THE PDE-BASED HYDROLOGIC MODEL PARFLOW PERFORMANCE IN FLASH-FLOOD NOWCAST

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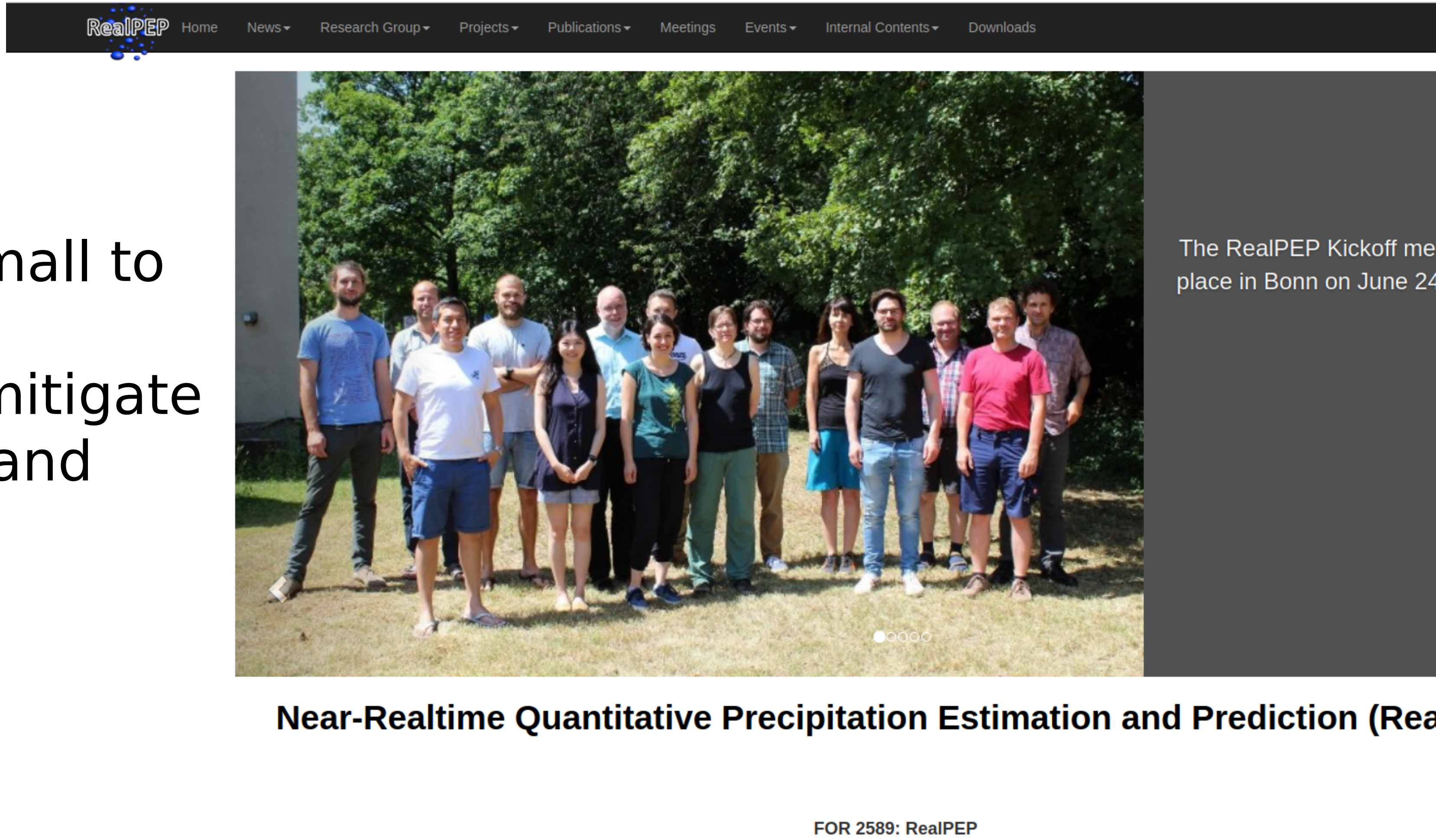
CONTENTS

- **Context: The HPSC-Terrestrial System Lab in Julich and our role in Re**
- **Methodology: Why ParFlow?**
- **Flash floods hindcasts and nowcasts in a sparsely gauged catchment**
- **How to provide a hydrological evaluation of precipitation products?**

REALPEP RESEARCH UNIT

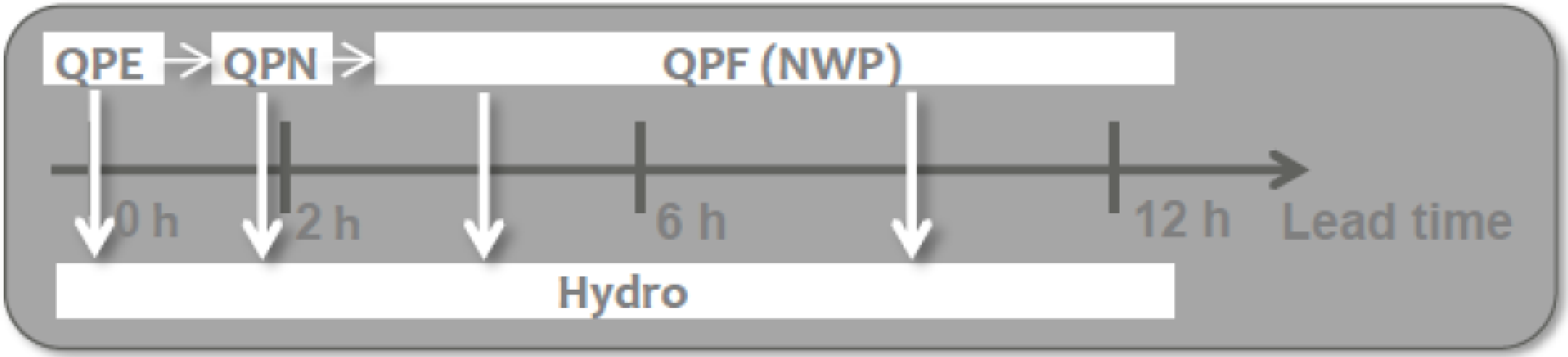


Improve flood prediction for small to meso-scale catchments to mitigate risks to society and ecosystems.

www2.meteo.uni-bonn.de/realpep

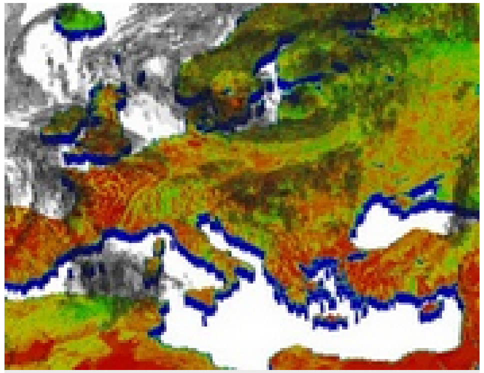
THE SUBPROJECT DOWNSTREAM

- Evaluate **Q**uantitative **P**recipitation **E**stimates (**QPE**), -**N**owcasts (**QPN**) and –**F**ore
(**QPF**)/**N**umerical **W**eather **P**redictions (**NWP**) improved by the other project group
- Apply a fully physically-based hydrologic model.



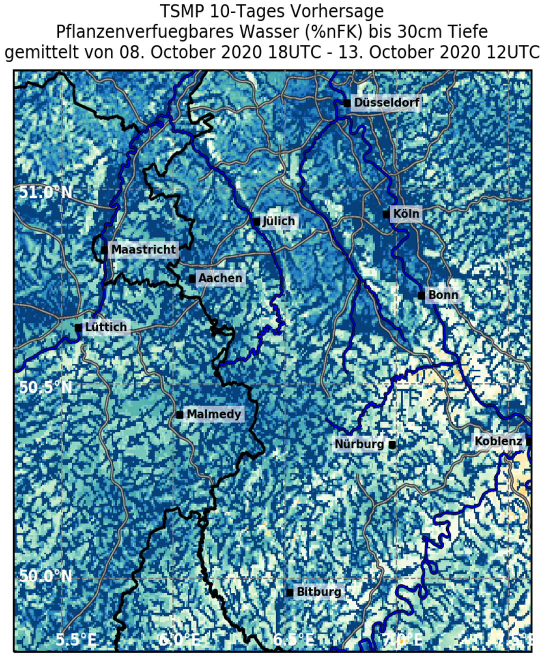
HPSC-TERRSYS

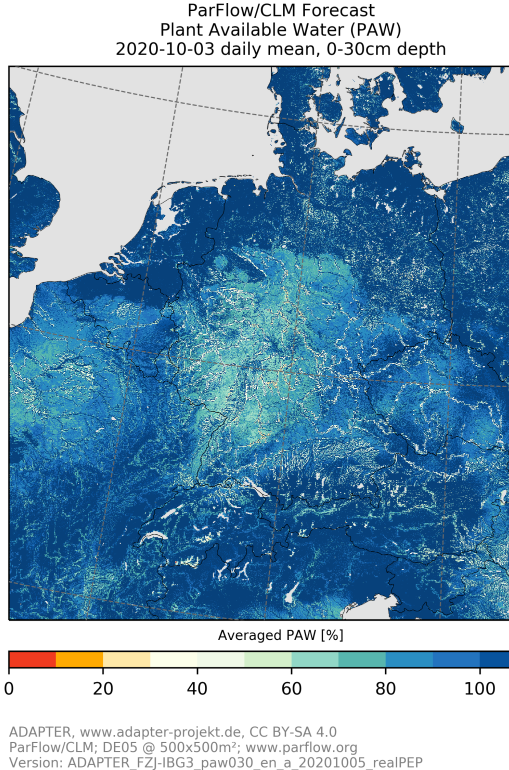
- Centre for High-Performance Scientific Computing in Terrestrial Systems
- http://www.hpsc-terrsys.de/
- https://www.terrsysmp.org/forecast/index.html

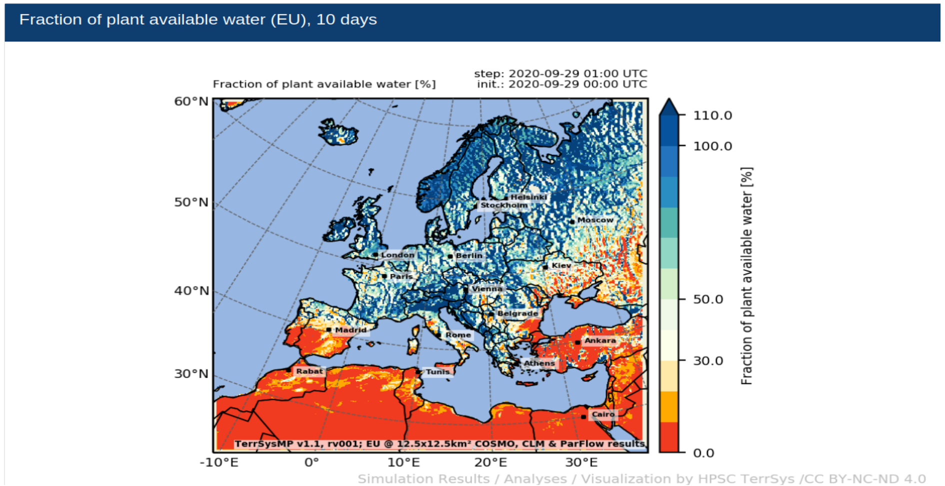


SimLab TerrSys

Research & Development
Jülich Supercomputing Centre (JSC





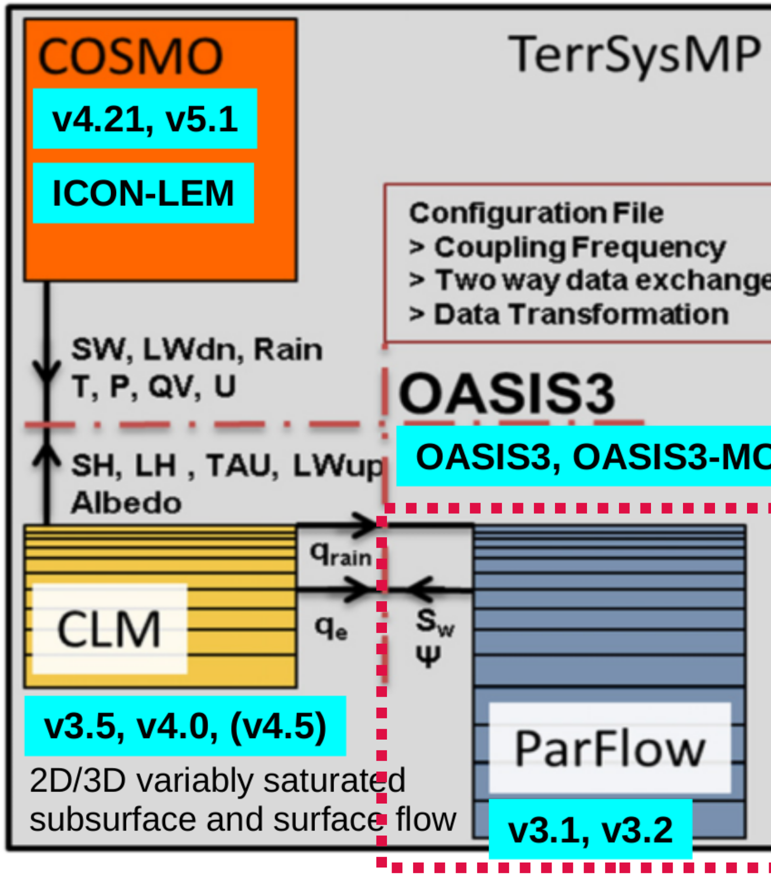


Alexandre Belleflamme, Adapter Project 2020

PARFLOW

Within the Terrestrial System Modeling Platform

- Holistic approach to modeling the geo-ecosystem
- Data assimilation via the Parallel Data Assimilation Framework (*Nerger et al., 2005*, *Kurtz et al., 2016*)
- ParFlow:
  - 3-D variably saturated groundwater flow model based on Richards' equation
  - 2-D overland flow based on the kinematic/diffuse wave approximation



TSMP model system features.

Shrestha et al. (2014)

FLASH-FLOOD MODELING WITH PARFLOW

But first of all, **why ParFlow**?

- Many operational services use conceptual hydrological models
- ParFlow needs powerful processing capacity – depending on the resolution, doma
precipitation to run in an acceptable time
- Nowcast is particularly time-sensitive

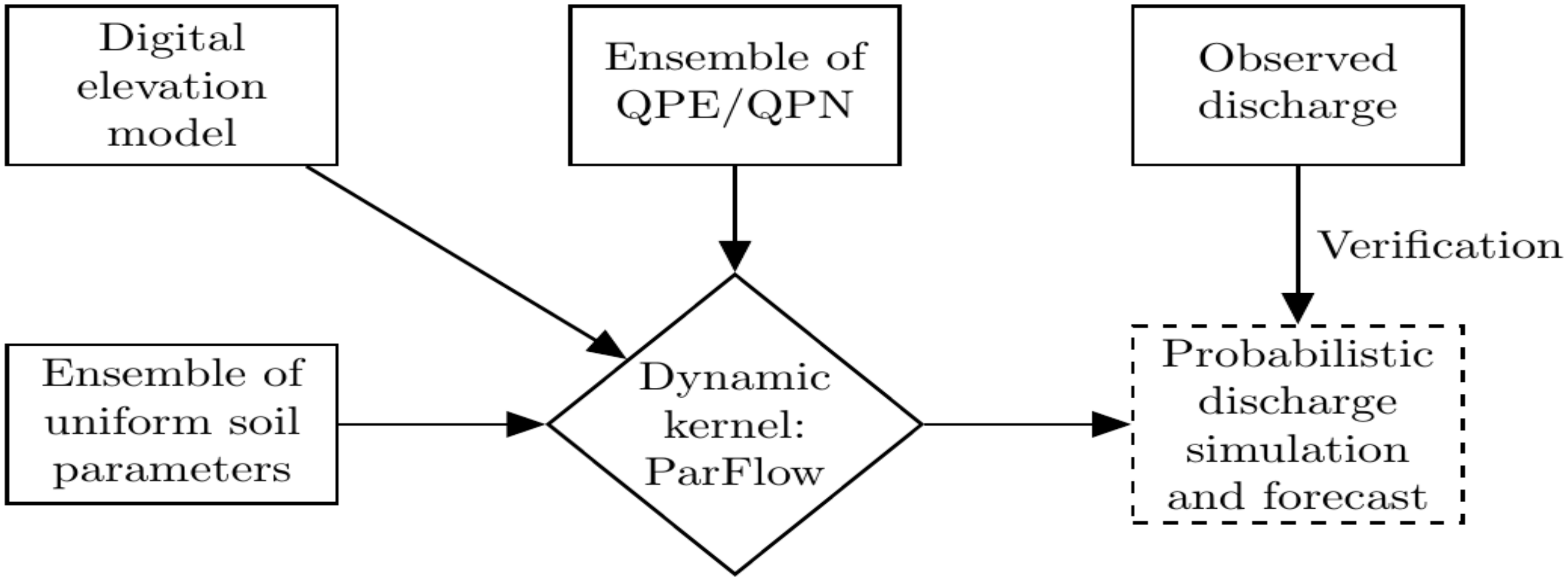
ParFlow does not require calibration

ParFlow benefits from precipitation products improvements

FLASH-FLOOD MODELING WITH PARFLOW

Parsimonious framework, homogeneous hydraulic properties

Input parameters: saturated hydraulic conductivity, porosity, specific storage, residua water content, van Genuchten n and alpha, Mannings' roughness



Parsimonious simulations framework. Pomeon *et al. (2020)*

FLASH-FLOOD MODELING WITH PARFLOW

How is the performance of the parsimonious setup, without calibration for hindcasts and nowcasts?

Is the model performance sensitive to different precipitation products?

- Test two QPE products (XPOL and RADOLAN)
- Account for model uncertainty- 2 key parameters (hydraulic conductivity and Manning's coeff n)
- Test lead time improvements achieved using preliminary QPN products.

04/06/2016 Flood dam

Daniel Koch, Hochwasser- und Starkregenrisik

water

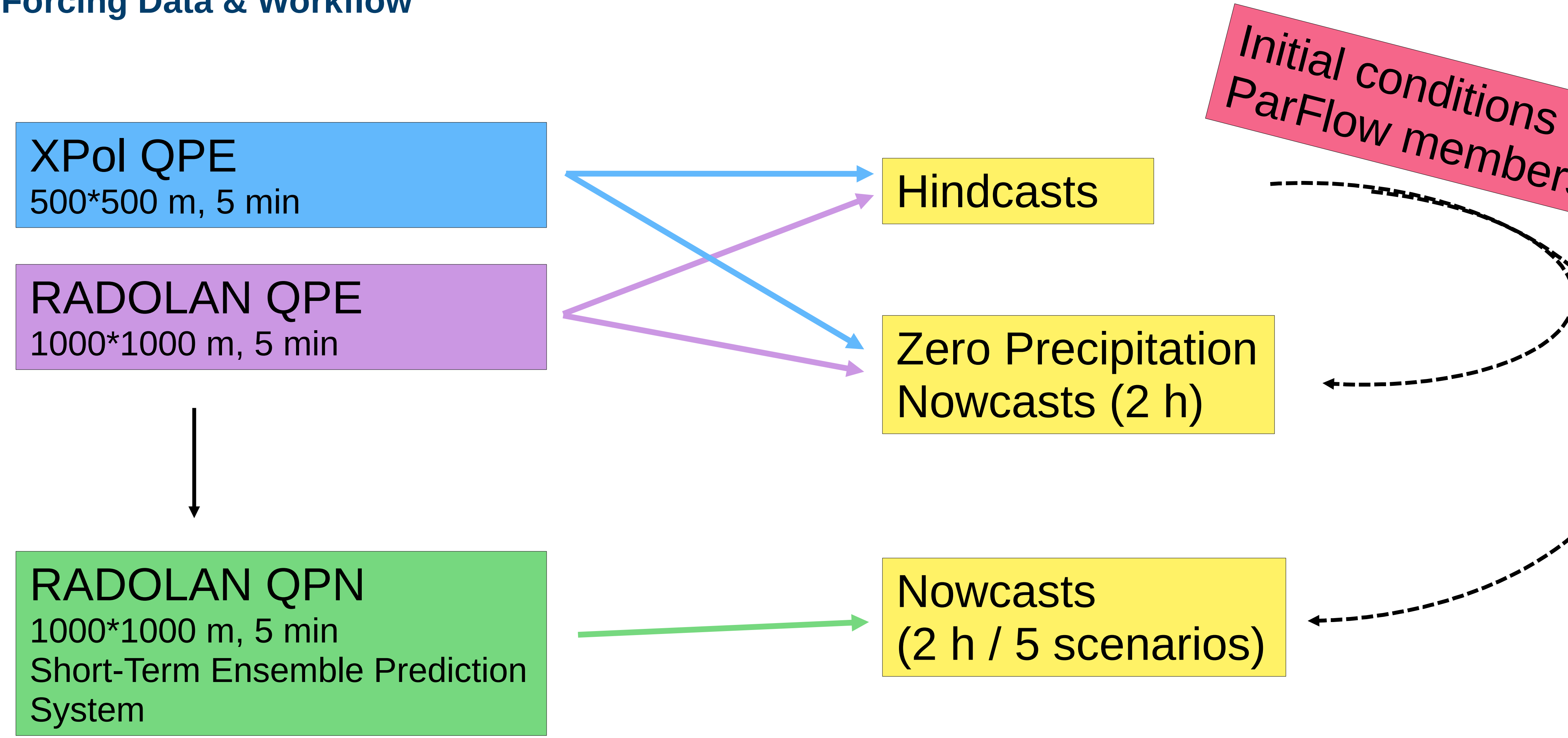
Article

Performance of a PDE-Based Hydrologic M a Flash Flood Modeling Framework in Sparsely-Gauged Catchments

Thomas Poméon [1,*], Niklas Wagner [1], Carina Furusho [1], Stefan Kollet [1], Ricardo Reinoso-Rondinel [2]

FLASH-FLOOD MODELING WITH PARFLOW

Forcing Data & Workflow



FLASH-FLOOD MODELING WITH PARFLOW

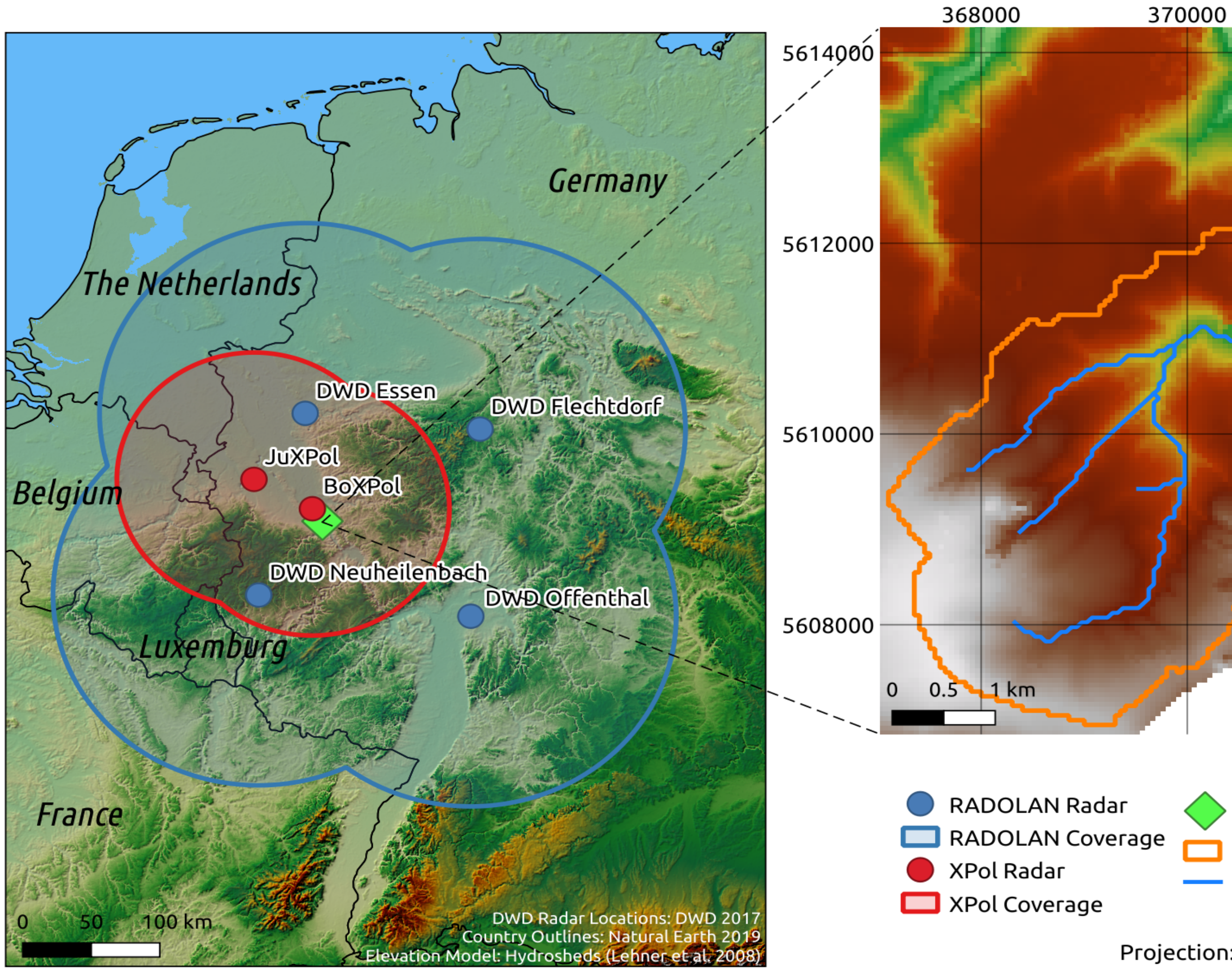
Study Area

- Mehlemer Bach catchment
- ~ 16.3 km² upstream of gauge
- Model Resolution x,y: 50 m

Vertical z: 0.2, 1, 2 and 4 m

Temporal: 5 min

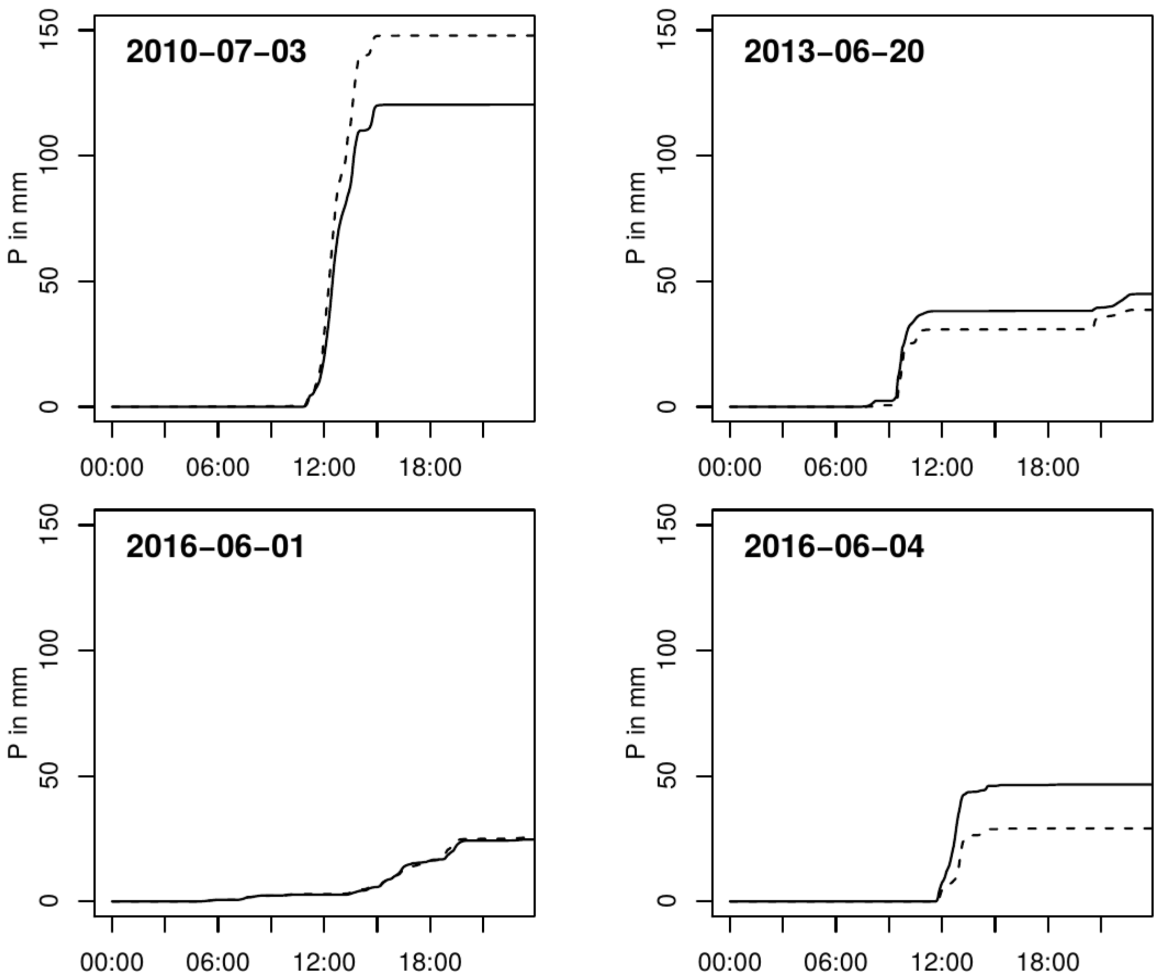
Problem size: 122*156*4 = 76.128



Study area overview

FLASH-FLOOD MODELING WITH PARFLOW

Results (1): QPE Comparison



Comparison
cumulative
RADOLAN a
XPol QPE ra
depth

RADOLAN QPE

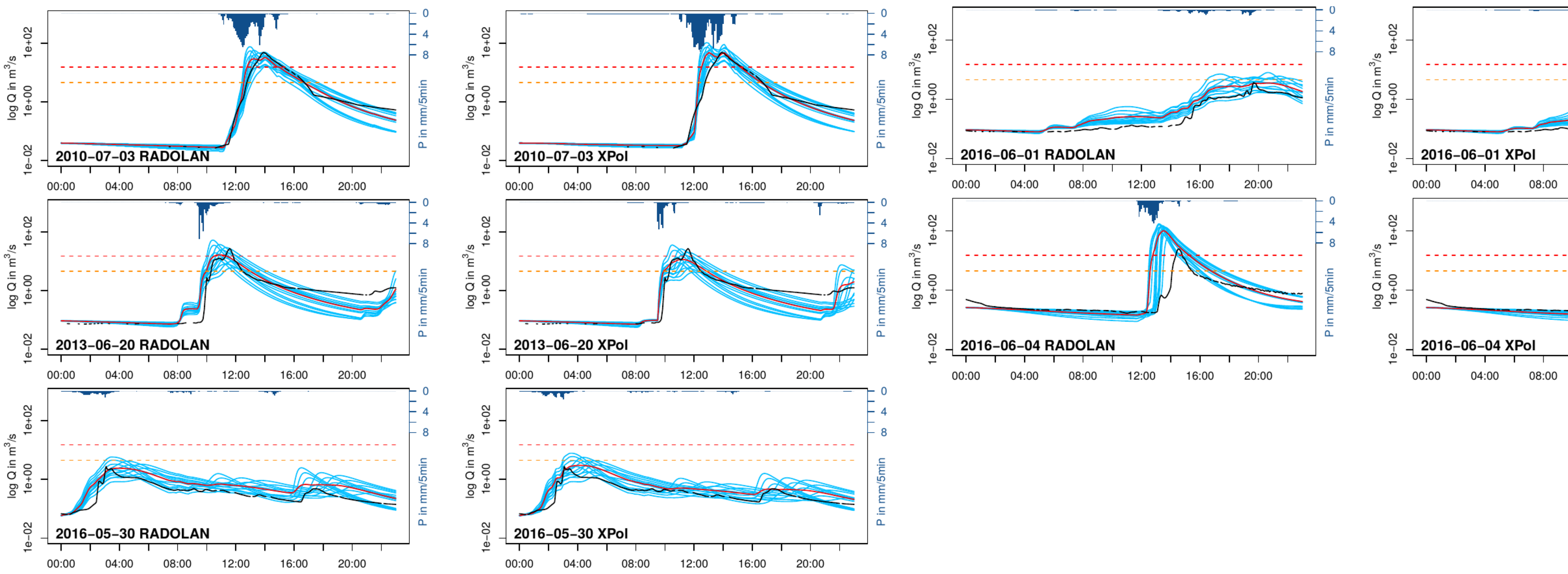
XPol QPE

FLASH-FLOOD MODELING WITH PARFLOW

Results (2): Hindcast

Observation
Ensemble
Ensemble Mean
Precipitation
Level 1 4.5 m^3
Level 2 15 m^3/

RADOLAN QPE | XPol QPE | RADOLAN QPE | XPo



ParFlow Reanalysis Discharge Timeseries Results

FLASH-FLOOD MODELING WITH PARFLOW

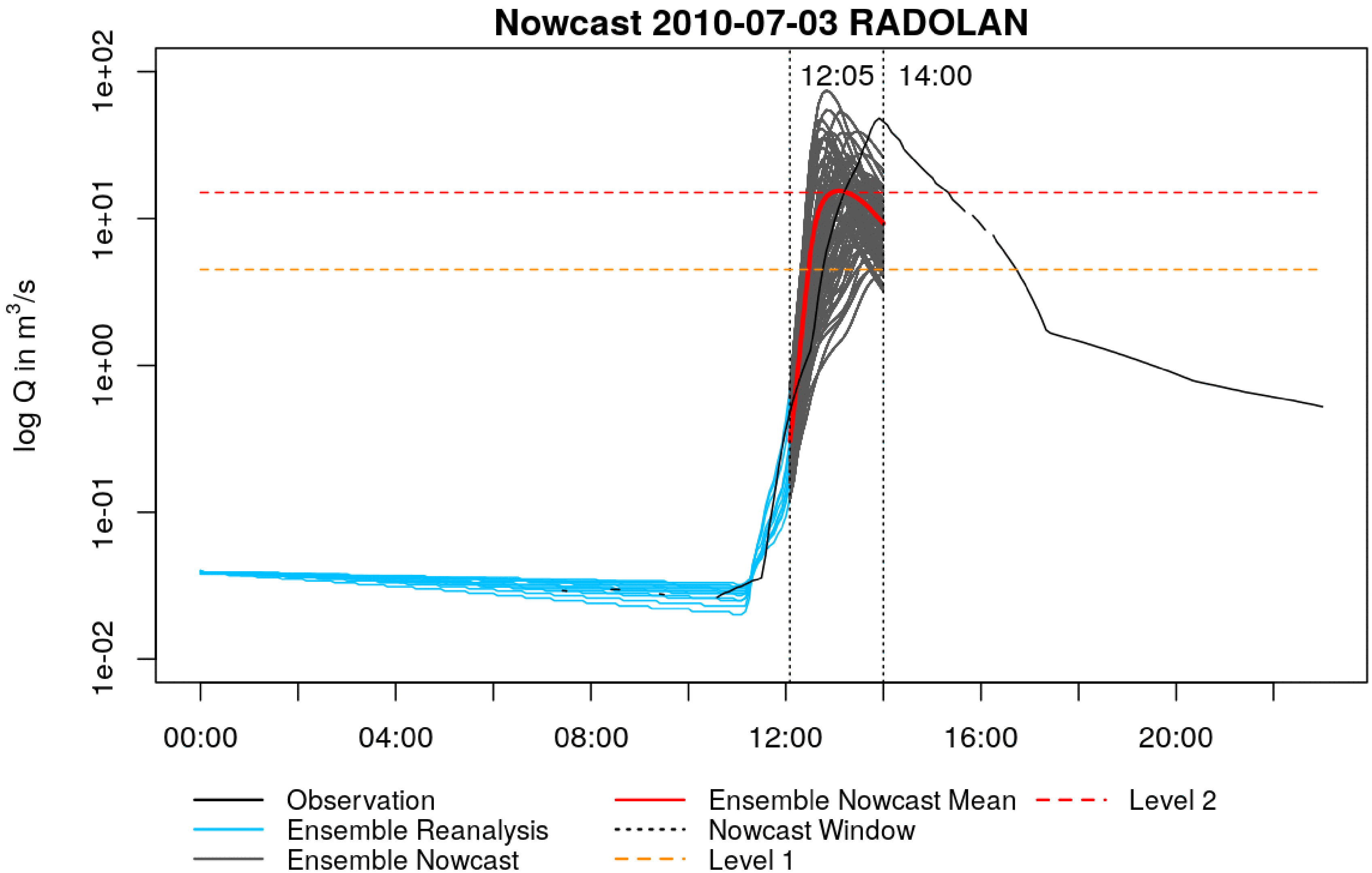
Results (3): Hindcast

ParFlow Reanalysis Ensemble Performance

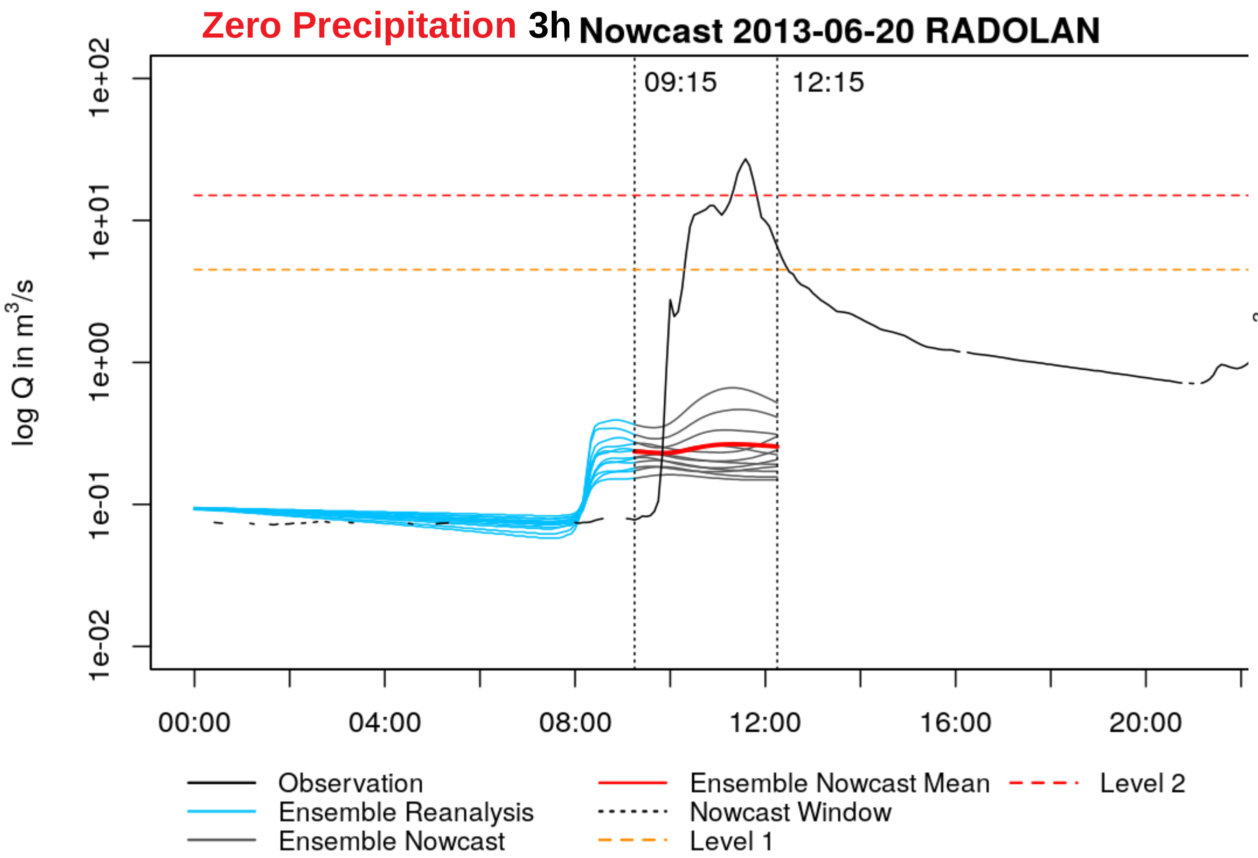
		% of obs bracketed	$\overline{CRPS}$	MAE	Ensemble Mean Performance R^2	NSE	PBIAS	RMSE
RADOLAN QPE — RADOLAN	2010-07-03	56	0.760 (0.047)	1.267	0.85	0.85	-5.9	3.46
	2013-06-20	37	0.588 (0.016)	0.826	0.78	0.78	4.8	1.93
	2016-05-30	57	0.193 (0.014)	0.353	0.81	-0.03	75.7	0.45
	2016-06-01	38	0.243 (0.025)	0.461	0.91	-0.02	84.1	0.73
	2016-06-04	57	4.007 (0.147)	5.817	0.07	-28.64	374.0	19.18
	Mean	49	1.158 (0.050)	1.745	0.68	-5.41	106.5	5.15
XPol QPE — XPOL	2010-07-03	48	1.056 (0.063)	1.544	0.75	0.59	31.2	5.71
	2013-06-20	41	0.613 (0.016)	0.698	0.81	0.77	-14.3	1.95
	2016-05-30	76	0.193 (0.013)	0.342	0.80	-0.63	74.1	0.56
	2016-06-01	33	0.274 (0.028)	0.511	0.94	-0.37	93.7	0.85
	2016-06-04	57	1.697 (0.084)	2.760	0.36	-4.37	172.9	8.17
	Mean	51	0.767 (0.041)	1.171	0.73	-0.80	71.5	3.45

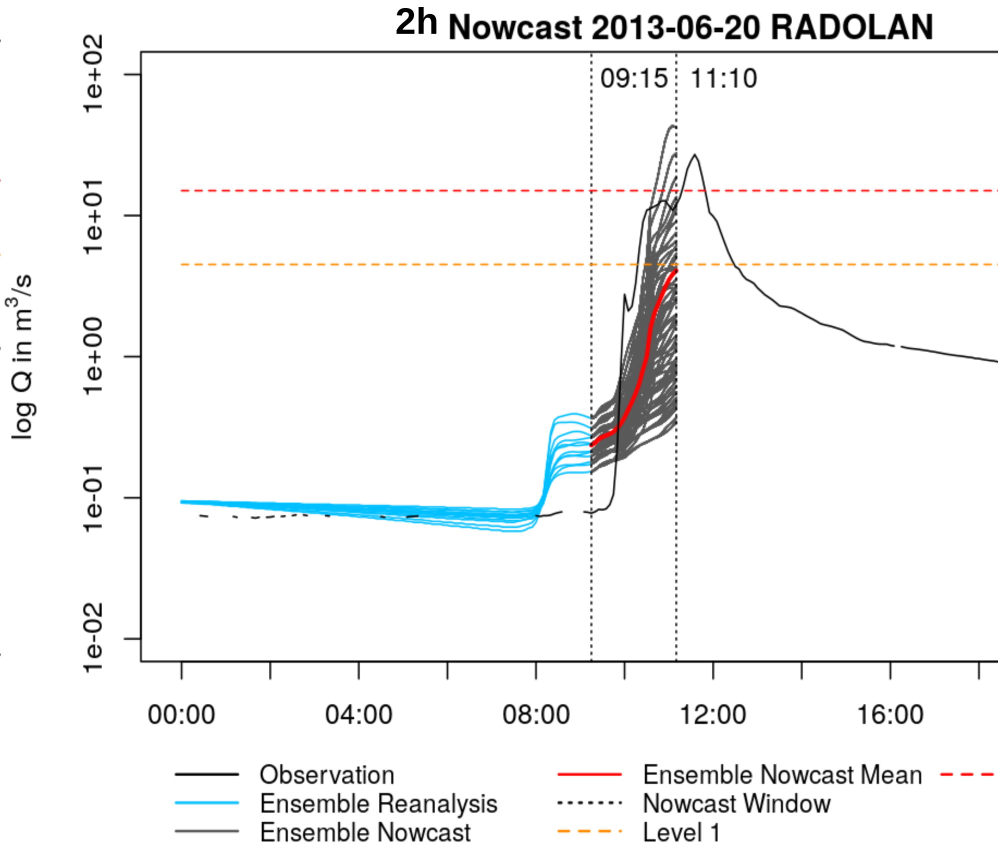
% of obs included: Percentage of observations bracketed in the ensemble uncertainty; CRPS: Continuous Ranked Probability Score; MAE: Mean Absolute Error; R^2: Coefficient of determination; KGE: Kling-Gupta Efficiency; NSE: Nash-Sutcliffe Efficiency; PBIAS: Percent BIAS; RMSE: Root mean squared error. CRPS, MAE and RMSE given in m^3/s. Standard deviations of CRPS estimated using the jackknife technique are given in brackets.

NOWCAST WITH PARFLOW

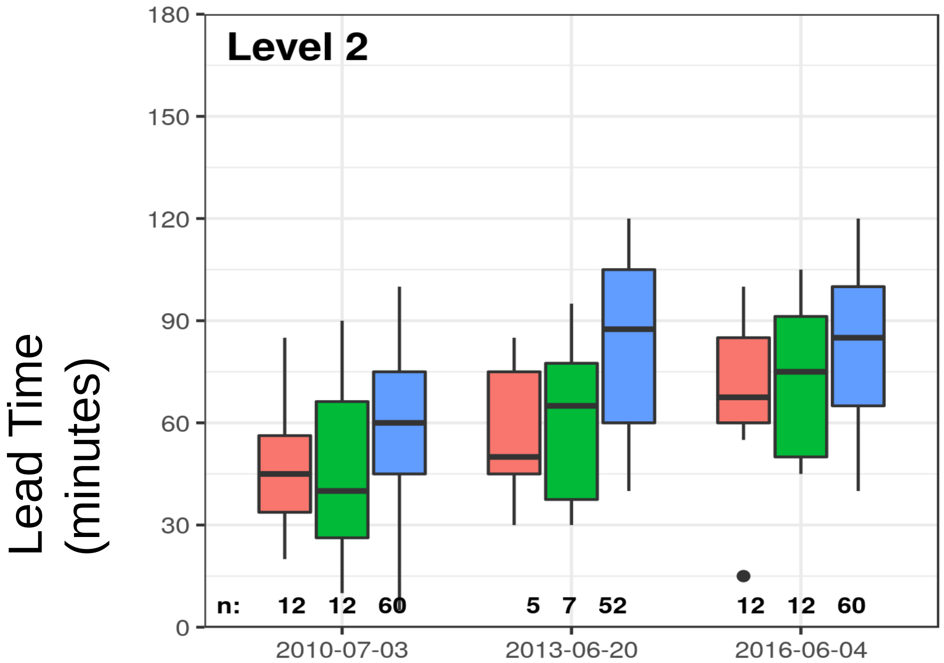


NOWCAST WITH PARFLOW





NOWCAST WITH PARFLOW



Parflow Nowcast Experiment Lead Times.

ZPFC = zero precipitation forecast

NC = nowcast

	XPol ZPFC	RADOLAN ZPFC	RADOLAN NC		
	$\overline{CRPS}$	$\overline{CRPS}$	min $\overline{CRPS}$	mean $\overline{CRPS}$	max $\overline{CRPS}$
2010-07-03	2.256	2.355	1.328	1.424	1.485
2013-06-20	1.136	1.052	0.726	0.735	0.745
2016-06-04	0.995	1.708	2.108	2.269	2.440

ZPNC: Zero Precipitation Forecast; NC: Nowcast; CRPS: Continuous Ranked Probability Score in m^3

Ensemble skill analysis for nowcast experiments

CONCLUSIONS

- ParFlow hindcast/Nowcast ensembles deliver acceptable results without calibratio
  - Model ensemble captures most of the observed discharge.
- Parflow ensemble hindcasts and nowcasts detect differences in precipitation input
  - Different scores even with similar catchment rainfall time-series → potential to capture rainfall spatial distribution improvements
- Lead times are improved with two-hour precipitation nowcasts.

OUTLOOK

What is still missing for the hydrological evaluation of precipitation input improvements?

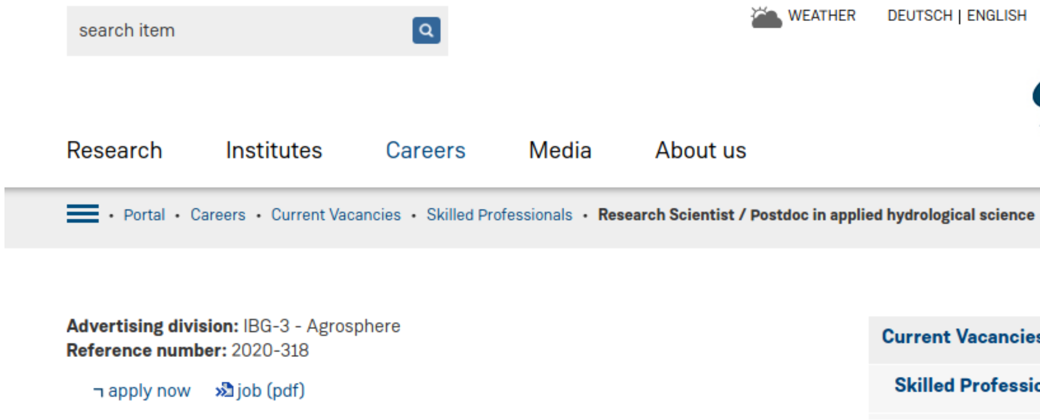
- Evaluate over many catchments, longer time-series
- Consider both timing and magnitude of discharge nowcasts
- Consider the streamflow observation uncertainty
- Include data assimilation, e.g. soil moisture if coupled to CLM
- …

OUTLOOK

What is still missing for the hydrological evaluation of precipitation input improvements?

- Evaluate over many catchments, longer time-series
- Consider both timing and magnitude of discharge nowcasts
- Consider the streamflow observation uncertainty
- Include data assimilation, e.g. soil moisture if coupled to CLM
- **Research Scientist / Postdoc in applied hydrological science**

https://www.fz-juelich.de/



Thank you

JUWELS Cluster used to run the model.

Jülich Super Computing Centre 2019

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German Research

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www2.meteo.uni-bonn.de/realpep

Final Discussion Panel Wednesday 4 pm

Linda Speight (Reading University, UK)
Pierre Javelle (Inrae, France)
Angelica Caseri (Energisa, Brazil)
Lionel Berthet (DGPR/SRNH/SDCAP, France)
Leandro Kazimierski (National Institute for Water, Argentina)
Stefan Kollet (FZJ, Germany)
Harrie-Jan Hendricks-Franssen (FZJ, Germany)
Carina Furusho-Percot (FZJ, Germany)

You can participate sharing your questions and discussion topics in sli.d
https://app.sli.do/event/zhgbqvbx/live/questions -event code, use R20

COMPARISON WITH HBV

Table 6. HBV and ParFlow ensemble statistics.

	HBV *MAE* in $m^3\ s^{-1}$		ParFlow $\overline{CRPS}$ in
	Simulation (a)	**Simulation (b)**	**RADOLAN**
3 July 2010	3.206	2.300	3.501
20 June 2013	1.706	1.499	1.821
30 May 2016	0.312	0.483	0.489
1 June 2016	0.517	0.436	0.436
4 June 2016	0.948	2.384	4.268
Mean	1.338	1.420	2.103

Notes: *MAE*: Mean Absolute Error; $\overline{CRPS}$: Mean Continuous Ranked Probability Scor
MAE for deterministic simulations, allowing for a direct comparison.

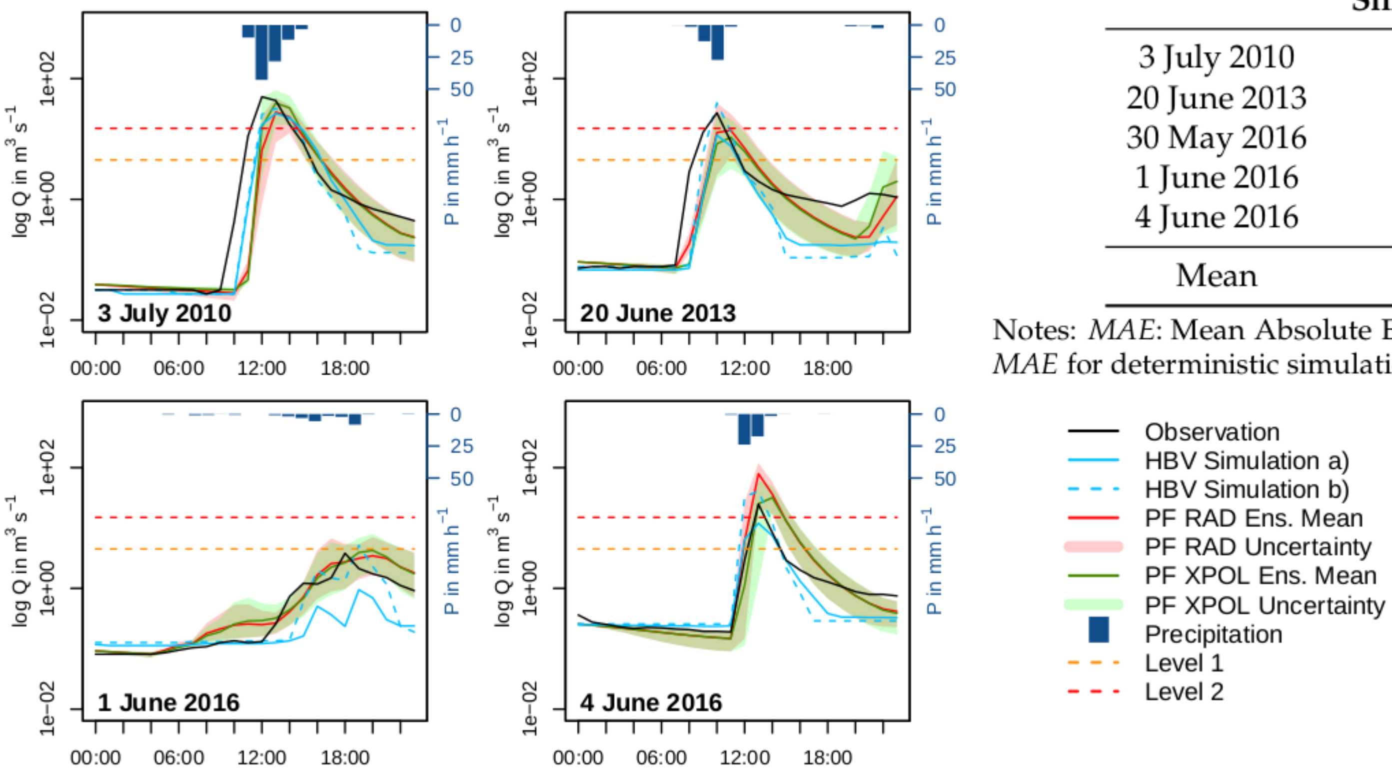
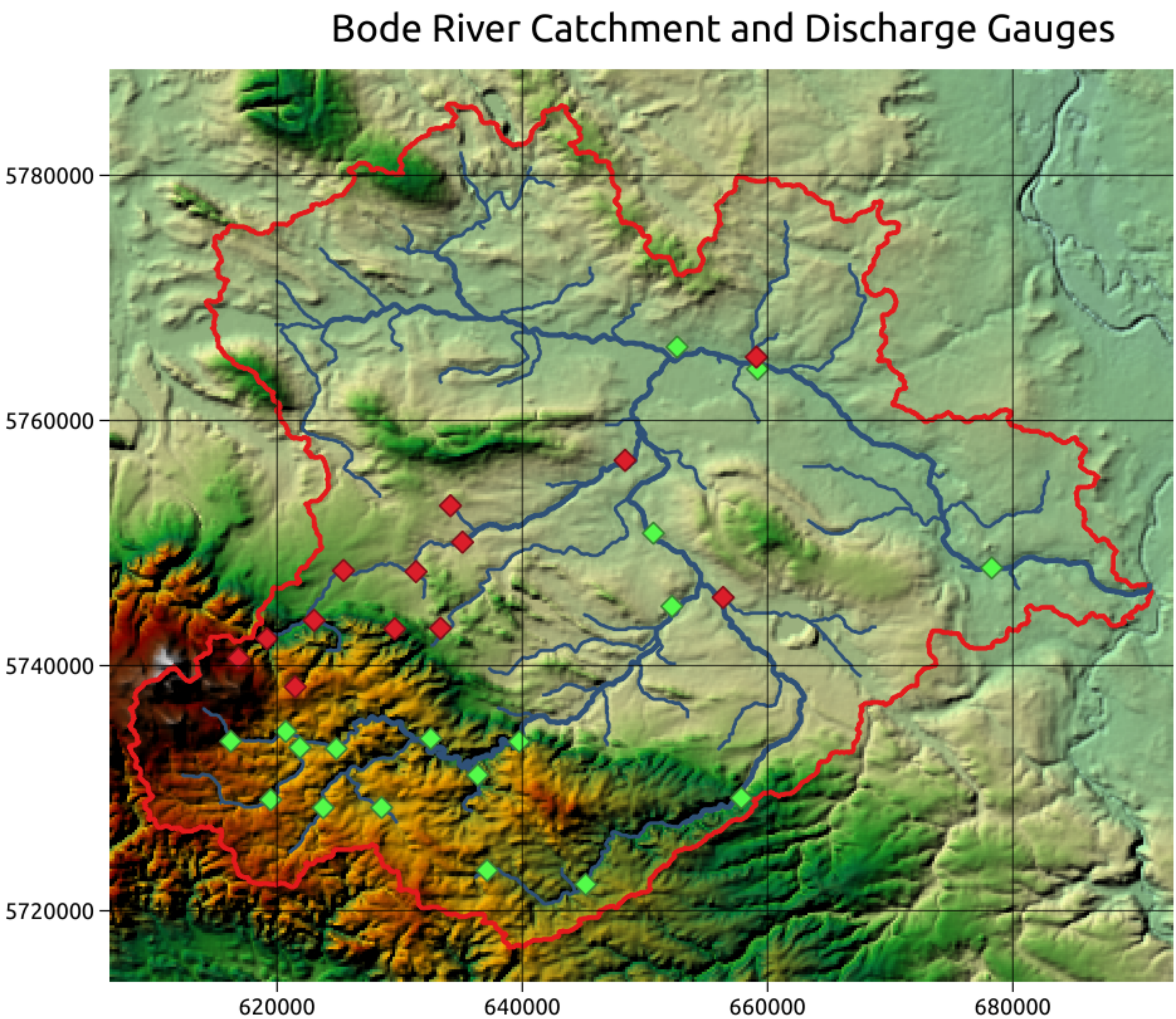


Figure 6. HBV validation results, where P is the precipitation in mm h^{-1} and Q is the discharge in $m^3\ s^{-1}$. Simulation (a) is based on a single calibration without all five events, whereas simulation (b) is based on calibrations for each event individually. ParFlow results aggregated from 5-min to hourly timesteps are included for reference. RAD and XPol denote the different ParFlow QPE forcings.

PART 2

Study area

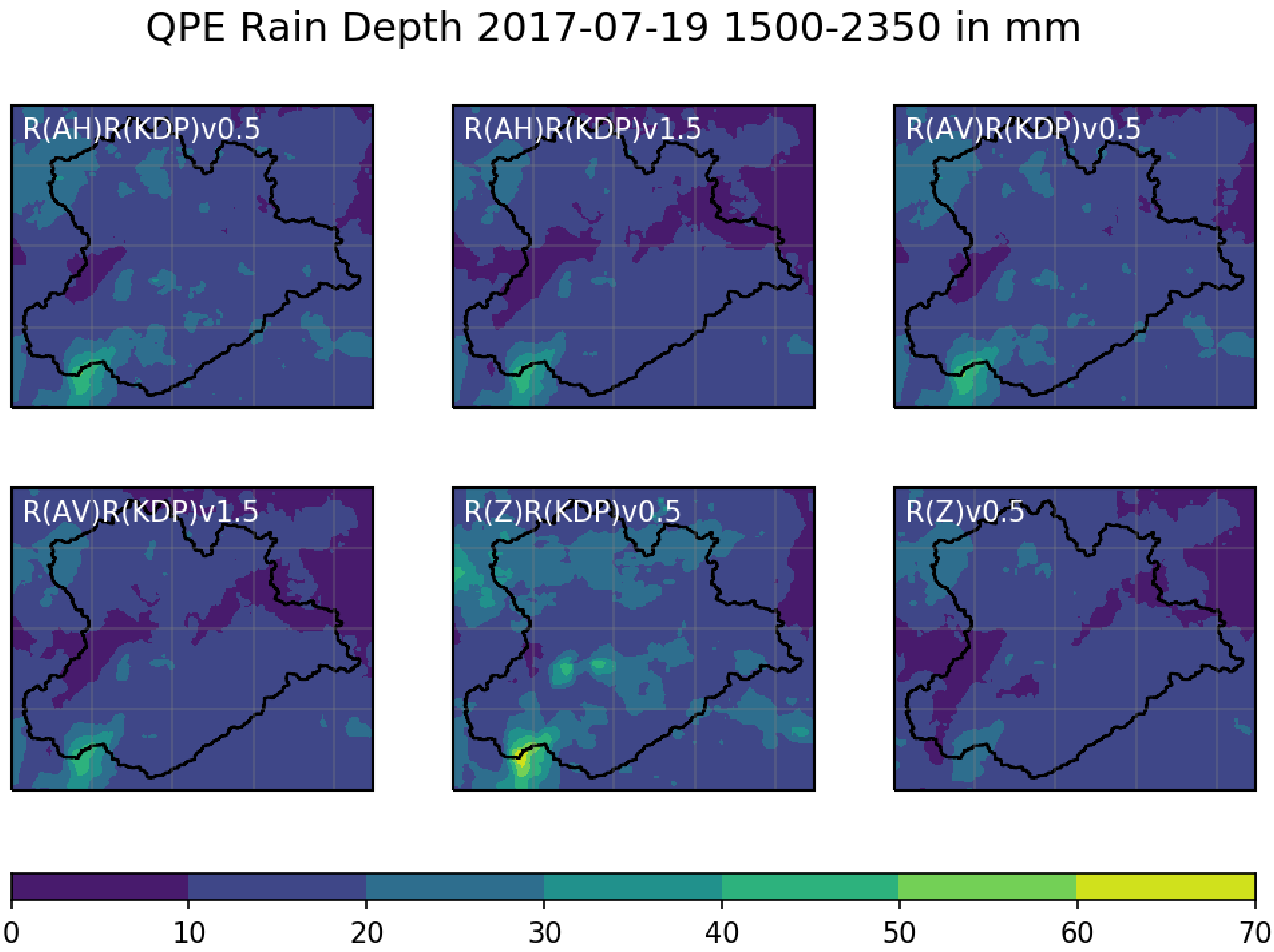
- Bode river catchment
- Harz Mountains
- ~ 3200 km²
- 11 raingauges
- 31 streamgauges
- Covered by German Weather Service radars
- Tereno observatory site



Study area overview

PART 2

QPE Comparison



QPE Comparison Case Study