VALIDATION OF VOLCANIC THERMAL EMISSION MODELS USING GROUND-TRUTHED DATA OF THE EREBUS VOLCANO (ANTARCTICA) LAVA LAKE: IMPLICATIONS FOR IO.

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Introduction: Ground-truth data is sorely needed to test the methods used to estimate lava eruption temperature from telescopic and spacecraft data. We are particularly interested in validating models used to interpret remote-sensing data of the intensely active volcanism on Jupiter's moon Io [1-3]. For this purpose, high spatial resolution infrared data were obtained in 2005 of the active lava lake at Erebus Volcano, Ross Island, Antarctica [4]. Analysis of these data yielded the temperature distribution on the surface of the lake, which was used to create the integrated thermal emission spectrum of the lava lake. This spectrum was used to test models of thermal emission used to model similar features on Io, to ascertain the accuracy of model output.

Observing volcanism on Io: To understand the evolving thermal emission from Io's wide range of volcanic activity and to determine the physical parameters of the eruptions taking place, we rely on models of thermal emission which seek to reproduce the temporal and spectral characteristics of thermal emission from different eruption styles (overturning lava lakes, insulated flows, channelized flows, lava fountains, and combinations of the above) [1-3, 5, 6]. The Davies (1996) model has been used to interpret many remote-sensing observations of volcanic thermal emission and estimate eruption parameters (e.g., areal coverage rate, effusion rate and temperature distribution) that broadly match observations of Io's volcanism. Although the model-derived lava cooling trend reproduces field data of cooling lava flows on a basalt lava flow [1] the Erebus data provide an opportunity to test the model output, in the form of the integrated thermal emission spectrum (and other derived products), against ground-truth. This yields a quantified assessment of how well the model reproduces what is actually happening.

Models of thermal emission: lava lakes: The expected thermal emission from a steadily overturning lava lake, that is, a thermal source of fixed surface area with a constant rate of surface renewal, is an ideal target for testing the model of Davies (1996) [1]. In the simplest case, this model determines the evolving thermal emission from a cooling lava surface that is expanding at a steady rate: in other words, the exact process that was taking place at Erebus volcano in 2005 [4]. The heat loss mechanisms from a lava lake, in effect a semi-infinite lava body losing heat via radiation and atmospheric convection from its upper, exposed surface, are well-understood. By inputting the appropriate environmental and magma physical quantioties, the cooling curve for silicate magma is derived and the evolution of the integrated thermal emission spectrum calculated. These curves are then used to fit actual thermal emission data, as determined from field measurements at the Erebus lava lake with an infrared camera (FLIR ThermaCAM P65) [4].

Mt. Erebus lava lake: Volcanic activity at Erebus is characterised by a persistent, convecting lake of somewhat unusual magmatic composition, an anorthoclase phonolite [7]. The magma is more viscous than that seen at basaltic lava lakes. The Erebus magma eruption temperature is ≈1300 K. In December 2005 the main Erebus lava lake had an area of 817 m^2 and a measured surface temperature distribution, subject to sub-pixel averaging, of 1090 K to 575 K with a broad peak from 730 K to 850 K [4]. Total heat loss was estimated to be 23.5 MW [4].

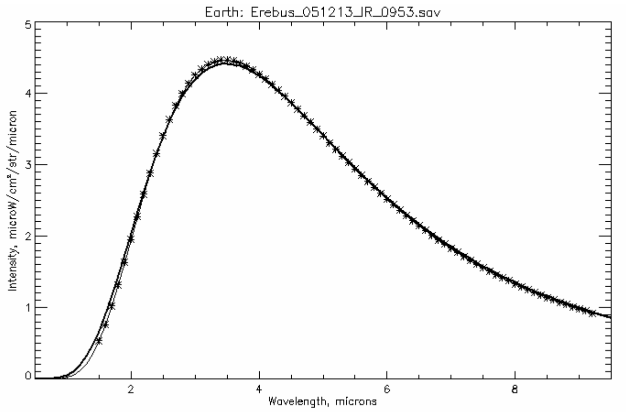

Figure 1: The Davies (1996) [1] model fit (solid line) to Erebus 2005 thermal emission spectrum (stars) as determined using a FLIR thernal camera [4]. The fit is excellent and reproduces all physical aspects of thermal emission.

Fitting data: The integrated thermal emission spectrum (Fig. 1) is created by summing thermal emission from all hot pixels. This spectrum is used to fit different models of thermal emission over short and thermal infrared wavelengths (0.5-10 µm, and especially the *Galileo* NIMS wavelength range of 0.7 to 5.2 µm). The shape of the thermal emission spectrum is similar to that seen at Pele, on Io. This is most likely an active, mafic lava lake, although one that is orders of magnitude larger in area than the Erebus lava lake [3,8].

Single temperature and two-temperature fits: Single temperature (1-T) and two-temperature (2-T) fits to integrated thermal emission spectra from individual volcanoes have been performed many times to interpret Io data (see examples in [3]). 2-T fits provide a much more realistic physical interpretation than a 1-T fit, but nonetheless the usefulness of 2-T fits for fine analysis has been called into question [9]. Wright and Flynn [9] determined that there was a continuum of temperatures present with lava flows, the same distribution theoretically proposed by the Davies (1996) model. A similarly complex temperature distribution was seen at the Erebus volcano lava lake [4].

The best 1-T and 2-T fits are shown in Table 1. The 1-T fit significantly underestimates area, as expected [3]. The 2-T fit overestimates total area by 9%. The best-fit high-temperature component underestimates the highest temperatures measured with the thermal camera by 181 K.

Table 1: Model fits to Erebus 2005 thermal spectrum

	Temp, K	Area, m^2	Difference from target, m^2	% of actual, m^2
Target area		**817**		
Single T fit	843	626	-191	-24
Two T fit	733	615		
	909	276		
Total area		891	+74	+9

Davies (1996) model input parameters: Davies (1996) model input parameters and values are given in [1-3]. To account for the vesicular nature of the crust a thermal conductivity (κ) of 0.5 W m^{-1} K^{-1} was used. This value yields accurate Davies (1996) model fits to Landsat TM data of lava flows at Etna and Kilauea. An eruption temperature of 1475 K was used, somewhat higher than the actual eruption temperature at Erebus (1300 K). The small effect this temperature difference has on model output is being evaluated. Other input values are as follows: emissivity (ε) = 0.9, density (ρ) = 2600 kg m^{-3} and specific heat capacity (c) = 1500 J K^{-1} kg^{-1}

The Davies (1996) model was run for Erebus environmental conditions. The resulting family of cooling curves was then used to fit the integrated thermal emission spectrum.

Davies (1996) Model fit: The Davies (1996) model yields the best fit to the data (see Figure 1). Output paramaters are given in Table 2. The model almost-perfectly reproduces the thermal emission spectrum and emitting area of the Erebus lava lake, especially the area of the lava lake. The inferred areal coverage rate appears to be generally consistent with observations, although further data analysis is required to ascertain an exact value of resurfacing rate.

Table 2: Davies (1996) model fit to Erebus data

Target area	**817** m^2 [4]
Best fit area	819 m^2
Difference from target	2 m^2, (+0.2%)
Temp range	1475 – 699 K
dA/dt	0.381 m^2 s^{-1}
Oldest surface age	2150 s (36 min)

Conclusions: (1) The Davies (1996) model can accurately reproduce the observed thermal emission from an active lava lake. **(**2) For similar lava lakes on Io, such as Pele, the estimates of temperature distribution, surface age distribution, total thermal emission and subsequent calculation of areal coverage rate and flux density (W m^{-2}) using the Davies (1996) model are equally robust. (3) This also gives us greater confidence in the estimates of areal coverage rate and effusion rates for other sytles of volcanism (e.g., insulated pahoehoe-like flows at Prometheus and Amirani [3]).

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