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Effusion Rate Variability at Zamama, Culann, Tupan Patera and Prometheus on Io during the *Galileo* Era

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Abstract

Zamama, Culann, and Tupan Patera are three large, persistent volcanic centers on the jovian moon Io. As part of an ongoing project to quantify contributions from individual volcanic centers to Io's thermal budget, we have quantified the radiant flux and effusion rates from all suitable observations made by the *Galileo* Near Infrared Mapping Spectrometer (NIMS) of these volcanoes [1], in some cases filling omissions in previous analyses. Eruption rates at these three volcanoes are on the order of 30 m^3 s^{-1}, consistent with a previous analysis of NIMS observations of Prometheus [2], and nearly an order of magnitude greater than Kilauea volcano, Hawai'i, Earth's most active volcano. We propose that future missions to the jovian system could better constrain activity at these volcanoes and others where similar styles of activity are taking place by obtaining data on a time scale of, ideally, at least one observation per day.

1. Introduction

It is well-known, and unsurprising, that Io's volcanoes exhibit variability of thermal emission [e.g., 2, 3], as even persistently active volcanoes on Earth exhibit considerable variation in thermal emission as individual eruption episodes wax and wane. This work is part of a larger effort to quantify the variability of thermal emission from Io's volcanoes, in order to better understand the styles of eruption at individual volcanic centers, to constrain the volumes of material erupted, and to chart both local and regional variability of volcanic thermal emission. We have analysed NIMS data of the lava flows at Zamama (174º W, 18º N) and Culann (161º W, 20º S), and of activity within Tupan Patera (141º W, 19º S). Results are compared with earlier analysis of Prometheus data. Measurements of radiant flux are used to estimate minimum silicate effusion rates [1, 2] and to identify peaks in activity for comparison with visible changes on the surface and plume activity.

2. Zamama, Culann and Tupan Patera

Zamama is the site of a 2100 km^2 lava flow field and intermittent plume source [e.g., 2]. Zamama was observed in isolation from other large volcanoes 34 times by *Galileo* NIMS between June 1996 and Oct 2001. Average radiant fluxes, thermal emission, areal coverage rates and eruption rates are given in Table 1. Variability of effusion rate is shown in Figure 1. Thermal emission from Zamama steadily dropped from June 1996 to September 1997, consistent with reducing effusion rate and the cooling of flow surfaces. A peak in activity in November 1997 coincided with detection of a volcanic plume. After this, thermal emission dropped steadily through 2001. Culann is a highly-colourful volcano where lava flows emanate from a patera. Results are given in Table 1 and Figure 1. Like Zamama, Culann exhibited a peak in thermal emission in November 1997. At Tupan Patera, activity is confined to within the patera, one of many caldera-like depressions set into the plains of Io. We examined 42 NIMS observations of Tupan Patera (Table 1 and Figure 1) and, prior to deeper investigation, do not find convincing evidence of any episodic activity, as previously suggested [4].

2.1 Prometheus

We update a previous analysis of thermal emission from Prometheus [2] by expanding the number of detections from 32 to 38. We also correct two errors where observations were mis-ordered, confusing spacecraft range and sub-spacecraft longitude. These edits do not change the conclusions of [2]. Figure 1 also shows estimated effusion rate variability of the enhanced Prometheus dataset.

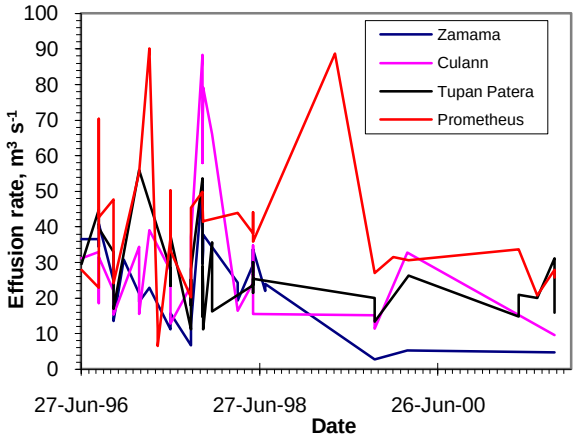

Figure 1: Variability of eruption rate (for observations obtained at emission angles < 70º) [1].

Table 1. Average values of eruption parameters for Zamama, Culann, Tupan Patera and Prometheus [1]

Volcano	Radiant flux at 4.7 or 5 µm, $I_{4.7,5}$ GW/µm	Thermal emission, Q_{rad} GW	Areal coverage rate, dA/dt m^2/s	Eruption rate 1996-2003 [b], Q_E m^3/s
Zamama (34/1) [a]	8 ± 4	89 ± 45	35 ± 17	25 ± 12
Culann (33/1) [a]	11 ± 8	142 ± 94	39 ± 26	32 ± 21
Tupan P. [a] (41/4)	6 ± 3	70 ± 29	40 ± 16	26 ± 11
Prometheus (38/2) [a, c]	12 ± 6	150 ± 73	47 ± 23	37 ± 18

Notes. a: Numbers in parentheses = no. observations / excluded due to emission angle >70º. b: See [1-2] for methodology. c: Updated numbers from [2].

3. Summary and Conclusions

The average effusion rates (or eruption rate, Q_F) calculated for Zamama, Culann, and Tupan Patera are similar to those seen at Prometheus (≈38 m^3 s^{-1} [2]. The variability of activity at these locations suggests a more or less constant supply of lava, with periods of increased effusion followed by periods of relative quiescence, during which time magma reservoirs are recharged before the next eruption episode commences. We do not see any instance when all four volcanic centers are very active (with effusion rates greater than one standard deviation above average) at the same time. Tupan Patera and Prometheus show peaks in activity in February and April 1997. Activity at all four volcanoes declines to relatively low levels in September 1997. Activity increases at all four volcanoes in November 1997, especially at Culann. Prometheus shows a peak in May 1999 as thermal emission from Zamama declines to a low level into and through 2001. Activity at Prometheus, Tupan Patera and Culann is not greatly different at the end of the *Galileo* epoch than at its beginning.

We consider future missions to Jupiter. The peak in thermal emission of the integrated thermal emission spectra for these volcanoes is typically in the range of ≈6-7 µm. The optimum frequency of observations to detect thermal variability at these wavelengths should be, ideally, an order of magnitude less than the time it takes for significant change at the wavelength observed to take place [5]. Observations charting variability at 5 to 7 µm should ideally be on a daily basis from an orbiter studying Io's volcanoes.

Acknowledgements

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