TITAN'S OUTER ICE SHELL STRUCTURE AND DYNAMICS CONSTRAINED FROM CASSINI DATA.

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Introduction: Observations of Titan by the Cassini spacecraft provide geophysical informations (long wavelength topography [1], gravity field [2],obliquity [3], atmospheric electric field [4]) as well as geomorphological informations (from Radar and VIMS instruments) that can be used to constrain the present-day interior structure and its past evolution. In particular, the detection of a large tidal response of the interior [2] in addition to the observed obliquity [3] and the detection of a Schumann resonance [4] indicate the presence of an internal water ocean (possibly doped in salts) a few tens of kilometers bellow the surface. The observed long-wavelength topography, which significantly differs from the equilibrium shape, suggest strong variations in density and/or thickness in the outer ice shell [5].

In the present work, we test various hypothesis for the compensation processes in the ice shell to explain the surface gravity and topography. We developed a generic interior structure model for Titan taking into account any thickness or density variations of the different internal layers. Using this model, we derive the thickness and density variations in the outer ice shell compatible with the observed topography and gravity field. By computing the vertical velocity of the surface and ice/ocean interface in response to topographic load, we then determine for which viscosity structure the derived density or thickness variations are mechanically stable. A final goal of our work is to evaluate the possible scenarii leading to the present-day configurations and to test them by using morphological proxys identified from global mapping of Titan's surface using RADAR and VIMS data.

Interior model and structure of the outer ice shell: Titan's interior is assumed to be composed of 3 to 5 internal layers with from the top to the center: a low pressure outer ice shell, an internal liquid ocean, an high pressure (HP) ice shell and a core (possibly differentiated). For simplicity, we assume a pure water system. For a given thickness, the averaged position of the ocean/HP ice interface is determined using the intersection of the adiabatic profile in the ocean with the melting curve of pure water ice computed using the approach of [6]. The averaged position of the rocky core interface is determined in order to match Titan's averaged density and a given fluid Love number value.

The deflections of these averaged interfaces are then calculated using the properties of the gravitational potential: on each interface, the potential is expressed as a sum of terms depending on the density jump and the elevation with respect to the mean radius for all interfaces. To explain the topography and gravity data, either density or thickness variations can be considered in the outer ice shell. Figure 1 present maps of ice shell thickness variations (assuming constant density) (a) and of density variations assuming that these variations are located in the 3-km uppermost of the shell (b). The observed topography variations are compatible either with total thickness variations of the order of 5-6 km or densities varying between 750 and 1100 kg.m^{-3} in the upper crust (for a 3km compensation depth). These two possible explanations have however different consequences for the dynamics of the outer shell.

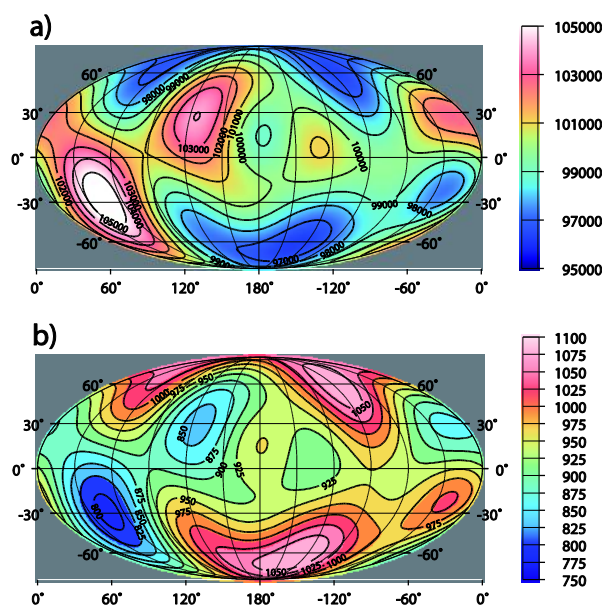

Figure 1: *a) Total Thickness (in meters) derived for a 100-km mean outer ice shell with a fluid Love number kf=1.0097, b) Density variations (kg/m^3) in the 3-km uppermost part of a 100-km outer ice shell considering a mean density of 935-kg/m^3 for the rest of the ice shell.*

Stability of the outer ice shell: Implications for the viscosity structure. To determine the stability of

the outer ice shell, we compute the mechanical readjustment of each interface in response to topographic load. In the case of thickness variations, loads due to positive or negative topography are imposed both at the surface and at the base of the ice shell. In the case of crustal density variations, loads due to crustal mass anomalies are imposed at the top of the ice shell (just beneath the icy crust). In order to test the mechanical stability, we define different viscosity structures for the ice shell corresponding to various thermal states / surface heat flows.

In the hypothesis of thickness variations, the derived variations may result from heterogeneous crystallization of the internal ocean [e.g. 5]. The derived ice shell structure may be stable only if the relaxation rate of the interface topography does not exceed the crystallization rate.

In the hypothesis of crustal density variations, the derived variations may result from clathration process at the surface [7], with dense ethane-rich clathrate at high latitude and less dense methane-rich clathrate at low latitude. The derived density may be stable only if the relaxation rate of the interface topography does not exceed the typical clathrate conversion rate.

Our computation show that in the case of thickness variations, the topography relaxation rate is much larger than the typical crystallization rate if the ice shell is convective, even for surface heat flux as low as $10 mW.m^{-2}$. Thickness variations required to explain the topography and gravity data are stable only if the ice shell is conductive and for a bottom viscosity of at least 10^{16} Pa.s. On the other hand, in the case of density variations in the upper crust, the topography relaxation rate is always very low (<10 m/My) even for a convective ice layer with heat flux as high as $40 mW.m^{-2}$, and this configuration can remain stable.

Past evolution and surface morphology: The thickness variation hypothesis is compatible only with a conductive viscous ice layer, implying a cold ocean. Following this scenario, the present-day configuration should result from a slow crystallization of the ocean, implying a progressive uplift of the regions associated with the maximal crystallization rate. On the other hand, following the scenario of [7], the crustal density variation hypothesis should be associated with a progressive subsidence in the polar regions. These two different configurations should lead to different stress patterns. We are currently investigating how the surface stress patterns may evolve as a function of time following these two different scenarii and assuming different viscosity structures for the ice shell. To better constrain those evolution scenarii, we are also producing a global mapping of Titan's surface features using VIMS data (global surface mosaic at 5 microns) and RADAR data (radar swath from TA to T77). The observed morphological features on the surface as well as the global shape of Titan may result from current or past endogenous and/or exogenous mechanisms. Possible relationship between the observed shape, the computed stress patterns and the observed surface features may provide a pertinent test for the evolution scenario of Titan.

References:

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Acknowledgements: The research leading to these results has received funding from the European Research Council under the European Community's 7th Framework Programme (FP7/2007-2013 Grant Agreement no. 259285).