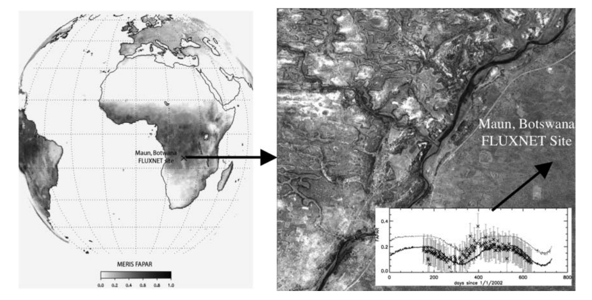
Data Assimilation

Data assimilation is a computer-based technique that uses complex mathematical code to “look” into systems that are being observed from outside. For example, carbon dioxide in the atmosphere has been measured for about 60 years and vegetation has been observed for the entire globe since the 1980s. But now, scientists increasingly need to better understand how the terrestrial biosphere works, which is responsible for a large part of the observations. Because it means going from the effect (here: of plant activity) back to the cause, data assimilation is characterised as an “inverse” technique.

From Site to Globe



RS-CCDAS assimilates the remotely sensed product FAPAR (fraction of absorbed photosynthetically active radiation), a measure of plant health and vigour at the land surface and measured using the MERIS instrument on-board ESA’s ENVISAT satellite. Space observation can thus identify where plants grow well, and where they wilt or shed their leaves, for example due to dry conditions. This is shown in the small inset above right, showing observed FAPAR (cross and bars), modelled FAPAR without assimilation dotted lines) and FAPAR after assimilation (solid line).

The RS-CCDAS project

- Project financed by the European Space Agency (ESA) through its European Space Research Institute (ESA/ESRIN).
- Duration: March 2007 to December 2010.
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Project Partners

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Nadine Gobron (design of space remote sensing retrieval algorithms), Bernard Pinty (modelling of radiative processes).

Carbon-Cycle Mission Design:

RS-CCDAS

Remote Sensing Input for Regional to global CO_2 Flux Modelling: the European Space Agency’s Flagship Mission Assessment Project for Carbon Cycle Modelling

RS-CCDAS is the first project to provide the European Space Agency (ESA) with a flexible tool to assess the value of space missions for the improvement of terrestrial carbon cycle models. It builds on the leading Carbon Cycle Data Assimilation System (CCDAS), a system that combines the power of inversion studies with the capabilities of terrestrial carbon cycle models to predict the impacts of climate change. While carbon cycle inversion to-date can only infer the state of the biosphere at it is now, RS-CCDAS can use various actual or hypothetical data streams to improve its underlying biosphere model and assess the associated improvement in accuracy for both present and future climate states.

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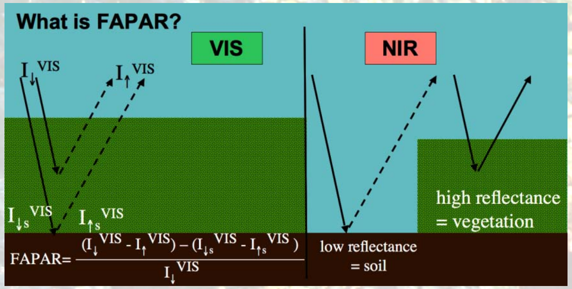
esa

Science Challenges

- Global warming poses a great threat to our planet. Because warming itself can make the land biosphere emit more of the greenhouse gas CO_2, there is a potential for a large extra warming not directly attributable to human emissions.
- To estimate the degree and risk of the additional greenhouse gas effect, we need better models of the terrestrial biosphere.
- Satellite observations of the plant-absorbed fraction of photosynthetically active radiation (FAPAR) are available for many years globally.
- To use those FAPAR observations for better descriptions of how the terrestrial biosphere works, two things are necessary: a biosphere model and an assimilation scheme.
- The biosphere model also needs to be able to predict FAPAR. It therefore requires a predictive model of leaf development (phenology).



Fraction of vegetation Absorbed Photosynthetically Active Radiation: Visible light (VIS) is photosynthetically active. FAPAR is therefore defined as total absorbed VIS radiation minus VIS radiation absorbed by the soil layer. The near-infrared (NIR) reflectance signal is used to distinguish soil from vegetation, because vegetation strongly reflects photosynthetically inactive NIR light, while soil is nearly equally absorbing in both bands. FAPAR biophysical products combine VIS and NIR reflectance data for use in data assimilation systems.

Elements

RS-CCDAS has seven core activities:

Biosphere modelling

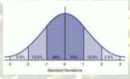
A model of leaf phenology tailor-made for the purpose of data assimilation has been developed.

Regional data assimilation

FAPAR is assimilated simultaneously into the extended CCDAS for six specially selected sites.

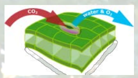
Global data assimilation

Multi-data stream assimilation for CO_2 and FAPAR.



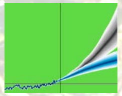
Estimating parameter accuracy

The additional accuracy of the process parameters in CCDAS are estimated.



Diagnostics of carbon and water fluxes

Based on parameter accuracy, RS-CCDAS maps these onto accuracy of computed carbon fluxes and key water-cycle quantities.



Making predictions

RS-CCDAS can also estimate improved accuracy of future projections as needed for better climate predictions.

Mission Design

Results of the previous activities are summarised using mathematical functions and implemented in a user-friendly mission design tool.

RS-CCDAS Publications

W. Knorr, T. Kaminski, M. Scholze, N. Gobron, B. Pinty, R. Giering, and P.-P. Mathieu. Carbon cycle data assimilation with a generic phenology model. *J. Geophys. Res.*, doi:10.1029/2009JG001119, 2010.

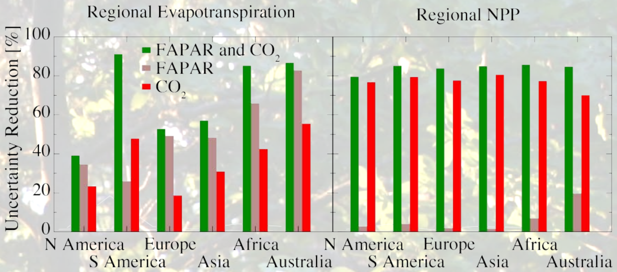
T. Kaminski, W. Knorr, M. Scholze, N. Gobron, B. Pinty, R. Giering, and P.-P. Mathieu. *Assimilation of MERIS FAPAR into a Terrestrial Vegetation Model and Mission Design*. In: Proceedings of ESA, iLEAPS, EGU joint Conference, Frascati, Italy, 2010.

T. Kaminski, W. Knorr, M. Scholze, N. Gobron, B. Pinty, R. Giering, and P.-P. Mathieu. *Assimilation of MERIS FAPAR into a Terrestrial Vegetation Model and Mission Design*. In Proceedings of ESA Living Planet Symposium, Bergen, 2010.

W. Knorr, T. Kaminski, M. Scholze, N. Gobron, B. Pinty, R. Giering, and P.-P. Mathieu. *Local-scale Carbon Cycle Data Assimilation using satellite-derived FAPAR with a generic phenology model.* I: Proceedings of 8th Carbon Dioxide Conference, Jena, 2009.

W. Knorr, T. Kaminski, M. Scholze, N. Gobron, B. Pinty, and R. Giering. *Remote Sensing Input for regional to global CO_2 flux modelling*. In Proceedings of 2nd MERIS/(A)ATSR User Workshop, Frascati, Italy. ESA, 2008.

Global Results



The results of RS-CCDAS show that global satellite-based FAPAR can be used to significantly narrow down estimates of evapotranspiration (water loss through the evaporation from plants and soils; left graphic), whereas atmospheric CO_2 measurements can help significantly improving estimates of carbon fluxes (NPP=net primary productivity, right graphic). Combining both data sources yields a modest additional gain in accuracy.

What RS-CCDAS Offers

- The Carbon Cycle Data Assimilation System (CCDAS) has full data assimilation capabilities: optimisation, making predictions, and assessing accuracy of diagnostics (how accurately can we measure current carbon or water fluxes indirectly through data assimilation?) and predictions (for future fluxes in the case of climate change).
- CCDAS is based on cutting edge automatic differentiation tools developed by FastOpt.
- By extending the CCDAS to include phenology and hydrology, we provide an indirect constraint on carbon and water fluxes also via FAPAR data.
- The new CCDAS is capable of using multiple data streams simultaneously.
- Both capabilities have been implemented in the interactive mission assessment tool.
- By varying parameters of existing or hypothetical FAPAR missions, users of the tool can estimate the accuracy gained when studying the global carbon and water cycles.
- Such estimates are essential for planning Earth observation missions. It is possible to extend RS-CCDAS to satellite products other than FAPAR.