Ground-based measurements of reflectance and sun-induced chlorophyll fluorescence

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Introduction

- During the several phase of an aircraft/space mission, strong efforts are focused on the formalization of **different Products** (chain of processing, algorithms development);

- At the same time strong efforts are devoted to generate specific **Cal/Val plans** for evaluating the quality of the collected data;

- In remote sensing, spectral radiance and **reflectance** are the first quantities object of a Cal/Val plans (beside higher level Products);

- More recently, increasing interest has been devoted also at the measurements of the **sun-induced chlorophyll fluorescence** (FLEX context);

- The design of **networks** and strategies for cal/val of reflectance and fluorescence is a crucial topic in remote sensing and the starting of long-term unattended monitoring networks are welcome.
Products and cal/val. Examples from new space missions

Processing chain, data and products. Cal/Val concept

Sentinel-3 mission has been designed to provide measurements to monitor the global environment

- Sea and Land Surface Temperature Radiometer (SLSTR)
- The Ocean and Land Colour Instrument (OLCI)

Sentinel-3 topography mission:
- Synthetic Aperture Radar Altimeter (SRAL) Instrument
- Microwave radiometer (MWR);
- Precise orbit determination (POD)

From raw data to geophysical products to cal/val activities
Optimized cal/val networks

Long-term and unattended measurements

The AERONET (AErosol RObotic NETwork) program is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire)

AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes
Comparison between field measurements and satellite estimates

Long-term and unattended measurements

*Eddy covariance network. Well established. Albedo and MODIS validation exercise*
Need to establish a (permanent) network of (hyper)spectral field meas.

Spectral radiance & reflectance (+ fluorescence)

Many issues. Harmonize field spectral measurements, target dependency, instruments, FOV, spectral range, protocols, nomenclature... Effort of the RS community

1975 →
Specific cal/val plan for each satellite mission

2003 →
SpecNet (Spectral Network). Network of terrestrial flux tower sites where proximal sensing is being conducted (mainly to improve the understanding biosphere-atmosphere)

2006 →
Cal/Val within Committee on Earth Observation Satellites (CEOS).

2009-2013
EUROSPEC (Spectral Sampling Tools for Vegetation Biophysical Parameters and Flux Measurements in Europe). CostAction. Main focus to develop and standardize protocols and new instruments for monitoring Biophysical Parameters

2014 →
OPTIMISE: innOvative oPtical Tools for proxIMal sensIng of ecophySiological procEsses COST Action oc-2013-1-15412. to promote and to develop near-ground optical sampling methods, analytical techniques to make best use of current and future satellite sensors and existing ground-based monitoring networks

Diff. devices, prototypes, variable costs, automation degree...

Imaging systems vs non imaging systems
especially, for the FLEX/S3 Tandem mission

The **FLuorescence EXplorer (FLEX)** is currently a candidate mission for the ESA 8th Earth Explorer. The FLEX mission aims to provide global maps of vegetation fluorescence at 300 m spatial resolution, which can be used to infer photosynthetic activity of natural and managed ecosystems.

It represents a novel method of monitoring the health of the Earth's vegetation through the observation of solar-induced fluorescence from space.
Specific aims

- To set up **field instruments** for reflectance and fluorescence retrieval at canopy level and to define a processing chain. Algorithms development;

- To collect ground based top of canopy high resolution **radiance and fluorescence measurements**, encompassing different level and ecosystems;

- To understand the **magnitude** of fluorescence and to evaluate time series;

- To **validate** maps of sun-induced fluorescence derived from HyPlant imageries;

- To compute **reflectance** values for traditional cal/val activities in the optical domain
Field spectroscopy systems for fluorescence retrieval

High spectral resolution spectrometers (OceanOptics, USA)

<table>
<thead>
<tr>
<th>Spectrometer</th>
<th>FWHM (nm)</th>
<th>Sampling interval (nm)</th>
<th>Spectral range (nm)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec 1</td>
<td>1</td>
<td>0.25</td>
<td>350-1050</td>
<td>Irrad. measurements, ρ and VIs computation</td>
</tr>
<tr>
<td>Spec 2</td>
<td>0.1</td>
<td>0.02</td>
<td>700-800</td>
<td>Sun-induced Chl fluorescence at O₂-A</td>
</tr>
</tbody>
</table>

**Manual** spectrometric system

**MRI, Multiplexer Radiometer/Irradiometer**

**HSI, HyperSpectral Irradiometer**

A clone of MRI has been also developed by compacting the instrument in a small box (s-FluorBox system).
Different instruments concept: several applications and purposes

Manual system

Stress experiments

GPP modelling

Validation points
Different instruments concept: several applications and purposes

HyperSpectral Irradiometer (HSI). Developed for continuous measurements of fluorescence; HSI employs two spectrometers sharing the same optical signal, one covering the VNIR range 400–1000 nm with a FWHM of 1 nm, and the other providing higher spectral resolution (0.1 nm FWHM) within a narrower spectral interval (700–800 nm) in the NIR.

HSI automatically acquires spectral data every 5 min during daylight. During operations, HSI employs the rotating arm to observe alternately the sky and the target surface (BHR).
Different instruments different results

- HDRF (ideal)
- DHR (ideal, black sky albedo MODIS)
- CCRF (sunphotometer type)
- HCRF (misure di campo) ex BRF in letteratura
- BHR (white sky albedo, HSI)

- e.g. sorgenti attive su misure con goniometro

![Graphs showing BHR and HCRF at different wavelengths and solar local times.](image_url)
Pre-processing chain

**λ calibration**

**FWHM**

**DC drift**

**CCD non linearity**

**Radiance calibration**

\[ y = a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6 + hx^7 \]

\[ R^2 = 0.83403519 \]

\[ P < 0.0001 \]

Clear Sky Radiance, Marmande 24/04/07, France

<table>
<thead>
<tr>
<th>WL (nm)</th>
<th>L (W m(^{-2}) sr(^{-1}) nm(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>0.05</td>
</tr>
<tr>
<td>500</td>
<td>0.1</td>
</tr>
<tr>
<td>600</td>
<td>0.15</td>
</tr>
<tr>
<td>700</td>
<td>0.2</td>
</tr>
<tr>
<td>800</td>
<td>0.3</td>
</tr>
<tr>
<td>900</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Counts ms\(^{-1}\) / max(Counts ms\(^{-1}\))

Counts

0 2000 4000 6000 8000 10000 12000 14000

Counts ms\(^{-1}\) / max(Counts ms\(^{-1}\))

Relative intensity

0.0 0.2 0.4 0.6 0.8 1.0 1.2

Number of pixels

-10 -5 0 5 10

Normalized response (-)

0.0 0.2 0.4 0.6 0.8 1.0 1.2

Wavelength (nm)

700 720 740 760 780 800 820

Relative intensity

0.0 0.2 0.4 0.6 0.8 1.0

Number of pixels

-10 -5 0 5 10

Normalized response (-)

0.0 0.2 0.4 0.6 0.8 1.0 1.2

Wavelength (nm)

700 720 740 760 780 800 820

Normalized response (-)

0.0 0.2 0.4 0.6 0.8 1.0 1.2

Wavelength (nm)

400 450 500 550 600 650 700 750 800 850 900

Counts

0 2000 4000 6000 8000 10000 12000 14000

Counts ms\(^{-1}\) / max(Counts ms\(^{-1}\))

Counts ms\(^{-1}\) / max(Counts ms\(^{-1}\))

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Spectral data acquisition and processing

Acquisition and processing performed with in-house developed software specific for field spectrometry

Specs thermally insulated

Nadir observations

Single beam, sandwiched

CF spectrometer (700-800nm)
Example of spectral data acquired

**Radiometric set up:** 2 OceanOptics spectrometers (HR4000):

- n. 1 (PRI and VIs): 400-1000 nm, FWHM 2.8 nm
- n. 2 (F at O₂– A): 700-800nm, FWHM 0.13 nm, 439 spectral channels (Fs @760nm)

Example of a single acquisition:

Downwelling and upwelling radiances and resulting reflectance

for Spec1 covering the full VIS-NIR range

and for Spec2, covering the restricted range 720-800 with higher resolution

Apparent reflectance!
Data acquisition

High resolution top-of-canopy spectral data have been collected in the context of different national and international projects, including several ESA funded projects, from 2005 to present.
Data acquisition

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- **ESA-CEFLES2**
- **ESA-SEN3EXP**
- **ESA-fluorescence**
High resolution top-of-canopy spectral data have been collected in the context of different national and international projects, including several ESA funded projects, from 2005 to present.
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Data have been collected with:
- same spectrometers (FWHM and SNR(300))
- same protocol of acquisition
- same viewing geometry
Selecting sites

Credit: A. Burkart
Accurate location of the measurement points

Canopy R + leaf sampling
Canopy R
Leaf sampling
Continuous canopy R
**Example of collected data**

*Crops*

- **View angle**: nadir
- **Field of view**: 25°
- **Height above the canopy**: 150 - 450 cm
- **Diameter of each observation**: 70 - 200 cm

*Forest*

*Sugar beet*
Diurnal cycles of fluorescence

Crops

Sugar beet
Canopy spectral measurements

Forest

June

July

DOY.dayfraction

NDVI (-)

Lin_{747.5} (mW m^{-2} sr^{-1} nm^{-1})

- Oak
- Hornbeam
- Pine
- Maple
- Larch
- Linden
- Lin_{747.5}
Canopy spectral measurements

Forest

- \( F_{760} \) under different illumination intensities vary from near 0 to 2.5 \( \text{mW m}^{-2} \text{ sr}^{-1} \text{ nm}^{-1} \)
- Different land cover classes and forest species are characterized by different \( F_{760} \) values, with generally the highest \( F_{760} \) (and \( F_{687} \)) emissions in crops followed by broadleaf and then needleleaf species
Time series

Diurnal and seasonal variability (alfa-alfa)
**Time series**

**Diurnal and seasonal variability (alfa-alfa)**

Fs patterns mirror the incoming radiance
Other applications

**Fig. 3.**  (a) Multiplexer radiometer irradiimeter (MRI), including the instrument box, a tripod and a mast holding the up-looking and down-looking optics, a webcam and the infrared thermal sensor installed at the sampling site in Mantua Superior Lake. (b) Schematic drawing of the MRI system.
Optical domain. Experience from Sen2Exp

To collect ground based spectral measurements (radiance and reflectance) to be used for radiometric vicarious calibration and for the validation of the atmospheric correction;

**Target selection**

Target characteristics required: 1) large enough to cover an area of 3x3 APEX pixels, 2) homogeneous, 3) fairly Lambertian and 4) encompassing a range of brightness levels (bright to dark) in all the spectral domain (VIS, NIR, SWIR).

- 4 Artificial targets (PVC coated canvas material): 2 black (9x9m and 6x6m), 1 grey (9x9m) and 1 white (6x6m)
Field spectral measurements

**Target selection**

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- 8 ‘Psuedo-invariant’ natural targets: concrete, gravel, different asphalt and pit material
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- 8 ‘Psuedo-invariant’ natural targets: concrete, different asphalt and pit material
- 2 Vegetation targets: soccer field and meadow
Point distribution and positioning

Target location in the study area

The four vertex coordinates were recorded with a GPS (GMS-2 Pro, Topcon - accuracy < 1m)

GPS location of target vertexes (example of gray panel – stop 1)
Cal/Val measurements

sampling scheme

- Fieldspec 4 (ASD Inc.) covering the range 400 – 2500 nm
- The white reference spectra were acquired every 5 target measurements
- Spectra were acquired in DN. Radiance and reflectance were calculated in post processing.

\[
\text{HCRF}_{\text{target}} = \frac{L_{\text{target}} \times R_{\text{wr}}}{L_{\text{wr}}}
\]
## Cal/Val Database Structure

<table>
<thead>
<tr>
<th>Target description</th>
<th>ID</th>
<th>Date of measurement</th>
<th>N</th>
<th>E</th>
<th>RUN APEX</th>
<th>File Google Earth (.kmz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black panel 9x9</td>
<td>01</td>
<td>17.06.2013</td>
<td>47°51'43.86&quot;N</td>
<td>7°24'21.89&quot;E</td>
<td>1</td>
<td>STOP1 (RUN 1 APEX)</td>
</tr>
<tr>
<td>Grey panel 9x9</td>
<td>02</td>
<td>16.06.2013</td>
<td>47°51'43.54&quot;N</td>
<td>7°24'21.90&quot;E</td>
<td>1</td>
<td>STOP1 (RUN 1 APEX)</td>
</tr>
<tr>
<td>Black panel 6x6</td>
<td>04</td>
<td>16.06.2013</td>
<td>47°51'46.67&quot;N</td>
<td>7°27'10.30&quot;E</td>
<td>3</td>
<td>STOP2 (RUN 3 APEX)</td>
</tr>
<tr>
<td>White panel 6x6</td>
<td>05</td>
<td>16.06.2013</td>
<td>47°51'46.57&quot;N</td>
<td>7°27'10.30&quot;E</td>
<td>3</td>
<td>STOP2 (RUN 3 APEX)</td>
</tr>
<tr>
<td>Gravel 1</td>
<td>06</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'20.28&quot;E</td>
<td>3</td>
<td>STOP2 (RUN 3 APEX)</td>
</tr>
<tr>
<td>Gravel 2</td>
<td>10</td>
<td>13.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Pfc</td>
<td>08</td>
<td>17.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Grey tiles</td>
<td>09</td>
<td>13.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Dark asphalt</td>
<td>12</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Light asphalt</td>
<td>13</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Asphalt</td>
<td>03</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Soccer field</td>
<td>11</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
<tr>
<td>Meadow</td>
<td>07</td>
<td>16.06.2013</td>
<td>47°51'46.66&quot;N</td>
<td>7°27'34.42&quot;E</td>
<td>5</td>
<td>STOP3 (RUN 5 APEX)</td>
</tr>
</tbody>
</table>
Temporal comparison

**Invariant targets comparison between the first and the second campaign.**

Reflectance of the same targets measured in the two campaigns were very similar (Differences < 0.2 % in all the spectral domain)
Some final considerations

Towards a network of spectrometer that operates unattended and carries out high frequency and long-term field spectral measurements of fluorescence

Need to combine field data and airborne imageries

Ideal configuration:
• Standardise field optical sampling methods;
• Standardise sensor characteristics-interoperability;
• Emphasis on greater automation using cost-effective technologies:
  • Tilting sensors, off-nadir measurements of HCRF;
  • Spatial sampling!
  • Multitemporal composite!
• Spatial and temporal mismatch should be minimised

Satellite pixel vs field data
View angle: off nadir, FOV > 25°, Sampled area (ellipse diameters)
Some final considerations

Field measurements, flight lines, pixel size, surface heterogeneity

- Quantitative evaluation of landscape heterogeneity and the representativeness of in situ measurements;
- Pixel size can be 100-1000 times larger than the footprint of in situ radiometric measurements!
- Need to characterise the spatial heterogeneity of reference sites using a combination of surface measurements, airborne and finer scale satellite imagery;
- Importance of the choice of the flight lines (CCD linear array, avoid hotspot..).
Conclusions

- Need to define Products and Cal/Val plans according to the specific mission requirements;

- Field spectroscopy is a crucial technique for Cal/Val activities;

- Long-lasting field spectroscopy campaigns based on manual measurements are extremely resource-demanding and do not ensure repeatability of the acquisition conditions as the instrument setup is initialized each day;

- Need to establish a spectral network for long-term and unattended measurements of Fs;

- Field measurements of sun-induced fluorescence are needed for validation purposes:

- A wide fluorescence dataset has been collected with a standardized state-of-the-art spectrometers setup and methodology, making the comparison of datasets collected at different times and locations easier;

- Different land cover classes and forest species are characterized by different $F_{760}$ values, with generally the highest $F_{760}$ emissions in crops followed by broadleaf and then needleleaf species;
Thank you