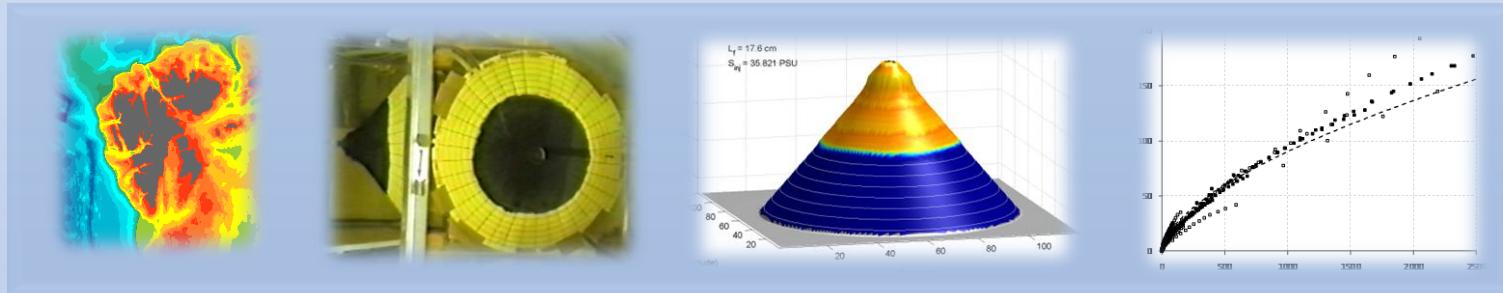




Simulating laboratory experiments of dense water cascades : a sensitivity study



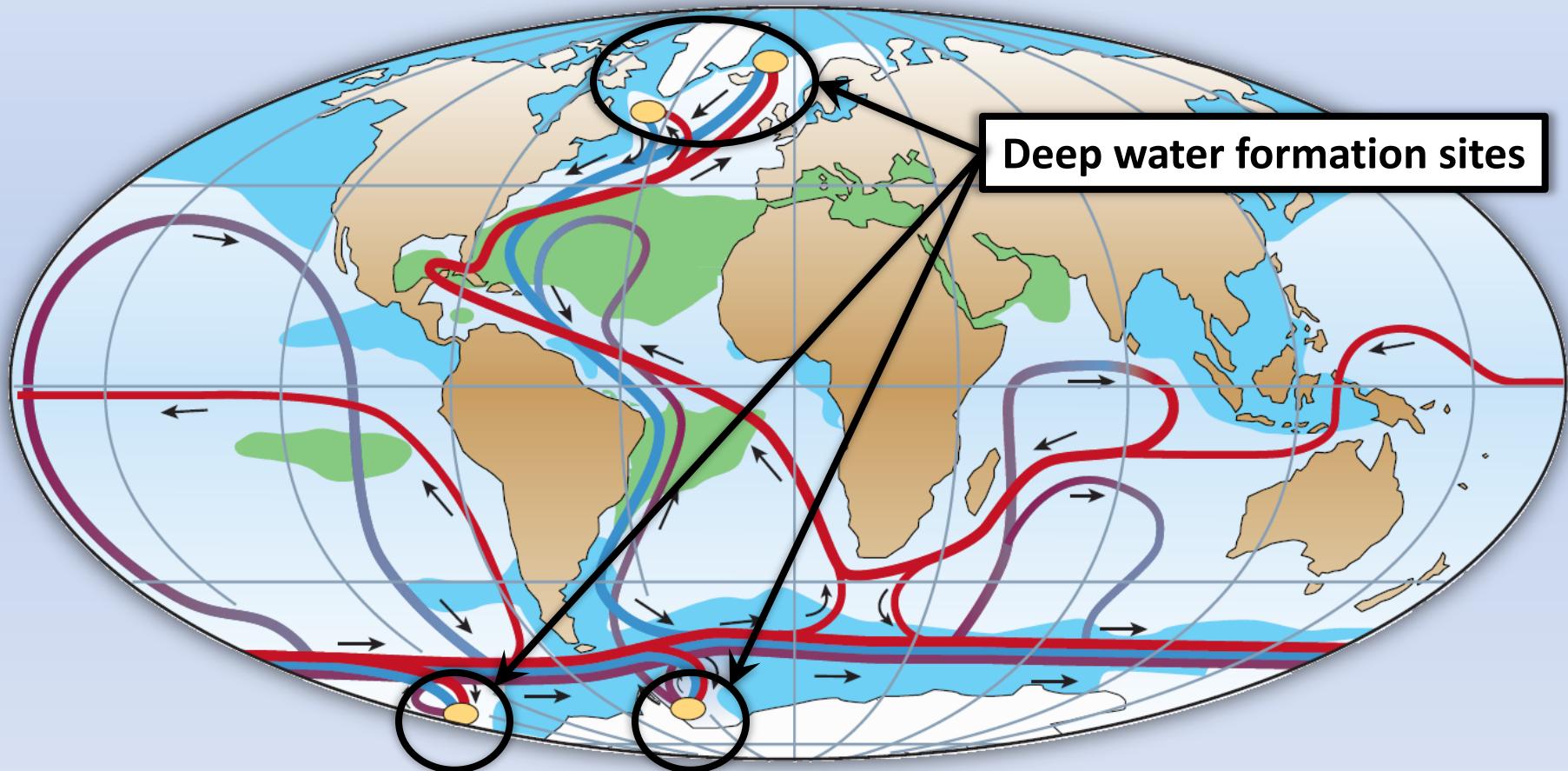
Fred Wobus

G.I. Shapiro, M.A.M. Maqueda, J.M. Huthnance

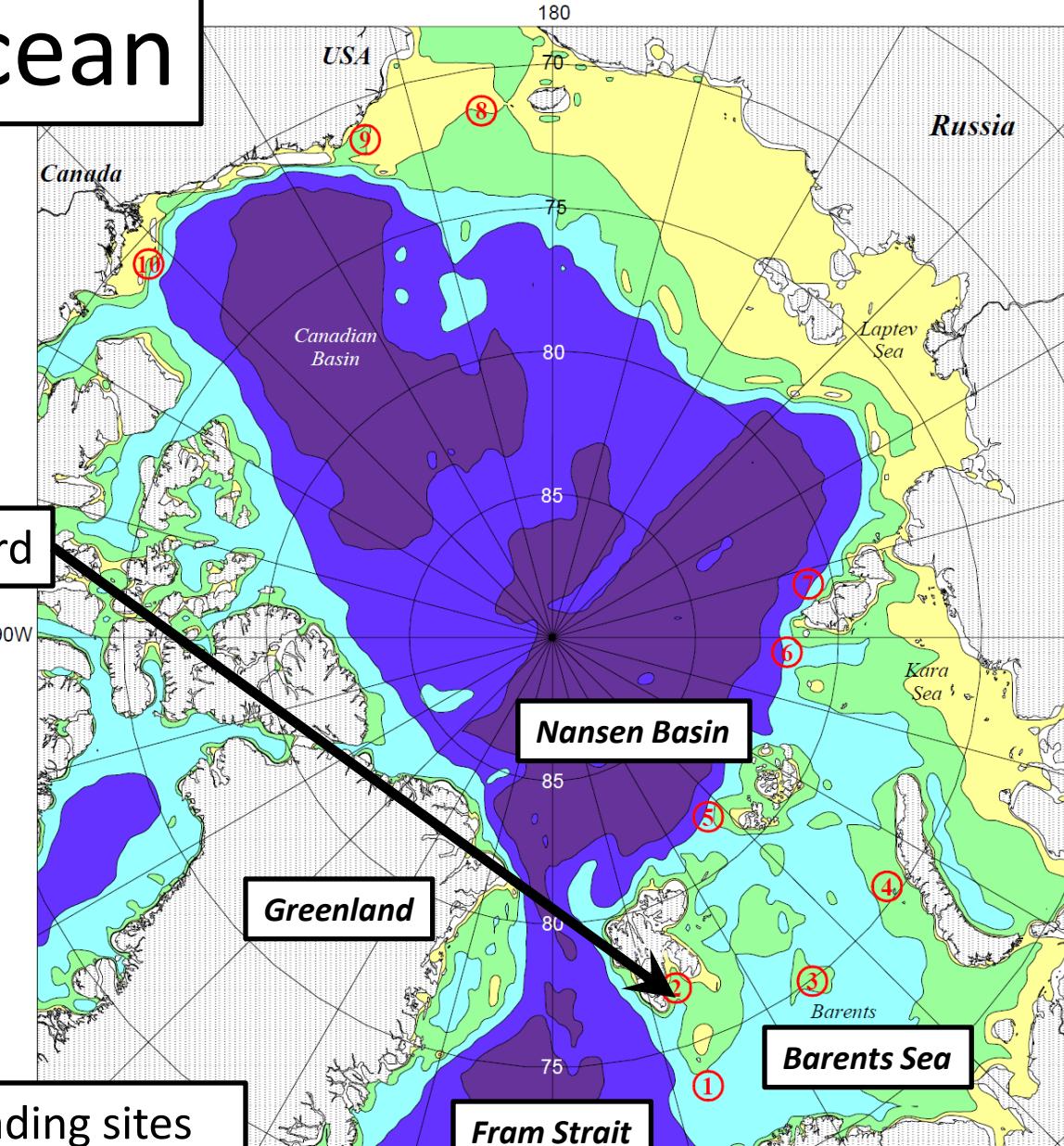
Challenger Conference for Marine Science

7th September 2010

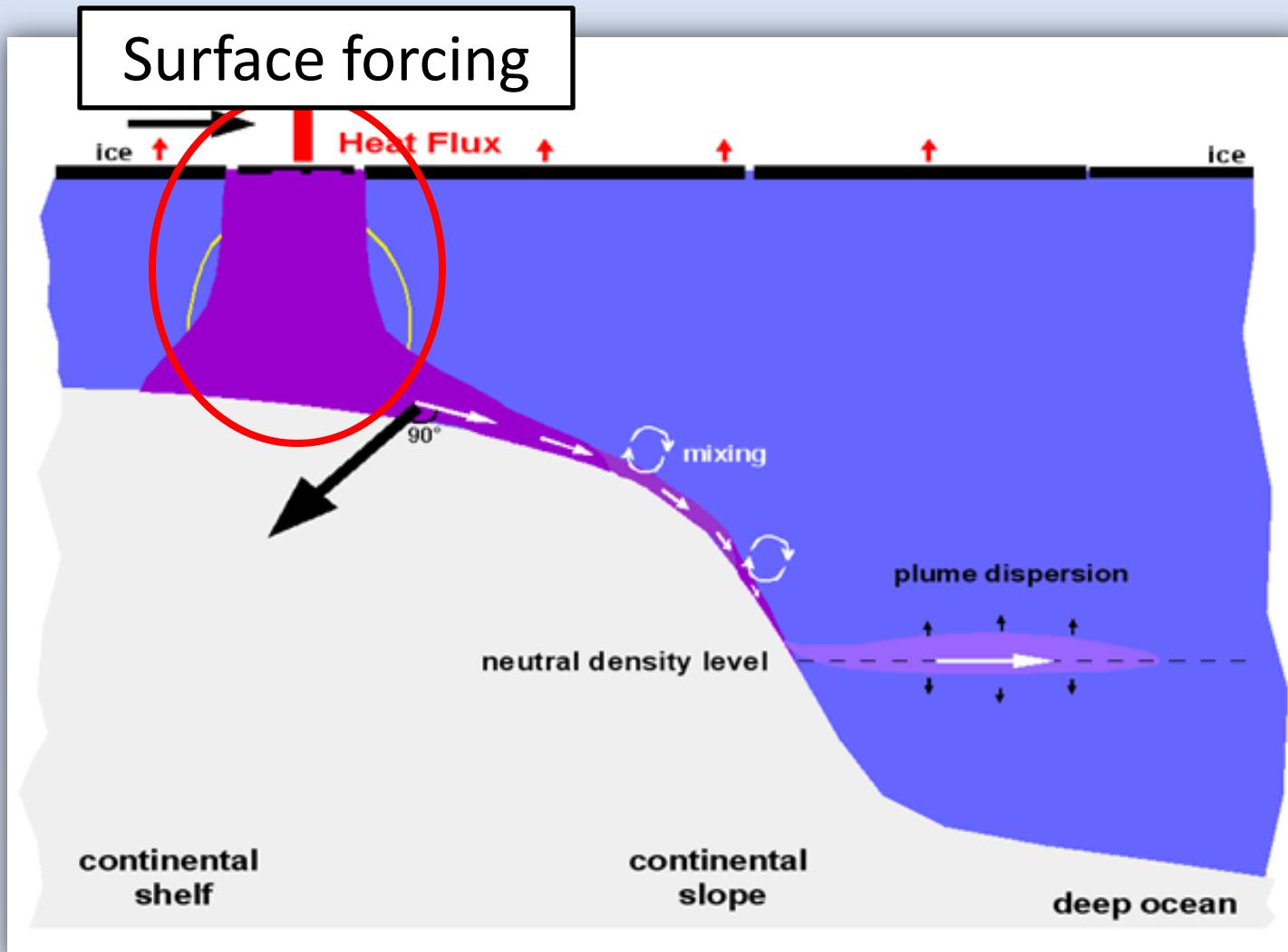
Ocean conveyor belt



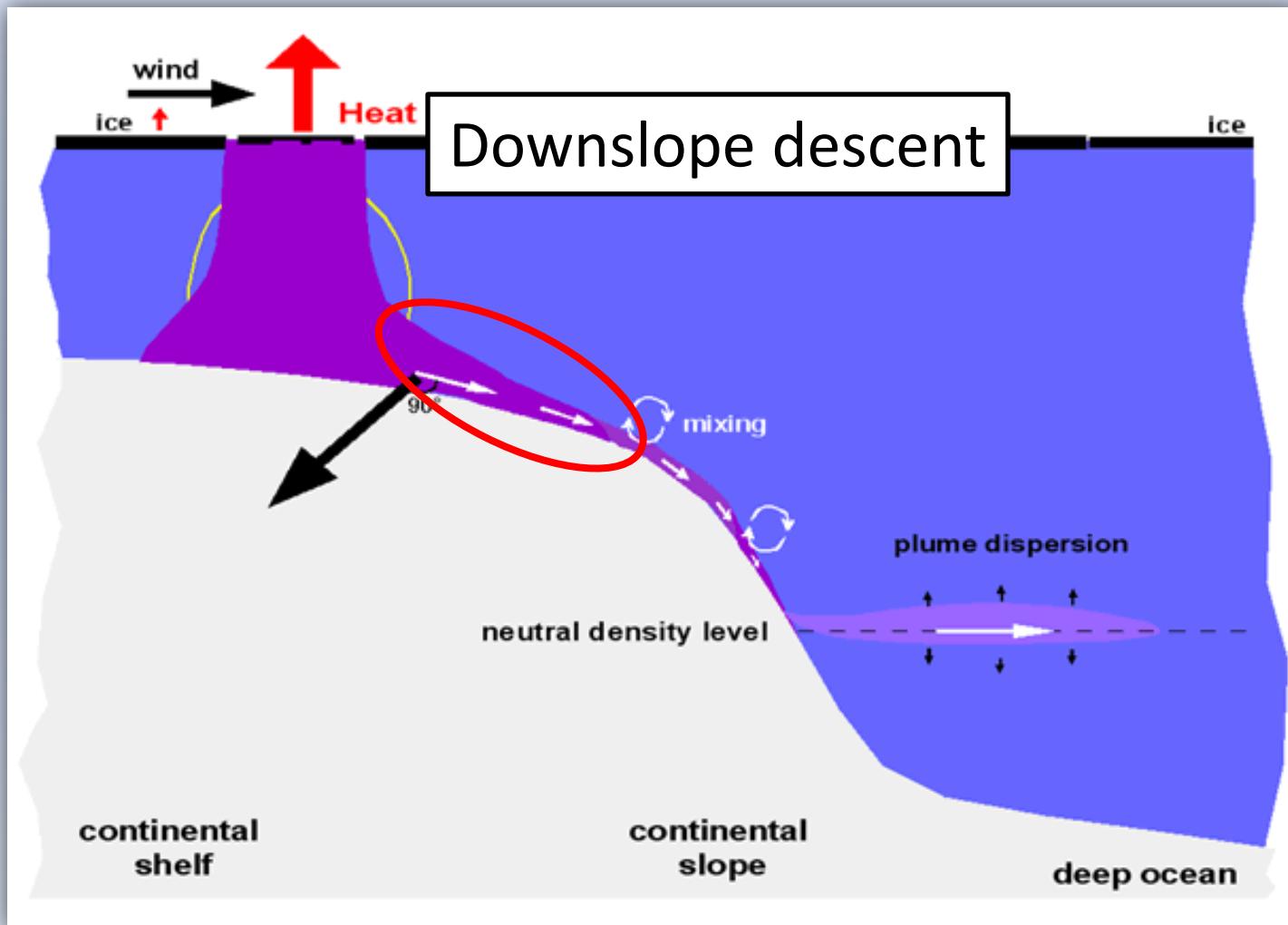
Arctic Ocean



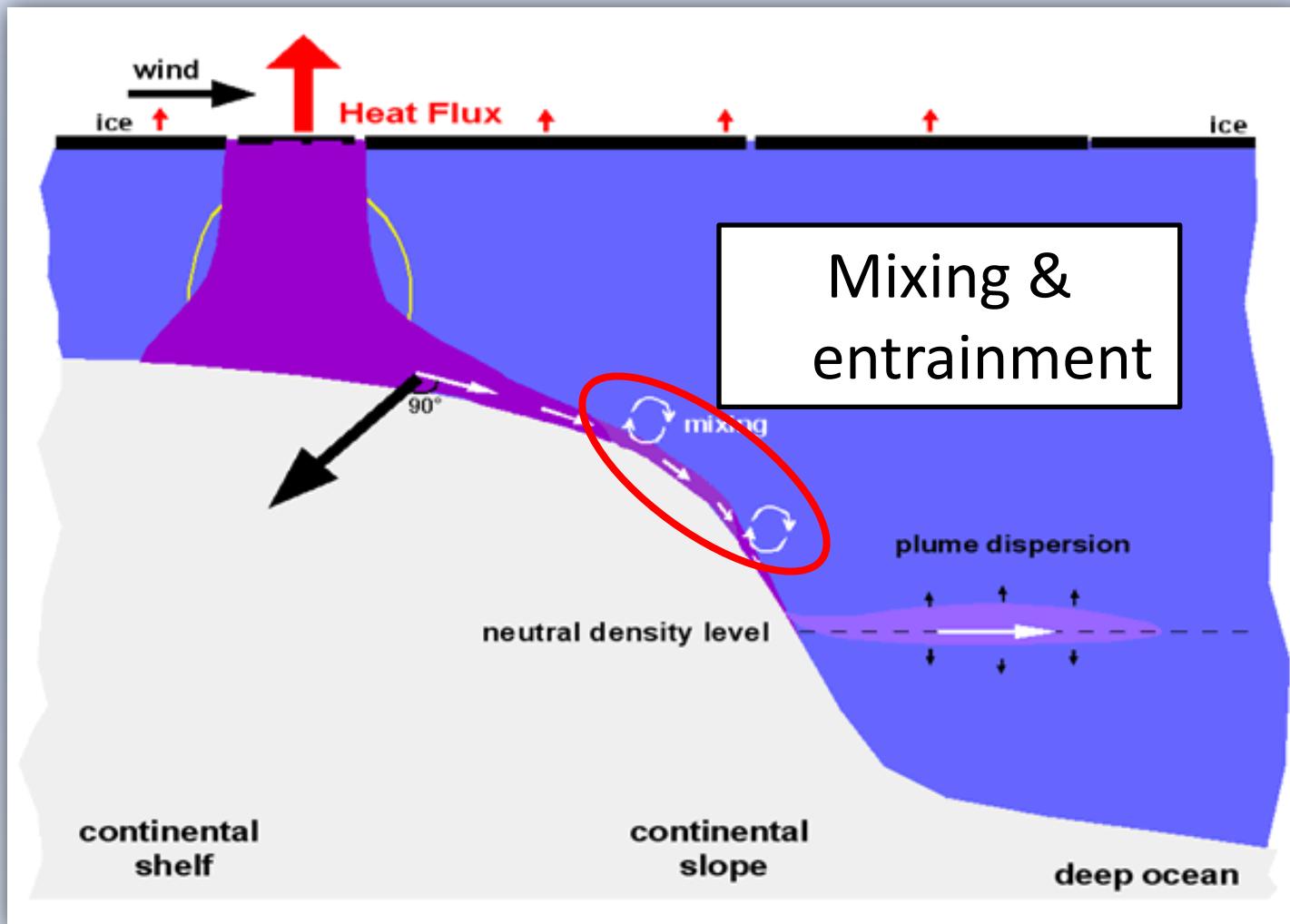
Dense water cascades



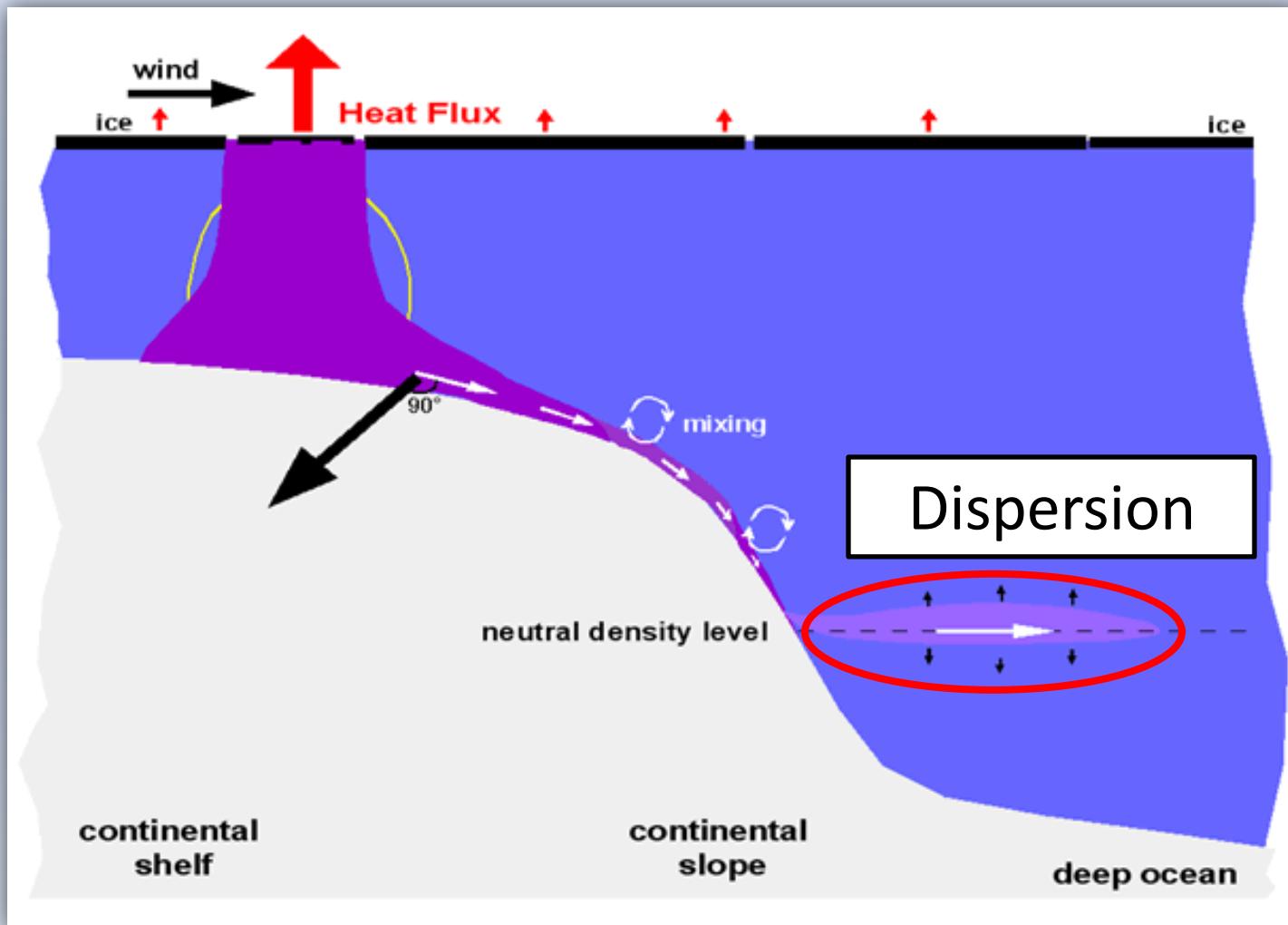
Dense water cascades



Dense water cascades



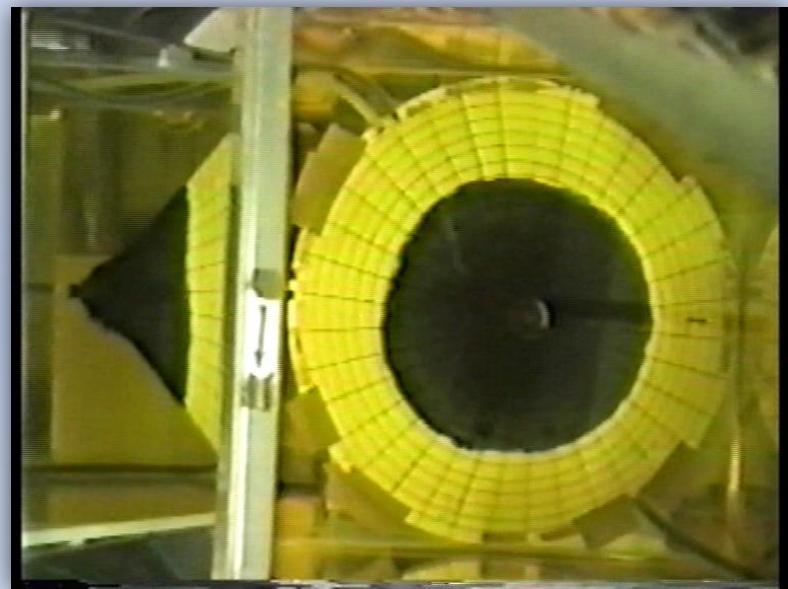
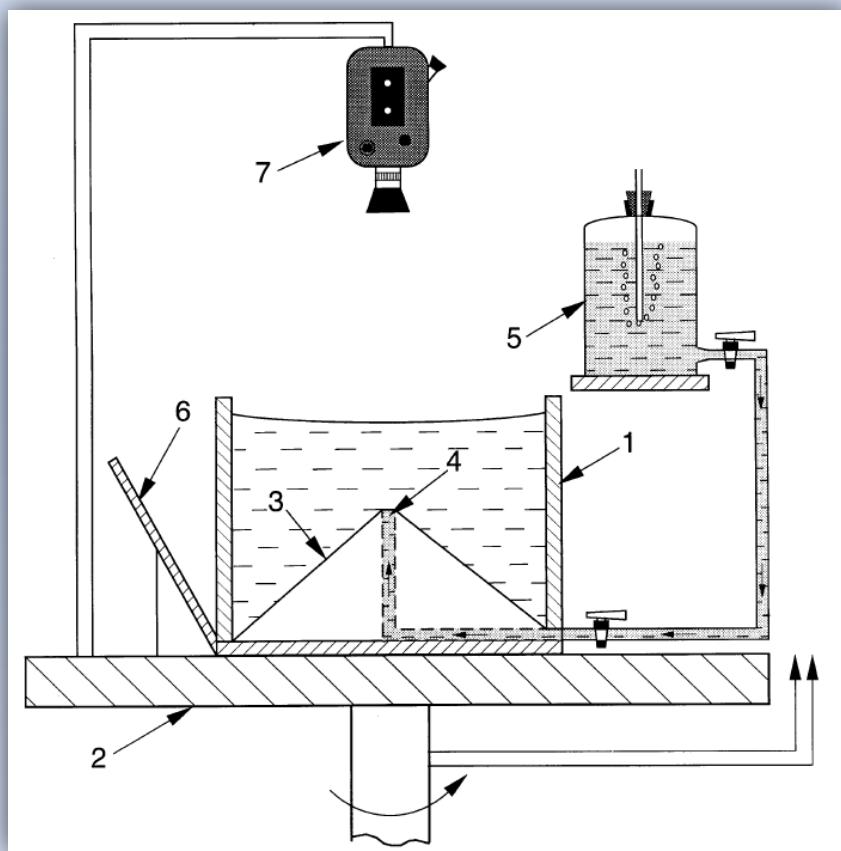
Dense water cascades



The problem

- Difficult to observe
 - Relatively small-scale, easily missed
 - Highly intermittent in space & time
- Difficult to model
 - Not resolved in global climate models
 - Turbulence, mixing and entrainment
 - Bottom friction
- **What are the important processes?**

Laboratory experiments

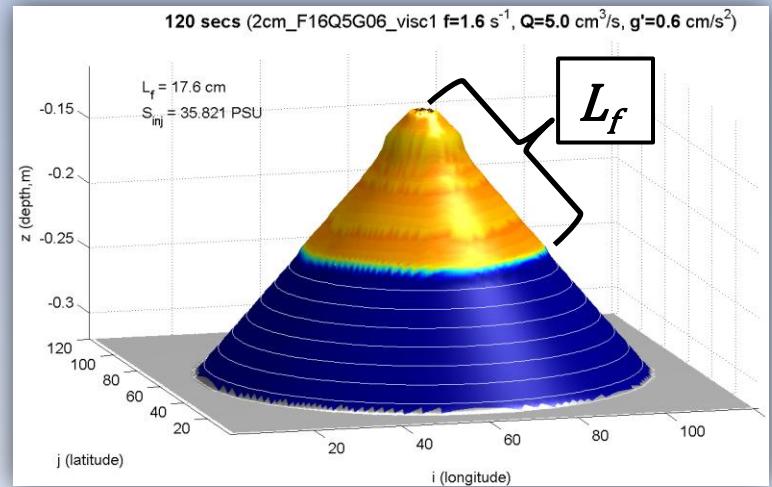
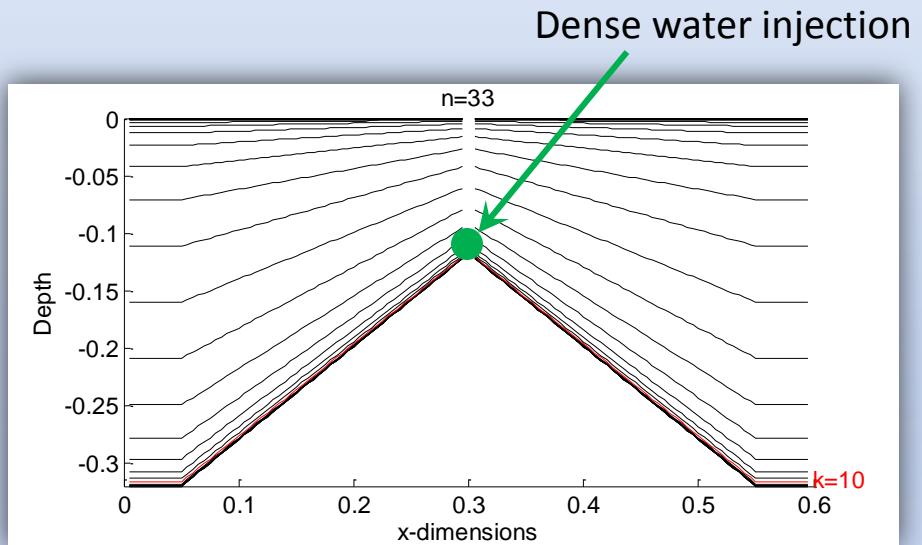


Experiment parameters

- Variables
 - Rotation rate f
 - Inflow rate Q
 - Reduced gravity $g' = g(\Delta\rho/\rho_0)$
- Fixed parameters
 - Slope angle θ
 - Kinematic viscosity ν

3D numerical model

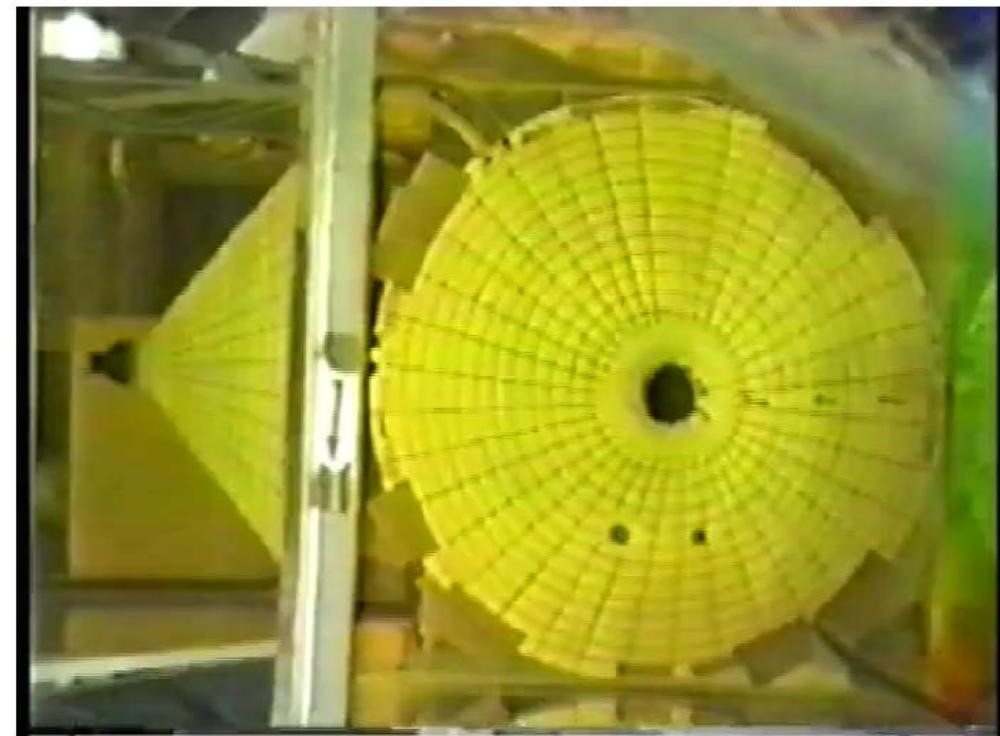
- POLCOMS
 - Hydrostatic model
 - Baroclinic B-grid
 - 120x120 nodes
 - $\Delta x = 5\text{mm}$
 - σ -coordinate system
 - 33 – 45 layers
 - $\Delta z = 0.1\text{mm} – 10\text{mm}$



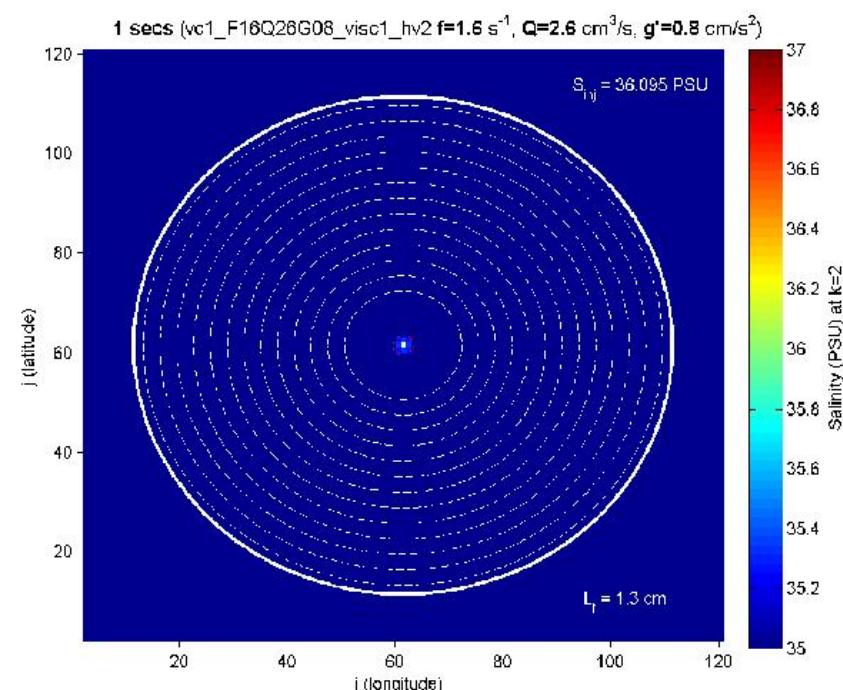
Model set-up

- Bottom boundary condition
- Horizontal/vertical resolution
 - Resolve bottom boundary layer
- Time step
 - CFL-condition
- Coriolis scheme
- ‘Injection’ of dense water
 - Into σ -layers spanning $3 \times$ Ekman depth

Qualitative comparison (video)

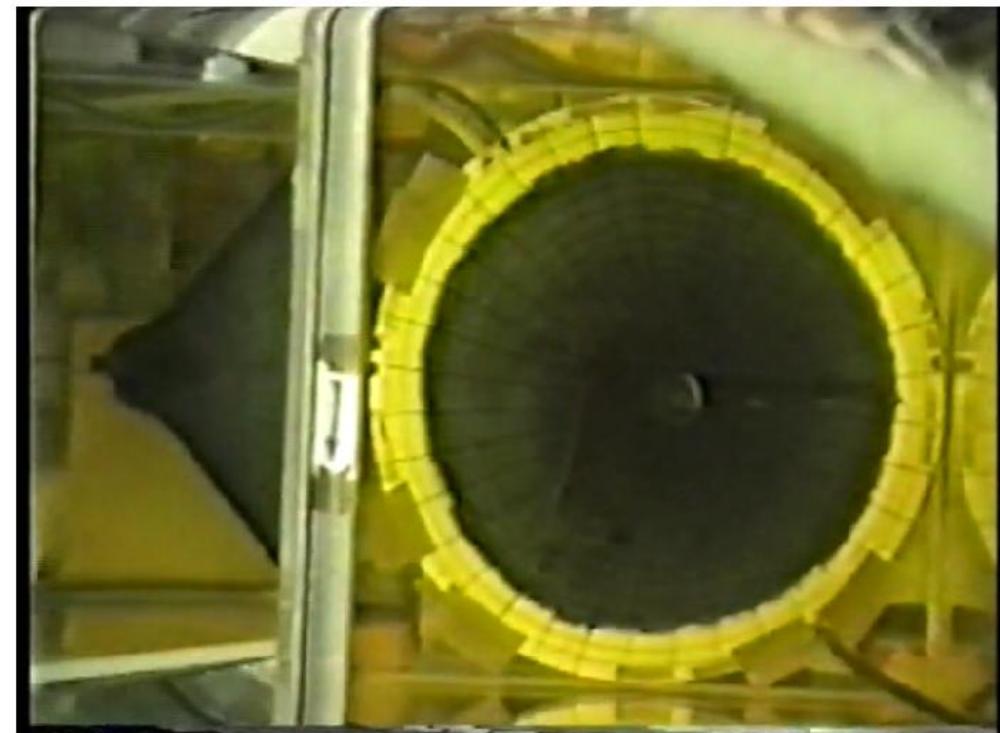


Laboratory

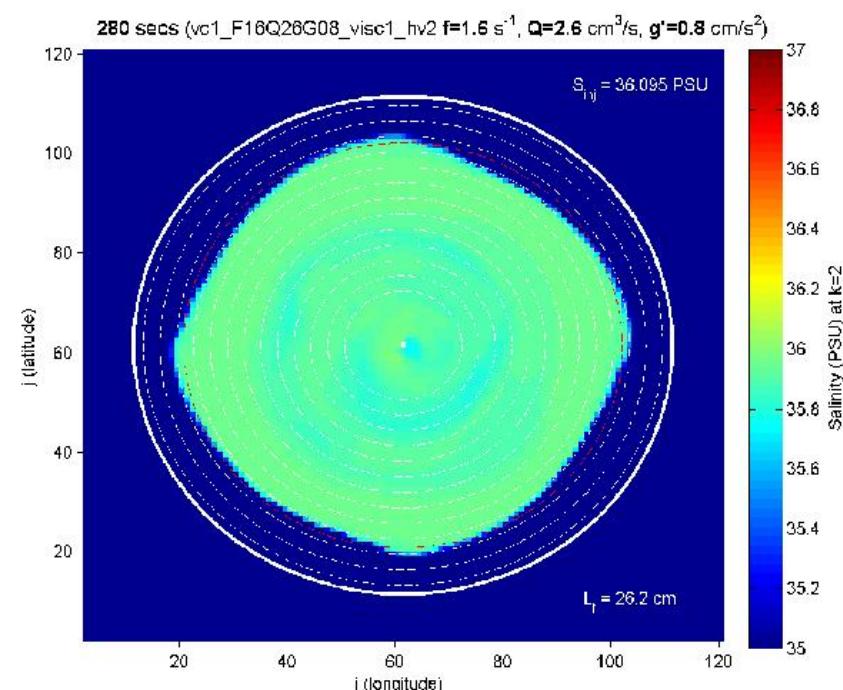


Model

Qualitative comparison (video)

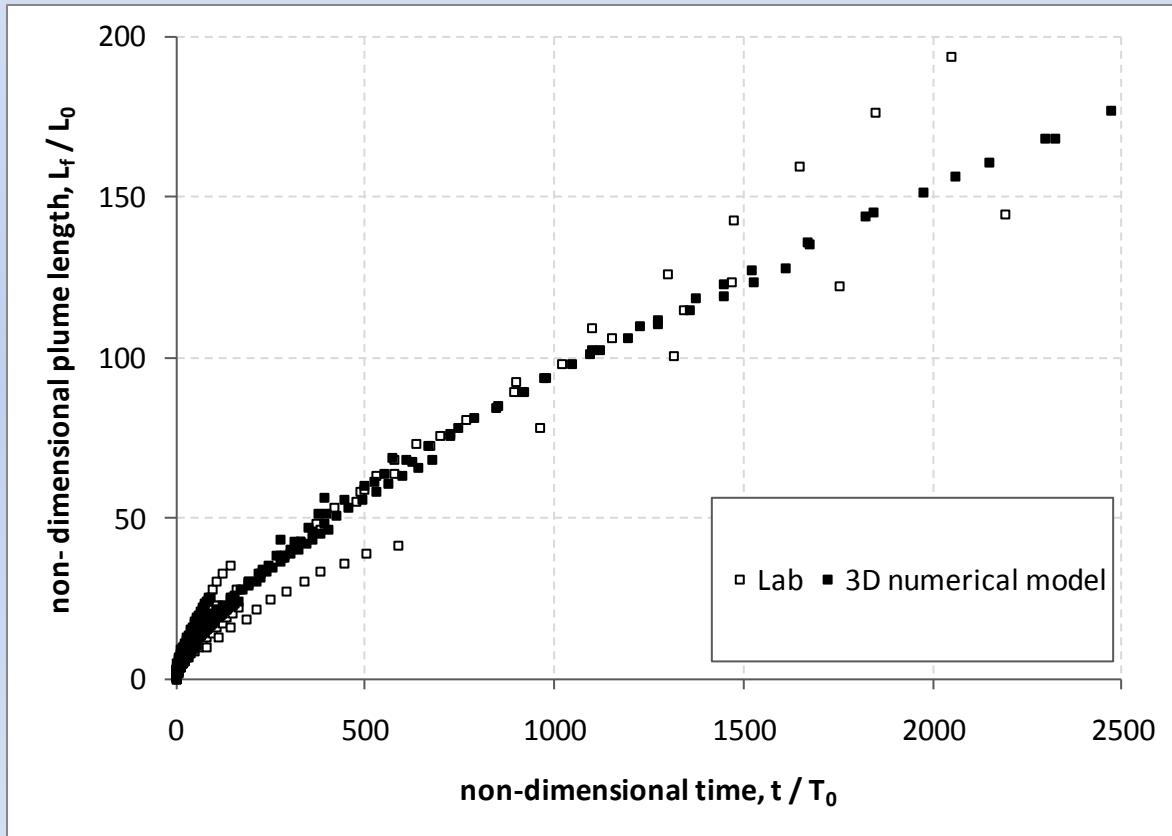


Laboratory



Model

Comparison Lab vs. Model



Non-dimensional coordinates

$$L_0 = \frac{Q}{2\pi H_E V_g G_m \cos \theta}$$

$$T_0 = \frac{\sqrt{2}L_0}{V_g}$$

$$V_g = \frac{g'}{f} \tan \theta$$

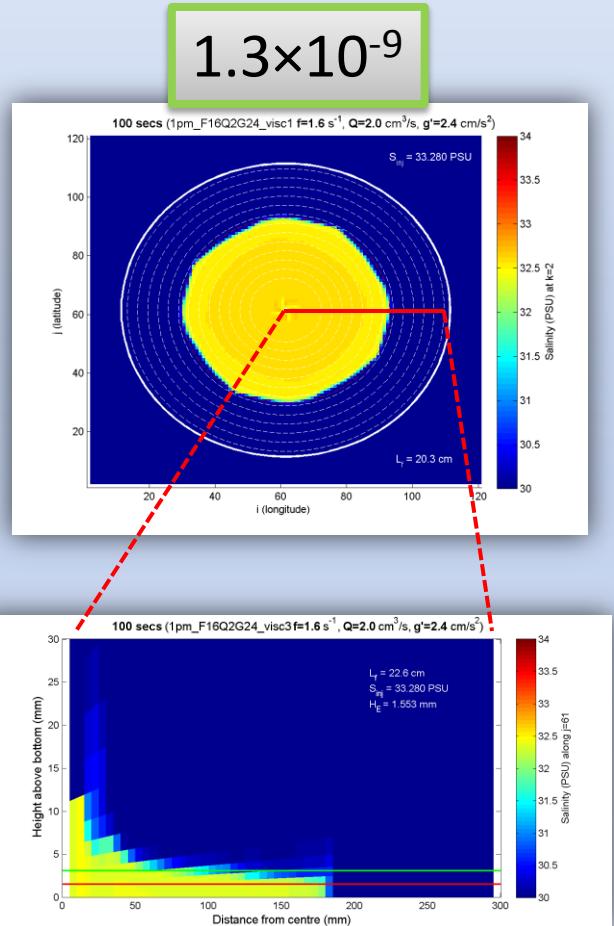
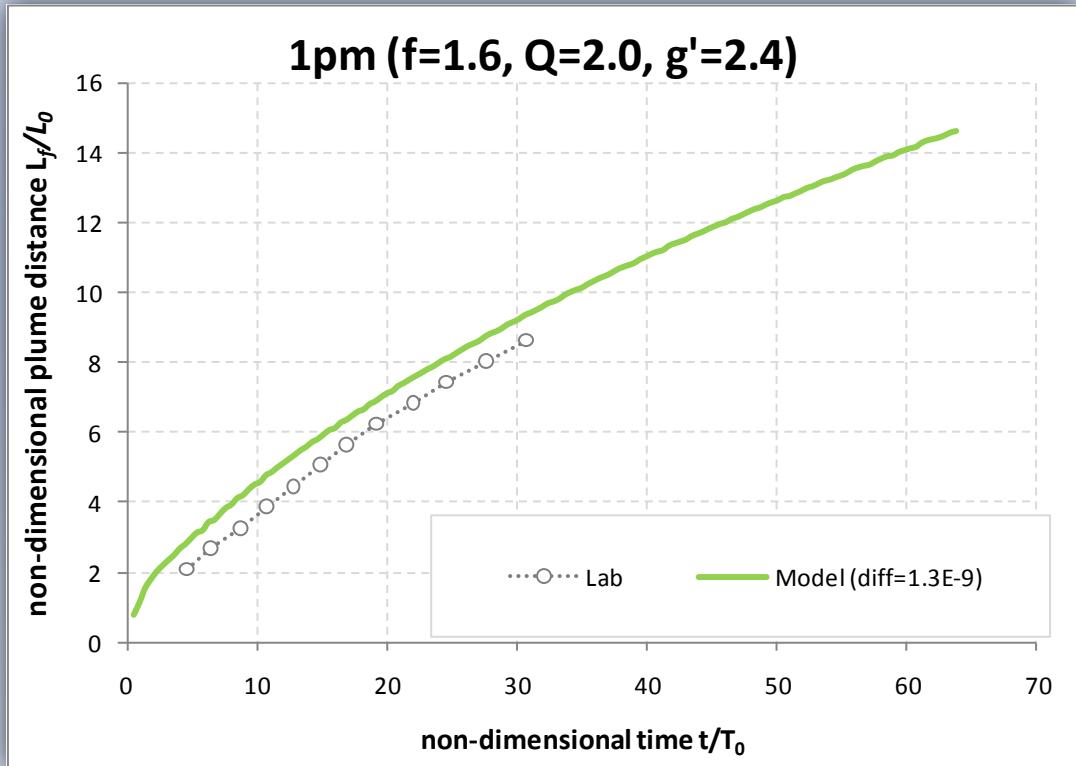
$$H_E = \sqrt{v/f \cos \theta}$$

$$G_m \approx 1.12$$

Model physics #1 - Diffusivity

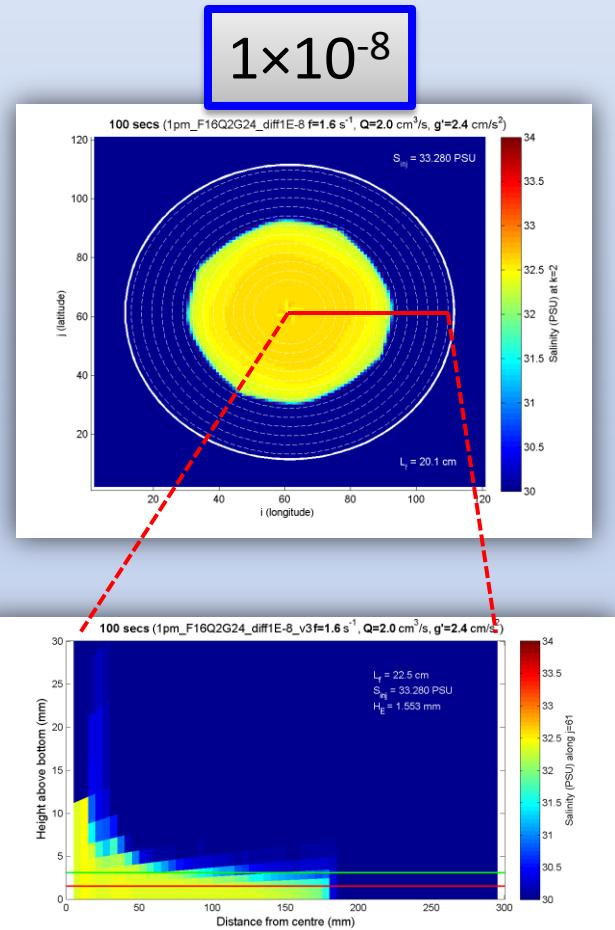
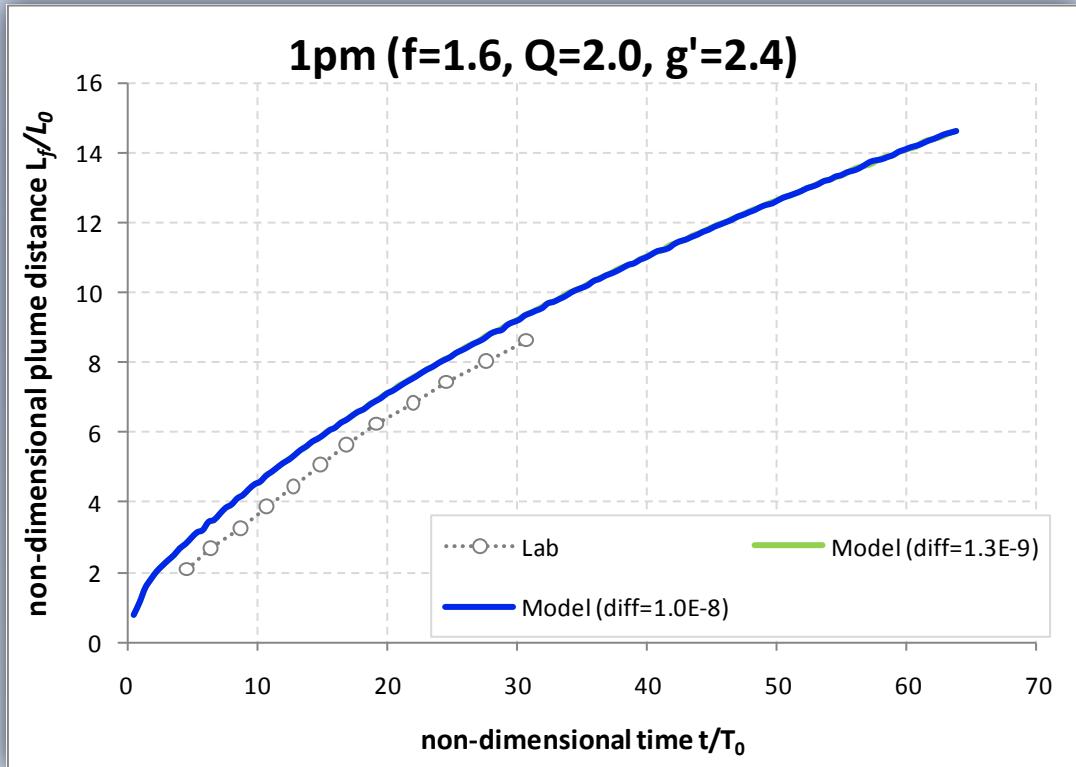
- Increasing vertical **diffusivity**
 - Increases diapycnal mixing (lower density contrast)
 - More diffuse plume → descent speed should eventually slow down (in dimensional co-ordinates)
 - physical assumptions of simplified model are for 2-layer system, not for stratified environment of a diffuse plume

Vertical Diffusivity



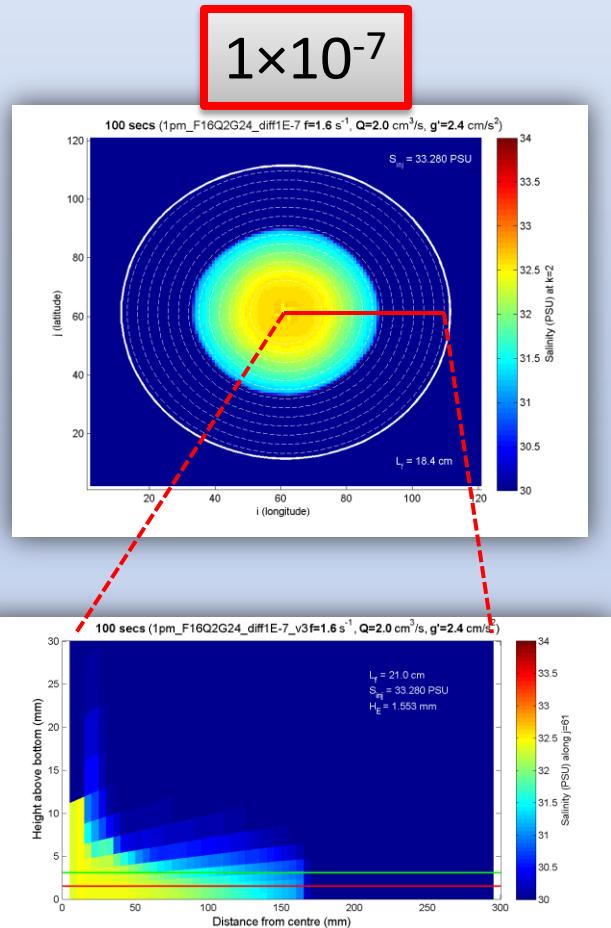
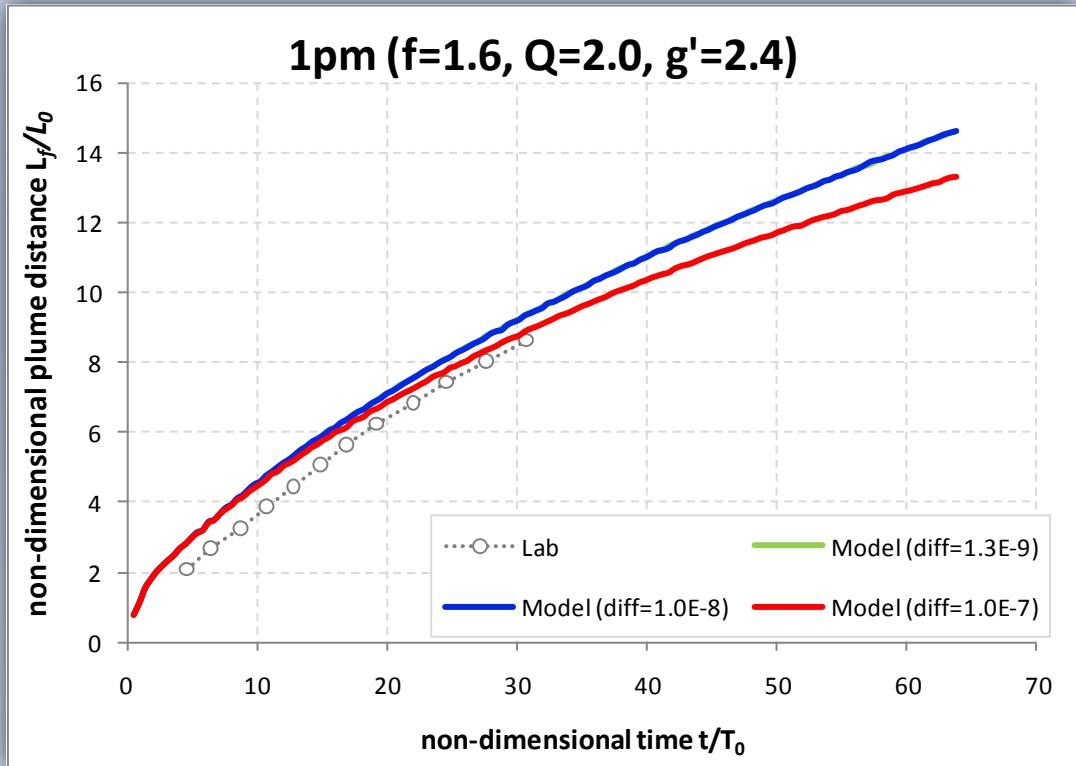
Values in $\text{m}^2 \text{s}^{-1}$

Vertical Diffusivity



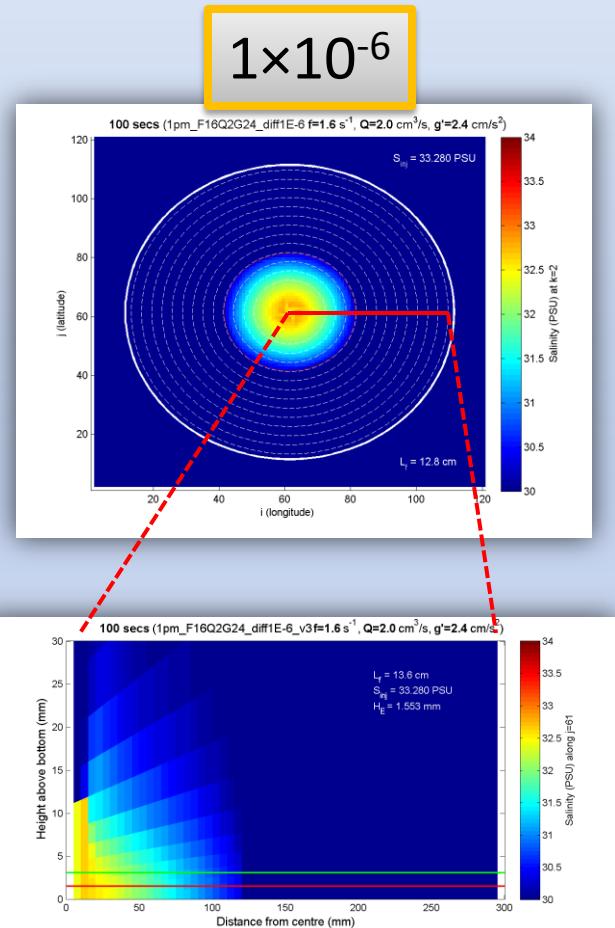
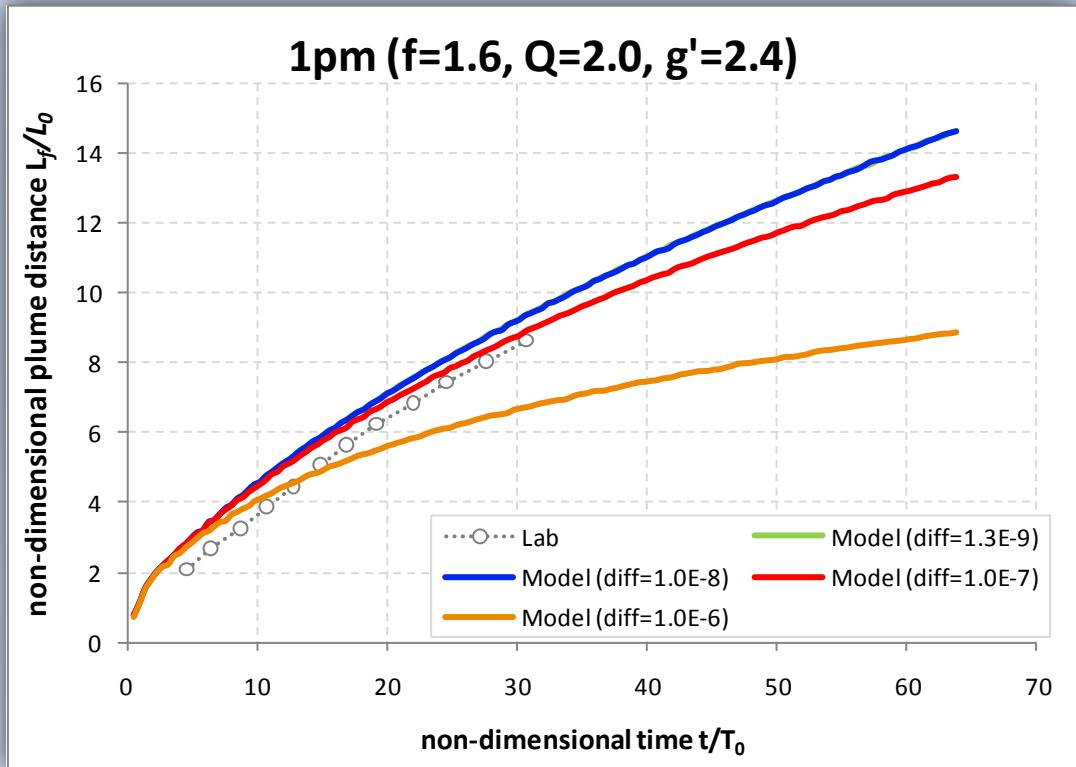
Values in $\text{m}^2 \text{s}^{-1}$

Vertical Diffusivity



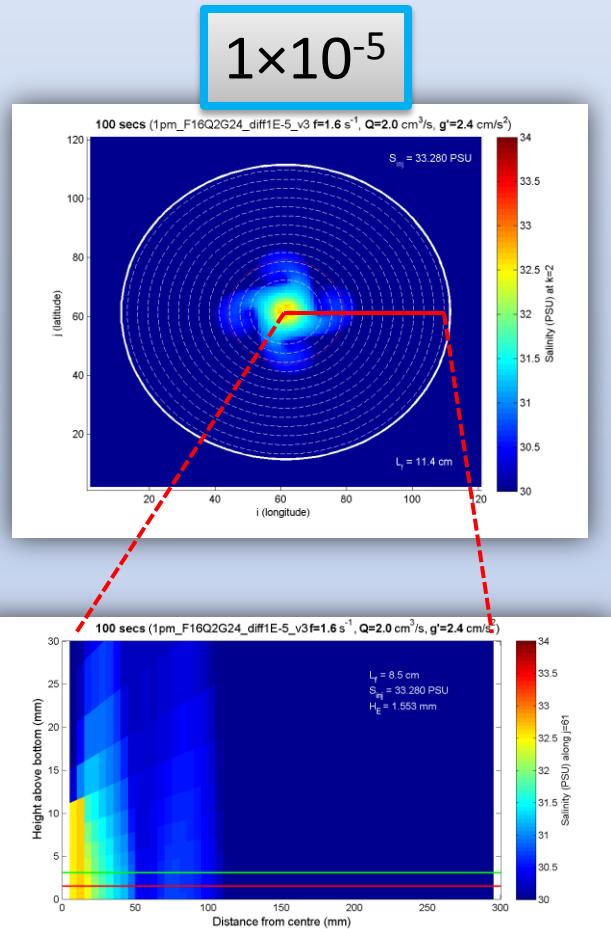
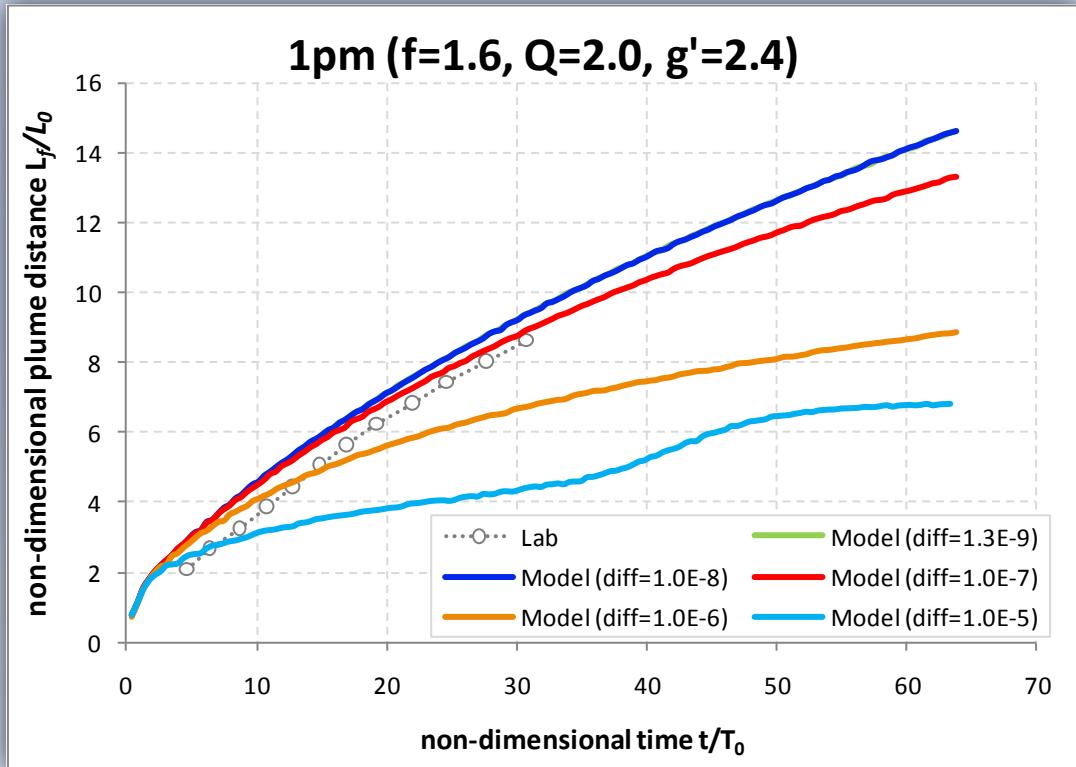
Values in $\text{m}^2 \text{s}^{-1}$

Vertical Diffusivity



Values in $\text{m}^2 \text{s}^{-1}$

Vertical Diffusivity

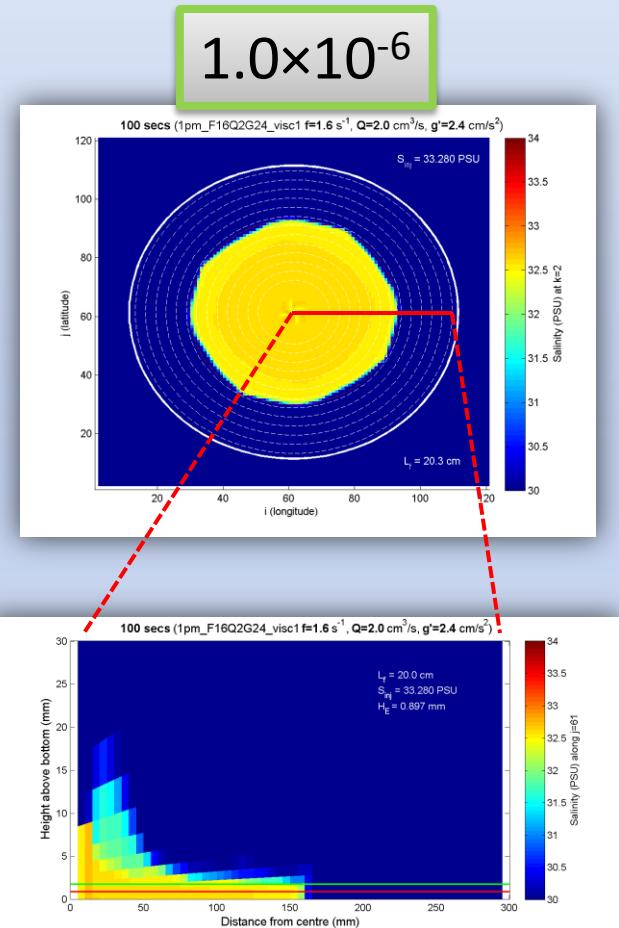
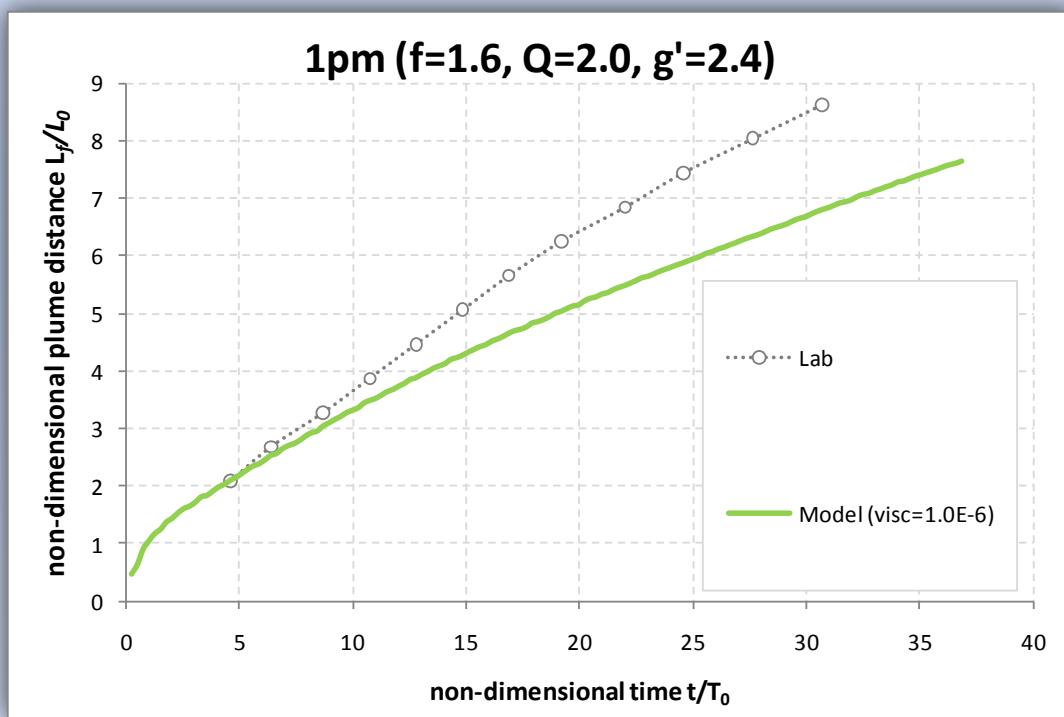


Values in $\text{m}^2 \text{s}^{-1}$

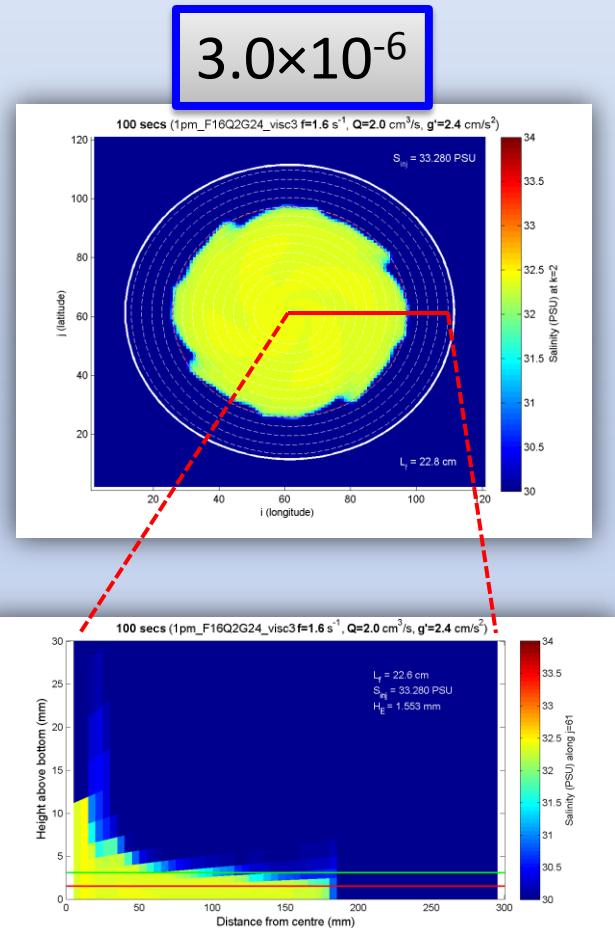
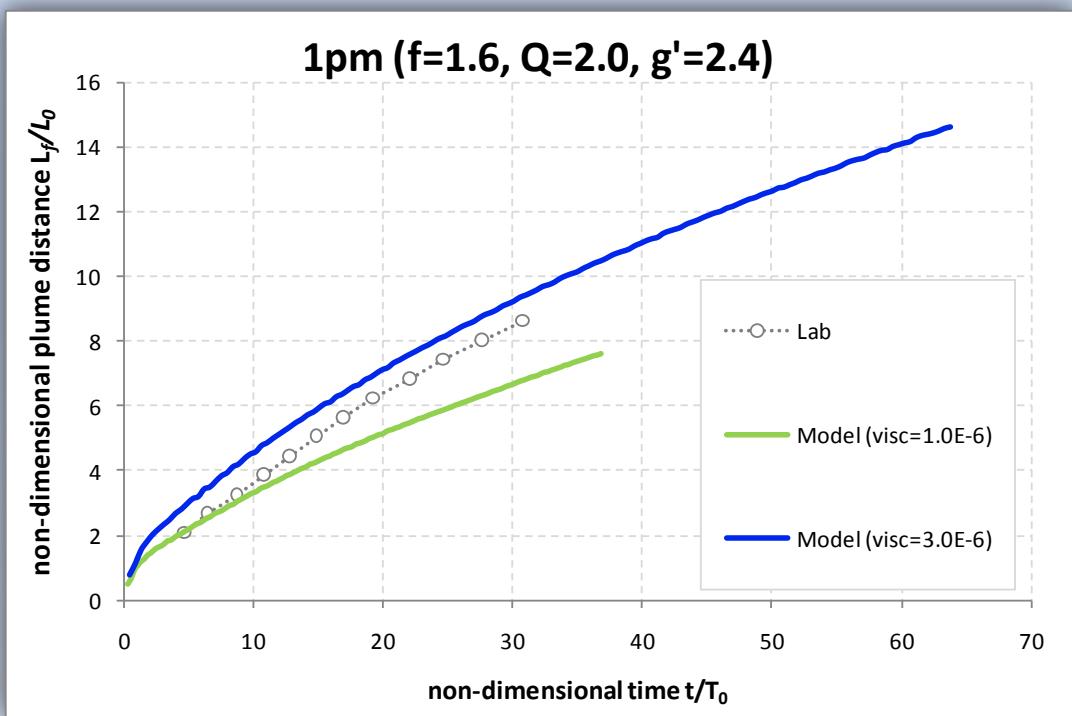
Model physics #2 - Viscosity

- Increasing vertical **viscosity**
 - Increases the thickness of bottom Ekman layer
 - Non-dimensionalisation includes viscosity
 - Thicker plume → descent speed should follow the same curve in non-dimensional space until underlying physical assumptions of simplified model are broken

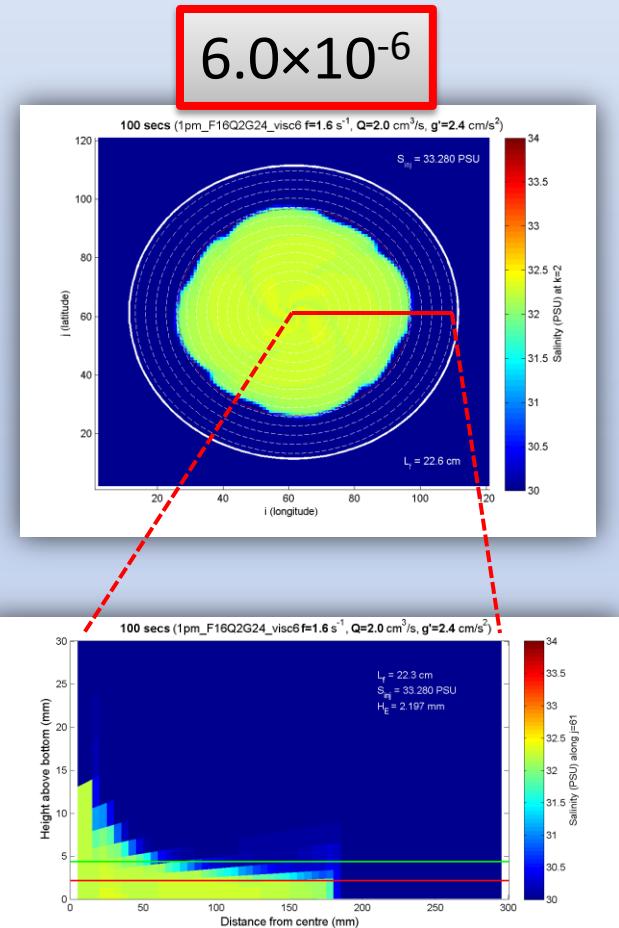
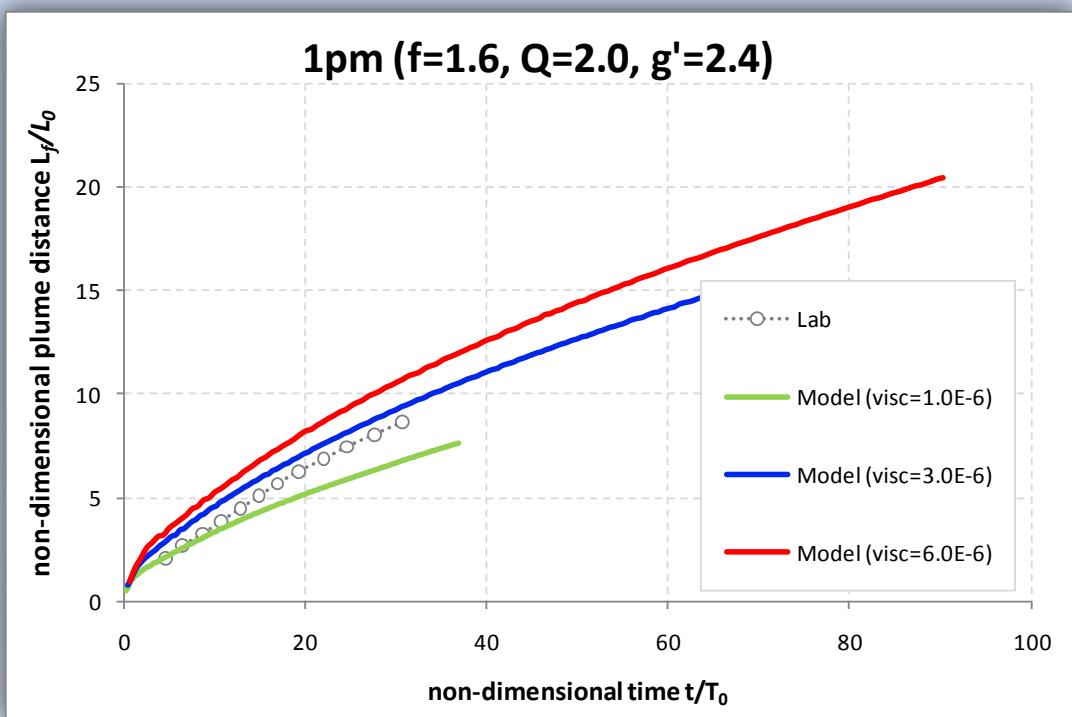
Vertical viscosity



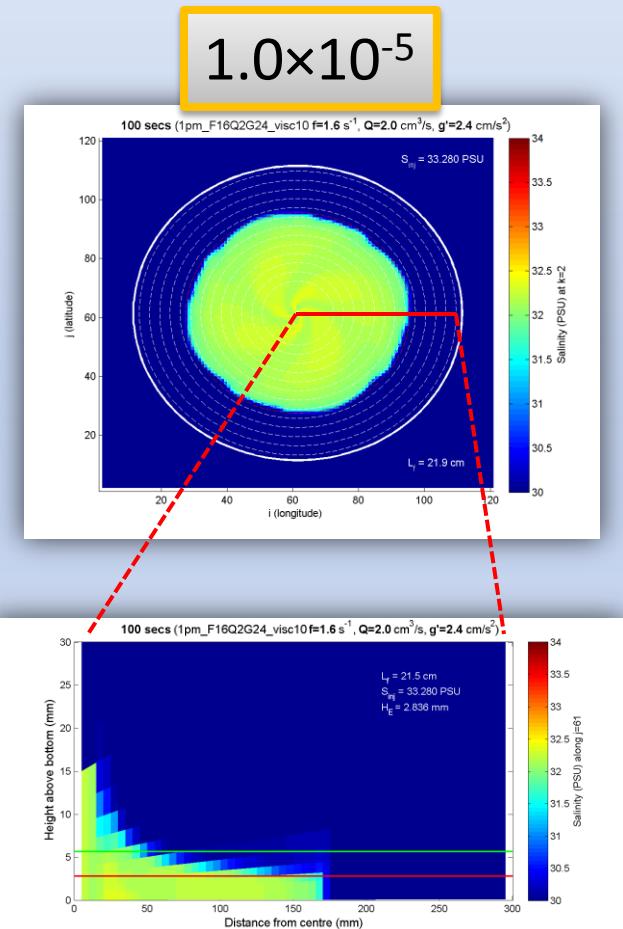
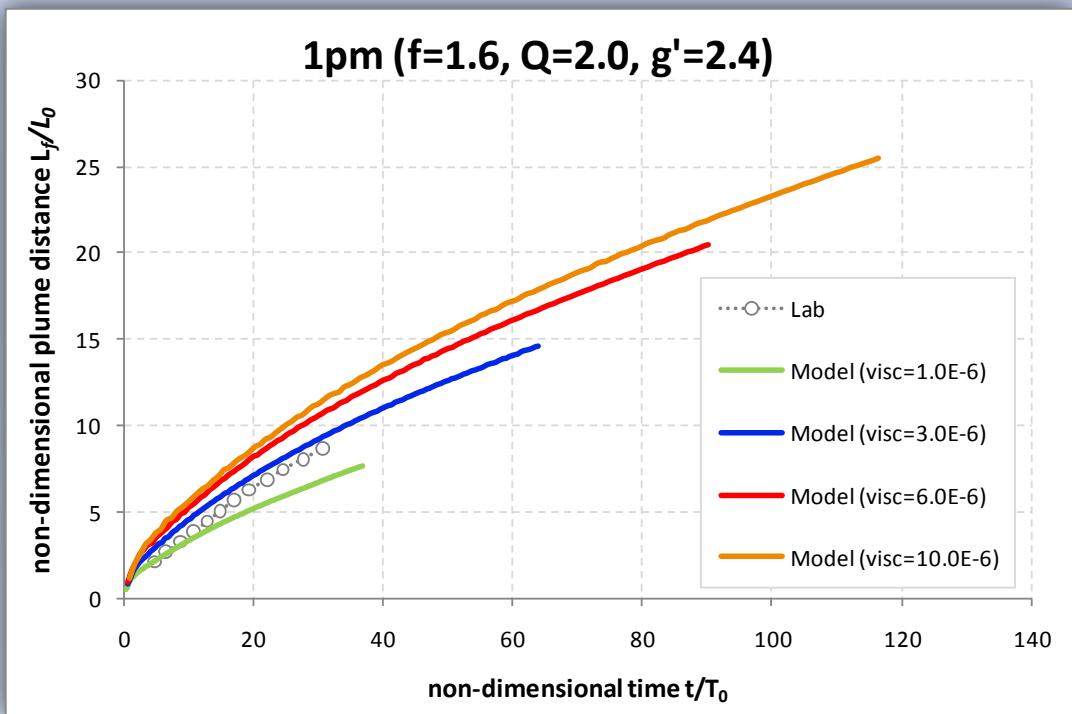
Vertical viscosity



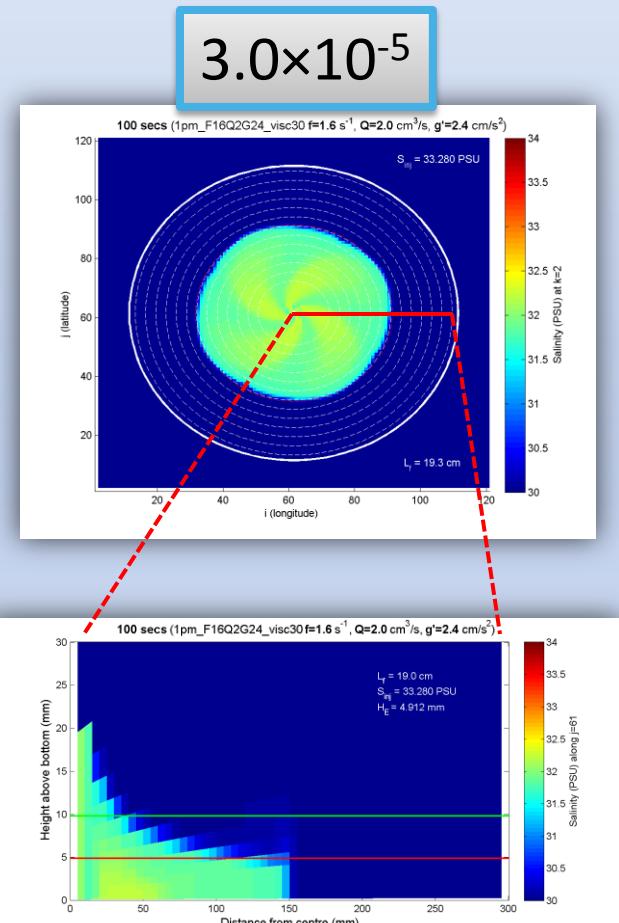
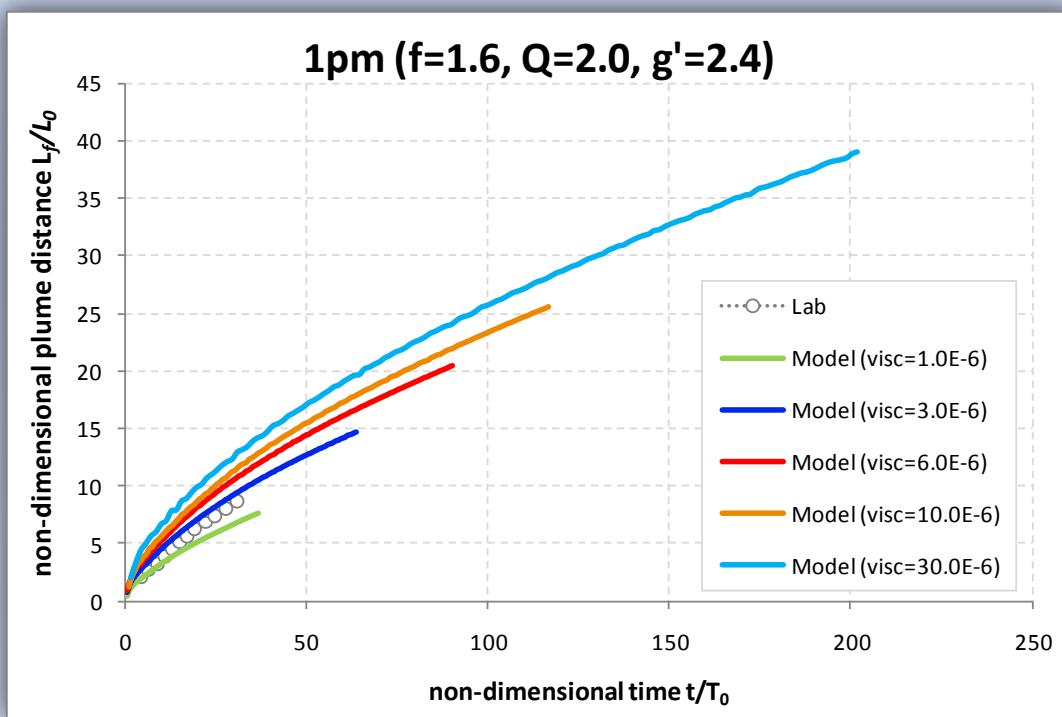
Vertical viscosity



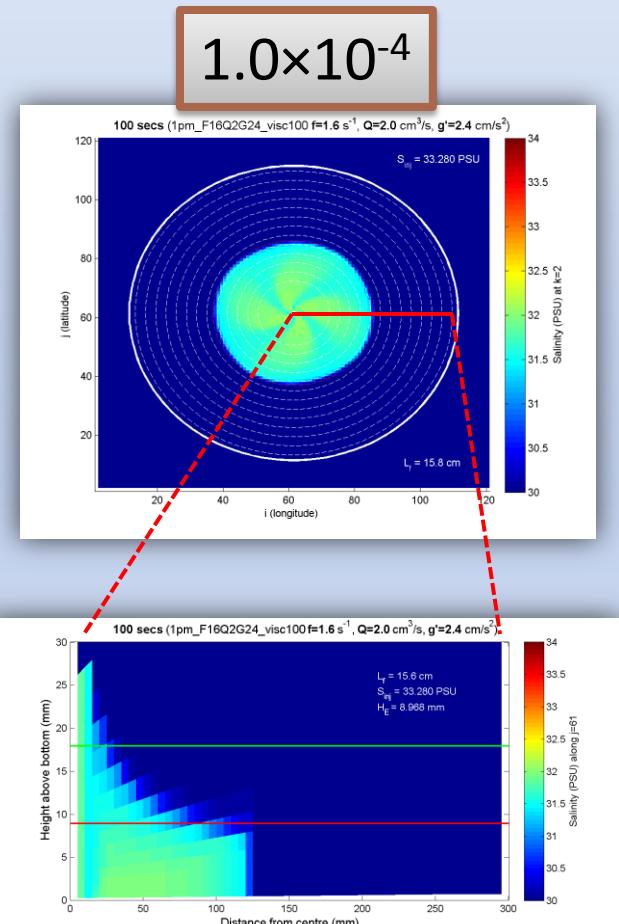
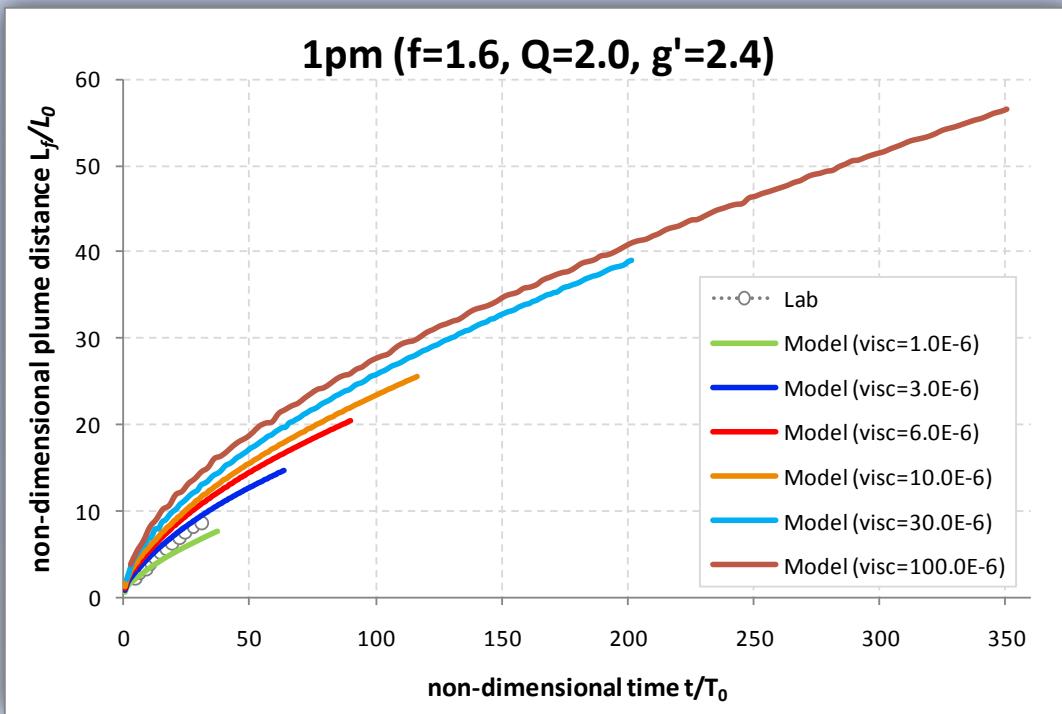
Vertical viscosity



Vertical viscosity



Vertical viscosity



Conclusions

- Hydrostatic model agrees well with laboratory
 - Good qualitative agreement
 - Validation by non-dimensional parameters
- Physics in the model behaves as expected
- Ekman dynamics
 - Very important to resolve bottom bound. layer
 - Thickness of Ekman layer affects propagation

Further research

- downslope transport capacity
 - bottom and interfacial Ekman layers
- model cascading in the Arctic Ocean
 - Example: Storfjorden cascade (Svalbard)
- **Influence on larger-scale ocean circulation?**

Thank You

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- Ivanov, V. V., Shapiro, G. I., Huthnance, J. M., Aleynik, D. L. and Golovin, P. N. 2004. Cascades of dense water around the world ocean. *Progress In Oceanography*, **60**, (1), 47-98.

Abstract

Simulating laboratory experiments of dense water cascades: a sensitivity study

The sinking of dense shelf waters down the continental slope – “cascading” – contributes to shelf-ocean exchange, ventilation of oceanic intermediate and abyssal layers and off-shelf carbon transport in the Arctic Ocean where dense waters form by brine ejection and surface cooling. Cascading over steep bottom topography is studied here in numerical experiments using POLCOMS. The model setup is based on laboratory experiments where a solid cone is placed in a rotating tank filled with water of constant density and a cascade is simulated by the injection of dense water at the tip of the cone. The down-slope propagation of the plume is expressed as the distance of the front from the cone tip, L_f , as a function of time which is studied for various physical and numerical parameters. The physical parameters governing the experimental setup are the reduced gravity g' , the flow rate Q and the Coriolis parameter f . The evolution

of L_f over time is compared to the results of the original laboratory experiments in model setups using the values of g' , Q and f of the original experiments while the sensitivity to several numerical parameters is analysed. These include the time step Δt , the vertical resolution (i.e. number and spacing of σ -layers), different formulations of the bottom boundary condition and the Coriolis term, and the vertical diffusion of momentum (viscosity). Turbulent flows are not considered, horizontal diffusivity of salt and heat as well as the horizontal viscosity are set to molecular levels and the geometry of the cone and tank remain unchanged for all runs. The behaviour of the sinking plume is expressed in non-dimensional variables which successfully validated the model against the laboratory experiments. This makes the model a valuable tool for the study of dense water cascading in a larger-scale setup of the Arctic Ocean.