Impacts of the modified sea ice edge on the polar lows forecast: case-study using the ICON model

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Motivations-Introduction

Past studies have shown that PMCs are very sensitive to surface conditions such as sea surface temperature and sea ice distribution [1, 2]. Research [3] focused on the impact of Svalbard's orography and sea ice cover in the Norwegian and Barents Seas on the development of PLs. The aim of this research is to enhance the understanding of the influence of sea ice in the north Atlantic on the formation and development of PLs using the ICON model. We analyzed the model's sensitivity to changes in the sea ice boundary, identifying key patterns in the model's response to the absence or presence of sea ice, depending on the mechanism driving the formation of PLs.

First, we have identified around 20 well-developed PLs by the daily analysis of satellite images during the cold period of 2021-2022 and 2022–2023 (November–March). We have chosen 2 the most illustrative cases of PL: 1) Long-lived PL appeared at 16.03.2022 near Island and destroyed near Novaya Zemlya at the 18.03.2022 (half of its route was across the ice-free North Atlantic and then over the frozen surface of the Arctic Ocean, a total distance of about 3,000 meters) (fig. 1a, here and after PL1); 2) The second PL originated on the evening of 18.01.2022 off the east coast of Greenland and moved through Jan Mayen and the Greenland Sea towards the shores of Norway, which it reached after about a day of its existence, the total distance was about 1500 m. (fig. 1b, here and after PL2).

Models and simulations

We used the ICON Limited-Area model [4], which have shown sufficient quality of the PL forecast over Norwegian and Barents seas [5]. The initial and boundary conditions for the ICON-LAM model in the Arctic region were taken from the global ICON model, which was run at the Hydrometeorological Center of Russia in a quasi-operational mode until February 28, 2022. Previous experiments with the ice boundary have shown that minor changes in its position have little effect on the forecast [6]. We have conducted three types of the model experiments: 1) the control experiment without sea ice changes, 2) strong artificial shift of the sea ice boundary northward: it was assumed that there was no sea ice south of 80N (SSIceCut experiment) and 3) strong artificial shift of the sea ice boundary southward (area from Noth Pole till 75N were covered with sea ice, SSIceBuild experiment).

Results

PL1 was originated near jet stream and transferred along this stream till its weakening (it can be seen from fig. 2). PL1 is seen clearly on the ICON forecast maps in the wind speed field, while it is likely recognizable in the pressure field (fig. 3a).

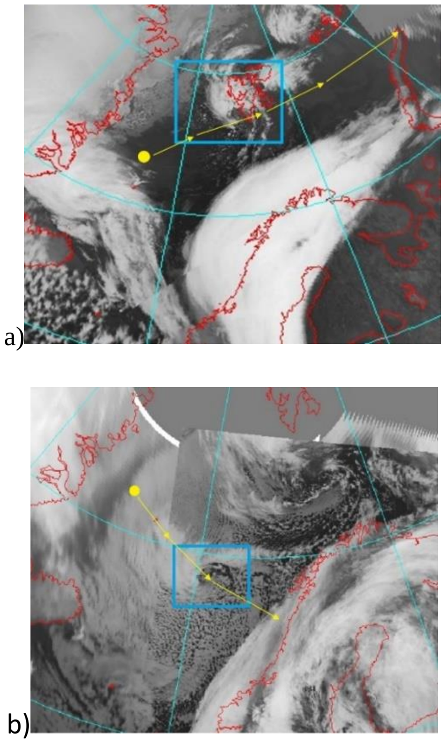

Figure 1. Satellite image of the polar lows, a) PL1: 13:00 UTC 17.03.2022. b) PL2: 8:00 UTC 19.01.2022 Available from the Antarctic Meteorological Research Center (AMRC, ftp://amrc.ssec.wisc.edu/archive). Preliminary trajectories showed by yellow narrows.

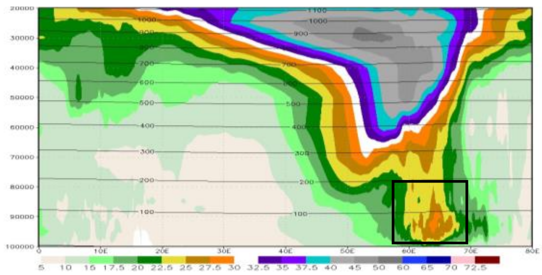

Figure 2. The vertical profile of wind speed along 77.2N at 13 UTC 18.03.2022. Black square shows assessed PL, huge area of the strong winds above is a jet stream.

We have compared SSIceCut and SSIceBuild experiments with the control one and came to the understanding that the model sensitivity to the presence of the artificial ice is much stronger then to its absence (fig. 3). From maps of PMSL and 10-m wind gusts we can notice that PLs in the control and SSIceCut looks very similar, besides they have the same trajectory. Small sensitivity of the PL to the sea ice can be explained by the nature of its formation. It is very likely that this vortex has a baroclinic origin and is closely related to the jet stream, after which it moves a distance of about 3000 km. Table 1 shows the main features of forecast changes during two experiments compared to the control one.

Results obtained during sea ice shifts in the model runs look reasonable. For instance, CAPE increases above ice-free area, latent heat fluxes also raised, wind gust in the PL is higher in the SSIceCut experiment; while in the SSIceBuild experiment, we have got decrease in the wind gust, low latent heat fluxes and higher atmospheric pressure (PL less deep then in control experiment). However, the trajectory of PL didn't change, as it can be seen from fig. 3, PL end up at the north of Novaya Zemlya in the all three experiment.

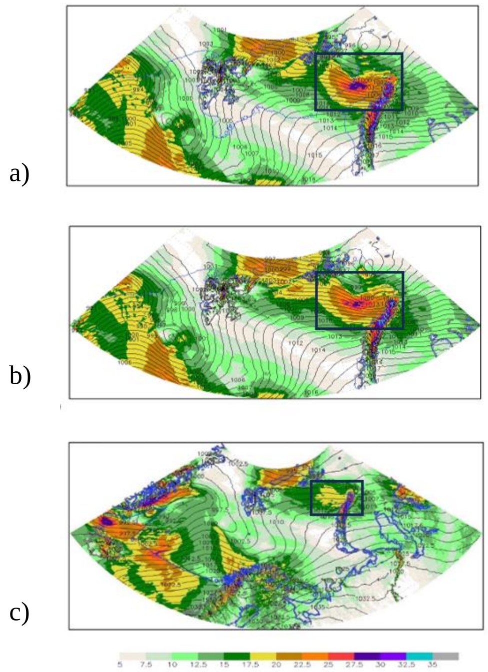

Fig. 3. Maps of PMSL and 10-m wind gusts for the control experiment (a), SSIceCut experiment (b) and SSIceBuild experiment (c) 12UTC 18.03.2021

Table 1. Differences in the main atmospheric characteristics between SSIceBuild and SSIceCut experiments compared to the control one.

	SSIceBuild	SSIceCut
CAPE	The changes are minor	**- 10…+50**; without ice CAPE is higher
PMSL	The pressure in the center of the PL increases by **3-4 hPa**	The changes are minor
Ts-Th500	**- 2..-6℃** above the area where there was an ice [in the control experiment*]; and **-10..-15℃** above the ice-free area*.	Diff. increases as the forecast lead time increases; over the ice-covered territory* the difference is initially zero, then increases to 4℃ at 28 h of forecast, to 6℃ after 36 h, to 10℃ after 56 h
latent heat fluxes	**20-30 Wm^{-2}**; latent heat fluxes in the SSIceBuild are zero, in the control the fluxes are -20…-30 Wm^{-2} (the surface absorbs)	**-10 -20 Wm^{-2}**; latent heat fluxes in the SSIceCut experiment are 10-20 Wm^{-2} higher (they are negative, the surface "emits")
wind gusts	**- 4…-10;** in the zone of the PL way, wind gusts are 4-10 m/s lower in the experiment with built-up ice	**3-5 m/s;** in the experiment without ice, wind gusts were 3-5 m/s higher

PMSL and wind gust in the case of **PL2** (fig. 1b) introduced in the fig. 4. We conducted two experiments for this case – the control one and the SSIceCut experiment. In the SSIceCut experiment polar low intensifies faster, the wind speeds and gusts grow faster, while the lifetime is reduced; the trajectory shifted to the west, closer to the coast of Greenland. The earlier and stronger intensification of the polar low in the SSIceCut experiment is apparently associated with a significant increase in the difference in Ts-Th500 (at the control experiment at the time of PL formation it does not exceed 30°C, while in the absence of ice this parameter overcomes the threshold of 40°C at the 20 hours lead time). The second reason of the quick intensification is the closeness to Greenland with its cold ice surface and, accordingly, higher horizontal temperature gradients.

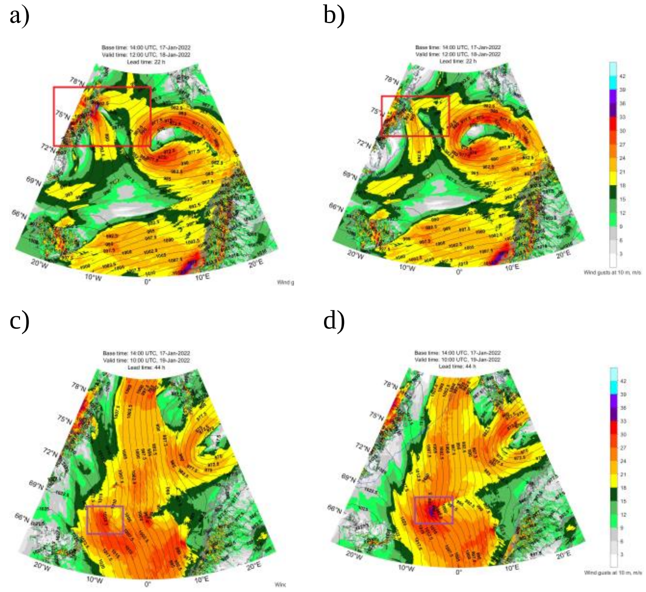

Fig. 4. PMSL and wind gusts at 10 m, ICON model forecast for 12:00 January 18 (a, b) and for 10:00 January 19 (c, d) from 14:00 January 17, 2022, SSIceCut experiment (left), control experiment (right). Polar low locations are highlighted by rectangles.

Conclusions

Our study of several cases of PL development and forecast shows that the model sensitivity to the presence of the artificial ice is much stronger then to its absence. Besides, influence of the sea ice edge on the PL is the strongest in the PL2 case where horizontal gradients in temperature play significant role. In the PL1 case where strong dependance on the jet stream took place an absence of ice didn't affect PL. But SSIceBuild experiment shows that artificial ice suppresses development of PL. Thus, model sensitivity depends heavily on the nature of PL origin.

References:

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