ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 416, No. 7, pp. 1062–1065. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © D.P. Zinin, G.M. Teptin, O.G. Khutorova, A.P. Shlychkov, 2007, published in Doklady Akademii Nauk, 2007, Vol. 416, No. 1, pp. 112–114.

GEOPHYSICS

Modeling the Dynamics of the Refraction Coefficient Field for Radiowaves of the Centimeter Range in the Lower Atmospheric Layer

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Presented by Academician G.S. Golitsyn December 18, 2006

Received December 18, 2006

DOI: 10.1134/S1028334X07070185

A mesoscale numerical model of the real nonstationary atmosphere (WRF with core ARW) [1–3] was applied for the first time in this work to calculate spatiotemporal variations of 3D fields of the refraction coefficient for radiowaves of the centimeter range (hereafter, CR radiowaves) in the lower atmospheric layer on regional scales. A numerical analysis of the influence of spatial resolution of the model (from 1 to 10 km in the horizontal direction) on the quality of modeling showed that the high-resolution model appears more stable despite the significantly smaller area of the coverage on small time scales (high-quality modeling of the largest possible areas is significant due to the transport processes). This analysis was made on the basis of comparison with unique experimental data of long-term monitoring of atmospheric parameters with a time step of 1 min for different time scales, time of the year, and meteorological conditions. Such model is more preferable for modeling the refraction coefficient of the CR radiowaves. The calculations were performed for the territory of the Tatarstan republic. The deviation of the model from the experiment did not exceed 3–4% with respect to the root-mean-square scattering over the entire 10-yr period of observations, while the deviations do not exceed 20–40% in specific cases.

The real continuous fields of the atmospheric parameters are presented in the models of the atmosphere dynamics [6–9] with their approximations in nodes of the 3D discrete grid, which makes impossible explicit account for the physical processes of subgrid characteristic scales and worsens the adequacy of the results. The results of global modeling of the atmosphere over the entire planet are always very coarse, and it is necessary to apply regional modeling with a relatively small step of the grid using the results of the global modeling as the initial and boundary conditions. The level of the modern numerical nonhydrostatic 3D regional and mesoscale models of the atmosphere [6, 1, 2] allows us to consider them as a possible tool for the solution of practically important problems [3] of radiowave propagation in the troposphere. Objective numerical estimates of the degree of adequacy of model calculations of individual interesting values in different real situations and the investigation of the influence of the spatial resolution of the model on the results are of practical interest.

Dry air and water vapor make the main contribution to the refraction coefficient of CR radiowaves n in the atmosphere. We used the formula from [13]:

$$n = \left(\frac{155.2 \cdot 10^{-6} P}{T} + \frac{7.45 \cdot 10^{-1} e}{T^2} + 1\right)^{1/2}, \qquad (1)$$

where P and e are partial pressures of dry air and water vapors (mbar), respectively, and T is absolute temperature (K).

A numerical hydrodynamic model of the atmosphere of the Tatarstan Republic was developed on the basis of the WRF and calculation cluster of the Faculty of Physics (Kazan State University) to determine the fields of partial pressure of dry air and water vapor. The real topography of the territory and the nonideal initial and boundary meteorological conditions (the data of the final analysis of global modeling using the EMC model [14, 15] given by the American National Center of Environment and Prediction (NCEP)) were used in the model. The model used the following numerical schemes of different physical processes [12]: the Lin microphysical scheme, the Rapid Radiative Transfer Model (RRTM) scheme of longwave radiation, the

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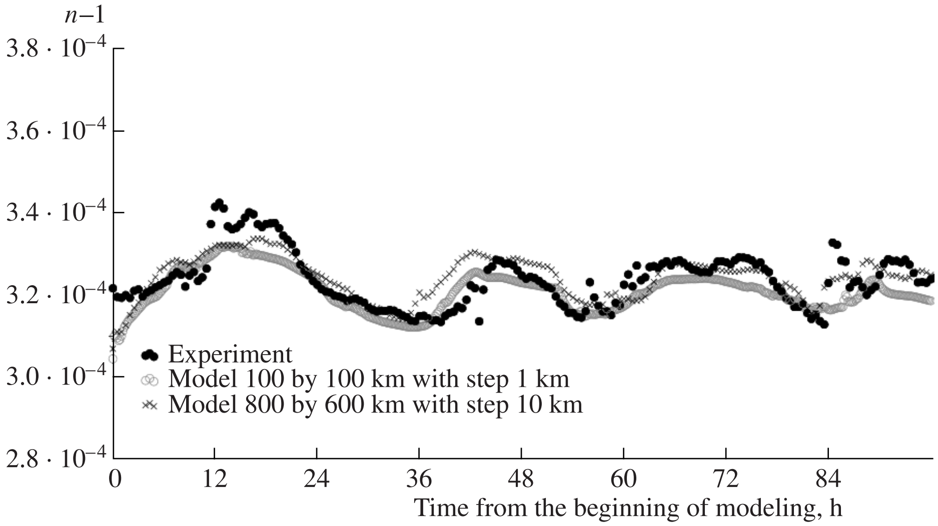

Fig. 1. Modeling during the period from July 1 to July 4, 2005. Time series of the model and experiment for the refraction coefficient of CR radiowaves.

Dudhia scheme of shortwave radiation, the Monin-Obukhov and Carlson-Boland MM5 similarity scheme of the surface layer, the RUC scheme of the Earth's surface, the Yonsei University scheme (YSU) of the planetary boundary layer, and the Cain-Fritz scheme of convection parameterization (only in one of the model versions). The model covers the lower atmospheric layer with a height up to 20 km. There are 30 horizontal layers with variable thickness increasing with height. The layer is 50 m thick near the Earth's surface. The calculations were performed for two versions of the model to study the influence of the spatial resolution. The first version covers a region with an area of 800 by 600 km (and the entire territory of Tatarstan) with a horizontal step of 10 km. The second version covers a region with an area of 100 by 100 km (the center is located in Aznakaevo) with a horizontal step of 1 km. In the latter case, the horizontal step of the model grid is rather small. Therefore, we must take into account the physical processes of the corresponding scales: parameterization of the convective motions is not used [9, 11, 12].

A dataset of meteorological parameters recorded at ten observation stations over several years with a time step of 1 min is available (see [10] for details). A comparison of the model results with the observation data was carried out to select time intervals that reflect the seasonal evolution of the real meteorological conditions. Here, we present an example of one of such time interval which reflects the general results of the work (54.88° N, 53.067° E, Aznakaevo, Tatarstan).

The root-mean-square difference between the corresponding time series of real and model data for different time intervals (windows) was calculated for the objective analysis of the correlation between the model results and experimental data:

$$S'(t_0, T) = \left(\frac{1}{T} \int_{t_0 - \frac{T}{2}}^{t_0 + \frac{T}{2}} (n_M(t) - n_E(t))^2 dt \right)^{1/2}, \qquad (2)$$

where n_M and n_E are the model and actually observed n values, respectively; T is the time window; and t_0 is location of the center of the window.

The deviation of the model from the experiment over the entire 10 yr of observations with respect to the root-mean-square scattering does not exceed 3–4%, while the deviation over a period of 4 days (the value of the order of the amplitude of the diurnal cycle) is not greater than 20–40% (Fig. 1).

The entire set of model calculations for both versions of the model, excluding specific cases, demonstrated a good correlation with the real observations (Fig. 1) on a time scale from 12 h and greater. Similar peculiarities of behavior, close locations of maxima and minima, and close amplitudes of perturbations are observed. Both versions of the model are characterized by small deviations from the experiment (Fig. 2). The difference is usually in favor of the model of high spatial resolution, but it is not significant (up to 10–20% of the difference in the absolute values of the root-mean-square deviation).

On smaller time scales (our analysis allows us to judge the behavior up to the windows of 0.5–1 h), individual sharp deviations of the experiment from the model were found (Figs. 1, 2; time values 12, 36–46, and 84 h). Beyond the time intervals of such irregular deviations, the correlation between the model and

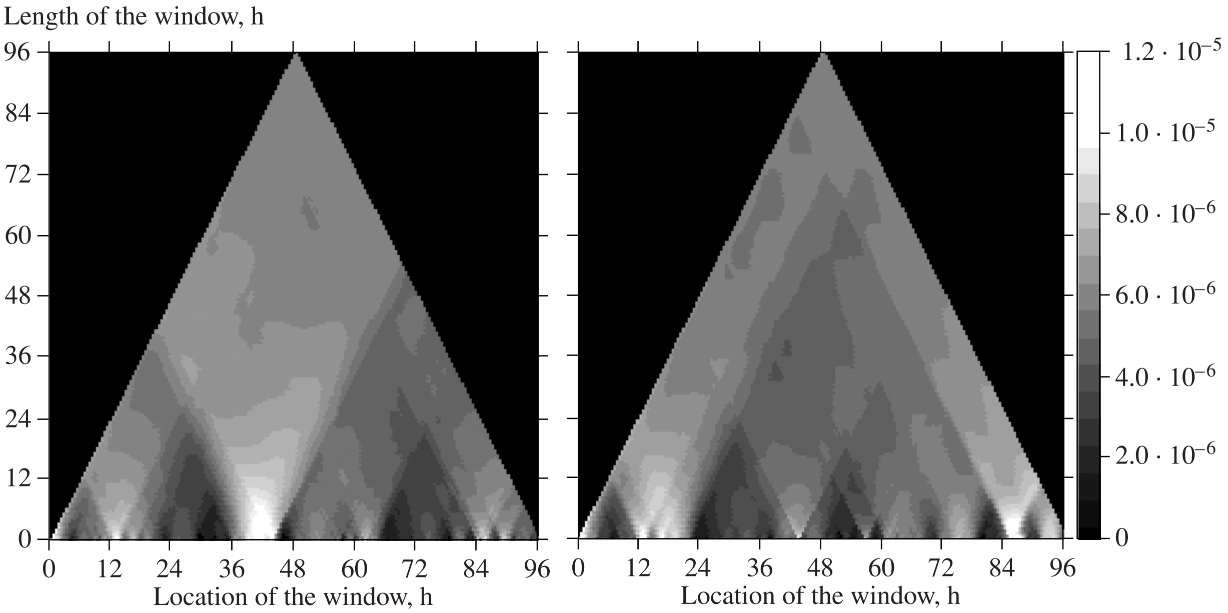

Fig. 2. Modeling during the period from July 1 to July 4, 2005, with the root-mean-square difference between the model and experiment for the refraction coefficient at the observation station in Aznakaevo. The modeling domain with a size of 800 by 600 km with 10-km resolution is shown on the left. The modeling domain with a size of 100 by 100 km with 1-km resolution is shown on the right.

experiment is regularly several orders of magnitude better than in the time windows greater than 12 h. A significant difference between model forecasts with different spatial resolution is found on such time scales. The high-resolution model regularly demonstrates either the presence or absence of sharp deviations from the experiment compared to the low-resolution model during the corresponding intramodel time or they are one order of magnitude weaker (Fig. 2, time period 36–46 h). The latter is related to the most prominent deviations of long duration in the coarse spatial model. However, for the smaller deviations in the coarse spatial model with shorter duration, the corresponding deviation in the high-resolution model can be manifested even more clearly (Fig. 2, time period of approximately 84 h). Such behavior is not regular, but a decrease in the value and duration of strong sharp perturbations compared to the increase in the manifestation of small deviations is predominant.

As a result, the low-resolution model demonstrates significant regular instability in the deviation of the experiment with large individual peaks. Despite a significantly smaller area of coverage (quality modeling of the largest area is significant due to transport processes), the high-resolution model appears more stable at small time scales at equal mean deviations with the previous model on time scales from 12 h and greater. It is preferable for modeling the refraction coefficient for the CR radiowaves.

ACKNOWLEDGMENTS

The authors thank Academician G.S. Golitsyn for attention to our work and advice that was taken into account in preparing the article.

This work was supported in part by the Russian Foundation for Basic Research (project no. 04-05-64194) and the NIOKR RT Foundation (project nos. 06-6.3-13 and 09-9.5-32).

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