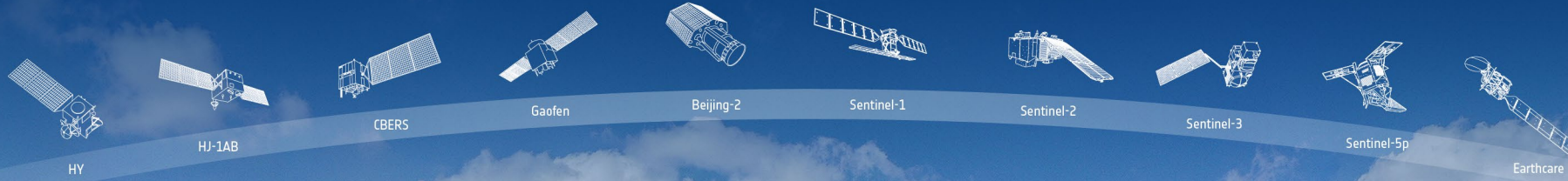




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2025 DRAGON 6 SYMPOSIUM

14-18 JULY 2025

PROJECT ID. 95441

SYNERGY OF THERMAL AND SOLAR-INDUCED FLUORESCENCE REMOTE SENSING FOR CROP WATER STRESS MONITORING



2025 Dragon 6 Symposium



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WEDNESDAY, 2025/07/16

ID. 95441

PROJECT TITLE: SYNERGY OF THERMAL AND SOLAR-INDUCED FLUORESCENCE REMOTE SENSING FOR CROP WATER STRESS MONITORING

PRINCIPAL INVESTIGATORS: PATRICK MATGEN¹, YELU ZENG²

CO-AUTHORS: TIAN HU¹, CHIARA CORBARI³, YAOKUI CUI⁴, XINJIE LIU⁵, PENG ZHU⁶

1. LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY, BELVAUX, LUXEMBOURG

2. CHINA AGRICULTURAL UNIVERSITY, BEIJING, CHINA

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4. PEKING UNIVERSITY, BEIJING, CHINA

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6. UNIVERSITY OF HONG KONG, HONG KONG, CHINA



PRESENTED BY: PATRICK MATGEN, TIAN HU, CHIARA CORBARI, YELU ZENG

香港大學

Transition to Smart Agriculture in the 21st Century

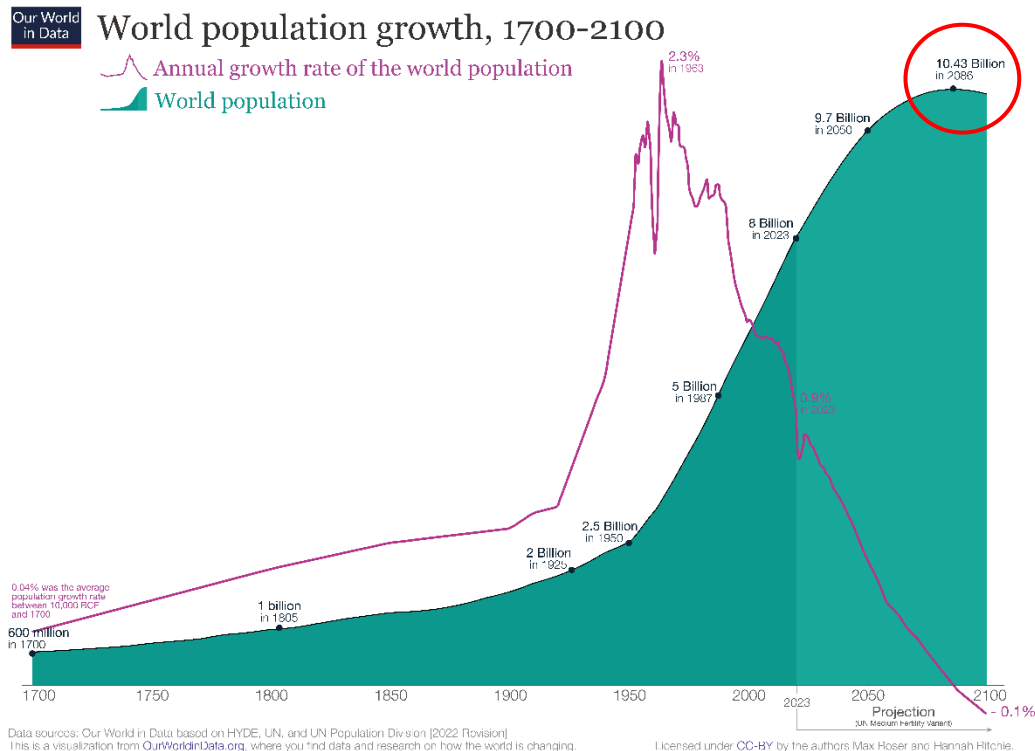


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Population 'explosion' in the 21st century



Urgency for new agricultural practices to meet the high demand of food!



Traditional agriculture

- Labor intensive
- Simple tools
- Dependent on the experience of farmers
- Low efficiency



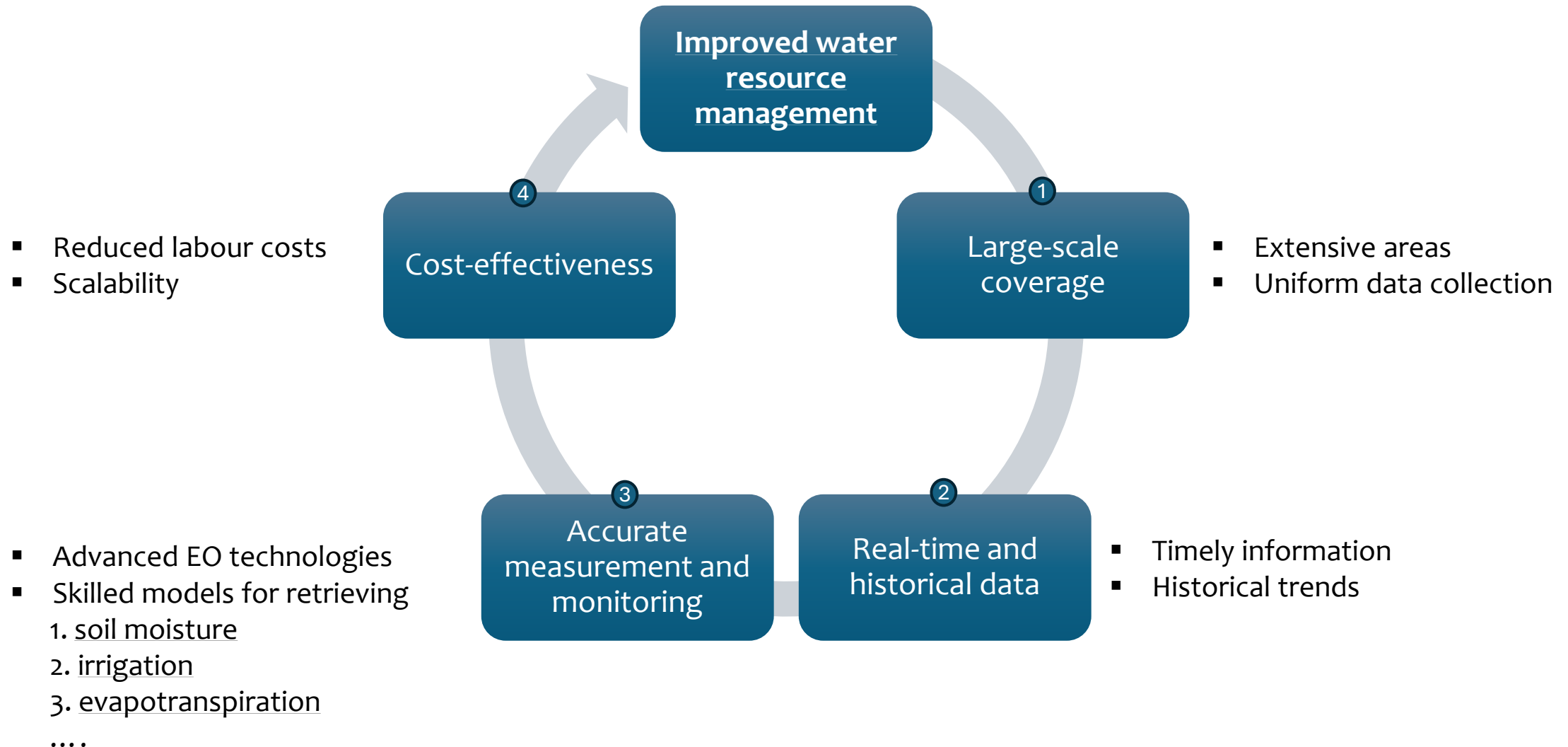
Smart agriculture

- Optimized human labor use
- Incorporation of advanced mechanization
- **Utilization of high-tech measures (e.g., EO, ML, 5G)**
- Enhanced productivity and efficiency



Advantages of EO in Agriculture Water Accounting

Smart Agriculture



Significance of Synergy of TIR and SIF



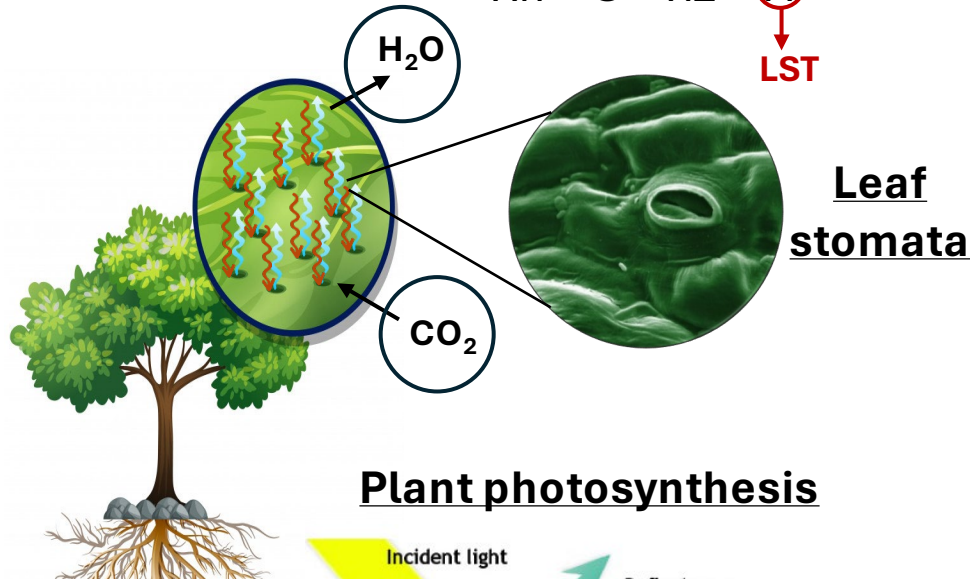
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Surface energy balance

$$R_n = G + \lambda E + \textcircled{H} \downarrow \text{LST}$$



Plant photosynthesis

☐ LST

1. LST is directly linked to canopy evapotranspiration due to the energy partitioning, modulated by stomatal conductance
2. Both **soil evaporation and plant transpiration** contribute to canopy evapotranspiration

☐ SIF

1. SIF is directly linked to plant's photosynthetic status, and observable before stomatal closure
2. SIF is sensitive to various plant physiological stressors, such as **water, heat, and biotic stress**

Combining TIR and SIF provides a robust diagnosis of water stress by linking the physiological cause (photosynthetic decline captured by SIF) with the physical consequence (evaporative decline measured by LST)

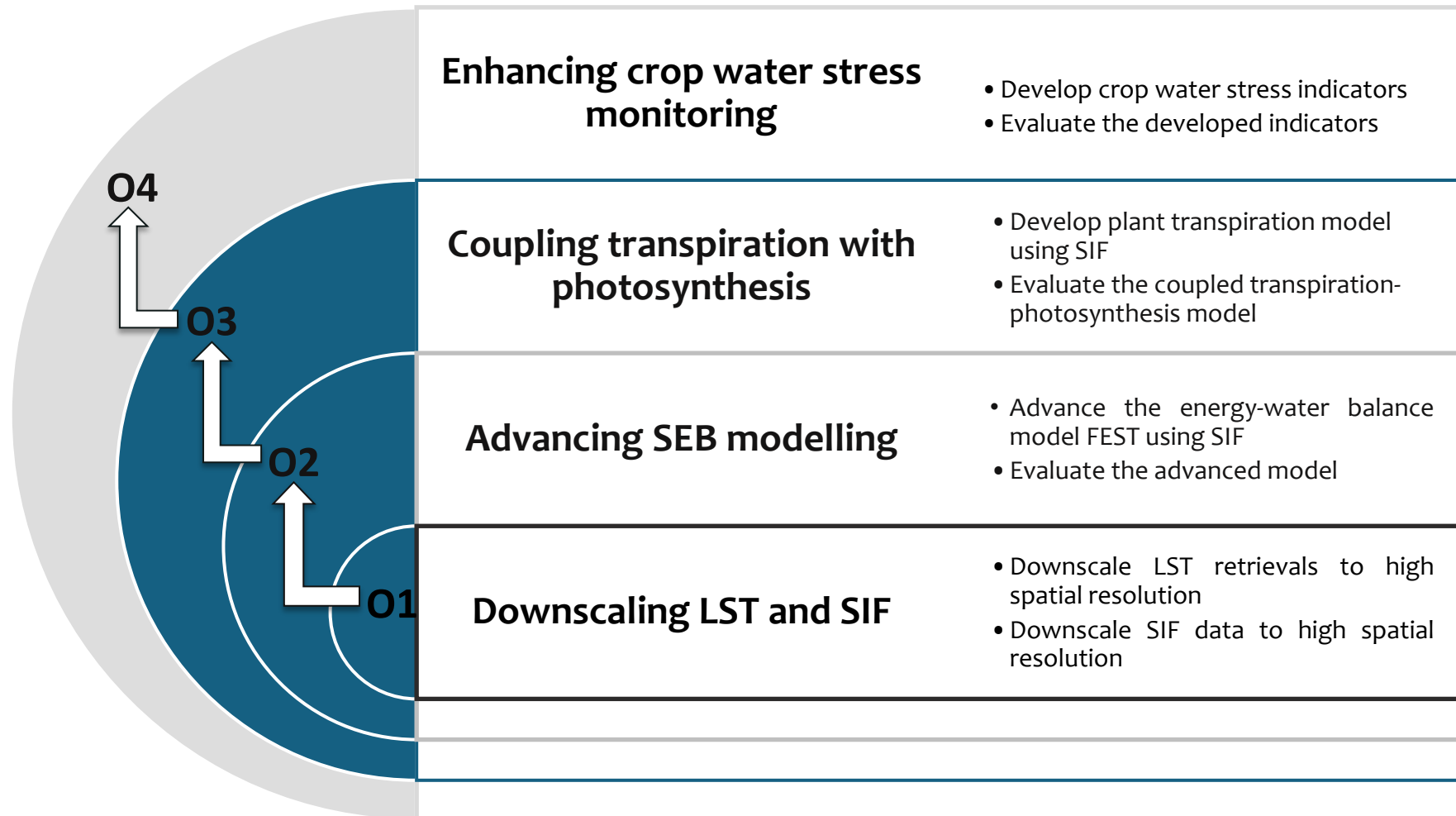
Objectives of the Project



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European Young Scientists Contributions in Dragon 6



Name	Institution	Poster title	Contribution including period of research
Pedro Torralbo Munoz	Politecnico di Milano	Evapotranspiration Estimation by the Combined Use of an Energy-Water Balance Model and Geostationary Land Surface Temperature Data	06/2024 – 06/2026, Integrating SIF into the energy-water balance model FEST for accurate retrieval of evapotranspiration

Chinese Young Scientists Contributions in Dragon 6



Name	Institution	Poster title	Contribution including period of research
Yongyuan, Gao	China Agricultural University	Vegetation drought monitoring in the Huang-Huai-Hai Plain of China using solar-induced fluorescence and near-infrared reflectance of vegetation	06/2024 – 06/2026, Investigating drought mechanisms by developing a monitoring framework that combines SIF and near-infrared data for the Huang-Huai-Hai Plain.
Qing, Li	China Agricultural University	Individual Tree Carbon Estimation with Integrated UAV-LiDAR and High-Resolution Optical Imagery	06/2024 – 06/2028, Developing a novel methodology for accurately estimating carbon storage in individual trees by fusing high-resolution optical imagery with UAV-LiDAR point clouds.
Yanan, Wei	China Agricultural University	Integrating UAV-Derived Enhanced Disease Detection Index and Texture Features for Monitoring Southern Corn Rust Severity	06/2024 – 06/2028, Creating and validating an enhanced index from UAV-based multispectral and texture data for the early detection and severity assessment of Southern Corn Rust.

Dragon 6 EO Data Delivery



Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since June 2024) 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”

ESA /Copernicus Missions	No. Scenes	ESA Third Party Missions	No. Scenes	Chinese EO data	No. Scenes
1. Sentinel-2 MSI Level 2a	50	1.		1. GF-1 WFV	
2. Sentinel-5P TROPOMI L2	50	2.		2. GF-6 WFV	
3. Sentinel-3 SLTSR		3.		3. SDGSAT-1 Thermal IR Spectrometer	
4.		4.		4.	
5.		5.		5.	
6.		6.		6.	
Total:		Total:		Total:	
Issues:		Issues:		Issues:	

In-situ Data Measurements



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Ground sites for LST measurements (Europe)

Site location	Site ID	Latitude (°)	Longitude (°)	Source	Surface type
Fuente Duque, Donana, Spain	FDU	36.998	-6.434	GCU	Marshland
Balsa Blanca, Cabo de Gata, Spain	CDG	36.939	-2.034	GCU	Woody savannas
Evora, Portugal	EVO	38.574	-7.914	KIT	Savannas

Eddy covariance sites for ET measurements (Europe)

Site ID	Surface type	Latitude (°)	Longitude (°)	Mean annual precipitation (mm)	Source
ES-LM1, Spain	Savannas	39.94	-5.78	700	EFDC
ES-Abr, Spain	Savannas	38.70	-6.79	400	EFDC

Ground sites for SIF measurements (China)

Site	Latitude (°)	Longitude (°)	Climate	Crop type
Huailai	40.3491	115.7880	Temperate continental monsoon	Winter wheat
Huairou	40.3804	116.6953	Warm temperate semi-humid	Winter wheat
Xiaotangshan	40.179	116.443	North temperate semi-humid monsoon	Winter wheat and summer corn rotation
Weishan-Gaoying Division	36.6487	116.0542	Warm temperate semi-humid monsoon	Winter wheat - summer corn rotation
Weishan	36.3874	116.1397	Warm temperate semi-humid monsoon	Winter wheat - summer corn rotation
Shangqiu	34.587	115.5753	sub-humid warm temperate monsoon	Winter wheat

Background (LIST)

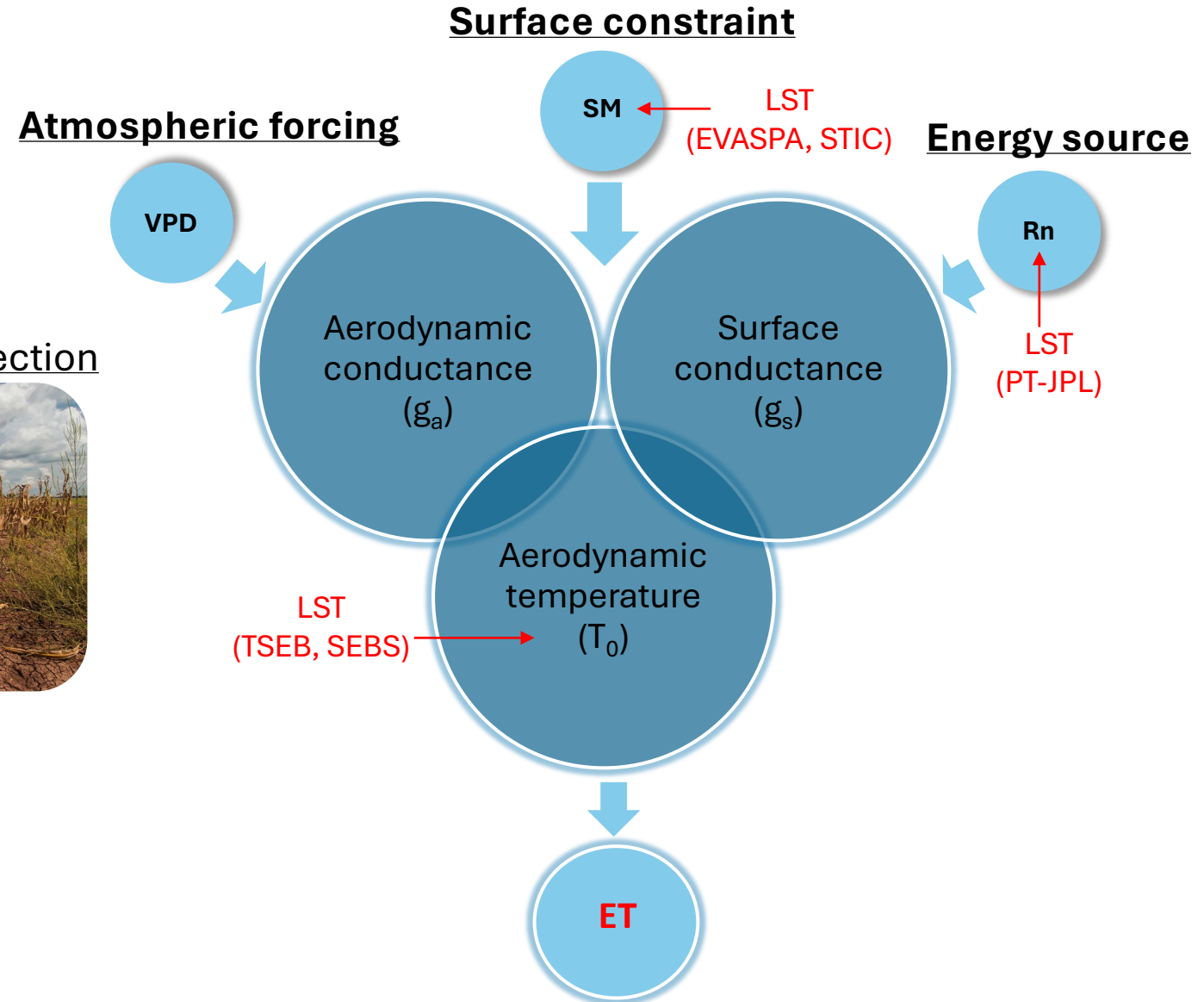
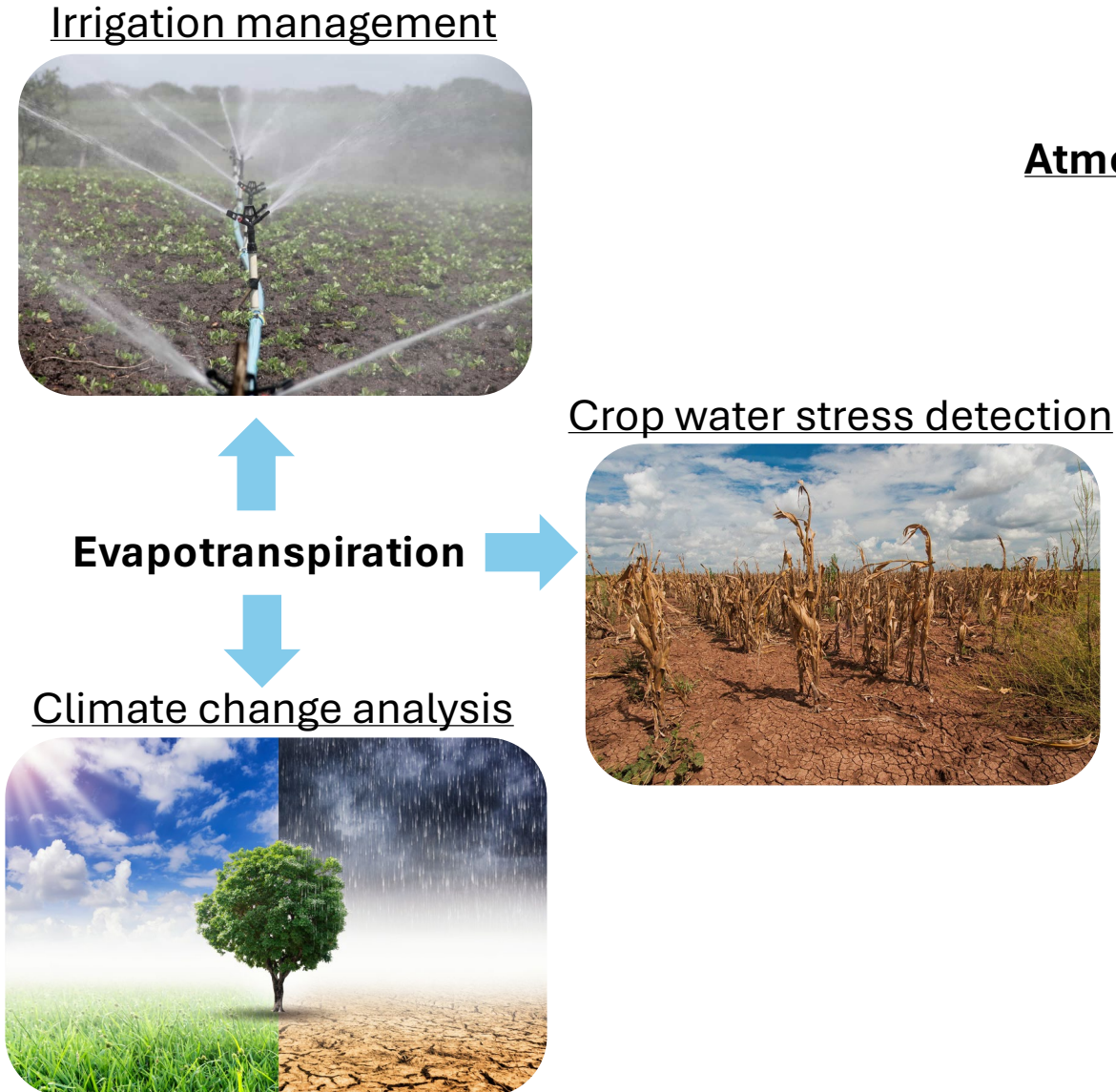


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Role of LST in surface energy balance



Progress at the European Side (LIST)

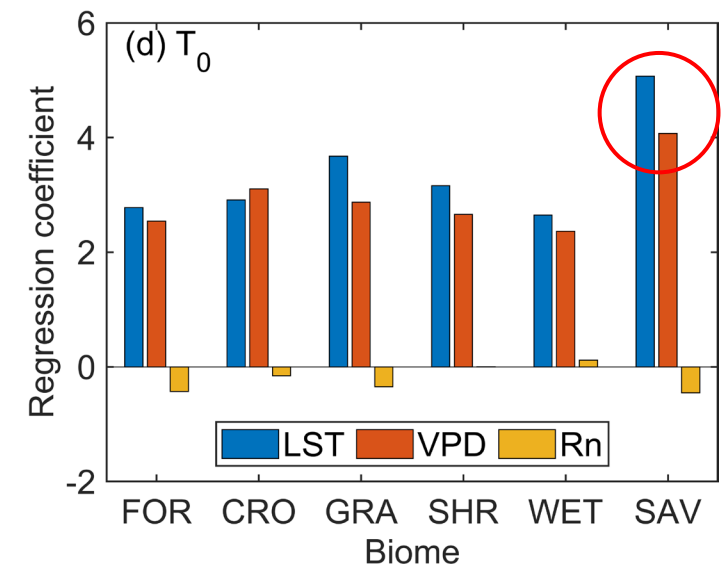
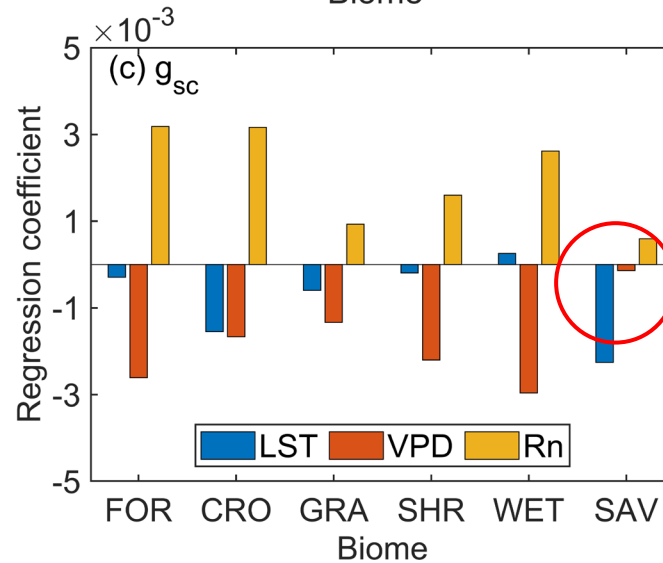
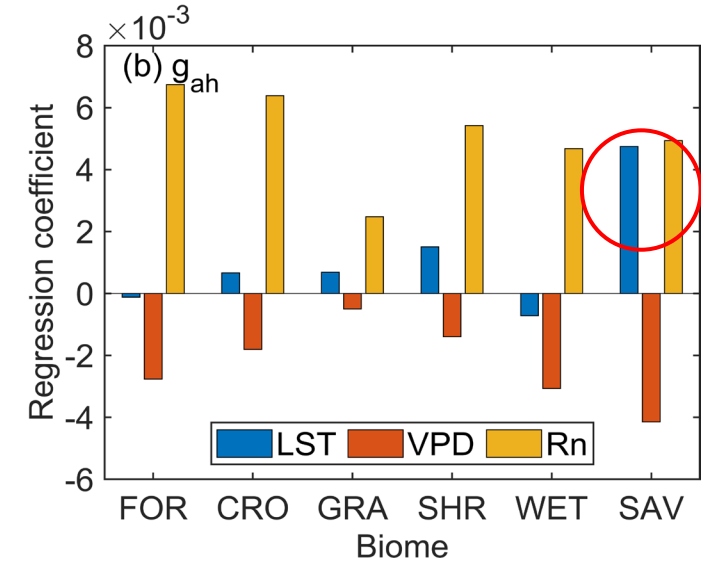
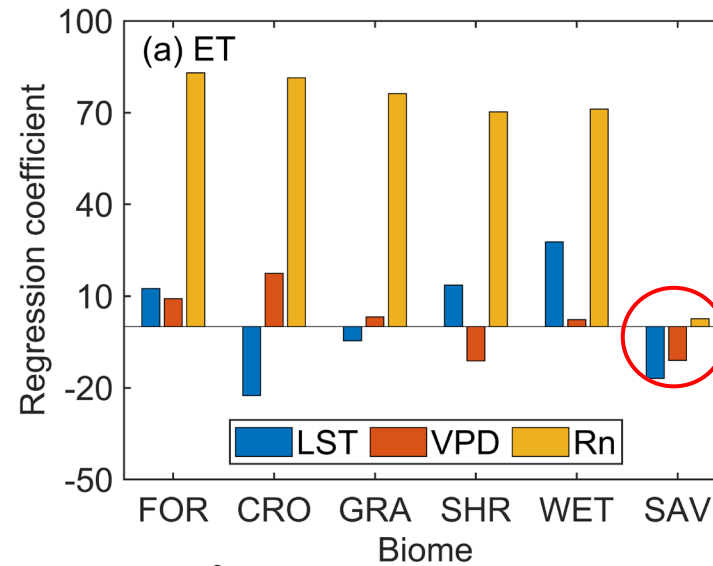


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How different
environmental
factors
influence ET and
biophysical
controls?



Progress at the European Side (LIST)

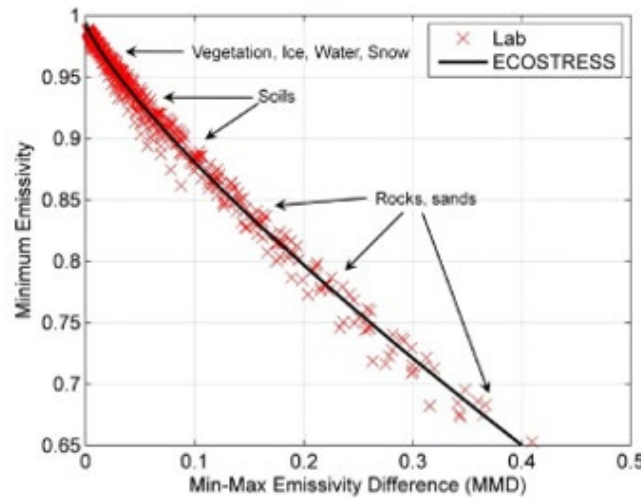


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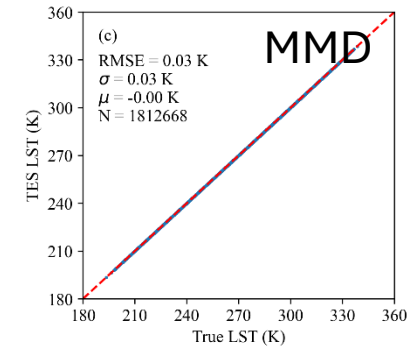
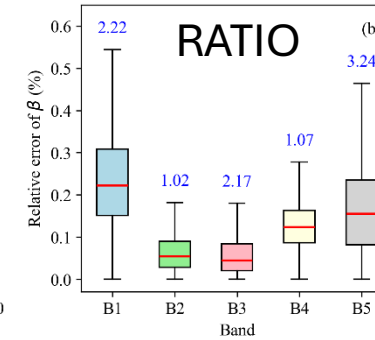
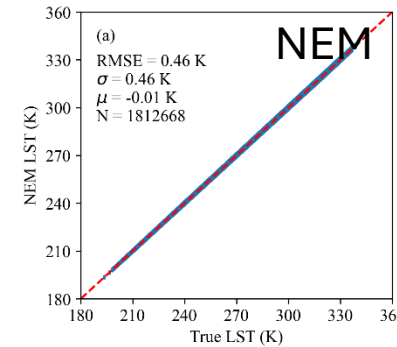


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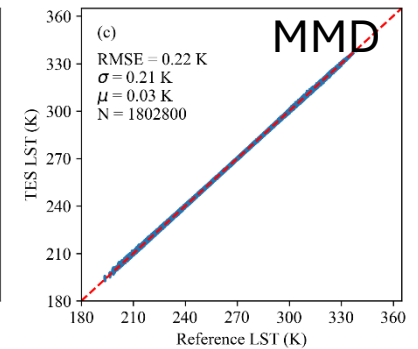
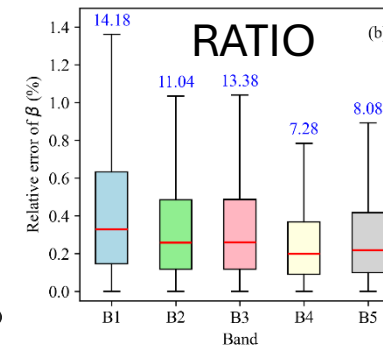
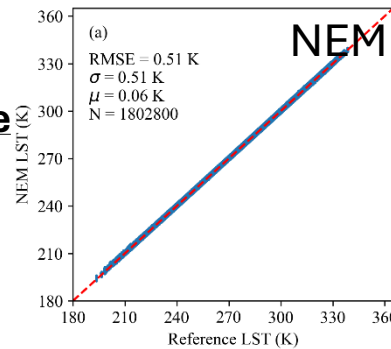
How different error sources affect LST retrieval in TES?



1. 'Perfect' TES (NEM and RATIO)

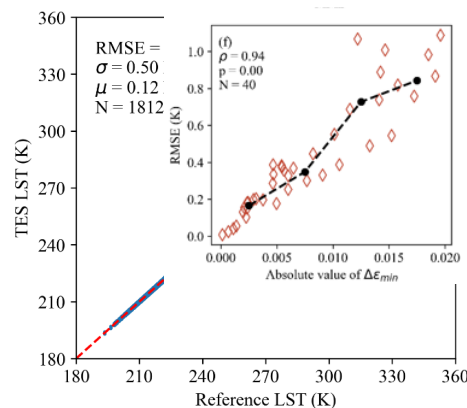
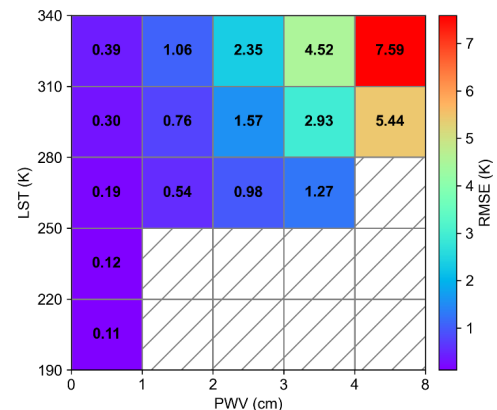


2. Measurement noise (NEdT of 0.1 K)

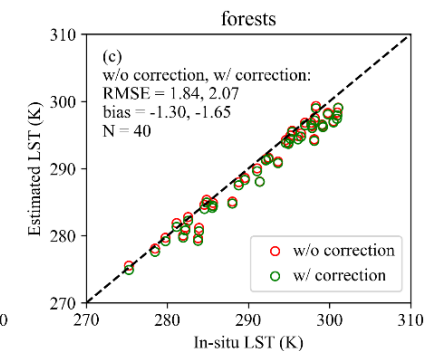
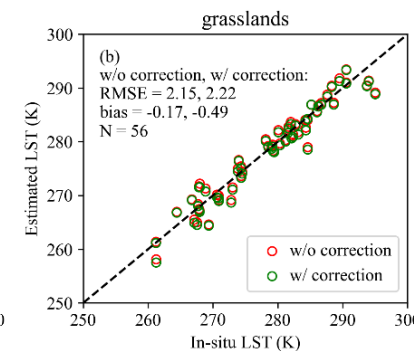
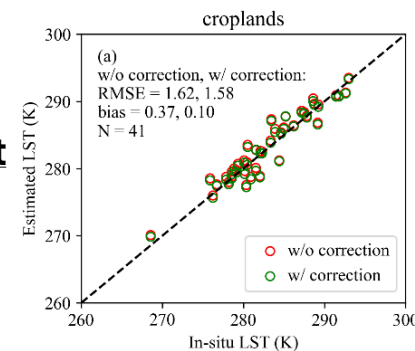


3. Atmospheric correction

4. MMD



5. Cavity effect



Progress at the European Side (LIST)



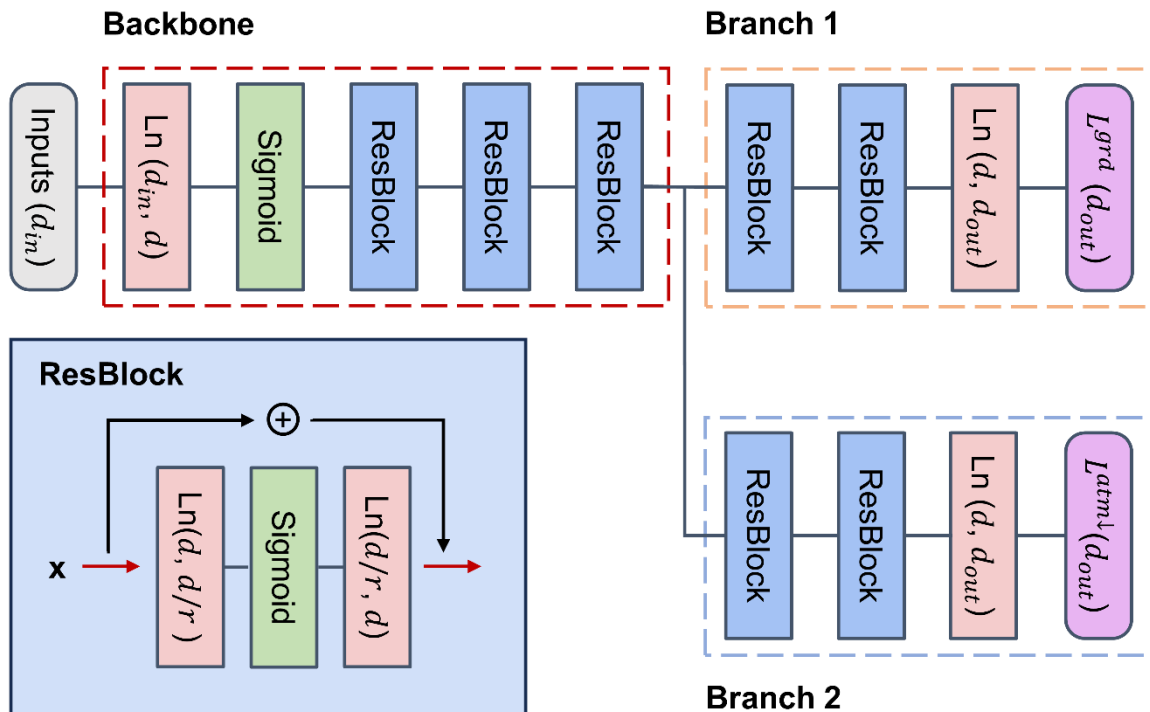
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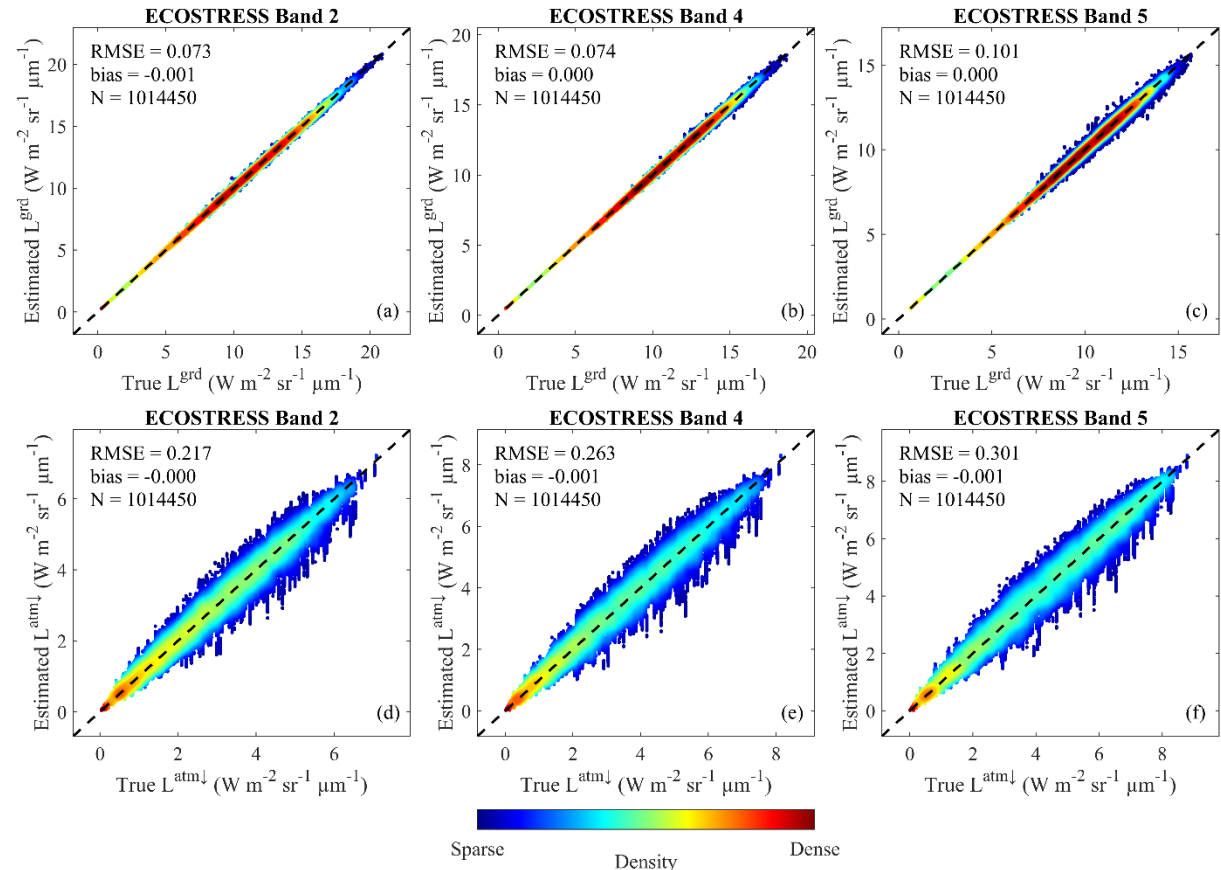
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Atmospheric correction empowered by DL

1. Simplified inputs (no need of atmospheric profiles)
2. Enhanced computation efficiency
3. Improved performance (scale and temporal mismatch)



Simultaneous estimation of L_{grd} and L_{atm} from the same network



Progress at the European Side (LIST)

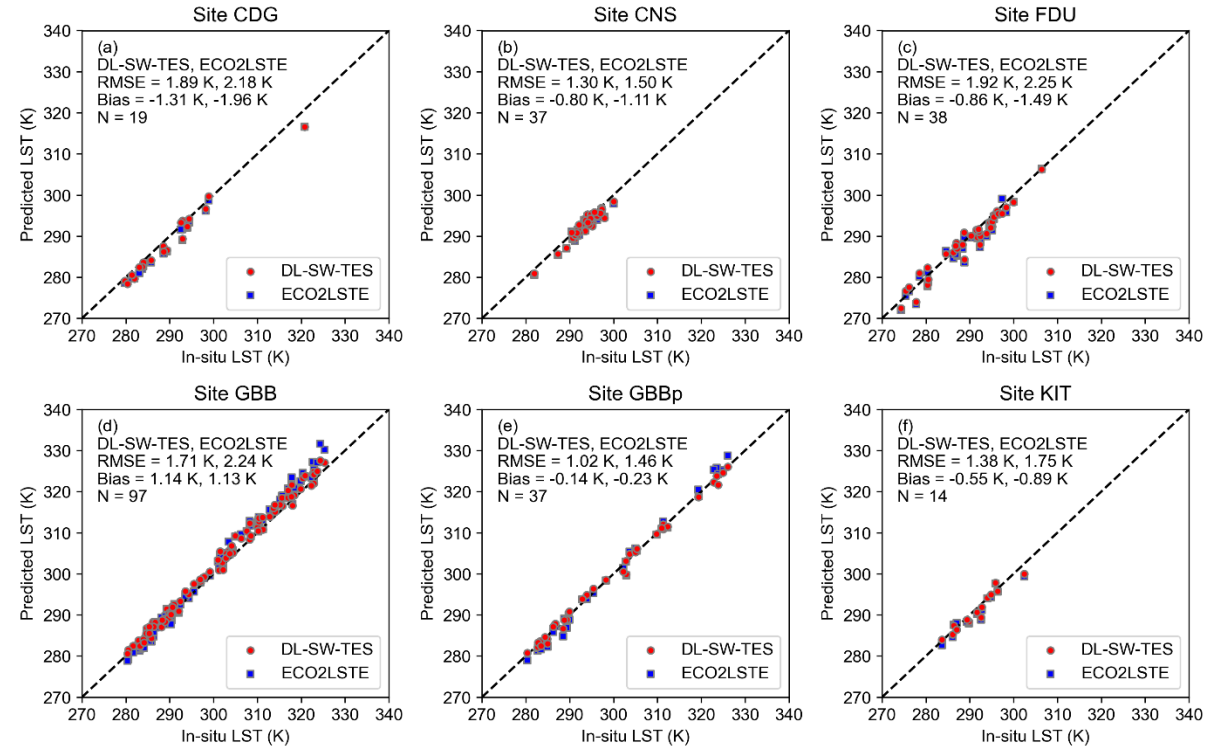
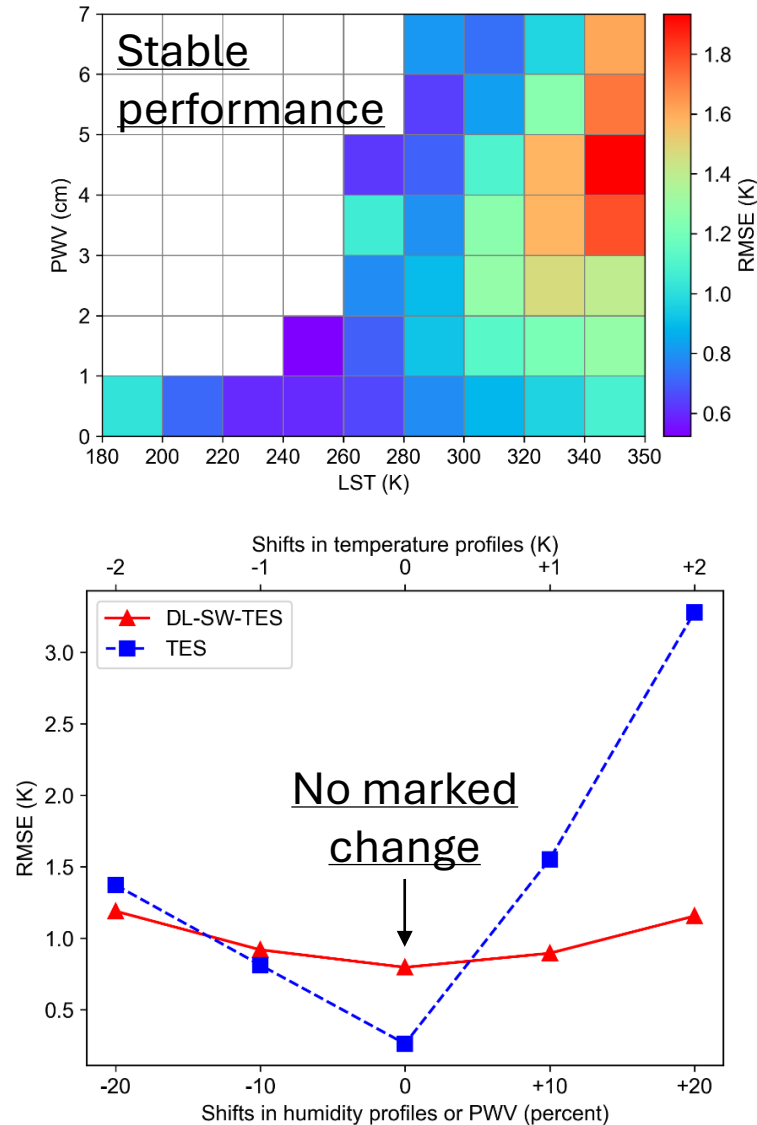


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Simulation analysis



The developed **DL-SW-TES** algorithm outperforms the operational ECOSTRESS LST consistently due to

1. Simplified input parameters
2. Robustness to uncertainties in the input parameters



Target: All-sky high spatiotemporal resolution LST

Advances in Methodology and Generation of All-Weather Land Surface Temperature Products From Polar-Orbiting and Geostationary Satellites: A comprehensive review

Publisher: IEEE [Cite This](#) [PDF](#)

Aolin Jia ; Shunlin Liang ; Dongdong Wang ; Kanishka Mallick ; Shugui Zhou; Tian Hu [All Authors](#)



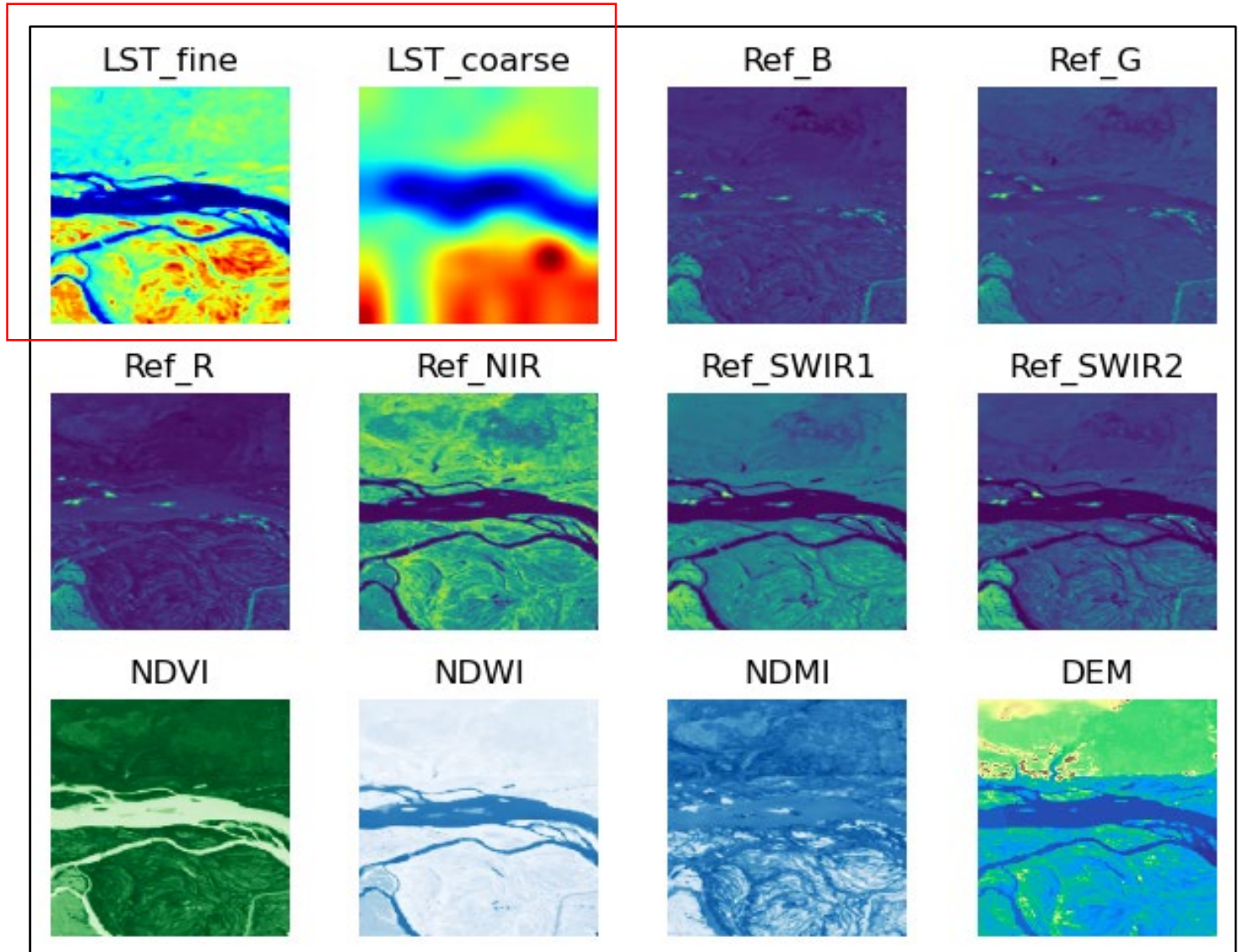
Remote Sensing of Environment

Volume 303, 15 March 2024, 113991



A practical two-step framework for all-sky land surface temperature estimation

Huanyu Zhang ^{a, b}, Bo-Hui Tang ^{c, a} , Zhao-Liang Li ^d



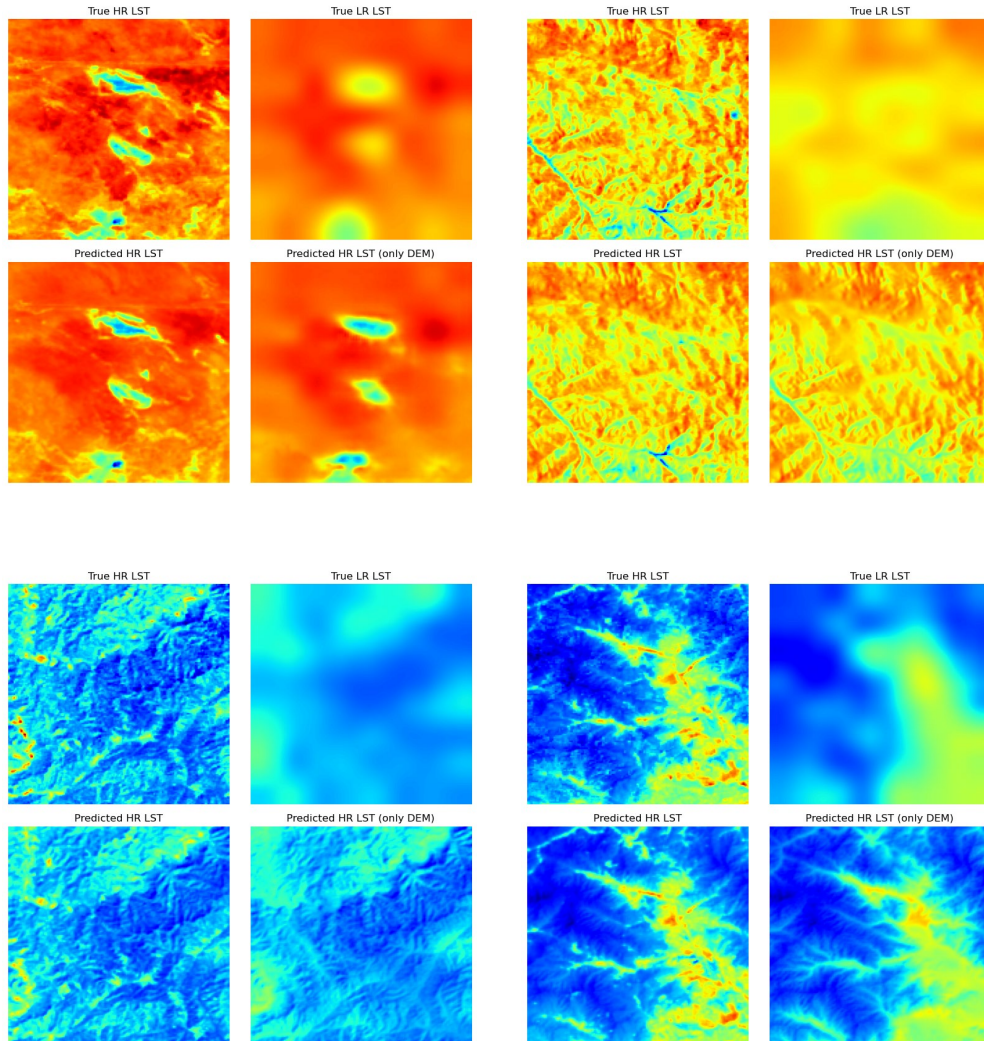
Progress at the European Side (LIST)



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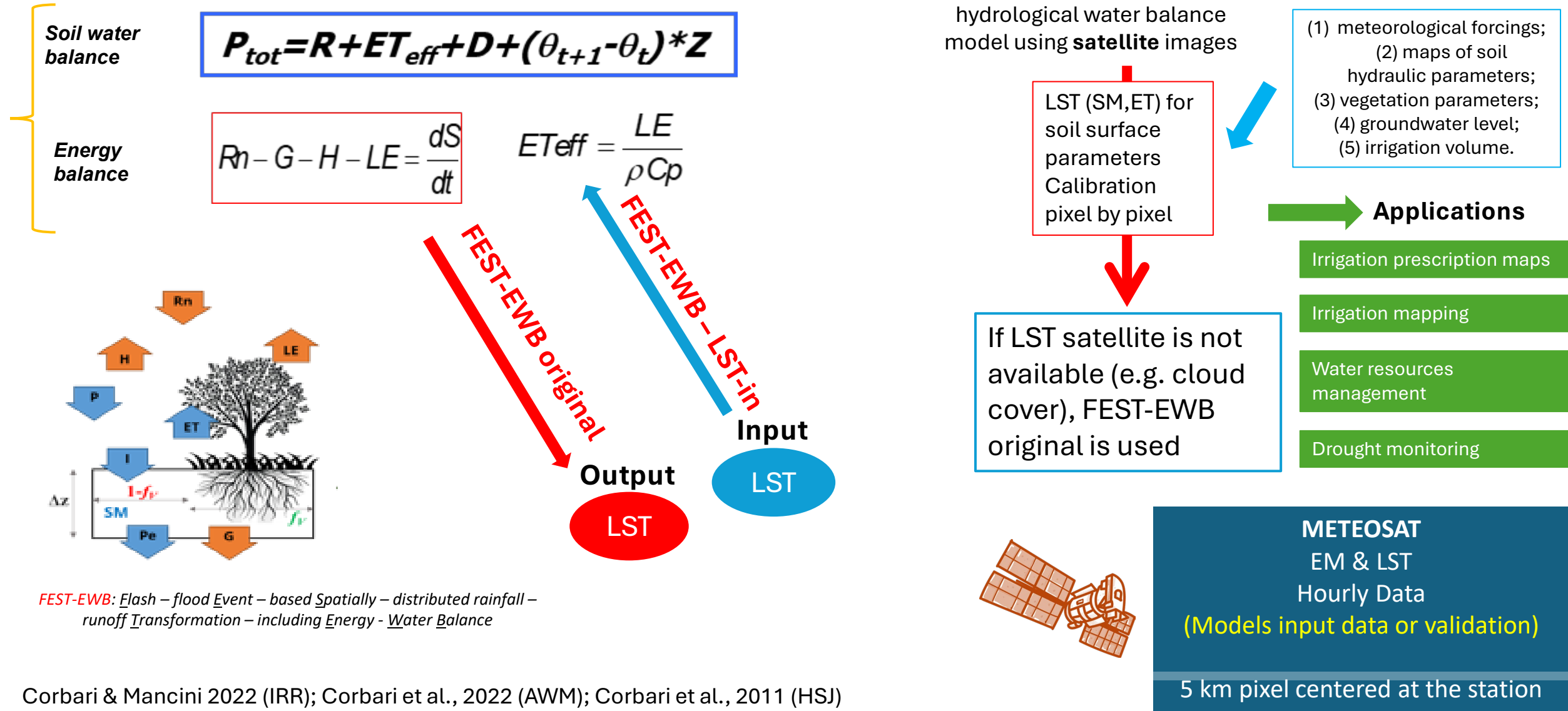
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Inputs	RMSE (K)
LST + DEM	1.341
LST + DEM + $[\rho_r, \rho_g, \rho_b, \rho_{nir}]$	0.896
LST + DEM + $[\rho_{swir1}, \rho_{swir2}]$	0.872
LST + DEM + [NDVI, NDWI, NDMI]	0.909
LST + DEM + $[\rho_r, \rho_g, \rho_b, \rho_{nir}] + [\rho_{swir1}, \rho_{swir2}]$	0.831
LST + DEM + $[\rho_r, \rho_g, \rho_b, \rho_{nir}] + [\text{NDVI}, \text{NDWI}, \text{NDMI}]$	0.846
LST + DEM + $[\rho_{swir1}, \rho_{swir2}] + [\text{NDVI}, \text{NDWI}, \text{NDMI}]$	0.828
LST + DEM + all optional	0.826

Downscaled LST achieves good accuracy through adding spatial details from VNIR and SWIR reflectance based on a hybrid model

FEST-EWB Model (POLIMI)



Improving Crop Resistance to Evaporation using SIF (PO4MI)



gc-Canopy
Jarvis:

Conductance

$$r_c = \frac{f_{smin} (FC - WP)}{LAI (\theta - WP)}$$

$$g_c = g_{c,max} F_1(R_s) F_2(D_{VPD}) F_3(T_a) F_4(\text{Moisture})$$

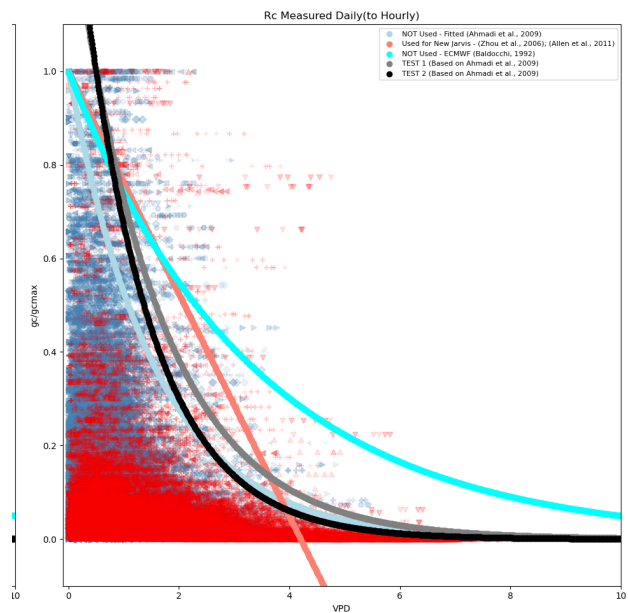
Torralbo, Corbari, Mallick, 2025

Inverted Penman Monteith equation

VS

$$g_c = \frac{\lambda \rho_w E_T \gamma g_a}{\Delta R_{net}^{veg} + \rho_a C_p g_a D_{VPD} - \lambda \rho_w E_T (\Delta + \gamma)}$$

Parametrization	$F_1(R_s)$	$F_2(D_{VPD})$	$F_3(T_a)$
Fitted (Ahmadi et al., 2009)	$\frac{R_s}{1000} \frac{1000 + k_c}{R_s + k_c}$	$\exp(-k_D D_{VPD})$	$\frac{T_a - T_{min}}{T_{opt} - T_{min}} \left[\frac{T_{max} - T_a}{T_{max} - T_{opt}} \right]^{\frac{T_{max} - T_{opt}}{T_{opt} - T_{min}}}$
(Zhou et al., 2006); (Allen et al., 2011)	$\frac{1.1 \times R_{PAR}}{R_{PAR} + 100}$	$1 - 0.238 D_{VPD}$	$\begin{cases} 1, T_k \geq 298 \\ 1 - 1.6 \times 10^{-3} (298 - T_k)^2, 273 < T_k < 298 \\ 0, T_k \leq 273 \end{cases}$
ECMWF (Baldocchi, 1992)	$\text{Min} \left[1, \frac{b R_s + c}{a (b R_s + 1)} \right]$	$\exp(-k_D D_{VPD})$	None



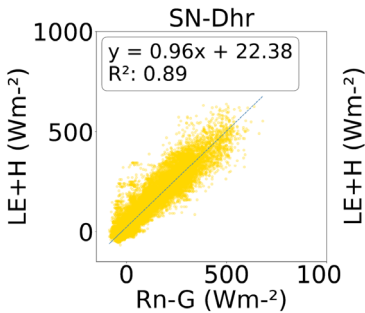
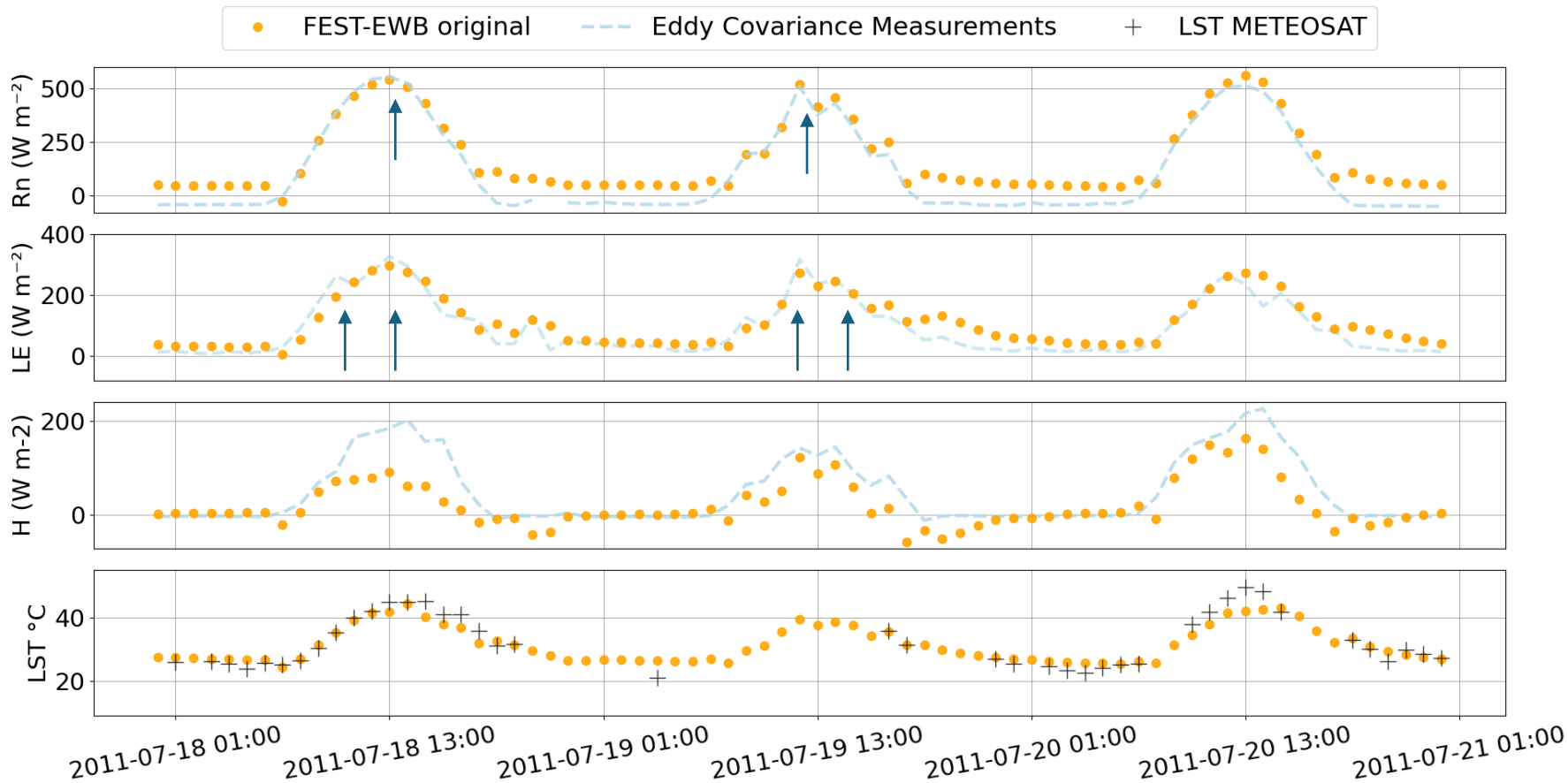


Station: Dahra – Savana Shrubland 49 m a.s.l

Arid station -> Aindex= 0.14

Potential Diurnal Asymmetry↑

Corbari, Torralbo, Mallick et al.



Results 2011 - 2014			
Fluxes	RMSE	MAE	R2
Rn (W/m2)	86.18	77.16	0.93
LE (W/m2)	50.52	34.33	0.63
H (W/m2)	46.10	34.97	0.84
LST (°C)	4.24	3.43	0.90

Model Intercomparison (POLIMI)

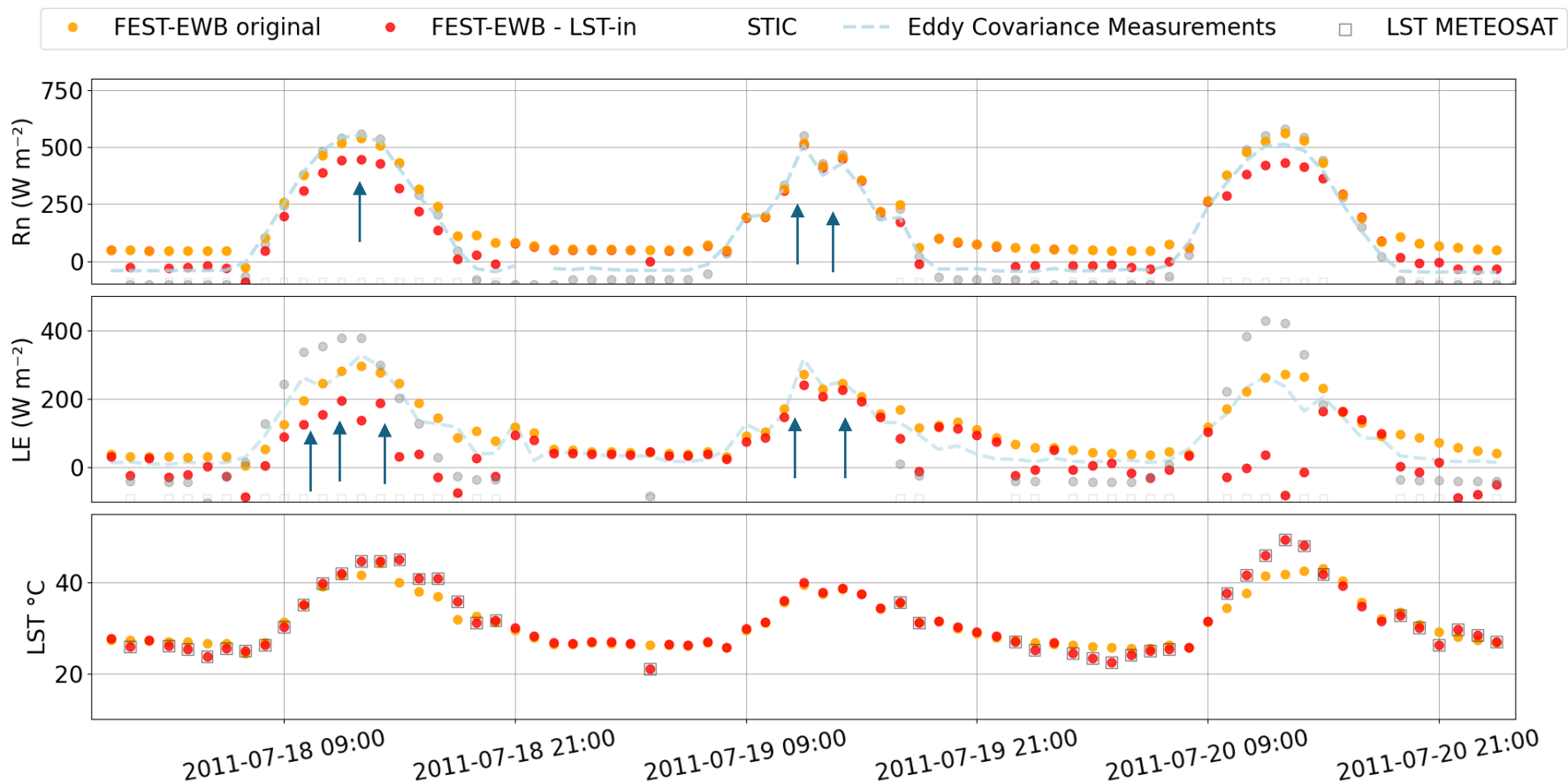


Station: Dahra – Savana Shrubland 49 m a.s.l

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Potential Diurnal Asymmetry↑

Corbari, Torralbo, Mallick et al.

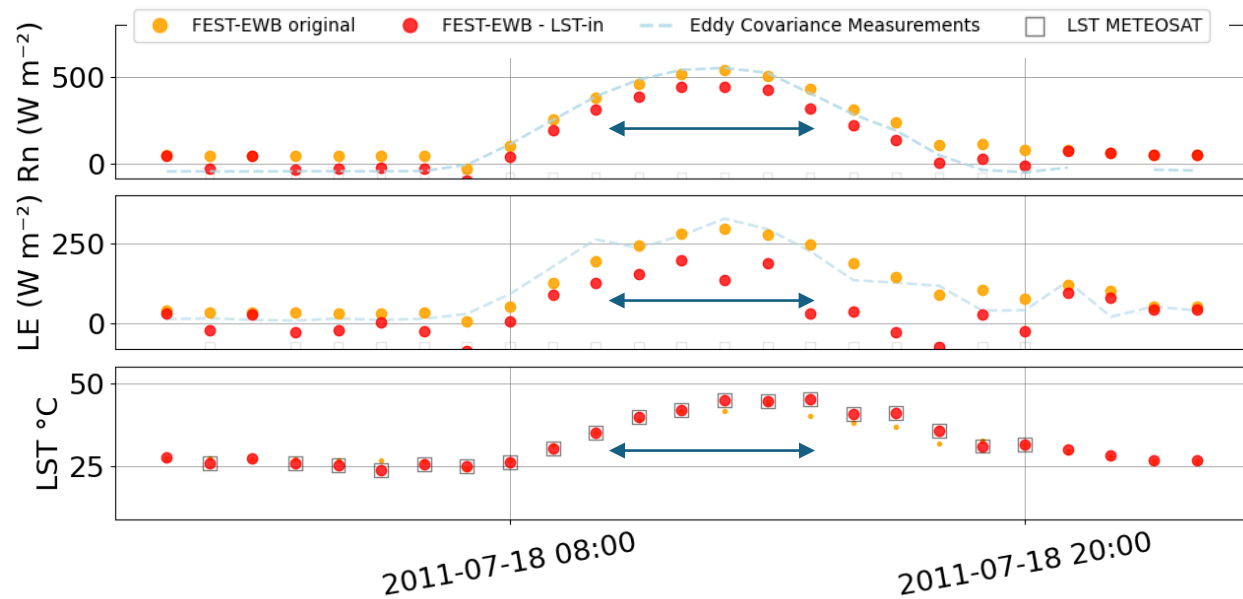


FEST – EWB original (all period)			
Fluxes	RMSE	MAE	R2
Rn (W/m2)	86.18	77.16	0.93
LE (W/m2)	50.52	34.33	0.63

FEST – EWB LST in (all period)			
Fluxes	RMSE	MAE	R2
Rn (W/m2)	65.03	53.89	0.92
LE (W/m2)	66.70	41.67	0.5

STIC (Example period)			
Fluxes	RMSE	MAE	R2
Rn (W/m2)	35.44	29.41	0.99
LE (W/m2)	94.30	77.29	0.81

Spatial Upscaling FEST-EWB: LST (POLIMI)



Corbari, Torralbo, Mallick et al.

Time period

1- 10:00

2- 11:00

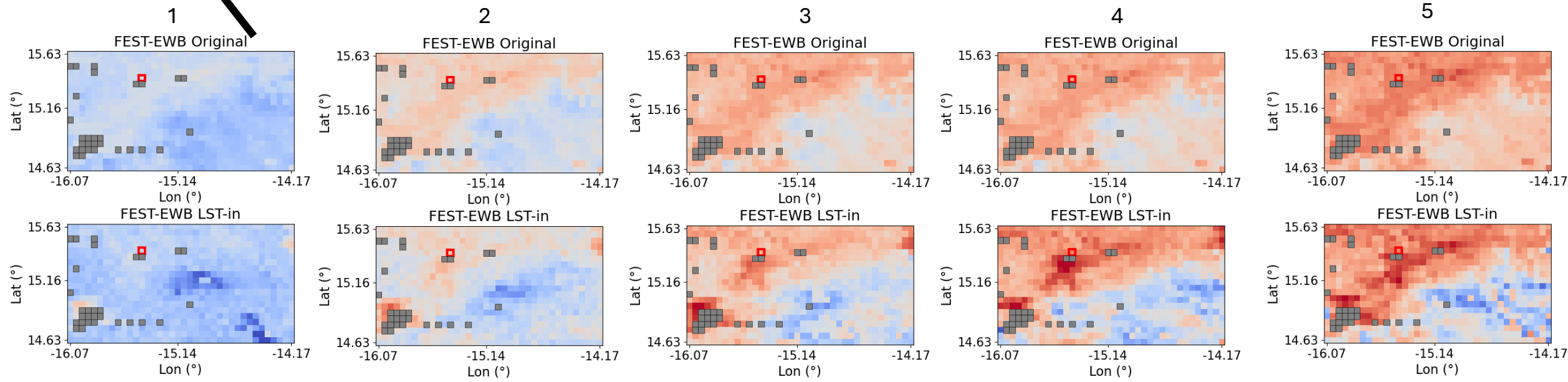
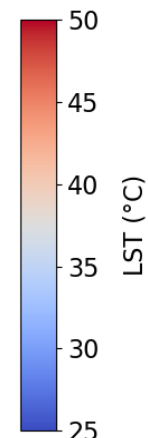
3- 12:00

4- 13:00

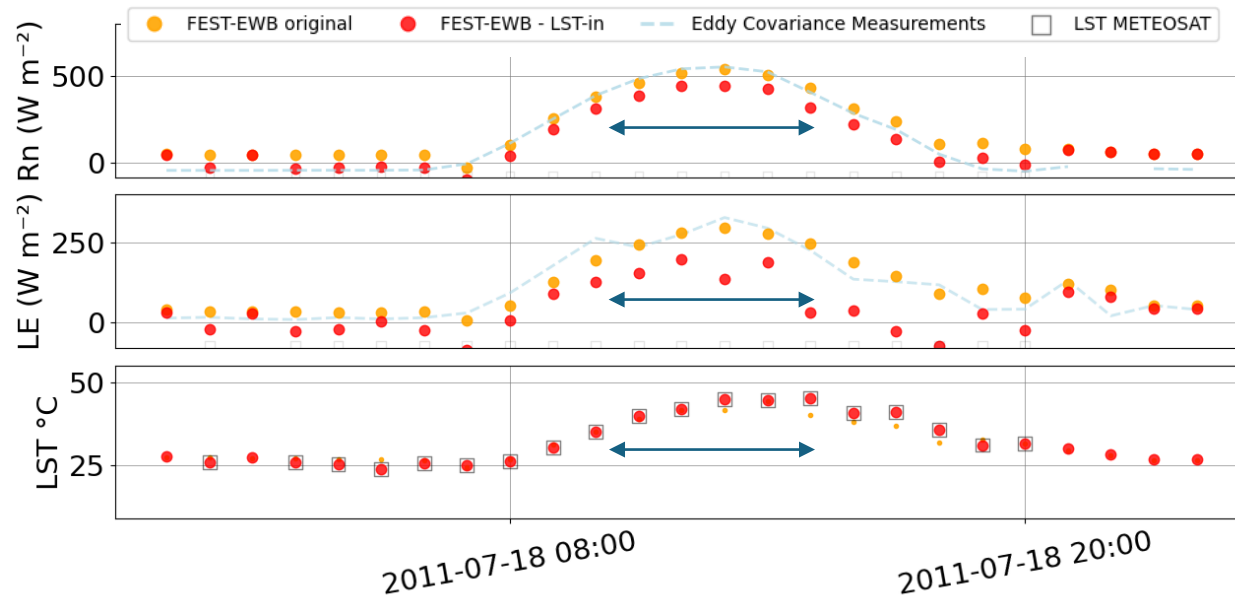
5- 14:00

 Dahra Station

 Urban areas



Spatial upscaling FEST-EWB: LE (POLIMI)



Corbari, Torralbo, Mallick et al.

Time period

1- 10:00

2- 11:00

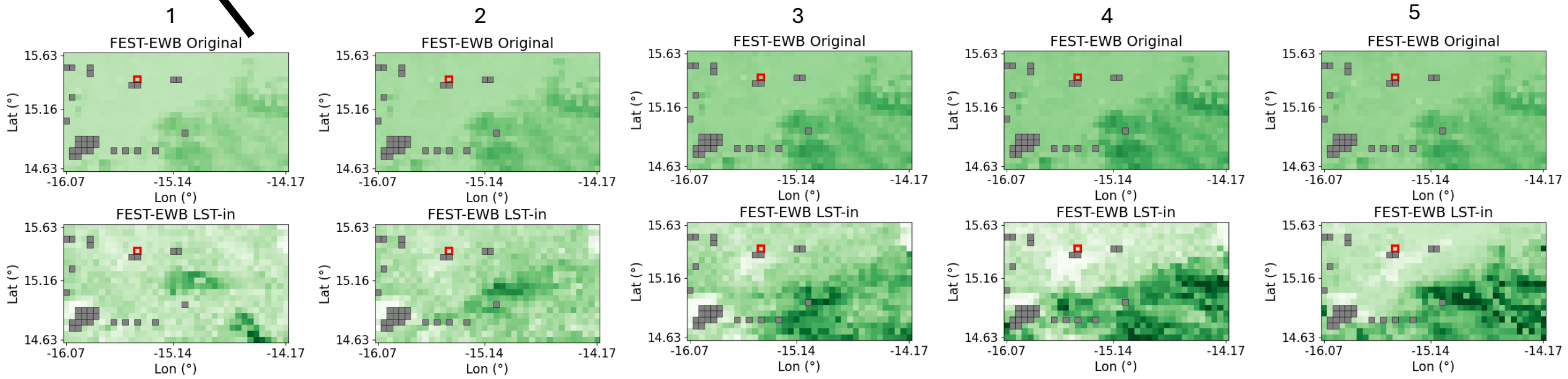
3- 12:00

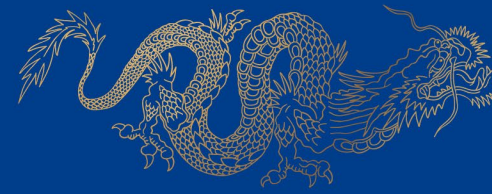
4- 13:00

5- 14:00

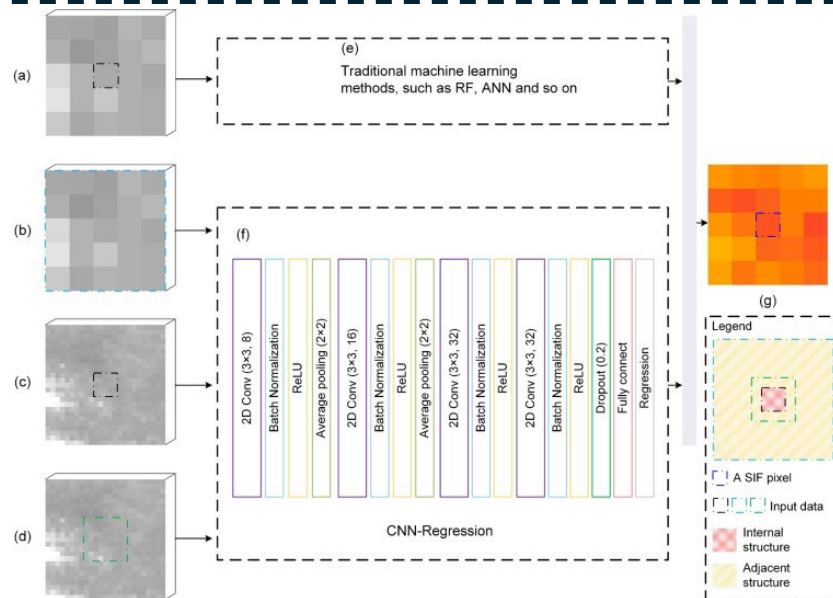
□ Dahra Station

■ Urban areas

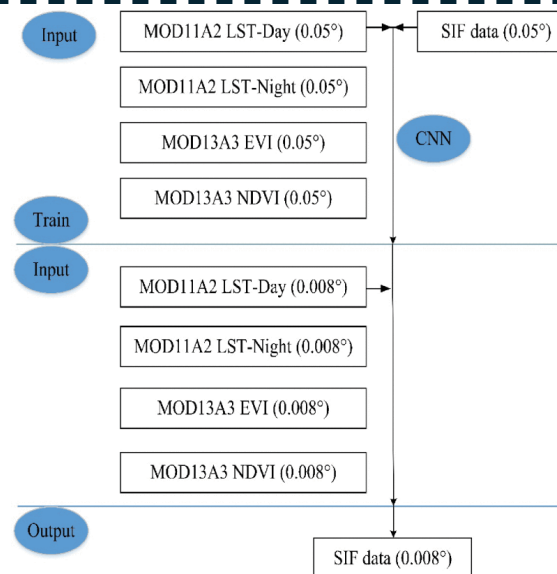




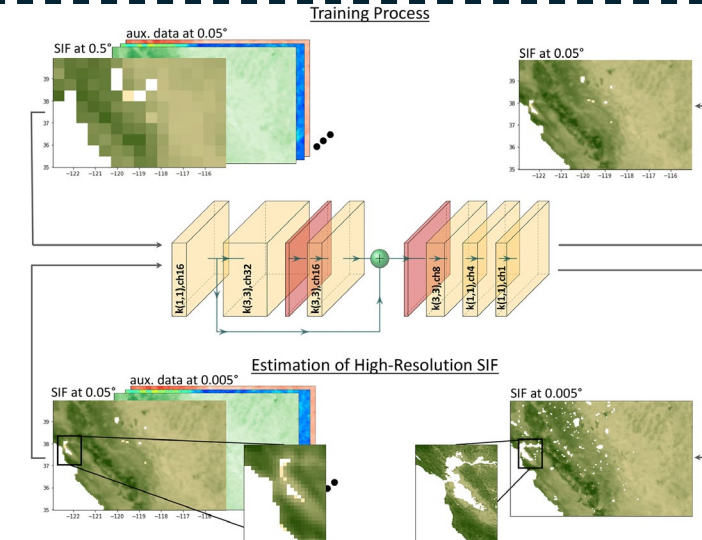
Reconstructed SIF Dataset



GOSIF Dataset @ 0.05°
(Kang et al., 2022, CEA)



Downscaling solar-induced chlorophyll fluorescence based on convolutional neural network method to monitor agricultural drought
(Zhang et al., 2020, IEEE TGRS)



A convolutional neural network for spatial downscaling of satellite-based solar-induced chlorophyll fluorescence (SIFnet)
(Gensheimer et al., 2021, Bio. Discuss.)

The focus is primarily on **large-scale global datasets**, but there is a **lack of methods suitable for precision agriculture**.

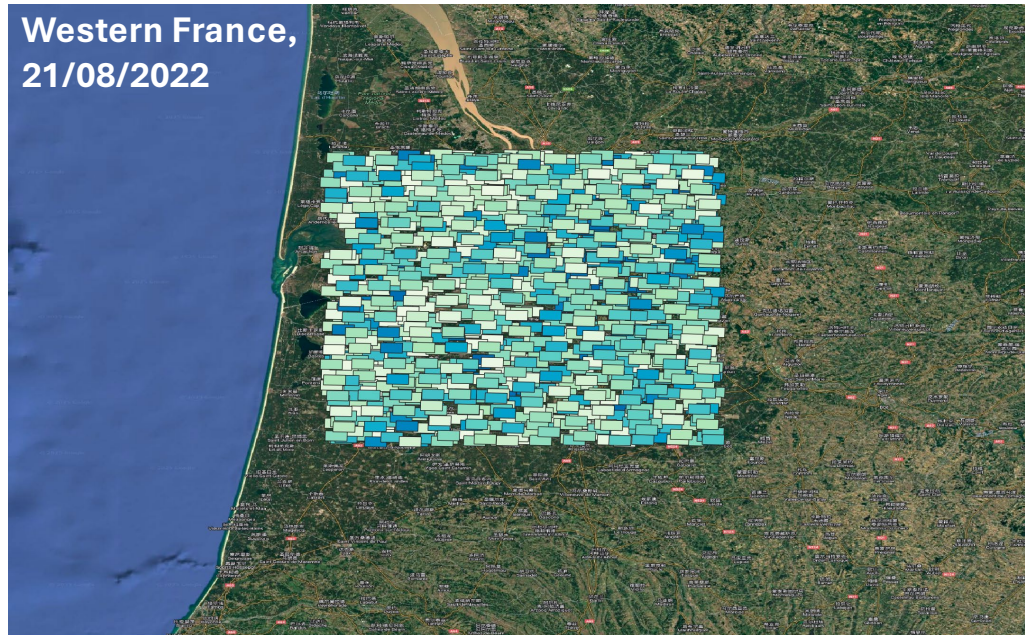
Background (CAU)



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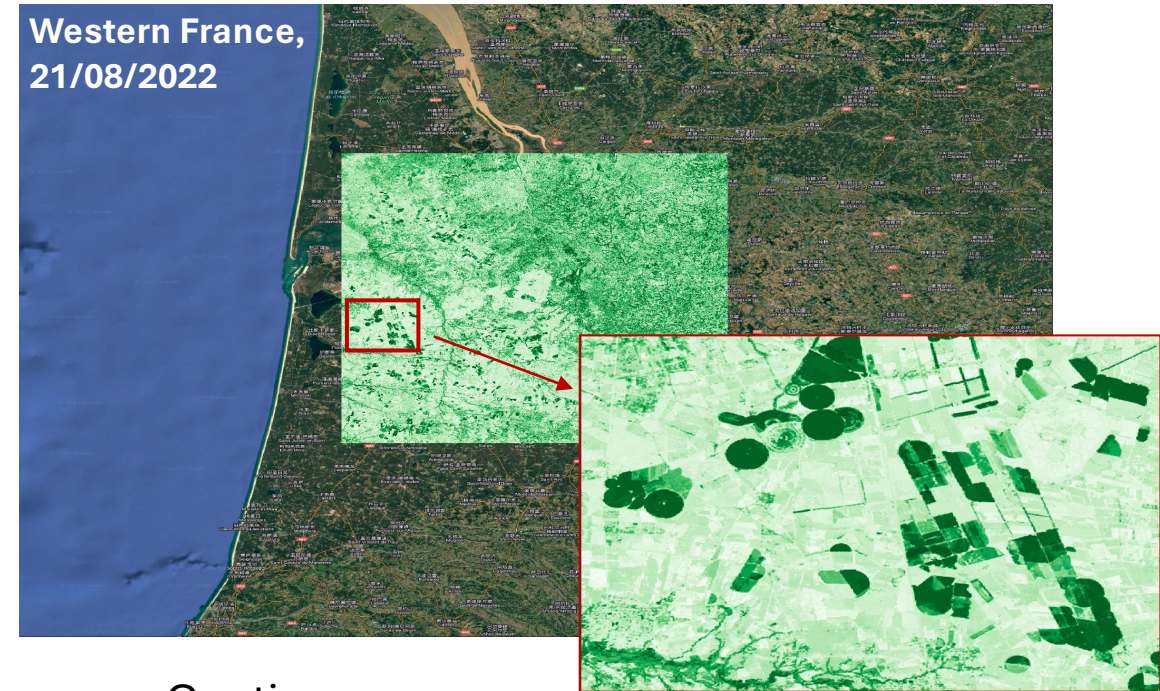


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TROPOMI SIF
Footprints

Discrete



Continuous

TROPOMI SIF
Raster

Downscaling Problems

- The **wide swath** of the TROPOMI sensor, spanning 2600 km, leads to significant **angular effects** in the measurements due to the large range of viewing angles.
- The **coarse spatial resolution** of the data makes it challenging to identify and analyze fine-scale features on the ground.
- The frequent presence of **clouds** obstructs the satellite's view, resulting in significant gaps and missing data points within the time series.

A Novel Approach to Address Uncertainties in SIF Observations

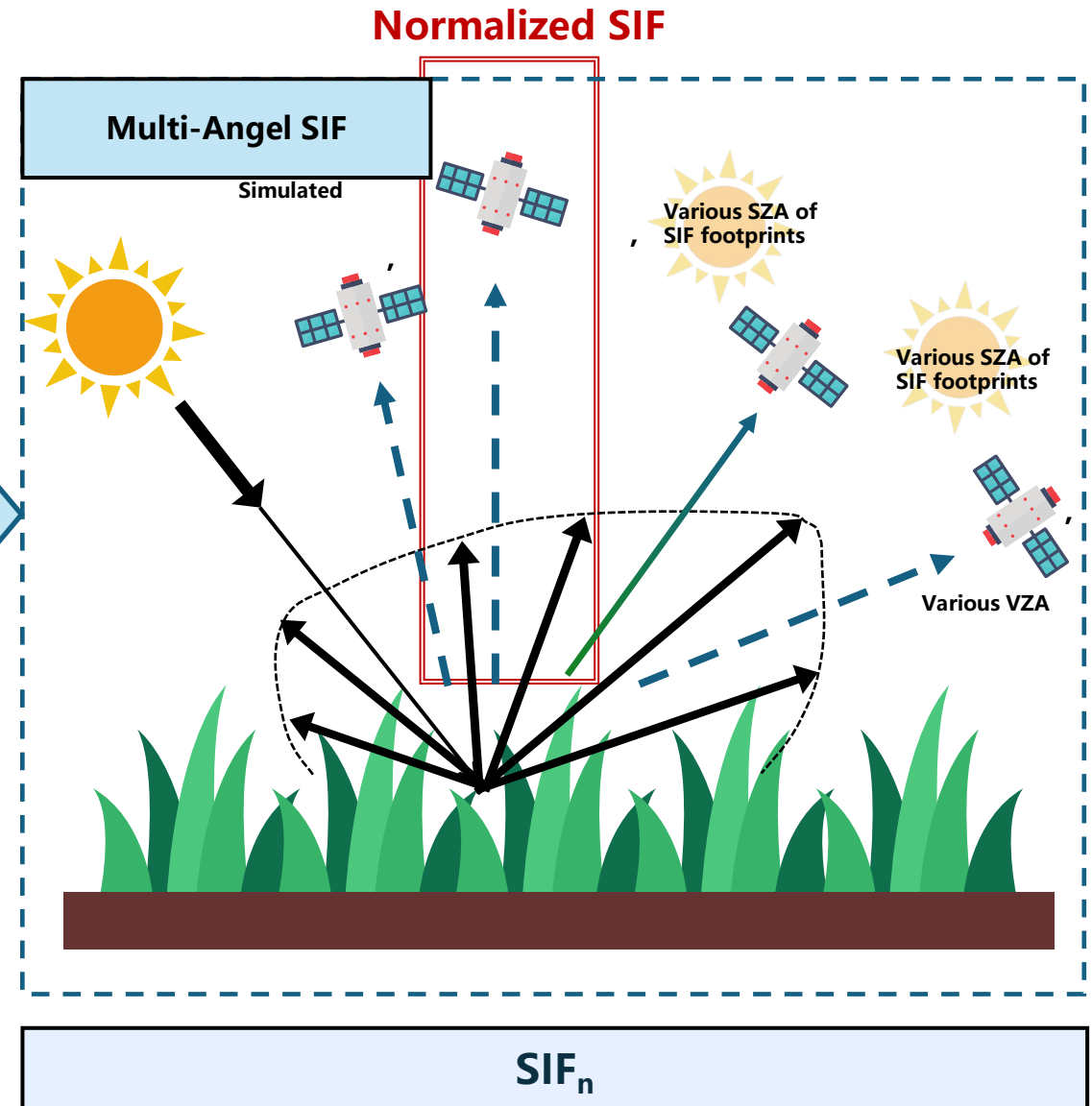
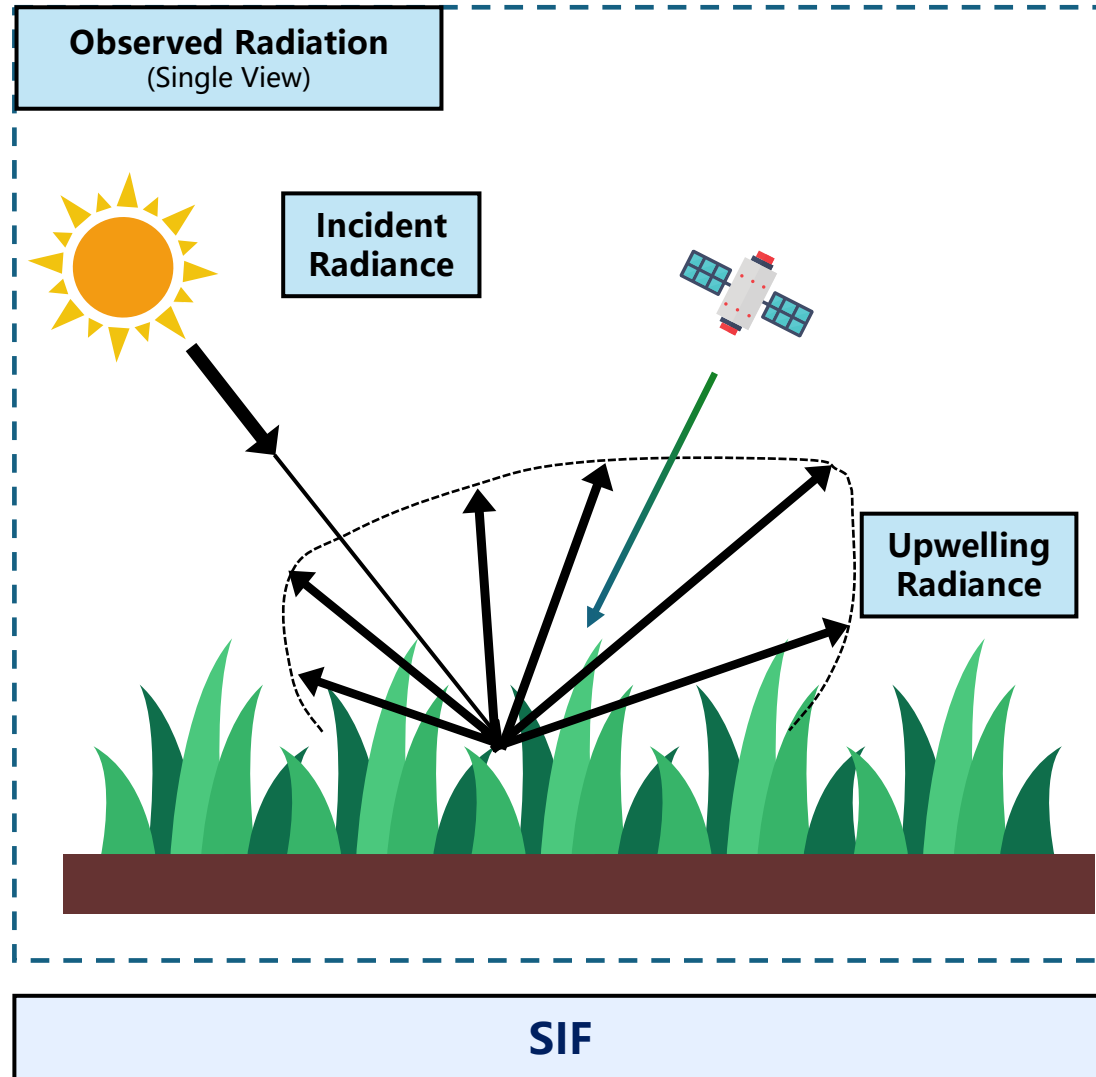


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Conceptual schematic of how normalize **SIF** to **SIF_n**



Progress at the Chinese Side (CAU)

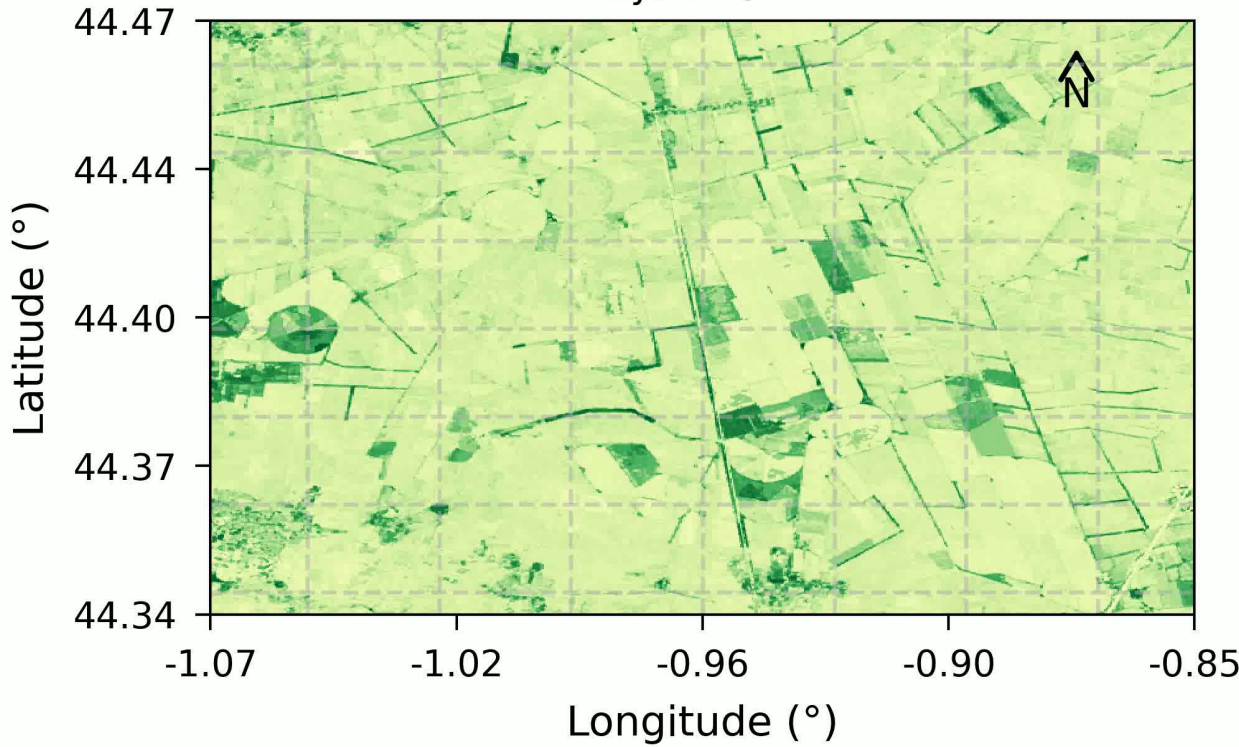


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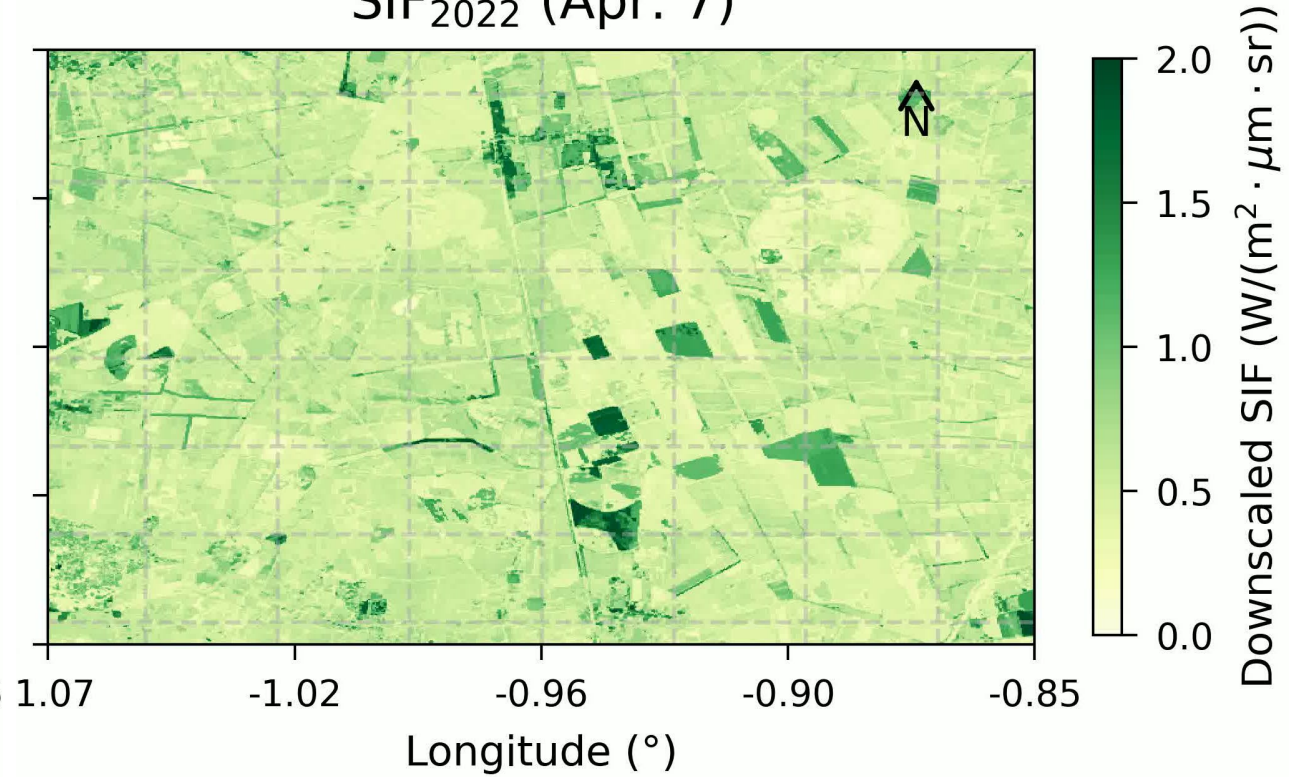


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SIF_{5yr} (Apr. 7)



SIF₂₀₂₂ (Apr. 7)



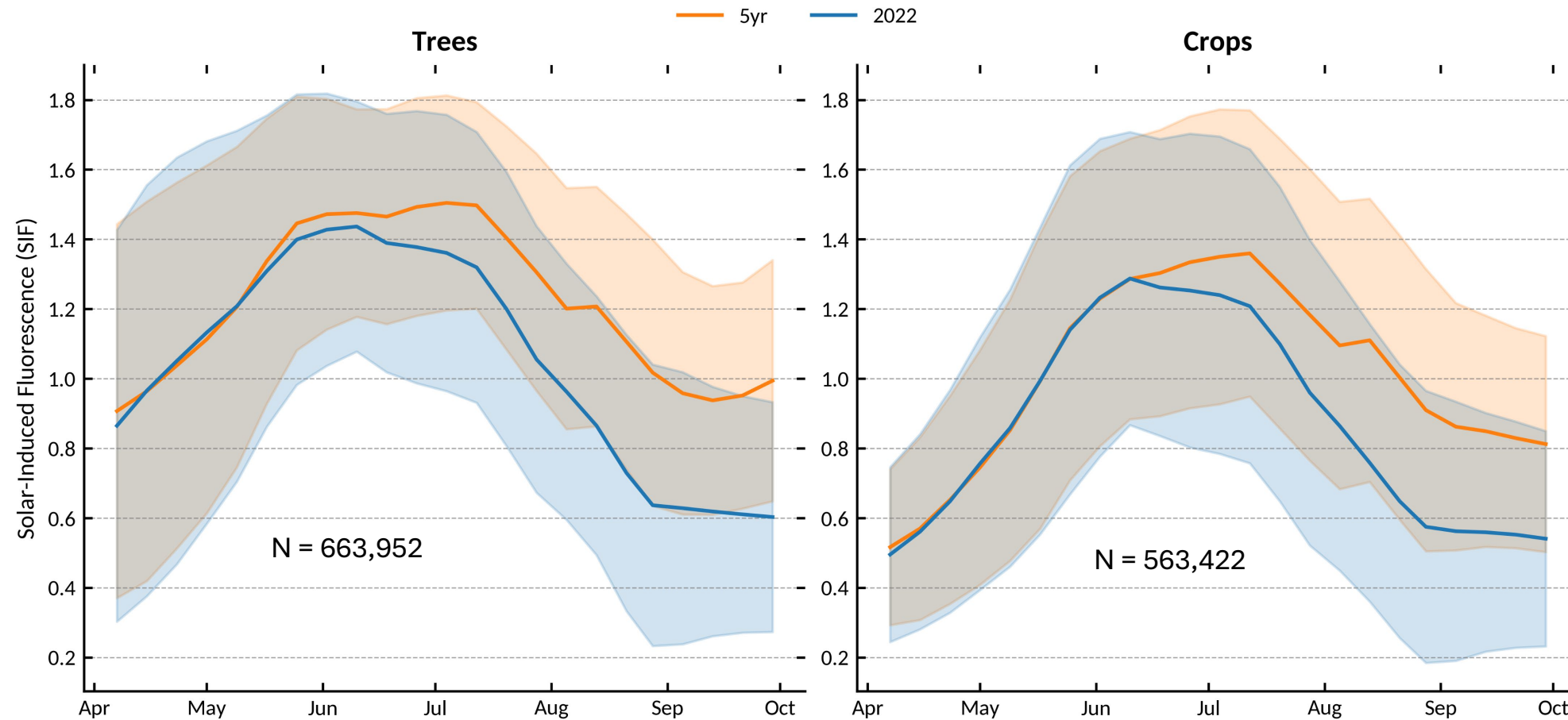
Progress at the Chinese Side (CAU)



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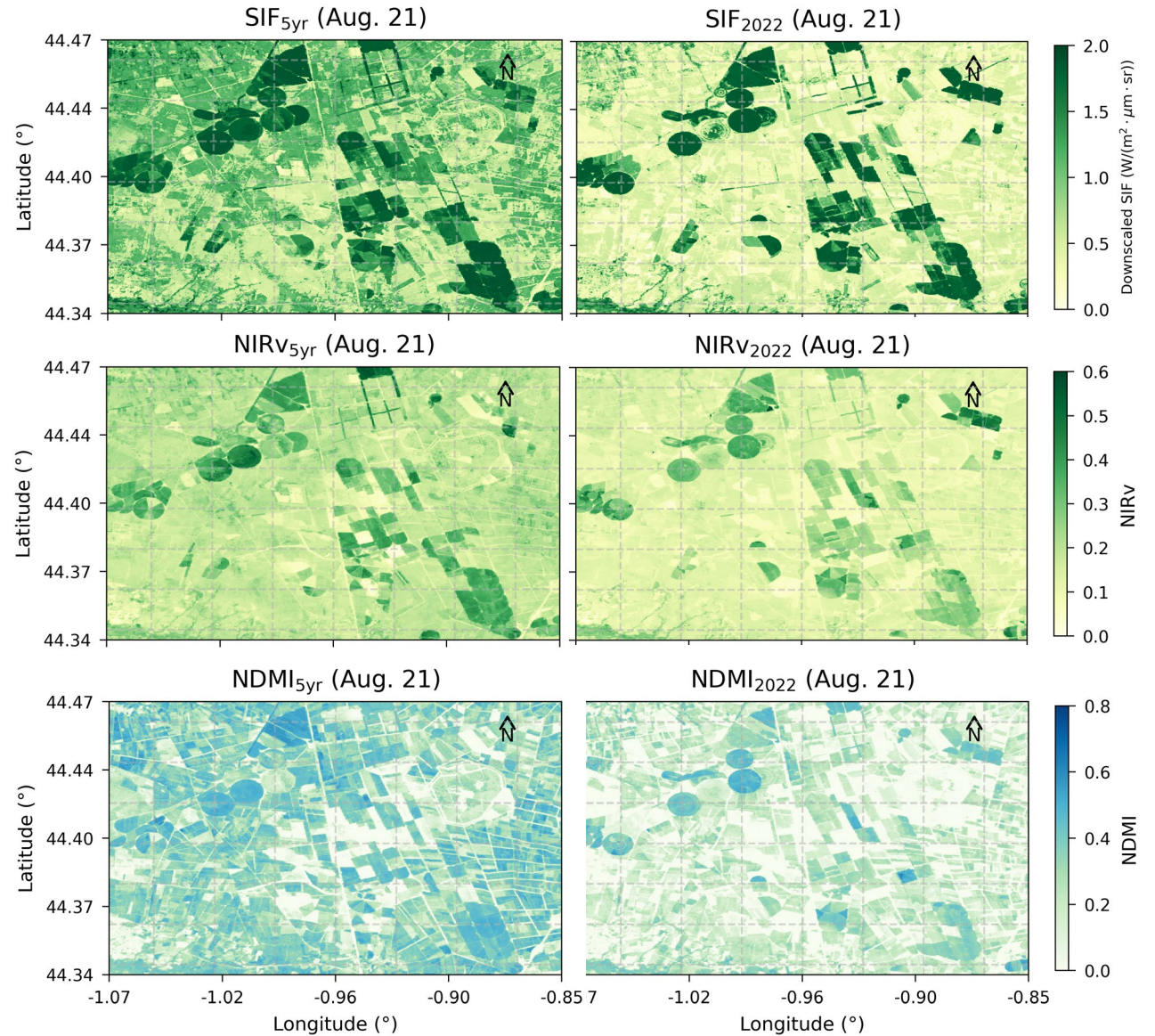
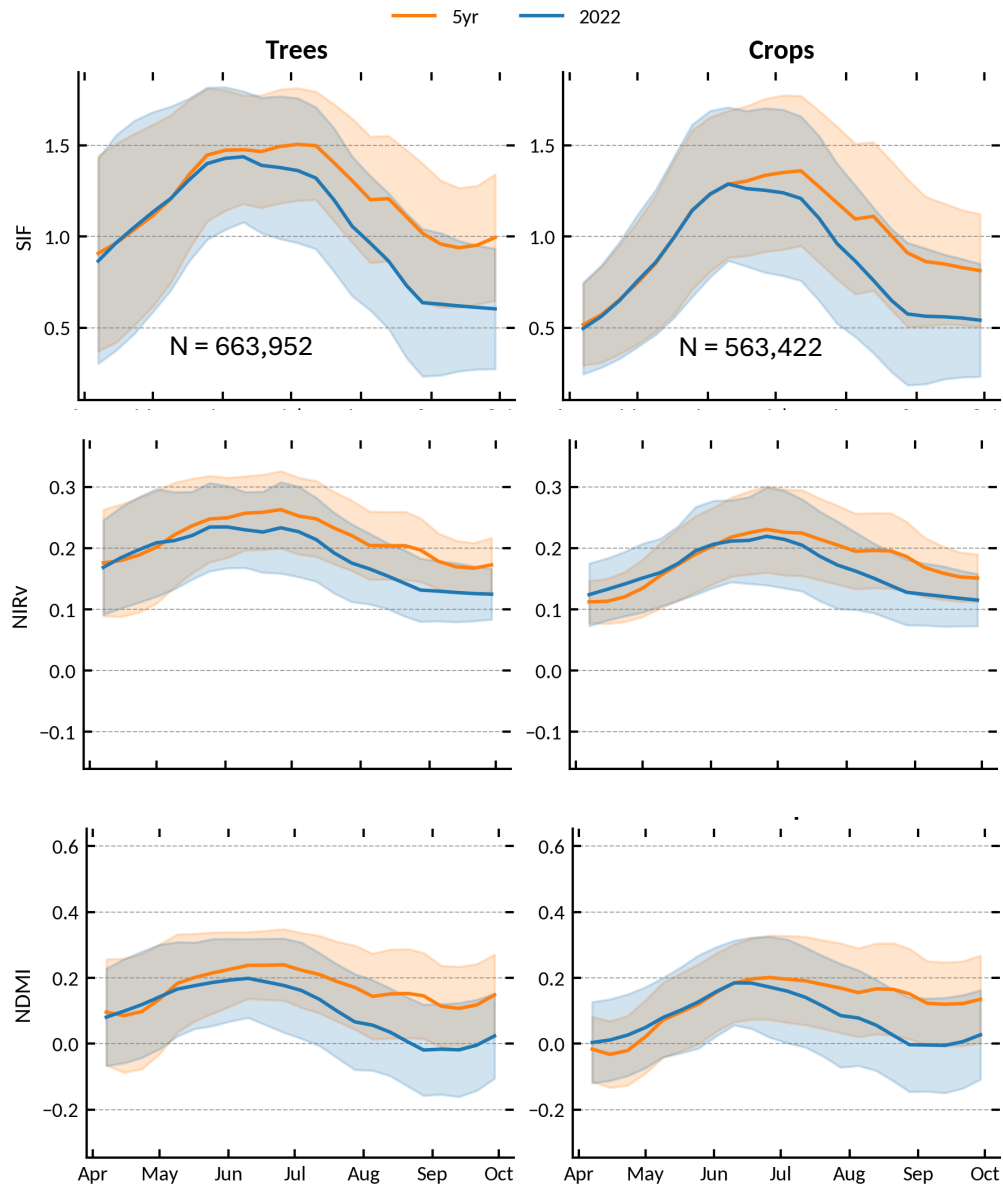
Progress at the Chinese Side (CAU)

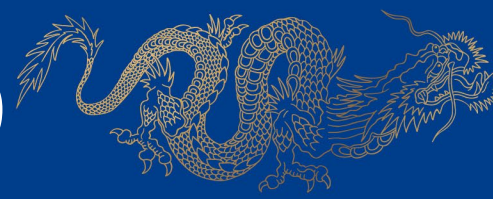


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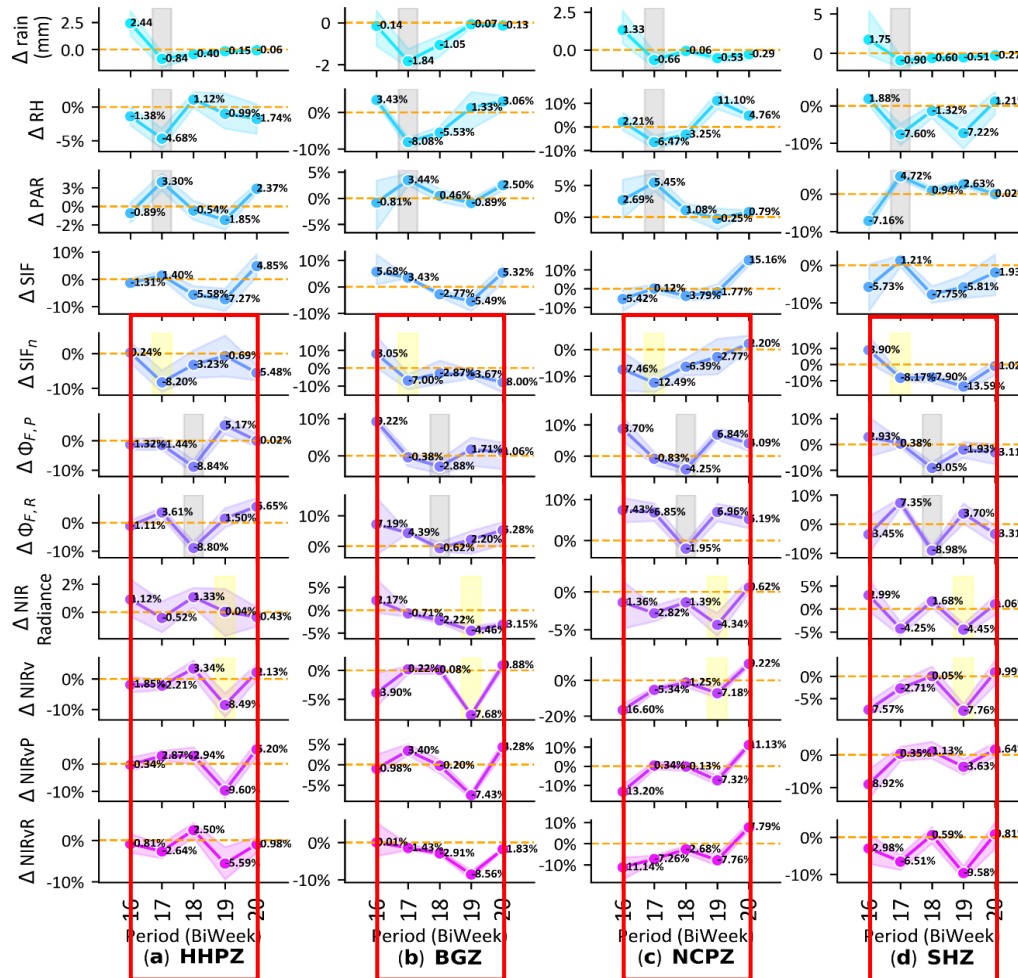


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Drought Monitoring in the Huang-Huai-Hai Plain of China in 2019



Anomalies of various indices in the Huang-Huai-Hai Plain during the B16 to B20 period in 2019

Vegetation Response to Water Stress

- The bi-weekly (BiWeek) timescale reveals the vegetation's response to water stress.
- During B17, the initial decrease in SIFn indicated a drop in photosynthetic efficiency.

BiWeek 17 (Drought Onset): SIFn Decreases

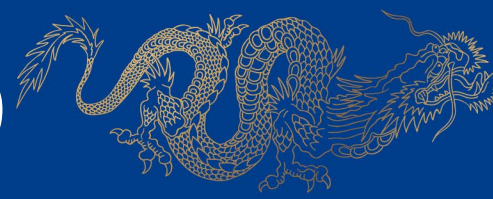
- ΔRH (Relative Humidity) dropped by -4.68%, -8.08%, -6.47%, and -7.60% in the four zones.
- Lower RH caused a high vapor pressure deficit (VPD), stressing the vegetation despite adequate soil moisture from prior rainfall (B16).
- This led to stomatal closure to conserve water, an early physiological stress response.
- Increased PAR (Photosynthetically Active Radiation) during B17 may have caused photoinhibition, damaging PSII.

BiWeek 17 (Sustained Drought): ΦF Decreases

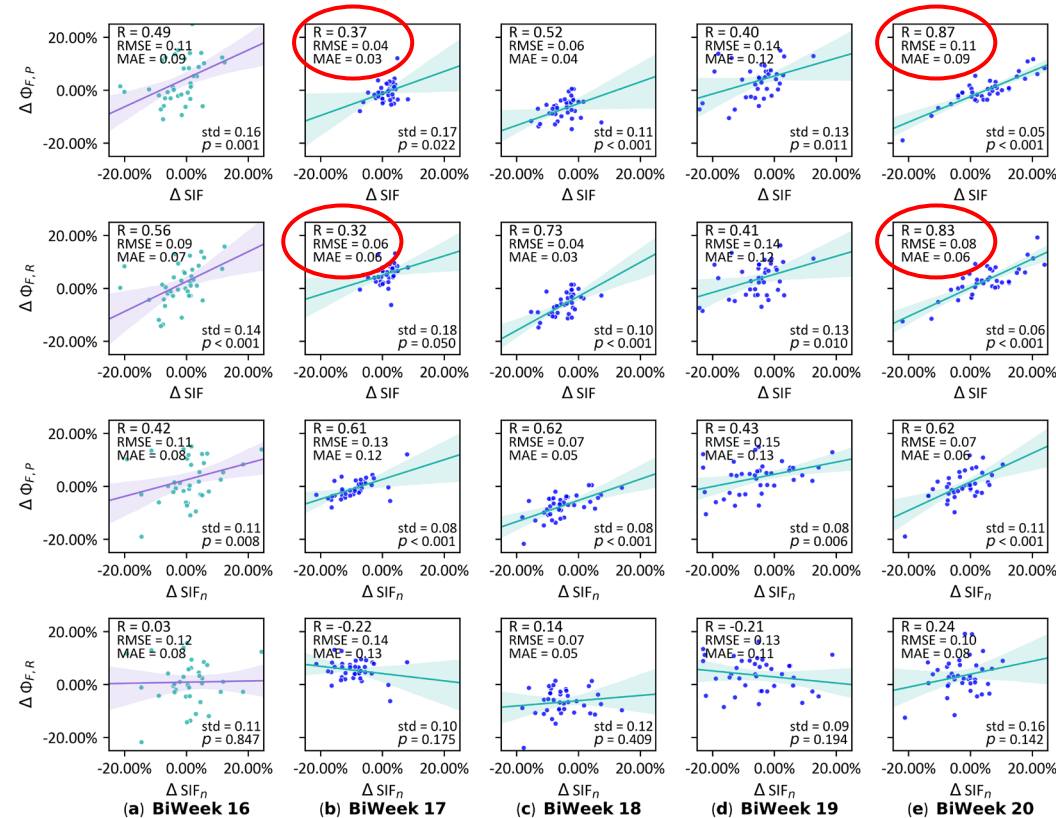
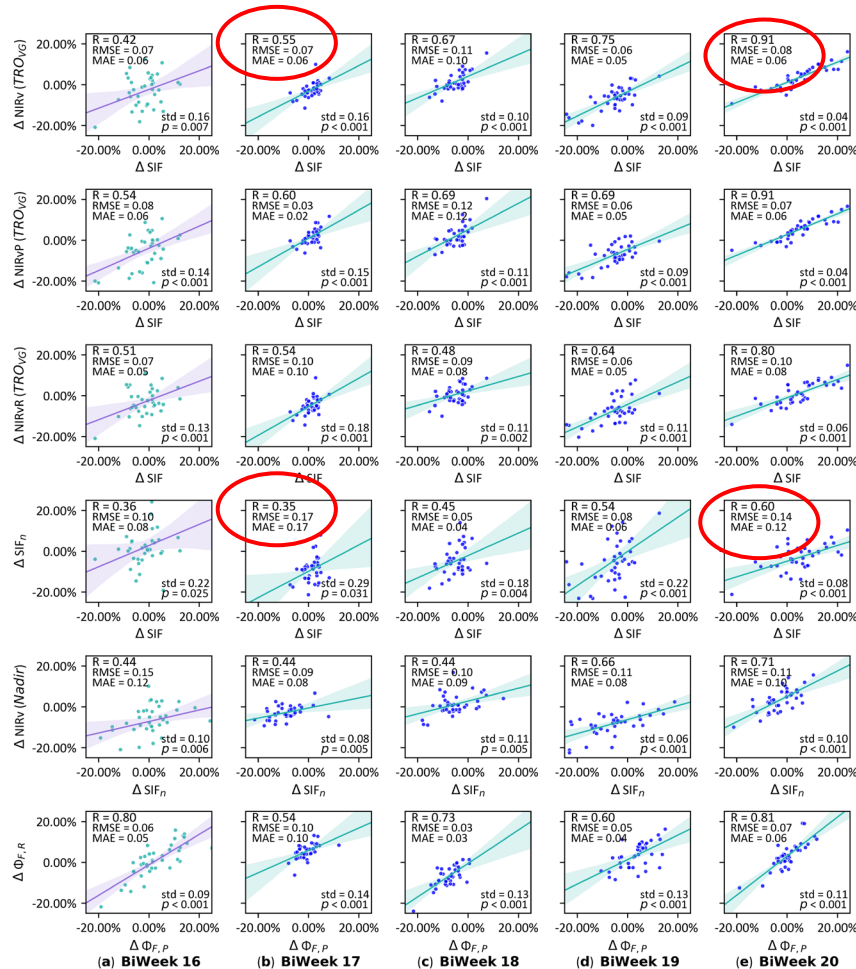
- After increased PAR and reduced rainfall in B17, the soil became drier.
- A further decrease in ΦF (Fluorescence Yield) in B18 reflected a drop in PSII quantum yield.

BiWeek 18 (Sustained Drought): NIRv Decreases

- The decrease in NIRv (Near-Infrared Reflectance of Vegetation) shows a shift from physiological to structural vulnerability.
- This was evident in reduced canopy density, biomass, and leaf curling, which are typical responses to long-term drought.



Correlation Analysis of VIs, SIF_n, and Raw SIF During Drought



- In the early stages of drought, the correlation between SIF and its proxy indices is weaker.
- As the drought alleviates, this relationship gradually strengthens.

- Vegetation indices such as NIRv are considered proxies for SIF due to their high correlation with SIF (Dechant et al., 2022; Zeng et al., 2022a, 2022b).

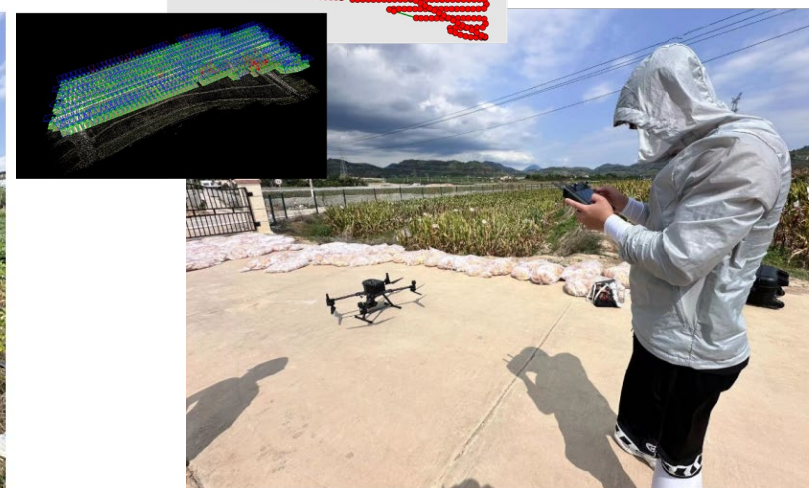
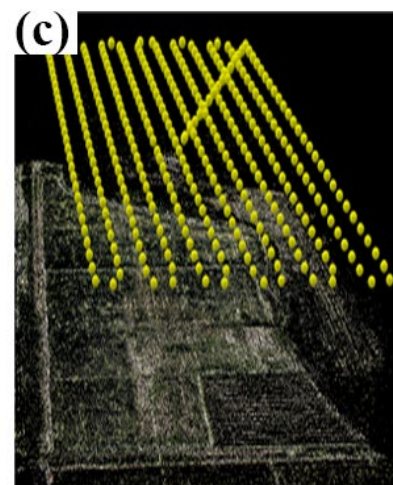
Field Campaigns



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UAV Soybean Observation

LiDAR



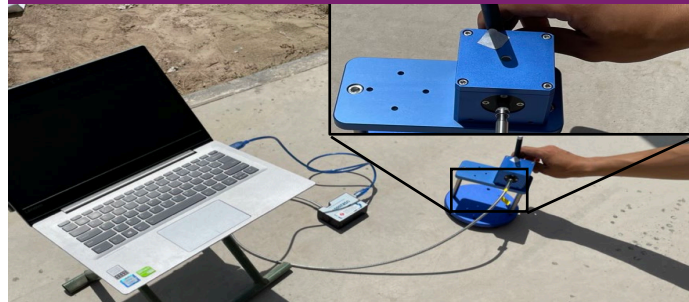
OCO3 SIF + TROPMI SIF Dual-Satellite Diurnal SIF Observation + UAV Experiments + Computer Simulations

- **Long-Term UAV Time-Series Data** — A two-year (2024-2025) field experiment observing changes in key crop indicators under different water and salt stresses throughout the **entire growth period**.
- **UAV Diurnal Data** — Data from 14 flights in one day, capturing short-term temporal changes in key crop indicators caused by **micro-environmental variations**.

UAV Canopy Data Acquisition



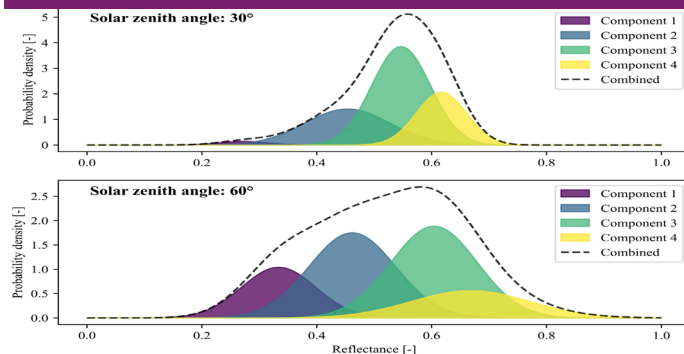
Incident Radiation Measurement



Leaf SPAD (LCC) Measurement



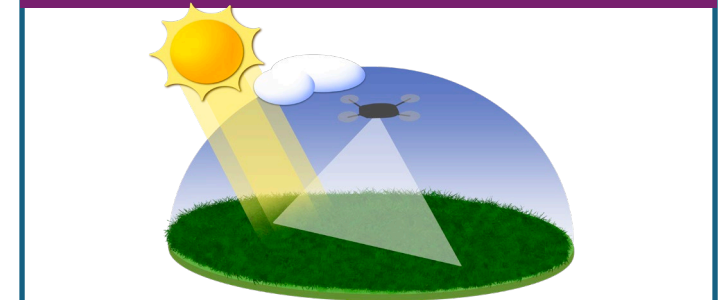
GMM Model



3D Modeling of Cotton Canopy



Diurnal Canopy Data Collection





❑ European side

1. Land surface temperature retrieval algorithm development
2. Land surface temperature downscaling
3. Energy-water balance model FEST

❑ Chinese side

1. SIF downscaling algorithm development
2. Crop water stress monitoring using SIF signal
3. SIF ground measurement

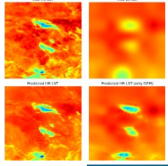
Planning for the Next Year



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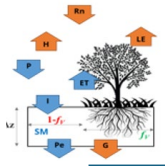


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Downscaling

- Finalisation of LST downscaling algorithm
- Finalisation of SIF downscaling algorithm



Modelling

- FEST model driven by SIF signal
- Transpiration-photosynthesis coupling model



Exchange

- Strengthening scientific exchange between the European and Chinese sides
- Synergize thermal and SIF observations for crop water stress monitoring through joint efforts



Thank you for your attention!

