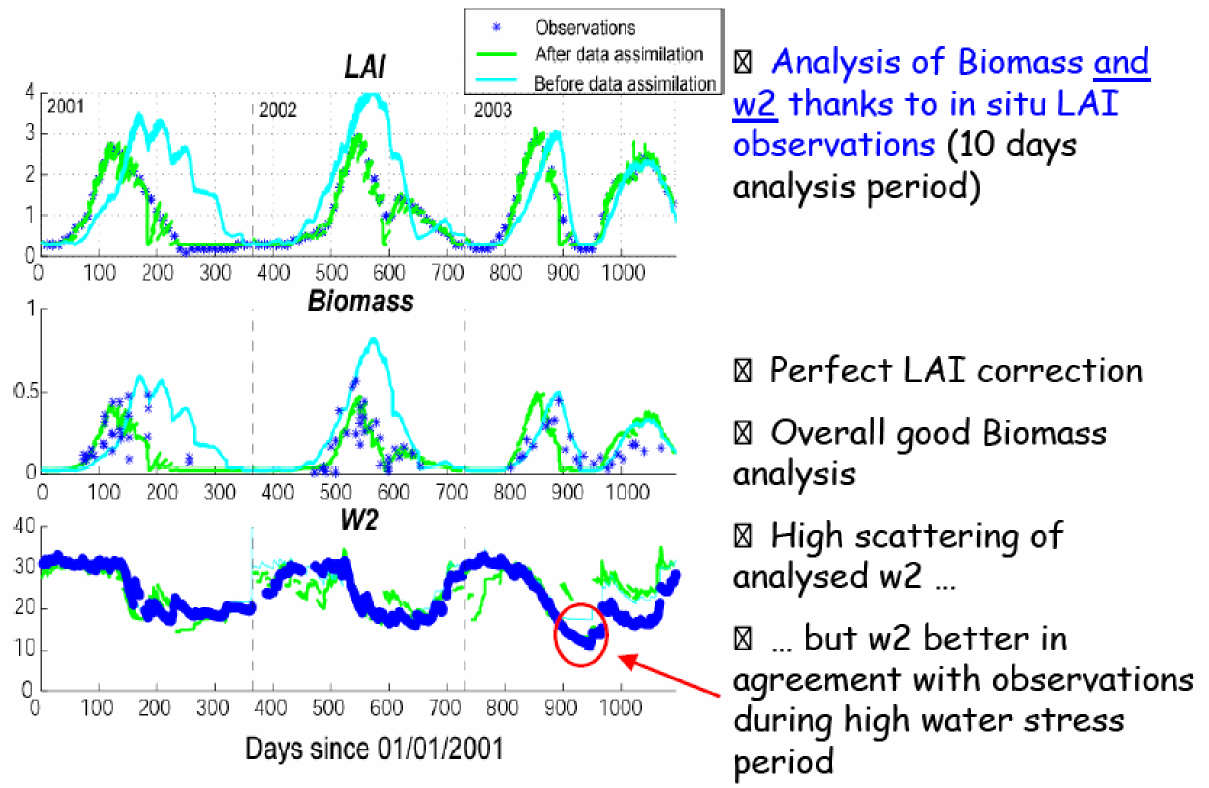


Figure 8 Application to the SMOSREX fallow of a simplified variational algorithm (adapted from Balsamo and Bouyssel): ground measurements of LAI are assimilated in ISBA-A-gs in order to analyse, the biomass, only (top), both the biomass and the soil moisture content (bottom).

Since models like ORCHIDEE, ISBA-A-gs, and C-TESSEL are able to calculate LAI, LAI estimates derived from satellite observations can be assimilated in this kind of model (Cayrol et al. [2000]) in order to analyse biomass and/or soil moisture, W. Fig. 8 shows that analysing biomass without analysing W can lead to severe drifts of W. Much better results are obtained by analysing biomass and W together. However, the analysed W is very unstable at wintertime, because LAI is little sensitive to W at wintertime. This result shows that LAI-sensitive and W-sensitive satellite data should be assimilated together in land surface models.

5. References

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