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Titan's climate explains the presence of its deep ocean

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Abstract

Titan is the only known moon with a dense atmosphere where organic molecules are produced, and the only body, besides the Earth, with liquids at its surface. Its climate is characterized by methane and ethane rains that can react with water ice to form a clathrate cap on top of Titan's crust. Owing to its thickness and strong temperature dependence of ice viscosity, Titan's crust is likely to convect in a regime with a thick stagnant lid that acts as a strong barrier for the exchange between the surface and the deep water ocean. We show that the presence of the clathrate cap dramatically reduces the thickness of the stagnant lid thus increasing the potential for exchange of organics between the surface and the ocean. Acting as an insulator, the clathrate cap also limits the amount of heat that can be extracted from the ocean by convection which prevents further freezing of the ocean and keeps the liquid present on a long time scale. As the water cycle on Earth is important for mantle dynamics, Titan's methane cycle controls the dynamics of its icy crust and provides an alternative explanation for the presence of a deep water ocean.

1. Introduction

The presence of large amounts of methane in Titan's atmosphere [9], the hydrocarbon lakes at its surface [8], and Titan's climate [6] suggest that its icy crust can be covered by a layer of methane clathrates [5]. The thermal properties of clathrates are very different from those of water ice - the thermal conductivity in particular is more than an order of magnitude lower than that of water ice at Titan's surface temperature [7]. The clathrate cap is thus acting as a powerful insulator. In this paper, we study the dynamics and heat transfer through Titan's clathrate capped ice crust.

2. Numerical model

We solve thermal convection of viscous fluid (ice) in a 2d Cartesian box assuming the incompressible Boussinesq approximation of the governing equations. We include the strongly nonlinear viscosity of ice which depends on temperature, grain size and stress using the composite law [2]. The temperature depedence of thermal conductivity [3] with values of 2.3 and 5.7 W m^{-1} K^{-1} at the ocean interface and surface, respectively, is taken into account. Finally, we also include the insulating effect of methane clatrates by prescribing a constant clathrate conductivity of 0.5 W m^{-1} K^{-1} in a layer of thickness h_c.

The governing equations are supplemented with the following boundary conditions: free-slip on all boundaries, fixed temperature at the bottom and top boundary, and thermally insulating side boundaries. The whole system is implemented in the open source Finite Element Method library FEniCS [4]. We have performed 20 numerical simulations to investigate the characteristics of the convection pattern for different values of the clathrate cap thickness and the grain size.

3. Results

We investigate the effect of the clathrate cap on the convection pattern in Titan's ice crust by comparing the results of simulations with h_c=0 and 9 km. In both cases, the grain size is 1 mm. Figure 1 shows the obtained average temperature profiles. For a pure ice layer (h_c=0 km, left), convection occurs in a stagnant lid regime with h_{sl}=42 km (cyan box). The inclusion of a 9 km thick layer of low conductivity clathrates (right) reduces the thickness of the stagnant lid to 15 km and thus brings warmer material much closer to Titan's surface. The presence of clathrates also increases the temperature of the convective interior (T_c) therefore reducing the temperature contrast at the hot thermal boundary layer (ΔT is smaller by $\sim$3 K when a 9 km clathrate cap is included). As a result, the buoyancy of warm ice at the ocean interface decreases, the efficiency of convection diminishes, and significantly less heat is extracted from the ocean - the heat flux (red dashed lines) decreases from 13.1 mW m^{-2} without clathrates to 7.8 mW m^{-2} with 9 km of clathrates.

Figure 2 shows the heat flux that can be extracted by convection from the ocean for different grain sizes (viscosity) and indicates that it further decreases with increasing clathrate layer thickness. However, for the

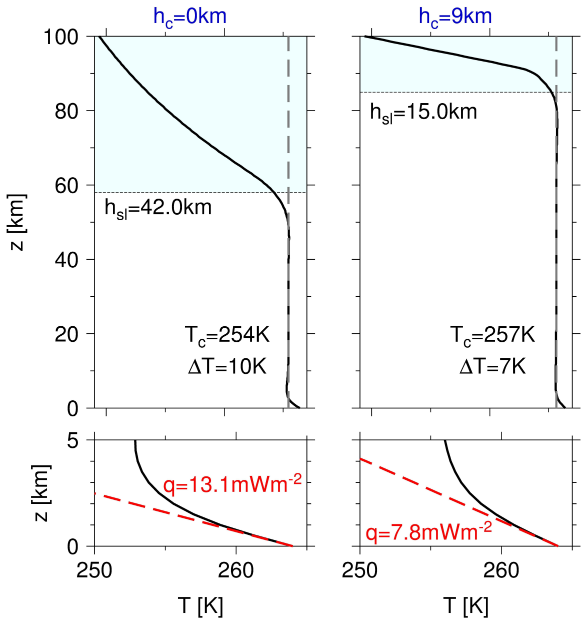

Figure 1: Horizontally averaged temperature profiles (black) for clathrate layer thickness of 0 (left) and 9 km (right). The grain size is 1 mm in both cases. The bottom panels give the detail of the bottom 5 km. The dashed lines show the temperature of the convective interior (T_c, gray) and the basal heat flux (red). The cyan box shows the stagnant lid.

range of viscosities and clathrates thicknesses investigated in the present study, it is still larger than the conductive heat flux (dashed line in Figure 2). Furthermore, comparison of the heat fluxes obtained from the numerical simulations with the estimated range of heat fluxes coming from Titan's silicate core assuming either CV or CI composition of the silicate fraction [1] (brown box in Figure 2) suggests that the presence of a clathrate layer ~7 to 13 km thick ensures the long term stability of Titan's deep water ocean without the necessity of additional dissipation or composition effects.

4. Conclusions

We investigated the effect of an insulating layer of methane clathrates on convection in Titan's ice crust. We found that the presence of clathrates dramatically reduces the thickness of the stagnant lid which allows the material from the ocean to get closer to the surface implying higher potential for the ocean-atmosphere exchange. The clathrate cap also increases the convective temperature which leads to a significant reduction of the heat flux that can be transferred by convection through Titan's ice crust. For a moderate range

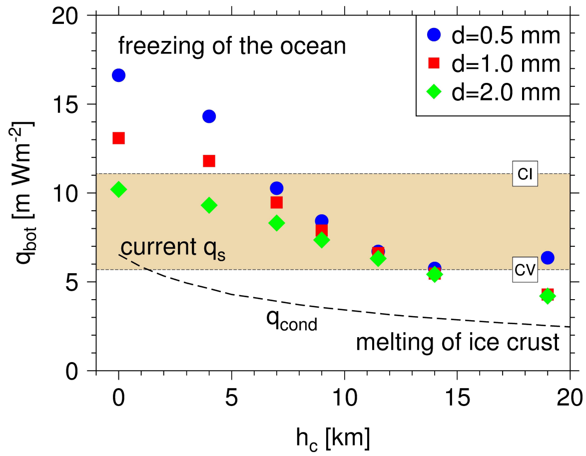

Figure 2: Effect of grain size (d, symbols) and clathrate layer thickness (h_c, x-axis) on the heat flux extracted from the ocean (q_{bot}). The brown rectangle gives the range of current heat flux from Titan's silicate core. The dashed line indicates the conductive heat flux through the crust.

of clathrate layer thicknesses (7-13 km), the heat flux obtained from numerical simulations is comparable to that predicted to be coming from Titan's silicate core which prevents further freezing of the ocean. The presence of a clathrate layer can thus explain the longterm stability of Titan's deep ocean. Similarly to the water cycle on the Earth which is important for mantle dynamics through the interaction with silicates, Titan's methane cycle controls the dynamics of its icy crust through the reaction with water ice and provides an explanation for the presence of a deep water ocean.

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References

[1] Braukmuller et al. (2018), *Geochim. Cosmochim. Acta*, **239**, 17–48. [2] Goldsby & Kohlstedt (2001), *JGR Solid Earth*, **106**, 11017–11030. [3] Hobbs & Hobbs (1974), *Ice Physics*, Clarendon Press. [4] Logg et al. (2012), The FEniCS Book. [5] Mousis et al. (2014), *Icarus*, **239**, 39–45. [6] Schneider et al. (2012), *Nature*, **481**, 58–61. [7] Sloan et al. (2007), *Clathrate Hydrates of Natural Gases*, CRC Press. [8] Stofan et al. (2007), *Nature*, **445**, 61–64. [9] Yung et al. (1984), *Astrophys. J. Suppl. Ser.*, **55**, 465–506.