

THERMAL EMISSION VARIABILITY OF ZAMAMA, CULANN AND TUPAN ON IO USING GALILEO NEAR-INFRARED MAPPING SPECTROMETER (NIMS) DATA.

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Introduction: The Jovian satellite Io is the most volcanically active body in the Solar System. Previous analyses [e.g., 1-4] indicate the presence of high-temperature silicate volcanism on Io, similar to silicate volcanism occurring on Earth. Instruments onboard the *Galileo* spacecraft, especially the Near Infrared Mapping Spectrometer (NIMS) and the Solid State Imager (SSI), provided much data of Io's active volcanoes throughout the duration of the *Galileo* mission (June 1996-September 2003). NIMS data is particularly sensitive to thermal emission from active and cooling lava over cooling times of seconds to a few years. The objective of this ongoing study of Io's volcanism is to determine the variability of thermal emission from volcanoes on Io's surface, in order to better understand the styles of eruption, and to constrain the volumes of material erupted. Ultimately, this will help to constrain the contribution of active volcanism to Io's thermal budget. Data have been analyzed for the volcano Zamama, located at 173 W, 21 N, and the power output of Zamama, the volumes of lava being erupted, and the eruption rate determined. Culann and Tupan have also been analysed in this way. This abstract primarily concentrates on Zamama.

NIMS Data Analysis: NIMS obtained 26 usable observations of Zamama during the *Galileo* mission. NIMS covered a spectral range from 0.7 to 5.2 microns. NIMS spectra consisted of up to 408 wavelengths, constructed using 24 different grating positions and 17 detectors. The 5- μ m thermal emission of Zamama was charted against time. NIMS 5- μ m data are used as, firstly, most volcanoes on Io emit the most thermal emission at this wavelength within the NIMS spectral range, and, secondly, the effects of daytime sunlight are minimized at this wavelength.

Methodology: In NIMS radiance data a volcanic hot spot can generally be recognized by a characteristic thermal ramp towards longer wavelengths. In NIMS "tube" (non-averaged) products values of two adjacent pixels in the direction of the mirror sweep are added to account for the instrument point-spread function. Care was taken to avoid data artifacts such as radiation spikes, noise, and boom hits. Data were converted from NIMS intensities (in units of $\mu\text{W}/\text{cm}^2/\text{str}/\mu\text{m}$) to power output ($\text{W}/\mu\text{m}$) [4]. This conversion also removes the effect of range to target and emission angle to allow observation-to-observation comparison.

Assumptions: A number of assumptions are made. It is assumed that the style of lava emplacement at Zamama has not fundamentally changed since the G1 orbit (June 1996). Temperatures representative of basaltic volcanism were derived from NIMS data obtained at this time [3]. The surface flows at Zamama seen during later orbits by SSI, and the shape of the thermal emission curve seen by NIMS, are characteristic of Hawaii-like pahoehoe flows. Subsequently, we scale the thermal emission from post-G1 orbits to the G1 thermal emission, using this ratio to determine mass eruption rate as a factor of mass eruption rate estimated from G1 data [5]. Having decided on an emplacement mechanism and composition, it is possible to estimate volumetric eruption rate by balancing the needed supply of cooling lava to generate the observed thermal emission [3-6].

Results: Figure 1 shows the calculated eruption volumetric fluxes for Zamama against time, with upper and lower limits shown by the blue and pink curves respectively. The average volumetric rates are shown in red. Volcanic activity at Zamama from 28 June 1996 to 2 May 1999 (1038 days) was as follows: there was a general decreasing trend after the first observation (G1) when Zamama was active with high-temperature components to the IR spectrum [3]. This decrease represents a lessening in effusive activity, or cooling of old flow surfaces. A later increase in activity begins at the highlighted area of the curve, indicating the beginning of an eruption. This period of time coincided with a plume at Zamama, seen by SSI (David Williams, pers. comm.). Following this episode there is another peak in emission: however, due to the sparseness of the data from this point we do not know the subsequent nature of activity over the following few months.

The total power output observed at Zamama from 28 June 1996 to 2 May 1999 was 1.25×10^{19} J, with an average power output of 139.8 GW. The total volume erupted from this hot spot throughout the time of observation, a total of 1038 days, is estimated at $3.5 \pm 1.4 \text{ km}^3$, with an average volumetric flux of $39.4 \pm 15.5 \text{ m}^3/\text{s}$.

The highlighted area under the curve covers 274 days of increased thermal activity suggesting a volcanic eruption from 8 June 1997 to 29 March 1998. This eruption episode yielded a total power output of 3.95×10^{18} J and an average power output of 167 GW. The total volume erupted was $1.1 \pm .45 \text{ km}^3$, the aver-

age volume rate was $47 \pm 18.5 \text{ m}^3/\text{s}$. The peak volumetric rate on 16 December 1997 was $101.1 \pm 39.8 \text{ m}^3/\text{s}$. A plume was seen by SSI above Zamama on 7 November 1997 (marked with an arrow in Figure 1). Figure 2 shows $5 \mu\text{m}$ emission from Zamama compared with Culann, Tupan and Prometheus, volcanoes that show similar styles of thermal emission [7].

Discussions: Having determined estimates of volumetric rate it is now possible to make volcano-to-volcano comparisons with other Io volcanoes and terrestrial volcanoes (Table 1). The average Zamama eruption rate falls into the same range as other Io volcanoes of the same eruption style, apparently pahoehoe-like eruptions which resulting in an insulated flow field. From Table 1 it is evident that Zamama has lower volumetric emission rates when compared to some other styles of eruption seen on Io. Nevertheless, Zamama is much more powerful than its terrestrial volcanic counterparts, such as Kilauea, Hawaii. This, once again, highlights the main difference between Ionian and terrestrial eruptions of the same style: Io eruptions have larger volumetric fluxes, and have much larger active areas. Despite the increased thermal activity seen by NIMS from 8 June 1997 to 29 March 1998, SSI did not see large new lava flows resulting from this activity. This implies that any new surface flows were emplaced on older flows, as seen at the other Io volcano Prometheus [8].

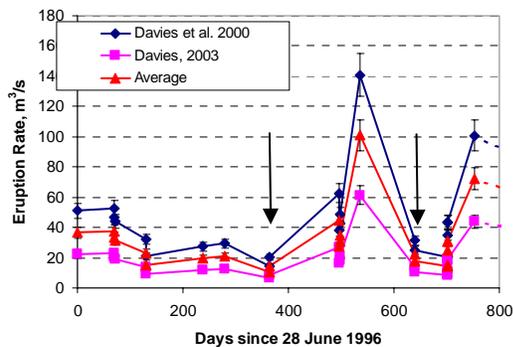


Figure 1 Calculated volumetric eruption rate (m^3/s) for Zamama plotted against number of days since the first usable observation on 28 June 1996 until 20 July 1998. The arrows denote the eruption peaking 16 Dec 1997.

References: [1] McEwen A. S. et al. (1998) *Icarus*, 135, 181-219. [2] Davies, A.G. et al. (2000) *Icarus* 148, 211-225. [3] Davies, A.G., (2003) *JGR*, 108, 5106, doi: 10.1029/2001JE001509. [4] Davies, A.G., et al., *JGR*, 106, 33,079-33,103, 2001. [5] Davies, A. G. (2003) *LPSC XXXIV*, Abstract 1445. [6] Harris, A. et al. (1998) *Bull. Volc.*, 60, 52-71. [7] Davies A. G.

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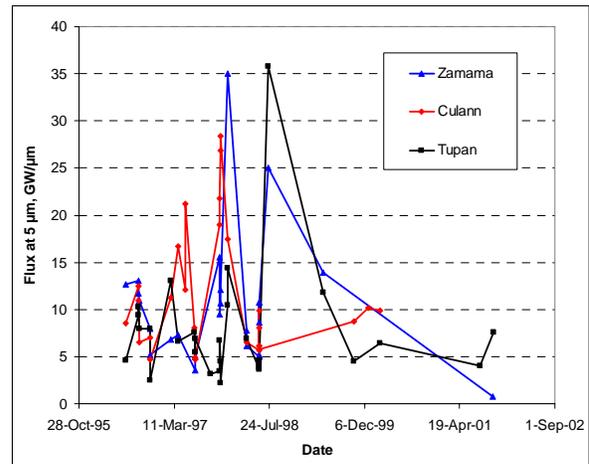


Figure 2. $5\text{-}\mu\text{m}$ variability of Zamama, Tupan, and Culann as seen by NIMS. The waxing and waning of individual eruptions are seen at all of these volcanoes, allowing mass eruption rates to be calculated.

Table 1 Comparison of volumetric eruption rate with other styles of eruptions on Io and on Earth assuming basaltic composition²

Eruption (style) and Volumetric Eruption Rate, m^3/s [3]	
Io	
Jan 1990 (outburst)	10^5 to 10^6
Pillan (open channel flow)	10^3 to 10^4
Pele (lava lake)	~250 to 350
Zamama (peak of activity)	~100
Amirani (average: insulated flow field)	58
Zamama (insulated flow field)	47
Prometheus (average: insulated flow field)	21
Earth	
Laki, Iceland (open channel flow)	8700 (max)
Mauna Loa, HI (a-a and channel flows)	10 to 1000
Kilauea Iki, HI (fire fountain)	100
Kupaianaha, HI (lava lake)	~5
Kilauea, HI (pahoehoe flow field)	typically ~2 to 5

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