ATMOSPHERE, IONOSPHERE, SAFETY

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Proceedings of International Conference "Atmosphere, ionosphere, safety" (AIS-2016) include materials reports on: (I) — response analysis of the atmosphere — ionosphere to natural and manmade processes, various causes related geophysical phenomena and evaluate possible consequences of their effects on the human system and process; (II) — to study the possibility of monitoring and finding ways to reduce risk. Scientists from different countries and regions of Russia participated in the conference. Attention was given to questions interconnected with modern nanotechnology and environmental protection. Knowledge of the factors influencing the atmosphere and ionosphere can use them to monitor natural disasters and to establish the appropriate methods on this basis.

Content of the reports is of interest for research and students specializing in physics and chemistry of the atmosphere and ionosphere.

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The Supercomputer Model of Atmospheric Processes of Common Access Shared via the Internet

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Lately, the problems of propagation of acoustic-gravity waves in the atmosphere and of influence of these waves on the atmosphere call significant interest. It is, for example, the problems of generation of waves by an auroral electrojet. These are also the problems of generation of waves by diverse meteorological phenomena and of influence of these waves on the upper atmosphere and ionosphere. These are the problems of origin and evolution of tornadoes and the problems of waves generated by tornadoes. These are the problems of atmospheric convection, storms and squalls and of influence of these phenomena on the upper atmosphere. These are also the problems of wave propagation from earthquakes, or of wave propagation from micro-oscillations of the Earth surface before earthquakes. Saying about influence of waves on the atmosphere, we first mean the heating the atmosphere by waves. On the modern representations, the heating of the upper atmosphere by propagated upward waves is significant; this heating is comparable to heating by the solar radiation. The waves can influence essentially on atmospheric flows; that is, they influence on the general atmospheric circulation. At last, breaking waves can create turbulence in the atmosphere; the investigation of formation and evolution of turbulence presents doubtless interest.

For modeling and examination of these diverse phenomena, the authors in the beginning of 2000's have developed a supercomputer numerical model based on numerical integration of non-linear complete three-dimensional system of hydrodynamic equations:

$$\frac{\partial\rho}{\partial t}+\frac{\partial\rho u}{\partial x}+\frac{\partial\rho v}{\partial y}+\frac{\partial\rho w}{\partial z}=0,$$

$$\frac{\partial\rho u}{\partial t}+\frac{\partial\rho u^2}{\partial x}+\frac{\partial\rho uv}{\partial y}+\frac{\partial\rho uw}{\partial z}=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x_i}\xi(z)\frac{\partial u}{\partial x_i}+2\rho\omega_z v,$$

$$\frac{\partial\rho v}{\partial t}+\frac{\partial\rho uv}{\partial x}+\frac{\partial\rho v^2}{\partial y}+\frac{\partial\rho vw}{\partial z}=-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x_i}\xi(z)\frac{\partial u}{\partial x_i}+2\rho\omega_z u,$$

$$\frac{\partial\rho w}{\partial t}+\frac{\partial\rho uw}{\partial x}+\frac{\partial\rho vw}{\partial y}+\frac{\partial\rho w^2}{\partial z}=-\frac{\partial P}{\partial z}+\frac{\partial}{\partial x_i}\xi(z)\frac{\partial w}{\partial x_i},$$

$$\frac{1}{\gamma-1}\left(\frac{\partial P}{\partial t}+\frac{\partial Pu}{\partial x}+\frac{\partial Pv}{\partial y}+\frac{\partial Pw}{\partial z}\right)=-P(\nabla\vec{v})+\frac{\partial}{\partial x_i}\kappa(z)\frac{\partial T}{\partial x_i}+\xi(z)\frac{\partial v_k}{\partial x_i}\frac{\partial v_k}{\partial x_i}+Q(z),$$

$$Q(z)=-\frac{\partial}{\partial z}\kappa(z)\frac{\partial}{\partial z}T_0(z)$$

In the equations, ρ is density, u, v, w are horizontal and vertical velocity components $\vec{v} = (u,v,w)$; P is pressure; g is the acceleration of gravity, γ is an adiabatic index; $\xi(z)$, $\kappa(z)$ are coefficients of viscosity and thermal conductivity; $T_0(z)$ is a background temperature. Here x and y axis are horizontal. The axis z is directed upward. In index labels; $i,k = 1,2,3$; $(x_1, x_2, x_3) = (x,y,z)$; $(v_1, v_2, v_3) = (u,v,w)$. The symbol t designates time and $P = \frac{\rho RT}{\mu(z)}$, where $\mu(z)$ is a gas molecular weight. ω_z represents local vertical component of the Earth's angular velocity. The equation system can include external sources of momentum or heat.

A background state of the atmosphere and dependence of equations coefficients on z has been taken from the empirical MSIS200 model of the atmosphere. The source $Q(z)$ is introduced into the model to make a background state be stable.

The considered model is a regional one. It allows modeling the behavior of the atmospheric gas in a field with a horizontal scale of several thousand kilometers and with a vertical size of from the Earth surface up to the altitude of 500 km. The boundary conditions at the altitude h=5000 km are standard:

$$\left(\frac{\partial T}{\partial z}\right)_{z=h}=0,\ \left(\frac{\partial u}{\partial z}\right)_{z=h}=0,\left(\frac{\partial v}{\partial z}\right)_{z=h}=0,(w)_{z=h}=0$$

The conservative numerical method is applied for solving the equation system. In a pattern, the numerical method scheme is similar to the known Lax-Wendroff method. Lax and Wendroff has considered hydrodynamic equations written in the form of conservation laws

$$r_t + (q(r))_x + (q(r))_y + (q(r))_z = 0$$

Here r is a column consisting of density, momentum density and energy density. Accordingly, $q(r)$-is a column-function of fluxes of the enumerated values. Lax and Wendroff has approximated these conservation laws as follows:

$$\frac{r_{ijk}^{j+1} - r_{ijk}^{j}}{\tau} + \frac{q_{i+1/2,j,k}^{j+1/2}(r) - q_{i-1/2,j,k}^{j+1/32}(r)}{h_1} + \frac{q_{i,j+1/2k}^{j+1/2}(r) - q_{i,j-1/2,k}^{j+1/2}(r)}{h_2} + \frac{q_{i,j,k+1/2}^{j+1/2}(r) - q_{i,j,k-1/2}^{j+1/2}(r)}{h_3} = 0$$

For evaluation of $r_{ijk}^{j+1/2}$, Lax and Wendroff used explicit methods. However, we use for evaluation of $r_{ijk}^{j+1/2}$ only implicit approximati

$$2 * \frac{r_{ijk}^{j+1/2} - r_{ijk}^{j}}{\tau} + \frac{q_{i+1/2,j,k}^{j+1/2}(r) - q_{i-1/2,j,k}^{j+1/2}(r)}{h_1} + \frac{q_{i,j+1/2k}^{j+1/2}(r) - q_{i,j-1/2,k}^{j+1/2}(r)}{h_2} + \frac{q_{i,j,k+1/2}^{j+1/2}(r) - q_{i,j,k-1/2}^{j+1/2}(r)}{h_3} = 0$$

It does simulations essentially more difficult, than within the limits of standard Lax-Wendroff method. Nevertheless, these complications caused by necessity. We need counteract against accumulation of the errors evoked by discretization of equations. It is well known, that the discretization errors of equations are accumulated. After a while, a numerical solution, as a rule, considerably differs from the exact solution. The rate of accumulation of these discretization errors essentially depends on structure of the used numerical scheme. The carried out mathematical investigations have shown the discretization errors from acoustic waves give a potential greatest contribution to the common computation error. For numerical methods of the suggested structure, these computation errors are not accumulated, but mutually canceled; it is confirmed by proven theorems and by test calculations. The analysis of accumulation of commutation errors is studied in details in [1—3]. In these papers and in [4], the outcomes of test simulations are given also; the test simulations have demonstrated the numerical solution gives three correct digits during several hours of real time simulation.

Therefore, the developed numerical method allows calculating correctly behavior of acoustic-gravity waves up to significant times, till several tens of hours. The horizontal scales of the simulated field can be of several thousand kilometers. The vertical size of the simulated field is from the Earth surface up to thermosphere altitudes. The simulations are performed without significant contortion of waves and allow us to calculate the influence of waves on the atmosphere with well accuracy.

High accuracy simulation is important at calculation of the influence of waves on the atmosphere parameters, because the influence of waves on the atmosphere is a final stage of wave evolution and takes place at major times. Besides, the separate wave often gives weak effect on the atmosphere, but this effect should be calculated correctly because the weak effects of influence on the atmosphere are accumulated. As a result, we can have a vital modification of the atmosphere parameters caused by influences of many waves during significant time.

All computations are performed a supercomputer in parallel at 3 levels. The calculations are in parallel within each processor kernel; the calculations are scheduled between node kernels at each node of a cluster, and computations are proportioned between the nodes of a computing cluster. Therefore, the supercomputer program is very productive and is one of the fastest.

The development of supercomputer programs demands a lot of special knowledge far from problematic of physics of atmosphere and ionosphere and belonging to both the mathematical field and the field of parallel supercomputer computations. A specialist in the field of physics of the atmosphere and ionosphere is not supposed to be a major specialist in mathematical and computer sciences. Taking this cicumstance in view, some special computer program with GUI that allows utilizing the supercomputer program without any skills in supercomputer computations and numerical methods is developed.

On the Internet, some special server is placed, and any scientist can work with the atmosphere simulation program. The program disposed on the server, after user registration, starts a dialogue with the scientist, and the program ask some questions about the problem interesting to the scientist.

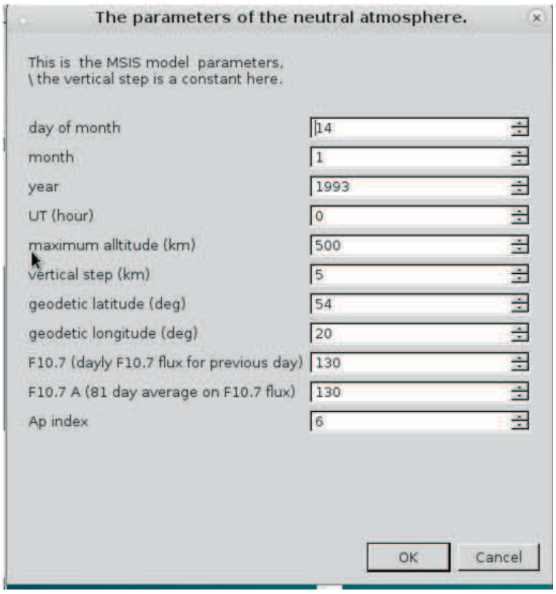

FIGURE 1. The questions about geographical location and time.

For example, the program ask the geographical place under consideration, date, time. These answers are necessary to use a built-in empirical model of the atmosphere to determine a background state of the atmosphere and the behavior of equations coefficients. Further, the user chooses dimensionality of a commutative grid, and decides, whether he will allow for a wind or not. At the next step, the user answers whether he considers an initial-value problem, or a boundary problem, or an initial-boundary-value one. The program asks also about presence of sources (heating, momentum transfer to gas from other processes).

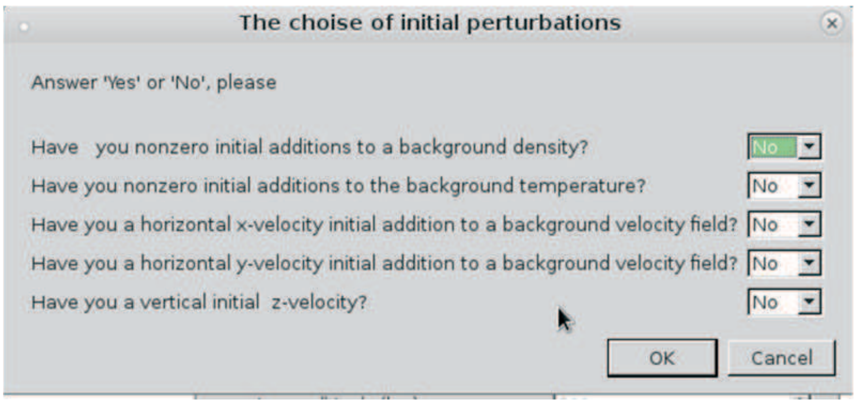

FIGURE 2. Some questions concerning of initial conditions.

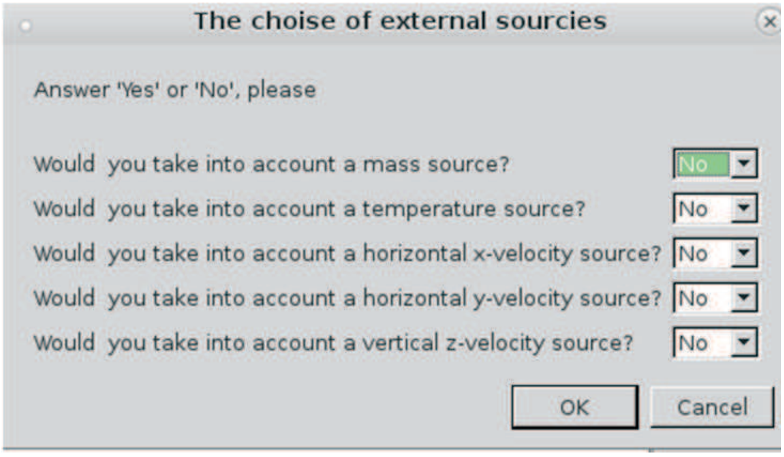

FIGURE 3. Some questions concerning sources.

The statement of initial and boundary conditions, also the statement of sources can demand inputting the complementary information. Namely, inputting of functions describing sources in field and on the boundary, or inputting the functions describing the initial conditions may be necessary. Taking in view this necessaty, some little possibility of programming and inputting the demanded data is represented to the user.

In the course of data input, the server inspects the information inputted by the user concerning syntactic errors; if the inputted data is correct, then the server makes tentative compilation of the program. If no errors are discovered, then, if the user considers the inputted data to be correct, then the server makes a contact with a supercomputer. It configures the program to a supercomputer, and sends the problem to a supercomputer. Since this step, the interaction of the user with the process is restricted. The problem is anew compiled and checked up by a supercomputer, and the task is putt to a sequential queue on fulfillment on a supercomputer. In the course of calculations, the supercomputer and the server regularly come into contact and are synchronized: outcomes of computations are systematically sent to the server.

The user can inspect the course of computations and can take the outcomes of simulations from the server. Thus, direct contact of the user to a supercomputer is absent. The developed complex of programs fulfills the parallel computations automatically. Knowledge of the mathematical theory of a solution of equation is not required, it is necessary only to answer questions asked by the program.

The program also allows the simulation of transfer of impurities.

In Fig. 4 an example of the supercomputer simulation of wave propagation from a small hot field localized near 100 km in the altitude is shown.

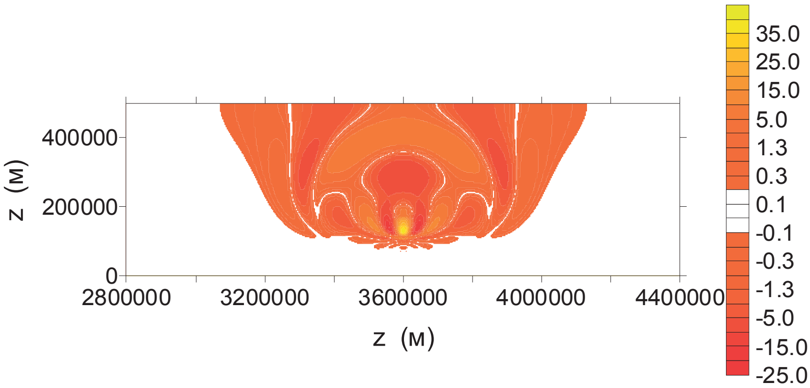

FIGURE 4. Temperature perturbation at t = 553 sec.

The authors hope that the developed complex of supercomputer programs will progress.

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On Analysis of N-wave Coseismic Ionospheric Response in Estimation of The Seismic Energy for Submarine Earthquakes

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N-wave type variations of Total Electron Content (TEC), registered via GPS during the first 15 minutes after the seismic event, are observed as the ionospheric response to the transition of acoustic waves, generated during the strong ($M_w \geq 8.2$) submarine earthquakes. The coseismic variations of TEC are filtered in acoustic