DLR

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living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

Project Overview

EUMETSAT ECMWF EUSPA

extrAIM: AI-enhanced uncertainty quantification of satellite-derived hydroclimatic extremes

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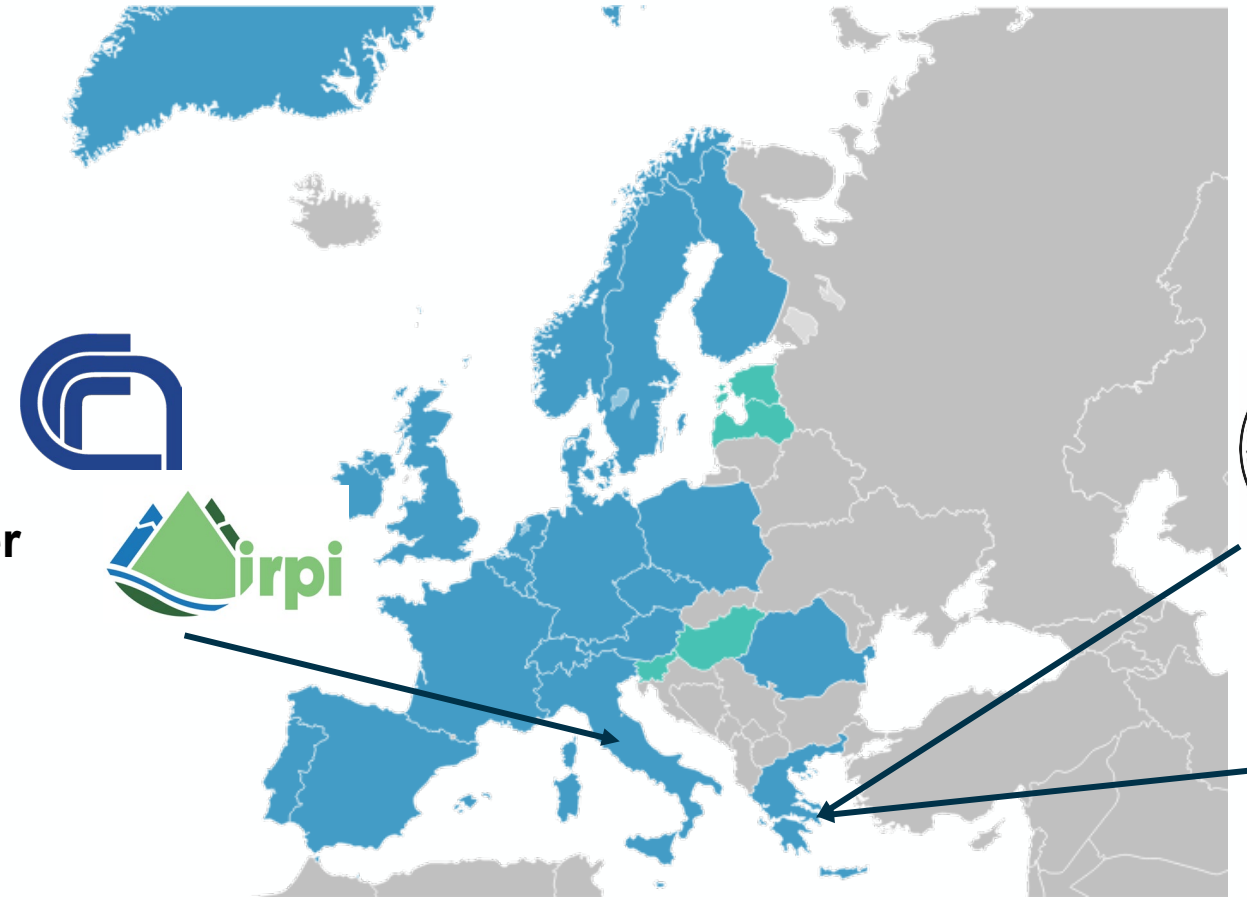
24/May/2022

Who is who?



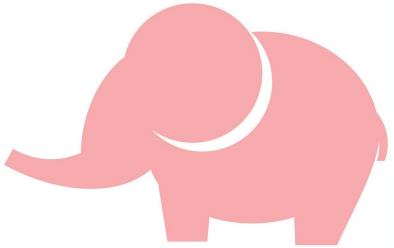
Istituto di Ricerca per la Protezione Idrogeologica

National Technical University of Athens
Laboratory of Hydrology an Water Resources

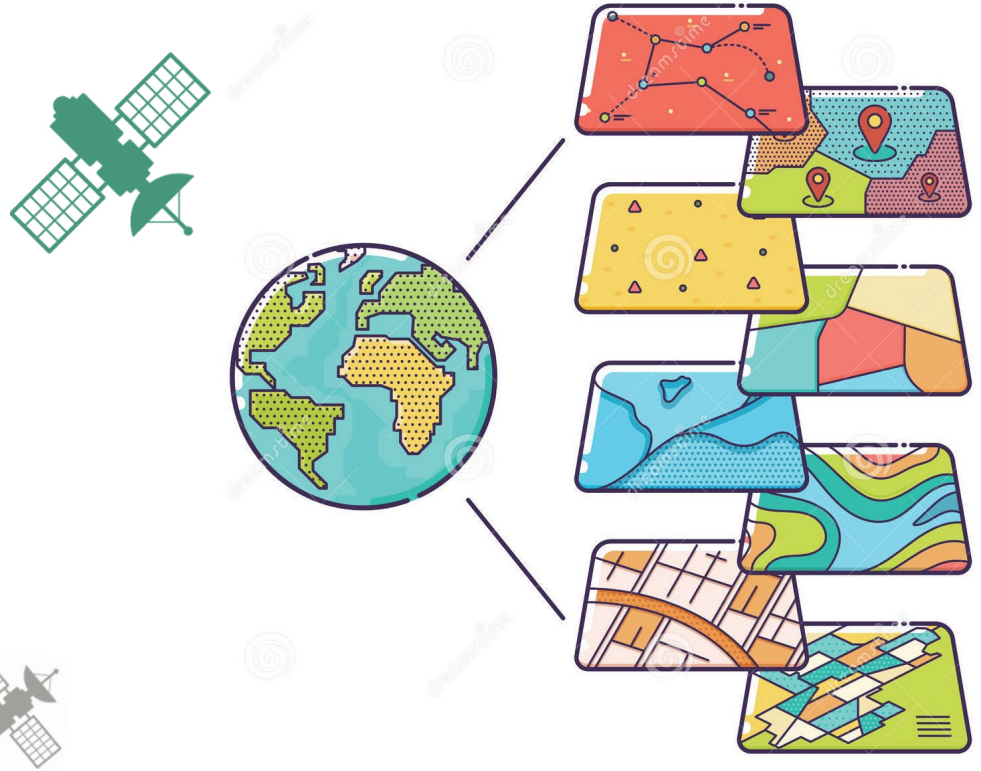
Tethys Consulting

Main challenge, idea & rationale

Address the elephant in the room (or slide)…



Satellite EO **data** exhibits significant **mismatches/differences** with **observation**-based **measurements** (i.e., in-situ).

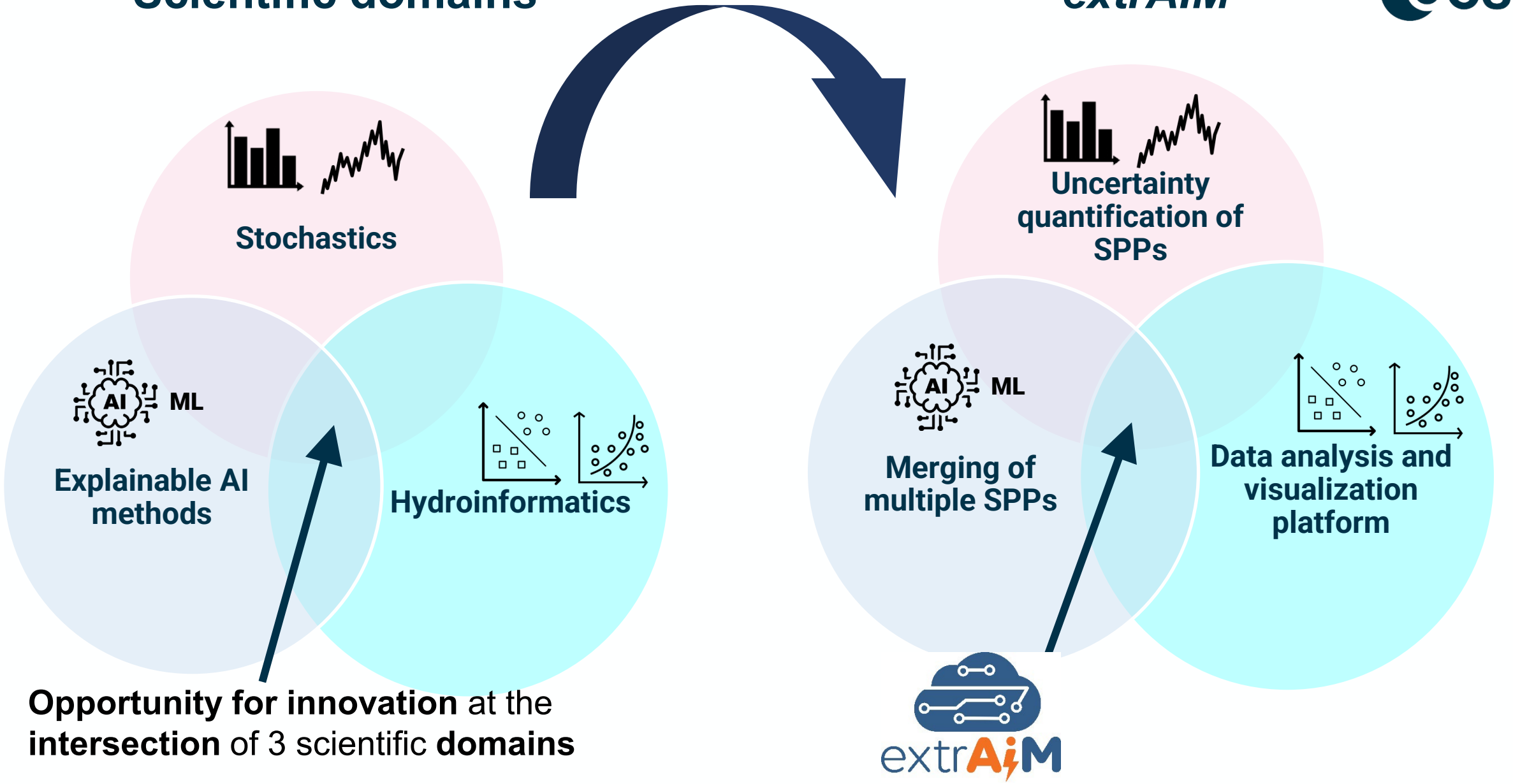


What extrAiM will do?

Develop/explore methods, frameworks and algorithms, tailored for EO data, to address this issue *per se*.

Scientific domains

extrAIM



Opportunity for innovation at the **intersection** of 3 scientific **domains**

Why multiple SPPs?

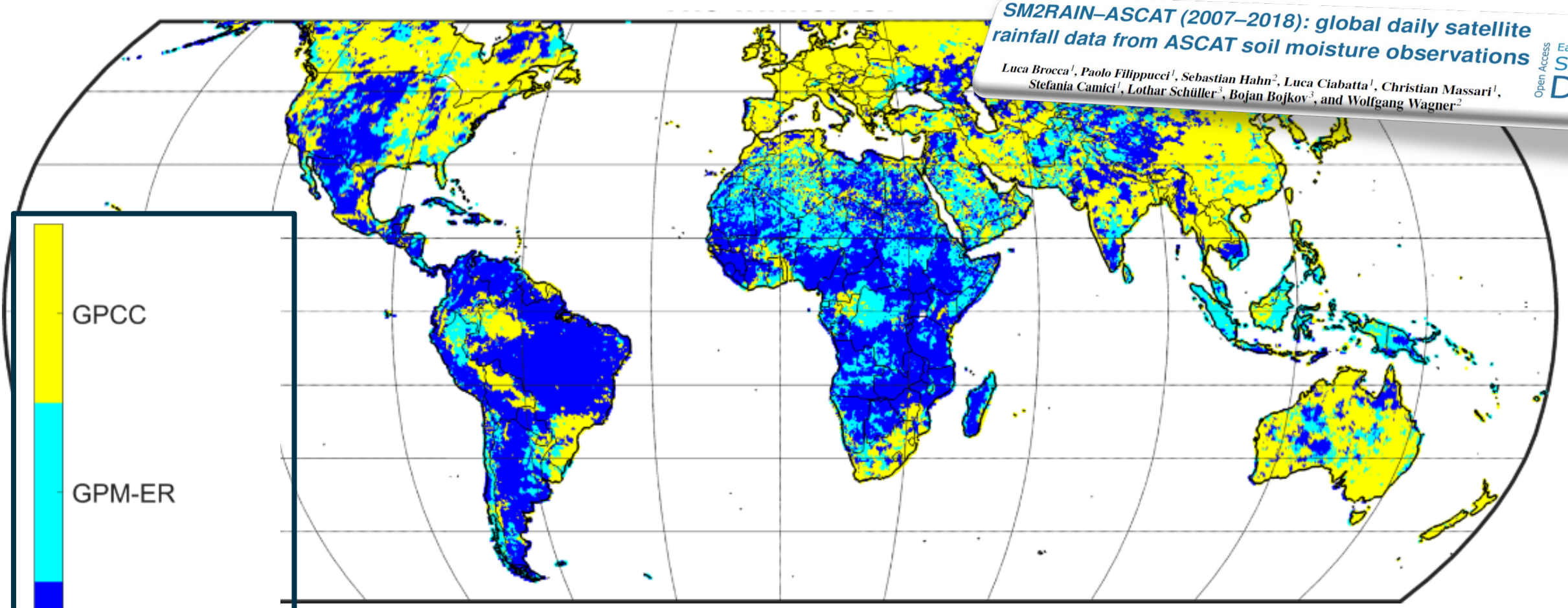
Global SM2RAIN project

EUMETSAT

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



BLUE AREAS where SM2RAIN-ASCAT is performing the best, even better than GPCC!

Brocca et al. (2019 ESSD), Massari et al. (2019 JoH)
Ciabatta et al. (2017 JoH, 2018 ESSD)

Why and How to **merge** multiple SPPs?

AI-enhanced and explainable generation of integrated satellite-based precipitation products

Can we open the Black-Box of AI/ML?

A typical situation: An SPP appears with an error 15% for Italy and 35% for Greece.

A ML *enthusiast*:

- **What a breakthrough!**
- **Why** does the model predict this outcome?
- **Which** features have the most impact?
- **When** can I trust this outcome?
- **Where** is the largest errors in the outcome?

A ML *denier*:

- **What?! This is just glorified regression!**
- **Why** should I trust this outcome obtained from a black (probably also magic) box?
- **Where** is the physical consistency?
- **What** is the explanation of this?

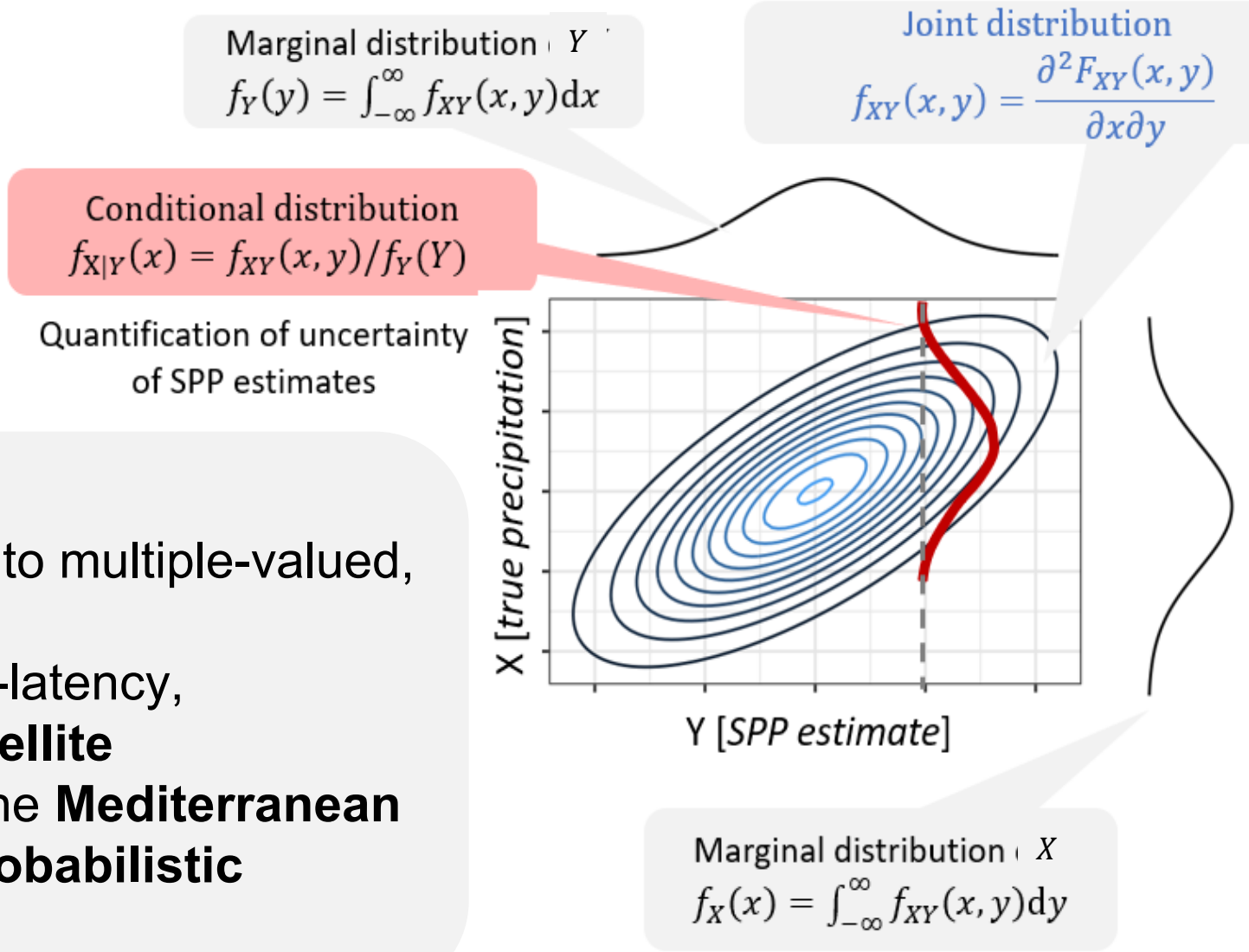
A possible remedy? Explainable AI (XAI) – also known as the third-wave of AI!

- XAI aims to **give answers to the "*wh-*" questions**, by **complementing predictions with explanations**.
- **Build trust and confidence** with **end-users**/society, aiming to enhance the uptake of AI.

Why **uncertainty quantification of** SPP's estimates?

Probabilistic framework for the uncertainty quantification of satellite-based precipitation estimates

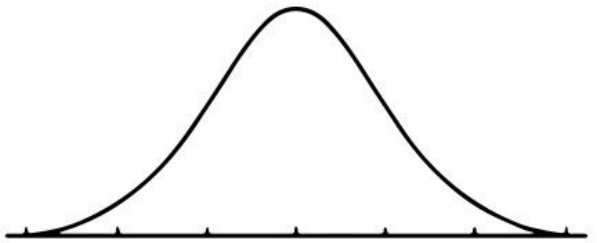
Quantification of uncertainty of SPP's estimates



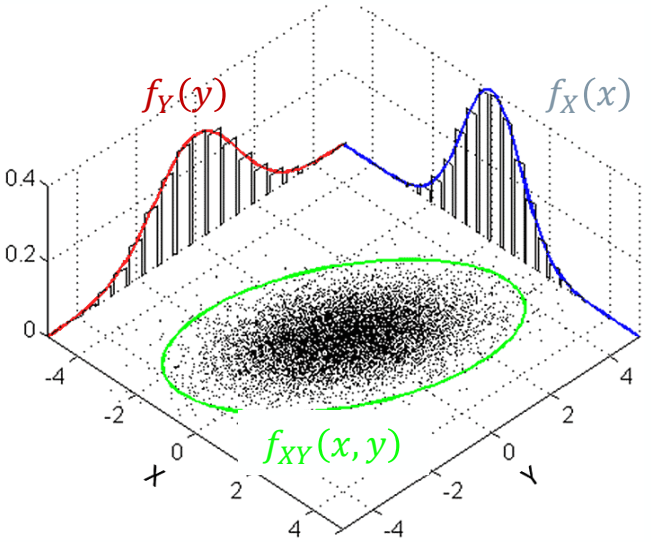
Aims

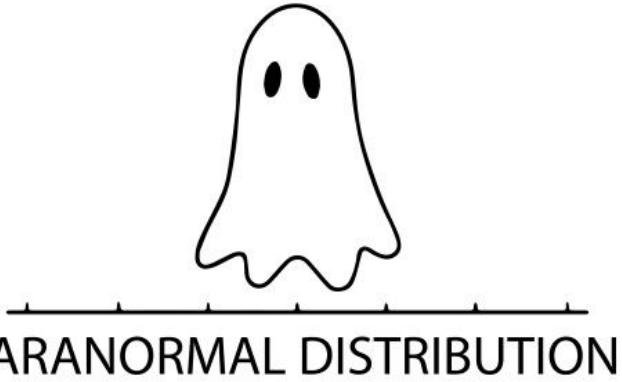
- Quantify SPP's uncertainty
- Move beyond single-valued QPEs to multiple-valued, equiprobable QPEs
- Creation of **a first-of-its-kind,** low-latency, **uncertainty-aware (UA) daily satellite precipitation product (SPP)** for the **Mediterranean**
- **Adjust SPPs to cope with the probabilistic behavior of for extremes**

Multivariate non-Gaussian distributions



NORMAL DISTRIBUTION





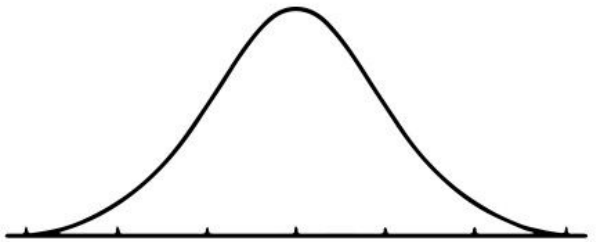
PARANORMAL DISTRIBUTION

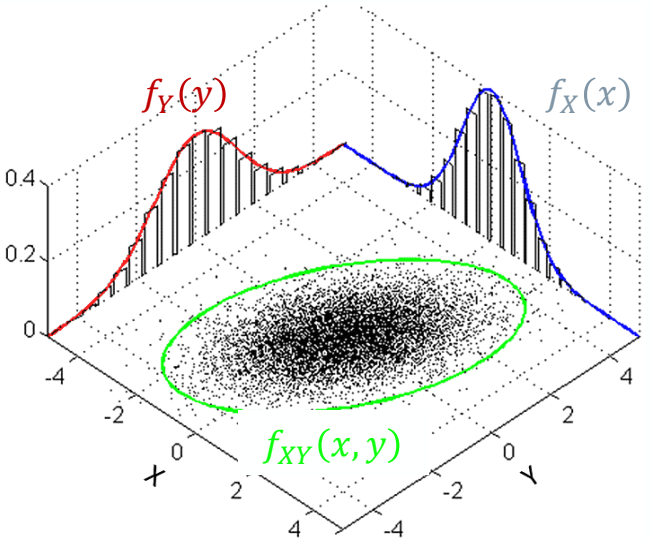
?

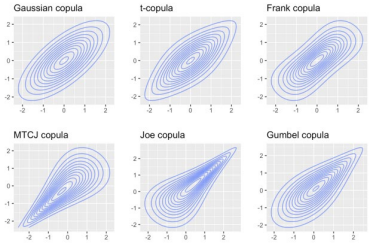
Correlated non-Gaussian random variables

*Oh, Lord, please **keep the world linear and Gaussian**.*
~Chester Kisiel's [1967] *pray* to the *theoretical hydrologist* Klemeš [1997 (p. 288)]

Multivariate non-Gaussian distributions







Copulas

Correlated non-Gaussian random variables

*Oh, Lord, please **keep the world linear and Gaussian**.*
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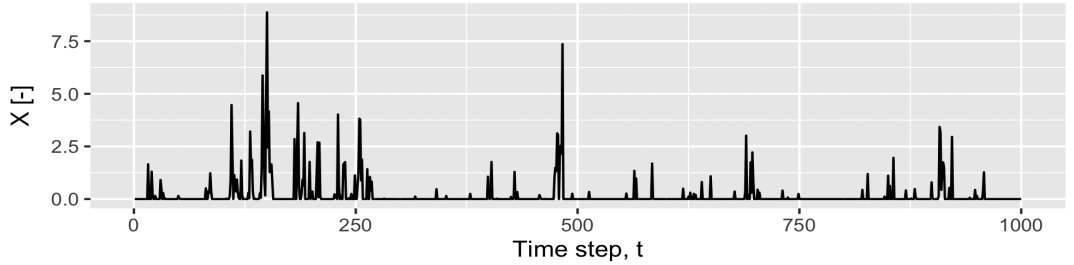
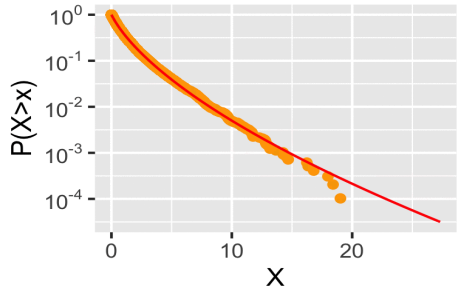
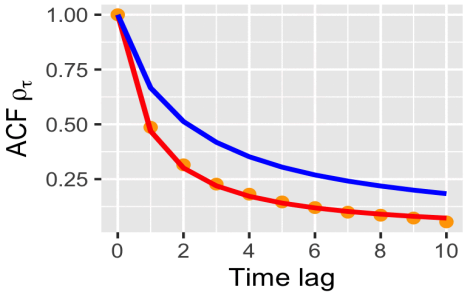
Modelling and simulation of non-Gaussian stochastic processes

Generic methodology for the stochastic simulation of processes (incl. **multivariate** ones) of **any time scale**, **any distribution**, **any correlation structure**:

- Stochastic simulation of **physical** (e.g., weather, hydrometeorological) and **non-physical processes** (e.g., water demand, energy demand).
- Stochastic **disaggregation** to support the reproduction of processes' characteristics at **multiple spatiotemporal** scales.







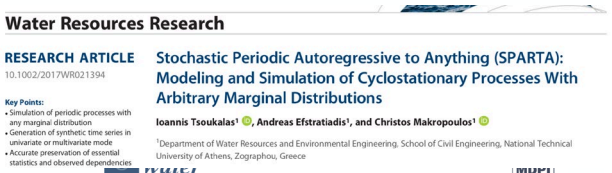

Water Resources Research

RESEARCH ARTICLE
10.1029/2017WR022462

Simulation of Stochastic Processes Exhibiting Any-Range Dependence and Arbitrary Marginal Distributions

Ioannis Tsoukalas[1], Christos Makropoulos[1], and Demetris Koutsoyiannis[1]

[1]Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Zographou, Greece

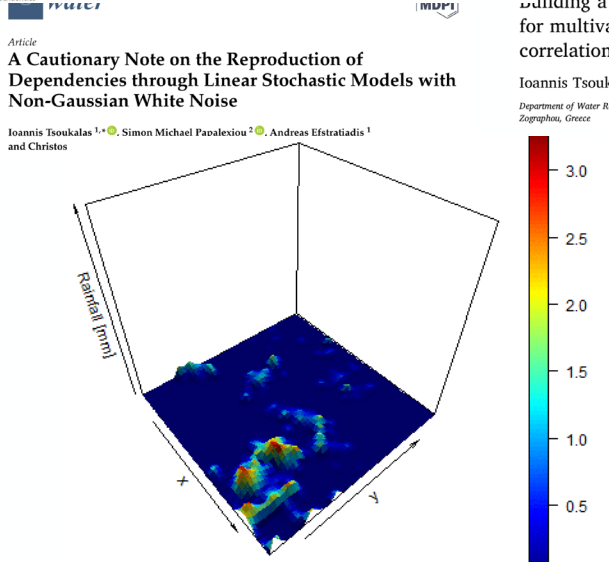

Water Resources Research

RESEARCH ARTICLE
10.1002/2017WR021394

Stochastic Periodic Autoregressive to Anything (SPARTA): Modeling and Simulation of Cyclostationary Processes With Arbitrary Marginal Distributions

Ioannis Tsoukalas[1], Andreas Efstratiadis[1], and Christos Makropoulos[1]

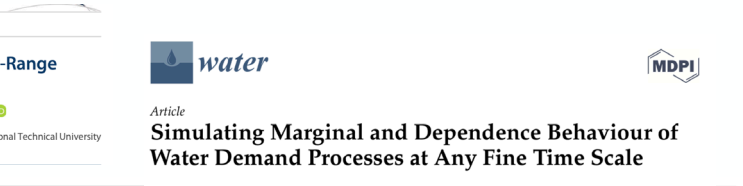
[1]Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Zographou, Greece


Article

A Cautionary Note on the Reproduction of Dependencies through Linear Stochastic Models with Non-Gaussian White Noise

Ioannis Tsoukalas[1,*], Simon Michael Papalexiou[2], Andreas Efstratiadis[1] and Christos

Rainfall [mm]


water

MDPI

Article

Simulating Marginal and Dependence Behaviour of Water Demand Processes at Any Fine Time Scale

Panagiotis Kossieris[1,*], Ioannis Tsoukalas[1], Christos Makropoulos[1,2] and Dragan Savic[2,3]


Journal of Hydrology

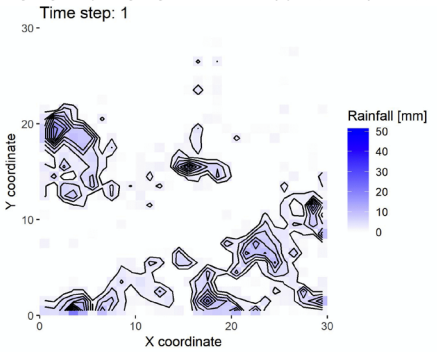
journal homepage: www.elsevier.com/locate/jhydrol

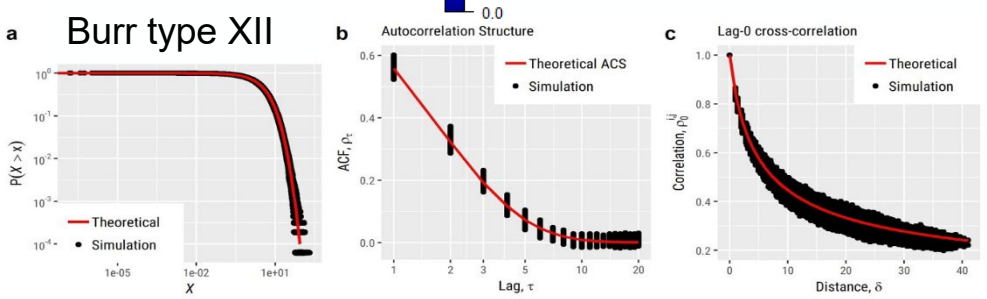
search papers

Building a puzzle to solve a riddle: A multi-scale disaggregation approach for multivariate stochastic processes with any marginal distribution and correlation structure

Ioannis Tsoukalas*, Andreas Efstratiadis, Christos Makropoulos

Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Heroon Polytechneiou 5, 15780 Zographou, Greece

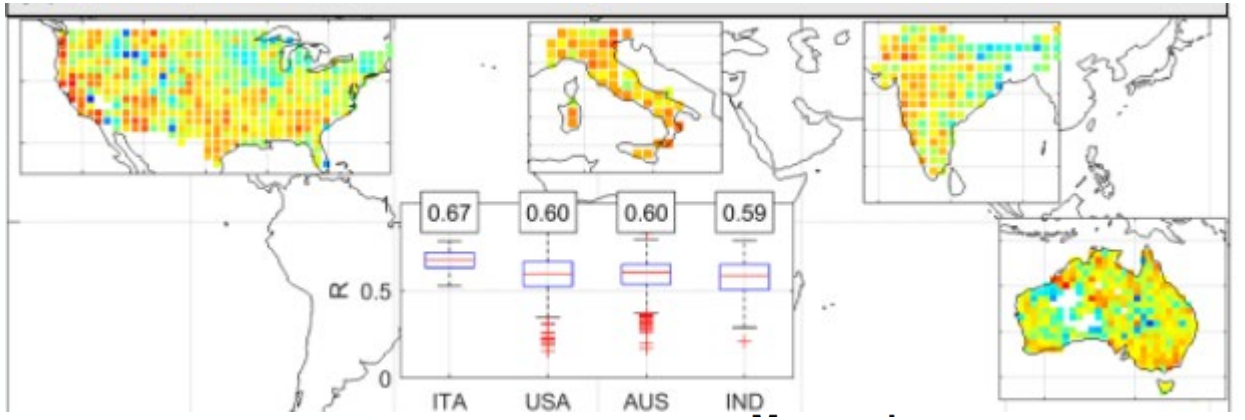




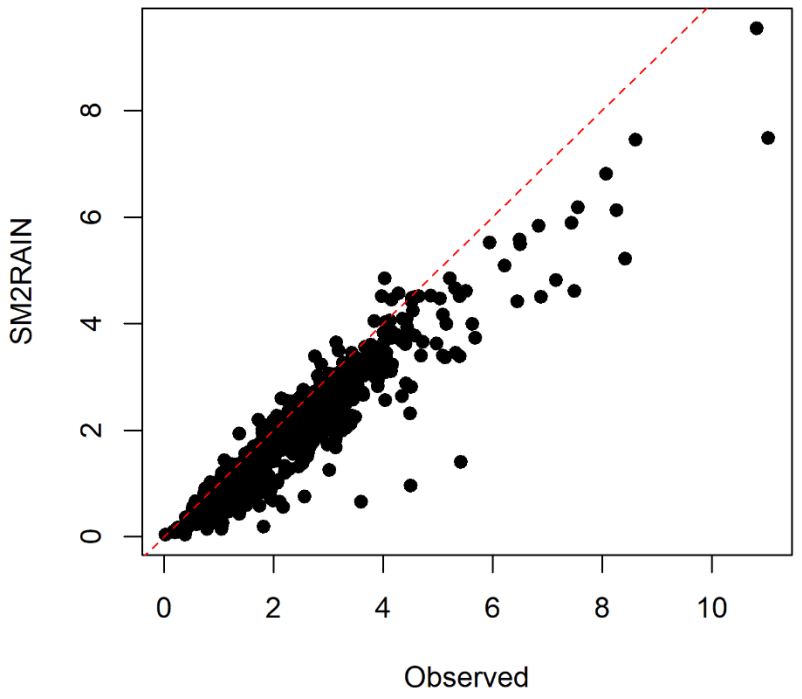
Some early results using SM2RAIN-ASCAT SPP [1]

“Test” dataset: 1009 stations, from:

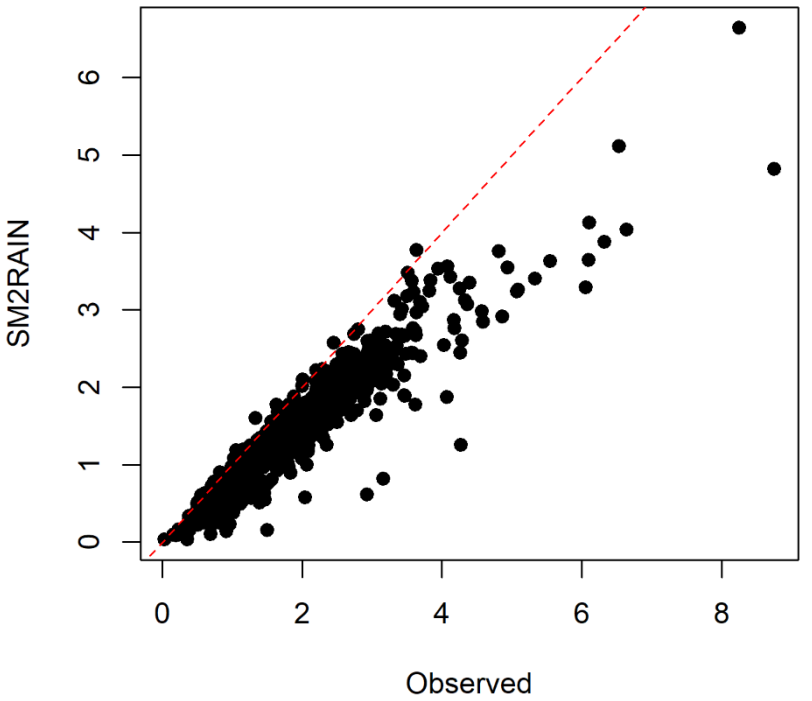
Brocca, L., Filippucci, P., Hahn, S., Ciabatta, L., Massari, C., Camici, S., Schüller, L., Bojkov, B., and Wagner, W.: *SM2RAIN–ASCAT (2007–2018): global daily satellite rainfall data from ASCAT soil moisture observations*, Earth Syst. Sci. Data, 11, 1583–1601.



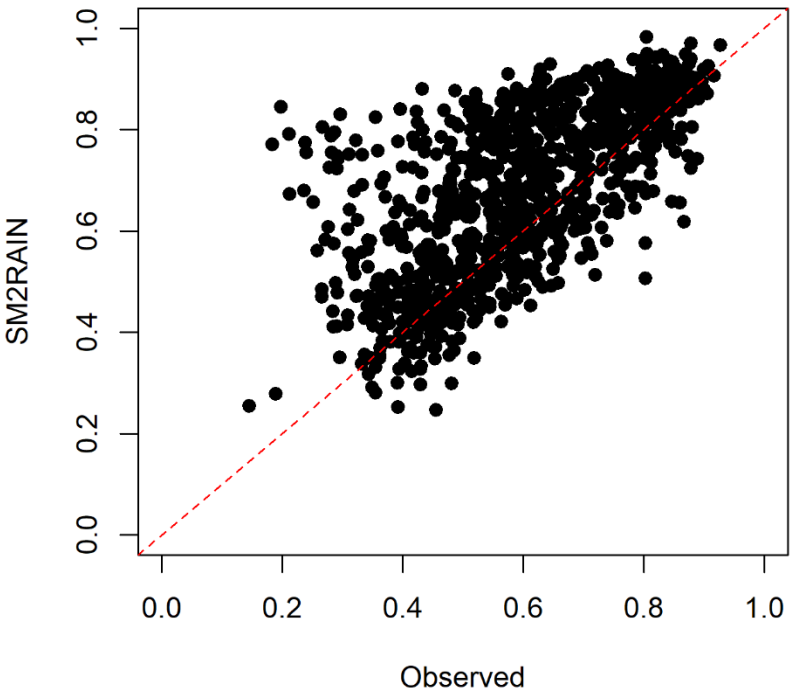
Mean value



L-scale



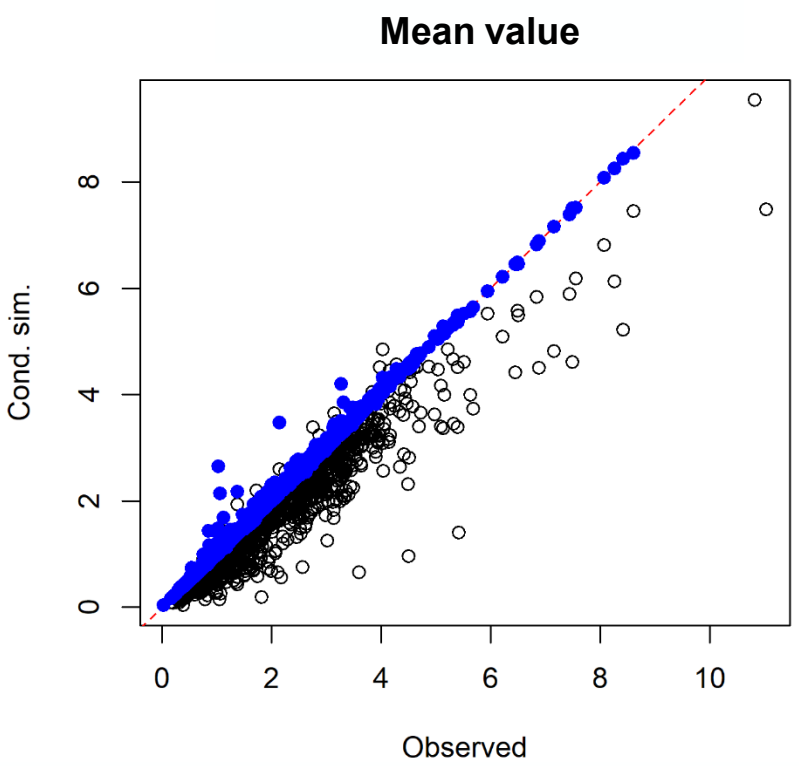
Probability of zero value

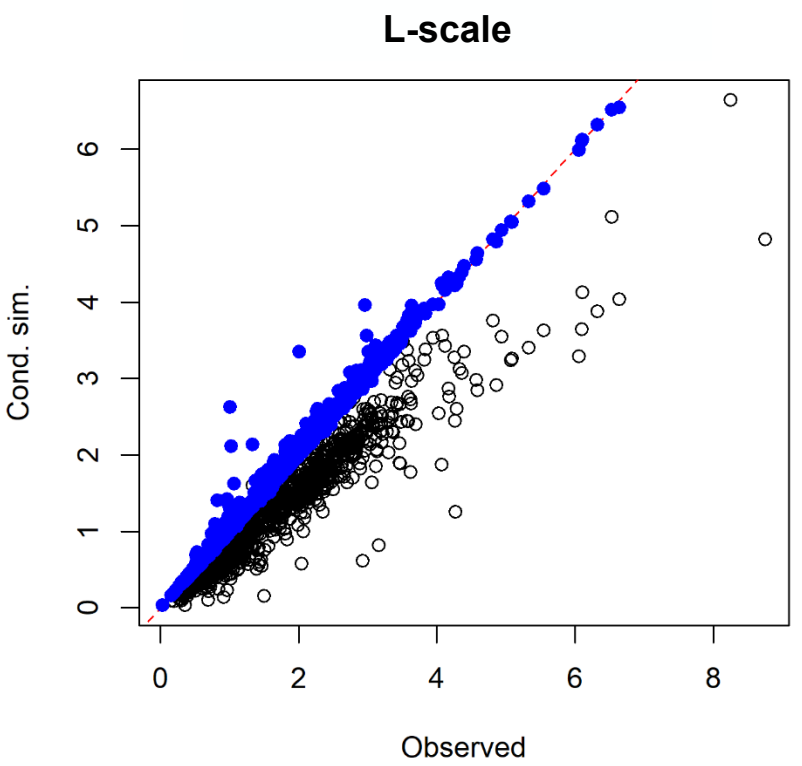


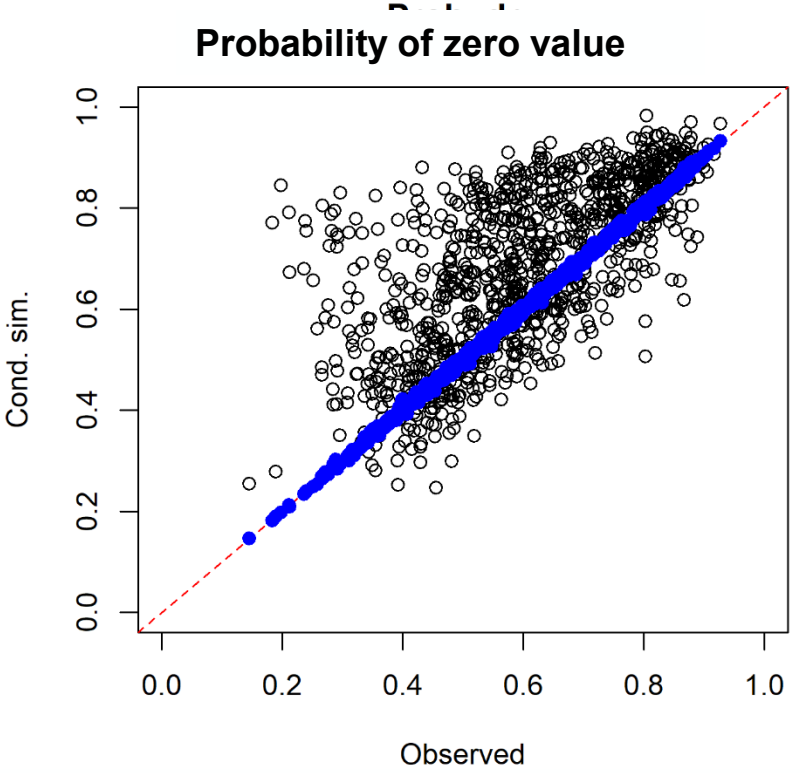
Some early results using SM2RAIN-ASCAT SPP [2]

Application: Copula-based modelling of predictive uncertainty

- **Marginal distribution**: Zero-inflated Generalized Gamma distribution (fitted using L-moments)
- **Dependence structure**: Gaussian copula (fitted using the maximum likelihood method)
- **Simulation**: Generation of 500 equally-probable realizations via conditional sampling







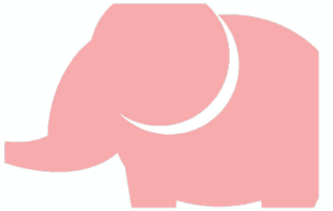
Why develop a Satellite-data analysis and visualization platform?

Candidate solutions

- Build upon **latest ICT** and **digital solutions** (cloud computing and big data analytics) to provide **a fast, reliable and user-friendly platform**.
- **Not a one-off service**: **Operation**, **maintenance** and **upgrade** also **after** the end of the **project**, by NTUA team, to guarantee continuous and high-quality service offering.
- Development of a **functional and interactive dashboard** to motivate and facilitate users **to access and analyse the uncertainty-aware extrAIM data products**.
- Candidate open-source visualization options: kepler.gl, Dash, bokeh, project jupyter, Dask.

A take-home message – and a wish!

- extrAIM aspires to catalyse a move **to a new era** of Satellite-based products: **from single-valued estimates to multi-valued uncertainty aware** estimates
- By also **opening up the "black" box for EO**: Provide Satellite-based products, with more accuracy, transparency, explainability and interpretability!
- Delivered through a **user-friendly and scalable web platform** to make easy the access and analysis of satellite-based products!
- And hopefully, **building trust** between (space) scientists and engineers (on the ground).



Thank you!