IO: CONTRIBUTIONS TO GLOBAL HEAT FLOW FROM DIFFERENT VOLCANIC ERUPTION CLASSES, AS SEEN BY *GALILEO* NIMS. A. G. Davies[1], G. J. Veeder[1], D. L. Matson[1], T. V. Johnson[1], D. L. Blaney[1] and J. C. Castillo[1]; [1]Jet Propulsion Laboratory-California Institute of Technology, ms 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109; email: Ashley.Davies@jpl.nasa.gov.

Introduction: Io is the most volcanically active body in the Solar System. Ground-based infrared telescopes and spacecraft instruments, especially those on *Galileo*, led to the identification of many obvious hot spots [e.g., 1-5]. From NIMS and other SWIR data the thermal emission from different styles of volcanic eruption has been quantified [6]. However, the restrictions imposed by variable spatial resolution and uneven coverage means that the total contribution to Io's global thermal emission from volcanic activity is not yet fully understood.

Hot spot contribution to global heat flow: Io's global thermal emission is ~10^{14} W [1]. Most of this energy is emitted at wavelengths longer than 12 µm and most of the thermal emission is the result of volcanic activity. *Galileo* NIMS, covering 0.7 to 5.2 µm, was sensitive to active and recently active volcanic areas. The locations of obvious hot spots have been identified in the NIMS and PPR datasets [2, 3, 5], but the presence of smaller, less-easily identifiable hot spots has not been fully explored [see also, Veeder *et al*., this volume].

Hot spot class and thermal emission: To gauge the relative importance of class of activity to Io's heat flow, it is necessary to estimate the total thermal contribution from ongoing eruptions.,. The yearly thermal emission from various hot spot classes detected at short-infrared wavelengths is shown in Table 1.

Outburst activity may be the most spectacular and easily detected type of eruption, but the total heat transport from such activity, even assuming 25 such events a year, makes up less than 2% of Io's yearly output. For example, a single Pillan-like event (>50 km^3 erupted) is responsible for transporting over 6 x 10^{19} J of heat to the surface [6]. Thermal emission is initially very high, but rapidly wanes and the remaining energy from the cooling flows is lost over many years. *Loki Patera* makes up the largest piece of observed volcanic heat transport (typically 10-20%). Steady *Pele* is responsible for less than 1% of Io's total annual heat flow. *Mid-sized, persistent hot spots*, including Prometheus, Amirani and Zamama, globally contribute another 10% [7]. *Small hot spots*, even assuming a number as high as 250 (based on the estimate in [3]) and with an average thermal output of 10 GW, contribute only ~2.5% to Io's total emission. A breakdown of detected or postulated volcanic thermal emission from NIMS data is shown in Table 1. The rest of the thermal emission, 70% of Io's heat flow, comes from a) a suite of eruptions conceivably emplaced over the last century resulting in a distribution of cooling flows down to Io's ambient temperature [1, 8]; and b) additional, as yet not quantified, conductive heat transport in and around volcanically active centres. This latter class includes heat conducted to the surface from intrusions that almost certainly exist, but which may not show any other manifestation of volcanic activity than increased surface heat flow.

Active volcanism from mid-sized hot spots is responsible for about 10% of Io's heat flow, representing a volume of ~43 km^3 of magma erupted per year [7]. Much of that lava is emplaced effusively within paterae, or emplaced on older lava flows (Prometheus and Amirani are prime examples) so there was little contribution to global resurfacing during the *Galileo* epoch from effusive activity from this hot spot class.

The above analysis assumes little or no heat loss by conduction through the lithosphere, a factor strongly dependent on the resurfacing rate. Io is being resurfaced at a prodigious rate, great enough to erase any impact crater to the limit of detection [9]. If the resurfacing rate is 1 cm $year^{-1}$ [e.g., 10], then at least 430 km^3 of material has to be erupted or remobilised every year to coat Io with a layer that thick [7,8]. If the resurfacing rate is much less than 1 cm $year^{-1}$ then the thermal gradient in the lithosphere increases, the lithosphere becomes warm, and the heat flow by conduction to the surface plays a greater role in removing heat from the interior.

It may be that most resurfacing comes not from lava flows but from plume deposits [7, 11], at least based on the *Galileo* dataset. Even so, if an outburst eruption takes place outside of a patera, then a large area can be covered by lavas (e.g., Pillan, 1997). Lei-Kung Fluctus covers over 5 x 10^4 km^2, and these flows were emplaced recently enough to be still warm when observed by *Galileo* [5].

Myriads of small hot spots?: The literature contains lists of 'obvious' hot spots {see previous citations]. But how well does the current catalog of hot spots reflect all active centers on Io? Is there a class of even smaller thermal anomalies not yet detected and documented? These sources would not be readily detectable in SSI and NIMS data as they are too small, with a low signal to noise ratio. In lower spatial resolution PPR data the small size and relatively high temperature of the hot spots again precludes ready identification.

There is a precedent for detection of a class of small hot spots in the *Galileo* data set. In an investigation of spectral emission from global NIMS data (with spatial resolution of ~130 km pix^{-1}), the existence of 'myriads' of smaller hot spots were proposed based on NIMS spectral ratios between 5 and 3 µm [12]. In higher-resolution NIMS data, these smaller hot spots were indeed seen [2, 3].

Might a similar investigation on high-resolution NIMS data would identify even smaller hot spots? Future work will examine these NIMS data to look for anomalous (non-background) thermal emission. If such emission is found, then the significance from such a new hot spot class to the global thermal heat flow can be assessed. If these features are not found, then this represents a cut-off in the distribution of thermal sources which can be utilized in modeling Io's heat flow.

The same analysis will seek to find larger but cooler sources that may not be obvious in either NIMS or PPR data, but might represent the release of heat from extensive, old (and therefore cool) volcanic material, and also from the slow transfer of heat to the surface from intrusions. The role of large and cool anomalies is yet to be fully understood, especially in Io's polar regions which are anomalously warm [5, 13], possibly the result of extensive volcanic activity [14].

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Table 1
Estimates of yearly heat transport by eruption class from NIMS data

	Typical output (W)	**Duration (days)**	**Number per year**	**Yearly output (J)**	**% of Io total emission [a]**
Outbursts	5.0×10^{12}	5	25 [b]	5.4×10^{19}	1.7
Pele [d]	2.8×10^{11}	Continuous	1	8.8×10^{18}	0.3
Mid-sized, persistent [e]	2.6×10^{11}	Continuous	40	3.2×10^{20}	10.3
Small hot spots [f]	10^{10}	Continuous	250	7.9×10^{19}	2.5
Total (excluding Loki P.)				4.6×10^{20}	14.8
Loki Patera [c]	1.5×10^{13}	Continuous	1	4.7×10^{20}	15.0
Total (including Loki P.)				9.4×10^{20}	29.7
Remainder [g]				2.2×10^{21}	70.3

a Io total thermal emission is 10^{14} W, or 3.2×10^{21} J $year^{-1}$ [1]
b Estimate, Spencer and Schneider (1996) *Ann. Rev. Earth Plan. Sci.*, *24*, 125-190.
c Veeder *et al.* (1994) [1]; Matson *et al.* (2006), *JGR*, 111, E09002, doi:10.1029/2006JE002703
d Davies *et al.* (2001), *JGR*, *106*, 33079-33104.
e Davies *et al.* (2000) [7], extrapolated to all of Io.
f Lopes *et al.* (2001; 2004) [2-3], extrapolated to all of Io.
g Other sources not seen by NIMS.

From Davies (2007) [6].