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Stochastic modeling of the connection between sea level pressure and discharge in the Danube lower basin by means of Hidden Markov Model

Ileana Mares (1), Constantin Mares (1), and Mihaela Mihailescu (2)

(1) National Institute of Hydrology and Water Management, Bucharest, Romania (ileana.mares@yahoo.com, 40-21-4113197), (2) Agricultural University, Bucharest, Romania

In the present study, first, we achieve a stochastic modeling between sea level pressure (SLP) and the Danube lower basin discharge using observational daily data (1958-1999) during spring and then, we use this modeling result to estimate the discharge of the 21st century. The Danube discharge is considered as states of Hidden Markov Model (HMM), and observations are represented by atmospheric circulation (emissions). We want to estimate the discharge behavior in the 21st century knowing the pressure at sea level simulated by climate models. We take into account the properties of HMM that both states and observations are considered simultaneously. From the physical point of view, this association is correct, that in all calculations we consider values SLP with 10 days before the discharges, the lag for which the correlations are the most significant.
For the Danube lower basin was considered Orsova station that is situated at the Danube entry in Romania. From the correlative analysis we found that the maximum correlation between SLP and Danube discharge at Orsova is in the grid point (47.5N; 20E), and the different atmospheric indices were calculated around this point. Thus, there were calculated indices like: vorticity, gradients S-N and W-E, centered on this point, as well as pressure mean values. All these measure were calculated considering both the values in the respective point and in the neighboring ones.
The tests have revealed the fact that the best predictor is the mean pressure on the considered area. The mean pressure values were classified in 3 equal probable classes that we considered as states of the atmospheric circulations.
Therefore we can conclude that the types of atmospheric circulation in their sequence give us the weather rainy or dry interval sequences which in turn is reflected in the succession of states of the Danube flows. Here we achieved a simple classification (3 states) of the SLP based on pressure mean values around the point considered significant for the discharge. It was considered a minimum number of three classes for atmospheric circulation to explain the extreme events like drought, rainy periods and non-extreme events with, hydrological impact more or less pronounced.

The time series of daily discharges was classified in 7 equal possible states by the quantiles method. The states 1 and 7 can be considered as extreme events namely hydrological droughts and discharges in excess that can produce floods.

The relation between the local scale (discharges at Orsova – 7 classes) and the atmospheric circulation (3 classes) is given by the emission matrix of a hidden Markov model with 7 discharge states and 3 types for the atmospheric circulation.
The three atmospheric circulation states represented by C, N and A, define a low pressure field associated with a cyclonic circulation in the area of the representative point, a value of the normal pressure and, respectively a high pressure field, namely an anti-cyclonic circulation type.

The emission matrix is a stochastic one, with 7 lines and 3 columns.
As expected, the discharge in deficit is associated with the anti-cyclonic state A, and the state defining a discharge in excess is associated with a cyclonic circulation C. The choice of more classes of the atmospheric circulation makes harder the estimation of the emission matrix and the construction of HMM.
Then, we assume that the statistical connection between SLP and discharges, quantified by the emission matrix calculated for the observation data remains the same for the 21st century. For each model from four models considered (CNRM, ECHAM5-MPI, EGMAM and IPSL), we determine the 3 classes (circulation types) of the atmospheric circulation in the representative area for the 2 periods of 42 years each of the 21st century, considered for this study 2009-2050 and, respectively, 2051-2092.

Taking into account these circulation types and on the basis of the transition matrix of the discharges from the observation data (1958-1999) and of the emission matrix for the same period, we estimate the probabilities of Danube discharges at Orşova in the 21st century. Thus, by means of the routine hmmdecode of MATLAB toolbox (http:// www. mathworks. com/ help/ toolbox /stats /hmmdecode.html) we have estimated the posterior probabilities for each of the 7 discharge states in association with the 3 types of the atmospheric circulation simulated for the 21st century.

Thus, it was obtained that the probability for producing the discharge extreme states, namely extreme deficit and severe surplus are slightly higher in the 21st century in comparison with the 20th century, this increase being more visible in the second half of the 21st century. The state defining a discharge in normal limits has diminution trend.