HYDROPREDICT CONFERENCE

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OBSERVED AND FUTURE CLIMATE AND HYDROLOGICAL TRENDS IN SERBIA

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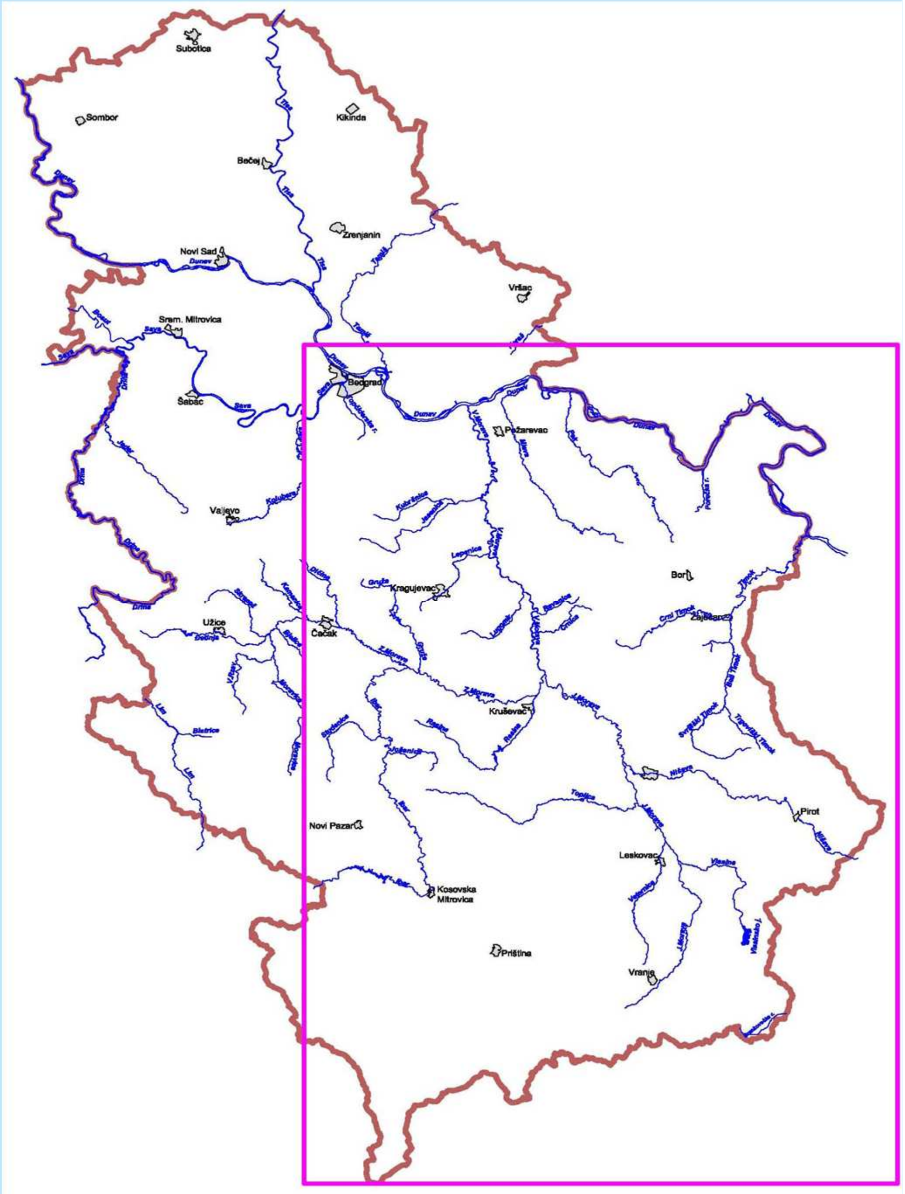
The topic of this presentation

With regard to future drinking water supply security, considerable pressures are expected in central and eastern Serbia, given the imminent increase in water demand and decrease in discharge (to a greater or lesser extent) of all rivers in the region.

The topic of this presentation is an assessment of the decline in average annual and monthly river discharges during low-flow periods, and their correlation with derived temperature and precipitation data and trends.

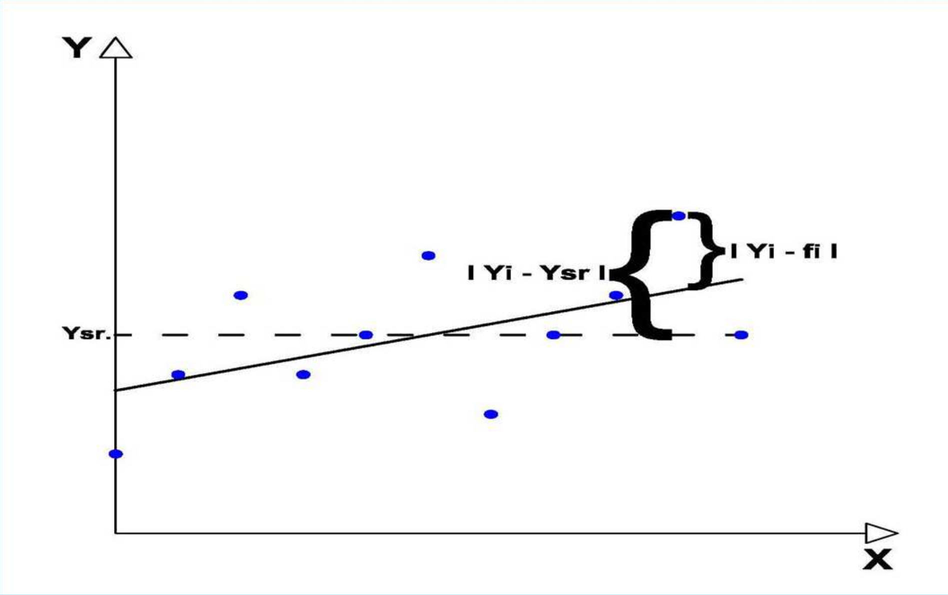
The presented results could be interesting, apart from Serbia and Southeast Europe, in some other parts of the world regarding the proposed methodology for the assessment of average temperature impact on average river discharge and precipitation.



Temperature and precipitation trends in Serbia

All global (GCM) and regional climate models (RCM) predict an increase in temperature, and most also predict a decrease in precipitation in Serbia. However, only a few of these models offer spatial (within Serbia) and temporal (yearlong) distributions. Each prediction is sensitive to assumption uncertainties and calculation imperfections. They need to be examined and critically assessed. The quality of a prediction grows with increasing validation (for near future period) by recorded data and especially by **trends**.

Of course, we must distinguish long-term and observed trend for one fix period.



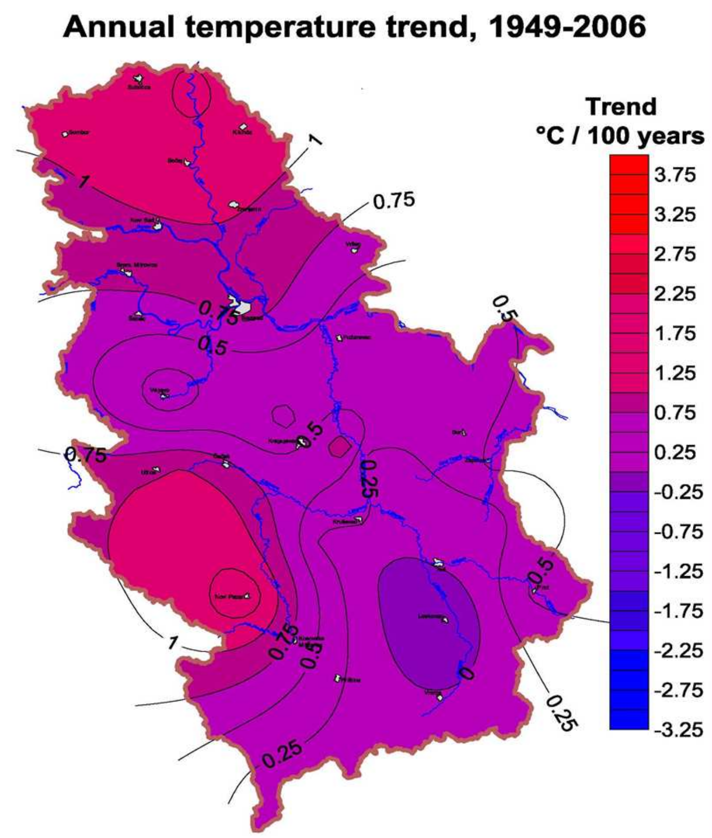
$$R^2 = 1 - \frac{SS_{err}}{SS_{tot}}$$

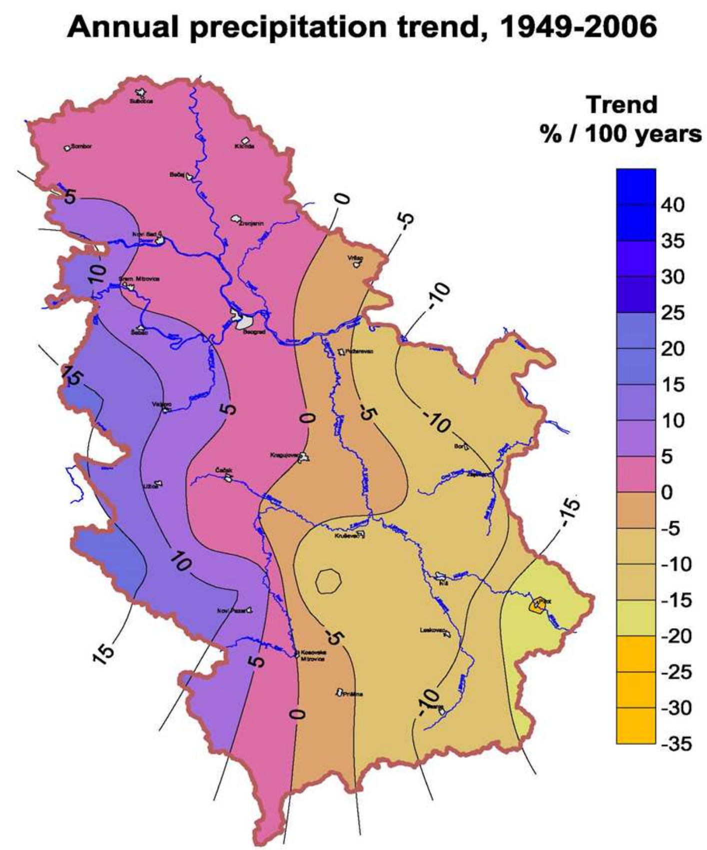
$$SS_{err} = \Sigma(y_i - f_i)^2$$

$$SS_{tot} = \Sigma(y_i - y_{sr})^2$$

Observed Temperature and Precipitation trends in Serbia

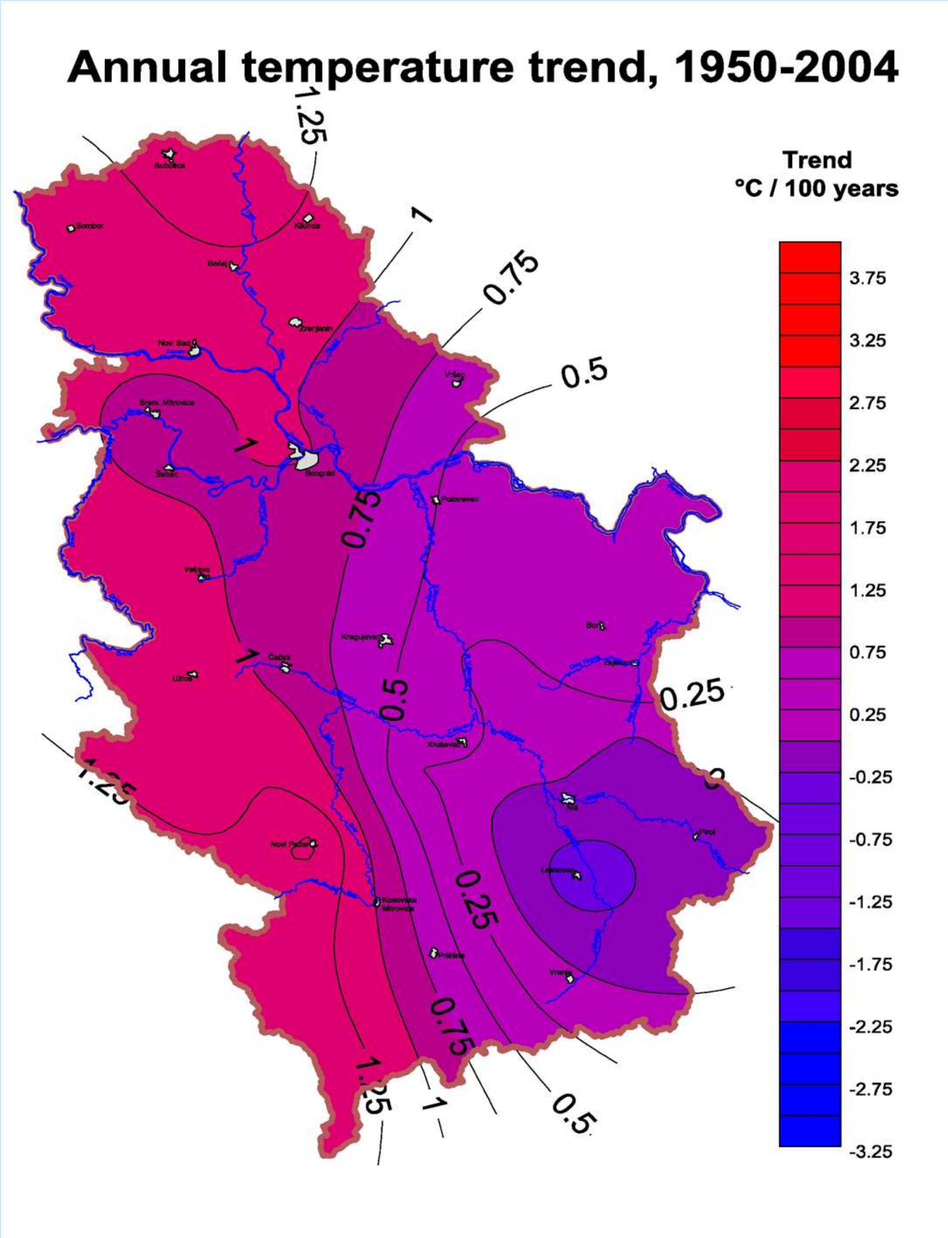
To assess past climate trends, 26 temperature and 34 precipitation stations were selected. The annual average temperature trend in Serbia was found to be about 0.6°C/100 years, while the annual average precipitation trend was slightly negative; the spatial distribution <u>with trend adjustment</u> is shown on this slide.

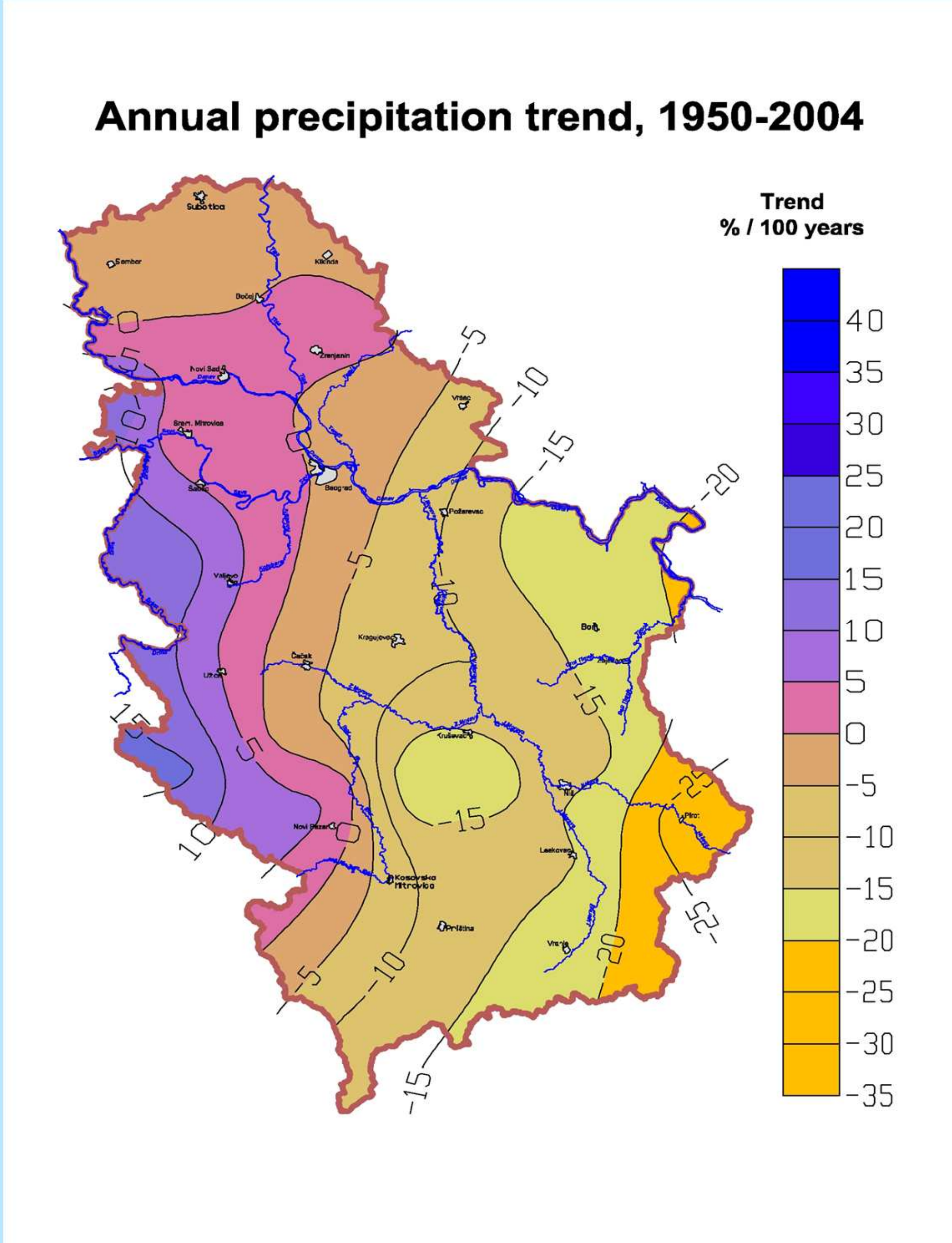




The period selected for analysis is from 1949 to 2006. This period is convenient because it is relatively long (58 years), data are available from numerous monitoring stations, and they exhibit a close similarity to estimated long-term temperature and precipitation trends, and particularly river discharge trends in Serbia.

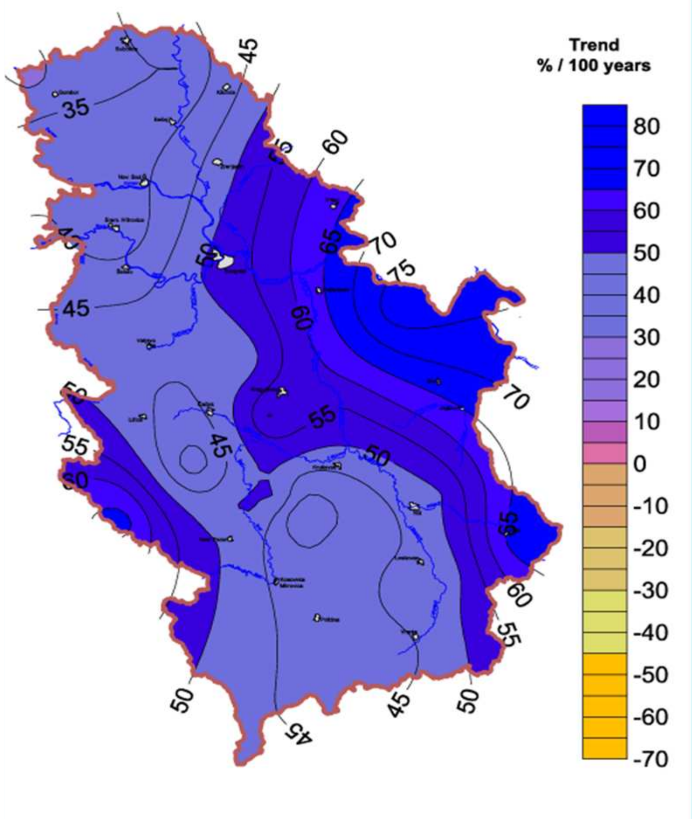
Observed Temperature and Precipitation trends in Serbia (1950 - 2004)



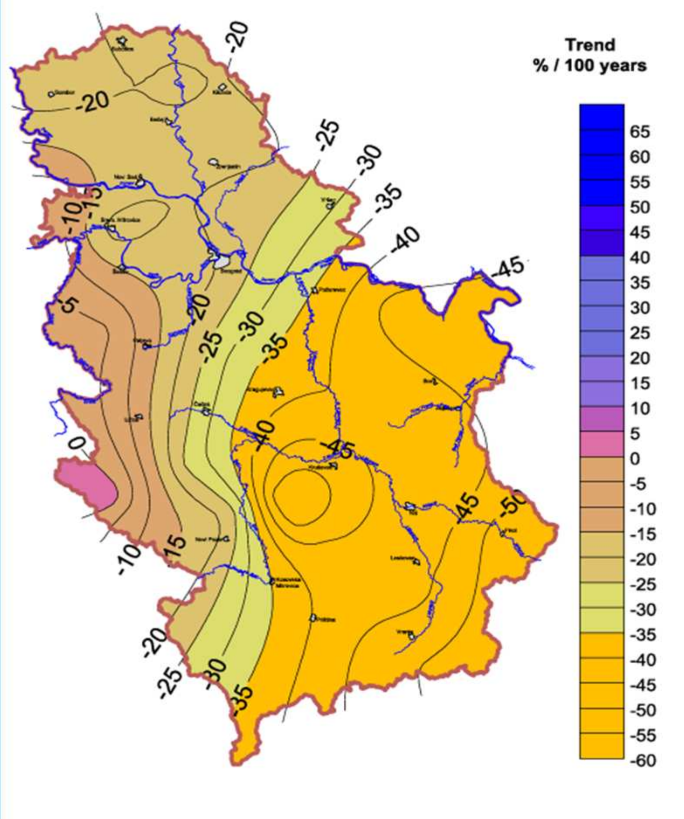


Observed Precipitation trends in different periods, with **extreme, long-term not realistic** spatial distribution

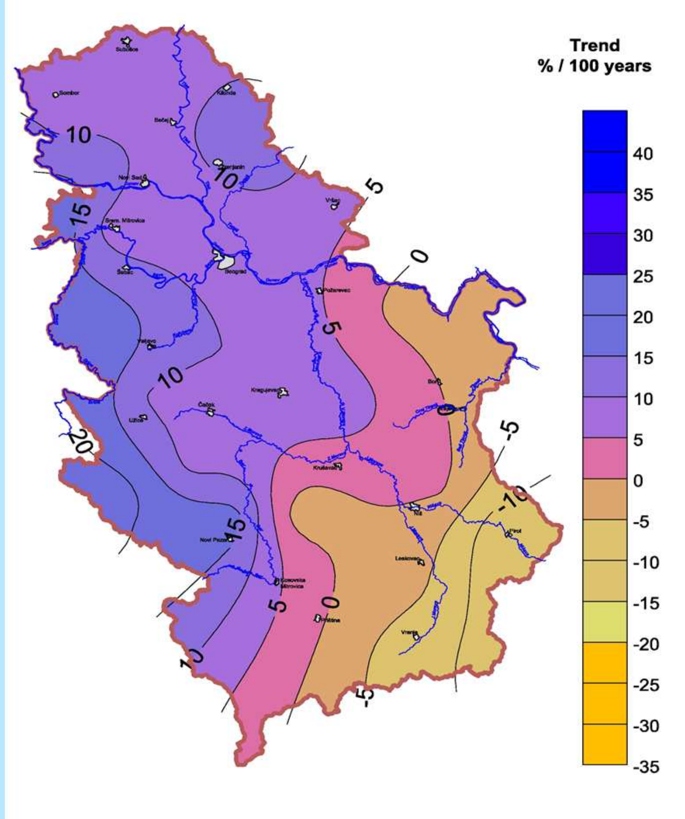
Annual precipitation trend, 1946-1980



Annual precipitation trend, 1954-2000



Annual precipitation trend, 1946-2006



Temperature and precipitation monthly trends in Serbia

The distribution of certain monthly **Temperature**, and especially **Precipitation** trends (in most number of analyzed RCM) are questionable :

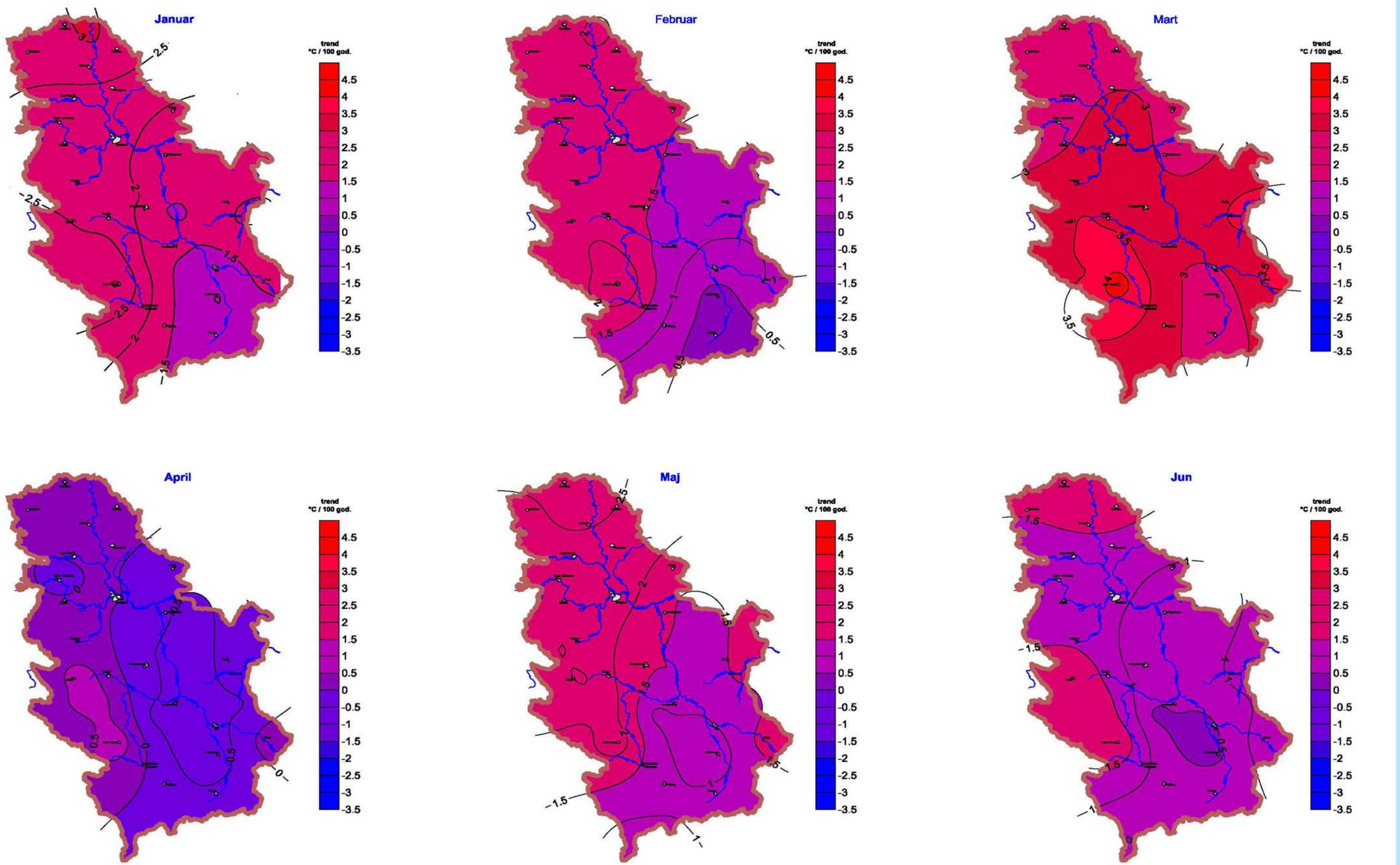
1. The highest upward **Temperature** trends have always been predicted for the months of July, August and September. As for July and August it's not exactly, but also it's not so far from the observed trends, for September it's quite different. This month, along with November and December, was the only month with a distinct negative temperature trend (in the order of -1.4°C/100 years).

2. The highest downward **Precipitation** trends was almost always predicted for the months of July, August and September (often in the order of -50%/100 years), which is inferior to the predicted annual trend, while the actual trends in July, August and September in Serbia were in the order of +10, +20 and +70%/100 years, respectively. September is at the same time the month with the highest and most consistent positive precipitation trend in all of Serbia.

Table 1 Registered 1949-2006 trends by month and annual averages

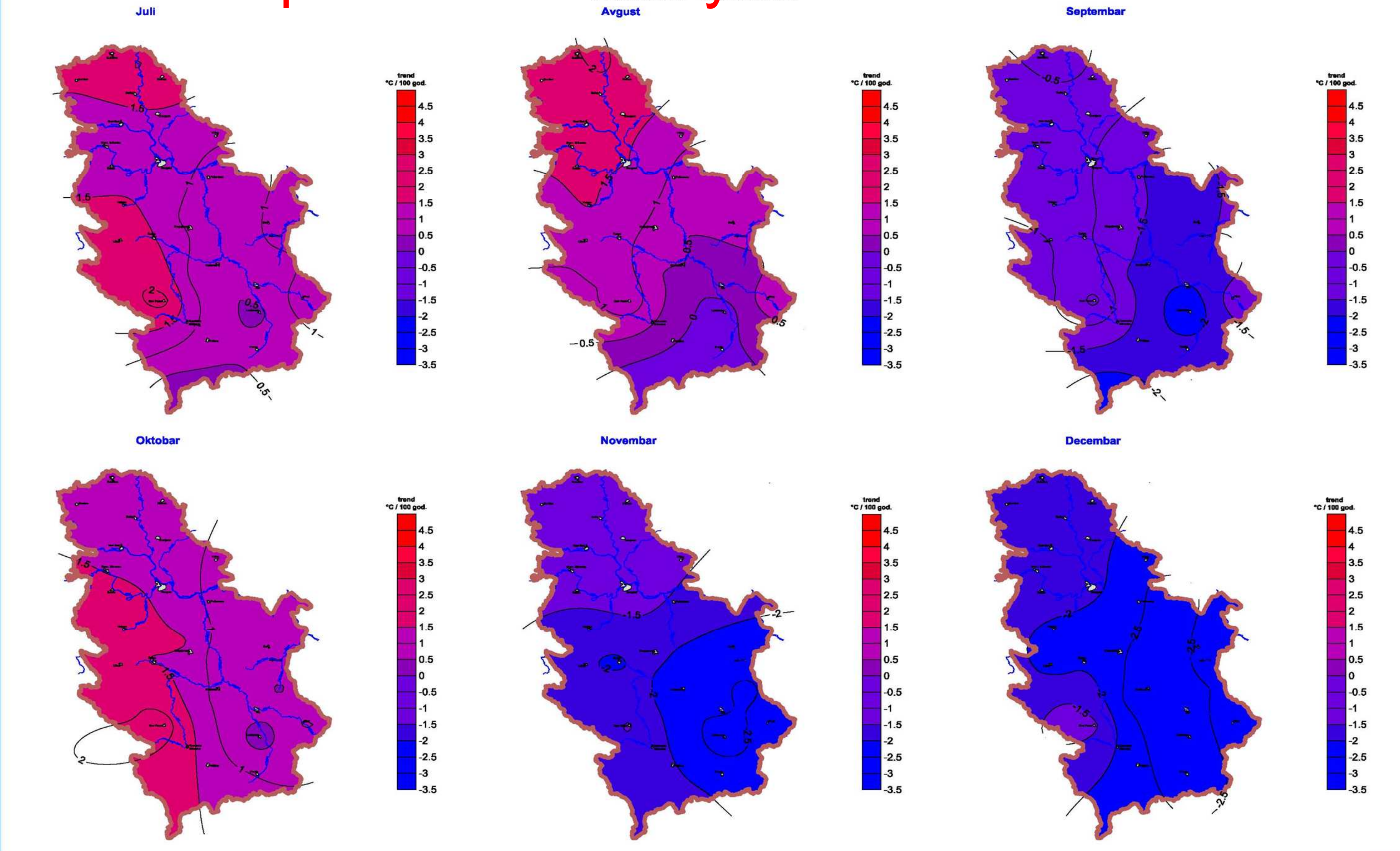
Type of station	Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Aver
Temperature (°C/100years)	Average of 26 stations	1.9	1.3	3.2	-0.1	1.7	1.1	1.1	0.8	-1.4	1.2	-1.9	-2.2	0.6
Precipitation (%/100years)	Average of 34 stations	-16.0	-21.7	-12.4	35.7	-43.7	-6.6	11.5	43.1	70.9	6.3	-41.4	-17.9	-0.3

Temperature monthly trends in Serbia



Temperature trend	JAN	FEB	MAR	APR	MAY	JUN	JYL	AUG	SEP	OCT	NOV	DEC	Ann. av.
Average (°C/100 yrs)	1.9	1.3	3.2	-0.1	1.7	1.1	1.1	0.8	-1.4	1.2	-1.9	-2.2	0.6

Temperature monthly trends in Serbia



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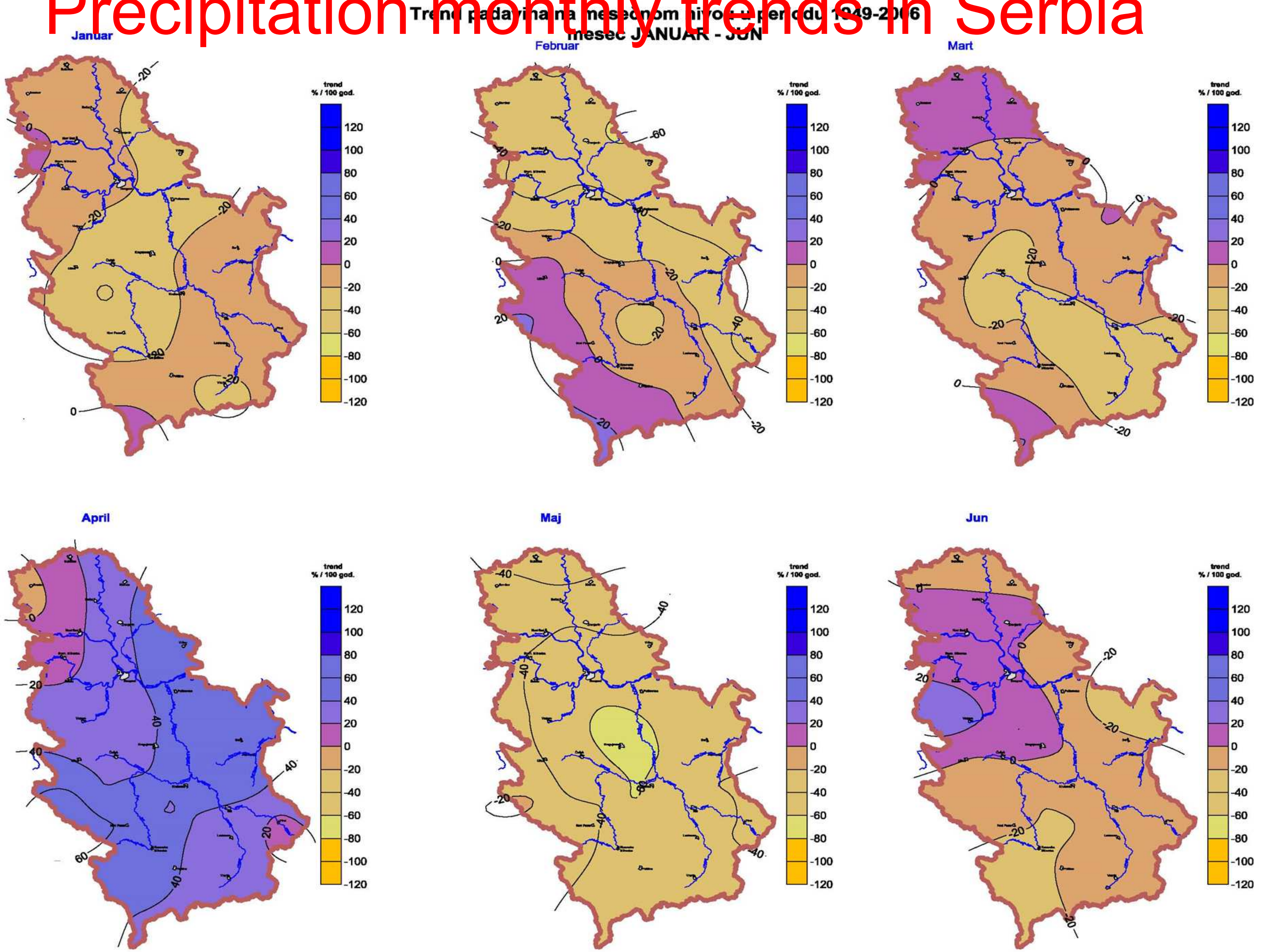
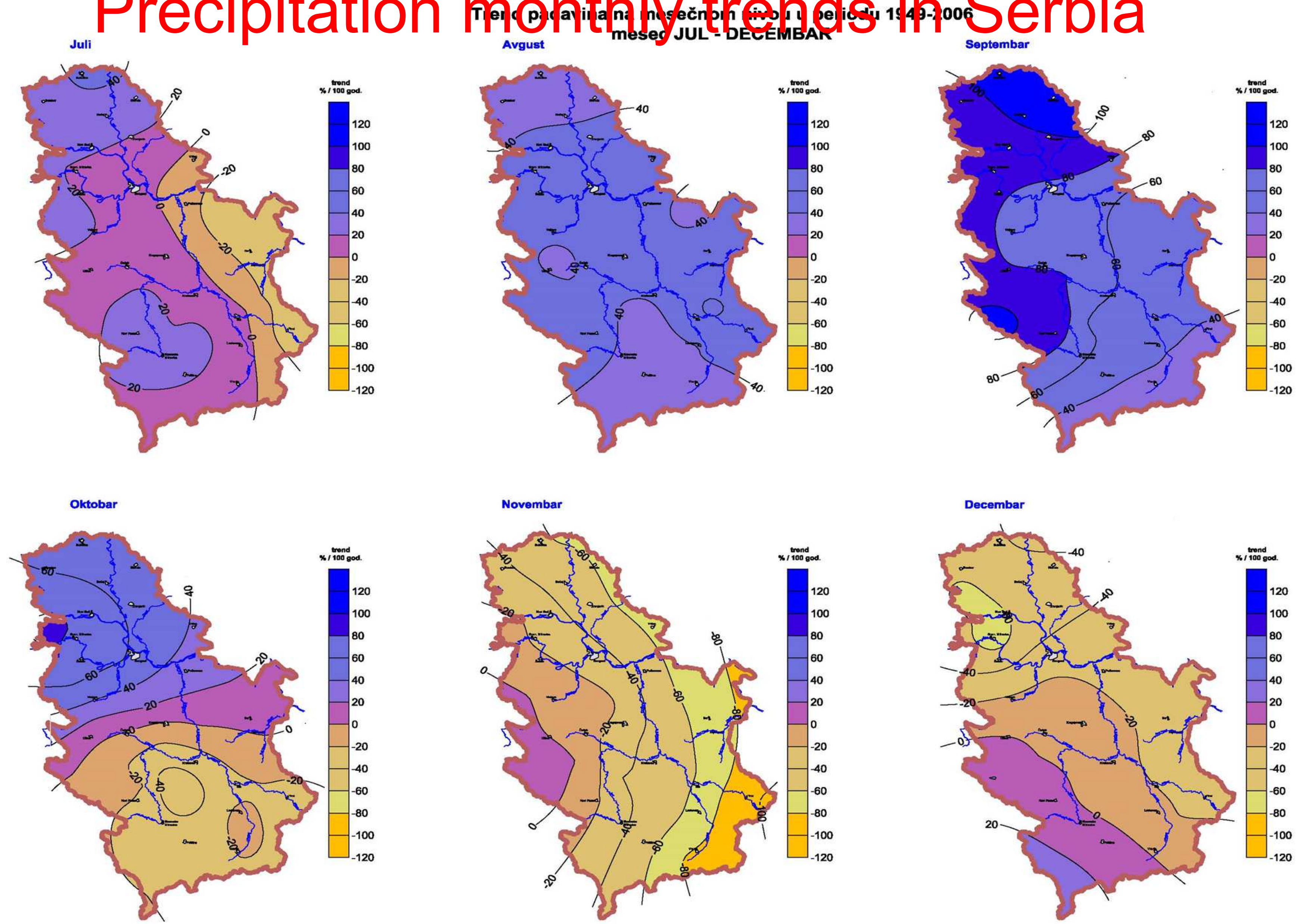
Precipitation monthly trends in Serbia



Precipitat. trend	JAN	FEB	MAR	APR	MAY	JUN	JYL	AUG	SEP	OCT	NOV	DEC	Annual av.
Average (%/100 y)	-16.0	-21.7	-12.4	35.7	-43.7	-6.6	11.5	43.1	70.9	6.3	-41.4	-17.9	-0.3

Precipitation monthly trends in Serbia

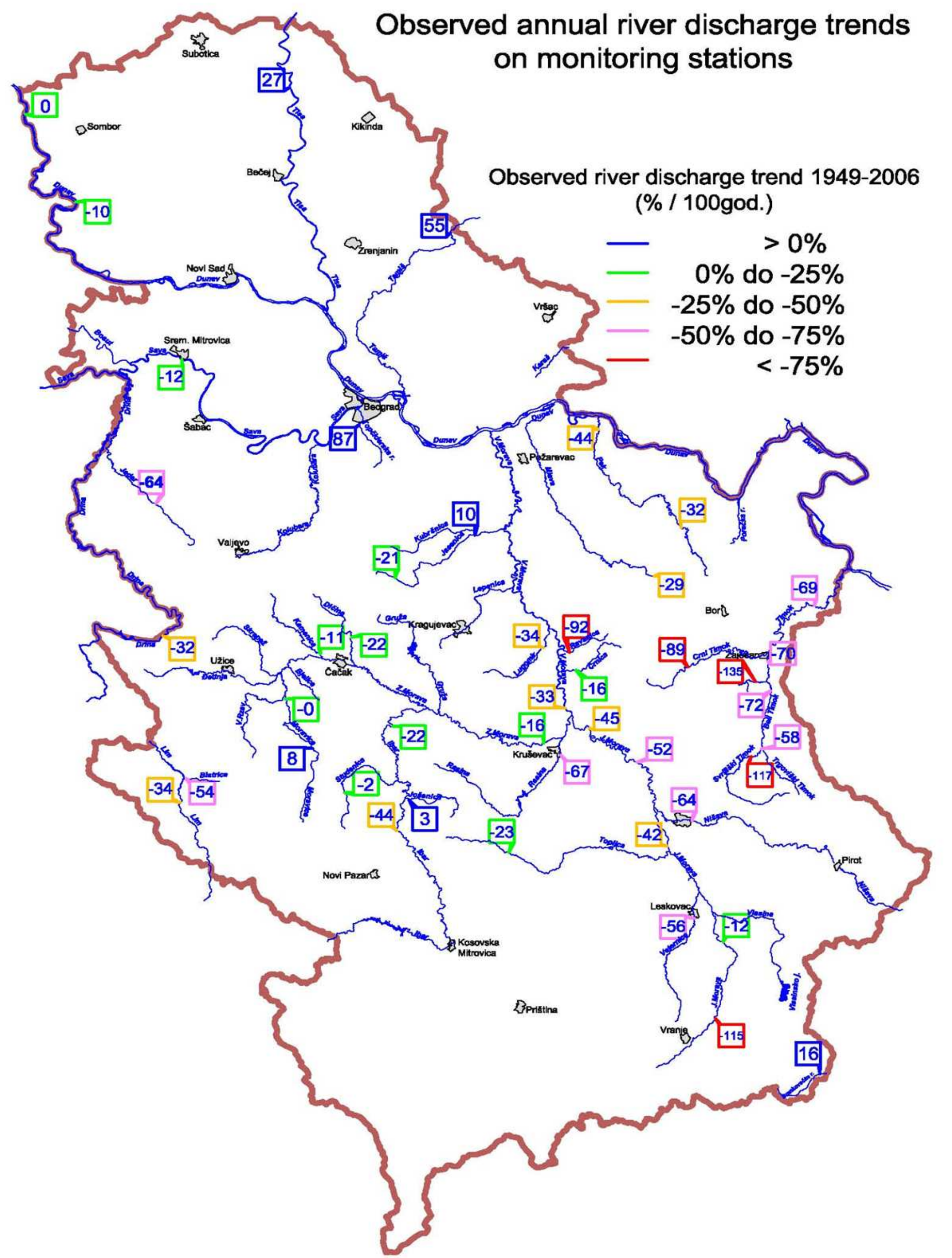


Precipitat. trend	JAN	FEB	MAR	APR	MAY	JUN	JYL	AUG	SEP	OCT	NOV	DEC	Annual av.
Average (%/100 y)	-16.0	-21.7	-12.4	35.7	-43.7	-6.6	11.5	43.1	70.9	6.3	-41.4	-17.9	-0.3

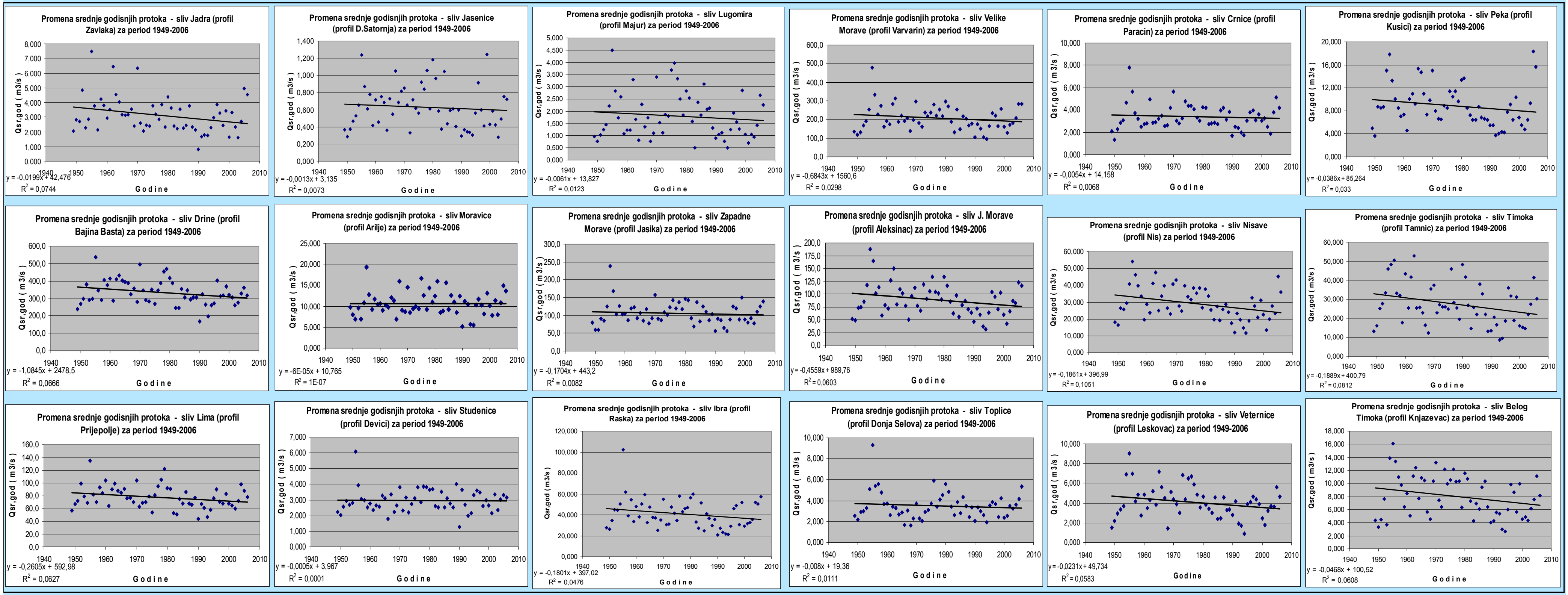
River discharge trends in Serbia

Serbia, especially its eastern part, experiences a downward river discharge trend (expressed as a percentage of the discharge per 100 years). However, contrary to climate parameters, it is difficult to spatially generalize because several factors affect these trends. The most important factors are :

1. The size of the river ,
2. The transfer of water, if any, between catchments upstream from a given hydrological station ,
3. The volume and the way of water used by man in a given C.A. ,
4. The presence or absence of river reservoir(s) in the C.A. ,
5. Any land use changes in the C.A. ,
6. Climate change (including differences associated with geographic locations within Serbia) .

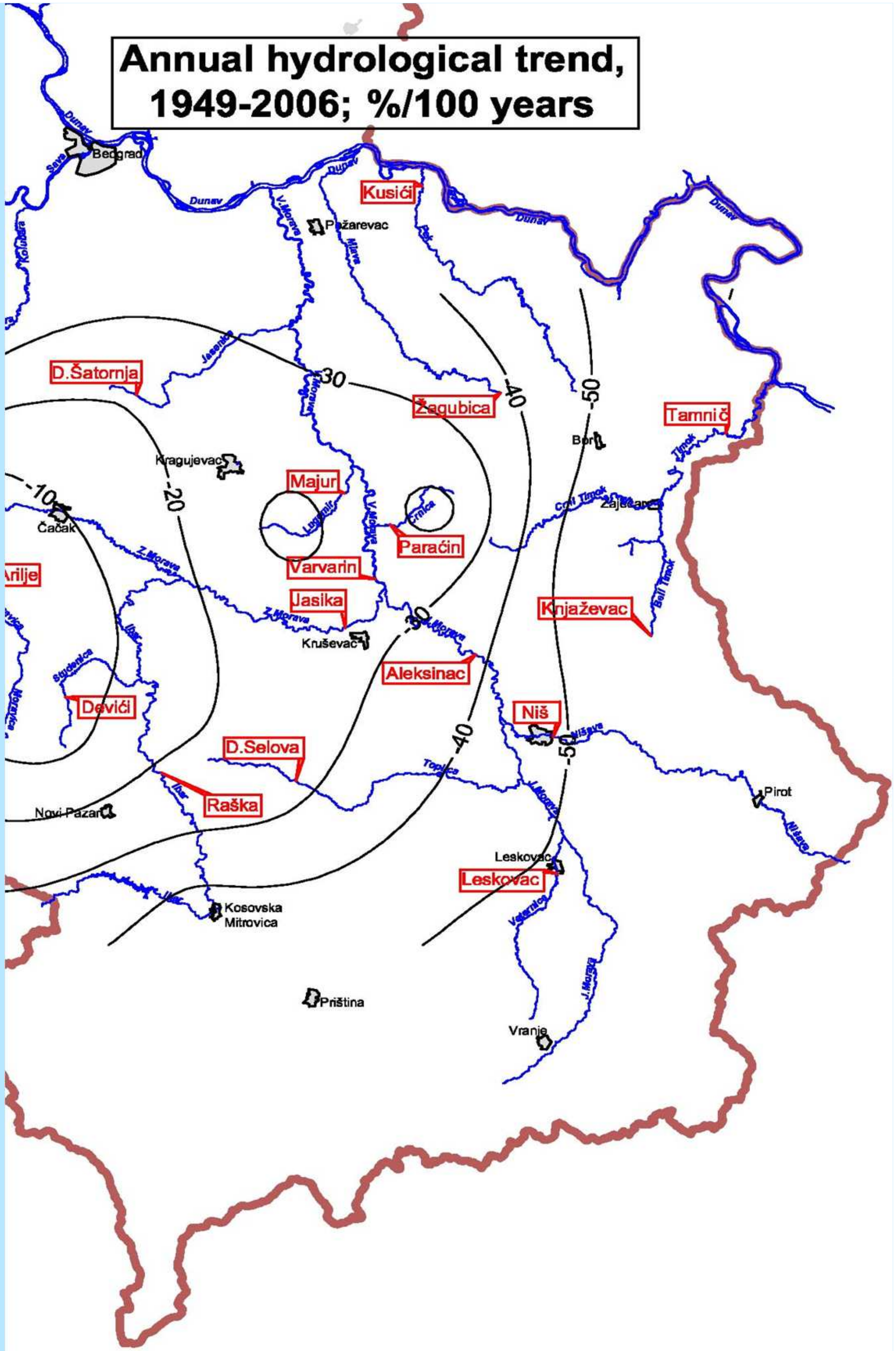


Observed river discharge trends in Serbia in period 1949 - 2006



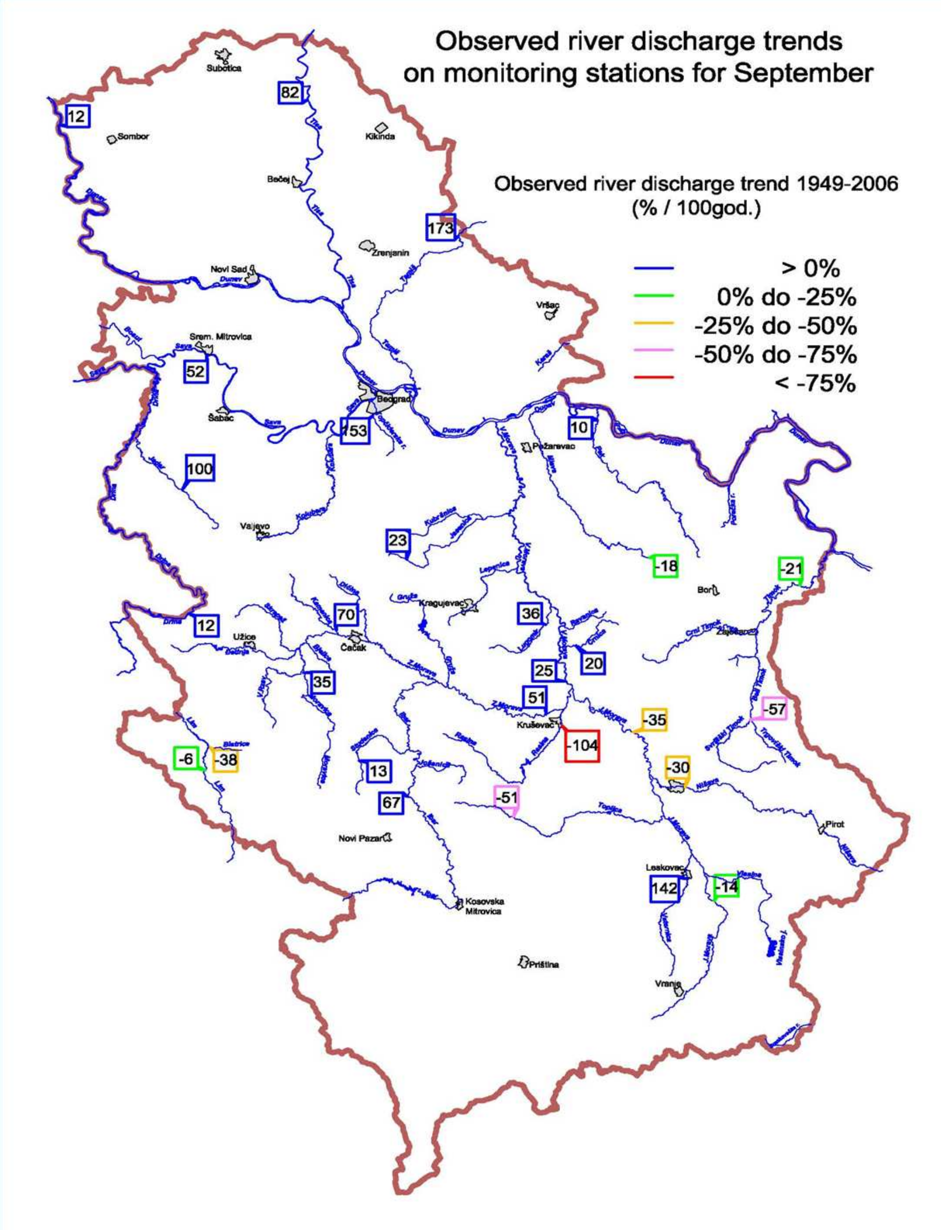
Geographical distribution of the downward average annual river discharge trends for central and eastern Serbia

A **<u>very approximate</u>** geographical distribution of the downward average annual river discharge trends for central and eastern Serbia is shown. <u>It should be noted that within all river discharge trend isolines there are rivers and monitoring stations which often exhibit significant trend variations (both up and down)</u>, as a result of Factors 1, 3, 4 and especially 2. This figure was compiled based on the trends recorded at 18 selected river monitoring stations across Serbia, where Factors 3 and 4 were assessed as having an acceptable degree of impact, and where Factor 2 was either absent or negligible.

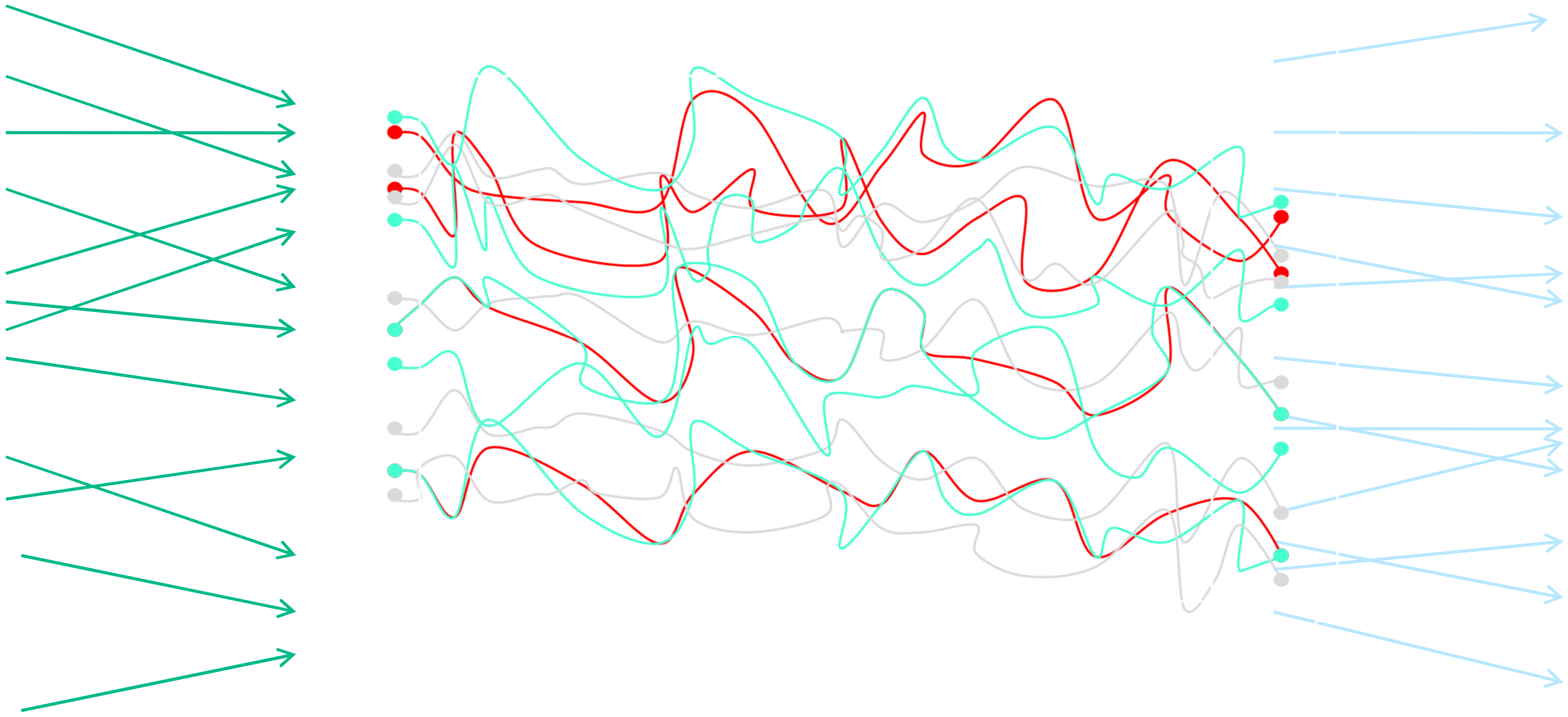


Observed river discharge monthly trends (low flow) 1949 – 2006 (%/100 yrs.)

	River – monitoring station	JYL	AUG	SEP	OCT	Ann. av.
1	Дрина – Бајина Башта	-44.4	-14.1	12.4	14.2	**-32.5**
2	Вел. Морава - Варварин	-16.6	21	25	-4.9	**-33**
3	Јуж. Морава– Алексинац	-43.9	18.6	-34.9	-23.6	**-51.7**
4	Западна Морава – Јасика	-12	15.5	51.1	-0.5	**-16**
5	Нишава– Ниш	-84.2	-1.1	-30.4	6	**-64.3**
6	Тимок – Тамнич	-32.3	11.1	-20.9	-29.4	**-69.1**
7	Бели Тимок – Књажевац	-121	-81.6	-56.5	-90.6	**-58.4**
8	Пек – Кусићи	-50.6	-4.5	9.6	3.5	**-43.5**
9	Ветерница – Лесковац	-29.1	30.2	142	29.1	**-56.4**
10	Топлица – Доња Селова	6.9	-23.8	-50.9	-119	**-22.9**
11	Црница – Параћин	-29.3	-110	20.3	-21.1	**-16.1**
12	Ибар - Рашка	-3.9	52.4	67.4	-42.8	**-44.2**
13	Лим - Пријепоље	-97.1	-60.1	-6.4	-20.6	**-33.5**
14	Моравица - Ариље	-59.8	-10.6	35.1	30.0	**-0.1**
15	Студеница - Девићи	-17.9	-6.3	13.0	-28.1	**-1.8**
16	Лугомир - Мајур	110	55.7	35.8	-56.5	**-33.8**
17	Јасеница - Доња Шаторња	59.1	-47.5	23.2	-8.5	**-20.2**
18	Јадар - Завлака	-16.0	21.4	100	-35.6	**-63.4**
	Average	**-26.8**	**-7.4**	**18.6**	**-22.1**	**-36.7**



What is to be expected in the future?



What is to be expected in the future?

What is to be expected in the future?

For each of the rivers, relative values of the following parameters were calculated :

- Average annual river discharge at a given monitoring site (Qav,year),
- Annual precipitation sum recorded at the reference rain gauge station (ΣPyear),
- Annual average temperature at the reference temperature recording station.

Relative values represent the number obtained by dividing a given data point with its average value for the entire series; the only exception is temperature where, instead of a quotient, the given value and the average value of the entire series are differentiated

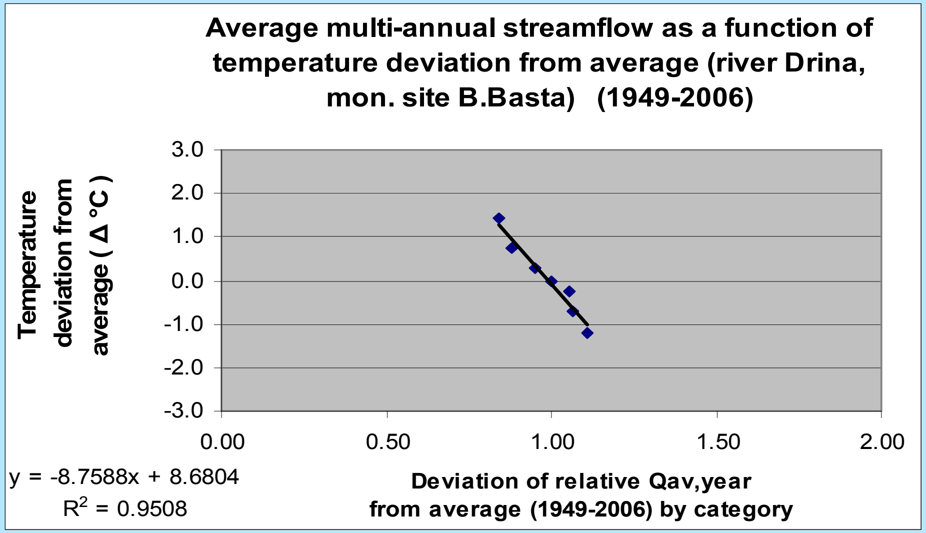
Relevant data were grouped into categories depending on deviations of average annual temperatures:

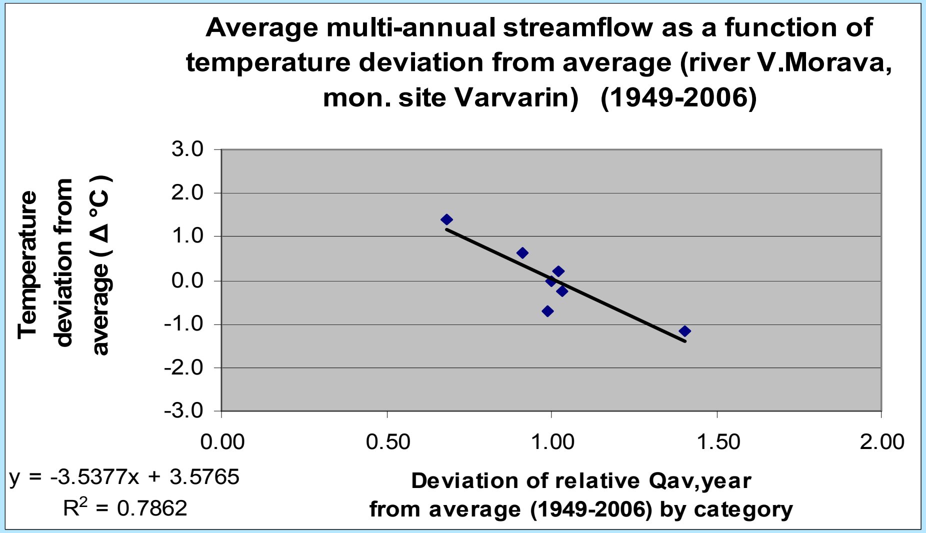
$T_{av}^{year} < -1.0$ °C
-1.0 °C $< T_{av}^{year} < -0.5$ °C
-0.5 °C $< T_{av}^{year} < 0.0$ °C
0.0 °C $< T_{av}^{year} < 0.5$ °C
0.5 °C $< T_{av}^{year} < 1.0$ °C
1.0 °C $< T_{av}^{year}$

Average values were calculated for each class and the obtained points were used to construct a graph of the dependency between the deviation of the average annual temperature and the given quantity (Q_{av}^{year} or ΣP_{year}). The graph shows the obtained linear trend and the coefficient of determination R2.

Relationships between Average Annual River discharges and Temperatures (rel. values) on 14 monitoring stations

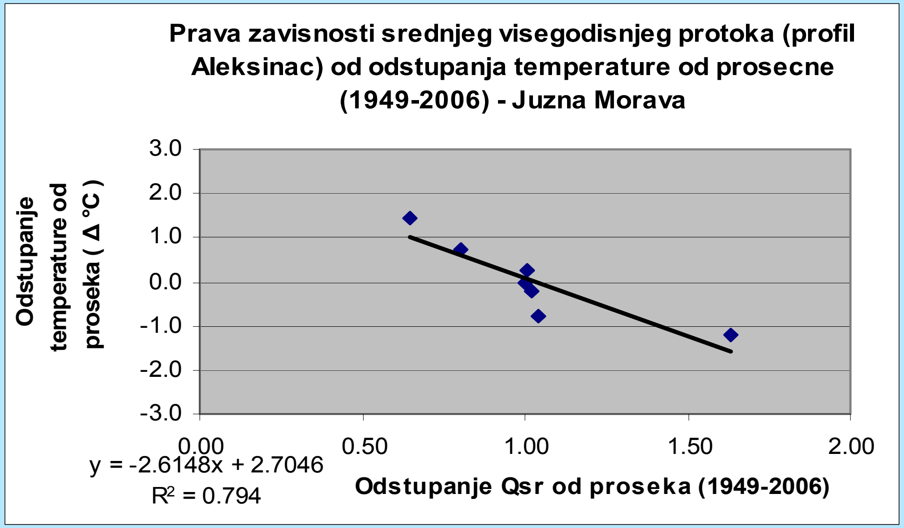
Average multi-annual river discharge as a function of temperature deviation from average for each river

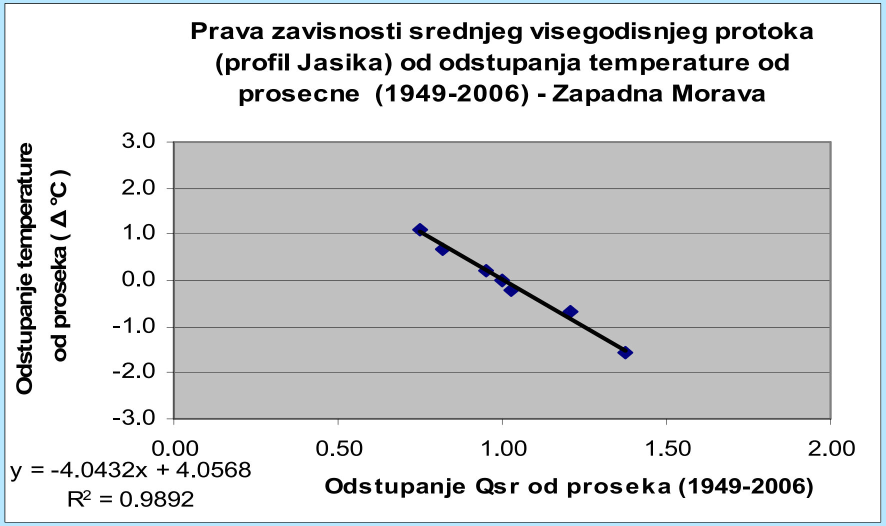


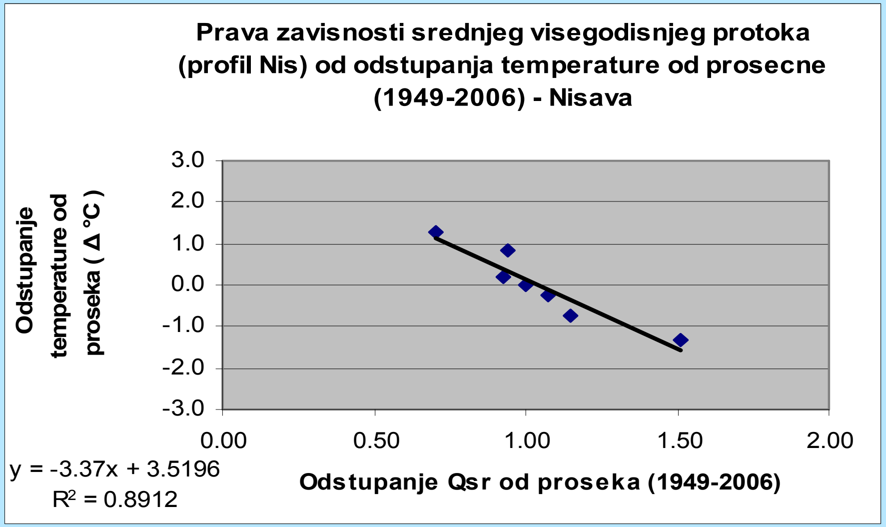


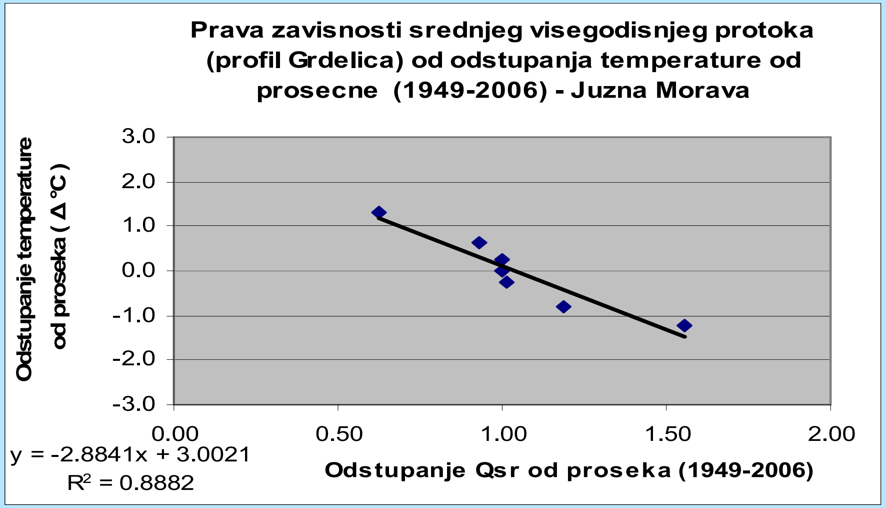
	River – monitoring station	Coef. R2
1	Дрина – Бај. Башта	0.95
2	Вел. Морава – Варварин	0.79
3	Јуж. Морава – Алексинац	0.79
4	Зап. Морава – Јасика	0.99
5	Нишава– Ниш	0.89
6	Јуж. Морава – Грделица	0.89
7	Тимок–Тамнич,	0.90
8	Бели Тимок – Књажевац	0.84
9	Пек – Кусићи	0.88
10	Расина – Бивоље	0.90
11	Ветерница – Лесковац	0.68
12	Топлица – Доња Селова	0.75
13	Црница – Параћин	0.98
14	Каменица – Пријевор	0.82

Average multi-annual river discharge as a function of temperature deviation from average for each river

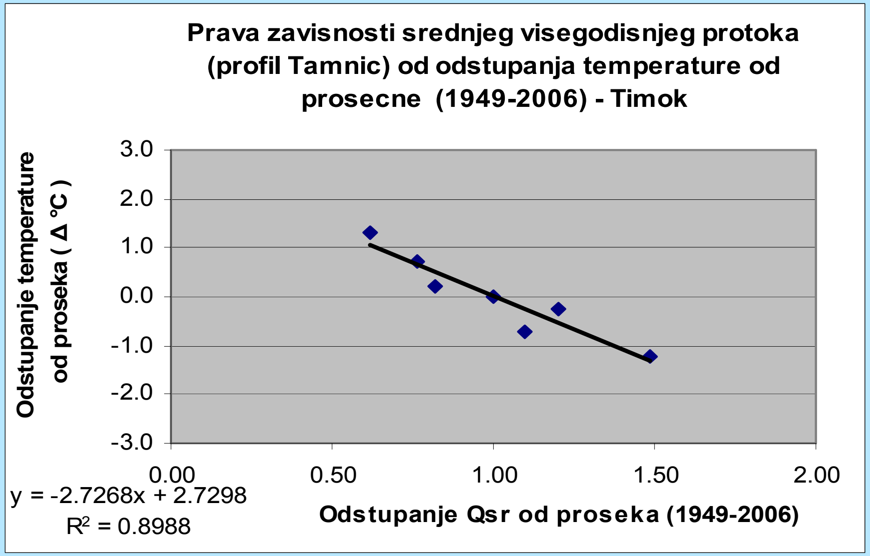


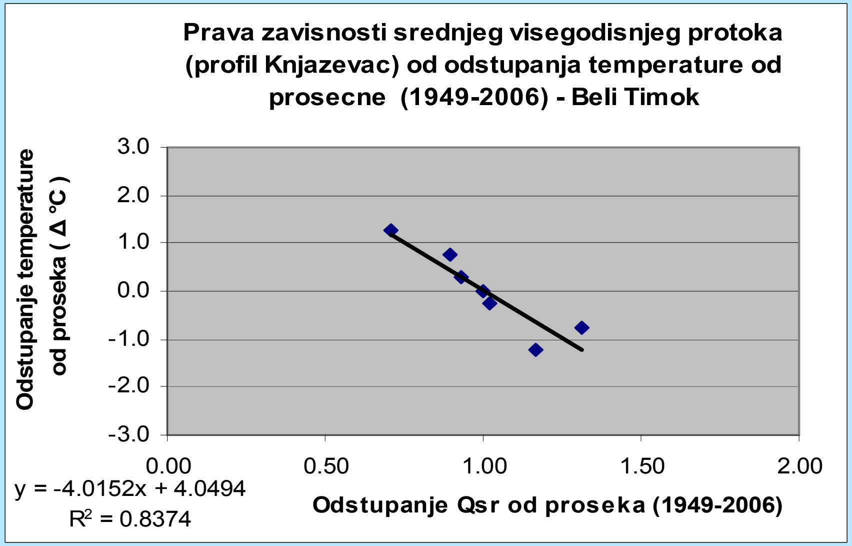


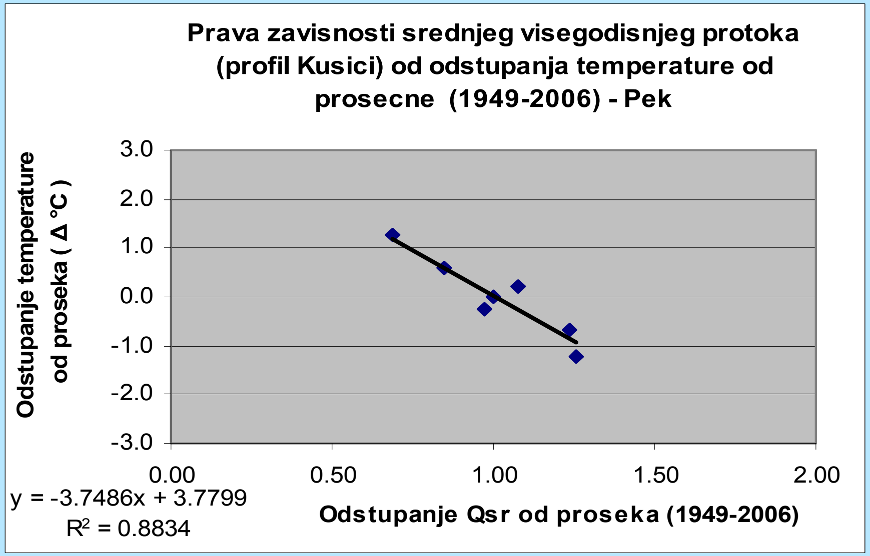


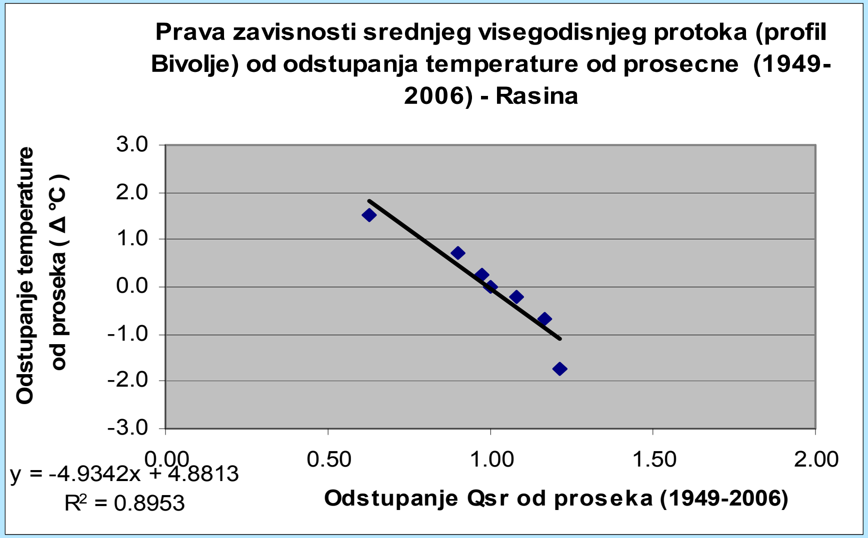


Average multi-annual river discharge as a function of temperature deviation from average for each river

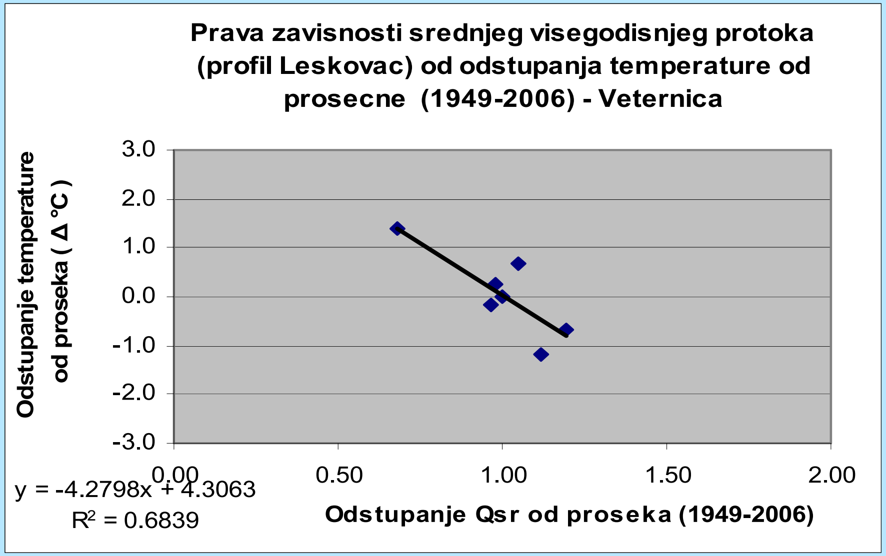


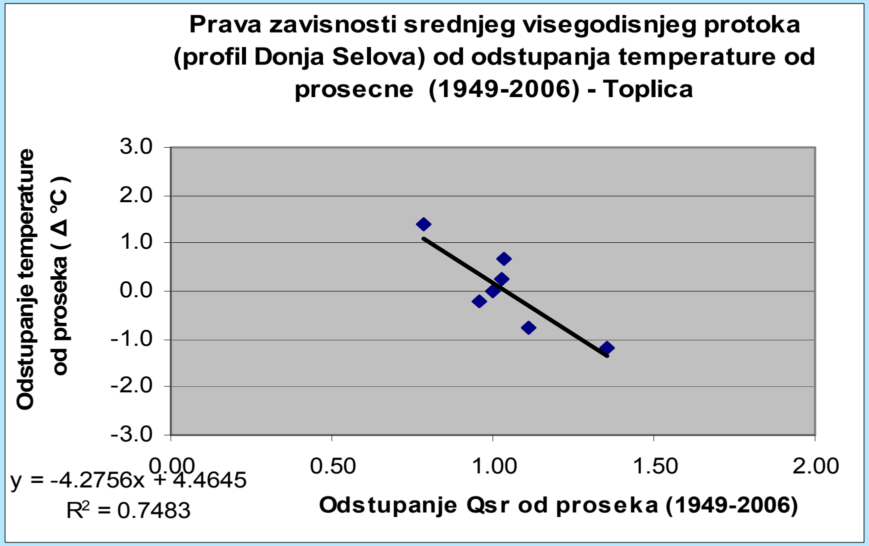


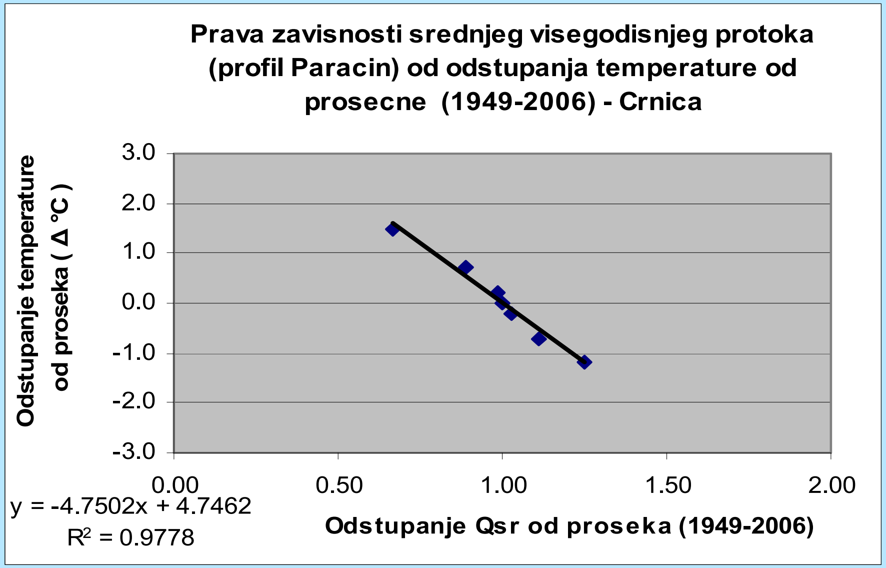


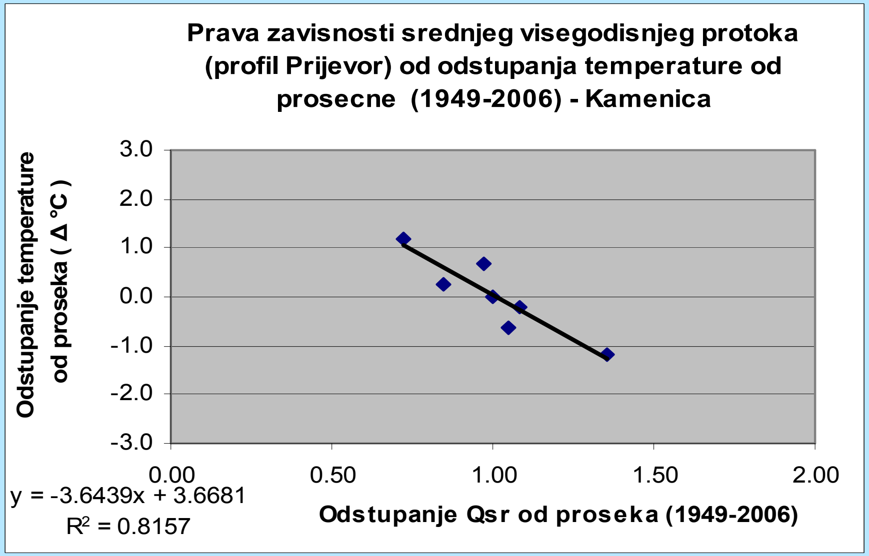


Average multi-annual river discharge as a function of temperature deviation from average for each river







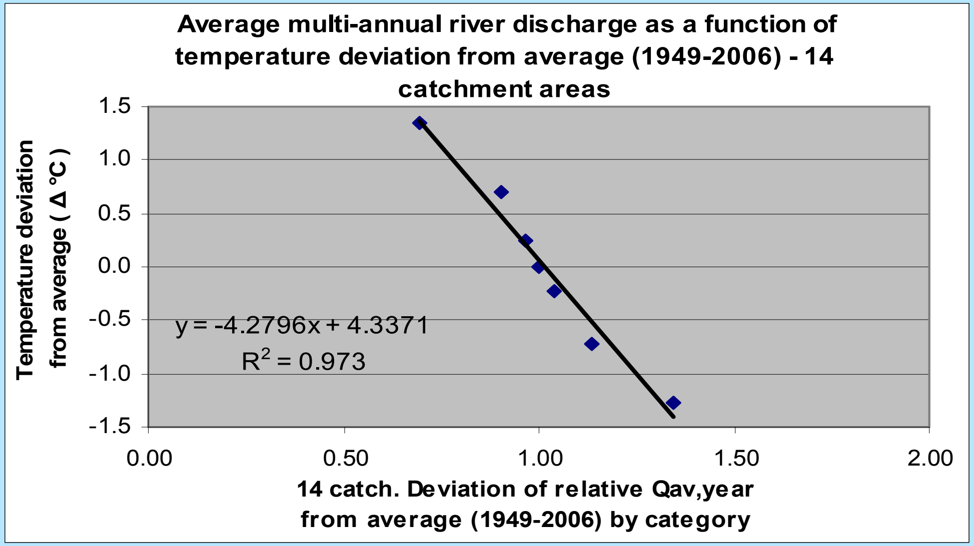


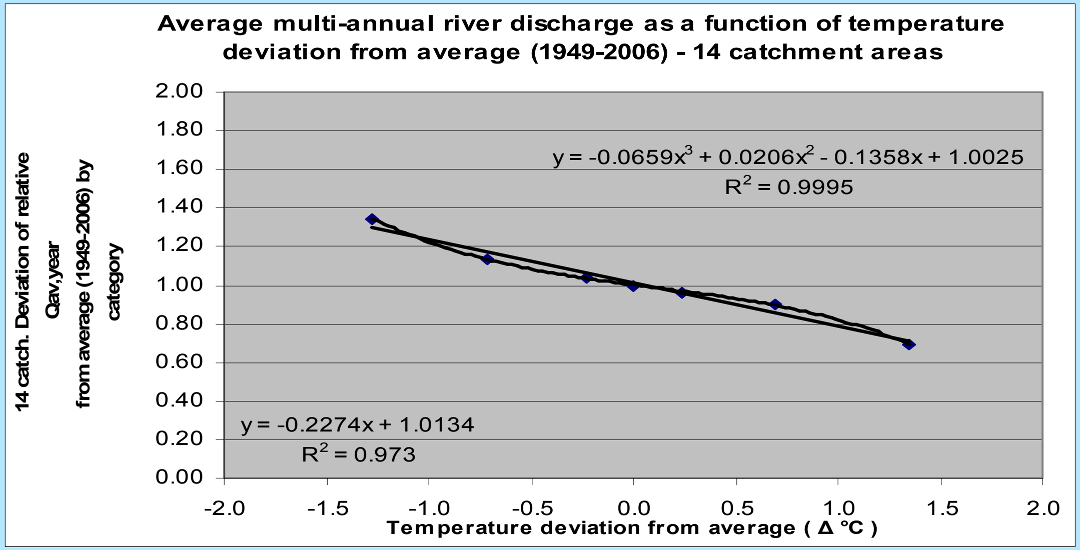
Average multi-annual river discharge (relative values) as a function of temperature deviation from average (1949-2006) – all 14 examples

Even though each of the 14 studied watersheds exhibits specific features, there is no dramatic difference between them (all show the expected trend of an average decline in stream flow with increasing temperature and vice-versa). It is, therefore, fully justifiable to synthesize all relevant data into a single data series.

This enlarges the data series by 58 members, of each of the analyzed series, to more than 800, and decreases the effect of random, non-standard years, especially in classes which otherwise have few data points.

Qav,y (-)	Precipit. (-)	Temperature (°C)
1.34	1.11	-1.27
1.14	1.07	-0.72
1.04	1.01	-0.23
1.00	1.00	0.00
0.96	1.00	0.24
0.90	1.00	0.69
0.70	0.84	1.34



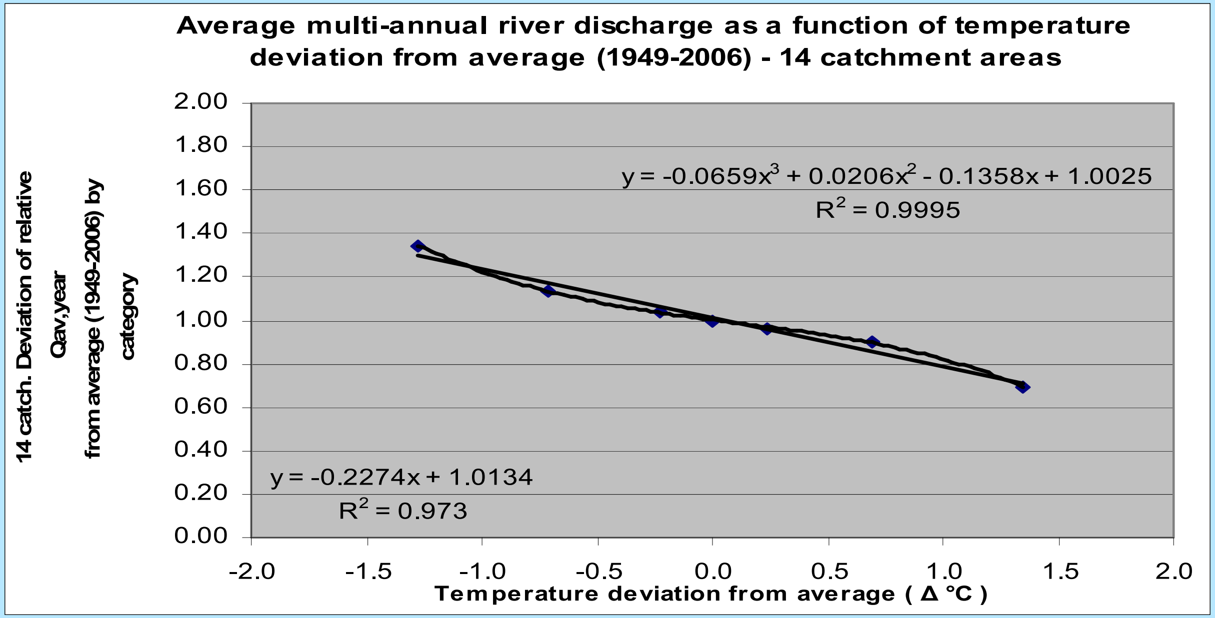


Average multi-annual river discharge (relative values) as a function of temperature deviation from average (1949-2006) – all 14 examples

Average relative river discharge and precipitation levels based on linear and 3rd degree polynomial trends for different increases in average annual temperatures

	ΔT_{av} (°C) →	**0.5**	**1.0**	**1.5**	**2.0**
Relative river discharge (Q_{rel})	Linear trend	0.90	0.80	0.70	0.60
	3rd degree polynomial trend	0.93	0.83	0.66	0.39
Relative precipitation (P_{rel})	Linear trend	0.97	0.93	0.89	0.86
	3rd degree polynomial trend	0.99	0.94	0.85	0.67

If the average annual temperature were to increase by +2ºC, based on the correlations established to date between average annual river discharges and average annual temperatures, we could expect, on average, approximately -50% less water in rivers whose catchment areas largely lie within Serbia.



Distribution of differences between observed and calculated relative discharges

Methodology:

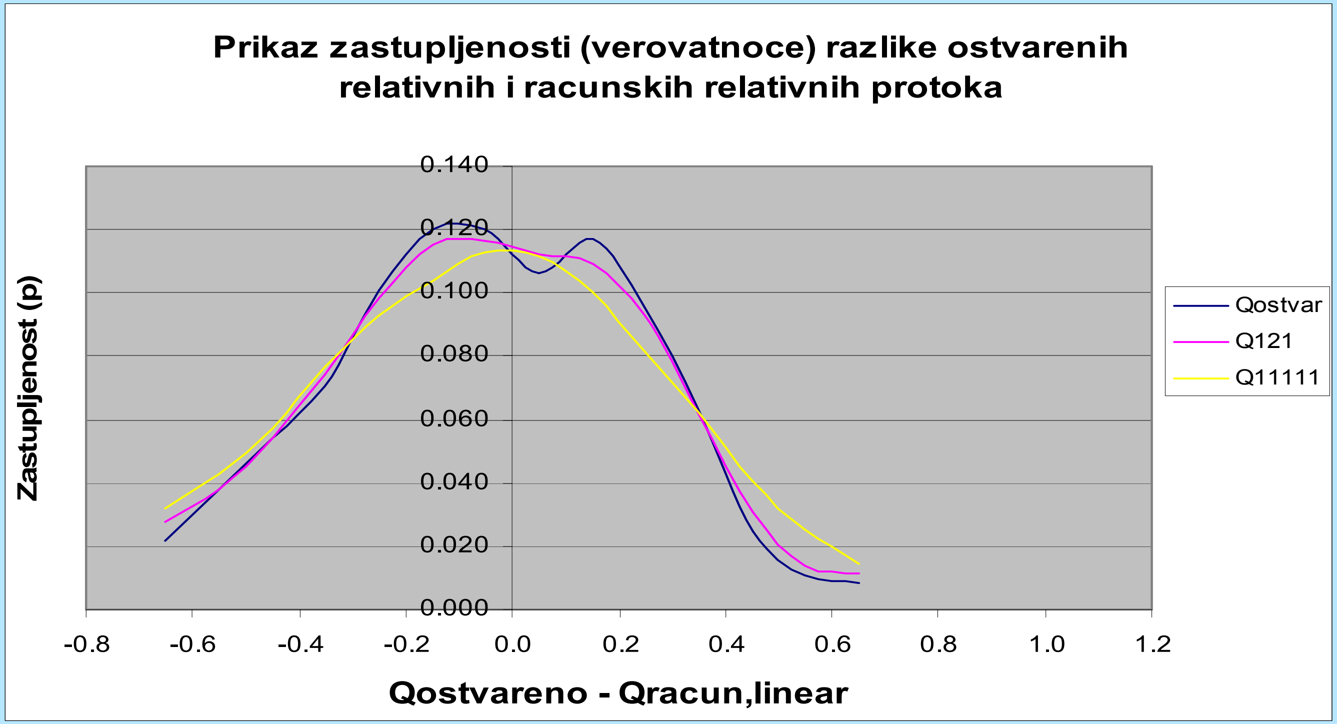
1. For all pairs of data relative T – relative Q (58 years x 14 hydrological and the nearest T stations) we calculate relative annual discharge using formula:

$$Q_{av.yrs.rel,\mathbf{calc}} = -0.2274 \times \Delta T_{av.yrs.} + 1.0134$$

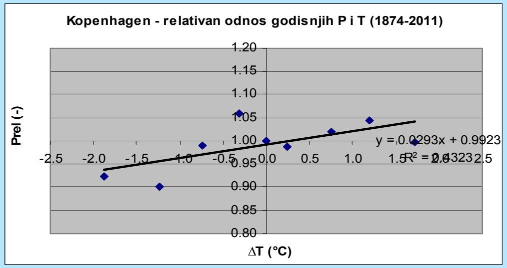
(separately for years with + relative temperatures, and for - relative temperatures)

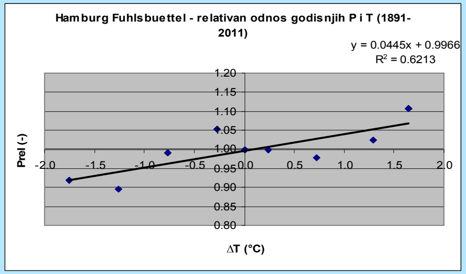
2. For all pairs of data we calculate difference: Qav.yrs.rel,**observ**. - Qav.yrs.rel,**calc**.

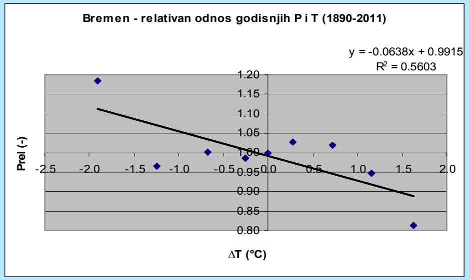
3. Then we group them in to the classes, count the number in each class and the resulting graph is as follows:

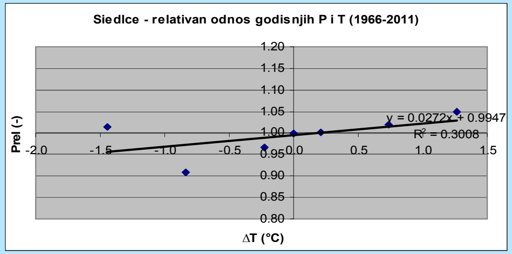


Relationships between summary annual Precipitations and average annual Temperatures (rel. values) in Europe

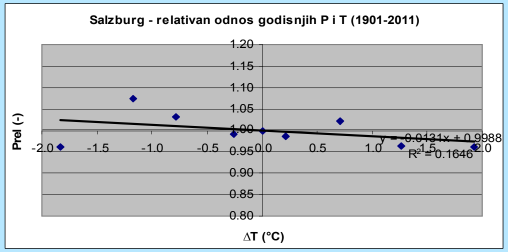


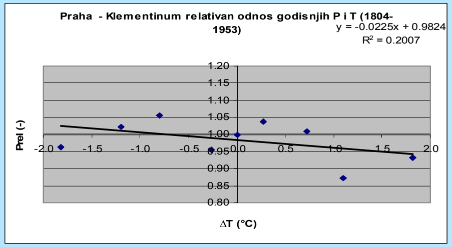


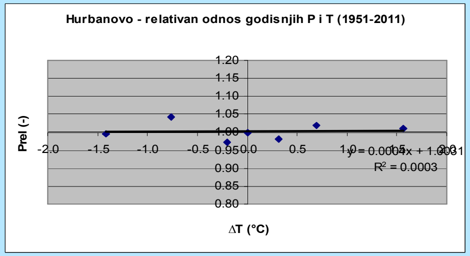


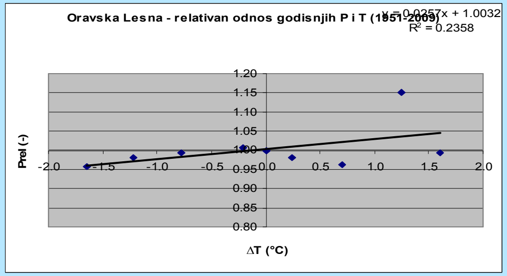


N O R T H M I D D L E E U R O P E









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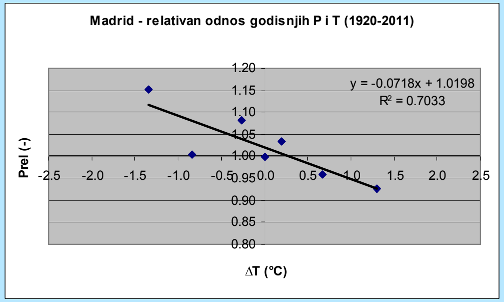
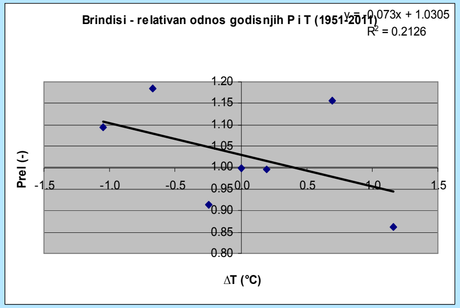
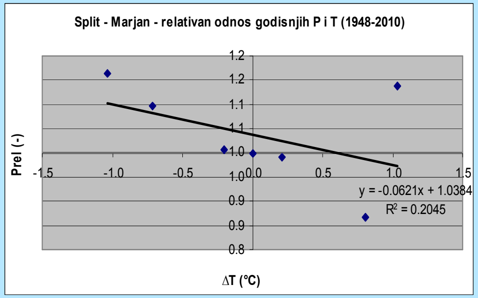
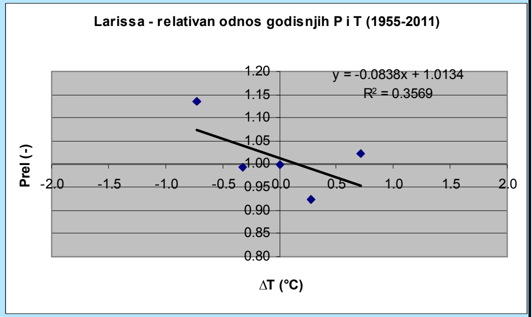


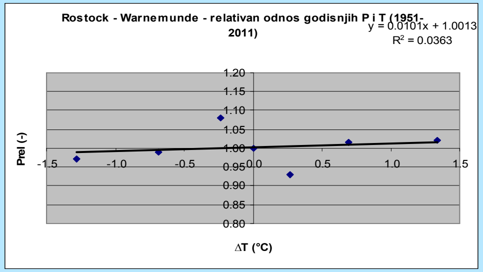


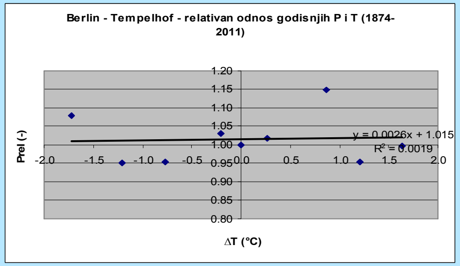


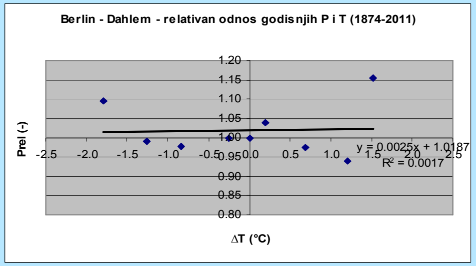


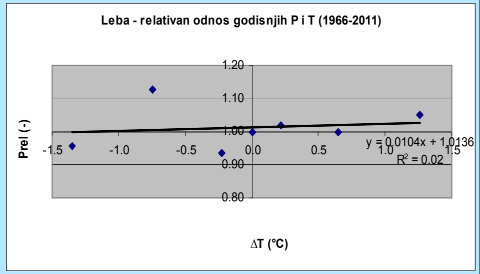
S O U T H E U R O P E

Relationships between summary annual Precipitations and average annual Temperatures (rel. values) in Europe









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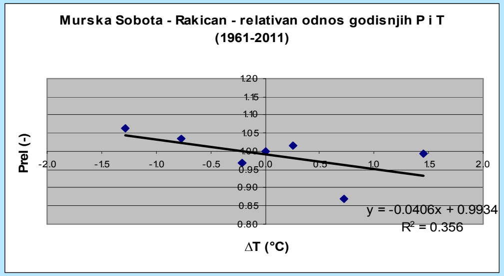

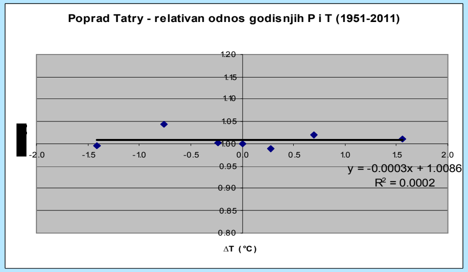

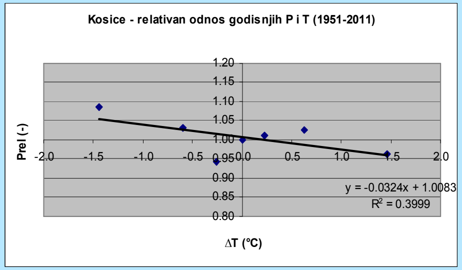

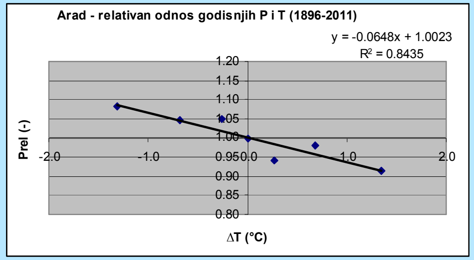

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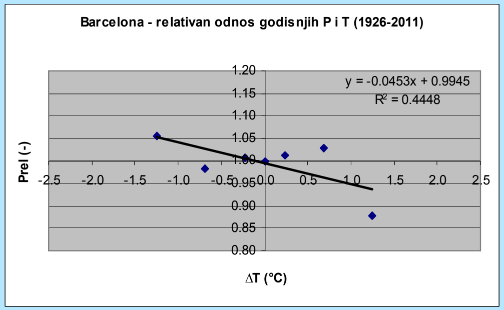

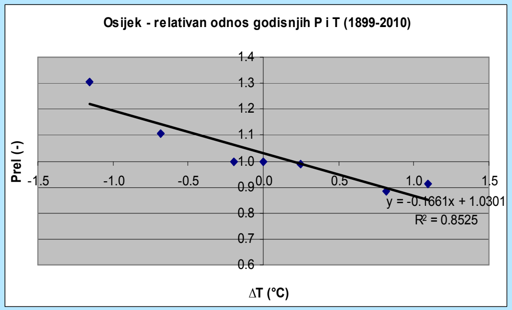

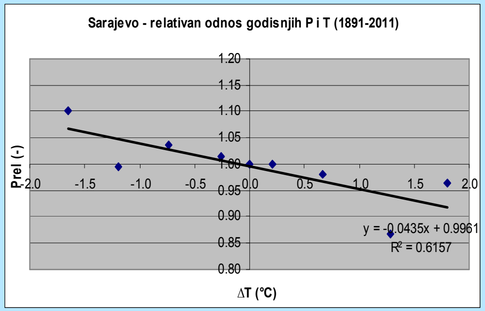

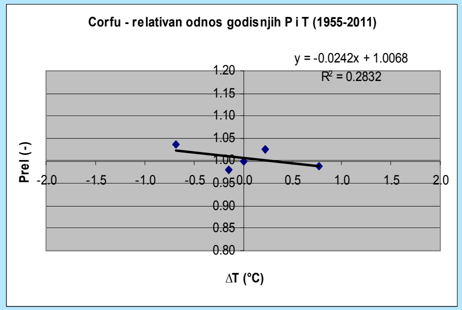

S O U T H   E U R O P E

Conclusions (related to Temperature and Precipitation in Serbia)

1. In Serbia, there is an upward temperature trend and a downward river discharge trend.

2. A trend of some 0.6 °C/100 years was derived from 26 analyzed temperature stations. A greater trend was noted in mountainous areas and in the north of the country (even exceeding 1°C/100 years). Southeastern Serbia exhibits the lowest trend (about 0°C/100 years). It is still unknown to what extent the trend includes a micro-location variation component. Claims of several regional climate models that the highest intra-annual temperature increase is to be expected during the summer have not been fully confirmed with observed trends. September (apart from November and December) is the only month in which a cooling trend has been recorded.

3. Based on 34 analyzed precipitation stations, the overall average trend in Serbia is slightly negative, but its geographic distribution varies. A distinct upward trend exists in the (south)western part of the country and a downward trend in the eastern part of the country. Most of Serbia (almost 90%) is in the ± 10%/100 years range. Claims of several regional climate models that the greatest intra-annual reduction in precipitation is to be expected during the summer and early autumn are in total conflict with observed trends. The greatest precipitation increase trend has been recorded in August and specially September.

Conclusions (related to Hydrology in Serbia)

1. River discharge trends depend on a large number of factors. Climate change is one of these factors, which is present at all monitoring stations, but its significance varies (it is generally dominant in the eastern part of the country, but is often less significant or even minor elsewhere).

2. The recorded downward trend of average annual river discharges is about -30%/100 years.

3. Annual and monthly data were analyzed → flood trends were not studied.

4. Based on precipitation and temperature trend distributions, the greatest negative trend changes were noted in eastern Serbia.

5. In general, there is a considerably lower trend (close to zero) during low-flow months (July through October), as a result of an upward temperature trend during these months, but also often due to the presence of a river reservoir upstream of a given monitoring station, which equalize annual flows (as expected, this trend varies considerably from station to station). However, this does not mean that such a trend will not appear (if temperature continues to rise), especially at stations where there are no upstream river reservoirs.

6. If the average annual temperature were to increase by 2ºC, based on the correlations established to date between average annual river discharges and average annual temperatures, we could expect, on average, approximately near 50% less water in rivers whose catchment areas largely lie within Serbia.

Conclusions - for who these results could be interesting (apart from Serbia)

Who can perhaps benefit from the outcomes of this research?

Apart from Serbia, it is believed that the presented results will be of interest to the entire region of Southeast Europe.

Further, the results indicate that an in-depth study of all observed data (above all temperature, precipitation and hydrological data) should be undertaken before a regional model is produced.

Ultimately, the proposed methodology for the assessment of average temperature impact on average river discharge and precipitation could certainly be applied in many parts of the world, especially in regions where a **long-term decreasing precipitation trend** is recorded. It may also be used in other regions, but the results might not be as straightforward.

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Thank you for your attention