MATHEMATICAL SIMULATION OF ATMOSPHERE DYNAMICS AND DUST ENVIRONMENT AT HIGH-POWER VOLCANIC EXPLOSIONS

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The physical mathematical model used to predict in a result of volcanic explosion the gasdynamic phenomena and dynamics of dust particles in the atmosphere and also the dust distribution settled out on the ground was developed and on its basis a three-dimensional code VEDEM was written. The physical model involves the consideration of explosive wave formation and propagation, the rising motion of explosion cloud containing dust particles, lifting and settlement of particles of ashes and dust. The factors and processes are investigated which have influence on the transportation of dust particles in the atmosphere. Dynamics of dust is described on the basis of the model of discrete representatives. For difference approximation of a set of gasdynamic equations, the two-stage Runge-Kutta TVD-scheme of the second order accuracy in space and time is used. Numerical simulation of volcanic explosions of different power and spatial scale was carried out and the results on dynamics of airflows and distribution of dust particles were analyzed.

Physical Mathematical Model of Volcanic Explosion

The physical model is based on separate description of the processes of dust transportation and dymamics of area perturbed by gasdynamic motion. The majority of energy, which is released in a result of explosion, is expended on the formation of shock wave. This wave propagates from the place of explosion with a supersonic velocity, actuates the air, and changes its pressure and temperature. Characteristics of cold atmosphere (density and pressure as a function of atmosphere height) are determined using the CIRA-86 model [1]. The model of dust cloud formation and transportation is based on three basic assumptions. At first, it is supposed that dust particles are moved with a velocity equal to local airflow one. This assumption is valid for a wide range of particle sizes as the time during which the velocity of dust particle reaches that of airflow has the order of several milliseconds. Secondly, the reliable evaluations of state of dust environment can be made in the assumption that gasdynamic fields are the same as in the absence of dust. Such approximation is valid, if the kinetic energy of dust particles is small compared with the total local energy of air and dust density is smaller air one. Thirdly, the motion of any dust particle or particle group does not depend on the presence either motion of any other particle or particle group. This assumption is valid, if the number of dust particles per unit volume is not so great. It is also supposed that the dust ejection and energy release are occurred instantly as a single explosion.

The basis of mathematical model to describe the dynamics of volcanic explosion in the atmosphere is the differential equations of gasdynamics. For difference approximation of these equations in space, the explicit second order accuracy TVD-scheme [2] is used. For transition from n-th time step to n+1-th the two-stage Runge-Kutta TVD-scheme [3] is applied which has also second order of approximation in time. The merit of the TVD-schemes is that they allow with a good accuracy to investigate gasdynamic flows the velocity of which is less the characteristic sound velocity. It is especially important at the simulation of dust cloud dynamics in late time moments when the velocity of air motion becomes low (10-20 m/s) and the state of dust cloud is determined by parameters of circulating air flows. The problem is considered in a three-dimensional Cartesian coordinate system. It is supposed that the axes X1 is directed upwards, the axes X2 - to the right, and the axes X3 is perpendicular to the plane (X1,X2). The plane (X2,X3) corresponds to the ground surface. The half-space X1>0 is occupied by the atmosphere. The source of energy release is placed on the plane (X2,X3) and in the upper half-space X1>0. The calculation of gasdynamic characteristics is performed on an irregular grid the size of which is determined by the area of air perturbed by motion. At reaching by the airflow of one of the grid boundaries the increase of mesh sizes using the law of geometrical progression with a specific factor is performed.

Model of Particles-Representatives

Volcanic ashes are considered as a polydispersible particle system of specific mass. Under term of dust in our model the large variety of matter ejected from the volcano crater is assumed. This matter can be characterized according to external appearance (mountain rocks, volcanic sinter, pumice, ashes, etc.), physical properties, chemical composition. The set of dust particles localized in some area and close in characteristics is represented as one particle-representative [4]. The mass of representative is determined to equal the total mass of the whole set of the same type dust particles. The state of each representative is defined with use of the specification of three spatial coordinates, three velocity components and mass. The transportation of representatives is simulated on the basis of the Monte-Carlo method. For this purpose the displacement in space during a small time interval is determined as a random function of local gasdynamic velocity and velocity which the representative gains due to gravity. Action on the dust particles of air turbulence is also taken into account using the semiempirical diffusivity. The mass distribution of representatives on sizes is determined using the lognormal law with constant dispersion and median.

Results of Numerical Simulation

Initially, it is supposed that the total energy release is contained in the thermal energy of gas having the temperature about 1700 K, density $1{,}29\cdot10^{-3}$ g/cm^3 and occupying the hemispherical volume with a specified radius. In consequent time moments, the expansion of hot area into the inhomogeneous atmosphere is considered. To describe the dust particles in the range of diameters from 0,2 microns up to 2 mm, 20 discrete sizes of particles (groups) was used. The number of particles-representatives in each of the groups was taken to equal 4000. The area of space contained in one quadrant was only considered, as the problem is symmetrical with respect to the vertical axes X1. The gasdynamic equations were approximated in the computational domain with a grid having 80x80x80 meshes.

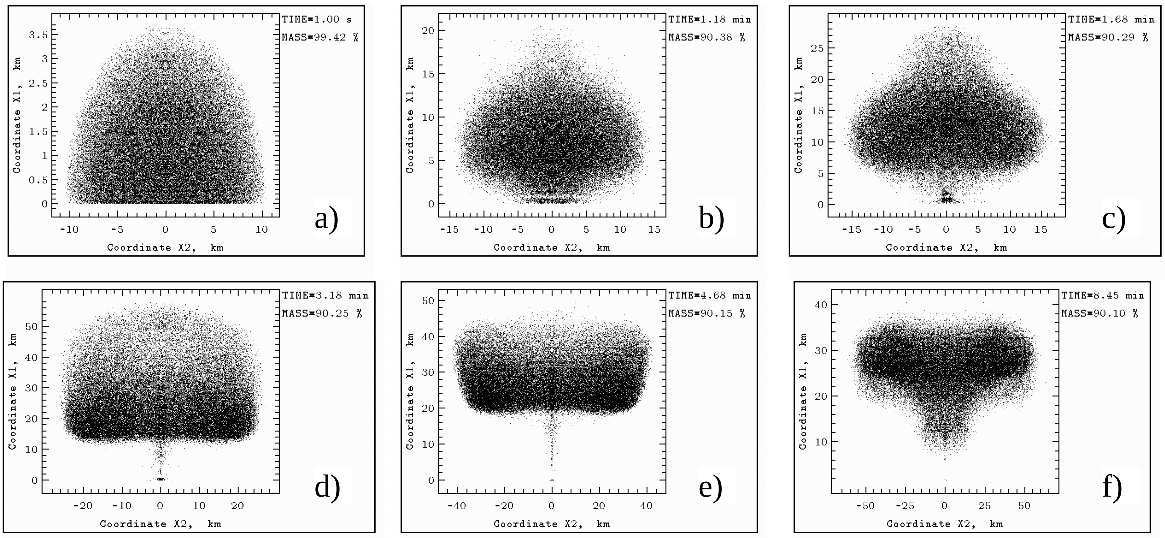

Fig. 1. The shape of dust cloud for different time moments. View along axis X3. Parameter MASS means the percentage of the dust mass in the atmosphere.

As an example the results on dynamics of dust cloud formation for explosion with the radius of 10 km and the energy release 800 Mt of trotyl equivalent in the hemisphere compressed in three times on the atmosphere height are shown in fig. 1. The mass of ejected dust was taken to equal 1 Gt. Initially the dust particles were distributed uniformly in the area of energy release (fig. 1a). Initial growth and formation of dust cloud is completed in a very short time period ~ 1 min (fig. 1b). Due to the formation of rarefied volume and its lifting the complex vortex motion of air is occurred in the area of explosion (fig. 2), which takes direct effect on a rise and formation of dust cloud. The amount of particles at the cloud bottom decreases with time (fig. 1c) as the particles float with the rarefied area. To the time moment about 1,7 min the separation of the dust cloud from the ground surface and the rise on the height up to 25 km (fig. 1c) are occurred. Due to gravity action, the amount of particles in the top of cloud decreases with time. The dust is concentrated close to the low boundary of cloud (fig. 1d). To the time moment about 4,7 min,

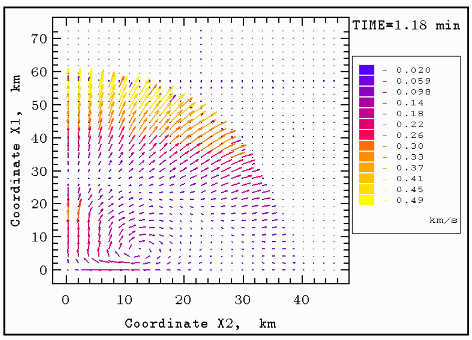

Fig. 2. Field of velocity.

the inverse airflows act on the cloud top in result of that a height of dust cloud is decreased and its top is flattened (fig. 1e). Due to action of horizontal airflows, the size of dust cloud to the time moment about 8,2 min reaches the radius more than 50 km (fig. 1f). To the given time moment the dust mass that is in the atmosphere makes 90,1 % of the ejection mass. On later stage the heavy dust particles that initially were raised by strong airflows on a significant height are concentrated at the cloud bottom and settled out on the ground surface.

Conclusion

1) The developed model of volcano eruption based on the TVD-schemes and the model of particles-representatives give a possibility to describe adequately the gasdynamic processes originating in the atmosphere and the dynamics of dust particles. The given model can be used to simulate the explosive phenomena in the inhomogeneous atmosphere such as the meteorite explosion at its impact on the Earth surface, the volcano explosion and to predict the consequences. **2)** It is found that the motion of shock wave front along the Earth surface for explosions of different powers has a property of similarity on distances larger the area of energy release in some times that corresponds to closeness of calculations to the results of the theory of point explosion. The shock wave causes the destruction of ground plants on a distance exceeding the initial area radius of energy release in 4-5 times. **3)** In a result of numerical experiment, it is found that formation and separation from the Earth surface of the dust cloud are occurred during the time period about 1 min. In consequent time moments the rise of dust cloud in the atmosphere, separation of dust particles on sizes and their settling on the Earth surface are observed. **4)** It is found that a main dust mass is settled out on the square of initial ejection. The area of significant dust settlement is more than twice exceeds the radius of energy release. **5)** The presented model was successfully evaluated for numerical simulation of volcanic explosion and dynamics of dust cloud in a three-dimensional Cartesian coordinate system in despite that the investigated problem has a cylindrical symmetry. It is rather good test for developed three-dimensional code VEDEM and also this model enables in future to investigate three-dimensional problems associated, for example, with a horizontal wind, etc.

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3. W. Mulder, S. Osher and J.A. Sethian, J. Comput. Phys., 100 (1992) 209.
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