On the climatology of storm cyclones entering European Russia

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Abstract. The goal of this study is to show all tracks of cyclones and the tracks of storm cyclones with moderate and severe storm wind entering European Russia (ER) from regions of different genesis. NCEP/NCAR DOE reanalysis data from 1979 to 2018 are used in the study. The storm tracks are calculated with an automated cyclone detection/tracking algorithm based on a 6-hourly MSLP. A significant part of the moderate and severe storms enters European Russia from the North and Baltic Seas, most of them are accompanied by an extreme sea level pressure. The maximum severe storm wind density in the western and central part of ER, both in winter and in summer, half of the year, is associated with cyclones from the Baltic Sea genesis region. The Mediterranean storm cyclones affect the Black Sea region and the south-east region of ER. Only about 57% of the Mediterranean storms entering ER are accompanied by an extreme sea level pressure. The cyclone center density and severe wind density patterns show that the position of the storm wind is shifted to south from the regions of cyclone centers. This feature is characteristic for all cyclone genesis groups, both in winter and summer, half of the year.

1. Introduction

Storms over the North Atlantic and Europe have a large impact on the population, shipping and offshore industries, forestry and agriculture, as well as on buildings and property. Storminess may be expressed either by direct measures like wind speed or sea-level pressure or by indirect measures, for instance, storm-related sea-level variations or storm losses. Several works point to an increase in the extreme cyclone activity and storminess over the North Atlantic and Europe in the recent decades until the late 1990s [1, 2, 3, 4] and document that the occurrence and intensity of storms in European region occurred under ‘preferred’ large-scale conditions over the North Atlantic and Europe.

Storms with strong wind speeds as a result of strong pressure gradients are defined as wind storms, and they may be accompanied by heavy precipitation, hail, thunder, and lightning. Intense wind storms constitute one of the most important natural hazards affecting Europe. To investigate wind storms and achieve a better understanding of the relation between large-scale atmospheric circulation and the occurrence of severe winter storm events in Europe, weather typing approaches are often used to classify large-scale weather situations and relate them to local variables. For instance, the circulation weather type (CWT) approach has been applied to Central European region in the context of investigating severe wind events in [3].

The study of severe winter storm events in the region and their relationship with large-scale atmospheric circulation includes consideration of the associated extratropical cyclones. Knowledge of the geographical distribution of the trajectories of extratropical cyclones, the origin, growth and, finally, decay of these systems is of central importance to characterize extratropical climate. For instance, Leckebusch and Ulbrich [1] showed a relationship between cyclones and extreme wind events over Europe under climate change conditions and pointed to a tendency towards more extreme wind events caused by deepening cyclones for several regions of Western Europe such as Spain, France, United Kingdom, or Germany.

The source and path of extratropical cyclones, namely, the cyclonic tracks, strongly influence the climate in midlatitudes. Consequently, detailed knowledge of cyclonic tracks is essential in forecasting...
weather, understanding the atmospheric dynamics, and determining the cyclone activity impact on regional climates. Over the last 20 years several numerical algorithms have been developed to objectively identify cyclones and their tracks by using different approximations in the definition of cyclonic centers based on data of different reanalyses. Cyclone centers have been defined in terms of pressure minima at sea level [5, 6, 7, 8, 9] or minima in 1000-hPa geopotential height [10, 11]. Alternatively, cyclones can be defined in terms of maximum of the Laplacian of MSLP [2] or maximum in low-level vorticity [e.g.,12]. Methods searching for pressure minima tend to overestimate deep and mature cyclones, while they miss small-scale systems that are better identified from their local maxima in relative vorticity, for example, fast-moving systems or cyclones in the early and late stages of their life cycle [13]. On the other hand, vorticity maxima are not always connected with local pressure minima. In this work, a cyclone detection/tracking algorithm based on MSLP data is used for studying long-time storms entering European Russia from different genesis regions of the North Atlantic and Europe. The track’s initial point is regarded as the location of cyclogenesis, and its final point as the location of cyclyolysis.

In many studies (mostly based on station data) intra-annual wind speed percentiles are chosen to assess changes in the storm climate within a particular area [e.g.,1]. Here, for instance, the 99th percentile denotes the wind speed that is (in a particular year) exceeded by only 1% of the observations. Thus, an increase or decrease in this wind speed percentile over several years provides an indication for a change in the storm climate. This change may be caused by more/less frequent or more/less violent storms or a combination of both. To distinguish between both effects, the Beaufort wind scale (BFN) is often used [3, 14]. The storm wind event is classified as a moderate storm (gale) whenever the highest wind speed that occurred during that event remained more than BFN 8 (17.2 m/sec) and smaller than BFN 10 (24.5 m/sec). Events with maximum wind speeds exceeding BFN 10 were classified as severe storms. According to this classification, the total number of storms is the number of moderate storms plus the number of severe storms.

The main focus of this study is analysis of the cyclone tracks entering European Russia from different genesis regions, their intensities and the storm wind events associated with cyclones.

2. Data and method

The storm tracks were calculated with an automated cyclone detection/tracking algorithm based on MSLP data. This study uses the 6-hourly MSLP from National Centers for Environmental Prediction – the National Center for Atmospheric Research, NCEP/NCAR DOE reanalysis-2 from January 1979 through December 2018 [15]. The reanalysis output has a global horizontal resolution of 2.5°x2.5°. Cyclones are identified in the region [30°N-80°N, 50°W-70°E]. The procedure of identifying all cyclones from a MSLP field at a certain time consists of the following steps:

1) Cyclone centers are determined as local minima in the array of MSLP grid point values. A grid point is considered a cyclone center if its MSLP value is smaller than the value at each of its eight neighboring grid points. This is a weak condition compared to the criteria applied in some earlier studies, and leads to a large number of identified cyclones. As summarized by Haak and Ulbrich [16], the number of cyclones is often reduced with additional criteria. For instance, the difference between the MSLP minimum and its neighboring values has to be larger than a certain threshold, and/or the curvature of the MSLP field at the local minimum must exceed a specific value.

2) The minimum SLP gradient between the center of the cyclone candidate and its eight surrounding grid points is required to be at least 0.15 hPa (100 km).

3) The minimum SLP gradient between the four surrounding points of the cyclone candidate and their outside adjacent grid points must be negative inward.

4) If cyclone candidates appear within a radius of 1200 km at the same time, they are considered to be one cyclone.

The cyclone track is defined as the trajectory of cyclone centers. If a cyclone’s location is within a radius of 600 km of the cyclone’s location at the previous 6-h time, this location is considered to be a new location of the existing cyclone. Otherwise, a new cyclone is generated. If a candidate’s lifetime
is shorter than 12 h, it is removed from the cyclone candidates. The method for identifying cyclone centers and an algorithm for calculating cyclone displacement trajectories are presented in the authors’ paper [4].

**Figure 1.** Genesis regions of cyclones reaching European Russia.

**Figure 2.** Examples of storm tracks entering the European region of Russia from different genesis regions: a) EUW, b) EUE, c) MW, d) ME, e) AN, f) AS. Legend: number of cyclone centers at point.

For the analysis, cyclone trajectories entering European Russia (47n – 67n,30e-60e) and with a life of 2 days or more were selected. All trajectories of the cyclones entering the European region of Russia (ER) are divided into groups according to the genesis regions (Figure 1). Examples of storm tracks for the genesis regions are shown in Figure 2. For every genesis region for the winter half of
each calendar year from October to March and the summer half from April to September, all numbers of cyclone tracks, the number of extreme cyclones with a central pressure from 970 hPa and less, the number of moderate and severe storm cyclone tracks, the integral cyclone density, and the storm wind density were calculated. The cyclone density and storm wind density were defined as the cyclone center number and storm wind speed observations at a point during the season. Storm cyclones were defined as cyclones with a wind speed from 17.2 to 24.5 m/sec (moderate storms) and more than 24.5 m/sec (severe storms). The maximum wind speed was selected from an area close to the center of the cyclone with a radius of 5 degrees and calculated based on 6-hour data on the components of the wind speed on the surface of 925 hPa. We used the 925-hPa winds throughout this paper as a measure of near-surface winds, because they represent the wind field above the surface boundary layer and are specifically calculated by the model. They are a more robust quantity than the model 10-m winds, which are diagnostically determined.

3. Results
According to the results of the study, about 65% of all moderate and more than 55% of severe storms entering European Russia during the winter half of the year (Figure 3a) started in the North and Baltic Sea regions (the cyclone genesis regions ‘EUW’ and ‘EUE’ or ‘3’ and ‘4’ in Figure 3).

![Figure 3](image_url)

**Figure 3.** The number of trajectories of cyclones entering the European region of Russia from different genesis regions from 1979 to 2018 during: a) October-March, b) April-September. Highlighted in color: gray - all cyclones; yellow - cyclones with atmospheric pressure in the center from 970 hPa or less; blue – all storm cyclones with a wind speed of 17.2 m/s or more; purple – the number of moderate storms with a wind speed of 17.2 to 24 m/s; red – severe storms with a wind speed of 24 m/s or more.
For the summer month this number is 67% and 60%, respectively. Most moderate storm cyclones and practically all severe storms entering the European region of Russia from north storm track regions, North and Baltic Seas are accompanied by extreme sea level pressure.

The Mediterranean cyclones (the genesis regions ‘MW’ and ‘ME’ or ‘6’ and ‘7’ in Figure 3) account for about 14% of moderate and about 41% of severe storms in the winter season and 16% and 35% in the summer months. Only about 57% of the Mediterranean storms entering the ER are accompanied by extreme sea level pressure. The number of severe storms accompanied by severe wind speed, both extremely low atmospheric pressure, increases in the summer months in all cyclone genesis regions.

The integral number of storms over the ER that originated in the subpolar region of the North Atlantic for severe storms is about 1% for the season, for moderate storms about 7% in winter and about 11% in the summer season. The number of Atlantic storms from other genesis regions is about 4% for severe storms and 8% for moderate storms. All cyclones entering the ER from the southern and eastern parts of North Atlantic were outstanding by a long life, extreme low sea level pressure, and storm wind along the track.

![Figure 4](image1.png)

**Figure 4.** Integral density of cyclones (a, c) and number observations of a storm wind speed more than 24.5 m/s in cyclone areas (b, d) entering ETR from the EUW genesis region (a, b) and the EUE genesis region (c, d). Winter half of the year. Study period: from 1979 to 2018.

Cyclones generated in the North Sea and Great Britain go out to northwestern regions of European Russia (Figure 4a). The maximum density of these cyclones is over the Scandinavian Peninsula and the Baltic Sea. The region of severe storm wind associated with these cyclones is in central Europe (Figure 4b), while in some areas of the western part of ETR only 4-5 cases of severe storm wind were noted. Cyclones generated in the Baltic region (Figure 4c) provide a high density of observations of storm wind speeds in the central and western areas of ETR, where the total number of observations of severe storm wind at individual points exceeded 17 cases for all period (Figure 4d).
The storm tracks from West Mediterranean enter the south-western region of ER and have a strong influence on the Black Sea region (Figures 5a and b). The storm tracks originated in the Eastern Mediterranean affect the south-eastern region of ER, where high density of the storm wind, especially during the winter seasons, is observed (Figures 5c and d). Polar storms do not differ in the high cyclone density (Figure 5e) and severe storm wind density in Russia (Figure 5f) due to the small number of such cyclones. The number of severe storm tracks entering ER and the number of storm wind events in these tracks in the summer seasons is more during the winter seasons. In the total number of storm cyclones in the summer months, the proportion of storms with a severe wind speed of more than 24.5 m/s and extremely low atmospheric pressure increases.

Figure 5. Integral density of cyclones (a, c, e) and number observations of a storm wind speed more than 24.5 m/s in cyclone areas (b, d, f) entering ETR from the genesis regions: MW (a, b), ME (c, d) and AP (e, f). Winter half of the year. Study period: from 1979 to 2018.

A comparison of the patterns of integral storm wind density and the patterns of integral cyclone density for severe storms entering European Russia from selected genesis regions in the winter season during the entire period of study shows that the position of the storm wind shifted to the south from the regions of cyclone centers. This feature is characteristic for all cyclone genesis groups, both in the winter and summer halves of the year.

An analysis of the interannual variability of the storm cyclones number shows (Figure 6) that the average number of all cyclones and the number of severe storms in the summer half of the year is more compared with the winter months. However, a tendency to a significant decrease in the number of cyclones and storms entering ER during the summer seasons was observed in the period from mid-
1990s to mid-2000s. In the last ten years, the tendency to a significant decrease in the number of cyclones and storms entering ER was observed during the summer seasons, and to their increase in the winter months.

![Figure 6](image_url)  
**Figure 6.** Interannual variability of the number of cyclone tracks entering ER during winter and summer seasons for 1979-2018: all cyclones *(blue)*, all storms *(green)*, severe storms *(brown)*. Bold lines – moving averages over 5 years.

![Figure 7](image_url)  
**Figure 7.** Interannual variability of the number of severe storm cyclone tracks (brown) entering ER from North (blue) and South (red) genesis regions during winter (a) and summer (b) seasons for 1979-2018.
The maximum number of severe storms entering ER was observed in years distinguished by active cyclogenesis in various regions of the northern and southern branches of the storm track (Figure 7), for example, in the winter seasons of 2005-2006 and 2013-2014. The minimum number of severe storms was observed in the years with weak cyclogenesis on both branches of the storm track in European region, for example, in the winter season of 2004-2005 and summer of 1998. The strengthening and weakening of cyclone activity in European region in some years are connected with a large-scale atmospheric circulation over the North Atlantic and Europe. Numerous studies show that synoptic variability over this region is related to the North Atlantic Oscillation and East Atlantic Oscillation. It can be assumed that the maximum and minimum of the number of severe storms entering ER can also be regulated by large-scale conditions.

4. Conclusions
The study shows that the greatest influence on European Russia is exerted by storm cyclones that are generated in the regions of the Baltic and Mediterranean Seas. These storms provide high density of observations of severe storm wind over European Russia in the winter, as well as in the summer seasons.

The maximum number of storms entering ER in the summer and winter seasons was observed in years distinguished by active cyclogenesis in the northern as well as in the southern branches of storm tracks in European Russia.

A tendency to decrease the number of cyclones and storms entering ER during the summer seasons and to increase them in the winter months is observed in the last decade.

Most moderate storm cyclones and nearly all severe storms entering European Russia from northern storm track regions are accompanied by an extreme sea level pressure. And only about a half of Mediterranean storms entering ER are accompanied by an extreme sea level pressure.

The percentage of storms with severe wind speed and extremely low atmospheric pressure increases in the total number of storm cyclones in the winter as well as in the summer seasons.

The position of storm wind is shifted to south from the regions of cyclone centers. This feature is characteristic for all cyclone genesis groups, both in winter and summer, half of the year.

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References
[1] Leckebusch G C, Ulbrich U 2004 On the relationship between cyclones and extreme windstorm events over Europe under climate change Global Planet Change 44 181
[2] Wang X L, Swall V R and Zwiers F W 2006 Climatology and Changes of Extratropical Cyclone Activity: Comparison of ERA-40 with NCEP–NCAR Reanalysis for 1958–2001 J. Climate 2006 19 3145
[3] Donat M G, Leckebusch G C, Pinto J C, Ulbrich U 2010 Examination of wind storms over Central Europe with respect to circulation weather types and NAO phases Int. J. Climatology 30 1289
[4] Viaziilova N A 2012 Cyclonic activity and fluctuations in circulation in the North Atlantic Russian Meteorology and Hydrology 7 5
[5] Graham N E and Diaz H F 2001 Evidence for Intensification of North Pacific Winter Cyclones since 1948 Bull.Amer. Met. Soc 82 1869
[6] Geng Q and Sugi M 2001 Variability of the North Atlantic Cyclone Activity in Winter Analyzed from NCEP–NCAR Reanalysis Data J. Climate 14 3863
[7] Gulev S K, Zolina O, Grigoriev S 2001 Extratropical cyclone variability in the northern hemisphere winter from NCEP/NCAR reanalysis data Clim. Dyn. 17 795
[8] Zhang X D, Walsh J E, Zhang J, Bhatt U S, Ikeda M 2004 Climatology and interannual
variability of arctic cyclone activity 1948-2002 J Climate 17 2300

[9] Wernli H and Schwierz C 2006 Surface cyclones in the ERA-40 data set (1958-2001). Part 1: Novel identification method and global climatology J. Atmos. Sci. 63 2486

[10] Paciorek C J, Risbey J S, Ventura V and Rosen R D 2002 Multiple indices of Northern Hemisphere Cyclone Activity Winters 1949-1999 Journal of Climate 15 573

[11] Trigo I F 2006 Climatology and interannual variability of storm-tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses Climate 26 127

[12] Flocas H A, Simmonds I, Kouroutzoglou J, Keay K, Hatzaki M, Bricolas V, and Asimakopoulos D 2010 On Cyclonic Tracks over the Eastern Mediterranean J. Climate. 5243

[13] Hoskins B J, Hodges K I 2002 New Perspective on the Northem Hemisphere Winter Storm Tracks J. Atm. Sci. 15 1041

[14] Viazziilova N A, Viazziilova A E 2014 Storm cyclones in the North Atlantic Russian Meteorology and Hydrology 6 19

[15] Kanamitsu M, W Ebisuzaki, Woollen J, Yang S K, Hnilo J J, Fiorino M, and Potter G L NCEP-DOE AMIP-II Reanalysis (R-2) 2002 Bull. Amer. Meteor. Soc. 83 1631

[16] Haak U, Ulbrich U 1996 Verification of an objective cyclone climatology for the North Atlantic. Meteorol. Z. 5 24