Climate Change and Runoff Statistics in the Rhine Basin: A Process Study with a Coupled Climate-Runoff Model

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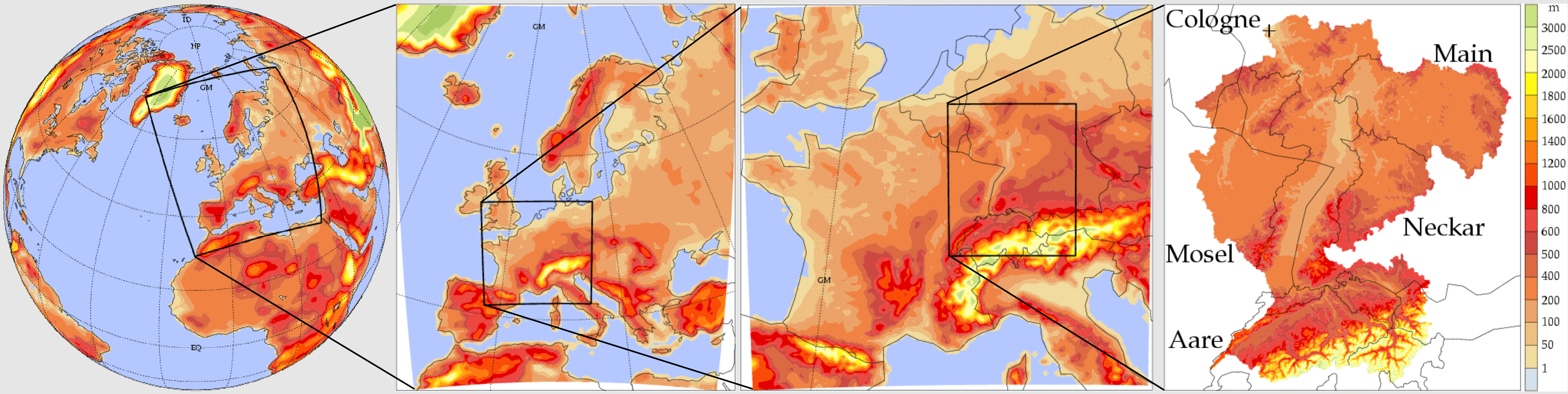
Motivation & Objectives

- Understand the processes of winter-time precipitation, runoff, and flood frequency in a warmer climate
- Recent winter floods in the Rhine basin:
  1993, 1995, 1998, 2001, 2002

Flood 2001 in Cologne, “Information for divers”, WDR Online

- Evaluate a high resolution regional climate model for studying hydrologic impacts
- Couple the runoff model with the high resolution regional climate model
- Evaluate the influence of a warmer climate on precipitation and runoff

Model Setup



ECMWF Reanalysis CHRM56 CHRM14 WaSiM 1 km

Climate model: Climate version of the HRM by the German Weather Service
56 and 14 km horizontal resolution
driven by observed data (ECMWF reanalysis, T106, ~120 km)

Runoff model: spatially distributed, gridbased model, 1 km horizontal resolution, Richards equation, groundwater model, time step: 1 hour

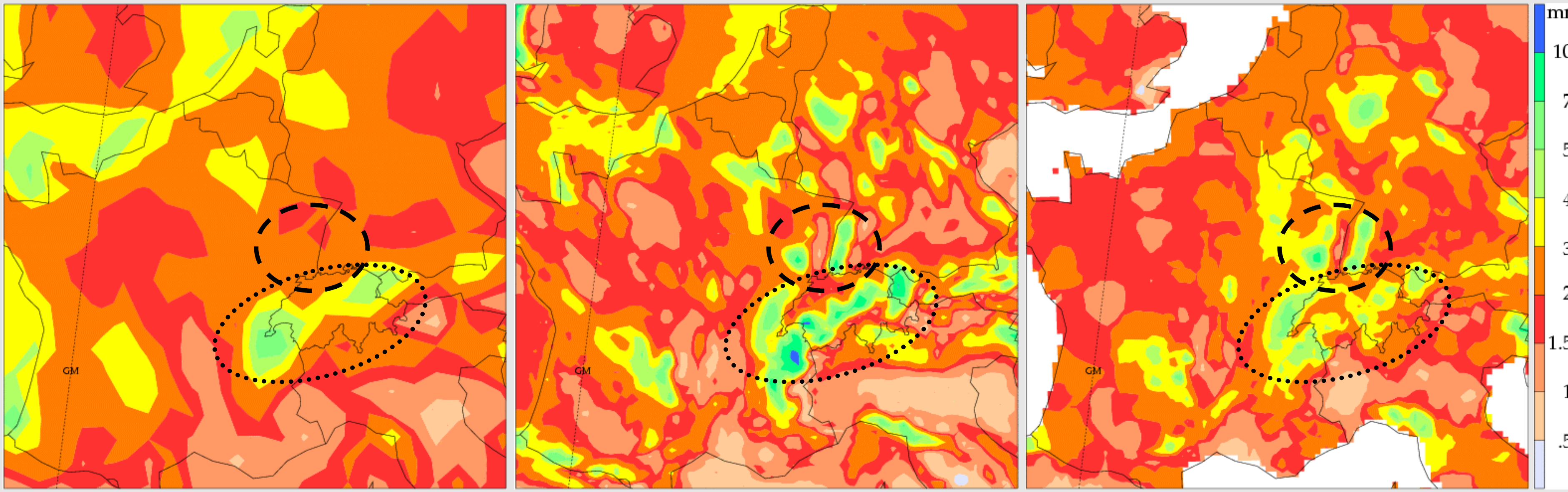
Simulation period: 09/1987 - 01/1994 for CHRM56,
5 winters (November to January each) for CHRM14, 1989/90 - 1993/94

Validation: daily precipitation fields, ~7’000 rain gauges, resolution ~25 km (Frei & Schär, 1998), daily runoff values from runoff gauges

Mean Daily Precipitation

5 winters (NDJ, 1989/90-1993/94)

CHRM56 CHRM14 Observation

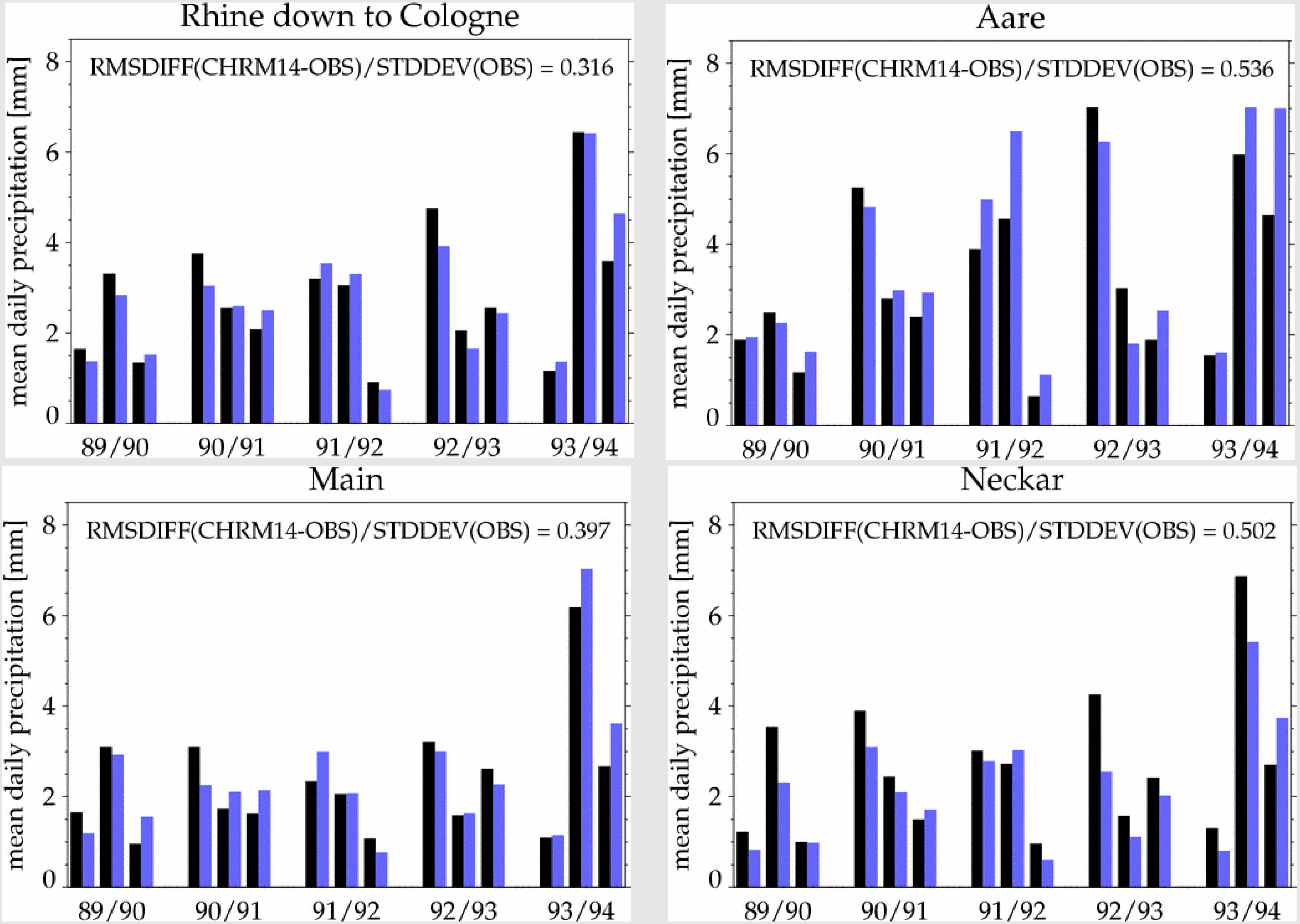


- Good spatial distribution at 14 km horizontal resolution
- Gain in information due to higher resolution
- Slight horizontal shift along topography

Bias CHRM14 – OBS

Aare	+ 12 %
Neckar	- 17 %
Main	+ 4 %
Mosel	- 26 %
Cologne	- 2 %

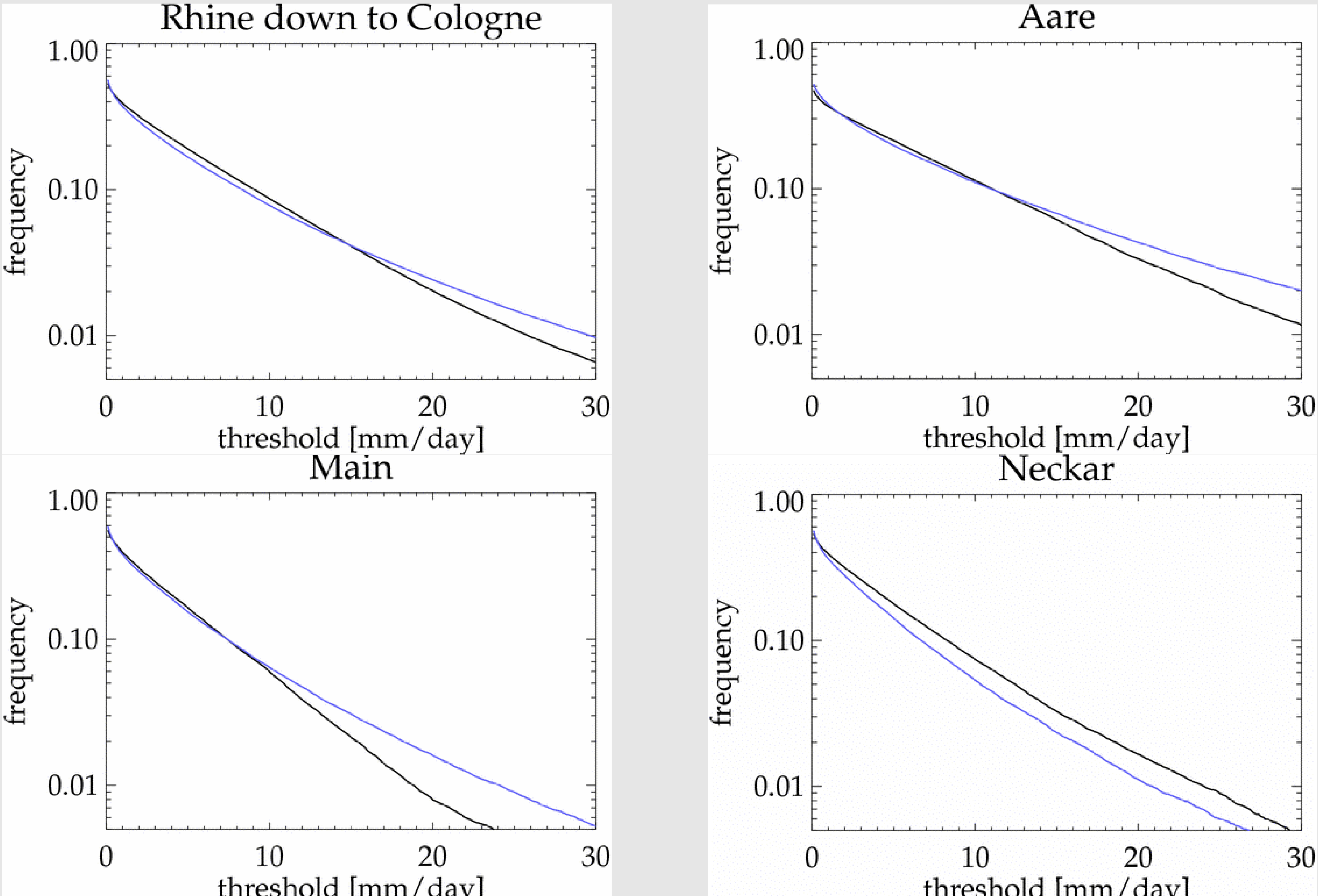
Monthly Domain Mean Precipitation



CHRM14
vs.
OBS

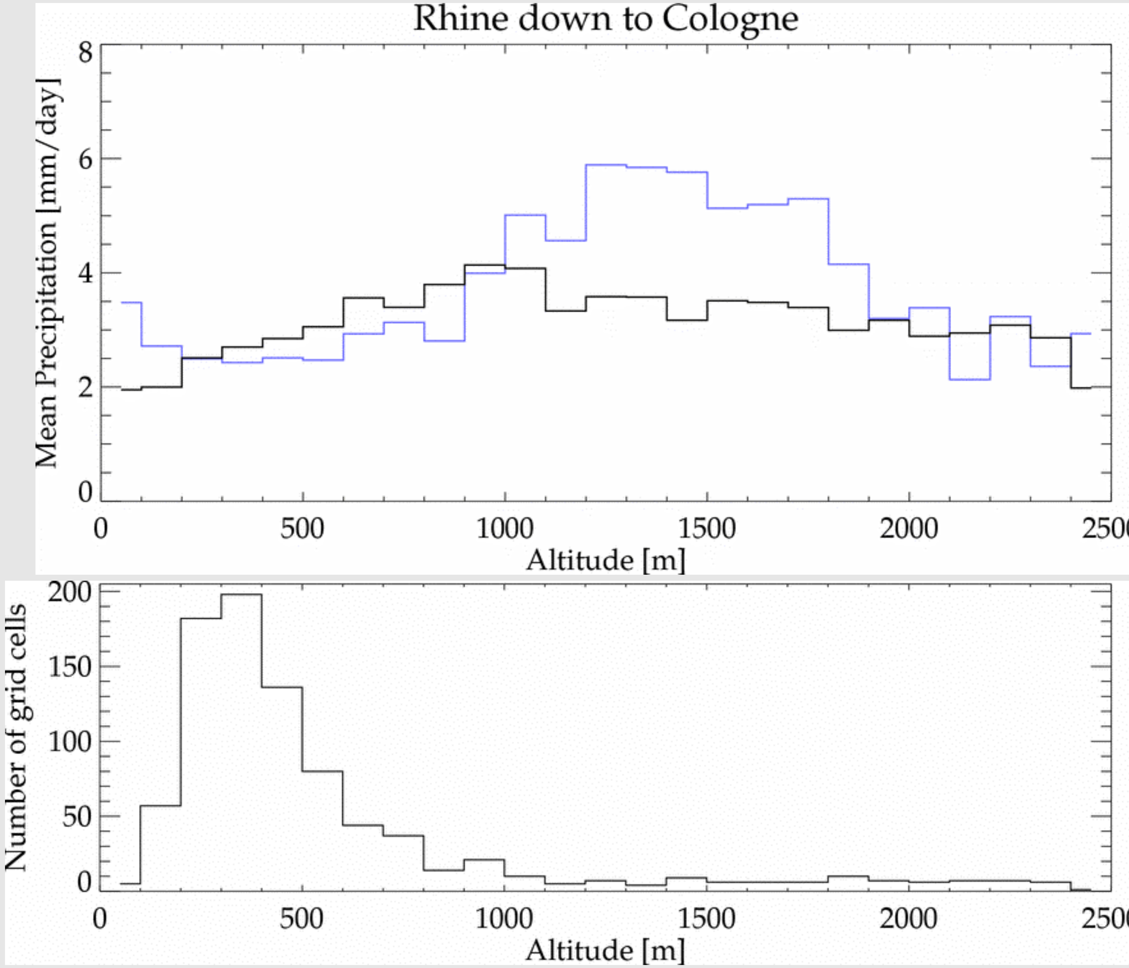
- Good representation of interannual variability

Precipitation Frequency, **CHRM14** vs. **OBS**



- Underestimation of small & overestimation of heavy precipitation events
- Regional differences are well represented

Altitude Distribution of Precipitation



CHRM14

vs.

OBS

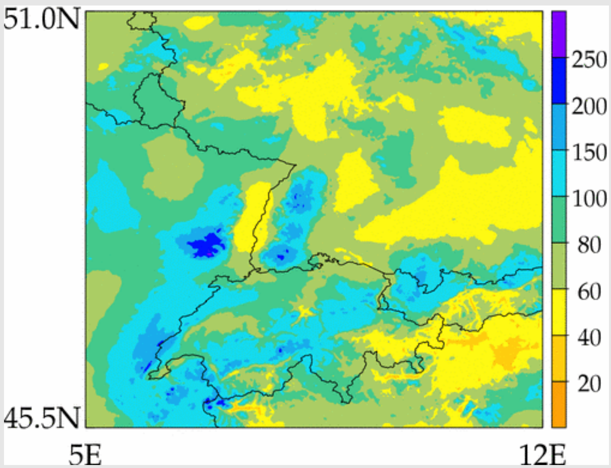
- Underestimation at low altitudes
- Overestimation at higher altitudes

  → Implication on snow distribution

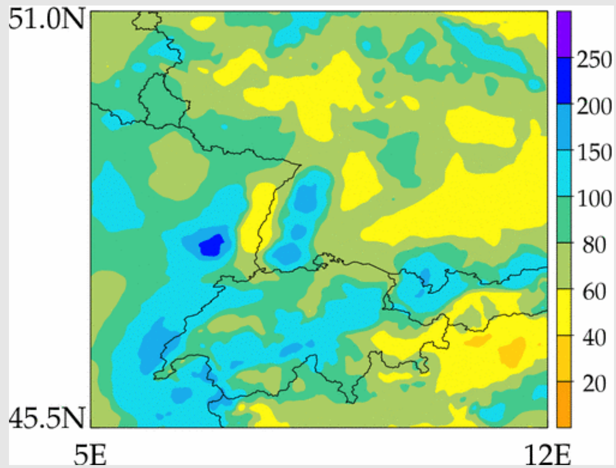
Model Interface

Temperature: using temperature gradient from climate model

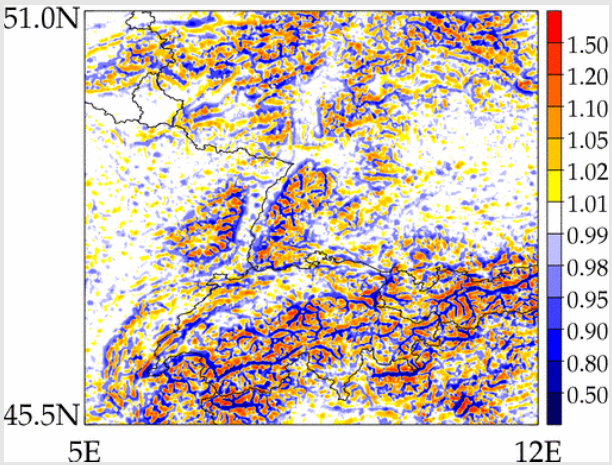
Precipitation: using a high resolution precipitation climatology by Schwarb et al. (2001) according to Widman & Bretherton (2000)



Original climatology, horizontal resolution ~2km



filtered climatology, ~14km

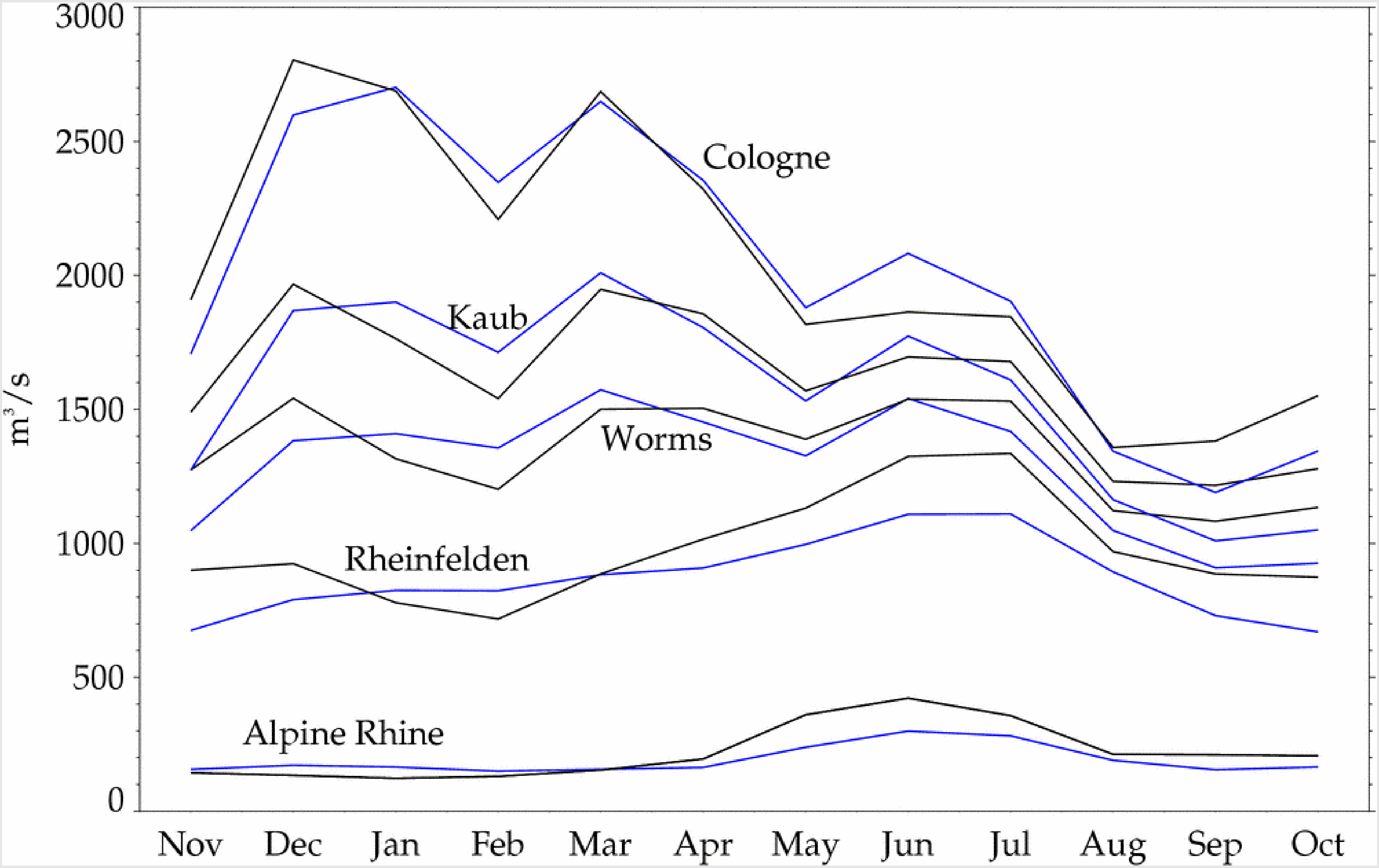


downscaling coefficient

Wind, radiation, humidity: bilinear interpolation

Bias correction for precipitation and temperature (seasonal only)

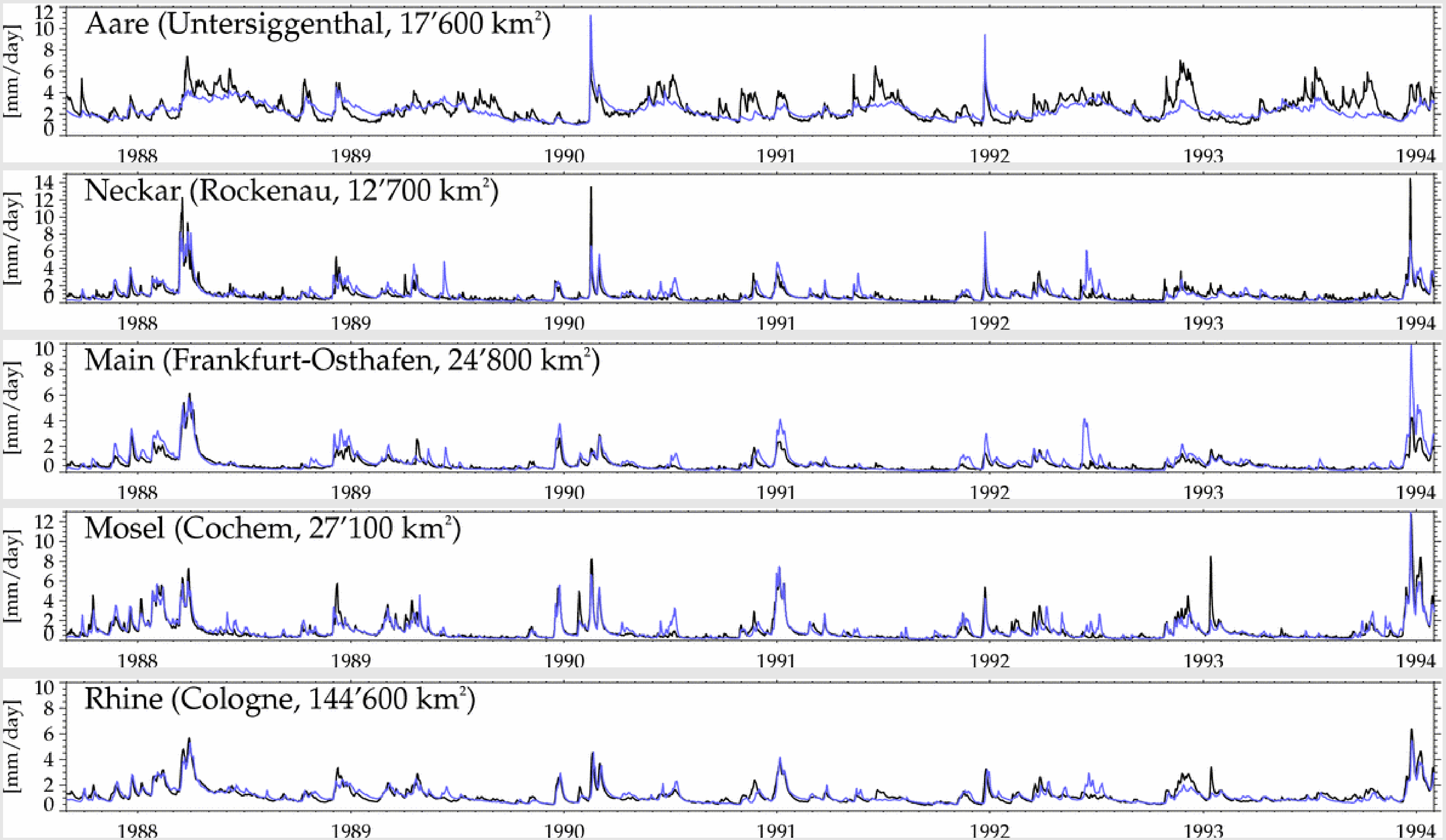
Annual Runoff Regime, CTRL vs. **OBS**



- Representation of annual runoff regime
- Representation of regime shift from nival to pluvial

Validation of Daily Runoff, CTRL vs. OBS

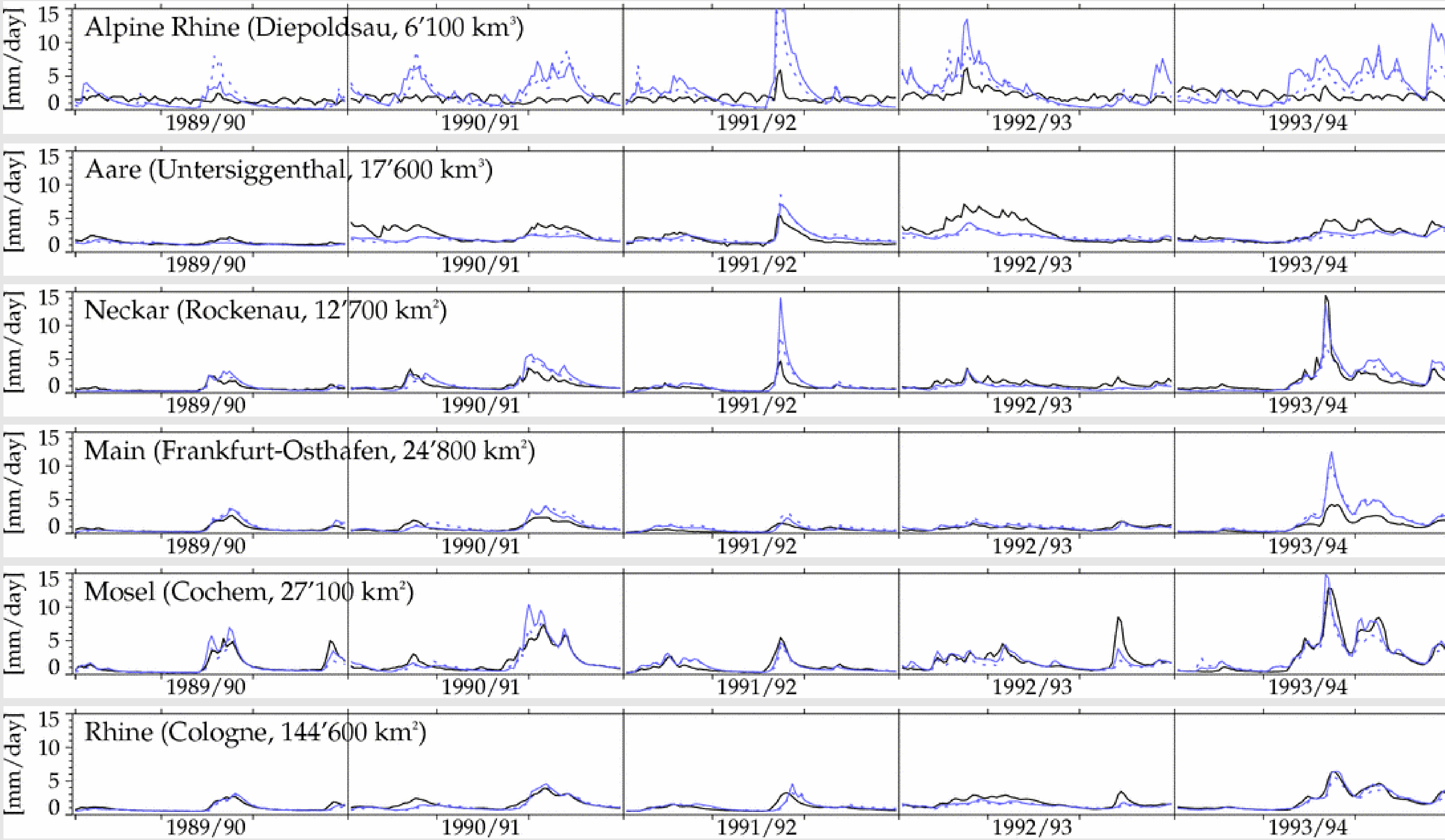
6 years (09/1987 – 01/1994) driven by CHRM56



Validation of Daily Runoff, CTRL vs. OBS

CHRM14 (solid)
CHRM56 (dashed)

5 winters (NDJ, 1989/90 – 1993/94) driven by CHRM14 and CHRM56

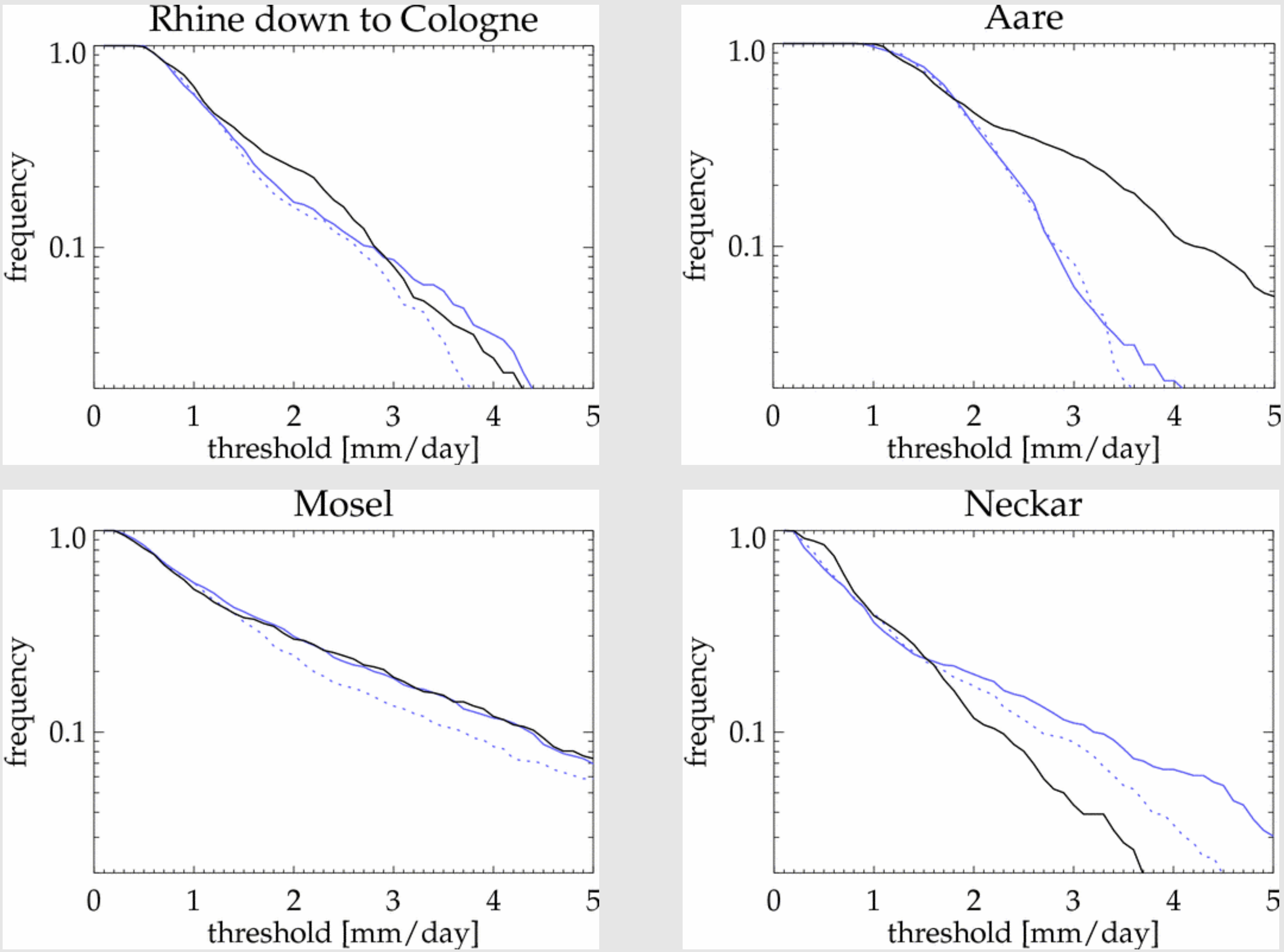


- Regional differences of the sub-basins are represented

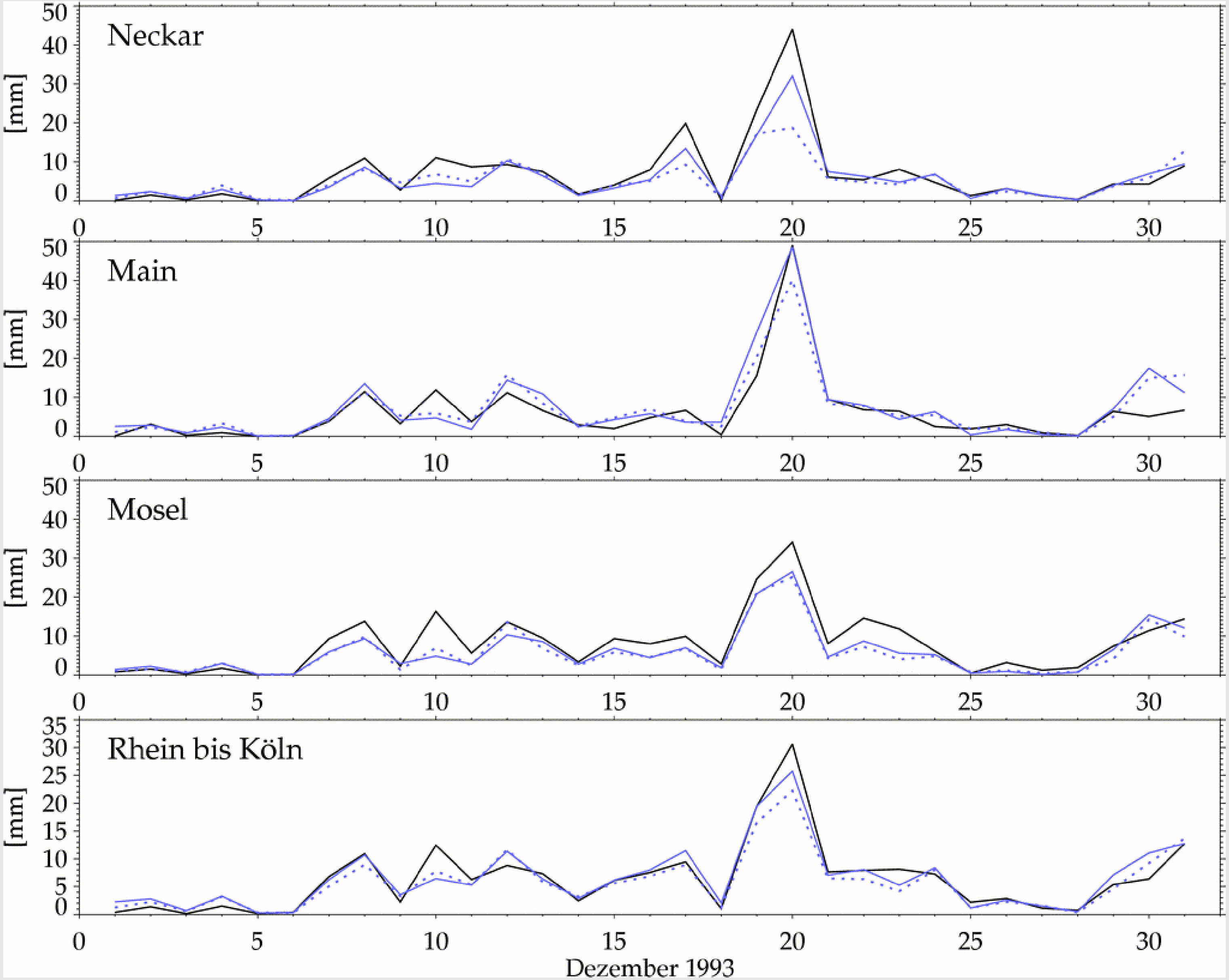
Runoff Frequency, **CTRL** vs. **OBS**

CHRM14 (solid)
CHRM56 (dashed)

5 winters (NDJ, 1989/90 – 1993/94) driven by CHRM14 and CHRM56



Flood December 1993, Daily Precipitation

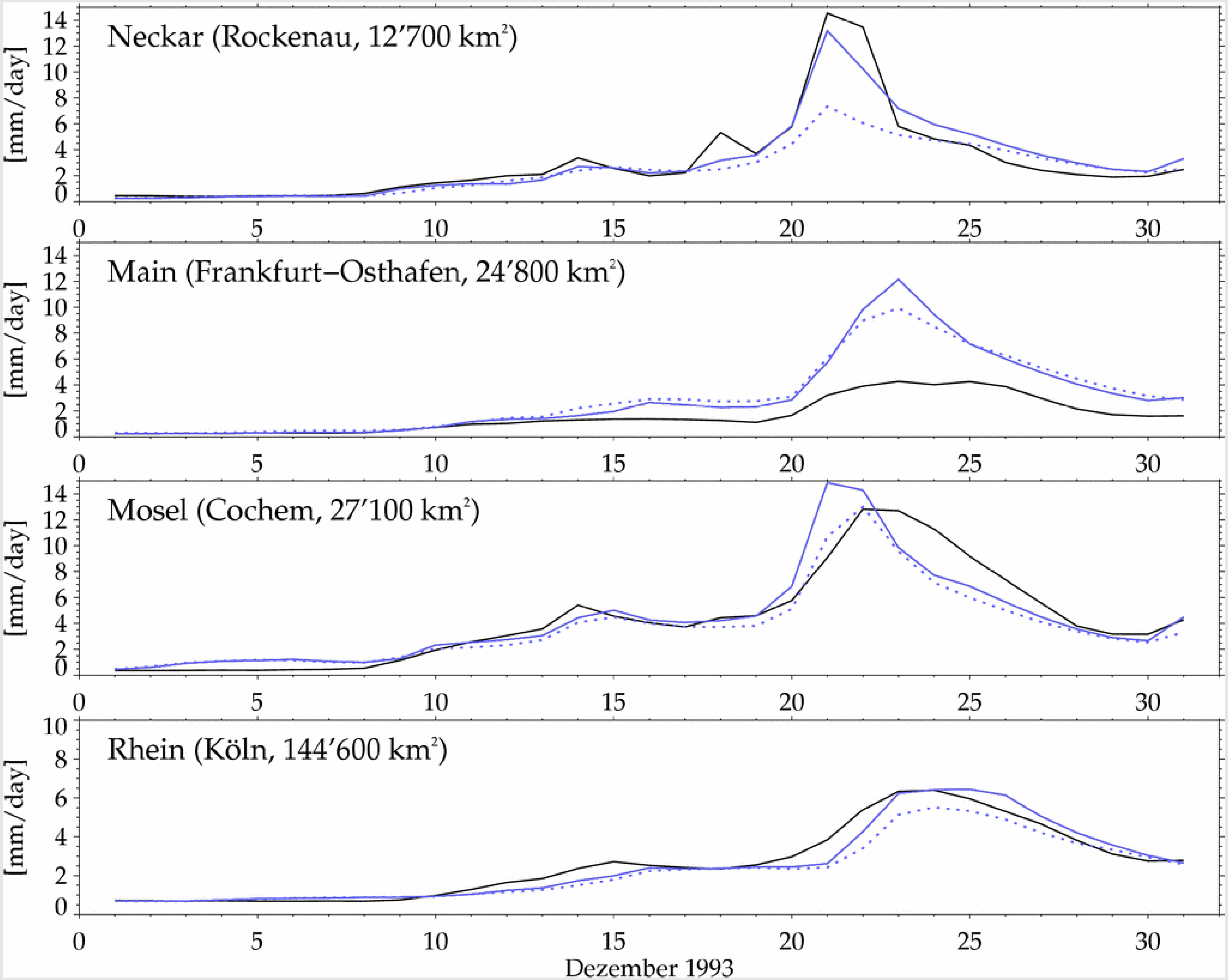


CHRM14 (solid)

CHRM56 (dashed)

OBS

Flood December 1993, Daily Runoff



CHRM14 (solid)

CHRM56 (dashed)

OBS

Sensitivity Analysis

- Uniform temperature increase in boundary fields (ECMWF Reanalysis) by 2 Kelvin (Schär et al. 1996)

- Constant relative humidity
  → ~15% increase in atmospheric moisture content

- Enables to study the sensitivity of the water cycle on a higher temperature

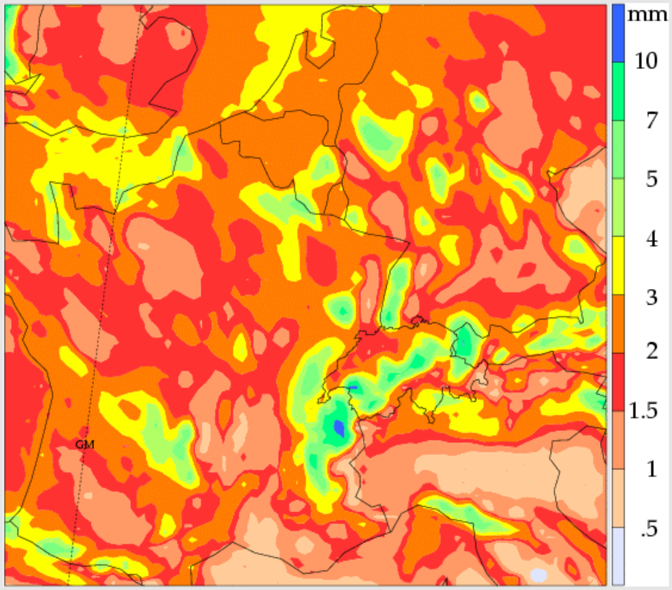
- **No climate change scenario**, changes in the synoptic climatology are not taken into account

- Applied by Frei et al. (1998)

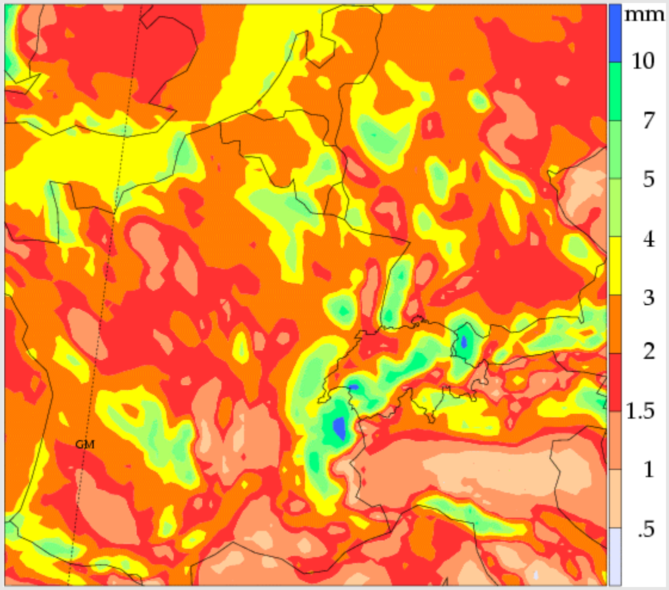
Precipitation in a warmer Climate

5 winters (NDJ, 1989/90 – 1993/94)

CTRL



WARM

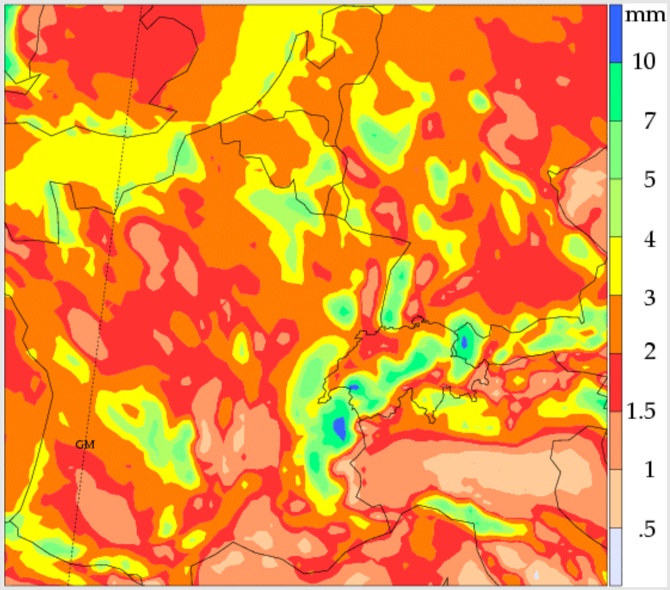


- Precipitation fields are very similar in WARM simulation

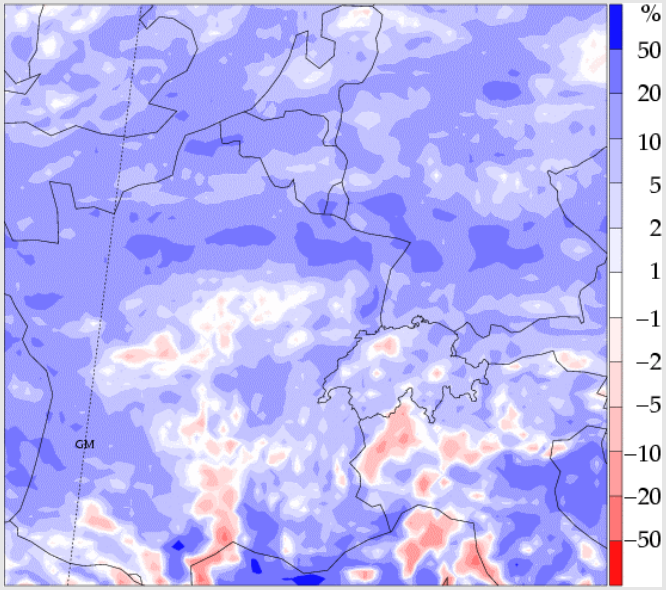
Precipitation in a warmer Climate

5 winters (NDJ, 1989/90 – 1993/94), difference in %

WARM



Total precipitation



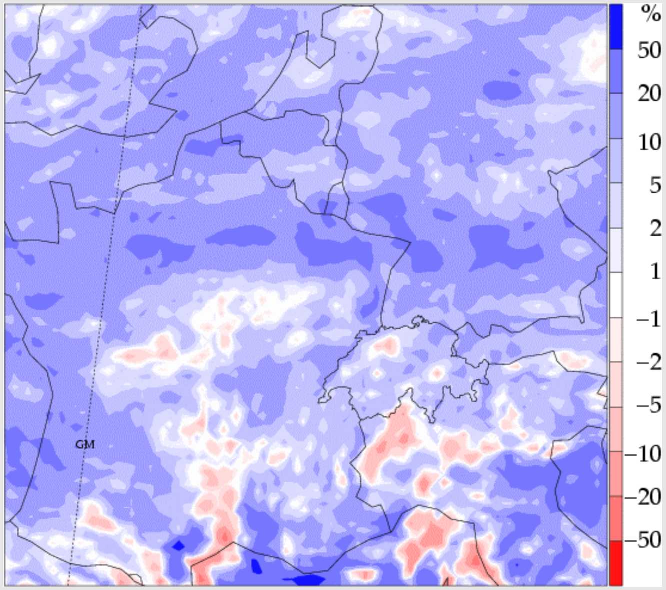
Aare	+ 7 %
Neckar	+ 17 %
Main	+ 10 %
Mosel	+ 14 %
Cologne	+ 11 %

- Increase in precipitation in most parts of Europe
- Slight decrease in precipitation south of the Alps, in the Swiss middle land, and in parts of France

Precipitation in a warmer Climate

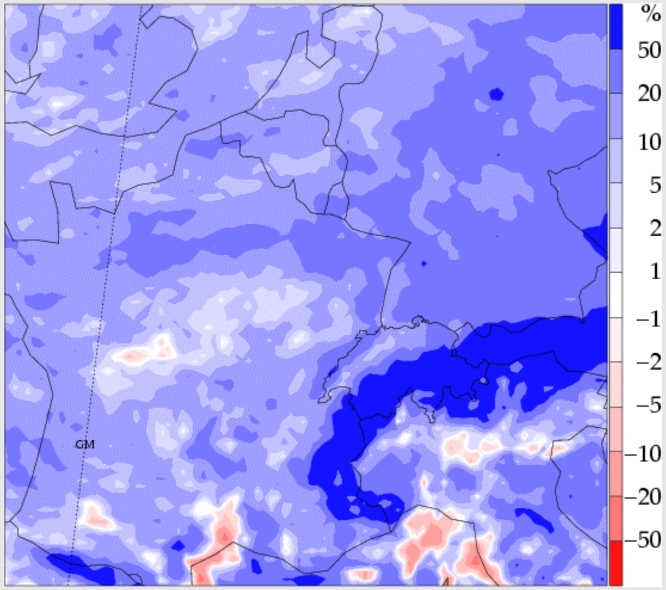
5 winters (NDJ, 1989/90 – 1993/94), difference in %

Total precipitation



Aare	+ 7 %
Neckar	+ 17 %
Main	+ 10 %
Mosel	+ 14 %
Cologne	+ 11 %

Liquid precipitation



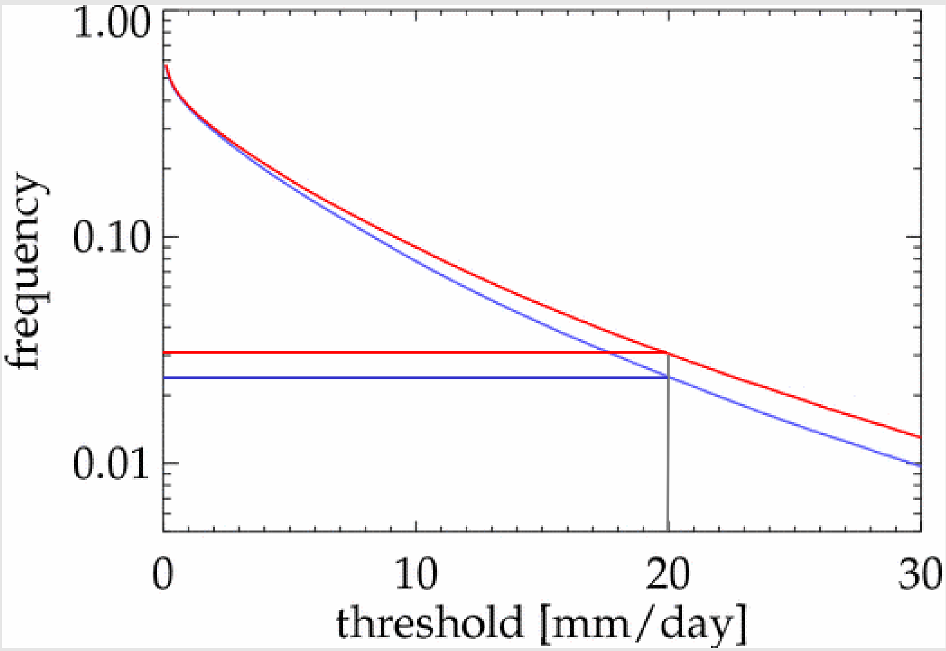
Aare	+ 40 %
Neckar	+ 28 %
Main	+ 21 %
Mosel	+ 21 %
Cologne	+ 26 %

- Increase in precipitation in most parts of Europe
- Strong increase in liquid precipitation

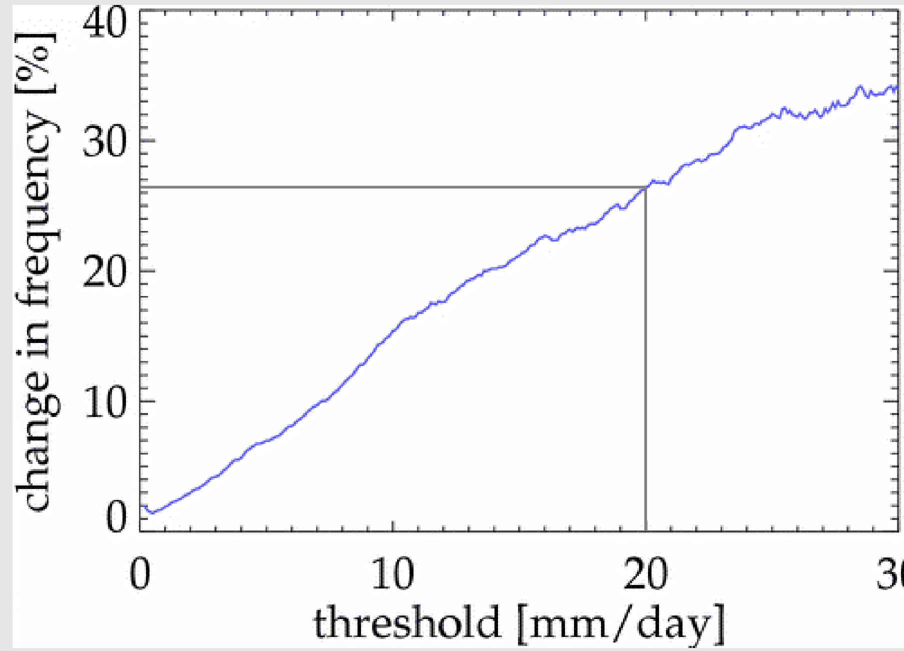
Precipitation Frequency in a warmer Climate

Rhine down to Cologne

WARM vs. **CTRL**

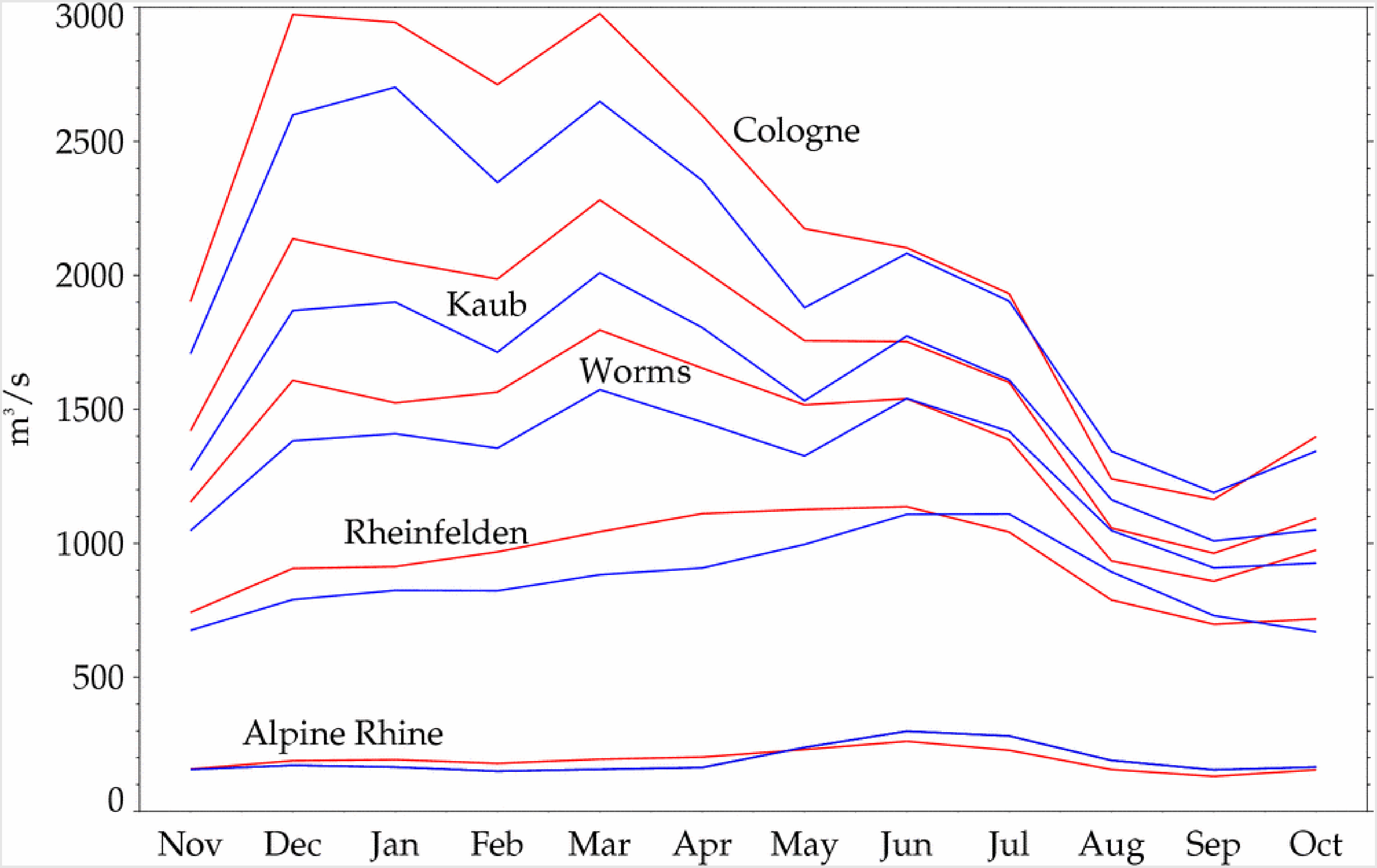


Increase in precipitation frequency



- Strong increase in the frequency of intense precipitation events
- Results agree with Frei et al. (1998)

Runoff Regime in a warmer Climate, **WARM** vs. **CTRL**

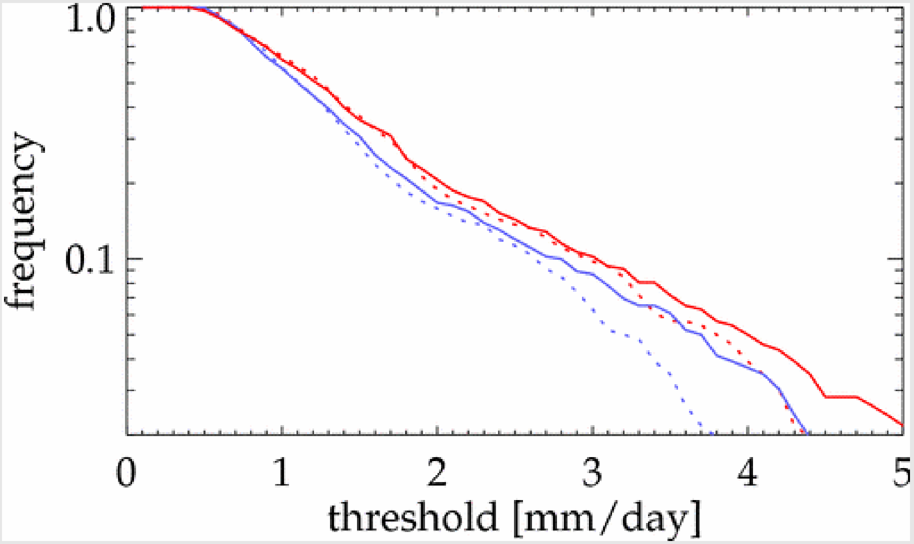


- Increase in winter discharge – decrease in summer discharge
- Attenuation of the yearly cycle in the Alps, amplification further downstream

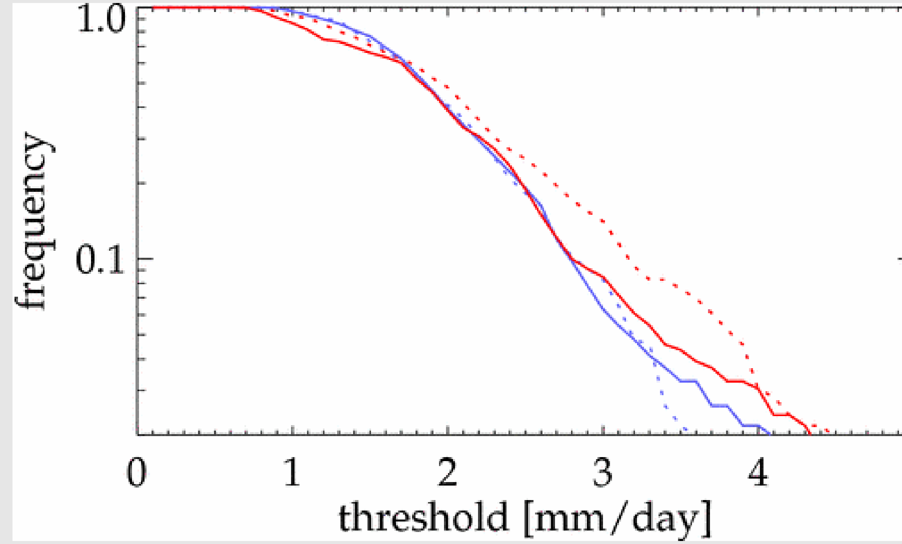
Runoff Frequency, WARM vs. CTRL

CHRM14 (solid)
CHRM56 (dashed)

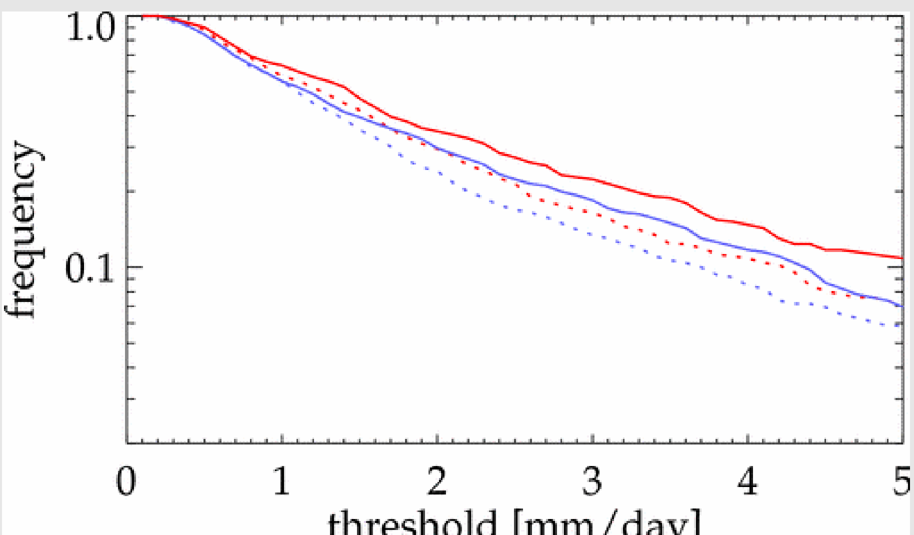
Rhine down to Cologne



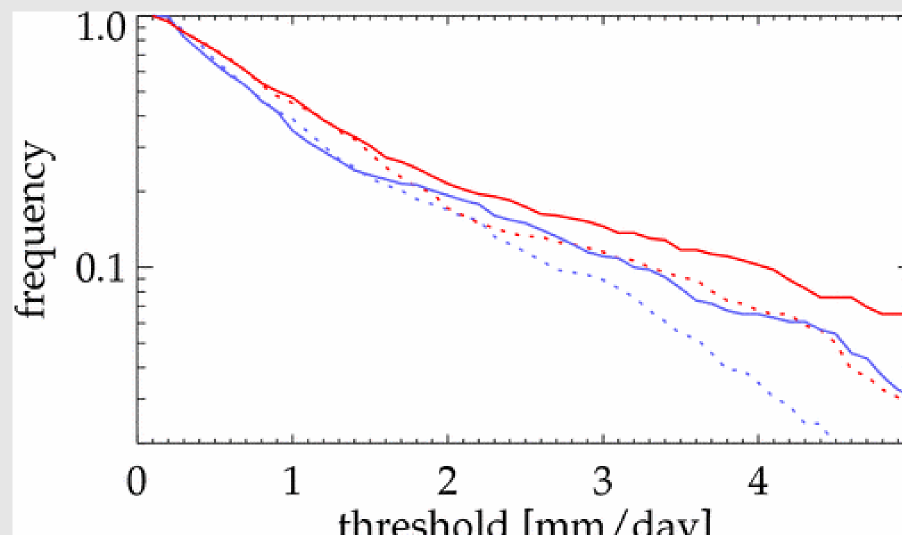
Aare



Mosel



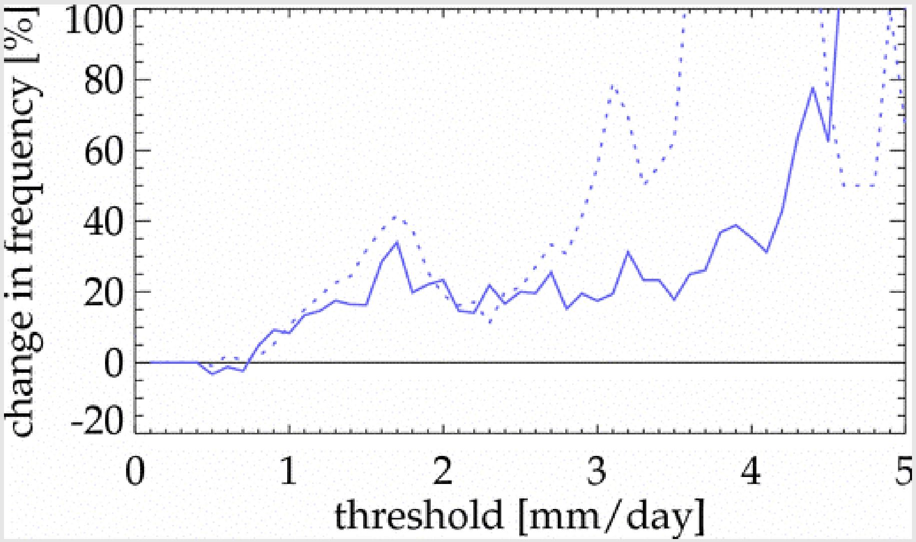
Neckar



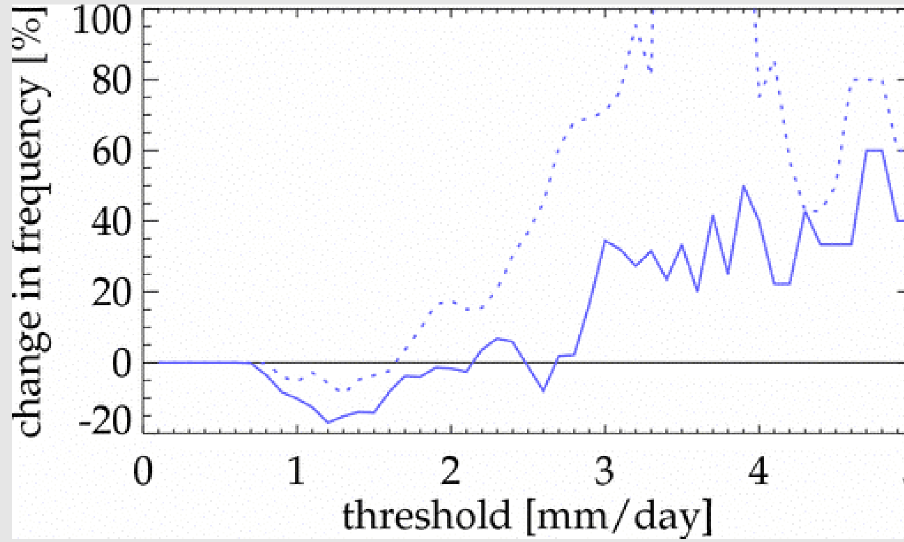
Runoff Frequency, difference **WARM** / **CTRL**

CHRM14 (solid)
CHRM56 (dashed)

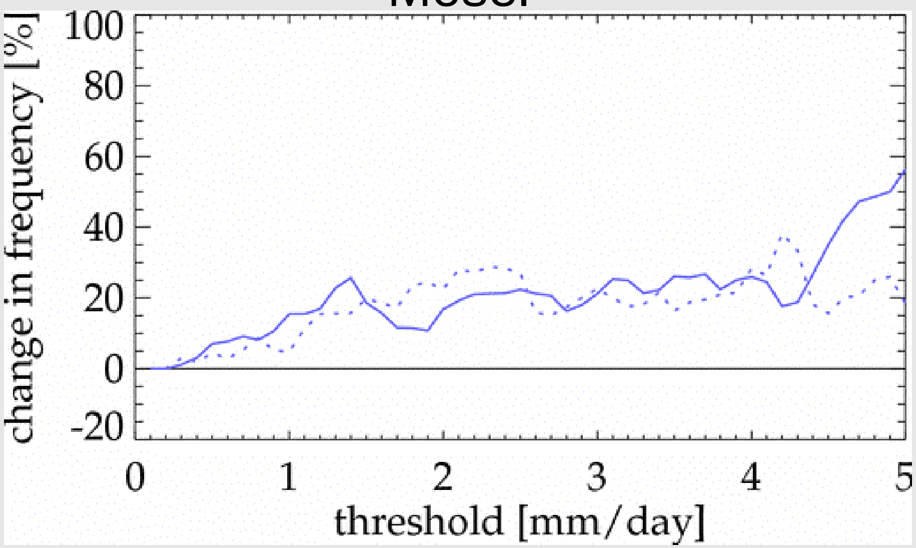
Rhine down to Cologne



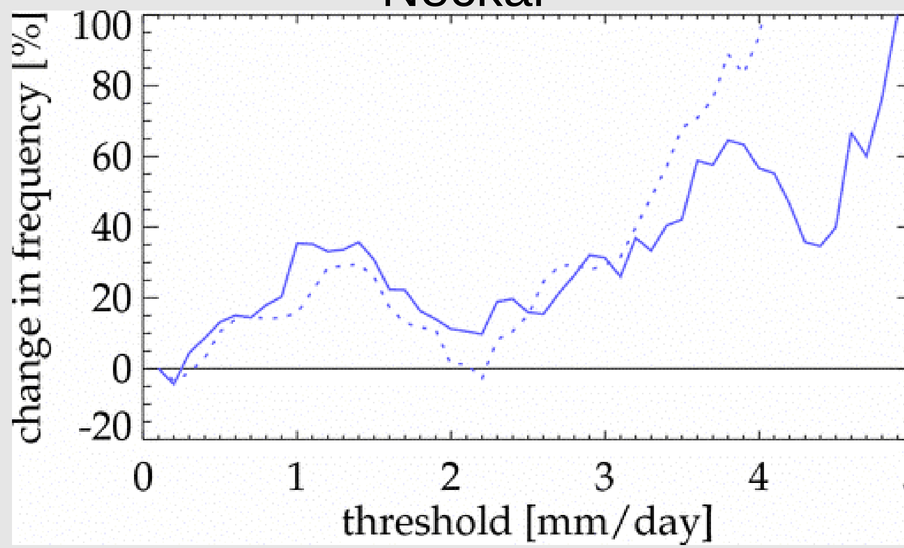
Aare



Mosel



Neckar



- Strong increase of intense runoff events: + 20% for events > 1 mm/day

Conclusions

- **Coupled climate - runoff modelling is a promising method to estimate the influence of a warmer climate on the hydrologic cycle**
  - good representation of the interannual variability, mesoscale spatial distribution, precipitation frequency
  - potential problems with small scale distribution of precipitation, precipitation – height relationship, and temperature
  - benefit from high resolution of climate model
- **Sensitivity of winter- time hydrology to a warmer climate:**
  - increase in precipitation (~10 % in Central Europe)
  - increase in heavy precipitation
  - more liquid precipitation, less snowfall
    - increase in winter-time discharge
    - increase in heavy runoff events

Outlook

- **Continuation within larger research projects**
  - Swiss Project NCCR Climate
  - EU-Project PRUDENCE

- **Longer simulations**
  - 15 years with CHRM56 driven by ERA15
  - 5 years with CHRM14 driven by CHRM56
  - CTRL and WARM with +2K

- **Simulations driven by GCMs**
  - 30 years with CHRM56 driven by time slice experiments
  - 5 years with CHRM14 driven by CHRM56
  - HadAM3 and ECHAM5
  - Current and future climate

- **Improvements in the model chain**

"All models are wrong, but some are useful."

C. Chatfield (1995)