THE CONTRIBUTION OF IO-RAISED TIDES TO EUROPA'S DIURNALLY-VARYING SURFACE STRESSES. Alyssa Rose Rhoden[1], Terry A. Hurford[2], and Michael Manga[1], [1]Univ. of California at Berkeley; Dept. of Earth and Planetary Sci.; 307 McCone Hall; Berkeley, CA 94720, [2]NASA Goddard Space Flight Center; Code 693; Greenbelt, MD 20771.

Introduction: Europa's icy surface records a rich history of geologic activity. Several features appear to be tectonic in origin and may have formed in response to Europa's daily-varying tidal stress [1]. Strike-slip faults and arcuate features called cycloids have both been linked to the patterns of stress change caused by eccentricity and obliquity [2][3]. In fact, as Europa's obliquity has not been directly measured, observed tectonic patterns are currently the best indicators of a theoretically supported [4] non-negligible obliquity.

The diurnal tidal stress due to eccentricity is calculated by subtracting the average (or static) tidal shape of Europa generated by Jupiter's gravitational field from the instantaneous shape, which varies as Europa moves through its eccentric orbit [5]. In other words, it is the change of shape away from average that generates tidal stress.

One might expect tidal contributions from the other large moons of Jupiter to be negligible given their size and the height of the tides they raise on Europa versus Jupiter's mass and the height of the tide it raises on Europa. However, what matters for tidally-induced stress is not how large the Io-raised bulge is compared to the Jupiter-raised bulge but rather the differences between the instantaneous and static bulges in each case. For example, when Europa is at apocenter, Jupiter raises a tide 30m lower than its static tide. At the same time, Io raises a tide about 0.5m higher than its static tide. Hence, the change in Io's tidal distortion is about 2% of the change in the Jovian distortion when Europa is at apocenter.

Methods and Results: We calculate the contribution of the Io-raised bulge to Europa's surface stress using equations for stress in a thin elastic shell, similar to the methodology presented in [5]. We find that the magnitudes and directions of the combined Jupiter and Io principal tidal stresses do differ from those of Jupiter alone with the variation depending on location and time in the orbit.

Due to the mean motion resonance between Io and Europa, the two moons are at closest approach when Europa is at apocenter. Thus, as we would expect, the magnitude of the tidal stress when Io's contribution is included changes most appreciably when Europa is at apocenter as shown in Figure 1. Because the instantaneous tide raised by Jupiter is lower than average here, Europa would become more spherical leading to compression at the bulges. However, the bulge raised by Io is larger than average at this time, so the two effects destructively interfere causing Europa to become slightly less spherical than it would have from Jupiter tides alone. Hence, the net change in stress at the bulges (longitude 0°/180°) with Io's contribution is positive; the stress is more tensile than it otherwise would have been. The tidal stress at this time differs from the Jupiter-only case by a few percent.

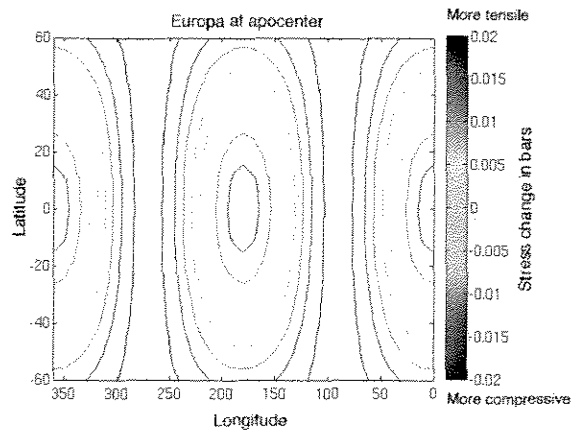

Figure 1: Contours of the change in magnitude of the most tensile principal stress when Io's tidal contribution is added to the calculation of eccentricity-driven tidal stress on Europa. Red indicates that the stress has become more tensile; blue indicates that the stress has become more compressive. The effect of Io is greatest when Europa is at apocenter, as shown here.

At pericenter and apocenter, the instantaneous tidal bulges raised by Io and Jupiter point directly toward Jupiter and are thus aligned with the static bulges. The locations of the instantaneous bulges then change throughout the orbit. The Jupiter-raised bulges migrate in longitude by ±2e from the location of the static bulge. Using the guiding-center approximation [6], we find that the angle subtended by the Io-raised bulges is more than an order of magnitude larger.

The location of the instantaneous bulge to a given point on the surface affects the direction of the principal stress in that region. Figure 2 shows contours of the differences between the direction of maximum tensile stress with and without Io's tidal contribution. The difference is least when the Io and Jupiter bulges are aligned (pericenter and apocenter, not shown) and greatest when they are most misaligned, when Europa is at 3/8 past pericenter and 1/8 past apocenter. The largest deviation at those times is about half a degree.

We find that incorporating Io's tidal effects makes very small differences in the magnitude and direction of the principal surface stresses on Europa. However, even these small differences may affect the paths of cycloids, which are often modeled as a concatenation of small fractures that form perpendicular to the direction of maximum tensile stress [7]. Matching the paths of observed cycloids using this formation mechanism has been used to characterize and constrain Europa's rotation state [2].

Our preliminary analysis shows that hypothetical cycloids paths are slightly altered when Io tides are incorporated into calculations of the stress field due to eccentricity. Future work will include incorporating obliquity into these calculations. Because the latitudinal variation in the tidal bulge due to obliquity will vary differently throughout an orbit relative to Io than to Jupiter, we expect that adding Io's contribution with obliquity will yield more dramatic changes in Europa's stress field and predicted fracture paths.

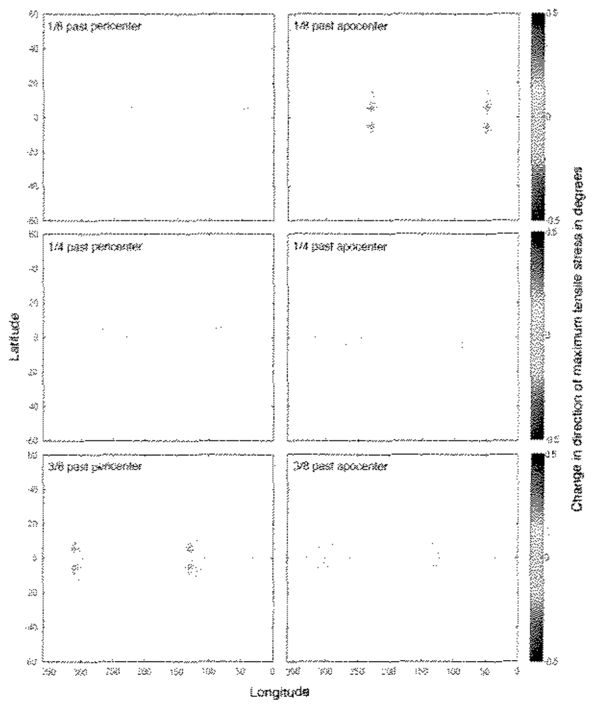

Figure 2: Contours of the change, in degrees, in the most tensile principal stress direction when Io's tidal contribution is included. A positive change indicates the direction has increased in a clockwise sense. The effect is largest when Europa is at 3/8 past pericenter and 1/8 after apocenter in its orbit because the Io and Jupiter bulges are maximally misaligned at these times. There is no difference in stress direction at apocenter or pericenter (not shown).

References: [1] e.g. Kattenhorn S. A. and Hurford T. A. (2009) Tectonics on Europa, In: *Europa.* [2] Rhoden A. R. et al. (2010) *Icarus, 210,* 770-784. [3] Rhoden A. R. et al. (2011) *Icarus,* in press. [4] Bills B. G. et al. (2009) Rotational Dynamics of Europa, In: *Europa.* [5] e.g. Hurford T. A. et al. (2009) *Icarus, 202,* 197-215. [6] Murray C. D. and Dermott S. F. (1999) *Solar System Dynamics.* [7] e.g. Hoppa G. V. et al. (2001) *Icarus, 153,* 208-213.