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Long-period deformations in Enceladus's ice shell

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Abstract

As Enceladus orbits Saturn on a slightly eccentric orbit, it is periodically deformed due to daily changes in their mutual distance. The deformation and stress can result in tidal dissipation and very likely also modulate the observed geysering activity near its south pole [1, 2]. Additional enhancement of stress and deformation magnitudes originates in the physical libration [3]. On decadal time scales, the deformation and stress in the shell are influenced by long-period libration and eccentricity variations. By means of numerical simulations, we investigate the decadal changes in the stress and deformation in the ice shell of Enceladus, and we discuss their implication on the variation in the plume activity depending on the rheological parameters of the shell.

1. Introduction

On short time-scale periods, deformation, stress and dissipation of Enceladus are controlled by the diurnal tides (due to eccentricity and short-period physical libration). In the ice shell, the stress/deformation modulates the observed geysering activity (the measured plume brightness [1, 2]). The observed activity is nevertheless approximately 5 hours delayed compared to theoretical models unless the shell is thick and highly dissipative [4]. During almost a decade of observation, the plume activity are possibly further modulated by seasonal changes, buildup of ice at the vents and/or eccentricity and libration variations [5, 6].

Here we investigate the latter possibility – variation of the plume activity due to changes in orbital parameters and libration, i.e. the variations related to indirect perturbations of Enceladus's orbit by Dione (on periods 11 years, and 3.7 years).

2. Model

In our model, we assume that the short-period deformations are elastic. For deformations due to the long-period libration, we take into account viscoelastic (Maxwell) rheology in order to describe deformation and stress patterns. Additionally, we assume that the libration amplitudes and eccentricity variations do not (or only weakly) depend on the rheology of the

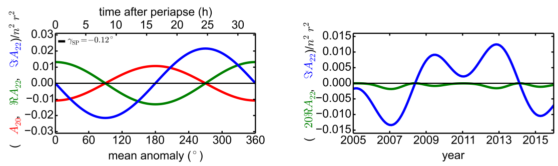

Figure 1: Coefficients of forcing potential for short-period (left) and long-period (right) forcing and the current eccentricity.

shell cf. [7, 8] and stress and deformation on different scales can be combined linearly.

The force acting on the shell on the different time scales is described using the potential V:

$$V = A_{20}Y_{20} + 2\Re A_{22}\Re Y_{22} - 2\Im A_{22}\Im Y_{22},$$

where Y_{jm} are spherical harmonics on degree j and order m. The amplitudes of the tidal potential A_{jm} are comparable for both processes (see Figure 1) and therefore the long-period libration can further modulate the opening/closing of the faults depending on the rheological parameters.

In order to evaluate the stress and deformation due to the tidal force numerically, we use a finite element code solving the mechanical response of a 3D compressible shell of variable thickness (possibly including faults) for the Maxwell viscoelastic and elastic rheologies [9, 10].

Following [4, 10], we compute theoretical curves of the geysering activity along the faults using the stress/displacement patterns and their time variations. We compare misfit between the predicted and observed data for models described by different values of the dissipation factor on periods 3-11 years. The time lags between the observed and predicted activities are described by a single free parameter.

3. Preliminary results

An example of the effect of the long-period libration on the predicted activity (without eccentricity changes) in a shell of variable ice shell thickness [11] and constant (or weakly depth dependent) rheological parameters is shown in Figure 2. If the shell is relaxed (stress is low) on periods of years, we do not

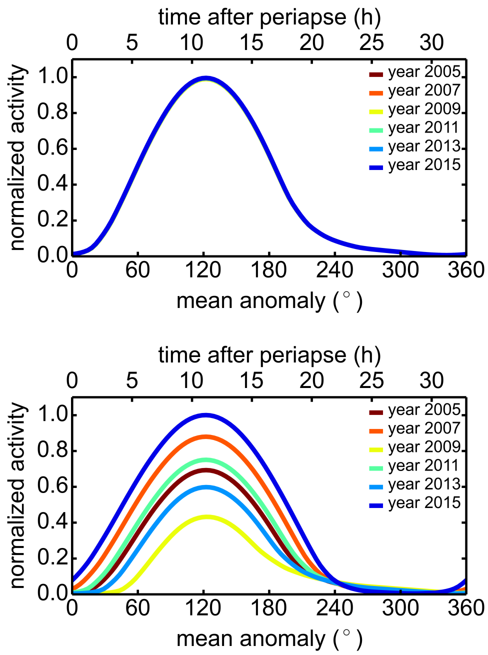

Figure 2: The predicted activity of the geysering activity as a function of the observation time for the shell characterized by η equal to 10^{14}Pa.s (top), 10^{16}Pa.s (bottom).

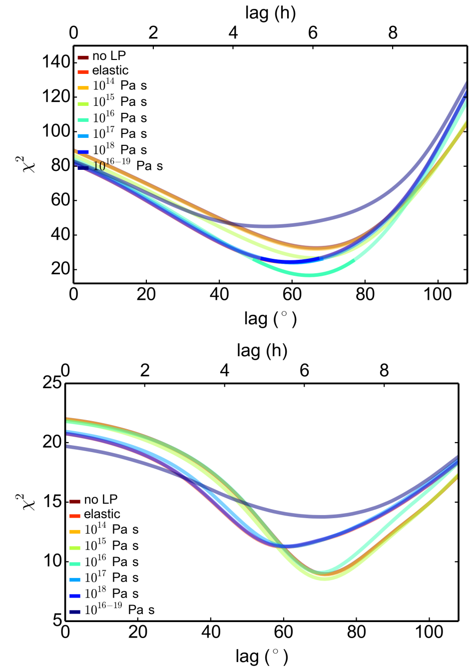

Figure 3: The reduced misfit between the predicted and VIMS (top) and ISS (bottom) data as a function of the parameterized lag.

naturally observe any significant influence on the predicted activity and the stress regime is controlled by the short-period forcing. For less relaxed solutions, the predicted activity depends on the year of observation. The enhancement/reduction in the predicted activity nevertheless depends on the rheological parameters. In order to obtain the best model, we compute the reduced misfit between the observation and prediction. The models with the smallest misfit are consistent with viscosities ranging between 10^{16}Pa.s and 10^{18}Pa.s ($Q = 1.001 - 5.5$) for the lag equal to 5 hours (Figure 3).

4. Conclusions

The long-period libration can result in decadal changes in the plume activity on Enceladus and can possibly provide an estimate of the dissipation factor on 3-11 years periods. An additional mechanism is nevertheless needed to explain the observed time lag between the predicted and observed activity on diurnal periods.

Acknowledgements

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