



GDR RHYMA

Groupement de recherche international-Sud : Risques Hydrologiques au Maghreb

Leveraging new Earth observation data for improving flood forecasting in Europe

Christian Massari

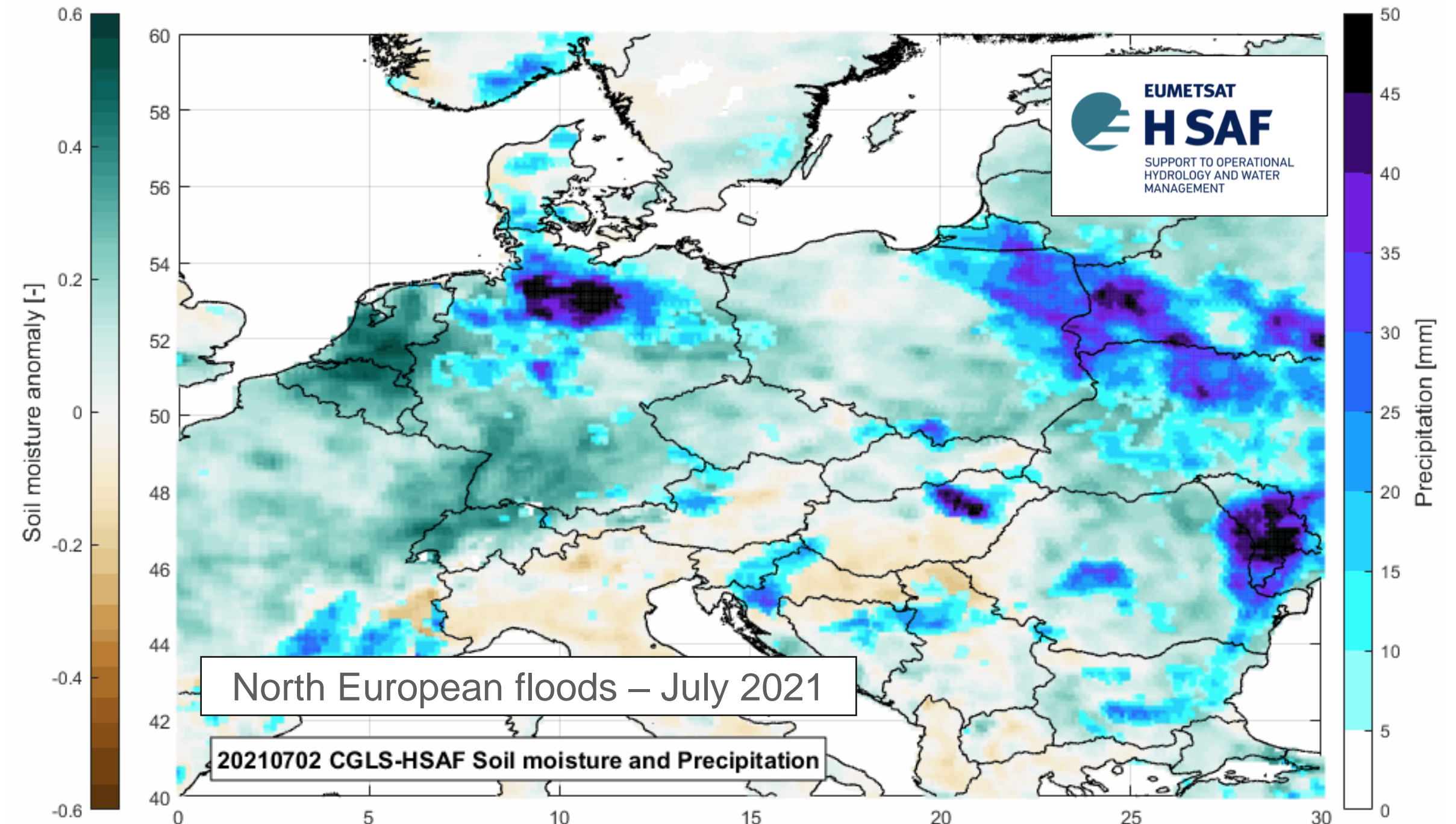
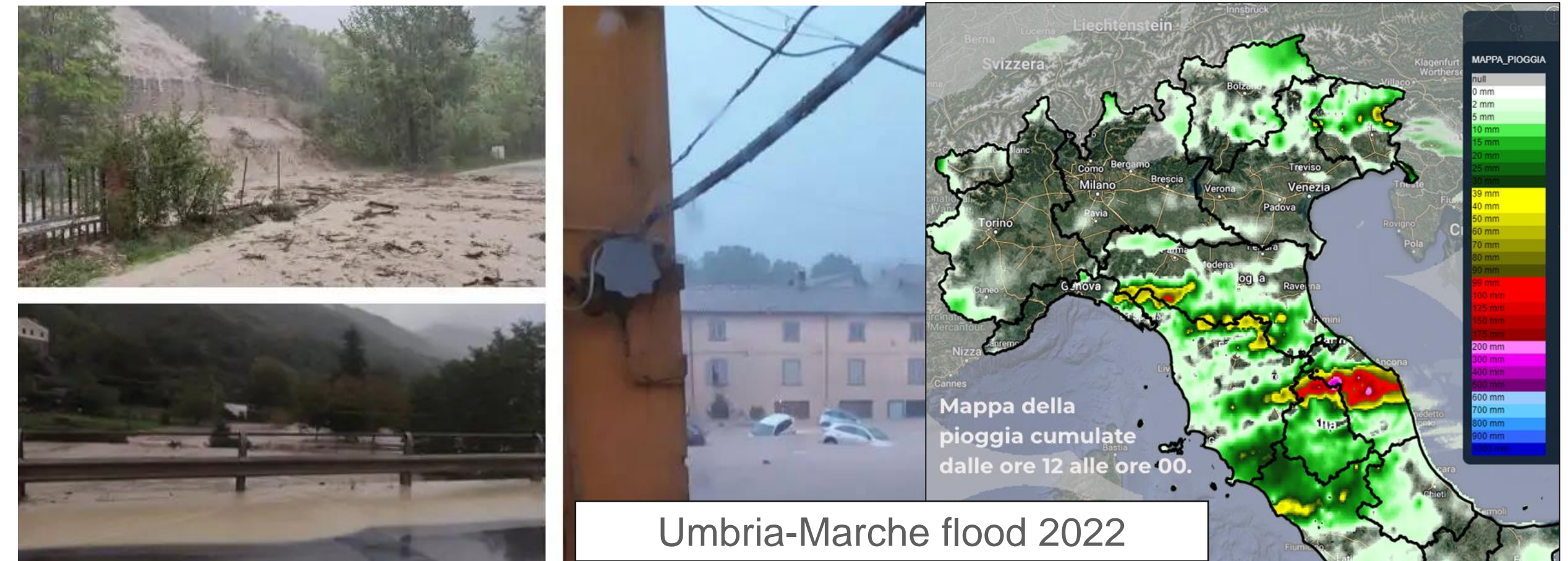
Azimi Shima, Bechtold Michel, Brocca Luca, Camici Stefania, Ciabatta Luca, Crow Wade, De Lannoy Gabrielle, De Santis Domenico, Filippucci Paolo, Giroto Emanuela, Grundemann Gaby, Hascoet Tristan, Marra Francesco, Modanesi Sara, Pellarin Thierry, Penna Daniele, Pellet Victor, Trambly Yves

20 September 2022

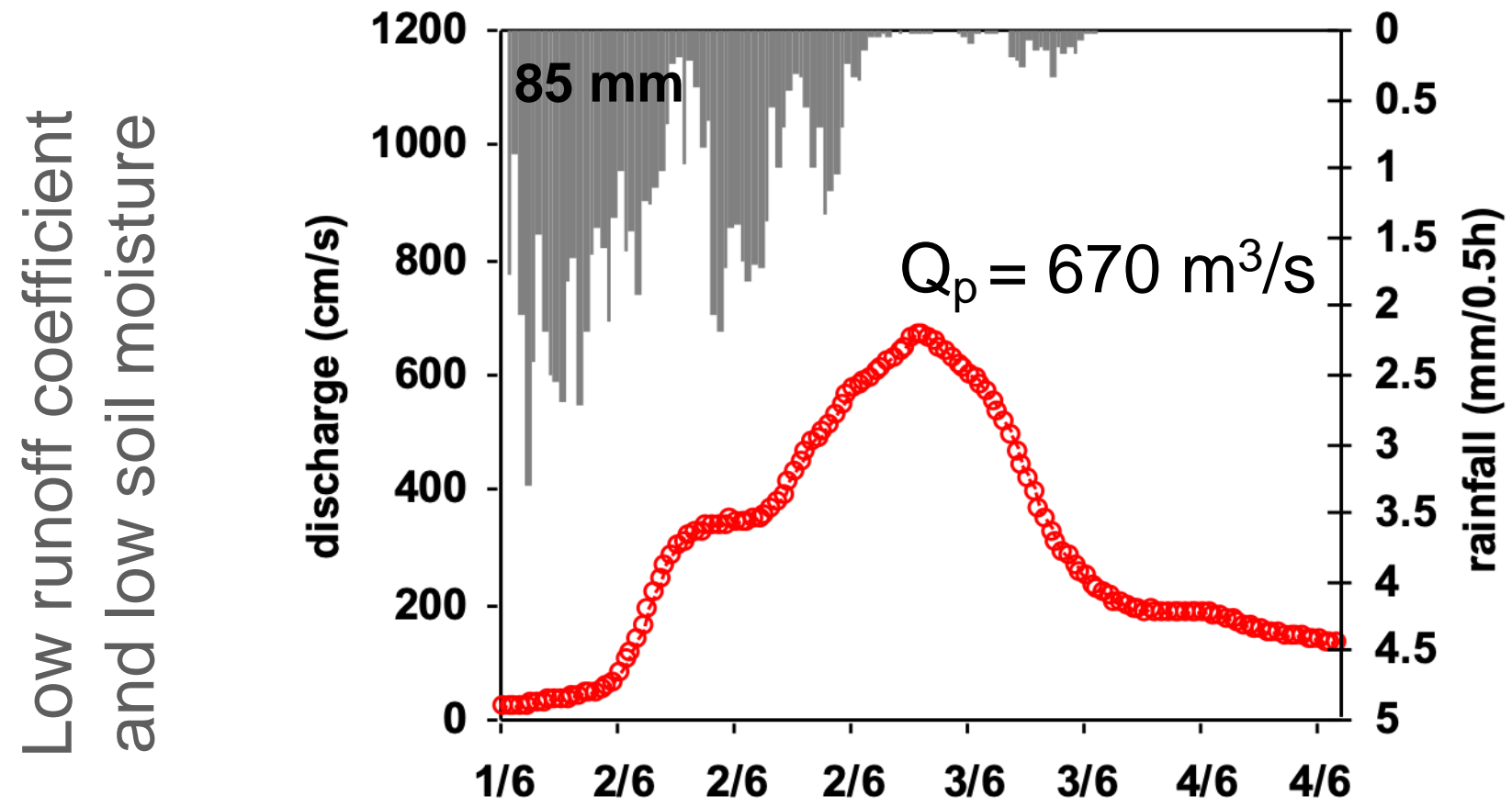
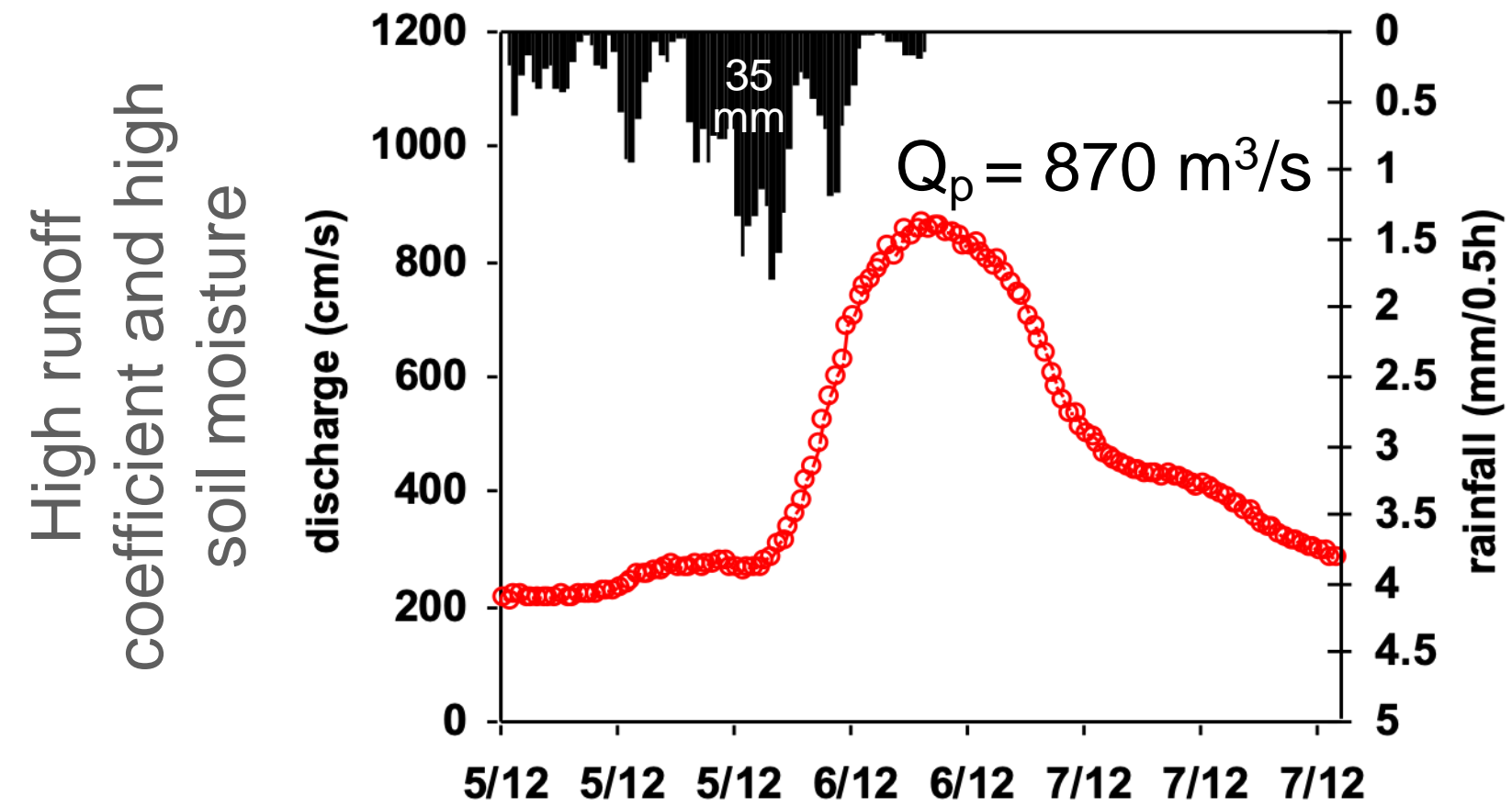
Floods in Europe

- 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.

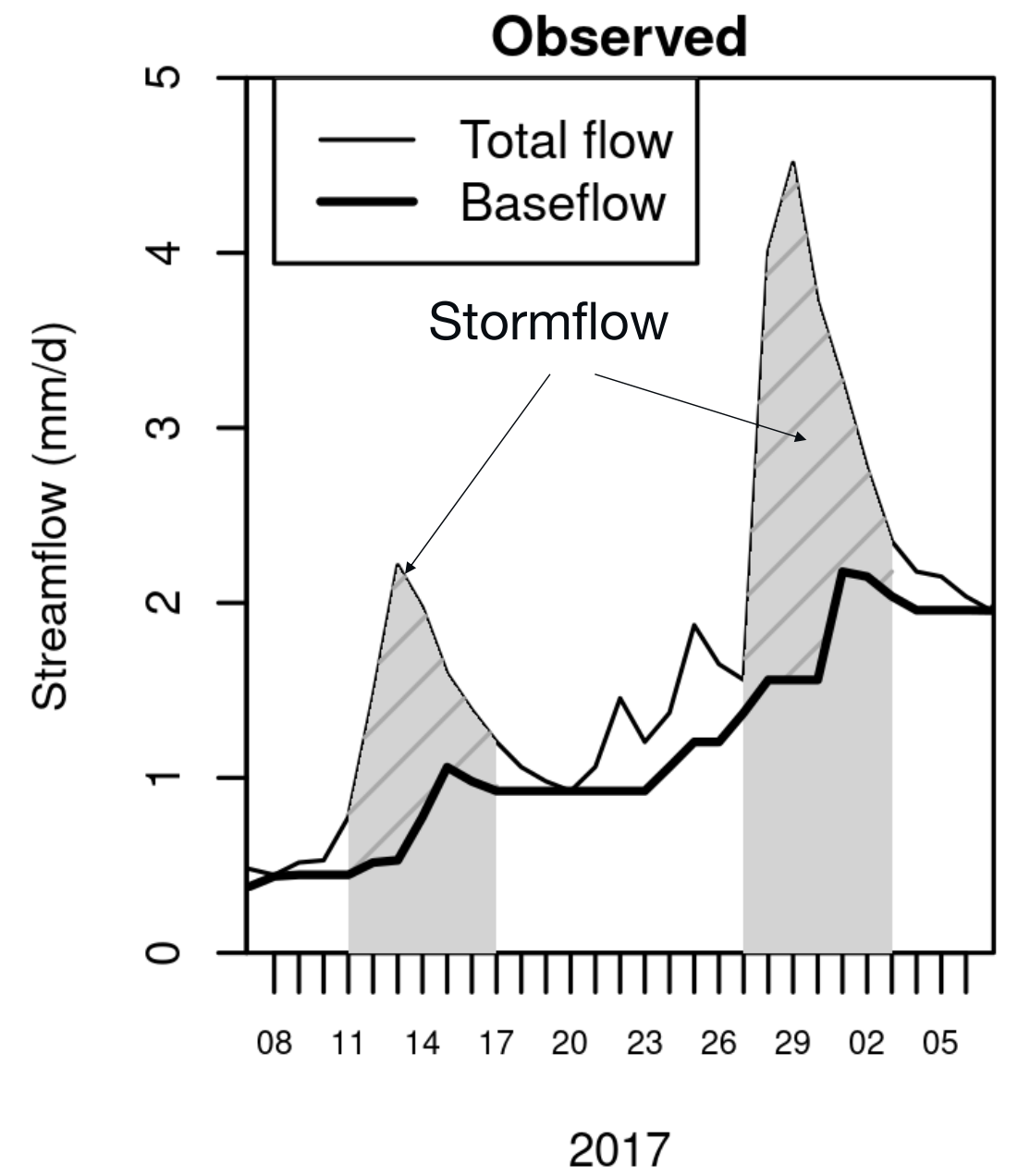
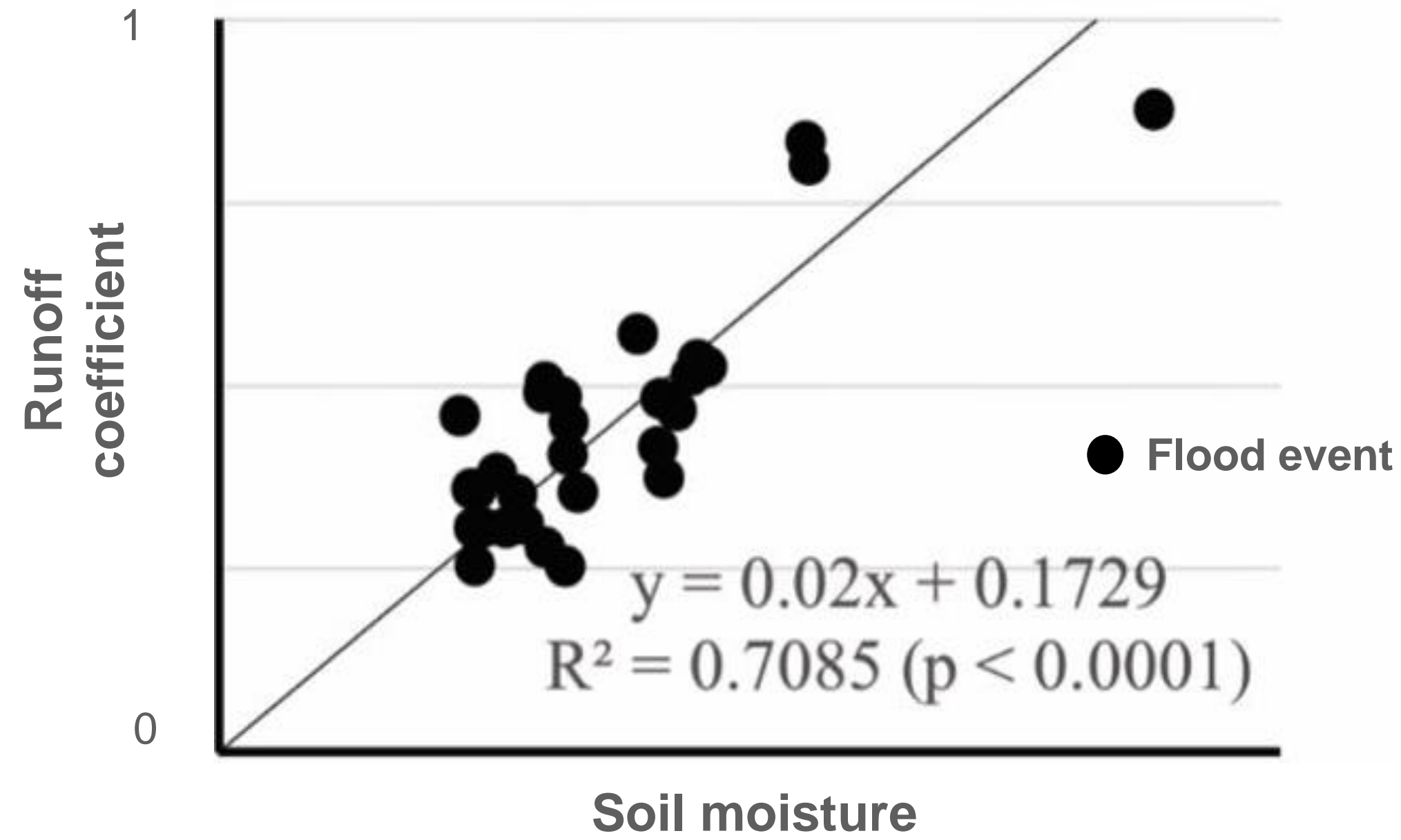
European Environment Agency (EEA, 2021)



However not only precipitation is important



Tiber River Basin - Central Italy



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

nature geoscience LETTERS

PUBLISHED ONLINE: 22 AUGUST 2010 | DOI: 10.1038/NCEO944

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 Livneh³, Dennis P. Lettenmaier³ and Rolf H. Reichle¹

Operational soil moisture products (COPERNICUS, H SAF)

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

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Soil moisture gridded data from 1978 to present

Currently the dataset provider is not able to process requests. Please try again later.

Overview Download data Documentation

This dataset provides estimates of soil moisture over the globe from a large set of satellite sensors. It is based on the ESA Climate Change Initiative soil moisture version 03.3 and represents the current state-of-the-art for satellite-based soil moisture climate data record production, in line with the "systematic observation requirements for satellite-based products for climate" as defined by GCOS (Global Climate Observing System). Data are on a regular latitude/longitude grid expectedly with gaps in space and time.

When dealing with satellite data it is common to encounter references to Climate Data Records (CDR) and Interim-CDR (ICDR). For this dataset both the ICDR and CDR parts of each product were generated using the same software and algorithms. The ICDR provides a short-delay access to current data where consistency with the CDR baseline is expected but was not extensively checked. The dataset contains the following products: "active", "passive" and "combined". The "active" and "passive" products were created by using scatterometer and radiometer soil moisture products, respectively. The "combined" product results from a blend based on the two previous products.

More details about the product are given in the Documentation section.

Volumetric Soil Moisture Uncertainty

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

Copernicus Global Land Service
Providing bio-geophysical products of global land surface

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Burnt Area NDVI
Dry Matter Prod. Soil Water Index
FAPAR Surf. Soil Moisture
FCOVER VCI
Leaf Area Index VPI
Land Cover

Soil Water Index

The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. Soil moisture is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Satellite measurements integrate over relative large-scale areas with the presence of vegetation adding complexity to the interpretation.

SWI product updates
SWI reformatting to netCDF4
Mon, 24 Sep 2018
Quality information on the SWI product available
Mon, 24 Sep 2018

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

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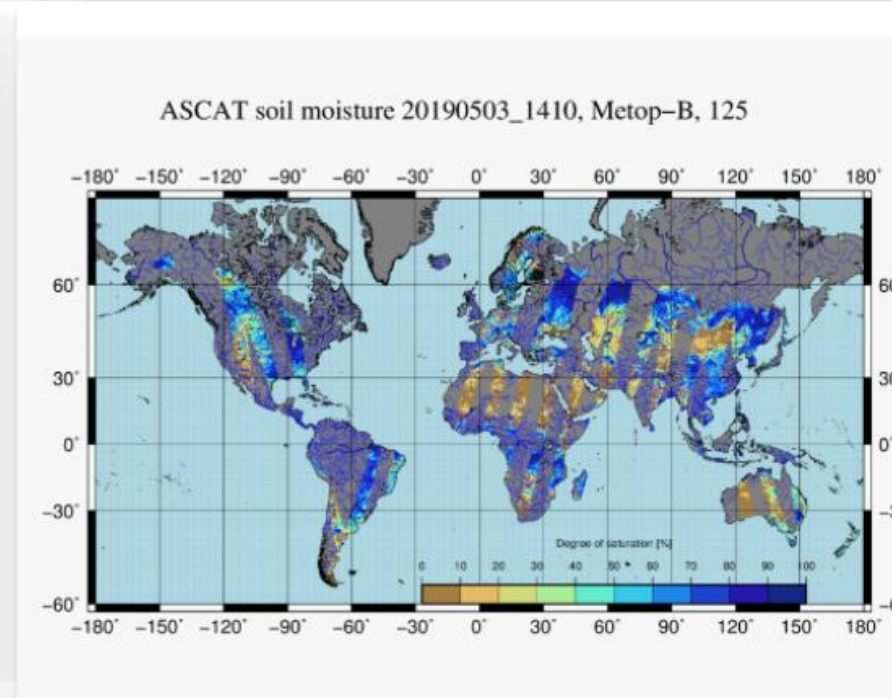
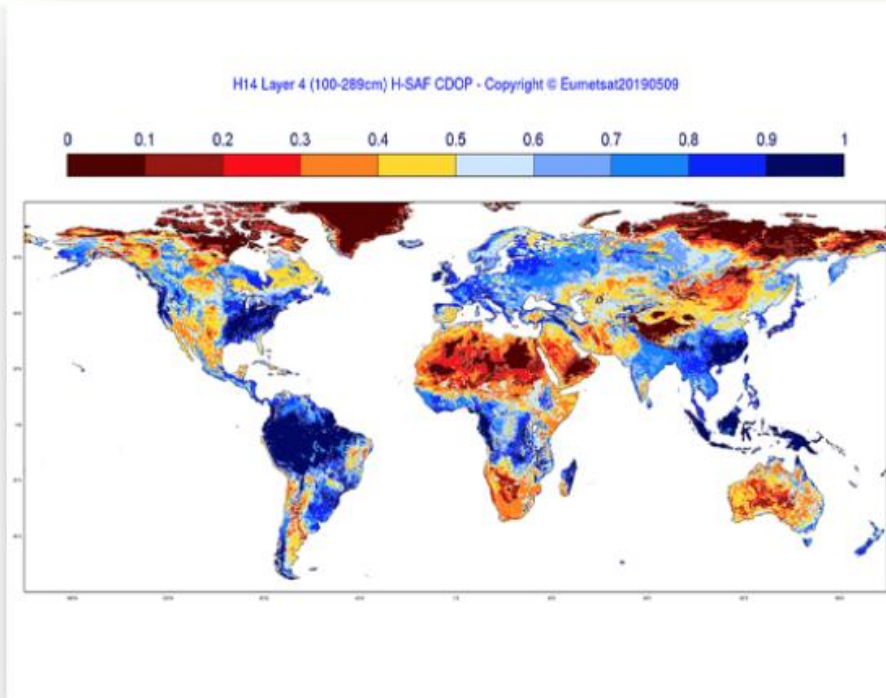
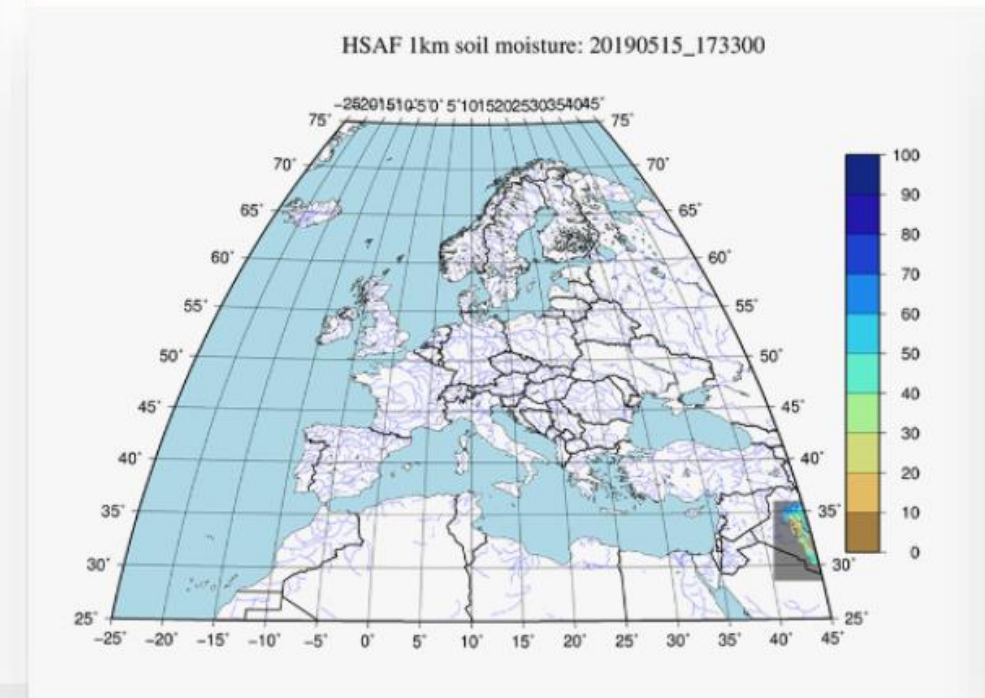
Burnt Area NDVI
Dry Matter Prod. Soil Water Index
FAPAR Surf. Soil Moisture
FCOVER VCI
Leaf Area Index VPI
Land Cover

Surface Soil Moisture

Surface Soil Moisture (SSM) is the relative water content of the top few centimetres soil, describing how wet or dry the soil is in its topmost layer, expressed in percent saturation. It is measured by satellite.

SSM product updates
Early Access - Surface Soil Moisture at 1km resolution over Europe
Mon, 24 Sep 2018

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



SSM-ASCAT-B-NRT-012.5 (H16)

Metop-B ASCAT NRT SSM orbit geometry 12.5 km sampling

Soil moisture content in the surface layer (0.5-2 cm) express in degree of saturation (0 – 100 %) g ASCAT Metop-B at 12.5 km sampling, processed shortly after each satellite orbit completion. Co validation restricted to following conditions: low to moderate vegetation regimes, unfrozen and moderate topographic variations and no wetlands and coastal areas.

[ATBD](#)
[PUM](#)
[PVR](#)

[DETAIL](#)
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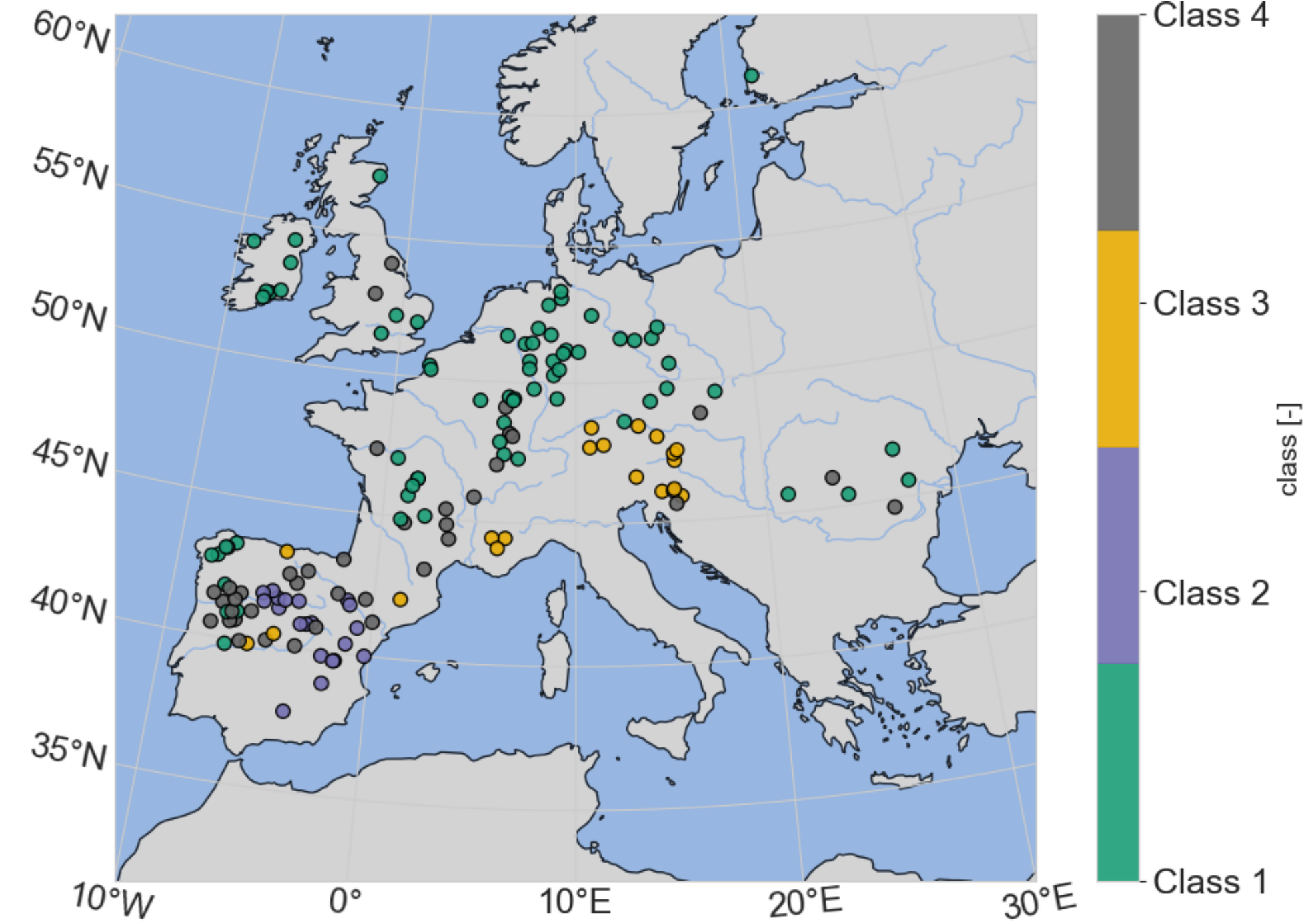
See presentations of Brocca et al., Ciabatta et al.
<https://www.eumetsat.int/eumetsat-meteorological-satellite-conference-2022>
 Next Thursday

EUMETSAT Meteorological
Satellite Conference 2022

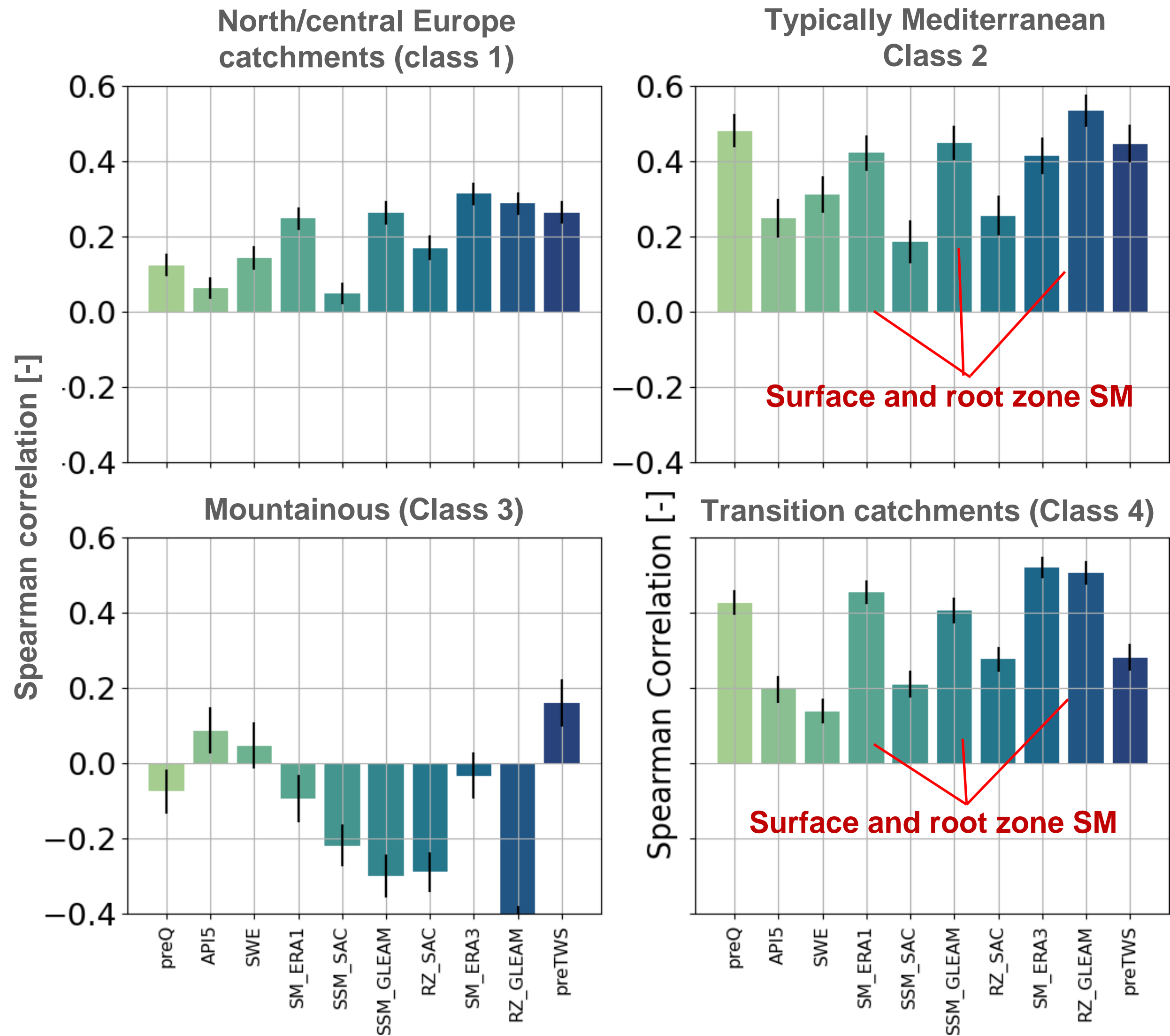
Brussels, Belgium, 19-23 September 2022

Pre-storm proxies and catchment runoff coefficients in Europe

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



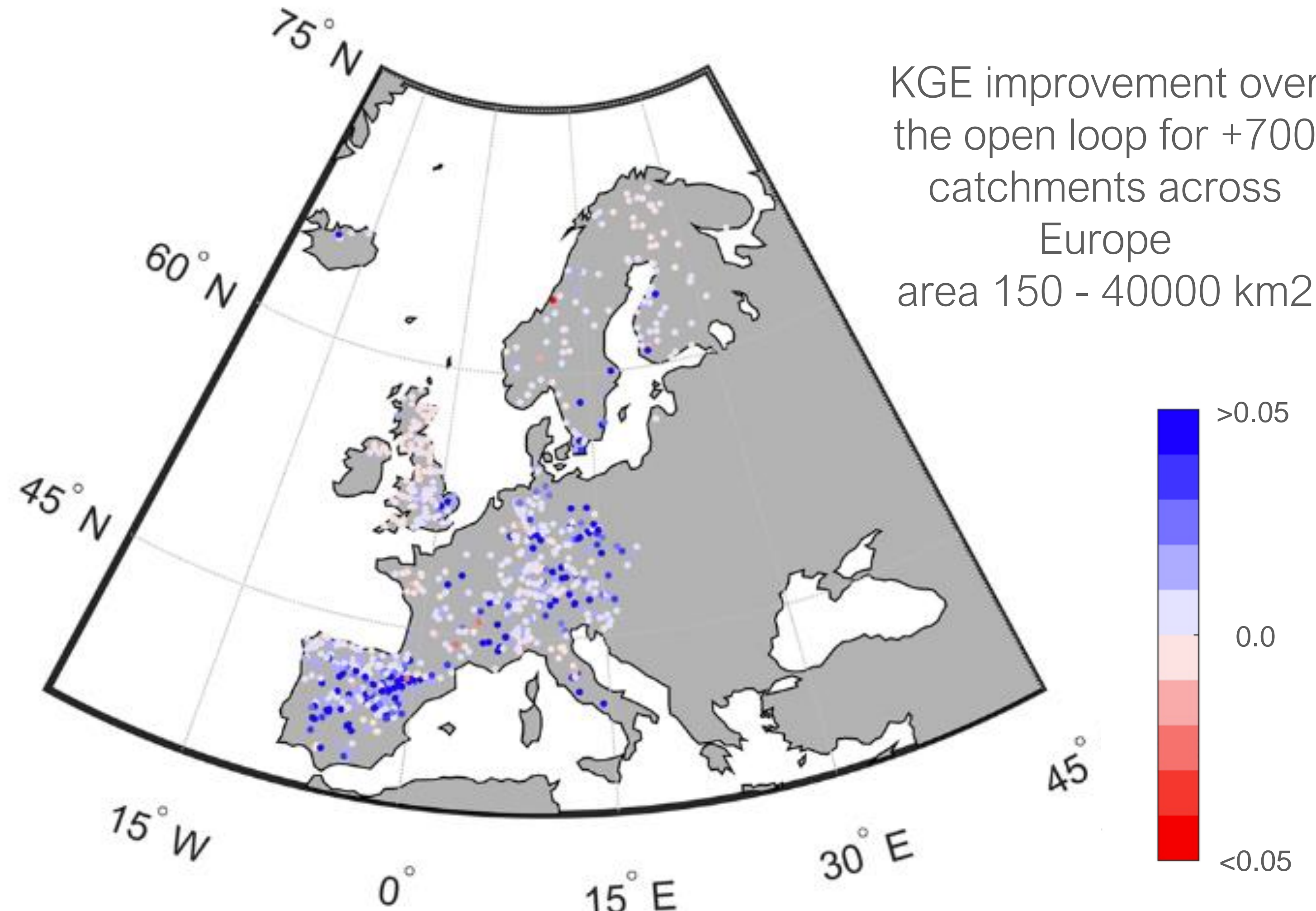
Catchment classification (k-means): **four different classes** based on topography, climate Land cover, hydrological behaviour (e.g., flashiness, BFI)



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

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



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

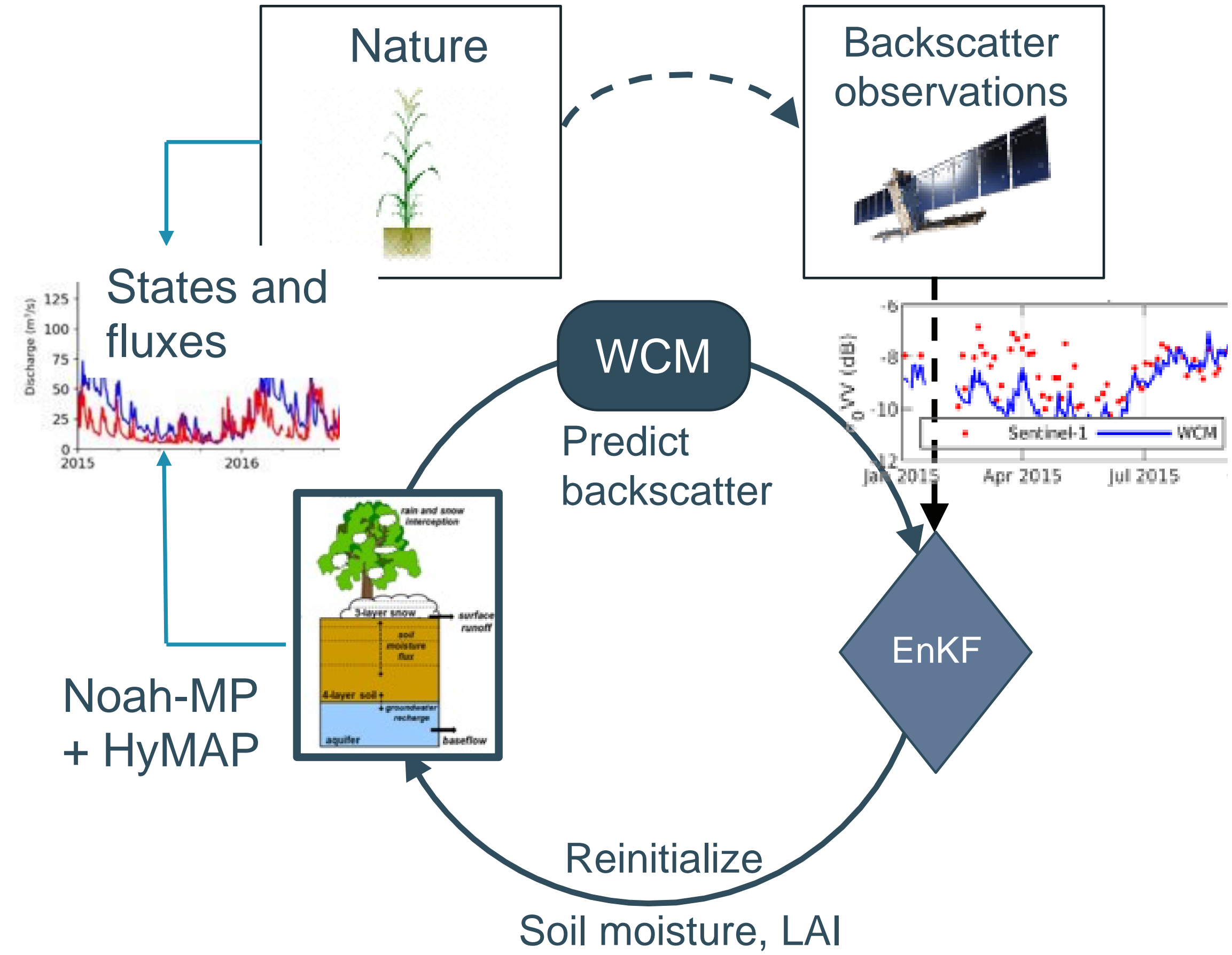
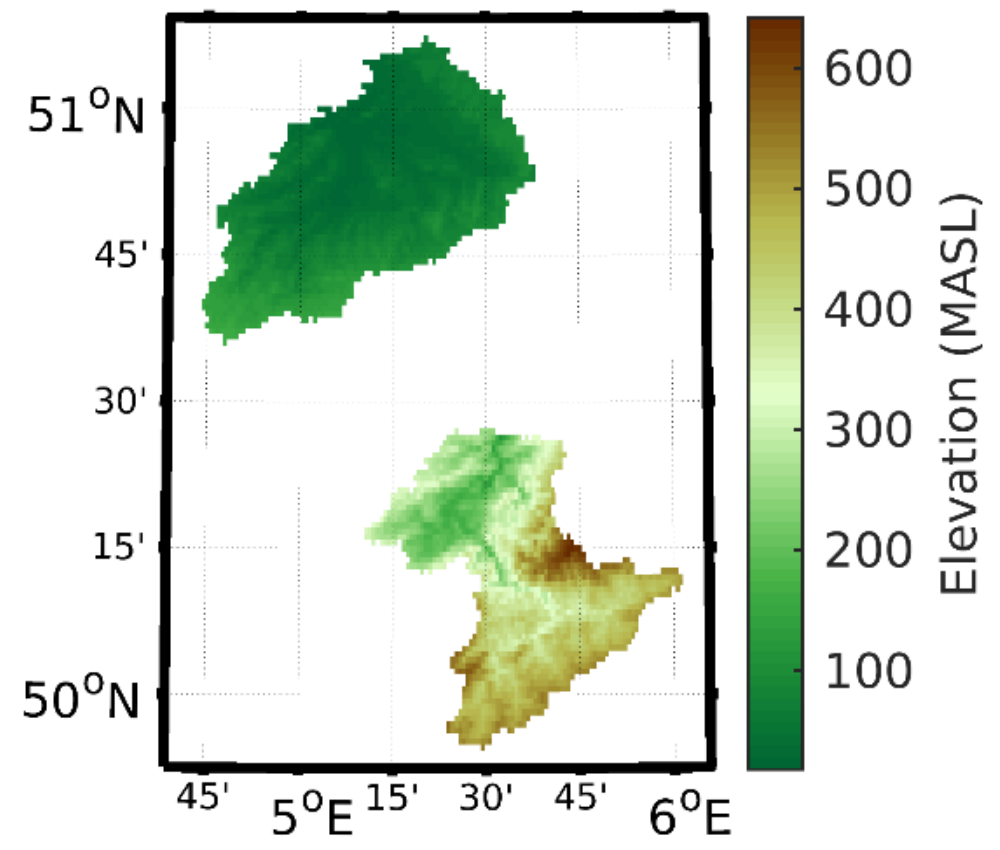
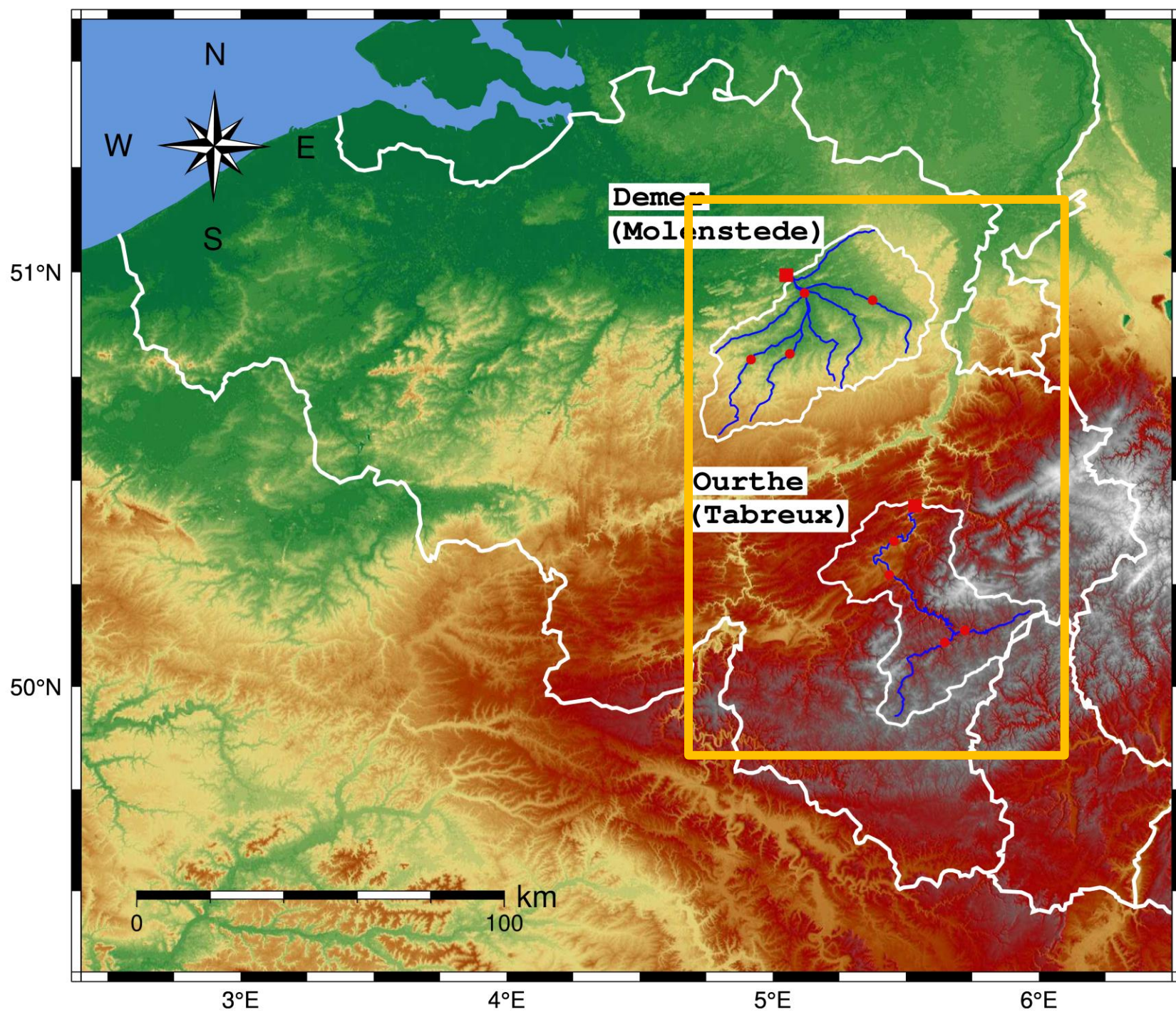
Rainfall and Temperature: data from the European 25km gridded data sets, E-OBS

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

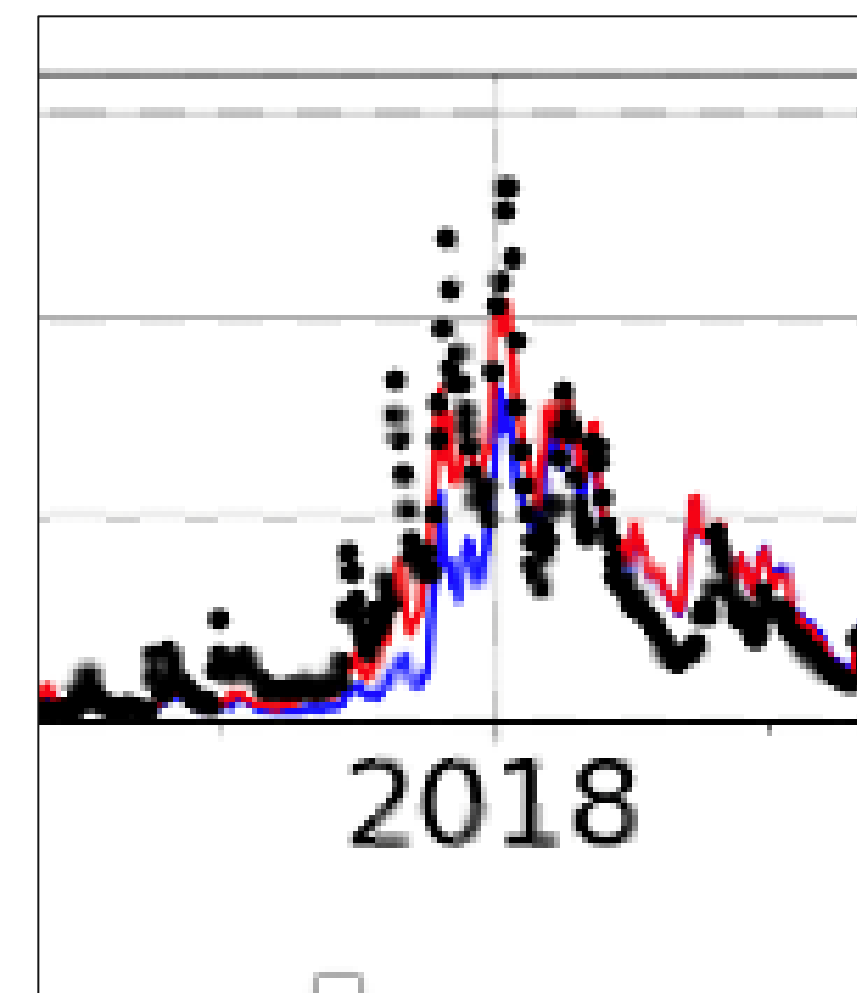
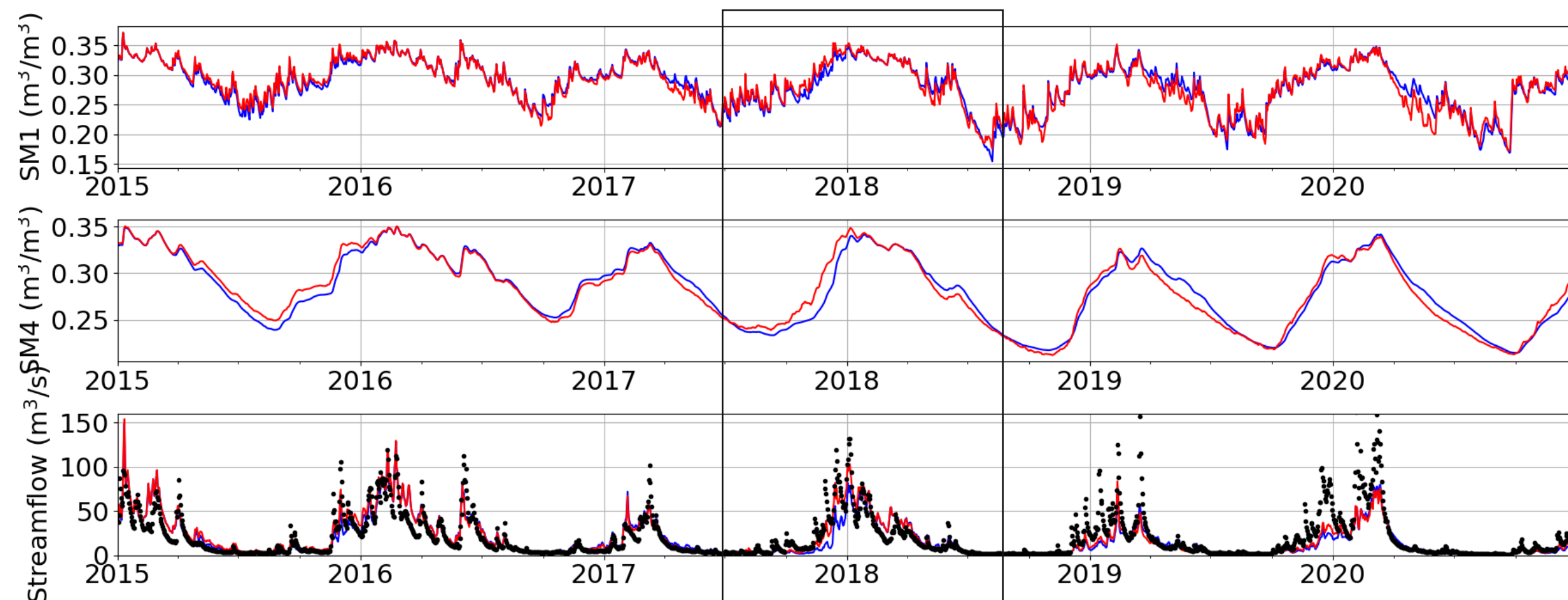
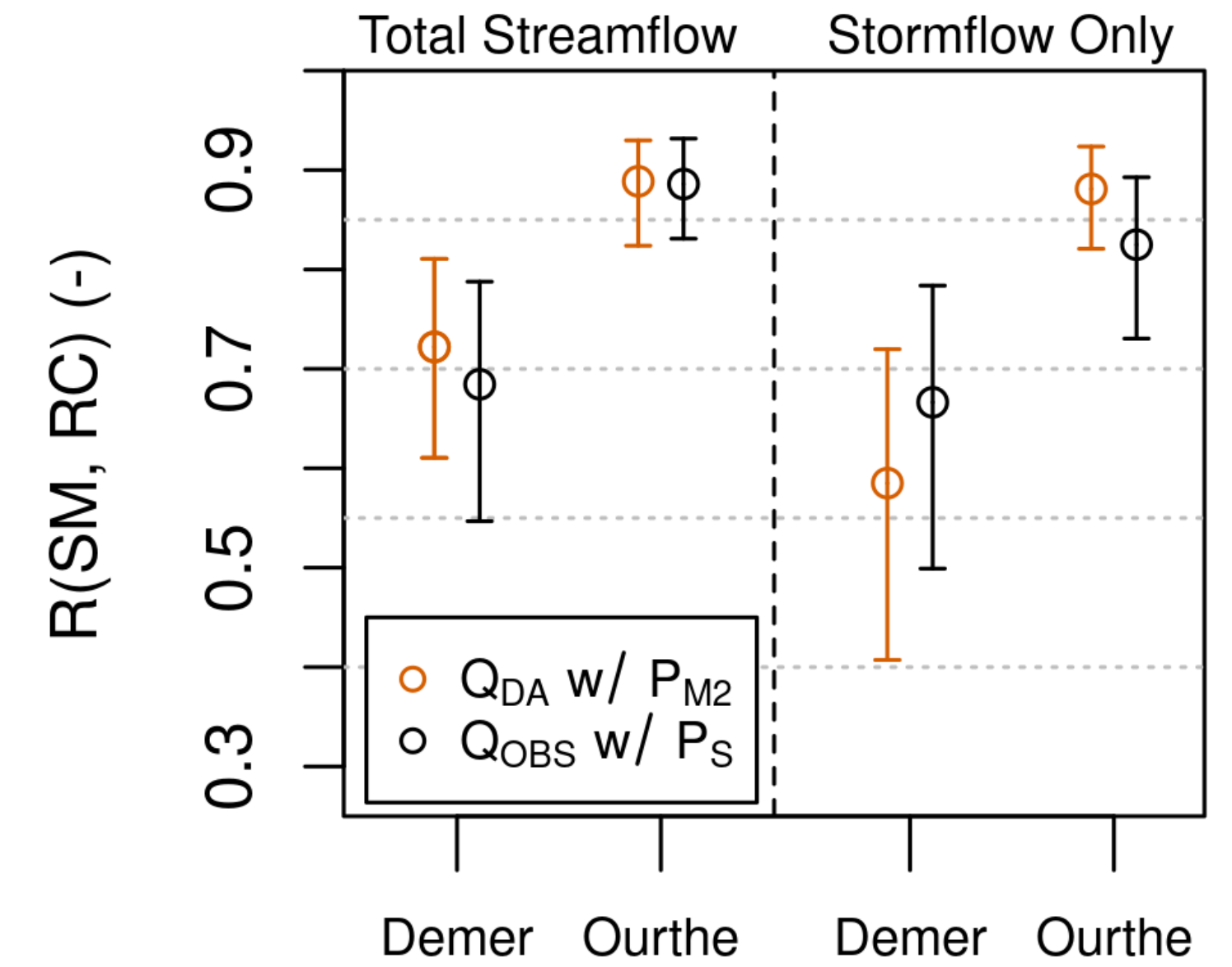
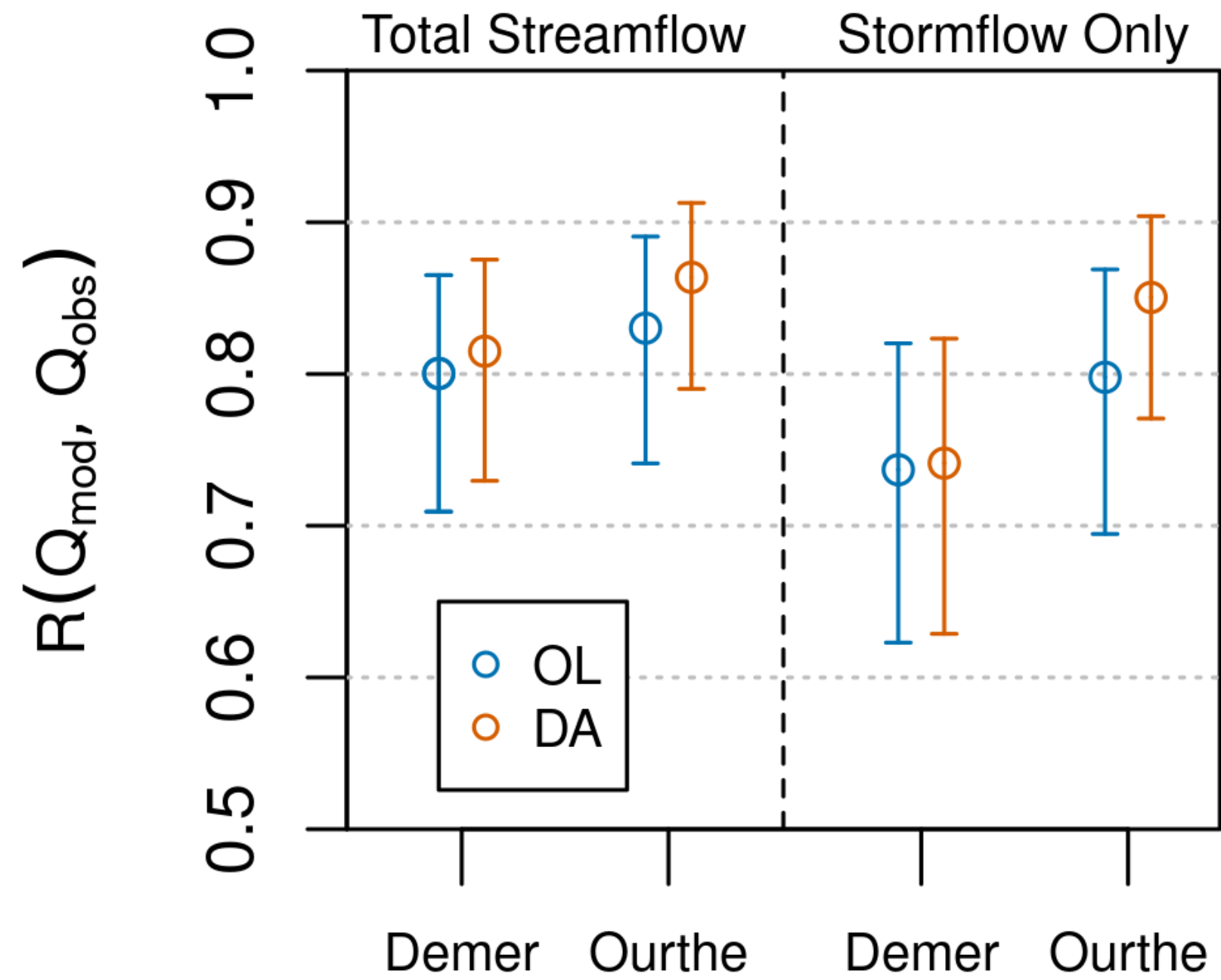
Sentinel 1 backscatter assimilation in Belgium for improving Noah-MP model runoff simulations (via correcting soil moisture and vegetation)



Demer 1950 km² less forested - agricultural land use

Ourthe 1616 km²: more forested

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

Data Assimilation (DA)

Open-Loop (OL)

Revisit time vs spatial resolution. What does it matter?

Hydrological model

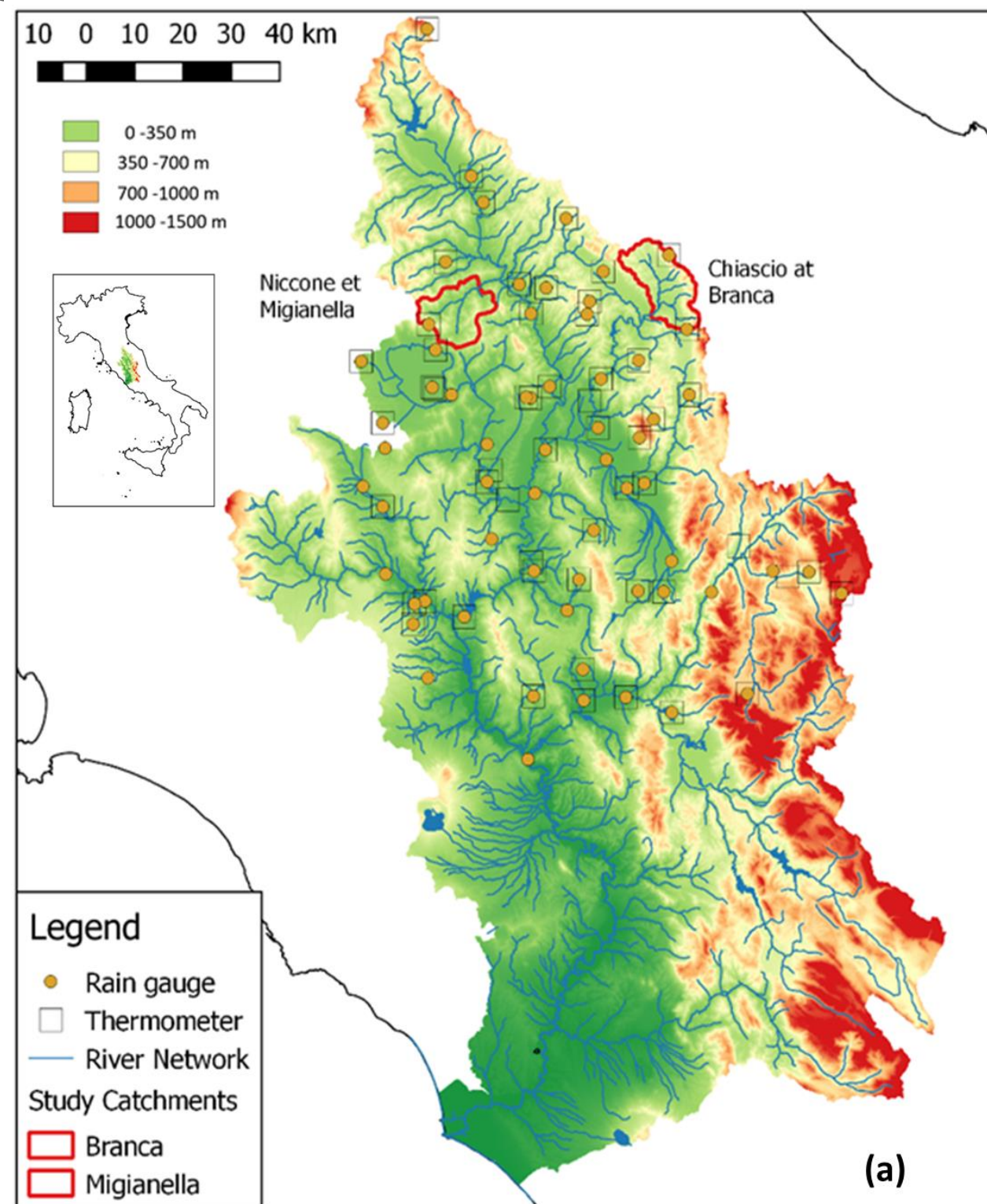
SWAT (physically based, distributed)

Assimilation scheme

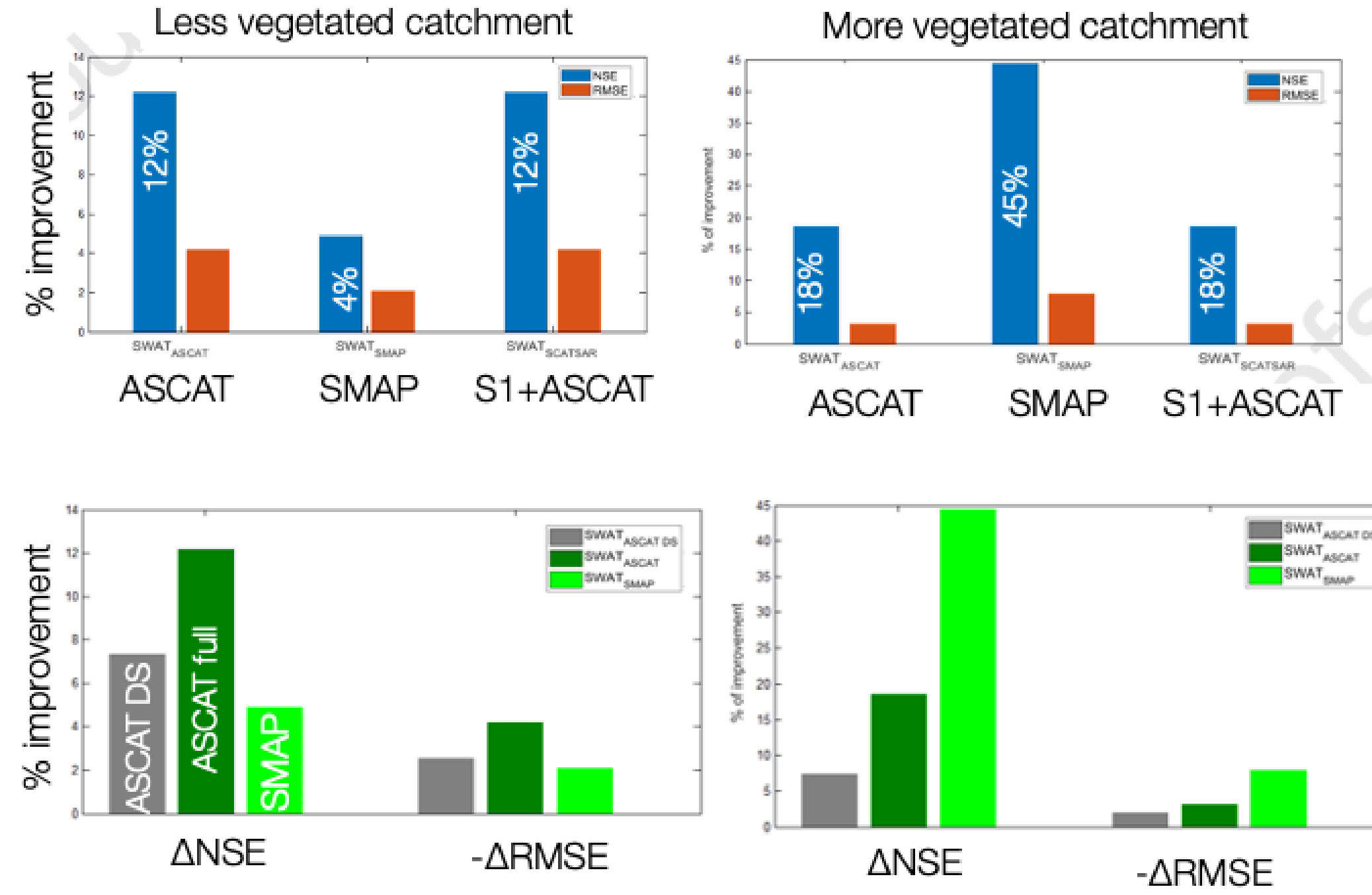
2D Ensemble Kalman Filter

Study area

Two small catchments in Tiber River
(area less than 100 km²) (Central Italy)



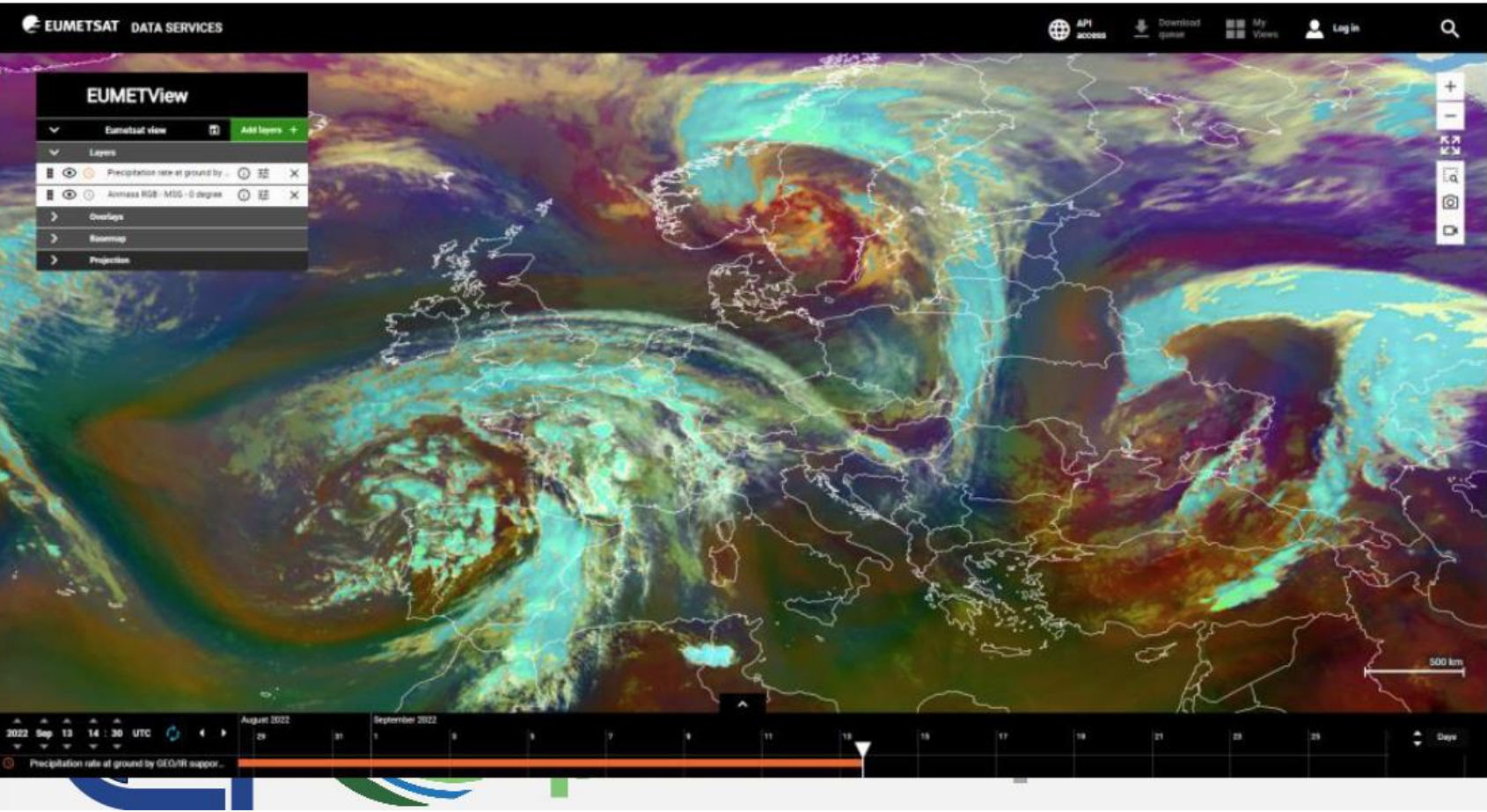
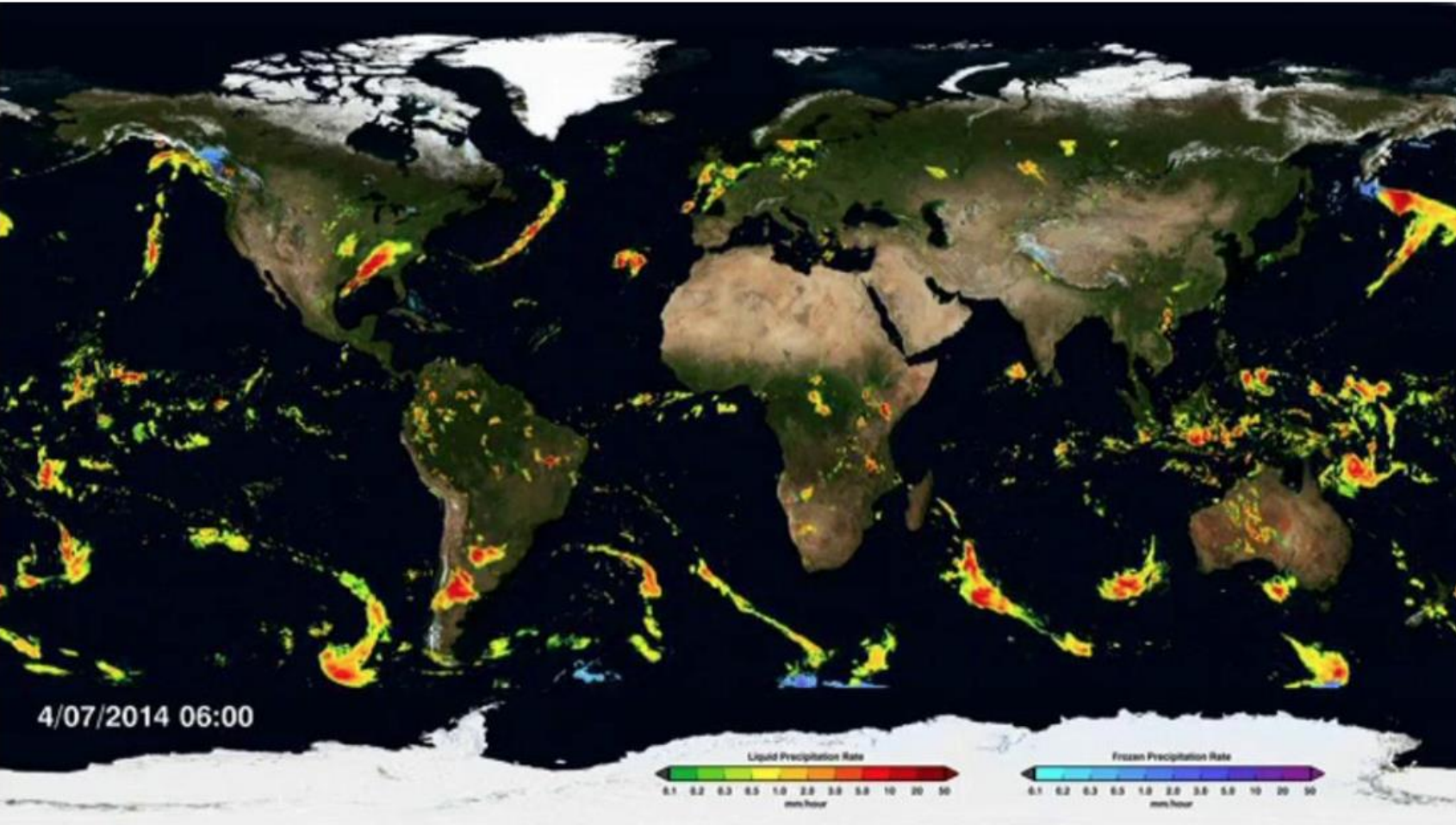
Impact of spatial resolution : **NSE** and **RMSE** improvement with respect of the OL



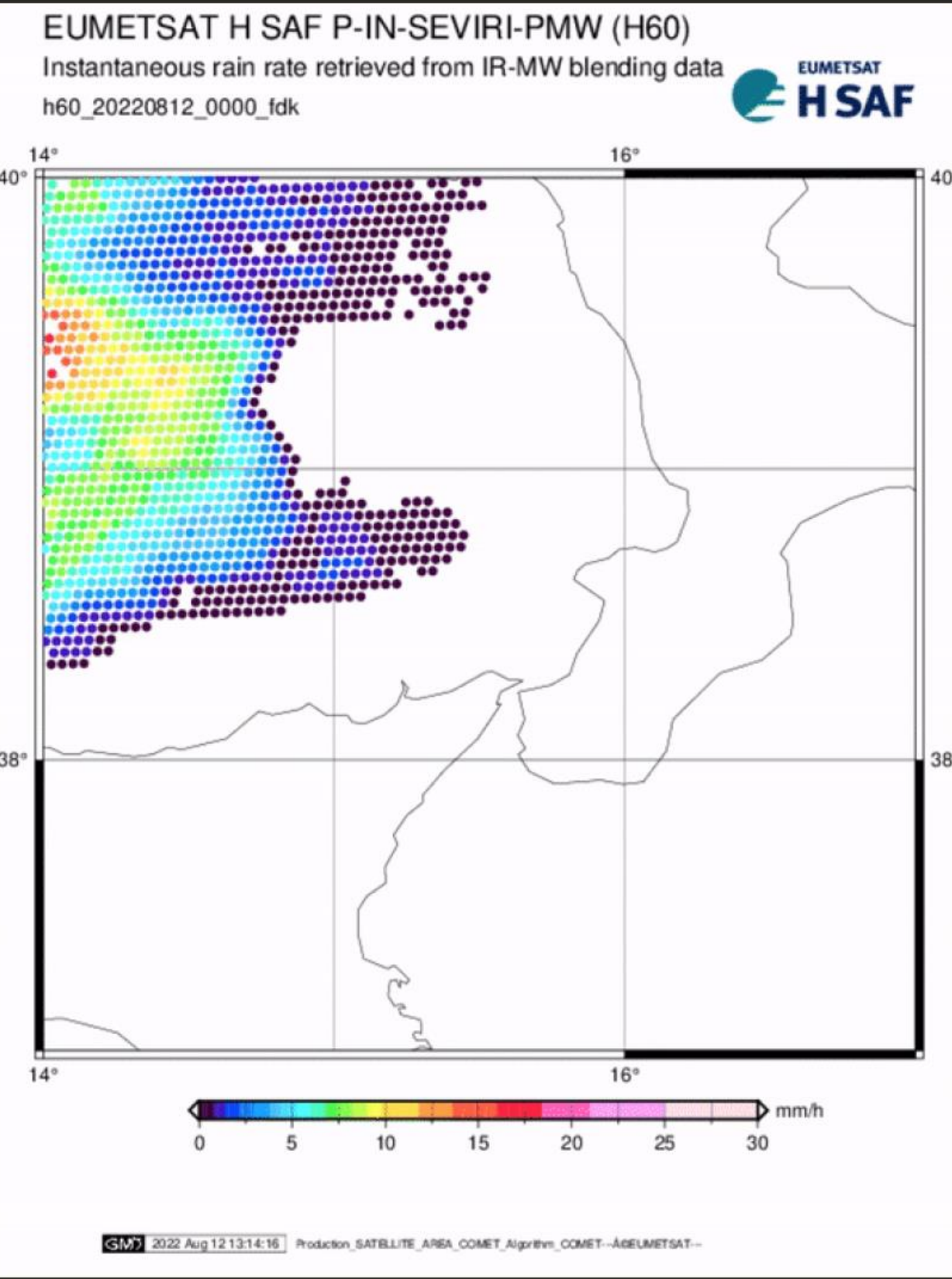
- The passive product (i.e., SMAP) tend to perform better over the forested catchment with respect to active products
- Higher spatial resolution soil moisture seems to not impact data assimilation results (with respect to coarse scale products)
- Data assimilation of more frequent observations (higher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

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

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

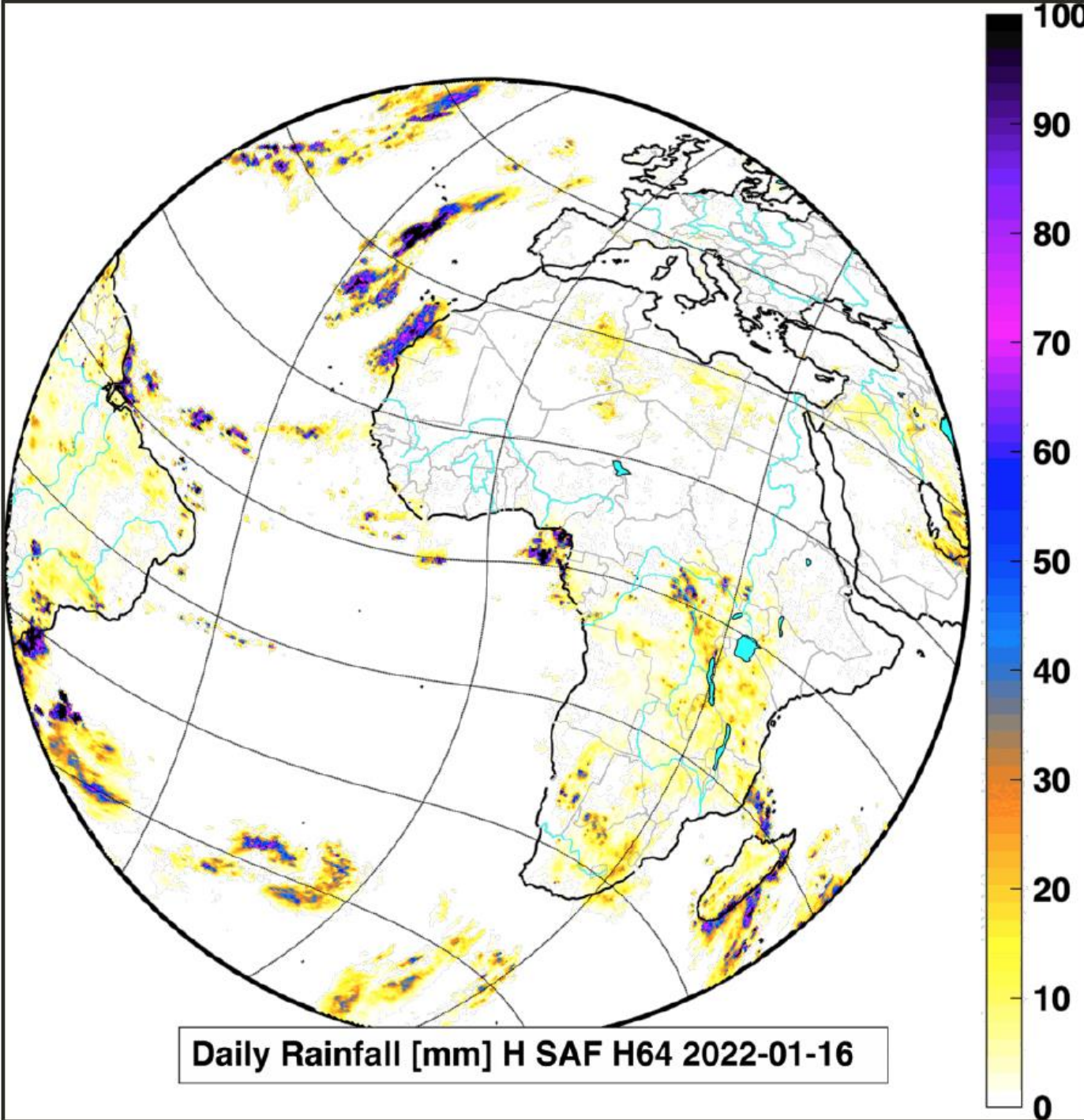


H SAF H60: real-time product 15-min, 0.05-degree



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

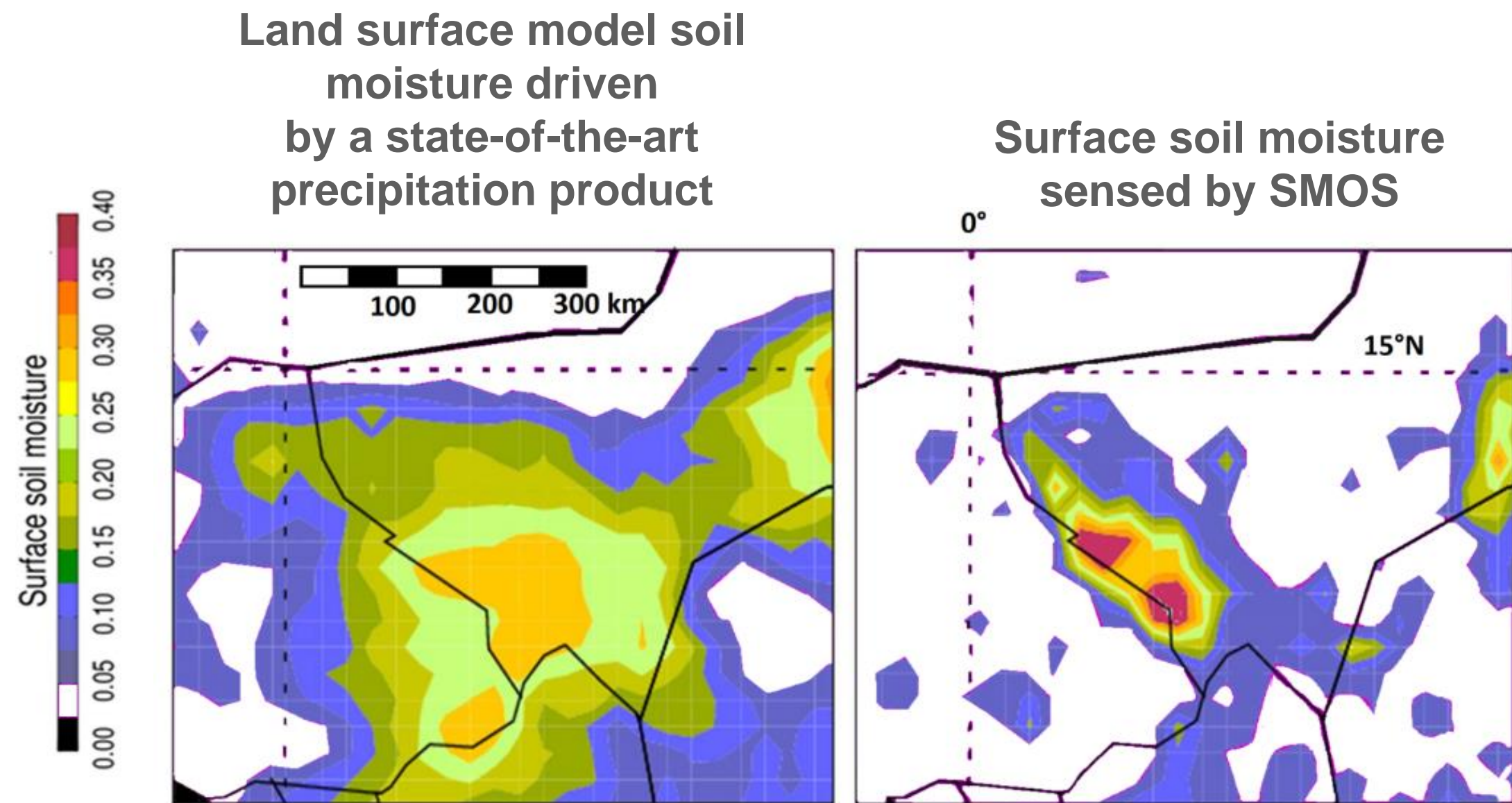
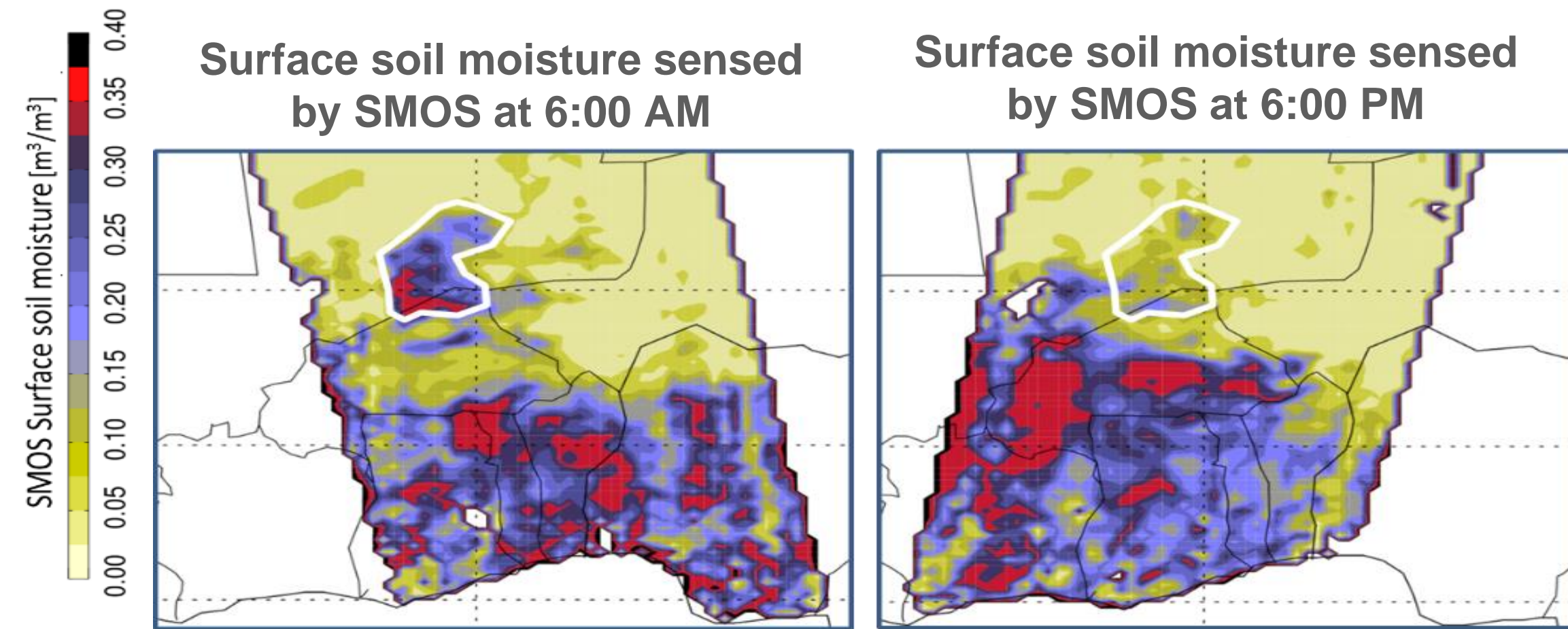
H SAF H64: 2020 to present 1-day, 0,25-degree



EUMETSAT Meteorological Satellite Conference 2022

Brussels, Belgium, 19-23 September 2022

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



Inversion of the soil water balance equation (SM2RAIN)

relative saturation Z precipitation surface runoff drainage

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

soil water capacity = soil depth X porosity evapotranspiration

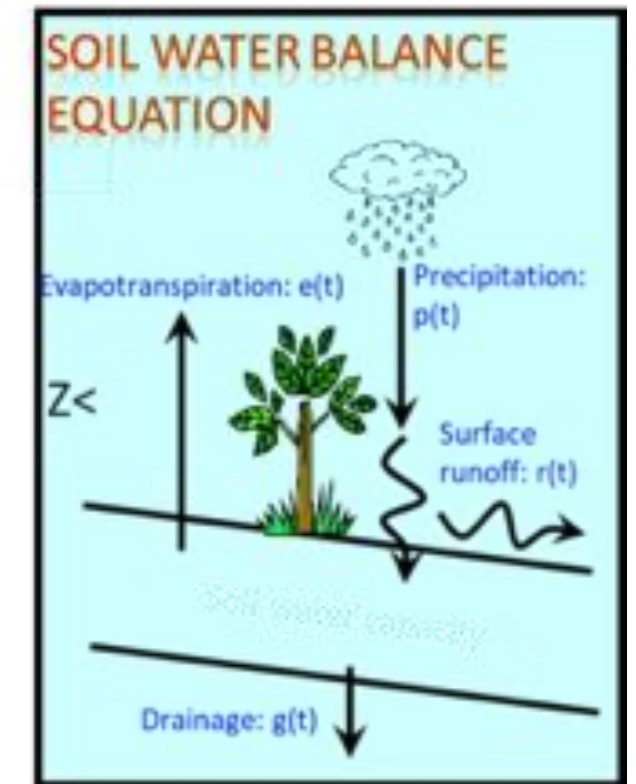
Inverting for $p(t)$:

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

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

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

Brocca et al 2013, GRL



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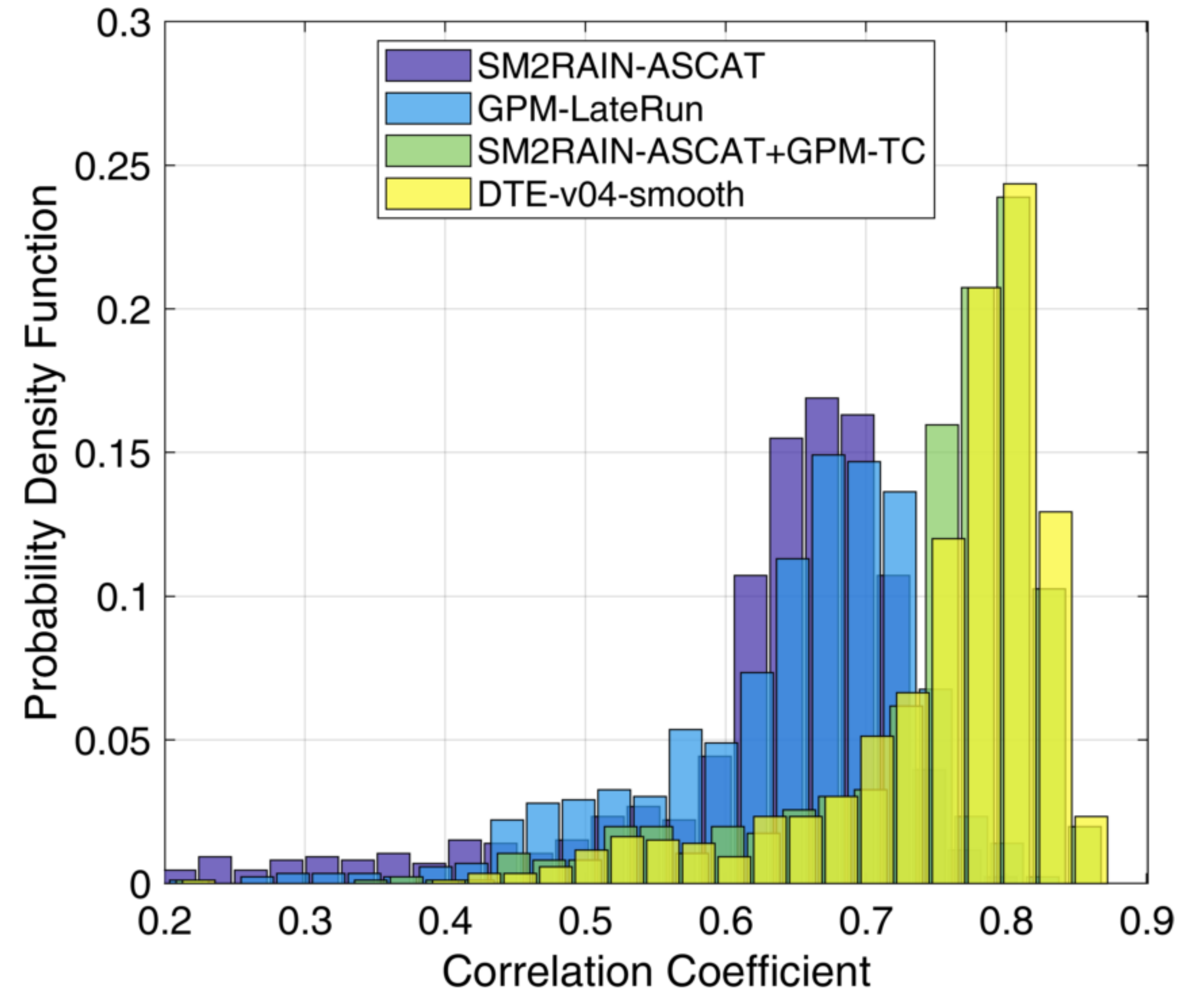
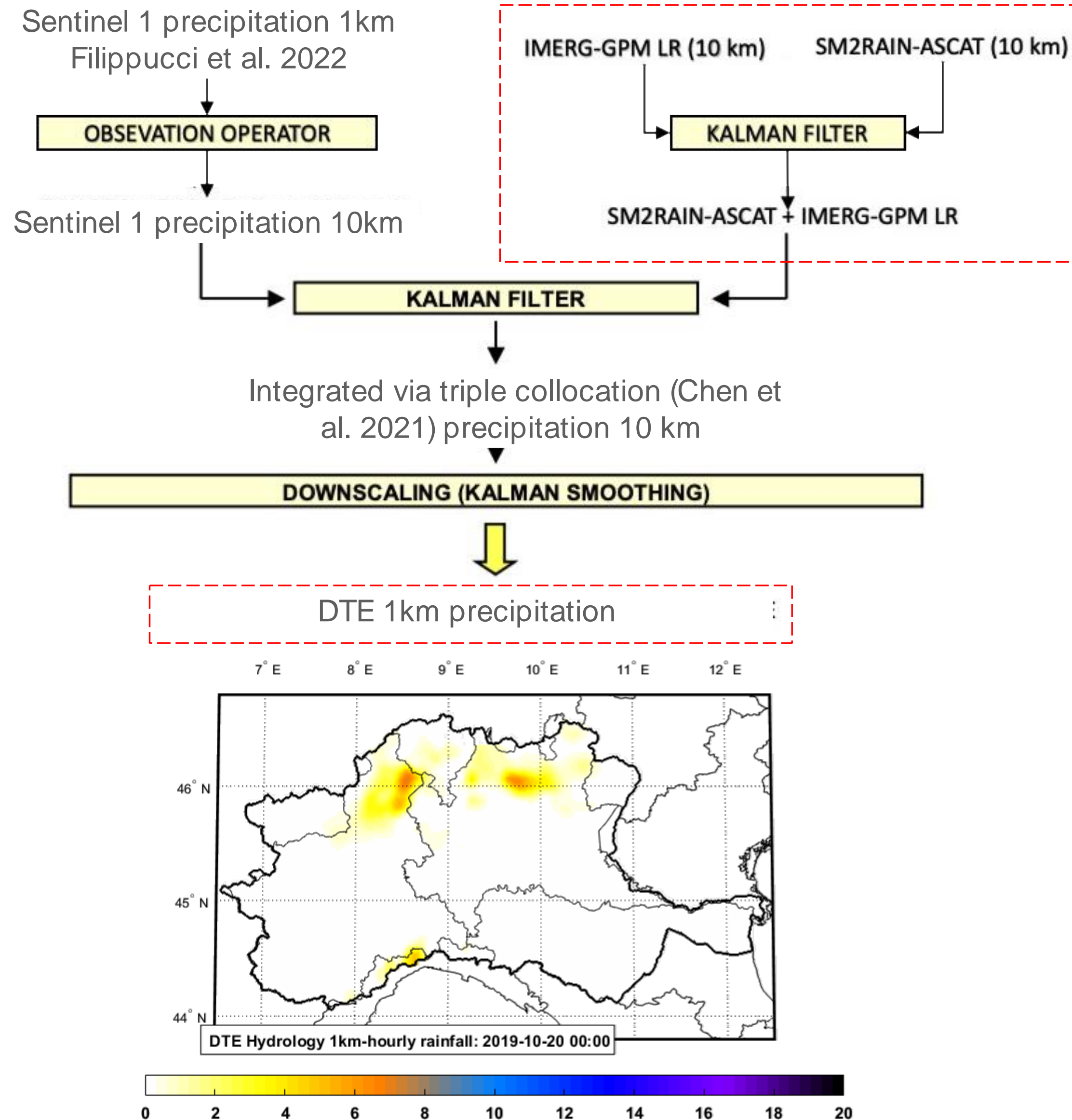
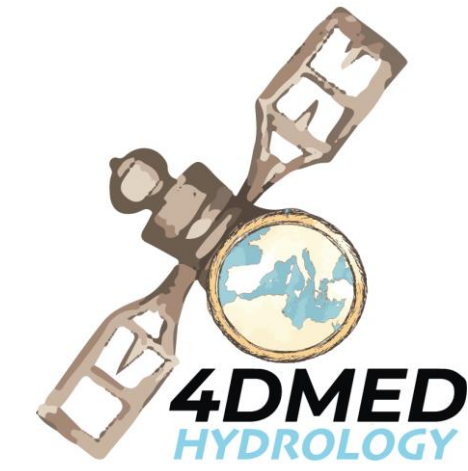


Hydrology and Earth System Sciences 

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 Massari¹, Luca Brocca¹, Thierry Pellarin², Gab Abramowitz³, Paolo Filippucci¹, Luca Ciabatta¹, Viviana Maggioni⁴, Yann Kerr⁵, and Diego Fernandez Prieto⁶

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



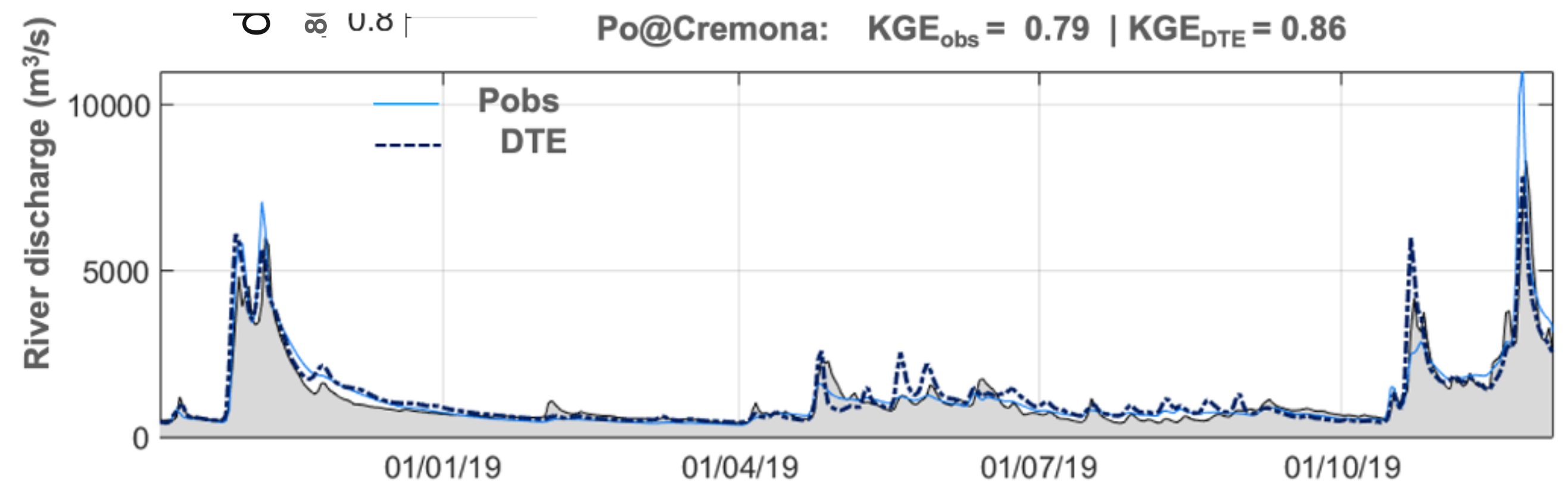
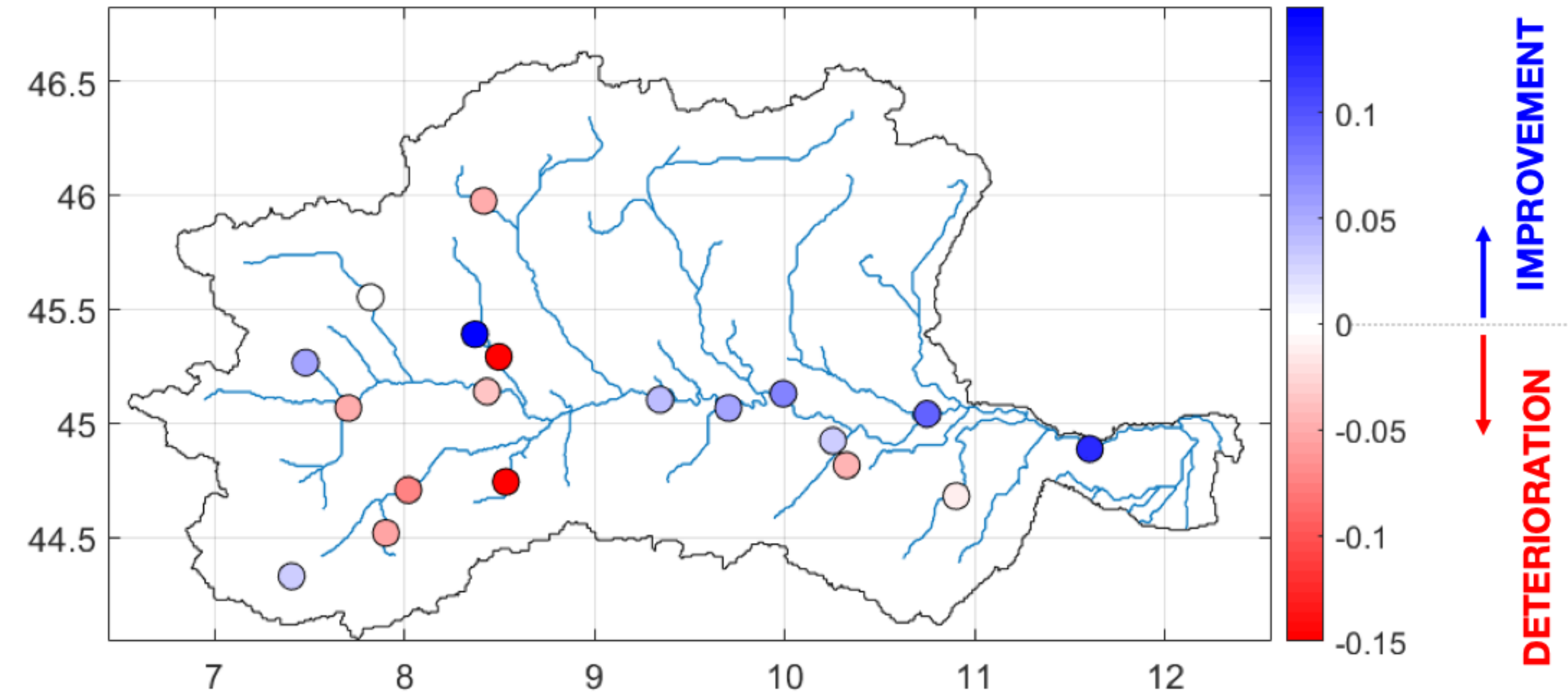
Other ways to use satellite soil moisture in flood forecasting: improving precipitation

Po River basin

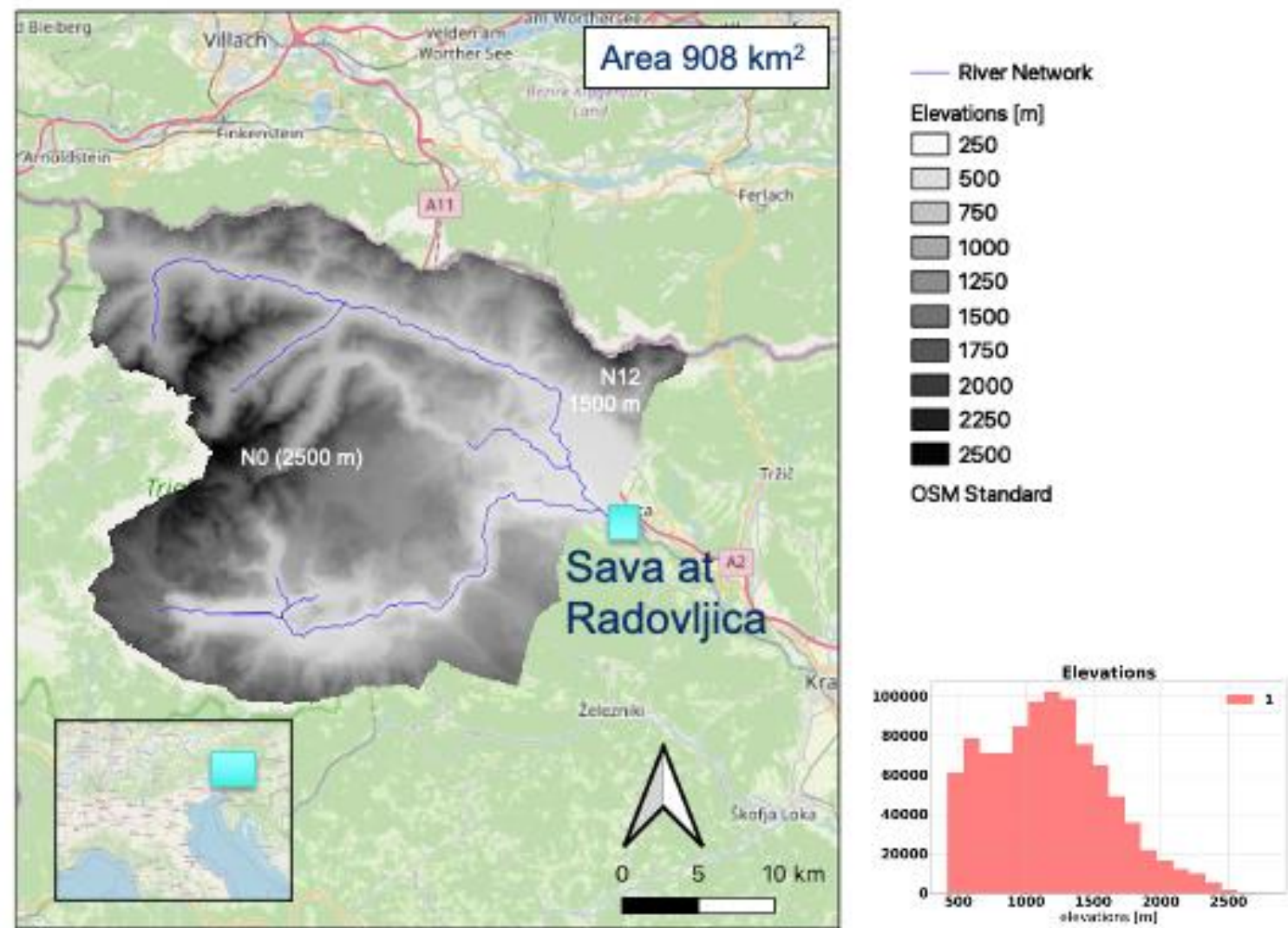
▲ Raingauges ● Hydrometric stations — River network

Basin area = 71'000 km²
 642 raingauges (~ 1 rainauge/100 km²)
 19 hydrometric stations!!
 Hourly rainfall, air temperature and river discharge (2016-2019)
 Simulation with MISDc 2L Hydrological model (Massari et al. 2018)

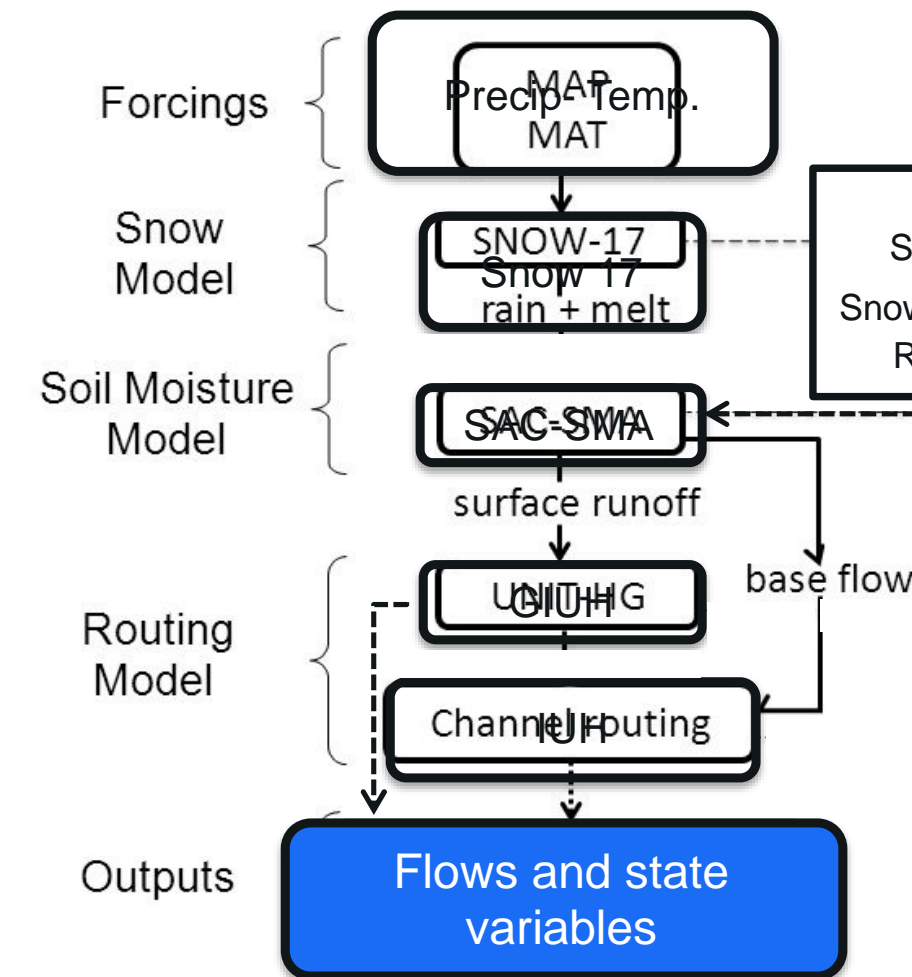
$$\Delta KGE = KGE_{DTE} - KGE_{OBS}$$



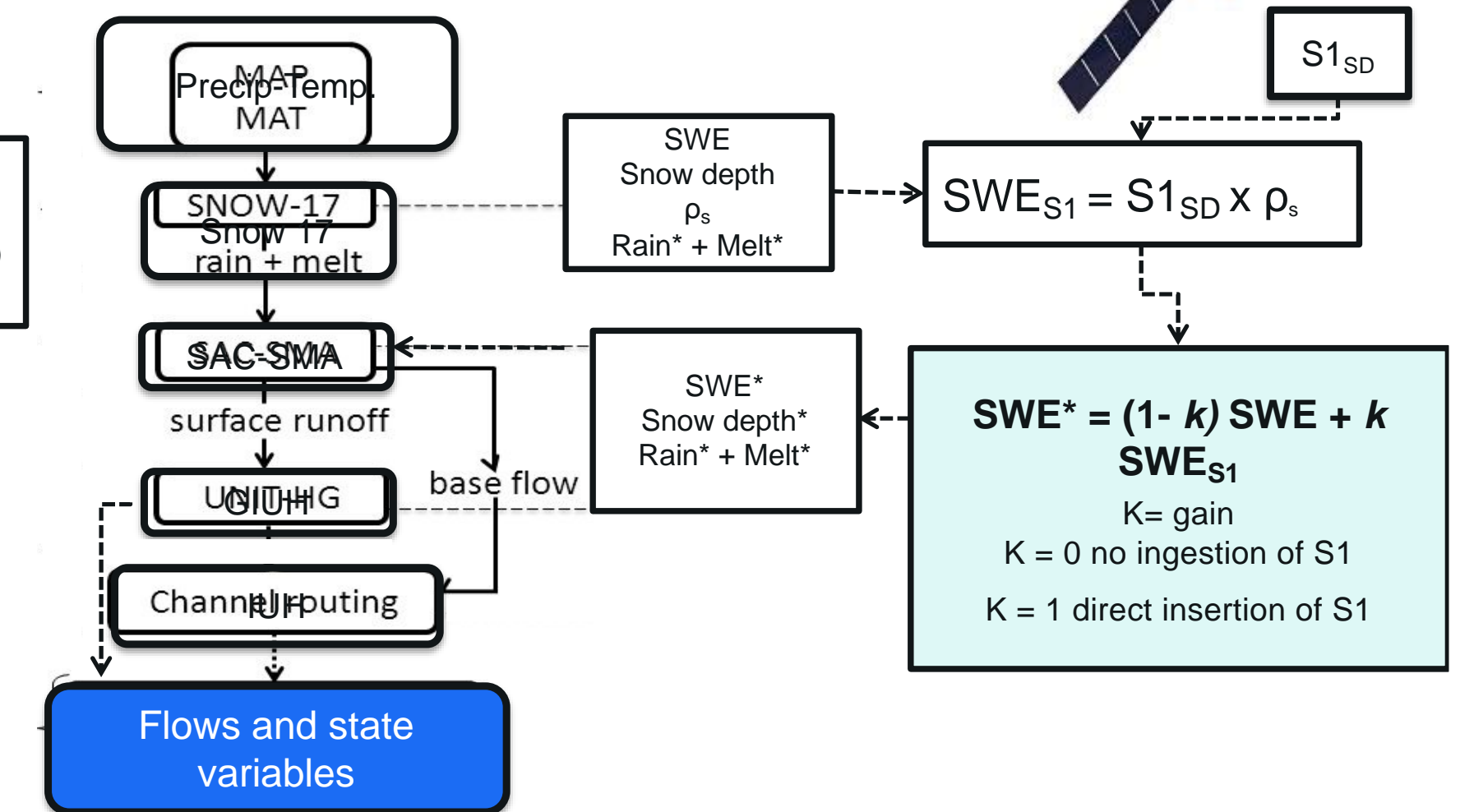
What about snow? Assimilating sentinel 1 snow depth observations



Open Loop Scheme



We sequentially update Snow-17 SWE estimates with S1 snow depth via a simple Nudging scheme



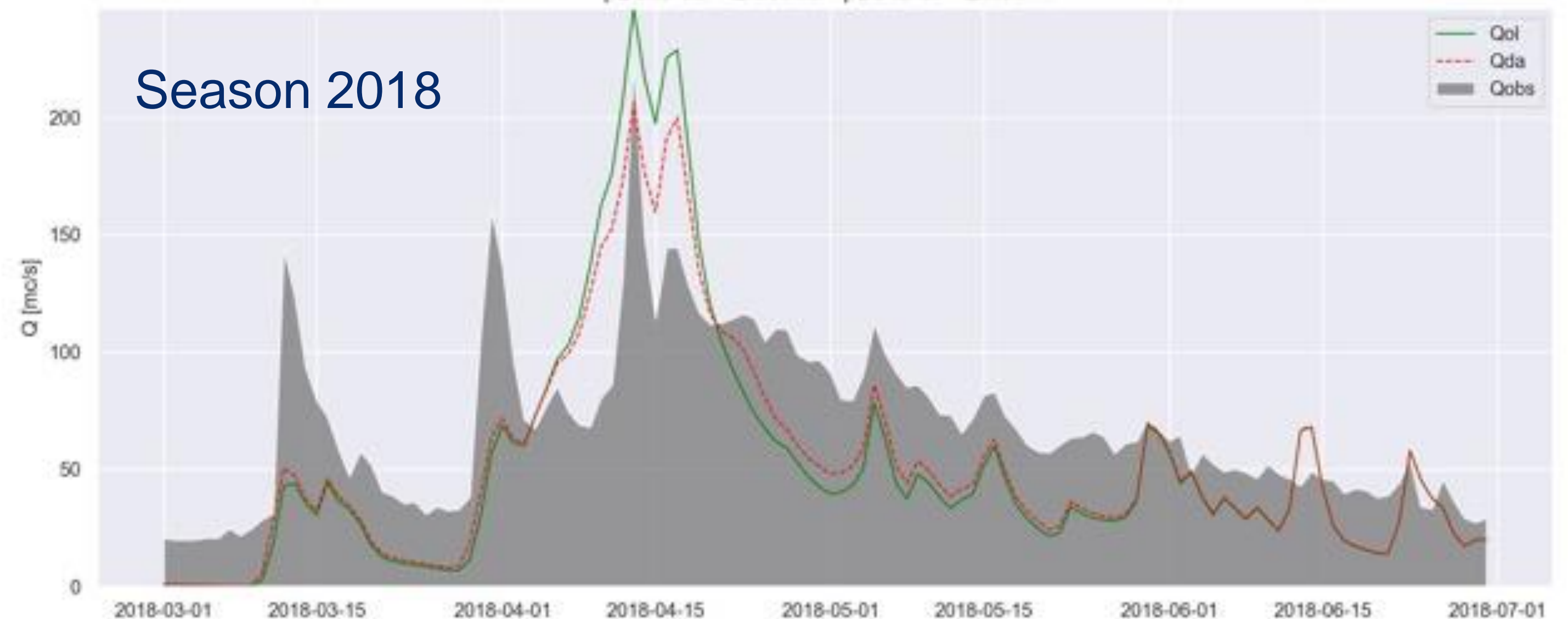
Article | Open Access | Published: 11 October 2019

Snow depth variability in the Northern Hemisphere mountains observed from space



- 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)

KGE OL= 0.43 → KGE DA = 0.60



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

Thanks a lot for your attention!

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<http://hydrology.irpi.cnr.it/people/christian-massari/>

