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Effect of obliquity on viscoelastic deformation and stresses at Europa's surface

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In this study we present a semi-analytical Maxwell-viscoelastic representation of surface diurnal deformations and stresses at Europa's surface. Europa's shell experiences forces on a diurnal scale as a result of the orbit's eccentricity, the spin axis' obliquity and physical librations. Here we take into account the first two effects. We show that a small obliquity ($< 1^\circ$) can have serious effects on deformations and stresses, mainly by disrupting the symmetric distribution of deformation and stress patterns with respect to the equator. The asymmetry in radial deformation is caused by the periodic displacement of the tidal bulge in north-south direction, which is largest when Europa is located 90° away from the nodes formed by the intersection of Europa's orbital and equatorial planes. As an additional deformation mechanism, the obliquity tide also leads to an increase of the amplitude of surface deformations. For obliquities larger than 0.7°, tidal deformations might become 20% larger in amplitude ($\sim$ 35 m) than in the zero-obliquity case ($\sim$ 29 m). Although the effect on the amplitude becomes rather small for obliquities smaller than $\sim 0.25^\circ$, local differences in magnitude of nearly 3 meters can take place even for an obliquity of 0.1°. Therefore, it will be important to accuraletely determine the position of Europa's spin axis in space before using future altimetric measurements of Europa's tidal deformation to retrieve some information about the thickness, rigidity and viscosity of the icy shell.

The influence of a small, but non-zero, obliquity on tidal deformations directly affects the diurnal stress field at the surface. Tensile and compressive regions on the surface are shifted in north-south direction, thereby changing the usual orientation of diurnal stress patterns. Due to the asymmetric distribution of diurnal stresses with respect to the equator, the possible existence of a non-zero obliquity has been recently used to improve the modeling of Europa's cycloidal features and strike-slip faults. This modeling, however, does not take into account the effect of viscoelasticity in the plausible case that the lowest portion of Europa's ice shell shows strong dissipation.

In order to model the effect of viscoelasticity, we assume that Europa's interior is differentiated in five homogeneous material layers: a liquid metallic core, a silicate mantle, a subsurface water ocean, a low-viscous and warm ice layer (asthenosphere, viscosity $10^{12} - 10^{17}$ Pa·s), and a high-viscous and cold upper ice layer (lithosphere, viscosity 10^{21} Pa·s). Viscoelasticity only affects the surface stress patterns through the viscoelastic response of the interior to tides. The importance of the viscoelastic response on surface stresses is proportional to the ratio between the relaxation time (τ_j) of a given viscoelastic mode and the period of the tidal excitation force (i.e. one orbital period). On a diurnal timescale, the fast relaxation of transient modes related to the low viscosity of the asthenosphere can alter the magnitude and phase shift of the diurnal stress field at Europa's surface. The effects are largest, up to 20% in magnitude and 7° in phase for ice rigidities lower than 3.487 GPa, when the value of τ_j corresponding to the aforementioned transient modes approaches the inverse of the average angular rate of Europa's orbit (i.e. $1/n$).