Contribution of Alos, Radarsat-2 and TerraSAR-X radar data for monitoring agricultural surfaces

By Rémy Fieuzal

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IGARSS – 24-29 July 2011
Objectives of the MCM’10 Experiment:

• Developing new approaches and algorithms for surface monitoring at high spatial resolution by using optical, thermal and radar data.

• Improving the estimate of biophysical parameters of the main crops encountered in the studied region (wheat, rapeseed, corn, sunflower, ...).

• Monitoring crop practices (tillage, sowing, ...)

Why choosing the high spatial resolution?

• Consistent scale with ground measurements.

• Evaluation of the upscaling approaches for analyses low resolution products (SMOS, ASCAT, AMSR-E...).

• Consistent with the actual and future satellite missions (Sentinel, Radarsat-2, TandemX, CosmoSky-Med,...).
• Use of spectral complementarities
• The approach consists in Multisensors quasi-synchronous acquisitions

- Microwave domain
  - TerraSAR-X,
  - RADARSAT-2,
  - ALOS,
  - ENVISAT.

- Optical and Thermal domains
  - SPOT 4-5,
  - FORMOSAT-2,
  - ASTER,
  - LANDSAT 5-7.

- Low resolution acquisitions
  - SMOS, AMSR-E, ASCAT...
Winter Crops
(Wheat – Rapeseed)

Summer Crops
(Corn – Sunflower – Soybean)

Objectives
Satellite Data
Study Area
Ground Measurements

MCM Experiment

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
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</table>

AP-L

RS-C

TS-X
Examples of L-, C- and X-Bands images

ALOS +

RDSAT-2 +

TSX +

L-, C- and X-Bands color-composed images

2010/04/14

2010/06/16
The study site is located in the South West of France, near Toulouse.

- Meteorological conditions are steered by a temperate climate
- Surface is mainly covered by crops (wheat, rapeseed, corn, sunflower, soybean...), sparse forests and urban areas.
All measurements and observations are performed quasi-synchronously with satellite acquisitions.

3 Levels of information:

- **Red fields (37):**
  - **Soil measurements**
    - Moisture (along transects)
    - Texture (along transects)
    - Roughness (2m pin profiler)
  - **Vegetation measurements**
    - Height (punctual)
    - Biomass
    - Water content

- **Yellow fields (350):**
  Observations concern crop types, field orientations, vegetation heights, roughness states...

- Land use → more than 10,000 fields.
**Soil moisture behavior at different scale**

*From regional to point scale*

**Mean over the 37 fields**

**High spatio-temporal changes of SSM**
### Complementary surface parameters

**Soil texture**

- Clay = 24%
- Sand = 24%
- Silt = 52%

*FAO triangle classification*

**Crop Biomass**

- ESU R
- ESU Q

**Soil roughness**

- MCM Experiment
• Empirical estimation of **SSM (first results)**

*Multi-angular approaches (from 28° to 53°)*

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**X-band @ 53°**

- Frequency: 9.65 GHz
- Incidence Angle: ~53°
- \(Y = 0.28 \times -15.27\)
- RMSE = 1.10 dB
- \(R^2 = 0.86\) \(n = 57\)

**C-band @ 40°**

- Frequency: 5.4 GHz
- Incidence Angle: ~40°
- \(Y = 0.25 \times -14.89\)
- RMSE = 1.65 dB
- \(R^2 = 0.31\) \(n = 35\)

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Less sensitivity to soil roughness at X band – higher potentialities for **SSM** estimation

Offset between satellites acquisitions and ground measurements (max of 2 days)

Correction of **SSM values in time.**
- Example of SSM maps performed at X-band

*Over bare soil (NDVI (Formosat-2) < 0.5)*

Before and after a rainfall event

0  30%
### MCM Experiment

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<th>Soil modeling</th>
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<td><strong>Models</strong></td>
<td><strong>L-Band</strong></td>
</tr>
<tr>
<td><strong>C-Band</strong></td>
<td><strong>X-Band</strong></td>
</tr>
</tbody>
</table>

- **Models**
  - L-Band
  - C-Band
  - X-Band

- **Modeling of the backscattering coefficient over bare soil**

- Oh 1992,
- Oh 2004,
- Dubois,
- IEM (Physical model)

\[
\sigma_{HH}^0 = 10^{-2.75} \frac{\cos \theta^{1.5}}{\sin \theta^5} \left( \frac{10^{0.029} \varepsilon \tan \theta (k \cdot hrms \cdot \sin \theta)^{1.4}}{\lambda^{0.7}} \right)
\]

\[
\sigma_{VV}^0 = 10^{-2.35} \frac{\cos \theta^{3}}{\sin \theta^3} \left( \frac{10^{0.046} \varepsilon \tan \theta (k \cdot hrms \cdot \sin \theta)^{1.1}}{\lambda^{0.7}} \right)
\]

*(Example for the Dubois model)*

**Input parameters:**

- Soil moisture (%)
- Soil roughness (Hrms, lc)
- Incidence angle (°)
- Frequency (GHz)
- Soil texture (%)
  - Clay 30%,
  - Sand 15%,
  - Silt 55%.

Parameters with variables values
High sensitivity to soil roughness (for all models)

Work on progress: taking into account soil texture heterogeneities and field row directions
Medium sensitivity to soil roughness (for the Oh 1992 and 2004 models)

Work on progress: taking into account soil texture heterogeneities and field row directions.

<table>
<thead>
<tr>
<th>Models</th>
<th>RMSE</th>
<th>$R^2$</th>
<th>Bias</th>
<th>$a$</th>
<th>$b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oh 1992</td>
<td>2,33</td>
<td>0,16</td>
<td>0,18</td>
<td>0,41</td>
<td>-5,14</td>
</tr>
<tr>
<td>Oh 2004</td>
<td>2,67</td>
<td>0,14</td>
<td>0,25</td>
<td>0,46</td>
<td>-4,55</td>
</tr>
<tr>
<td>Dubois</td>
<td>3,81</td>
<td>0,06</td>
<td>0,54</td>
<td>0,42</td>
<td>-4,64</td>
</tr>
<tr>
<td>IEM</td>
<td>3,52</td>
<td>0,07</td>
<td>1,08</td>
<td>0,39</td>
<td>-4,39</td>
</tr>
<tr>
<td>opt IEM</td>
<td>2,60</td>
<td>0,14</td>
<td>1,36</td>
<td>0,33</td>
<td>-4,61</td>
</tr>
</tbody>
</table>

HH polarization

<table>
<thead>
<tr>
<th>Frequency = 5.4 GHz</th>
<th>Bias (Mes-Sim) = 0.18 dB</th>
<th>RMSE = 2.33 dB</th>
<th>$R^2 = 0.16$</th>
<th>$n = 206$</th>
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<td>Frequency = 5.4 GHz</td>
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Medium sensitivity to soil roughness (for the Oh 1992 and 2004 models)

Work on progress: taking into account soil texture heterogeneities and field row directions
Small sensitivity to soil roughness (for the Oh 1992 and 2004 models)
Work on progress: taking into account soil texture heterogeneities and field row directions

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<tr>
<td>Oh 1992</td>
<td>2.22</td>
<td>0.47</td>
<td>-0.76</td>
<td>1.02</td>
<td>-0.60</td>
</tr>
<tr>
<td>Oh 2004</td>
<td>2.77</td>
<td>0.43</td>
<td>0.69</td>
<td>1.20</td>
<td>2.61</td>
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<tr>
<td>Dubois</td>
<td>4.75</td>
<td>0.34</td>
<td>0.22</td>
<td>1.71</td>
<td>7.04</td>
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<tr>
<td>IEM</td>
<td>6.41</td>
<td>0.00</td>
<td>-0.33</td>
<td>-0.21</td>
<td>-11.91</td>
</tr>
</tbody>
</table>

HH polarization

Frequency = 9.65 GHz
Bias(Mes-Sim) = -0.76 dB
RMSE = 2.22 dB
$R^2 = 0.47$
n = 251
<table>
<thead>
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<th>Soil moisture estimation</th>
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<th>Vegetation monitoring</th>
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<td>• Crop types</td>
<td>• Temporal radar signatures</td>
<td>• Sensitivity to crop parameters</td>
<td></td>
</tr>
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</table>

- **Wheat**
- **Rapeseed**
- **Sunflower**
- **Corn**
- **Soybean**
- **Hemp**
• Example over a wheat field

*Multi-frequency results (L-, C- and X-Bands)*

Relation with top soil moisture at L-band?

Same behavior at X- and C-band.

Higher dynamic at X-band (growing period).

- **RADARSAT-2 - HH**
  - 7 dB

- **ALOS - HH (38.7°)**
  - 11 dB

- **TerraSAR-X - HH**
  - 10 dB
Promising results are obtained at C-band with HV, VH and VV polarizations and polarization ratio will be more investigated in the near future.

**MCM Experiment**

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**Summary of multispectral capabilities for crop monitoring**

*Results for HH polarization*

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Rapeseed</th>
<th>Corn</th>
<th>Sunflower</th>
<th>Soybean</th>
<th>Hemp</th>
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</thead>
<tbody>
<tr>
<td>X-Band</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>+++</td>
</tr>
<tr>
<td>C-Band</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>L-Band</td>
<td>-</td>
<td>+</td>
<td></td>
<td>No high resolution data</td>
<td></td>
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</tbody>
</table>
• Example of Relationship with LAI (Leaf Area Index) and crop height

\[ \text{LAI} = -6.247 \times \ln(0.946 - 0.643 \times MTVI2) \]

(Liu et al., 2009)

\[ MTVI2 = \frac{1.5[1.2(R_{800} - R_{550}) - 2.5(R_{670} - R_{550})]}{\sqrt{(2R_{800} + 1)^2 - (6R_{800} - 5\sqrt{R_{670}}) - 0.5}} \]

(Modified Triangular Vegetation Index, Haboudane et al., 2004)
MCM Experiment

- It provides a unique dataset for the investigation of multi-sensor crop monitoring.
- Ground and satellite data must be improved (angular normalization of satellite data and SSM values have to be corrected in time).

Soil moisture estimation

- Higher potentialities of X-band data for SSM monitoring and mapping (compare to C- and L-band data)
-Empirical estimates of SSM must be investigated for the whole satellite angular range (from 20 to 55°) at field and point scales (potential for SSM monitoring inside an agricultural field ?).
Soil modeling

- Oh 1992 (X and L-band) and IEM (C-band) provide best results ($r^2=0.47-0.35-0.26$).
- Taking into account soil texture and field orientation.
- Reducing the roughness effect in Oh 1992 model.
- Testing other available models?
- Inversion of models for SSM estimates.

Vegetation monitoring:

- Crop cycles can be monitored by using multi-frequency radar data in complement with optical data.
- Relationship between LAI, crop height, biomass and water content must be extended to other crops.
- Multi-sensor index must be investigated by using optical, radar and thermal data.
**Land use**

*Multi-frequency Classification*

- Soybean
- Harvested Wheat
- Sunflower
- Corn
- Forest

**Irrigation survey**

*On going irrigation*

*Color-composed image:*
- C-Band, VV (14/07/2010)
- X-Band, HH (15/07/2010)
- C-Band, HV (14/07/2010)
Deep ploughing

Smooth soil

Smooth soil with clods

**Tillage distinction**

*Color-composed image done with 3 TerraSAR-X acquisitions from 23\textsuperscript{th} to 25\textsuperscript{th} of November 2010 (VV45° – HH27° – HH53°).*
• Pol-In-SAR investigations

Pauli representation
Thank you for your attention

Thanks to the CSA, ESA, DLR and JAXA for providing radar data