ASTER/AVHRR Data Hybridization to determine Pyroclastic Flow cooling curves *(V41B-4805)*

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Introduction

- Shiveluch volcano has been active for the past 15 years, producing sub-plinian events, dome growth and collapse, debris flows from collapse
- June 25-26, 2009 Shiveluch debris flow emplaced, onset recorded by seismic station over several hours, visual/remote sensing confirmation of onset obscured by clouds
- Orbital remote sensing able to image flow over several months after emplacement using the ASTER and AVHRR sensors
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor – high spatial resolution (90 m), low temporal resolution (2-4 days at poles, 16 days at equator) sensor on Terra satellite
- Advanced Very High Resolution Radiometer (AVHRR) sensor – low spatial resolution (1 km), high temporal resolution (minutes to hours) on NOAA satellite series
- These data can be combined to clearly define flow surface area and produce and meaning amount of data points relating to the cooling of a pyroclastic flow over time.

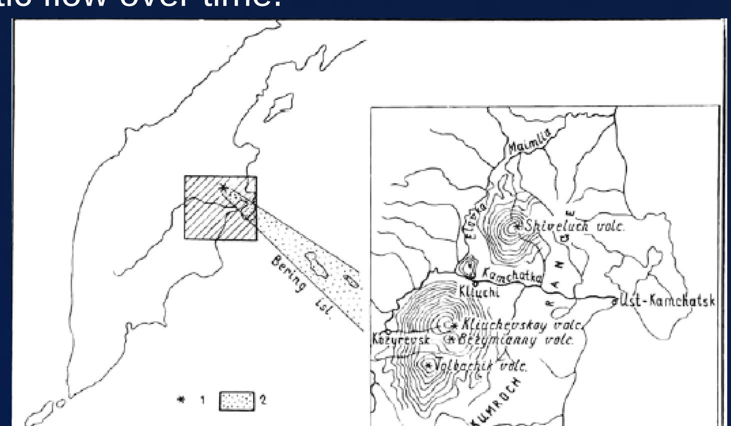

Figure 1: Location map of Shiveluch volcano found in the Kamchatka peninsula and a topographic map of Shiveluch and the surrounding area *Modified from [1].*

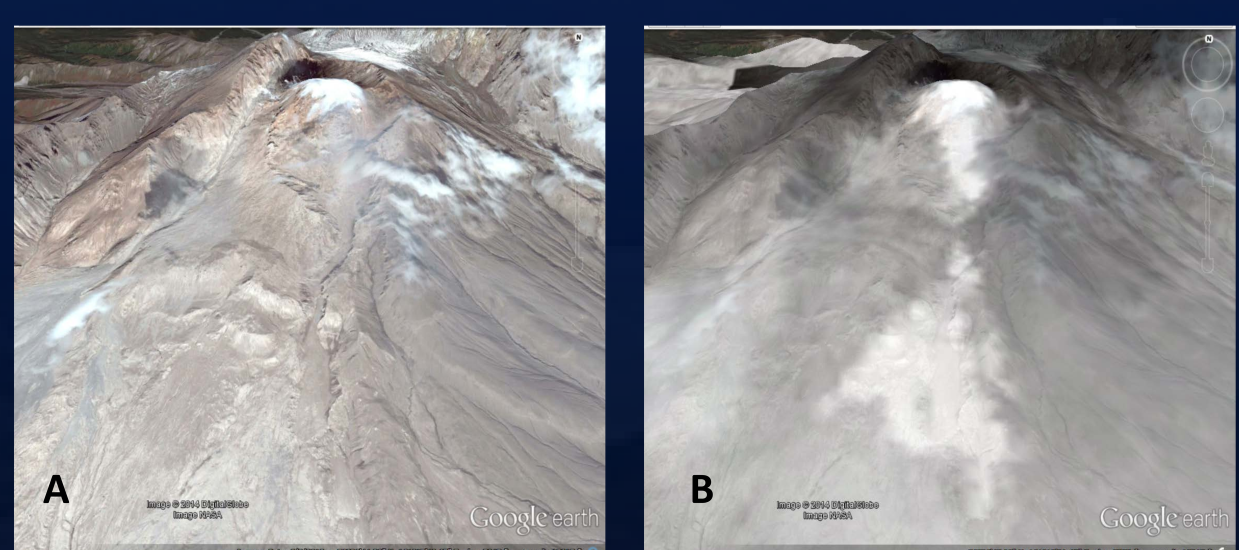

Figure 2: GoogleEarth image of Shiveluch volcano: A) true color image, B) draped ASTER thermal infrared brightness temperature data acquired July 29, 2009, 00:32 UTC

ASTER Data

- ASTER data collected over Shiveluch observed for clear scenes of a thermally elevated pyroclastic flow using USGS Glovis database
- Four clear scenes collected over 39 days, first image ~35 days after onset (Figure 3)
- Average surface temperature of flow calculated through an ROI of total pixel elevated by the lower pyroclastic flow and normalized over adjacent background temperatures (Figures 4,5)

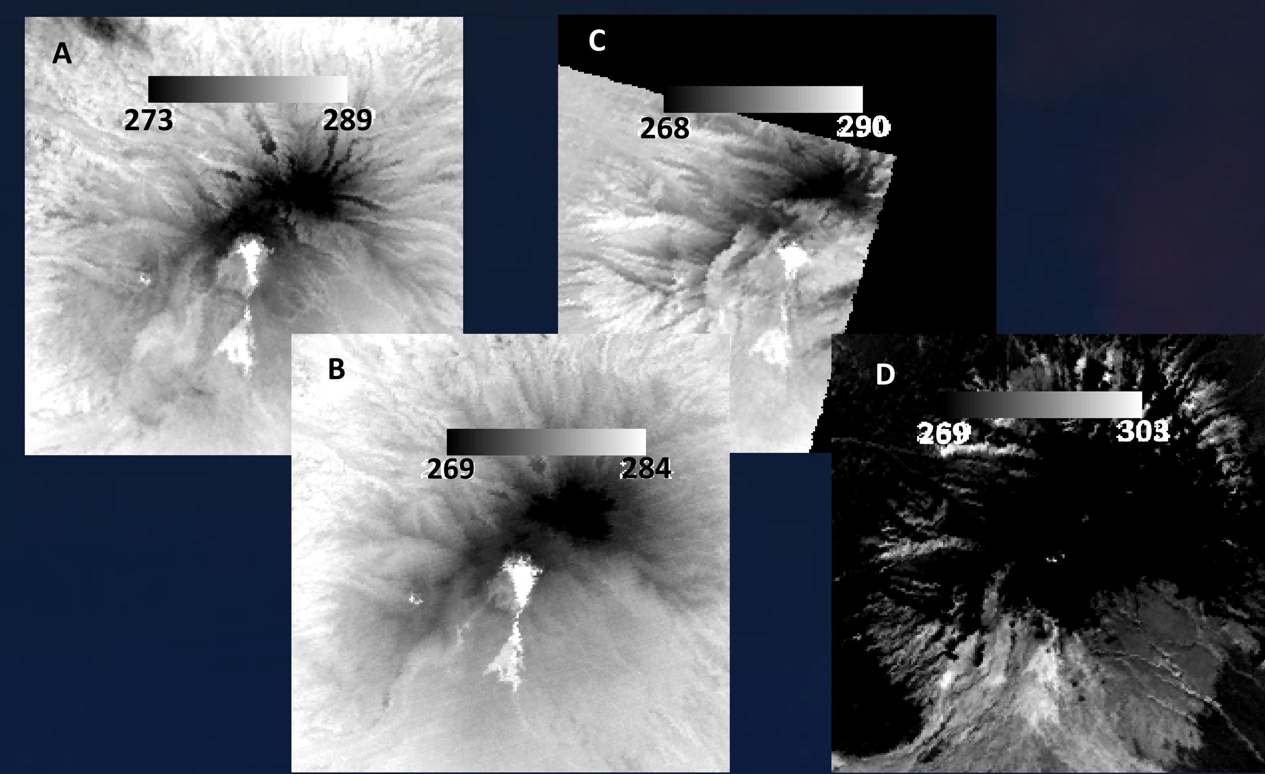

Figure 3: Thermal infrared brightness temperature data of Shiveluch Volcano with all temperatures in degrees Kelvin. (A) ASTER data acquired on 30 July 2009 @ 10:50 UTC. (B) ASTER data acquired 15 August 2009 10:50 UTC (C) ASTER data acquired 28 August 2009 00:44 UTC (D) ASTER data acquired 6 September 2009 00:38 UTC

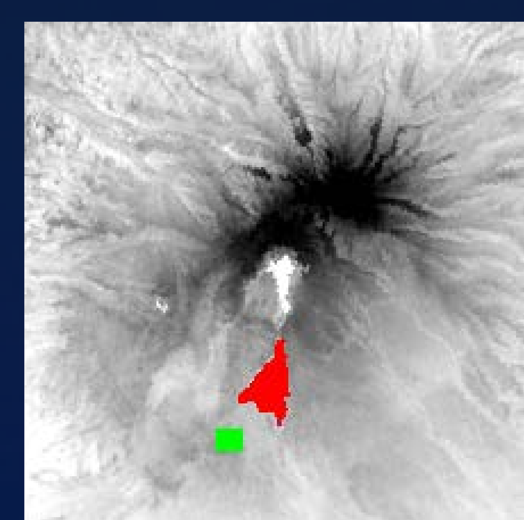

Figure 4: ROI of the area used to determine the average surface temperature of the flow (red) and the background (green) overlain on top of figure 3A. All ASTER scenes were warped and the to cover the same lat and long and the same ROIs were used for every scene to keep a consistent area. The background temperature from every scene was recorded and averaged. The flow surface temperature was then augmented by how far the background temperature diverted from the average temperature.

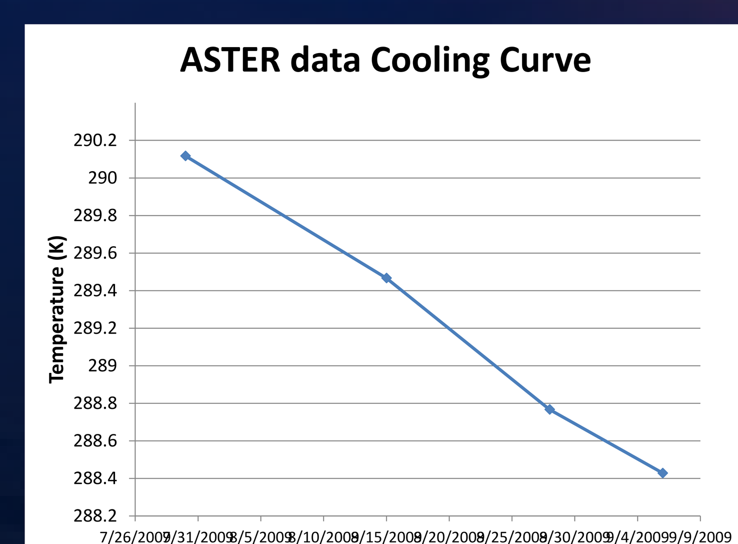

Figure 5: Flow temperature above background plotted in a Temperature vs. time graph. A clear cooling trend can be observed, however the exponential decrease in heat is missing, due to the lack of data captured immediately after the eruption. For the beginning period the contrast between the flow temperature and atmospheric temperature are at their greatest and the largest cooling features can be observed.

AVHRR Data

- AVHRR scene captured 25 June 2009, shortly after flow emplacement (Figure 6)
- Six AVHRR captures of the pyroclastic flow added to the dataset (Figure 6)
- Thermally integrated pixel equation used to determine accurate flow surface temperatures (Figure 7)
- New data points added to cooling curve graph (Figure 8)
- Adding these AVHRR data allows for 6 data points to be added to the set before any clear ASTER data is available. Combining the flow surface area derived from high spatial ASTER data to the high temporal resolution AVHRR brightness temperature data allows accurate values of the surface temperature to be derived.

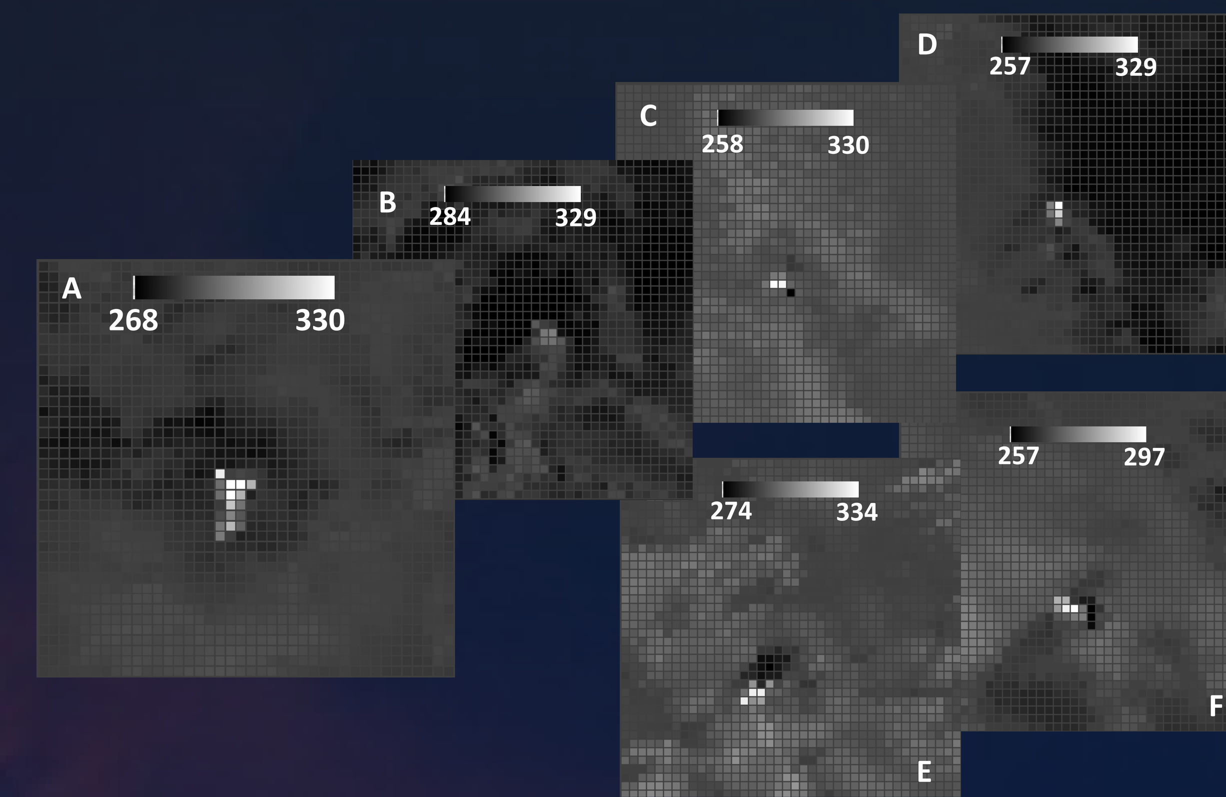

Figure 6: AVHRR thermal IR temperature data of Shiveluch Volcano collected on: (A) 25 June 2009, 15:21 UTC, (B) 29 June 2009 20:15 UTC, (C) 2 July 2009 15:48 UTC, (D) 3 July 2009 15:38 UTC, (E) 4 July 2009 01:20 UTC, and (F) 7 July 2009 16:45 UTC. All temperatures are in K.

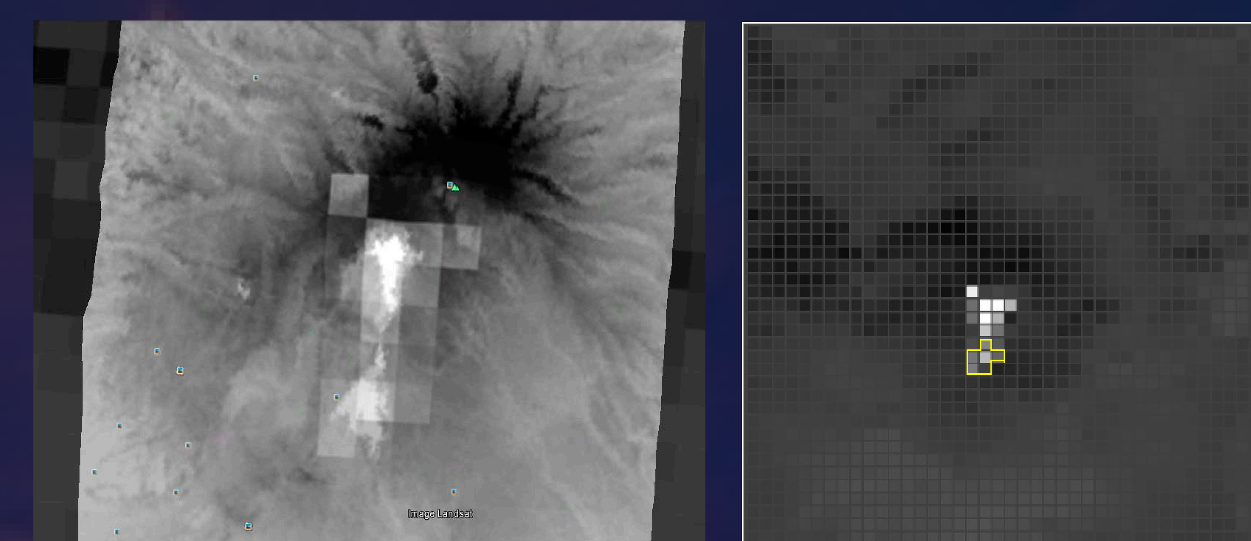

Figure 7: (A) Overlaying AVHRR image 6A on ASTER image 3A pixels impacted by thermal elevation of the lower pyroclastic flow can be observed. (B) The thermally integrated pixel equation: $T_{pixel} \alpha \; T_{flow}(A_{flow}) + T_{background}(A_{pixel}-A_{flow})$ is the applied to impacted pixels (outlined in yellow) to determine average pyroclastic flow surface temperature

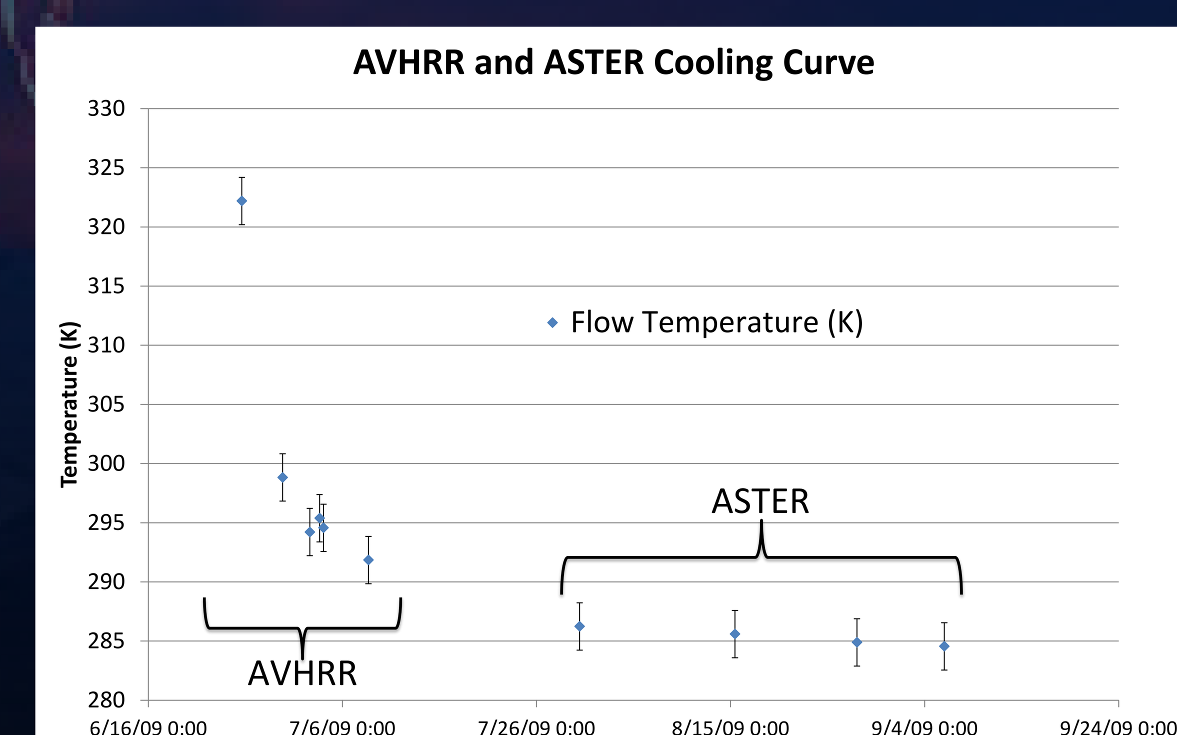

Figure 7: Graph of temperature vs. time of the temperature of the pyroclastic flow obtained from both AVHRR and ASTER data. Including AVHRR data produces a clear exponential decrease in heat. Error bars were included to indicate the 2 K error ASTER data exhibits in brightness temperatures. AVHRR has been proven to produce a 1 K error in brightness temperatures. However, due to both background and AVHRR pixel temperatures being used in the thermally integrated pixel equation, this error reaches 2 K as well.

Results

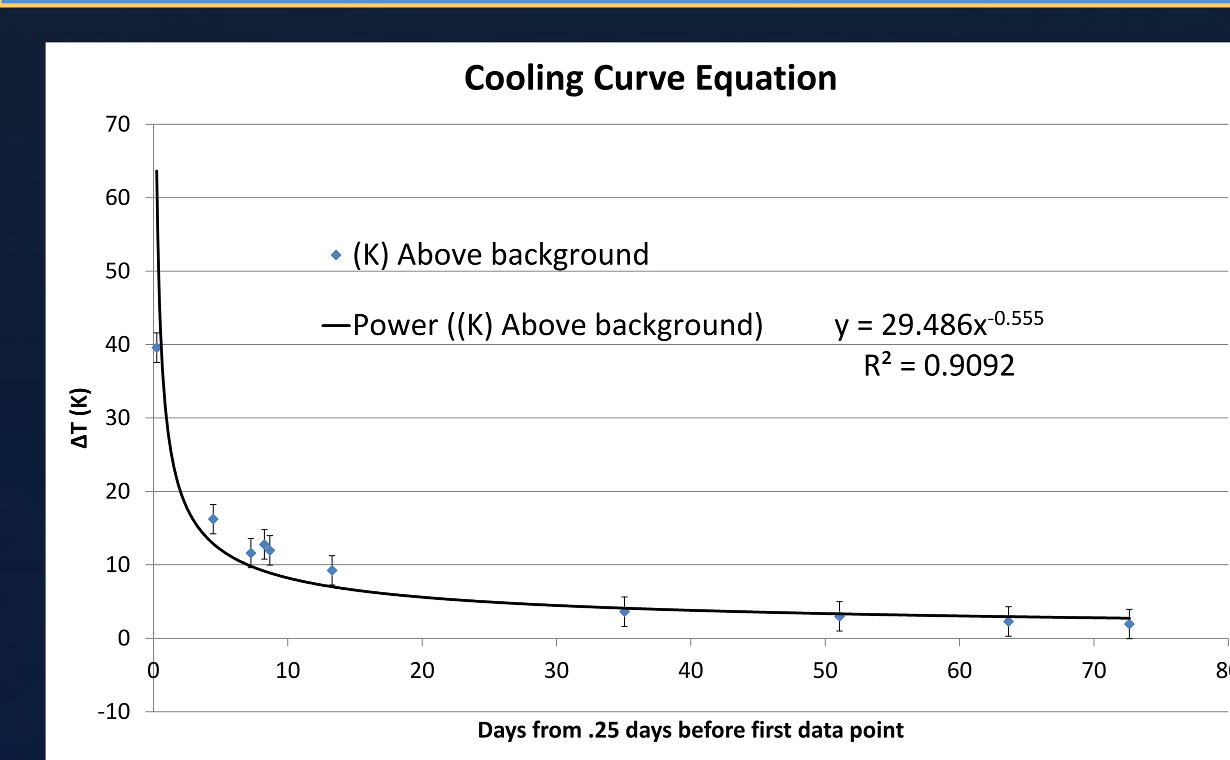

Figure 8: ΔT over background vs time graph with a power rule equation fit to the cooling curve data points.

- The equation $y = 29.486x^{-0.555}$ is found the fit the cooling of the flow
- Flow onset temperature determined from the hottest pixel at the summit, 95.174 K, when y=95.174, x=0.121076
  - Time of emplacement = June 25, 2009 12:18 UTC
- For negligible thermal output of 1, when y = 1, x=444.87
  - Time for negligible output = August 13, 2010 12:14 UTC
- For flow volume, cooling equation integrated from x=0.121076 to 444.87
  - Pyroclastic flow mass-heat balance equation: $Q_{tot} = v \bullet \rho_{flow} \; [cp_{flow} \bullet \Delta T_{stop}]$ (Amended from [2])
  - Total flow volume = 578175 m^3
  - Average Thickness = .195 m

Conclusions

By incorporating both AVHRR and ASTER data a cooling curve of a pyroclastic flow can be created. In this case, the high spatial resolution of ASTER produced information of the total surface area of the flow (2.965 km^2) and four data points of the average surface temperature of the flow over time. The high temporal resolution of AVHRR allowed scenes of the pyroclastic flow to be captured shortly after emplacement. By utilizing the thermally integrated pixel equation along with the surface area of the flow determined from ASTER data, an accurate measurement of the temperature of the flow in the AVHRR data could be calculated. With these data an equation can be matched to the cooling curve of the flow. From this equation the time of flow emplacement, the point at which the flow reaches a negligible temperature, and the total flow volume can be calculated.

References

[1] Gorshkov, G. S., & Dubik, Y. M. (1970). Gigantic directed blast at Shiveluch volcano (Kamchatka). Bulletin Volcanologique, 34(1), 261-288.**[2]** Smithsonian Institute, Kliuchevskoi Volcano Eruptive History, Global Volcanism Program, 12/5/2013, http://www.volcano.si.edu/volcano.cfm?vn=300260

[2] Harris, A. J., Flynn, L. P., Keszthelyi, L., Mouginis-Mark, P. J., Rowland, S. K., & Resing, J. A. (1998). Calculation of lava effusion rates from Landsat TM data. Bulletin of Volcanology, 60(1), 52-71.

Acknowledgements

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