Satellite and Slow-Scan Television Observations of the Rise and Dispersion of Ash-Rich Eruption Clouds from Redoubt Volcano, Alaska

Juergen Kienle
Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska, U.S.A.

A. W. Woods
Institute of Theoretical Geophysics, Dept. of Applied Mathematics and Theoretical Physics, Silver Street, Cambridge, England

S. A. Estes, K. Ahlnaes, K. Dean, and H. Tanaka
Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska, U.S.A.

ABSTRACT

Polar-orbiting NOAA 10 and 11 weather satellites with their Advanced Very High Resolution Radiometer (AVHRR) imaging sensors and the Landsat 4 and 5 satellites have provided over 30 images of the 1989/90 eruptions of Redoubt Volcano. Between December 14 and April 21, about 20 major explosive eruptions occurred with ash plumes rising to heights of 10 km or more, most of them penetrating the tropopause. The ash severely impacted domestic and international air traffic in Alaska with a near disaster on December 15, 1989, when a KLM 747-400 jet aircraft with 247 people aboard intercepted an ash plume and temporarily lost all four engines. Fortunately, the engines were eventually restarted after several attempts and the plane landed safely in Anchorage. We have used satellite and also slow-scan television (TV) observations to study the dynamics and thermodynamics of rising eruption plumes in order to better understand plume dispersal.

SATELLITE DATA

We have used satellite imagery of eruption plumes to map ash dispersal into the far field from the volcano. The pervasive snow cover that existed near Redoubt Volcano from December 1989 to April 1990 preserved even micron-thin ash layers. For example, a NOAA 10 satellite image of April 21, 1990 shows three ash trajectories on the snow to distances of over 400 km from the vent. Dispersal areas for these three plumes of Redoubt eruptions of March 23, April 12 and April 15 range from about 4000 to 21,000 km^2. A numerical simulation of the ash dispersal involving calculations of the 3-D windfield, 3-D diffusion, and gravitational fallout and satellite images of the ash dispersals suggest that diffusion was not an important process. The ash on the snow formed three narrow undispersed fallout patterns that looked like spokes radiating from the volcano.

Satellite imagery of eruptive plumes was also used to map radiometric plume top temperatures. By convolving these data with radiosonde measurements of atmospheric temperature versus altitude we could derive details of plume top topography, important for the study the dynamics of plume rise and dispersion in the atmosphere.

The infrared (IR) bands of the AVHRR of the NOAA 10 and 11 satellites have proven especially useful to detect eruptions at night or in overcast conditions, a common condition for the 1989/90 eruptive cycle of Redoubt Volcano, which occurred in mid-winter. Even though the volcano was often not visible from the ground, we could still track the high altitude plumes above overcasts or at night, using the IR channels.

SLOW-SCAN TELEVISION OBSERVATIONS

Real-time slow-scan TV observations of volcanic eruptions at Redoubt Volcano have also been most useful for supplementing the satellite observations for warnings to the public. On December 16, 1989, within 48 hours of the first

eruption of Redoubt's latest eruptive cycle, a slow-scan TV camera was installed at Kasilof, 80 km east of the volcano (Figure 1). Kasilof is the closest location with a view of Redoubt, AC power and an established microwave telecommunication link with the geophysical laboratory of the Alaska Volcano Observatory (AVO) at the Geophysical Institute of the University of Alaska Fairbanks, 530 km from Kasilof.

On April 15, 1990 and April 21, 1990, two explosive eruptions occurred, lasting about 4 and 8 minutes respectively, based on seismicity. On both occasions the erupted material traveled as a pyroclastic flow down an ice canyon on the north flank of the volcano. Using slow-scan TV recordings of the eruption and the seismic record from both near and far field stations, Wood and Kienle [1992] deduced that on each occasion, after a few minutes, the upper part of this pyroclastic flow became buoyant and a large, hot and dusty ash cloud rose from the flow. These thermals ascended to a height of about 12 km, at which point they began to spread laterally, as umbrella clouds. Thus, initially dome-shaped eruption plume tops collapsed to form top hat–shaped plumes, as material surged radially outward at the level of neutral buoyancy.

TV monitoring of volcanic eruptions in Alaska by ultra–low light cameras is particularly useful during the winter season when daylight drops to as little as 5 hours. We were able to clearly observe eruptions at local midnight under starlight conditions. For future monitoring, we plan to install such TV systems on two other active volcanoes that lie near Alaskan population centers in the Cook Inlet area, at Mt. Spurr and Mt. St. Augustine.

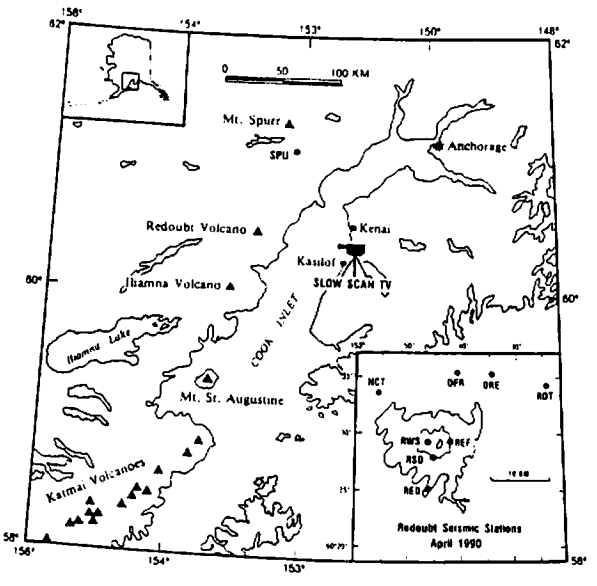

Figure 1. Map of Cook Inlet, showing location of active or Holocene volcanoes (solid triangles), location of the three seismometers REF, RSO and RWS (near the Redoubt vent) and SPU (far from vent), and also the location of the slow-scan television camera at Kasilof. The photographs shown in Figure 2 were taken at Kenai, 20 km north of Kasilof.

RESULTS

Using predictions of a new model for the dynamics governing the ascent of coignimbrite thermals and comparing them with the slow-scan TV observations of April 15, 1990, Wood and Kienle [1992] predict that the cloud initially ascended rather sluggishly, since it is only just buoyant on rising from the pyroclastic flow. However, as it ascends, it entrains and heats up more air, and hence generates more buoyancy. Therefore it accelerates upwards (this process is called super-buoyant plume rise). Only much higher in the cloud does the velocity decrease again, as the thermal energy of the plume becomes exhausted. The model also predicts that the height of rise of such coignimbrite thermals is a function of the initial mass and temperature of the cloud, but is almost independent of the initial velocity.

During the April 21 eruption, a sequence of photographs recorded the lateral spreading of the umbrella cloud during an interval of about 10 minutes after the eruption (Figure 2). Wood and Kienle [1992] analyzed these photographs and successfully compared the observed growth with a simple model for the spreading of the umbrella cloud as a gravity current in a stratified environment.

Using these simple thermodynamic models, Wood and Kienle [1992] estimated that the clouds had a temperature in the approximate range 600-700 K as they rose buoyantly from the flow after entraining and heating ambient air and melting and vaporizing ice. They also estimated that in each eruption approximately 10^9 kg of fine ash was injected into the atmosphere.

It is well known that fine volcanic ash and H_2SO_4 droplets in the stratosphere can affect climate for months, and even years, following eruptions that eject SO_2 and fine ash high into the stratosphere. Our studies help track particles in the troposphere and stratosphere and contribute to the understanding of the physics of their dispersal.

KEY REFERENCE

Woods, A. W., and J. Kienle, The dynamics and thermodynamics of volcanic clouds: Theory and observations from the April 15 and April 21, 1990 eruptions of Redoubt Volcano, Alaska, *Bull. of Volcanology (Redoubt Volume)*, in press, 1992.

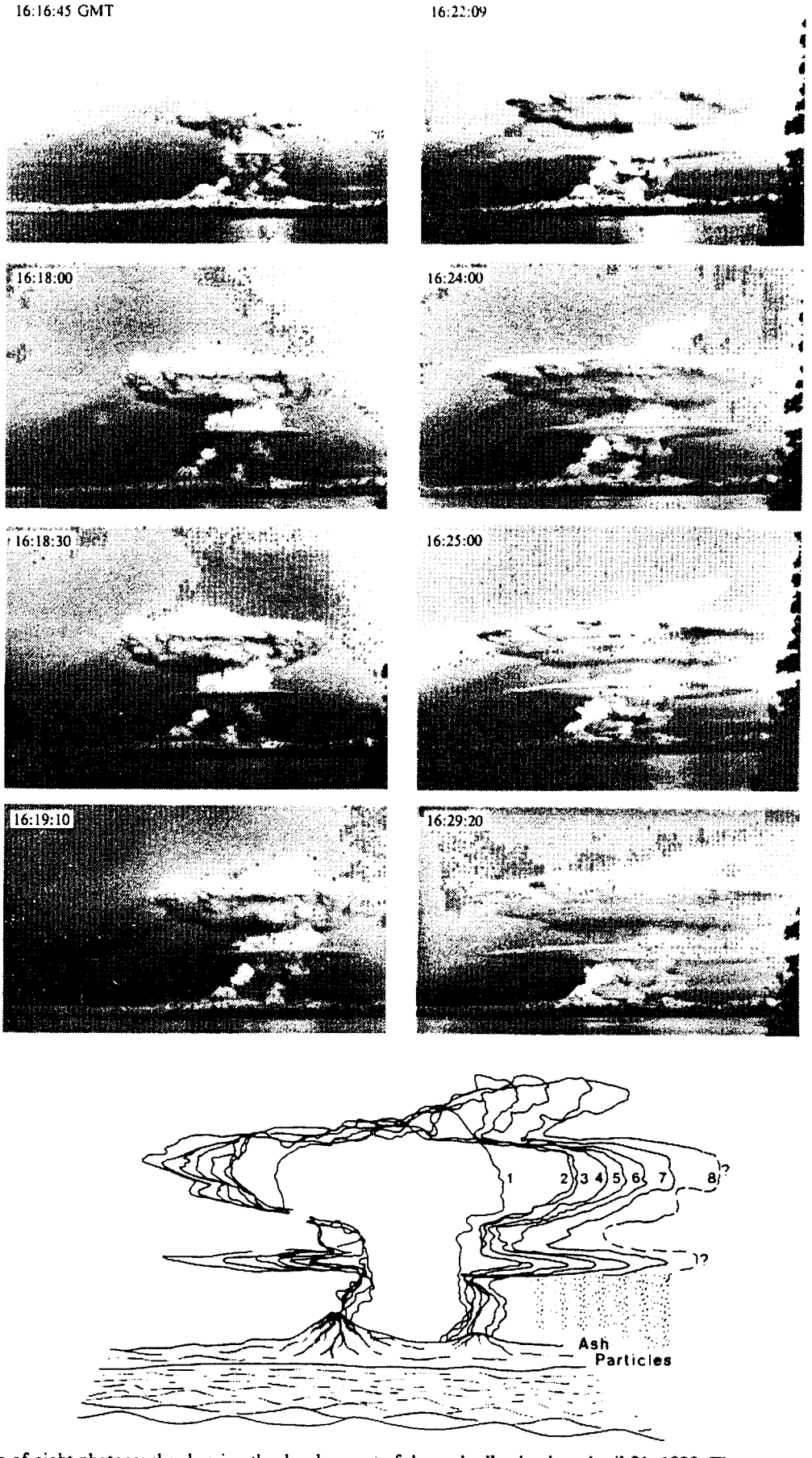

Figure 2. Sequence of eight photographs showing the development of the umbrella cloud on April 21, 1990. These photographs were taken by Mark and Audrey Hodgins from Kenai at the times (in GMT) noted (subtract 10 hours to obtain local time). The bottom drawing shows the growth of the plume and umbrella cloud based on these photographs.