Monitoring Crop Status at Field Scale using High Revisit Frequency Satellite Observations

Ruxandra Vintila
Frederic Baret
Claire Lauvernet
Nadia Rochdi
Helene Deboissetz, et al.
Monitoring Crop Status at Field Scale using High Revisit Frequency Satellite Observations

Roxana Vintila¹, Frédéric Baret², Claire Lauvernet³, Nadia Rochdi³, Hélène Deboissezon¹, Jean-Claude Favard¹ and Cristina Radnea¹

¹National Research Institute of Soil Science, Agrochemistry and Environment (ICPA), Romania
²National Research Institute of Agronomy (INRA), France
³National Space Agency (CNES), France

Abstract: This study aims at defining the revisit frequency of future space missions dedicated to the monitoring of agriculture at the field scale. It was developed within the ADAM Project, during which a unique series of high spatial resolution and high revisit frequency observations were acquired by the concurrent use of three SPOT satellites.

The approach focused on the monitoring of the green leaf area index (LAI) dynamics. The definition of the satellite revisit frequency was based on weekly LAI estimates derived from the available observations, using a model of LAI time course (MODLAI). The scenarios investigated contrasted LAI dynamics of wheat crops, three levels of uncertainties characterizing LAI estimation from remotely sensed data (10%, 20% or 25%), six satellite revisit frequencies (from 1 to 30 days), two probability levels for cloudy days (0.5 or 0.7).

Results indicated that the rms error between estimated and reference LAI is low up to seven days revisit frequency whatever the LAI error levels and cloud occurrence. This can be explained by the good temporal interpolation performances of MODLAI associated with a significant number of acquisitions. For the lower revisit frequency satellite observations, weekly LAI estimates are very sensitive to the measurements and model uncertainties associated with the individual LAI retrieval.

1. Introduction

This study was developed during the ADAM Project investigating the “Assimilation of spatial Data within Agronomic Models” (http://medias.obs-mip.fr/adam/). One of its major objectives was to define the main characteristics, including the revisit frequency, required for future space missions dedicated to monitoring crops at the field scale.

The ADAM database (Favard, Deboissezon et al., 2004) provided great opportunities for this study: (1) unique possibility to integrate both high spatial resolution and high revisit frequency of remotely sensed data, acquired by the concurrent use of three SPOT satellites; (2) consistency of the “top of canopy” reflectance data, with the best present knowledge about image radiometric and geometric corrections; (3) contrasted crop dynamics over large fields.

The study focused on the monitoring of the green leaf area index (LAI) evolution, which is related to productivity and can be estimated from the available multispectral SPOT data. Watson (1947) gave the LAI definition correlated to crop productivity as “total one-sided area of leaf tissue per unit ground area”.

At present, LAI dynamics is currently monitored only at coarse and medium spatial resolution from the large swath sensors, such as VEGETATION, MODIS or MERIS, and used as input in global models of biosphere-atmosphere exchanges of energy, carbon dioxide, water vapor and other materials (Asner et al., 2003).

Preliminary results of ADAM (Baret et al., 2004) demonstrated the capacity to monitor the LAI dynamics also at high spatial resolution, by using the depointing capability of SPOT series of satellites to increase the revisit frequency. They proved that both knowledge and technology are mature enough for future space missions characterized by high spatial resolution and high revisit frequency.

This paper focuses on the definition of the optimal satellite revisit frequency that allows fulfilling the basic requirements of decision makers at the field scale: getting weekly estimates of LAI at a spatial resolution between 10 to 20 meters.

2. Data and method

Data. The ADAM site (http://medias.obs-mip.fr/adam) is a 20 x 20 km² level landscape dominated by large agriculture fields (15-40 ha). It is located close to Bucharest (Romania). The soils are homogeneous, and most of the variability comes from the cultural practices that could have background effects over several years (Canarache, 2002).

From October 2000 to July 2001, 39 SPOT satellite images were acquired in multispectral mode (XS) at 20x20 m² spatial resolution. The high revisit frequency was routinely achieved by the concurrent use of SPOT1, SPOT2 and SPOT4 satellite sensors.

A consistent time series of satellite images was produced under the supervision of the National Space Agency of France. The radiometric corrections implied sensor inter-calibration and atmospheric corrections, using data gathered by a Cimel sun-photometer connected to the AERONET network, and made available “top of canopy” reflectance data. The geometric corrections used a digital elevation model and were performed by spatio-triangulation techniques, leading to less than 0.5 pixel co-registration accuracy.
LAI was continuously measured by the direct destructive methods over forty elementary sampling units (ESUs), each unit (30mx30m) being representative of a small number of SPOT pixels (Baret et al., 2004). Only wheat crops were considered. The 40 ESUs sampled represented the largest range of crop conditions accounting for variation in cultivar, sowing date, precedent crop (favorable and unfavorable), fertilization level, and micro-topography.

**Method.** The satellite revisit frequency was determined by simulations of LAI estimated from remotely sensed data, and comparison with a reference LAI data set generated from measurements performed over the ESUs. The simulations took into account:

1. three levels of overall uncertainties characterizing LAI retrieval from remotely sensed data, caused both by measurements uncertainties and radiative transfer model adequacy (10%, 20% and 25%);
2. six scenarios of satellite revisit frequency, covering the current capabilities of sensors of high, medium and coarse spatial resolution (1, 2, 3, 7, 15 and 30 days);
3. two probabilities of daily cloud occurrence (0.5 and 0.7). The method proposed for simulation is shown in Figure 1 and included the following stages:

1. **Generation of one weekly reference LAI data set.** The results obtained in a previous phase of the ADAM Project concerning the “daily true LAI” (Baret and Vintila, 2003) were used to generate one weekly reference LAI data set. This was achieved over the 40 ESUs.
2. **Generation of LAI data sets for simulation of satellite acquisition scenarios.** First, several “daily noisy LAI” data sets were generated from the “daily true LAI”, to account for measurements and models uncertainties. Three levels of additive white Gaussian noise were considered: 10%, 20% and 25%. Second, the assumption on the satellite revisit frequency transformed the “daily noisy LAI” data sets into “observable LAI” data sets (i.e. LAI at dates depending on the revisit frequency). The start day of the revisit cycle was randomly selected. Finally, the drawing of cloud masking within the cloud occurrence probability law transformed the “observable LAI” into “observed LAI” data sets.
3. **Generation of weekly estimated LAI.** The lack of continuous temporal coverage of estimated values of LAI was overcome using the MODLAI evolution model (Baret, 1986):

\[
LAI = K \left[ \frac{1}{1 + e^{-b(T-T_i)}} - e^{-a(T-T_s)} \right]
\]

where T represents the accumulated daily mean air temperature above 0° C (for wheat) starting from sowing, K is the amplitude of maximal leaf area, b is the relative growth rate at the first inflexion point Ti, a is the relative senescence rate, and Ts is the disappearance time of the green leaves. The parameters were estimated by model inversion, using the Gauss-Newton iterative method for non-linear optimization, and look-up tables for global optimization (Knyazikhin et al., 1998).

Once the parameters were estimated, MODLAI was run in the forward direction to generate LAI at the same fixed weekly dates as in the reference LAI data set.

4. **Evaluation of performances.** Finally, the root mean square error (rmse) was calculated between the estimated LAI and the reference LAI for each couple of weekly dates during the growth cycle.

**Results and discussion**

This method was repeated 35 times over the 40 ESUs (i.e. 1400 cases simulated) to get values statistically meaningful while accounting for the random character of cloud occurrence and individual LAI retrieval uncertainties. Figure 2 shows the overall performances as a function of satellite revisit frequency, for the two levels of cloudiness and the three levels of errors in individual LAI retrieval.

Results indicated that the uncertainties of the weekly LAI estimates as compared to the reference LAI are very low and quite similar up to 7 days revisit frequency, regardless of measurements and radiative transfer model uncertainties or the two cloud occurrence probability levels. This is explained by the good interpolation capacity of the MODLAI dynamics model, which exploited the high temporal consistency of crop growth. MODLAI was always well adjusted to the ensemble of individual observations, when their number was large enough, i.e. around 12 to 18 observations spanning over the 9 months growth cycle.

For lower revisit frequencies (15 and 30 days), results show that the quality of individual LAI retrieval is very important, calling for improved radiometric accuracy and an accurate radiative transfer model and inversion procedure.
4. Conclusion and perspectives

This study was conducted over a given set of conditions and under specific assumptions. The degree of generality of the results acquired could be enlarged by more documented assumptions and simulations for other crops, including summer crops such as maize or sunflower that have shorter growth cycles. However, results clearly highlighted the importance of the canopy structure dynamics modeling to exploit efficiently the temporal dimension of the remotely sensed data. This is in agreement with findings published by Koetz et al. (2005), who found significant improvement on maize LAI estimates using similarly the MODLAI model.

Besides the temporal constraints studied, results on data assimilation developed within ADAM showed that the satellite revisit frequency could be decreased if spatial constraints are considered (Lauvernet, 2005). In the same way, replacing this simple MODLAI model by a true crop functioning one, accounting for more detailed processes, may result in increased accuracy as well as direct access to high level outputs of interest, such as biomass and yield production, water and nitrogen balance.

This study shows that combining reasonably high revisit frequency observations (about 1 week) at high spatial resolution (10-20m) with knowledge on canopy functioning may provide a pertinent answer to decision makers at the field scale. This may also fulfill the requirements at larger scales by aggregation of the local information. It is therefore mandatory to launch as soon as possible such a satellite mission to replace in a timely manner the current series of sensors and ensure at the same time the continuity and improvement of Earth monitoring from space.

Acknowledgment

The National Research Programs of France and Romania financed the ADAM Project, which included this study. The authors express their gratitude to all the institutions committed to the ADAM Project.

References


Address:
Roxana Vintila and Cristina Radnea: ICPA, 61, Marasti Str., 011464 Bucharest, Romania (rvi@icpa.ro; radneacris@yahoo.com)
Frédéric Baret, Claire Lauvernet and Nadia Rochdi: INRA-CSE, Dom. St. Paul, Site Agroparc, 84914 Avignon France (baret@avignon.inra.fr; lauverne@avignon.inra.fr; Nadia.Rochdi@CCRS.NRCan.gc.ca)
Hélène Deboisseyzon and Jean-Claude Favard: CNES, 18 Av. Ed. Belin, 31055 Toulouse, France (helene.deboisseyzon@cnes.fr; jean-claude.favard@cnes.fr)