A New Perspective on Lava Lake Dynamics from Thermal Remote Sensing

E. Bonny[1,2]*, P. Mouginis-Mark[1], R. Wright[1]

1-Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu, HI; 2-Department of Geology and Geophysics, University of Hawai'i at Mānoa, Honolulu, HI

*ebonny@hawaii.edu

EGU2018-10022
X2-390

I. Motivation

- Thermal flux used for proxy in magma supply rate at lava lakes around the world [1, 2]
- Still unknown for Halema'uma'u lava lake at Kīlauea volcano, Hawai'i. Its large ground-based dataset can help us understand better lava lake dynamics through heat flux measurements
- **10th year anniversary of the lava lake** (Fig 1). This eruption provides us with an unprecedented set of satellite images to explore the utility of thermal data for assessing magma supply rate

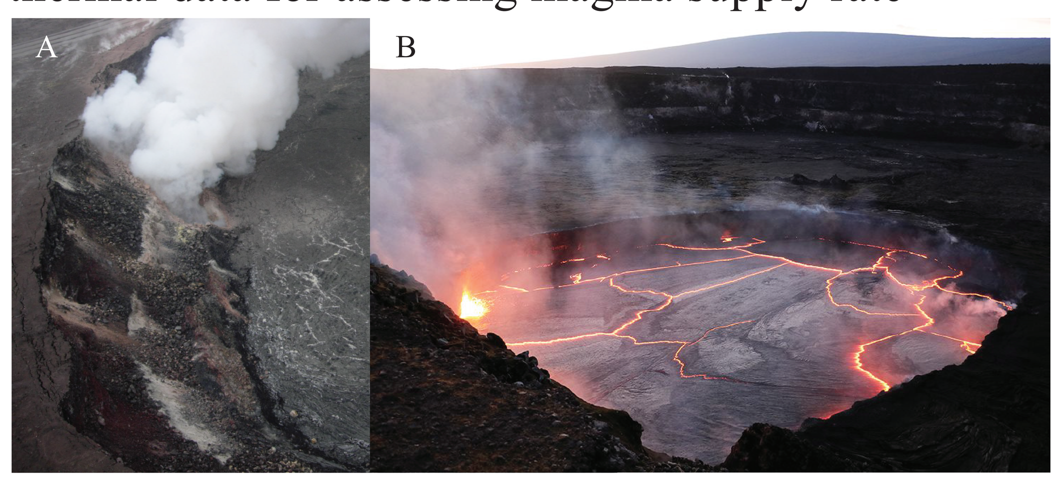


Fig.1: A) Opening of Halemaumau lava lake on March 19, 2008 on the SE side of Halemaumau crater. B) The lava lake 10 years later (view from the SE, Mauna Loa in the background). All pictures are from the USGS

II. Methods

Thermal Remote Sensing Heat Flux

- MODIS Terra and Aqua, night time [3]
- 4 µm radiance used
- Online at http://modis.higp.hawaii.edu/
- 2681 acquisitions from 2008 to Nov 2017 (up to 2 per night)

→ 10x increase from 100MW to 1GW

Lava lake level measurement [4]

- Ground-based thermal cameras (HVO)
- Laser rangefinder data used to convert lake level to meters a.s.l.
- Hourly measuments averaged daily
- Measurement from 2009 to Oct 2017

→ 2 visible overflows (>1023 m.a.s.l)

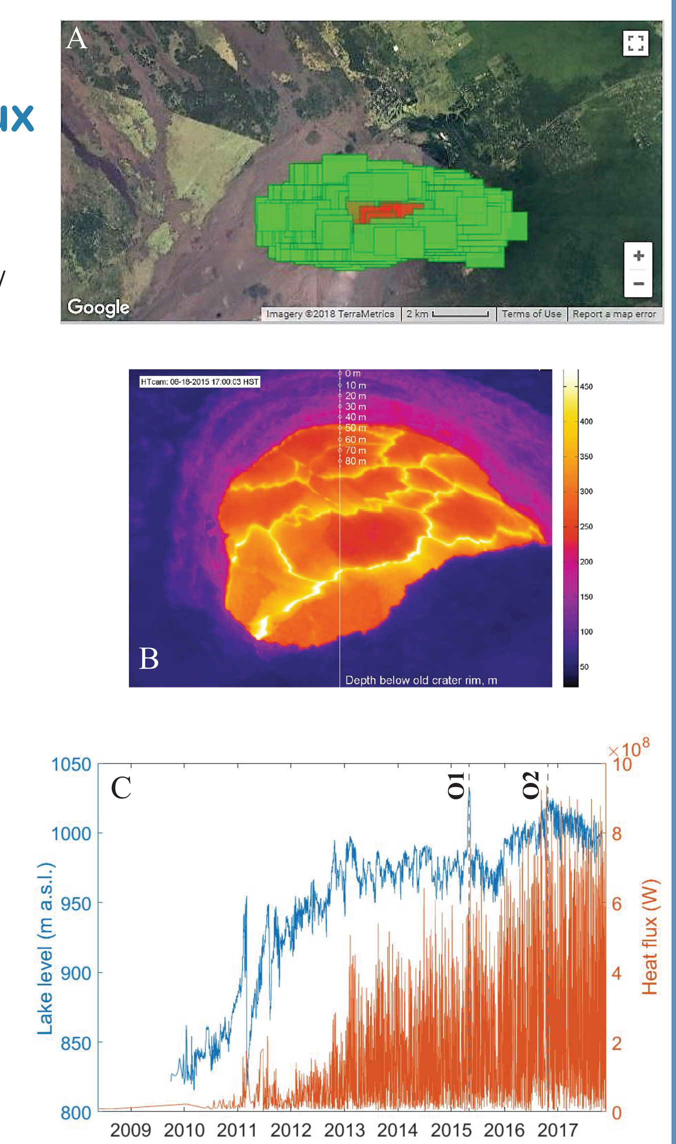
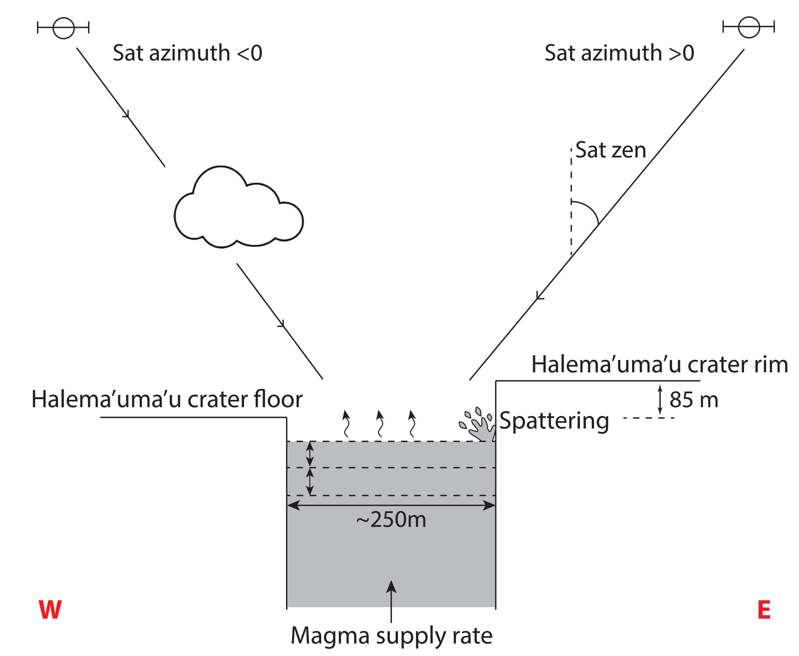


Fig.2: A) Screenshot of the MODVOLC website recording the radiant heat flux of Kilauea summit lava lake Halemaumau from the opening of the lake to November 2017. Each square is a recorded anomalous pixel. B) Thermal image of the lava lake from HVO cameras explaining the lake elevation measurement. C) Lava lake level in blue and Heat flux in orange against time since the lava lake opening, O for overflows

III. Field conditions

- Crater lake area increased ~10x since its opening (Fig 4B) just like the heat flux = large influence on heat flux measurement
- Higher ledge on the East side of the lake (85m) and main spattering location is on the lake's SE corner. Only small influence on heat flux



How many variables can influence the satellite thermal heat flux?

1. Surface activity of the lake ?
2. Area of the lake
3. Lava lake level
4. Satellite zenith angle
5. Satellite azimuth angle ?
6. Clouds/fumes obscuration
7. Magma supply rate ?

(2–4:) 8. Visible lake area to the sensor

Fig.3: Schematic of the summit lava lake Halemaumau with the different parameters that could influence our remote measurement of heat flux

IV. Results

1. Fig 4A No correlation between seismic tremor (proxy for surface lake activity) and high heat flux

3. Fig 2C Lava lake oscillates rapidly. Strong lake level increase corresponds to high heat flux

4. Fig 4C As satellite zenith angle increases the maximum heat flux detected decreases

6. Fig 4C Heat flux data affected by cloudy scenes producing very low values. We consider the upper envelope to be the least cloud-contaminated measurements.

7. Heat flux would suggest a 10x increase in magma rate, probably not a good proxy for Halema'uma'u

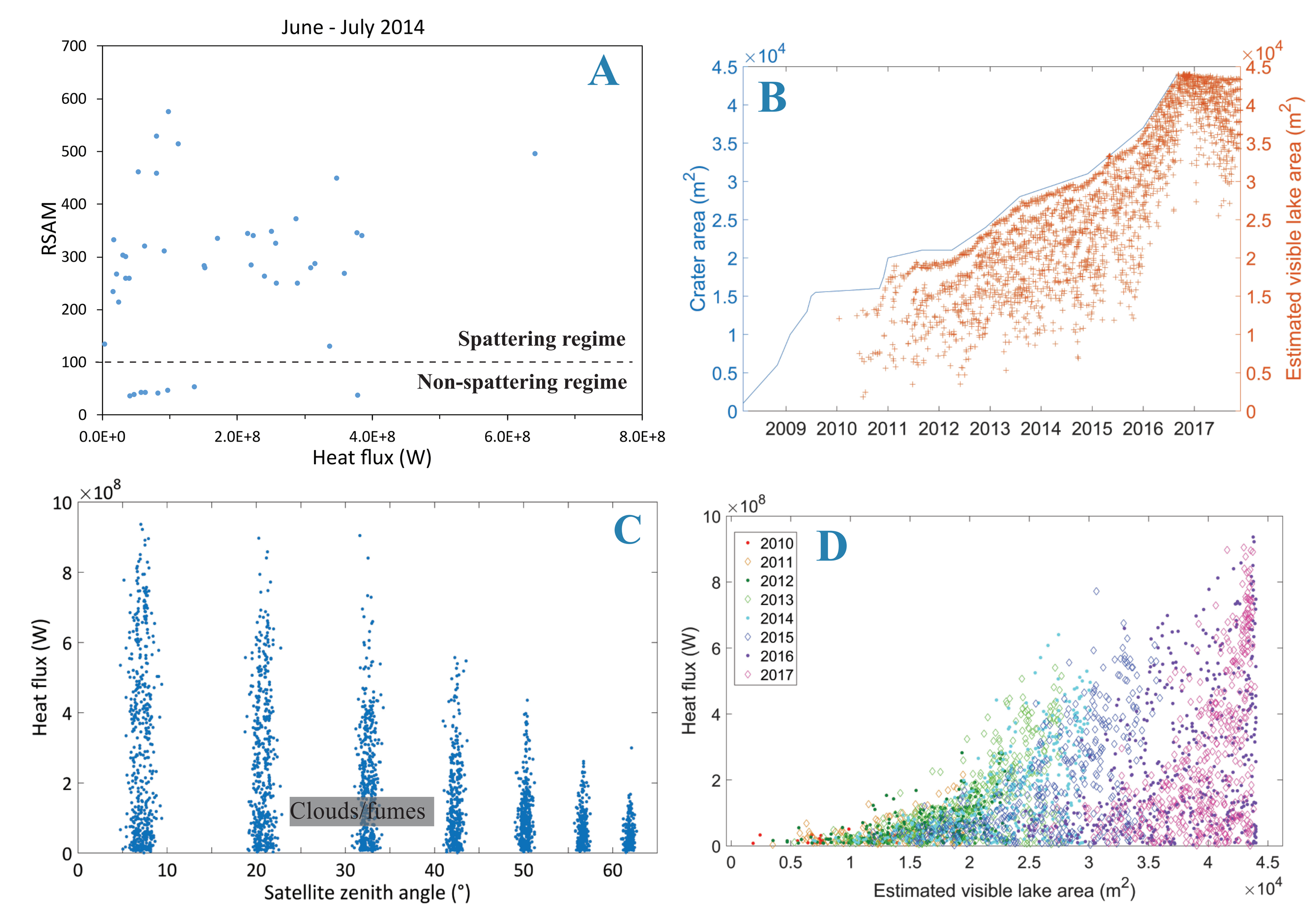


Fig.4: A) Seismic tremor at the summit against heat flux (closest minute); B) Crater lake area and estimated visible lake area against time; C) Heat flux against satellite zenith angle; D) Heat flux against the estimated visible lake area

8. Estimated the lake area visible to the sensor at each acquisition based on the crater size, lake level and satellite zenith at that time. Fig 4D Increase of visible area as the lava lake widened over time.

Fig 5 shows a clear jump off in the normalized heat flux in early 2013. Before 2013, usually ~10000 W/m² and after closer to 20000 W/m²

→ What happened in early 2013? Critical crater size or level reached?

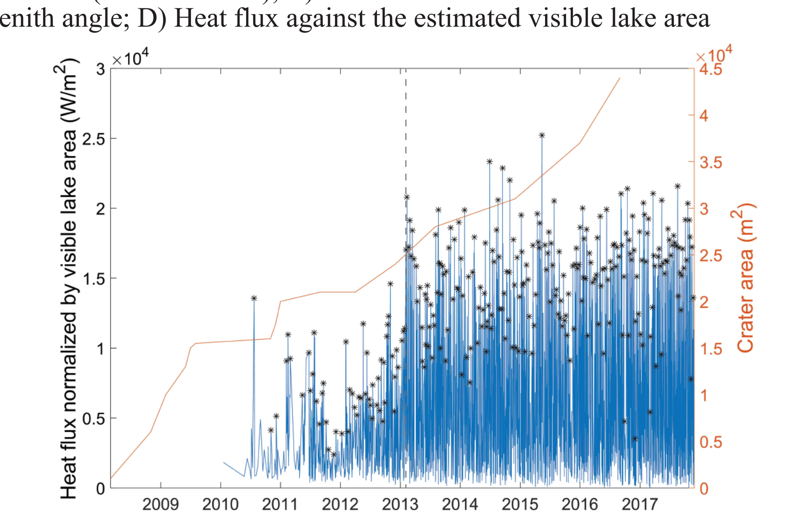


Fig.5: Heat flux normalized by visible lake area with identified high heat flux in black asterisks and crater area in orange.

V. Conclusions

- Heat flux seems to correlate with lava lake level (Fig 2C). Satellite zenith angle decreases the heat flux detectable >30° (Fig 4C). Very low heat flux values may be due to clouds/fumes. The lake surface activity does not affect the heat flux (Fig 4A)
- Issue: Heat flux trend opposite to SO_2 flux (Fig 5). But gas flux is also used as proxy for magma supply rate. Recycling of previously degassed magma?

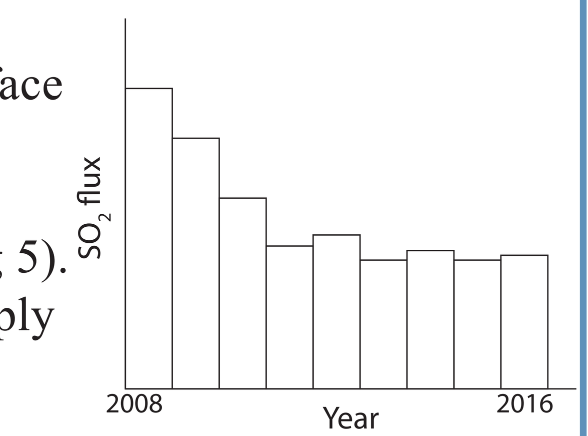


Fig.5: Simplification of annual SO_2 flux at the summit of Kilauea from 2008 to 2016. Personal communication

Cautionary note: For this open vent basaltic volcano we can NOT directly convert heat flux to magma supply rate.

VI. Future work/ Where to go from here?

- Do GPS measurements of deformation correlate with a change in lake level and heat flux?
- Was there an important change in the eruption in early 2013, resulting in a ~two-fold increase in normalized heat flux (W/m²)?
- Summit reservoir linked with eruptions along the ERZ? (Fig 7, [5]) Does summit inflation correspond with a change in discharge at Pu'u 'O'o?

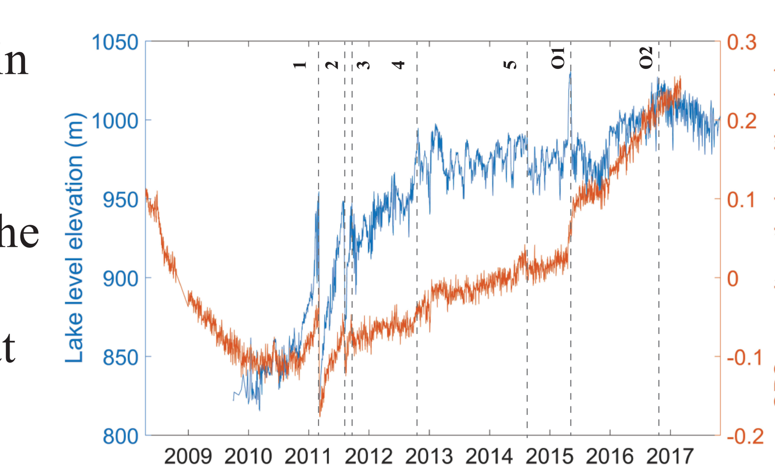


Fig.6: Lava lake level and GPS summit vertical elevation (proxy for inflation and pressurization of magma chamber) over time. 1-ERZ eruptive event (Kamoamoa erption), 2-ERZ eruptive, 3-ERZ eruptive, 4-ERZ intrusive, 5-ERZ intrusive [6], O1-O2 for overflows

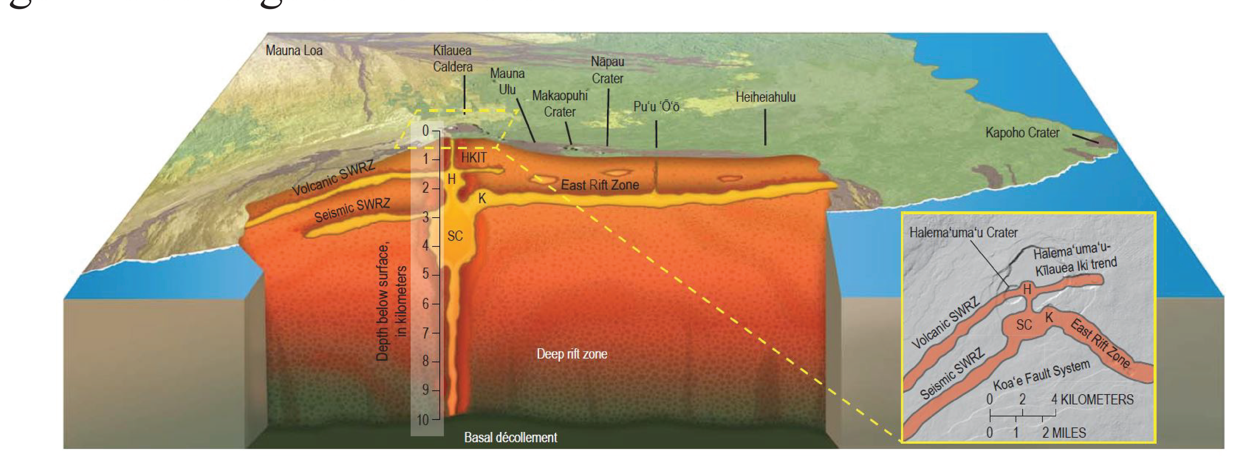


Fig.7: Schematic of the Kilauea's magma plumbing system taken from [7]. H is the Halema'uma'u reservoir, K is the Keanakako'i reservoir, SC is the south caldera reservoir and SWRZ is the Southwest Rift Zone. Magma pathways and storage areas are not to scale

References

[1] Oppenheimer and Francis 1997. Remote sensing of heat, lava and fumarole emissions from Erta `Ale volcano, Ethiopia, *Int. J. Remote Sensing*, vol. 18, no. 8 [2] Harris et al., 1999. Mass flux measurements at active lava lakes: Implications for magma recycling, Mass flux measurements at active lava lakes: Implications for magma recycling, *JGR*, vol 4(B4) [3] Wright and Pilger 2008. Satellite observations reveal little inter-annual variability in the radiant flux from the Mount Erebus lava lake, *JVGR,* 177 [4] Patrick et al. 2016. Automated tracking of lava lake level using thermal images at Kīlauea Volcano, Hawai'i, *J. Applied Volcanol.*, 5:6 [5] Orr et al., 2015. Kılauea's 5–9 March 2011 Kamoamoa Fissure Eruption and Its Relation to 30+ Years of Activity From Pu'u 'O 'ō, in *Hawaii volcanoes from source to surface* Chapter 18 Geophysical Monograph 208 [6] Patrick et al., 2015. Lava lake level as a gauge of magma reservoir pressure and eruptive hazard, *Geology* v.43, n.9 [7] Poland et al. 2014b. Magma Supply, Storage, and Transport at Shield-Stage Hawaiian Volcanoes in *Characteristics of Hawaiian Volcanoes* Chapter 5 U.S.G.S Professional Paper 1801

Ackowledgments

We would like to thank Matt Patrick for collaborating on this project and without whom this work wouldn't be possible. Thanks to HVO for accomodating my stay in the park. EB and RW were funded by NASA Grants (NNX14AP34G and NNX14AP37G).