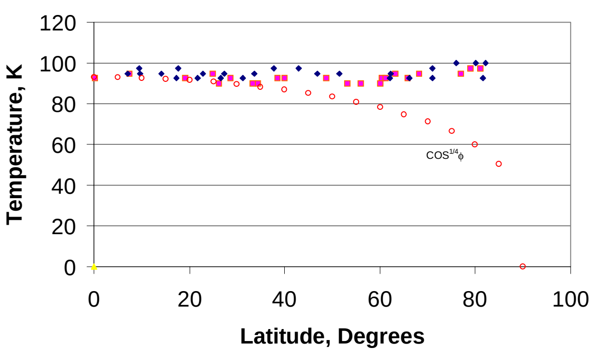
THE MYSTERY OF IO'S WARM POLAR REGIONS: IMPLICATIONS FOR HEAT FLOW.

D. L. Matson, G. J. Veeder, T. V. Johnson, D. L. Blaney, and A. G. Davies Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109. dmatson@jpl.nasa.gov

Introduction: Io's polar temperatures are higher than expected for any passive surface. Data from the *Galileo* Photopolarimeter (PPR) show that minimum nighttime temperatures are in the range of 90-95 K virtually everywhere [1]. This is particularly striking at high latitudes, within the polar regions. These Ionian temperatures (~5 AU from the Sun) even exceed comparable values for the Moon (~1 AU). Furthermore, the distribution of nighttime temperatures across the surface of Io (away from the sunset terminator) shows little variation with latitude and/or time of night [1,2,3,4]. See Fig. 1. We discuss in the following a number of explanations that have been suggested for this elevated-minimum-temperature effect. Passive mechanisms appear to be unworkable.

Fig. 1. Surface temperature vs. latitude on Io. Two



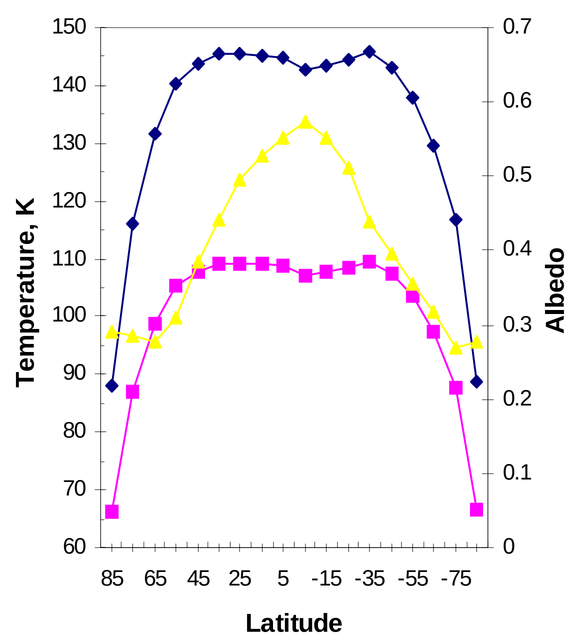
north-south traverses sampled the distribution of "minimum temperatures" from a contour plot of derived PPR temperatures [1]. A strong, decreasing trend with latitude was expected; but is not seen. The curve, labeled cos$^{1/4}\phi$, illustrates such a latitudinal trend for typical thermophysical models [4,6]. Simultaneously, the time-of-night variation is sampled many times. The clustering of the diamond and square data shows that temperature does not decrease significantly as the night progresses.

Polar terrain is warm because it is rough: Areas that are inclined toward the Sun reach higher temperatures than adjacent flat-lying surfaces. However, as some surfaces are tilted to intercept more sunlight, other areas receive less or are even shadowed. Thus, only favored viewing directions offer the perception of higher surface temperatures (*i.e., 'beaming'* back towards the Earth). Weakening this hypothesis is the low abundance of mountains on Io.

Spacecraft are not constrained to observe from special directions. In particular, high-latitude *Galileo* data, taken at more normal viewing angles, do not support the roughness hypothesis.

Higher latitudes have lower albedos: A plot of albedo versus latitude, Fig. 2, lends support to this idea. However, a plot of (low-thermal inertia model) maximum noon-time surface temperatures, upper curve in Fig. 2, show that while decreasing albedo can keep the temperatures from declining up through the mid-latitudes, at latitudes higher than about 45 degrees the effect of diminishing insolation overwhelms the effect of decreasing albedo and temperatures plunge rapidly near the poles even though the albedo decreases by about a factor of two [5]. High latitudes still have low nighttime temperatures. Thus, this hypothesis helps but does not solve the problem.

Fig. 2. Albedo and temperature vs. latitude on Io. Averaged bolometric bond albedo is plotted as yellow



triangles (right axis). Polar albedos are about half those near the equator [5]. Corresponding noon temperatures plot as black diamonds (left axis). Maximum night temperatures are pink squares (left axis).

Thermal inertia increases with latitude: To test this idea we examined the extreme case of infinite thermal inertia (the lower curve in Fig. 2.) [6]. This model has the highest possible nighttime temperatures for all passive thermophysical models. At latitudes higher than about 75 degrees the limiting temperatures still fall below 90 K. Moreover, the rapid fall-off of temperature after sunset on Io and its relative constancy later in the night, argues strongly for a surface with a relatively small thermal inertia (*i.e.,* less than that for the Moon). Nighttime temperatures for these more realistic cases are much lower than those plotted in Fig. 2. Variable thermal inertia within the context of a diurnal model cannot fit all of the available data. At latitudes above ~75 degrees, it fails to produce high enough, temperatures.

Cooling lava controls nighttime temperatures: It has been suggested that almost all of Io is covered by cooling lava [3,4,7]. Volcanic resurfacing occurs everywhere, except at a few locations of high elevation such as mountains. Calculations for the cooling of lava show that temperatures in the range of 90-95 K are reached on time scales of ten to ten thousand years depending upon the details of the eruption scenario [8]. At these temperatures cooling proceeds ever more slowly and the cooling curves become asymptotic. Reaching significantly lower temperatures takes a very long time. Resurfacing by fresh flows takes place and the cooling cycle begins again. Additional, evidence for these hypothesized cooling flows comes from an analysis of Io's observed thermal anomalies. Fig. 3 shows a plot of such data [4]. Extrapolation of the trend to the surface area of Io predicts an ambient temperature in the 90-95 K range. Several areas at lower temperatures are known [2,9]. These are older surfaces that for some reason (*e.g.,* elevation) have not been resurfaced in a very long time.

The discovery of more small NIMS hot spots in areas observed at higher resolution [10,11] provides additional support for the paradigm of ubiquitous volcanic activity with global cooling lava fields on Io. The main advantage of the global lava field model is that it is intuitive and requires no special assumptions to explain the nighttime temperatures. It's main disadvantage is that it displaces the unit that has been used to explain the unexpectedly low 20µ daytime emission [6]. This point is an important focus of current work.

Heat Flow: Former models for thermal anomalies yield a lower bound on Io's heat flow of ~2.5 W m^{-2} [6]. Recent analysis has yielded an upper bound of ~13 W m^{-2} [3,4,7]. Warm polar regions appear to require some heat flow through very large areas to support their elevated nighttime temperatures. An additional constraint on permitted model heat flow is the inferred maximum equatorial daytime temperature from 20µ IRTF observations [6]. Preliminary results from one self consistent model, which includes both a warm night-side and warm poles as well as some global volcanism, suggests a total heat flow of approximately 4 W m^{-2}. Thus, the 'best' heat flow value remains constrained (somewhere) between our upper and lower bounds.

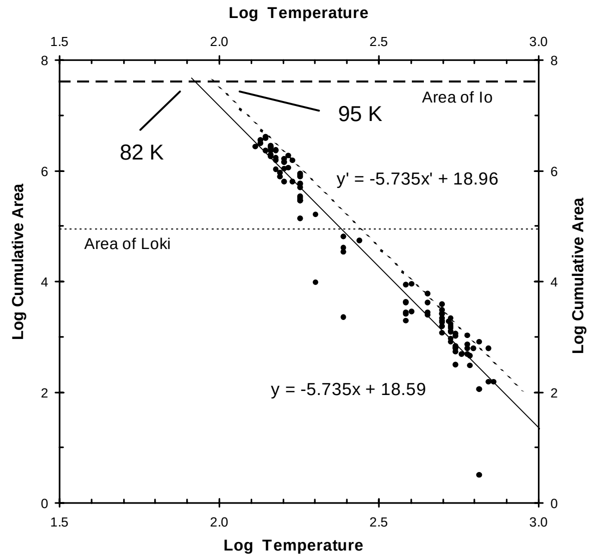


Fig. 3. Log cumulative area vs. log temperature for Io's thermal anomalies. Data are from our IRTF campaign [6]. The finite total surface area of Io leads to our upper bound on heat flow [3,4,7].

Acknowledgement: We thank Damon Simonelli for making his bolometric Bond albedo map of Io available to us. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

References: [1] Spencer J. R. *et al.* (2000) *Science, 288,* 1198-1201. [2] Rathbun J. A. *et al.* (2001) *Eos Trans. AGU, 82*, P11A-11. [3] Matson D. L. *et al.* (2001) *LPSC XXXII*, 1938. [4] Matson D. L. *et al.* (2001) *JGR*, in press. [5] Simonelli D. P. *et al.* (2000) *Bull.A.A.S., 32*, 30.02. [6] Veeder G. J. *et al.* (1994) *JGR, 99*, 17095-17162. [7] Matson D. L. *et al.* (2000) *Eos*, 81, F788. [8] Davies A.G. *et al.* (2000) *Icarus, 148,* 211-225. [9] McEwen *et al.* (1996) *LPSC XXVII*, 843-844. [10] Lopes-Gautier R. *et al.* (2000) *LPSC XXXI*, 1767. [11] Lopes-Gautier R. *et al.* (2000) *Science, 288,* 1201-1204.