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Relationship between monthly precipitation, the Sava river discharge and large-scale circulation

Krešo Pandžić and Dušan Trninić

Meteorological and Hydrological Service, Grič 3, 10000 Zagreb, Croatia

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The relationship between monthly precipitation and discharge fields have been considered over the Sava river basin including their linkage with the European-Northern Atlantic sea-level pressure distribution. For that purpose, 30-year (1961–1990) time series of the precipitation, discharge and sea-level pressure data have been used. Their consideration was made by means of the Principal Component Analysis (PCA) technique. Two slightly different subregions have been discovered within the Sava river basin, regarding their annual precipitation and discharge regimes, respectively. Also, four anomaly patterns have been established including a rather high correlation between the meteorological and the hydrological fields. Finally, an interpretation of the Sava river precipitation and discharge in terms of the European-Northern Atlantic sea-level pressure anomaly field has been stated.

Keywords: precipitation, river discharge, large-scale circulation

1. Introduction

The Sava river is one of the Danube right-side tributaries. Its basin covers an area between the southern edge of the Alps, north-eastern part of Dinaric mountains including southern part of the Pannonian lowland (area of about 10^5 km^2). Great number of its tributaries come from the mountainous regions, mainly from its right-side (Figure 1a). Here, a moderate continental climate prevails with maximum precipitation during the summer part of the year (Penzar and Makjanić, 1978; Penzar and Penzar, 1982).

A study devoted to the precipitation and discharge in the area was made by Srebrenović (1986). According to his results the annual ratio of runoff water and precipitation water is about 40 percents (the average annual precipitation for the area is about 1000 millimetres). Some details may be found in the papers by Stančik et al. (1988) as well as in Pandžić and Trninić (1996).

The goal of this paper is to obtain a more profound explanation of the relationship between the monthly precipitation and discharge over the area, as well as their link to the atmospheric circulation over Europe, *i.e.* to the large-scale sea-level pressure field (Figure 1b). The approach is similar to that de-

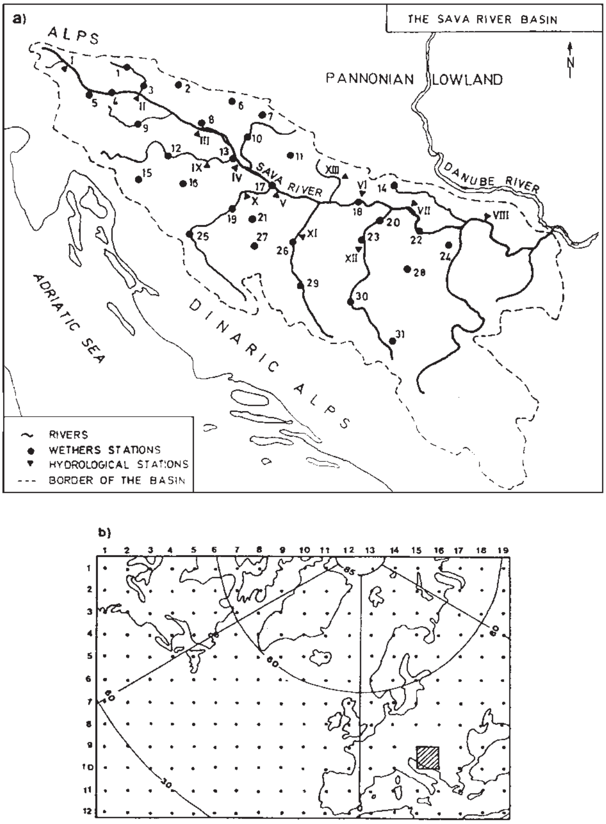

Figure 1. The Sava river basin (a) and European map with 12×19 grid points (b). A shaded square indicates approximately an area of the Sava river basin.

scribed by Pandžić and Trninić (1991, 1992). In the first two papers a small part of the Sava river basin was considered, *i.e.* the Kupa river catchment (south-western part of the Sava basin). A part of the results (for the whole basin) considered here, has been presented in the extended abstract by Pandžić and Trninić (1996). In all cases, the results indicate a high correlation between the parameter fields (of precipitation, discharge and sea-level pressure).

2. Methodology

A clustering technique for space regionalisation (grouping of variables with similar time patterns) and time typisation (grouping of similar variable field space patterns, realised at different times) has been considered. For that purpose, observed variable fields were transformed into a set of orthogonal (uncorrelated) variables. This technique of transformation and corresponding analysis is called the Principal Component Analysis (PCA) which is widely used in geophysical research.

First applications of the PCA appeared during the second half of the 19th century, but wider applications emmerged during the 20th century. It was established in meteorology around the middle of the 20th century (Wadsworth, 1947; Lorenz, 1956). Some of the scientific papers dealing with the matter have been published by Croatian meteorologists and oceanographers (Pandžić, 1986; Pandžić, 1988; Grbec, 1996). A number of books devoted to the PCA have been published *e.g.* by Fulgosi (1979), Jolliffe (1986) and Preisendorfer (1988).

From the technical point of view, transformed variables are more fundamental than the observed ones, their number is less than of the observed variables and they are uncorrelated. These facts are some of the reasons for application of the PCA in this paper. However, several general questions may be raised:

1) Which percentage of the total variances can be explained by PCs?

2) Do we need to make rotation of PCs' frames (this term will be considered later)?

3) What is analytical or prediction power of the method?

4) What is the advantage of procedure of clustering?

One criterion for deternination of the PC number is the percentage of the total variance which can be explained by PCs. If they describe, *e.g.* more than 90 % of total variance, their number is acceptable. A rotation of PCs is useful in general. As PCs represent orthogonalised stohastic variables their use as predictors has advantage over the use of original variables. Beside others, it seems that the most important advantage of the method of clustering could be the elimination of possible white noise from the data. Because of special aspect of PCA as used in this paper, a short description of the method is presented below.

Let $z(t,x)$ represent deviation from a time average[1] of observed variable at a location x and at time t (Preisendorfer, 1988). Let there be $x = 1, 2, ..., p$ observation locations (weather or hydrological stations or grid points) and let observation were made at $t = 1, 2, ..., n$ times (in our case during n-months). Each measurement (for all stations or grid points) can be represented by a column $p \times 1$ vector $\mathbf{z}(t) = [z(t,1), ..., z(t, p)\,]^{\mathrm{T}}$ (T indicates a transpose operation), and by a point in a p-dimensional Euclidean space E_p *i.e.* in the state space (Figure 2a). On the other hand, all measurements at a station (grid point) can be represented by a column $n \times 1$ vector $\mathbf{z}_x = [z(1, x), ..., z(n, x)\,]^{\mathrm{T}}$ in an n-dimensional Euclidean space E_n *i.e.* in the sample space (Figure 2b). Al-

1 Time average can be defined as arithmetic mean of the whole sample of the data or for each month in a year when annual »periodic« component is removed. In the last case deviations are refered to as anomalies (deviations from climatic normal). If deviations are centred at time average then S-mode will be in consideration. However, if they were centred at space average then T-mode would be used. In this paper S-mode is used.

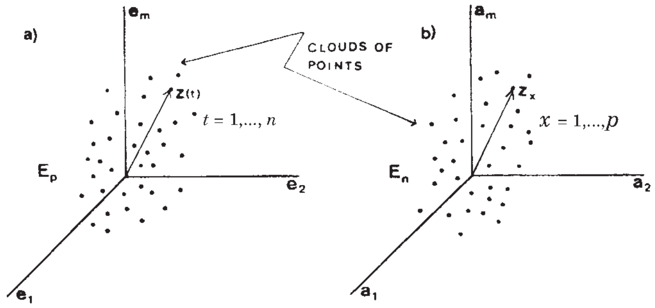

Figure 2. A schematic representation of observed variable data sets in: a) Euclidean vector space E_p (E-frame) and b) Euclidean vector space E_n (A-frame).

ternatively, the state $\mathbf{z}(t)$ of the system at time t can be represented as a linear combination of PCs' scores (amplitudes[2]) $a_j(t)$ and PCs' loadings (element of eigenvectors or empirical orthogonal functions[3]) $\mathbf{e}_j = [e_{1j}, ..., e_{pj}]$, *i.e:*

$$\mathbf{z}(t) = \sum_{j=1}^{p} a_j(t)\, \mathbf{e}_j\,, \qquad t = 1, 2, ..., n \qquad (1)$$

This may be considered as a representation in the *E*-frame (Figure 2a).

On the other hand, the time series of data *i.e.* variable samples $\mathbf{z}_x$ can be represented as linear combination of the above cited quantities but in a different combination, where PCs' loadings and PCs' scores $\mathbf{a}_j = [a_{1j}, ..., a_{nj}]$ have been changed their roles, *i.e.*

$$\mathbf{z}_\mathrm{x} = \sum_{j=1}^{p} e_j(x)\, \mathbf{a}_j\,, \qquad x = 1, 2, ..., p \qquad (2)$$

This can be interpreted as a representation in the *A*-frame (Figure 2b).

These representations can be used for classification of space and time deviation patterns into homogeneous groups (clusters, types). Those points in the vector spaces (Figure 2) which are rather close represent similar space (time) patterns.

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2 PCs' scores are also called amplitudes in analogy with spectral Fourier representation of time-space functions.

3 Eigenvectors in this case define »principal« directions of the new coordinate system axes, obtained from empirical correlation matrices (matrices whose elements are correlation coefficients between two particular variables are described *e.g.* by Fulgosi (1979) and Pandžić (1988)). An atribute »orthogonal« means that PCs are not correlated one to each other (see Preisendorfer, 1988).

Different approaches can be used for clustering. One way is the subjective division of the points in the vector spaces using two by two components (see Fulgosi, 1979; Pandžić, 1986). In addition to this approach, there are different objective methods. One of them is Golovkin's procedure (Vilfand, 1977) which will be applied here. In addition to classification itself, it offers a criterion for the choice of the cluster number. This criterion takes Euclidian distances between points in the above discussed vector spaces into consideration. Two cumulative quantities of these distances, depending on the cluster number, have been defined by Vilfand (1977). When they start to rise abruptly, as hypothetical number of typical clusters becomes smaller, this number of clusters can be chosen as typical (see Pandžić and Kisegi, 1990).

3. Data

Time series of monthly precipitation amounts for 31 weather stations as well as the corresponding time series of the average monthly discharge for 13 hydrological stations both for the time period from 1961 to 1990 have been considered (Figure 1a; Table 1). Also, the average monthly values of the European sea-level pressure data for 12 × 19 grid points, for the same period, have been used (Figure 1b; Table 1). All of them are available at the Meteorological and Hydrological Service of Croatia. They have been compiled from the corresponding services of Slovenia, Bosnia and Herzegovina as well as from the Berliner Wetterkarten published by University of Berlin.

Table 1. Description of data time series used in the paper

Monthly parameter	Number of stations or grid points	Time period
Precipitation	31	1961–1990
Discharge	13	1961–1990
Sea level pressure	12 × 19	1961–1990

4. Application and results

Two kinds of deviations can be considered for a meteorological or hydrological field: the first one including a »periodic« annual course and the other with this annual course removed. The first approach can help to explain climatological characteristics of the fields and the second one may be used to perform the anomaly analysis. As it is noted before, anomalies are deviations from the climatological normals. However, the normals theirselves are time averages depending on the part of the year. These are, in fact, the above mentioned »periodic« annual courses. Their consideration in this paper could help us to better understand the considered fields as a whole.

a) Annual courses

Using 31×30 and 13×30 data matrices, corresponding 31×31 and 13×13 correlation matrices have been calculated for precipitation and discharge variable fields respectively. As expected, higher correlation coefficients have been obtained for geographically closer stations (especially in the case of precipitation), and they are positive in the whole basin for both fields. They are ranging from 0.30 to 0.95 for precipitation and from 0.01 to 0.95 for the discharge field. This range of differences can be explained by pertaining to the same river flow in the discharge case.

Further analysis of these matrices can be achieved by consideration of VARIMAX[4] rotated PCs' loadings (not presented). The first precipitation PC has the highest influence on the eastern part of the basin, the second one on the western, the third one on the south-western and the fourth one on the north-western part. The first PC is the most important because it describes 38 percent of the total field variance, the second 36 percent, the third and the fourth about 4 percent each. The other components have a small influence and may be ignored. Similar patterns have been observed for the discharge field. It can mean that discharge field, to a large extent, is exposed to the similar influences as the precipitation, *i.e.* to the precipitation itself. Although these patterns are similar, the correlation coefficients between two kinds of PCs are not so high: for the first ones it amounts to 0.38 and for the second pair to 0.51. The reason for that, in addition to others, is evaporation, which is more pronounced during the summer and in the lower part of the basin (see Pandžić and Trninić, 1991).

Using a similar procedure as in Pandžić and Trninić (1991), two homogeneous subregions have been obtained for both the precipitation and the discharge (Figures 3a and 3b). A representant of each subregion (stations numbered by 5 and 19 for precipitation and by II and XII for discharges) has been chosen to represent annual climatological regime of these fields. In both precipitation subregions, the annual regime of this parameter has a similar shape with some slight deviations. Thus, in the first subregion during August, September and October the average precipitation is above the annual average and in the second it is not. But in both cases the maximum of the climatological average appears in June. The average monthly discharge maximum occurs in spring (April) and the minimum in summer (August) with a greater amplitude in the lower part of the basin than in the upper one. These patterns are mainly influenced by the water accumulation during the winter season (including snow cover) as well as by the evaporation during the summer (Pandžić and Trninić, 1991).

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4 It means rotation of PCA frames according to the principle of maximum variance of PCs' loadings (Preisendorfer, 1988) .

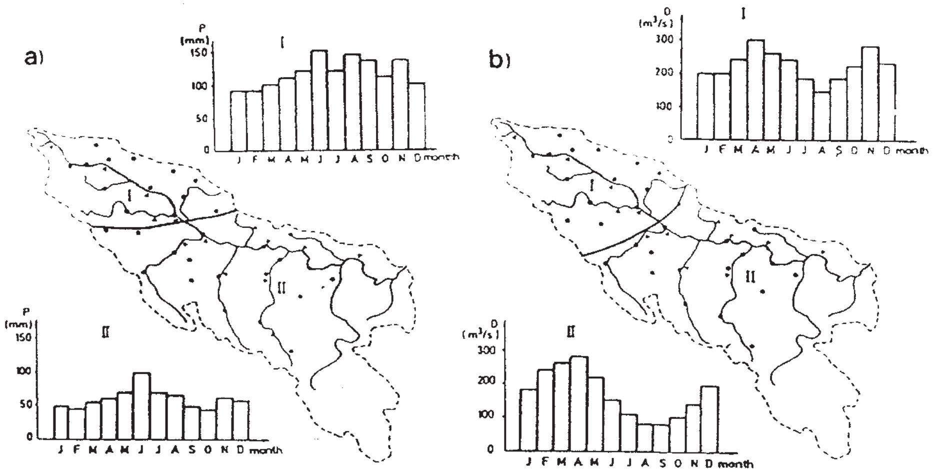

Figure 3. Annual courses of monthly: a) precipitation and b) discharge over the Sava river basin.

b) Anomaly analysis

After removing mean annual courses, the same procedure has been applied as described above. Nevertheless, very similar results have been obtained in relation to the PCs' spatial distribution. The time aspect is, however, different because there is no annual regime in this case. An application of the clustering technique as in Pandžić and Kisegi (1990) gives also useful results.

Four patterns (types) for precipitation, discharge and the European-Northern Atlantic sea-level pressure anomaly field have been obtained[5]. The first one is related to the precipitation above normal in the eastern part of the basin, the second one with the negative anomalies in the whole area, the third one represents a more normal situation, while the fourth one indicates positive anomalies in the western part of the basin (Figure 4). Although it is obvious, it is useful to say that similar corresponding patterns can be observed for discharge field (Figure 5), which may indicate that they have a high correlation (the highest coefficient is 0.77 between the first precipitation and second discharge PC). Characteristic distribution of the sea-level pres-

5 These anomalies have been calculated as average anomalies within a type. But corresponding anomalies for discharge and European-Northern Atlantic sea-level pressure have been calculated using precipitation clustering. The number of types has been determined using Golovkin's criterion but it has not been very successful here because a rather small number of variables (weather stations) have been considered. It can be mentioned that the same procedure has also been used for the choice of the number of homogeneous subregions described before.

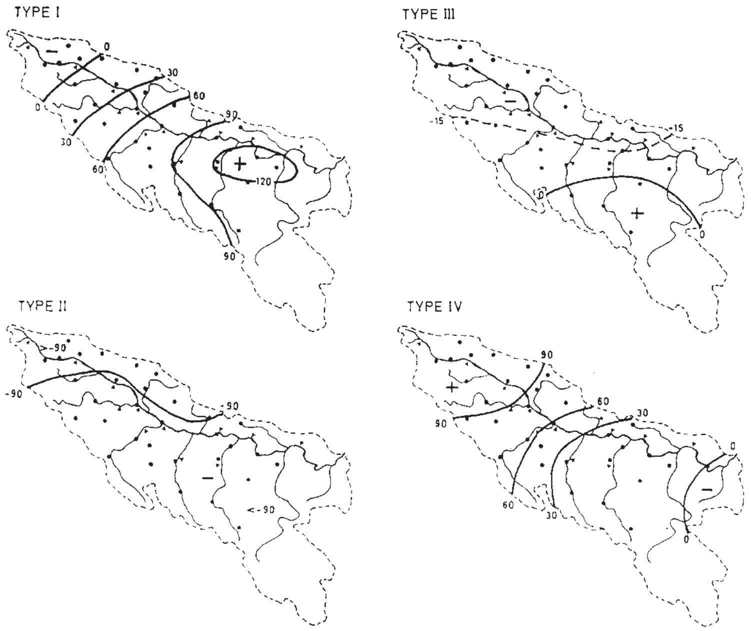

Figure 4. Anomaly patterns of monthly precipitation over the Sava river basin

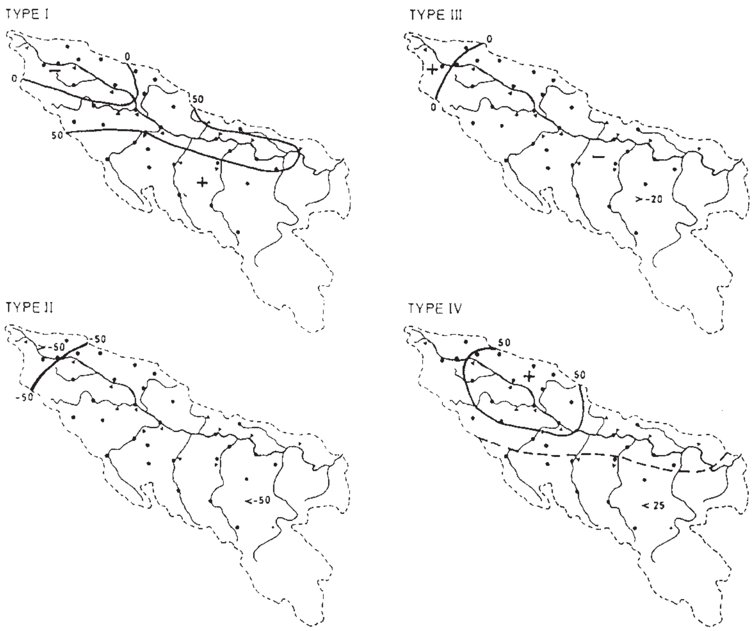

Figure 5. Anomaly patterns of monthly discharge over the Sava river basin

sure anomalies can be also observed (Figure 6). In the first case, the values below normal are concentrated near Black Sea area, indicating a cyclonic activity. The consequence of that is precipitation and discharge above normal in the eastern part of the basin. Positive pressure anomalies above the Adriatic-Pannonian region cause a lack of precipitation over the basin. Similar explanation can be made for the other two types. It means that a possible forecast of the European-Northern Atlantic sea-level pressure anomalies could be used for estimation of precipitation and discharge anomalies over the basin.

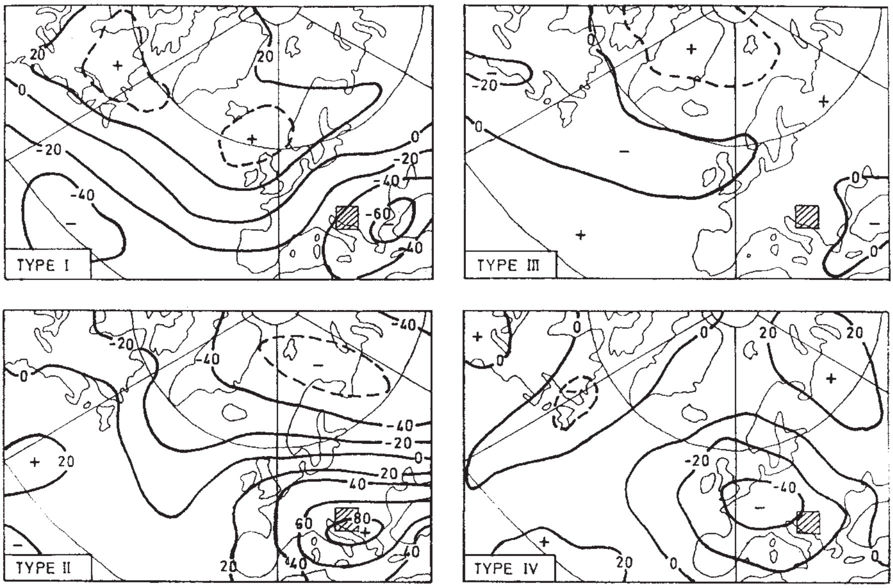

Figure 6. Anomaly patterns of monthly means of sea-level pressure over European-Northern Atlantic area.

5. Conclusion

An application of the PCA for a comprehensive study of the Sava river precipitation and discharge fields is possible. Two sets of input data have been prepared: the first including the annual courses and the second one without them. In the first case some aspects of the annual courses can be considered. Two slightly different subregions according to the annual precipitation and discharge courses have been obtained. Difference between the discharge and the precipitation annual courses, however, are rather significant. It is a consequence of the annual fluctuation of evapotranspiration, snow melting, *etc.*, by which annual course of discharge are additionally influenced.

Four characteristic anomaly patterns (types) have been detected for every variable field considered. The distribution of the European-Northern Atlantic sea-level pressure anomalies strongly influences the Sava river precipitation anomaly patterns and these have a strong influence on the discharge patterns. Thus, a possible pressure anomaly forecast could be used for estimation of the other two considered fields. Until now a reasonable successful forecast of the pressure field is not available on a monthly scale, but for the short time periods (*e.g.* 5 and 10 days) better results can be expected.

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SAŽETAK

Povezanost mjesečnih oborina, protoka na rijeci Savi i makrocirkulacije

Krešo Pandžić i Dušan Trninić

Razmatrana je povezanost polja mjesečnih oborina i protoka na slivu rijeke Save međusobno kao i njihova povezanost s razdiobom tlaka zraka na morskoj razini za europsko-sjevernoatlantsko područje. Za tu svrhu upotrebljeni su 30-godišnji (1961–1990) vremenski nizovi podataka oborine, protoka i tlaka zraka na morskoj razini. Njihovo razmatranje obavljeno je metodom glavnih komponenata. Područje sliva rijeke Save podijeljeno je na dva, s obzirom na godišnji hod oborine i protoka, neznatno različita područja. Također su ustanovljena četiri tipa razdiobe anomalija uključujući i visoku korelaciju između meteoroloških i hidrološkog polja. Konačno, ustanovljena je mogućnost interpretacije polja oborine i protoka na slivu Save pomoću anomalija tlaka zraka na morskoj razini za europsko-sjevernoatlantsko područje.

Ključne riječi: polje oborine, riječni protok, makrocirkulacija

Corresponding author's address: Dr. Krešo Pandžić, Meteorological and Hydrological Service, Grič 3, 10000 Zagreb, Croatia