The impact of meteorological and hydrological memory on compound peak flows in the Rhine river basin.

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SYSTEM RISK ETN

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Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

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Motivation

- The most destructive compound river floods in the Netherlands
  - **1926** (heavy rainfall episodes leading to dike breach)
  - **1993** (heavy rainfall episodes on saturated soil)
  - **1995** (rain on frozen soil due to multiple cold spells)

- Memory in the atmosphere does not entail more than a few days *(Lorenz, 1969).*

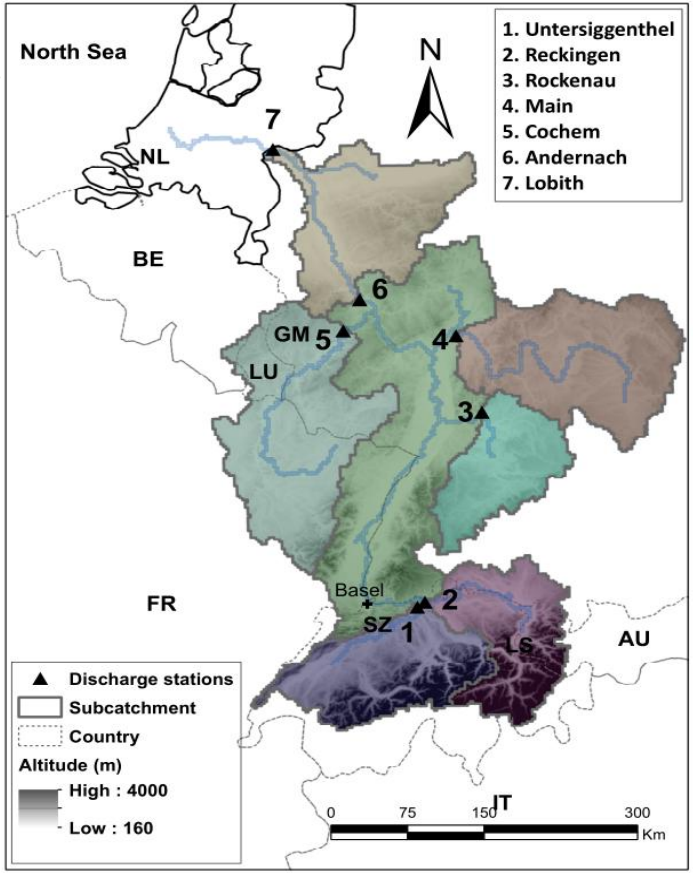
- Hydrological storages, for instance soil moisture, snow packs, glaciers, riverine storages and ground water, remember the past anomalies for longer term.

- In reality, many phenomena act simultaneously, and their compound occurrence is highly influential in determining the final state of the system *(Zscheischler et al., 2018).*

- To what extent does memory in hydro-meteorological systems affect the generation of extreme discharge?

Data and models

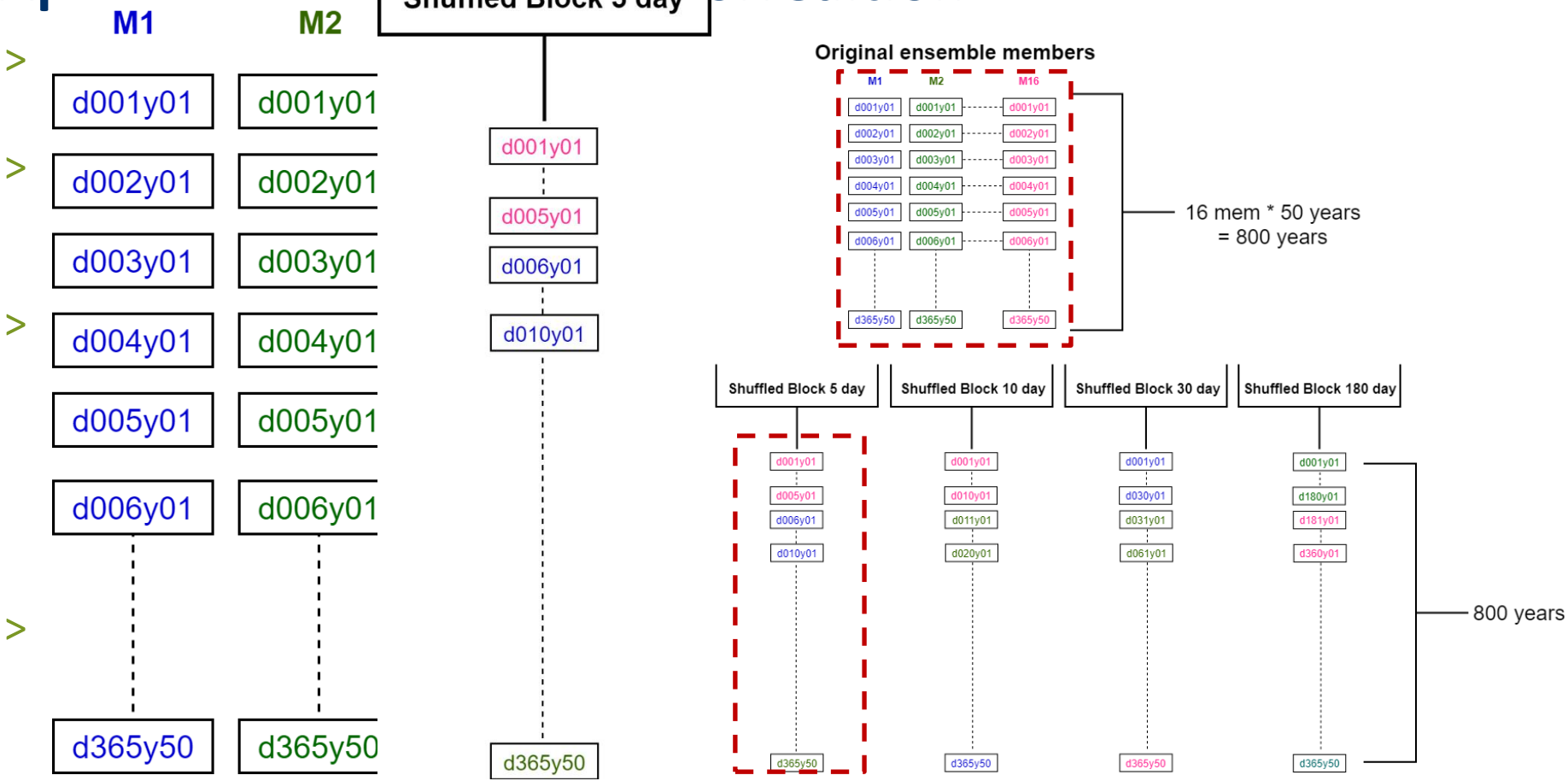
- Dynamically downscaled 16 EC-Earth ensemble using RACMO2 (van Meijgaard et al., 2008) at 0.11° resolution for the time 1951-2000.
- Distributed cryospheric-hydrological model (SPHY) at 2.5 km resolution calibrated at several locations.
- Forcing and observations
  - E-OBS v14 daily gridded precipitation and temperature data (Haylock et al., 2008)
  - Observed flow data (GRDC, 2016)
- PCR-GLOBWB2 kinematic routing scheme for flood routing (Sutanudjaja et al., 2018).



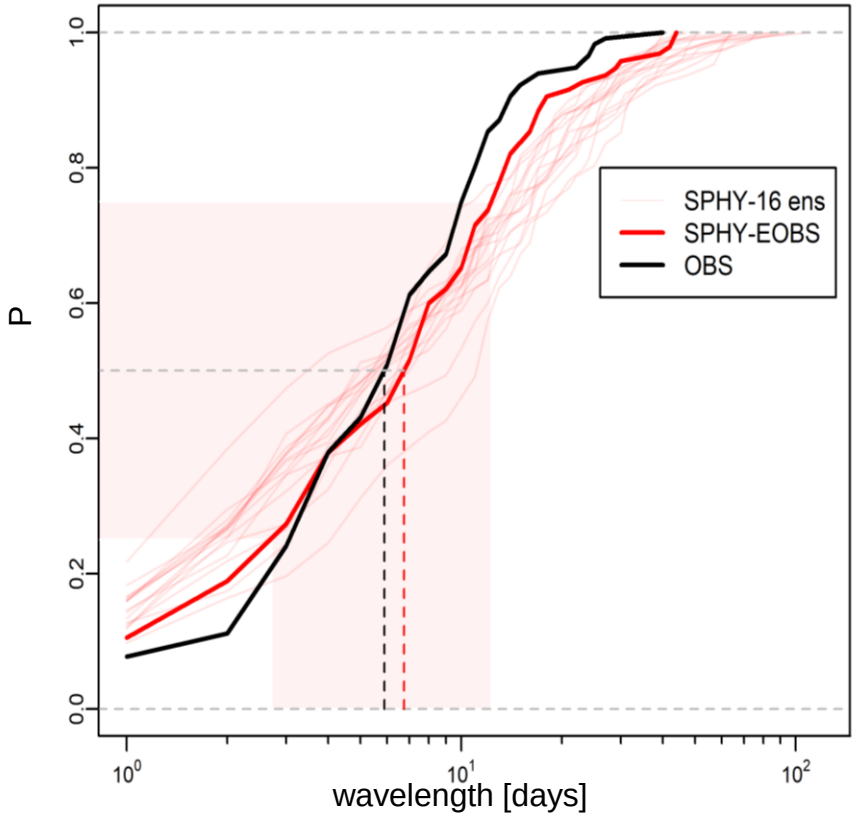
Memories of snow and soil moisture

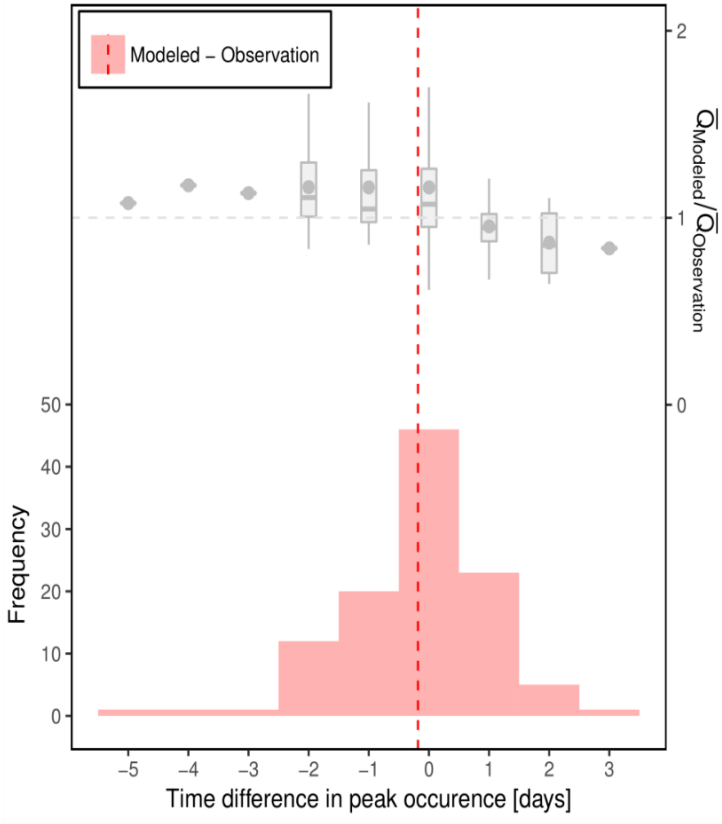
- Years above and below average snowfall year in a hydrological year (Oct-Sep) and its effects on the peak discharges are investigated.
- The effect of 10-day precipitation sum exceeding the long-term 95% percentile values on discharges are assessed.
- Interaction of precipitation in combination with soil moisture on discharge is assessed based on a multi-conditional sampling method.

Approach to re… orrealtion

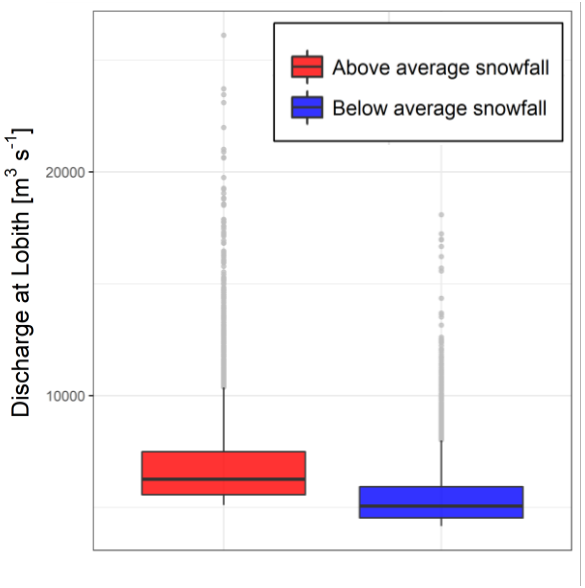


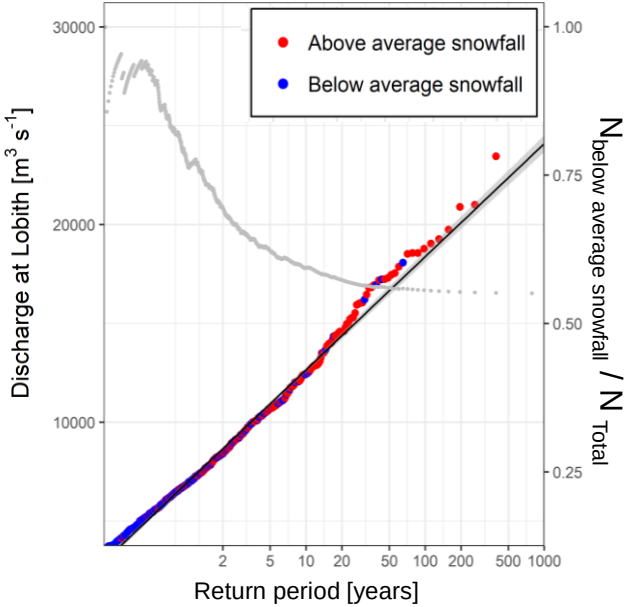
Flood wave duration and timing

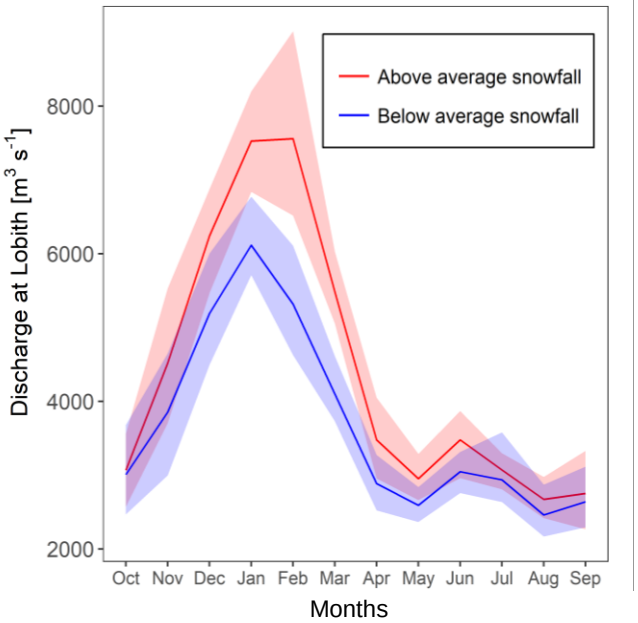




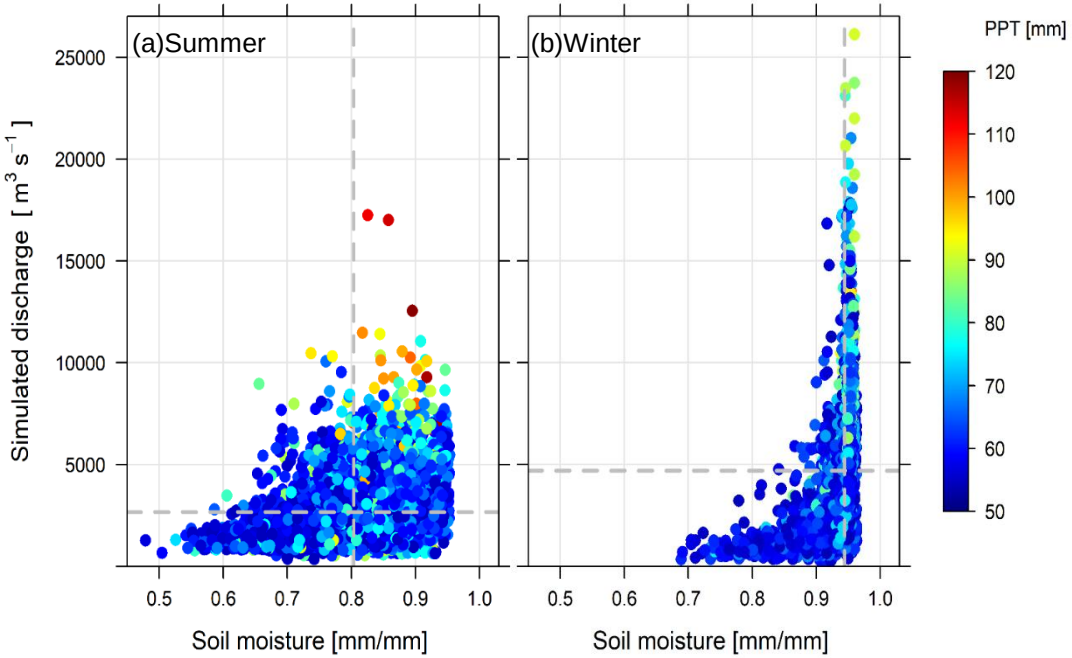
Snow memory

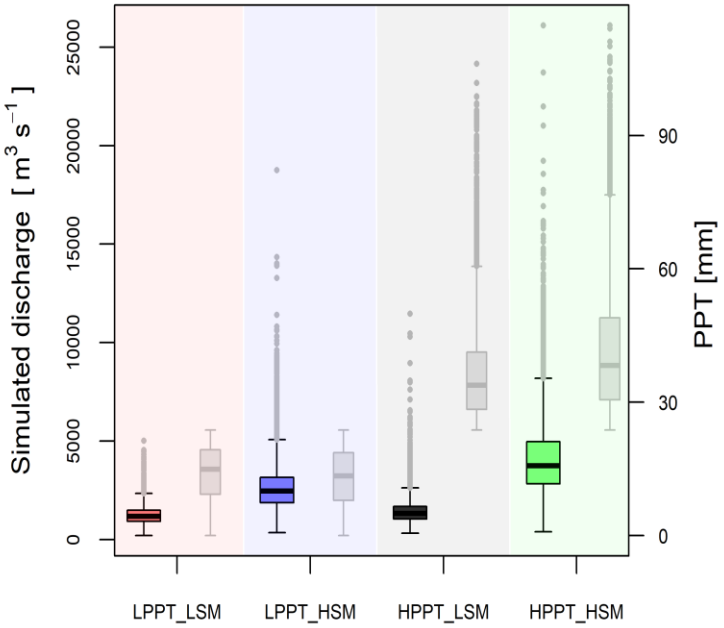

Above average snowfall
Below average snowfall
Discharge at Lobith [m3 s-1]
20000
10000


Above average snowfall
Below average snowfall
Discharge at Lobith [m3 s-1]
30000
20000
10000
1.00
0.75
0.50
0.25
Nbelow average snowfall / N Total
2
5
10
20
50
100
200
500
1000
Return period [years]


Above average snowfall
Below average snowfall
Discharge at Lobith [m3 s-1]
8000
6000
4000
2000
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Months

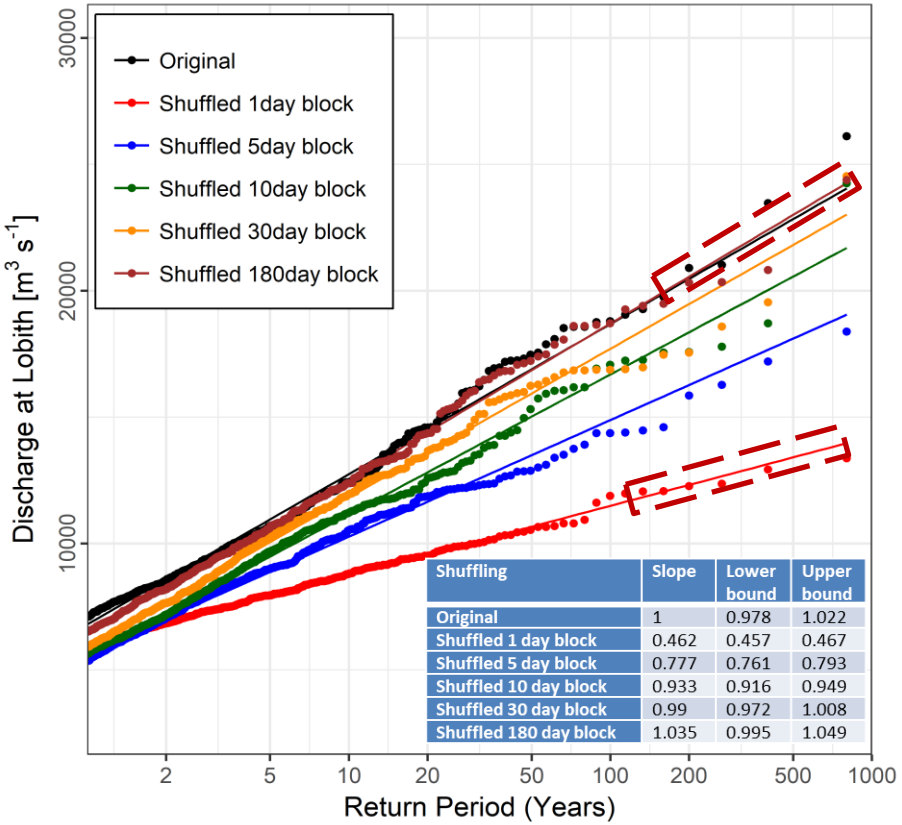
Soil moisture memory



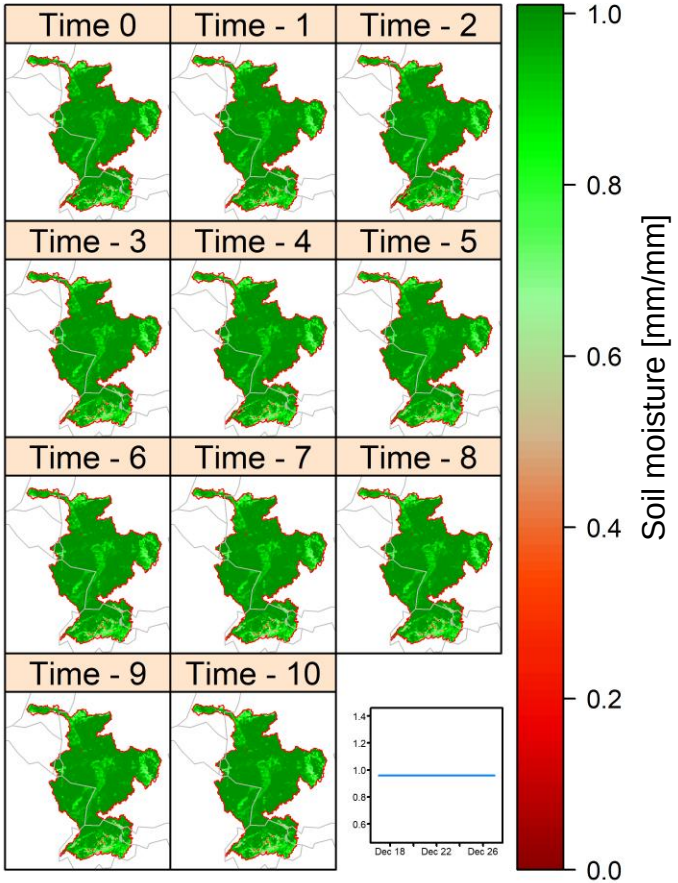


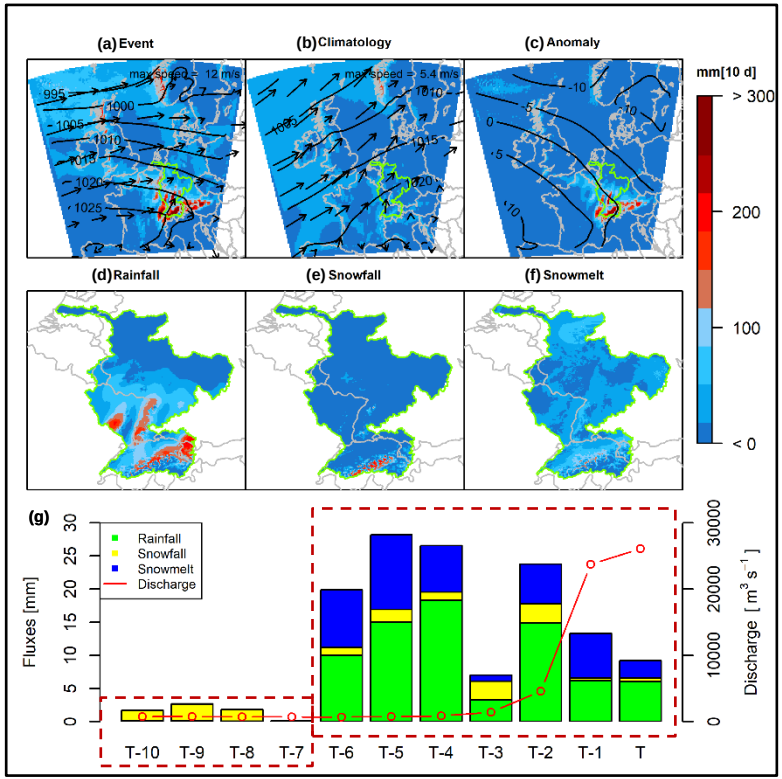
Importance of autocorrelation

- Removing the meteorological memory reduces the slope of GEV distribution down to 45%.
- High discharge peaks originate from multi-day precipitation events.
- Preserving the meteorological memory for 5 days retains almost 80% of the original GEV slope.
- The monotonic decrease in maximum discharge with incremental increase in the block length shows a relatively large jump at timescales 1 to 5 days.



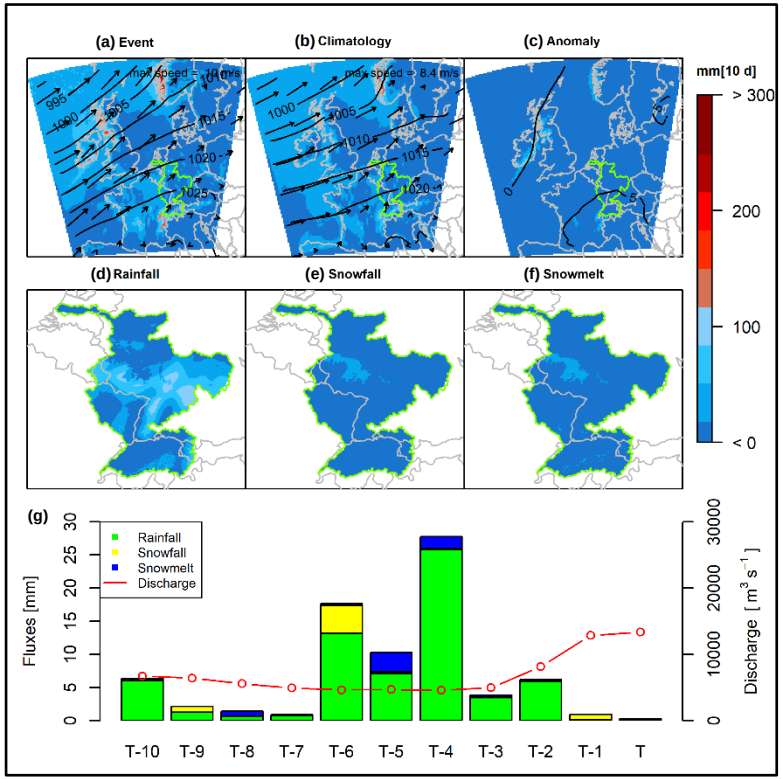
Shuffling	Slope	Lower bound	Upper bound
Original	1	0.978	1.022
Shuffled 1 day block	0.462	0.457	0.467
Shuffled 5 day block	0.777	0.761	0.793
Shuffled 10 day block	0.933	0.916	0.949
Shuffled 30 day block	0.99	0.972	1.008
Shuffled 180 day block	1.035	0.995	1.049


Time 0
Time - 1
Time - 2
Time - 3
Time - 4
Time - 5
Time - 6
Time - 7
Time - 8
Time - 9
Time - 10
Dec 18
Dec 22
Dec 26
1.0
0.8
0.6
0.4
0.2
0.0
Soil moisture [mm/mm]


(a) Event
(b) Climatology
(c) Anomaly
mm[10 d]
> 300
200
100
< 0
(d) Rainfall
(e) Snowfall
(f) Snowmelt
(g)
Rainfall
Snowfall
Snowmelt
Discharge
Fluxes [mm]
Discharge [m3 s-1]
T-10
T-9
T-8
T-7
T-6
T-5
T-4
T-3
T-2
T-1
T

Experiments: 1 day shuffling

- Removal of memory from precipitation resulted in 50% reduction in peak flows.
- The snow memory effect hardly plays a role in this event.
- The event is solely dominated by rainfall-runoff mechanism.



Conclusions

- Snow memory is important in the Rhine as snowfall above average tend to shift the peak discharge regime by a month time scale.
- Soil moisture modulates the rainfall-runoff relationship and generates a strong runoff response at high soil moisture levels and buffers the generation of runoff peaks at low levels.
- Meteorological autocorrelation has a strong impact on the magnitude of peak discharge.
- Autocorrelation at time scales longer than 30 days plays a minor role. Most memory in the meteorological system in the Rhine basin is found at time scales around 5 days.

THANK YOU!

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