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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

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First, a stochastic modeling between sea level pressure (SLP) and the Danube lower basin (Orsova) discharge using observational daily data (1958-1999) during spring is achieved. The Danube discharge is considered as states of Hidden Markov Model (HMM) and observations are represented by atmospheric circulations (emissions)

Then, this modeling for observations is used to estimate the discharge of the 21st century. The discharge behavior in the 21st century knowing the pressure at sea level simulated by climate models is achieved.

I. Daily discharge associated with SLP (springtime)

From the correlative analysis of the daily values we found that the maximum correlation between SLP and Danube discharge at Orsova is in the grid point (47.5N; 20E) (FIG.1). The mean pressure values around the key point were classified in 3 equal probable classes that we considered as states of the atmospheric circulations. 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 (FIG. 2a,b >>>> Composite map of SLP, corresponding to the extreme discharges). The graphical representation of the emission matrix (7 lines and 3 columns) is given in the FIG.3. 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. The posterior probabilities estimated for each of the 7 discharge states in association with the 3 types of the atmospheric circulation simulated for the 21st century (FIG.4).

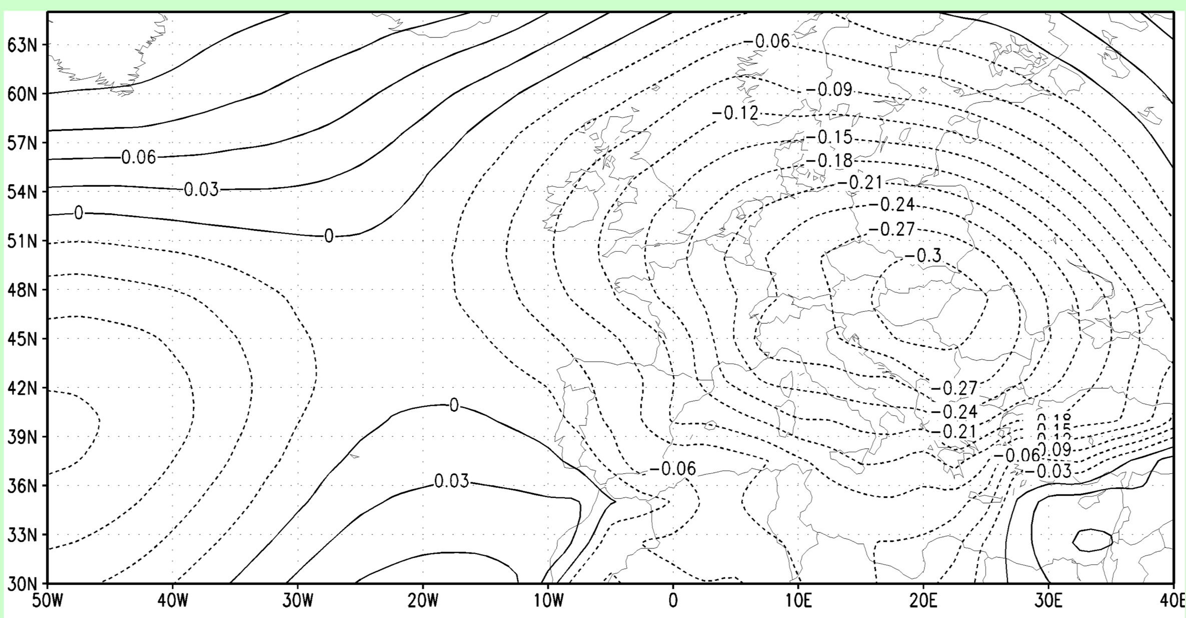
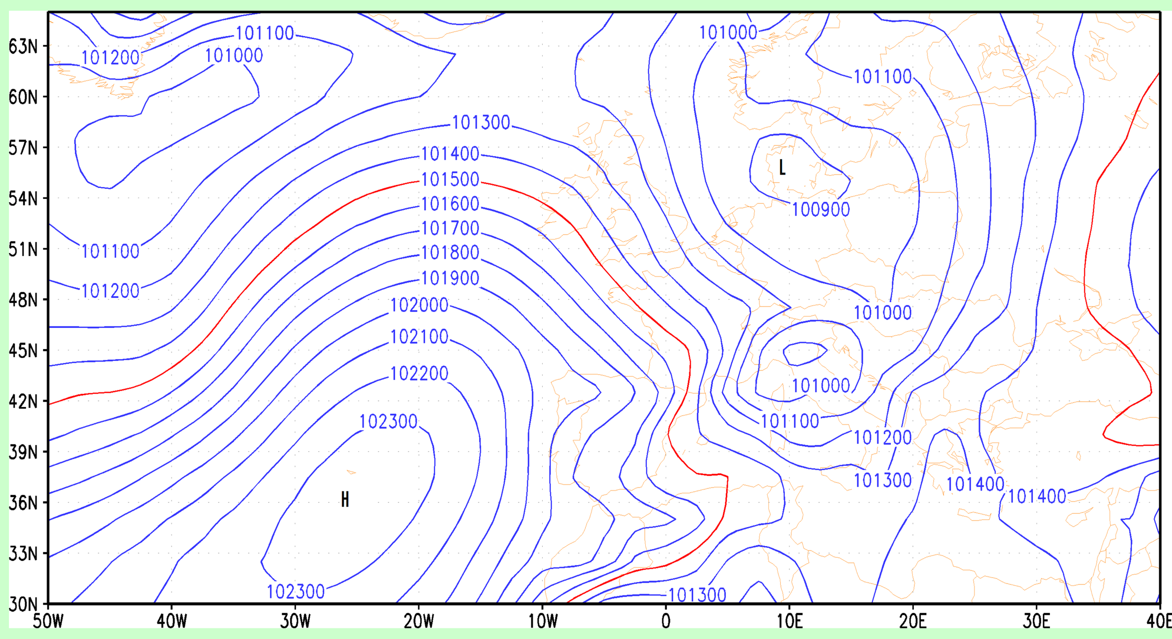
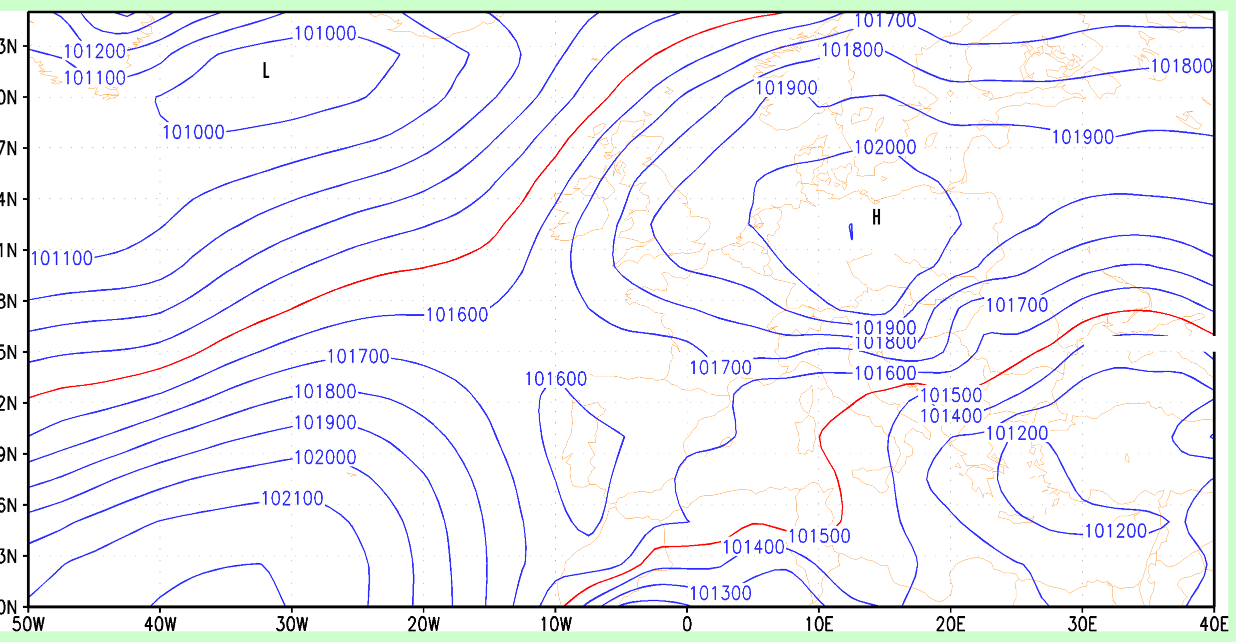


FIG. 1. The distribution of the correlation coefficients between the daily discharges at Orsova and the pressure values over the Atlantic-European sector, considered 10 days before the discharges.



a)



b)

FIG. 2. Mean sea level pressure distribution (distance between curves is of 100 Pa) associated with discharges occurring at Orsova in the extreme case of discharges: excess (a), deficit (b).

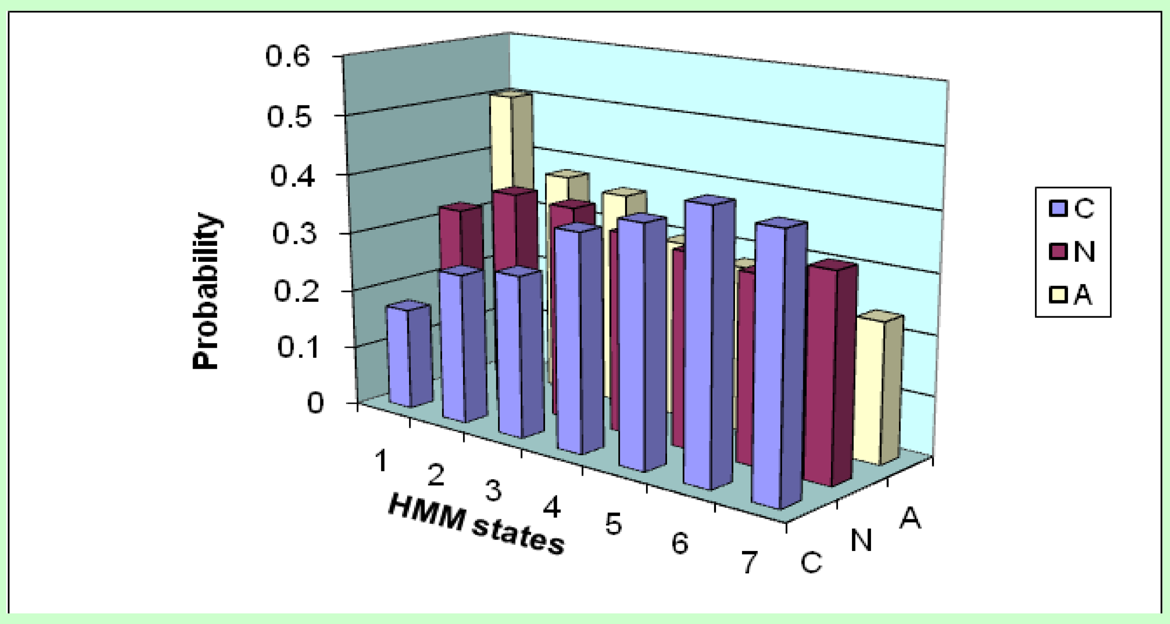


FIG. 3. Probabilities of emission matrix of the HMM states for discharge level, associated with the atmospheric circulation (sea level pressure) classified in 3 states.

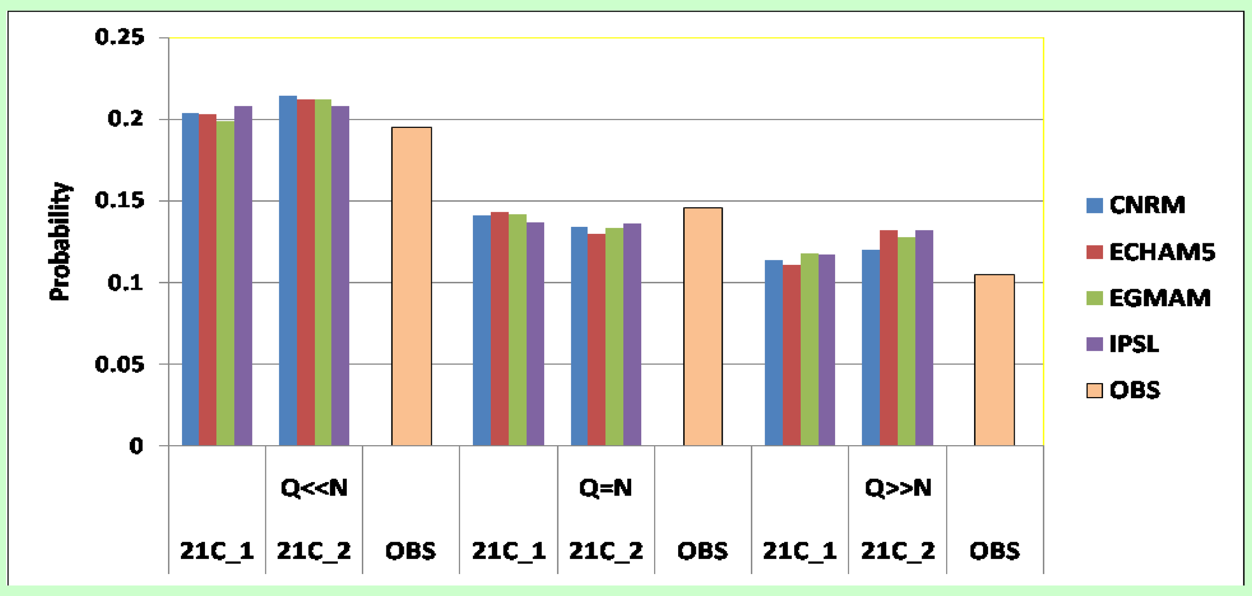


Fig. 4. Mean of the posterior state probabilities for 3-states of the Danube discharge (Q) at Orsova with predictor mean pressure centered on the point 47.5[0]N; 20[0]E.

Capacity of models to simulate the mean pressure at sea level during spring, tested by means of the spatial correlation analysis.

Model	*R*	r_1	n_e	*Significant level*	*RMSE*	*E*
CNRM	0.471	0.838	22	~ 98 %	1.816	0.059
ECHAM5-MPI	0.664	0.774	32	> 99 %	1.107	0.339
EGMAM	0.528	0.881	16	95-98 %	1.870	-0.473
IPSL	0.314	0.910	12	< 90 %	2.857	-3.375

($E = 1-\sigma D2 / \sigma Obs2$). *D* the difference between the simulated and observed long term mean pressure; *σ2D* the spatial variance of *D*. *σObs²* the explaining spatial variance of the observed field (van Ulden and van Oldenborgh, 2006). *r1* is pooled estimated value of the lag-1 correlation coefficient between two time series; *ne* is the effective number.

II. Seasonal precipitation associated with SLP (wintertime)

A correlation analysis has been carried out between principal component (PC1) of the total seasonal precipitation defined at 15 stations along the Danube middle basin (Fig. 5) and Orsova discharge for each season. It was result that the precipitation during wintertime is a very good predictor for Orsova discharge for the springtime. For the modeling by HMM a correlative analysis between precipitation and SLP was achieved. A dipole with very significant correlations (FIG. 6) was obtained. A circulation index was introduced taking into account the difference between SLP in Greenland and SLP in Balkan (BIN index). The BIN was divided in three equiprobable classes. The composite maps are given in the FIG. 7 constructed for SLP over 100-years (1901-2000). For the precipitation field represented by PC1, was considered 5 classes and composite maps for the deficit and heavy precipitation are shown in FIG. 8. The emission matrix corresponding to 5- HMM states for precipitation, associated with circulation index (BIN) the classified in 3 states is given FIG 9.

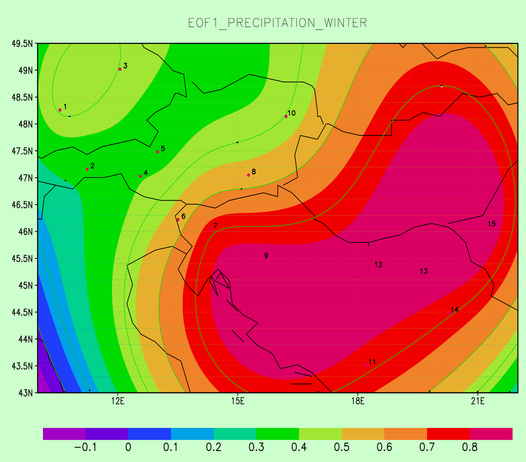


FIG. 5. Spatial distribution of EOF1, for the 15 stations among the Danube middle basin for observations (1958-1999) during winter time.

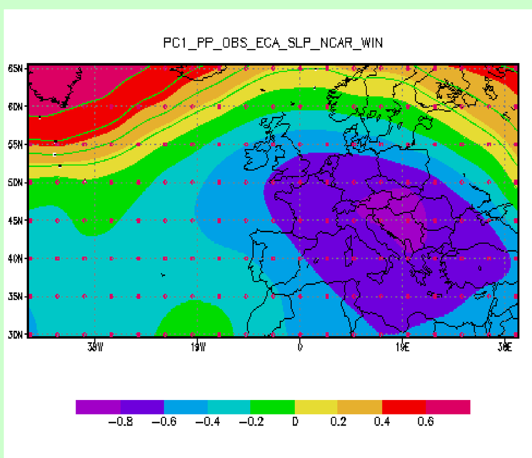
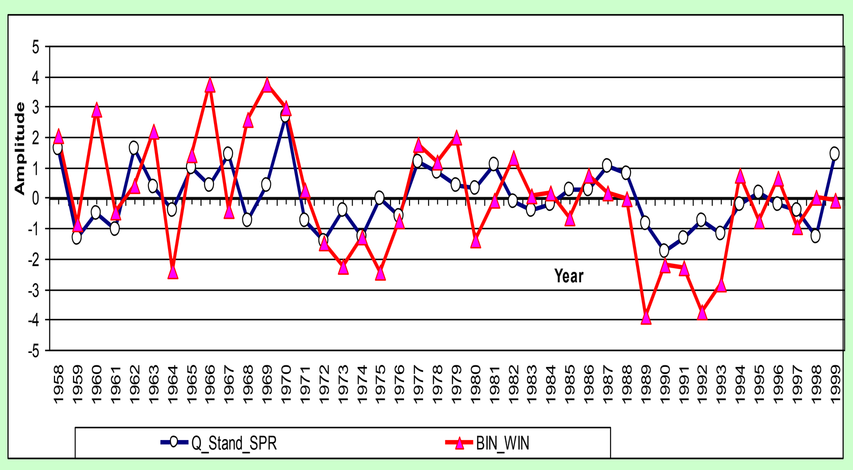
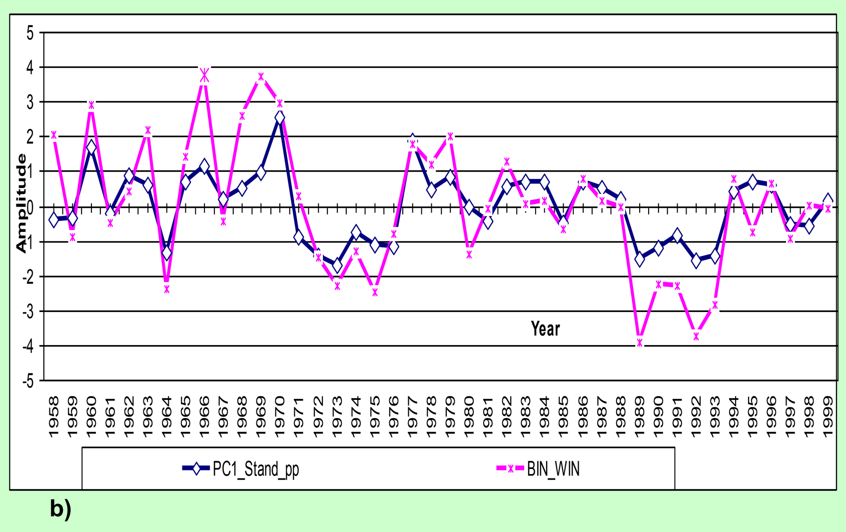


Fig.6 Spatial distribution of the correlation between PC1 precipitation and SLP during winter observations (1958-1999).



a)



b)

Temporal variations:
a) Orsova discharge and Balkan Index (BIN)
b) PC1-precipitation and BIN

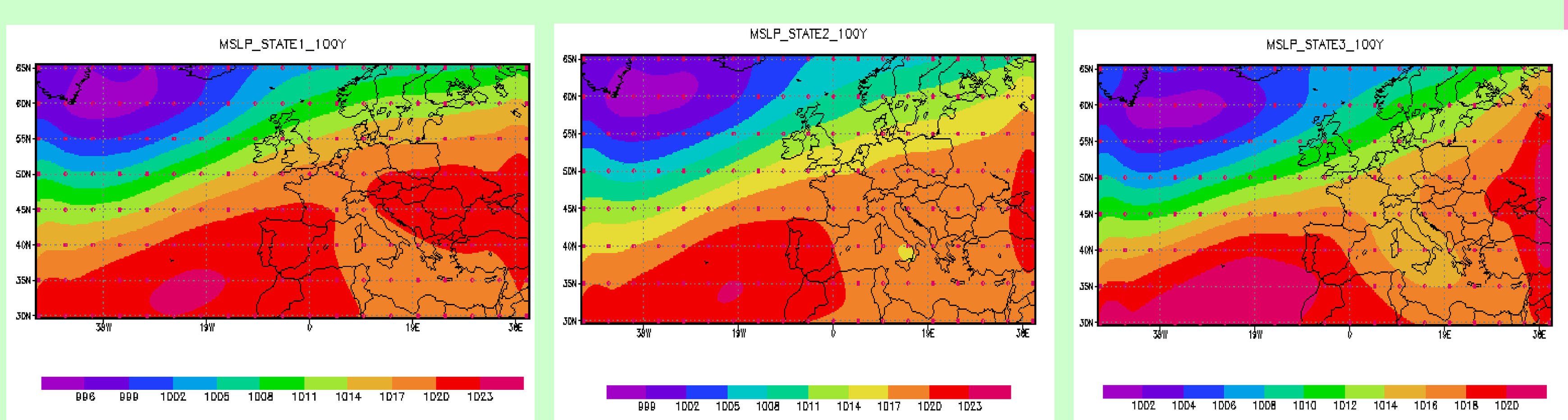


FIG.7. Composite maps of SLP corresponding to three states of the Balkan index (BIN) for winter (1901-2000).

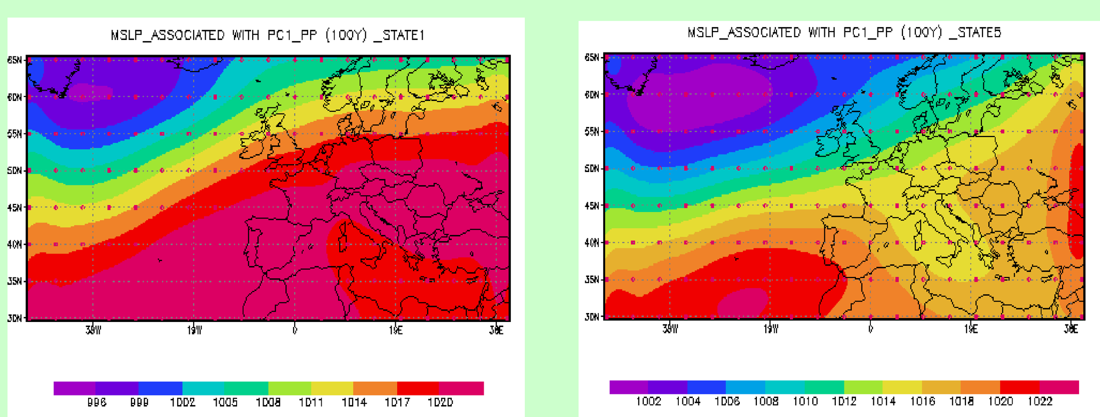


FIG.8. Composite maps of SLP corresponding to the deficit precipitation (state 1) and heavy precipitation (state 5) during winter (1901-2000).

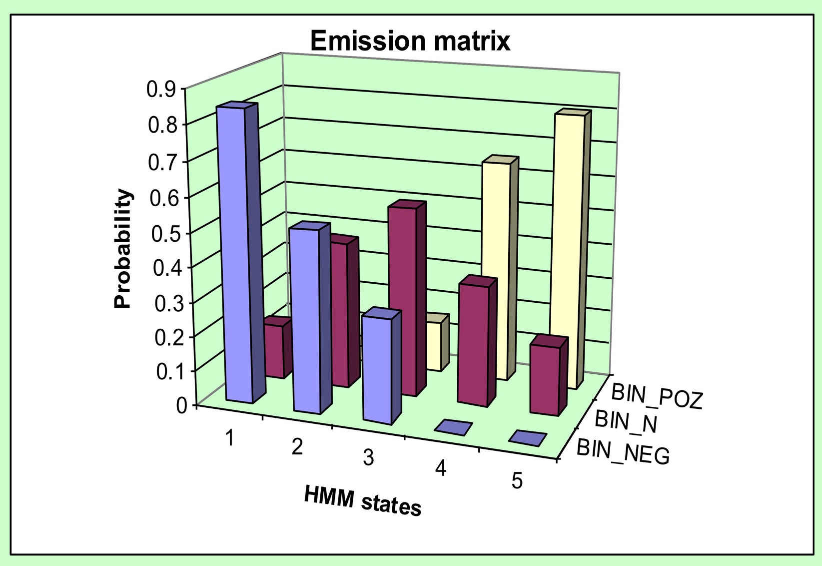


FIG. 9. Probabilities of emission matrix of the HMM with 5-states for precipitation, associated with circulation index (BIN) the classified in 3 states.

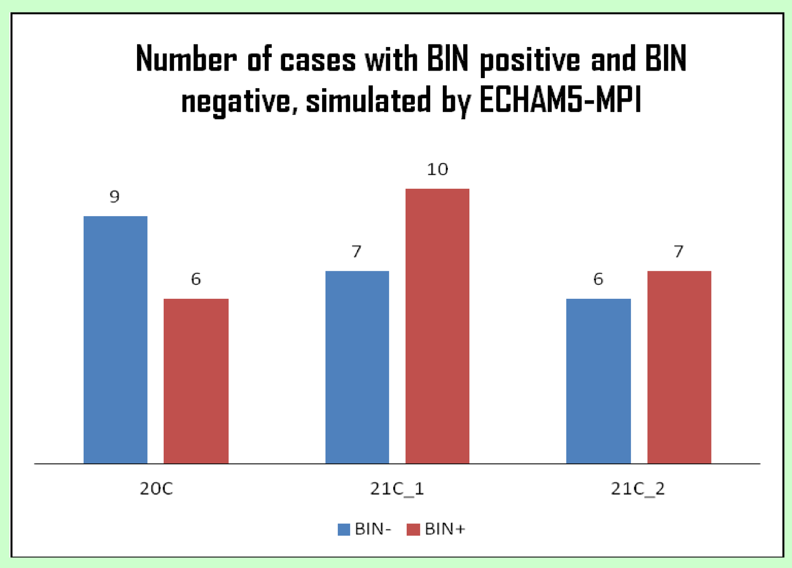


FIG.10. The frequency of circulation index (BIN) simulated by model ECHAM5-MPI, for 20C(1958-1999) and 21C_1(2009-2050) ; 21C_2 (2051-2092).

CONCLUSIONS

- **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 (FIG.4).**
- **Emission matrix, that link the precipitation along Danube middle basin with the atmospheric circulation quantified by the new index, introduced by authors and named Balkan index (BIN) reveals that a negative BIN leads to a deficit precipitation and a positive BIN indicates a heavy precipitation (FIG.9).**

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