Irrigation mapping, detection and quantification

Jacopo Dari

27/09/2023

PRESENTATION OVERVIEW

Why irrigation?

Irrigation practices and the role of soil moisture

Irrigation monitoring through satellites

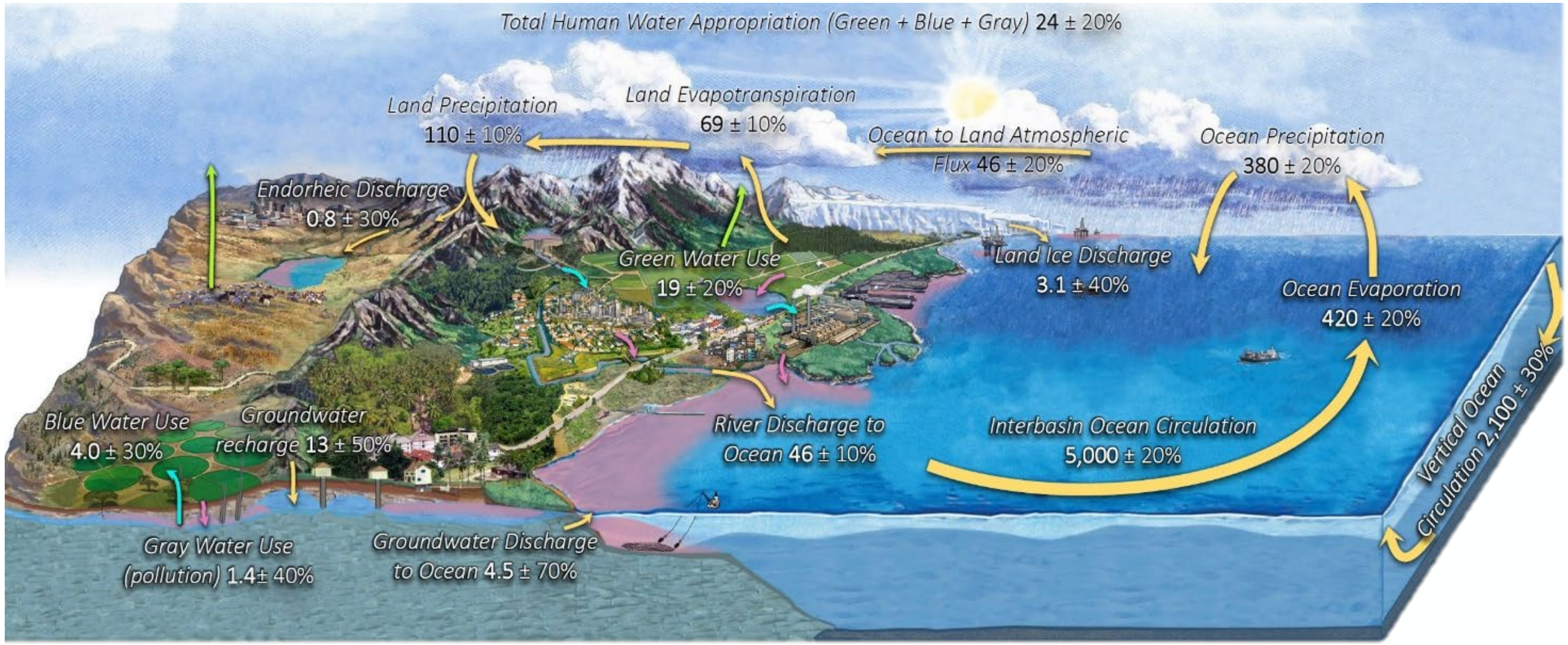
- Overview on irrigation monitoring through satellites
- How much information on irrigation dynamics can be retrieved by satellite soil moisture?

Outlook

- Main challenges to be faced
- How can satellite-derived irrigation products be useful/used?

WHY IRRIGATION?

Many scientists suggest to rename the era we are living in as the **Anthropocene**. Humans are modifying the **natural water cycle** at an unprecedented scale.



Blue water: the water available in rivers, lakes, shallow aquifers.

Green water: the water stored in unsaturated soil and later used for agricultural purposes (i.e., irrigation).

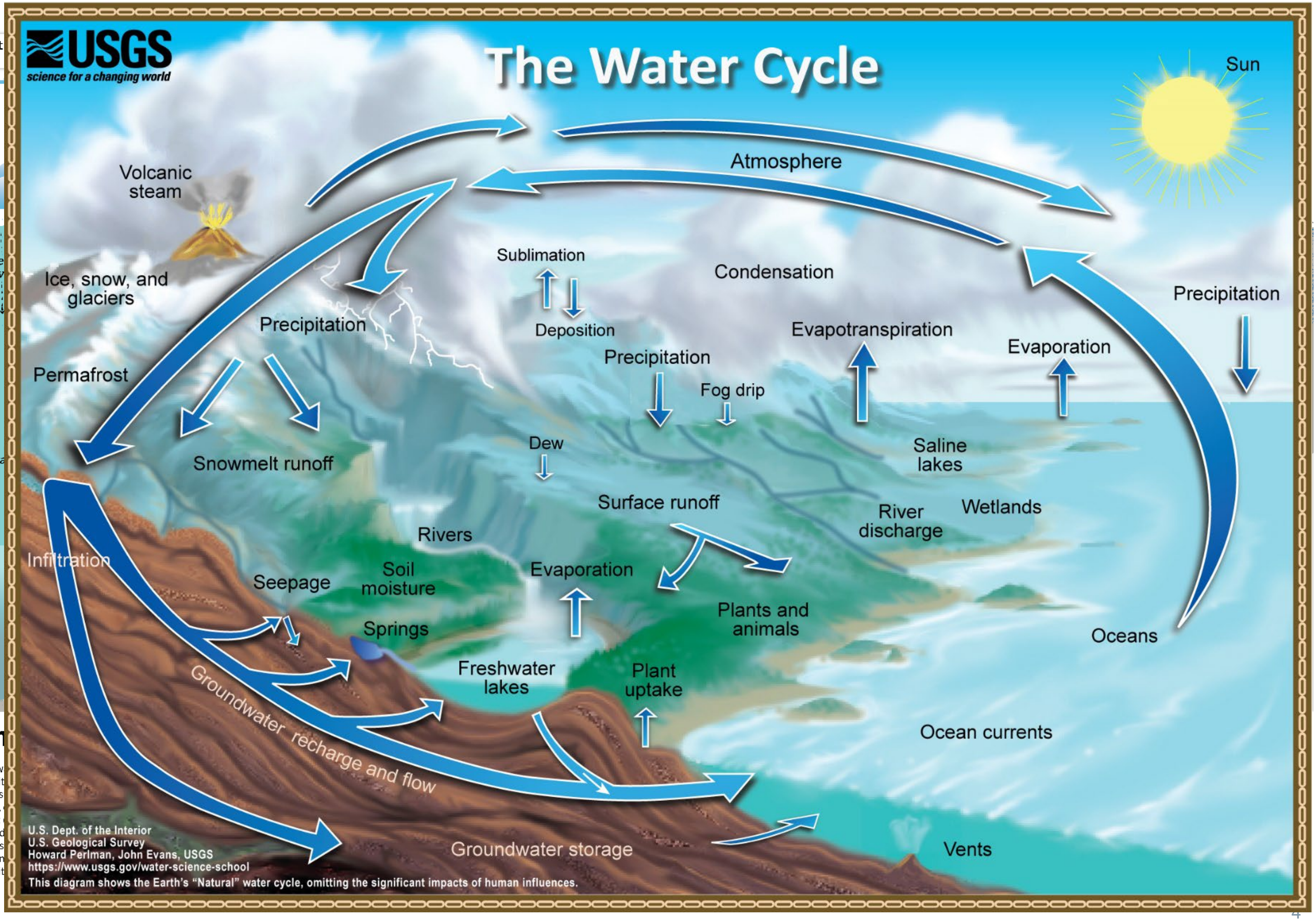
Grey water: fresh water needed to dilute the pollutant load.

(Abbott et al., 2019; https://doi.org/10.1038/s41561-019-0374-y)

WHY IRRIGATION?

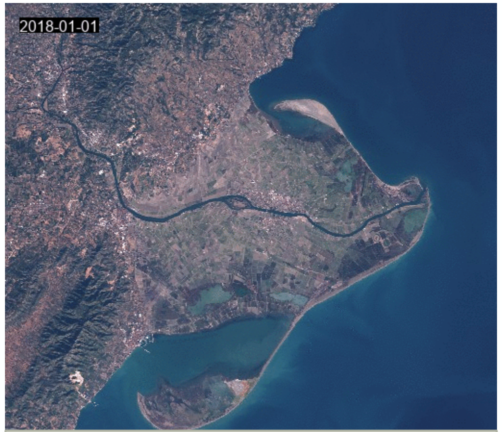
The «NEW» WATER CYCLE

*«... **We** alter the water cycle. **We** redirect rivers, **we** build dams to store water. **We** drain water from wetlands for development. **We** use water from rivers, lakes, reservoirs, and groundwater aquifers. **We** use that water to supply our homes and communities. **We** use it for agricultural irrigation and grazing livestock. **We** use it in industrial activities...»*



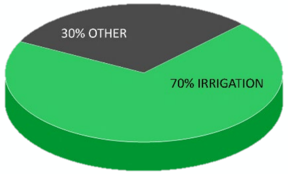
WHY IRRIGATION?

Saudi Arabia irrigation, 1984-2012



Rice fields, Spain, 2018

Among the human activities altering the natural water cycle, **irrigation** is the most impactful one.



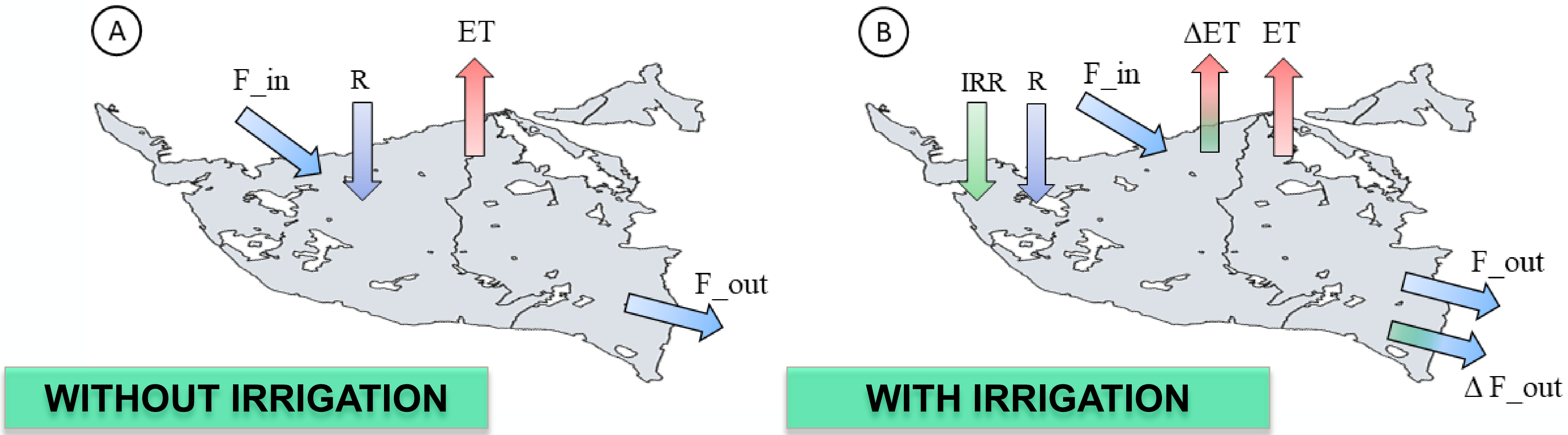
More than 70% (almost 90% in some countries) of global freshwater withdrawals are destined to irrigation practices.
(Foley et al., 2011; doi:10.1038/nature10452)

BUT

Detailed information on irrigation dynamics (i.e., timing, mapping, and amounts) is generally lacking worldwide.

WHY IRRIGATION?

From the **hydrological** point of view



Irrigation water is often delivered in a site different from where it is withdrawn (from rivers, dams, groundwater)

Irrigation water alters surface and sub-surface flows

Irrigation increases evapotranspiration, as crops have the optimal amount of water allowing the evapotranspiration at the potential rate

WHY IRRIGATION?

From the **hydrological** point of view

Potential for sustainable irrigation expansion in a 3 °C warmer climate

Lorenzo Rosa[a,1,2], Davide Danilo Chiarelli[b], Matteo Sangiorgio[c], Areidy Aracely Beltran-Peña[a], Maria Cristina Rulli[b], Paolo D'Odorico[a], and Inez Fung[a,d,1]

[a]Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720; [b]Department of Civil and Environmental Engineering, Politecnico di Milano, 20133 Milano, Italy; [c]Department of Electronics, Information, and Bioengineering, Politecnico di Milano, 20133 Milano, Italy; and [d]Department of Earth and Planetary Science, University of California, Berkeley, CA 94720

PNAS, Nov 9, 2020; https://doi.org/10.1073/pnas.2017796117

ARTICLE

https://doi.org/10.1038/s41467-019-14075-4 OPEN

Warming of hot extremes alleviated by expanding irrigation

Wim Thiery[1,2]*, Auke J. Visser[3], Erich M. Fischer[1], Mathias Hauser[1], Annette L. Hirsch[4], David M. Lawrence[5], Quentin Lejeune[6], Edouard L. Davin[1] & Sonia I. Seneviratne[1]

Nat Communication, Jan 15, 2020; https://doi.org/10.1038/s41467-019-14075

ARTICLES

https://doi.org/10.1038/s41561-020-00650-8

nature geoscience

Check for updates

Moist heat stress extremes in India enhanced by irrigation

Vimal Mishra[1,2], Anukesh Krishnankutty Ambika[2], Akarsh Asoka[2], Saran Aadhar[1], Jonathan Buzan[3], Rohini Kumar[4] and Matthew Huber[3]

Nat Geoscience, Oct 26, 2020; https://doi.org/10.1038/s41561-020-00650-8

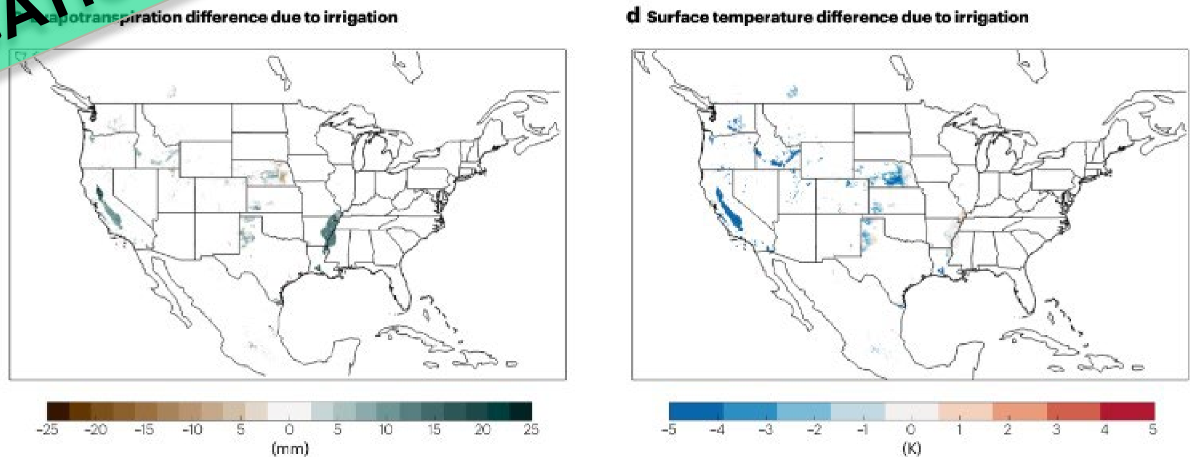
nature reviews earth & environment https://doi.org/10.1038/s43017-023-00438-5

Review article

Check for updates

Irrigation in the Earth system

Sonali McDermid[1,2], ..., Patricia Lawston-Parker[4,5], Jessica Keune[6], Yadu Pokhrel[7], Meha Jain[8], Jonas Jägermeyr, ..., Luca Brocca, ..., Christian Massari[11], Andrew D. Jones[12,13], Pouya Vahmani[12], Wim Thiery[14], Yi Yao[14], ..., Wouter Dorigo[17], Naota Hanasaki[18], Scott Jasechko[19], Min-Hui Lo[20], ..., Nathaniel D. Mueller[23,24], Dev Niyogi[25,26], Sam S. Rabin[27,28], Lindsey Sloat[24,29], ..., Luca Zappa[17], Fei Chen[28], Benjamin I. Cook[2], Hyungjun Kim[31], Danica Lombardozzi[28], ..., Dongryeol Ryu[33], Joe Santanello[4], Yusuke Satoh[31], Sonia Seneviratne[34], Deepti Singh[35] & ... Yokohata[36]

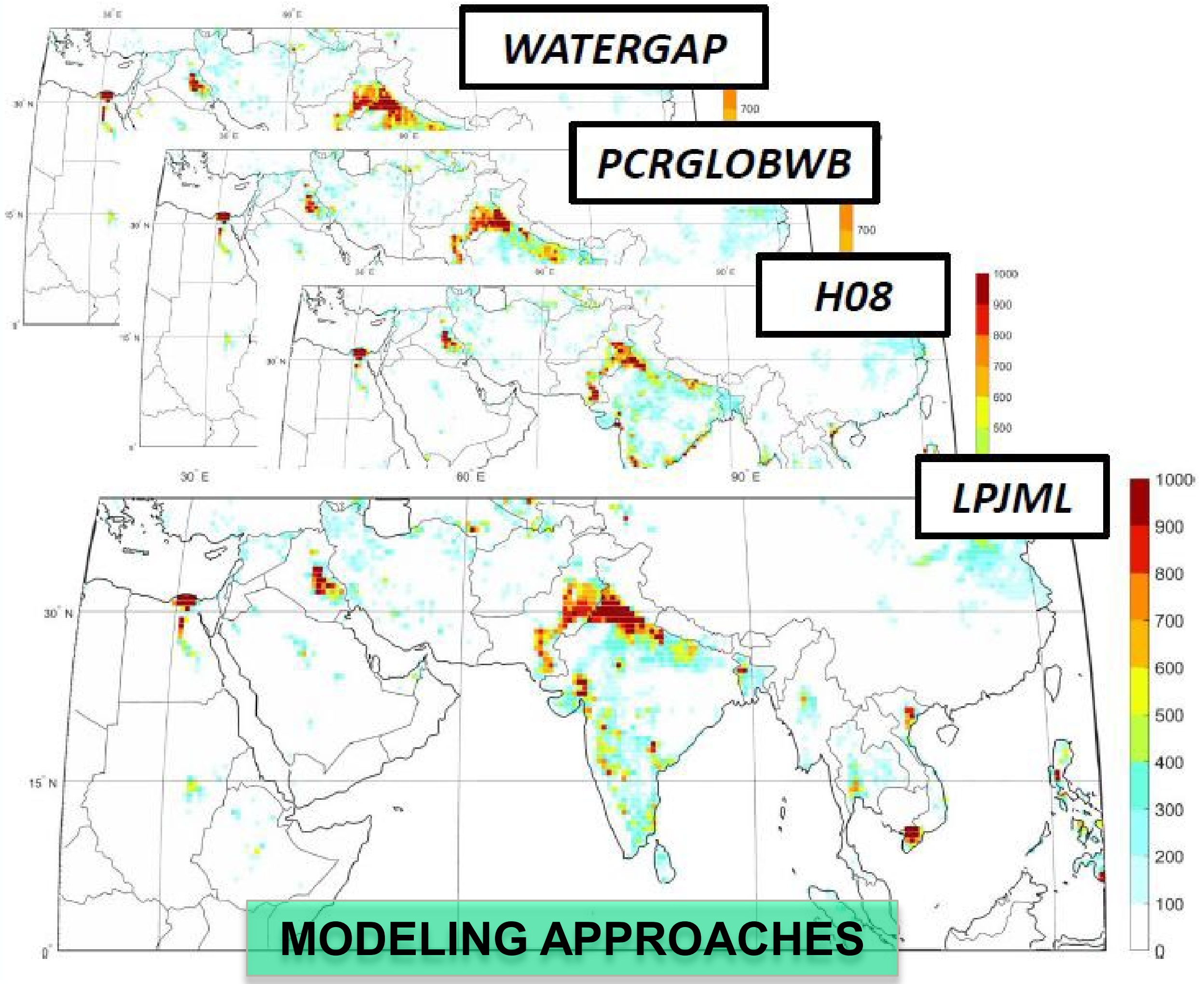


ALL THESE STUDIES RELY ON MAPS OF AREAS EQUIPPED FOR IRRIGATION AND SIMULATED DATA

(*McDermid et al., 2023*; https://doi.org/10.1038/s43017-023-00438-5)

WHY IRRIGATION?

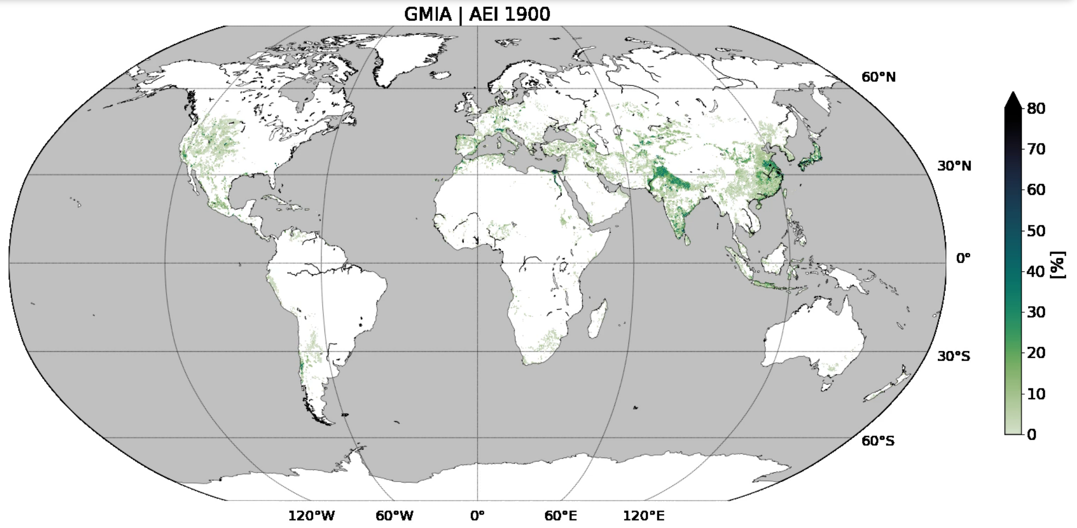
Aivailable irrigation data



MODELING APPROACHES

(Huang et al., 2018; https://doi.org/10.5194/hess-22-2117-2018)

SATISTICAL SURVEYS / STATISTICAL SURVEYS + REMOTE SENSING



(Siebert et al., 2015; doi:10.13019/M20599)

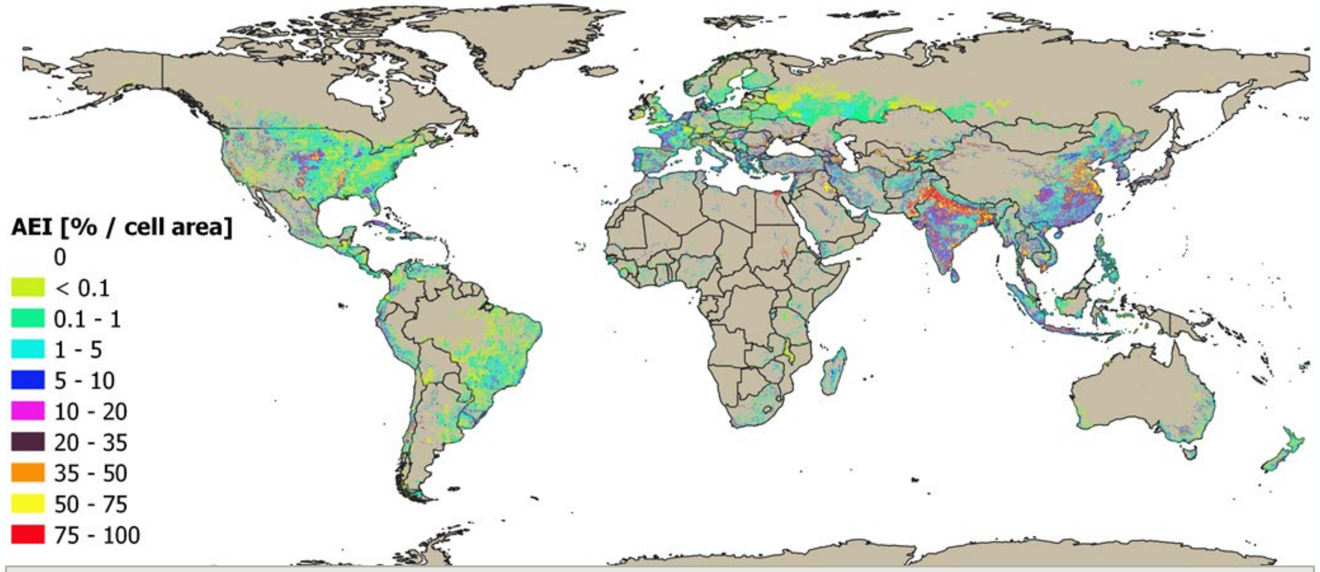
... et al.

(Salmon et al., 2015; http://dx.doi.org/10.1016/j.jag.2015.01.014)

(Nagaraj et al., 2021; https://doi.org/10.1016/j.advwatres.2021.103910)

WHY IRRIGATION?

- The only information available is often represented by statistical surveys at the country (or even at a coarser) scale
- Farmers are generally reluctant to share information on irrigation doses, as agricultural water is often paid on the basis of concessions and not on the basis of actual consumption
- Information on irrigation practices are often collected through surveys relying on self-declarations, which can be affected by several uncertainties
- Information on actually irrigated areas is often dynamic in time



Areas equipped for irrigation, GMIA–FAO (Siebert et al., 2015)

Key (unsolved) questions:

Do we know when and where irrigation practices actually occur?

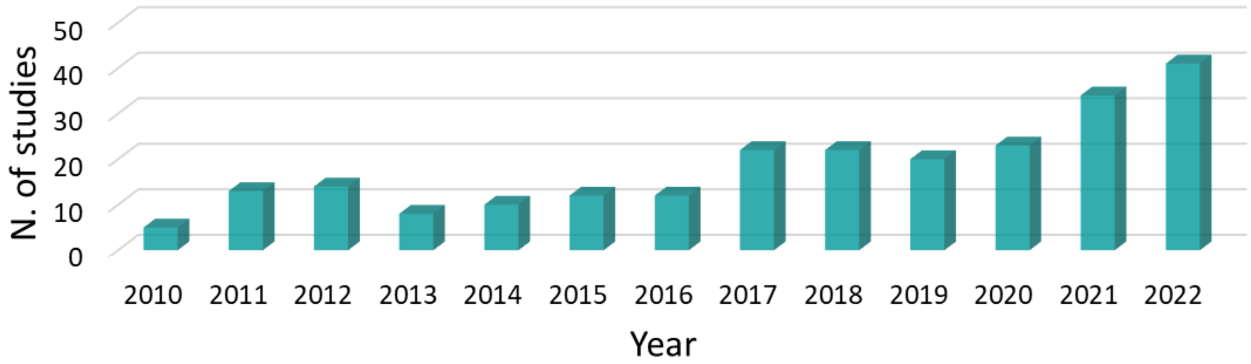
How much water is used for irrigation?

WHY IRRIGATION?

Satellites can help!

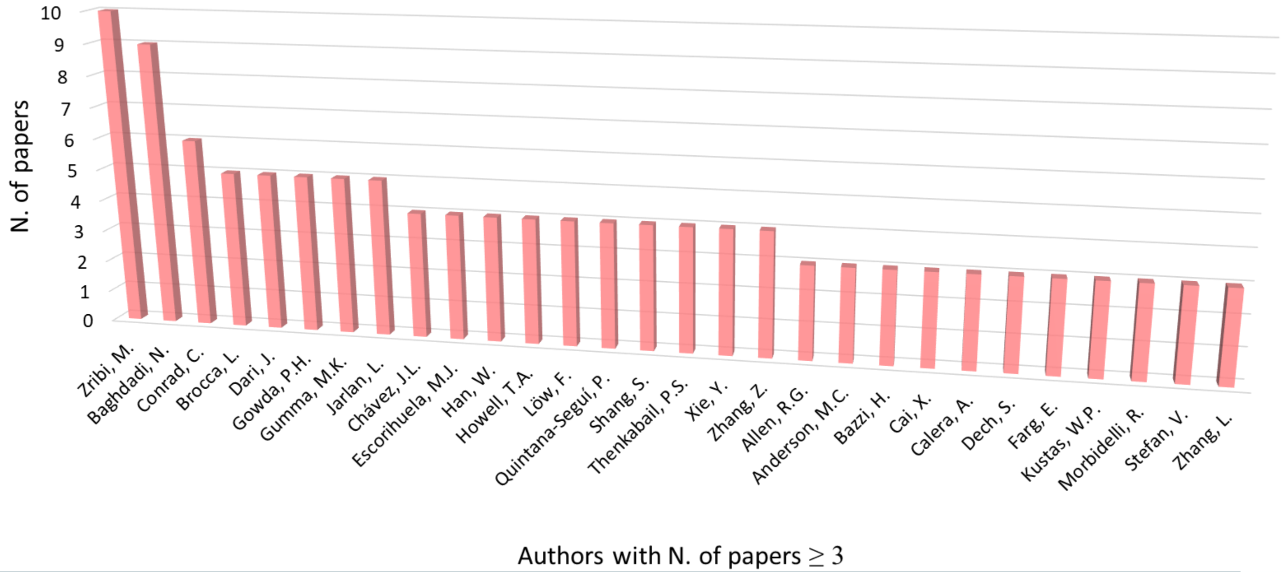
Scopus

Results of a bibliographic search based on the keywords: «irrigation amounts, irrigation estimates, irrigation mapping, irrigation timing» AND «satellite, remote sensing»



Since 2010, the number (per year) of papers aimed at monitoring irrigation dynamics through remote sensing observations increased by +720% (from 5 to 40+ per year).

During the same time span, 29 scientists published 3+ papers on the topic.



WHY IRRIGATION?

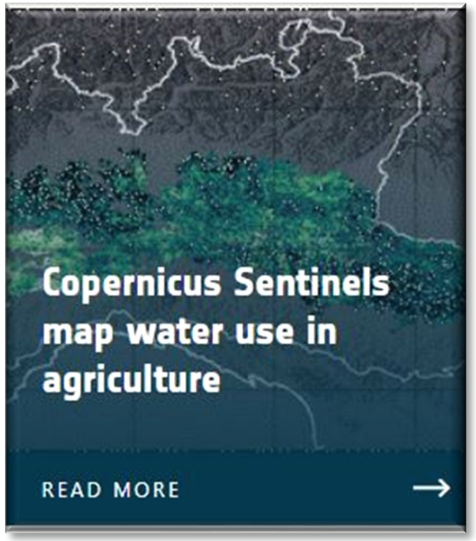
The interest of ESA on this topic: The IRRIGATION+ Project

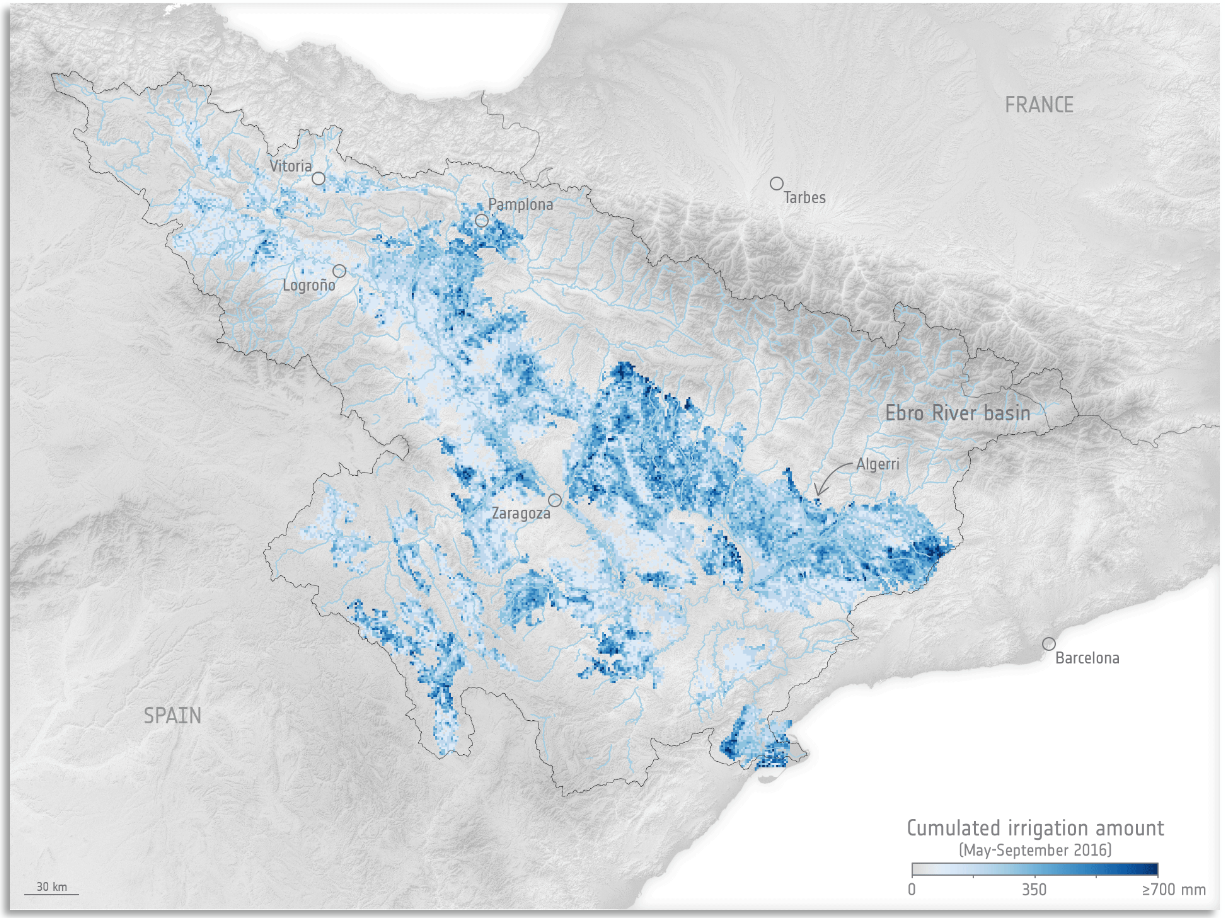
The ESA IRRIGATION+ project aims to explore, develop and validate advanced EO-based algorithms and techniques for irrigation mapping, quantification and detection of seasonal timing of irrigation from field to regional/global scale.

IRRIGATION+

Sentinel Success Stories

https://sentinels.copernicus.eu/web/success-stories/-/copernicus-sentinels-map-water-use-in-agriculture/2.4





https://www.esa.int/Applications/Observing_the_Earth/FutureEO/How_much_water_do_we_use_for_irrigation

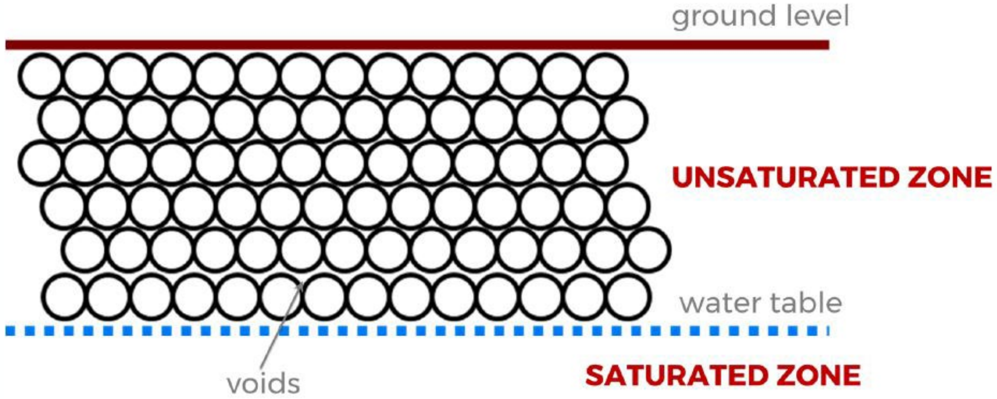
IRRIGATION PRACTICES AND THE ROLE OF SOIL MOISTURE

The aim of irrigation practices is to improve the productivity of an agricultural soil → optimization from an economic point of view

Many factors affect the design of the irrigation network

- Soil texture
- Kind of crop
- Topograhy
- Water availability

Soil moisture (i.e., the amount of water stored in the unsaturated zone) is essential for irrigation management

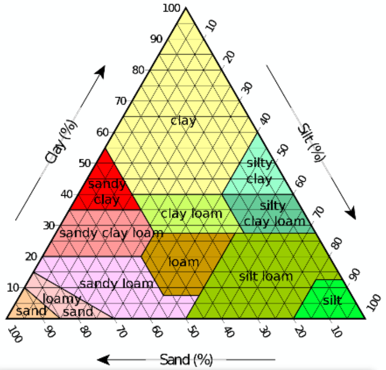


$$\theta = \frac{V_{Water}}{\Delta x \Delta y \Delta z}$$ **Soil Moisture**

$$\vartheta_{wp} \leq \vartheta \leq \vartheta_{fc}$$

ϑ_{wp} → Wilting point

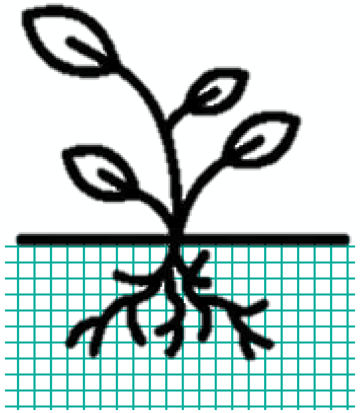
ϑ_{fc} → Field capacity



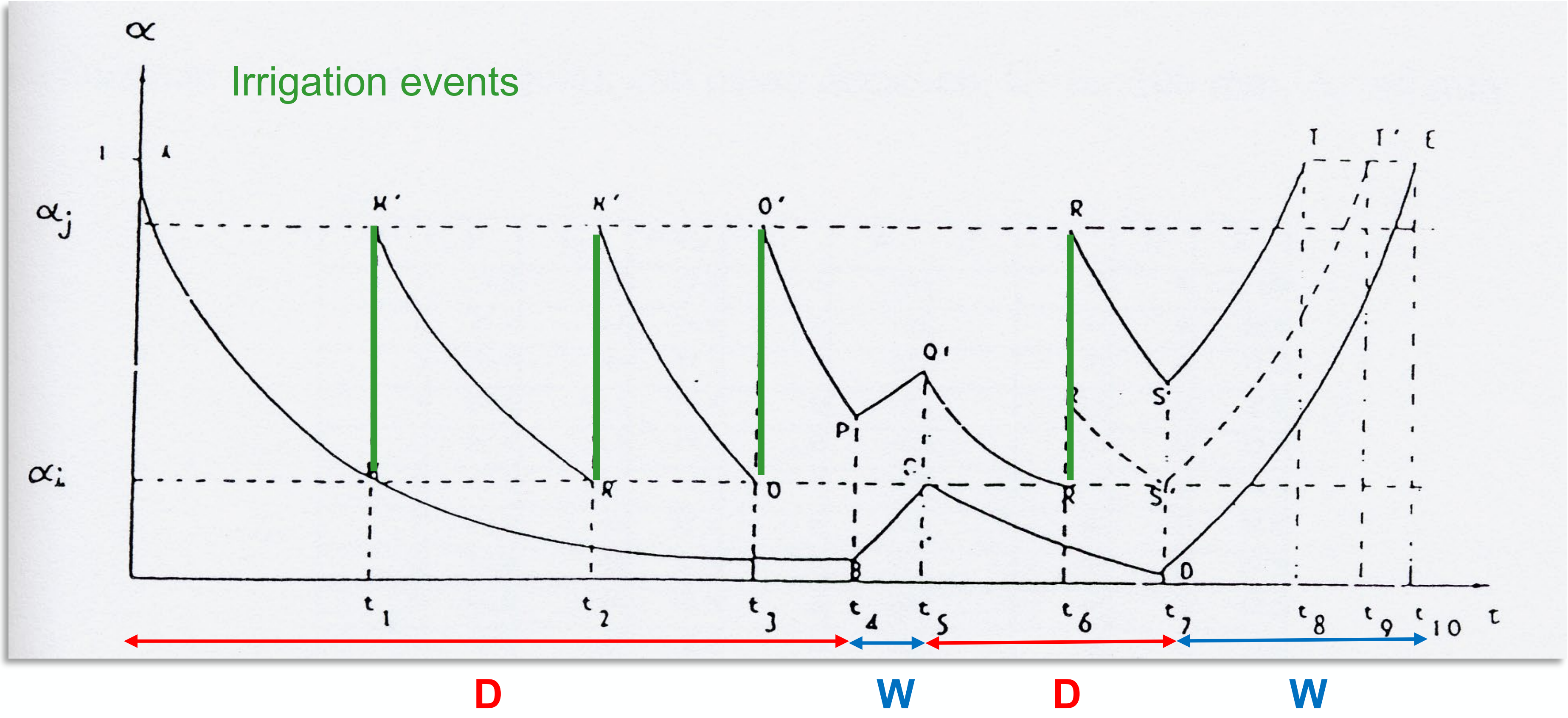
IRRIGATION PRACTICES AND THE ROLE OF SOIL MOISTURE

The irrigation scheduling is **theoretically** regulated by **soil moisture**

$$\alpha = \alpha_{max} e^{-\lambda}$$



What really cares is the volume of water retained by capillarity

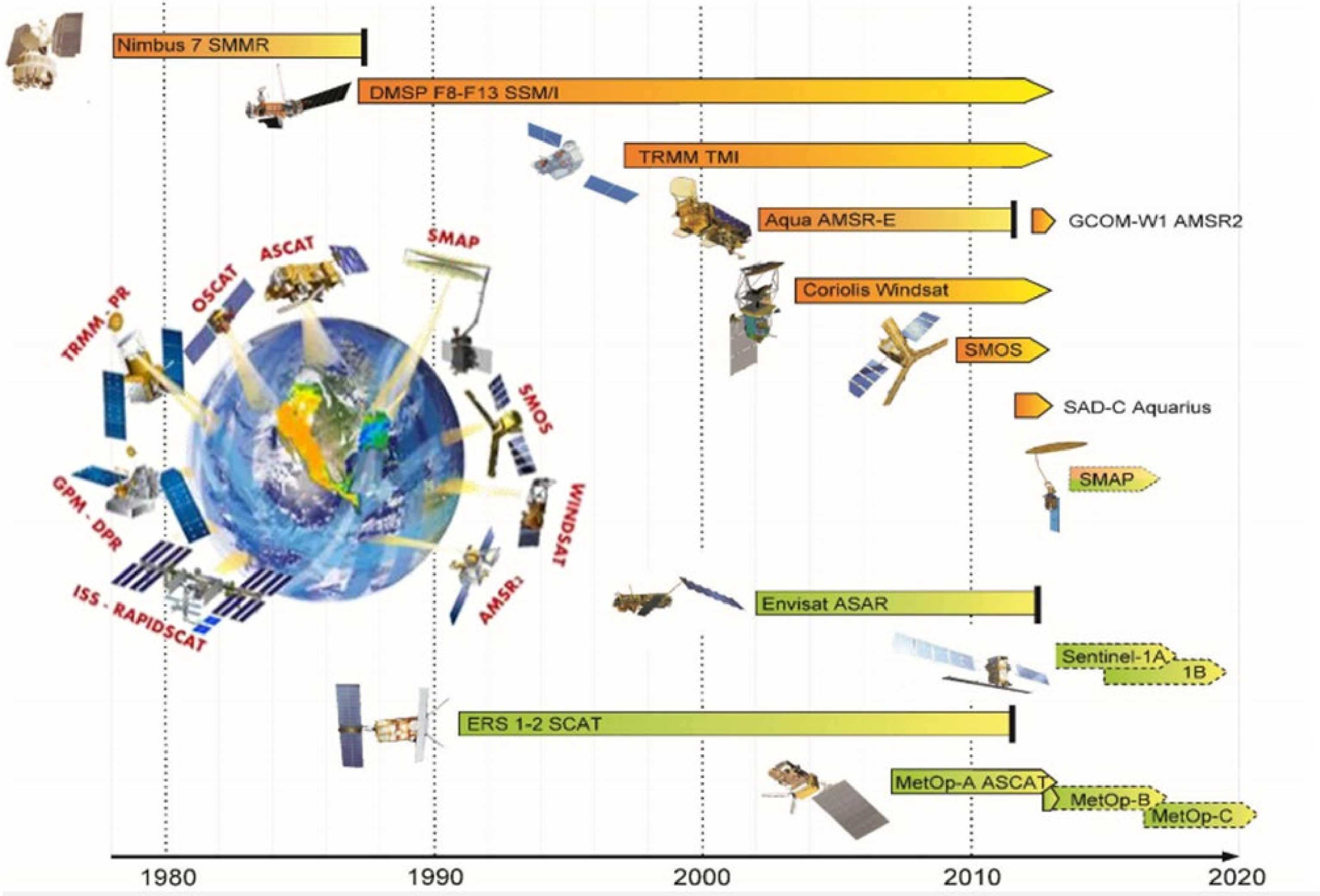


Satellite soil moisture

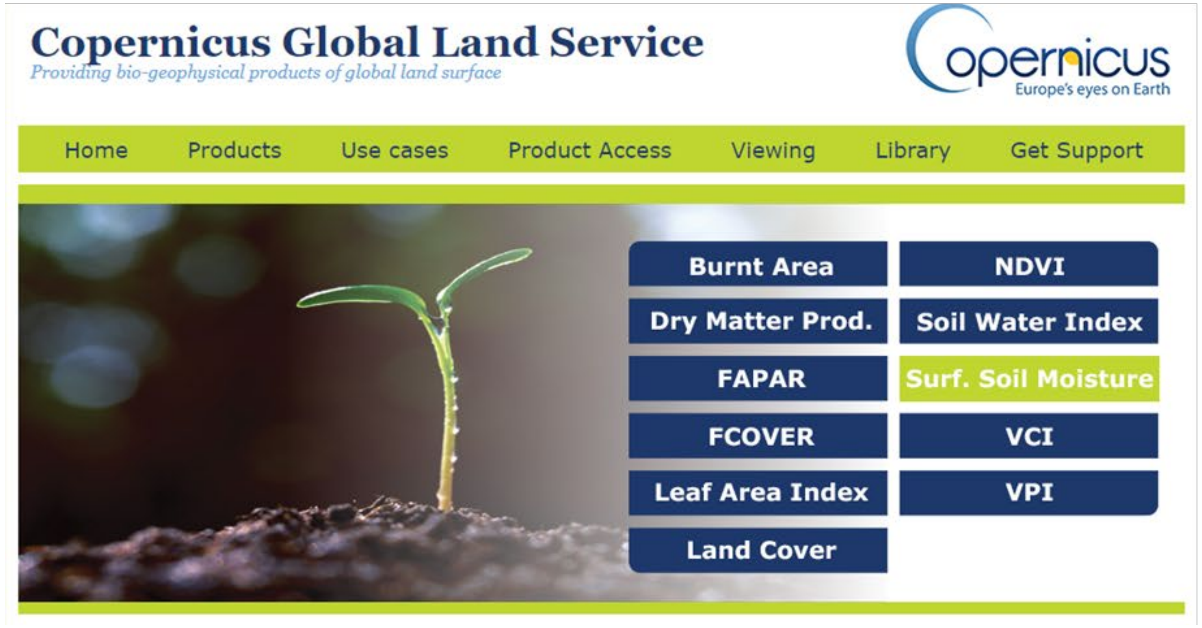
Soil moisture is an essential variable for monitoring irrigation dynamics (also from space)

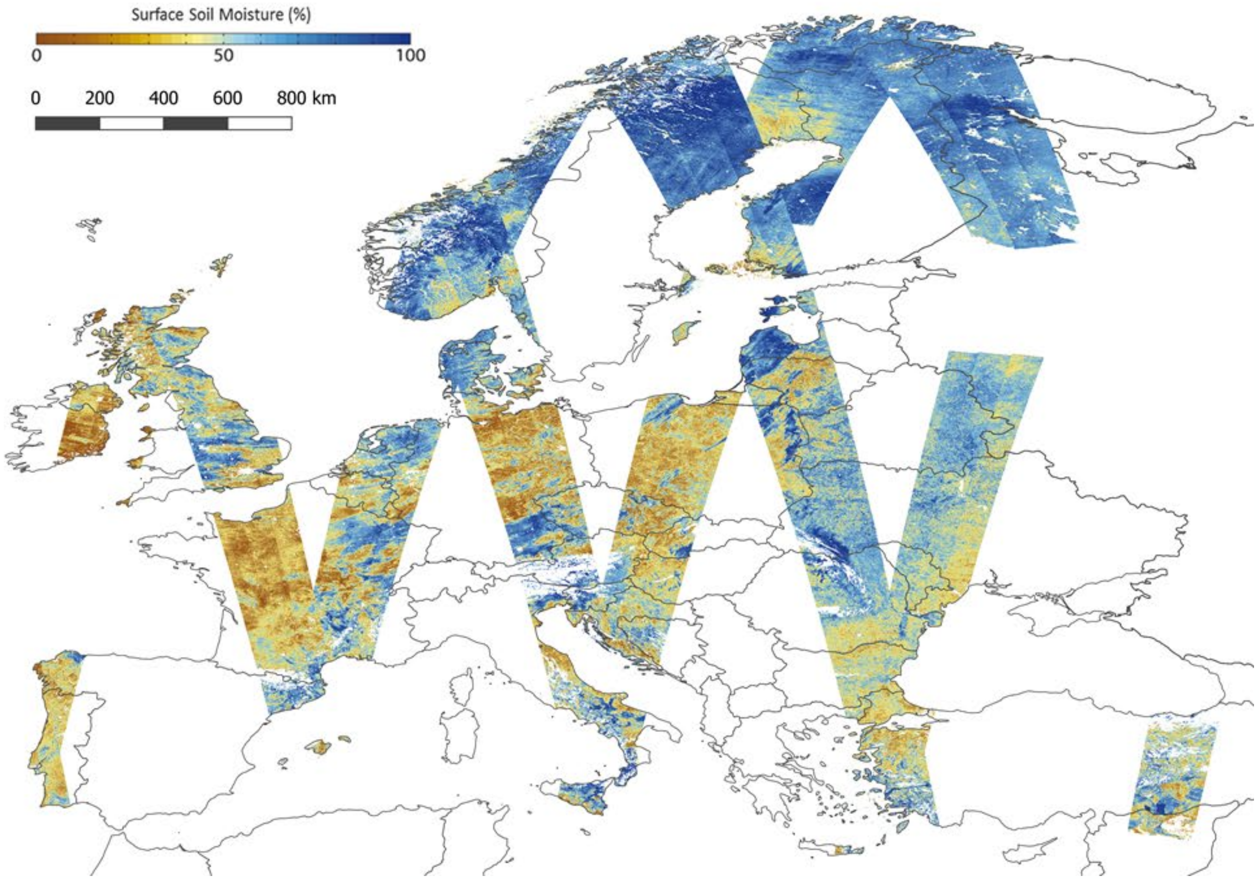
A constellation of satellite sensors for measuring soil moisture is available

High spatial and temporal resolutions are achievable with the latest missions, e.g., Sentinel-1, CYGNSS



Operational soil moisture products

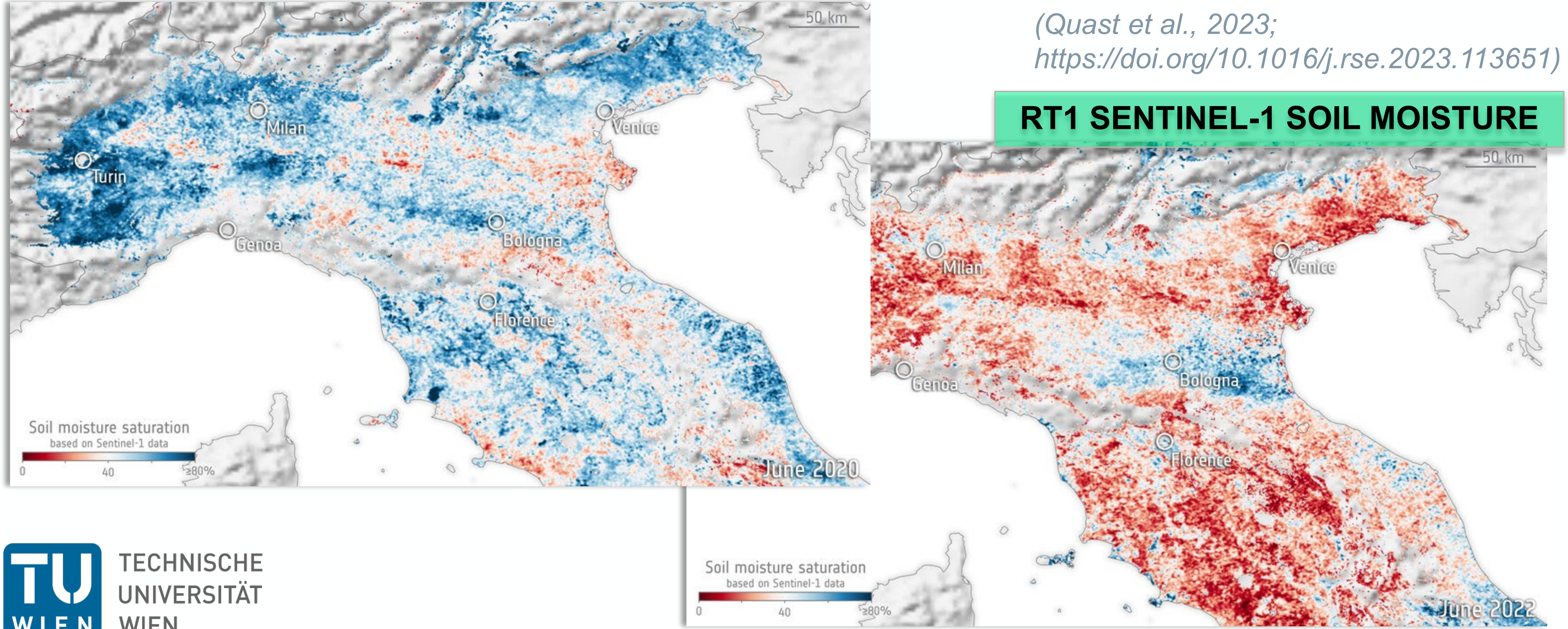




High-resolution era: unprecedented opportunities

(Quast et al., 2023; https://doi.org/10.1016/j.rse.2023.113651)

RT1 SENTINEL-1 SOIL MOISTURE



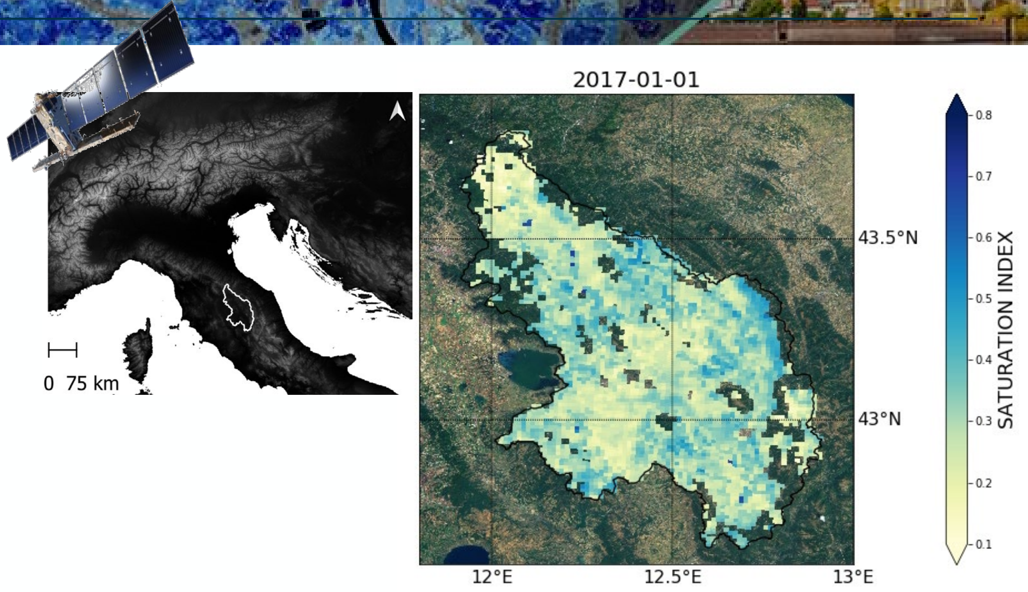
TECHNISCHE UNIVERSITÄT WIEN

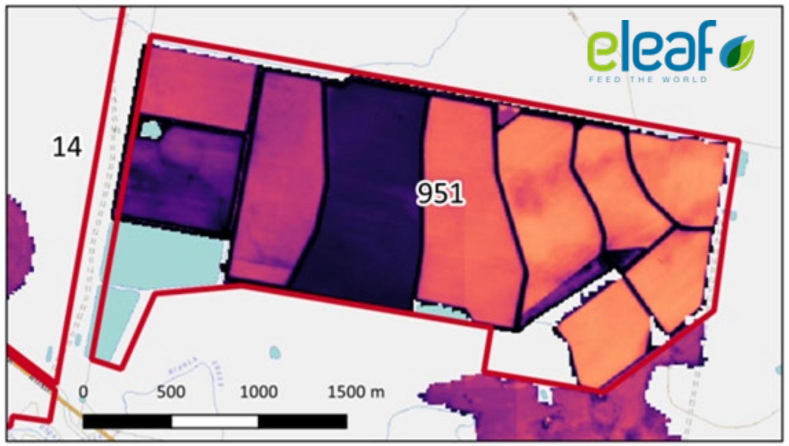
IRRIGATION MONITORING THROUGH SATELLITES

Soil moisture is an essential variable for monitoring irrigation dynamics (also from space)

... But not the only one!

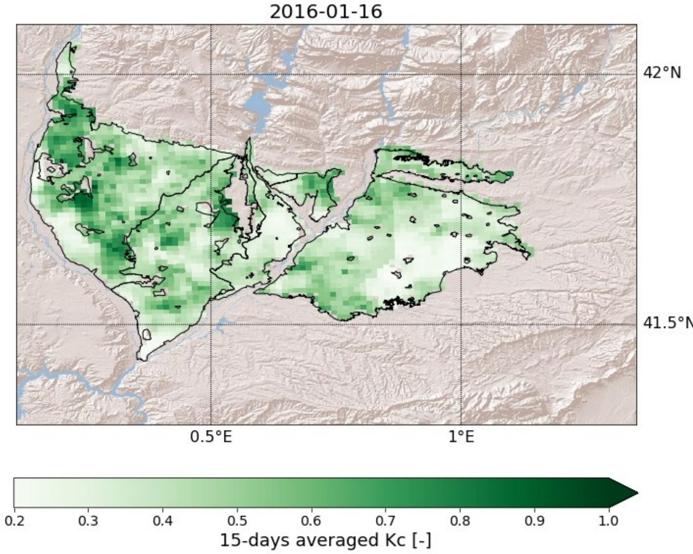
Satellite-derived estimates of **evapotranspiration fluxes**, **vegetation indices**, and **crop coefficients** are widely used as irrigation proxies.





Satellite-derived ET produced by **eleaf**

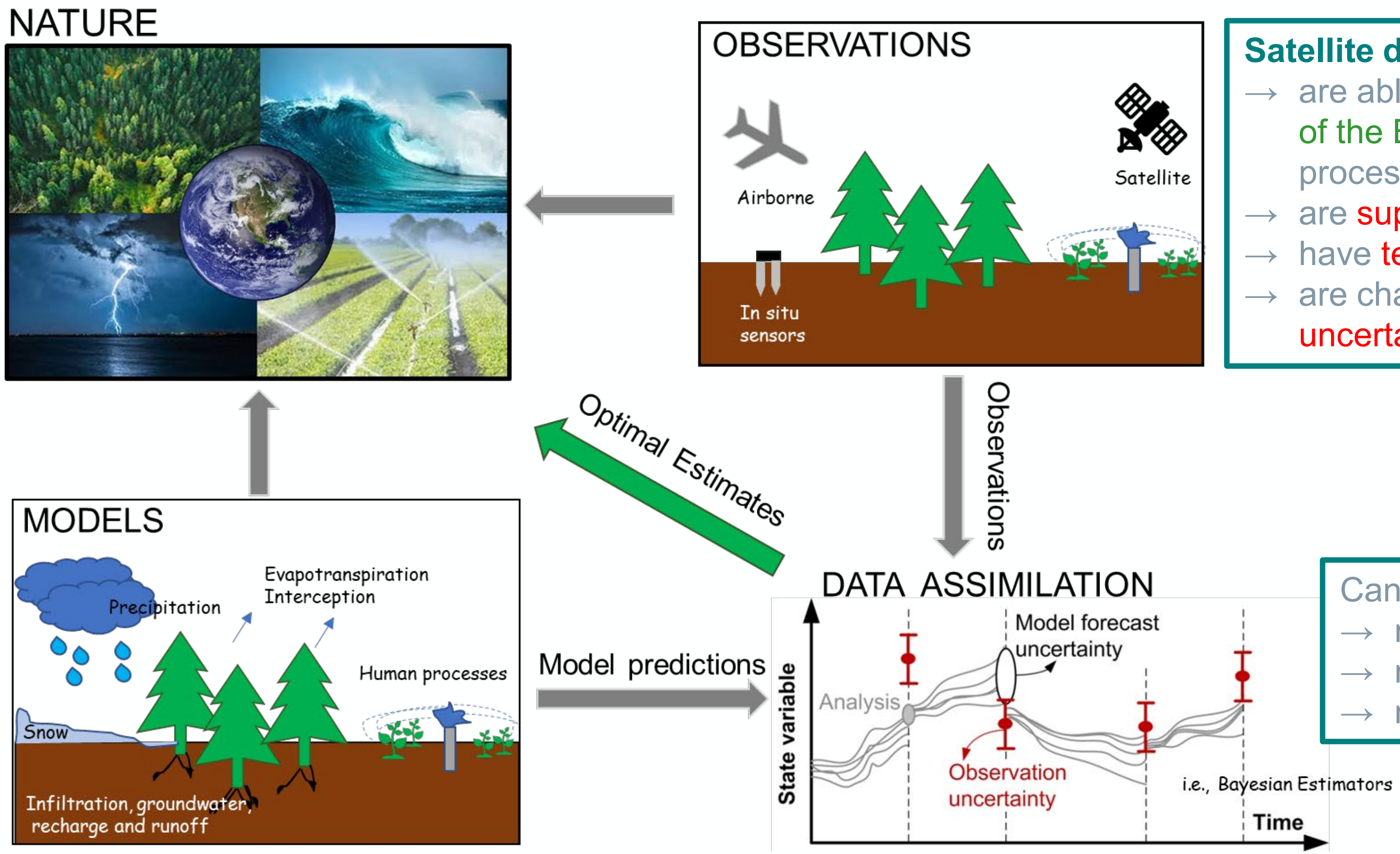
(*Dari et al., 2020*, https://doi.org/10.3390/rs12162593)



Satellite-derived **Kc** in Spain

Data assimilation

Land modeling systems:
- → are able to predict and simulate physical processes
- → are based on the principle of mass and energy conservation
- → are able to provide continuous simulations in space and time
- → are characterized by errors, uncertainties (i.e. input data) and simplified assumptions



Satellite data:
- → are able to observe the true state of the Earth surface (i.e., human processes)
- → are superficial measures
- → have temporal and spatial gaps
- → are characterized by errors and uncertainties

Can be used to optimize:
- → model parameters
- → model forcing
- → model state

Courtesy of S. Modanesi

esa

How can we use satellites for monitoring irrigation?

IRRIGATION

remote sensing

MDPI

Review

A Review of Irrigation Information Retrievals from Space and Their Utility for Users

Christian Massari [1,*], Sara Modanesi [1,2,3], Jacopo Dari [1,4], Alexander Gruber [2], Gabrielle J. M. De Lannoy [2], Manuela Girotto [5], Pere Quintana-Seguí [6], Michel Le Page [7], Lionel Jarlan [7], Mehrez Zribi [7], Nadia Ouaadi [7,8], Mariëtte Vreugdenhil [9], Luca Zappa [9], Wouter Dorigo [9], Wolfgang Wagner [9], Joost Brombacher [10], Henk Pelgrum [10], Pauline Jaquot [10], Vahid Freeman [11], Espen Volden [12], Diego Fernandez Prieto [12], Angelica Tarpanelli [1], Silvia Barbetta [1] and Luca Brocca [1]

(*Massari et al., 2021;* https://doi.org/10.3390/rs13204112)

IRRIGATION MONITORING THROUGH SATELLITES

How can we use satellites for monitoring irrigation?

Microwave (MW) sensors

MW satellite products (e.g., **soil moisture**) can be used to detect and quantify irrigation. The main advantage is that they are not affected by weather conditions.

Detection and Mapping methods based on MW soil moisture

- Discrepancies between satellite (including, theoretically, irrigation) and modeled (not including irrigation) data sets
- Analysis of satellite soil moisture data sets and their features

How can we use satellites for monitoring irrigation?

Microwave (MW) sensors

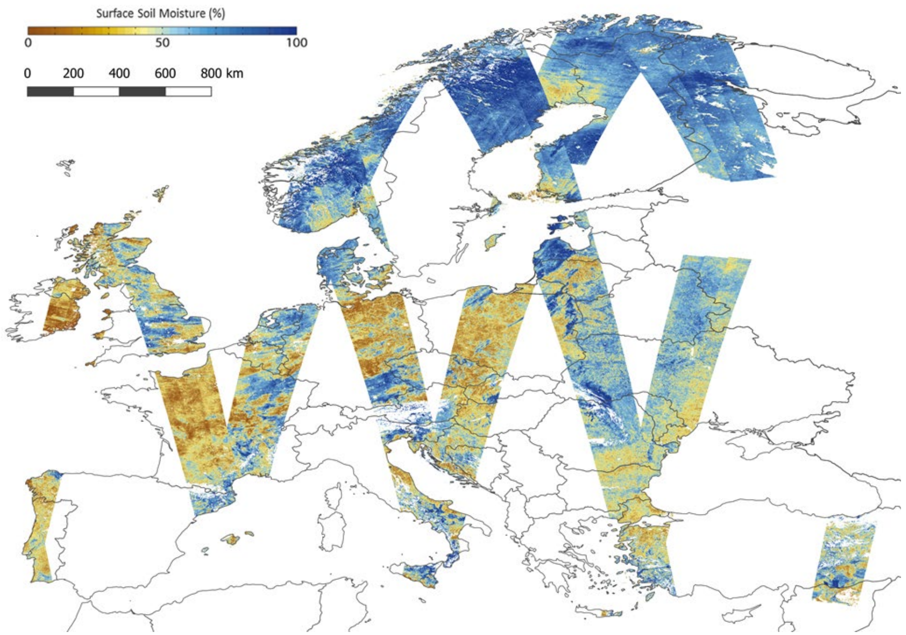
MW satellite products (e.g., **soil moisture**) can be used to detect and quantify irrigation. The main advantage is that they are not affected by weather conditions.

Quantification methods based on MW soil moisture

- Soil water balance
- Discrepancies between satellite (including, theoretically, irrigation) and modeled (not including irrigation) data sets

HOW MUCH INFORMATION ON IRRIGATION DYNAMICS CAN BE RETRIEVED BY MW SENSORS (MAINLY SOIL MOISTURE DATA)?

Two operational approaches based on data retrieved by MW sensors and aimed at mapping the actual extent of irrigated areas will be presented and compared



Two approaches based on remotely sensed soil moisture aimed at quantifying irrigation will be presented

IRRIGATION DETECTION AND MAPPING THROUGH SATELLITE SOIL MOISTURE

Exploiting the temporal stability concept for irrigation mapping:

Also called as «DARI» model in later studies

CORE IDEA: During the irrigation season, irrigated areas are characterized by higher soil moisture values with respect to the temporal mean and with respect to rainfed areas.

How can this information be translated into statistical features? → The temporal stability theory

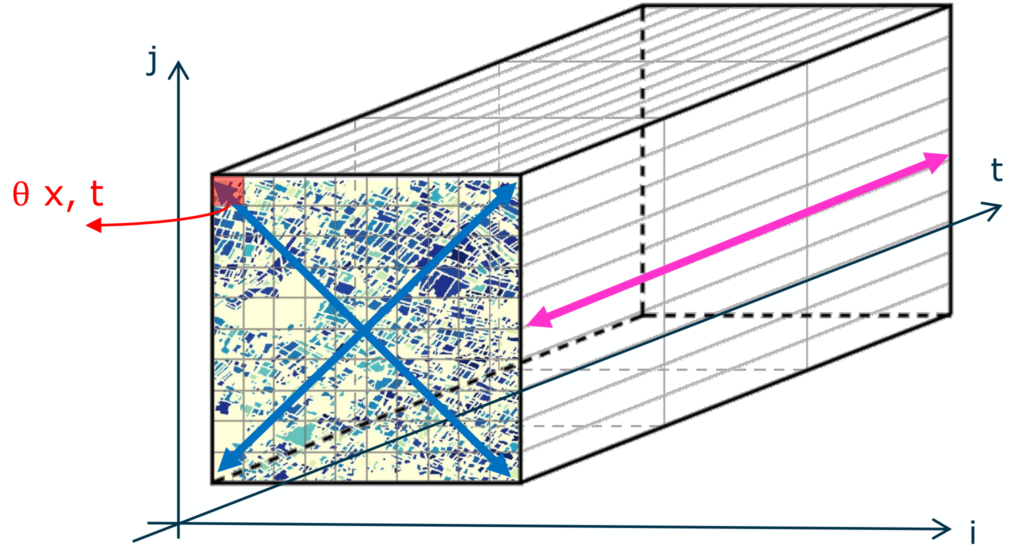
Indices derived from the temporal stability theory

$\bar{\theta}_t$ Spatial mean at day t

$\bar{\theta}_x$ Temporal mean

Relative differences: $RD = (\theta_{x,t} - \bar{\theta}_t)/\bar{\theta}_t$

Temporal anomalies: $TA = (\theta_{x,t} - \bar{\theta}_x)/\bar{\theta}_x$



Ex. of data set

(Vachaud et al., 1985)

(Dari et al., 2021; https://doi.org/10.1016/j.jhydrol.2021.126129)

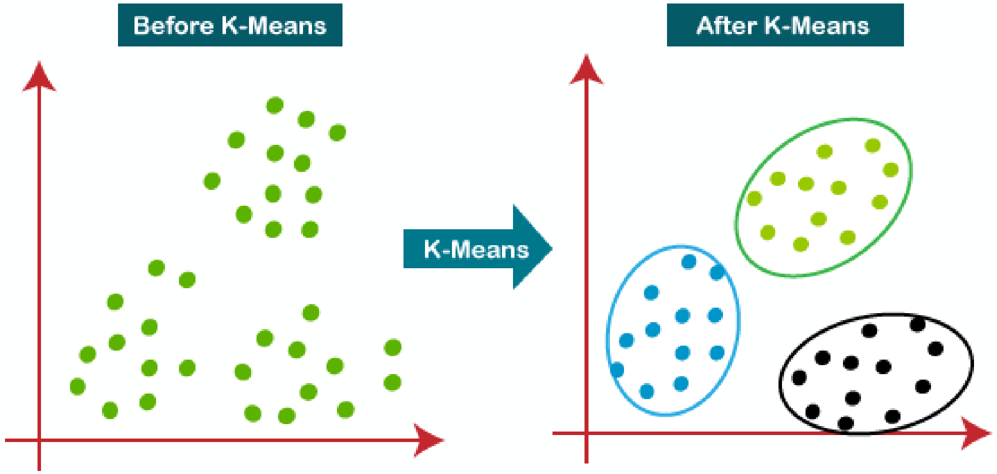
IRRIGATION DETECTION AND MAPPING THROUGH SATELLITE SOIL MOISTURE

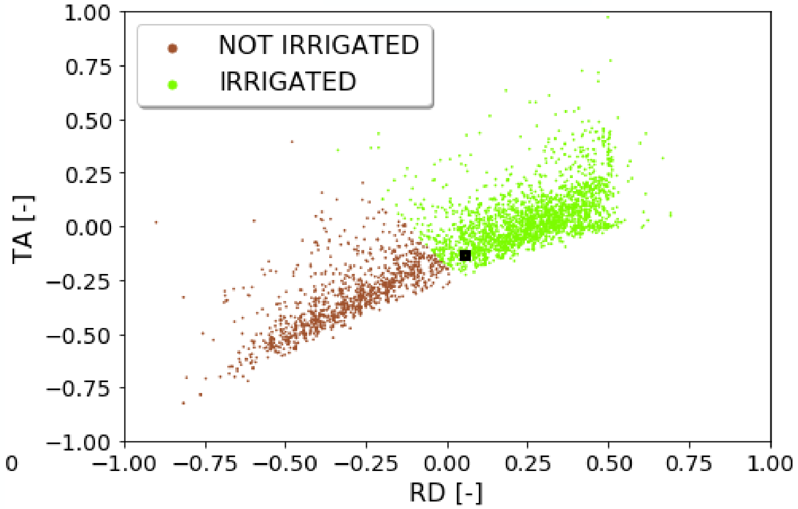
Pixels with associated higher values of spatial relative differences and of temporal anomalies likely belong to irrigated areas.
The temporal stability indices are used as input in the k-means clustering algorithm, which allows to group n data points into k clusters on the basis of predefined characteristics.

Indices derived from the temporal stability theory

↓

Irrigation mapping through the k-means algorithm





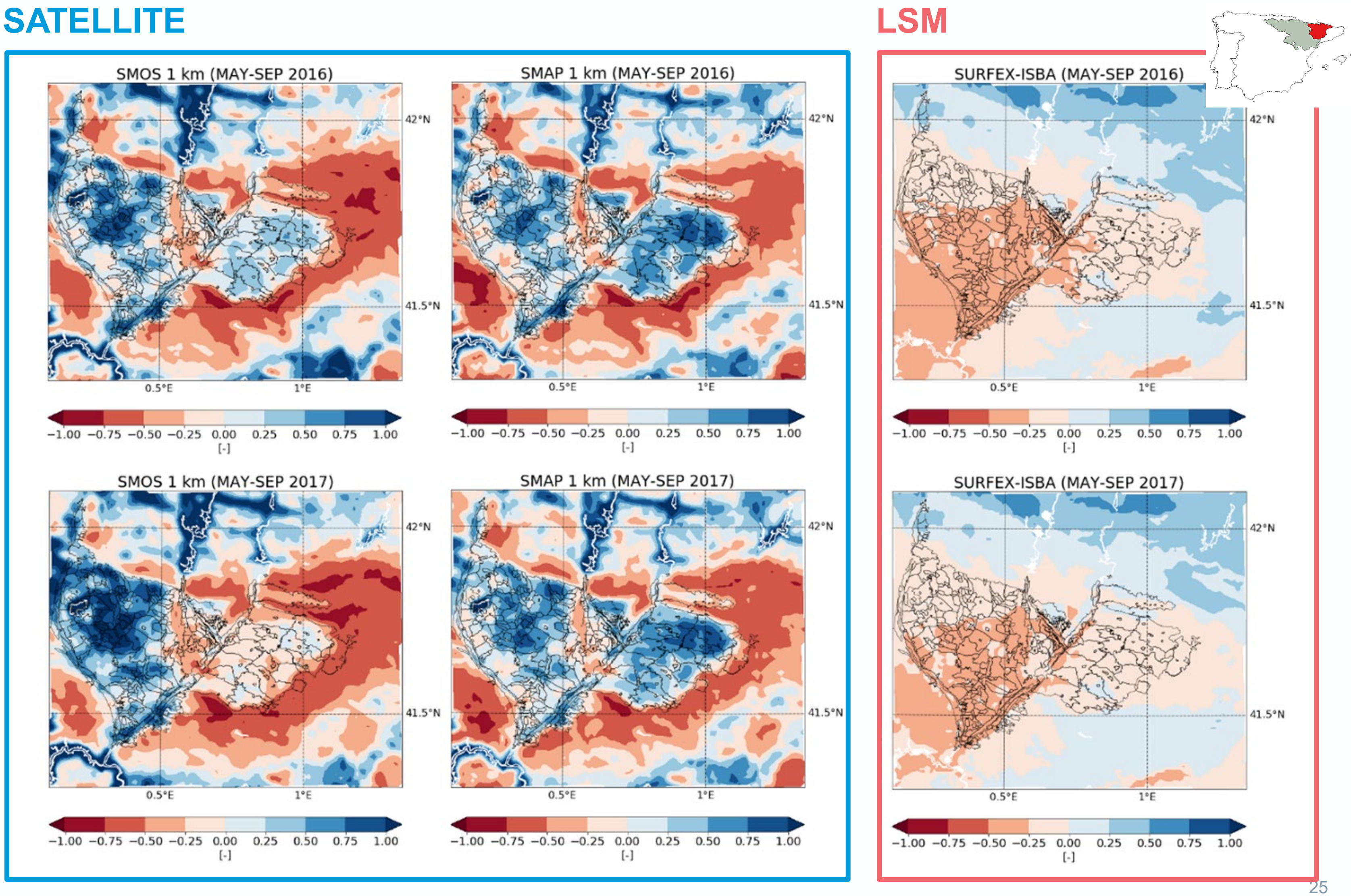
Unsupervised classification algorithm

IRRIGATION DETECTION AND MAPPING THROUGH SATELLITE SOIL MOISTURE

SPATIAL RELATIVE DIFFERENCES

How much the soil moisture value of a pixel differs from the spatial mean

The satellite detects irrigation, which is not reproduced by LSM

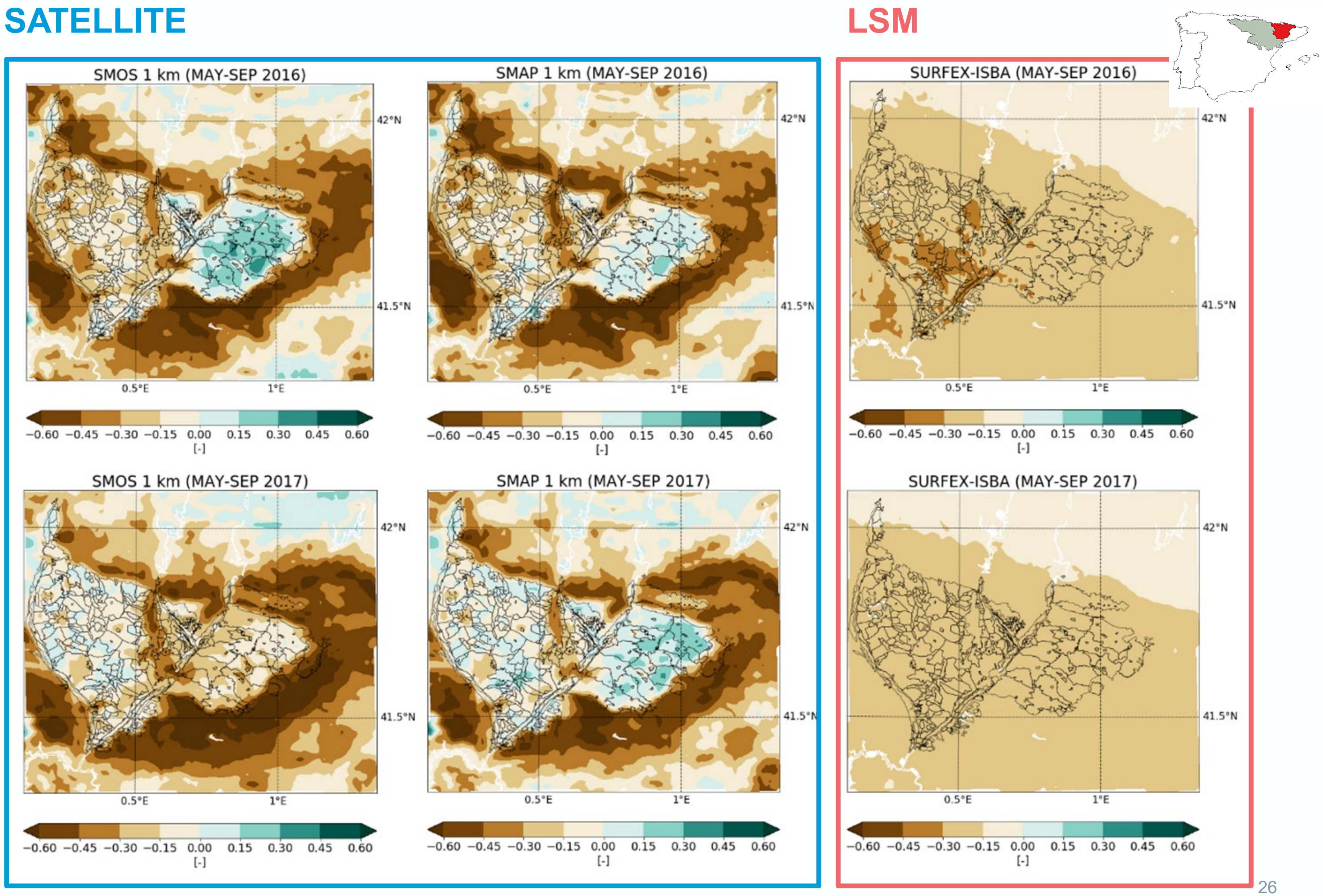


IRRIGATION DETECTION AND MAPPING THROUGH SATELLITE SOIL MOISTURE

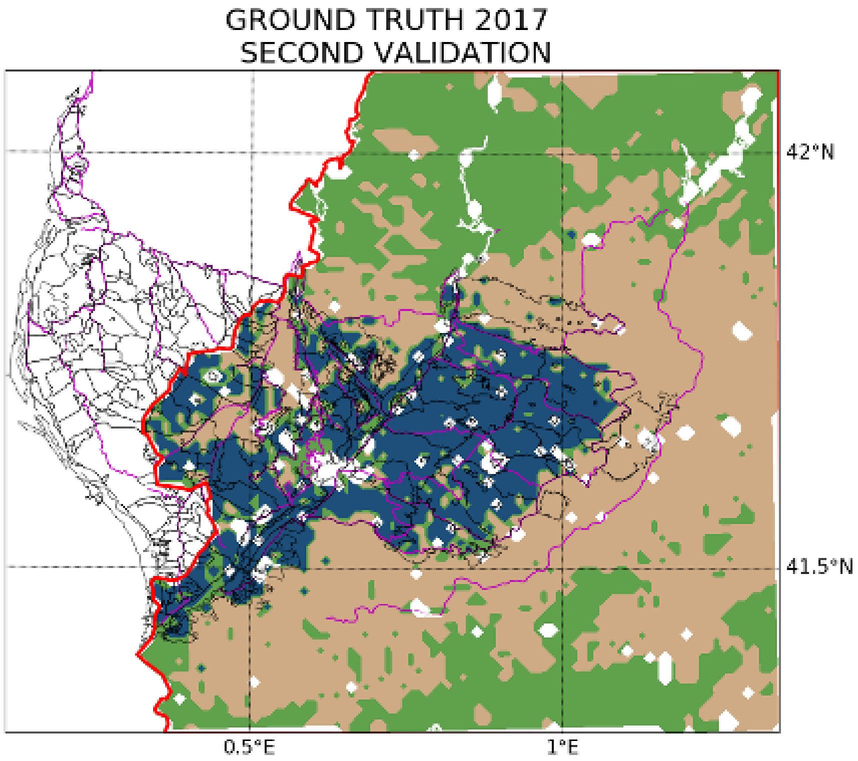
TEMPORAL ANOMALIES

How much the soil moisture value of a pixel differs from its temporal mean

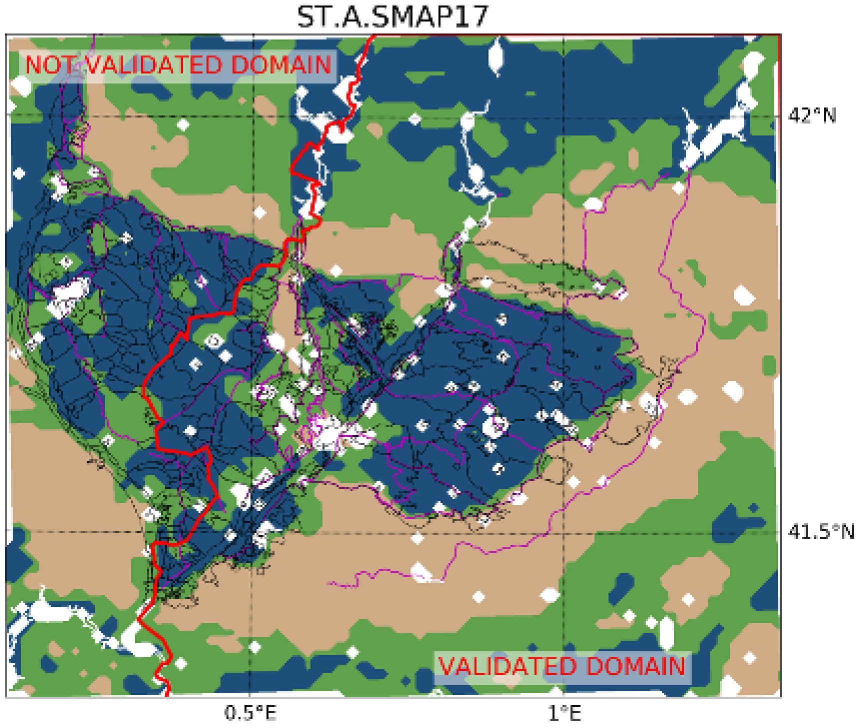
The satellite detects irrigation, which is not reproduced by LSM



IRRIGATION MAPS AT 1 KM SPATIAL RESOLUTION



GROUND TRUTH

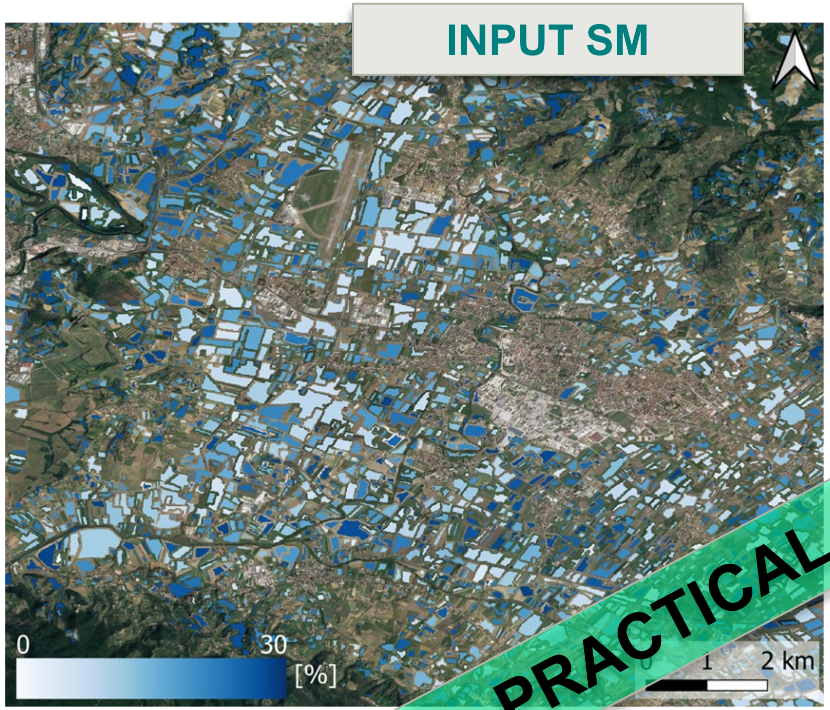


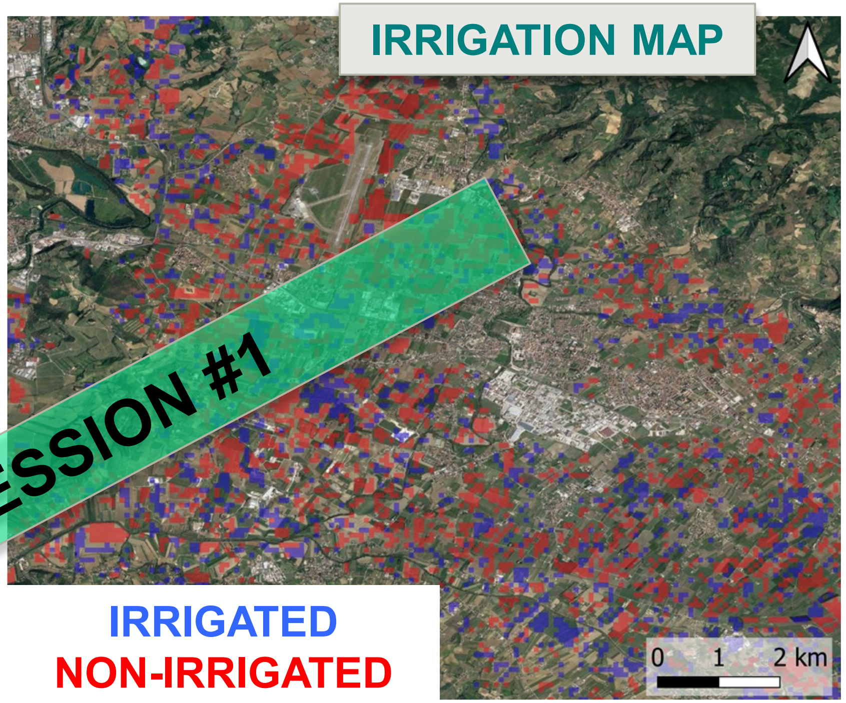
PROPOSED MAPS

Irrigated areas
Forest/natural areas
Dryland

78% ACCURACY
Result obtained through remote sensing soil moisture only

IRRIGATION MAPS AT THE PLOT SCALE



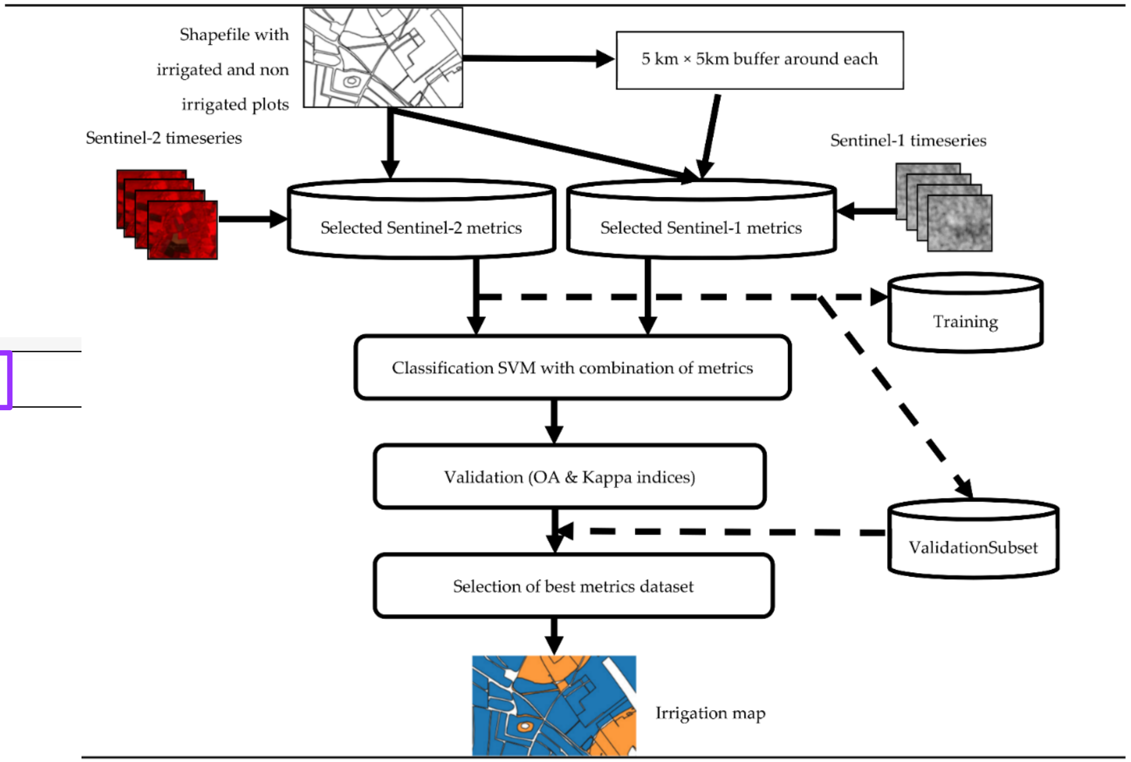


S^{2}MP soil moisture (Sentinel-1 + Sentinel-2): https://thisme.cines.teledetection.fr/map?c=0.7570594,42.4745842,7.05

The S²IM method

The method relies on statistical features of Sentinel-1-derived (backscatter VV, VH, and VH/VV) and of Sentinel-2-derived (NDVI) parameters used as an input in a Support Vector Machine (SVM).

Sentinel-2 Optical Parameters	Sentinel-1 SAR Parameters
μ (NDVI_field)	μ (VV_field)
Var(NDVI_field)	Var(VV_field)
μ (NDVI_5 km)/μ (NDVI_field)	μ (VH_field)
VAR(NDVI_5 km)/VAR(NDVI_field)	Var(VH_field)
	μ (VH/VV_field)
	μ (VV_5 km)/μ (VV_field)
	Var(VV_5 km)/Var(VV_field)
	μ (VH_5 km)/μ (VH_field)
	Var(VH_5 km)/Var(VH_field)
	μ (VH/VV_5 km)/μ (VH/VV_field)
	Var(VH/VV_5 km)/Var(VH/VV_field)

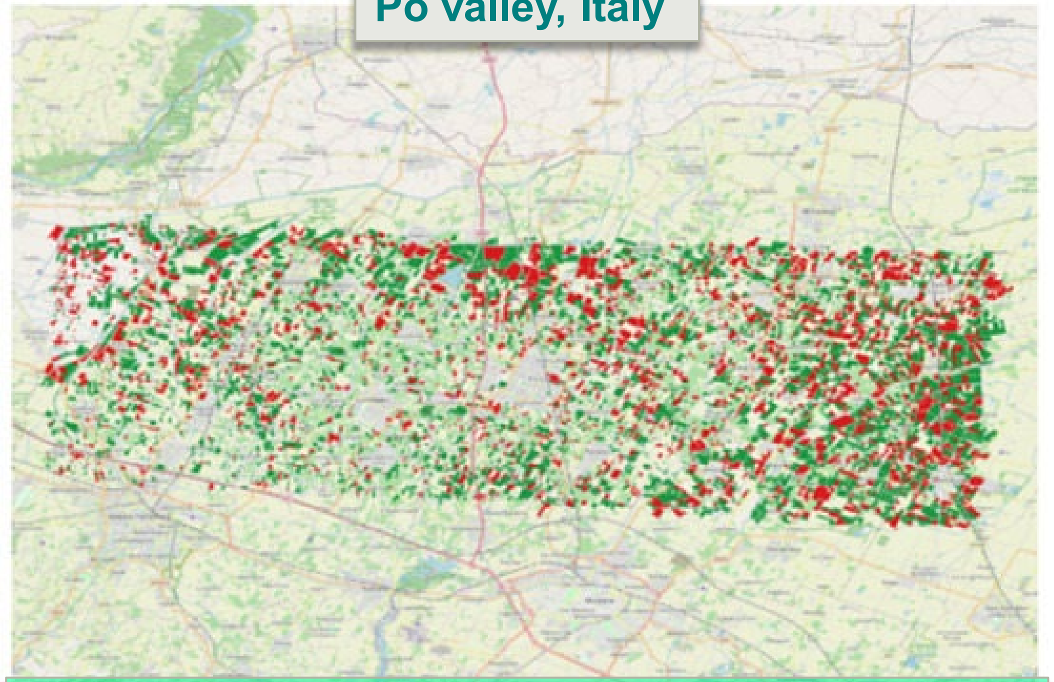


(*Elwan et al., 2022*; https://doi.org/10.3390/w14050804)

IRRIGATION DETECTION AND MAPPING THROUGH MW SENSORS

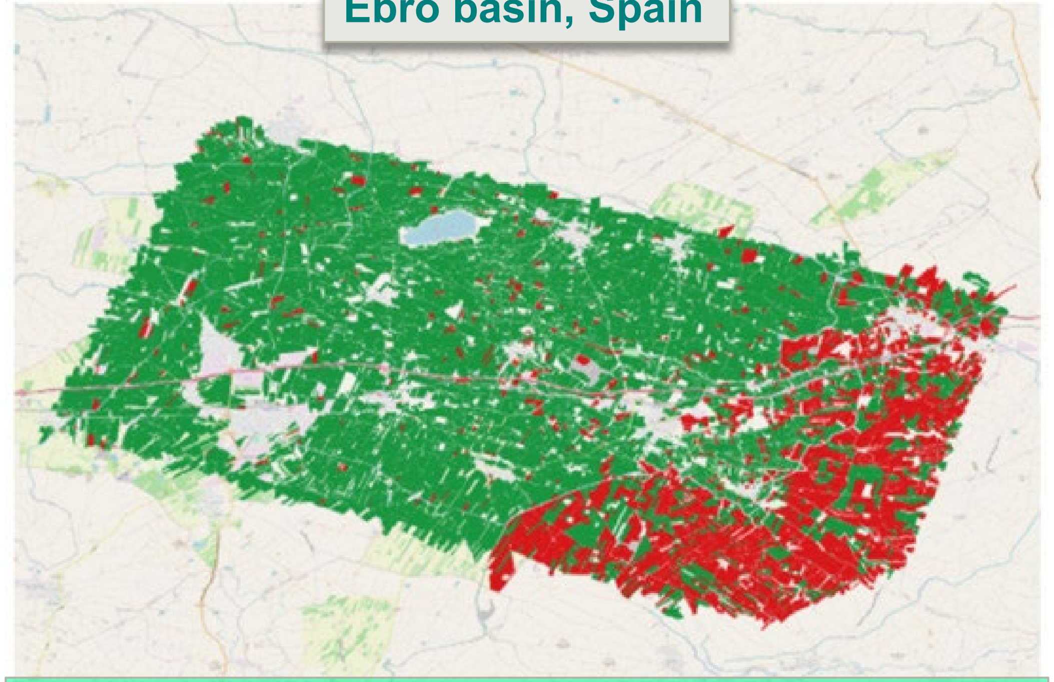
PLOT-SCALE IRRIGATION MAPS IN ITALY (1) AND SPAIN (2)

(1)



87% OVERALL ACCURACY

(2)



90% OVERALL ACCURACY

DARI vs S²IM (over France)

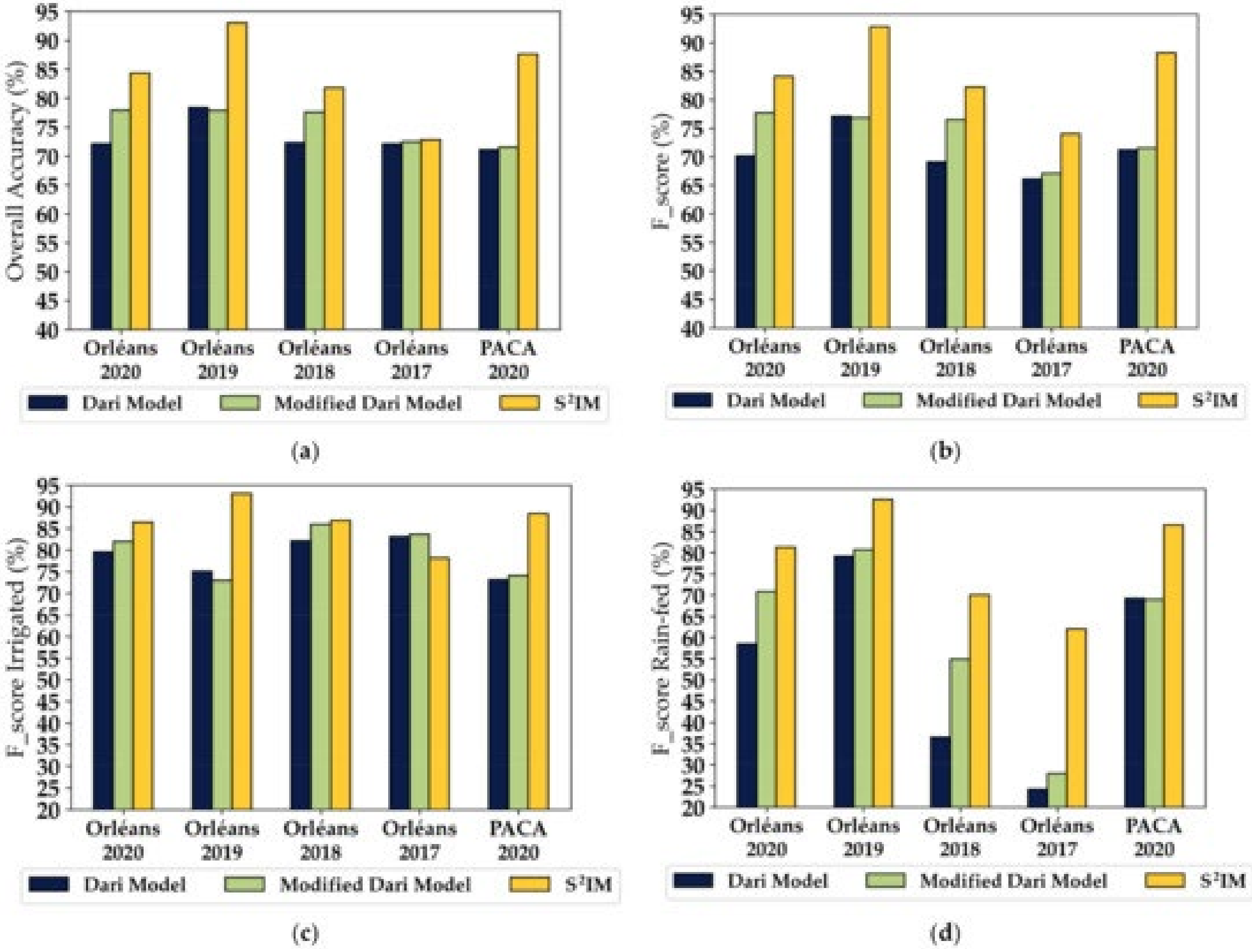
(*Bazzi et al., 2022*; https://doi.org/10.3390/w14091341)

S²IM outperforms DARI method, especially in humid conditions

S²IM requires more input information with respect to the DARI model

The DARI model is more friendly for end-users

The DARI model is a useful tool for speditive irrigation mapping applications



IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

Irrigation quantification from space is generally more challenging than detection

Quantification methods based on MW soil moisture

- Soil water balance
  - SM-based inversion
- Discrepancies between satellite (including, theoretically, irrigation) and modeled (not including irrigation) data sets
  - SM-based delta

The SM-based inversion approach

The method relies on the inversion of the soil water balance for backward estimating water entering into the soil. Over agricultural areas, the output is the sum of rainfall plus irrigation. Hence, by removing rainfal rates, it is possible to estimate irrigation amounts.

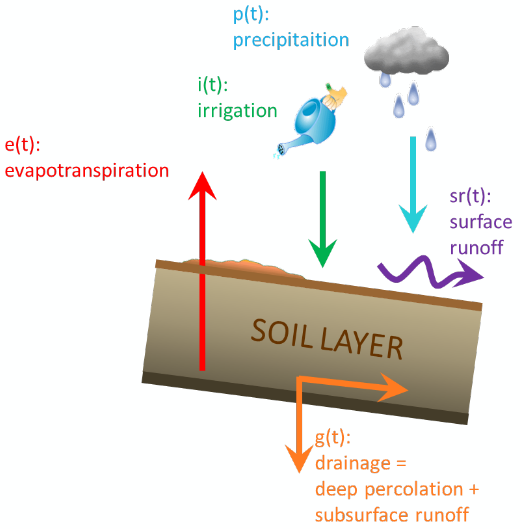
$$\boldsymbol{nZ\frac{dS(t)}{dt} = i(t) + p(t) - g(t) - sr(t) - e(t)}$$

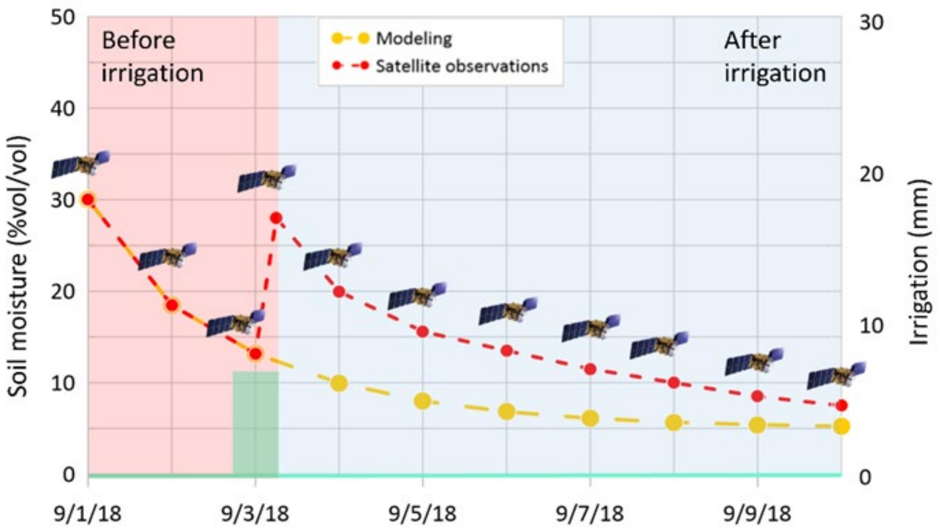
$$g(t) = aS(t)^b \qquad\qquad sr(t) = 0$$

$$W_{in}(t) = nZ\frac{dS(t)}{dt} + g(t) + e(t)$$

$$W_{in}(t) = Z^*\frac{dS(t)}{dt} + aS(t)^b + F \cdot S(t) \cdot PET(t)$$

$$\boldsymbol{W_{in}(t) - p(t) = i(t)}$$



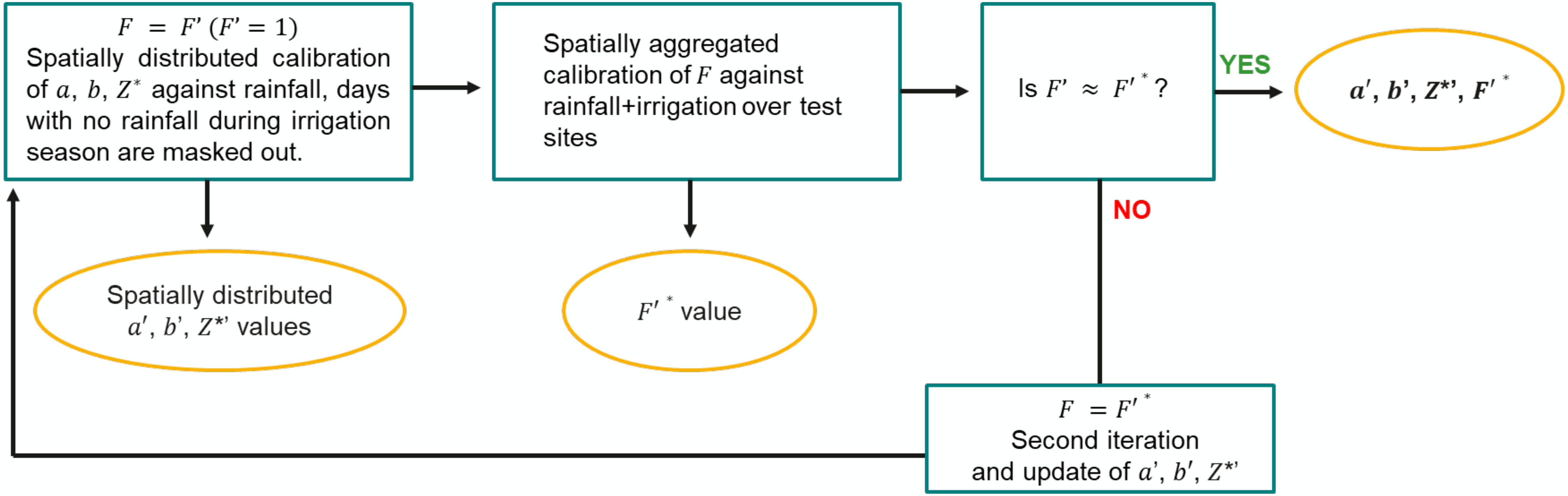


IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

esa

The SM-based inversion approach

Parameters: $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{Z^*}$, $\boldsymbol{F}$



+ OTHER POSSIBLE OPTIONS... TO BE EXPLORED IN THE PRACTICAL SESSION #2

The SM-based inversion approach: Its EVOLUTION

(1)
SM2RAIN can be adapted to estimate irrigation as well, not only rainfall!

(2)
The role of the evapotranspiration (ET) term within the algorithm

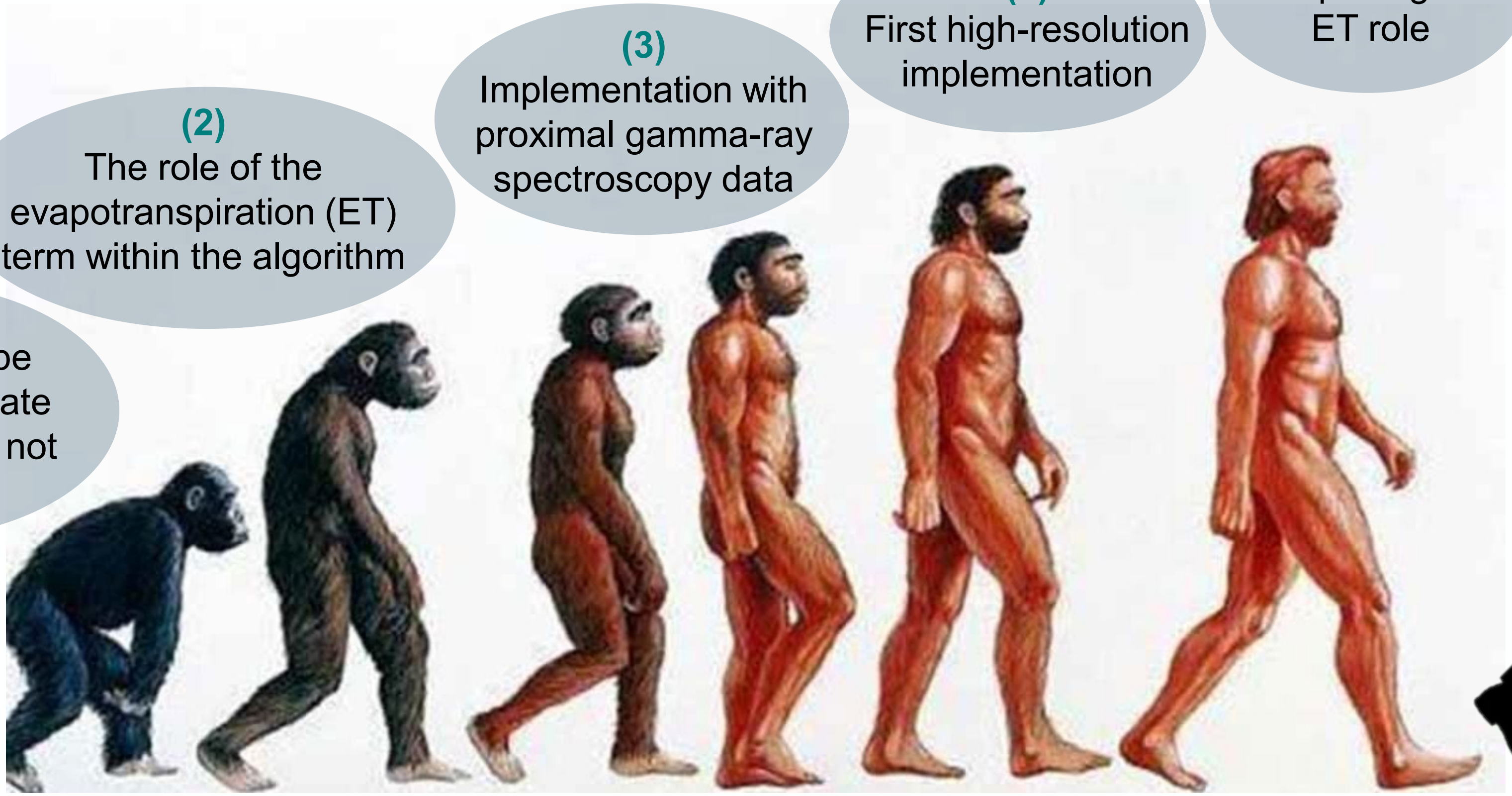
(3)
Implementation with proximal gamma-ray spectroscopy data

(4)
First high-resolution implementation

(5)
Deepening the ET role

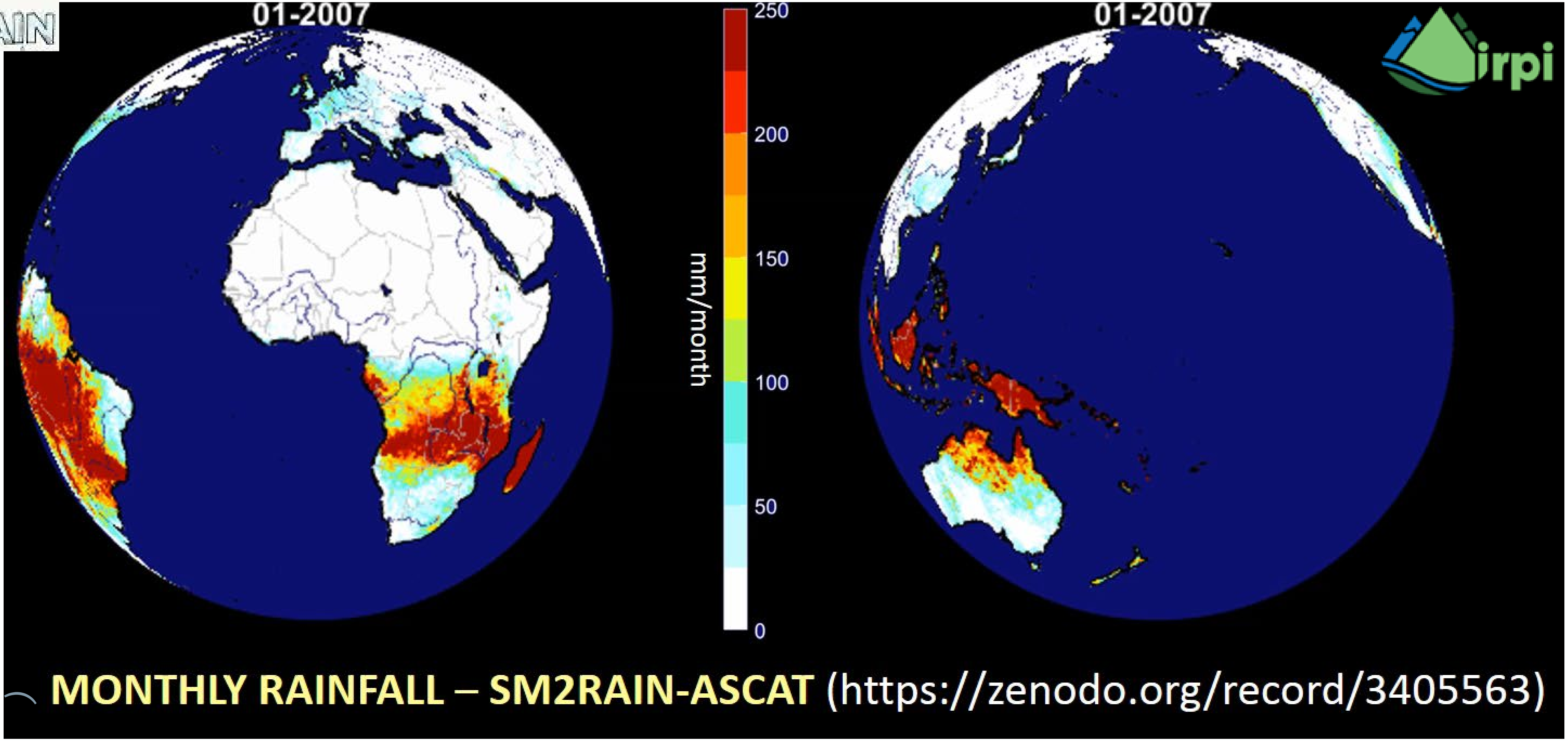
(6)
First high-res., regional data sets

WHAT'S NEXT?



The SM-based inversion approach, an evolution of the SM2RAIN algorithm

(Brocca et al., 2014; https://doi.org/10.1002/2014JD021489



(Brocca et al., 2019; https://doi.org/10.5194/essd-11-1583-2019)

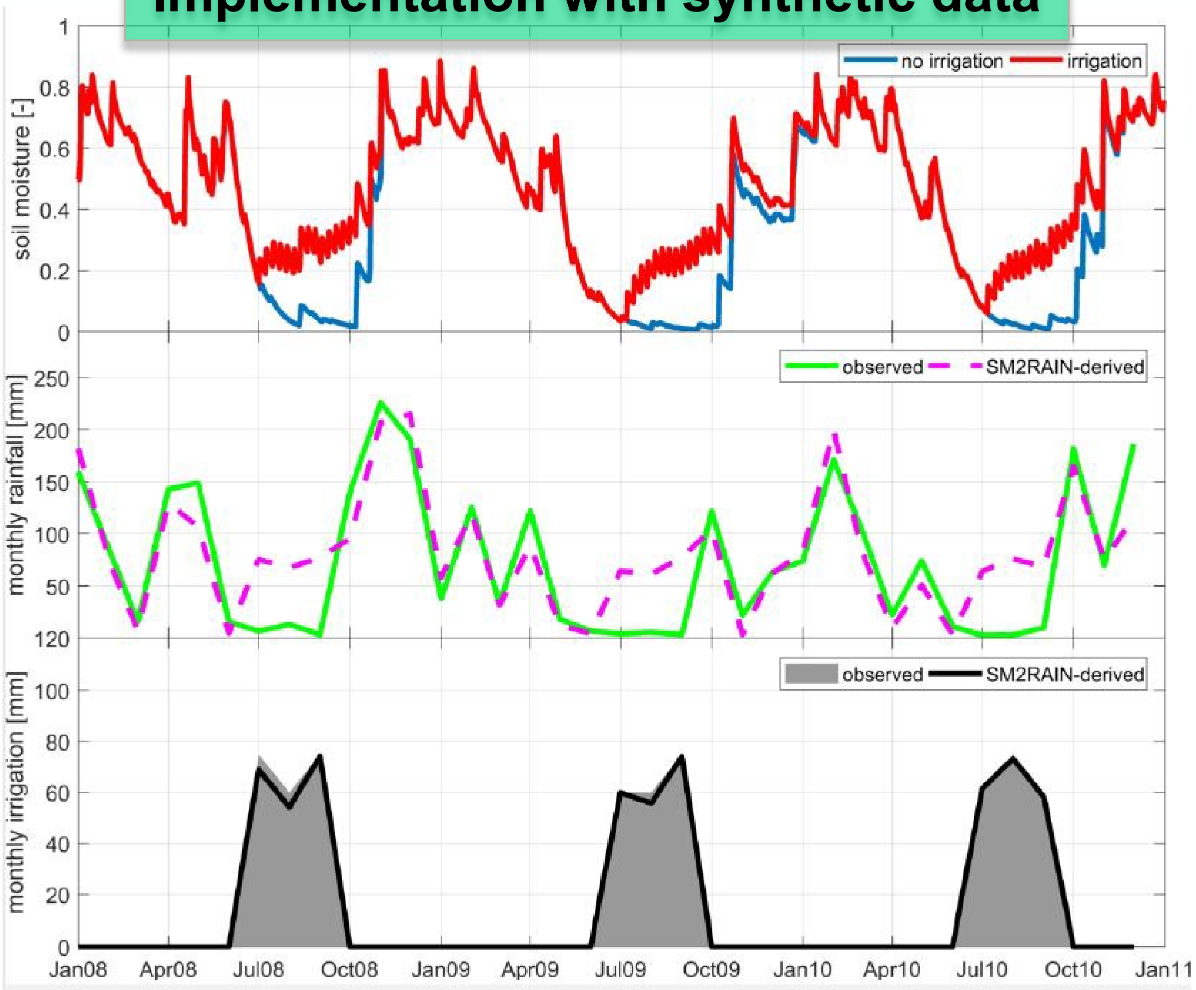
IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

The SM-based inversion approach, an evolution of the SM2RAIN algorithm

The idea was born after a reviewer comment on a SM2RAIN paper.

We simulate soil moisture without (blue line) and with (red line) irrigation. We apply SM2RAIN to synthetic soil moisture to obtain SM2RAIN-derived rainfall+irrigation (magenta line), compared with observed rainfall (green line).
We subtract observed rainfall (green line) from SM2RAIN-derived rainfall+irrigation (magenta line) to obtain irrigation (black line), compared with observed irrigation (grey area).

Implementation with synthetic data

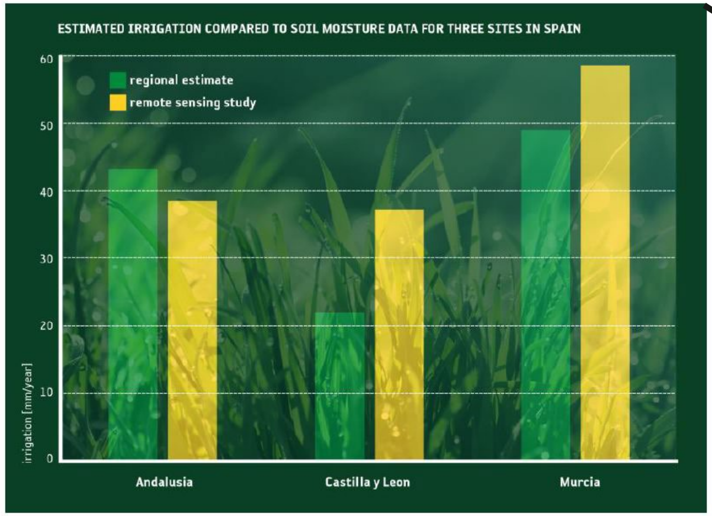


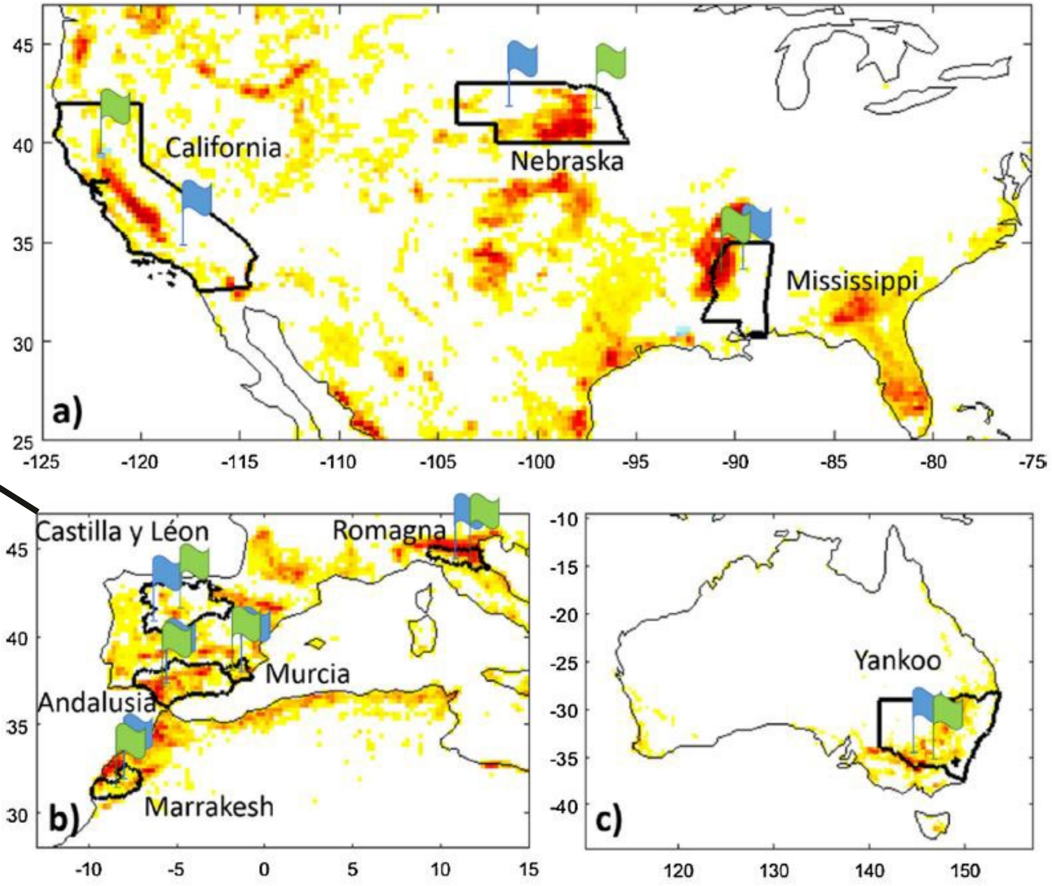
The method showed its reliability with in-situ data as well, as demonstrated by (3) Filippucci et al. (2020; https://doi.org/10.1016/j.advwatres.2019.103502).

The SM-based inversion approach: implementation with coarse-resolution satellite soil moisture

The potential of the method in quantifying irrigation was shown

Limitations due to the coarse resolution of the considered soil moisture products were highlighted





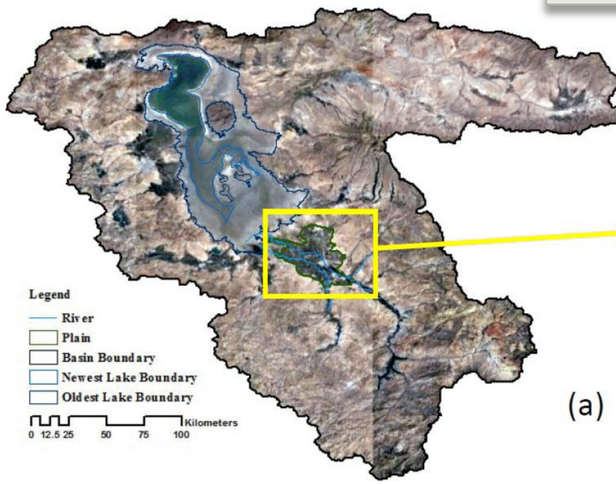
(Brocca et al., 2018; https://doi.org/10.1016/j.jag.2018.08.023)

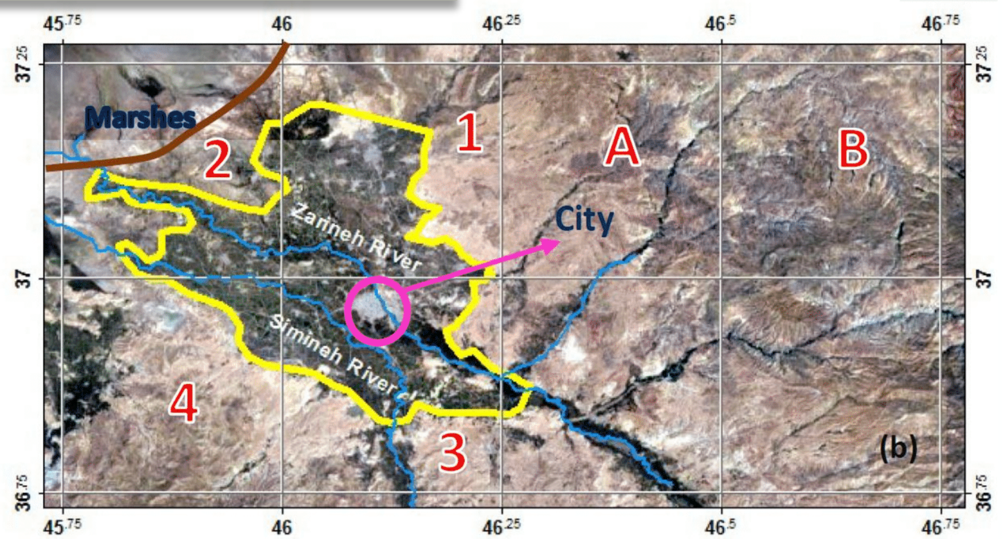
IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

The SM-based inversion approach: implementation with coarse-resolution satellite soil moisture

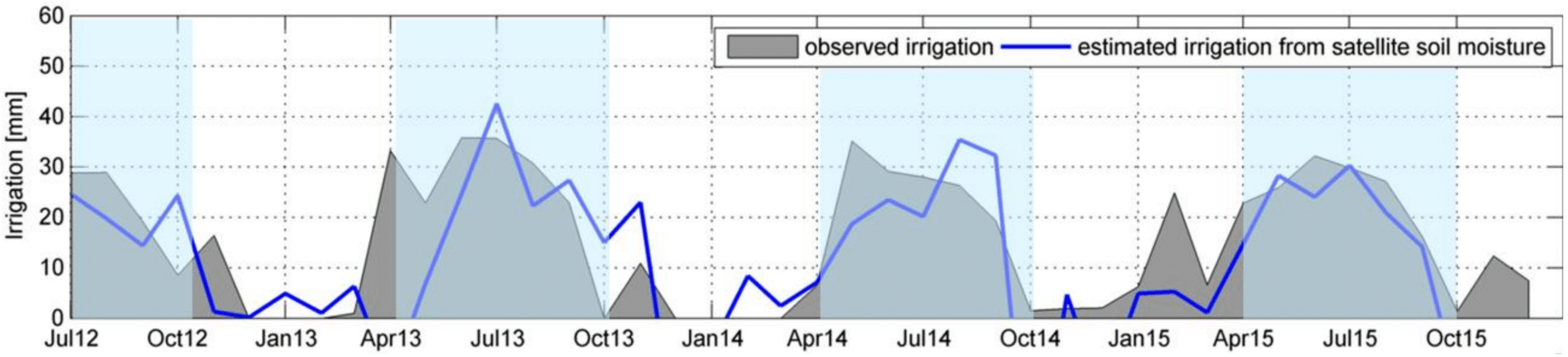
URMIA LAKE, IRAN

The role of the ET term cannot be neglected, especially over semi-arid regions





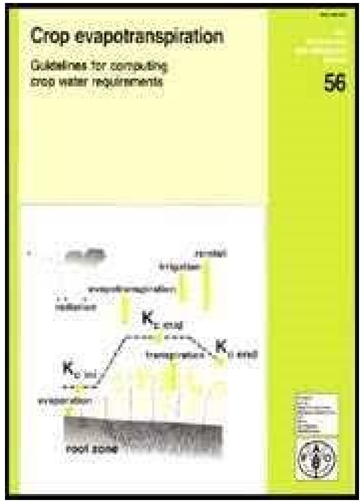
Potential of AMSR2-JAXA soil moisture in detecting irrigation

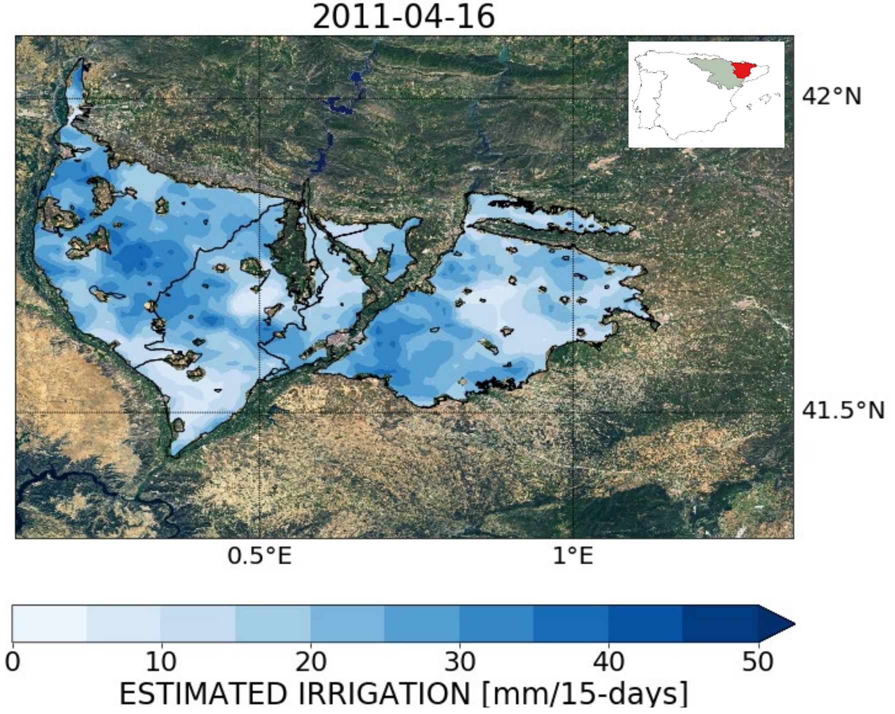


(Jalilvand et al., 2019; https://doi.org/10.1016/j.rse.2019.111226)

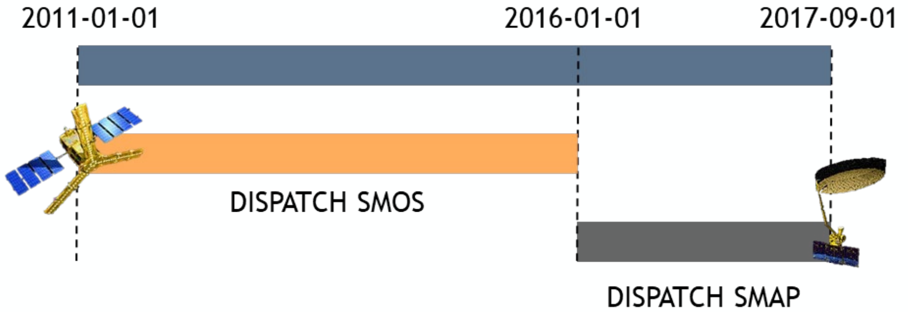
The SM-based inversion approach: implementation with high-resolution satellite soil moisture

Inclusion of the guidelines provided by the FAO paper n.56 (Allen et al., 1998) for modeling crop ET





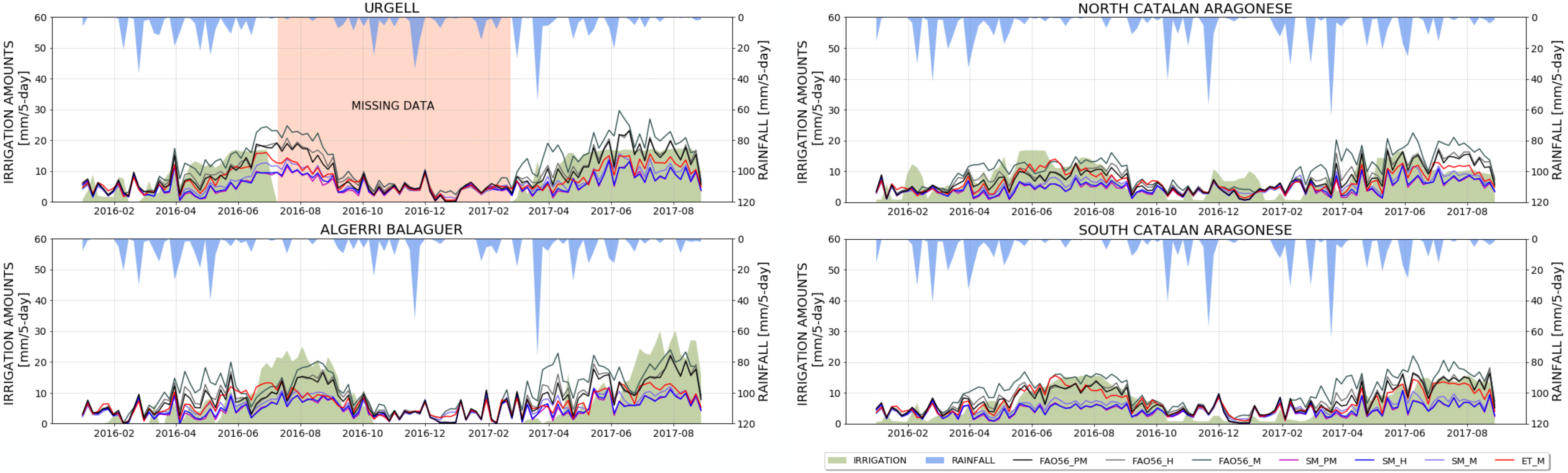
Almost 7 years of irrigation estimates from space at 1 km spatial resolution



(Dari et al., 2020; https://doi.org/10.3390/rs12162593)

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

The SM-based inversion approach: implementation with high-resolution satellite soil moisture



Multiple ET modeling approaches and sources

Opening the perspective of an algorithm configuration forced with remote sensing data only

(Dari et al., 2022; https://doi.org/10.1016/j.agwat.2022.107537)

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

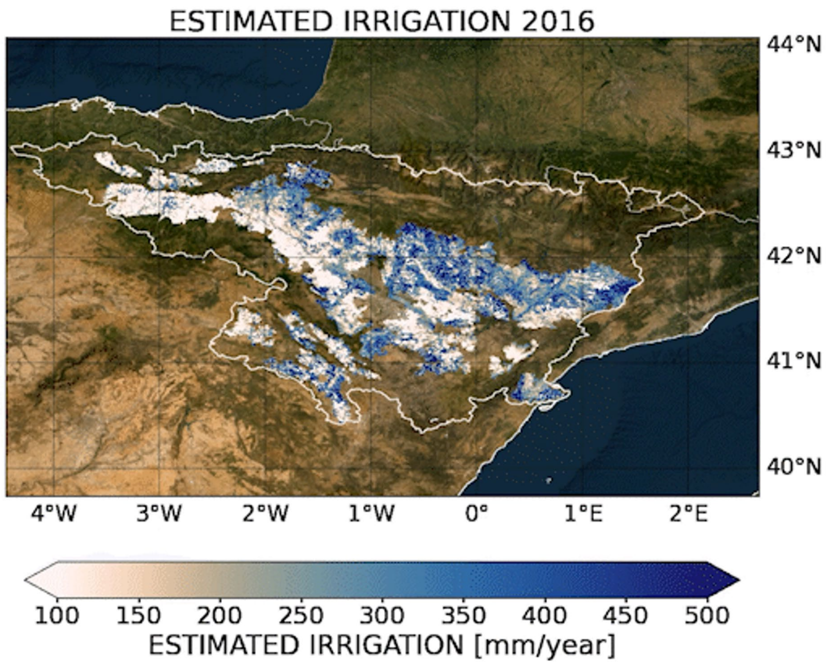
The SM-based inversion approach: first regional-scale high-resolution irrigation products

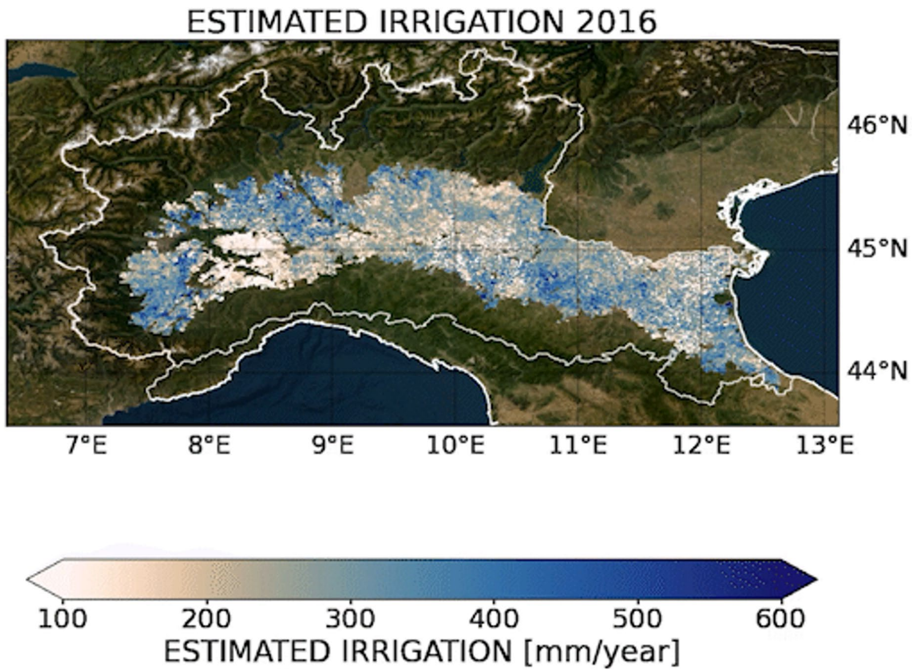
Irrigation products at regional scale over the **Ebro** basin and the **Po** valley

- Period: **[version 1.0] 2016 – 2020 (July), [version 1.1] 2016 – 2021**
- Spatial resolution: **1 km**

DATA FREELY AVAILABLE HERE:

zenodo





(Dari et al., 2023; https://doi.org/10.5194/essd-15-1555-2023)

TECHNISCHE UNIVERSITÄT WIEN

RT1 SENTINEL-1 SOIL MOISTURE

IRRIGATION

4DMED HYDROLOGY

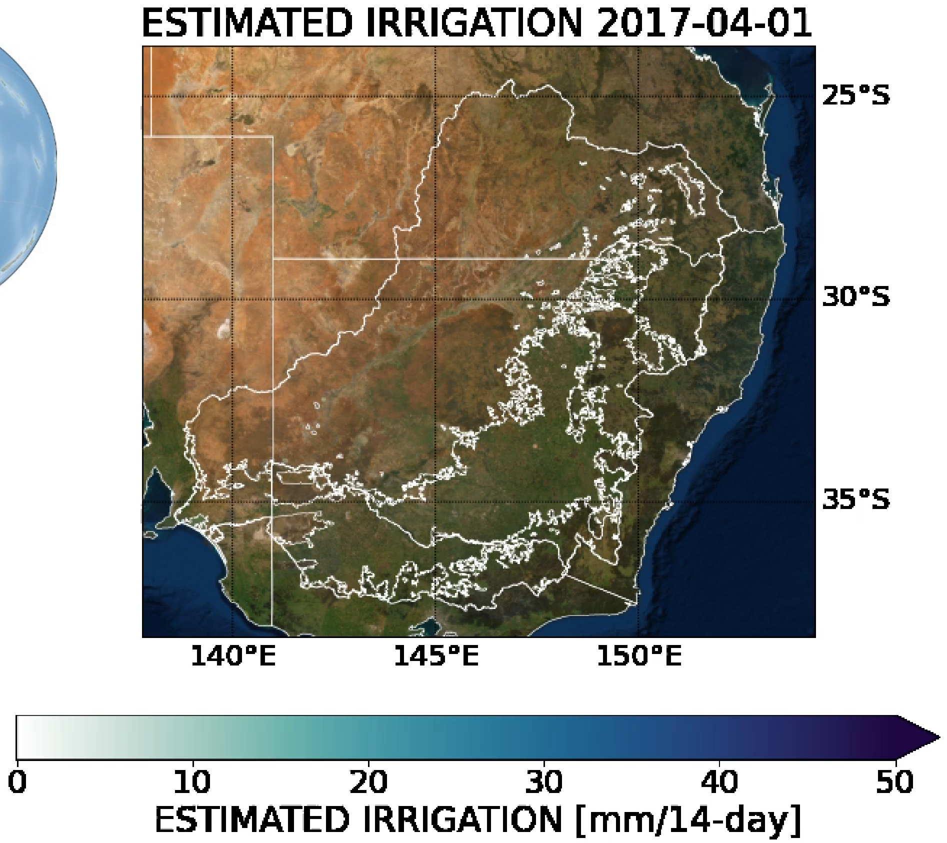
The SM-based inversion approach: first regional-scale high-resolution irrigation products

Irrigation products at regional scale over the **Murray-Darling** river basin

- Period: **2017 (April) – 2020 (July)**
- Spatial resolution: **6 km**

DATA FREELY AVAILABLE HERE:

zenodo



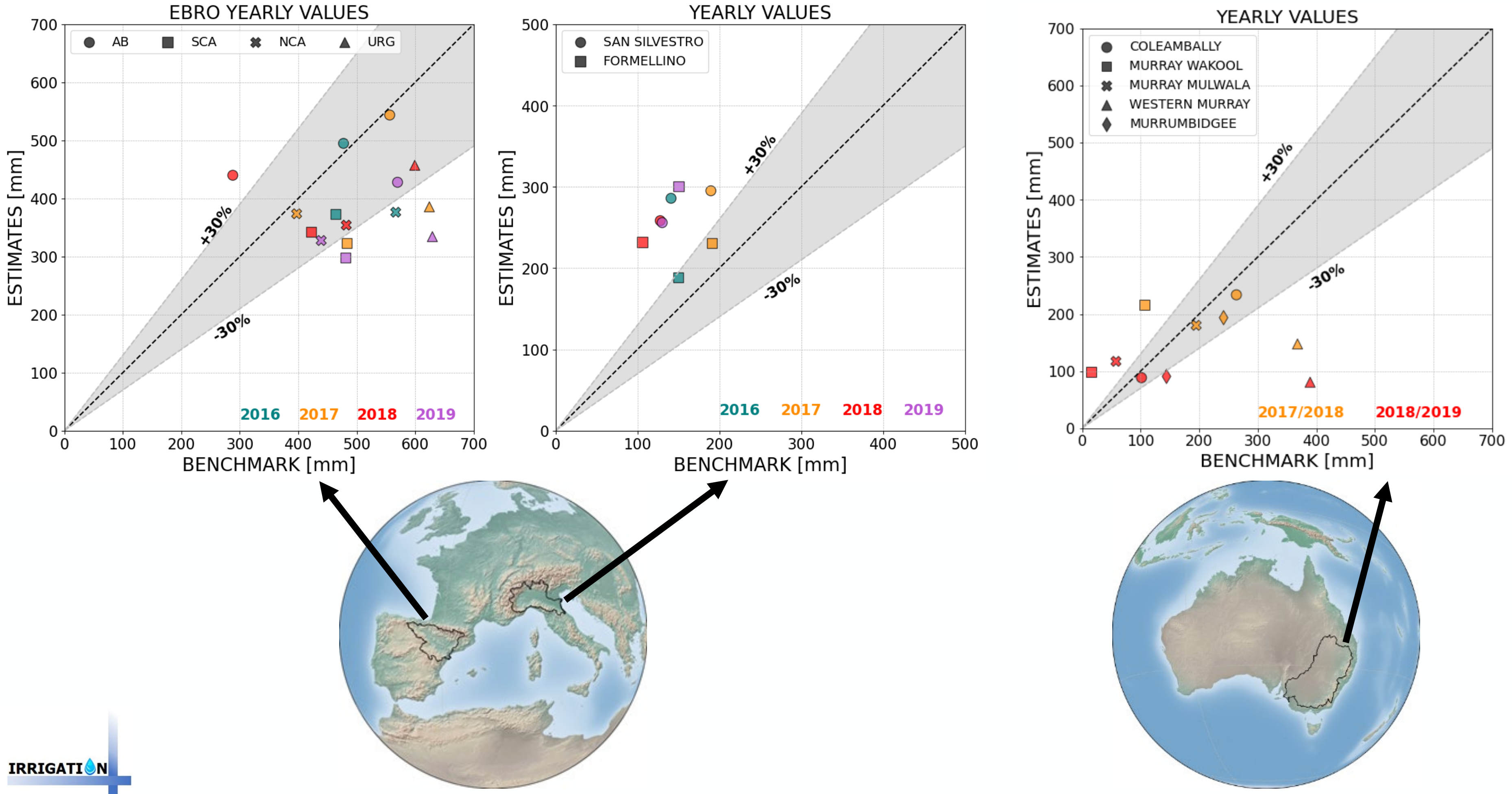
spire

CYGNSS SOIL MOISTURE

IRRIGATION

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

The SM-based inversion approach: first regional-scale high-resolution irrigation products



…Further validation from the scientific community (**you!**) is strongly encouraged!

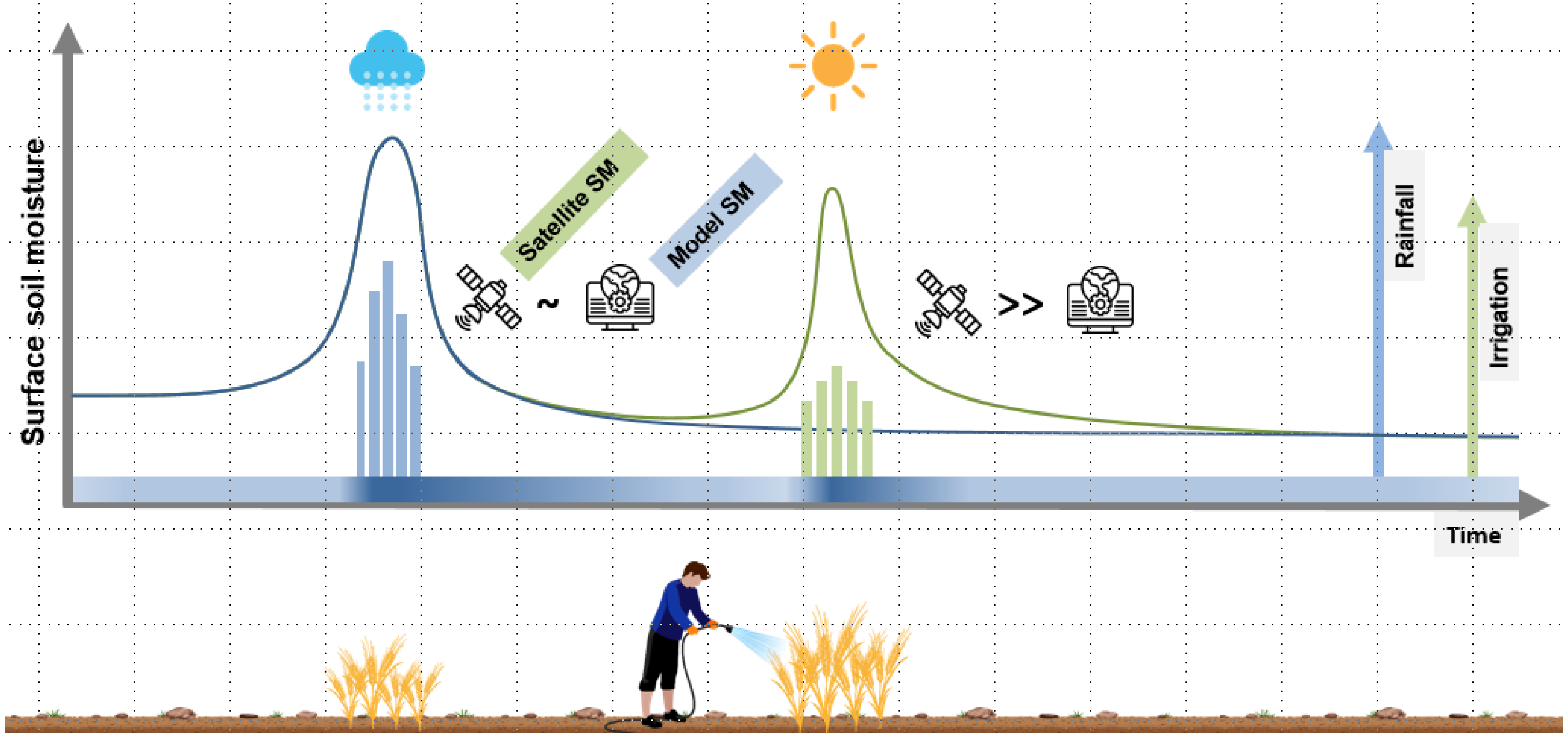
So far, (at least) 4 intercomparison papers are submitted or under review:

Kragh et al. (2023)
Zappa et al. (2023)
Laulet et al. (2023)
Paolini et al. (2023)

IRRIGATION

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

The SM-Delta approach



The idea behind this approach is: satellite SM observations contain irrigation signal, while model simulations do not (neither directly nor indirectly – eg through assimilation of air temperature).

Based on this, and assuming all terms of the water balance equations identical, it is possible to obtain irrigation as the difference between satellite and model SM

Satellite SM | Precipitation | Irrigation | Evapo-transpiration | Runoff | Sub-surface water storage changes

$$\frac{d\Theta^{sat}}{dt} = P(t) + I(t) - \mathrm{ET}(t) - R(t) - \Delta S_{rest}$$

$$\frac{d\Theta^{mod}}{dt} = P(t) - \mathrm{ET}(t) - R(t) - \Delta S_{rest}$$

$$I(t) = \Delta SM = SM^{sat} - SM^{mod}$$

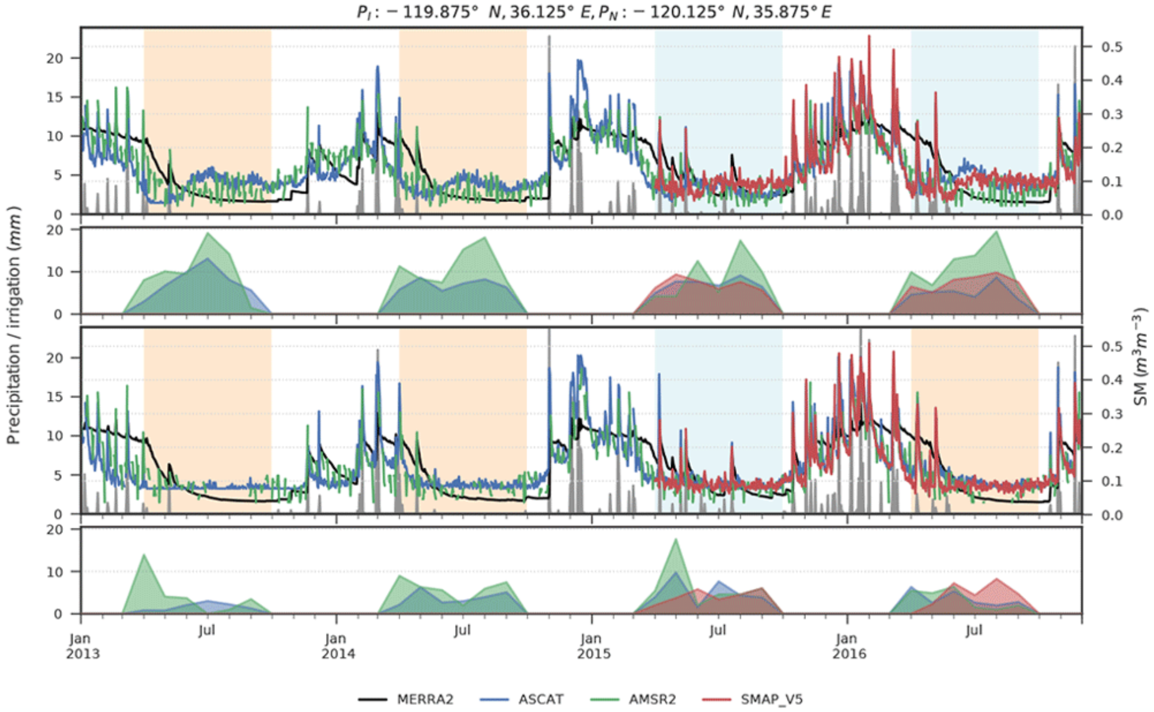
(Zaussinger et al., 2019; https://doi.org/10.5194/hess-23-897-2019)

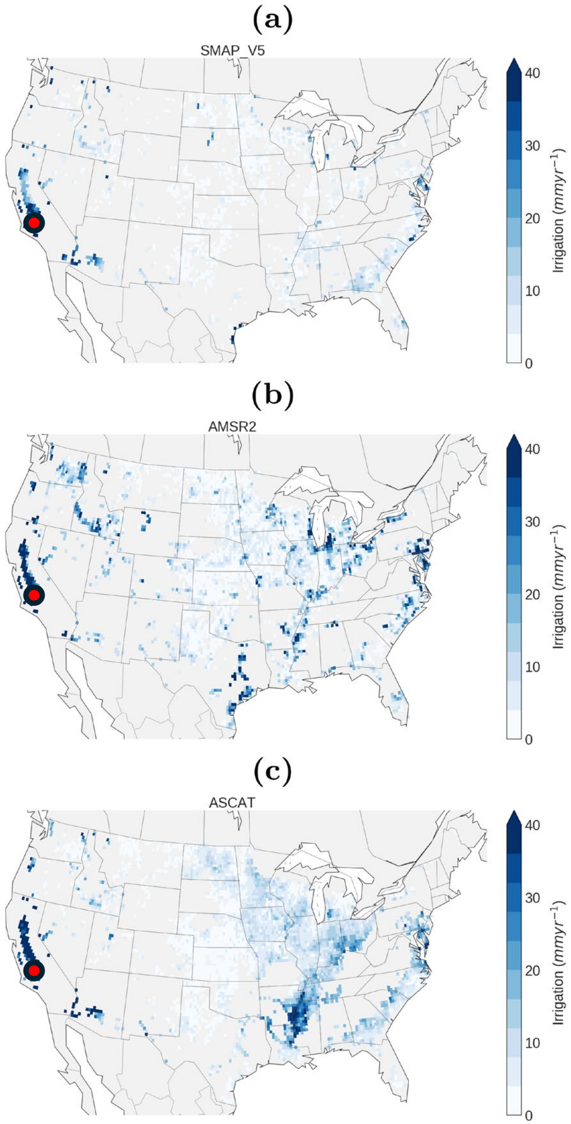
Courtesy of L. Zappa

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

Tested over CONUS using coarse-resolution soil moisture

- Spatio-temporal discrepancies depending on satellite SM product considered (i.e., ASCAT, SMAP, AMSR2)
- Spatial and temporal resolutions of SM, as well as wavelength, have an important effect on the accuracy of results



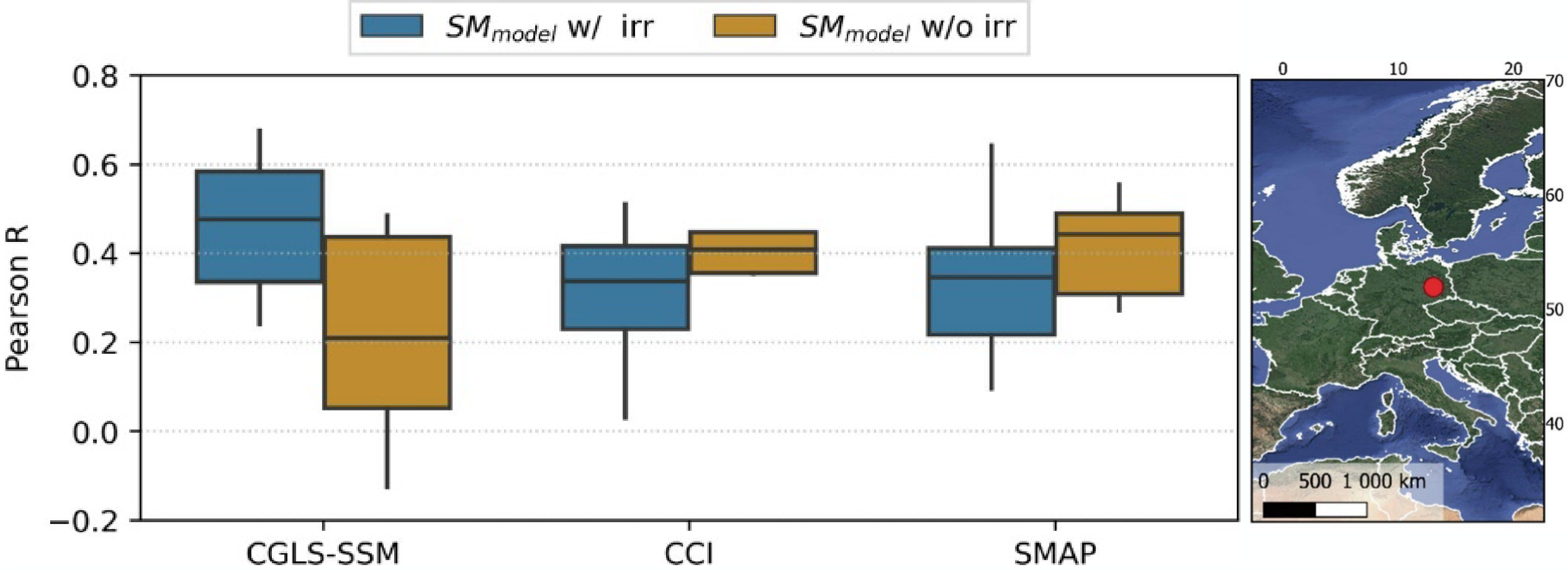


Courtesy of L. Zappa

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

Towards applications at high spatial resolution

- Pearson´s correlation between satellite SM (high- and coarse- resolution products) and model simulations (with and without irrigation)
- Coarse-resolution products do not respond to irrigation (in a highly fragmented agricultural region – Northern Germany)
- **need for high-resolution soil moisture observations**



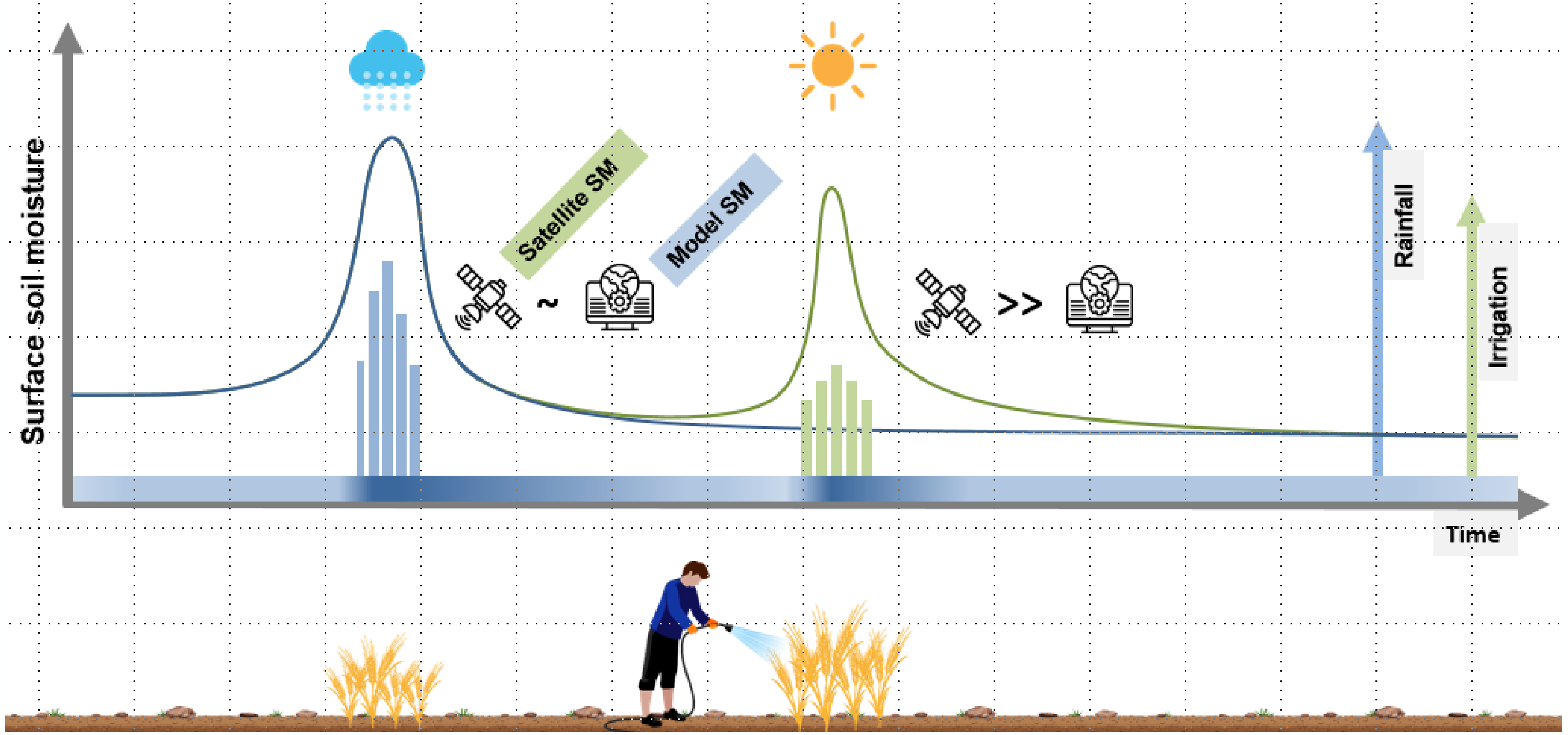
(Zappa et al., 2022; https://doi.org/10.1016/j.jag.2022.102979)

Courtesy of L. Zappa

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

SM-Delta updated for high-resolution soil moisture

- Because of lack of high-res model SM, surrounding pixels are used instead



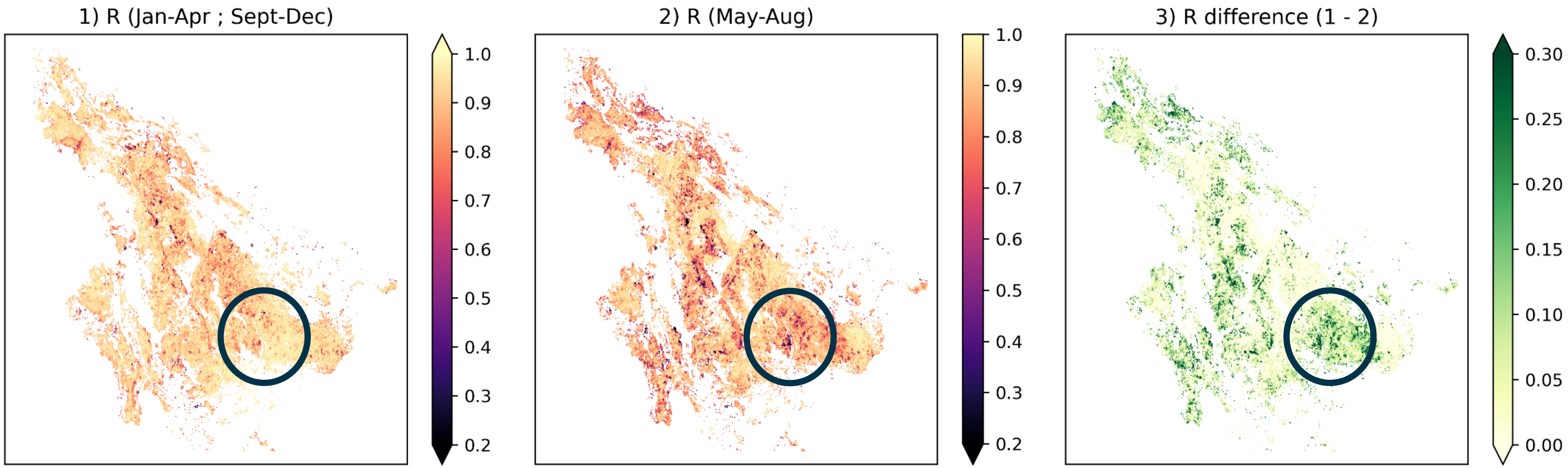
(Zappa et al., 2021; https://doi.org/10.3390/rs13091727)

Courtesy of L. Zappa

SM-Delta updated for high-res soil moisture – The Ebro basin case study

Pearson´s R between individual pixels and their surroundings

- High correlation during non-irrigation period (left)
- Low correlation during irrigation period, over irrigated districts (center)
- Difference between the two highlights irrigated area (darker green, right)



Courtesy of L. Zappa

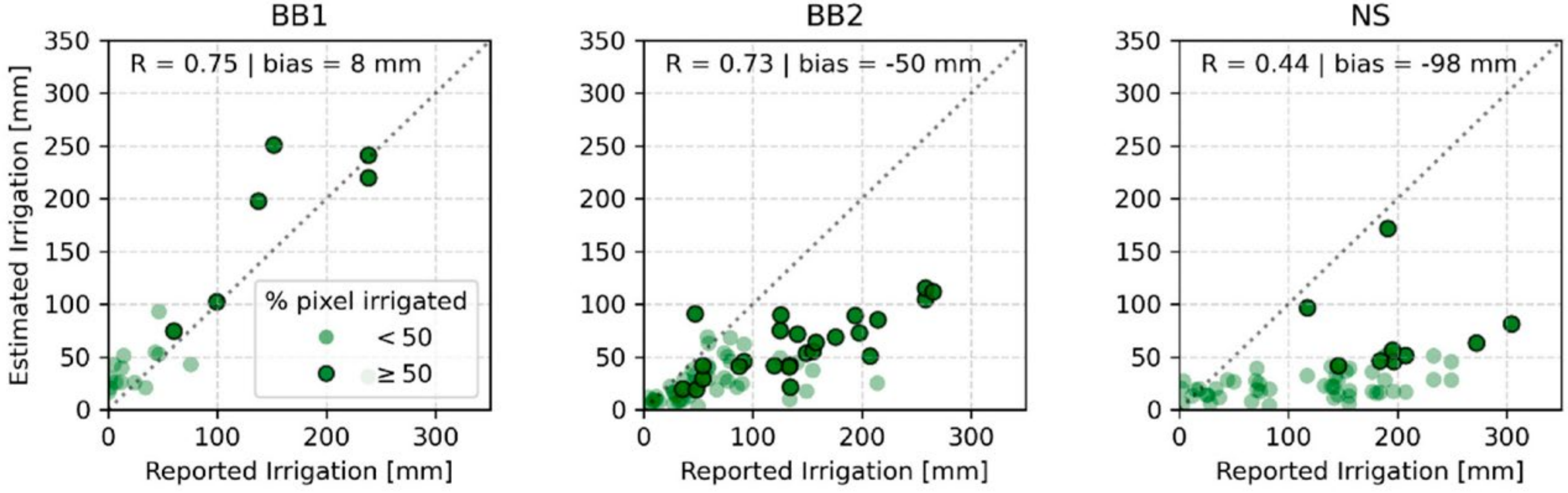
IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

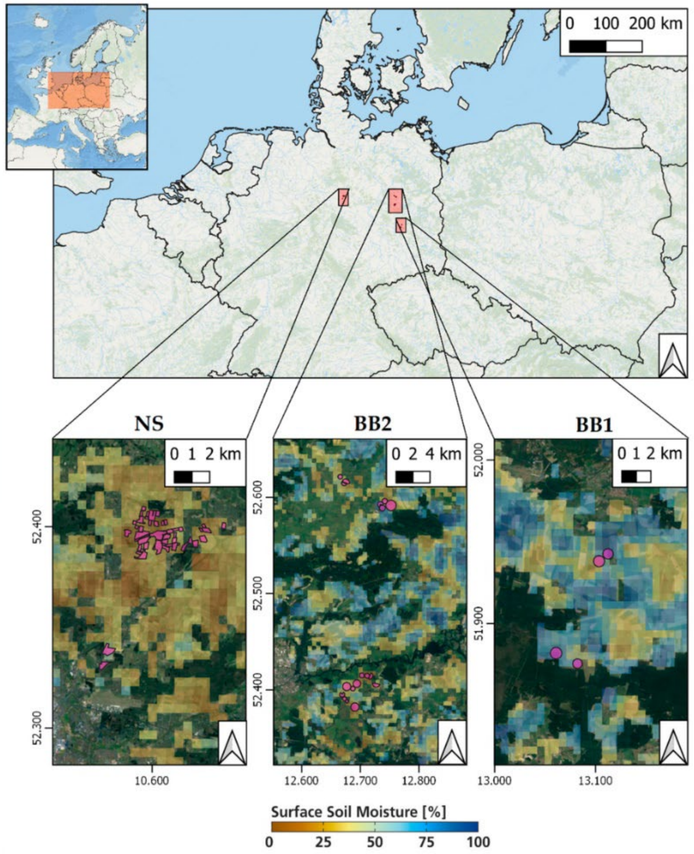
Estimated irrigation at 500 m tested against field-scale irrigation in Germany

- Good correlation of seasonal irrigation water amounts

Lower revisit time of Sentinel-1 leading to:

- challenging detection of irrigation timing
- underestimation of irrigation water volumes



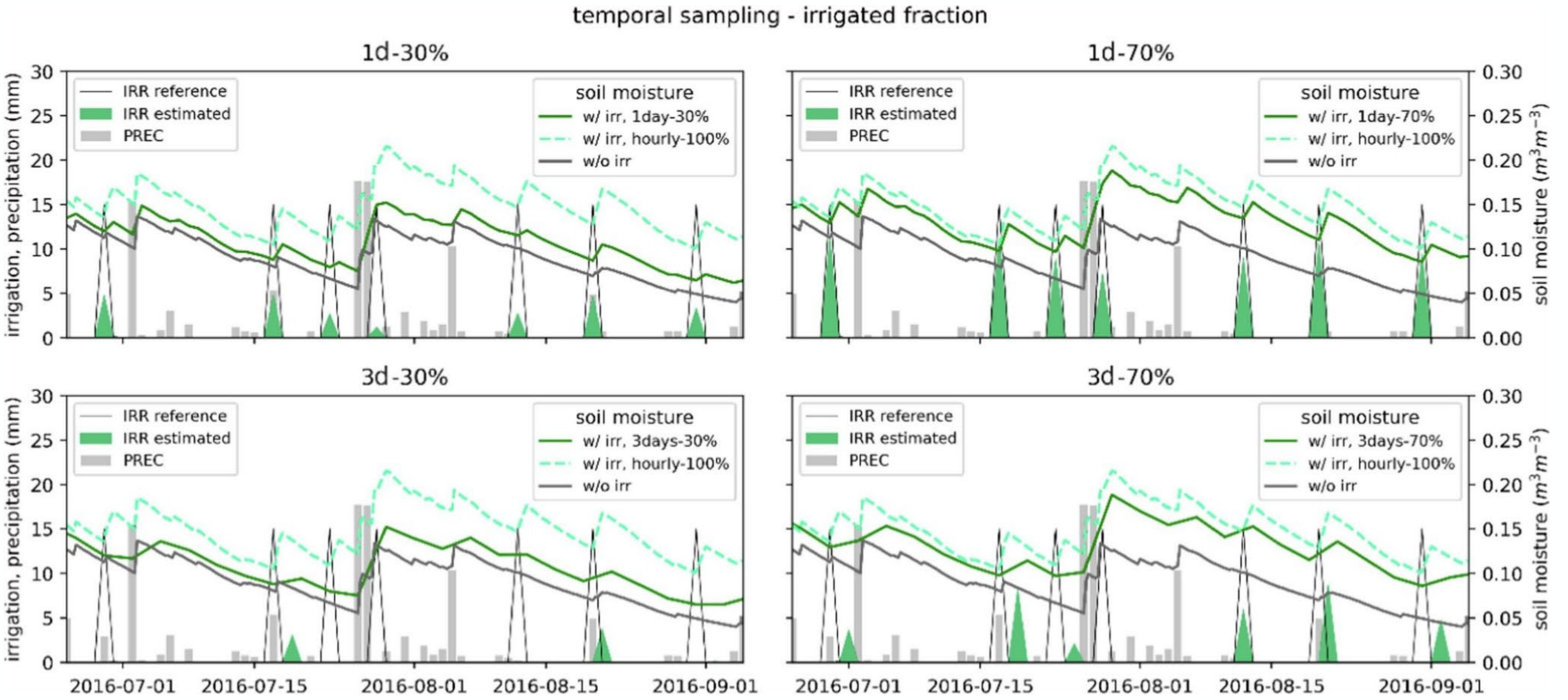


Courtesy of L. Zappa

IRRIGATION QUANTIFICATION THROUGH SATELLITE SOIL MOISTURE

Synthetic experiment addressing impact of spatial-temporal resolution on accuracy of irrigation estimates

- Frequent revisit time (1 day) allows to capture irrigation timing
- High spatial resolution (i.e. high irrigated fraction) allows to capture amplitude of irrigation water volumes

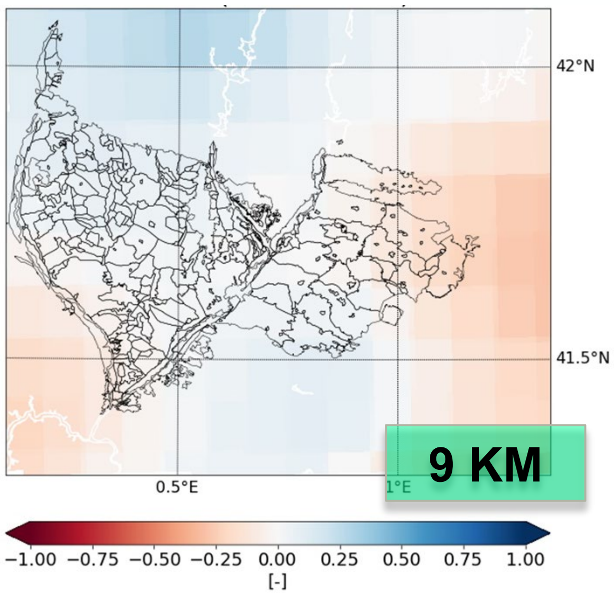


Courtesy of L. Zappa

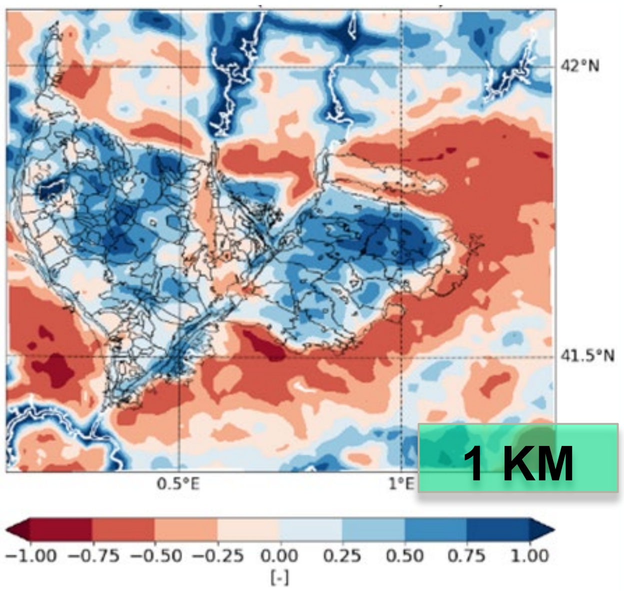
OUTLOOK

Main challenges to be faced

- **Spatial and temporal mismatch between satellite products and irrigation dynamics**



VS



In order to capture irrigation dynamics, the spatial resolution of satellite data should match with the irrigation extent. Similarly, the irrigation timing can be properly reproduced if revisit times are less than or equal to irrigation frequency

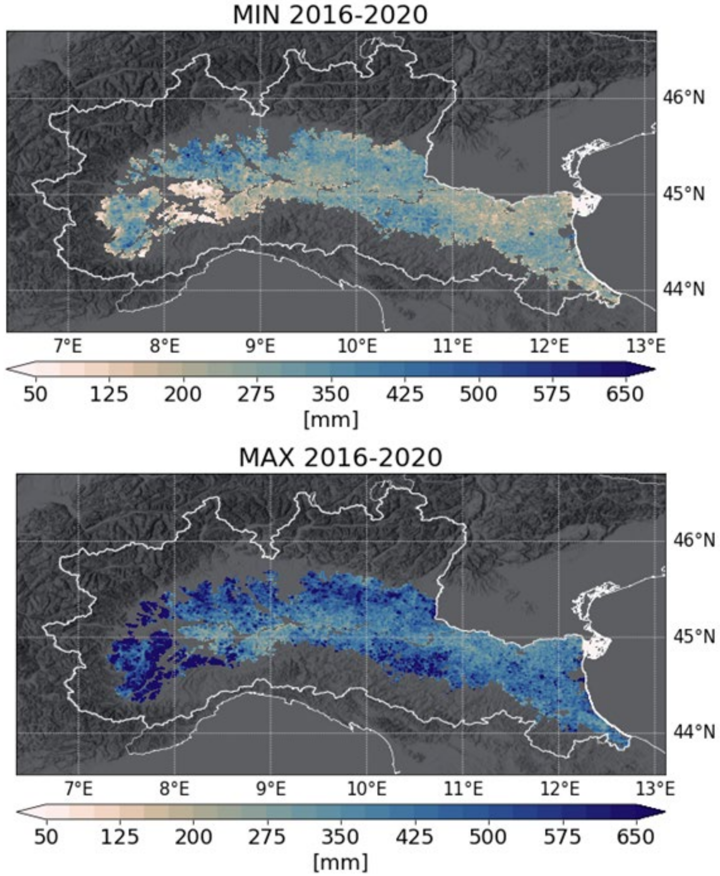
- **The lack of in-situ data: main driver of this research line but, at the same time, one of the main limitations. Reference data is needed for calibration and validation purposes!**

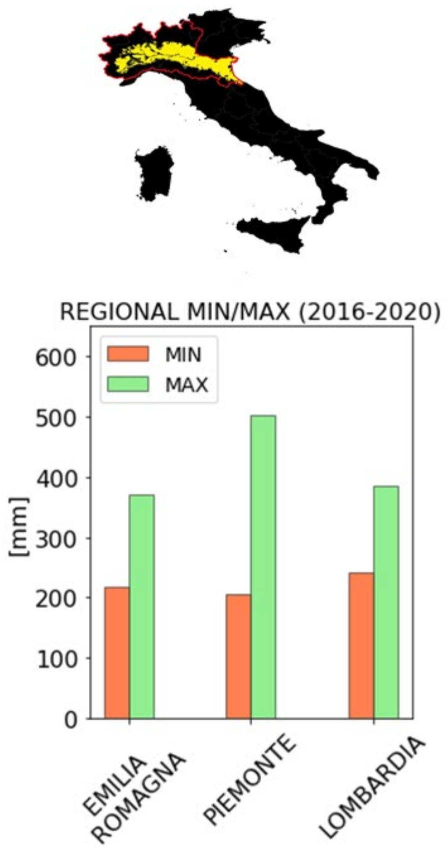
How can satellite-derived irrigation products be useful/used?

- Agricultural water management

For each pixel, minimum value among the seasons 2016, 2017, 2018, 2019.

For each pixel, maximum value among the seasons 2016, 2017, 2018, 2019.





Development of irrigation statistics at the regional level. In the next future, longer time series of irrigation estimates will ease the building of reliable statistics useful for water resources managers, e.g., by comparing the water needed with the actual amounts applied.

Final aim of building an operational system for high-resolution irrigation water monitoring from space

OUTLOOK

How can satellite-derived irrigation products be useful/used?

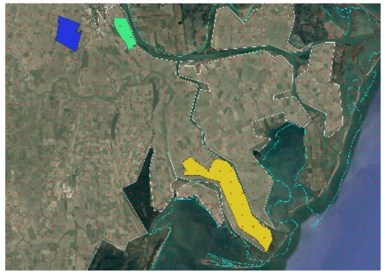
- **Ingestion in systems providing irrigation advices**

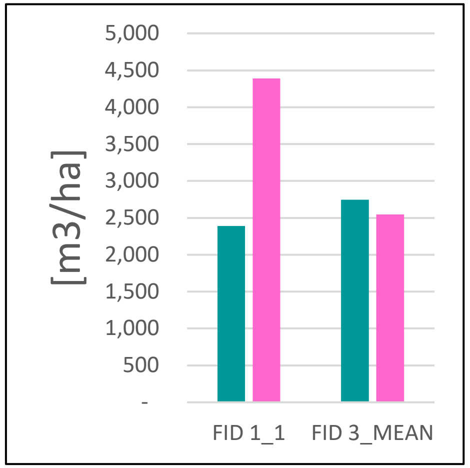
Update of systems providing irrigation advices with actual irrigation amounts

NORTHERN ITALY (PO DELTA)

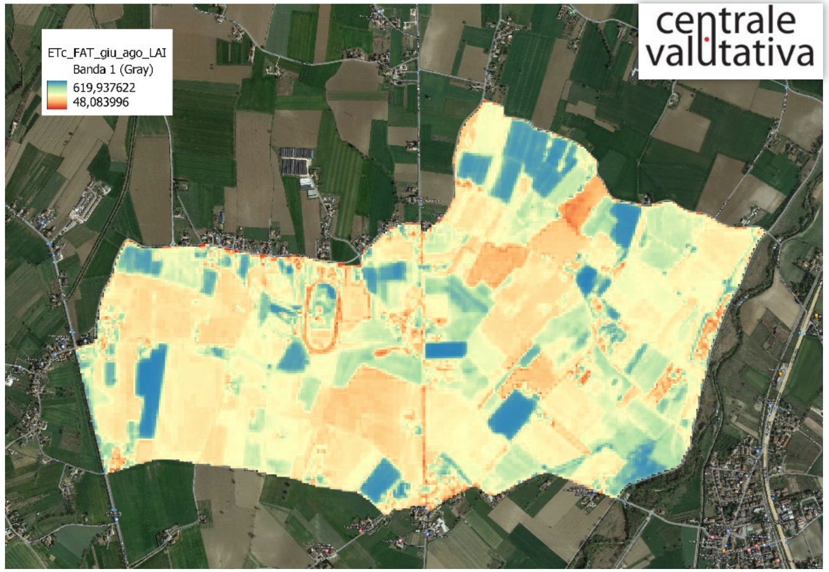
Satellite info

Irr. advice





- **Monitoring illegal water withdrawals**



Method: *Dari et al. (2021)*; https://doi.org/10.1016/j.jhydrol.2021.126129

Sentinel-1/Sentinel-2 derived soil Moisture product at Plot scale (S2MP)

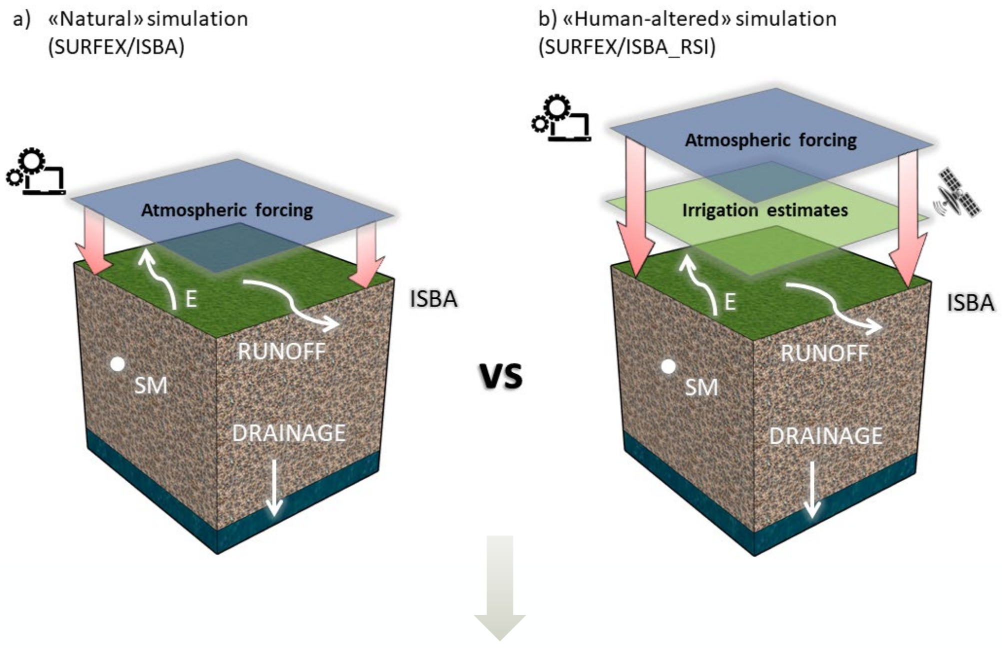
CENTRAL ITALY

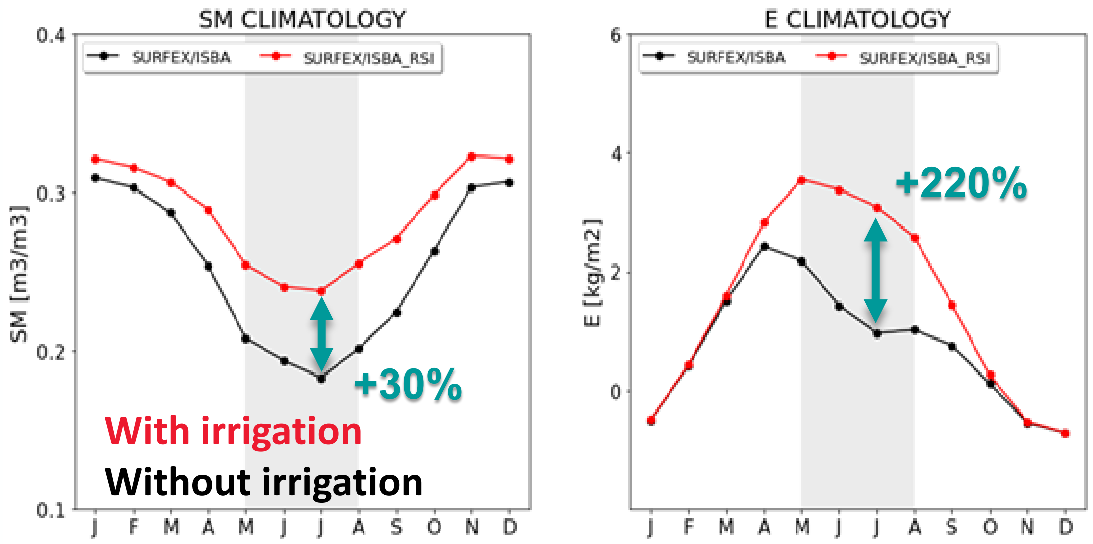
How can satellite-derived irrigation products be useful/used?

- Ingestion in LSMs

With the aim of assessing the impacts of irrigation

SURFEX/ISBA LSM





ΔSM, ΔE, ΔRUNOFF, ΔDRAINAGE

(Dari et al., 2023; under review)

OUTLOOK

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Hydrology UNIPG: https://twitter.com/HUnipg

Irrigation+ website: https://esairrigationplus.org/