Automated field spectroscopy systems for collecting continuous measurements of radiance/reflectance in support of hyperspectral satellite missions

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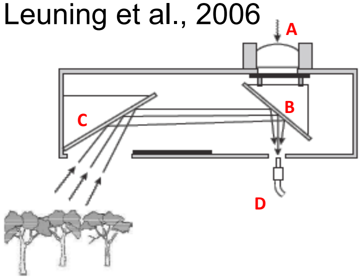
Outline

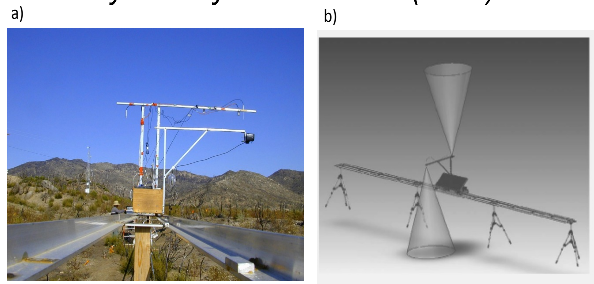
1. Scientific framework
2. MRI/S-Fluor box instruments
    - Instrument concept
    - data-processing and data quality
3. Unattended measurements
    - Vegetation monitoring
    - In-land water quality
    - Atmospheric parameters retrieval
4. Final remarks

Past and current experiences

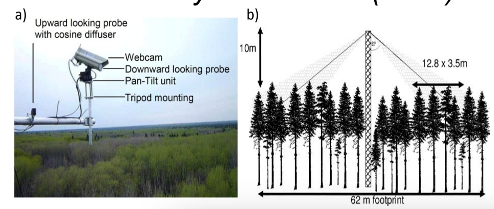
Leuning et al., 2006



Tram system by Gamon et al. (2006)



AMSPEC II by Hilker et al. (2010)



SpecNet Spectral Network

Linking optical sampling to flux measurements around the world.

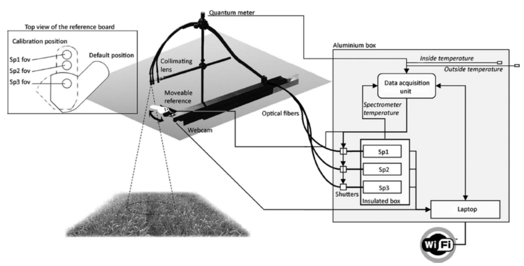
European Cooperation in Science and Technology

cost www.cost.eu **Action ES0903:** Spectral Sampling Tools for Vegetation Biophysical Parameters and Flux Measurements in Europe

V-NIR reflectance

HSI by Meroni et al., 2011

TriFLEX instrument - Daumard et al. (2010)



FUSION – Corp et al., (2010)

Balzarolo et al., reviewed the optical systems used at the EC towers

OPTIMISE

V-NIR reflectance & fluorescence

Observational features:

- Spectral coverage and resolution
- different FOV (hemispherical/narrow)
- multi-angular observations Vs. fixed view angles

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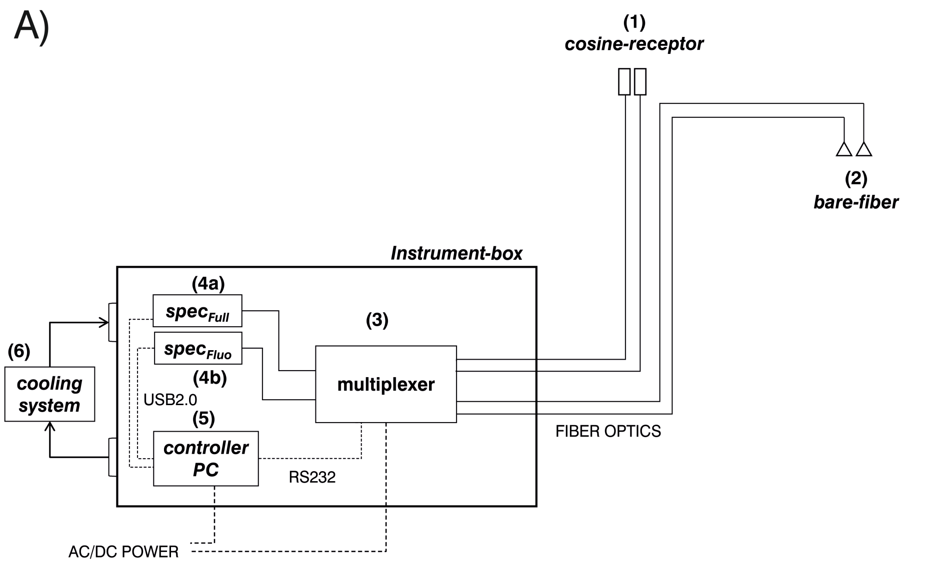
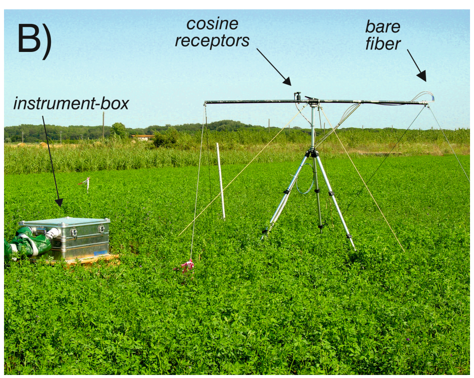
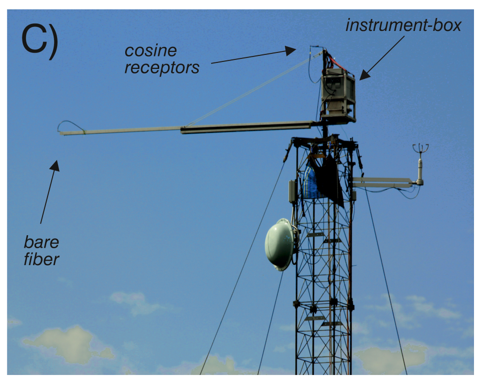
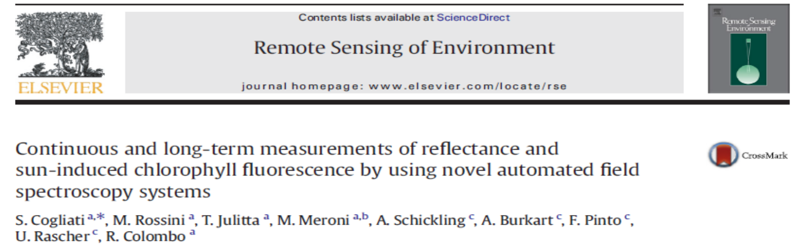
MRI/SFLUOR box systems – optical design








Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

Continuous and long-term measurements of reflectance and sun-induced chlorophyll fluorescence by using novel automated field spectroscopy systems

S. Cogliati [a,*], M. Rossini [a], T. Julitta [a], M. Meroni [a,b], A. Schickling [c], A. Burkart [c], F. Pinto [c], U. Rascher [c], R. Colombo [a]

- instrument concept based on an optical switch which selects between up/down-looking entrance foreoptics
- commercial-grade devices
- acquisition time frequency about of 3 min

High Resolution HR4000 holographic grating spectrometers (Ocean Optics Inc., USA)

Spec.	FWHM (nm)	Sampling Interval (nm)	Spectral Range (nm)	Application
1	1 (fine)	0.25	400-1000	Irrad. measurements, ρ computation
2	0.1 (ultra-fine)	0.02	700-800	Fluorescence at O_2-A (F@760)

The integration of 2 spectrometers is required to provide both VNIR spectra and high-resolution for fluorescence retrieval

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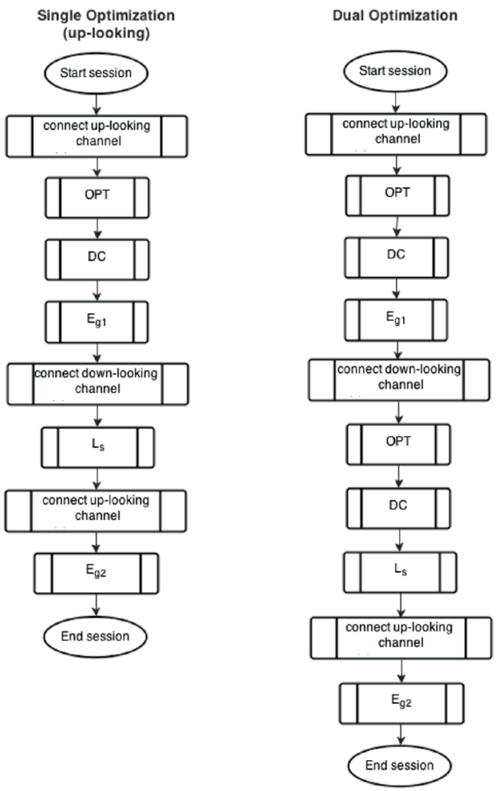
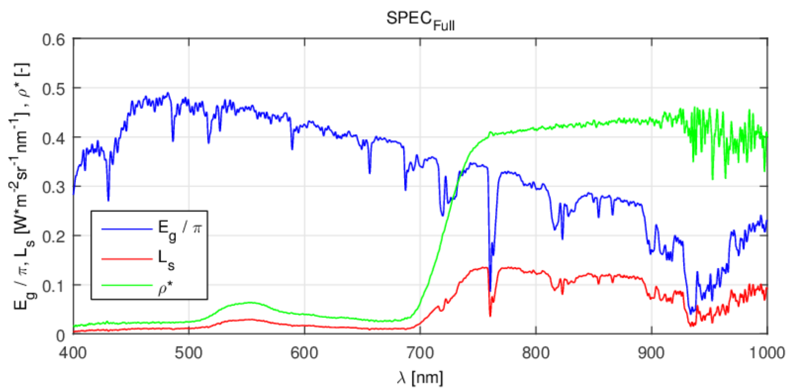
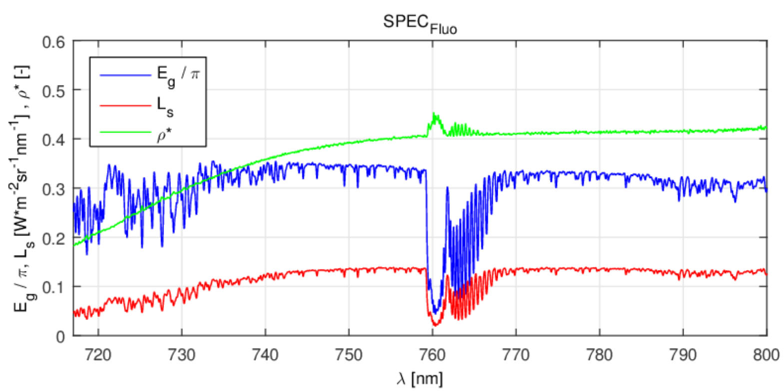
Data collection technique

‘Single beam sandwiched’



spectra collected by MRI during a single acquisition session





Data collection software

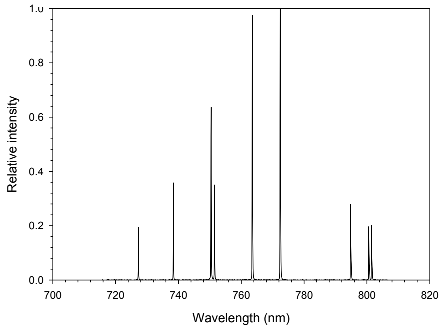
Auto3S software

Spectral systems are operated automatically by Auto-3S, a custom designed software that controls the IT optimization and the collection of the following spectra: DC, incident and upwelling irradiance

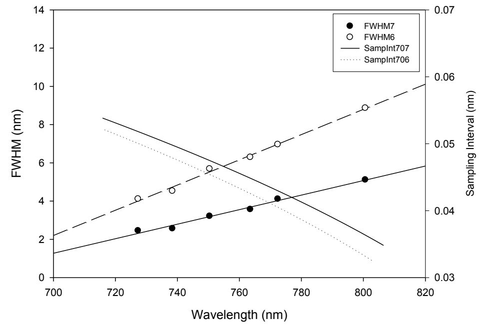
Instrument characterization and calibration

A regular calibration is relevant for instruments aimed at long-term data collection operated outdoor and continuously exposed to varying environmental factors

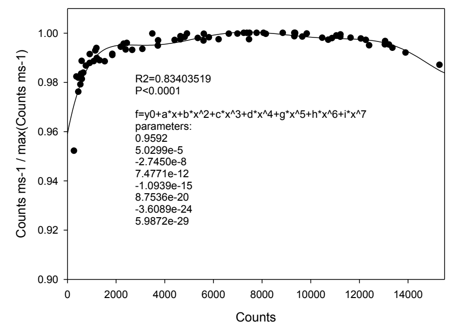
λ calibration



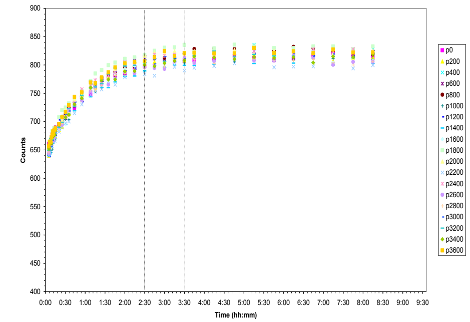
stray-light



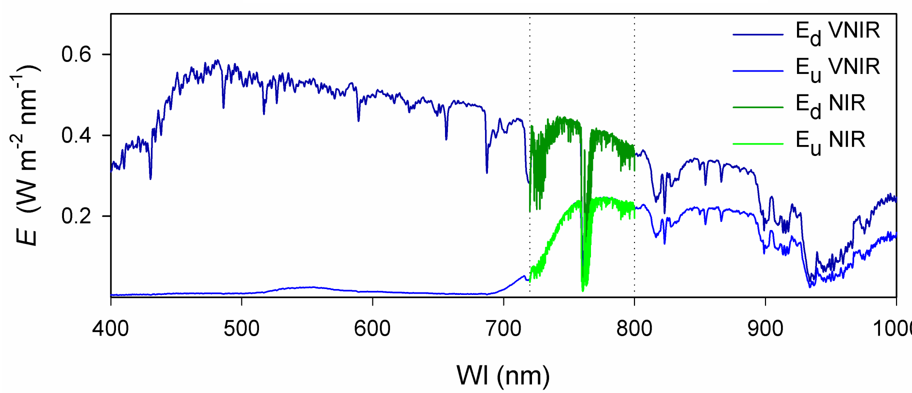
CCD non linearity



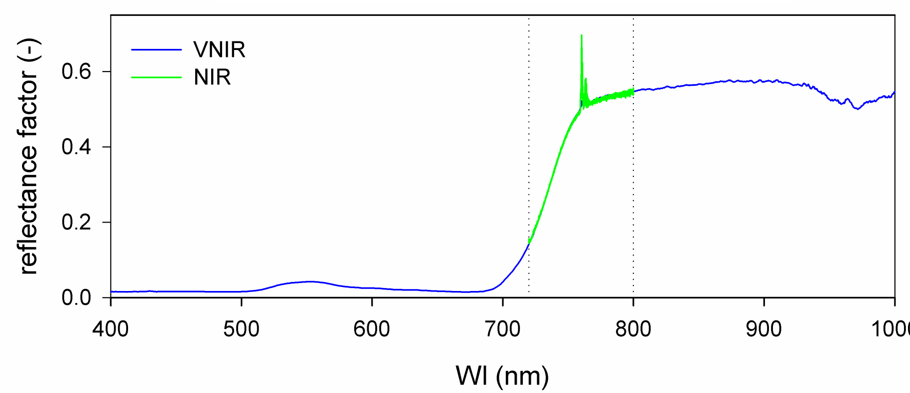
DC drift



radiometric calibration



reflectance computation



Well-established calibration methods have been combined with in-field vicarious techniques

spectral calibration

Stability of the spectral calibration is regularly assessed using **field measured data** and the **SpecCal algorithm**

20 May 2010 / Vol. 49, No. 15 / APPLIED OPTICS

Characterization of fine resolution field spectrometers using solar Fraunhofer lines and atmospheric absorption features

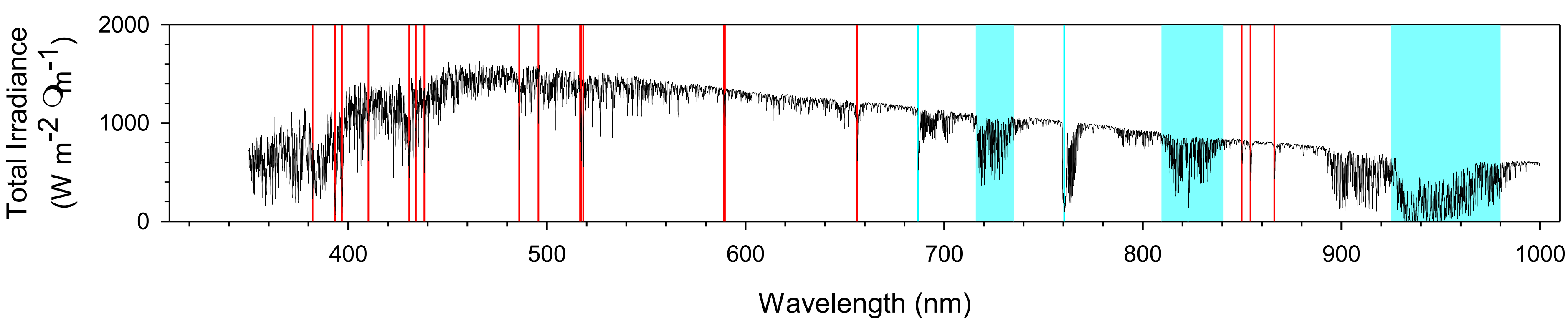
Michele Meroni,[1,*] Lorenzo Busetto,[1] Luis Guanter,[2] Sergio Cogliati,[1] Giovanni Franco Crosta,[3] Mirco Migliavacca,[1] Cinzia Panigada,[1] Micol Rossini,[1] and Roberto Colombo[1]

Spectrometer **SS** and the **FWHM** in the VNIR are determined by **comparing** the **measured incident irradiance** to a **MODTRAN simulation**

The method is applied in selected spectral windows present in the measured signal:

solar Fraunhofer lines

atmospheric absorption features

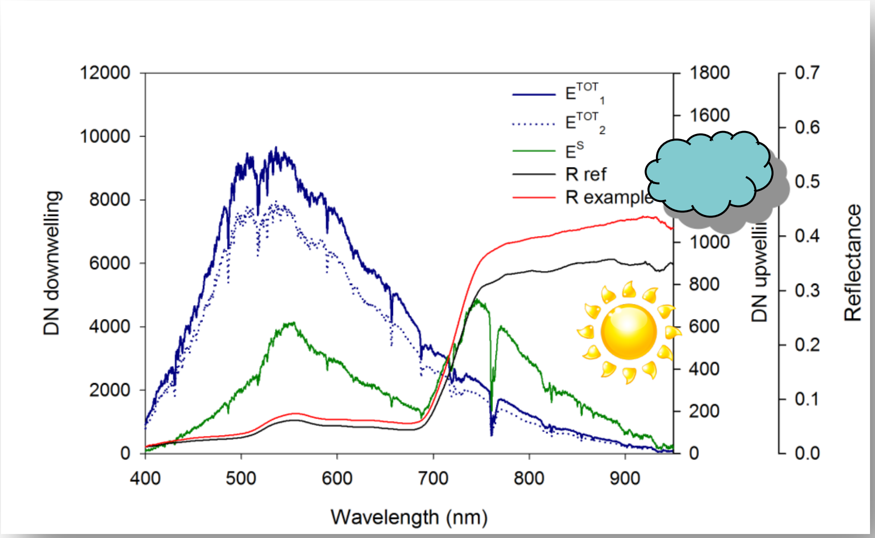


Data quality and filtering of spectral time series

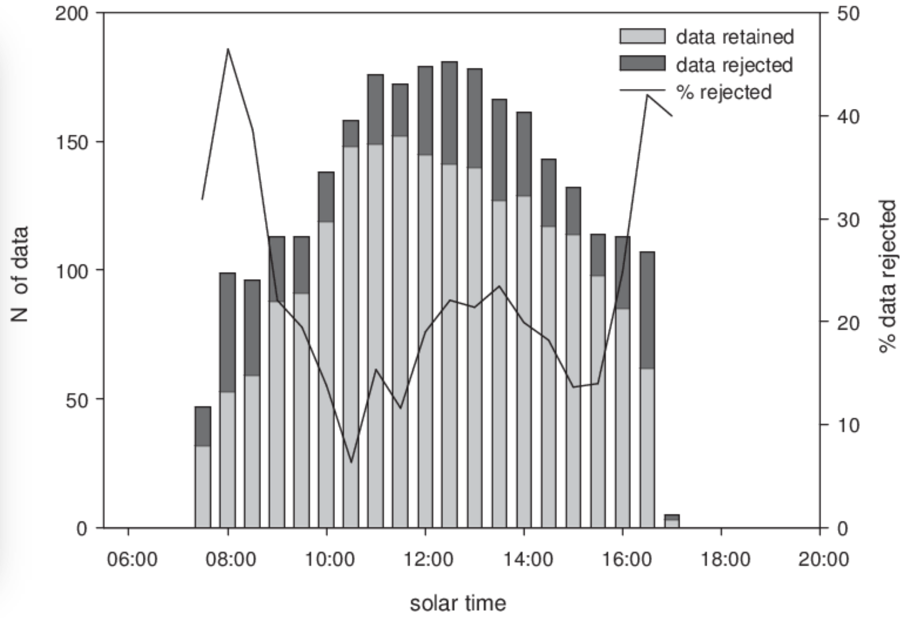
Data quality & filtering criteria

Label	Description	Computation	Threshold
DQ_{sza}	Solar zenith angle		<60°
DQ_{sat}	Spectrum saturation	counts < sv	0
DQ_s	E_g stability	$\lvert E_{g,1} - E_{g,2} \rvert * 100 / E_{g,1}$	<10%
DQ_d	E_g vs. L_s stability	$\pi L_s / E_g * 100$	>100%
DQ_l	Optimization lower limit	E_g (counts) / DC * 100	>30%
DQ_h	Optimization higher limit	max E_g > 0.5 sv	1

Short-term variation in illumination condition and its effects on reflectance



Occurrence of data rejection (SEN3EXP camp.)



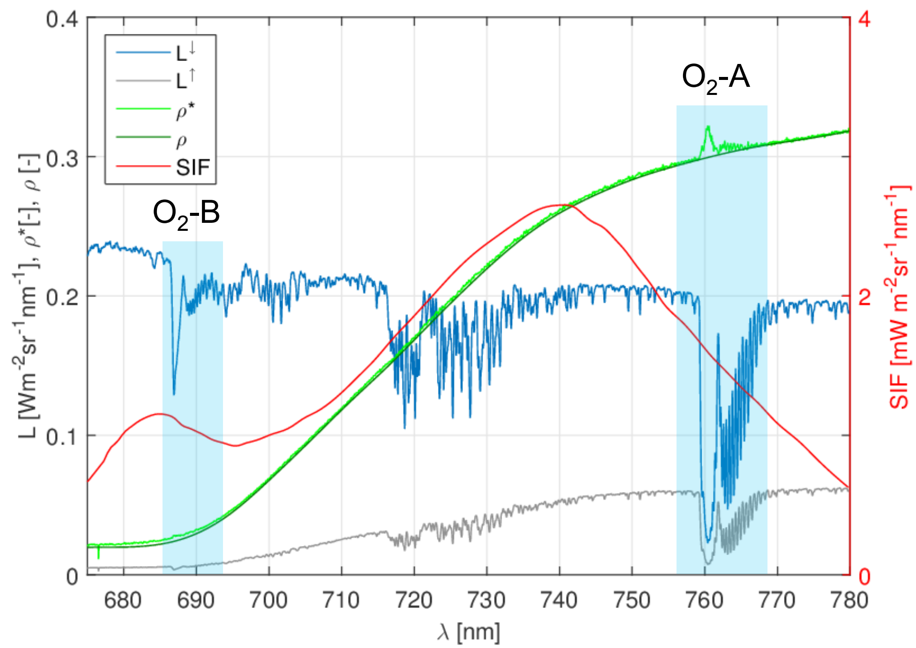
Data processing – data quality and filtering

Spectral fitting methods

$$L\upuparrows (\lambda)=SIF(\lambda)+\rho(\lambda)L\uparrow\downarrow (\lambda)$$

Non linear Least Square optimization

$$min\sum\lambda\uparrow(L\upuparrows (\lambda)-SIF(\lambda)-\rho(\lambda)L\uparrow\downarrow (\lambda$$



Advantages:

- the use of tens of spectral bands to reduce the instrumental noise
- estimate more parameters

Unattended measurements – vegetation

Field surveys:

2009 – **San Rossone (IT)** (ESA/SEN3EXP)

→ alfalfa

2012 – **Selhausen (DE)** (ESA/HyFLEX)

→ grassland

2012 – **Campus Klein Altendorf (DE)** (ESA/HyFLEX)

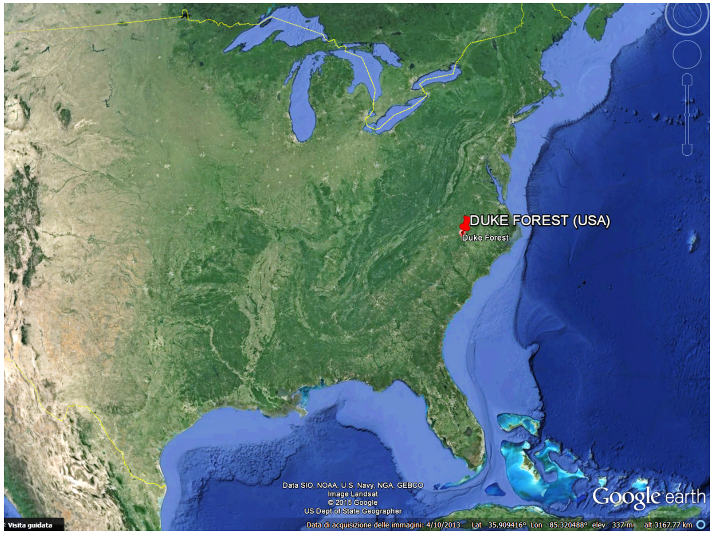
→ sugar beet

2012 – **Bily Kriz (CZ)** (ESA/HyFLEX)

→ lawn carpet

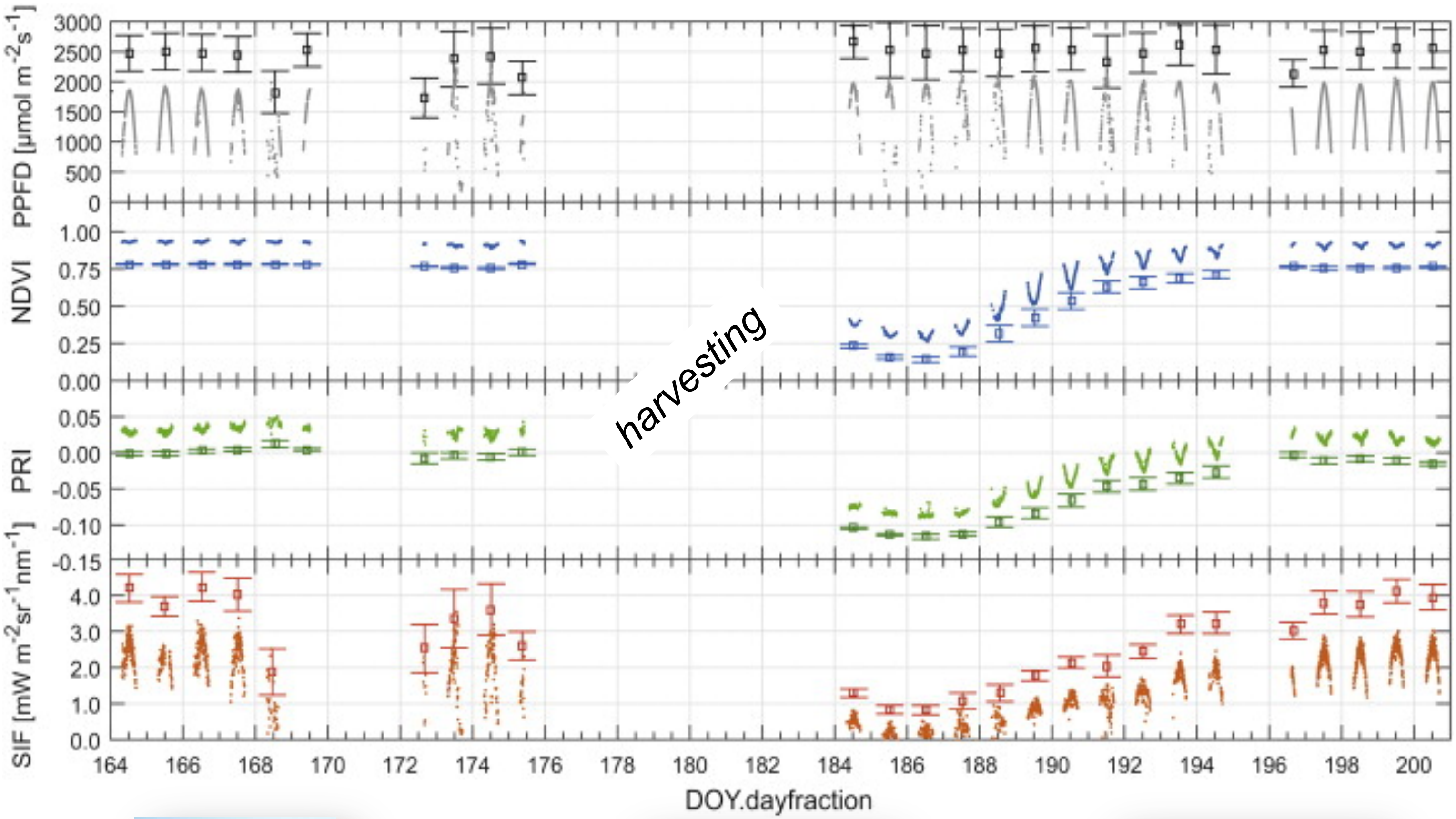
2013 – **Duke Forest (USA)** (ESA/FLEX-US)

→ Hardwood tower (Hickory)



Unattended measurements – vegetation (1)

Time series during the entire vegetation growing cycle of an agricultural crop

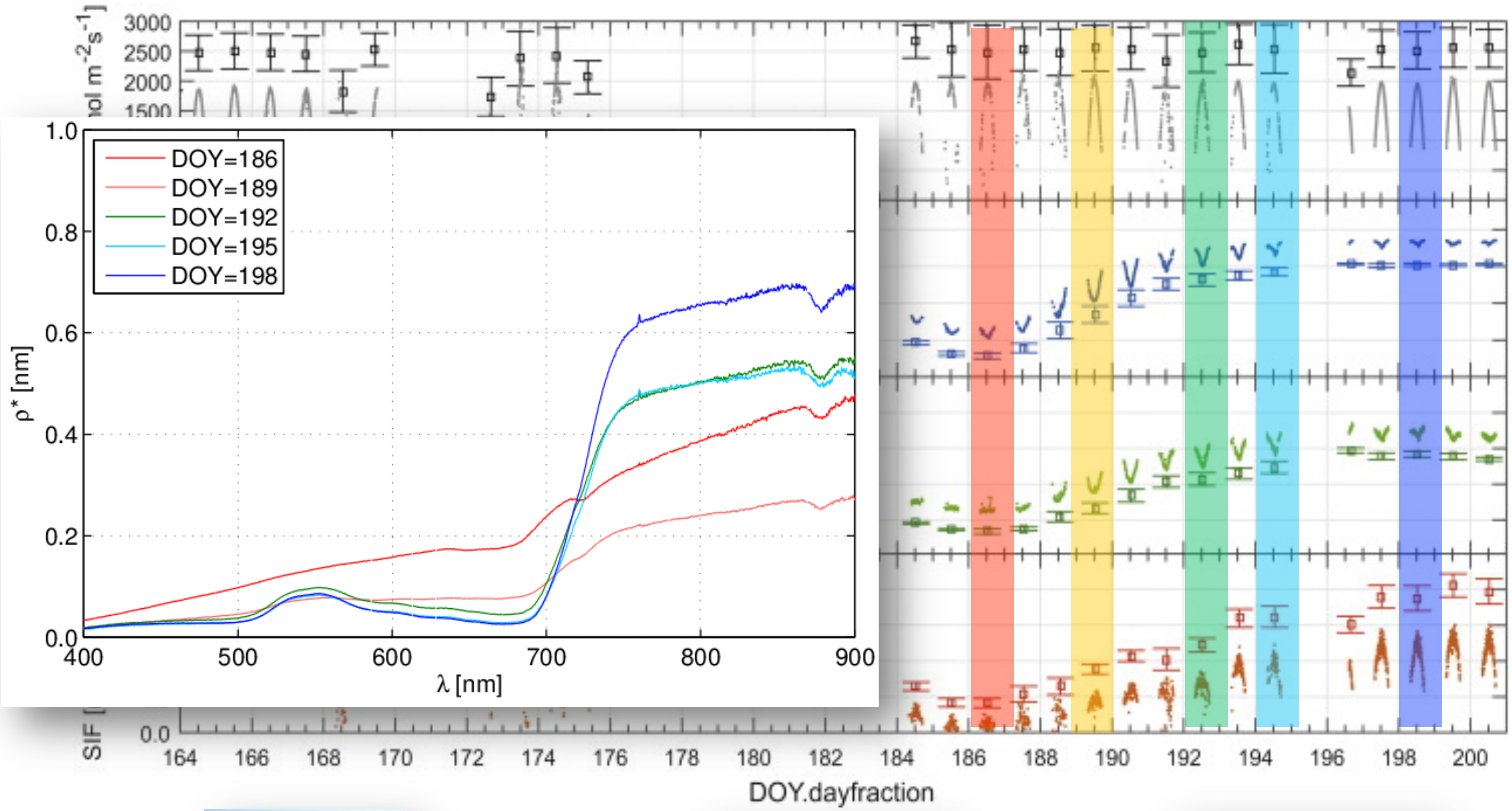


June 13th

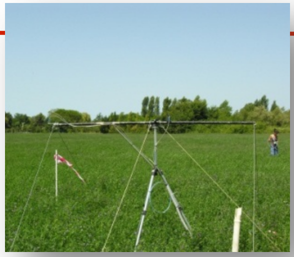
July 19th

Unattended measurements – vegetation (1)

Time series during the entire vegetation growing cycle of an agricultural crop



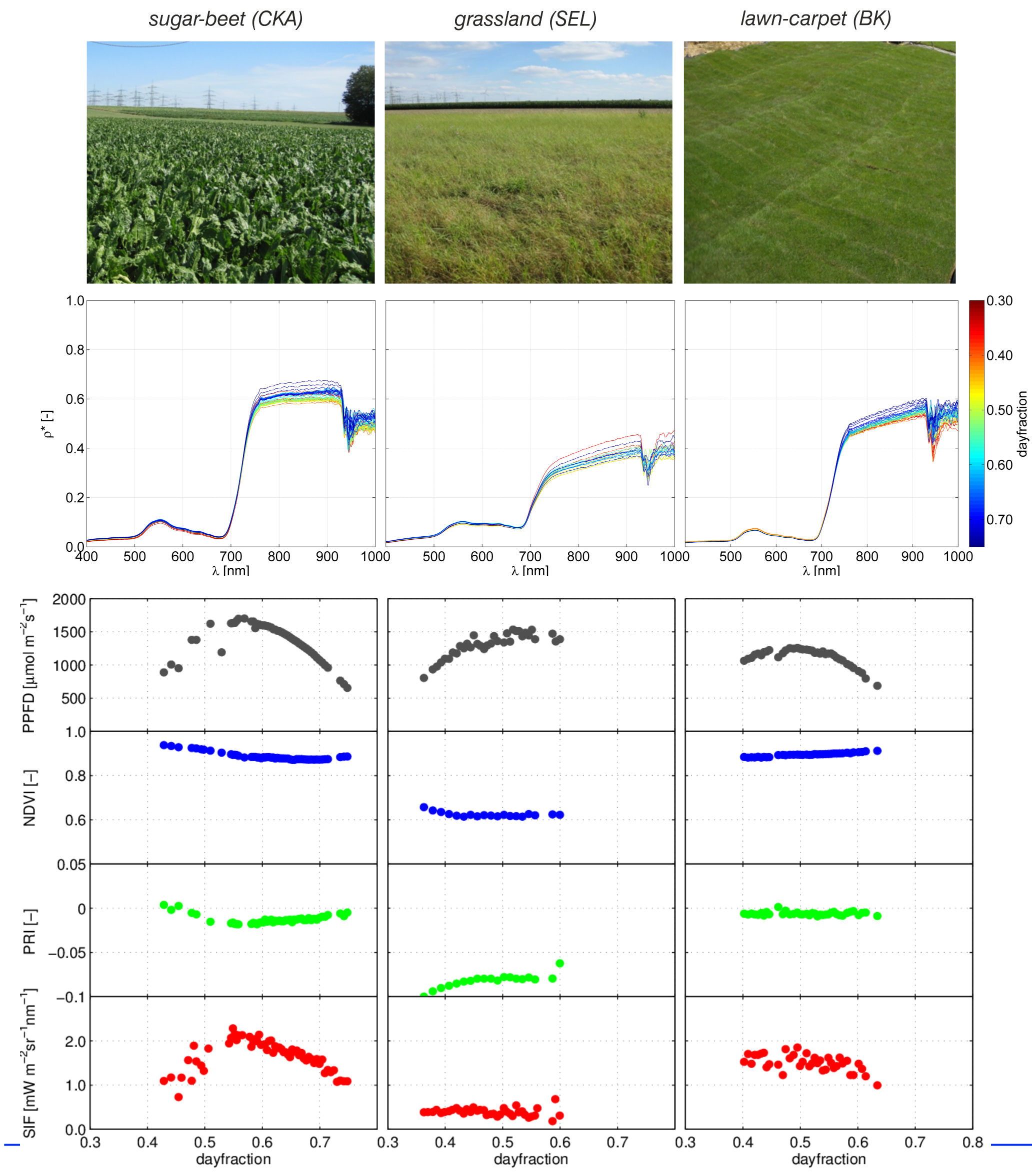
June 13th



July 19th

Unattended measurements – vegetation (2)

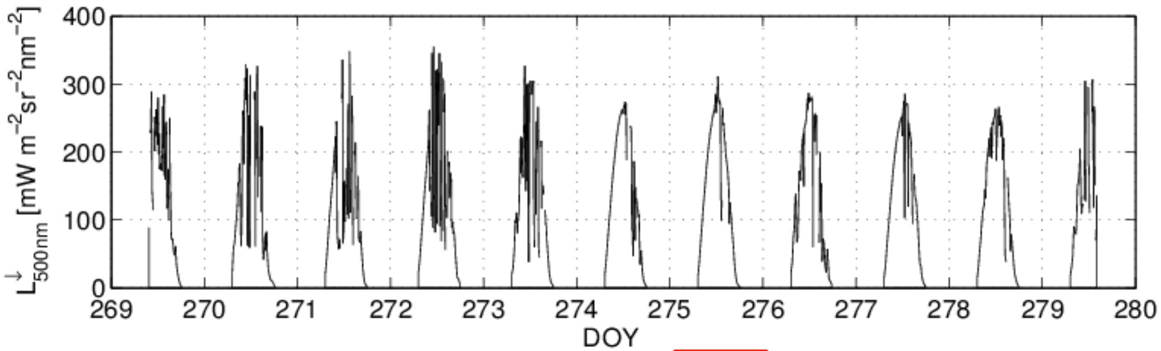
Diurnal course measurements for different types of vegetated canopies

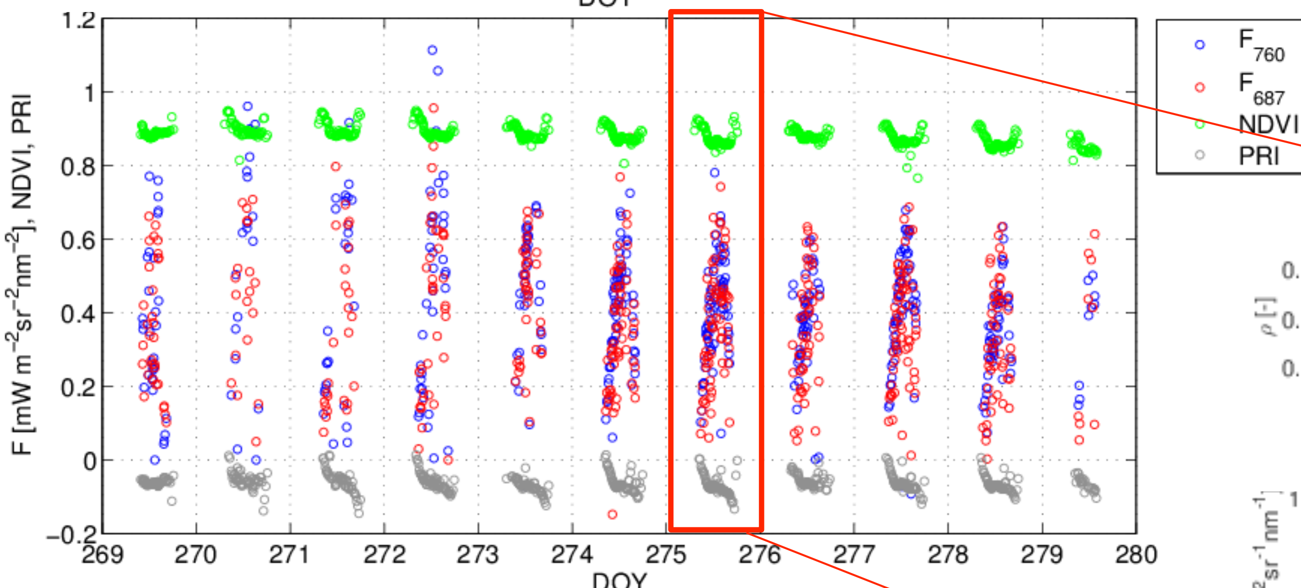


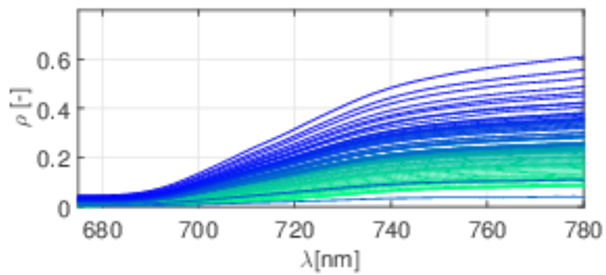
Unattended measurements – vegetation (3)

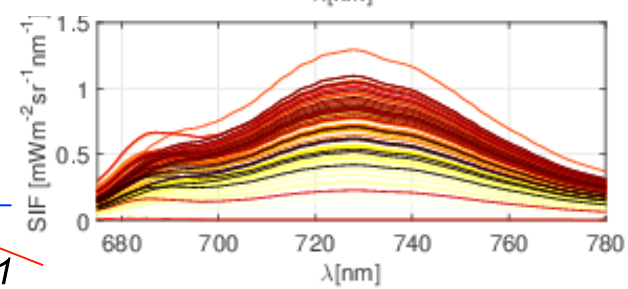
Time series measurements at Duke forest, Hardwood tower (Hickory)

Sept 26th until Oct 6th(11 days)









Field surveys – in land water quality

CSIRO PUBLISHING

Marine and Freshwater Research, 2013, 64, 303–316
http://dx.doi.org/10.1071/MF12229

Analysis of within- and between-day chlorophyll-*a* dynamics in Mantua Superior Lake, with a continuous spectroradiometric measurement

M. Bresciani[A,B,F], M. Rossini[C], G. Morabito[D], E. Matta[A], M. Pinardi[B], S. Cogliati[C], T. Julitta[C], R. Colombo[C], F. Braga[E] and C. Giardino[A]

(*a*)

- Mantova superior lake, Italy (shallow eutrophic lake)
- MRI continuous spectral measurements collected between Sep 2nd to Oct 2nd 2011 (30 days)
- 31 different samples in 7 different locations, and different days (6, 9, 14, 20, 29 Sep)
- ASD-FR spectral measurements (6° FOV) (above/below water)
- Water samples for limnological, fluorimetric measurements and phytoplankton composition

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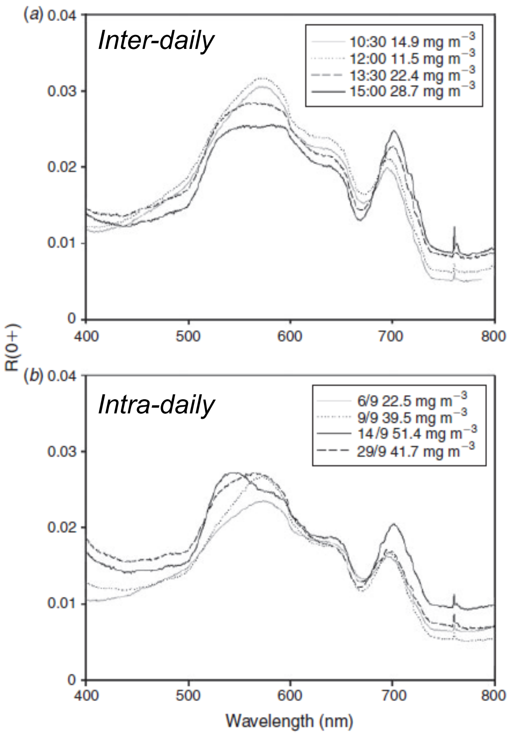
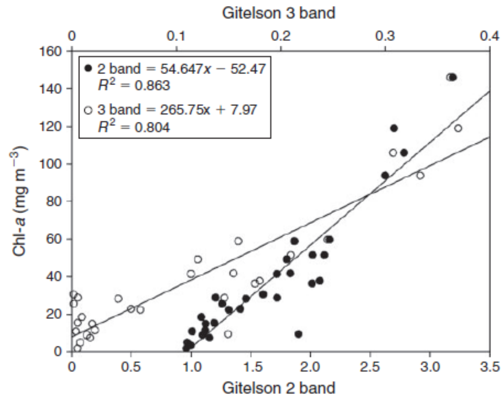
Field surveys – in land water quality

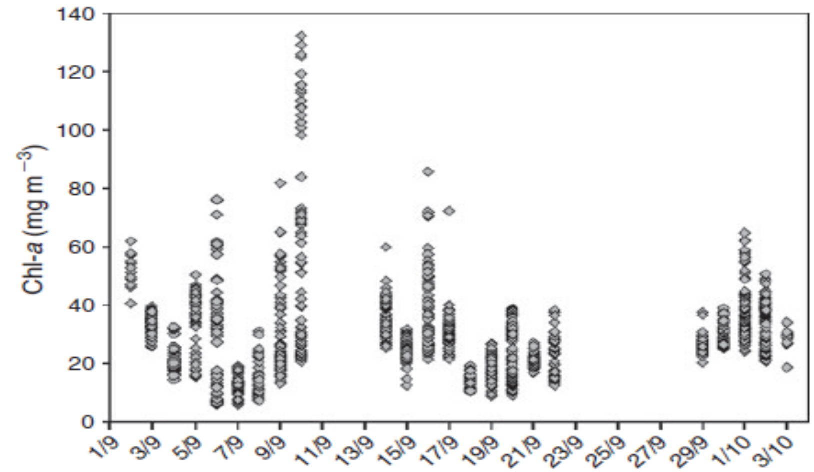
Variability of the water leaving reflectance



empirical relationship



Time serie of Chl-a from MRI data



- the spectra were in agreement to the typical reflectances recorded in other productive turbid waters (and with ASD-FR measurements)
- semi-empirical algorithm to retrieve Chl-a (Gitelson et al., 2007)
- in general, Chl-*a* varied between 1.8-146.1 mg m^{-3}
- 9 Sep huge variation between 11:00-13:00 Chl-a arised from 28.3 to 119.0 mg m^{-3}
- high temporal-frequency spectroscopy measurements allowed monitoring inter- and intra-day variation of Chl-a

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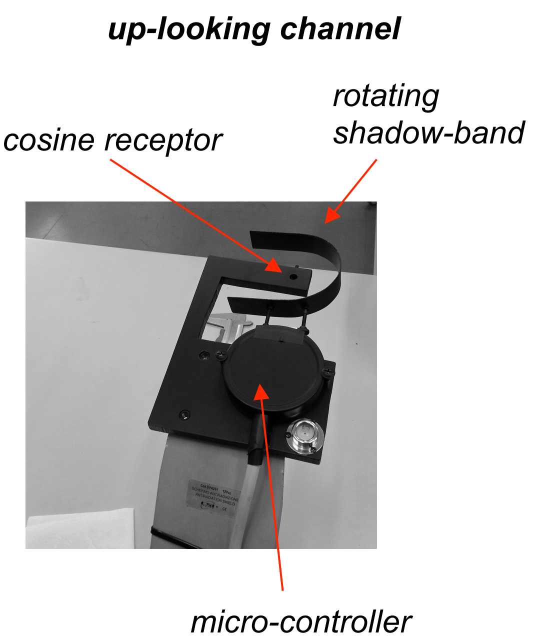
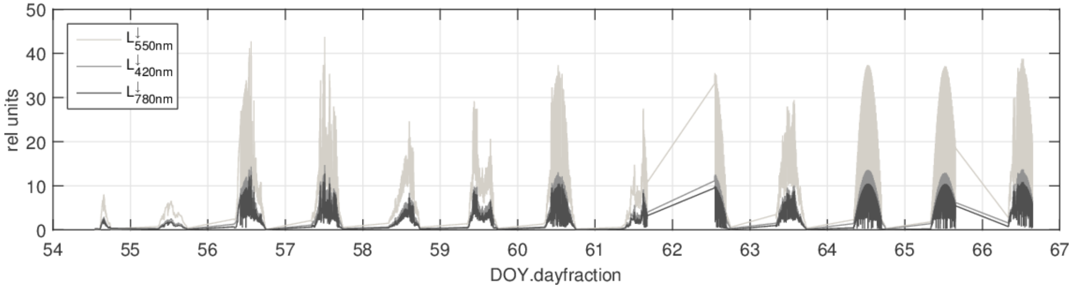
Field surveys – atmosphere

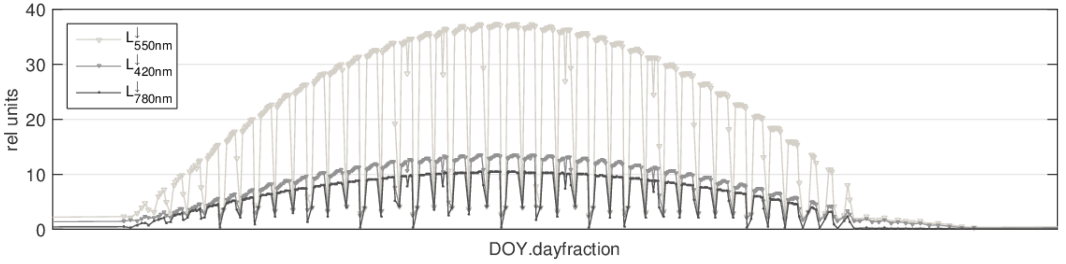


- A pilot survey ongoing in the last few months aims evaluating the possibility of retrieving atmospheric parameters from downwelling hyperspectral radiation
- The uplooking channel of MRI has been equipped with a shadow-band to collect both global and diffuse downward light fluxe
- Aethalometer, Optical Particulate Counter (OPC), Condensation Particle Counter , meteo station….

Field surveys – atmospheric studies

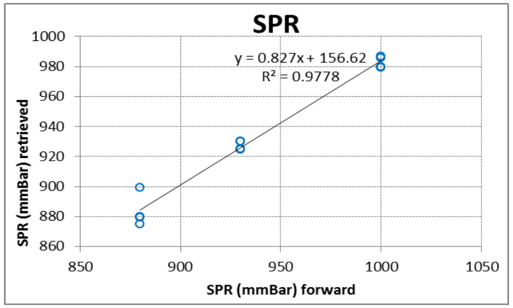
Preliminary results

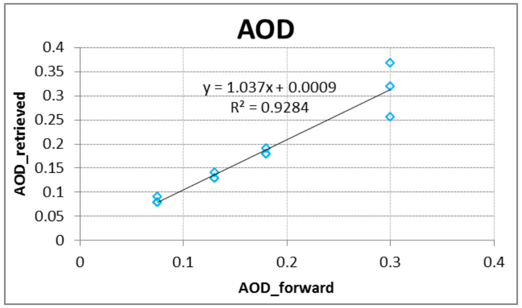




modeling down-welling radiance and AOD, SPR retrieval By LUT inversion

$$L_{wr}^{mod} = \rho_{so}\frac{E_s^o\cos\theta_s}{\pi} + \left[\begin{array}{l}\tau_{ss}r_{so}E_s^o\cos\theta_s/\pi + F_s \\ +\dfrac{(\tau_{sd}+\tau_{ss}\overline{r_{sd}}\rho_{dd})E_s^o\cos\theta_s/\pi+\overline{F_d}\rho_{dd}}{1-\overline{r_{dd}}\rho_{dd}}r_{do}\end{array}\right]\tau_{oo} + \frac{(\tau_{sd}\overline{r_{dd}}+\tau_{ss}\overline{r_{sd}})E_s^o\cos\theta_s/\pi+\overline{F_d}}{1-\overline{r_{dd}}\rho_{dd}}\tau_{do}$$





Conclusions (1)

- Continuous and long-term measurements represent a novel and valuable approach for observing temporal dynamics of the Earth's surface; these type of measurements can be further used for developing current and upcoming optical satellites such as HyspIRI, Landsat 8, S-2, S-3, FLEX, OCO-II, GoSAT, GOME, TROPOMI…

- Field surveys proved the capability of providing reliable ground-based hyperspectral data for studying temporal dynamics; few case studies have been presented (i) agricultural crops and natural environments; (ii) in-land water; (iii) atmosphere (ongoing)…

- data collected are strongly affected by canopy directional effects, therefore the multi-angular observations as provided by FUSION (Goddard) and AMSPEC (Hilker et al.,2010) can help in understanding and quantifying directional effects

- The use of canopy RT models will be fundamental to improve the understanding of the measured signals and it may provide an essential tool for further upscaling of the signal at satellite level

- UAVs platforms equipped with miniaturized spectrometers (Burkart et al., 2014; Zarco-Tejada et al., 2012) might provide unprecedented opportunities for high-spatial, spectral field measurements. This novel approach, in combination with the continuous and long-term field measurements and RT models, will provide a description of the investigated ecosystem in the spatial, spectral, temporal and angular domains

Conclusions (2)

- The international initiatives are helpful for sharing new instrumental concepts, data collection/ processing methods, and interpretation of the results; (COST Actions, Specnet)
- The downwelling spectral measurements can be helpful for operational atmospheric correction of RS data, it might become a valid support for the current AERONET network;
- The detection of SWIR (1.1-2.5 um) is currently missed in continuous field spectroscopy measurements (Hyspiry/aviris-NG sensor can help in this direction)
- The link between ground-based point measurements and airborne/satellite data is not obvious, and upscaling techniques must be improved to have a better comparison
- However, we encourage an extensive usage of automated ground-based spectrometers and believe that the establishment of an international network involving the scientific community and space agencies will offer several benefits toward a better understanding of terrestrial

Thank you

$$GPP = \varepsilon \times APAR = \varepsilon \times f_{APAR} \times PAR$$

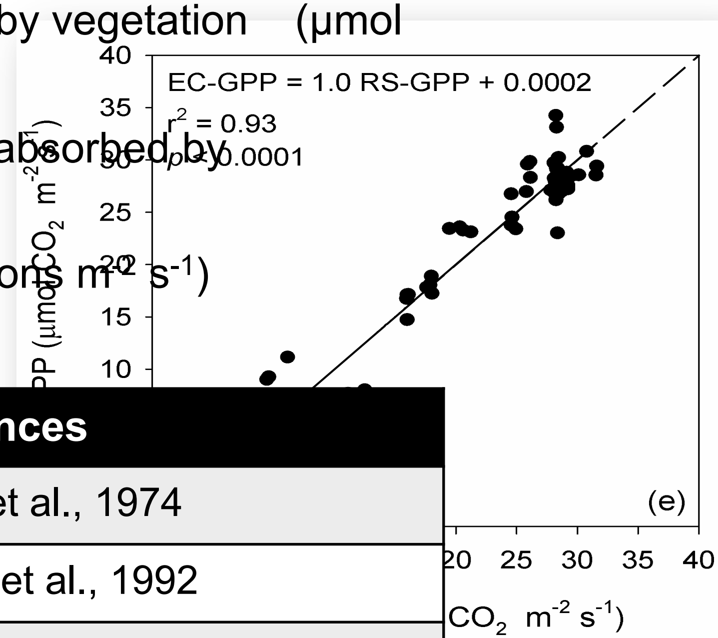
GPP: Gross Primary Production (μmol CO_2 m^{-2} s^{-1})

ε: light use efficiency (μmol CO_2 $μmol^{-1}$ photons)

APAR: photosynthetically active radiation absorbed by vegetation (μmol photons m^{-2} s^{-1})

f_{APAR}: fraction of photosynthetically active radiation absorbed by vegetation (-)

PAR: photosynthetically active radiation (μmol photons m^{-2} s^{-1})



Index	Target	Formulation	References
NDVI	f_{APAR}	$(R_{800}-R_{680})/(R_{800}+R_{680})$	Rouse et al., 1974
PRI	ε	$(R_{531}-R_{570})/(R_{531}+R_{570})$	Gamon et al., 1992
Fy_{760}	ε	$F@760/PAR_i$	Meroni and Colombo, 2006
F@760	APAR		Meroni and Colombo, 2006

Indici RS - LUE

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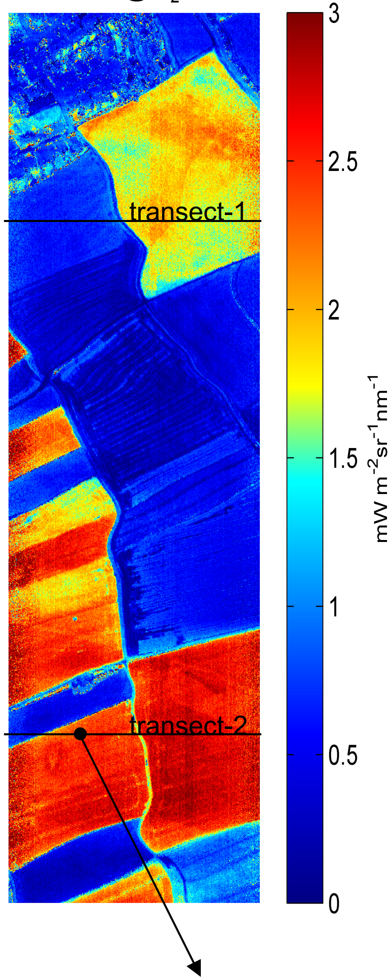
F@760	APAR		Meroni and Colombo, 2006

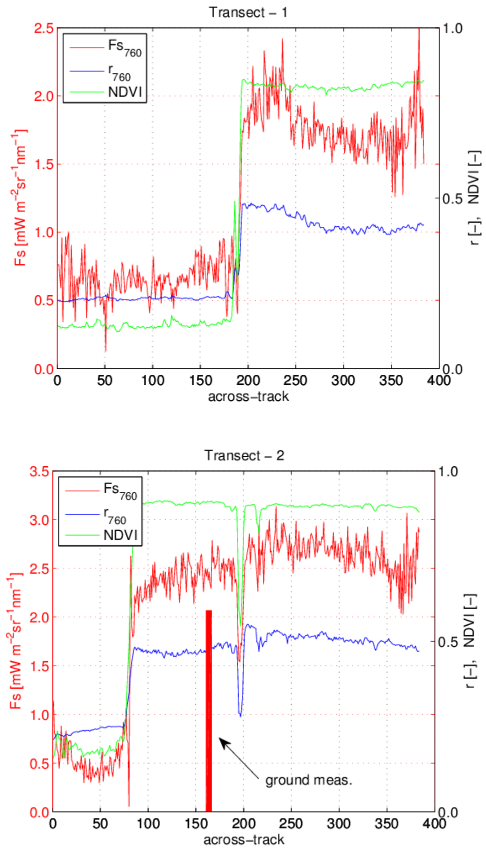
Results – HyPlant – comparison ground meas.

SFM@O$_2$-A

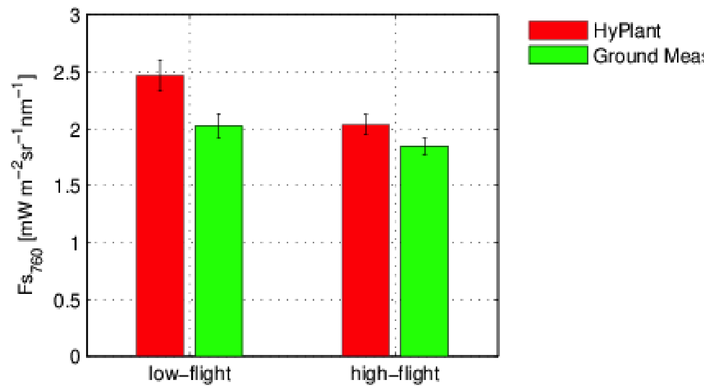


Field spectroscopy measurements

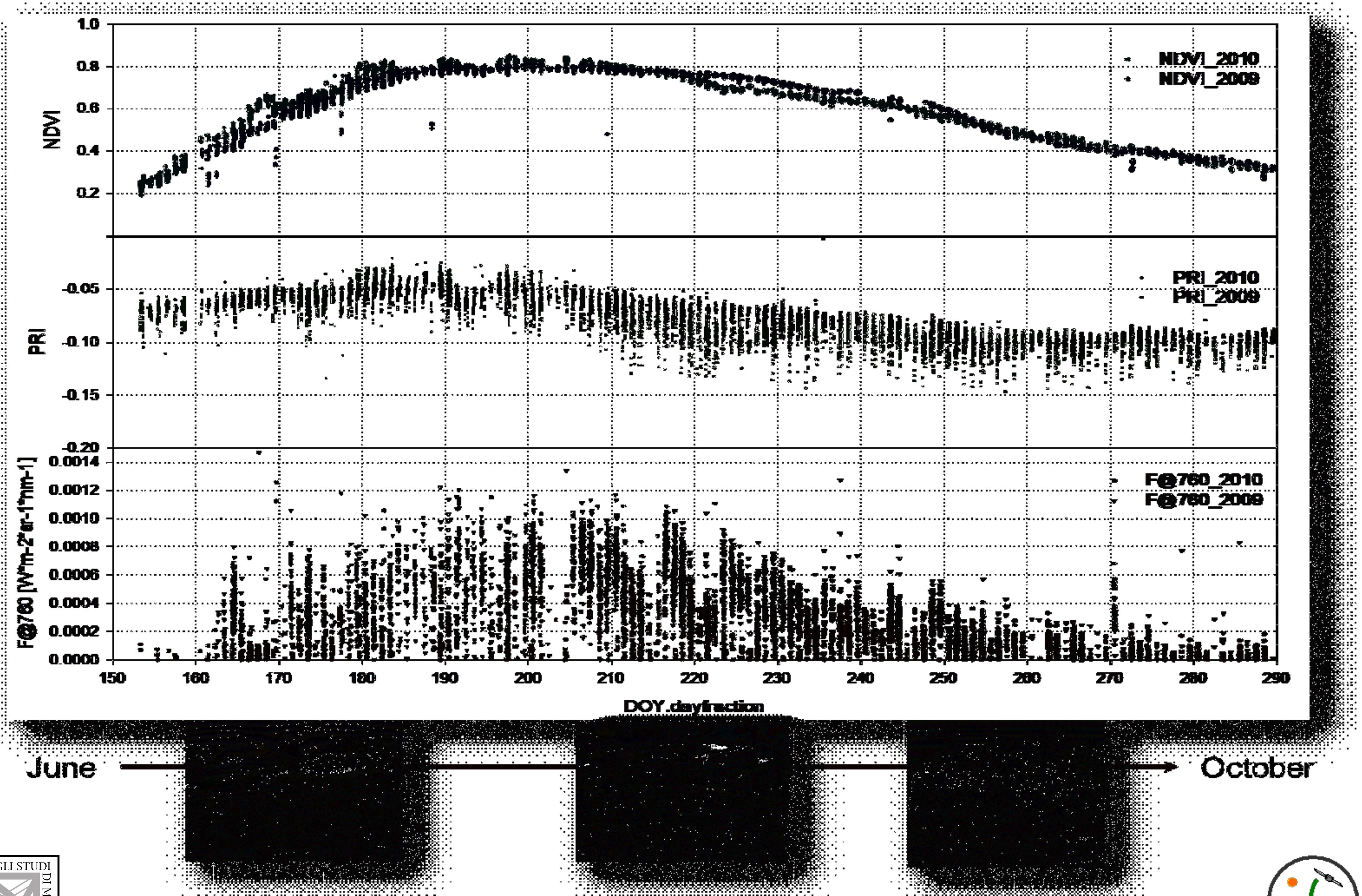
Across-track transects



Comparison with ground measuremets



- ROI of 3x3 pixels compared to ground measurements
- F values are in the range of ground measurements, a small bias of 0.5mW for the low-altitude flight is almost the same residual error found in the spatial transects



NDVI
NDVI_2010
NDVI_2009
PRI
PRI_2010
PRI_2009
F@760 [W*m-2*sr-1*nm-1]
F@760_2010
F@760_2009
DOY.dayfraction
June
October

The Hyperspectral UAV - HyUAV

IEEE SENSORS JOURNAL, VOL. 14, NO. 1, JANUARY 2014

A Novel UAV-Based Ultra-Light Weight Spectrometer for Field Spectroscopy

Andreas Burkart, Sergio Cogliati, Anke Schickling, and Uwe Rascher

Anteos

- Four-rotor platform with hovering capability, maximum payload of 2 Kg and flight time of 20 min
- GPS/IMU
- Radio connection to the ground control station

Optical payload

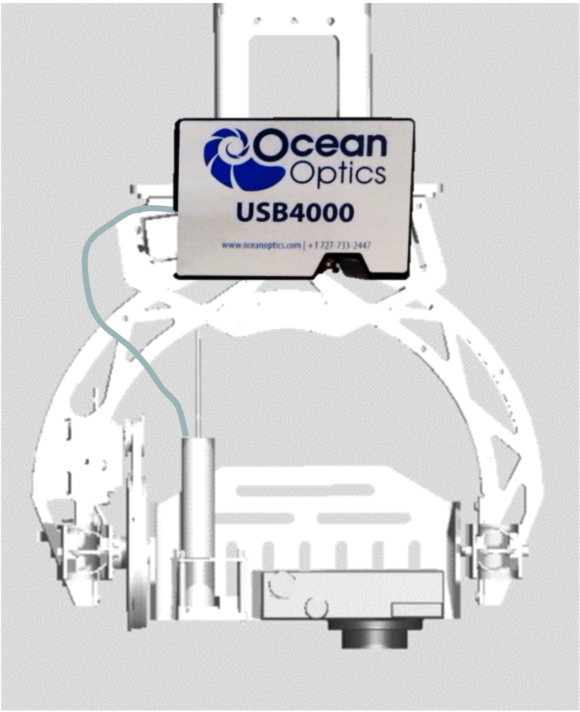
Ground control station

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

LTDA

Optical Payload

Schematic drawing



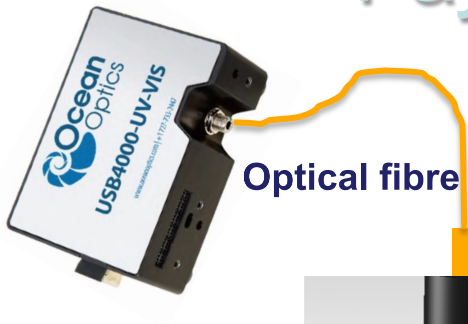
Picture

Mounted on a stabilized platform to reduce the impact of platform vibrations

+ RGB camera (Canon S100)
+ USB4000-VIS-NIR spectrometer

- Simultaneous measurements
- on board controlled

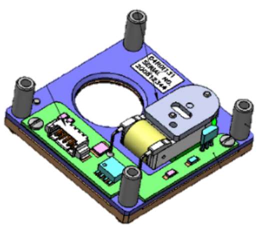
Payload - Entrance Optic Receptor



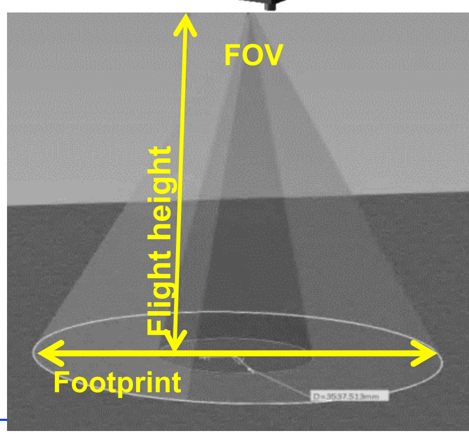
Holder for Reflective Neutral Density Filters
to avoid saturation for high intensity light levels

Variable length fore-optics with Iris Diaphragms
to adapt the spectrometer field of view (FOV)

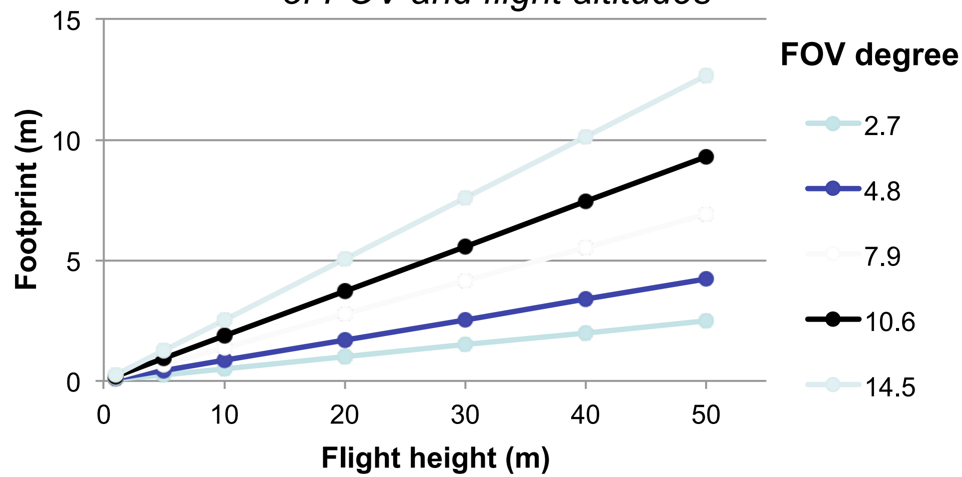
Shutter



Shutter with Integrated Controller
to allow a regular in-flight dark-current measurements



Sampled areas (footprint) as function of FOV and flight altitudes



Payload - Spectrometer

Ocean Optics USB4000-VIS-NIR
Miniature Fiber Optic Spectrometer

Physical	
Dimensions:	89.1 mm x 63.3 mm x 34.4 mm
Weight:	190 grams
Detector Specifications	
Detector:	Toshiba TCD1304AP CCD
Pixels:	3648 pixels
Spectroscopic	
Wavelength range:	350-1000 nm
Optical resolution:	~1.5 nm FWHM
A/D resolution:	16 bit