CLIMATE CHANGE IMPACT ON HYDROLOGICAL EXTREMES

# The influence of HBV model parameters nonstationarity on flow predictions for future climate; Nysa Klodzka case study

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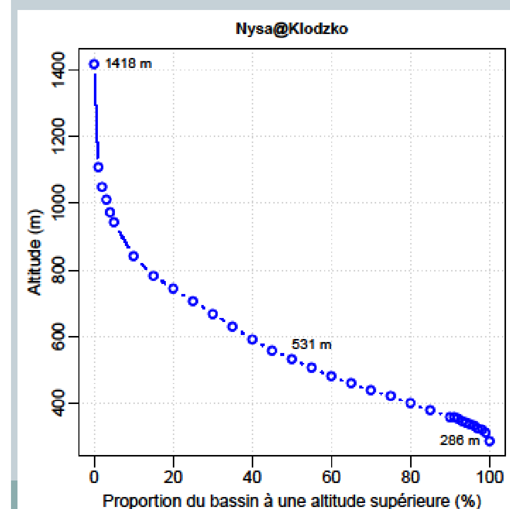
# Outline

- Case study – Nysa Klodzka
- Methodology
  - Calibration and validation HBV model
  - Sensitivity analysis - Model simplification
  - Regression models - Dependence of model parameters on climate characteristics
  - Flow and flood quantiles predictions in future climate
- Results
- Conclusions

# Nysa Klodzka case study

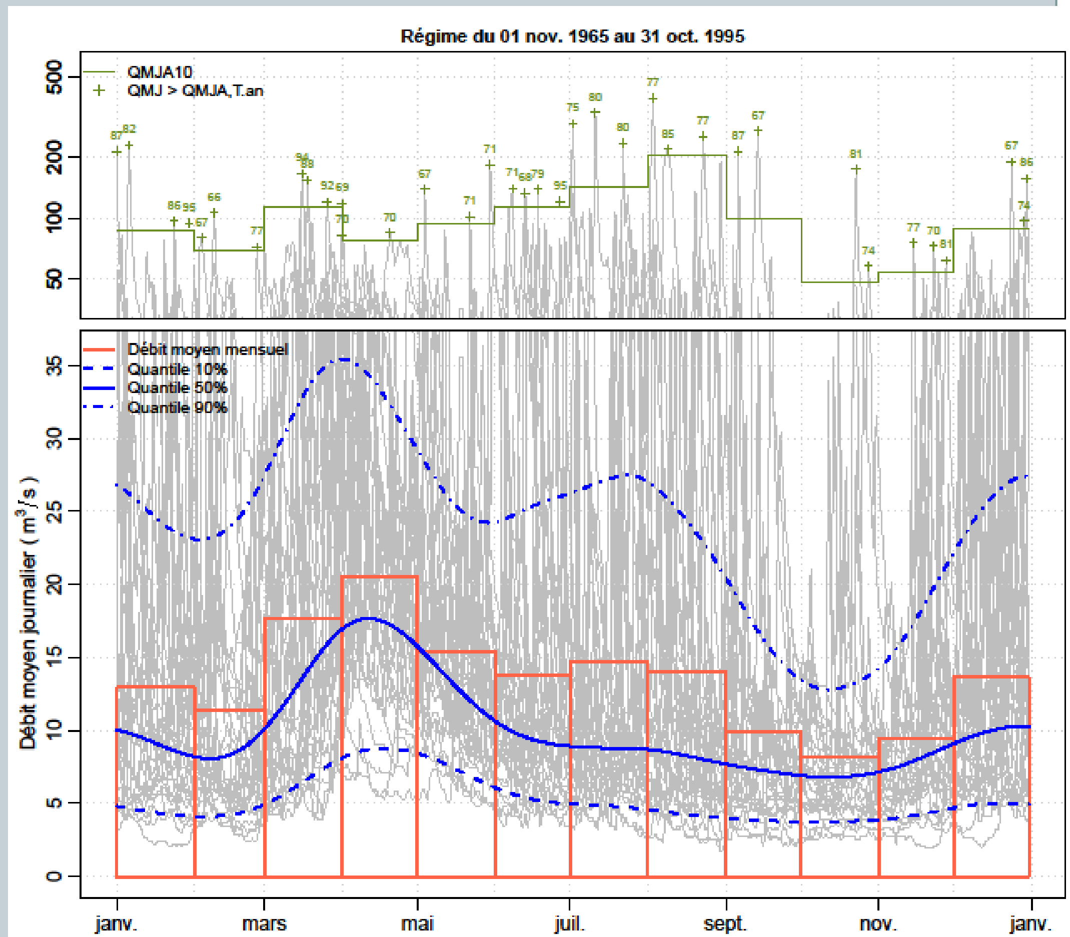
- Located in southern part of Poland
- Catchment area 1083 km² up to Klodzko gauging station
- Typical mountainous catchment with a bottom slope about 1%, zmin=286, z50=531, zmax=1418
- This catchment has been affected by several devastating floods e.g. in 1967, 1975, 1977, 1980, 1982, 1985, 1997, 1998, 2006 and 2009.





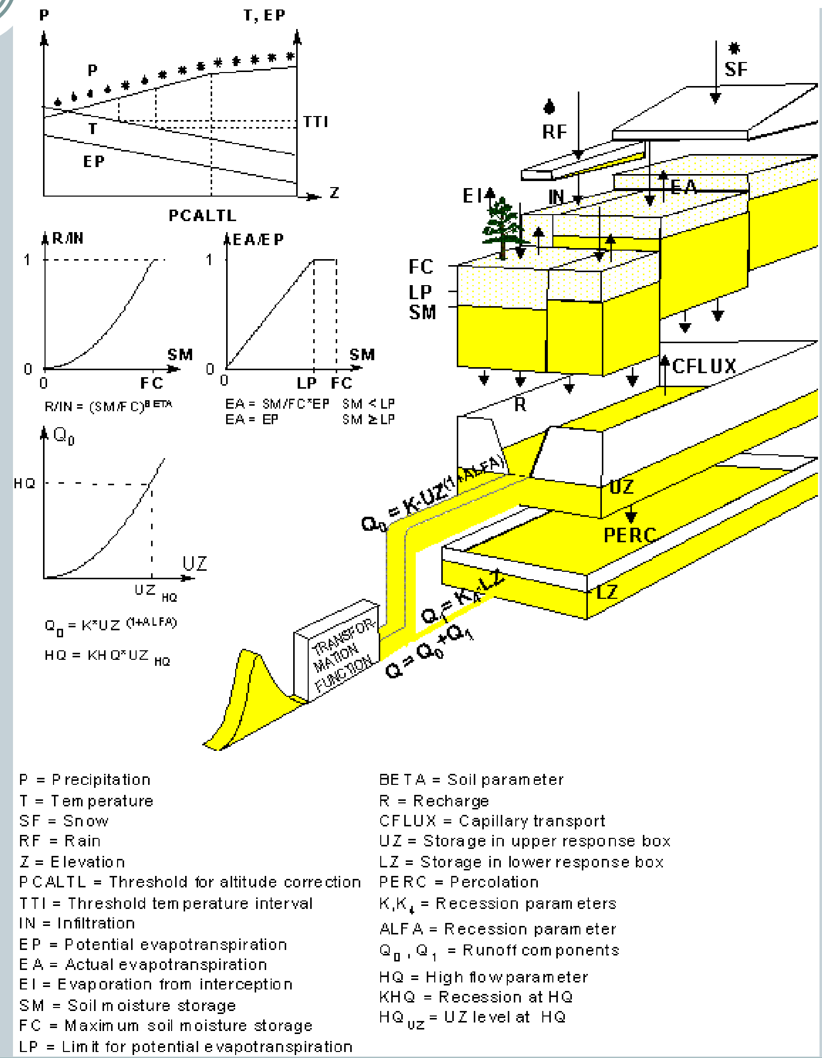
# Nysa Klodzka flow regime

- Available data from 01/11/1965 to 31/10/2010
- Flow regime - mixed
  - Spring floods due to snowmelt
  - Summer floods due to convective rainfall
- Natural flow conditions without significant changes in land use and water management



# Methodology: R-R model

- Nordic version of HBV model
- Conceptual lumped rainfall-runoff model with 15 parameters
- Inputs: precipitation, air temperature and discharges at daily time step
- Optimization method – DEGL Differential Evolution with Global and Local neighbours
- Problems with calibration for long time series
- Model calibration for five consecutive year periods, moving window



# Calibration/validation

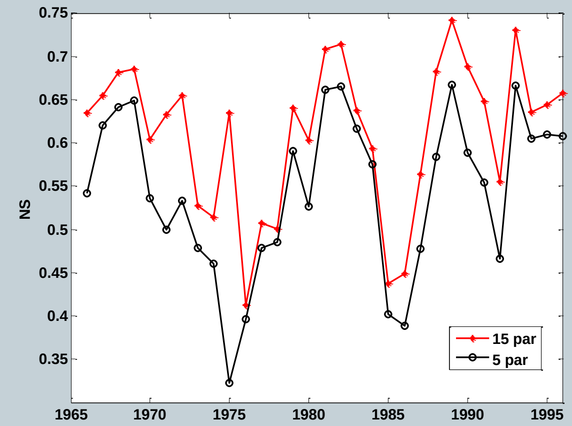
- Results of optimization – 5 year period
- Nash Sutcliffe criterion –three periods with NS>0.7

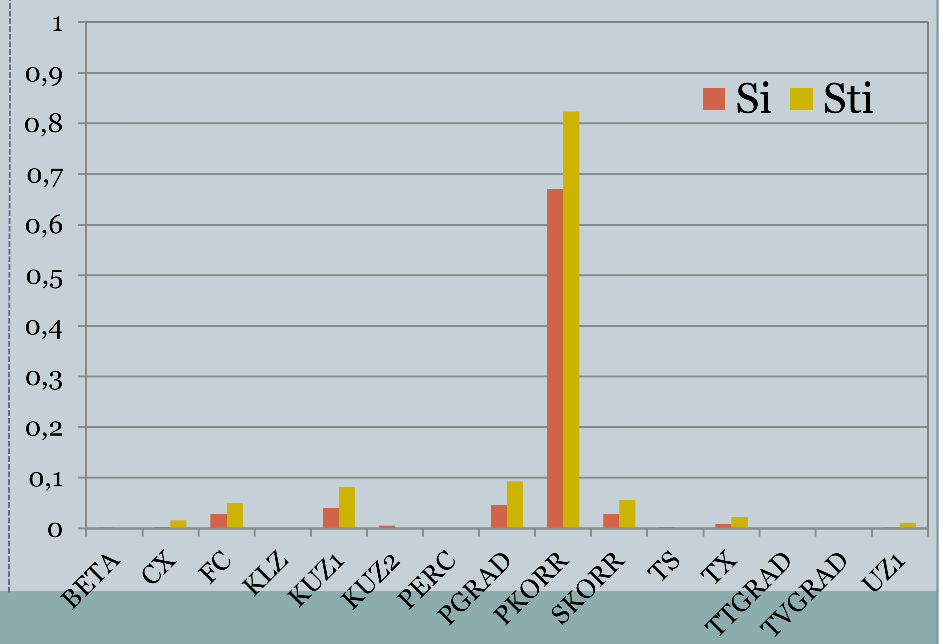
validation

| | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | 0.63 | 0.53 | 0.44 | 0.53 | 0.21 | -0.04 | 0.28 | 0.04 | 0.21 | 0.63 | 0.40 | 0.43 | 0.49 | 0.04 | 0.14 | 0.46 | 0.33 | 0.49 | 0.45 | 0.30 | 0.34 | -0.44 | 0.16 | 0.28 | 0.13 | -0.20 | 0.04 | -0.49 | 0.14 | 0.16 | -0.66 |
| 1967 | 0.59 | 0.65 | 0.63 | 0.64 | 0.33 | -0.05 | 0.26 | 0.01 | 0.20 | 0.59 | 0.47 | 0.49 | 0.57 | 0.00 | 0.11 | 0.48 | 0.46 | 0.47 | 0.43 | 0.27 | 0.26 | -0.56 | 0.07 | 0.22 | 0.13 | -0.29 | -0.07 | -0.58 | 0.05 | 0.06 | -0.91 |
| 1968 | 0.47 | 0.65 | 0.68 | 0.66 | 0.35 | -0.05 | 0.13 | -0.10 | 0.11 | 0.47 | 0.49 | 0.47 | 0.56 | NaN | -0.05 | 0.47 | 0.47 | 0.42 | 0.37 | 0.16 | 0.08 | -0.85 | -0.14 | 0.05 | 0.04 | -0.47 | -0.16 | -0.67 | -0.09 | -0.04 | -1.12 |
| 1969 | 0.50 | 0.64 | 0.66 | 0.69 | 0.39 | 0.00 | 0.15 | -0.10 | 0.14 | 0.50 | 0.48 | 0.50 | 0.57 | NaN | NaN | 0.47 | 0.48 | 0.44 | 0.42 | 0.21 | 0.16 | -0.73 | -0.05 | 0.13 | 0.07 | -0.38 | -0.11 | -0.60 | -0.08 | -0.04 | -1.05 |
| 1970 | 0.39 | 0.51 | 0.51 | 0.56 | 0.60 | 0.49 | 0.41 | 0.41 | 0.42 | 0.39 | 0.51 | 0.51 | 0.52 | 0.27 | 0.34 | 0.43 | 0.45 | 0.40 | 0.38 | 0.39 | 0.29 | 0.15 | 0.30 | 0.36 | 0.34 | 0.25 | 0.22 | 0.29 | 0.33 | 0.32 | 0.10 |
| 1971 | 0.39 | 0.35 | 0.37 | 0.41 | 0.57 | 0.63 | 0.52 | 0.51 | 0.54 | 0.39 | 0.47 | 0.44 | 0.46 | 0.37 | 0.41 | 0.40 | 0.36 | 0.43 | 0.40 | 0.41 | 0.33 | 0.20 | 0.34 | 0.36 | 0.31 | 0.38 | 0.44 | 0.52 | 0.48 | 0.49 | 0.44 |
| 1972 | 0.46 | 0.40 | 0.37 | 0.44 | 0.51 | 0.56 | 0.66 | 0.61 | 0.62 | 0.46 | 0.48 | 0.47 | 0.51 | NaN | NaN | 0.46 | 0.37 | 0.45 | 0.42 | 0.42 | 0.38 | 0.21 | 0.43 | 0.44 | 0.38 | 0.44 | 0.46 | 0.43 | 0.54 | 0.54 | 0.45 |
| 1973 | 0.38 | 0.31 | 0.29 | 0.31 | 0.37 | 0.42 | 0.52 | 0.53 | 0.52 | 0.38 | 0.39 | 0.35 | 0.40 | 0.44 | 0.39 | 0.32 | 0.28 | 0.34 | 0.30 | 0.29 | 0.30 | 0.18 | 0.33 | 0.34 | 0.25 | 0.33 | 0.38 | 0.37 | 0.44 | 0.44 | 0.35 |
| 1974 | 0.36 | 0.31 | 0.30 | 0.31 | 0.38 | 0.43 | 0.49 | 0.50 | 0.51 | 0.36 | 0.39 | 0.35 | 0.37 | 0.42 | 0.38 | 0.31 | 0.28 | 0.33 | 0.30 | 0.27 | 0.27 | 0.15 | 0.30 | 0.30 | 0.23 | 0.31 | 0.36 | 0.36 | 0.40 | 0.43 | 0.32 |
| 1975 | 0.23 | 0.26 | 0.24 | 0.23 | 0.08 | -0.18 | 0.06 | -0.12 | 0.03 | 0.23 | 0.29 | 0.27 | 0.25 | -0.23 | -0.08 | 0.21 | 0.20 | 0.09 | 0.06 | -0.07 | -0.02 | -0.45 | -0.12 | -0.04 | -0.05 | -0.15 | -0.12 | -0.54 | -0.20 | -0.07 | -0.65 |
| 1976 | 0.34 | 0.32 | 0.30 | 0.30 | 0.27 | 0.08 | 0.24 | 0.15 | 0.21 | 0.34 | 0.41 | 0.39 | 0.37 | 0.10 | 0.12 | 0.26 | 0.25 | 0.23 | 0.20 | 0.12 | 0.13 | -0.17 | 0.12 | 0.15 | 0.01 | 0.05 | 0.13 | -0.07 | 0.11 | 0.18 | -0.21 |
| 1977 | 0.37 | 0.40 | 0.37 | 0.37 | 0.33 | 0.03 | 0.20 | 0.05 | 0.12 | 0.37 | 0.48 | 0.51 | 0.45 | 0.03 | 0.09 | 0.34 | 0.35 | 0.27 | 0.23 | 0.14 | 0.07 | -0.34 | 0.02 | 0.09 | -0.03 | -0.07 | 0.01 | -0.20 | 0.04 | 0.13 | -0.55 |
| 1978 | 0.40 | 0.41 | 0.36 | 0.37 | 0.38 | 0.18 | 0.26 | 0.10 | 0.23 | 0.40 | 0.48 | 0.50 | 0.50 | NaN | NaN | 0.40 | 0.39 | 0.34 | 0.31 | 0.24 | 0.17 | -0.15 | 0.15 | 0.20 | 0.11 | 0.06 | 0.12 | -0.01 | 0.15 | 0.21 | -0.33 |
| 1979 | 0.49 | 0.46 | 0.39 | 0.42 | 0.44 | 0.31 | 0.50 | 0.44 | 0.42 | 0.49 | 0.49 | 0.52 | 0.54 | 0.64 | 0.57 | 0.48 | 0.45 | 0.46 | 0.44 | 0.42 | 0.39 | 0.28 | 0.44 | 0.45 | 0.34 | 0.33 | 0.35 | 0.39 | 0.43 | 0.42 | 0.19 |
| 1980 | 0.49 | 0.42 | 0.30 | 0.36 | 0.28 | 0.09 | 0.38 | 0.19 | 0.26 | 0.49 | 0.31 | 0.40 | 0.46 | NaN | 0.60 | 0.54 | 0.48 | 0.41 | 0.42 | 0.37 | 0.39 | 0.26 | 0.32 | 0.37 | 0.47 | 0.20 | 0.12 | 0.10 | 0.19 | 0.19 | -0.20 |
| 1981 | 0.60 | 0.56 | 0.45 | 0.53 | 0.41 | 0.08 | 0.30 | -0.08 | 0.20 | 0.60 | 0.47 | 0.51 | 0.57 | 0.14 | 0.45 | 0.71 | 0.63 | 0.58 | 0.59 | 0.44 | 0.46 | 0.33 | 0.42 | 0.44 | 0.57 | 0.37 | 0.37 | -0.32 | -0.38 | -0.24 | -0.46 |
| 1982 | 0.55 | 0.60 | 0.50 | 0.58 | 0.47 | 0.06 | 0.26 | -0.10 | 0.21 | 0.55 | 0.51 | 0.55 | 0.57 | -0.02 | 0.36 | 0.69 | 0.71 | 0.63 | 0.61 | 0.47 | 0.37 | 0.25 | 0.30 | 0.37 | 0.50 | 0.33 | 0.34 | -0.34 | -0.53 | -0.32 | -0.63 |
| 1983 | 0.53 | 0.53 | 0.44 | 0.51 | 0.50 | 0.38 | 0.38 | 0.21 | 0.37 | 0.53 | 0.49 | 0.52 | 0.54 | 0.12 | 0.34 | 0.57 | 0.58 | 0.64 | 0.62 | 0.54 | 0.41 | 0.32 | 0.39 | 0.44 | 0.46 | 0.45 | 0.49 | 0.09 | -0.02 | 0.11 | -0.08 |
| 1984 | 0.48 | 0.44 | 0.35 | 0.43 | 0.44 | 0.35 | 0.33 | 0.14 | 0.31 | 0.48 | 0.44 | 0.48 | 0.47 | 0.11 | 0.32 | 0.52 | 0.49 | 0.58 | 0.59 | 0.53 | 0.42 | 0.36 | 0.38 | 0.42 | 0.44 | 0.42 | 0.42 | 0.06 | -0.01 | 0.10 | -0.04 |
| 1985 | 0.30 | 0.23 | 0.11 | 0.23 | 0.26 | 0.30 | 0.27 | 0.21 | 0.24 | 0.30 | 0.22 | 0.28 | 0.25 | 0.27 | 0.28 | 0.27 | 0.24 | 0.39 | 0.40 | 0.44 | 0.36 | 0.33 | 0.31 | 0.34 | 0.30 | 0.29 | 0.23 | 0.31 | 0.29 | 0.32 | 0.25 |
| 1986 | 0.34 | 0.18 | 0.05 | 0.17 | 0.21 | 0.27 | 0.25 | 0.19 | 0.22 | 0.33 | 0.18 | 0.23 | 0.18 | 0.32 | 0.28 | 0.23 | 0.19 | 0.35 | 0.34 | 0.42 | 0.45 | 0.40 | 0.40 | 0.38 | 0.26 | 0.24 | 0.15 | 0.29 | 0.26 | 0.28 | 0.20 |
| 1987 | 0.34 | 0.12 | -0.08 | 0.14 | 0.18 | 0.26 | 0.24 | 0.08 | 0.17 | 0.34 | 0.14 | 0.21 | 0.15 | 0.23 | 0.27 | 0.25 | 0.14 | 0.36 | 0.33 | 0.49 | 0.54 | 0.56 | 0.47 | 0.44 | 0.31 | 0.26 | 0.17 | 0.24 | 0.20 | 0.24 | 0.25 |
| 1988 | 0.54 | 0.35 | 0.23 | 0.39 | 0.28 | 0.13 | 0.44 | -0.01 | 0.39 | 0.54 | 0.34 | 0.33 | 0.42 | 0.35 | 0.35 | 0.49 | 0.36 | 0.54 | 0.43 | 0.52 | 0.56 | 0.42 | 0.68 | 0.66 | 0.51 | 0.49 | 0.28 | 0.00 | 0.30 | 0.36 | -0.18 |
| 1989 | 0.62 | 0.42 | 0.31 | 0.45 | 0.39 | 0.25 | 0.51 | 0.06 | 0.47 | 0.62 | 0.38 | 0.41 | 0.54 | 0.44 | 0.49 | 0.63 | 0.50 | 0.63 | 0.54 | 0.61 | 0.60 | 0.44 | 0.74 | 0.74 | 0.68 | 0.62 | 0.42 | 0.13 | 0.39 | 0.44 | -0.01 |
| 1990 | 0.29 | 0.32 | 0.29 | 0.37 | 0.41 | 0.30 | 0.38 | 0.02 | 0.33 | 0.29 | 0.36 | 0.40 | 0.51 | NaN | NaN | 0.56 | 0.36 | 0.55 | 0.52 | 0.56 | 0.41 | 0.37 | 0.51 | 0.55 | 0.69 | 0.66 | 0.48 | 0.19 | 0.32 | 0.39 | 0.13 |
| 1991 | 0.30 | 0.31 | 0.29 | 0.38 | 0.41 | 0.34 | 0.37 | 0.09 | 0.35 | 0.30 | 0.37 | 0.40 | 0.48 | 0.28 | 0.36 | 0.48 | 0.33 | 0.54 | 0.52 | 0.52 | 0.37 | 0.34 | 0.49 | 0.53 | 0.60 | 0.65 | 0.50 | 0.27 | 0.36 | 0.41 | 0.21 |
| 1992 | 0.29 | 0.33 | 0.30 | 0.34 | 0.42 | 0.34 | 0.32 | 0.25 | 0.29 | 0.29 | 0.36 | 0.40 | 0.43 | 0.25 | 0.25 | 0.37 | 0.30 | 0.39 | 0.36 | 0.31 | 0.20 | -0.35 | 0.27 | 0.34 | 0.27 | 0.45 | 0.56 | 0.47 | 0.41 | 0.46 | 0.38 |
| 1993 | 0.34 | 0.37 | 0.38 | 0.38 | 0.62 | 0.65 | 0.56 | 0.59 | 0.56 | 0.34 | 0.53 | 0.57 | 0.51 | 0.58 | 0.53 | 0.39 | 0.42 | 0.48 | 0.49 | 0.38 | 0.27 | 0.26 | 0.35 | 0.33 | 0.33 | 0.35 | 0.56 | 0.73 | 0.69 | 0.70 | 0.66 |
| 1994 | 0.35 | 0.36 | 0.38 | 0.37 | 0.57 | 0.57 | 0.54 | 0.56 | 0.52 | 0.35 | 0.51 | 0.52 | 0.49 | NaN | NaN | 0.39 | 0.41 | 0.45 | 0.45 | 0.33 | 0.25 | 0.22 | 0.32 | 0.30 | 0.30 | 0.31 | 0.51 | 0.61 | 0.64 | 0.64 | 0.61 |
| 1995 | 0.36 | 0.37 | 0.39 | 0.38 | 0.57 | 0.58 | 0.53 | 0.55 | 0.51 | 0.36 | 0.51 | 0.53 | 0.50 | 0.57 | 0.54 | 0.40 | 0.43 | 0.46 | 0.47 | 0.35 | 0.27 | 0.24 | 0.34 | 0.32 | 0.32 | 0.32 | 0.52 | 0.62 | 0.64 | 0.64 | 0.62 |
| 1996 | 0.35 | 0.35 | 0.37 | 0.37 | 0.58 | 0.60 | 0.54 | 0.56 | 0.51 | 0.35 | 0.51 | 0.53 | 0.49 | NaN | NaN | 0.41 | 0.43 | 0.48 | 0.49 | 0.39 | 0.32 | 0.40 | 0.37 | 0.35 | 0.38 | 0.36 | 0.52 | 0.62 | 0.64 | 0.64 | 0.66 |

# Model simplification

- Sensitivity analysis by Sobol method
- 5 parameters with significant influence on NS value
  - FC – field capacity (soil zone)
  - KUZ1 – recession constant (upper zone 1)
  - PGRAD – precipitation lapse rate
  - PKORR – rainfall correction factor
  - SKORR – snowfall correction factor



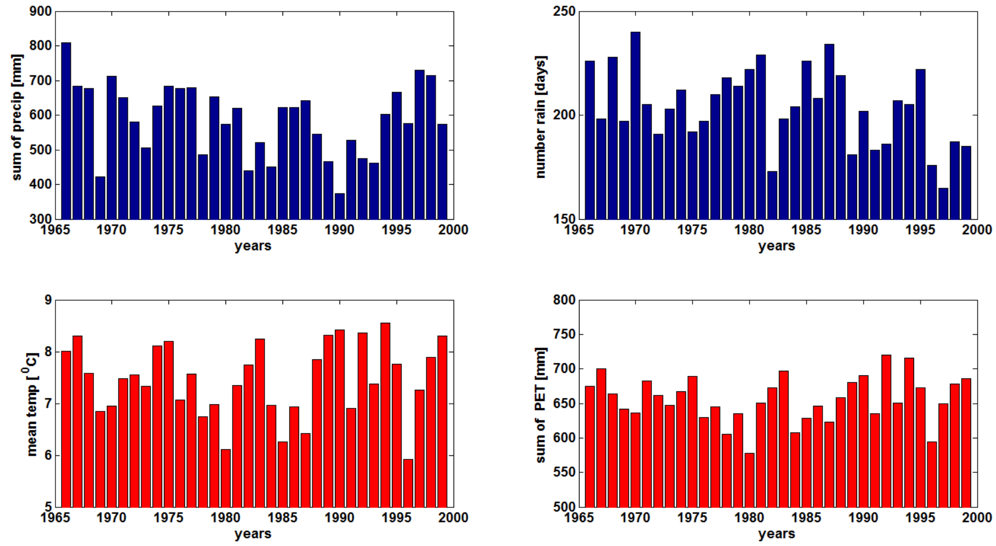
# Climatic conditions

Climatic variables:

- Precipitation
- Air temperature
- Potential evapotranspiration

Statistical descriptors:

- Maximum value
- Mean value
- Median




| | min | max | mean |
|---|---|---|---|
| Sum of precip [mm] | 374 | 810 | 590 |
| Number rain [days] | 165 | 240 | 204 |
| Mean temp [°C] | 5.9 | 8.6 | 7.5 |
| Sum of PET [mm] | 578 | 720 | 656 |

# Linear regression

- We developed two regression models
1. For all periods

**All periods**

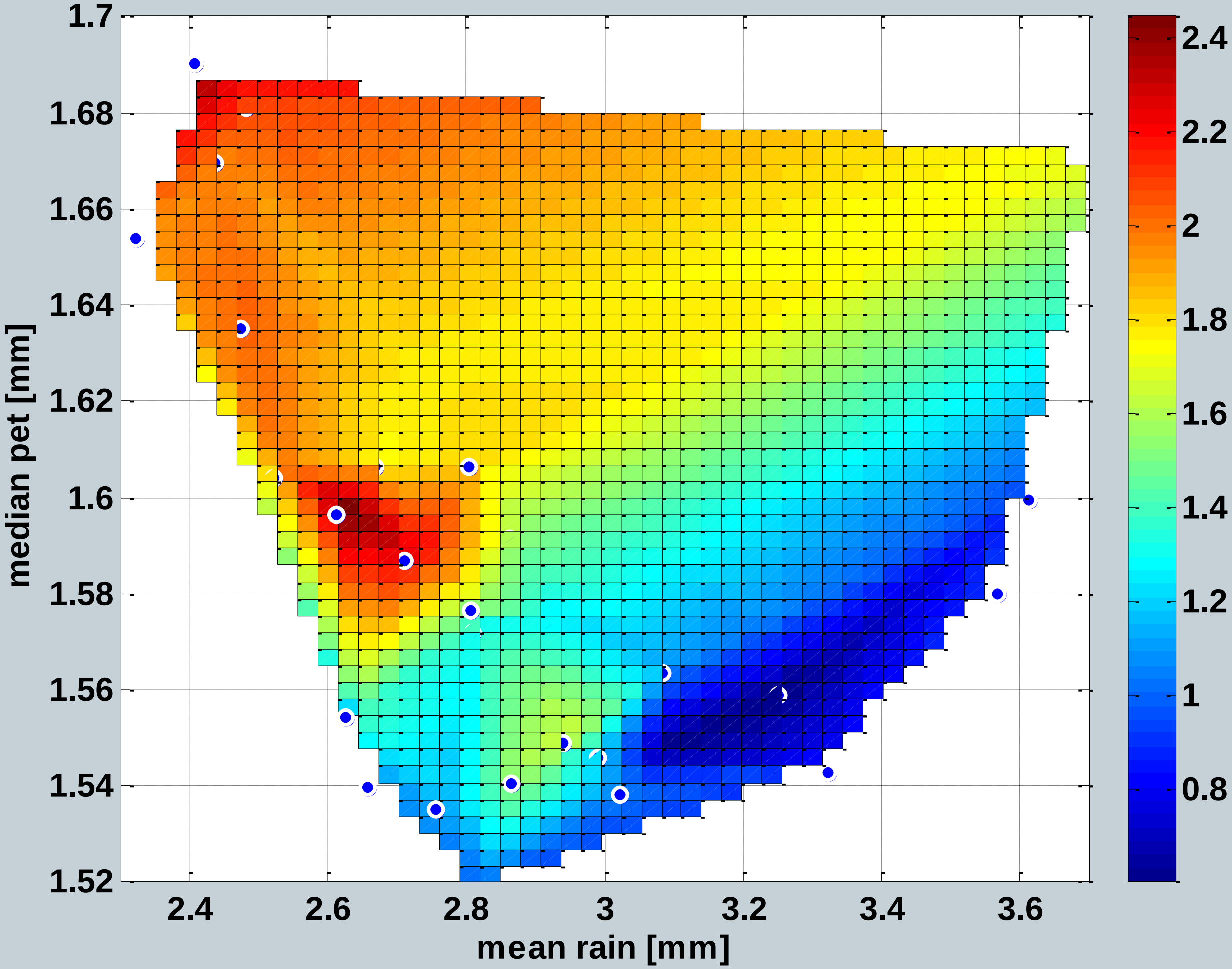
| Param | Climatic indices | R2 |
|---|---|---|
| FC | Max precip, number of days with rainfall | 0.6031 |
| KUZ1 | Mean temp, max temp | 0.4179 |
| PGRAD | Median rainfall, max pet | 0.2431 |
| PKORR | Mean rainfall, median rainfall | 0.5409 |
| SKORR | Mean precip, median PET | 0.7004 |

2. For periods with good results of model calibration NS>0.5

**NS > 0.5**

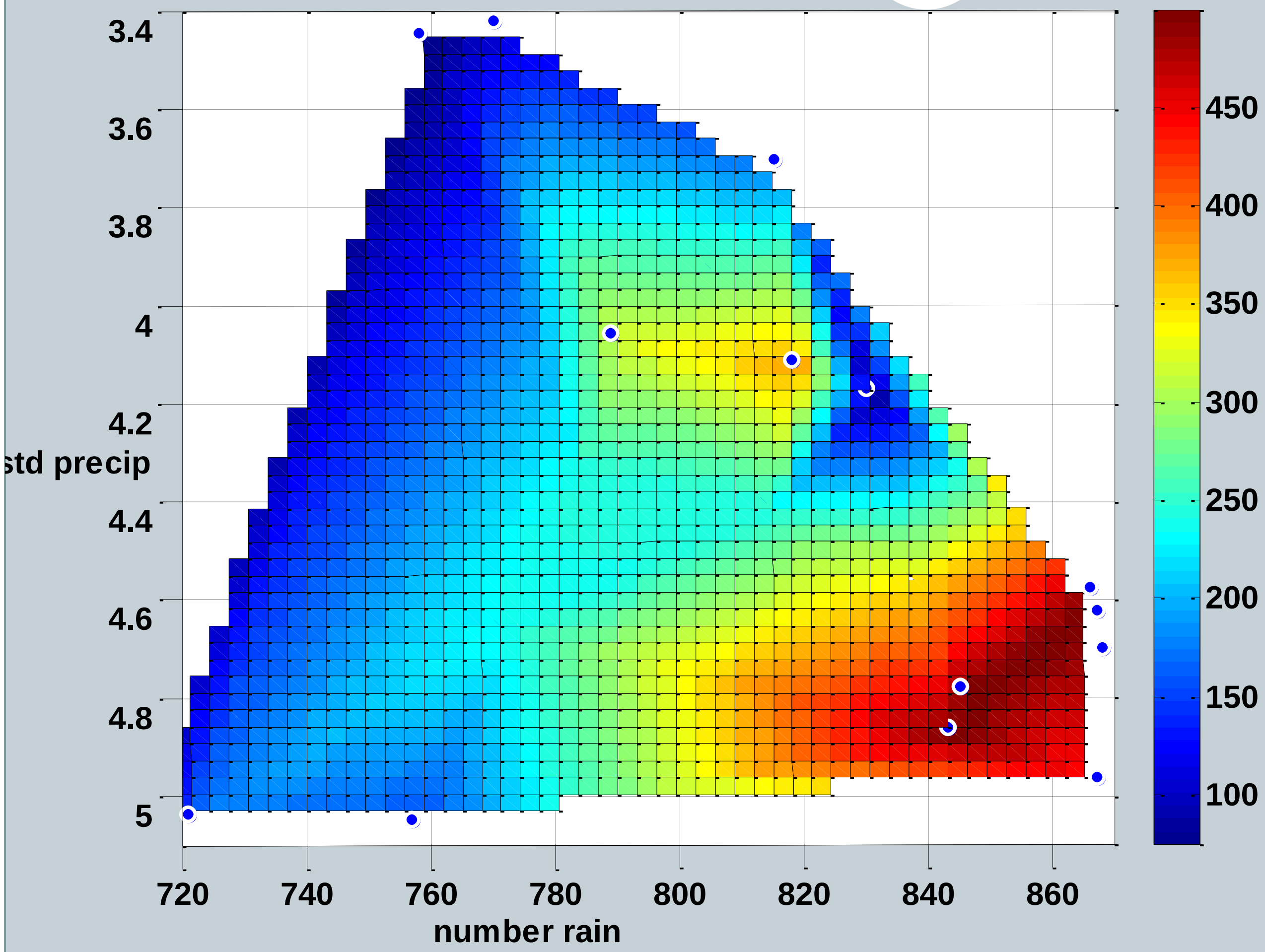
| Param | Climatic indices | R2 |
|---|---|---|
| FC | Std precip, number of days with rainfall | 0.7392 |
| KUZ1 | number of days with rainfall, max temp | 0.5080 |
| PGRAD | Median rain, max pet | 0.3482 |
| PKORR | Mean rain, median rain | 0.4782 |
| SKORR | Mean precip, median PET | 0.6010 |

# All periods




- SKORR=f(mean rain, median PET)
- Blue dots represent estimated points (31 points-all periods)
- SKORR values are positively correlated with median PET and negatively correlated with mean rainfall

# NS>0.5




- FC=f(number rain, std precip)
- FC value depends mostly on std of precip and number of days with rainfall
- The higher std of precip and number of days with rainfall the larger the FC value

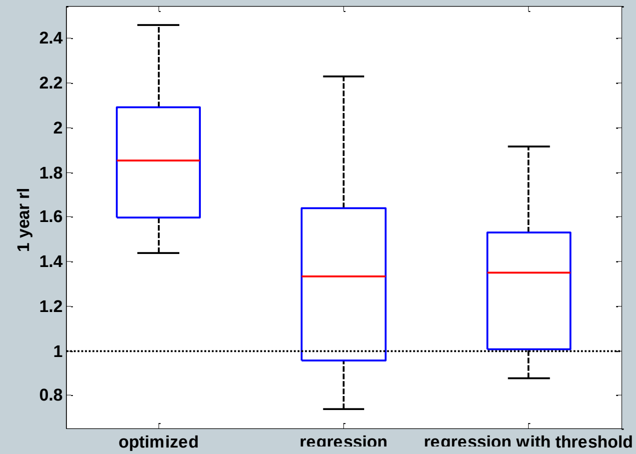
# Simulations of future flows

- 15 RCM/GCM with Emission scenario A1B provided in the framework COST FloodFreq
  - Reference period -1961-1990
  - Future period – 2071-2100
- Bias correction - Empirical Quantile Mapping provided in the framework COST FloodFreq
- Hydrological projections:
  - Stationary conditions - one parameter set optimized for complete period
  - Nonstationary conditions - parameters estimated by linear regression for all periods
  - Nonstationary conditions - parameters estimated by linear regression for periods with NS > 0.5
- Flood quantile – POT method, the software provided in the framework COST FloodFreq

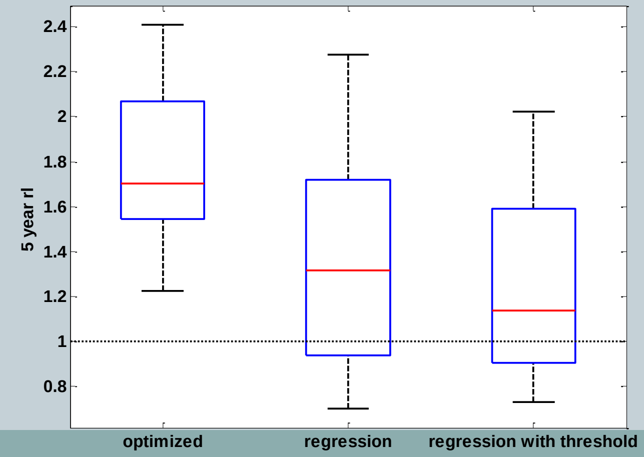
# Results: REF vs OBS

- A comparison of **relative changes in flood quantiles (sim/obs): 1 and 5 year rp** estimated for simulated versus observed time series
- Application of regression models leads to better estimates of median from RCM/GCM ensemble
- Second regression model gives smaller variability of projected changes between RCM/GCMs

## 1 year rp



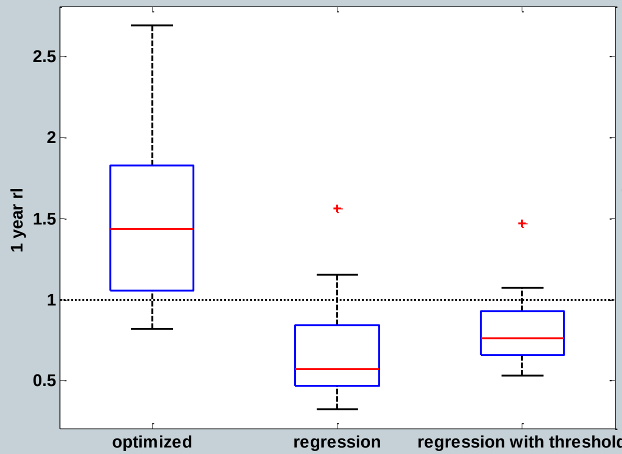

## 5 year rp



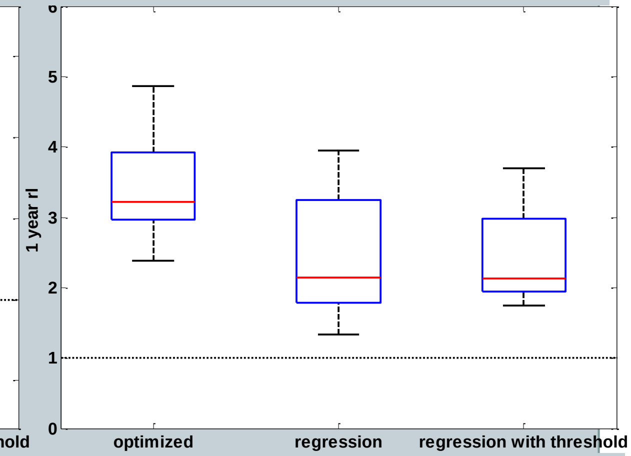
# Results: REF vs OBS

- **Seasonal changes** in flood quantiles derived based on simulated vs observed time series 1 year rp
- **Similar tendency** of changes between methods is estimated **for spring (MAM) and summer (JJA)**
- **Differences for winter (DJF) and autumn (SON)**

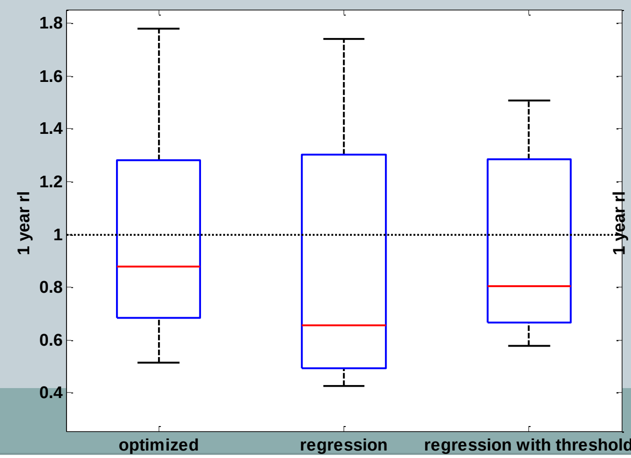
## DJF



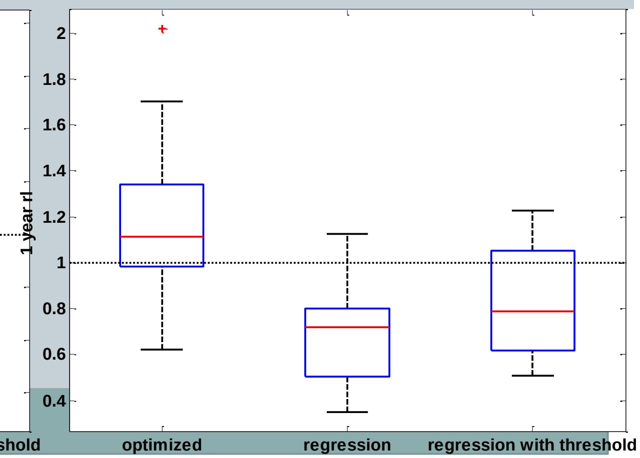

## MAM




## JJA



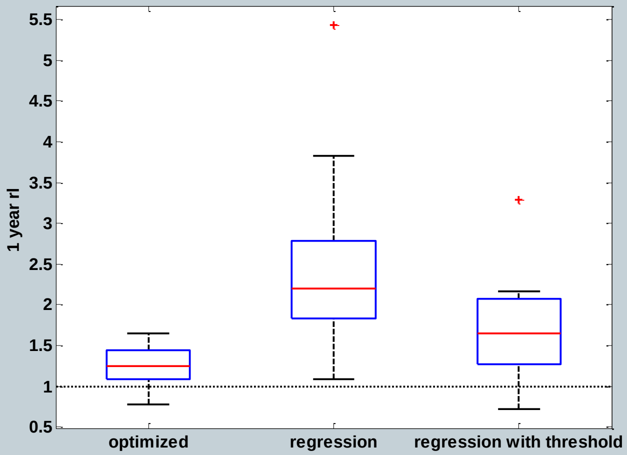

## SON



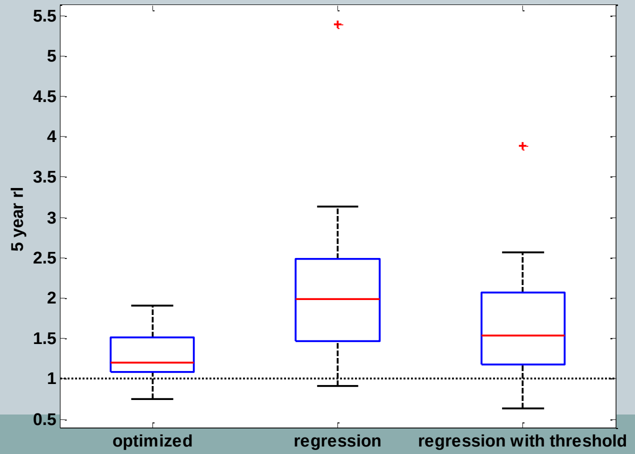
# Results: CLIM vs REF

- Analysis of **changes in flood quantiles 1 and 5 year rl** between future and reference periods
- Similar tendency of changes – an increase of flood quantiles 1 and 5 year rl
- Applications of regression models lead to higher changes in flood peaks
- Regression with threshold (NS>0.5) gives smaller variability of projected changes in flood quantiles compared to regression without threshold

**1 year rl**

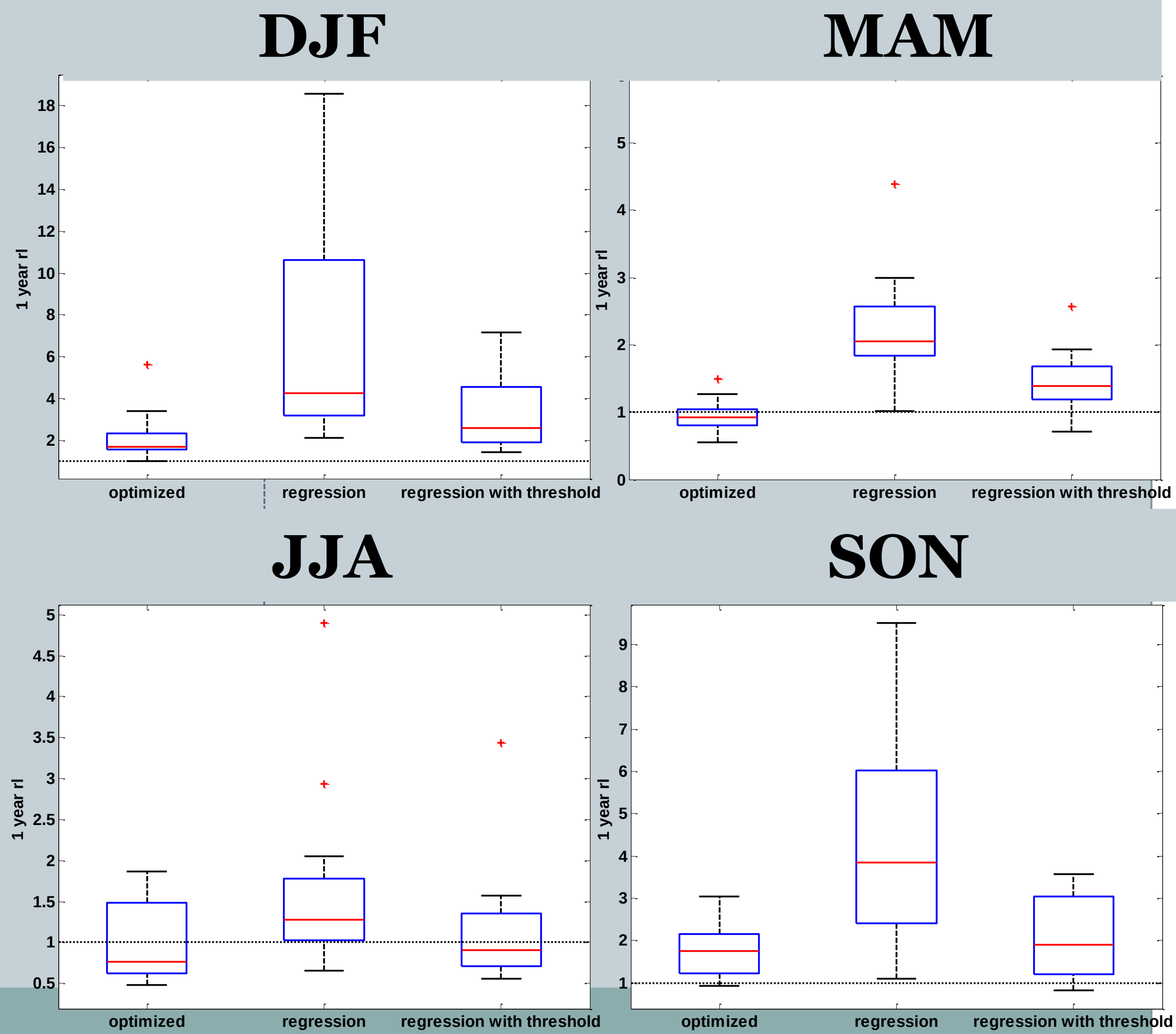



**5 year rl**



# Results: CLIM vs REF

- **Seasonal changes in flood quantiles, 1 year rl**
- Similar tendency of changes is estimated for winter and autumn
- Differences between methods for spring (MAM) and summer (JJA) seasons
- A very large variation of changes in winter (DJF) and autumn (SON) for regression model without threshold



# Summary

- We have presented an assessment of the impact of climate change on flood quantiles taking into account dependence of HBV model parameters on climate characteristics.
- We derived two regression models for 5 parameters that have the largest impact on the value of the objective function (NS).
- Parameters of HBV model depend on: number of days with rainfall, mean rainfall, mean temp and median PET.
- Analysis of flood quantiles estimated for simulated and observed time series indicates that regression models give better estimates.
- Comparison of changes in flood quantiles between changed climate and reference periods indicates that application of regression models results in potentially larger changes.