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# Temporal variability of deformation in Enceladus' ice shell with faults

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## Abstract

Enceladus' geysers emanating from faults at the south polar region (SPR) provides a unique opportunity to sample the internal ocean. The temporal variability of the geysering activity observed by the Cassini mission suggest modulation by diurnal tides [3, 6] and, on longer time scale, possibly by seasonal changes, buildup of ice at the vents and/or eccentricity and libration variations [5, 7]. The fact that the ice shell is estimated to be very thin at the south pole [2] suggests that the faults might extend through the whole shell thickness, possibly controlling the stress and the deformation in the south region [9, 1, 10]. Here, we address the impact of diurnal tides including short-period libration and highly deformable core, and effect of long-period libration and eccentricity variations on the stress and the deformation in the south polar region and along the faults. We show the sensitivity of the temporal changes in the observed brightness on long-period viscoelastic deformation.

## 1. Model and Method

We investigate periodic stress and deformation variation in Enceladus' ice shell due to the interaction with neighboring bodies. On short periods (1.37day), the deformation is induced by the diurnal tides with enhancement originating in the physical libration [11]. On longer time scales, we take into account the long-period libration and eccentricity variations related to indirect perturbations of Enceladus's orbit by Dione (on periods 11 years, and 3.7 years). The internal model also includes (i) variable ice shell thickness consistent with the gravity, topography and libration measurements, e.g. [2], (ii) idealized faults mechanically decoupling the south polar region into blocks, (iii) parameterized deformation of the core. We neglect the dependence of the libration amplitudes and eccentricity variations on the rheology of the shell [8, 12].

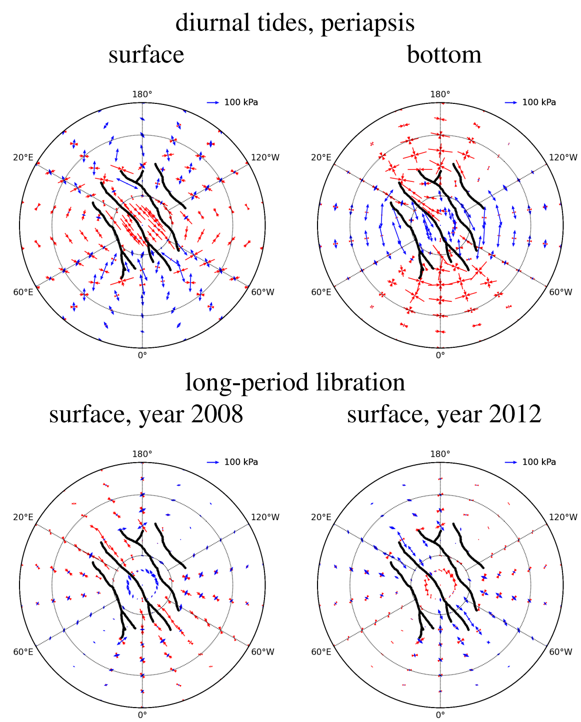


Figure 1: Example of principal stress axes (red – compression, blue – tension), elastic model.

In order to evaluate the stress and deformation numerically, we use a finite element code solving the mechanical response of a 3D compressible shell for the Maxwell viscoelastic and elastic rheologies [9, 1, 10]. We assume linearity of the problem ensuring superposition and scalability of the stress and deformation originating in forcing on different time scales.

## 2. Stress regime

An illustration of the stress regime in the case of the diurnal tides (with short-period libration) is shown in Figure 1. Our results suggest an important role of the bending stresses near the SPR: While outside the SPR the stress is either tensile or compressional and

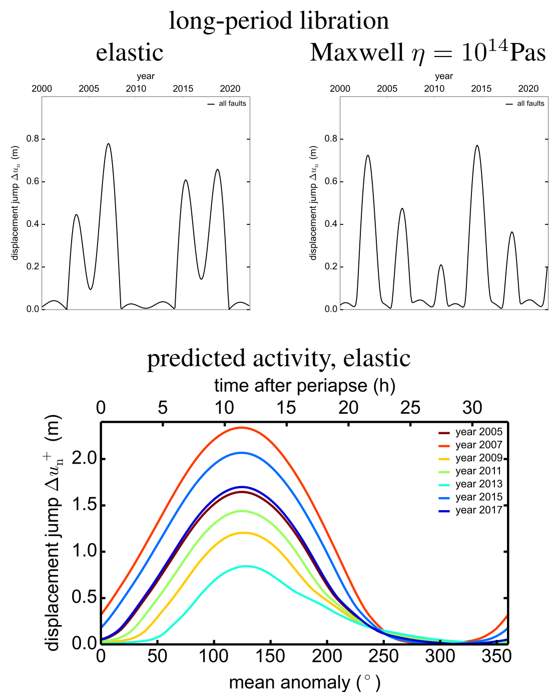


Figure 2: Changes in predicted activity due to long-period libration.

the regime does not changes with the depth, near and inside the SPT, the regime changes with depth from compressional to tensile (and vice versa).

Figure 1 demonstrates different nature of the stress due to the long-period libration. Whereas the orientation of the principal axes of the stress tensor evolves with the mean anomaly in the case of the diurnal forcing, the orientation principal axes induced by the libration remains unchanged (approximately parallel and perpendicular to the faults) and only magnitude changes. Note that the stress and displacement due to long-period libration has comparable (though somewhat smaller) magnitude to the diurnal forcing for elastic rheology.

# 3. Temporal variability of activity

Assuming linear relationship between the observed activity (brightness) and the modeled opening of the faults (positive displacement jump across the faults, following e.g. [6, 1]), we can predict timing of the geysering activity. Similarly to previous models, the observed activity is delayed by 5-6 hours compared to theoretical (diurnal) models. The nature of the delay is still unclear and it cannot be resolved by our model. The scaling analysis indicates that the impact of the long-period variation in eccentricity on the displacement jump is approximately $5\%$ (for eccentricity varying between 0.0045 and 0.0049). The effect of the core is even smaller even for highly deformable and dissipative core. The sensitivity to the long-period libration (for two end-member models) is shown in Figure 2 (top). The peaks in the displacement jump predicts periods of an enhanced activity. In the case of the viscoelastic model, each mode has different phase delay compared to forcing due to different periods. The modes superpose differently possibly influencing the predicted temporal changes in activity. An example of the effect of the long-period libration on the predicted activity is shown Figure 2 (bottom).

# 4. Conclusions

We found that the bending stresses near the SPR may not be negligible in a thin and fractured ice shell. The amplitude of the stress and displacement due to long-period libration is comparable to the diurnal forcing. Our prediction shows that they may contribute to the observed temporal variability in geysering activity.

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