Validation of Sentinel-2 Biophysical Prototype Products using ESA Field Campaigns

Frédéric Baret1, Fernando Camacho2, Beatrice Berthelot3, Richard Fernandes4, Marie Weiss1, Riccardo Duca5

1 INRA-EMMAH Avignon, France
2 EOLAB, Valencia, Spain
3 Magellium, Toulouse, France
4 CCRS, Otawa, Canada
5 ESA/ESTEC, Noordwijk, The Netherlands
Objectives

• Provide first evaluation of Sentinel2 Level2B potential land biophysical products performances
  – LAI
  – FAPAR
  – CCC (Canopy Chlorophyll Content)
  – CWC (Canopy Water Content)

• Propose guidelines for the validation of decametric products

• Propose additional campaigns
Outlook

• Prototype products considered
• Campaigns available
• Simulation of S2 L2a products
• Available ground measurements
• Results
• Conclusion
The prototype products considered

- **CFI: Neural-networks trained on radiative transfer model simulations**
  


- **Non-CFI: Vegetation indices calibrated with radiative transfer model simulations**

  - **LAI: NDRE**
    

  - **FAPAR: MGVI**
    

  - **CCC: MTCI**
    

  - **CWC: NDWI**
    
The campaigns available

AGRISAR 2006
EAGLE 2006
CEFLES 2007
SEN3EXP 2009
SEN3EXP 2009
SEN2FLEX 2005
SPARC 2003-2004
Available ground measurements

<table>
<thead>
<tr>
<th>CAMPAIGN</th>
<th>LAI, FAPAR, FCover</th>
<th>WC</th>
<th>Ch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DHP</td>
<td>LICOR</td>
<td>AccuPAR</td>
</tr>
<tr>
<td>SEN3EXP</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>SEN2FLEX</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>CEFLEx</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>AGRISAR</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SPARC</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

Several methodologies, often poor documentation  
Need for a guidelines!!

Mostly crops were sampled  
Need for other experiments!

Only few data available for some variables  
Difference between effective and actual variables
Ground data: checking the methods

**LICOR vs LICOR**

\[ y = 0.25 + 0.88x \]

RMSE \approx 0.5

**LICOR vs DHP**

\[ y = 0.19 + 0.83x \]

RMSE \approx 0.75

---

**Leaf Chlorophyll Content: CCM vs SPAD**

The uncertainty attached to the CCM can be estimated considering the uncertainties of LCC (~5 mg cm\(^{-2}\)) and LAI (~0.5 for effective estimates).

**Example:**

Canopy LA\(_{eff}\) = 3 and LCC = 35 mg cm\(^{-2}\) \(\Rightarrow\) CCM = (110±30) mg cm\(^{-2}\), about 30%

**Canopy Water Content: Sampling1 vs Sampling2**

The uncertainty attached to the CWC can be estimated considering the uncertainties of LWC (~50 g m\(^{-2}\)) and LAI (~0.5 for effective estimates).

**Example:**

Canopy LA\(_{eff}\) = 3 and LWC = 330 g m\(^{-2}\) \(\Rightarrow\) CWC of (10±3) \(\times\) 10\(^2\) g m\(^{-2}\), about 30%
Simulation of S2 L2a products

- A range of available airborne sensors
- Not always the proper spectral sampling to simulate S2 (red-edge, SWIR)
- Geometric performances not always very good
- Radiometric calibration sometimes questioning
- Atmospheric correction uncertainties
- Use of the S2 simulator to get S2 L2a products

Need for better sensors (APEX, HYPER) … and actual S2 data!!
Results (1): available database

- Ground data well organized with metadata
- Airborne data and simulated S2 L2a well organized

<table>
<thead>
<tr>
<th>Plot #</th>
<th>Plot Label</th>
<th>ESU #</th>
<th>ESU Label</th>
<th>Northing Coord</th>
<th>Easting Coord</th>
<th>Extent (m) of ESU</th>
<th>Land Cover</th>
<th>Start Date (dd/mm/yyyy)</th>
<th>End Date (dd/mm/yyyy)</th>
<th>Method</th>
<th>Nb. Replications</th>
<th>LAI</th>
<th>Uncertainty</th>
<th>LAI</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>1</td>
<td>A1-E1</td>
<td>39.0472</td>
<td>-2.10851</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR2</td>
<td>17</td>
<td>0.74</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
<td>1</td>
<td>A1-E1</td>
<td>39.0472</td>
<td>-2.10851</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR3</td>
<td>21</td>
<td>0.74</td>
<td>0.1</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
<td>1</td>
<td>A1-E1</td>
<td>39.0472</td>
<td>-2.10851</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR2</td>
<td>15</td>
<td>0.63</td>
<td>0.08</td>
<td>1.08</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
<td>2</td>
<td>A1-E2</td>
<td>39.0458</td>
<td>-2.11167</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR3</td>
<td>21</td>
<td>0.82</td>
<td>0.11</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
<td>3</td>
<td>A1-E3</td>
<td>39.0471</td>
<td>-2.11259</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR2</td>
<td>15</td>
<td>0.56</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
<td>3</td>
<td>A1-E3</td>
<td>39.0471</td>
<td>-2.11259</td>
<td>20</td>
<td>Alfalfa</td>
<td>11/07/2005</td>
<td>11/07/2005</td>
<td>LICOR3</td>
<td>21</td>
<td>0.71</td>
<td>0.08</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Nb. Replications</th>
<th>LAfEff</th>
<th>Uncertainty</th>
<th>LAI</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>LICOR2</td>
<td>17</td>
<td>0.74</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR3</td>
<td>21</td>
<td>0.74</td>
<td>0.1</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>DHP</td>
<td>16</td>
<td>0.89</td>
<td>NA</td>
<td>1.16</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR2</td>
<td>15</td>
<td>0.63</td>
<td>0.08</td>
<td>1.08</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR3</td>
<td>21</td>
<td>0.82</td>
<td>0.11</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>DHP</td>
<td>16</td>
<td>0.62</td>
<td>NA</td>
<td>0.90</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR2</td>
<td>15</td>
<td>0.56</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR3</td>
<td>21</td>
<td>0.71</td>
<td>0.08</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>DHP</td>
<td>16</td>
<td>0.62</td>
<td>NA</td>
<td>0.90</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR2</td>
<td>24</td>
<td>3.54</td>
<td>0.15</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LICOR3</td>
<td>24</td>
<td>3.05</td>
<td>0.12</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>DHP</td>
<td>14</td>
<td>4</td>
<td>NA</td>
<td>9.78</td>
<td>*</td>
</tr>
<tr>
<td>DHP</td>
<td>10</td>
<td>5.4</td>
<td>NA</td>
<td>9.15</td>
<td>NA</td>
</tr>
</tbody>
</table>
Results(2): methods for validation

Baret, F. and Fernandes, R., 2012. Validation Concept, European Space Agency,
Results(3.1): LAI-AHS

Large discrepancies!!
Results(3.2): LAI-AHS

LAI(NDRE) not reliable
Problem in the calibration?
Results (3.3): LAI-AHS / LSA SAF

Very good consistency with LSA SAF
Question for the high LAI values
Results(3.4): FAPAR

Very good spatial consistency
Some tuning for MGVI(S2)
Results(3.5): FAPAR

Good performances
Some underestimation for MGVI(S2)
Results (3.6): CCC

Relatively Good performances for CFI
Some inconsistencies for MTCI: calibration problem?
Results (3.7): CWC

Relatively good performances for CFI
Some inconsistencies for NDWI: calibration problem?
Conclusions

• Organizing validation experiments
  – Need proper guidelines for ground measurements
  – Devices, protocols, sampling, processing
  – A guideline was proposed
  – Difficulties in getting proper S2 simulations from airborne campaigns
  – Geometric uncertainties, radiometric calibration, atmospheric correction, spectral sampling …
  – As a result only few campaigns have been exploited
  – Need additional campaigns (forests, with the dynamics!)
  – A campaign was completed in June-September over the Hardth Forest (Mulhouse)

• S2 CFI algorithm shows potentials
  – Needs further validation including over simulated 3D scenes
  – Non CFI (spectral indices) need probably a better calibration
  – Will probably need fine tuning when actual S2 will be available
  – Application to other sensors (Landsat8, DMC, Rapide-eye …)
  – Need compositing/fusion algorithms to fully exploit the temporal dimension
  – Need for specific algorithms for LAI, CCC and CWC exploiting the knowledge on the landcover