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Environmental Impact of the Powerful Eruption of Sarychev Peak Volcano (Kuril Islands, 2009) According to Satellite Imagery

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Abstract—The powerful Sarychev Peak eruption (Matua Island, Central Kuril Islands) in June 2009 is analyzed on the basis of remote sensing data (satellite images) and ground-based observations carried out in summer 2009. The nature of the eruption and catastrophic impact on ecosystems of the island is described.

Keywords: eruption, pyroclastic flows, lava flows, vegetation, catastrophe, succession, Sarychev Peak, Matua Island, Kuril Islands.

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INTRODUCTION

A powerful eruption of the most active volcano of the Kuril Islands—Sarychev Peak—occurred in the middle of June 2009. The volcano is located in the Central Kuril Islands, on the uninhabited Matua Island. Unique images were published on the Internet, made in the heat of the eruption from the International Space Station (ISS) and just after the eruption (half of the island was turned into a desert, http://earthobservatory.nasa.gov/NaturalHazards/event.php?id=38937). This work is based of the analysis of satellite images and ground-based data received during expeditions on the island in summer 2009. The aim of this work is the description of changes in the ecosystems of the island caused by the eruption.

The Sarychev Peak stratovolcano (1446 m high) occupies a major part of Matua Island (52 km^2 in area and 12 × 6 km in size) and is the most active volcano of the archipelago. The relief genesis and activity of the volcano are described in (Gorshkov, 1967). The volcano erupted every 2–3 decades on average during the last century; the eruptions were explosive or effusive-explosive with andesite-basalt tephra. Eruptions lasted from several hours to several days. The greatest historical eruptions occurred in 1760, 1930, 1946, and 2009. The most important result of powerful explosive eruptions was formation of pyroclastic flows, thick deposits of which are revealed on the island's coast. The stratovolcano cone is covered with many lava flows of previous eruptions.

Matua Island is characterized by the cold climate of the Northern Kuril Islands with a large amount of precipitation, prevailing clouds, frequent fogs, and constant strong winds. Dominating vegetation is represented by low (1–3 m) alder elfin wood, meadows, heathland, and, before the eruption, rare plant cover on the volcano cone. The data on vegetation distribution before the eruption of 2009 were obtained from satellite images of 2001–2008 (ASTER/Terra, Landsat, etc.). Asymmetry and fragmentariness of the elfin wood belt is characteristic of the vegetation of the volcano. The elfin wood is solid only to the southeast from the cone and on the northeast piedmont slopes. The elfin wood belt went up to altitudes of 350–400 m above sea level; areas of low elfin wood, thinned meadows, and wasteland propagated to an altitude of 500 m, and the blowing cone was located above. The northwestern part of the volcano had no solid elfin wood belt (http://static.panoramio.com/photos/original/12299241.jpg). The vegetation cover there probably consisted of thinned herb and bush associations and groups of plants on volcanogenic substrata.

FEATURES OF THE ERUPTION OF 2009

Toward the beginning of the eruption, the ecosystems of the island were transitioning from spring (volcano slopes) to summer (piedmonts). Satellite images made before the eruption showed that the middle and upper parts of the cone were totally covered with snow on May 9, 2009; snowflakes fell to sea level along notches. The piedmonts of the volcano thawed on May 20, but vegetation did not begin, and the general color of vegetation cover was brown. Thick snow patches were seen on the cone on May 31; the largest of them descended from the volcano peak in southwest and east-northeast directions and extended for up to 2 km; vegetation began near the piedmonts in places.

The powerful explosive eruption of the volcano occurred on June 12–15. A series of images was made on June 12 from the ISS. The sector of southwestern coast of the island and the southern slope of the cone

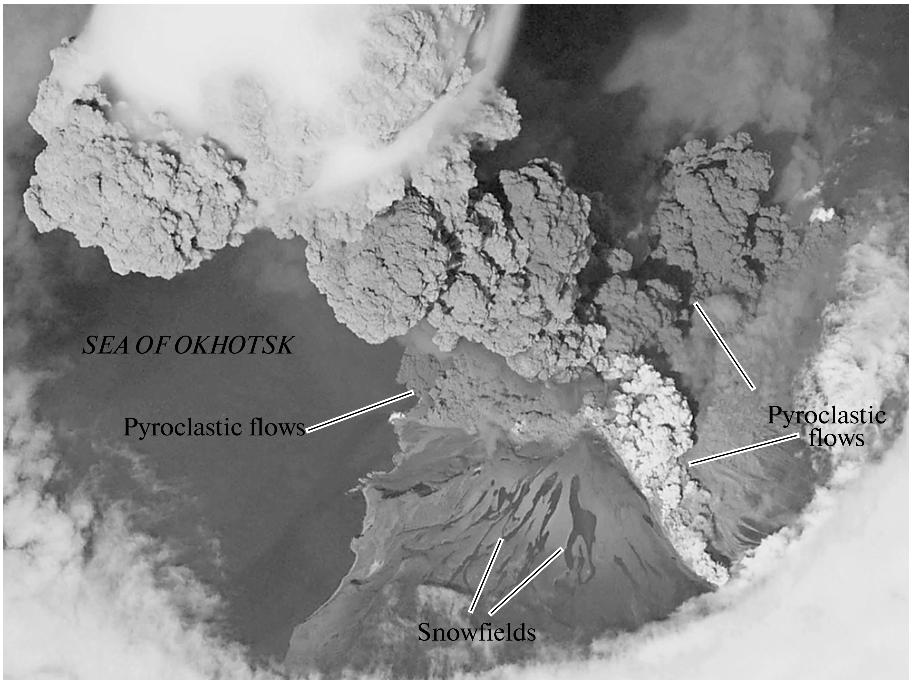

Fig. 1. Eruptive column of the Sarychev Peak eruption of June 12, 2009.

are distinguishable there (Fig. 1). The giant eruptive column rises above the cone. Pyroclastic flows came down the slopes from the marginal parts of the column. The flows are of different sizes and colors: from dark, almost black, to nearly white. The cone slopes, especially in the upper part, are covered with recent volcanic rocks. Dark regions on the slope are snow patches covered with tephra wet because of the melting snow. Green slopes and the coast are evident; they are free of pyroclastics.

ISS images made on June 14, 16, and 17 show that the eruption actively continued. The slopes were totally covered with volcanic rocks. Lava flows on the northeastern and northern slopes are pronounced on the images of June 17 and 18 (Fig. 2). The northeastern flow propagated in a deep hollow, apparently filled beforehand with pyroclastic deposits, and finished its propagation at a height of about 220 m. Raised sides of the flow are pronounced. The second flow propagated southward, then deviated westward by approximately 40°, apparently owing to the relief, and stopped at a height of about 430 m. According to the measurements, the width of the flows was about 120–200 m and the length was about 2 and 2.5 km (in horizontal projection). Assuming the thickness of the flows to be 10–15 m, one can calculate the volume of lava—about 10 million m^3. It should be noted that the volcanological expedition that worked on the island at the end of June 2009 (Levin et al., 2009) did not reveal lava flows.

The ASTER/Terra images made on June 25 and 30 (see the link above), first showed the scale of environmental changes on the island: more than half of the island (the northwestern part—volcano cone, its slopes and piedmonts up to the seacoast) were covered

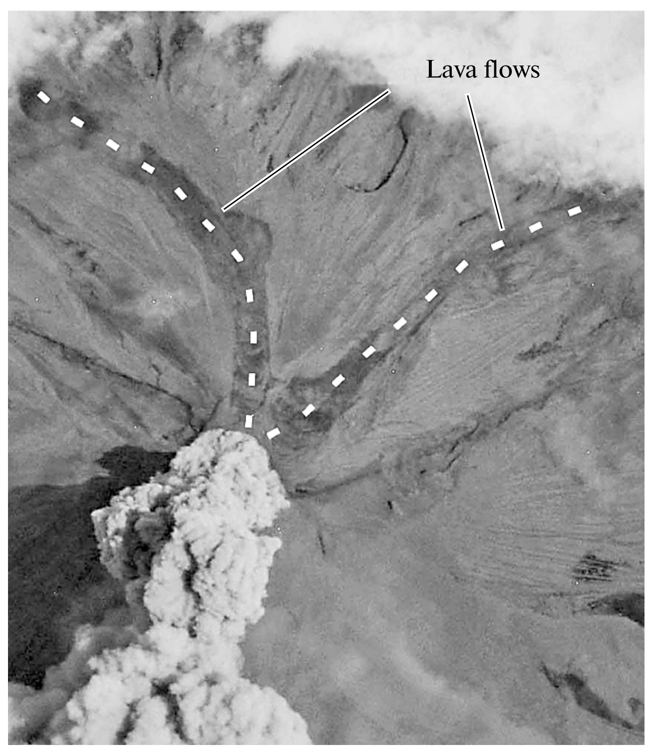

Fig. 2. Lava flows, June 18, 2009. Fragment of an ISS image.

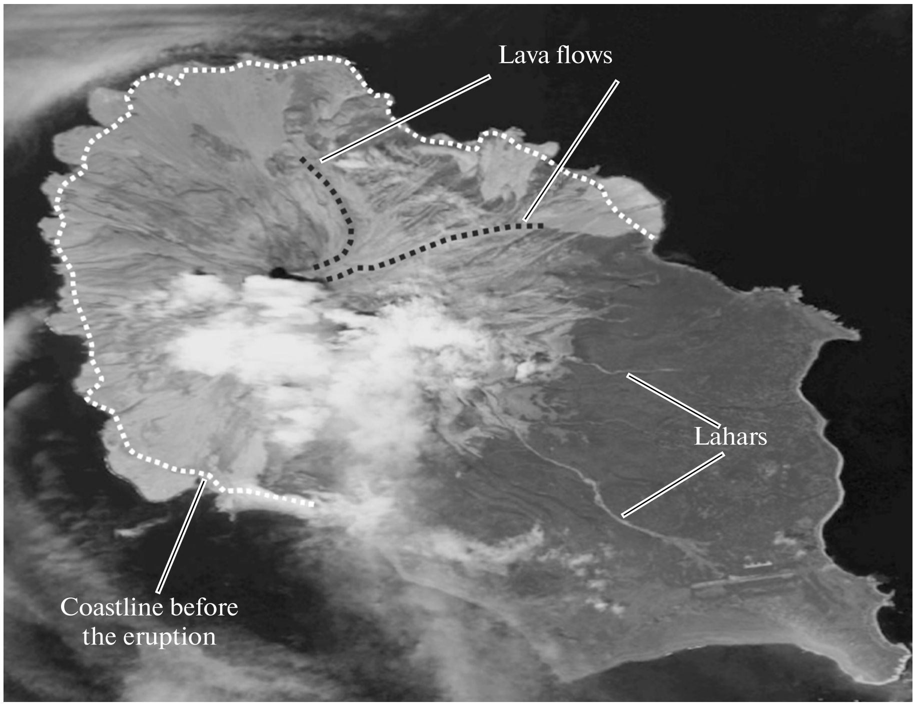

Fig. 3. Situation on Matua Island after the eruption (August 2, 2009). QuickBird 2 image.

with recent deposits and turned into a volcanic desert. Moreover, deposits of pyroclastic flows penetrated into the sea and formed new land. The coastline drew back by 400 m at three segments and to a lesser value at many other segments; as a result, the total built-up area attained 1–1.5 km^2 (Fig. 3). Pyroclastic flows were accompanied by gas-sand pyroclastic surges. While the former propagated along any low relief, including hollows, where lava flowed earlier, the surges propagated along any surfaces, even raised. As a result, the lava flows of 1976 (in the northwestern sector) became less distinct; their relief was partly leveled by recent thick (up to several meters) deposits of flows and surges.

EFFECT OF ERUPTION ON ECOSYSTEMS OF THE ISLAND

According to assessments (in cooperation with O.A. Girina), about 150 ± 50 million m^3 of volcanic rocks, most (more than half) of which consisted of deposits of piroclastic flows, were erupted during this powerful effusive-explosive eruption. During it, ecosystems of the island were affected by pyroclastic flows and accompanying pyroclastic surges, lahars, lava flows, and ashfall. The effect of pyroclastic flows was the largest in scale and the most destructive. The slope angle (more than 30°) provided for high velocities of flows. They deposited mainly on the volcano piedmonts. As follows from the ASTER TIR IR image of the island's surface (Fig. 4), the deposits mainly covered the western part of the cone, including sectors on the northern, northeastern, and southern slopes, penetrating far into the sea in places. Thick (apparently several meters) high-temperature deposits covered an area of about 13–15 km^2. Deposits on the island's coast intensely steamed in the end of June 2009. Deposits of pyroclastic flows of previous eruptions remained hot for many years (Gorshkov, 1967).

Pyroclastic flows and accompanying pyroclastic surges along with tephra deposits turned the volcano cone into a volcanic desert. The flows propagated along channels, leaving a thick (several meters) layer of deposits, and the walls were covered with relatively thin (fractions of a meter) deposits of pyroclastic surges. The surges were characterized by high velocity (tens of meters per second), temperature (up to several hundred degrees), and enrichment with sandy materials. Powerful (and, probably, multiple) thermal and mechanical shocks, as well as chemical poisoning and partial covering with hot materials, resulted in killing of alder elfin wood on the volcano slopes. This implies a 150–200 m vertical lowering of the interface between the cone slag desert and vegetation-covered slopes on the southeastern slope; its passes now at a height of about 400 m.

The pyroclastic flows and surges provoked catastrophic melting of the thick snowfield. The volcanic slopes were cover by millions of cubic meters of dense snow and firn just before the beginning of the eruption; their melting resulted in formation of lahars. It is seen in Fig. 1 that the pyroclastic flow, propagating on the snow patch, causes intense evaporation, and the rolling cloud above the flow becomes white, in contrast to dark clouds above other flows propagating simultaneously on other slopes. Lahars are well seen on the southeastern slope; the visible part of the largest of them is 4 km in length. It propagated along a blind creek, sweeping plants on the walls by mud mass within a creek width of 50–60 m.

Lava flows occupied an area of about 0.8 km^2. The flows covered vegetation on slopes with hot mass and, according to eyewitnesses from a ship, burned it upon contact. The hot surface was manifested by an absence of snow in the late autumn, when most of the area of the island was covered with recent snow (IKONOS image of November 7, 2009). The ASTER TIP images made in summer 2009 to winter 2009–2010 showed the location of these flows and their state: long-term thermal anomalies are clearly pronounced in all images.

The thickness of tephra deposits on the island is relatively small, from 1–2 cm in the southeastern low part to 5 cm on the southeastern slope of the volcano at a height of 600 m. Since eruptive columns reached significant altitudes (up to 16.5 km), the main part of the tephra probably fell into the sea, and fine tephra propagated far beyond the island and was noted on some of the Kuril Islands, on Sakhalin, and in Alaska.

A significant change in the coastline is seen in satellite images made in August–November 2009. This occurred owing to washing out of recent volcanic rocks. Intense carryovers (to distances of up to 3 km from the coast) of washed-out volcanic rocks into the sea are evident in the QuickBird image of September 22, 2009. The IKONOS image of October 8, 2009 shows a smoother coastline on the northeastern coast in comparison with the ASTER/Terra image of June 30, 2009; in 100 days, the coastline became scalloped owing to multiple carryovers and had a smoother shape. Intervals between the scallops were filled with materials that fell from slopes or recent volcanic rocks, washed out and redeposited by the sea. In November, the coast was a smooth curve, without any peaks, owing to accumulation of volcanic rocks. The WorldView image of November 20, 2009, shows the snow-covered island with noticeable regions of pyroclastic deposits free of snow, which were evidently still hot. They remained hot at the end of the winter as well (The WorldView-2 AES image of March 29, 2010).

The eruption significantly changed the relief of the volcano slopes and the shape of the coastline. In general, burning-hot pyroclastic flows and surges and lava flows killed vegetation within an area of about 25 km^2. It was one of the most intense eruptions in the last century; it exceeded (or was comparable with) the intense eruptions of the Severgin (1933), Alaid (1972, 1981), and Tyatya (1973) volcanoes on the Kuril Islands in the area of ecosystem damage (25–30 km^2) (Grishin 2003; Grishin et al., 2009). Recovery of vegetation to the state existing before the eruption will require from several decades to several centuries for different types of substrata and altitudinal belts.

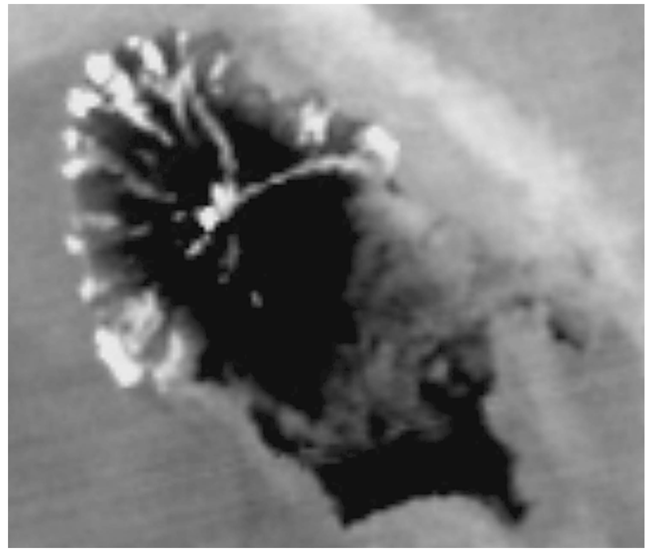

Fig. 4. ASTER TIP IR image of the island's surface of October 10, 2009. Light regions are zones of increased temperature.

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