Assimilation of multi-sensor and multi-temporal remote sensing data to monitor vegetation and soil : the Alpilles-ReSeDA project

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ABSTRACT

This paper presents the Alpilles-ReSeDA project, which aims at improving methods for interpreting remote sensing data for a better evaluation of soil and vegetation functioning (primary production, crop yield, energy balance and water budget). The proposed approach is based on the assimilation of remote sensing data into soil and vegetation functioning models. It emphasizes the multi-temporal, multi-spectral and multi-angular properties of space observations.

INTRODUCTION

In the coming years, more and more sensors aboard satellites will allow observation of the Earth over the whole spectrum, from the visible to the microwave domains. This should permit a better understanding of biospheric processes since these various sensors will allow to estimate several biophysical surface variables such as biomass and vegetation structure, surface temperature and water content. Making full profit of these complementary informations requires the development of robust and consistent methods for interpreting remote sensing data (RS data). Since land surfaces are dynamically changing over time and since the RS data coming from the various sensors will no be obtained simultaneously, coupling (or assimilating) RS data with dynamic models that simulate soil and vegetation functioning appears to be the best methodology. This should allow interpretation of the various RS data in a co-operative manner and permitting their use when acquired at different path times.

Vegetation and soil functioning models synthesize our current understanding of the biophysical processes occurring between the atmosphere, vegetation and soil.

- Canopy functioning models (CF models) describe the biophysical processes that govern crop canopy functioning: phenological development, photosynthesis, respiration, evapotranspiration, carbon, nitrogen and water allocation between the various parts of the canopy. They require informations on climate, soil type and species/variety and provide estimates of time courses of biomass, canopy structure, soil water and nitrogen budget.
- Soil Vegetation Atmosphere Transfer models (SVAT models) describe the processes controlling energy and mass transfers in the soil-vegetation-atmosphere continuum. As CF models, they require informations on climate, soil and vegetation types, but also on canopy structure since they are usually not designed to simulate long term vegetation processes. SVAT models may be coupled with CF models to describe energy and mass transfers along a full growth cycle.
- Both CF and SVAT models contain a description of the biophysical characteristics determining the radiative transfers of soils and canopies (structure, optical/dielectric properties, temperature and moisture content) and can simulate RS data when coupled with radiative transfer models (RT models).

The Alpilles-ReSeDA project is funded by the EEC-DG XII and by the French *Programme National de Télédétection Spatiale* and *Programme National de Recherches en Hydrologie*. The IRSA-MARS project provided access to ground data and SPOT images. The ESA-ESRIN provided ERS images. The POLDER airborne sensor was provided by the LOA (Lille, France). The DAIS-LSF program supported the DAIS flight. The Chinese Academy of Science supported the MAIS flights. The STAAARTE program founded the flights of the IROE radiometers aboard the ARAT airplane.

The main objective of the Alpilles-ReSeDA (**Re**mote **S**ensing **D**ata **A**ssimilation) project is to develop and test methods that could lead to a better monitoring of the soil and vegetation functioning. The approach is based on the assimilation of remote sensing data into soil and vegetation functioning models and therefore emphasizes the multi-temporal, multi-spectral and multi-angular properties of space observations. This project was initiated by the French remote sensing community and now federates many European laboratories. The program is decomposed in three main tasks:

• data acquisition, processing and data base: a year long experiment over a small agricultural region aimed at providing a consistent and comprehensive dataset allowing the calibration and the validation of inversion and assimilation procedures;

• inversion of RT models: several techniques will be evaluated and compared to retrieve soil and canopy biophysical variables from multi-spectral-directional-polarization remote sensing observations; they will include formal RT model inversion as well as empirically based techniques;

• assimilation of remote sensing data into SVAT or CF models: several approaches will be evaluated and compared using the multi-temporal data acquired during the experiment.

Since the campaign recently terminated, this paper is mainly devoted to the experimental aspects of the project.

EXPERIMENT

The experiment included field measurements, airborne and satellite RS data acquisitions, covering the whole growing season of winter and summer crops (from October 96 to November 97). The experimental site is a flat agricultural area whose dimensions are approximately 4 km x 5km. It is located in the Rhone valley (SE of France, N 43°47', E 4°45'). Fields are large enough (200 m x 200 m) to extract pure pixels from Earth observation satellites, as well as to implement atmospheric fluxes measurements. Three main crops (wheat, sunflower and alfalfa) were chosen for their very different cultural cycles, but some data were also collected on grass and corn fields.

Ground measurements

Standard meteorological data were acquired close to the center of the site (see Fig.1) along with characterization of incoming radiations and aerosols. In order to calibrate and validate CF and SVAT models, we performed a continuous monitoring of surface energy balance components, surface temperature, albedo, soil water balance, rainfall, vegetation characteristics (height, biomass distribution, LAI), soil characteristics (temperature, moisture and water pressure profile, surface soil moisture, roughness and dry bulk density). Additional measurements such as root density profiles, leaf water potential, stomatal conductance, leaf photosynthesis, plant and soil nitrogen content, leaf chlorophyll content, canopy CO_2 fluxes, soil hydraulic and thermal conductivities, dry bulk density profiles and soil texture were performed at critical periods. The ground data were acquired with three different levels of details:

• a full and continuous characterization was done on *calibration fields* (1 wheat, 1 sunflower and 1 alfalfa, see Fig.1) which will be used for setting up and calibrating models and methods;

• a less detailed continuous characterization was performed on *validation fields* (2 wheat and 2 sunflower) which will be used for validating models and methods;

• measurements on *remote sensing* fields (4 wheat, 1 sunflower, 1 grass and 3 corn) were limited to soil surface and vegetation characterization, concurrently to aircraft campaigns and to some satellite image acquisitions. They will permit further testing of inversion procedures and spatial extension of the previous results.

Some additional measurements were also performed:

– specific measurements in relation with scaling issues were conducted at some periods, close to the center of the site: air temperature, pressure and humidity transects at different heights with a small unmanned aircraft, spatially integrated measurements of heat flux using large aperture scintillometers, radiosoundings to characterize vertical profiles of wind, temperature and humidity;

– semi-quantitative characterization of the soil surface and vegetation status was conducted over 12 segments outside the site, in order to test further extension of the inversion methods.

Airborne remote sensing measurements

Airborne measurements were performed to provide multi-spectral and multi-angular RS data with a high temporal repetitivity (monthly or better). They are expected to be tools for extending the results from the field scale to the small region. Three main sensors were operated:

• the Vis-NIR multi-angular polarimeter POLDER and a thermal IR multi-angular INFRAMETRICS camera, both aboard a Piper AZTEC, provided images with a 20 meters ground resolution, every 15 of 30 days (16 POLDER and 21 INFRAMETRICS acquisitions); 5 flight axes allowed to determine the BRDF and its thermal IR equivalent;

• the microwave multi-angular scatterometer ERASME (C and X bands, HH, VV and sometimes HV), aboard an helicopter, provided along track profiles with a 20 meters ground resolution, during 9 weeks chosen at specific periods in the crop cycles; 14 flight axes permitted to observe the ground-truth fields with view azimuths perpendicular and parallel to the crop rows.

Additional sensors were occasionally operated: the RENÉ polarimetric radar (S band), the IROE microwave radiometers (6.8, 10 and 37 GHz, H and V), the German DAIS and the Chinese MAIS imaging spectrometers (Vis, NIR, MIR, thermal IR).

Satellite images

As much as possible satellite images were acquired during the campaign: SPOT-HRV (5 images), Landsat-TM

(1 image), ERS2-SAR (15 images), RadarSat (7 images at 23° and 38°), NOAA-AVHRR (continuously from October 96), ERS2-AATSR (6 images/month). All these data will be calibrated corrected for atmospheric effects and geo-referenced to provide data equivalent to the ground level.

INVERSION

Retrieving soil and vegetation biophysical characteristics from RS data will be studied using both empirical approaches and formal inversion of radiative transfer models in all spectral domains. Emphasis will be put on the use of multi-angular RS data. The simultaneous use of different spectral domains will also be investigated. Inversion methods will be first implemented and tested at the field scale, then at the scale of the coarse resolution sensors such as AVHRR or VGT, which allow the high temporal repetitivity required for monitoring soil and canopy processes.

ASSIMILATION

Coupling RS data with functioning models (CF and SVAT) can be achieved either by using canopy and soil characteristics obtained by inversion of RT models as inputs in functioning models, or by tuning the parameters of a functioning model coupled to a RT model so as to simulate the observed RS data. Both approaches will be investigated with the different functioning models available (CF: [1,2] SVAT: [3,4,5,6]).

Similarly to the inversion methods, the functioning models will be first implemented *(calibration fields)* and tested *(validation fields)* at the field scale. Then, high-resolution RS data from airborne and Earth observation satellites will permit extension to the whole studied area, generating a spatialized distribution of soil and vegetation processes. Assimilation of RS data at the scale of coarse resolution sensors will be finally addressed using "effective" parameters or spatialization methods in SVAT models, and "top-down" [7] or "bottom-up" [8] approaches in CF models.

CONCLUDING REMARKS

The experimental part of the Alpilles-ReSeDA project was conducted with success: remote sensing and ground-truth data were collected over a wide range of situations representatives of various types of crops. The large number of airborne and satellite data along with the detailed ground measurements should allow investigating many aspects of RT models inversion and assimilation in SVAT and CF models. Additional informations on the program may be found at http://www.synoptics.nl/reseda.

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Figure 1: 5 km x 5 km SPOT-XS image acquired on March 25, 1997 over the Alpilles-ReSeDA site, along with ground-truth fields; **M**: meteorological site; **W**: wheat; **S**: sunflower; **A**: alfalfa; **C**: corn; **G**: grass; **c**: calibration fields; **v**: validation fields; **r**: remote sensing fields.