# Monthly and Seasonal Forecasting of Rhine water-levels and streamflow based on hydrologic, atmospheric and oceanic data

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# Motivation

- 70 % of the German waterways are of international relevance.
- River Rhine is one of the most frequented inland waterways in the world.
- 240 million tons per year are carried by inland waterway transport (IWT).
- Strengthening of the inland waterway transport is necessary to handle the continuing transport growth economically and ecological sustainably.
- Low flows are the main hydrological impact on the reliability of IWT

| Country | Dry cargo fleet | | Tanker fleet | |
|---|---|---|---|---|
| | Units (no.) | Capacity (tonnes) | Units (no.) | Capacity (tonnes) |
| The Netherlands | 4,555 | 5,729,642 | 986 | 1,389,197 |
| Belgium | 1,102 | 1,502,987 | 228 | 342,169 |
| Luxemburg | 10 | 9,789 | 18 | 36,189 |
| Germany | 1,698 | 2,035,164 | 462 | 809,451 |
| France | 1,240 | 1,028,815 | 40 | 53,338 |
| Switzerland | 18 | 33,728 | 55 | 140,839 |
| Total | 8,623 | 10,340,125 | 1,789 | 2,771,183 |

*Source*: CCNR and European Commission (2011)

# Objectives

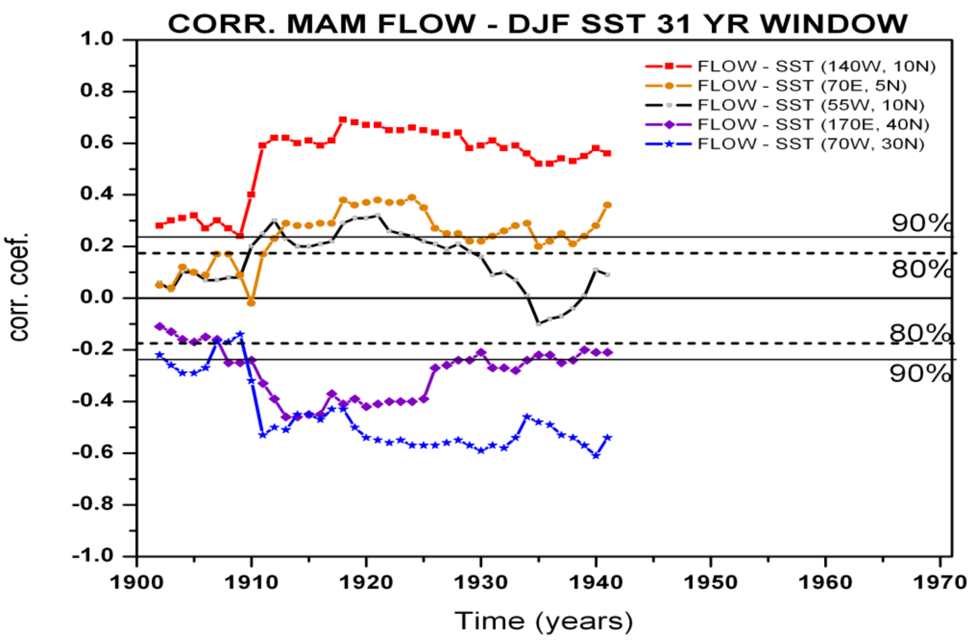
- To identify large scale predictors for monthly and seasonal streamflow (low flow, mean flow and high flow) and water levels for the Rhine, Elbe, Weser and Danube rivers
- To develop a statistical algorithm for the monthly and seasonal prediction
- To test if the proposed methodology can be used as an operational system for monthly and seasonal outlook

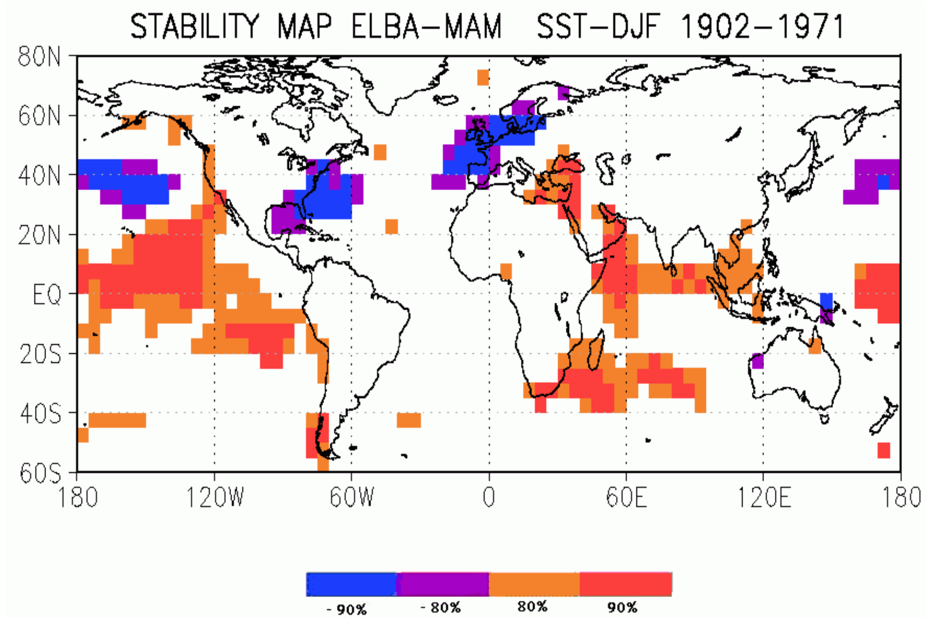
# Methodology I

- Detection of stable teleconnections: 21(31) – year window correlation between streamflow (NM7Q, MQ and HQ) and large scale factors (e.g Sea Surface Temperature (SST), Temperature over land (TT), precipitation (PP)) → Stability map
- Define SST, TT, PP, SLP, RH,etc indices based on stability maps.
- EOF analysis of the indices.
- Comparison between PC1 and flow anomalies.
- Apply multiple regression to the indices identified based on the stability maps
  - Choose the optimal predictors based on stepwise and backward regression

# Methodology II - Stability criteria

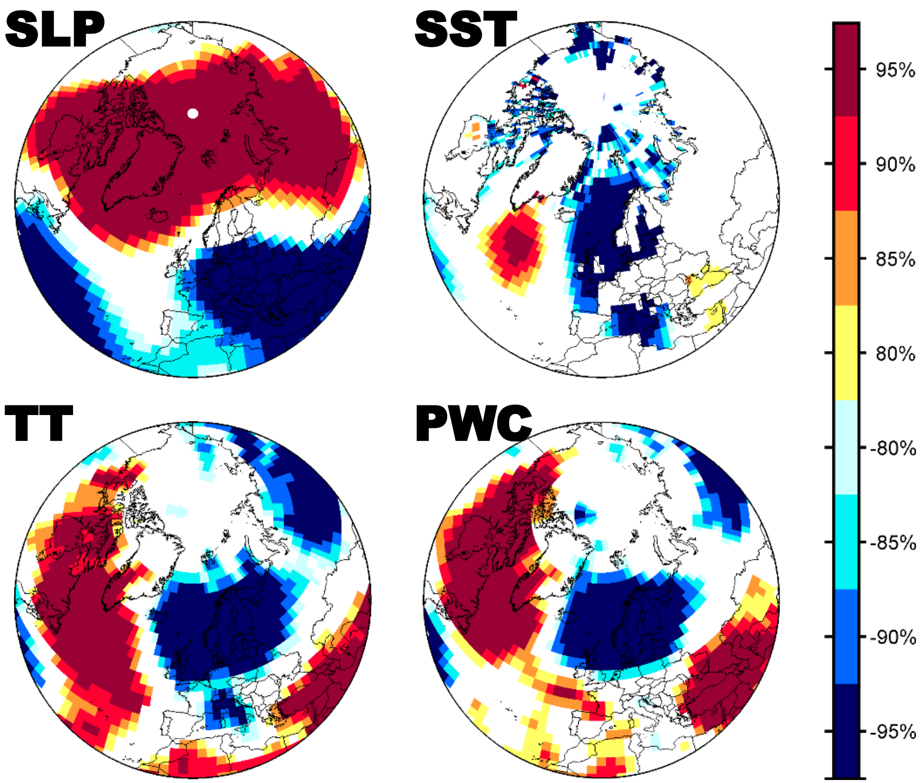
- more than 80% of the 31-yr windows are above 90% level (r = 0.24) - STABLE
- more than 80% of the 31-yr windows are above 80% level (r= 0.17) - STABLE
- more than 80% of the 31-yr windows are above 90% level (r = -0.24) – STABLE
- more than 80% of the 31-yr windows are above 80% level (r= -0.17) – STABLE
- less than 80% of the 31-yr windows are correlated - UNSTABLE



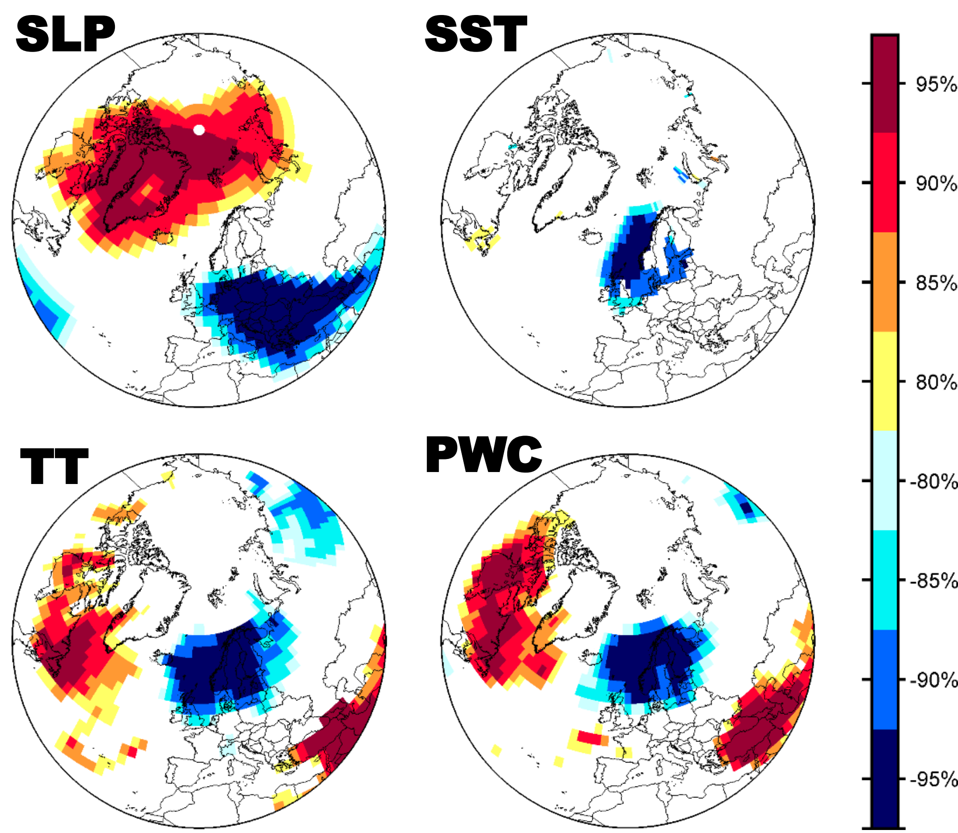
# Non-stationarity issues

„Normal“ Correlation




Rhine MAM – Climate Variables DJF

„Stable“ Correlation




SLP – Sea Level Pressure
SST – Sea Surface Temperature
TT - Air Temperature
PWC – Precipitable Water Content

# Data

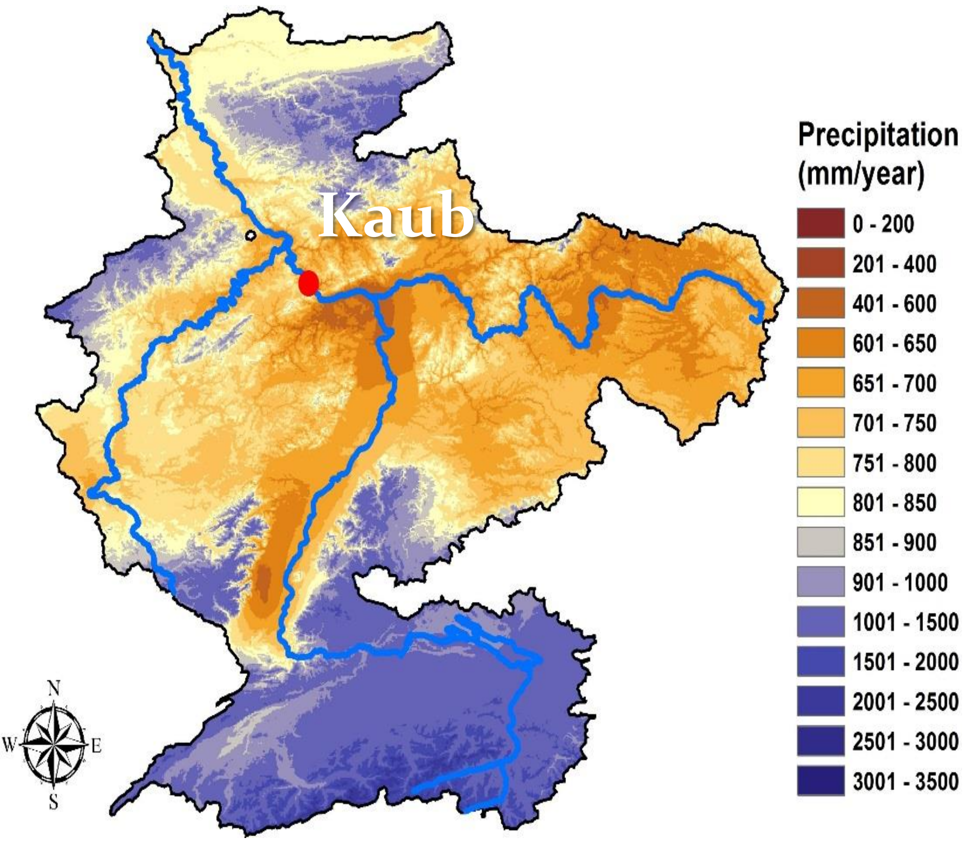
- **Monthly/daily streamflow data (NM7Q, MQ and HQ) measured at Neu Darchau (Elbe)  and Kaub (Rhine), provided by Bfg.**

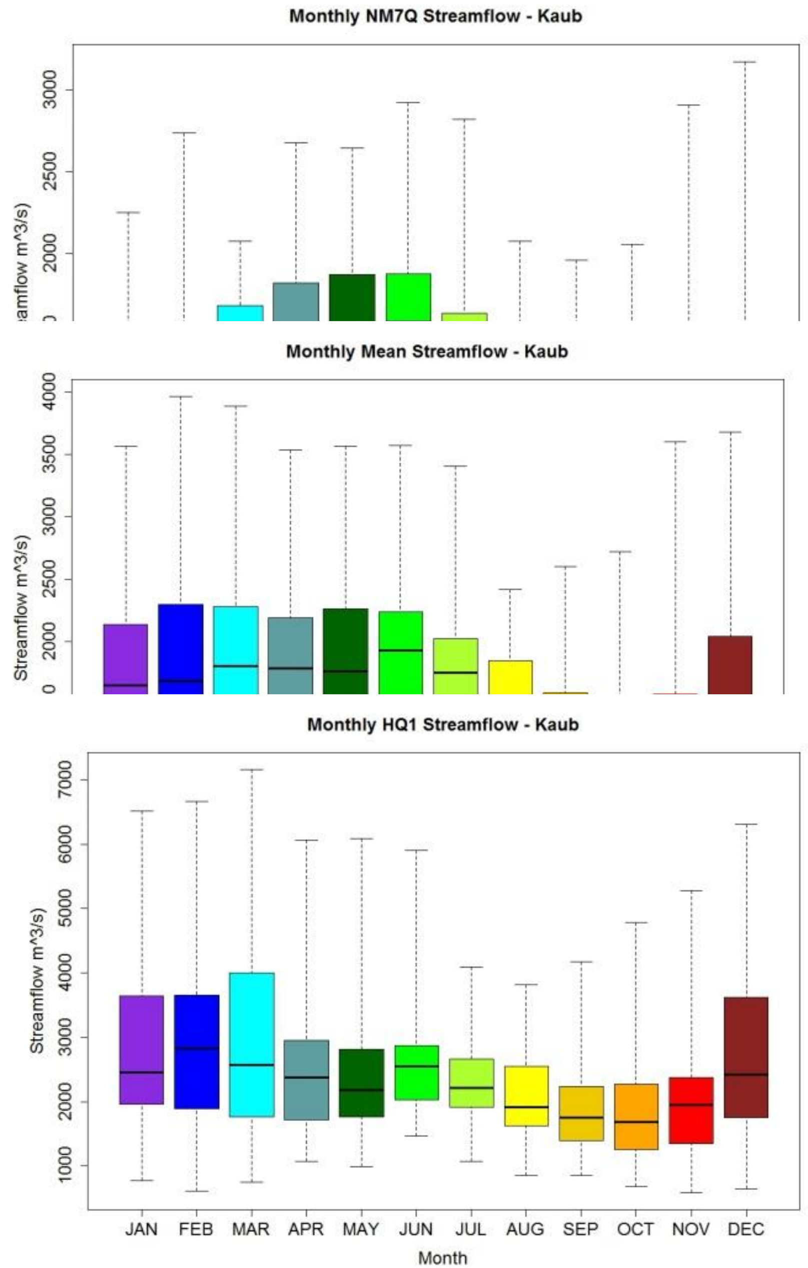
- **ERSST v4b (2°x2°) (1948-2017) (Smith and Reynolds, 2003)**

- **Precipitation (PP) and temperature (TT) data from the German Weather Service (DWD) (5km x 5km) (1948-2017).**

- **Sea level pressure (SLP), Geopotential Height, Relative Humidity, Soil Moisture, Ground Temperature, data (2.5 º x 2.5 º) covering the period 1948-2015 from NCEP/NCAR data base  (Compo et al., 2011).**

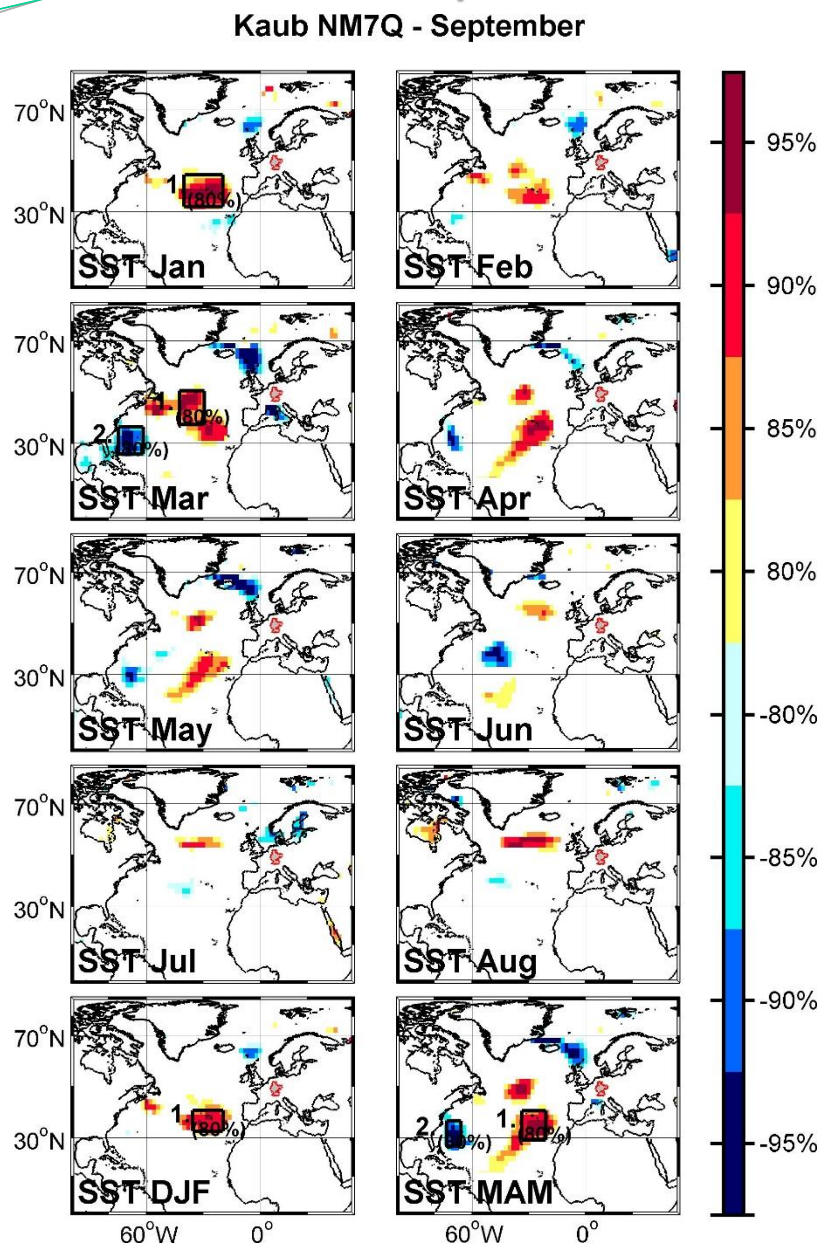
# Case study: Rhine River



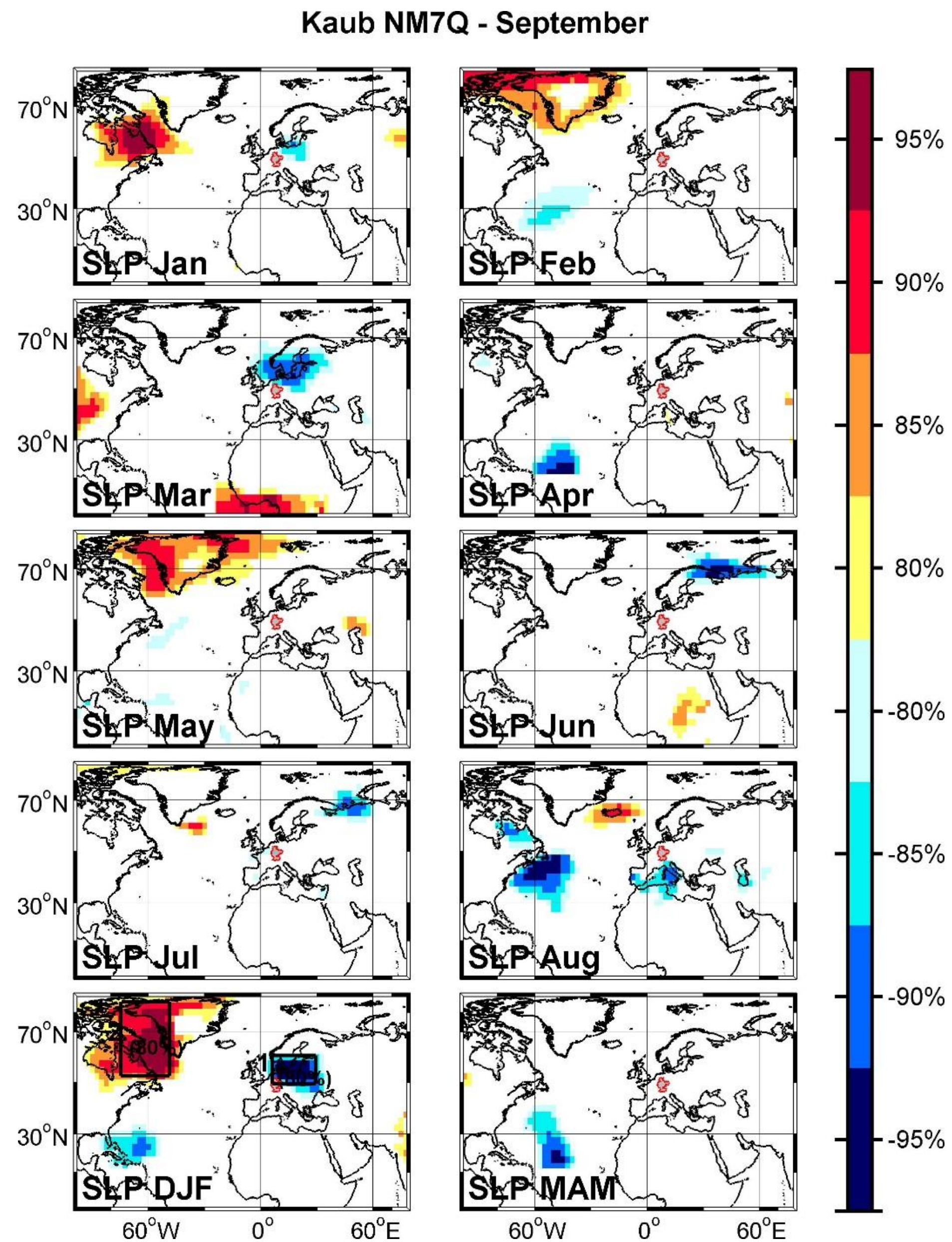



# Monthly Low Flow (NM7Q) - September

## Sea Surface Temperature

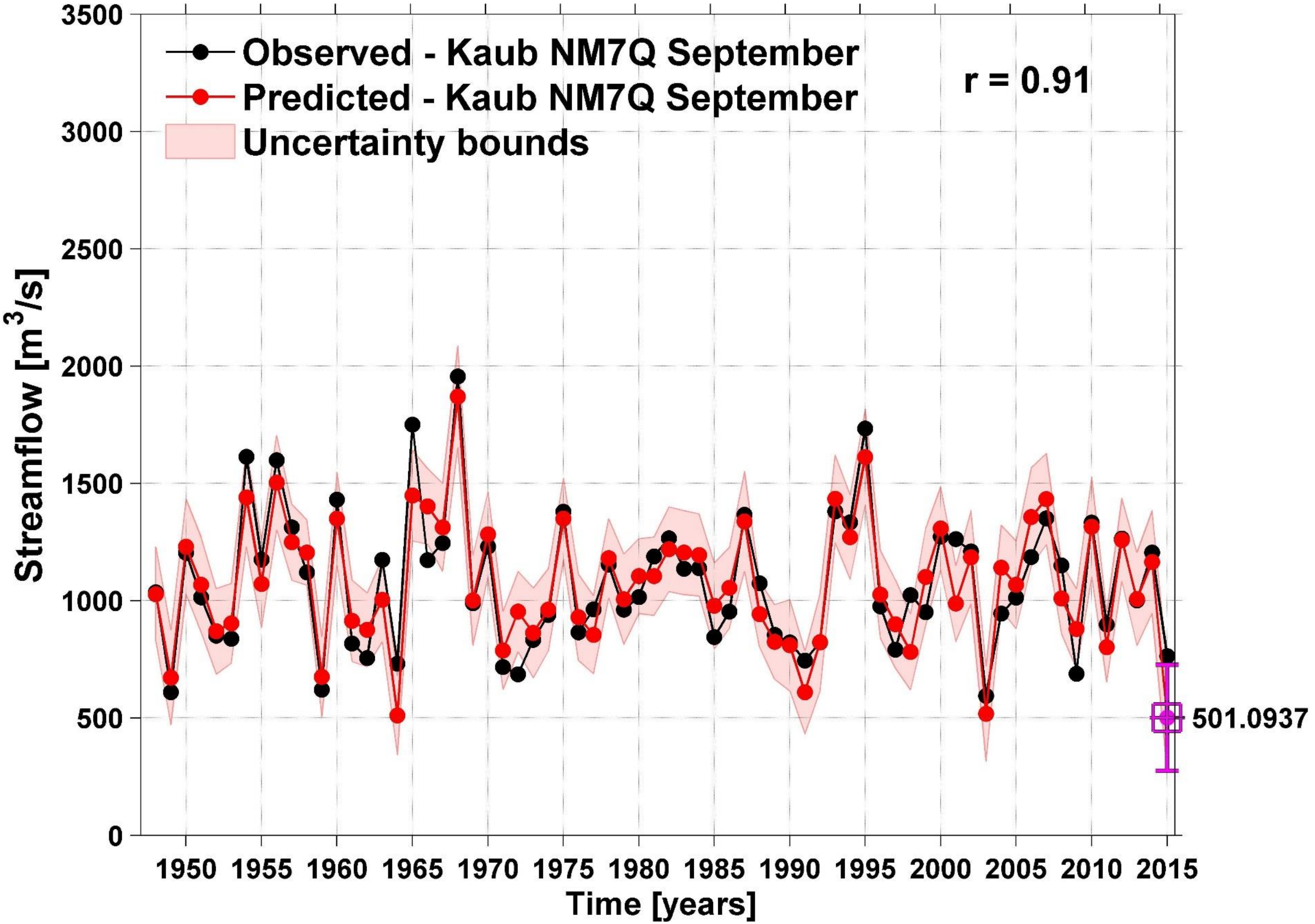



## Sea Level Pressure

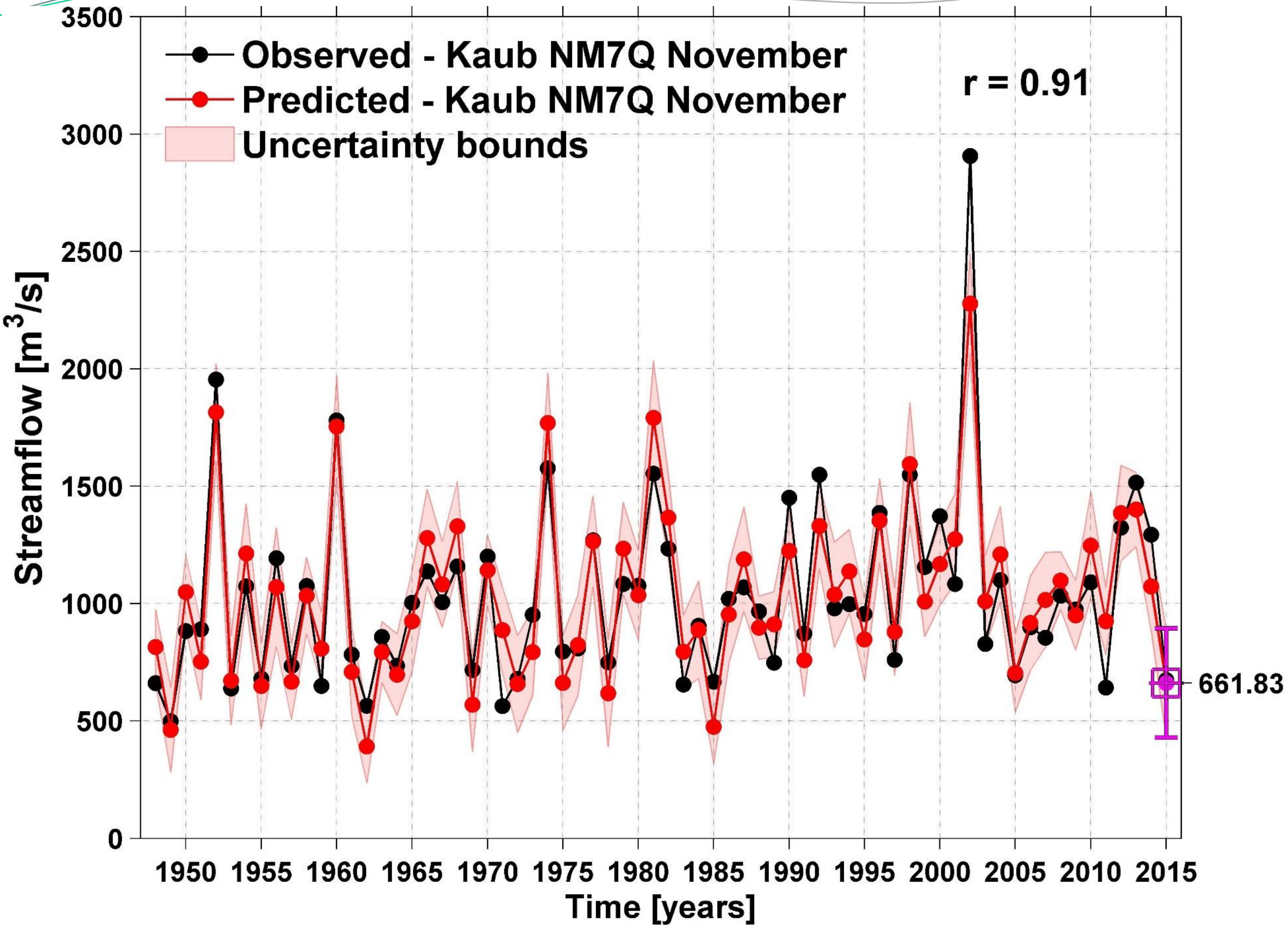


# NM7Q Kaub - September

**Final predictors: precipitation, temperature, soil moisture, SST, SLP, Z700 and U700**

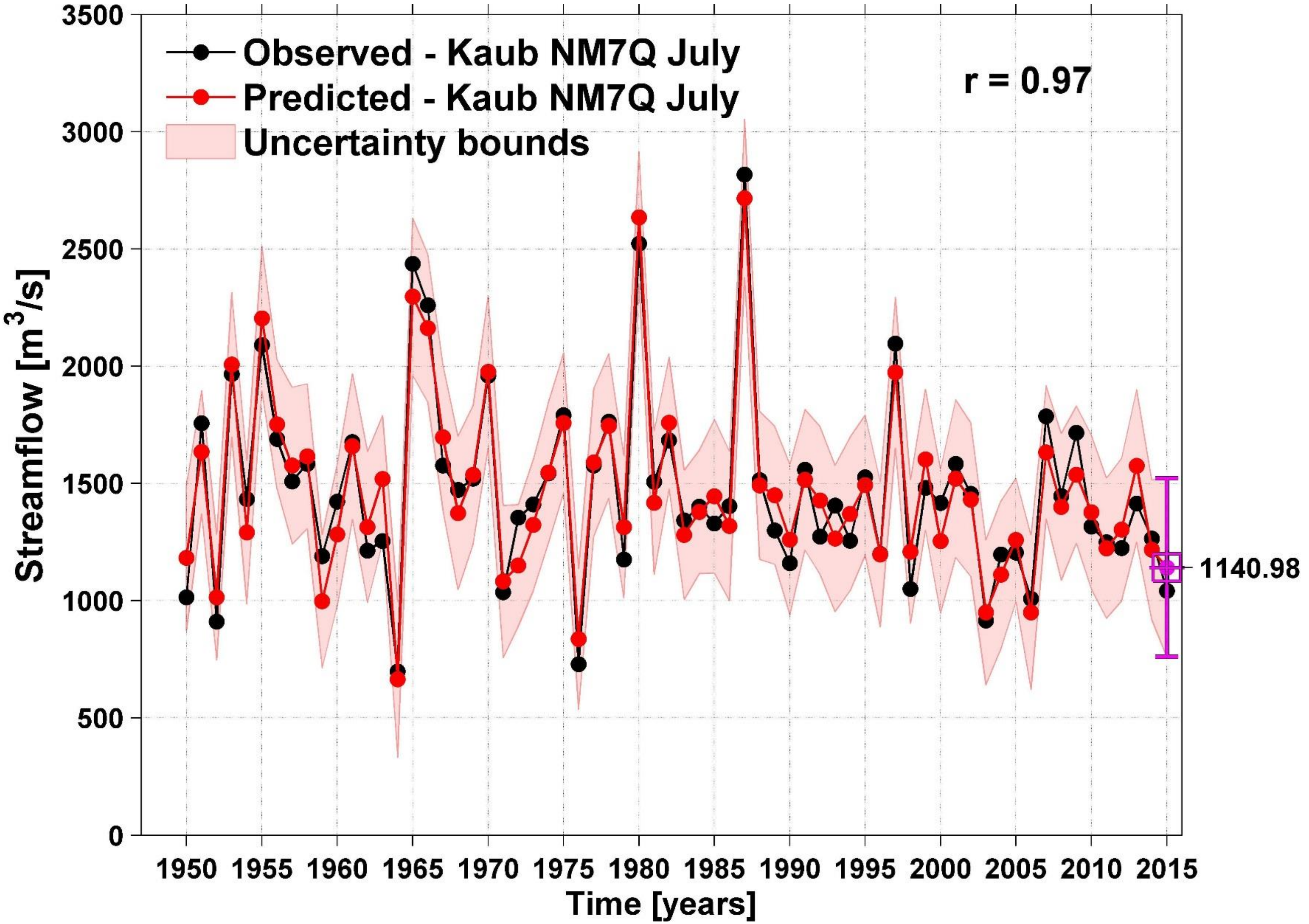


# NM7Q Kaub - November



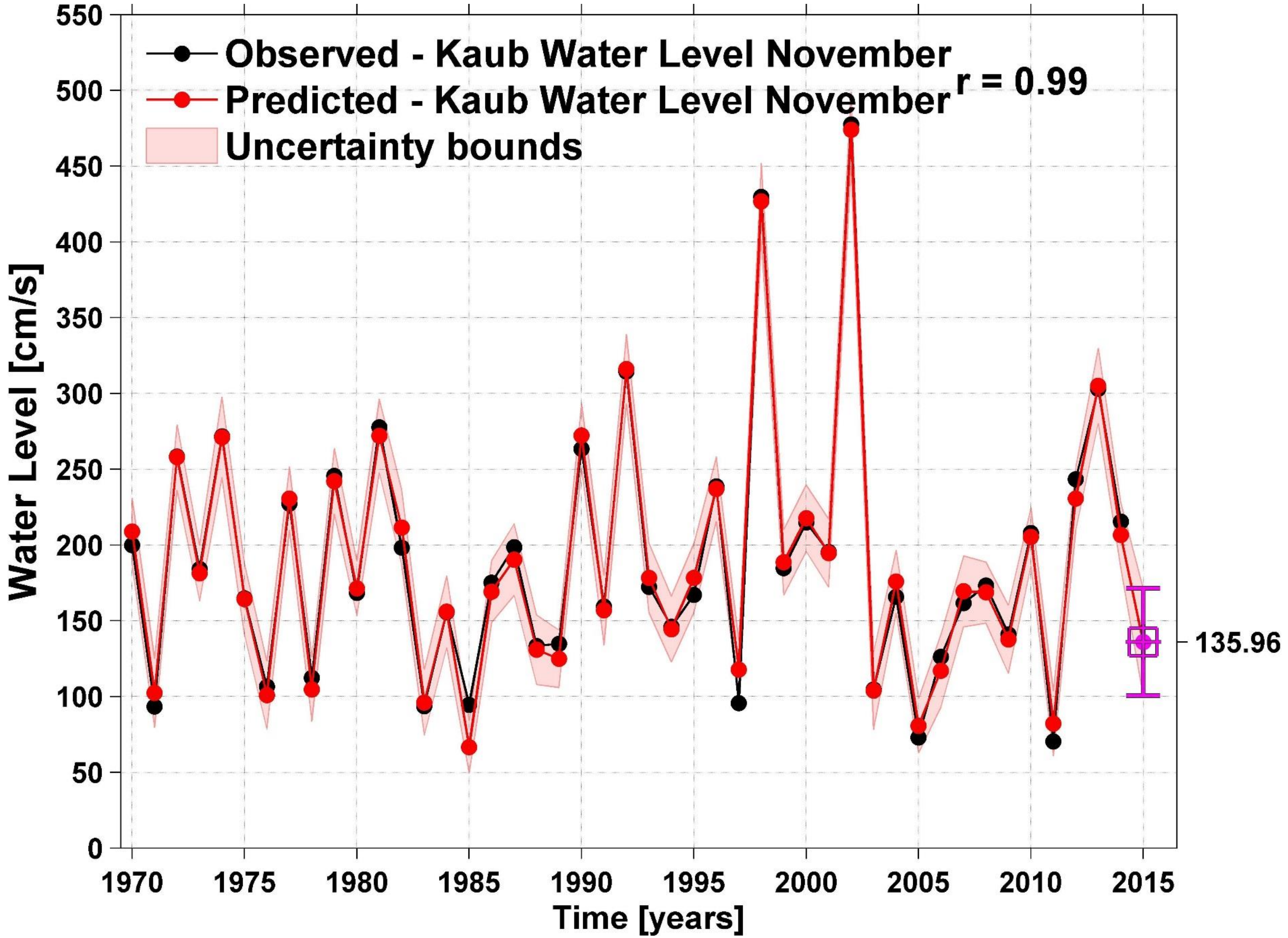
# Monthly Low Flow (NM7Q) - July

**Final predictors: precipitation, temperature, soil moisture, SST, SLP, Z700 and U700**

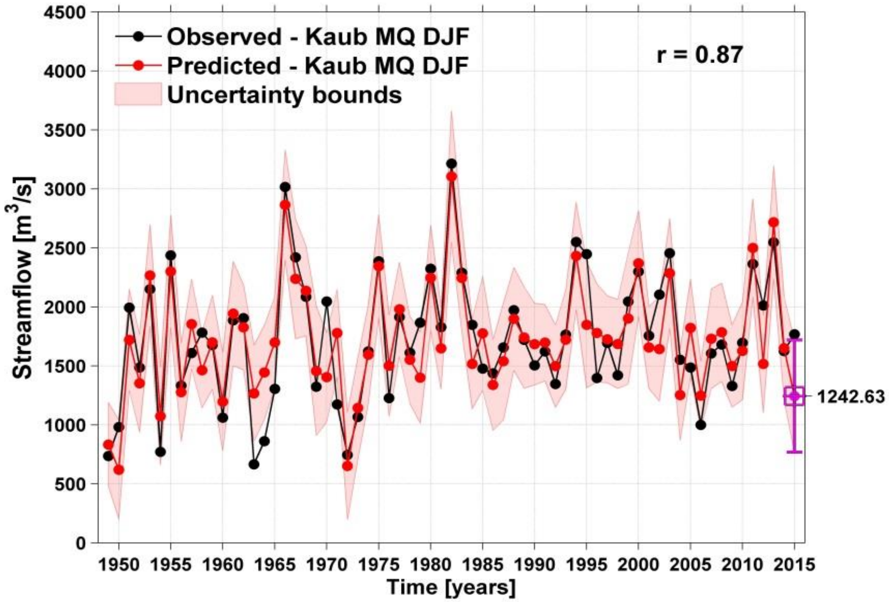


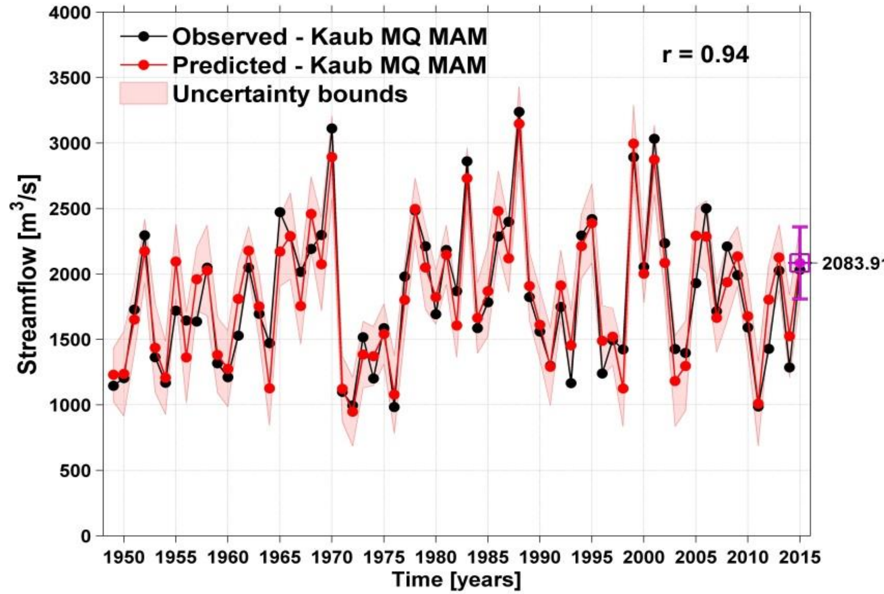
# Monthly water levels – Kaub October

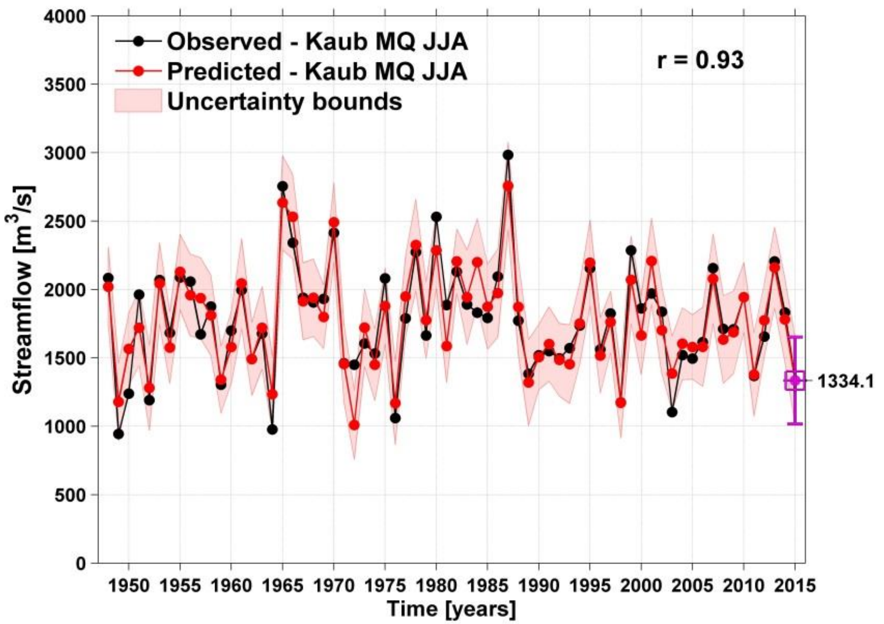
**Final predictors: precipitation, temperature, SST, SLP, zonal wind, meridional wind**

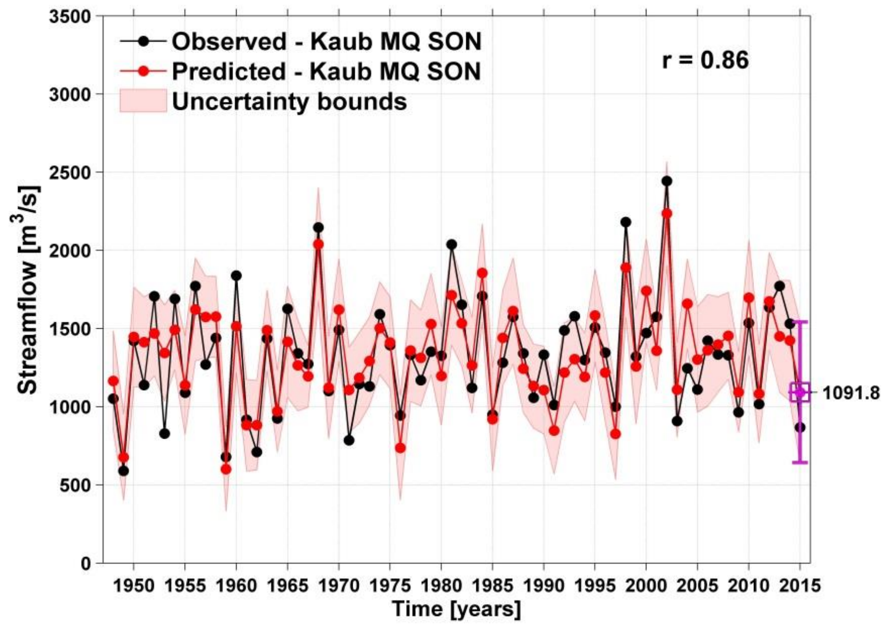


# Seasonal forecast MQ – Kaub



# Model evaluation

## NM7Q

| | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hit | 57 | 62 | 63 | 55 | 61 | 40 | 66 | 38 | 57 | 51 | 54 | 63 |
| Miss | 9 | 4 | 3 | 11 | 5 | 26 | 0 | 28 | 9 | 15 | 12 | 3 |
| Hit % | 86 | 94 | 95 | 83 | 92 | 61 | 100 | 58 | 86 | 77 | 82 | 95 |
| Miss % | 14 | 6 | 5 | 17 | 8 | 39 | 0 | 42 | 14 | 23 | 18 | 5 |

## MQ

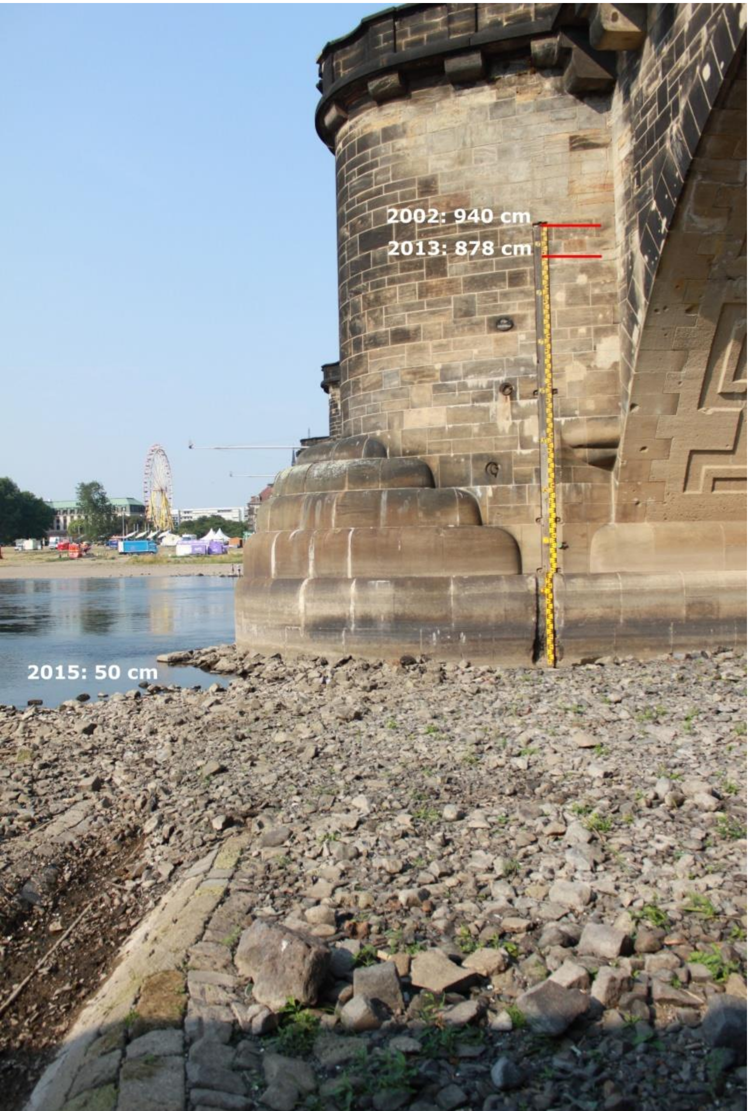
| | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hit | 62 | 54 | 61 | 58 | 64 | 38 | 57 | 49 | 61 | 60 | 51 | 46 |
| Miss | 5 | 13 | 6 | 9 | 4 | 30 | 11 | 19 | 7 | 8 | 17 | 22 |
| Hit % | 93 | 81 | 91 | 87 | 94 | 56 | 84 | 72 | 90 | 88 | 75 | 68 |
| Miss % | 7 | 19 | 9 | 13 | 6 | 44 | 16 | 28 | 10 | 12 | 25 | 32 |

## Seasonal

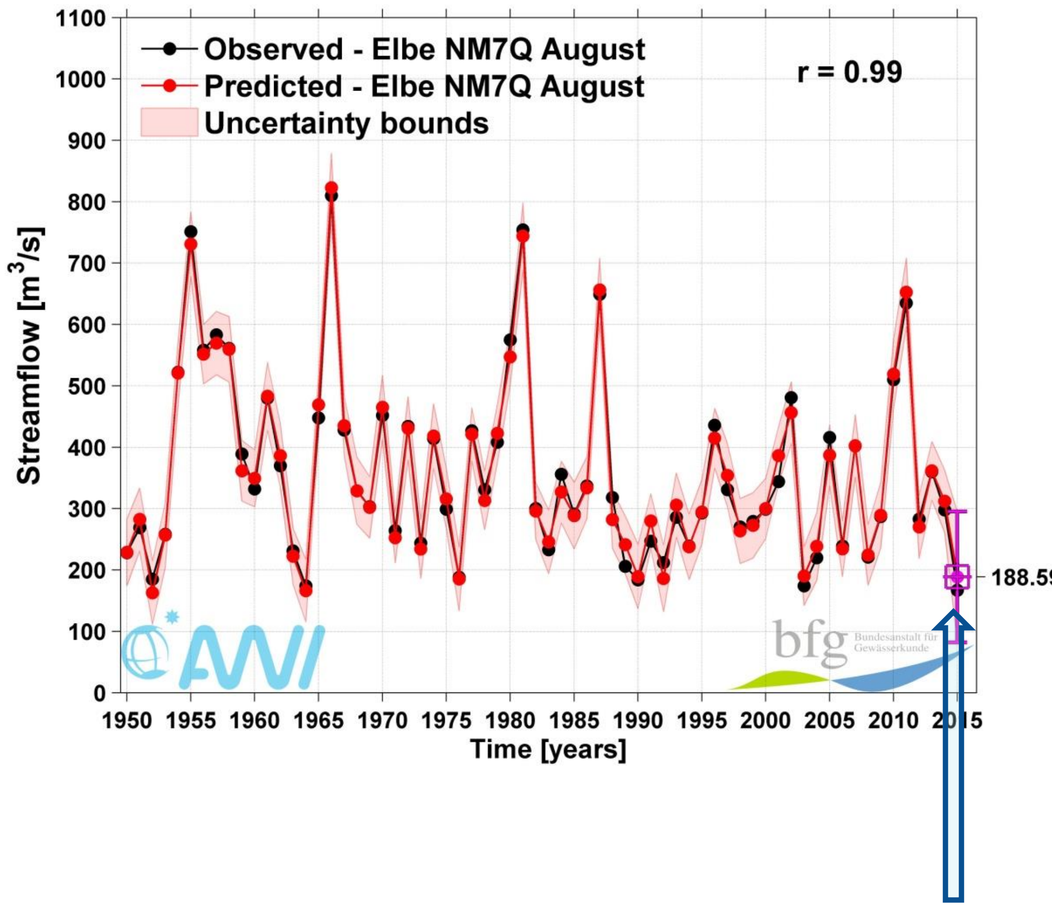
| | DJF | MAM | JJA | SON |
|---|---|---|---|---|
| Hit | 57 | 56 | 63 | 61 |
| Miss | 10 | 11 | 5 | 7 |
| Hit % | 85 | 84 | 93 | 90 |
| Miss % | 15 | 16 | 7 | 10 |

# Transferability of the method – Elbe River

**Final predictors: precipitation, temperature, SST, SLP, zonal wind, meridional wind**




**Source: Andy Philipp**




**July 2015**

# Advantages of this methodology

- It is inexpensive in terms of computationally and human resources.
- It does not require the use of a hydrological model, which is mostly not freely available and has high computational costs.
- It does not require the access to operational ensemble forecast data, like most of the available flood prediction products.
- It deals, at least partially, with the issues of stationary/non-stationary relationship between two variables.

# Perspectives

## Apply the same methodology to:

- Drought indices (e.g Standardize Precipitation Index, Standardized Streamflow Index)
- Seasonal/annual minimum
- Smaller catchments

## Possible improvements:

- Use observed/measured soil moisture
- Include snow cover (when and where available) to improve the potential predictability of winter and spring months

**BfG is developing monthly to seasonal forecast products for the German waterways based on this statistical approach as well as hydrological and climatological model-based methods investigated in-house.**

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Thank you!