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THE COMPARATIVE CHARACTERISTIC OF MACROCIRCULATION PROCESSES OF THE NORTHWEST BLACK SEA REGION, WHICH CONTRIBUTE TO SURFACE WIND STRENGTHENING

Komparativne karakteristike mikrocirkulacijskih procesa sjeverozapadne oblasti Crnomorske regije koje doprinose pojačanju prizemnog vjetra

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Abstract: Features of the geographical position of Ukraine, synoptic processes and a variety of climatic conditions conduce to frequent occurrence of natural hydrometeorological phenomena and create extreme complexity of their distribution in space and time. Today the problem of storm winds is quite actual. One of the conditions for successful forecasting of strong winds is the knowledge of wind characteristics on the studied area and synoptic conditions that cause them (Bagrov 1973, Gruza, Rankova, Oesterle 1976, Ivus 2012, 2014, 2015). Synoptic analysis of the material reveals the general regularities of such processes. The results presented below are the continuation of work (Katz 1959 Klimenko 1976, Kononova 2009, Martazinova, Ivanova 2004, Martazinova 2005, Rossby 1939, Vasiukov, Zverev, Ped 1962) on search for the best synoptic classification that reflects the completeness of the macroscale synoptic processes that lead to the formation of the wind, including strong wind, over the south of Ukraine and allows predicting it as accurate as possible.

Key words: macrocirculation processes, northern Black sea region, Katz's circulation index, storm winds

Sažetak: Zemljopisni smještaj Ukrajine, sinoptički procesi i raznolikost klimatskih osobina dovode do učestale pojave prirodnih hidrometeoroloških fenomena i do pojave izuzetne kompleksnosti njihove raspodjele u prostoru i vremenu. Danas je vrlo aktualan problem pojave olujnog vjetra. Jedan od uvjeta za prognoziranje jakog vjetra je poznavanje osobina vjetra nad istraživanim područjem i sinoptičke situacije koje ga uzrokuju (Begrov 1973, Gruza, Rankova, Oesterle 1976, Ivus 2012, 204, 2015). Sinoptička analiza ukazuje na pravilnost tih procesa. Prikazani rezultati nastavak su istraživanja (Katz 1959, Klimenko 1976, Kononova 2009, Martazinova, Ivanova 2004, Martazinova 2006, Rosby 1939, Vasiukov, Zverev, Ped 1962) najbolje klasifikacije koja odražava ukupnost mikroskalnih sinoptičkih procesa koji dovode do formiranja vjetra, uključujući jak vjetar iznad južne Ukraine, i omogućuje što točniju prognozu.

Ključne riječi: makrocirkulacijski procesi, sjeverni Baltik, Katzov indeks cirkulacije, olujni vjetar

INTRODUCTION

The first twenty years of the XXI century is the transition period from the domination of the most unstable southern meridional processes to the prevalence of the northern meridional processes. Due to the fact that the length of the southern meridional processes is currently almost twice as much as the average duration (Savter 2014), the resulting probability of disaster is high, and the circulation conditions require careful study to improve the accuracy of the natural hydrometeorological phenomena forecasts. General properties of the atmospheric circulation are often described using various indices, including the best known indexes of circulation of C.-G. Rossby (1939) and E.-N Blinova. Later A.-L. Katz (1959) developed the typing and zonal and meridional circulation indexes, which are discussed in details below.

M.A. Petrosyants and D. Hushchina proposed a new modified circulation index, which is similar to E-N. Blinova's index. With the help of this index it is calculated the speed circulation of the zonal real wind component, that reflects the large-scale features of global circulation zone and allows characterizing the features of the atmosphere motion in different latitudinal zones more detailed. In this principle, M.A. Petrosyants and D. Hushchina introduced two integrated circulation indexes as integral characteristics of wind fields: 1) zonal circulation velocity vector component along a circle of latitude and 2) the circulation of wind velocity vector of the contour. These indexes are introduced to the study of distant relationships between processes in the tropics and temperate latitudes. These circulation indexes do not carry any information about weather anomalies in the relevant areas, but abnormal circulation of the wind velocity vector can be an indicator of temperature and precipitation anomalies. Despite the attractiveness of this index its further review is beyond the scope of the article.

In the paper the connection between circulation indexes of E.N. Blinova and A.L. Katz (1959) and the Northern Hemisphere circulation types of B.L. Dzerdzeyevskyi (Voskresenskaia 2009) is illustrated for the first time. Because the research is (Kononova 2009) performed on output ranks of the first half of the XX century and cannot reflect present changes in circulation conditions, it is interesting to make a similar analysis.

In general, there are several classifications of large-scale atmospheric circulation of the Northern Hemisphere, among which the most famous is Dzerdzeyevskyi's synoptic classification of large-scale atmospheric processes (Kononova 2009). These classifications schematize the circulation of the atmosphere, casting small parts of the baric field that simplifies the description of synoptic processes. Methods of statistical cluster analysis are used in the creation of formal classification, which is close in physical meaning to Dzerdzeyevskyi's classification. As noted by the authors of the formal classification, part of types and groups of types from synoptic classification of Dzerdzeyevskyi is observed quite synchronously with the types from classification, based on formal algorithms for partitioning of observing baric fields on clusters.

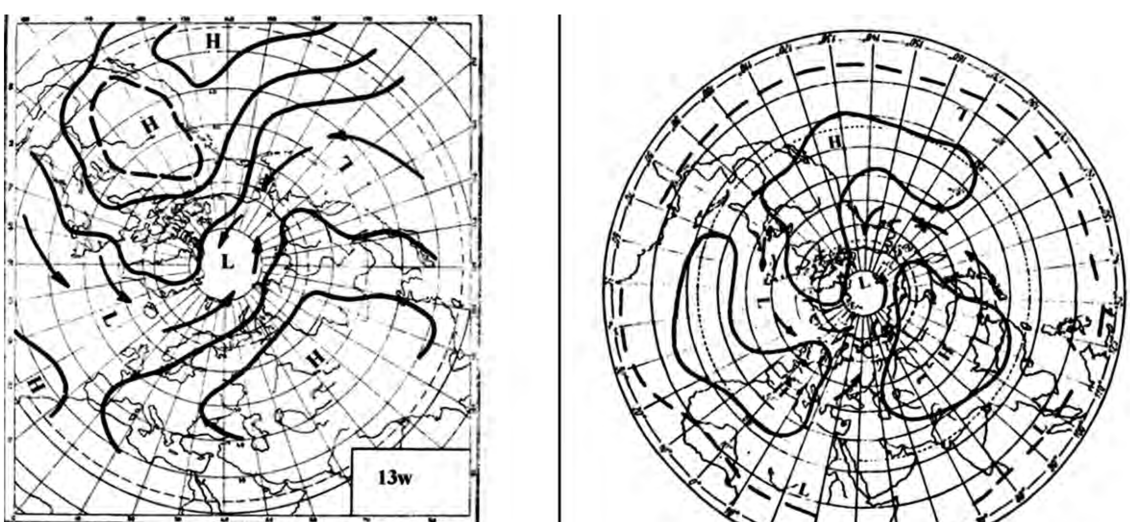

Figure 1. Elementary Circulation Mechanism (ECM) -13 w (www.atmospheric-circulation.ru)

Slika 1. Osnovni cirkulacijski mehanizam (ECM) - 13 w (www.atmospheric-circulation.ru).

Let's remind (Kononova 2009) that in Dzerdzeyevskyi's classification the type of large-scale atmospheric circulation for extratropical latitudes of the Northern Hemisphere is determined by the position and nature of main synoptic processes in the lower troposphere, i.e. the movement of southern cyclones and anticyclone trajectories, connected with Arctic invasion. These processes reflect relatively stable in time the geographical position of the altitude baric basins and ridges. So called elementary circulation mechanisms (ECM) differ in number and geographical location of basins and ridges in the middle troposphere pressure field and position of baric surface formation trajectories. The number of ECM imposed by Dzerdzeyevskyi equals 13. Slight bias of basins and ridges in space and seasons leads the variants of circulation schemes to 41. This set allows any observed state of the atmosphere attributing to a specific type of circulation, so that circulation changes in time are reduced to changes in types (during the day there is only one type). Circulation types form 15 groups that differ at isobaric surface of 500 hPa level in number and direction of prevailing airflow deviation from purely zonal. Groups are not confined to the seasons.

Calendar of successive change of ECM for the period of 1899-2008 years is represented by Kononova (2009), and from 2008 till 2014 is available online[1]. Classification and calendar are the most detailed and prolonged compared to other classifications.

MATERIALS AND METHODS OF RESEARCH.

The aim of given research is to analyze the interaction between large-scale atmospheric circulation to unfavorable weather conditions in the Northwest Black Sea region which are manifested as strong and very strong winds. The paper uses information from the archives of the synoptic data analysis software "ARMsyn"[2]: surface weather maps, maps of baric topography 850mb, 500mb, telegram storm alerts. Research was carried out for the period of cold season (October-March) 2011-2014 in order to exclude squally wind enhancements caused by the development of convection that occurs mainly in warmer months. Therefore, only cases of graded winds observed in the south of Ukraine were taken into account. Minor intensification of wind was not taken into account.

ANALYSIS

The main factor of wind speed change in the cold season is a change in the baric gradient. During this period there were recorded 4 cases of strong wind strengthening to 25 m/s and more: 7 February 2012, 8 February 2012, 12 March 2012 and 23 March 2013. It should be noted that under the influence of storm winds there were only southern parts of the region, especially stations, located on the sea coast and estuaries (Belgorod-Dniesterovsky, Ust-Dunaysk, Pivdennyi port, Paromna Pereprava). Strong winds have distributed quite unevenly from season to season for years. Thus, in the cold season of 2011-12 years 19 cases of dangerous winds were registered, in 2012-13 years there were 23 cases and in 2013-14 - only 15 cases. Most often strong winds blow from the northeast, north and northwest. These directions are typical for moving of cyclonic vortices from the southwest when in the zone of warm front influence the northeast, and after the passage of a cold front northwest and north winds increase. In contrast to these directions south, southwest and western winds occur much less frequently. Very strong winds on 07-08 February 2012 had a northeast direction, 23 March 2013 - northwest direction, and 3 December 2012 the direction varied from 120 to 350 degrees.

To determine the nature of macroscale synoptic processes that lead to emergence of storm winds in the North-Western Black Sea region, we will use A.L. Katz's typing (Katz 1959). Calculations were carried out for the first sector of the temperate zone - Atlantic-European, which is between 20° E - 80° E and 35° N - 70° N.

According to the formulas (1-2) we define the indexes of zonal and meridional circulation

[1] www.atmospheric-circulation.ru
[2] Software "ARMsyn" (avtomaticheskoye rabocheye mesto sinoptika) is commonly used at the post-soviet space

Table 1. The frequency of synoptic situations in various forms of atmospheric circulation during the cold period of 2011 - 2014

Tablica 1. Učestalost pojave sinoptičkih situacija pri raznim oblicima atmosfereske cirkulacije u hladnom razdoblju 2011-2014.

Type of synoptic situation		Circulation types				
		Zonal	Meridional			
			Western	Central	Eastern	Mixed
1		2	3	4	5	6
Western cyclone			1		1	
Southern cyclone		5	1	3	2	8
Diving cyclone		4	8		1	1
Zone of interaction	Anticyclone is in the east, the cyclone is in the west	1		5	2	3
	Anticyclone is in the west, a cyclone is in the east		4			2
	Anticyclone is in the north, the cyclone is in the south		2	2	1	

and at the ratio of the meridional index to zonal one we get the index of general circulation (formula 3):

$$I_z = \frac{\sum_{1}^{6} (n_3 - n_c)\cdot b}{6 \cdot 3{,}5} \quad (1)$$

where n_3 is the number of intersections of six meridians by isohypses between 35°N and 70 °N which are directed from west to east; nc is the number of intersections of meridians, which are directed from east to west; b is the coefficient, equal to 4 gp. dam on map AU-500 hPa;

$$I_m = \left[\frac{n_{45}\cdot\frac{1}{\cos 45}}{120} + \frac{n_{55}\cdot\frac{1}{\cos 55}}{120} + \frac{n_{65}\cdot\frac{1}{\cos 65}}{120} \right]\cdot \frac{b}{3} \quad (2)$$

where n 45, 55, 65 is the number of intersections of these parallels by isohypses, regardless of their direction;

$$I_{ym} = \frac{I_m}{I_z} \quad (3)$$

where I_m and I_3 are indexes of meridional and zonal circulation respectively. If Igen Ë 0,75, it is considered to be a meridional circulation.

It is known (Katz A.L,1959) that zonal type of circulation is characterized by latitudinal orientation of isohypses on map AU-500, and meridional (m) type of circulation is divided into four forms: western (W), eastern (E), central (C) and mixed (Mix), which differ from each other significantly in territorial distribution of altitudinal ridges and basins.

As expected, strong wind over the south of Ukraine was marked mainly in the meridional type of atmospheric circulation (77.2%) the zonal type of circulation has 22.8% of all cases. Meridional type of circulation, in turn, is mostly represented by mixed (24.6%) and west (22.8%) forms. Slightly rarely the central (17.5%) and eastern (12.3%) circulation form were observed. All cases of wind strengthening up to 25 m/s and more are connected exclusively with meridianal circulation of different forms. The number of index ranges from 0.76 to 2.11. So we can assume that the meridional character of atmospheric circulation creates favorable conditions for wind strengthening in the Northwest Black Sea region to the criteria of strong and very strong wind.

Exploring the impact of baric objects on the strong and very strong wind formation, there were highlighted the main types of synoptic situations causing storm conditions in the Northwest Black Sea region (Table 1). Wind increasing up to 25 m/s and more during cold seasons of 2011-13 years is connected with the

Table 2. The repeatability combination (%) of ECM and subtypes of synoptic processes with indexes of Katz and Vmax. Cold period of 2011-2014. Note: each cell on the left indicates repeatability (%), on the right - Katz's circulation index and value Vmax, m/s (below).

Tablica 2. Učestalost ponavljanja (%) ECM i podtipova sinoptičkih procesa s Katzovim indexom i Vmax. Hladno razdoblje 2011-2014. Napomena: u svakoj ćeliji tablice lijevo ponovljivost (%), desno Katzov indeks cirkulacije i vrijednost Vmax m/s .

Type of ECM	Subtypes of synoptic processes					
	5.1	**5.2**	**6.1**	**6.2**	**6.3**	**6.4**
5 a, 5 b				5.3 0,95 m ix 0,91 m mix 1,11 m east 22		
6		3.5 0,76 m west 0,79 m east 16				
8 bz, 8 gz	1.7 0,67 zon 16			3.5 0,48 zon 1,18 m west 18		
11 a, 11 b, 11w, 11 g		3.5 1,64 m mix 2,11 m westzah 26	7 1,30 zm 1,45 mc 1,71 mc 1,13 mc 25	1.7 0,59 z n 20	3.5 0,70 zon 0,97 m mix 22	5.3 1,50 m mix 0,55 zon 0,99 м ц 21
12	5.3 1,16 m mix 0,79 m mix 0,65 zon 20		5.3 1,10 m c 1,03 m c 0,99 m mix 20	10.5 1,32 м зм 0,97 m west 1,08 m west 0,98 m west 1,39 m west 22	5.3 0,97 m east 0,75 m east 0,72 zon 20	5.3 0,77 m mix 0,60 zon 0,77 m east 27
12 bw		3.5 1,29 m c 0,55 zon 20	3.5 0,80 m c 0,95 zon 22	1.8 0,76 m mix 25	1.8 0,76 m mix 16	
12 vw		5.3 1,02 m mix 1,05 m msx 0,53 zon 20	1.7 1,16 m west 16	1.8 0,94 m east 22		
13 w	3.5 0,82 m west 1,11 m west 20	7 3,01 m c 1,53 m c 1,12 m c 0,74 zon 22		1.8 0,95 m west 21		1.8 2,85 m mix 22

release of southern cyclones. A common feature of the mechanism of southern cyclones occurrence is meridional character of macroscale processes that influence the formation of favorable local cyclogenesis of thermodynamic conditions. It should be noted that all the cases were characterized by extremely close location of Arctic Front system to Polar system that led to increased activity of cyclonic vortices.

Southern cyclones also conditioned by strong wind (19 cases), and the type of atmospheric circulation was meridional in 14 cases, and in 5 cases it was zonal. Diving cyclones from the Scandinavia area caused wind strengthening to storm values 14 times. Western cyclones moving was accompanied by strong wind only twice. The zone of cyclone and anticyclone interaction of different geographical location also significantly influenced the formation of strong winds. Most often they were blocking anticyclones from the east (11 cases, both Arctic and Siberian anticyclones). In 6 cases there was an opposite picture when anticyclone was located over Western Europe, and the cyclone was in the east (mainly over the Volga region) and 5 cases where anticyclone was located in the north and cyclone was in the south. Thus, the peripheral processes are extremely important in storm wind forecasting in the Northwest Black Sea region.

Table 2 shows all the cases of strong wind, observed in southern Ukraine during the cold season of 2011-2014, in the corresponding group of circulation conditions according to Katz, Dzerdzeyevskyi or classification of synoptic processes developed at the Department of Meteorology and Climatology OSEU.

Strong wind is generally formed during synoptic processes assigned to 5 and 6 type of classification. Type 5 is peripheral atmospheric processes of atmospheric fronts. Subtype 5.1 is eastern and western transfer on the eastern-southeastern periphery of the anticyclone. Wind speed increases under the influence of the Black Sea depression and storm zone ($\partial P / \partial n \geq 3.5$ hPa / 111 km) from the front. Subtype 5.2 - east and southeast transfer occurs on the south-southwestern periphery of anticyclone during the passing of arctic or polar fronts; in the area of high pressure gradients without fronts or if there is a vague front. Type 6 is cyclonic circulation with high pressure gradient ($\partial P / \partial n \geq 2.5$ hPa / 111 km). Subtype 6.1 is eastern part of cyclone or storm zone between cyclone in the west, northwest and anticyclone in the east.

Subtype 6.2 is the type of cyclone that moves with speed ≥ 40 km/h. Subtype 6.3 is a basin with fronts, and subtype 6.4 is the southern cyclone, carrying out air masses transfer from the south. However, in its northern part it may be occurred a wind of northern and south-eastern directions, in the center of cyclone (with fronts) wind may be of all directions, including the north-eastern. Strong and very strong wind over the south of Ukraine is marked at 6 types (13 subtypes) and 2 types (6 subtypes) of ECM of the department classification. According to Table 2 the greatest repeatability of strong wind (10.5%) has a combination of ECM 12a and subtype 6.2 in the meridional type of Katz's circulation. ECM 12a provides 18 of 57 examined cases, including maximal wind speed (27 m/s) in the region 12 March 2012, when 11 regional stations fixed the speed ≥ 20 m/s. The wind direction changed in the investigated area on stations from 170 ° (Pivdennyi port) to 350 ° (Bolhrad); the atmospheric front passed with waves (subtype 6.4). Also, strong wind was often observed at ECM 13z, mainly in the meridional processes while south cyclones were moving.

Let's consider one of the typical synoptic situations, which was formed by type ECM-11 and subtypes 5.2, 6.1. Thus, on the 26-29 January, 2014 (Figure 2) unfavorable weather conditions in the Azov-Black Sea basin and adjacent areas were predetermined by interaction of the north-western anticyclone ridge with maximal pressure 1053 hPa that shifted from the Baltic sea region to Moscow and southern cyclone basin with minimal pressure 997 hPa, which emerged on the wave of polar front over Italy and shifted to the east of the Black sea.

Pressure drop in front of the cyclone along the coast of Turkey was insignificant (1.1-1.6 hPa / 3h), pressure increasing in the rear part near

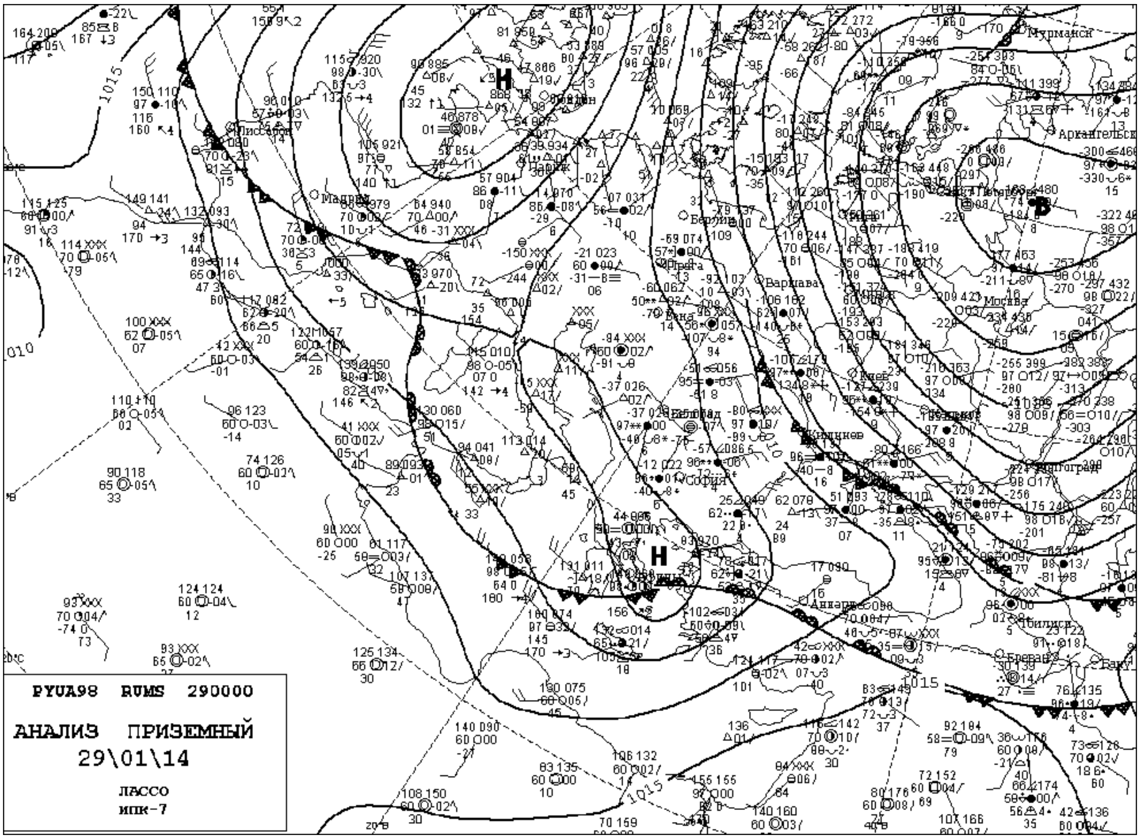

Figure 2. Surface Analysis for 29 January 2014, 00 UTC

Slika 2. Prizemna analiza za 29.1.2014. u 00 UTC

the Dardanelles Strait reached 6.7 hPa / 3h according to 09 (11)h. 29 January2014.

High level or tropospheric cyclone outlined by one enclosed isohypse 132 dam over the northern regions of the Aegean Sea corresponded to surface cyclone on the map 850 mb, on the map 700 mb it was tall trough , which axis was focused from the British Isles through central Europe to the Balkans. Geopotential gradients of high frontal zone over the Sea of Azov on the map CS 500/1000 was about 8-10 dam / 1000 km.`

In front of the cyclone advection of heat from the eastern Mediterranean Sea held in the south-eastern regions of the Black Sea, air temperature of the Turkish and Caucasian Black Sea coast at 18 (20) hours on the 29 of Jan. was 14 ... 18 °C, while above the Sea of Azov it decreased to 9 ... 14 °C. Cyclone shifted from the Sea of Marmara on the eastern regions of the Black Sea per day, the pressure at the center grew to 1010 hPa. The presence of a blocking anticyclone supported significant thermal and baric (about 5 hPa / 111 km) gradients near the Earth's surface above the Sea of Azov, which contributed to the northeastern wind strengthening to the criteria of natural hydrometeorological phenomena. In the water area of the seas wind speed reached 15 ... 24 m/s, in Henichesk, Berdyansk and Mariupol it was 25 ... 28 m/s. The combination of strong wind with snow led to strong blizzard. Wind strengthening was accompanied by dangerous icy and wind-surge phenomena, quick icing of ships (Ivus, 2014). OHSS caused damage to t ports and maritime industry enterprises located on the Azov Sea coast, cargo operations and shipping were terminated, power lines were damaged (Ivus, 2014).

CONCLUSIONS

As a result of research of features of macrocirculation processes structure in the troposphere over Ukraine using Katz's circulation index, circulation classification mechanisms by B.L. Dzerdzeyevskyi and synoptic processes typing revealed the following:

1. In the study of formation conditions of a strong wind in the cold season in the south of Ukraine it was found that strong and very strong winds often occur in southern and central regions, particularly in stations located on the shores of the seas and estuaries (Belgorod-Dniestrovskyi, Ust-Dunaysk, Pivdennyi port, Paromna Pereprava).
2. Meridional nature of atmospheric circulation (77.2%) creates favorable conditions for wind strengthening in the Northwest Black Sea region to the criterion of strong and very strong, the zonal type of circulation has 22.8% of the total amount. Meridional circulation type is mainly represented by mixed (24.6%) and western (22.8%) forms according to Katz's typing.
3. There were identified the main types of synoptic situations (Ivus 2012, Katz 1959) of the department typing which caused strong winds. Often strong wind occurred during the moving of cyclonic vortices from the south (type ECM 12a, 13z) and in the area of interaction between cyclones and anticyclones. All these four cases of the wind strengthening to the criterion of very strong are connected with the southern cyclones movement.

The conclusions have a preliminary character and need confirmation on more volumetric statistical material.

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