HydroPredict'2012
Session M: Methodology, modelling, prediction and uncertainty
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Runoff-rainfall modelling:
Predicting areal precipitation from runoff observations

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Motivation

- Precipitation exhibits a high spatio-temporal variability, especially in complex terrain

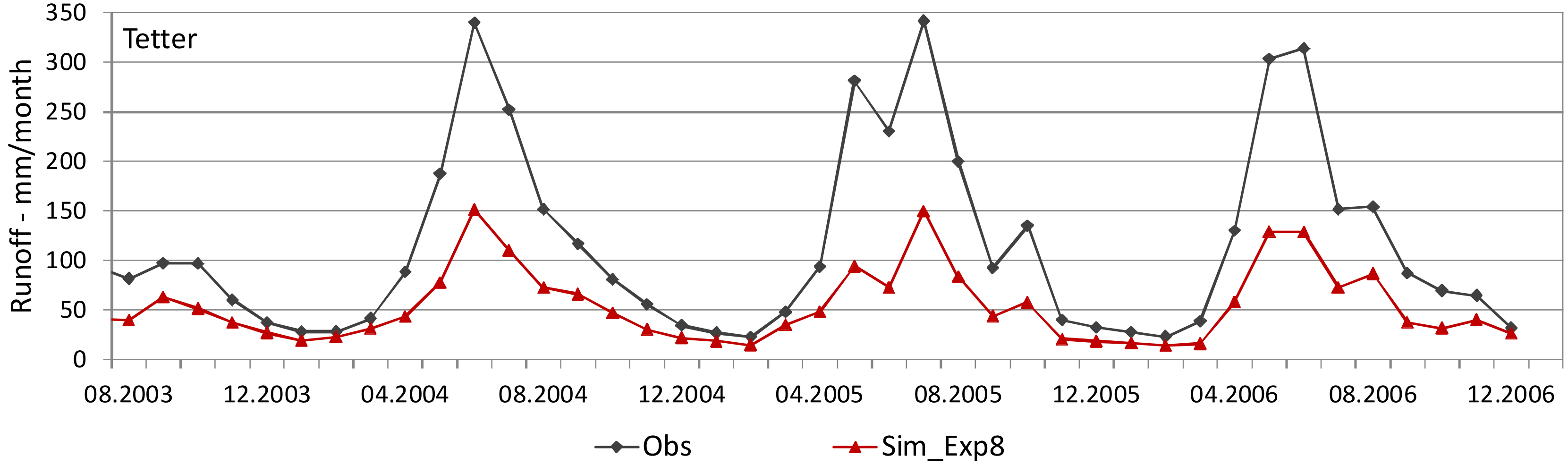
- Detection difficult
  - Monitoring network density is generally low
  - Measurements (point/radar) are subject to major errors

Systematic error	Magnitude
Wind-induced errors	2 - 10 % (liquid precipitation) 10 - 50 % (snow)
Wetting losses	2 - 10 %
Evaporation losses	0 - 4 %
Splash-out and splash-in	1 - 2 %
Flog and dew	4 - 10 %

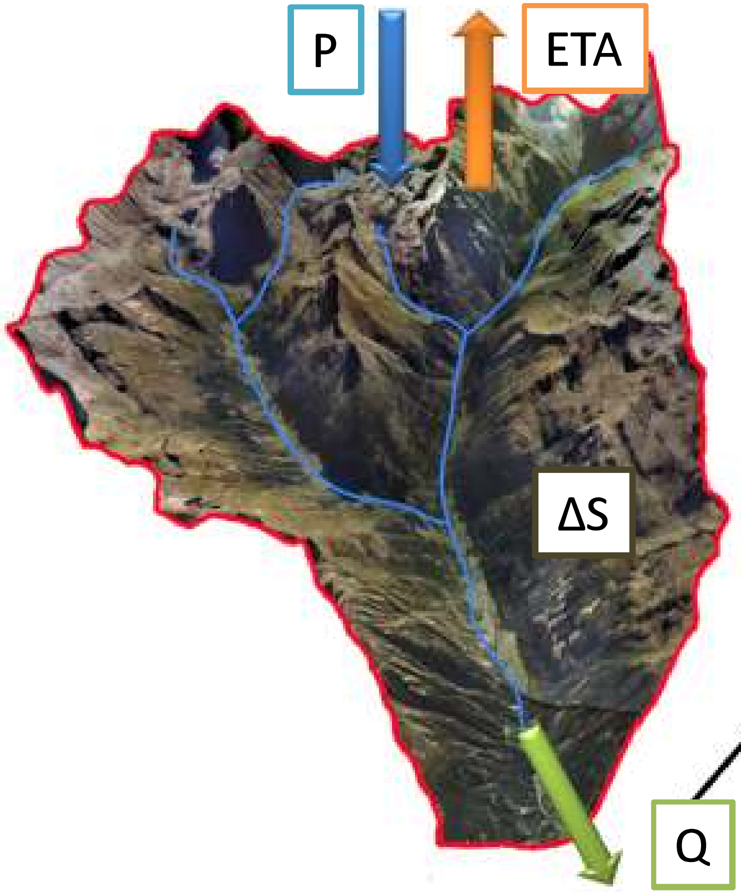
  - Further uncertainties during interpolation of areal precipitation fields

Motivation

- In consequence biased precipitation inputs for water-related modelling problems



Idea – Use runoff!

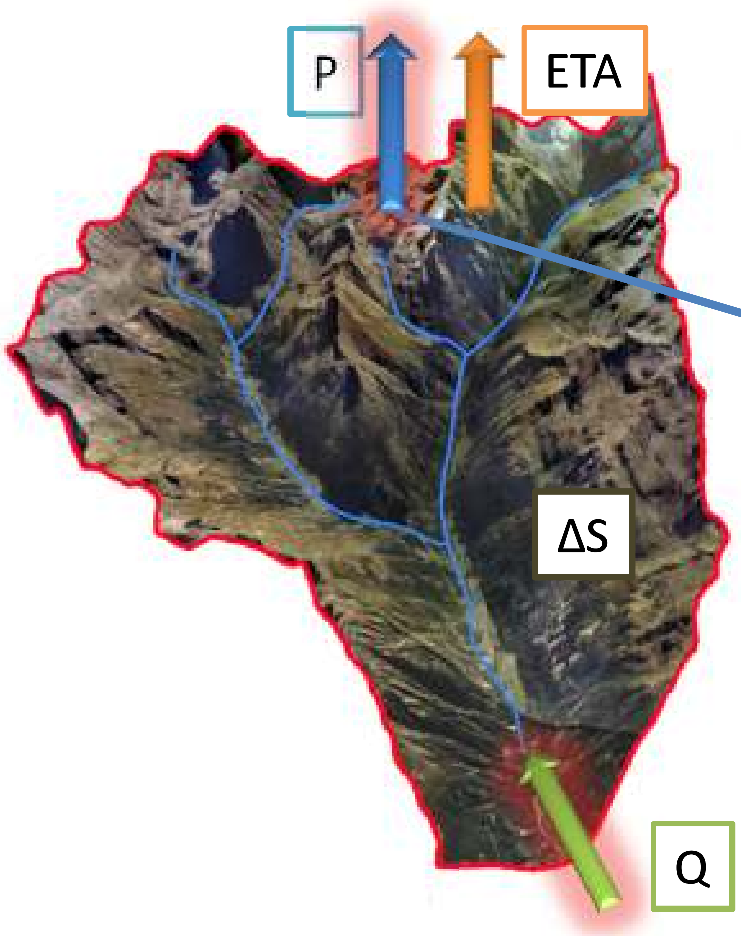


Runoff is the most reliable hydrological variable observed, with errors of about 5 – 20 % (Di Baldassarre and Montanari, 2009 (HESS); Pelletier, 1987 (Can. J. Civ. Eng.))

- integral of precipitation over a certain period, considering evapotranspiration losses and water storage differences
- Simulation with rainfall-runoff model **(Forward model)**

$$Q = \int_0^t (P - ETA \pm \Delta S)\, dt$$

Idea – Runoff-rainfall model (inverse model)



Inverse rainfall-runoff model with

- observed runoff (Q) as input

returns the temporally disintegrated areal rainfall

- Catchment as measurement area
- Inverse model (runoff-rainfall model)

Forward model

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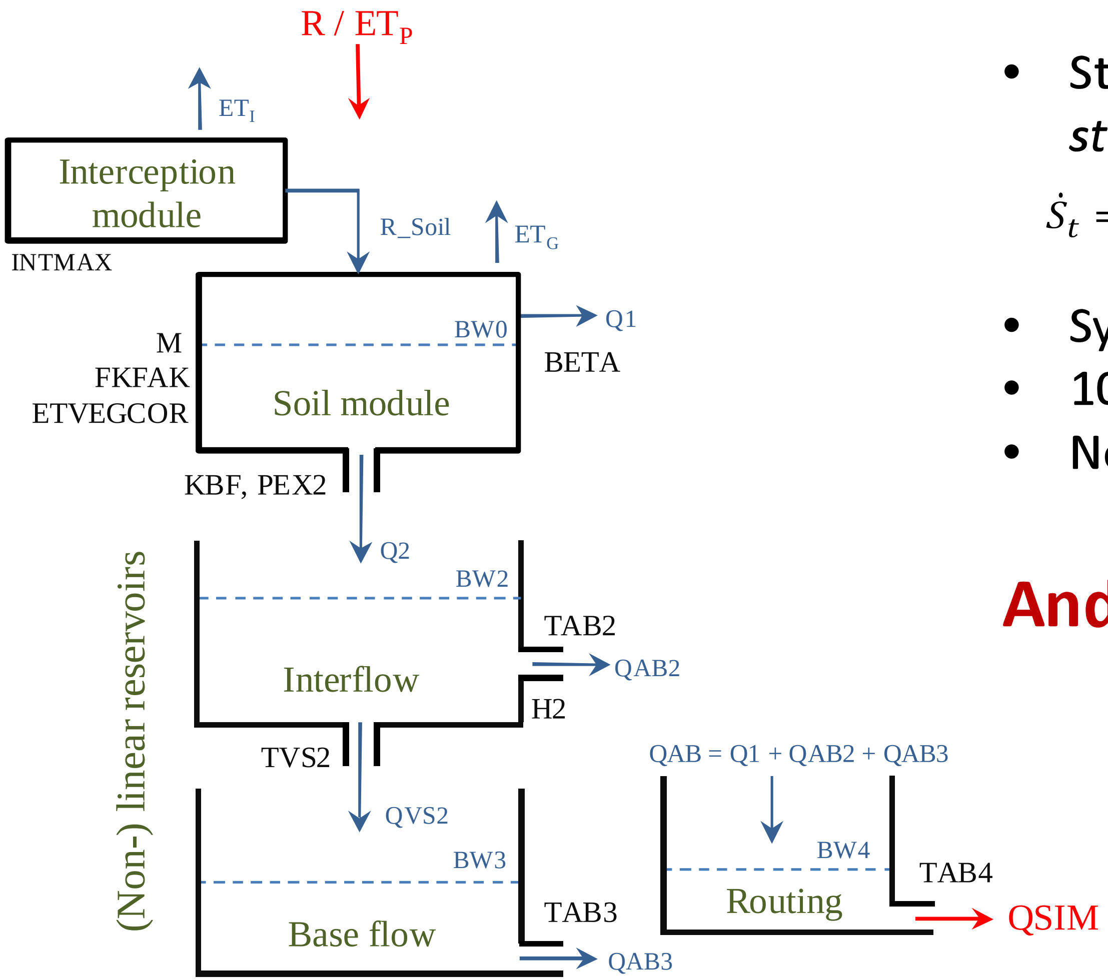
HBV-type rainfall-runoff model



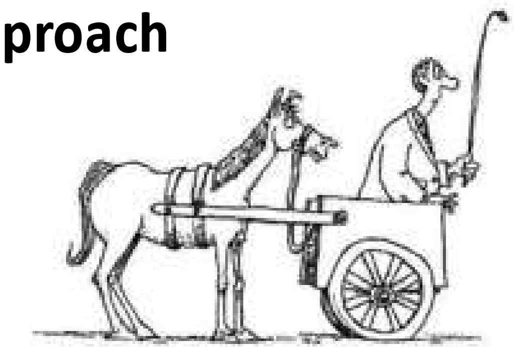
- State space formulation with *state transition* and *output functions*

$$\dot{S}_t = f(\dot{S}_{t-1}, \dot{I}_t) \qquad \dot{O}_t = g(\dot{S}_{t-1}, \dot{I}_t)$$

- System states (S - BW0, BW4,...)
- 10 Parameters (Φ - TAB4, BETA,....)
- No snow-processes

And now the other way round...

1. Analytical inversion of model equations (similar to Kirchner, 2009 (WRR))
2. **Iterative approach**



http://tinyurl.com/bqt7fhh

Inverse model – Iterative approach

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Which rainfall-input leads to simulated runoff that agrees with observed runoff?

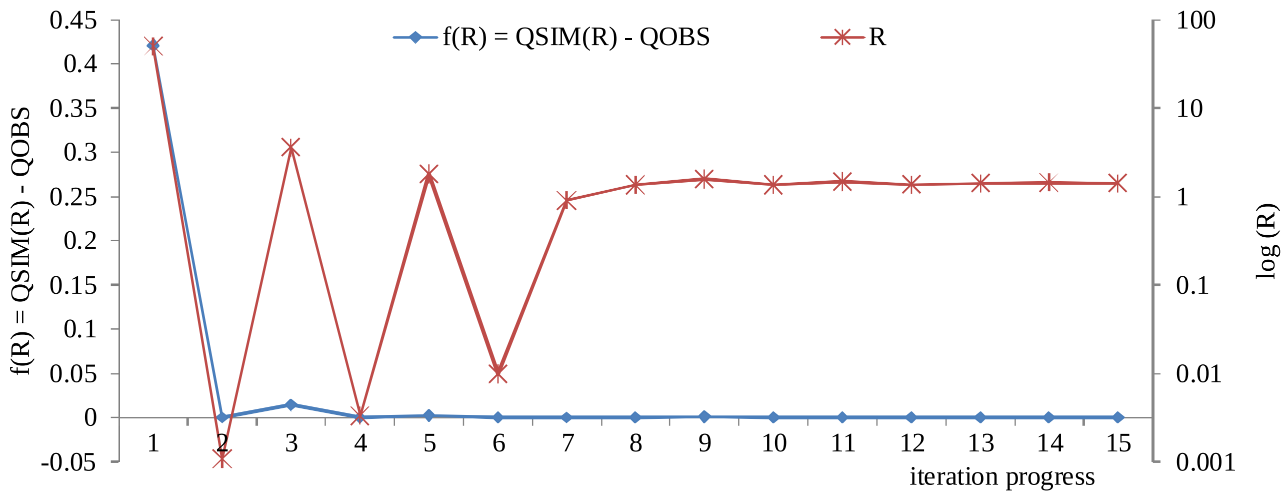
$$f(R_t) = QSIM_t(R_t) - QOBS_t = 0$$

→ Root-finding problem

- Forward R-R-model is embedded in a root-finding algorithm (Brent, 1973)
- Results for every time step are R_t **and** $QSIM_t$

Iteration example for 1 time step

(Upper and lower bracket: R_1 = 50 mm/h; R_2 = 0 mm/h (no negative R))



Herrnegger, M., Nachtnebel, H.P. (submitted): From runoff to rainfall: Inversion of HBV-based conceptual rainfall-runoff models (Part I - Methods). J. Hydrol.

Inverse model – Validation

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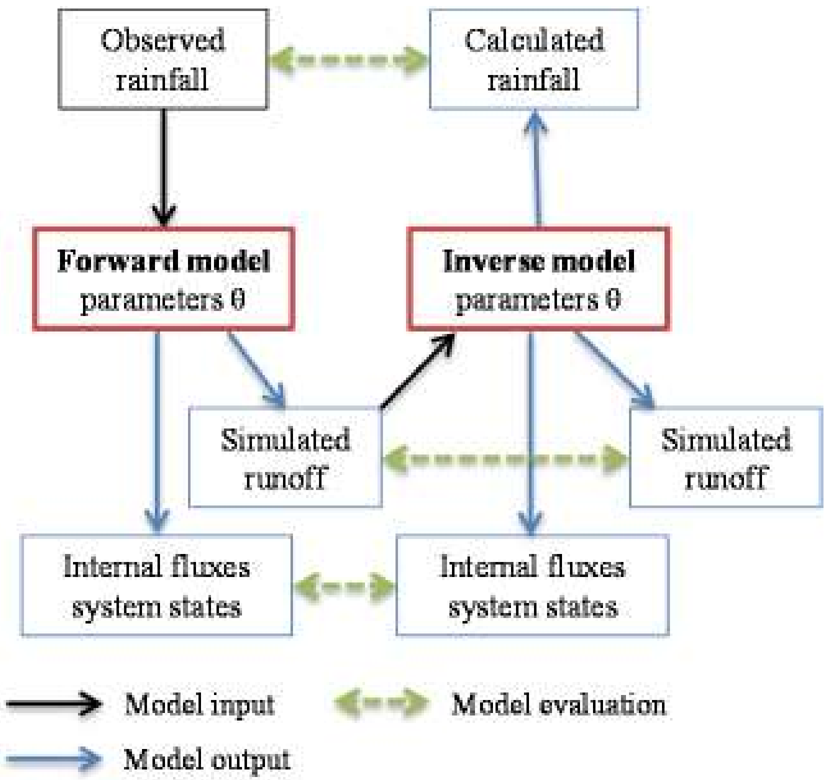
Does the inverse model work?

- Tests performed with *numerical experiments,* neglecting uncertainties in measurement errors, model structure and parameters



- 20.000 synthetic hydrographs generated with the forward model with Monte Carlo simulations, varying model parameters, are used as input in the inverse model

- System states, variables and fluxes from the forward model are known at every point in time and are used for validating the inverse model

Validation successful → Application with real world data

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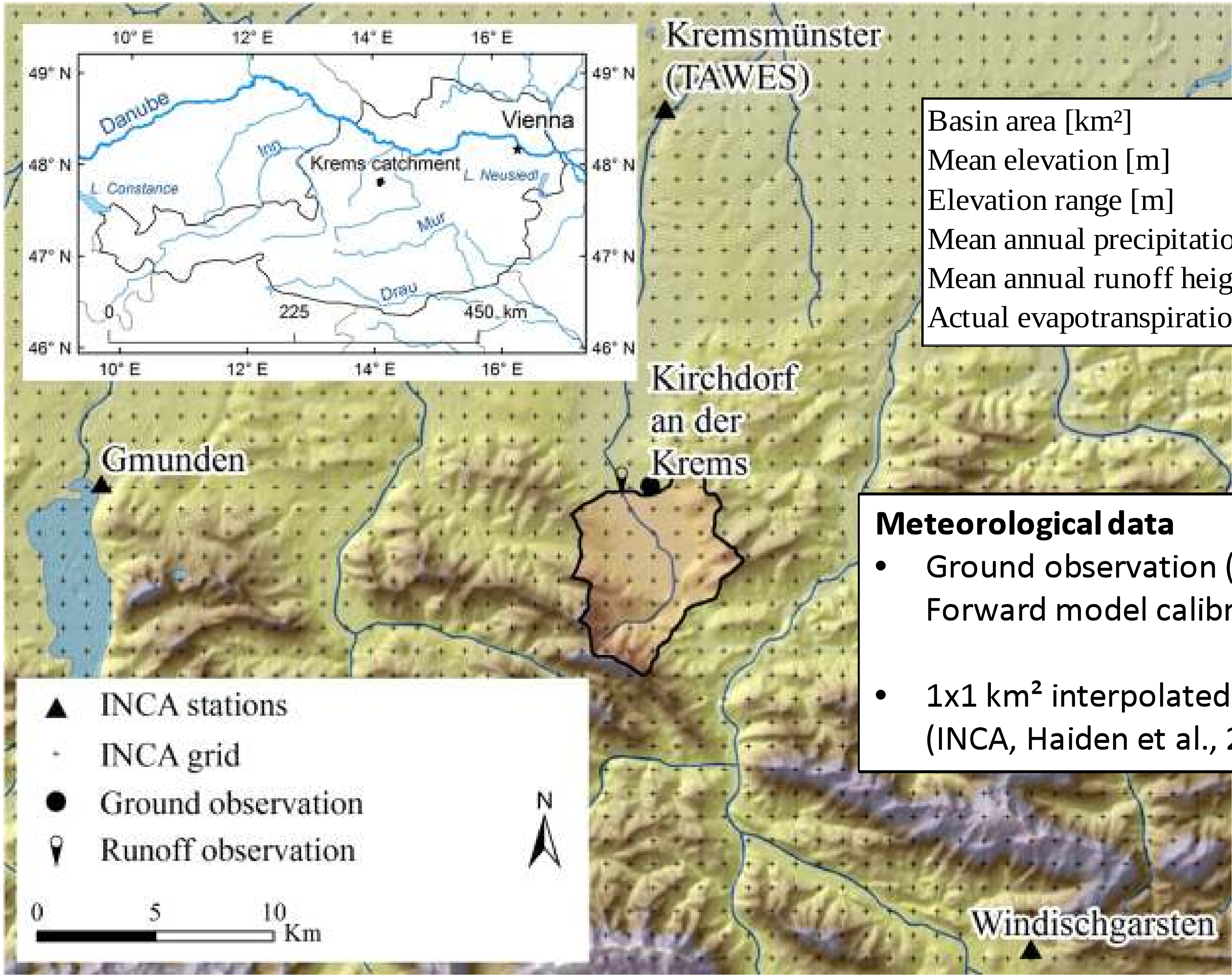
Study area & Data sets



Basin area [km²]	38.4
Mean elevation [m]	654
Elevation range [m]	413-1511
Mean annual precipitation [mm]	1345
Mean annual runoff height [mm]	740
Actual evapotranspiration [mm]	605

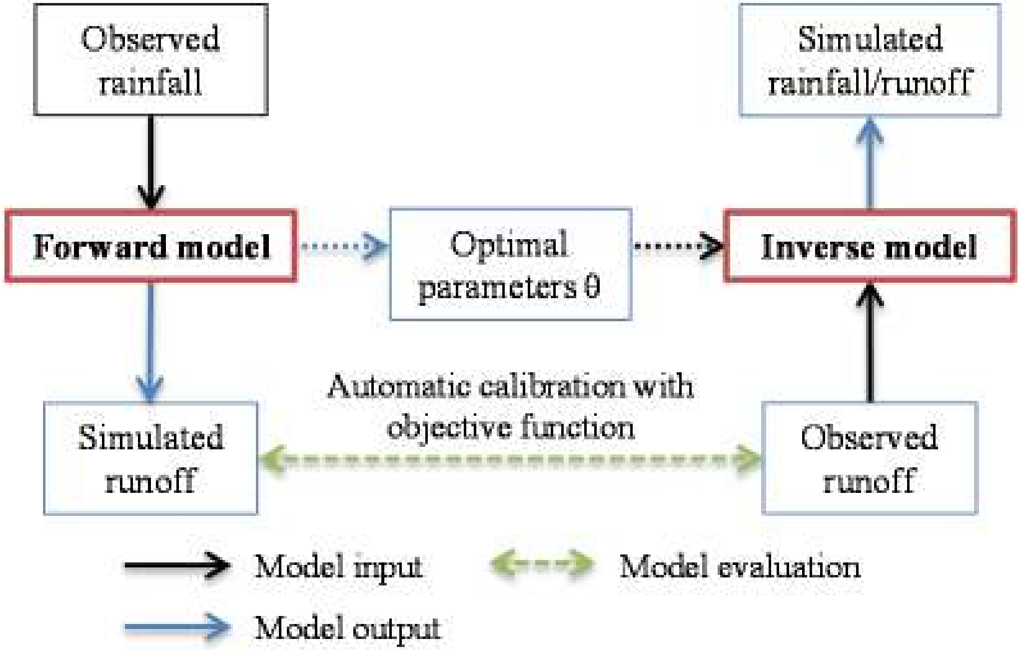
Meteorological data

- Ground observation (Kirchdorf/Krems): Forward model calibration / Evaluation
- 1x1 km² interpolated precipitation fields (INCA, Haiden et al., 2011): Evaluation

Parameter optimisation & Model setup

Assumption

- Calibrated forward model reflects catchment properties leading to runoff
- Inverse model with identical parameters therefore yields catchment precipitation

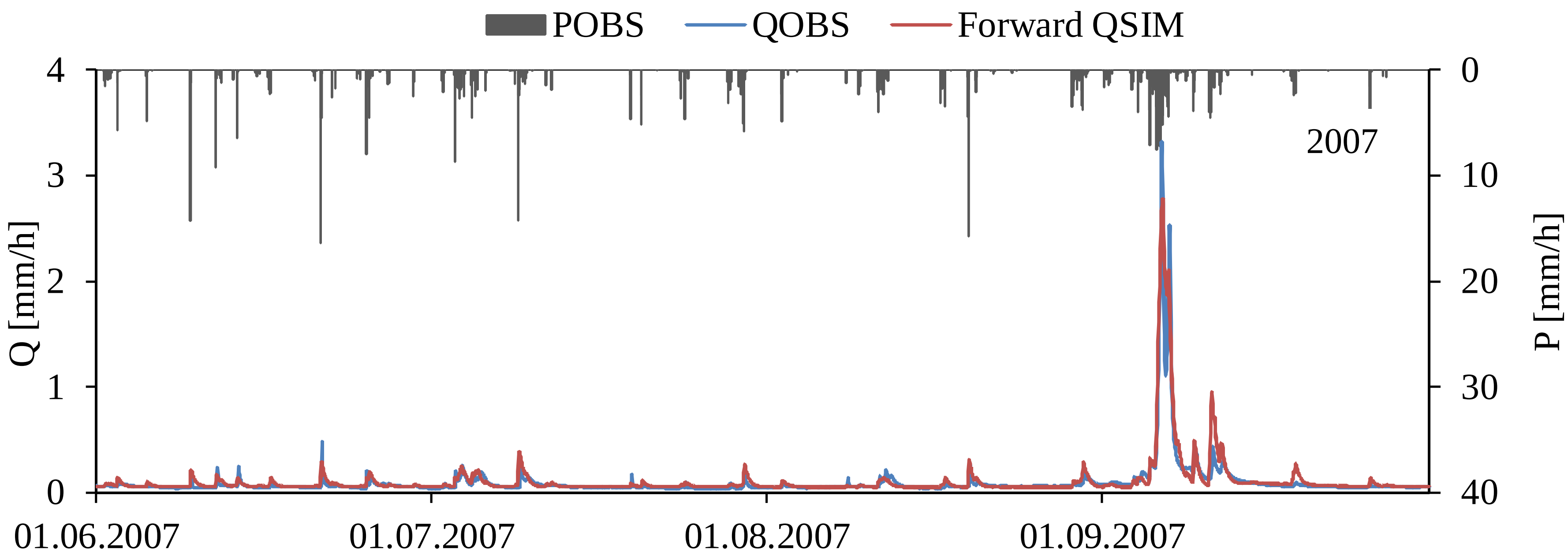


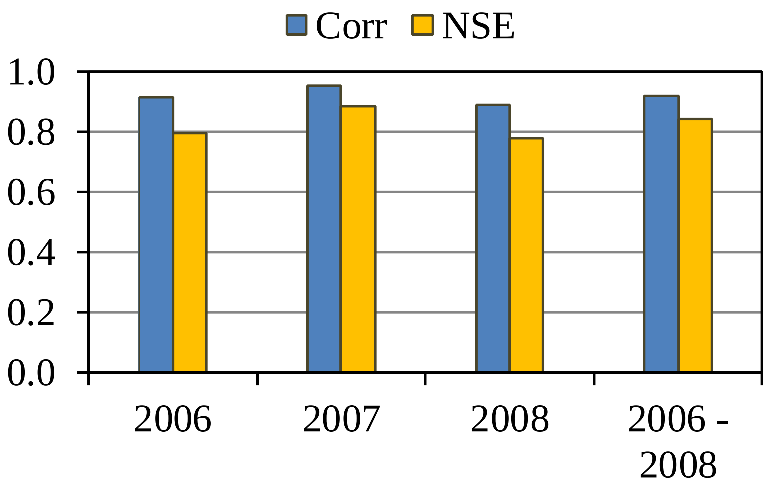
Model setup

- **Simulation period**
  2006 – 2008 (Δt = 60min)
- **Lumped model setup**
- **Evaluation**
  June / July / August / September (snow-free periods)

Results – Runoff (Forward model)

Does the calibrated forward model reflect catchment properties leading to runoff correctly?





Model performance

- Nash-Sutcliffe-Efficiency: 0.78 – 0.89
- Correlation: 0.89 – 0.95

Model performance satisfactory
→ inverse simulation legitimate

Results – Inverse Rainfall

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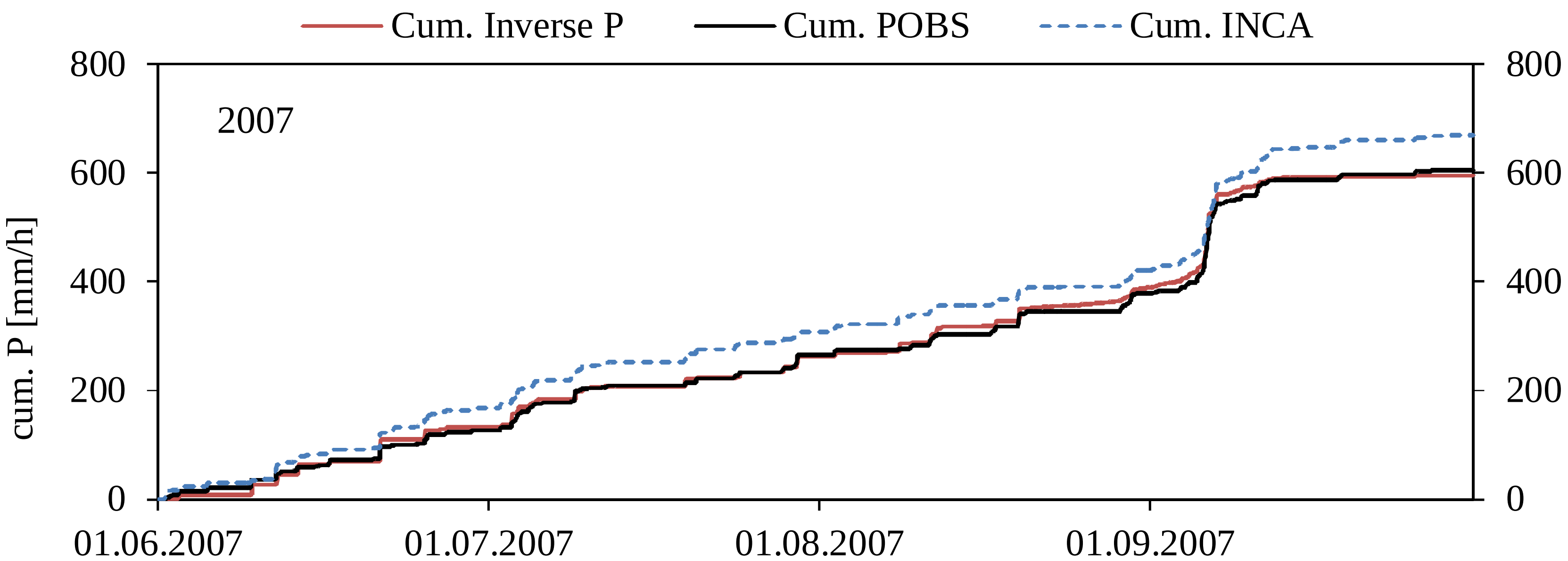
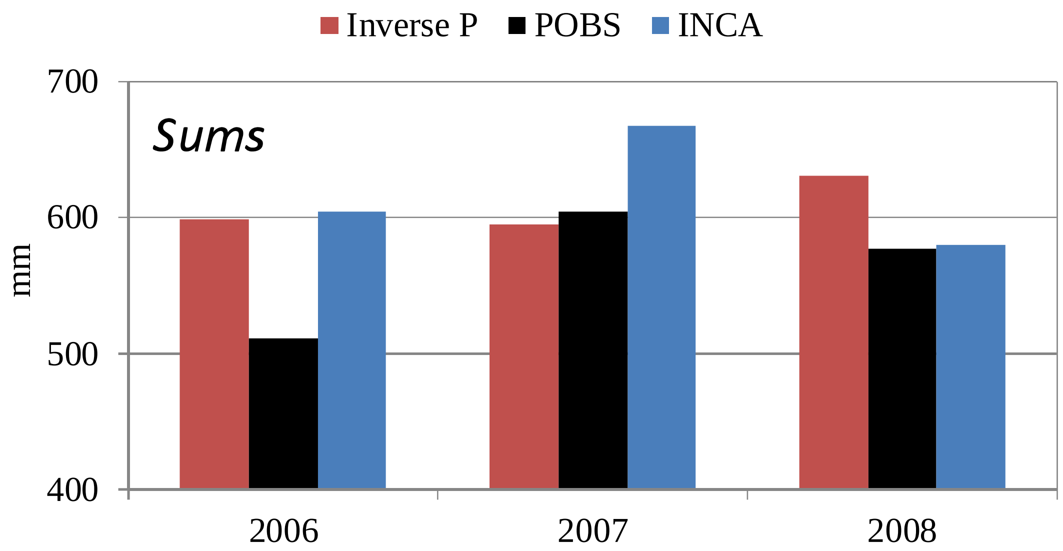
Cumulative rainfall distribution





- Significant variability in rainfall sums
- Deviations from the ground observation are similar for inverse & INCA rainfall

Results – Inverse Rainfall

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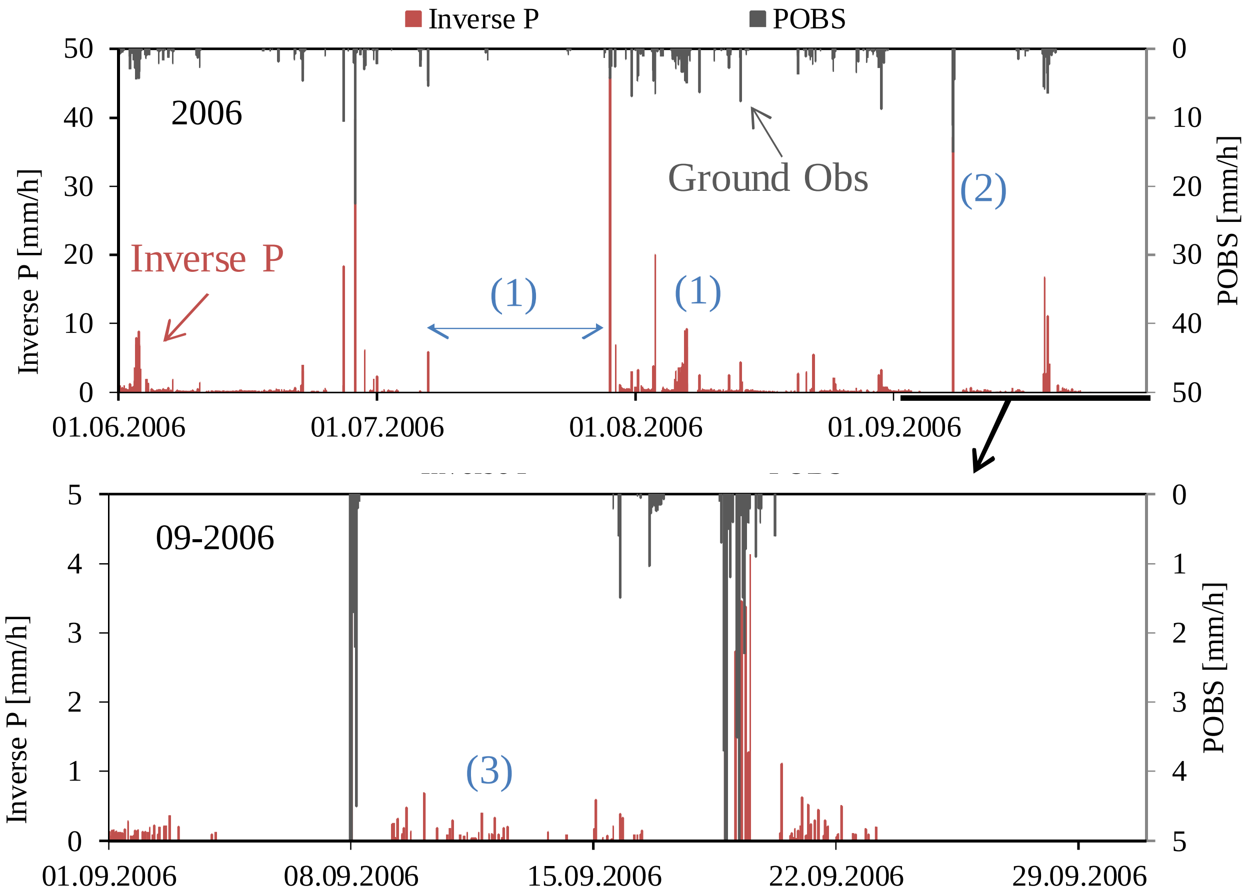
Temporal precipitation development



- Dry and wet periods are generally captured by the inverse model (1)
- Inverse model predicts higher intensities (2)
- In some periods the inverse model predicts low intensity rainfall, which is not supported by ground observations (Fog, Dew?) (3)

Results – Inverse Rainfall

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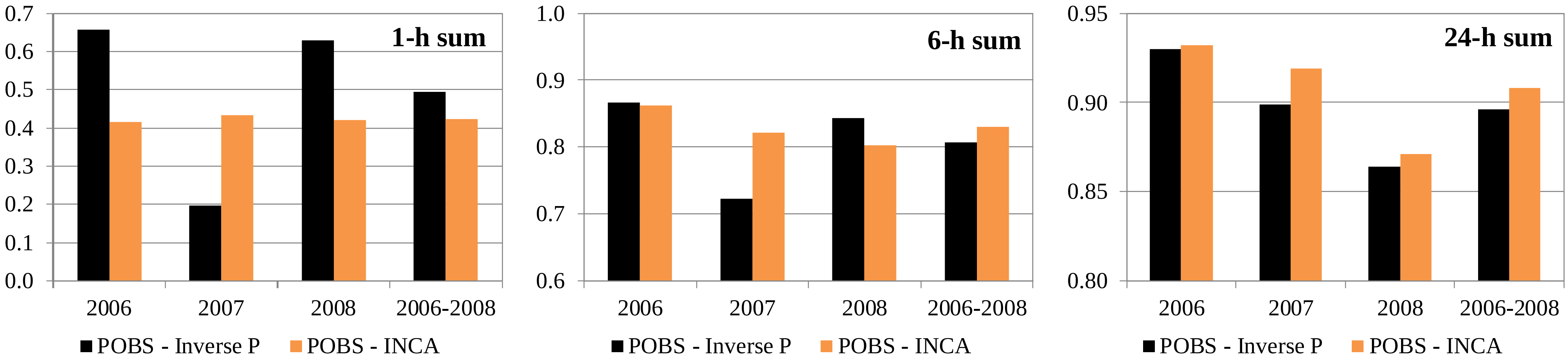
Correlation between different precipitation realisations & temporal aggregation levels (6-h & 24-h sums)



- 1-h sum: Correlation between POBS and Inverse P mostly higher than POBS-INCA
  Correlation between POBS and INCA stable for different years

- Correlation coefficient increases considerably with temporal aggregation
- Correlation between POBS and INCA mostly higher at longer aggregation levels

Summary & Conclusions

- A method was presented to invert widely used conceptual R-R-models, with the aim to estimate catchment precipitation from runoff observations
- Quality of inverse rainfall estimates is higher or of the same magnitude compared to interpolated precipitation data
- Runoff-Rainfall modeling is a feasible approach to estimate areal rainfall, which can be used for, e.g.
    - Estimation of P-correction factors or parameterisation of elevation dependency
    - Calibration of radar data
    - Flood forecasting systems, e.g. as an additional information source for ensemble precipitation estimates
- Approach is limited to catchment sizes, which can be modeled in a lumped approach & snow-free periods

Thank you for your attention!

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