Definition of the required satellite revisit frequency
to fulfill farmer information needs -
Use of GNSS in precision agriculture

Roxana Vintilă (ICPA Romania), Frédéric Baret (INRA France),
Hélène de Boissezon, Jean-Claude Favard (CNES France)
At present, the leading domains of Earth Observation applications are **Meteorology** and **Oceanography**, where satellite images are integrated in operational systems.
As compared to the operational systems used in Meteorology and Oceanography, Agriculture is one step behind.

However, in accordance with a French Feasability Study (2000)

- about 500,000 farmers are potentially interested by near-real time agronomic information (Lat: 30° - 50°N & 30°- 40° S)
- the affordable price of information: 7-8 Euro/year/ha
Evaluating the data assimilation technique in Agriculture to fulfill farmer information needs was the objective of the “ADAM” Project: “Assimilation of spatial Data by AgroModeling”

Participants

France:
- French Space Agency (initiative)
- Institute for Agronomic Research
- College of Agriculture Purpan

Romania:
- Romanian Space Agency
- Institute for Soil and Agrochem. Research
- Institute for Cereals Research
- InterGIS srl (GNSS measurements provider)
Concept of Spatial Data Assimilation in Agriculture

“ADAM” aimed to define the specifications of a spatial mission
“Agriculture”
adapted to the assimilation data technique
Specifications of a spatial mission “AGRICULTURE”

• satellite revisit frequency ?

• spatial resolution ?

• spectral bands ?

to fulfill farmer information needs, at an affordable price
ADAM web page: http://medias.obs-mip.fr/adam/
**ADAM Data Base**

- **Meteo - Atmosph.**
  - 2000/2001 campaign
  - 2001/2002 campaign
  - ******

- **Soil**
  - 2000/2001 campaign
  - 2001/2002 campaign
  - ******

- **Vegetation**
  - 2000/2001 campaign
  - 2001/2002 campaign
  - ******

- **Maps**
  - Permanent maps
  - 2000/2001 campaign
  - 2001/2002 campaign
  - ******

- **Satellite images**
  - SPOT (TOA, TOC, aux.data, ext., QL)
  - ERS (intensity, aux. data, ext., QL)
  - RADARSAT (intensity, aux.data, ext., QL)
  - Reference image

- **Meetings**
  - Steering Committees
  - Technical Meetings

- **Temp**

- **Export**

---

**All ground data**

**were located**

**by GNSS measurements**

**Yield maps**

**produced by YMS**

**The reference satellite images**

**were registrated**

**using ground control points**

**located by GNSS measurements**

**Measurements in differential mode**
“ADAM” Site (40 x 60 km²)
Localization: Romania, Fundulea, 35 km East of Bucharest
In this topic we are dealing with the most important biophysical variable retrievable from radiometric data: the Leaf Area Index (LAI).

LAI is required for decision making with:
- a weekly update of the values
- a given accuracy (to be defined)

What is the required satellite revisit frequency to produce pertinent agronomic information, that can be derived by LAI data assimilation?
STEP I: DERIVING LAI
FROM “ADAM” SATELLITE TIME SERIES

Input data and algorithm

• 33 SPOT XS images from the ADAM campaign 2000-2001
• Green, Red and Near Infrared Bands (“top of canopy” reflectance)
• 30 classes of radiometric evolution found by k-means algorithm
• LAI evolution model parameters found by minimisation of distances among measured and simulated data
Comparison between the measured and simulated LAI values

RMSE = 0.27574
R2 = 0.95952
**STEP II: Definition of the satellite revisit frequency**

**APPRAOCH OVERVIEW**

- **TRUE LAI** (from the ADAM experiment)
- **OBSERVABLE LAI** (depending on the revisit freq.)
- **OBSERVED LAI**

**Flowchart:**
- Weekly values
- +10% NOISE
- Reference LAI
- RMSE
- CLOUDS
- FITTING THE LAI MODEL
- Estimated LAI
Assumptions used

(1) Simulations are enough realistic
   • variability of situations, as observed over the ADAM experiment
   • uncertainties levels on LAI estimates from RS observations: 10%, 20% and 25%

(2) Consideration of 6 revisit frequency scenarios:
   1-day, 2-days, 3-days, 7-days, 15-days and 30-days

(3) Probability levels to have clouds: 0.5 and 0.6, independent with time

(4) Phasing of the orbit cycle variable (start day randomly drawn)

(5) Reference case made of the “true” LAI observed weekly (fixed dates)
Generation of the “true and reference” LAI data set

Empirical Transfer Functions
(previously obtained, see article IGARSS’03)

LAI = \alpha_0 + \sum_{i=1}^{3} \alpha_i \rho_i

For 40 Sampling Units:

\widehat{\text{LAI}}

at SPOT acquisition dates
(28 dates between 15 Oct 2000 – 6 June 2001)

Linear interpolation

Daily \widehat{\text{LAI}}

Weekly \widehat{\text{LAI}}
(2) Generation of an “observable” LAI dataset taking into account measurement and model uncertainties, in the form of an additive gaussian noise

Exemple
(3) Generation of **time series of good images**

considering:

- six scenarios of satellite revisit frequency
- two probability levels to have clouds (clear sky)
- different starting date for the acquisition cycle
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1-day revisit</td>
<td>2-days revisit</td>
<td>3-days revisit</td>
<td>7-days revisit</td>
<td>15-days revisit</td>
<td>30-days revisit</td>
<td>Clear sky</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>31</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>32</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>34</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>35</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>37</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>38</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>41</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Fitting the LAI evolution model (1/2)

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

where \( K \) is the amplitude of maximal leaf area,
\( b \) is the relative growth rate at the first inflexion point, called \( Ti \),
\( a \) is the relative senescence rate,
\( Ts \) is the disappearance time of green leaves
\( T \) is the accumulated daily mean air temperature
Fitting the LAI evolution model (2/2)

Fitting of the LAI evolution model

Method:
Non-linear optimisation using the Gauss-Newton iterative method (solution for the non-linear least squares problem)

Optimisation

Successful LAI Model Parameters

Failed
RELEVANT RESULTS

(I) Example of retrieved LAI dynamics
as compared with the weekly reference LAI dataset

for

• one sampling unit

• six revisit scenarios

• one replicate
(II) Overall results over:

- 40 sampling units
- 6 revisit frequency scenarios
- 30 replicates (clouds occurrence scenarios)
CONCLUSION

The results indicate that a 3 days to 1 week revisit frequency could be enough to generate enough accurate LAI values to produce information needed by farmers.

At present, the propagation of LAI uncertainties on yield estimation and on other higher level products is investigated, by running data assimilation techniques.

Remark:

On-going studies performed within “ADAM” (Claire Lauvernet) show that the revisit frequency could be dropped to 15 days, if information on spatial structures is added.

Follow-up the ADAM web page!
Thank you for your attention!