Fourth Workshop on Water Resources in Developing Countries: Hydroclimate Modeling and Analysis Tools

A two-stage transfer function time series model for monthly hydrologic projections under climate change for the Lim River Basin in Serbia/Southeastern Europe

Milan STOJKOVIĆ, Ph.D. Civil Eng.

Research Associate

Jaroslav Černi Institute for the Development of Water Resources, Belgrade, Serbia

The Abdus Salam International Centre for Theoretical Physics

Jaroslav Černi Institute for the Development of Water Resources

Introduction

- Water resources are particularly vulnerable to climate change and this tendency is expected to continue in the future (IPCC, 2013).

- **The hydrologic models have been widely applied in Southeast Europe** to assess **water-related impacts of climate change** (Haddeland, 2013; World Bank, 2014; World Bank 2017).

- The results of hydrologic simulations with future climate suggest that the **temporal and spatial changes in the runoff pattern should be expected in this region.**

- These changes have **a dominant regional character** and present the consequence of **the expected chages in climatic drivers in the lower Danube River basin.**

Introduction

- Assessment of relations among the hydrological and meteorological processes is essential for developing hydrological models.

- Two approaches to obtaining hydrologic response under different climate change scenarios are common in hydrologic practice (Zeng et al. 2012).

- The first approach uses the physically based hydrologic models, in which the precipitation and runoff relationship is described with a set of physical laws and/or some conceptual methods.

- Alternatively, data-driven (empirical or statistical) models can be employed to assess the relationship between the hydrologic response and climate parameters in a basin.

- Both model types use the climate projections from the Global Climate Models (GCMs), downscaled by the Regional Climate Models (RCMs), are used.

Introduction

- The long-term prediction of hydrologic time series can also be obtained with **the stochastic models** developed from the observed hydrologic pattern (e.g. Pekarova et al. 2003; Pekarova and Pekar, 2006).

- The stochastic models can be used to **identify long-term hydrological behaviour** (trend and/or multi-decadal cycles) expressed as a function of time, which can then be extrapolated in the future.

- This approach brings **a considerable uncertainty** that is closely connected to the nature of multi-decadal flow variation that is referred to as "sudden shifts" (Sveinsson and Salas, 2003).

- Also, this approach does not take into account the climate projections under a particular climate change scenario.

Introduction

- We have used <u>the deterministic-stochastic modelling scheme</u> (Stojkovic et al. 2017) to develop **a two-stage transfer function time series model**.

- Such an idea can be used to convey the <u>influence of the climate drivers on the variability of the hydrologic time series</u>.

- This approach is applied to examine the impact of the climate change on hydrological regime for **the Lim River** basin (Serbia).

Methodology

- The methodology is developed with an assumption that **the future changes in climate variables are the major driver for the changes in hydrologic response**.

- The methodology is applied in **two stages (Figure 1)**:

  - ***In the first stage*** **the Annual Transfer Function Model (ATFM)** is applied with climate scenarios.

  - The results of the first stage are then used in ***the second stage*** to identify the deterministic components, which in turn provides the long-term projections instead of simply extrapolating the deterministic components into the future.

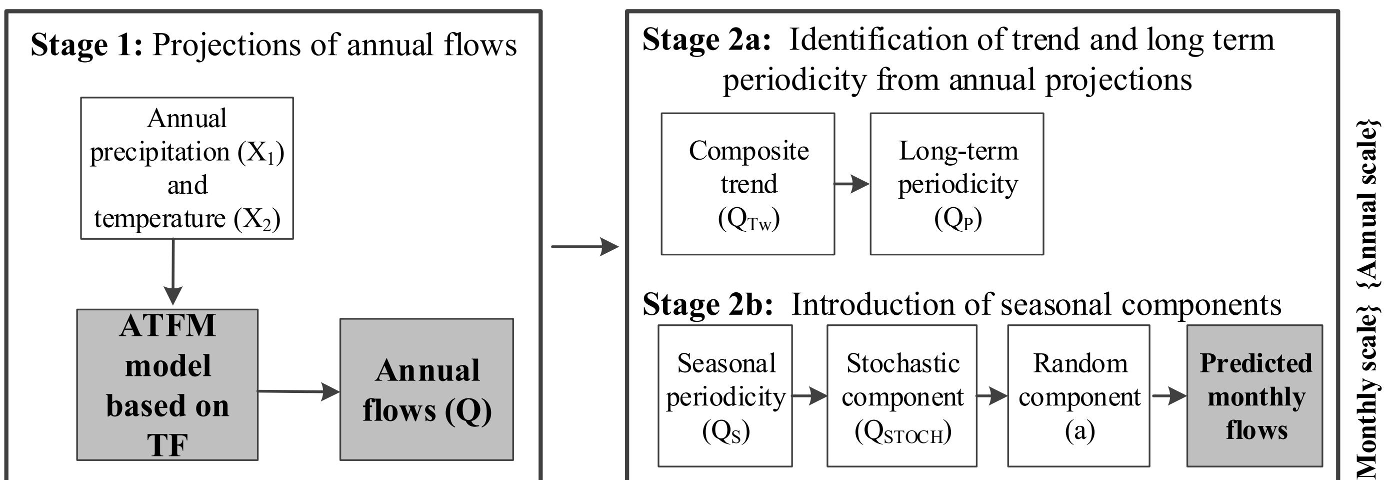

Figure 1. Illustration of the two-stage procedure for long-term hydrologic projections with time series models based on transfer functions

Methodology

➢ In the first stage, **the Annual Transfer Function Model (ATFM) is used**:

$$y_u = \frac{\omega_1(B)}{\delta_1(B)} x_{1u} + \frac{\omega_2(B)}{\delta_2(B)} x_{2u} + \frac{\theta(B)}{\phi(B)} a_u .$$

the differenced annual flow series,
the differenced annual precipitation,
the differenced annual temperature,
ne yearly time index,
$\omega_1(B)$, $\delta_1(B)$, $\omega_2(B)$ and $\delta_2(B)$ - the TF model parameters.

➢ Identification of ATFM (Figure 2) involves the following steps:

- ❑ defining the observed input and output time series,
- ❑ standardizing and first-order differencing of inputs and outputs,
- ❑ estimating the parameters of TF by the prewhitening method,
- ❑ verifying TF by means of the Haugh's statistic.

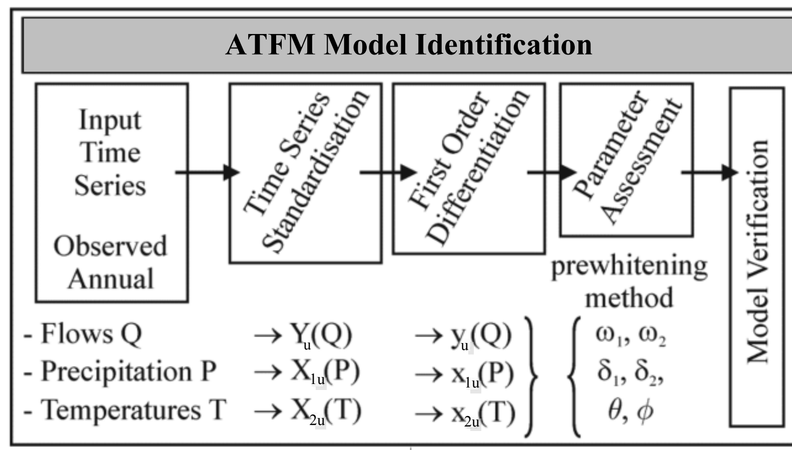

Figure 2. Schematic representation of the ATFM (Annual Transfer Function Model) identification procedure.

Methodology

- At the second stage, **the composite trend and long term periodicity** are identified by using **the annual flow projections** from stage 1 (derived from ATFM).

- The components with monthly time discretisation (**seasonal periodicity, stochastic and random components**) are assessed at the second stage.

- Having determined components from Stage 2, the monthly flow projections are determined as a sum of all predicted components.

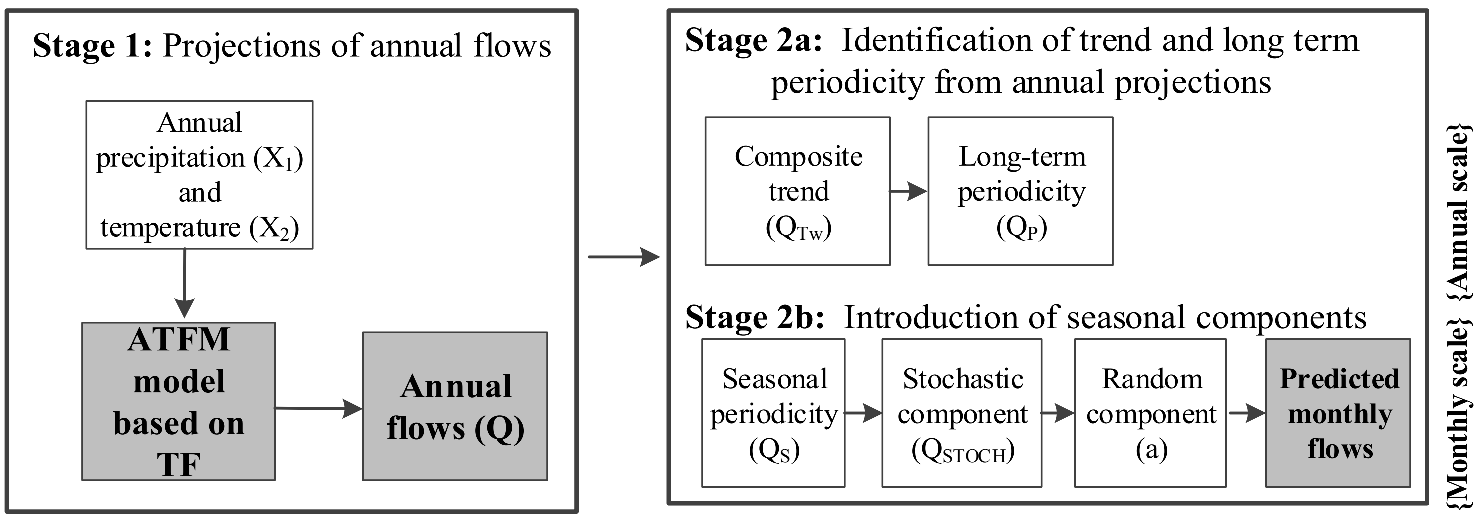

Figure 3. Illustration of the two-stage procedure for long-term hydrologic projections with time series models based on transfer functions

Data

➢ The study is performed for **the Lim River basin** to the Prijepolje hydrological station (h.s.) (Figure 4).

➢ <u>Hydrological and meteorological records are available</u> from **1950 to 2012.**

➢ Records were obtained by:

- Hydro-meteorological Service of Republic Serbia,
- Hydro-meteorological Service Republic Montenegro.

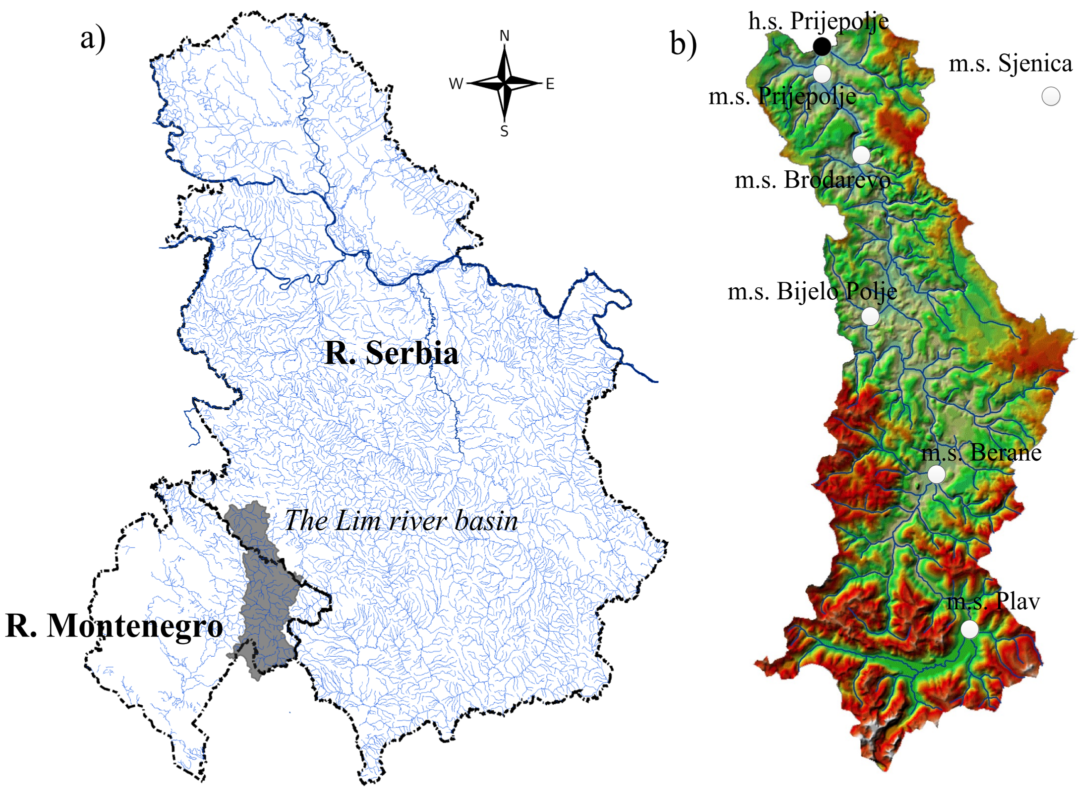

Figure 4. (a) Location of the Lim River basin (grey polygon); (b) The Lim River basin to Prijepolje hydrologic station with locations of meteorological stations (m.s.).

Data

- Projections of precipitation and air temperature are available as a result of simulations with **the EBU-POM regional climate model** (Đurđević and Rajković, 2008) under the greenhouse gas emission scenarios **A1B and A2** (IPCC 2013; IPCC 2007).

- The simulations covered period **2013-2100**, while the baseline period is chosen to be **1961-1990** due to the availability of the observed data.

- The simulated climate generally shows **a decrease in annual precipitation and an increse of annual temperature** for the future time frame (2013-2010) relative to the basline period (1961-1990).

- A decrease of annual precipitation is equal **to 13% (A1B) and 8% (A2).**

- Air temperature shows an overall rise of **2.4^{0}C (A1B) and 2.8^{0}C (A2)**.

Results

- Identification of the model components is conducted under **the stochastic-deterministic modelling scheme**.

- The basic assumption of the proposed scheme that monthly flow time series can be decomposed into deterministic, stochastic and random part:

$$Q_t = Det_t + Stoch_t + error_t \rightarrow Q_t = \left[Q_T + Q_P + Q_S\right]_t + \left[Q_{STOCH}\right]_t + \left[e\right]_t \qquad t = 1, 2, \ldots, N$$

Q_T - the composite trend,

Q_P - the long-term periodic component,

Q_S - the seasonal component,

Q_{STOCH} - the stochastic component,

e_t - is the error term (random time series).

Results

- **The annual deterministic component** (composite trend Q_T and macro-periodic component Q_P) is identified from the observed data (**Figure 5a, 5d**).

- The identified annual deterministic component is downscaled to the monthly time step using the low-pass filter.

- The residuals are used to assessed **monthly seasonal component (Q_s) (Figure 5c)**.

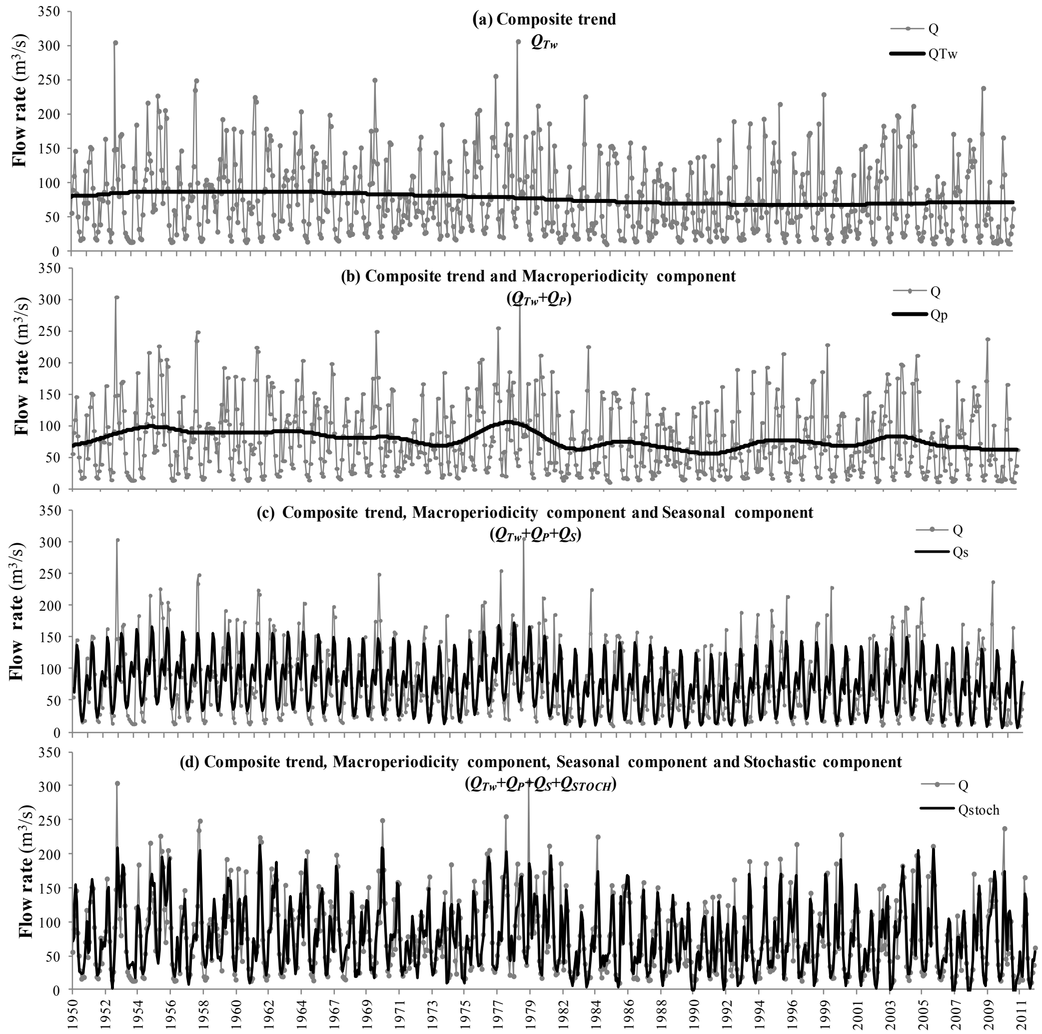

Figure 5. Modelling monthly flows of the Lim River at Prijepolje: Q - observed monthly flows, Q_{Tw} - composite trend, Q_P - macro-periodic component, Q_S - seasonal component, Q_{STOCH} - stochastic component.

Results

- The last part is **the monthly stochastic component (Q_{stoch}).**

- It is modelled by separately developed TF model by using monthly climatic series.

- All components are aggregated to obtain **the modelled mohthly flows** (**Figure 5d**).

- The Nash-Sutcliffe efficiency (NSE) is used as a model performance indicator.

- The value of **NSE = 0.829** suggests a very good agreement between the modelled and observed monthly flows.

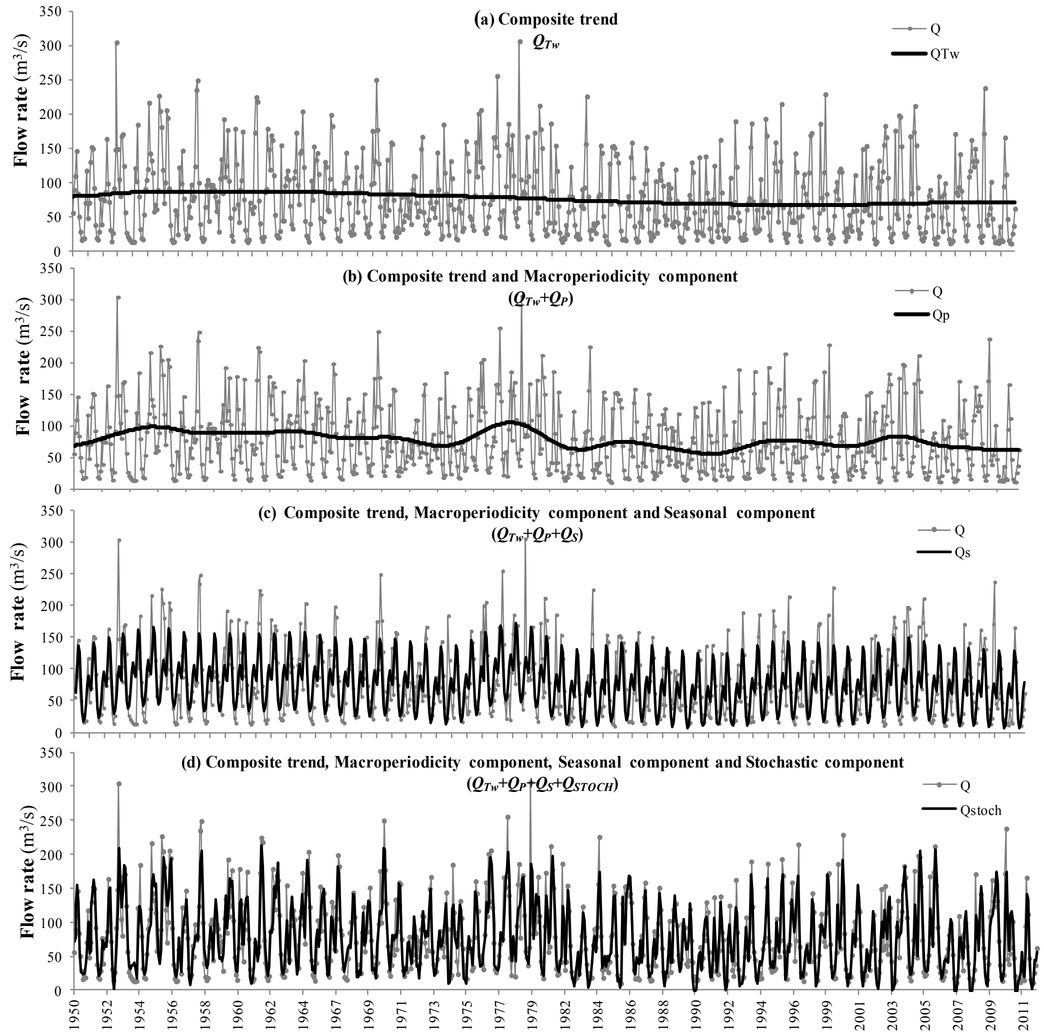

Figure 5. Modelling monthly flows of the Lim River at Prijepolje: Q - observed monthly flows, Q_{Tw} - composite trend, Q_P - macro-periodic component, Q_S - seasonal component, Q_{STOCH} - stochastic component.

Results

- Together with the stochastic-deterministic modelling scheme designed to monthly flows, we also use **the ATFM model for annual time series.**

- **Observed anual precipitation and temperature are used to assess the parameters.**

- **The estimated parameters of the ATFM** are given in the following equation:

$$\hat{y}_u = \frac{(0.615 - 0.187B - 0.337B^2)x_{1u}}{1 + 0.482B + 0.318B^2} + (-0.418B + 0.120B^2)x_{2u} + (1 + 0.113B)a_t.$$

$\hat{y}_u$ is the differenced series of annual flows,

x_{1u} and x_{2u} are the differenced annual precipitation and temperature series,

a_t is the residual term.

- **In the first application stage**, the ATFM is used for **initial projection of annual flows in the future.**

- For this purpose, **precipitation and temperature from climate modelling under emission scenarios A1B and A2** are used instead of the observed time series.

Results

- In the second application stage

  - **The future composite trend Q_{Tw} and macro-periodic component Q_P** are identified from the predicted annual flows (derived from ATFM) in the same manner as for the observation period.

  - **The monthly seasonal component Q_S** is derived for three 30-year time frames:

    - 2013-2040 (near future),
    - 2041-2070 (mid-distant future),
    - 2041-2070 (distant future).

  - It is assumed that the intra-annual distribution <u>does not change within a 30-year time frame, but it differs for each of the three periods</u>.

  - The long-term projection of **the stochastic component Q_{STOCH}** is computed using the TF model <u>with monthly precipitation and temperature projections from climate modelling</u>.

Results

- The monthly flow predictions for the Lim River are computed by summing all predicted components.
- **The obtained projections of annual flows** under emission scenarios A1B and A2 are shown in Figure 6.
- The annual flows is expected to reduce in the range from **6% (A1B) to 14% (A2) up to the end of 21th century.**

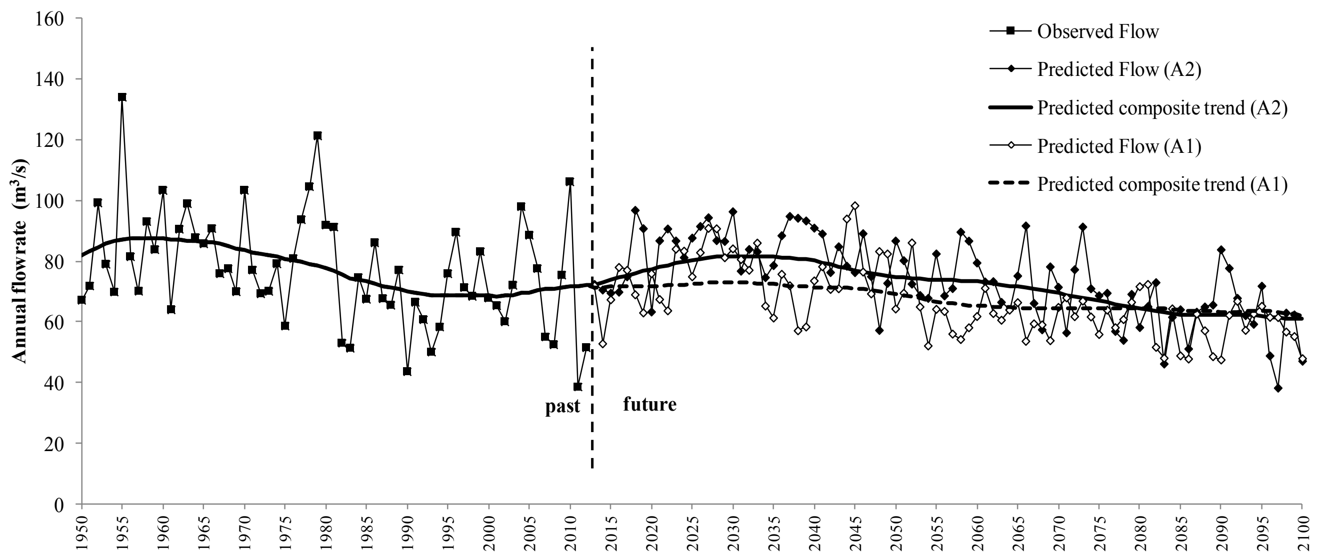

Figure 6. Observed and projected annual flows of the Lim River at Prijepolje with the composite trend under A1B and A2 emission scenarios.

Results

- The flow projections for **the near future (2013-2040)** suggest a decrease in the annual flows by **7% (A1B)** and an increase by **5% (A2)**.

- **The mid-distant future (2041-2070)** is expected to bring a greater reduction in annual flows from **1% (A1B) to 12% (A2).**

- The greatest decrease in annual flows is expected in **the distant future (2071-2100),** with the annual flow medians dropping **by 18% (A1B) and 22% (A2)**.

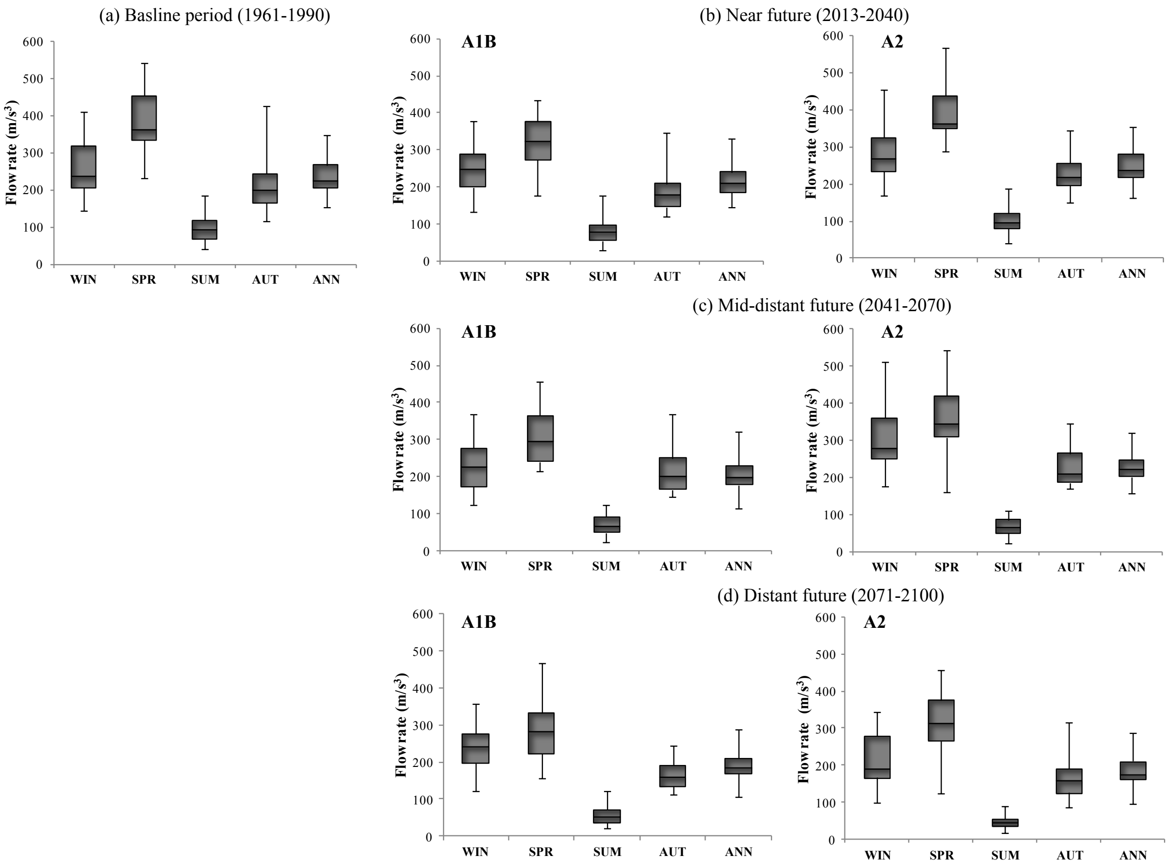

Figure 7. Distributions of the seasonal and annual flows for the Lim River at Prijepolje under A1B and A2 emission scenarios for (a) baseline period 1961-1990, (b) near future 2013-2040, (c) mid-distant future 2041-2070, (d) distant future 2071-2100.

Results

- The change in the intra-annual distribution of precipition and an increase of temperature brings **a significant change in the intra-annual flow distribution**.

- The greatest reduction is expected **for the summer flows**, in the distant future.

- An increase can be seen for **the winter flows** in the mid-distant future.

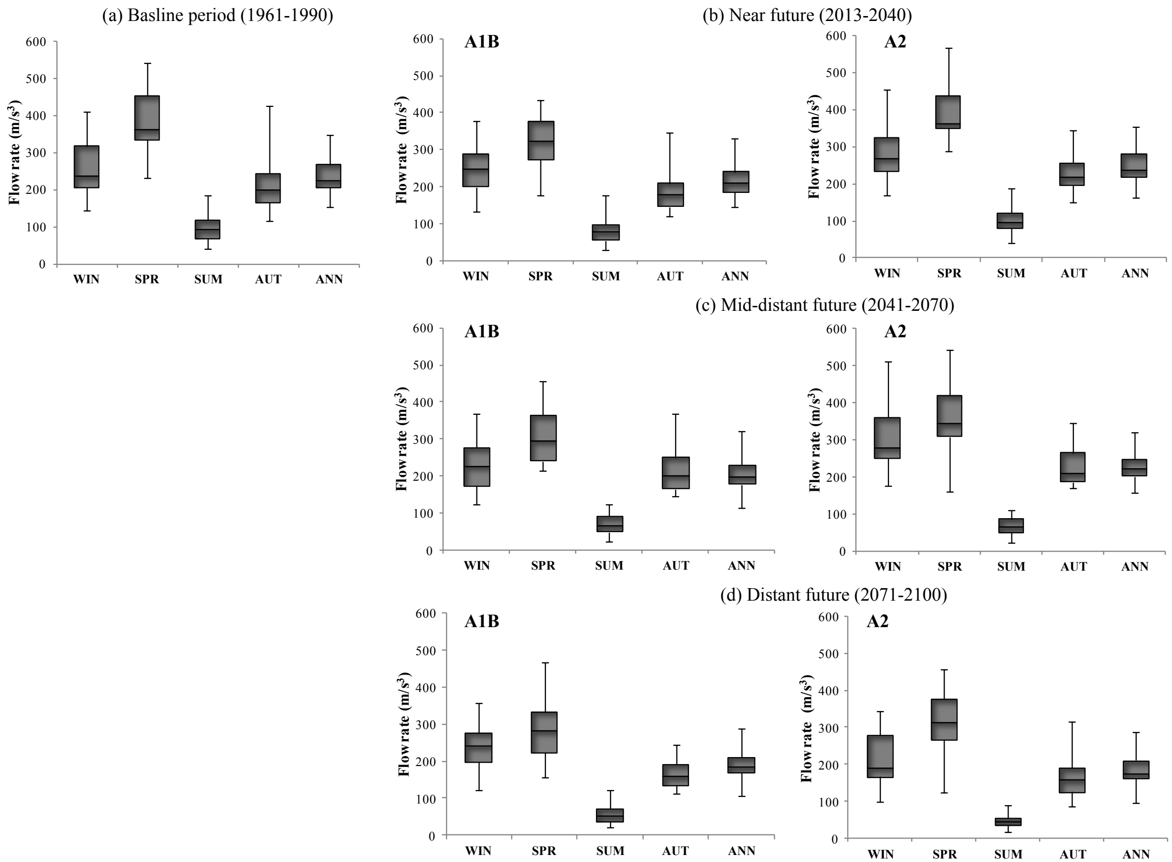

Figure 7. Distributions of the seasonal and annual flows for the Lim River at Prijepolje under A1B and A2 emission scenarios for (a) baseline period 1961-1990, (b) near future 2013-2040, (c) mid-distant future 2041-2070, (d) distant future 2071-2100.

Conclusions

- The presented study has brought **an alternative deterministic-stochastic model** for estimation of monthly flow predictions which uses **two-stage time series modelling based on the transfer functions**.

- As opposed to a number of recently developed methods for flow prediction, the proposed model is capable for modelling observed **short-run and long-run statistical dependence of flow series.**

- This is provided by employing **time series decomposition at annual and monthly time scale**, **which separates the high, seasonal and low frequency components**.

Conclusions

- The study results can be used for implementation **in a climate change adaptation strategy for the Lim River basin**.

- The proposed model could be used for making **the effective water management** plans **in Suthestern European region**.

- These plans can present a reliable foundation **to optimize the operation rules of the constructed water systems and to design new water facilities**.

- The challenge of these water systems in the future will be **dealing with the potential water scarcity in Southeast Europe caused by climate change**.

Thank you for attention!