Modelling density-stratified cascades on a steep slope

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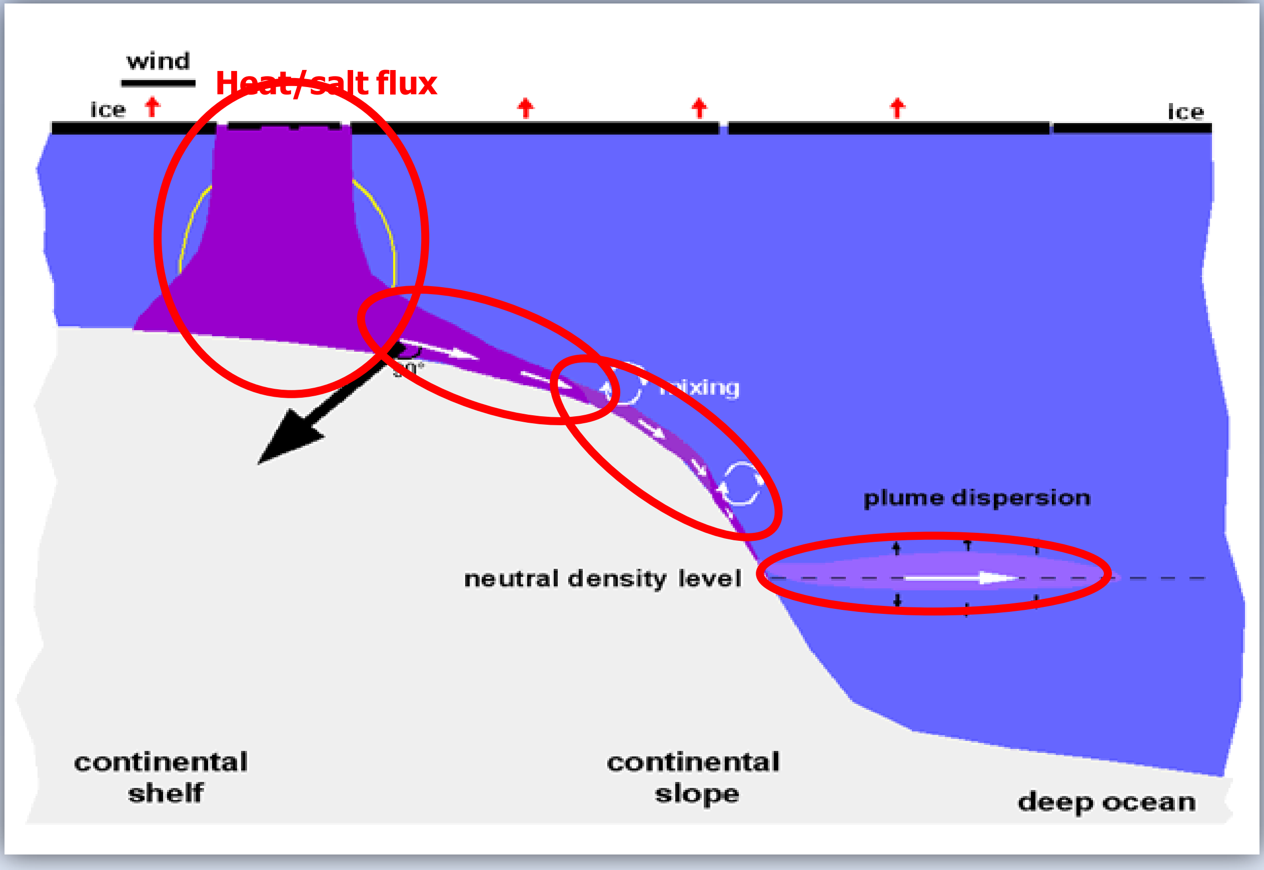
UK Arctic Science Conference, Leeds, 14-16/09/2011

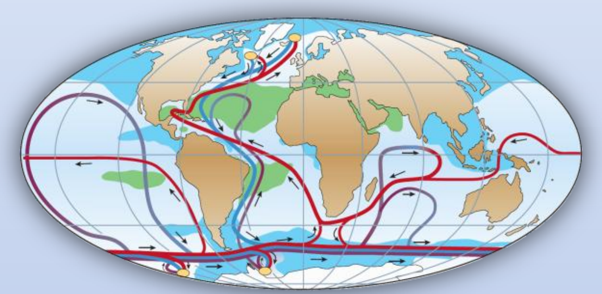
Dense water cascades

- **Pre-conditioning**
- **Active stage**
- **Main stage**
- **Final stage**



Ivanov *et al*. (2004) *Progress in Oceanography*, **60** (1), 47–98 / Graphics: RAPID project, NOC-L

Why are cascades important?



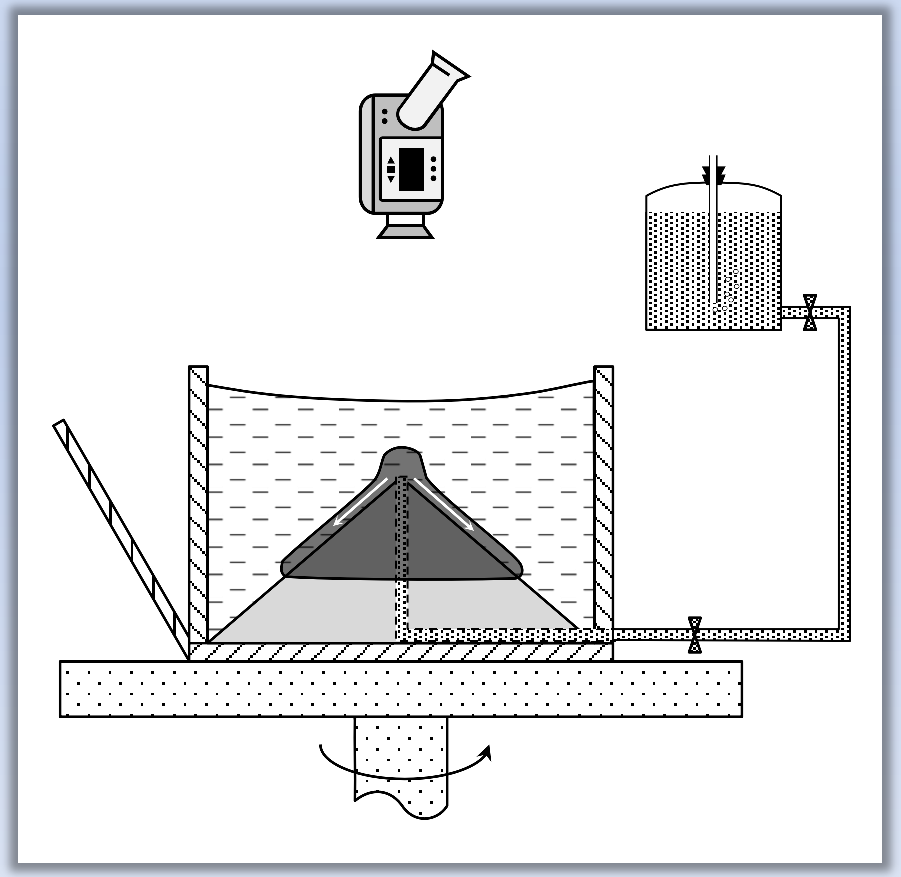
- Global overturning circulation
  - shelf waters ventilate intermediate and bottom waters
- Off-shelf transport of carbon and other matter
  - important link between shelf waters and the deep ocean
- Formation and maintenance of the Arctic halocline

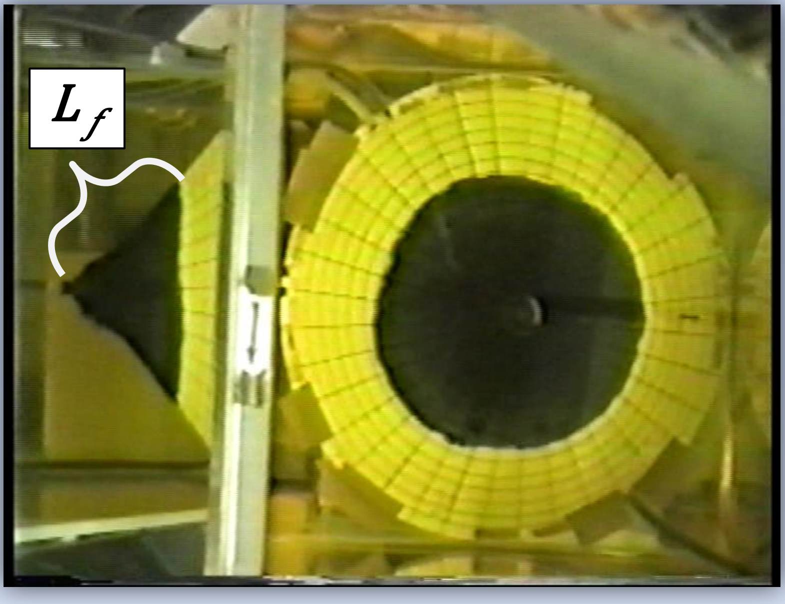
- **Difficult to observe** intermittent in space & time
- **Difficult to model** not resolved in global models
  - Bottom boundary layer processes are important!

Graphics reference: Rahmstorf (2002) *Nature*, **419**, (6903), 207-214 / Photo credit: RTR/AP

Laboratory experiments

- Shapiro & Zatsepin (1997)



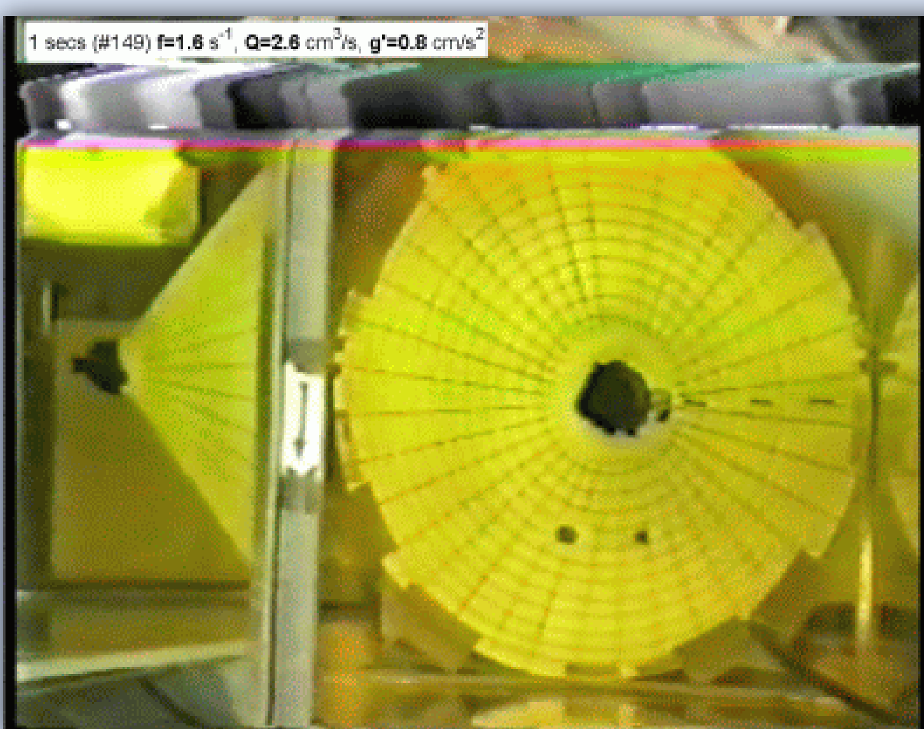


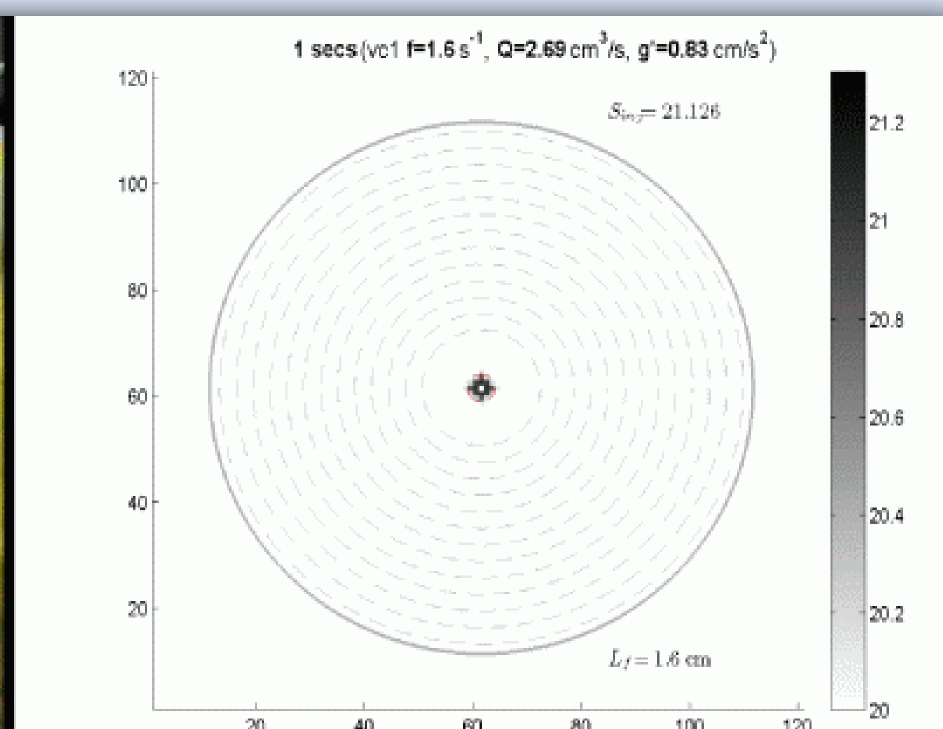
Shapiro & Zatsepin (1997) *Annales Geophysicae*, **15** (3), 366-374

Modelling pilot study

- POLCOMS, 3-D hydrostatic ocean model
  - Grid 120×120 nodes, σ-coordinate 45 layers
- Setup based on SZ97 laboratory experiments
  - Controlled environment, Reduce complexity
  - Simplified parameter space
    - Rotation rate f
    - Inflow rate Q
    - Density difference $g' = g(\Delta\rho/\rho_0)$
    - Diffusivity, Viscosity κ, υ

Comparison to lab experiment



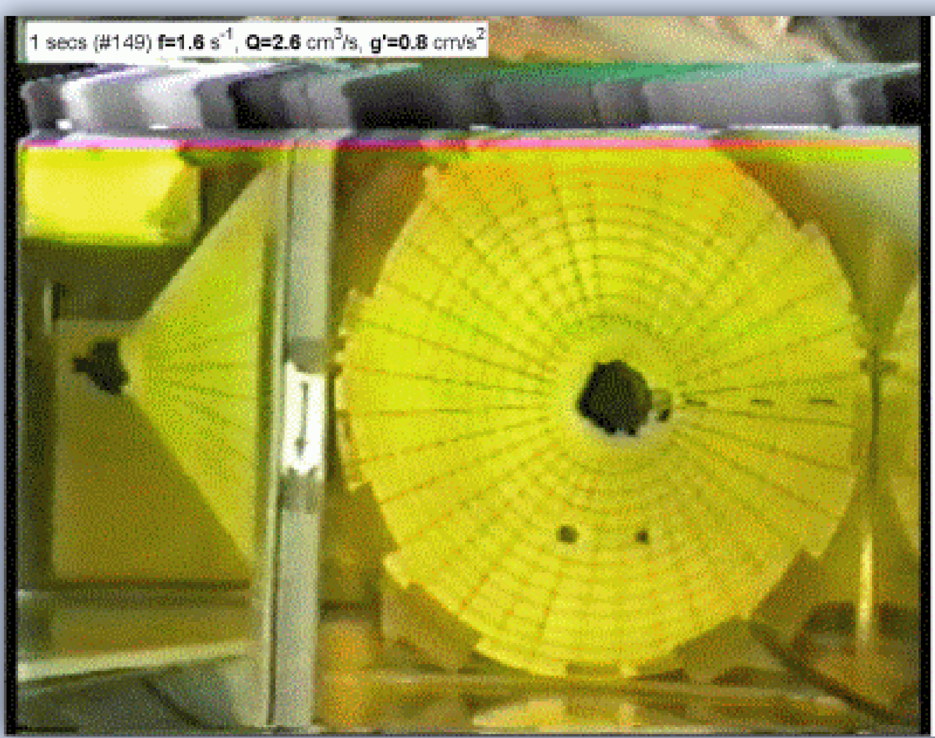


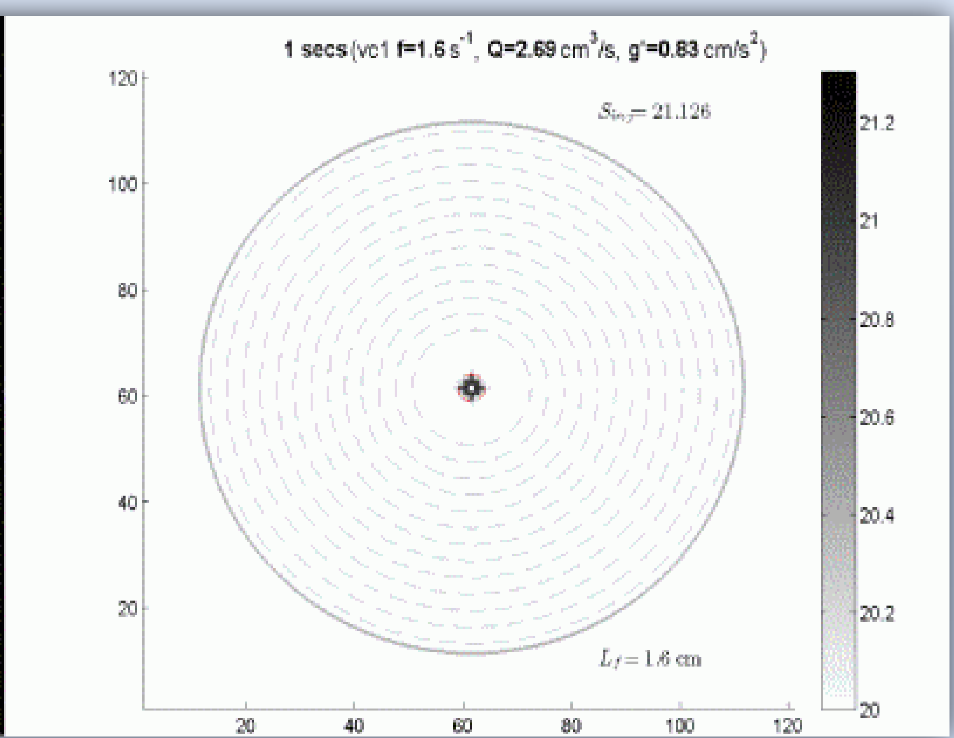
Laboratory

Model

Video credit: A.G. Zatsepin, Shirshov Institute of Oceanology, Moscow

Comparison to lab experiment



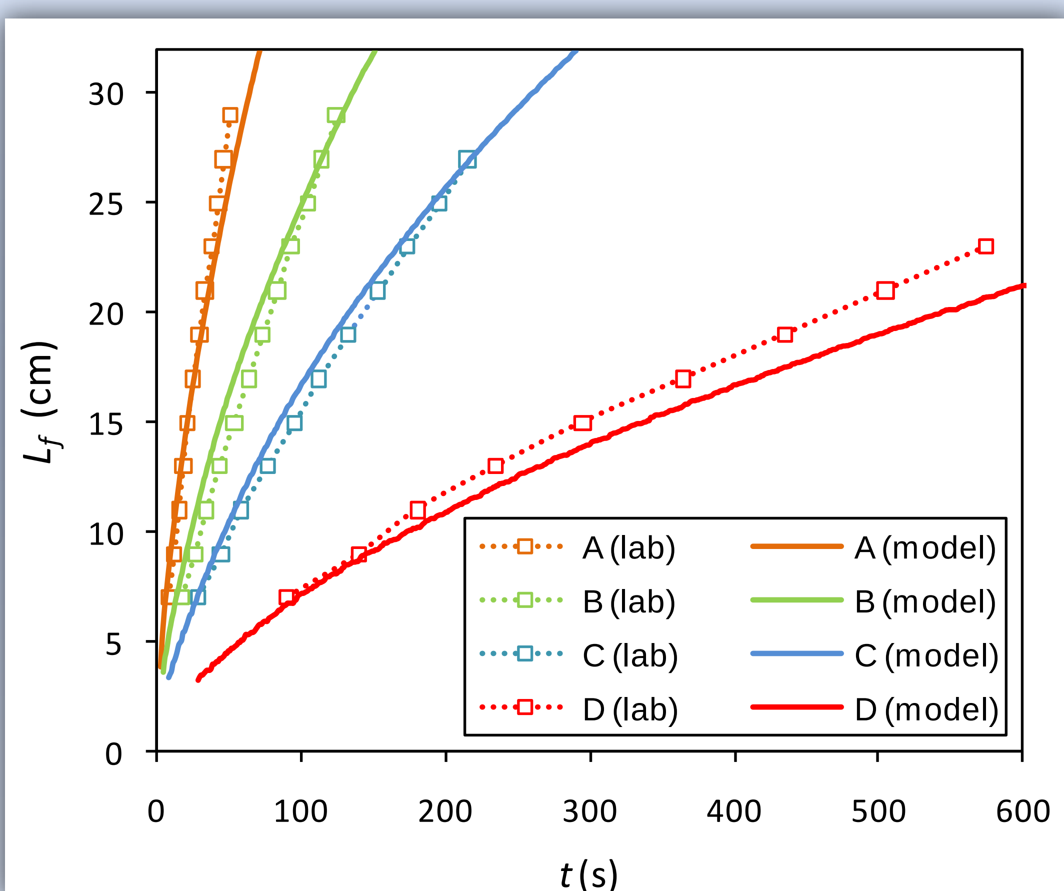


Laboratory

Model

Video credit: A.G. Zatsepin, Shirshov Institute of Oceanology, Moscow

Model validation

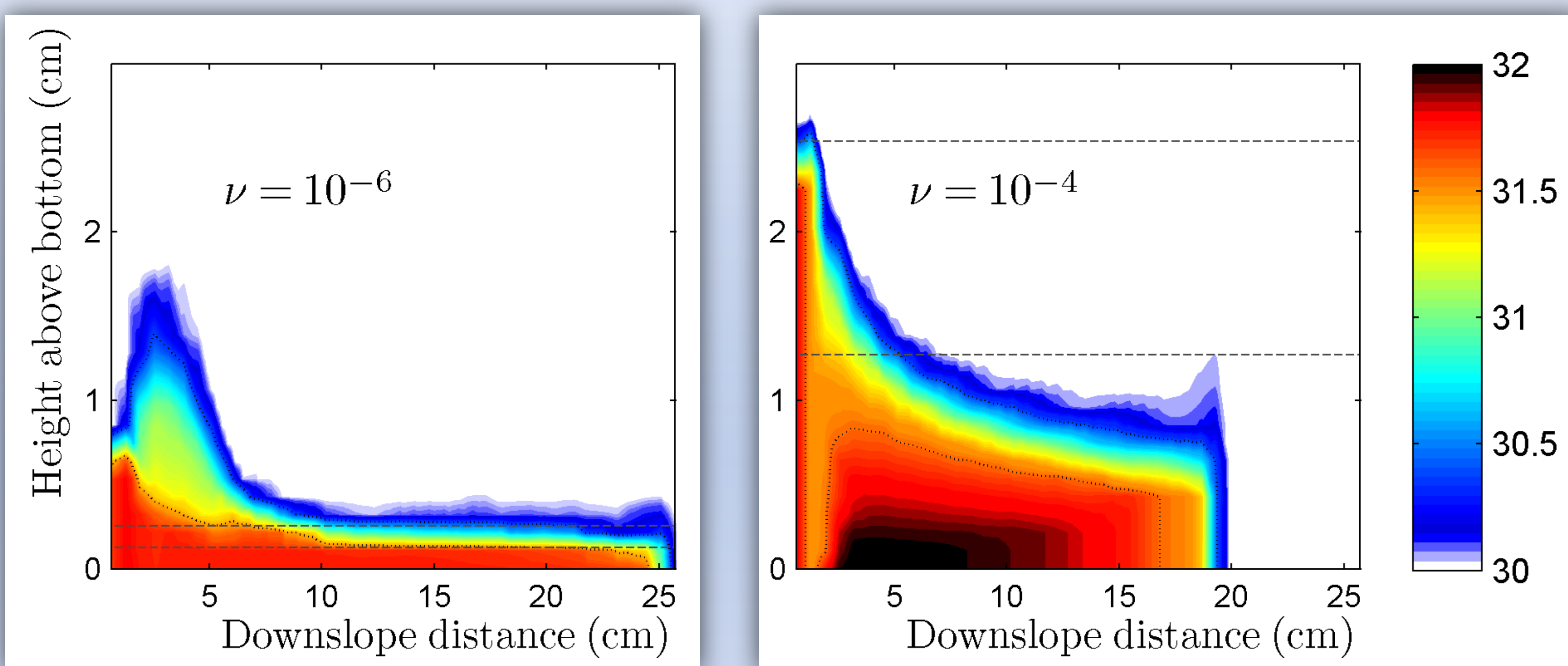


Downslope plume propagation

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

Wobus *et al.* (2011) *Journal of Marine Research* (under review)

Ekman layer height

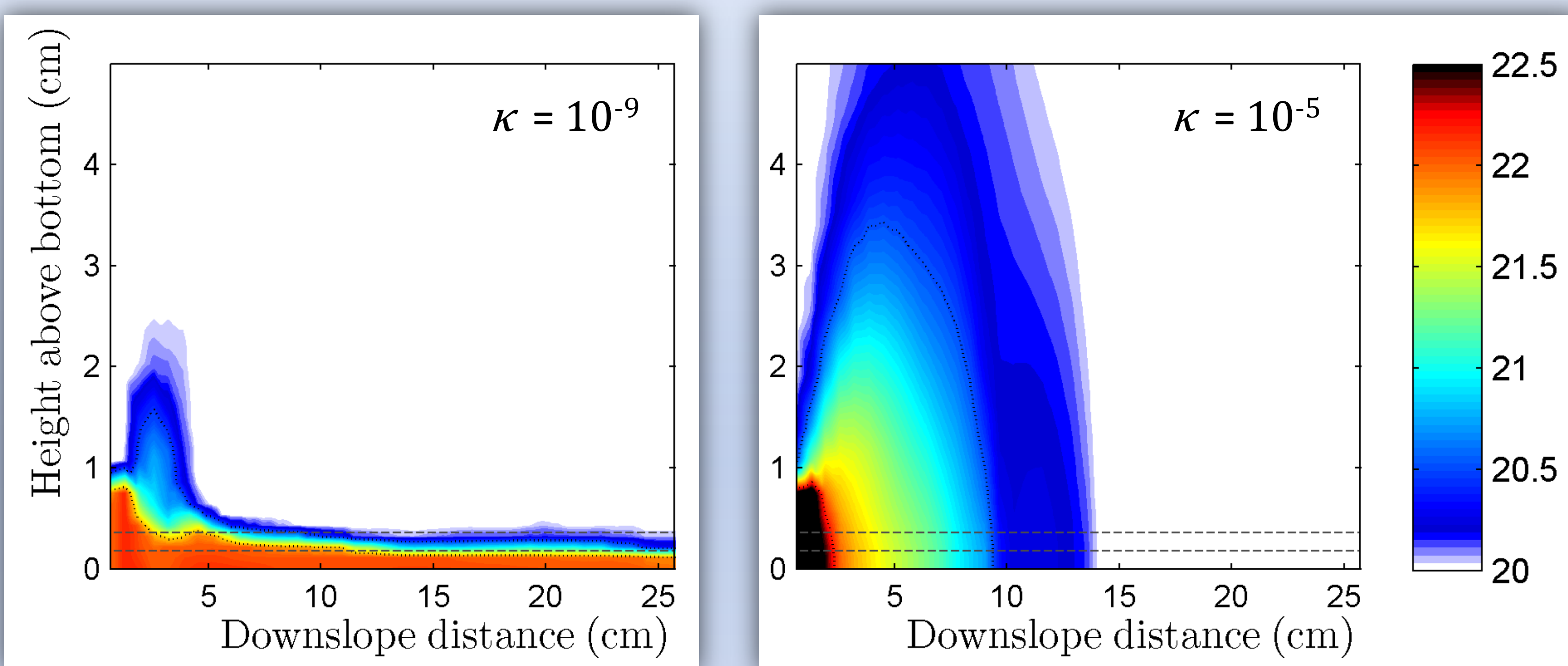


t = 144s t = 144s

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

Wobus *et al.* (2011) *Journal of Marine Research* (under review)

Diapycnal mixing

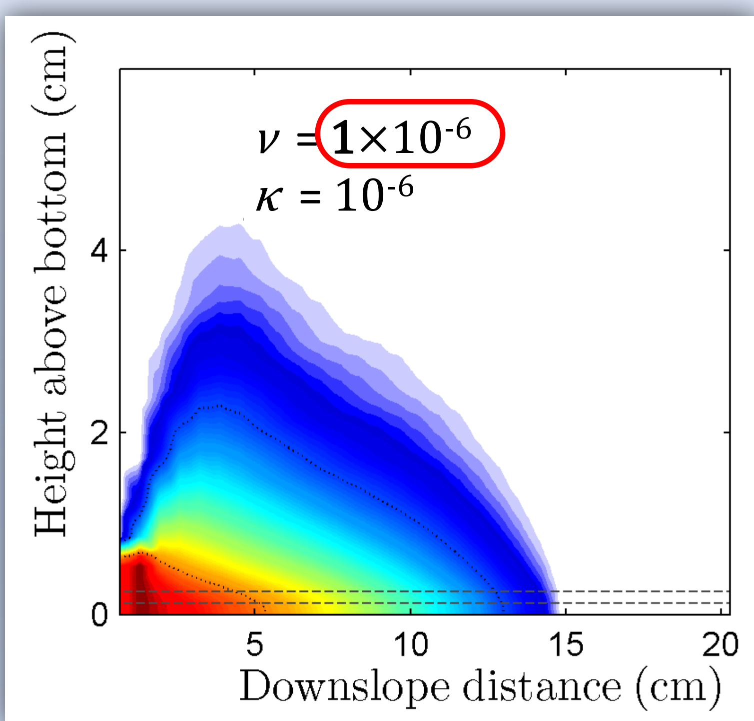


t = 144s   *t* = 144s

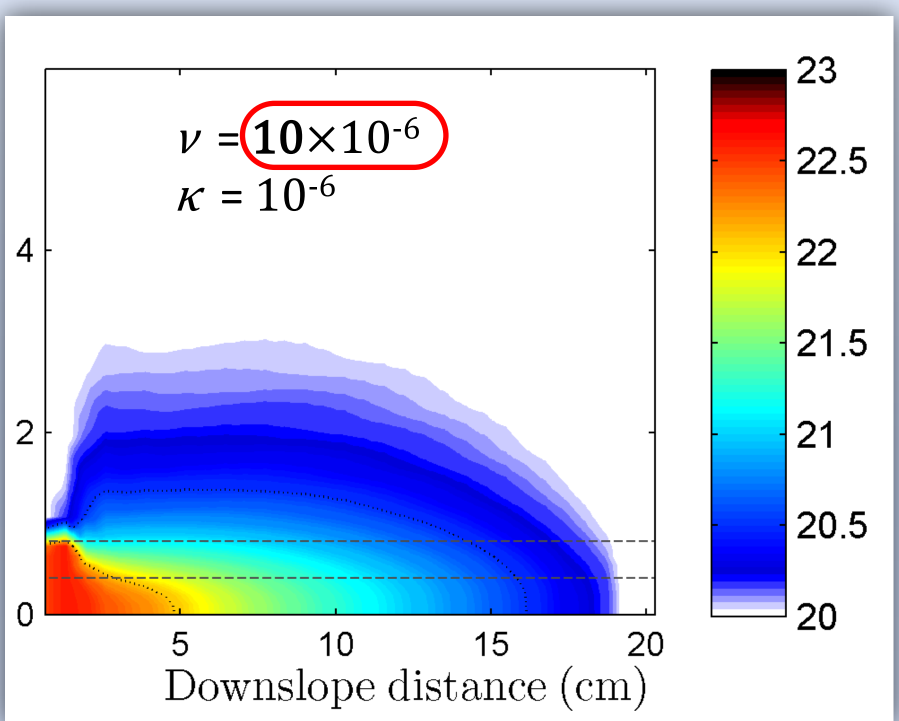
- Diffusivity κ: $10^{-9} \rightarrow 10^{-5}$ m^2 s^{-1}
- plume becomes blurred, no longer 2 layers
- downslope transport is reduced

Wobus *et al.* (2011) *Journal of Marine Research* (under review)

Diffusivity + Viscosity



t = 144s



t = 144s

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

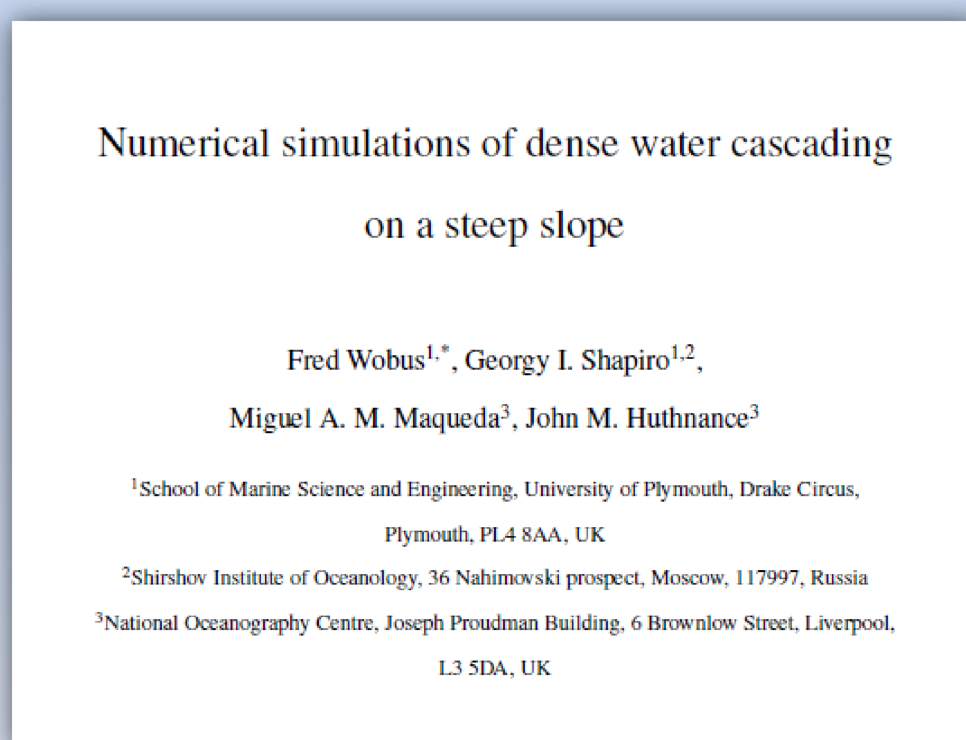
Wobus *et al.* (2011) *Journal of Marine Research* (under review)

Conclusions

- Hydrostatic model accurately captures cascading
  - 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)

Paper

- Journal of Marine Research
  - Currently under review



Numerical simulations of dense water cascading on a steep slope

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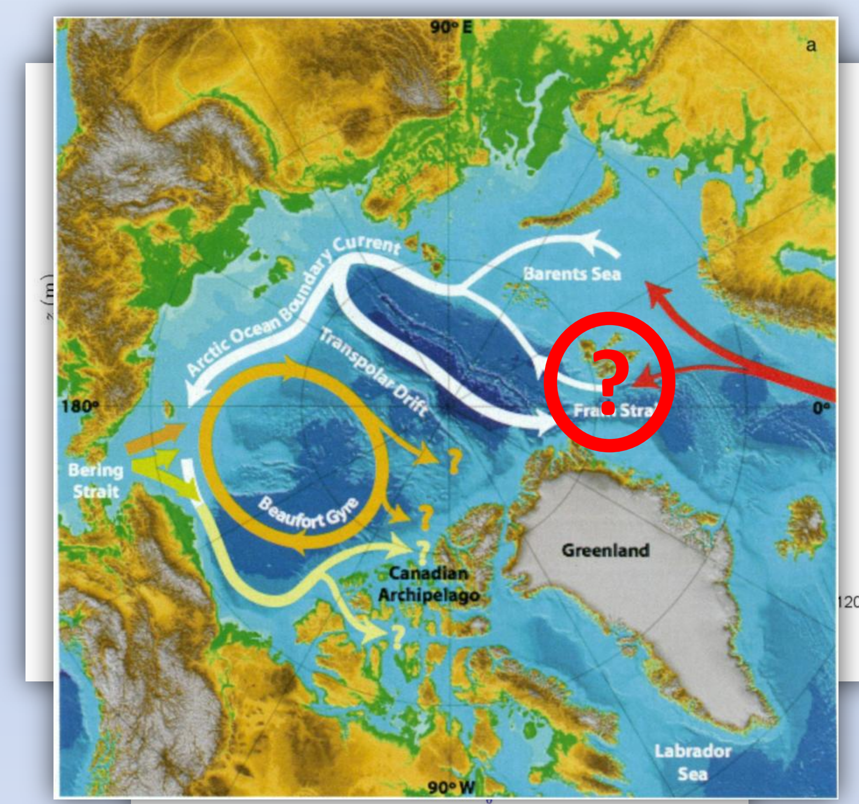
Further work

- Model runs in NEMO
  - Oceanic dimensions
  - Idealised bathymetry
  - Ambient stratification (Storfjorden data)



- **Influence on larger-scale ocean circulation?**

Profile from: Ilker Fer (2006) *Coastal and Shelf Seas conference*, Bangor, 18-21 April 2006

Graphics from: Fig 2 in Greene *et al.* (2008) *Ecology*, 89(11), S24-S38

Thank You

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Photo © British Antarctic Survey

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Abstract

Modelling density-stratified cascades on a steep slope

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Flows of dense water down the continental slope – cascades – are initiated in Arctic shelf regions by surface cooling or sea ice formation. Dense water cascading contributes to the formation of intermediate and bottom waters and is believed to be influential in the off-shelf transport of carbon and other suspended or dissolved matter. 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 descent of the dense water mass 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 against a series of previous 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. Our 3-D modelling confirms 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.