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Geoscientific Instrumentation Methods and Data Systems
Discussions

Interactive comment on "Autonomous thermal camera system for monitoring the active lava lake at Erebus volcano, Antarctica" *by* N. Peters et al.

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The authors wish to extend their thanks to both reviewers for their insightful comments on the discussion paper. Many thanks also to the editor and the rest of the editorial team for their swift and efficient handling of this paper from beginning to end.

Detailed Response to Comments of Reviewer A. L. Sobisevich

- As stated in section 3.3 of the manuscript, all software (including source code) created for this project is available under the terms of the Gnu Public License from http://dx.doi.org/10.6084/m9.figshare.784942.

Detailed Response to Comments of Reviewer M. Patrick

The below responses have been incorporated into the revised manuscript.

- The IR window used in the camera enclosure is 3 mm thick Germanium with a 8-12 μm anti-reflective coating.
- The camera has a built-in calibration source and surface temperatures could, in principle, be obtained per pixel. As Dr. Patrick states, this would require parameterisation of in-band emissivity of the lava lake surface and atmospheric transmittance. While a reasonable estimate might be made for the former, the atmospheric transmittance is highly variable in space and time due to the fluctuating column amounts of volcanic gases in the optical path between the camera and the lake surface (approx. 350 m range). Several magmatic gas species emitted from the lake absorb in the detector's waveband. In an instantaneous image, the transmittance will likely differ widely for each pixel due to the inhomogeneity of the volcanic plume. And from frame to frame, the plume structure may vary considerably. Thus, no unique value of transmittance would be appropriate to correct all the images to surface temperatures. Sawyer [2006] (referenced in the main text) has shown how use of open-path Fourier transform spectroscopy to measure absorbing species in the optical path can provide some traction on this problem but only an imaging system would be able to constrain both the spatial and temporal variability in transmittance (and it would require a vast amount of data processing). Consequently, we have recorded images in the "radiometric" setting on the camera - in which the recorded signal is linearly proportional to in-band radiance reaching the detector. While these data are not well suited to estimating surface temperatures on the lake or radiative power outputs, they are valuable for studying lava lake motion, which we discuss in the main article.
- The camera has three possible temperature ranges that it may be set to. In

general we use the range 273-923 K, however, we have occasionally used the higher temperature range of 573-2273 K. The temperature range used for each image is stored in the PNG header data of the image file.

- The approximate cost of the main components of the system are outlined in Table 1. It should be noted however, that the control system could be used with any camera unit provided that it supports the GenICam interface.
- In the view of the lake shown in Fig. 5, it is approximately 40 m wide. As stated above, we have not recorded absolute temperatures, so the colour scale is uncalibrated.

Component	Approximate Cost
Thermal Camera	£20,000
Single Board Computer	£300
GPS	£80
Solid-state Hard-disc	£300
Sensors, SSR and Interface	£200
Enclosure (inc. IR window)	£400

Table 1. Approximate cost breakdown of thermal camera system.

Updated Results and Discussion

Since the original submission of this article we have conducted an additional field campaign on Erebus, and therefore have more up-to-date information on the performance of the camera system. On returning to the volcano in November 2013, we discovered that the battery bank which serves the camera system had failed. Several of the batteries had cracked casings and all registered $\sim$6 V. The exact cause for this failure was never determined, however, we suspect that it was caused by a faulty wind turbine system which allowed the batteries to over-discharge and subsequently freeze. As a result, power was never restored to the camera after the winter, and therefore images

were only acquired up until 26 April 2013. It is worth noting however, that when power was restored, the system resumed acquisition without any further intervention. The wind turbine and associated controller have now been replaced with a new, redundant system which we hope will provide a greater degree of protection for the battery bank.

A further failure of the system was that the stainless-steel mounting bolt which secures the camera enclosure to the tripod had bent, allowing the enclosure to rotate such that the camera was no longer pointing at the lake. Fortunately, this had happened after the power had failed, and so no additional data were lost. It is somewhat surprising that such a small enclosure can provide enough wind-resistance to bend a 5 mm diameter bolt! We have replaced the bolt with a much larger one, and plans are underway to replace the entire tripod setup with a more substantial mounting system during the 2014 field campaign.

Despite the problems outlined above, the camera system worked well until late April when the sun stopped rising and solar charging ended. Almost four million images were acquired; the largest thermal infrared dataset ever recorded on Erebus. The system was left running after the 2013 field season and, with the improved power system in place, we are hopeful of achieving year-round data acquisition during 2014.

In addition to the images collected, the system also recorded its power consumption and the temperature both inside and outside of the enclosure. As expected, the power consumption was stable at $\sim$11 W throughout the period of operation. Figure **??** shows the recorded temperatures. The sharp drops in internal temperature are caused by power outages, and the subsequent rapid heating clearly demonstrates the ability of the system to keep itself warm simply using waste heat from the SBC and hard-disc. It should be noted that the external temperature sensor seems to over-read by $\sim$10°C compared to measurements made with a handheld thermocouple. This is likely caused by heat leakage from the camera enclosure into the external temperature sensor enclosure.

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., 3, 627, 2013.

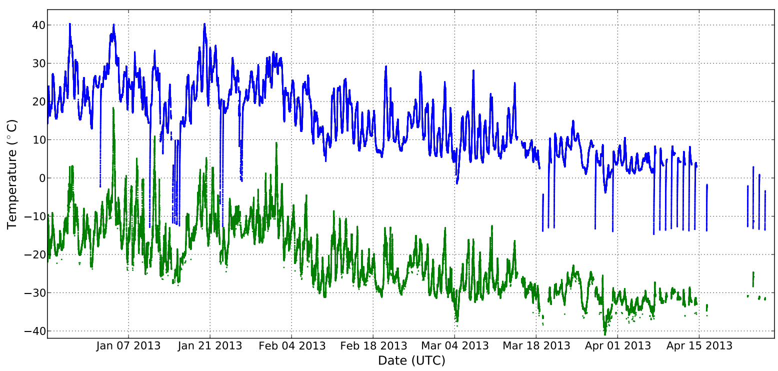

Fig. 1. Time series of temperature readings both inside (upper) and outside (lower) of the camera enclosure. It should be noted that the external temperature sensor appears to over-read by ∼10C.