# MODELS OF VOLCANIC ASH PROPAGATION FOR THE EXPLORATION OF EXPLOSIVE ERUPTIONS OF KAMCHATKA VOLCANOES

**Malkovsky[1], S., Sorokin[1], A., Korolev[1], S., Girina[2], O., Loupian[3], E.**
[1] *Computing Center, FEB RAS, Khabarovsk, Russia*
[2] *Institute of Volcanology and Seismology, FEB RAS, Petropavlovsk-Kamchatsky, Russia*
[3] *Space Research Institute, RAS, Moscow, Russia*

At present, numerical modeling is one of the main tools used in the study of ash clouds and plumes produced during explosive volcano eruptions. Among the models used for calculations, it is possible to distinguish those that are used in the volcanic ash advisory centers (VAAC). These centers were founded in the 1990s by an international civil aviation organization. Their goal is to provide advisory information on the volume and movement of volcanic ash in an atmosphere that poses a danger to air traffic. To do this, they actively use the following numerical models: CANERM (D'Amours, 1998), FALL3D (Costa et al., 2006), HYSPLIT (Stein et al., 2015), JMA (Iwasaki et al., 1998), MLDPn (D'Amours et al., 2015), MOCAGE (Sič et al., 2015), NAME (Ryall and Maryon, 1998) and PUFF (Searcy et al., 1998). According to the approach used to describe the dispersion of air pollutants in the atmosphere, each of them can be classified as a Lagrangian, Eulerian (Belihov et al., 2013) or hybrid models.

In Lagrangian models, an ash cloud is represented as a set of model particles, each having its own individual position in space, the coordinates of which are calculated by the iteration formula at each time step of the simulation. The advantages of this class of models is the high speed of their work in the operative mode, when you need to get a qualitative idea of the trajectory of the cloud. If it is necessary to determine the quantitative characteristics of the ash cloud (for example, the ash concentration at some point in the cloud, the volume of ash deposited on the surface, etc.), a significant increase in the number of model particles is required, which leads to an increase in the computational complexity of the model (Scollo et al., 2011). In this regard, these models have limited applicability in modeling the propagation of ash on a global scale. The Lagrangian models include the JMA, MLDPn, NAME, and PUFF models.

Unlike Lagrangian ones, the Eulerian models are based on the continuity equation for a certain class of pollutant, numerically solved by various discretization methods. Their main field of application is to determine the quantitative characteristics of the ash cloud, especially when moving it over large distances from the volcano. This model class includes models CANERM, FALL3D and MOCAGE.

Application of the hybrid approach is an attempt to combine the strengths of the models considered above, in which, at a short distance from the volcano, the propagation of the ash cloud is described using the Lagrangian approach, and when it is moved from the volcano, the Eulerian approach begins to be applied. An example of such a model is the HYSPLIT model.

The authors provide a research of different classes of models, and their approbation for modeling explosive events on Kamchatka volcanoes. The authors use the PUFF (the implementation of Puff-UAF (Peterson, 2003)) and FALL3D models. This choice is due to the successful practice of their continued use for exploring explosive volcanic eruptions in various parts of the world, as well as the availability of their open-source software implementations. The first line of work is the adaptation of these models to the specific features of the scientific problems being solved, the observational tools used, which form the values of the input parameters for the models, as well as the availability of operational meteorological data. For example, the PUFF model was adapted to the use of modern formats of storing meteorological data (Malkovsky et al., 2017), which led to a reduction in the total calculation time and an increase in modeling accuracy. The updated version of the software package formed the basis for a software platform for a comprehensive analysis of ash plume propagation from explosive eruptions of Kamchatka volcanoes (Sorokin et al., 2016). The results of the modeling carried out with it are supplied to external specialized information systems VOKKIA (Romanova et al., 2012) and VolSatView (Efremov et al., 2012; Gordeev et al., 2016).

Another direction of work is the validation of the results of the work of the models in question. For this, they were compared with Earth remote sensing data (data from NOAA, Terra and Aqua satellites were used). The obtained results show a good correlation of the simulation results with the actual data, which made it possible to develop recommendations for choosing the initial parameters for the models considered. An example of such a comparison is shown in Fig. 1a for the PUFF model and Fig. 1b for the FALL3D model.

The conducted researches show that the use of the developed tools allows to make operative forecasting of ash propagation and to specify the parameters of the occurred explosive events. Further efforts of the authors will be aimed at incorporating the FALL3D model in the developed software platform and

improving the methods of comparative analysis of the results of modeling the propagation of ash plumes with data obtained using different observation technics.

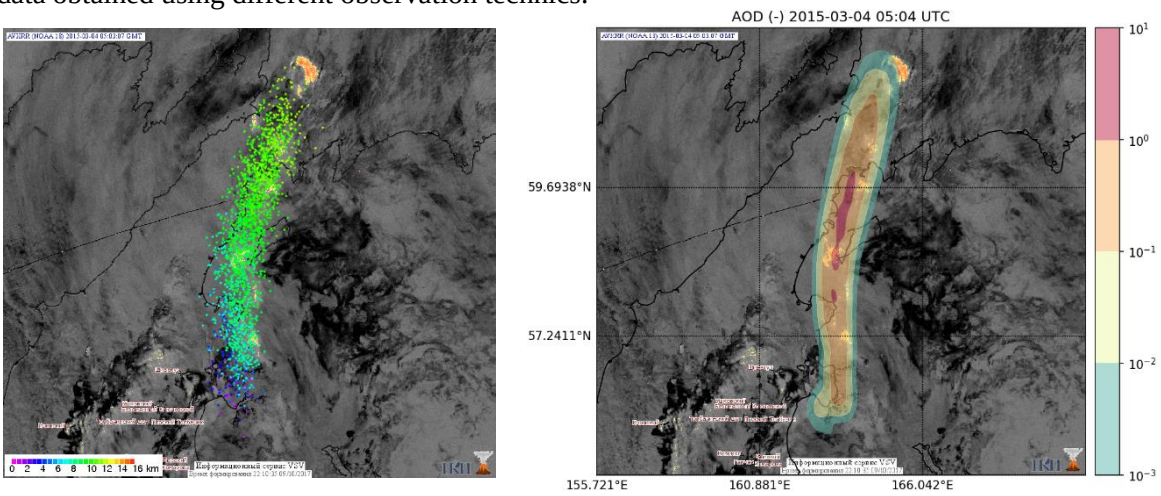


*Fig.1. Comparison of the results of modeling the dispersion of ash after the explosive event on the Shiveluch volcano, which occurred on 03.03.2015 at 22:50 UTC, with the results of processing the AVHRR data from the NOAA 18 satellite. a – PUFF model; b – FALL3D model.*

All calculations performed within the framework of the study were carried out in the Shared Facility Center "Data Center of FEB RAS" (Khabarovsk).

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References

Belihov A.B., Legotin D.L., Suhov A.K. Sovremennye kompjuternye modeli rasprotraneniya zagryaznyauschih veschestv v atmosphere // *Vestnik Kostromskogo Gosudarstvennogo Universiteta Im. N. A. Nekrasova*, 2013. No. 1. Pp. 14-19.

Costa A., Macedonio G., Folch A. A three-dimensional Eulerian model for transport and deposition of volcanic ashes // *Earth and Planetary Science Letters*, 2006. Vol. 241. No. 3–4. Pp. 634-647. doi: 10.1016/j.epsl.2005.11.019.

D'Amours R. Modeling the ETEX plume dispersion with the Canadian emergency response model // *Atmospheric Environment*, 1998. Vol. 32. No. 24. Pp. 4335-4341. doi: 10.1016/S1352-2310(98)00182-4.

D'Amours R., Malo A., Flesch T. et al. The Canadian Meteorological Centre's Atmospheric Transport and Dispersion Modelling Suite // *Atmosphere-Ocean*, 2015. Vol. 53. No. 2. Pp. 176-199. doi: 10.1080/07055900.2014.1000260.

Efremov V.Yu., Girina O.A., Kramareva L.S. et al. Sozdanie informatsionnogo servisa "Distantsionnyi monitoring aktivnosti vulkanov Kamchatki i Kuril" (Creating an information service "Remote monitoring of active volcanoes of Kamchatka and the Kuril Islands") // *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, 2012. Vol. 9. No. 5. Pp. 155-170.

Gordeev E.I., Girina O.A., Loupian E.A. et al. The VolSatView information system for Monitoring the Volcanic Activity in Kamchatka and on the Kuril Islands // *Journal of Volcanology and Seismology*, 2016. Vol. 10. No. 6. Pp. 382-394. doi: 10.1134/S074204631606004X.

Iwasaki T., Maki T., Katayama K. Tracer transport model at Japan meteorological agency and its application to the ETEX data // *Atmospheric Environment*, 1998. Vol. 32. No. 24. Pp. 4285-4295. doi: 10.1016/S1352-2310(98)00171-X.

Malkovsky S.I., Sorokin A.A., Korolev S.P. Improving the system of numerical simulation of volcanic ash propagation using the PUFF model // *Russian Journal of Earth Sciences*, 2017. Vol. 17. No. 5. ES5003. Pp. 1-6. doi:10.2205/2017ES000612.

Peterson R.A. Puff UAF User's Manual. 2003. Available at: http://web.archive.org/web/20121119195411/http://puff.images.alaska.edu/doc.shtml (accessed on 23.03.2016).

Romanova I.M., Girina O.A., Maksimov A.P. et al Sozdanie kompleksnoj informacionnoj veb-sistemy «Vulkany Kurilo-Kamchatskoj ostrovnoj dugi» (VOKKIA) // *Informatika i sistemy upravleniya*, 2012. No 3(33). Pp. 179-187.

Ryall D.B., Maryon R.H. Validation of the UK Met. Offices name model against the ETEX dataset // *Atmospheric Environment*, 1998. Vol. 32. No. 24. Pp. 4265-4276. doi: 10.1016/S1352-2310(98)00177-0.

Scollo S., Prestifilippo M., Coltelli M. et al. A statistical approach to evaluate the tephra deposit and ash concentration from PUFF model forecasts // *Journal of Volcanology and Geothermal Research*, 2011. Vol. 200. No. 3-4. Pp. 129-142. doi: 10.1016/j.jvolgeores.2010.12.004.

Searcy C., Dean K., Stringer W. PUFF: a high-resolution volcanic ash tracking model // *Journal of Volcanology and Geothermal Research*, 1998. Vol. 80. No. 1-2. Pp. 1-16.

Sič B., El Amraoui L., Marécal V. et al. Modelling of primary aerosols in the chemical transport model MOCAGE: Development and evaluation of aerosol physical parameterizations // *Geoscientific Model Development*, 2015. Vol. 8. No. 2. Pp. 381-408. doi: 10.5194/gmd-8-381-2015.

Sorokin A.A., Korolev S.P., Girina O.A. et al. The integrated software platform for a comprehensive analysis of ash plume propagation from explosive eruptions of Kamchatka volcanoes // *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, 2016. Vol. 13. No. 4. Pp. 9-19.

Stein A.F., Draxler R.R., Rolph G.D. et al. NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System // *Bulletin of the American Meteorological Society*, 2015. Vol. 96. No. 12. Pp. 2059-2077. doi: 10.1175/BAMS-D-14-00110.1.