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Case study of polar lows in Barents and Kara Seas during 2014

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ABSTRACT

It is known that polar lows, due to their small horizontal scale, can be hardly observed through currently used synoptic observational network. The paper deals with the study of polar lows on the basis of forecasts produced by the atmospheric model COSMO-Ru. The forecast of the evolution of a polar low formed 26 March 2014 above Barents Sea was calculated with the use of this model. The satellite data and observational data from the coastal hydrometeorological stations Amderma, Kolguev Island and Bolvansky Cape were used for the verification of the obtained forecast. It is shown that the model reproduces wind gusts speed rather accurately. Comparison of the forecast of wind gusts speed with the results of calculations based on the methods recommended by ISO 19901 standard shows some discrepancies due to neglecting unstable air stratification in the latter case.

Review of polar lows and their impact on ice coverage

Atmospheric processes being an integral part of ocean-atmosphere system are mainly defined by the evolution of pressure systems.

Characteristic dimension of pressure systems such as cyclones and anticyclones is about thousand km. Such objects are well detected on synoptic maps, they can be easily observed via land network of standard meteorological observations. Yet the size of pressure systems varies over a wide range. In many regions of the globe, in particular over water area of the Barents Sea, mesoscale cyclones with spatial scale less than 1000 km are observed. This term describes rather various meteorological objects starting with small atmospheric vortexes visible only in cloud field and ending with polar lows in which heavy precipitation and storm (in specific cases – hurricane) wind speed are observed.

According to the definition from (Rasmussen and Turner, 2003), polar low is a small but fairly intense maritime cyclone that forms poleward of the main baroclinic zone (polar front or other major baroclinic zone). The horizontal scale of polar lows varies from 200 to 1000 km, and surface winds near or above gale force.

The European workshop on polar lows specifies this definition. (Günther and Øyvind, 2013) defines the term "mesoscale cyclones" for all polar cyclones poleward of the main polar front having scales smaller than 2000 km. The classical "polar low" (PL) is included as a subtype that is restricted to maritime systems with near surface winds exceeding 15 m/s.

For the first time polar lows were detected over the water areas of Norwegian and Barents Seas. Such vortexes are also observed in other regions of the globe, for example, in the north of the Pacific Ocean, in Sea of Okhotsk, Sea of Japan and Labrador Sea as well as in Antarctic waters.

Polar lows are formed during cold season from October to May. They develop rapidly, their characteristic lifetime is about a day. Meteorological conditions in polar lows are characterized by intense precipitation and wind speeds reaching 18,5-23,5 m/s on average (Noer and Lien, 2010). However according to observations on 25 April 1985 wind speed in a polar low exceeded 33 m/s reaching hurricane values and for observation period from 2000 to

2009 maximum fixed wind speed in a polar low was 35 m/s (Gunnar et al., 2011). Travel speed of polar lows is usually from 50 to 70 km/h, but can reach 90 km/h and more. Air pressure fall in the centre of a low-pressure system is approximately 2-3 hPa. Sensible and latent heat fluxes in area on average are 200 W/m^2, and in some places can reach 290 and 520 W/m^2 respectfully (Brummer and Muller, 2009). A small area with downward motion of air is situated in a centre of a polar low (“eye of the storm”).

Studies of forming process and evolution of polar lows carried out during the last 30 years with the help of aviation and land observations and numerical modeling (Shapiro et al., 1987, Kristjansson et al., 2011, Føre et al, 2011, Føre et al, 2012) allowed to establish, that the main mechanism of polar lows' forming was advection of cold air (primarily from ice-covered area) to water surface free of ice (see figure 1 and 2).

This leads to the development of strong vertical instability and convection. Usually it occurs in low-level baroclinic zones (so-called “old occlusions”). Large temperature differences (>43°C) between water surface and 500 hPa pressure level (height about 5,5 km) also contribute to the development of polar lows.

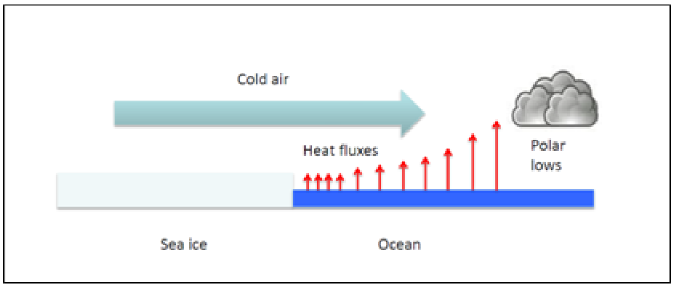

Figure 1. Forming mechanism of polar lows

Studies showed, that atmosphere in areas of polar lows’ appearance does not have enough supplies of instability energy for maintenance of so high wind speeds. Probably, the main source of kinetic energy of polar lows is a turbulent heat flux from open water surface.

Therefore polar lows arise above rather warm sea surface but quickly destroy above land or ice cover, when feeding them heat flux disappears. In spite of rather short lifetime from 12 hours to 3 days polar lows can threaten significantly offshore platforms, navigation and coastal infrastructure.

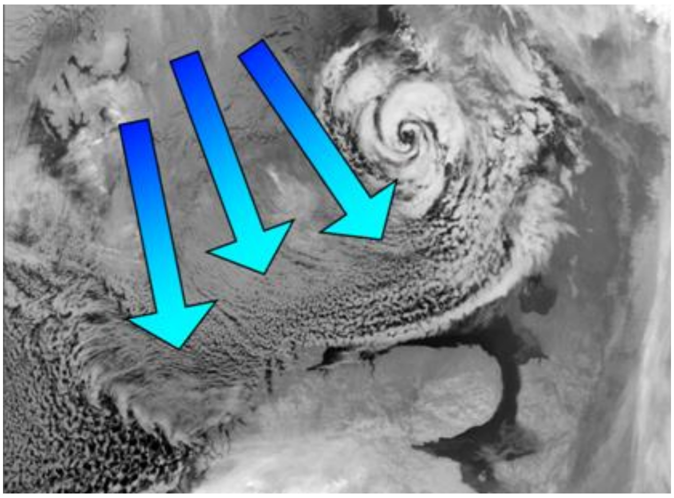

Figure 2. Space image of a polar low

Over the water area of Norwegian and Barents Seas 2-3 polar low a month are observed on average during the cold season, yet according to observations referred to the period of the end

of 1990s and the beginning of 2000s polar lows were not observed in the water area of Kara Sea.
As we have already mentioned, since 2005 stably high average annual air temperatures have been observed in the whole Arctic region, which determine stably high duration of ice free season and decrease ice coverage. In particular, in Barents Sea reduce of mean distance from south-west cost of Novaya Zemlya to the ice edge is observed, and in south-west part of Kara Sea decrease of ice compaction in spring and increase of polynyas' and fractures' amount as well as their extension and width are detected.
It is known that polynyas and fractures play an important role in provision of processes of heat exchange in the system ocean-atmosphere, and hence increase of their amount leads to intensification of heat flux incoming to the atmosphere during the ice season.
Taking into account the mechanism of forming and evolution of polar lows given above, totality of the described factors determines intensification of mesoscale cyclonic activity over the water area of Kara Sea. This conclusion is confirmed by the results of modelling of climate changes done under the aegis of IPCC which was created in 1988 with the purpose of provision of general estimation of the state of scientific and technical and socio-economic knowledge about climate change, its causes, potential consequences and response strategies as well as by observational data for the last years.
Areas of predictable intensification of mesoscale cyclonic activity according to results of climate changes modelling are shown in figure 3 (Kolstad and Bracegirdle, 2008). One of them includes the water area of Kara Sea and Baydaratskaya Bay.

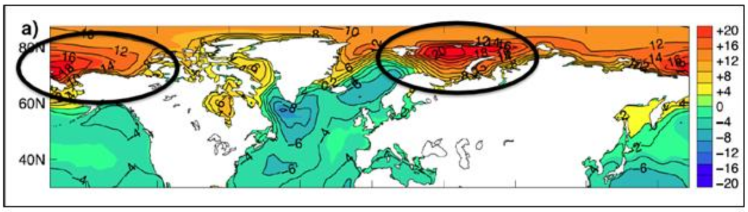

Figure 3. Areas of predictable intensification of mesoscale cyclonic activity according to results of climate changes modeling done under the aegis of IPCC

Numerical modelling of polar lows using mesoscale COSMO-Ru model

Since the end of 2013 specialists of Laboratory for offshore structures from LLC "Gazprom VNIIGAZ" in collaboration with specialists from "Hydrometcenter of Russia" conduct studies of polar lows forming over Barents Sea and moving to the water area of Kara Sea during the process of their evolution. In this research results of hydrodynamic modelling with the help of mesosale weather forecast system COSMO-Ru as well as remote-sensed data are used. COSMO-Ru is a base operational system at "Hydrometcenter of Russia" and other forecasting institutions of Roshydromet and has enough spatial resolution for reproduction of polar lows' evolution.
Grid step of the model COSMO-RuENA (Europe – Northern Asia, ENA) is 13,2 km. The grid covers area of 13200 km × 6600 km including a large part of the water area of Arctic Ocean. The model versions with grid steps of 6,6 and 2,2 km were used for more detailed study of polar lows. The second grid (1000 × 1100 grid points) contains a part of water areas of Barents and Kara Seas and nearby coast.
As a result of the conducted research several cases of polar lows passing over the water area of Kara Sea in 2014 were revealed.
The model COSMO-Ru reproduced the beginning of a polar low to the south of Spitzbergen and its evolution above Barents Sea. At 14:00 UTC 26 March 2014 the cyclone appeared over

the water area of Kara Sea. Wind speed (with 10-second average) exceeded 25 m/s during its moving over the water area of Barents Sea and gust velocities reached 40 m/s.
Map of sea-level surface pressure and wind speed at a reference elevation 10 m (10-meter wind speed) obtained by the model COSMO-Ru with grid step 2,2 km 00 UTC 26 March 2014 is shown in figure 4. From the figure 1 can see that wind ran up to 20 m/s speed in the seaward part of Baydaratskaya Bay. Motion paths (storm tracks) of the studied polar low can be seen on figure 5.

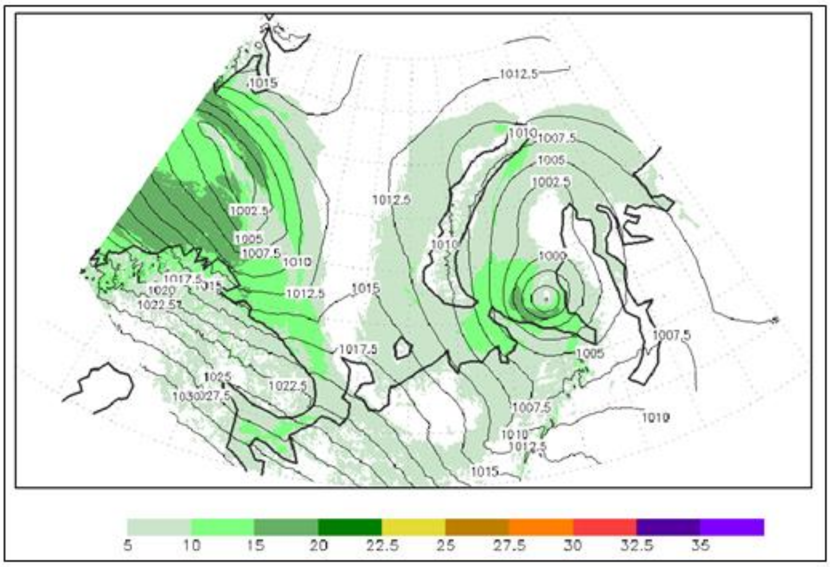

Figure 4. Map of surface pressure (sea level), hPa, and 10-meter wind speed, m/s, (model COSMO-Ru with grid step 2,2 km, forecast for 14 hours from 00 UTC 26 March 2014).

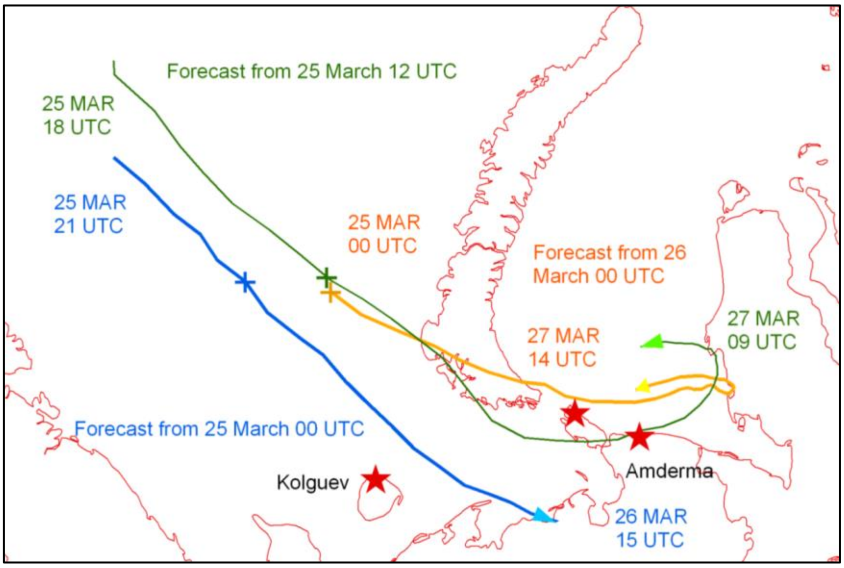

Figure 5. Motion paths (storm tracks) of the studied polar low depending on forecast lead time, time of the beginning and filling of the polar low (model COSMO-Ru with grid step 2,2 km).
It is clear that a motion path strongly depends on forecast lead time. From start hour 00 UTC 25 March the model COSMO-Ru reproduced the beginning of the polar low with 21-hours lead time. Forecast from 12 UTC 25 March essentially specified the polar low trajectory, forecast from 00 UTC 26 March didn't give so wide scale corrections. Analysis of motion

path shows that when reaching Yamal shore the polar low changed its motion direction to the opposite and ceased to exist in the region of Kara Strait.
Such a motion path of the polar low determined the rise of strong offshore winds at the Ural coast of Baydaratskaya Bay and Kharasavey Cape. According to data from hydrometeorological station (HMS) “Ust’-Kara” speed of west and south-west wind increased almost two times from 12:00 to 18:00 local time, reaching 14 m/s, and wind gusts were 24 m/s.
Analysis of satellite images showing ice conditions in south-west part of Kara Sea (figure 6 and 7) 26 and 27 March 2014 in the morning allows to conclude that passing of the polar low resulted in widening of a flaw lead (polynya) near the Ural coast of Baydaratskaya Bay and its forming near Kharasavey Cape. In conditions of observed high compaction of drift ice in the axial region of the bay expansion of flaw polynya activated the processes of pressing and hummocking of heavy one-year ice. This could potentially bring to increase of keel sizes of hummocks and intensification of exaration influence on the sea bottom.

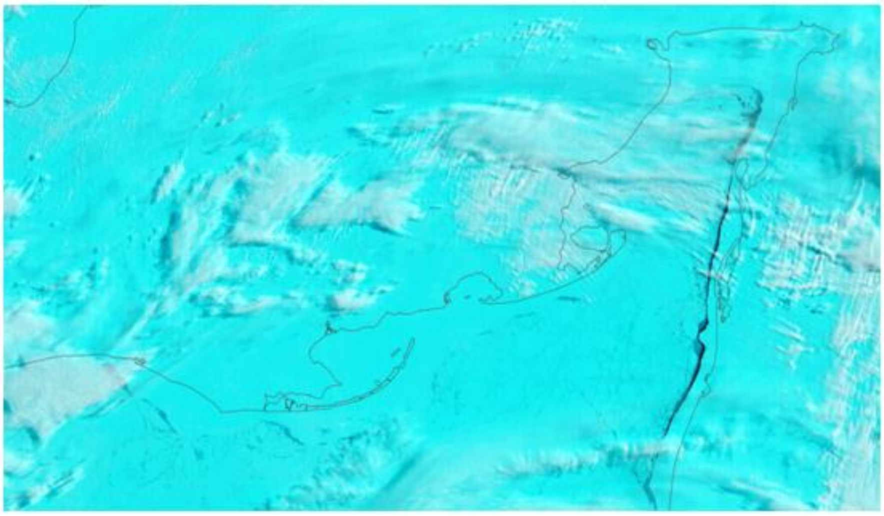

Figure 6. Ice conditions according to satellite “Terra”, morning 26.03.2014.

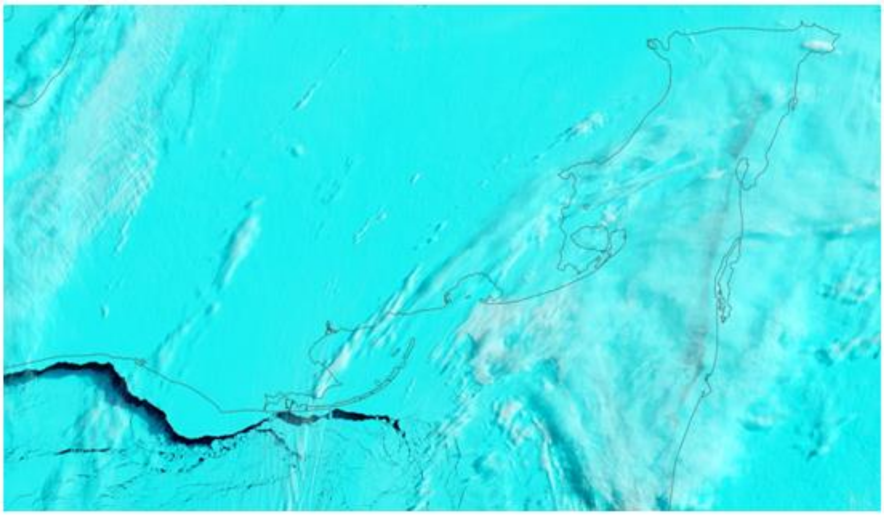

Figure 7. Ice conditions according to satellite “Terra”, morning 27.03.2014.
Observational data from coastal HMS Amderma, Kolguev Island and Bolvansky Cape were used for the verification of the obtained results (stations’ location is shown on figure 5). Wind speeds and gust velocities at station Kolguev Island are compared (figure 8). One can see that the model COSMO-Ru rather underestimates wind speed. The model reproduces wind gusts

more accurately, but it also underestimates their speed in single time moments. Similar can be observed on stations Amderma and Bolvansky Cape.

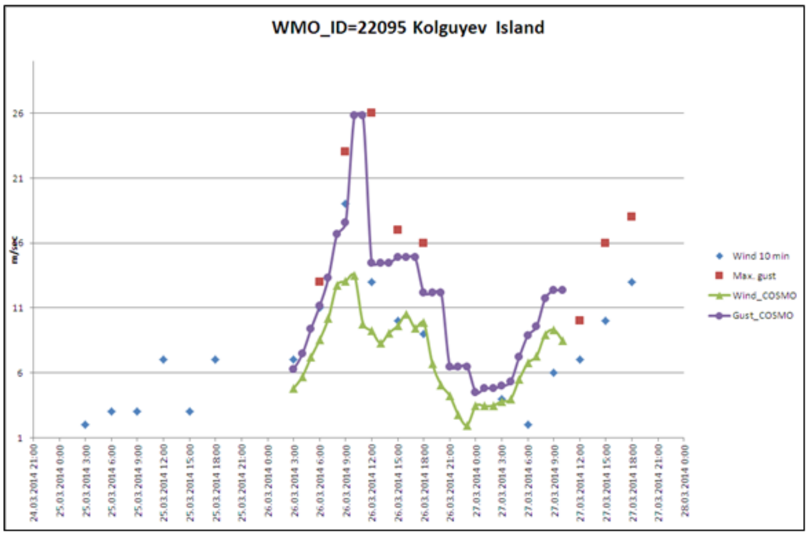

Figure 8. Wind speed and gusts speed (m/s) on the meteorological station Kolguev Island 25-27 March 2014. Green line – wind speed forecast of the model COSMO-Ru (grid step 2,2 km), violet line – wind gusts in the model COSMO-Ru (grid step 2,2 km). Dots – observational data: blue– wind speed, red – wind gusts.

Except meteorological observations, images from MODIS (Moderate-Resolution Imaging Spectroradiometer) were used for verification of the obtained results.

Polar low born on 13 May 2014 to the south of Spitzbergen is shown on figure 9. It is well noticed in cloud cover field and pressure field, and at the same time the model results are in accord with observations.

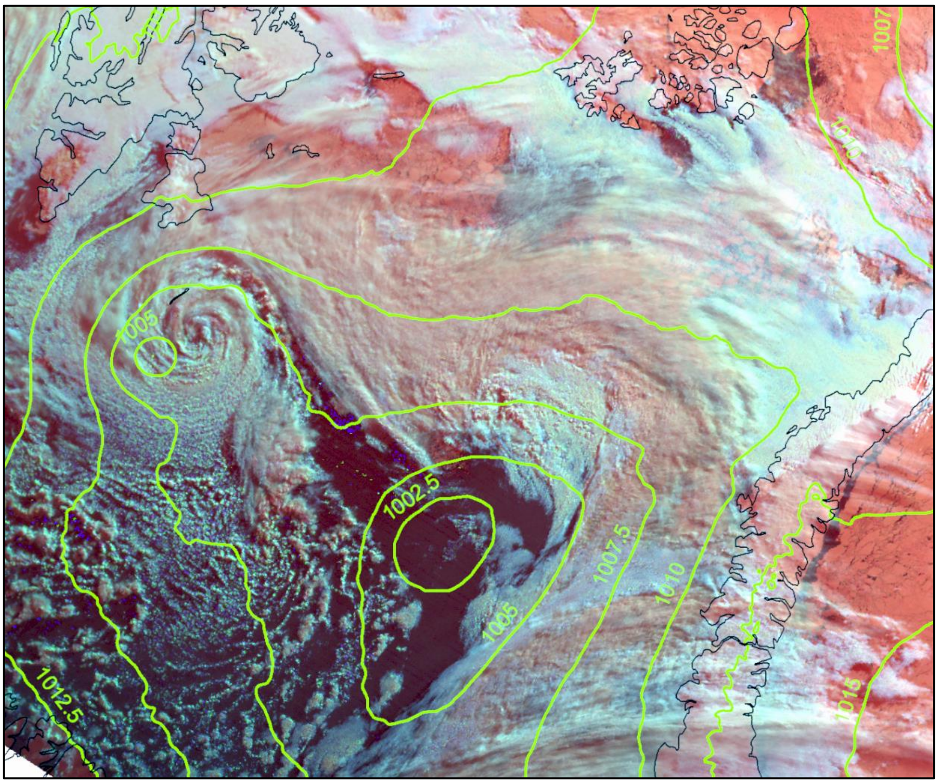

Figure 9. Cloud cover (according to MODIS data, 00:15 14 May 2014) and pressure (the model COSMO-Ru, forecast from 00 UTC 13 May 2014 on 24 hours).

When polar lows forecasting, it is interesting to know not only 10-minutes mean wind speed but also short-term gusts due to its possible impact on offshore structures and maritime operation. Following the definition given in ISO 19901 gust wind speed is maximum value of the wind speed of a gust averaged over a short (3 s to 60 s) specified duration within a longer (1 min to 1 h) specified duration.

At present day in offshore engineering and design practice widely used the method for calculation of wind speed with different periods of averaging recommended by Norwegian Petroleum Directorate (ISO 19901). Wind speed $u(z,t)$ (m/s) at height z (m) above the sea level, corresponding to a period of averaging t (s) for 1 hour and less ($t \leq t_0 = 3600$ s), of strong winds (at almost neutral stratification) is calculated by the equation:

$$u(z,t) = U(z)[1 - 0.41 I_u(z) \ln(t/t_0)] \quad (1)$$

where $U(z)$ (m/s) is a mean wind speed for 1 hour at height z and is equal to:

$$U(z) = U_0 \left[1 + C \ln\left(\frac{z}{10}\right)\right], C = 0.0573\sqrt{1 + 0.15 U_0} \quad (2)$$

where U_0 – wind speed at 10 m height with 1-hour averaging. Turbulent parameter $I_u(z)$ at height z is calculated as:

$$I_u(z) = 0.06[1 + 0.043 U_0]\left(\frac{z}{10}\right)^{-0.22} \quad (3)$$

So at practice, gust speed is determined based on 10-minute averaging wind speed that was measured at HMS in particular.

It should be noted that the Eqs. 1-3 are derived for conditions of almost neutral stratification, yet stratification can be different from neutral in polar lows. Take into account that square of Brunt-Väisälä frequency is used for the estimation of air vertical stratification:

$$N^2 \equiv \frac{g}{\theta}\frac{d\theta}{dz} \quad (4)$$

where g – acceleration of gravity, θ – potential temperature, z – height.

When N^2 is positive stratification is considered to be stable, when negative – unstable. According to calculations done by the model COSMO-Ru, during the polar low passing unstable air stratification is observed in the lower 200-meters layer. Therefore the question of application of Eqs. 1-3 for wind gusts calculation under polar low conditions arises.

According to Eqs. 1-3 gust speed depends only on wind speed. Hence strong gusts couldn't be in regions with low wind speed.

In the model COSMO-Ru gusts at the surface are considered to originate from air parcels flowing at higher levels in the boundary layer, which are deflected downward. The mechanism causing the deflection is ascribed to turbulent eddies. It is assumed that if the turbulent eddies have sufficiently large mean turbulent kinetic energy (TKE) to overcome buoyant forces between the surface and a given height, the parcel flowing at that height will be able to reach the surface and produce gusts. So for estimation gust speed used sophisticated diagnostic formula which includes predictive values of mean wind speed and coefficient of turbulent momentum transport.

The advantage of this method lies in the fact that it is entirely based on physical considerations. It is, however, highly sensitive to the accuracy of the modelled meteorological fields.

According to COSMO-Ru calculations maximum wind gusts (41 m/s) were in areas with rather moderate wind speeds (16 m/s). Gust velocity calculated by Eqs. 1-3 doesn't exceed 20 m/s in these places. Thus the gust velocity difference between two methods surpasses 20 m/s (figure 10).

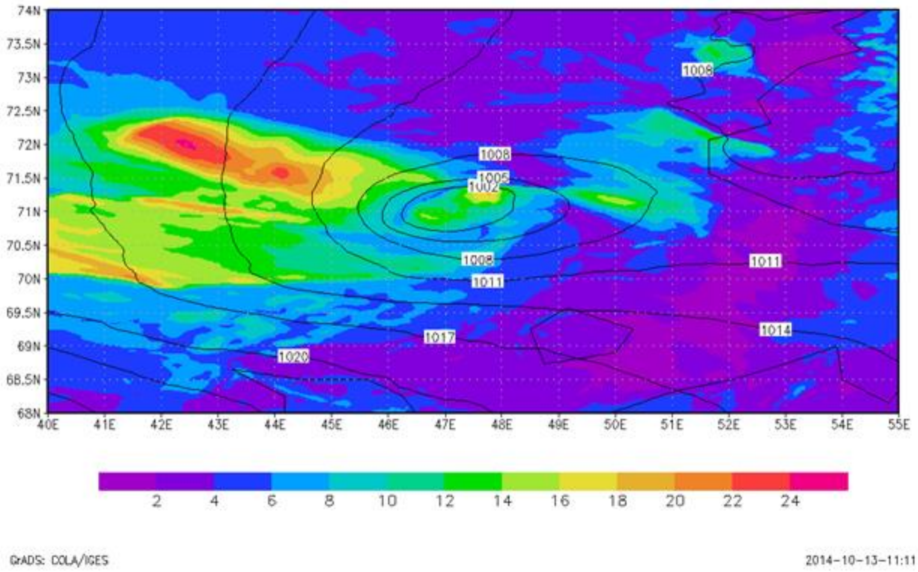

Figure 10. Difference between gust velocity at 10-meter height according to COSMO-Ru forecasts and calculated by the method (ISO19901), m/s (model COSMO-Ru with grid step 2,2 km, forecast from 00 UTC 25 March 2014).

The above discrepancy in assessments of the gusts speed apparently is due to ISO formulae neglects unstable air stratification caused by the passage of the polar low and uses a crude approximation for turbulence (Eq. 3). It should be noted that in order to confirm this conclusion additional numerical experiments are required for accumulation of statistical data on wind speed and gusts during the passage of other polar lows and for evaluation of possible discrepancies with the values calculated by the ISO formulae.

As a result of the fulfilled work the following conclusions could be done:

i. Numerical atmospheric model COSMO-Ru is capable to reproduce dynamics and evolution of polar lows realistically. Results of modelling are verified via satellite images and observational data from meteorological station network.
ii. Forecast of motion path of a polar low strongly depends on forecast lead time.
iii. The calculation method of gust speed recommended in ISO standard doesn't take unstable stratification of air in polar lows into consideration. So, gust speed calculated on the basis of ISO standard formulae may be differs significantly from the COSMO-Ru model data, which considers more physical factors.

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