Hydrological Application of OS Data: The Lambro Catchment Case Study

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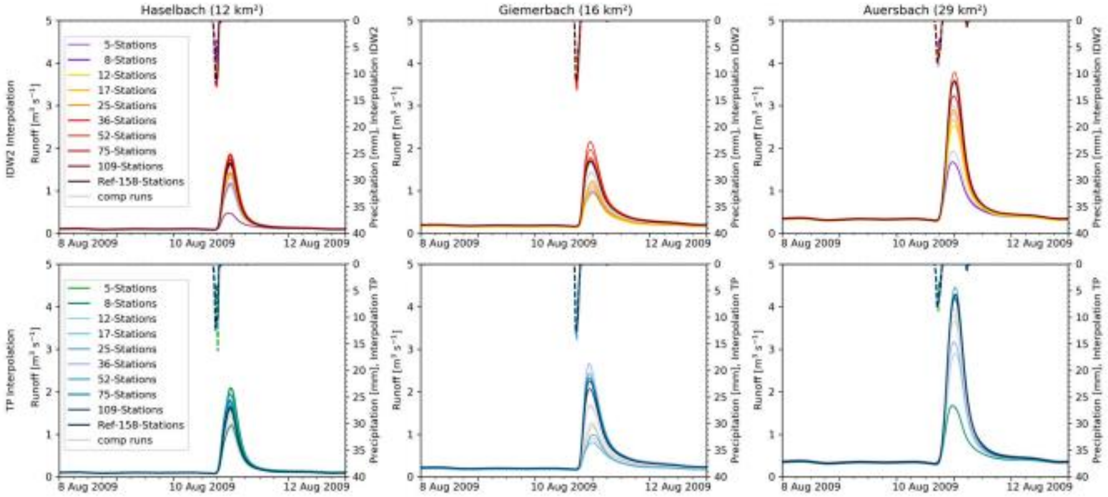
OpenSense

Hydrological modelling

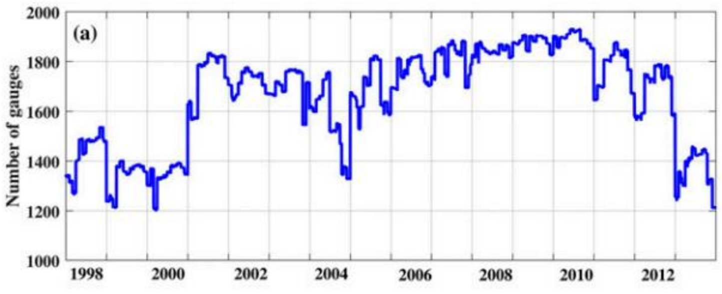
- Hydrological (rainfall-runoff) models are essential for sustainable water resources management
  - Estimation of values of hydrological variables (e.g., flows at ungauged sites, or flows in the future, i.e., streamflow forecasting)
  - Analyses of various scenarios
- Rainfall data is of utmost importance for hydrological modelling
  - Information on rain depth, rainfall dynamics and its spatial variability are needed



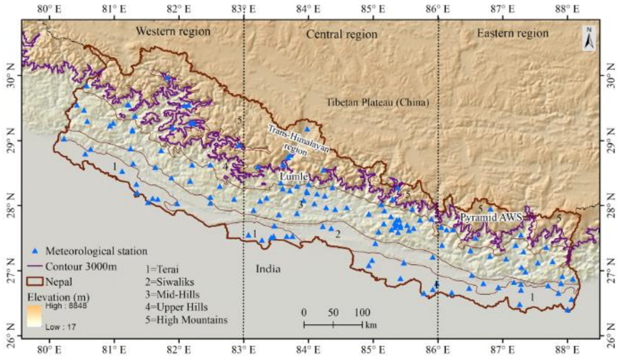
Hohmann et al., 2021
https://doi.org/10.3390/w13101381

Rainfall data in hydrological modelling

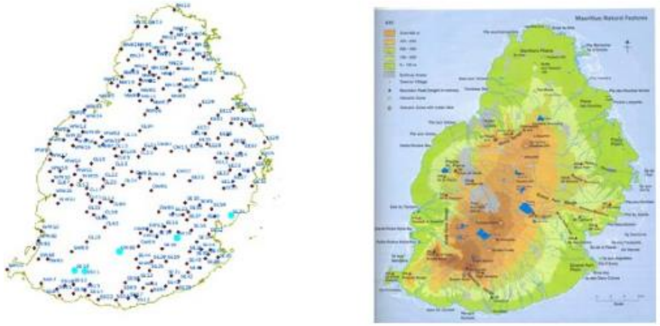
- Rainfall data are traditionally being obtained from the raingauges
  - Rain gauge observations are affected by the wind, the number of the gauges can decrease over time, majority of gauges are located at lower elevation…



Prakash et al., 2019
https://journals.ametsoc.org/downloadpdf/view/journals/hydr/20/5/jhm-d-18-0161_1.pdf

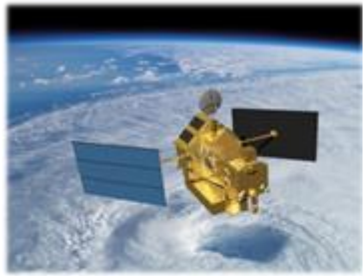


Sharma et al., 2020
https://doi.org/10.1029/2020EA001315



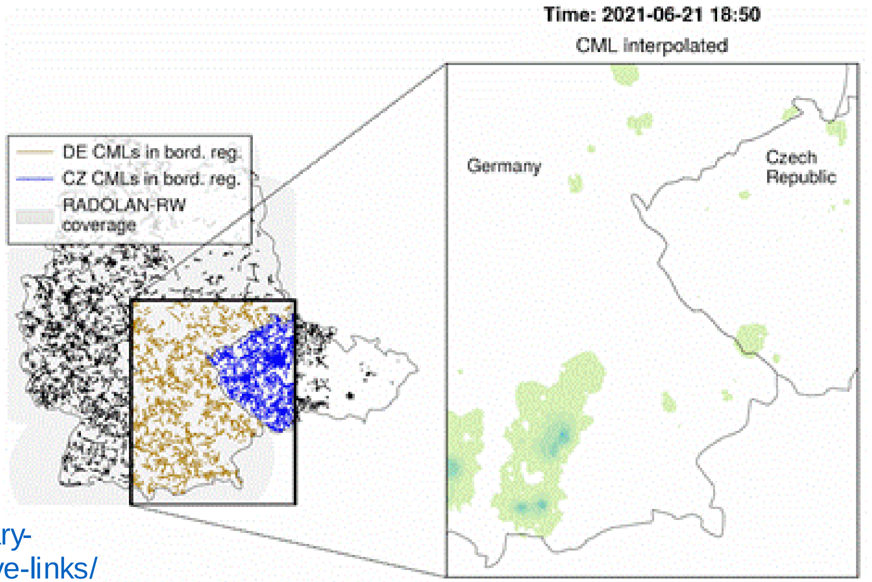
Dhurmea et al., 2009
Conference: 3rd Research Week 2009-2010, International Conference, University of Mauritius

- Recent tendencies to use radar- or satellite rainfall data
  - Indirect rainfall observations

Why using OS data in hydrological modelling?

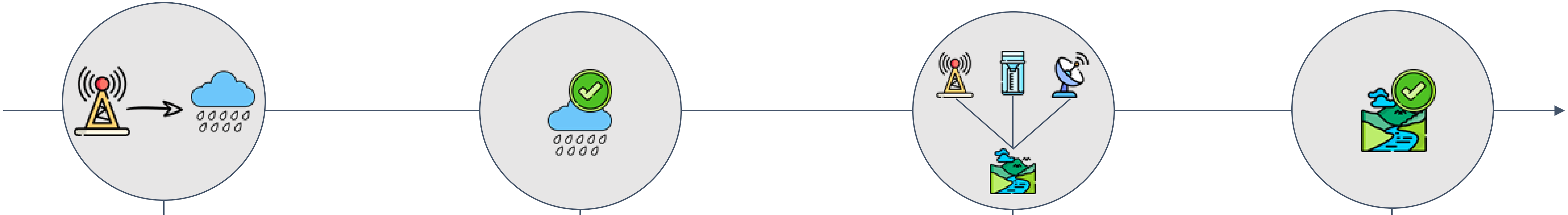
- Obtaining rainfall data remains costly, and these data remain accompanied by uncertainties
- A promising avenue for future development: opportunistic sensing
  - Potential to extend the monitoring network and get rainfall data (almost) at no additional costs
  - … and to advance hydrological modelling
- Some of the opportunistic sensing (OS) techniques: personal weather stations, satellite microwave links, *commercial microwave links (CML)*



COST OpenSense
https://opensenseaction.eu/news/transboundary-rainfall-estimation-using-commercial-microwave-links/

Our project

Investigating the potential of CML-retrieved rainfall data for hydrological modelling



Rainfall retrieval from CML transmitted and received power levels

Nebuloni et al., 2020
https://doi.org/10.3390/s22093218

Nebuloni et al., 2022
https://www.ursi.org/Publications/RadioScienceLetters/Volume2/RSL20-0062-final.pdf

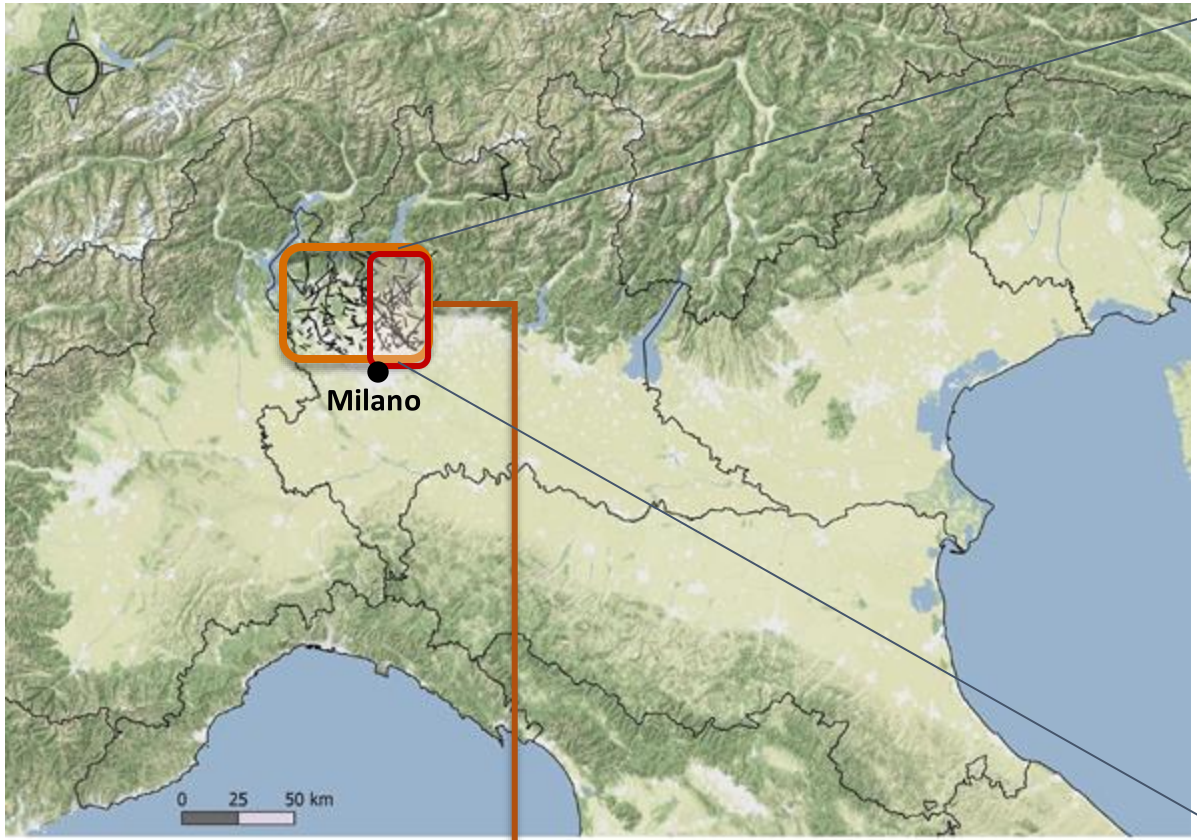
Validation of CML-retrieved data against RG data on different hydrological spatial scales

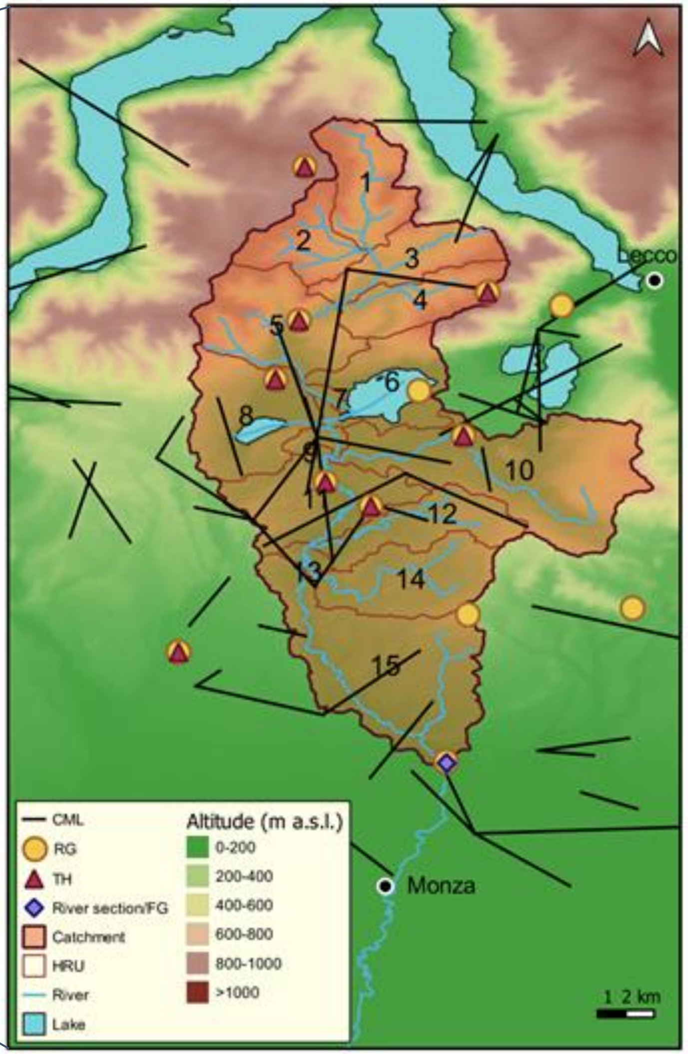
Hydrological modelling with multiple rainfall data sources (RG, CML, radar)

Validation of river discharge (RG vs CML vs radar)

Cazzaniga et al., 2022
https://doi.org/10.5194/hess-26-2093-2022

The Lambro catchment





Peri-urban region

(*Lambro-Seveso-Olona*)

The Lambro catchment

Rainfall measurements

50 commercial microwave links (CML)

13 rain gauges (RG)

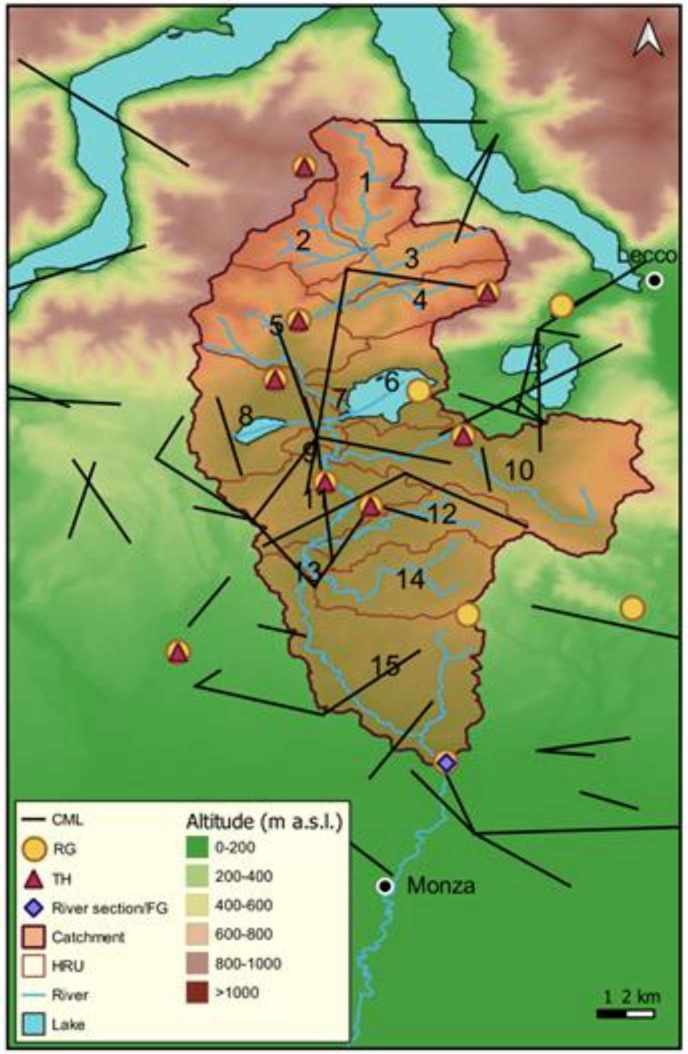
radar

Temperature

8 thermometers

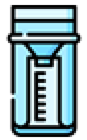
River discharge

hydrometer



Rainfall datasets on the Lambro catchment

Rain gauges

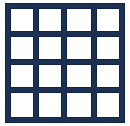


TIME RESOLUTION
10 minutes

ACCURACY
0.2 mm

AVAILABILITY
- Available at https://www.arpalombardia.it/
- Data from January 2018 until June 2020

Radar



TIME RESOLUTION
5 minutes

SPATIAL RESOLUTION
1km x 1km

AVAILABILITY
- Available on demand from MétéoSuisse with a small fee for data extraction
- Data from October 2019 until June 2020

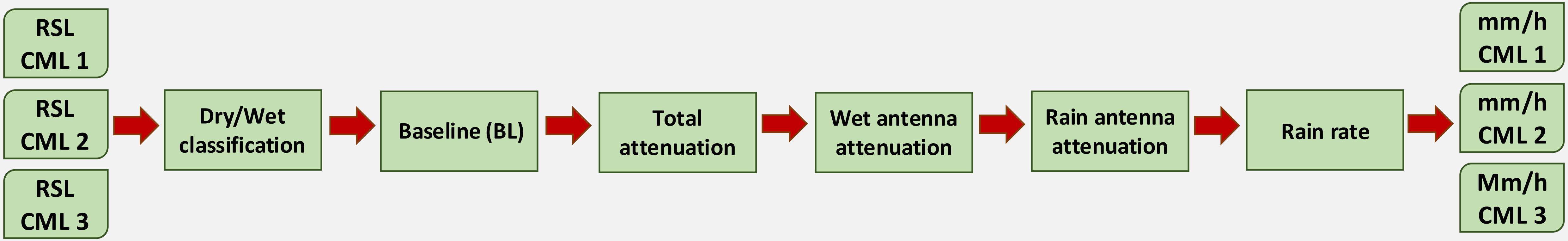
Commercial microwave links

TIME RESOLUTION
15 minutes MIN-MAX power data

ACCURACY
1 dB

AVAILABILITY
- For a fee and confidential (provided by Vodafone)
- 12 rainy events from June 2019 until June 2020

Rainfall retrieval from CML data



Overeem et al. 2016
https://doi.org/10.1073/pnas.1217961110

Some details on the data processing:

→ $A = LkR^{\alpha}$ Calibration of k and α parameters from the Drop Size Distribution of hydrometeors (from disdrometers)

Nebuloni et al., 2022

→ $\bar{R} = \frac{1}{1.14} \cdot \frac{R_{min} + R_{max}}{2}$ Unbiased estimator for 15 minutes average rain intensities

Nebuloni et al., 2020

Rainfall measurements: CML vs rain gauges

Comparison between CML and rain gauges accumulated rainfall

High intensity events
(max rain depth $\geq$ 15 mm per hour)

Low intensity events
(max rain depth $<$ 15 mm per hour)

Cazzaniga et al., 2022

Rainfall measurements: CML vs rain gauges

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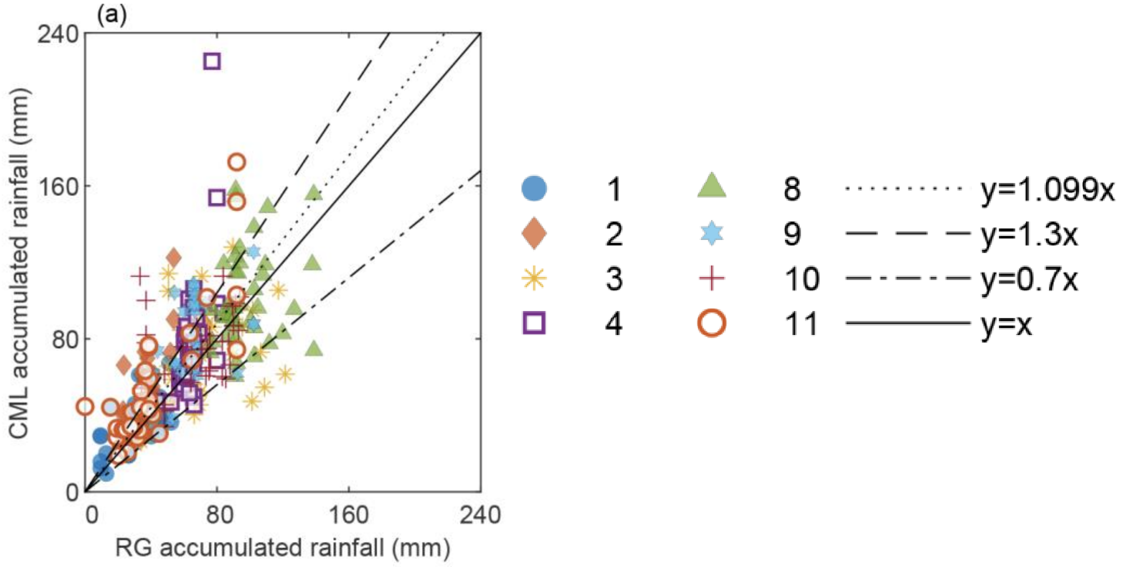
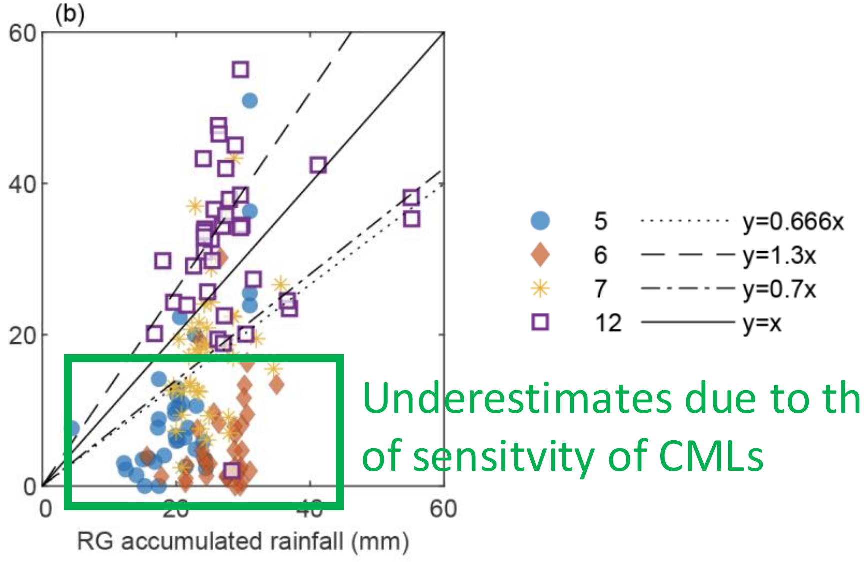
(max rain depth ≥ 15 mm per hour)

Low intensity events
(max rain depth < 15 mm per hour)



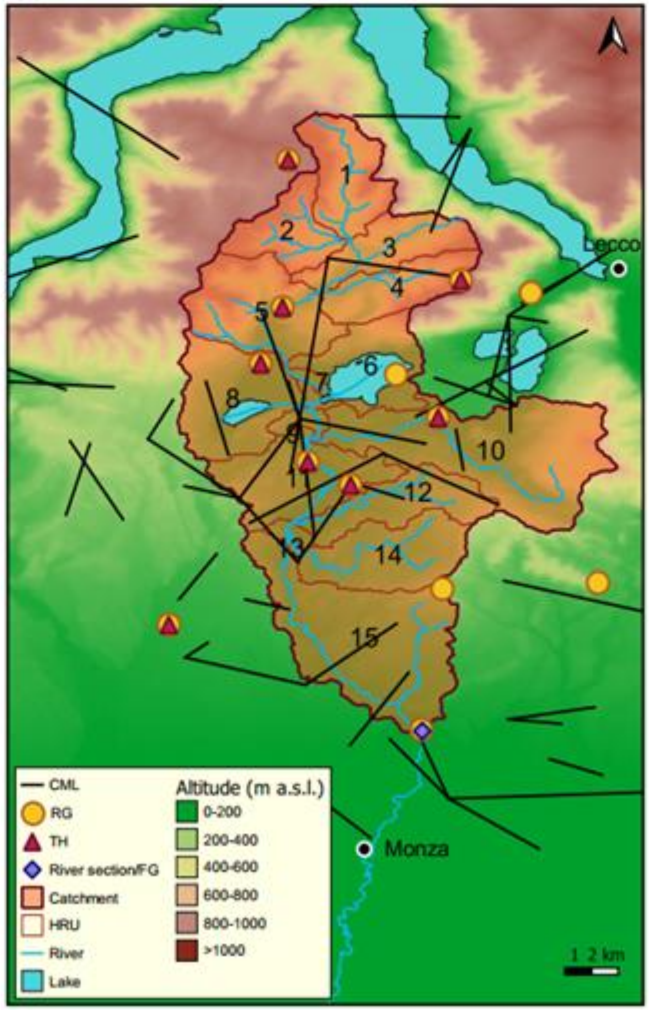


Underestimates due to the lack of sensitvity of CMLs

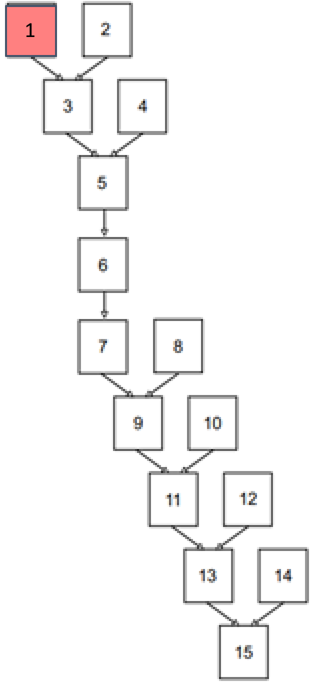
Cazzaniga et al., 2022

The hydrological model

Semi-distributed model



Sub-catchment or hydrological response unit (HRU)



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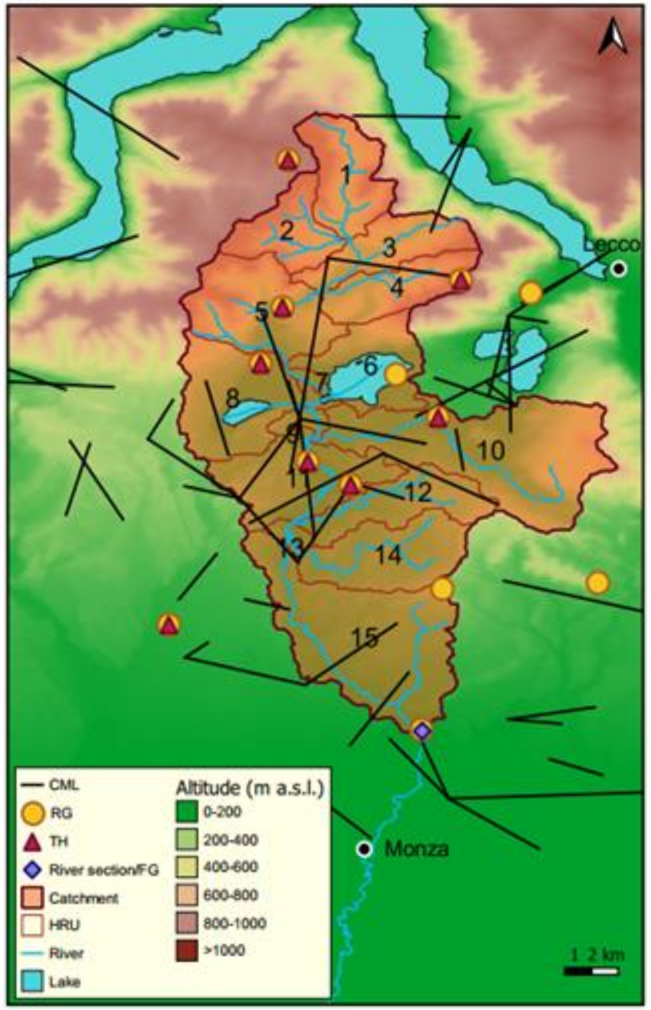

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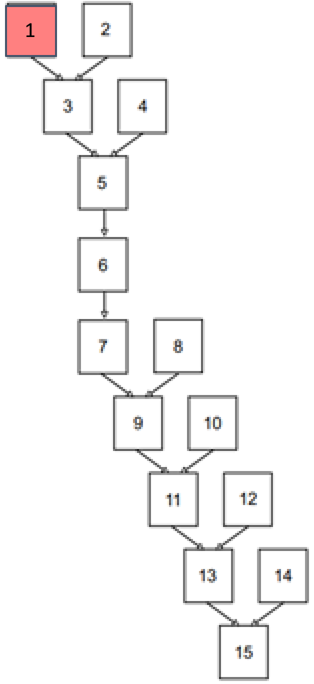
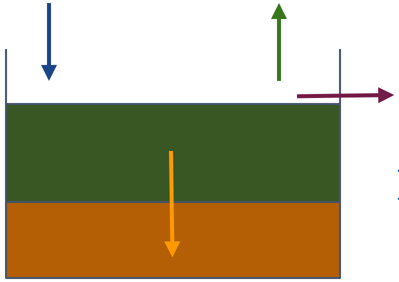


Evapotranspiration

Hargreaves and Samani, 1985 https://doi.org/10.13031/2013.26773

Ravazzani et al., 2015 https://doi.org/10.1080/02626667.2014.916405

Precipitation



Surface runoff

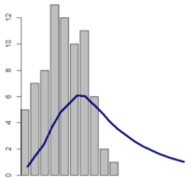
SCS-CN method

https://doi.org/10.1007/978-94-017-0147-1

Discharge

linear reservoir model

Doodge, 1973

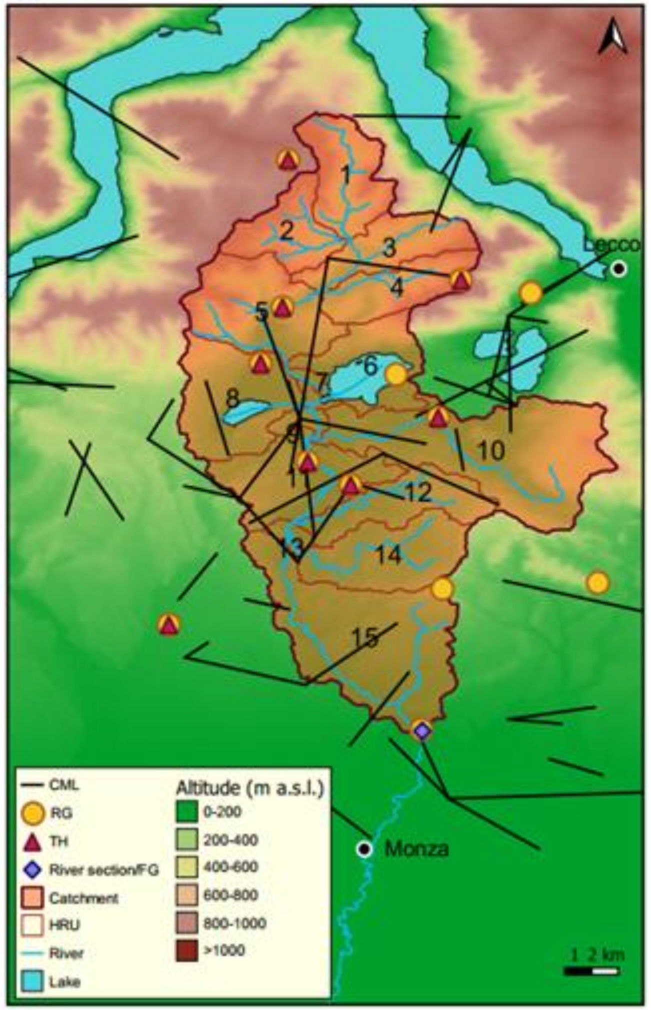


Drainage flux

Brooks and Corey, 1964

The hydrological model

Semi-distributed model



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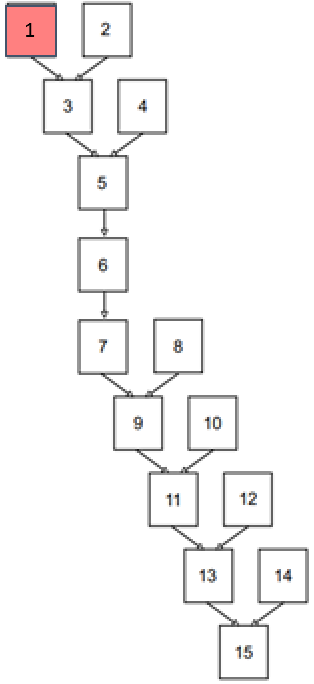

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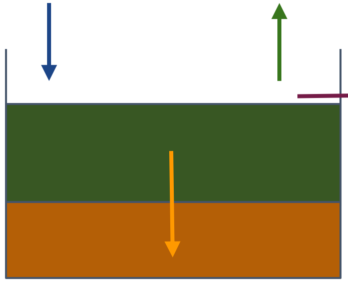

Surface runoff
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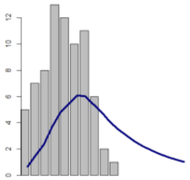
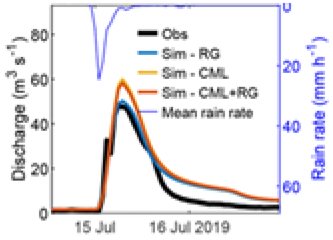


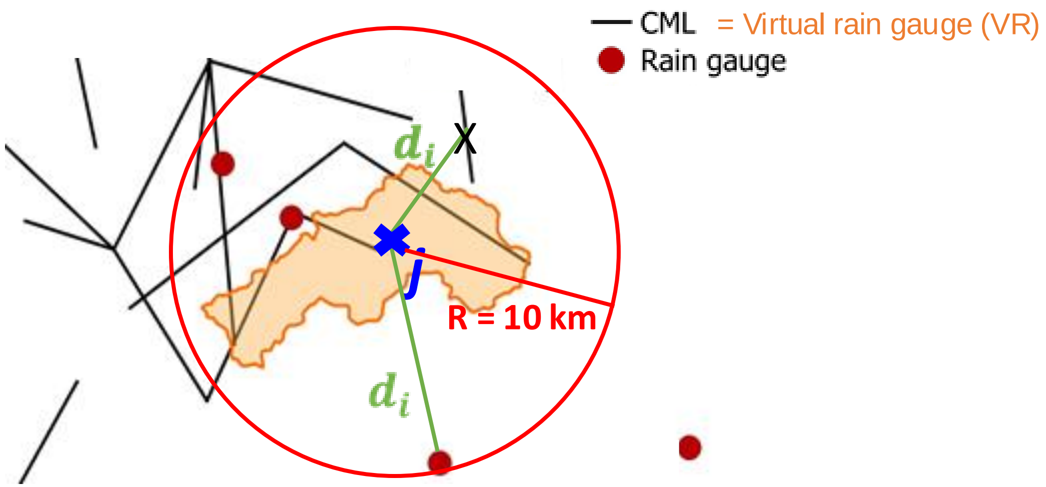
Drainage flux
Brooks and Corey, 1964

- Continuous and event-based simulation at hourly time scale
- Calibration over 1 year of data, maximizing the Nash-Sutcliffe efficiency



Integration of rainfall data into the hydrological model

CML- and RG-based data:
Inverse distance weighting method



$$R_j = \frac{\sum_{i=1}^{N} w_i P_i}{\sum_{i=1}^{N} w_i} \qquad w_i = \frac{1}{d_i^3}$$

Integration of rainfall data into the hydrological model

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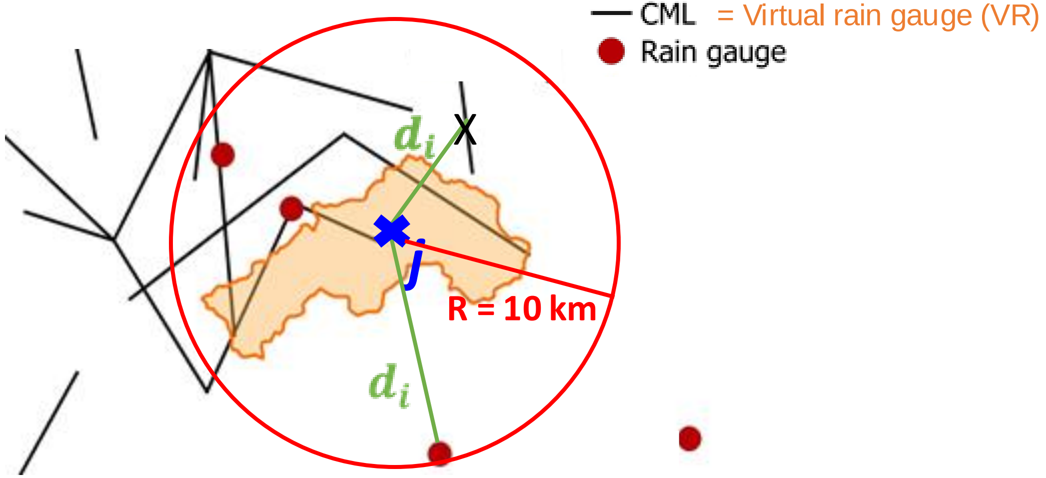
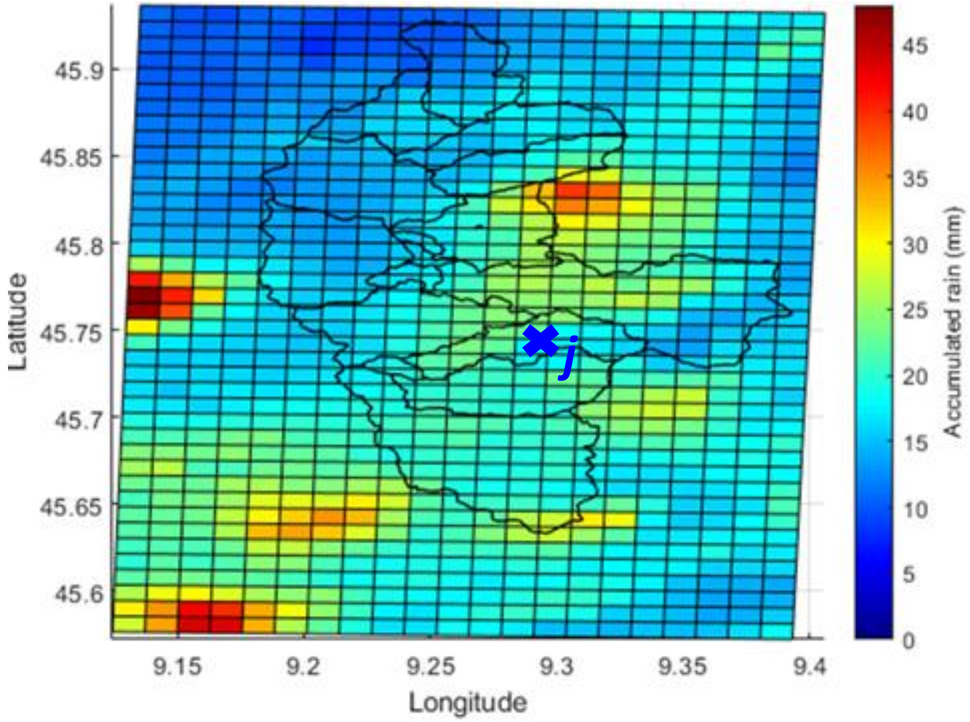


$$R_j = \frac{\sum_{i=1}^{N} w_i P_i}{\sum_{i=1}^{N} w_i} \qquad w_i = \frac{1}{d_i^3}$$

Radar-based data: spatial average



$$R_j = \frac{1}{N} \sum_{i=1}^{N} R_i \qquad i = \text{pixel inside the j} - \text{th HRU}$$

Rainfall measurements: CML vs rain gauges vs radar

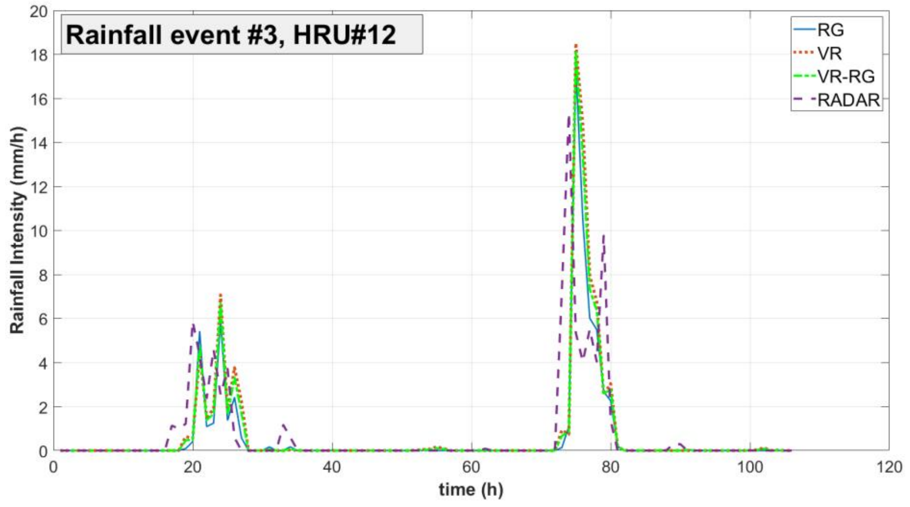
Event #3

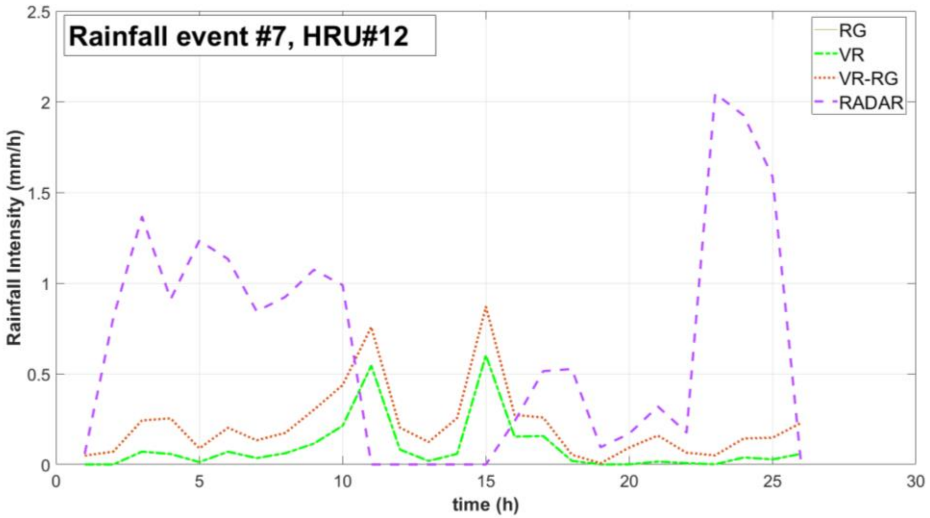
HRU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
RG	68.47	71.64	60.74	60.11	80.44	76.48	76.39	71.3	81.97	85.27	84.27	91.03	84.57	70.1	58.83	74.77
VR	70.67	67.9	72.37	72.49	69.1	74.3	81.44	66.57	91.86	94.22	63.72	84.76	77.48	82.59	61.34	75.39
VR-RG	69.32	70.06	71.67	71.12	79.59	76.11	81.18	67.2	90.75	93.38	64.61	86.74	77.65	77.63	61.27	75.89
RADAR	53.69	59.5	52.63	45.19	56.82	48.02	64.22	59.02	48.65	47.06	48.81	62.42	62.56	51.33	41.22	53.41

Cumulative rainfall depth (mm)

HRU

Underestimates due to the presence of mountains





RG - rain gauge

VR - virtual rain gauge (CML data)

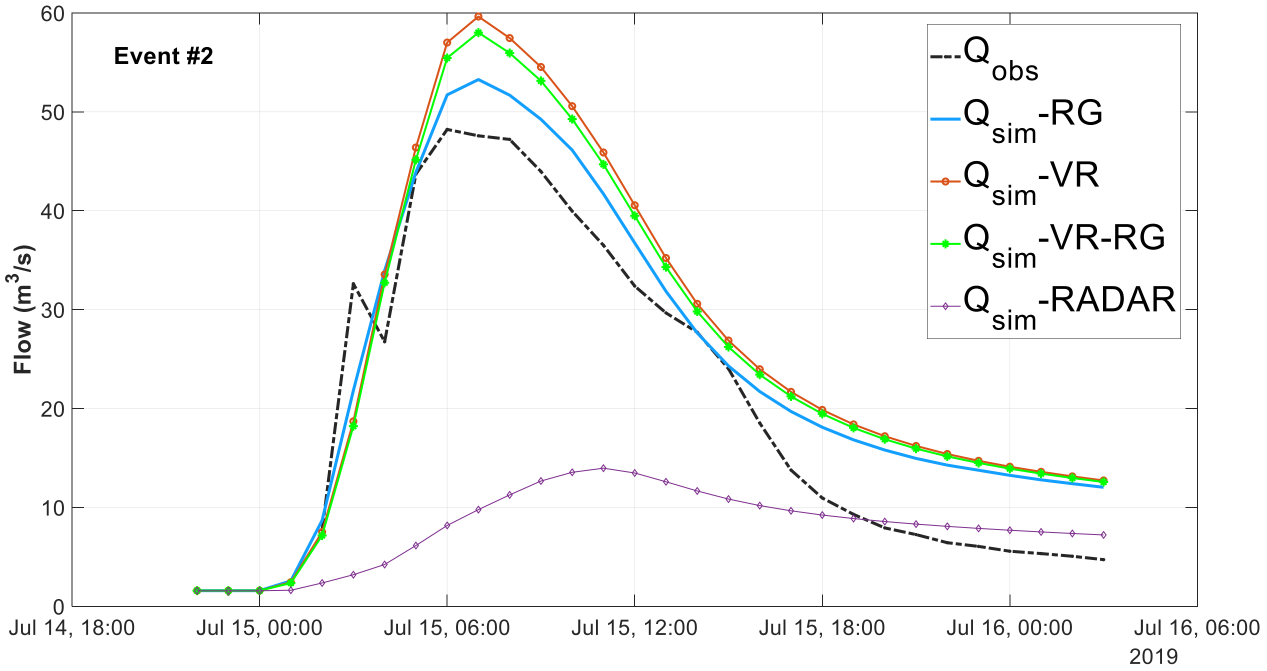
VR-RG - rain gauge and CML data combined

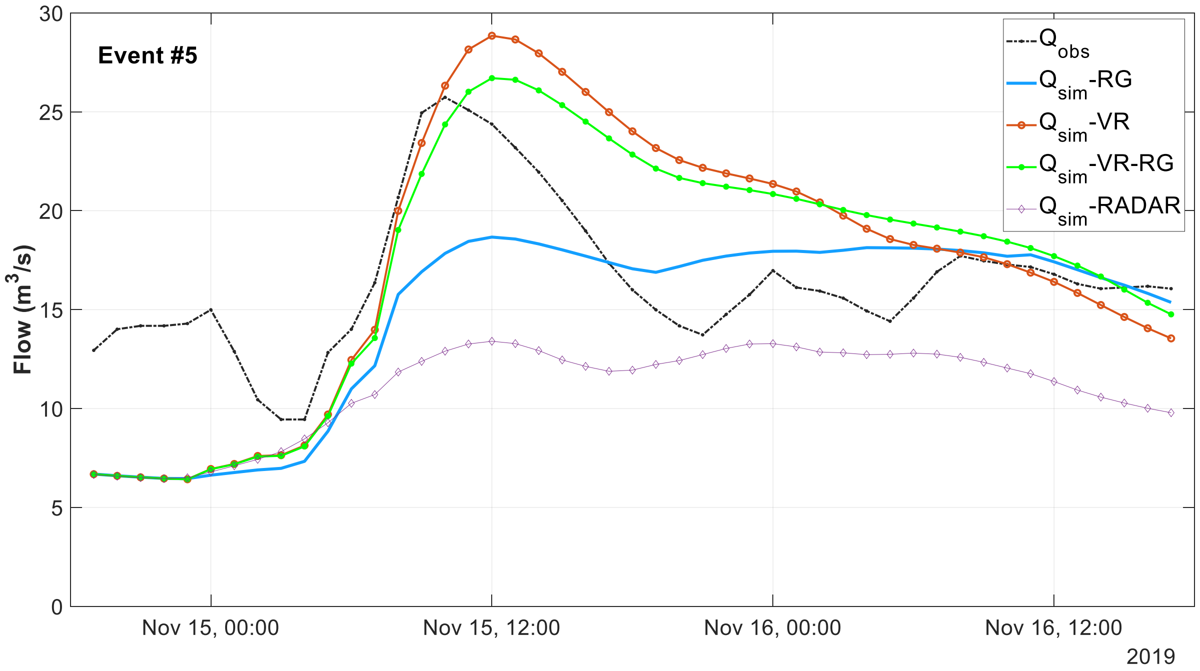
RADAR data

For some events the radar is unable to capture the rainfall dynamics

Results – Sensitivity to the rainfall input

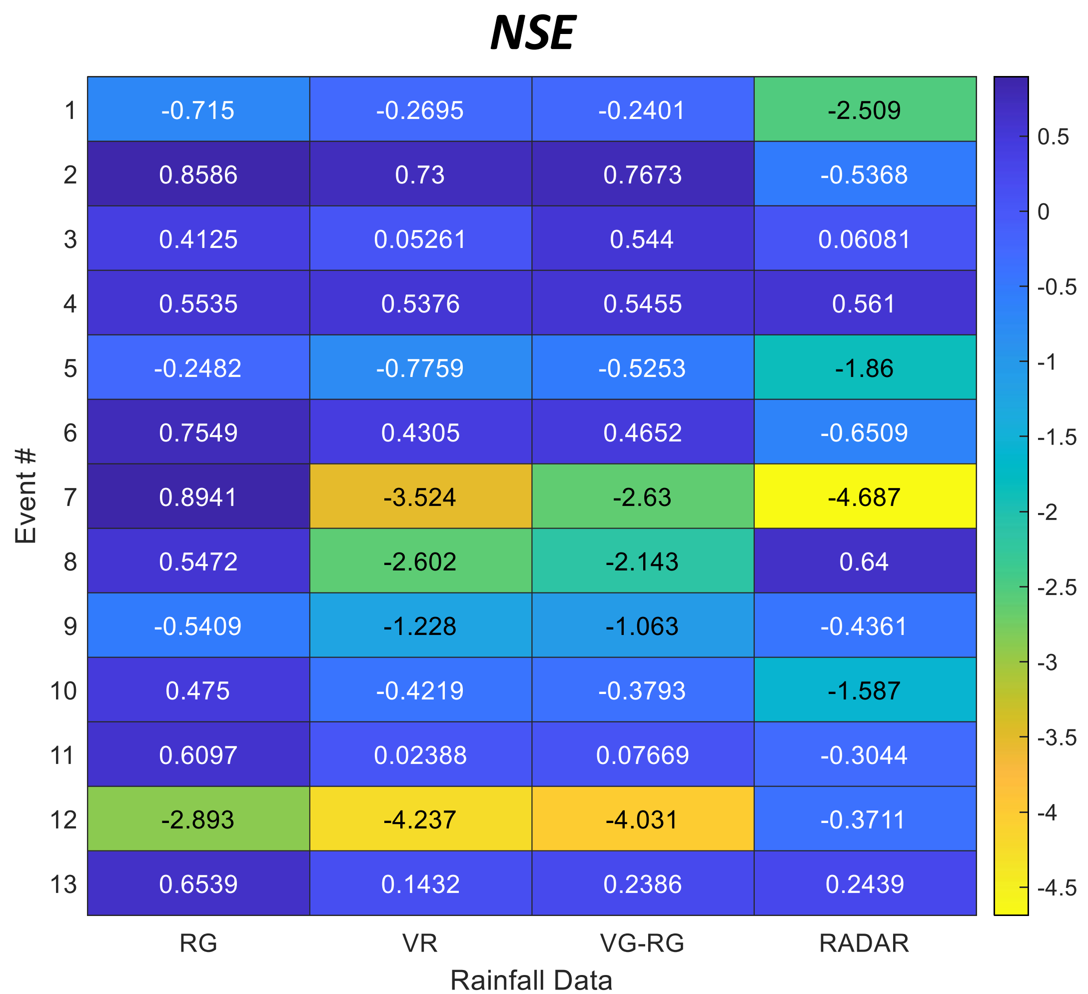
Rainfall input affects simulated hydrographs by the reference model

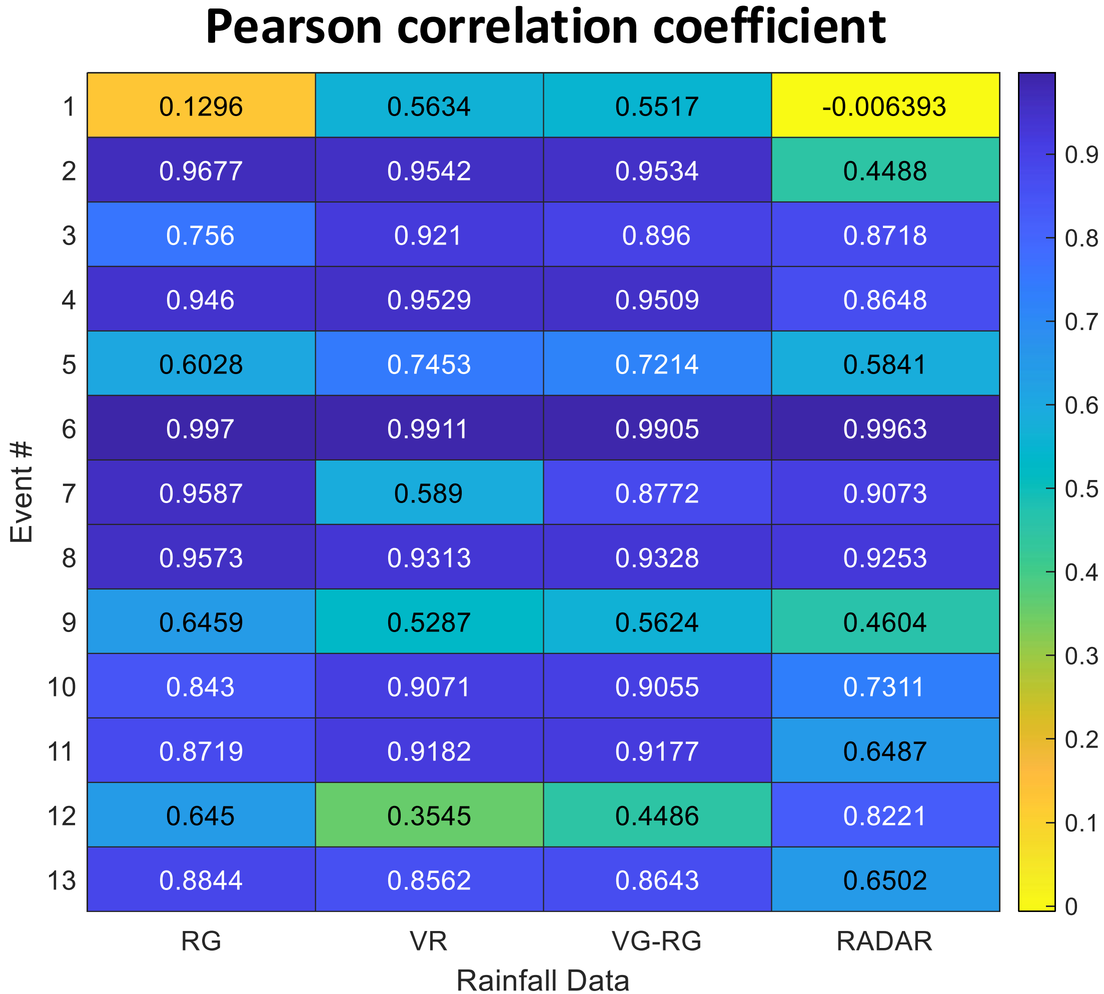




Results – Sensitivity to the rainfall input

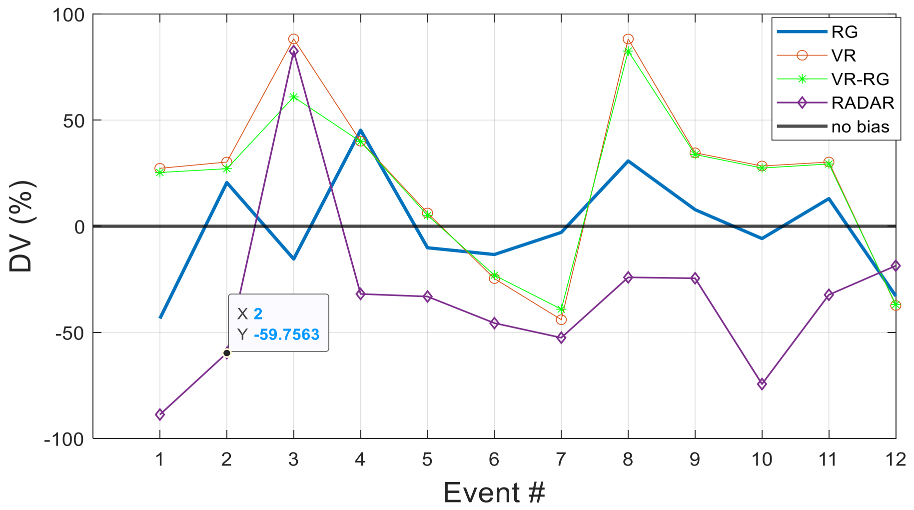
Observed vs simulated streamflows by the reference model

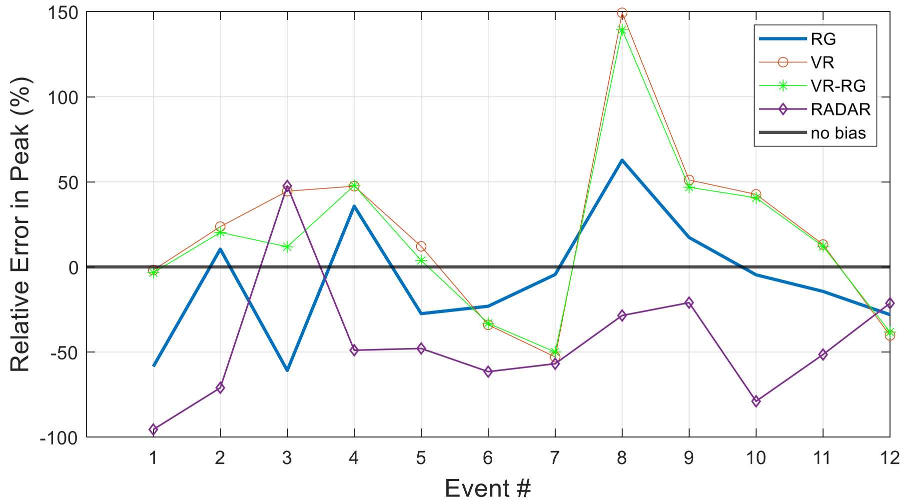


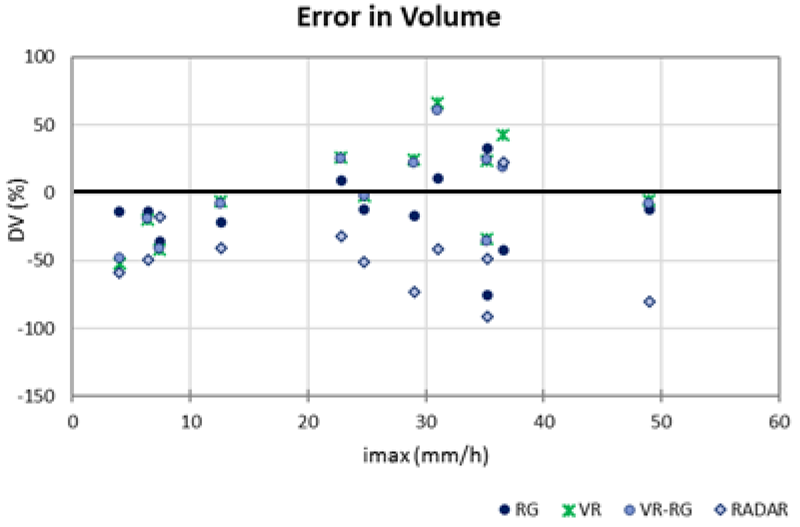


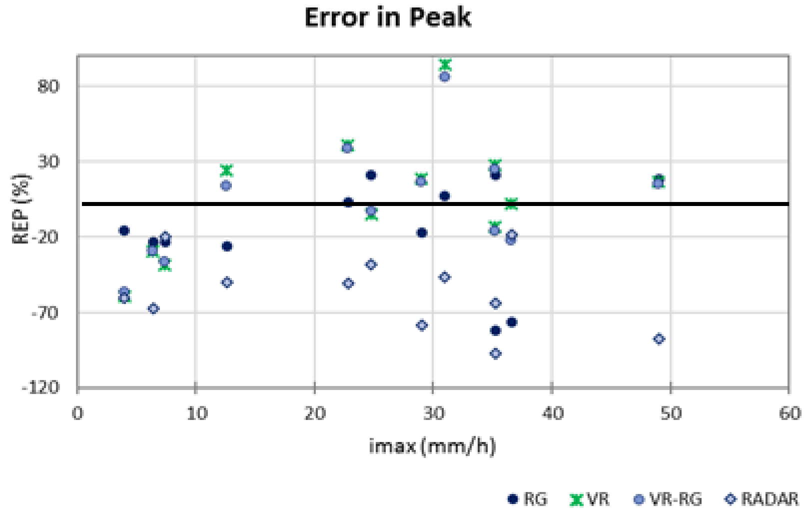
Results – Sensitivity to the rainfall input

Errors in the simulated streamflows by the reference model





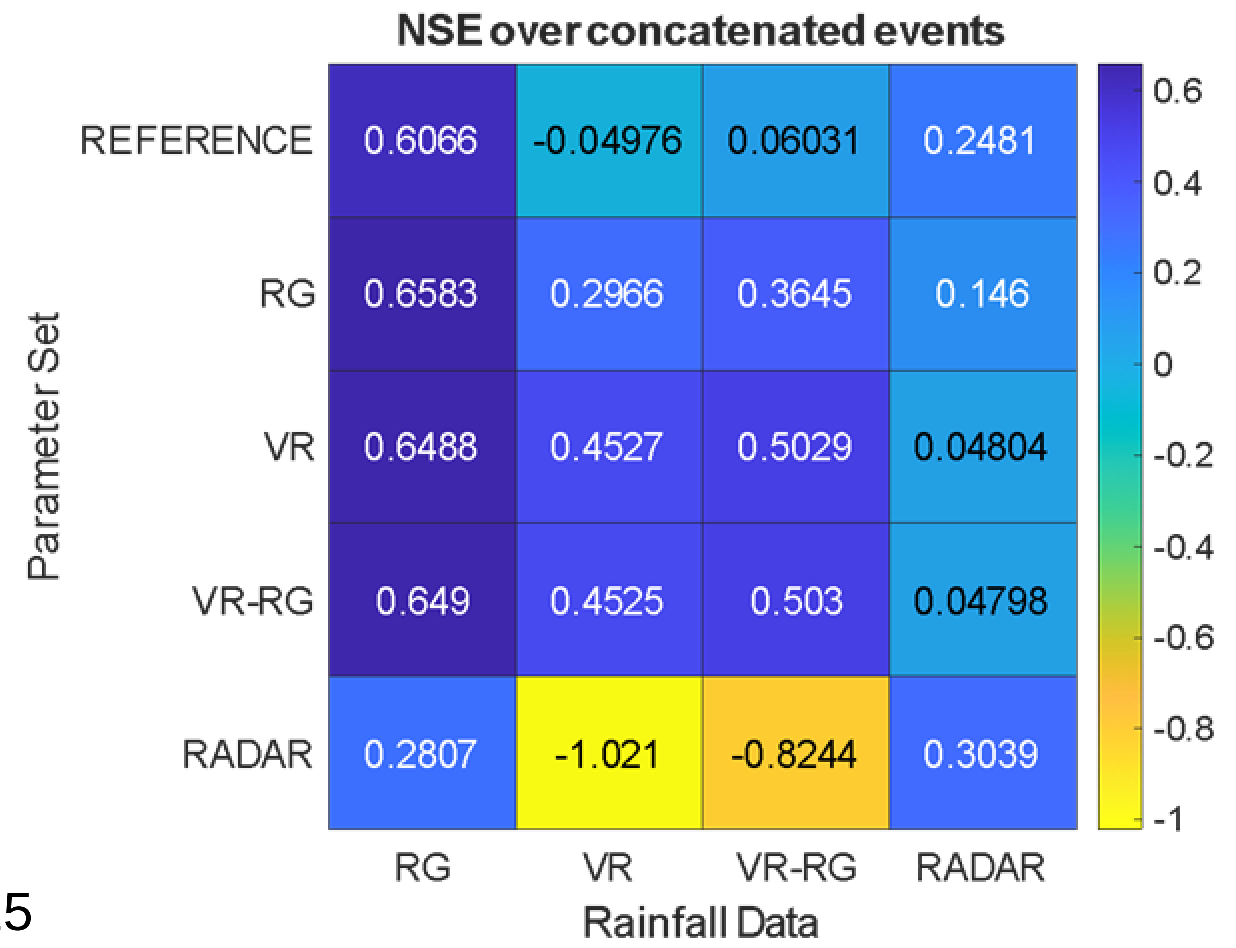


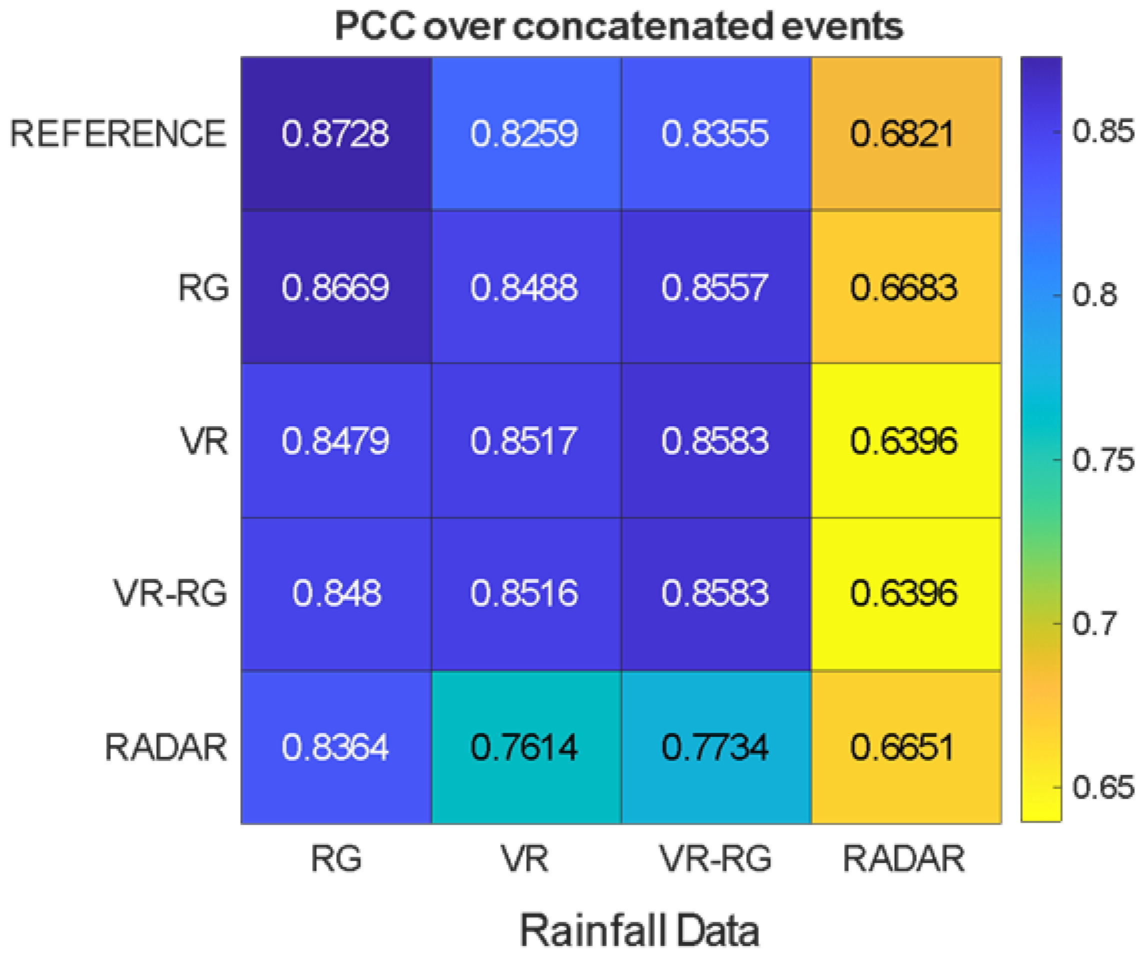


Results – Transferability across rainfall data

Parameter optimisation cannot compensate for the adequacy of rainfall data

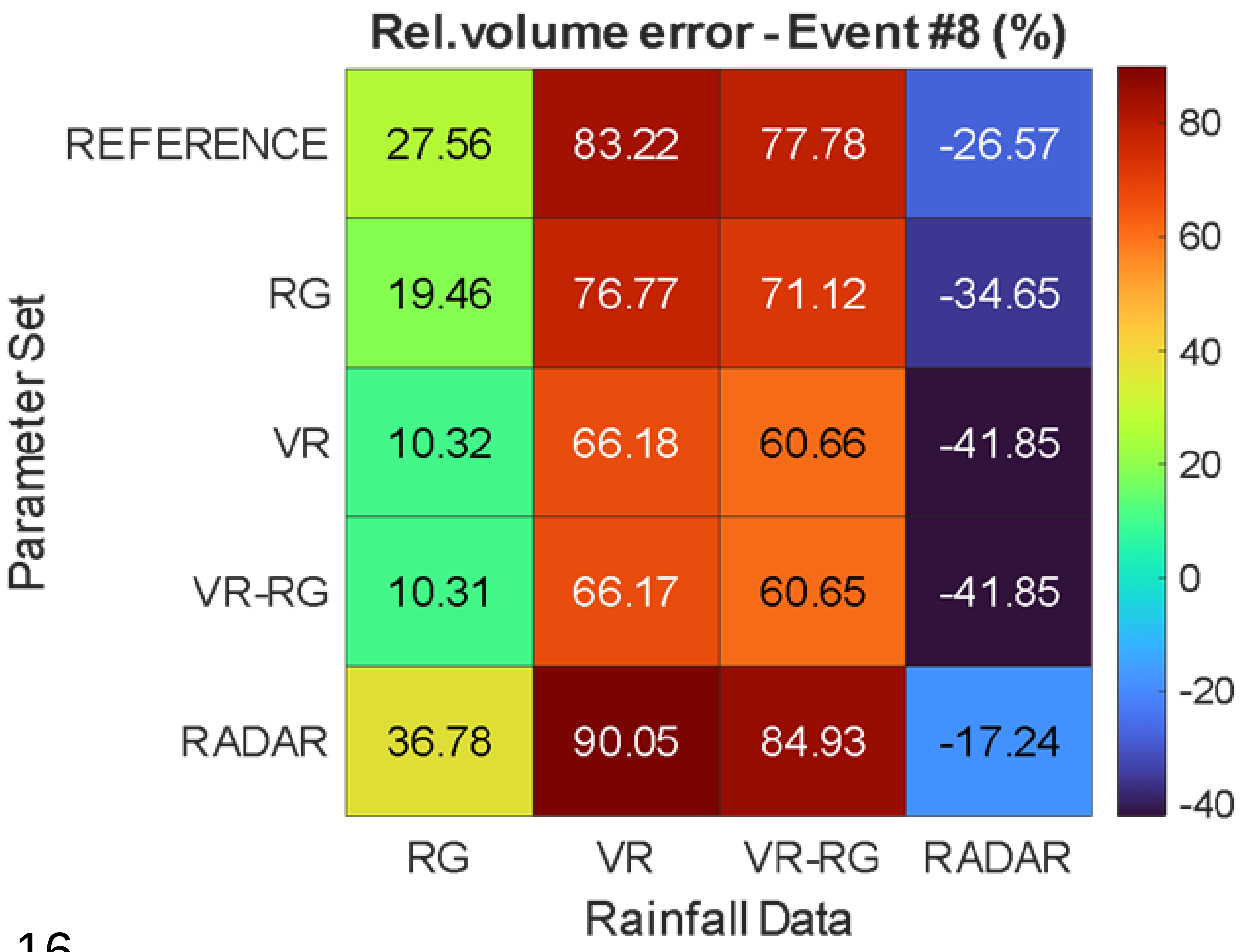
- Additional model calibrations were performed for different rainfall data

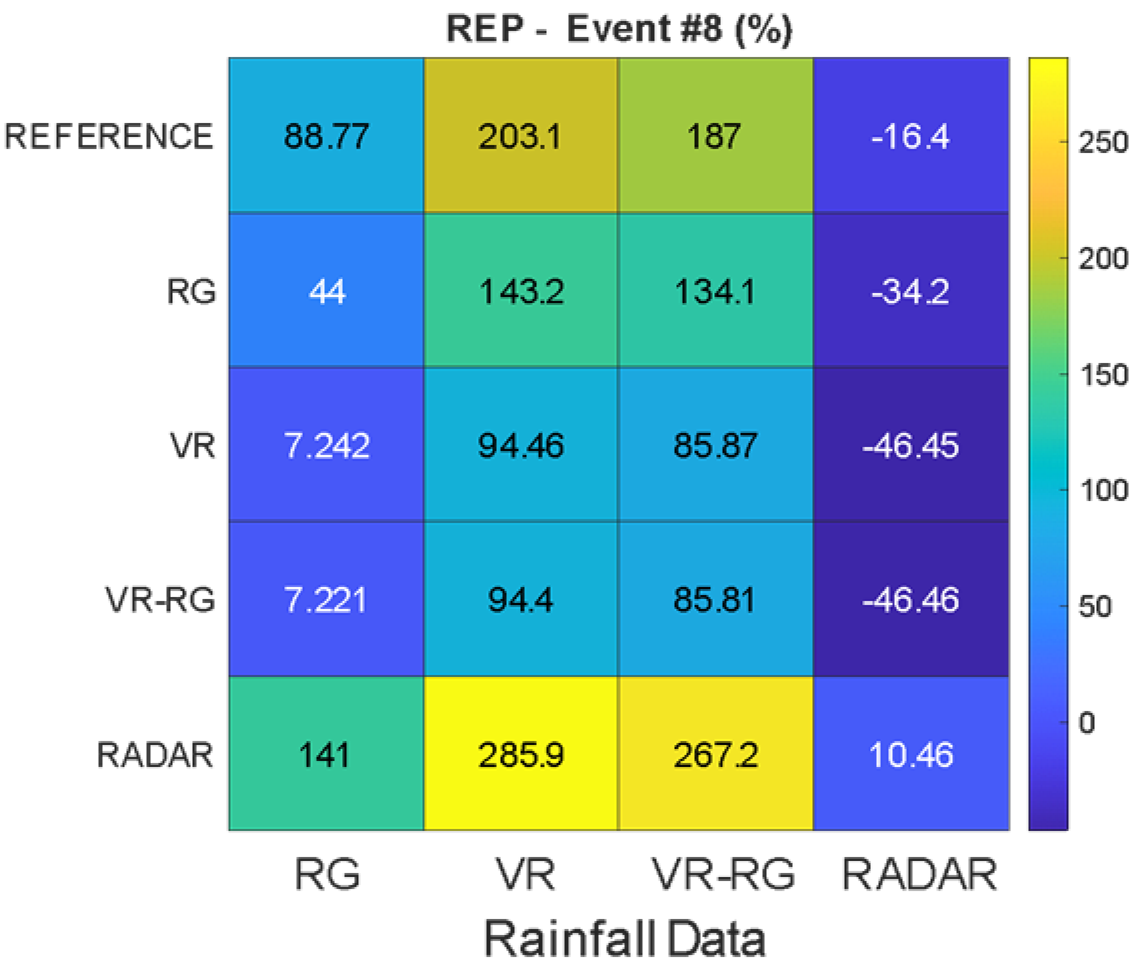




Results – Transferability across rainfall data

Performance during a single rain event





Conclusions

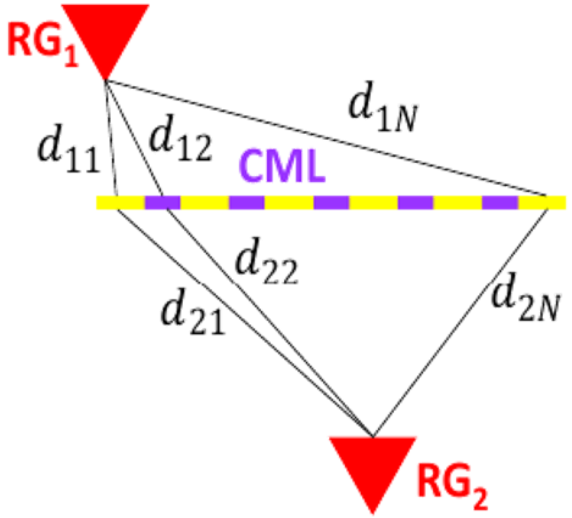
Validation of rainfall measurements

- **high-intensity events** detected by CML are **in a good accordance** with RG measurements;
- **inability of CMLs** to detect **low rain rates**, due to the coarse 1dB quantization step of raw data
- **radar**-based rainfall measurements tend to **underestimate** with respect to RG and CML data, due to the presence of mountains in the study region.

Validation of CML-derived streamflows

- **high model performance** can be obtained with the CML-derived rainfall data, although performance can vary across the events;
- **limited transferability** of models with the respect to the different **rainfall data**.

CML - nearby RGs comparison



$$\bar{d}_{\mathrm{RG1-CML}} = \frac{1}{N}\sum_{i=1}^{N} d_{1i} \longrightarrow R = \frac{\sum_{i=1}^{N_{RG}} w_i R_{RG_i}}{\sum_{i=1}^{N_{RG}} w_i}, \; w_i = \frac{1}{d^3_{RG_i-CML}}$$