The airborne sensor *HyPlant* – the history of the first dedicated airborne fluorescence sensor (established 2012)

Uwe Raescher, Andreas Burkart, Maria-Pilar Cendrero, Maria Matveeva, Anke Schickling, Luis Alonso, Sergio Cogliati, Roberto Colombo, Alexander Damm, Matthias Drusch, Yves Goulas, Jan Hanus, Andreas Huth, Elizabeth Middleton, Franco Miglietta, Gina Mohammed, Micol Rossini, Dirk Schüttemeyer, Christiaan van der Tol, Wout Verhoef, Frantizcek Zemek

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ESA’s Earth Observation satellites

Meteorological Missions

Driven mainly by weather forecasting and climate monitoring needs, these missions developed in partnership with EUMETSAT include the Meteorological Operational satellite programme (MetOp), forming the space segment of EUMETSAT’s Polar System (EPS), and the new generation of geostationary Meteosat satellites (MTG & MT6 satellites).

Copernicus Sentinel Missions

Driven by user needs to contribute to the European Global Monitoring of Environment & Security (EGEMS) initiative, these satellite missions developed in partnership with the EU include C-band imaging radar (Sentinel-1), high-resolution optical (Sentinel-2), optical and infrared radiometer (Sentinel-3) and atmospheric composition monitoring capability (Sentinel-4 & Sentinel-5 on board Met mission MTG and EPS-SG respectively).

Earth Explorer Missions

Driven by scientific needs to advance our understanding of how the ocean, atmosphere, hydrosphere, cryosphere and Earth’s interior operate and interact as part of an interconnected system. These research missions, exploiting Europe’s excellence in technological innovation, pave the way towards new development of future EO applications.
FLEX Satellite Mission – a tandem concept with Sentinel-3

**Spatial coverage:**
-56 to 75 degree latitude, land + major islands, coastal zones 50 km

**Temporal co-registration:**
< 6s (G) / 15s (T)

**Revisit time:** up to 19 days

**Spatial resolution:**
90000 m²

**Altitude:** ~815 km

**Local solar time:** 10:00 LTDN

**Links:**
- FLORIS HR
- FLORIS LR
- SLSTR
- OLCI
1. Chlorophyll molecules emit fluorescence. The intensity of the fluorescence signal depends on light intensity, the concentration of chlorophyll (LAI) and the functional status of photosynthesis.

2. The fluorescence signal is rather weak (2-5 % of intensity of reflected light in this spectral region).
Photosynthesis is a highly regulated process that involves a cascade of electron transfers (*Light reaction*) to fuel carbon fixation (*Calvin cycle*).

Fluorescence is emitted from the cores of the photosynthetic machinery: Photosystems I and II.

Two-peak feature of fluorescence.
Pigments, photosystems and photosynthesis: a highly structured biological ‘super-complex’ that emits fluorescence

Sun-induced fluorescence can be measured in the solar and atmospheric absorption lines. Atmospheric oxygen and solar absorption lines can be used to retrieve the fluorescence signal from the surface reflectance (under apparent reflectance).
**HyPlant**: A high-resolution airborne imaging spectrometer with FLEX like measurement characteristics

- **DUAL module** (380 – 2500 nm)
  - VIS/NIR: 3-4 nm FWHM, 1.7 nm SSI, SNR 510
  - SWIR: 13 nm FWHM, 5.5 nm SSI, SNR 1100

- **FLUO module** (670 – 780 nm)
  - 0.25 nm FWHM, 0.11 nm SSI, SNR 210

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HyPlant: modelling the importance of sensor characteristics

Modeling the impact of spectral sensor configurations on the FLD retrieval accuracy of sun-induced chlorophyll fluorescence

Alexander Damm a,b, André Erler b, Walter Hillen c, Michele Meroni d, Michael E. Schaepman a, Wout Verhoef e, Uwe Rascher b
**HyPlant: modelling the importance of sensor characteristics**

- Optimized imaging spectrometer for fluorescence retrieval having
  - High spectral resolution
  - good SNR
  - Low stray light
  - Stable sensor configuration

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**HyPlant: real sensor characteristics**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Dual-channel module</th>
<th>Fluorescence module</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelength range [nm]</td>
<td>380-970</td>
<td>970-2500</td>
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<tr>
<td>Bands</td>
<td>350</td>
<td>272</td>
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<tr>
<td>Wavelength sampling interval [nm]</td>
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<td>Wavelength resolution (FWHM) [nm]</td>
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<td>Band broadening [nm]</td>
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<tr>
<td>Spectral shift [nm]</td>
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<td>2.4</td>
</tr>
<tr>
<td>Smiling [nm]</td>
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<td>1.2</td>
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<tr>
<td><strong>Radiometric performance</strong></td>
<td>(510)</td>
<td>(1100)</td>
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<tr>
<td>SNR with full-scale signal</td>
<td>(240)</td>
<td>(240)</td>
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<tr>
<td>Stay light and pixel cross talk [%]</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
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<tr>
<td><strong>Spatial performance</strong></td>
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<tr>
<td>Spatial pixels</td>
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<tr>
<td>Field of view [deg]</td>
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<tr>
<td>Instantaneous field of view [deg]</td>
<td>0.0832</td>
<td>0.0832</td>
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<tr>
<td>Swath [m]</td>
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<td>380 at 600 m agl</td>
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<tr>
<td></td>
<td>1140 at 1780 m agl</td>
<td>1140 at 1780 m agl</td>
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<tr>
<td>Spatial sampling interval (across track) [m]</td>
<td>0.98 at 600 m agl</td>
<td>0.98 at 600 m agl</td>
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<tr>
<td></td>
<td>2.94 at 1780 m agl</td>
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<td><strong>Sensor type</strong></td>
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<td>Type</td>
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<tr>
<td>Dynamic range [bit]</td>
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<td>14</td>
</tr>
</tbody>
</table>

Optimized imaging spectrometer for fluorescence retrieval having:

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KyPlant: real sensor characteristics

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![Graphs showing spectral shift and FWHM across different wavelengths](image-url)
HyPlant: 2012 campaigns

- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
HyPlant: 2012 campaigns

➤ Used to demonstrate the uncoupling of ‘greenness’ and fluorescence

➤ First demonstration that functional blockage of photosynthesis can be mapped from aircraft
HyPlant: Having a closer look at radiometric performance. Point spread function and stray light

- Optical path and detector was exchanged / upgraded
- SNR improved 4 times
- Point spread function greatly improved

Since 2014
**HyPlant:** Having a closer look at radiometric performance. Point spread function and stray light

- Optical path and detector was exchanged / upgraded
- SNR improved 4 times
- Point spread function greatly improved
- Additional deconvolution algorithm developed and now routinely applied to all flight lines of *HyPlant*

Since 2014
HyPlant: processing becomes consolidated

- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes
**HyPlant: processing becomes consolidated**

- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes
  - Advanced and careful pre-processing including deconvolution for point-spread function (PSF)
**HyPlant: processing becomes consolidated**

- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes
  - Advanced and careful pre-processing including deconvolution for point-spread function (PSF)
  - Three way to retrieve fluorescence (both peaks and total fluorescence)
HyPlant: processing becomes consolidated

- SVD: good first estimate that works in about 70% of the cases
- 3-FLD: not usable because of strong dependency of surface reflectance
- iFLD: ‘working retrieval’ as long as we have non-vegetated reference targets in the scene
- Spectral fitting: method of choice that was recently adapted also for HyPlant. (need for good characterization of atmospheric parameters)
HyPlant: 2014 campaigns

- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence

- First demonstration that functional blockage of photosynthesis can be mapped from aircraft

- Fluorescence improves modelling of diurnal changes in GPP
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What are we doing to complement airborne mapping of fluorescence?

- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display

Pinto et al. (2016) *Plant, Cell and Environment*, 39, 1500–1512

Pinto et al. (2017) *Remote Sensing*, 9, article no. 415, doi: 10.3390/rs9050415
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- Link passive sun-induced fluorescence measurements with active fluorescence approaches that allow deeper insight into the photosynthetic machinery
- Aggregate flight lines to produce FLEX like data and understand fluorescence on the 300 x 300 meter pixel
What are we doing to complement airborne mapping of fluorescence?

- High-resolution point spectrometer developed, optimized and standardized system available
- ~10 systems have been employed and are operational

Understanding sun-induced fluorescence: A matter to understand Structure / Function Relations

Many thanks to my group
Many thanks to the numerous partners