Numerical simulation of double-diffusive Processes in Ocean and in Stars

Metstrm Meeting Berlin

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Aim of this work / open questions

- Understanding mixing processes in various double-diffusive regimes (star, ocean, coffeecup).
- What is the role of relevant dimensionless numbers according to mixing time-scales?
- How efficient is double-diffusive convection ? (power laws, $\kappa_{\rm eff}$)
- Is double-diffusive convection in liquid and gaseous regimes comparable ?

Saltfingers and Semiconvection

- Saltfingers occur when the **faster** diffusing component stabilizes and the **slower** diffusing component destabilizes
- Semiconvection occurs when the **slower** diffusing component stabilizes and the **faster** diffusing component destabilizes

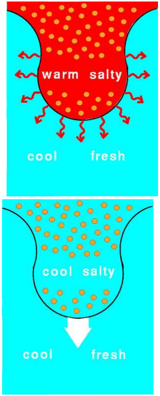
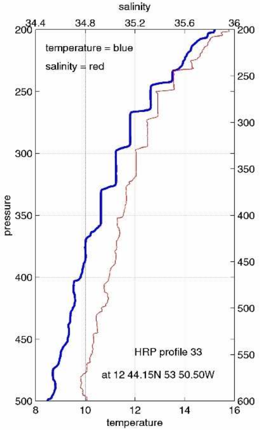


Figure: Saltfinger instability

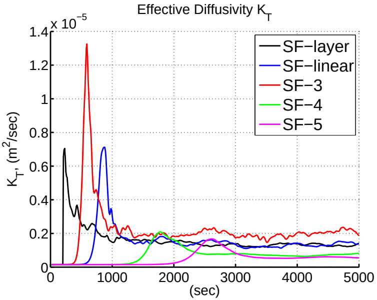
Characteristic of Saltfingers

- Internal instabilities by growing Saltfingers
- Saltfingers producing staircase structures in the ocean, probably.
- Interface in staircase is an area of vertical salinity transport by Saltfinger (resp. Semiconvection)

Staircases



Effective Diffusivities



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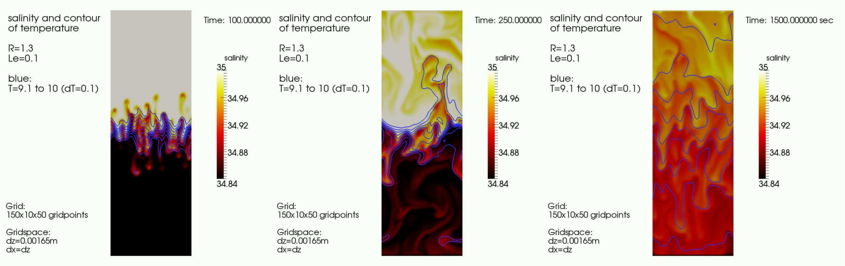
Turbulent mixing by Saltfingers



Arising Saltfingers (left), turbulent mixing (middle) and equilibrium state (right)

Results for Saltfingers and Semiconvection

- possible parametrisation for effective diffusivities

$$K_S = f(R_\rho^f, \gamma, \tau), \qquad \text{and} \qquad K_T = \frac{\gamma}{R_\rho^f} K_S$$

- estimated effective diffusivities are compareable with measurements and labor experiments of Saltfingers
- Semiconvection leads to stable stratification (see below)

Semiconvection

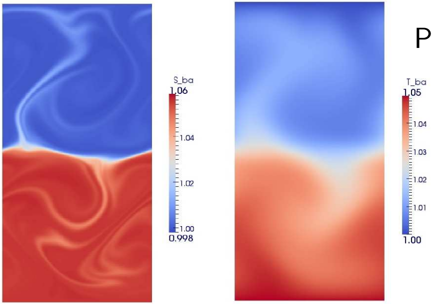


Figure: Semi-convective double layer simulation. (Salinity/Temperature)

Properties:

- 'stabilized convection' - counteracting concentration gradient
- Semiconvection leads to layering (Latte Machiatto)
- $\kappa_S \ll \kappa_T$
- $R_\rho = \frac{Ra_S}{Ra_T} > 1$
- σ and τ $[10^{-2} - 10^{1}]$

How do σ, τ, R_ρ and Ra_T influence the SC mixing process?

To answer this question 2D numerical simulations have been done. The influence of the initial parameter space is measured in terms of the Nusselt numbers Nu_T and Nu_S.

- non-dimensional approach for idealized water and gaseous regimes
- compressible / incompressible (Boussinesq approximation / fully explicit ideal gas)
- wide range of σ, τ, R_ρ and Ra_T
- Question 1: $Nu_T \sim Ra_T$ (power law)?
- Question 2: $Nu_T \sim Nu_S$?

Mathematical approach (Antares code)

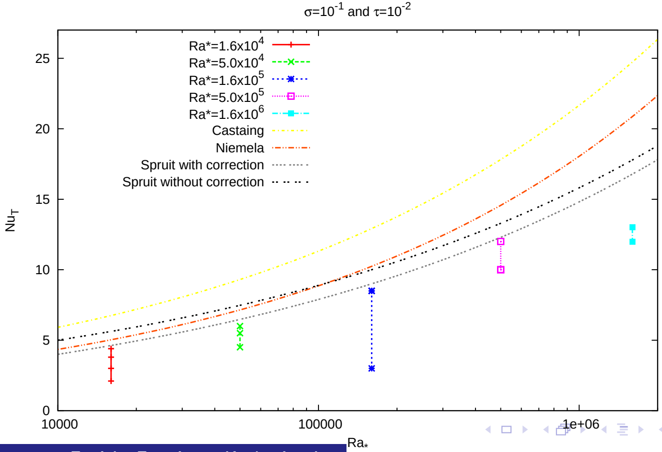
- Low Mach number solver for binary mixture equations (explicit and implicit)
- Gaseous SC firstly solved in characteristics with WENO 5th order.
- Time integration: TVD2, optional: Boussinesq equations solved with SDIRK (fixed point iteration)
- Numerically stable solutions on staggered grid for WENO and Poissonsolver. (**BiG**rid **M**arker **A**nd **C**ell)
- Parallelisation: Efficient Poisson solver based on Schur Complement method. Hybrid parallelisation (OpenMP and MPI).
- Local grid refinement

Physical outcome 1/2

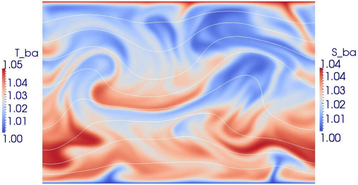
- Compressible and incompressible SC regimes are (numerically and physically) comparable as long as $H < H_P$.
- $Nu_S = \tau^{-1/2}(Nu_T - 1)$
- Stable multilayer simulations for $\sigma < 1$.
- An extrapolation into stellar relevant regime is valid (under the diffusion correction assumption) and has already been done (next slide).
- Next step: Direct layer formation, 3D.

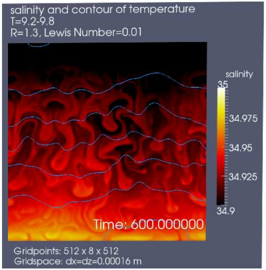
Physical outcome 2/2

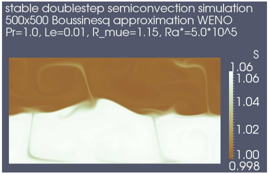
Modified power law: $Nu_T = (\sigma Ra_T)^{-0.25} + 1$
for $Ra_* = \sigma Ra_T < 10^6$ in the limit $R_\rho \downarrow 1$

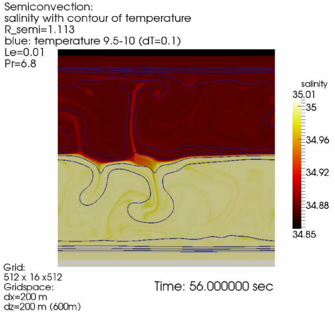


Comparison between Saltfingers and Semiconvection









Publications and Presentations

Theses:

T. Zweigle: Direkte Numerische Simulation von Salzfingern im Ozean

F. Zaussinger: Numerical simulation of double-diffusive convection (submitted)

Publications:

F. Zaussinger, H. Spruit: The mixing rate of Semiconvection (to be submitted to Astronomy & Astrophysics in Nov/Dec)

Cooperations

- Egbers / Harlander (BTU Cottbus)
- Behrens / Wirth and Horenko / Klein / Munz :
  Model intercomparison study. Test case: Bubble test case from Robert (1992)

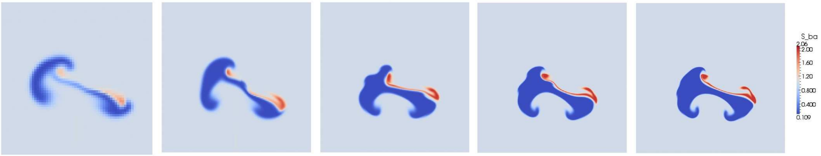


Figure: Saline bubble experiment for increasing resolution ($62^2 \longrightarrow 1000^2$)