Contribution of hyperspectral data for environmental monitoring

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Outlook

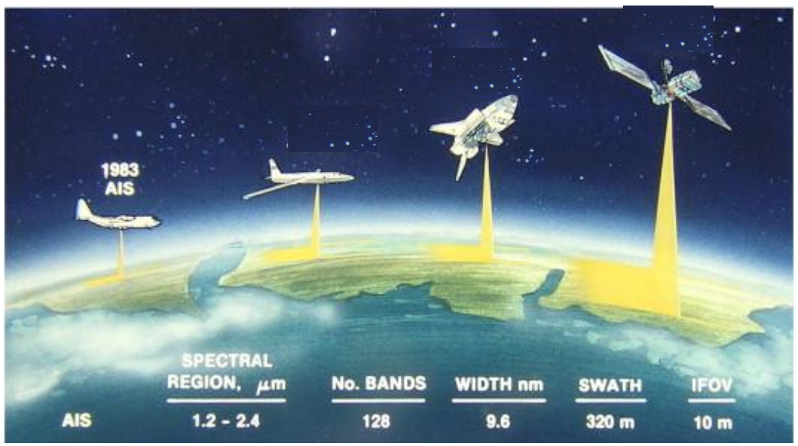
1. Hyperspectral remote sensing and environmental applications;

2. Analysis at different scale, from lab to spaceborne imaging spectroscopy missions;

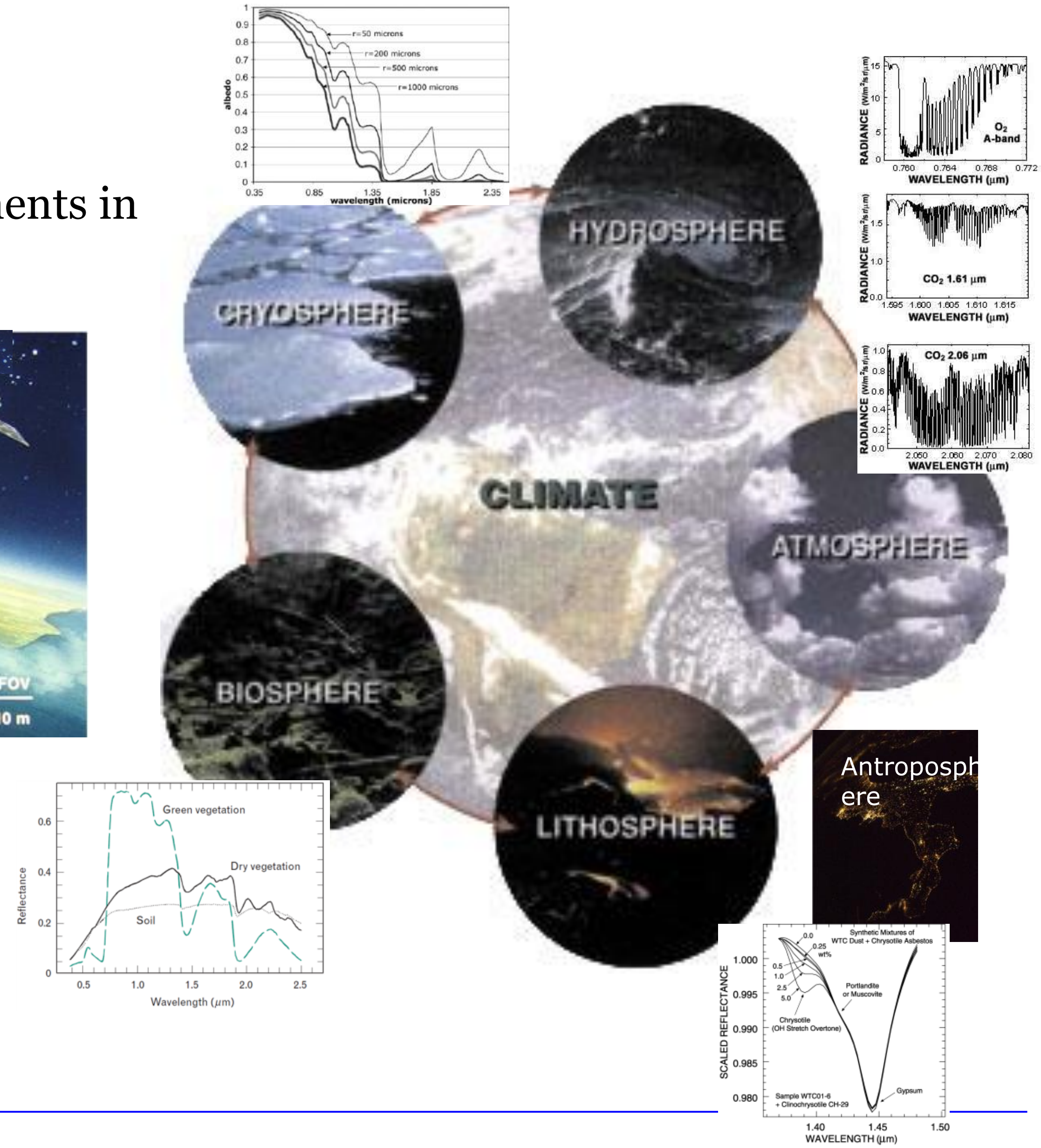
3. Challenges and conclusions

Environmental monitoring by hyperspectral data

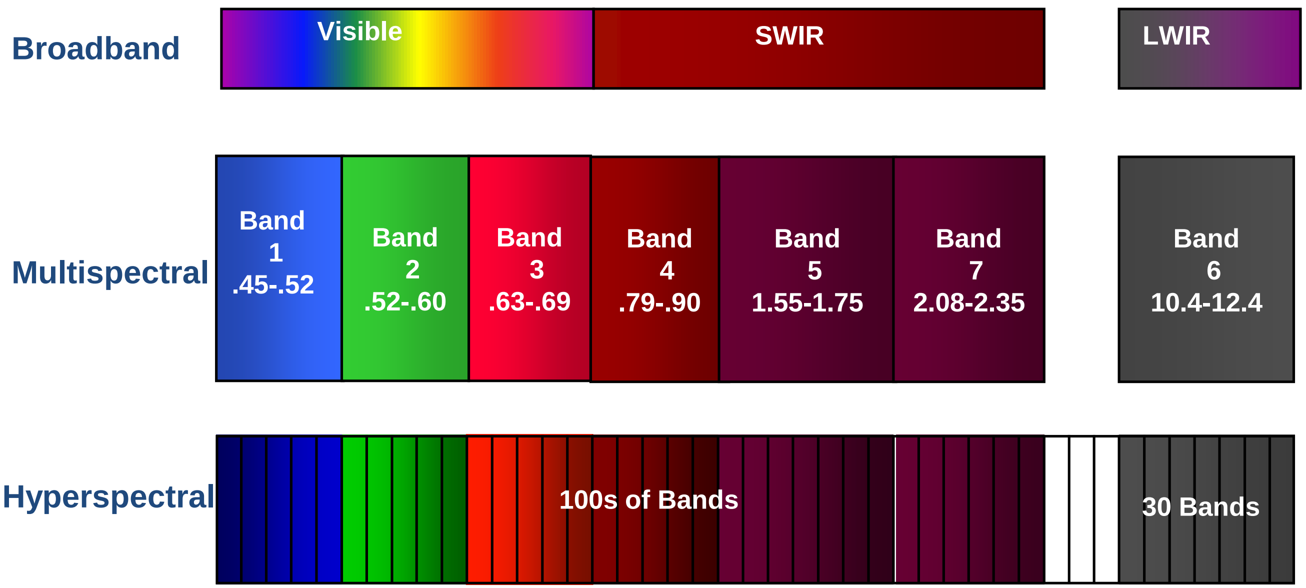
1970's from field spectral measurements in support of Landsat-1



Airborne Imaging Spectrometer (Goetz et al., 1985)



Spectral resolution and hyperspectral domains



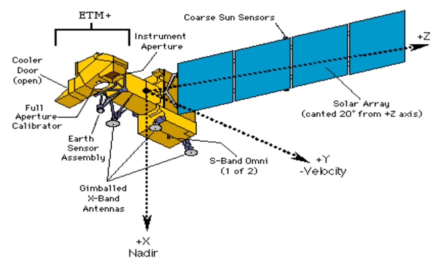
Spectral resolution *vs* spectral range *vs* spectral contiguity

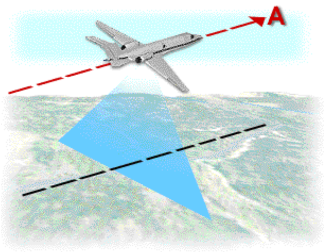
- Reflected radiance VSWIR;
- Emitted radiance TIR
- Emitted radiance 670-780 nm VIS NIR

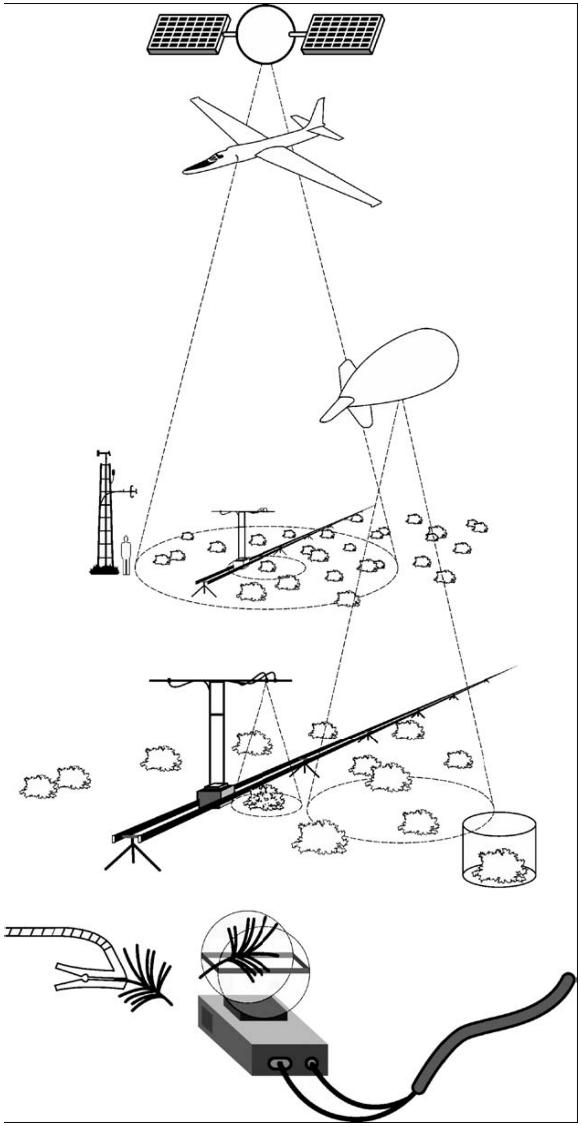
VISIBILE		VIS	~0.40 µm	~0.75 µm
INFRAROSSO	VICINO	NIR	~0.75 µm	~1.3 µm
	ONDE CORTE	SWIR	~1.3 µ	~3.0 µ
	MEDIO	MIR	~3.0 µ	~6.0 µ
	TERMICO	TIR	~6.0 µ	~15.0 µ

Different platforms and scales of investigation

Multisource hyperspectral remote sensing







Gamon et al, 2006

Laboratory instruments

e.g. HyIce system

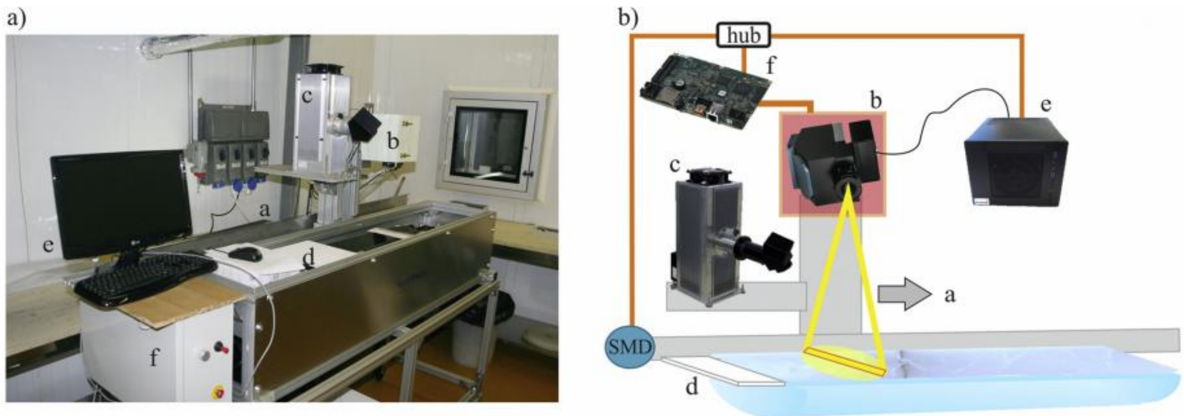
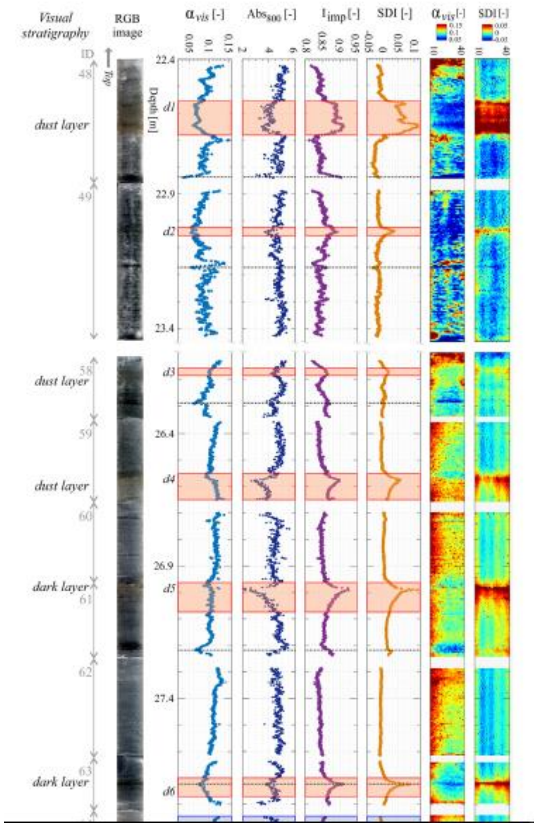
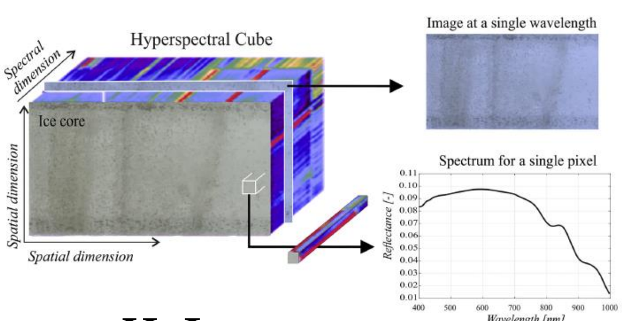


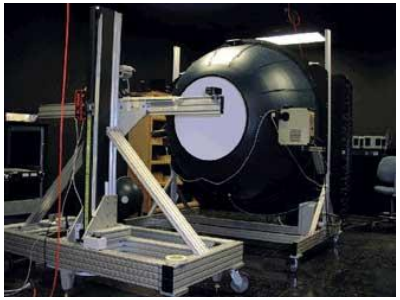
Fig. 1. Image of the HyIce system (left) and its schematic drawing (right). HyIce consists of: a) high-precision linear stage with samples holder and motor driver; b) HeadWall VNIR camera thermostated using heaters; c) stable halogen lamp that lights the surface uniformly; d) calibrated Lambertian Spectralon® panel used to calculate reflectance; e) PC connected to the spectrometer by using a dedicated interface; f) Single-Board RIO with Ethernet TCP/IP wireless connection.



Imaging vs non imaging systems



HyIce

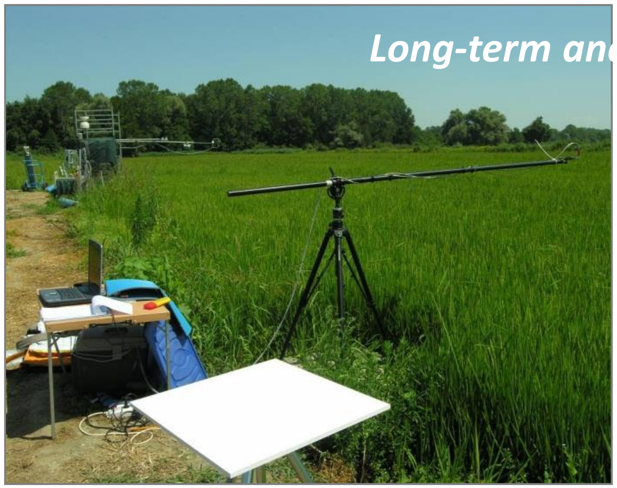


Reflectance and transmittance (e. g. leaf spectra)

Field spectroscopy

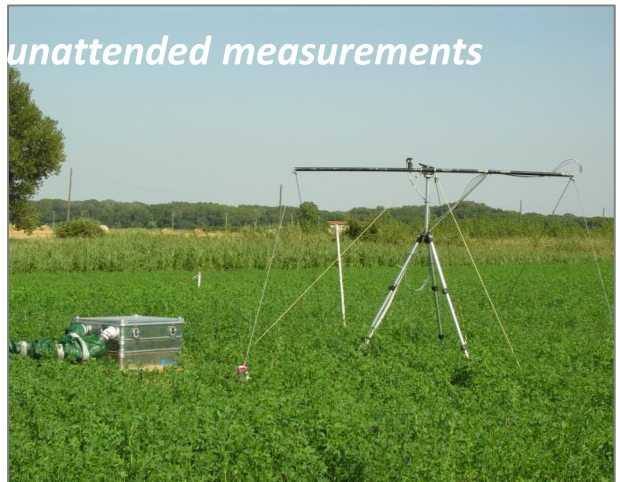
- *Need of automatic systems*
- *Diurnal, seasonal, dynamics vs instantaneous satellite observations*
- *Cal/Val strategies*

Manual spectrometric system

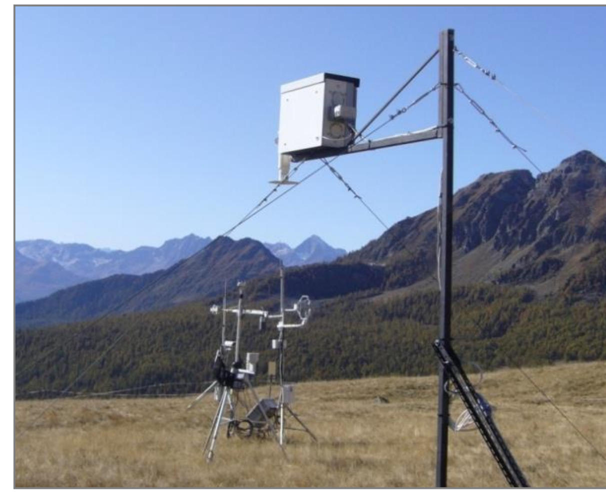


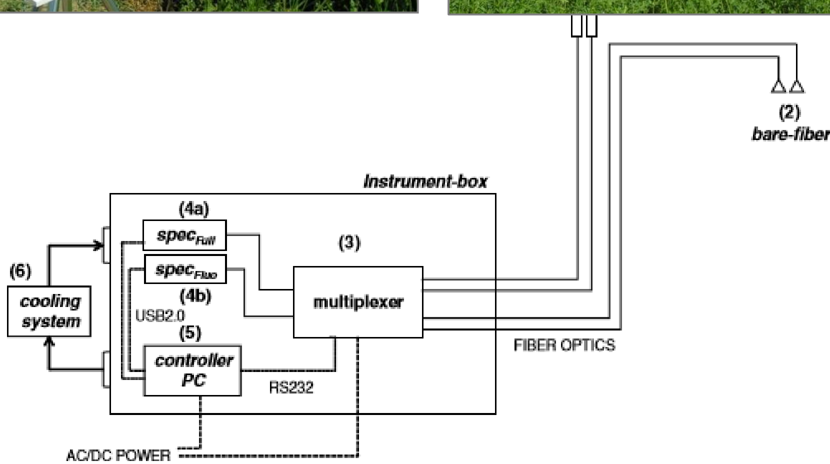
MRI, **M**ultiplexer Radiometer/**I**rradiometer
sFLUORBOX

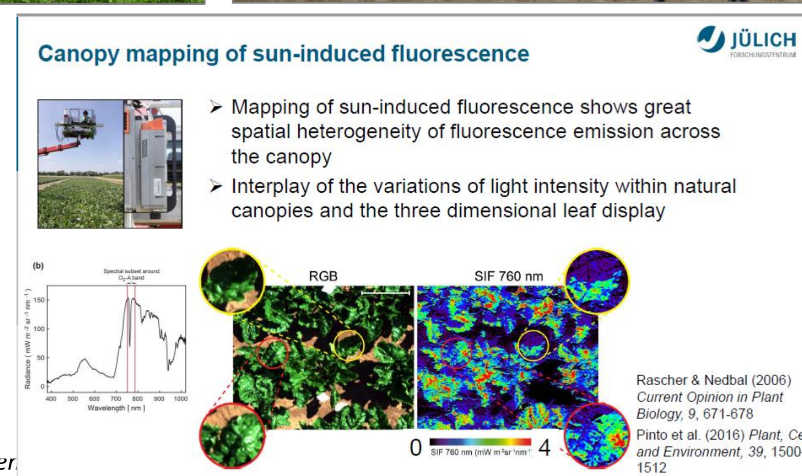
Long-term and unattended measurements



HSI, **H**yper**S**pectral **I**rradiometer

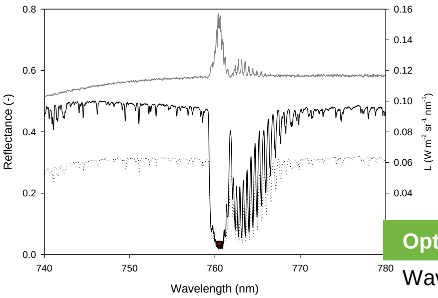




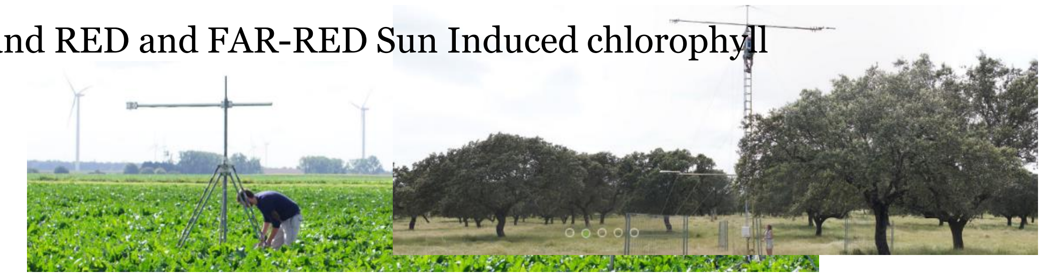


Instruments for fluorescence measurements

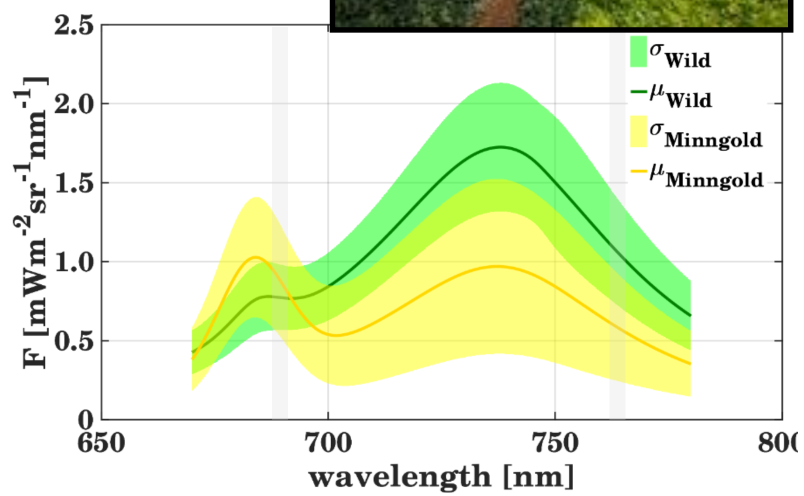
For long term measurements of reflectance hcrf and RED and FAR-RED Sun Induced chlorophyll



FLEX reference



Optic	
Wavelength range	650—800 nm
Spectral Sampling Interval (SSI)	0.17 nm
Spectral resolution (FWHM)	0.3 nm
Signal to Noise Ratio (SNR)	1000
Field Of View (FOV)	Dual FOV. Upwelling radiance 25°. Downwelling radiance 180°
Operational	
Signal Optimization	Automatic adaption to varying light conditions
Dark current	Accurate dark current determination at each measurement cycle
Automatic acquisition	Fully autonomous measurement mode
Quick measurements	20 seconds under bright sunshine 60 s
Stability	Reference system stability check
Simultaneous metadata	Spectrometer temperature, Outside temp
Case	Robust and Waterproof housing ba
Dimension	Small form factor (50 x 30 x 20 cm) su
Power supply	12 Volt. From battery a
Power consumption	Average consumption of 60 Watt. (20



HYPERSPECTRAL DEVICES

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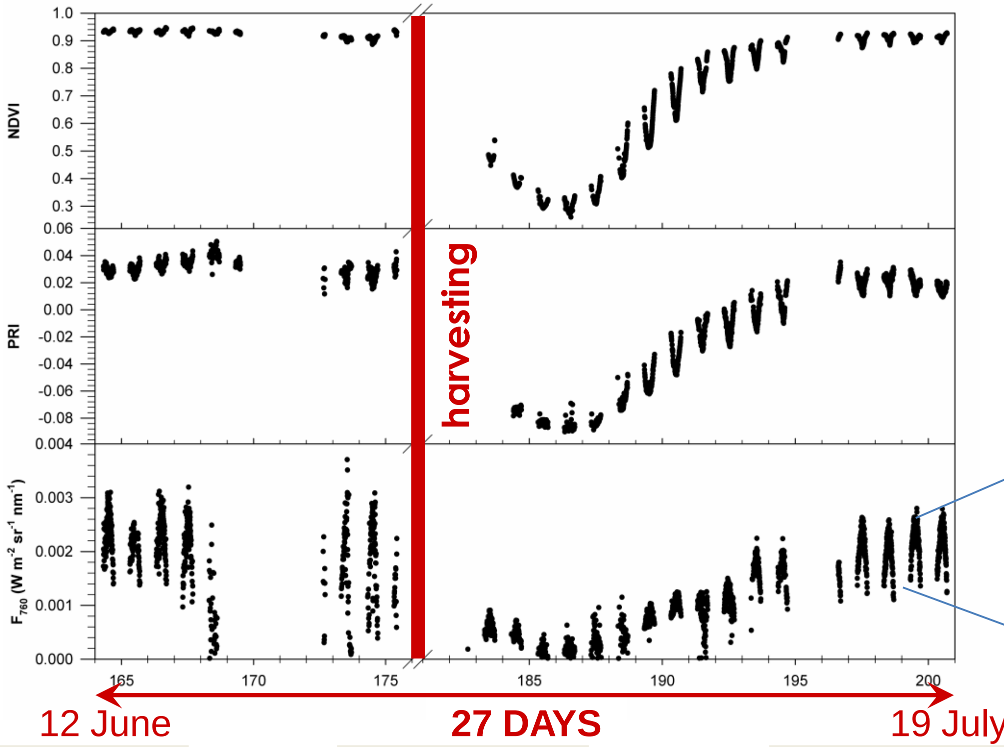
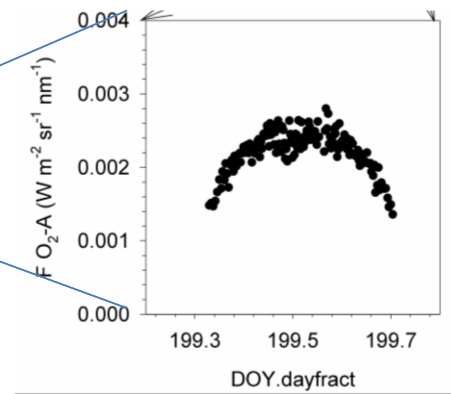
JÜLICH FORSCHUNGSZENTRUM

Example of time series from automatic systems





- diurnal and seasonal variability (alfa-alfa)

- a new tool for environmental monitoring

- cal/val context, vicariuos calibrations vs product validations

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Hyperspectral UAV: spatial vs temporal domain

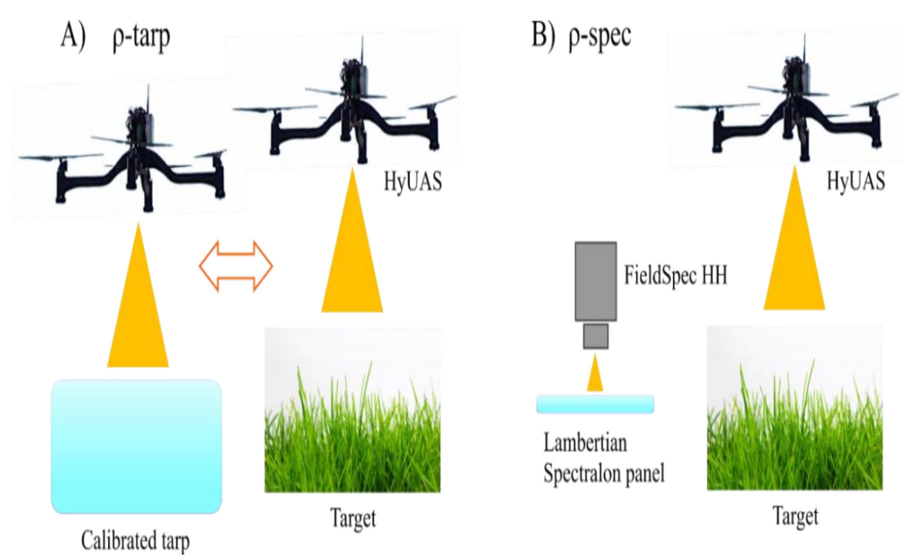
e.g. HyUAS system

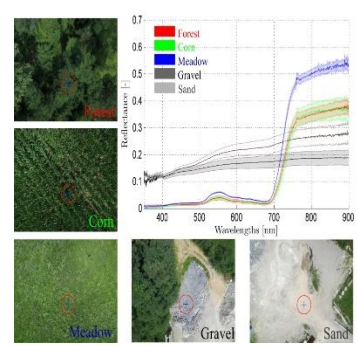
Anteos platform

- Four-rotor platform with hovering capability, maximum payload of 2 Kg and flight time of 20 min
- Global Position System (GPS) coupled with the Inertial Movement Unit (IMU)
- Radio connection to the ground control station

Optical payload

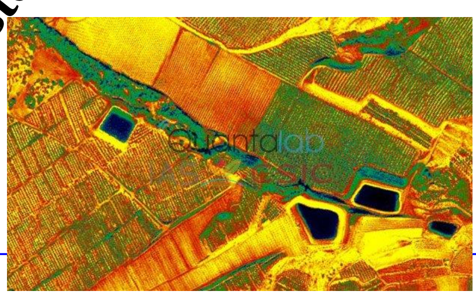
- RGB digital camera (Canon S100)
- Ocean Optics USB4000 VNIR non-imaging spectrometer (350 -1000nm, 1.0 nm FWHM, 16bit)
- DC from shutter





Garzonio et al.,2017

Non imaging vs imaging systems



Credit P. Zarco-Tejada

Field and airborne instruments and campaigns

Field spectroscopy

HyPlant: a novel high performance spectrometer to measure sun-induced chlorophyll fluorescence

Module 1: Imaging spectrometer (380 – 2500 nm) with 3 nm (VIS) and 10nm (SWIR) spectral resolution; 1-3 meters spatial resolution

Module 2: Fluorescence module (670 – 780 nm) with 0.25 nm (FWHM)

Rascher et al.,2015

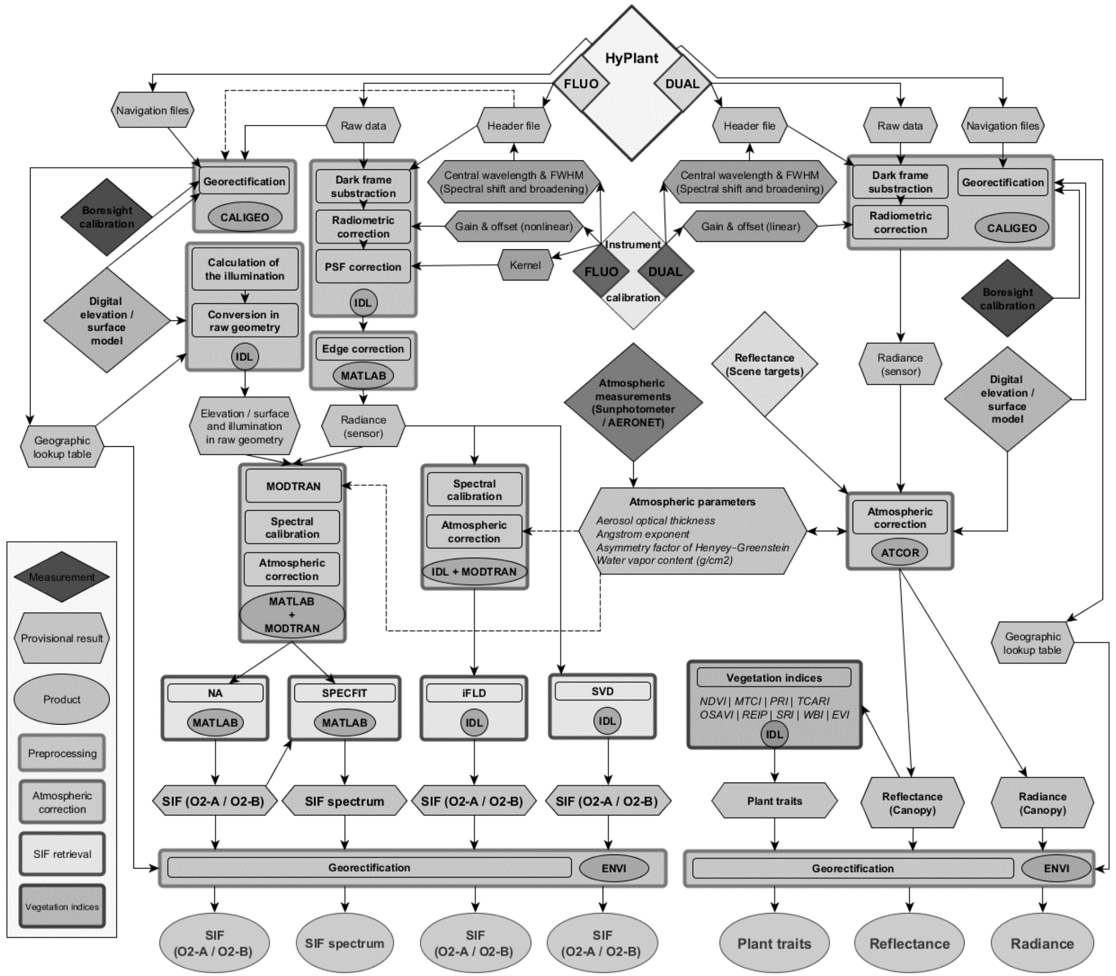
Airborne imaging spectroscopy

O2-A and O2-B

...now using also FL (The Chlorophyll Fluorescence Imaging Spectrometer CFIS, Frankenberg et al., 2018)

.............beside current optical and thermal sensors

Processing chain. Level and Products



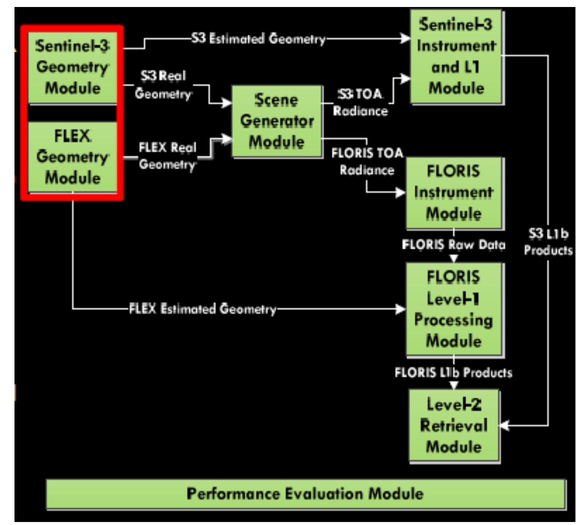
Credit HYPER Project (ESA)

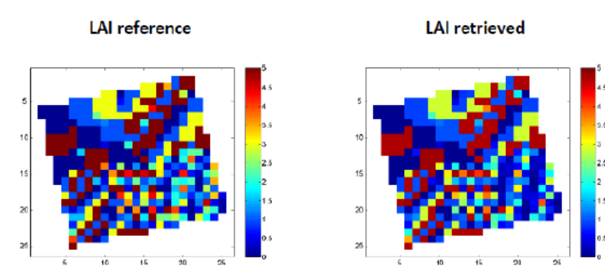
HyPlant example

- Different algorithms and products

FLEX example

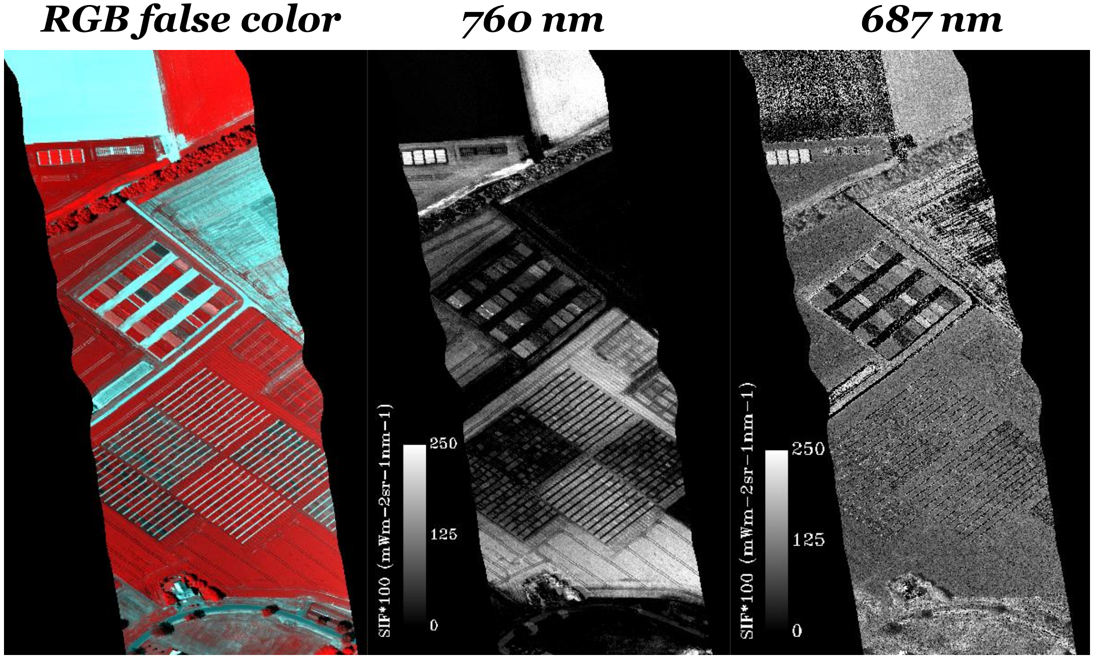
- Different sensors – E2E

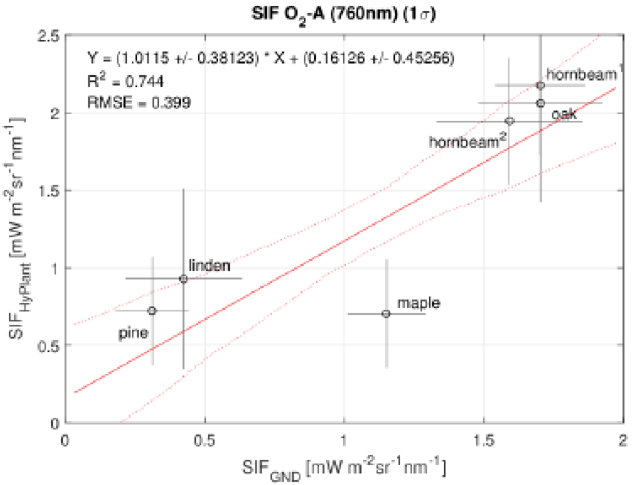


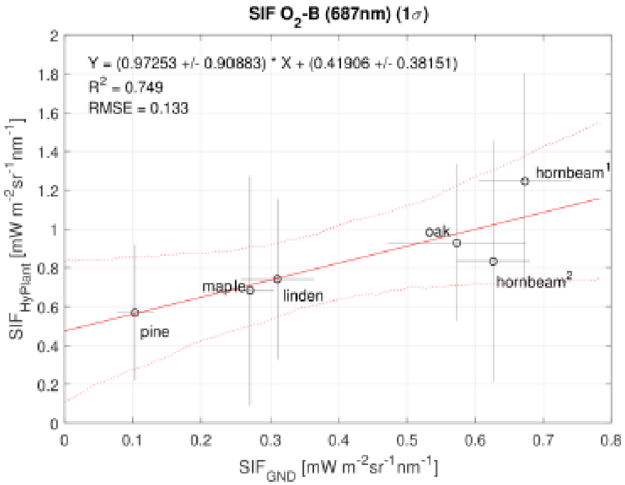


Credit J. Vicent

HyPlant reflectance and fluorescence







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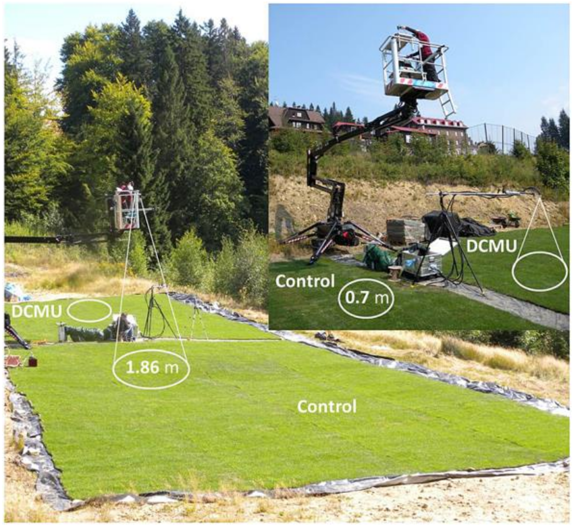
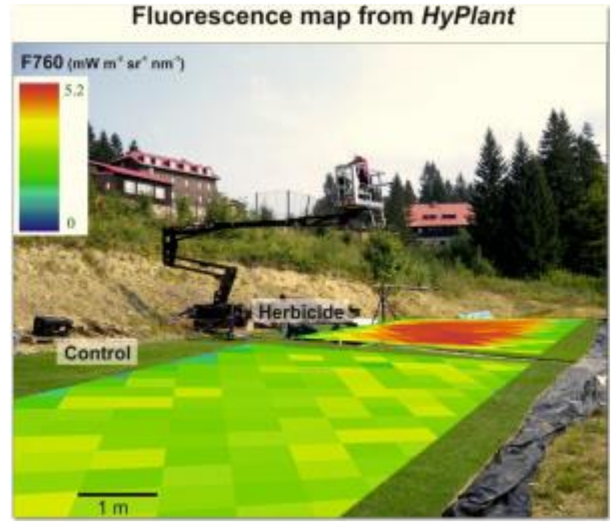
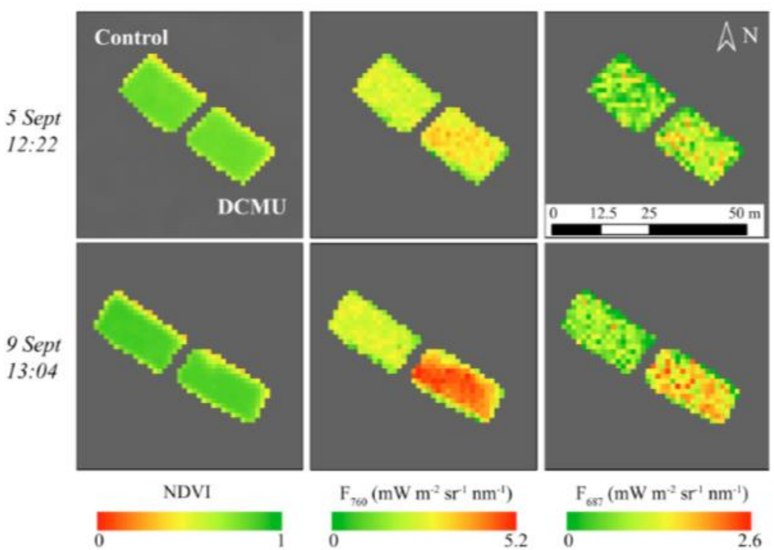
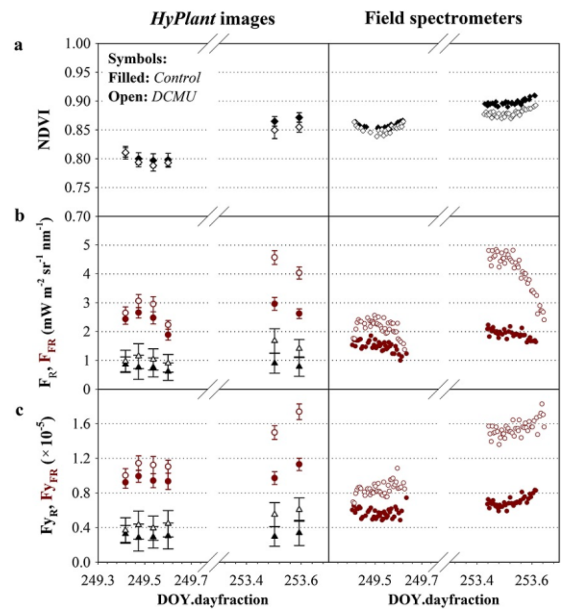
Ground and airborne experiments





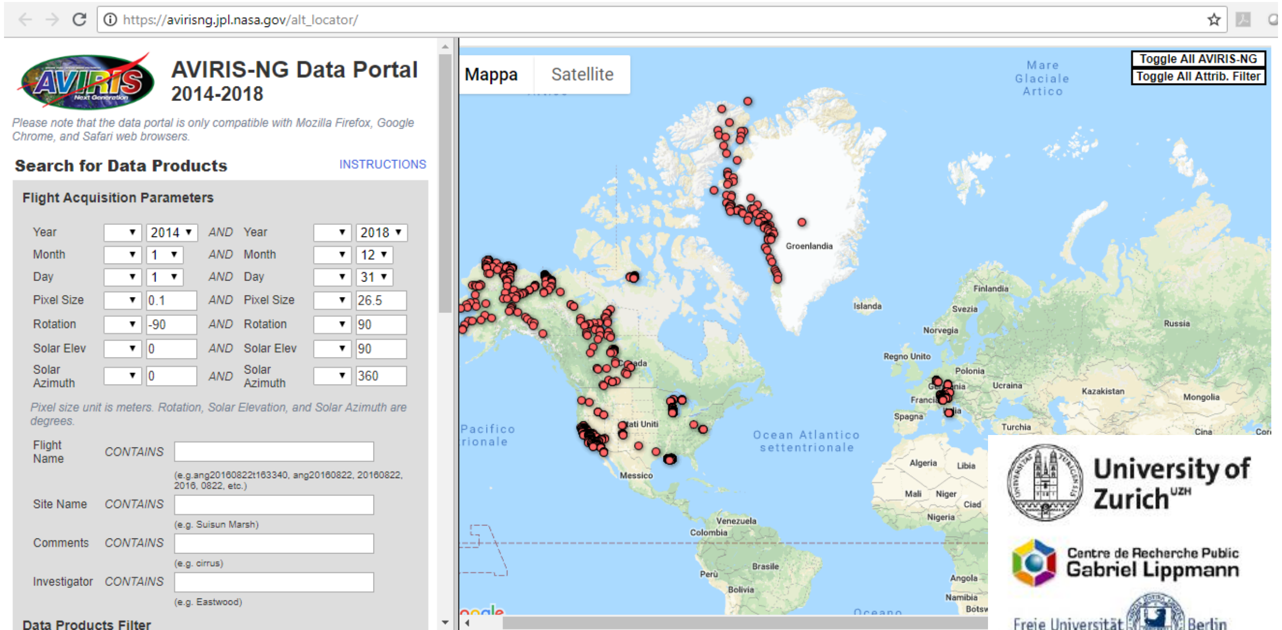
Rossini et al.,2015





Hyperspectral campaign in 2018

Different activities in the context of future space imaging spectroscopy missions



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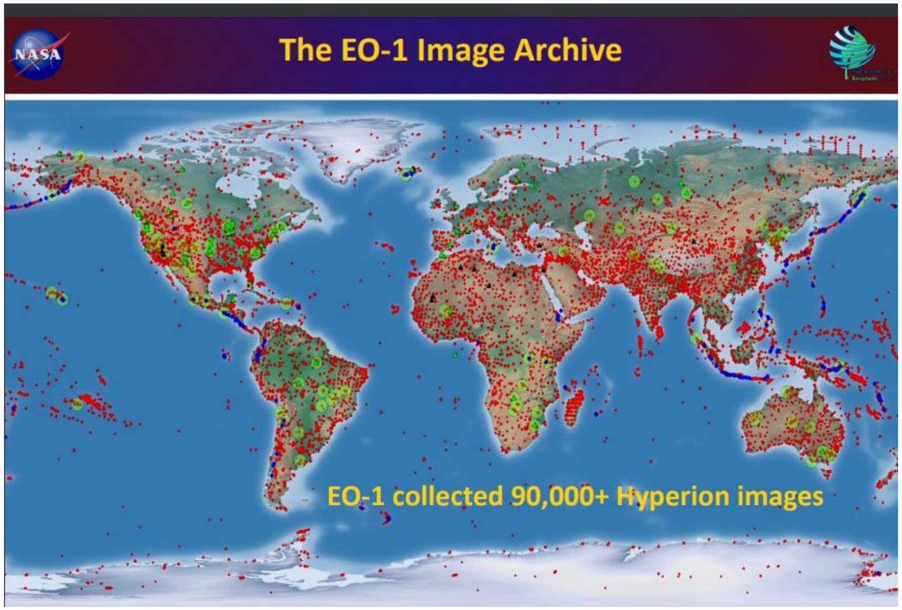
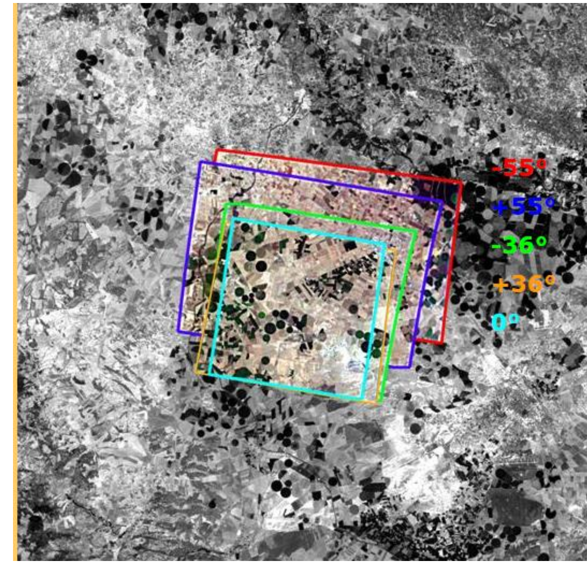
Hyperspectral imaging spectrometry heritage

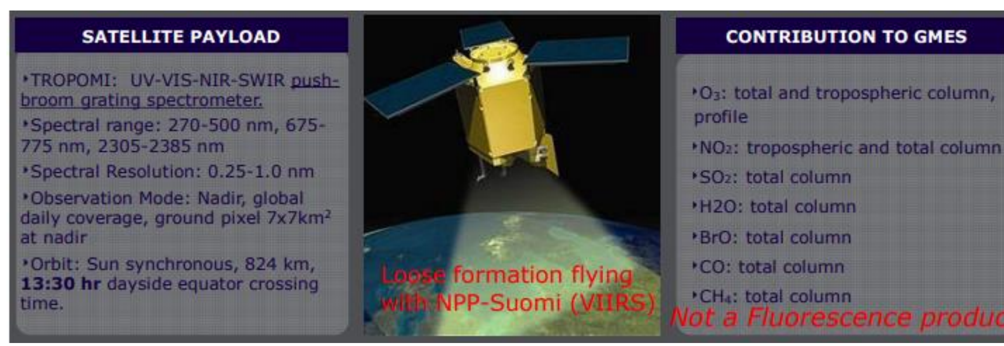
ESA's Proba-1/CHRIS
NASA EO-1 Hyperion



Credit E. Middleton



Hyperspectral atmospheric chemistry missions (e. g. OCO-2, S-5 TROPOMI)

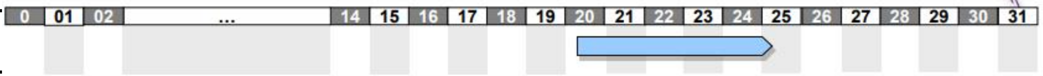


PRISMA and EnMAP missions

Swath / FOV /IFOV	30 km / 2.77° / 48 µrad
Ground Sampling Distance (GSD)	Hyperspectral: 30 m / PAN: 5 m
Spectral Range	VNIR: 400 – 1010 nm (66 spectral bands) SWIR: 920 – 2505 nm (173 spectral bands) PAN : 400 – 700 nm
Spectral Width (FWHM)	≤ 12 nm
Radiometric Quantization	12 bits
VNIR SNR	> 200:1
SWIR SNR	> 100:1
PAN SNR	> 240:1
Absolute Radiometric Accuracy	5%
MTF@ Nyquist freq.	VNIR/SWIR along track > 0.18 VNIR/SWIR across track > 0.34 PAN along track > 0.10 /PAN across track >0.20
Co-registration (Keystone, Smile)	≤ 0.1 pixel
Thermal Control System	Double stage passive radiator (1 for each channel) + stabilization heater
Mass	Optical Head: 175kg Thermal Shield: 25kg Main Electronics: 11kg
Power Consumption	Earth Observation /calibration: 90W Idle: 80W

Credit PRISMA Science team

EnMAP (Germany)



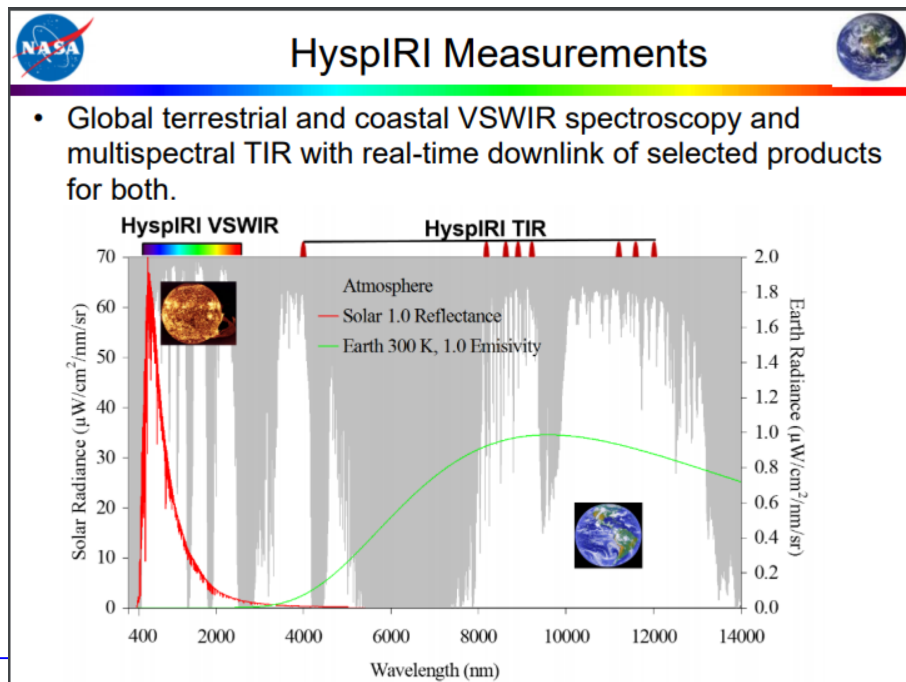
Parameter	Value
Mission	Germany's first hyperspectral Earth observing satellite mission, scientific path finder mission for later operational services, for environmental monitoring, process understanding
Spectral Range	420 nm – 1000 nm (VNIR), 900 nm – 2450 nm (SWIR)
Bandwidth	6.5 nm ± 1.25 nm (VNIR), 10 nm ± 2.50 nm (SWIR)
No of Bands	98 bands (VNIR), 130 bands (SWIR)
Spatial Resolution	30 m
Swath	30 km
Orbit	Sun-Synchronous at 653 km
Revisit	≤ 4 days (± 30° off-nadir tilt) and ≤ 21 days (± 5° off-nadir tilt)
Special features	Mission fully funded
Link	www.enmap.org http://www.grss-ieee.org/wp-content/uploads/2017/hyperspectral_igarss_sessions/05_2017-07-24_IGARSS17_EnMAP_FINAL.pdf
CEOS Database	http://database.eohandbook.com/database/missionsummary.aspx?missionID=600

Credit EnMAP Science team

NASA missions

Recommended NASA Priorities: Designated

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		



Combining VSWIR and TIR

Credit HyspIRI Science team

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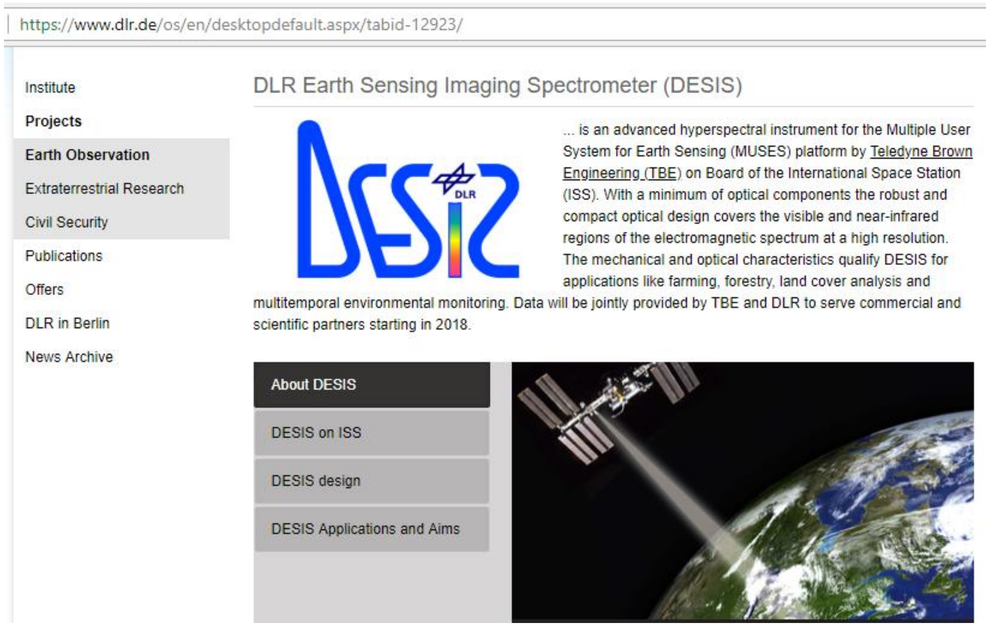
Desis and EMIT missions



https://www.dlr.de/os/en/desktopdefault.aspx/tabid-12923/

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- DLR in Berlin
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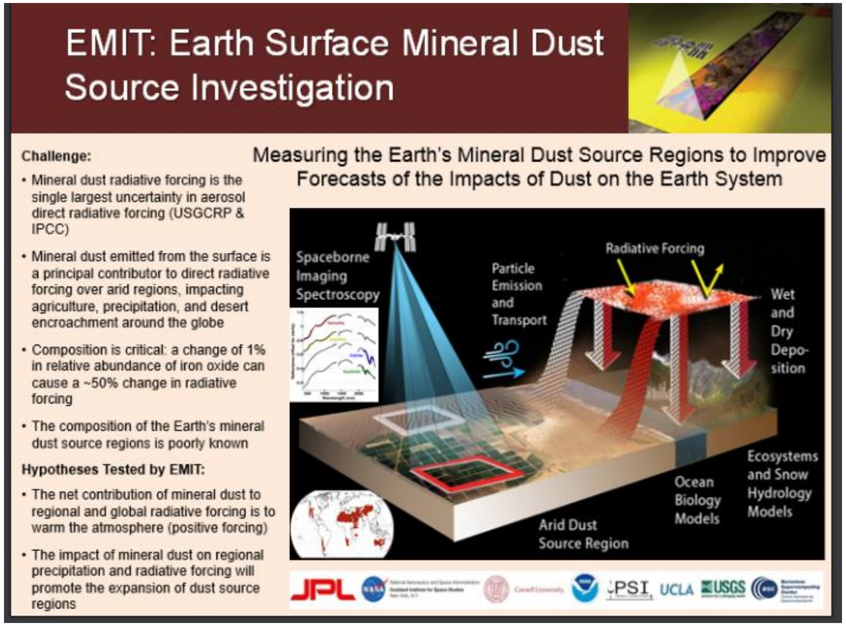
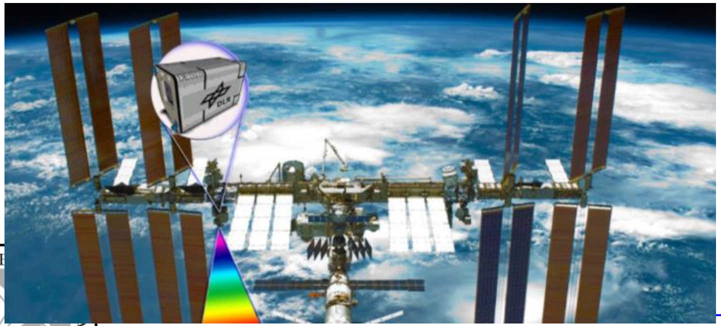
DLR Earth Sensing Imaging Spectrometer (DESIS)

... is an advanced hyperspectral instrument for the Multiple User System for Earth Sensing (MUSES) platform by Teledyne Brown Engineering (TBE) on Board of the International Space Station (ISS). With a minimum of optical components the robust and compact optical design covers the visible and near-infrared regions of the electromagnetic spectrum at a high resolution. The mechanical and optical characteristics qualify DESIS for applications like farming, forestry, land cover analysis and multitemporal environmental monitoring. Data will be jointly provided by TBE and DLR to serve commercial and scientific partners starting in 2018.

- About DESIS
- DESIS on ISS
- DESIS design
- DESIS Applications and Aims

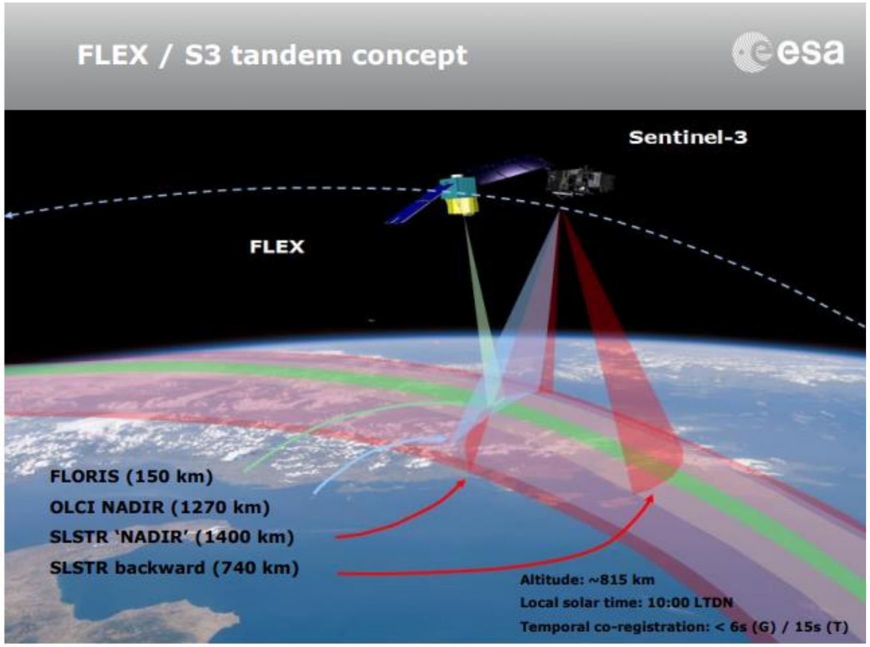


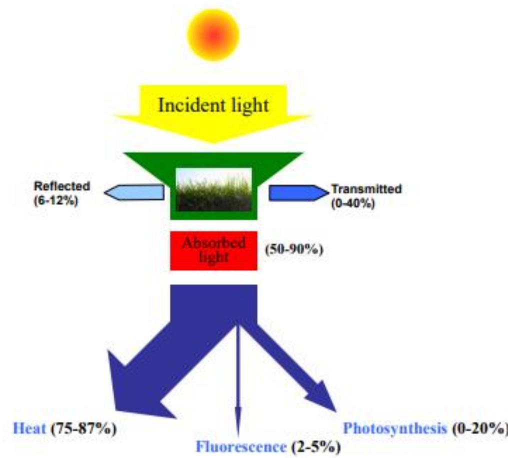
Sahara Mineral Dust on Snow in Europe March 2018



Both on ISS +

ESA Earth Explorer programme – FLEX mission





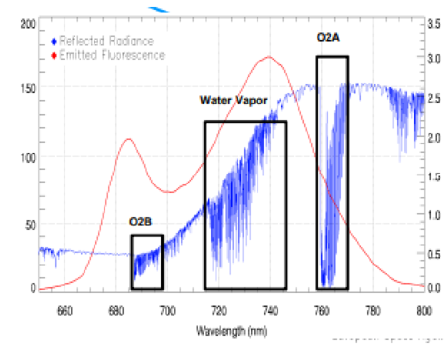
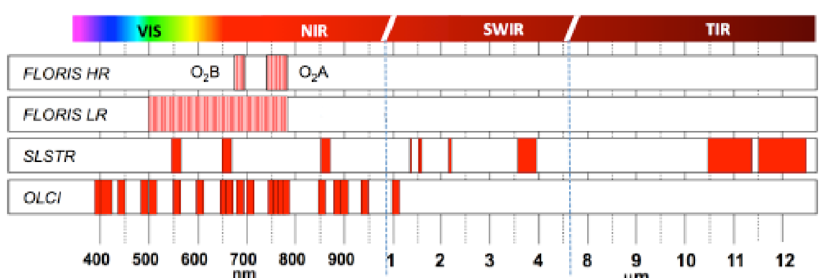


Table 1
Technical characteristics of the FLORIS spectra in terms of spectral resolution (SR), spectral sampling interval (SSI), and signal to noise ratio (SNR) for the different spectral regions.

Spectral region	Visible	SIF_{red}		Red-edge			$SIF_{far-red}$		
λ (nm)	500–677	677–686	686–697	697–740	740–755	755–759	759–762	762–769	769–780
SR (nm)	3.0	0.6	0.3	2.0	0.7		0.3		0.7
SSI (nm)	2.0	0.5	0.1	0.65	0.5		0.1		0.5
SNR	245	340	175	425	Linear from 510 to 1015	1015	115	Linear from 115 to 455	1015



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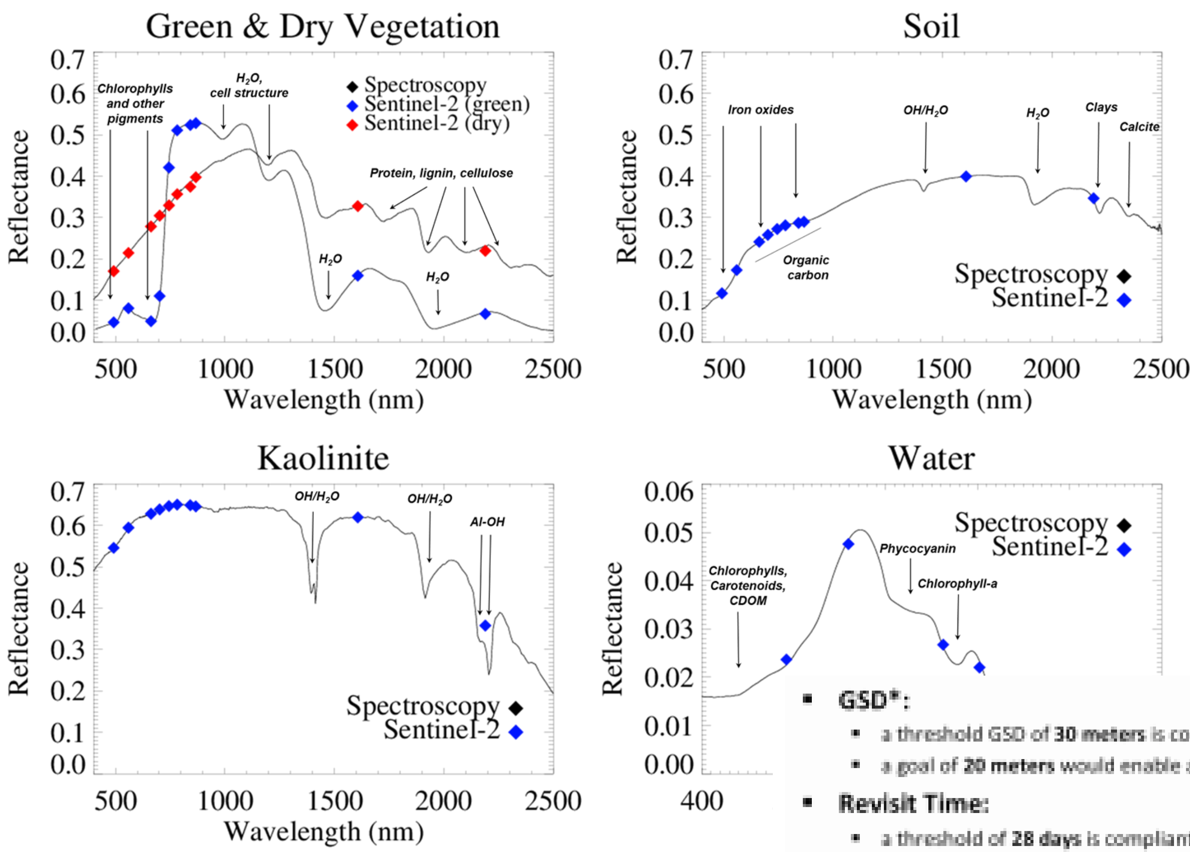
CHIME mission

Copernicus Hyperspectral Imaging Mission (CHIME)

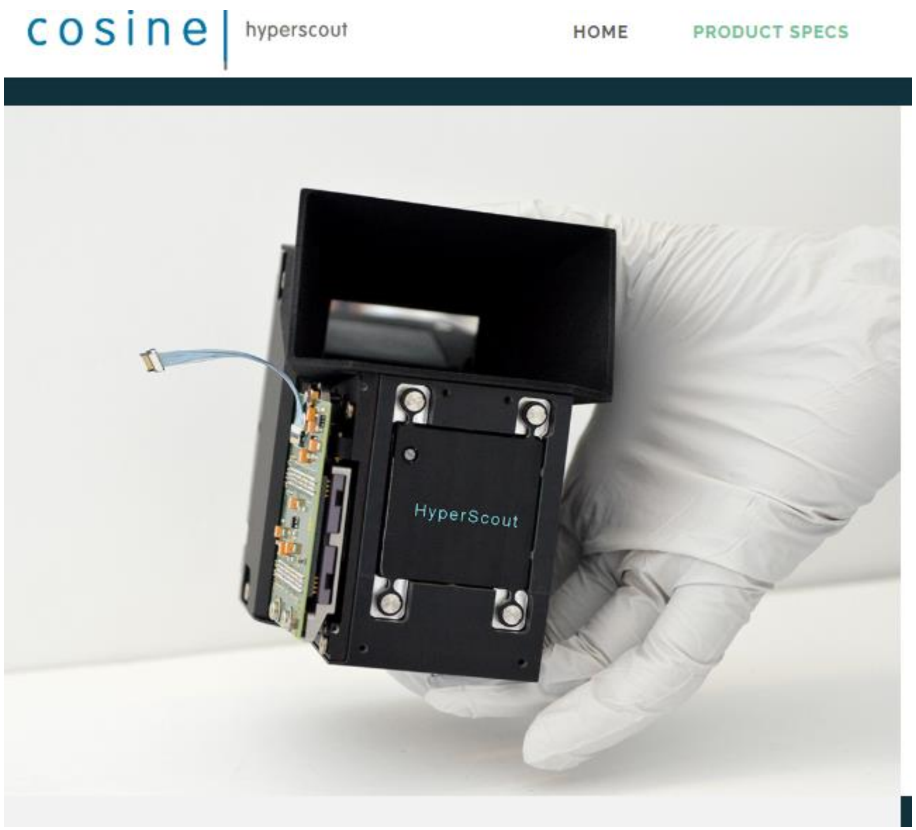


- **GSD*:**
  - a threshold GSD of **30 meters** is compliant with most of the UR
  - a goal of **20 meters** would enable additional relevant URs
- **Revisit Time:**
  - a threshold of **28 days** is compliant with most of the UR
  - given the relevance of specific URs (e.g. Agriculture/Food Security), a goal of **15 days** should be achieved
- **Spectral Ranges:**
  - **VNIR** and **SWIR**, spanning from **400 nm** to **2500 nm** resulted the key spectral ranges needed for almost all URs
- **Spectral resolution:**
  - **10 nanometres** is the best choice enabling almost all identified URs
- **Signal-to-Noise Ratio** (GSD=30m, ρ=0.3, SZA=30°):
  - VNIR: **threshold=400:1, goal 600:1; @ 650 nm**
  - SWIR: **threshold=300:1, goal 300:1; @ 2100 nm**

Observational parameter	Threshold	Goal
GSD	30 meters	20 meters

Microsatellite missions

HyperScout is a miniaturized hyperspectral imager to operate upon nano, micro and larger satellites.



HyperScout® specification

HyperScout®		
Orbit		500 km
FoV (ACT x ALT)		31° (23°) x 16°
GSD		~ 70 m
Swath		350 km (220 km)
Active Resolution		~ 4000 x 2000 px
Spectral range (res)	High res	470 – 900 nm (5 nm)
	Ext. range	400 – 1000 nm (~14 nm)
Dynamic range		up to 12 bits
SNR		50 - 100
Mass		1.3 kg
Volume		1.5 L
Avg Power		10 W

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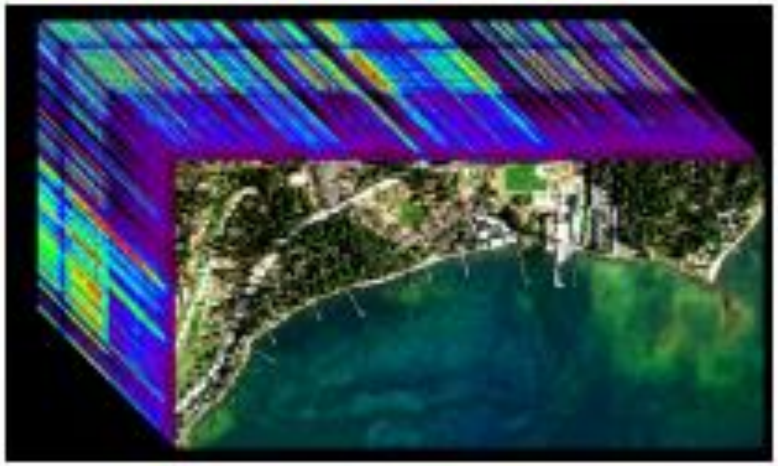
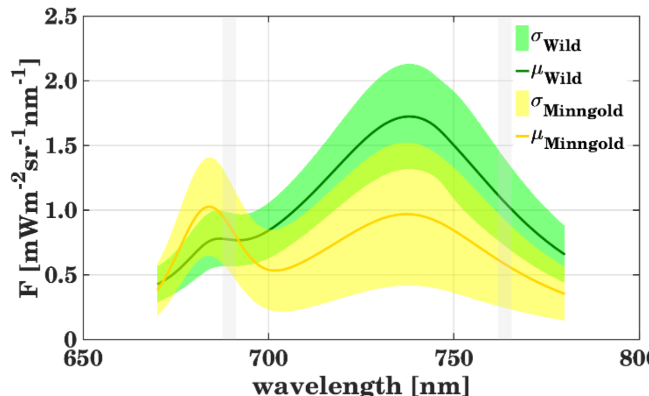
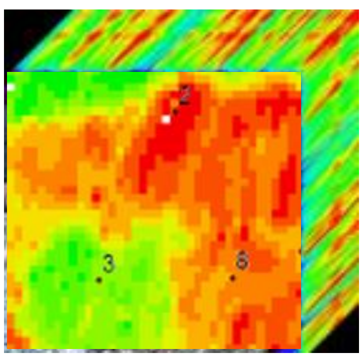
Hyperspectral cubes



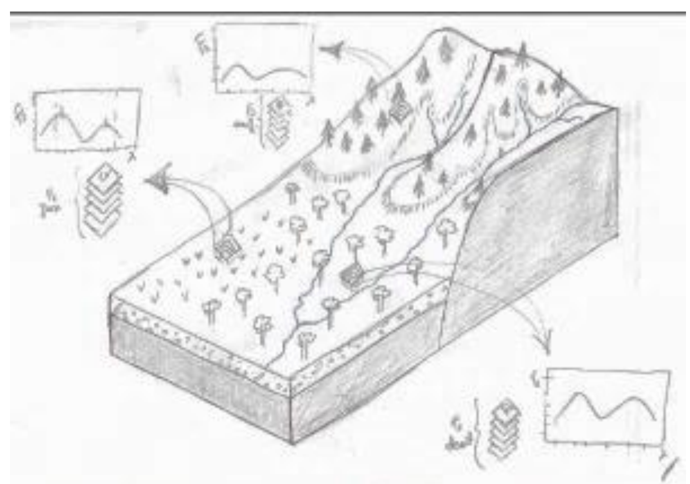
Reflectance (400-2500nm)

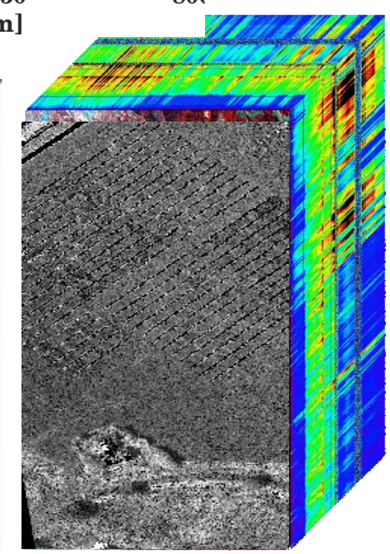
Fluorescence (670-780 nm)



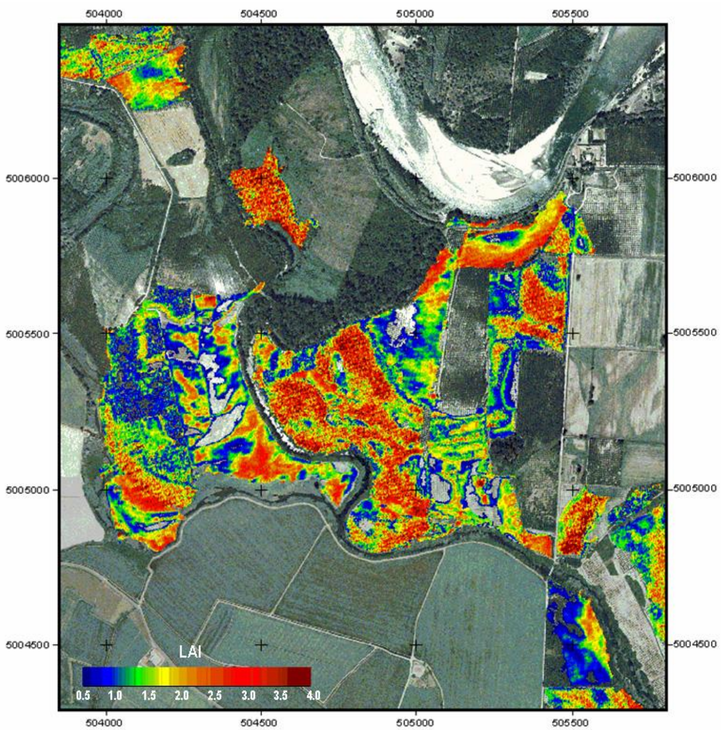


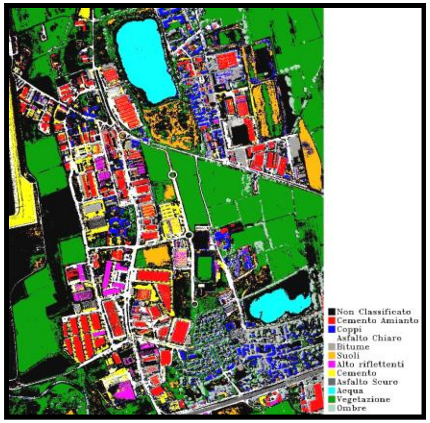
Emissivity/TIR reflectance (8-11 um)

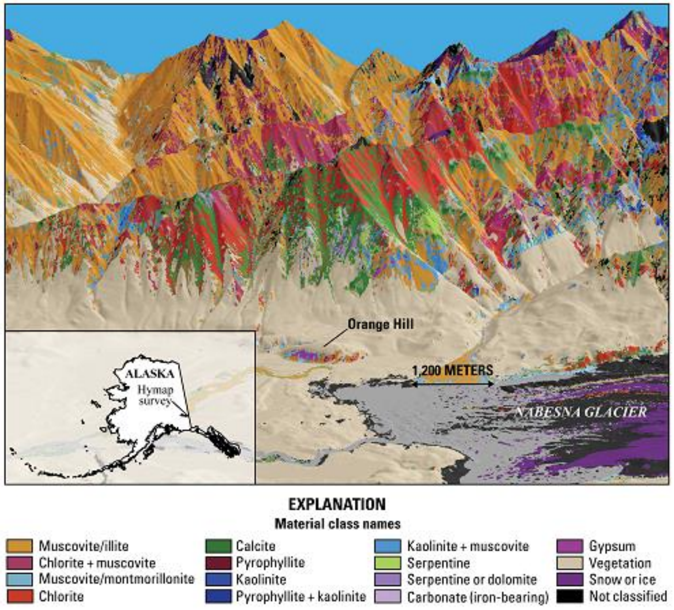


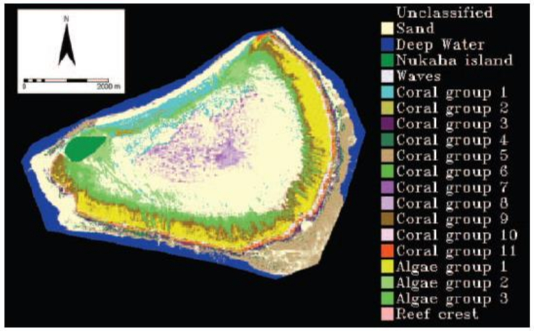


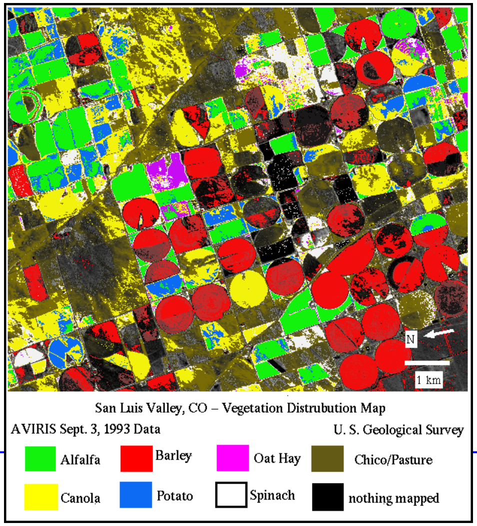
Environmental benefits

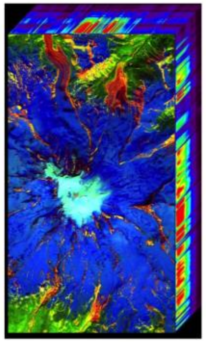


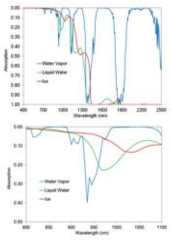


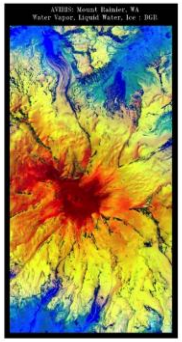












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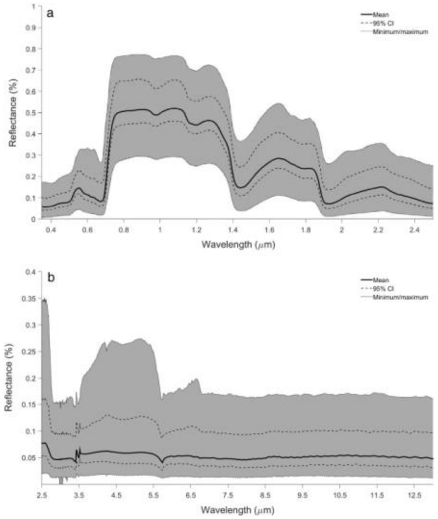
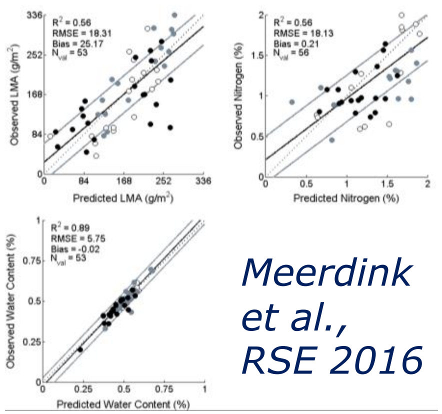
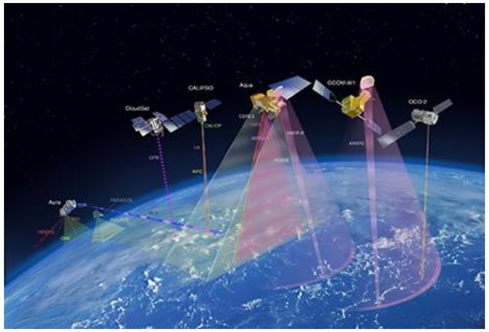
Cubes integration, model develoments, spaial details, temporal assimilation, data processing and synergies with other EO

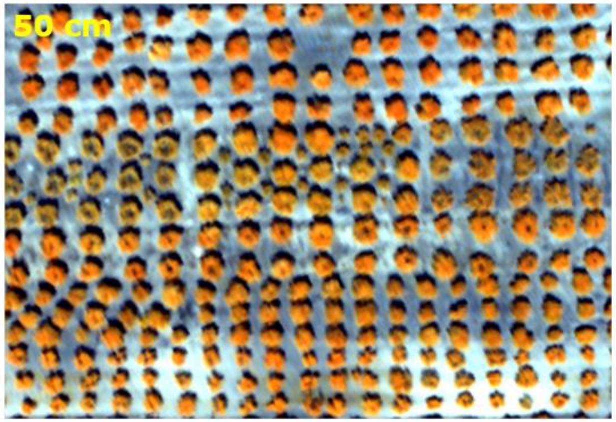
Current challenges

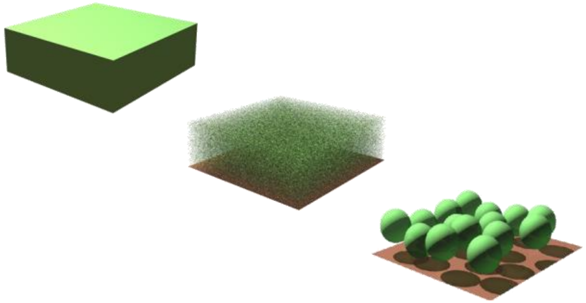


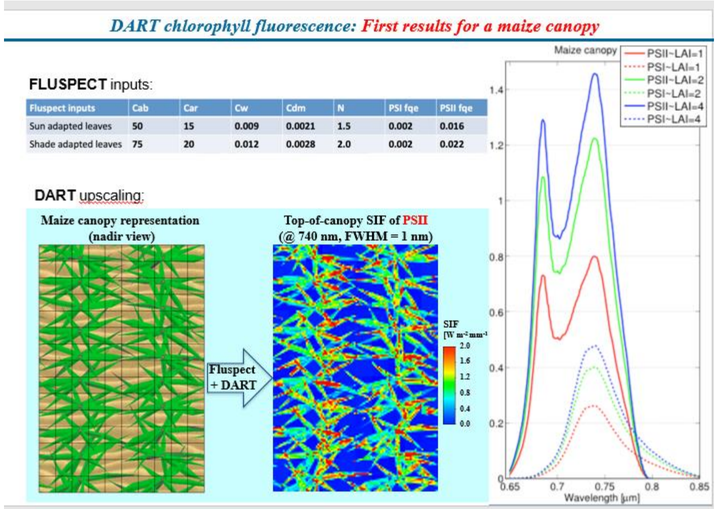


Meerdink et al., RSE 2016









Credit Gastellu-Etchegorry

Conclusions

- Hyperspectral data, point or imaging systems are essential for improving environmental modelling;

- The combination of multiplatforms data allow to understand the accuracy of the retrieved variable;

- Integration of VIS-NIR-SWIR-TIR data permit to improve the estimation of biophysical parameter;

- A new era of spaceborne imaging spectroscopy system is just started


Thank you