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RADAR OBSERVATIONS OF KLYUCHEVSKOI ACTIVITY IN 1987

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This paper presents the results of radar observations of Klyuchevskoi eruptive activity in 1987. It is demonstrated that radars can be used to monitor eruptive activity even in the presence of cumulus.

Various methods are used to monitor explosive activity at Klyuchevskoi Volcano. Conventional visual observations help identify the character of volcanic activity and appraise the heights of eruption clouds and incandescent bombs. Seismic measurements of tremor level provide information on the intensity of eruptive activity. Combinations of these techniques give insight into the dynamics of volcanic eruptions [2], [3], [8].

Unfortunately, thermal convection and turbulent air exchange above the Klyuchevskoi group of volcanoes produce stable convective (cumulus) clouds which obstruct visual observations. For example, during the 1985-1987 eruptions of Klyuchevskoi Volcano its summit was visible less than 60 percent of time.

Radar observations have been recently employed to monitor ash eruptions. Meteorological radars help determine the vertical and horizontal structure and the upper and lower edges of eruption clouds and appraise the intensity of eruptive activity [5], [9], [10]. The aim of this experiment was to examine the application of a meteorological radar at Klyuchi to monitor explosive activity at Klyuchevskoi.

Radar observations of eruption clouds above the Klyuchevskoi summit were carried out for a year, from December 1986 to December 1987, using the MRL-1 radar installed at Klyuchi, a town situated at a distance of 31 km from the volcano. The height of the upper boundary of radio echo (H_{rad}) and reflectivity (Z) were determined from the output of the range-height indicator.

The reflectivity of clouds and precipitation depends on the number (N) and diameter (d) of the particles [6]

$$Z=\sum_{1}^{N} N_i d_i^6$$

and is related to the echo power of the reflected wave (P_{refl}) as

$$P_{refl}=K_1 \cdot K_2 \frac{\sum_{1}^{N} N_i d_i^6}{R^r} \cdot P_{rad}$$

where K_1 is the coefficient incorporating the radar transmitter and antenna performance; K_2 is the coefficient accounting for the dielectric constant of the medium, and R is the distance between the recording site and the target. We determined Z using a conventional technique.

The formation of radio echo from eruption clouds is not only influenced by the presence of ash but also by the dielectric constant of the medium which in its turn depends on the molecular weight, density, absolute temperature, and electrical properties of the molecules. All of these parameters differ greatly in eruption clouds and meteorological formations (clouds, snow, rain, etc.). Therefore in our case we deal with "effective" rather than true reflectivity of eruption clouds.

During the period of radar observations, explosive activity at the volcano was as follows. In December 1986 steam and gas columns rose to a height of 200 or 300 m above the crater [2]. In January 1987, white eruption clouds, occasionally containing some ash, rose to heights of 1000 to 1800 m. On February 7, the mild Strombolian activity changed to violent Strombolian-Vulkanian eruptions which lasted to February 22 and were characterized by the periods of intense explosive and effusive activity which lasted a few hours and the intermissions when practically all active manifestations ceased. During the active periods, eruption columns grew rapidly in height from 1-2 km to 3-4 km with a simultaneous growth of ash load. Two more renewals of activity occurred in August-September and in December, 1987. Those were periods of moderate Strombolian eruptions with gas columns ranging between 400 m and 1000 m in height.

With the radar operated four times a day the height of the upper boundary of radio echo above the crater, ΔH_{rad}, was measured within a 100-meter accuracy and reflectivity Z was determined at intervals of 0.6 log unit. The resulting Z and ΔH_{rad} values can be compared in Figure 1 with variations in the height of gas and ash-loaded columns, ΔH_{vis}, observed visually by Zharinov et al. [2]. One can see that the Z and ΔH_{rad} graphs clearly display the February reactivation of the volcano.

According to visual observations [2], the heights of gas and ash columns during the renewals of activity in August-September and December were comparable, as were the levels of volcanic tremor, whereas the Z and ΔH_{rad} values differed markedly: ΔH_{rad}=0.9 km and Z=-0.9 in August-September and ΔH_{rad}=1.3 km and Z=-1.5 in December. This difference can be explained by seasonal variations in atmospheric pressure and temperature at altitudes over 5 km. According to Ivanov [4], the shaping and rise of eruption clouds are strongly dependent on these parameters. The effect of atmospheric

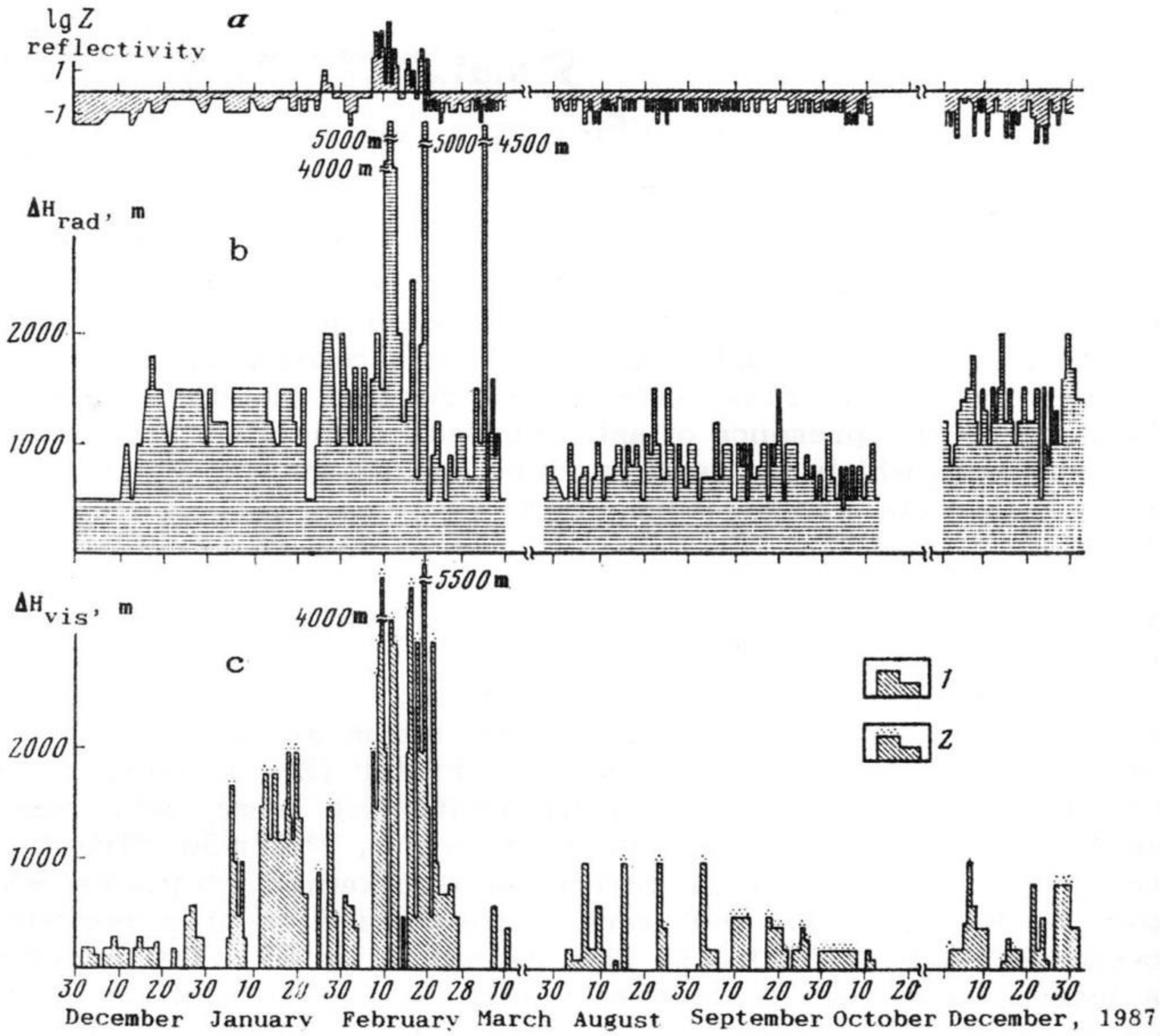

Figure 1 Comparison of Z (a) and H_{rad} (b) variations with changes in the height of gas (1) and ash-loaded (2) columns from visual observations, H_{vis} (c).

pressure and temperature on the behavior of radar echoes reflected by eruption clouds invites further investigation.

Figure 2 shows correlation between ΔH_{rad} and Z for the period of February 1 to March 18, 1987. Also indicated are Z ranges for clouds of the stratus and stratus-cumulus form. Effective reflectivity ranges between -1.5 and 3 for the eruption clouds and between -3 and 2 for the strato-cumulus and stratus. Thus, even mild explosive activity can be detected by radar in the presence of strato-cumulus.

The correlation coefficient for a sample of data n=118 was r_s=0.53. We checked the null hypothesis that the general correlation coefficient equals zero for the competitive hypothesis $r_g \neq 0$. We found the observed T-test value [1] to be

$$T_{obs} = \frac{r_s\sqrt{n-2}}{1-r_s^2} = 7.9$$

Using the significance level 0.05 and the number of the degrees of freedom k=118-2=116, we found the tabular value t_c=1.98 (T_{obs}>t_c), that is the correlation between lg H_{rad} and log Z was different significantly from zero. Using the least squares method we found the regression equation to be lg H_{rad}=a+b·lg Z and obtained the relation

$$lg\Delta H_{rad}(km) = 0.074 + 0.16\, lgZ\left(\frac{mm^6}{m^3}\right) \quad or \quad Z\sim\Delta H_{rad}^{6.2}.$$

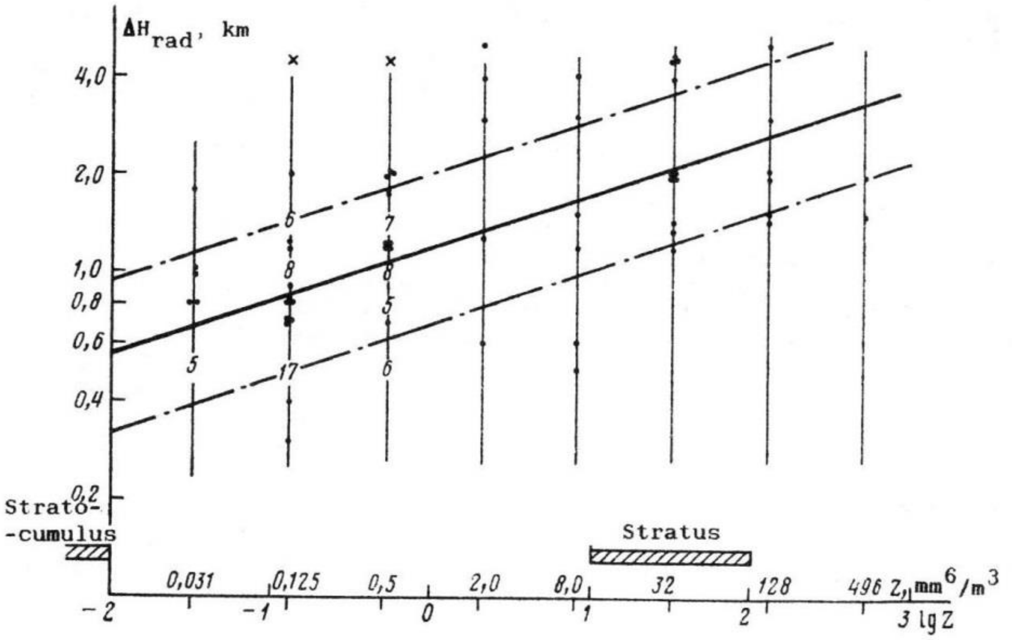

Figure 2 The height of the upper boundary of radio echo above the crater, H_{rad}, as a function of reflectivity, Z, for the period of February 1 to March 18, 1987. Figures on the lines are the numbers of data points.

As the hight of eruption clouds is controlled by the quantity of heat Q produced by the eruption, it is directly related to the rate of discharge of finely dispersed hot pyroclastics ejected into the atmosphere. According to Fedotov [7], Q~$\Delta H^{3.5-4.5}$, whereas in our case Z~$\Delta H_{rad}^{6.2}$, that is the dependence Q=f(ΔH) is stronger than the relation Z=f(ΔH). A tenable explanation is that with the increasing rate of discharge, the grain size of ash changes (median diameter increases), and this enchances reflectivity.

To conclude, the radar located in Klyuchi can be used to monitor the eruptive activity at the Klyuchevskoi summit crater even in the presence of cumulus. It can also be employed to observe all kinds of explosive events on the north flank of the volcano [3].

Apart from Klyuchevskoi, four other volcanoes are situated around Klyuchi: Ploskii Tolbachik (63 km), Bezymyannyi (42 km), Ushkovskii (35 km), and Shiveluch (46 km). The Klyuchi radar can be used to trace the propagation of eruption clouds and hence assess potential volcanic hazards, in case large explosive eruptions occur at these volcanoes.

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