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Diurnal tidal stresses on Titan

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Abstract

Interior models and amplitude patterns of diurnal tidal stresses on Titan are calculated. The structural models are required to satisfy the satellite's mean density, polar moment-of-inertia factor MoI, and tidal potential Love number k_2 as derived from Cassini gravity field data. The tidal stress pattern is found to correspond to the locations of cryovolcanic candidate areas on Titan's leading hemisphere. A relatively warm, low-ammonia water ocean could further increase Titan's habitable potential.

1. Introduction

In spite of its ice-rich bulk composition, Titan, Saturn's largest satellite, has many similarities to the early Earth, particularly in terms of atmospheric composition and organic chemistry. Gravitational field data acquired by the Cassini spacecraft suggest that Titan's state of internal differentiation is intermediate between partly separated Callisto and fully differentiated Ganymede [1]. Titan is tidally locked with respect to Saturn and thereby subject to solid body tides resulting in diurnal stresses at the satellite's surface. The tidal response depends on its interior structure, thermal state, tidally effective rheology, and the frequency of tidal forcing. The existence of a shallow liquid-water ocean is the most probable interpretation of the Cassini measurements of the tidal contributions to the nonspherical part of Titan's gravity field [2]. The tide-induced internal redistribution of mass results in variations of surface gravity, tilt, stress and strain, which could play a major role in triggering processes that are visible in Titan's geological surface record. Here we focus on the tidal deformation pattern and possible links to geodynamical surface features on Titan.

2. Model

We subdivide Titan's interior into four chemically homogeneous reservoirs and construct spherically symmetric structural models that are required to satisfy the satellite's mean density, polar moment-of-inertia factor MoI, and tidal potential Love number k_2 as derived from Cassini gravity field data. The structural models consist of a hydrated rock core overlain by high-pressure ice layer, a water-ammonia ocean, and a floating outer ice shell. The outer ice shell thickness and the radial extent of the subsurface water-ammonia ocean are closely related to each other. Following [3] in application to Europa, we first calculate the degree-2 body-tide Love numbers h_2 and k_2 and the Shida number l_2 for our structural models of Titan's interior. Using corresponding linear combinations of the body tide Love-Shida numbers [e.g., 4], we then calculate the expected amplitude patterns of tidal stresses at Titan's surface in response to the tidal forcing.

3. Results and Discussion

The calculated reference model of Titan's present interior structure as shown in Fig. 1 satisfies the 2-sigma observational data for MoI and k_2 acquired by the Cassini mission. The hydrated rock core is about 2100 km in radius with an average density of 2600 kgm^{-3}. While the central pressure is 4.9 GPa, the pressure at the core-mantle boundary is about 0.80 GPa. The tidal gravity field of Titan is found to be consistent with a subsurface water-ammonia ocean of more than 180 km thickness with relatively low ocean ammonia contents of less than 5 wt.-% and ocean temperatures in excess of 255 K, i.e., higher than previously thought. The calculated thickness of the outer ice shell is in the order of 100 km, being consistent with previous estimates using the spectral admittance between Titan's large-scale gravity and topography [5].

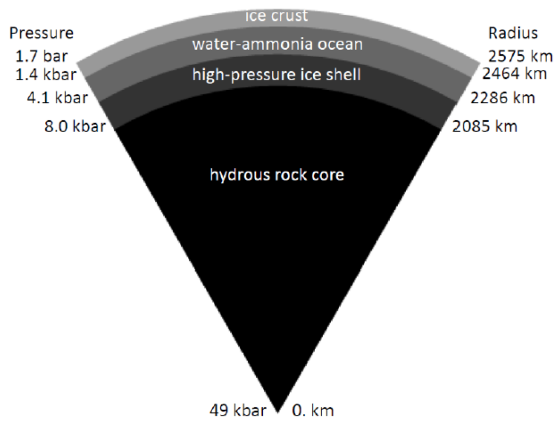

Figure 1: Interior structure model of Titan [8].

We then calculate the expected amplitude patterns of diurnal tidal stresses at Titan's surface and find peak-to-peak amplitudes on the order of 15 kPa. These are likely to accumulate over several tidal cycles to much larger values that even may exceed the tensile strength of ice. Episodic stress release accompanied by localized tectonic quakes may occur where a certain threshold stress limit value is exceeded. The superposition of the amplitude patterns of both areal and shear stresses suggest that tidal flexure and stress accumulation are significantly enhanced in four adjacent, near-equatorial, mid-latitude zones (Fig. 2).

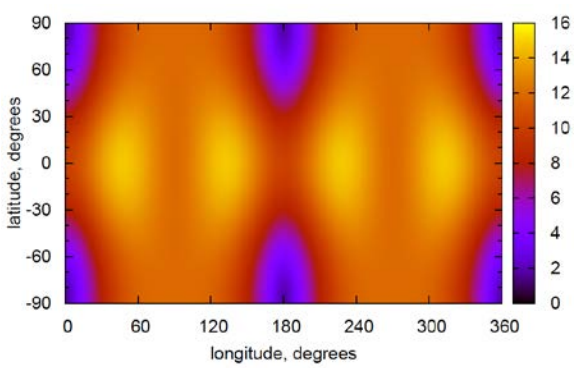

Figure 2: Global amplitude pattern of diurnal tidal stresses color-coded in units of kPa [8].

These are compliant with the distribution of active regions such as cryovolcanic candidate areas (Tui Regio, Hotei Regio, Sotra Patera) on Titan's leading hemisphere [6]. Considering Titan's high resurfacing rate, the apparent absence of similar cryovolcanic candidate features in the trailing hemisphere could be linked to seasonally asymmetric distributions of erosional or resurfacing processes on both hemispheres [7].

4. Summary and Conclusions

Interior models and amplitude patterns of diurnal tidal stresses are calculated. The characteristic pattern of tidal stresses is found to correspond to the locations of cryovolcanic candidate areas on Titan's leading hemisphere. These may provide possible pathways for the release of methane in the satellite's atmosphere with important implications for Titan's habitability that could be further increased by a relatively warm and extended low-ammonia water ocean. Future observations of Titan's surface should focus on the near-equatorial, mid-latitude zones in the trailing hemisphere that are tidally flexed symmetrically to those on the leading hemisphere [8].

Acknowledgments

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