Saltfingers

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Short Introduction to Saltfingers

- warm and saline water lies over cold and less saline water with density ratio R_ρ

$$1 \leq R_\rho = \frac{|\alpha|\partial_z \overline{T}}{\beta \partial_z \overline{S}} \leq \frac{\kappa_T}{\kappa_S}$$

with α = thermal expansion coefficient

β = saline contraction coefficient

T, S = temperature and salinity

$R_\rho < 1$ stratification is unstable
(not get confused with Semiconvection)

Definitions

Reynolds Average: $X = \overline{X} + X'$

Density ratio: $R_\rho = \frac{\alpha \partial_z \overline{T}}{\beta \partial_z \overline{S}}$

Lewis Number: $\tau = \frac{\kappa_S}{\kappa_T}$

Flux Ratio: $\gamma = \frac{\alpha \overline{w'T'}}{\beta \overline{w'S'}}$

Turbulent Fluxes: $\overline{w'X'}$

Why We Do Saltfinger Simulations

- Thermohaline staircases are a possible result from saltfingers (William Merryfield „Origin of thermohaline staircases“ (2000) , Timour Radko (2005))
- Saltfingers play an important role in mixing processes where double–diffusion occur
- Study the structure of saltfingers there are high resolved 3D–simulations necessary
- Resolve the Lewis Number $\tau = 0.01$

- Today there are a lot of different systems known where double–diffusion occur (e.g. massive He^3 stars, earth core, compositions of metals, coffee and milk, ...)[Turner 1985]
- These systems are compareable (e.g eddy size of turbulences in the ocean and stars both $\approx$ 1cm but convective scales are quiet different)

3D and $2\frac{1}{2}$D Saltfinger Simulations

Simulations with 512^3 and with $512x8x512$ gridpoints in a regular grid

Initial conditions:

Gridspace: $\Delta x = \Delta y = \Delta z = 160\mu$m

Lewis Number: $\tau = \frac{\kappa_S}{\kappa_T} = 0.01$

Density Ratio: $R_\rho \approx 1.3$

We have $\approx$ 170 sec modeltime of 3D–simulation and over 1400 sec modeltime of $2\frac{1}{2}$D–simulation

Mean Turbulent Fluxes, $\overline{w'T'}$ and $\overline{w'S'}$

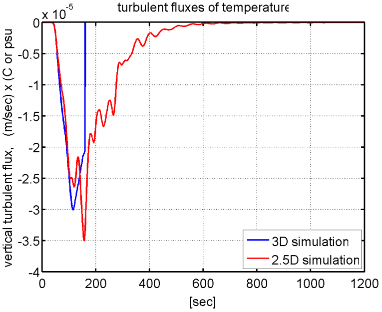


Abbildung: 3D and $2\frac{1}{2}$D simulation, tubulent flux of temperature

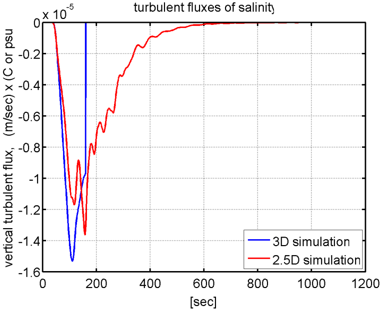


Abbildung: 3D and $2\frac{1}{2}$D simulation, turbulent flux of salinity

Fluxratio $\gamma = \frac{\alpha \overline{w'T'}}{\beta \overline{w'S'}}$

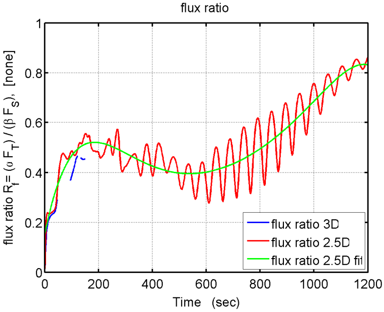


Abbildung: Flux Ratio of 3D and $2\frac{1}{2}$D simulation

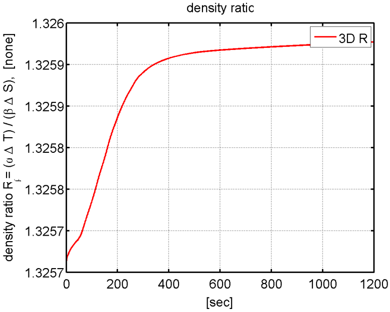


Abbildung: Density Ratio, 3D and $2\frac{1}{2}$D

Lewis Numbers $\tau = 0.01$ and $\tau = 0.1$?

Differences resulting from varied Lewis Numbers

$$\tau_1^{-1} = 100 \qquad \text{and} \qquad \tau_2^{-1} = 10$$

other initial conditions are identically ($R_\rho = 1.32$, ...)

Snapshot of Saltfingers with different Lewis Numbers

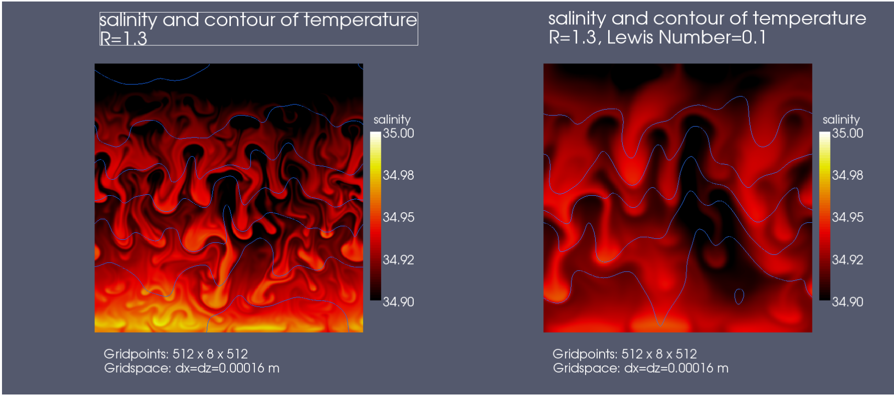


Abbildung: $\tau = 0.01, \ t = 500$sec

Abbildung: $\tau = 0.1, \ t = 500$sec

Turbulent Fluxes $\overline{w'T'}$ and $\overline{w'S'}$

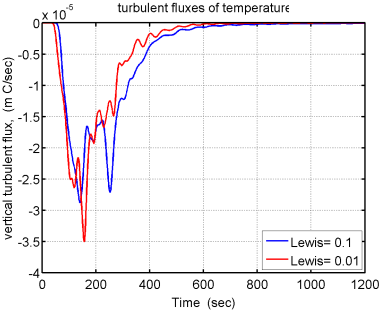


Abbildung: Turbulent fluxes of temperature

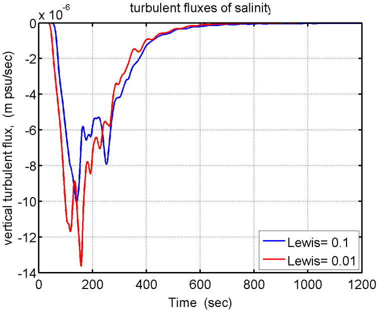


Abbildung: Turbulent fluxes of salinity

Flux Ratio $\gamma = \frac{\alpha \partial_z \overline{w' T'}}{\beta \partial_z \overline{w' S'}}$ and Density Ratio R_ρ

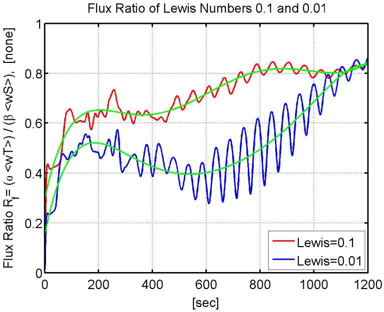


Abbildung: Flux Ratio

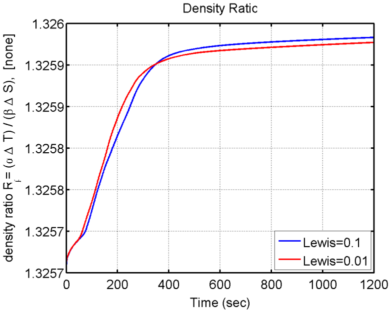


Abbildung: Density Ratio

Mean Values of Temperature and Salinity

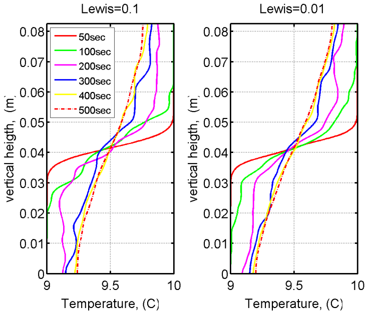


Abbildung: Mean temperature

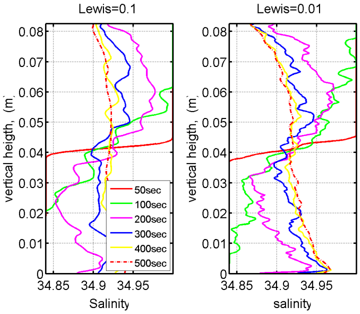


Abbildung: Mean salinity

Conclusions For Further Work

- 3D simulations are expensive
- Mean values between 3D– and $2\frac{1}{2}$D simulations do not differ signifficant
- For our case (estimate vertical fluxes) we can use $2\frac{1}{2}$D simulations for further work

Aims

- get an estimate of the vertical fluxes of heat and salinity
- find good initial coditions for simulations
- find the effective vertical diffusivity of heat and salinity
- e.g Merryfield found a parametrisation for the case of saltfingers like

$$K_S^f = 0.17 \times \frac{1 - \tau R_\rho}{R_\rho - \gamma}$$

where K_S^f is the effecitve diffusivity of salinity

Initial Conditions for $2\frac{1}{2}$D–Simulations

Initial conditions of simulations

- ${}^{1}R_{\rho} \approx 1.7$ ${}^{2}R_{\rho} \approx 1.07$
- ${}^{1/2}\sigma = \frac{\nu}{\kappa_T} = 7$ Prandtl Number
- $\tau = \frac{\kappa_S}{\kappa_T} = 0.01$ Lewis Number

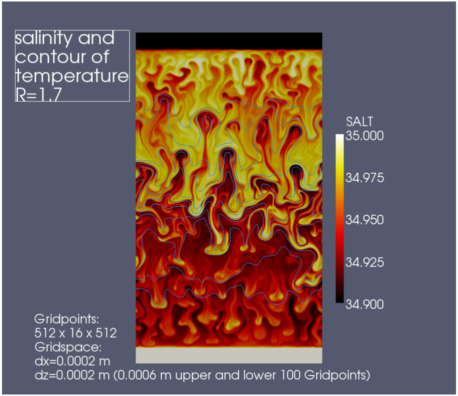
- use a stretched coordinate system in vertical direction with $\Delta z = 200\mu$ m ($\Delta z = 600\mu$ m upper and lower 100 gridpoints)
- use a damping layer to absorb vertical fluxes at the upper and lower boundaries

$512 \times 16 \times 512$	gridpoints
$0.1024 \times 0.0032 \times 0.1824$	m^3

Saltfingersimulation $R_\rho = 1.7$

salinity and contour of temperature

- $R_\rho = 1.7$
- fingerwidth about $d \approx 0.005$m



Saltfingers with $R_\rho = 1.7$ and $R_\rho = 1.07$

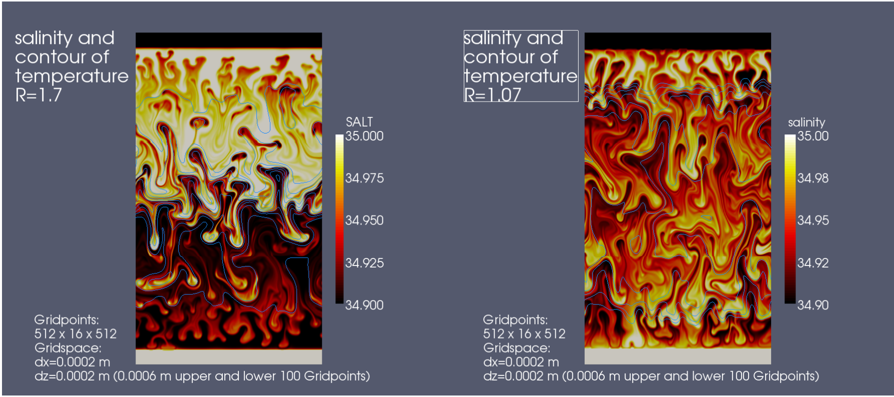


Abbildung: snapshot of salinity at modeltime $t = 400$

Abbildung: snapshot of salinity at modeltime $t = 400$

Mean Values of Temperature and Salinity

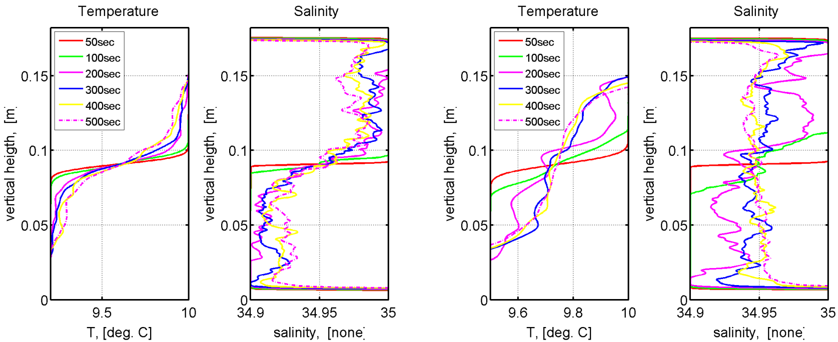


Abbildung: mean values of temperature and salinity with $R_\rho = 1.7$ (left side) and $R_\rho = 1.07$ (right side)

Mean Values of Temperature and Salinity

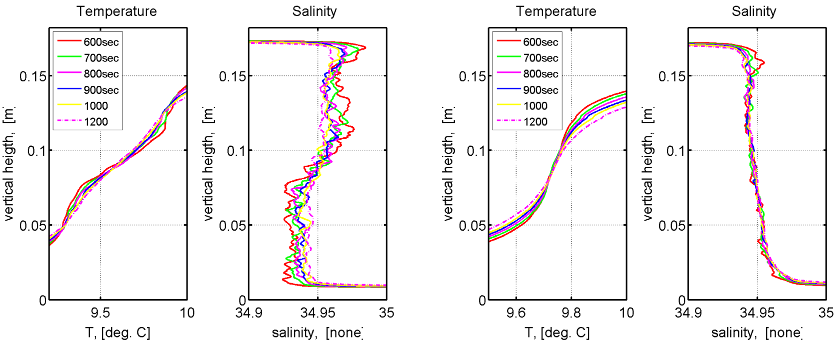


Abbildung: mean values of temperature and salinity with $R_\rho = 1.7$ (left side) and $R_\rho = 1.07$ (right side)

Density Ratio of Saltfingers

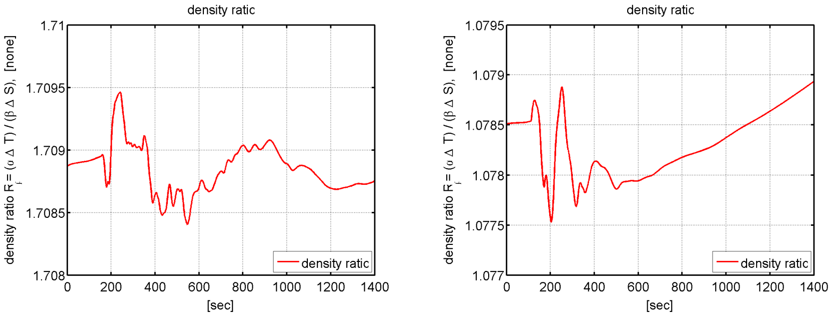


Abbildung: densityratio $R_\rho = \frac{\alpha \partial_{\mathbf{z}} \overline{T}}{\beta \partial_{\mathbf{z}} \overline{S}}$
left side $R_\rho = 1.7$, right side $R_\rho = 1.07$

Turbulent Fluxes

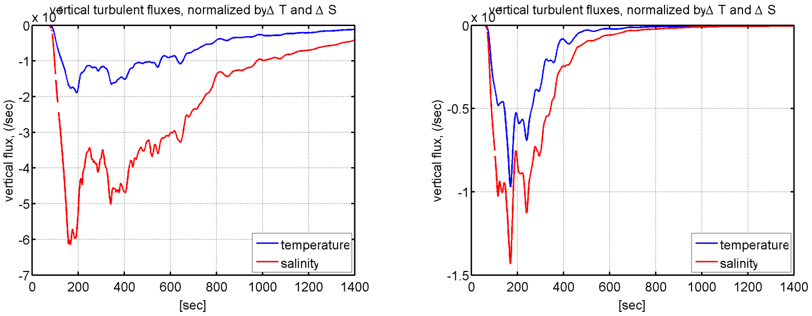


Abbildung: turbulent fluxes $\frac{\overline{w'T}}{\partial_z \overline{T}}$ $(\frac{\overline{w'S'}}{\partial_z \overline{S}})$
$R_\rho = 1.7$ (left side) and $R_\rho = 1.07$ (right side)

Buoyancy

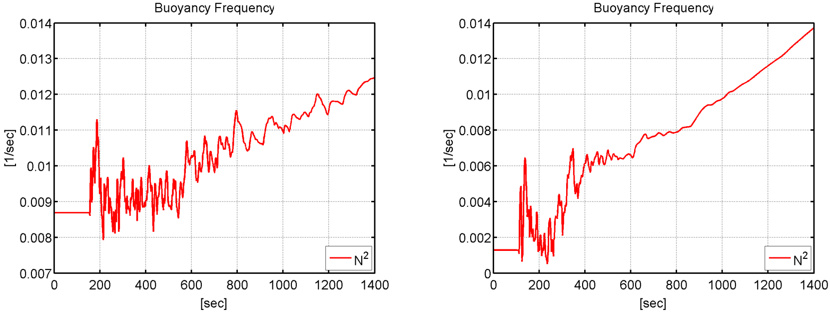


Abbildung: buoyancy $N^2 = -\frac{g}{\rho}\partial_z \rho$
$R_\rho = 1.7$ (left side) and $R_\rho = 1.07$ (right side)

Fingerwidth

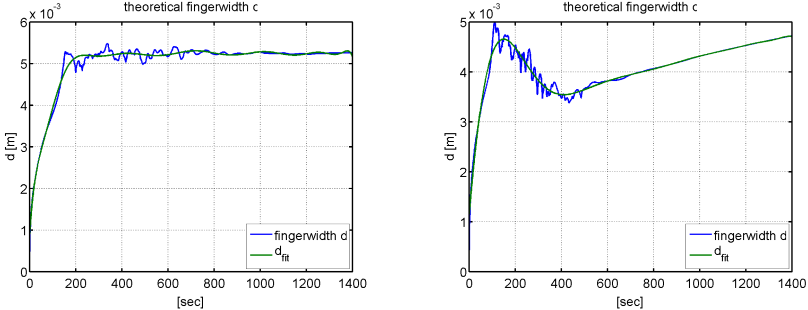
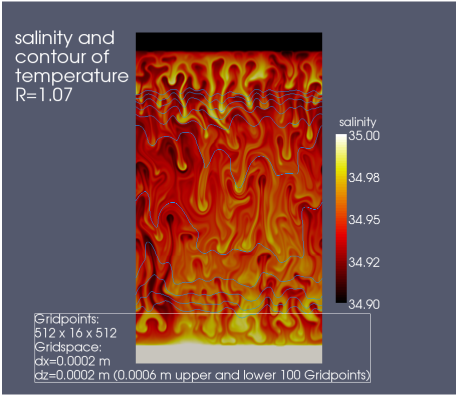


Abbildung: Fingerwidth $d^4 = \frac{\nu\kappa_{\boldsymbol{T}}}{g\alpha\partial_{\boldsymbol{z}}\overline{\overline{T}}}$
$R_\rho = 1.7$ (left side) and $R_\rho = 1.07$ (right side)

Simulation of Saltfingers

salinity and contour of temperature

- $R_\rho = 1.07$
- 512x16x512 Gridpoints
- fingerwidth about $d \approx 0.004 - 0.005$m



Unstable Case

salinity and contour of temperature

- $R_\rho = 0.6$
- $512 \times 16 \times 512$ Gridpoints

salinity and contour of temperature

Conclusions

- stability is allways preserved (except in $R_\rho = 0.6$ simulation)
- flux ratio $\gamma = \frac{\alpha \overline{w'T'}}{\beta \overline{w'S'}} \approx 0.5$
- ...

If we compare our data with the work from Shen (1997):

- similar fingerwidth: ≈ 0.5 cm
- $\tau_{shen}^{-1} = 80$ where $\tau_{awi}^{-1} = 100$
- higher grid resolution as Shen
- 3–dimensional not 2–dimensional
- Shen‘s simulation end before mixing begins and diffusive Saltfingers occur

Critical Points

- is our vertical domain wide enough?
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