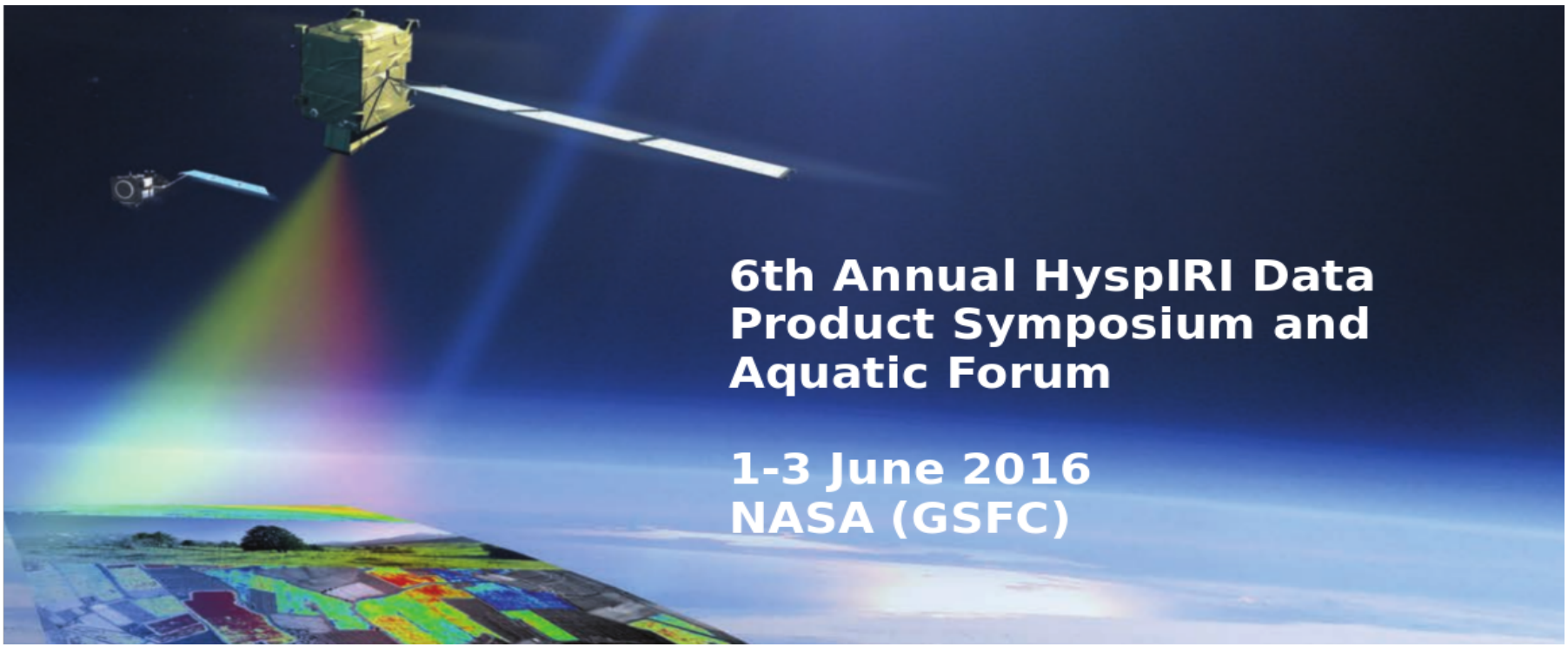
The FLuorescence EXplorer (FLEX) space mission



Neus Sabater [(1)] Jose F Moreno[1] and Elizabeth Middleton [2] on behalf of the FLEX team.

[(1)] Faculty of Physics, University of Valencia, Spain

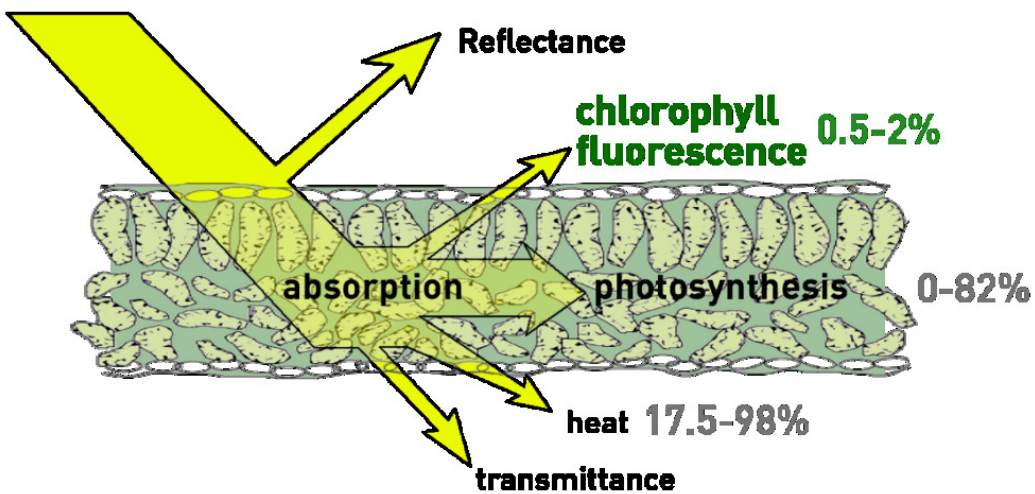
[(2)] Laboratory for Biospheric Sciences, NASA/Goddard Space Flight Center, Greenbelt, Maryland

ESA's 8^{th} Earth Explorer FLuorescence EXplorer (FLEX) mission will be the first space mission specially dedicated to map sun-induced chlorophyll fluorescence (SIF) of the terrestrial vegetation at a global scale.

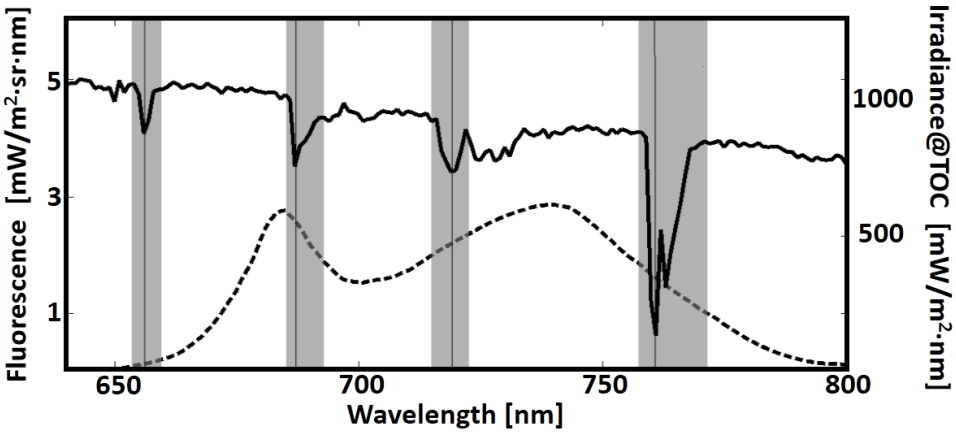
Vegetation chlorophyll fluorescence

Vegetation chlorophyll fluorescence is light re-emitted by chlorophyll molecules during return from excited to non-excited states and used as indicator of photosynthetic energy conversion.
Excited chlorophyll dissipates the absorbed light energy :

- by driving photosynthesis (photochemical energy conversion).
- as heat in non-photochemical quenching.
- by emission as fluorescence radiation.



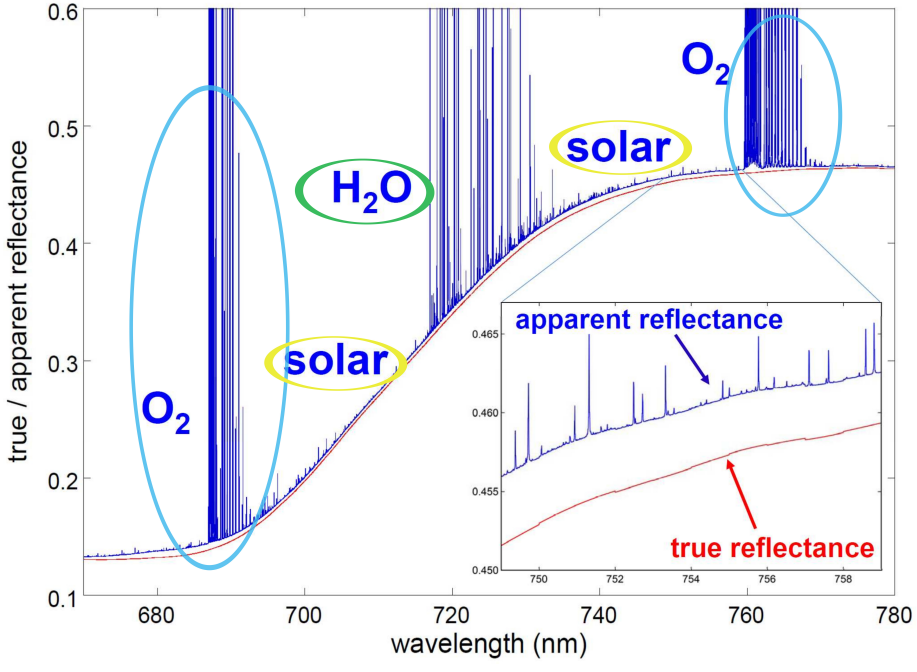
Vegetation chlorophyll fluorescence



Sun-Induced Chlorophyll fluorescence (SIF) is orders of magnitude lower than sun-reflected radiance. Thus, it is necessary to make use of the absorption bands to measure SIF.

The FLEX mission will mainly make use of the O_2-A and O_2-B absorption bands to measure SIF at high spectral resolution.

[Report for mission selection, FLEX ,(ESA-2015)]

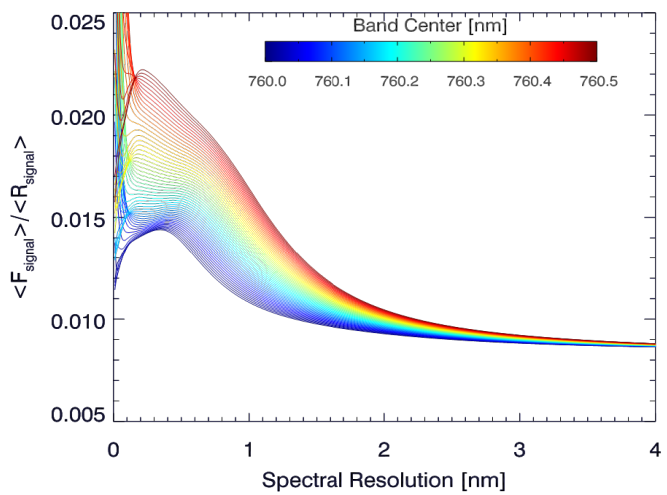


FLORIS instrument

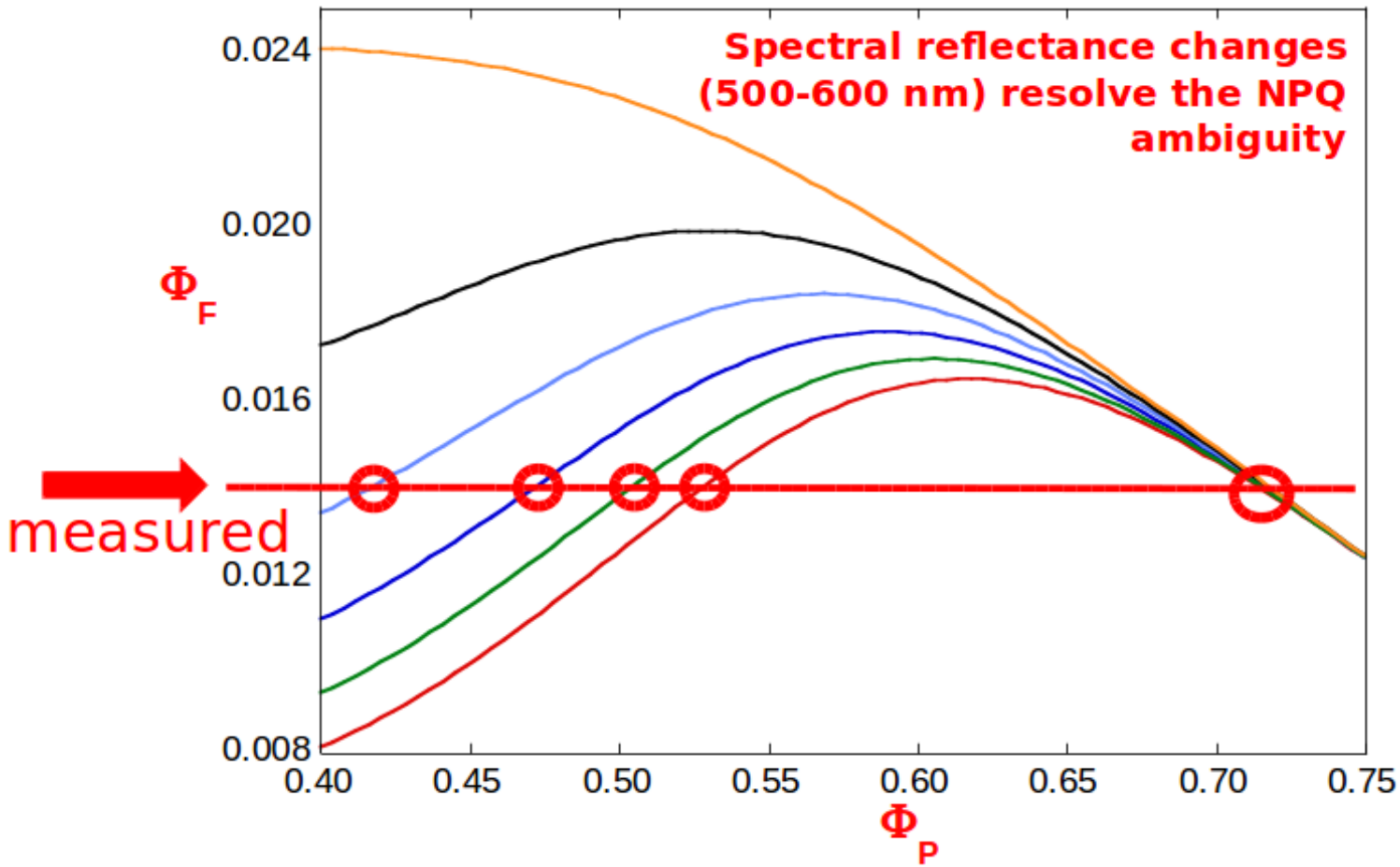
FLEX will be equipped with the FLORIS instrument covering from 500−780 nm. In this table FLORIS spectral and Signal to Noise Requirements (SNR) for the mission objective are listed:

Band	Band I	O_2-B		Band II			O_2-A		
λ [nm]	500–677	677–686	686–697	697–740	740–755	755–759	759–762	762–769	769–780
SR Full Width at Half Maximum (FWHM)	3.0	0.7	0.3	2.0	0.7		0.3		0.7
SSI	2.0	0.5	0.1	1.0	0.5		0.1		0.5
SNR	245	340	175	425	Linear from 510 to 1015	1015	115	Linear from 115 to 455	1015

[Report for mission selection, FLEX ,(ESA-2015)]



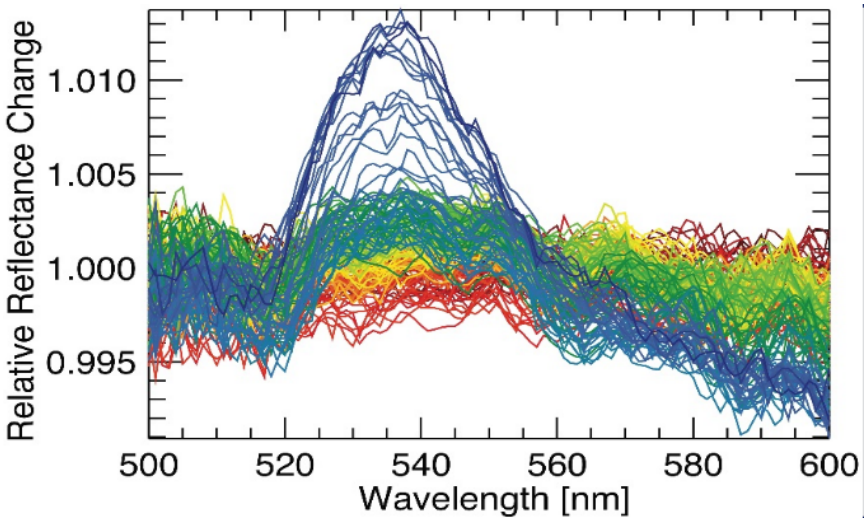
Linking chlorophyll fluorescence and photosynthesis



[Moreno, J. University of Valencia.]

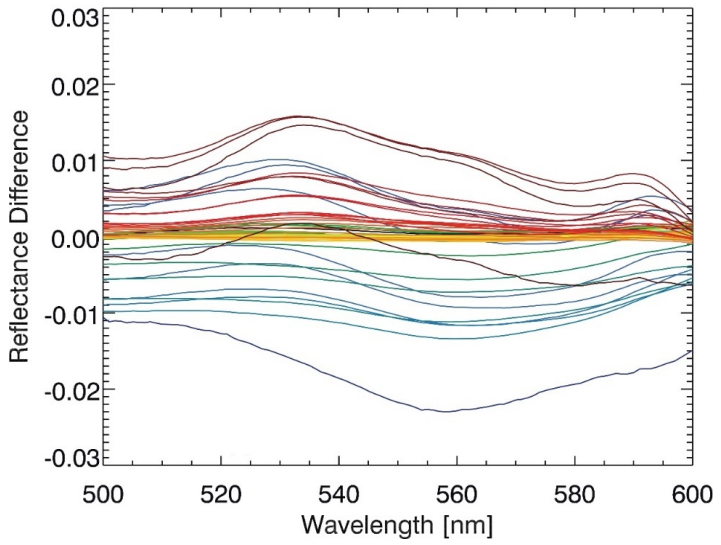
Reflectance changes between 500-600 nm

(∼ minutes)



[Report for mission selection, FLEX ,(ESA-2015)]

(∼ days)

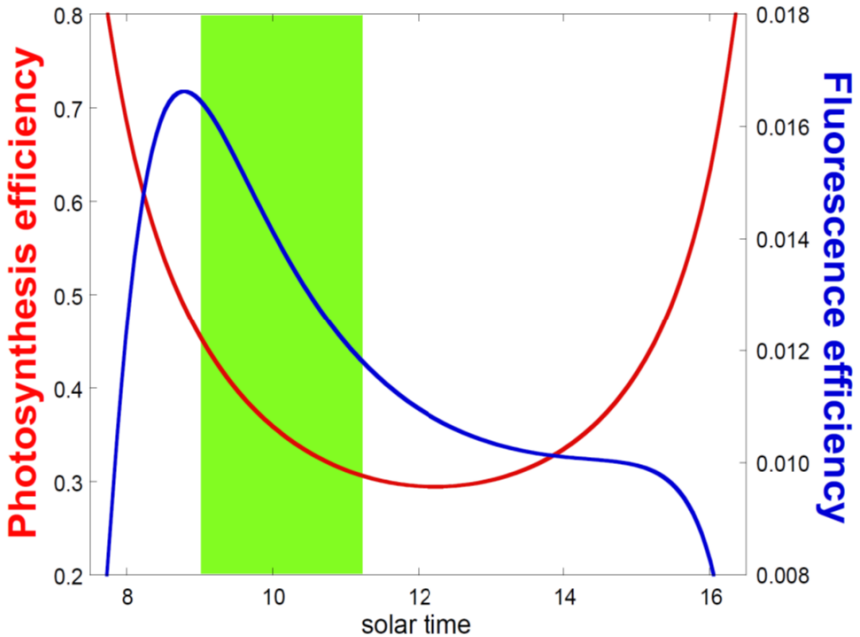


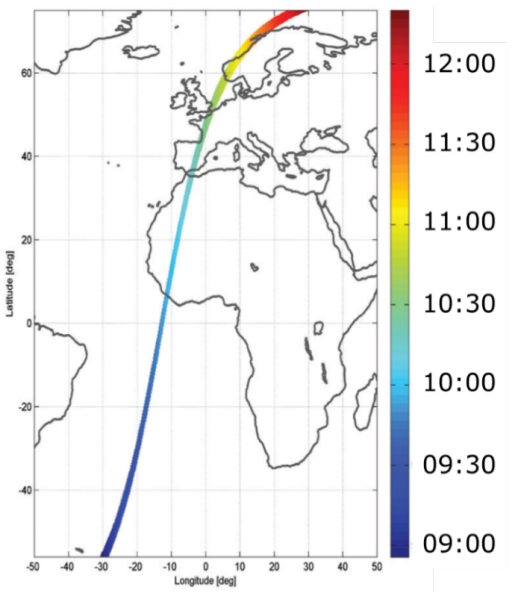
[Report for mission selection, FLEX ,(ESA-2015)]

Measuring surface reflectance changes between 500-600 nm allows a better understanding of the relationship between fluorescence and photosynthesis.

Local Time of Observation

By choosing 10:00 as the equatorial crossing time, the resulting solar illumination hours as a function of latitude guarantee adequate measurements in most areas and for most times of the year and when plants are photosynthetically active.

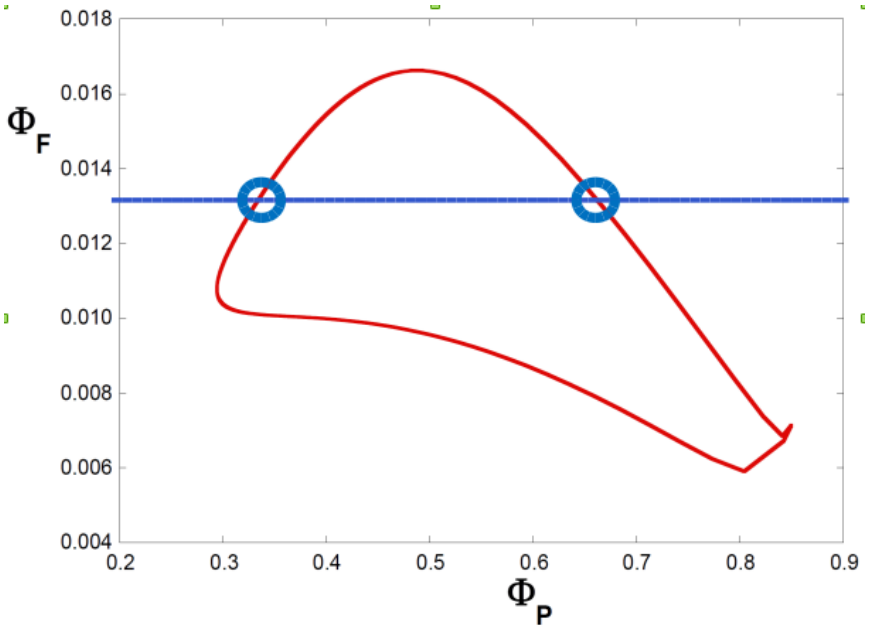




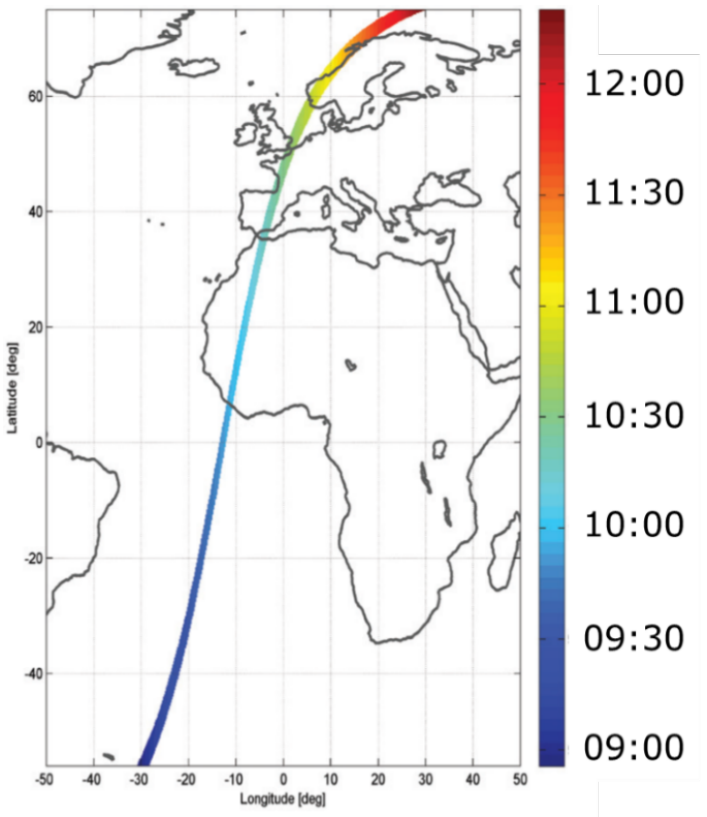
[Report for mission selection, FLEX ,(ESA-2015)]

Fluorescence diurnal cycle

Measuring SIF at different times implies measuring SIF at different positions of its diurnal cycle



[Moreno, J., University of Valencia]

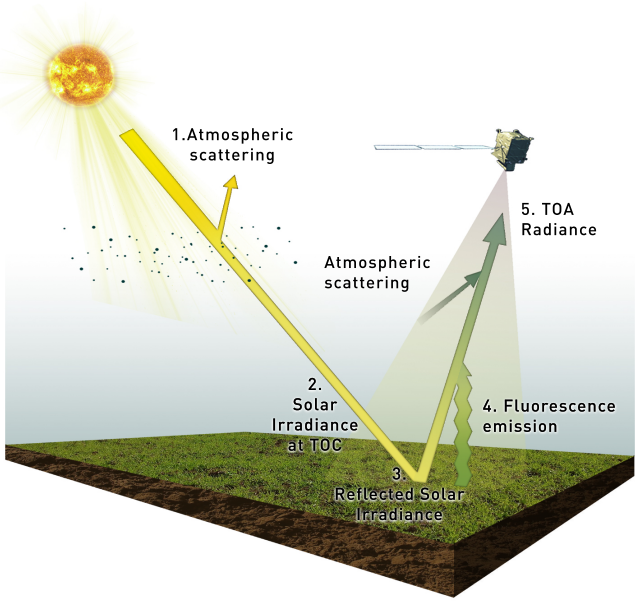


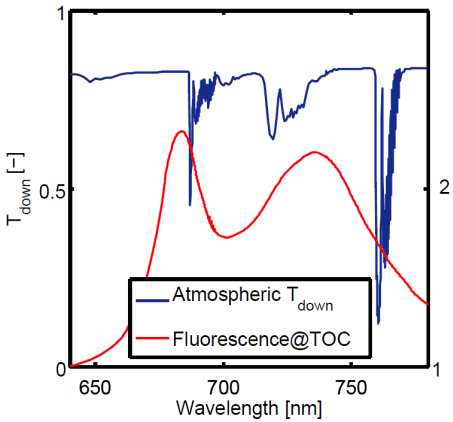
[Report for mission selection, FLEX ,(ESA-2015)]

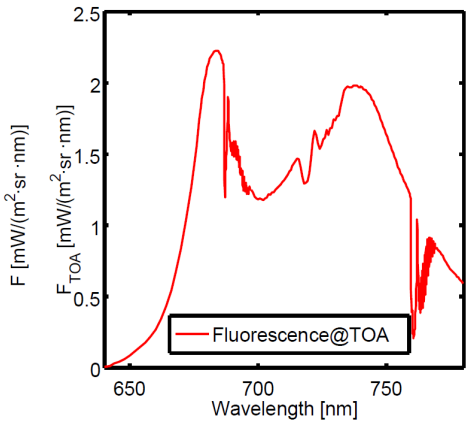
This fact becomes essential to a proper photosynthesis interpretation at a global scale.

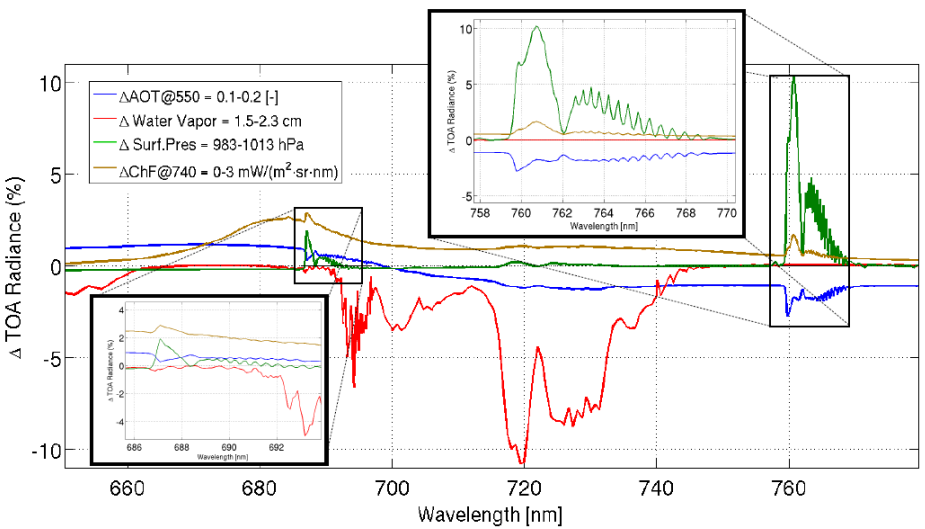
Vegetation chlorophyll fluorescence

As it passes through the atmosphere SIF signal is also attenuated



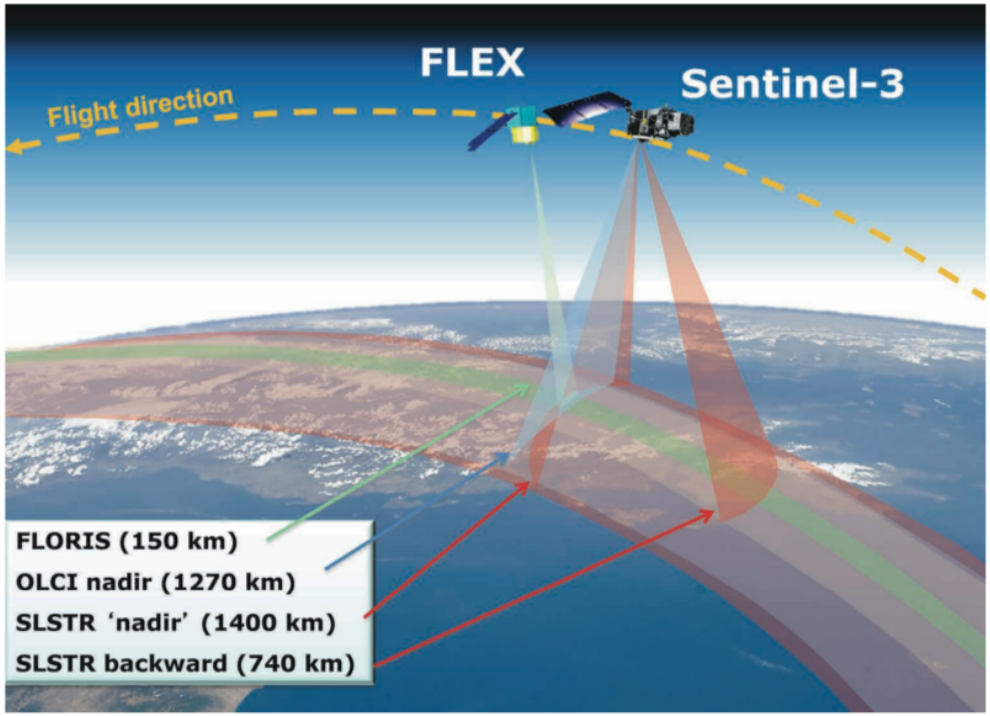






Making use of the O_2 absorption bands implies a good characterization of the atmospheric state, specially aerosols, and surface pressure.

FLEX/Sentinel-3 tandem mission

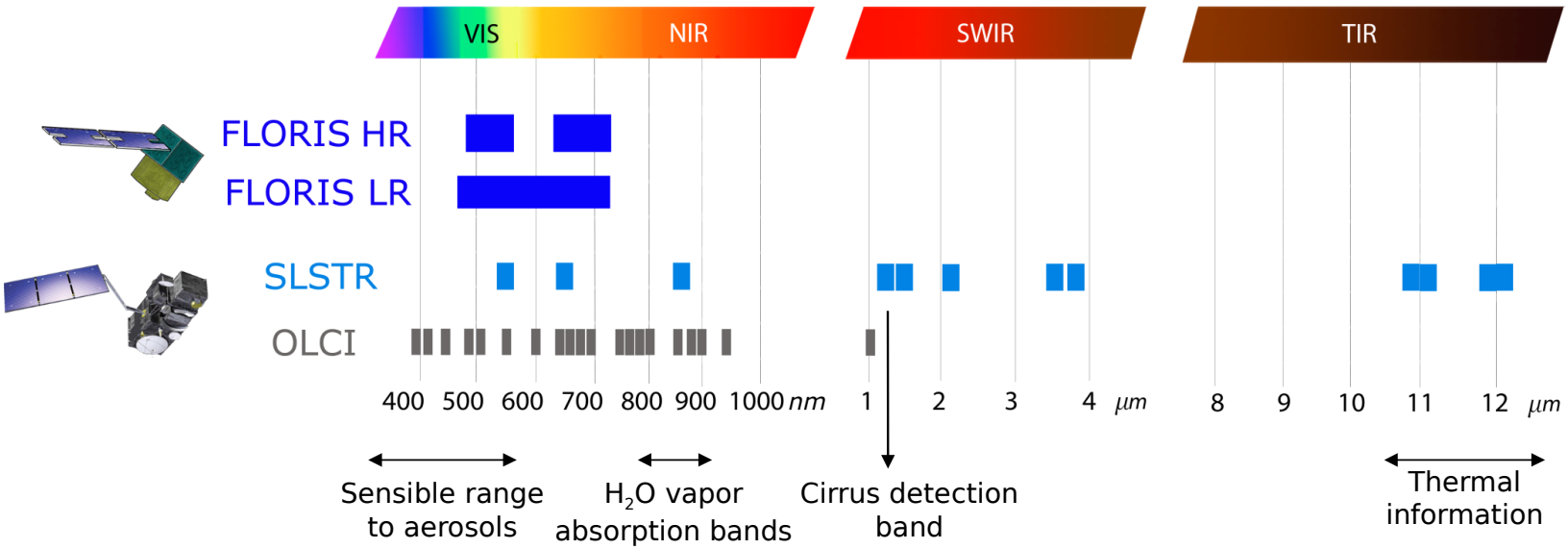


The tandem mission concept fits with the spatio-temporal FLEX mission requirements.
In addition it provides additional supporting measurements for :

- atmospheric correction
- deriving vegetation biophysical parameters

FLEX/Sentinel-3 tandem mission

To fully characterize the atmospheric state and perform an accurate atmospheric correction process, FLEX is designed to fly in tandem with the Sentinel-3 mission.



More technical information can be found at the *Report for mission selection, FLEX ,(ESA-2015)*

FLEX/Sentinel-3 atmospheric correction inversion process

Making use of high spectral resolution spectrometers (SSI $\sim$ 0.1nm) provides an accurate description of absorption band regions. However:

- Atmospheric functions i.e. L_0,E_{TOC}, T and S, must be grouped before being convolved according to the ISRF

$$L_{TOA} = L_0 + \frac{E_{TOC} \cdot T \cdot \rho_{app}}{(1 - S\rho)}$$

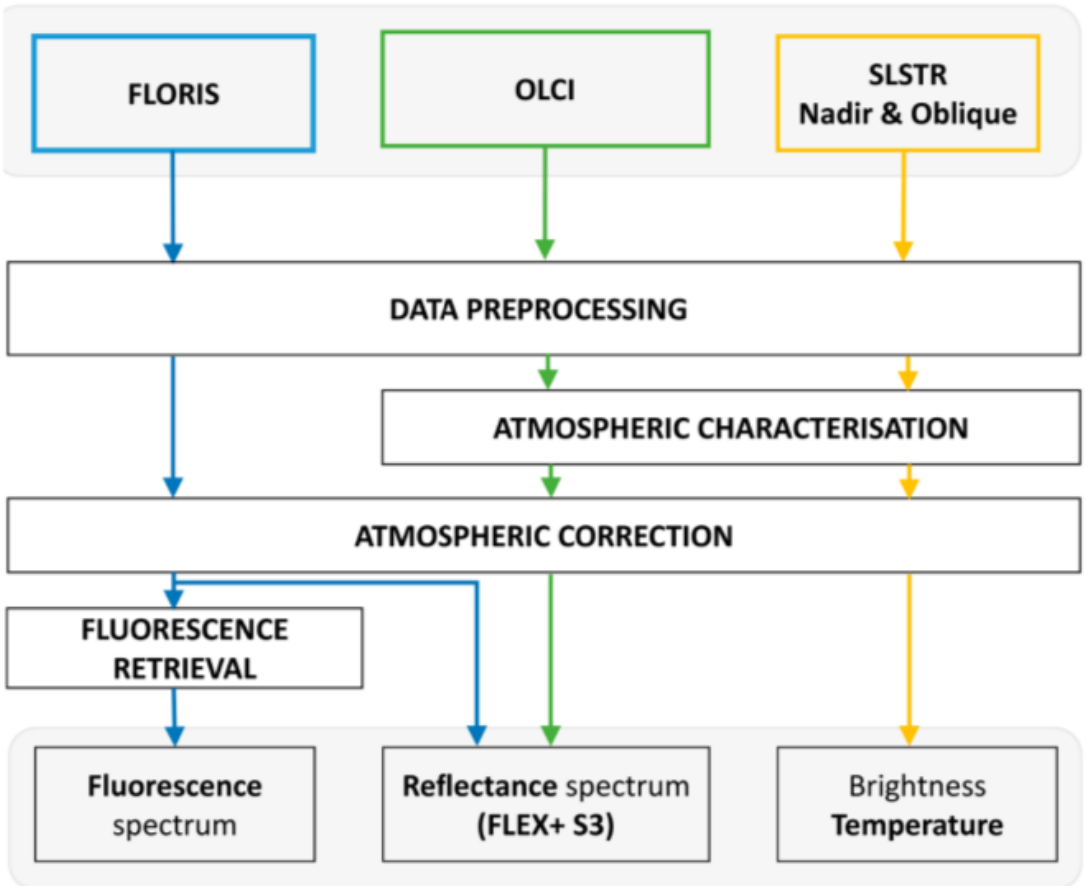
The series expansion of L_{TOA} expression is used instead

$$L_{TOA} = \int_{\lambda_i}^{\lambda_f} (L_0 * f) d\lambda + \frac{1}{\pi} \int_{\lambda_i}^{\lambda_f} (TE_{TOC}\rho_{app} * f) d\lambda + \quad (1)$$
$$+ \frac{1}{\pi} \int_{\lambda_i}^{\lambda_f} (TE_{TOC}S\rho_{app}^2 * f) d\lambda$$

- Spectral instrumental ISRF must be accurately characterized.
  - Spectral shift
  - Band-broadening
  - ISRF shape

Level-2 processing scheme

Schematic view of the processing chain for the FLEX mission to retrieve surface reflectance and fluorescence from measurements from FLORIS, OLCI and SLSTR.



[Report for mission selection, FLEX ,(ESA-2015)]

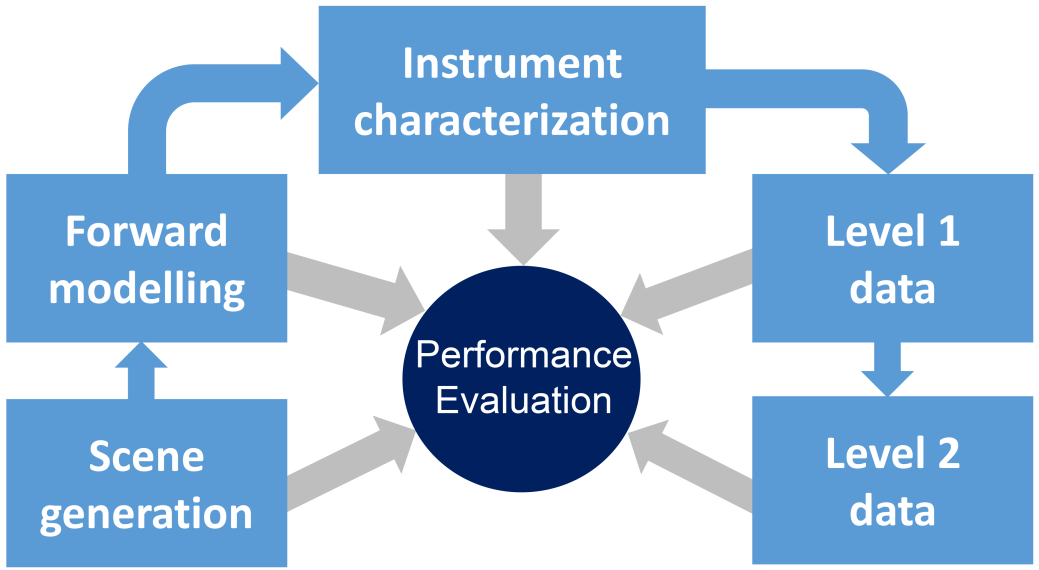
Level-2 products

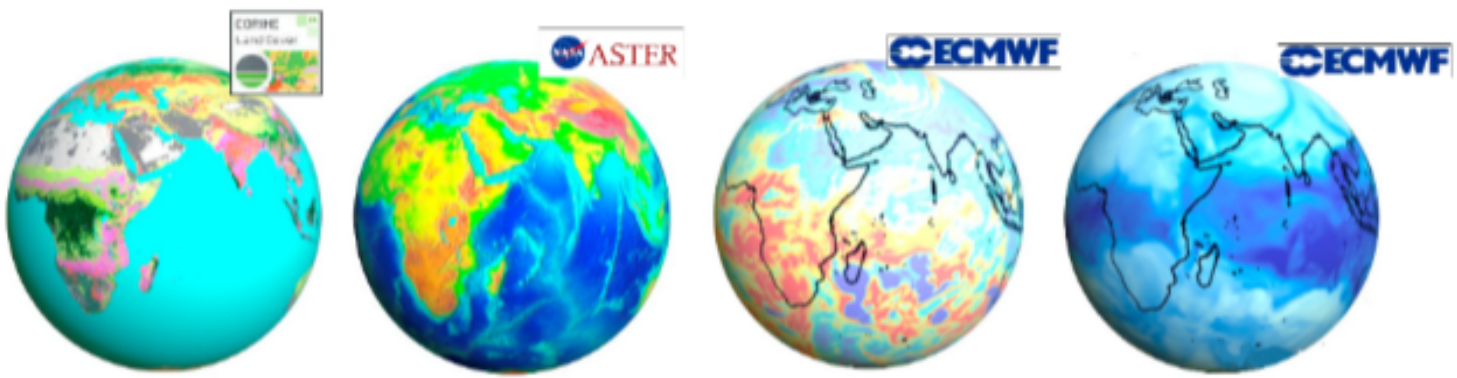
List of Level-2 products that will be provided by FLEX.

Level-2 Products	Definition
O_2-A and O_2-B emission values (F_{761} and F_{687})	Accuracy requirement at 300 × 300 m^2 spatial resolution: 0.2 mW m^{-2} sr^{-1} nm^{-1}
Total fluorescence emission (spectrally-integrated value)	Accuracy requirement at 300 × 300 m^2 spatial resolution: 10% of the integrated value
Peak values ($\lambda_{\langle 680\rangle}$,$F_{\langle 680\rangle}$ and $\lambda_{\langle 740\rangle}$,$F_{\langle 740\rangle}$)	Accuracy requirement at 300 × 300 m^2 spatial resolution: 0.2 mW m^{-2} sr^{-1} nm^{-1}
Surface temperature	Accuracy: 1–2K, derived from Sentinel-3 SLSTR
Non-photochemical energy dissipation	Regulated energy dissipation, accounts for the fraction of light absorbed by non-photochemical pigments (carotenoids/chlorophyll ratio and violaxanthin/ zeaxanthin ratio, anthocyanin)

[Report for mission selection, FLEX ,(ESA-2015)]

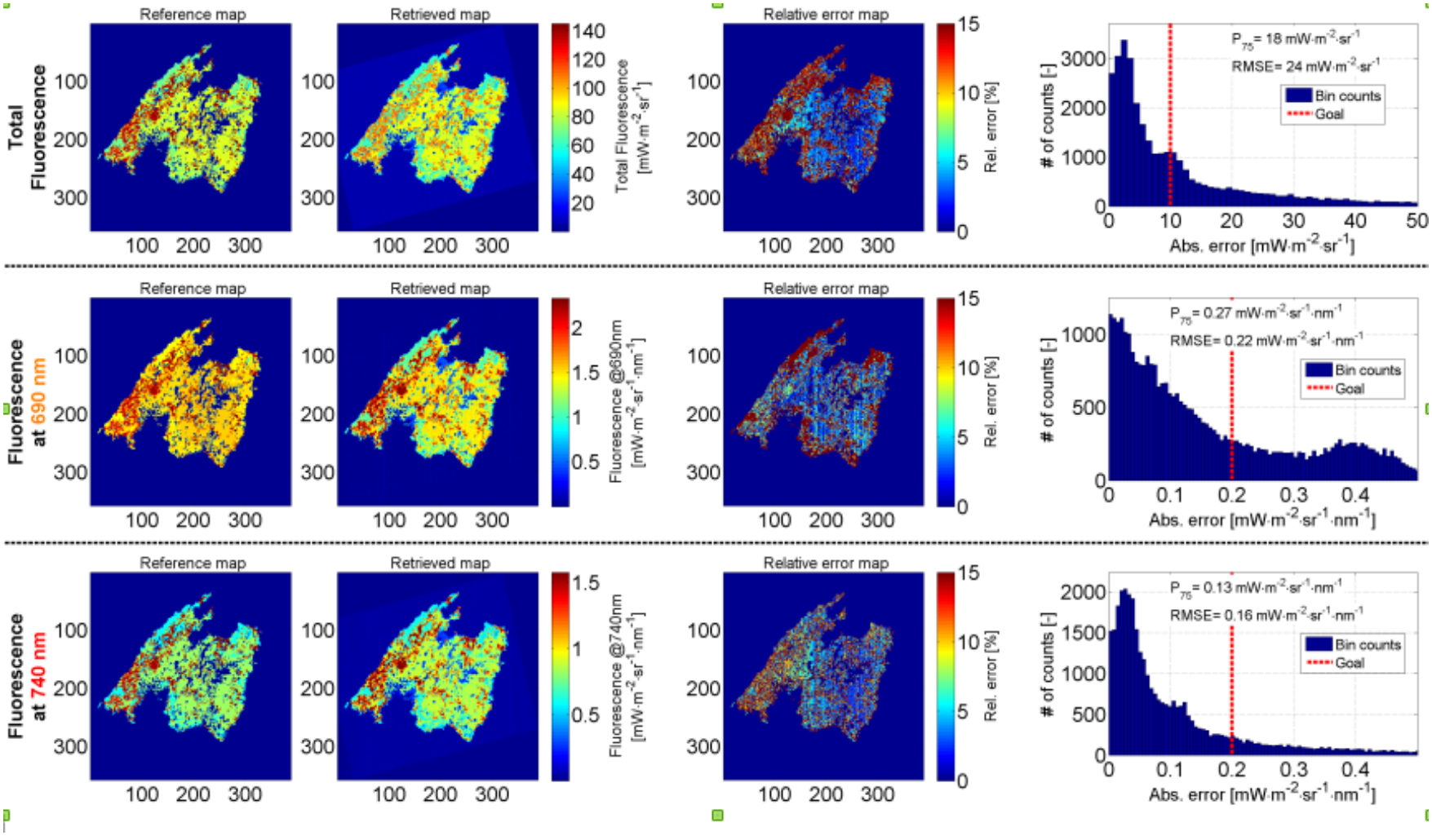
FLEX-End-To-End Simulator scheme





CORINE Land cover class map | Digital Elevation Model | Aerosol Optical Thickness | Atmospheric water vapor

FLEX-End-To-End Simulator: Realistic simulation



- FLEX formally approved by ESA PB-EO by 19 November 2015
- **Launch date : 2022**
- Definition of FLEX Science Plan ongoing (activities for 2016-2022):
  - Dedicated scientific studies
  - Campaigns
  - Workshops and conferences
  - Promotional and educational activities

For more information about FLEX activities:

`http://www.esa.int/Our_Activities/Observing_the_Earth/New_satellite_to_measure_plant_health`

FLEX Mission selection report

Regarding the End-To-End Simulator:


Vicent, Jorge et al. (2016). FLEX end-to-end mission performance simulator. *IEEE Transactions on Geoscience and Remote Sensing* 54(7), 4215–4223.

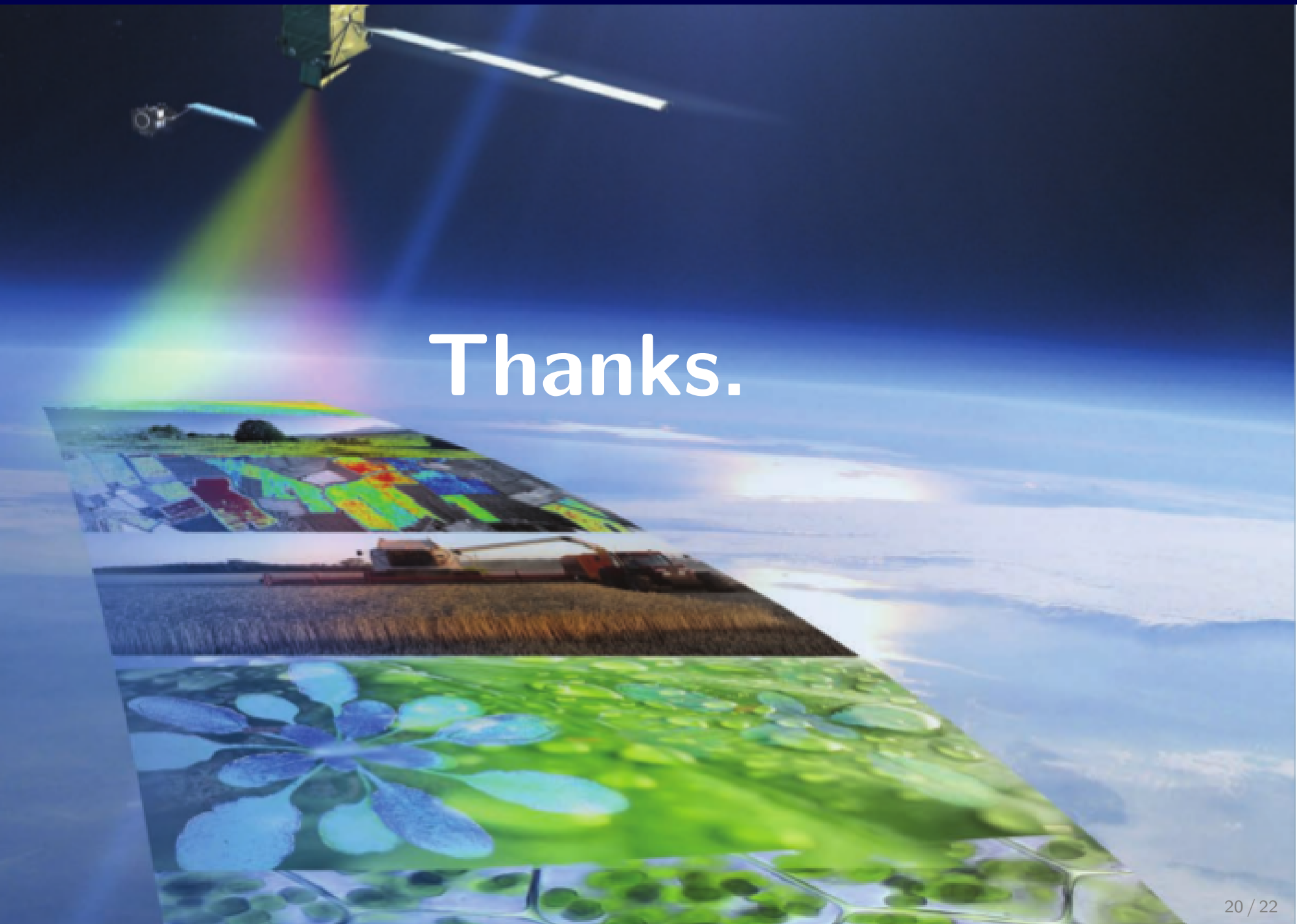
Regarding the ISRF requirements:


Vicent, Jorge et al. (2015). Propagation of spectral characterization errors of imaging spectrometers at level-1 and its correction within a level-2 recalibration scheme. *Proc. SPIE* 9611, 96110T-96110T-12.

Regarding the atmospheric correction process and the fluorescence retrieval method:


Sabater, Neus et al. (2015). A sun-induced vegetation fluorescence retrieval method form top of atmosphere radiance for the FLEX/Sentinel-3 tandem mission. *2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*,2669 - 2672


Cogliati, Sergio et al. (2015). Retrieval of sun-induced fluorescence using advanced spectral fitting methods. *Remote Sensing of Environment* 169, 344–357


Thanks.

Back-up slides

Higher Level Products	Definition
PS I-PS II contributions	Derived from $F_{\langle 680 \rangle}$ and $F_{\langle 740 \rangle}$ to give the $F_{PS\,I}$, $F_{PS\,II}$ corresponding missions
Fluorescence quantum efficiency	Ratio between energy emitted as fluorescence versus actual chlorophyll specific absorbed energy (dimensionless)
Photosynthesis rate	Effective charge separation at PS II, interpreted as actual electron current resulting in photosynthetic reactions
Vegetation stress	Defined as 'actual photosynthesis/potential photosynthesis' using the ratio of the two emission peaks and estimate of non-photochemical energy dissipation
Spatial mosaics	Regional/continental/global maps
Temporal composites	Monthly/seasonal/annual composites
Activation/deactivation of photosynthetic machinery	Determines actual length of the growing season
Dynamic vegetation stress	Derived by data assimilation with dynamical vegetation model accounting for temporal changes
GPP	Derived by data assimilation with usage of external inputs (meteorological data, land-cover maps)

Back-up slides

All available absorption bands used to retrieve full fluorescence spectrum: