Thermal infrared data of active lava surfaces using a newly-developed camera system

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Introduction

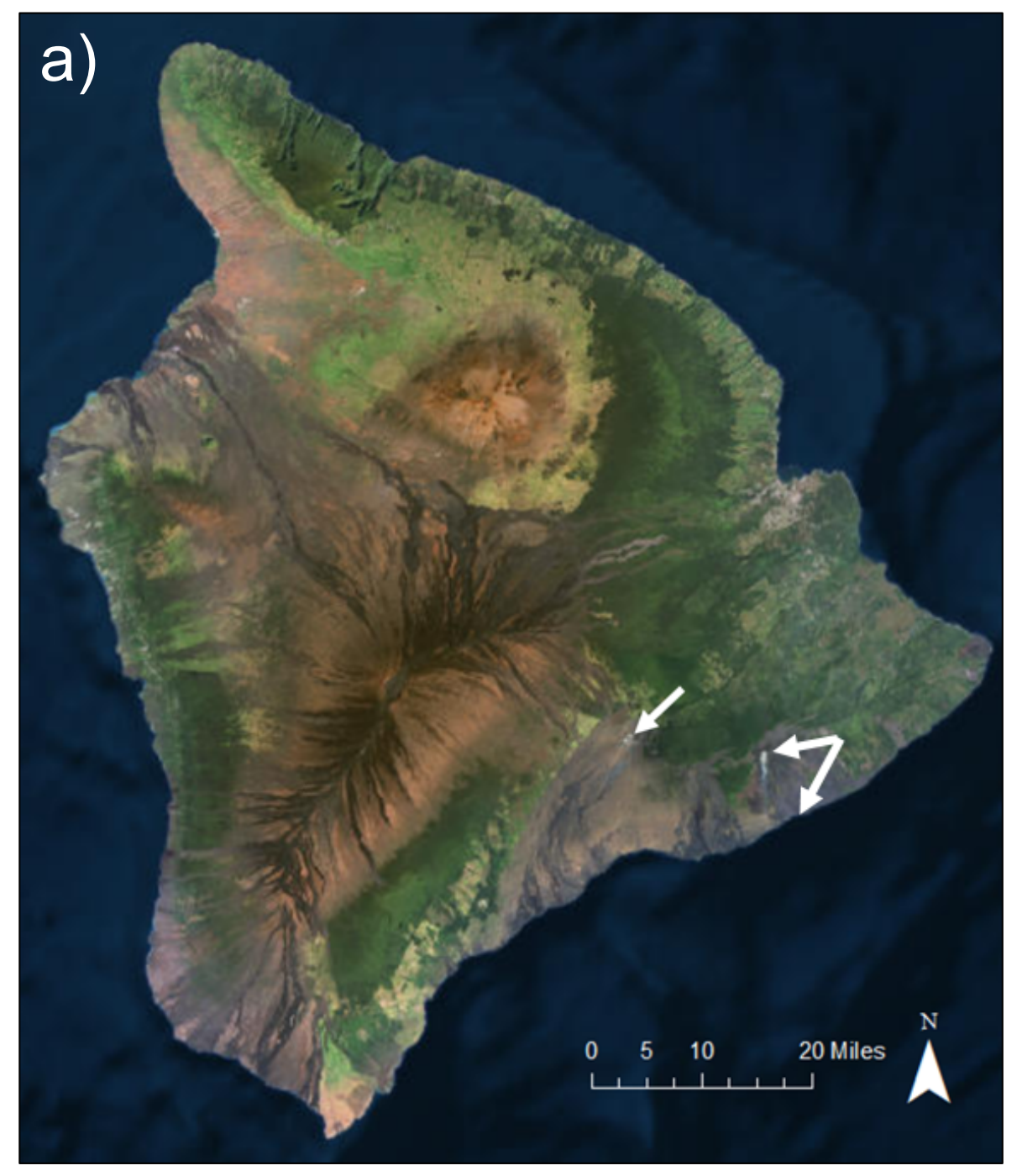
A field-portable miniature multispectral thermal infrared camera (MMT-Cam) was developed as part of the January 2017 HyspIRI Preparatory project. The goal of the project is to assess the research applications that are possible with thermal infrared (TIR) data, at spatial and spectral resolutions proposed by this mission. The MMT-Cam was built to acquire accurate emissivity data *in situ* with changing temperature on active lava surfaces. Furthermore, constraining the relationship between the emissivity spectral change and radiance derived from TIR data will provide more accurate temperatures[1]. Collection of accurate temperature and emissivity data during lava flow emplacement will greatly improve models designed to predict flow dynamics and down-flow hazard potential[1]. Finally, through spatial degradation analysis, constraints can be improved for the identification of changes in temperature and emissivity during cooling at lower spatial resolutions.

Location

The first field campaign was conducted at Kīlauea volcano, Hawai'i in January 2017 (Fig. 1a). Kīlauea volcano is a basaltic shield volcano located on the eastern slope of Mauna Loa volcano[2]. During the campaign two volcanic processes were targeted:

1. Lava flows (primary) – the surface lava flow activity on the pali and coastal plains on the eastern slopes of Kīlauea volcano produced by the episode 61g flows (July 2016 - present) from Pu'u 'Ō'ō vent (Fig. 1b)[3].
2. Lava Lake (secondary) – the 250 m long and 190 m wide active lava lake within the Halema\`uma\`u crater[4] (Fig. 1c).

Additionally, further testing was undertaken at the lava pour experimental facility run by the Syracuse University Lava Project team, where melts of basaltic compositions are poured onto a sand substrate (Fig. 1d).



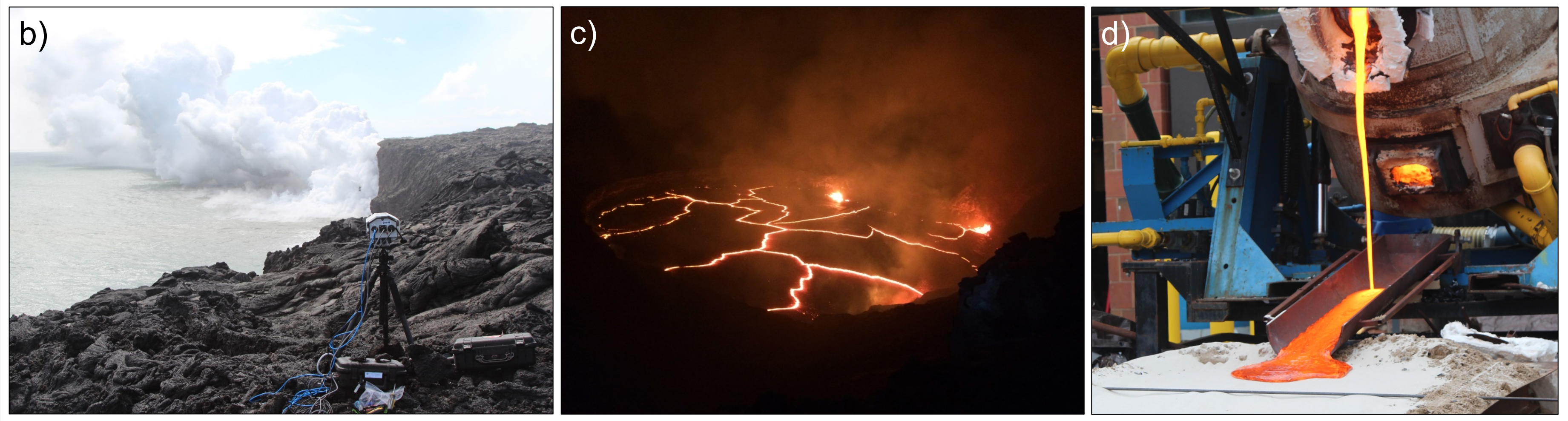
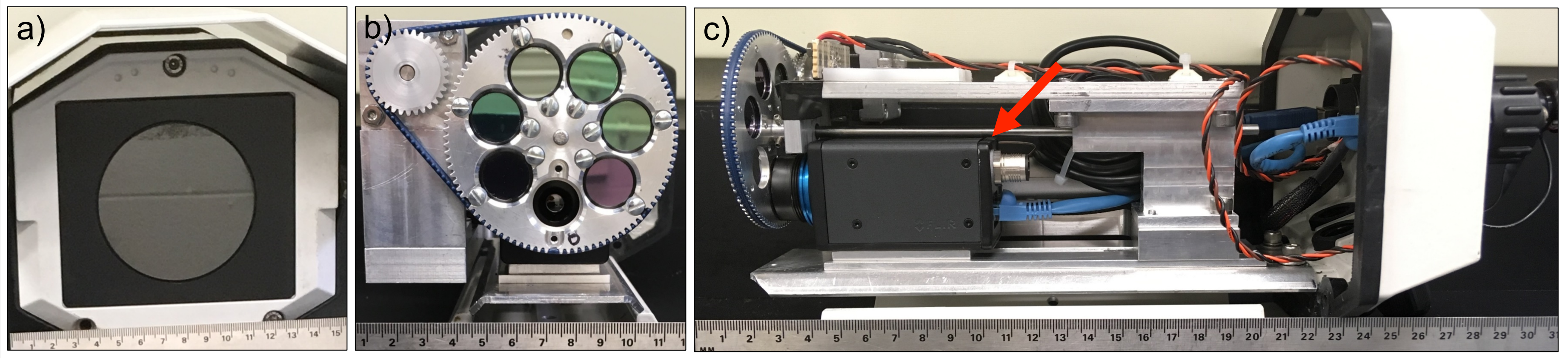


Figure 1: a) The island of Hawai'i, white arrows showing field areas (source: ESRI). **b)** MMT-Cam deployed at the lava flow entering the ocean near Kamokuna and **c)** Halema\`uma\`u lava lake. **d)** Lava pour at Syracuse University.

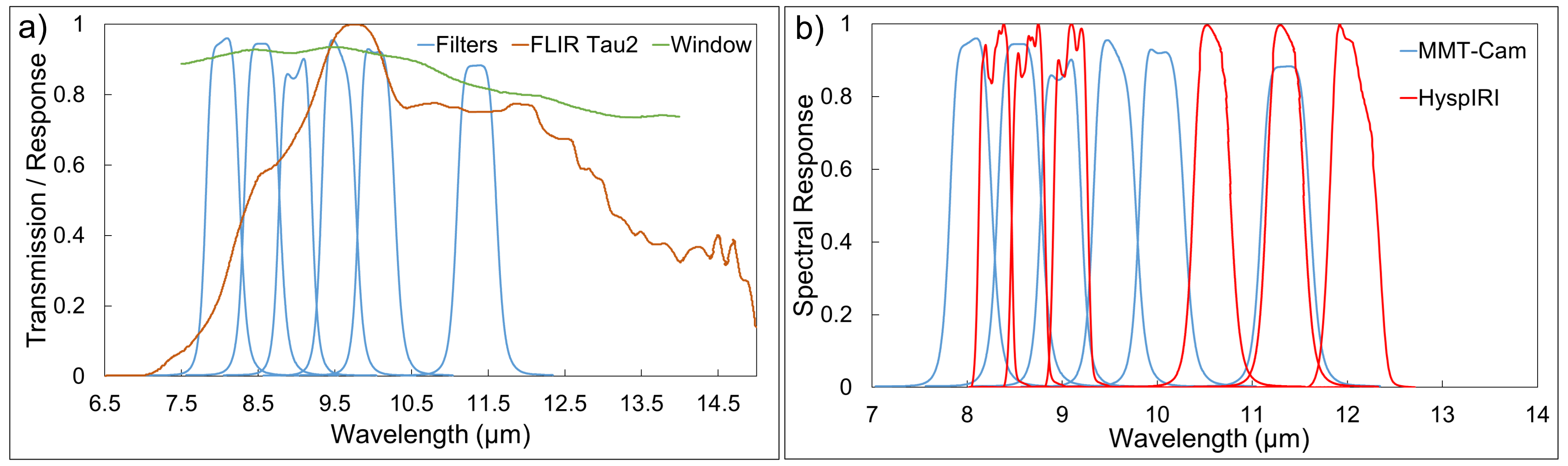
Instrumentation



Specification	MMT-Cam
Core	FLIR A65 (2nd generation)
Spatial resolution	640 x 512 pixels
Field of view (FOV)	45° x 37° with 13 mm lens
Image frequency	30 Hz
Gain settings	-25°C to 135°C / -40°C to 550°C
Detector	Uncooled VOX microbolometer
Spectral resolution	7.5 – 13.0 µm
Filter Wheel	7 port – 6 IR filter + 1 open port

Figure 2: a) Front of the MMT-Cam enclosure showing the germanium window, **b)** inside front of the enclosure showing the filter wheel, **c)** interior side of the MMT-Cam enclosure. The red arrow indicates the location of the FLIR A65.

Table 1: Techniqual specifications of the new MMT-Cam .



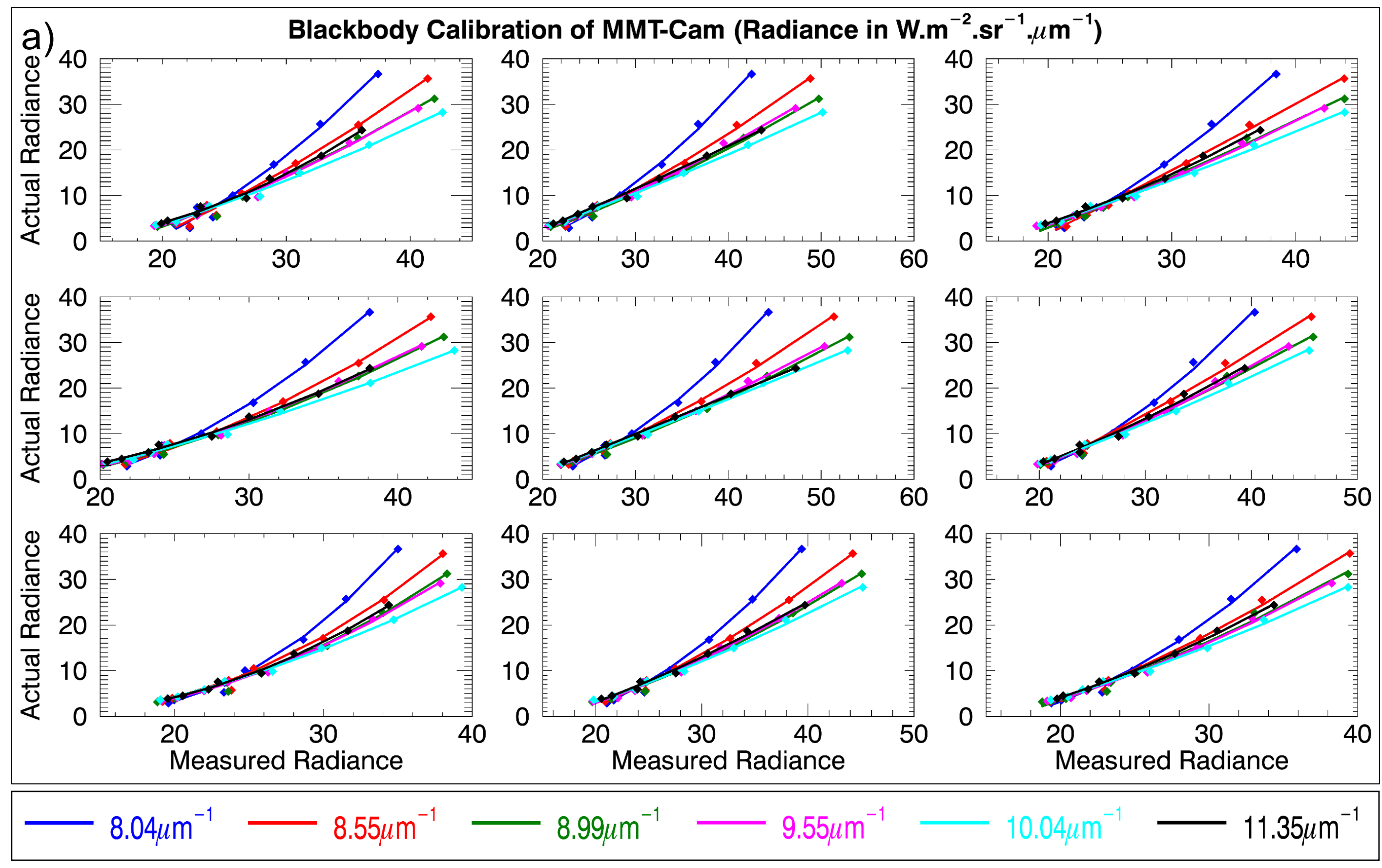
Band Number	Band Center [µm]	Peak Transmission [%]	Spectral Range (FWHM) [µm]	
			Min	Max
Broadband	11.00	91.5	7.500	13.000
1	8.04	88.6	7.814	8.266
2	8.55	89.1	8.313	8.787
3	8.99	84.1	8.766	9.211
4	9.55	90.0	9.320	9.777
5	10.04	86.7	9.805	10.289
6	11.35	73.5	11.086	11.616

Figure 3: a) Spectral response of the six filters plotted with the FLIR Tau2 sensor response and the transmissivity of the enclosure's germanium window. These are used to determine the complete response for each band in the MMT-Cam. **b)** Comparison of TIR band locations between the MMT-Cam and proposed HyspIRI instrument.

Table 2: Spectral specifications of the new MMT-Cam.

Calibration

The MMT-Cam system calibration incorporates only data where the camera and filters are perfectly aligned. Second, blackbody experiments were conducted at the Aerospace Corporation using environmentally controlled blackbodies at temperatures from 10 to 200 °C. The per-pixel radiance measured at the focal plane array (FPA) were compared to the actual filter and broadband blackbody radiance values (Fig. 4a). Second order polynomial models were produced to correct for any attenuations and errors associated with the system design.



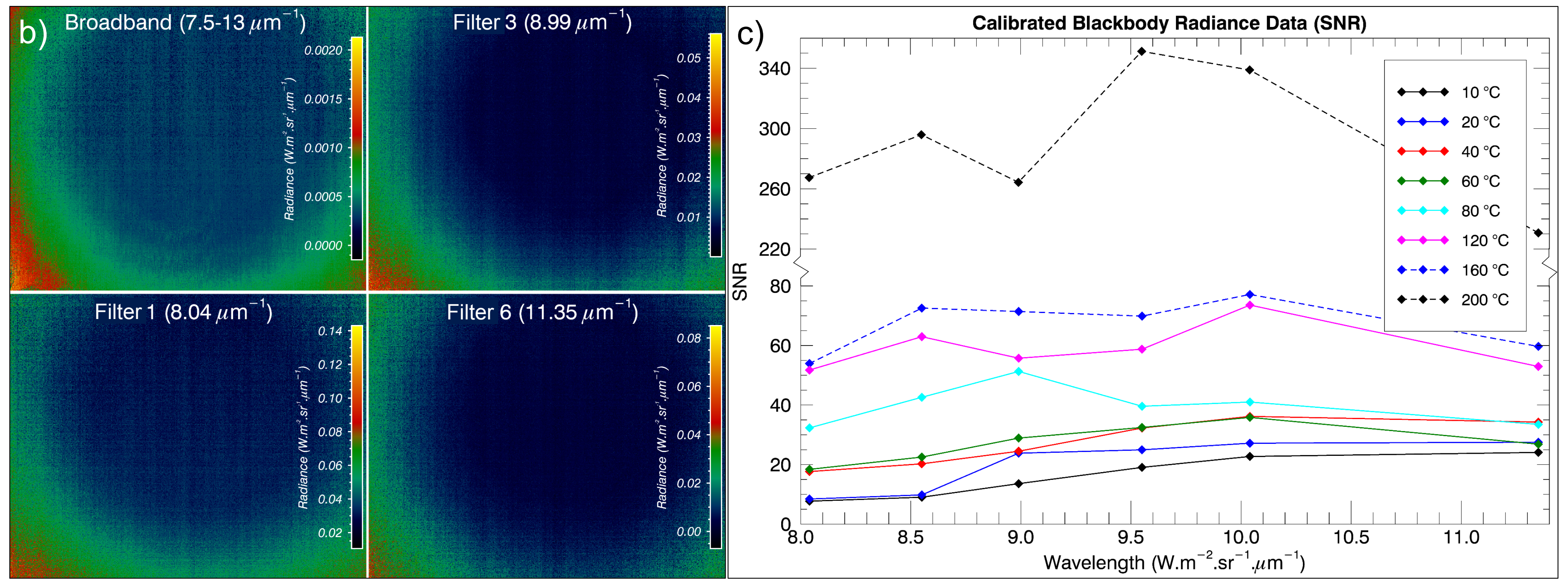


Figure 4:
a) Comparison between the measured and actual blackbody radiance for different pixels across the FPA for all six filters. The location of the plots corresponds to the location on the FPA.
b) The power gain correction maps for the broadband and the 8.04, 8.99, and 11.35 µm filters. Warmer colors represent higher values.
c) The calibrated blackbody signal to noise ratios (SNR) for the different filters at various blackbody temperatures.

Results and Conclusions

Multispectral TIR data acquired during a lava pour experiment at Syracuse University show a change in emissivity spectra of basaltic lava surfaces as they cool. During emplacement and subsequent cooling from 1270 to 730 ºK, the emissivity spectra (Fig. 5b) shallow and spectral contrast increases.

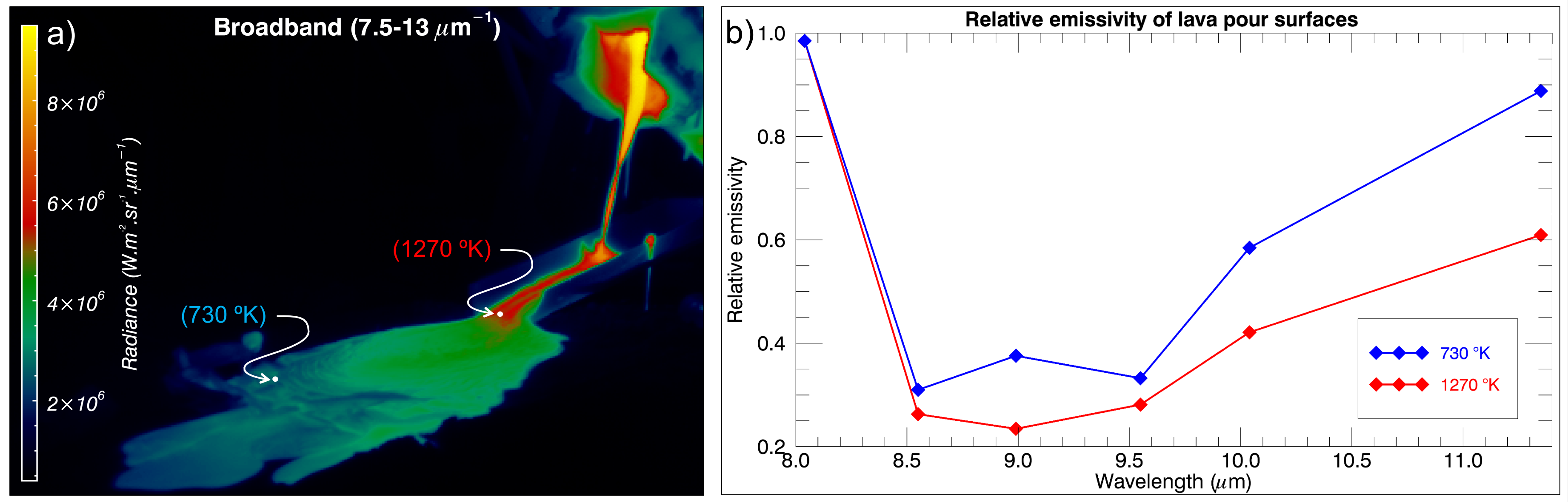


Figure 5: a) Calibrated broadband TIR image acquired during the lava pour experiment, the labels indicate the location where the emissivity spectra were extracted from. **b)** Emissivity spectra, calculated using the Emissivity Normalization method [5], from the proximal molten channel of the flow (1270 ºK) and the distal cooling lobe of the flow (730 ºK).

The preliminary lava lake data (Fig. 6a) show that the primary emissivity absorption feature (around 8.5 to 9.0 µm) transitions to emissivity between 9 to 10 µm and shallows as the lava surface cools from 760 to 520 ºK, forming a progressively thicker crust. The spectrum is likely a mixture of both the lava surface and SO_2. The feature transitioning to longer wavelengths is partially due to the structural and physical state change as the glassy crust forms over the molten material (Fig. 6b). This change in the Si-O-Al bond structure is postulated to be changing the emissivity and with time, the spectrum should approach that of a solid cold basalt. This is the first time that accurate, unsaturated emissivity data with changing temperature has been measured *in situ* on active lava surfaces.

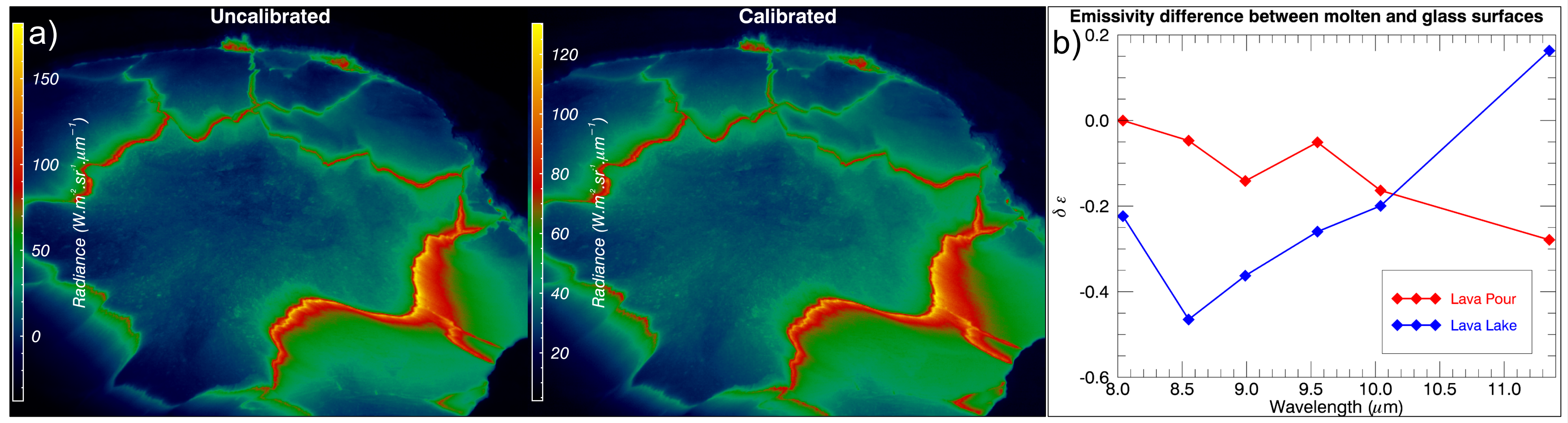


Figure 6: a) Before and after calibration TIR images of the Halema\`uma\`u crater lava lake acquired with the 8.04 µm filter. **b)** Emissivity difference spectra of molten and glass lava surface, acquired from the lava pour and lava lake [5].

Future Work

Future work will include applying the current methodology to evaluate the spatiotemporal variability in temperature and emissivity during natural lava flow emplacement and cooling. A correction for the influence of SO_2 on the emissivity spectra will be developed. The corrected spatiotemporal variability in emissivity of propagating lava flows will be incorporated into prediction models to improve outputs. Finally, these results and methodologies will be compared to current and proposed satellite datasets, including ASTER and HyspIRI, to determine future capabilities.

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