

## Frequency of catastrophic climatic phenomena in Ukraine under the influence of global warming

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**Abstract** Data obtained from various historical records and annals (manuscripts) are examined. The statistical analysis of these data shows that the long-term dynamics of frequency or repeatability of the catastrophic climatic phenomena in the territory of Ukraine (in particular, of phenomena determining the regional freshwater resources) depends on the global climatic regime. Global warming or global cooling can influence the repeatability of catastrophic climatic phenomena in the Ukraine. It is found that the repeatability of the events considered is a non-monotonic function of temperature fluctuations. Regression models for the intensity of catastrophic climatic phenomena in Ukraine as a function of an index of climatic anomalies are constructed. These models are used as a scenario for the possible dynamics of repeatability of catastrophic climatic phenomena in the Ukraine as a result of global warming.

**Key words** catastrophic phenomena; droughts; floods; rainy summers; regression models and scenarios; temperature anomalies

### INTRODUCTION

The main aim of this research is to obtain quantitative estimates of the basic tendencies of the dynamics of repeatability of catastrophic climatic phenomena in the Ukraine and adjacent regions in Europe as related to global climate fluctuations in the last millennium. These estimates are used to compile scenarios of a possible increase or decrease of the frequency or repeatability of catastrophic climatic phenomena for the first half of the twenty-first century.

Catastrophic climatic phenomena, such as droughts, floods, extremely cold or very warm winters, occurring at a large scale and great intensity are rather rare events. These phenomena, typically, occur only a few times per century. Because of this, statistically estimating the basic characteristics of the dynamics of the repeatability of these events is difficult. Direct instrumental observations are not helpful because of the very short record lengths. It is therefore necessary to use other (proxy) data as well. In our opinion, apart from historical records, different annals and manuscripts are most suitable for this purpose. In this research we examined data obtained from historical records, annals and manuscripts. These records were very carefully compiled and described in the monasteries of the Russian plain.

The analysis is done on the basis of historical records and annals from the last millennium (800–1700 or 1800). The following phenomena were considered: droughts, rainy summers, floods, cold winters, late springs, cold spells at the beginning of a summer, catastrophic thunderstorms, catastrophic storms, etc. We use the names

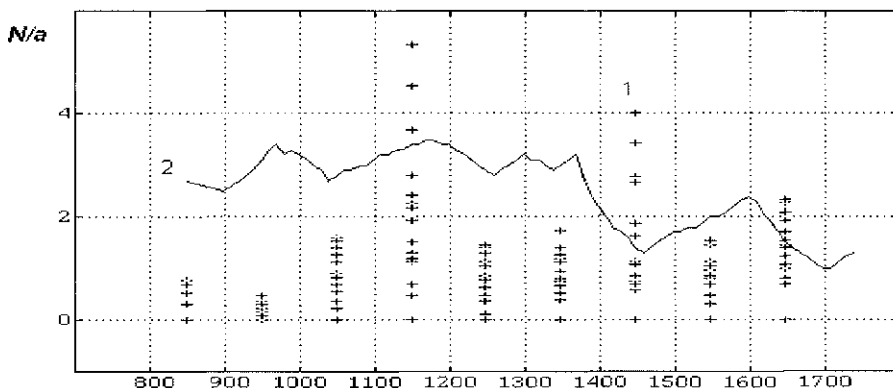
of these events as described in historical records and annals (manuscripts). Some of these phenomena directly characterize regional freshwater resources and others are more indirectly related to them.

The empirical time series of repeatability of catastrophic events for the last millennium were constructed by the analysis of these records. On the basis of these time series it is possible to estimate statistical characteristics of the 100-year dynamics of repeatability of catastrophic events in a given physical-geographical region of the planet.

### SECULAR SCALE REPEATABILITY OF CATASTROPHIC CLIMATIC PHENOMENA IN THE UKRAINE FOR THE PERIOD OF 800–1700

The number of catastrophic climatic phenomena in each century (frequency or repeatability, per 100 years) for the period of 800–1700 was estimated, mainly by generalization of the data published in Borisenkov & Pasetsky (1988).

The statistical analysis of these data shows that the long-term dynamics of repeatability of the climatic catastrophic phenomena in the Ukraine cannot be represented by a stationary Poisson process. For example, some groupings of events can be precisely traced over time. Such groupings of events cannot behave as a stationary Poisson process. This means that a factor controlling the repeatability or frequency of events exists. Boychenko (1999, 2000) and Voloshchuk & Boychenko (2001) showed that the temperature fluctuations in Europe could be such a factor (see Fig. 1). As suggested by Fig. 1, the repeatability of the considered events is a non-monotonic function of temperature fluctuations, i.e. the repeatability or frequency of catastrophic climatic phenomena in the Ukraine was higher when the temperature in Europe was above (the Little Climatic Optimum) or below (the Little Ice Age) a given level.



**Fig. 1** Comparison frequency of catastrophic phenomena in Ukraine (1) with the long-term dynamics of temperature anomalies in Europe in the last millennium (2).  $N$  is the number of events for each of the 100-year periods, normalized by their average over the period of 900–1700 which is denoted as  $a$ . Temperature anomalies are shown in relative units.

## INDEX OF CLIMATIC ANOMALIES

In the analysis of the catastrophic phenomena a parameter is introduced to characterize the anomalies of climatic conditions. In our opinion, this parameter can be formulated as follows:

$$q = |\kappa \Delta T + \delta_o|. \quad (1)$$

In this equation,  $q$  is the index of climatic anomaly,  $\kappa$  is a dimension factor,  $\Delta T$  represents temperature anomalies and  $\delta_o$  is a dimensionless empirical parameter that characterizes an optimum level of a global temperature regime. The reference point and the geographical region can be taken into account by readjusting parameters  $\kappa$  and  $\delta_o$ . If the temperature anomalies of Europe are computed relative to the period of 1880–1890, the value of  $\delta_o$  is  $0.16 \pm 0.02$  and  $\kappa$  is  $\sim 1 \text{ K}^{-1}$ .

For this analysis, empirical data of temperature fluctuations in Europe from White (1977) are used. These data have been obtained by various researchers through an indirect assessment of the consequences of climatic changes in Europe for the last millennium. The long-term dynamics of temperature anomalies in Europe for the last millennium are shown in Fig. 1.

## ASSESSMENT INTENSITY OF CATASTROPHIC CLIMATIC PHENOMENA

The empirical time series of the repeatability of catastrophic climatic phenomena were re-scaled to reduce possible biases due to psychological factors inherent in the records and the statistical data processing.

Let us introduce the following notation:

$$x_k(j) = \frac{n_k(j) - a_k}{s_k} \quad (2)$$

where  $n_k(j)$  is the number of the  $k$ -th event for the  $j$ -th century,  $a_k$  and  $s_k$  are, respectively, the time average and the standard deviation of  $n_k(j)$  for the period 800–1700. The values of  $a_k$  and  $s_k$  are presented in Table 1.

**Table 1** Main statistical characteristics of catastrophic climatic phenomena in Ukraine for the period 800–1700.

Phenomenon	Average of repeatability (per 100 years) $a_k$	Root-mean-square deviation (per 100 years) $s_k$	Coefficient of linear correlation between $x_k$ and $q$ , (%)
Droughts	10.67	7.01	65.4
Rainy summers	5.11	3.31	37.4
Floods and high waters	6.33	4.35	78.7
Cold winters	9.33	6.86	52.5
Late springs	2.56	2.63	56.2
Cold spells at the beginning of summer	1.22	1.03	66.8
Catastrophic thunderstorms	4.11	3.66	73.3

Let us assume that  $x_k(j)$  represents independent random values for the  $j$ -th century of some generalized characteristic of climatic catastrophic phenomena in the Ukraine, which we shall denote by  $\chi$ . The value of  $\chi$  can be termed the intensity of catastrophic climatic phenomena, including the phenomena determining the regional resources of freshwater. By definition,  $\chi$  should not depend on an individual phenomenon but represents the general characteristics of all catastrophic phenomena. The characteristics of an individual phenomenon are embodied in the parameters  $a_k$  and  $s_k$ .

In a second step, linear correlations between  $x_k$  and  $q$  were examined. The coefficients of correlation between  $x_k$  and  $q$  are given in Table 1. For some phenomena such as droughts they are reasonably high, but for other phenomena a parabolic relationship may be more appropriate.

These results suggest that the repeatability of catastrophic climatic phenomena in the Ukraine is closely connected to the index of climatic anomaly,  $q$ . Therefore, the parameter  $q$  is used below for constructing regression models of the dependence of the repeatability of catastrophic climatic phenomena on the index of climatic anomaly.

### REGRESSION MODELS FOR UKRAINE

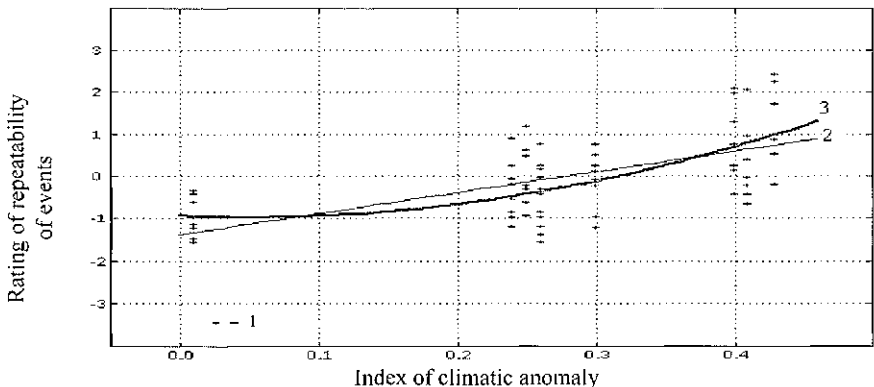
Let us assume that the intensity  $\chi$  for the  $j$ -th century mainly depends on values of  $q$  for the same century. The empirical dependence of  $\chi$  on  $q$  for all considered events for the period of 800–1700 is shown in Fig. 2. The simplest dependence of  $\chi$  on  $q$  is a linear regression equation:

$$\chi = 5.1 q - 0.3 \tag{3}$$

The coefficient of correlation between  $\chi$  and  $q$  for all events is 58.8%. As an alternative, a parabolic regression was fitted:

$$\chi = 15.0(q - 0.06)^2 - 0.95. \tag{4}$$

The empirical root-mean-square deviation from this equation,  $\sigma$ , is 0.77.



**Fig. 2** Dimensionless repeatability or frequency of climatic catastrophic phenomena in Ukraine as a function of the index of climatic anomaly: 1: empirical (historical) data, 2: linear model (3), 3: parabolic model (4).

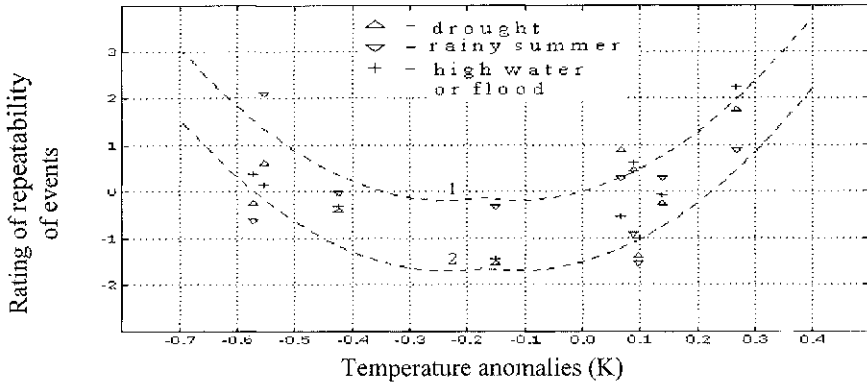


Fig. 3 Repeatability or frequency of droughts, rainy summers and floods in Ukraine as a function of temperature anomalies in Europe (averages over centuries): 1 and 2 are results of the calculation by the parabolic model (4) shifted upwards and downwards by  $\sigma$ .

In a water resources context, the frequencies of droughts, rainy summers and floods are of most interest. These are shown in Fig. 3, which suggests that the results from the parabolic model agree very well with the empirical data for the last millennium.

## REGRESSIONS FOR WESTERN EUROPE AND THE RUSSIAN PLAIN

To find out whether the relationship so obtained is specific to the Ukraine or more globally valid, the dependence of the repeatability of natural catastrophic processes on temperature anomalies in Western Europe and the Russian (east-European) Plain was examined. To eliminate the psychological factor which can influence the processing of the data, the Borisenkov–Pasetsky's time series for the Russian Plain were used directly (without additional generalization) (Borisenkov & Pasetsky 1988). These analyses indicate that a non-monotonic dependence of the repeatability of the phenomena from global temperature anomalies in the last millennium existed in other regions of Europe as well (see Fig. 4 and Fig. 5). This suggests that the regression model (4) can be used for constructing scenarios of the occurrence of catastrophic climatic phenomena due to global warming, both in Ukraine and all of Europe.

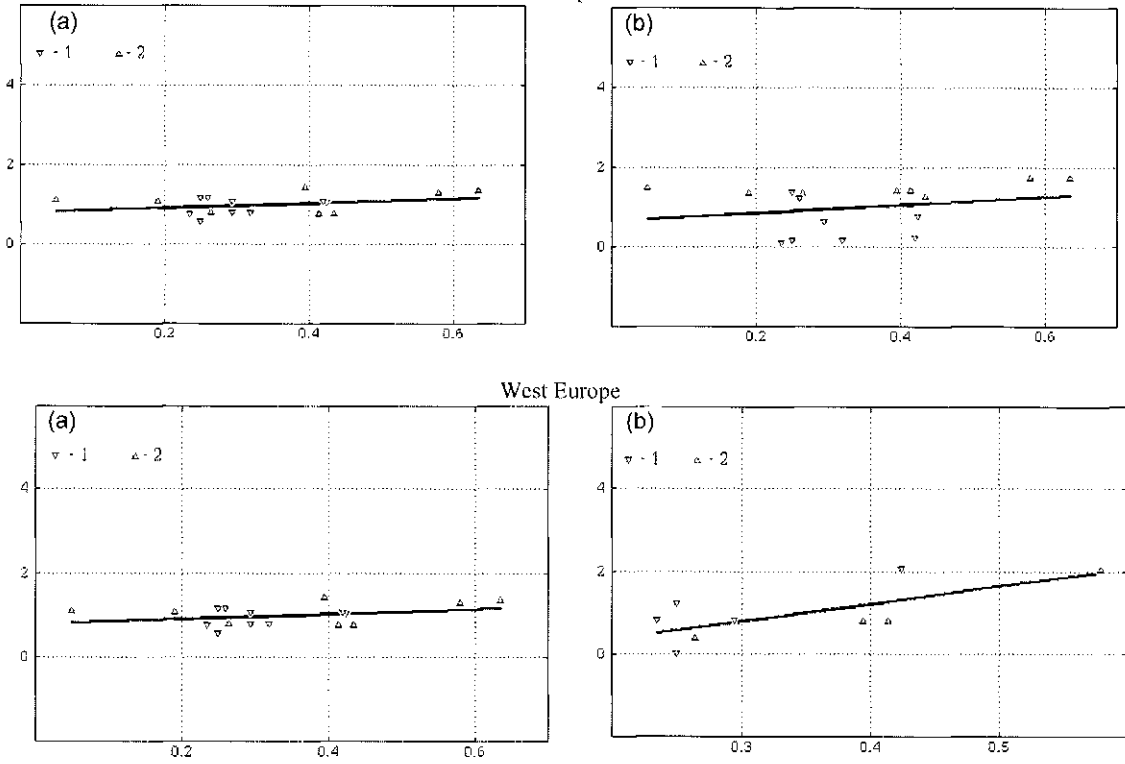
## A SCENARIO OF POSSIBLE DYNAMICS OF CATASTROPHIC CLIMATIC PHENOMENA IN UKRAINE

Let  $P_k(\Delta t, \Delta T)$  denote the probability of the  $i$ -th event to occur  $k$  times in time interval  $\Delta t$ , in which the average anomaly of temperature is  $\Delta T$ . For a given  $\Delta T$  we can calculate the index of climatic anomaly  $q$  from equation (1). Using equation (4), we obtain the following scenario for possible dynamics of repeatability of climatic catastrophic phenomena in Ukraine as a result of further global warming:

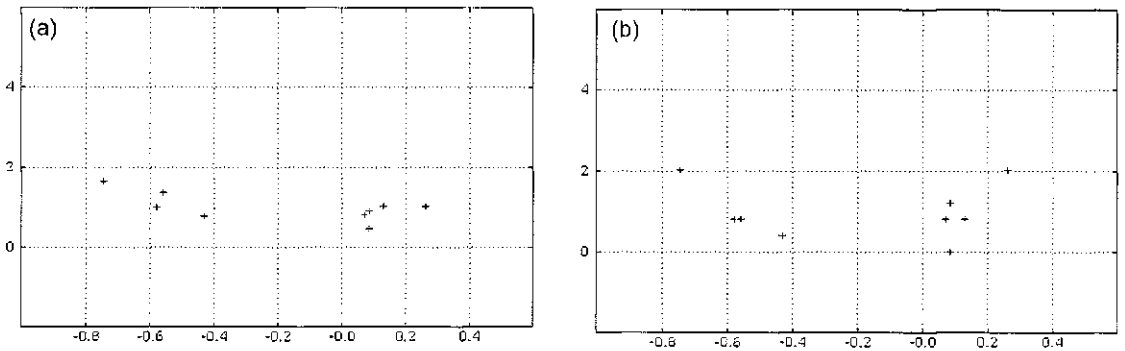
$$P_k(\Delta t, \Delta T) = \frac{v^k}{k!} e^{-v}, \quad v = a_i + s_i \chi \quad (5)$$

$$\chi = 15.0(q - 0.06)^2 - 0.95 \pm \sigma, \quad \sigma = 0.77,$$

Russian plain



**Fig. 4** Dependence of relative repeatability of droughts (a) and catastrophic storms (b), on the Russian plain and in Western Europe, on the index of climatic anomalies (the linear model (3)): 1 relates to positive anomalies of temperatures in Europe; 2 relates to negative anomalies of temperatures in Europe. The horizontal axis is the index of climatic anomaly,  $q$ , according to (1).



**Fig. 5** Dependence of relative repeatability of droughts (a) and catastrophic storms (b) in Western Europe on the anomalies of European air temperatures (900–1800). The horizontal axis represents the secular temperature anomalies, in K.

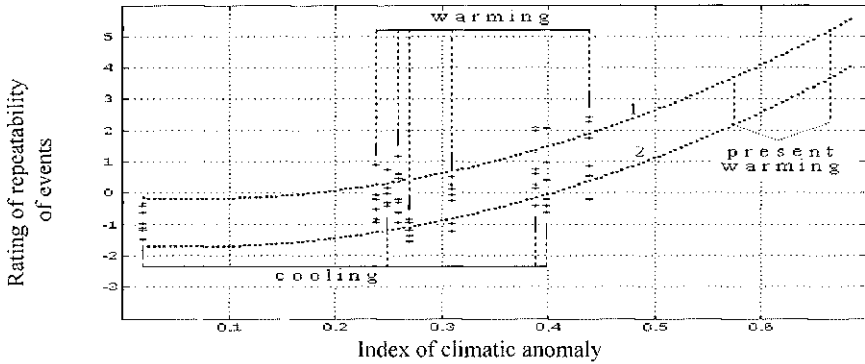


Fig. 6 Assessment and scenarios of the repeatability of catastrophic climatic phenomena in Ukraine as a function of the index of climatic anomaly: 1 and 2: parabolic model (4) shifted upwards and downwards by  $\sigma$ .

where  $a_i$  and  $s_i$  are empirical parameters of repeatability of the  $i$ -th event (the average and standard deviation of the repeatability for the last millennium, see Table 1), and  $\sigma$  is the root-mean-square error of this scenario.

The present global warming is about 0.5–0.6 K in comparison with the pre-industrial era. As follows from equation (4) (see Fig. 6), in this case the frequency of catastrophic phenomena in the Ukraine should be 2–5 times that in the pre-industrial era. As a result of further global warming one may expect a further increase of  $\chi$ . However, this result should be treated with caution. Periods of global warming caused by different physical mechanisms do not necessarily lead to analogous environmental consequences. The present global warming is commonly considered to be caused by anthropogenic amplification of the global greenhouse effect while the processes in the past millennium may have been different.

## CONCLUSIONS

The statistical analysis indicates that the long-term dynamic of the repeatability of catastrophic climatic phenomena in the Ukraine was not a stationary Poisson process during the last millennium. Some groupings of events can be traced over time. This means that a factor controlling the frequency or repeatability of the events considered here may exist. The results suggest that the fluctuations of global temperature may be such a factor. It was found that the repeatability of the events is a non-monotonic function of temperature fluctuations, i.e. the repeatability or frequency of climatic catastrophic phenomena in the Ukraine was higher when the temperature in Europe was above or below some optimal level. This relationship was not only apparent in the Ukraine but also in Western Europe and the Russian Plain. Regression models for the intensity of catastrophic climatic phenomena in the Ukraine, as a function of an index of climatic anomalies, were constructed. Finally, a scenario for the possible dynamics of the frequency of catastrophic climatic phenomena in the Ukraine due to further global warming has been derived from the regression models.

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