Data assimilation of remote sensing observations into hydrological (and land surface) models: challenges and perspectives in light of a new era of Earth observations

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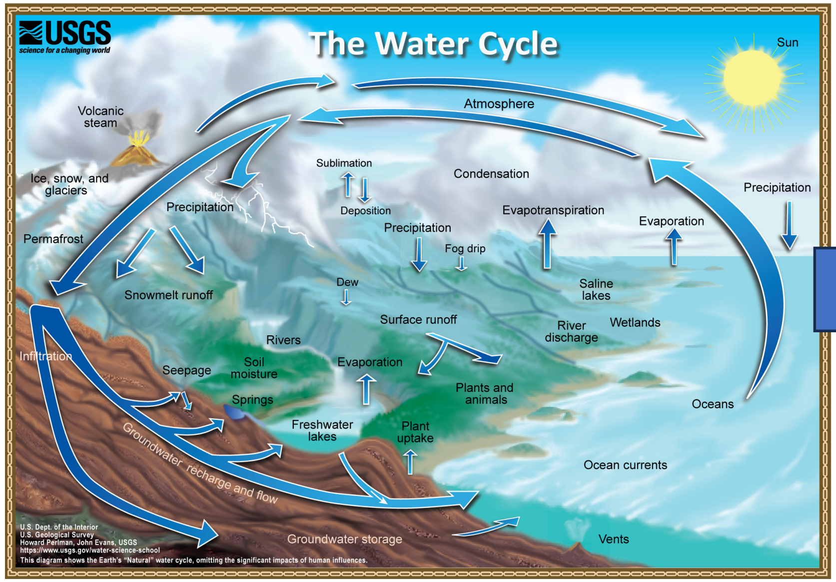
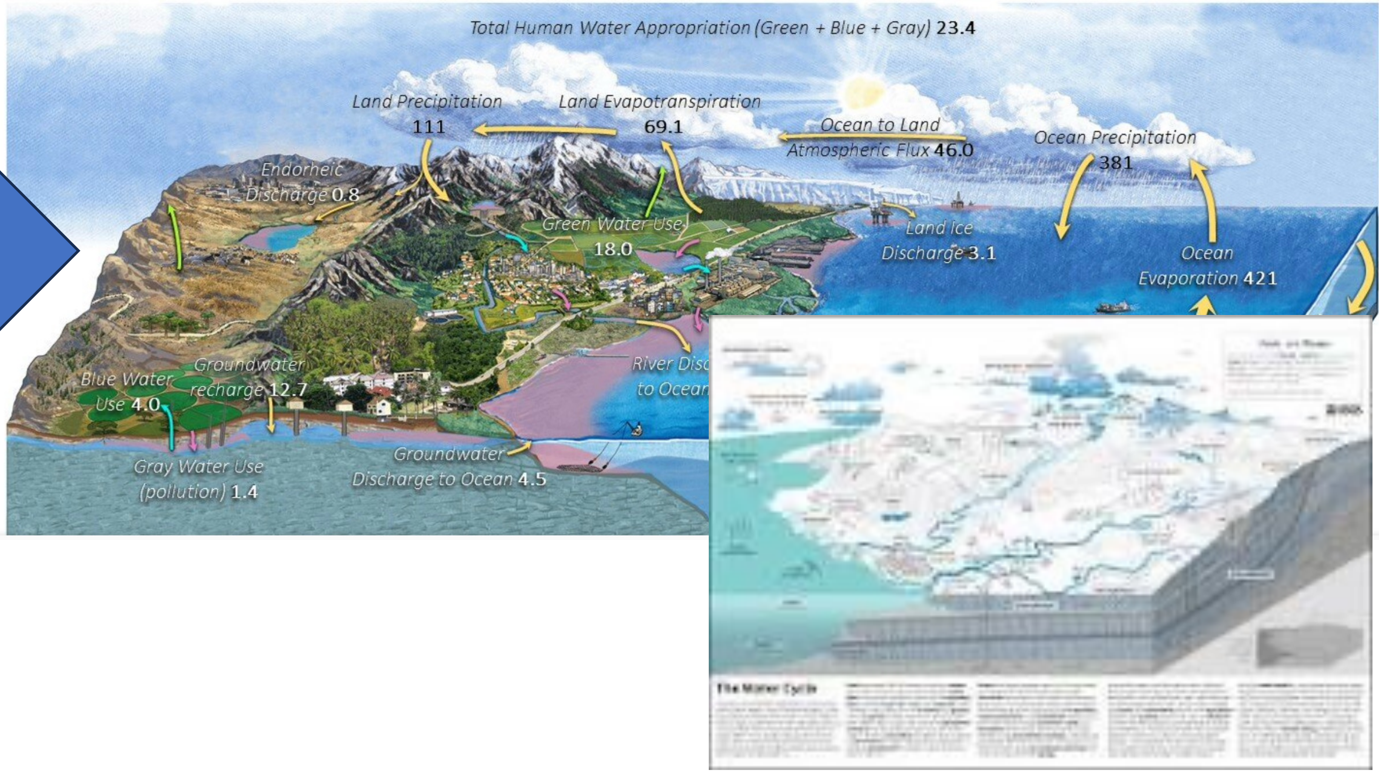
irpi

Not Your Childhood Water Cycle

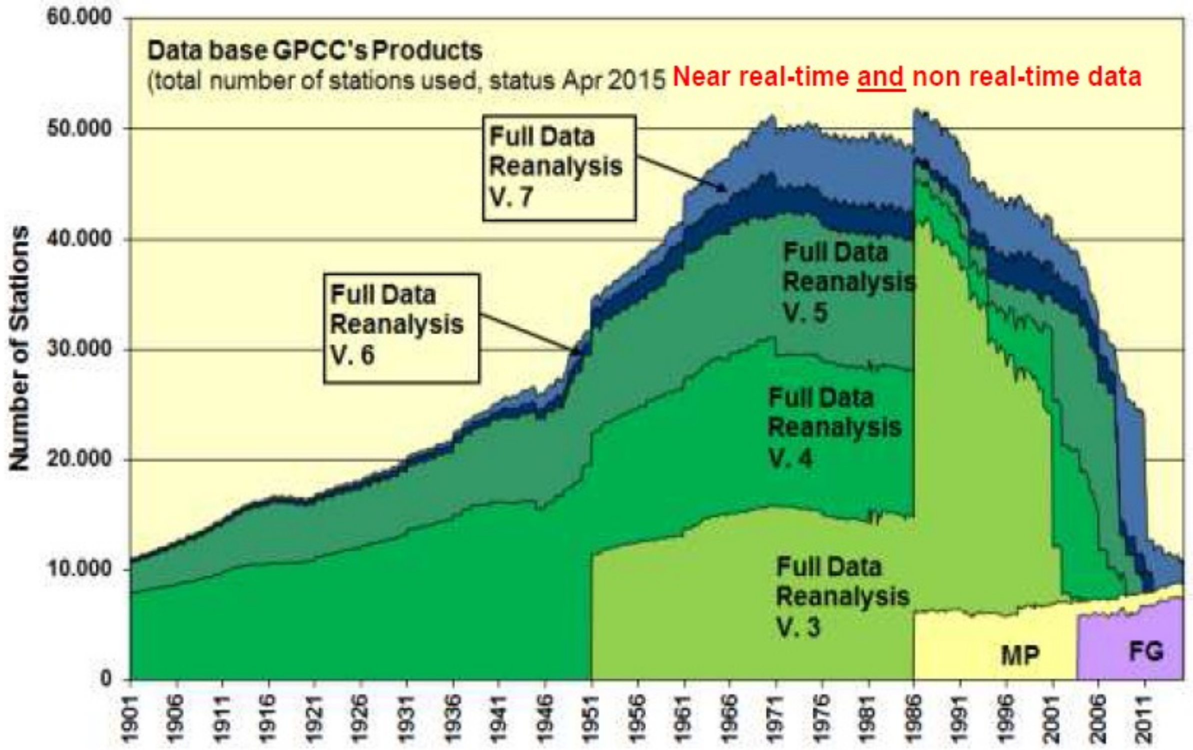


https://www.usgs.gov/media/

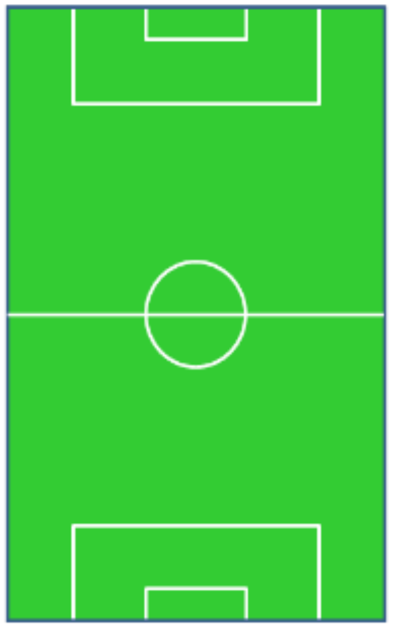


Courtesy of Abbott et al. 2019, NG

You can't manage what you don't measure (Peter Drucker)



Number of GPCC stations in time
https://psl.noaa.gov/data/gridded/data.gpcc.html



Soccer pitch

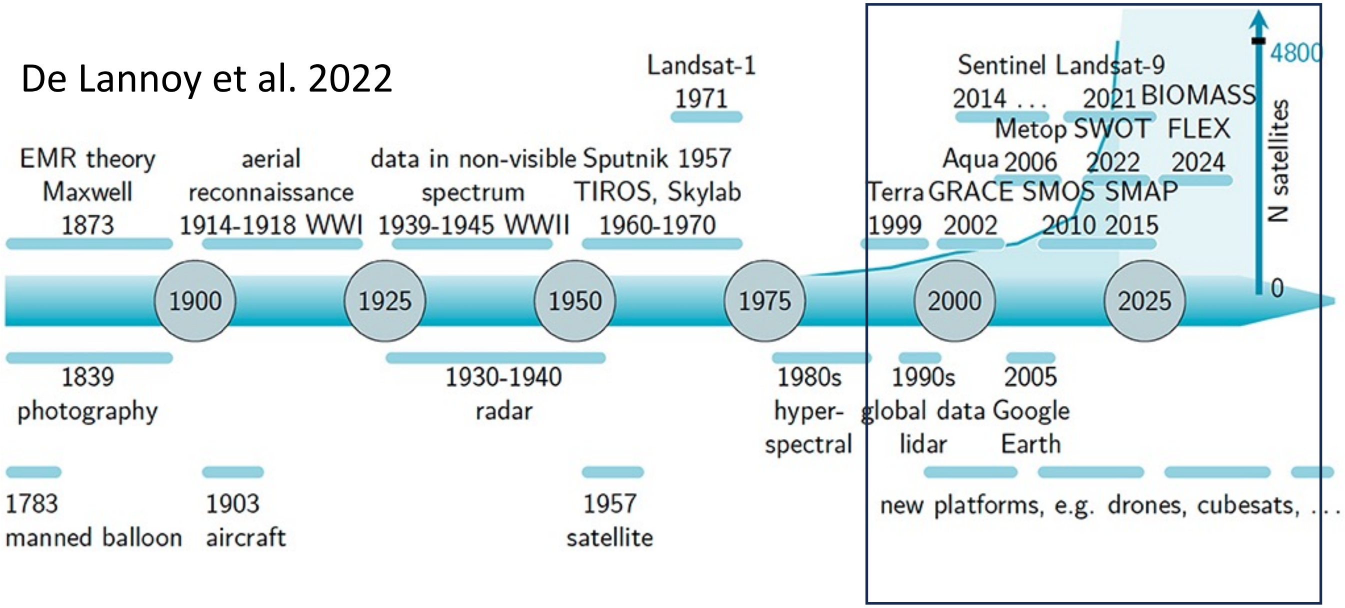
Equivalent area covered by the orifices of the rain gauges of the GPCC network

. Kidd et al. (2017)

- Ground observations are declining everywhere (WMO, 2020)
- Observations of evaporative fluxes and soil moisture are rare
- Observations of irrigation are mostly absent (Massari et al. 2022, RS)

The era of Earth Observation data from satellites: challenges and opportunities

De Lannoy et al. 2022

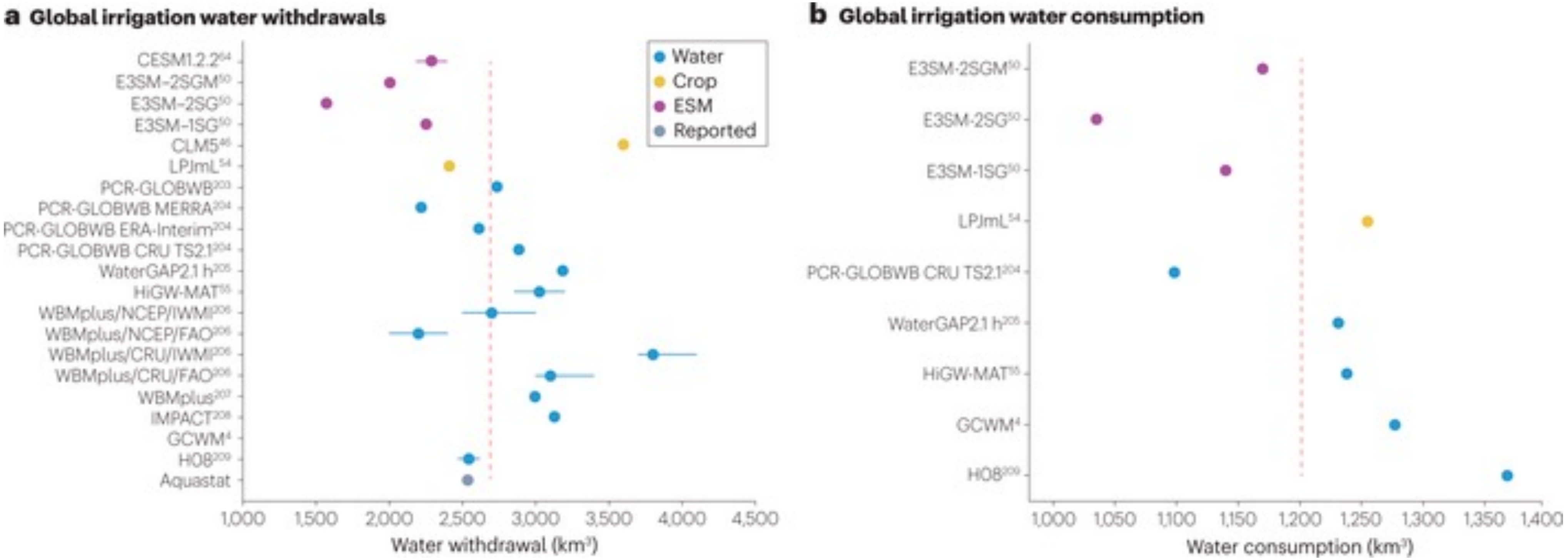


The Sentinel-1A and Sentinel-1B satellites (the last no more operational) produce over **10,000 GB (10 TB) of data every day** (one year of data is about 3 PetaByte of storage for Sentinel 1 and 2 missions)

Which are opportunities offered by the new Earth Observation data? And, which the main challenges?

1. How much water is used for irrigation
2. Improving the representation of pre-storm soil moisture
3. Correcting orographic precipitation

How much water is used for irrigation?

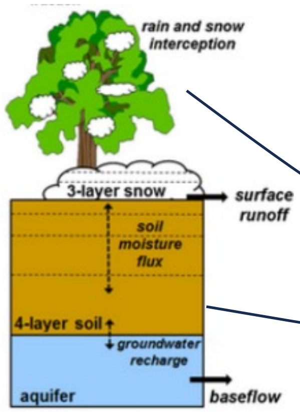


- Models omit explicit representations of human decision-making (people often do not irrigate in agronomically ideal ways)
- Models lack representation of water infrastructure and management
- Simulation of crop growth, including evapotranspiration, phenology and cropping calendars, and water and nutrient limitation, contain myriad uncertainties

McDermid et al. 2023, Nature Earth Review and environment
Massari et al. 2022, RS

Improving representation of irrigation in land surface models (1)

NOAH-MP LSM
Niu et al. (2011)



Water Cloud Model (Attema et al. 1978)

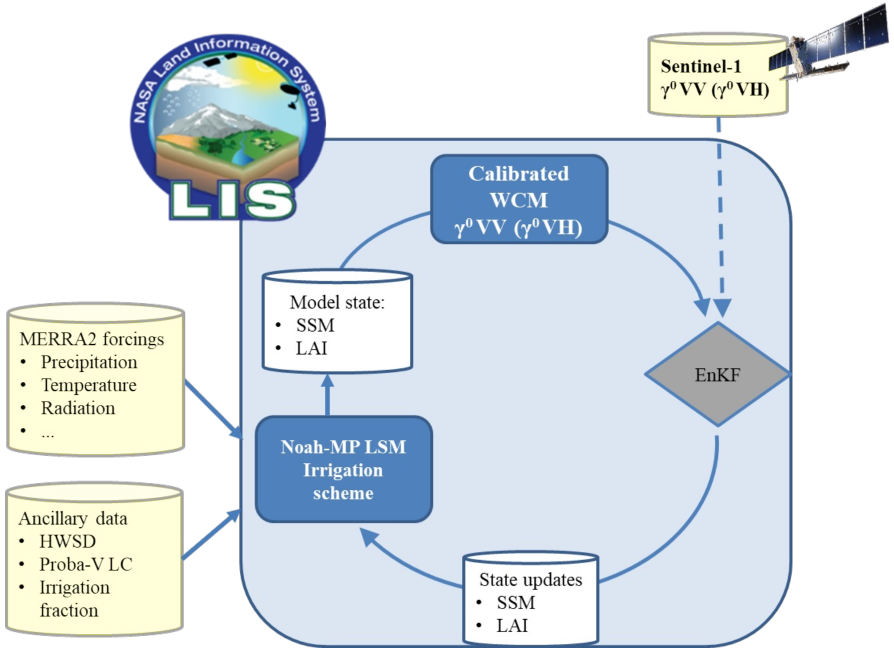
$$\sigma^0 = \boldsymbol{A} V_1 \cos\theta \,(1 - t^2) + t^2(\boldsymbol{C} + \boldsymbol{D} * SM)$$

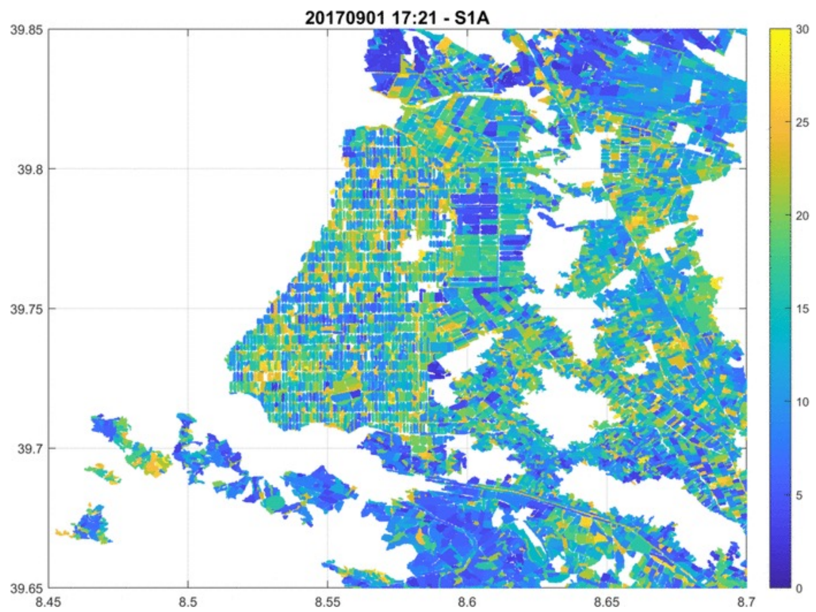
σ^0_{veg} σ^0_{soil}

Sprinkler irrigation
(Ozdogan et al. 2010)

Irrigation when root zone soil moisture availability (MA) <50% of Field Capacity (FC)

$$MA = \frac{(SM - SM_{WP})}{(SM_{FC} - SM_{WP})}$$

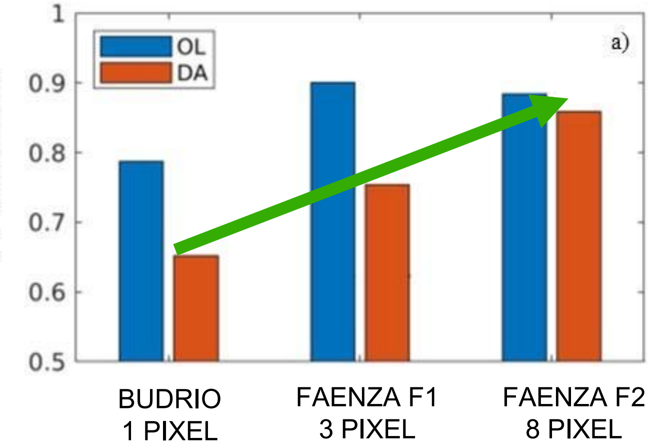




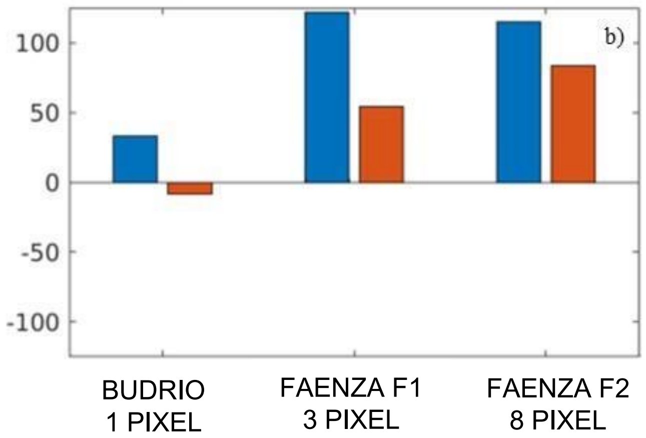
Modanesi et al. 2021, HESS

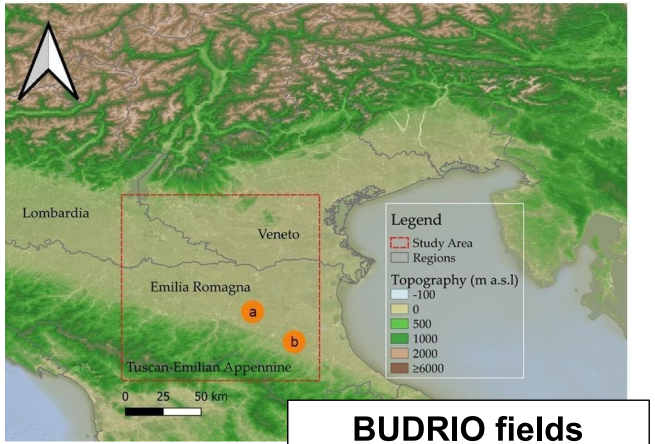
Improving representation of irrigation in land surface models (2)

Irrigation
Pearson-R

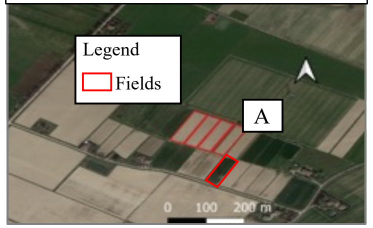


Irrigation
Bias %





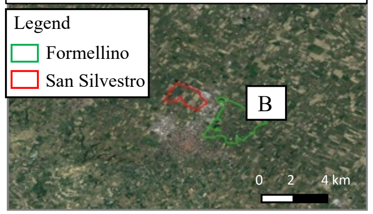
BUDRIO fields
~1 ha



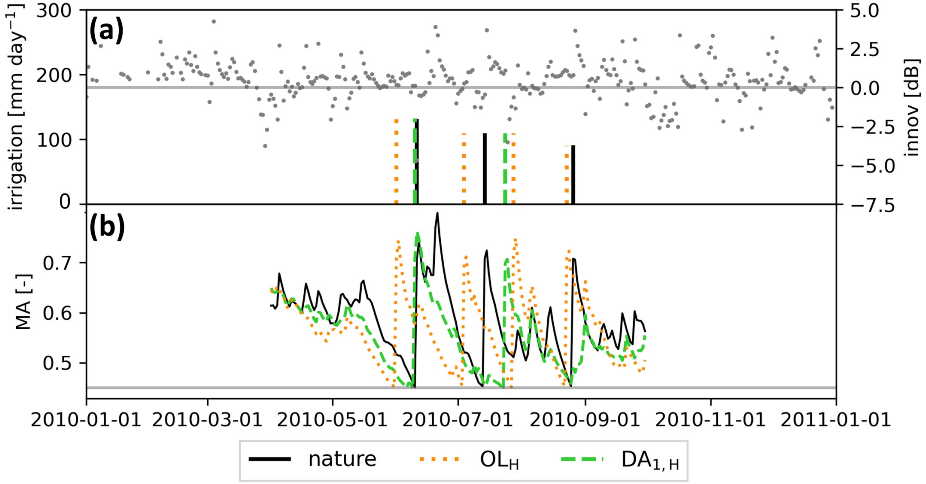
Modanesi et al. 2022, HESS

Poor correlations likely due to interactions between soil moisture correction and irrigation activation and to too small revisit times of Sentinel 1 observations (large spatial extend higher presence of irrigation events)

FAENZA fields
300 and 760 ha



Research shall focus on techniques able to first detect irrigation events (see ***Busschaert et al. 2023***, under review). Smaller revisit time very important.

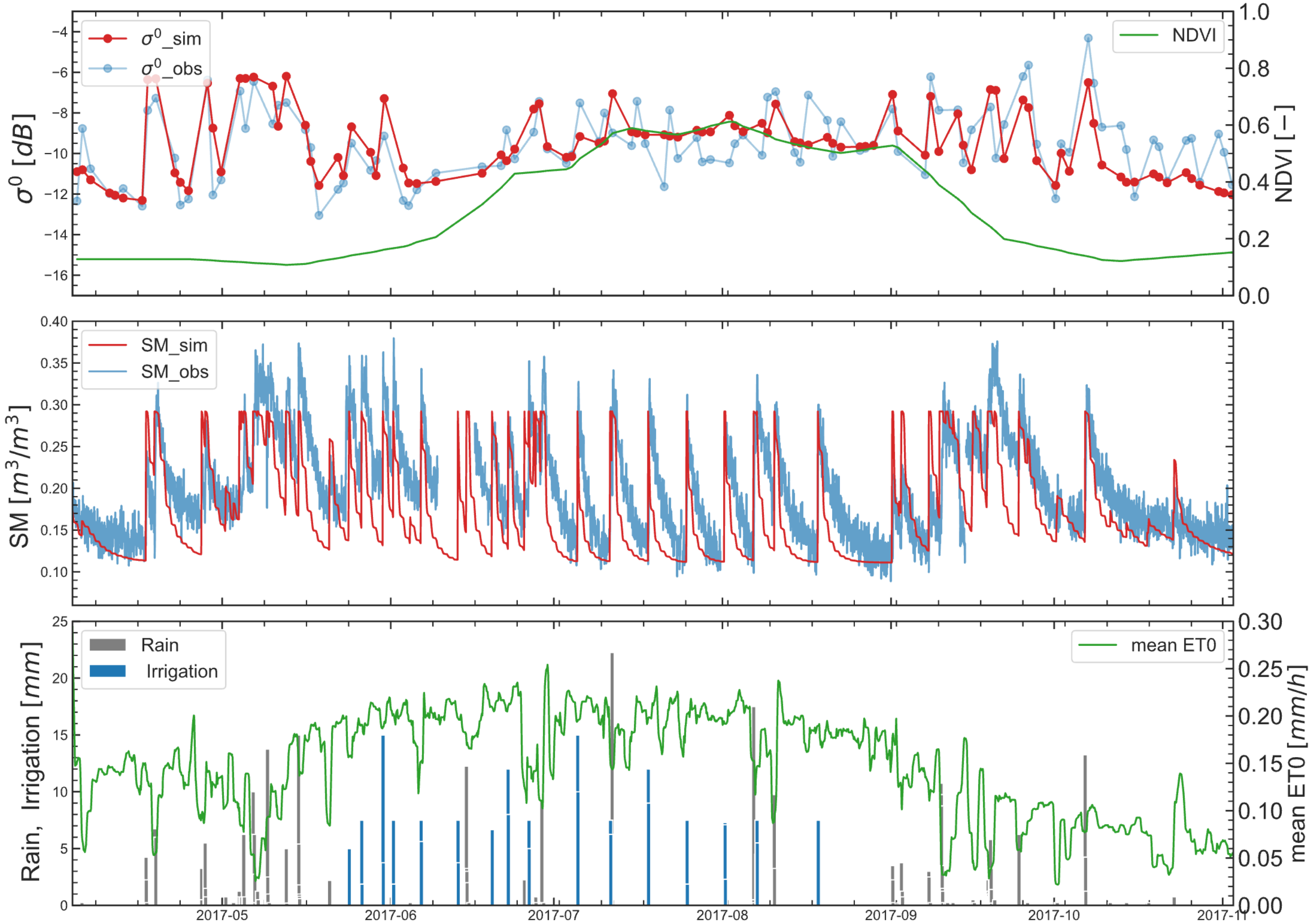


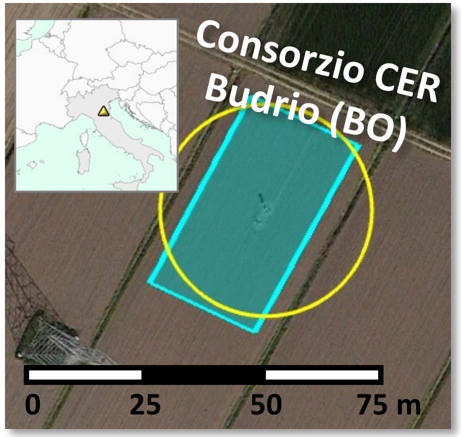
Modanesi et al. 2022, HESS

Improving representation of irrigation in land surface models (3)

$$\sigma^0_{obs} \leftrightarrow \sigma^0_{sim} \leftarrow \mathrm{WCM}(A, B, C, D, NDVI, SM) \leftarrow SM = \mathrm{SWB}(\delta, K_{c,0}, \rho_{st}, W_{fc}, W_w, P, I, ET_0, K_c)$$

Sentinel-1 (σ^0_{obs}) · Empirical parameters (A, B, C, D) · Sentinel-2 (NDVI) · Empirical parameters ($\delta, K_{c,0}$) · Field observables (ρ_{st}, W_{fc}, W_w) · Agrometeorological inputs (P, I, ET_0, K_c)





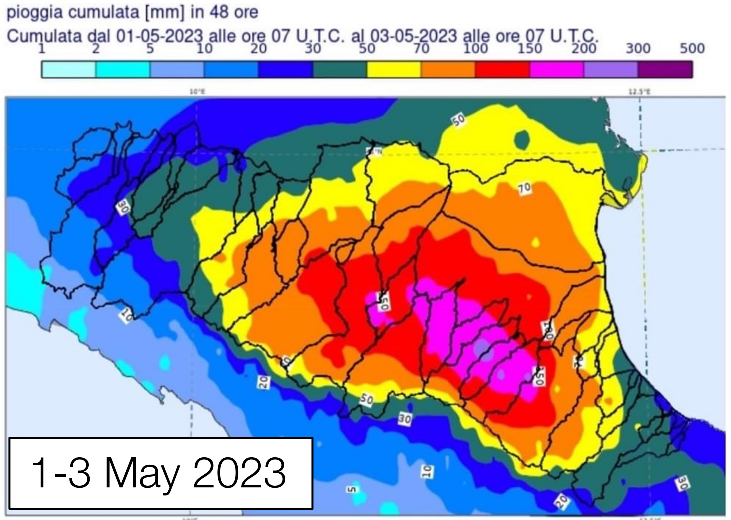
Natali et al. In preparation

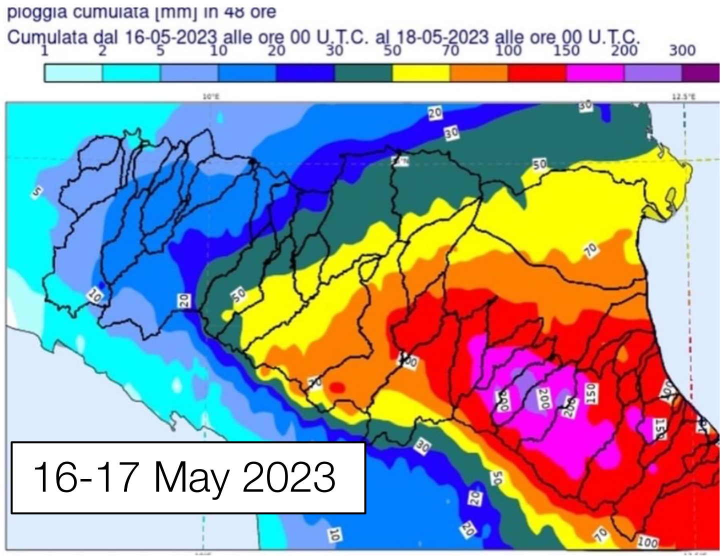
Model calibration with σ^0, (instead of **in-situ soil moisture measurements)**

	KGE	R	R^2	bias
σ^0 [dB]	0.70	0.70	0.49	-0.01
SM [m^3m^{-3}]	0.68	0.72	0.52	-0.03

Importance of pre-storm soil moisture in flood forecasting

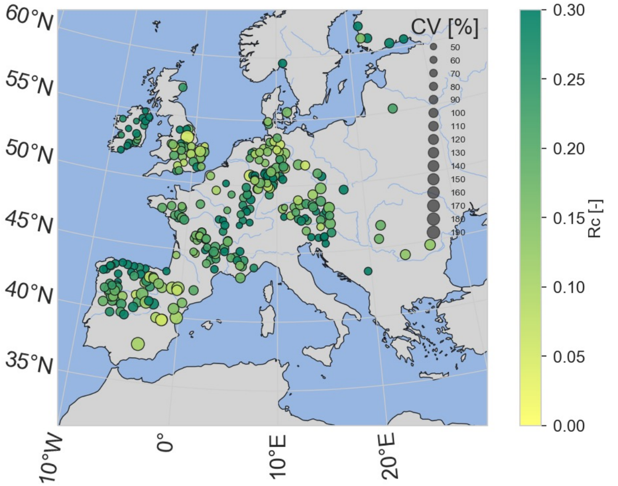
Recent Emilia Romagna Floods



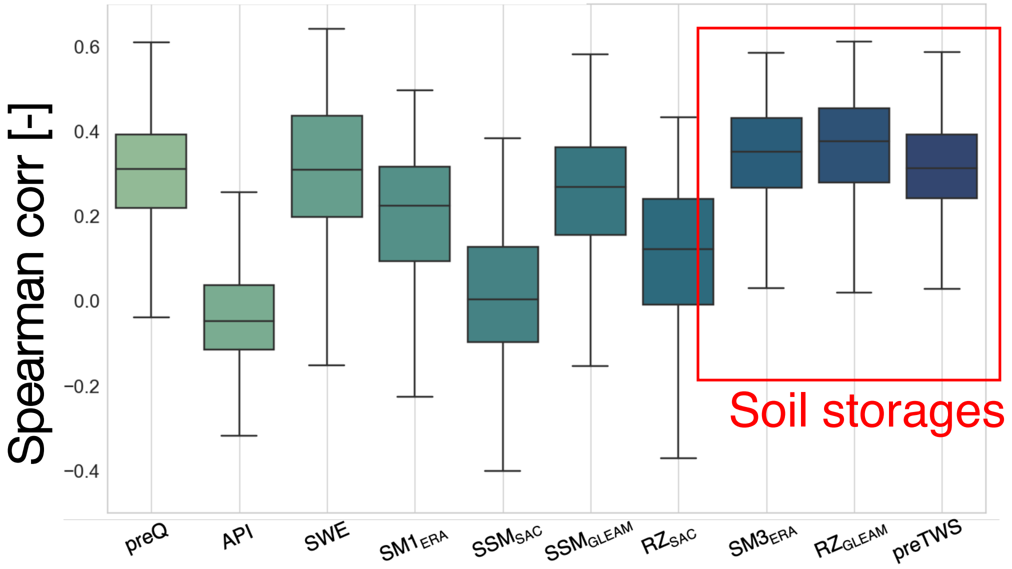


50000 displaced people
About 7bn € of damages and some fatalities

Runoff coefficient distribution



Analysis of predictors of runoff coefficients for 284 basins across Europe for +60000 flood events



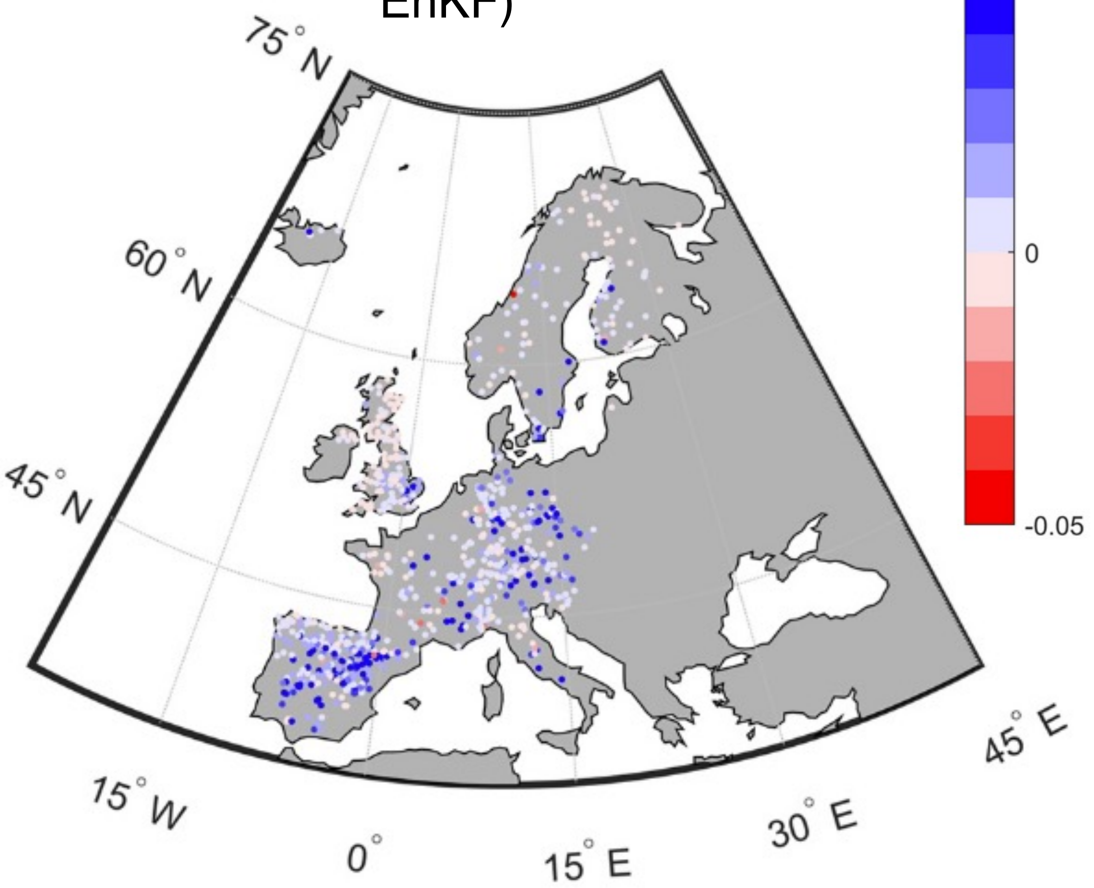
Correlations between pre-storm proxies and runoff coefficient

Massari et al. 2023, JoH (under review)

Coarse scale satellite soil moisture data assimilation to improve flood modelling

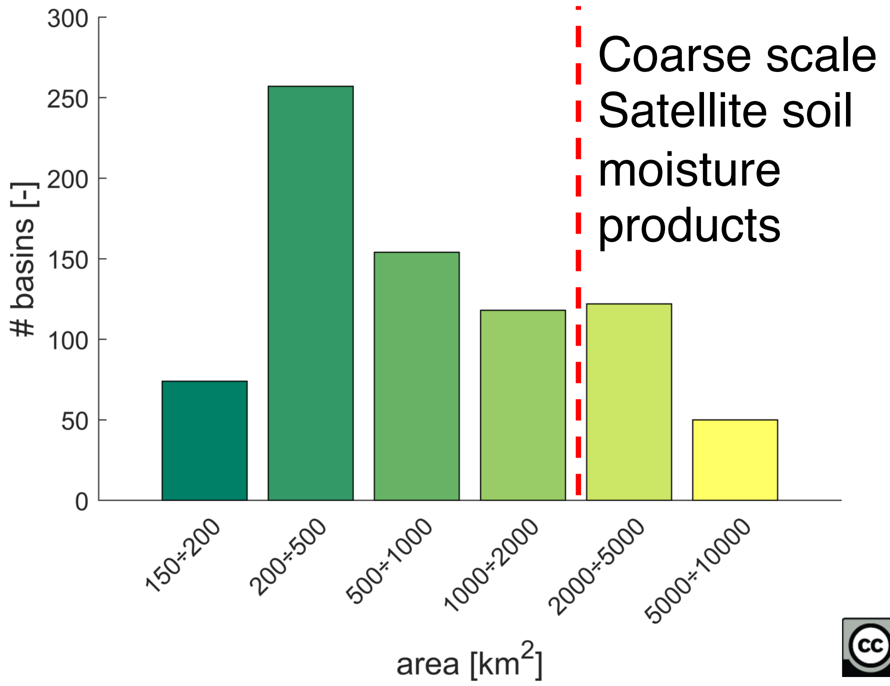
<u>Limited KGE improvements</u> over the hydrological model open loop (MISDc 2L, Massari et al. 2018) for +700 catchments across Europe in data assimilation of **coarse scale** satellite soil moisture (CCI soil moisture with EnKF)

De Santis et al. (2021) WRR

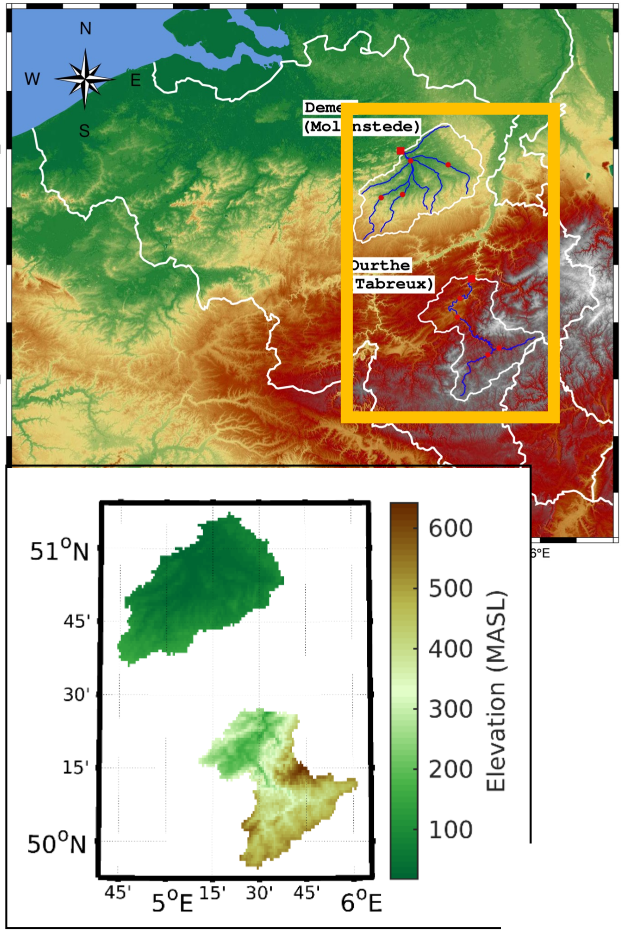


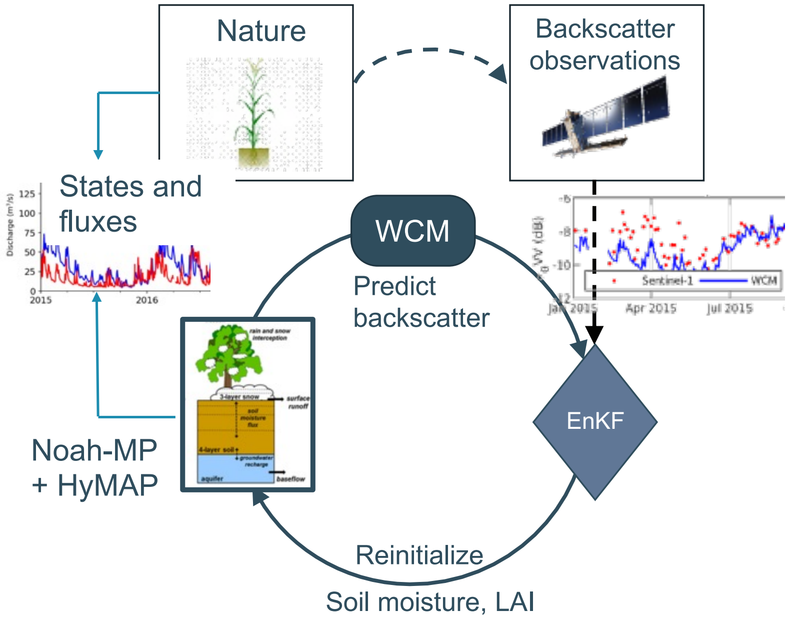
Possible reasons:

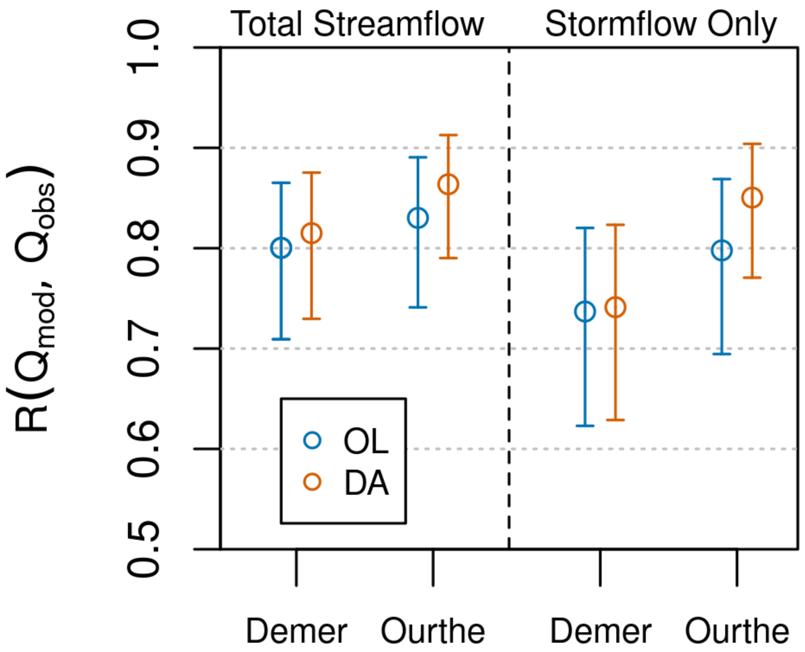
1. Quality and support of satellite soil moisture obs.
2. Good starting model performances
3. Low importance of SM over energy limited regions
4. Assimilation of coarse scale (> 25km products) much larger than basin areas (see also Matgen et al. 2011)



Sentinel 1 backscatter observations in flood modelling



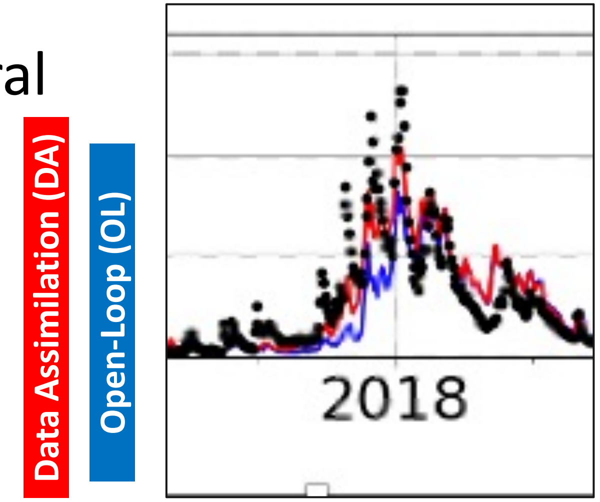




Bechtold et al. 2023, under review

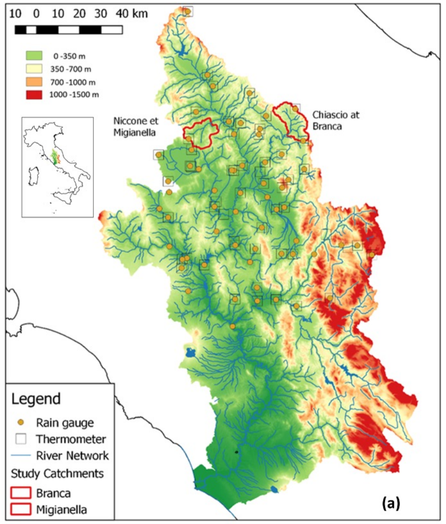
Demer 1950 km^2 less forested - agricultural land use

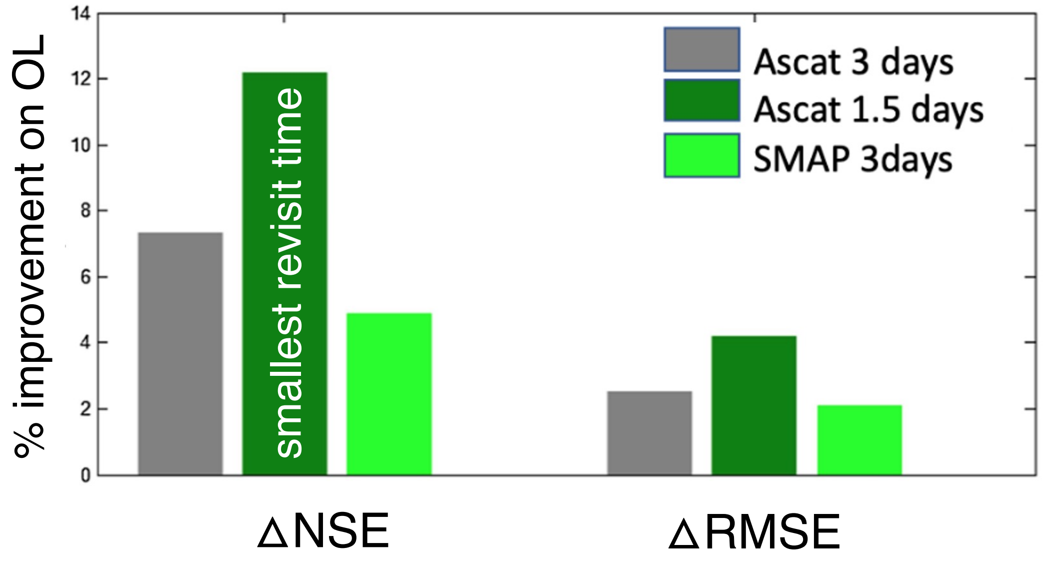
Ourthe 1616 km^2: more forested



Better performance over forested basin likely due to the more stable land cover that favors a more reliable modelled backscatter operator

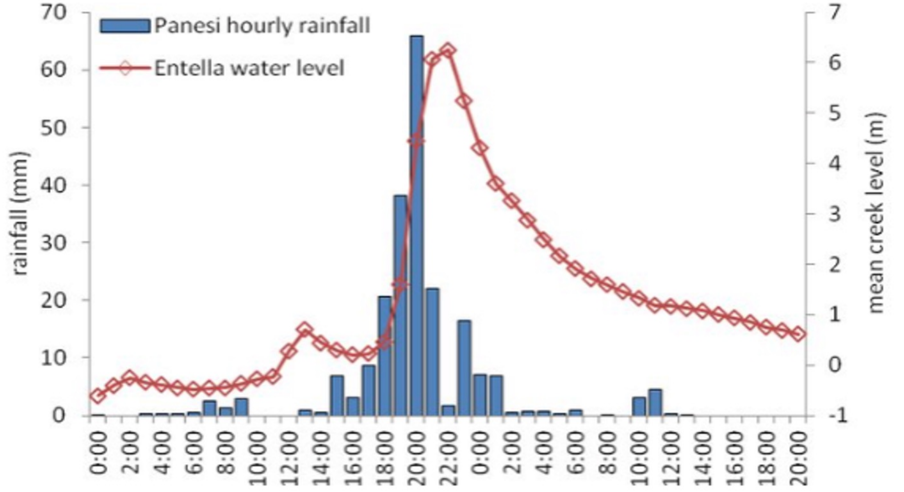
The revisit time for small basins is important



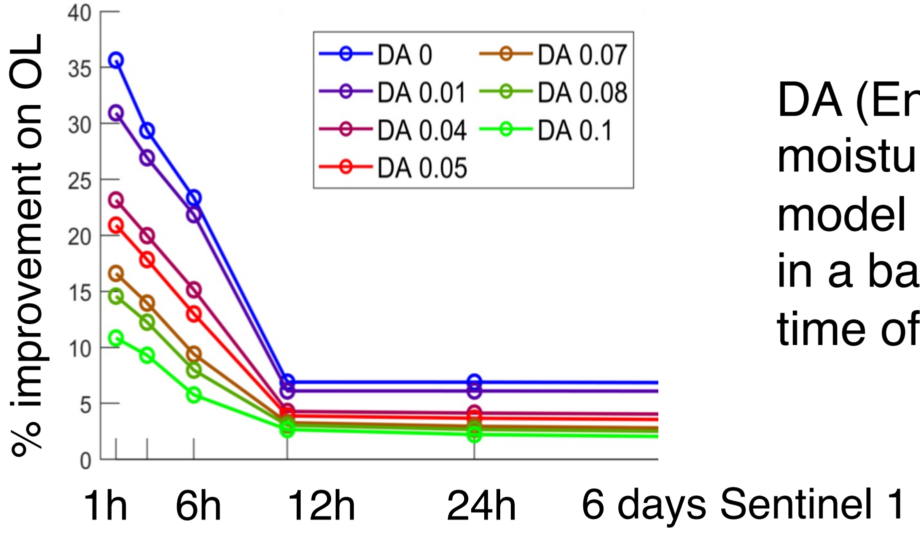


DA (EnKF 2D) of coarse satellite soil moisture into SWAT Hydrological model in two basins in central Italy (area < 200 km^2)

Azimi et al. (2019) Journal of Hydrology



Faccini et al. (2015)

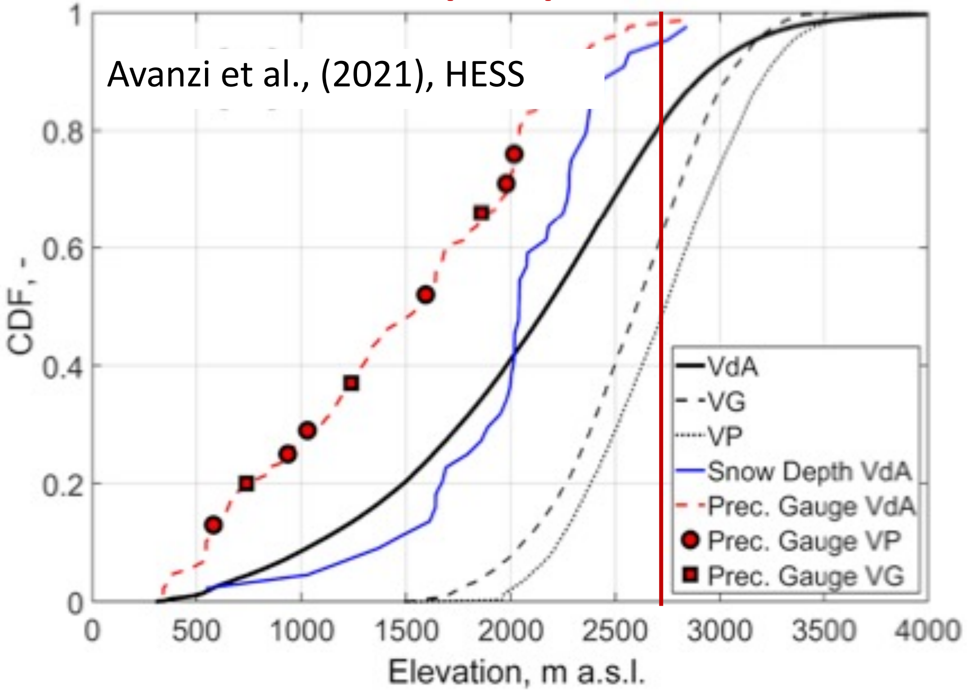


DA (EnKF) 2D soil moisture into MISDc 2L model (Massari et al. 2018) in a basin with response time of 12 hours

De Santis et al. 2023 ESA Report SLAINTE

Challenges in estimating orographic precipitation

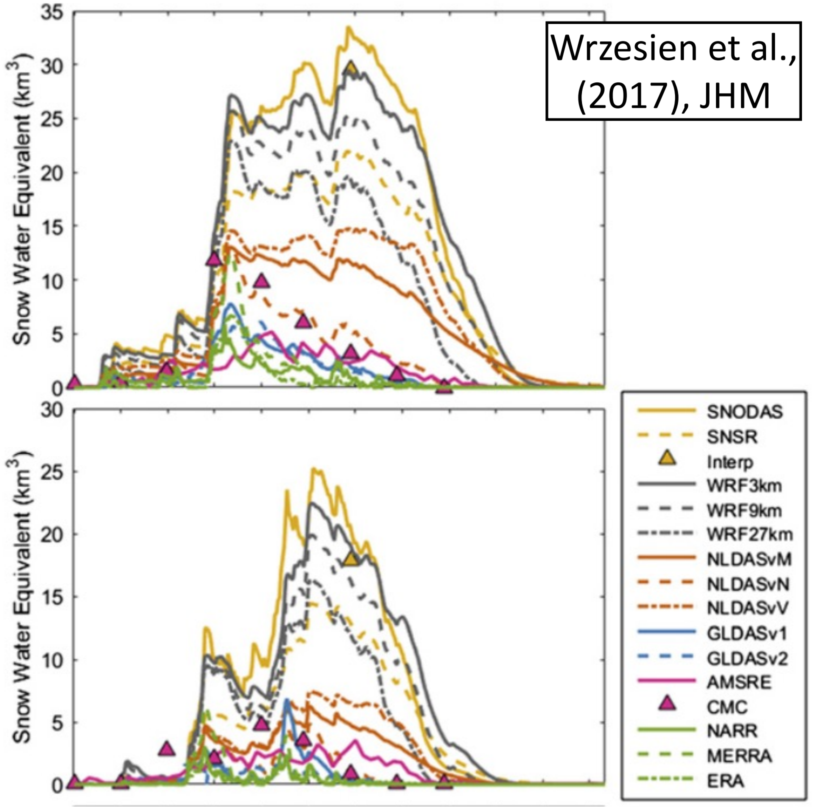
No information about precipitation above 2700 m a.s.l



Distribution of the location of precipitation measurement points (heated and unheated) in the Valle d'Aosta region.

Undercatch & No precipitation measurements

Uncertainty of snow estimates in mountainous catchments provided by different models



Can we correct mountain precipitation with Sentinel-1 data?

Correcting orographic precipitation enhancement via Sentinel 1

Article | Open Access | Published: 11 October 2019

Snow depth variability in the Northern Hemisphere mountains observed from space

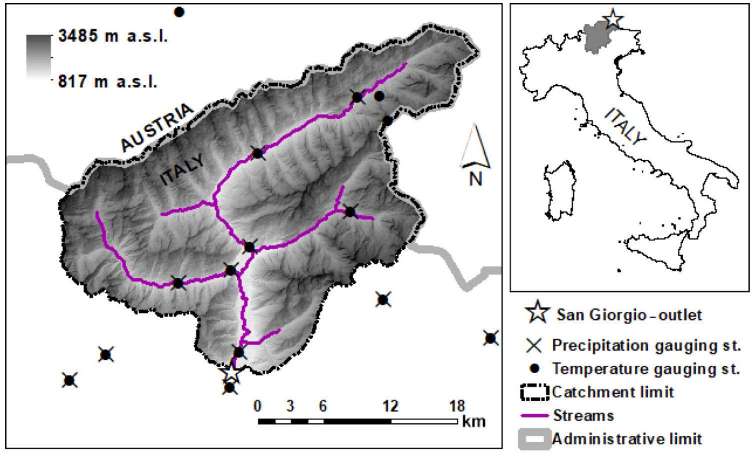
Lievens et al. (2019), NC
Snowdepth obs. 500m res. from S1

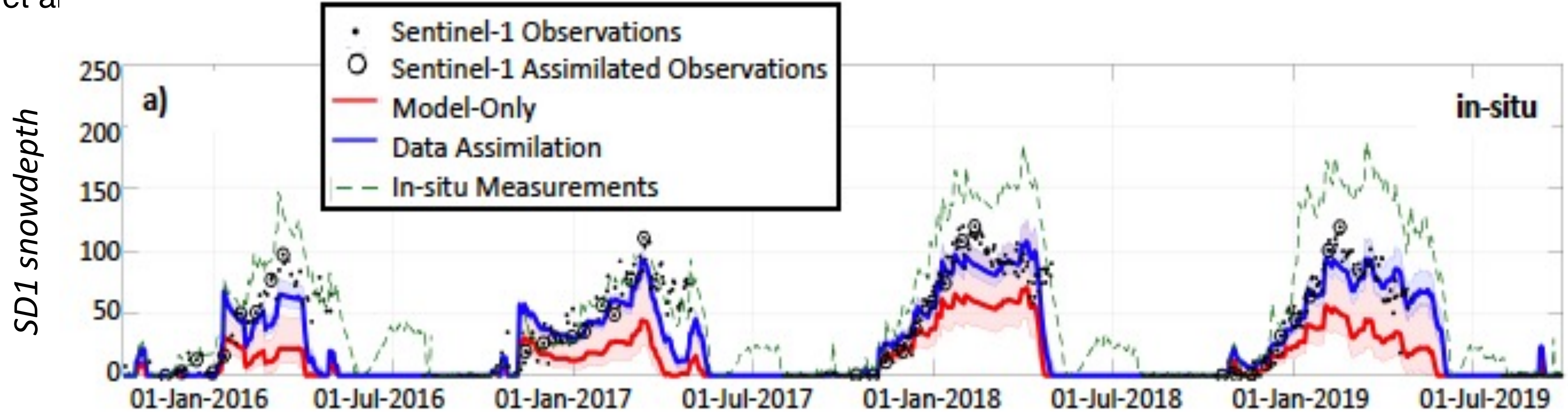
Snow model: **Snow-17** (Andreson, 2006)
Snow density: **Snobal** (Marks et al., 1999)
Streamflow: **HyMod** (Boyle et al., 2000)
Data Assimilation: **Particle Batch Smoother**
(Margulis et al

Correcting P to match the snowdepth observed by Sentinel 1 via a particle batch smoother

$$\alpha * P$$

Aurino Basin, northern Italy (614 km^2)

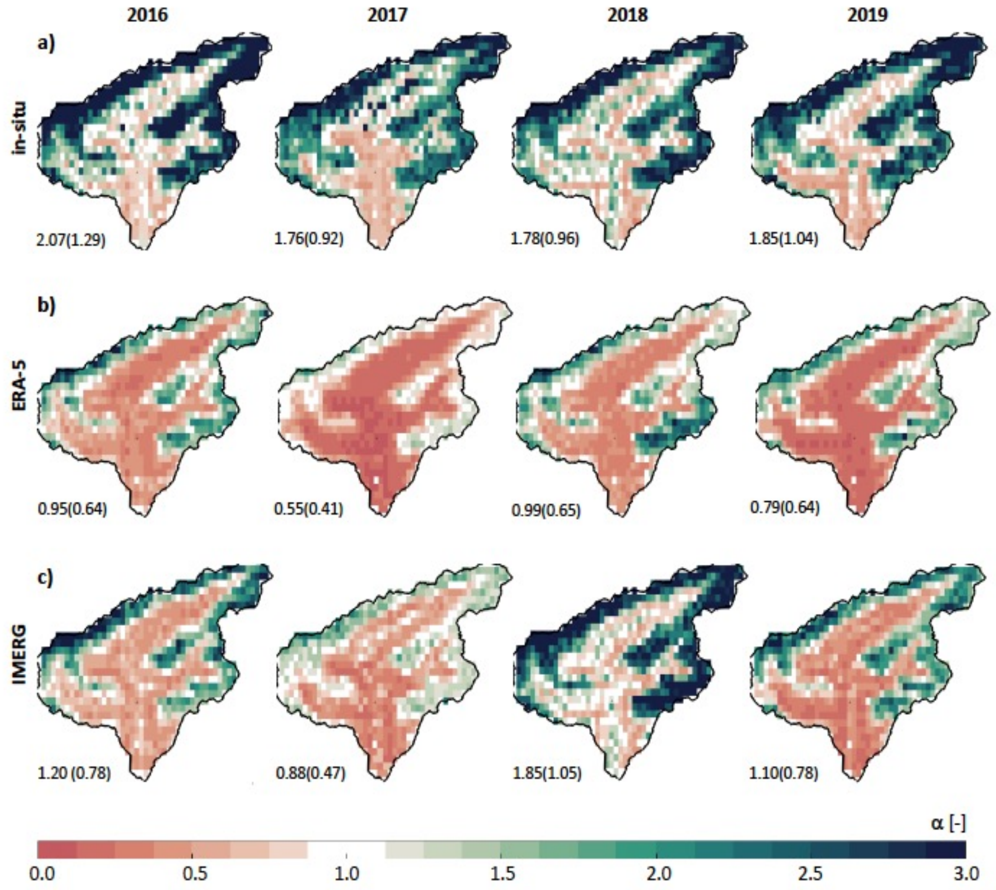


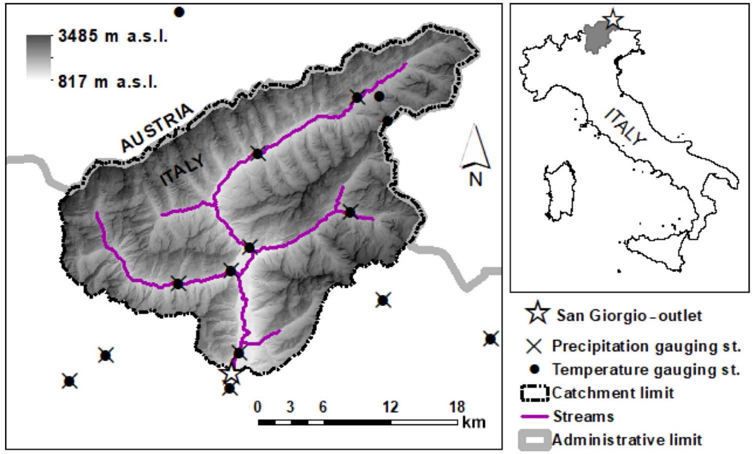


Girotto et al. 2023, STOTEN Under review

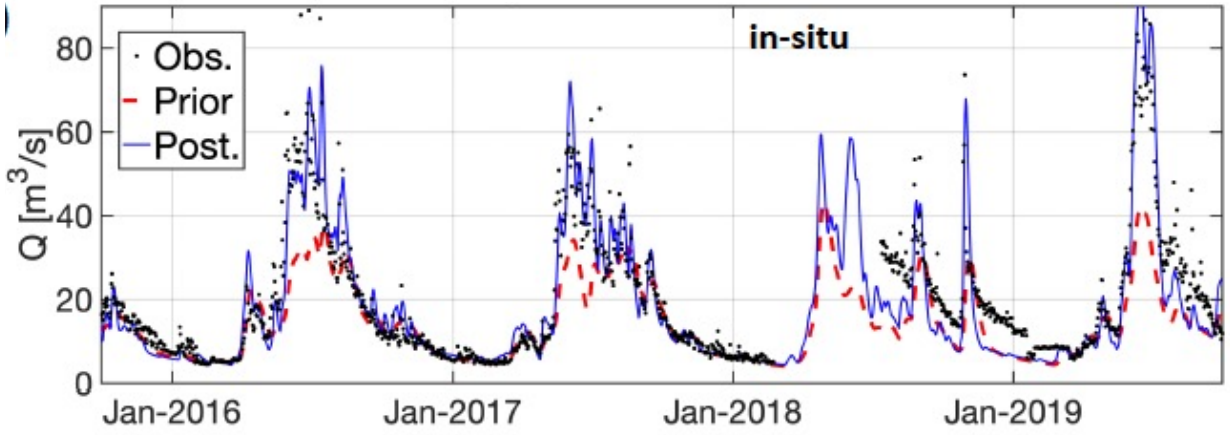
Correcting orographic precipitation enhancement via Sentinel 1

Snowfall correction factor [-]





	in-situ		ERA-5		IMERG	
	prior	post	prior	post	prior	post
KGE	0.38	0.75	0.65	0.67	0.68	0.75



Girotto et al. 2023, STOTEN Under review

Take home message

The growing amount of satellite data offer new opportunities for many fields of hydrology, eco-hydrology and related disciplines (we focused here on SAR applications)

New high resolution Earth Observation data are viable solutions for overcoming model weaknesses in the representation of natural and human processes (e.g., irrigation) and can complement current gaps in ground based networks but there are still many challenges

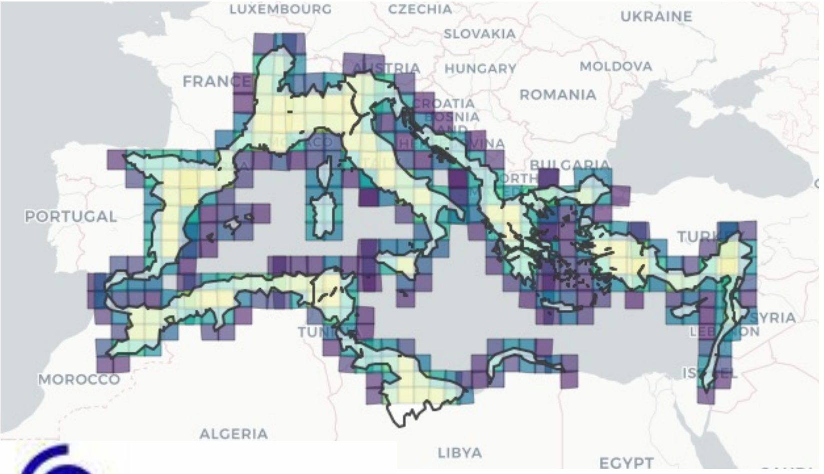
Limitations are for the revisit time of current missions (currently 12 days for Sentinel 1), noise and complexity of retrieval of SAR data

New opportunities will come from future NASA NISAR and ESA ROSE-L missions that will provide new L-Band data (but will not fill the gap of sub-daily revisit times)

Thanks for your attention

Special thanks to co-authors/collaborators: Sara Modanesi, Michel Betchold, Manuela Girotto, Gabrielle De Lannoy, Louise Busschaert, Domenico De Santis, Martina Natali, CNR-IRPI collagues and many others

Thanks to the support of the **ESA 4DMED-Hydrology** project



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https://www.4dmed-hydrology.org