LAYER FORMATION AND EVOLUTION IN EUROPA'S SUBSURFACE OCEAN BY DOUBLE-DIFFUSIVE CONVECTION. T. Wong[1], U. Hansen[1], T. Wiesehöfer[1], S. Stellmach[1], W. B. McKinnon[2], [1]Westfälische Wilhelms-Universität Münster, Münster, Germany (t.wong@uni-muenster.de), [2]Washington University in St. Louis, St. Louis, MO, USA.

Introduction: The existence of Europa's subsurface ocean is suggested by the induced magnetic fields by Galileo and recent images by Hubble Space Telescope. Colored bands and disrupted terrains on the surface are enhanced in hydrated minerals, potentially indicative of the composition of the subsurface ocean. These observations invoke various hypotheses of how materials are being transported from the seafloor to the surface by hydrothermal plumes, and raise questions on heat transfer. Previous studies assessed the occurrence of double-diffusive convection as a possible mechanism affect heat and material transport by analyzing the stability of the subsurface ocean mainly based on linear stability [1, 2]. However the onset of convection predicted by linear theory has been shown to be inadequate for the non-linear behaviour of the fluid from laboratory and numerical experiments [3, 4].

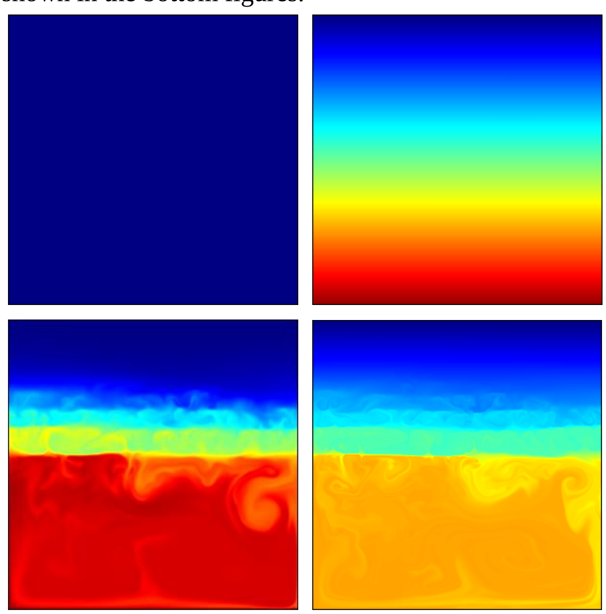
We perform numerical simulations of double-diffusive convection to test the hypothesis that the heat and material can be transported from the interior through the subsurface ocean to the base of the icy shell, and ultimately expressed and posited on the surface. We observe layer formation and its subsequent evolution in the subsurface ocean.

Double-diffusive convection: Double-diffusive convection is a mixing process driven by the difference in thermal and chemical diffusivities when two chemical constituents are present. 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. The compositional density difference may provide an additional driving or restoring force to thermal convection, depending on their distribution. The different combinations of driving and restoring forces with different diffusive timescales give rise to very different dynamics in the convecting layer.

We model this subsurface water layer in Europa subjected to a destabilizing temperature gradient (warm at the bottom, cold on top) and simultaneously to a stabilizing compositional (salt) distribution. This configuration favours the formation layers, which form in a self-organized manner as they can evolve from a gradient without imposing a prior stratification of material or temperature [5, 6]. Layers can buffer heat transport through the ocean. Depending on initial conditions and material properties as represented by the Rayleigh numbers, different numbers of layers will evolve. We test three possible initial conditions: (1) uniformly cold with a smooth compositional gradient; (2) uniformly warm with a smooth compositional gradient; (3) in both temperature and compositional gradients.

Numerical calculations are performed with a finite volume code for double-diffusive convection in finite Prandtl number, where the chemical constituent (salt or other hydrated minerals) is treated in a field approach, meaning a further advection/diffusion equation for the constituent is solved. The temperature difference across the depth of the layer are fixed, while there are no chemical fluxes into or out of the system. Varying concentration will be modeled in the future.

Layer formation and evolution in the subsurface ocean: The figure panel below presents an example system that is initially cold, compositionally light on top and heavy at the bottom. Top figures show the initial temperature (left) and concentration (right) field (red=high, blue=low). Layers develop in a self-organized manner from a concentration gradient, as shown in the bottom figures.



The dynamics of the double-diffusive system is governed by three dimensionless parameters: (1) the buoyancy ratio $R\rho = Ra_C/Ra$, the ratio of compositional Rayleigh number $Ra_C = \beta\rho g \Delta C d^3/\kappa_T\eta$, to that of the thermal $Ra = \alpha\rho g \Delta T d^3/\kappa_T\eta$, both of which are dimensionless measures of the driving or restoring forces, (2) Lewis number $Le = \kappa_T/\kappa_c$ the ratio of thermal diffusivity to chemical diffusivity, and (3) Prandtl number $Pr = \nu/\kappa_T$, the ratio of momentum diffusivity $\nu = \eta/\rho$ to thermal diffusivity. Other variables are the density ρ, gravity g, coefficient of thermal expansion α, and coefficient of compositional expansion or saline contraction β. Parameters of the system for this figure panel are $R\rho=3$, $Ra = 10^{10}$, Le=100, Pr=7.

The dynamics of layering is known to often exhibit intermittent behaviour. Individual layers can suddenly merge, increasing overall transport substantially. These intermittent changes in the layer pattern can potentially induce sudden large motion in the icy shell. The questions are how long would these layers last? How many layers can it develop? How deep are these layers? Do they depend on the entire depth of the ocean? Basic theoretical models were proposed for the terrestrial ocean [4, 7-9]. We discuss these theories in relation to our numerical simulations. As layers can buffer heat transport through the ocean, in this study we observe the evolution of the ocean and discuss its impact on the icy shell.

References: [1] Vance, S., and Brown, J. (2005) *Icarus*, *177(2)*:506-514. [2] Vance, S., and Goodman, J. (2009) In Pappalardo, R. T., McKinnon, W. B., and Khurana, K. K., editors, Europa, pages 459-482, The University of Arizona Press. [3] Huppert, H. E. and Moore, D. R. (1976) *J. Fluid Mech., 78(4):*821-854. [4] Fernando, H. J. S. (1989) *J. Fluid Mech., 209:*1-34. [5] Hansen, U. and Yuen, D. A. (1995) In Double-Diffusive Convection, edited by Brandt, A. and Fernando, H., AGU, Washington, D. C. [6] Radko, T. (2013) Double-diffusive Convection, Cambridge University Press, Cambridge, UK. [7] Fernando, H. J. S. (1987). *J. Fluid Mech., 182*:525-541. [8] Molemaker, M. J. and Dijkstra, H. A. (1997) *J. Fluid Mech., 331:*199-229. [9] Radko, T. et al. (2014). *J. Physical Oceanography, 44(5):*1285-1305.