Assimilation of remote sensing data to monitor the terrestrial carbon cycle: the carbon observatory of geoland

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1. Introduction

Global or continental-scale land data assimilation systems (LDAS) have been developed in the last few years to characterize the surface energy and water budget, including changes in soil water and snow mass. The pioneering effort, coordinated by NASA, brings together a large community of meteorologists and hydrologists and runs currently in real-time, for the globe (GLDAS, at ¼ degree resolution) and North America (NLDAS, at 1/8 degree resolution). In Europe, the **geo**land Integrated Project (2004-2007) co-funded by the European Commission, aims at addressing European and global environment issues, based on the use of remote sensing data. The carbon observatory of **geo**land, hereinafter referred to as "**geo**land/Carbon", will provide a pre-operational global carbon accounting system, dealing with the impact of weather and climate variability on ecosystems fluxes and carbon stocks. The **geo**land/Carbon partners (ECMWF, KNMI, Météo-France, Alterra) are involved in the European LDAS (ELDAS, at 0.2 degree resolution) European project (http://www.knmi.nl/samenw/eldas/), which will create a daily dataset spanning the year 2000 and the European continent. LDAS systems collect all available remote sensing and in-situ information to create precipitation and surface radiative field, together with near-surface meteorology from atmospheric data assimilation centres (Hollingsworth et al. 2003). These fields are used to force state-of-the-art land-surface models, producing as output surface energy and water fluxes, soil water and snow mass. Uncertainty estimates can be obtained from varying the forcing and/or using different land-surface models. LDAS outputs document best estimates of the fields governing surface-atmosphere interface; in particular, the soil moisture and snow mass fields can be used as initial conditions for weather prediction and monthly to seasonal forecasts. As far as carbon fluxes are concerned, a number of land surface models (LSM) used in NWP and climate studies now include photosynthesis and respiration modules coupled with biomass allocation schemes. For example, ISBA-A-gs at Météo-France (Calvet et al. 1998, Calvet and Soussana 2001) and ORCHIDEE at LSCE (Botta et al. 2000) are interactive vegetation LSMs able to simulate the leaf area index and the vegetation biomass. Furthermore ORCHIDEE includes the slow carbon reservoirs of the soil and the dynamics of ecosystems after disturbance.

2. The geoland project

geoland is an European project (2004-2007) coordinated by Infoterra GmbH and Medias-France. The **geo**land's goal (Fig. 1) is to reach pre-operational GMES capabilities by:

- federating different demands to create a maximum of synergies,
- avoiding duplications by considering previous initiatives of EC, ESA and national entities,

- considering an active integration of users,
- including partners of all relevant science & technology stakeholders in the team,
- demonstrating the implementation of pre-operational services that have been identified and requested throughout many studies in the past.

geoland combines 56 European service providers, research institutions, and user organisations. The broad range of "land applications" addressed by European Directives and Policies is treated by eight sub-projects (observatories) providing products and services addressing regional monitoring and reporting for nature protection, water and soil issues, spatial planning, and strategic information on food security and crop monitoring, global land cover and forest change, and natural carbon fluxes. The Earth observation data are 1)- processed by two core services (according to the observatories' requirements) and 2)- analysed by the observatories (addressing end-user needs).

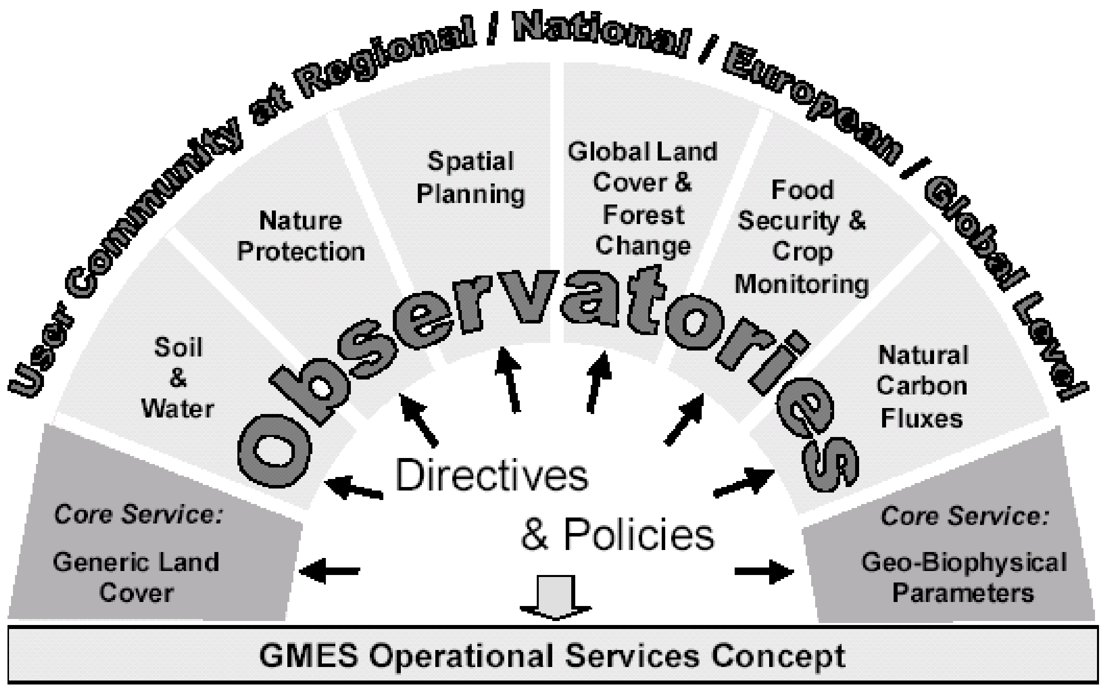

*Figure 1. The **geo**land European project (2004-2007). The global monitoring for environment and security (GMES) activities of the European Commission (EC) and European Space Agency (ESA) is a joint effort to provide operational information by using available Earth observation resources and integrating them with existing models into pre-operational end-user applications. The **geo**land/Carbon (Natural carbon fluxes) observatory addresses one of the global vegetation monitoring priorities of GMES: assess carbon fluxes and stocks in the biosphere.*

3. The geoland/Carbon observatory

The existing assimilation LDAS projects (NLDAS, GLDAS, ELDAS) do not include interactive vegetation LSM, which limits the use of remote sensing data. The analysed variable in LDAS is soil moisture, only, and there is a need to account for vegetation biomass to monitor the biosphere vegetation-atmosphere CO_2 exchange. The solution chosen in **geo**land/Carbon is to merge the LDAS approach and the interactive vegetation models, by making two communities work together: the meteorologists involved in ELDAS and the carbon modellers.

The overall objective of **geo**land/Carbon is to demonstrate the feasibility of monitoring vegetation-atmosphere CO_2 exchange at the global scale, on daily to seasonal and inter-annual time scales. In particular, we will investigate the relationship between weather and climate variability and terrestrial CO_2 fluxes (Bousquet et al. 2000). The integration of in situ meteorological measurements (Houser et al. 2003) and different satellite remote sensing sources of information (Van den Hurk 2001, Calvet and Noilhan 2000) will be made by implementing and using assimilation techniques in global land surface models. The carbon observatory will collect the remote sensing products provided by the **geo**land core service “Geo-Biophysical Parameters” and the atmospheric forcing provided by ECMWF. In order to integrate the existing approaches and to deliver an assessment based on independent modelling results, two land surface models will be used: 1) an operational scheme (ECMWF) used in numerical weather forecast models, modified to describe an interactive vegetation (based on ISBA-A-gs, Météo-France); 2) a carbon-water-energy land surface scheme, fitted with carbon dynamics in biomass and soil pools, and with ecosystem dynamics (LSCE). The two models were used in numerous studies and validated against both in situ (e.g. eddy covariance towers) and global datasets (e.g. satellite maps of biophysical variables) but they were developed independently. A method to assimilate remote sensing products will be designed and evaluated based on existing field campaigns devoted to the assimilation of multi-spectral satellite data. The assimilation system will then be run at the global scale with both carbon models. The assimilated output fields will be checked against global observations of different nature, such as eddy covariance networks, long term ecological time series (e.g. IGBP transects), forest and soil carbon inventories, or satellite products that were not used at first in the assimilation procedure. At the end of this project, ECMWF will be able to propose a single near-operational system based on components of the two approaches. The end-product of the system will be a near real-time analysis of biospheric CO_2 fluxes, released by ECMWF every 3 or 6 months. The other products of the service will consist of water and energy fluxes, biomass and soil moisture estimates which are fully compatible with CO_2 exchange.

4. Potential impact

geoland/Carbon will deliver an improved scientific understanding of natural terrestrial carbon fluxes, in support of the implementation of the Kyoto protocol. More specifically, we envision building a global full carbon accounting modelling system, treating in particular the impact of weather and climate variability on ecosystem fluxes and carbon stocks. The observatory will deliver a unique tool to evaluate the inter-annual variability of the terrestrial carbon cycle at global and regional scales. Since the same assimilation method will be applied to the whole globe, although with ecosystem-specific parameterisations, the products will serve as a basis for comparing the carbon balance of one region with another. The users will be 1) international organisations in charge of assessing the carbon balance (e.g. IGBP, IGOS, IPCC), 2) the scientific community itself (global carbon cycle studies, ecology, meteorology, hydrology), 3) decision makers involved in CO_2 emission control or reduction policies (e.g. carbon sequestration). The verification of the Kyoto protocol, as requested in the treaty and subsequent conferences of parties, is beyond the scope of the carbon observatory. Indeed, the verification would require the estimation of anthropogenic emissions and of the natural fluxes, at scales that are not always compatible with the one addressed here. The state-of-the-art in global modelling does not permit to perform accurate stand scale (e.g. 1 ha) biomass, carbon fluxes, nor anthropogenic source inventories, or to convincingly address the transformation of soil carbon, which may depend on disturbances which have acted a long time ago but still influence the carbon fluxes today. Accounting for anthropogenic sources of CO_2 requires an extensive and accurate space and time mapping of emissions and this activity will be better addressed by a project devoted to atmospheric measurements. However, the carbon observatory is, indirectly, policy-relevant: it will provide the scientific basis on natural terrestrial fluxes which may be used in the context of international negotiations and carbon sequestration policies. It is likely that the knowledge gained on the natural fluxes will be used in atmospheric transport studies based on remotely sensed atmospheric CO_2 concentration. The products of the carbon observatory will permit to improve the atmospheric inversions and, over some regions, to help constrain the uncertainties of the anthropogenic sources.

5. Implementation plan

The land remote sensing products to be assimilated will be processed together with the required in situ meteorological observations (Fig. 2). The ECMWF operational data processing system will be used to perform this task. The remote sensing products will be provided by the core service: leaf area index, heating rates, surface soil moisture will be assimilated, and incident short- and long-wave radiation, albedo, corrected precipitation fields will be prescribed to the land surface models. An operational scheme used in numerical weather forecast models, modified to describe an interactive vegetation, will be implemented at the global scale. The model and data assimilation products (state variables, fluxes) will be validated against in situ observations (Dolman et al. 2002, Valentini et al. 2000). The Carbon observatory will be interfaced with the ELDAS project in the areas of exchange of expertise, code, data sets and demonstration studies.

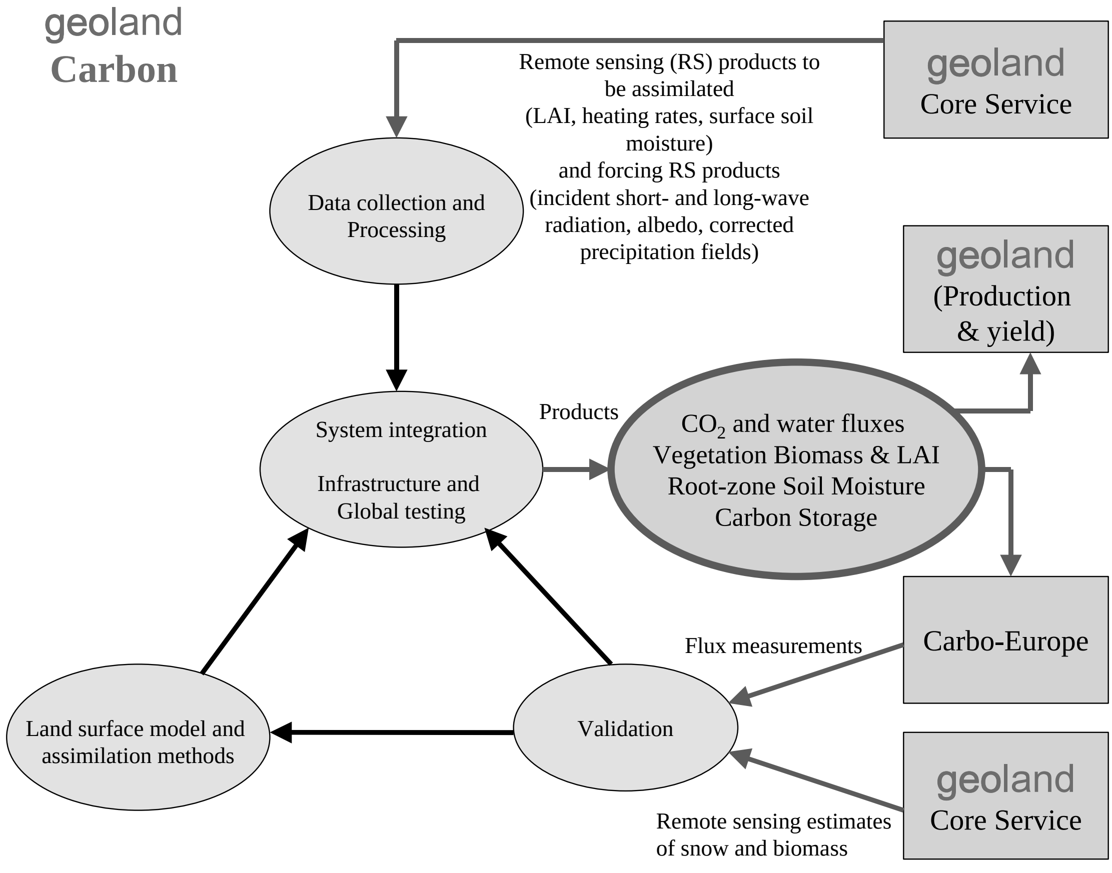

*Figure 2. Structure of the **geo**land/Carbon work plan. Carbo-Europe is a EC funded research project.*

The main difficulties have been identified and a number of solutions are proposed:

Spatial resolution: The spatial resolution considered in this project is about 1/2 degree. At this rather coarse spatial resolution, few "homogeneous" grid-cells are observed. A solution is to account for the sub-cell heterogeneity by using a “multi-patch” version of the used land surface model, i.e. a version able to simulate distinct water and energy budgets in the same grid-cell for the three main surface types which are likely to be found (namely bare soil, woody vegetation and herbaceous vegetation). This tiling strategy will be also applied to the remote sensing data which will be aggregated for each tile. The tiling of remote sensing data will be possible for the data presenting a spatial resolution sufficient to discriminate the different surface types. Data presenting coarser spatial resolution like AMSR brightness temperatures will provide spatially averaged products only.

Atmospheric forcing: The success of an assimilation system to monitor land largely depends on the quality of the atmospheric forcing. ECMWF analysis provide good estimates of air temperature and humidity, wind speed, and atmospheric radiation, but the incident solar radiation, as well as precipitation estimates may present large errors. The analysed precipitation fields present a large error: up to 50% on monthly totals. It is therefore necessary to correct these fields by using observations. The density of available rain gauges and radar-derived precipitation vary from one region of the globe to another, and it is expected that the quality of the precipitation fields, and therefore of the model simulations will not be uniform. Europe and North-America are data-rich areas for which the proposed assimilation system will be most efficient.

Imperfect modeling: Like any model, the existing land surface models are not perfect and the model error needs to be quantified. Indeed, for example, root-zone soil moisture is somewhat model-dependent. Furthermore, the biological processes (plant growth, soil water stress, respiration) are empirically parameterized, in a different way from one model to another. A pragmatic solution consists in running several models. In this project, we will use a new version of the ECMWF land surface model TESSEL (Beljaars and Viterbo 1999, van den Hurk et al. 2003), based on ISBA-A-gs (Météo-France) able to describe an interactive vegetation, and a carbon-water-energy land surface scheme, ORCHIDEE (LSCE). At the end of the project, a single near-operational system will be derived from the two approaches.

Different time scales: The length of the assimilation period may vary according to which variable is to be analyzed. It is about 10 days for soil moisture, and from 1 to 6 months for plant biomass. Two different assimilation systems will be employed, one for soil moisture and one for the plant biomass. The product of each system will be used to constrain the other system.

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