
# Flood modelling with satellite rainfall data

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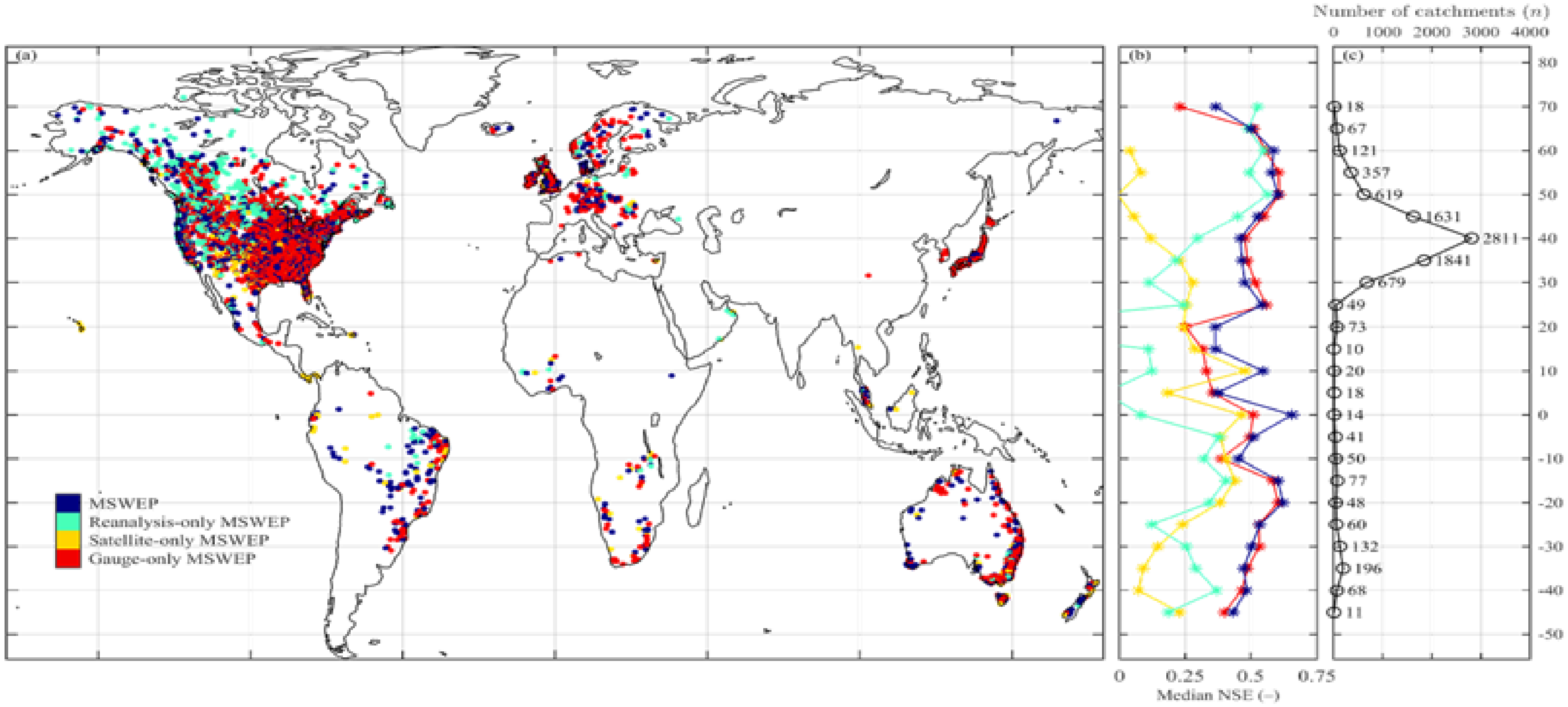
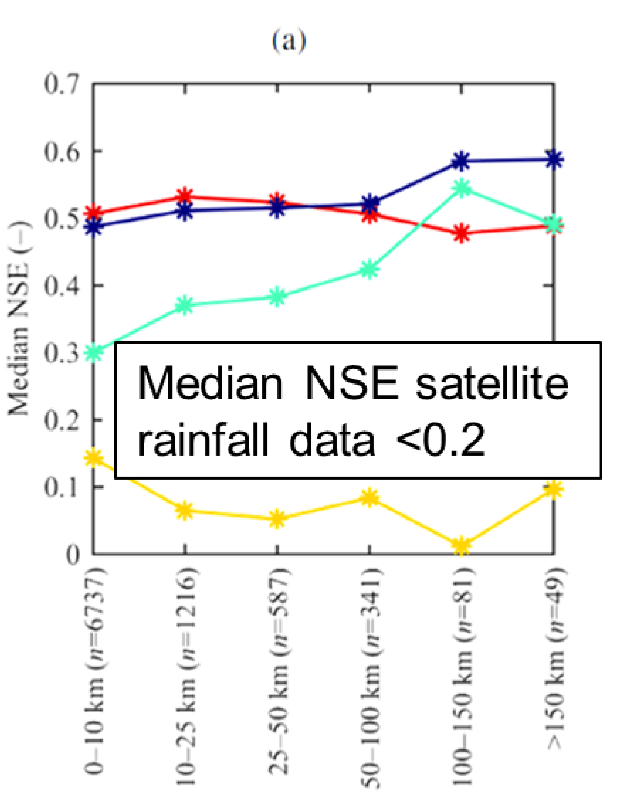
# Hydrological models and forcing data

Beck et al. (2017)




RED: GAUGE-BASED
CYAN: REANALYSIS
YELLOW: SATELLITE-BASED
BLUE: MSWEP

# Research questions

1. How useful are satellite-based rainfall estimates (SRE) as forcing data for hydrological applications?
2. Which SRE should be favoured for hydrological modelling? Is there any connection between rainfall quality and hydrological modelling?
3. What could researchers do to increase the performance of SRE-driven hydrological simulations?

## How useful are satellite-based rainfall estimates (SRE) as forcing data for hydrological models?

# “Physically-based hydrological models

State-of the art “physically based” models simulate soil moisture and then runoff through energy and water balance. models

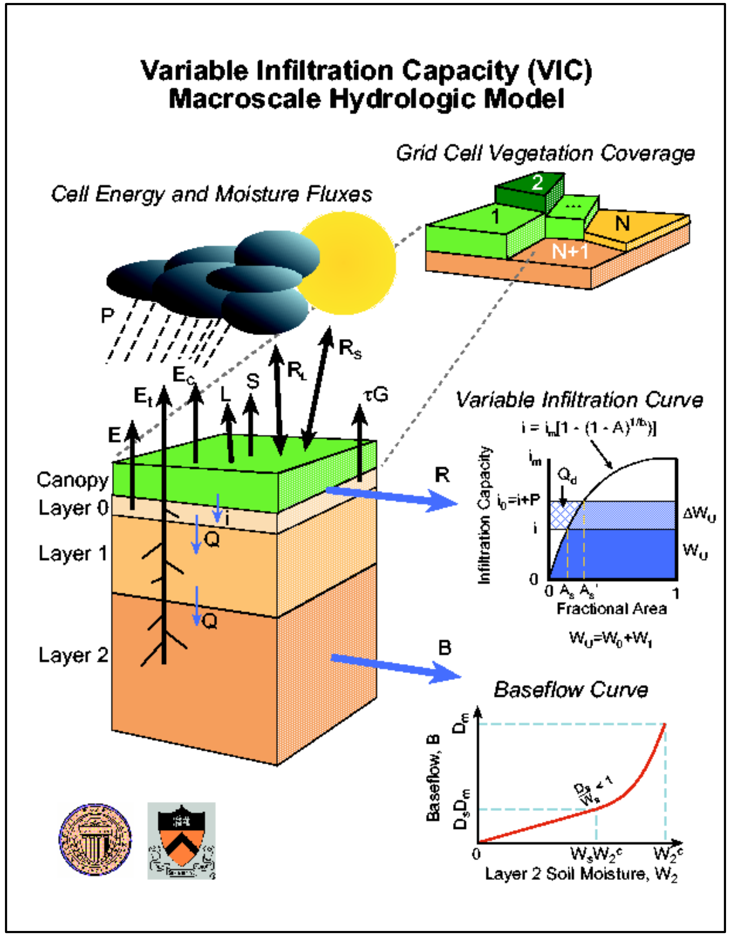
**Rainfall**

Temperature

Radiations

Soil type

Land cover




Runoff

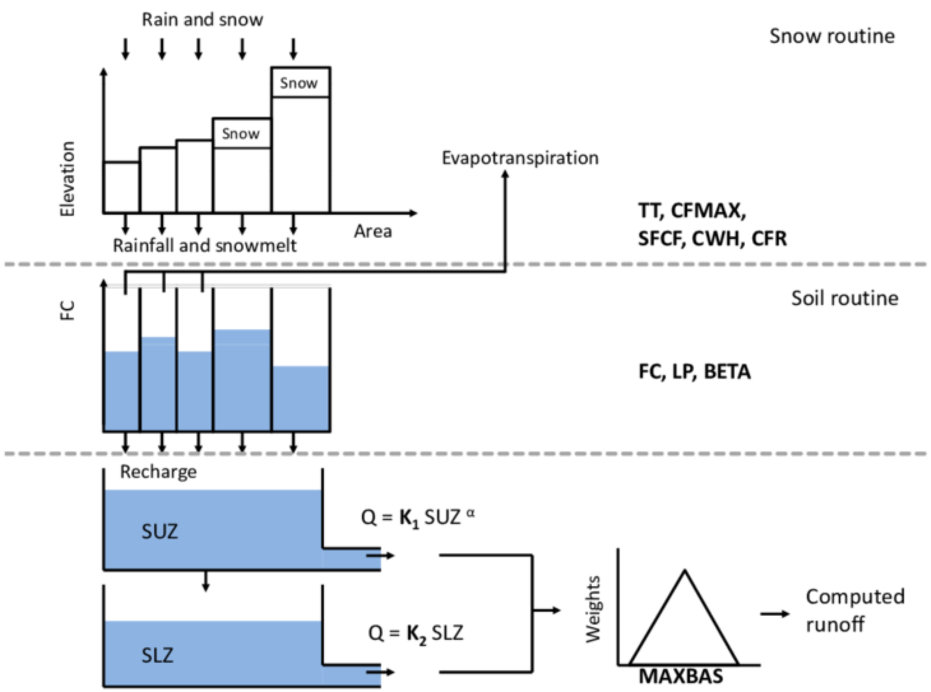
# Conceptual hydrological models

Conceptual hydrological models are used when spatial information of driving forcing

Soil moisture accounting

**Rainfall**

Temperature

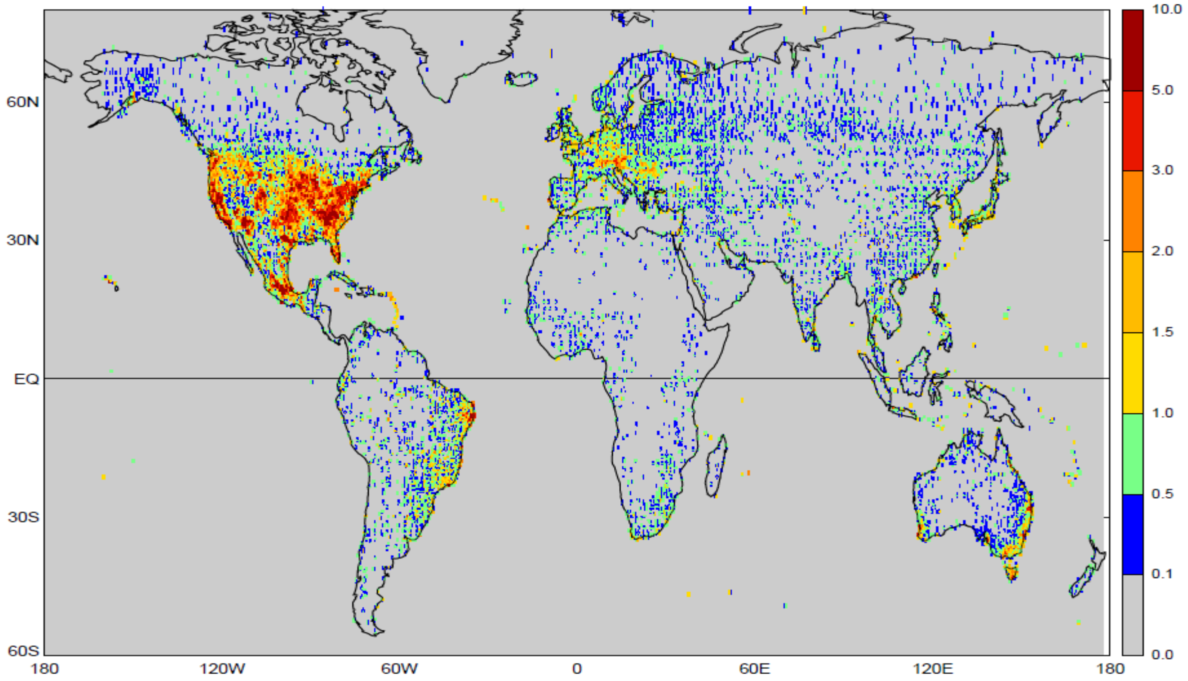



Bergström, 1992. HBV model

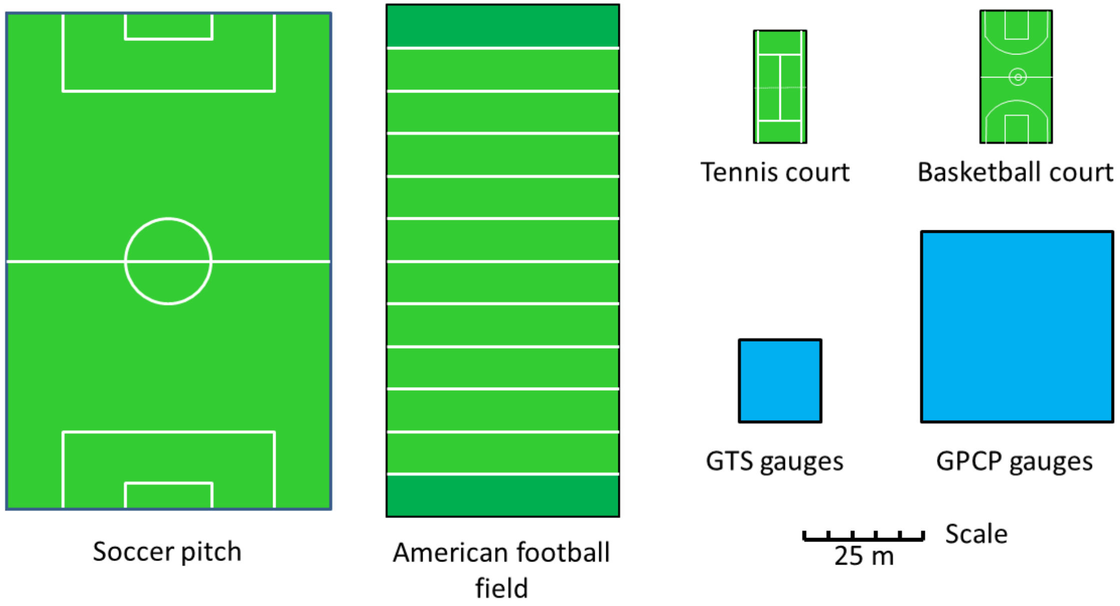
Runoff

# Rain gauge distribution over land

Global precipitation climatology project rain gauge stations

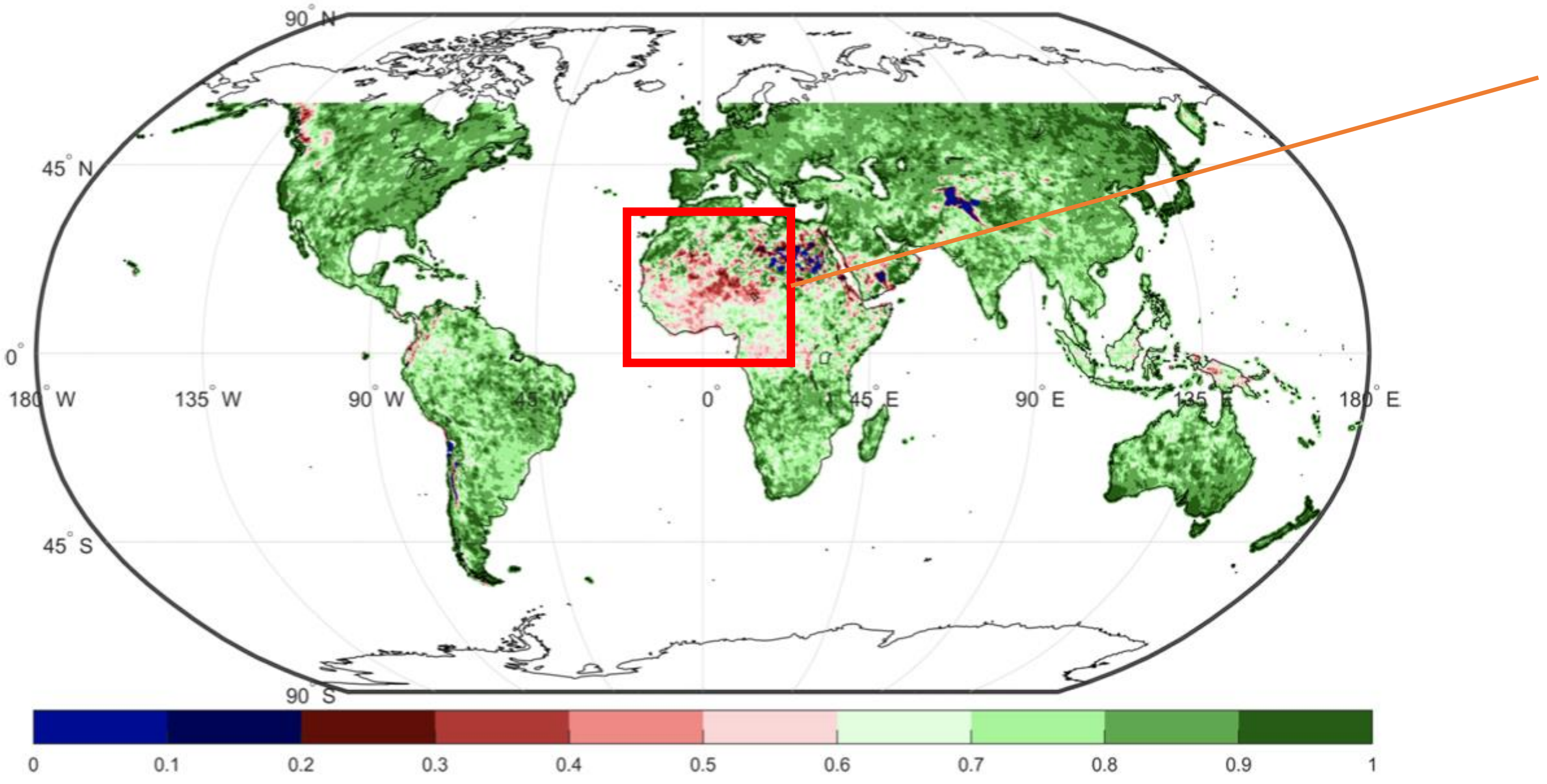



Equivalent areas of common sports pitches and courts compared with the total areas of orifices of all GTS and GPCC gauges (Kidd et al. 2015)



# Models vs Satellite rainfall estimates

Global ERA5 correlation calculated with Triple Collocation analysis (Massari et al. 2020)



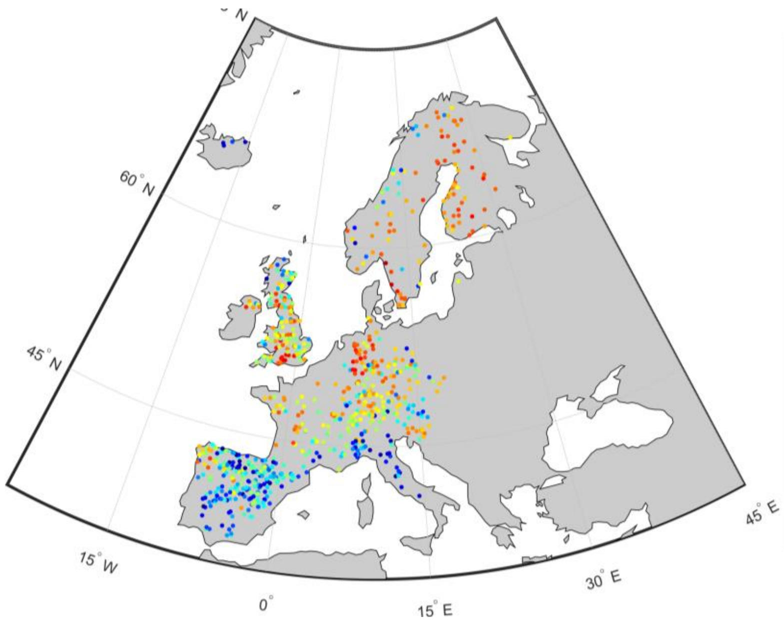

Models can suffer from problems over areas dominated by convection. Here SRE show relatively better accuracy (Ebert et al. 2007)

**SREs are useful especially over data scarce regions where models do not perform well but are also useful to complement other rainfall estimates…**

**Which SRE should be favoured for hydrological modelling? Is there any connection between rainfall quality and performance in hydrological models?**

# A large scale experiment

**To answer to this question we need a relatively large sample size of basins, multiple models and different rainfall products**




TMPA 3B42-RT

- MW & IR radiometers + MW radar
- Sampling 0.25°(~25 km)
- 3h coverage for the 50° N – 50° S band
- 1997 - ongoing

SM2RAIN$_{ASCAT}$

- ASCAT soil moisture derived rainfall
- Sampling 12.5 km (~12 km)
- Daily global coverage
- 2007 – ongoing

CMORPH

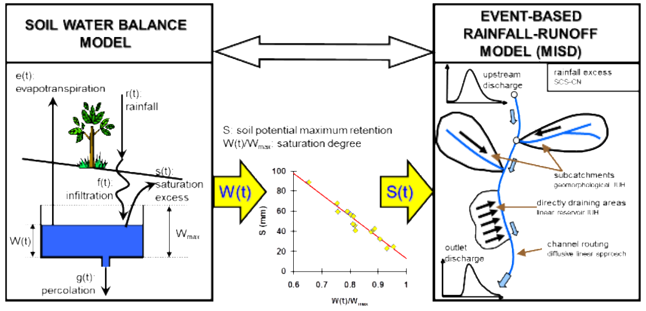
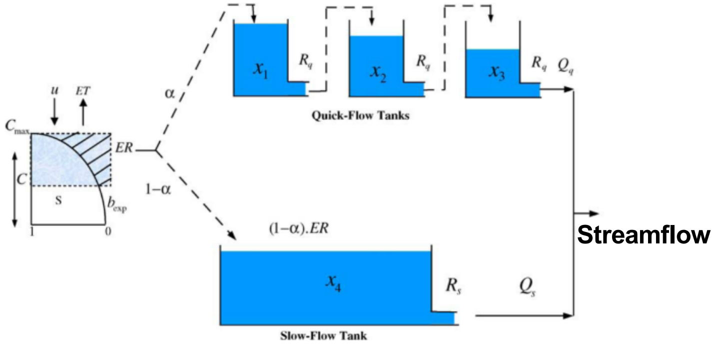
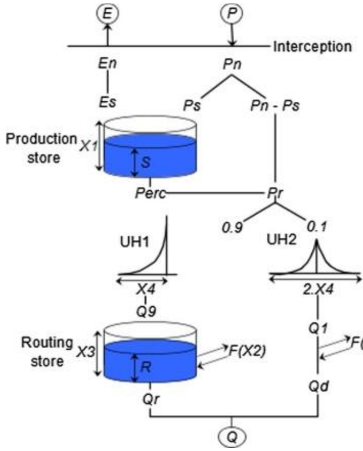
- MW+IR data
- Sampling 0.25°(~25 km)
- 3h coverage for the 60° N – 60° S band
- 2002 - ongoing

EOBS (gauge based)

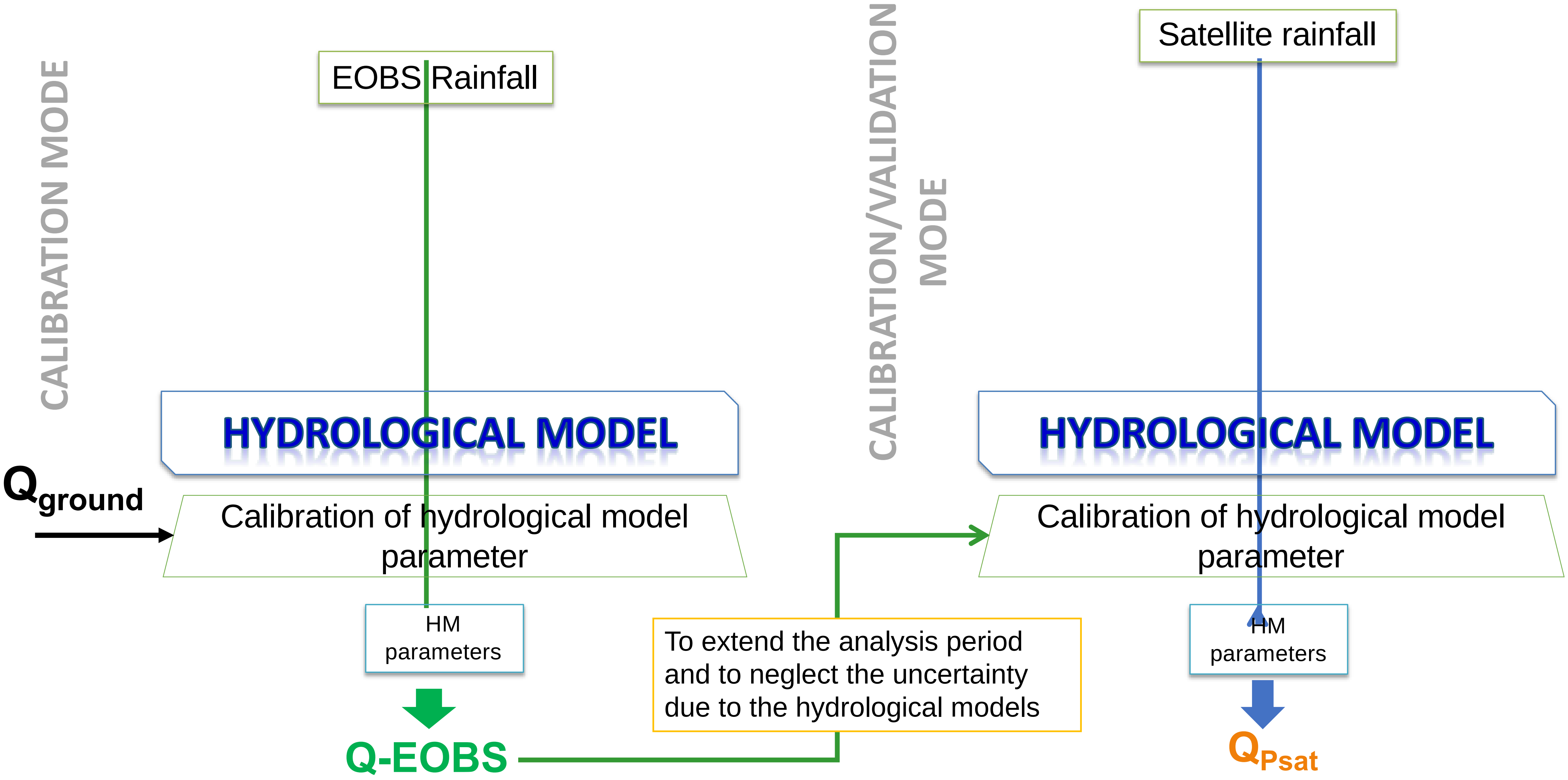
- Ground-based data
- Sampling 0.22°(~25 km)
- Daily coverage over Europe
- 1950 - ongoing

We designed a large-scale experiment by forcing **three conceptual hydrological models** with **different SREs** using **1318 basins in Europe** covering different climatic and physiographic conditions. (Camici et al. 2020, HESS)

# Conceptual hydrological models

| NAME | **MISDc** (Brocca et al., 2011)<br>MODELLO IDROLOGICO SEMI-DISTRIBUITO IN CONTINUO | **HYMOD** (Boyle 2011)<br>HYDROLOGIC MODEL | **GR4J** (Perrin et al., 2003)<br>GÉNIE RURAL À 4 PARAMÈTRES JOURNALIER |
|---|---|---|---|
| MODEL REPRESENTATION |  |  |  |
| NUMBER OF FREE PARAMETERS | 9 | 5 | 4 |
| REPRESENTED CATCHMENT STORES | surface; root zone | surface (x3); root zone | root zone |

# Experiment design



# Kling-Gupta index as calibration score

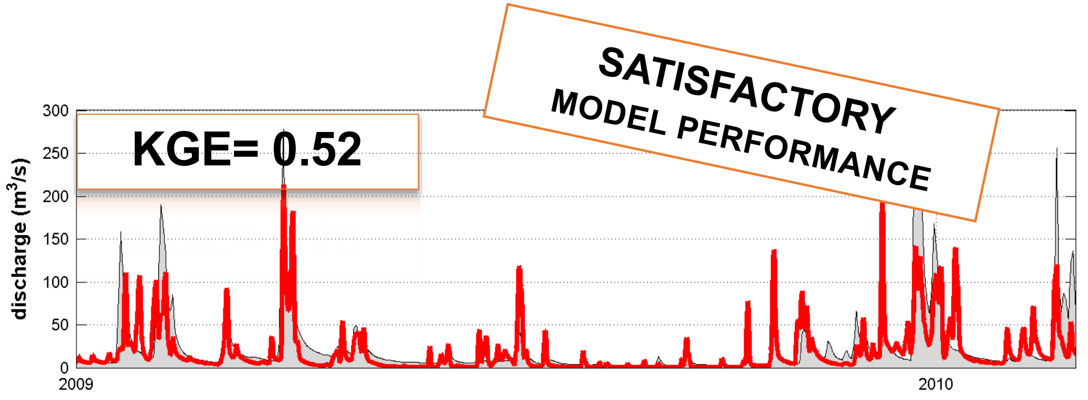
**Kling-Gupta Index** (Gupta et al., 2009)

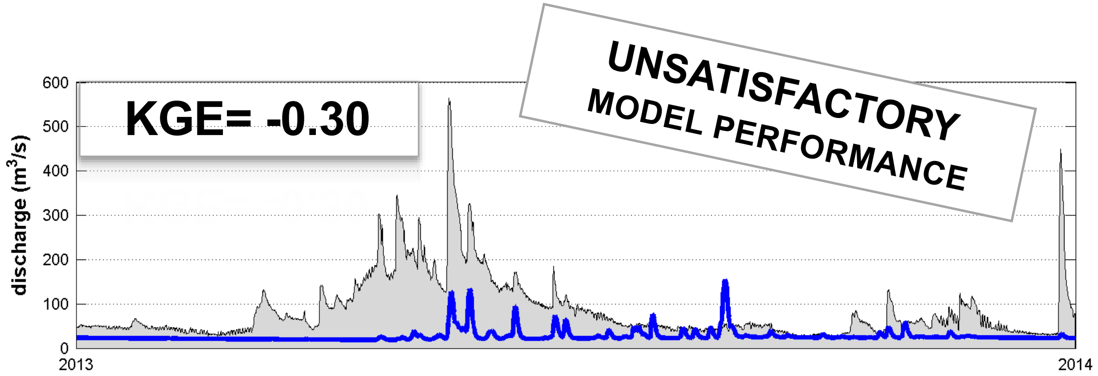
$$KGE = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2}$$

***r*** = correlation coefficient

***α*** = relative variability between observed and simulated discharge (i.e. ,conditional bias index)

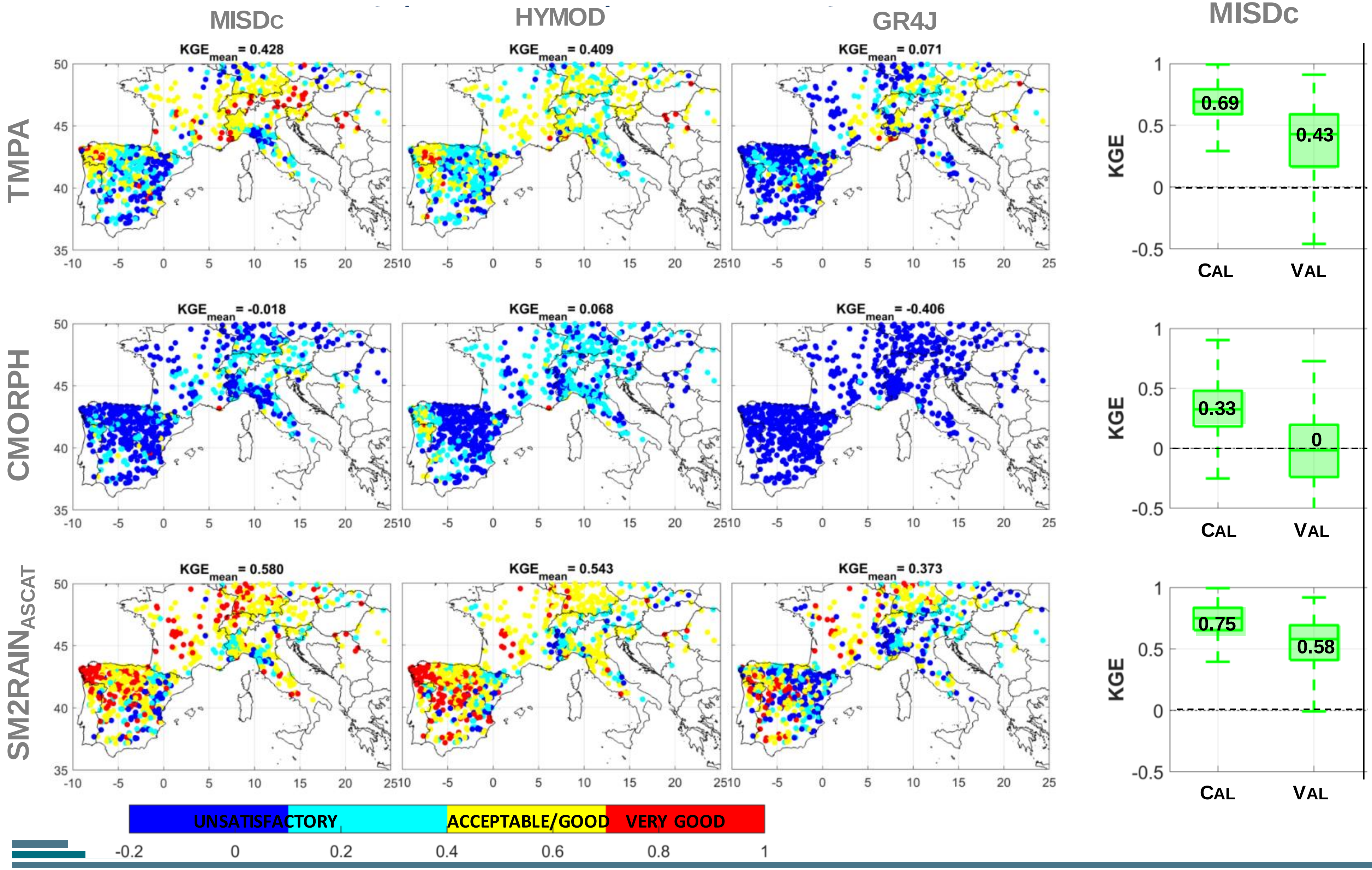
***β*** = bias normalized by the standard deviation.



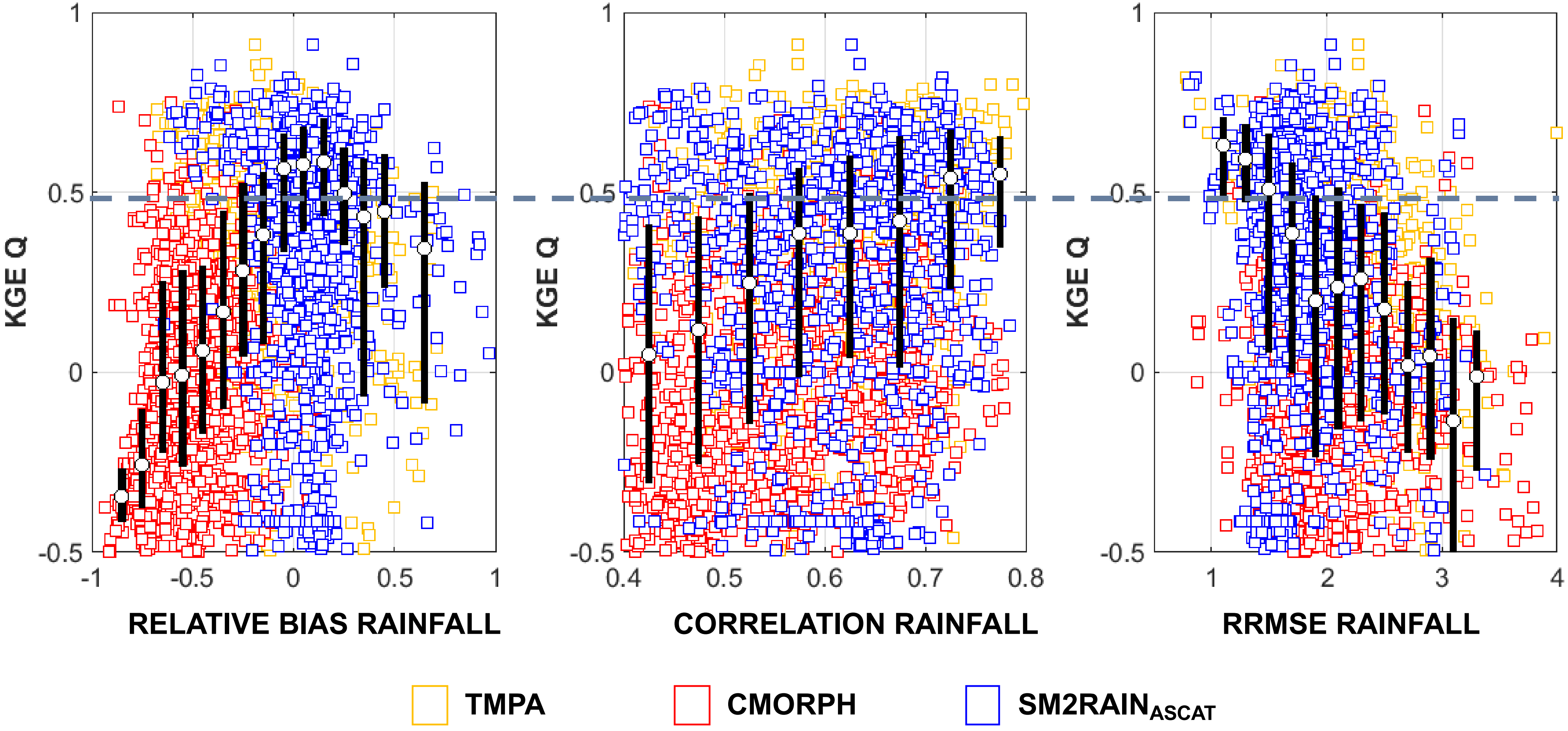




| $-\infty < KGE \leq 0.1$ | $0.1 < KGE \leq 0.4$ | $0.4 < KGE \leq 0.7$ | $0.7 < KGE \leq 1$ |
|---|---|---|---|
| UNSATISFACTORY MODEL RESULTS | UNSATISFACTORY MODEL RESULTS | ACCEPTABLE/GOOD MODEL RESULTS | VERY GOOD MODEL RESULTS |

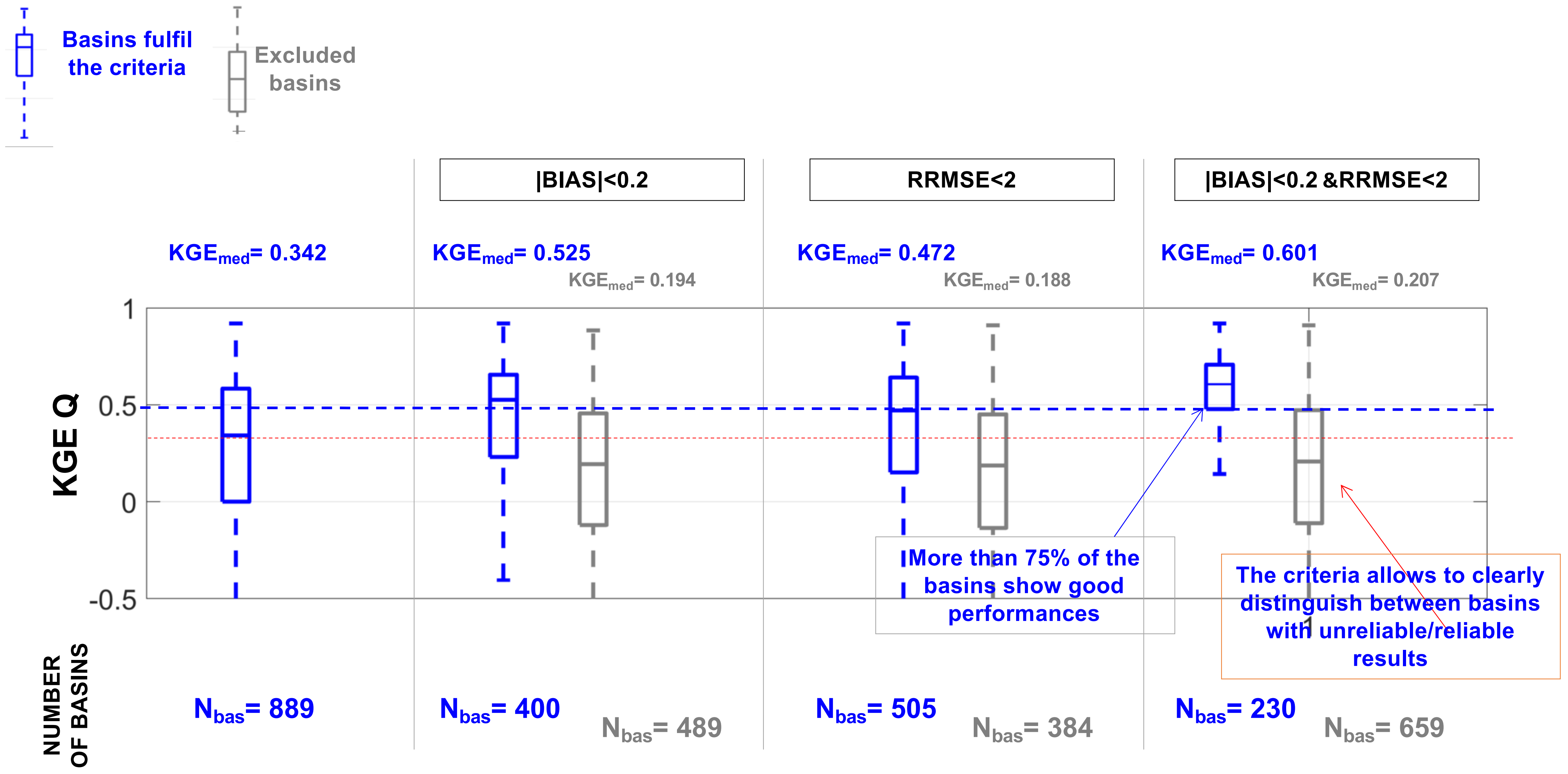
# Models vs rainfall products performance



# Why do some products performs better than others?



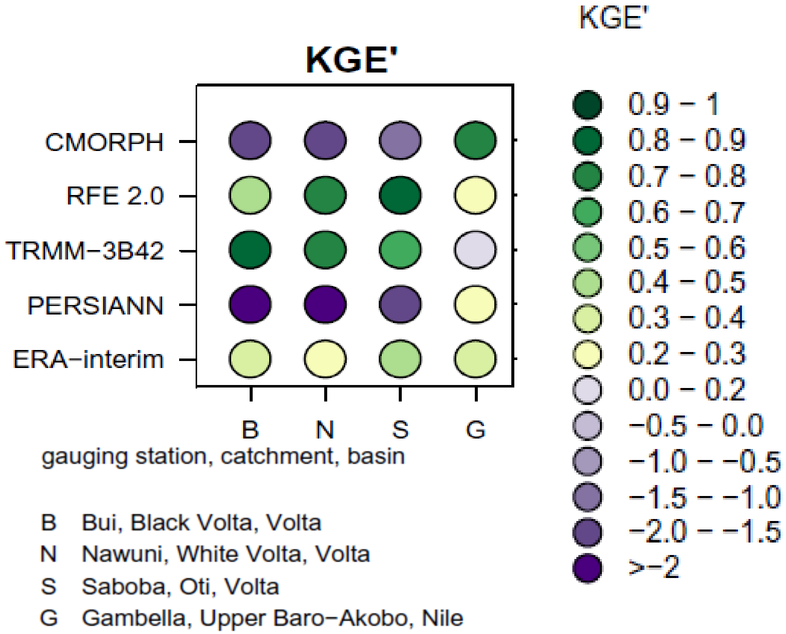
# Why do some products performs better than others?

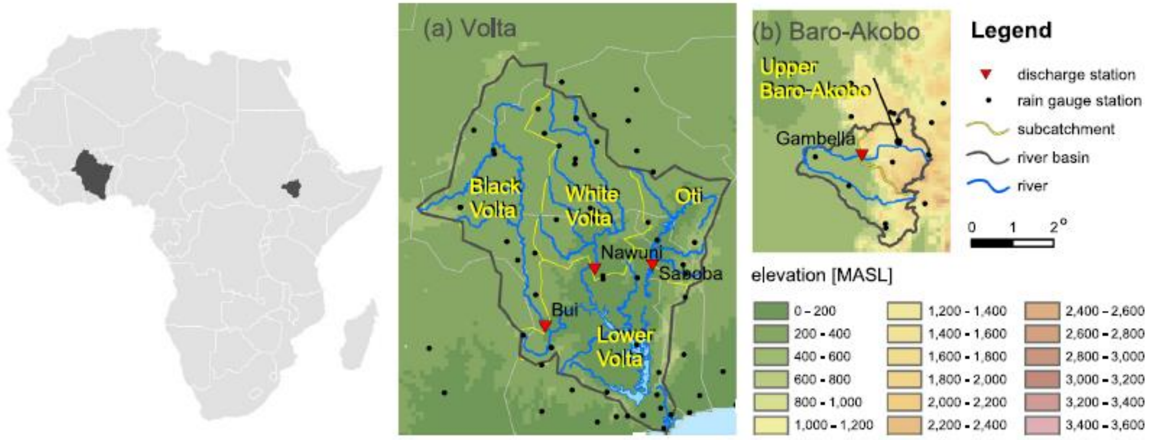


**Bias and relative error can help to understand the intrinsic quality of the SRE in hydrological model**

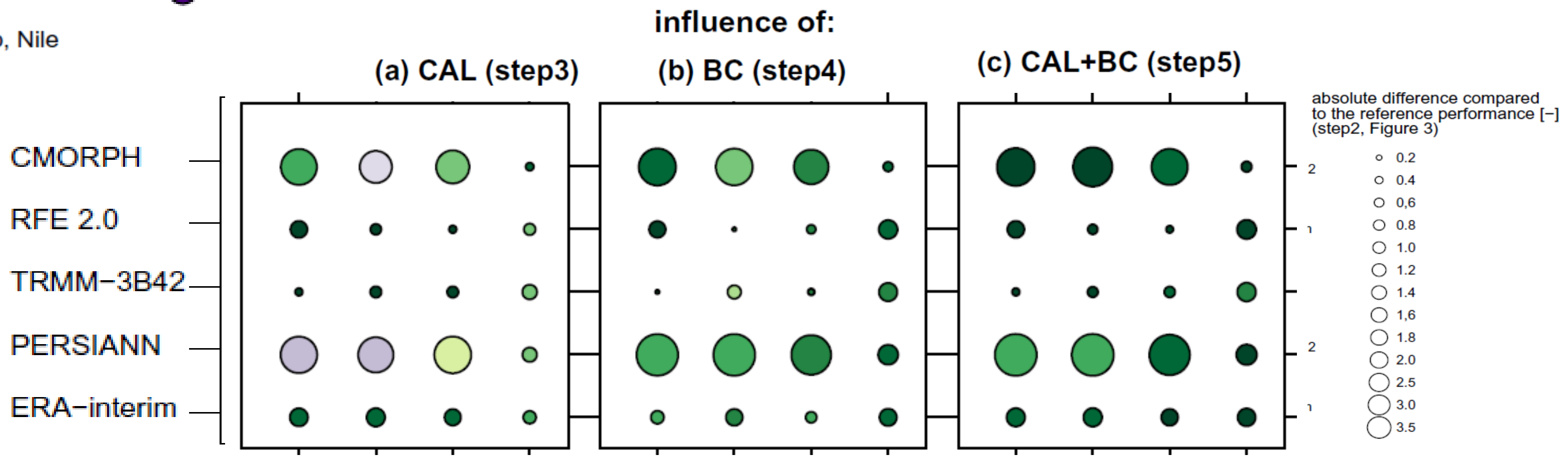
**What could researchers do to increase the performance of SRE-driven hydrological simulations?**

# Bias correction and model specific calibration



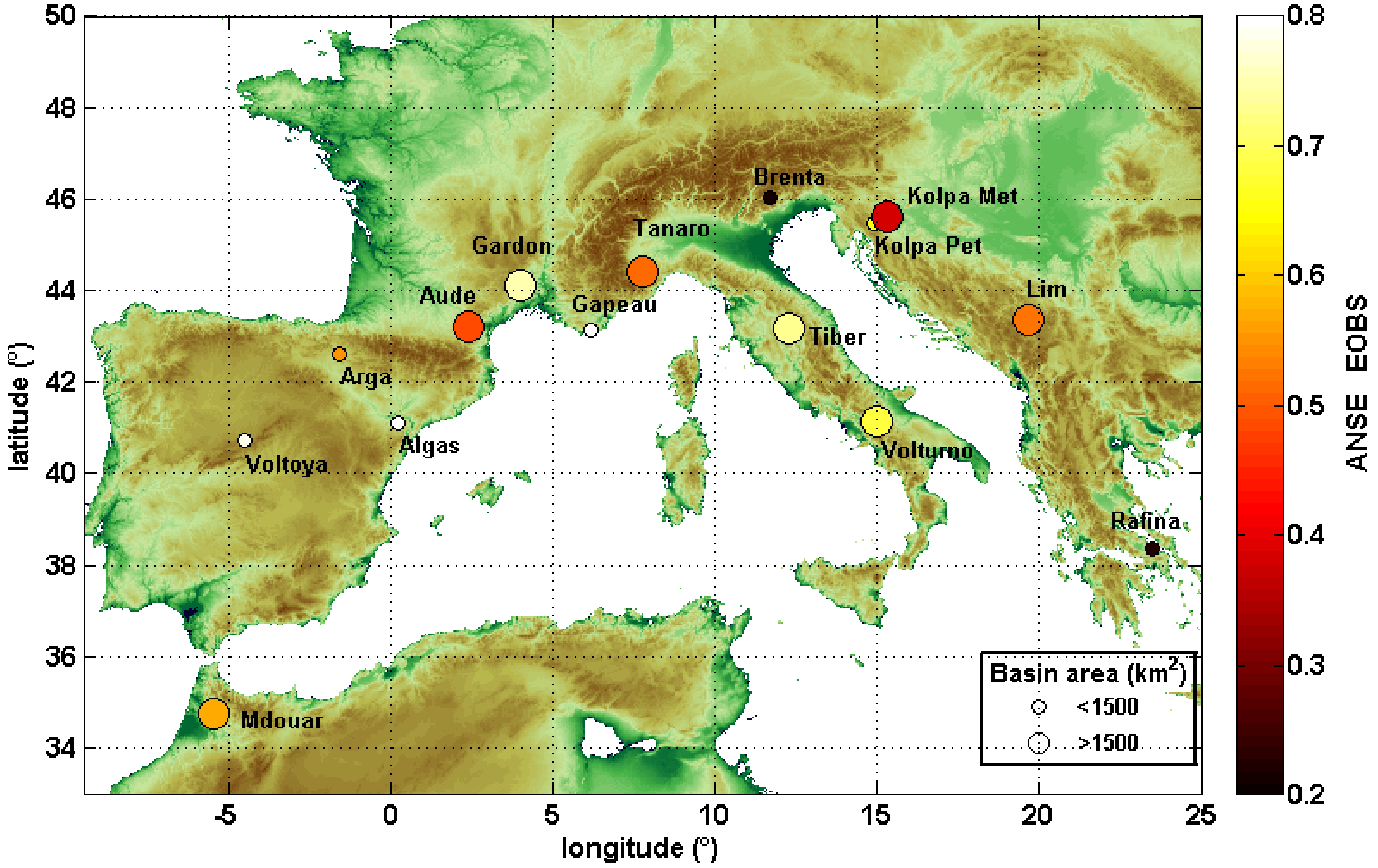




Thiemig et al. (2013)



# An experiment in the Mediterranean area

15 basins over the Mediterranean area with catchment area ranging from 100 to ~5000 km2




| # | Study basins | Area (km$^2$) | Topographic complexity index | Mean basin elevation (m.a.s.l.) | Available observed discharge data |
|---|---|---|---|---|---|
| 1 | Rafina @ Fladar | 109 | 11.80 | 86.5 | 2009-2014 |
| 2 | Voltoya @ Mediana | 140 | 7.60 | 1116.0 | 2000-2011 |
| 3 | Algas @ Batea | 335 | 4.80 | 255.0 | 2000-2011 |
| 4 | Gapeau @ Hyeres | 451 | 9.80 | 163.0 | 2000-2008 |
| 5 | Kolpa @ Petrina | 460 | 13.40 | 629.0 | 2000-2012 |
| 6 | Arga @ Arazuri | 741 | 7.80 | 558.7 | 2002-2014 |
| 7 | Brenta @ Berzizza | 1506 | 32.30 | 1362.0 | 2010-2014 |
| 8 | Gardon @ Russan | 1530 | 9.70 | 514.4 | 2008-2014 |
| 9 | Aude @ Carcassonne | 1770 | 9.20 | 105.0 | 2000-2012 |
| 10 | Mdouar @ Elmakhazine | 1800 | 8.90 | 304.3 | 2000-2012 |
| 11 | Kolpa @ Metlika | 2002 | 10.00 | 197.0 | 2000-2012 |
| 12 | Volturno @ Solopaca | 2580 | 14.80 | 610.8 | 2010-2014 |
| 13 | Lim @ Prijepolje | 3160 | 17.00 | 612.0 | 2000-2010 |
| 14 | Tanaro @ Asti | 3230 | 18.90 | 927.4 | 2010-2014 |
| 15 | Tiber @ Monte Molino | 4820 | 10.80 | 434.7 | 2000-2016 |

Camici et al. (2018), JoH

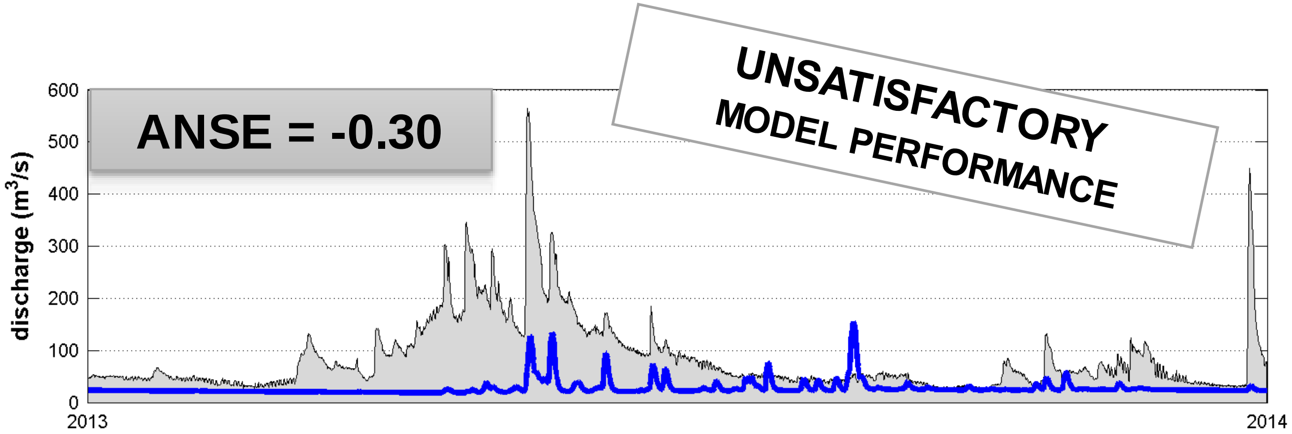
# Adapted Nash-Sutcliffe Efficiency index

## Adapted Nash-Sutcliffe Index

$$ANSE = 1 - \frac{\sum_{t=1}^{n} \left(Q_{obs} + \overline{Q_{obs}}\right)\left(Q_{sim} - Q_{obs}\right)^2}{\sum_{t=1}^{n} \left(Q_{obs} + \overline{Q_{obs}}\right)\left(\overline{Q_{obs}} - Q_{obs}\right)^2}$$

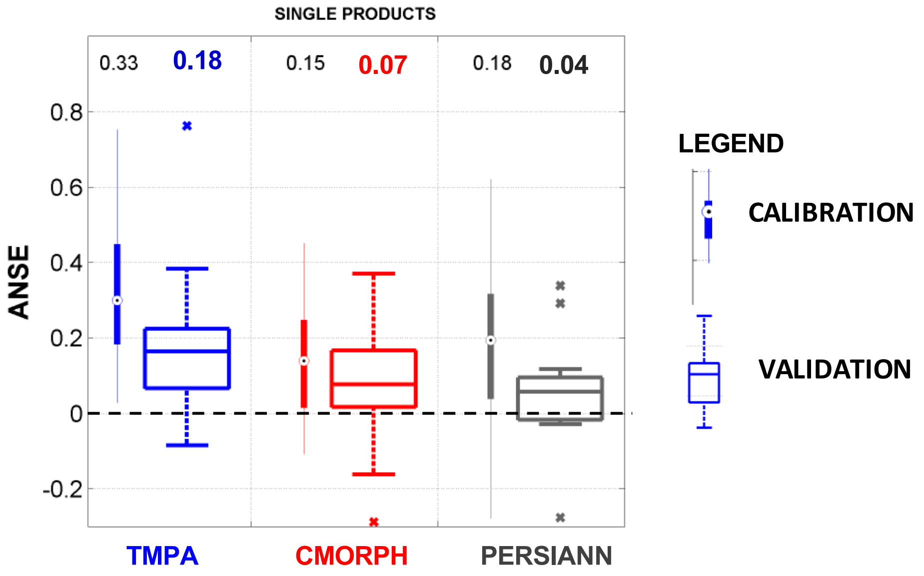
**Ranges between 1.0 (perfect fit) and −∞**

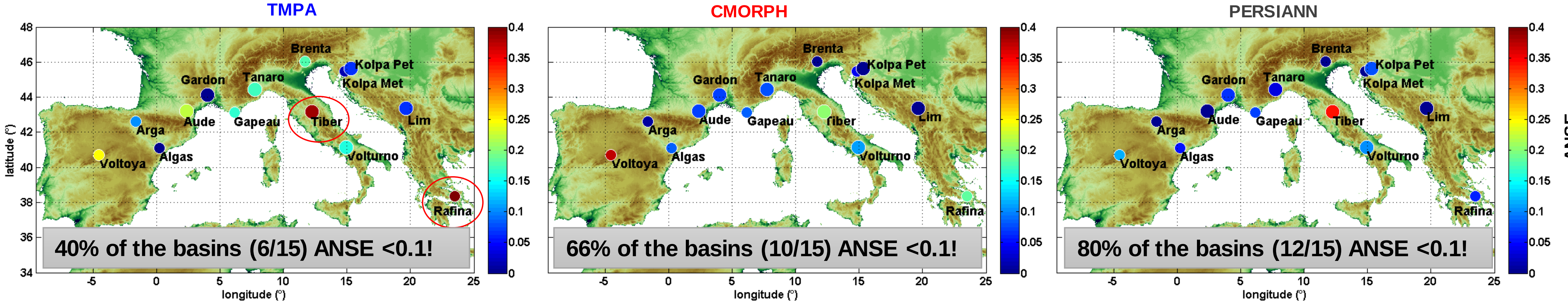
ANSE index is specifically tailored for high flow conditions.

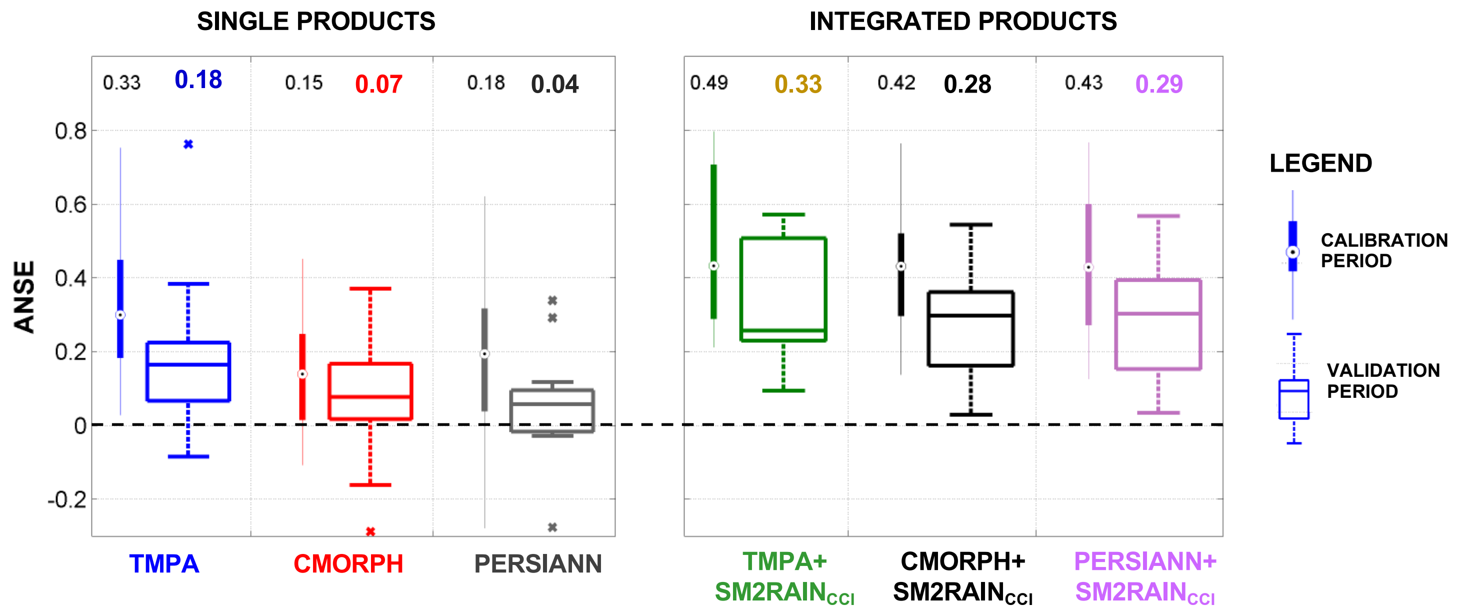
# Are model recalibration and bias correction really effective?

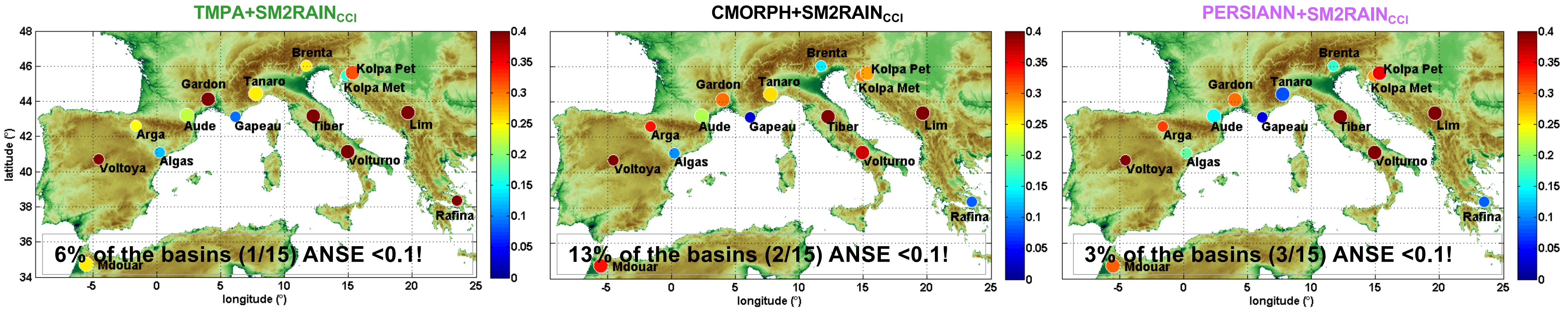
**Bias correction and model recalibration are not always sufficient to obtain satisfactory hydrological performances**



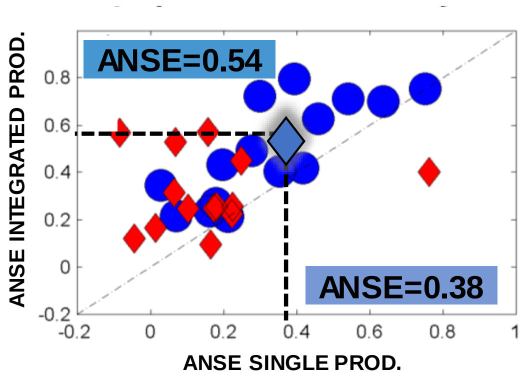
# Integration with different rainfall sources can be highly effective

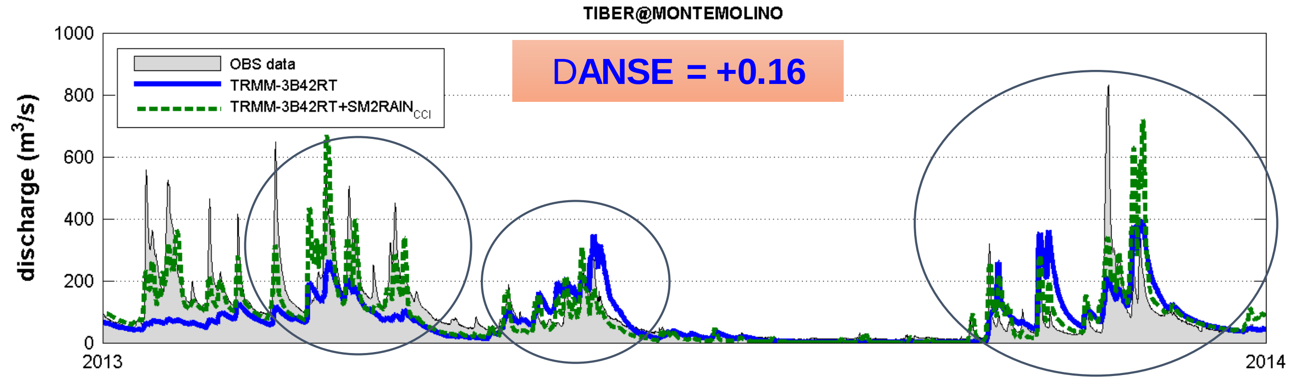


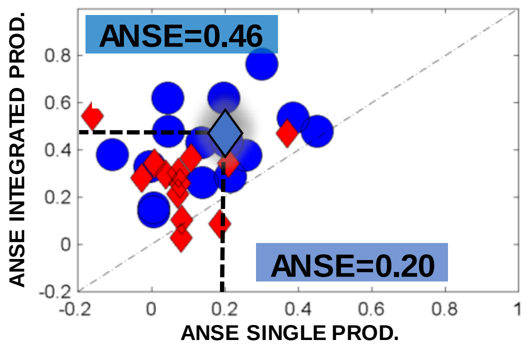
# Integration with different rainfall sources can be highly effective (2)

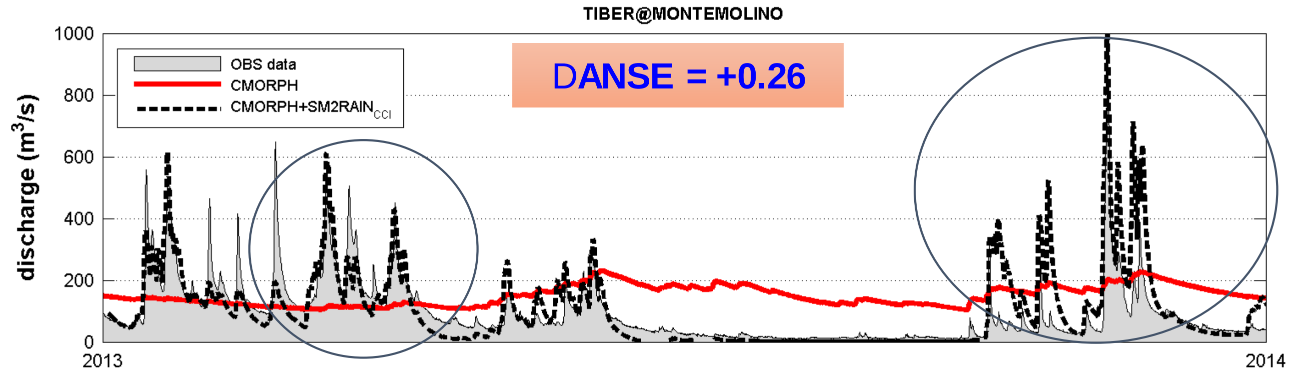
TMPA



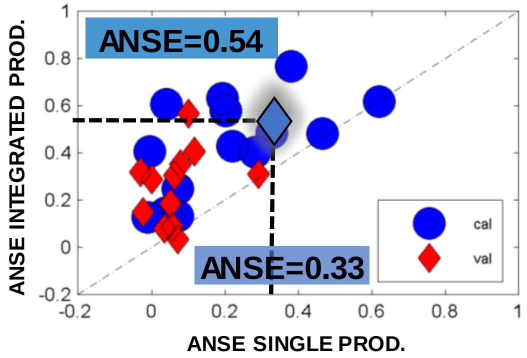



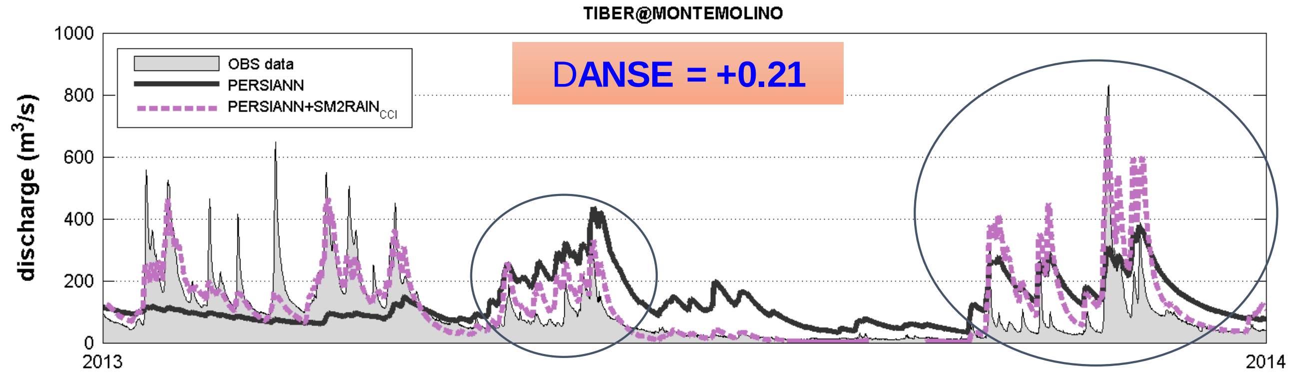

CMORPH



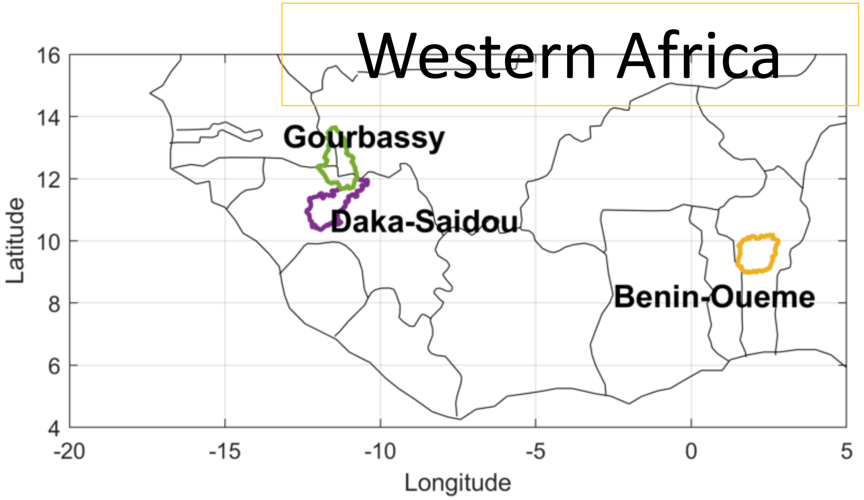

PERSIANN



# Benefit over data scarce regions

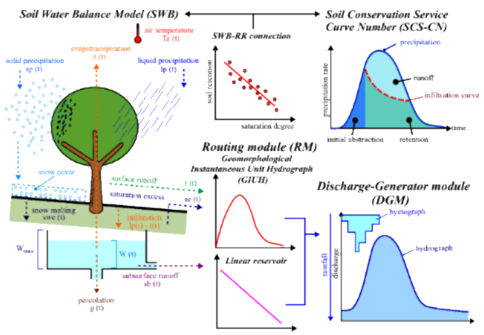
2015-2018



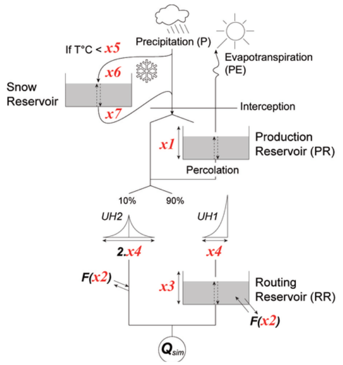

| Basin Name | Area (km²) |
|---|---|
| Gorbassy | 16134 |
| Daka Saidou | 15659 |
| Benin-Oueme | 1200 |

| Product | Latency |
|---|---|
| **GPCC** | 15-45 days |
| **ERA5** | 3 months |
| **IMERG-Final Run** | >1 month |
| **IMERG-Early Run** | 4-12 hours |
| **IMERG-ER +SM2RAIN** (ASCAT, SMOS, SMAP) | 2-3 days |
| **PRISM** | 1 day |

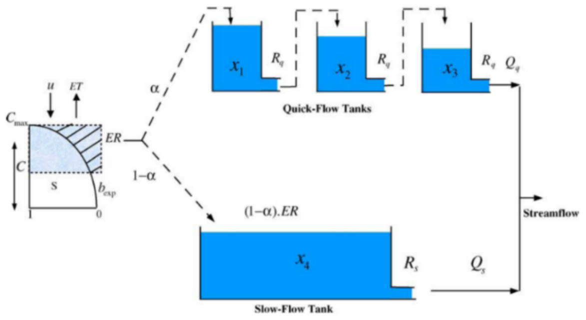
**MISDc model**
(Massari et al., 2018)



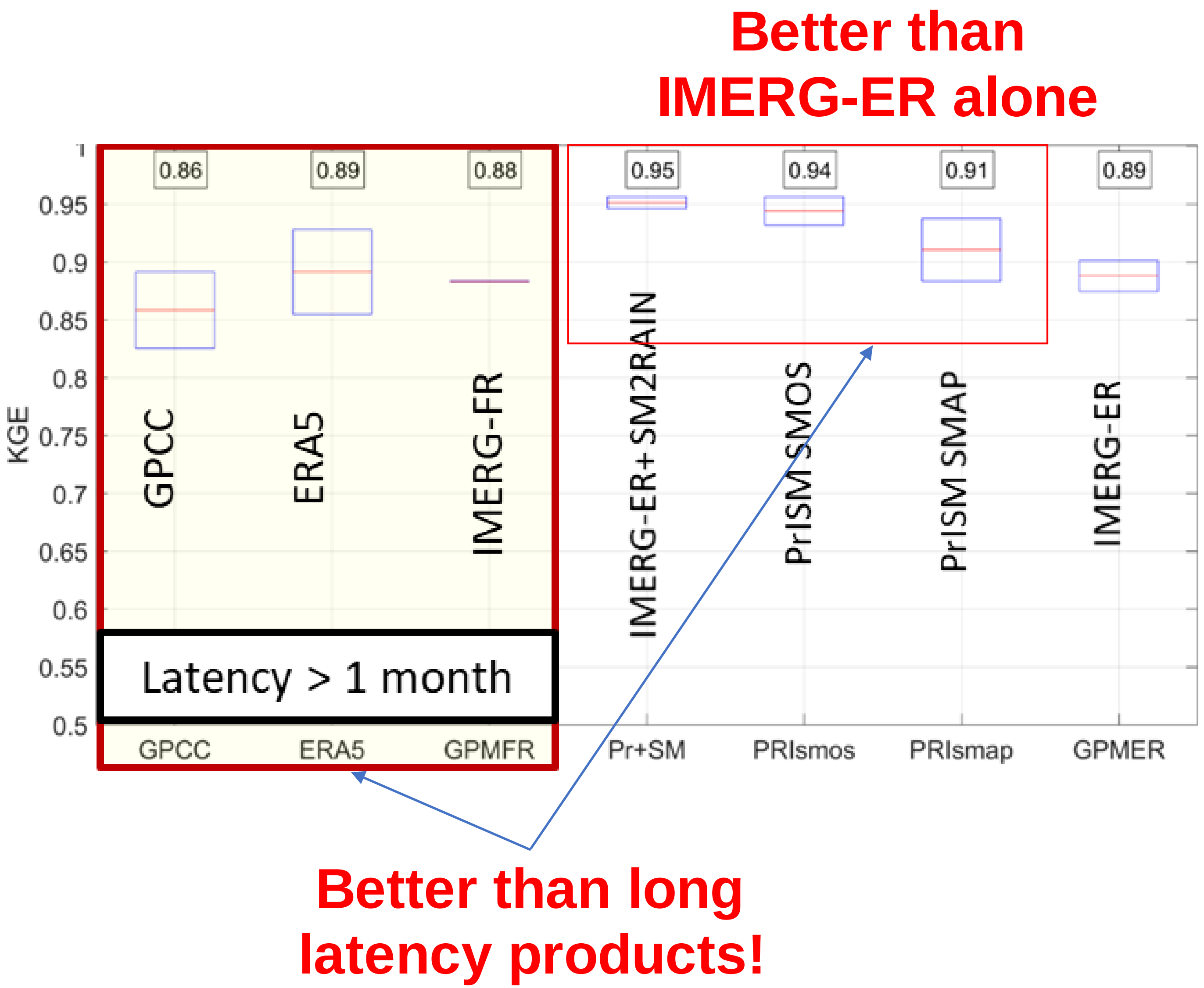

**HYMOD model**
(Wagener et al., 2001)




**GR4J model**
(Perrin et al., 2004)



# Satellite rainfall vs gauge vs model in Africa




Brocca et al. (2020), SR

# Take home message #3

Bias correction and model recalibration are two options to improve hydrological simulations with SREs but they do not always work. Integration is a promising technique that can help

# Most important references (for the topic)


Camici, S., Ciabatta, L., Massari, C., & Brocca, L. (2018). How reliable are satellite precipitation estimates for driving hydrological models: A verification study over the Mediterranean area. *Journal of hydrology*, *563*, 950-961.

Camici, S., Massari, C., Ciabatta, L., Marchesini, I., & Brocca, L. (2020). Which rainfall score is more informative about the performance in river discharge simulation? A comprehensive assessment on 1318 basins over Europe. *Hydrology and Earth System Sciences*, *24*(10), 4869-4885.

Massari, C., Brocca, L., Pellarin, T., Abramowitz, G., Filippucci, P., Ciabatta, L., ... & Fernandez Prieto, D. (2020). 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. *Hydrology and Earth System Sciences*, *24*(5), 2687-2710.

Brocca, L., Massari, C., Pellarin, T., Filippucci, P., Ciabatta, L., Camici, S., ... & Fernández-Prieto, D. (2020). River flow prediction in data scarce regions: soil moisture integrated satellite rainfall products outperform rain gauge observations in West Africa. *Scientific Reports*, *10*(1), 1-14.

Thiemig, V., Rojas, R., Zambrano-Bigiarini, M., & De Roo, A. (2013). Hydrological evaluation of satellite-based rainfall estimates over the Volta and Baro-Akobo Basin. *Journal of Hydrology*, *499*, 324-338.

Beck, H. E., Van Dijk, A. I., Levizzani, V., Schellekens, J., Gonzalez Miralles, D., Martens, B., & De Roo, A. (2017). MSWEP: 3-hourly 0.25 global gridded precipitation (1979-2015) by merging gauge, satellite, and reanalysis data. *Hydrology and Earth System Sciences*, *21*(1), 589-615.