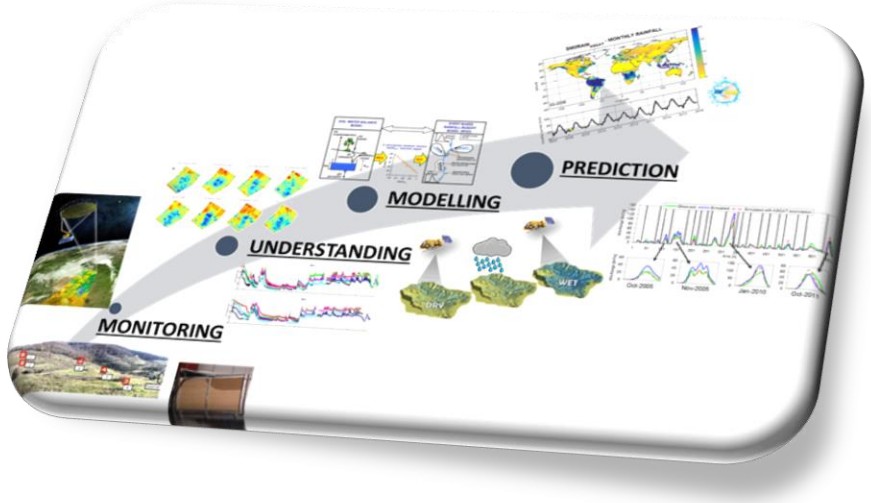
http://hydrology.irpi.cnr.it

18 December 2020

Luca Brocca and the IRPI Hydrology Group

Research Institute for Geo-Hydrological Protection (CNR-IRPI)

Perugia, Italy



"OBSERVING" SOIL MOISTURE AND IRRIGATION FROM SPACE

IRRIGATION IMPACT ON THE WATER CYCLE

- We, as human beings, are modifying the water cycle
- Irrigation is the major water consumer of our planet (70%), over Mediterranean >75%
- 2+ billion people affected by water stress - a number that will only increase with population growth, continued economic development and climate changing
- Global blue water availability: 5'000-9'000 km³/year
  Global water consumption: 3500-5000 km³/year

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

IRRIGATION IMPACT ON THE WATER CYCLE

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

"We find that in up to 35% of currently rain-fed croplands, irrigation could be expanded as an adaptation strategy to climate change without negative environmental externalities on freshwater resources."

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/s41467-019-14075-4

"Here we provide observational and model evidence that expanding irrigation has dampened historical anthropogenic warming during hot days, with particularly strong effects over South Asia."

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]

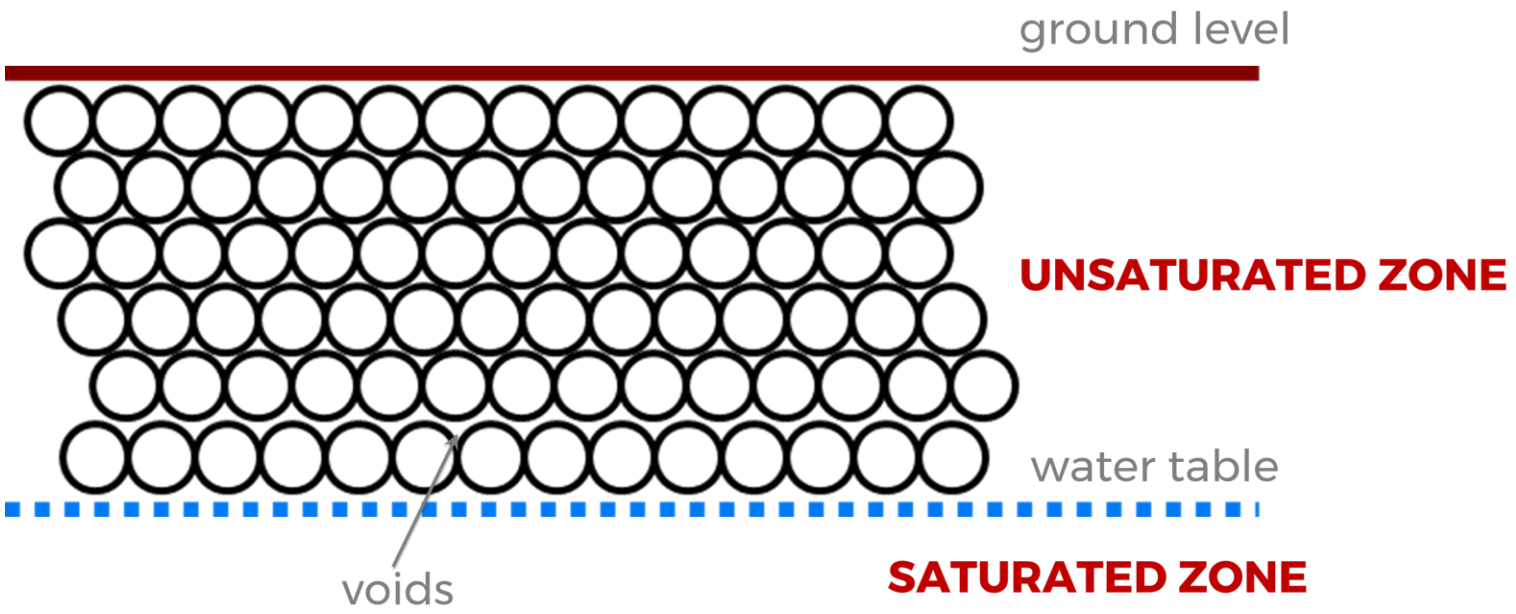
Nat Geoscience, Oct 26, 2020; https://doi.org/10.1038/s41561-020-00650-8

"heat stress projections in …regions dominated by semi-arid/monsoon climates that do not include the role of irrigation overestimate the benefits of irrigation on dry heat stress and underestimate the risks."

All these studies rely on the global map of irrigation areas dated 2005 (areas equipped for irrigation) and simulated data

CAN WE USE SOIL MOISTURE FOR IRRIGATION QUANTIFICATION?

What is soil moisture?



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

Soil Moisture

Soil moisture is a key variable of the climate system.

Soil moisture generally refers to the amount of water stored in the unsaturated soil zone.

Seneviratne et al. (2010 ESR)
https://doi.org/10.1016/j.earscirev.2010.02.004

15 YEARS OF RESEARCH ON SOIL MOISTURE!!!

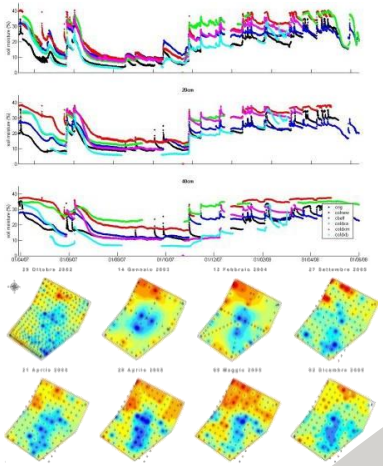
2005

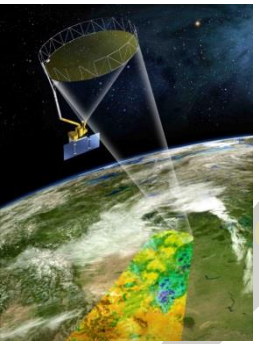
2007
JoH paper

2010
HESS paper

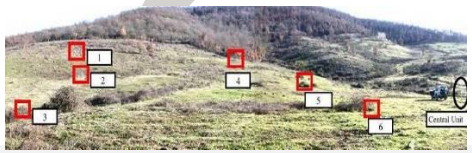
2014
JGR paper

2018
JAG paper

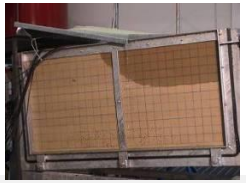




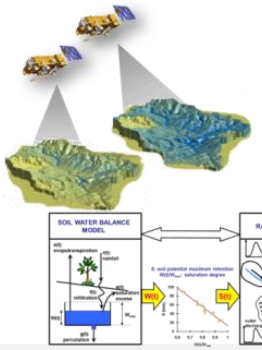
Soil moisture **monitoring** with in situ and remote sensing



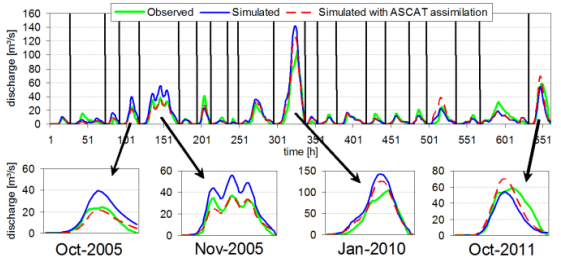
Understanding the spatial-temporal **variability** of soil moisture at different spatial scales



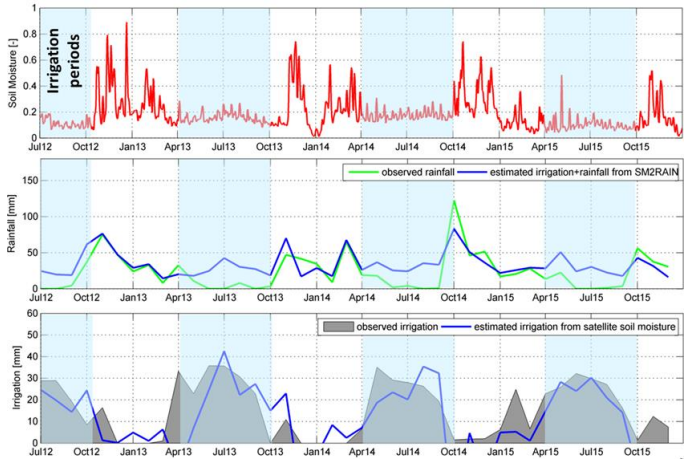
Assimilation of in situ and remote sensing soil moisture measurements for **hydrological applications**

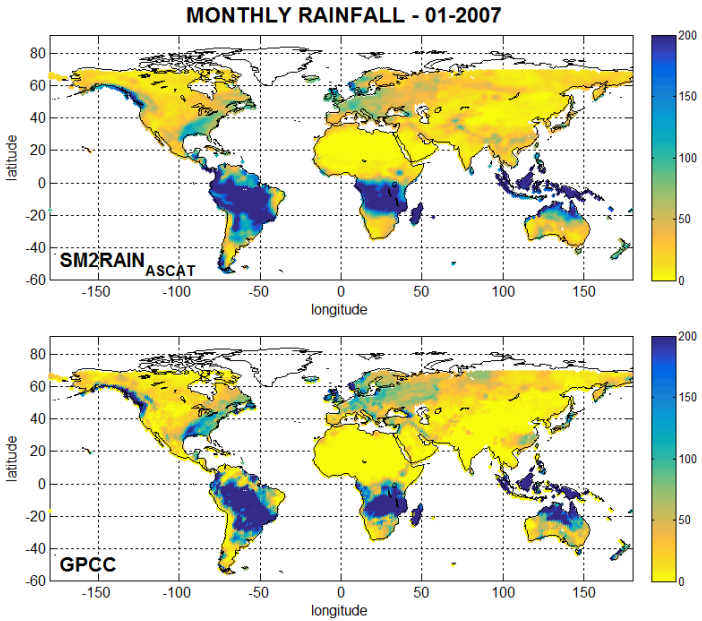


Detecting rainfall from the bottom up: using soil moisture observations for measuring rainfall (**SM2RAIN**)

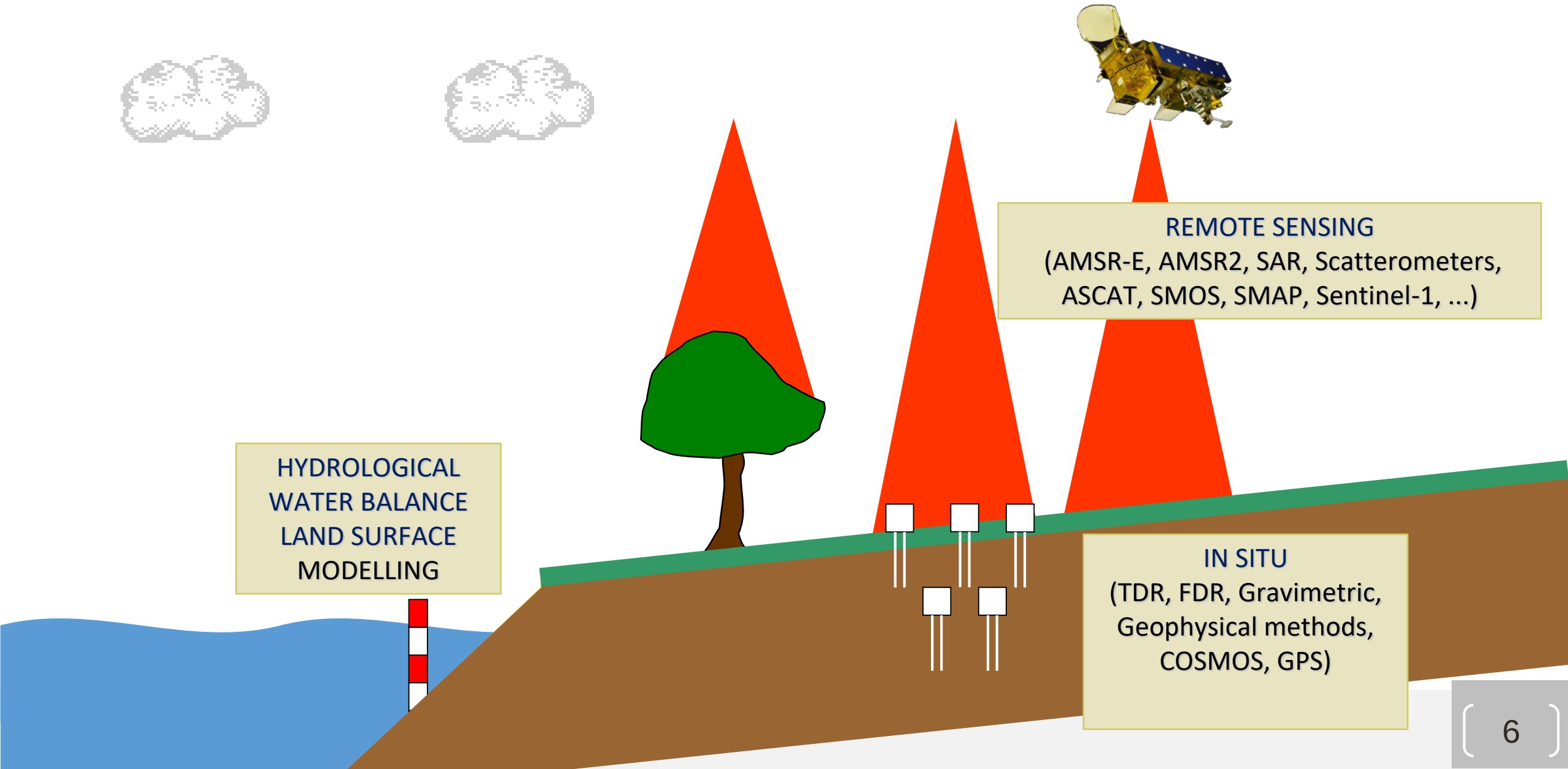


Irrigation from space



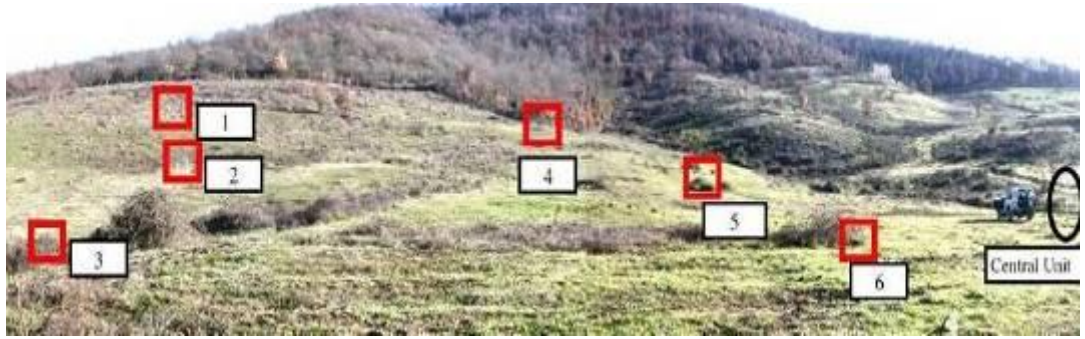


SOIL MOISTURE MONITORING

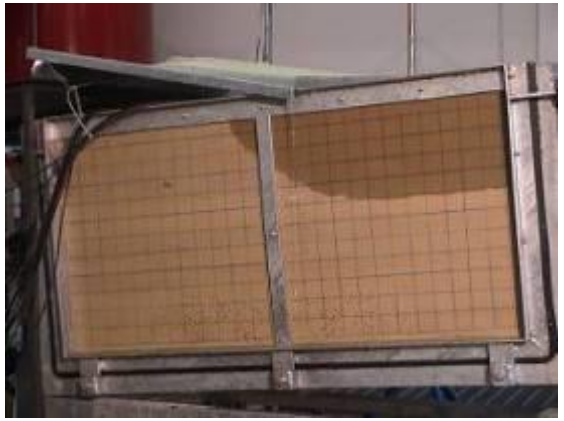


SOIL MOISTURE MONITORING

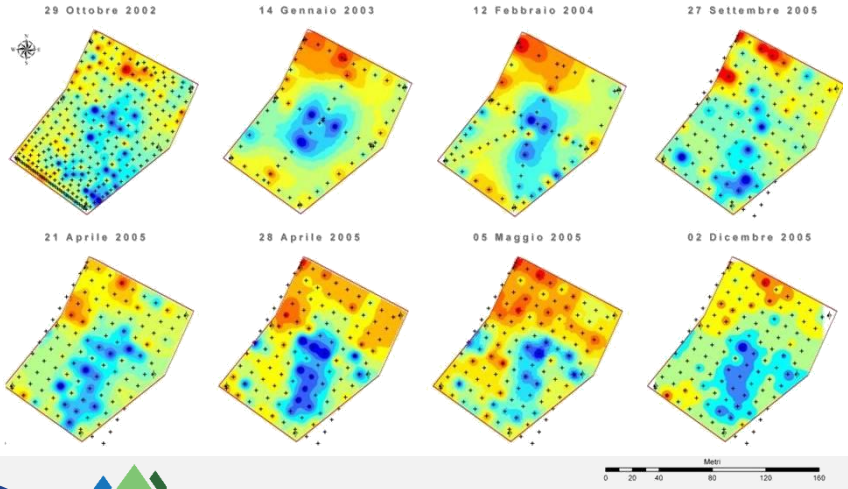
Experimental catchments



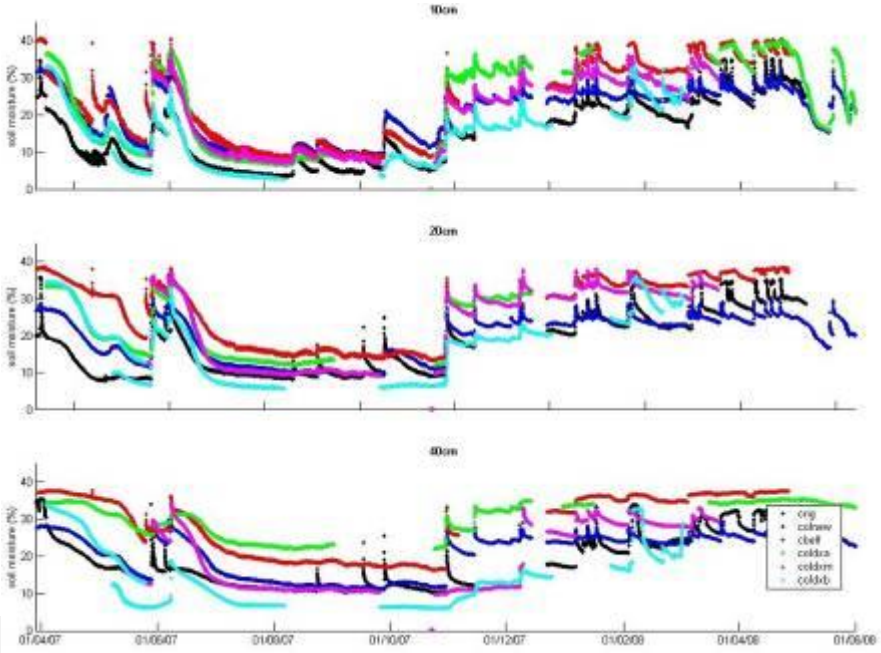
Laboratory



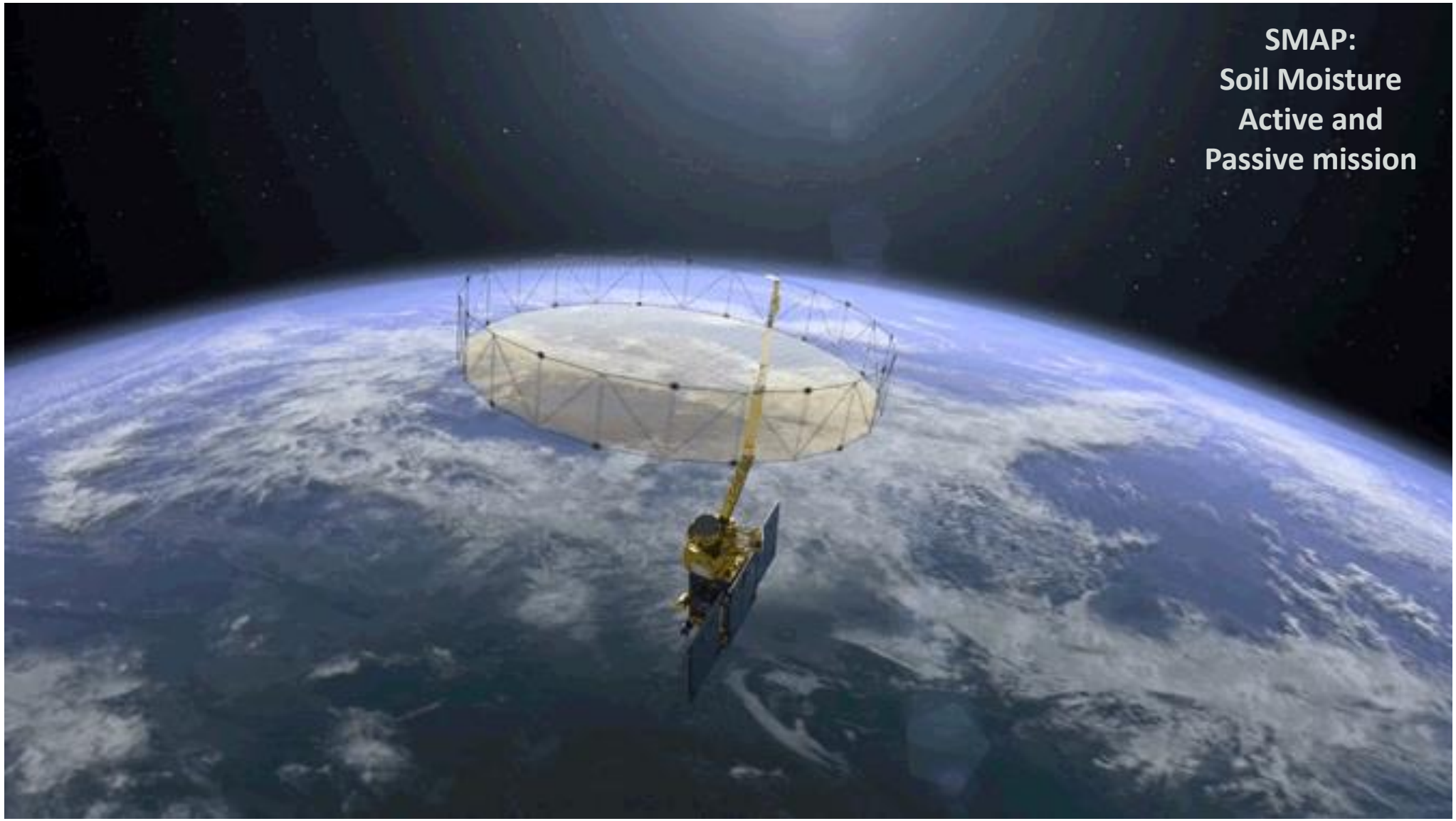
TDR spot measurements



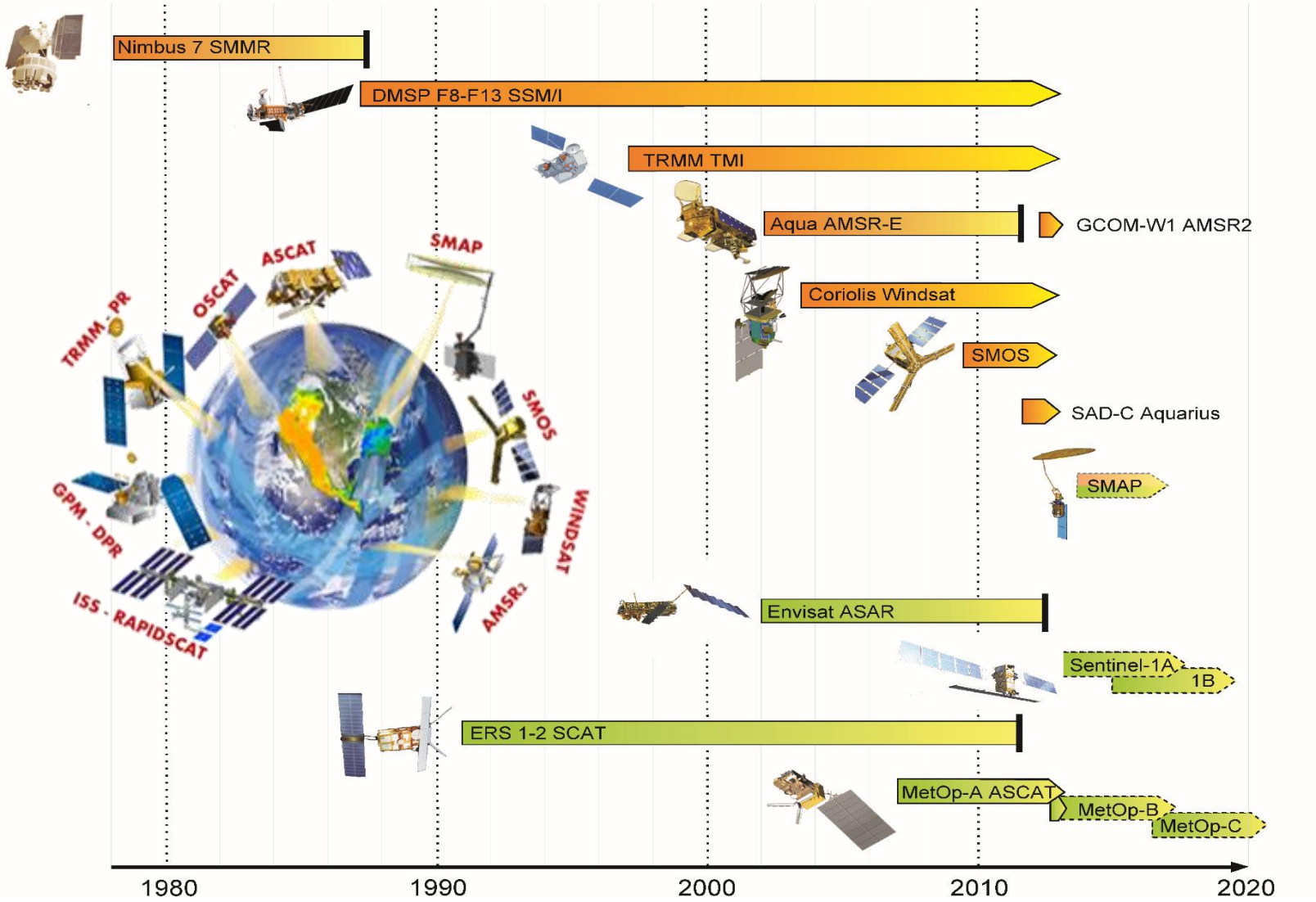
Continuous monitoring probes



REMOTE SENSING OF SOIL MOISTURE



REMOTE SENSING OF SOIL MOISTURE



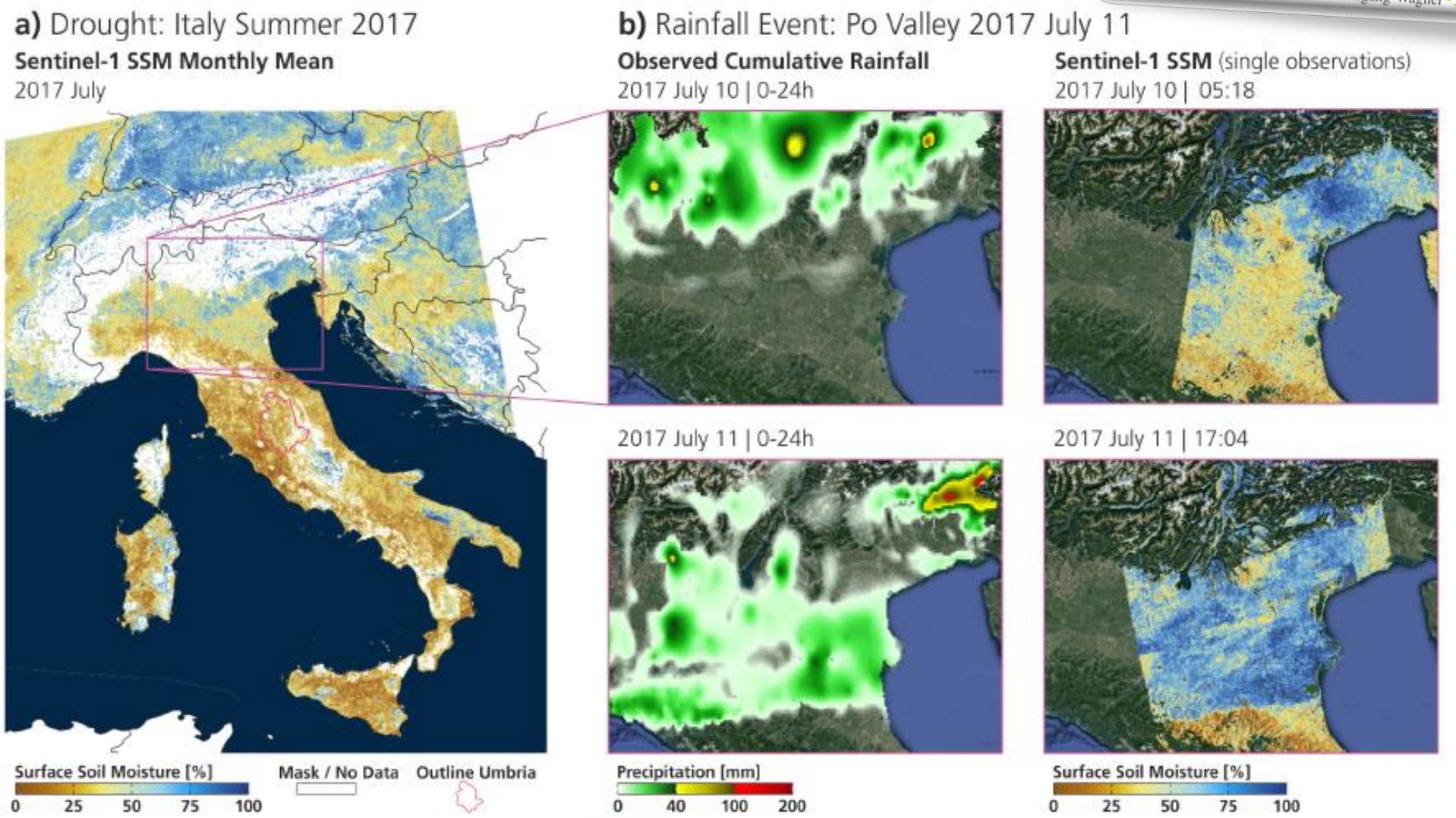
- A constellation of satellite sensors for measuring soil moisture is available
- High temporal and spatial resolution only recently:
  - Sentinel-1
  - CYGNSS
- future missions:
  - FSSCat
  - L-band SAR
  - HYDROTERRA (EE10)

Brocca et al. (2017 WATER)
https://doi.org/10.3390/w9020140

HIGH RESOLUTION SOIL MOISTURE FROM SENTINEL-1

Toward Global Soil Moisture Monitoring With Sentinel-1: Harnessing Assets and Overcoming Obstacles

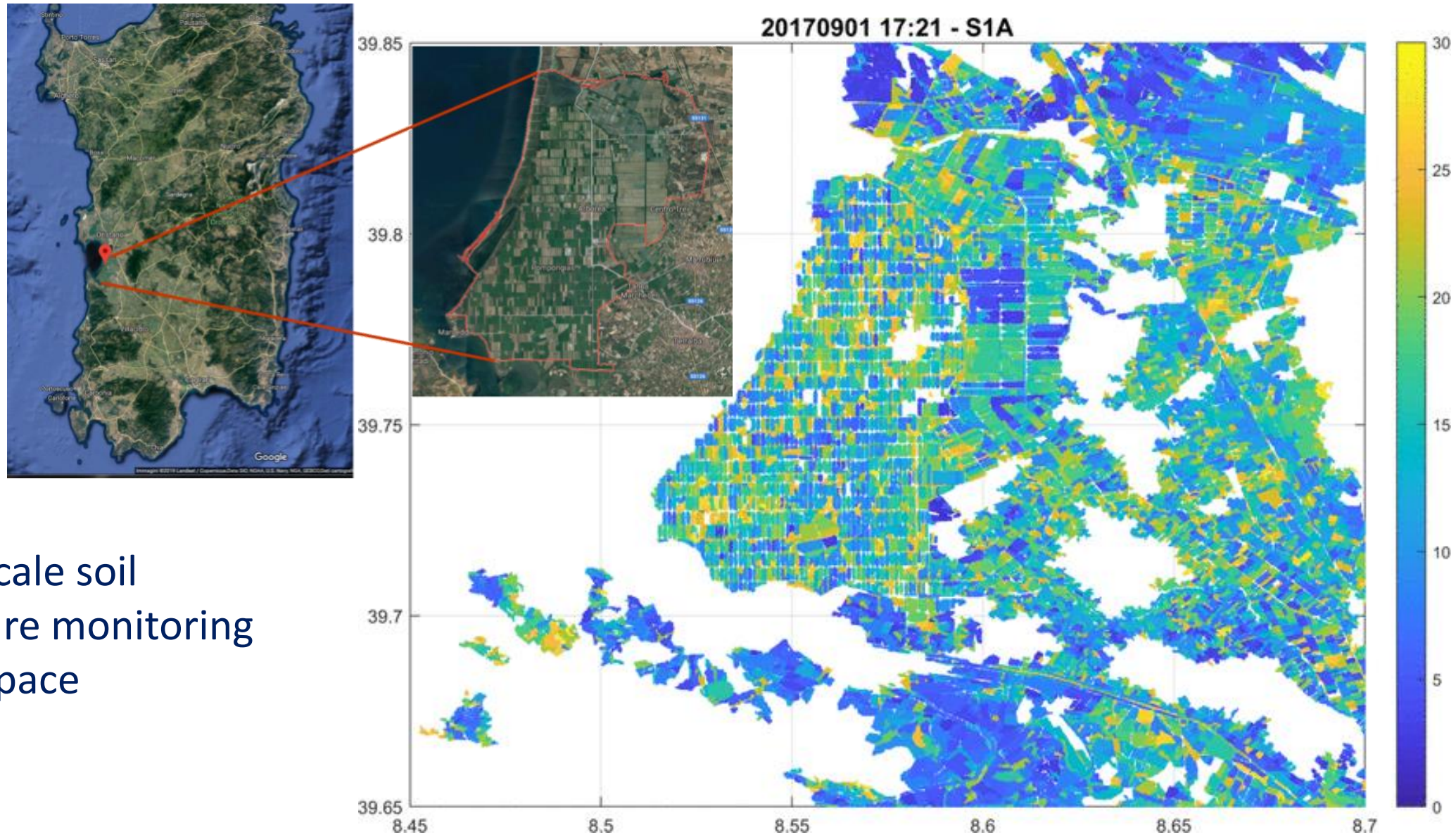
Bernhard Bauer-Marschallinger, *Member, IEEE*, Vahid Freeman, Senmao Cao, Christoph Paulik, Stefan Schaufler, Tobias Stachl, Sara Modanesi, Christian Massari, Luca Ciabatta, Luca Brocca, and Wolfgang Wagner, *Senior Member, IEEE*



Sentinel-1 Soil Moisture

Bauer-Marschallinger et al. (2018 IEEE TGRS) https://doi.org/10.1109/TGRS.2018.2858004

HIGH RESOLUTION SOIL MOISTURE FROM SENTINEL-1



Field scale soil moisture monitoring from space

Bazzi et al. (2020 JSTARS)
https://doi.org/10.1109/JSTARS.2019.2927430

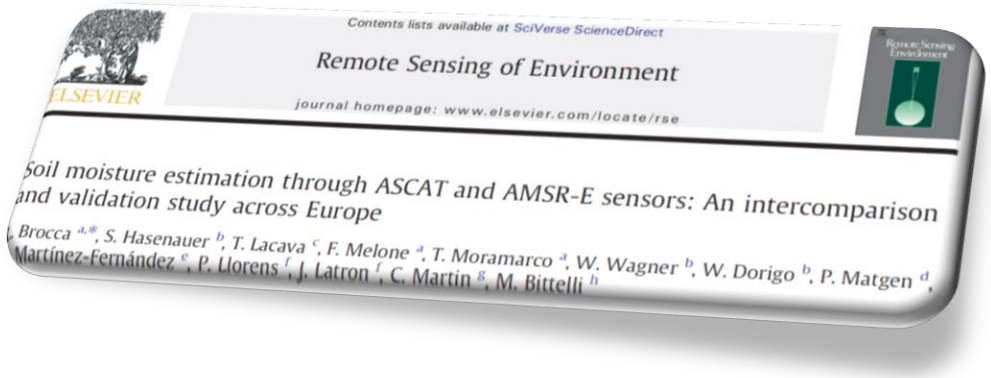
VALIDATION OF SATELLITE SOIL MOISTURE PRODUCTS

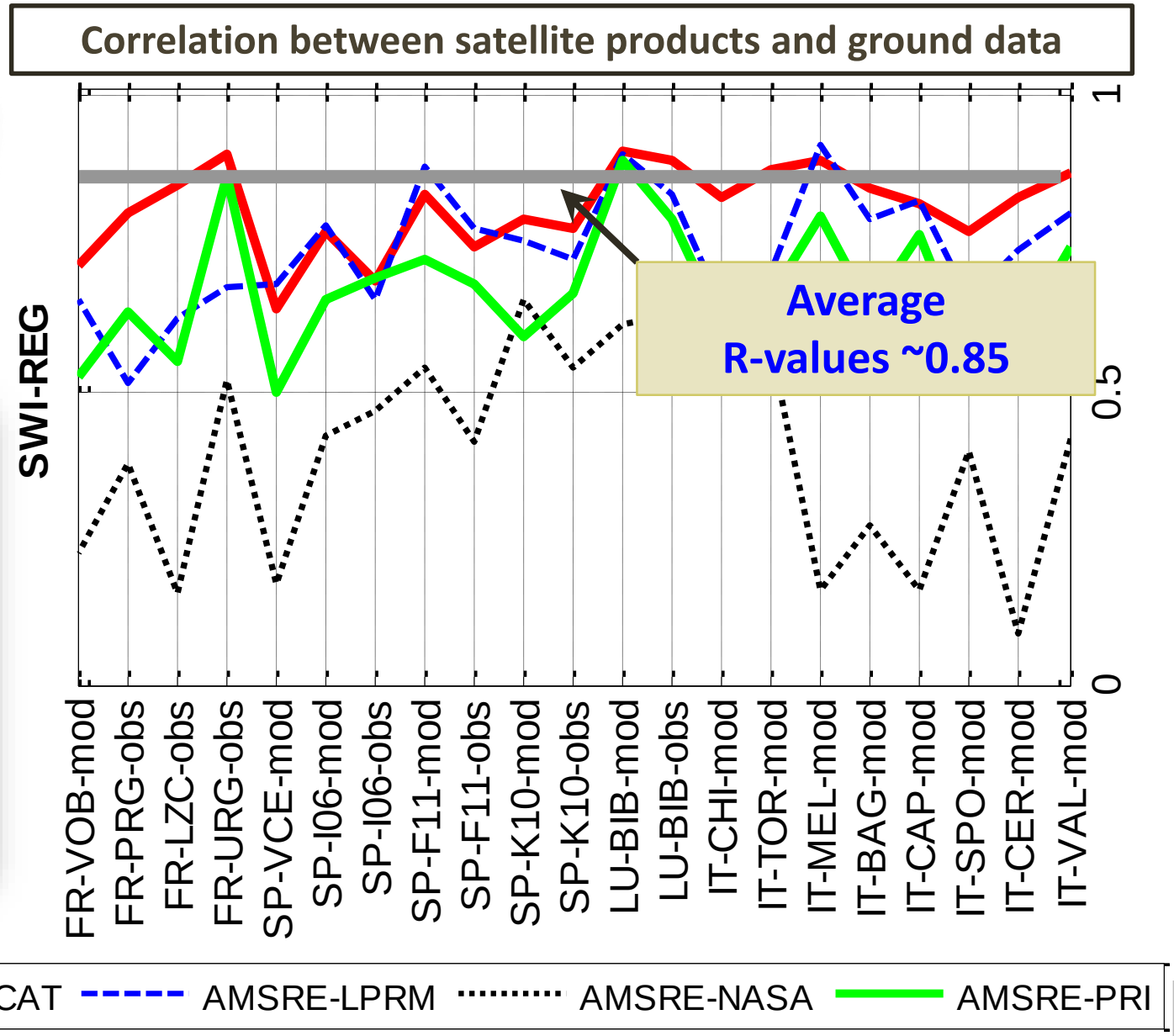
EUMETSAT H SAF
SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

Location	Site	LAT (°)	LON (°)	Elev (m a.s.l.)	Soil texture	Land use	Z (cm)	Data set	MAR (mm)	MAT (°C)
Italy - IRPI	VAL	43.22	12.15	315	sandy loam	grass	10	obs & mod	900	13
	CER	43.56	12.38	300	loamy sand	grass	10	mod	900	13
	SPO	42.88	12.85	435	sandy loam	grass	10	mod	900	13
Italy - UMSUOL	CAP	44.30	11.30	10	sandy loam	grass	10	obs & mod	750	16
Italy - Campania and Calabria	BAG	40.83	15.06	560	sandy loam	grass	30	obs & mod	920	17
	MEL	41.16	14.51	180	sandy clay loam	grass	30	obs & mod	920	17
	TOR	39.51	16.15	100	?	?	30	obs & mod	850	21
	CHI	38.67	16.48	550	?	?	30	obs & mod	850	21
Luxembourg	BIB	49.63	6.23	270	loam	grass	5	obs & mod	860	9
Spain - REMEDHUS	K10	41.35	-5.22	770	sand	corn	5	obs & mod	380	12
	F11	41.24	-5.54	830	loamy sand	grass	5	obs & mod	380	12
	I06	41.38	-5.43	730	sand	bare soil	5	obs & mod	380	12
Spain - Vallcebre	VCE	42.17	1.83	1180	silt loam	grass	20	obs & mod	860	9
France - SMOSMANIA	URG	43.64	-0.44	150	silt	grass	5	obs	?	?
	LZC	43.17	2.73	70	clay loam	grass	5	obs	?	?
	PRG	43.67	0.22	170	silt	grass	5	obs	?	?
France - Valescure	VOB	43.79	4.35	430	sandy	grass	30	obs & mod	1500	12

Brocca et al. (2011 RSE)
https://doi.org/10.1016/j.rse.2011.08.003

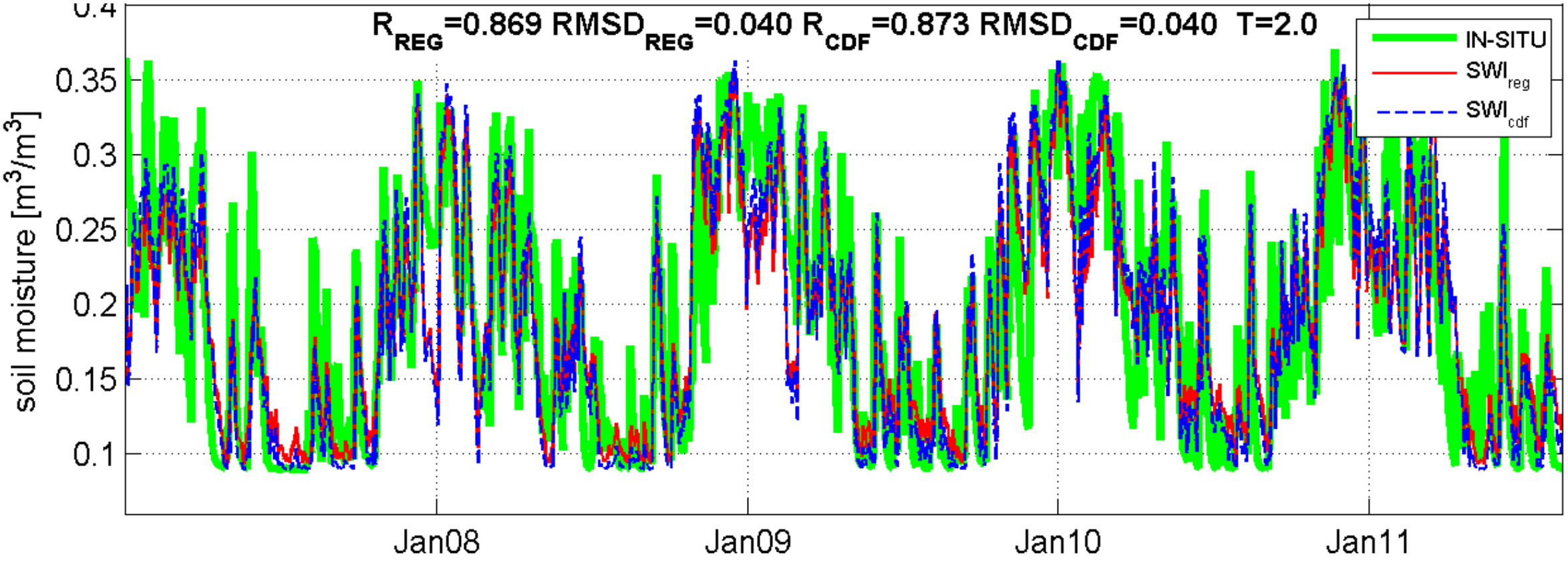
VALIDATION OF SATELLITE SOIL MOISTURE PRODUCTS





Brocca et al. (2011 RSE)
https://doi.org/10.1016/j.rse.2011.08.003

VALIDATION OF SATELLITE SOIL MOISTURE PRODUCTS



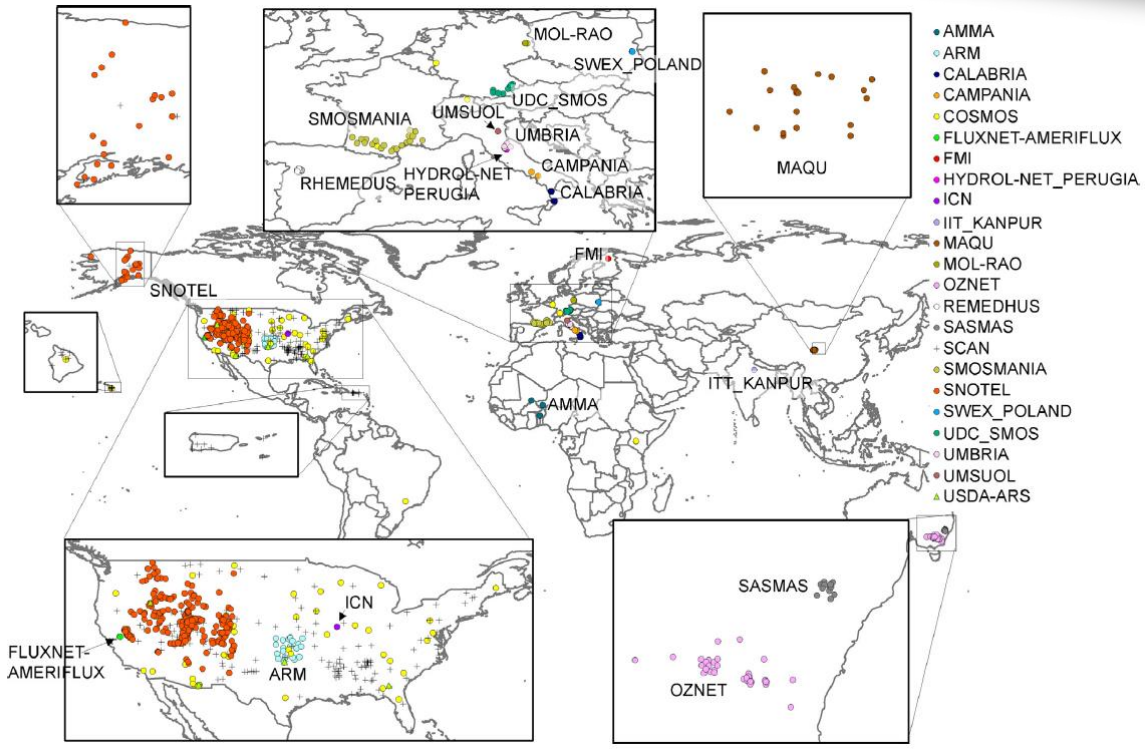
ITALY

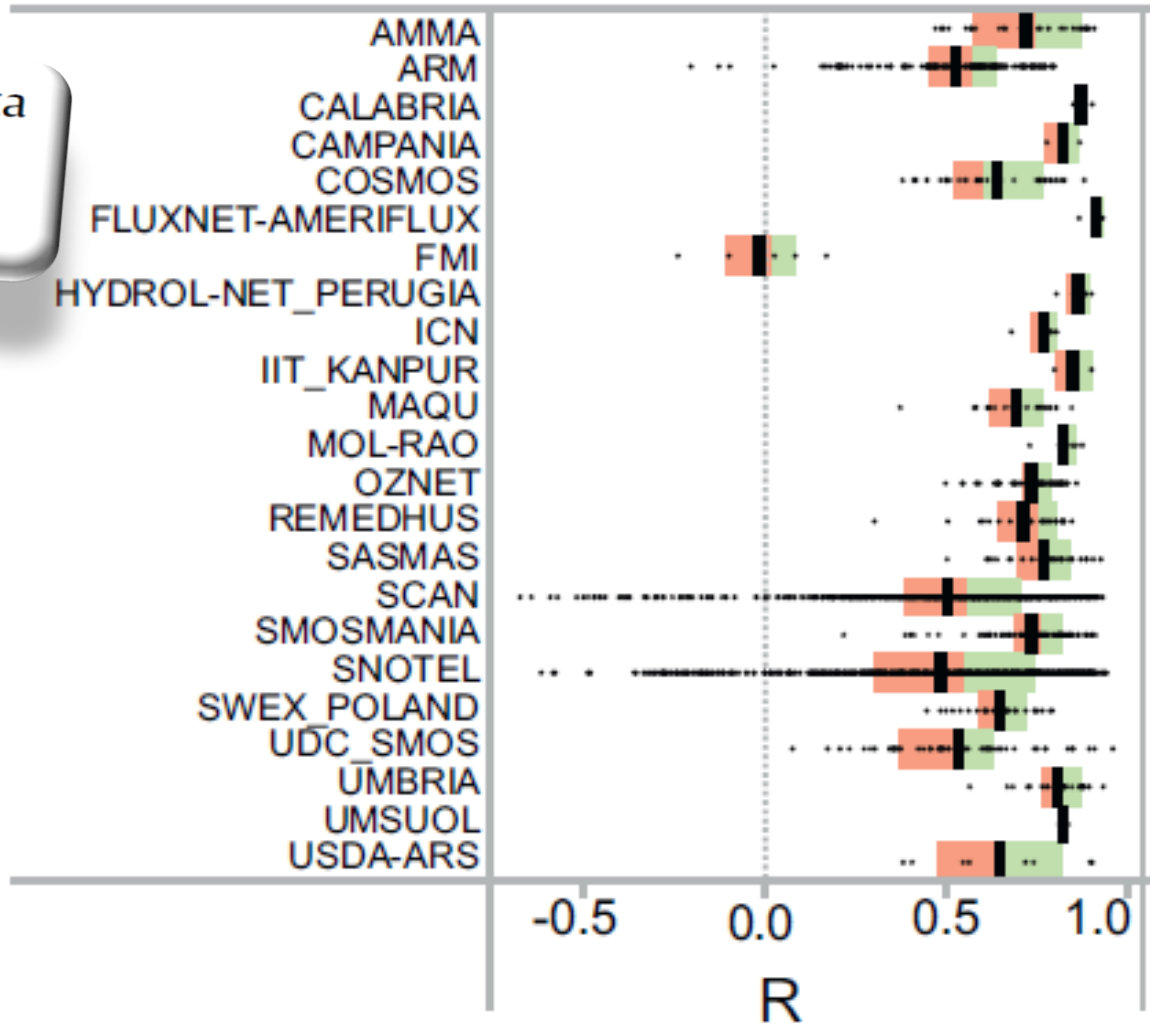
Brocca et al. (2011 RSE)
https://doi.org/10.1016/j.rse.2011.08.003

VALIDATION OF SATELLITE SOIL MOISTURE PRODUCTS

Validation of the ASCAT Soil Water Index using in situ data from the International Soil Moisture Network

Christoph Paulik, Wouter Dorigo, Wolgang Wagner, Richard Kidd*



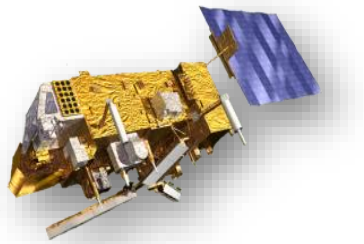


1’800’000 measurements !!!

Paulik et al. (2014 JAG)
https://doi.org/10.1016/j.jag.2014.01.007

OPERATIONAL SOIL MOISTURE PRODUCTS (EUMETSAT H SAF)

Large-scale surface soil moisture observed by radar scatterometer (ASCAT)
Resolution 25 km (Sampling 12.5 km)
Daily coverage, 0-5 cm
2007 – ongoing



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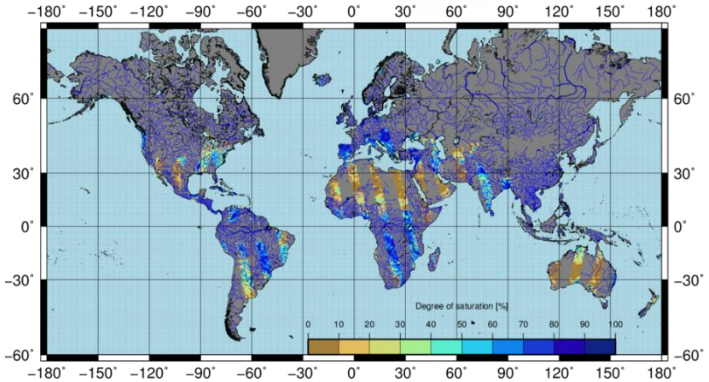

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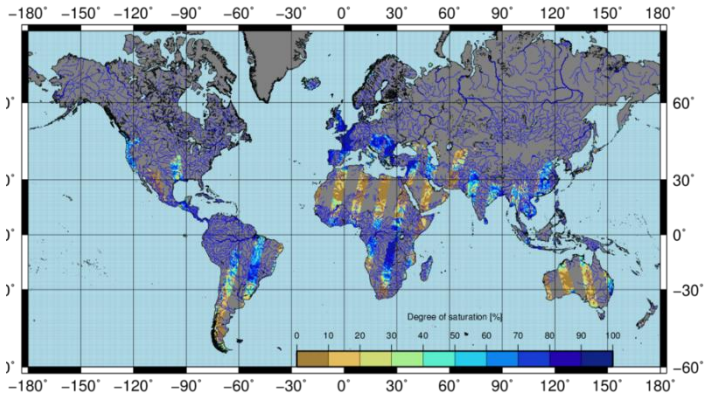
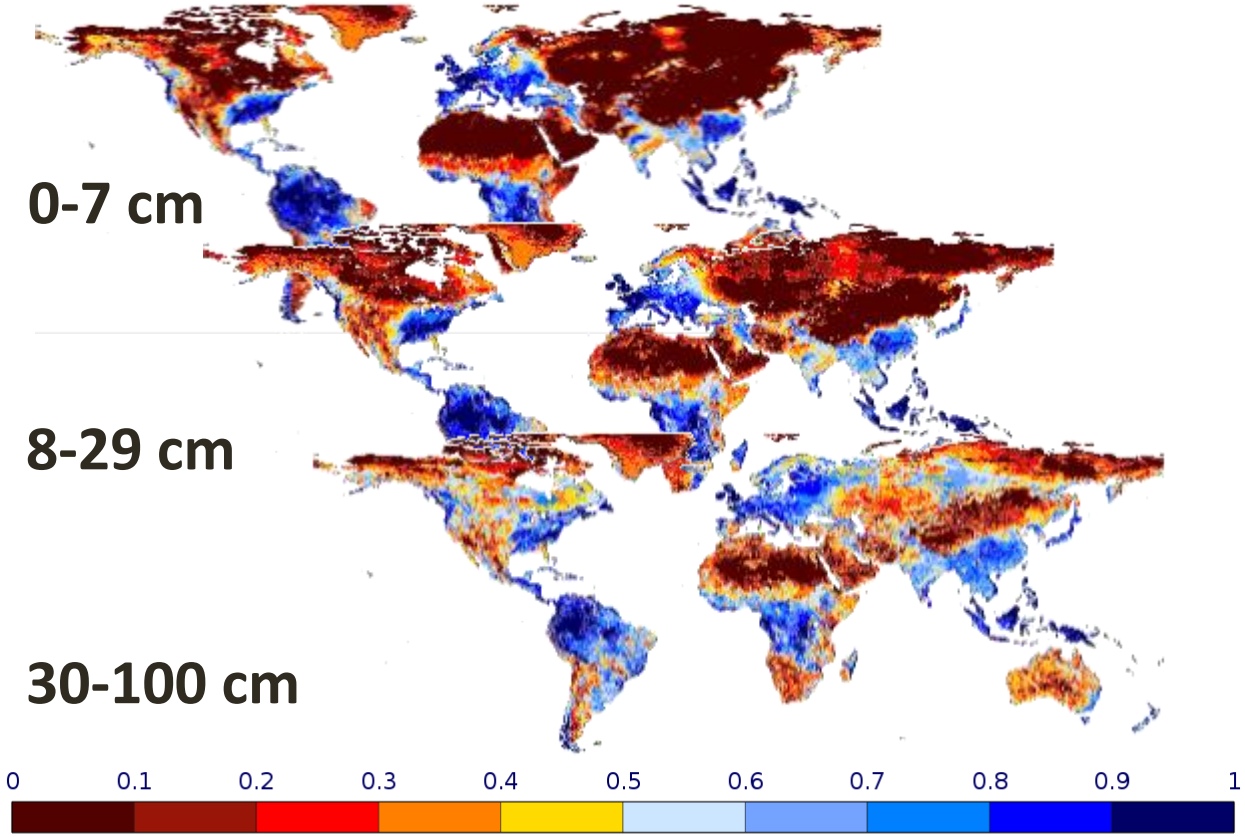


Volumetric soil moisture (roots region) by assimilation the large scale soil moisture product in NWP model (IFS-ECMWF)
Resolution 16 km
Daily coverage, 4 soil layer
1992 – ongoing



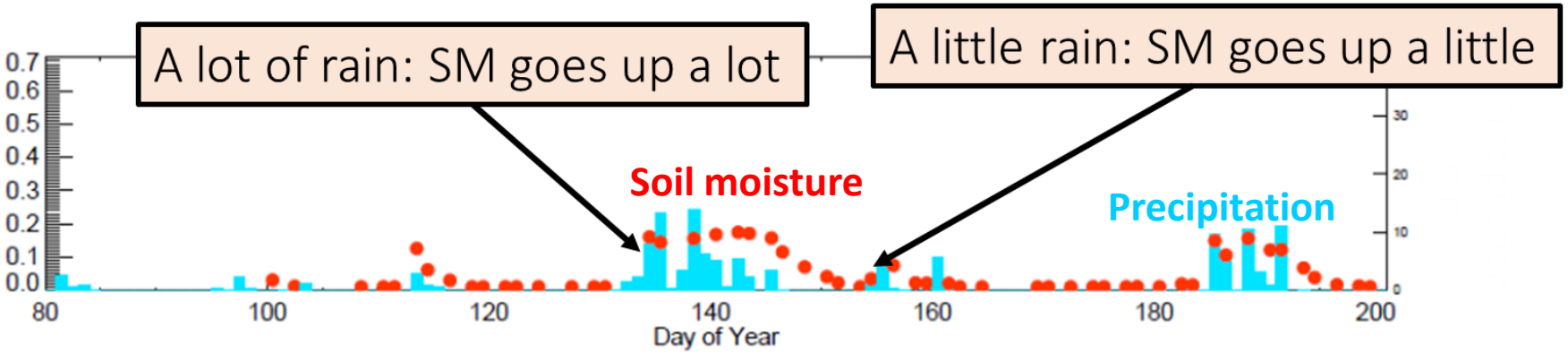
OPERATIONAL SOIL MOISTURE PRODUCTS (COPERNICUS)

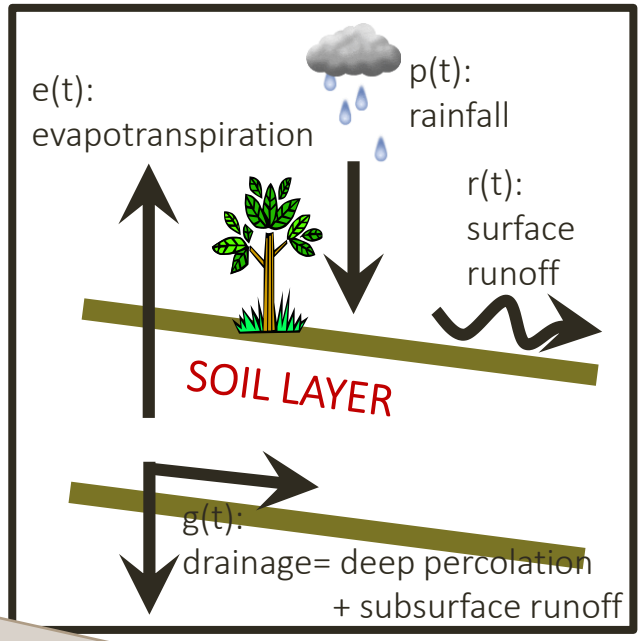
COPERNICUS C3S SOIL MOISTURE
1978 to present, 1/10-day, 0.25-degree

SOIL WATER INDEX: 2007 to present, 1/10-day, 0.1-degree

SURFACE SOIL MOISTURE: 2014 to present, 5-day, 1 km

SM2RAIN: RAINFALL ESTIMATION FROM SOIL MOISTURE





relative soil moisture

precipitation

surface runoff

drainage

$$Z^* \frac{ds(t)}{dt} = p(t) - r(t) - e(t) - g(t)$$

soil water capacity = soil depth X porosity

evapotranspiration

1 equation
3 parameters (Z^*, a, b) + s(t)
… very SIMPLE!

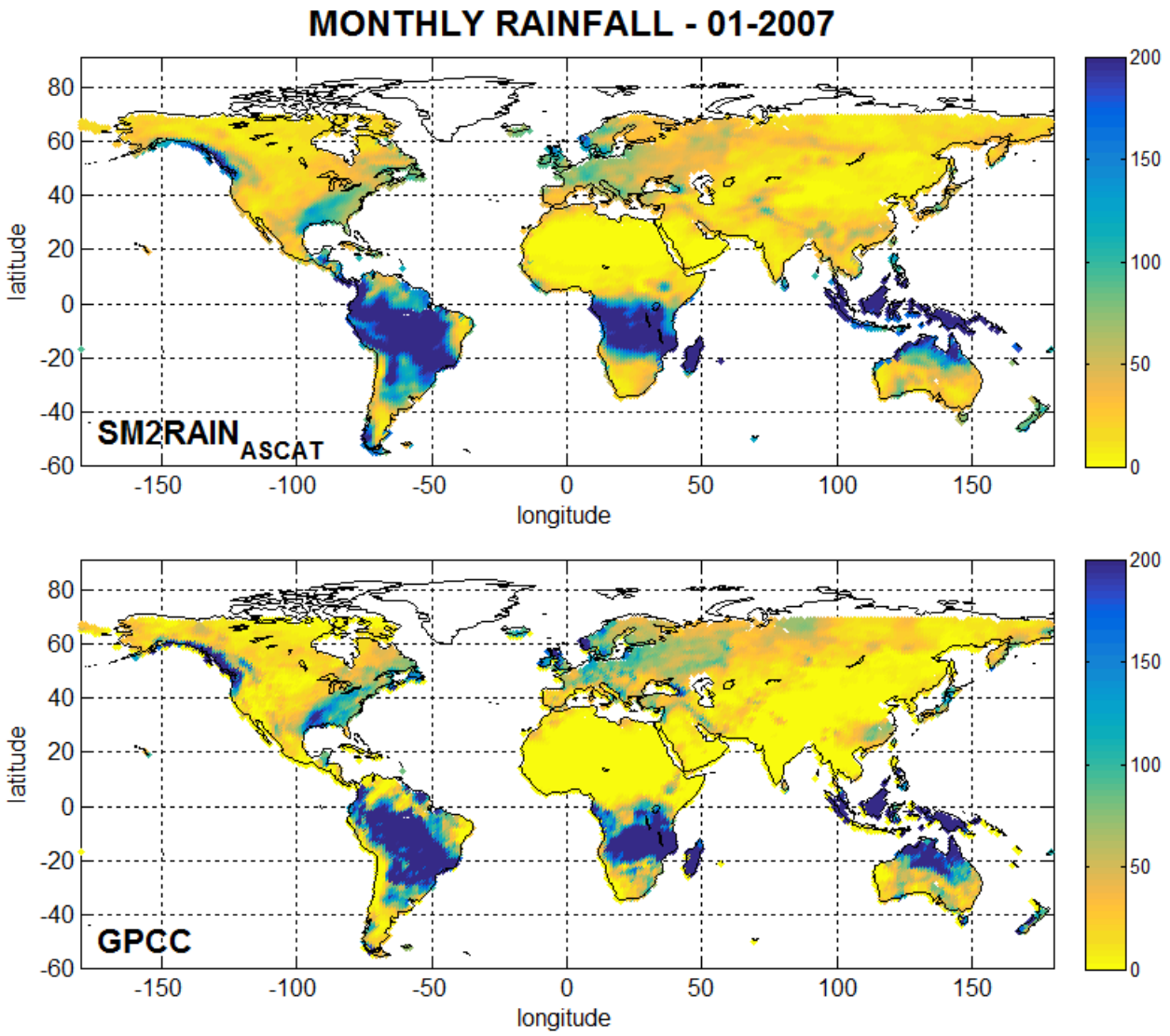
During rainfall, surface runoff and evapotranspiration are assumed to be negligible (demonstrated in Brocca et al., 2015 JHH):

$g(t) = a s(t)^b$
$r(t) = 0$
$e(t) = 0$

$$p(t) = Z^* \frac{ds(t)}{dt} + a s(t)^b$$

Brocca et al. (2015 JHH)
http://dx.doi.org/10.1515/johh-2015-0016

SM2RAIN: RAINFALL ESTIMATION FROM SOIL MOISTURE



SM2RAIN is a new "bottom-up" approach (Brocca et al., 2014 JGR) for estimating the ACCUMULATED RAINFALL from satellite (and in situ) soil moisture observations

Brocca et al. (2014 JGR) https://doi.org/10.1002/2014JD021489

SM2RAIN: GLOBAL RAINFALL PRODUCTS

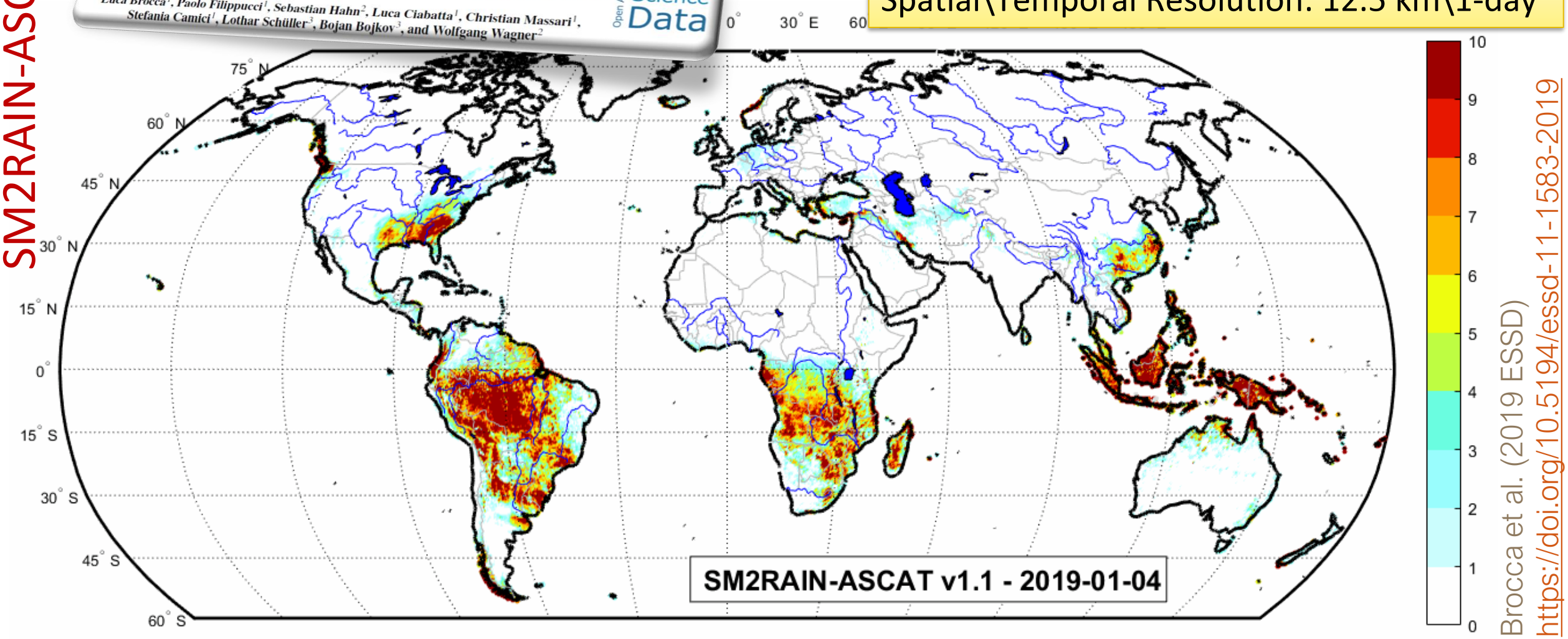
SM2RAIN-ASCAT

SM2RAIN–ASCAT (2007–2018): global daily satellite rainfall data from ASCAT soil moisture observations

Luca Brocca[1], Paolo Filippucci[1], Sebastian Hahn[2], Luca Ciabatta[1], Christian Massari[1], Stefania Camici[1], Lothar Schüller[3], Bojan Bojkov[3], and Wolfgang Wagner[2]

Open Access Earth System Science Data

Data Period: 2007-2019
Spatial\Temporal Resolution: 12.5 km\1-day



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

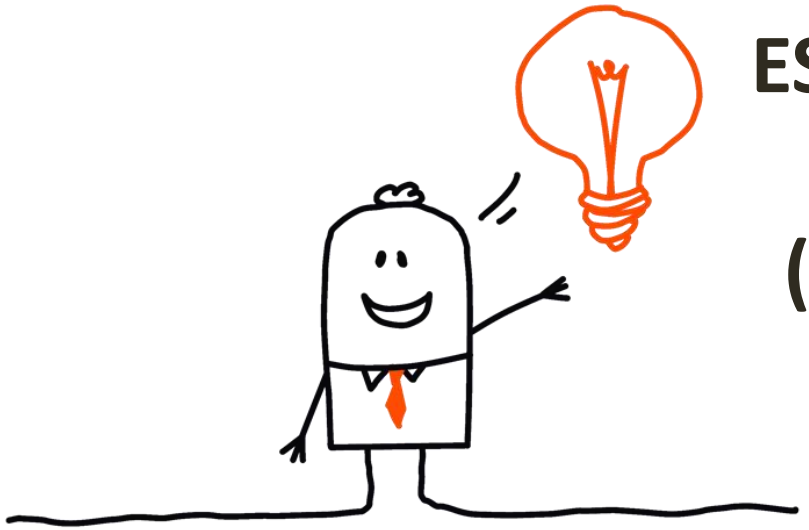
Freely available @ Zenodo
https://doi.org/10.5281/zenodo.2591214

WE HAVE A PROBLEM WITH SM2RAIN ☹

Reviewer comment in one of our SM2RAIN paper

Through soil moisture you don't see rainfall, but the total amount of water entering into the soil.

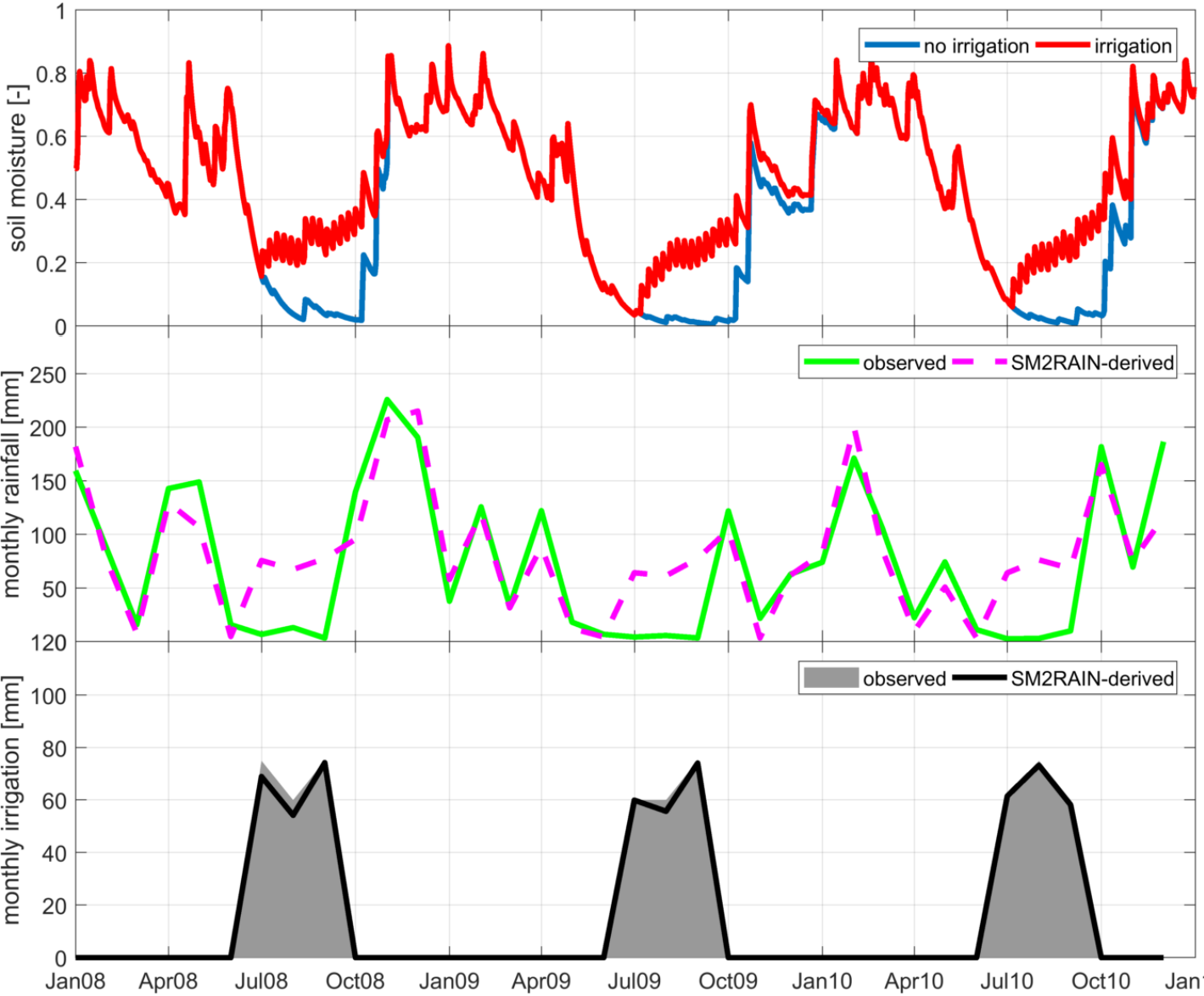
You are getting WRONG results over irrigated areas



CAN WE USE SOIL MOISTURE FOR ESTIMATING IRRIGATION WATER VOLUMES?

(The missing variable in the WATER CYCLE)

IRRIGATION WATER FROM SOIL MOISTURE OBSERVATIONS



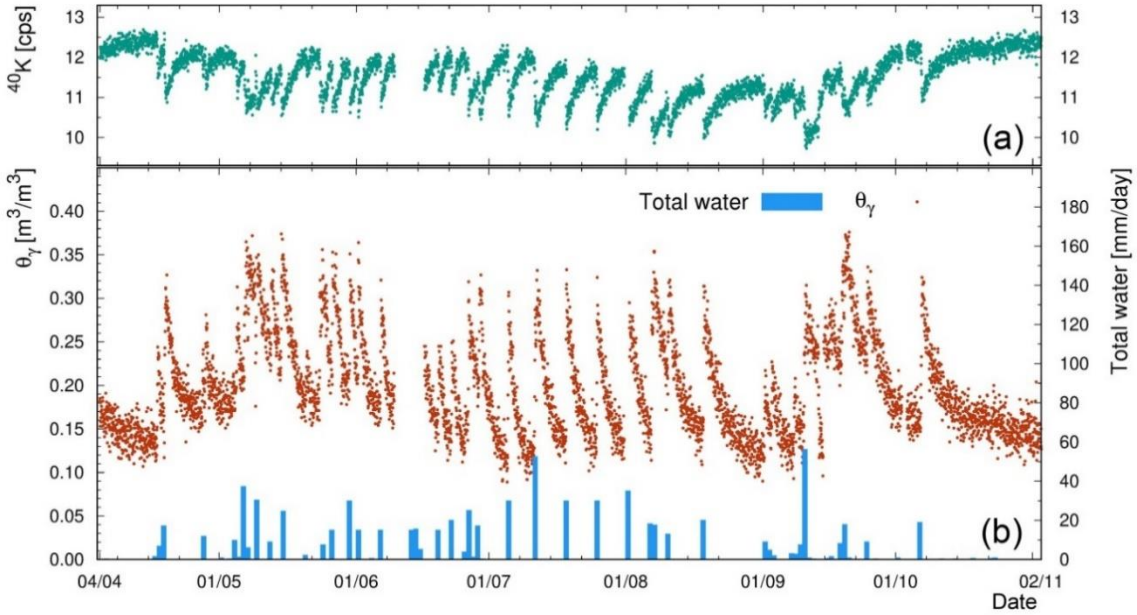
We simulate soil moisture without (blue line) and with (red line) irrigation

We apply SM2RAIN to synthetic soil moisture to obtain SM2RAIN-derived rainfall+irrigation (magenta line), compared with observed rainfall (green line).

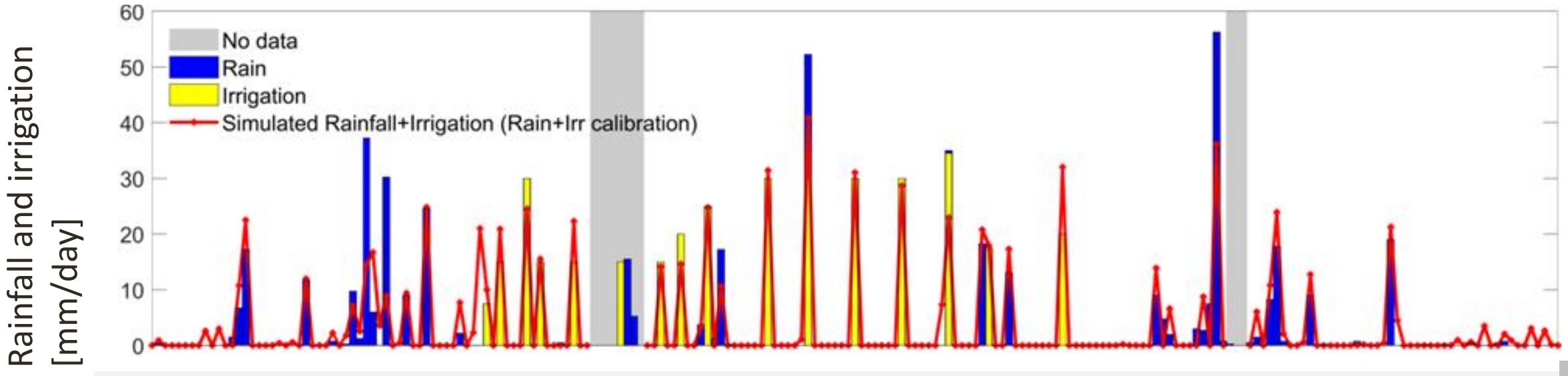
We subtract observed rainfall (green line) from SM2RAIN-derived rainfall+irrigation (magenta line) to obtain irrigation (black line), compared with observed irrigation (grey area)

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

IRRIGATION WATER FROM IN SITU SOIL MOISTURE OBSERVATIONS



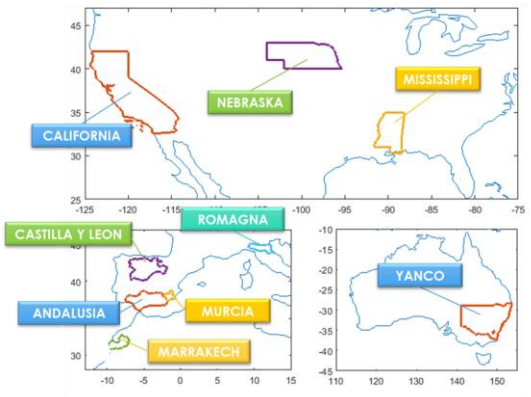
Emilia Romagna (Italy)

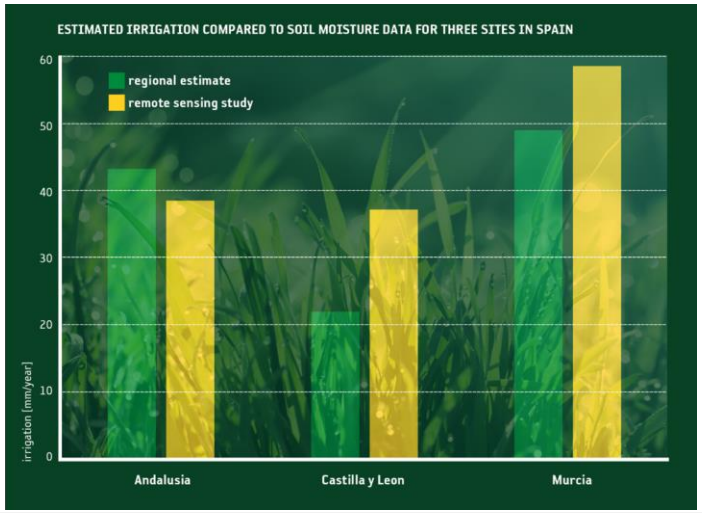


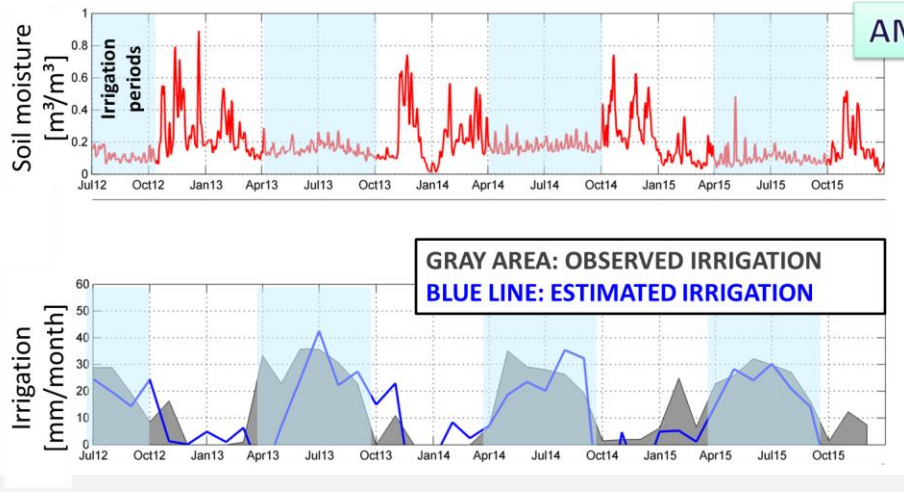
Filippucci et al. (2020 ADWR)
https://doi.org/10.1016/j.advwatres.2019.103502

REMOTE SENSING OF IRRIGATION FROM SOIL MOISTURE OBSERVATIONS

Authors	Year	Doi	Location
Brocca et al.	2018	10.1016/j.jag.2018.08.023	“Global”
Jalilvand et al.	2019	10.1016/j.rse.2019.111226	Iran
Zaussinger et al.	2019	10.5194/hess-23-897-2019	United States
Filippucci et al.	2020	10.1016/j.advwatres.2019.103502	Italy
Dari et al.	2020	10.3390/rs12162593	Spain
Zohaib & Choi	2020	10.1016/j.scitotenv.2020.136719	Global
Abolafia-Rosenzweig et al.	2019	10.1029/2019MS001797	United States

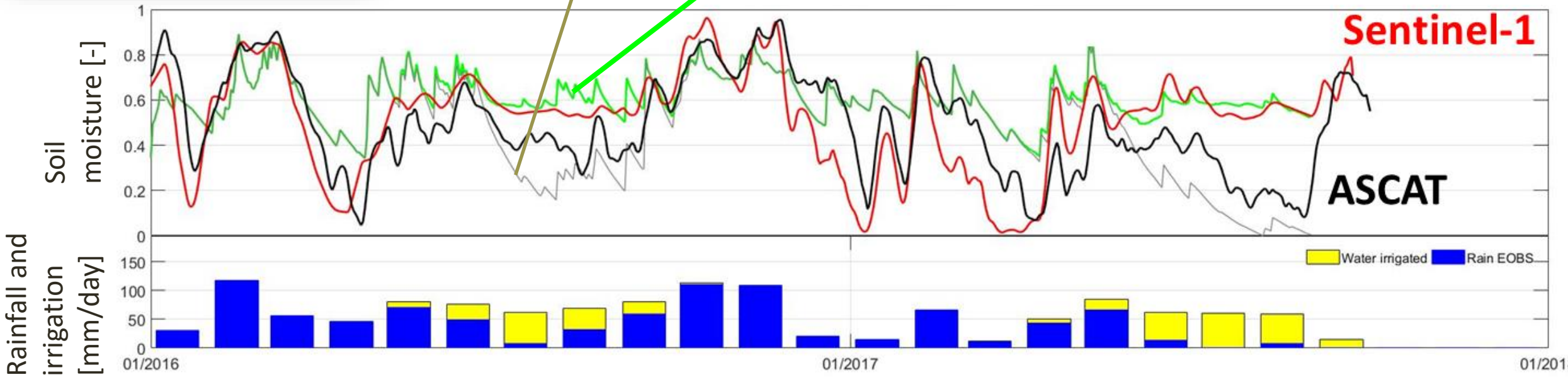






SPACE-IRR

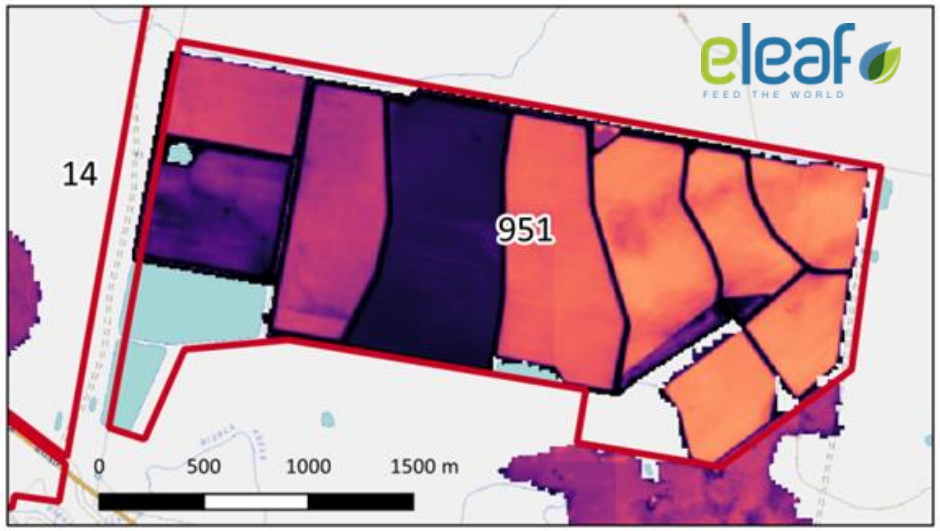
We have won the "BayWa Smart Farming Challenge" at 2018 COPERNICUS MASTER for the idea "SPACE-IRR – How Much Water for Irrigation?"



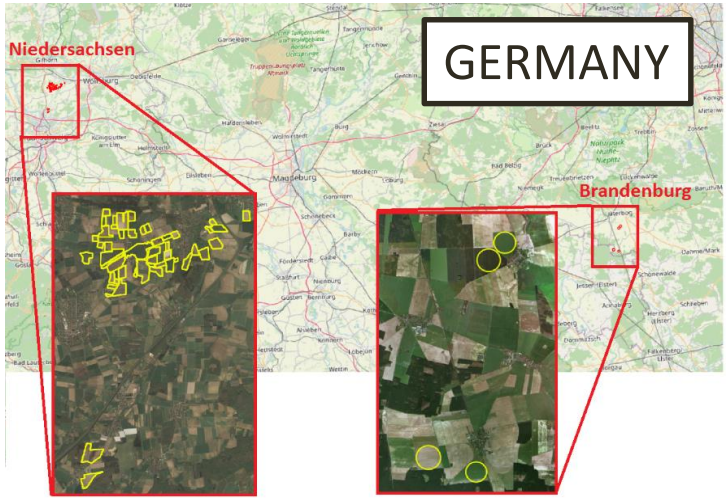
Sentinel-1 (S1) seems to be able to see the irrigation signal at small spatial scale

IRRIGATION+ PROJECT

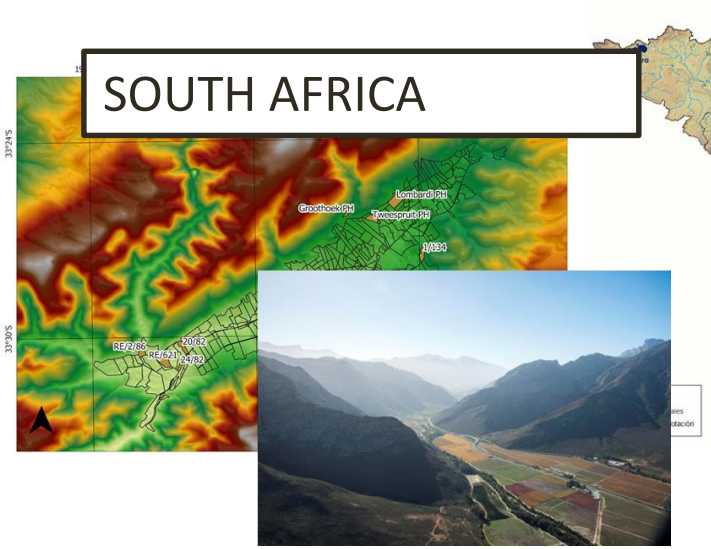
The IRRIGATION+ ESA project aims to explore, develop and validate advanced EO-based algorithms and techniques for irrigation mapping, quantification and detection of seasonal timing of irrigation from field to regional/global scale.



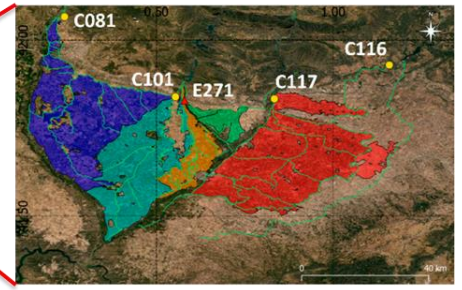
IRRIGATION+ PROJECT



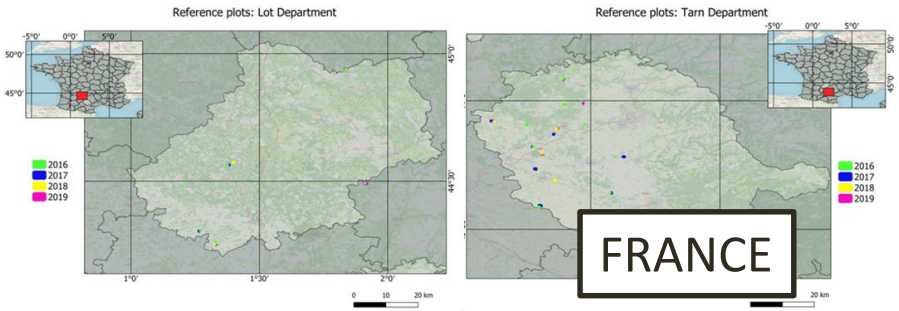
GERMANY



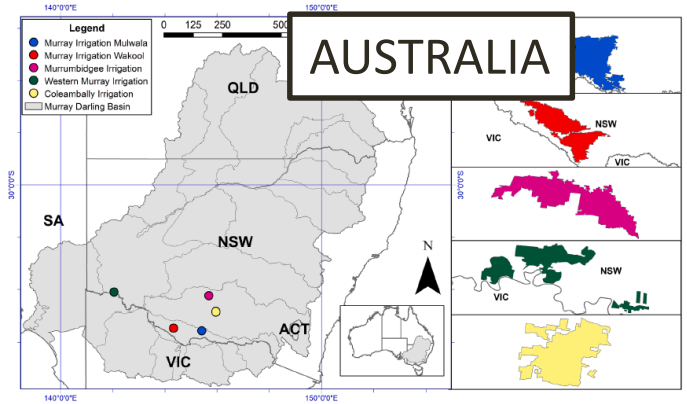
SOUTH AFRICA



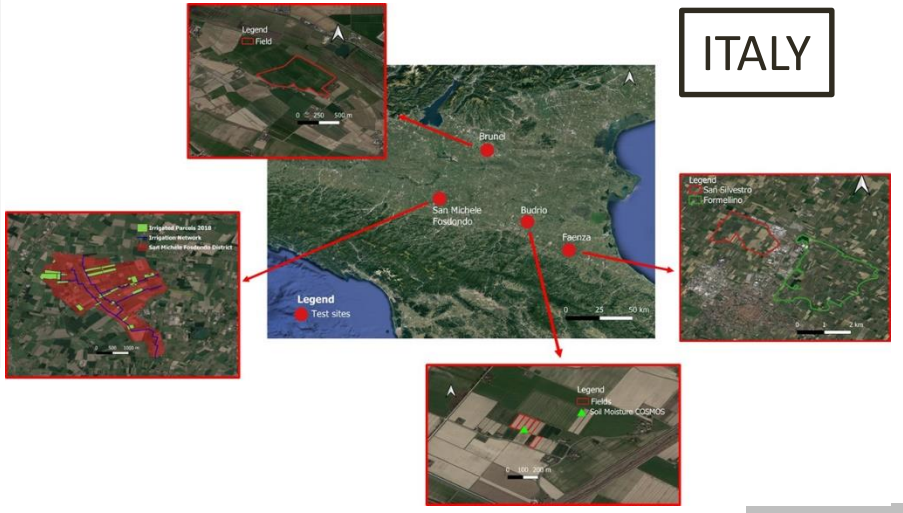
SPAIN



FRANCE

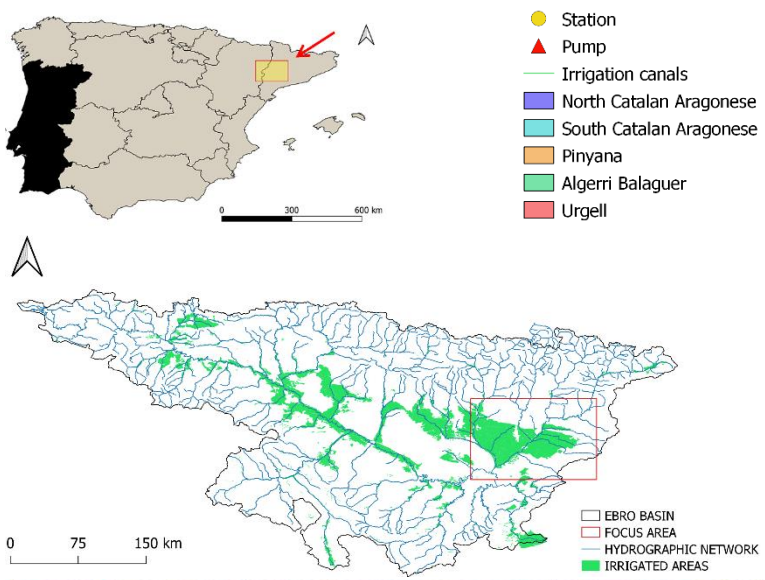


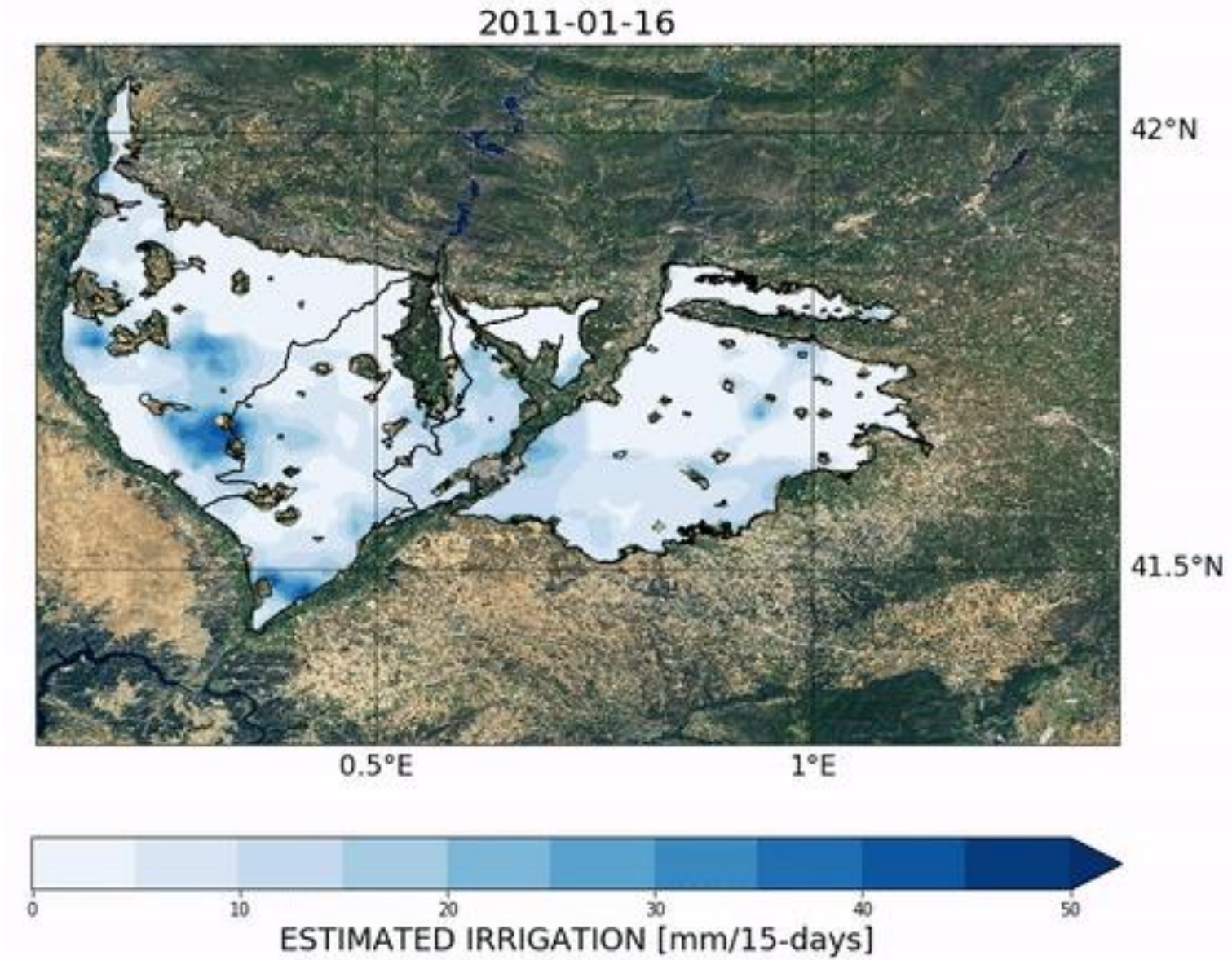
AUSTRALIA



ITALY

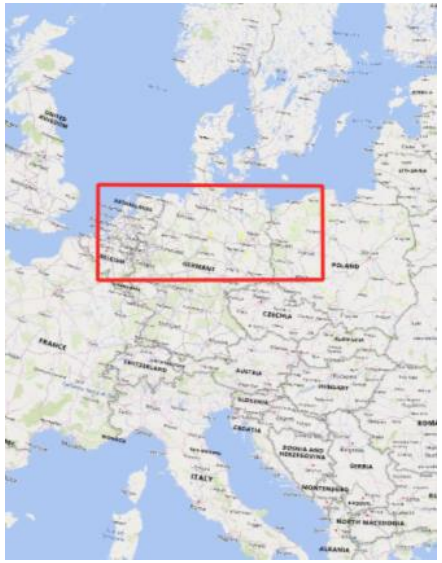
IRRIGATION+ FIRST RESULTS

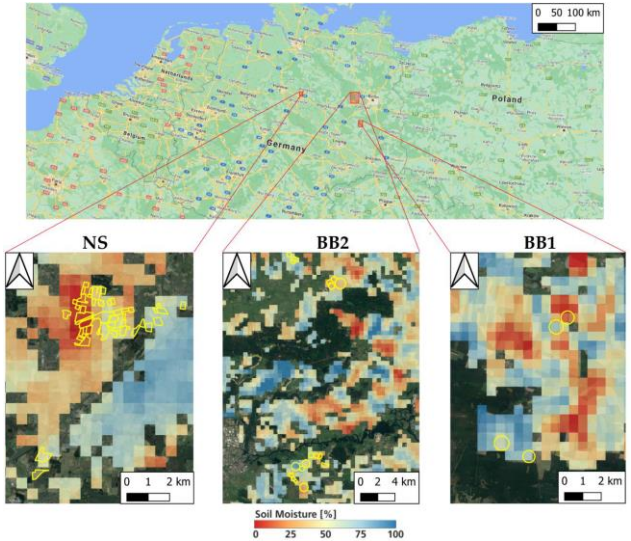




Dari et al. (2020 RS)
https://doi.org/10.3390/rs12162593

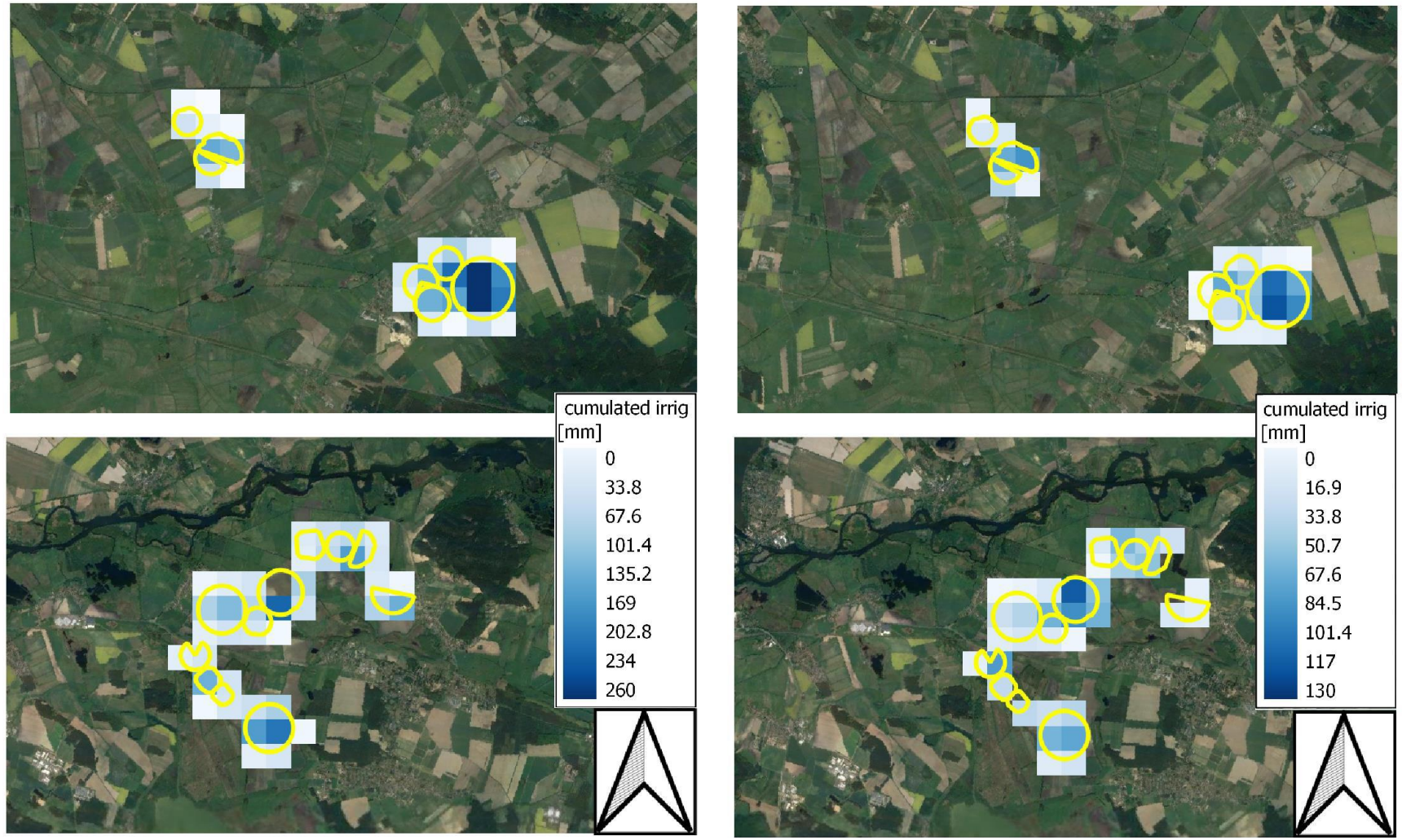
IRRIGATION+ FIRST RESULTS





REPORTED

ESTIMATED



Zappa et al. (2020 ESA EO4WATER)
https://livestream.com/esa/events/9394033/videos/213543876

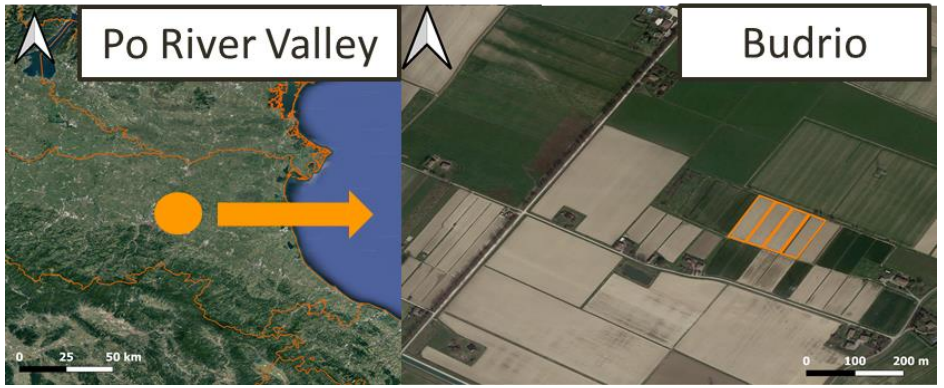
IRRIGATION+ FIRST RESULTS

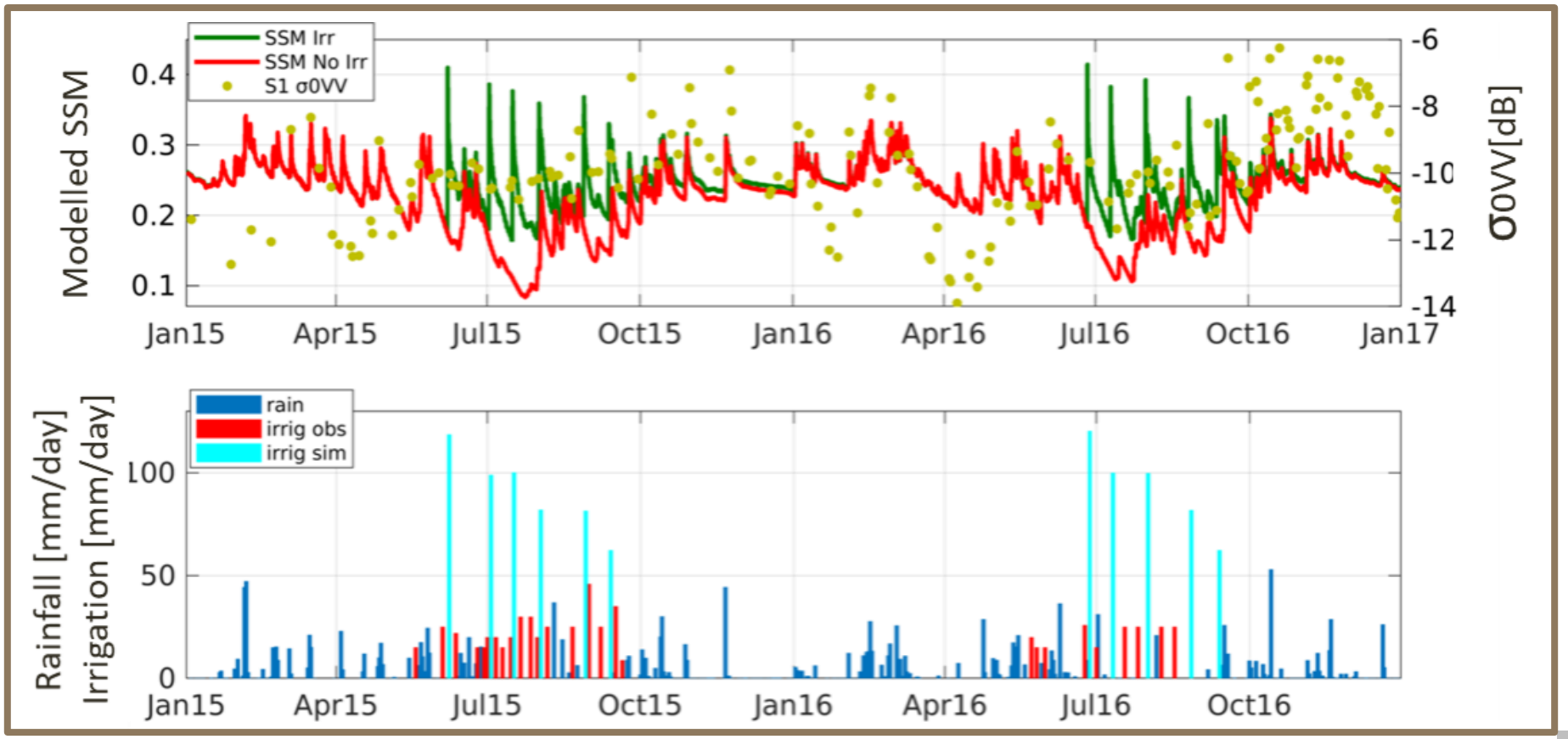
Data Assimilation

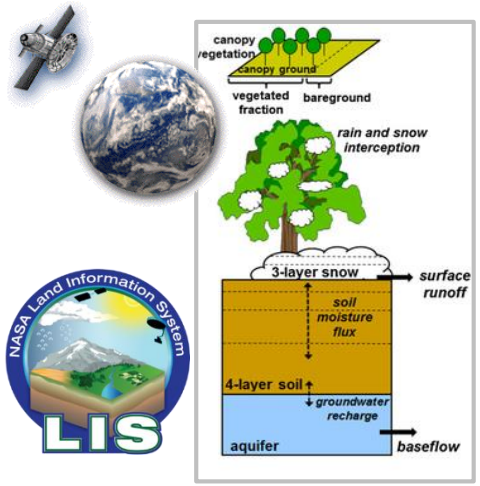
$$x^{+}=x^{-}+K\left(y-h\left(x^{-}\right)\right)$$

Noah MP v.3.6
with/without irrigation
(DOI: 10.1175/2009JHM1116.1)
+
Water Cloud Model (WCM)
(DOI:10.1029/RS013i002p00357)

Sentinel-1
backscatter (σ^0)
VV- VH







Modanesi et al. (EO4WATER, 2020)
https://www.youtube.com/watch?v=o0fRDBGedJA

KEEP HOME MESSAGE

- Irrigation is (very likely) the most important unknown in the water cycle
- High resolution hydrological modelling (DTE Hydrology) cannot be separated from the knowledge of human intervention on the water cycle (including irrigation)
- Remote sensing has potential to provide information on irrigation (where, when and how much)

ADDITIONAL INFO

http://hydrology.irpi.cnr.it/research/irrigation/

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How much water is used for irrigation?