LAVA FLOW COOLING ON VENUS AND IMPLICATIONS FOR MICROWAVE EMISSION.

I. Ganesh[1], I. T. W. Flynn[2,3], A. Akins[4], P. K. Byrne[5], L. M. Carter[6]. [1]University of Alaska Fairbanks, (email: iganesh@alaska.edu), [2]University of Pittsburgh, [3]University of Idaho, [4]NASA Jet Propulsion Laboratory, [5]Washington University in St. Louis, [6]University of Arizona.

Introduction: Past spacecraft observations of the surface and atmosphere of Venus indicate that the planet might be volcanically active [1–3]. Scaling studies of terrestrial volcanic eruption rates predict 40–120 discrete eruptions per year on Venus [4,5]. In order to quantify the current rates, styles, and distribution of volcanism, two upcoming missions to Venus (VERITAS and EnVision) will employ complementary observation strategies such as repeat SAR and InSAR imaging, near-infrared (NIR) spectroscopy, and microwave radiometry [6,7]. Among these different strategies, NIR and microwave techniques are theoretically capable of detecting both active and actively cooling lava flows, which are bound to have higher surface emission (at both wavelengths) than the background surface [8,9]. However, the thermal evolution of a lava flow on the surface of Venus, and its impact on surface emission at microwave wavelengths, are not well understood. Here, we present a theoretical approach to investigate the relation between the thermal characteristics and microwave emission of an actively cooling lava flow on Venus, and subsequent implications for the detectability of recent volcanic activity using microwave radiometry measurements from the EnVision mission's VenSAR synthetic aperture radar instrument.

Methodology: Emission from the surface recorded by orbital microwave radiometers is commonly expressed in terms of brightness temperature, T_B. T_B is controlled by the temperature within a surface layer of thickness ~3 × the microwave penetration depth (δ_P) at any given wavelength [9]. Quantifying the magnitude and duration of excess microwave emission from actively cooling flows therefore requires an understanding of the temporal evolution of not only the surface temperature of the flow but also the thermal state of its interior.

Surface and interior temperature estimates. To track the evolution of the surface and interior temperatures of a lava flow on Venus after its emplacement, we use a 1D cooling model with the following considerations. First, we assume that the lava flow has a finite thickness between 1 and 30 m, encompassing the range of flow heights observed in recent terrestrial eruptions [10, 11]. Preliminary measurements of lava flow heights on Venus, using the Magellan stereo topography data, are between 20 and 60 m. This suggests that some of the Venusian flows have thickness ~2 times the maximum value considered here. Our approach is in contrast to previous studies, which had assumed semi-infinite flow thickness leading to overestimates of cooling times [12, 13]. Second, we consider the flow to be basaltic in composition with an eruption temperature of ~1400 K, a conservative value compared to predicted eruption temperatures for basalts on Venus [14]. Third, we assume that the difference between the eruption temperature and the ambient temperature (737 K) establishes a surface heat flux, in the form of coupled convection-radiation [15,16] (Fig 1). Fourth, heat from the lava flow is modeled as being transported into the substrate via conduction (Fig 1). Fifth, heat loss from both the upper and basal surface of the flow leads to the development of crusts that thicken with time. Finally, we assume that, once the upper and basal crusts meet, the flow is essentially completely solid, and any further heat transfer occurs only via conduction. Our assumptions give rise to a set of flow cooling equations similar to those described in Davies et al. (2005) [17] and Wittman et al. (2017) [18], with the main difference being the surface heat loss mechanism considered [15]. The equations are solved numerically using an explicit, finite-difference scheme to compute temperatures within the flow as a function of depth and time.

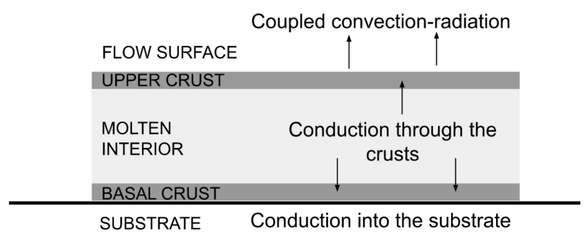

Fig. 1. Schematic representation of different heat loss mechanisms considered in the 1D flow-cooling model.

Microwave emission estimates. We compute T_B at the VenSAR wavelength (~9.4 cm) using the relation for emission from a medium with a non-uniform temperature profile [9]. We assume temperature invariance for the complex dielectric permittivity of the flow ($5 + 0.05i$). The corresponding δ_P at nadir is ~0.7 m. Our results are expressed as brightness temperature express (ΔT_B), i.e., difference between T_B of the lava flow and T_B of the background at 737 K.

Results and Discussion: We use a flow 10 m thick as an example to present results from our cooling model. Fig. 2 shows the modeled surface and interior temperature of the flow from one Earth day up to 10 Earth years after emplacement. The relatively low heat flux across the flow surface leads to slow cooling. The flow surface equilibrates to the ambient temperature after ~108 minutes; surface equilibration times for terrestrial flows is of the order of a few minutes [19]. The temperature profiles in Fig. 2 therefore show the lava surface at 737 K. Complete solidification (i.e., the meeting of the upper and basal crusts) occurs ~6 months after emplacement (solid line in Fig. 2). The temperature in the flow interior remains above ambient temperatures for several years after emplacement.

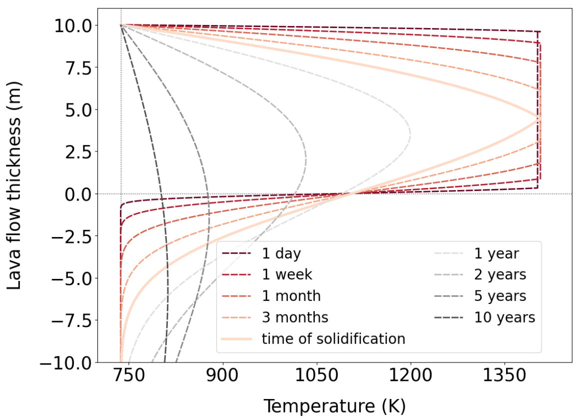

Fig 2. Modeled interior temperatures of a 10 m-thick lava flow from one Earth day to 10 Earth years after emplacement.

Modeled 9.4 cm-microwave emission (at nadir) from a 10 m thick flow is shown in Fig. 3 (brown triangles). Initial values of ΔT_B are greater than 400 K, indicating reliable detection during the initial stages of cooling. Although ΔT_B remains greater than zero for up to 10 years, it drops below the 3σ limits of the distribution of Magellan T_B data after 3.5 months (~10^7 s), suggesting that unambiguous detection of young lava flows on the basis of high T_B might be challenging beyond the first few months following new activity.

Fig. 3 also illustrates how variations in flow thickness impact the magnitude and duration of elevated T_B. For up to a year after emplacement, we find no major difference in ΔT_B between a 10 m- and a 30 m-thick flow owing to similar temperature distribution at depths < $3\delta_P$ below the flow surface. The ΔT_B value for a 1 m-thick flow is notably smaller and drops below Magellan-3σ limits within a week of emplacement due to small flow thickness, which promotes rapid cooling and increased contribution from the colder substrate.

Conclusions and Future work: We have thus far explored microwave emission from an actively cooling lava flow on Venus by modeling the thermal evolution of the flow in 1D. Our results suggest that basaltic flows that are tens of meters thick should have distinctly high T_B values for 3–4 months after emplacement. However, flows of sub-meter scale thickness will likely not have elevated T_B values after a few days to a week. An important control on the detectability of lava flows that has not been considered in our modeling yet is the areal extent of the flow and its relation to VenSAR radiometry spatial resolution (≤ 50 km). Next steps in this work will focus on the impact of flow extent on the microwave radiometry measurements of cooling lava flows.

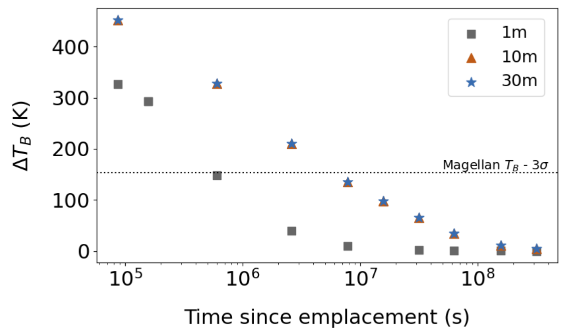

Fig. 3. Expected brightness temperature excess (ΔT_B) from actively cooling flows of 1 m, 10 m, and 30 m thicknesses.

Acknowledgments: This was work supported by NASA VenSAR ST grant # 80NSSC23K0033.

References: [1] Herrick, R. R. & Hensley, S. (2023) *Science, 379(6638),* 1205-1208. [2] Smrekar, S. E. et al. (2010) *Science, 328(5978),* 605-608. [3] Marcq, E. et al. (2013) *Nat. Geos., 6(1),* 25-28. [4] Byrne, P. K. & Krishnamoorthy, S. (2022) *JGR: Planets, 127(1),* e2021JE007040. [5] van Zelst, I. (2022) *JGR:Planets, 127(12),* e2022JE007448. [6] Smrekar, S. et al. (2022) *IEEE Aero. Conf. (AERO),* 1-20. [7] Widemann et al. (2020) *AGU fall meeting,* Vol. 2020, P022-02. [8] Mueller, N. T., et al. (2017) *JGR: Planets, 122(5)*, 1021-1045. [9] Ulaby, F. T. et al. (1986) *Artech House, 22(5),* 1223-122. [10] Dirscherl, M. & Rossi, C. (2018) *Rem. Sensing of Env., 204,* 244-259. [11] Lundgren, P. R. et al. (2019) *GRL 46(16),* 9554-9562. [12] Bondarenko, N. V. et al. (2010) *GRL, 37(23).* [13] MacKenzie, S. M., & Lorenz, R. D. (2020) *Rem. Sensing, 12(16),* 2544. [14] Shellnut, J. G. (2016) *Icarus, 277,* 98-102. [15] Snyder D. (2002) *JGR: Planets, 107(E10),* 10-1. [16] Flynn, I. T. W. et al. (2023) *JGR: Planets, 128(7),* e2022JE007710. [17] Davies, A. G. et al. (2005) *Icarus, 176(1),* 123-137. [18] Wittman, W. et al. (2017), *JGR: Solid Earth, 122(2),* 946-965. [19] Keszthelyi, L, & Denlinger, R. (1996) *Bulletin. of Volc., 58,* 5-18.