MODELLING OF THE CARBON CYCLE IN THE GEOLAND PROJECT

geoland

Co-funded by the European Commission within the GMES initiative in FP-6

Jean-Christophe Calvet – Météo-France – ECMWF Seminar – 06.09.2005

Modelling of the carbon cycle in the geoland project

Contents

- Overview of geoland/ONC

- Models used in geoland/ONC
  - ISBA-A-gs / C-TESSEL (Météo-France / ECMWF)
  - ORCHIDEE (LSCE)

- Representation of land surface patchiness

- VALIDATION:
  - LAI
  - FaPAR
  - water flux comparison with operational models
  - ground based flux measurements
  - crop production

- Data Assimilation

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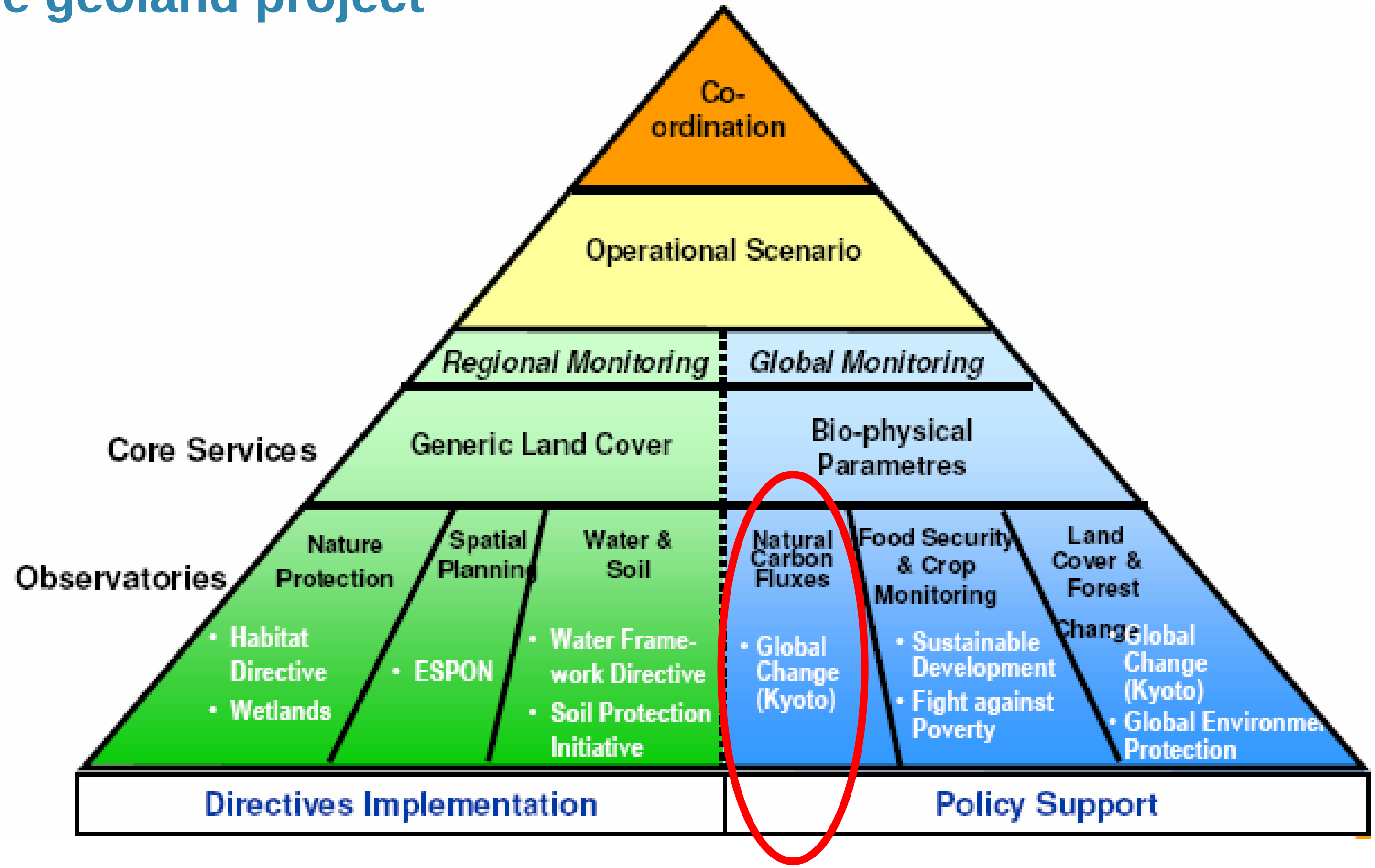
Overview

The geoland project



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The Observatory of Natural Carbon Fluxes of geoland

Partners

- Research partners: KNMI, LSCE, ALTERRA
- Service providers: ECMWF, Météo-France
- Associated user: LSCE

Objectives

- Kyoto protocol
- Transpose the tools used for weather forecast to the monitoring of vegetation and of natural carbon fluxes:

Near real-time monitoring at the global scale (ECMWF) based on

- modelling,
- in situ data,
- assimilation of satellite data.

- Scientific validation of the system

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Overview

The products

- The terrestrial biospheric CO_2 flux at the soil-vegetation-atmosphere interface
- The water flux at the soil-vegetation-atmosphere interface
- The vegetation biomass
- The leaf area index
- The root-zone soil moisture
- The carbon storage.

SPATIAL RESOLUTION: ½ degree

The anthropogenic fluxes are not accounted for here: to be treated in atmospheric analysis projects (e.g. GEMS).

The fluxes produced by geoland will be used by GEMS.

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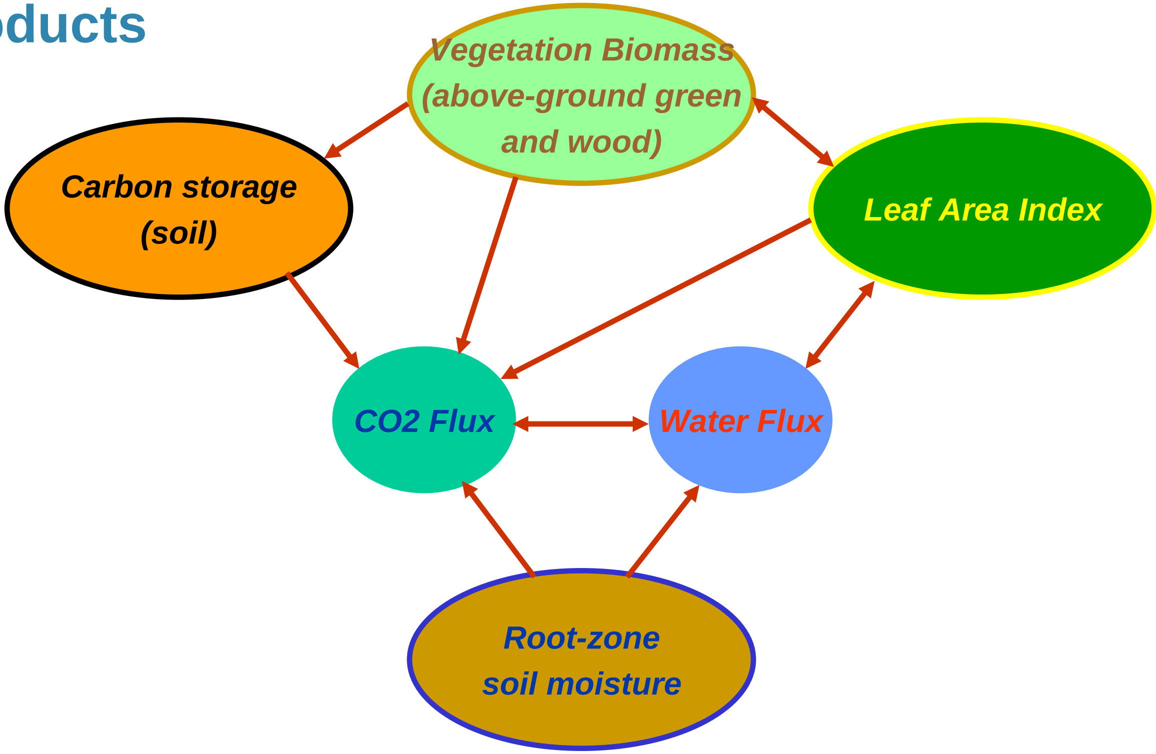
Overview

The products



STRONG PHYSICAL LINKS BETWEEN THE PRODUCTS:

All these quantities interact and need to be fully consistent, i.e. produced at the same time by a physically-based model

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Overview

Usefulness of remote sensing data

- Land use maps (e.g. ECOCLIMAP)

- Analysis of the above-ground biomass by assimilation

• Model error	➔ Bias reduction
• Atmospheric forcing	➔ Precipitation + Radiation
• Model parameters	➔ Assimilation
• Scaling issues	➔ Tiling

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Overview

Maturity

• Assimilation of Ta & qa to analyse soil moisture already operational at ECMWF and Météo-France

• Assimilation of NDVI to analyse vegetation biomass is well advanced at LSCE

• ELDAS FP5 project

• New versions of operational land surface models are able to simulate the CO_2 fluxes

•Modelling: ISBA-A-gs at Météo-France, ORCHIDEE at LSCE, both involved in the PILPS-Carbon international intercomparison exercise

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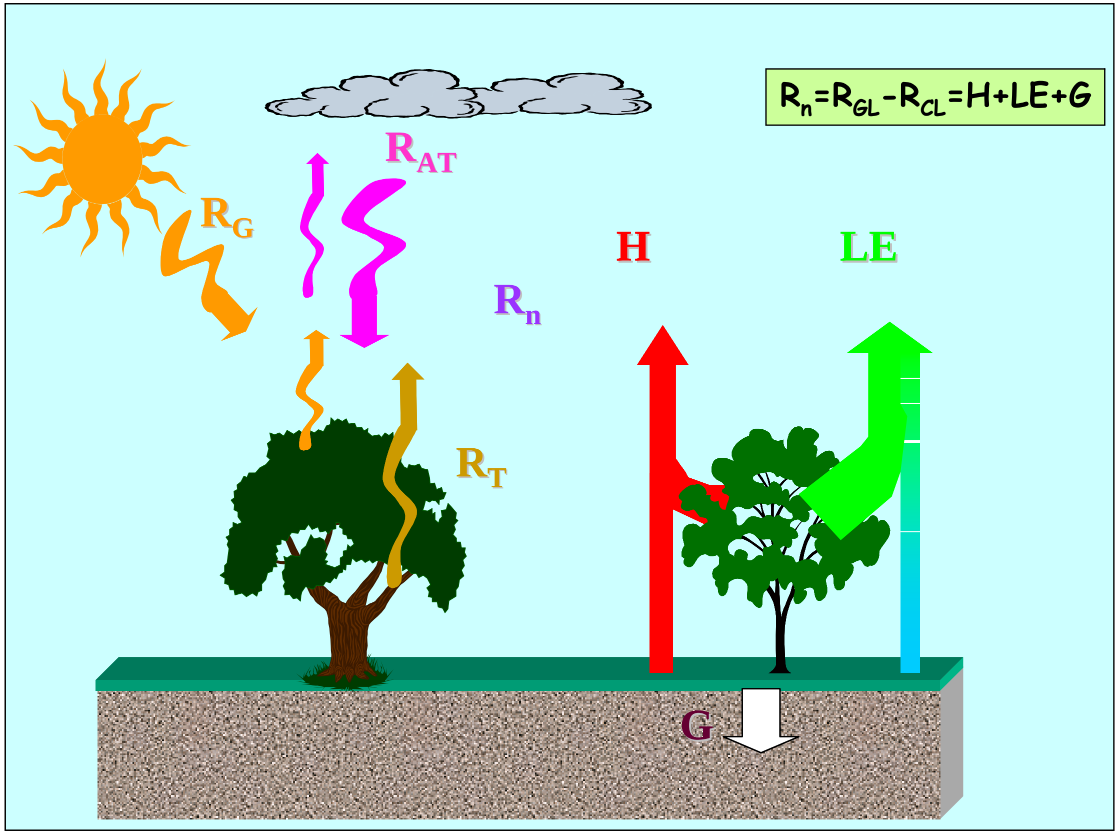
Models



Land-surface modelling: the energy budget

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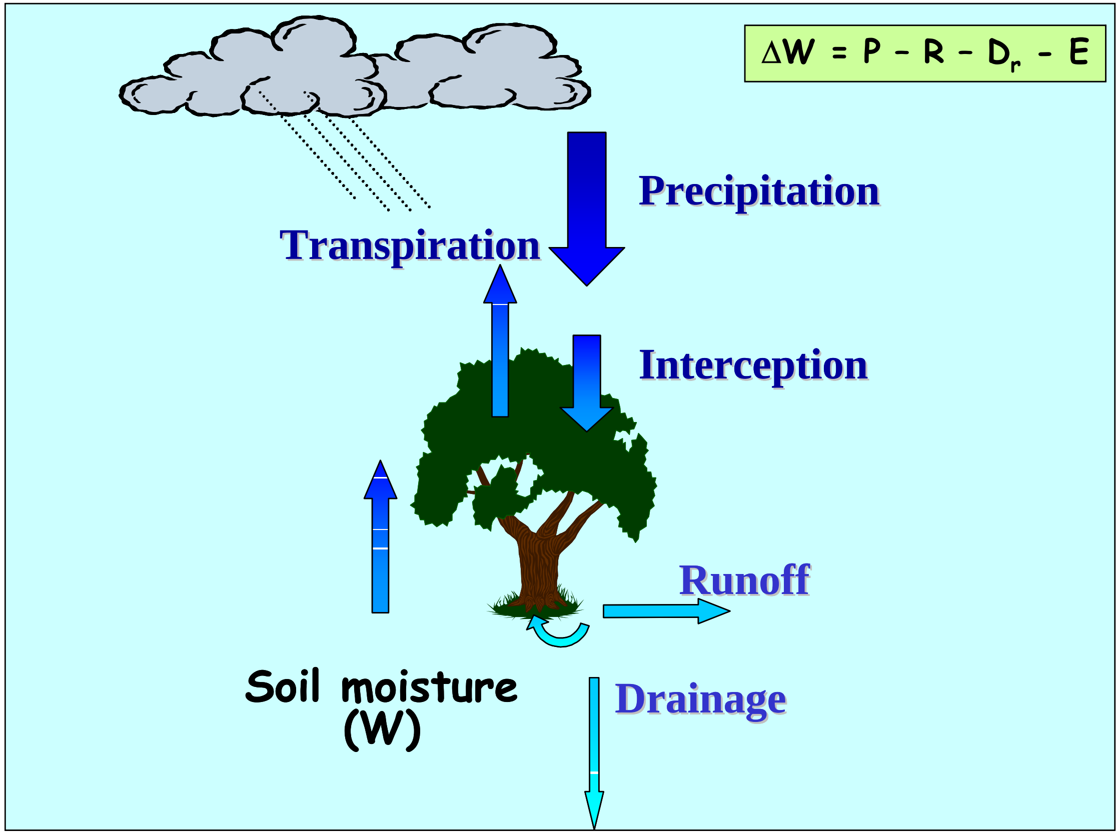
Models



Land-surface modelling: the water budget

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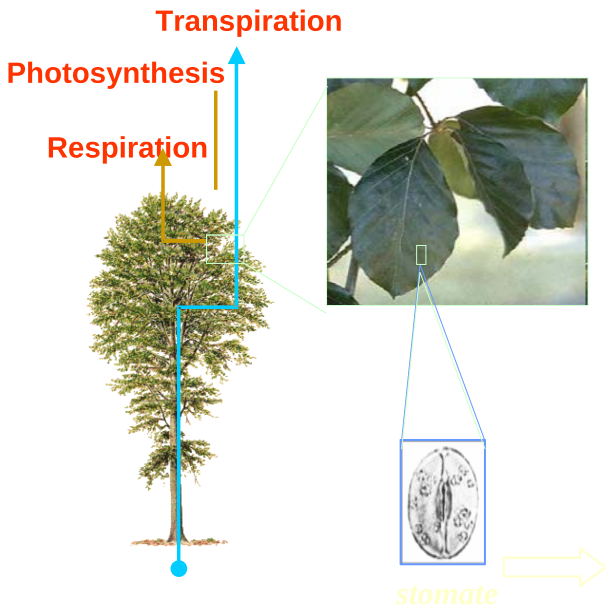
Models

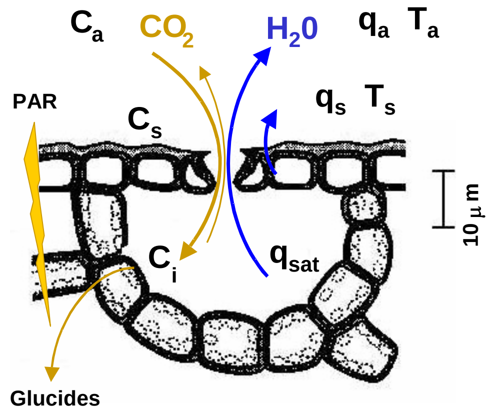


The stomatal aperture controls the ratio:

Photosynthesis/Transpiration

according to the environment conditions

Light, temperature, air humidity
soil moisture, atmospheric [CO_2]



Land-surface modelling: the role of stomatal control

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Models

ISBA-A-gs (Calvet et al. 1998-2004, Gibelin et al. 2005)

A new version of the operational SVAT of Météo-France

C-TESSEL (Voogt et al. 2005)

A new version of the operational SVAT of ECMWF,
based on ISBA-A-gs

ORCHIDEE (Krinner et al. 2005)

A research dynamic vegetation model with a high level of complexity

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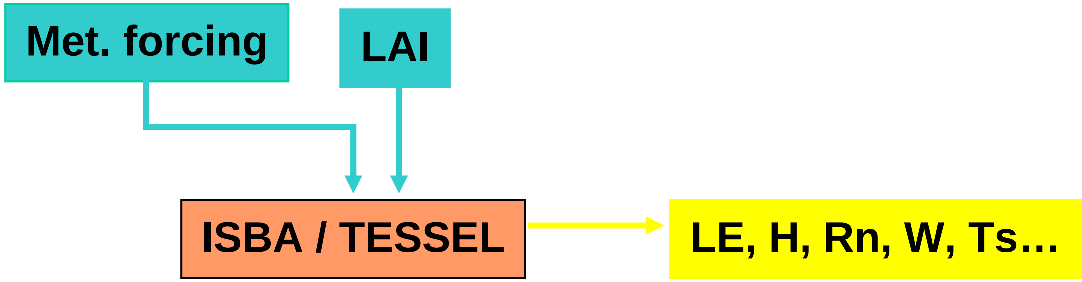
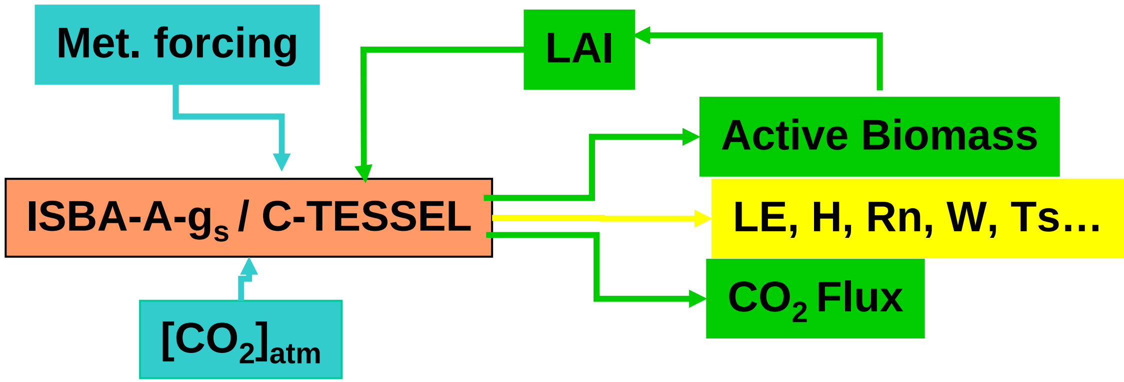
Models





ISBA-A-g_s / C-TESSEL are CO_2-responsive land surface models, new versions of operational schemes used in atmospheric models

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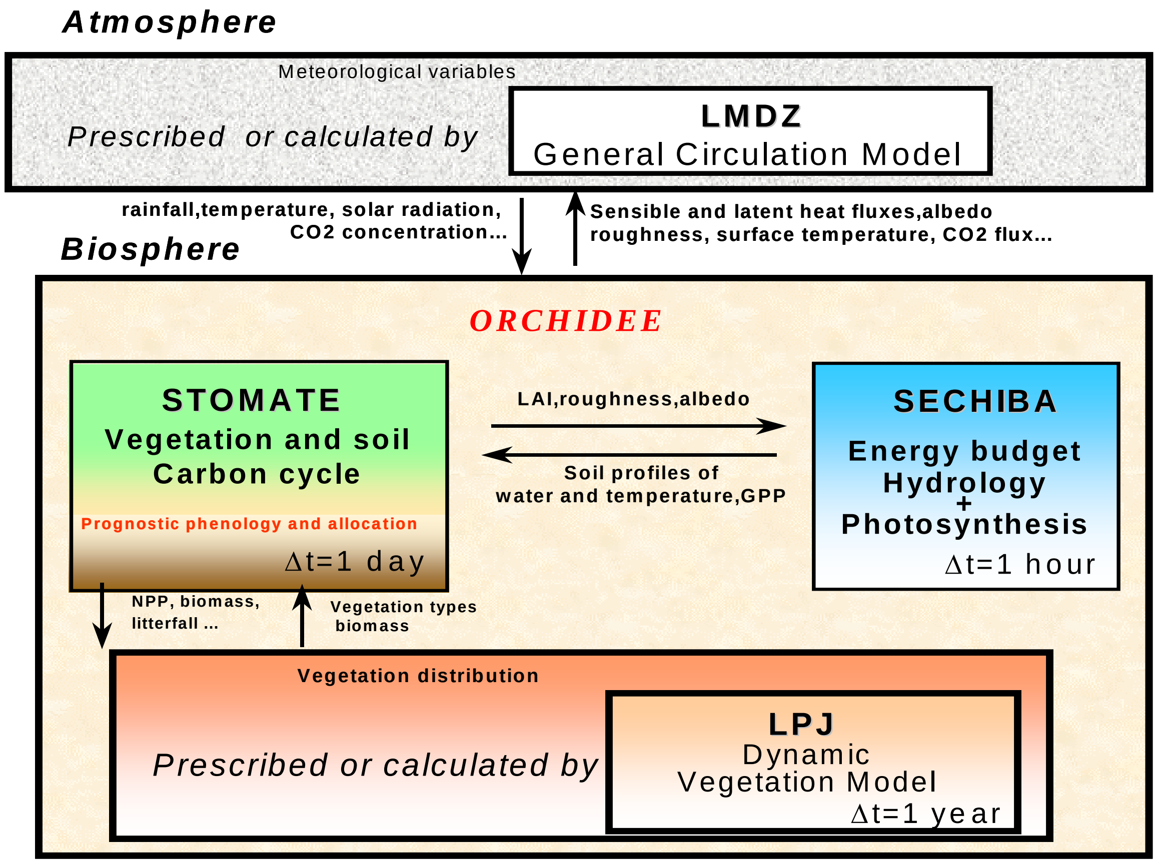
Models



ORCHIDEE is a research dynamic global vegetation model

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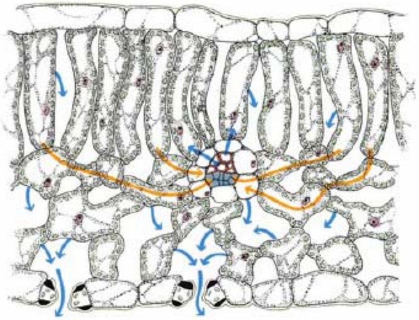
ISBA-A-gs / C-TESSEL

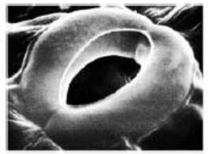
Photosynthesis

• SVAT approach (time step = minutes)



• Biochemical approach (explicit simulation of photosynthesis): *Jacobs et al. 1996*

• Big-leaf but radiative transfer within the canopy for photosynthesis and stomatal conductance



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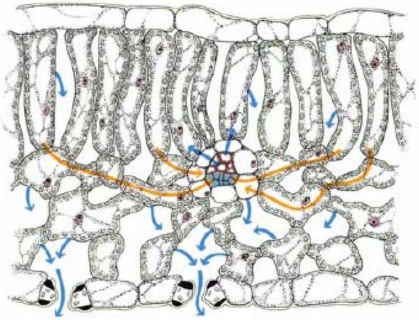
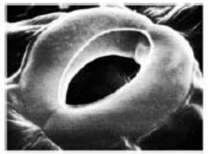
ISBA-A-gs / C-TESSEL

Photosynthesis



Other global models using
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)



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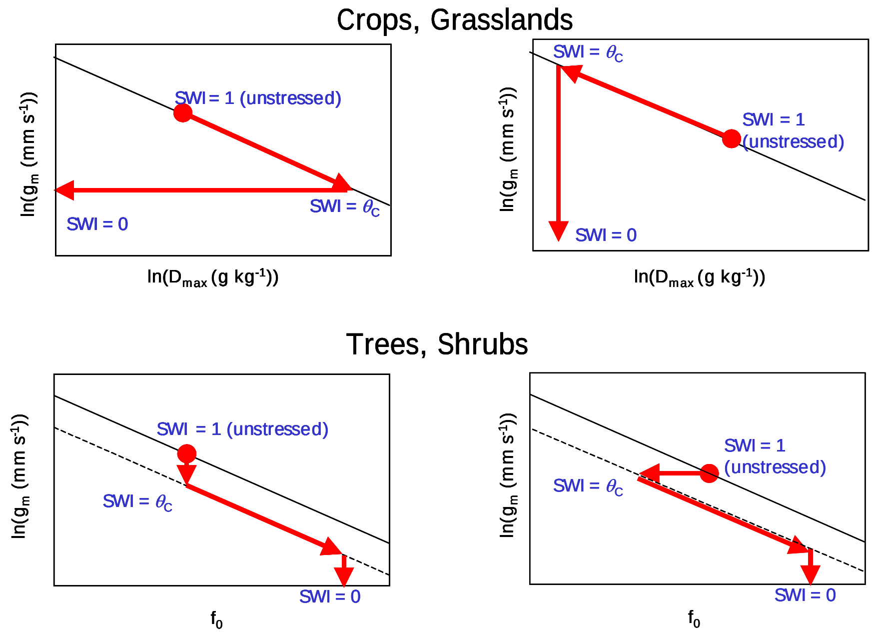
Soil water stress

• Key parameters of the photosynthesis model are affected by drought:
the well-watered value are adjusted by using the Soil Wetness Index (SWI)

• 2 possible strategies: drought-avoiding / drought-tolerant:

DROUGHT-TOLERANT DROUGHT-AVOIDING



Mesophyll conductance g_m
Max leaf-to-air saturation deficit D_{max}

Mesophyll conductance g_m
Max C_i coupling factor f_0

Calvet 2000, Calvet et al. 2004

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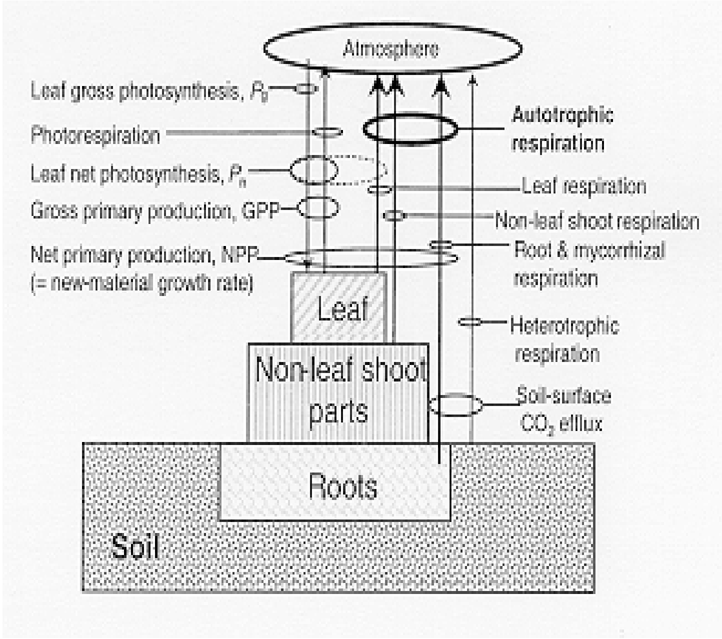
Respiration

• Ecosystem respiration is calculated by using a simple Q_{10} function depending on soil temperature

this is enough to calculate a net CO_2 flux but NPP cannot be simulated

• Autotrophic respiration is calculated for the above-ground biomass only

• Heterotrophic respiration is not explicitly calculated in the present version



Gifford 2003

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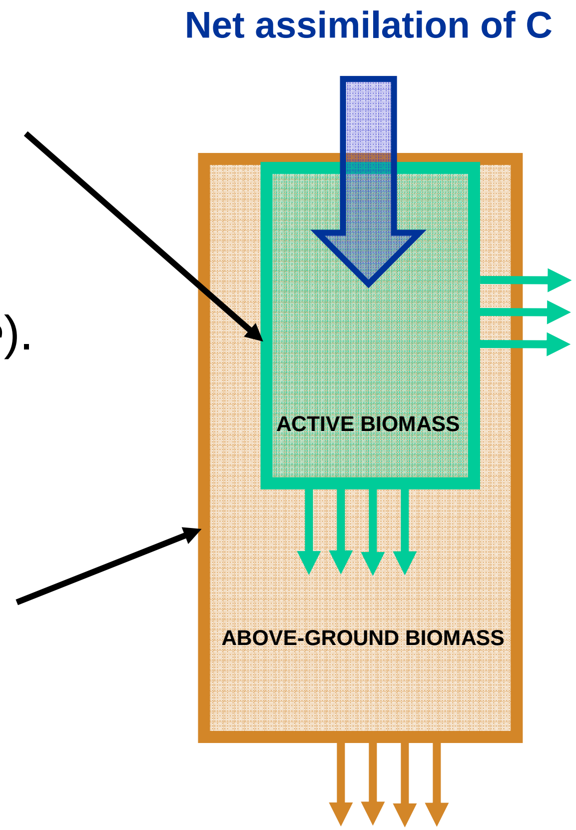
Allocation

• 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 above-ground biomass (non-woody) is derived from the active biomass:

- Growing period: a logarithmic nitrogen dilution equation is used
- Senescence: respiration losses and exponential decline



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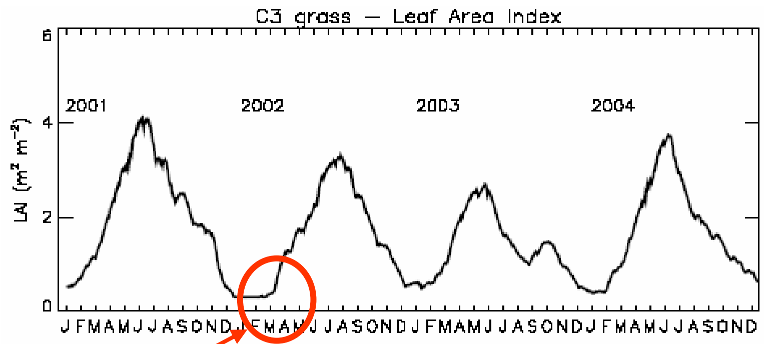
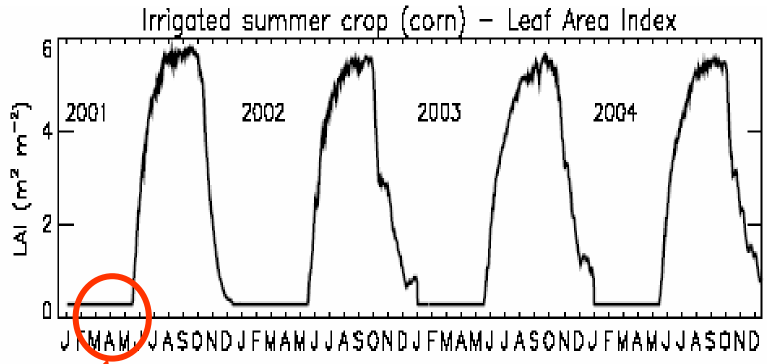
Phenology

- 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
- Possibility to cut the vegetation or to maintain LAI at its minimum value, for agricultural applications





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Phenology

Merits of this methodology

• Simple

• Leaf onset and offset dates don‘t have to be prescribed

(permitting to simulate the interannual variability and climate change effects)

• No use of empirical degree-day sums

(all the factors are accounted for, not only temperature)

Other models using this approach

AVIM (Ji 1995, Dan et al. 2005)

STEP (Mougin et al. 1995)

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Parameters at a global scale for the ECOCLIMAP vegetation types

	Photosynthesis			Allocation/Phenology				
Vegetation type	***g_m (mm s^{-1})***	***g_c (mm s^{-1})***	***θ_c***	***τ_m (d)***	***LAI_{min} (m^2m^{-2})***	***e (m^2kg^{-1} $\%^{-1}$)***	***f (m^2kg^{-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

Mesophyll conductance

Cuticular conductance

Critical SWI

Max leaf span time

N Plasticity parameters

Leaf N

Gibelin et al. 2005

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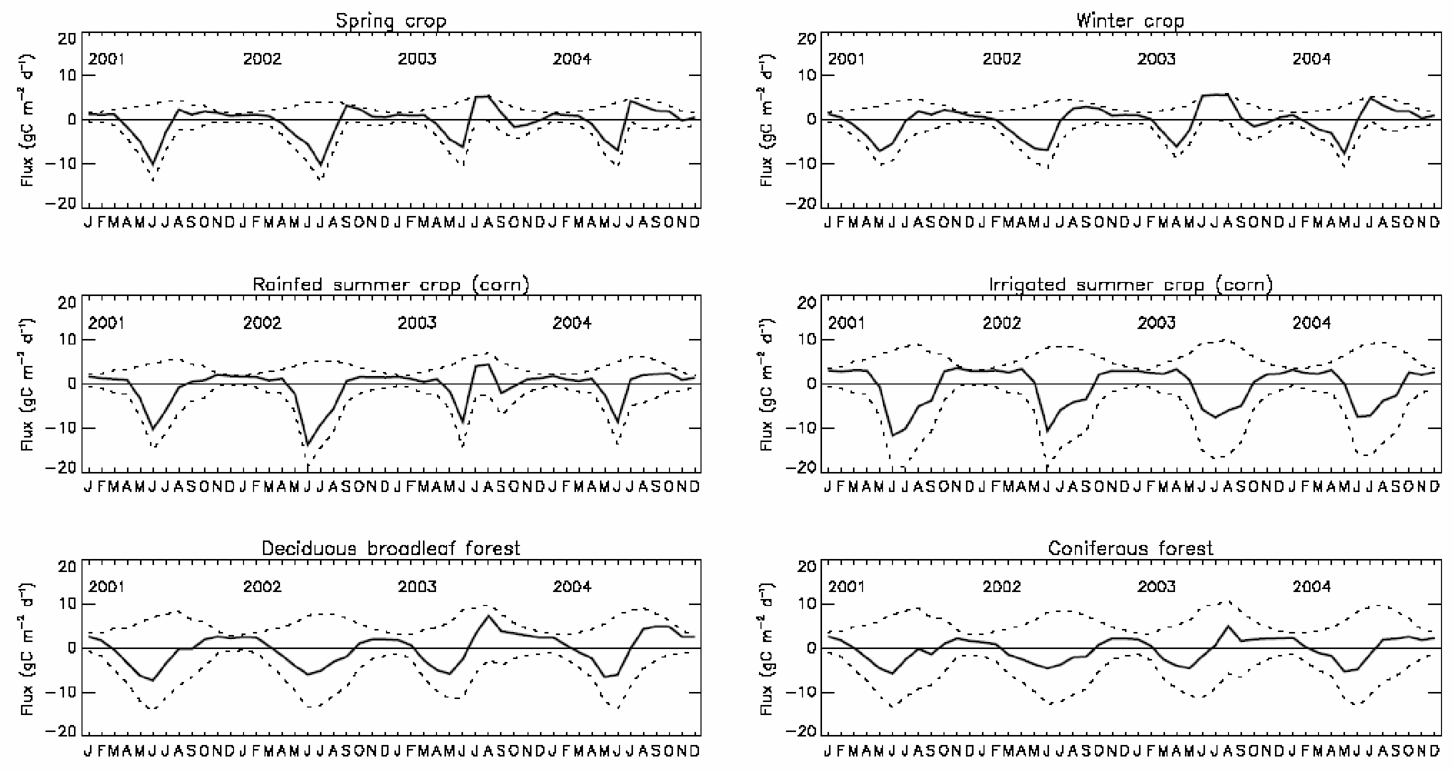

Example of Carbon flux simulations by ISBA-A-gs for Southwestern France (Toulouse)

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Photosynthesis	• Biochemical approach (Farquhar, Ball & Berry)
Autotrophic respiration	• Maintenance respiration: linear response to temperature (Ruimy et al.), and possible adaptation to climate change • Growth respiration: a fixed part of net assimilation
Heterotrophic respiration	• CENTURY-like model
Allocation	• Allocation to leaves/stems/roots function of resources: water, light, nutrients (Tilman 1998) • 8 pools of living biomass
Phenology	• Degree-day model for leaf onset, accounting for soil moisture, tuned at a global scale by using satellite data • Senescence: soil moisture and temperature are accounted for
Competition	• Grass/tree competition and competition between tree species described in LPJ
Fires	• Fire occurrence described in LPJ
Carbon storage	• Litter (above/below ground, structural/metabolic, natural/agricultural) • 3 soil organic matter pools (active, slow, passive)

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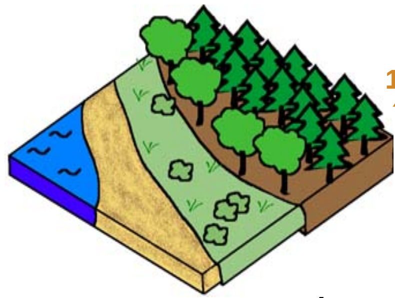
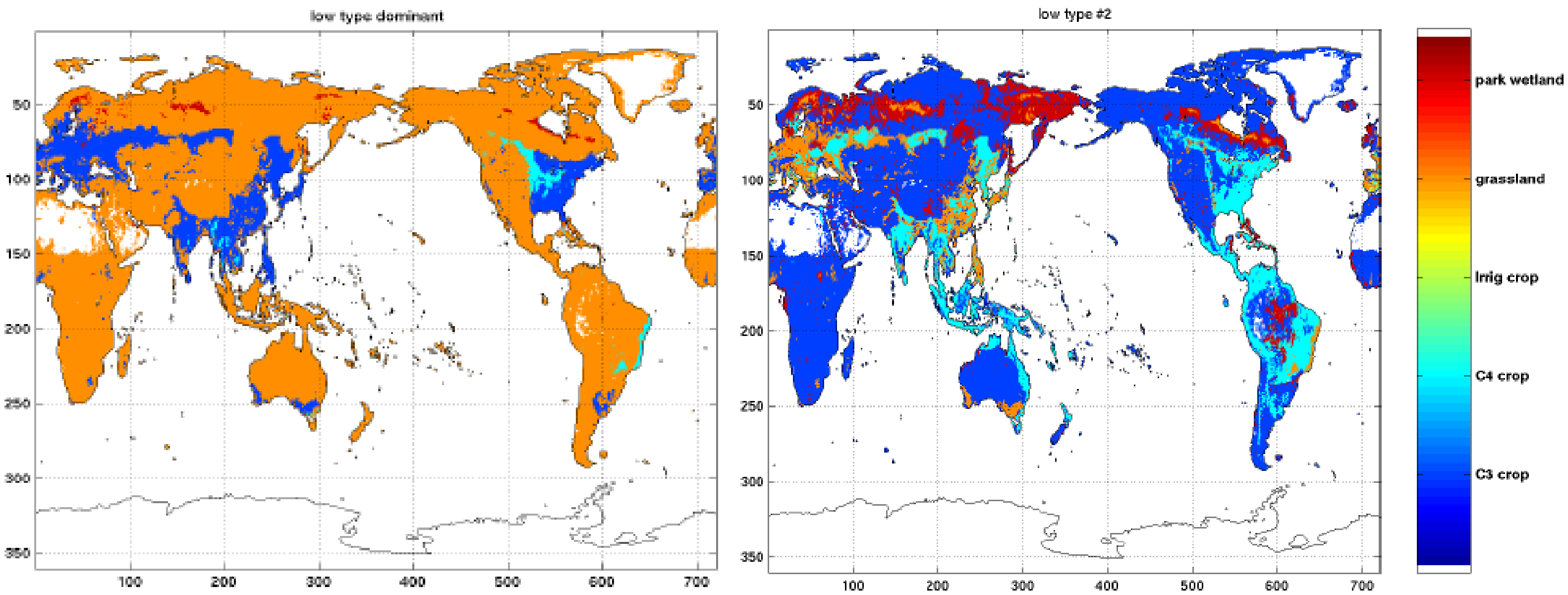
Representation of land surface patchiness

- ❑ **Usefulness of tiling**



Herbaceous classes of ECOCLIMAP:
Mainly 4 'metaclasses'

type 1 ***type 2***



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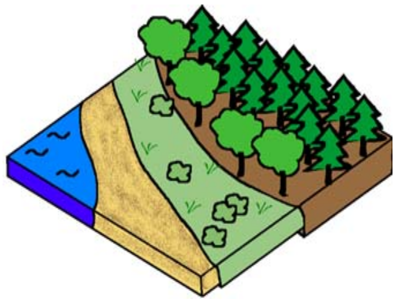
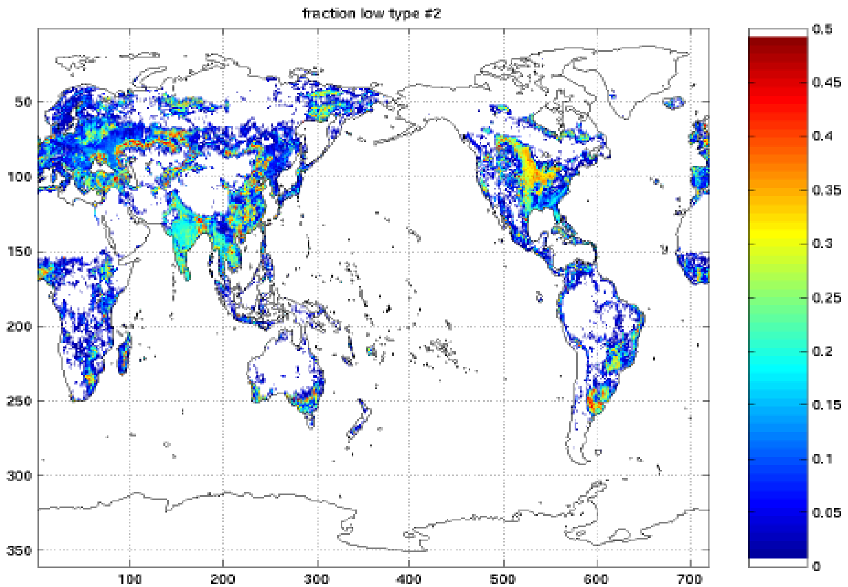
Representation of land surface patchiness

- Usefulness of tiling

Herbaceous classes of ECOCLIMAP:
Fraction of type 2 can be high





8 tiles:

- bare soil (and rock/snow)
- Deciduous forests
- Coniferous forests
- Evergreen forests
- grass C3
- grass C4
- crops C3
- crops C4

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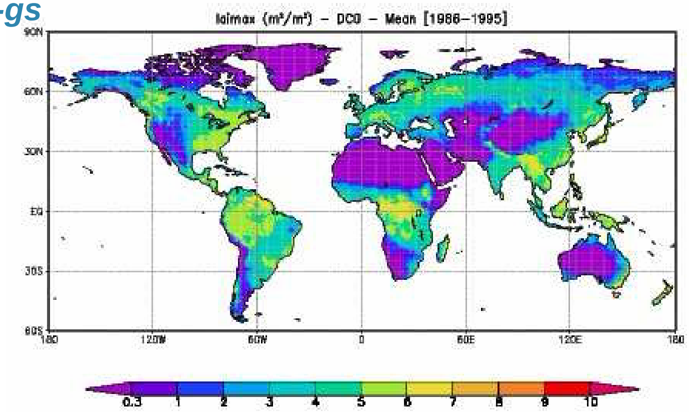
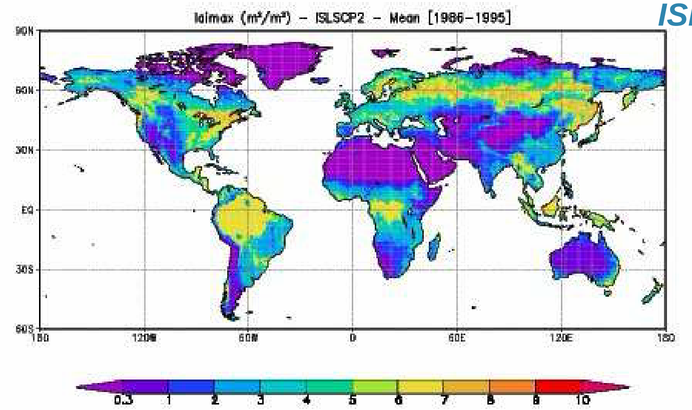
VALIDATION: LAI

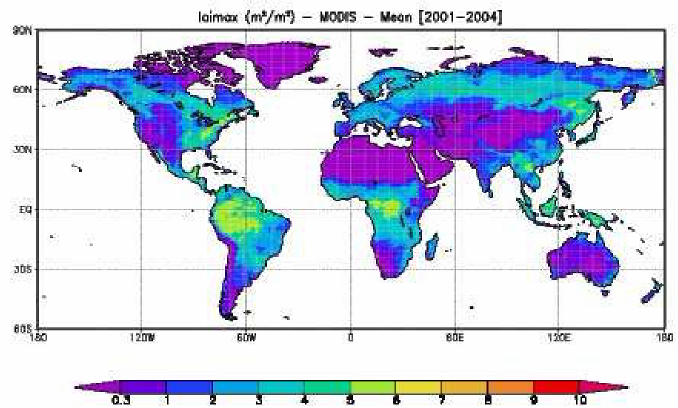
ISBA-A-gs



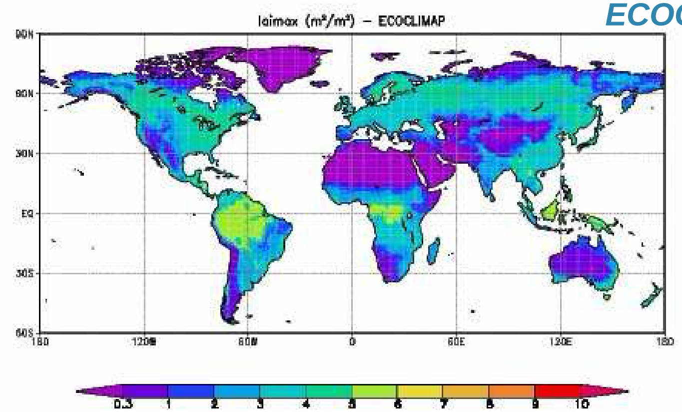
ISLSCP-2



MODIS



ECOCLIMAP



Yearly maximum of LAI

Gibelin et al. 2005

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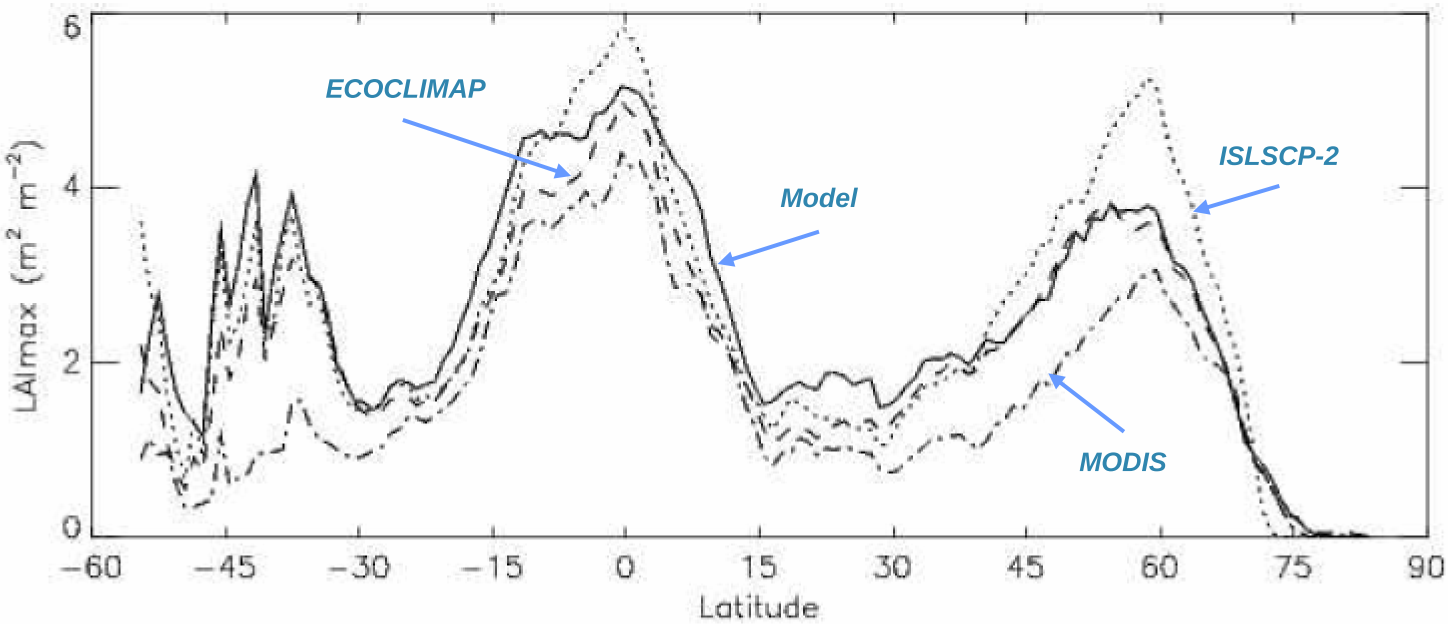
VALIDATION: LAI



Zonal mean of the maximum of LAI

simulated by ISBA-A-gs (mean 1986-1995), ISLSCP-II data set (mean 1986-1995), MODIS data set (mean 2001-2004), ECOCLIMAP data set (climatology).

Gibelin et al. 2005

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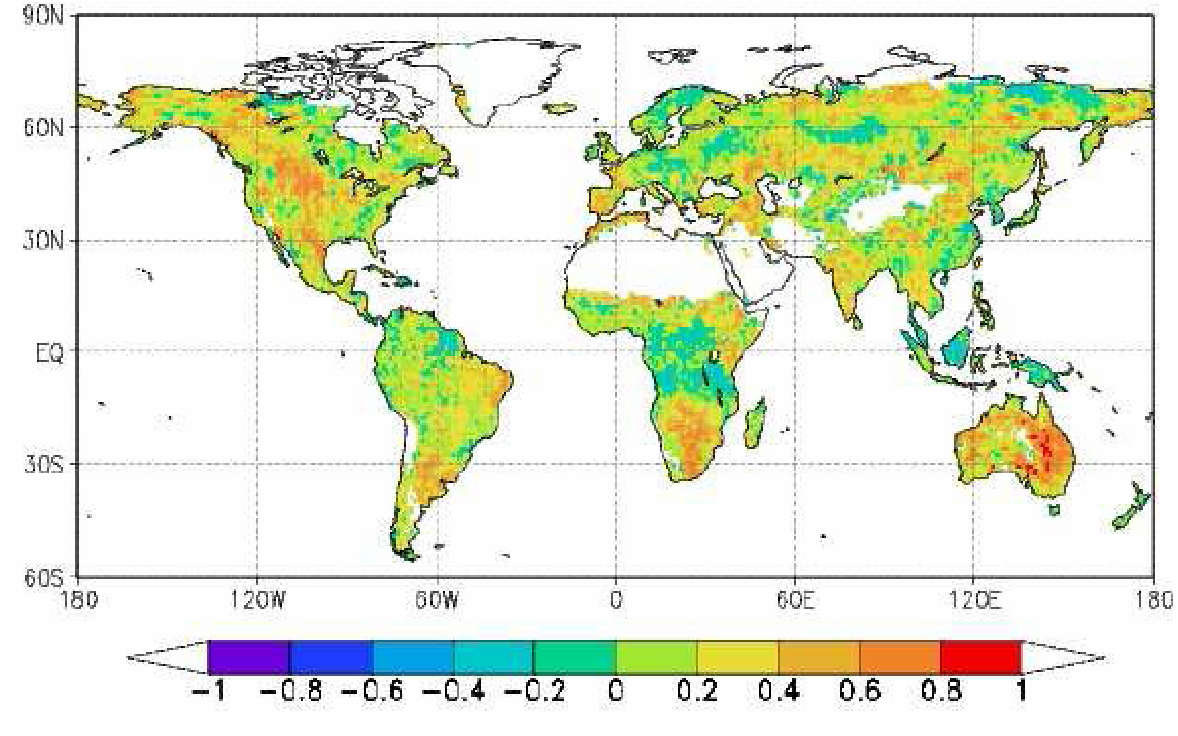
VALIDATION: LAI



Correlation of the monthly LAI anomaly (difference between monthly LAI and the mean annual cycle) between ISBA-A-gs and the ISLSCP-II data (1986-1995).

Gibelin et al. 2005

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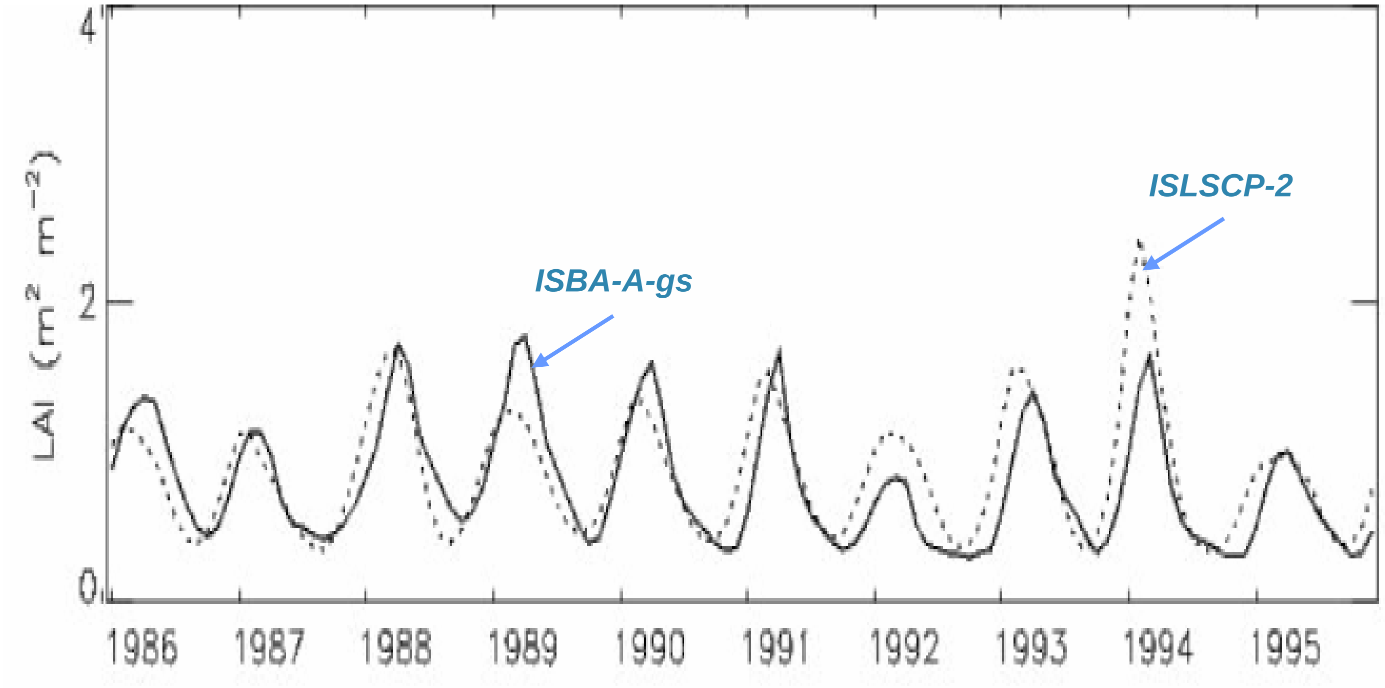
VALIDATION: LAI



***Monthly time series of LAI from ISBA-A-gs and ISLSCP-II over Southern Africa** [-35°N:-15°N, 10°E:40°E]*

Gibelin et al. 2005

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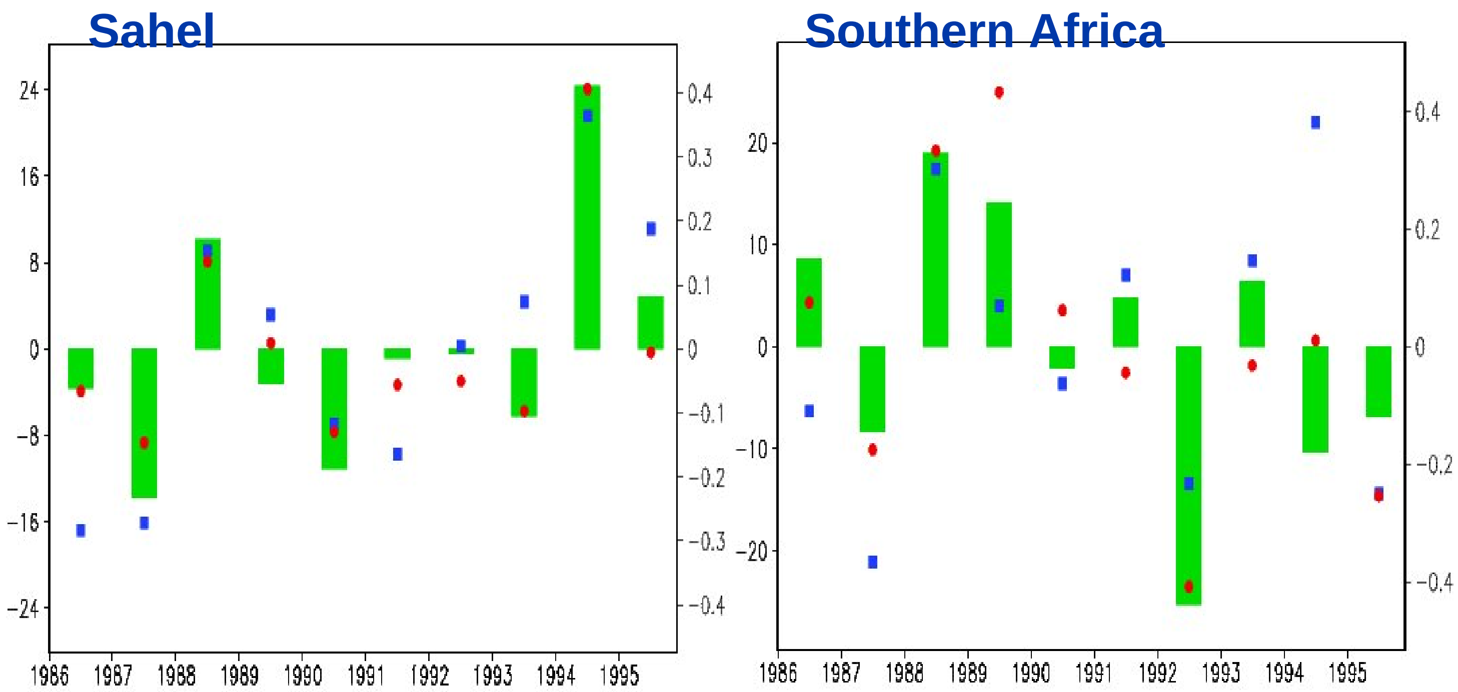
VALIDATION: LAI



Relative anomaly of LAI (%) versus precipitation anomaly (mm d^{-1})

(blue boxes: ISLSCP2 ; red dots: ISBA-A-gs ; green bars: precipitation)

Gibelin et al. 2005

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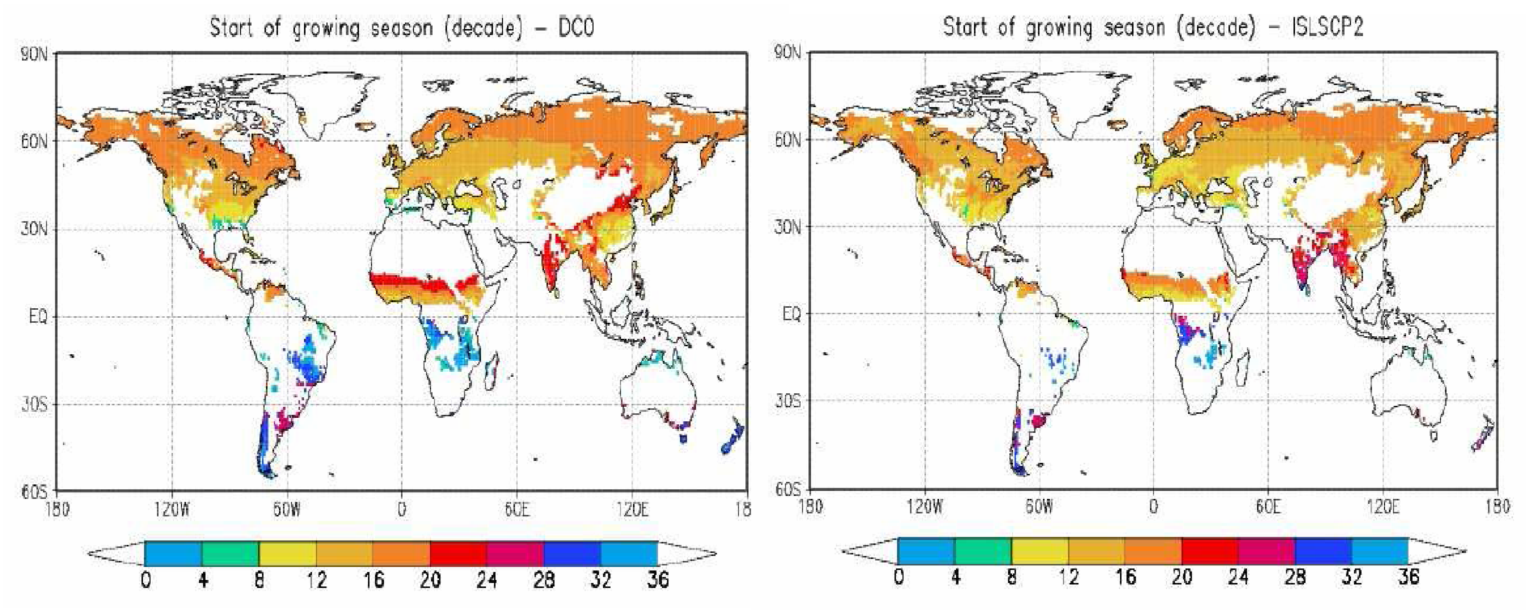
VALIDATION: LAI



ISBA-A-gs

ISLSCP-2

Start of the growing season (mean 1986-1995) simulated by ISBA-A-gs and observed in ISLSCP-II

Gibelin et al. 2005

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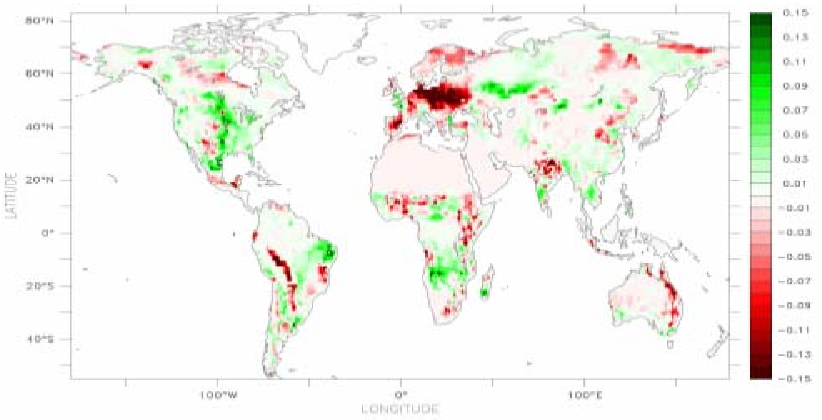
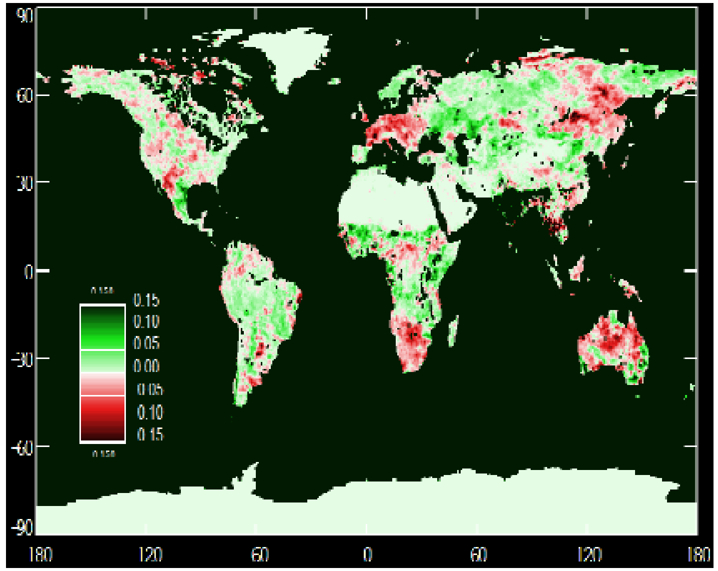
VALIDATION: FaPAR





ORCHIDEE *MODIS*

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2003 FaPAR anomaly:
ORCHIDEE (2003-1972/2002)
MODIS (2003-2000/2002) – Reinstein

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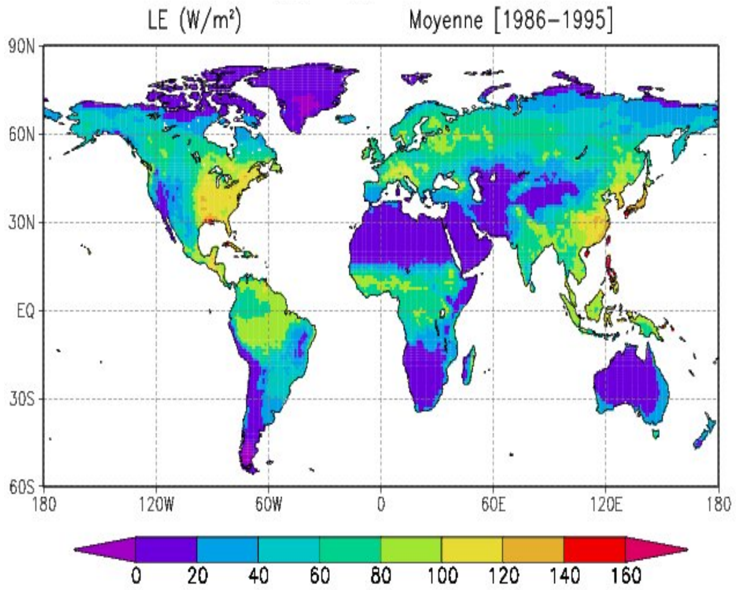
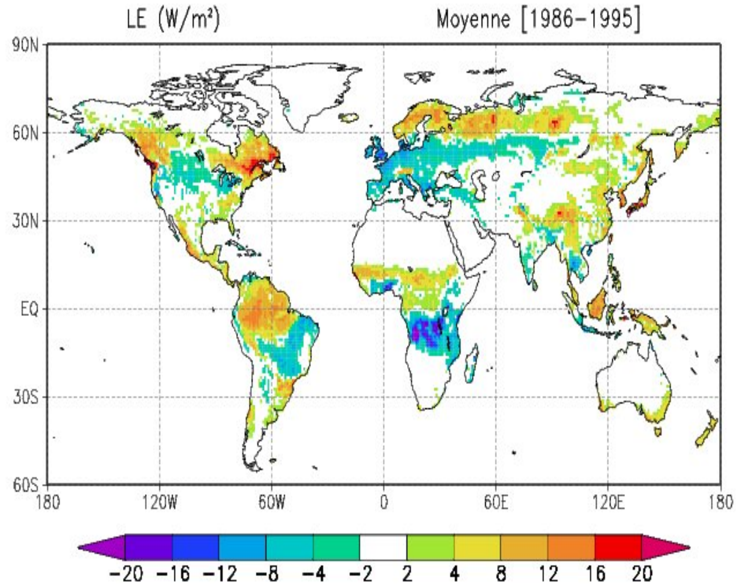
VALIDATION: water flux comparison with operational models

ISBA standard



ISBA standard – ISBA-A-gs



Comparison of the evapo-transpiration flux (JJA) of ISBA and ISBA-A-gs

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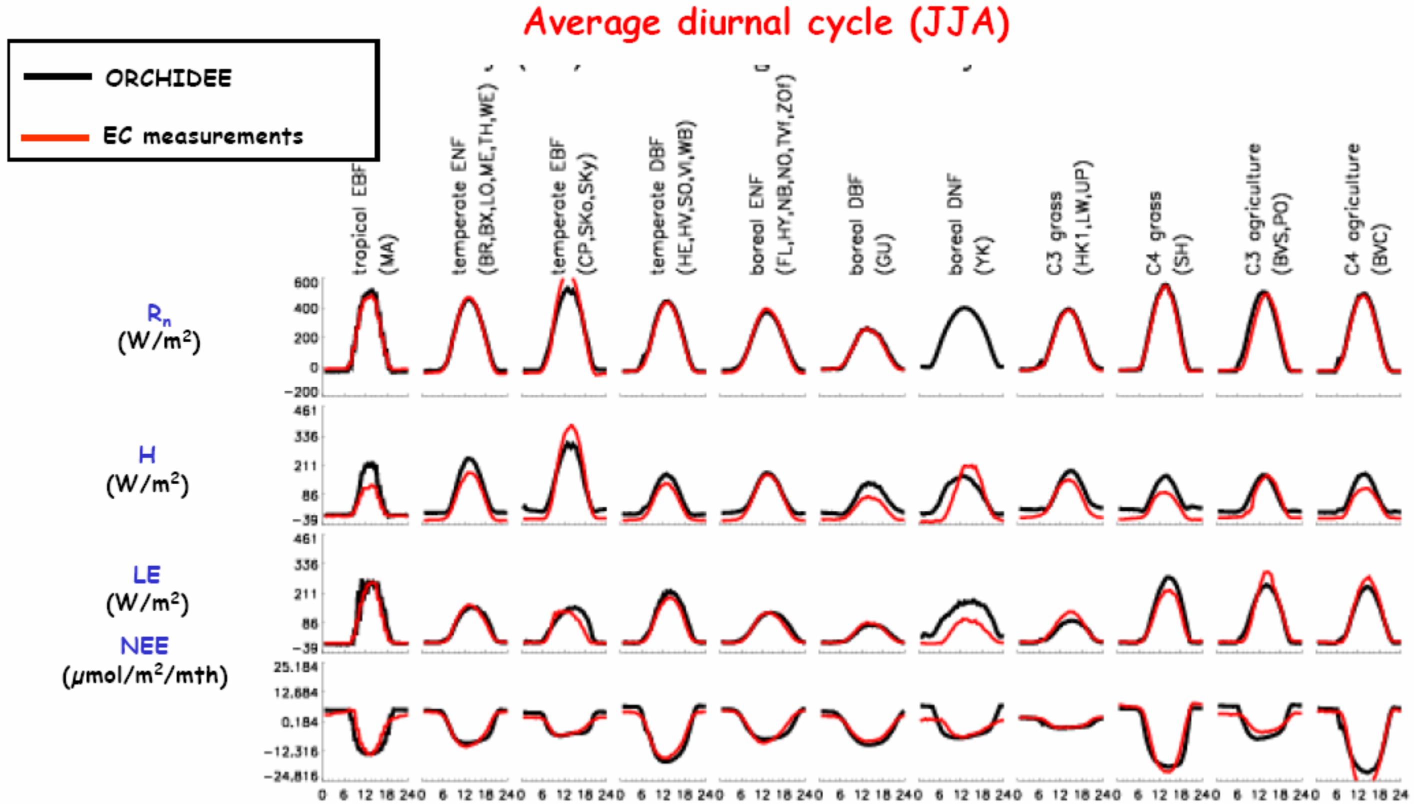
VALIDATION: ground-based flux measurements



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

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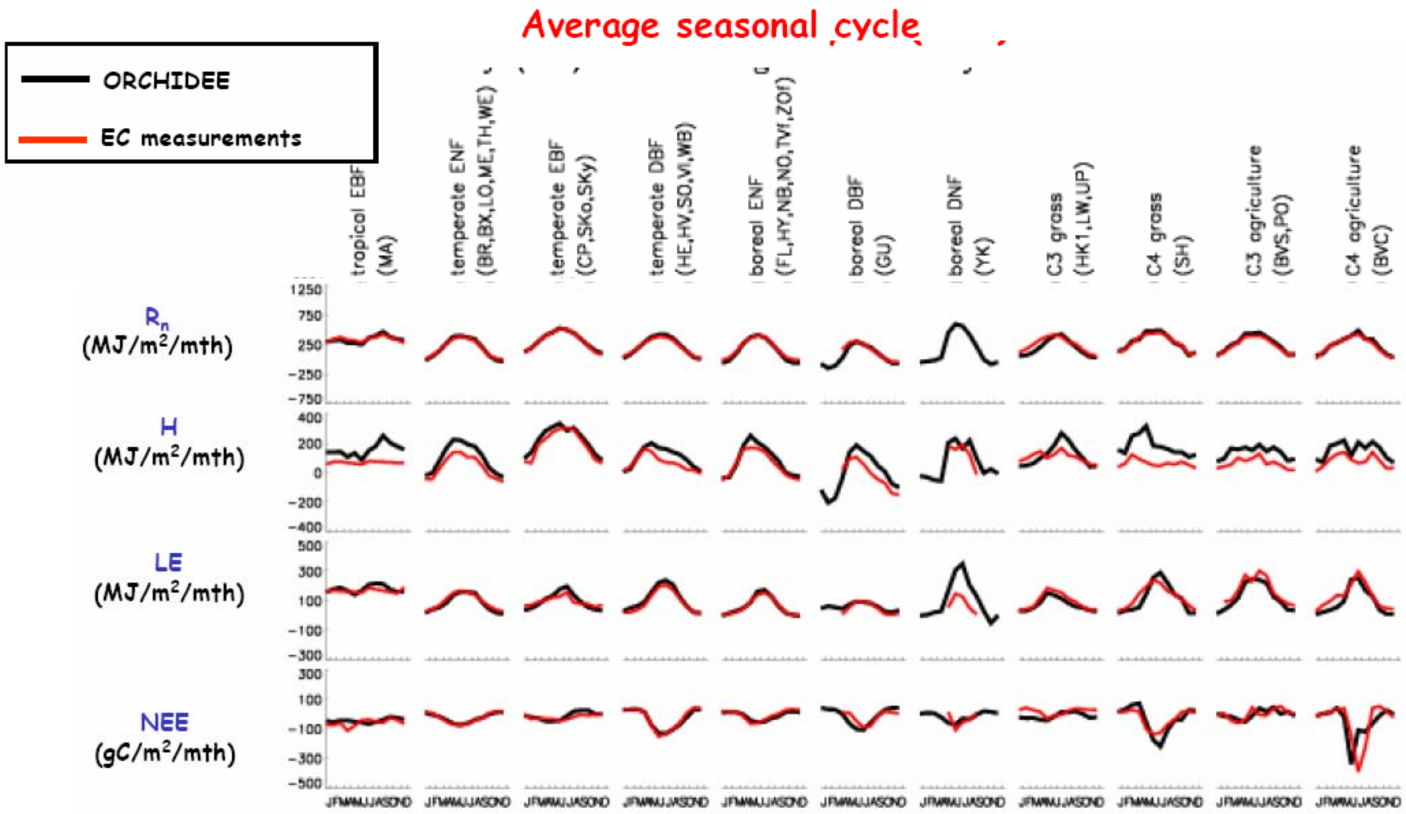
VALIDATION: ground-based flux measurements



Validation of the ORCHIDEE fluxes by using more than 30 FLUXNET sites: Average seasonal cycle

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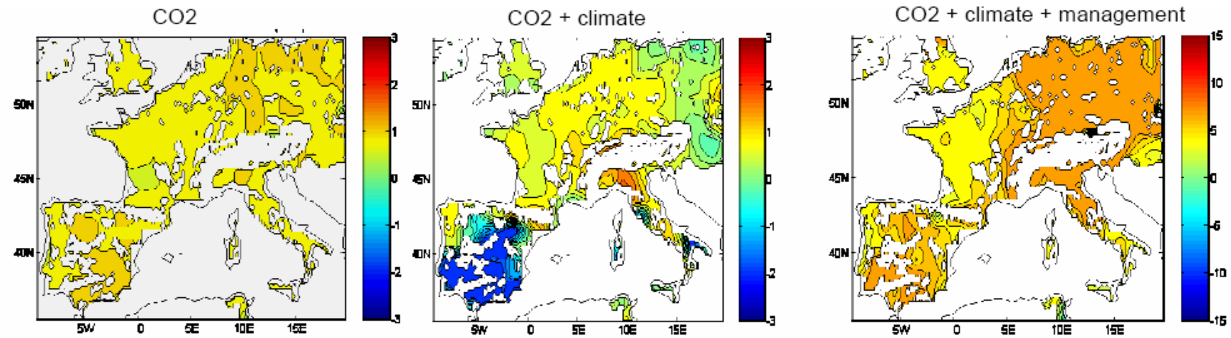
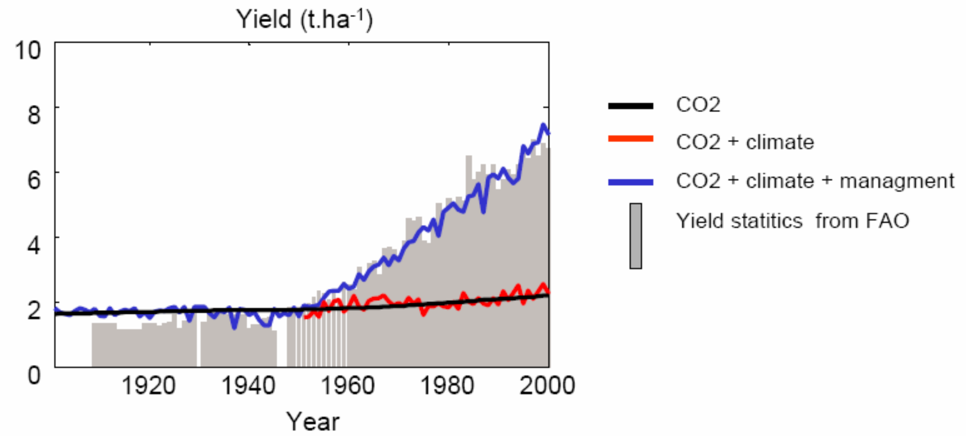
VALIDATION: crop production



Evolution of production (tC/ha/y)



1900-2000 crop production simulated by the STICS module of ORCHIDEE over Europe:

the management effect

N. Viovy

Jean-Christophe Calvet
Météo-France

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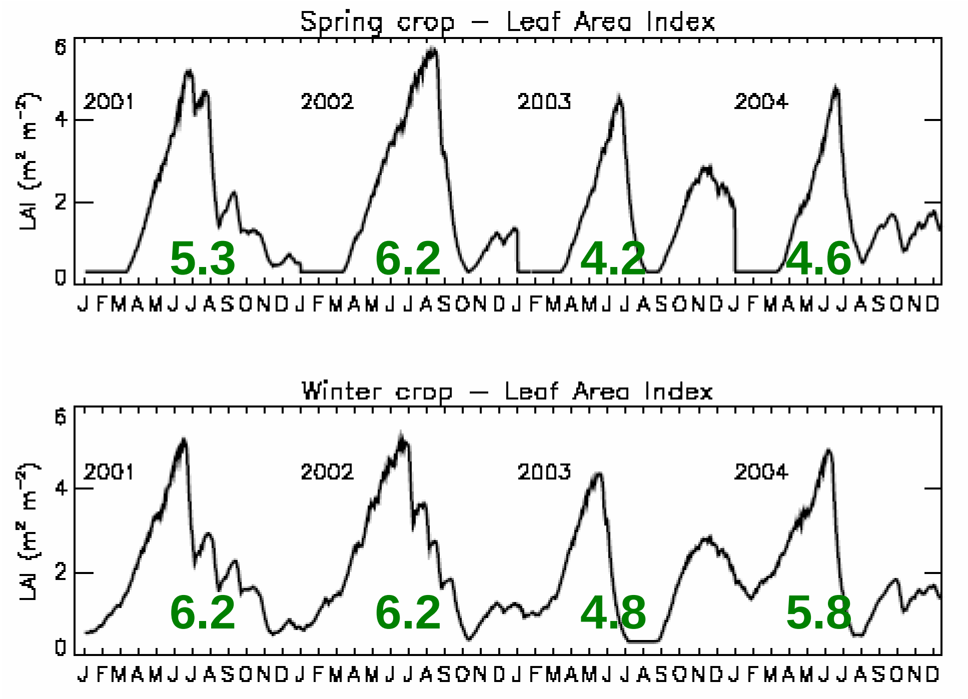

Spring wheat

Winter wheat

-	5.9	4.6	5.7	*Observation for Midi-Pyrénées*

Wheat yield (t ha^{-1}) estimated by ISBA-A-gs for the area of Toulouse, by assuming a Harvest Index of 0.5

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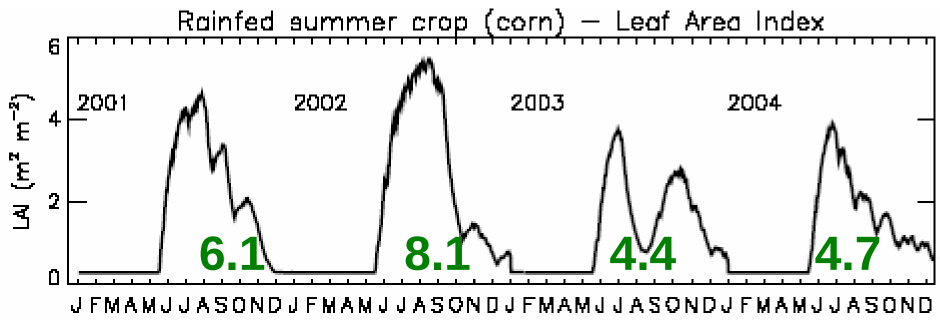
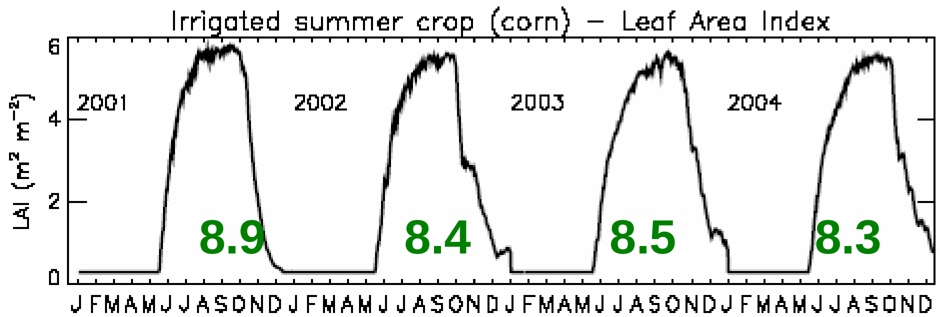


Rainfed maize



Irrigated maize

-	8.6	6.0	8.1	*Observation for Midi-Pyrénées*

Maize yield (t ha^{-1}) estimated by ISBA-A-gs for the area of Toulouse, by assuming a Harvest Index of 0.5

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Data Assimilation

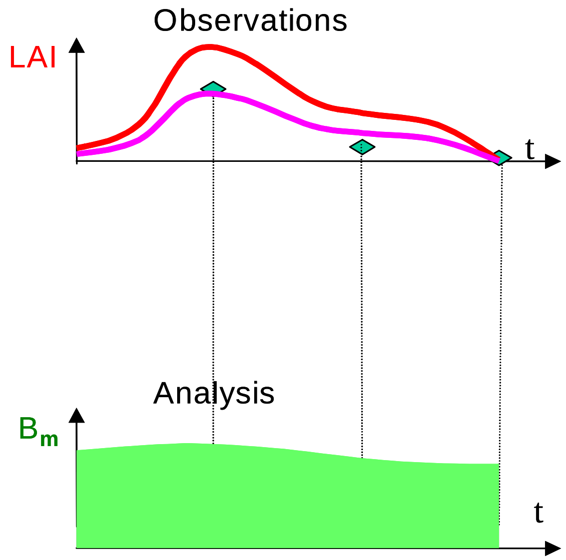
The variational approach

- Formalism: Minimization of a cost function

$$J(\mathbf{x}) = J^{b}(\mathbf{x}) + J^{o}(\mathbf{x})$$

$$= \tfrac{1}{2}\,(\mathbf{x} - \mathbf{x}^b)^T\,\mathbf{B}^{-1}\,(\mathbf{x} - \mathbf{x}^b) + \tfrac{1}{2}(\mathbf{y} - H(\mathbf{x}))^T\,\mathbf{R}^{-1}\,(\mathbf{y} - H(\mathbf{x}))$$

x is the control variables vector
y is the observation vector
H is the observation operator



The analysis is obtained by the minimization of the cost function $J(\mathbf{x})$

B is the background error covariance matrix

R is the observation error covariance matrix

⇨ Litteral solution for linear model :

$$x^a = \mathbf{x}^b + K(y - Hx^b)$$

$$\text{with } K = BH^T(HBH^T+R)^{-1}$$

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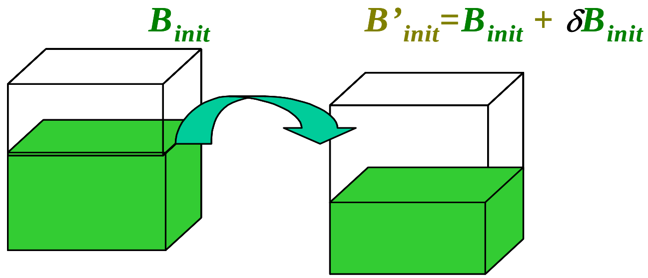
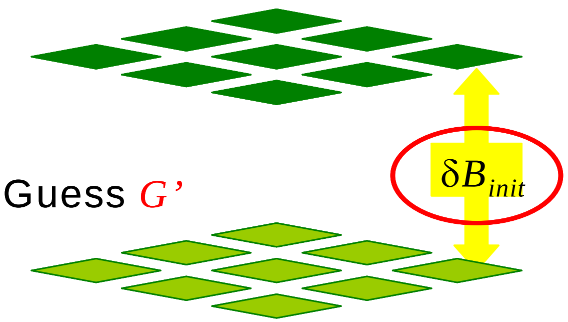
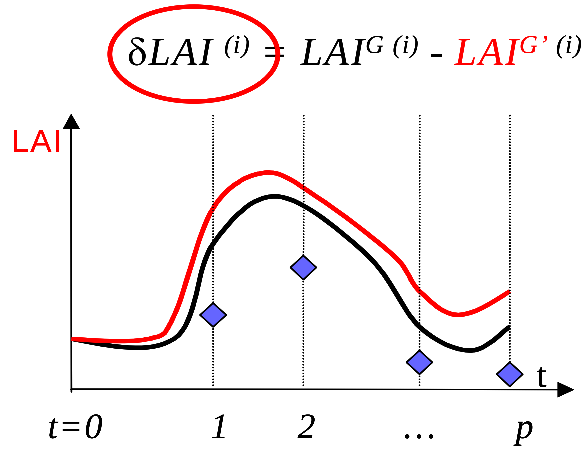
Data Assimilation

A simplified algorithm (adapted from Balsamo and Bouyssel)

From a perturbation of the initial total biomass δB_{init} applied on each model land grid-point.







$$H^T = \begin{pmatrix} \frac{\delta LAI^{(1)}}{\delta B_{init}} \\ \ldots \\ \frac{\delta LAI^{(p)}}{\delta B_{init}} \end{pmatrix}$$

⇨ Numerical linearization of the observation operator H

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Data Assimilation

A simplified algorithm (adapted from Balsamo and Bouyssel)

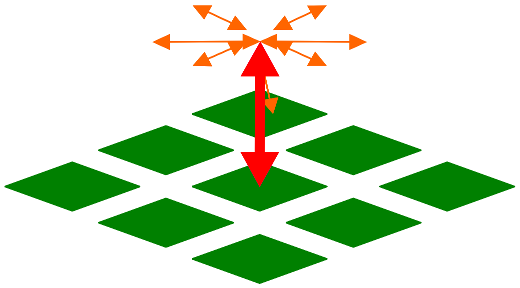
Two main hypotheses have to be validated

- ***TL*** (linearity)

⇨ **Minimization of the cost function with a look up table …**

⇨ **… + comparison to a sequential stochastic approach (Ensemble Kalman Filter, not shown)**

- ***2D*** (horizontal decoupling)



⇨ **Verified at our spatial scale ?**

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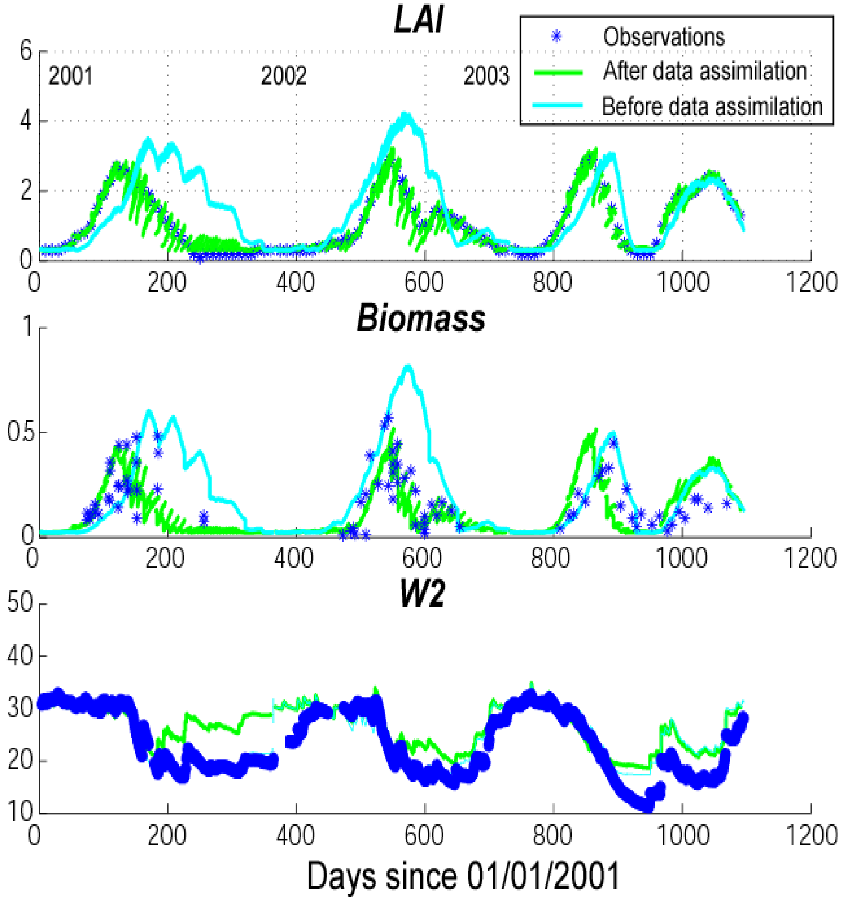
Data Assimilation

Application to the SMOSREX fallow



✓ Analysis of Biomass thanks to in situ LAI observations (10 days analysis period)

- Perfect LAI correction
- Overall good Biomass analysis (particularly in 2002)
- Low impact on w2 (different LAI → different root water extraction and transpiration rates)

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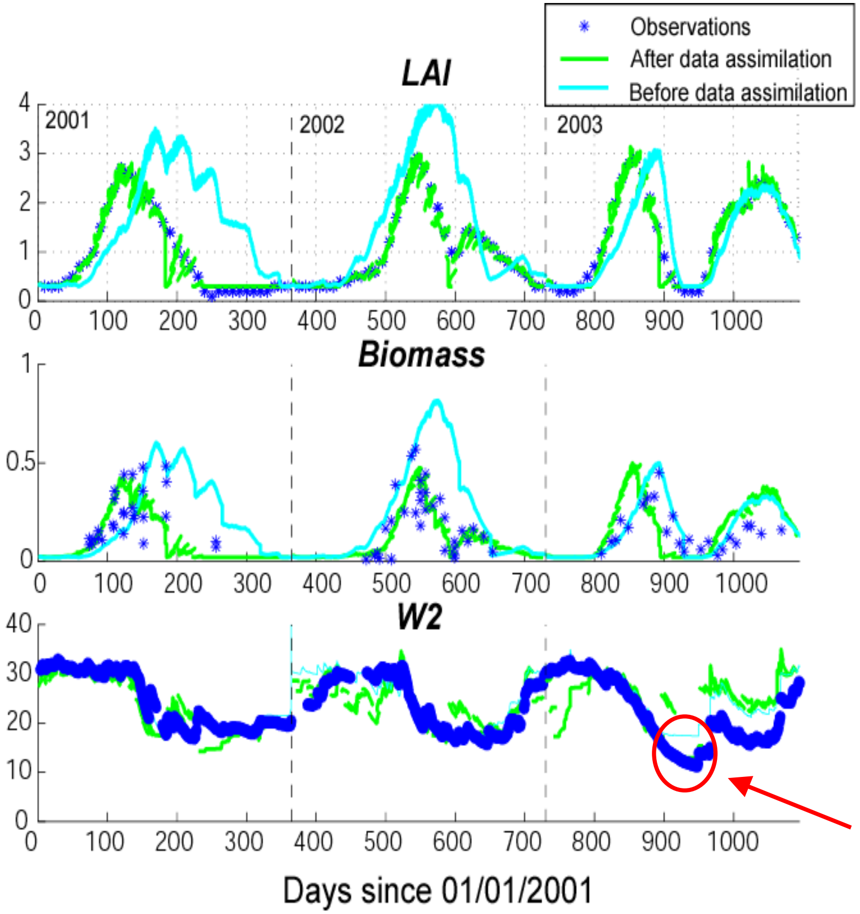
Data Assimilation

Application to the SMOSREX fallow



✓ Analysis of Biomass and w2 thanks to in situ LAI observations (10 days analysis period)

- Perfect LAI correction
- Overall good Biomass analysis
- High scattering of analysed w2 …
- … but w2 better in agreement with observations during high water stress period

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Prospects

- ISBA-A-gs / C-TESSEL (Météo-France / ECMWF)
  - ➢ Roots
  - ➢ Wood
  - ➢ Soil carbon
  - ➢ NPP
- Representation of land surface patchiness
  - ➢ Regional applications (5-10 km) at Météo-France and LSCE
- VALIDATION:
  - ➢ Test of C-TESSEL global simulations of LAI
  - ➢ Test of ISBA-A-gs and C-TESSEL using the FLUXNET data
- Data Assimilation
  - ➢ ISBA-A-gs: Use of a 2D assimilation system over South-Western France using SPOT/VGT data (1999-2005)
  - ➢ Global assimilation of LAI products in ORCHIDEE and C-TESSEL

Thank you for your attention!

www.gmes-geoland.info

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