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Numerical simulation of polar lows in seas of Russian Arctic

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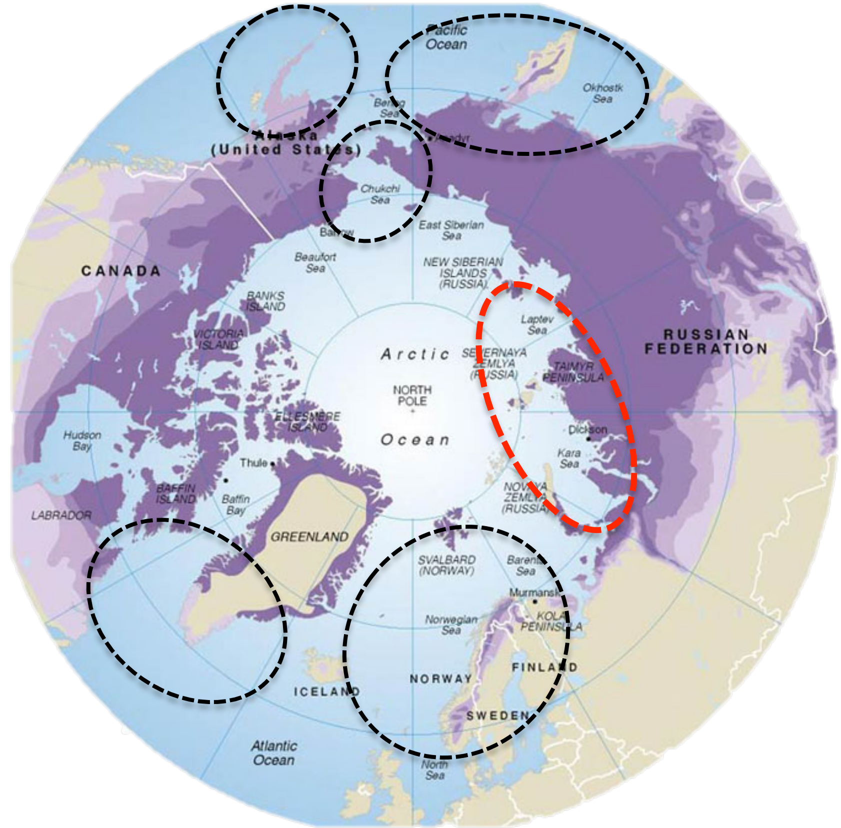
Polar lows

«Classical» polar lows:

- intense, short-living, typically winter-time
- $T_{air} > T_{sea}$, ΔT up to 20-30°
- have gale wind speeds (>15 m/s)
- dangerous for sea operations
  (Turner, Rasmussen, 2003)



Main intensification mechanisms:

- ➢ **Convective instability;**
- ➢ **Secondary baroclinic zones**, within land-sea and sea-ice boundaries;
- ➢ **WISHE** (wind induced surface heat exchange)
- ➢ **CISK** (conditional instability of second kind);
- ➢ **Baroclinic zone interaction with upper-level potential vorticity anomaly;**

No mechanism alone can explain the observed intensity of the polar lows

The research goal:

diagnostics of physical mechanisms responsible for development of selected polar lows (case studies)

Data and methods:

Satellite data:

- Spectroradiometer MODIS (Aqua) and AVHRR (NOAA) (IR cloudiness – **1 km and 1.1 km** respectively), 10 m wind speed and integral water vapor content **(500 m)** two times a day over the region under study
- SAR ASAR Envisat ocean surface radar reflectivity **(75 m)**

Modeling:

- Weather Research and Forecasting ARW model (5x5 km spatial resolution)
- NCAR Command Language

Computational resources:

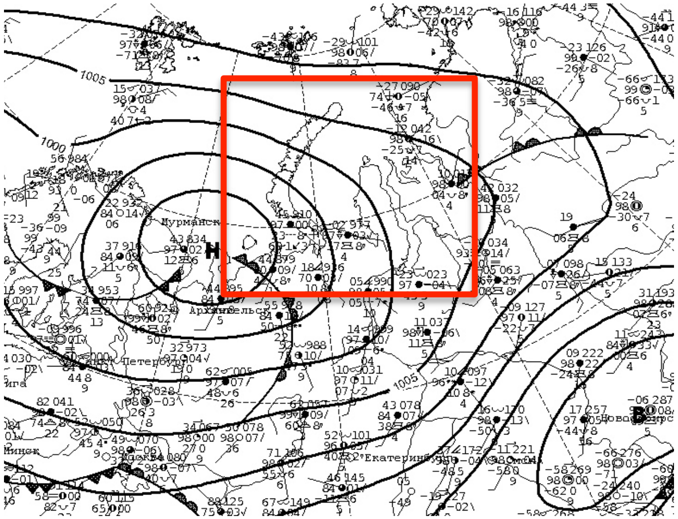
Lomonosov Supercomputer of MSU

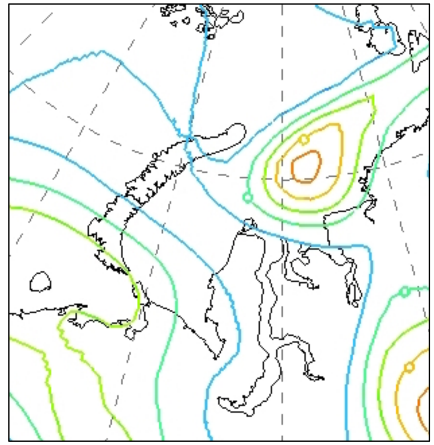
Ancillary data:

- Surface and upper-level analysis charts
- ERA-Interim reanalysis data (**0.25 x 0.25°)**

Cyclone in Kara Sea 30.09.08 and the numerical experiments setup

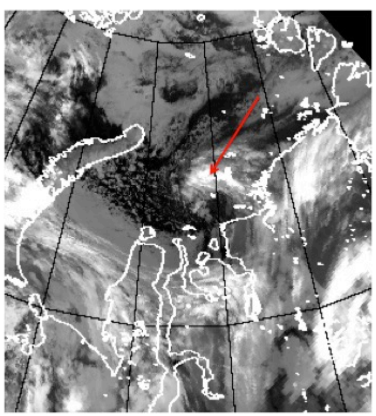
Surface analysis chart 00:00 30.09.08





Potential vorticity on 300 hPa level, 00:00 30.09.08

Infrared pictures of cloudiness at:



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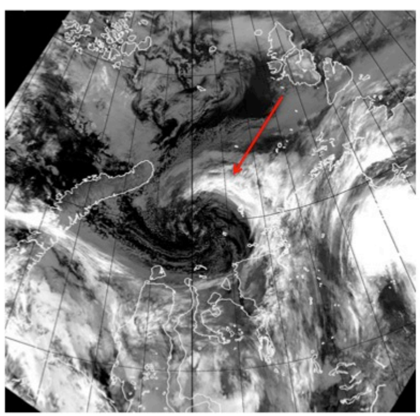

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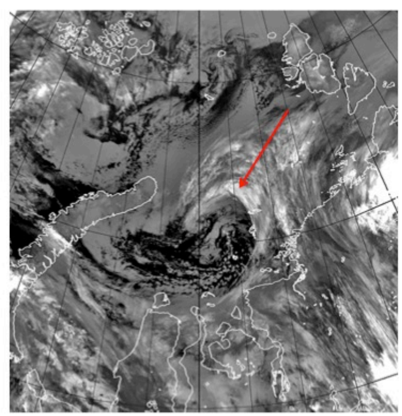

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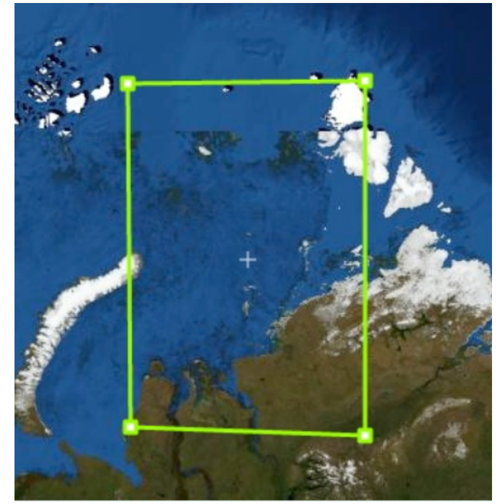
Model domain and setup



- 5 km spatial resolution
- Simulation time span: 00:00 29.09- 18:00 01.10.08
- Boundary and initial conditions: ERA-Interim 4 times a day

2 numerical experiments:

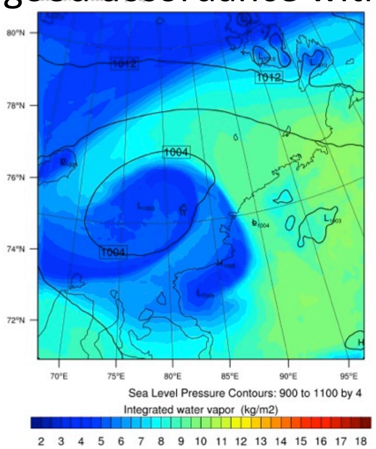
- Microphysical scheme turned on (Goddard center scheme, 5 types of hydrometeors);
- Microphysical scheme turned off.

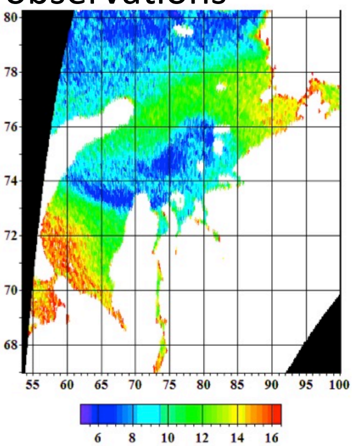
Each run took 5 h computer time at 64 processors

Comparison with observation data

- Water vapor content is 5-10% underestimated, field structure matches that in satellite data
- Wind speed is simulated close to what is observed
- Model mesoscale cloudiness structure is in good accordance with observations

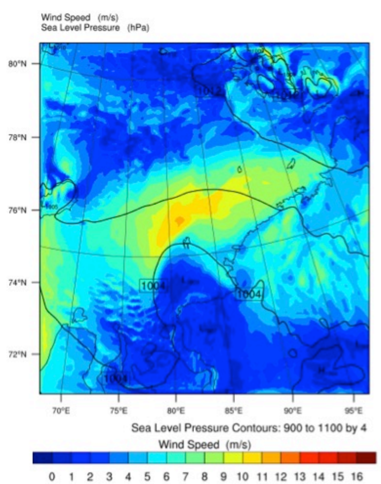
Water vapor content, kg/m^2

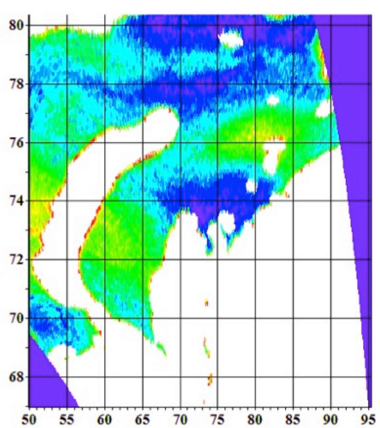




Model **Observations**

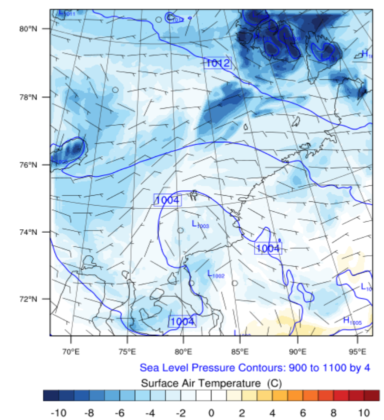
Surface wind speed, m/s





Polar low development

08:00



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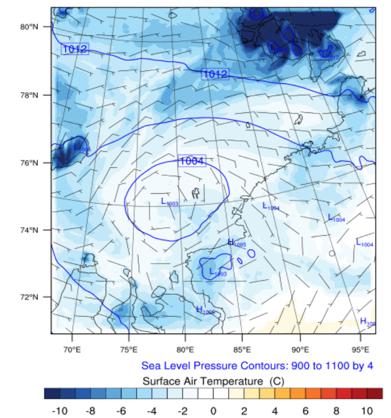
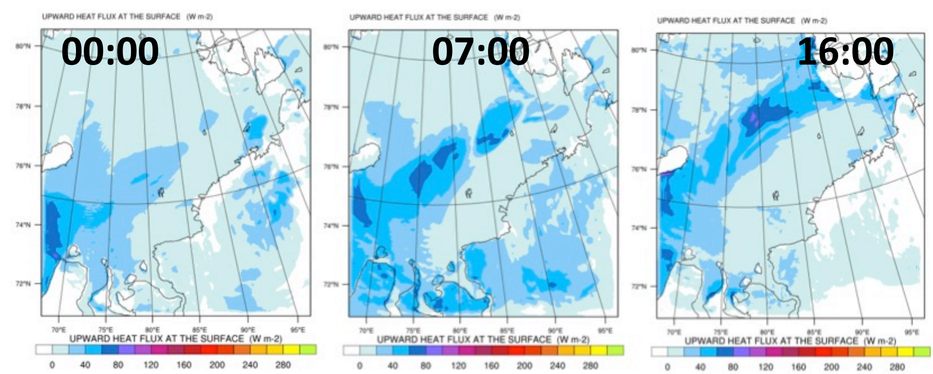
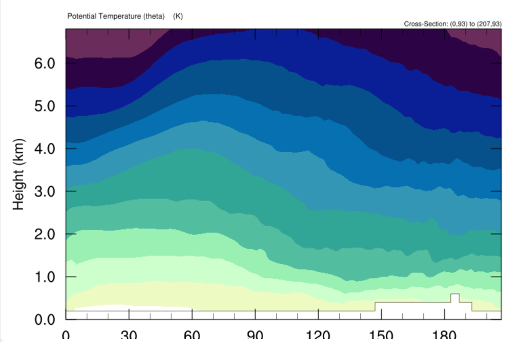


Temperature, °C, wind, m/s, pressure, hPa



Surface sensible heat flux, W/m^2



Potential temperature, K

Atmosphere is:

- Almost horizontally homogenous;
- statically stable
- no significant surface fluxes

CISK and potential vorticity anomaly

Experiments comparison – CISK effects

Microphysics parameterization	On	Off
Cyclone appearance in pressure field (hours, 30.09)	At 12:00	At 16:00
Maximum wind speed, m/s	14	11
Potential vorticity anomaly intensity, PVU	3	0.8
Latent and sensible heat fluxes, W/m²	82 & 64	< 40

CISK mechanism:

1. Latent heat release in cloud formation;
2. Convergence below heat source;
3. Intensification of cyclone anomaly and moisture convergence;
4. Vertical velocity growth;
5. Initialization of new convection in conditionally unstable air and then:

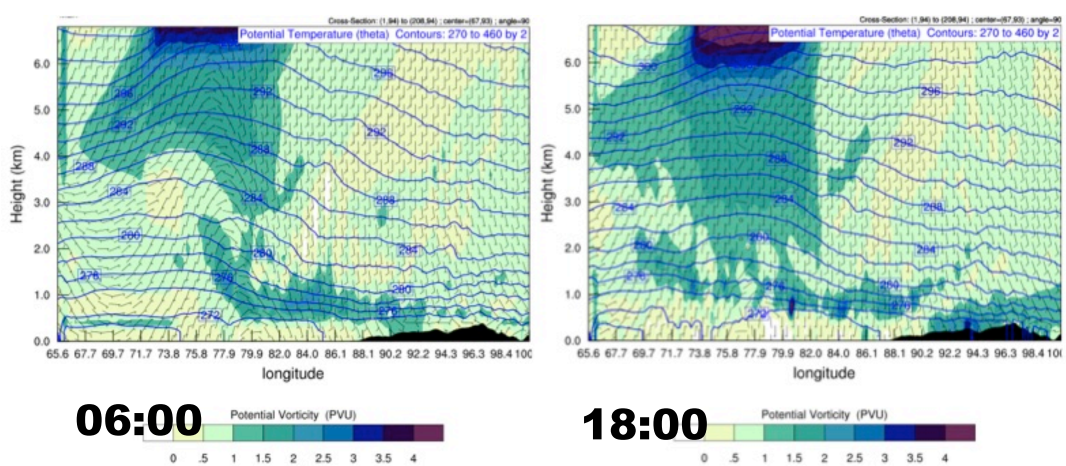
1. Latent heat release!

$$P = \frac{\xi_{\mathbf{a}} \cdot \nabla\Theta}{\rho}$$

- Ertel potential vorticity ([PVU] = 10^{-6}K m² кg^{-1} s^{-1})

Potential vorticity anomaly at **400 hPa level** (~ 7 km) – 9 PVU
Low-level anomaly, **associated with PL** – ~2.9 PVU

Potential vorticity, PVU



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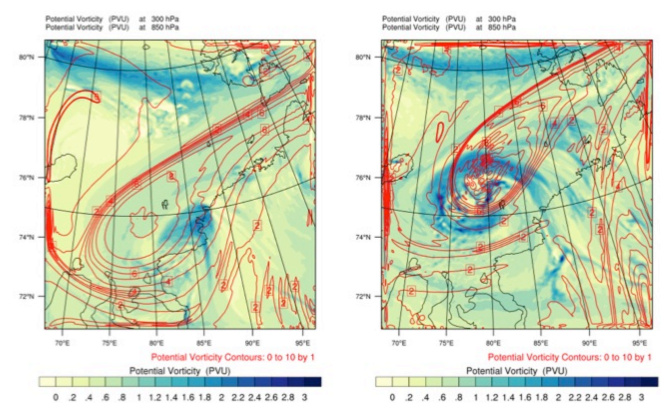
Potential vorticity, PVU at 850 hPa (colored) and 400 hPa (red lines) levels



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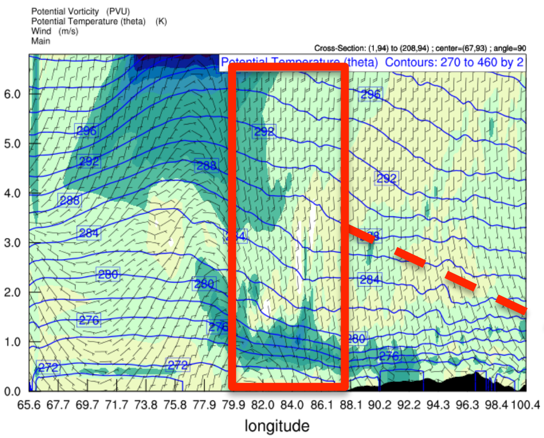
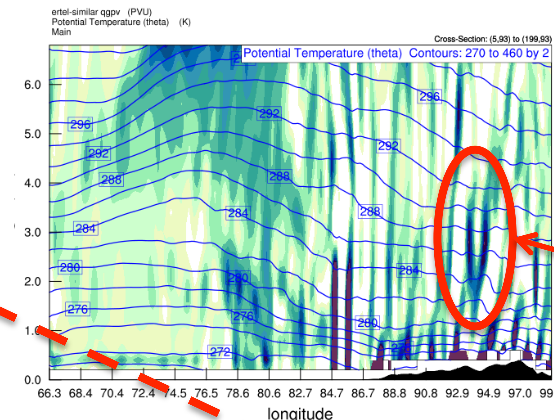
Quasigeostrophic assumption and Green's function

$$q = \xi_g + f + \frac{f_0 g}{N_0^2 \Theta_0} \frac{\partial \theta}{\partial z}$$ - quasigeostrophic potential vortex

$$P_g = \frac{\Theta_0 N_0^2}{\rho_0 g} \left[\xi_g + f + \frac{f_0 g}{N_0^2 \Theta_0} \frac{\partial \theta}{\partial z} \right]$$ - Ertel vortex in quasigeostrophic approximation





$$R = \frac{\frac{1}{k}\sum_{i=1}^{k}(m_i - \overline{m})(n_i - \overline{n})}{\sigma_m \sigma_n}$$

R = 0.46 – 0.59 (whole domain)

R = 0.69 – 0.82 (above water surface)

Ro = 7.13 >>1

$$N^2 \nabla_h^2 w + f_0^2 \frac{\partial^2 w}{\partial z_2^2} = f_0 \frac{\partial}{\partial z}(\mathbf{v_g} \cdot \nabla \xi_g) - \frac{g}{\theta_0} \nabla_h^2 (\mathbf{v_g} \cdot \nabla \theta)$$ - Quasigeostrophic omega-equation

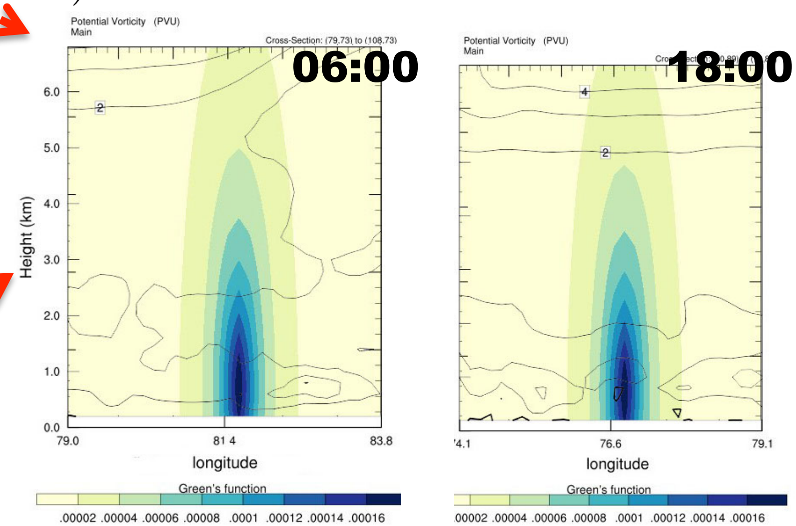
$$\nabla^2 \tilde{w} - \left(\frac{f_0}{2NH_p}\right)^2 \tilde{w} = F \rho_0^{1/2} \exp\left(-\frac{z' f_0}{2NH_p}\right)$$

The solution for unbounded problem is:

$$\tilde{w}(\mathbf{r_0}) = \frac{1}{4\pi} \iiint_V G(\mathbf{r_0}, \mathbf{r}) F(n) dx dy dz'$$

Where $$G(\mathbf{r_0}, \mathbf{r}) = \frac{\exp\left(-\frac{f_0}{2NH_p} R(\mathbf{r_0}, \mathbf{r})\right)}{R(\mathbf{r_0}, \mathbf{r})}$$

- Green's function in point with radius-vector $\mathbf{r_0}$



Green's function

Conclusion

1. We studied the **unusual event** of a mesoscale polar mesocyclone;
2. We put **two numerical experiment** with on and off microphysical processes parameterization, compared the results with observational data. The **model reproduces** the mesoscale **structure** of clouds, the wind field and distribution of integrated vapor content in mesocyclones.
3. An assessment of the significance of mechanisms of intensification in vortex dynamics, showing:

- The contribution of the **WISHE mechanism is negligible** (Hmax, LEmax <80 W / m2);
- In this cyclone the **atmosphere was static stability**, the implementation of the mechanism of **convective instability was impossible**;
- **The absence** of horizontal temperature gradient exclude the development **of baroclinic instability**;
- **Interaction with higher-level potential vorticity anomaly** (H_{Ro} = 6800 m), **influe** on the cyclone intensification;
- A **significant contribution** to the intensification of the vortex cores **make realization of the latent heat of condensation** in the middle troposphere (15 to 60% intensity).

4. The **possibility of using quasigeostrophic theory** in calculations applied to mesoscale cyclone **was shown;**
5. Green function was calculated, the foundation for the study of the mechanism of interaction anomalies of potential vorticity in the dynamics of polar mesocyclones was started.

In particular it was supposed to find out:

- Study of the evolution and structure of the selected mesocyclone;
- Determination of the prevailing in mesocyclone's dynamics mechanisms of generation and intensification;
- Examination of the nature of the mechanisms that affect the dynamics of the vortex.

Main investigating methods:

- **Analytical modeling**,
- **Ideal vortexes simulations,**
- **Real case studies**:
- - using three-dimensional atmospheric models
- - using multisensoric satellite data