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Spatio-temporal changes in energetic characteristics of eddy atmospheric circulation in the troposphere of West Siberia in the end of XX – the beginning of XXI centuries

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Abstract. In the framework of the study based on ERA-Interim reanalysis dataset the analysis of average values of available potential energy, kinetic energy, their eddy components and parameter of relative vorticity, characterizing cyclonic and anticyclonic types of circulation, was carried out over the period of 1979-2015 for the territory of West Siberia. Also coefficients of their linear trends were calculated. It was revealed that the distribution in positive and negative tendencies of energetic characteristics was significantly changed upon transition from the period of 1979-1998 to the period of 1999-2015 along with considerable increase in their trend values. Their trend areas with negative values were located close to each other and were slightly covered in zone 60°-64°N. The greatest dissipation intensity was observed in the middle troposphere. At the earth's surface eddy circulation generation along the Arctic coast was shifted to East Siberia. The beginning of XXI century was characterized by the significant decrease in eddy circulation activity over West Siberia that was especially pronounced in winter. Furthermore, eddy circulation (cyclonic type) increased just in the certain zones - in the interfluve area of the Ob and the Irtysh rivers. This indicates the possibility of anomalies in meteorological parameters formation there.

1. Introduction

Global climate tendencies lead to considerable changes of atmospheric circulation patterns, causing meteorological parameters anomalies in certain regions [1]. This, in particularly, is connected with change in activity of vortices that provide inter-latitude heat and moisture transfer [2]. One of circulation variability effects is in the fact, that anomalous weather phenomena such as waves of heat and cold, heavy rains and snowfalls, storms, floods and droughts became widespread [3]. West Siberia is not an exception here. According to [4], in general warming process in West Siberia was replaced by climate cooling at the beginning of the XXI century, the atmospheric pressure rise was observed together with precipitation amount increase during 1976-1998, and the most statistically significant increase is observed in the northern part of West Siberia in warm season. On the contrary, there was a tendency to negative anomalies of precipitation amount in the south. In the north convective precipitation area expanded on 10% during a warm season.

The tendencies can be related to more frequent events of convective (cumulonimbus) cloudiness development, formation of which are caused by eddy circulation processes. All main aspects of atmospheric processes are expressed through sources and dissipation of distribution of available potential energy, its transport and transformation [5]. Moreover, the important place in research of atmospheric circulation is taken by a question, that deals with the energy of movement (including eddy and wave) of various scales. In [6] components of energy transformation cycle (Lorenz cycle) are estimated for baroclinic eddies. It is shown that only about 10% of eddy energy converted from potential energy to kinetic one, evolved into kinetic energy of main stream, and the rest of 90% are spent for dissipation of eddies relating to processes of surface friction and radiation relaxation.

In [7] it is reported that global "vortex energy" associated with storm, eddy and turbulence generation significantly increased last decades.

Therefore, investigation in energy characteristics of atmospheric circulation and the corresponding analysis allow us to better describe dynamics of separate elements of regional climatic system and to reveal their important features.

Main goal of the study is in estimation of spatio-temporal variability of eddy components of available potential and kinetic energies and, also to obtain parameter of the relative vorticity in the territory of West Siberia over the period of 1979-2015.

2. Materials and Methods

Average values of available potential energy (APE), kinetic energy (KE), their eddy components (EAPE and EKE, respectively), parameter of relative vorticity (Vort) and coefficients of their linear trends (here and after - trends) over the period of 1979-2015 were calculated for the territory of West Siberia (50°-70°N, 60°-90°E) and separately to its Arctic part (60°-70°N., 60°-90°E). ERA-Interim reanalysis dataset (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim) were used. Calculations of energetic components were carried out at several levels in the troposphere (1000 hPa and 500 hPa), according to Lorenz's formulas [8]. The term *eddy* was meant as a part of energy that differs from its zonally averaged values.

Used parameter of relative vorticity characterized both anticyclonic (positive values — Vort+) and cyclonic (negative values — Vort-) types of circulation.

Median of cumulative distribution function (CDF) was used as the averaged by the territory characteristic. The statistical significance of the derived values was determined by the two-sided t-test of null hypothesis at a significance level of 0.05.

Calculation of characteristics was carried out separately for two time intervals: during intensive global warming - 1976-1998 and during temperature slowdown - 1999-2015.

In order to define the nature of changes passing from one period to another, for each time interval spatial distribution maps of linear trend estimates were constructed for all calendar months and for all seasons. Spatial distribution maps were presented for the Asian territory of Russia to consider tendencies of these parameters in adjacent regions. Interannual variability was also analyzed. Special attention was paid to the changes in the Arctic part of West Siberia, because there is the highest linear correlation between the Arctic climate presented by the surface air temperature and the meridional energy flux on the border of 70°N [9]. Moreover, the border of 70°N in a considerable degree coincides with the influence area border of annular stationary mode of high-latitude climatic variability - the Arctic Oscillation [10].

3. Results and Discussion

Analysis of annual averaged parameters values and their trends allow us to reveal the following features: all considered types of energy have a pronounced annual course with the maximum values in autumn and winter and minimum - in summer.

Kinetic and available potential energy values had inhomogeneous distribution over the territory of West Siberia, especially at the surface, over the period of 1979-1998. APE maxima, characterizing the enhancement of temperature latitudinal contrast, were located in the south of the territory, areas of minima – to the northward and along the western border of the region. The greatest variability of APE was observed in the lower troposphere (up to 3 km). For KE, on the contrary, areas of maxima were located in the Arctic zone, extending into the central part of the territory. In the middle troposphere (500 hPa) there was zonal distribution in KE with decreasing from south to north. In the beginning of XXI century (1999-2015) the APE increase of APE took place at the surface in the southern part of Siberia whereas its almost total disappearance of minima area was in the west. At the same time decrease of KE values was observed in the central part of the region, however, the area of positive values became higher in the north and it was already extended along the whole Arctic coast. At the level of 500 hPa, as well as at 1000 hPa, there was a KE decrease in the central part, and changes in APE were not observed.

Despite the fact that due to great variability of APE and KE values of their trends were statistically insignificant at α=0.05 (however, they were significant at α=0.1), it was possible to reveal the following tendencies. Firstly, analyzing constructed maps of spatial distribution in trends of the studied parameters, it could be noted that positive and negative tendencies had significantly changed from one time interval to another, and secondly, trend values (figure 1,2) had notably increased.

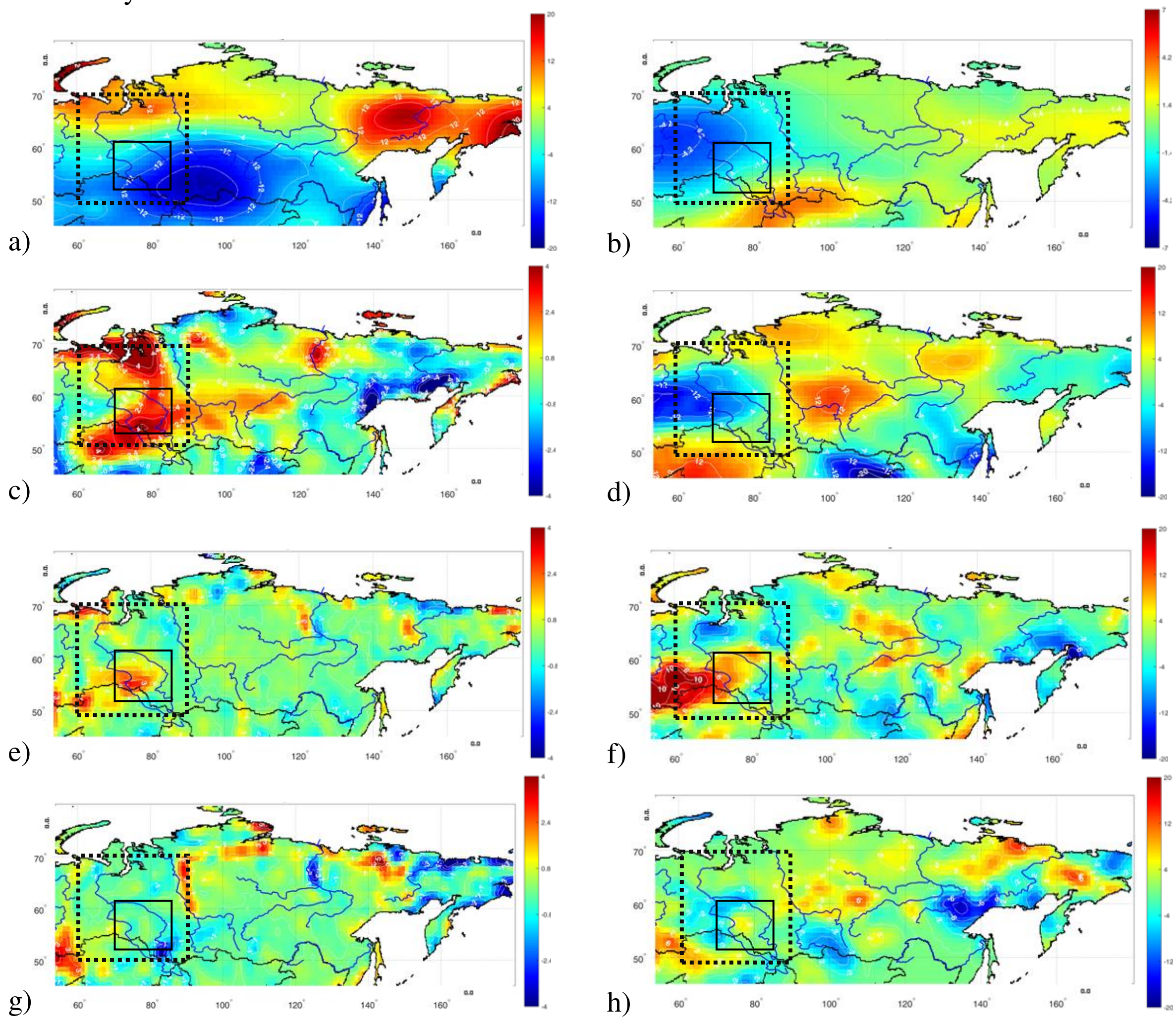

Figure 1. Spatial distribution of trend values over the period of 1979-1998: available potential energy, J/m2/decade (a,b), kinetic energy, J/m2/decade (c,d), relative vorticity (s-1/decade) of cyclonic (e,f) and anticyclonic types (g,h). Left panel - 1000 hPa, right panel - 500 hPa. Dash figure – the territory of West Siberia. Solid figure - the interfluve of the Ob and the Irtysh rivers.

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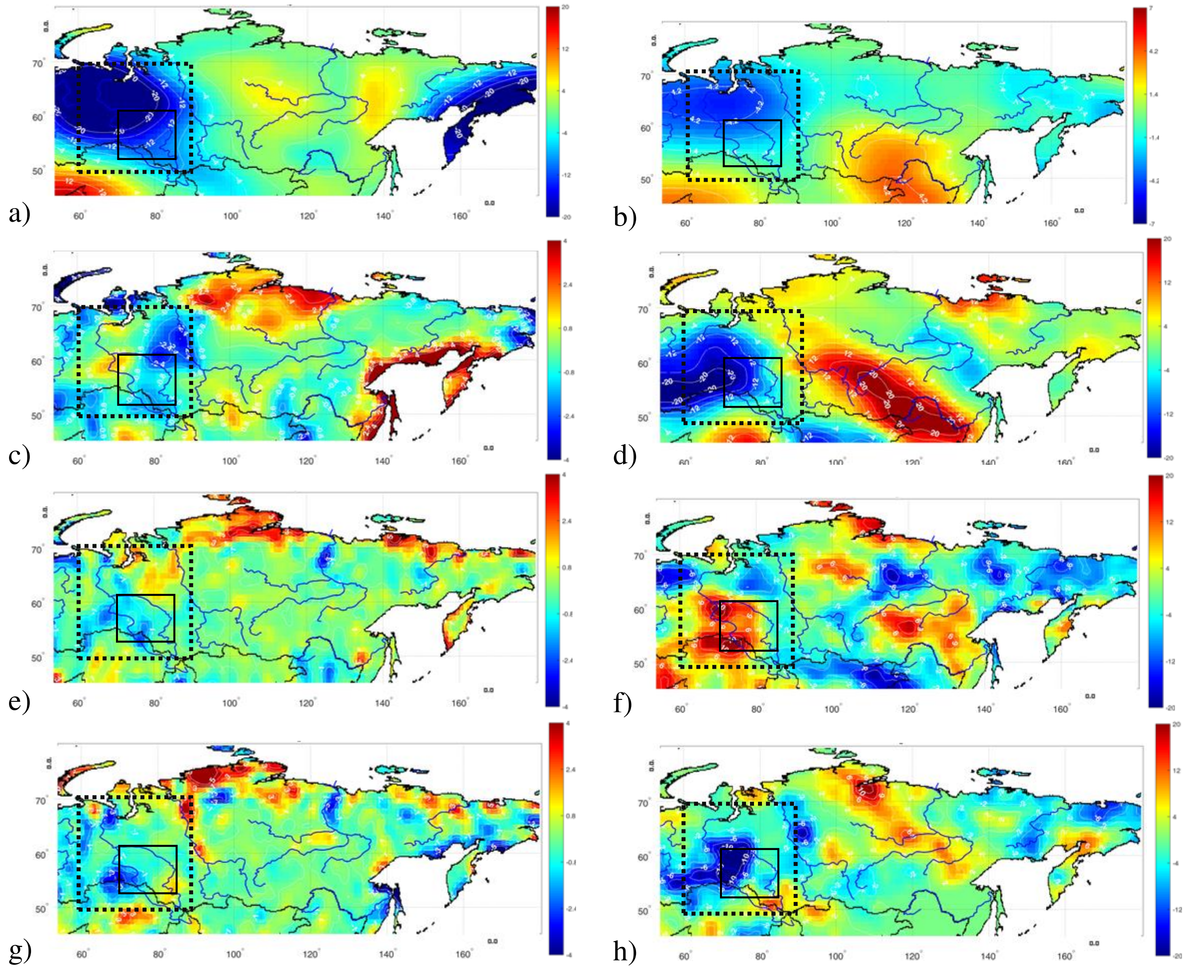

Figure 2. Spatial distribution of trend values over the period of 1999-2015: available potential energy, J/m2/decade (a,b), kinetic energy, J/m2/decade (c,d), relative vorticity (s-1/decade) of cyclonic (e,f) and anticyclonic types (g,h). Left panel - 1000 hPa, right panel - 500 hPa. Dash figure - the territory of West Siberia. Solid figure - the interfluve of the Ob and the Irtysh rivers.

Thus, in the beginning of the XXI century a vast range of negative values of APE trends was formed over the Arctic and the central part of the region, that confirmed the decrease in horizontal temperature gradients. The area stretches up to the middle troposphere (figure 2a, b). The same time interval showed almost widespread KE reduction (figure 1, 2) over the whole territory from the surface to the middle troposphere (that indicates the decrease in medium velocity of atmospheric flow), except for existence of the individual centers of positive trends in the center and in the north of the region. While APE negative trends continued to exist in the middle troposphere, a large center of the decrease in air transfer speed was formed for KE almost over all central part of West Siberia. Places where APE and KE trends with the same sign were observed, indicated generation sites (positive) of eddy energy or the sites of its dissipation (negative). Thus, in Siberia APE and KE trend centers with negative values were located under each other (KE – to the southward) and were slightly covered in zone of 60°-64°N (by the isoline corresponded to the half of the maximum value). The greatest dissipation intensity was revealed at 500 hPa. This effect was less pronounced in the boundary layer. It was observed the decrease in eddy activity due to dissipation and radiation relaxation in the energy flux areas.

Areas of eddy circulation generation in the surface layer over West Siberia, reveled along the Arctic coast in beginning of XXI century, moved to East Siberia, whereas no changes occurred in the middle atmosphere – it was located in the north of the Altai.

The CDF showed that in the beginning of XXI century the greatest changes of eddy components parameters of available potential and kinetic energy (EAPE and EKE) occurred at the surface. The second time interval was characterized by significant increase of range in EAPE values, here about 70% of the territory (in comparison with 40% over the first interval) was in the area of negative values (figure 3a). Changes in the Arctic part of the region were not pronounced. EAPE trends were mainly negative in winter and spring and positive in rest of the year. Over the second time interval, positive and statistically significant tendencies were observed in cold season, negative and statistically insignificant - from March to October. In the Arctic part there was a statistically significant decrease in EAPE during the whole year, except for certain months. Noticeable changes for EKE were not determined in the territory of West Siberia (figure 3c). This was confirmed by the distribution of trend estimations: significant tendencies were positive ones (specific for mid-seasons), and their parameters showed the increase over the second time interval. At the same time, in contrast to EAPE, the greatest changes were observed at 500 hPa in the Arctic part of the region. However, there was a tendency to the extending areas of positive values.

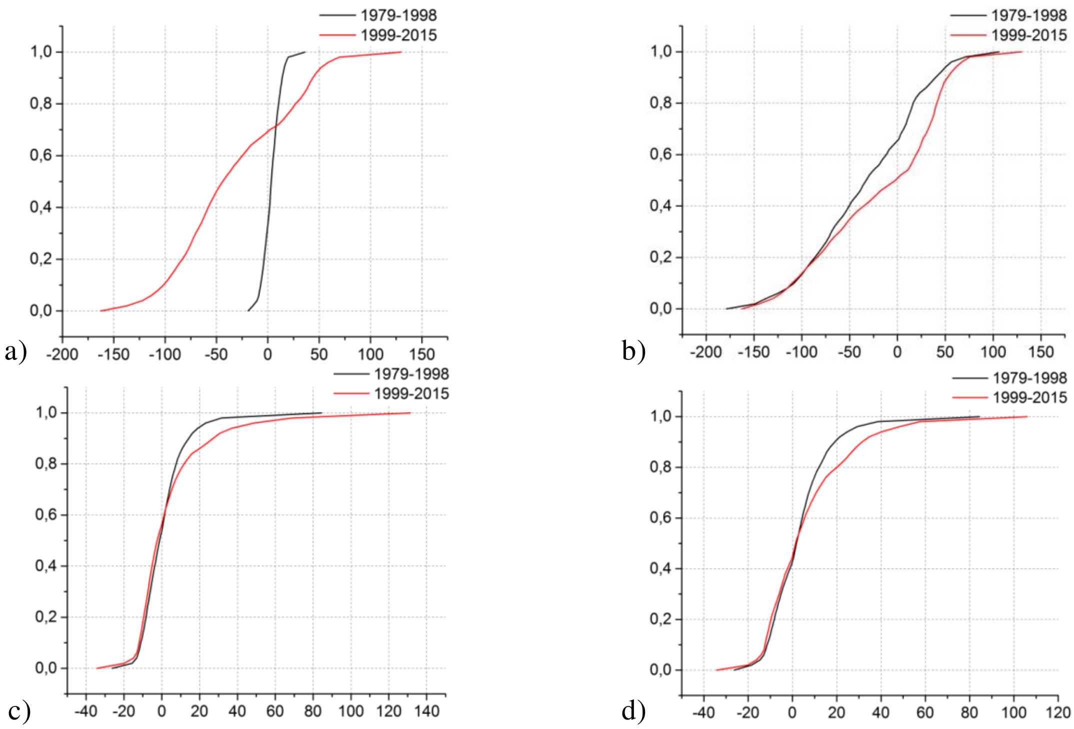

Figure 3. CDF of averaged values at 1000 hPa in January in West Siberia: eddy available potential energy (a,b) and eddy kinetic energy (c,d) Right panel (b,d) – for the Arctic part of the region.

In general, the decrease in eddy components existed in winter season over the whole West Siberia during the period of 1999-2015. Transformation process of available potential energy into kinetic one (kinetic energy generation) is caused by baroclinic processes of cold air descending and warm air raising. It is just baroclinic instability or instability of an air flow with a horizontal temperature gradient and, therefore, with vertical gradient of wind speed in the field of Coriolis force, which plays the greatest role in the formation of atmospheric vortices of synoptic scale. If atmosphere stratification is stable, temperature at the fixed altitude increases with air masses descending and vice versa. Consequently, the process would decrease horizontal gradients of temperature until to their total disappearance [11]. Hence, the less horizontal gradients of temperature together and more stability, lower kinetic energy values and, as a result, lower available potential energy values. This was observed in West Siberia in the beginning of XXI century. The revealed tendencies in zonal and eddy energetic characteristics were confirmed by dynamics of relative vorticity (Vort) parameter, describing both cyclonic and anticyclonic processes. Negative sign of values corresponds to the vorticity of cyclonic type (Vort-), positive sign – to vorticity of anticyclonic type (Vort+). It is necessary to consider when analyzing maps that the increase in cyclonic and anticyclonic types of vorticity will be in different colors.

Analysis of relative vorticity variability showed that, in general, average Vort values in the troposphere of West Siberia by 1.5-2 times exceed the relevant estimates at the earth's surface. There was the Vort decrease (though statistically insignificant) from one period to another, whereas it increased in the middle troposphere. Comparison of average values for the northern and the southern parts of West Siberia revealed that the greatest Vort variability was observed in its Arctic part. The decrease of relative vorticity was the most intensive in the north in winter over the early of XXI century.

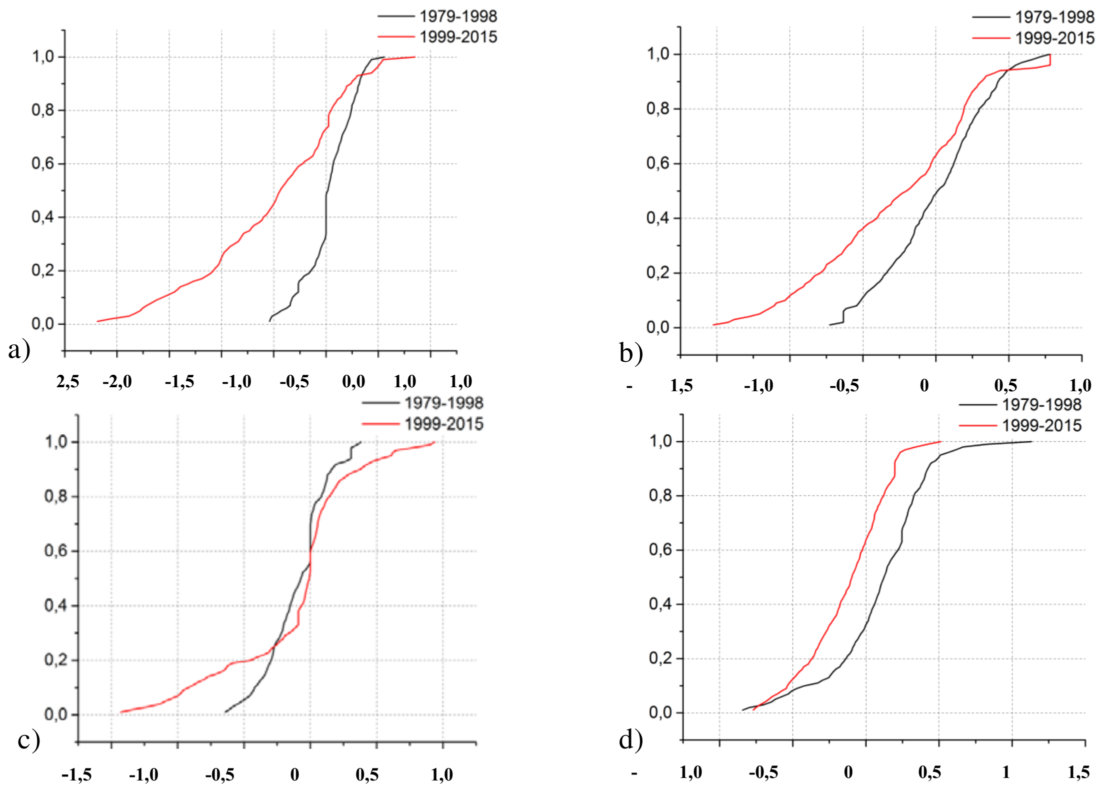

Figure 4. CDF of averaged values of relative vorticity at 500 hPa in West Siberia: cyclonic type (a,b) anticyclonic type (c,d). The upper panel (a,b) – for January, the lower panel (c,d) – for July

As for its spatial distribution, over 1999-2015, in comparison with the previous decades, there was cyclonic circulation increase in the surface layer in January that appeared in the central part of West Siberia - interfluve area of the Ob and the Irtysh rivers. The decrease in cyclonic circulation intensity stretched up to the middle troposphere (500 hPa). In West Siberia the intensity of anticyclonic circulation decreased in both surface layer and the middle troposphere, especially near EAPE and EKE dissipation area. It should be noted that those areas where there was a decrease of anticyclonic activity in the Arctic zone, became more extensive and intensive. The tendencies were confirmed also by the CDF, and in January cyclonic activity decrease occured on the most part of the territory, in comparison with anticyclonic one (80% and 60% respectively) (figure 4).

In summer the situation with Vort+ was similar: there was the decrease of thшы parameter over the second interval, the curve of distribution function was shifted to the area of negative values. Concerning Vort-, the general situation from one period to another was not changed. It should be noted that in the beginning of the XXI century the increase in Vort- distribution function values in the range of extreme negative ones (below 10^{th} percentiles) was observed both in January and in July. For Vort+ this happened only in January. It means that considerable decrease in eddy activity in the certain areas occured over the whole West Siberia during last decade. This was especially pronounced in winter.

4. Conclusion

The conducted research showed that the distribution in positive and negative tendencies of energetic characteristics was significantly changed upon transition from the period of 1979-1998 to the period of 1999-2015 along with considerable increase in their trend values.

In the beginning of XXI century available potential energy values at the earth's surface increased in the south of the territory while almost total disappearance of its minimum area was observed in the western part. Kinetic energy values decreased in the central part of the region, however, positive values area in the north became more intensive and stretched along the entire Arctic coast. In the middle troposphere kinetic energy values also decreased in the central part, and there were no significant changes in available potential energy values.

Moreover, the tendency to decrease in cyclonic circulation intensity was revealed in West Siberia in the beginning of XXI century in the middle troposphere, whereas in the surface layer in January it increased in the central part of West Siberia – in the interfluve area of the Ob and the Irtysh rivers. Anticyclonic circulation intensity in Siberia decreased both in the surface layer, and in the middle troposphere, especially over the dissipation areas of EAPE and EKE. Their trend areas with negative values were located close to each other and were slightly covered in zone 60°-64°N. The greatest dissipation intensity was observed in the middle troposphere and this effect was less pronounced in the surface layer. Here eddy circulation generation along the Arctic coast was shifted to East Siberia. It means that the last decade was characterized by the considerable decrease in eddy circulation activity over West Siberia that was especially pronounced in winter. Furthermore, eddy circulation increased in certain zones, it indicates the possibility of anomalies in meteorological parameters formation there.

Thus, the research in energetic characteristics variability and relative vorticity parameter provides in more detail understanding and description into dynamics of regional climatic system elements and atmospheric circulation processes, in particular.

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References

[1] IPCC 2013 *Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 2013* ed T F Stocker, D Qin et al (Cambridge – New York: Cambridge University Press) p 1535
[2] Akperov M G and Mokhov I I 2013 Estimates of the sensitivity of cyclonic activity in the troposphere of extratropical latitudes to changes in the temperature regime *Izv. Atmos. Ocean. Phys.* **49**(2) 113–20

IOP Conf. Series: Earth and Environmental Science **190** (2018) 012030 doi:10.1088/1755-1315/190/1/012030

[3] Pan Y et al 2017 Earth's changing global atmospheric energy cycle in response to climate change. *Nat. Commun.* **8** 14367

Parmesan C 2006 Ecological and evolutionary responses to recent climate change. *Ann. Rev. Ecol. Evol.* **37** 637-69

[4] Kharyutkina E V, Loginov S V and Ippolitov I I 2016 Influence of radiation and circulation factors on climate change in Western Siberia at the end of the 20th century and beginning of the 21st century *Izv. Atmos. Ocean. Phys.* **52**(6) 579–86

[5] Kalinin N A and Sviayzov E M 2008 *Transformation of Kinetic Energy in Midlatitude Cyclones* (Perm: University Publishing) p 116 (in Russian)

[6] Eliseev A V 2017 Linear and nonlinear models of baroclinic waves in atmosphere *Nonlinear Waves 2016* ed A M Sergeev and A V Slunyaev (Nizhniy Novgorod: IAP RAS) pp 129-42

Li L et al 2007 Lorenz energy cycle of the global atmosphere based on reanalysis datasets *Geophys. Res. Lett.* **34**(16) L16813

[7] Pan Y et al 2017 Earth's changing global atmospheric energy cycle in response to climate change *Nat. Commun.* **8** 14367

[8] Lorenz E N 1967 *The Nature and Theory of the General Circulation of the Atmosphere* (Geneva, Switzerland: World Meteorological Organization) p 161

[9] Van der Swaluw E, Drijfhout S and Hazeleger W 2007 Bjerknes compensation at high northern latitudes: The Ocean Forcing the Atmosphere *J. Clim.* **20** 6023–32

[10] Thompson D W J and Wallace J M 1998 The Arctic oscillation signature in the wintertime geopotential height and temperature fields *Geophys. Rev. Lett.* **25** 1297–300

[11] Kalinin N A 1999 *Energetics of Midlatitude Cyclones* (Perm: Perm University Publishing) p 192 (in Russian)