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Sun-stirred Kraken Mare: Circulation in Titan's seas induced by solar heating and methane precipitation

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Abstract

Density-driven circulation in Titan's seas forced by solar heating and methane evaporation/precipitation is simulated by an ocean circulation model. If the sea is transparent to sunlight, solar heating can induce anti-clockwise gyres near the sea surface and clockwise gyres near the sea bottom. The gyres are in geostrophic balance between the radially symmetric pressure gradient force and Coriolis force. If instead the sea is turbid and most sunlight is absorbed near the sea surface, the sea gets stratified in warm seasons and the circulation remains weak. Strong summer precipitation at high latitudes causes compositional stratification and increase of the near-surface methane mole fraction towards the north pole. The resultant latitudinal density contrast drives a meridional overturning with equatorward currents near the sea surface and poleward currents near the sea bottom. Weak precipitation induces gyres rather than meridional overturning.

1. Introduction

A large fraction of Titan's northern high latitudes is covered by liquid hydrocarbon seas and lakes. Meanwhile, the global distribution of Titan's seas has been mapped to a large extent [1], so that explicit simulations of the sea/lake circulation on Titan became feasible. Two aspects of ocean circulation in Titan's seas have so far been simulated by ocean circulation models: Tidal currents forced by Saturn [2] and wind-driven circulation [3]. An aspect that was neglected in these studies is the impact of density gradients on the circulation. Total absence of density gradients is an unrealistic assumption for open seas that are not entirely covered by sea ice. In Earth's oceans, differential solar heating and non-uniform freshwater fluxes at the sea surface cause variations in the temperature and salinity, which induce thermohaline or density-driven circulation.

In this study we present numerical simulations of density-driven circulation in Titan's seas associated with solar heating and methane precipitation by an ocean circulation model. The study especially addresses the seasonal and spatial structure of the dynamics of the sea that is difficult to investigate analytically.

2. Model outline

Density-driven circulation in Titan's seas is predicted by a baroclinic ocean circulation model, which was previously used to simulate tides [2] and wind-driven circulation [3]. The driving mechanisms of density-driven circulation considered in this study are solar heating (thermal forcing), which change the density of the liquid by thermal expansion and contraction, and local imbalance between methane evaporation and precipitation (precipitation forcing), which change the density by variable sea composition. Major differences to the model version of [3] concern the treatment of temperature and sea composition, which were previously kept constant. Thermal forcing is given by the surface heat flux along with the vertical profile of light extinction in the sea. Precipitation forcing analogous to freshwater influx or outflux in Earth's oceans is imposed by the surface methane flux, which consists of evaporation and precipitation. The density of the liquid is calculated as a function of temperature and composition.

3. Results

If surface methane fluxes are negligible, density gradients develop only due to differential solar heating of the sea (thermally forced circulation). Negligible surface methane fluxes could occur if there methane precipitation does not reach the sea surface and there is no methane evaporation because of methane paucity in the seas. In such a scenario the stratification and circulation depend on the vertical profile of the absorption of sunlight in the sea. If most sunlight is deposited near the sea surface, the sea surface temperature depends only on depth, resulting in negligible horizontal density gradients and circulation. If the sunlight penetrates deeper to the sea, the coastal area in summer becomes warmer than the central part of the sea because of topographic heat accumulation. This causes the density in the entire liquid column to decrease towards the shore. The combination of radial pressure gradient force and Coriolis force maintains a stable geostrophic gyre, which is anti-clockwise near the sea surface and clockwise near the sea bottom.

Methane precipitation is another possibility to force a circulation in Titan's seas, but the significance of the precipitation forced circulation is likely to strongly depend on the precipitation distribution and magnitude. As long as the maximum precipitation rate is of the order of 0.1 mm/day or less, the seasonal variation in the sea composition and thus density near the sea surface is too small to generate a density-driven circulation comparable in magnitude with the thermally forced circulation. The model predicts several local gyres, which are less structured than the gyres caused by solar heating. If the precipitation rate in summer exceeds the order of 1 mm/day and the precipitation increases with latitude, the top layer of the sea becomes seasonally methane-enriched and the methane mole fraction in the top layer increases towards the north pole. This creates a compositional stratification and large latitudinal density gradients, especially in warm seasons. The resultant circulation is a meridional overturning with southward (equatorward) currents near the sea surface and northward (poleward) currents near the sea bottom.

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