THE PULSE OF THE VOLCANO: DISCOVERY OF EPISODIC ACTIVITY AT PROMETHEUS ON IO. A. G. Davies. Jet Propulsion Laboratory-California Institute of Technology, ms 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109-8099. (tel: 818-393-1775. email: Ashley.Davies@jpl.nasa.gov).

Introduction: The temporal behaviour of thermal output from a volcano yields valuable clues to the processes taking place at and beneath the surface. Galileo Near Infrared Mapping Spectrometer (NIMS) data show that the ionian volcanoes Prometheus and Amirani have significant thermal emission in excess of non-volcanic background emission in every geometrically appropriate NIMS observation. The 5 µm brightness of these volcanoes shows considerable variation from orbit to orbit. Prometheus in particular exhibits an episodicity that yields valuable constraints to the mechanisms of magma supply and eruption. This work is part of an on-going study to chart and quantify the thermal emission of Io's volcanoes, determine mass eruption rates, and note eruption style.

Prometheus and Amirani: background. Located at 154 W, 2 S the flows at Prometheus cover over 6000 km^2 [1] and were emplaced in the years between Voyager (1979) and the first Galileo encounters in 1996. Flow morphology and thermal emission is consistent with insulated silicate lava flows, with resurfacing rates of 5-35 m^2/s [2, 3] and volumetric eruption rates estimated at ~35 m^3/s [3]. The flows are estimated to be ~1 m thick [3]. Prometheus is a volcanic plume source, active at least since the Voyager epoch. The surface flows appear to have overflowed from Prometheus Patera. Amirani is located at ~116 W, 23 N, on the anti-jovian hemisphere of Io (like Prometheus). The Amirani flow field is the longest active lava flow in the Solar System [2]. Insulated silicate lava flows are emplaced at areal coverage rates of 50-80 m^2/s. Mass eruption rates from G1 and I24-I27 Galileo data are estimated to be up to 100 m^3/s [2, 3]. At both Prometheus and Amirani, NIMS 4.5-5 µm data show elevated thermal emission along the entire flow [4]. The bulk of the thermal emission seen by NIMS and SSI comes from small fractions of each pixel.

Thermal output variation: episodic Prometheus! Like the current eruption of Kilauea, Hawai'i [5], these two ionian volcanoes exhibit periods of elevated activity (Prometheus thermal output is shown in Figure 1). A study of the 5 µm thermal emission in all NIMS observations (both night and day-time) from June 1996 (Orbit G1) to May 2001 (Orbit C30) shows a Prometheus thermal output (corrected for emission angle, e, for cases where e < 60º) yields an average output of 13.3 GW/µm (standard deviation of 7.3 GW/µm) and a larger average Amirani thermal output of 44 GW/µm (standard deviation of 26 GW/µm). Prometheus showed its greatest e-corrected thermal emission during November 1997 (33 GW/µm), more than four times that seen in June 1996 (orbit G1; see [3]) and Amirani showed its greatest thermal emission (up to May 1998) during May 1997 (orbit G8), nearly 100 GW/µm, nearly five times that seen during orbit G1. Including observations where e > 60º, Amirani's maximum observed 5 µm output is 291 GW/µm (May 1998), and the Prometheus maximum is 54 GW/µm (May 1998).

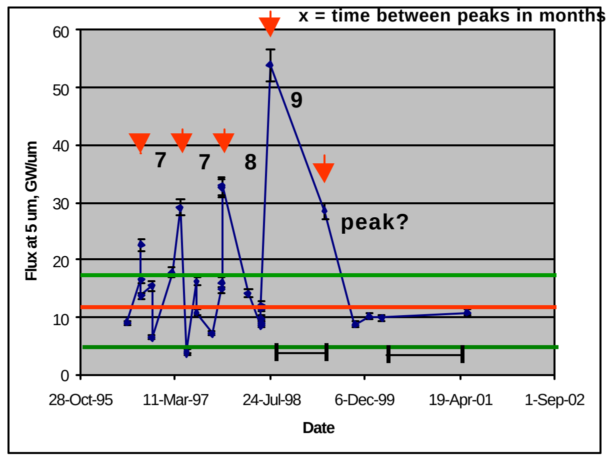

Figure 1. Plot of 5 micron emission from Prometheus as seen by NIMS. The red line is the average thermal output. (18 GW/mic). The green lines are one standard deviation from the average value. The peaks of thermal emission are 7-9 months apart. The black bars represent periods with no data collected.

The volcano's heartbeat? Prometheus shows four peaks of activity between June 1996 and January 2000, suggesting episodic activity on a time frame of 7-9 months, peak to peak, and possibly another peak in May 1999. This raises the question: is activity at Prometheus periodic? Testing the dataset with a Lomb Normalised Periodogram for temporally sparse data [6] yields a significance of 0.624, the high value suggesting that a period is *not* real (although running the algorithm on the first 80% of time covered yields a low score of 0.213). More data points would improve the statistics of the fit, and hopes are pinned on high-resolution monitoring with Earth-based telescopes [e.g., 7].

Prometheus-Amirani comparison: Such episodic activity is not seen at Amirani. This may be due to the great areal extent of the Amirani flows, and because there are a number of separate thermal sources: variations at individual sites tend to be swamped by emission from other locations. It is noted that other small volcanoes contribute to thermal emission in the Prometheus region [4]. However, thermal output from these sources are orders of magnitude less than from Prometheus itself, and unlikely to cause the observed changes.

Discussions: eruption style: It is noted that Prometheus and Amirani thermal spectra obtained both at night and from deconvolved dayside data [8] show that the spectral shape from 1 to 5 µm, the "thermal signature" of the eruption, does not greatly change even with large variations in intensity. This is an indication that the eruption style is not changing (no fire fountaining, for example), but what is changing is the areal extent of activity:- more of the same, so to speak. Prometheus and Amirani exhibit the thermal signature of laminar, low energy pahoehoe or a-a flow emplacement, effusive but not explosive. This is very like current Kilauea flank activity, a more-or-less continuous eruption with the emplacement of low-energy, laminar, insulated flows, punctuated with periods of increased activity (see [5]). Activity at Prometheus and Amirani are on a much greater areal scale than at Kilauea, a hallmark of Ionian activity compared to that of Earth [3, 9-12]. If like Kilauea in 2000-2002, magma from a deep source is stored in near-surface storage chambers where some degassing takes place, before erupting at the surface.

Thermal and mass fluxes: The total flux from Prometheus over the 1790 days covered by this dataset is 3.6×10^{19} J, an average of 2.3×10^{11} W, assuming a surface colour temperature of 437 K [1, 3]. These Prometheus data enable a rare look into the rate of supply of magma to the surface. Eruption volumetric rates derived from scaling rates derived from G1 (June 1996) NIMS data [3] yield maximum and average volumetric eruption rates of 337 and 154 m^3/s for Amirani, and 128 and 52 m^3/s for Prometheus (for cases where e < 60º). Including all data at all emission angles, rates at Prometheus range from 14 to 210 m^3/s, and at Amirani from 87 to 869 m^3/s (the maximum being 11 times that seen during G1).

Single-event mass flux: Of particular interest, however, is the volume of material erupted during one eruption episode. Taking one cycle of activity, from 19 Sept 1997 to 31 May 1998, a period of 8.4 months, the total thermal output is 5×10^{18} J. The eruption builds to a peak and dies away, like terrestrial eruptions [13]. Using models of thermal emission to estimate volume of erupted material [3, 14] the total volume erupted during this time is between 0.8 and 3 km^3, with average supply rates of 40 to 143 m^3/s. It is also noted that previous estimates of mass eruption rate from G1 [1, 3] and I24-I27 data [1, 2] were made from data when Prometheus was relatively quiescent, and may be underestimates of average eruption rate. The total pulse volume of material provides another constraint for modelers of the mechanisms of supply, ascent and eruption at Prometheus. The period might, for example, be the eruotion-recharge period of a magma chamber after an eruption. The volume of the magma chamber (or at least the volume evacuated) has a radius of 600-900 m for the calculated total mass erupted.

Summary, questions and comments: Prometheus appears to be episodic, though not apparently periodic. The episodicity greatly strengthens the Kilauea-Prometheus analogy, as Kilauea undergoes a similar episodicty in activity as magma pulses move through the complex plumbing system. With estimates of magma discharge rate and an established time scale, the dynamics of magma recharge may be modelled. The episodicity of Prometheus is similar to that observed at Loki where the volcanic activity has been demonstrated to be periodic (with a 540 day period) and the cause of this of periodicity has been proposed to be due to the foundering of a thickening crust on a lava lake [15]. It should be noted that Loki apparently departed from this periodicity in the fall of 2001 [16]. As demonstrated here, the proposed Loki resurfacing method is not necessarily diagnostic of a particular mode of lava emplacement. Only lava flows have been observed at Prometheus: no lava lake has been seen.

References: [1] Davies, 2003, *JGR*, under revision. [2] Keszthelyi *et al*., 2001, *JGR*, *106*, 33,025-33,052. [3] Davies *et al.*, 2000, *Icarus*, 148, 211-225. [4] Lopes *et al.*, 2001, *JGR*, *106*, 33,053-33,078. [5] wwwhvo.wr.usgs.gov/kilauea/summary/main.html. [6] Press *et al.*, 1992, Numerical Recipes; [7] Marchis F. *et al.* (2002) *EOS*, AGU Fall abstract. [8] L. Soderblom (2002) pers. comm. [9] Carr, M. H. (1986) *JGR, 91*, 3512-3532. [10] Davies A. G. *et al*. (2001) *JGR, 106*, 33,079-33,103. [11] Keszthelyi L. *et al*. (2001) *LPSC 32* abstract #1523 [12] Davies A. G. (2001) *Astro. Geophys., 42*, no. 2, 10-15. [13] Wadge G. (1981) *J. Volc. Geotherm. Res., 11*, 139-168. [14] Harris A. *et al*. (1998) *Bull. Volc. 60*, 52-71. [15] Rathbun J. *et al*., 2002, *GRL*, *29*, no. 10, 84-88. [16] Rathbun, J, (2002) pers. comm.

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