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CYCLONIC ACTIVITY IN COLD SEASON OVER TERRITORIES OF BELARUS AND UKRAINE AND ITS RELATION TO THE WARM SEASON DROUGHTS

Ciklonalna aktivnost u hladnom dijelu godine iznad Bjelorusije i Ukrajine i njezina povezanost sa sušama u toplom dijelu godine

INNA SEMENOVA[1], KATSIARYNA SUMAK[2]

[1]Odessa State Environmental University, Ukraine
[2]Republican Center for Hydrometeorology and Control of Radioactive Contamination and Environmental Monitoring of the Republic of Belarus

innas.od@gmail.com

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Abstract. Cyclonic activity is a main mechanism for replenishing the soil moisture content due to precipitation. Low number of cyclones in winter can become a trigger for a drought in the subsequent summer period. This paper examines the conditions of cyclonic activity over the territory of Ukraine and Belarus and the drought frequency under current climate using synoptic analysis and meteorological drought indices. Since the appearance of a drought is associated with a certain blocking structure of the high-level pressure field, such patterns have been obtained and examined using proposed blocking index. Also it is shown that a decreasing of the amount of southern cyclones in winter has been accompanied by an increasing of droughtness in summer, mainly over the southern regions of Ukraine. At the same time some shifting of the tracks of southern cyclones toward to the territory of Belarus was observed.

Key words: cyclone, cyclonic activity, drought, blocking process.

Sažetak: Ciklonalna aktivnost je osnovni mehanizam za obnavljanje vlage tla pomoću oborina. Mali broj ciklona u zimskom razdoblju može postati okidač za sušu u toplom dijleu godine. U radu su istraženi uvjeti za ciklonalnu aktivnost nad područjem Ukrajine i Bjelorusije te čestina suša u aktualnoj klimi upotrebom sinoptičke analize i meteoroloških indeksa suše. Pojava suše povezana je s određenim blokingom u višim slojevima polja tlaka, a ti su parametri dobiveni i istraženi upotrebom indeksa blokinga. Pokazano je da je sve veći broj južnih zimskih ciklona povezan s ljetnim sušama, i to uglavnom nad južnim dijelovima Ukrajine. Istovremeno je opažen manji pomak trajektorija južnih ciklona prema području Bjelorusije.

Ključne riječi: ciklona, ciklonalna aktivnost, suša, bloking

INTRODUCTION

Precipitation in cold season depends upon the cyclones passing through the territory of country (Babkin et al, 2005). The cyclones are formed in different regions under various climatic conditions and may generate different moisture regimes (Krichak, 1956). For example, southern cyclones bring considerable precipitation during the winter season and associated with strong winds and snowstorms. The

Figure 1. Agroclimatic zones of Ukraine and schematic location the territories of Ukraine (orange) and Belarus (green) on the map of Europe

Slika 1. Agro-klimatske zone Ukrajine (1 - miješana šuma (Polissya), 2 - šuma-stepa, 3 - stepa, 4 - planine) i shematski prikaz položaja Ukrajine (plavo) i Bjelorusije (crveno) u Europi.

Atlantic cyclones in winter bring to Belarus and mainly in north regions of Ukraine mild weather with snowbreak.

Numerous studies have been assessed a cyclonic activity in different seasons over Northern hemisphere. Gulev et al. (2001) analyzed frequency of cyclones in winter time and found that the total number of cyclones has decreased over the central Atlantic and increased significantly in the areas of Icelandic Low and European Arctic. A lot of researches (McCabe et al, 2001; Zhang et al, 2004) came to the same conclusions.

The territory of Ukraine and Belarus belong to the central and southern parts of East European Plane (Figure 1), which are characterized by intensive cyclonic activity in winter season (McCabe et al, 2001; Sepp, 2005; Sepp, 2009; Partasenok et al, 2014). The region of the study in cold season is affected by cyclones of different types: southern (or Mediterranean) cyclones come from the Mediterranean region, western cyclones - from Atlantic region or the Western and Central Europe, north-western (north or "diving") cyclones - from Scandinavia, the Norwegian and the Barents Sea (Khandozhko, 1988; Gulev et al, 2001, Partasenok et al, 2014, Buzyan et al., 1958).

During the winter period the Mediterranean basin is a place of active cyclogenesis due to favorable thermodynamical and orographical conditions, which lead to intensive frontogenesis and cyclogenesis processes in the region (Trigo et al., 1999; Campins et al., 2000; Maheras et al., 2001; Trigo et al., 2002; Horvath et al., 2008; Ulbrich et al., 2009). The cyclones are formed, as a rule over the north regions of Italy, Adriatic Sea and Gulf of Genoa and actively move to the different regions of Europe (Lepeshko, 1989b; Jansa, 1997; Campins et al, 1997; Carlson, 1999). According to Lepeshko (1989b), the average frequency of Mediterranean storms moving to the territory of Belarus is 5 cases per month. The number of cyclones sharply increases from October to December.

Moreover, in cold season the basin of the Black sea is the additional area of cyclogenesis similar to the Mediterranean basin (Balabukh, 2004; Sepp et al., 2005b). Winter seasonal cen-

ter of action of atmosphere named as a "Black sea depression" is especially active in January, when the processes of anticyclogenesis increase over Eastern Europe. Due to blocking of cyclones' tracks by stationary anticyclone a storm zone with the heavy snowfalls, icestorms and snowstorms is formed over southern areas of Ukraine.

There are several typical trajectories of southern cyclones, which move over the territories of Ukraine and Belarus (Lepeshko, 1989b; Balabukh, 2004; Mandla et al, 2012; Belskaya, 1949; Bogatyr, 1957).

J. Degirmendžić and K. Kożuchowski (2017) distinguish the following four classes of Mediterranean cyclones: E - the eastern class of cyclones whose trajectory runs through the western regions of Ukraine and central part of Belarus, resembling van Bebber's Vb track; C - the central class of cyclones with trajectories passing through the territory of Poland; W - the western class of cyclones moving along the track west of Poland and S - the southern class of cyclones moving from the west to the east along the track south of Poland through the territory of Ukraine from the south-western to north-eastern regions.

The Balkan and Black Sea cyclones are formed over the south-western regions of the Black Sea, Balkan Peninsula or Peninsula of Asia Minor and move northward to the territory of Ukraine, where the one part of the cyclones turns to the north-west and comes to the northern regions of Belarus and another part of the cyclones passes easterly to the Moscow region. Under the influence of these cyclones the precipitation covers the vast areas of both countries.

"Diving" of cyclones occurs in the presence of pronounced meridionality of the tropospheric frontal zone. Exactly in cold season the greatest temperature contrasts in the high levels' frontal zone are sufficient to forming and moving of "diving" cyclones with northward trajectories. "Diving" cyclones that influence weather conditions and precipitation regime in Belarus, form over the Norwegian Sea and move along three typical trajectories (according to Lepeshko, 1989a; Sepp et al., 2005b, Partasenok et al, 2014):

1) the Gulf of Bothnia, north-western regions of European territory of Russia to the Middle Urals. Short-term precipitation (about 1-5 mm/12h in average) is observed in 100% of cases and caused by the displacement of atmospheric front, when cyclones of this type move;
2) the Baltic Sea to the central part of Belarus and then to the south of European territory of Russia. The movement of these cyclones determines 100% coverage of the territory of Belarus by precipitation. The most amount of precipitation is associated with cyclones of this trajectory, because through the territory of Belarus pass not only atmospheric fronts but also the cyclones themselves;
3) the Baltic Sea (area of Kaliningrad), southwestern regions of Belarus, Ukraine to the Sea of Azov. The cyclones cause small precipitation in some parts of the country, and only in the south-west regions there is a big possibility of heavy precipitation.

In Ukraine "diving" cyclones have a small frequency (2-3 cases per cold season in average) and due to high speed of moving and character of trajectories they play a considerable role in the precipitation regime of mainly the north, central and east areas of Ukraine (25-46 mm per year in average). In south west part of Ukraine sum of precipitation reduce up to 10-14 mm per year. (Bogatyr, 1957; Semenova, 1997).

Western (or Atlantic) cyclones are formed under the stable zonal flow in the middle troposphere over the European sector. The trajectories of western cyclones an pass to the north or south of the territory of Belarus and also directly through the country (Amelchenko et al., 1961, Sepp, 2005).

Partasenok et al. (2014) distinguished two groups of Atlantic cyclones over the territory of Eastern Europe: the cyclones which trajectories lie within 50-56° N moving in a zonal direction from the west and the second type of cyclones moving within 56-65° N. The assessment of the dynamics of Atlantic cyclones for the period of 1948-2012 showed noticeable tendency to increasing of cyclones number for the second group per winter season during the 60 years. This increase is an evidence of shifting the Atlantic cyclones tracks to northward.

The probability of precipitation during of moving western cyclones is about 85-100%. Precipitation falls mainly as a rain or a sleet. Western cyclones produce the maximum amount of precipitation in the north-western part of the Belarus but to the southeast their amount decreases approximately twice. Maximum number of western cyclones is observed in the coldest months of the year (January-March).

Western cyclones, which are moved over the territory of Ukraine, are unconnected directly with Atlantic storm cyclones. The tracks of western cyclones can pass through the south, central or north regions of Ukraine, but due to a relatively small size and depth of these cyclones, precipitation covers only narrow part of the trajectory of moving (Bogatyr, 1957).

Variability of cyclones paths and its frequency in the Atlantic-Europe sector strongly associates with phases of the regional teleconnection pattern NAO (the North Atlantic Oscillation). As indicated in the research of Polonskii at al. (2007), due to changes in the NAO fluctuations during the period 1952-2000 was observed a decrease in the number of cyclones from the regions of the Black Sea and the south of Ukraine and the shift of their trajectories northward.

Cyclones are the main synoptic processes, which determine precipitation and moisture regime in the middle latitudes during cold season as well as in summer due to ability of accumulation water in the soil layers. Therefore possibility of drought in vegetation period is higher, if the amount of cyclones during preceding winter season has been small. The modern period of meteorological observations is characterized by the enhanceable frequency of droughts of any intensity in all seasons except winter. Almost every year at least one of the agroclimatic areas in Ukraine has been affected by the drought at any time of vegetation season (Semenova, 2014). In the troposphere of European sector the certain structure of the pressure field is formed, which results to anomalies in the fields of meteorological parameters both on heights and the surface (Cherenkova et al., 2015).

The objective of the study is the analysis of the frequency of cyclones, which were moving over the territories of Ukraine and Belarus during winter seasons (November-March) of 1994-2012 and the search for relationships with warm seasons' droughts.

DATA AND METHODS

For the analysis of cyclones frequency in this study only those cyclones were considered, which moved by the surface center through the territory of Belarus or Ukraine. The depressions over the Black Sea were selected as a separate type. Deep troughs with active atmospheric fronts were also fixed over Ukraine. Cyclone was considered over Ukraine or Belarus, if its central isobar at the sea level pressure (SLP) map crossed any region of country at any moment of time and the cyclone existed not less than three days from the moment of formation to the stage of filling.

Three databases were used, which contained information about the position of pressure formations. For the period of 1994-2003 the the cyclones' centers were determined on the basis of reanalysis data ECMWF ERA-Interim with spatial resolution 1.5 1.5° and time scale of 6 h. For the period of 1998-2003 were used additionally the surface pressure field of World Forecasting Center Brecknell (United Kingdom), the time scale of 24 h. For the period of 2004-2012 the surface pressure fields of the Center Offenbach (Germany) were analyzed with time scale of 6 h. The output of the tracking includes the geographical coordinates, time and corresponding SLP values. The results were visualized with the graphic package GMT (Generic Mapping Tools) (http://gmt.soest.hawaii.edu/).

Atmospheric circulation is important for determining of regional hydrometeorological regime, which causes the extreme weather events including drought. Drought is a relative term, which generally defines a complex natural phenomenon as a period of below-average precipitation in given region, resulting in prolonged shortages in the water supply whether in the atmosphere, soil, surface water or ground water. In Ukraine all droughts divided according its physical mechanism (Climate of Ukraine, 2003) to atmospheric (or meteorological) drought, soil (or agricultural) drought and common drought. Atmospheric drought as a state of the atmosphere occurs as a result

of the prolonged absence of precipitation (10 days and more) under the high air temperature. Agricultural drought often occurs as a sequel of atmospheric drought and result to adverse crop responses, usually because plants cannot meet potential transpiration due to low water content in the soil and air. Common drought considered as a coupling of atmospheric and soil drought.

To determine the periods of drought, we used the data on the Standardized Precipitation Evapotranspiration Index (SPEI), which introduced by Vicente-Serrano at al. (2010), from the Global SPEI database, which contains robust information about drought conditions at the global scale, with a 0.5 degrees spatial resolution and a monthly time resolution (http://spei.csic.es/database.html).

The SPEI is calculated using monthly difference between precipitation and potential evapotranspiration (PET) as the input data. A set of averaging periods are selected to determine the typical time scales for precipitation deficits to affect the different types of usable water sources. So, time scales from 1-2 months corresponds to meteorological drought, period is about 3-7 months characterize a soil (or agricultural) drought, longer time scales corresponds to low water reserves in storages and characterizes a hydrological drought.

A drought event for selected time scale is defined here as a period, in which the SPEI is continuously negative. Drought intensity is defined for values of the SPEI with the following categories: values from 0 to -0.99 correspond to mild drought; from -1.00 to -1.49 correspond to moderate drought; from -1.50 to -1.99 correspond to severe drought; values less than -2.00 characterize an extreme drought.

Drought conditions in Ukraine during period of 1995-2012 has been estimated using the drought index SPEI. Three agrometeorological seasons were considered during the vegetation period: spring-summer (April-June), summer (June-August), summer-autumn (August-October). Three main agroclimatic zones in Ukraine have been chosen for a drought analysis: Steppe, Forest-Steppe and Mixed Forest (Fig. 1). The SPEI values on time scales 3 and 7 months from the Global SPEI database were averaged over agroclimatic zones.

Assessment of the variability of regional atmospheric circulation may be studied by the method of analogs, which allows to receive most probable structure of the pressure field. This method was applied to determine the pattern of regional troposphere field in the European sector during the drought periods in Ukraine over the period of 1995-2012.

Mean monthly fields of geopotential height 500 hPa for the calculation of analogue criteria were taken over the region 40-65N, 0-60E from reanalysis database of NCEP-NCAR (2.5 2.5° regular grid). Data was chosen for months with maximum values of drought index during the drought season in Ukraine. For this purpose was used the authors' drought catalog (Semenova I., 2016; Semenova I., 2017), which consists the data about drought indices averaged over agroclimatic zones of Ukraine, for vegetation period of 1995-2012. Catalog is based on chronology of seasonal droughts with using an comparison of five drought indexes such as the Palmer drought severity index (PDSI), standardized indexes of precipitation and evapotranspiration (SPI, SPEI), Selyaninov hydrothermal coefficient (HTC), Ped' index of atmospheric droughtyness (Sa). Almost all the indices (except SPI) are based on air temperature and precipitation and are used in different countries both in operational work and scientific research (WMO and GWP, 2016). In catalog criteria of all indices were unified to one scale, from 0 (beginning of drought episode) to 4 (extreme drought). When catalog is used, a drought is determined if at least four indices from five indicated to a drought of any intensity. The initial matrix included 28 months, in which 9 months belong to spring time (April, May), 8 months belong to summer (July, August) and 11 months fit to autumn (September, October).

An objective classification of monthly fields was done using the criterion of similarity (introduced by N.A. Bagrov (1969) and developed in the research of V.F. Martazinova (2005). It characterizes a geometrical similarity of two fields of anomaly of 500 hPa level geopotential heights:

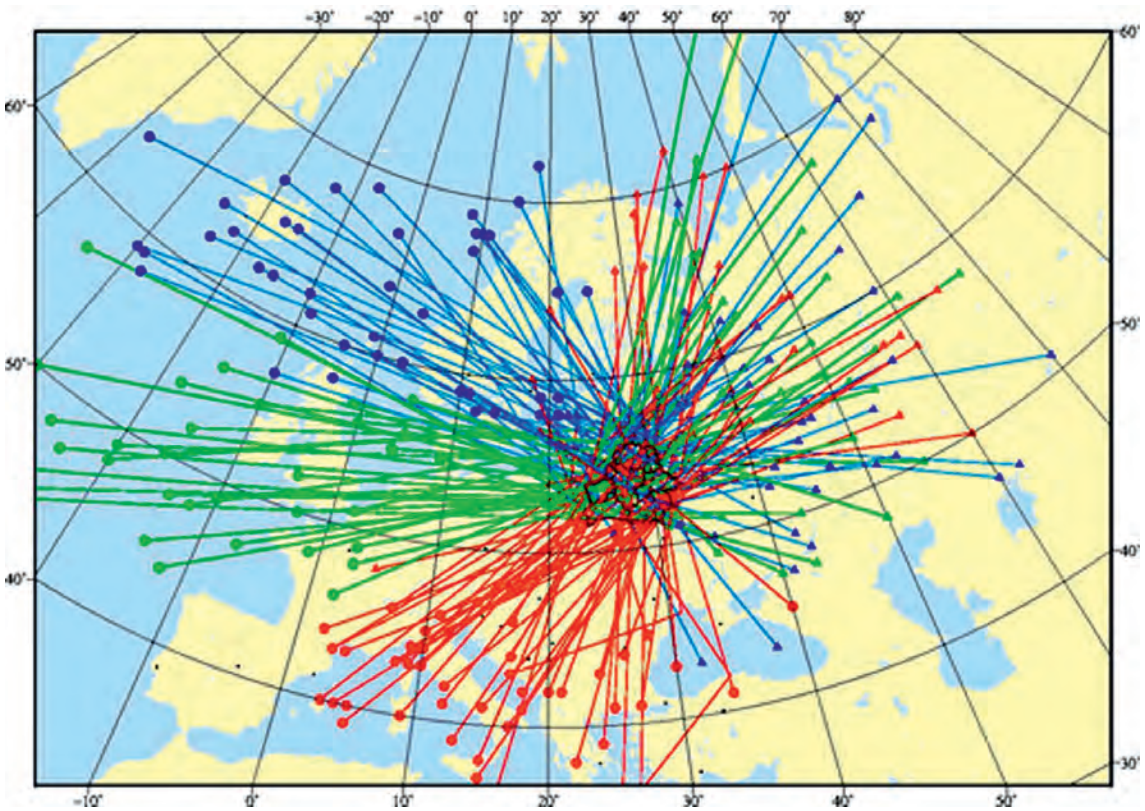

Figure 2. Trajectories of cyclones in cold seasons during the period of 1994-2012 (red - southern cyclones, green - western cyclones, blue - north-western ("diving") cyclones; circle - region of formation, triangle - region of filling)

Slika 2. Trajektorije ciklona u hladnoj sezoni 1994. - 2012. (crveno - južne, zeleno - zapadne, plavo - sjeverozapadne "diving" ciklone, kružići - područje formiranja, trokutići - područje popunjavanja)

$$\rho = \frac{n_+ - n_-}{n_+ + n_-} \qquad (1)$$

where n is a total number of points in the gridded field; $n+$ is a number of points, in which the sign of anomaly of heights is coincides; $n-$ is a number of points, in which a sign of anomaly of heights is opposite.

As the most probable patterns were chosen the height fields with maximum average . The patterns with the smallest average are the least probable and represent the cases of the rare synoptic situations.

The blocking process in region has been estimated using the ECBI (European Continental Blocking Index), which was proposed for assessment of the state of zonal flow at pressure level 300 hPa (according to Semenova, 2013). This index was calculated using the data of NCEP-NCAR reanalysis for the region, which is restricted by coordinates of 10-60E and 40-60N:

$$ECBI = 1 - \frac{\bar{u}_{pt}}{\bar{u}_{cl}}, \qquad (2)$$

where is a current pentad value of the zonal component of wind at the pressure level of 300 hPa averaged over the area of region; is a climatic value of a zonal component of wind at the same level averaged over the area of region (over the basic period of 1981-2010).

The positive values of ECBI indicate the blocking of a zonal flow; the negative ones correspond to amplification of a zonal flow. Values of the index ±1 indicate to the relatively extreme cases. Data of pentad index ECBI during last 100 days is regularly updated on web-site of Educational Weather Bureau

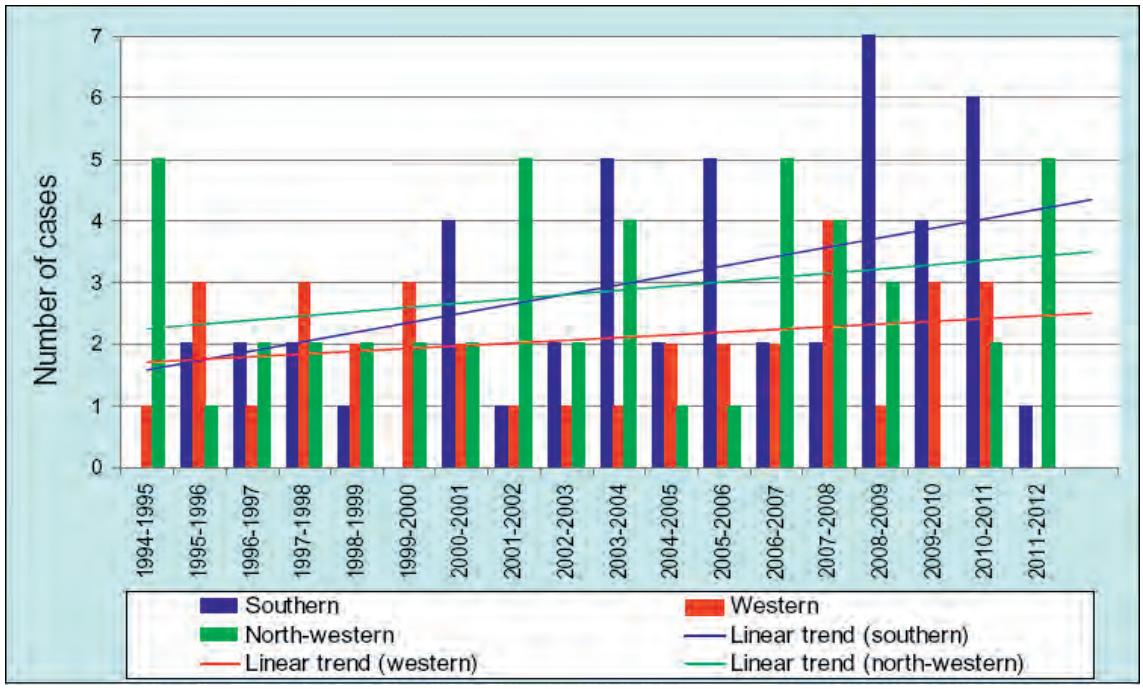

Figure 3. Frequency and linear trends of cyclones of different types during the winter seasons of 1994-2012 over Belarus

Slika 3. Frekvencija i linearni trend za ciklone (Zn) različitih tipova, zimska sezona 1994. - 2012. iznad Bjelorusije.

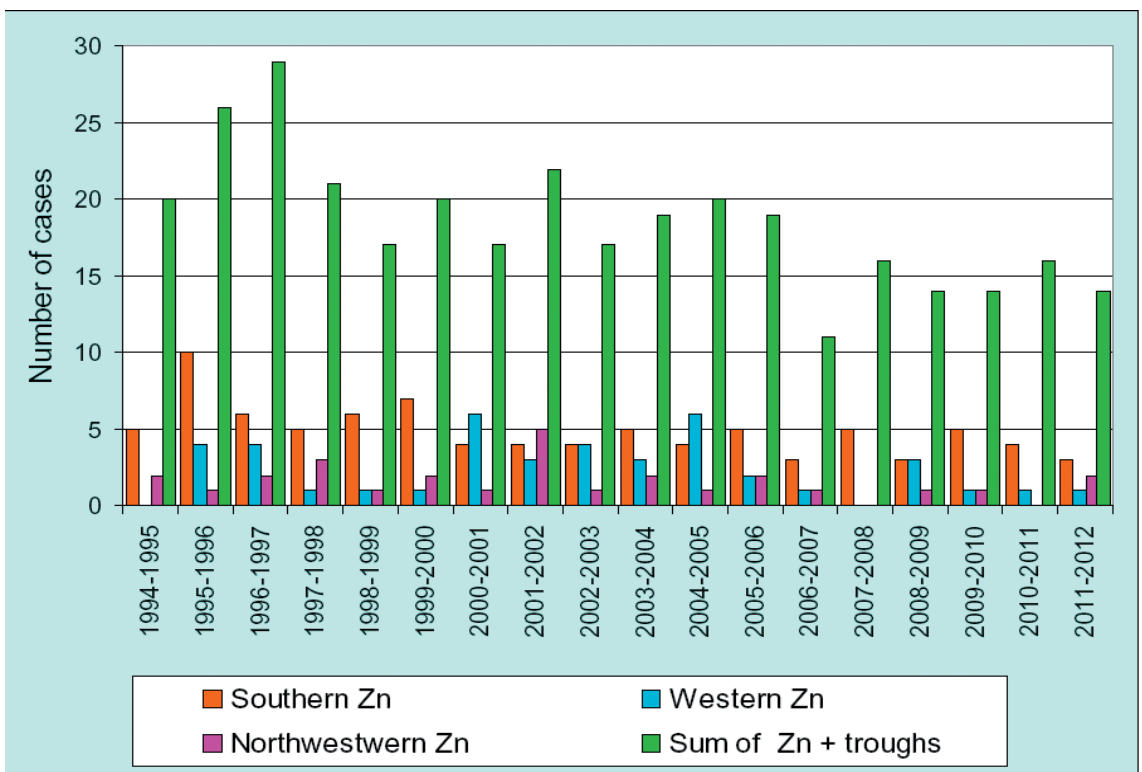

Figure 4. Frequency of cyclones (Zn) of different types during the winter seasons of 1994-2012 in Ukraine (troughs include also Black sea depressions)

Slika 4. Frekvencija ciklona (Zn) različitog tipa u zimskoj sezoni 1994. - 2012. u Ukrajini (doline uključuju i Crno more).

of Odessa State Environmental University (http://pogoda.odeku.edu.ua). Monthly values of the ECBI, which using in investigation, were obtained by averaging of pentad values within each month.

RESULTS AND DISCUSSION

1. Cyclonic activity during the winter period of 1994-2012 over Belarus and Ukraine

The performed analysis showed that 131 cyclones of all types moved over the territory of Belarus during the study period (Fig. 2), i.e. about 7 cyclones influenced the weather conditions of the country each winter season. Summarizing of frequency of three types of cyclones over Belarus is presented in Fig. 3

The maximum of cyclones of all types has shifted during the study period through the territory of Belarus (10-11 cases per season) in 2003-2004, 2007-2008, 2008-2009 and 2010-2011. Southern and north-western cyclones contribute mainly to the total frequency (either 48 cases or 73%).
Generally, 3 southern cyclones per season influenced the weather conditions of the country, but their amount increase to 5-7 cases in cold seasons of 2003-2004, 2005-2006, 2008-2009 and 2010-2011.

The frequency of the north-western cyclones was basically 1-2, but in some cold seasons (as 1994-1995, 2001-2002, 2003-2004, 2006-2007, 2007-2008 and 2011-2012) their amount were 4-5 cases per season.
35 western Atlantic cyclones (27% from all types of cyclones) moved through the territory of Belarus during the study period, i.e. their average frequency was about 2 cyclones per

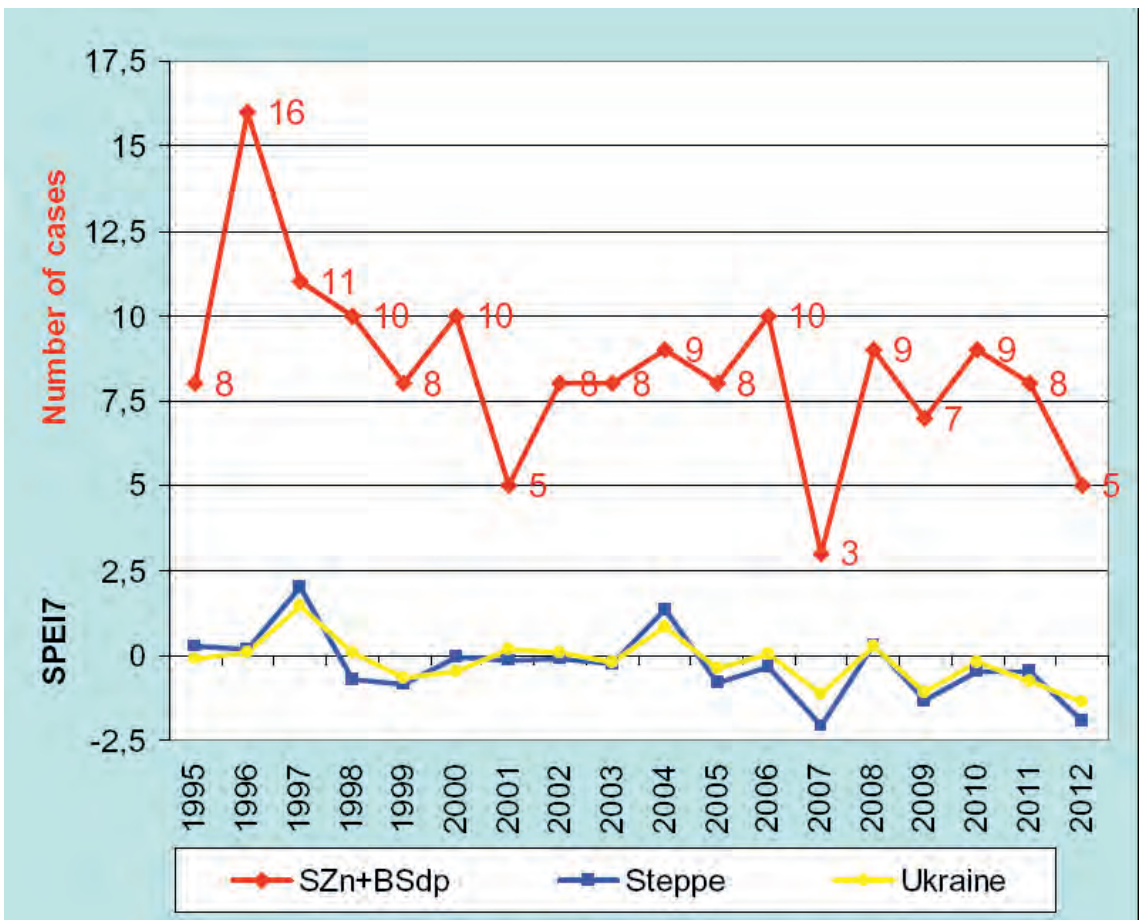

Figure 5. Dynamics of sum of the southern cyclones (SZn) and the Black sea depression (BSdp) in winter seasons and values of the SPEI7 for the warm seasons of 1995-2012 in Steppe and over Ukraine

Slika 5. Promjena broja južnih ciklona (SZn) i ciklona nad Crnim morem (BSdp) za zimsko razdoblje i vrijednosti SPEI7 za tople sezone 1995. - 2012. nad područjem Steppe i nad Ukrajinom.

season and maximum of 5 cases moved in season 2007-2008.

As seen on Fig. 3, the cyclones of different trajectories were absent in some seasons (e. g. 1994-1995, 1999-2000, 2009-2010, 2011-2012). Generally, in the first half of study period (until winter season of 2003-2004) a total sum of cyclones in Belarus was less then in the second half: in average 6 and 8 cases respectively.

As shown at Fig. 4, at the same period there was the gradual decreasing of amount of all types of cyclones over Ukraine. From 1994 to 2000 five from six winter seasons had the total amount of the cyclones exceeded 20 cases, with maximum up to 29 cases in the winter of 1996-1997. During the next six seasons (2000-2006) only two times were fixed, when the total amount of cyclones reached up to 20-22 cases. After the minimum in the winter season 2006-2007 (11 cyclones) the general amount of the cyclones didn't exceed 16 cases.

The analysis of frequency of different types of cyclones showed that main contribution in total amount is given by southern cyclones, because their cases exceeded amount of other types of cyclones considerably almost in all winters. In average, about 5 cyclones per season were observed. The frequency of western cyclones was about 2.3 cases per season, and the frequency of "diving" cyclones was about 1.3 cases per season. The southern cyclones were observed in every season, but western and "diving" cyclones were absent in some years (1994-1995, 2007-2008 and 2010-2011). An important role is played by deep troughs, because their amount in average is about 6 cases per season. Maximum of them (12 cases) was observed in the winter of 1996-1997, which was characterized by the highest cyclonic activity.

Analysis showed that the total amount of southern cyclones and the Black Sea depressions was compiled the half of all types of observed cyclones in winter time.

As seen on Fig. 5, there is a general tendency to decreasing of sum of these baric types during the study period. Maximum sum (16 cases)

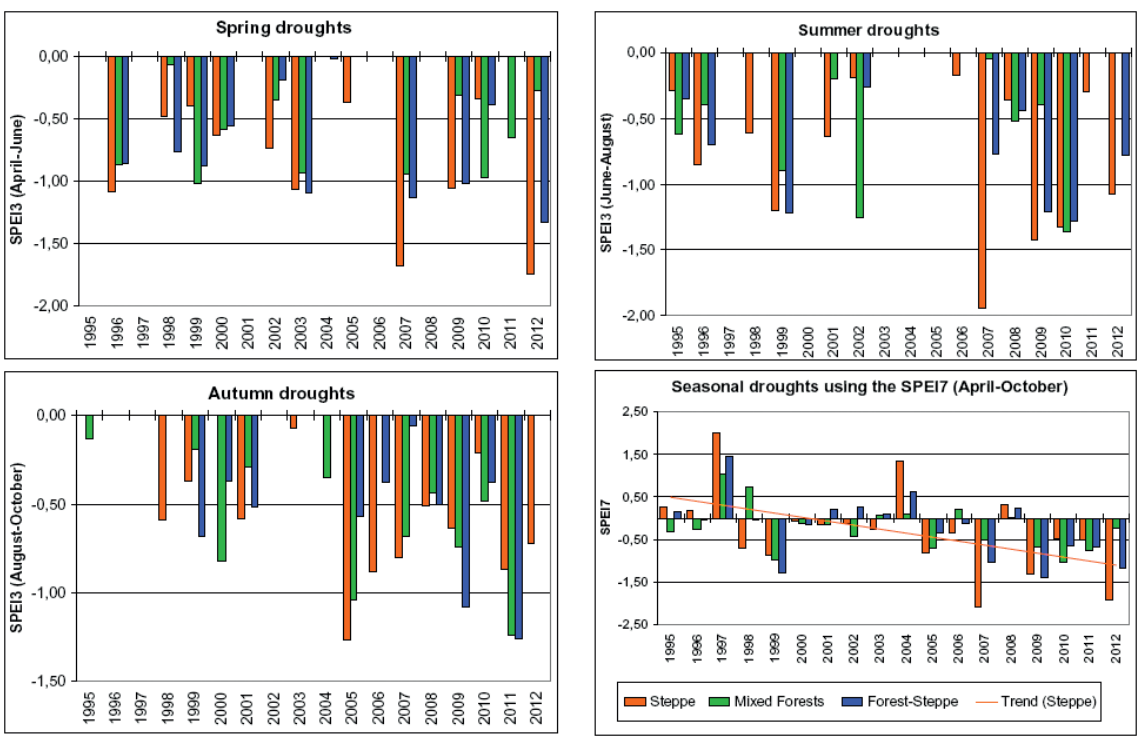

Figure 6. Spatiotemporal distribution of drought during the vegetation periods of 1995-2012 in Ukraine (with linear trend for seasonal droughts)

Slika 6. Vremensko-prostorna raspodjela suše za vrijeme vegetacijskog razdoblja 1995. Đ 2012. u Ukrajini (s linearnim trendom za sezonske suše).

was observed in winter season of 1995-1996. During the next period the number of cyclones decreased gradually to 8 cases per season in average. Minimum of sum (only 3 cases) was observed in 2006-2007.

2. Frequency of droughts in the vegetation period and the previous winter time cyclonic activity

Analysis using the SPEI at time scale of 3 months (SPEI3) showed that the spring-summer droughts prevailed in Ukraine at all zones (Fig. 6). In the Steppe 7-8 droughts occurred in every season. Full vegetation period droughts were observed in 2007, 2009 and 2012. The drought in 2007 appeared the most intensive and reached the criteria of strong and almost extreme drought in spring and summer (the SPEI3 was -1.68 and -1.94 respectively). In 2009 the highest negative indexes were marked only in summer period (-1.43), and drought in 2012 was a strong intensity in spring (-1.74). Generally, in summer the drought frequency increased in Steppe and decreased in other zone.

In the Forest-Steppe area an amount of spring-summer and summer droughts reduced to 3-4. Most droughty season was in 2009, when a moderate drought was during the vegetation period: the SPEI3 values varied from -1.02 to -1.21 in different seasons. In 2007 moderate and weak drought lasted for all spring and summer seasons (-1.13 and -0.77 respectively), and in 1999 moderate summer drought (-1.22) has passed into weak autumn drought (-0.68).

In the area of Mixed Forests the temporal distribution of spring-summer droughts has differed from south regions. There were mainly weak droughts in April-June, with the SPEI3 from -0.07 to -0.97. And one moderate drought (-1.02) occurred in spring 1999. In summer period an amount of droughts is halved, and in autumn the number of droughts is compared with the spring. Summer-autumn droughts were especially intensive in 2005 and 2011 (-1.04 and -1.24 respectively). Most

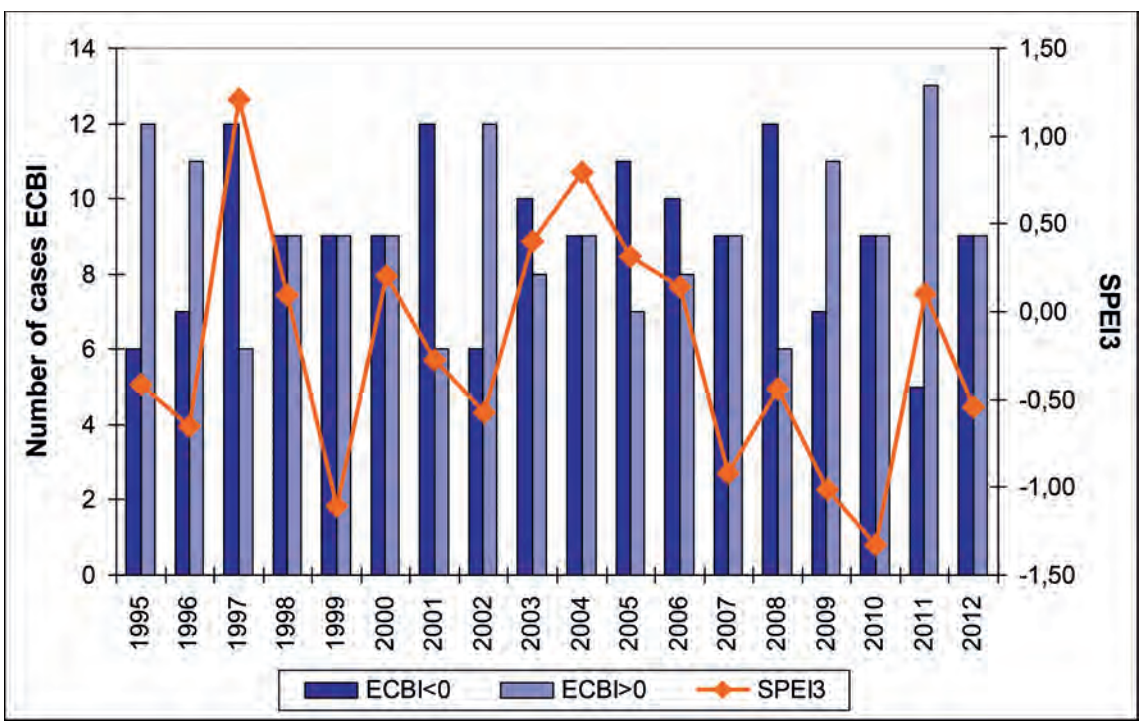

Figure 7. Summary frequency for cases of the pentad ECBI values (ECBI>0 and ECBI<0 respectively) during April-June and time course of the drought index SPEI3 (cover the period June-August), averaged over three main agroclimatic zones of Ukraine

Slika 7. Ukupna frekvencija slučajeva pentadnih ECBI vrijednosti (ECBI > 0 i ECBI < 0) za razdoblje travanj - lipanj i vremenski niz indeksa suše SPEI3 (koji pokriva razdoblje lipanj - kolovoz) usrednjen za tri glavne agroklimatske zone u Ukrajini.

droughty season occurred in 1999, when a moderate-to-weak drought (the SPEI3 from -1.02 to -0.90) was observed during the spring and summer seasons.

Most important vegetation season droughts, which were defined using SPEI at time scale of 7 months (SPEI7), were identified in 1999, 2007, 2009 and 2012. Severe (-1.92 in 2012) and extreme (-2.08 in 2007) droughts occurred mostly in Steppe. In the Forest-Steppe and Mixed Forests areas only weak and moderate seasonal droughts were observed. There is a trend of increasing intensity and frequency of droughts at present period.

In the early studies it has been already noted that the probability of droughts in Ukraine during the summer time strongly depends on the amount of southern cyclones and precipitation brought by them in winter season (Kudryan, 1981).

In this study a comparison of sum frequency of the southern cyclones and the Black Sea depressions was made in a cold period with the degree of aridity for next vegetation period. Drought seasons were detected using the index of SPEI for time scale of 7 months (April - October). As seen on graph at Fig. 5, there's a clear relationship between decreasing of cyclones amount and increasing the intensity of droughts (more of the negative SPEI values). The correlation analysis between the number of southern cyclones during winter months and values of the drought index SPEI7 for growing season (April - October) showed the correlation coefficients (r) were 0.53 for all Ukraine and 0.58 for Steppe and both coefficients were significant under the 95% confidence level.

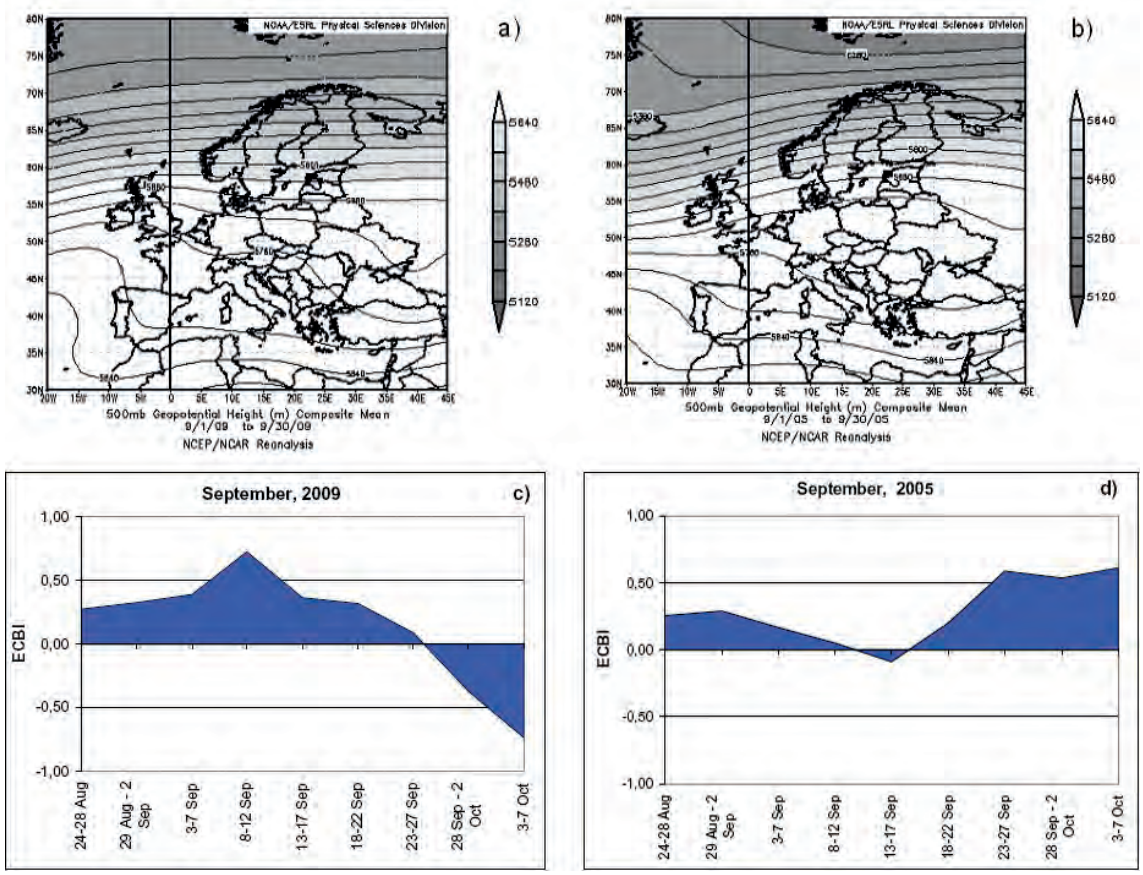

Figure 8. Geopotential height monthly composites at 500-hPa pressure level for September, 2009 (a) and September, 2005 (b), time course of blocking index ECBI for the same months (c, d)

Slika 8. Mjesečni kompoziti geopotencijala na 500 hPa za rujan 2009. (a) i rujan 2005. (b), vremenski niz bloking indeksa ECBI za iste mjesece (c i d).

Thus, during the study period important changes were detected in the cyclonic activity in the winter season over the territory of Ukraine, especially at the beginning of current century that in general consistent to the risk of occurring of droughts in warm season.

3. Pressure fields patterns characterized by periods of droughts in Ukraine

An increasing of the number of droughts in vegetation period usually connected with higher frequency of blocking structures over the study region. In some researches, which provided for Eastern Europe, notes that the last period (1998 to present) characterized by the increasing of number of blocking processes in the Northern Hemisphere and in Eastern Europe in particular. This situation leads to an increase in the duration of the anticyclonic circulation, which, in turn, causes the drought conditions (Kononova, 2014; Cherenkova at al. 2013; Cherenkova and Kononova, 2009).

An assessment of the relation between intensity of drought and frequency of blocking process in the atmosphere may be done using drought index and blocking index. As seems in Fig. 7, most cases of the summer drought over territory of Ukraine (SPEI<0) observed under conditions of summary prevalent in previous period the cases of ECBI>0, which correspond to blocking of zonal flow. As mentioned in similar studies (Lupo at al., 2014), dry summer may be connected with active blocking in the study region during the previous season, but this relationship statistically is weak (correlation coefficient ranges from 0.17 to 0.24). In our study the correlation analysis between the number of blocking cases during the April-June and values of the drought index SPEI3 for summer period (June-August) showed the correlation coefficient was 0.34 and it was significant under the 95% confidence level. This result correspond to the fact that the anticyclonic circulation in spring leads to deficit of precipitation and reduce of the soil moisture. Therefore, in summer period due to high air temperatures and irregularly precipitations the drought formation is appears easy. Concerning to use the ECBI on more short-term predictability of drought period, in previous study (Cherenkova at al., 2015) has been shown that four and more consecutive pentads with ECBI>0 during a month provided or extended an existing drought episode. Summarizing, we should note that the blocking process may be a necessary condition, but insufficient for the drought formation.

In this study were defined the pressure fields, which correspond to formation a drought located during the long time on restricted area, e.g. as territory of Ukraine. The main idea is the elements of the typical blocking pattern will be seen in the structure of the monthly high-level pressure field.

Analysis of the calculated criteria of similarity using the method of analogs has shown that all considered monthly fields of 500 hPa level geopotential heights are characterized by high r that specifies their belonging to one class (Martazinova, 2005).

The most typical monthly fields of H-500 were defined in September, 2009 and September, 2005 (Fig. 8, a and b). These fields were plotted using NCEP reanalysis data from NOAA ESRL/PSD data source (https://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl). In both cases the height pressure fields over Europe were characterized by the quasi-zonal flows in high and subtropical latitudes. In mid-latitudes an expressed ridge is located westerly from Pyrenean Peninsula and relatively small pressure gradients are observed along the latitudes of 40-55N. Easterly from territory of Ukraine and Belarus high level baric trough is pronounced. The time series of the ECBI index for both months show that during all period the processes of blocking of the zonal flow prevailed in the region (Fig. 8, c and d). Average monthly values of ECBI for September 2009 and 2005 were 0.26 and 0.25 respectively.

Obtained fields have an important element, which characterize the blocking structure in the troposphere: the splitting of the zonal flow that flows around the block, which located over Ukraine as a low-gradient pressure zone at monthly maps (e.g. https://www.theweatherprediction.com/blocking). Detailed structure of typical "block" (as an omega-block, Rex-block (dipole) etc.), which is developed for daily high-level maps, is not detected on monthly maps due to averaging.

CONCLUSIONS

Cyclonic activity in cold season during the study period of 1994-2012 is characterized by high frequency of all types of cyclones over the territory of Belarus and Ukraine.

About 7 cyclones of all types per each winter season affected the weather conditions of Belarus. 27% from them belong to the western cyclones, 36% to the northwestern types and 37% to the southern cyclones. During the study period the seasonal sum of all type cyclones does not changed significantly from year to year: ±1-2 cases from average value.

For the territory of Ukraine during the winter seasons general tendency to decreasing of all types of cyclones was observed. Number of cyclones reduced from more then 20 cases per winter during 1994-2000 to 12-14 cases during 2006-2012. The negative tendency in number of southern cyclones especially pronounced. Comparison between the frequency of southern cyclones over territories of Belarus and Ukraine showed that during the study period an increasing number of cyclones over Belarus and decreasing the same ones over Ukraine were observed. Cyclones of other types didn't have important trends in the interannual variability of the frequency.

Thus, we have observed the shift of winter cyclone tracks from southern latitudes to northward that may be connected with the existing climate changes in regional atmospheric circulation at the modern period. This fact corresponds to other researches, e.g. as pointed in part of IPCC report (Hartmann, D.L., 2013) and supplements the information on the regional changes of cyclones trajectories in the study period.

Comparison between a frequency of southern cyclones in the cold period and a degree of aridity for the next growing season has shown that the statistically significant tendency (r = 0.49 at 95% confidence level) to reduce the number of cyclones coincides with the increasing of drought episodes in Ukraine. Especially intensive droughts were fixed from 2007 to 2012 and during the warm season of 2007 (with minimum of cyclones in preceding winter) there was one of the most severe droughts in Ukraine.

In turn, the increasing of probability of drought in summer often accompanied by the high frequency of blocking processes over Eastern Europe during the preceding spring time. This relationship generally, statistically is weak, but significant (r = -0.34 at 95% confidence level). Blocking ridges at west and split zonal flow at east of Europe were found as the main features of monthly high-level pressure patterns during the periods of droughts over Ukraine.

The obtained results describe and clarify the role of atmospheric circulation in the middle latitudes as a main physical factor in drought evolution pattern that is one of the steps for development the methods of evaluation a drought risk in warm season.

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