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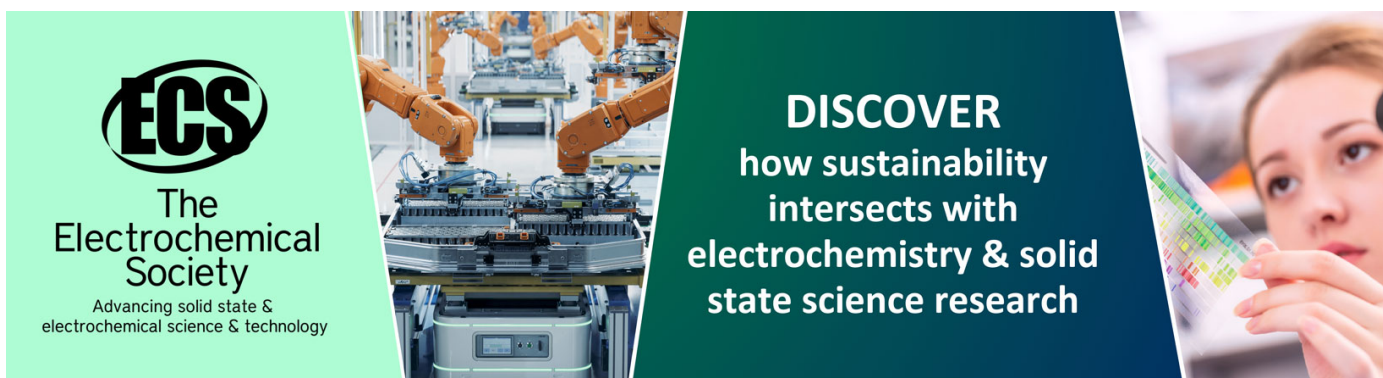
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Regionalization of the INM RAS global climate model data by the Polar WRF model in the Arctic

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Abstract. In this paper we present first results on the use of Polar WRF model for regionalization of the atmospheric circulation in the Arctic region produced by the global climate model INM-CM48 developed in INM RAS. We demonstrate that Polar WRF does not show run off effects in the first year of integration, gives reasonable results with respect to the global model with more details in the regions of complex topography and coast line.

1. Introduction

It is known, that since 70-80s of the twentieth century the warming in the Arctic region is more intense than global one [1,2].

Due to the growing economic importance of the region for Russia the assessment of the future state of the Arctic climate system is very important, with the estimation of the safety degree of navigation via the Northern Sea Route in particular.

As a rule, global climate models have low spatial resolution. The methodology for using regional climate models, which for a region of particular interest includes a regional model with a much smaller step, has already been developed for a long time, and global models are used to produce boundary and initial conditions. Here we present the first results of the development of the complex of models: the regional model Polar WRF (PWRF) [3] and the INM RAS global climate model [4], aimed to a detailed description of the future Arctic climate. In [5], some estimates of the quality of the results obtained with integration for one year are presented. In this publication, work on the analysis of the results is continued.

There are extremely few publications on this subject in Russia. A brief review of several important, in our opinion, works is given in publication [5].

Figure 1 shows a map of the regional model area (left), on the right there is a map of meteorological stations operating in the regional model area.

All model runs were produced with supercomputer of the Joint Supercomputer Center of the Russian Academy of Sciences (JSCC). Figure 2 shows parallel scalability of regional model in log scale. We can see that 500-700 processors are the approximate optimum for experiments with the selected model setup (see below).



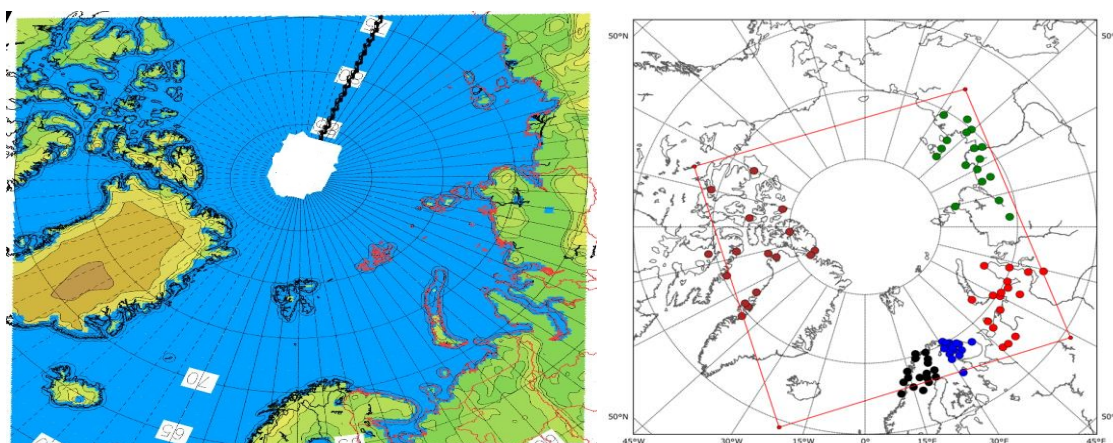


Figure 1. Model area and absolute surface heights for the polar version of the regional model (left). Groups of 17 random meteorological stations in the area of calculations for the regional model (right). Each region on the map corresponds to a certain color: Norway-1 – black, Norway-2 – blue, Canada-Greenland – brown, Russia-1 – red, Russia-2 – green.

It is known, that there are not so many observations in the Arctic region, and they are mainly located on the seashores, in regions, for example, in Norway, which are heavily indented by deep bays. To analyze the quality of reproducing atmospheric parameters in different regions, these stations are divided into five regions: Norwegian-1, Norwegian-2, Canada-Greenland and two Russian. The division into these geographical regions can further contribute to the understanding of the advantages and disadvantages of describing the physical processes characteristic of different regions in both models, primarily in the description of surface thermal and water balances in different regions of the Arctic.

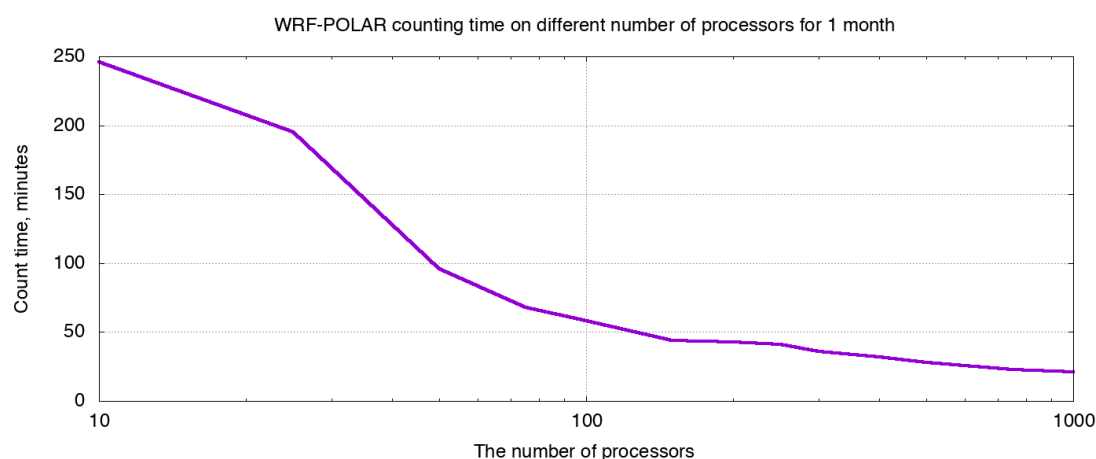


Figure 2. Parallel scalability of regional model setup on the JSCC supercomputer.

We emphasize that at this stage of our work, our task was not a quantitative comparison of models, but only a qualitative understanding of what a regional non-hydrostatic model with a higher resolution can bring to the climate modeling of the Arctic at time scales of several decades. This paper focuses on the analysis of reproduction by two models and the Arctic reanalysis of precipitation in the Arctic region.

2. Description of the complex of models and experimental design

In our work, we use the most modern version of the Russian global climate model [4] using the protocols of the CMIP6 project [<https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6>.] and the polar regional model PWRF version 3.9 .1 (USA) [6]. It is with the help of this combination that, at further stages of work, we intend to obtain reliable and detailed estimates of climatic changes in the Arctic in the first half of the 21st century.

A polar version of the PWRF model was prepared with horizontal resolution of 30 km and 42 vertical sigma levels, including the stratosphere for the region shown in Fig. 1, and two numerical experiments were carried out with initial data and boundary conditions from the global climate model of the INM RAS. The physical parameterizations used in experiments with PWRF are given in Table.1 (with the corresponding references).

Table 1. Schemes of parameterization of physical processes in numerical experiments

Parameterization	Experiment 1	Experiment 2
Microphysics	WSM6 [7]	WDM6 [8]
Boundary layer	MYJ TKE [9]	MYNN 2.5 [10]
Convection	MV5 [3]	MYNN [11]
Ground layer	G-D [12]	K-F [13]
Long wave radiation	RRTM [14]	RRTMG [15]
Shortwave radiation	Goddard [16]	RRTMG [15]
Soil processes	Noah-MP [17]	Noah [18]

The boundary conditions for the regional model were taken from a numerical experiment with the global climate model INM-CM48, where the climate was simulated over 30 years from 1986 to 2015. A description of the model and analysis of the reproduction of modern climate are given in [21]. The resolution of the model in the atmospheric block is 2×1.5 degrees in longitude and latitude, respectively, and 21 vertical levels including the stratosphere, in the ocean block the horizontal resolution was 1×0.5 degrees and 40 vertical surfaces. In addition to the blocks of atmospheric dynamics and ocean dynamics, the model also contains an aerosol block.

All impacts on the climate system were set in accordance with the CMIP6 protocol [<https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6>], namely, in accordance with the available observations for 1986–2015. The concentrations of carbon dioxide, methane, nitrous oxide, ozone, the emissions of anthropogenic aerosols, the concentration of volcanic stratospheric aerosol, the solar constant and the distribution of solar radiation over the spectrum were set.

Every 6 hours, model predictive fields of atmospheric dynamics were stored (i.e. sea level pressure, temperature, specific humidity, zonal and meridional components of wind speed, soil temperature and humidity profiles, surface temperature, sea ice concentration, amount of accumulated snow, temperature, specific and relative humidity at a height of 2 m, zonal and meridional components of wind speed at a height of 10 m).

3. Results

Since calculations with the regional model were carried out only for one year 2004, we began the analysis of the model results by comparing reproduction of the annual cycle of surface pressure, surface temperature, surface wind and precipitation with respect to the synoptic station data.

In Figure 3 shows examples of the annual change of monthly mean values of surface pressure (upper row), temperature at 2 m (second row), wind at a height of 10 m (third row) and precipitation (lower row) at synoptic stations interpolated at stations from Arctic reanalysis data, global climate model and from the results of two numerical experiments with the PWRF model. In addition, the same figure shows the variability of the annual cycle of each parameter. The same can be said about precipitation.

The upper left figure shows that visually neither models nor reanalysis, adequately observed the date of the monthly minimum pressure. It is also seen that the pressure in 2004 reached an absolute minimum for 10 years. The closest to the observations was reproduced for both stations the annual surface pressure in the experiment of the INM RAS the upper left figure shows that visually not a single model, even Arctic reanalysis, adequately observed the date of the monthly minimum pressure. It is also seen that the pressure in 2004 reached an absolute minimum for 10 years. The closest to the observations was reproduced for both stations the annual surface pressure in the experiment of the INM RAS, in the Arctic reanalysis and experiment 2 PWRF for the station Allaikhovsky Ulus (Yakutia), the absolute error is 4.62 hPa, for the station village Pervomaisky (Yakutia) - 2.73 hPa, while the error in the global model is 5.6 and 4.3 hPa, respectively, for Arctic reanalysis - 2.9 and 1.4 hPa. It can also be seen that both the climate model and Experiment 2 of the regional WRF model lie near the region of variability. The annual pressure variation for the Pervomaiskaya station lies almost completely within the variability of the annual pressure variation closer to the observations approximately one and a half times than the pressure according to the INM RAS model.

Let us consider second row of figure 3 with the annual cycle of surface temperature for two stations. We see that, in general, the annual variation in surface temperature in all experiments was reproduced well. For almost all experiments, the temperature is within variability. The best results are obtained with the INM RAS model and WRF model with experiment 2 settings. The absolute errors in the annual temperature variations for the regional model in experiment 2 are also slightly less than the errors of the global model.

The third row of the figure shows the annual variations of the monthly average values of the wind speed module by 10 m. It is shown that the spread in reproducing wind speed is much higher. Average values range from 1.5 to 4.8 m/s. Correlation coefficients - from -0.5 to 0.7 for reanalysis. Nevertheless, the absolute errors in the regional model for both stations are less than in the global model. So, for the first station, the absolute error is 1.19 m/s instead of 1.73 m/s. for the second - 0.6 m/s instead of 1.3 m/s.

The bottom row of the figure shows the annual variations of the monthly average values of precipitations. We can see that experiment 2 (figure b) better than experiment 1 (figure a) for that stations.

An analysis of the experiments shows that in most regions in experiments with the regional model the annual variation is restored much closer to the observations than in the global one.

Thus, judging by the analysis of the annual cycle of the basic characteristics of the surface atmosphere and its interannual variability, the polar version of the regional model in the configuration of the second experiment slightly improves the annual cycle of the surface pressure, temperature, and wind speed and makes the calculation results closer to observations and Arctic reanalysis. It should be emphasized that the global climate model, like the regional one, does not use meteorological observations for 2004. The next field that we will include in the analysis in this paper is precipitation.

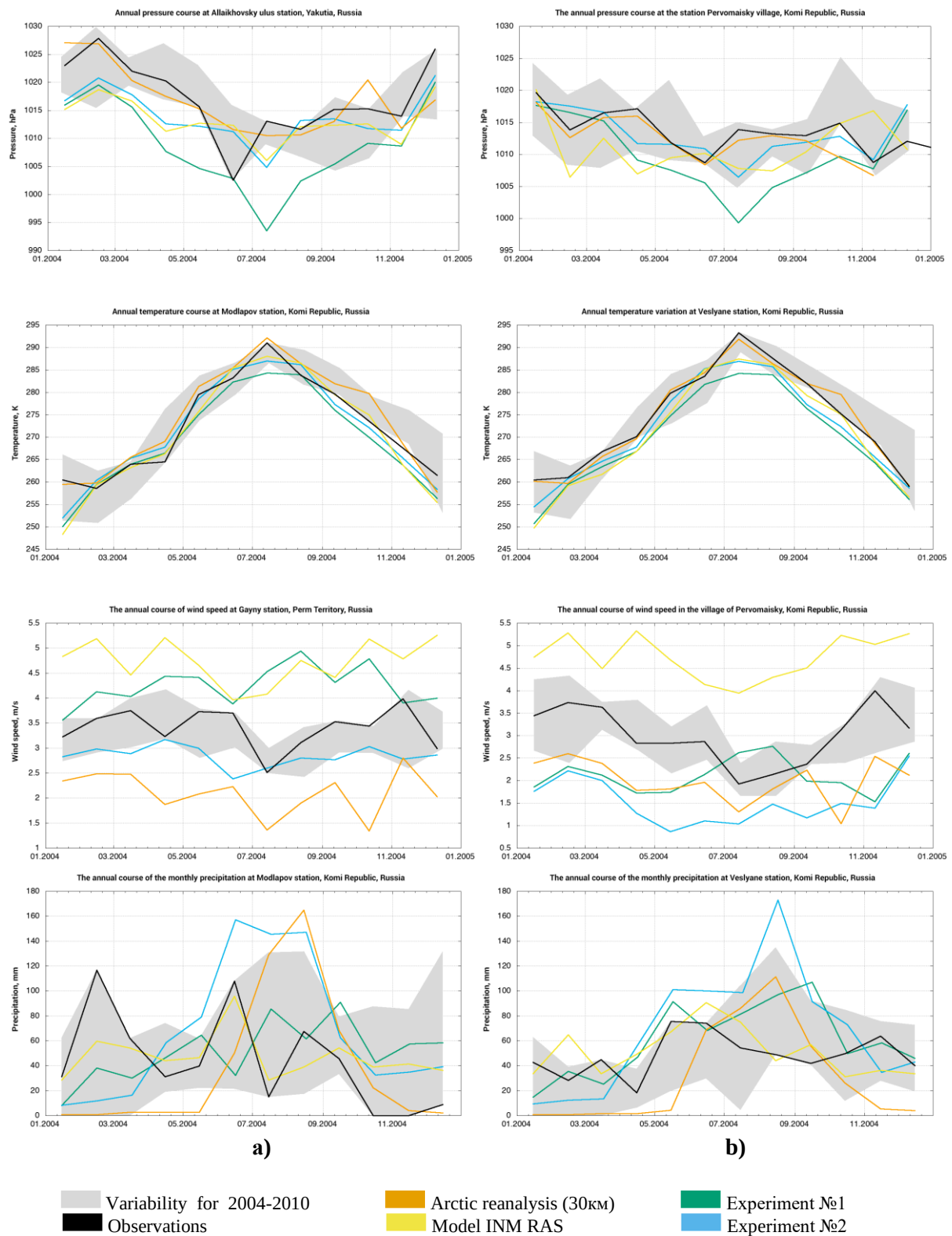


Figure 3. Examples of annual pressure passages (top row), temperatures (second row) wind (third row), precipitation (bottom row) for the first (a) and second (b) experiments with the polar version of the PWRF, observational data and Arctic reanalysis.

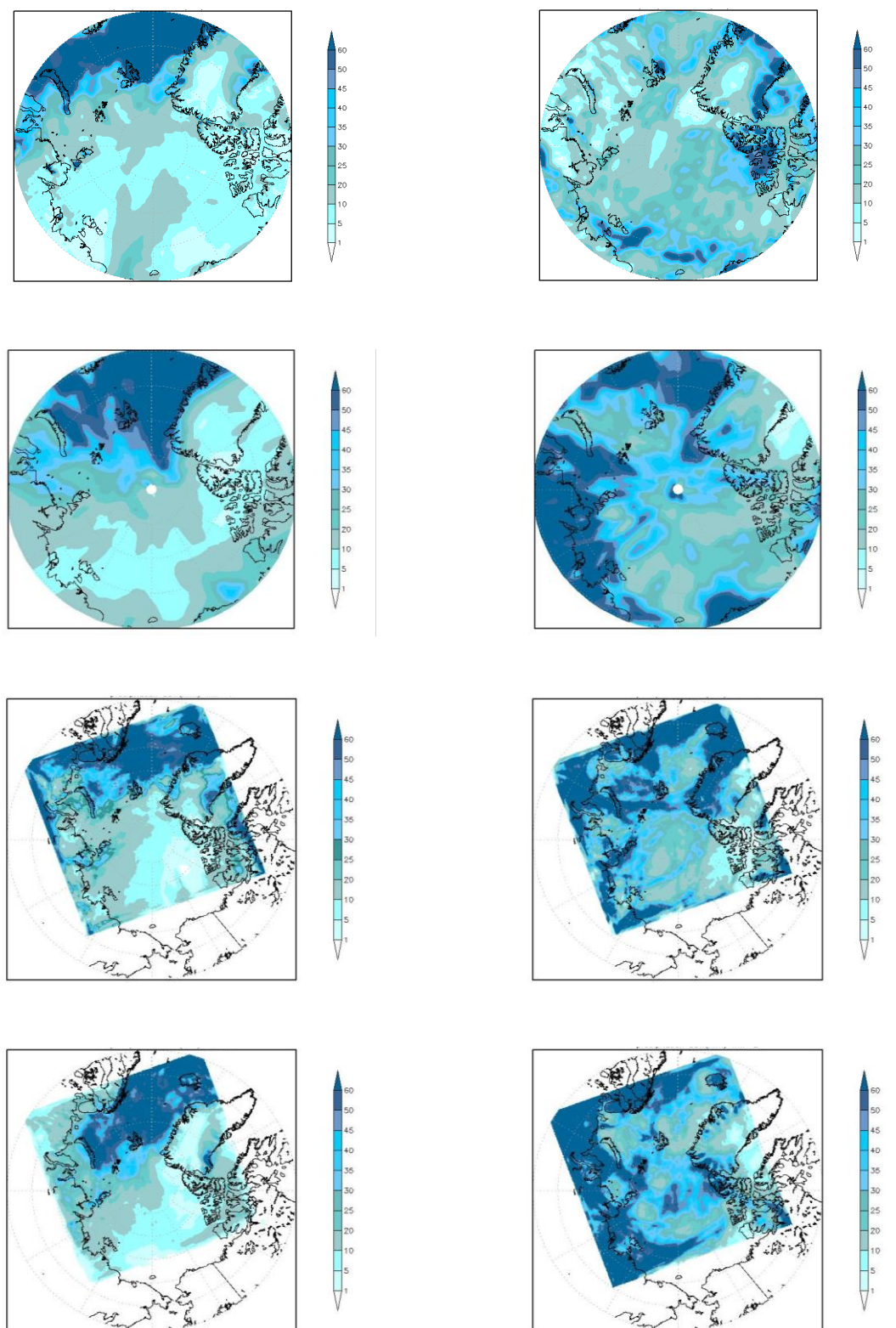


Figure 4. Maps of total precipitation for January (left) and for July (right) obtained in Arctic reanalysis (top line), in the INM-C48 experiments (second line) in the first experiment with the PWRF model (third row) and in the second experiment with the PWRF model (lower row).

Figure 4 shows the maps of total precipitation in January (left column) and in July (right) obtained in the Arctic reanalysis (upper row), in the experiment using the global INM RAS model, (second row) and in two experiments with the Polar WRF model.

It can be seen that the scale of precipitation in all experiments is close. The location of winter precipitation obtained in experiments with WRF-ARW is noticeably closer to the location obtained in the Arctic reanalysis. The results of the first experiment with the Polar WRF model are somewhat closer to reanalysis than the second.

It is more difficult to qualitatively assess the summer precipitation shown in the right column. The localization of precipitation minima is closer to reanalysis in experiments with the INM RAS model. The configuration of the maxima seems closer in 1 Polar WRF experiment. In the future, we intend to conduct a quantitative analysis for individual characteristic regions highlighted in Figure 1.

4. Conclusion

The system of the global climate model and the embedded regional one was developed, which makes it possible to refine climate projections in the Arctic by using higher spatial resolution, non-hydrostatic approach, and special parameterization of physical processes tuned for the polar region.

It must be emphasized that the results are preliminary. They do not yet allow us to make unambiguous conclusions about whether or not the runs with the regional model improve the climate obtained by the global model, but only show that there are no errors in the technical procedure for regionalization.

Acknowledgments

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