COMBINED EFFECTS OF DIURNAL AND NONSYNCHRONOUS SURFACE STRESSES ON EUROPA.

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Introduction: To date, modeling of the surface stresses on Europa has considered tidal, nonsynchronous, and polar wander sources of stress [1-6]. The results of such models can be used to match lineament orientations with candidate stress patterns. We present a rigorous surface stress model for Europa that will facilitate comparison of principal stresses to lineament orientation, and which will be available in the public domain.

Nonsynchronous rotation and diurnal motion contribute to a stress pattern that deforms the surface of Europa. Over the 85-hour orbital period, the diurnal stress pattern acts on the surface, with a maximum magnitude of ~0.1 MPa. The nonsynchronous stress pattern sweeps over the surface due to differential rotation of the icy shell relative to the tidally locked interior of the moon. Nonsynchronous stress builds cumulatively with ~0.1 MPa per degree of shell rotation.

Modeling Surface Stresses: One approach toward understanding the surface stresses on Europa is to determine the stress difference induced in a thin shell by a change in flattening [e.g. 4]. We instead derive the surface stresses from the tidal potential by calculating the surface deformations, strain, and stresses from the Love numbers.

Stresses on the surface of a planetary body can be modeled by calculating the vector components of displacement **s** at the surface, which are functions of the potential V:

$$V(r,\theta,\phi,t) = Z\,(r/a)^2\,[T+T_0+T_2].$$

The potential is a function of radial distance within the satellite r, colatitude θ, eastward longitude ϕ, and time t (assumed to be zero at perijove). Z is a constant that depends on the gravitational constant G, mass of Jupiter M, radius of Europa (assuming a sphere with $r = a$), and Europa-Jupiter distance R. T is a nonsynchronous term, which depends on the nonsynchronous rotation rate b; T_0 and T_2 are diurnal terms, which are dependent on eccentricity e, and mean motion n, and rate of rotation b such that:

$$Z = (3Gma^2)/(2R^3),$$
$$T = (1/2)\sin^2\theta\cos(2\phi+2bt),$$
$$T_0 = -(e/2)(3\cos^2\theta-1)\cos(nt),$$
$$T_2 = (e/4)\sin^2\theta[-\cos(2\phi+nt+2bt)+7\cos(2\phi-nt+2bt)].$$

Displacement vector components are calculated from the degree 2 Love numbers (h_2, l_2) for a given ice shell thickness and for the expression for the potential [7]. The displacement vector **s** is used to determine the stress tensor τ. Eigenvectors and eigenvalues of the tensor τ, which are the directions and magnitudes of the principal surface stresses, are converted into the right-handed spherical coordinate system of Europa for plotting.

The nonsynchronous term T is two orders of magnitude larger than the diurnal stress magnitudes from T_0 and T_2 (because of the factor of $e = 0.01$), so when a significant degree of nonsynchronous rotation (~5°) is included in the model, it quickly dominates the stress pattern. However, for 1° of nonsynchronous rotation, the stresses are of similar magnitude as the diurnal stresses.

Results: Calculating the diurnal stresses for any point in Europa's orbit allows us to determine the least compressive surface stresses that occur for any point on the surface over the course of an entire orbit (Figure 1a). The icy surface is most likely to fail under the maximum amount of tension experienced during an orbital cycle. With some exceptions, the least compressive diurnal stresses on the surface of Europa are predominantly north-south. This predicts a preferred east-west direction for lineaments formed by diurnal stressing.

Nonsynchronous stresses for any amount of rotation can be added to the diurnal stresses at any point in the orbit. We consider a combination of 1° of nonsynchronous stress and diurnal stresses, and we record the least compressive stress experienced for a given location during an entire orbital cycle (Figure 1b). Because the two mechanisms for stressing the surface contribute approximately equal stress magnitudes, we find that the equatorial compressional zones [7] due to nonsynchronous rotation are nearly cancelled by the diurnal tension experienced at those locations. However, the equatorial tensile zones are doubled in magnitude by the addition of 1° of nonsynchronous rotation.

A comparison of Figure 1b to global features shows an offset of ~20° between a region of predicted equatorial tensile stress, centered at 230° W, and the wedges region, centered near 210° W. Additionally, regions that experience very little net tensile stress, centered at 310° W and at 130° W, are associated with relatively sparse prominent global-scale surface deformation.

Further Applications: The surface stress model we have developed is being used in conjunction with precise stratigraphic mapping for both global and local lineament relations, using the Geographic Information System (GIS) [9]. The ability to compare a precise stratigraphy with combined stress patterns, for any point in Europa's orbit or integrated over a full orbit, and for an arbitrary amount of nonsynchronous rotation [10]. allows for the development of a more thorough and accurate history of linement formation.

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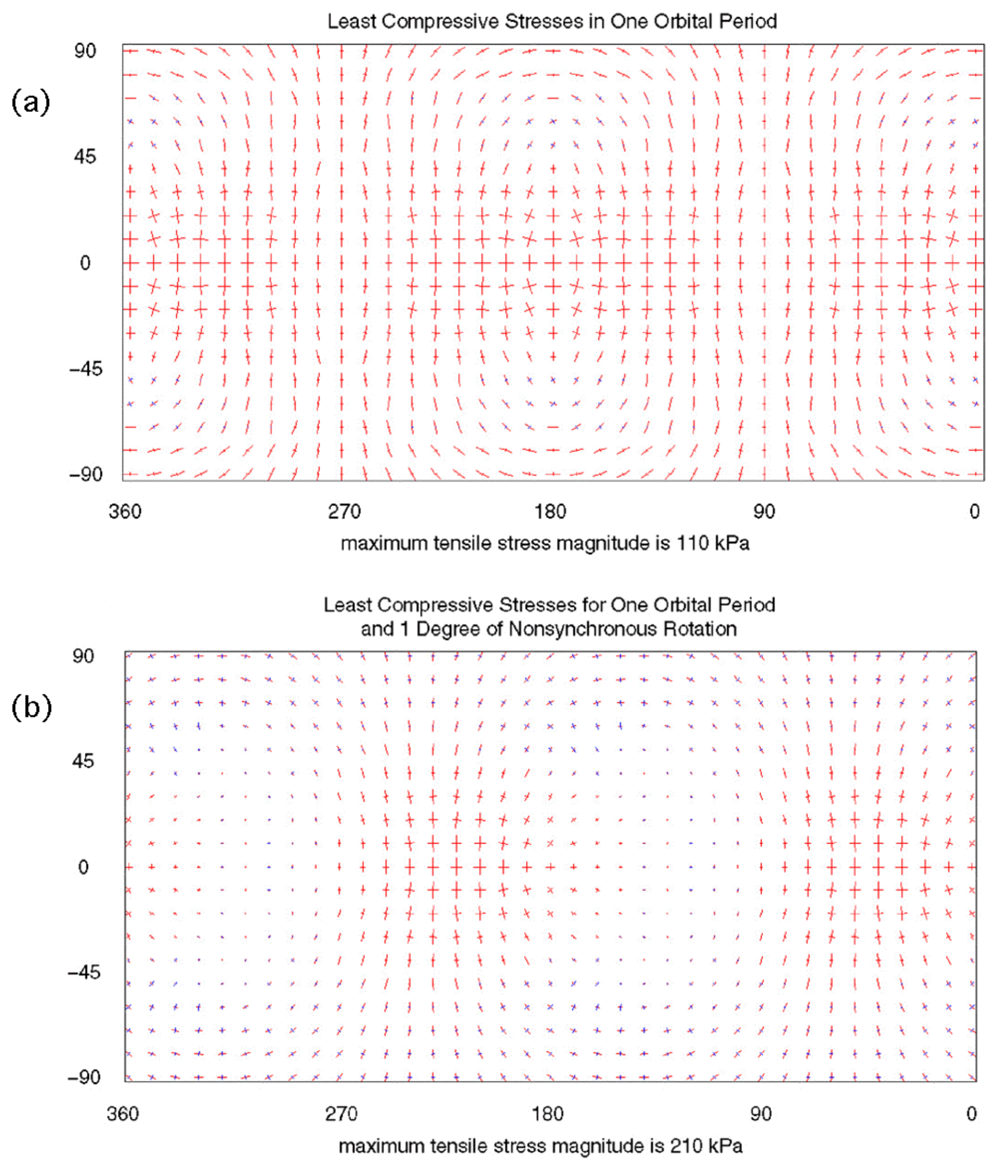

Figure 1. (a) This plot records the least compressive surface stresses from diurnal stressing of Europa achieved for a given point over the course of an entire orbit. Red is tensile stress and blue is compressive stress. The maximum diurnal tensile stress is 0.11 MPa, using a Young's modulus of $9.3x10^9$. (b) This plot combines 1° of nonsynchronous stress with diurnal stresses, recording the least compressive stress achieved at a given location during an entire orbital cycle. The maximum nonsynchronous tensile stress is 0.10 MPa, using the same Young's modulus. These new stress patterns may be used to match the complex pattern of observed structures on Europa.