FLEX & Sentinel 2/3
Mission Development & Validation

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Limassol, February 2017
Overview of my presentation

• Overview: Campaigns at Work
• Latest developments at ESA
• FLEX Phase A/B
• FLEX Phase C/D
• Sentinel 2/3 & FLEX
• Some brief conclusions
Why are ESA Earth Observation campaigns required?

- Explore EO possibilities before going to space
- Prove EO measurement concepts work
- Develop interpretation methodology
- Develop calibration approach
- Develop validation methods using independent data
- Simulate data products (pre-launch)
- Validate results using independent data
- Develop applications

Close range observation during new development phase
Programmatic Background

ESA campaign activities started in 1981
142 campaigns as of September 2016
Typically 6 -10 campaigns/year

Strategic objectives:
Support strategic goals of EO Science Strategy
Transnational access to airborne facilities in member states
Foster partnerships with national and international organisations

Campaign activities address:
Testing technology/Observing techniques
Optimising requirements/design and reducing mission risk
L1-L2 Algorithm prototyping/Product simulation
Calibration/Validation

Campaign data archive supporting science and applications
Campaigns for different project phases

ESA campaigns are performed during full life cycle of a typical ESA space mission

Different types of campaigns are performed during specific phases of a space mission (concept, feasibility, development and operations)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Phase A</th>
<th>Phase A Feasibility</th>
<th>Phase B Design</th>
<th>Phase C/D Development</th>
<th>Phase E1 Commissioning</th>
<th>Phase E2 Operation</th>
<th>Data Archive</th>
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<tbody>
<tr>
<td>Technology</td>
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<td>Cal/Val</td>
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<td>Science/ Applications</td>
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</tbody>
</table>
Access to ESA Campaign Data

ESA campaign data available to interested PIs

- Formatted and documented datasets
- Data Inventory
- Final report with full description of campaign activity and analyses

Final report accessible directly through web

Access to datasets provided through Category 1 mechanism (short proposal incl. identification of desired datasets)

Currently 64 campaign datasets available

https://earth.esa.int/web/guest/campaigns
Recent developments

Key role of campaigns in preparation of future EO missions (up to Phase-0/-AB)

EE8 FLEX Mission Consolidation
New campaign initiatives supporting future mission concepts (e.g. SAOCOM-CS/Convoy or Satellite companion concepts)
Several cross-cutting activities addressing multiple missions (e.g. MULTIPLY for EarthCARE/ADM and other missions)

Use of campaign data in Thematic Exploitation Platforms or TEPs (e.g. BIOMASS)
International cooperation (Member states, EU, NASA)
Pooling of resources and enhanced technical/science return
Remotely Piloted Aircraft Systems

- Remotely Piloted Aircraft Systems (RPAS) can bridge the gap between satellite Earth observation and ground measurements
- In particular, RPAS enabling persistent (> 4 weeks), high resolution, local-to-regional scale observations would fill a critical niche within Earth Observation data:

**Satellites:** Global perspective on changes in the Earth-ocean-atmosphere system

**In-situ sensors:** local measurements at fine spatio-temporal scales

Critical link between small scale and regional/global long-term processes

⇒ Stratospheric platforms (h > 18000 m, endurance > 4 weeks)
Cross-Tasking

Wide Swath

1. RPAS

2. High Resolution

3. Wide Swath
ESA position vis-à-vis European Industry and potential users for HAP RPAS

- Industry involved in study and development of HAP RPAS is the same involved in space programme

- There is a great deal of technology overlap that provides an opportunity for rationalisation at the benefit of competitiveness

- ESA can augment the application potential and make it sustainable through complementarity with space systems

- Existing users of ESA assets (e.g. scientists, Agencies and Public Bodies) would be exposed to new services, so reinforcing the mutual bonds

- ESA is the only R&D body in Europe that can enable the economic potential stemming from HAP through technological advances
Phase A Feasibility Campaigns

2012: *HyPlant* becomes operational Campaign in Finland and Germany
   ⇒ First airborne maps of $F_{760}$

2013: *HyPlant* technically refined Campaign in Germany, France, Czech Republic and USA
   ⇒ Two peaks of fluorescence are retrieved

2014: *HyPlant* technically refined Campaign in Germany, Czech Republic and Italy
   ⇒ Time series of dynamic stress detection in vegetation
   ⇒ Improvement of GPP estimates

2015: *HyPlant* optical path fundamentally improved and great improvement of the Point Spread Function; campaign in Germany, Czech Republic and Italy
   ⇒ Virtual cloud experiment

2016: *HyPlant* flown over Germany, CZ & Italy
   ⇒ Field Laboratory: ‘FLEX takes on mutants

Control
Phase C/D FLEX Activities

• **SS10 (start 2016 / 24 months):**
  Fluorescence Network Data Base / Validation Anchor Sites - Initial Phase

• **SS11 (start 2018 / 48 months):**
  Fluorescence Network Data Base / Validation Anchor Sites – Maintenance and Expansion Phase

• **C1 (2017 / 72 months): ContiFLEX**
  Ensure continuation of long time series for retrieval verification, investigate SNR / FR performance relationship experimentally, support selection and location of ground based in-situ measurements at the suggested Anchor sites.

• **C2 (2017 / 12 months): AtmoFLEX**
  Support L1 to L2 algorithm development, verification of final algorithm, support atmospheric parameter retrieval.

• **C3 (2018 / 18 months): TransFLEX**
  Verify the fluorescence retrieval over heterogeneous targets and a wide range of biomes.

• **C4 (2019 / 12 months): PhytoFLEX**
  Understanding of the added value of FLEX over coastal areas (oceans).

• **C5 (2021 / 6 months): Commissioning Rehearsal**
Phase C/D FLEX Activities

1. **Step: Atmospheric correction**

Make use of existing infrastructure related to S2 and S3
enable ground-based longterm measurements by means of FloX Boxes
perform dedicated airborne campaigns coordinated with S2/S3
evaluate the option of deploying a high altitude platform for FL measurements

=> Link to ContiFLEX

2. **Step: ContiFLEX**

Perform airborne campaigns in the coming years
2017 to cover test-sites in Germany, Belgium?, Italy by also underflying S2/S3

=> Link to AtmoFLEX & Networks

3. **Step: TRANSFLEX heterogeneous targets and a wider range of biomes.**

Potential activity together with NASA
A tandem mission concept ensures simultaneous measurements with a minimum impact of spatial and temporal co-location errors.
Introduction

✓ “Validation is the process of assessing, by independent means, the quality of the data products derived from a system outputs.”

✓ Missions:

✓ Provide an overview of the approach foreseen by ESA for the validation of land operational products.
## Land Operational Products

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Product</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>Surface Reflectance</td>
<td>Bottom-of-atmosphere and topography corrected reflectance</td>
</tr>
<tr>
<td>OGVI</td>
<td>OLCI Global Vegetation Index</td>
<td>Green Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)</td>
</tr>
<tr>
<td>OTCI</td>
<td>OLCI Terrestrial Chlorophyll Index</td>
<td>Index related to related to the total chlorophyll content.</td>
</tr>
<tr>
<td>LST</td>
<td>Land Surface Temperature</td>
<td>Radiative skin temperature (°K) of the ground.</td>
</tr>
</tbody>
</table>

✔ Many more coming soon...
Sentinel-2

✔ SR (Surface Reflectance)

Algorithm description at:
https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/level-2a/algorith
Sentinel-2

☑ SR (Surface Reflectance)

Asterisks: Sunphotometer test sites [9x9 km²] for validation of AOT, WV and SR products
Black plus signs: Test sites for ad-hoc campaigns in 2015 with surface reflectance measurements
Green diamonds: Test sites for ad-hoc campaigns in 2016 with surface reflectance measurements
Orange squares: Test sites [100x100 km²] for Cloud Screening and Scene Classification Validation
Sentinel-2

✓ SR (Surface Reflectance)

Belsk site in Poland, August 14, 2015
OGVI (OLCI Global Vegetation Index)

Use information in blue, red and near-infrared OLCI bands for deriving the Fraction of Absorbed Photosynthetic Active Radiation (Gobron et al., 1999, Gobron, 2012).

\[ g_n[\tilde{\rho}(\lambda_i), \tilde{\rho}(\lambda_j)] = P(\lambda_i, \lambda_j) / Q(\lambda_i, \lambda_j) \]

\[ P(\lambda_i, \lambda_j) = l_{n1}(\tilde{\rho}(\lambda_i) + l_{n2})^2 + l_{n3}(\tilde{\rho}(\lambda_j) + l_{n4})^2 + l_{n5} \tilde{\rho}(\lambda_i) \tilde{\rho}(\lambda_j) \]

\[ Q(\lambda_i, \lambda_j) = l_{n6}(\tilde{\rho}(\lambda_i) + l_{n7})^2 + l_{n8}(\tilde{\rho}(\lambda_j) + l_{n9})^2 + l_{n10} \tilde{\rho}(\lambda_i) \tilde{\rho}(\lambda_j) + l_{n11} \]

\[ \text{FAPAR} = g_0(\rho_{Rred}, \rho_{Rnir}) = \frac{l_{01}\rho_{Rnir} - l_{02}\rho_{Rred} - l_{03}}{(l_{04} - \rho_{Rred})^2 + (l_{05} - \rho_{Rnir})^2 + l_{06}} \]
Sentinel-3

✓ OGVI (OLCI Global Vegetation Index)

OGVI mean, 20-21-22-23 September 2016

RMSE = 0.07198

Scatter plot: OLCI(NR) vs MODIS

(2016-09-02 - 2016-10-23)

RMSE = 0.07198

$R^2 = 0.9571$

slope = 0.7776

interc. = 0.0479
Sentinel-3

**✓** OTCI (OLCI Terrestrial Chlorophyll Index)

Use of the high spectral resolution of OLCI to track the position of the Red Edge (Dash and Curran, 2004 Dash 2012).

\[
OTCI = \frac{R_{\text{Band}10} - R_{\text{Band}9}}{R_{\text{Band}9} - R_{\text{Band}8}}
\]

The magnitude of the OTCI is related to the total chlorophyll content.
Sentinel-3

✓ OTCI (OLCI Terrestrial Chlorophyll Index)

OTCI Global Mean, 4 days 20-21-22-23 September 2016
Challenges

- Lack of networks for validation of land products, to give continuity to the validation activities.
- Lack of international standards (with some exceptions: CEOS LPV “Global Leaf Area Index Product Validation Good Practices”).
- Product uncertainties not always assessed through a statistically representative set of locations and time periods.
- Spatial representativeness of the in situ measurements, and upscaling to satellite resolution.
- Need to automate individual measurements (drones?).
ESA Validation Approach

1. **Multi-mission** approach for the validation of all land products:
   - Sentinel-2 Surface Reflectance
   - Sentinel-3 OGVI
   - Sentinel-3 OTCI
   - Sentinel-3 Land Surface Temperature
   - FLEX products (>2022)

2. **Combine validation approaches**, with particular emphasis on Fiducial Reference Measurements (FRM).

3. **Network of sites** for ensuring a comprehensive validation (sites selected in coordination with existing international networks).
Validation approaches

- Statistical Analysis
  - Generation of level-3 products for trend analysis as well as sensor intercomparison over spatial and temporal domains.

- Match-up Comparisons
  - Comparison of match-ups from different product sources or missions.

- Fiducial Reference Measurements (FRM)
  - Next slide...
Fiducial Reference Measurements (FRM)

✓ **fiducial** *(adj)* Regarded or employed as a standard of reference, as in surveying

[Late Latin fiducialis, equivalent to fidi(a) trust, from fidere, to trust.]

✓ Fiducial Reference Measurements:

• Validation of Mission Requirements
• Linked to a mission’s Cal/Val plan activities
• Building on the existing capabilities
• Not necessarily mission specific and can address multi-mission needs

✓ FRM4VEG project planned for Cab, FAPAR and LAI validation (Kick-off Q2 2017).
Land Products Validation Concept

Globe
50-100 sites

Site
10-50 ESU

ESU (Elementary Sampling Unit)
10-50 IM

IM (Individual Measurement)

Reference maps for validation at HR/MR resolution

HR Imagery (S2)
Instrumentation

- Ground spectrometers for reflectance and fluorescence
- Instruments for atmospheric characterization
- Spectrometers on drones
- Airborne sensors
- Additional measurements (e.g. ecological)

Both satellite products and ground measurements have associated uncertainties from contributors such as:

- Instrument accuracy caused by random and systematic noises.
- Natural variability of target optical properties at different spatial scales, modulated by sampling strategy.
- Environmental variations in illumination during ground truth measurements.
- Error propagation in retrieval algorithms or radiative transfer modeling (indirect estimation).
<table>
<thead>
<tr>
<th>Site requirement</th>
<th>Indicator</th>
<th>Evaluation</th>
<th>Relative Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science question</td>
<td>ESA SP-1329/2, 2015</td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>Size&amp;homogeneity</td>
<td># of endmembers and size</td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>Land cover</td>
<td>Representativeness</td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>Topography</td>
<td>Slope</td>
<td></td>
<td>FI</td>
</tr>
<tr>
<td>Sun angles</td>
<td>Cosθ</td>
<td></td>
<td>SI</td>
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<tr>
<td>Site position</td>
<td>Nadir</td>
<td></td>
<td>SI</td>
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<tr>
<td>Meteorology</td>
<td>Cloud cover</td>
<td></td>
<td>FI</td>
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<tr>
<td>Flight</td>
<td>High risk/medium/low</td>
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<td>FI</td>
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<tr>
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<tr>
<td>Pixel story</td>
<td>SNR NDVI/Ts</td>
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<tr>
<td>Membership to other EO cal/val</td>
<td>Yes/No</td>
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<td>FI</td>
</tr>
<tr>
<td>Nationality</td>
<td>Yes/No</td>
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<td>SI</td>
</tr>
</tbody>
</table>

**FINAL SITE SCORE (E·R):**
International Networks Considered

- **ICOS**: Standardized network of eddy towers across Europe.
- **FLUXNET**: Hyperspectral sensors across the globe
- **COST action OPTIMIZE**: Network to standardize methods for vegetation reflectance and fluorescence.
- **EMPHASIS**: European network to link plant phenotyping infrastructure.
OLIVE is a platform designed to quantify the performances of land products.
Supported by CEOS LPV (Land Products Validation) sub-group.
Some general summary comments

• ESA campaign activities responding directly needs of the EO programmes in efficient and effective way and play a key role in
  • preparing future EO missions
  • supporting mission development
  • Cal/val for missions in orbit
  • supporting wider science community through the ESA campaign database on the EOPI portal
• Expanding industrial interest in airborne sensors and activities in the context of UAVs/Drones and medium and high altitude platforms
• Expanding international collaboration (NASA, EC e.g. EUFAR, National Agencies) leading to pooling of resources and enhanced science and mission related return (e.g. enabling campaign activities not possible in isolation)
• No dedicated airborne programme at ESA at present (i.e. no regular calls for industry or similar). Requirements and implementation solutions usually through advisory mechanisms, PIs and knowledge of opportunities.
FLEX summary comments

• Large amount of data available from campaigns starting in 2012
• Latest data might be used in the context of your activities
• Upcoming activities focus on atmospheric correction and extending time series
• Focus on a mix of ground-based and airborne activities
• Planning for related activities just started

• We need your input!!!
Summary Validation S2/S3 + FLEX

1. **Multi-mission** approach for the validation of all land products:

2. **Combine different validation approaches** with particular emphasis on Fiducial Reference Measurements (FRM).

3. **Network of sites** for ensuring a comprehensive and long-term validation.
Many thanks!