TIDAL STRESSES AND VOLCANISM ON IO. D. A. Patthoff[1] and A. G. Davies[2], [1]Planetary Science Institute (apatthoff@psi.edu), [2]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: The *Galileo* spacecraft's observations of Jupiter's moon Io revealed numerous volcanoes with variable eruption volumes and intensities. The intense volcanism observed on Io is a result of the eccentric orbit (0.0044) and relatively close (4.21 x 10^5 km semi-major axis) proximity of the satellite to its parent planet. Tidal forces generate significant heat within the body and large stresses near the surface. Here we explore the range of magnitudes of tidal stresses near the surface at locations of known eruption locations.

Stress Calculations: Tidal flexing is a result of the changing gravitational field a moon, with an eccentric orbit, experiences as it moves closer and farther away from its parent planet. The eccentric orbit also causes the orbital velocity to change; however, the spin rate of the satellite remains constant. This difference in velocities will induce a small libration of the moon. In other words, an observer on the parent planet would see the moon oscillate a minor amount in an east-west direction as the moon orbits. These combined motions result in diurnal tidal stresses that will change in orientation and magnitude throughout the orbit. Nearly each point on the surface will experience periods of compression, shearing, and tension throughout a single day.

Here we use SatStressGUI [1, 2] to model the magnitude and orientation of the diurnal tidal stresses. SatStressGUI is based on SatStress [3] and can be used to calculate stresses on a satellite surface resulting from a variety of sources such as diurnal tides, nonsynchronous rotation, and obliquity in a viscoelastic body. The program uses a four-layer viscoelastic satellite model where the outer two layers are divided into an upper more-viscous layer and an inner less viscous layer. The third layer must be a liquid and the fourth is the core (or combined core and mantle). A possible liquid layer on Io is a reasonable assumption [4] for the purpose here. Model parameters include: mass of the parent planet; eccentricity of satellite; semi-major axis; and the density, thickness, viscosity, Young's Modulus, and Poisson's ratio of each of the four layers. However, for Io, there is much uncertainty for the values of these properties; therefore, we calculate the magnitudes of the stresses for a range of parameters (see Table 1 for the range of values used here).

***Galileo* Observations:** We use Near Infrared Mapping Spectrometer (NIMS) data from the 1995-2003 *Galileo* mission to identify the locations of active volcanoes and determine the level of activity. NIMS was particularly well-suited to observing thermal emission from ongoing or recent high-temperature (silicate) volcanic activity [5]. The NIMS wavelength range (0.7 to 5.2 μm) meant that it was sensitive to a wide range of surface temperatures (>1000 K to ~220 K) and lava surface exposure times (seconds to days) (Davies et al., 2010). The *Galileo* Photopolarimeter-Radiometer (PPR) was most sensitive to much older, cooler and non-volcanic surfaces. The *Galileo* SSI (Solid-State Imager) camera was sensitive to thermal emission from only the hottest, highly-variable and small areas present. The thermal emission detected by SSI is only a small part of the total thermal emission from the active areas of an eruption. NIMS data are therefore the best data for comparison of ongoing volcanic activity with tidal stresses. A more detailed description for the NIMS Io data can be found in [5].

Temporal resolution of individual targets was also highly variable. For example, during *Galileo* orbit E4, the Loki Patera region was observed 15 times in less than a day. On some other *Galileo* orbits only single observations of Io were obtained (see Table 3.2 in [5]). Io longitudinal coverage was also highly variable over the course of the mission, with most regional (resolution ~100-300 km/pixel) and global observations (>300 km/pixel) of the anti-Jovian hemisphere [6]. However, enough data were obtained to measure thermal emission from all of Io's medium to large volcanoes [7-9] and some very small ones [10] to establish a background level of volcanic activity [11].

Layer	Density (kg/m^3) (x1000)	Young's Modulus	Poisson's Ratio	Thickness (km)	Viscosity (Pa s)
Brittle outer layer	2.3-3	$1E^9$-$1E^{11}$	0.2-0.3	$2E^3$-$9E^3$	$1E^{20}$-$1E^{25}$
Ductile inner layer	2.5-3.2	$1E^9$-$1E^{11}$	0.2-0.3	$1E^4$-$1E^6$	$1E^9$-$1E^{14}$
Ocean	3.3-3.7	0	0.5	$1E^4$-$1E^6$	0-$1E^5$
Core	4.5-5	$1E^9$-$1E^{12}$	0.2-0.3	$1E^5$-$1E^7$	$1E^{23}$-$1E^{27}$

Table 1: Range of values used to calculate tidal stresses.

Discussion: Here we compare the magnitudes of the diurnal tidal stresses (Figure 1) to the measured activity of a select number of volcanoes observed during the *Galileo* mission. Previous studies have explored a possible tidal control of Io's volcanoes [12]; however, their study only looked at a single location (Loki Patera). We expand on that study to include Amirani, Culann, Marduk, and Prometheus. Those volcanoes were chosen for

their relative abundant observations from *Galileo* and moderate geographical distribution (Figure 2).

Our stress calculations show, as expected, the peak tension and compression occur at different times and with different magnitudes for the four volcanoes. The timing of the peak stresses is dominantly dependent on the location on the surface and mean anomaly. Changing the properties of the layers, i.e. viscosity, has a negligible effect on when the peak stresses occur. However, the thickness and viscosities of the layers controls the magnitude of the tidal stresses. For our calculations here, we record the stresses expected at the surface. We do not take into account any lithostatic load at depth which would decrease these values for locations deeper beneath the surface. We expect the peak tension for these volcanoes to be on the order of ~1.6 MPa, with larger stresses resulting if the outer layers are thinner and have lower viscosities.

Future work: We will compare the tidal stress magnitudes to the timing (mean anomaly) and magnitudes of the eruptions observed by *Galileo* to determine if a correlation exists. Similar studies for the plume activity observed at Saturn's moon Enceladus, have suggested a possible tidal control on the timing of that activity [13-15]. We will use the full data set from the *Galileo* mission to constrain the level of activity for each of these locations and a statistical approach to establish the level of confidence in any potential correlation.

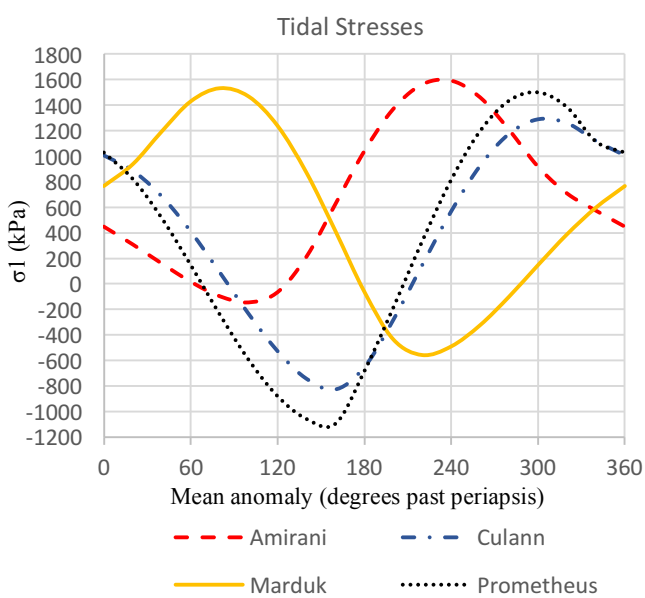

Figure 1: Plot of σ1 tidal stresses for the locations at Amirani (red dash line), Culann (blue dash-dot line), Marduk (yellow line) and Prometheus (black dotted line). Tension is positive.

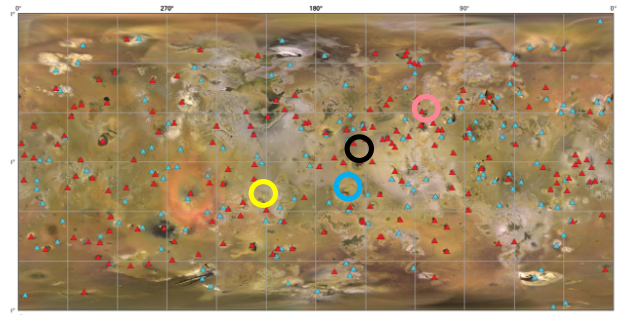

Figure 2: Global mosaic of Io from [16]. Circles show locations of Amirani (red), Culann (blue), Marduk (yellow), and Prometheus (black).

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