SOLAR INDUCED CHLOROPHYLL FLUORESCENCE (SIF), linking the ecosystem carbon (EC) flux and remote sensing

HYPERSPECTRAL DEVICES

Paul Naethe
JB Hyperspectral Devices

Eddy Covariance Workshop for ChinaFlux
August 2024

Agenda

Part I – General Introduction

1. Introduction of SIF
2. Introduction of SIF retrievals

Part II – Specialized Introduction

1. Introducing the company JB Hyperspectral Devices
2. Introducing the FloX as automated field spectrometer to measure SIF
3. The FloX data processing and output

Part III – Scientific applications and current challanges

1. The FloX application for advanced SIF retrievals and atmospheric correction
2. The FloX application for linking remote sensing to photosynthesis
3. The FloX application for linking remote sensing and EC fluxes
4. Conclusion and outlook
5. Q&A

HYPERSPECTRAL DEVICES

Introducing SIF and photosynthesis

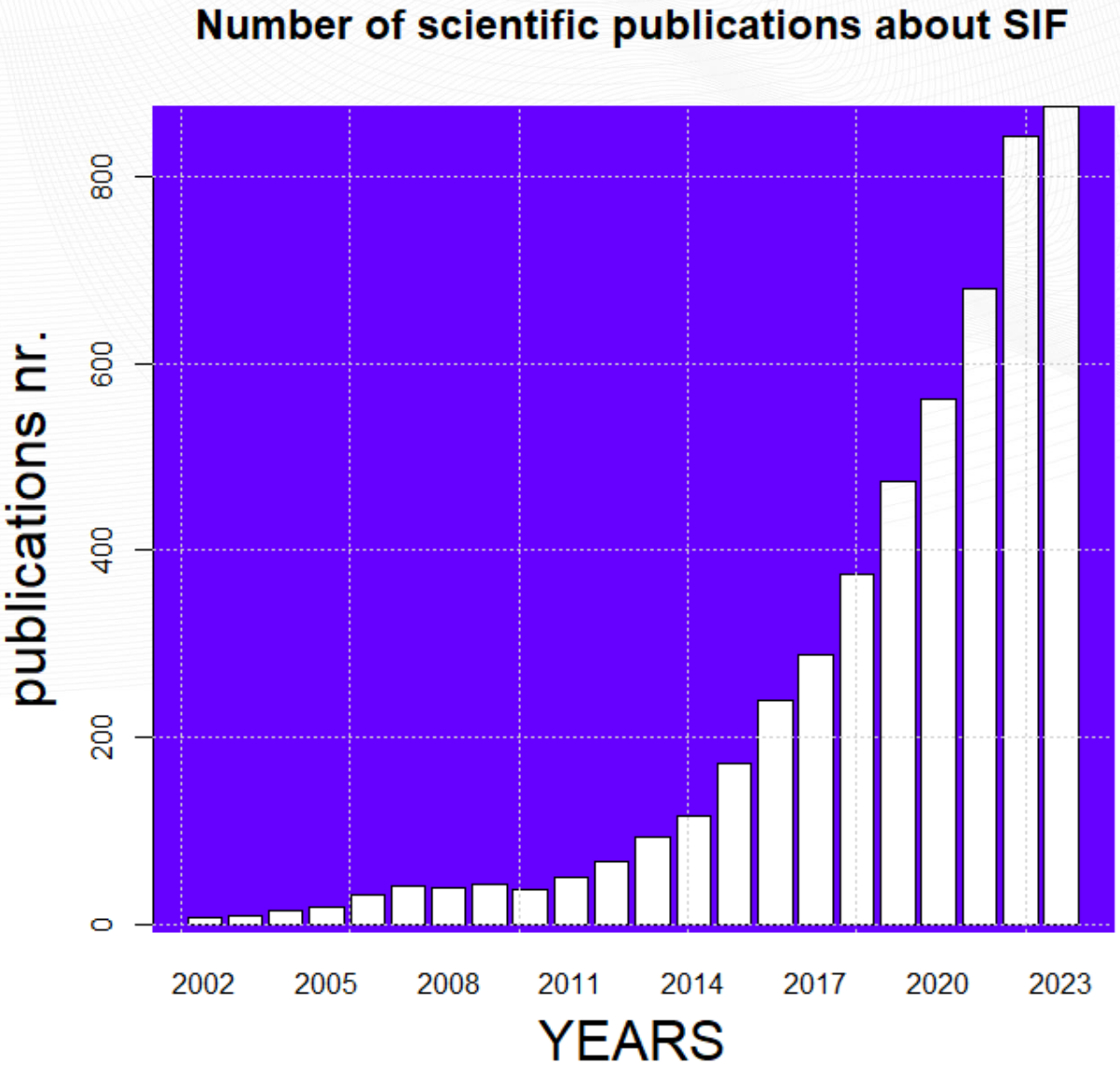
Introducing retrieval methods

WHY SIF?

HYPERSPECTRAL DEVICES

SIF for:

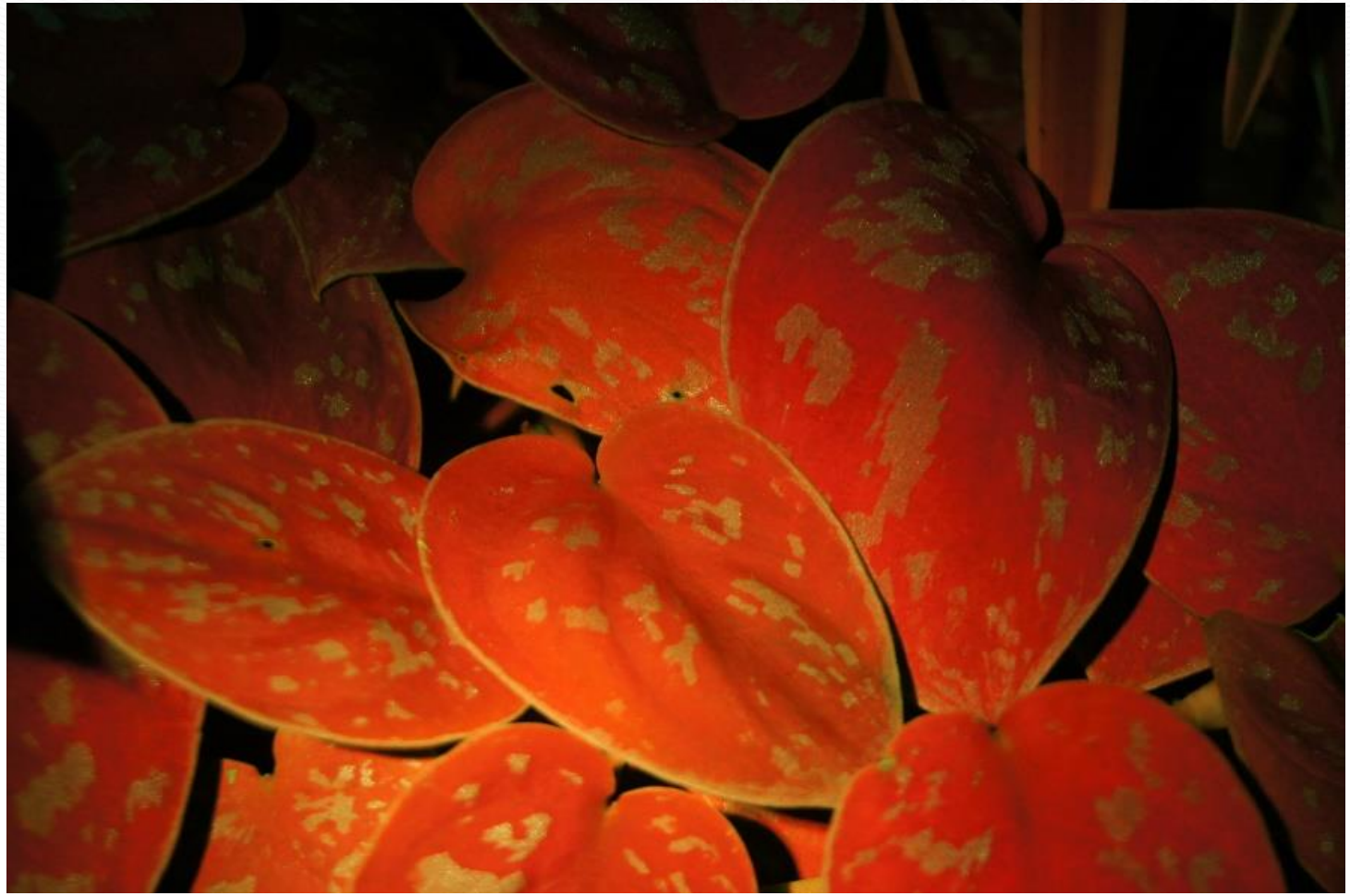
- Ecosystem monitoring
- Photosynthesis – biomass
- Crop yield
- Early warning - stress detection
- Phenotyping
- Biodiversity
- Tree ages, wood harvest
- GPP partitioning
- ….



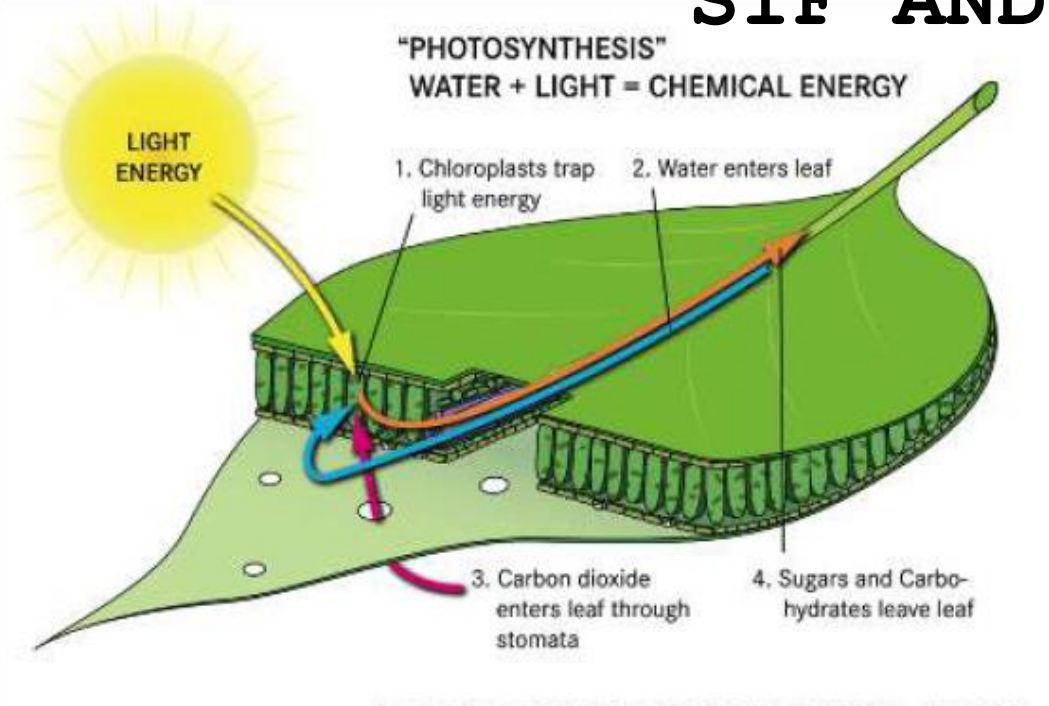
SIF

HYPERSPECTRAL DEVICES

LIGHT EMITTED BY CHLOROPHYLL AT LOWER ENERGY

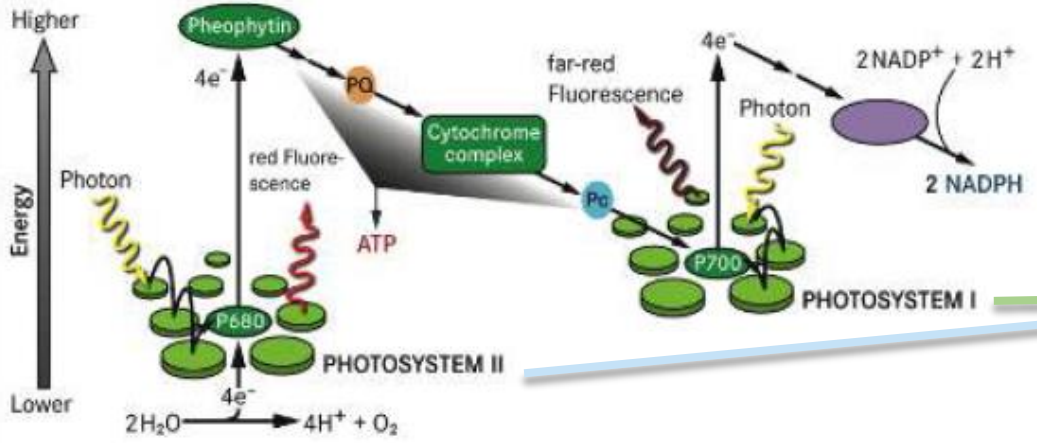


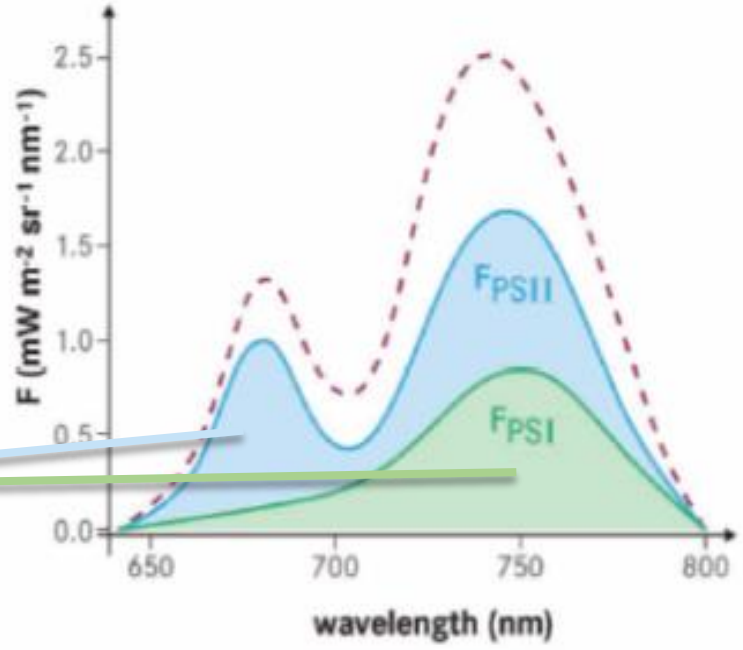
SIF AND PHOTOSYNTHESIS



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 II and I

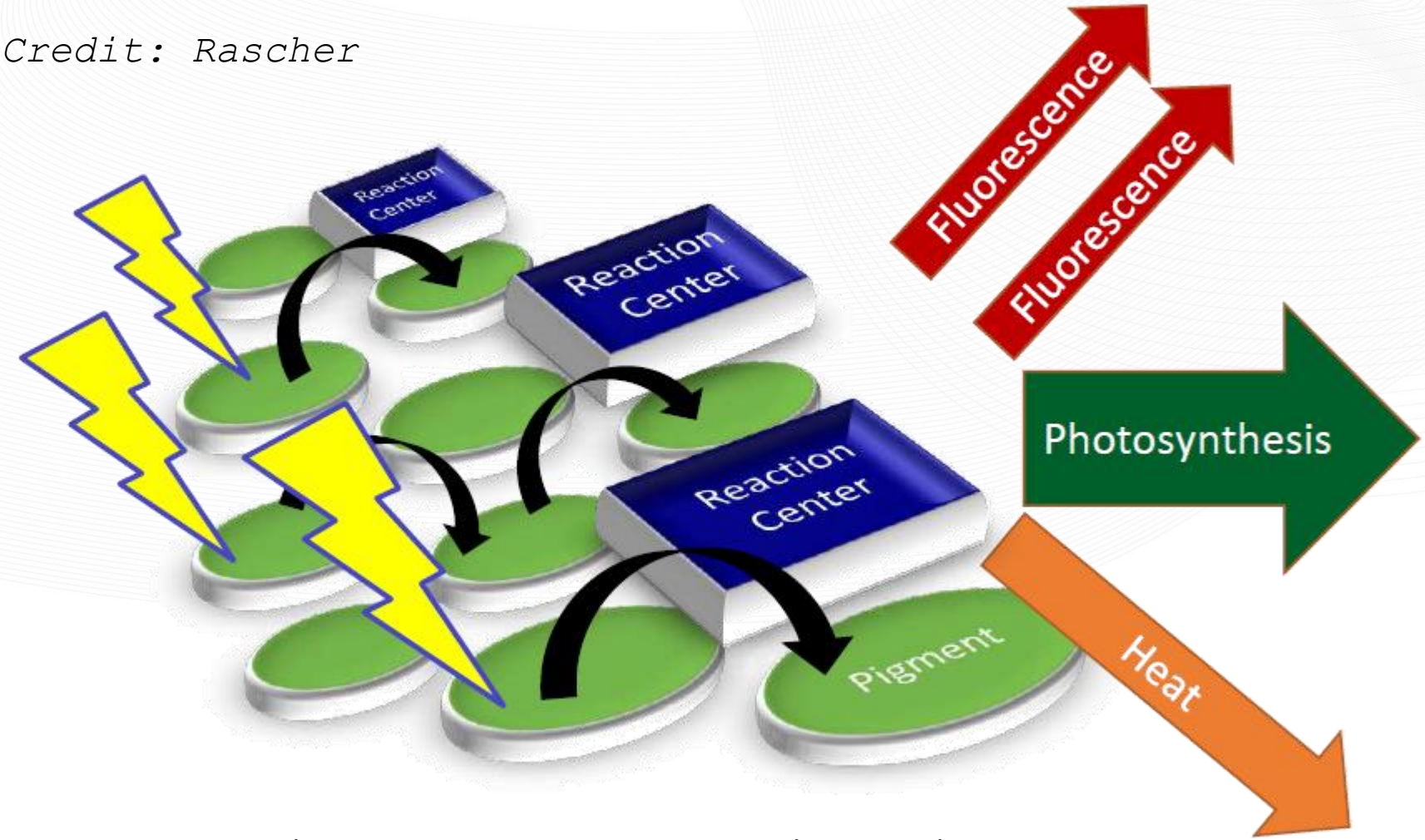




SIF AND PHOTOSYNTHESIS

HYPERSPECTRAL DEVICES

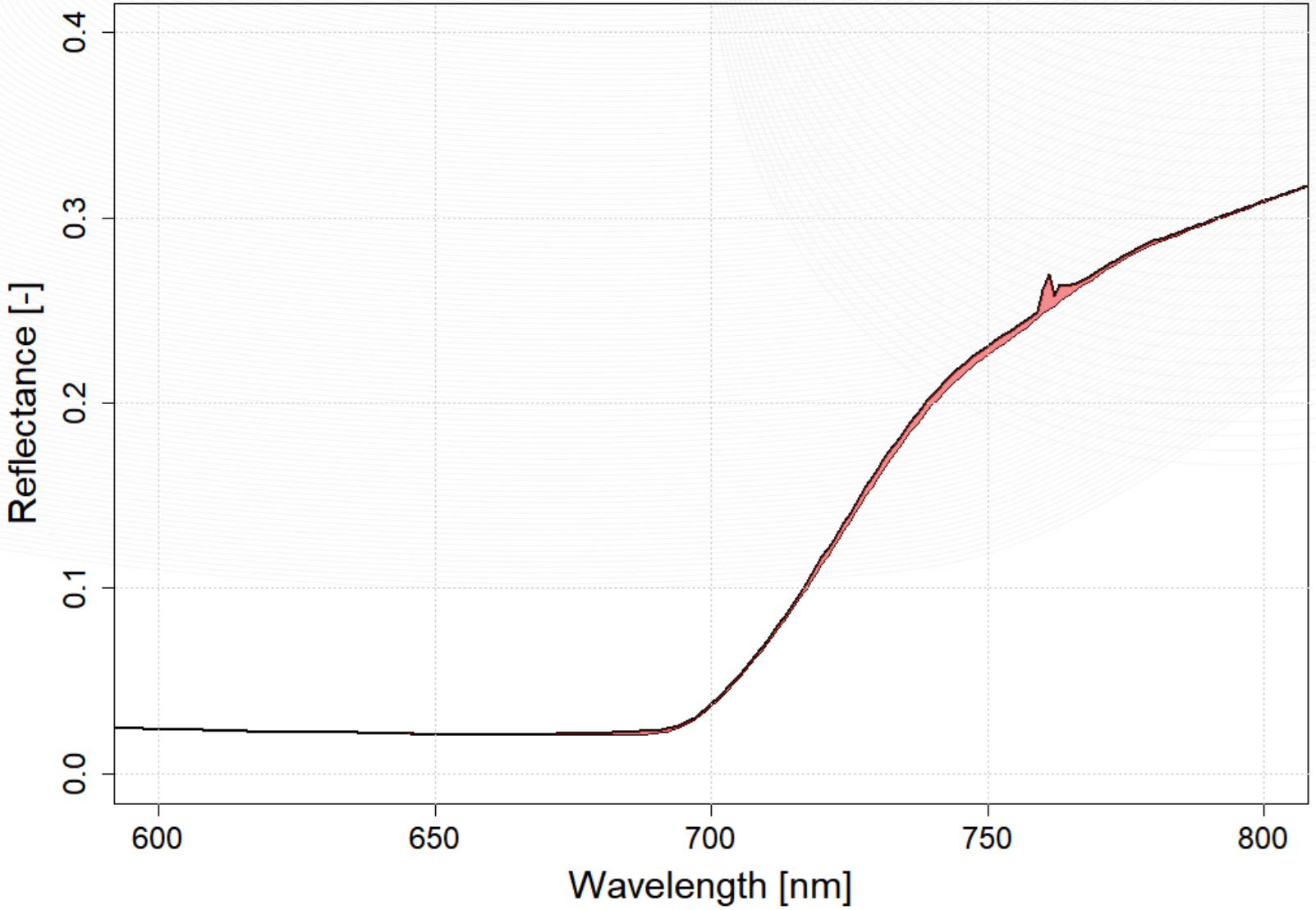
Credit: Rascher



Chlorophyll molecules emit fluorescence. The intensity of the fluorescence signal is a function of light intensity, the concentration of chlorophyll and the efficiency of photosynthesis (functioning of photosynthesis)

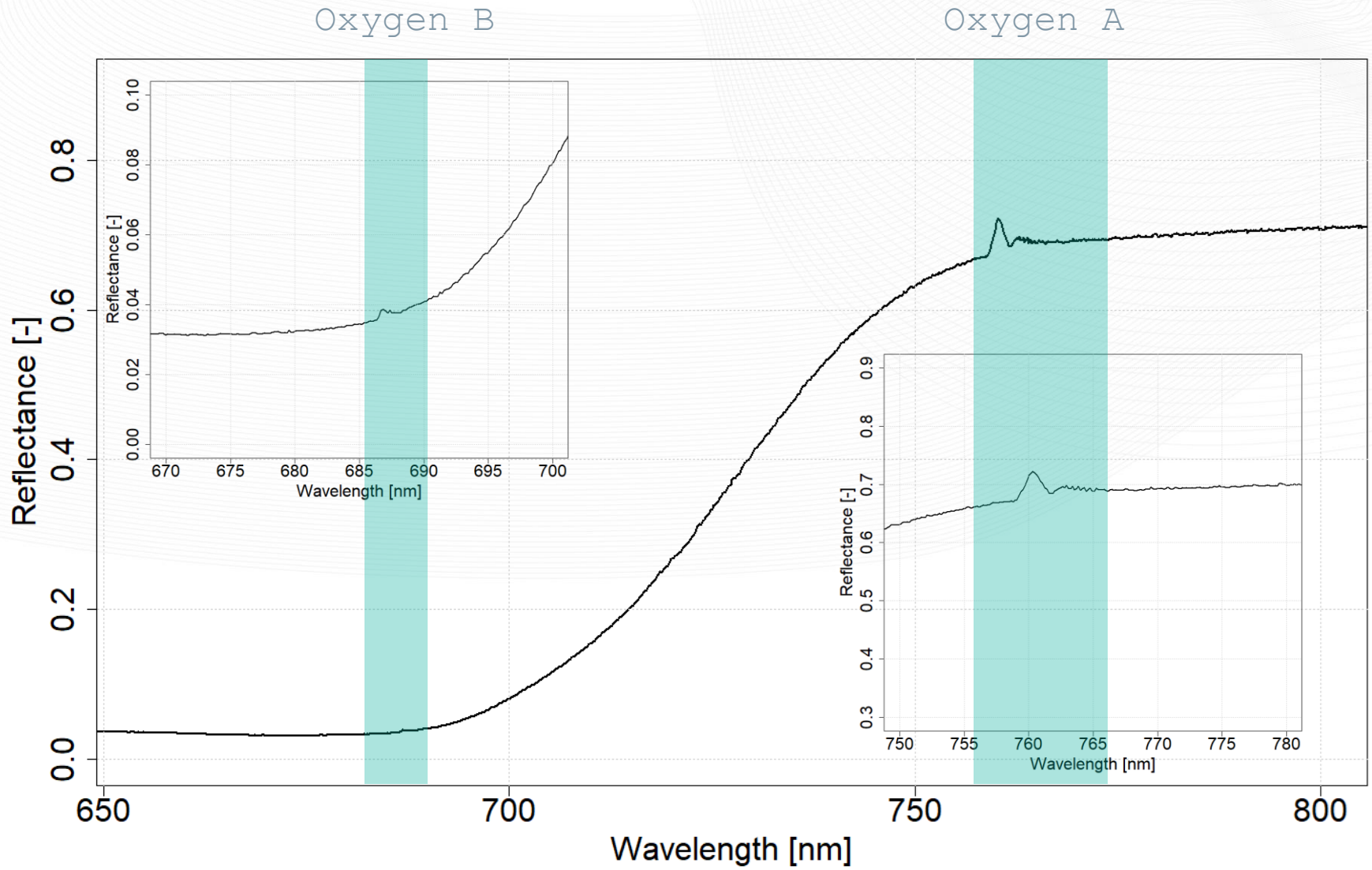
SIF RETRIEVALS

HYPERSPECTRAL DEVICES



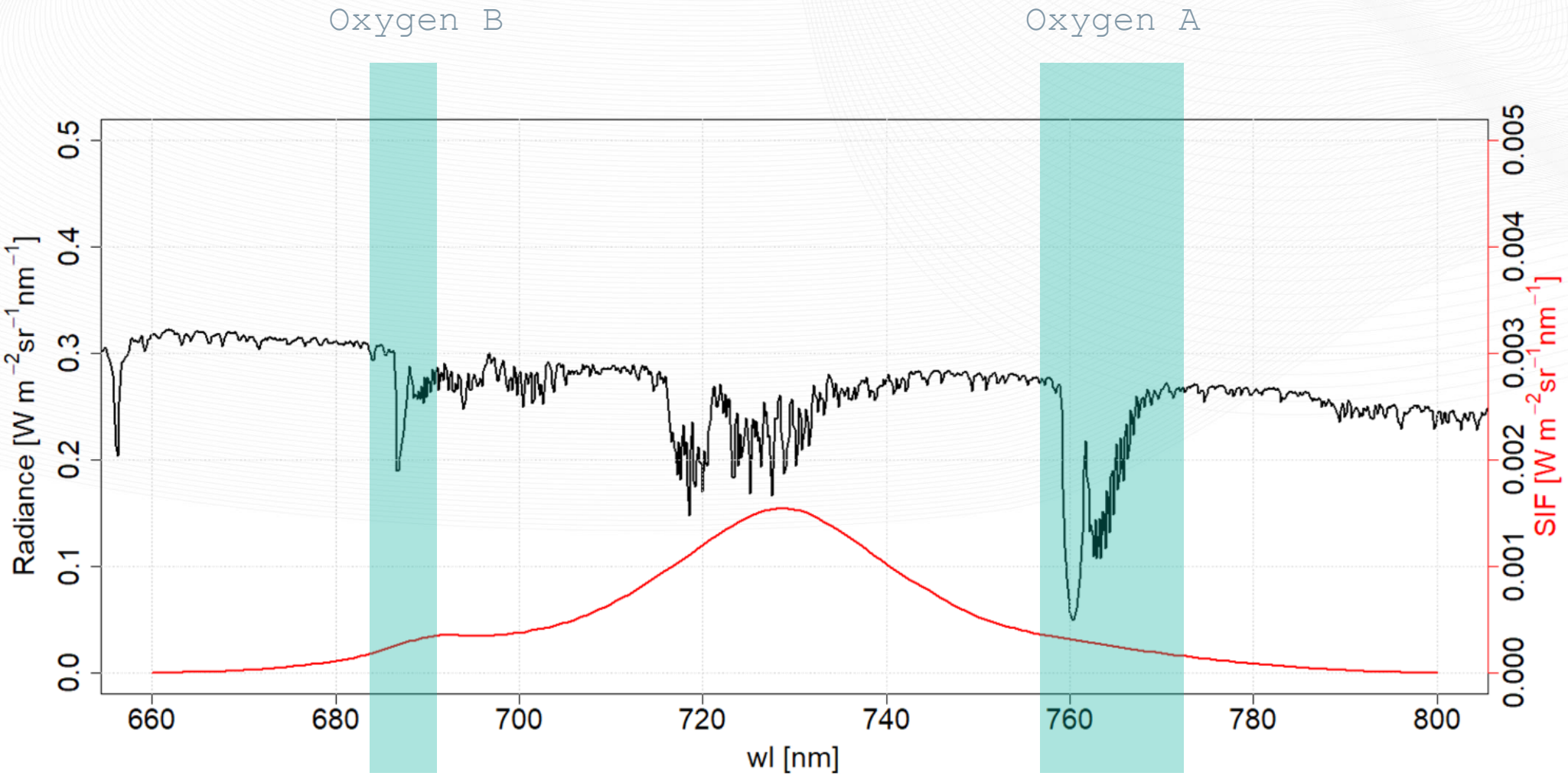
SIF RETRIEVALS

HYPERSPECTRAL DEVICES



SIF RETRIEVALS

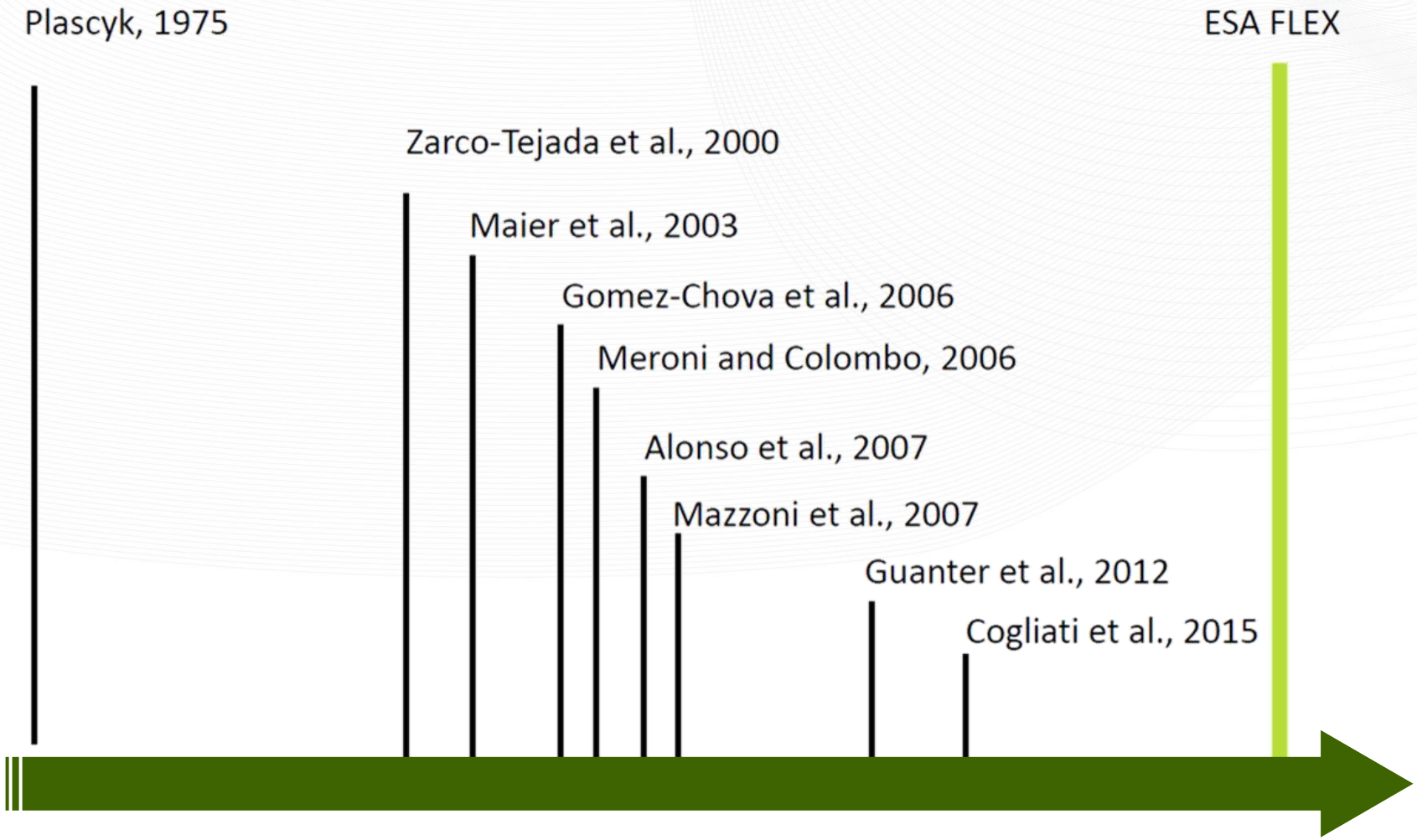
HYPERSPECTRAL DEVICES



SIF RETRIEVALS

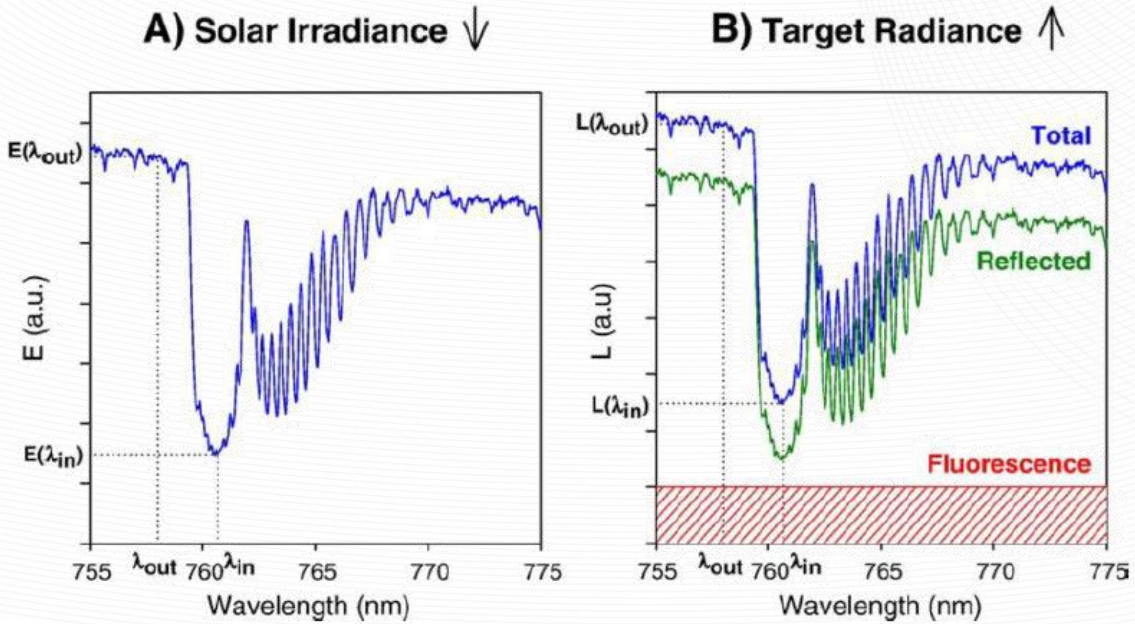
HYPERSPECTRAL DEVICES

Brief history of top of canopy sun-induced Cholorphyll fluorescence retrieval methods



HYPERSPECTRAL DEVICES

Fraunhofer Line Depth (FLD)



Credits: Meroni et al., 2009

$$r = \frac{L(\lambda_{out}) - L(\lambda_{in})}{E(\lambda_{out}) - E(\lambda_{in})} \cdot \pi$$

$$F = \frac{E(\lambda_{out}) \cdot L(\lambda_{in}) - L(\lambda_{out}) \cdot E(\lambda_{in})}{E(\lambda_{out}) - E(\lambda_{in})}$$

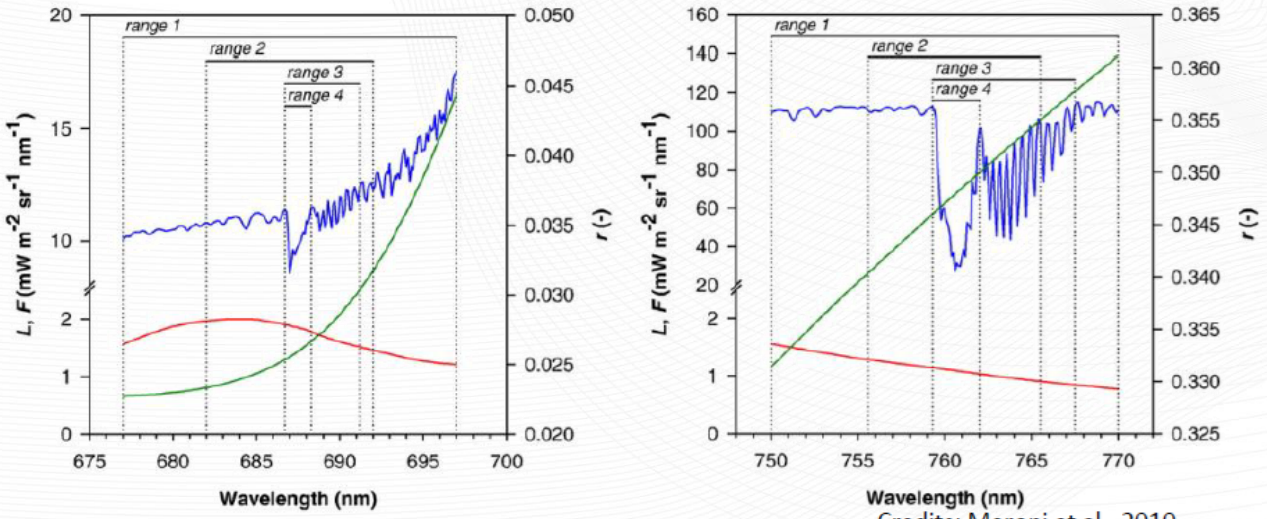
ASSUMPTION: Fluorescence and reflectance are **considered constant** in the selected range

1975

SIF RETRIEVALS

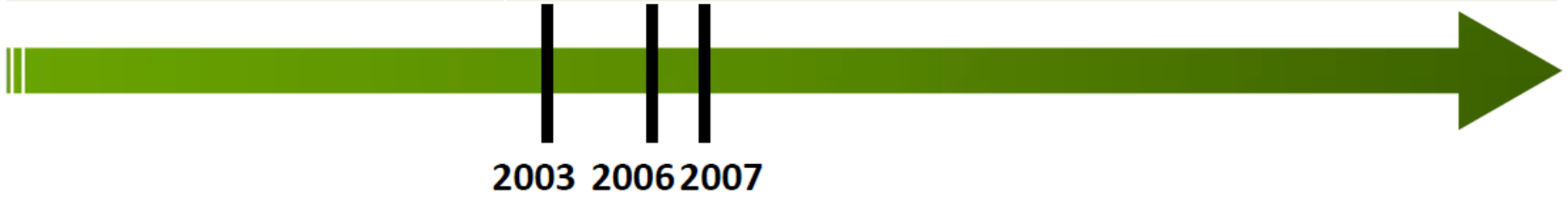
FLD like approach

Assumptions improved on the variation of reflectance in the range used for SIF estimation



Credits: Meroni et al., 2010

Method	Assumption
3FLD	Reflectance and fluorescence vary linearly
cFLD	Reflectance varies according to polynomial functions, fluorescence according to leaf emission
eFLD	Reflectance varies according to polynomial functions
iFLD	Reflectance varies according to cubic splines functions



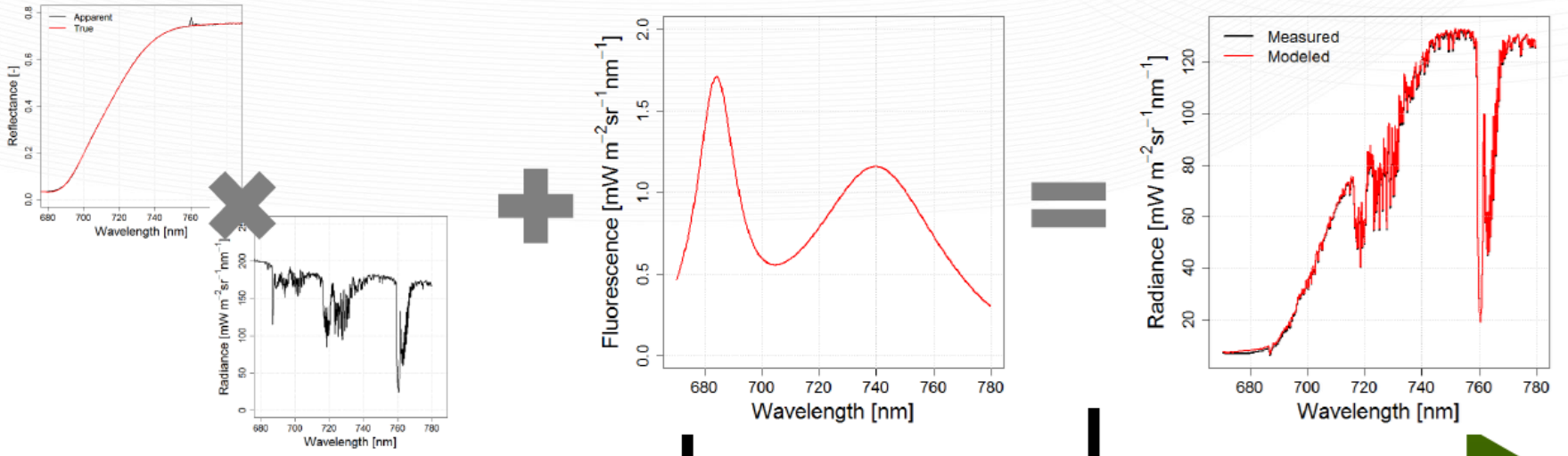
Spectral Fitting Methods (SFM)

Theory: $$L(\lambda) = \frac{r(\lambda)E(\lambda)}{\pi} + F(\lambda)$$

True reflectance is modelled as cubic spline Based on apparent reflectance

Fluorescence emission is modelled as Voigt function Based on iFLD estimates

Modeled reflected radiance



2006 2015

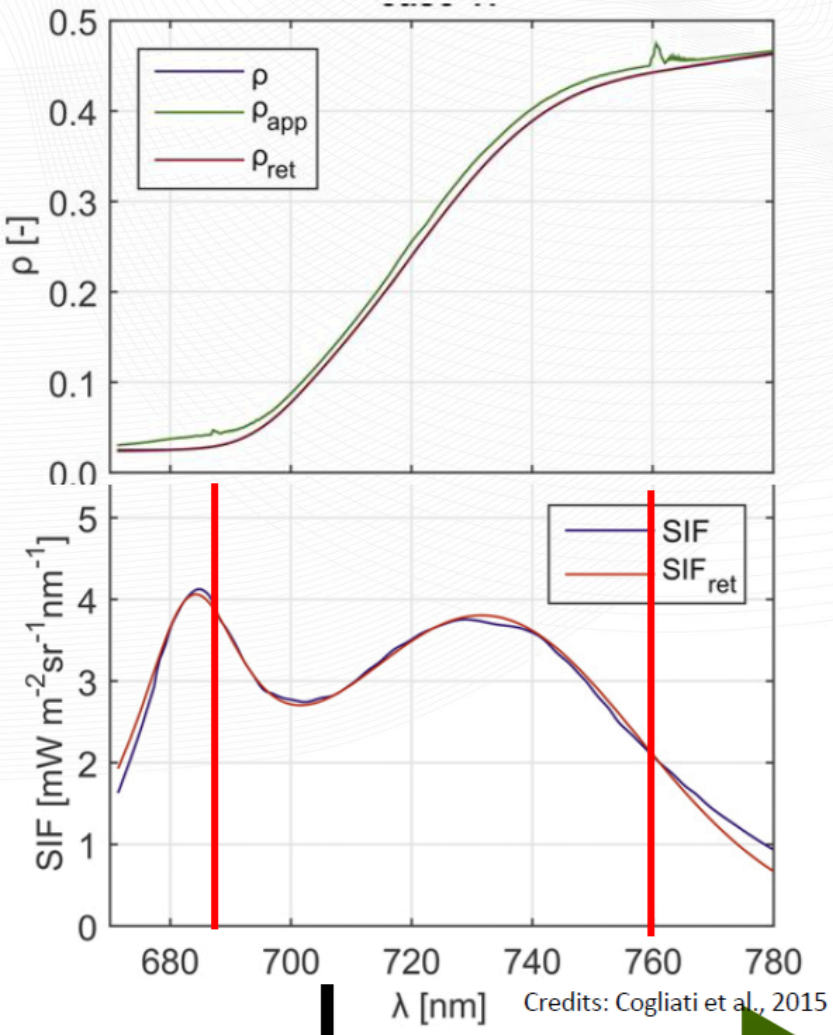
SIF RETRIEVALS

HYPERSPECTRAL DEVICES

Spectral Fitting Methods (SFM)

Cost function optimization:

$$min \sum (L - L_{mod})^2$$



Credits: Cogliati et al., 2015

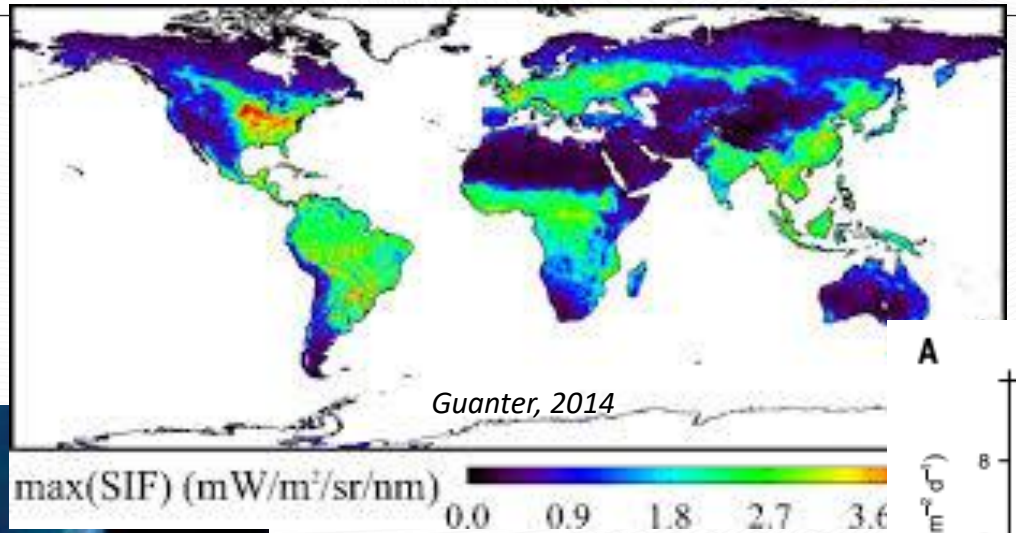
2006 2015

SIF FROM SPACE

HYPERSPECTRAL DEVICES

SIF SATELLITES

OCO2 (3)



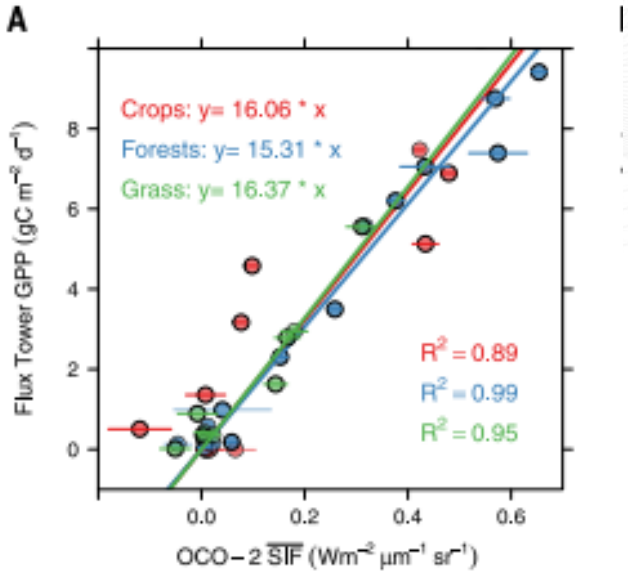
Guanter, 2014

TanSat

GOSAT

GOME-2

TROPOMI



SIF FROM SPACE

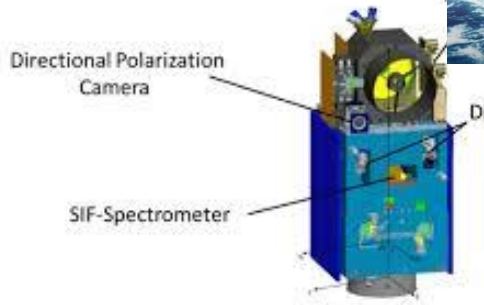
HYPERSPECTRAL DEVICES

Specific for SIF

The **FLuorescence EXplorer (FLEX)** is the next ESA Earth Explorer 8 mission. The FLEX mission aims to provide global maps of vegetation fluorescence at 300m spatial resolution, which can be used to infer photosynthetic activity of natural and managed ecosystems.

Terrestrial Ecosystem Carbon Inventory Satellite (TECIS 1)

Chlorophyll Fluorescence Hyper-Spectral Monitor (SIFIS). It is intended to evaluate forest biomass, measure atmospheric aerosol content, and detect photosynthetic fluorescence



CNSA

PART II

The company JB-Hyperspectral devices.

The FloX.

Progress in field spectroscopy

HYPERSPECTRAL DEVICES

ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 113 (2009) S92–S109

Remote Sensing of Environment
www.elsevier.com/locate/rse

Progress in field spectroscopy

Edward J. Milton [a,*], Michael E. Schaepman [b], Karen Anderson [c], Mathias Kneubühler [d], Nigel Fox [e]

[a] School of Geography, University of Southampton, SO17 1BJ, UK
for Geo-Information, Wageningen University, Droevendaalsesteeg 3 6708 PB Wageningen, The Netherlands
[c] Department of Geography, University of Exeter, EX4 4QJ, UK
note Sensing Laboratories, University of Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland
[e] National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK

Received 7 November 2006; received in revised form 14 June 2007; accepted 13 August 2007

Incoming/**Reflected**	**Directional**	**Conical**	**Hemispherical**
Directional	Bidirectional Case 1	Directional-conical Case 2	Directional-hemispherical Case 3
Conical	Conical-directional Case 4	Biconical Case 5	Conical-hemispherical Case 6
Hemispherical	Hemispherical-directional Case 7	Hemispherical-conical Case 8	Bihemispherical Case 9

similar to satellite,
suited as ground reference

JB COMPANY

HYPERSPECTRAL DEVICES

JB Hyperspectral Devices is a company founded in 2016 and based in Düsseldorf, Germany.

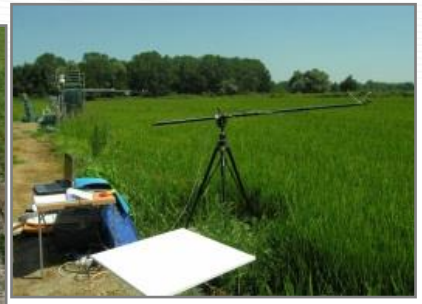
The prime focus of our work is the design and production of advanced **hyperspectral field instruments.**

FLOX

ROX

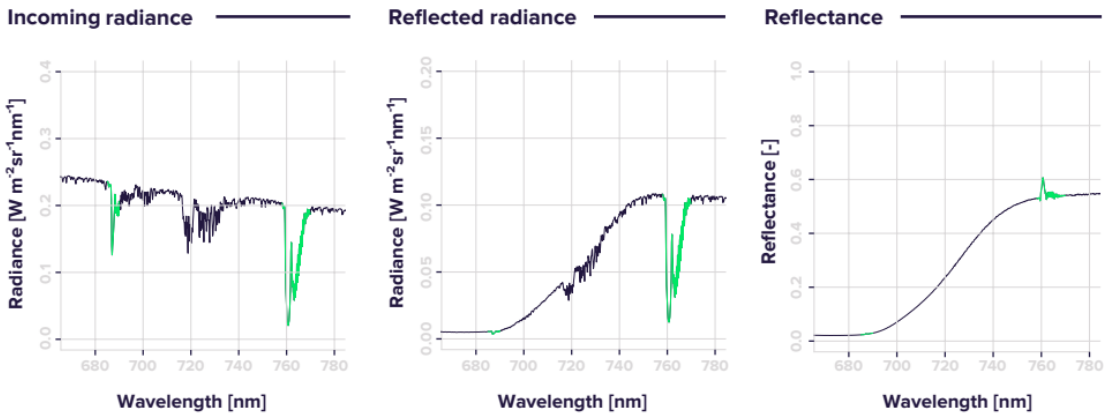
NOX

2005 2008 2012 2016

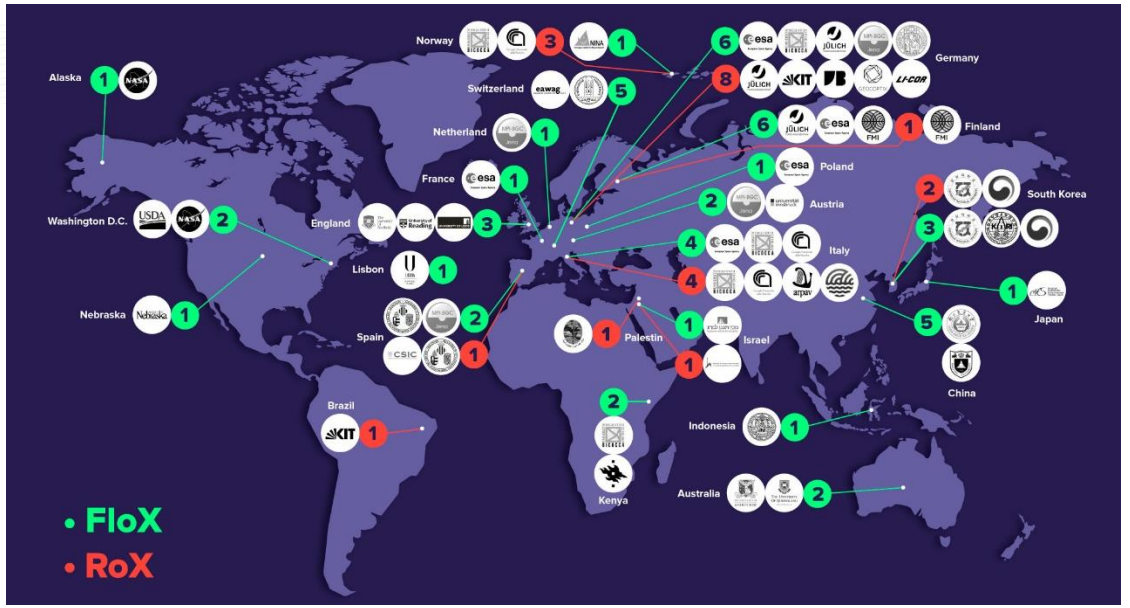


European Space Agency

FloX – The Fluorescence boX



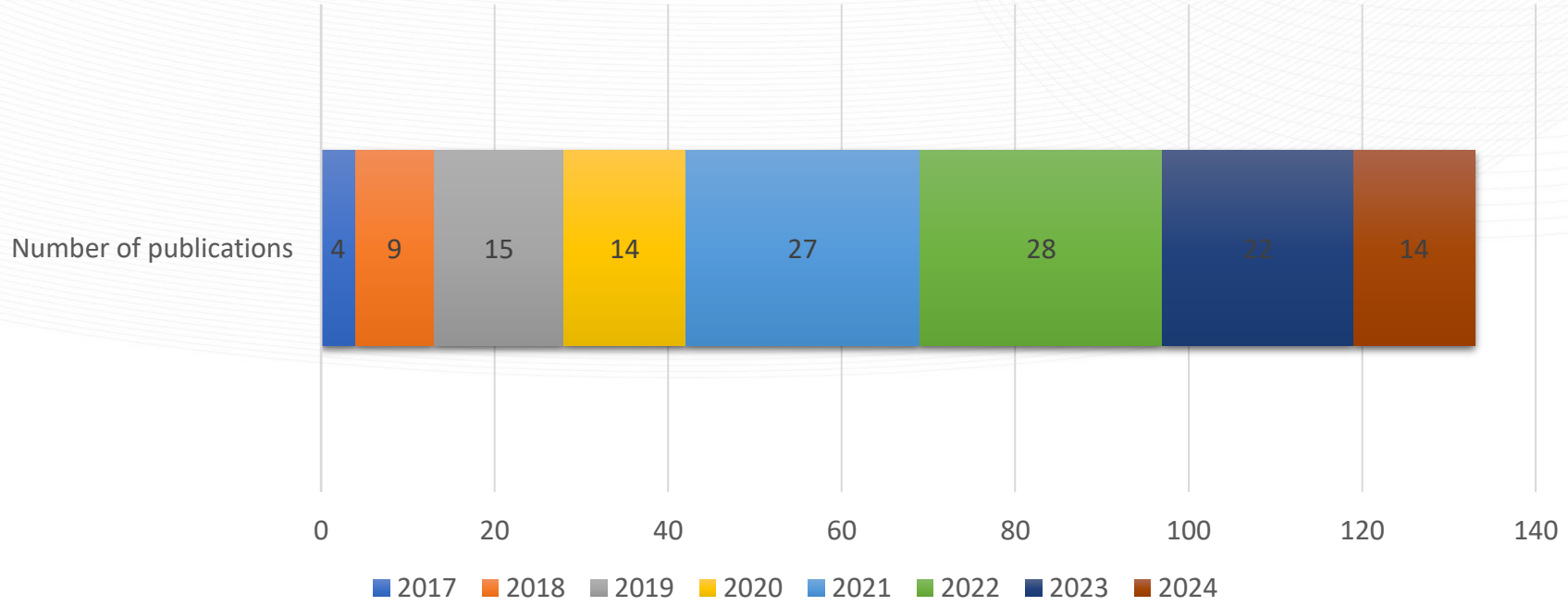
OPTIC	Spec1	Spec2
Wavelength range	~ 650–800 nm;	~ 400–950 mn
Spectral Sampling Interval (SSI)	~ 0.17 nm	~ 0.65 nm
Spectral resolution (FWHM)	~ 0.3 nm	~ 1.5 nm
Signal to Noise Ratio (SNR)	~ 1000	~ 250
Field Of View (FOV)	Dual FOV. Upwelling radiance ~25°. Downwelling radiance 180°	



CREDITS

The FloX has an outstanding scientific record and was used already in over 137 publications world wide.

FloX related scientific publications



Based on Google Scholar search for "FLOX JB Hyperspectral", accessed on Jul. 11, 2024

CREDITS

HYPERSPECTRAL DEVICES

Some of the latest FloX-related publications are:

ELSEVIER

Remote Sensing of Environment
Volume 304, 1 April 2024, 114043

Deriving photosystem-level red chlorophyll fluorescence emission by combining leaf chlorophyll content and canopy far-red solar-induced fluorescence: Possibilities and challenges

Linsheng Wu [a b], Yongguang Zhang [a b c] ✉, Zhaoying Zhang [a b], Xiaokang Zhang [a b], Yunfei Wu [a b], Jing M. Chen [a d e]

ELSEVIER

Remote Sensing of Environment
Volume 311, 1 September 2024, 114294

Comparing the quantum use efficiency of red and far-red sun-induced fluorescence at leaf and canopy under heat-drought stress

Sebastian Wieneke [a b c] ✉, Javier Pacheco-Labrador [d e], Miguel D. Mahecha [a b f], Sílvia Poblador [c g], Sara Vicca [h], Ivan A. Janssens [c]

ELSEVIER

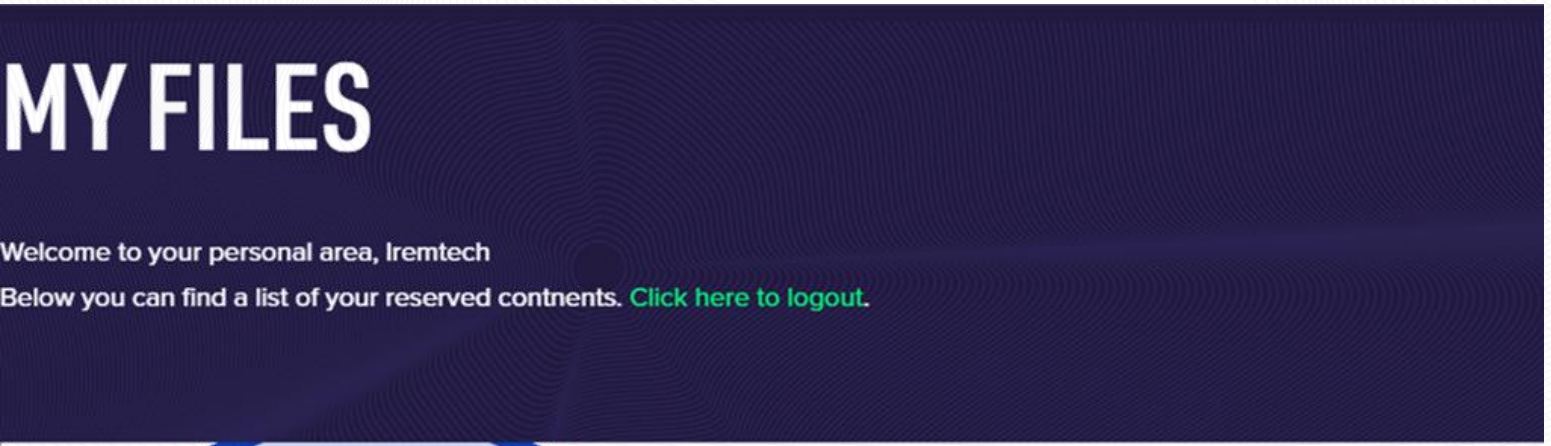
Remote Sensing of Environment
Volume 303, 15 March 2024, 114013

Towards a standardized, ground-based network of hyperspectral measurements: Combining time series from autonomous field spectrometers with Sentinel-2

Paul Naethe [a] ✉, Andrea De Sanctis [a], Andreas Burkart [a], Petya K.E. Campbell [b c], Roberto Colombo [d], Biagio Di Mauro [e], Alexander Damm [f g], Tarek El-Madany [h], Francesco Fava [i], John A. Gamon [j k], Karl F. Huemmrich [b c], Mirco Migliavacca [l], Eugenie Paul-Limoges [g m], Uwe Rascher [n], Micol Rossini [d], Dirk Schüttemeyer [o], Giulia Tagliabue [d], Yongguang Zhang [p], Tommaso Julitta [a]

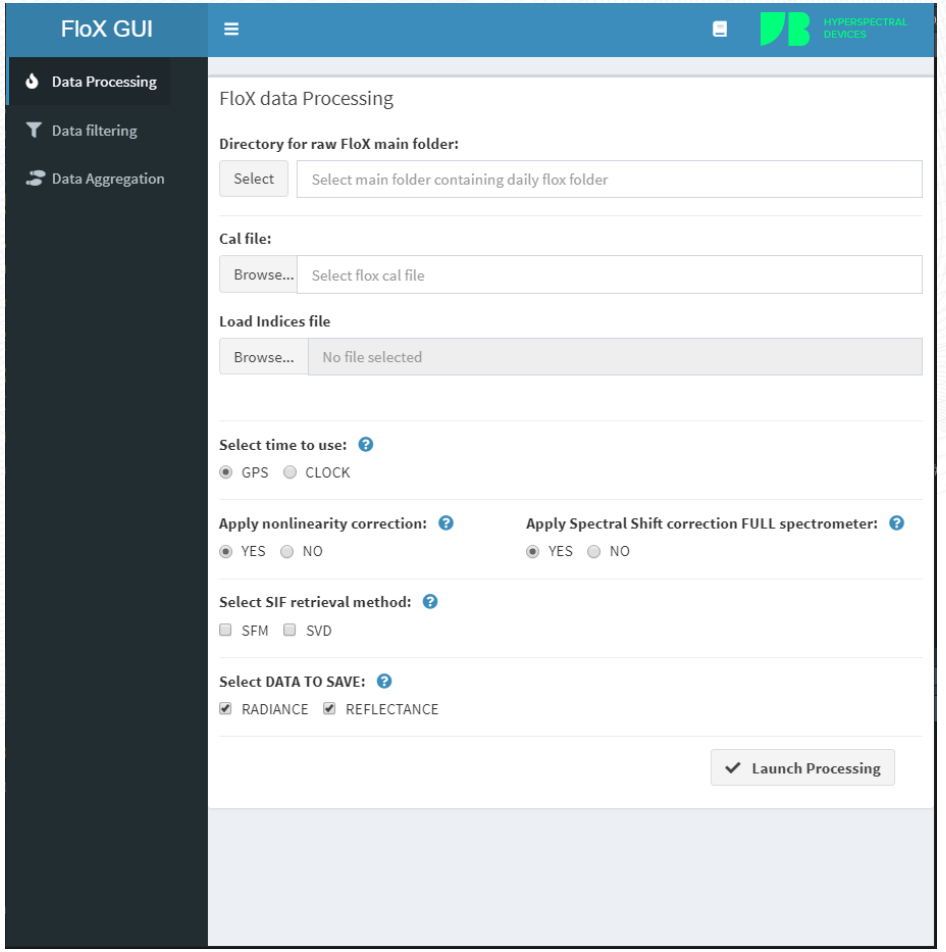
FLOX PROCESSING

HYPERSPECTRAL DEVICES



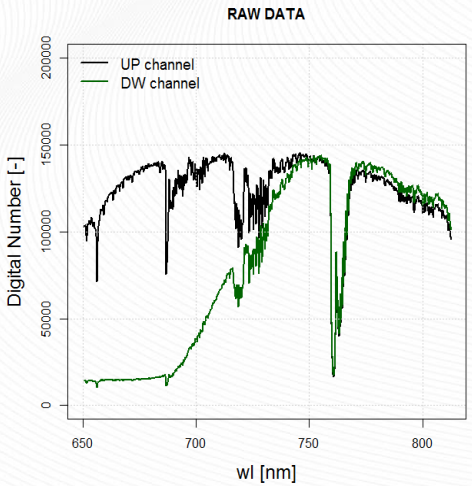
FLOX DATA PROCESSING GUI - JB-031-SK - IREMTECH

DISCOVER



DATA PROCESSING

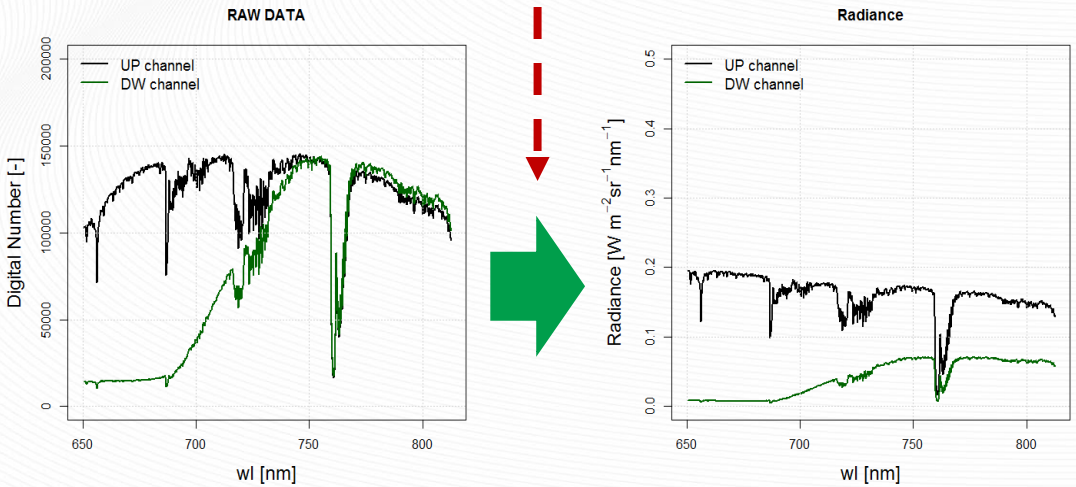
HYPERSPECTRAL DEVICES



DATA PROCESSING

HYPERSPECTRAL DEVICES

Calibration coefficients



DATA PROCESSING

HYPERSPECTRAL DEVICES

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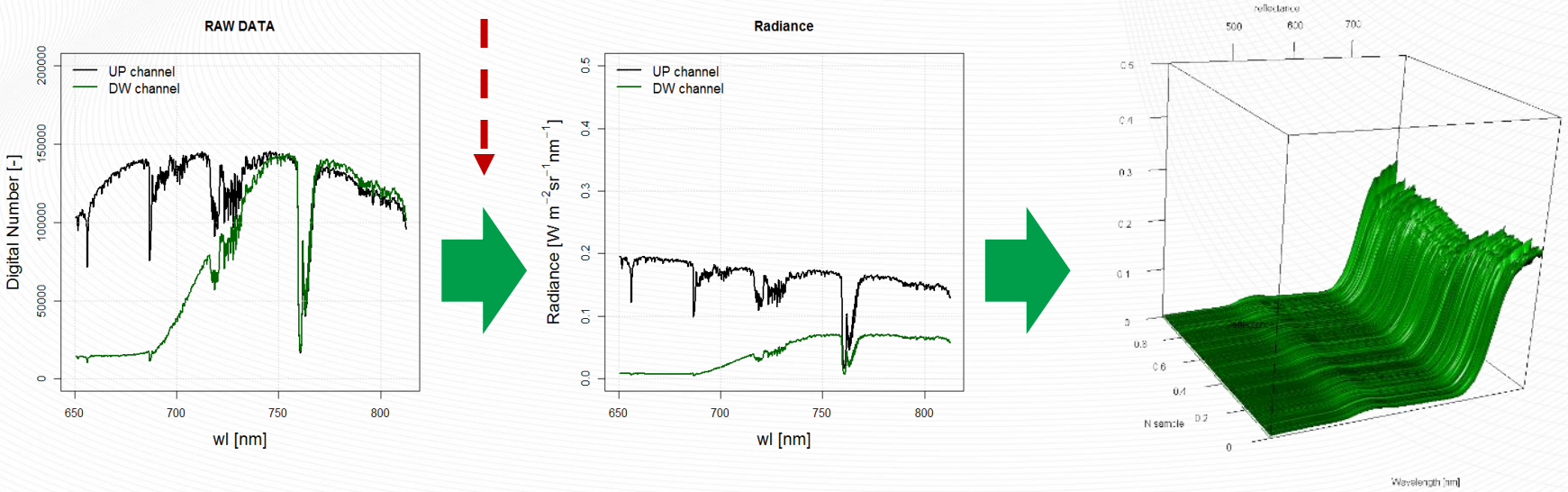
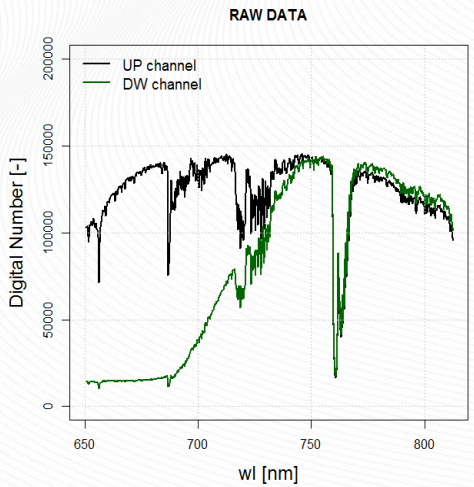


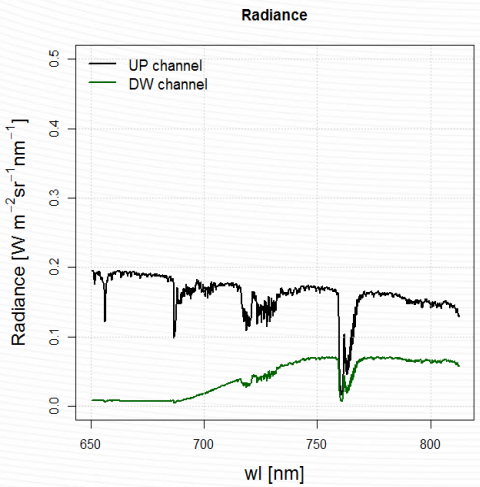
DATA PROCESSING

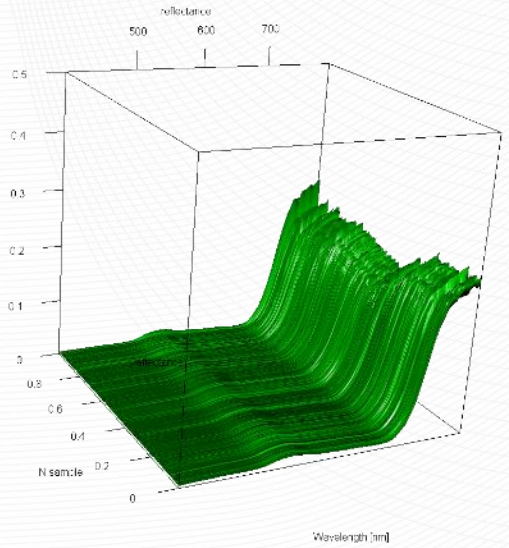
HYPERSPECTRAL DEVICES

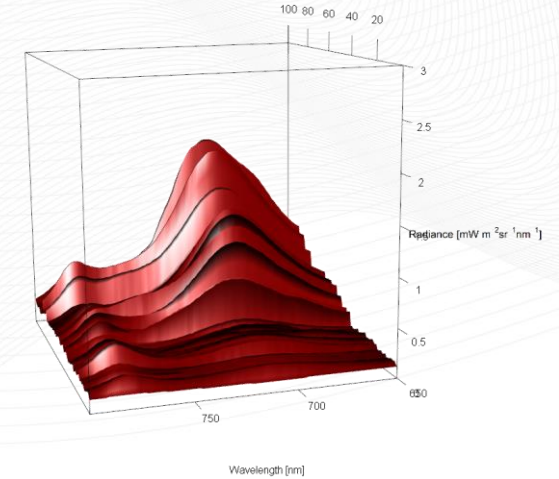
Calibration coefficients

SIF retrieval and Index formulation









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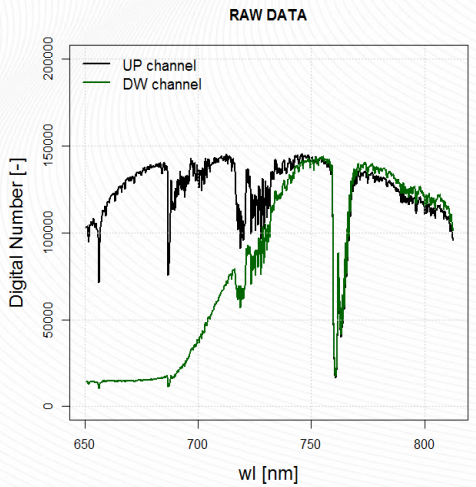
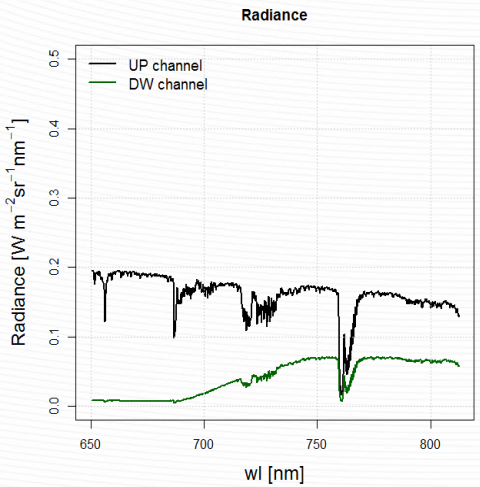
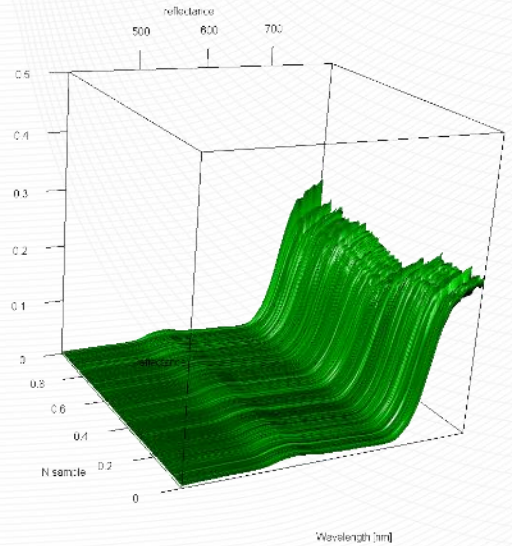
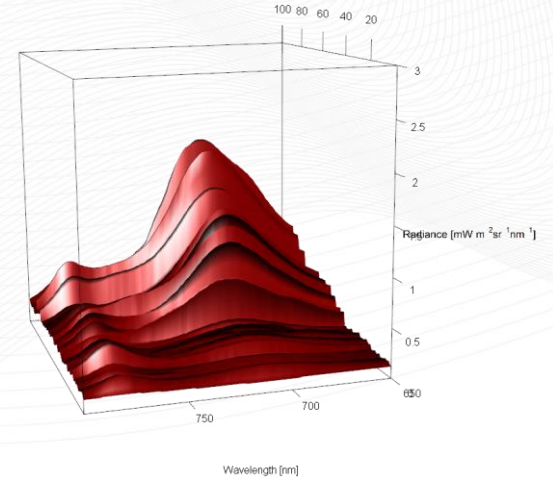
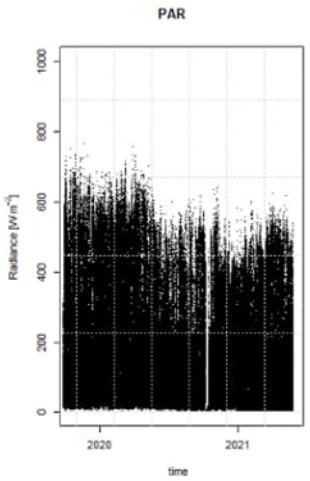
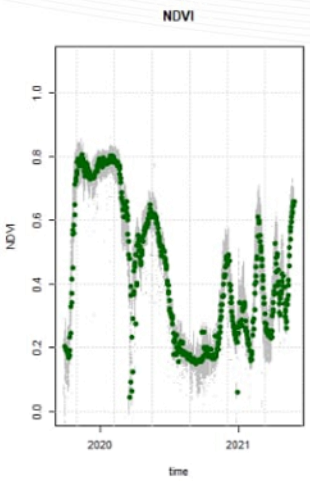


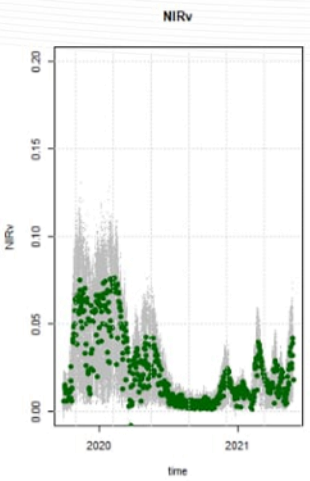


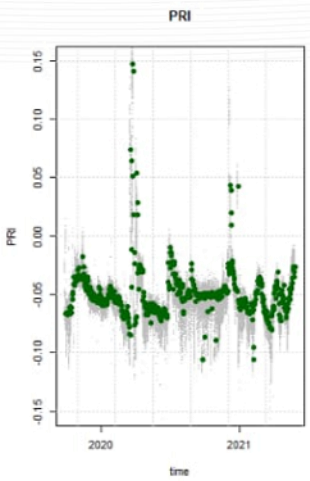


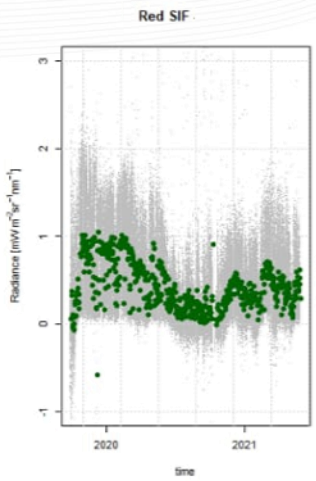


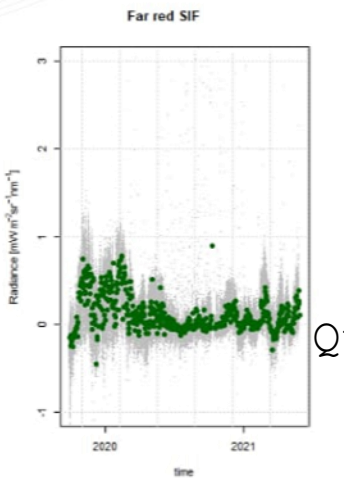












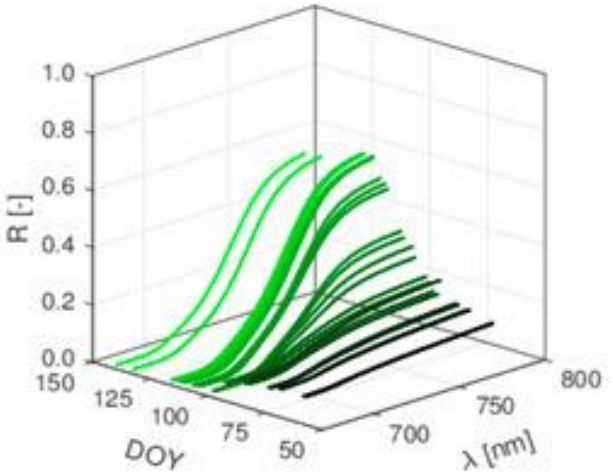
Quality Flag Criteria

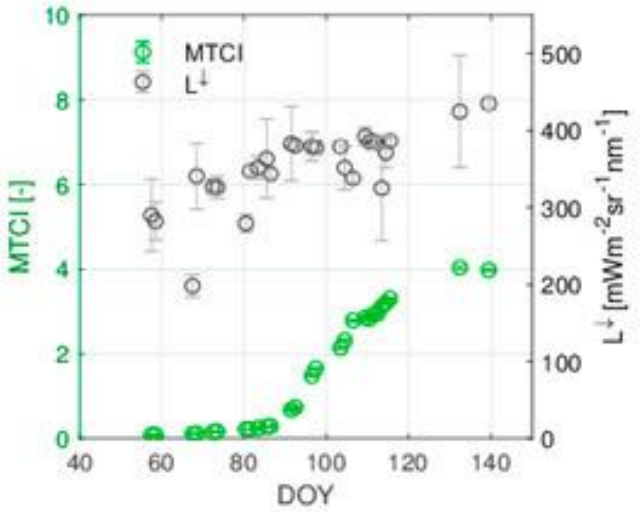
ADVANCED SIF METRICS

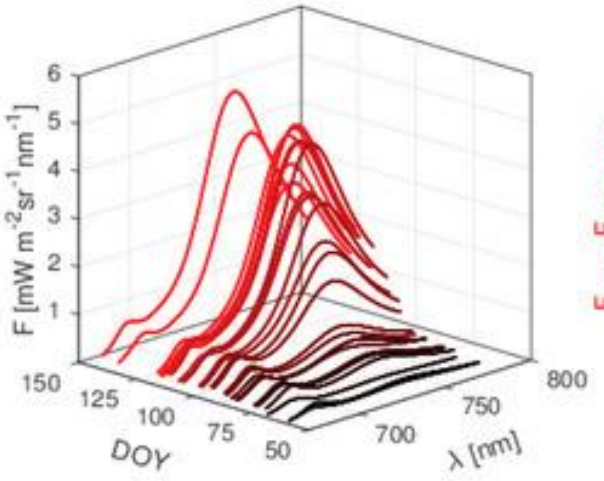
HYPERSPECTRAL DEVICES

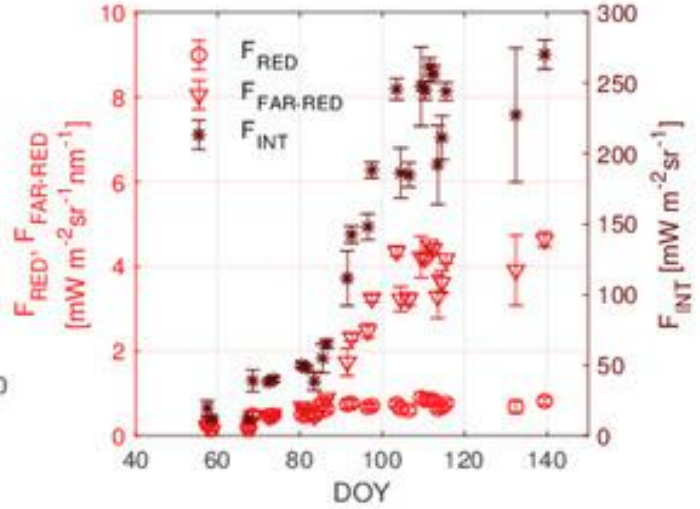
SIF is more than just one numeral value

Exploiting time series and new SIF metrics





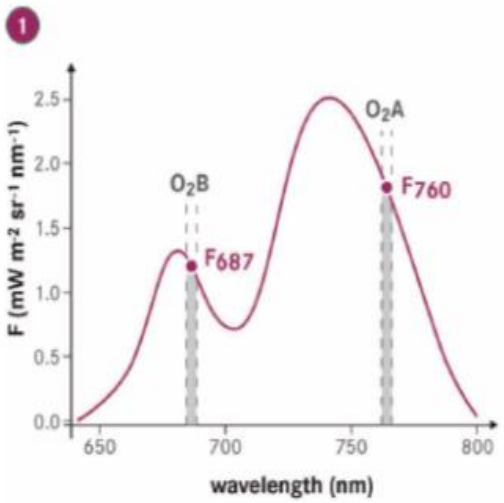


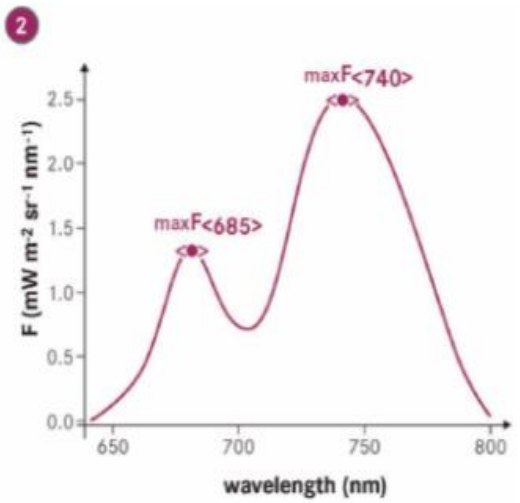


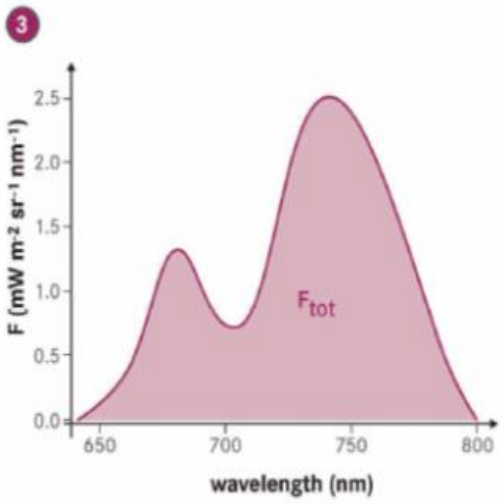
Cogliati et al, 2019

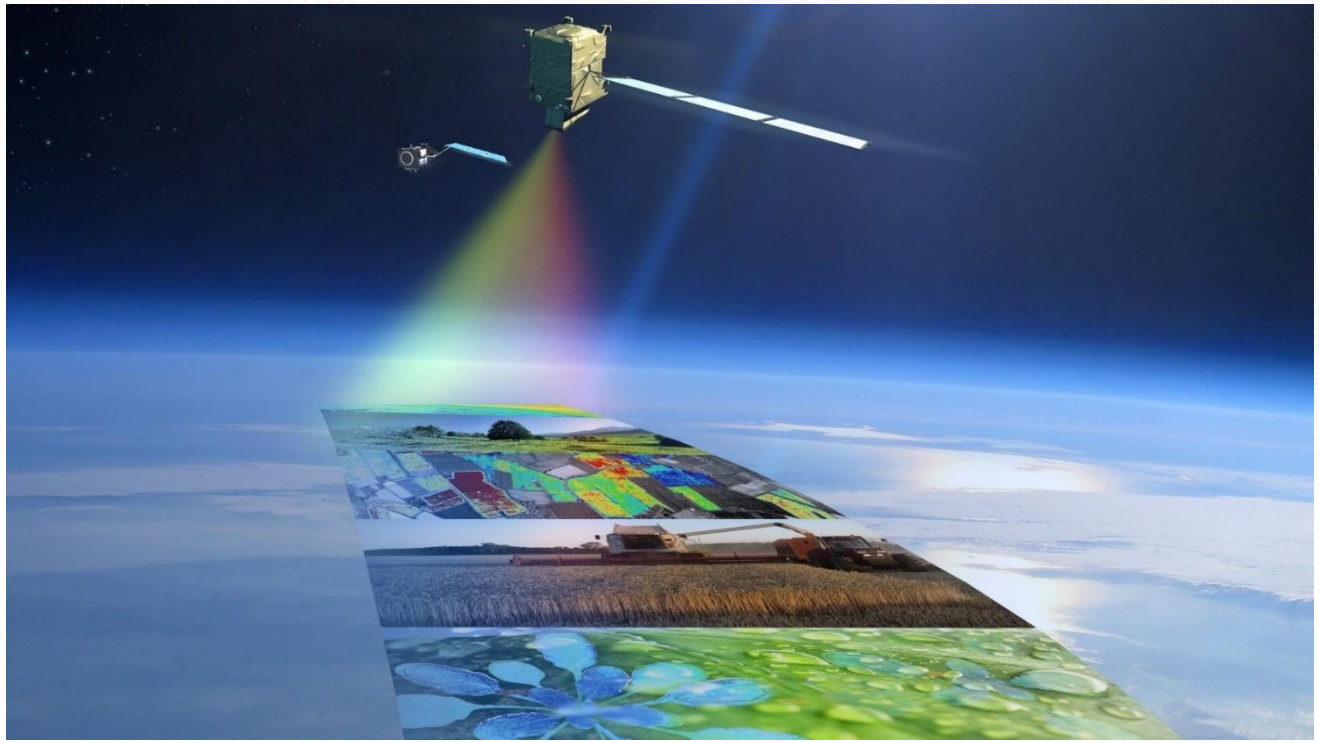
ADVANCED SIF METRICS

HYPERSPECTRAL DEVICES









Main goal. To assess the quality of different FLEX fluorescence products:

- O_2-A and O_2-B TOC fluorescence emission values (F687 and F760):
- Peak values and peak position of TOC fluorescence emission (maxFred, λred, maxFfar-red and λfar-red)
- Total TOC fluorescence emission (F_{tot})

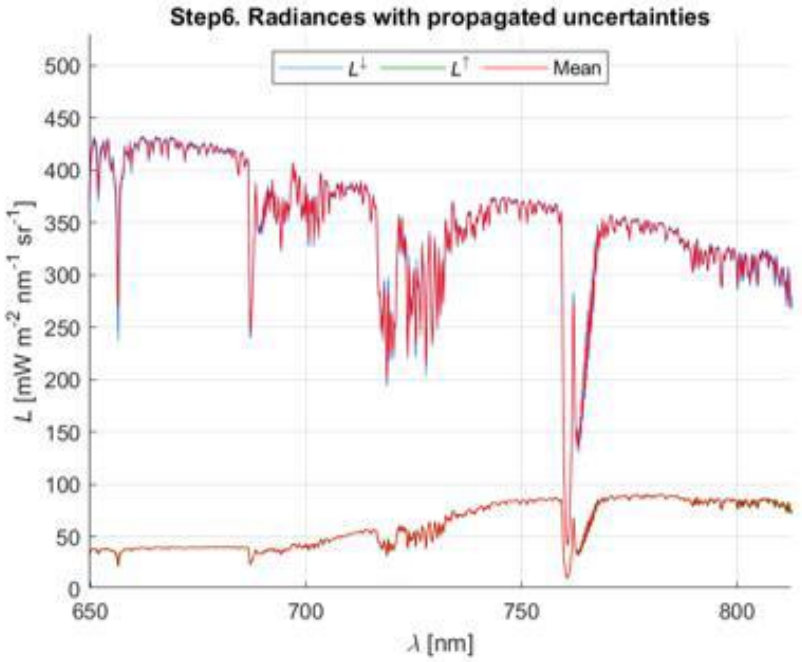
TRACEABILITY OF UNCERTAINTIES

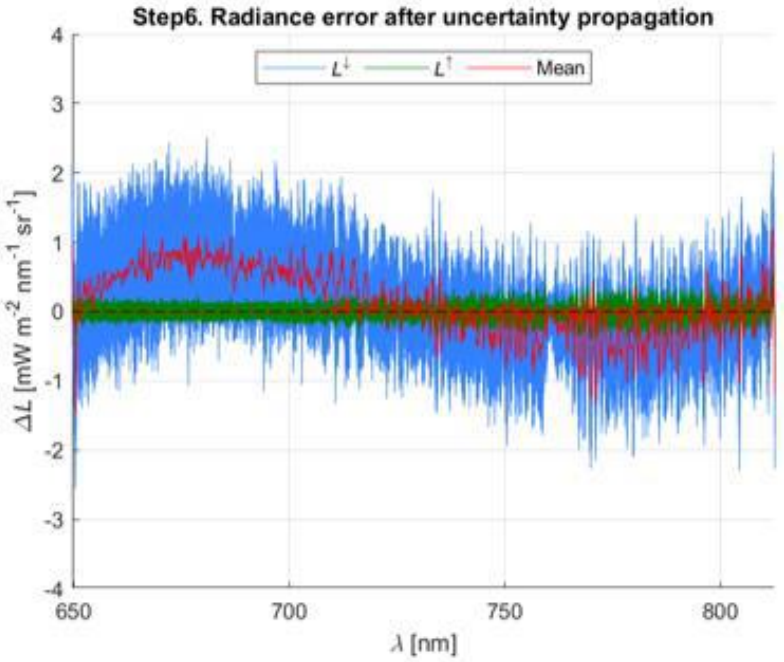
HYPERSPECTRAL DEVICES

All relevant uncertainties are modelled with a dedicated module and the output will be included in future data products.

Uncertainty emulation: Spectral, radiometric, SNR(noise), Dark Current (DC), cosine diffusor response function and SZA

Full traceability of uncertainty is aimed for to support the upcoming launch of the FLEX satellite.

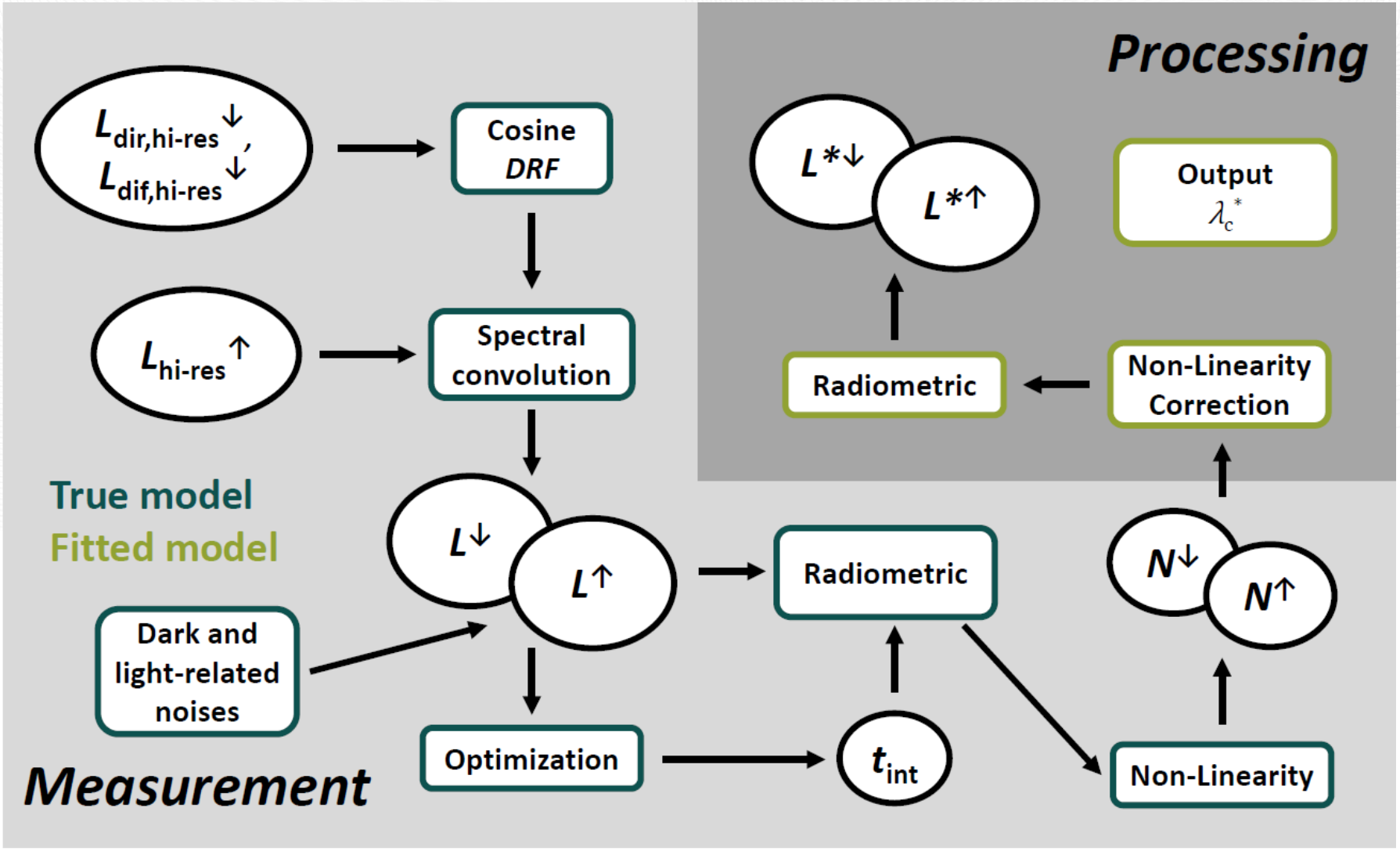




TRACEABILITY OF UNCERTAINTIES

HYPERSPECTRAL DEVICES

Addressed by a comprehensive emulator of the FloX

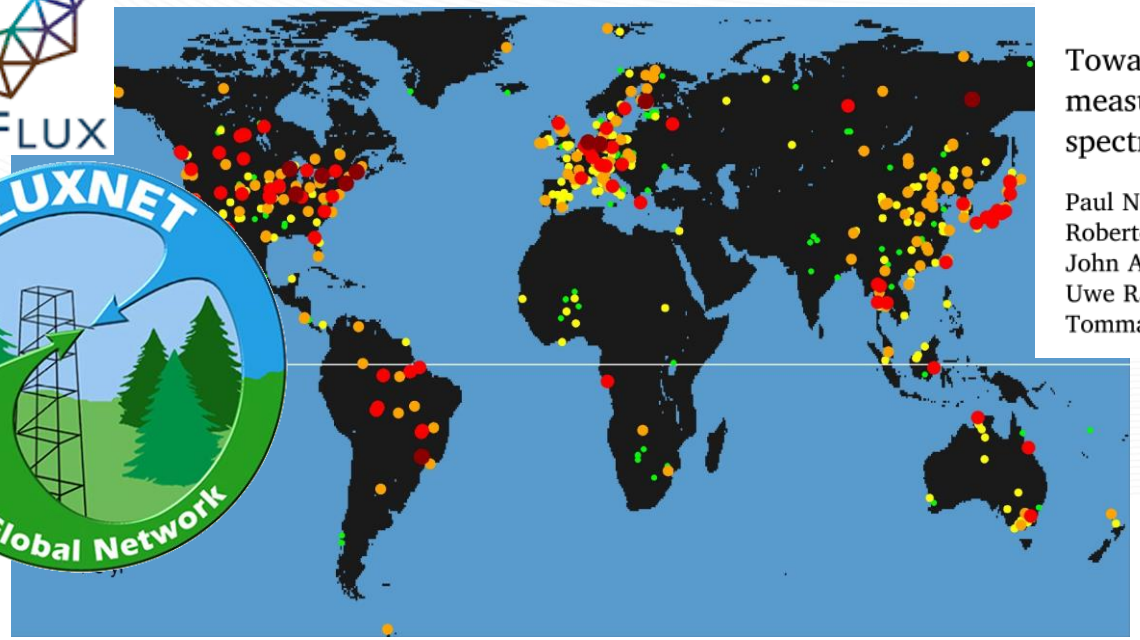


TOWARDS FLOX INTEGRATION IN FLUX NETWORKS

NSF | neon Operated by Battelle

AMERIFLUX

FLUXNET A Global Network



ICOS Integrated Carbon Observation System

Remote Sensing of Environment 303 (2024) 114013

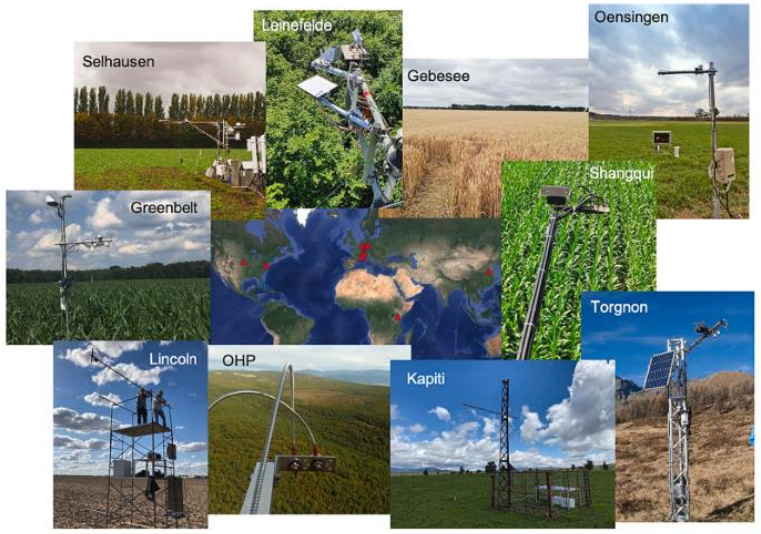
Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Towards a standardized, ground-based network of hyperspectral measurements: Combining time series from autonomous field spectrometers with Sentinel-2

Paul Naethe [a,*], Andrea De Sanctis [a], Andreas Burkart [a], Petya K.E. Campbell [b,c], Roberto Colombo [d], Biagio Di Mauro [e], Alexander Damm [f,g], Tarek El-Madany [h], Francesco Fava [i], John A. Gamon [j,k], Karl F. Huemmrich [b,c], Mirco Migliavacca [l], Eugenie Paul-Limoges [g,m], Uwe Rascher [n], Micol Rossini [d], Dirk Schüttemeyer [o], Giulia Tagliabue [d], Yongguang Zhang [p], Tommaso Julitta [a]



DATA STREAMING

HYPERSPECTRAL DEVICES

Since 2023 all JB devices are compatible with Li-COR SmartFluX for a real time visualization of the data out of the box.

Communication is using the SDI-12 interface and allows a minute based data transfer. A subset of 9 variables (SIF and Vegetation indices) calculated by FloX internal ARM processor can be streamed out after every measurement cycle.

LI-COR

FLOX DATABASE AND NETWORK

HYPERSPECTRAL DEVICES

API

Automatic upload

Server including data storage layer, data processing layer and web interface layer

Website

API

Manual file upload from SD card

User Interface, Web visualization hosted on server

HYPERSPECTRAL DEVICES

FloX – key features

HYPERSPECTRAL DEVICES

Why FloX? – Be part of the community!

- Hemispherical/ Conical optical configuration. Allows precise point measurements of vegetation in well defined ROI. Easy to locate in satellite scene or flux tower footprint.
- Uses JB's Cosine receptors, which have low error <10% with respect to 80° SZA (e.g. CC3 is 90% at 80° SZA).
- Stable 2-spectrometer duplex design enables internal quality flags and tracking of calibration. In combination with flux-tower equipment is further cross-validation with PAR sensors possible (e.g. LI-190).
- Full dark current measured in each cycle, temperature, humidity, GPS and many more quality flags natively included.
- Low maintenance. No moving parts and long re-calibration interval, > 1 year in static use cases. Automatic calibration device under development to enable re-calibration of installed instruments on site.
- Flexible power supply. Works natively with 12V/DC or external switching power supply on 100- 230V AC. 100W max. consumption enable solar power.
- Broad operating conditions. Operated from Antarctica to Dessert in -25°C / +55°C.
- Transparent and continuously improved open-source data processing in R, future online.
- Proven by scientific record: used by many scientist in high-ranking publications around the world.

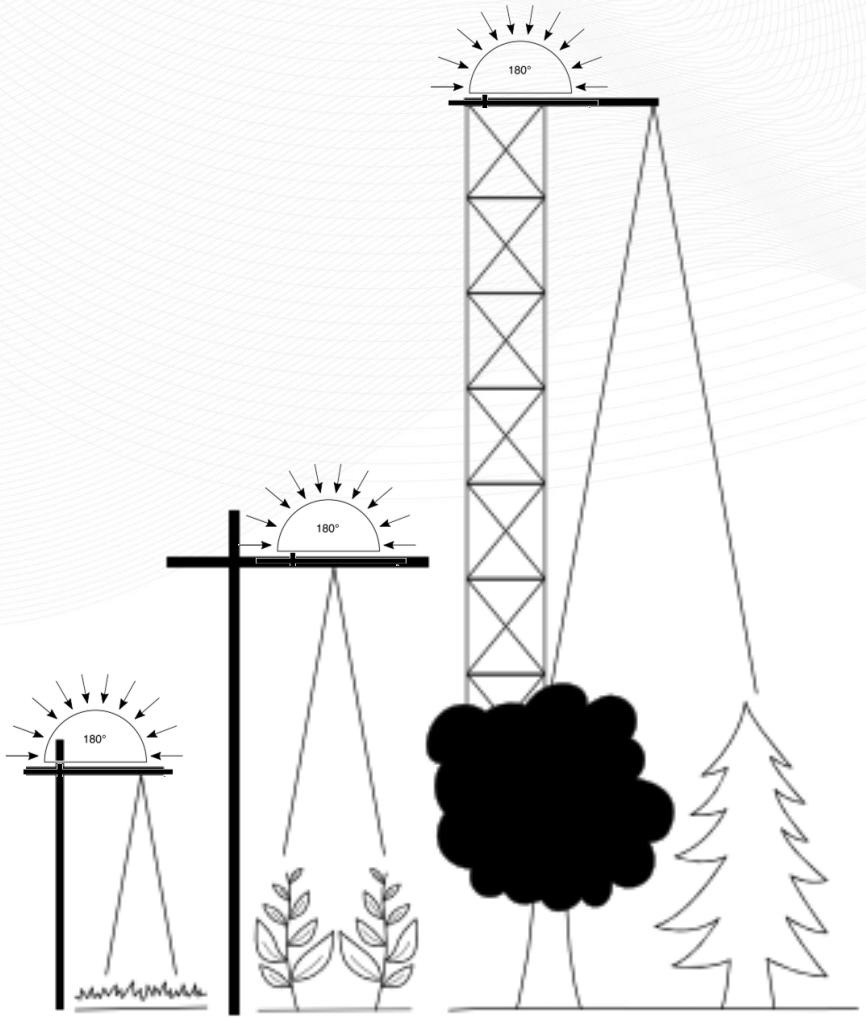
Using remote sensing as a proxy for vegetation photosynthesis at canopy level – a few challenges.

Linking remote sensing and EC flux at landscape and global scale using the FloX.

ATMOSPHERIC EFFECT

HYPERSPECTRAL DEVICES

HOW TO CORRECT FOR OXYGEN REABSORPTION?



ATMOSPHERIC EFFECT

HYPERSPECTRAL DEVICES

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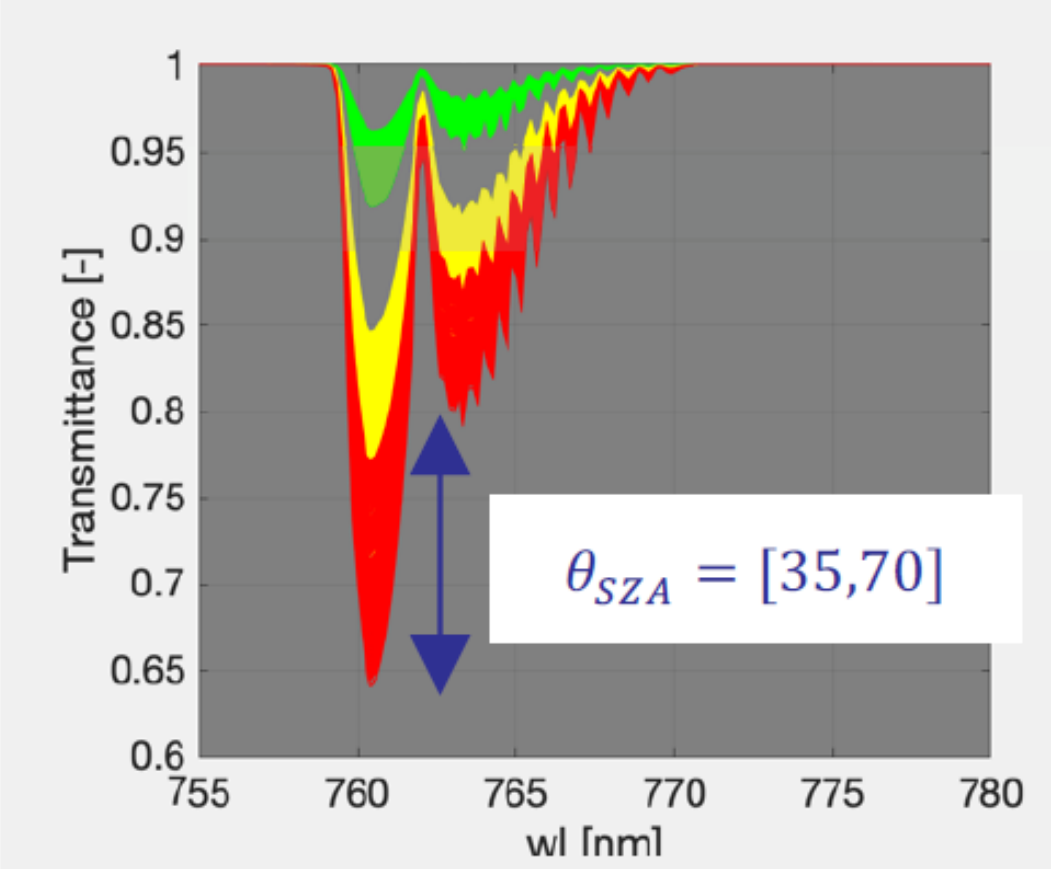
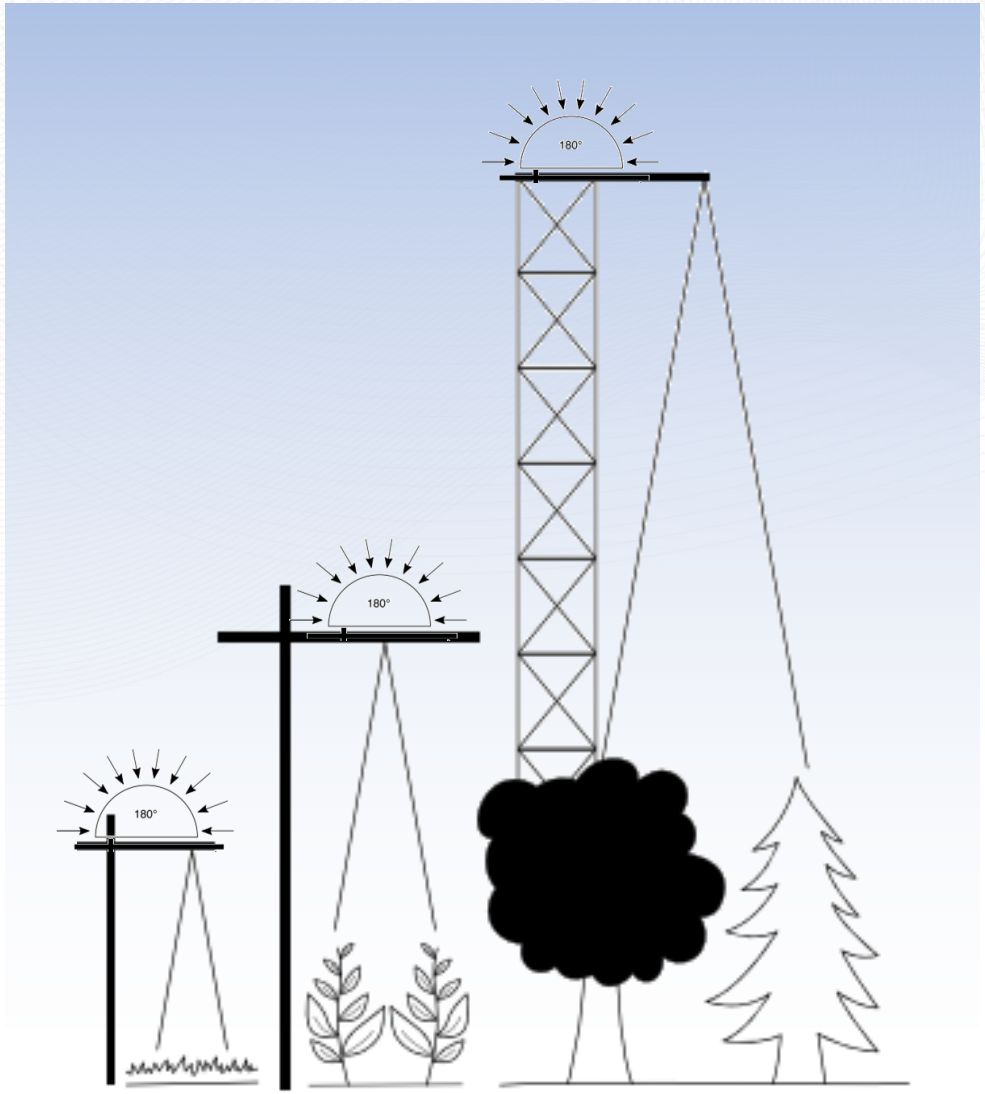




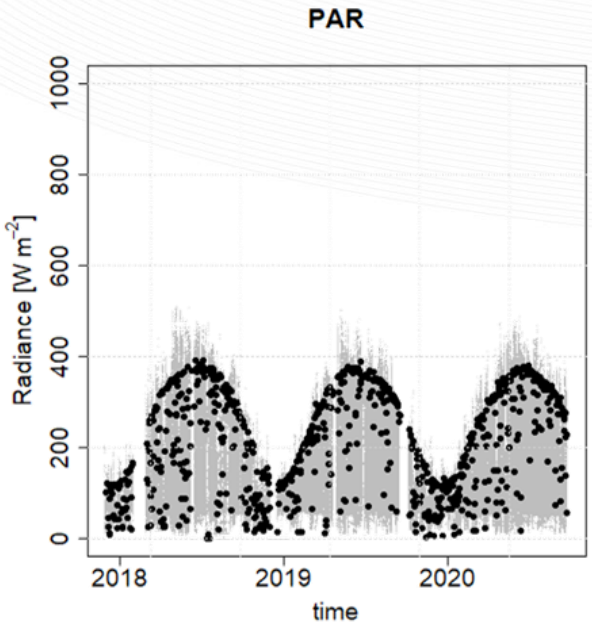
ATMOSPHERIC EFFECT

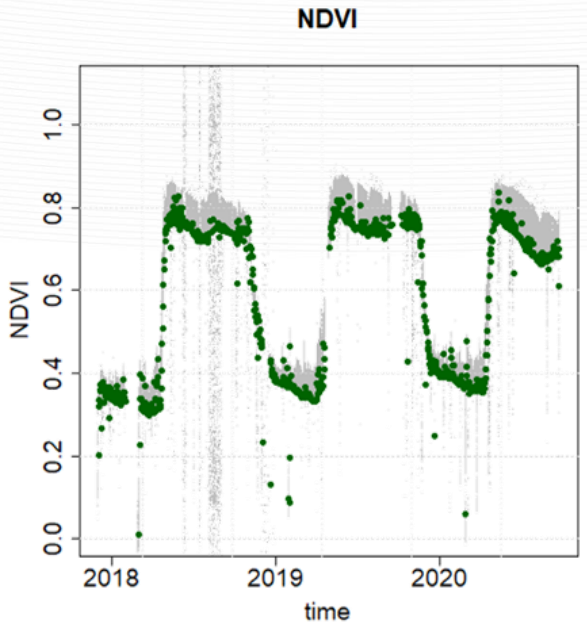
HYPERSPECTRAL DEVICES

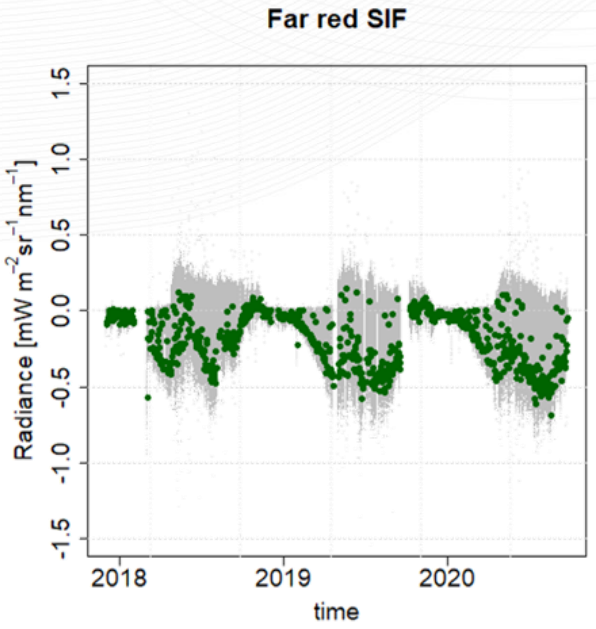
EFFECT EXAMPLE:

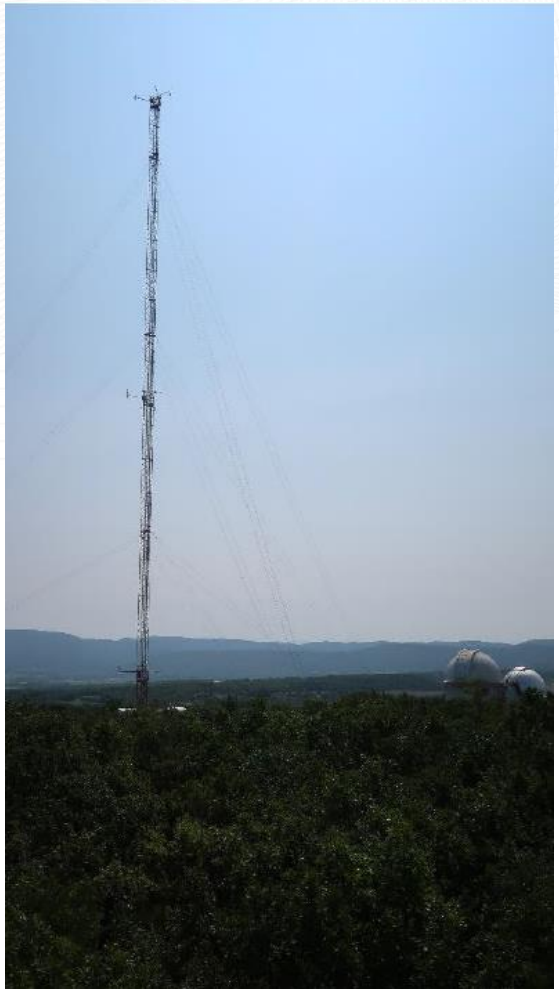
FLOX measurements collected at the Observatoire de Haute Provence 2018-2020

Negative SIF retrieved from 100 m









ATMOSPHERIC EFFECT

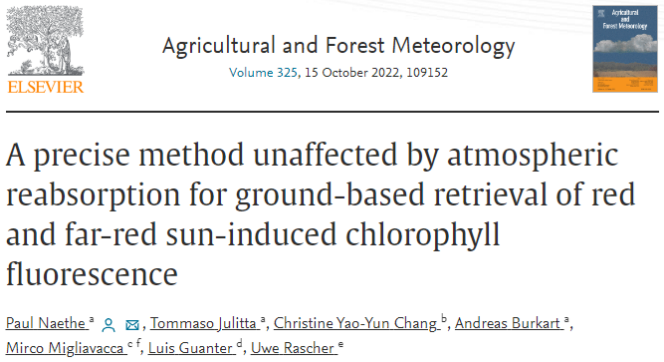
HYPERSPECTRAL DEVICES

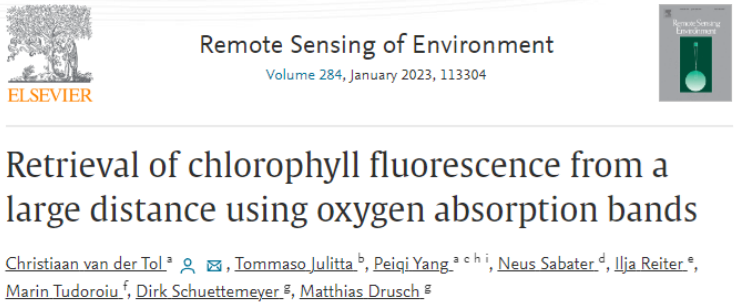
Addressed by three novel retrieval methods

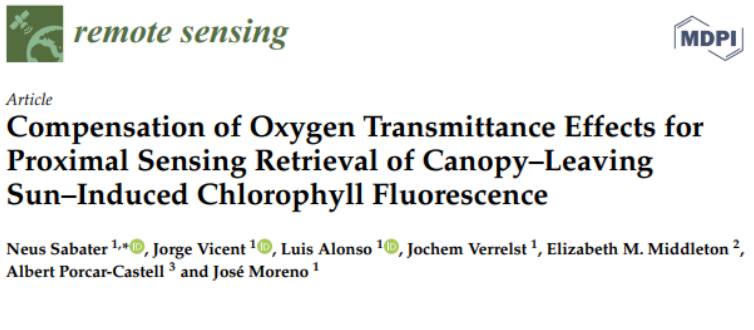
PLS: A machine learning approach to retrieve SIF undisturbed by reabsorption using Solar Faunhofer lines.

BSF: An approach which uses the curvature of the oxygen bands to determine the absorption and SIF.

O2-TRANS – SFM. Data correction based on Oxygen transmittance modelling and SIF Full spectrum retrieval via SFM.

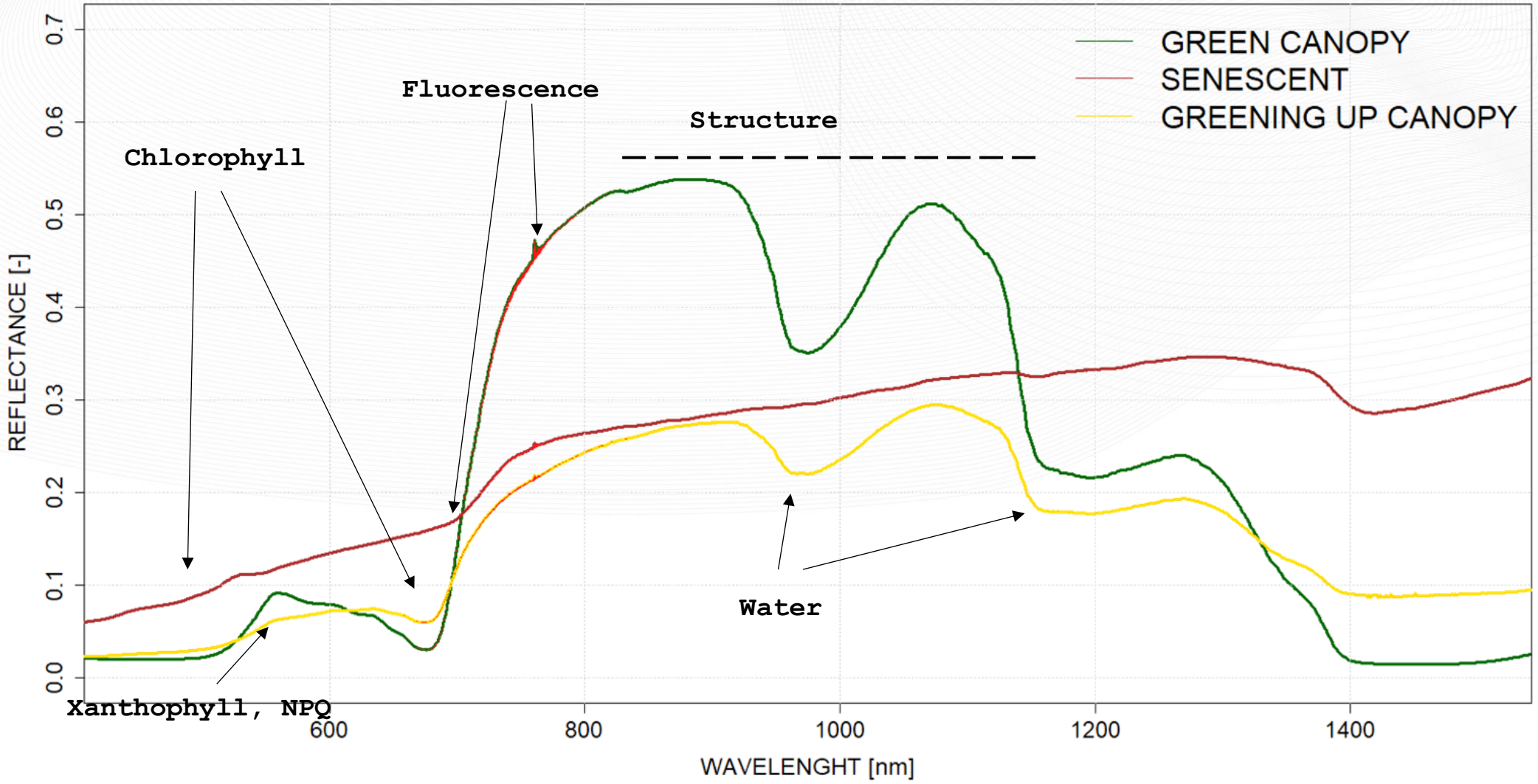






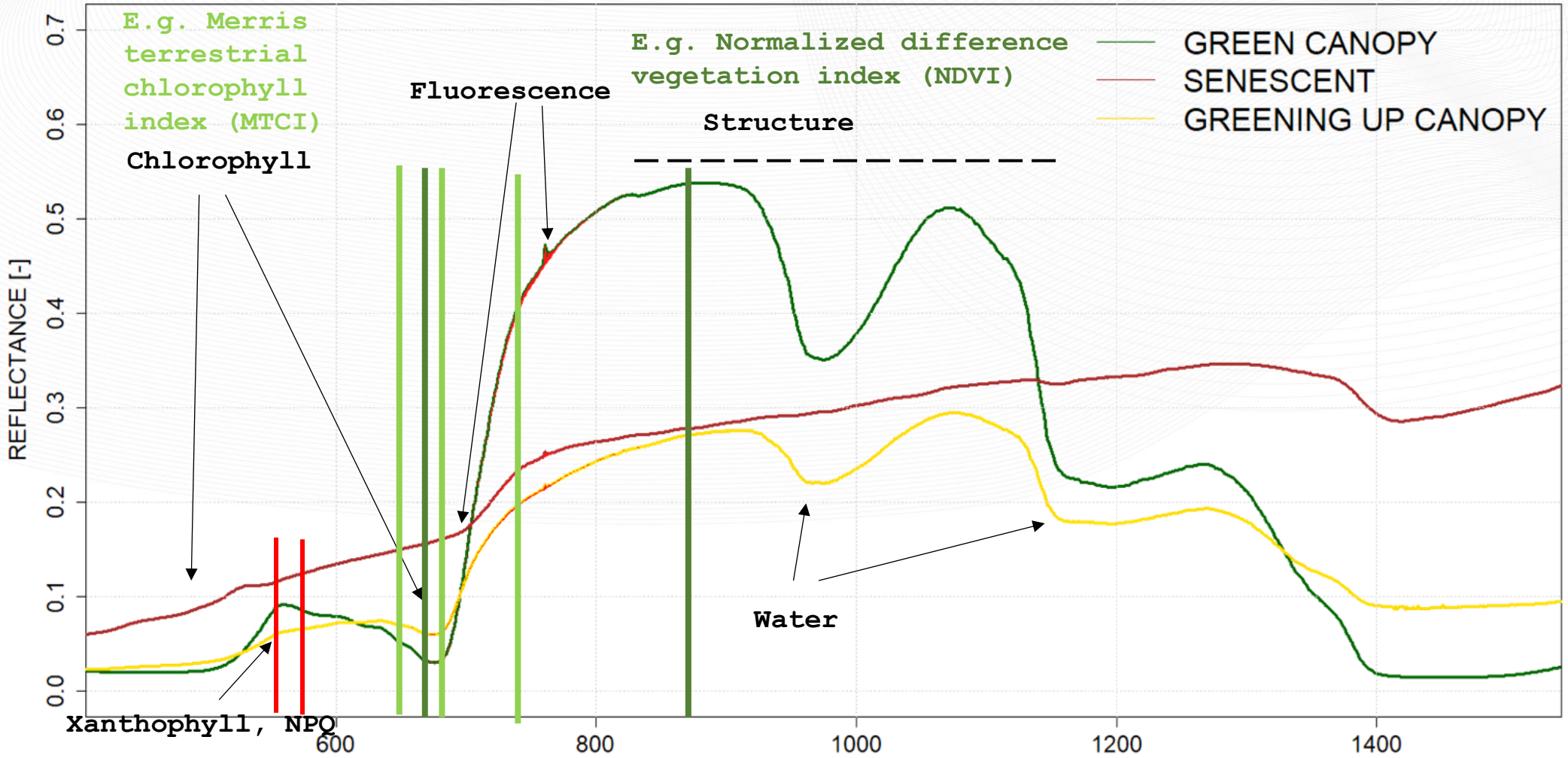
FIELD SPECTROSCOPY

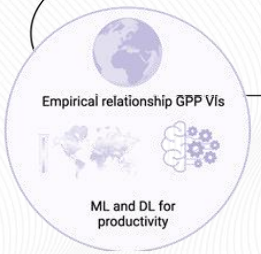
HYPERSPECTRAL DEVICES



FIELD SPECTROSCOPY

HYPERSPECTRAL DEVICES





JGR Biogeosciences

RESEARCH ARTICLE
10.1029/2021JG006588

Key Points:

- Tower-based solar-induced chlorophyll fluorescence (SIF) closely tracks gross primary productivity (GPP) over two years in a mixed-species boreal forest
- Light saturation of photosynthesis drives non-linearity between SIF and GPP
- The SIF-GPP relationship is seasonally variant due to dynamics between LUE_F and LUE_P

Diurnal and Seasonal Dynamics of Solar-Induced Chlorophyll Fluorescence, Vegetation Indices, and Gross Primary Productivity in the Boreal Forest

Zoe Pierrat[1], Troy Magney[2], Nicholas C. Parazoo[3,4], Katja Grossmann[5], David R. Bowling[6], Ulli Seibt[1], Bruce Johnson[7], Warren Helgason[7], Alan Barr[7], Jacob Bortnik[1], Alexander Norton[3], Andrew Maguire[3], Christian Frankenberg[4], and Jochen Stutz[1]

[1]University of California Los Angeles, Los Angeles, CA, USA, [2]University of California Davis, Davis, CA, USA, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]California Institute of Technology, Pasadena, CA, USA, [5]University of Heidelberg, Heidelberg, Germany, [6]University of Utah, Salt Lake City, UT, USA, [7]University of Saskatchewan, Saskatoon, SK, Canada

$$GPP = APAR \times LUE_P$$

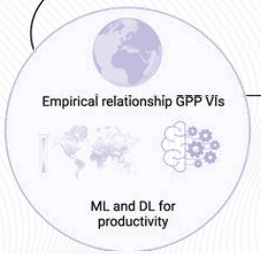
$$LUE_P = \frac{GPP_{max}}{c + APAR}$$

$$GPP = SIF \times \frac{LUE_P}{LUE_F \times f_{esc}}$$

$$GPP = \frac{SIF \times GPP_{max}}{a + SIF}$$

CASE STUDY

HYPERSPECTRAL DEVICES



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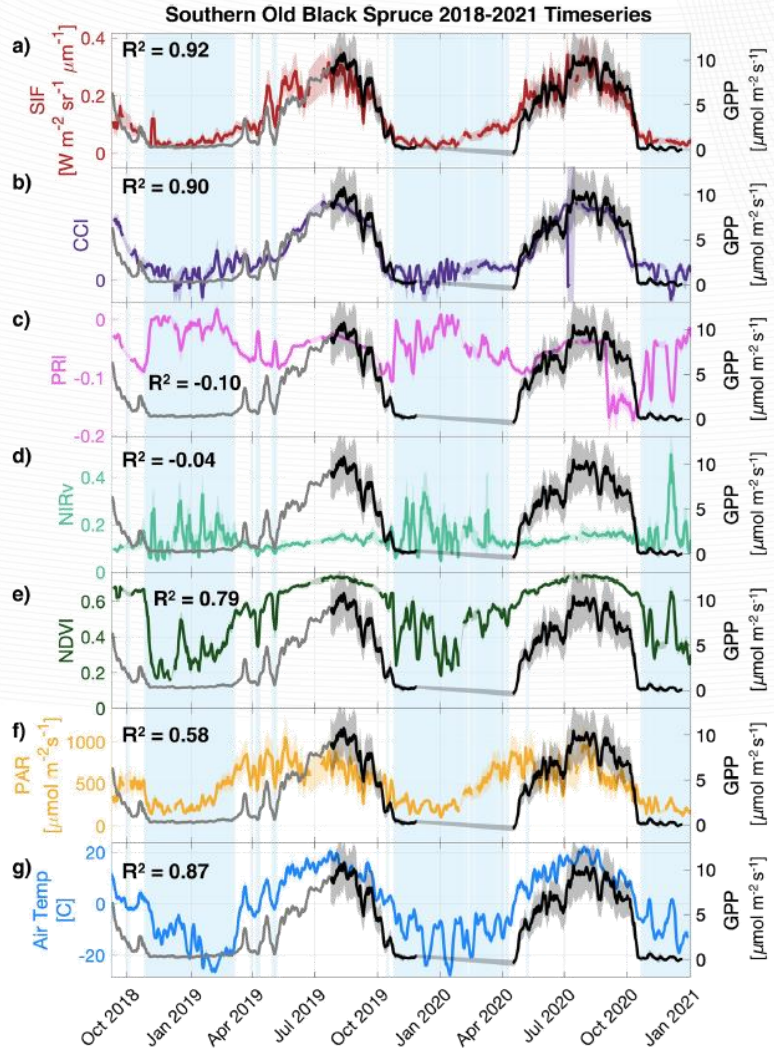

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CASE STUDY

HYPERSPECTRAL DEVICES

Empirical relationship GPP VIs

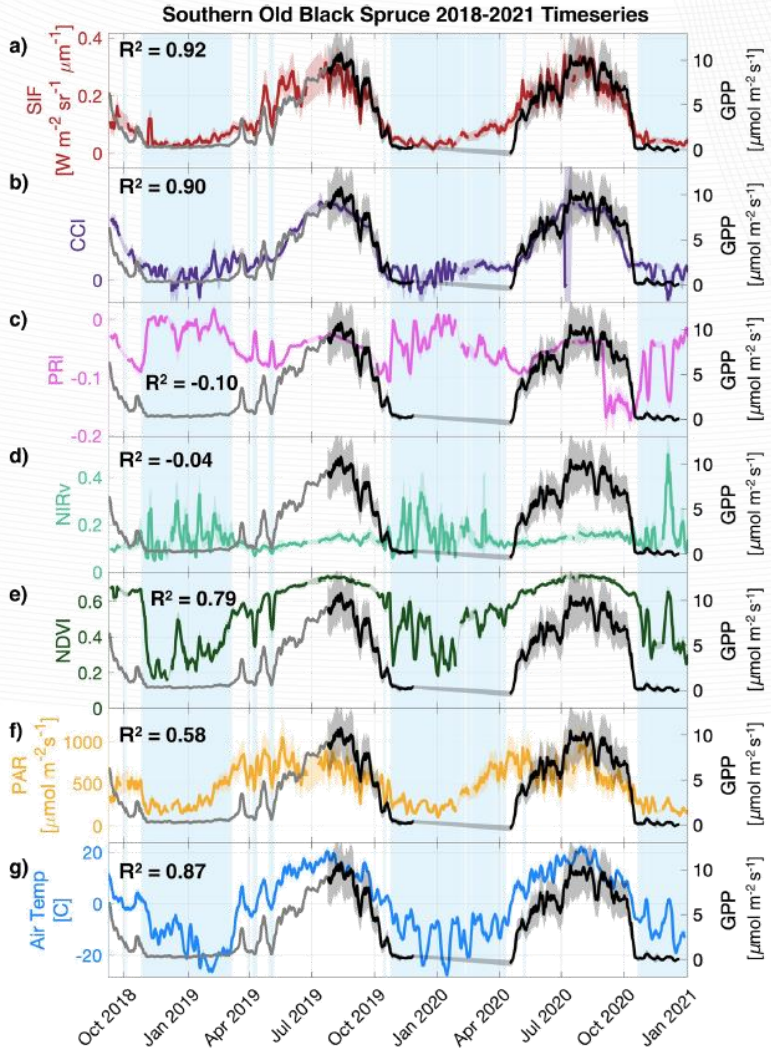
ML and DL for productivity

$$GPP = APAR \times LUE_P$$

$$LUE_P = \frac{GPP_{max}}{c + APAR}$$

$$GPP = SIF \times \frac{LUE_P}{LUE_F \times f_{esc}}$$

$$GPP = \frac{SIF \times GPP_{max}}{a + SIF}$$



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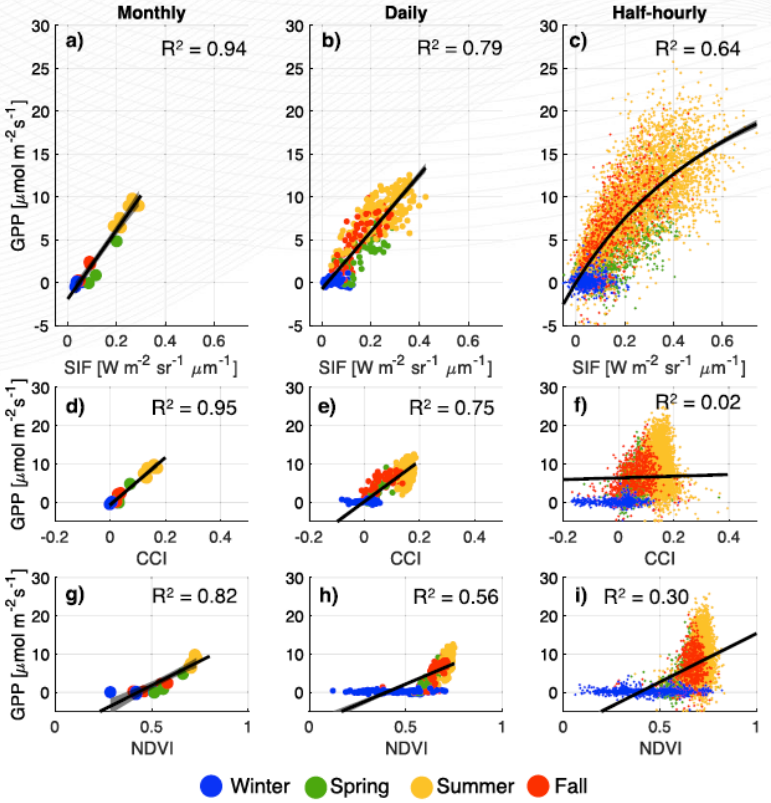
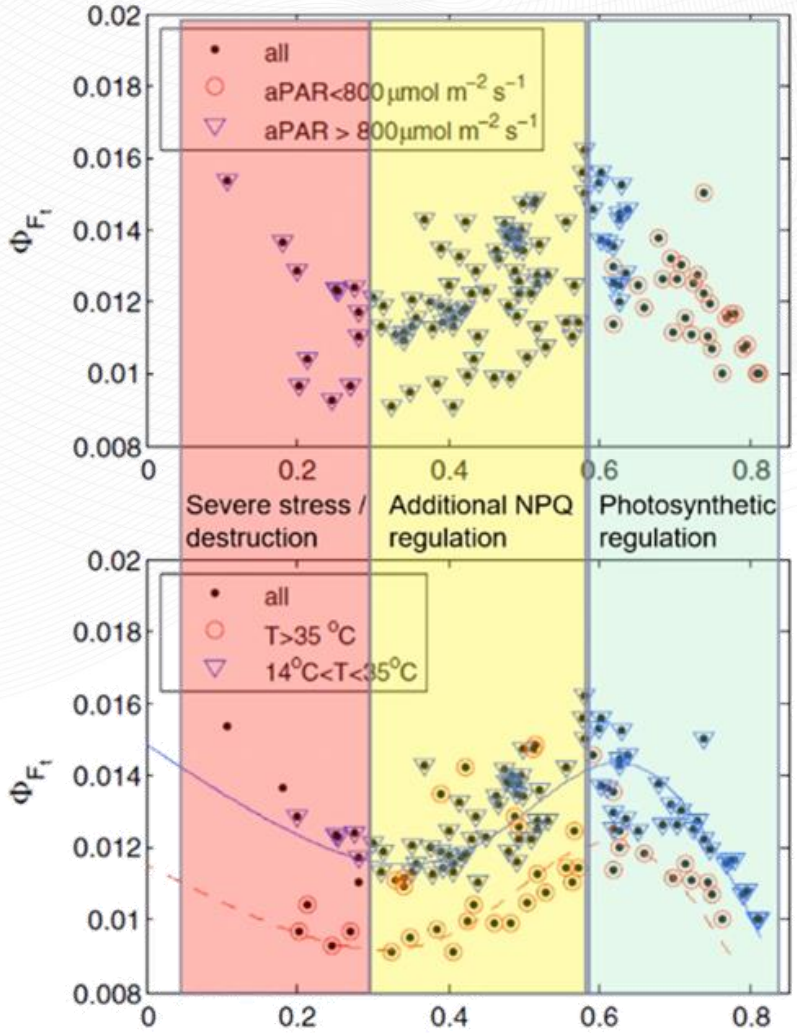


CASE STUDY



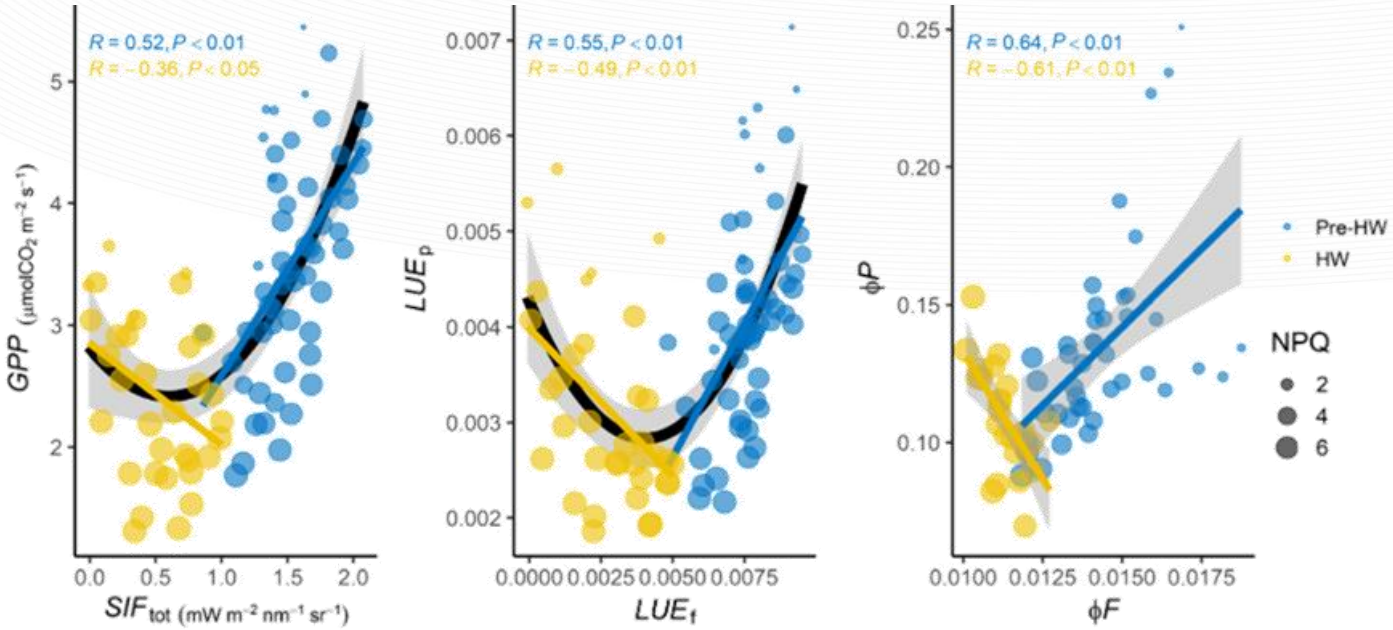
van der Tol C., Berry J.A., Campbell P.K.E. & Rascher U. (2014) Models of fluorescence and photosynthesis for interpreting measurements of solar-induced chlorophyll fluorescence. Journal of Geophysical Research - Biogeosciences, 119, 2312-2327.

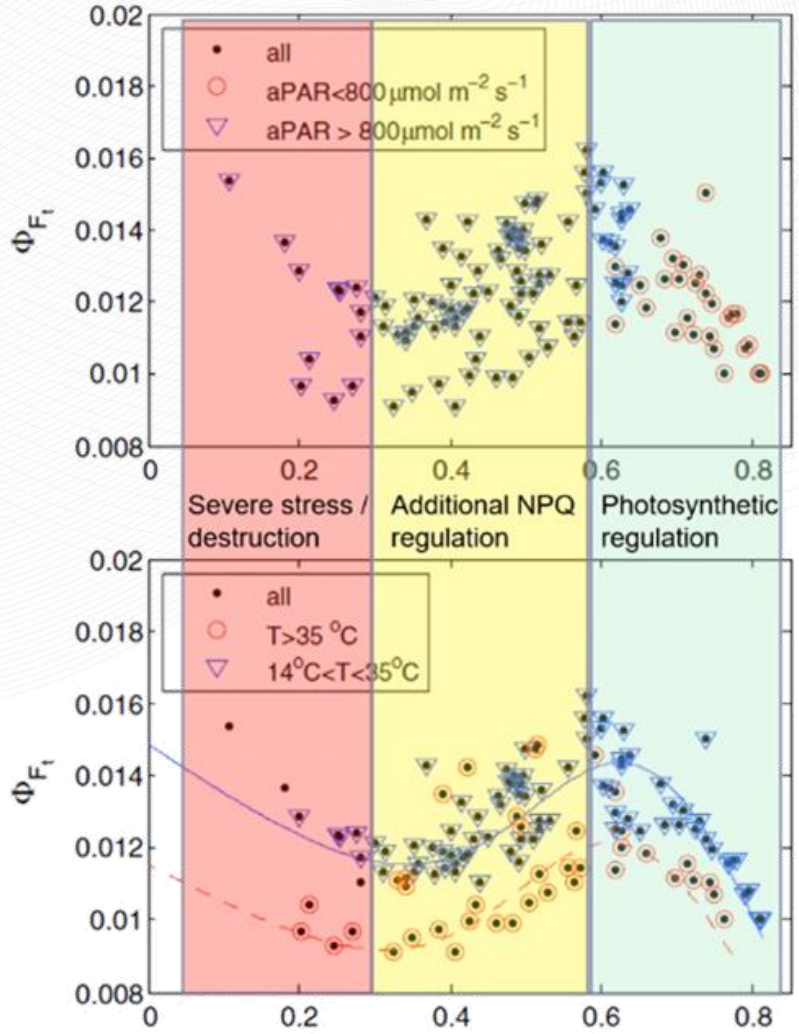
CASE STUDY

New Phytologist
Research

Heatwave breaks down the linearity between sun-induced fluorescence and gross primary production

David Martini[1], Karolina Sakowska[2], Georg Wohlfahrt[3], Javier Pacheco-Labrador[1], Christiaan van der Tol[4], Albert Porcar-Castell[5], Troy S. Magney[6], Arnaud Carrara[7], Roberto Colombo[8], Tarek S. El-Madany[1], Rosario Gonzalez-Cascon[9], María Pilar Martín[10], Tommaso Julitta[11], Gerardo Moreno[12], Uwe Rascher[13], Markus Reichstein[1], Micol Rossini[8] and Mirco Migliavacca[1,14]





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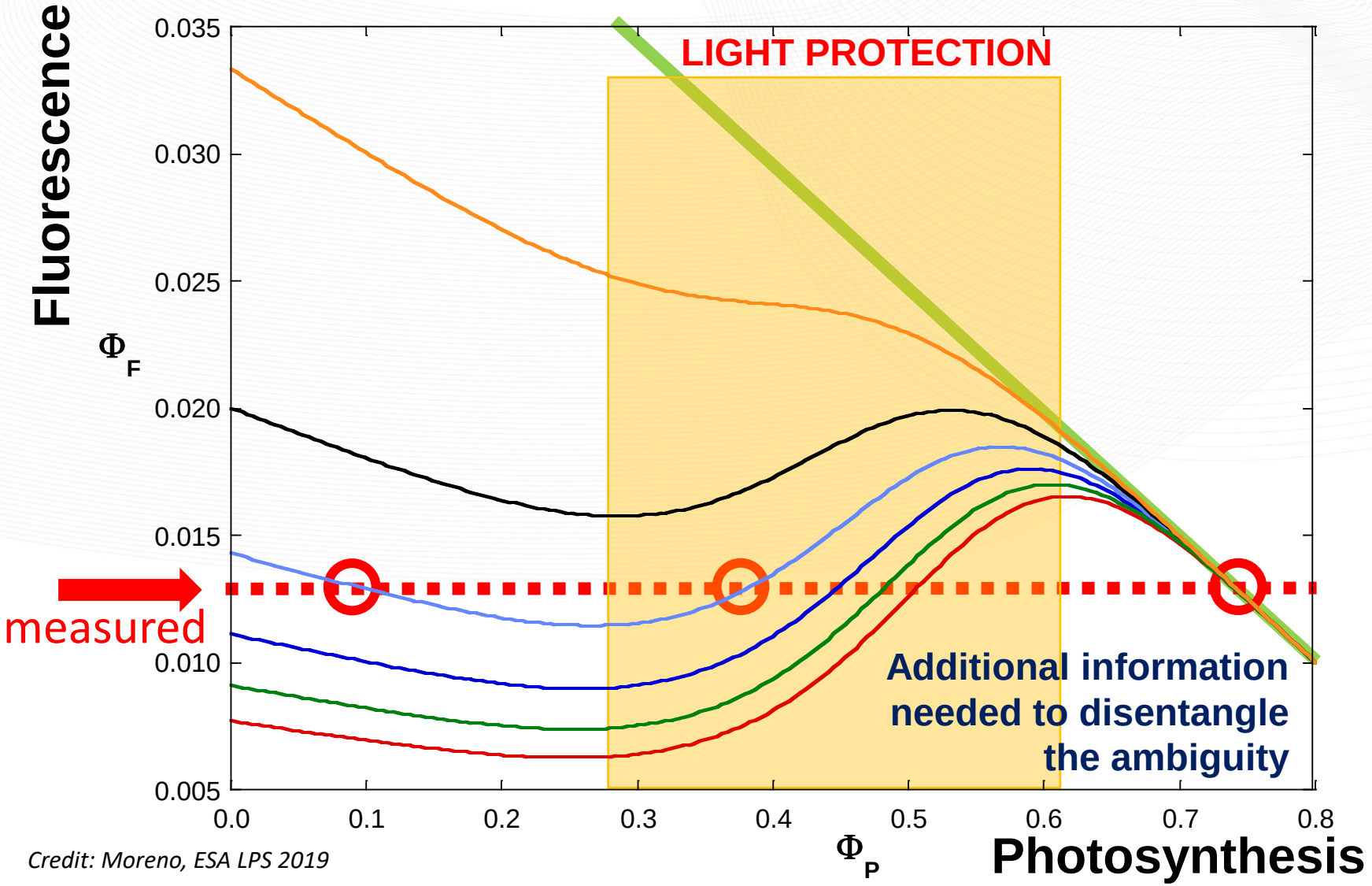
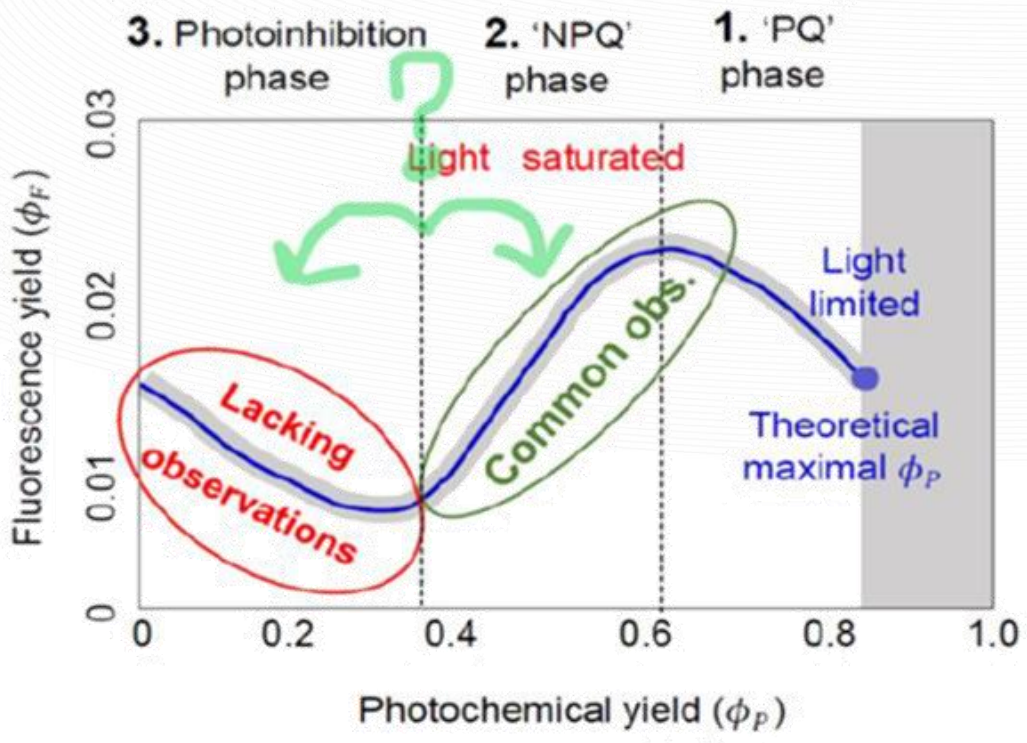


Credit: Moreno, ESA LPS 2019



credit: Van Wittenberghe

Fluorescence yield is not enough to predic photochemical yield + identify in which NPQ phase we are

Retrieval of Fluorescence Quantum Efficiency (FQE) + **Xanthophyll detection**

e.g. PRI

Photochemical efficiency

- Sun induced Chlorophyll fluorescence is a promising variable to **predict photosynthesis**.
- The growing scientific interests speeded up research in the last years and enable to get first results at global level using **satellite data**. New mission to come will improve our understanding at global scale.
- SIF **scaled linearly** with GPP is a **simplification** which can cause misleading results.
- Frequent acquisition at local scale can help better understanding of the process to later **scale up globally**.
- SIF alone is not enough to explain the full photosynthetic process, but **hyperspectral** measurements can help in quantifying **NPQ** as well.
- An effort on joining the **spectral community and flux community** is ongoing enabling new investigations.

CURRENT STUDY

HYPERSPECTRAL DEVICES

Field Spectroscopy and Eddy techniques:
Footprint mismatch

Field Spectroscopy and Eddy techniques: Footprint mismatch

ELSEVIER

Agricultural and Forest Meteorology 87 (1997) 179–200

AGRICULTURAL AND FOREST METEOROLOGY

Experimental design for flux measurements: matching scales of observations and fluxes

H.P. Schmid [a,b]

[a] *Department of Geography, Indiana University, Bloomington, IN 47405, USA* [1]
[b] *GGIETH, Swiss Federal Institute of Technology (ETH), Zürich, Switzerland*

Received 12 June 1996; received in revised form 11 January 1997; accepted 18 January 1997

ELSEVIER

Agricultural and Forest Meteorology 93 (1999) 195–209

AGRICULTURAL AND FOREST METEOROLOGY

Spatial representativeness and the location bias of flux footprints over inhomogeneous areas

Hans Peter Schmid[a,*], Colin R. Lloyd[b]

[a]*Department of Geography, Indiana University, Bloomington, IN 47405, USA*
[b]*Institute of Hydrology, Wallingford OX10 8BB, UK*

Received 3 April 1998; accepted 21 August 1998

SPATIAL VARIABILITY

HYPERSPECTRAL DEVICES

Field Spectroscopy and Eddy techniques: Footprint mismatch

AtmoFacts

Agricultural and Forest Meteorology 255 (2018) 68–80

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FLUX MAPPER CASE

Surface-atmosphere exchange in a box: Making the control volume a suitable representation for in-situ observations

Stefan Metzger[a,b,*]

Credit: Wiesner et al. (2022)

SPATIAL VARIABILITY

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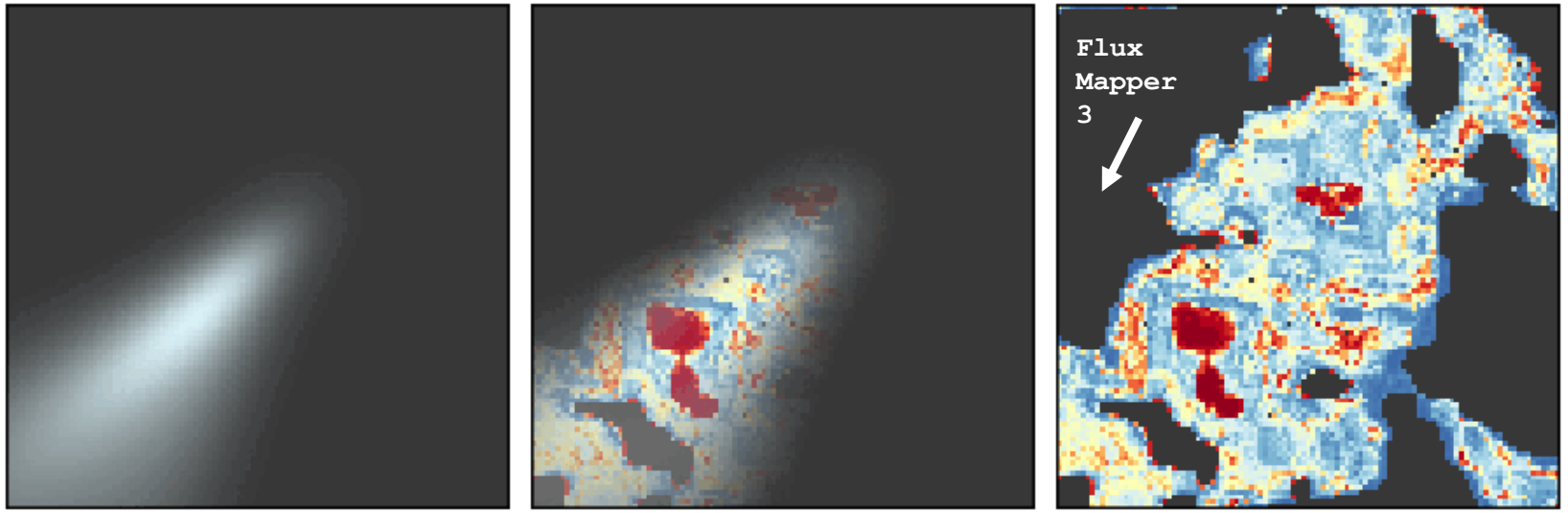
Classical eddy-covariance | **Flux Mapper 1** | **Flux Mapper 2**



Credit: US-PFa tower data (desai@aos.wisc.edu), Flux Mapper (smetzger@atmofacts.com)

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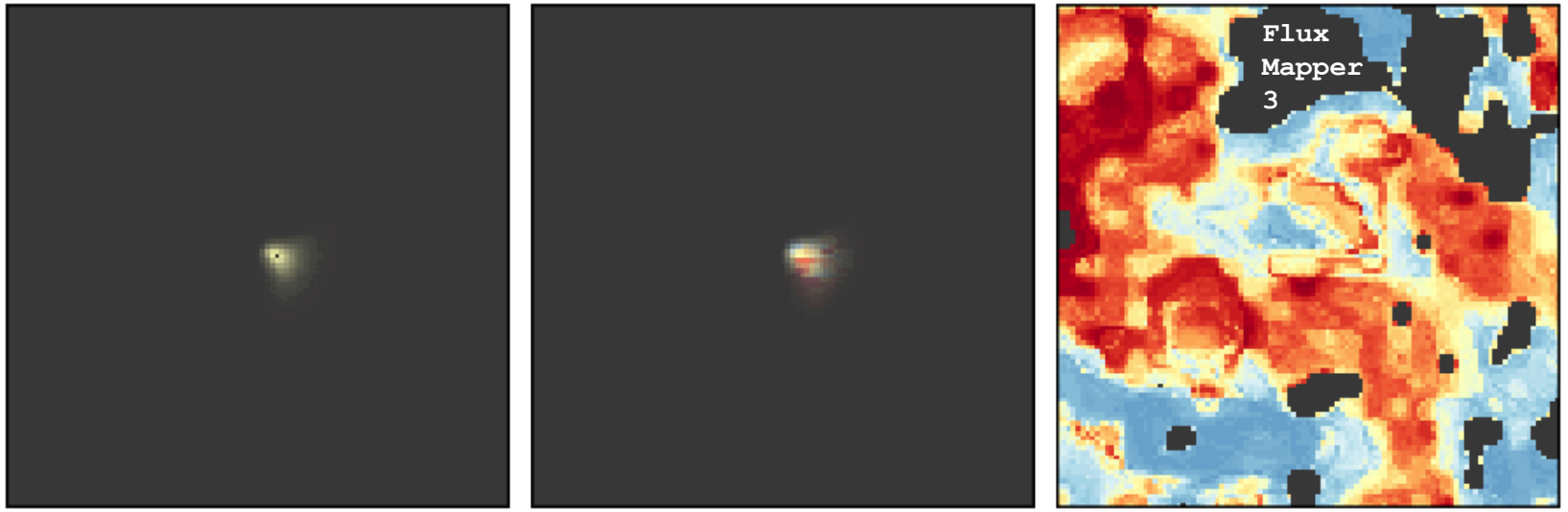

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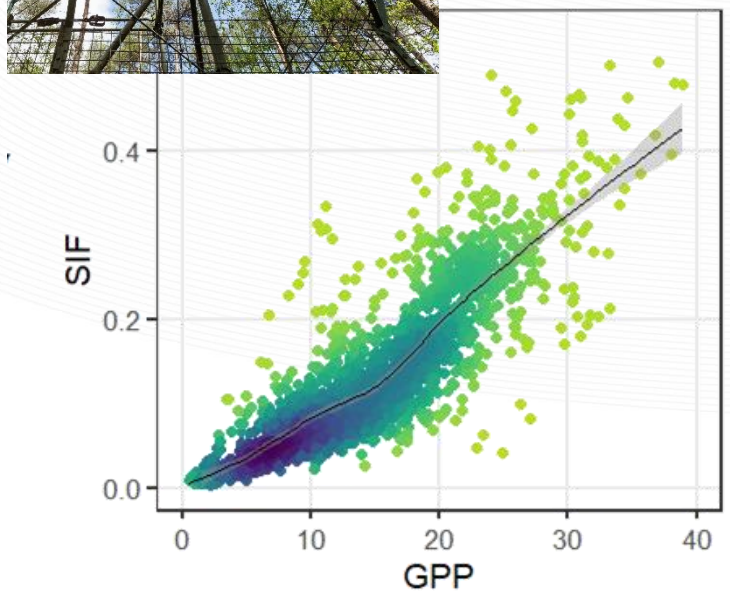
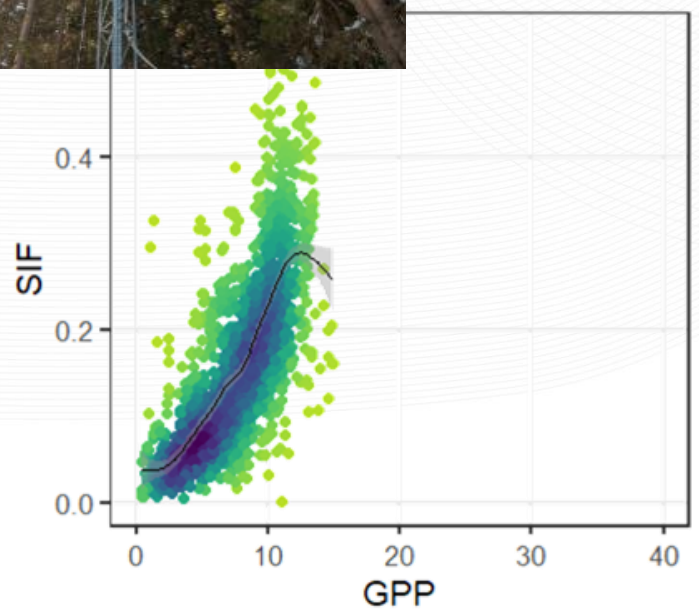
RS vs Fluxes



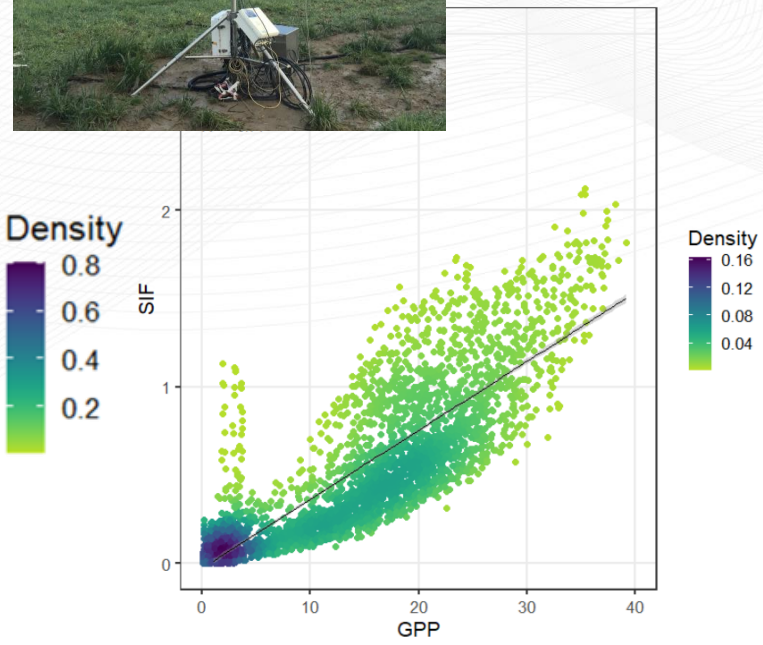
Brasschaat, Belgium

Credits: Marilyn Roland



Davos, Switzerland

Credits: Alexander Damm

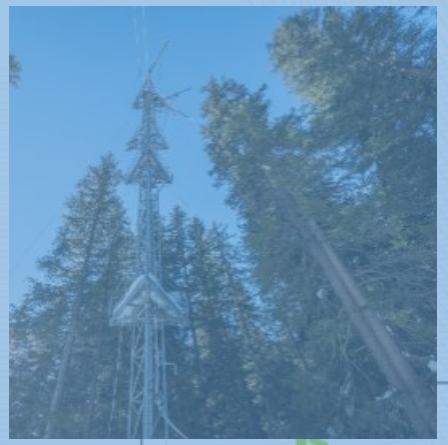


Selhausen, Germany

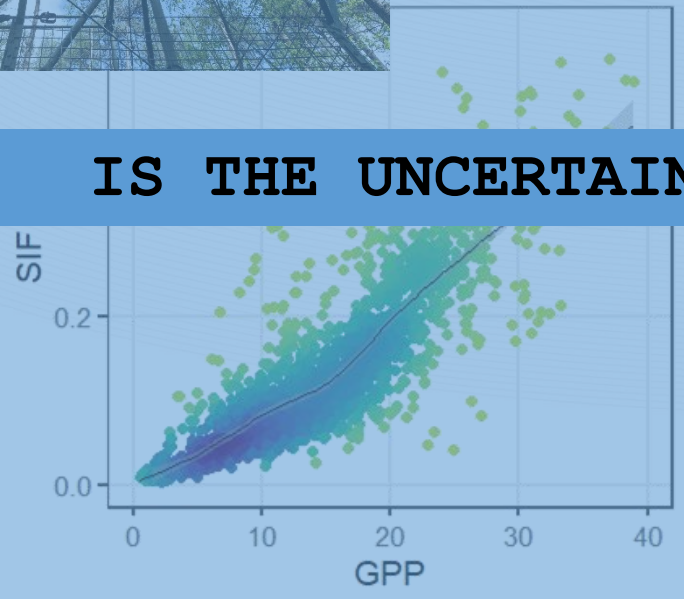
Credits: Uwe Rascher

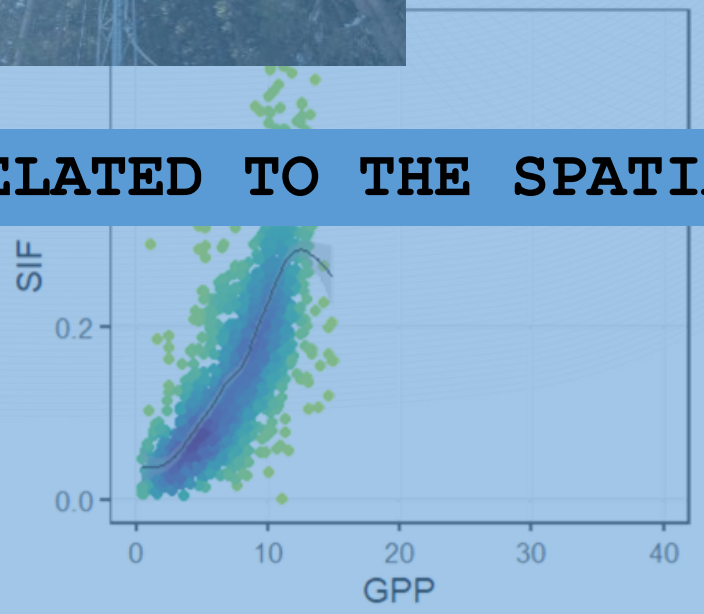
RS vs Fluxes

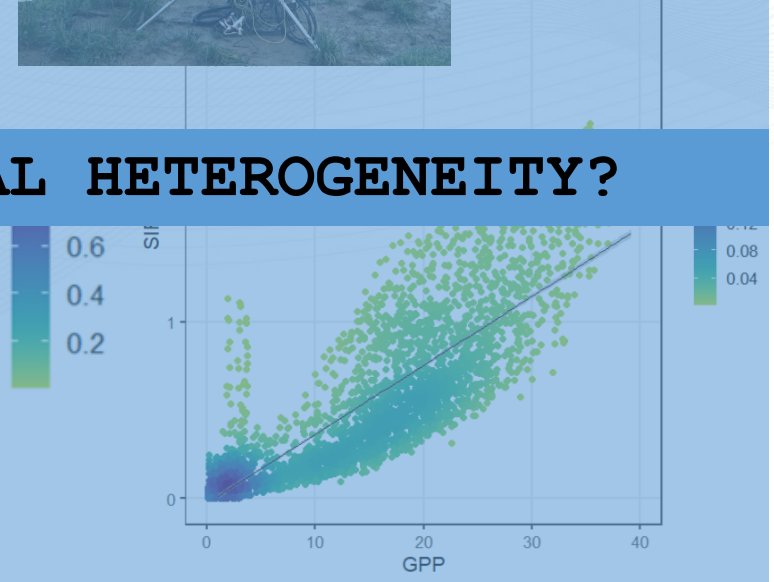
HYPERSPECTRAL DEVICES



IS THE UNCERTAINTY RELATED TO THE SPATIAL HETEROGENEITY?







Brasschaat, Belgium
Credits: Marilyn Roland

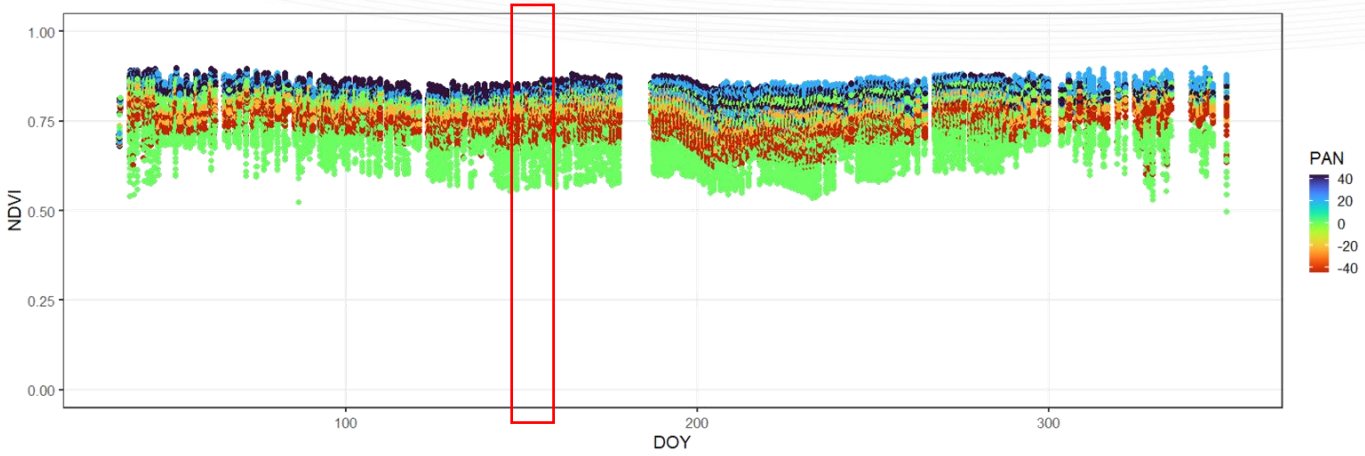
Davos, Switzerland
Credits: Alexander Damm

Selhausen, Germany
Credits: Uwe Rascher

PILOT STUDY

HYPERSPECTRAL DEVICES

Climate zone	Hot-summer mediterranean (Csa)
Main ecosystem	Evergreen Needleleaf Forests
Mean annual temperature	15.3 °C
Mean annual precipitation	950.0 mm
Mean annual incoming SW radiation	175.0 W/m^2



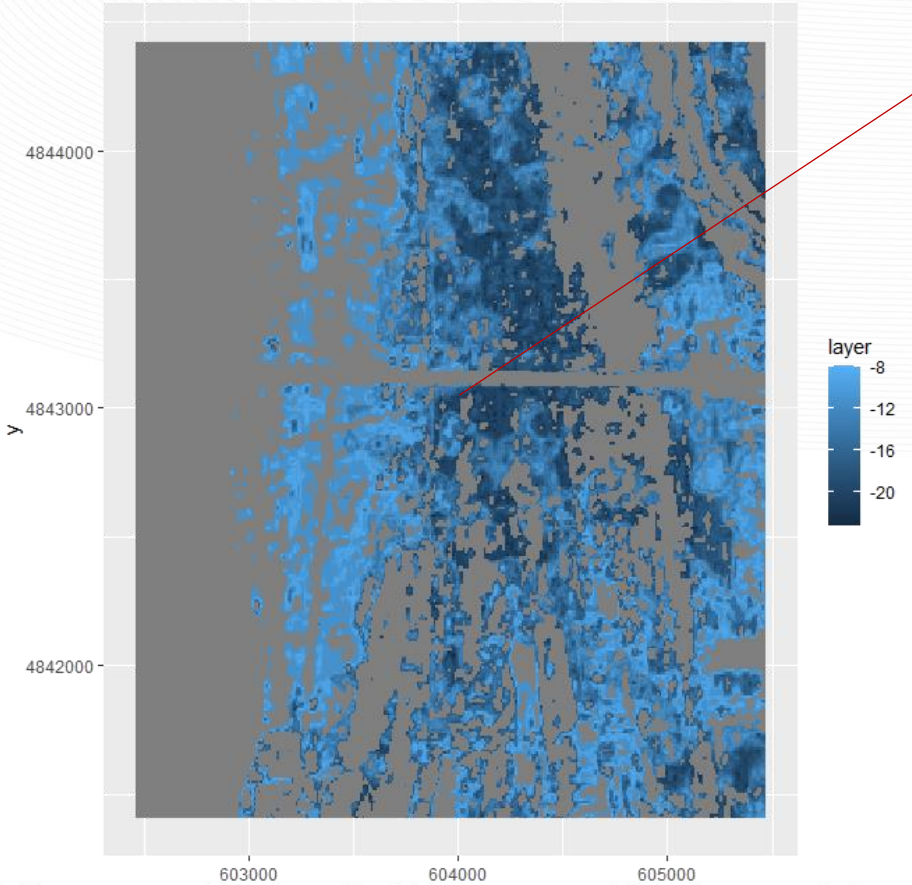
Credit: Giulia Tagliabue, University of Milano Bicocca

PILOT STUDY

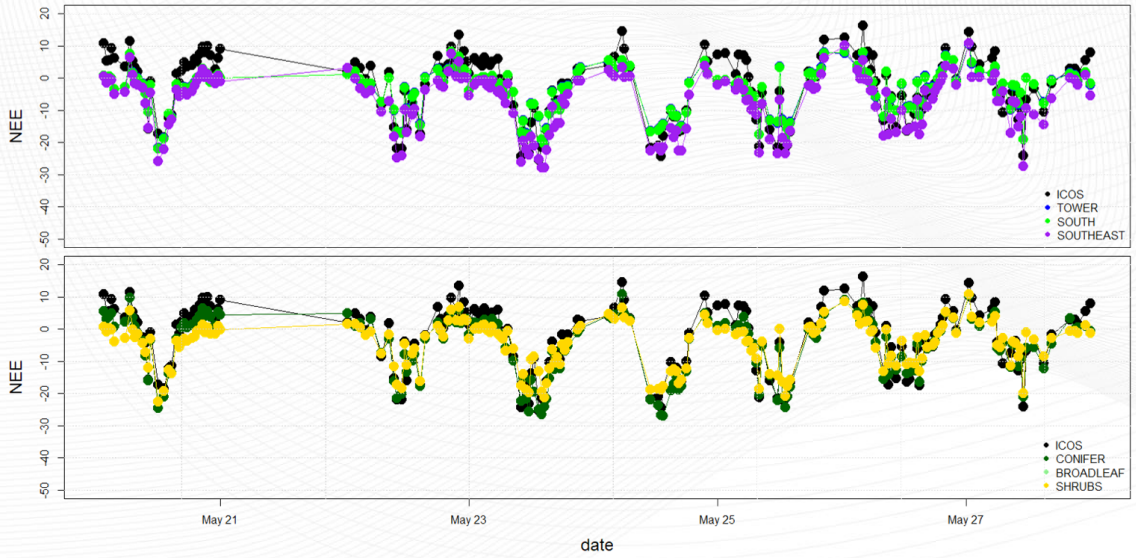
HYPERSPECTRAL DEVICES

NEE MAPS provided at 30 mins resolution

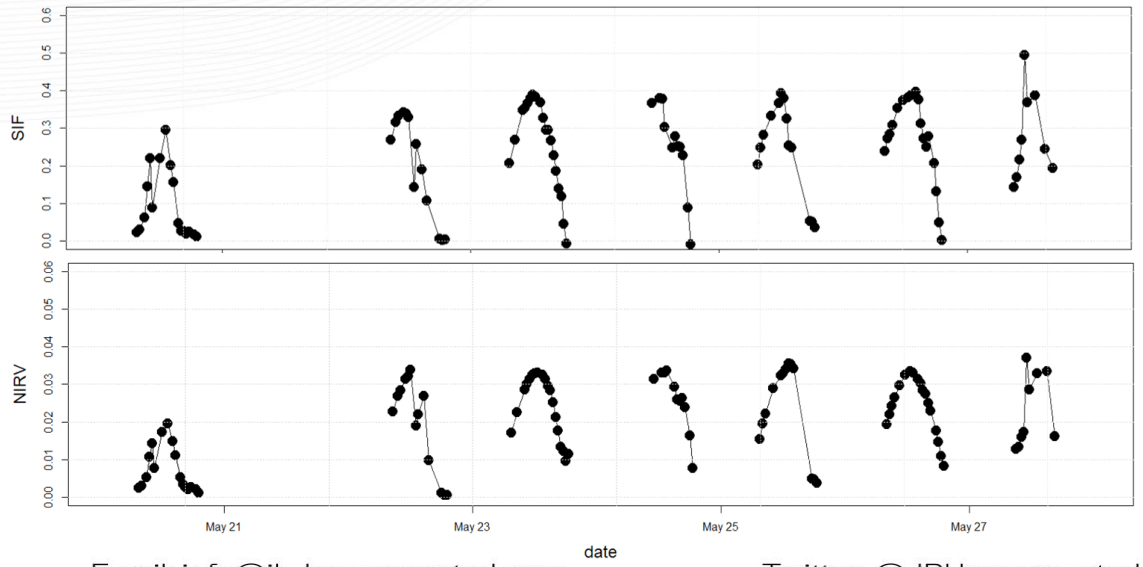
Exploited in terms of:
- pixel locations
- Classified based on land cover



FLUXES



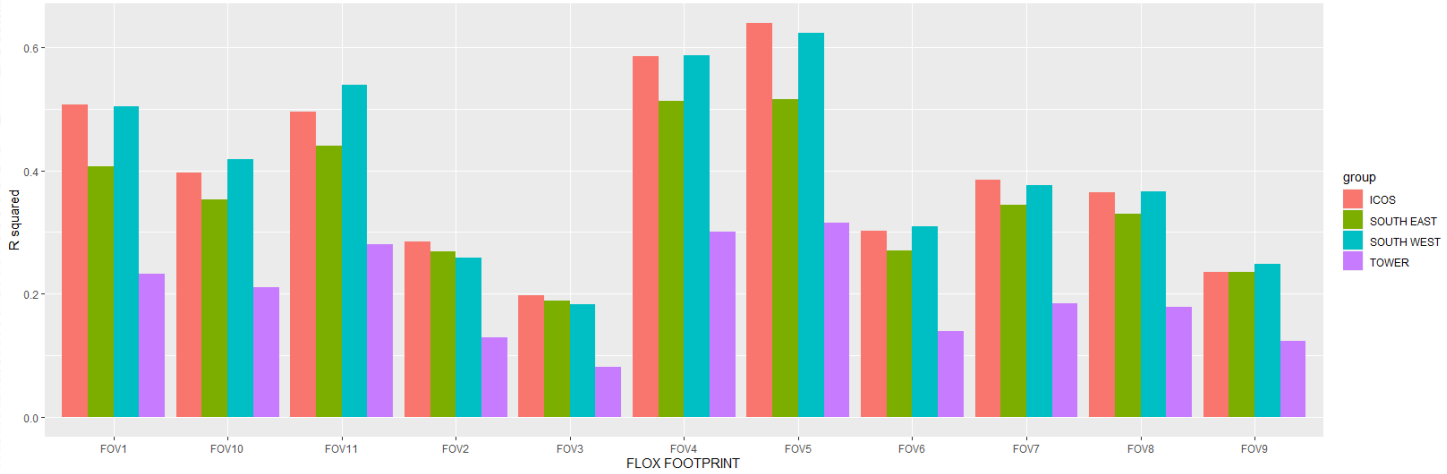
RS VARIABLES

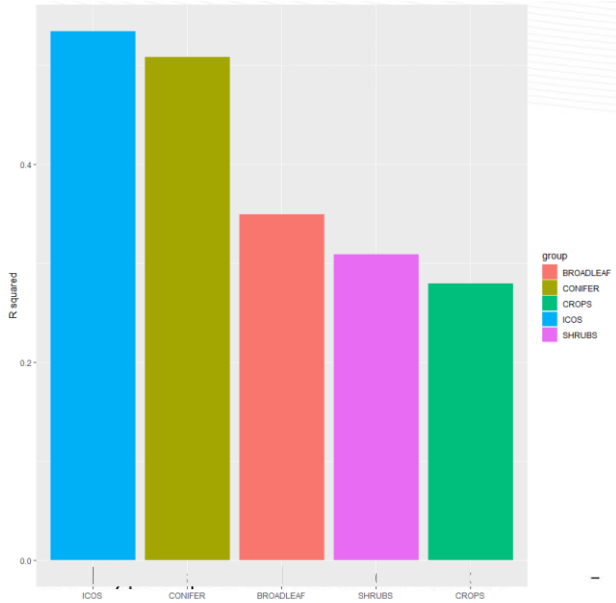


PILOT STUDY

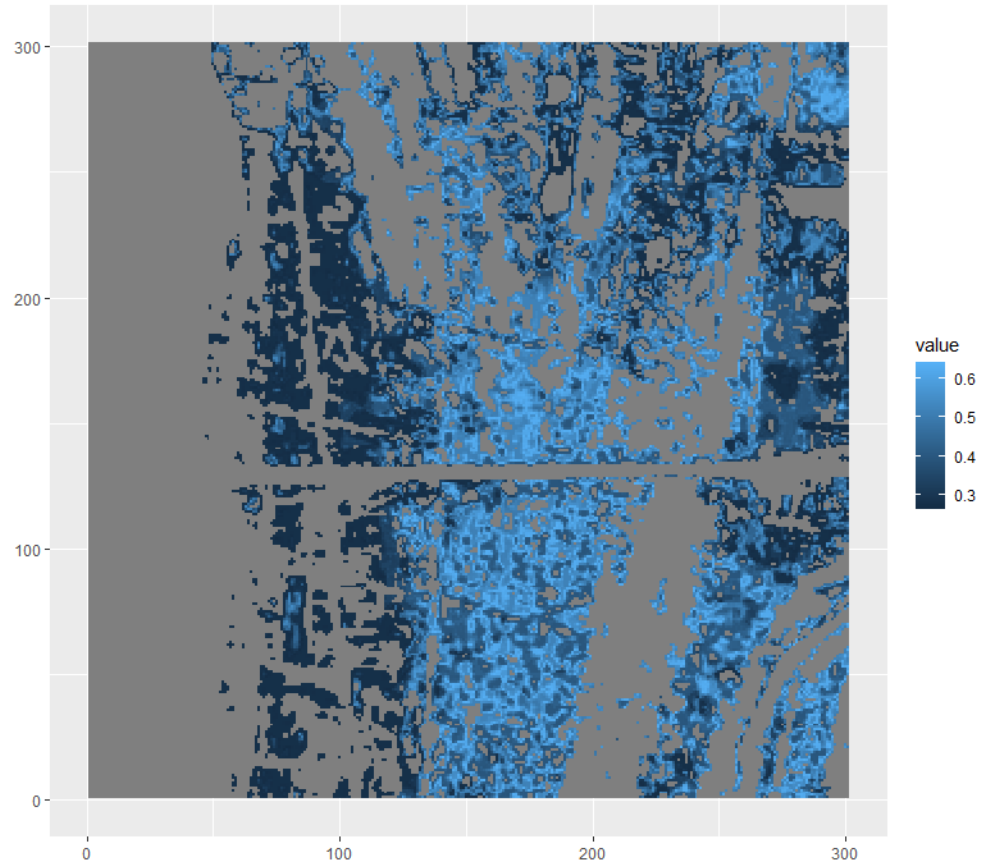
HYPERSPECTRAL DEVICES

Results indicates footprint heterogeneity has an impact does but not explain the total variety





Results on classified land covers showed that the higher correlation is coming from conifer



Hot spots can be found over conifer crowns

CONCLUSION AND OUTLOOK

HYPERSPECTRAL DEVICES

Field spectroscopy provides a link between in situ data and remote sensing. The spectra contain information about the vegetation (Chl content, structure, physiology, water, etc.) and improves our **understanding of the processes** at canopy scale.

Pilot study presented that the **heterogeneity** of the footprint and its representativeness **is not** the major source of uncertainty when combining EC-flux with proximal sensing data. Micro and macro meteorological influences required **further investigation.**

JB's systems acquire hyperspectral data continuously with high temporal resolution. The measurements improve the process understanding at **local level** and support scaling up to **global level.**

The SIF retrievals are proven and continuously improved to include instrumental models providing **uncertainty traceability, atmospheric correction** and extended **data quality** flags.

Investigation of new ways combining in situ flux data and optical sensors is ongoing, FloX is natively **compatible** with **LICOR's DAQM.**

The **FloX** is a proven and widely used instrument, which enables the application of **remote sensing** linked to the investigation of photosynthesis in situ at **the leaf level** and scale it to the EC fluxes at **the canopy scale.** It also serves as a ground reference for upcoming satellite missions at the **global scale.**

The **combination** of **SIF and EC** flux measurements is especially interesting for understanding larger dynamics and to close the gap of **monitoring photosynthesis** from the **leaf-level** to the **global scale.**

HYPERSPECTRAL DEVICES

HANK YOU FOR LISTENING

CONTACTS: website: www.jb-hyperspectral.com | mail: info@jb-hyperspectral.com | twitter: @JBHyperspectral