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Remote Sensing of Lava Temperature Distributions on Earth and Io

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Abstract

Remote sensing of planetary volcanism typically does not spatially resolve the emitting region therefore interpretation of the observed spectrum in terms of geologically interesting parameters, such as eruption temperature and effusion rate, requires models of eruption characteristics such as spreading behavior and cooling rate. We are testing the models we employ for interpreting Io volcanism using observations of analogous terrestrial activity. The models assume a near-power-law cooling behavior for temperature with time, and predict a related power-law dependence of surface area with temperature. Measurements of spreading pahoehoe flows at Kilauea do closely match the models, with subtle deviations which suggest some as yet unmodeled physical effects. Besides their use in Io modeling, these analytical models should prove useful for interpreting terrestrial observations.

1. Introduction

In ground-based and spacecraft observations of volcanism on Io, as well as many remote sensing observations of terrestrial volcanism, each pixel typically contains a wide range of temperatures because of the rapid cooling of lava surfaces. While such cooling can be modeled numerically [1, 2] that potentially hides important insight amid the numerical details.

An alternative approach [3, 4, 5] is to develop analytical approximations for cooling which capture the essential physics and can closely approximate the more precise numerical results. For lava flows and lakes we have shown previously [4] that that surface temperatures (*T*) cool with time (*t*) approximately as

$$T(t) \propto t^{-1/8} \tag{1}$$

and when we combine that with the assumption that new surface is created at some constant rate we see a distribution of surface area (*A*) with temperature given by

$$dA/dT \propto T^{-9} \quad . \tag{2}$$

Different cooling environments lead to a different power laws. In eqn. (1) the -1/8 power law results from the T^4 dependence of thermal radiation combined with the $t^{1/2}$ dependence of heat diffusion from the flow interior. However for cooling of small droplets in optically thin fire fountains, diffusion is no longer the rate limiting process [4, 5] and that changes the cooling exponent from -1/8 to -1/3 and the area exponent from -9 to -4.

The analytical approximations and the power laws do begin to break down under some circumstances, for example at temperatures just below the solidus (i.e. for just created surfaces). To first order that merely causes a shift in the power law index. However as described below, comparison of our observations with these power law models suggests we are seeing additional physical effects at this high temperature limit.

2. Terrestrial volcanism tests

To test the accuracy of the Io models we have recently been obtaining spatially resolved near-infrared measurements of surface temperatures on terrestrial lava lakes and lava flows, such as those at Marum, Vanuatu and at Kilauea. We have also been examining published lava cooling curves.

Figure 1 shows the Kilauea pahoehoe cooling curve denoted F1 in [7], on a log-log plot. On such a plot power laws appear as straight lines with slope equal to the power law index. Except for the first few points, where the analytical approximations are less accurate and the measured surface age may be poorly defined, the observations are remarkably well fit by a power law with an index close to the expected -1/8 value.

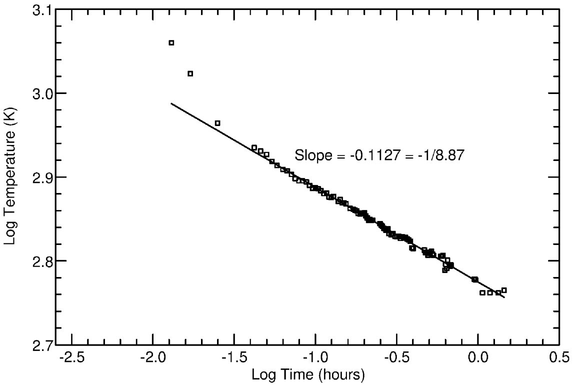

Figure 1: Cooling of pahoehoe flow "F1" from [7], fit with a power-law model.

To test the area vs. temperature distribution we obtained images of spreading pahoehoe flows at Kilauea using "Kerby", our prototype multi-wavelength (visible to 0.9 µm) camera system, then counted pixels in the different temperature bins.

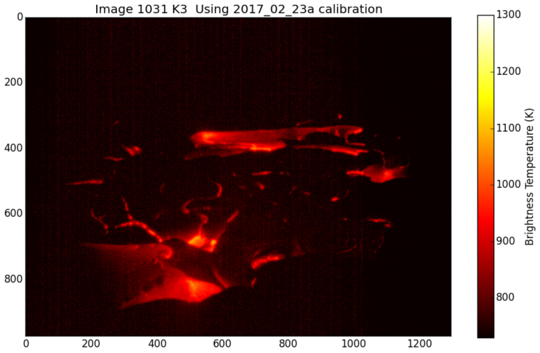

Figure 2: Observed flow temperatures at Kilauea.

Figure 3 shows a typical distribution, which does closely follow a power law with slope near the expected -9 value, till at some T_{roll_off} the area begins to drop more rapidly. The value of T_{roll_off} increases with eruption vigor. We suspect the break is due to the presence of a thin visco-elastic crust even on the youngest surfaces, which is not included in current models.

We will discuss our efforts to include the effects of the visco-elastic crust, and also our observations of lava lake surfaces and fire fountains.

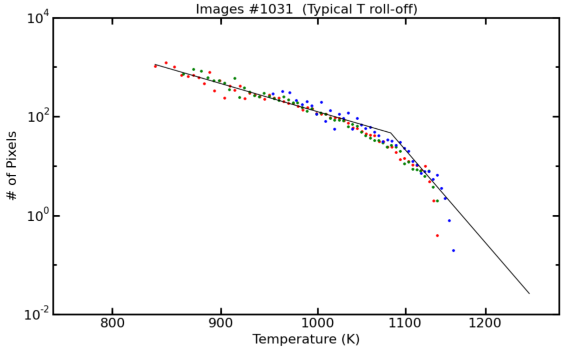

Figure 3: Area-temperature distributions.

3. Io occultation data for the PDS

While separate from the above modeling, we are in the final stages of a PDART supported program to submit to the NASA Planetary Data System (PDS) our several-decade long ground-based observational record of Io volcanism, obtained through Jupiter and mutual-satellite occultations. We will also report briefly on the status of that effort.

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