Assessment of the impact of a modified sea ice edge on the forecast and development of polar lows: simulation of the case-study using the ICON model

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Motivations-Introduction

Polar lows (PLs) which are small in size and have a relatively short lifetime, can lead to a variety of extreme weather events that's why their prediction by numerical modelling is a crucial task. Appearance and development of PLs are dependent on sea ice cover, especially for the cases with a thermal nature of their formation. This study focuses on the influence of the sea ice cover in the Norwegian, Barents and Kara Seas on polar low development. Previous studies using the COSMO model focused on the various factors of polar lows formation, such as sea surface temperature, the presence and position of the ice edge, the strength and presence of a jet stream [1,2,3] and investigated the dependence of the forecast on the lead time and on the model's grid steps [4]. This work presents the first assessment of ICON model forecast of PL development in dependency on sea ice edge.

First, we have identified 7 well-developed PLs by the daily analysis of satellite images during the cold period of 2020–2021 (November–March). The area of investigation with the trajectories of the identified PLs is presented in Figure 1.

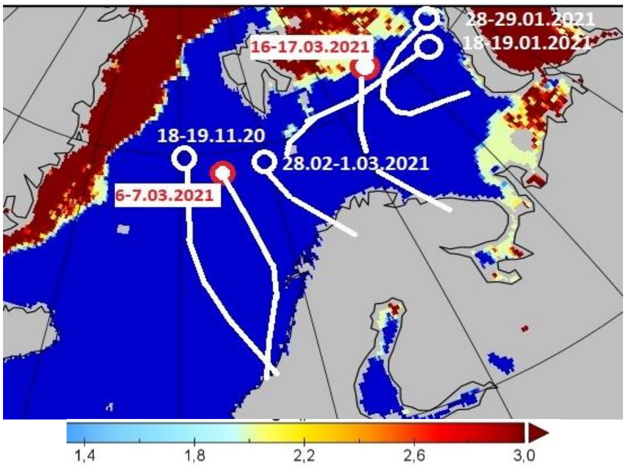


Figure 1. Trajectories of polar lows (lines) and the sea ice thickness (color). Cold period 2020–2021. The dates on the map mark the start points of the trajectories (the brown/white color of the date indicates which trajectory it belongs to). The sea ice distribution was obtained from the NSIDC (National Snow and Ice Data Center, https://nsidc.org/home) for 31.01.2021. The end of white lines shows the area where PL starts to break down.

The case of PL development that appeared on satellite images on January 28, 2021 in the Barents Sea is one of the most illustrative examples of the formation of PLs during the studied period. The polar low formed off the western coast of Novaya Zemlya. As can be seen from the sea ice distribution map (Fig.1) the sea was covered with ice to the east and north of Novaya Zemlya. East wind contributed to the westward transport of icy air formed over sea ice and triggered PL formation in the Barents Sea.

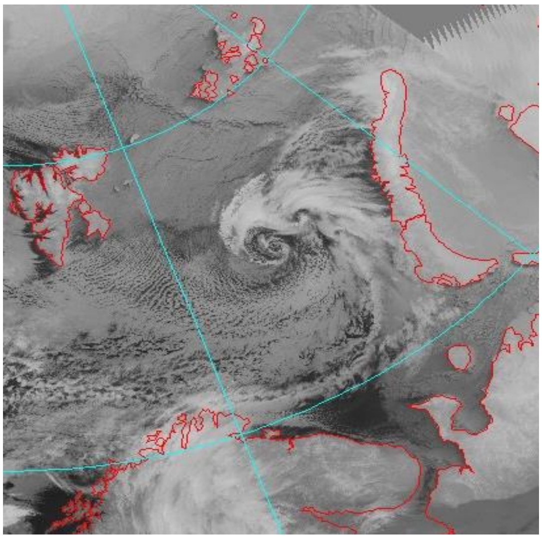


Figure 2. Satellite image of the polar low, 18:00 UTC 28.01.2021. Available from the Antarctic Meteorological Research Center (AMRC, ftp://amrc.ssec.wisc.edu/archive).

Models and simulations

We used the ICON Limited-Area model [5]. The initial and boundary conditions for the ICON-LAM model in the Arctic region were taken from the global ICON model, which run at the Hydrometeorological Center of Russia in a quasi-operational mode until February 28, 2022. We have conducted three types of the model experiments: first – the control experiment without sea ice changes. Other experiments were carried out with changes in the sea ice boundary:

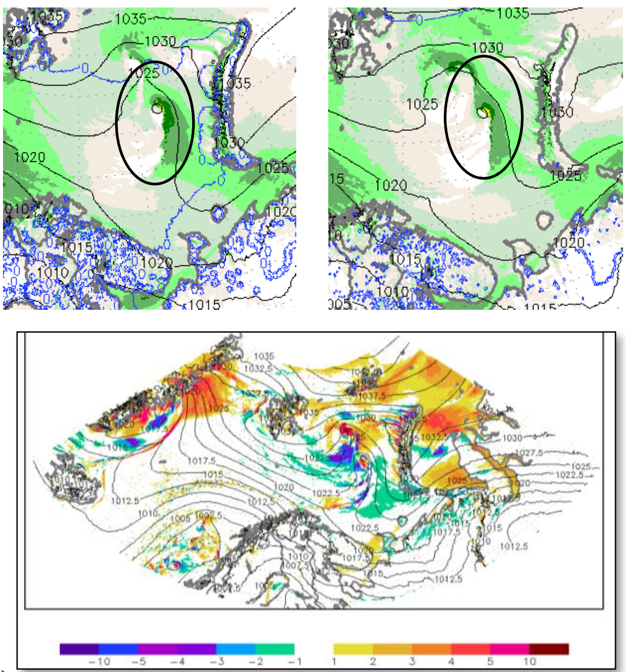
1) During a forecast, the evolution of the ice edge was specified according to the ICON analysis for the subsequent days. With this approach, changes in the position of the ice boundary during the modelled period (3 days) were small and had a very insignificant effect on the PLs forecast.
2) A strong artificial shift of the sea ice boundary: it was assumed that there was no sea ice south of 80N (SSIce experiment). The Kara Sea and the territory east of Svalbard were artificially freed from ice.

We have compared these two types of experiments with the control one and came to the understanding that the model sensitivity to the minimal changes in the sea ice boundary (type 1) on short (up to 3 days) time scales is insignificant. Therefore, for further assessments of the influence of the sea ice location on the formation and development of the PLs, we used more radical changes in the ice boundary - experiments of the second type (artificial shift of the boundary to the north to 80 N). It is important to note that in the SSIce experiment the ice cover is removed from the initial data, while all others meteorological parameters "remember" the existence of the sea ice and therefore, they have the structure of the atmosphere as above sea ice (for example, inversion). This peculiarity of experiment design very likely would be reflected in the results.

We carried out numerical experiments with the ICON-Ru model in the West_Arctic_2km configuration, for two PL cases: 28-29.01.2021 and 18-19.11.2020. Different starting dates have been used: 02 UTC January 26, 02 UTC January 27, 02 UTC January 28. The qualitative assessment showed that the forecasts starting from 02 UTC on November 27, 2021 are most representative for our study, they more accurately reproduce the PL itself, while the model response to the modified ice field has time to form.

It follows from Fig. 3 that the absence of ice cover to the east of Novaya Zemlya (SSIce experiment) did not affect the presence of the PL and sea surface pressure (PMSL), but had an insignificant effect on the wind speed at 10 meters (V10) in the PL and the size of PL. It can be seen that by 28.01.2021 6:00 pm (40 hours lead time), the difference in wind speeds over a large area of the Arctic region reaches noticeable values. The maximum differences are achieved in the area where PL is located: the wind in the SSIce experiment slightly increases *in the center* of PL (by 4–5 m/s), while *on most part of the cloudy "comma"* the wind speed decreases (by 5-10 m/s).

(a) (b)



c)

Fig. 3. Maps of PMSL and V10m for the control experiment (a) and SSIce experiment (b); difference in V10m between the SSIce and the control experiments (c). 01/28/2021, 18:00 UTC.

It should be noted how the wind speeds change over the Arctic (especially above the Kara sea), which is covered with ice in the control experiment, and is free of ice in the SSIce experiment. It is worth to notice that almost everywhere V10 increases by 1-5 m/s (Fig. 3c). This increase in V10 starts from the first hour of the forecast and periodically becomes as high as 5-10 m/s. Such changes in the wind field over a wide area are probably associated with the creation of an artificial perturbation over huge territory. This disturbance occurs due to a sharp change in the underlying surface, which is not consistent with other parameters, and it probably leads to an intensification of turbulent flows and an increase in wind speed.

Figure 4 shows the differences in PMSL between two experiments for the same date. Atmospheric pressure in the central part of the PL is lower in the control experiment, thus PL turns out to be deeper if there is "true ice" in the model. On the vast territory of the Arctic, which was artificially "liberated" from ice, there was a decrease in atmospheric pressure by 1-5 hPa.

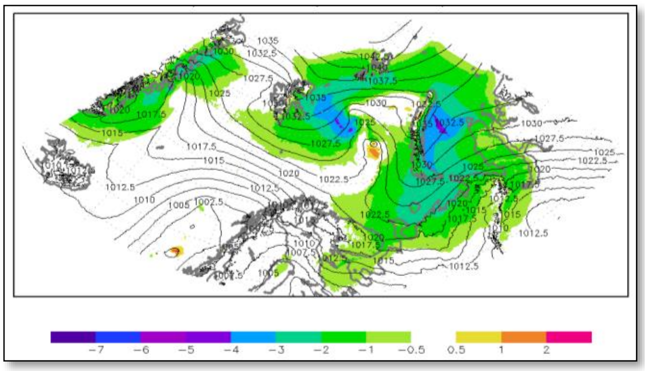


Figure 4. Differences in PMSL between the SSIce experiment and the control experiment. 01/28/2021 18:00 UTC.

Conclusions

Our study of several cases of PL development and forecast shows that the change in the sea ice edge, even its existence is the trigger of the formation of the PL (thermal convection), does not affect the reproduction of the PL by the model. The reason for this might be the fact that initial data have prevailing influence on PL production. The meteorological fields that are used as initial data "remember" where the true ice edge is located. However, the change in the sea ice location affects the wind speed and pressure inside the PL. Changes in forecast quality related to the sea ice modification demand more deep assessment of PL development cases preferably in the areas with observational data available. We plan to continue work in this direction. Information about high-resolution simulation of polar lows during the cold season of 2019–2020 can be found in [4].

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