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Double diffusion in Astrophysics and Oceanography Metstroem presentation Hannover

F. Zaussinger (MPA) and T. Zweigle (AWI)

23. July 2008

DD in Astrophysics and Oceanography

Compare the incomparable

Astrophysics - Semiconvection

Massive stars SC in massive stars - Preparation Simulations of SCZ

Oceanography - Saltfingers Simulations



Oceanography - Saltfingers

Compare the incomparable

Modelling double diffusive convection

2 gradients:

• Astro:
$$\nabla := \frac{\partial \ln T}{\partial \ln P}$$
, $\nabla_{\mu} := \frac{\partial \ln \mu}{\partial \ln P}$

2 diffusivities:

• Astro:
$$\kappa_{\tau}$$
, κ_{γ} , ν



Oceanography - Saltfingers

Compare the incomparable

Modelling double diffusive convection

2 gradients:

• Astro:
$$\nabla := \frac{\partial \ln T}{\partial \ln P}$$
, $\nabla_{\mu} := \frac{\partial \ln \mu}{\partial \ln P}$

• Ocean:
$$\nabla T = \frac{\partial T}{\partial z}$$
, $\nabla S = \frac{\partial S}{\partial z}$

- 2 diffusivities:
 - Astro: κ_τ, κ_γ, ν

• Ocean:
$$\kappa_{\tau}$$
, κ_{s} , ν



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Compare the incomparable

Structure of interest in Astrophysics

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Semiconvection:
He/Salt stabilizes, T destabilizes
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Compare the incomparable

Structure of interest in Oceanography

Saltfingers: T stabilizes, He/Salt destabilizes



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Compare the incomparable		
Comparable? YES!		

- Plasma and water are both fluids. Using (nearly) the same equations.
- $\blacktriangleright \ \frac{Le}{Pr} \approx \frac{1}{100}$
- > 2 gradients (He/T and Salt/T) for double diffusive convection.

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Comparable? YESI		

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- ▶ 2 gradients (He/T and Salt/T) for double diffusive convection.

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- saltfingers in stars: off center burning
- semiconvection in ocean: close to melting icebergs

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Massive stars

ASTROPHYSICS – SEMICONVECTION



Oceanography - Saltfingers

Massive stars

Structure of massive stars



• $M \ge 9M_{\odot}$, $9 * 2 * 10^{33}g \sim 3Mio * M_{earth}$



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Massive stars

Structure of massive stars



- $M \ge 9M_{\odot}$, $9 * 2 * 10^{33}g \sim 3Mio * M_{earth}$
- convective core, radiative envelope

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Massive stars

Structure of massive stars



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- central hydrogen burning (T ~ 40MioK)



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Massive stars

Structure of massive stars



- $M \ge 9M_{\odot}$, $9*2*10^{33}g \sim 3Mio*M_{earth}$
- convective core, radiative envelope
- central hydrogen burning (T ~ 40MioK)
- semiconvection zone is a layer "between" core and envelope
- SCZ is left behind by shrinking core (during evolution)

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Massive stars

Semiconvection Zone in massive stars



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Massive stars

Stability and instability criterions

$$\blacktriangleright \nabla_{\mu} := \frac{\partial \ln \mu}{\partial \ln P}, \ \nabla_{ad} := \left(\frac{\partial \ln T}{\partial \ln P}\right)_{ad}, \ \nabla := \frac{\partial \ln T}{\partial \ln P}$$



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Massive stars

Stability and instability criterions

•
$$\nabla_{\mu} := \frac{\partial \ln \mu}{\partial \ln P}$$
, $\nabla_{ad} := (\frac{\partial \ln T}{\partial \ln P})_{ad}$, $\nabla := \frac{\partial \ln T}{\partial \ln P}$
• $R_{\mu} = \frac{\nabla_{\mu}}{\nabla - \nabla_{ad}}$ stability parameter



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Massive stars

Stability and instability criterions



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Massive stars

Stability and instability criterions

$$\begin{array}{l} \nabla_{\mu} := \frac{\partial \ln \mu}{\partial \ln P}, \ \nabla_{ad} := (\frac{\partial \ln T}{\partial \ln P})_{ad}, \ \nabla := \frac{\partial \ln T}{\partial \ln P} \\ R_{\mu} = \frac{\nabla_{\mu}}{\nabla - \nabla_{ad}} \ \text{stability parameter} \\ N^2 = g H_p^{-1} (\nabla_{\mu} - (\nabla - \nabla_{ad})) \ \text{Brunt-Väisälä frequency} \\ \\ \hline \frac{\text{semiconvection, if:} \ \nabla - \nabla_{ad} > 0 \ \nabla_{\mu} > 0 \ R_{\mu} > 0}{\text{stable:} \ N^2 > 0 \ \nabla_{\mu} > \nabla - \nabla_{ad} \ R_{\mu} > 1} \\ \hline \text{unstable:} \ N^2 < 0 \ \nabla_{\mu} < \nabla - \nabla_{ad} \ R_{\mu} < 1 \end{array}$$

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SC in massive stars - Preparation

- ▶ Prandtl number: $Pr = \sigma = \frac{\nu}{\kappa \tau} = \frac{\text{kinematic viscosity}}{\text{thermal diffusivity}}$
- \blacktriangleright water \sim 7 , mercury \sim 0.015 , in stars \ll 10^{-6}



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- ▶ small Pr = heat diffuses very quickly compared to the velocity

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- Lewis number: $Le = \tau = \frac{\kappa_{He}}{\kappa_{T}} = \frac{\text{mass diffusivity}}{\text{thermal diffusivity}}$

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SC in massive stars - Preparation

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- small Pr = heat diffuses very quickly compared to the velocity
- Lewis number: $Le = \tau = \frac{\kappa_{He}}{\kappa_{T}} = \frac{\text{mass diffusivity}}{\text{thermal diffusivity}}$
- in stars $Le \ll Pr \ll 1$, $\frac{Le}{Pr} \approx \frac{1}{100}$ and $\kappa_{He} \ll \nu \ll \kappa_T$

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Simulations of SCZ		
Simulation 1		

► Grid: 160 vertical x 240 horizontal \cong 1500km x 2250km $\cong \triangle x = 9,43$ km, $\triangle t = 5 * 10^{-3}$ scrt

total simulation time: 33min

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- LES

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Simulations of SCZ

Simulation 1 - stable - mass-fraction He and x-momentum



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Simulations of SCZ		
Simulation 2 - unstable		

► Grid: 160 vertical × 240 horizontal \cong 1500km × 2250km $\cong \triangle x = 9,43$ km, $\triangle t = 5 * 10^{-3}$ scrt

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Simulations of SCZ

Simulation 2 - unstable – mass-fraction He and x-momentum



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OCEANOGRAPHY – SALTFINGERS



Oceanography – Saltfingers

- ► Thermohaline staircases are a possible result of Saltfingers.
- ► Double-diffusion can have an effect on large scale results.

(see Merryfield et al 1999, Journal of Phys. Oceanography)



Oceanography – Saltfingers

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Mediterranean outflow into Atlantic



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- Mediterranean outflow into Atlantic
- River mouthes (Po outflow into Adriatic sea)

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Oceanography – Saltfingers

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- Mediterranean outflow into Atlantic
- River mouthes (Po outflow into Adriatic sea)
- Tropical western Atlantic

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Oceanography – Saltfingers

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(see Merryfield et al 1999, Journal of Phys. Oceanography) Saltfingering occurs e.g.:

- Mediterranean outflow into Atlantic
- River mouthes (Po outflow into Adriatic sea)
- Tropical western Atlantic
- Polar regions (Semiconvection)

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Oceanography - Saltfingers

Simulations

Ocean Model and Data



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Simulations

Ocean Model and Data

•
$$\sigma = \frac{\nu}{\kappa_{\tau}} \approx 7$$
 (Prandtl number)



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Simulations

Ocean Model and Data

•
$$\sigma = \frac{\nu}{\kappa_T} \approx 7$$
 (Prandtl number)
• $\tau_{ocean} = \frac{\kappa_T}{\kappa_S} = 100$ (Lewis number)



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Simulations

Ocean Model and Data

•
$$\sigma = \frac{\nu}{\kappa_T} \approx 7$$
 (Prandtl number)

•
$$\tau_{ocean} = \frac{\kappa_T}{\kappa_S} = 100$$
 (Lewis number)

•
$$Ra \sim 10^5$$
 (Rayleigh number)



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Simulations

Ocean Model and Data

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Simulations			
Simulation			
2D–Simulation of Salt	fingers		
5	12 imes 1024	Gridpoints	

 16.5×33 cm^2



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Simulations			
Simulation			
2D–Simulation of Saltfinge	rs		
512 × 16.5 ×	1024 33 с	Gridpoints cm ²	

• $\Delta T = 1^{\circ}C$, $\Delta S = 0.33$



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Simulations			
Simulation			
2D–Simulation of Saltfing 512 × 16.5 ×	ers 1024 33	Gridpoints cm ²	

$$\Delta T = 1^{\circ}C, \ \Delta S = 0.33$$

•
$$\sigma = 6.2, \ \tau_{ocean} = 100$$

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Simulations			
Simulation			
2D–Simulation of S	511 × 1024 512 × 1024 16.5 × 33	Gridpoints cm ²	

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• $\Delta T = 1^{\circ}C$, $\Delta S = 0.33$

•
$$\sigma = 6.2, \tau_{ocean} = 100$$

• time \approx 90 sec with $\Delta t = 0.001$ sec

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Simulations		
Simulation		
2D–Simulation of Saltfinge	rs	
512 imes	1024 Gridpoints	
16.5 $ imes$	33 cm ²	
	2	

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- ▶ $\sigma = 6.2, \tau_{ocean} = 100$
- time \approx 90 sec with $\Delta t = 0.001$ sec

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Simulations



Figure: t = 30 sec

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Simulations



Figure: t = 40 sec

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Simulations



Figure: t = 50 sec

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Simulations



Figure: t = 60 sec

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Simulations

Running Simulation

3D–Simulation



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Simulations

Running Simulation

3D-Simulation

$\begin{array}{ll} 512\times512\times512 & \mbox{Gridpoints}\\ 8.25\times8.25\times8.25 & \mbox{cm}^3 \end{array}$

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Simulations

Running Simulation

3D-Simulation

$\begin{array}{ll} 512\times512\times512 & \mbox{Gridpoints}\\ 8.25\times8.25\times8.25 & \mbox{cm}^3 \end{array}$

• $\tau_{ocean} = 100, \ \sigma \approx 6.77$



Saltfingers

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Simulations

Running Simulation

3D-Simulation

 $\begin{array}{ll} 512\times512\times512 & \mbox{Gridpoints}\\ 8.25\times8.25\times8.25 & \mbox{cm}^3 \end{array}$

•
$$\tau_{ocean} = 100, \ \sigma \approx 6.77$$

•
$$\Delta T = 1^{\circ}C$$
, $\Delta S = 0.17$



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Simulations		

Running Simulation

3D-Simulation

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•
$$\tau_{ocean} = 100, \ \sigma \approx 6.77$$

•
$$\Delta T = 1^{\circ}C$$
, $\Delta S = 0.17$

• estimated time pprox 80 sec with $\Delta t = 0.001$ sec

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Simulations		

Running Simulation

3D-Simulation

 $\begin{array}{ll} 512\times512\times512 & \mbox{Gridpoints}\\ 8.25\times8.25\times8.25 & \mbox{cm}^3 \end{array}$

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	Astrophysics - Semiconvection

▶ The intention are simulations with

$1024 \times 1024 \times 1024 \qquad \text{Gridpoints}$



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Simulations		
Next Steps		

The intention are simulations with

$1024 \times 1024 \times 1024$ Gridpoints

Test existing models



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Simulations		
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