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Improving field lava flow temperatures with lab-based spectral emissivities for the 2014–2015 Holuhraun eruption

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Spectral emissivity (ϵ) is the fundamental and physical capacity of a material to emit heat radiation.

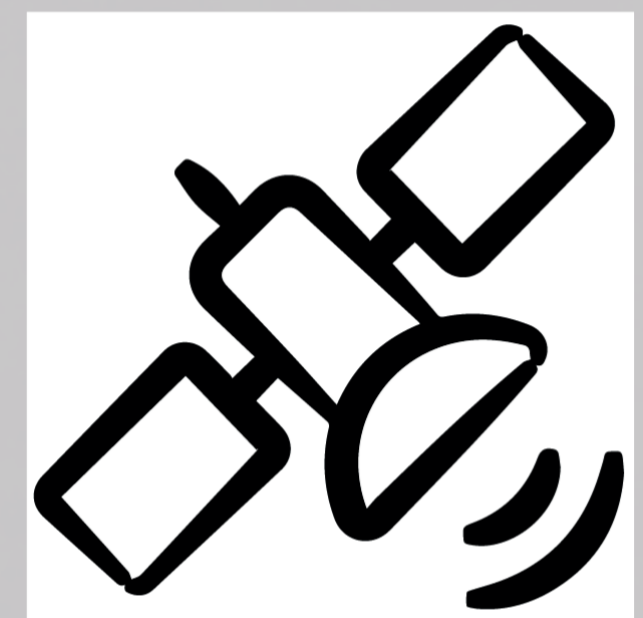
$$\epsilon_{\lambda}(\sigma, T, \theta) = \frac{L_{\lambda}(\sigma, T, \theta)}{L_{\lambda}^{\text{Sample}}(\sigma, T, \theta)} = \frac{\text{Sample}}{BB}$$

INTRODUCTION

How to measure lava flow temperature more precisely?

Lava flows are one of the main hazards related to effusive basaltic volcanism. To minimize their impact during emplacement, we use lava flow distance-to-run predicted by propagation models. These models rely on surface Temperature (T), a key source term parameter that is commonly determined using infrared (IR) measurements of lava radiative heat fluxes by remote sensing (RS) techniques (ground- or satellite-based) [1]. Their results are however subjected to important errors related to the poor knowledge of spectral emissivity (ϵ), commonly considered constant (e.g., 0.97 for basalts) [2, 3]. This oversimplification is an important source of uncertainties in derived temperatures, which restrain our capacity to accurately model active lava flows.

In this study, we confront thermal maps modeled with constant ϵ and based on ϵ laboratory measurements. We describe the methodology used to improve previous RS thermal maps using lab-based ϵ measurements. We discuss the potential impacts from improvements of temperature accuracy on lava flow thermo-rheological modelisation.



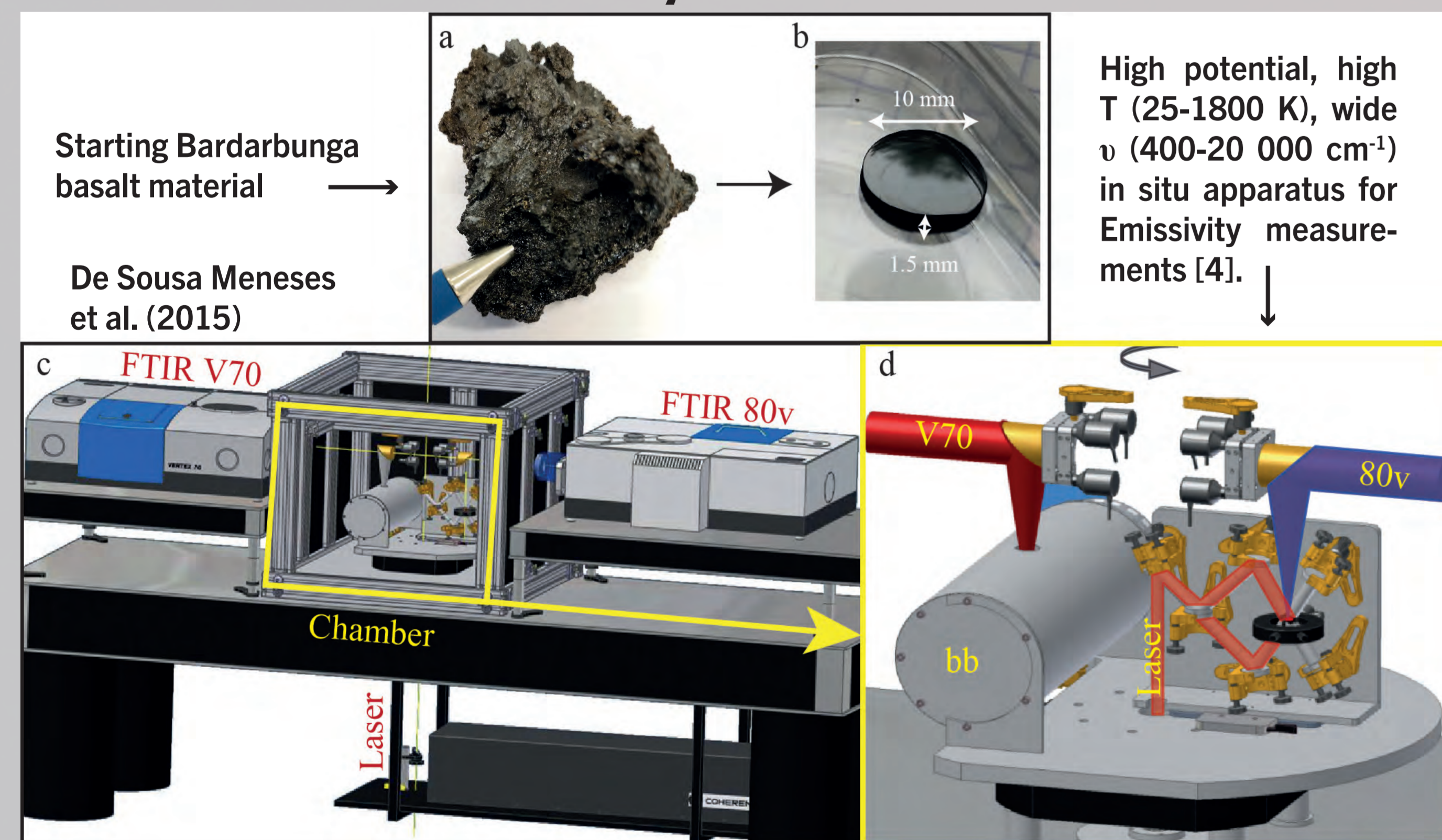
Remote Sensing



Holuhraun eruption, Bardarbunga volcano (2014-2015), Iceland

11 09 2014
Credit: IMO

Laboratory measurement



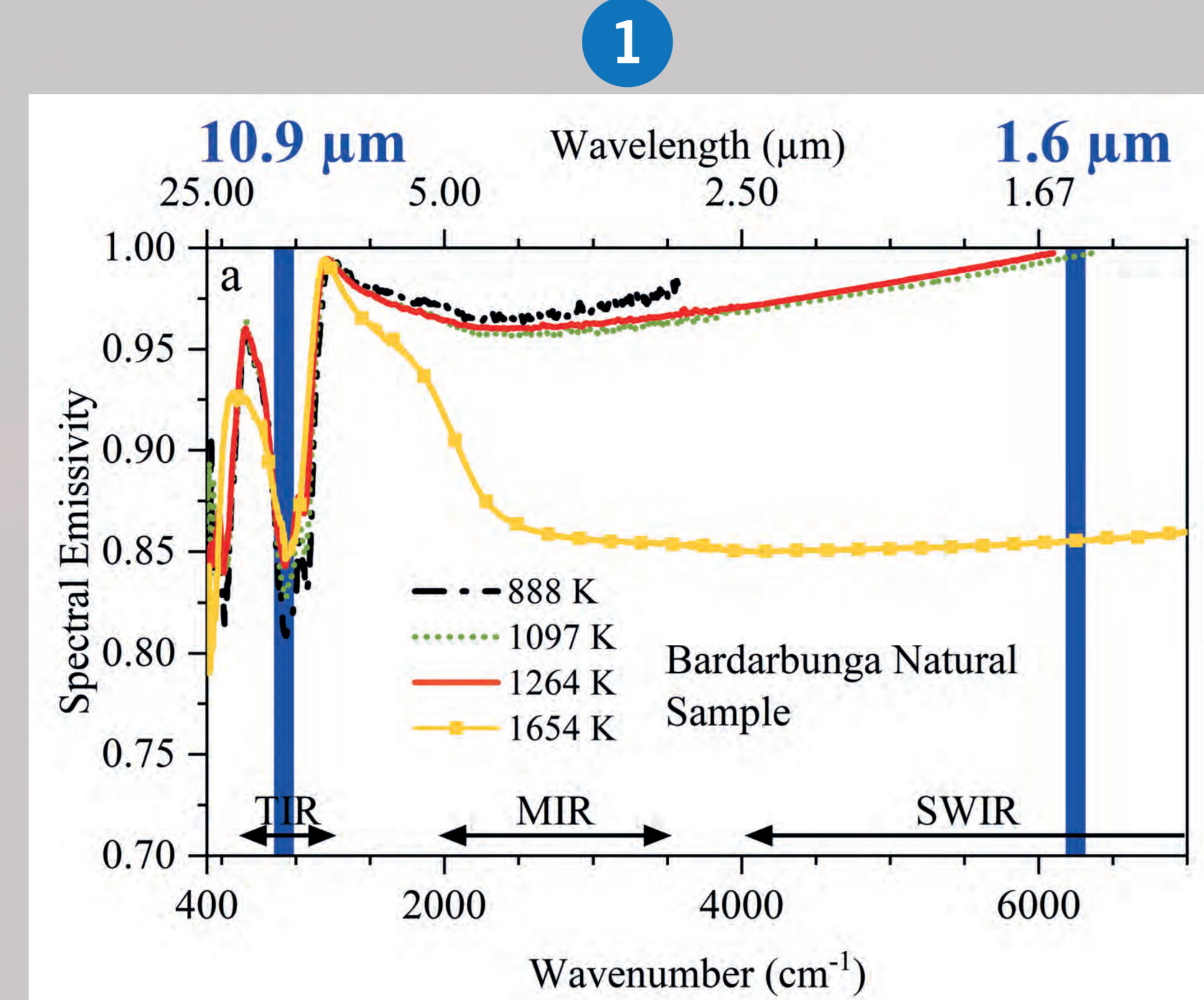
High potential, high T (25–1800 K), wide ν (400–20 000 cm^{-1}) in situ apparatus for Emissivity measurements [4].

METHOD

Spectral emissivity of basaltic magma from the 2014–2015 Holuhraun eruption was measured in situ. Spectra were systematically acquired over a wide spectral range (400–8000 cm^{-1}) covering TIR, MIR and SWIR, and up to ~1800 K using IR emission apparatus [4]. Then, we transformed the ϵ –T relationship into equations at two wavelengths of interest for RS; 10.9 μm (TIR), and 1.6 μm (SWIR). Finally, we implemented these equations in AUFARISTAMA et al. (2018) [5] thermal model and run the refined model as follow:

- 1- First iteration with constant ϵ (0.97) to determine T.
- 2- Creation of emissivity map for each band using T to calculate ϵ .
- 3- Second iteration with $\epsilon_{\text{calculate}}$ to refine lava flow T.

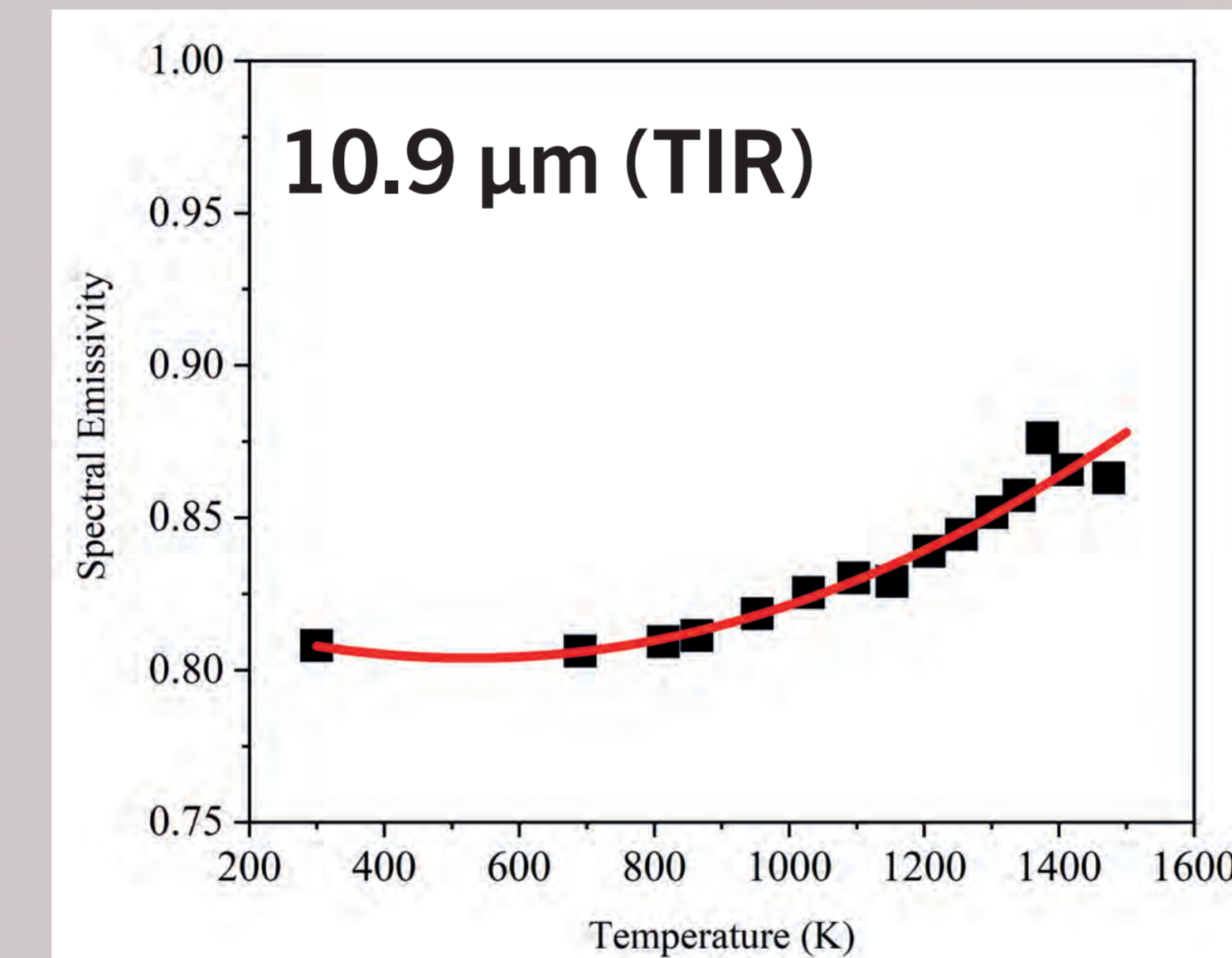
Measured Emissivity–Temperature relationship



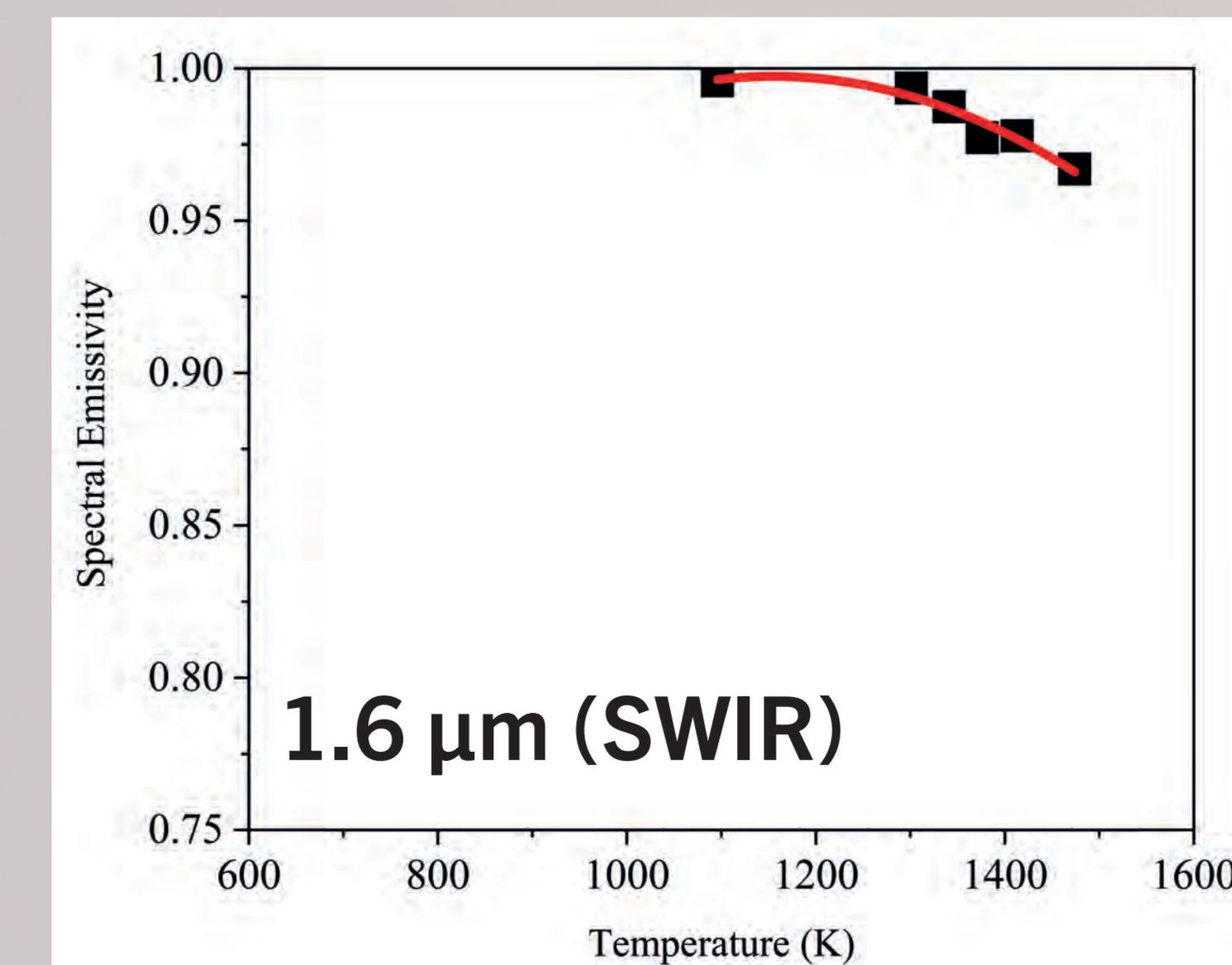
For more information, refer to «V23A-04, Thermal Radiative Properties of Bardarbunga Basalts: Importance of Emissivity in Magma Rheology and Volcanic Hazard», Jonas Biren et al.

Quanti. of Emissivity–Temperature relationship

$$\text{Radiative eq.: } R_{\text{TIR-SWIR}} = [L(\lambda_{\text{TIR-SWIR}}) - L_{\text{U-R}}(\lambda_{\text{TIR-SWIR}})] / \epsilon_{\text{TIR-SWIR}}$$



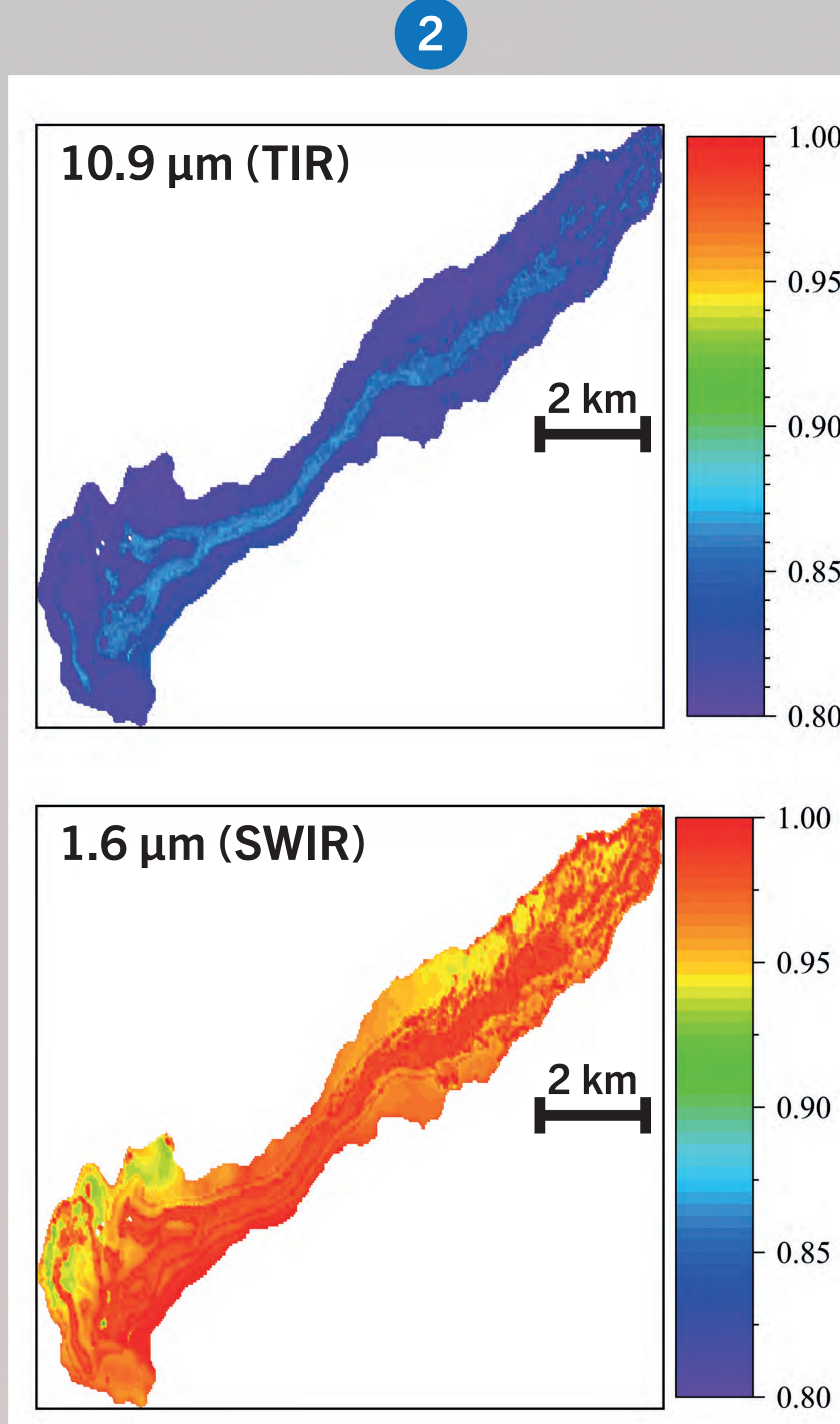
$$\text{Derived eq.: } \epsilon_{\text{TIR}} = 0.826 - 8.235 \cdot 10^{-5} \times T + 7.818 \cdot 10^{-8}$$



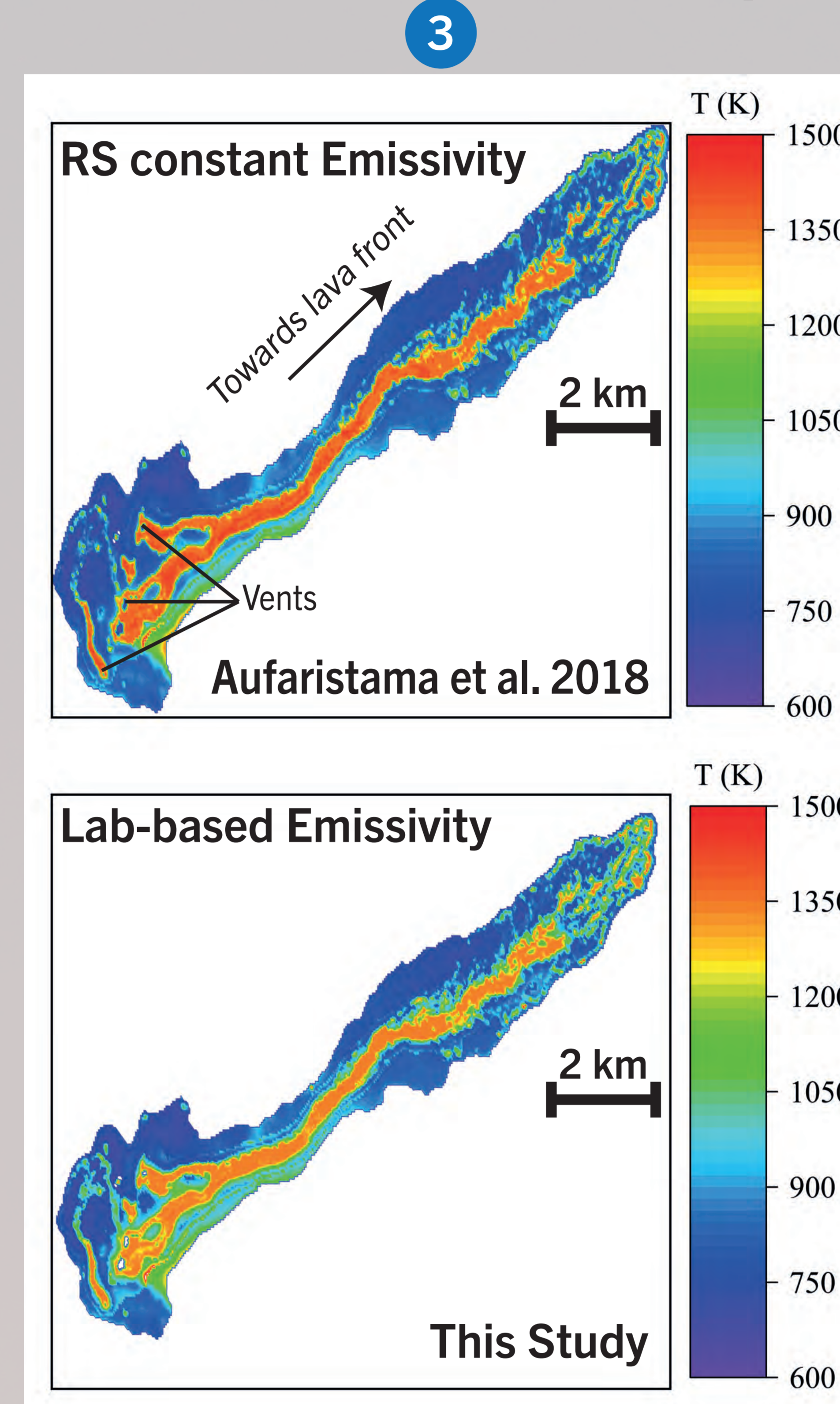
$$\text{Derived eq.: } \epsilon_{\text{SWIR}} = 0.586 + 7.123 \cdot 10^{-4} \times T - 3.084 \cdot 10^{-7}$$

NH25A-0528

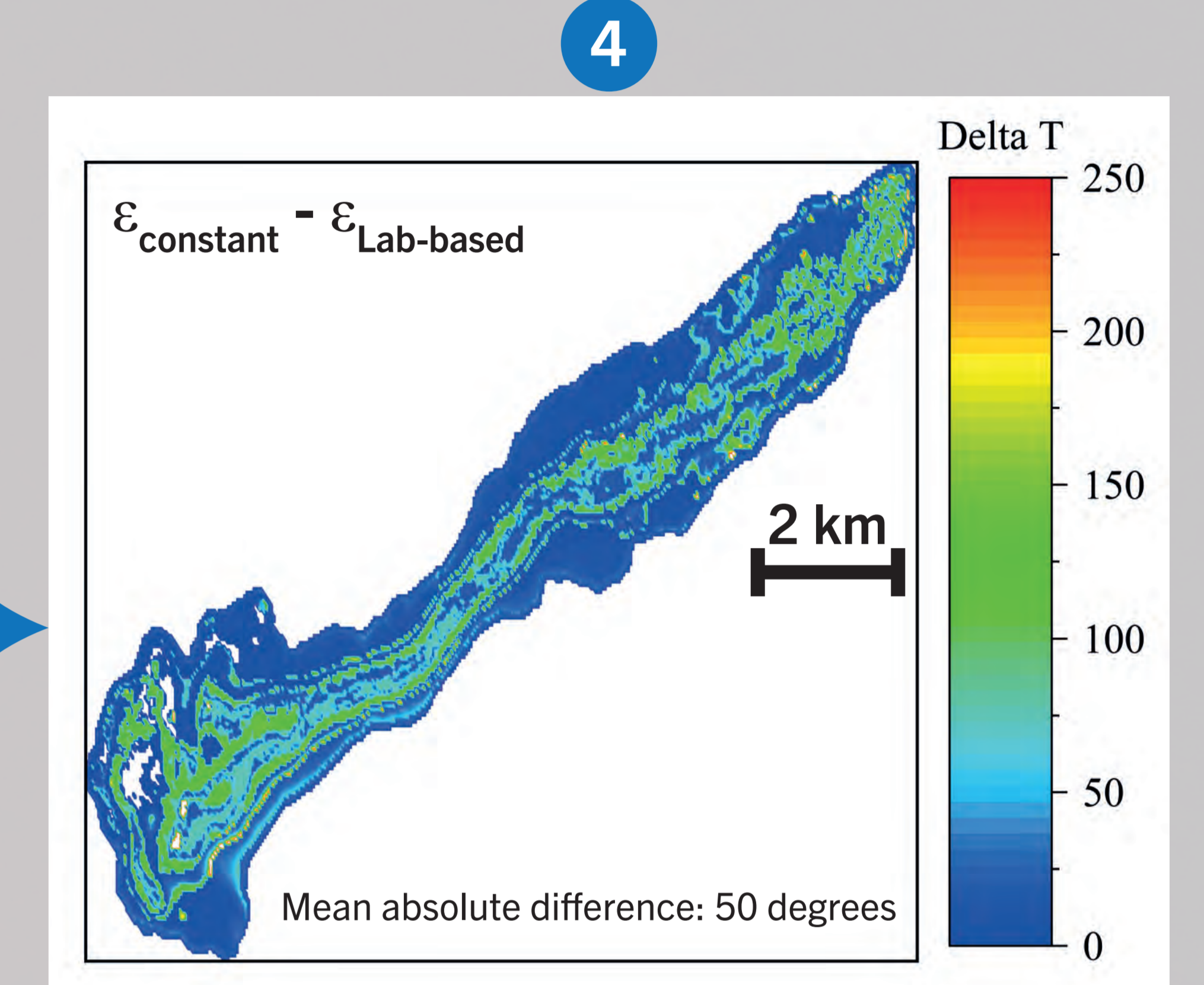
Lab-based Emissivity Maps



RS vs. Lab-based Thermal Maps



Difference in T due to lab-based Emissivity



CONCLUSIONS

Lab-based IR results help increasing accuracy in temperature retrieval by Remote Sensing techniques (by $\geq 50^\circ$). These observations imply that lava is less likely to lose heat radiatively thus taking longer time to dissipate. In turn, it allows for longer distances to be reached increasing ultimately the associated hazard especially in inhabited area. Consecutively, our results will help reduce the error related to thermo-rheological models [6] of lava flows and support hazard assessment during effusive volcanic crisis.

RESULTS

- 1 Spectral emissivity depends on λ and T [7]: ϵ increases linearly with temperature at 10.9 μm (TIR), and changes non-linearly and with greater amplitude at 1.6 μm (SWIR).
- 2 When lab-based emissivity maps are compared, derived ϵ values are higher in SWIR (0.9–1.0) than in TIR (0.8–0.9). High ϵ values are characteristic of molten lava (e.g., lava channel and levées are well visible) whereas lower ϵ values are characteristic of the lava flow surroundings (e.g., lava front).
- 3 When Thermal maps are compared, T distribution varies between RS- and Lab-based thermal maps. Lava channel shows lower temperatures whereas levées and lava front show higher temperatures. The temperatures of the cooled surroundings remain constant.
- 4 The mean difference between RS- and lab-based thermal maps is $\sim 50^\circ$ for lava channel, while is greater for lava levées and lower for cooled surroundings.

Emissivity is key for Remote Temperature determination



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