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Late Pleistocene and Holocene Climatic Variability in the Carpathian-Balkan Region

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Trends of climate change in the Ukrainian Carpathians during last 130 years

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Driven by multi-level natural cycles and reinforced by anthropogenic influences climate variability considers the most dynamic landscape process. The last century serves as a clear evidence for significant dynamics, especially in mountain regions. In response to last workshops of the regional science network Science for the Carpathians (S4C) and Forum Carpaticum (Kohler, 2009; Björnsen Gurung et al. 2009, Kozak et al., 2010; Chalai et al. 2012), pan-Carpathian international climate research is still not coordinated though seems to be rather specific to the European region. Gaps in data, lack of representative stations and their time-series at high latitudes, restricted access to meteoinformation in the Eastern part of Carpathians suggest the main difficulties for the holistic interpretation of Carpathian climate.

The analysis of climate variability in Ukrainian Carpathians turns out to be a crucial chain in solving of the problem in the whole. Consequently, the paper deals with an attempt to interpret the climate dynamics of the Ukrainian part of Carpathians during the final two centuries in order to provide the basis for a regional climate model as well as to distinguish periods and spaces still to be analyzed. Several studies in the light of the problem were conducted by the scientists of Yuriy Fedkovich Chernivtsi National University. In particular, the analysis of mesoclimatic peculiarities of landscapes of Ukrainian Carpathians was fulfilled by Kynal O. (2008) and Kholiavchuk D. (2012). The climate features of adjacent territories like the region of the Middle Dnister river valley were investigated by Kholiavchuk D. (2009).

The topic of the research concerns centennial transformations of annual average values of air temperatures and precipitation within the area under consideration. Hence, the primary tasks of the paper suggest several issues. They are: 1) the time analysis of dynamics of temperature and precipitation and their space fields in Rahiv region, Precarpathian, Transcarpathian regions, and the adjacent territory of the Middle Dnister valley; 2) the indication of the changes of climate conditions during the end of the 19th up to the beginning of 21th century; 3) the establishment of regional features of climate variabilty.

The data of long-term observations of meteostations used in the study are located in the Ukrainian Carpathians and the region of the Middle Dnister region: Ushgorod (1881-2013), Rahiv (1881-2013), Kolomyya (1876-2013), Chernivtsi (1881-2013), Ivano-Frankivsk (1951-2013), Kamyanets-Podilskyy (1936-2013), Mogyliv-Podilskyy (1926-2013). Still, the meteorological time-series differ in time duration in response to historical backgrounds of the regions.

Methods

The basic methods of climate statistics, with the emphasis on the average values were used for meteorological analysis. Average indexes deal with the scale of the certain feature that varies for the whole integrity and for the separate parts as well (arithmetic mean, square mean, geometric mean). Graphical analysis of centennial moving averages determined by the methods of smoothing is applied as well. It enables to level short-periodical or local deviations of time series or space distribution. The most appropriate option of smoothing supposes the exchange of elements of series by moving averages in order to provide a statistical filter. Such a filtering excludes amplitudes of short-term fluctuations while they tend to be rather diminished.

When examining a variable character in a data collection, it is sometimes not enough to calculate only the average values from single variants, as one and the same average value can belong to collections that differ in composition. Hence it is necessary to measure the variation of a character in a collection, that is the amplitude A= Xmax-Xmin, which is the difference between the maximum (Xmax) and the minimum (Xmin) value of a character in the given variation series.

As a result of statictical calculations, curves of average annual air temperatures, precipitation, moving averages of temperatures and precipitation for 5-year and 10-year time periods. On the basis of the figure of curves of development of the main meteorological elements and the degree of deviation of the moving average values, one determines the general trends of development of meteorological indicators, the amplitude of such changes, the relative periodicity. The method of computer-aided data processing enables obtaining the trend curve, which provides a general picture of the trends of climatic changes.

For the sake of comparison of regional climatic changes in the researched region, we have also used the method of calculation of deviation of the meteorological indicators from their long-term average values. For this purpose we have calculated the long-term average values of temperature and precipitation. A contingent division of series of meteorological indicators into groups within the gradations selected at random enables determining and comparing the degree of deviation of the long-term average values of the meteorological elements (Tc, Rc) from the average annual values (t, r) in various parts of the researched region.

In order to compare regional climate changes method of deviation from average long-term values for temperature and precipitation was applied. Comparison of regional climate changes was enabled by the use of integral curves of differences built using module coefficients. Deviations of module coefficients from chronological series of average temperatures from multiannual values ([∑(k-1)]) are added gradually in series while building the curve.

Module coefficient

$k=t/T_c$ (1)

$k=r/R_c$, (2)

where t – temperature, ^{o}C; r – precipitation, mm.

It should be noted that the integral curve formed in this way has certain properties. For instance, a deviation of the average value (in this case, of the module coefficient) in any time interval of m years from its average value established in many years of observation (equal to one) is characterized by the slope ratio of the line connecting the points of beginning and end to the horizontal line. The numerical value of this deviation is determined by the difference between the final and the initial coordinate in the given interval of time divided by the number of years m in the interval:

K_{av}-1=l_f-l_i/m, (5),

where l_f and l_i stand for the final and the initial coordinates of the integral curve for the considered interval of time, and m stands for the number of years in the interval.

The period of time for which the section of the integral curve rises above the horizontal line (indicating the deviation equal to zero) has a positive value of K_{av}-1, that is, it corresponds to a phase of growth of temperature and increase of precipitation. The period of time for which the section of the integral curve goes down beneath the zero level, where K_{av}-1 is negative, corresponds to a phase of fall of temperature or decrease of rainfall.

Results

Taking into account restricted volume of meteodata from the last centuries in Ukraine, the temperature raws in different time series are analyzed. The time periods of annual temperatures for the analyzed meteostations are Rahiv – 132 years, Chernivtsi – 132, Kolomyia – 137, Uzhgorod – 132, Kamianets-Podilskyi – 77, Mogyliv-Podilskyi – 75, Ivano-Frankivsk – 70 years. The time series with rainfall data are the following: Rahiv, Chernivtsi, Uzhgorod – 132 years, Kolomyia – 120, Kamianets-Podilskyi – 77, Mogyliv-Podilskyi -87 and Ivano-Frankivsk – 62 years. Average multiannual values for each of the stations are measured within the periods and established in the form of average value of all the average annual temperatures of annual rainfall out of the whole period. They are – 7,5°C and 661 mm consequently in Ivano-Frankivck; 7,3°C i 1139 mm for Rahiv; 7,9°C i 623 mm for Chernivtsi, 9,5°C i 758 mm Uzhgorod; 7,3°C i 639 mm for Kolomyya; 7,9°C i 588 мм for Kamianets-Podilskyi; 9,0 °C i 751 mm for Mogyliv-Podilskyi. Mountain conditions are represented by the data of Rahiv; Transcarpathian lowland – Uzhgorod, Precarpathian region – Chernivtsi, Kolomyia and Ivano-Frankivsk, the Middle Dnister region valley – Kamianets-Podilskiy, Mogyliv-Podilskiy.

Deviations of average values from long-term for the main climate elements are determined for all the stations. In special, temperature annual means in Mogyliv-Podilskyi during the fourth part of analyzing period exceeded average long-term with more than 1°C that is rather similar to the ones in South Carpathians (Kholiavchuk, 2012). The same variability (23%) of temperature annual means defines the conditions in Ivano-Frankivsk. The regimen of annual average temperatures is relatively fixed in Chernivtsi, but mountainous conditions represented by Rahiv are determined by the lowest variability. Consequently, the long-term regimen of temperatures is less variable for mountainous regions in comparison to the flat ones. In especial, in five cases from the hundreds more than 1^{O}C deviations of temperature annual means from the long-term value are expected to have place. Going off from the mountain ranges the centennial variability of annual means of temperatures rises.

Conversely, in the case of the precipitation regimen, the greater variability is observed in the mountainous regions. The analysis of centennial precipitation regimen revealed several peculiarities. The series of rainfall data was split into three groups in response to annual values. They are distinguished grounding in the values of annual deviation from the long-term average value and are within the following groups: 1-100 millimeters; 101-200 mm; and more than 200 mm. The reduction in the precipitation variability is observed in the direction outside from the mountains. In particular, the deviations in Rahiv in 38 from 100 cases consider nothing more than ±100 mm. In 43 cases, deviations reach 200 mm. In the adherent with Precarpatia regions the deviation up to 200 mm is expected in only 5 cases out of 100. Still, 58 cases suggest deviation within 100 mm.

Deviations of model coefficients for all the locations within the centennial period are found. Along the way, different in duration series of data were taken into account. Difference integral curves were given to the comparison of regional climatic changes. As a result, Kolomyia was marked with relatively long period (1893- 1907), where module coefficients had positive value from 0 to 1. Similar peculiarities are noticed in Chernivtsi and Kamianets-Podilskyi, but inside a much smaller periods of time (1876-1903; 1898-1911), and significantly smaller range within 0,2-0,4. In other locations module coefficients didn't exceed zero values (Fig.1).

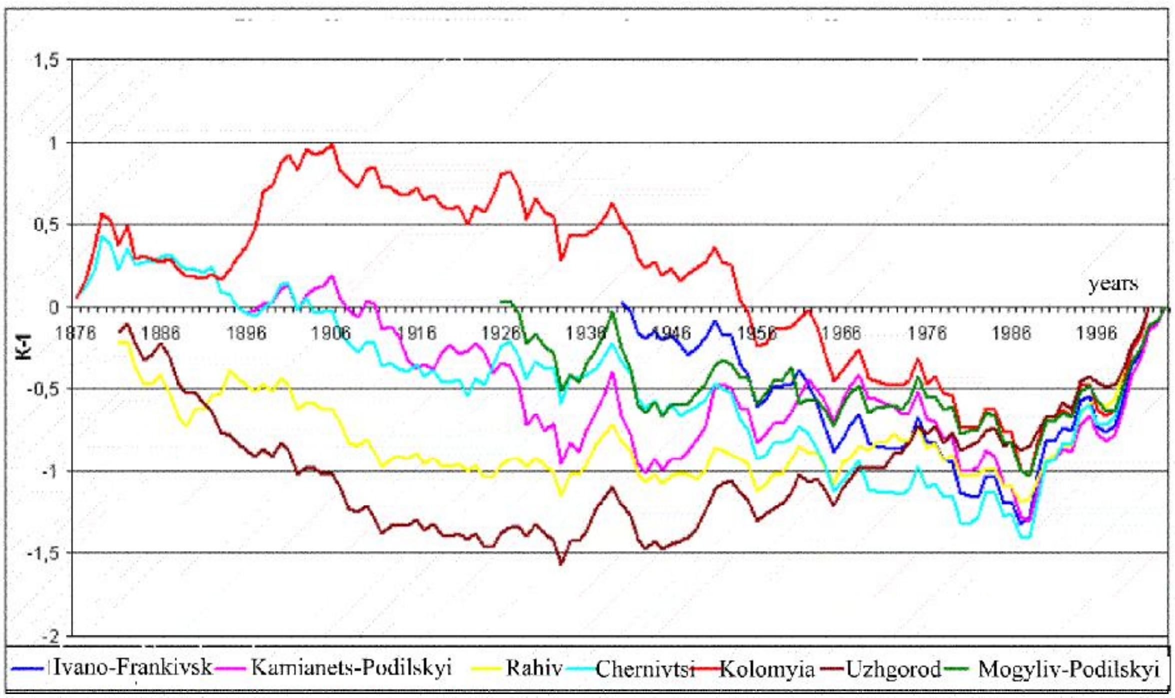

Fig. 1 Difference integral curves of temperature annual means for the region of Ukrainian Carpathians.

Hence, two different periods of the temperature regime can be delineated:

1) 1879-1987 years. The decrease of temperature was noted. The temperature decreased gradually and without any significant peaks up to 1933. Since 1933 the temperature decrease slowed. Instead, cyclic oscillations of temperature became more apparent. The phases of relative increase and decrease that are different in duration are distinguished. They are 1933-1965 and 1956-1965 that are seen to increase, 1942-1949 and 1969-1974 - for decrease. Moreover, the periods became shorter in response to the duration of meteorological observations. In general, since 1987 the trend of temperature decrease has not been observed anymore in any of the places. Since 1956 the range of module coefficients has narrowed. Such facts contribute to the idea of similar climate changes within the region known for its increase of temperature annual means.

2) Since 1987. The value of module coefficients rises from year to year, that is accompanied by the speedy increase of mean annual temperatures. Uzhgorod in contrast to other stations can be characterized by the increase of temperatures since 1968. Built up in the one graphical model space, integral curves are seen with substantial differences and were visually different up to 1987. Subsequently, the graphs tend to lay on each other. Consequently, the trends of

temperature changes since 1987 are very similar for all the stations. Synchronic bends of curves, that response to the relatively cold periods of 1996, 1997 and 1998 are further replaced by the rapid increase of average annual temperatures in all the regions since 1999. In comparison, such a period in Europe in general is known to have started in 1970s and is the most apparent for mountainous regions (Kholiavchuk, 2012). In addition during this period an increase of amplitudes of extremes is noticed that corresponds with the Polish part of Carpathians (Wypych et al., 2010; Kholiavchuk, 2012).

Precipitation deviations are analyzed in the same manner. In especial, taking into account graphical analysis, several periods of increase and decrease in the centennial regime of rainfall were distinguished. Yet, in contrast to the temperature regime with vivid time boundaries, the periods of precipitation are not easily understood that is also observed in the studies of Polish and Slovakian parts of the Carpathians (Kholiavchuk, 2012). Possible changes refer to the enhanced variability of precipitation distribution during different seasons. Still, three periods of relative growth or decrease are noticed:

1) 1881- up to the beginning of 1940-s. The growth in the annual amount of precipitation is followed that well correlates with the values typical for Europe in the whole (Kholiavchuk, 2012). The highest value of module coefficients is typical for Uzhgorod – 2.48 (1927) that represents the most variable regimen of precipitation. The reverse image can be noticed in Rahiv from 1985 since the precipitation decreases significantly, and the module coefficient is minimal 3.34 (1942), while maximal values are fixed in all the rest of the positions. It is supposed to be influenced by the mesoclimate features of local oroclimatogenetic conditions.

2) From the beginning up to the end of 1960-s: (in Uzhgorod - to 1974). The annual rainfalls decrease rather significantly.

3) From the beginning of 1940-s. The reduction of module coefficient values is converted with the increase and is identified with smaller amplitudes. Since 1981 some decrease of rainfall has been recognized to have placed in Ivano-Frankivsk, Uzhgorod and Chernivztsi. But for the rest the trend is not altered. Since 1998 integral curves drift together to the extent of superposition. This is the very first time the phenomenon is observed in all the period under consideration. Hence, every annual rainfall for today aren't varying significantly.

The analysis of built curves contributes to the existence of several periods with increase and decrease in the centennial regime of climate elements within the territories of Ukrainian Carpathians and adjacent territories: 1) the period with decrease of temperature annual means (1881-1936); 2) the period of relative stability in the tempreture regime from 1920 up to 1988; 3) period with well defined trend of warming since 1989 (annnal temperature grows with 0,7°C more than average long-term in the whole). Cenntennial precipitation regimen is known to be more complex. Periods with rainfalls lower than the average long-term norm are well regarded in all the locations, except of Uzhgorod.

Conclusions

The difficulties of climate variability analysis are found out by multi-level cyclic natural fluctuations together with anthropogenic influences. Climate dynamics in Ukrainian Carpathians during last centuries correlates in general with the trends known in the whole Carpathian region. Still, a strong need in the detailed analysis of the most variable local and topoclimatic changes of Ukrainian Carpathian landscapes exists. The fulfilled studies enable to make the quality of transformation of climate studies in air temperatures and precipitation within the Ukrainian

Carpathians as a part of Carpathian region during the end of the 19th century till the start of the 21th century in response to global warming. Statistical analysis of meteorological time-series is fulfilled for Uzhgorod (1881-2013), Rahiv (1881-2013), Kolomyia (1876-2013), Chernivtsi (1881-2013), Ivano-Frankivsk (1951-2013), Kamianets-Podilskyi (1936-2013), and Mogyliv-Podilskyi (1926-2013). The peculiarities of continual changes of the main climate elements are specified. The curves of distribution of mean annual temperatures and rainfall, running averages are built in 5-year and 10-year periods. Grounding on deviations from average long-term values, regional climate changes were studied. The changing characteristics of mean elements according to the time periods and the time limits of regional climate changes are accomplished. The issues of the rising frequency of extreme seasons, increase of extremal values of moistening and thermal regimens, and the growing probability of dangerous atmospheric phenomena in the region of Ukrainian Carpathians in the light of global climate changes suggest the subjects that need further testing.

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