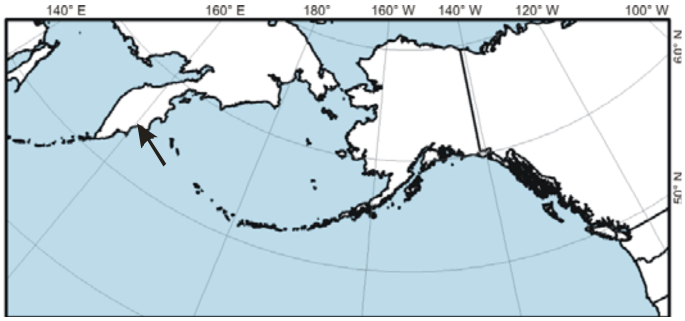

The 2005 and 2007 Eruptions of Klyuchevskoy Volcano, Russia: Behavior and Effusion Mechanisms

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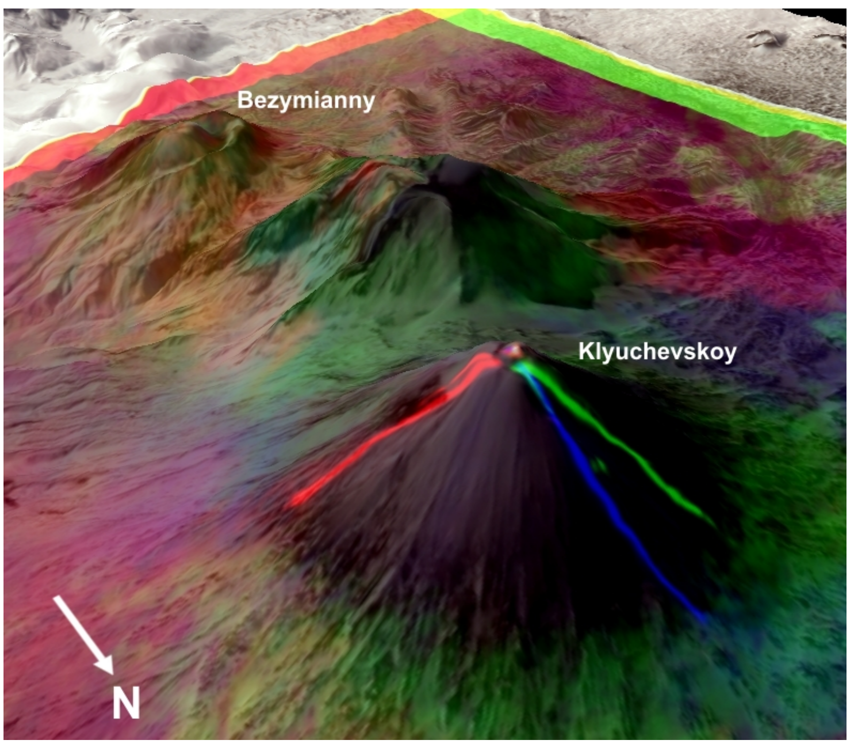

Fig. 1. Lava flowing down the flanks of Kliuchevskoi Volcano detected on Multi-temporal ASTER SWIR band 4 (1.6 µm) composite of the 2007 eruption. Brightness temperature images from 12 May, 28 May and 6 June are displayed in B, G and R, respectively. The composite image has been draped over the 12 May ASTER-derived DEM and oriented looking to the southwest. Bezymianny volcano (9 km south of Kliuchevskoi) can be seen in the background for reference.

Name	Kliuchevsloi Volcano		
Type	Stratovolcano		
Latitude	56°3'24"N	Longitude	160°38'18"E
Date	2005, 2007	Time	N/A
Platform	TERRA	Sensor	ASTER
Spatial Resolution	15 - 90 m	Zenith Angle at Summit	N/A
Visible	3	Wavelength	0.78-0.86 µm
SWIR	4	Wavelength	1.60-1.70 µm
TIR	10, 11, 13	Wavelength	8.125-10.95 µm
Image ID	Multiple		
Archive	NASA		

Activity Description

Kliuchevskoi volcano is located in far-eastern Russia within the ~700 km long Kurile-Kamchatka volcanic arc, containing 29 active volcanoes. The 4850 m tall symmetrical stratovolcano is composed of high-magnesian to high-aluminous basaltic-andesite lavas most commonly erupted during effusive to Plinian style activity from the 750 m diameter summit crater. On average, ~6.0×10^7 tons of material is produced annually. Large Strombolian eruptions occur approximately every two years and last 6-8 months; the most recent eruptions have taken place in 2005, 2007, and 2010 (Fig. 1). Less common paroxysmal eruptions can also occur, with the most recent in 1994, which produced large ash plumes that extended thousands of kilometers to the east (Fig. 2).

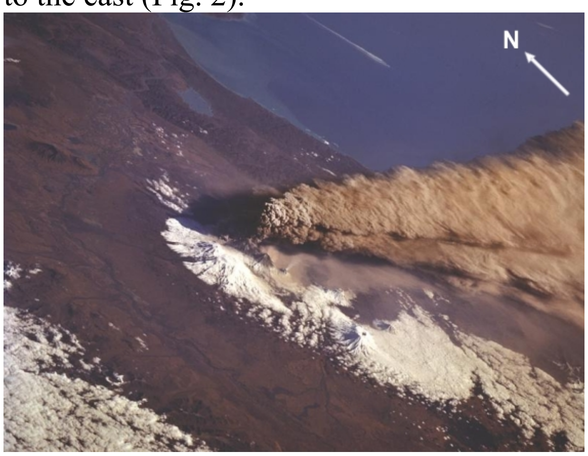

Fig. 2. An eastward-looking oblique photo taken from the space shuttle Endeavor in 1994. During this paroxysmal eruption of Kliuchevskoi, the ash plume reached an altitude of 18 km ASL and migrated southeast over the North Pacific Ocean.).

Data Processing

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) operates in an Urgent Request Protocol (URP) mode during Kliuchevskoi,s most active periods acquiring data as frequently as every 1-5 days. The instrument acquires variable spatial and spectral resolution data in the visible/near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) during both the day and nighttime overpasses. Three spectral channels at 15m/pixel are acquired in the VNIR, six channels at 30 m/pixel in the SWIR, and five channels at 90m/pixel in the TIR. However, due to a cryo-cooler malfunction in 2009, the SWIR subsystem is no longer operational.

The TIR images acquired by the ASTER URP Program in 2005 and 2007 were processed from radiance at the surface into the wavelength dependent emissivity and wavelength independent pixel integrated brightness temperatures using the emissivity normalization process. An average background temperature for each image was calculated using a 400 pixel area at the same elevation as, but not including, the thermally-elevated pixels. Pixels with integrated brightness temperatures of 10 ºC or more above the background were considered thermally-anomalous. High-temperature thermal data supplemented by the higher-spatial resolution SWIR and VNIR data provided extensive details in determining maximum temperatures of thermal features such as the lava and pyroclastic flows (Fig. 3). Pixel integrated brightness temperatures from the SWIR and VNIR were extracted using the reference channel method with a maximum assumed emissivity value of 1.0 in bands 4 and 3, respectively; and a time series for the 2005 and 2007 eruptions was constructed over the 5-6 month period (Fig. 4). All image processing was completed using the ENVI software package.

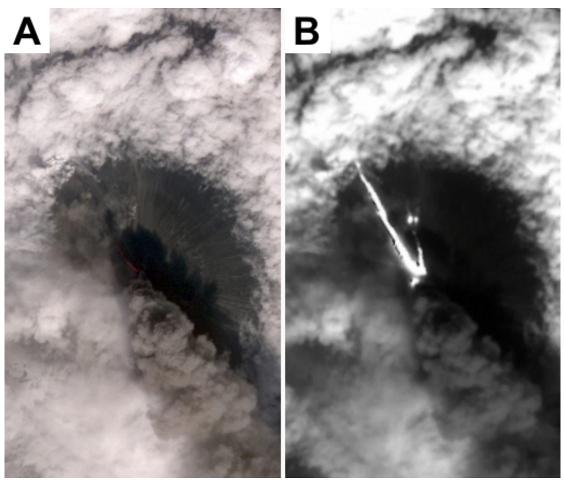

Fig. 3. 28 May 2007 eruption captured by ASTER. **A.** 15m/pixel false color VNIR data, with red showing the incandescent lava channel (maximum derived temperature = 862 °C) in the shadow of the plume. **B.** 30m/pixel SWIR data (Band 4) with a lower temperature sensitivity (maximum = 467 ºC in Low2 gain setting) produces numerous saturated pixels but also highlights the cooler flows further down the flank. Each image is ~4 km wide with north oriented toward the top.

Ash plume compositions were determined using a decorrelation stretch (DCS) performed on the original at-surface TIR radiance data. Using bands 13, 11, and 10, concentrations of silica-rich ash, SO_2, and water/steam could be identified through the RGB channels, respectively. Conversely, the lava flow compositions were determined by comparing lab-derived emissivity spectra of samples collected during a 2005 field campaign (resampled to the spectral resolution of ASTER) with those extracted from the ASTER images.

In August 2005, high spatial resolution forward looking infrared (FLIR) camera data were also collected during a helicopter overpass, synchronous with digital photography (Fig. 5). The purpose of these images was to validate the spaceborne ASTER data and to study the detailed thermal structures of the lava flows and summit crater. The FLIR data also allowed eruption mechanisms to be identified and characterized.

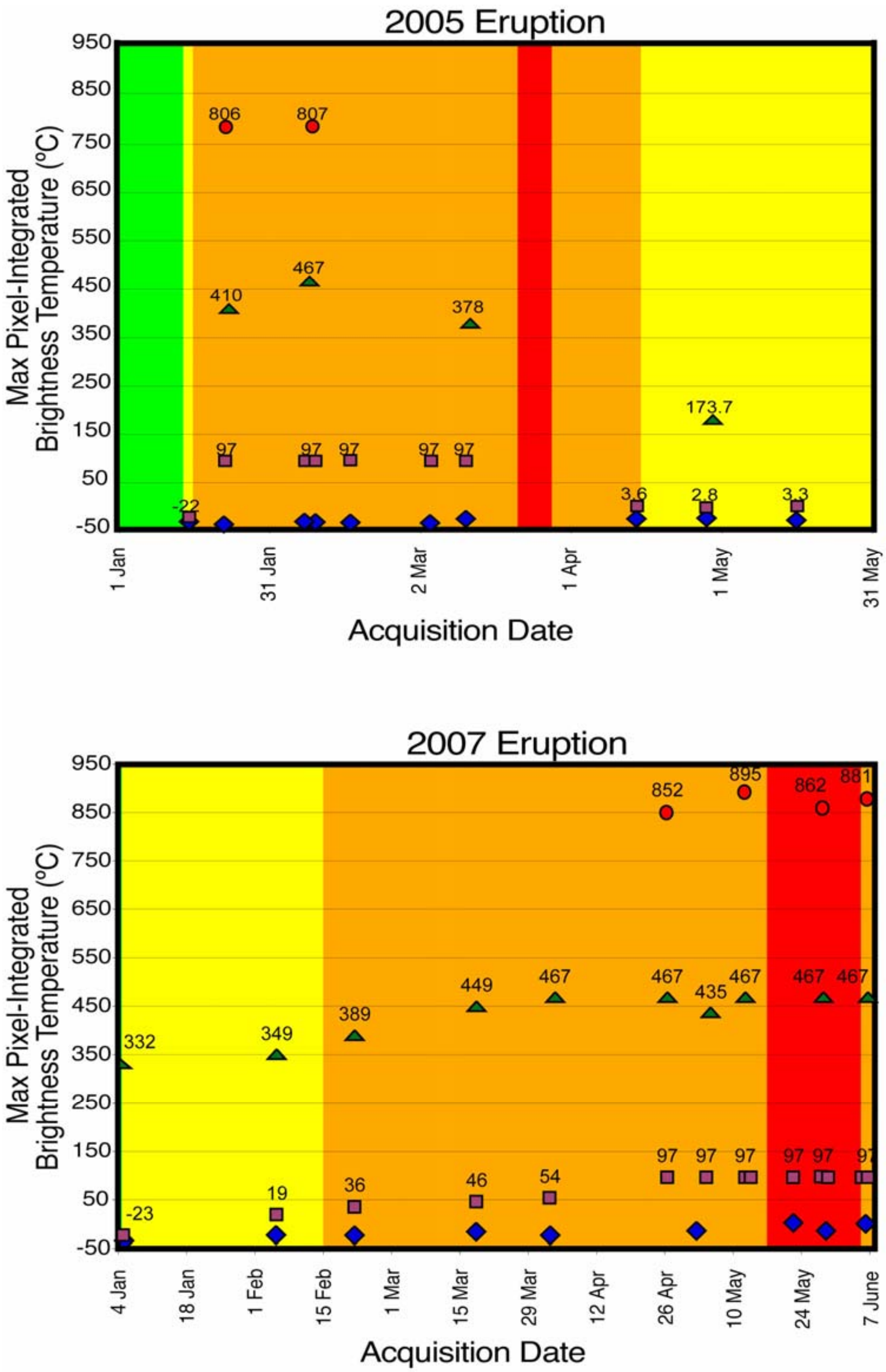

Fig. 4. Maximum ASTER-derived eruption temperatures detected during the 2005 and 2007 eruptions of Kliuchevskoi. Background colors represent the color code (green = volcanic quiescence to red = high potential for large earthquakes and/or explosions).

Interpretation

The time series graphs of the maximum pixel integrated brightness temperatures for the 2005 and 2007 eruptions are presented in Fig. 4. The presence of incandescent lava within the summit crater and down the northwestern Krestovsky channel resulted in saturation of the TIR and SWIR subsystems. However, the high radiance detected by the VNIR allowed accurate, non-saturated temperatures in excess of 800 ºC to be extracted. Although lava temperatures from Kliuchevskoi can commonly reach 1100 ºC, each VNIR pixel is integrating radiance over a 15 m area. Therefore, portions of each pixel commonly contain incandescent lava as well as fractions of cooled lava and crusts. In 2005, the maximum temperatures were detected during the first week of activity whereas the 2007 eruption reached maximum thermal output at the end of extrusive phase.

Near Real-Time Analysis

ASTER is operated in an URP mode for volcanic eruptions or other situations where near real-time data (NRT) is required. During the 2005 and 2007 eruptions of Kliuchevskoi Volcano, data was requested and analyzed in NRT to ascertain the nature of the eruption and assess potential hazards associated with this event. ASTER provides information at spatial resolutions much higher than those used for hourly monitoring.

In Depth Analysis

By combining reported seismic activity levels with observations from the ASTER instrument and the Kamchatka Volcanic Eruption Response Team (KVERT), each eruption was separated into three phases: 1) explosive 2) explosive/effusive 3) and cooling. The explosive phase is characterized by the presence of incandescent lava within the crater, and volcanic bombs from Strombolian activity may be observed coincident with gas-steam plumes containing variable amounts of ash, water vapor and sulfur dioxide. These plumes can commonly be traced for hundreds of kilometers from the source, using ASTER (Fig. 3). In addition, a persistent thermal anomaly is observed in the summit crater, which typically saturates both the TIR and SWIR data. The explosive/effusive phase begins when incandescent lava flows effuse along the flanks of the volcano. In the 2005 and 2007 eruptions, the Krestovsky channel was the primary location of the first lava flow. In the 2007 and 2010 eruptions, continued effusion led to the development of subsequent lava flows to the northwest, west and southeast flanks (Fig. 1). Lower temperature linear thermal anomalies at the flow termini are caused by lahars formed by the interaction of the lava with the persistent snow/ice cover. Concomitant Strombolian style explosions and gas-steam/ash plumes during this phase are observed and characterized by saturated TIR and SWIR pixels. A comparison between the emissivity spectra of the lava flow samples collected during a 2005 field campaign and the ASTER derived emissivity spectra show a very strong correlation indicating that ASTER TIR can be used for surface compositional analyses. However, in instances where thermally-mixed pixels are present, such as along the flow margins, emissivity spectra take on a negative slope toward longer wavelengths, which must be corrected using the higher spatial resolution and temperature sensitivity of the SWIR and VNIR data. Ultimately, the final cooling phase is characterized by a significant decrease in thermal output and the lack of saturated TIR and SWIR pixels. In addition, KVERT informational releases describe a decrease in seismic energy to background levels during this latter phase. Although the eruption eventually ceases, it is not uncommon for a summit thermal anomaly to remain many months to years during periods of quiescence due to cooling lavas and persistent fumarolic degassing.

Examination of the saturated SWIR pixels in the 2005 and 2007 explosive/effusive phase datasets reveal a detachment between the nested summit crater lava pond and the lava flows within the Krestovsky crater, suggesting that the lava flow originated from a breakout point below the elevation of the nested summit crater. This may be due to a structurally weak zone at or near the summit, a feeder dike rooted from the main conduit, or development of a lava tube.

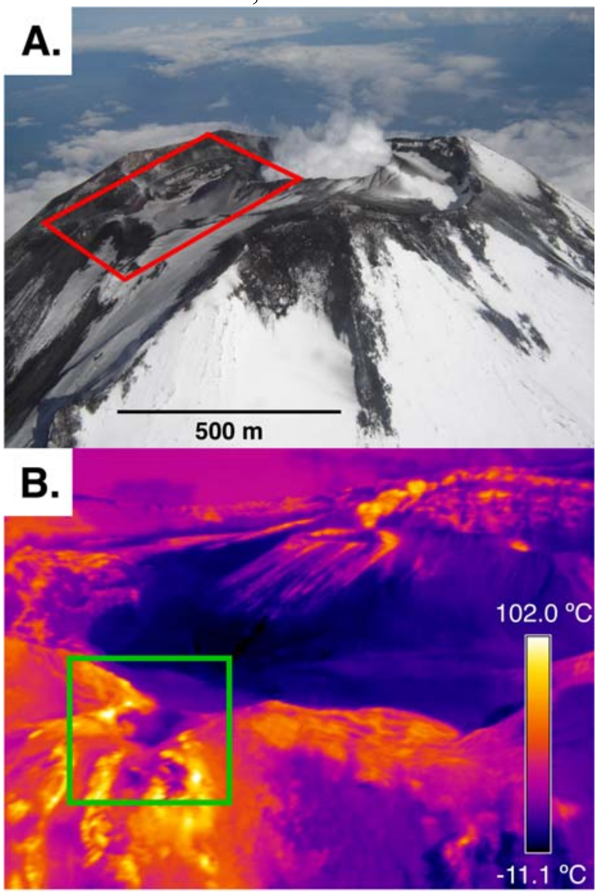

Fig. 5. Aerial images of the summit crater acquired in August 2005. **A.** Visible image with the red box indicating the coverage of the FLIR image in B. **B.** FLIR image with the lava breakout point at the top of the Krestovsky channel highlighted by the green box. White/yellow = hot pixels; black/blue = cold pixels.

The FLIR data (Fig. 5) confirms the presence of a breakout point approximately 90 m below the rim of the nested summit crater, and does not reveal the presence of thermal anomalies within the main crater that would indicate a flow had breached the nested summit crater and traveled down the Krestovsky channel. Pixel-integrated brightness temperatures within the main summit crater remained at background levels (approximately −9 °C ± 5 °C), whereas the lava flow and portions of the nested crater had maximum brightness temperatures in excess of 100 °C over the six months following their emplacement. These data, in conjunction with volume change observations, suggest that a small lava pond within the summit crater either drained back into the main conduit, or into a weak fractured zone to the breakout point at the top of the Krestovsky channel.

Other Atlas Entries for this Volcano

None.

Associated Publications

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