The model of moisture-induced phase transitions as a tool for prediction of mesoscale precipitation.

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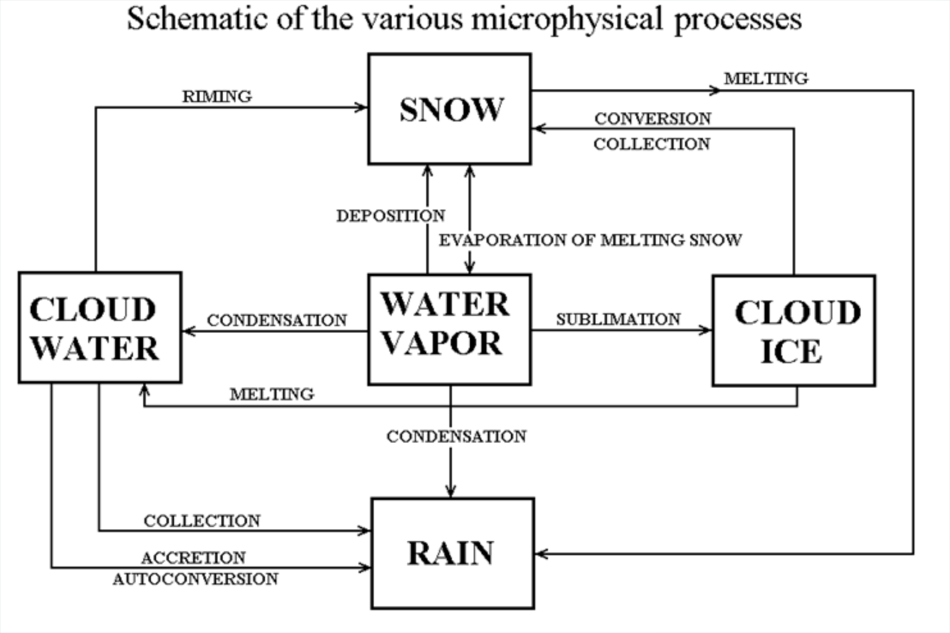
Climate change will have a substantial impact on the processes of cloud and precipitation formation which are of pronounced mesoscale nature. Due to complex multifactorial process of moisture transformation the precipitation field has high spatial and temporal variability, and its model description is the most challenging and ambiguous in prediction system calculation. Approbation of the model of formation of clouds and liquid and crystal precipitation using prognostic fields of the Russian Hydrometeorological Center and the IEM RPA "Typhoon" was fulfilled. The Kessler’s parameterization was adopted as a working tool for precipitation forecast. More than 130 calculations for different regions of the country and different seasons were performed. Mean rate of precipitation forecast success was near 70%.

Parameterization [Rutledge, Hobbs, 1983] based on aerodispersion representations of Kessler was adopted for precipitation forecast.

The model is formulated for five spectral averaged components of the atmospheric moisture: water vapor, suspended droplet and crystalline water, rainfall, and snow


Schematic of the various microphysical processes

The system of non-stationary equations of moisture transport and precipitation contains operators of advection and turbulent exchange for these components, and their right sides contain velocities of phase transitions (i = 1, ..., 13) written as a function of the required meteorological fields. Equations for heavy fractions also contain the terms of gravity sedimentation.

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$$\frac{dq}{dt} = D_{xy}q + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}K_H\frac{\partial q}{\partial z} - \Phi_1 - \Phi_2 - \Phi_3 - \Phi_4 - \Phi_5 - \Phi_6,$$

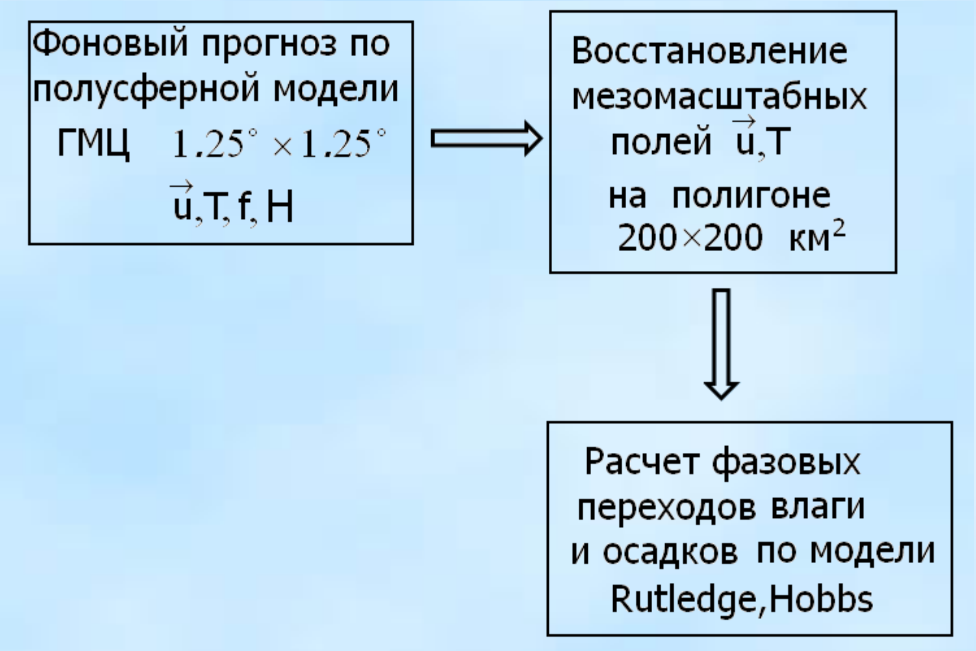
$$\frac{dq_c}{dt} = D_{xy}q_c + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}K_H\frac{\partial q_c}{\partial z} + \Phi_1 + \Phi_7 - \Phi_8 - \Phi_9 - \Phi_{10},$$

$$\frac{dq_i}{dt} = D_{xy}q_i + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}K_H\frac{\partial q_i}{\partial z} + \Phi_1 - \Phi_7 + \Phi_8 - \Phi_{11} - \Phi_{12},$$

$$\frac{dq_r}{dt} - \frac{1}{\bar{\rho}}\frac{\partial \bar{\rho}W_r q_r}{\partial z} = D_{xy}q_r + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}K_H\frac{\partial q_r}{\partial z} + \Phi_2 + \Phi_8 + \Phi_9 + \Phi_{10} - \Phi_{13},$$

$$\frac{dq_s}{dt} - \frac{1}{\bar{\rho}}\frac{\partial \bar{\rho}W_s q_s}{\partial z} = D_{xy}q_s + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}K_H\frac{\partial q_s}{\partial z} + \Phi_3 + \Phi_4 + \Phi_{10} + \Phi_{11} + \Phi_{12} + \Phi_{13},$$

Calculations were based on actual meteorological fields calculated in the system of weather forecast.



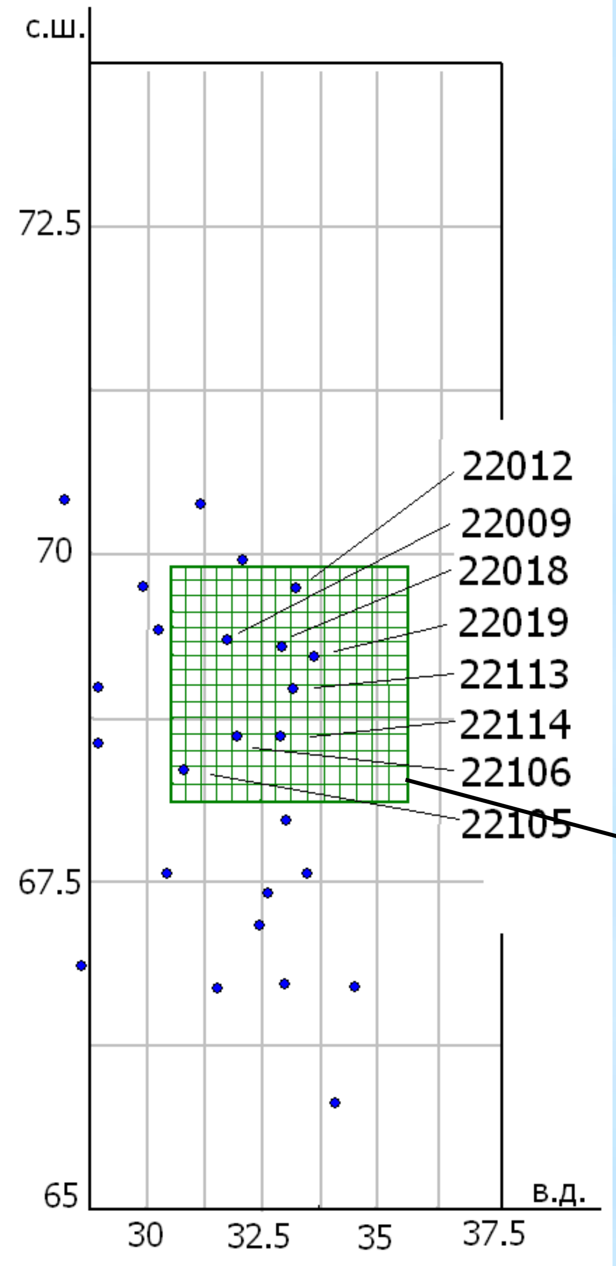
Фоновый прогноз по
полусферной модели
ГМЦ $1.25^\circ \times 1.25^\circ$
$\vec{u}, T, f, H$

Восстановление
мезомасштабных
полей $\vec{u}, T$
на полигоне
200×200 км^2

Расчет фазовых
переходов влаги
и осадков по модели
Rutledge,Hobbs

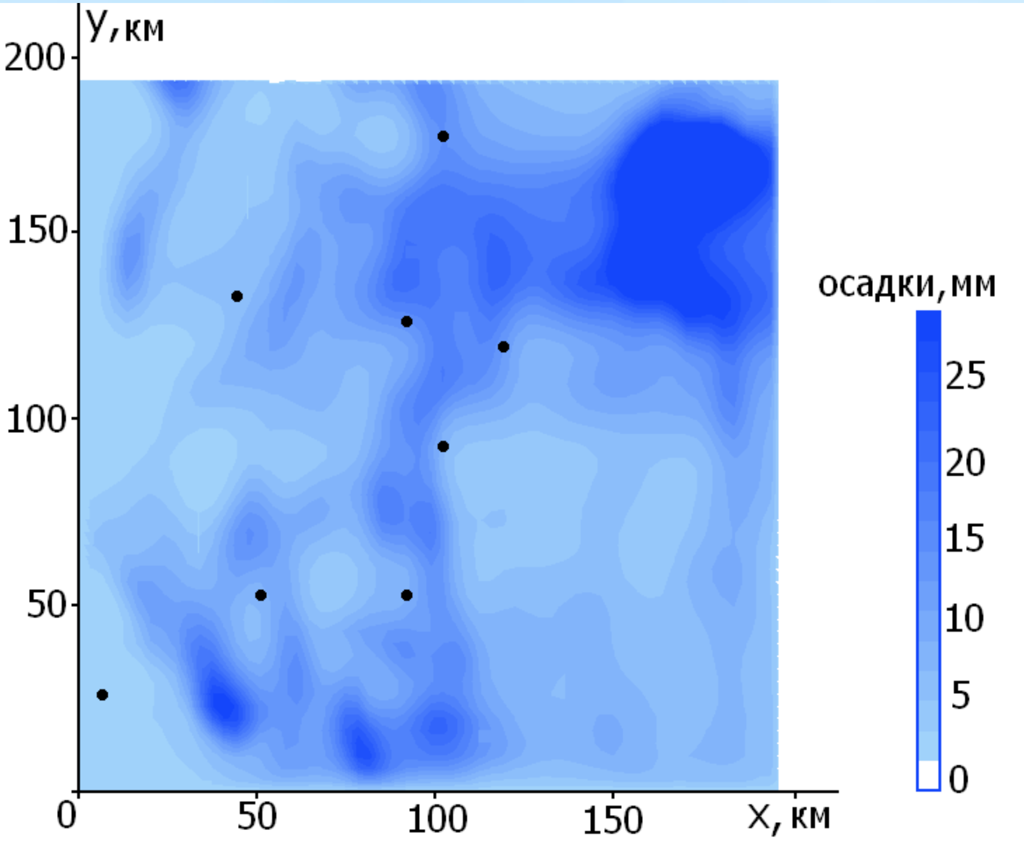
For this purpose, results of short-term weather forecasting RF Hydrometeorological Center performed with a hemispherical model with resolution of 1.25° × 1.25°, which provided large-scale dynamics of velocity, temperature and relative humidity fields on standard isobaric levels. From these data a fragment of 200×200 km^2 was isolated, where the numerical experimentation was carried out with a model of water phase transitions.

The aim was to reproduce the structure of near-surface precipitation using prognostic mesoscale meteorological information on wind and temperature fields. Estimated precipitation values were compared with actual ones measured at meteorological stations in the same time period.

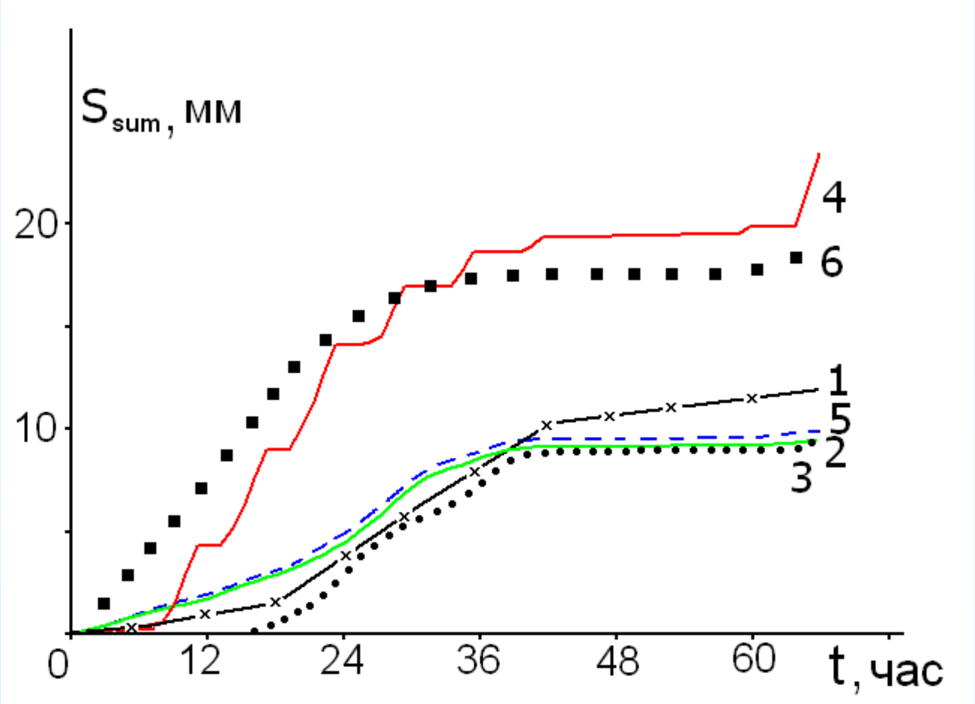


The figure shows the size of "large scale" area of 8.75° × 8.75° with the center in Murmansk city and the location of mesoscale polygon. Dots indicate weather stations among which a spatial interpolation of actual precipitation was performed.

As an example, consider a numerical prediction of precipitation for the period of 8 to 10 October 2007. Procedure of initialization of the specific humidity field is based on the Magnus formula with the assigned fields of T, p, f.



Estimated field of total precipitation for the period of 66 hours.
Here a pronounced mesoscale structure of precipitation is observed.

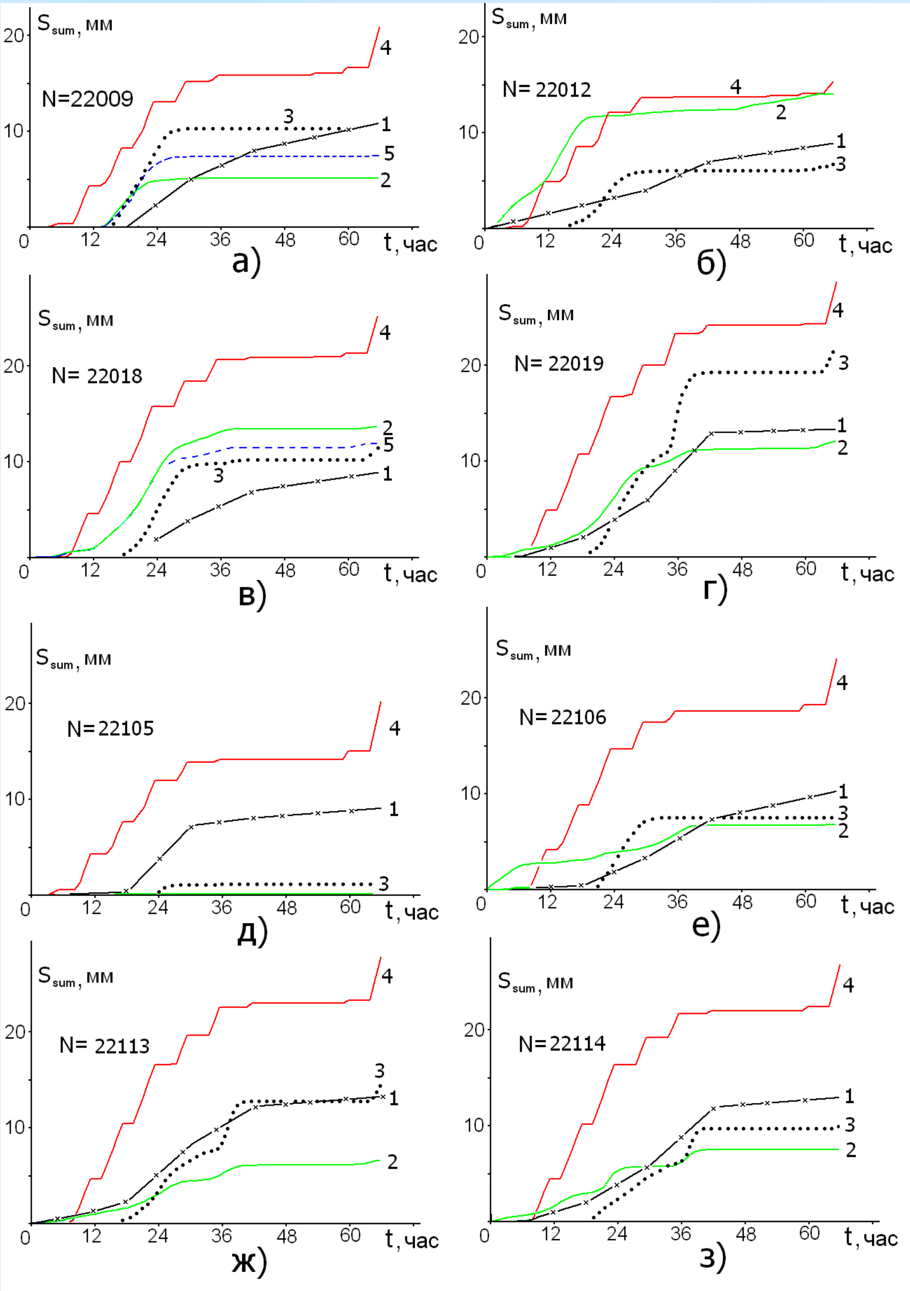


The course of the layer area-averagedprecipitation.

1 – observations;
2 - model calculation with Δt = 600 s;
3 - calculation with a background velocity field;
4 - initial data of "effective precipitation rate";
5 - model calculation with Δt = 60 s; and
6 - baseline data.

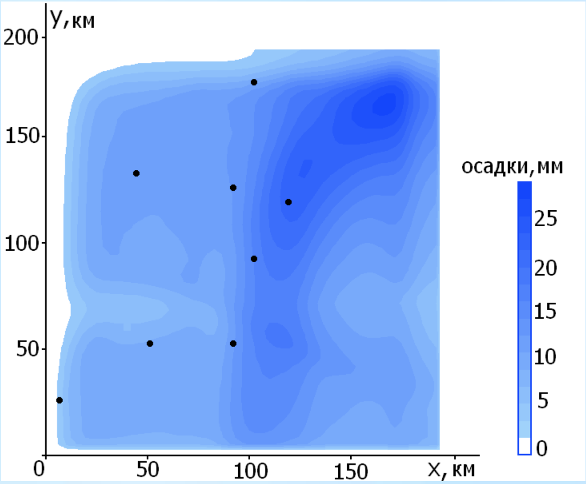
Analysis of the curves 1, 2 suggests that the numerical model satisfactorily reproduces the area averaged dynamics of precipitation.

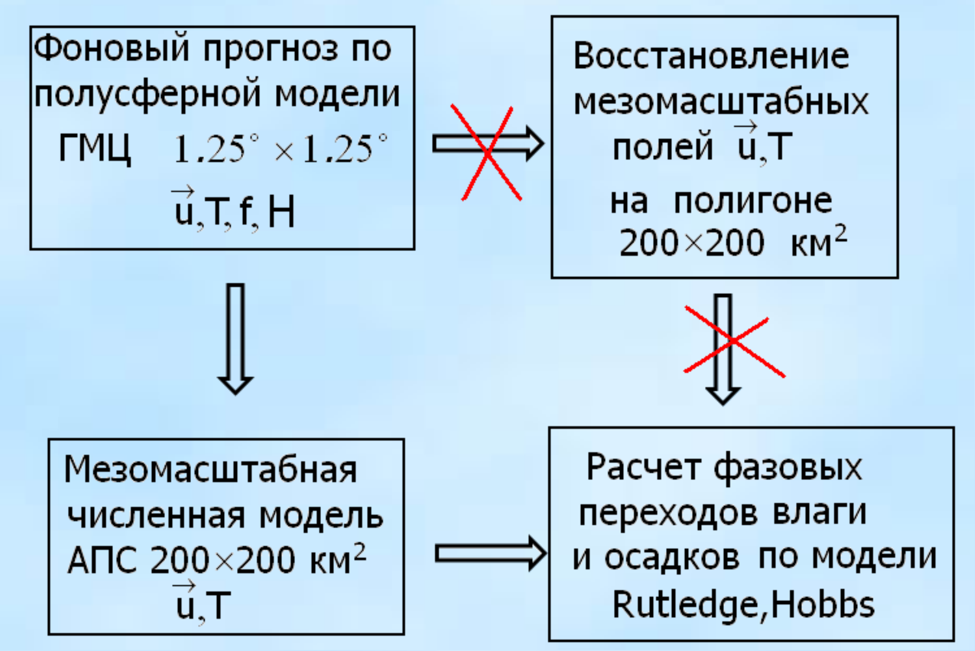
Comparison of precipitation between different weather stations



Local precipitation characteristics are worse than averaged ones. Calculated precipitation at observation points may be either lower (Fig. а,ж,з) or higher (Fig. б,в) than actual, and may be quite similar (Fig. г,е). Calculated layer of precipitation at the weather station No.22105 (Fig. д) was even close to zero.

Analysis of causes of errors led to the conclusion about high sensitivity of precipitation model to mesoscale wind fields. Thus, the forecast calculation using relatively smooth "background" precipitation rates gave a small-gradient precipitation field in which mesoscale details were leveled by a smoother field of advection. Almost all stations have improved prognosis.





Фоновый прогноз по полусферной модели ГМЦ $1.25^\circ \times 1.25^\circ$ $\vec{u}, T, f, H$

Восстановление мезомасштабных полей $\vec{u}, T$ на полигоне 200×200 км^2

Мезомасштабная численная модель АПС 200×200 км^2 $\vec{u}, T$

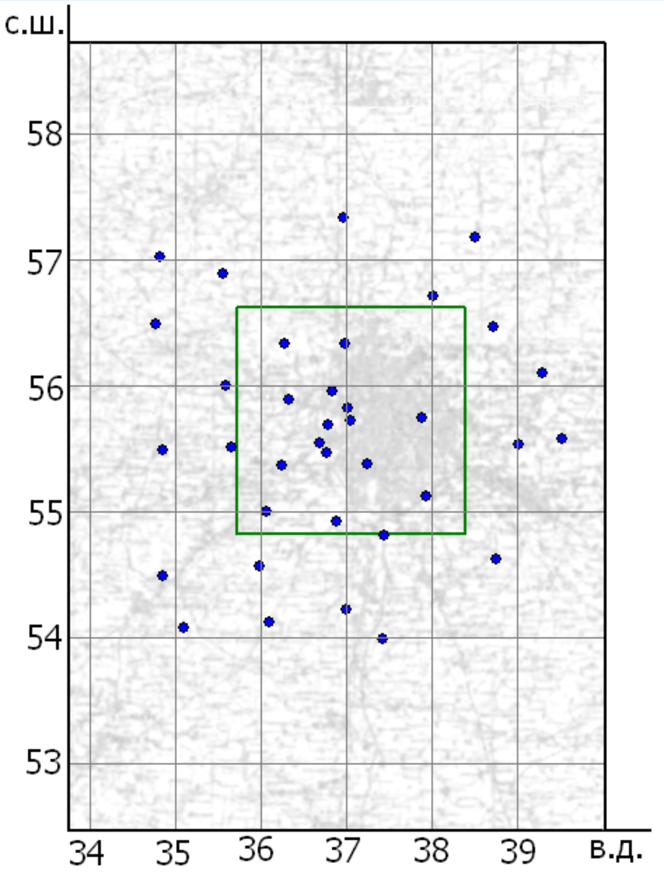
Расчет фазовых переходов влаги и осадков по модели Rutledge, Hobbs

In this connection, a calculation was performed, which used mesoscale numerical model of the ABL instead of non-hydrodynamic (parametric) reconstruction of mesoscale velocities. The quality of precipitation forecast increased, but this approach did not develop because of high resource-intensity, what did not suit the needs of practice on the criterion of efficiency.

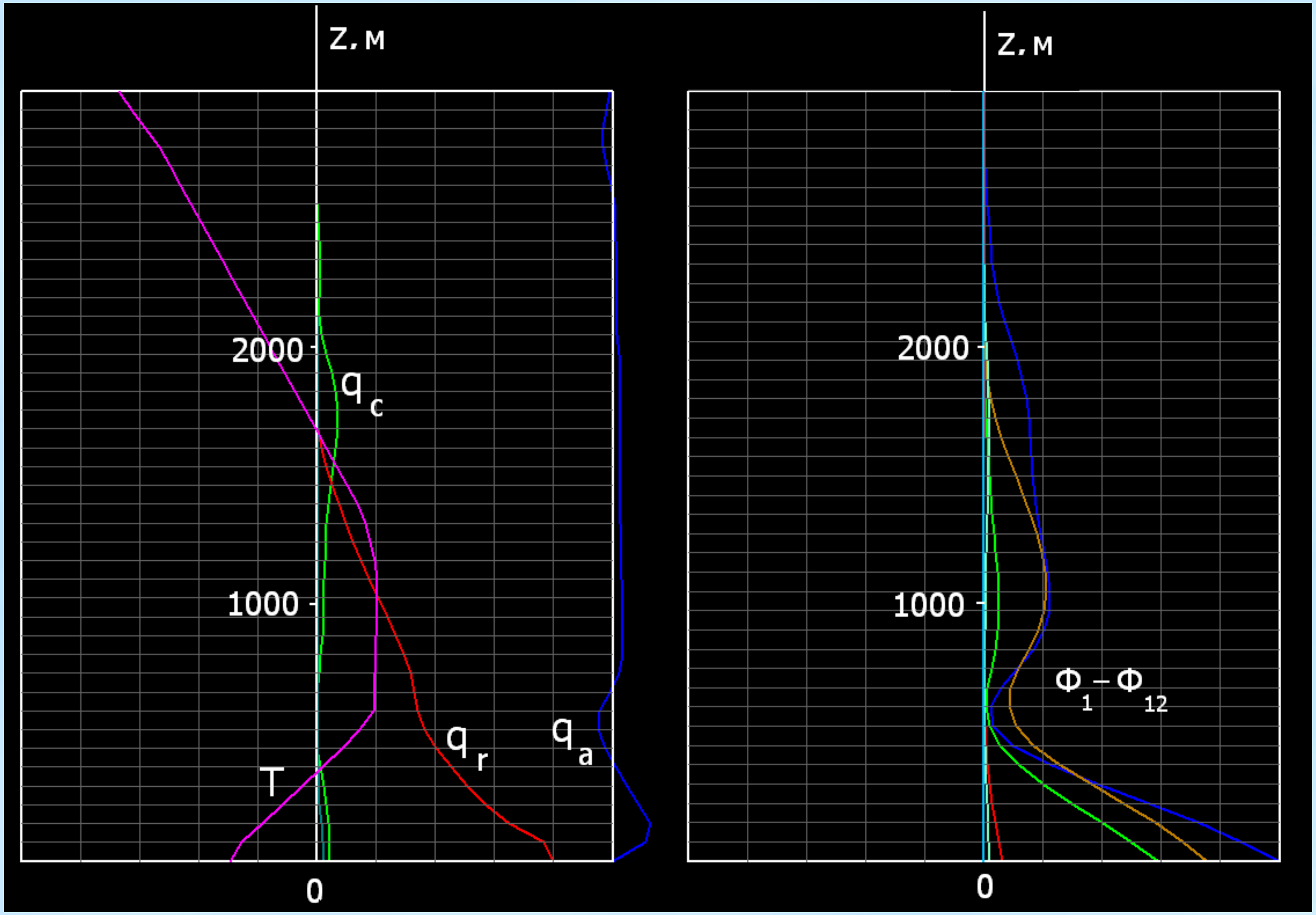
In general, more than 130 calculations for different regions of the country and for different seasons were performed. The average accuracy of precipitation forecast was about 70%, what can be considered as a positive result of a model of phase transition testing.

The model was tested to evaluate the ability to reproduce a so-called freezing rain - a rare and dangerous phenomenon causing damage to human health and economy. Meteorological background was presented by data of December 25-26, 2010 in the Moscow region, when freezing precipitation was recorded. Adequately description of the freezing rain required to supplement the model of moisture dynamics with equations for precipitation temperature, which were absent in the original paper [Rutledge, Hobbs, 1983].

Temperature of precipitations rarely is posed as a sought quantity in numerical models - it is usually assumed that it does not differ from the ambient air temperature. In describing the phenomenon of freezing precipitation the temperature of the liquid substance essentially determines the character of precipitation (sleet, rain). For reliable predictions of freezing rain the temperature should be determined in the course of solving the problem.



Background and mesoscale areas on the map of Moscow.

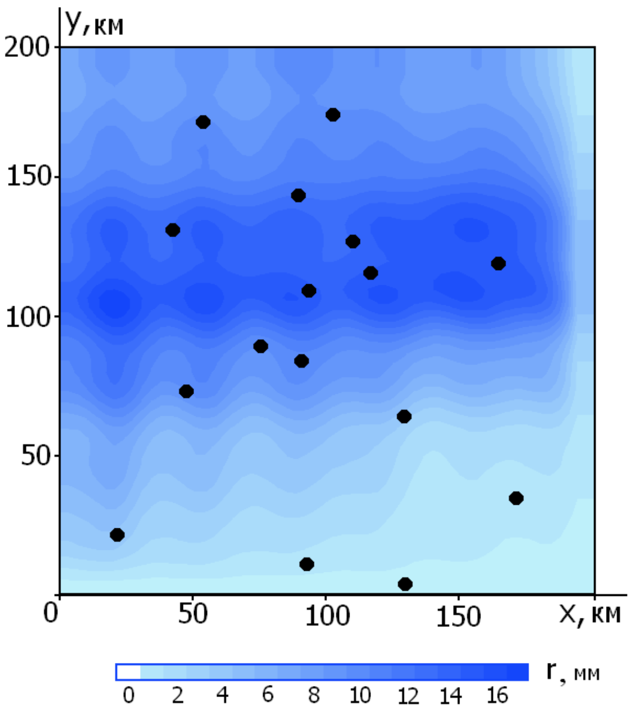


Vertical profiles of temperature (T) and components of the moisture field (normalized by the value q_{sat}).

Graphs at the right present components of the balance of phase transformations $\Phi_1 - \Phi_{12}$

Statistical characteristics of precipitation comparison by time ranges

№	date	t,h	M_{fact}, mm	M_{model} ,mm	σ, mm
1	25.12.2010	06	0.69	0.92	0.02
2	25.12.2010	18	4.11	4.32	0.04
3	26.12.2010	06	9.3	8.3	0.14
4	26.12.2010	18	4.87	4.86	0.05



The figure illustrates the estimated distribution of total precipitation at the time of 6:00 on December 26 characterized by a maximum intensity of precipitation. Note the spatial heterogeneity of precipitation: the maximum (17 mm) is located in the central region, with several local extrema nearby. The portion of liquid water in precipitation was 89%, that of the snow - 11%.

Summary

Presented mesoscale model for moisture field transport and transformation in the atmospheric boundary layer can be used for short-term forecasting of precipitation and, in particular, for the prediction of freezing precipitation.