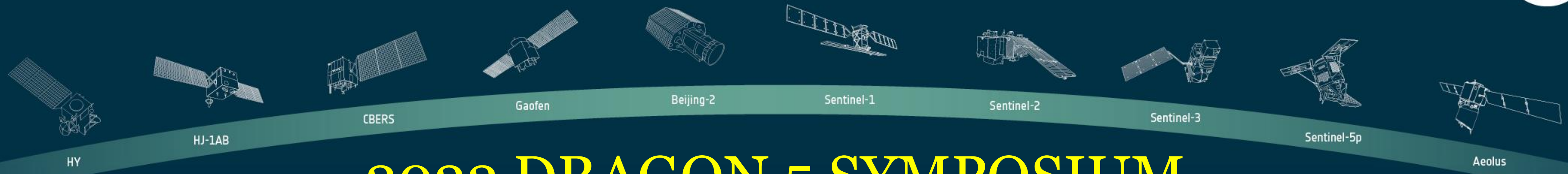


2022 DRAGON 5 SYMPOSIUM

MID-TERM RESULTS REPORTING

17-21 OCTOBER 2022

PROJECT ID. 59061

Satellite Observations For Improving Irrigation Water Management (SAT4IRRIWATER)

October 17, 2022

ID. 59061

PROJECT TITLE: SATELLITE OBSERVATIONS FOR IMPROVING IRRIGATION WATER MANAGEMENT (SAT4IRRIWATER): 2ND YEAR PROGRESS

PRINCIPAL INVESTIGATORS: Jia, Li; Mancini, Marco

CO-AUTHORS: Zheng, C.[1]; Corbari, C. [2]; Chen Q. [1] , Paciolla N. [2]; Jiang, M.[1]; Bai, Y. [1]; Zhao, T.[1]; Lu, J.[1]; Hu, G.C. [1]; Menenti, M.[1]

1 Aerospace Information Research Institute, Chinese Academy of Sciences (AIR-CAS)
2 DICA, Politecnico di Milano, Italy (POLIMI)

PRESENTED BY: Chiara Corbari (POLIMI), Li Jia (AIR-CAS)

Outline

- Project Objective
- Results Highlights
- Access to EO Data of ESA, Chinese and ESA Third Party Missions
- Young Scientists Contribution & Plans for Academic Exchanges
- Plan for Next Year

Project Objective and Work-packages

Objectives:

The main objective of the **Sat4IrriWater** project is to **assess irrigation water needs and crop water productivity based on the integrated use of satellite data with high resolution, ground hydro-meteorological data and numerical modelling** (the Chinese ETMonitor and Italian FEST-EWB-SAFY energy-water-crop balance models, and other hydrological models), which is particularly significant for large ungauged agricultural areas.

Work packages:

WP 1: Land surface variables from satellite observations

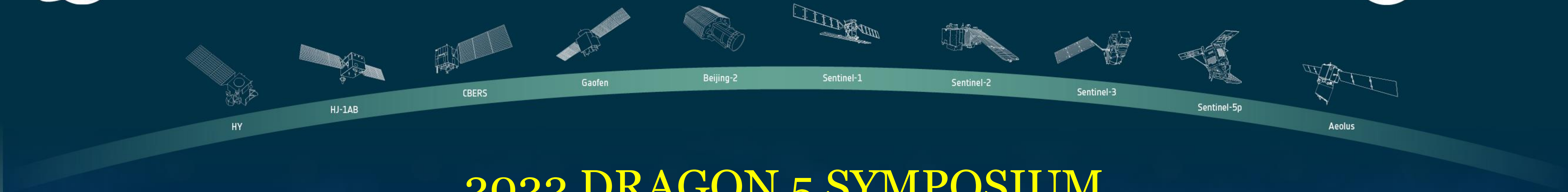
WP 2: Development and improvement of hydrological models to estimate crop water and irrigation needs

WP 3: Assessment of irrigation water needs

WP 4: Crop water productivity

Outline

- Objectives
- **Results Highlights: Progress by European Team**
- Access to EO Data of ESA, Chinese and ESA Third Party Missions
- Young Scientists Contribution & Plans for Academic Exchanges
- Plan for Next Year



2022 DRAGON 5 SYMPOSIUM

MID-TERM RESULTS REPORTING

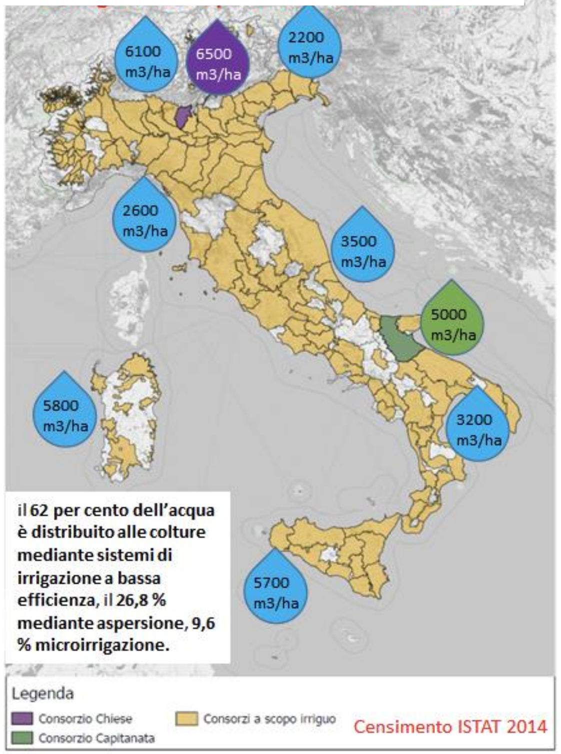
17-21 OCTOBER 2022

DRAGON 5 ID. 59061
PROJECT TITLE: SAT4IRRIWATER

Water SAVING… why?

Agriculture is the largest water user with about 70% of total freshwater consumption (FAO 2008)

2009-2010, the volume of water used for irirgation is of 11.6 milion m^3



2nd year activities

<u>FEST-EWB model improvement in evapotranspiration estimates over crop trees areas (</u>where arboreal canopy is interspersed with bare soil or low-cut grass land cover<u>) for optimizing crop irrigation efficiency</u>

The model can work both in the single-source version and in its double-source one. The former uses a single balance equation for the pixel, while the latter, although requiring the same amount of input data, distinguishes between the vegetated and non-vegetated areas in the pixel

The model has been applied, both in its single- and two-source structure, over field sites featuring walnut (Italy, 2019-21), vineyard (Spain, 2012 and Italy, 2008) and pear trees (Italy, 2022).

62 % of water is distributed with low efficiency (27.2 and 34.8 respectively for surface sliding and lateral infiltration and submersion),

UN Sustainable Development Goals - 2030

FEST-EWB: Single- and Two-sources modelling

FEST-EWB model

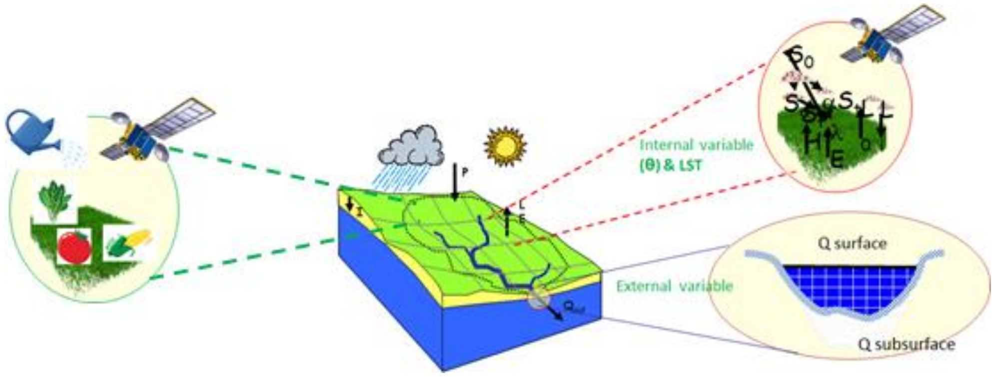
Soil water balance

$$P_{tot}=R+ET_{eff}+D+(\theta_{t+1}-\theta_t)*Z$$

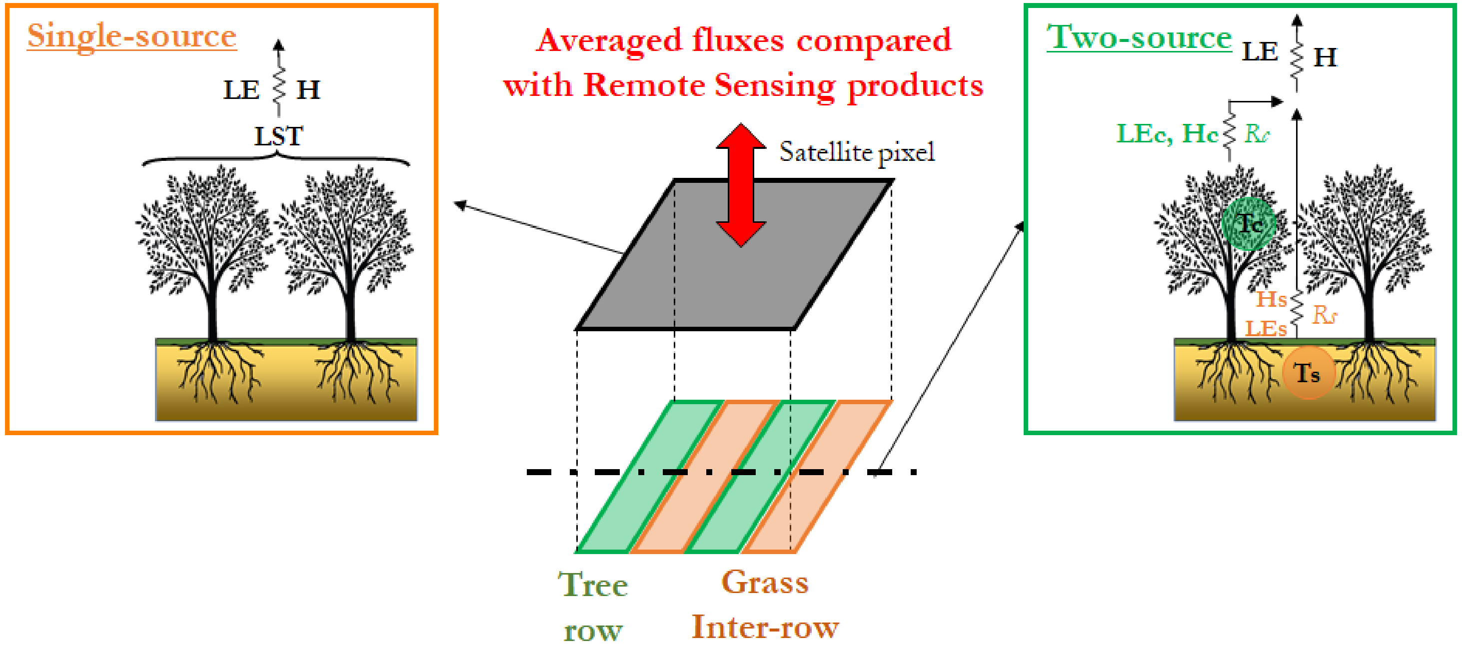
Energy balance

$$Rn - G - H - LE = \frac{dS}{dt} \qquad ETeff = \frac{LE}{rCp}$$

Corbari & Mancini, 2014 (JHM)
Corbari et al., 2014, (HSJ)



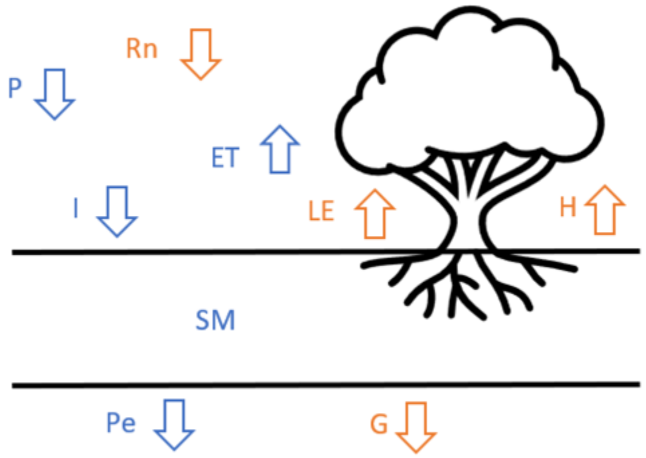
FEST-EWB: Flash – flood Event – based Spatially – distributed rainfall – runoff Transformation – including Energy - Water Balance

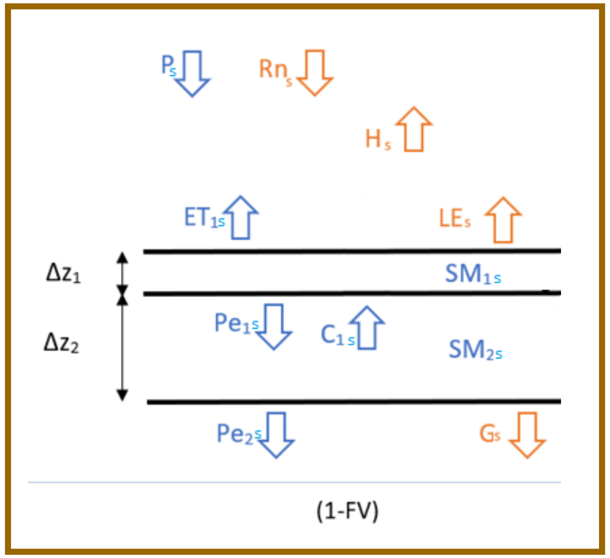


While single-source models hold one single energy balance for the whole pixel, assuming intra-pixel homogeneity, two-source ones identify separate fluxes for the vegetated and non-vegetated portions of the pixel, closing two distinct energy balances, each with its own surface temperature.

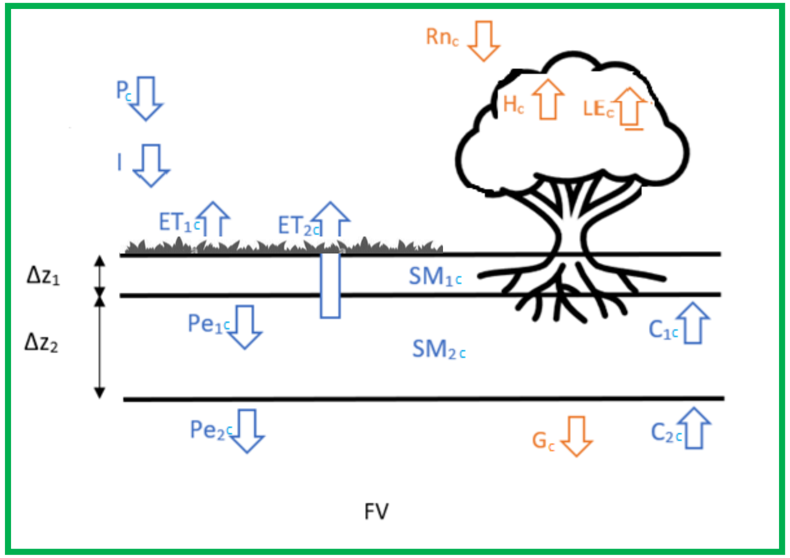
FEST-2X2-EWB scheme: two soil layers and two energy balances

The total fluxes





Soil water+energy fluxex (1-fv)



Vegetated water+energy fluxex (1-fv)

- SM, soil moisture
- Δz, layer's depth
- P, precipitation
- I, irrigation
- Pe, percolation
- ET, evapotranspiration
- Rn, net radiation
- G, soil heat flux
- LE, latent heat flux
- H, sensible heat flux
- FV, fraction of vegetation

Two soil layers and two-source energy budgets: one for soil and one for the vegetated part

Corbari & Mancini, 2014 (JHM)
Corbari et al., 2011, (HSJ)
Paciolla et al., 2022

Hydrological model PARAMETERS

SENTINEL-2 MSI

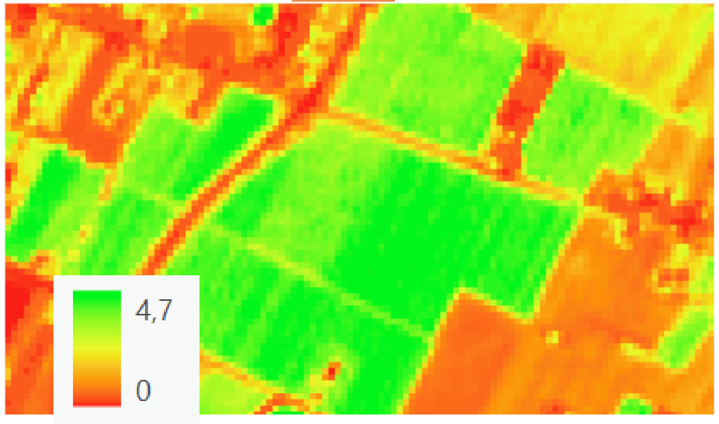
30 July 2019

copernicus
observing the earth

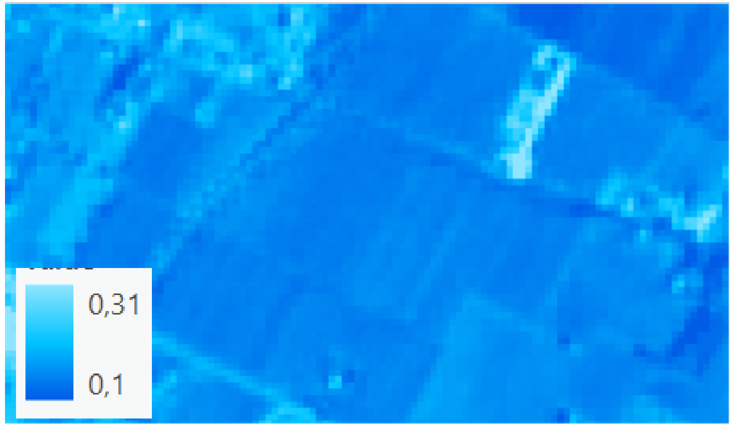
esa

FVC

LAI



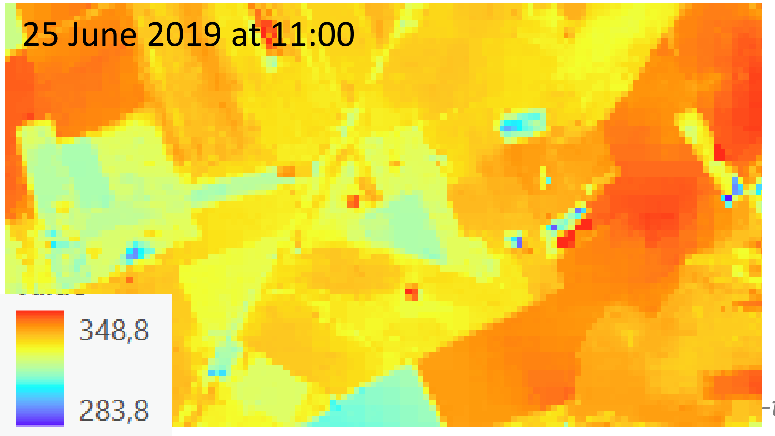
Albedo



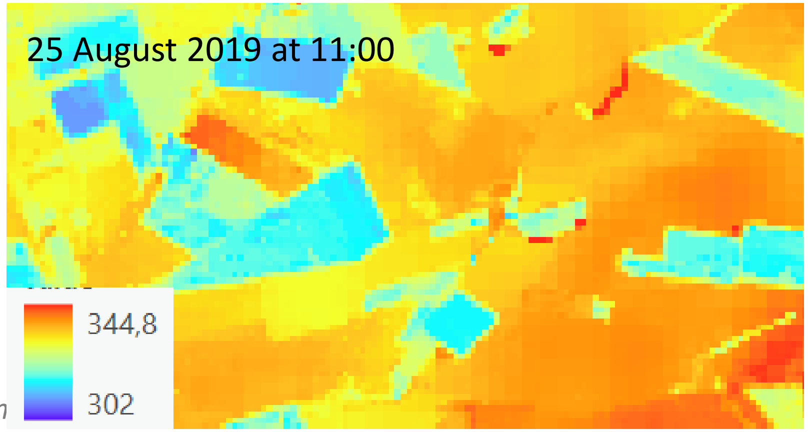
Hydrological model STATE VARIABLE

LANDSAT-8
OLI/TIRS

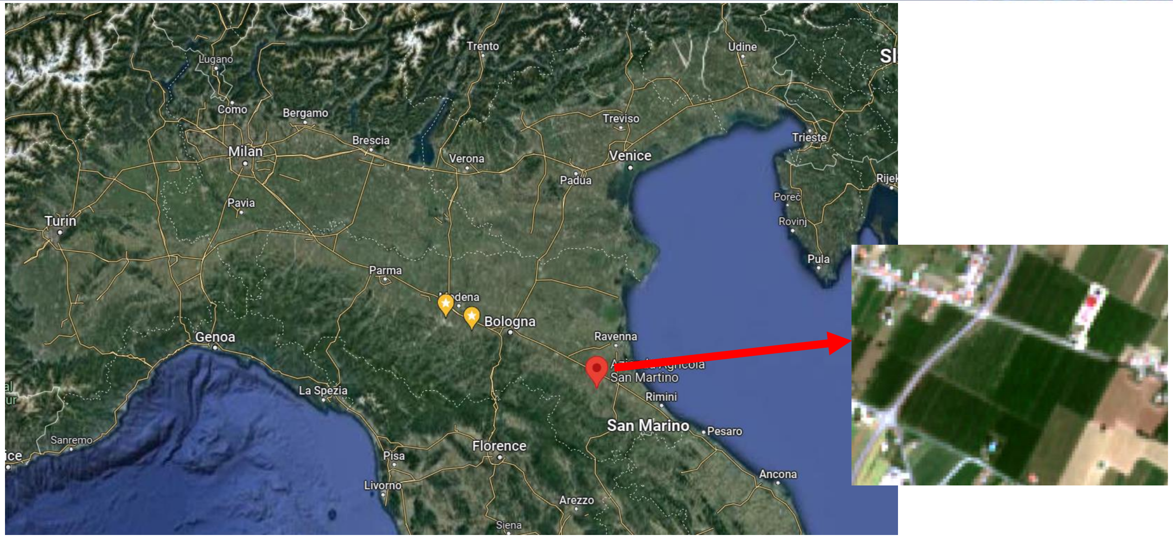
LST

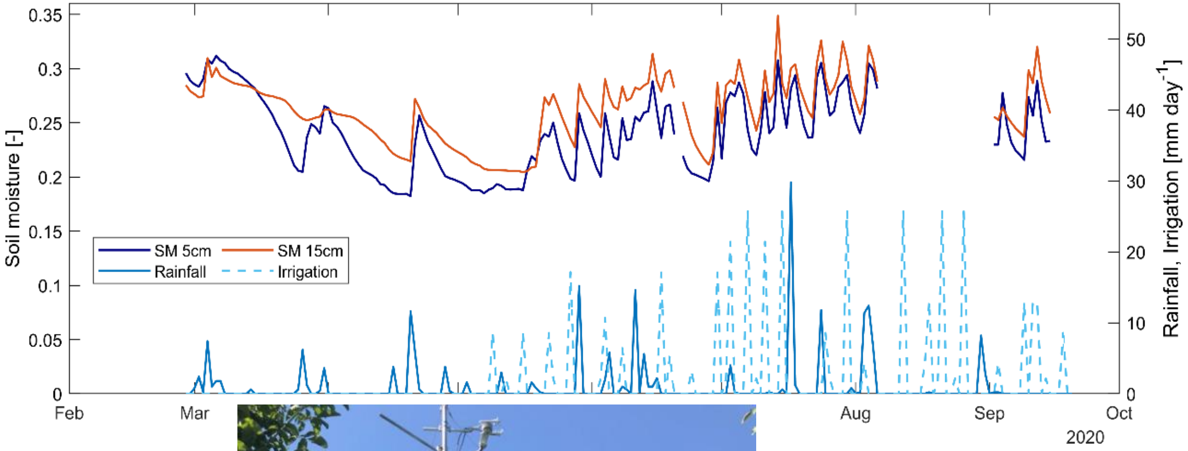


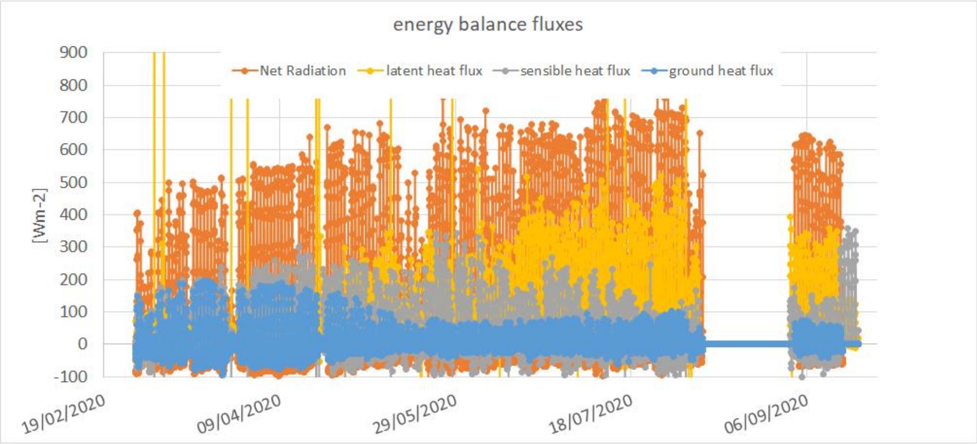
-term



Walnut trees field drip irrigated







Data from 2019 to 2021

Eddy covariance station: ET and SM fluxes

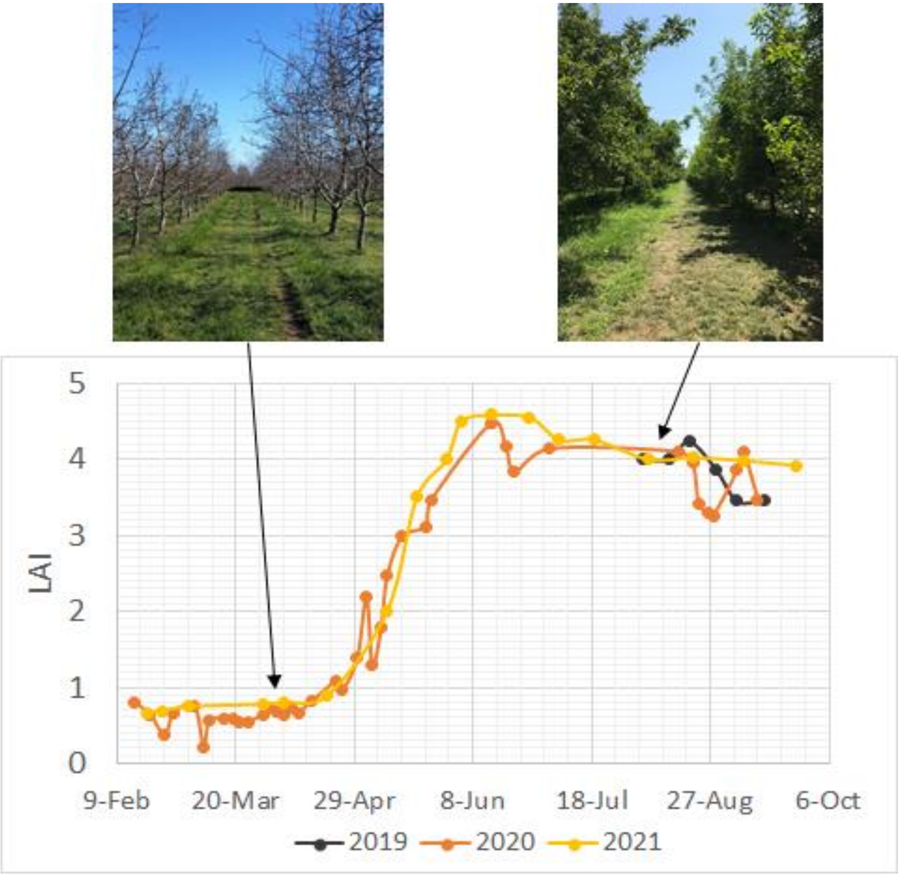
About **150 mm** of season **precipitation**

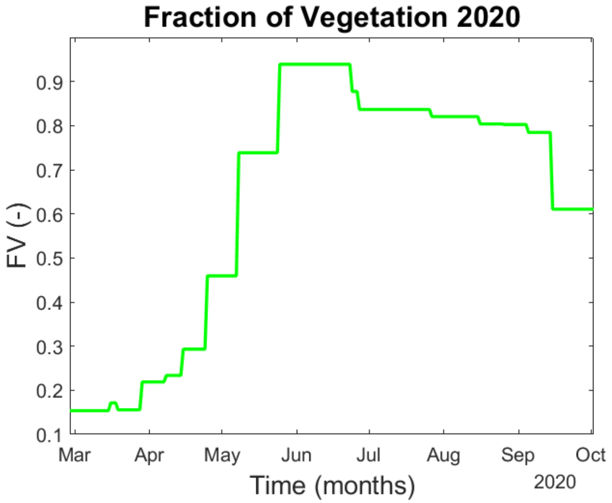
450 mm of irrigation

Satellite vegetation variables Sentinel 2 images

52 satellite images were processed through *SNAP software*:

- biophysical processor to retrieve *LAI* and *FV* with a spatial resolution of 10 m
- $\alpha = \sum_i b_i \cdot \omega_{b_i}$ *albedo* retrieval with b_i surface reflectance and ω_{b_i} weighting coefficient





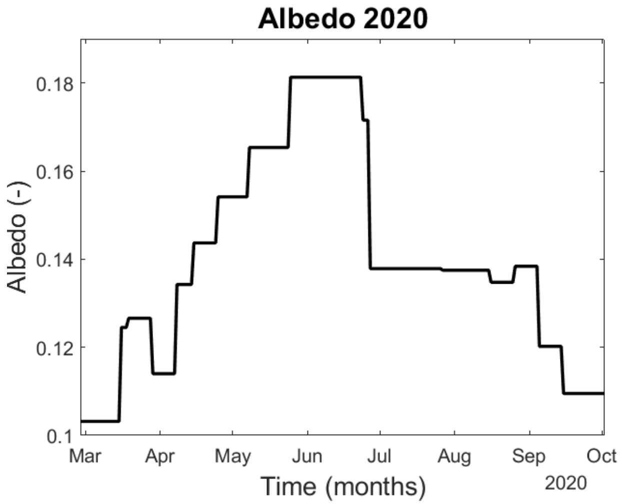
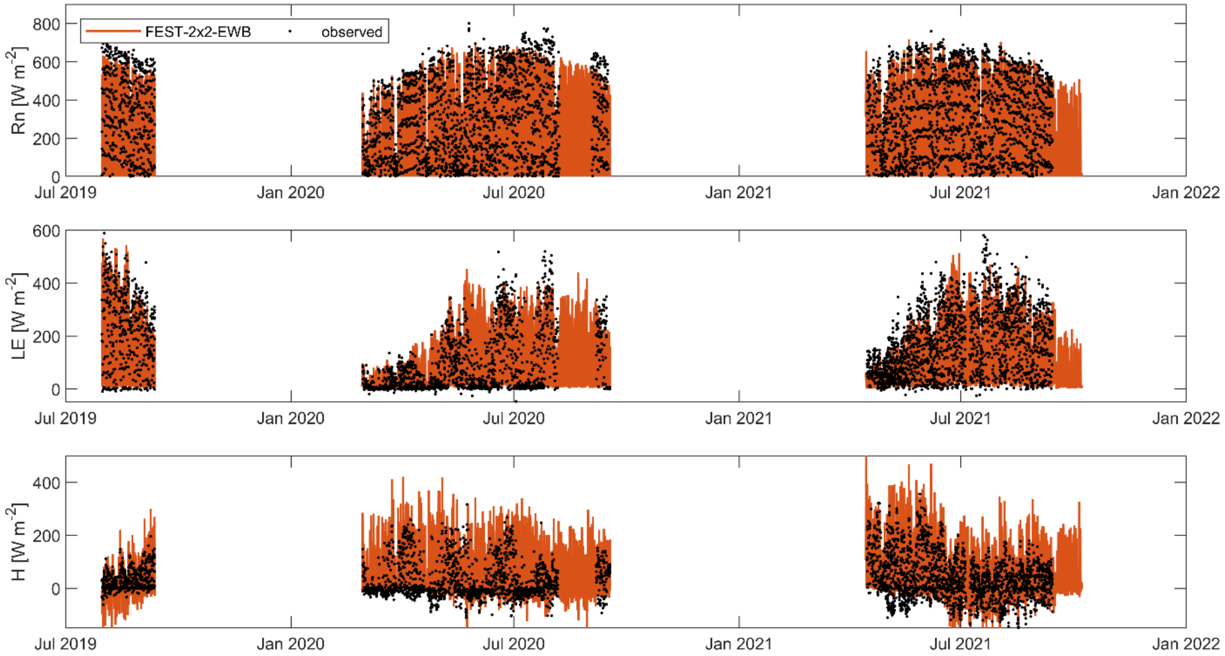


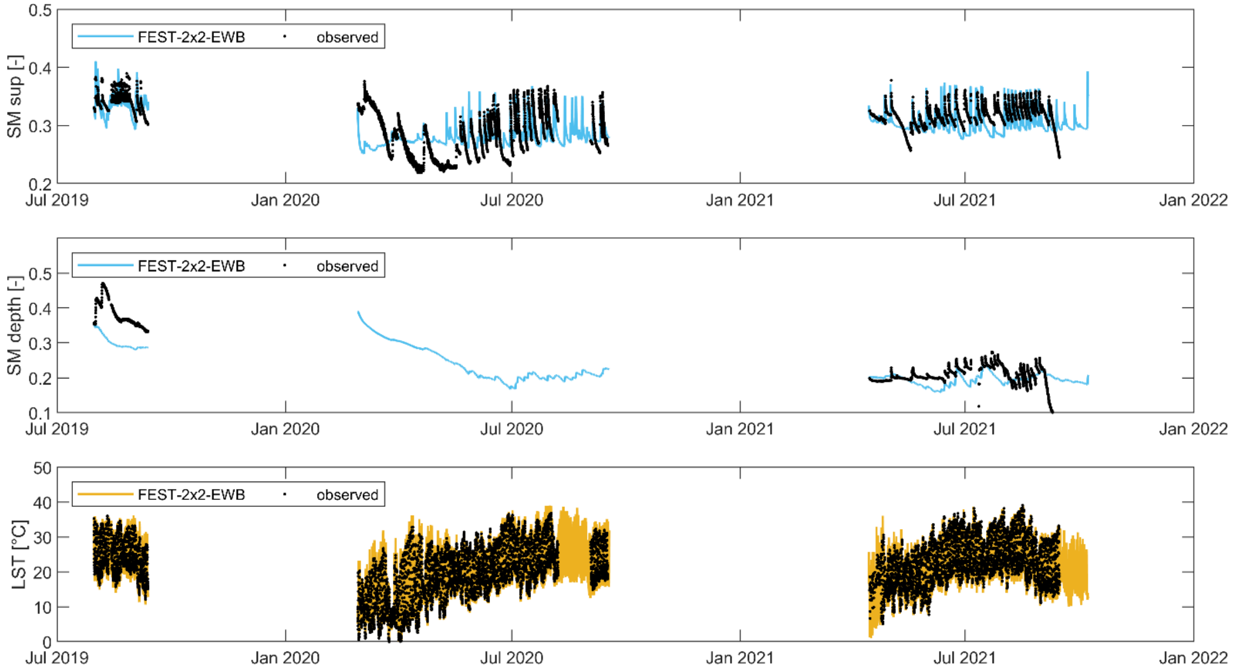
Fig: Time series of LAI, FV and albedo in the Eddy Covariance station’s cell.

FEST-2X2-EWB model calibration against LST and SM

The energy fluxes



Soil moisture and LST



	RMSE (W/m2)	Angular coeff.	R2	dmean (W/m2)
Rn	61.0	0.88	0.94	45.7
LE	66.3	0.89	0.73	46.0
H	56.7	1.04	0.63	40.7
LST	2.02	1.05	0.95	1.70
SM sup	0.03	0.89	0.78	0.02
SM dep	0.08	0.90	0.85	0.08

Comparison among FEST-EWB, FEST-EWB-2layers and FEST-2x2-EWB models against EC data

FEST-EWB: single soil layer, hybrid-one source

FEST-2-EWB: single soil layer, two-sources

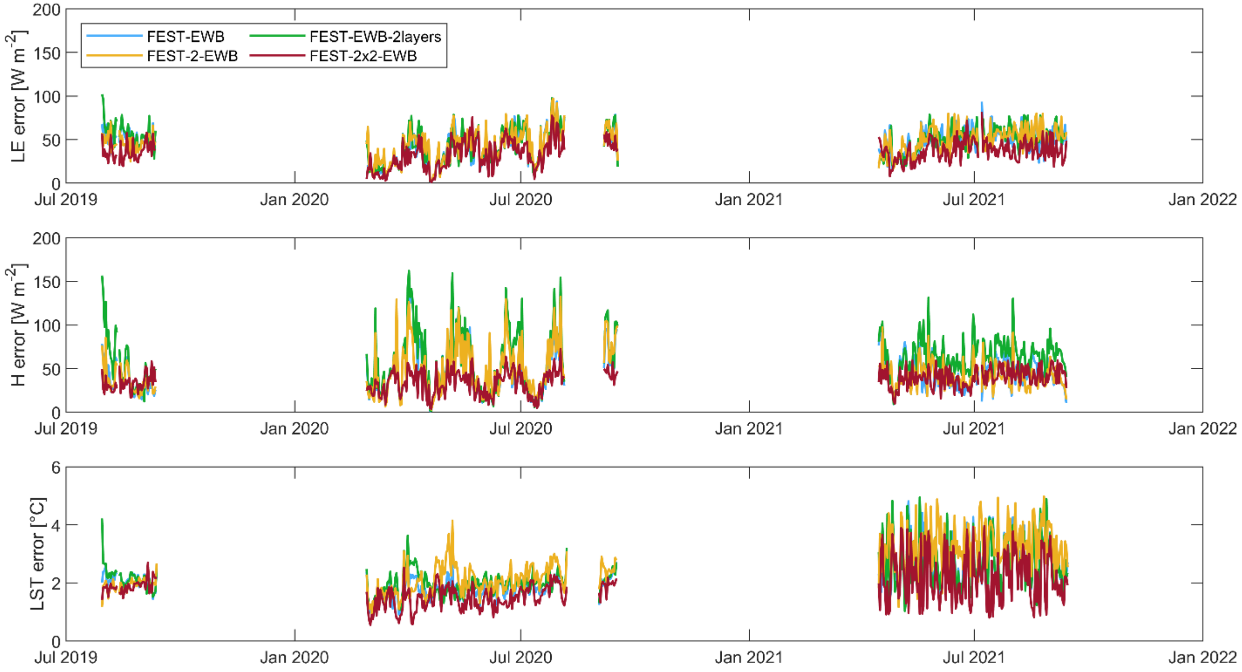
FEST-EWB-2layer: two soil layers, hybrid-one source

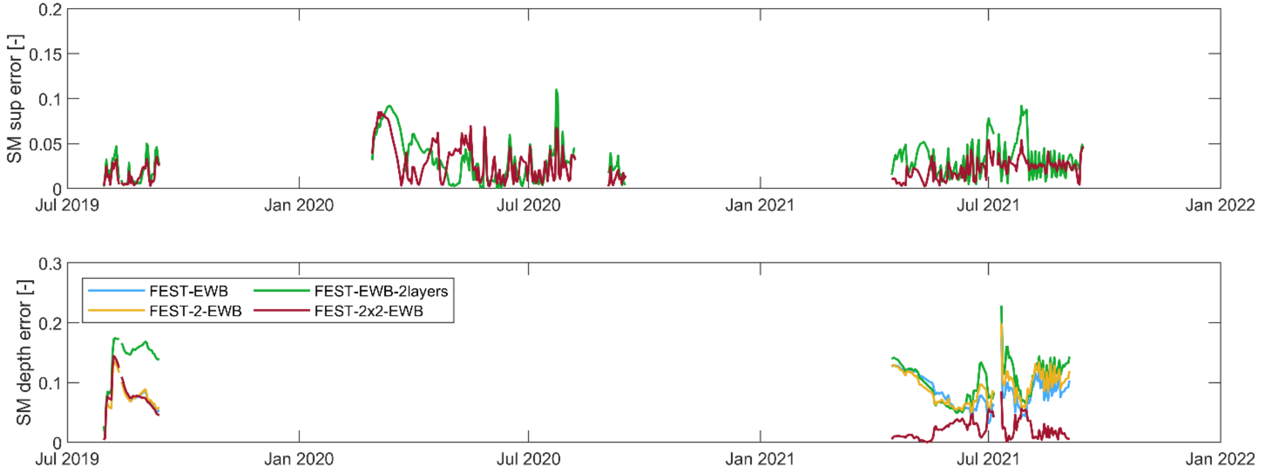
FEST-2X2-EWB: two soil layers, two-sources →

General lower errors in latent and sensible heat fluxes (40 W/m2) and LST (1.7 °C)

Similar errors with the 2layers model for SM (0,.05)

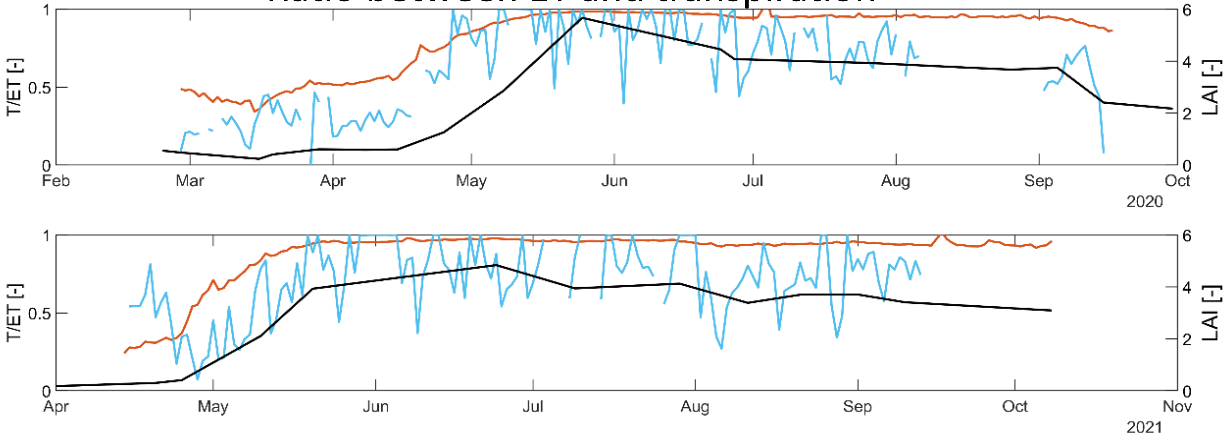
Fluxes differences





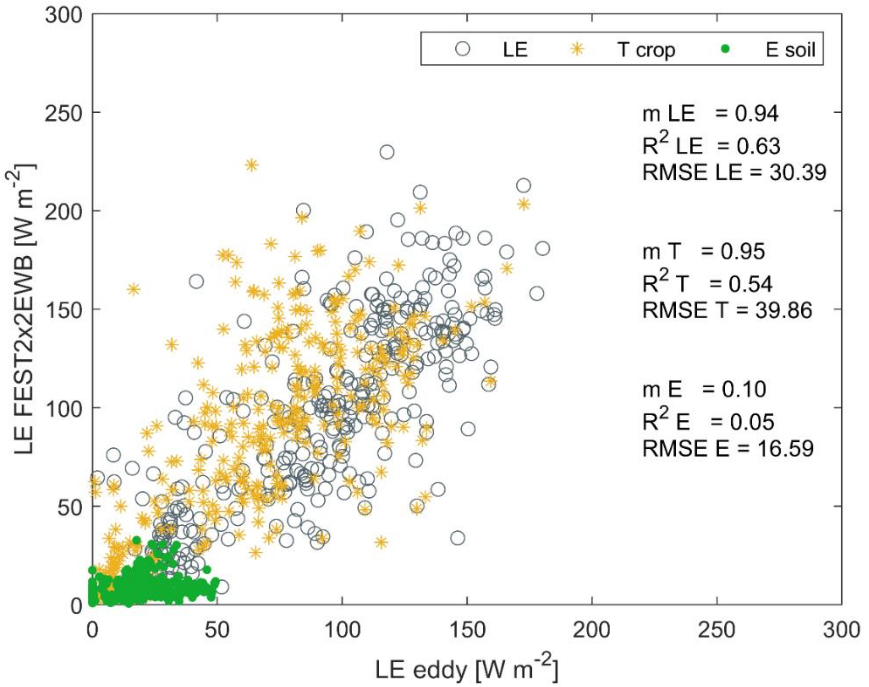
Flux partitioning: comparison between FEST-2X2-EWB and Eddy covariance data

Ratio between ET and transpiration



eddy FEST-EWB LAI

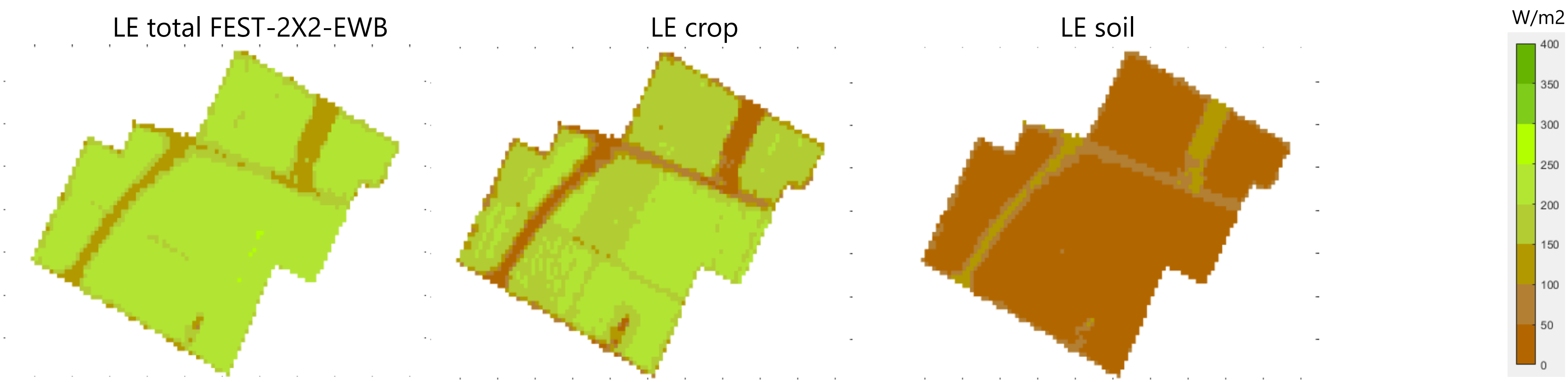
scatterplot between daily LE estimates from FEST-2X2-EWB and from EC with the uWUE method



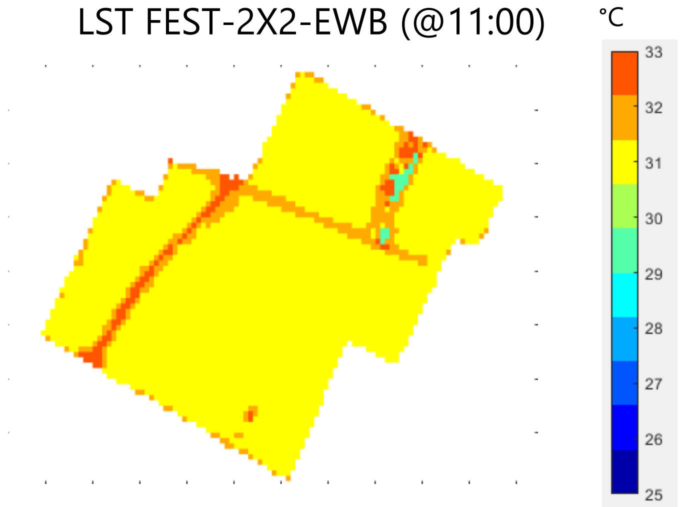
Flux partitioning: comparison between FEST-2X2-EWB and Eddy covariance data

4 August 2019

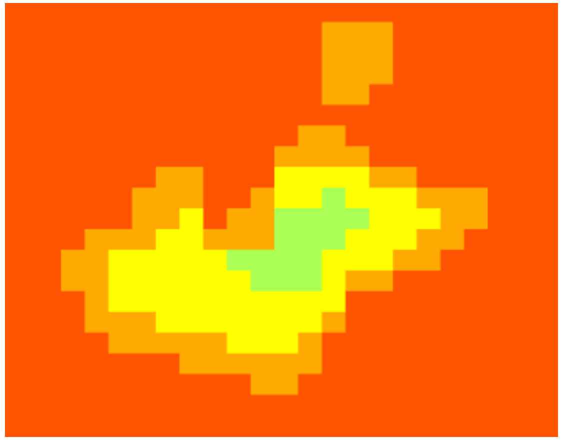
LE total FEST-2X2-EWB | LE crop | LE soil



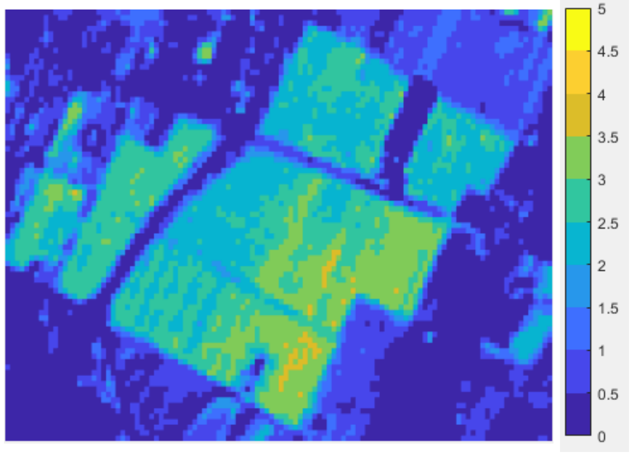
LST FEST-2X2-EWB (@11:00)



LST Landsat8 (@11:00)

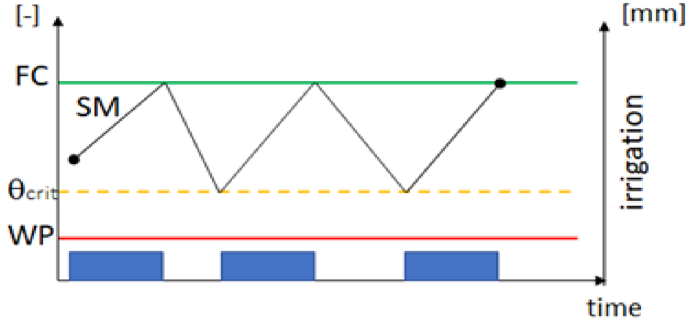


LAI Sentinel2 (30 July 2019)



Optimized irrigation volumes from FEST-EWB and from FEST-2X2-EWB

Irrigation strategy– criterion for soil moisture depletion: maintain soil moisture above Θ_{crit}

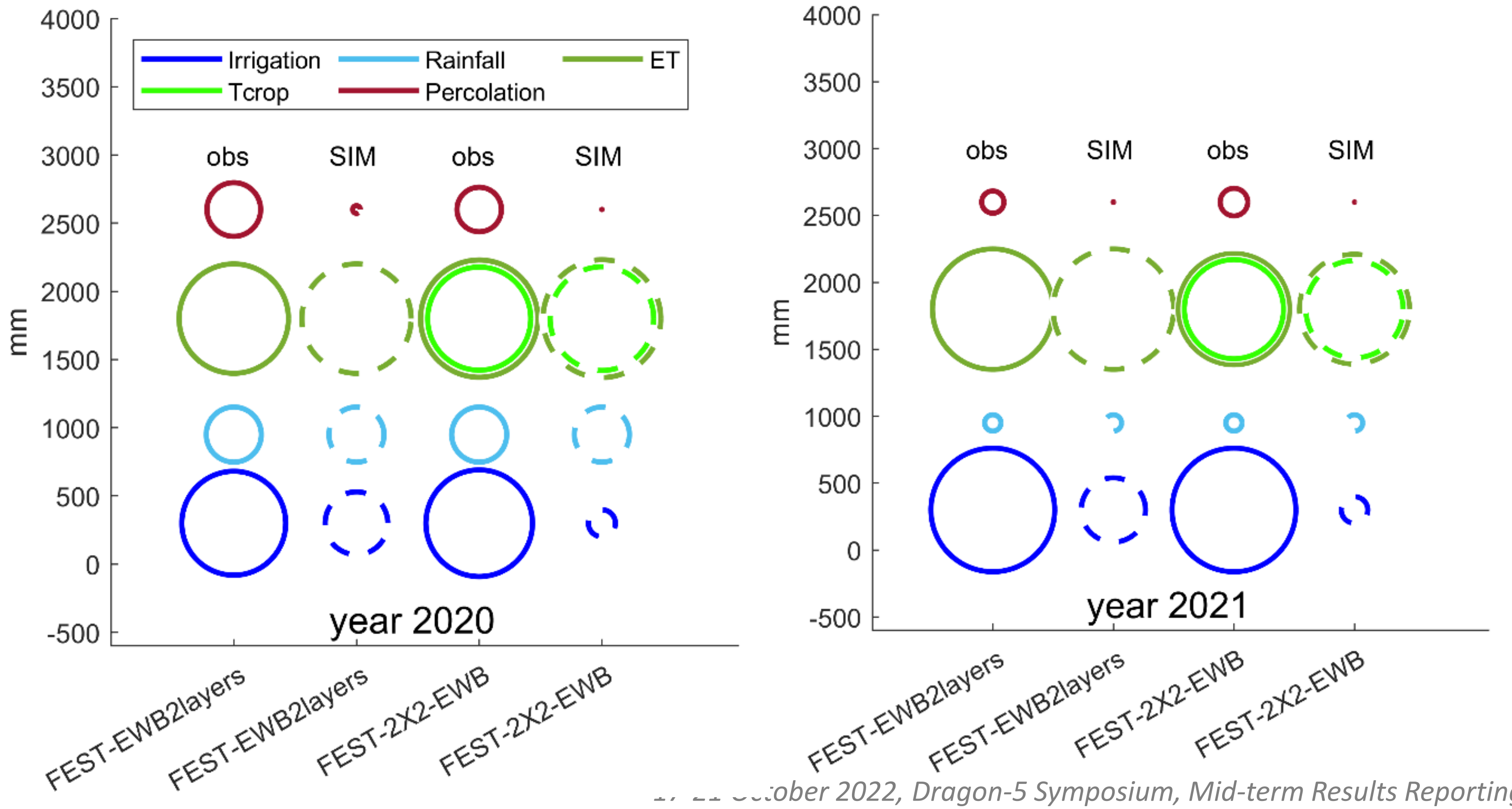


the SMARTIES strategy allows to reduce the passage over the FC threshold reducing the percolation flux with a saving of irrigation volume

$$\Theta_{crit} = f(crop, cultivar, soil, climate)$$

defined through p (FAO) ⇒

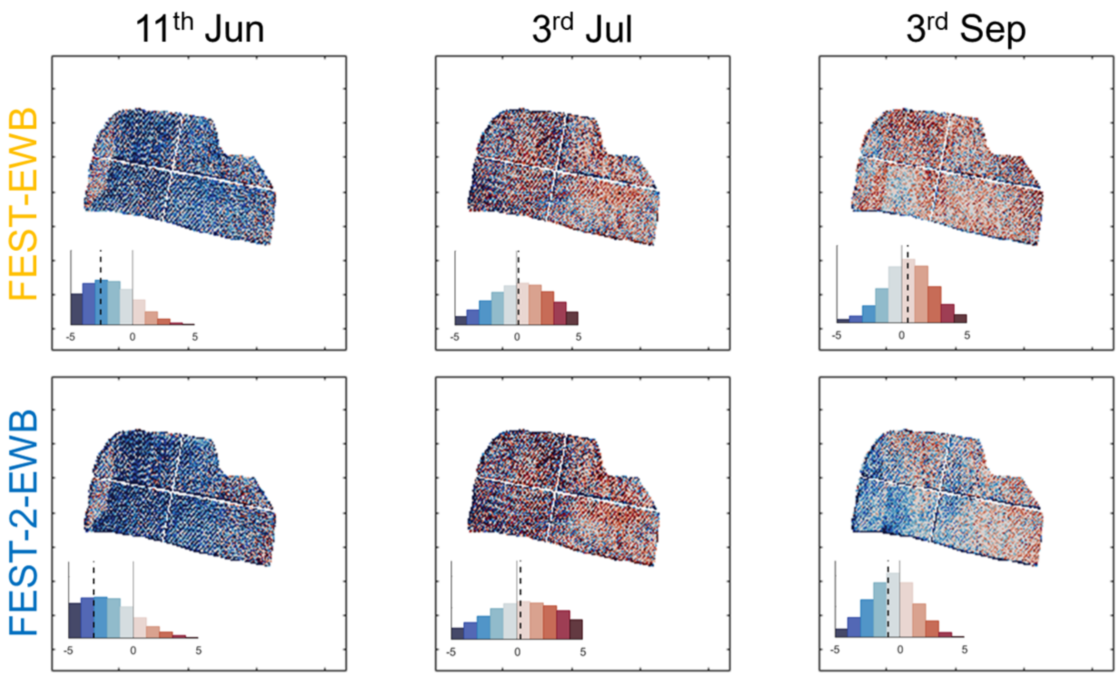
$$\Theta_{crit} = FC - p\,(FC - WP)$$



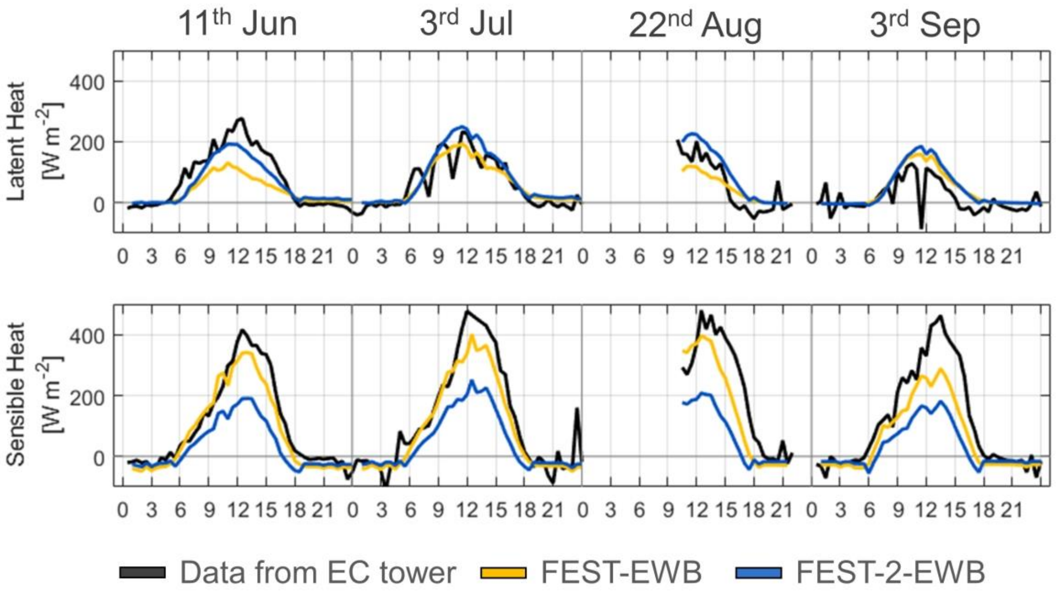
Corbari and Mancini, 2022 IR

Rapitalà vineyard (Italy): FEST-EWB vs FEST-2-EWB

- Vineyard with drip irrigation, with high-resolution (1.7 m) acquisitions carried out via airborne
- Three dates employed for calibration, with similar results (FEST-EWB average RMSE = 2.95°C, FEST-2-EWB = 3.37°C)
- Most pixels cluster within 3°C of the zero-error, with some error patches that could be assigned to temporary cloud transit

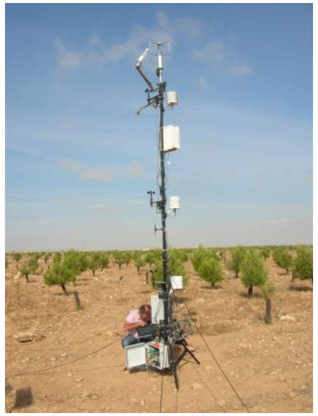


The behavior of the models seems specular: while FEST-EWB captures more closely the Sensible Heat and tends to underestimate the Latent Heat, FEST-2-EWB does the opposite.



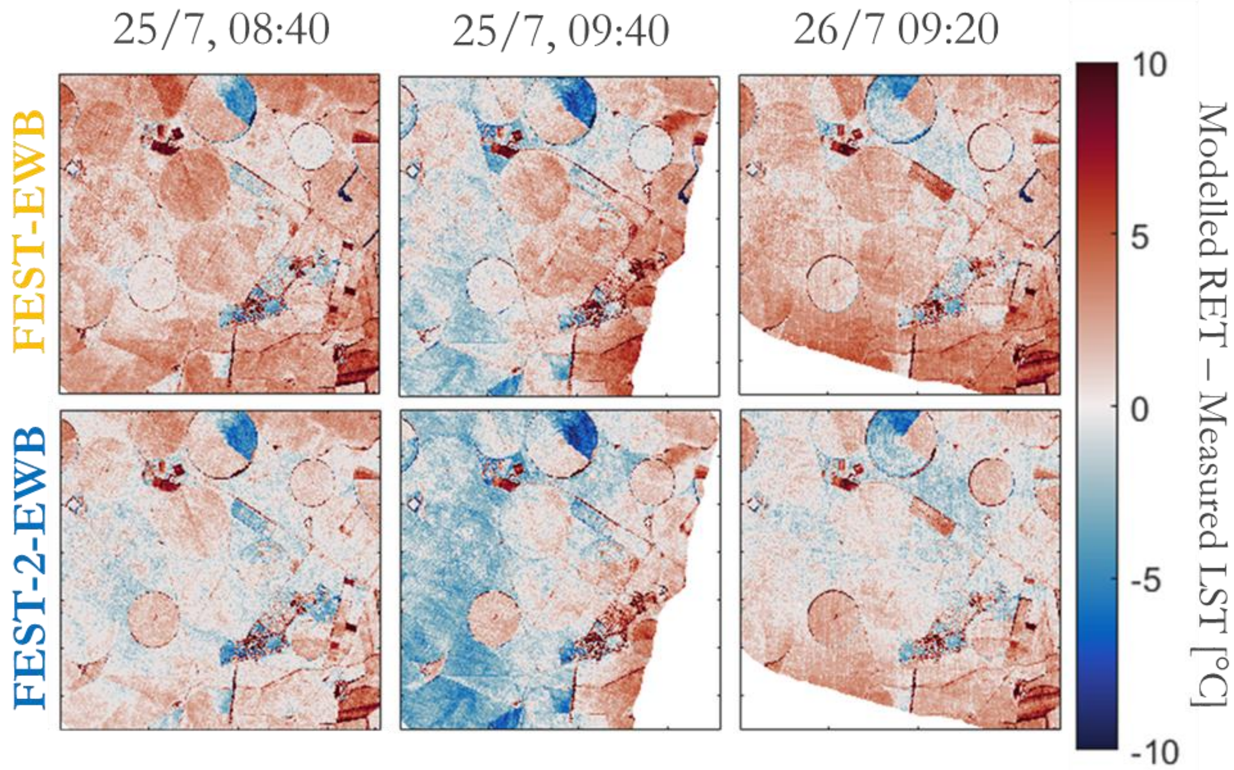
Barrax agricultural area (Spain): FEST-EWB vs FEST-2-EWB

16 to 28 July 2012: **Regional Experiments For Land-atmosphere Exchanges** (REFLEX) - EUFAR (Timmermans et al. 2014)



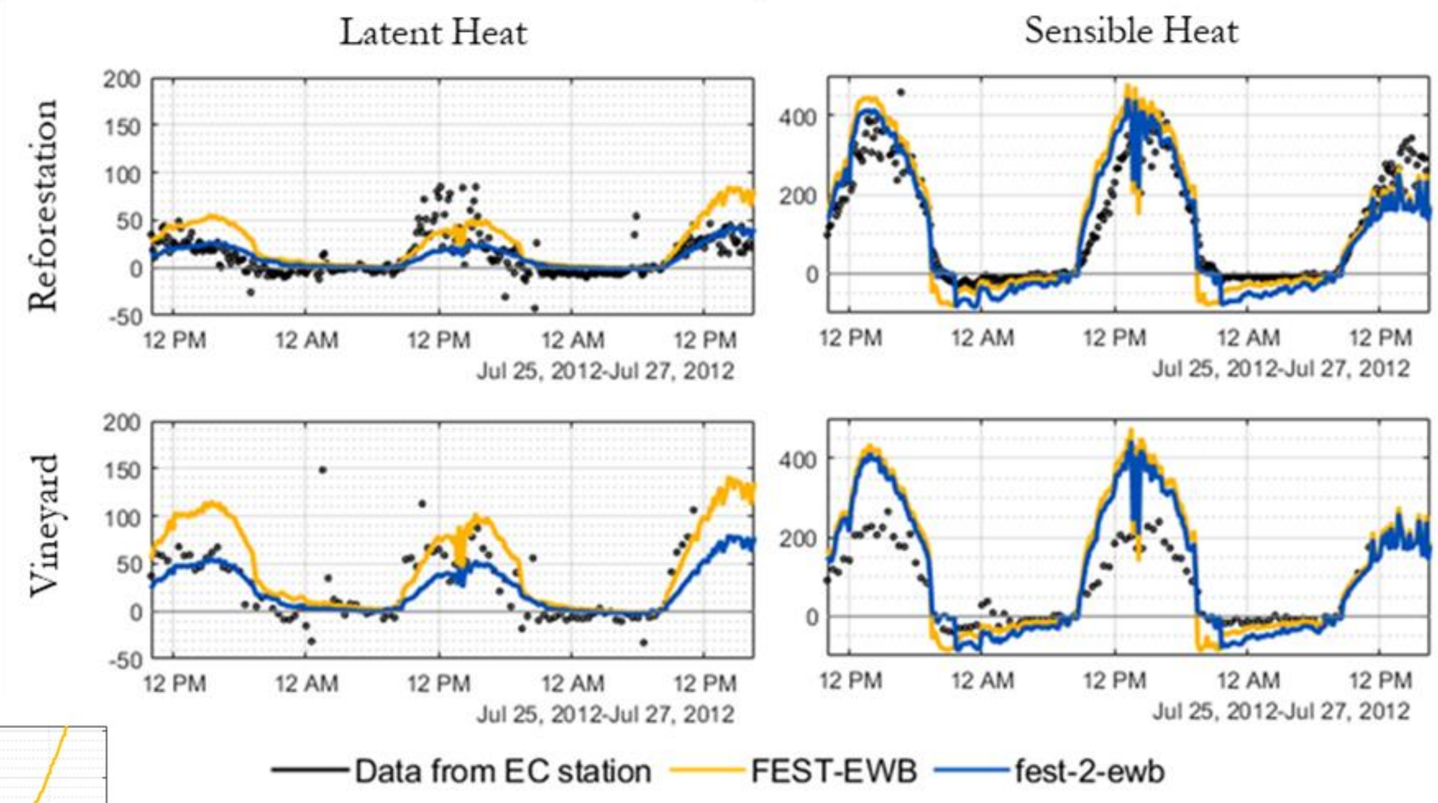
Hyper-spectral and thermal airborne images (AHS) at the resolution of 5 m

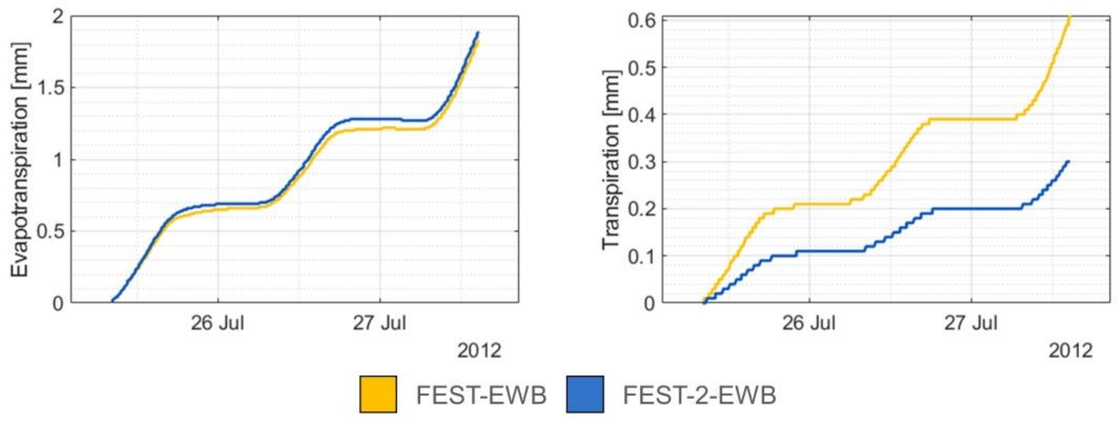
- Mix of pivot-irrigation areas, heterogeneous sectors (orchard, vineyard) and bare soil
- Surface temperature errors are similar for both FEST-EWB (average RMSE = 3.32°C) and FEST-2-EWB (3.37°C)
- **Patch-like error areas** are mainly related to uncertainties related to irrigations volumes data or to ongoing harvest operations not caught by the models



Barrax agricultural area (Spain): FEST-EWB vs FEST-2-EWB

Global Latent Heat peaks are alternatively well-represented by the two models, with no one definitely prevailing over the other. Sensible Heat is partially overestimated, with better results from FEST-2-EWB

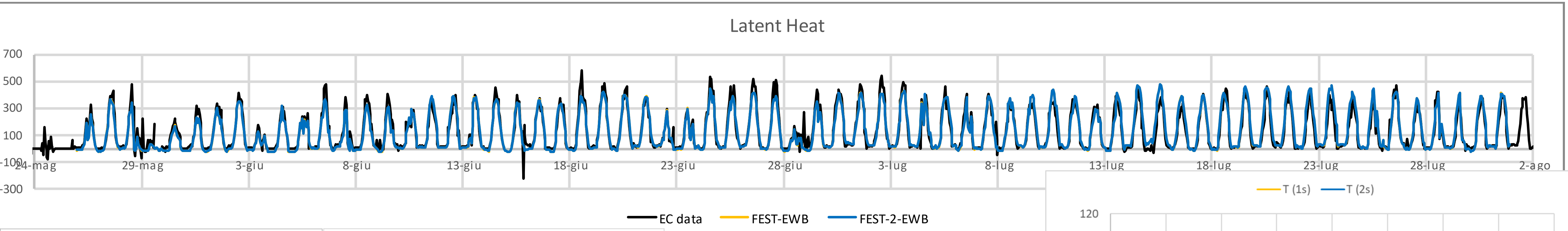


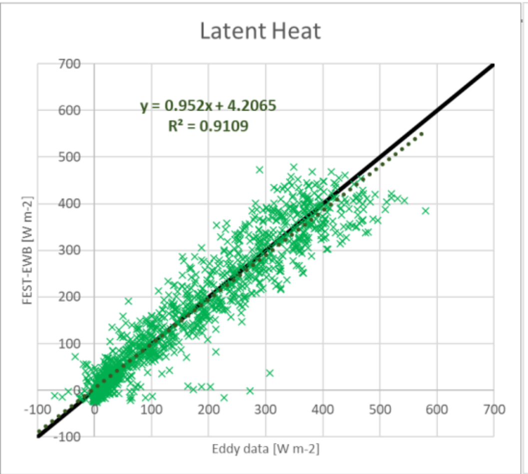


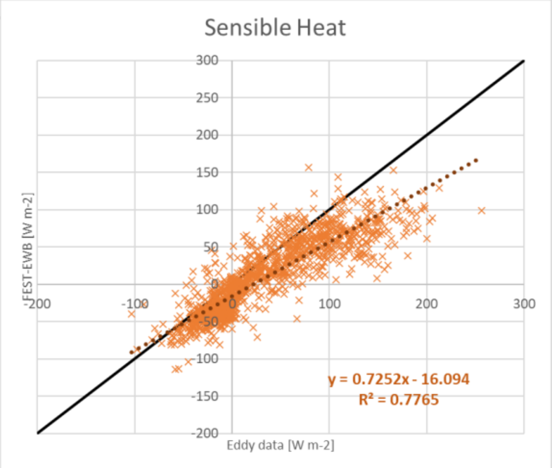
FEST-2-EWB identifies lower amounts of Transpiration, regulated by the cooler crop temperature.

Burana Consortium Italy (first results)

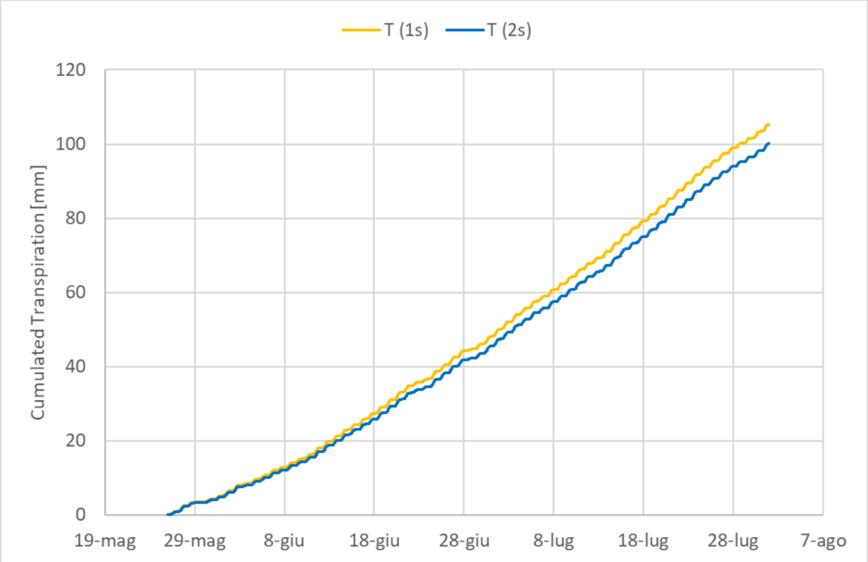
- **Tree crops** area with pears and cherries in Emilia Romagna (Po Valley)
- EC tower in place from late May 2022 + **field measurement campaign** in mid-July 2022
- **Proximal sensing** image acquisitions from airborne instrument at 1 m and 4 m
- Modelling with **FEST-EWB** and **FEST-2-EWB**







At 1 m of spatial resolutions the pixels are almost uniform-> the models are the same



Outline

- Objectives
- **Results Highlights: Progress by Chinese Team**
- Access to EO Data of ESA, Chinese and ESA Third Party Missions
- Young Scientists Contribution & Plans for Academic Exchanges
- Plan for Next Year

Dragon 5 Mid-term Results

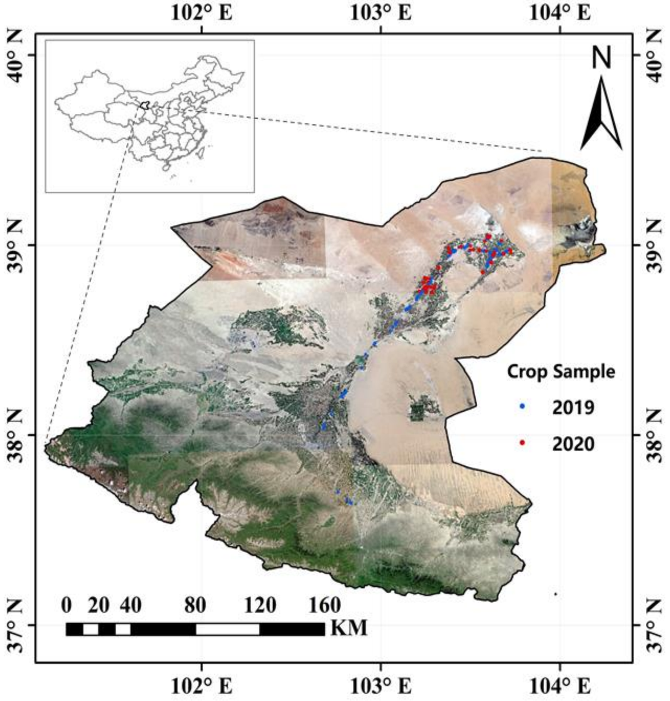
- New algorithm to simultaneously retrieve soil moisture, vegetation optical depth, soil roughness parameter and effective scattering albedo by **SMOS data**, better performance than existing methods
  - Bai Y., Zhao T.J.*, Jia L.*, Cosh M. H, Shi J.C., Zhiqing Peng, Xiaojun Li, Jean-Pierre Wignerone, 2021, A multi-temporal and multi-angular approach for simultaneously retrieving soil moisture and vegetation optical depth from SMOS data, **Remote Sensing of Environment**, 2022, 280, 113190; https://doi.org/10.1016/j.rse.2022.113190. [**also see poster ID 208 by Bai Y.**]
- Global Cropland Gross Primary Production (GPP) by Integrating Water Availability Variable in Light-Use-Efficiency (LUE) Model
  - Du, D.; Zheng, C.; Jia, L.*; Chen, Q.; Jiang, M.; Hu, G.; Lu, J. Estimation of Global Cropland Gross Primary Production from Satellite Observations by Integrating Water Availability Variable in Light-Use-Efficiency Model. **Remote Sensing**, 2022, 14, 1722. https://doi.org/10.3390/rs14071722.
- Crop irrigation efficiency assessment at farmland scale by ETMonitor and **Sentinel-2** MSI data
  - Phan, Jia, et al., 2022, under review
- Crop mapping by **Sentinel-2** MSI data
  - Yi, Jia, Chen et al., 2022, under review
- Calibration and validation of SWAT model in ungauged basins [**see poster ID 216 by Bennour A.**]
  - Bennour, A.; Jia, L.*; Menenti, M.; Zheng, C.; Zeng, Y.; Asenso Barnieh, B.; Jiang, M., 2022, Calibration and validation of SWAT model by using hydrological remote sensing observables in the Lake Chad Basin, Remote Sensing, 2022, 14(6), 1511; https://doi.org/10.3390/rs14061511. Published: 21 March 2022.

(1) Crop early-season mapping by Sentinel-2 MSI data and deep learning algorithms

❑ Objective & Study area

- explore the potential of deep learning algorithms and Sentinel-2 data for early-season crop identification and mapping
- fully exploit the spectral and phenological information in the early to middle crop growing season

Shiyang river basin,
northwestern China



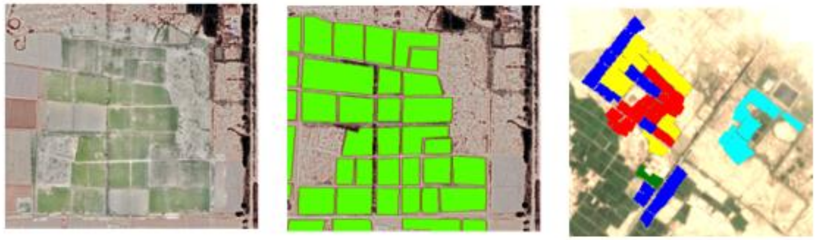
- arid and semi arid
- crops: spring wheat, maize, sunflower, fennel, alfalfa, melon.

Field campaign:
Collection of ground samples

Crop type	Field-plot number		Pixel number	
	2019	2020	2019	2020
Wheat	29	58	2636	4030
Corn	62	166	3702	5358
Melon	78	162	3562	6580
Fennel	30	77	1549	1626
Sunflower	39	159	2522	5352
Alfalfa	30	32	2909	4897

Yi, Jia et al., 2022, under review

Ground samples by field survey

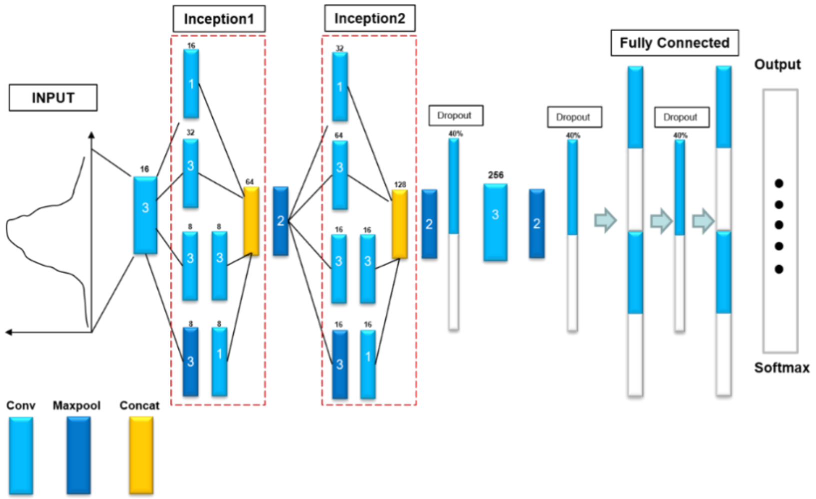


Ground samples by drone

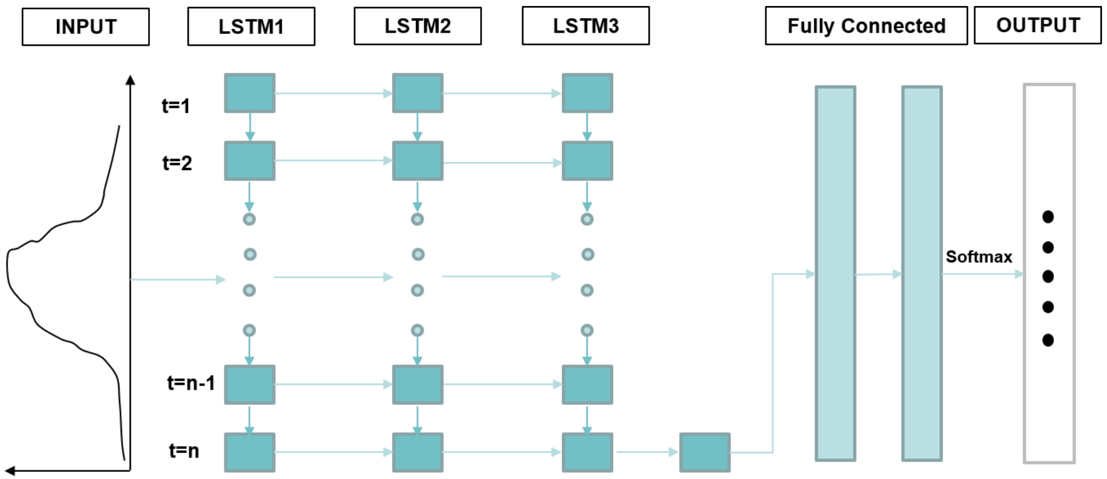
(1) Crop early-season mapping by Sentinel-2 MSI data and deep learning algorithms

❑ Deep learning models

- one-dimensional convolutional neural network (Conv1D)



- long short-term memory (LSTM)



❑ Shallow machine learning models

- Random Forest (RF)
- Support vector machine (SVM)

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(1) Crop early-season mapping by Sentinel-2 MSI data and deep learning algorithms

❑ Feature selection

Sentinel-2 bands

Bands	Name	Central wavelength (nm)	Band width (nm)	Spatial resolution (m)
2	Blue	490	65	10
3	Green	560	35	10
4	Red	665	30	10
5	RE-1	705	15	20
6	RE-2	740	15	20
7	RE-3	783	20	20
8	NIR	842	115	10
11	SWIR-1	1610	90	20
12	SWIR-2	2190	180	20

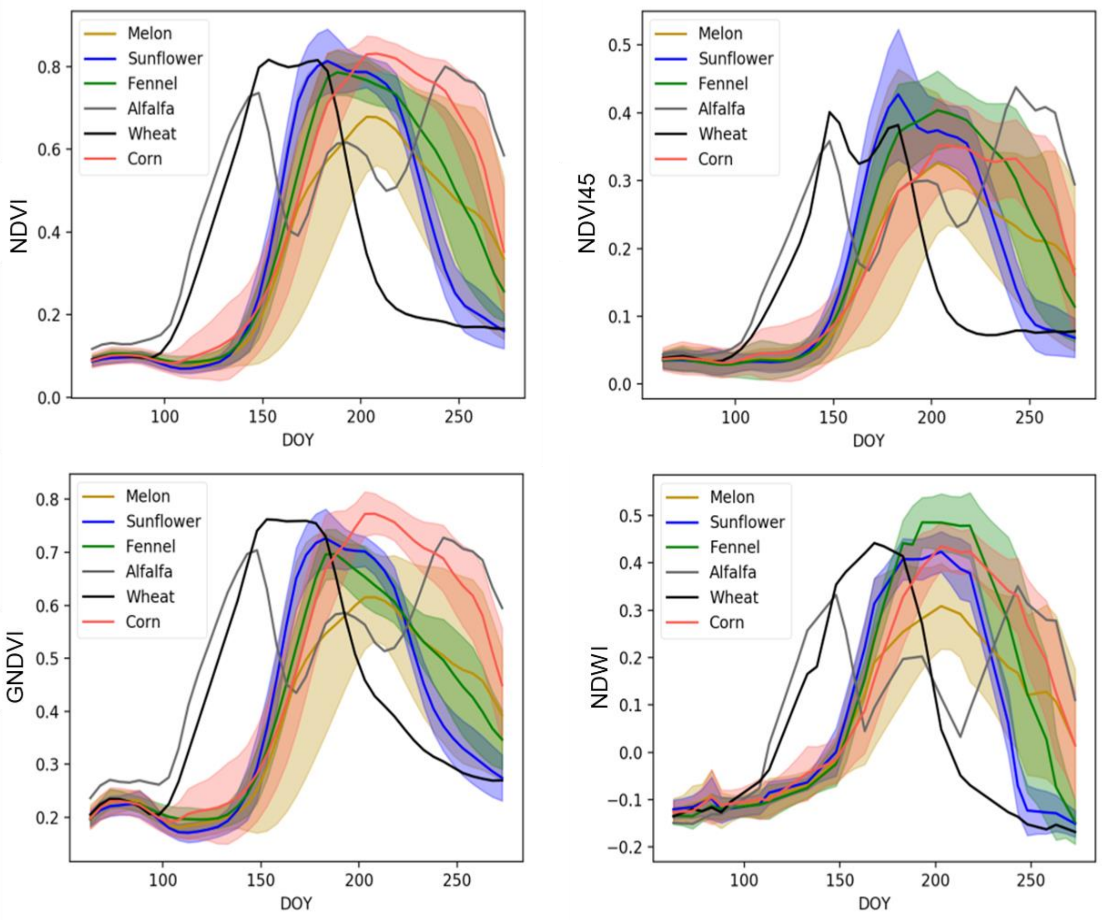
Sentinel-2 based spectral index

$$NDVI = \frac{NIR - R}{NIR + R}$$

$$NDVI45 = \frac{RE1 - R}{RE1 + R}$$

$$GNDVI = \frac{NIR - G}{NIR + G}$$

$$NDWI = \frac{NIR - SWIR1}{NIR + SWIR1}$$



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Dragon 5 Mid-term Progress Highlights

(1) Crop early-season mapping by Sentinel-2 MSI data and deep learning algorithms

❑ Results

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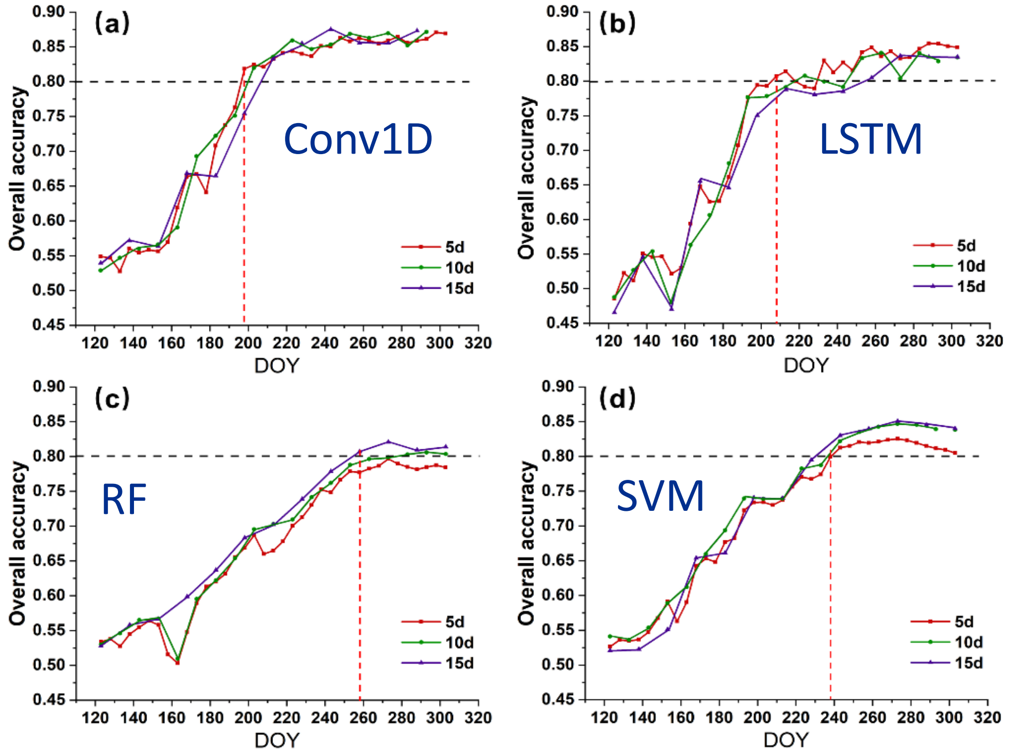
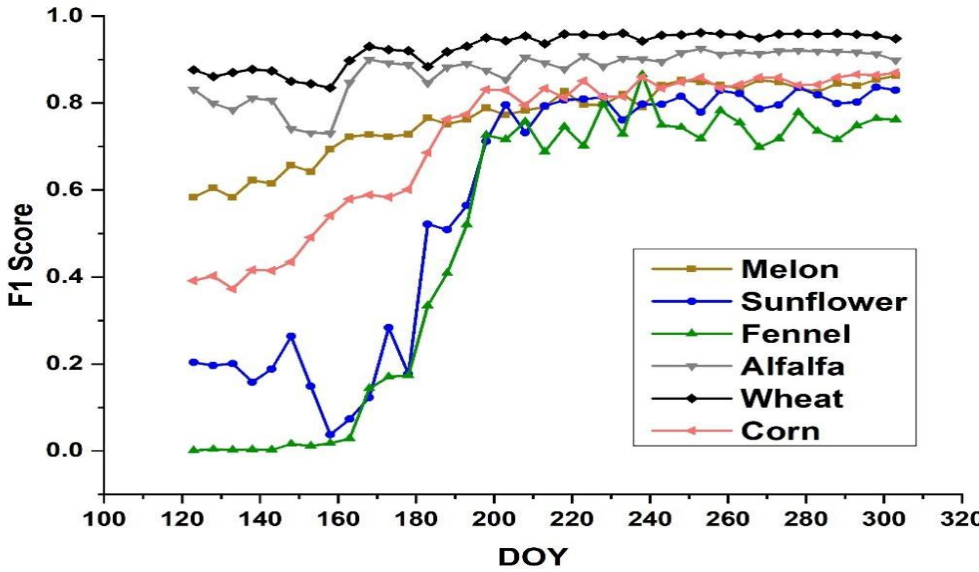
overall accuracy based on the four classifiers and time-series of Sentinel-2 data with different time intervals (5-day, 10-day, and 15-day)





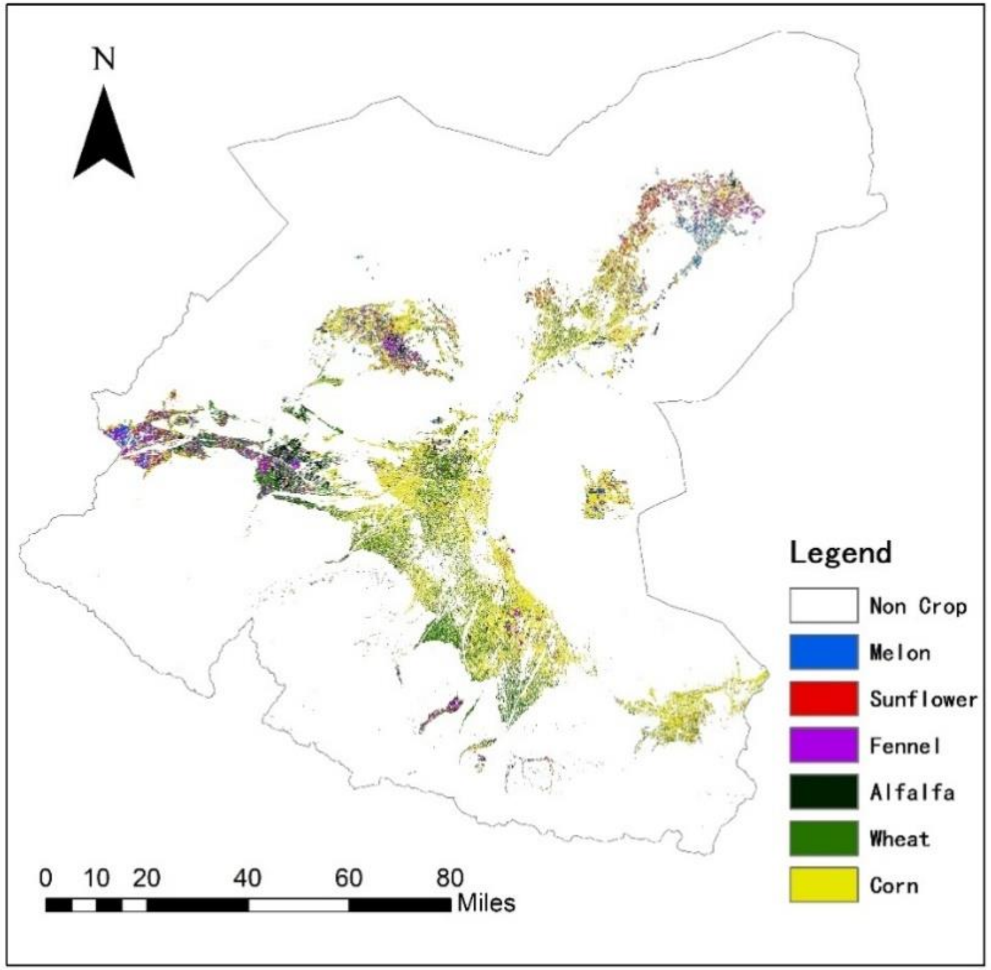
by Conv1D

Month	Mar.	Apr.			May			June			July			Aug.			Sept.			Oct.		
Croptype		E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Sunflower				1		2			3		4		5		6		7					
Fenel			1			2				3		4						5				
Alfalfa	1								2						3					4		
Wheat	1	2				3			4				5									
Corn				1		2				3			4		5		6	7				

(1) Crop early-season mapping by Sentinel-2 MSI data and deep learning algorithms

❑ Results (cont.)

Early-season crop map of 2020
Shiyang River Basin



- Early-season crop map of 2020 by Conv1D and images acquired from DOY63 (early March) to DOY198 (mid of July) in 2020,
- Conv1D network was trained using the images acquired before DOY198 in 2019 and samples from 2019

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(2) Global Cropland GPP Estimation by Integrating Water Availability Variable in LUE Model

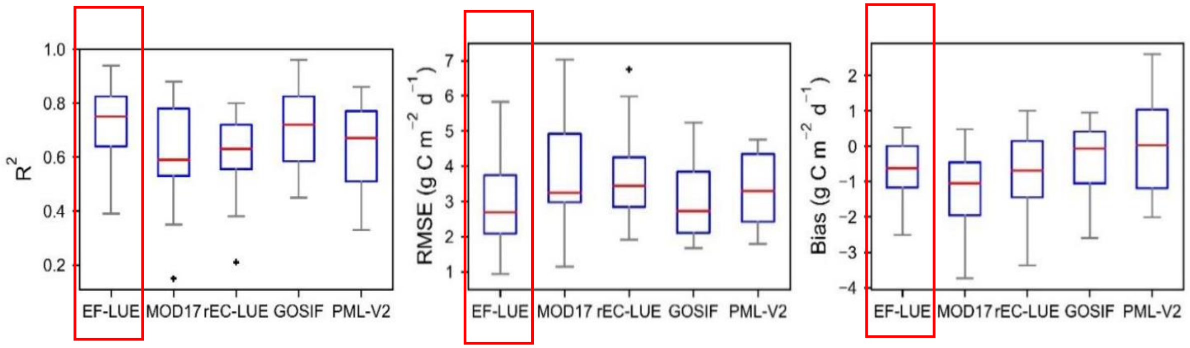
Significance: GPP is a critical variable to assess water use efficiency (WUE). **EF-LUE model** for cropland GPP estimation, driven by remote sensing data, was developed by integrating evaporative fraction (EF) as limiting factor accounting for soil water availability.

$$GPP = APAR \times \varepsilon_{max} \times F_T \times F_{VPD} \times F_W$$

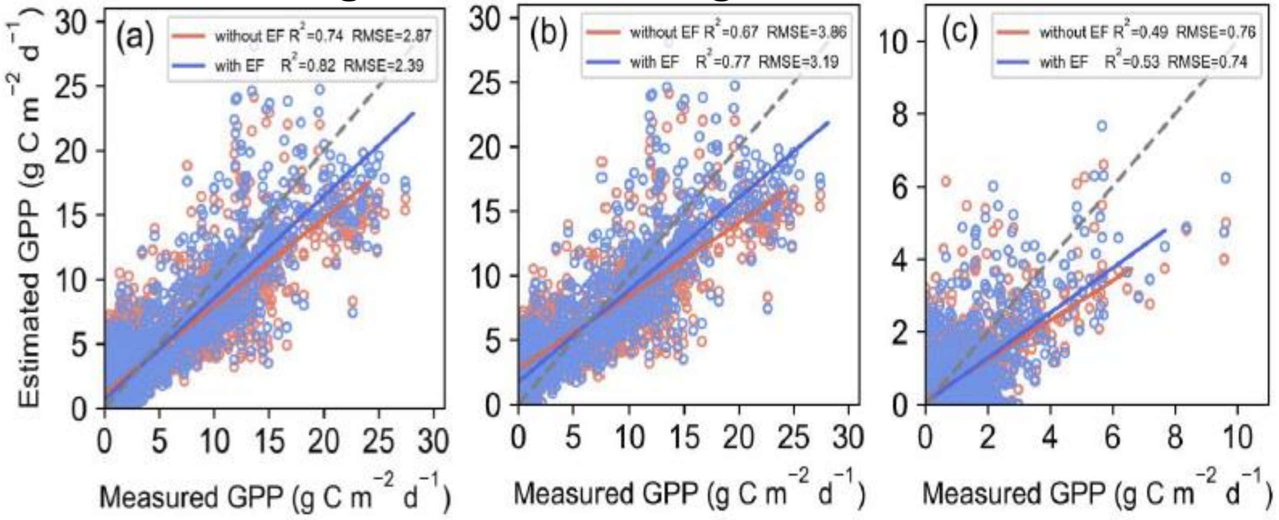
$$F_W = \min\{1, \max(0, EF)\}$$

$$EF = \frac{LE}{LE + H} = \frac{LE}{R_n - G}$$

- GEOV2/VTG FAPAR data were used
- Global cropland GPP product (2001-2018) were generated



Validation against flux tower ground measurements

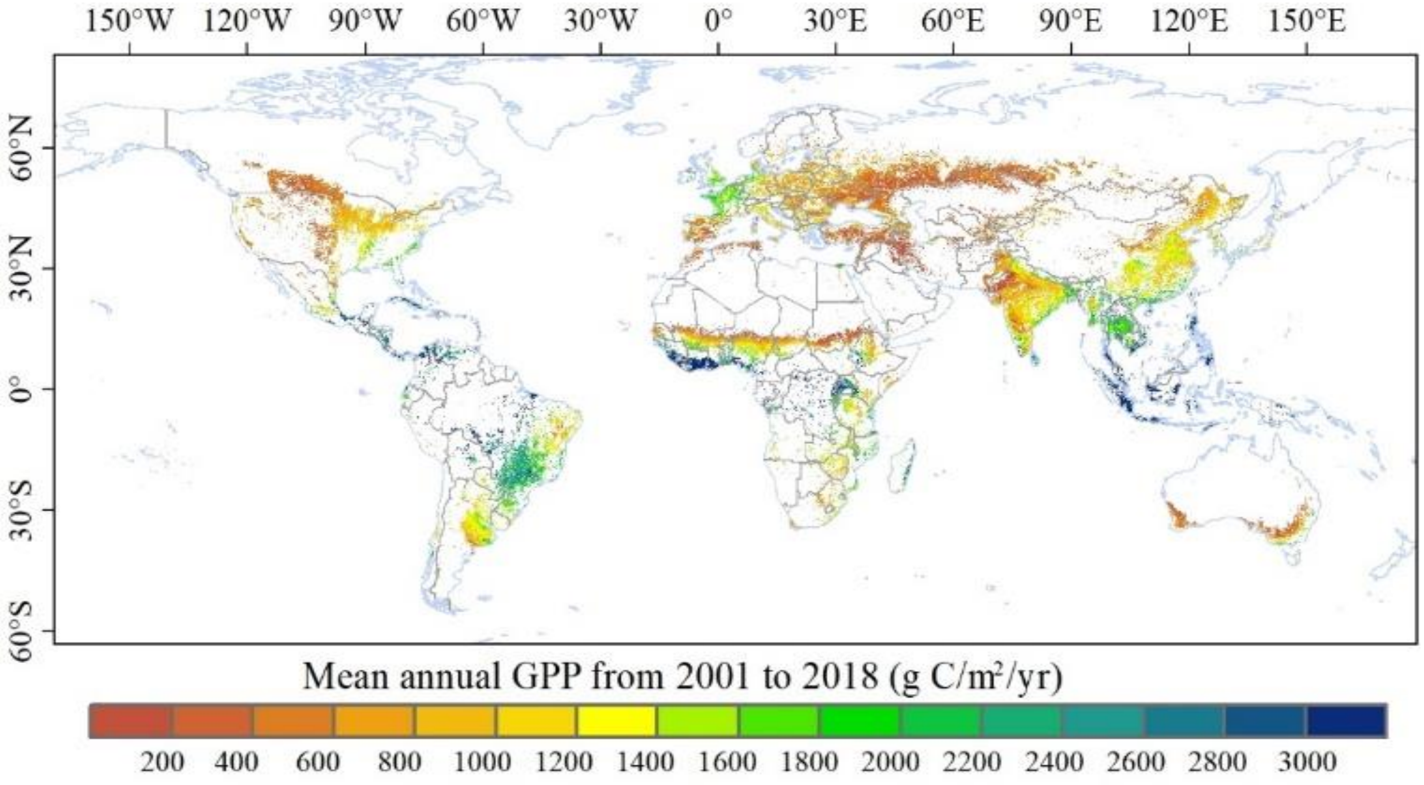


✓ EF-LUE model shows better accuracy

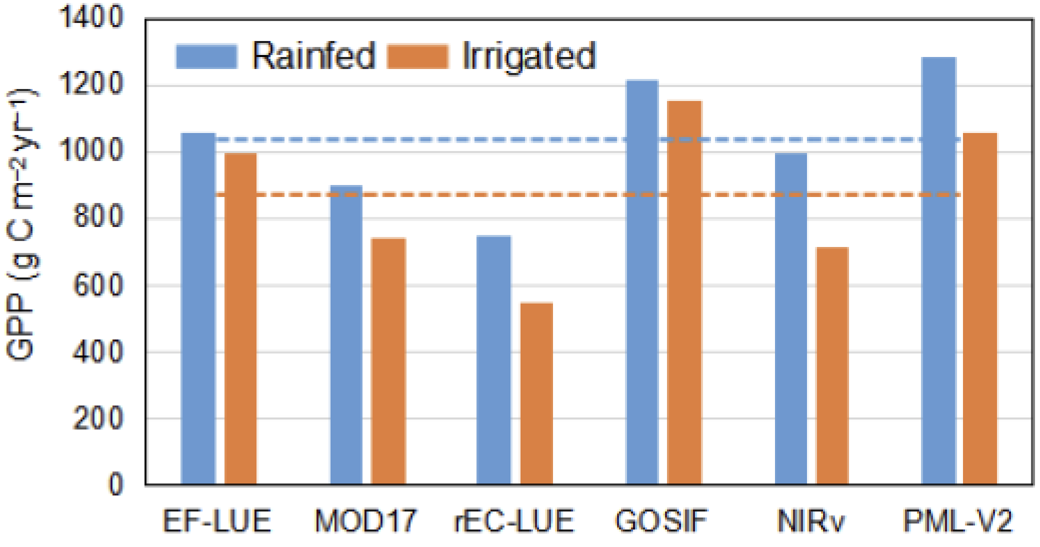
Du, Zheng, Jia, et al. 2022, RS

(2) Global Cropland GPP Estimation by Integrating Water Availability Variable in LUE Model

Global cropland GPP product (2001-2018)



Annual mean GPP by the EF-LUE model and other GPP products in rainfed and irrigated croplands (2002 – 2018)



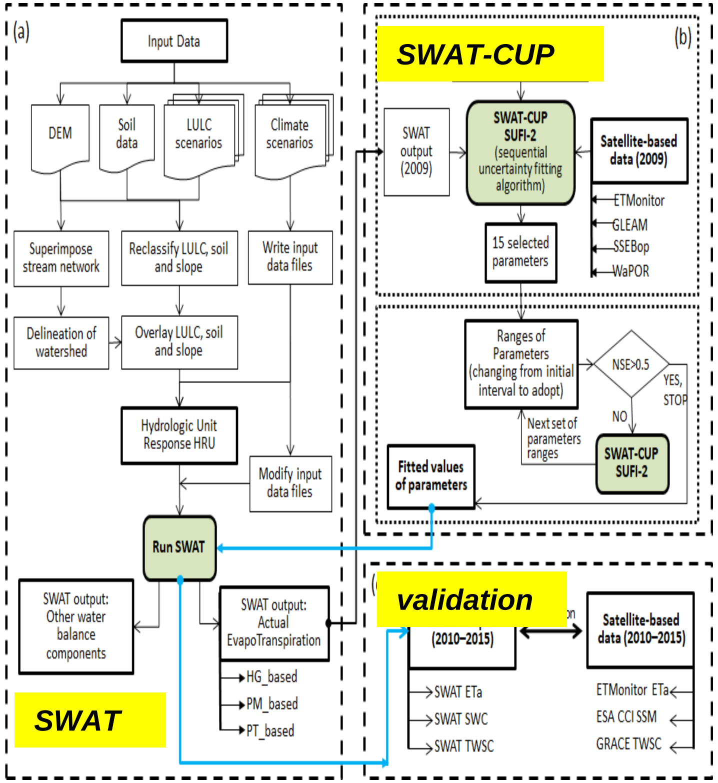
GEOV2/VTG FAPAR data were used

Du, Zheng, Jia, et al. 2022, RS

(3) Improving Hydrological Modelling by Satellite Observations/Products in Ungauged Regions

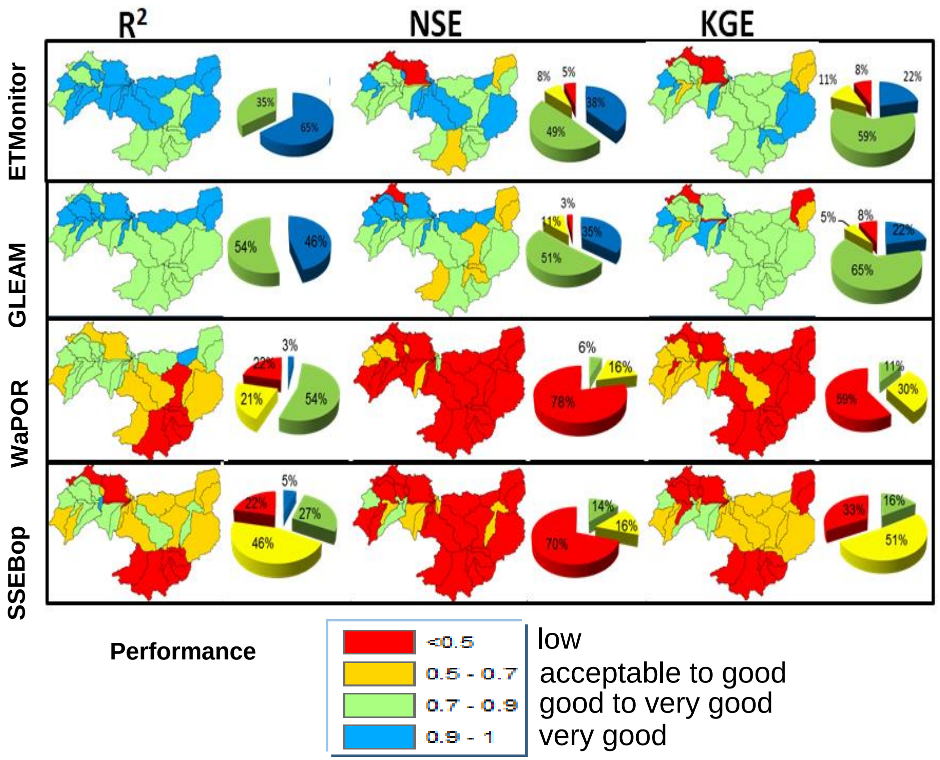
- Evaluate the performance of SWAT model after a limited calibration period using multiple remote sensing ET products
- Validate the model using remote sensing ET, TWS, and SM in a distributed manner in the Lake Chad Basin

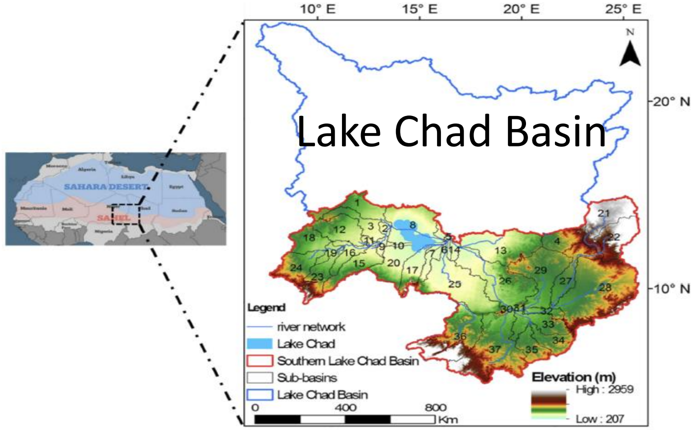
Algorithm



Bennour, Jia et al., 2022, RS

Calibrating SWAT by remote sensing ETa

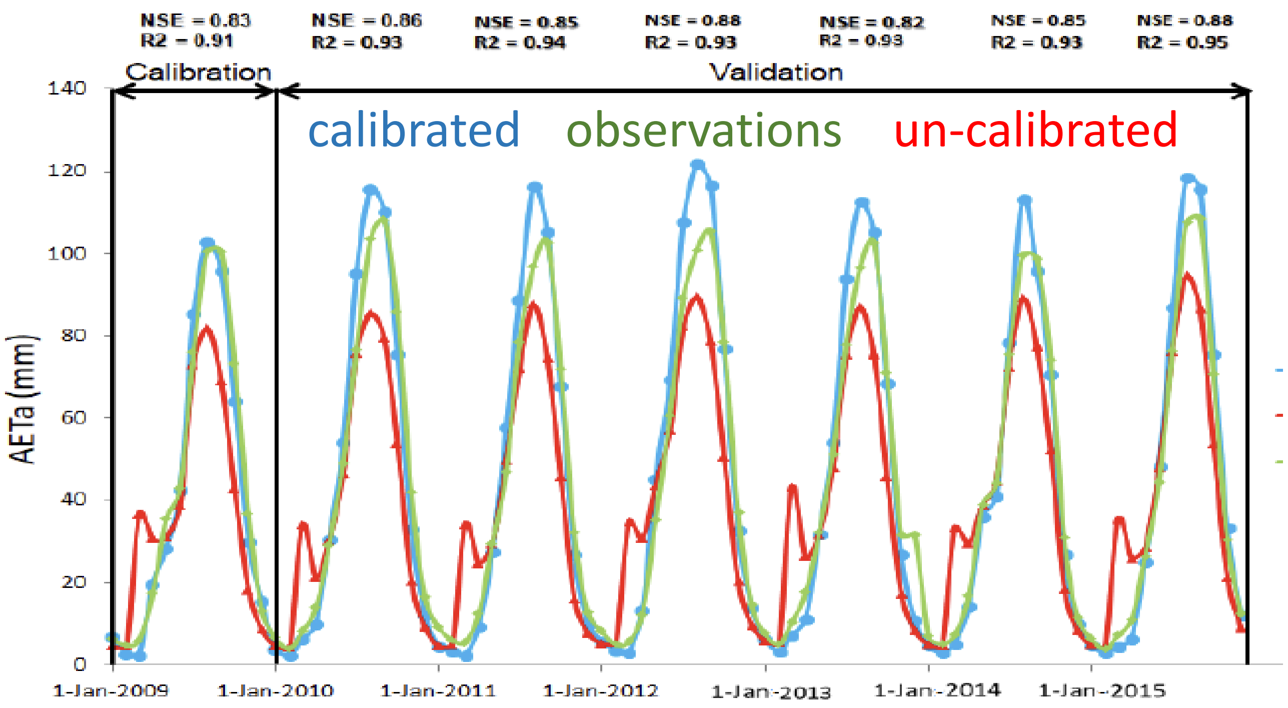




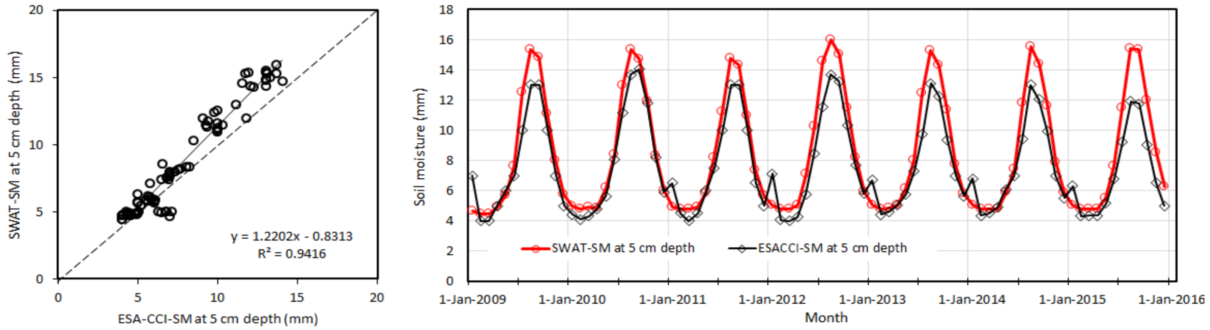
Spatial distribution of performance metrics (R^2, NSE, and KGE) of SWAT_Hargreaves, when calibrated in 2009 against ETMonitor, GLEAM, WaPOR, and SSEBop the Lake Chad Basin.

(3) Improving Hydrological Modelling by Satellite Observations/Products in Ungauged Regions

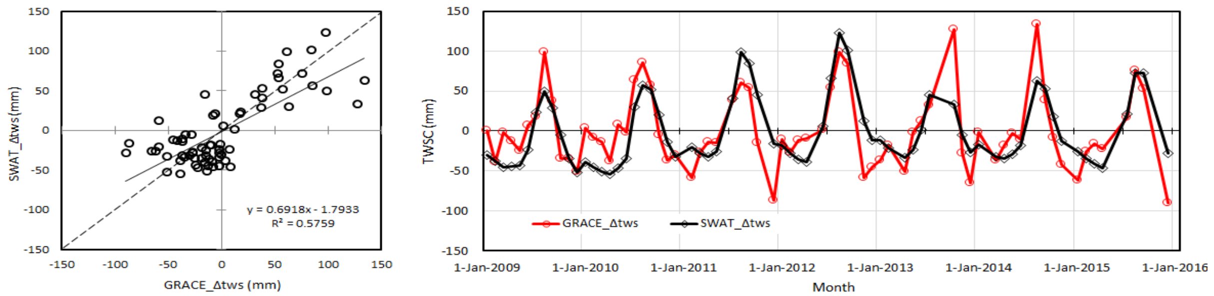
Comparison of simulated ET before and after calibration



SM validation



TWSC validation



- The limited calibration (one year on a monthly timescale) results showed that the remote sensing products are useful to calibrate and validate the SWAT model in arid and semi-arid basins with poorly gauged condition.

Bennour, Jia et al., 2022, RS

EO Data Access

ESA Missions	No. Scenes
1. Sentinal-2	1766
2. Sentinal-1	40
3. SMOS	FTP
4. ASCAT	FTP
Total:	1806

ESA Third Party Missions	No. Scenes
1. Landsat 7/8/9	100
2. Planet	4
3. SMAP	FTP
4. SPOT/VTG	FTP
Total:	104

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

Young Scientists Contributions & Plans for Academic Exchanges

❑ Chinese Young scientists contributions

Young scientists	Institution	Contributions	Poster title
Yu Bai	AIRCAS	SMOS soil moisture algorithms and dataset	[poster ID 208] A Multi-temporal and Multi-angular Approach for Systematically Retrieving Soil Moisture and Vegetation Optical Depth from SMOS
Ali Bennour	AIRCAS	SWAT model calibration and validation	[poster ID 216] Calibration and Validation of Hydrological Model by Applying Satellite-Based Observables in the Lake Chad Basin
Zhiwei Yi	AIRCAS	Crop mapping	
Dandan Du	AIRCAS	GPP estimation	
Qiting Chen	AIRCAS	Crop classification, crop yield estimation, crop water use	
Peejush Pani	AIRCAS	Water use and irrigation efficiency assessment	
Chaolei Zheng	AIRCAS	Water use and field data collection campaigns	
Min Jiang	AIRCAS	Field data collection	
Guangcheng Hu	AIRCAS	Water use estimation	

❑ European Young scientists contributions

Name	Institution	Contributions	Poster title
Nicola Paciolla	Politecnico di Milano	Modeling and data analysis activities	ET estimates across scales using remotely sensed LST and an energy-water balance model

❑ Plans of academic visits by Chinese YS to Europe:

- Dr. Chaolei Zheng visit in 2022-2023
- Dr. Min Jiang visit in 2023-2024

Plan for Next Year

- Data-assimilation of LST, LAI and SM into the FEST-EWB-SAFY crop-energy-water balance model for ET and yield update
- Upscaling of the developed models at Consortium scale
- Assessing high resolution irrigation water demand maps with different techniques
- Assessing farmland crop water use efficiency using high resolution data using ETMonitor and EF-LUE models

- Generating global SMOS products using the new algorithm
- Assessing global crop water use efficiency

Thank you!

DRAGON 5 ID. 59061

PROJECT TITLE:

SATELLITE OBSERVATIONS FOR IMPROVING IRRIGATION WATER MANAGEMENT (SAT4IRRIWATER)

PRINCIPAL Investigators Project Summary Presented By
Li Jia (AIR-CAS) and Marco Mancini (POLIMI)