Institut de Recherche pour le Développement
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Organisation des Nations Unies pour l'éducation, la science et la culture
Programme hydrologique intergouvernemental

GDRI RHYMA
Groupement de recherche international-Sud : Risques Hydrologiques au Maghreb

Leveraging new Earth observation data for improving flood forecasting in Europe

Christian Massari

Azimi Shima, Bechtold Michel, Brocca Luca, Camici Stefania, Ciabatta Luca, Crow Wade, De Lannoy Gabrielle, De Santis Domenico, Filippucci Paolo, Girotto Emanuela, Grundemann Gaby, Hascoet Tristan, Marra Francesco, Modanesi Sara, Pellarin Thierry, Penna Daniele, Pellet Victor, Tramblay Yves

20 September 2022

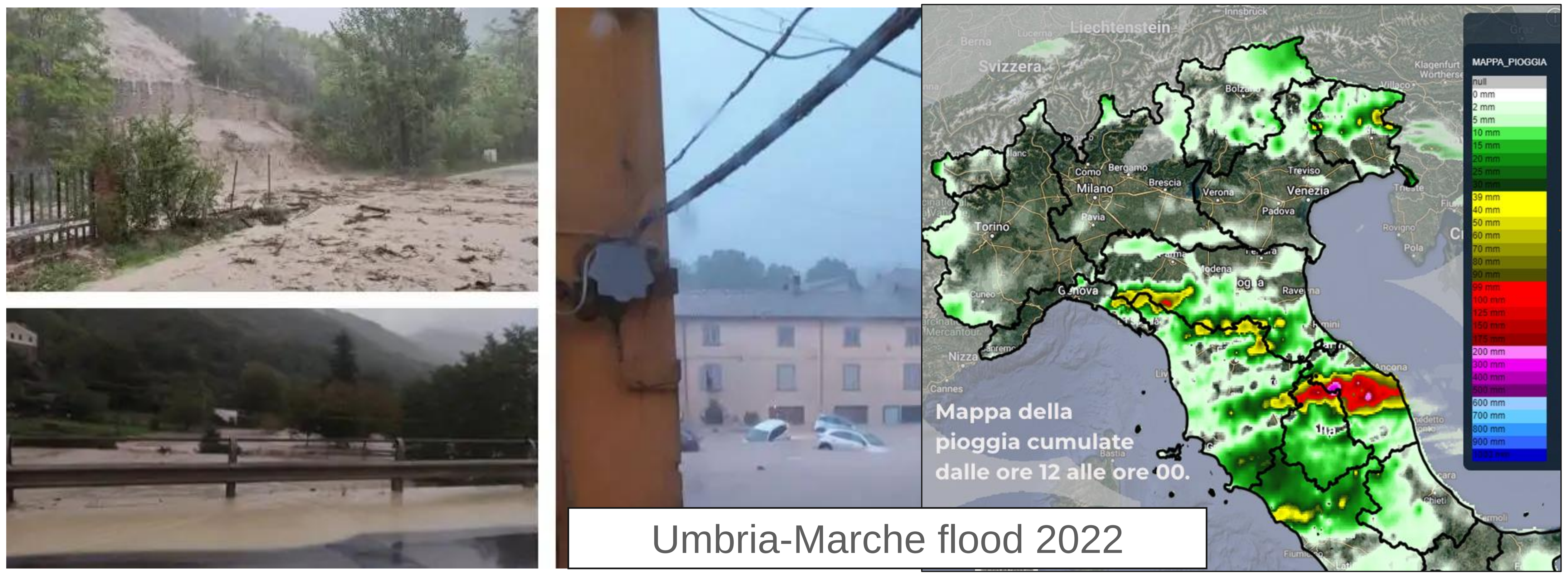
Floods in Europe

- Between 1980 and 2017, floods have taken some **4,300 lives and cost Europe's economy more than €170 billion**, representing nearly a third of the total damage from natural hazards (EEA, 2020: Economic losses from climate-related extremes in Europe).

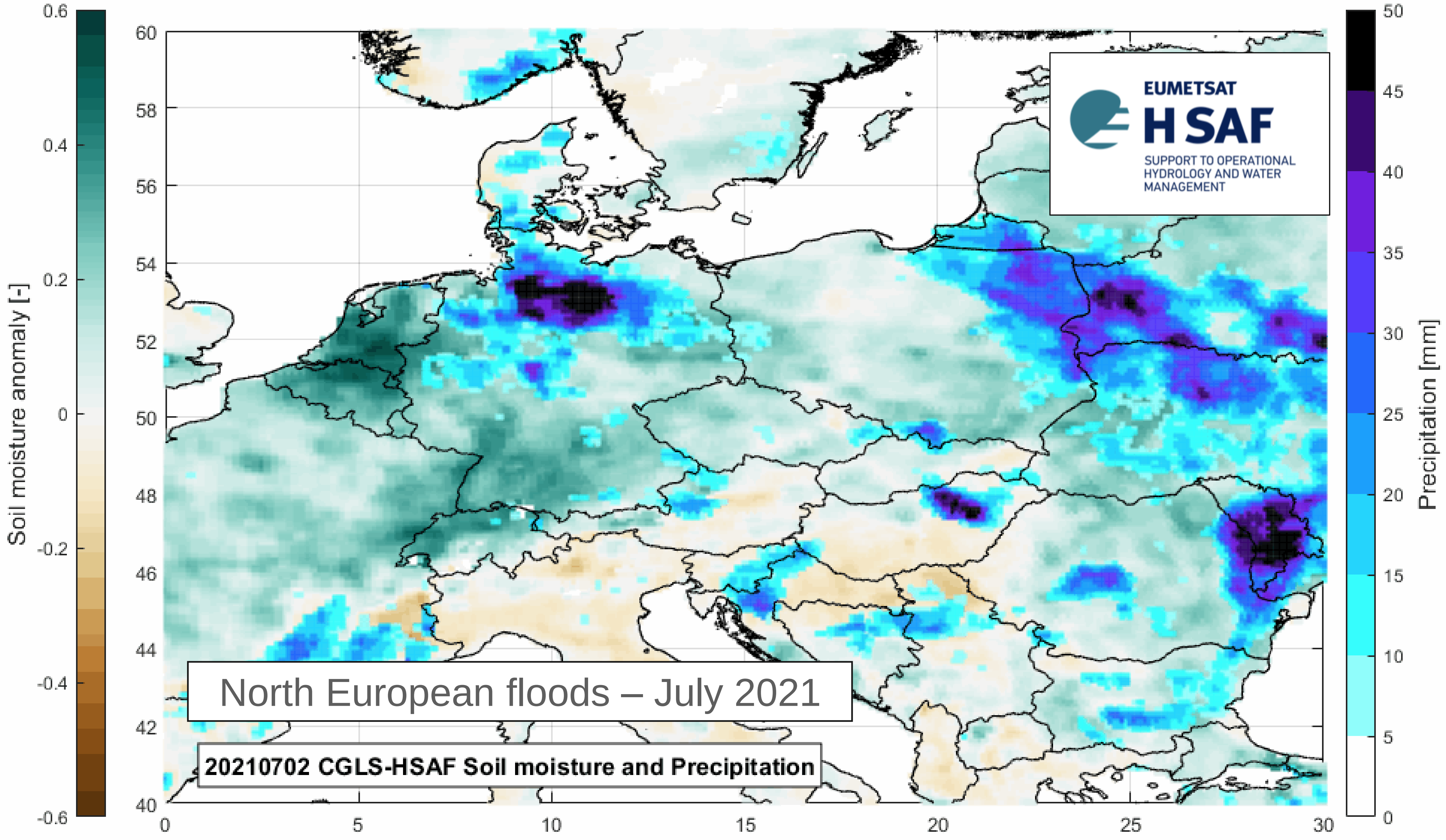
- Under a **high-emissions scenario**, **climate change could triple the direct damages from river floods** during the 21st century in the absence of additional adaptation measures

- **Pluvial floods and flash floods**, which are triggered by intense local precipitation events, are likely to become **more frequent** throughout Europe.

European Environment Agency (EEA, 2021)

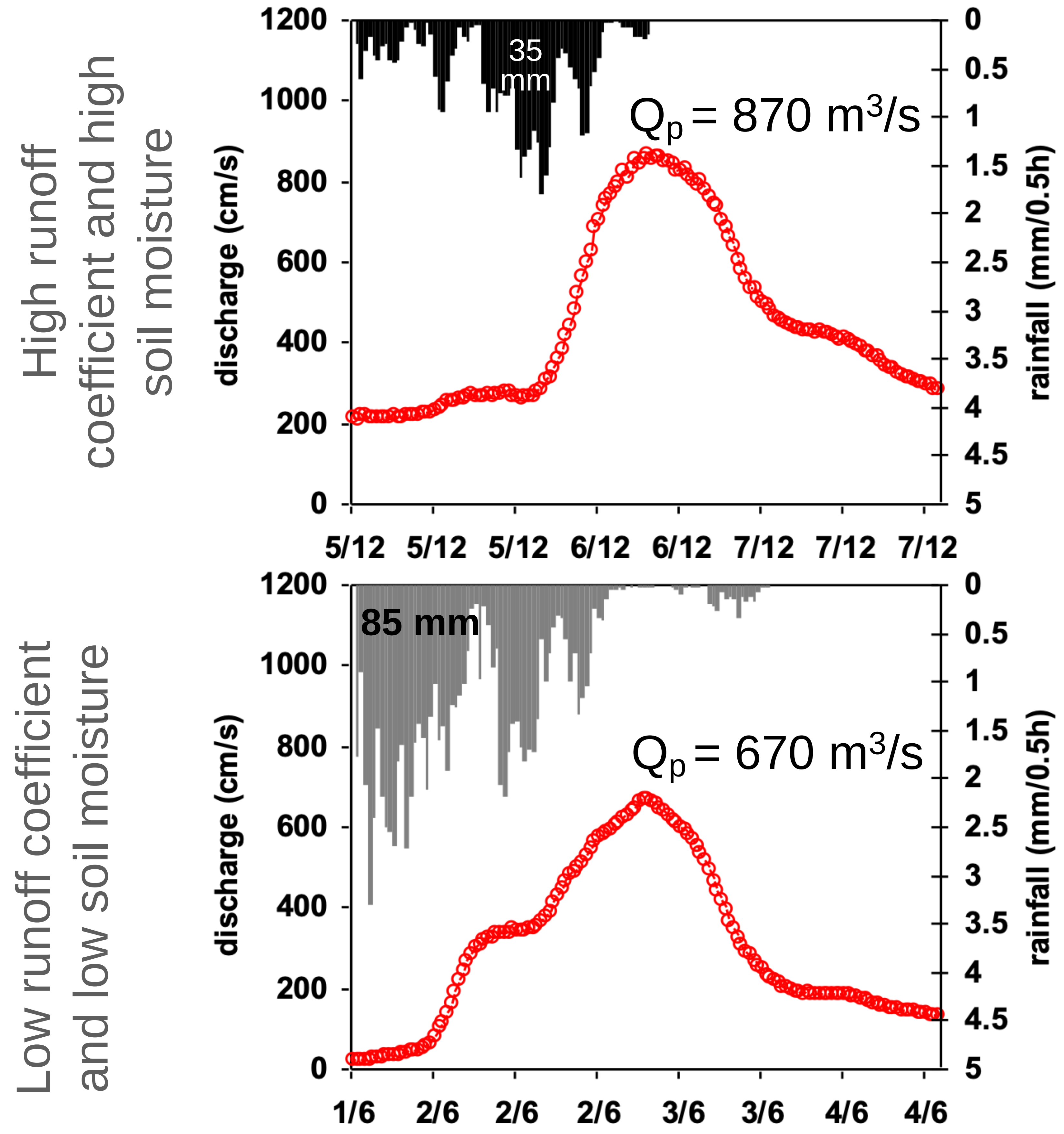


Umbria-Marche flood 2022

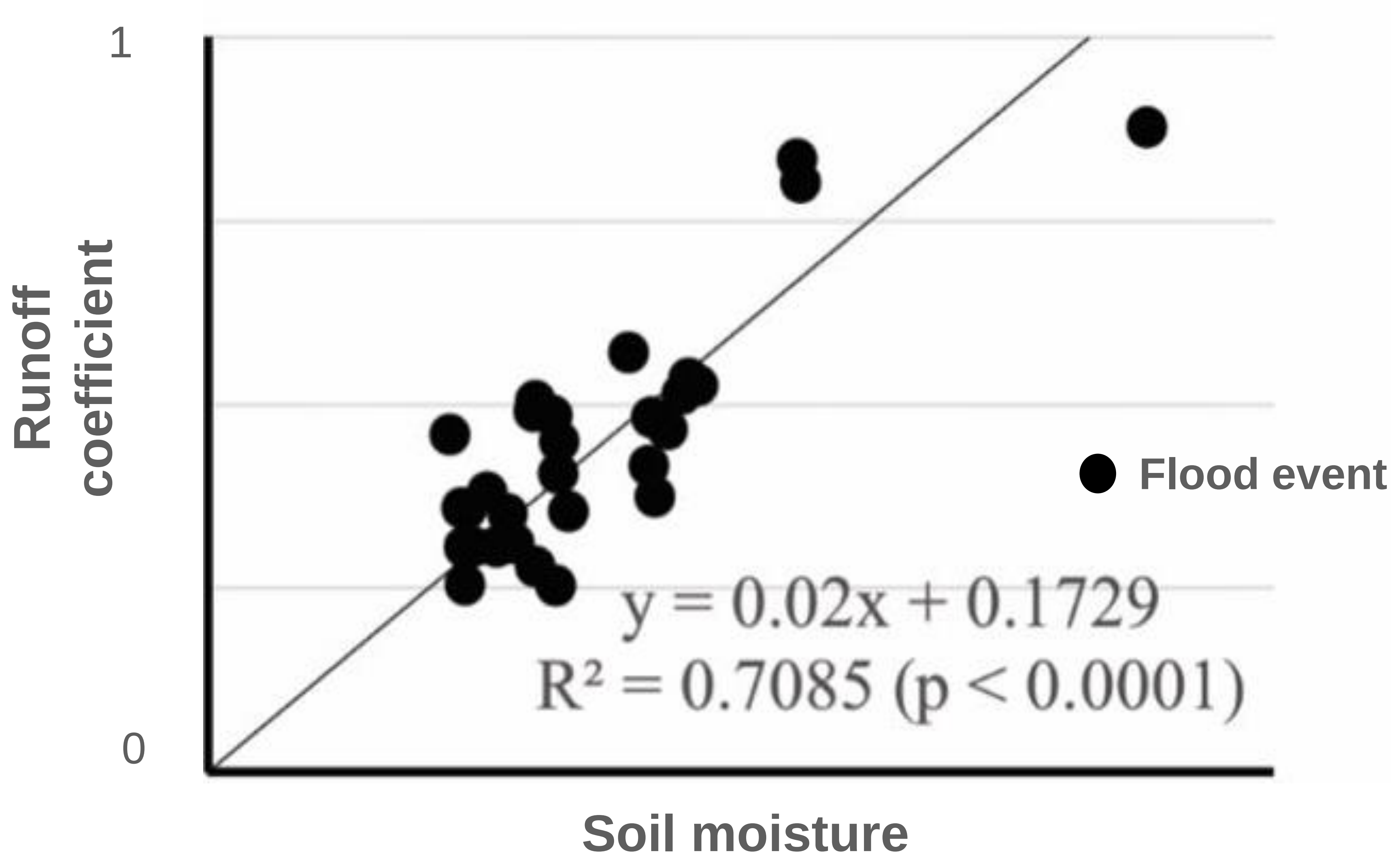


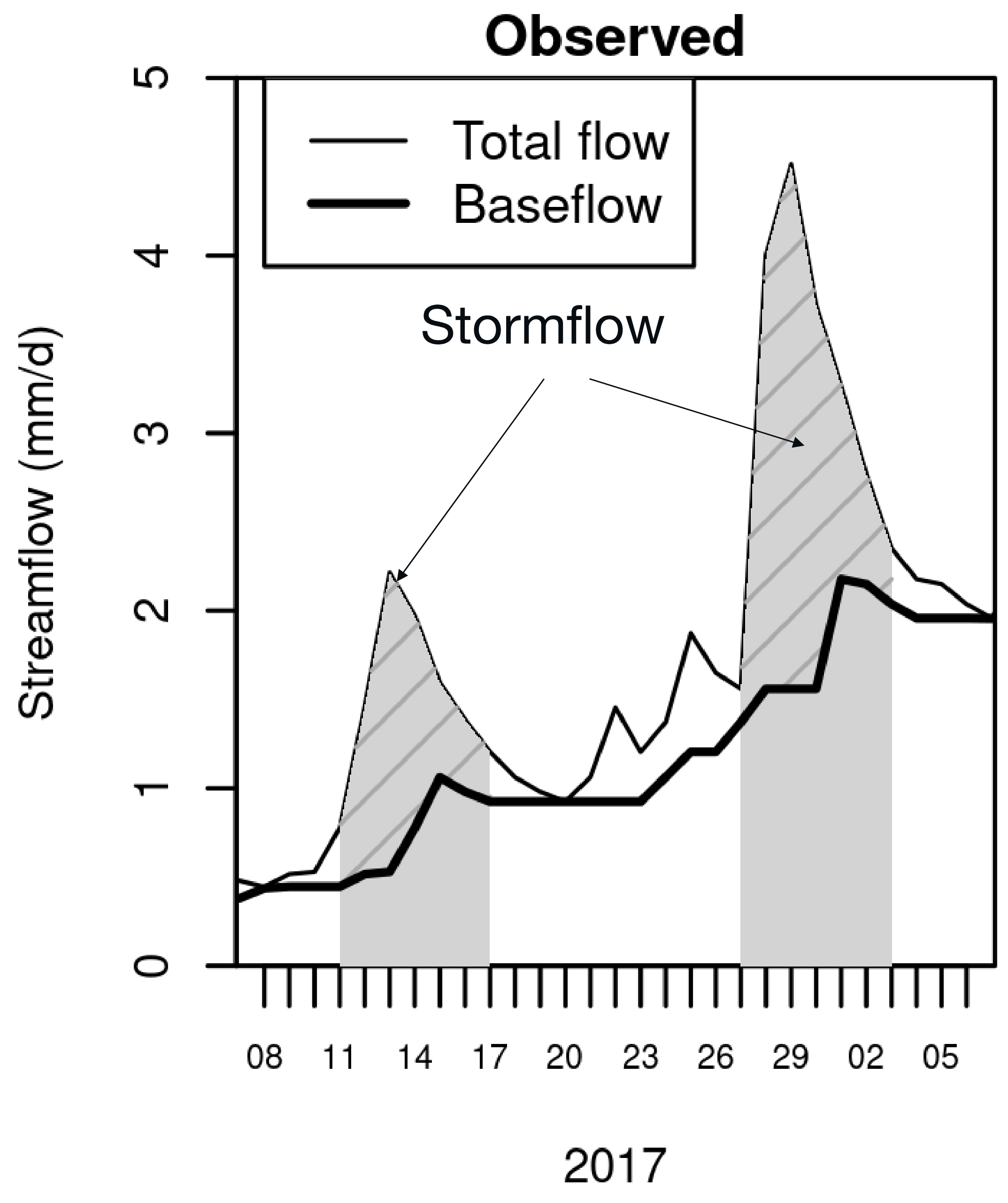
North European floods – July 2021

However not only precipitation is important

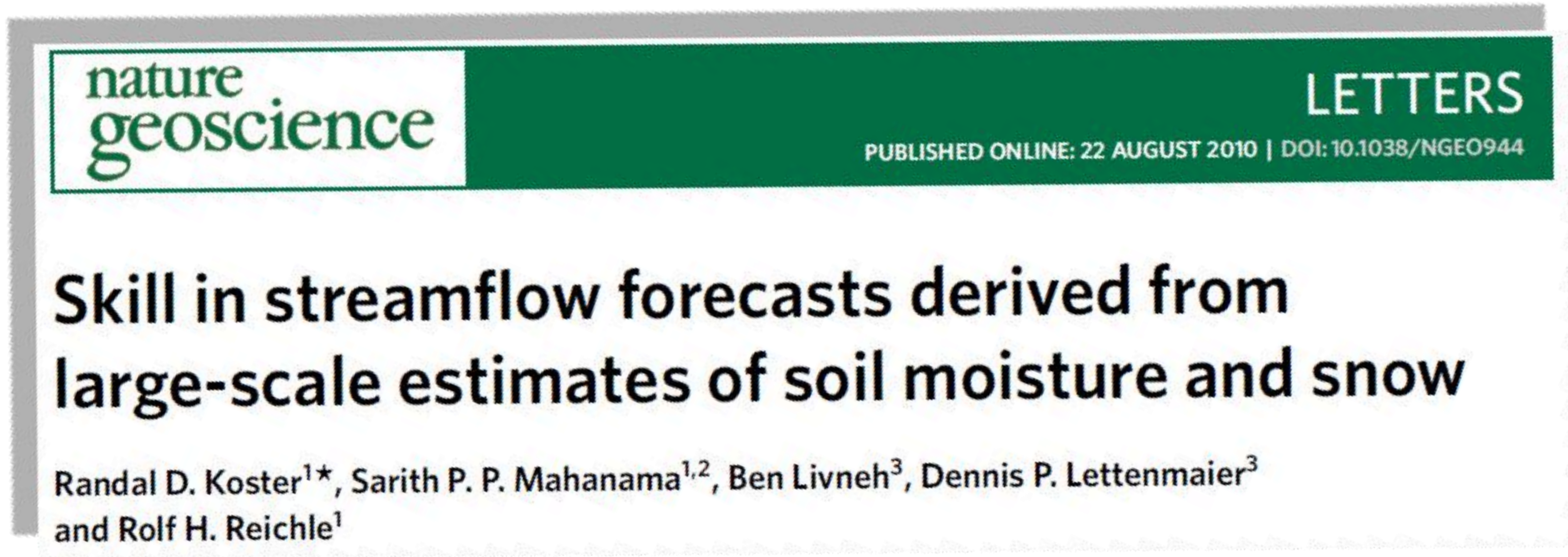


Tiber River Basin - Central Italy





$$\text{Runoff coefficient} = \frac{stormflow\ event}{Precipitation}$$



nature geoscience

LETTERS

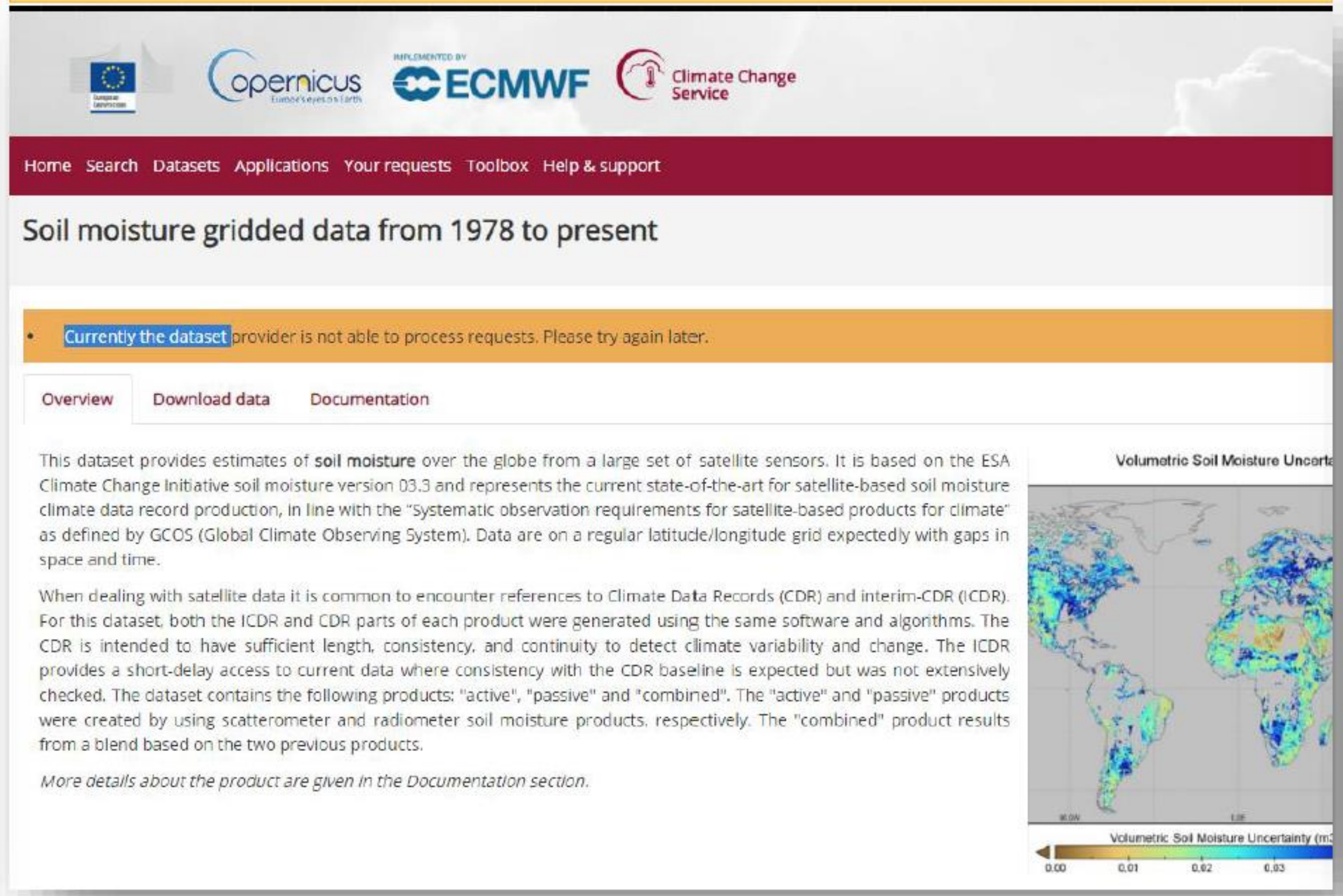
PUBLISHED ONLINE: 22 AUGUST 2010 | DOI: 10.1038/NGEO944

Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow

Randal D. Koster[1]*, Sarith P. P. Mahanama[1,2], Ben Livneh[3], Dennis P. Lettenmaier[3] and Rolf H. Reichle[1]

Operational soil moisture products (COPERNICUS, H SAF)

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

H SAF SOIL MOISTURE: 1992 (2007) to present, 1-day, 1-10-12,5 km

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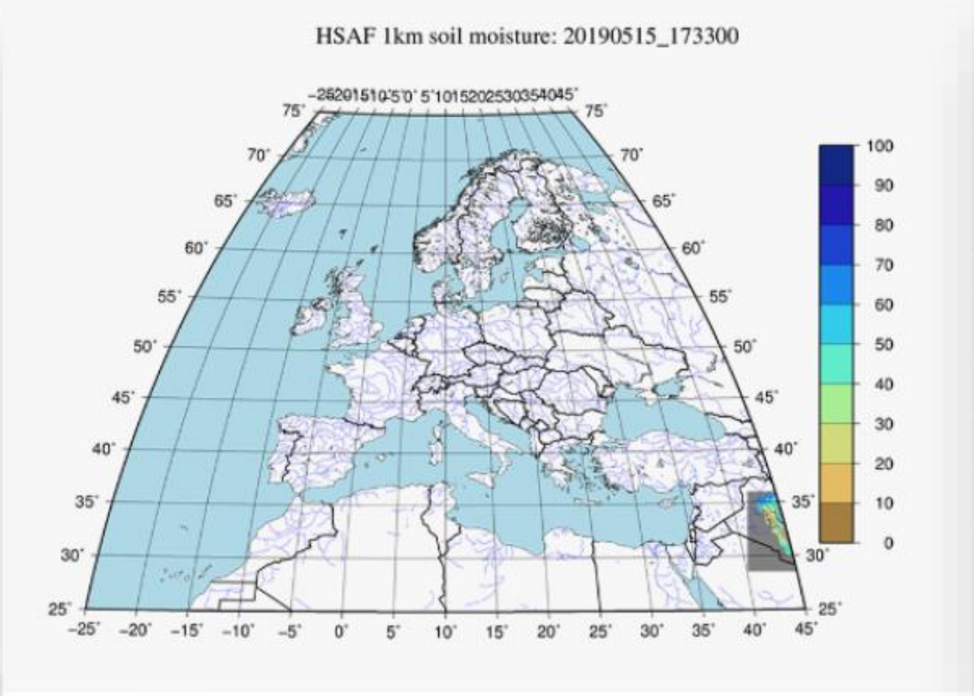
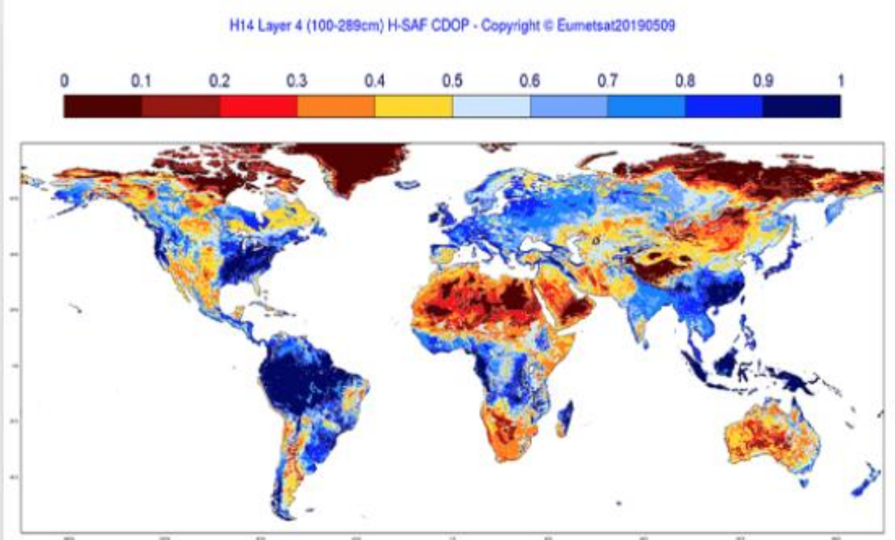
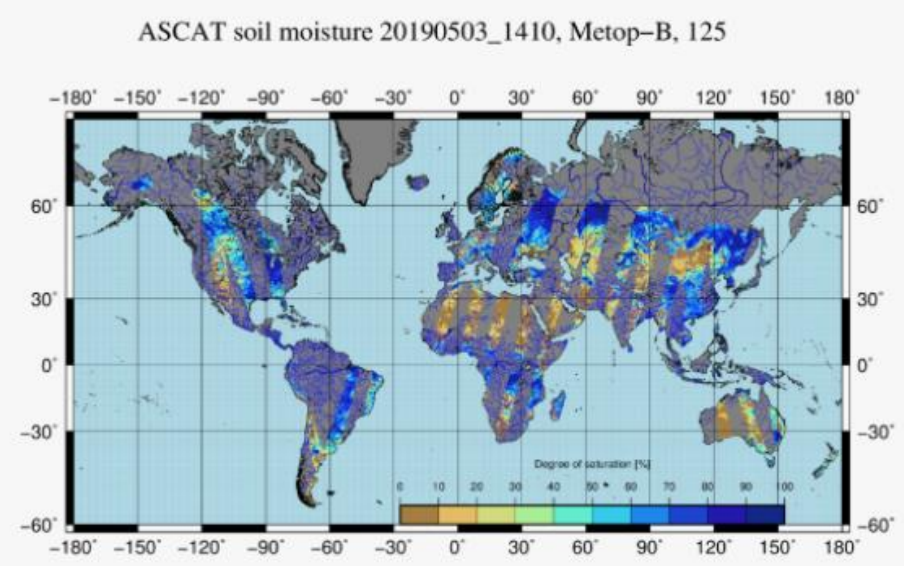
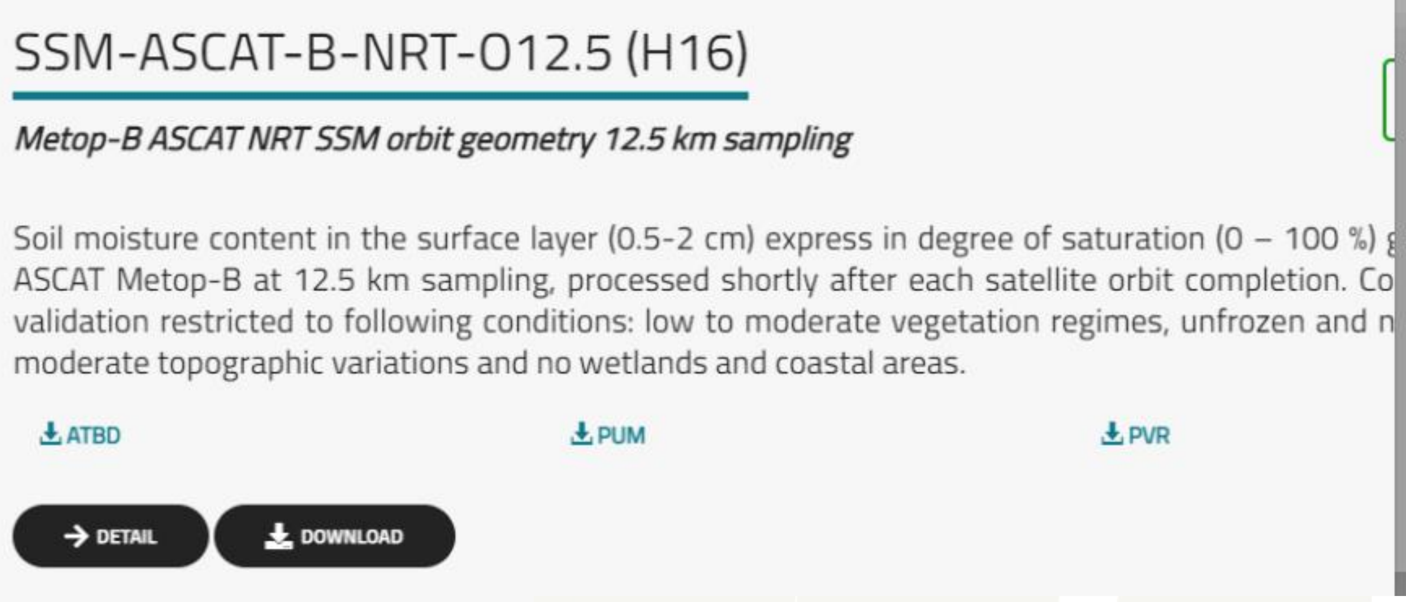






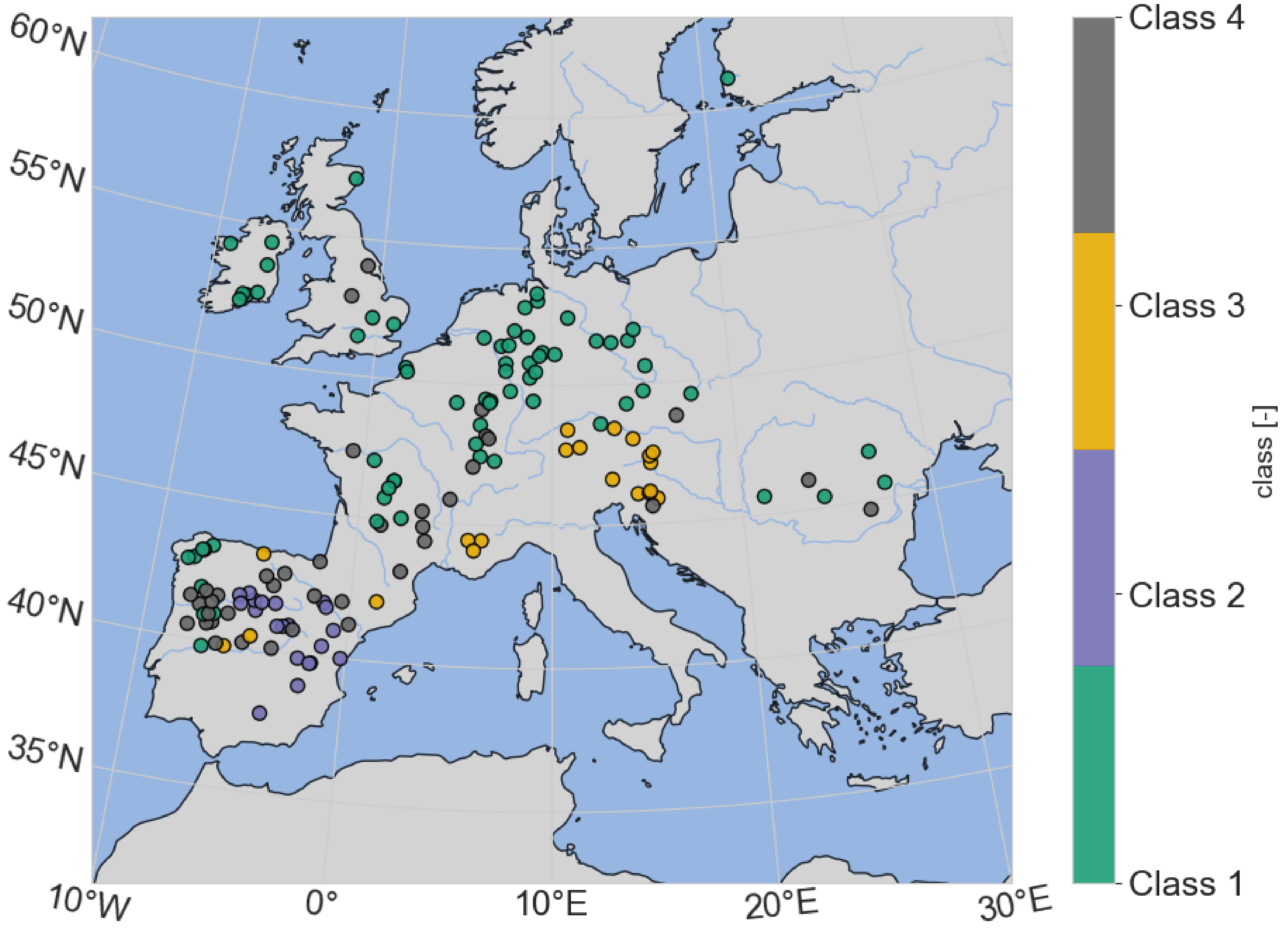


See presentations of Brocca et al., Ciabatta et al.
https://www.eumetsat.int/eumetsat-meteorological-satellite-conference-2022
Next Thursday

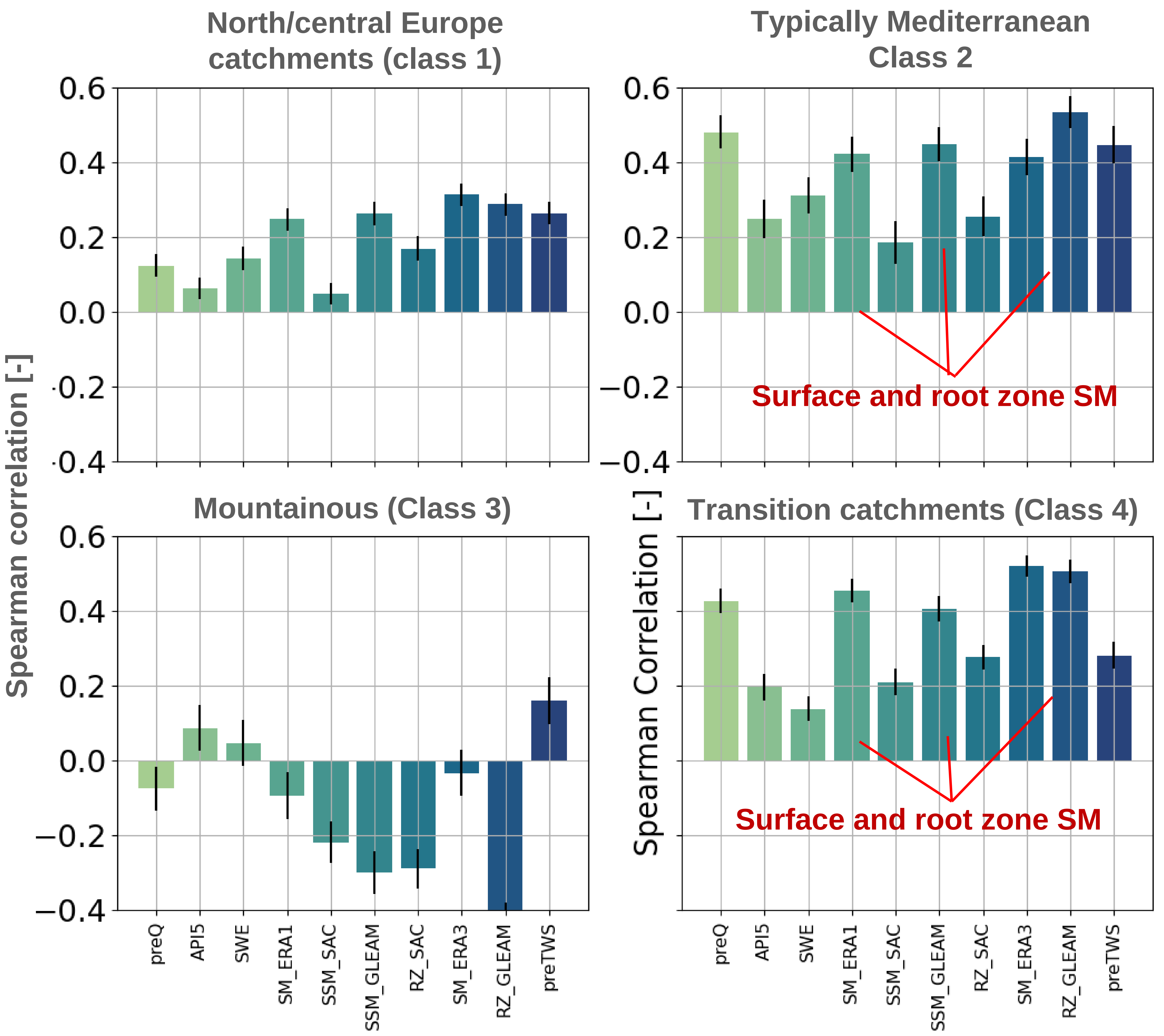
EUMETSAT Meteorological Satellite Conference 2022
Brussels, Belgium, 19-23 September 2022

Pre-storm proxies and catchment runoff coefficients in Europe

3109 flood events extracted from river discharge observations of 149 catchments from 1980 to 2016



Catchment classification (k-means): **four different classes** based on topography, climate Land cover, hydrological behaviour (e.g., flashiness, BFI)



Massari et al. 2020 (IGARSS), Massari et al. 2022 (submitted to Journal of Hydrology)

Which is the impact on flood modelling and data assimilation? Data assimilation of satellite surface soil moisture observations in Europe

Research hypothesis: pattern of improvements in flood simulation looks highly conditioned by the coupling strength of the soil moisture with runoff coefficient

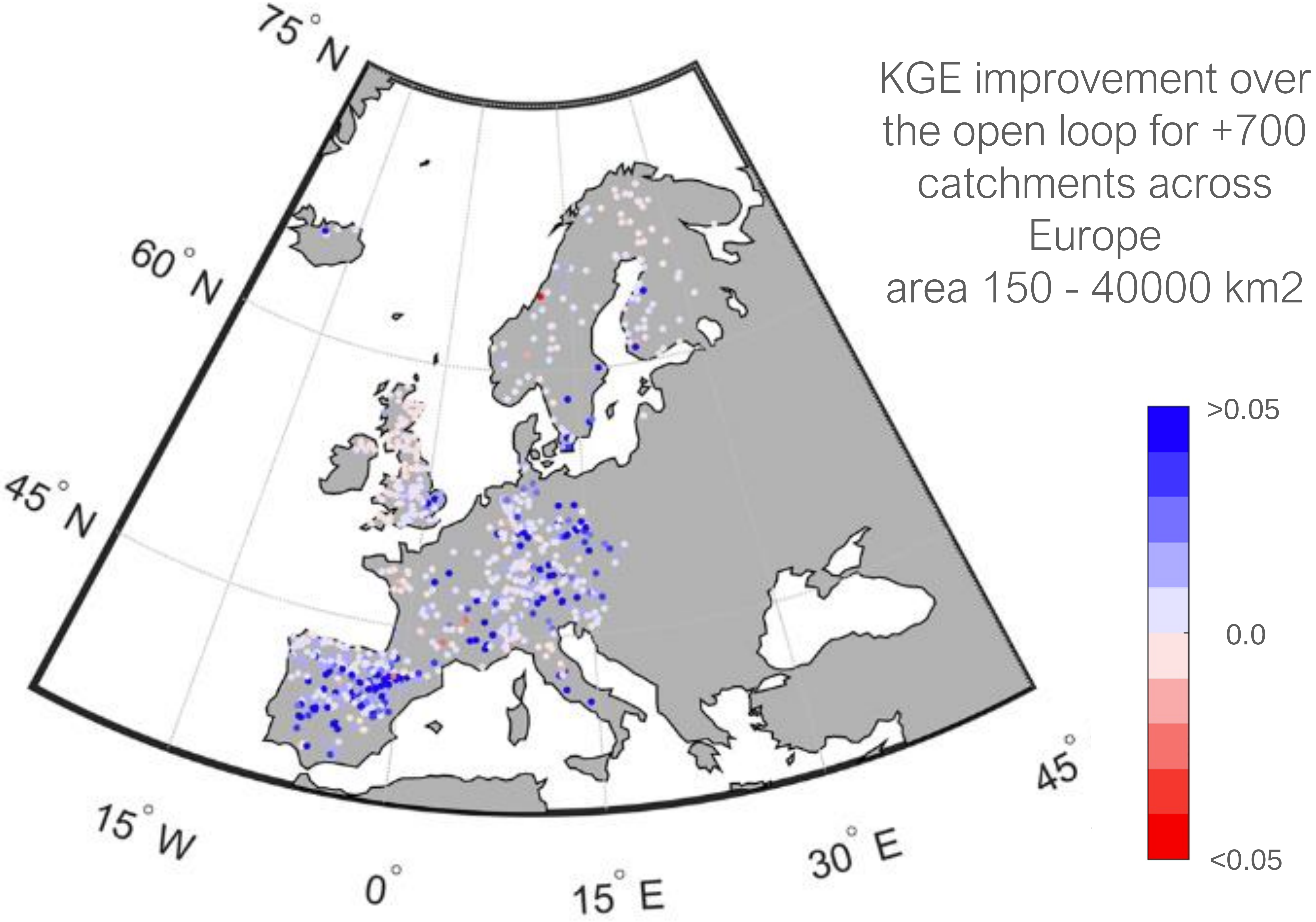
Runoff: Global runoff data Center (GRDC) and European Water Archive (EWA) datasets, period 2002-2016

Rainfall and Temperature: data from the European 25km gridded data sets, E-OBS

Hydrological model: 2 Layers version of MISDc hydrological model (Massari et al. 2018). Run in lumped mode.

Data Assimilation scheme: 1-D Ensemble Kalman Filter

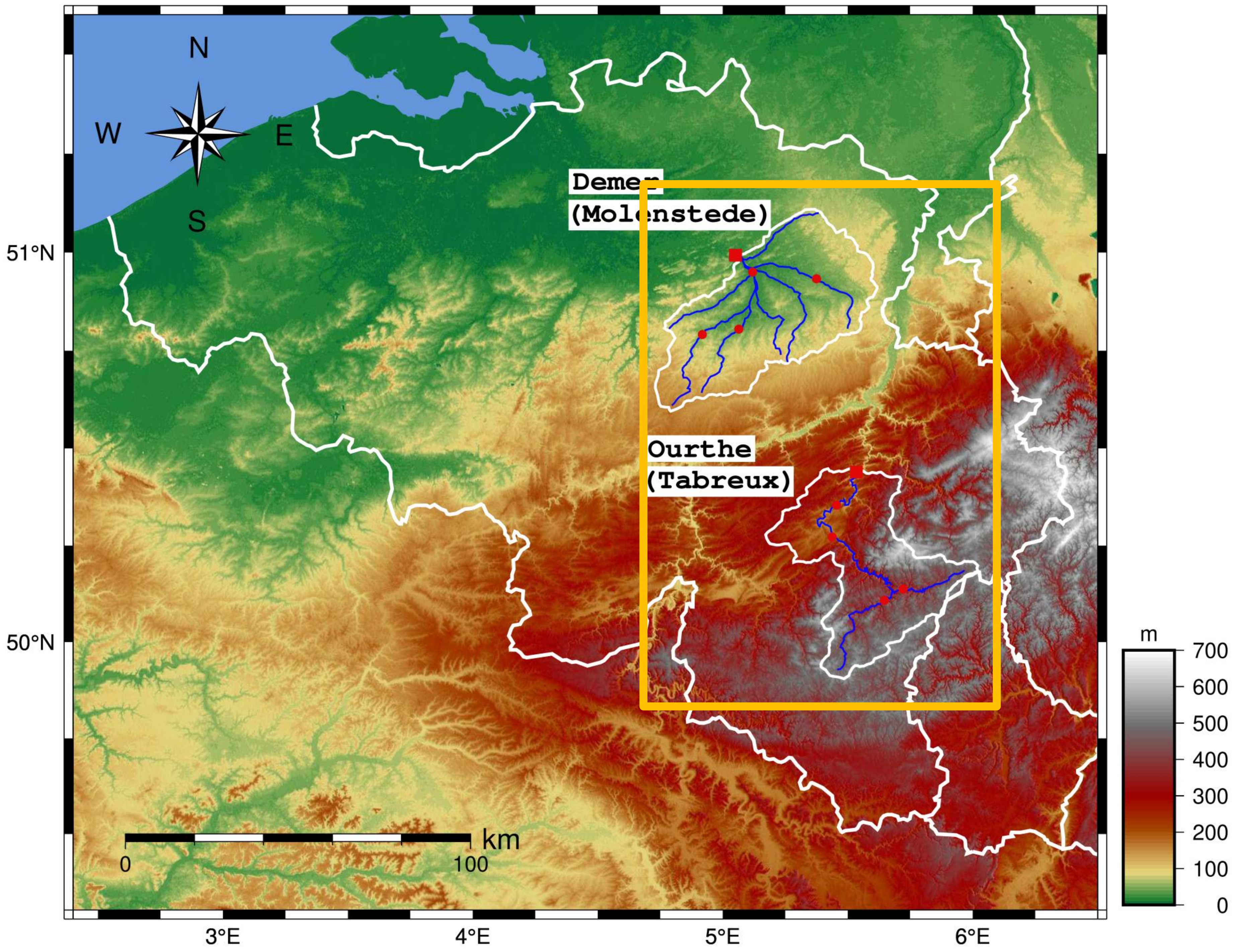
Products assimilated: ESA-CCI **soil moisture** Active and Passive products v03.2

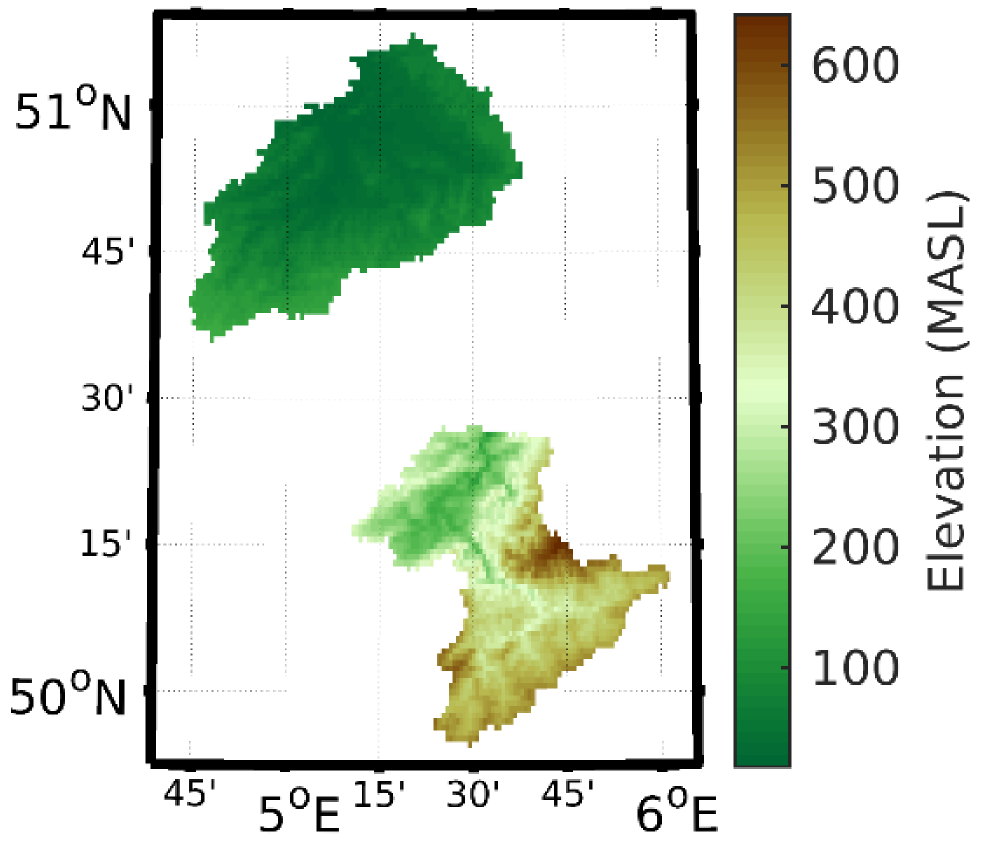


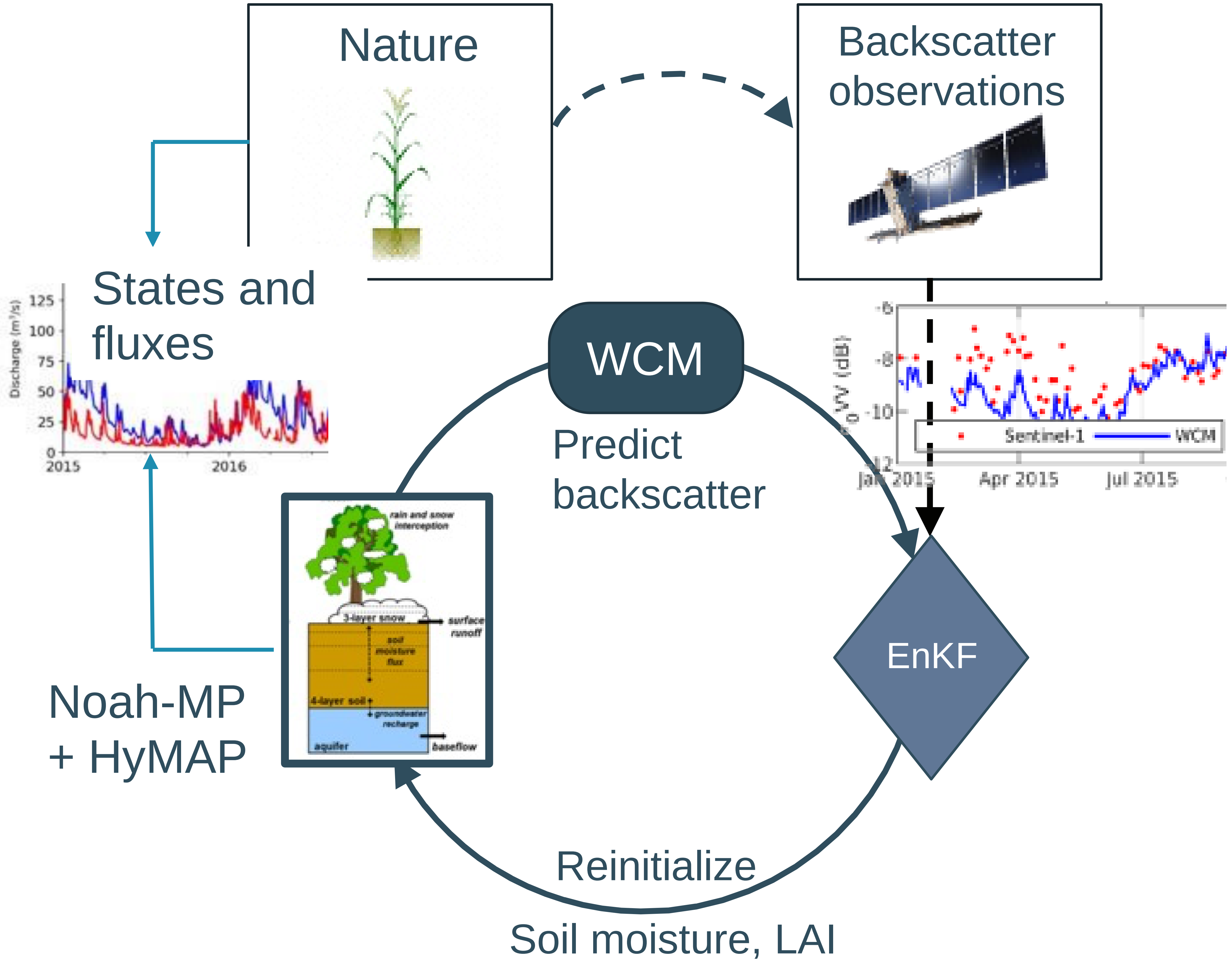
KGE improvement over the open loop for +700 catchments across Europe
area 150 - 40000 km2

De Santis et al. 2021, Water Resource Research

Sentinel 1 backscatter assimilation in Belgium for improving Noah-MP model runoff simulations (via correcting soil moisture and vegetation)





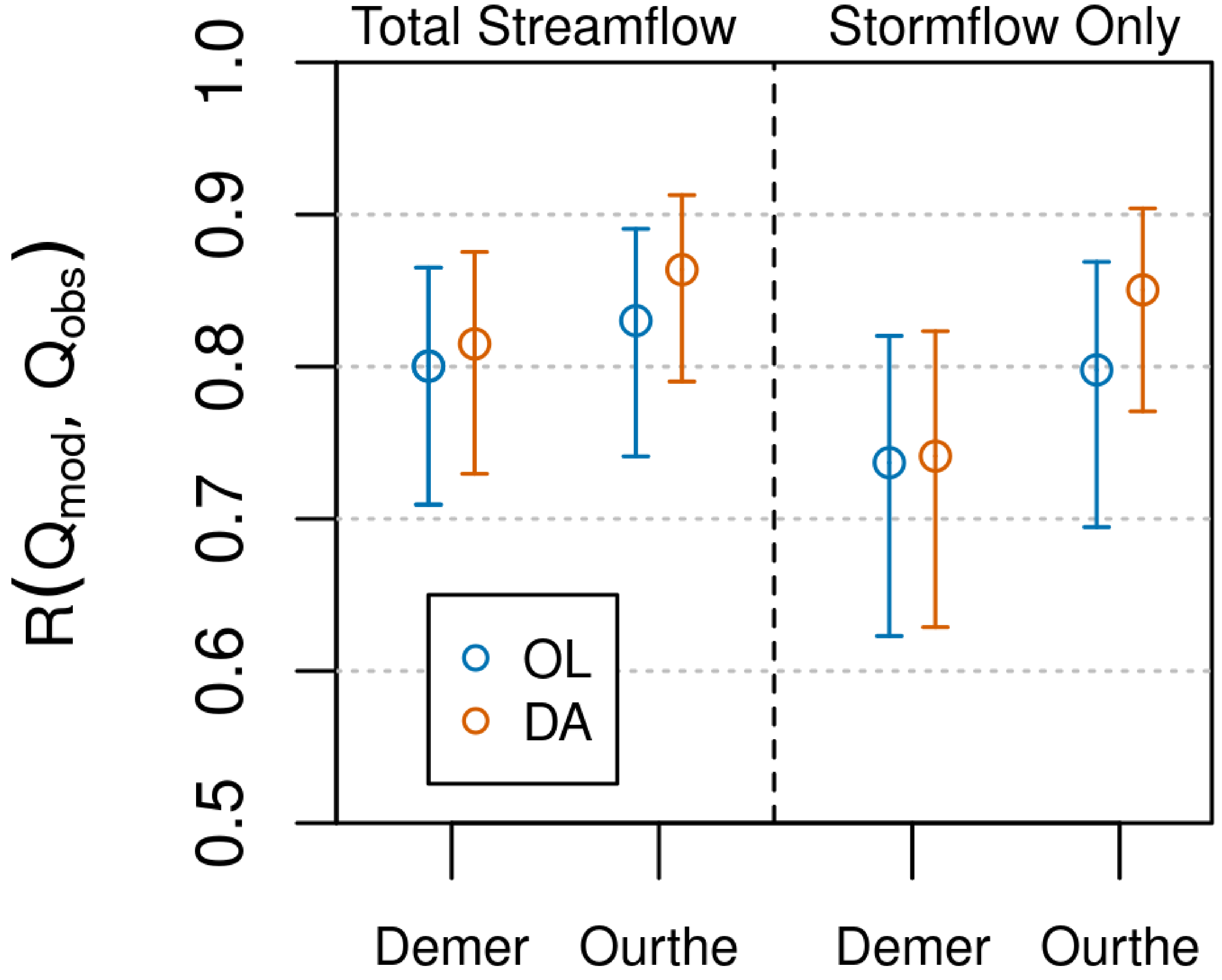


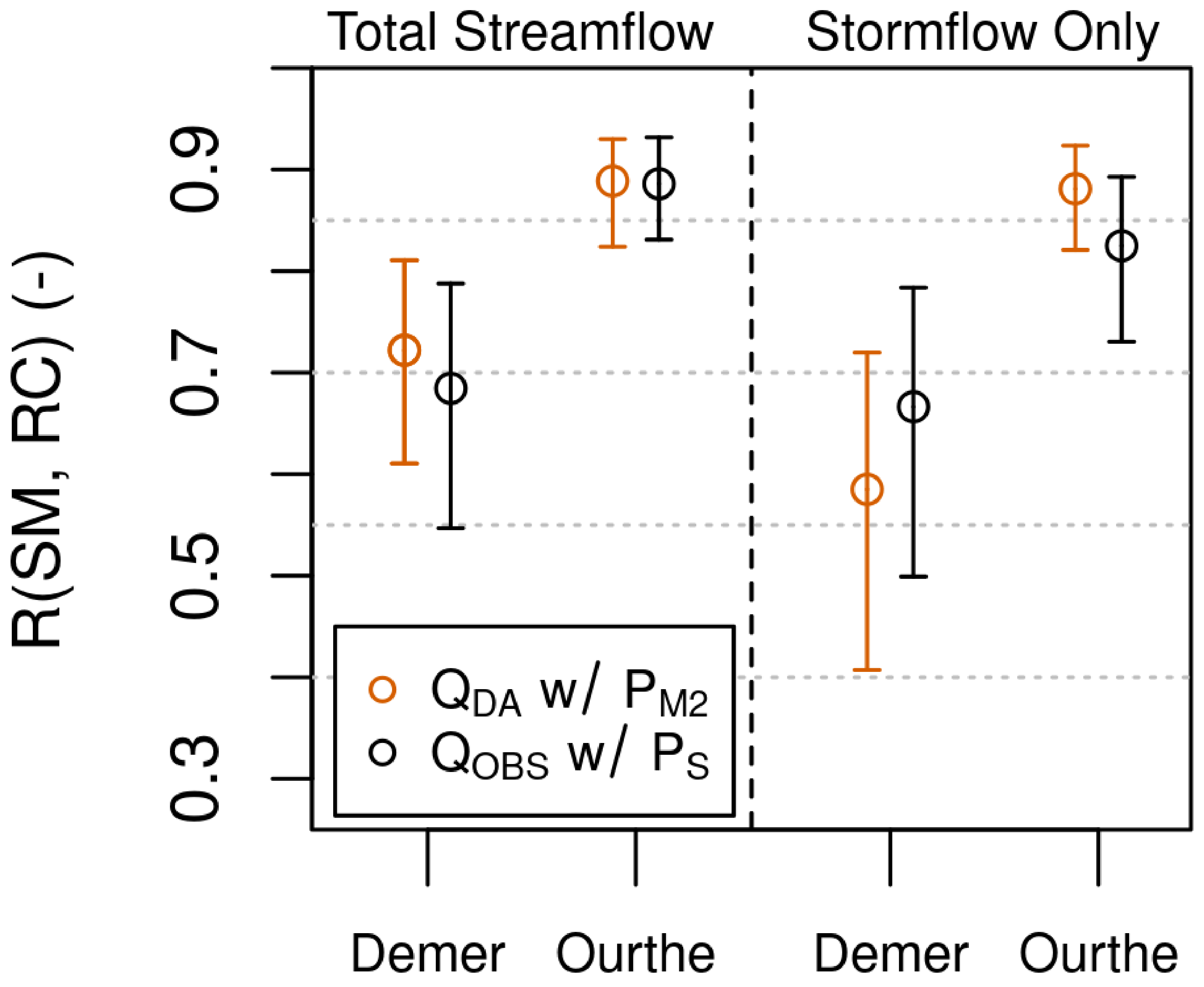
Demer 1950 km^2 less forested - agricultural land use

Ourthe 1616 km^2: more forested

Bechtold et al. 2022, in prep.

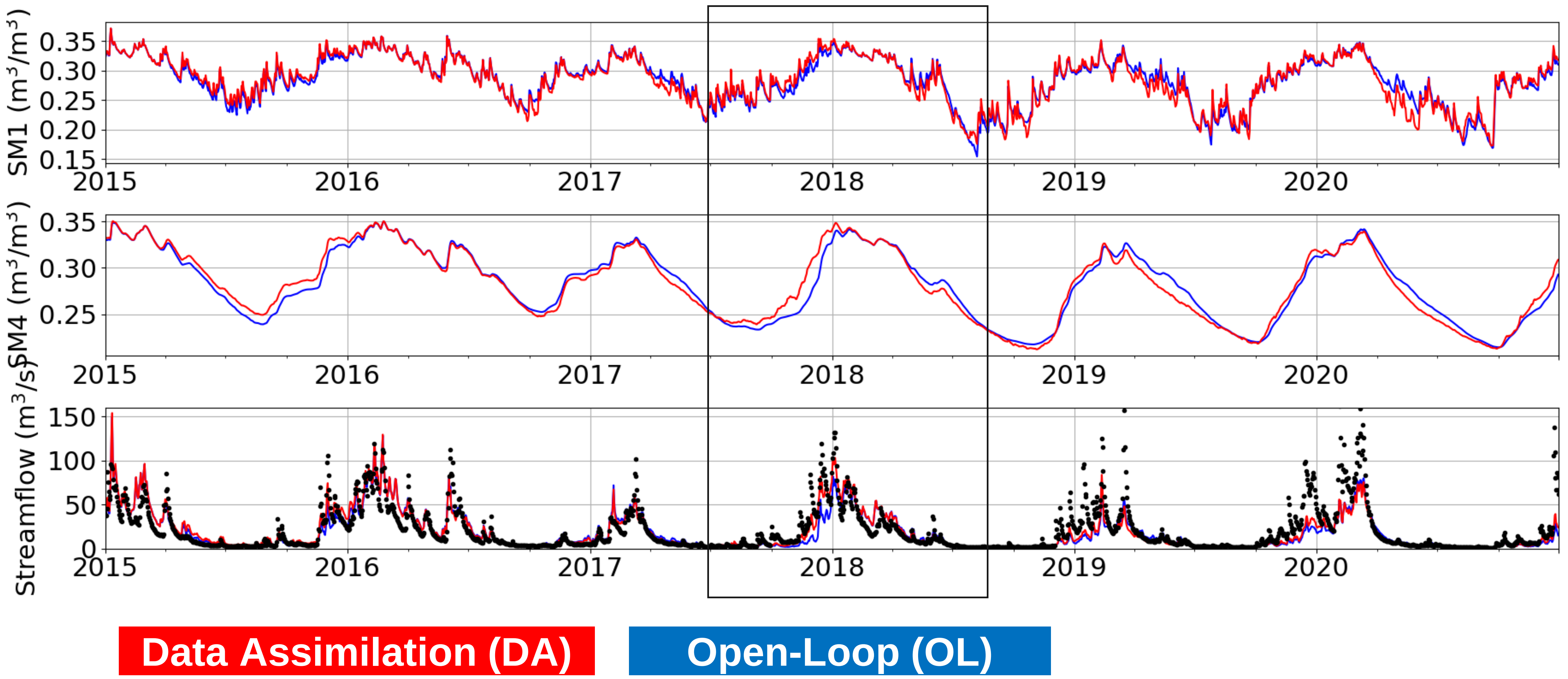
Sentinel 1 backscatter assimilation in Belgium for improving Noah-MP model runoff simulations (via correcting soil moisture and vegetation) (2)

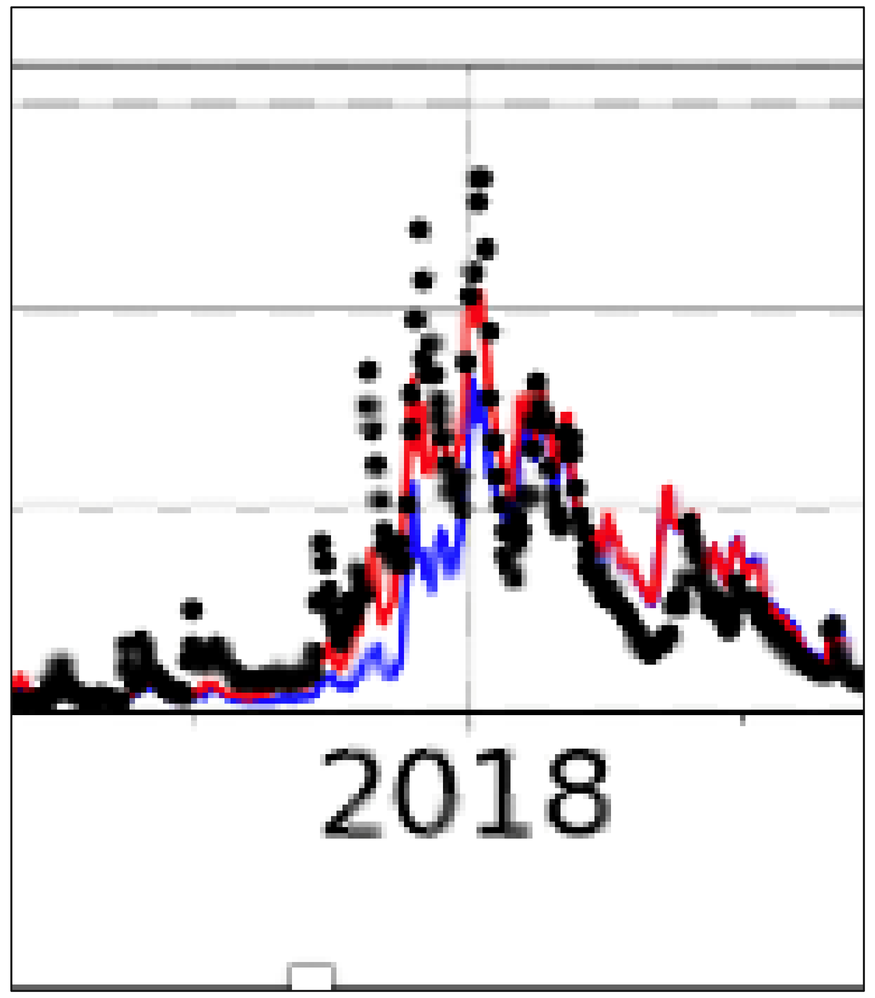




stronger SM-runoff coupling (both observed and modeled)

stronger impact from SM DA on river discharge





Bechtold et al. 2022, in prep.

Revisit time vs spatial resolution. What does it matter?

Hydrological model

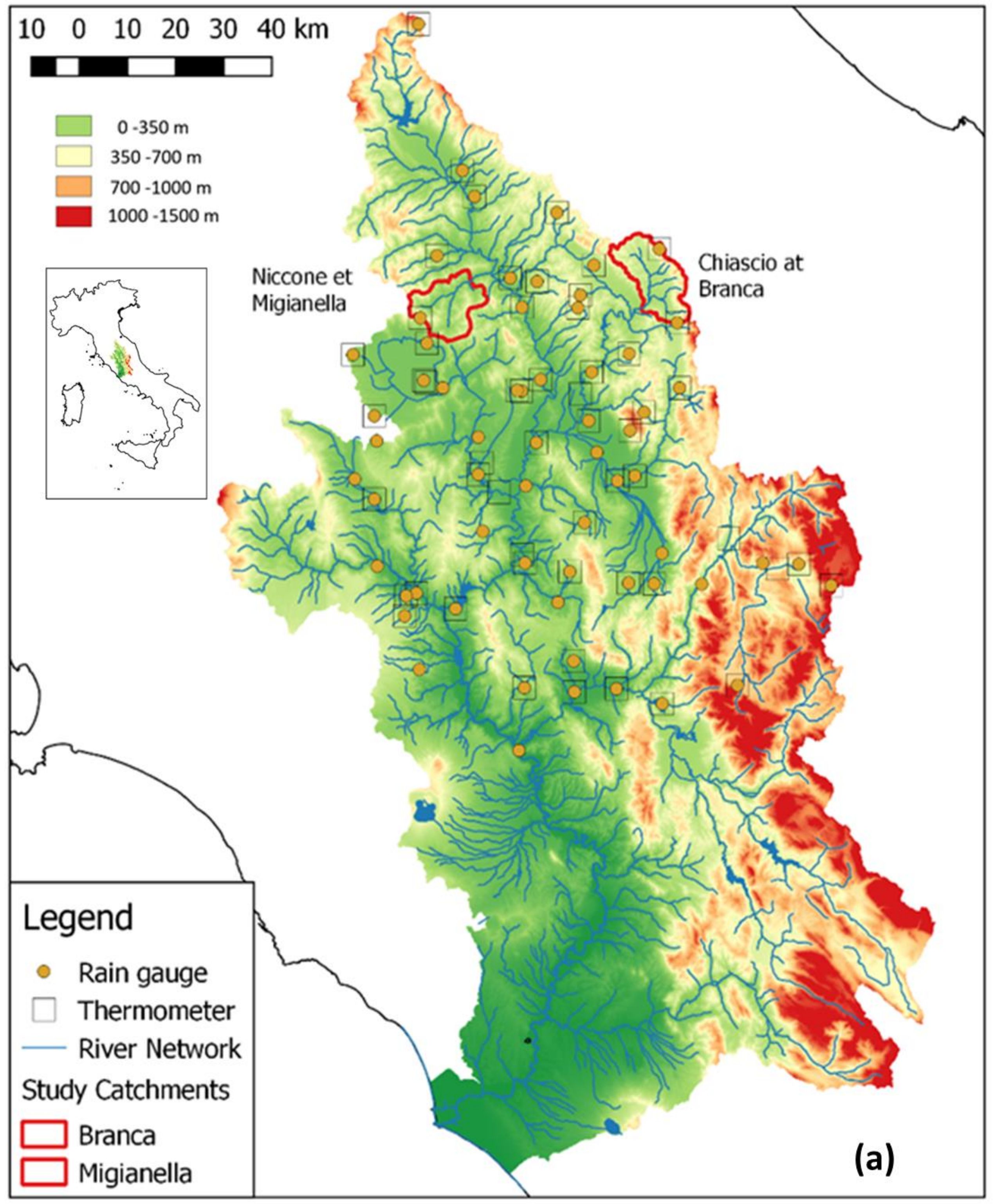
SWAT (physically based, distributed)

Assimilation scheme

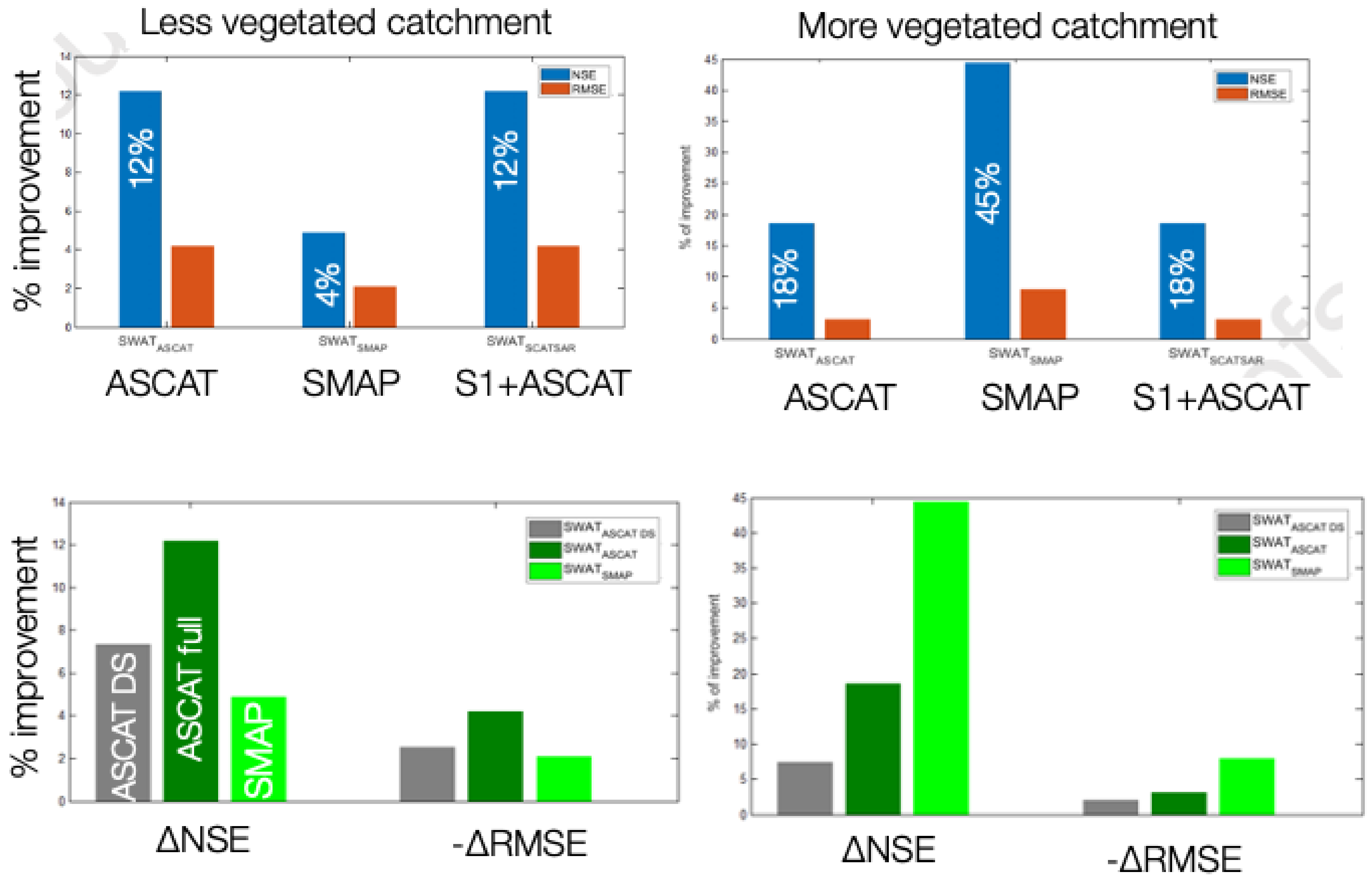
2D Ensemble Kalman Filter

Study area

Two small catchments in Tiber River (area less than 100 km^2) (Central Italy)



Impact of spatial resolution : NSE and RMSE improvement with respect of the OL



- The passive product (i.e., SMAP) tend to perform better over the forested catchment with respect to active products
- Higher spatial resolution soil moisture seems to not impact data assimilation results (with respect to coarse scale products)
- Data assimilation of more frequent observations (higher revisit time) have a large impact on flood simulation skills

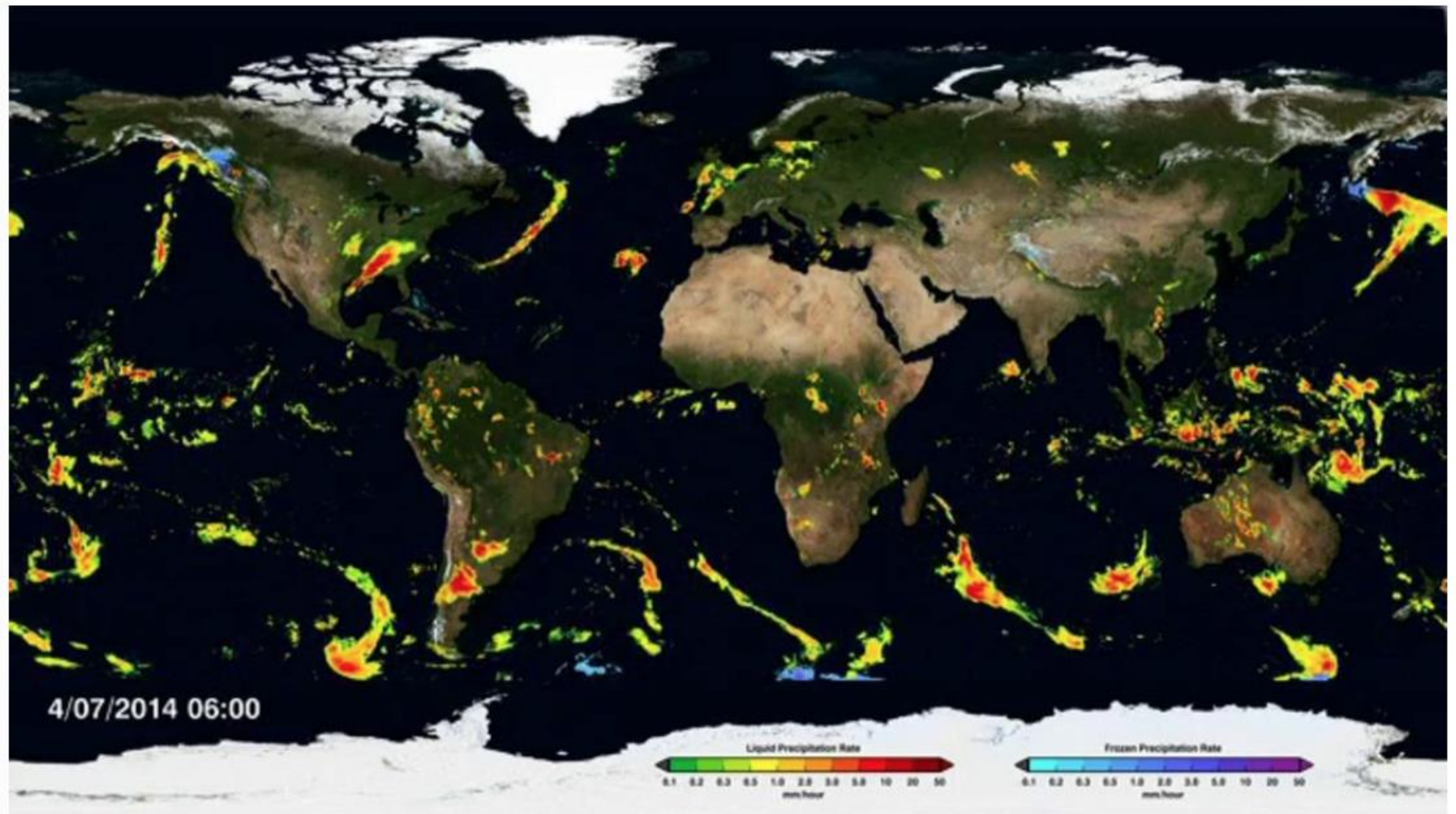
Azimi et al. (2019), Journal of Hydrology

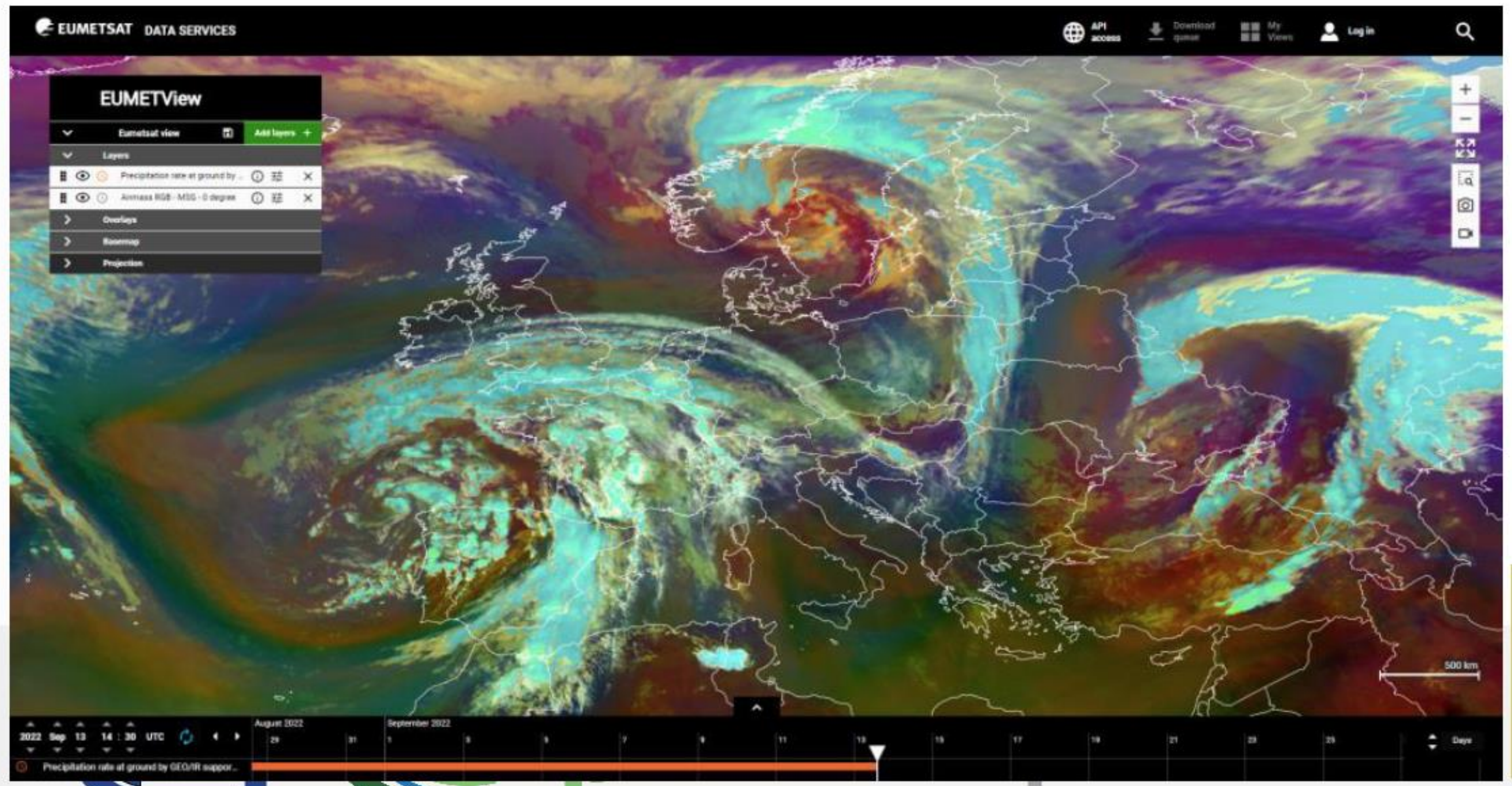
Other ways to use satellite soil moisture for flood forecasting: improving precipitation

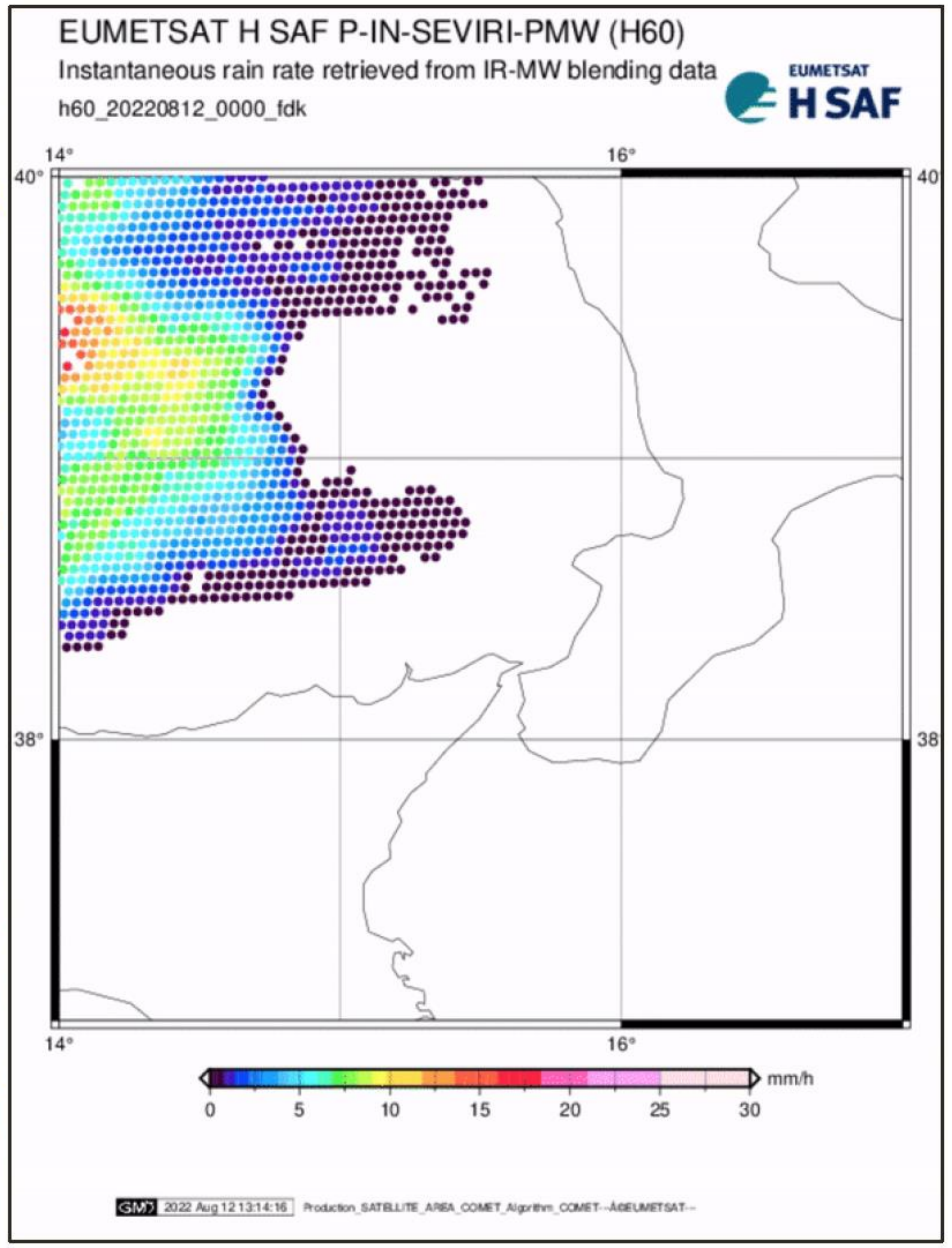
GPM IMERG: 2000 to present,
30-min, 0,1-degree

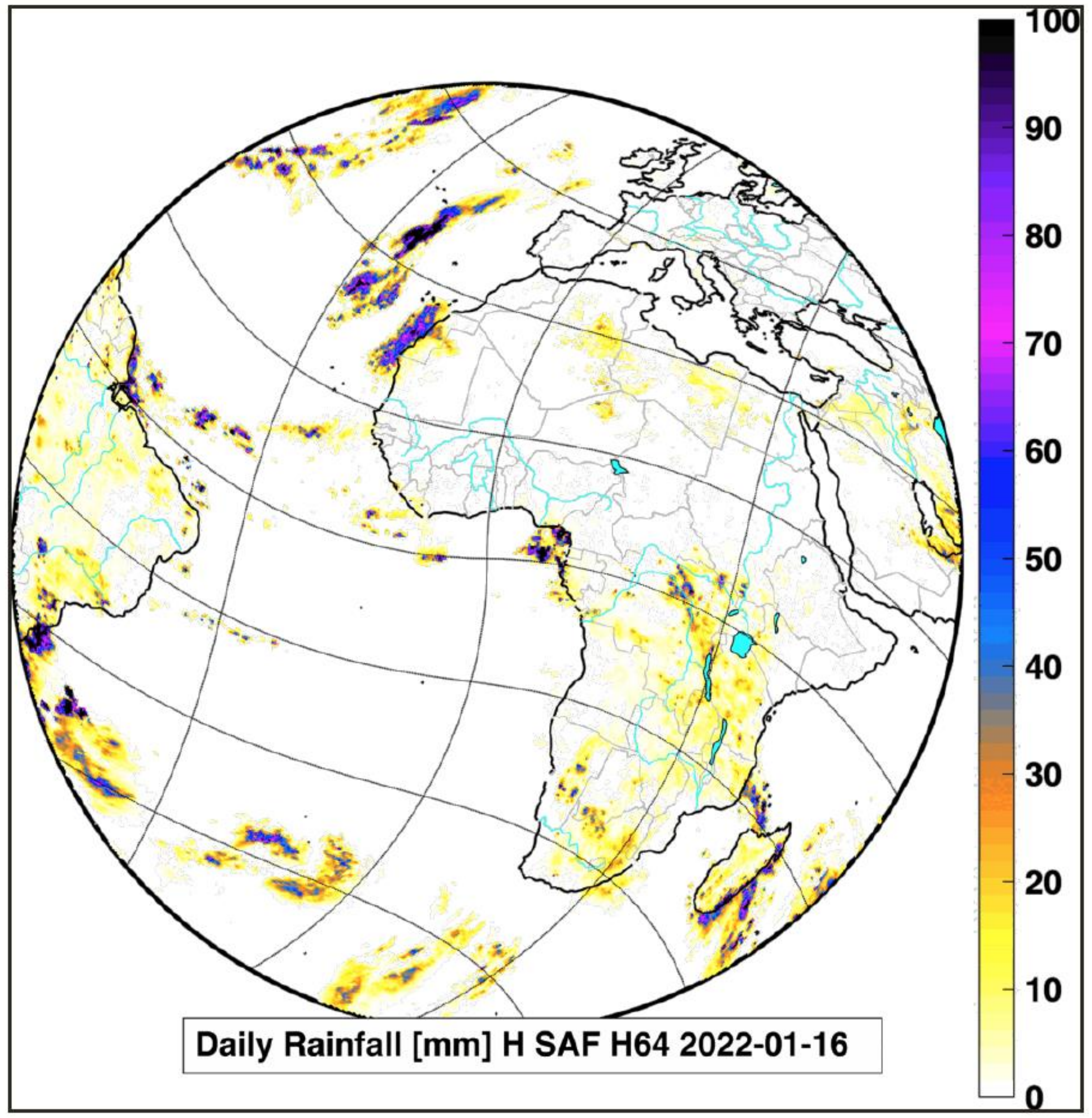
H SAF H60: real-time product
15-min, 0.05-degree

H SAF H64: 2020 to present
1-day, 0,25-degree





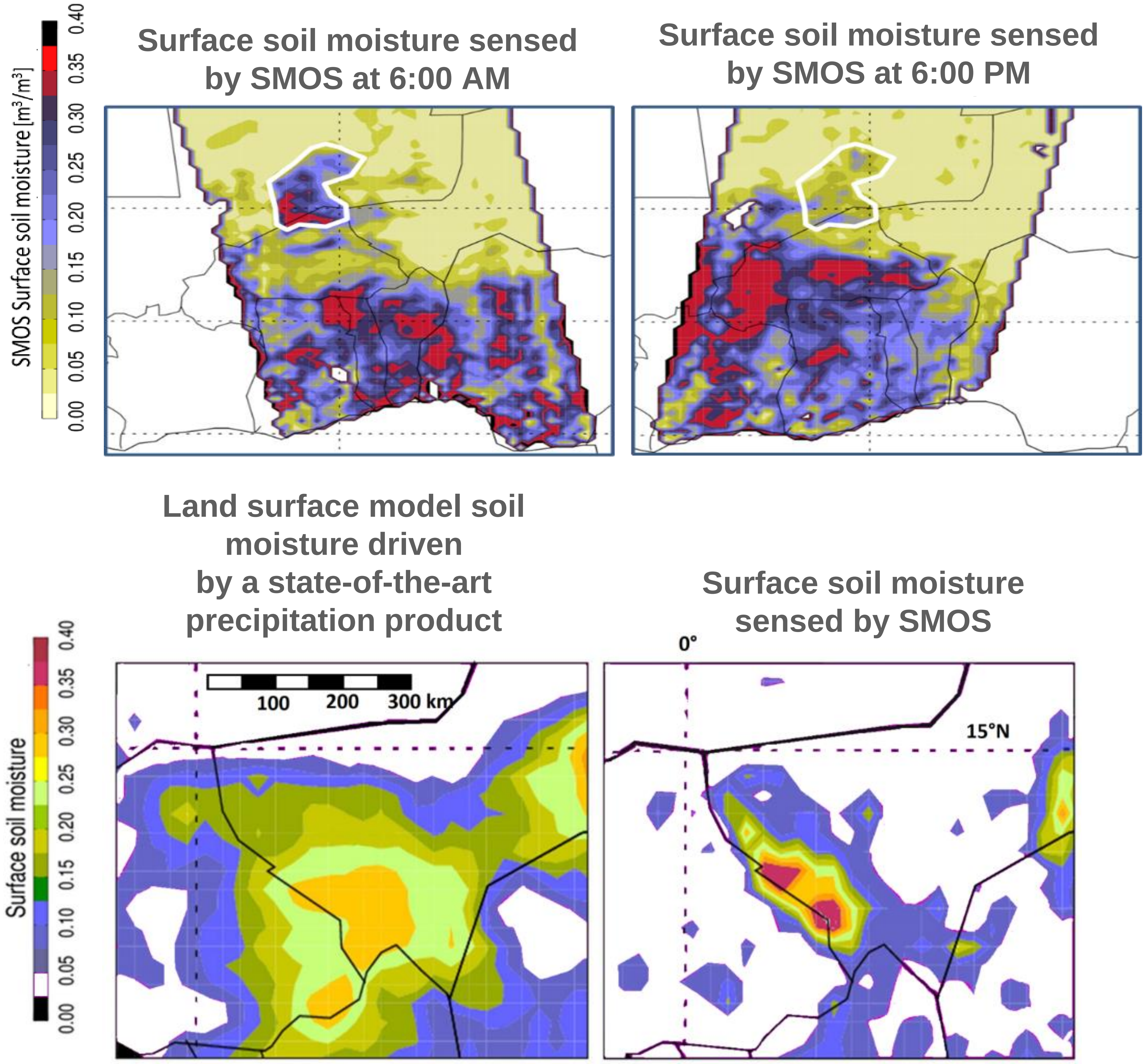




EUMETSAT

EUMETVIEW: real time monitoring of precipitation (H03 from H SAF)

Other ways to use satellite soil moisture for flood forecasting: improving precipitation



Inversion of the soil water balance equation (SM2RAIN)

Brocca et al 2013, GRL

relative saturation, precipitation, surface runoff, drainage

$$Z\,ds(t)/dt = p(t) - r(t) - e(t) - g(t)$$

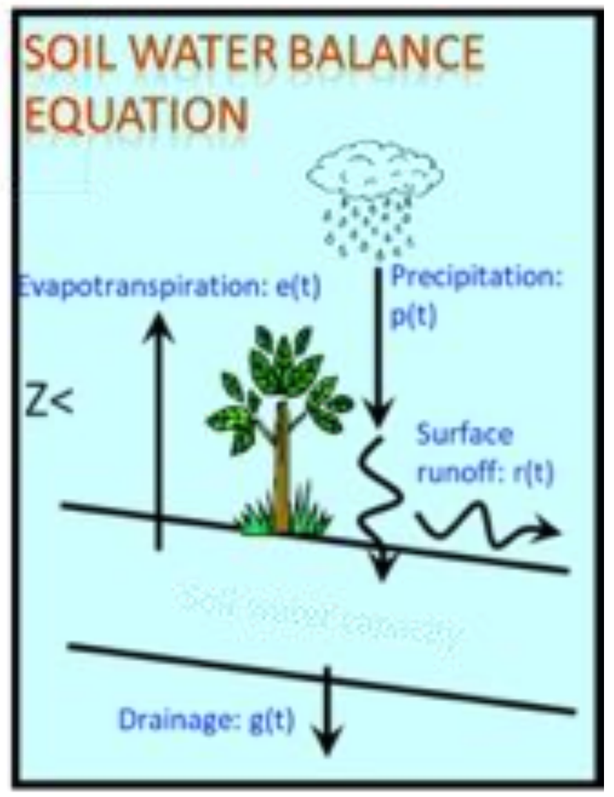
soil water capacity = soil depth X porosity; evapotranspiration

Inverting for *p(t)*:

$$p(t) = Z\,ds(t)/dt + r(t) + e(t) + g(t)$$

Assuming: $g(t) = a\,s(t)^b$ + $e(t)=0$ + $r(t)=0$ during rainfall

$$p(t) \cong Z\,ds(t)/dt + a\,s(t)^b$$



Hydrol. Earth Syst. Sci., 24, 2687–2710, 2020
https://doi.org/10.5194/hess-24-2687-2020

Hydrology and Earth System Sciences — Open Access — EGU

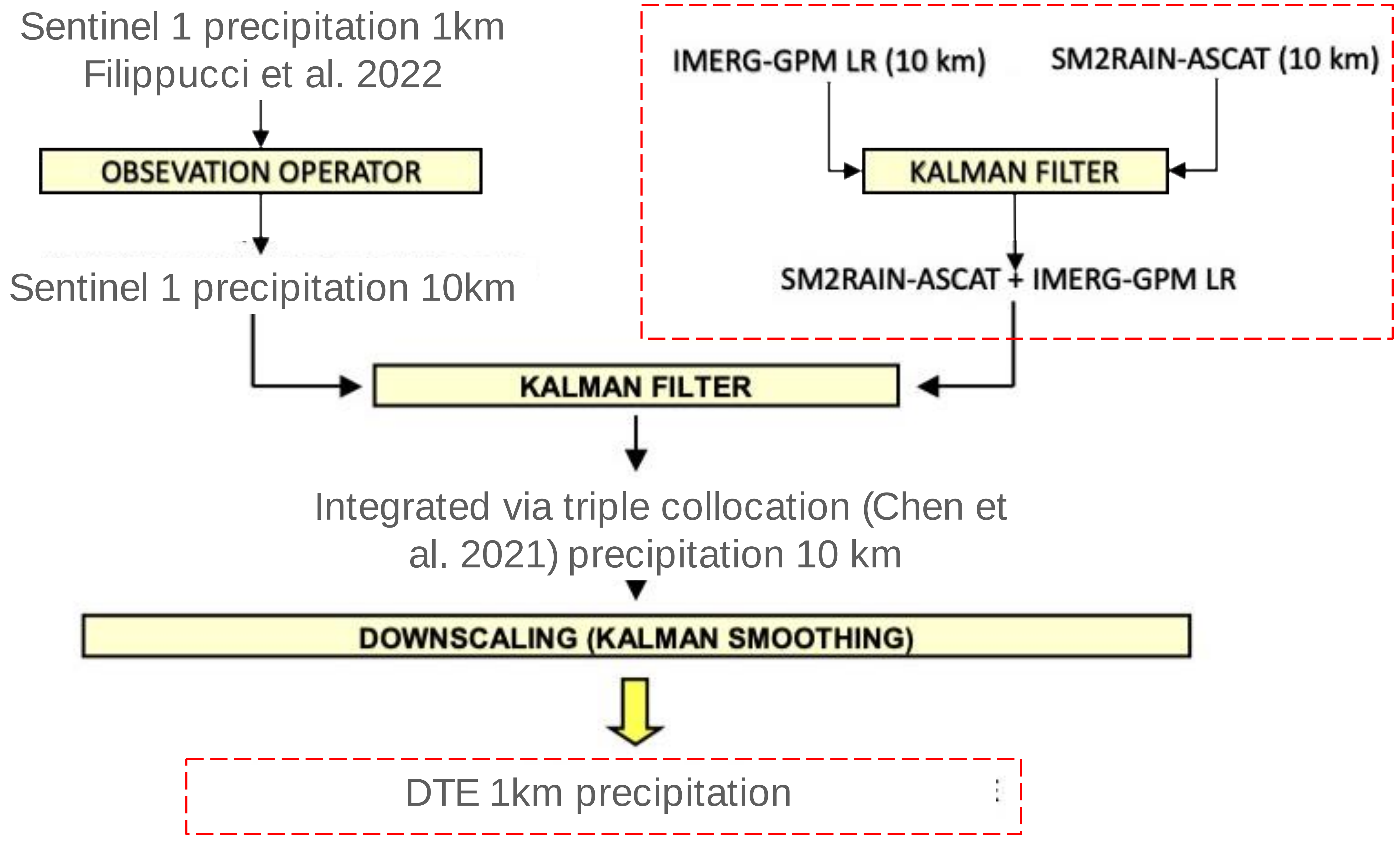
A daily 25 km short-latency rainfall product for data-scarce regions based on the integration of the Global Precipitation Measurement mission rainfall and multiple-satellite soil moisture products

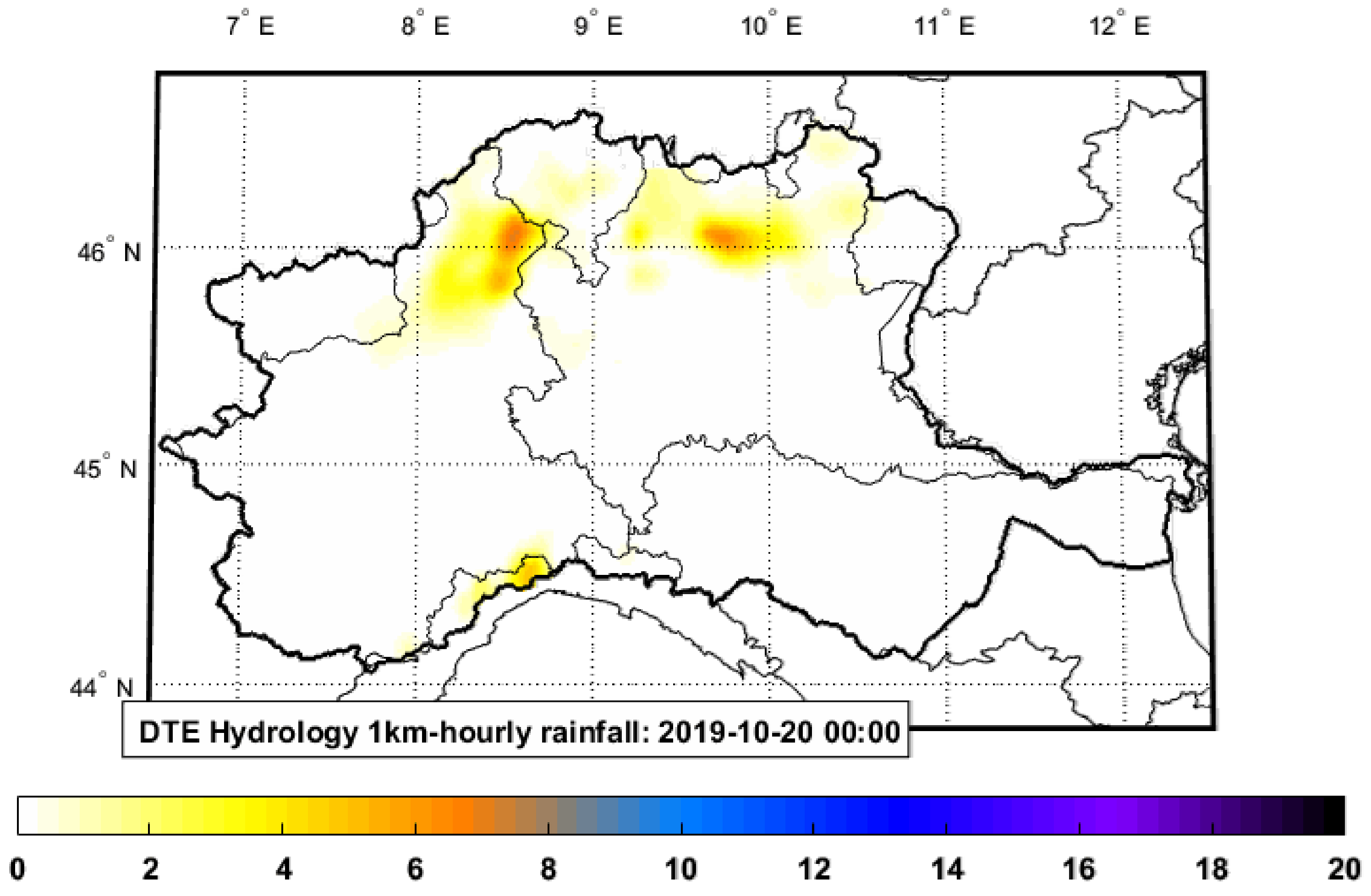
Christian Massari[1], Luca Brocca[1], Thierry Pellarin[2], Gab Abramowitz[3], Paolo Filippucci[1], Luca Ciabatta[1], Viviana Maggioni[4], Yann Kerr[5], and Diego Fernandez Prieto[6]

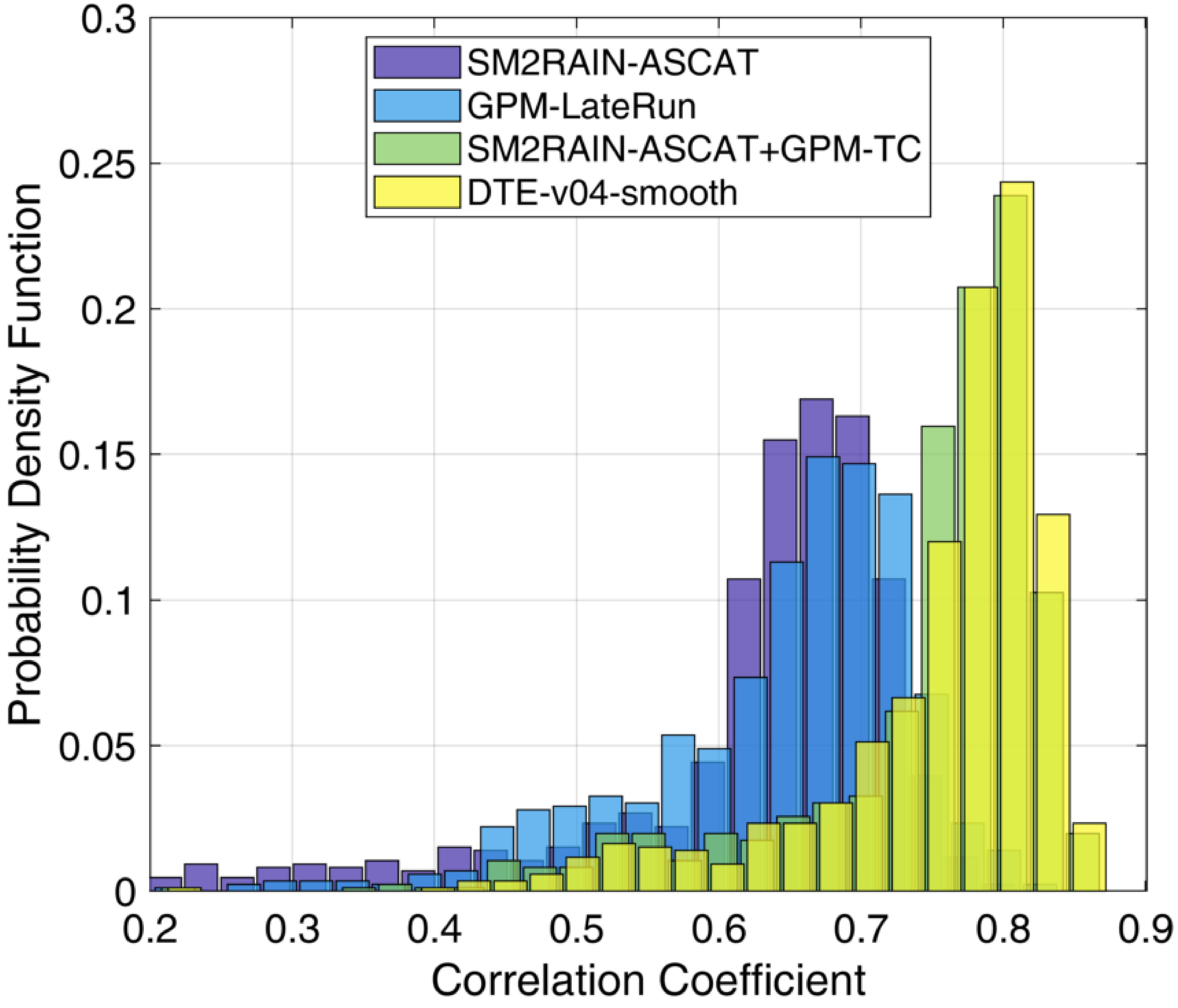
SMOS + RAINFALL · esa

Pellarin et al. 2013 (GRL), Brocca et al. 2014 (GRL), Massari et al. 2020 (HESS)

Other ways to use satellite soil moisture in flood forecasting: improving precipitation





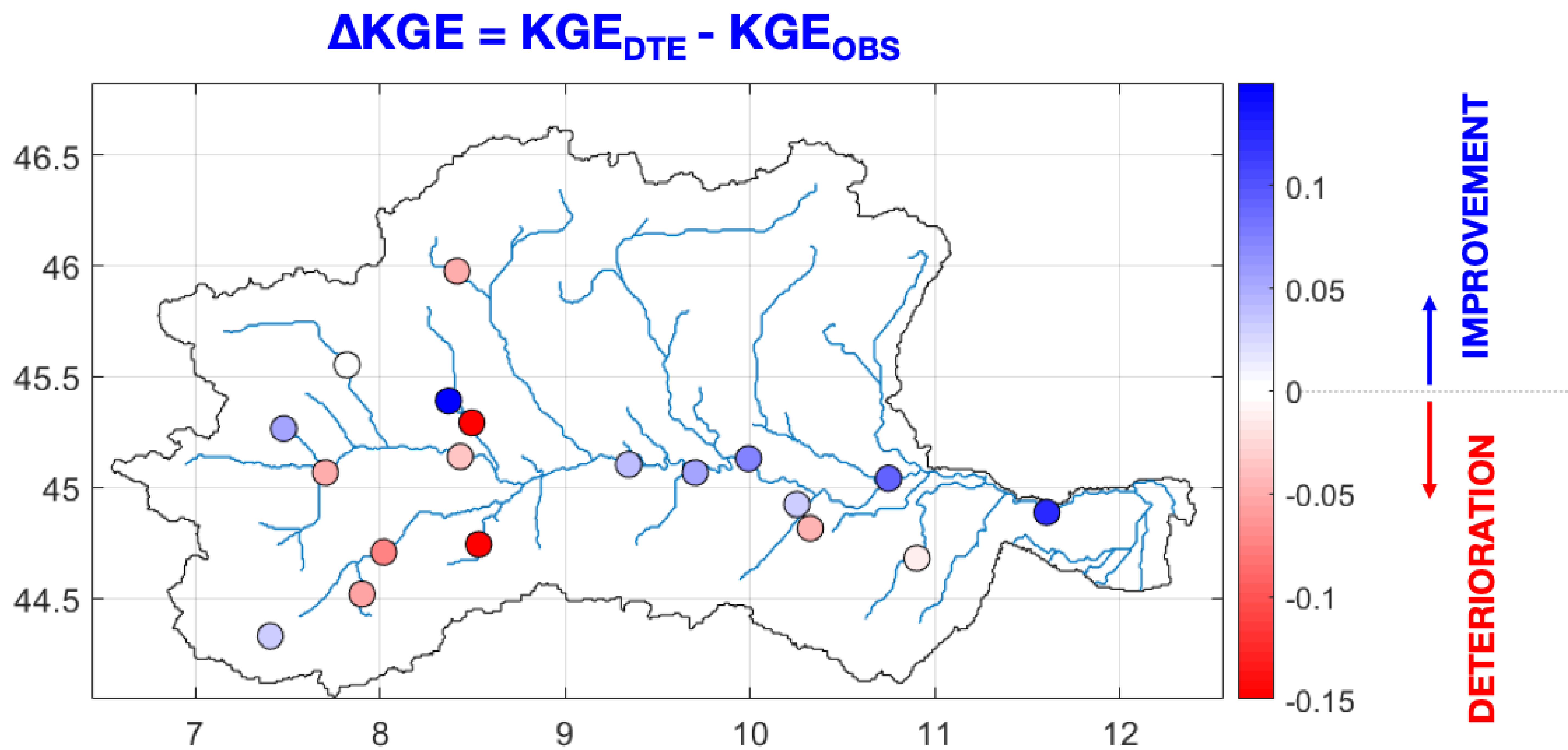


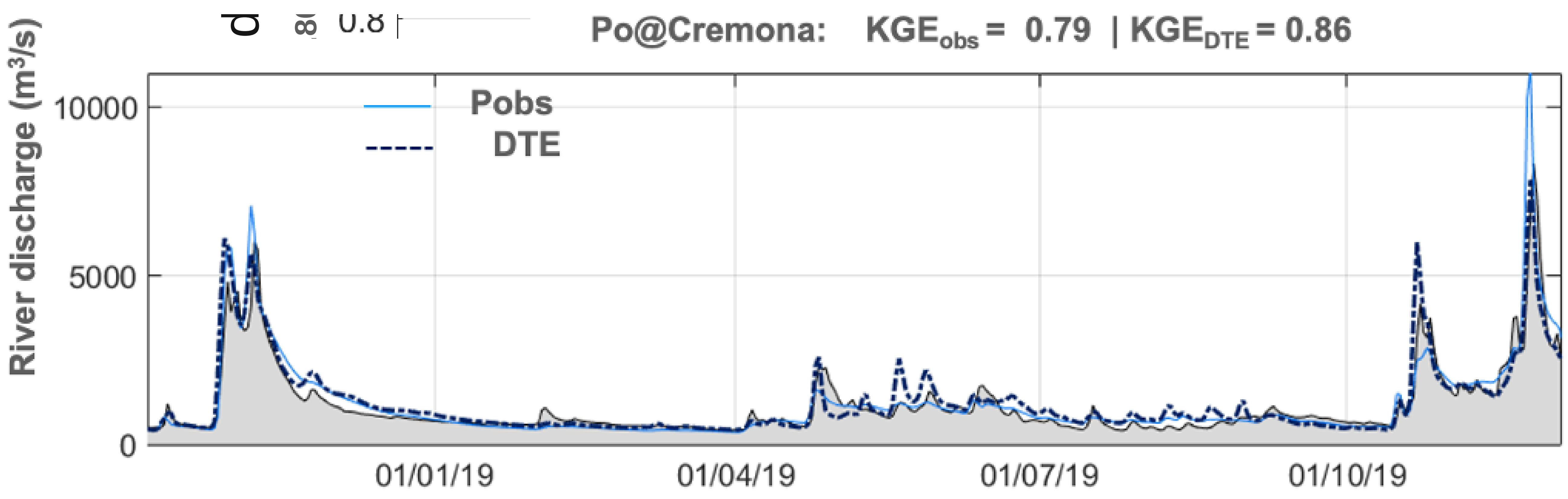
DTE, 4DMED-Hydrology - Mosaffa & Filippucci et al. 2022 in prep.

Other ways to use satellite soil moisture in flood forecasting: improving precipitation

Po River basin

△ Raingauges ● Hydrometric stations ~ River network

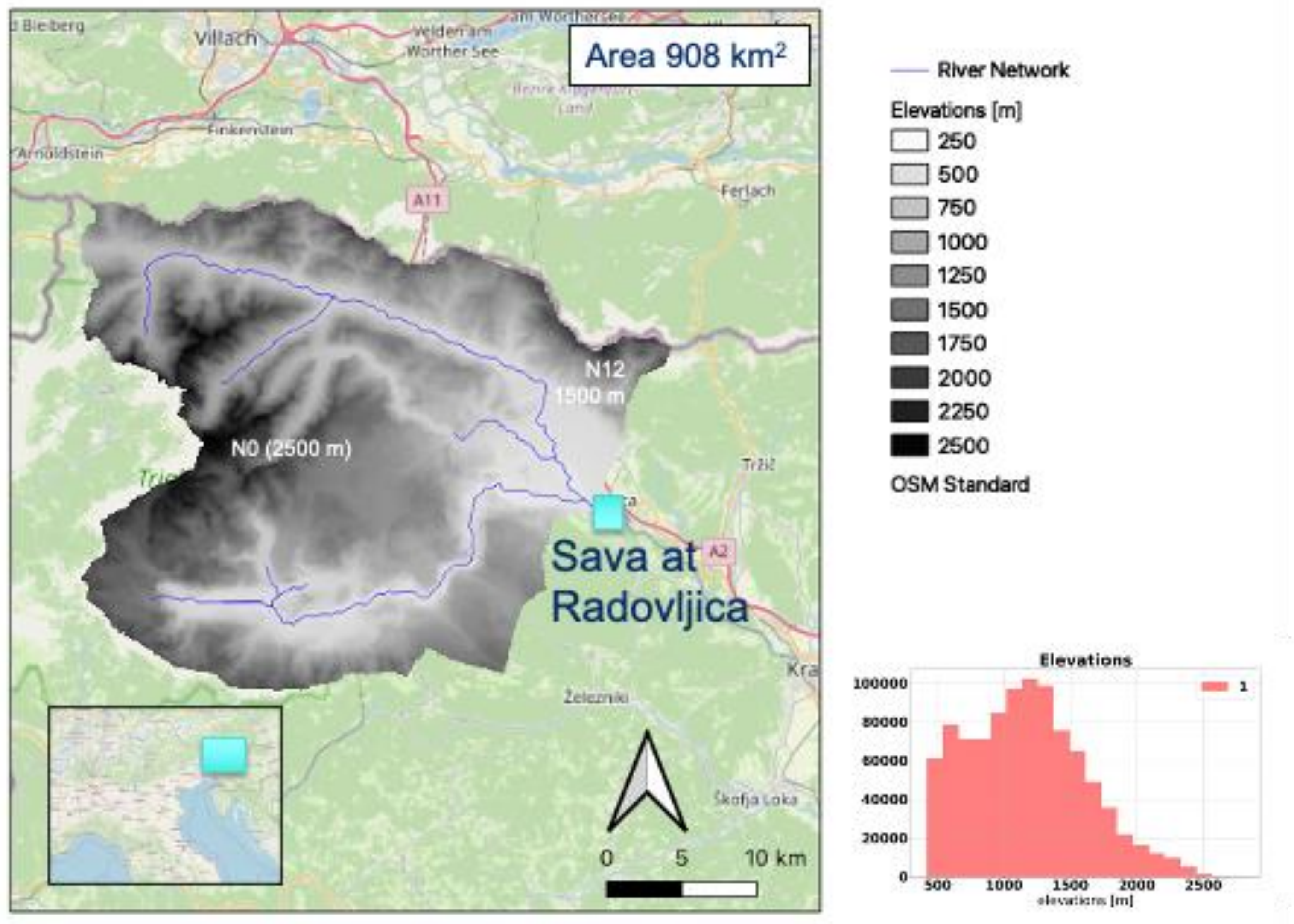


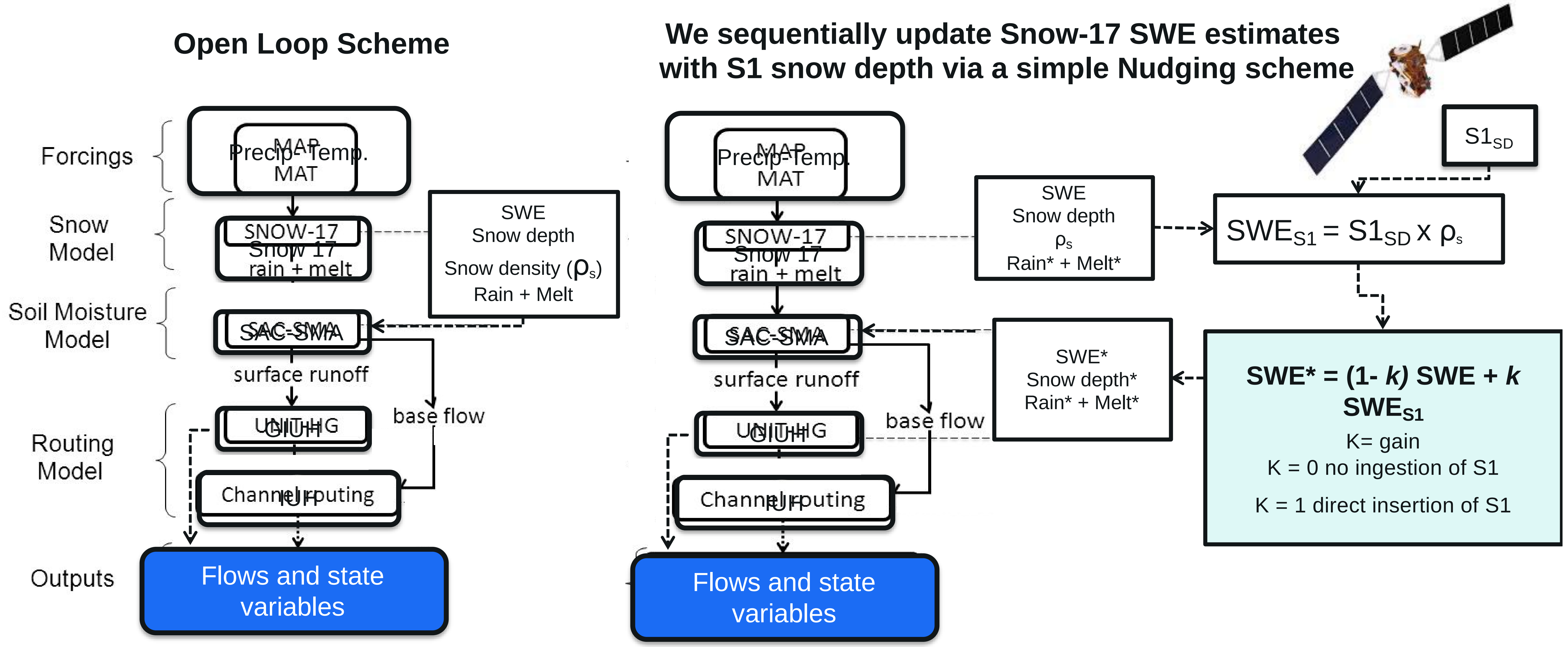


Basin area = 71’000 km^2
642 raingauges (~ 1 raingauge/100 km^2)
19 hydrometric stations!!
Hourly rainfall, air temperature and river discharge (2016-2019)
Simulation with MISDc 2L Hydrological model (Massari et al. 2018)

ESA Digital Twin Earth Hydrology project, Camici et al. 2021 EUMETSAT conf

What about snow? Assimilating sentinel 1 snow depth observations



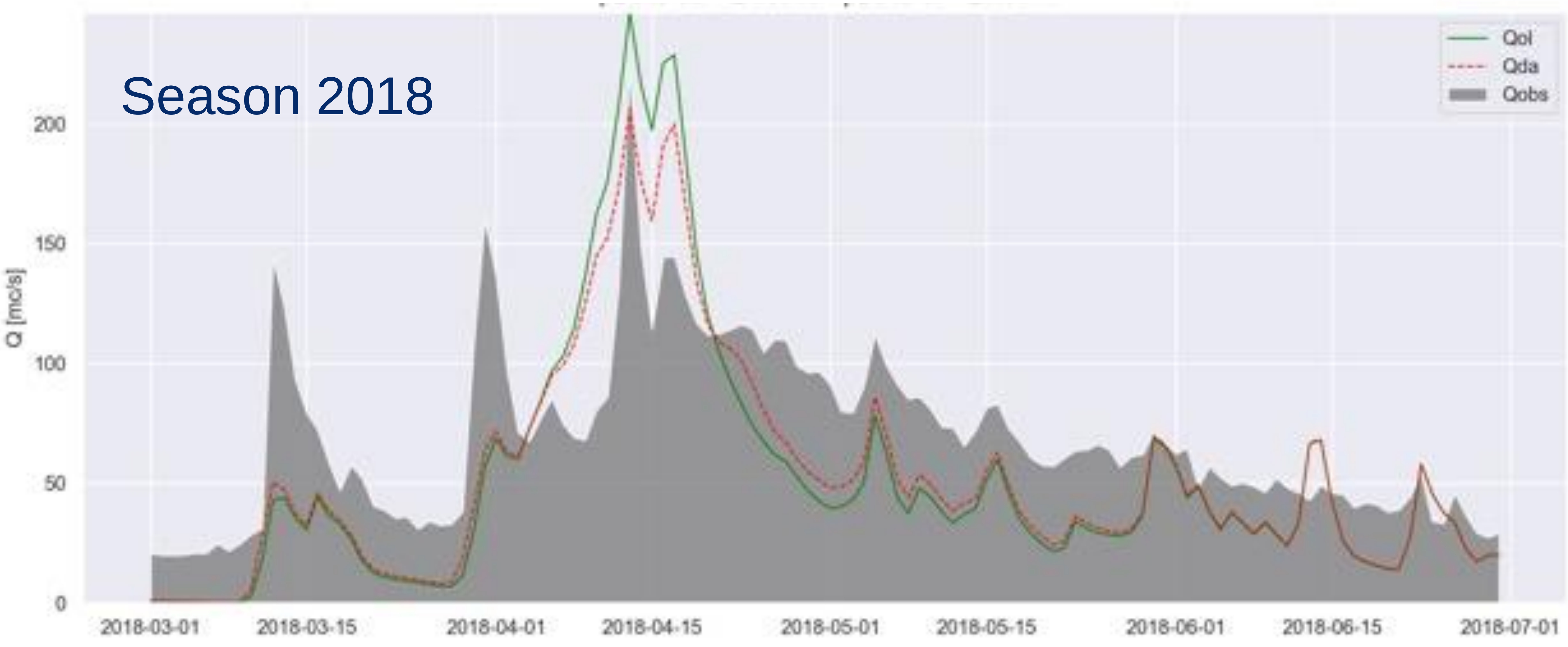



Article | Open Access | Published: 11 October 2019

Snow depth variability in the Northern Hemisphere mountains observed from space

Lievens et al. 2019

KGE OL= 0.43 → KGE DA = 0.60



- Precipitation: IMERG-FR (Satellite 10km)
- Temperature: ERA5 (Reanalysis 36km)
- Sacramento Model (SAC-SMA) (run with 1 km spatial grid)
- Snow-17 model (modified for the calculation of snow density and snow depth - courtesy of Mark Railegh)

Massari et al. (AGU 2020), Girotto et al. in prep

Lessons learnt and take home messages

- New Earth Observation data show promising results for improving model forecast of floods across different areas of Europe (provided that they are used for the right reasons)

- Current data availability of Sentinel 1 is good but the revisit time of this product (3/6 days) can be too large for its use for flood forecasting (especially for flash flood and flood forecasting in small to medium catchments as those of the Mediterranean areas)

- We hope a new efforts from space agencies to provide sub-daily microwave observations as to predict better catchment pre-storm conditions and provide near real time correction of precipitation

Email: christian.massari@irpi.cnr.it
http://hydrology.irpi.cnr.it/people/christian-massari/

Thanks a lot for your attention!

Email: christian.massari@irpi.cnr.it
http://hydrology.irpi.cnr.it/people/christian-massari/