Modelling of shelf water cascades on the continental slope

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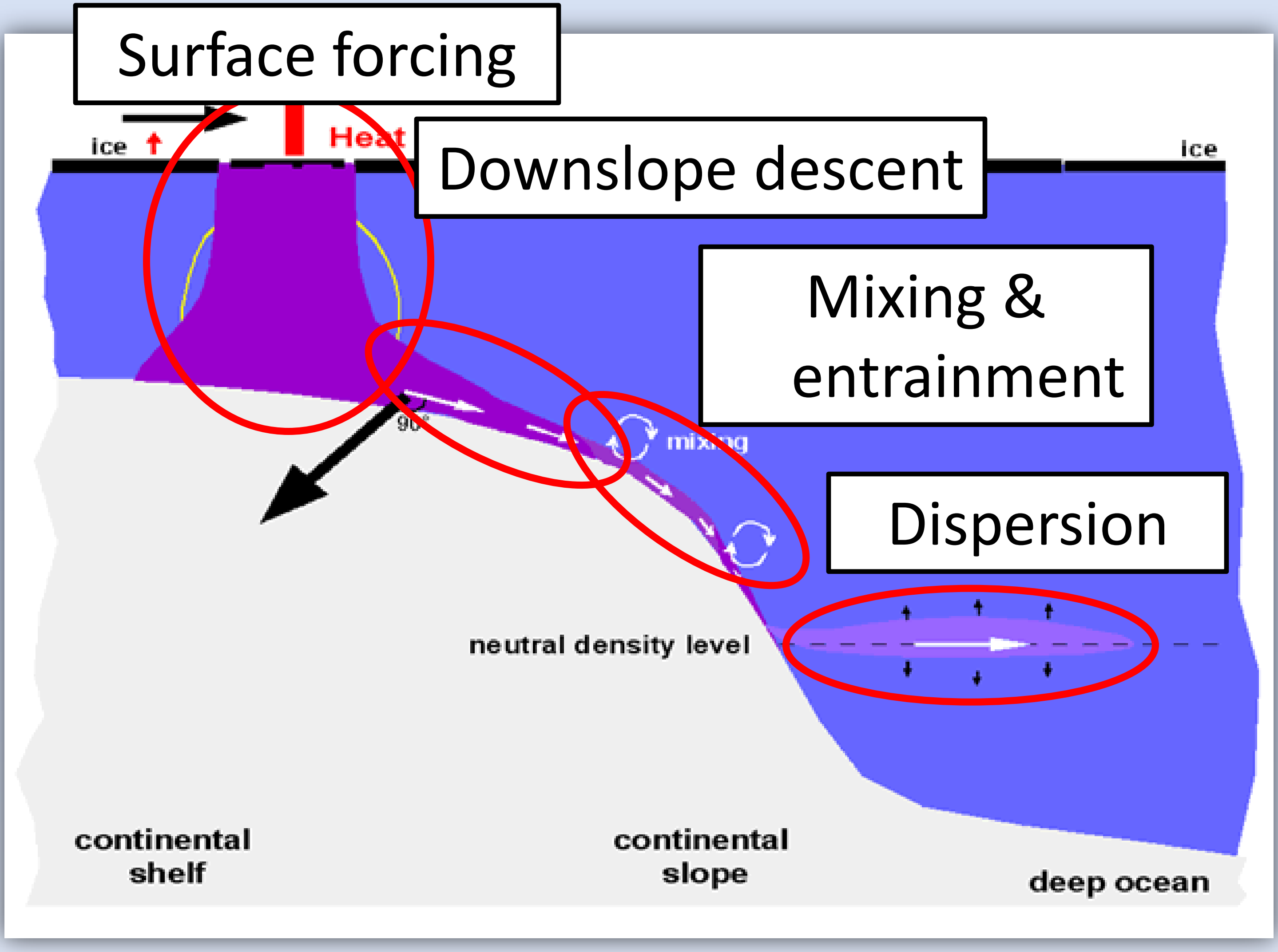
Dense water cascades



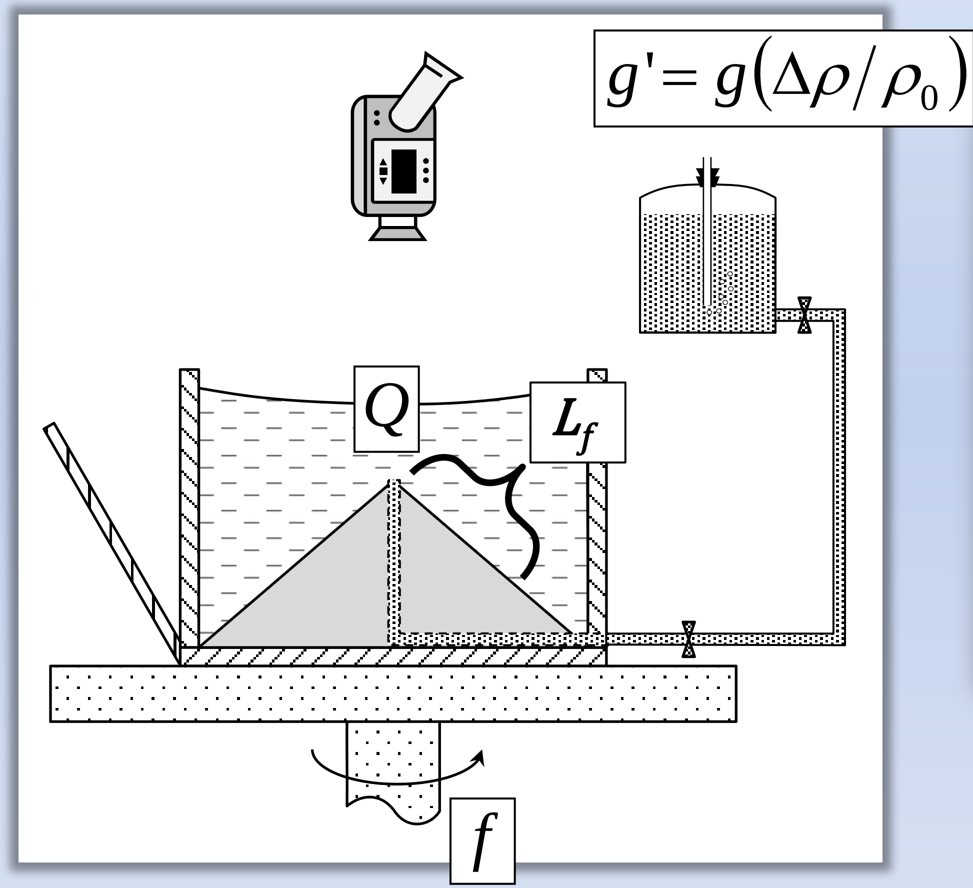
graphics: RAPID project, NOC-L

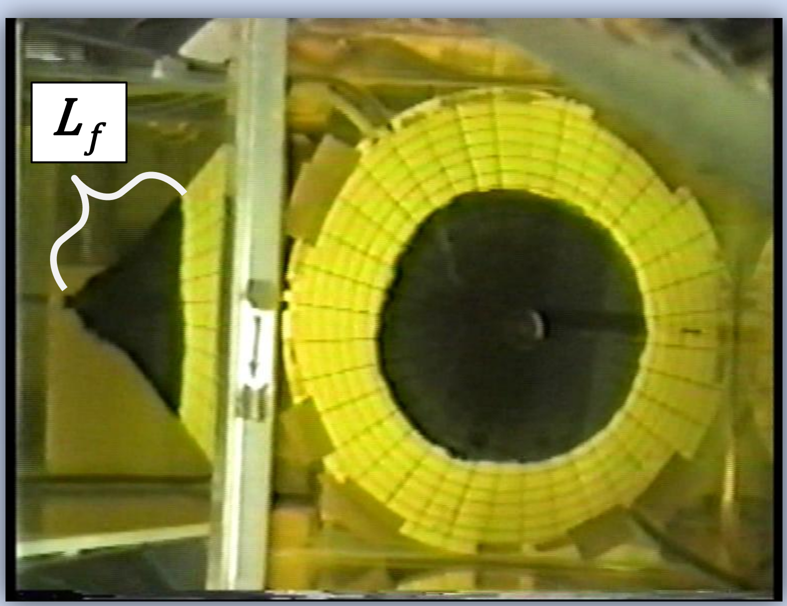
The problem

- Difficult to observe
  - Highly intermittent in space & time
  - Process is difficult to study in-situ
  - Observations (at least of their outcome) exist
- Difficult to model
  - Not resolved in global climate models
  - Turbulence, mixing and entrainment
  - **Bottom boundary layer processes?**

e.g. Ivanov *et al*. (2004) *Progress in Oceanography,* **60** (1), 47–98

Laboratory experiments

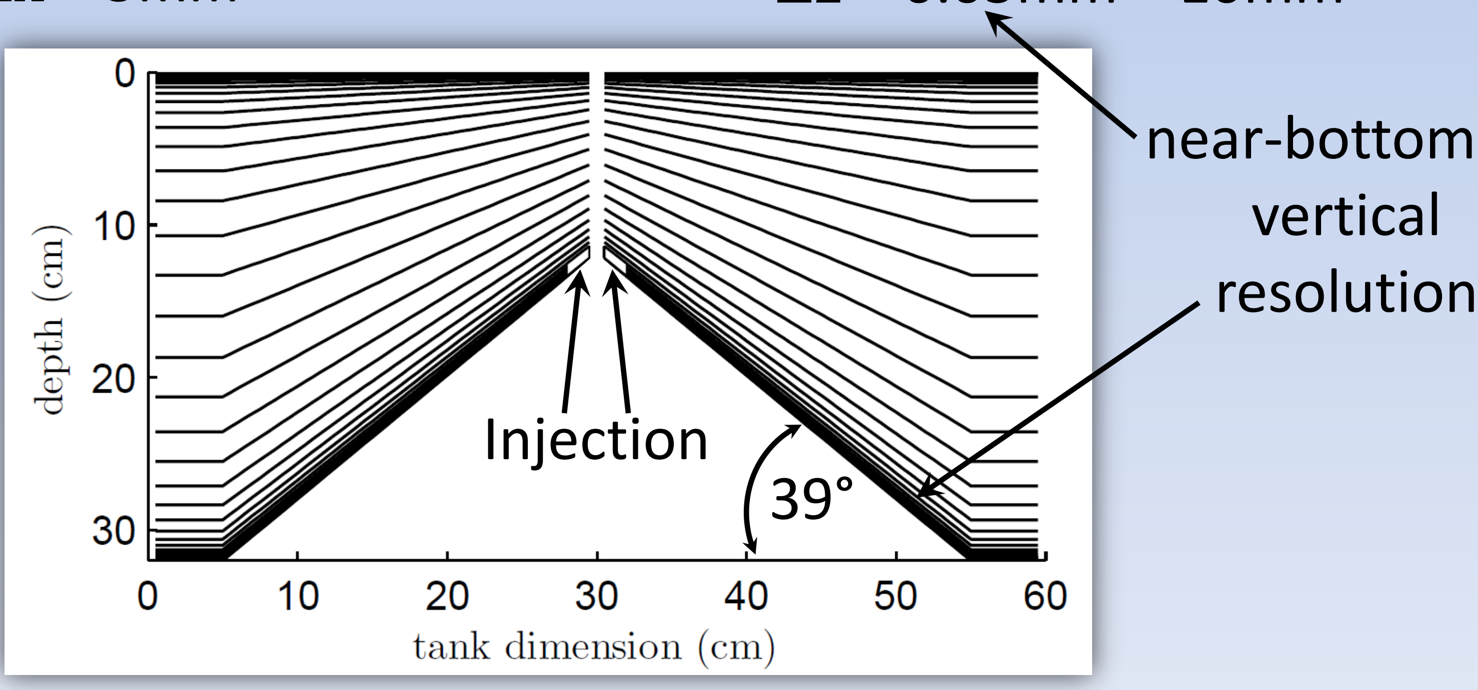




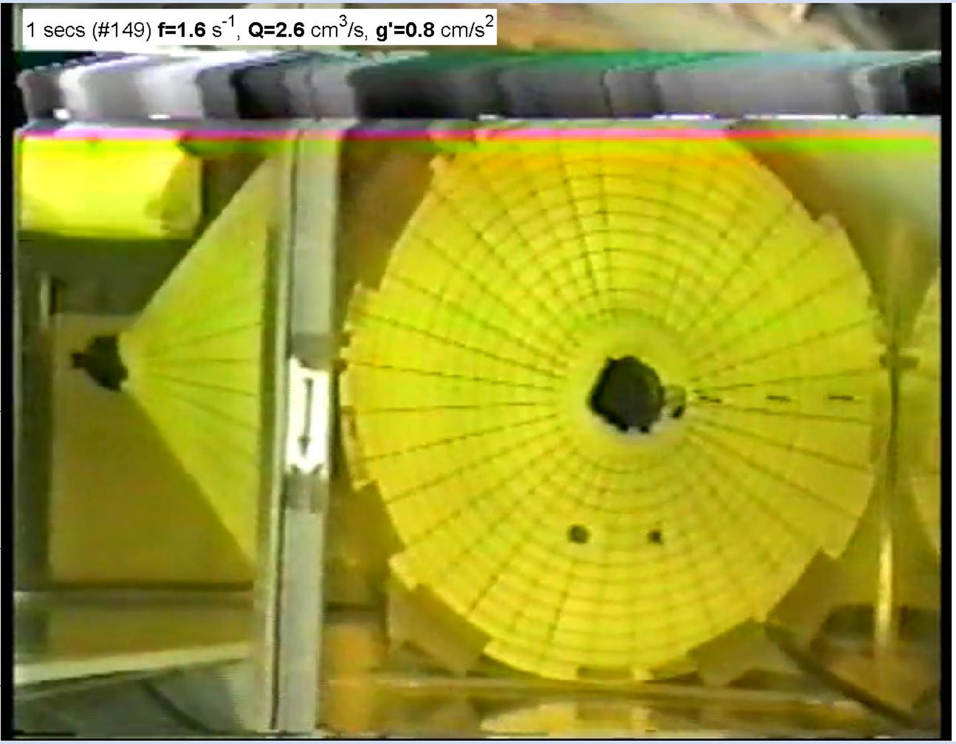
see: Shapiro & Zatsepin (1997) *Annales Geophysicae*, **15** (3), 366-374

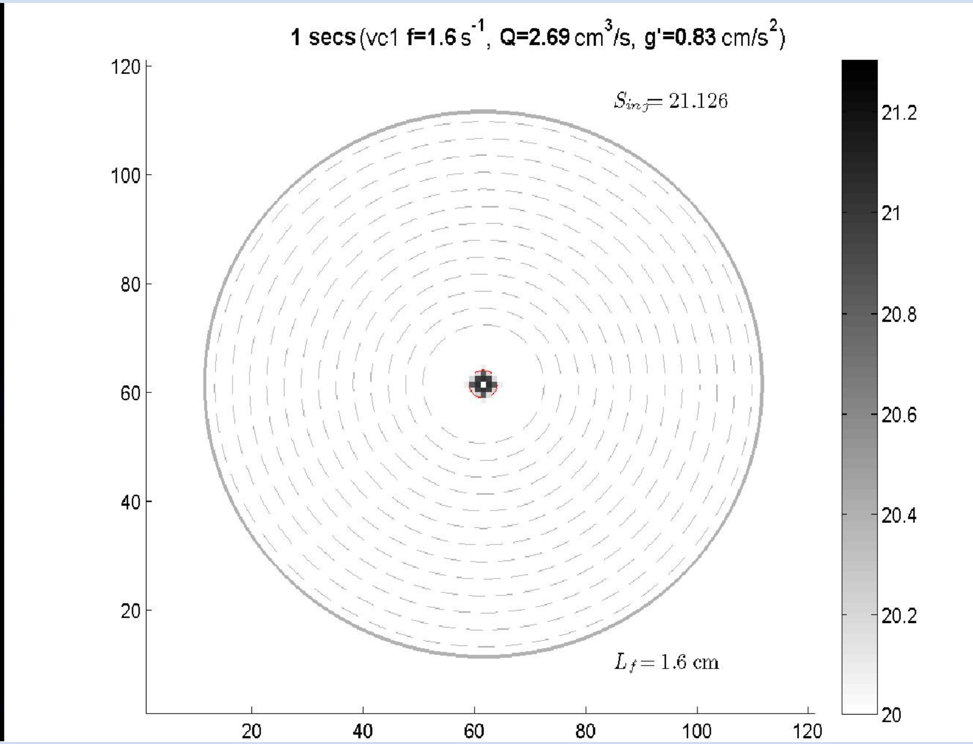
3-D numerical model

- POLCOMS – a hydrostatic ocean model
  - Baroclinic B-grid
    - 120x120 nodes
    - Δx = 5mm
  - *s*-coordinate system
    - 45 computational layers
    - Δz = 0.05mm – 10mm



Comparison to lab exp (video)

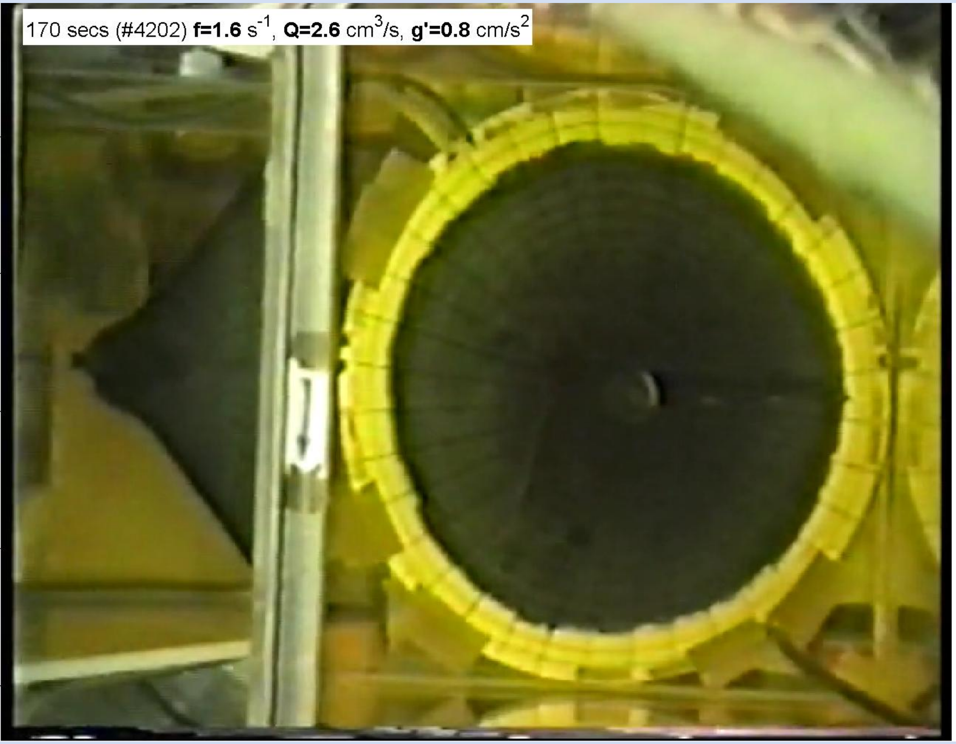


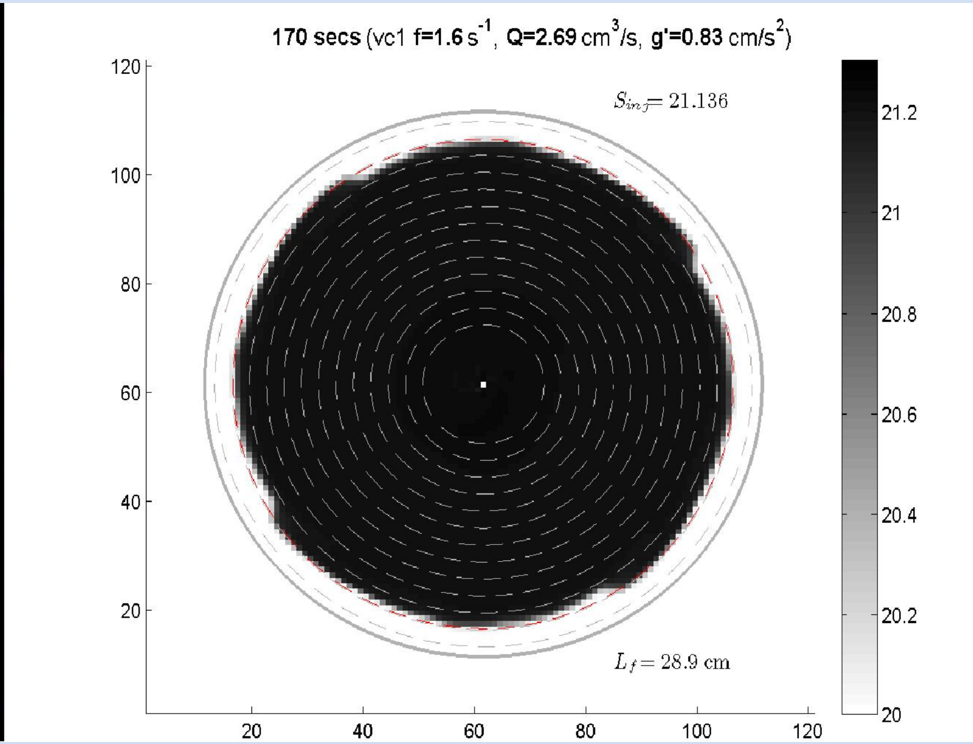


Laboratory

Model

Comparison to lab exp (video)

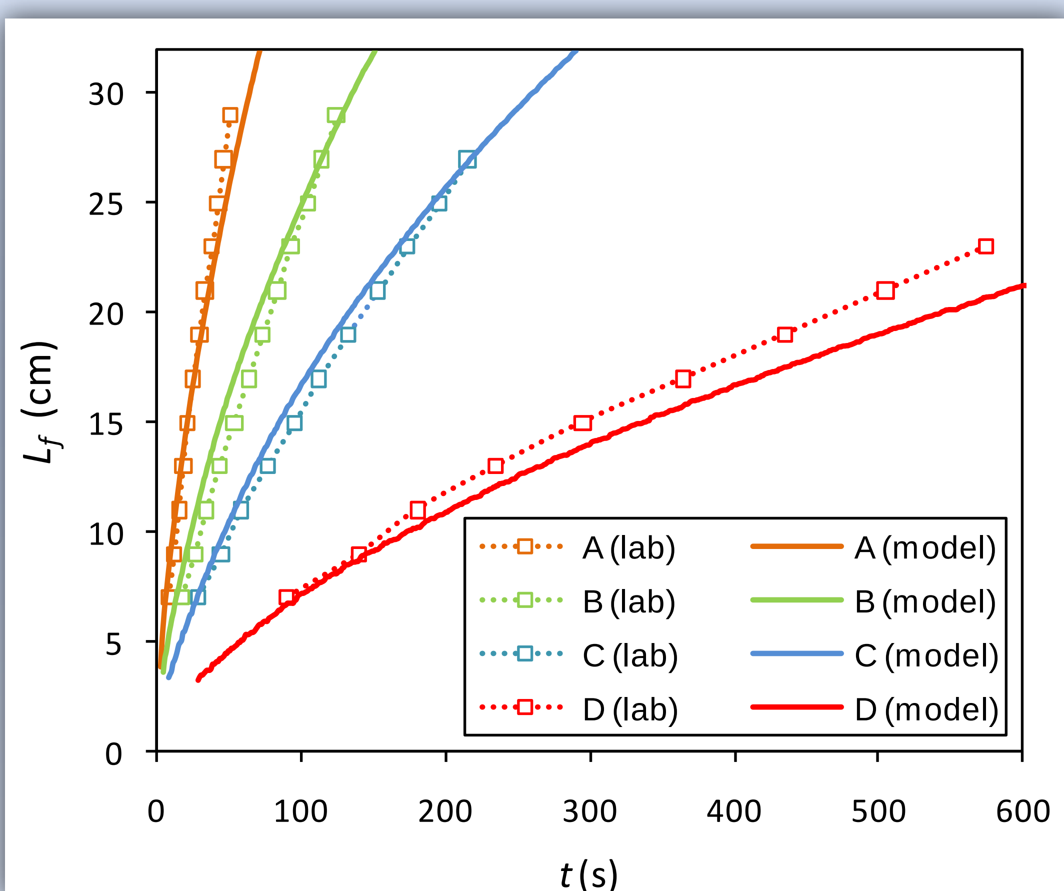




Laboratory

Model

Model validation

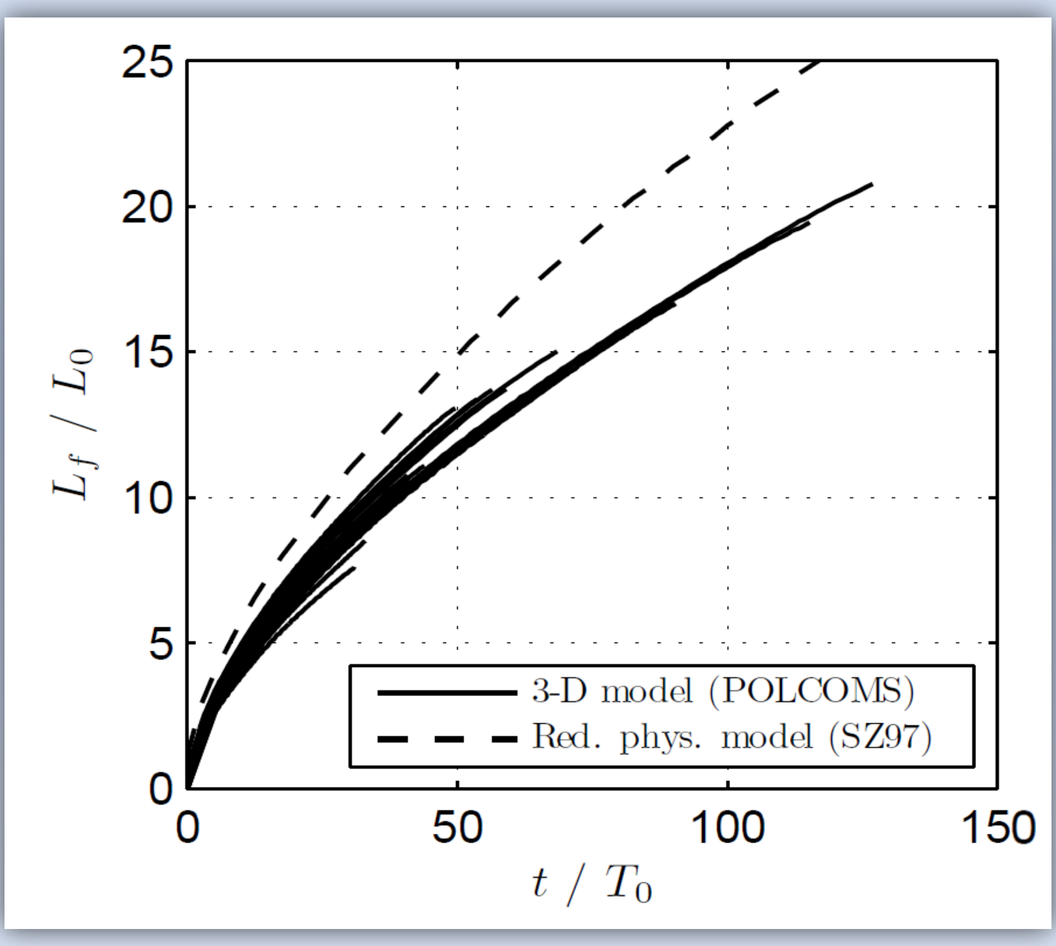


Downslope plume propagation

Length of front from cone tip L_f (in cm) as a function of time t (in s)

Downslope speed is not comparable between experiments where the governing parameters f, Q and g' vary.

Comparison with theory



Non-dimensional scaling scheme

$$L_0 = \frac{Q}{2\pi\sqrt{2}H_e V_{Nof} G_m \cos\theta}$$

$$T_0 = \frac{\sqrt{2}L_0}{V_{Nof}}$$

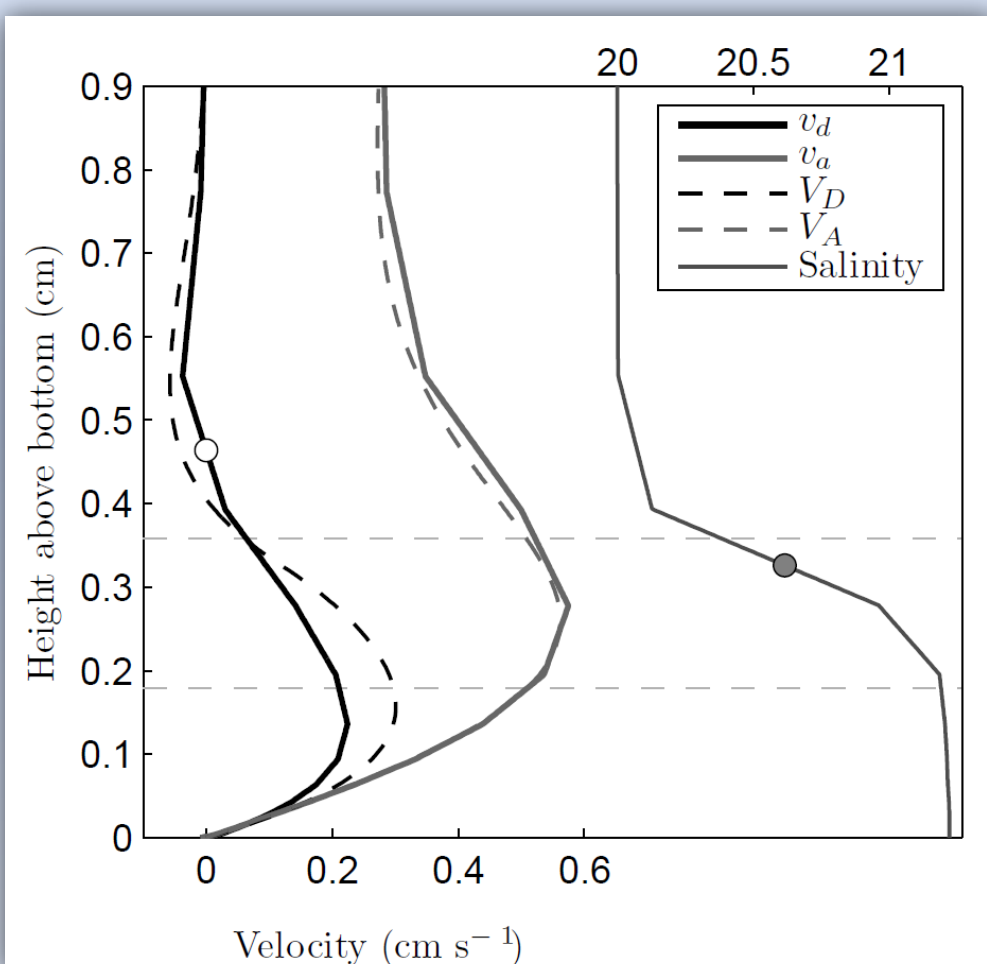
$$V_{Nof} = \frac{g'}{f}\tan\theta$$

$$H_e = \sqrt{2\upsilon / f \cos\theta}$$

$$G_m \cong 1.12$$

see also: Shapiro & Zatsepin (1997) *Annales Geophysicae*, **15**, (3), 366-374

Comparison with theory



Horizontal velocity profiles

Modelled velocities → Ekman spiral (v_d , v_a)

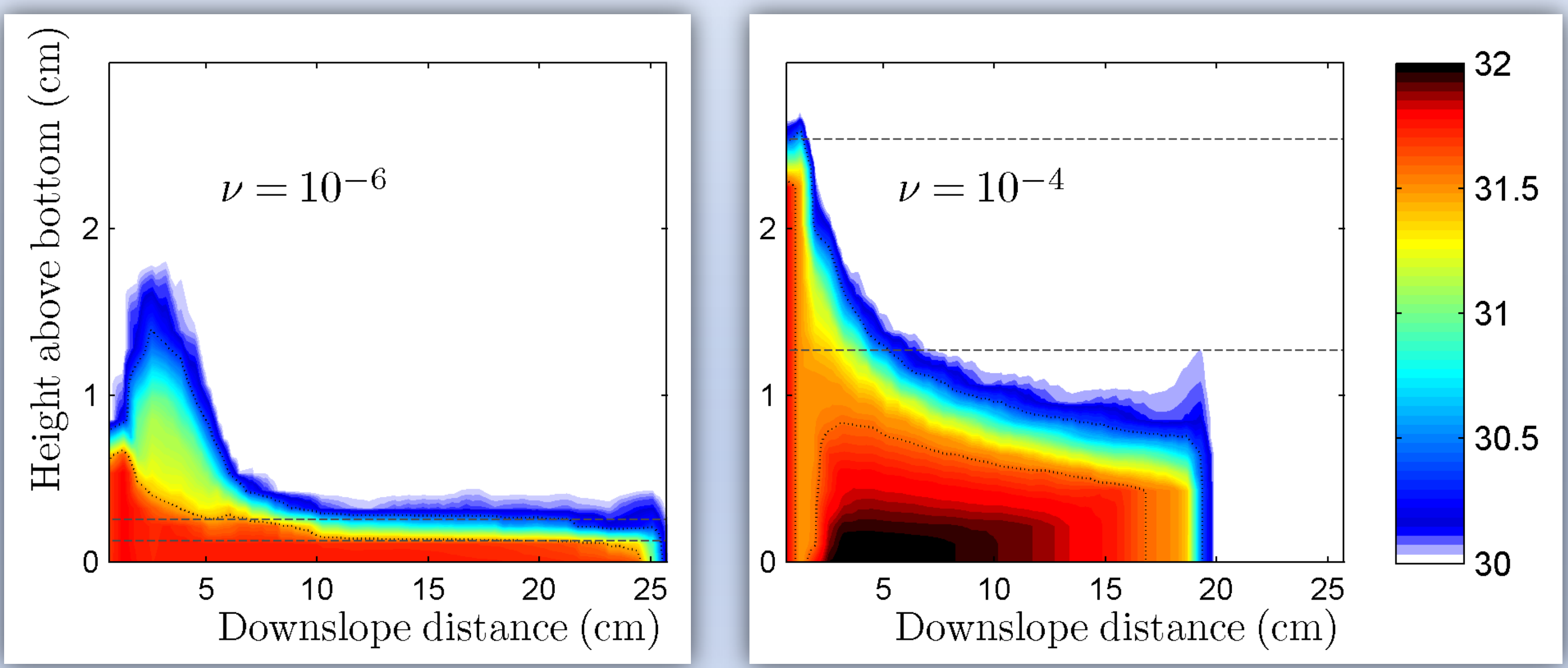
Prediction by reduced physics model (V_D , V_A)

2-layer density regime

Downslope flow within Ekman layer (≈ $2 \times H_e$)

see also: Shapiro & Hill (1997) *J. Phys. Oceanogr.*, **27** (11), 2381–2394

Ekman layer height

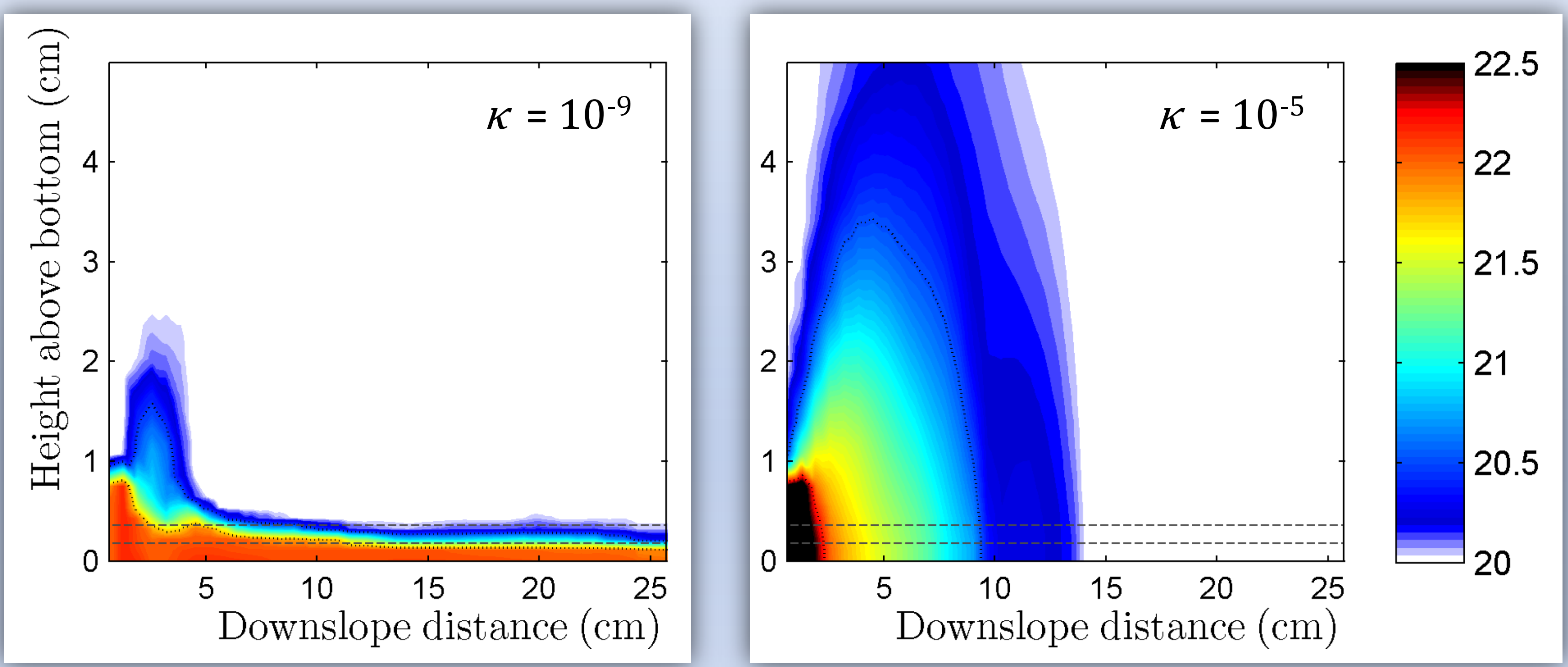


t = 144s

t = 144s

- Viscosity ν: 10^{-6} → 10^{-4} m^2 s^{-1}
- plume thickness adjusts to Ekman layer height

Diapycnal mixing

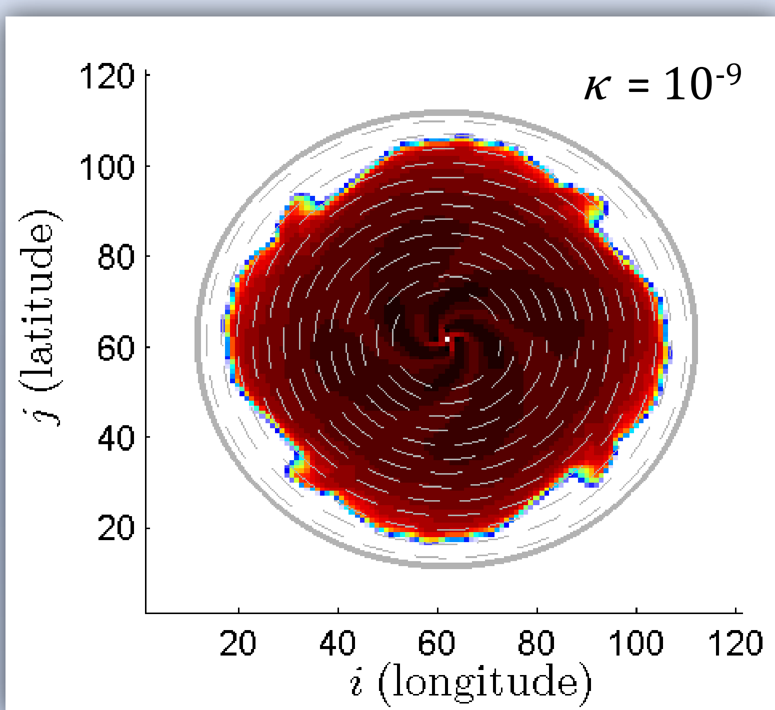


t = 144s

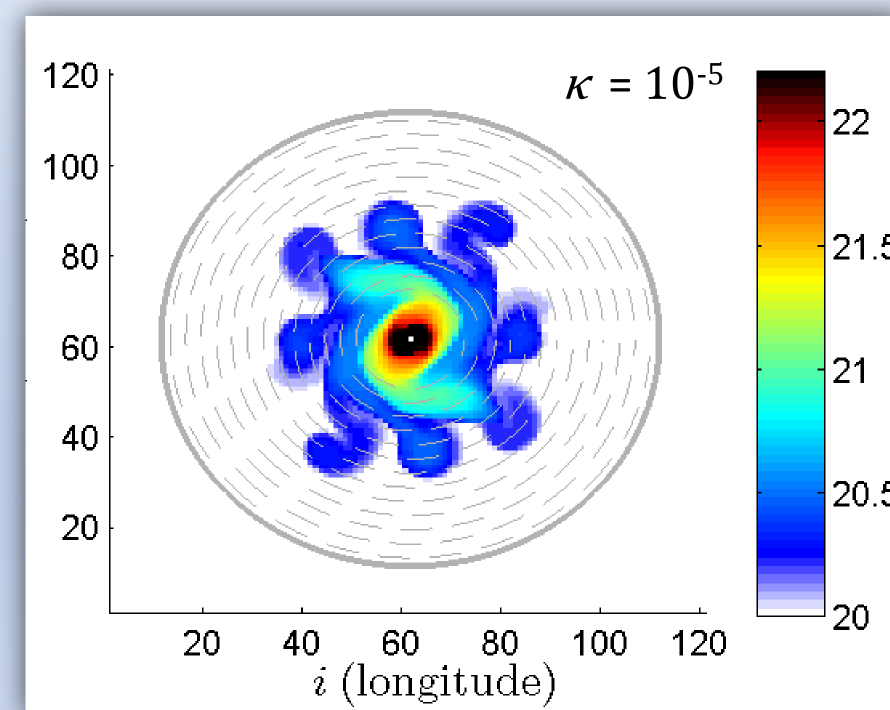
t = 144s

- Diffusivity κ: 10^{-9} → 10^{-5} m^2 s^{-1}
- plume becomes blurred, no longer 2 layers
- downslope transport is reduced

Diapycnal mixing



t = 144s

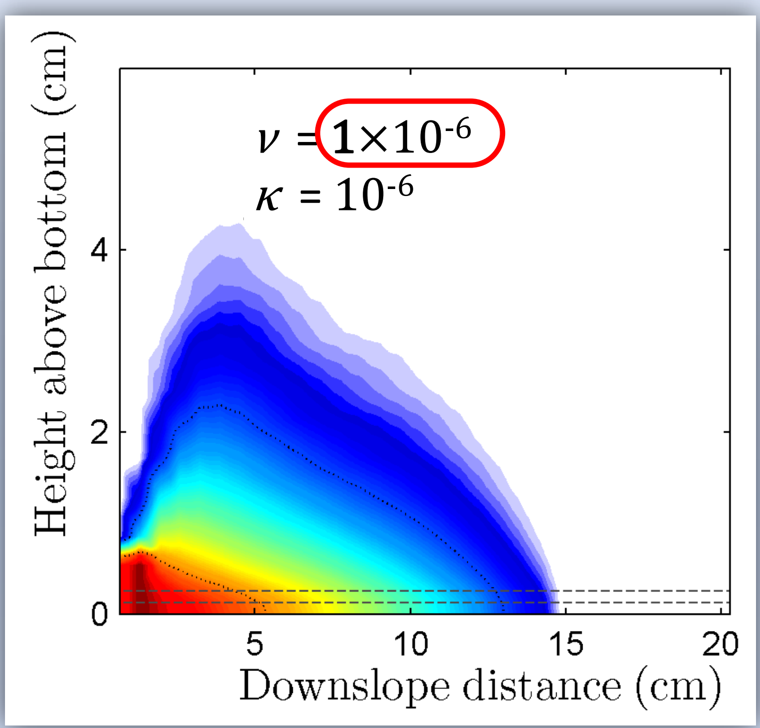


t = 216s

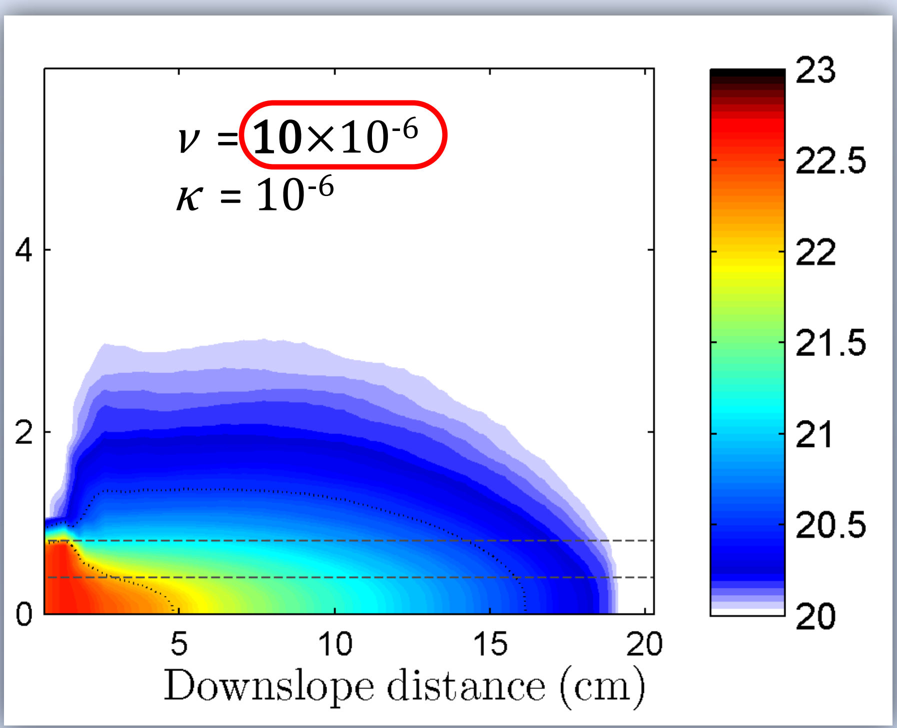
- Different flow regime
- swirls and eddies (Cenedese, 2004)

see: Cenedese *et al.* (2004) *J. Phys. Oceanogr.*, **34**, 188–203

Diffusivity + Viscosity



t = 144s



t = 144s

- diffuse plume travels faster if viscosity is high
- thicker Ekman layer increases transport

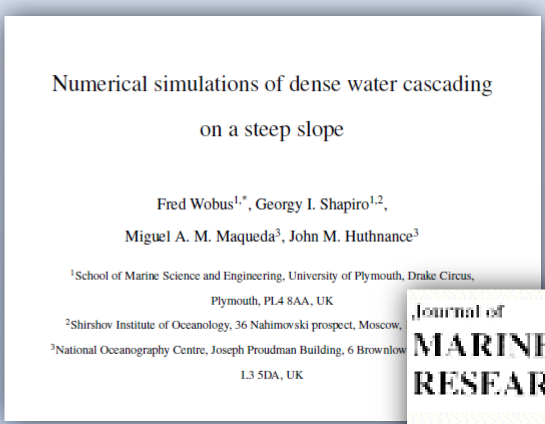
Conclusions

- Hydrostatic model accurately captures cascading
  - Bottom boundary condition
  - Sufficient vertical resolution
  - Friction fully resolved (not parameterised!)
- Transition from 2-layer regime to blurred plume shows limits of reduced physics models
- Transport reduced by diffusion, but enhanced by higher viscosity, as observed in real ocean
  - E.g. tidal turbulence in Antarctica (Padman, 2009)

see: Padman *et al.* (2009) *Deep-Sea Res. Pt II*, **56** (13-14), 818–834

Further work

- Upscale geometry to model cascading in the Arctic Ocean
  - Example: Svalbard (Storfjorden cascade)
- Development of a parameterisation for downslope transport
  - To include cascading in larger-scale models
- **Influence on larger-scale ocean circulation?**



Numerical simulations of dense water cascading on a steep slope

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Thank You

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Abstract

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Modelling of shelf water cascades on the continental slope

The sinking of dense shelf waters down the continental slope "cascading" contributes to oceanic water mass formation and the off-shelf transport of carbon. Using a process-based approach we study cascading over idealised bottom topography in numerical experiments using POLCOMS, a 3-D ocean circulation model employing a terrain-following *s*-coordinate system. The model setup is based on a laboratory experiment of a continuous dense water flow from a central source on a steep conical slope (39°) in a rotating tank. The vertical resolution and bottom boundary condition are configured specifically to resolve the physics of Ekman veering in the bottom and interfacial boundary layers. The descent of the dense flow as characterised by the length of the plume as a function of time is studied for a range of experimental parameters, mainly the density difference between plume and ambient water, the flow rate and the speed of rotation.

The model is successfully validated in a series of runs accurately reproducing the laboratory experiments. Our results demonstrate that a hydrostatic model is capable of reproducing the essential physics of cascading on a very steep slope if the model correctly resolves velocity veering in the bottom boundary layer. On the other hand, numerical simulations utilising the standard parametrisation of the bottom boundary layer (instead of resolving it) fail to reproduce the lab experiments. Our 3-D modelling confirms the findings previously obtained by reduced physics models for a 2-layer flow.

We further explore the dynamics of cascading outside of the controlled laboratory conditions in model runs where viscosity and/or diffusivity are modified. The limits of the reduced physics theory are identified in simulations with increased diffusivity where the cascade has a blurred interface between plume and ambient water and can no longer be considered a 2-layer flow. We show that downslope transport is reduced when the plume interface is strongly diffused, but enhanced in a regime that simulates cascades with increased turbulence where diffusivity and viscosity are both increased.