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How long can layers last in the subsurface oceans of icy satellites?

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Abstract

Layering in the subsurface ocean is possible by the process of double-diffusive convection. The sustenance of layers may depend on the boundary conditions, which alter the chemical distribution and thus the balance between thermal and chemical buoyancies. If layers persist, they may inhibit heat and material transport through the subsurface ocean from the silicate interior to the base of the icy shell.

1. Introduction

Double diffusive convection occurs when the density of a fluid is influenced by at least two components, for example heat and composition, with different molecular diffusivities. Images of colored bands and disrupted terrains on Europa's surface, and measurements from Enceladus' plumes are potentially indicative of the composition of the subsurface ocean, which means that the ocean may consist of hydrated minerals (salts). If double-diffusive convection occurs in the subsurface ocean, it can cause dynamical layering within the subsurface ocean, in which convection does not go through the whole layer but within discreet sublayers. This is a vital mechanism that might have profound consequences on the heat transport from the rocky interior to the surface through the ocean. Layers may prevent upward transport of heat and material from the silicate seafloor to the bottom of the icy shell, as hypothesized by previous studies of subsurface oceans [1]. What controls the formation of layers, and the duration of their existence? We model the evolution of the subsurface ocean with different boundary conditions to address these questions.

2. Layering from double-diffusive convection in the subsurface ocean

In a double-diffusive convection system, the compositional density difference may provide an additional driving or restoring force to thermal convection. The chemical diffusivity is usually orders of magnitude smaller than the thermal diffusivity, which means temperature of the perturbed fluid is adjusted much more rapidly to its surroundings than the concentration, such that the small diffusivity acts to preserve the concentration of the fluid. If the destabilizing or driving force is dominant, convection is considered "supercritical"; otherwise it is "subcritical". Double-diffusive convection can take place even if the net-density stratification is stable. Under subcritical conditions, since the driving and stabilizing forces act on the fluid on different timescales, convection can still occur even if linear theory predicts stability.

Depending on the distribution of temperature and salts, double-diffusive convection can be categorized into different regimes. When the colder and compositionally lighter (or less saline) fluid overlies a hotter and denser fluid, the temperature is the destabilizing force whereas the composition is the stabilizing force. This regime is termed the "diffusive" regime. In the diffusive regime under subcritical conditions, layers are known to form in a self-organized manner as they can evolve from a gradient without imposing a prior stratification of material or temperature. Layer formation has long been recognized for parts of the Earth's ocean [2], and it is believed to happen in magmatic system [3].

We study this phenomenon by performing numerical calculations using a finite volume code for double-diffusive convection in finite Prandtl number, where the chemical constituent is treated in a field approach, meaning a further advection/diffusion equation for the constituent is solved.

3. Can layers sustain in the subsurface ocean?

In a non-linear system, the initial condition has an important role in the evolution. We initialize our system with a concentration that increases with depth, and a cold or warm uniform temperature (in our setting the hot initial temperature would be a symmetrical case of the cold start). The temperatures on the top and bottom boundaries and set to be cold and hot respectively. We try out different types of compositional boundary conditions: one is a closed system with no salt fluxes, and the other having a fixed low concentration on the top boundary and high concentration on the bottom boundary allowing salt fluxes to go in and out. We have previously demonstrated that in a system with no salt fluxes, the layers are not stable and can eventually merge and become well-mixed [4]. However when salt is allowed to be replenished, the initial growth of the layers is significantly prolonged (Fig. 1, left figures), as does the stage where convecting sublayers are developed (Fig. 1, right figures).

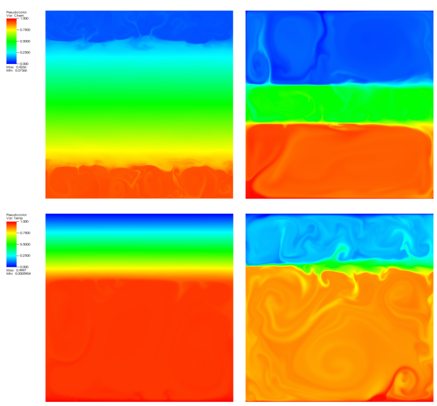

Figure 1: Snapshots of the initial growth of layers (left column) and the convecting sublayers (right column) for the initially cold (top row) and the initially warm (bottom row) cases.

The subsurface ocean likely has compositional changes from melting of the icy shell and water-rock interactions. Are there any conditions, for example with changing temperatures and composition at the boundaries, in which the layers can exist for a long time? Can the layers sustain for a substantial part of the moon's history? How are these individual sublayers affected by systematic properties and boundary conditions? What are the depths of the layers? Do the numbers and depths of these sublayers depend on the depth of the subsurface ocean, or is the layer growth timescale a local property that is independent of the entire depth? These questions constitute a fundamentally new aspect of layer growth and merging in double-diffusive research. We will discuss these problems and their implications on the role of subsurface ocean layering in the thermal evolution of the icy

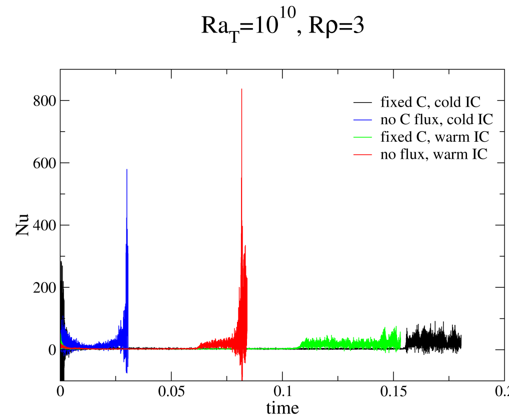

Figure 2: Time evolution of heat flux (Nu, non-dimensional) under different initial and boundary conditions. The heat flux becomes statistically steady as the first layers emerges from the boundaries, thinning the conductive part (sublayer) of the cell (left figures in Fig. 1). When sublayers merge, or when the conductive sublayer starts to convect, the fluctuation in heat flux increases ($t \sim$0.11 in the green case, $t \sim$0.16 in the black case, right figures in Fig. 1). The heat flux surges when the all layers merge and the system becomes well-mixed ($t \sim$0.03 in the blue case, $t \sim$0.08 in the red case.)

moons.

Acknowledgements

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References

[1] Vance, S., and Brown, J.: Layering and double-diffusion style convection in Europa's ocean, Icarus, 177(2), pp. 506 - 514, 2005.

[2] Fernando, H. J. S.: Oceanographic implications of laboratory experiments on diffusive interfaces, Journal of Physical Oceanography, 19(11), pp. 1707 - 1715, 1989

[3] Martin, D., Griffiths, R. W., and Campbell, I. H.: Compositional and thermal convection in magma chambers, Contributions to Mineralogy and Petrology, 96(4), pp. 465 - 475, 1987

[4] Wong, T., Hansen, U., Wiesehöfer, T., McKinnon, W. B.: Layer formation in Europa's subsurface ocean by double-diffusive convection, European Planetary Science Congress, September 2018, Berlin, 2018.