Extracting accurate temperatures from non-contact thermal infrared radiance data

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Introduction

- A common method used to study active basaltic volcanism is with thermal infrared (**TIR**) radiance data. **Temperature** (T) and emissivity (ε_λ) are related through the **Planck Equation**:

$$B(\lambda, T) = \varepsilon_\lambda \left[\left(\frac{c_1 \lambda^{-5}}{e^{(c_2/\lambda T)} - 1} \right) \right]$$

- A *fixed* emissivity can be assumed in order to solve for temperature. However, laboratory-based emissivity measurements show that **emissivity** is *variable* with changes in **physical state**.[2]

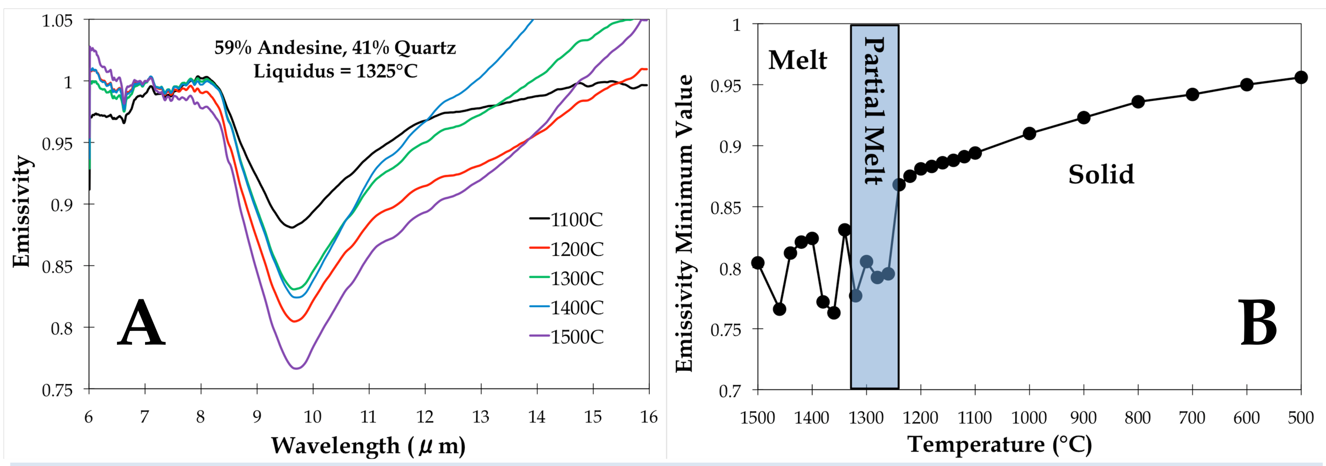

Figure 1: (**A**) Emissivity spectra of actively melting silicate glasses showing (**B**) a decrease in emissivity as samples are heated past their liquidus temperatures.

- The research presented here examines the possibility of variable emissivity in a silicate's **molten state** and the effect that has on deriving accurate surface temperature of active lava flows with field-based TIR cameras.

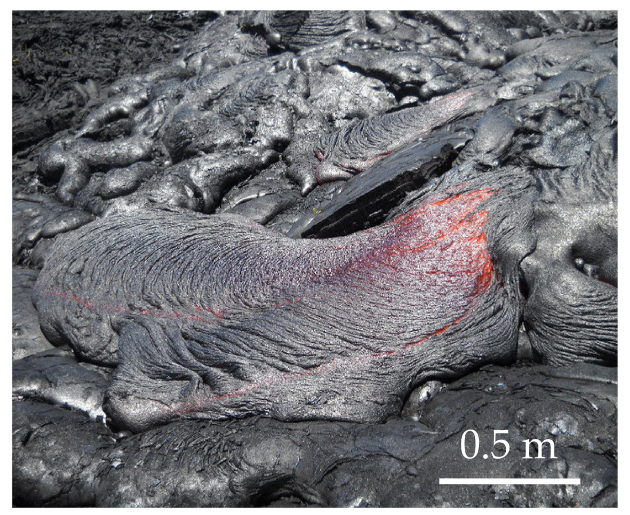

Figure 2: Active basaltic lava flow at Kilauea volcano in Hawaii on 15 July 2010. As molten material cools, a glassy crust forms which begins to fold. This image contains molten material, hot glassy crusts, and relatively cool glassy crusts in the background. (Photo: H.A. Morgan).

Significance

- The findings of this work have implications for understanding basaltic flow emplacement, cooling, and crust formation, as well as for extracting accurate lava temperature from remote TIR data.
  - The temperature of a lava flow relates directly to parameters such as *composition*, *rheology*, and *emplacement processes*.
  - Temperature also serves as a critical input into flow cooling and propagation models used for hazard prediction.

Methodology

- TIR radiance data were collected at Kilauea volcano, Hawaii (region shown in **Figure 3**) with a forward-looking infrared (**FLIR**) camera.

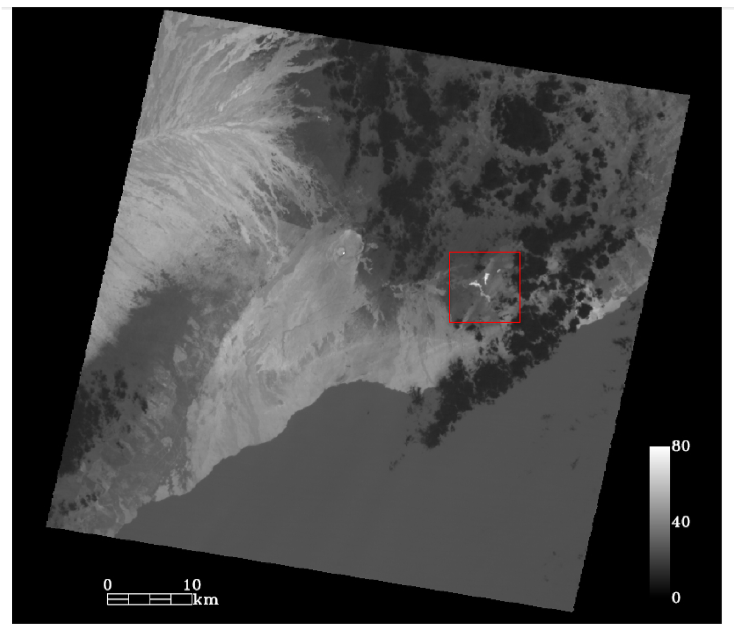

Figure 3: This Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) temperature image acquired on 9 Mar 2011 shows the southeast coast of the island of Hawaii, including Kilauea volcano. The red boxed area illustrates the region where a relatively hot, active lava flow is located, as well as where the FLIR data were collected.

- Temperature data were analyzed along linear transects (**Figures 4 and 5**) using the ThermaCam Researcher Professional 2.7 software after accounting for several object parameters (**Table 1**).

Object Parameters			
Emissivity	Distance	Atm. Temp.	Hum.
1.00	2 M	38.9°C	32%

Table 1: In order to produce accurate temperature images, several parameters were either measured in the field or assumed, one of which is emissivity.[1]

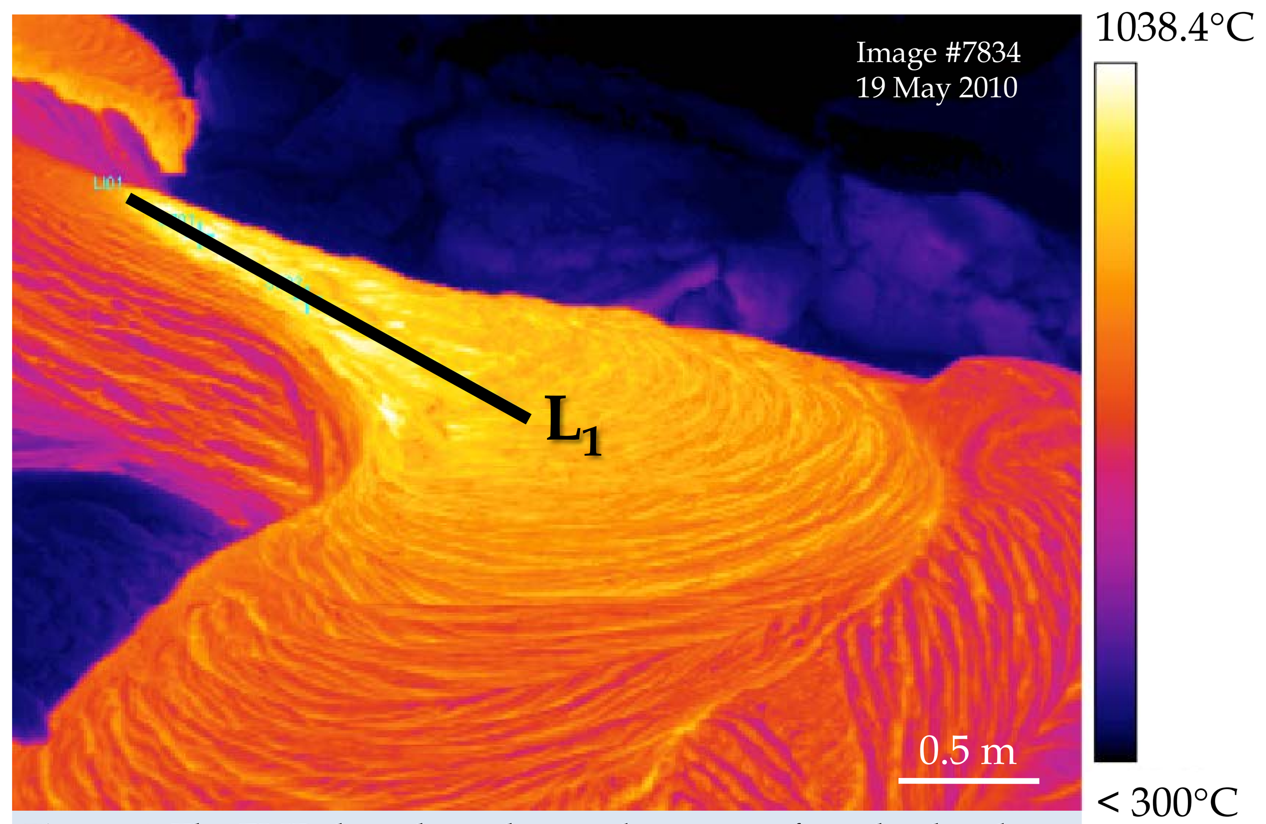

Figure 4: The FLIR data show the emplacement of a pahoehoe lava lobe, including the appearance of molten lava (yellow – white) at a breakout point until it cools to form a glassy crust (orange – pink) that begins to fold.

Methodology (cont.)

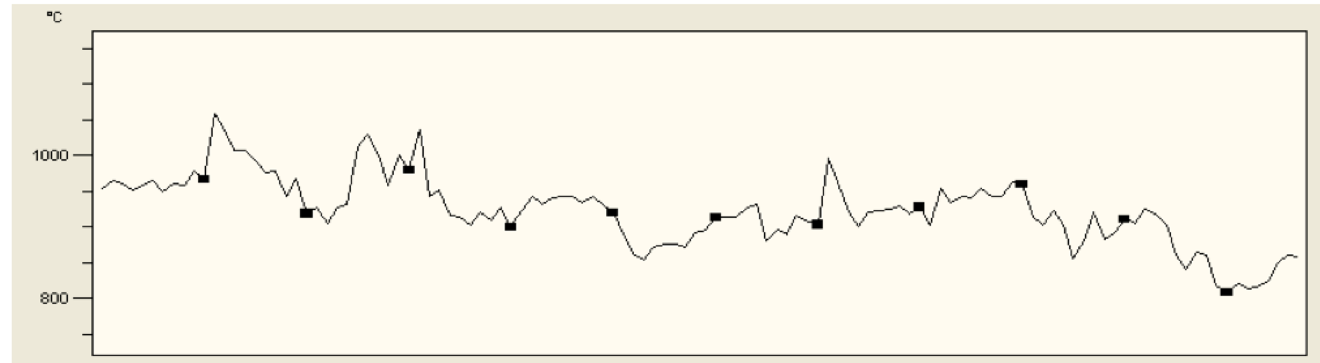

Figure 5: Temperature profile for the linear transect (L_1) shown in Figure 4 at an assumed emissivity of 1.0.

- **Emissivity** was then adjusted sequentially from **1.0** to **0.6** until the temperature measured in the image matched the known lava temperature measured in the field with a thermocouple (**~1140°C**).

Results

- At an emissivity of 1.0, temperature along the linear transect varied between ~800 - 1050°C (**Figure 5**).
- Emissivities of **0.86** and **0.93** produced an **average** and **maximum** temperature along the transect of 1140°C, respectively (**Figure 6**).

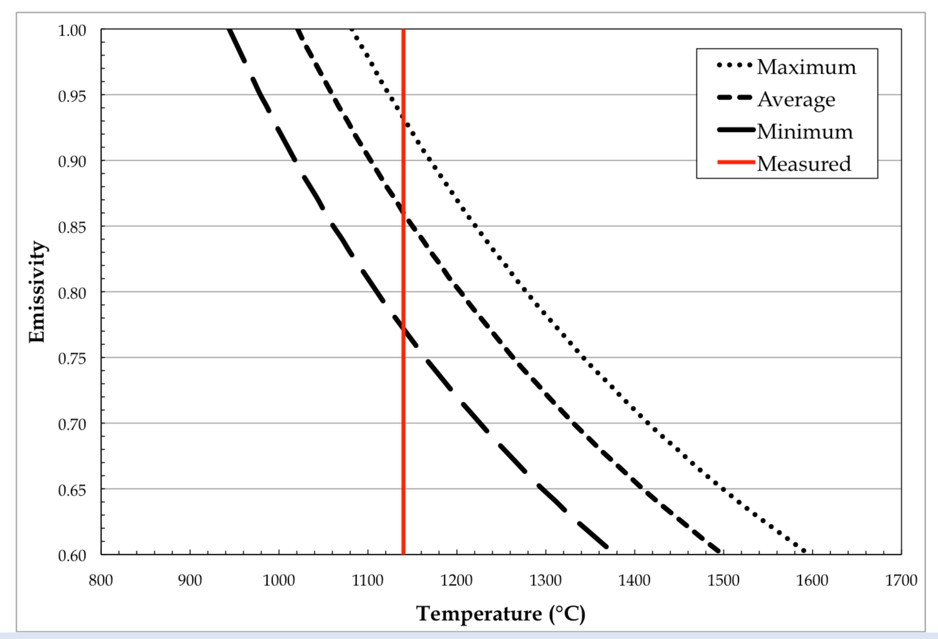

Figure 6: Plot showing increasing temperature with decreasing emissivity. The maximum, average, and minimum temperatures for a linear transect are shown, as well as the actual flow temperature of ~1140°C (red line) measured with a thermocouple.

- This suggests that the TIR temperatures in the images rose above the known lava temperature at emissivity values less than **~0.89**. The average emissivity of cooled glassy Kilauea basalt is between 0.93 and 0.96. This indicates a *decrease* in emissivity occurs with a change of state, due to changes in the atomic bond structure of the melt.[3]

Discussion

- Basaltic lava in the field appears to display less dramatic changes between its glassy and molten states than rhyolite samples melted in the laboratory.[2]
- This is due to the higher melting and glass transition temperatures of basalt and the quick formation time of the crust.[3]
- The change in emissivity for molten rhyolite could therefore impact derived surface temperatures in a much more significant way than it would for basalts.

Conclusions

1. Variations in emissivity due to a change in state observed in the laboratory are also apparent in field-based IR camera data.
2. Emissivity generally decreases with an increase in temperature due to changes in the atomic bond structure with a change of state.

References

[1] Harburger, A.M. and M.S. Ramsey. "Measuring Basaltic Flow Viscosity from Crustal Thickness." *GSA Annual Meeting*. Minneapolis. 9-12 Oct. 2011.

[2] Lee, R.J., M.S. Ramsey and P.L. King. "Development of a New Laboratory Technique for High temperature Thermal Emission Spectroscopy of Silicate Melts." *Journal of Geophysical Research:* 118 (2013): 1-16.

[3] Ramsey, M. S., R. J. Lee, S. W. Anderson and D. A. Crown. "Multiscale Parametric Imaging of Basaltic Lava Flows." *IAVCEI Scientific Assembly*. Japan, Kagoshima. 20-24 July 2013.

Acknowledgements

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