Numerical Simulations of double-diffusive Processes in Oceans

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1 Introduction

The ocean is mostly stratified with light water overlying dense water. But, double-diffusive processes can erode this statically stable stratification. Double-diffusion is a concequence of the two dynamically active scalars temperature (T) and salinity (S) having molecular diffusivities that differ by two oders of magnitude.
There are two main types of double-diffusive processes in the ocean:

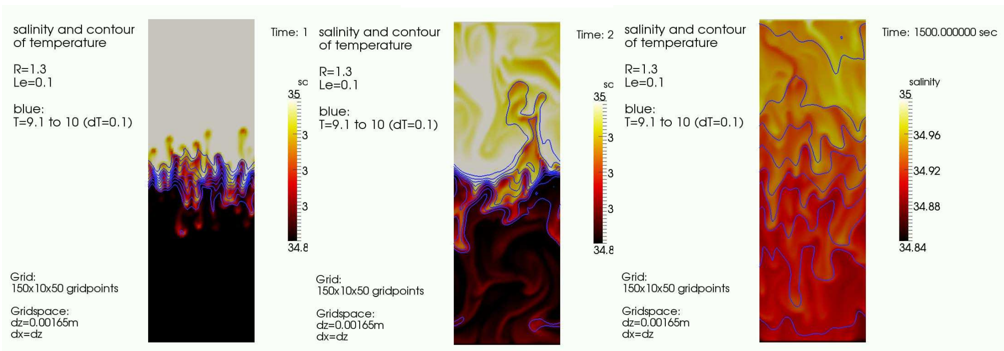
1. **Saltfingering:** warm and saline water overlies cold and fresh water. The vertical salinity gradient tends to destabilize and the temperature gradient stabilizes the water column (e.g. Tyrrhenian Sea, Caribbean Sea)
2. **Semiconvection:** cold and fresh water overlies warm and saline water. The vertical salinity gradient stabilizes and the temperature gradient tends to destabilize the water column (e.g. in the Arctic, underneath melting sea ice).

Saltfingers and Semiconvection are also reported in different classes of regimes like big helium stars, liquid metal, gas tanks, meromimic lakes, etc. Despite to the small scale of molecular diffusivities, these processes cannot be neglected and enlarge the vertical transport of temperature and salinity.

Double-diffusive processes are simulated with the non–hydrostatic finite–volume code of the Massachusetts Institute of Technology general circulation model (MITgcm) [1]. Several **D**irect **N**umerical **S**imulations of 2D and a 3D problem provide estimates of turbulent fluxes of heat and salinity.
Left and mid posterside: Simulations with 50×150 gridpoints with fixed boundarys in temperature and salinity, $\tau = 0.1$ and $\Delta z = 0.00165$ m. Estimating the effective diffusivities of temperature and salinity by saltfinger induced turbulent transports.
Right posterside: In 3D we used 50^3 gridpoints and Lewis Number $\tau = 0.1$, while the 2D simulations were carried out with $512 \times 8 \times 512$ gridpoints and $\tau = 0.01$, $\tau = 0.1$ respectively. Pointing out the structure of Saltfingers.

2 Saltfingers merging layers

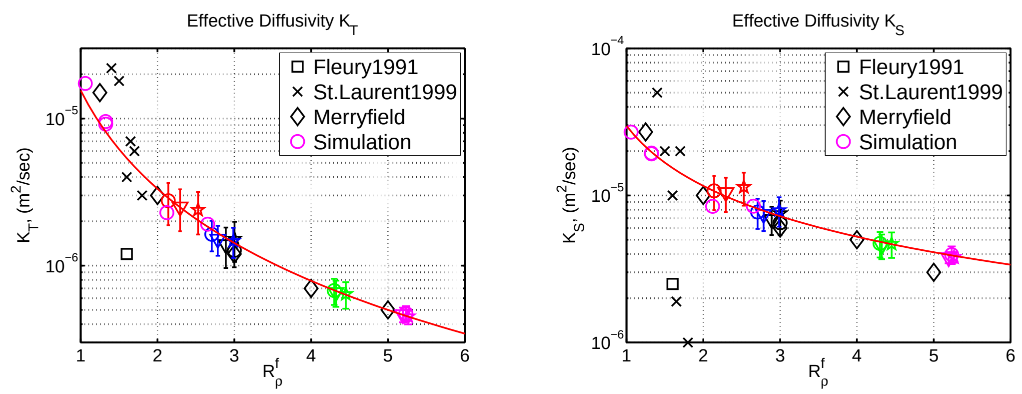
The stability of the water column following linear theory (e.g. [2]) is preserved, but because of the non–linearity of the equations **saltfingers** develop from local instability at the initially sharp density interface (left). Effective diffusivities are estimated before turbulent mixing appear. **Turbulent mixing** (middle) by growing instabilities with chaotic and not predictable processes. **Equilibrium state** (right) with vertical transport by saltfingers as result of turbulent mixing. Effective diffusivities are calculated by an average over long time period.



Keep in Mind: Mixing and vertical transport of temperature and salinity is an effect, depending only on molecular diffusivity.

3 Effective Diffusivities

The **first generation of Saltfingers**, before turbulent mixing arise, gives an idea for the potential of effective diffusivities K_T and K_S. These values result from maximum fluxes and are also compareable to ocean data.
Saltfingers of second generation result in an equilibrium state. Averaging over long time period shows mean effective diffusivities (colored marks with errorbars) which fit perfectly into literature values.

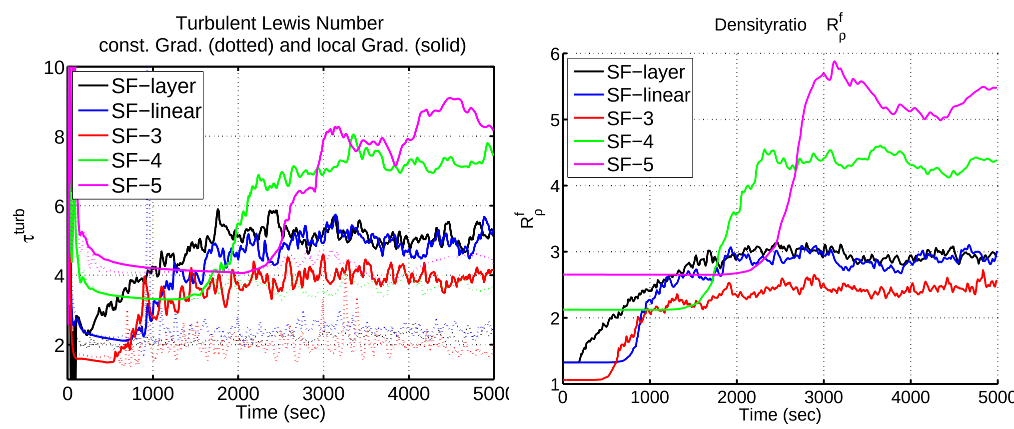


4 Semiconvection versus Saltfingers

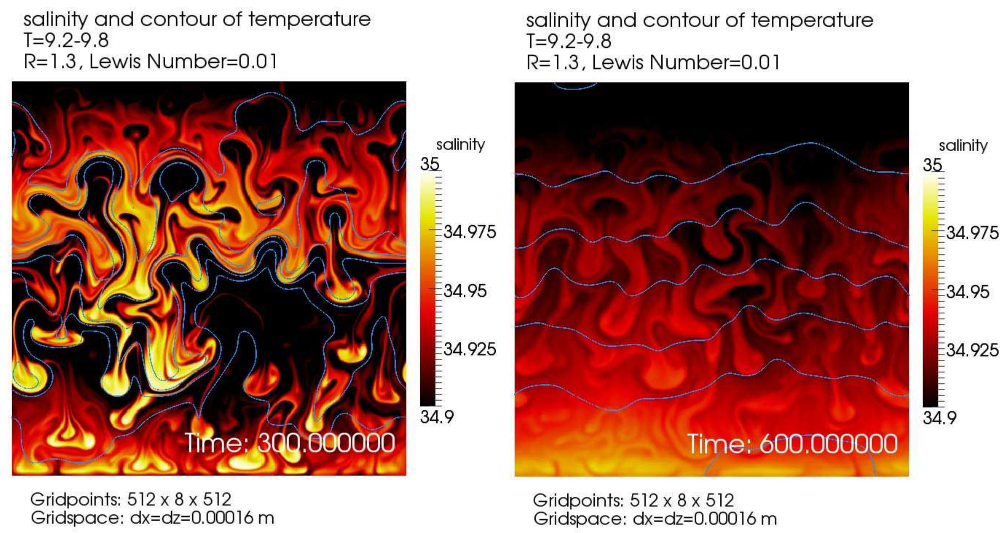
Semiconvection produce **oscillating** structures and should be a powerful mixing component like Saltfingers. But, DNS could not support this effect very well as linear theory promise.
Nevertheless, there are compareable simulations of Saltfingers and Semiconvection carried out by DNS (AWI-Bremerhaven) and LES (MPA-Garching) methods.
Thermohaline steps, observed in tropical and mediterranean regions (probably by Saltfingers) are much more larger ($10 - 100$ m) than those, supposed by Semiconvection in arctic and deep sea regions ($0.5 - 5$ m).

5 Turbulent Lewis Number and Stability

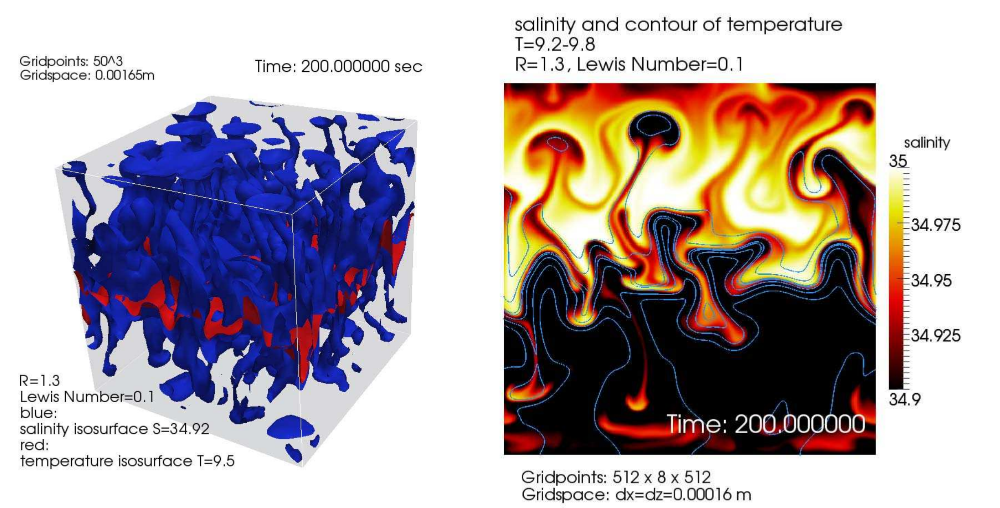
Turbulent Lewis Number described by the ratio of effective diffusivities $\mathcal{T} = \frac{K_S}{K_T}$, scale the parameterized temperature flux. The increase of stability $R_\rho^f = \frac{\alpha T_z}{\beta S_z}$ is one effect of saltfingers.



6 Turbulent and Diffusive Regime:



7 Compare 3D- and 2D- Simulation of Saltfingers



8 Observations and Conclusions

The release of potential energy by diffusion of heat produdces much bigger effective diffusivities of salinity than of temperature. Fluxes obtained from **saltfingering must be included** when thermohaline steps are considered.
Different molecular Lewis Numbers lead to different structures of the saltfingers, but seems **not to influence** the mean turbulent fluxes very much. Resolving the molecular Lewis Number is one of the most difficult problem. The Experiments suggest that 2D simulations are sufficient for estimating the effective transport of temperature and salinity. To study the physics of the plumes 3D simulations are neccesary.

References

[1] **M**assachusetts **I**nstitute of **T**echnology **G**eneral **C**irculation **M**odel, http://mitgcm.org

[2] P.G. Baines and A.E. Gill, On thermohaline convection with linear gradients, J- Fluid Mech. vol.37, part 2, pp. 289-306, (1969)