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Extreme Wind Speed Long-Term Trends Evaluation in the Russian Arctic Based on the COSMO-CLM 36-Year Hindcast †

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Abstract: The high-resolution long-term hydrometeorological "COSMO-CLM Russian Arctic hindcast" based on nonhydrostatic regional atmospheric model COSMO-CLM v.5.06 for 1980–2016 period covering the North Atlantic, Barents, Kara and Laptev Seas with ~12 km grid size utilized to estimate climatological trends of extreme wind speed. In this study, we used the 95 Russian weather stations 10 m wind speed data inside the hindcast domain. Trends in mean, maximal, 0.90, 0.95, 0.99 quantiles wind speed values, occurrences of wind speed above 20, 25, 30 and 33 m/s were calculated for all stations and corresponding nearest model grids for yearly and 4 months data. Yearly mean wind speed and quantiles values increases over northern Kara Sea, decreases over western Barents Sea and northern Atlantic. Extreme wind speed grows in January in the eastern Evenkia and northern Yakutia, declines over the north-eastern European Russia. The 0.99 values increase in July near Gyda peninsula coastline, decreases over polar regions, Pechora Sea and White Sea coastline. Maximal wind speed declines in October over the north-western European Russia, eastern Taymyr, Norway Sea, grows over the Eastern-Siberian Sea.

Keywords: COSMO-CLM Russian Arctic hindcast; Arctic climate changes; extreme wind speed

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1. Introduction

The Arctic region is characterized by rapid climate changes. Warming rate in the Arctic regions is two to four times larger than in the entire globe [1–3]. The cause of this phenomenon lies in a whole complex of physical processes including intense meridional heat transport in atmosphere and ocean from Atlantic [4], and closely related to a dramatic decrease of sea ice cover [5–7]. However, regional features of the Arctic warming are significantly different and are challenges to be clarified and detailed [8].

The observed sea ice retreat and extending of open sea areas in the Arctic Ocean contributes to an increase of extreme winds occurrence [9, 10]. Drastic decline of summer Arctic sea ice cover induced by earlier onset of surface melting [11], later freezing and consequently longer period of sea ice retreat and open water [12, 13]. This is conducive to increase the extreme winds caused by enhancement of the baroclinic instability over the water-ice borders. This manifested also in the severe weather events frequency increase, e.g., polar lows [14–17]. Arctic warming and corresponding sea ice decline has significant impact on synoptic-scale processes leading to new regions of polar lows formation, e.g., more frequent storm-tracks from the Pacific Ocean to the Laptev, East-Siberian and Kara Seas due to meridional circulation processes intensification [18, 19]. These areas are now exposed to polar lows development having less sea ice [20]. Another notable synoptical feature is the wintertime Arctic anticyclone westward shift, Atlantic cyclones blocking and, consequently, its storm-tracks shift poleward [21].

Coastal regions in the Arctic are characterized by the severe events caused by a compounding of large-scale circulations and surface properties (e.g., tip jets, channel winds, barrier effects, downslope windstorms, etc. [22, 23]), but are often an essential part of synoptic-scale systems [24, 25]. Striking examples of interactions of hydrodynamic flow with mountain ranges are downslope windstorms, in the Russian Arctic there are Novaya Zemlya bora, Pevek yuzhak, foehn in Svalbard and Tiksi [26]. Large polynya areas, puddles and hummocks, moving cracks forms heat fluxes significantly higher in comparison with concentrated ice fields [27. Besides, growth of the open water area leads to an increase of the probability of the wind waves formation and significant wave height growth at seas [28, 23, 29].

Thus, significant part of severe wind speed features is closely related to and/or caused by different mesoscale phenomena. Therefore, the detailed description of these processes required appropriate spatial horizontal and vertical (especially, in surface and boundary layers) resolution. The available datasets in the Arctic region are or fragmentary (stations and expeditions data), either have too coarse spatial resolution (climatic datasets, reanalyses, climate models – dozens km), or restricted time span (satellite data), that does not allow to resolve many of severe weather events and describe processes, responsible for heat exchange in a surface layer, correctly. Therefore, underestimation of the role of mesoscale processes affects many aspects and regional features of the Arctic climate changes.

The high-resolution "COSMO-CLM Russian Arctic" hindcast covering 1980–2016 period with ~12 km grid size [30] provides wide opportunities to study regional Arctic climate changes features in more details including the surface wind speed patterns. Primary assessments of the hindcast demonstrated appropriate reproduction of the main climatological patterns of the surface wind speeds, the details are manifested in many regions, which were not reflected in the parental ERA-Interim global dataset. The high wind speeds frequency increased significantly, over the Barents Sea, Arctic islands and some seacoasts and mainland areas, especially at well-known sites with high frequency of strong winds (Novaya Zemlya, Svalbard, Tiksi, etc.) [30]. The detailed COSMO-CLM Russian Arctic hindcast application provides an opportunity to get more justified estimates of observed Arctic climate changes, specifying regional features of surface wind speed trends pattern in the Russian Arctic.

2. Materials and Methods

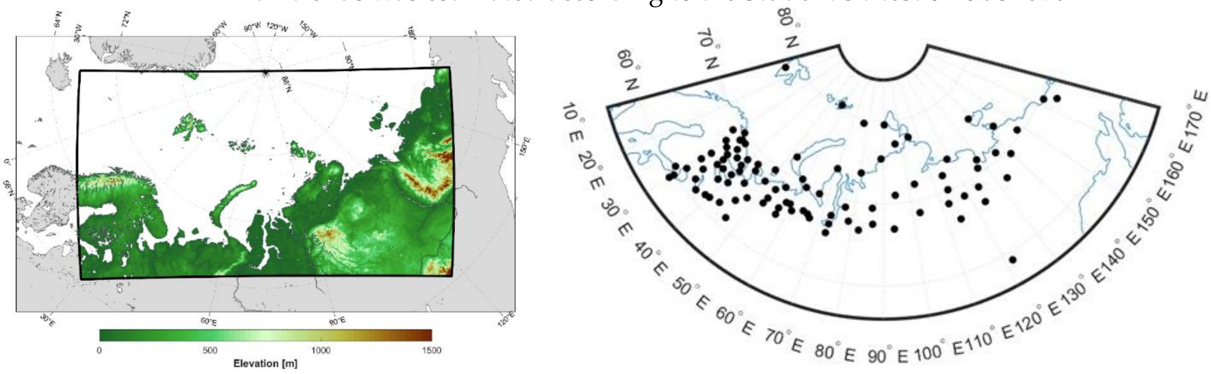
2.1. COSMO-CLM Russian Arctic hindcast

The "COSMO-CLM Russian Arctic" hindcast including just a hundred different hydrometeorological parameters on the surface and 50 model levels, was created using the long-term COSMO-CLM v.5.06 regional atmospheric hydrodynamic modeling and spanned the Barents, Kara and Laptev Seas with grid size 0.108° (~12 km) (Fig. 1a). The final long-term experiments were forced by the ERA-Interim reanalysis [31, 32], including the spectral nudging technique.

All variables have been written out with 1 hour step, and the total data volume is about 120 Tb. The "COSMO-CLM Russian Arctic" hindcast data are in part available on the figshare repository for periods 1980–2008 and 2010–2016 [33] and includes the most important surface fields: 2-m air temperature and humidity, sea level pressure, zonal and meridional 10-m wind speed components, surface radiation and heat fluxes, and precipitation with 3-hourly timestep. More detailed information on the hindcast creating and its initial evaluations, can been found in [32, 30]. Primary surface wind speed hindcast's evaluations according to stations and satellite data were presented in [34], showing good reproduction of average wind speed, underestimation of extreme quantiles up to 8–10 m/s. Spatial verification according to the FSS method showed the relevance of simulated strong wind speed patterns to given model resolution ~12 km.

2.2. Weather Stations Data

In this study, we used the 95 Russian weather stations data on 10-minutes average 10 m wind speed inside the hindcast domain from Roshydromet [35] (Fig. 1b). Trends in mean, maximal wind speed, 0.90, 0.95, 0.99 quantiles values, occurrence above 20, 25, 30 and 33 m/s were calculated for all stations, nearest model grids and whole model domain for yearly and 4 months data: January, April, July and October. Statistical significance of all trends was estimated according to the Student's t-test on 0.95 level.



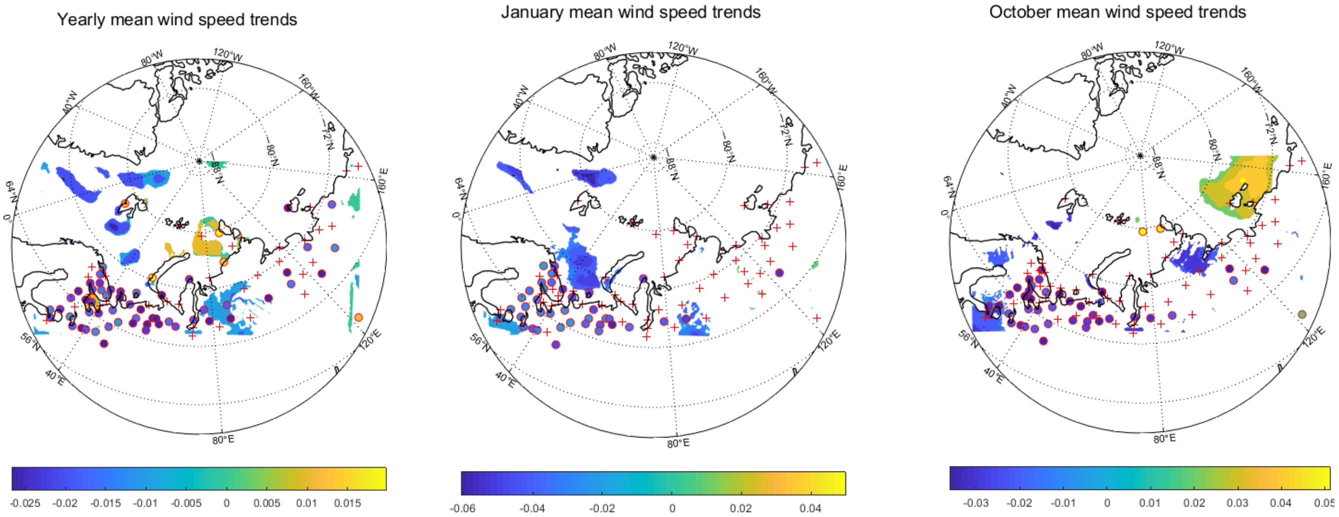
(**a**) (**b**)

Figure 1. The "COSMO-CLM Russian Arctic" hindcast area [30] (**a**), and weather stations used in this study **(b)**.

3. Results and Discussion

3.1. Mean Wind Speed

The hindcast data shown significant positive mean wind speed trends (Fig. 2a) over the north of the Kara Sea (up to 0.4 m/s per 36 years), i.e., in region among the most exposed to sea ice decline. Another areas indicated west from the Novaya Zemlya islands, and the White Sea. Significant negative trends covered the northern Atlantic, central Barents Sea, Gyda peninsula and central Evenkia (up to -0.8 m/s per 36 years). It should be noted good coincidence with station trends in regions where it is possible to be compared. Exceptions are negative stations trends at northern Sakha and north-western Russia without significant model trends. In January (Fig. 2b) there are significant negative trends only (up to 1.5 m/s per 36 years): over the Barents Sea, Fram strait, northern Atlantic, and central Evenkia, confirmed by stations data. For April, model does not capture any significant trends showed by stations mostly over the north-west of Russia. Negative trends in July are over polar regions north of Kara, Laptev Seas and Greenland, Pechora seacoasts (up to 1.5 m/s per 36 years). Slight positive trends indicated over the Gulf of Finland and White Sea (up to 1 m/s per 36 years). In October (Fig. 2c), there is a large area of positive trends over the East Siberian Sea (up to 1 m/s per 36 years), and negative trends over Scandinavia, weatern Barents Sea and Taymyr peninsula (up to -1 m/s per 36 years).

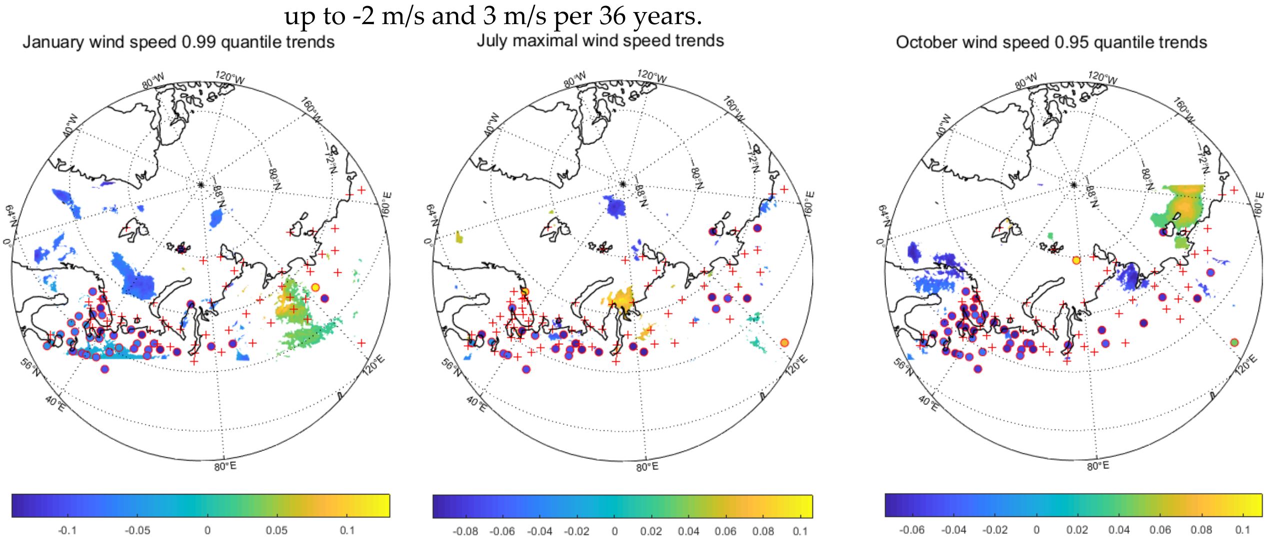


(**a**) (**b**) (**c**)

Figure 2. Trends (m s-1 per year / month) in yearly (a), January (b) and October (c) mean wind speed. The hindcast significant trends given in color; stations with significant trends are given in circles in the same colorbar; stations with insignificant trends are given in crosses.

3.2. Extreme Wind Speed

Maximal wind speed and the largest quantiles have similar patterns. Yearly wind speed maxima according to the hindcast have sporadic small areas of significant trends. At the same time, stations shown positive trends over the western coasts, but rest are slight negative trends. Interestingly, there are just no significant trends at Malye Karmakuly, Tiksi, Teriberka, which are well-known for high wind speed climatology. In specific months, the most interesting 0.99 quantile pattern demonstrates January (Fig. 3a) with significant negative trends over the Barents Sea, northern Atlantic, some polar regions (up to -2.5 m/s per 36 years), positive trends over western Sakha and eastern Evenkia (up to 2 m/s per 36 years). There is a notable increase of maximal wind speed in July over the Gyda and Yamal coasts of the Kara Sea (up to 3 m/s per 36 years) (Fig. 3b), however not proven by stations data with significant positive trends at Teriberka. The 0.95 quantile October pattern resembles to the abovementioned one for mean wind speed (Fig. 3c) having values up to -2 m/s and 3 m/s per 36 years.



(**a**) (**b**) (**c**)

Figure 3. Same as in Figure 2, but for January 0.99 quantile (a), July maximal wind speed (b), and October 0.99 quantile (c).

3.3. Wind Speed Occurrences

Trends of wind speed occurrences became partly restricted due to small values on yearly and even more monthly scales. Therefore, many areas became insignificant or absense of trends according to the hindcast. For the most extreme wind speed thresholds, 30 and 33 m/s, there are just no stations and hindcast grid points with significant trends of occurrence. For 20 m/s threshold, yearly occurrence shown slight positive trends over the northern Barents Sea and negative over small part of north Atlantic. Acoording to stations data, there are no significant positive trends, but negative are indicated at Tiksi, im. Popova, GMO im. Krenkelya and some others. Trend in Tiksi persists significant up to 33 m/s threshold. In specific months, there are significant negative trends over the central Barents Sea and northern Atlantic for 20 and 25 m/s thresholds.

3.4. Discussion

Considering the differences in trends values and sign according to the hindcast and stations data, we'll evaluate the model capability to capture real wind speed climate changes by given spatial resolution. It should be noted, that significant negative trends by stattons on continents turn out to be always significant by hindcast. However, if trends are both significant, its order of values and sign tends to match. As for positive trends, they are usually, on the contrary, overestimated by the hindcast. Moreover, in this study we can't estimate reproduction of wind speed climatology over the sea areas without stations data.

4. Conclusion

Summarizing presented patterns for wind speed statistics trends, we can conclude prevailing of negative trends of mean and maximal wind speed over the Barents Sea and northern Atlantic during the most part of year with main contribution in January. At the same time, there are significant increase of mean wind speed and extreme quantiles for the Kara Sea and its coastlines, as well at the White Sea and Gulf of Finland, especially in July. Significant maximal wind speed growth over the East Siberian Sea was indicated in October. On the continents, there is significant decrease of wind speed at Taymyr and western Evenkia, and growth of extreme wind speed at northern Sakha in January. Generally, the COSMO-CLM Russian Arctic hindcast is relevant for observed surface wind speed trends estimations in the Russian Arctic, including extremes. It is specifically important for sea areas, which are not covered by stations observations.

Finally, the COSMO-CLM Russian Arctic hindcast could be applied in future for assessments of diurnal wind speed cycles, satellite climatology estimations over the Russian Arctic, severe and extreme events statistics evaluation (polar lows, downslope windstorms, marine cold air outbreaks, etc. climatology using satellite data), quality of wind speed reproduction based on other datasets (e.g., ERA5, NORA3, CARRA, etc.).

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Data Availability Statement: The "COSMO-CLM Russian Arctic" hindcast data are openly available in the FigShare repository at [https://doi.org/10.6084/m9.figshare.c.5186714], [https://figshare.com/collections/Arctic_COSMO-CLM_reanalysis_all_years/5186714] (accessed on 7 October 2023), reference number [5186714].

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Conflicts of Interest: The authors declare no conflict of interest.

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