

Improvement of crop water use and crop productivity using PRISMA hyperspectral data

EOAfrica's Explorers initiative



Frascati, Italy
20-October-2022

H. Nieto, M.P. Martín, **V. Burchard-Levine***, R. Gusinski, M. Munk, D. Ghent, M. Perry, N. Majozi, A. Ramoelo, A. Sawadogo, K. Dikgola



Project Objectives

EO-MAJI:

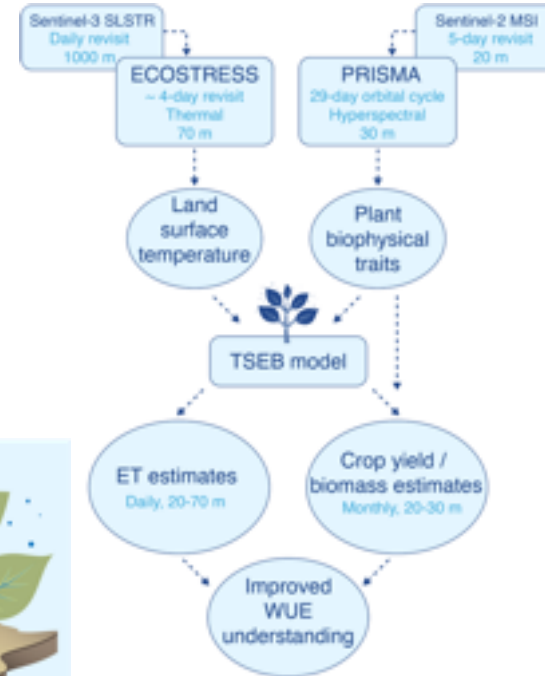
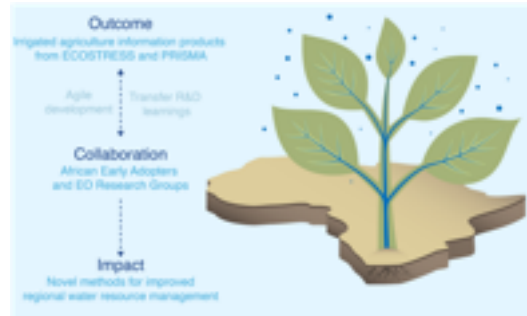
- **Earth Observation** system to **Manage Africa's** food systems by **Joint**-knowledge of crop production and **Irrigation** digitization

Main objectives:

- Develop innovative prototype to fully exploit **ECOSTRESS** and **PRISMA** (+Sentinel Constellation) to **monitor irrigation schemes**
- **Transfer** and **co-design** novel algorithms and processing chains with **African stakeholders**

Main Products:

- ET mapping
- Irrigation accounting
- Crop yield



Past Projects

ESA's Sentinels for Evapotranspiration (Sen-ET)

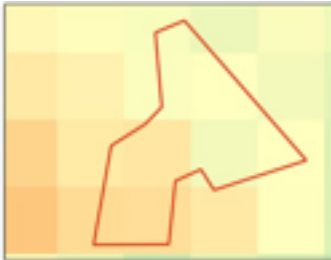
- Operational ET at high spatial resolution
- Data fusion: VSWIR: Sentinel-2 and TIR: Sentinel-3
- ET model review
- Open-Source software



Sentinel-2
Reflectance (20m)



Sentinel-3 LST
(1km)

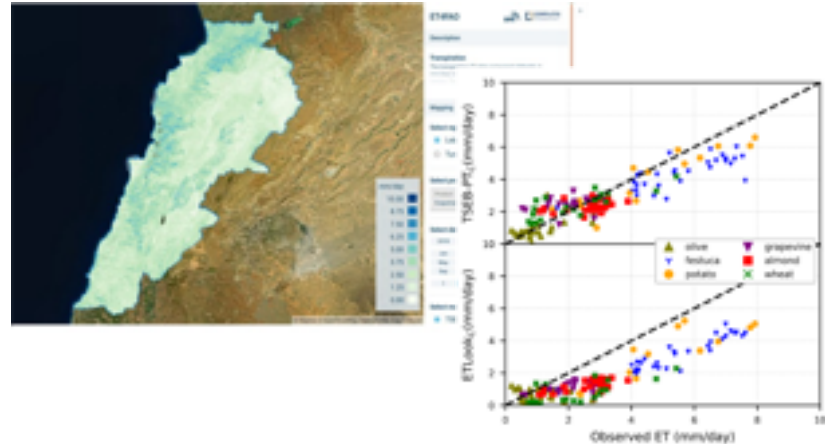


Fused LST
(20m)



ET4FAO

- Demonstrated use of Copernicus data for ET within FAO's WaPOR platform
- Dekadal ET at 30m, 100m and 250m at national scale



Prototyping for Copernicus Expansion

Current gap of high temporal and spatial resolution TIR

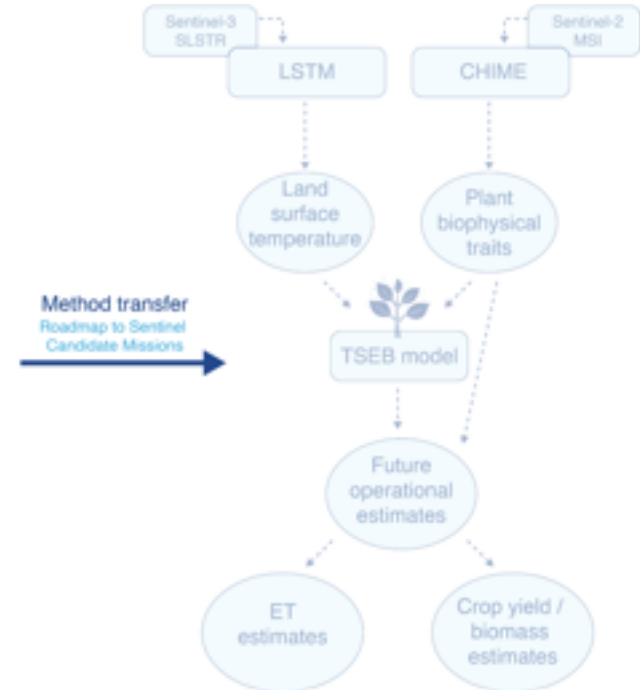
ECOSTRESS → LSTM:



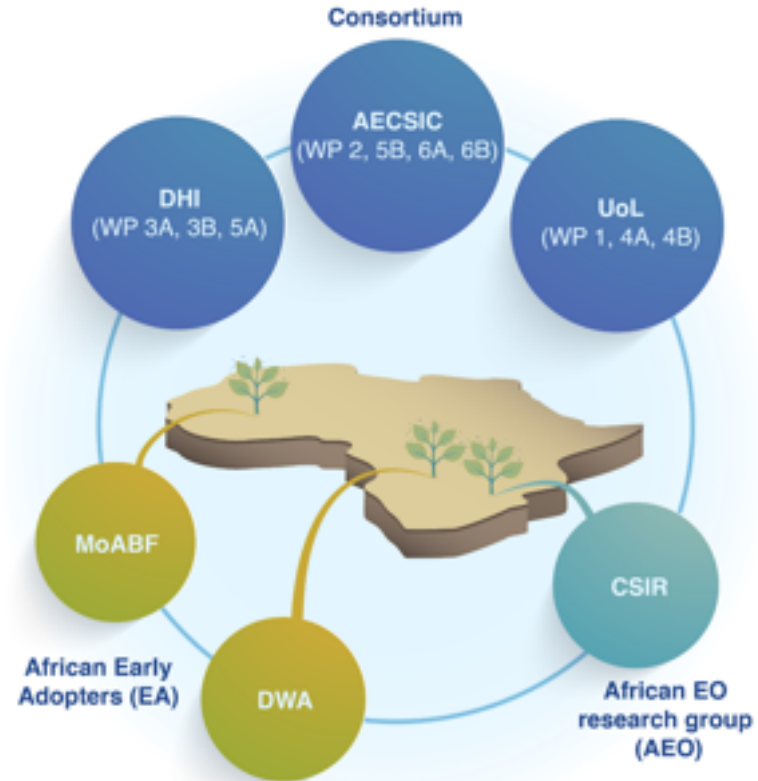
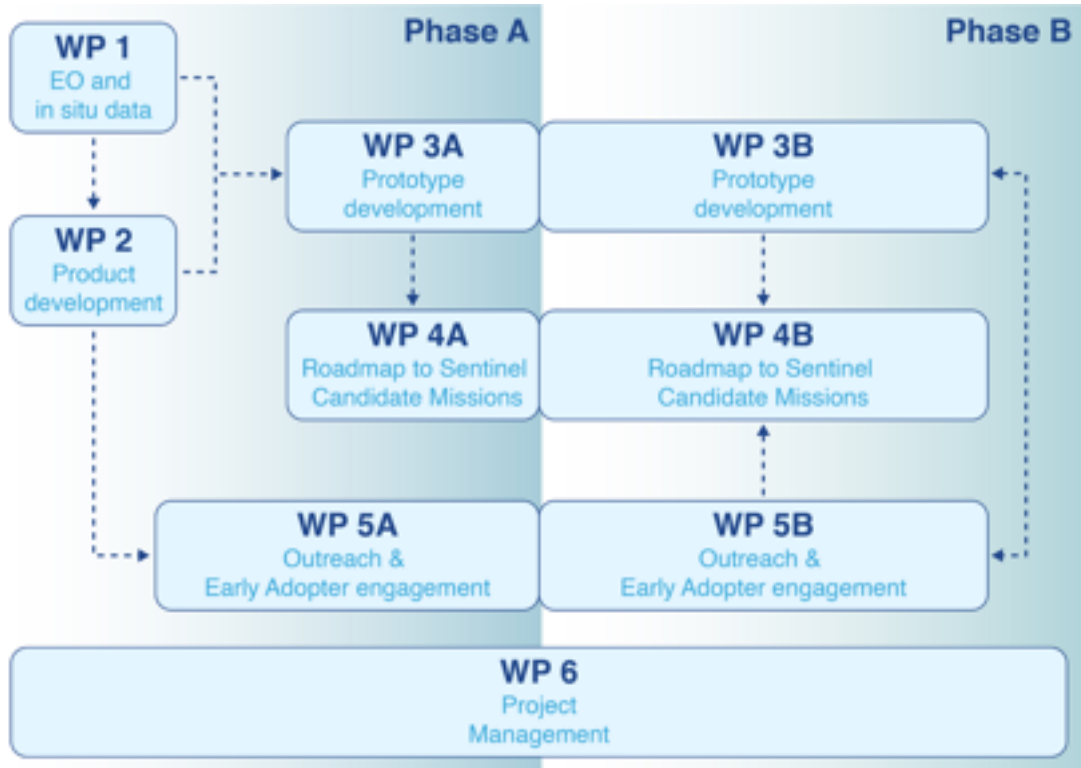
- Interpolation to daily ET at ~13:30 overpass
- Uncertainty propagation in TSEB (Jacobian)
- Crop-stress as covariate for crop-yield prediction

PRISMA → CHIME:

- Robust biophysical traits estimation
 - Non-photosynthetic vegetation
- Evaluation of retrieval models
 - Data-driven with in-situ measurements
 - Radiative transfer models (RTMs)



Project Structure

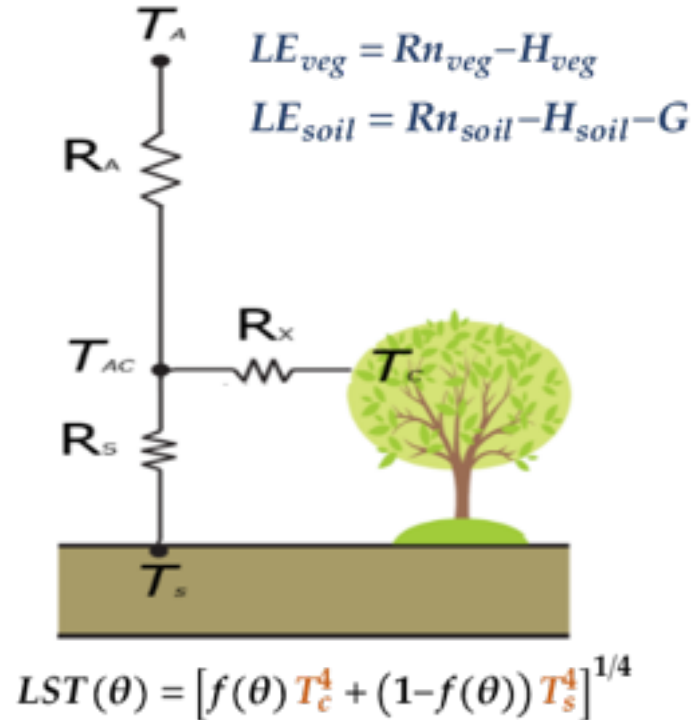


Two-Source Energy Balance Model (TSEB)

Partitions **transpiration** and **evaporation**

Requires detailed and accurate **biophysical traits**:

- **Plant Area Index** → radiation interception
- **Green LAI** → maximum transpiration/photosynthetic capacity
- **Leaf pigments/albedo** → radiation absorption
- Also canopy architecture



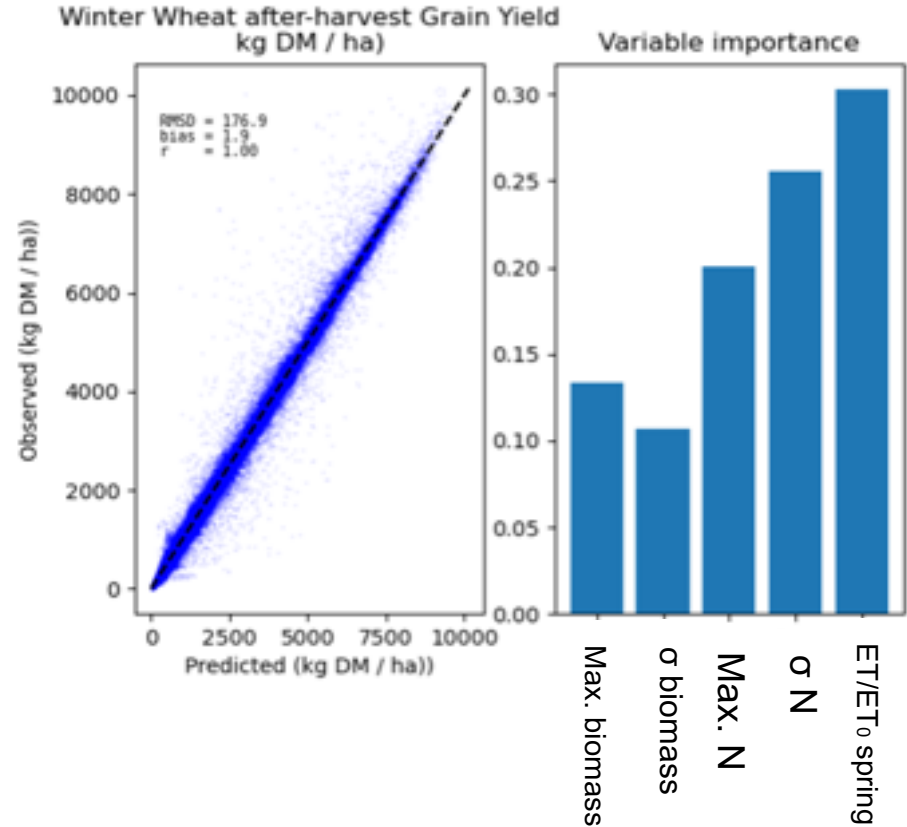
Crop Yield modeling from EO

Crop model simulations (Daisy) for exploring **EO explanatory variables**:

- LAI / leaf biomass (LAIx C_m)
- Chlorophyll / N concentration
- Crop stress (ET/ET₀)

D3: **State-of-art-review** of EO-based Crop Yield modeling

D6.1 Compare in-silico simulations using **crop models** vs **data-driven** from EO time series



Conclusions

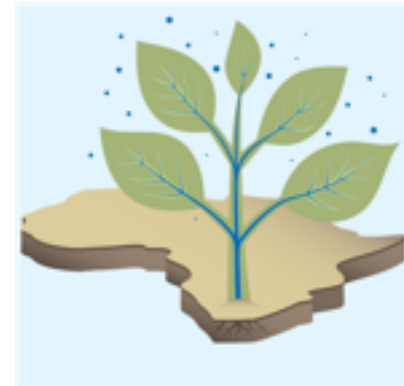
- Spectroscopy from PRISMA (CHIME) would allow robust and accurate biophysical inputs for:
 - ET models
 - Crop Yield Assessment
- To be validated with:
 - in-situ measurements [e.g. Majadas/Barrax (ES), Kruger (ZA)]
 - Official yield statistics [e.g., Spanish Ministry, Burkina Faso Ministry of Agriculture]



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LEICESTER



Thanks!



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Vicente Burchard-Levine
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2nd Workshop on International Cooperation
in Spaceborne Imaging Spectroscopy
19–21 October 2022 | La Collinetta Eventi, Frascati IT

Frascati, Italy
20-October-2022

Monitoring Key Ecosystem Properties with Hyperspectral Remote Sensing in a Complex Tree-Grass Ecosystem

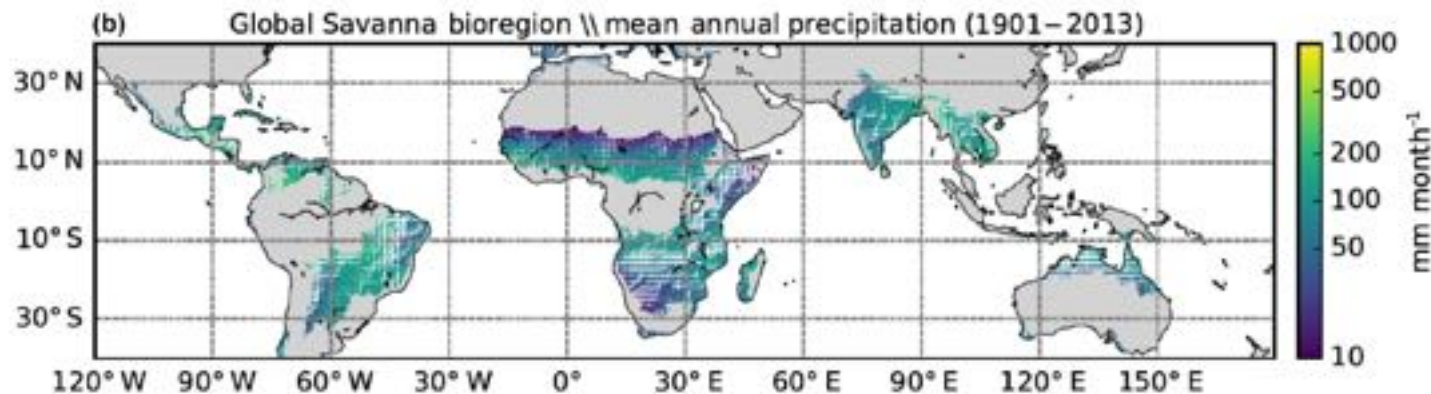
Vicente Burchard-Levine*, M. Pilar Martín, Héctor Nieto, Javier Pacheco-Labrador, Rosario González-Cascon, Gerardo Moreno, Victor Rolo, Mirco Migliavacca, Tarek El-Madany, Sung-Ching Lee and Arnaud Carrara

Tree-Grass Ecosystems (TGEs)

- ~16-35% of global land-surface
- High socio-economic and ecological value
 - Agro-pastoral systems
 - Dominant role in global biogeochemical cycles
- TGEs sensitive to climate change
- EO models poorly constrained
 - e.g. misclassified in global LULC maps, large bias in ET products
- Heterogeneity in space and time



Pinty et al., 2001

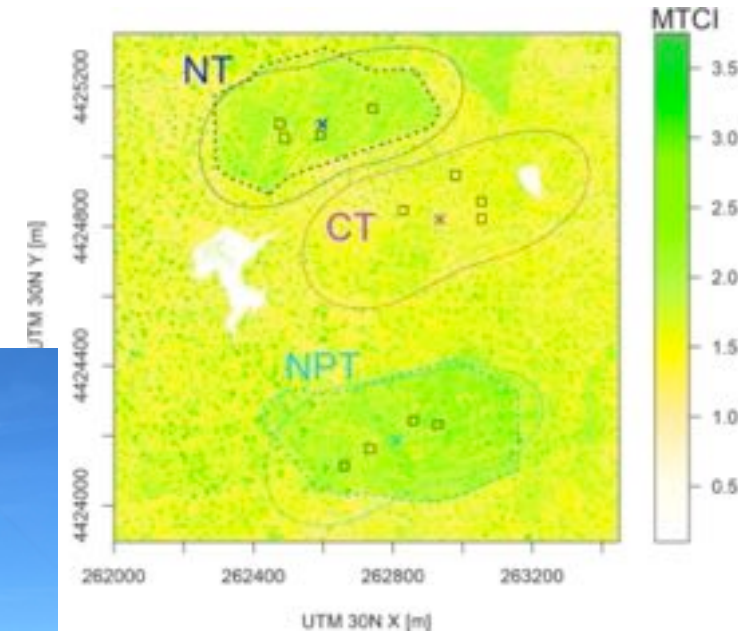
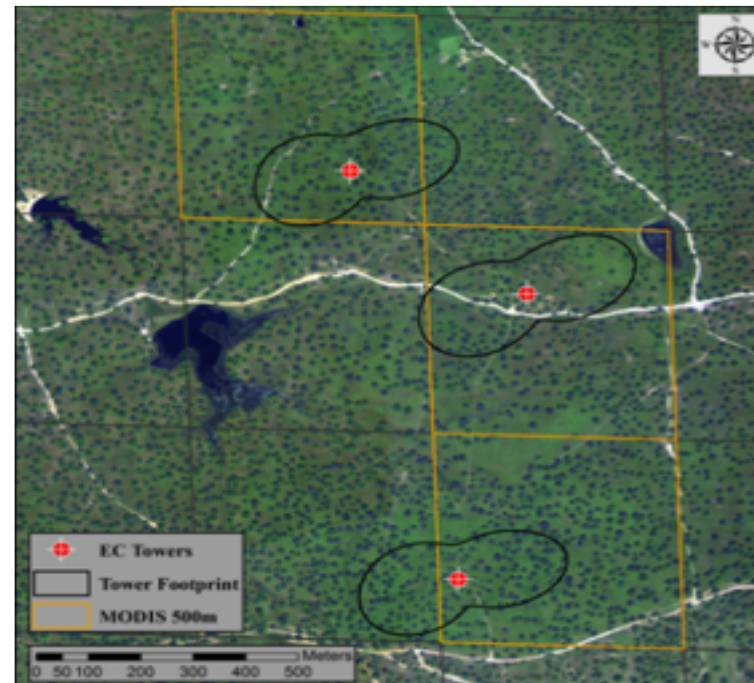


Source: Whitley et al. 2017



Majadas de Tiétar Research Station

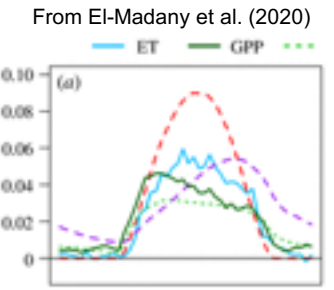
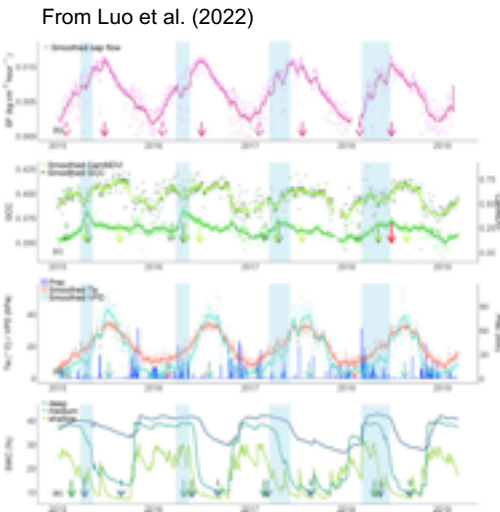
- Located in Extremadura, Spain
- EC flux tower set-up in 2003 (CEAM)
 - In 2014, +2 ecosystem towers + 3 sub-canopy (MPI-BGC)
 - MANIP: Large-scale nutrient manipulation experiment



Data and Research Areas

□ Unique dataset: **Multidisciplinary and complementary**

■ **Intensive and continuous sampling**



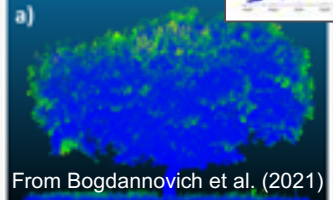
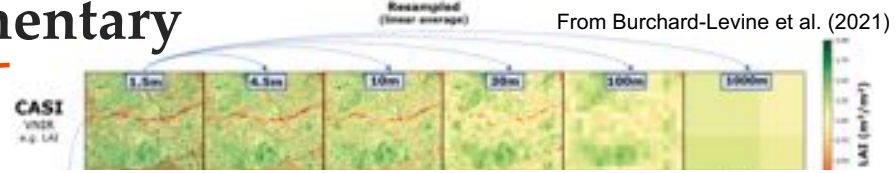
- ◆ Fluxes: EC systems
- ◆ Meteo+Radiometric
- ◆ Sap flow + lysimeters

Fluxes and biometeorological
Since 2003

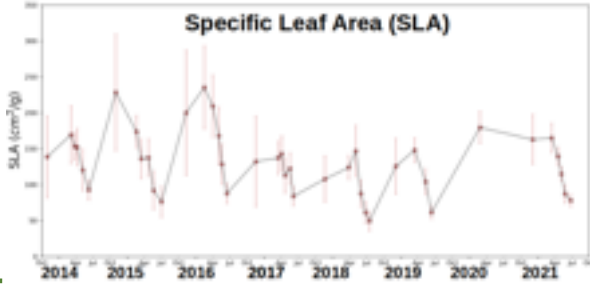
Multi-scale Remote Sensing
Since 2009

Biophysical and Ecological
Since 2009

- ◆ Automated Proximal sensing
- ◆ Portable field spectroscopy
- ◆ Airborne/UAV campaigns
- ◆ Terrestrial LiDAR

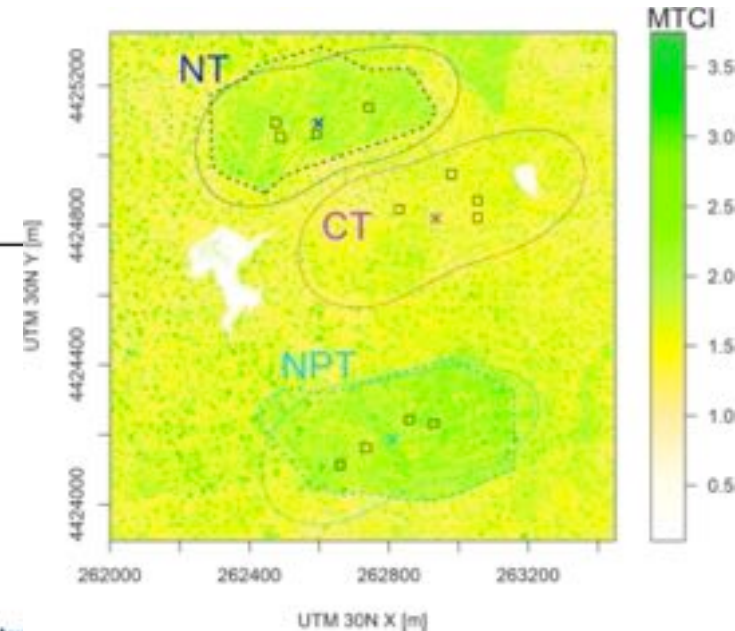


- ◆ Plant Traits (LAI, Cab, etc)
- ◆ Plant Diversity
- ◆ Soil sampling



In-Situ Flux Observations

- **Three Eddy-Covariance (EC)+ meteo systems**
 - Both **overstory** (15m, ecosystem) and **understory** (1.6m, grass-soil)
 - LE, H, G, CO₂, Vertical wind/temperature/humidity profile
 - **Radiation components** (SW/LW in/out)
 - Ecosystem, Tree canopy, grass-soil
 - **Soil:** moisture, temperature, hydraulic properties.
- **Tree transpiration**
 - Sap flow+dendrometers - 6 trees per tower
- **Three Lysimeters: Grass-soil ET**



IGR Biogeosciences

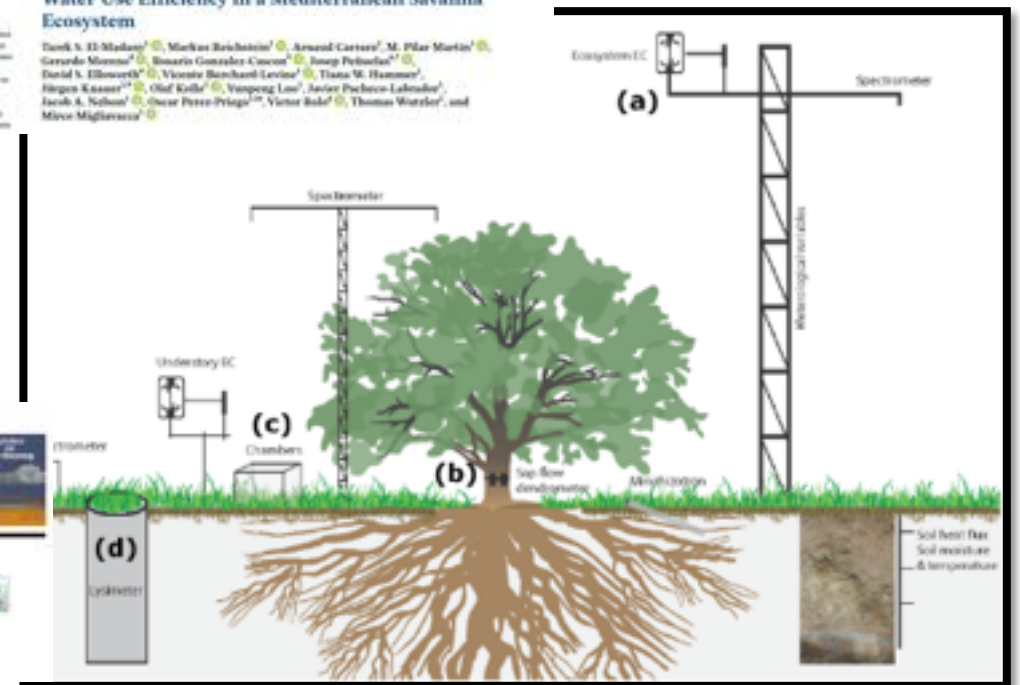
RESEARCH ARTICLE
15 JULY 2022

Key Points

- Measurements of P and N uptake by trees in a Mediterranean savanna ecosystem
- High nitrogen availability increases carbon uptake and changes the composition of a carbon-stable carbon isotope
- Ecosystem-scale functional relationships are observed through measurements of carbon and nitrogen

How Nitrogen and Phosphorus Availability Change Water Use Efficiency in a Mediterranean Savanna Ecosystem

Tarek S. El-Madany^{1,2}, Markus Reichstein¹, Arnaud Carrara¹, M. Pilar Martin¹, Gerardo Moreno¹, Benigno Gonzalez-Causse¹, Josep Peñuelas¹, David S. Ellsworth³, Vicente Sanchez-Lorenzo¹, Diana W. Hammer⁴, Hagen Kasper⁵, Olaf Kolle⁶, Yun-Peng Lau⁷, Javier Pacheco-Labrador¹, Jacob A. Nelson⁸, Oscar Perez-Prigo^{1,2}, Victor Rode⁹, Thomas Wutzler¹, and Mirco Migliavacca¹



PI/Contact:

- Arnaud Carrara (CEAM)
- Sung-Ching Lee (MPI-BGC)
- Tarek El-Madany (MPI-BGC)

Automated Proximal Sensing



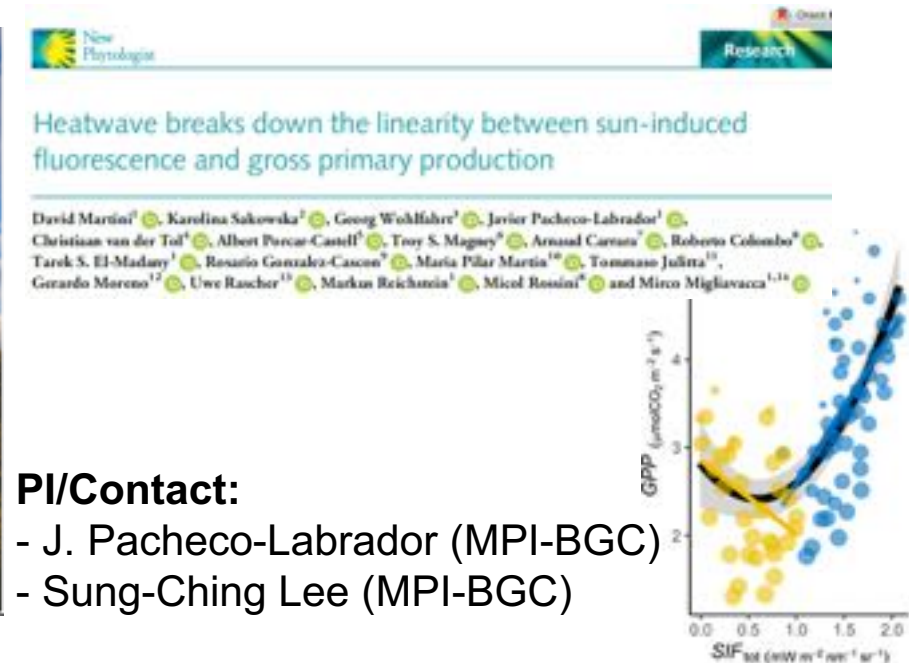
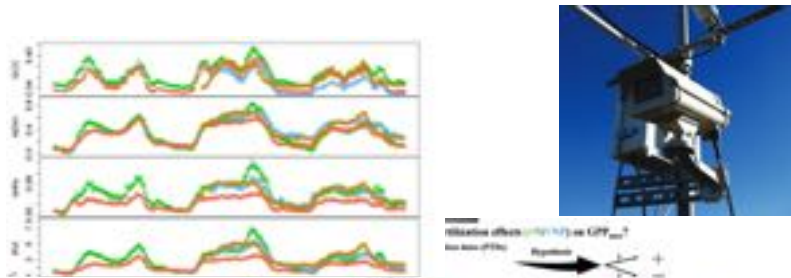
- **Phenocams** (each tower)
 - Blue, Green, Red, and NIR
- **NDVI/PRI sensors** (each tower)
- **Apogee TIR sensors** (each tower)
 - 0°, 35°, 55° view angle

- **FLuorescence bOX (FLOX)**

- High-res: SIF retrievals O₂ A and B bands
- VNIR (400-950nm)
- Sampling grass and tree crown alternatively (time step=5min)

- **AMSPEC-MED** (2years, not operational now)

- Multi-angular hyperspectral sampling (Unispec DC)



Received 4 December 2018 | Accepted 16 April 2020
 DOI: 10.1111/nph.15836

PRIMARY RESEARCH ARTICLE

Nutrients and water availability constrain the seasonality of vegetation activity in a Mediterranean ecosystem

Yunpeng Luo¹ | Tarek El-Madany¹ | Xianlong Ma^{2,3} | Richard Nair¹ | Martin Jang¹ | Ulrich Weber¹ | Glaukka Filippa² | Solveig F. Bacher^{4,5} | Gerardo Moreno⁶ | Edoardo Cremonese⁷ | Arnaud Carrara⁷ | Rosario Gonzalez-Cascon⁸ | Yonatan Cáceres Escudero⁹ | Marta Galvagno³ | Javier Pacheco-Labrador¹ | M. Pilar Martín¹⁰ | Oscar Perez-Priego¹¹ | Markus Reichstein^{1,5} | Andrew D. Richardson^{12,13} | Annette Menzel¹⁴ | Christine Rösemann^{2,4,5} | Mirco Migliavacca¹

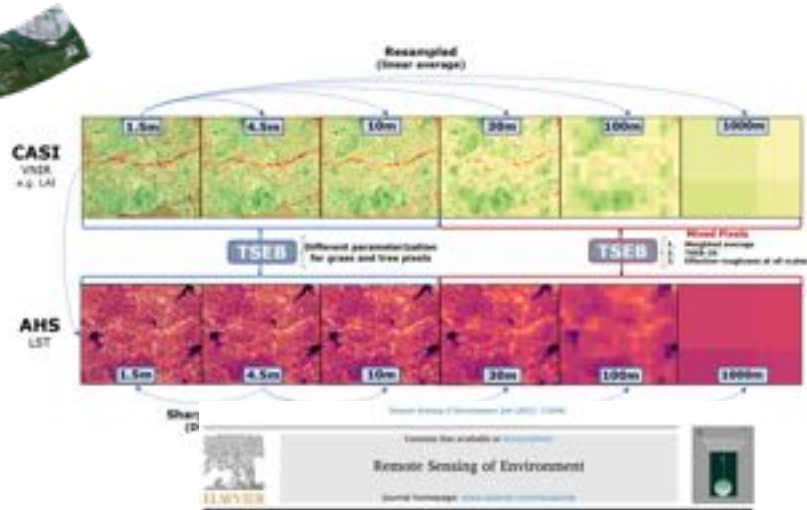
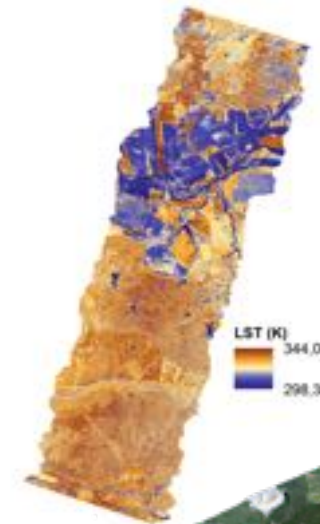
Airborne/UAV Acquisitions

- Airborne campaigns (2010-2018)

- INTA: 2010-2017 (8 campaigns)
 - CASI (VNIR, 1.5m) and AHS (SWIR-TIR, 4.5m)
- ESA-FLEXSENSE: 2018 (2 campaigns)
 - June 2018: HYPLANT (VSWIR+SIF, 1.5 & 4.5m) TASI (TIR, 1.8 & 3.6 m)
 - July 2018 APEX (VSWIR, 2 & 3m)

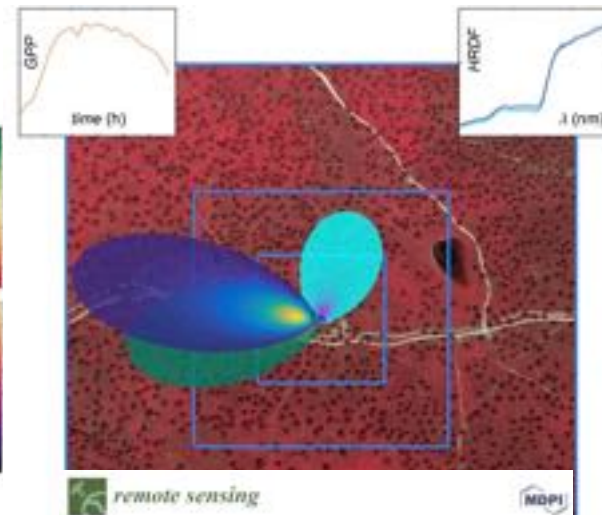
- UAV campaigns (2020-2021)

- DAAD/MONSOON/U. Augsburg:
 - May 2021: Micasense Altum (VNIR+TIR)
 - >30 overpasses between 5-20 May
- Diverspec/SpecLab-CSIC/UEX
 - May 2022: Sequoia (VNIR)



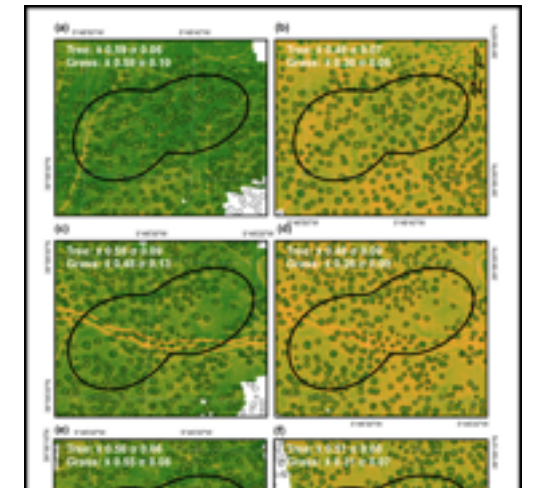
The effect of pixel heterogeneity for remote sensing based retrievals of evapotranspiration in a semi-arid tree-grass ecosystem

Vicente Bachard-Lavigne¹, Hector Nieto¹, David Rizo¹, Mirco Migliavacca², Tarek S. El Madiaty³, Radosław Guzikowski⁴, Anand Casassa⁵, M. Pilar Martín¹



Spatio-Temporal Relationships between Optical Information and Carbon Fluxes in a Mediterranean Tree-Grass Ecosystem

Javier Pacheco-Labrador^{1,2}, Tarek S. El Madiaty³, M. Pilar Martín¹, Mirco Migliavacca², Micol Bonini⁴, Anand Casassa⁵ and Pablo J. Zarco-Tejada²



UAS-based high resolution mapping of evapotranspiration in a Mediterranean tree-grass ecosystem

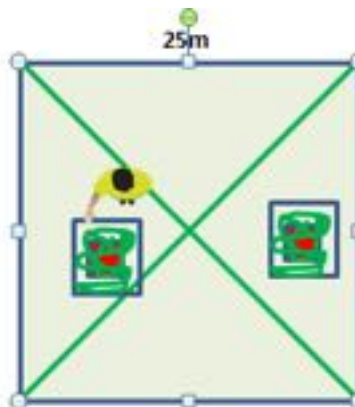
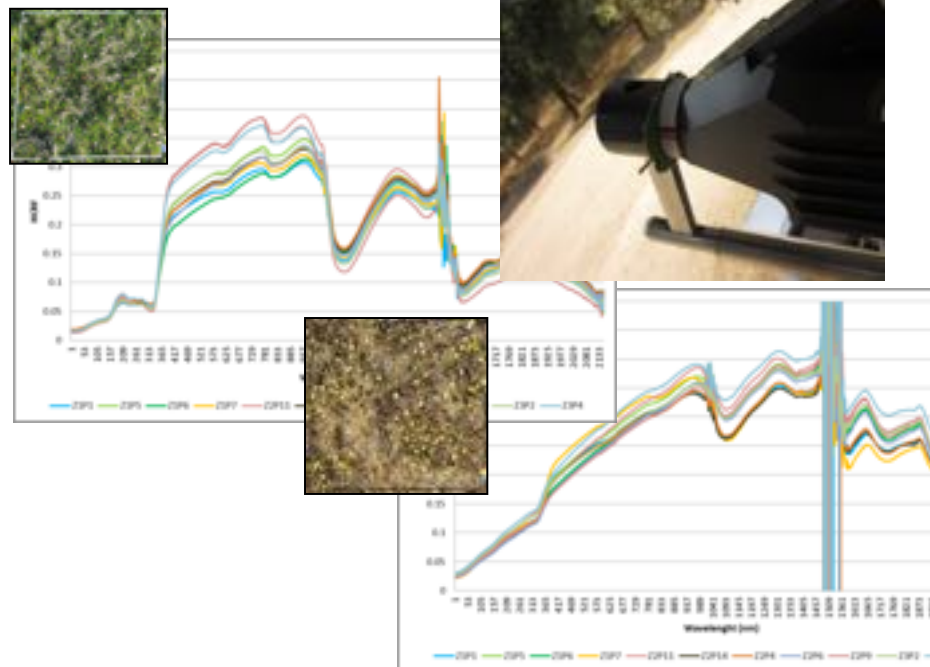
Jake E. Simpson¹, Steven H. Hollman¹, Hector Nieto¹, Tarek S. El Madiaty², Mirco Migliavacca³, M. Pilar Martín¹, Vicente Bachard-Lavigne¹, Anand Casassa⁴, Robert Bieker⁵, Peter Fries⁶, Jodi D. Kaplan⁷

PI/Contact:
 - M.Pilar Martín (SpecLab-CSIC)
 - Javier Pacheco (MPI-BGC)

In-Situ Spectroscopy

• ASD Spectral measurements since 2009

- Simultaneous to biophysical sampling in 25mx25m plots
- Ad hoc acquisition protocols
- Grass canopy: 5-6 times/y
 - 10-40 samples/campaign
- Tree leaf-level (plant-probe): 2-3 times/y
 - 5-15 trees/campaign

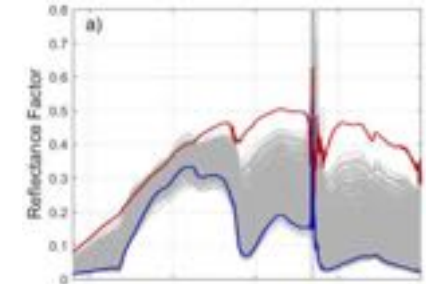
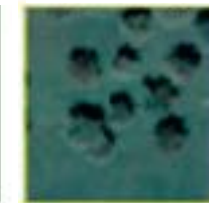
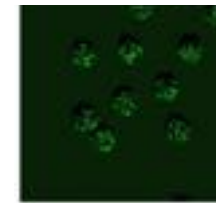


Improving the Performance of 3-D Radiative Transfer Model FLIGHT to Simulate Optical Properties of a Tree-Grass Ecosystem

José Esteban Melendo-Vega ^{1,*}, M. Pilar Martín ¹, Javier Pacheco-Labrador ¹, Rosario González-Cascón ¹, Gerardo Moreno ¹, Fernando Pérez ¹, Miroslav Migliavacca ¹, Mariano García ¹, Peter North ², David Riaño ^{1,3}

PROSAIL+FLIGHT

CASI image

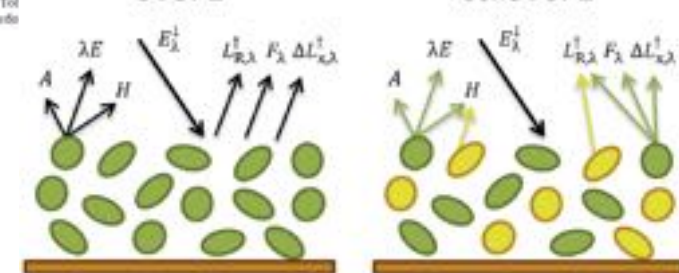


senSCOPE: Modeling mixed canopies combining green and brown senesced leaves. Evaluation in a Mediterranean Grassland

Javier Pacheco-Labrador ^{1,*}, Tarek S. El-Modayr ¹, Christian von der Tol Román González-Cascón ¹, Oscar Pérez-Priego ¹, Jianhong Guo ¹, Gerardo Antonio Casas ¹, Markus Reichert ¹, Miroslav Migliavacca ¹

SCOPE

senSCOPE



In-Situ Plant Traits

Long-term biophysical, chemical and spectral dataset of trees and grasses (2009-2022)

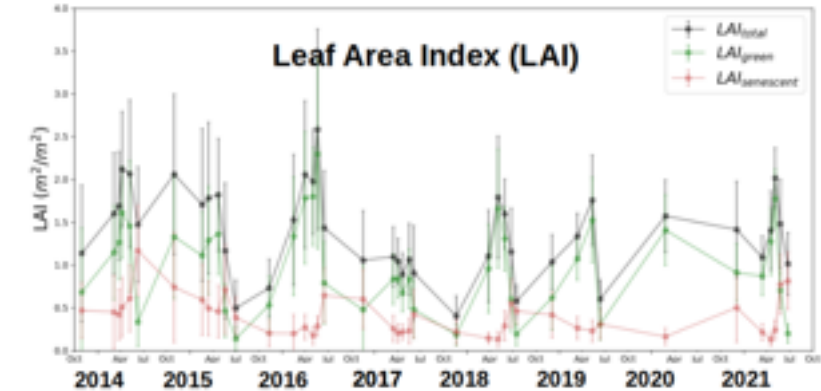
Tree leaf-level data

■ Biophysical

- Structural (LA, SLA)
- Water content (FMC, EWT, LWC)
- Pigments and nutrients (Chl a+b, carotenoids, N, C)

Tree canopy data

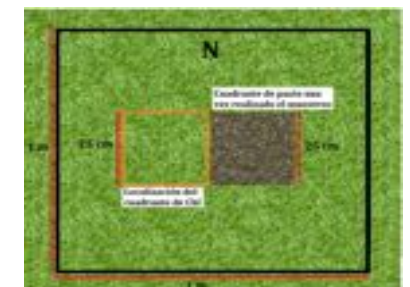
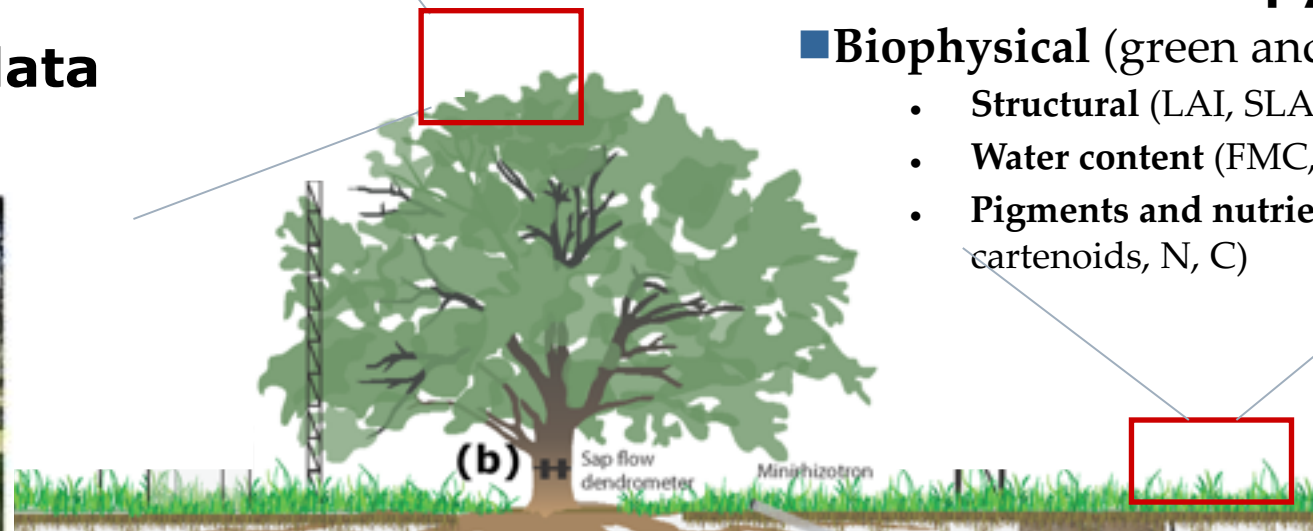
- LAI (using LAI-2200C)



Grass canopy data

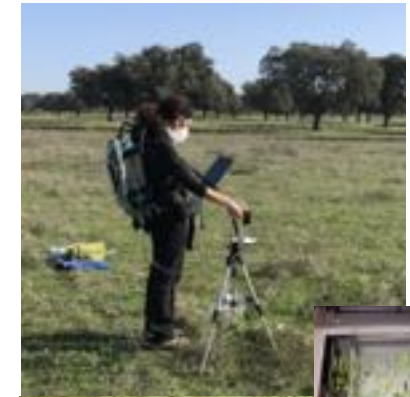
■ Biophysical (green and non-green)

- Structural (LAI, SLA, SLW, ABG)
- Water content (FMC, EWT, LWC, CWC)
- Pigments and nutrients (Chl a+b, carotenoids, N, C)

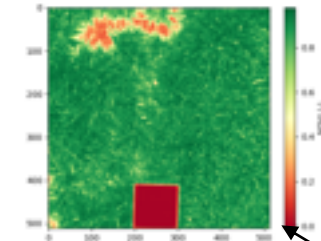


Plant Diversity and gas exchange

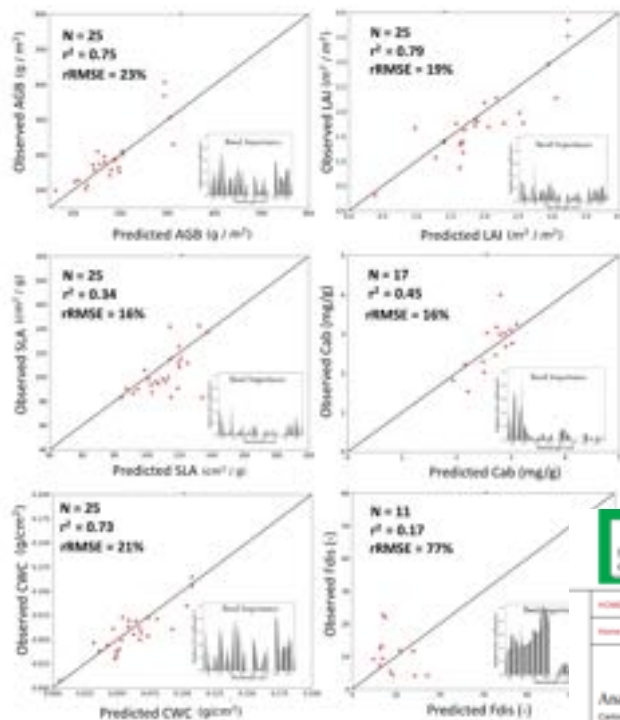
- Since 2019, joint **Speclab-UXE** campaigns to sample **functional diversity + gas exchange**
 - Relating grassland **spectral diversity/traits** with **functional diversity (Fdis, RaoQ)**
 - Portable hyperspectral camera (**Specim-IQ**) for within-plot spectral variability
 - Now processing data from 2022 campaign



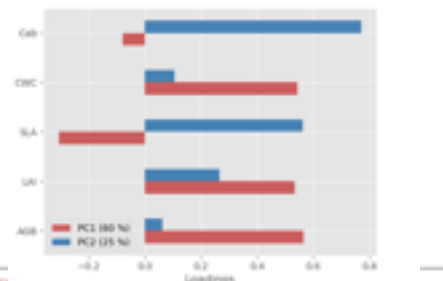
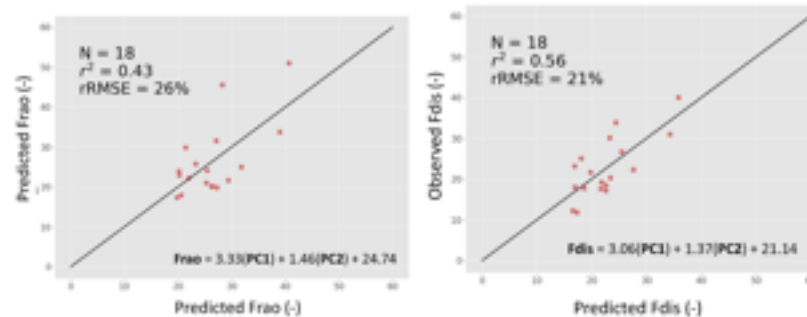
Specim-IQ



Hyperspectral Models using PLSR and ASD bands



Relation between PTs and FD



CLAUDENOS DE INVESTIGACIÓN GEOGRÁFICA GEOGRAPHICAL RESEARCH LETTERS

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Analysis of the functional diversity of the herbaceous stratum in a 'dehesa' ecosystem using in situ hyperspectral proximal sensing

Carles González, Víctor Roldán-Lianda, Víctor Rolo, Ricardo González-Castro, Claudio Moreno, et al. Plant Methods

PI/Contact:

- M.Pilar Martín (Speclab-CSIC)
- Gerardo Moreno (UEX)
- Victor Rolo (UXE)

Key ongoing (hyperspectral) work

- Upscaling **functional diversity models** from proximal sensing to space-borne data
 - Acquisitions of **PRISMA** images (2020-2022) over Majadas
 - Daily acquisitions of Venµs sensor (4m, CNES) since March 2022 (PI: J. Pacheco-Labrador)
- Using hyperspectral data to quantify **non-photosynthetic vegetation**
 - Important in semi-arid grasslands
 - Affects **plant trait retrievals** (especially in mixed phenological periods). **Not well represented in RTMs**
 - Burchard-Levine et al. (2022) suggested important influence for heat and water fluxes
- Better characterize ‘**background**’ **dry grass** in **3D RTM modeling** (using DART)
- Quantifying **spectral influence of tree cover** over mixed pixels and effect on **plant trait retrievals** from medium resolution sensors (Sentinel-2,3, PRISMA, DESIS, Venµs)

Conclusions

- Ideal CALVAL site as a **well-instrumented** and characterized **long-term monitored ecosystem**
 - Complex landscapes but globally very relevant
 - Scientific gap to better represent these heterogeneous systems
- **Long-term simultaneous datasets** over permanent plots (>13 years)
 - Multi-scale spectral data: leaf, canopy, UAV, Airborne, spaceborne
 - Both intensive periodic campaigns and continuous sampling
 - Coupled spectral and plant trait sampling strategy
- **Multidisciplinary research teams**
 - Important complimentary data and expertise (Micrometeorology, eco-hydrology, ecology, etc)
- Datasets available for **scientific collaborations**



Thanks!

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Frascati, Italy
20-Oct-2022

Vicente Burchard-Levine*, M. Pilar Martín, Héctor Nieto, Javier Pacheco-Labrador, Rosario González-Cascon, Gerardo Moreno, Victor Rolo, Mirco Migliavacca, Tarek El-Madany, Sung-Ching Lee and Arnaud Carrara