21^{st} CENTURY DISCHARGE ESTIMATION IN THE DANUBE LOWER BASIN WITH PREDICTORS SIMULATED THROUGH EGMAM MODEL

CONSTANTIN MAREŞ[1], ILEANA MAREŞ[1], MIHAELA MIHĂILESCU[2], HEIKE HÜBENER[3], ULRICH CUBASCH[3], PETRE STANCIU[1]

[1]*National Institute of Hydrology and Water Management, Sos. Bucuresti-Ploiesti 97, Bucharest, Romania*
[2]*Agricultural University, Bucharest, Romania*
[3]*Free University, Berlin, Germany*

L'estimation du débit dans le basin inférieur du Danube pour le 21^e siècle en utilisant les prédicteurs simulés à l'aide du modèle EGMAM. Au début on a réalisé une estimation des débites dans le 21^e siècle avec un modèle Markov nonhomogène caché en utilisant la pression au niveau de la mer. On a appliqué un modèle Markov caché avec 7 états pour les débites de printemps á Orşova, située á l'entrée du Danube en Roumanie. Les états 1 et 7 peuvent être interprétés comme événements extremes, notamment sécheresse extrême et débites au dessus de normal (possible inondations). Les valeurs SLP ont été obtenues de ERA–40 (ECMWF) et des simulations pour le 20^e siècle (20 C) et le 21^e siècle (A1B - IPCC scénario) avec le modèle EGMAM réalisé par l'Université Libre de Berlin dans le cadre du projet ENSEMBLES. Pour obtenir l'estimation des débites dans le 21^e siècle on a cherché d'abord la relation entre les observations (SLP de ERA–40) et le débit du Danube. La meilleure relation entre SLP et le débit a été trouvée avec un décalage de 10 jours dans la zone centrée sur 47.5^0N; 20^0E. Ensuite, on a analysé la capacité du modèle EGMAM de reproduire la pression au niveau de la mer. Parce que le modèle reproduit assez bien la pression dans la zone-clé, la pression simulée pour le 21^e siècle a été considérée comme prédicteur pour estimer le débit du Danube dans le basin inférieur. De l'analyse des probabilités des états cycloniques et anticycloniques pour deux périodes du siècle 21 (2009–2050 et 2051–2092) a résulté une croissance de la persistance de ces circulations atmosphériques conduisant á une augmentation de la persistance des débites extrêmes surtout de celles avec des valeurs diminuées. Dans la deuxième partie du travail on a appliqué la théorie des valeurs extrêmes (EVT) aux précipitations journalières en printemps (mars, avril, mai) pour la station Bacău, située á l'est de la Roumanie. On a analysé aussi les tendances climatiques des extrêmes á la station Bacău en utilisant les valeurs journalières (sans tenir compte de la saison) des précipitations, des températures maximums et minimums simulées pour les siècles 20 et 21 avec le modèle EGMAM. Du modelage, par la distribution GEV des précipitations journalières maximums dans la saison du printemps, a résulté une transformation de la distribution Weibull dans le 20^e siècle á la distribution Frechet dans le 21^e siècle ayant la queue avec les précipitations excessives plus étendue. Cela est en concordance avec le niveau de revenu estimé qui augmente avec approximativement 4 mm dans le siècle 21 en comparaison au 20^e siècle. L'analyse des indices climatiques des extrêmes est en concordance pour la plupart avec les résultats obtenus par la modélisation Markov et EVT.

Key words: extreme event theory, hidden Markov model, climate extreme indices.

1. INTRODUCTION

The main cause of the extreme events occurrence at the regional scale is the anormal behaviour of the atmospheric circulation at the large scale. There are many studies that investigated this relation both for the diagnosis and for the estimating of the changes in the 21^{st} century produced in the extremes due to the climate changes.

Realizing a classification of the atmospheric circulation in accordance with the study purpose, for example the determination of atmospheric conditions (circulation types) that produce precipitation between some limits is also very important in obtaining the relation between local and synoptic scale (Goodess and Palutikof, 1998, Palutikof *et al.*, 2002). As Zheng and Katz (2008) showed, the modelling of the relation between precipitation and the atmospheric or oceanic indices is very important because depending on this relation we will be able to estimate the impact of the climatic changes on the hydropower generation capacity of the studied region.

Regarding the predictors (inputs) at large scale, their selection is a rather difficult problem. The atmospheric fields must be filtered in order to reduce the data volume, but, in the same time, we must keep sufficient information about those fields for the association with the precipitation. In compressing of atmospheric variables, it will be taken into account that circulation regimes have intrinsic time scales of several days to a week, and exert a control on local weather (Robertson and Ghil, 1999). Also the study of the atmospheric variables on components as wave-like allows the connection with oscillatory phenomena (Ghil and Robertson, 2002).

The post processing of the coupled atmosphere/ocean general circulation model (GCM) results in comparison with regional climate model (RCM) are discussed in the recent publication of Hagemann *et al.* (2008) with the projections on the hydrological changes over large European catchments (land part of Baltic Sea, Danube and Rhine).

There are several methods that use the information about the atmospheric circulation in estimating climate events at regional or local scale. Among them we mention the Markov chain modelling (in particularly hidden Markov model), the application of the extreme value theory (EVT) and the analysis by calculating the indices of climate extremes.

Hidden Markov Models (HMM) were first described in a series of statistical papers by Baum and Petrie (1966) and other authors in the second half of the 1960s. The most cited publication regarding the solutions of practical and theoretical problems that appear related to HMM application is that of Rabiner (1989). Although the first applications of HMM in meteorology, hydrology or climate change studies appeared relatively late in comparison with the 1960s, in the last years it can be noted a substantial increasing of the investigations based on fitting by HMM. The first investigations related to the HMM applications to the discharges in the Danube lower basin in association with Circulation Weather Types (CWTs) over Europe have been recently presented in Hübener *et al.* (2007). A long range forecasting of monthly discharge of the Danube in Bratislava was obtained by Pekárová *et al.* (2007), who applied two types of models, a hidden Markov model derived from Fourier series and a stochastic seasonal auto-regression model of moving averages.

In Mareş *et al.* (2008c), in the first step, a hidden Markov model (HMM) is fitted to the daily rainfall records at 19 meteorological stations, in the springtime, for the period 1958–2001. A nonhomogeneous HMM (NHMM) is then applied to precipitation occurrence associated with the information about atmospheric circulation over the Atlantic–European region. The atmospheric circulation is quantified by the first 10 components of the decomposition in the Empirical Orthogonal Functions (EOF) or multivariate EOF (MEOF). Also the predictors taking into account Circulation Weather Types for Sea Level Pressure (SLP) and the first summary variable using the Singular Value Decomposition (SVD) are tested. The atmospheric predictors are derived from: SLP, geopotential, temperature, specific and relative humidity at 850 hPa. The test of the NHMM performances revealed that SLP and geopotential at 850 hPa are the best predictors. For the computing algorithm the toolbox realized by Kirshner (2005) was used.

Katz *et al.* (2002) studied the changes of hydrological extremes in connection with the modifications of atmospheric circulation both for the connection between the phenomena occurred at local scale and the circulation at large scale, proposing to replace the conventional regression analysis technique by using the properties of the statistics of extremes. In order to quantify the uncertainty of extreme events Katz *et al.* (2002, 2005) applied Bayesian approximations for hydrological extremes, and Tebaldi *et al.* (2005) applied these approximations for analyzing the variables resulted from multi-models' ensembles.

In Mareş *et al.* (2008a) the North Atlantic Oscillation (NAO) and the first ten principal components (PCs) of the decomposition in MEOF of three atmospheric fields (sea level pressure, 500 hPa and 500–1000 hPa thickness) over the Atlantic-European region (ERA-40), have been introduced as covariates in the modelling of extreme events in the discharge (Danube lower basin). An improvement over the model without covariate is found incorporating NAO as covariate in location parameter, especially for the spring maxima having as predictor NAO during the winter. Related to the atmospheric circulation influence the most significant results are obtained by incorporating the first 10 PCs of MEOF in location parameter of Generalized Extreme Value (GEV) distribution with a month before the month of discharge level. Although there are more software packages applying the statistical analysis of extreme values (Mareş *et al.*, 2008a), a procedure carried out by Gilleland and Katz (2005), and Katz *et al.* (2005) was used because this software, *Toolkit* for extremes (*extRemes*), fits the applications used in the weather and climate field, and gives the possibility to introduce covariates information in estimating the parameters.

Regarding the changes in extreme events in the temperature and precipitation fields using the analysis of climate extreme indices (CEI), the specialists as part of WMO in climate change problems and in extreme events studies made special efforts for the development of a software easy to use (Peterson *et al.*, 2001). So, the expert team for climate change detection monitoring and indices (ETCCDMI), as part of the project regarding the climate variability and predictability – CLIVAR (Climate Variability and Predictability), recommended the software *RClimDex* to calculate 27 indices related to the behaviour of daily extremes in the temperature and precipitation fields. Recent versions of the *RClimDex* program can be obtained at (*http://cccm2.3.1.seos.uvic.ca/ETCCDMI/RClimDex/rclimdex.r*).

The analysis of the changes in extremes (for example the number of days exceeding the 90 percentile) using these indices needs a very long and homogeneous daily data set (Klein Tank *et al.*, 2002). There are many relatively recent studies that analyse those indices. So the analysis of indices at global scale was realized by Alexander *et al.* (2006), at continental scale by Klein Tank and Konnen (2003), Frei *et al.* (2005), Haylock *et al.* (2006), Beniston *et al.* (2007) – for Europe, by Klein Tank *et al.* (2006) – for Asia. Frich *et al.* (2002) analysed changes in a heat wave duration index over a region encompassing most of Europe, the United States, Canada, China, the former Soviet Union and Australia. In Haylock (2004) several studies regarding the analysis of trends in indices of extreme temperature and precipitation over Europe are mentioned. For one country (national), as Klein Tank *et al.* (2006) showed, there are few studies based on the CEI analysis. Among them we mention Yan *et al.* (2002) and Liu *et al.* (2005) for China, Roy and Balling (2004) for India, Haylock *et al.* (2006) for UK, Sensoy *et al.* (2008) for Turkey. In Mareş and Mareş (2006) the evolution of extreme climate indices for Vienna in the 20th century was analysed.

In the present study the results of the analysis of discharge level in association with atmospheric circulation over European region are presented. At the local scale the Orşova station situated in the south-western part of Romania was considered as representative. Also for the estimating of discharges an important input is represented by precipitation and the maximum and minimum temperature evolution. Therefore the changes in maximum daily precipitation during spring time using EVT modelling and in the CEI for daily minimum and maximum temperatures and the daily precipitation at the Bacău station were estimated. The data were obtained from the EGMAM model simulations both for the 20th century and for the 21st century.

After a short presentation of the data and methods given in section 2, in the section 3 the main results are presented; 3.1 contains those obtained by Markov modelling of the discharges at Orşova in springtime and the relation between the sea level pressure and the discharges; 3.2 presents the fitting by EVT of spring precipitation at the Bacău station and 3.3 contains the trends in climate extreme indices in the 21st century compared to the 20th century, considering daily values during the entire year. The conclusions are presented in section 4.

2. DATA AND METHODS

2.1. DATA

The data used were as follows:

– Daily values of the discharge level in the Danube lower basin (Orşova) in the period 1900–2005;

– Daily values of precipitation and of minimum and maximum temperatures at Bacău for the 20th century (1901–1999) and the 21st century (2001–2099) simulated by the EGMAM model. The reason of selecting the Bacău station is related to the fact that it is the closest station situated in the vicinity of the latitudes and longitudes intersection of the resolution grid of the EGMAM model and it is situated on the Siret River that flows in Danube and has the greatest hydrographic basin from Romania.

– Observed daily values of sea level pressure (SLP) (1958–2001, ERA-40, available from ECMWF web-site) for Atlantic European region (30^0–65^{0}N; 50^{0}W–40^{0}E);

– Simulated daily of SLP for the springtime (months March, April and May in the period 1958–1999 for the experiments achieved with EGMAM for 20th century and for 21st century (SRESA1B). For the 21st century two periods of 42 years (in order to be compatible with observations) were chosen: 2009–2050 (21 C_1) and 2051–2092 (21 C_2). The data are downloaded from the web-site: (http://cera-www.dkrz.de/CERA). The EGMAM is achieved by Free University of Berlin and is a fully coupled AOGCM with middle atmosphere. The model was extensively used to simulate historical periods and 21st century climate projections. The ERA-40 data were used as the reference for the validation of the historical simulations in order to understand deficiencies of the model. Details on the model characteristics can be found in Niehörster *et al.* (2008) and in Niehörster (2008). In Niehörster *et al.* (2008) an overview of the future projections (SRES A2, A1B, B1) included in the stream one simulations of the ENSEMBLES project and relevant information for users of the data is given. The three scenarios were considered as a result of the proposal made by Cubasch *et al.* (2001) in the third assessment report of IPCC WG1, regarding the increasing number of scenarios (from the existing number in that period SRES A2) in order to obtain more information about the uncertainties of the projections. Details about the characteristics of each scenario are given in *IPCC Special Report on Emissions Scenarios* (http://www.grida.no/climate/ipcc/emission/).

2.2. METHODS

Hidden Markov Model

Considering HMM applied to a climate variable at local scale in association with variables at large scales (the atmospheric factors or other predictors) the transition matrix of HMM is modified, the chain becomes in this way nonstationary (NHMM) and of course this modelling approaches best the reality. The NHMMs are useful tools for statistical downscaling of global climate scenarios for hydrological impact analysis. Recent applications of NHMM are found in Robertson *et al.* (2006), Vrac and Naveau (2007), Mareş *et al.* (2008 b, c), Zheng and Katz (2008).

There we will present only some basic concepts that can help to understand and interpret the results. In accordance with Rabiner (1989) we have:

1) N, number of states, S_1 S_2,..., S_N. Although the states are hidden, for many applications from some physical consideration these states can be observed;

2) M, the number of distinct observation symbols per state;

3) The state transition probability distribution: $A = \{a_{ij}\}$

$$a_{ij} = P[q_{t+1} = S_j / q_t = S_i] \qquad 1 \le i, j \le N$$

4) The observation symbol probability distribution in state j, $B = \{b_j(k)\}$, where

$$b_j(k) = P[v_k \ at \ t / q_t = S_j] \qquad 1 \le j \le N \,;\, 1 \le k \le M$$

with

$$V = \{v_1, v_2 ..., v_m\}$$

which denote the individual symbols (observations);

5) The initial state distribution: $\pi_i = P[q_1 = S_i] \qquad 1 \le i \le N$.

An application of HMM requires specification of two model parameters (*N* and *M*), and of the three probability measures (*A,B* and *π*).

The complete parameter set of the model is given by: $\lambda = (A, B, \pi)$
B is named emission matrix.

The extreme value theory

The extreme value theory (EVT) aims at studying the statistics of extreme phenomena, appearing in different scientific branches. Extreme events are rare events situated at the extremities of distribution, if the distribution satisfies the central limit theorem. There is no universal definition for them. In many cases these are defined as those events that go beyond a certain threshold. Extreme events can also be defined as the maximum (or minimum) of a variable for a certain period. There are two principal methods to analyze from the statistical point of view the extreme values. The first method consists in fitting data to a model, by using traditional statistic techniques and then analyzing the extreme quantiles (Gilleland and Nychka, 2005; Chandler, 2005). The second method is to fit data to a distribution of extreme values.

In the present investigation we refer only to the second method, which implies **two alternative studies.** The first consists in the analyse of the values from *the blocks* of equal lengths and fit the data to the maximums of each block (**block maxima**). The second approach is referring to the analysis of values exceeding certain thresholds, well known as the **POT** (Peaks Over Threshold) analysis. For the first case (block maxima) the generalized extreme value (GEV) in accordance with Katz *et al.* (2005) has the following cumulative distribution function:

$$F(x;\mu,\sigma,\xi) = \begin{cases} \exp\left\{-[1+\xi(x-\mu)/\sigma]^{-1/\xi}\right\} \ \ with \\ 1+\xi(x-\mu)/\sigma > 0 \qquad \xi \neq 0 \\ and \\ \exp\left\{-\exp[-(x-\mu)/\sigma]\right\} \qquad \xi = 0 \end{cases} \tag{1}$$

where μ, $\sigma > 0$ and ξ are the parameters of *location*, *scale* and *shape*.
Depending of the value of shape parameter, GEV distribution has three possible distributions types:

$$\begin{array}{ll} \text{(i) } \xi \longrightarrow 0 & \text{Gumbel} \\ \text{(ii) } \xi > 0 & \text{Frechet} \\ \text{(iii) } \xi < 0 & \text{Weibull} \end{array} \tag{2}$$

In case of the extremes fitting method by POT the generalized Pareto (GP) distribution is used. Details regarding the fitting by GPD of the daily discharges at Orşova are found in Mareş and Mareş (2006) and Mareş *et al.* (2008a).

In most cases when we consider the extreme values of a random variable we are interested to know the return level of an extreme event. If we denote with z_p the return level, we define the return level as the probability *p* to exceed the z_p threshold in a given year or alternative the level is expected to be exceeded on an average of one time in each *1/p* years. *1/p* is named the *return period*. For example, if the return level at 100 years for precipitation at a given location is 15 mm then the probability for precipitation to exceed 15 mm is 1/100 = 0.01.

The return level is obtained from the GEV or GP distributions by considering the cumulative distribution function equal to the probability/the wanted quantile 1-p; and then we find the return level. For example for the GEV distribution given by (1), the return level is given by the following equation:

$$z_p = \begin{cases} \mu - \dfrac{\sigma}{\xi}[1 - \{-\log(1-p)\}^{-\xi}] & \textit{pentru} \quad \xi \neq 0 \\ \mu - \sigma \log\{-\log(1-p)\} & \textit{pentru} \quad \xi = 0 \end{cases} \tag{3}$$

3. RESULTS DISCUSSION

3.1. HMM APPLICATION TO DISCHARGE AND LINK WITH THE ATMOSPHERIC CIRCULATION

We define the following seven states for the Orşova discharge for which we construct a hidden Markov model:

State 1 – severe drought; State 5 – slight above normal situation;
State 2 – drought; State 6 – above normal situation;
State 3 – slight drought; State 7 – heavy above normal situation.
State 4 – normal state;

Before calculating the composite maps, we have analysed the lag correlations between the daily SLP defined in 555 grid points and Orşova daily discharge, irrespective of month. The best correlations were found for a lag of 10 days between Orşova discharges and SLP. The spatial distribution of the correlation coefficients is presented in Figure 1. The key zone is centred on (47.5^{0}N; 20^{0}E). The correlation coefficients in the key zone have a high statistical significance because the correlation is achieved between two time series with large size (daily values from 44 years, 1958–2001).

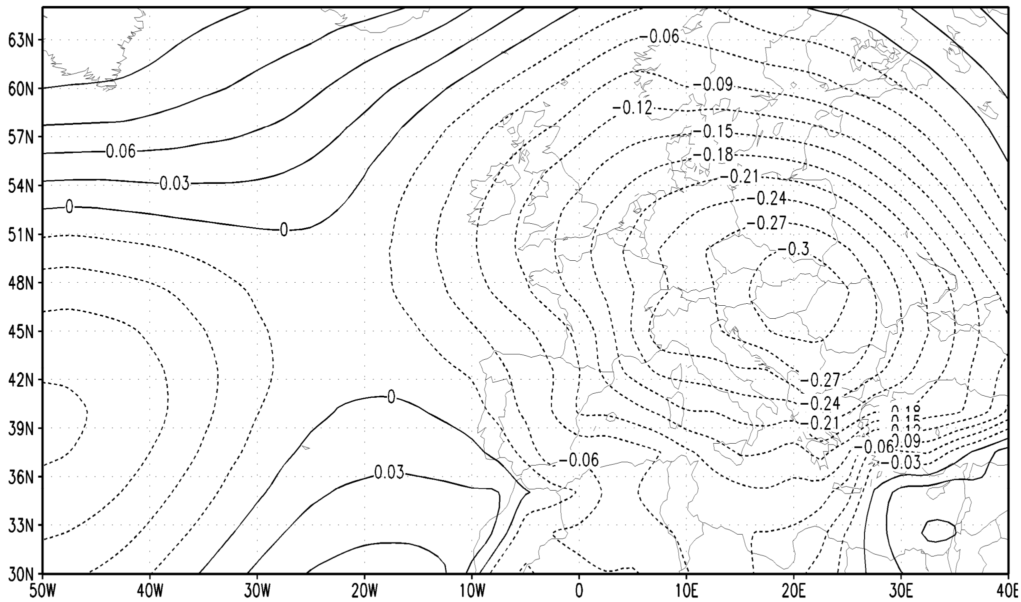


Fig. 1– Correlation of daily Danube discharge at station Orşova with daily SLP over Euro Atlantic (1958–2001) with a lag of the SLP field preceding the discharge data by 10 days.

The distributions of composites of SLP associated with the extreme states (1 and 7) of HMM for discharge level at Orşova are shown in Figures 2a and 2b. From Figure 2a we can notice the high pressure field centred in the zone of the key point in accordance with the state with the lowest discharges at Orşova. Figure 2b emphasizes a low pressure field which is certainly associated with the state 7 that is assigned to the greatest discharges in the inferior basin of the Danube. The spatial distribution of the composites for all the seven states is found in Mareş *et al.* (2008b).

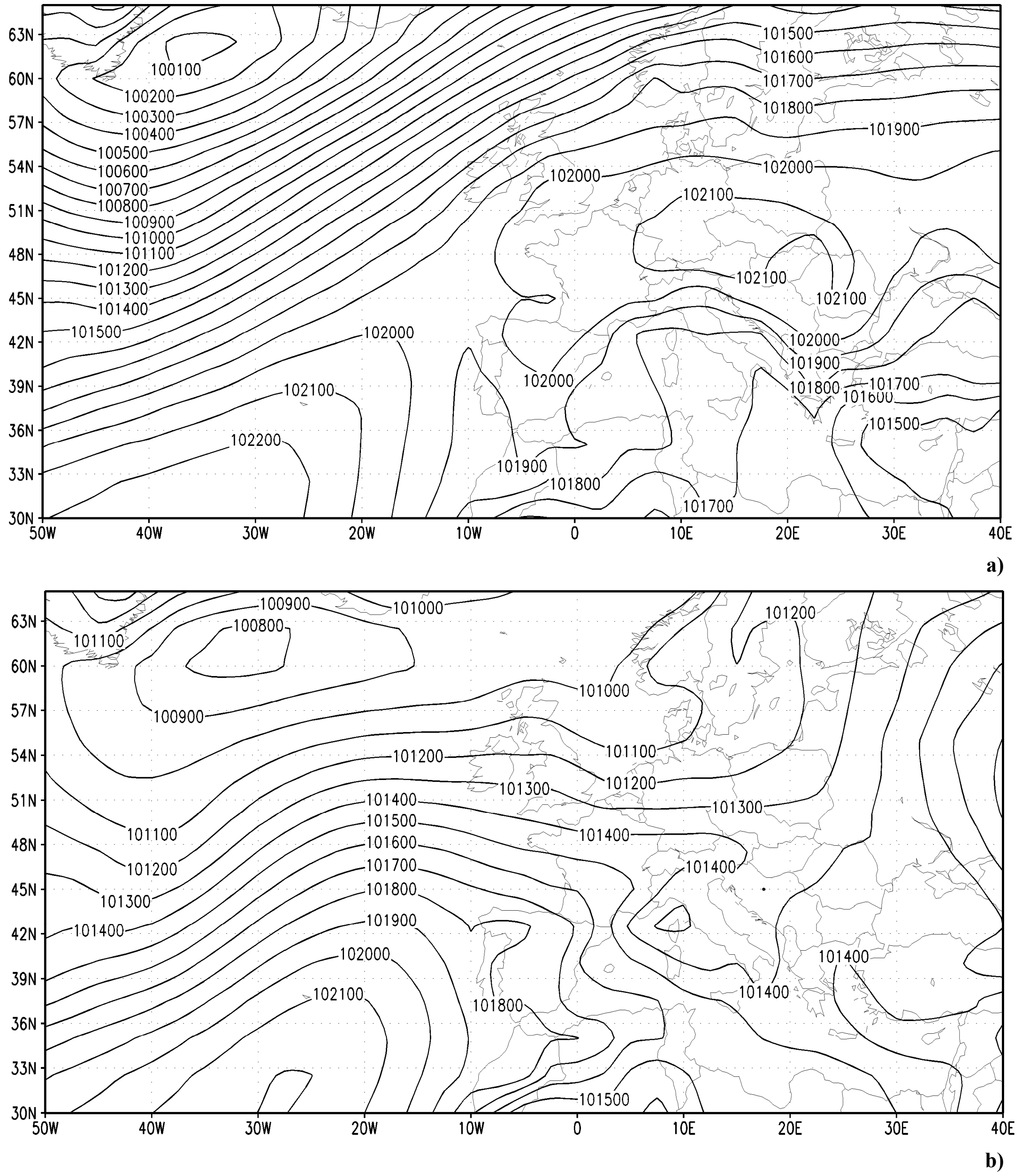


Fig. 2 – Composite distributions for sea level pressure (SLP) taken with 10 days before the hydrological states at discharges at Orşova during spring time: a) state 1; b) state 7.

Because there are some difficulties to apply a HMM with seven states for discharge level and to associate also seven states for atmospheric circulation, we have used in this HMM application only three states for atmospheric circulation. We have classified in three patterns the SLP over the Atlantic European region depending on the values in the key zone, centred on (47.5^{0}N; 20^{0}E), namely cyclonic, normal and anticyclonic circulation. In this case we have three distinct observation symbols (C, N, A), which differs of the classification in seven states. For example, in the classification with three states, the first state represents a cyclone type circulation and, in the seven state classifications of the atmosphere, the first state represents an anticyclone type circulation. For this reason, in the following interpretations we must take into account this change of the significance of the three states. The link quantification between seven-states of discharge levels at Orşova in spring time and three-states of atmospheric circulation (sea level pressure) is estimated by means of the emission matrix. The transition probabilities of the emission matrix are graphically represented in Figure 3. Using both the probabilities of the transition matrix of discharges and of the emission matrix, a simulation is achieved for each of states.

Estimation of discharges in the 21st century

The pressure values over the European region (65^0 – 30^{0}N; 0 – 40^0 E) for two periods of 42 years, namely 2009–2050 and 2051–2092 have been considered in order to be compared with observations. The SLP values simulated by the EGMAM model have been analysed. The model was prepared for the IPCC Fourth Assessment for the 20th century and for the 21st century (SRA1B experiment) and this model beside other models is used within ENSEMBLES EU-project.

We analysed the results from four situations: observations, simulation from the EGMAM model of the historical data (20C), of the data from the first half of the 21st century (SRESA1B experiment) and from the second half of this century, noted here with 21C_1 and 21C_2. The comparative analysis has been carried out by means of EOF components, the difference of the means, probabilities matrices, and frequency of the states. The difference between the mean of the observations and the mean of the pressure simulated for 20th century is shown in Figure 4. One can see that in the zone centred on the key point (47.5^{0}N; 20^{0}E) found for the observation, the difference between the observed pressure and that simulated for the 20th century is relative low. That means that the model performance in this zone is high and this zone will remain a key zone in the 21st century for the Orşova discharge. Also in the scenario, the mean of the pressure does not present essential change in the key zone. But we have to see what happen with the transitions of the three states (C = cyclone, N = normal pressure, A = anticyclone). The transition probabilities of Markov chain for 21C_1 and 21C_2 comparative with observations (Obs) are presented in Table 1.

The differences between the probabilities assigned to the first part of the 21th century (21C_1) and the probabilities for observations and those between the probabilities for the second part of the 21th century (21C_2) and the probabilities for observations (Obs) are presented in Figures 5a and 5b, respectively.

Table 1

Transition matrices of Markov chain with three states applied to the observed SLP (1958–1999) and to simulated SLP for two intervals in the 21st century obtained with EGMAM, SRES A1B experiment

	Obs (1958–1999)			21C_1: (2009–2050)			21C_2 (2051–2092)		
	C	N	A	C	N	A	C	N	A
Type C	**0.681**	0.254	0.064	**0.696**	0.264	0.040	**0.711**	0.264	0.025
Type N	0.265	0.510	0.225	0.284	0.508	0.208	0.261	0.521	0.217
Type A	0.052	0.251	**0.697**	0.025	0.236	**0.739**	0.034	0.220	**0.747**

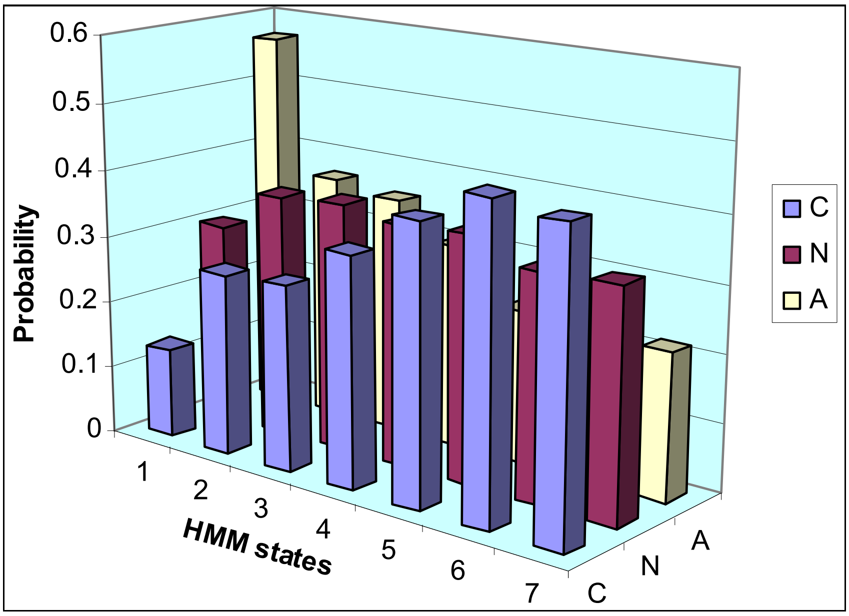


Fig. 3 – Probabilities of the emission matrix of the HMM states for discharge level, associated with the atmospheric circulation (sea level pressure) classified in three states.

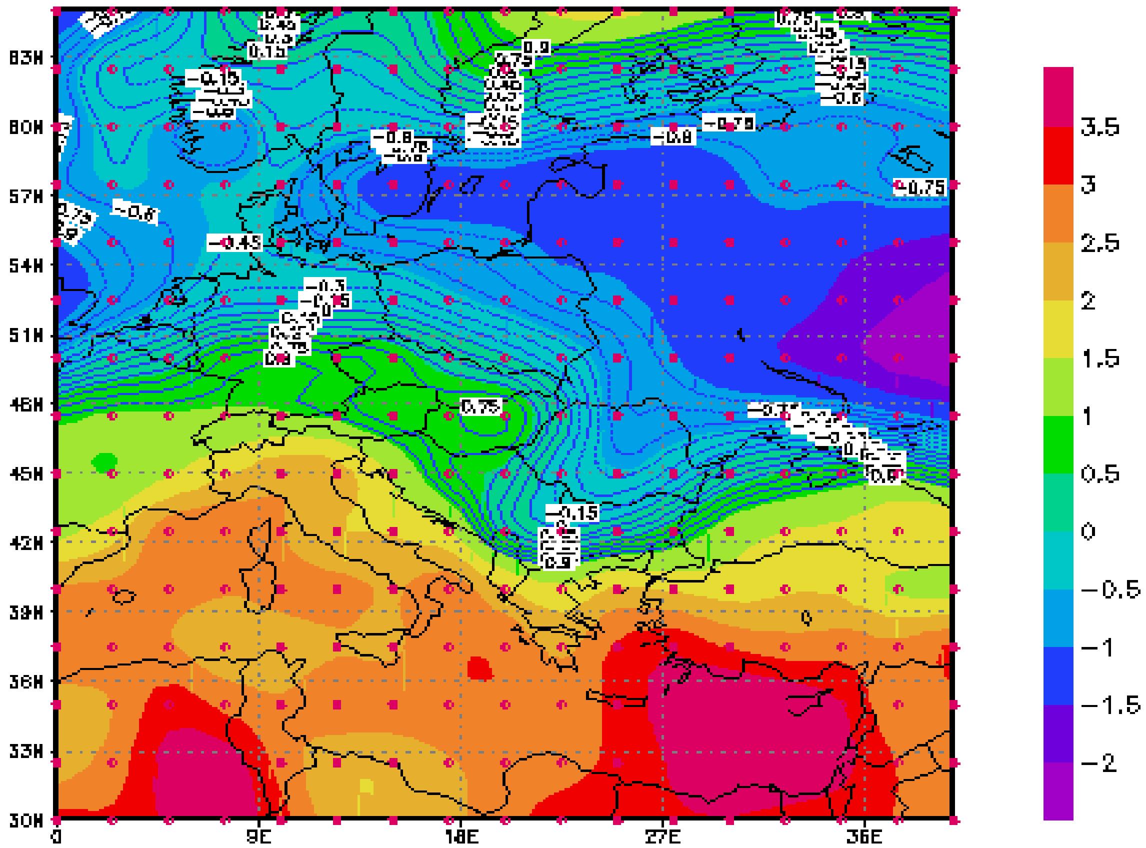


Fig. 4 – Difference between SLP simulated with EGMAM and observations averaged over the period 1958–1999 (spring months).

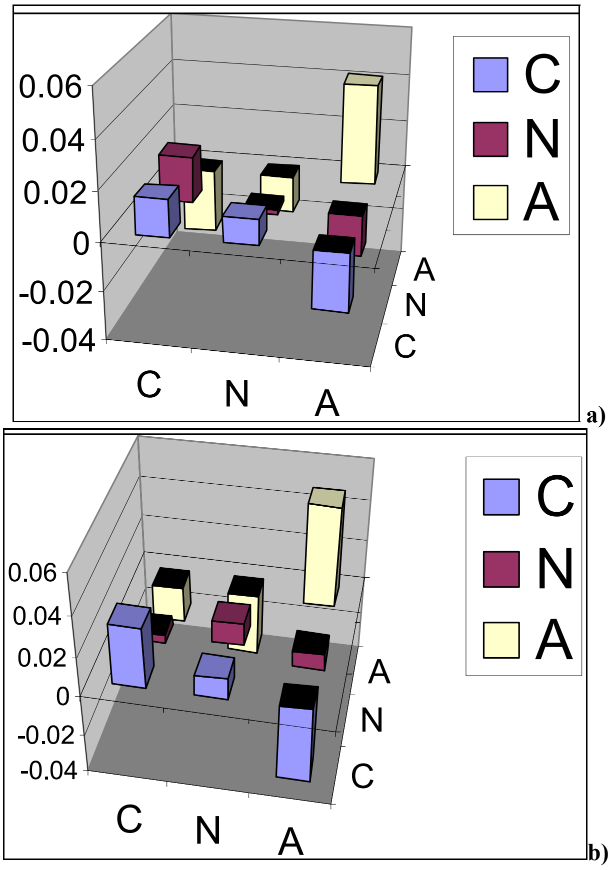


Fig. 5 – The probability differences of Markov chain with 3 states applied to simulated SLP for two intervals in the 21st century obtained with EGMAM, SRA1B experiment and observations: a) 21C_1 – Obs.; b) 21C_2 – Obs.

From the Table 1 and Figure 5 one can see that the persistence of the cyclonic and anticyclone states increases in the 21st century comparative with observations. In the 21C_2 period, the persistence of these atmospheric states is higher than in the first half of the 21st century. The significant increase is observed in the anticyclone type circulation, defined in the key zone considered in this study. These results lead to the conclusion that an increase of the extreme hydrological events occurrence in the 21st century is expected, with the predominance of the drier episodes.

3.2. MAXIMUM DAILY PRECIPITATION DURING SPRINGTIME

The daily precipitation for Bacău station in springtime (March, April, May) for the 20th century (1901–1999) and the 21st century (2001–2099) were obtained from the outputs of EGMAM model (20C and SRESA1B, respectively, run3). The maximum daily precipitation for the spring season was fitted using a generalized extreme values distribution (GEV).

The GEV distribution parameters (location, scale and shape) for the 20th century (with subscript 1) and 21st century (2 as subscript) corresponding to the distributions from Figures 6 and 7, are the following:

$$\mu_1 = 18.47 \qquad \mu_2 = 19.38$$
$$\sigma_1 = 3.73 \qquad \sigma_2 = 3.78$$
$$\xi_1 = -0.07 \qquad \xi_2 = 0.01$$

The location parameter, μ, indicates that the precipitation at the Bacău station increase in average in the 21st century in comparison with the 20th century.

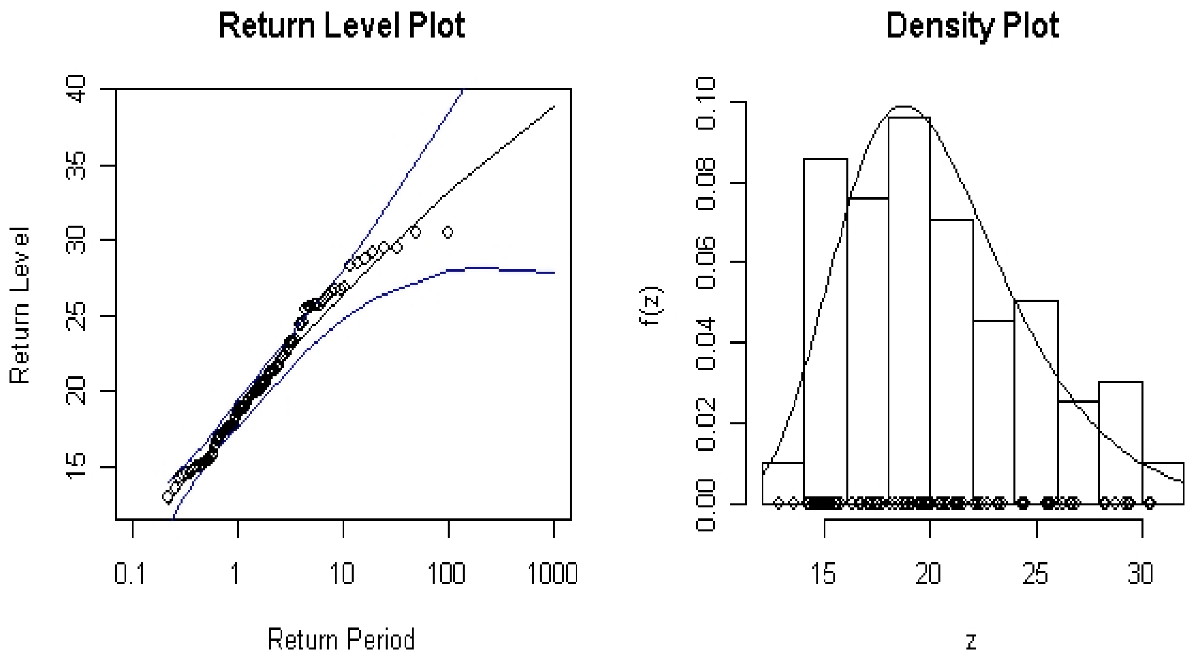


Fig. 6 – Spring daily maximum precipitation at Bacău for 20th century (1901–1999) simulated with EGMAM (run3). The estimated return level = 33.16 mm for 100-year, with 95% confidence interval approximately (29.74, 33.16 mm).

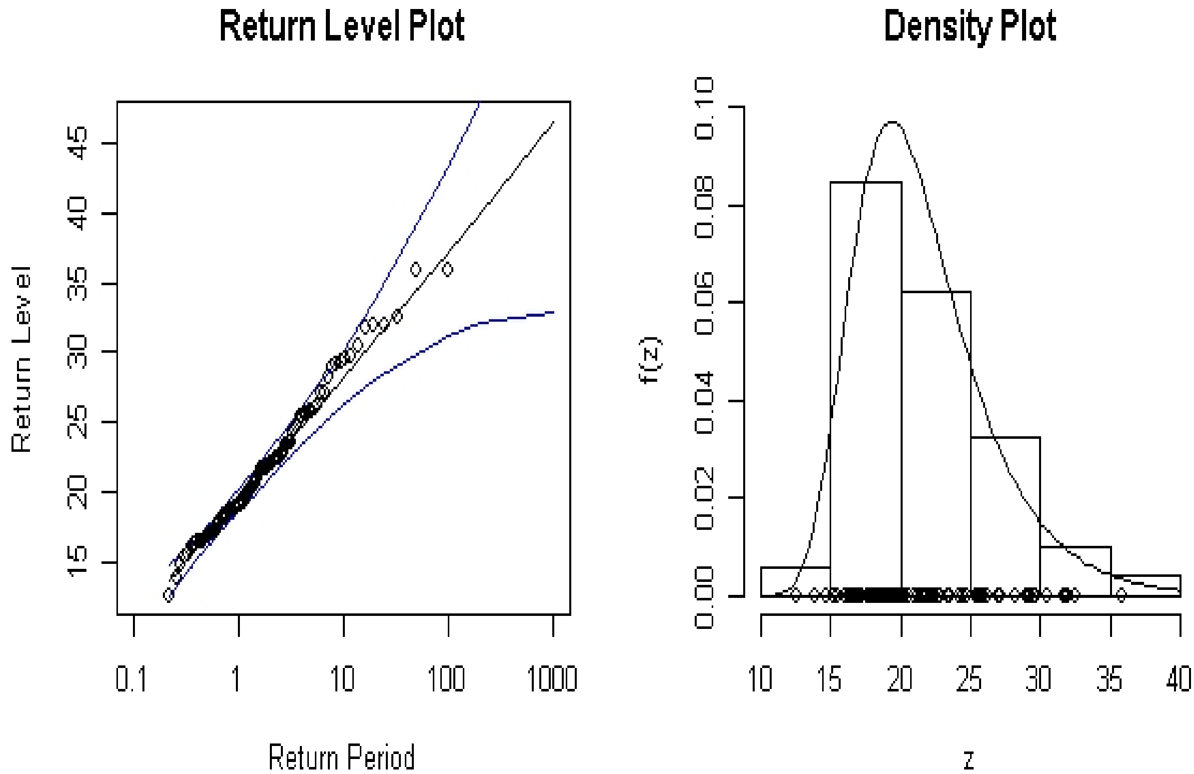


Fig. 7 – Spring daily maximum precipitation at Bacău for the 21st century (2001–2099) simulated with EGMAM (run3) A1B scenario. The estimated return level = 37.25 mm for 100-year, with 95% confidence interval approximately (32.92, 37.25 mm).

The shape parameter, ξ, shows a change of distribution type from Weibull in the 20th century to Frechet distribution in the 21st century having the tail with high precipitation more extended. This is in accordance with the estimated return level which increases from 33.16 mm in the 20th century to 37.25 mm in the 21st century.

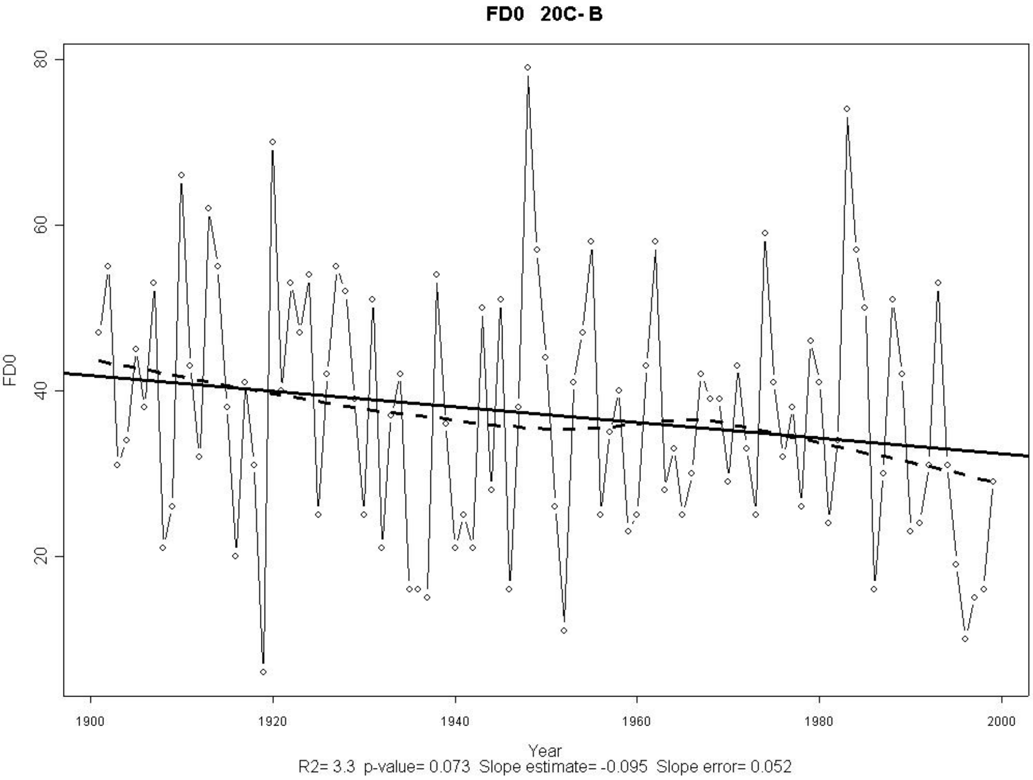
3.3. TRENDS IN CLIMATE EXTREME INDICES

Daily values of precipitation, minimum and maximum temperature at Bacău station were analysed from the point of view of occurred changes in the climate indices of extremes in 21st century compared to the 20th century, considering values simulated with the EGMAM model, achieved by the Free University of Berlin. Compared to the EVT analysis from the previous paragraph, when only the spring season values were used, these climate indices were calculated for the entire year, regardless the month, for periods of 99 years, 1901–1999 and respectively 2001–2099. The reference period for the 20th century was 1970–1999, and for the 21st century it was chosen a period closer to the previous one, namely 2001–2030. From the 27 calculated indices, we will present here only four of them. Two of them refer to the evolution of temperatures (FD0 and SU25) and the other two to the precipitations (CDD and R99p). The FD0 index refers to the frost days in a year, that is annual count when daily minimum temperature $< 0^0$C and is represented in Figure 8a for the 20th century and Figure 8b for the 21st century. We can observe a decreasing trend in the number of frost days in the 21st century compared to the 20th century. The SU25 index represents summer days, namely the days with daily minimum $> 25^0$C. Figure 9b shows almost a triple number of summer days in a year towards the end of the 21st century compared to the 20th century (Fig. 9a).

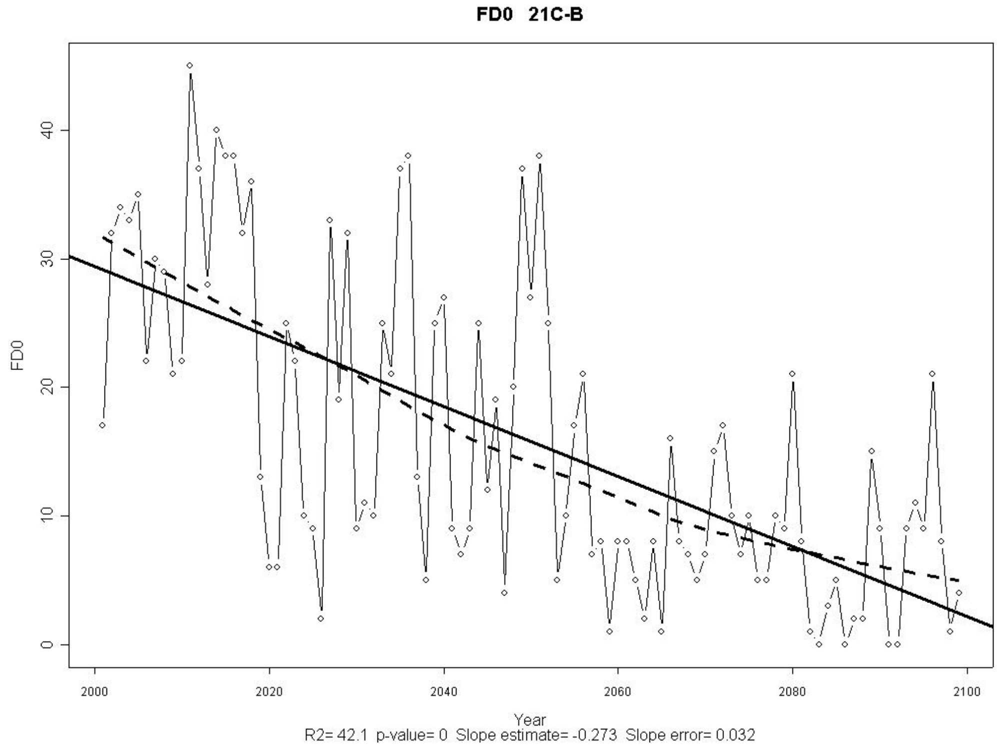
As the CDD index for precipitations is concerned, it is a measuring unit of the number of consecutive dry days (days with precipitation < 1 mm). The evolution of the CDD index for the 20th and 21st century is represented in Fig. 10a and, respectively, Fig. 10b. We can observe a slight tendency of increase in the maximum number of consecutive dry days in the 21st century compared to the 20th century. The extremely wet days are indicated by the R99p index, which represents the total precipitation amounts in the case in which the precipitation exceed the 95 percentile (PP>95-th percentile). The graphic representation of this index is shown in Figure 11a for the 20th century and Figure 11b for the 21st century. Although, there is a slight tendency of decrease in the evolution of precipitation reflected by this index in general, we can observe isolated cases in the 21st century when the total of precipitation exceeds the value of 100 mm, reaching 140 mm, while during the 20th century, the 100 mm value is exceeded only in one case. This result is in accordance with the one obtained through GEV fitting of maximum precipitation during spring, when a slight increase (of 4 mm) of the return level in the 21st century compared to the 20th century at Bacău Station is observed.

In Mareş and Mareş (2006) the evolution of the CEI for the 20th century (1901–2000) was analysed for the values observed in Vienna. The tendencies of indices concerning temperatures are the same as the Bacău ones, but the increase or decrease slopes of the tendencies are slightly different from the Bacău ones. Concerning the precipitation, the same situation as Bacău is found for the data observed at Vienna, namely the tendencies of the climatic indices are not very clear. The R99p index which refers to the cases with abundant amounts presents the same slight decrease tendency both in the precipitations in Vienna and the precipitation simulated by the EGMAM model for the 20th century in Bacău, but the precipitation amounts in Bacău are lower. This is due both to local climate, and the fact that the general circulation models underestimate the precipitation amounts.

Although our results for the 21st century are obtained from simulations with a general circulation model, the tendency of the indices which refer to precipitation is in accordance with the tendency of the indices for the southern Europe, obtained by Beniston *et al.* (2007), who analyze regional circulation models outputs.

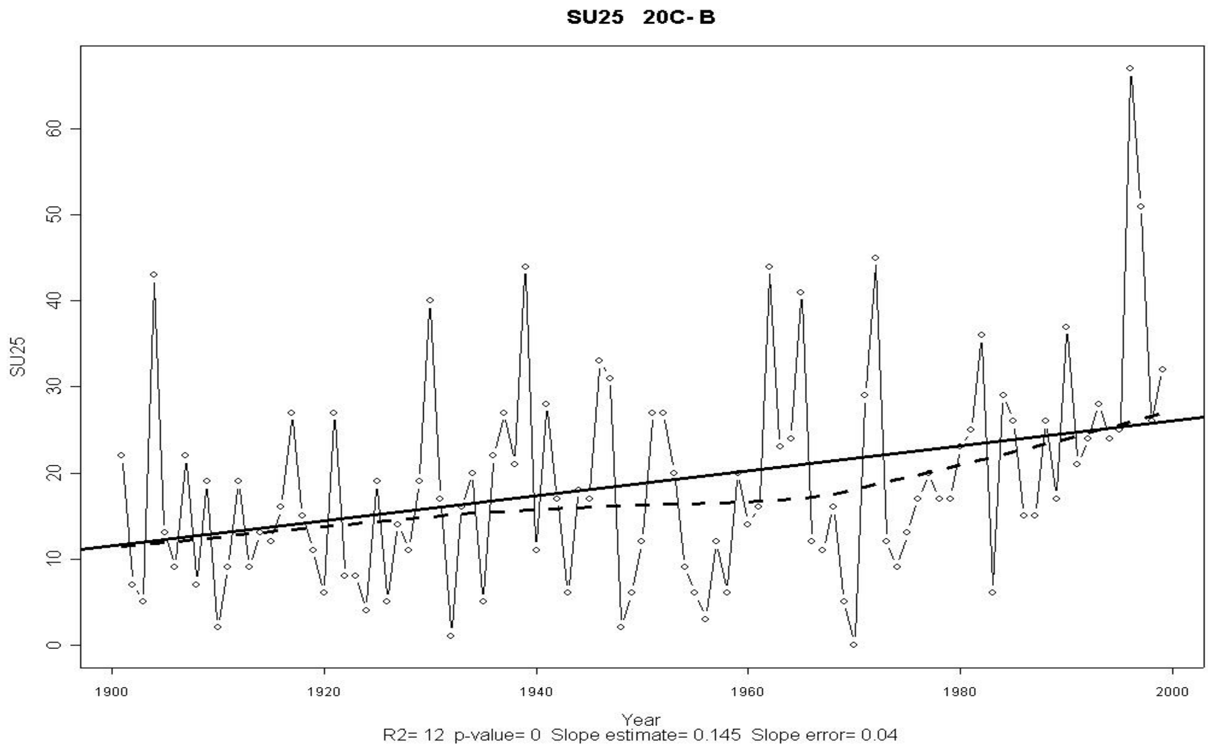


a)

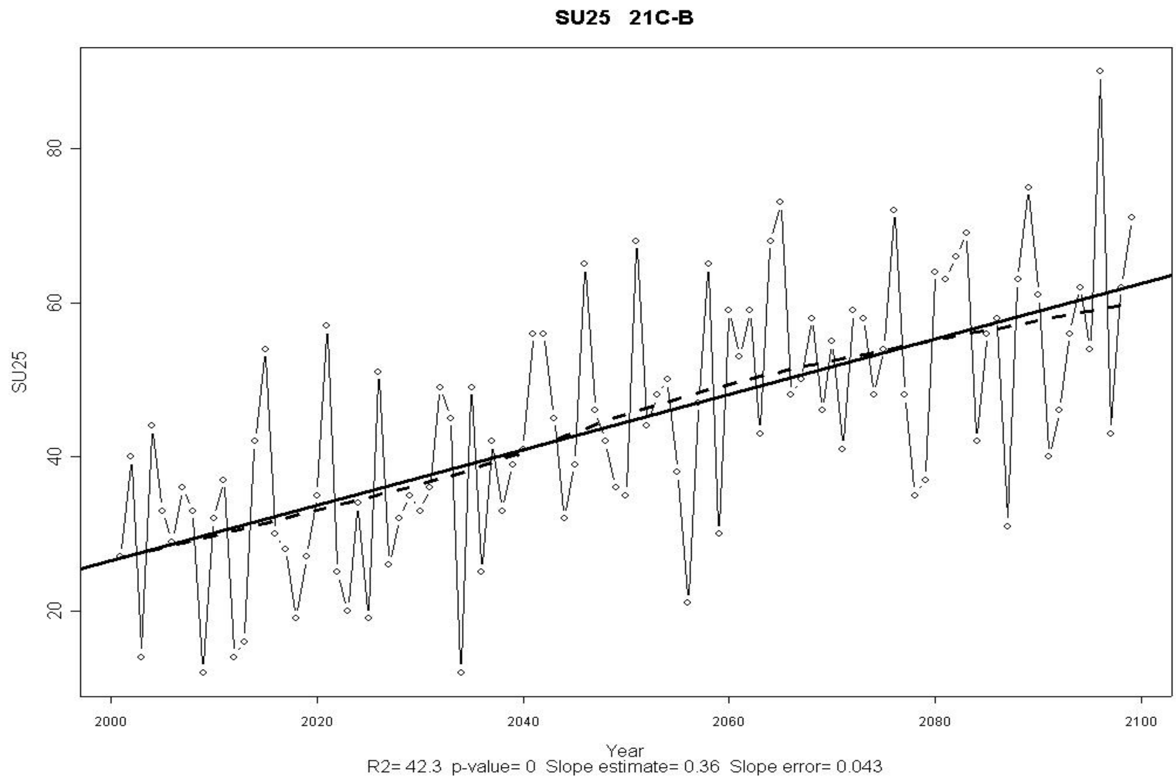


b)

Fig. 8 – Annual account of the frost days at Bacău for: a) the 20th century; b) the 21st century.

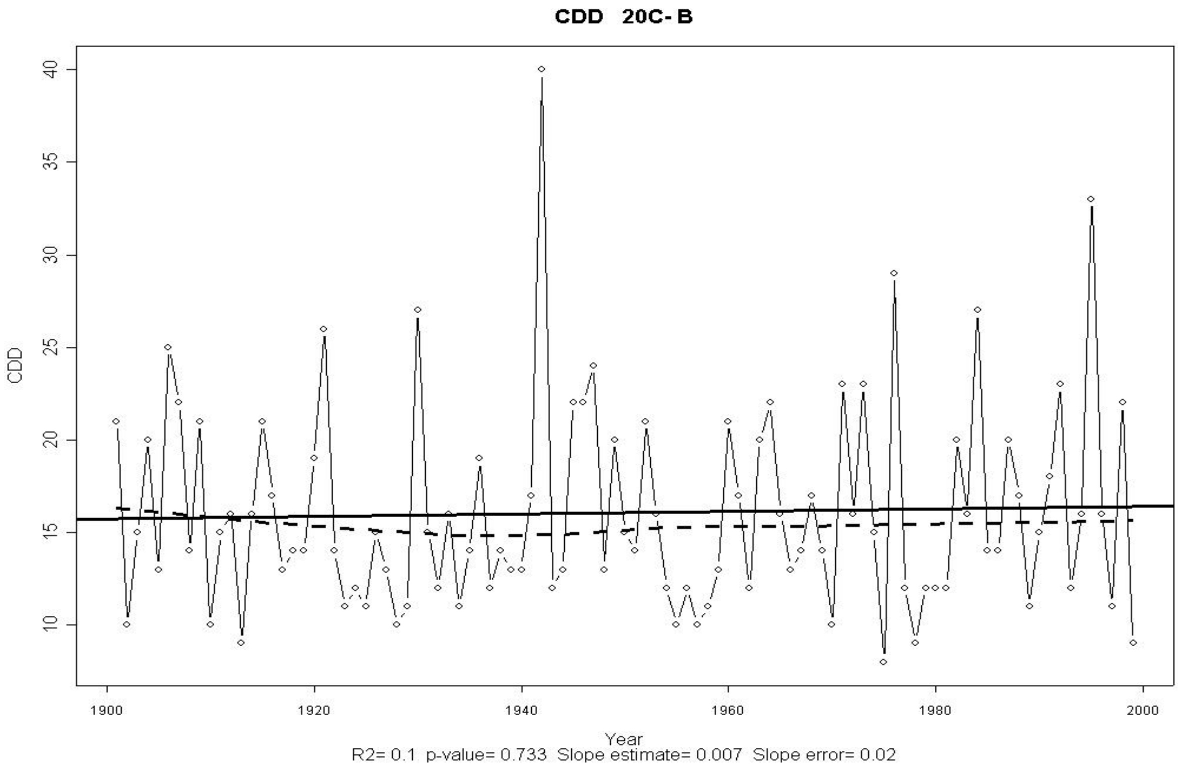


a)

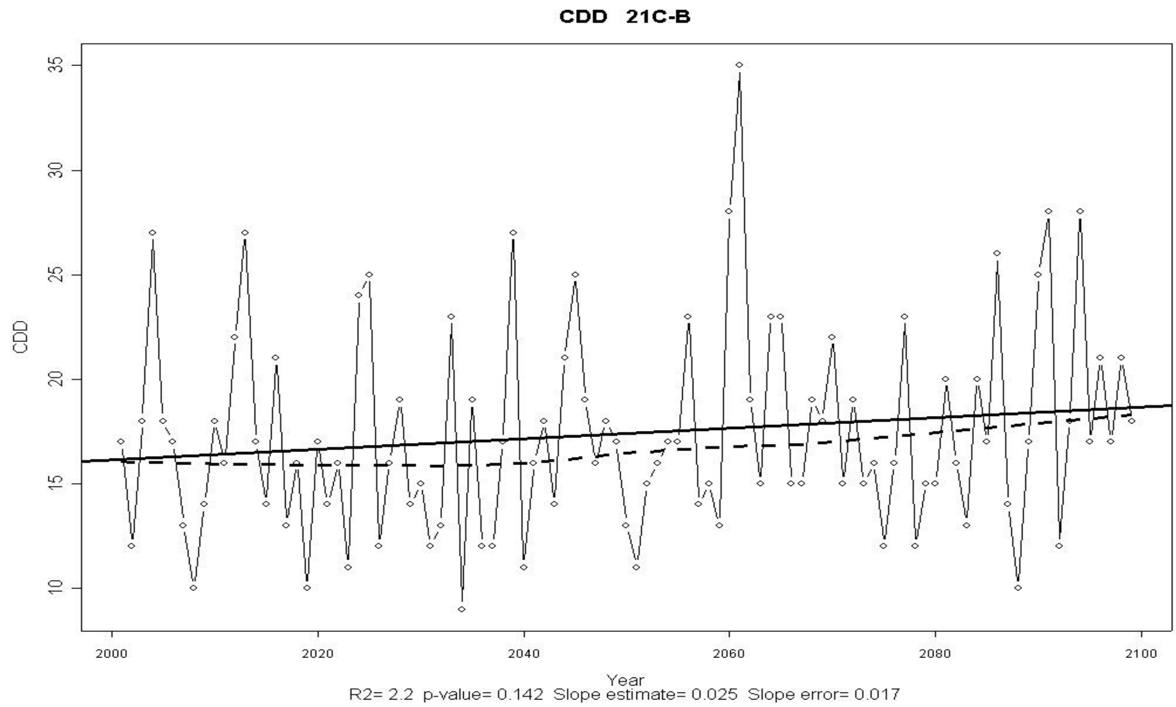


b)

Fig. 9 – Annual account of summer days at Bacău for: a) the 20th century; b) the 21st century.

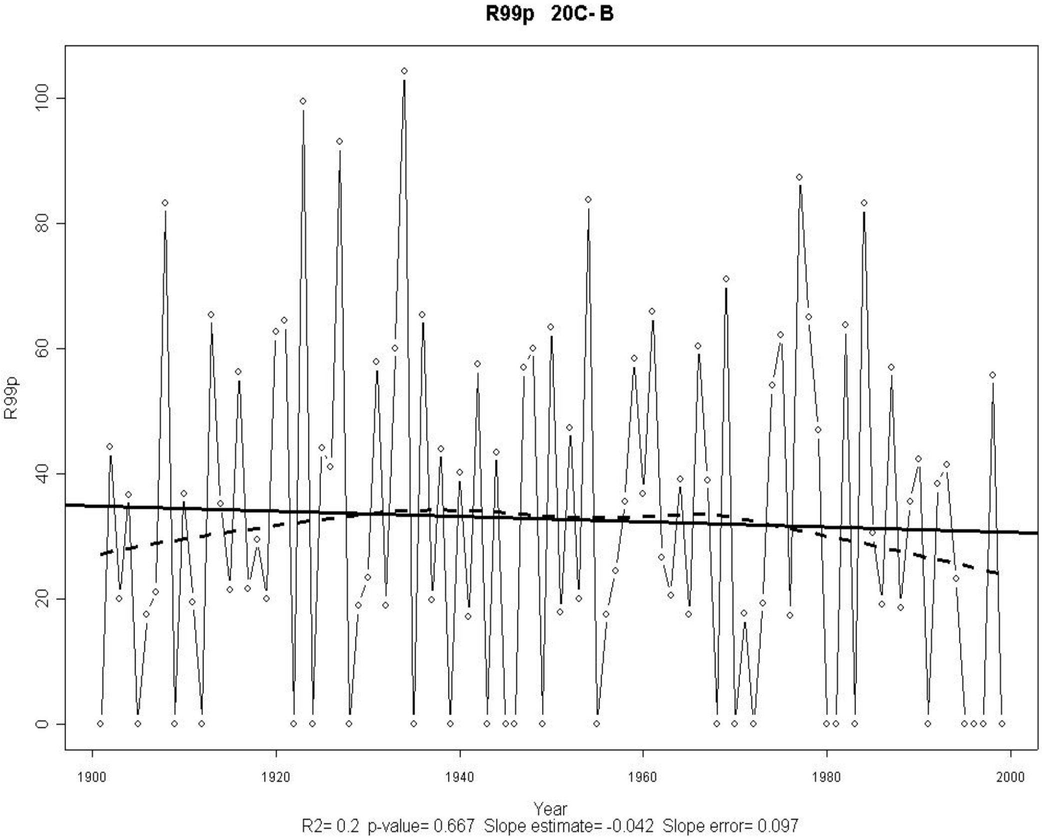


a)

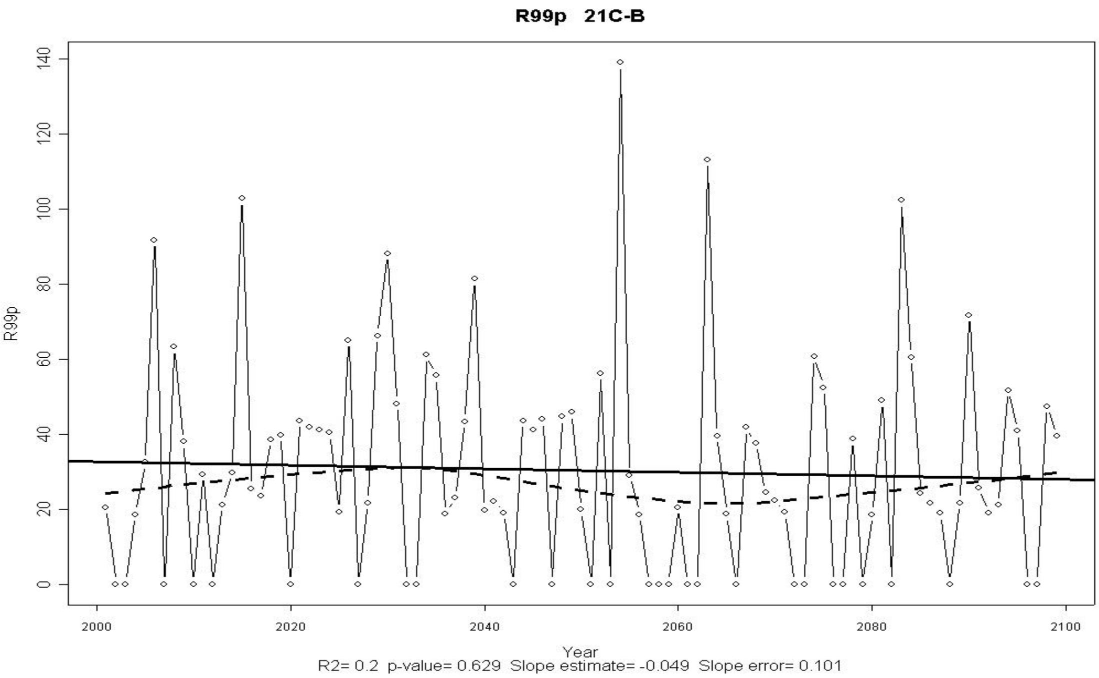


b)

Fig. 10 – Maximum number of consecutive dry days at Bacău for:
a) the 20th century; b) the 21st century.



a)



b)

Fig. 11 – Annual total of precipitation in the extremely wet days (precipitation >95th percentile) at Bacău for: a) the 20th century; b) the 21st century.

4. CONCLUSIONS

Although in this study statistical methods are applied in estimating the Danube discharge in the 21st century, these are in present (Fowler *et al.* (2007) comparable with the dynamical methods, particularly for estimating extreme events using general circulation models outputs. In case of applying statistical procedures it is recommended (Goodess *et al.*, 2007) to apply more statistical methods and to consider more GCM models or RCM models.

In the present study, three methods were applied, based on: HMM, EVT and climate extreme indices (CEI), using the simulations for the 20th and 21st centuries from one general circulation model (EGMAM). The estimation of the Danube discharge in the lower basin in the spring season in the 21th century comparative with the 20th century was achieved indirectly by estimating the probabilities of the extreme events occurring in the discharge values, associated with the probabilities of occurring cyclonic or anticyclonic atmospheric circulation types in the zone considered key for modifying discharges. This key zone was determined from observations (1958–2001) using daily sea level pressure from ERA–40 and the Danube discharge at Orşova. The Orşova discharge represents an integrator of precipitation from the higher and middle basin of the Danube. These results were supplied by those obtained from estimating the expected changes in the 21st century in the daily extreme precipitation field or in the daily maximum and minimum temperatures at Bacău station. Both the values from the 20th century and those from the 21st century are obtained from EGMAM model outputs. The Bacău station was considered taking into account both the EGMAM model resolution and the hydrographic basins size in Romania, associated to the Danube tributaries.

Taking into account the link between the local scale (Orşova discharges) and the atmospheric circulation (SLP in the key zone) obtained for the observed data, the estimations of the states of the atmospheric circulation in the 21th century is achieved, by means of the simulations provided by the climate global model EGMAM. The results lead to the conclusions that an increase of the extreme hydrological events occurrence is expected especially in the second part of the 21st century. The predominance of the drier episodes is estimated in comparison with floods. But in comparison with normal situations the frequency of the states with the high discharges increases.

From the climate extreme indices analysis for the extreme temperatures in the 21st century comparative with the 20th century the most significant results show a significant increasing of the tropical night's number and of summer days, a decreasing of intervals with cold days and days with frost. Concerning the precipitation processing, as Niehörster *et al.* (2008) show, signal to noise ratio for precipitation is much lower than in case of temperatures for all cases analysed by authors (namely several models and scenario). In the present study also regarding the extreme precipitation the results are not as evident as in the temperatures case, but it can be noticed a light trend of increasing of the maximum number of drought consecutive days. Regarding the excess, the GEV analysis of daily maximum precipitation in springtime presents a light increasing in the 21st century compared to the 20th century. From the CEI analysis for the whole year it can be noticed a light trend of decreasing of the wet day's number and of the annual total amount of precipitation in the extremely wet days, but there are years with annual amount of precipitation in the 21st century exceeding that of the 20th century, this being in accordance with the EVT analysis results.

Although three statistical methods were used for estimating the Danube discharge in the 21st century, the results regarding the input given by precipitation and temperatures are not contradictory and the EGMAM results are comparable with those obtained by other authors using data simulated with RCM (see Beniston *et al.*, 2007). Also, the results for the spring and annual precipitation are in accordance with those obtained by Giannakopoulos *et al.* (2005), who found for the eastern part of

Romania a light increasing of precipitation in the spring season. For the whole year, the conclusion of the present study regarding the light decreasing of the precipitation are also in accordance with Giannakopoulos *et al.* (2005), because in their study it is emphasised a pronounced decreasing of summer precipitation that evidently leads to a diminution for the whole year.

The results obtained in this study corroborated with those obtained by other authors for larger regions that include also Romania lead to the conclusion that the precipitation diminution in the 21st century, being associated to the temperature increasing, will have an important impact on water resources, agriculture, etc.

It is however necessary to extend the study at more stations from Romania with outputs obtained from several climate change models.

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