Final Report: A Comparison of Simple Models of Deep Convection

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Introduction

Deep convection regions are associated with the downwelling limb of the Meridional Overturning Circulation (MOC) and to the (related) release of heat from the deep/mid-depth ocean. As such, these regions are an important component of our climate system and their variability has been linked to both past and future climate change. Yet, because of the multitude of time and space scales involved, accurate modeling of deep convection is still beyond the reach of even the highest resolution GCMs. An alternative approach to address the variability of convection is to employ an idealized model: a technique commonly employed to address the long-term variability of simplified ocean and atmosphere systems.

The idea behind an idealized model is to include (even if in parameterized form) all of the processes thought to be relevant to the problem addressed, but to simplify the description enough such that a solution can be found and the mechanisms understood. Up to now, idealized models of convection were basically box models that started with Stommel's (1961) model, followed by Welander's (1982) and, most recently, by that of Rahmstorf (2001). In these later models, the convection region is forced at the surface by some form of atmospheric variability while the lateral exchange, with the surrounding ocean, is parameterized via lateral fluxes of heat and salt. In all of these models, these lateral fluxes effectively amount to restoring boundary conditions, i.e. the convection region is continuously relaxed towards some fixed temperature and salinity profile.

Clearly there are two problems with this formulation, especially given that the goal is to understand what regulates the variability of deep convection. First, one has to question the extent to which these depth dependent lateral property fluxes are physically representative of the actual convection-region/surrounding-ocean exchange. Second, if one attempts to understand long-term variability one has to ask how changes in the convective activity will, in time, impact the transport of heat and salt towards the high-latitudes and hence introduce a time-variability in the restoring boundary condition. In this project, I have primarily concentrated on the first one of these problems, but have also set the stage for addressing the second.

Project Report

As part of this project I developed a revised simplified model for a deep convection system. Unlike previous models, this model is not limited to the convection region alone but also includes the surrounding boundary current. This boundary current supplies the convection region with the buoyant water (that seasonally restratifies the convection region) and with a pathway for the export of the dense water formed. It is assumed to be both buoyancy and wind-driven. The exchange between the two is parameterized as a function of the isopycnal slope between the convection region and the boundary current. This formulation is based on a number of recent modeling and analysis studies which highlight the role of the interior/boundary current exchange in determining the conditions in the convective region. When adapted to the Labrador Sea, the model is found to reproduce well both the observed mean (annually averaged) conditions as well as the seasonal cycle (see Figure). Its ability to represent interannual variations is shown in a `shut-down of convection' simulation, where the model is compared to data from the Labrador Sea from 1968 to 1972, when the passage of the Great Salinity Anomaly contributed to the shutdown of convection (see Figure).

The model provides a simple, explicit tool with which to relate MOC and thermohaline circulation relevant parameters to convection. It shows that the conditions in the convective basin are a function of the ability to exchange properties with the boundary current. This exchange, in turn, is a time-dependent parameter which questions the use of fixed boundary conditions in the earlier models. These results are now accepted in the Journal of Physical Oceanography.

The next step is to close the model by attaching a simplified representation of the larger scale ocean. This will allow the variability exported by the convection region to feed back into convection, and hence allow us to explore possible amplification or damping effects. I am currently working on this extension with A. Levermann and S. Rahmstorf, from the Potsdam Institute for Climate Impact Research (PIK) in Germany, who were amongst the designers of an earlier, idealized model of convection and who are actively working on the variability of the MOC. As part of this project I was able to spend a week at PIK, where I presented these new results. Together we outlined a strategy for the theoretical model's extension and devised a number of experiments, to be conducted with PIK's reduced complexity climate model, to test some of the findings of this new model.

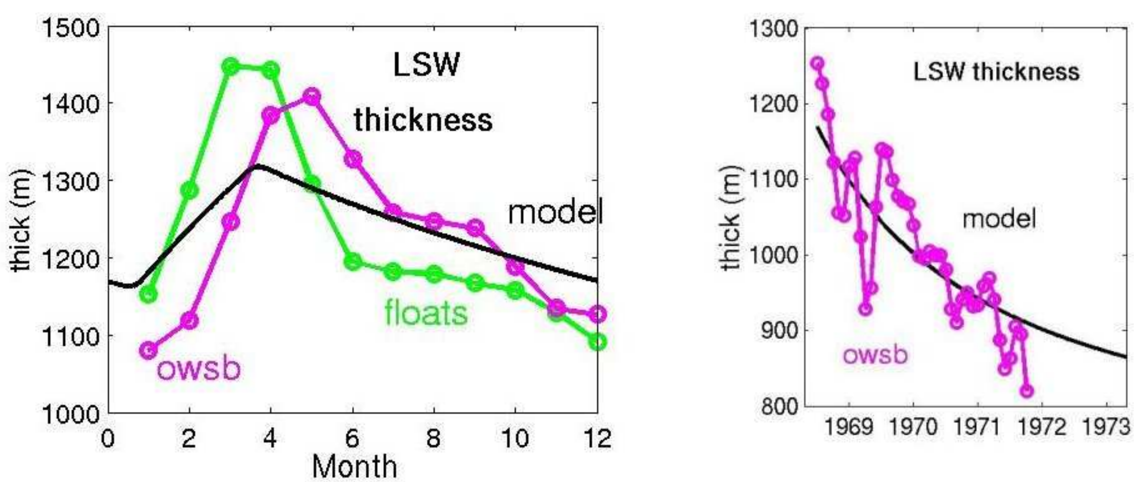

Figure: Left --- model's seasonal cycle versus data from the Labrador Sea (1964-1974, magenta and 1996-2000, green). Right --- model representing convection shutdown versus data from the Labrador Sea (1969-1972).

Publication resulting from this project:

Straneo F., 2005: On the connection between dense water formation, overturning, and poleward heat transport in a convective basin. *Journ. Phys. Ocean.,* accepted 08/05.