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Numerical simulation of tides and oceanic angular momentum in Titan's hydrocarbon seas

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Abstract

Tides in Titan's hydrocarbon seas are numerically simulated by a 3-dimensional ocean circulation model using a bathymetry map constrained by Cassini. The tide predictions are used to calculate the oceanic angular momentum in the seas. The tidal currents in Kraken Mare are mainly oriented along the major axis of the sea, i.e. in the north-south direction. The variation in the oceanic angular momentum is primarily caused by changes in the tensor of inertia of the seas due to mass redistribution of liquids in Kraken Mare, with the tidal currents playing a minor role. The high-latitude location of the seas causes all three components of the oceanic angular momentum to have similar amplitudes, unlike the atmospheric angular momentum.

1. Introduction

Hydrocarbon seas/lakes on Titan's surface represent a geophysical fluid with a substantial mass, in addition to the atmosphere and putative subsurface ocean. There is no reason to assume that these seas are motionless relative to the sea bottom. Titan's eccentric orbit causes radial and librational tides, which should manifest themselves in tides and tidal currents in the seas [2]. They in turn changes Titan's rotation and causes tidal dissipation analogously to Earth's oceans. Recent direct measurements of the bathymetry of Ligeia Mare [4] and detailed, complete mapping of the coastline of the three maria (Kraken, Ligeia and Punga) [3] allow us to perform more confident numerical tide simulations than previously [6, 8]. This work presents tide simulations using the bathymetry constrained by Cassini and calculations of the oceanic angular momentum and tidal dissipation rate using these simulations.

2. Model outline

Tides and tidal currents are simulated by a 3-dimensional ocean circulation model for Titan's seas [8], which is based on the Bergen Ocean Model [1]. The model domain covers an area of 1700 km x 1400 km near the North Pole, including Kraken Mare, Ligeia Mare, Punga Mare and numerous lakes. The bathymetry map of [3] is used in the model, with a total sea volume of ~30000 km³ and maximum depth of 197 m. However, the depth of the Throat of Kraken (strait in the southern portion of Kraken Mare) is treated as a free parameter since the tides are more sensitive to the depth of this narrow strait than to the depth elsewhere. The tide-raising potential calculated after [2] is scaled by the Love number reduction factor γ_2 considering the tidal deformation of the ice shell (γ_2=0.1 assuming a subsurface ocean).

3. Tides and tidal currents

The tidal range depends on both volume and geographical location of the seas. The largest tidal range occurs along the southern and northern shore of Kraken Mare. Tides in Kraken Mare vary see-saw-like along the major axis of the sea. Tides in Ligeia Mare are strongly affected by Kraken Mare, while the opposite is not the case. The depth of the Throat of Kraken has a strong control on the pattern of tides especially in the southern basin of Kraken Mare as well as on the tidal current direction and speed. The typical current speed in the interior of basins is of the order of cm s^{-1}, yet there is a reversing, strong hydraulic current in the Throat of Kraken generated by the large sea level difference across the strait. Further areas of relatively fast tidal currents include the area surrounding Mayda Insula and the bottleneck between Kraken Mare and Ligeia Mare.

4. Oceanic angular momentum

As a geophysical fluid, which can move around, Titan's seas possess an oceanic angular momentum (OAM), which varies relative to the angular momentum of the underlying ice shell. The OAM varies with a period of 1 Titan day due to tides and can contribute to variations in Titan's rotation rate (length-of-day variation) and spin orientation (polar motion), in addition to the variation in the atmospheric angular momentum (AAM). We quantified the three components of the OAM of Titan's seas and its temporal variation using the model output of the instantaneous sea surface displacement and tidal currents analogously to [7]. There are qualitative and quantitative differences to the terrestrial counterpart [5, 7] owing to the relative smallness of the total mass of Titan's seas, the high-latitude location of the seas and the lack of circumpolar seas. The OAM varies with a period of 1 Titan day and mainly changes by redistribution of liquids in Kraken Mare. The axial OAM becomes smallest when most liquids are shifted poleward so that the tensor of inertia of the seas minimizes. The equatorial OAM has similar amplitudes as the axial OAM. Tidal currents are less important for the OAM variation than tidal sea surface displacements, but they too change the OAM with a clear diurnal cycle. The time derivative of the OAM (oceanic torque) is two orders of magnitude smaller than the mountain torque [9], which is the atmospheric counterpart of that type of oceanic torque that is discussed here, but exhibits a similar diurnal pattern.

5. Concluding remarks

In principle, signals of the oceanic torque are detectable in observational data of planetary rotation, provided that precise measurements are available. Another, more promising way of constraining the OAM of Titan would be a direct detection of sea tides that cause the OAM variation. Tides in Titan's seas could be detectable in a number of ways: by migration of the shoreline, by the change in depth at specific points, and by tidal currents. Shoreline migration associated with floods and ebbs is perhaps the most obvious signal of the tidal cycle, as it is on Earth. The presence of even a small depth of liquid causes a profound change in reflectivity of a surface, in both radar and the near-infrared, due to quenching of the contrast between air and solid by liquid. Thus the shoreline can be readily picked out in image data. To enable qualitative interpretation of possible shoreline migration to be observed we predict the direction and magnitude of shoreline migration and relative sea level change at specific locations for specific periods, which could directly be compared with observations of shorelines or tides.

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References

[1] Berntsen, J.: User's guide for a modesplit σ-coordinate numerical ocean model. University of Bergen, Norway, http:/math.uib.no/BOM/BOM-4.1-guide.pdf

[2] Dermott, S. F, Sagan, C.: Tidal effects of disconnected hydrocarbon seas on Titan, Nature, Vol. 374, pp. 238-240, 1995.

[3] Lorenz, R. D., et al.: A radar map of Titan seas: tidal dissipation and ocean mixing through the Throat of Kraken, submitted to Icarus, 2014.

[4] Mastrogiuseppe, M., et al.: The bathymetry of a Titan sea, Geophys. Res. Lett., doi:10.1002/2013GL058618, 2014.

[5] Ponte, R. M., Rosen, R. D.: Oceanic angular momentum and torques in a general circulation model. J. Geophys. Res., Vol. 24, pp. 1966-1977, 1994.

[6] Sears, W. D.: Tidal dissipation in oceans on Titan. Icarus, Vol. 113, pp. 39-56, 1995.

[7] Seiler, U.: Periodic changes of the angular momentum budget due to the tides of the world ocean. J. Geophys. Res., Vol. 96, pp. 10287-10300, 1991.

[8] Tokano, T.: Simulation of tides in hydrocarbon lakes on Saturn's moon Titan, Ocean Dyn., Vol. 60, pp. 803-817, 2010.

[9] Tokano, T.: Mountain torque and its influence on the atmospheric angular momentum on Titan. Icarus, Vol. 220, pp. 863-876, 2012.