Monitoring soil and vegetation fluxes of carbon and water at the global scale: the land carbon core information service of GEOLAND2

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Abstract

The vegetation/land component of GMES is called 'Land Monitoring Core service' (LMCS). The GEOLAND2 European project (FP7, 2008-2012) is a demonstrator of the evolution of the LMCS, including the consolidation of prototype services and the test of their operational capacity. In particular, the perimeter of the LMCS is extended, with a global component (biogeophysical parameters), and thematic core information services.

The main mission of the land carbon core information service (LC-CIS) of GEOLAND2 is to assess the impact of weather and climate variability on terrestrial biospheric carbon fluxes, in the context of international conventions. The LC-CIS aims at monitoring the global terrestrial carbon fluxes (e.g. to support reporting obligations in the course of the Kyoto Protocol) and setting-up pre-operational infrastructures for providing global products, both in near real time and off-line mode. A multi-model carbon accounting system is developed, coupled with EO data assimilation schemes. Emphasis is put on validation (in-situ data), with downscaling on reference European countries (France, the Netherlands, Hungary). The C-TESSEL and SURFEX modelling platforms (of ECMWF and Météo-France, respectively) are used for production. The ORCHIDEE modelling platform (LSCE) is used for benchmarking and validation purposes.

The ECWMF reanalysis (ERA-Interim) will be used to build a global 20-y climatology of carbon and water fluxes, LAI and vegetation biomass, in order to rank the near-real time simulations. Gradually, EO data will be integrated in the modelling platforms, in order to improve the atmospheric constraint on the model (e.g. downwelling solar radiation from the EUMETSAT's Land-SAF), analyse soil moisture and vegetation biomass (e.g. assimilate the EUMETSAT's ASCAT soil moisture product and MODIS and/or SPOT/VGT LAI estimates). Finally, EO data will be used for model verification (e.g. land surface temperature).

1. Brief description of the service

GEOLAND2 intends to constitute a major step towards the implementation of the GMES Land Monitoring Core Service (LMCS). The three components (Local, Continental, and Global) of the LMCS are addressed. The architecture of GEOLAND2 is made of two different layers, the Core mapping Services (CMS) and the Core Information services (CIS). The Land Carbon CIS (LC-CIS) is one of the global CIS of GEOLAND2. LC-CIS aims at setting-up pre-operational infrastructures for providing regional (France, the Netherlands, Hungary) and global variables related to the terrestrial carbon cycle, in near real time, for describing the continental vegetation state (LAI and biomass), the surface fluxes (carbon and water), and the associated soil moisture. These variables are produced daily by models able to assimilate Earth Observation (EO) data. This land data assimilation system (LDAS) will be implemented gradually during the GEOLAND2 time frame (2008-2012). The overall objective is to understand and assess the impact of weather and climate variability on terrestrial biospheric carbon fluxes, in the context of international conventions (UNFCCC, Kyoto agreements).

The key daily products of LC-CIS are:

- Global daily estimates of analysed: LAI, soil moisture, carbon flux, water flux, vegetation biomass, carbon storage (ECMWF ; CTESSEL model (Voogt et al. 2006); spatial resolution similar to the operational NWP ECMWF model, i.e. 16km in 2010)
- Focus on European test countries: France, the Netherlands, Hungary (Meteo-France, KNMI, OMSZ, respectively ; SURFEX modelling platform including the ISBA-A-gs model ; spatial resolution ranging from 1km to 10km).

The LC-CIS products are analysed biophysical variables. 'Analysed variables' means that they are produced by a land surface model using atmospheric information together with ancillary data on soil characteristics and land cover, able to use EO products through direct forcing and/or data assimilation (e.g. LAI, soil moisture). The analysed variables constitute a merged product accounting for diverse sources of information and for the physics of the model. The data assimilation accounts for the uncertainties in the model simulations and in the observations, which ensures that the analysis is optimal.

2. Methods

2.1. Models

Vegetation has a strong impact on the exchange of energy, water and carbon between the land surface and the atmosphere. In particular, it influences the uptake and release of carbon dioxide from and to the atmosphere through photosynthesis and respiration. In addition, the plant growth is governed by the climate. Improving the modelling of the land surface physiological processes is required to provide quantitative estimates of the surface fluxes for meteorological, hydrological and climate applications. Soil-vegetation-atmosphere transfer (SVAT) models were originally designed to simulate exchanges of matter and energy between the surface and the atmosphere, with vegetation leaf area index (LAI) as a forcing variable, rather than a prognostic state. A number of models have recently evolved to include biogeochemical processes (Foley et al., 1996; Sellers et al., 1996; Calvet et al., 1998; Pitman, 2003), in order to improve the representation of the dynamical behaviour of the vegetation. In such models, the active biomass is often represented by the amount of leaf surface area per unit ground area, expressed through LAI.

In LC-CIS, the ISBA-A-gs model of Meteo-France (Calvet et al., 1998, 2004, 2008) is used as a baseline. New developments in ISBA-A-gs are transferred to ECMWF, in the CTESSEL land surface model (Fig. 1). ISBA-A-gs is a CO_2-responsive model, which accounts for the vegetation assimilation of CO_2. It is able to simulate energy, CO_2 and water vapour fluxes at the surface-atmosphere interface. Gibelin et al. (2006) evaluated the model performances at a global scale in the context of climatologic simulations, using atmospheric forcing fields from Numerical Weather Prediction (NWP) reanalyses and observations at a 1 degree resolution. They compared 10 years of simulation of LAI with three satellite-derived LAI datasets. It was found that the ISBA-A-gs model is able to capture the general patterns of LAI observed from space and that the simulations fall within the range of variability of satellite-retrieved LAI. Brut et al. (2009) made the same exercise at the regional scale at a 8km resolution, for a 3-year period. They demonstrated the potential of LAI remote sensing products for identifying and locating models' shortcomings at a regional scale.

ISBA-A-gs contains a simplified representation of ecosystem respiration and does not simulates all the autotrophic respiration terms, nor the carbon storage. A new version of ISBA-A-gs, called ISBA-CC (Gibelin et al. 2008), has been implemented in the SURFEX modelling platform of Meteo-France. ISBA-CC simulates the main processes of the terrestrial carbon cycle (Fig. 1), i.e. the evolution of the carbon reservoirs in the vegetation and in the soil, and the net ecosystem exchange flux components (gross primary production, autotrophic and heterotrophic respiration). The energy and carbon fluxes simulated by ISBA-CC were validated against in situ measurements at 26 FLUXNET (www.fluxdata.org) sites located at temperate and high latitudes of the Northern Hemisphere, sampling the main biomes present in the area (Gibelin et al. 2008). It is shown that the scores obtained by ISBA-CC are similar to those obtained by the ORCHIDEE model.

2.2. Data assimilation

To quantify carbon and water fluxes between the vegetation and the atmosphere in a consistent manner, land surface models now include interactive vegetation components in which the vegetation biomass is a prognostic model state, allowing the model to adapt the vegetation growth to environmental conditions. However, the quality of its performances depends on forcing data and on model parameters that generally require continuous corrections. A number of studies (Jarlan et al. 2008, Sabater et al. 2008, Rüdiger et al. 2010) have shown the potential of assimilating leaf area index and/or surface soil moisture observations to correct vegetation model states using variants of the Extended Kalman Filter (EKF).

Mahfouf et al. (2009) transformed the data assimilation system used in the two previous studies to a comprehensive EKF for its operational use within the limited area numerical weather prediction (NWP) system ALADIN of Météo-France [Bubnova et al., 1995]. This new EKF version was adapted for the purpose of LC-CIS to allow the joint assimilation of remotely sensed LAI and surface soil moisture observations for the analysis of the above-ground photosynthetically active vegetation biomass and the root-zone soil moisture within ISBA-A-gs, as previously proposed by Sabater et al. (2008).

In its current form, the EKF assimilates observations over an interval of 24 hours at 6 am, when available, by analysing the initial state via the information provided by an observation at the end of the assimilation window (i.e. the observation operator contains the forward model propagation and the conversion of the model state into an observation equivalent). The propagation of the background error covariance matrix by the tangent linear forward model in the EKF allows for observations to be available less frequently than the chosen assimilation window length (thereby providing a similar solution as a variational assimilation system over a long assimilation window but without making the assumption of a perfect model). The choice of a one-day assimilation window allows the joint assimilation of LAI with other observations available more frequently (e.g. soil moisture content, screen-level observations). Rüdiger et al. (2010) show that increasing the length to 10 days (availability of satellite LAI products) leads to significantly reduced Jacobians and consequently a significant loss of the model's response at the end of the assimilation window to the initial perturbations of the model states. Moreover, a length of ten days for an assimilation window would jeopardize near-real time applications because of the very long cut-off needed to obtain the required observations. Such window lengths also lead to questioning the linearity and perfect model assumptions, when compared to shorter windows.

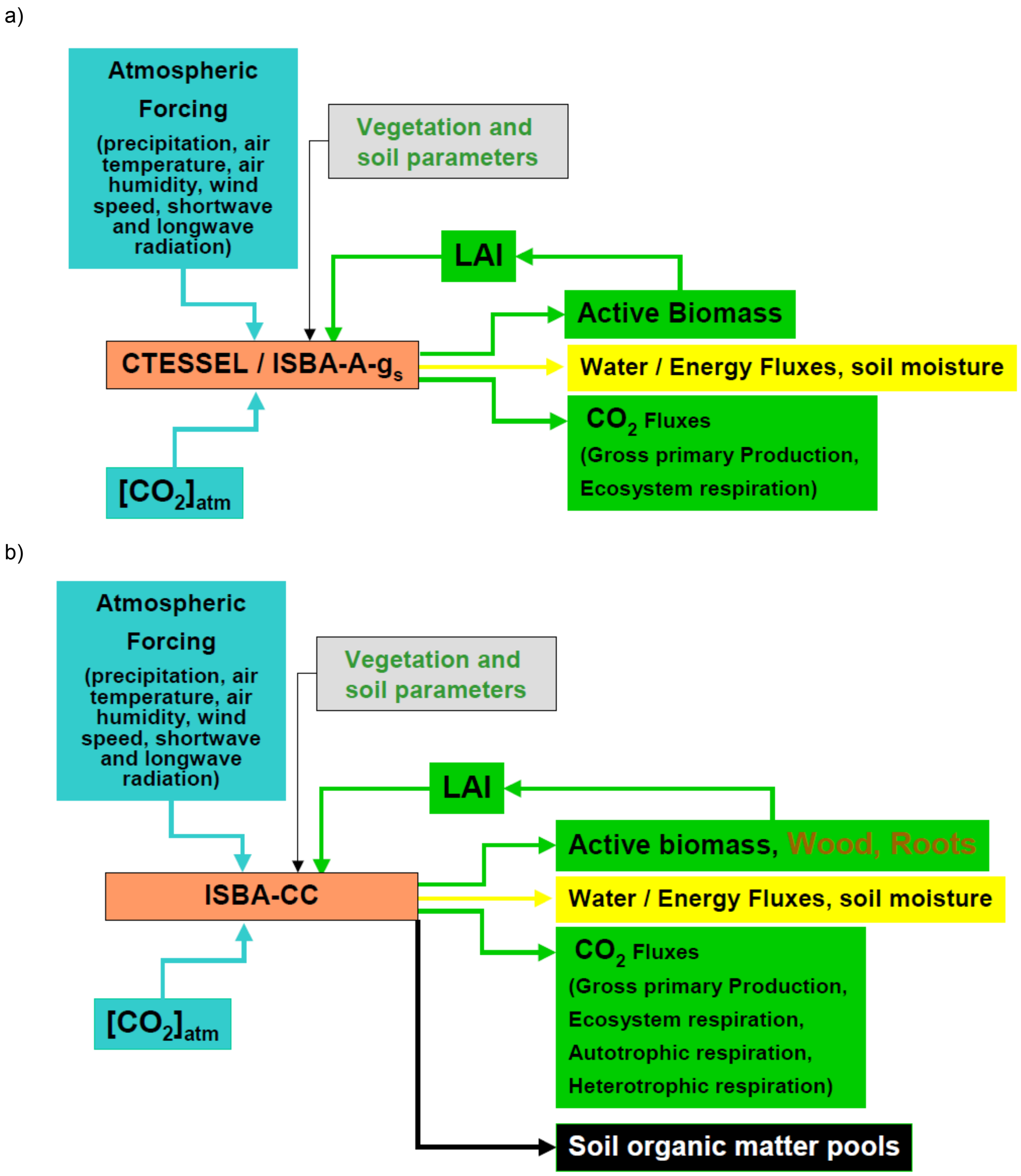

Figure 1: Input and output variables of (a) CTESSEL and/or ISBA-A-gs, (b) ISBA-CC.

2.3. Verification approaches

2.3.1. Soil moisture

Rüdiger et al. 2009, Scipal et al. 2008, Albergel et al. 2009, have shown that local soil moisture observations can be used to verify low-resolution model or EO soil moisture products. Most of the FLUXNET sites are now measuring soil water content at different depths. Météo-France has developed a soil moisture network in southern France (SMOSMANIA, Calvet et al. 2007, Albergel et al. 2008) now including 21 stations.

2.3.2. Fluxes

The whole system (including the generation of the atmospheric forcing) is verified against in situ local observations of eddy correlation fluxes. In SURFEX, several patches are considered, and the patch corresponding to the observed vegetation type can be selected. In CTESSEL, the number of patches is limited, and the consistency between the model vegetation type and the observed vegetation type will have to be checked. The FLUXNET sites are available in different countries, climates and for various vegetation types, but they have commonly a footprint no larger than 1km around the measurement point. A homogeneity analysis of the footprint will be performed and the consistency between the modelled and observed vegetation will be checked. Cluster of towers will be selected for small regions including different vegetation types and local scale data-driven upscaling will be performed. Validation approaches will include statistical analysis of flux magnitude, daily to annual cycles, anomalies and ecosystem response functions parameters, accounting for the spatial resolution difference.

2.3.3. LAI

Anomaly correlation (e.g. 2003 heat wave in Europe or 2007 drought in southeastern USA) between modelled and EO derived LAI estimates can be used as a verification.

2.3.4. Biomass

In situ biomass measurements are available from Luyssaert et al. (2006). The data base provides estimates of carbon stocks and carbon fluxes (GPP, Reco, NPP). Existing simulations for these sites by CEA using ORCHIDEE and the CRU atmospheric forcing will be used. CEA will rerun ORCHIDEE with ERA-INTERIM (period 1989 to present) for a subset of the forest sites growing after 1989. This will permit to assess the impact of the improved atmospheric forcing derived from ERA-INTERIM. The same simulations will be performed with ISBA-CC for benchmarking purposes.

2.3.5. Atmospheric forcing

ERA-INTERIM can be GPCP corrected (GPCP uses in situ data). A comparison of various atmospheric fields (in particular precipitation) will be made with higher resolution atmospheric analyses over France (8km, using a dense precipitation gauge network).

2.3.6. Carbon stocks

In a first stage, equilibrium modelled stocks can be compared with existing/available in situ derived estimates. This concerns ISBA-CC, only.

3. Discussion

An important aspect of the verification is benchmarking, i.e. a comparison of performance with other models and approaches. In LC-CIS, benchmarking activities will include at least an intercomparison of CTESSEL, SURFEX and ORCHIDEE models.

Assessing the added value of the assimilation can be done by measuring its impact on the overall agreement of the model with in situ observations (fluxes, soil moisture, and, in the case of a land surface model used in a weather forecast model, on the atmospheric variables). A realistic target for an interactive vegetation model (run in open-loop mode) should be reproducing LAI climatologies (at least in areas where the model precipitation bias is not compromising vegetation growth). In presence of large anomalies (e.g. European summer 2003, US summer 2007), the interactive vegetation model is expected to capture the sign and magnitude of the LAI anomaly in seasonal integrations where the soil preconditioning is already present in the initial conditions. EO-derived vegetation variables will be the main spatially available observation proxy for seasonal carbon uptake.

The choice of a relatively long assimilation window (ie. 10 days), dictated by the current availability of satellite derived LAI (operational LAI products are provided as 8 day composites), would make such surface assimilation incompatible with atmospheric data assimilation systems that have much shorter assimilation intervals (between 3h and 12 h). Mahfouf et al. [2009] transformed the 2D-VAR used in Jarlan et al. [2008] and in Sabater et al. [2008] to a comprehensive Extended Kalman Filter (EKF) for its operational use within the limited area numerical weather prediction system ALADIN of Meteo-France. This new EKF version was then adapted to allow the joint assimilation of remotely sensed LAI and surface soil moisture observations (Rüdiger et al. [2010]). In its current form, the EKF assimilates observations over an interval of 24 hours at 6 am, when available, by analysing the initial state via the information provided by an observation at the end of the assimilation interval (i.e. the observation operator contains the forward model propagation and the conversion of the model state into an observation equivalent). The propagation of the background error covariance matrix by the tangent linear forward model in the EKF is performed through the Jacobians of the forward model. This allows for observations to be available less frequently than the chosen assimilation interval length (thereby providing a similar solution as the simplified 2D-VAR over a long assimilation window but without making the assumption of a perfect model).

Addressing the weather, seasonal, and interannual climate variability of the fluxes will be the primary added value of the service. In a second stage, it is expected that adaptations of the system will be needed in order to account for crop and forest harvest/fires. The verification component of LC-CIS will compare the model outputs with field data concerning, in particular, carbon fluxes (tower data). It has to be recognized that the link to inventories is challenging. However, the atmospheric CO_2 represents, undoubtedly, the best observed carbon stock. The global LC-CIS CO_2 flux product will be tested in the framework of MACC to produce integrated CO_2 concentrations at a global scale. This methodology will provide a solid benchmarking ground since large inaccuracies in the prescription of land surface fluxes are likely to produce atmospheric drifts in CO_2 concentrations. The ultimate goal of a fully interactive and data-constrained carbon cycle can be progressively improved, once the land carbon component has been coupled with the MACC system.

In order to properly address the issues raised by the carbon reporting, we will explore several ways to initialize the carbon pools that will be more appropriate than performing equilibrium runs:

- adjusting/constraining the models to reach the carbon pools provided by aggregated in situ data or by the national inventories,
- performing a statistical analysis of the difference with the carbon fluxes inferred produced by MACC from atmospheric inversions based on the atmospheric mixing ratios of CO_2 (in collaboration with MACC)
- running the model with the best-known history of climate and disturbance for the last century. The eddy-covariance flux measurements and biometric carbon pools measurements can help to verify the maps of carbon pools at the corresponding locations.

These solutions are being explored with the ORCHIDEE model and its adjoint while the first stage of the LC-CIS is being set up.

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