Bull. Nov. Comp. Center, , (2013), 1–5

Analysis of particle size distribution in fields loss volcanic ash

T.V. Yaroslavtseva, V.F. Raputa

Abstract. A model estimating the size of the particles of ash at different distances from the source of the volcanic eruption is proposed. In these field studies of tephra deposits in the vicinity of the volcano Chikurachky (Paramushir, the Kuril Islands, the fields of a characteristic size of particles precipitated from the atmosphere, are numerically reconstructed.

1. Introduction

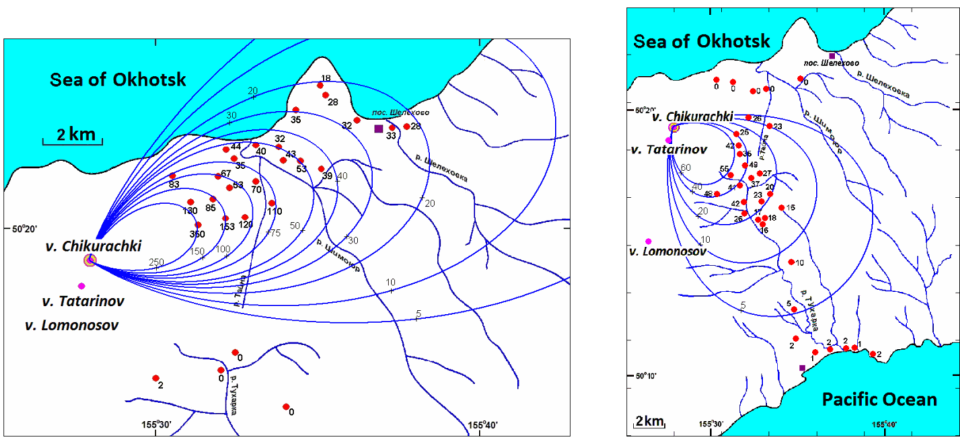
The differentiation of a substance thrown out in the course of volcanic eruption essentially depends on its intensity and in defined by the proceeding explosive processes. When volcanic explosions are strong, there occurs either a sudden outburst of gases or an intensive leaking of a gas jet, thus providing cracking and fragmentation of leaking rocks. A pyroclastic material subject to the winds action spreads up to hundreds and thousands kilometers from a volcano. Intensities of ash accumulations at distances up to tens kilometers can attain decimeters and meters [1]. The behavior of different size particles in the air is far from being the same, which brings about the differentiation of a pyroclastic material in the process of explosive volcanic eruptions. The established regularities of its fall-outs can be used for a rational classification of fragments. In particular, ballistic studies make possible to determine the way of the movement of large fragments of rocks, a probable initial movement velocity, etc., which is important for a correct understanding and analysis of the problem of a fragment material scattering around a volcano. In order to describe the processes of propagation and falling out of an ash material, one should employ models with allowance for heights of clouds, the direction and speed of the governing wind, observational data on particles scattering [1, 2].

2. Results of field studies of tephra deposits in the vicinity of the volcano Chikurachki (Paramushir, the Kuril Islands)

The volcano Chikurachki (1,816 meters) ranks third in height on the Kuril Islands and is the highest point on Paramushir. Chikurachki is one among the most active volcanos of the Kuril arc. Powerful Plinian eruptions over the historical period occurred twice, in 1853 and 1986. According to the satellite data and aircraft observations, a maximum absolute height of the eruptive column attained 10.5–11 km (SEAN, 1986). Over the mentioned eruption period, the satellite snapshots indicate to the ash trail propagating at a distance of up to 400 km from the volcano [2].

For obtaining the quantitative data about the dynamics of Plinian stages of eruptions in 1853 and 1986, their pyroclastic deposits were investigated. The pyroclastics of the Plinian stages of the 1853 and 1986 eruptions is significantly represented by tephra, which due to its wide occurrence and considerable thickness, was well conserved in faults of the soil-pyroclastic covers. The tephra deposits of 1853 and 1986 are similar in appearance. Figure 1 displays the results of measurements of tephra particles in the fall-out zones. Histograms of the size distribution are one-modal. The deposits are well sorted. The average size of tephra particles and total thickness of the layer decrease with distance from the volcano.

The isopicnic and index lines of tephra of each eruption form extremely extended ellipses: in 1853, to the NE and in 1986, to the SE (see Figure 1). This proves of the fact that at the plinian stages of both eruptions the wind was strong, and its direction did not essentially change. The latter indirectly indicates, also, to the fact that the plinian stages were not long (conditionally, less than a day).



a b

Figure 1. Schemes of selecting tephra samplings in the vicinity of the volcano Chikurachki: a) the 1853 eruption and b) the 1986 eruption. Isopleths (lines of an equal maximum size of particles) of tephra of the plinian stages of the volcano Chukurachki eruptions restored with model (6); • marks points of sampling selection, digits denote the sizes of particles in millimeters

3. A model of evaluating sizes of tephra particles

The results of carried out field surveys have shown that the ash fall-out in the zones under study, Paramushir, in the first place, occurred as part of large fractions of particles having rather high velocities of sedimentation in the atmosphere. This circumstance makes possible to restrict ourselves to a kinematic scheme of depositing ash particles in the direction of the axis x, coinciding with the horizontal wind direction when constructing a model of recovering the fall-out fields. In this case, the following relation holds:

$$\frac{H}{w} = \frac{x}{U}. \tag{1}$$

Here H is an effective height of the torch hoisting, w is the sedimentation rate in the atmosphere of a certain fraction of particles, x is a distance from the volcano with the fall-out of a fraction under consideration onto the underlying surface, U is the average wind speed in the sedimentation layer. Let us describe the turbulent particles diffusion in the transverse to the wind direction by the following formula [3, 4]:

$$f(x, y) = \frac{1}{\sqrt{2\pi}\sigma(x)} \exp\Big(-\frac{y^2}{2\sigma^2(x)}\Big), \tag{2}$$

where $\sigma^2(x)$ is the horizontal dispersion of particles, characterizing the width of the particles cloud in the perpendicular to the average wind direction. In the case of a light impurity, for an ever-acting source the interpolation $\sigma^2(x)$ is of the form [4]:

$$\sigma^2(x) = \frac{\bar{\nu^2}(x/U)^2}{1 + x/2UT_L}. \tag{3}$$

Here ν is the wind speed pulsation in the transverse to the axis x direction, T_L is the Lagrangian time scale.

From relation (3) it follows that with relatively small x, $\sigma^2(x) \sim x^2$, while for large distances from the source $\sigma^2(x) \sim x$. With sedimentation of a cloud of heavy particles, the horizontal dispersion σ^2 depends not only on a distance to a source, but also on the sedimentation rates of such particles in the atmosphere. In particular, for relatively large x, the following relation is valid [4, 5]

$$\sigma^2 \longrightarrow kx^{2\omega}, \tag{4}$$

where k is a proportionality factor, $\omega \geq 0.5$. Using relation (1) and the Stokes formula $w = cd^2$ for the particles sedimentation rates in the atmosphere [3] for diameters d of ash particles, there are valid the following relations:

$$d = \sqrt{\frac{w}{c}} = \sqrt{\frac{HU}{cx}}. \tag{5}$$

Then with allowance for (1)–(5), the size of particles, fallen at the point w with the sedimentation rate (x, y), can be described with the help of the relation

$$P(x, y, \vec{\theta}) = \theta_1 x^{\theta_2} \exp\Big(-\frac{\theta_3 y^2}{x^{2\omega}}\Big), \tag{6}$$

where

$$\theta_1 = \sqrt{\frac{kHU}{2\pi c}}, \quad \theta_2 = -\omega - 0.5, \quad \theta_3 = \frac{1}{2k}.$$

An unknown vector of parameters $\vec{\theta}$ is assessed employing the least squares method [6]. The following functional is minimized:

$$J(\vec{\theta}) = \sum_{j=1}^{M} [D_j - P(x_j, y_j, \vec{\theta})]^2 \longrightarrow \min_{\vec{\theta} \in \Omega}. \tag{7}$$

Here D_j is the most typical measured size of particles fallen at the point (x_j, y_j), Ω is the domain of admissible values of the vector $\vec{\theta}$.

Remark. Employing properties of the function $P(x_j, y_j, \vec{\theta})$, it seems reasonable to seek for a minimum of functional (7) in two stages. First, using the measurements data of sizes of particles along the axis of a trace (i.e., for $y = 0$), we determine the parameters θ_1, θ_2, then estimate the parameter θ_3 from the observational points, located on the trace periphery.

4. Numerical reconstruction of zones of fall-outs of tephra particles of an equal size from the 1853 and 1986 volcano Chukurachki eruptions

Based on the available observational data and model (6), the trace of fall-outs was reconstructed by a restricted number of reference points (see Figure 1).

According to the above remark in both cases, the parameters θ_1, θ_2 were evaluated with the help of model (6) by three reference measurement points that are closely-spaced to the axes of ash fall-outs. Also, for the assessment of the parameters θ_3 the reference measurements points taken three at a time that were located at different distances from axes, were used. The assessments of the parameters θ_2 appeared to be fairly close for both eruptions, while those of θ_3 are markedly different. This is explained by a difference in the wind speeds in the course of eruptions. Respectively, this difference manifested in a lesser extension of isolines with respect to the axis (see Figure 1b).

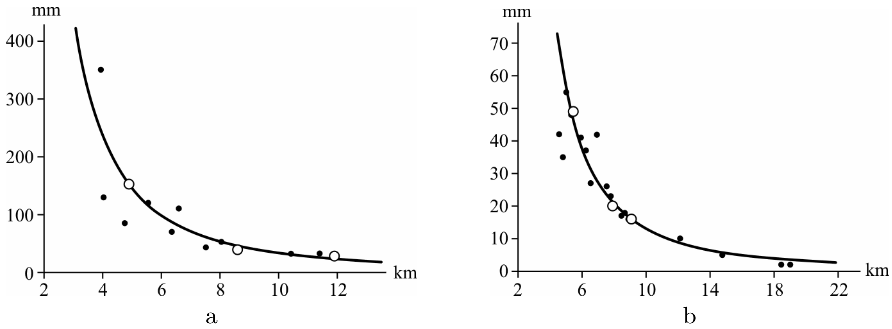


Figure 2. Measured and numerically reconstructed sizes of tephra particles along the ash fall-outs axes: a) the 1853 eruption, b) the 1986 eruption; ◦ reference points, • control observational points

The analysis of Figure 2 reveals a fairly satisfactory agreement between the measured and numerically reconstructed values of the sizes of tephra particles at the points of sampling selection lying next to the axes of ash fall-out.

It should be noted that in order to reconstruct a fall-out field, rather a restricted number of measurement points can be used. This has the advantage when analyzing the available data.

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