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Precipitation Inequality over Ukraine

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The aim of the paper is to study the annual and seasonal precipitation inequality over Ukraine in the last 55 years and to discuss their trends.
Place and Duration of Study: Marine Hydrophysical Institute of National Academy of Sciences of Ukraine (MHI NASU), Sevastopol, Ukraine. Air-Sea Interaction Department, January 2012 - June 2013.
Methodology: Concentration index (CI) method was used to analyze a precipitation inequality over Ukraine and standard statistical procedures.
Results: The annual values of concentration index ranges from 0.54 to 0.71 over Ukraine. It increases in southward direction from north-west and north-east of the country. Seasonal scale is characterized by CI maximum values in spring (0.71) in the south-west regions. Linear CI trends above Ukraine are predominantly negative; the positive ones are typical for south-east region.
Conclusion: It was shown that the typical space structure of precipitation inequality over Ukraine is characterized by southward CI increasing during annual and all seasons for 1951 - 2005 from the north-west and north-east region.
At the same time, linear trends are characterized mostly by a negative sign in all seasons. That indicates a reduction of daily precipitation inequality in the last 55 years associated with low-frequency processes in the global climate system.

Keywords: Daily precipitation; concentration index; inequality; trend.

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1. INTRODUCTION

Precipitation is one of the most important climate elements that directly affect the availability of water [1]. Extreme precipitation can significantly influence on the efficiency of the activities in many sectors of economy. They can lead to flooding threat, erosion and landslides in the mountains. Snowfall in the usual snow-free areas brings damage to agriculture. Intense snowfall paralyzes traffic; causes damage to trees, power lines, buildings and can cause snow avalanches in the mountains. Extremely small amounts of precipitation leads to drought, forest fires, swallowing of rivers, difficulties for navigation and water supply, crop losses. Interest in study of precipitation behavior including extreme anomalies is increasing in recent decades.

Linear trends of precipitation were studied by recent authors for many regions. Significant positive trends were found in the east of the North and South America, Northern Europe, Northern and Central Asia, Australia and South Africa [2-4], as well as in the daily intensity in winter in the UK, but not in summer [5]. Increasing aridity was characterized for Sahel, the Mediterranean basin, South Africa and parts of south Asia [6-10]. IPCC report [11] put attention on increasing precipitation amount in 1900 – 2012 due to global warming in the area to the north of 30 N.

Positive trends of extreme precipitation in summer and winter were found in Klein Tank and Konnen [12] over Europe in the period 1946 – 1999 while the other authors [13] showed that the trends in number of wet days 90th percentile for the period 1961 – 1990 have different signs. Similar results were obtained in the global and regional studies [14-17]. These findings were confirmed in the 4th Assessment Report of the Intergovernmental Panel on Climate Change [18], which states that the frequency of extreme precipitation in the last 80 years in Europe is growing. However, some studies of regional climate changes show contradictory results. The current state of research in this field shows significant uncertainties in the evaluation of extreme precipitation magnitude.

To analyze the distribution of rainfall many researchers have widely used annual and monthly data. However, the averaged characteristics cannot explain differentiation of rainfall during the certain period and the contribution of extreme precipitation in their total amount. Thus we used daily precipitation data to analyze precipitation inequality. Heavy precipitation is concentrated in a small number of days in a year and divided into prolonged dry periods, which can reach up to 2 – 3 months [19]. Therefore, the study of inequality is a key issue, as it allows emphasizing area affected by soil erosion, floods and other catastrophic events.

A quantitative description of the frequency of extreme climatic events is challenging since the frequency of such events by definition is sparse, and difficult to apply to the standard statistical methods. Martin-Vide [19] proposed a concentration index (CI) to evaluate the contribution of the days of greatest rainfall to the total amount. Later CI index was applied for several geographical regions: Iran [20], Pearl River basin in China [21] and Europe [22].

The climate of Ukraine is generally favorable for agriculture but it has periodic droughts and winterkill of crops [23]. It is temperately continental, only the southern coast of Crimea is subtropical. Over half of the land of Ukraine, which is one of the largest countries in Europe, has fertile black soils. Precipitation amount decreases from the north and northwest to the south and southeast [24]. Most of it falls during the warm period of the year except the Southern Coast of Crimea. The highest amount of rainfall is in the Carpathians (1500 mm) and in the Crimean Mountains (1000 – 1200 mm). The smallest one falls on the shores of the Black Sea and the Sea of Azov (300 – 450 mm), in the western part (600 – 650 mm) and in the southwestern part of Ukraine (400 – 450 mm).

At the same time many authors discuss the regional manifestations of global climate variability [25,26]. Pacific Decadal Oscillation (PDO) is one of the most prominent quasi periodical (about 20 to 30 years) global climate signal located between 20 and 60 N in the Pacific Ocean. PDO is characterized by positive and negative sea surface temperature. Manifestation of PDO in the Atlantic-European region was shown in cyclones activity [27], decadal variability of river runoff and some hydrometeorological characteristics (see for example, [28,29]). However there were no investigations devoted to manifestation of PDO in precipitation anomalies.

Some studies forecast that precipitation is increasing in winter season for central and northern Europe, including Ukraine but decreasing in summer [30]. However the important tasks of present work are to study the precipitation inequality over Ukraine, their recent tendencies and decadal anomalies associated with PDO.

2. DATA AND METHODS

2.1 Data

Daily precipitation data from 28 national hydrometeorological stations of Ukraine were analyzed in the paper. Period of observations is from 1951 to 2005. At the same time the datasets from the European Climate Assessment (ECA) and Dataset [31] and the National Oceanic and Atmospheric Administration (NOAA) data were used too [32]. Geographical positions of hydrometeorological stations demonstrate Table 1 and Fig. 1.

Fig. 1. Hydrometeorological stations location over Ukraine

The hydrometeorological stations of Ukraine are located in different soil-climatic zones (Fig.2), mainly: forest, steppe and forest-steppe. At the same time there are mountainous terrains: the Crimea Mountains (Ai-Petri) and Carpathian foothills (Ivano-Frankovsk, Ternopol, et al.). Several stations are at the hill ridge (Donetsk, Dnepropetrovsk, Debal`tsevo) and in the Black Sea and the Sea of Azov coast regions (Odessa, Izmail, Sevastopol, Feodosia, Kerch, Genichesk). So, the topographic differences influence strongly on precipitation inequality over the Ukraine.

Table 1. Station names, geographic coordinates and altitude

Station name	Latitude (°N)	Longitude (° E)	Altitude (m)
Ai-Petri (AP)	44° 28'	34° 04'	1180
Askania Nova (AN)	46° 27'	33° 53'	30
Chernovtsy (CH)	48° 22'	25° 54'	246
Debal`tsevo (DE)	48° 21'	38° 62'	334
Dnepropetrovsk (DN)	48° 22'	35° 04'	148
Donetsk (DO)	48° 06'	37° 48'	259
Feodosia (FE)	45° 02'	35° 23'	26
Genichesk (GE)	46° 10'	34° 49'	15
Ivano-Frankovsk (IF)	48° 54'	24° 42'	276
Izmail (IZ)	45° 22'	28° 51'	30
Kerch (KE)	45° 24'	36° 25'	49
Kharkov (KH)	49° 58'	36° 08'	155
Kiev (KY)	50° 24'	30° 34'	167
Kirovograd (KI)	48° 28'	32° 15'	171
Lubny (LB)	50° 01'	33° 00'	158
Lugansk (LG)	48° 35'	39° 20'	59
Lvov (LV)	49° 49'	23° 57'	323
Odessa (OD)	46° 26'	30° 46'	42
Poltava (PO)	49° 34'	34° 34'	160
Sevastopol (SE)	44° 36'	33° 32'	23
Shepetovka (SH)	50° 10'	27° 03'	277
Simferopol (SI)	44° 41'	34° 08'	181
Sumy (SU)	50° 52'	34° 46'	177
Ternopol (TE)	49° 34'	26° 36'	334
Uman (UM)	48° 46'	30° 13'	214
Uzhgorod (UZ)	48° 38'	22° 16'	124
Vinnitsa (VI)	49° 14'	28° 36'	298
Zhytomir (ZH)	50° 16'	28° 37'	219

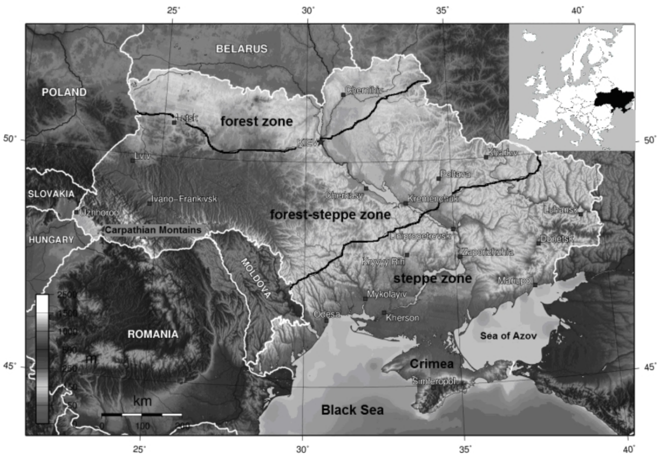

Fig. 2. Topographic map of Ukraine

2.1 Method

The approach of Ginny index or concentration index (CI) analyses was used for the study of precipitation inequality. Concentration index in economics is commonly applied as a measure of income or wealth [33]. This method based on analyses of concentration Index was adopted for climatology by J. Martin-Vide in [19] and supplemented by Cortesi et al. in [22]. In present study CI was calculated using daily precipitation data from hydrometeorological stations of Ukraine. CI explains general characteristics of the daily rainfall distribution.

In this case, CI characterizes the inequality of the precipitation intensity distribution. Percentage of rain contributed by the days falling in each precipitation class was calculated. Index is based on the fact that contributions of rainy days into the total amount have to be well described by an exponential distribution [34].

According to [19], this method consists of the following stages. At the beginning the observed precipitation is ranging into the number of intervals equal to the number of classes. Then determines the relative impacts of the different classes. The cumulative percentage of rainy days X and the associated amount of precipitation Y are obtained by equations (1) and (2):

$$Y_j = \frac{\sum_{i=1}^{j} p_i}{\sum_{j=1}^{N} p_j} \cdot 100 , \tag{1}$$

$$X_j = \frac{\sum_{i=1}^{j} n_i}{\sum_{j=1}^{N} n_j} \cdot 100 . \tag{2}$$

where p_i and n_i are precipitation and the number of rainy days, respectively, in the *ith* class, N is the total number of classes. These percentages are related with an exponential curve of the form:

$$Y = aX \exp(bX) , \tag{3}$$

where a and b can be determined by means of the least-squares method based on equations (4) and (5):

$$\ln a = \frac{\sum X_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i^2 \sum \ln X_i - \sum X_i \sum X_i \ln Y_i}{N \sum X_i^2 - \left(\sum X_i\right)^2} , \tag{4}$$

$$b = \frac{N\sum X_i \ln Y_i + \sum X_i \sum \ln X_i - N\sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{N\sum X_i^2 - \left(\sum X_i\right)^2}. \tag{5}$$

After definition constants *a* and *b* daily precipitation concentration index (CI) can be determined as follows:

$$CI = S/5000, \tag{6}$$

where S is the area limited by the exponential curve and the line Y=X:

$$S = (10000/2) - A, \tag{7}$$

where A is the definite integral of the exponential curve $aX\exp(bX)$ from 0 to 100, i.e. area under the curve:

$$A' = \left[\frac{a}{b}e^{bx}\left(x - \frac{1}{b}\right)\right]_0^{100}. \tag{8}$$

Note that the CI value is a number between 0 and 1 and geometrically, it is equivalent to the percentage of triangle formed by the line Y=X and exponential curve. The CI value is 0 when contributions of each precipitation class to the total amount is the same (i.e. exponential curve coincides with the line Y=X), and CI is about 1 when precipitation falls in one class and exponential curve coincides with the line Y=0 (Fig. 3). It is seen from this figure that cumulative percentage of rainy days and rainfall amounts vary between 0 and 100. Thus, integral limits are 0 and 100, because area A' is the area bounded by exponential curve and axes.

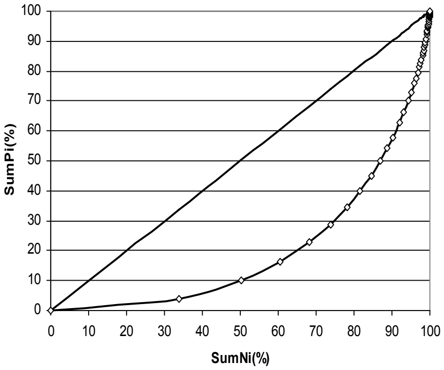

Fig. 3. Concentration curve for Sevastopol station (1951 – 2005)

Exponential curves of this type for all selected hydrometeorological stations over Ukraine for the period 1951 – 2005 are calculated for all the seasons and a whole year. The linear trends of annual and seasonal CI values were also calculated and analyzed.

3. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Concentration Index

Spatial precipitation inequality over Ukraine both on the annual and seasonal scales was studied using computed CI series for 1951-2005.

The map of the annual concentration index is shown in Fig. 4a. It demonstrates that annual CI ranges vary from 0.58 to 0.64. The feature of the spatial distribution is the following. CI increases southward from the north-west (forest zone) and the north-east (forest steppe zone) of Ukraine. The maximum values are located in the coastal regions of the Black Sea and the Sea of Azov. At the vicinity of the northern part of the Sea of Azov it exceeds the range of 0.64, while it reaches 0.57-0.58 in the East of Ukrainian Carpathians. Annual CI spatial distribution indicates that the contribution of extreme precipitation into annual totals is most significant at the boundary zone between steppe and marine regions. At the same time precipitation pattern at the foothill of Carpathian Mountains is more homogenous. It means that contribution of extreme precipitation into annual total amount is insignificant there.

Analysis of the seasonal maps in Figs.5-8b has shown more wide ranges of concentration index. The CI minimum values (0.54) are typical for the foothill of Ukrainian Carpathians near Lvov, in winter season. The maximum CI value reached 0.71 in spring in the steppe zone of the Black Sea coast in the vicinity of Odessa station. It should be noted that the greatest range of CI maximum and CI minimum deviation is typical for spring. It is associated with patterns of cyclone trajectories in that season.

3.2 Spatial Distribution of CI Trends

Linear trends of precipitation inequality were calculated on the basis of above mentioned time series for 28 hydrometeorological stations of Ukraine. The spatial distributions of CI seasonal and annual trends in 1951 to 2005 are presented on the maps in Figs. 4-8. The circles of different sizes and colors on these maps are characterized by the sign and value of trends. Negative trends are marked by black color, while positive ones - by white color. The sizes of the circles are proportional to the trends value: larger circle corresponds to larger values of the linear trends.

It is visible from Fig.4,b that the annual positive trends are only in the east of steppe zone of Ukraine at the Donbas region and in the center of steppe zone of Ukraine, near Dnepropetrovsk. It means that the biggest part of Ukraine is characterized by tendency to decrease the contribution of extreme precipitation into the total amount of precipitation. The CI negative annual trends are typical mostly for the forest zone. Their values reach -0.02 / 10 years.

Figs 5-8b demonstrates that linear trends are predominantly negative in all seasons. In winter their negative values reach of -0.014/ 10 years in the western part of Ukraine and the Black Sea coastal zone. Positive CI trends up to 0.0017/ 10 years are located in the south-east of Ukraine. Spring negative linear trends reach -0.013/ 10 years, the maximum by absolute values in the central part of Ukraine (forest-steppe zone) and in Crimean Peninsula. Increasing of precipitation inequality is typical for boundary zone between forest-steppe and steppe soil-climatic zones.

In summer negative trends are less than in winter-spring over the biggest territory of Ukraine except small northern and east regions (Debal`tsevo) which are about -0.019/ 10 years. At the same time the maxima values of positive linear trends are comparable with the ones in other seasons and vary from 0.001/ 10 years to 0.011/ 10 years. It should be noted that summer positive trends are different for the soil-climatic zones including mountains.

In autumn the largest area of negative trends was located in the west of the country. Their typical values vary from -0.0054/ 10 years to -0.015/ 10 years. However the autumn maximum by absolute value negative trend reaches -0.024/ 10 years, it is located in the eastern part of Crimea (Kerch). At the same time, over the east of Ukraine the linear trends both positive and negative are insignificant (P = . 05).

So, we can conclude now that linear trends over Ukraine are predominantly negative in all seasons. It means that daily precipitation inequality has a decreasing tendency during the last 55 years. It is connected with pattern of regional cyclonic activity associated with global climate change [28]. But the question arise whether this tendency was stable within the period of 1951 – 2005 taking into account the climate shift in the mid of 1970-th associated with PDO.

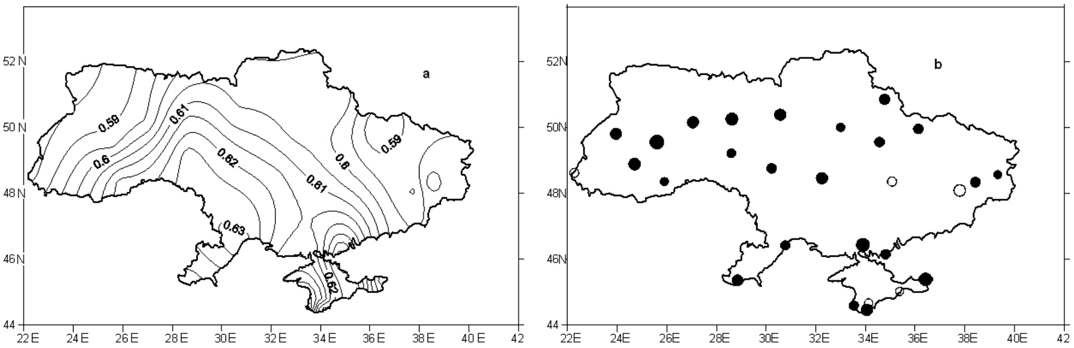

Fig. 4. Annual CI (a) and CI linear trend (b) distribution over Ukraine in 1951 – 2005. Black circles mean negative trends, white – positive

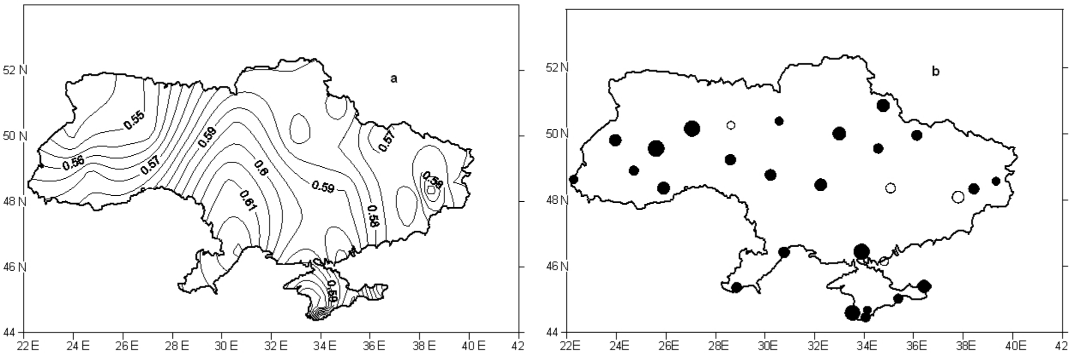

Fig. 5. The same as in Fig.4 but for winter

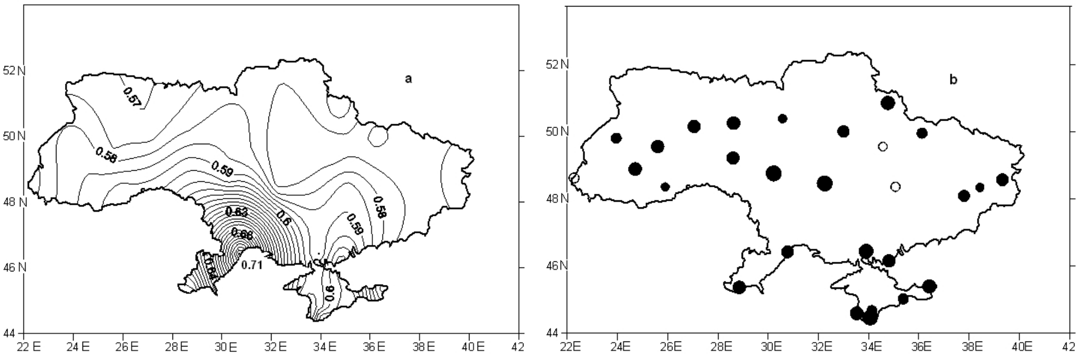

Fig. 6. The same as in Fig.4 but for spring

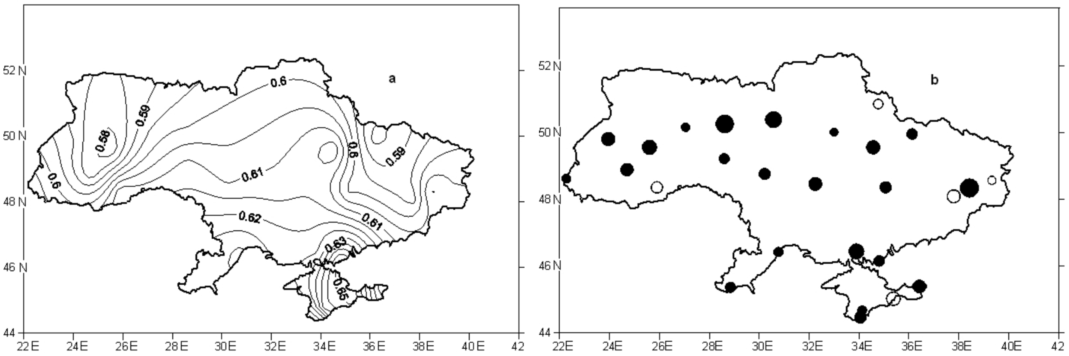

Fig. 7. The same as in Fig.4 but for summer

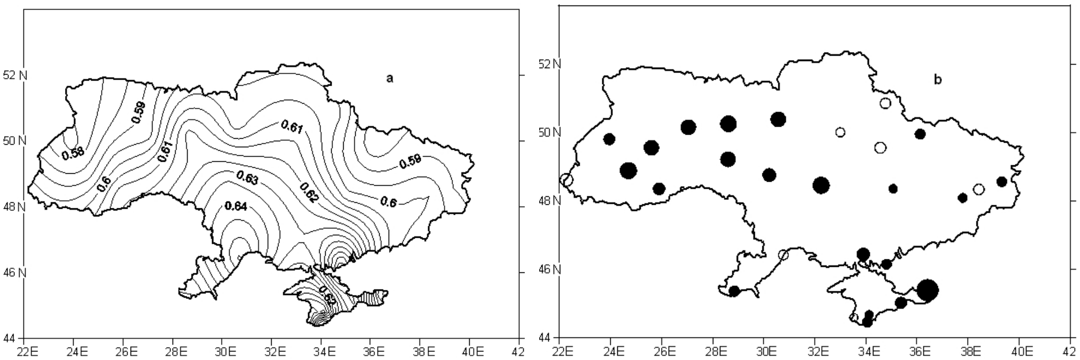

Fig. 8. The same as in Fig.4 but for autumn

3.3 Decadal Variability of Precipitation Inequality

To show the quasi periodical variability in time realizations of precipitation inequality several most long term data series were used. The example of visible change of CI sign in the late 1970`s (so called “climate shift” after PDO switch from negative into positive phase) for Odessa station in 1894 – 2005 is demonstrated in Fig. 9.

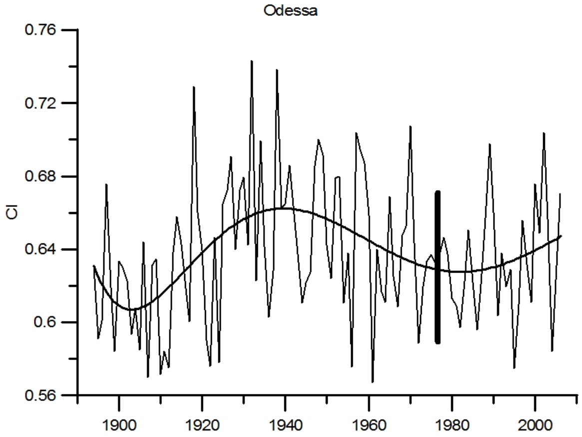

Fig. 9. Long-term variability of concentration index for Odessa station

PDO manifests itself in the regional decadal anomalies mainly through the processes of atmospheric circulation. At the same time precipitation inequality is associated with cyclonic activity. It is true also for Europe and the Black Sea region. As a main mechanism of a large-scale cyclonic activity over Europe usually considered is the North Atlantic Oscillation. However, in fact joint activity of large-scale climatic signals is responsible for the regional climate anomalies. In positive PDO phase the Mediterranean storm tracks shift to the Northern Europe. Negative PDO phase is accompanied by situation when the cyclones trajectories are shifted over Central Europe, including the Black Sea and its coastal regions [27]. In this case for biggest territory of Central and Southern Ukraine the CI ranges in negative PDO phase exceed the CI ranges in positive one. This is true both for all seasons and for annual mean value. Such example is demonstrateв in Fig. 10. The CI differences in positive (before 1977) and negative PDO phase (after 1977) for the annual, winter, spring, summer and autumn are presented for Odessa station.

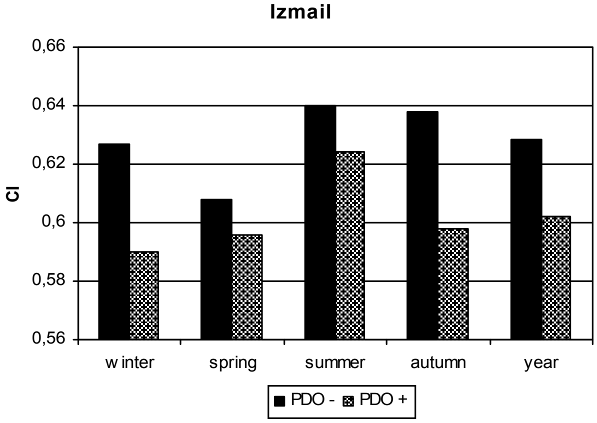

Fig. 10. Example of CI differences in negative and positive phase of PDO

Thus, the manifestation of decadal processes in the ocean-atmosphere system in the precipitation inequality pattern over the Central and Southern Ukraine is also confirmed in this study.

4. CONCLUSION

The annual and seasonal daily precipitation behavior in Ukraine during 1951 – 2005 was studied. It was shown that concentration index (CI) was increasing over the Ukrainian territory from north-west and north-east to the south in all seasons. The maximum values of daily concentration index are in seaside of the Black and Azov seas. They are typical for the southern part of Ukraine during spring (0.71). Linear trends are predominantly negative in all seasons. It means that daily precipitation inequality has a decreasing tendency during the last 55 years associated with global climate change. Decadal-scale anomalies of precipitation inequality over the Central and Southern Ukraine are partly associated with PDO.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Randall DA, Wood RA, Bony S, Colman R, Fichefet T, Fyfe J, et al. Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press (UK) and New York (US); 2007.
2. Suppiah R, Hennessy KJ. Trends in total rainfall, heavy-rain events and number of dry days in Australia, 1910 – 1990. Int J Climatol. 1998;10:1141–1164.
3. Hennessy KJ, Suppiah R, Page CM. Australian rainfall changes 1910 to 1995. Australian Meteorol Magazine. 1999;48:1–13.
4. Mason SJ, Waylen PR, Mimmack GM, Rajaratnam B, Harrison JM. Changes in extreme rainfall events in South Africa. Clim Change. 1999;41:249–257.
5. Osborn TJ, Hulme M, Jones PD, Basnett TA. Observed trends in the daily intensity of United Kingdom precipitation. Int J Climatol. 2002;20:347 – 364.
6. Hess TM, Stephens W, Maryah UM. Rainfall trends in the North East Arid Zone of Nigeria 1961–1990. Agricultural and Forest Meteorology. 1995;74:87–97. DOI:10.1016/0168-1923(94)02179-N.
7. Sharma KP, Moore B III, Vorosmarty CJ. Anthropogenic, climatic, and hydrologic trends in the Kosi basin, Himalaya. Clim Change. 2000;47:141–165. DOI: 10.1023/A:1005696808953.
8. Hamilton JP, Whitelaw GS, Fenech A. Mean annual temperature and total annual precipitation trends at Canadian biosphere reserves. Environ Monit and Assess. 2001;67:239–275. DOI: 10.1023/A:1006490707949.
9. Boyles RP, Raman S. Analysis of climate trends in North Carolina (1949–1998). Environ Int. 2003;29:263–275. DOI: 10.1016/S0160-4120(02)00185-X.
10. Liu Q, Yang Z, Cui B. Spatial and temporal variability of annual precipitation during 1961–2006 in Yellow River Basin, China. J Hydrol. 2008;361:330–338. DOI:10.1016/j.jhydrol.2008.08.002.
11. Solomon S, Qin D, Manning M, Alley RB, Berntsen T, Bindoff NL, et al. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, et al., editors. Technical Summary. Climate Change 2007: The Physical Science Basis, Cambridge: University Press (UK); 2007.

12. Klein-Tank AMG, Konnen GP. Trends in indices of daily temperature and precipitation extremes in Europe, 1946–1999. J Clim. 2003;16:3665–3680.
13. Haylock MR, Goodess CM. Interannual variability of European extreme winter rainfall and links with the mean large scale circulation. Int J Climatol. 2004;24:759–776.
14. Easterling DR, Evans JL, Groisman PYa, Karl TR, Kunkel KE, Ambenje P. Observed Variability and Trends in Extreme Climate Events. A Brief Review. Bull of the American Meteorol Society. 2000;81(3):417–425.
15. Frei C, Schaer C. Detection probability of trends in rare events: theory and application to heavy precipitation in the Alpine region. J Clim. 2001;14:1568–1584.
16. Zolina O, Simmer C, Kapala A, Gulev SK. On the robustness of the estimates of centennial scale variability in heavy precipitation from station data over Europe. Geophys Res Lett. 2005;32(14). Accessed 23 July 2005. doi:10.1029/2005GL023231. Available: http://onlinelibrary.wiley.com/doi/10.1029/2005GL023231/abstract
17. Zolina O, Simmer C, Kapala A, Bachner S, Gulev SK, Maechel H. Seasonally dependent changes of precipitation extremes over Germany since 1950 from a very dense observational network. J Geophys Res. 2008;113(D6). Accessed 27 March 2008. doi: 10.1029/2007JD008393.
Available: http://onlinelibrary.wiley.com/doi/10.1029/2007JD008393/abstract
18. Pachauri RK, Reisinger A, editors. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, IPCC. Geneva (CH); 2007.
19. Martin-Vide J. Spatial distribution of a daily precipitation concentration index in Peninsular Spain. Int J Climatol. 2004;24:959–971.
20. Alijani B, O`Brien J, Yarnal B. Spatial analysis of precipitation intensity and concentration in Iran. Theor Appl Climatol. 2008;94:107-124.
21. Zhang Q, Xu CY, Gemmer M, Chen YQ, Liu CL. Changing properties of precipitation concentration in the Pearl River basin, China. Stoch Environ Res Risk Assess. 2009;23:377-385.
22. Cortesi N, Gonzalez-Hidalgo JC, Brunetti M, Martin-Vide J. Daily precipitation concentration across Europe 1971 – 2010. Nat Hazards Earth Syst Sci. 2012;12:2799-2810.
23. Fertilizer use by crop in Ukraine. First ed. FAO: Rome; 2005.
24. Lipinskyi VM, Djachuk VA, Babichenko M, editors. Climate of Ukraine. Publishing house Raevskogo: Kyiv (UA); 2003. Ukrainian.
25. Polonsky A, Voskresenskaya E. Interannual variability in the Tropical and North Atlantic associated with the Pacific Ocean ENSO events, Contemporary Climatology, Proc. of the Meeting of the Commission on Climatology of the IGU, Brno. 1994;467–472.
26. Trigo RM, Pozo-Vazquez D, Castro-Diez Y, Osborn T,Gamis-Fortis S, Esteban-Parra MJ. NAO influence on precipitation, river flow regimes and hydroelectric power generation in the Iberian peninsula. Geophys Res Abstr. 2003;5:05494.
27. Voskresenskaya EN, Maslova V.N. Winter-spring cyclonic variability in the Mediterranean-Black Sea region associated with global processes in the ocean-atmosphere system. Adv Sci Res. 2011;6:237–243.

28. Voskresenskaya E.N. Variability of the European rivers' runoff associated with global climate processes. Environmental monitoring systems, Sevastopol. 2003;144–147 (in Russian).
29. Pekarova P, Miklanek P, Pekar J. Long-term trends and runoff fluctuations of European rivers. Fifth FRIEND World Conference (Havana, Cuba, November 2006). IAHS Publ; 2006.

30. Alcamo J, Moreno JM, Novaky B, Bindi M, Corobov R, Devoy RJN, et al. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Parry ML, Canziani OF, Palutikof JP, Van der Linden PJ, Hanson CE, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge: Cambridge University Press (UK); 2007.
31. Klein Tank AMG et al., 2002, updated by Klok and Klein Tank; 2008. Available: http://eca.knmi.nl/
32. The National Oceanic and Atmospheric Administration. Available: http://www.ncdc.noaa.gov/cdo-web/search
33. Gini C. On the Measure of Concentration with Special Reference to Income and Statistics. Colorado College Publication. 1936;208:73–79.
34. Brooks C, Carruthers N. Handbooks of statistical methods in meteorology. Meteorological Office: London, Great Britain Meteorological Office, Publication Official 1953;538.

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