Dynamics of a dense gravity current flowing over a corrugation

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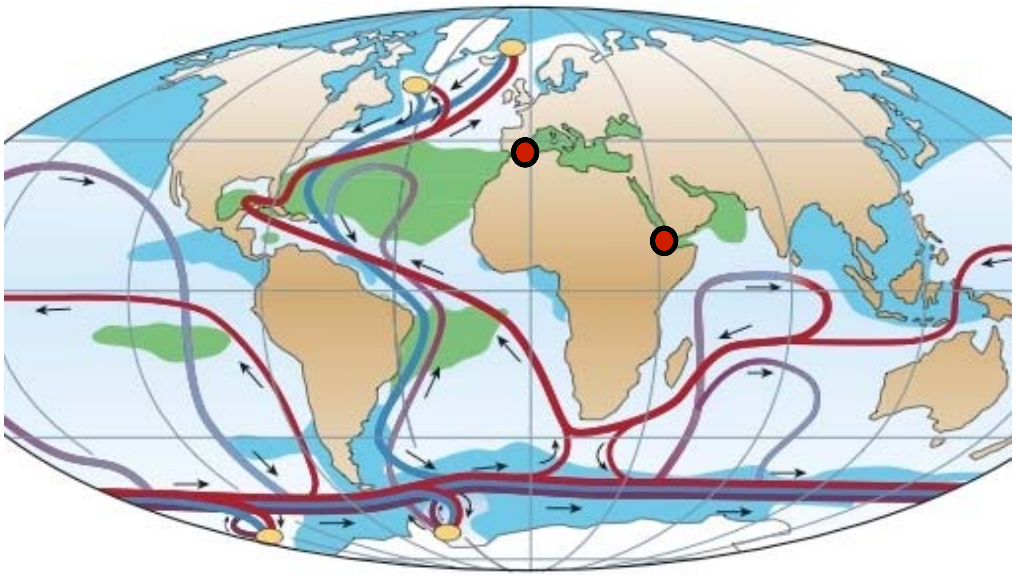
Outline

- Motivation
- Model setup
- Experiment with smooth topography
- Experiments with a single ridge/canyon
- Parameterization
- Conclusion

Motivation

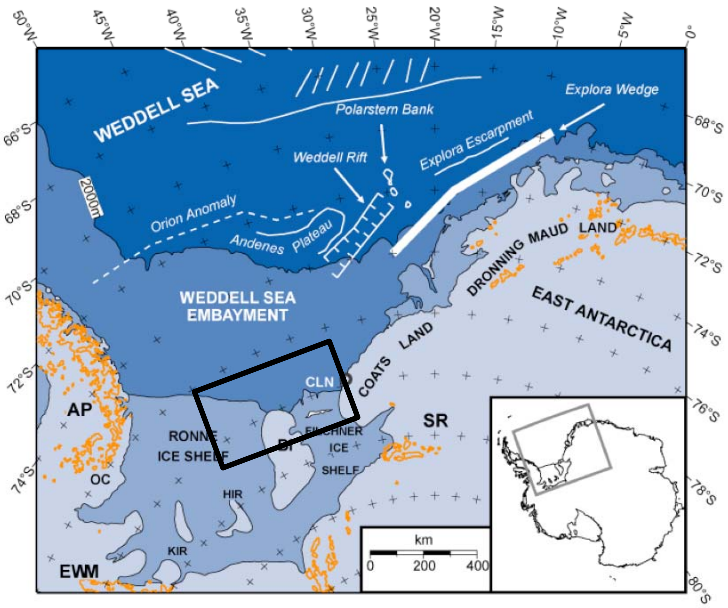


Rahmsdorf et al. (2002)

- Climate models are too coarse to resolve these ridges/canyons.
- How is the dense water transported and mixed over a corrugation?
- Is there a single parameter that describes the flow for different corrugations and different regimes?

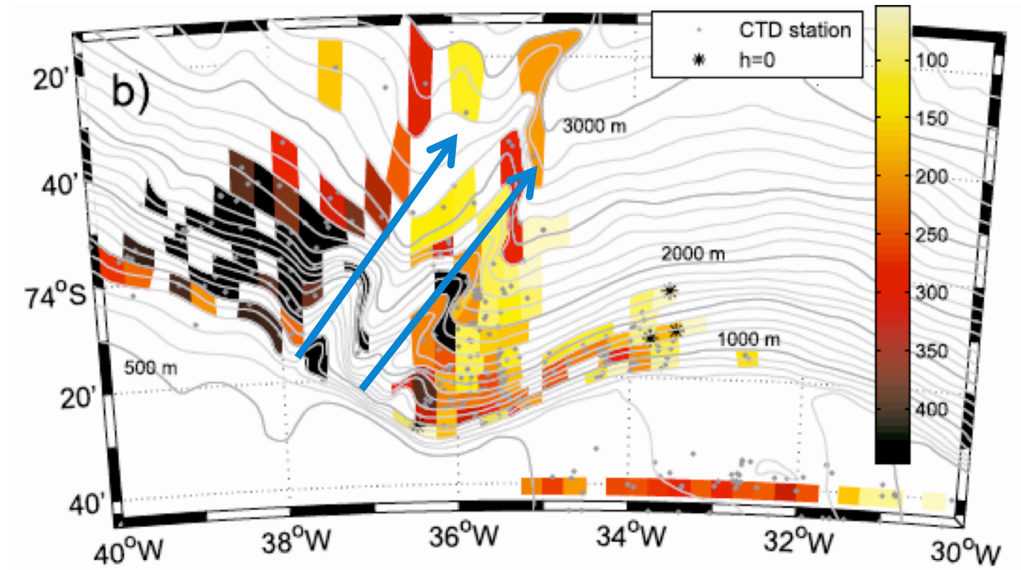
- Deep water formation is a key process for the ocean thermohaline circulation.
- “Many of the dense waters formed by oceanic convection, which are integral to the global MOC, must flow over ocean ridges or down continental slopes. The entrainment of ambient water around these topographic features is an important process determining the final properties and quantity of the deep waters.” IPCC AR4

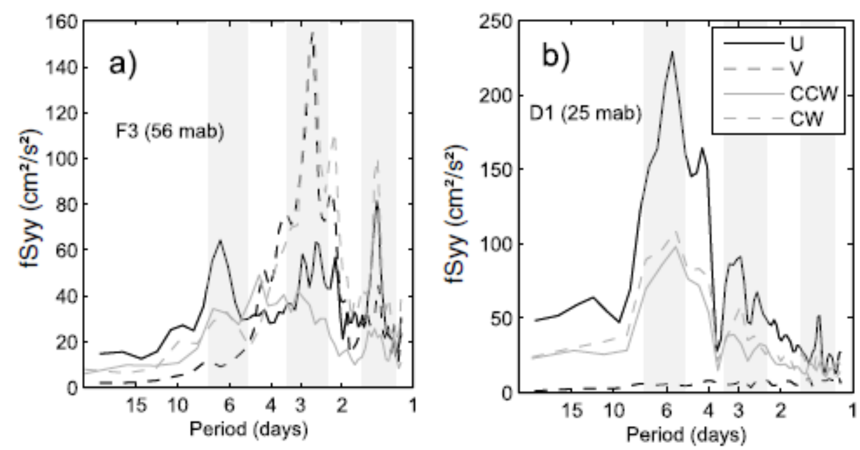
Motivation: Weddell Sea



http://www.ldeo.columbia.edu/~mstuding/weddell_map.html

Overflow thickness

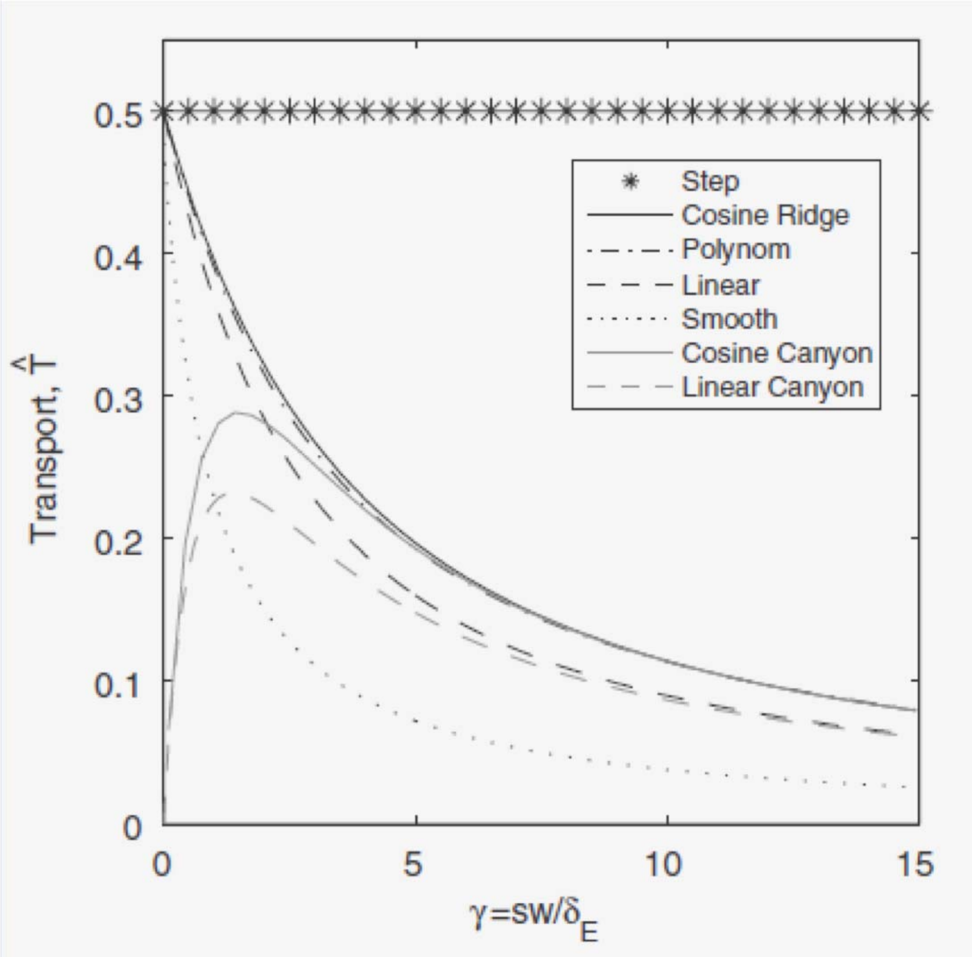




- Do the ridges steer the overflow offshore?
- Does the increase in thickness indicate mixing after the ridges?
- There are 3 distinguished frequencies in U, V, and T fields; 140, 70 and 35 hours. Why?

Darelius et al. (2009)

Analytical theory for a single obstacle

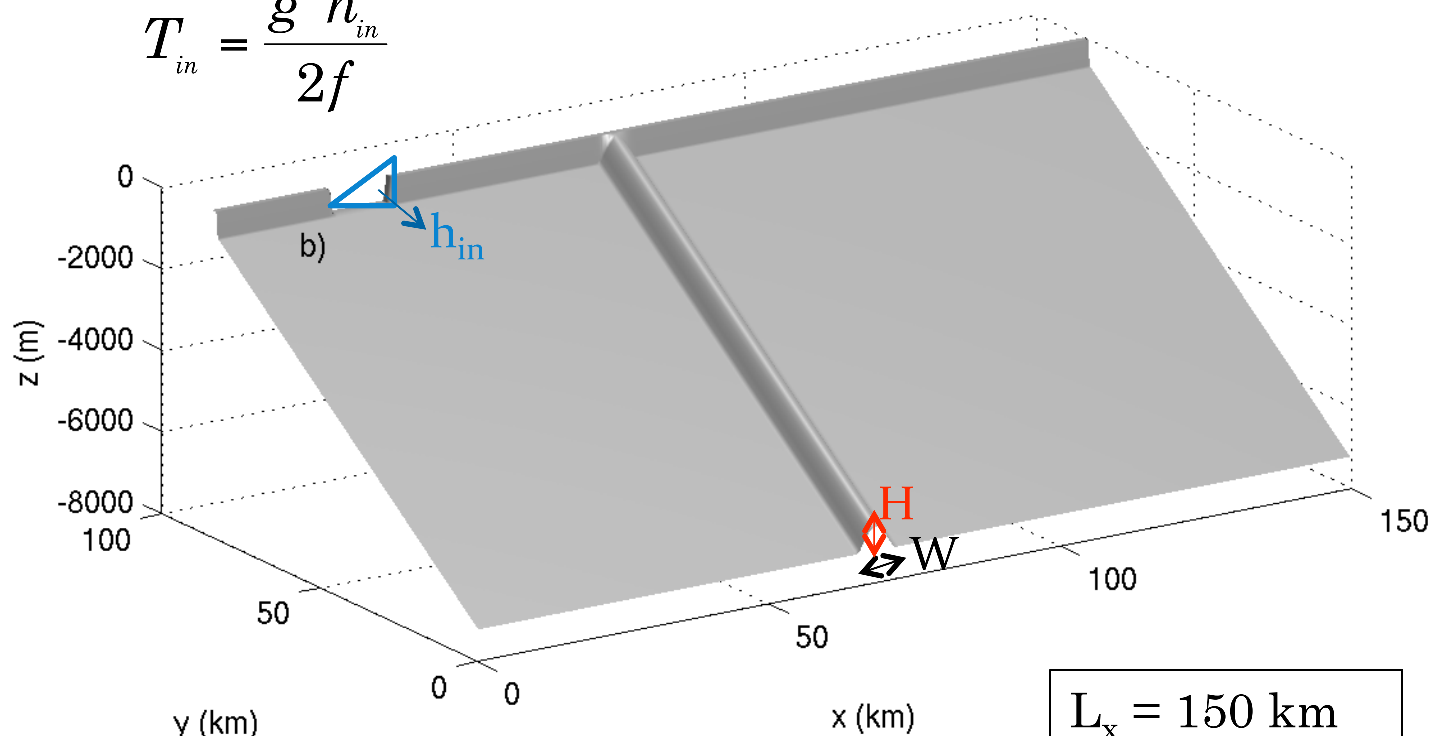


Darelius and Wahlin (2007)

- The overflow leaning on a ridge is governed by non-dimensional number $\gamma = sW/\delta_E$.
- The maximum downslope transport occurs at the corrugation with a step shape.
- Ridges are more effective than canyons to transport the gravity current downslope.

Model Setup

$$T_{in} = \frac{g' h_{in}^2}{2f}$$

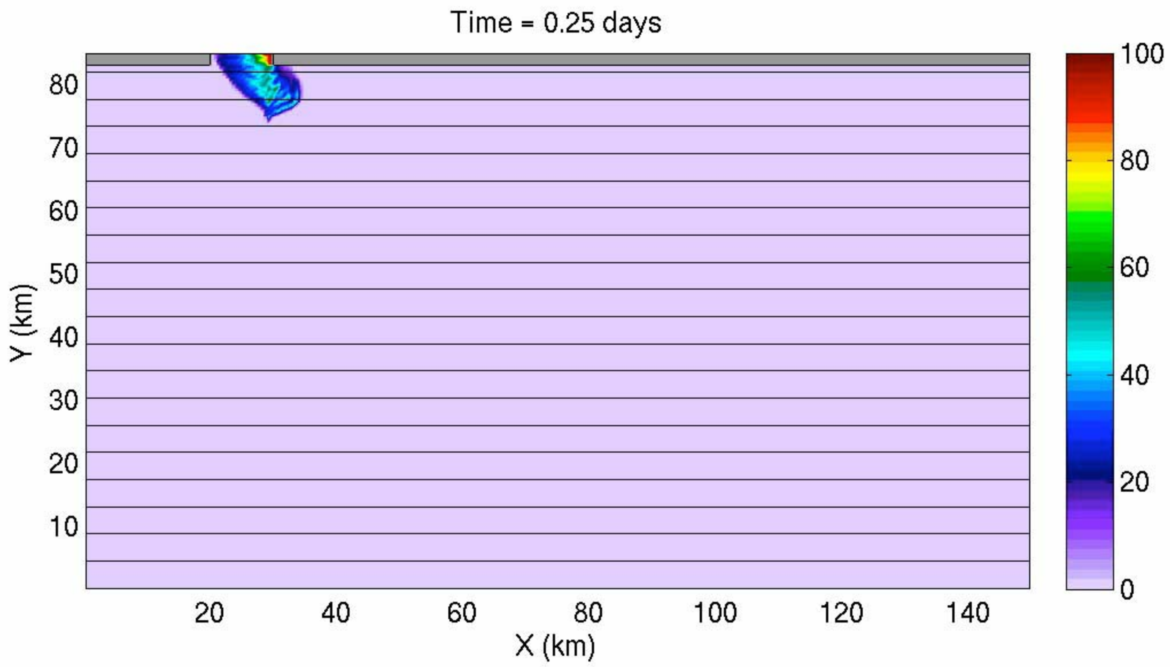


L_x = 150 km
L_y = 85 km
D = 7000 m
slope = 0.08

Model Setup

- Generalized Ocean Layer Dynamics (GOLD).
- 500 m horizontal resolution in x and y direction ($R_D \approx$ 4-5 km).
- 25 isopycnal layers.
- Initially unstratified domain.
- Jackson et al. (2008) shear-driven mixing parameterization.
- Smagorinsky type horizontal viscosity ($C_s = 0.17$).
- Quadratic bottom drag with $C_d = 2\times10^{-3}$.

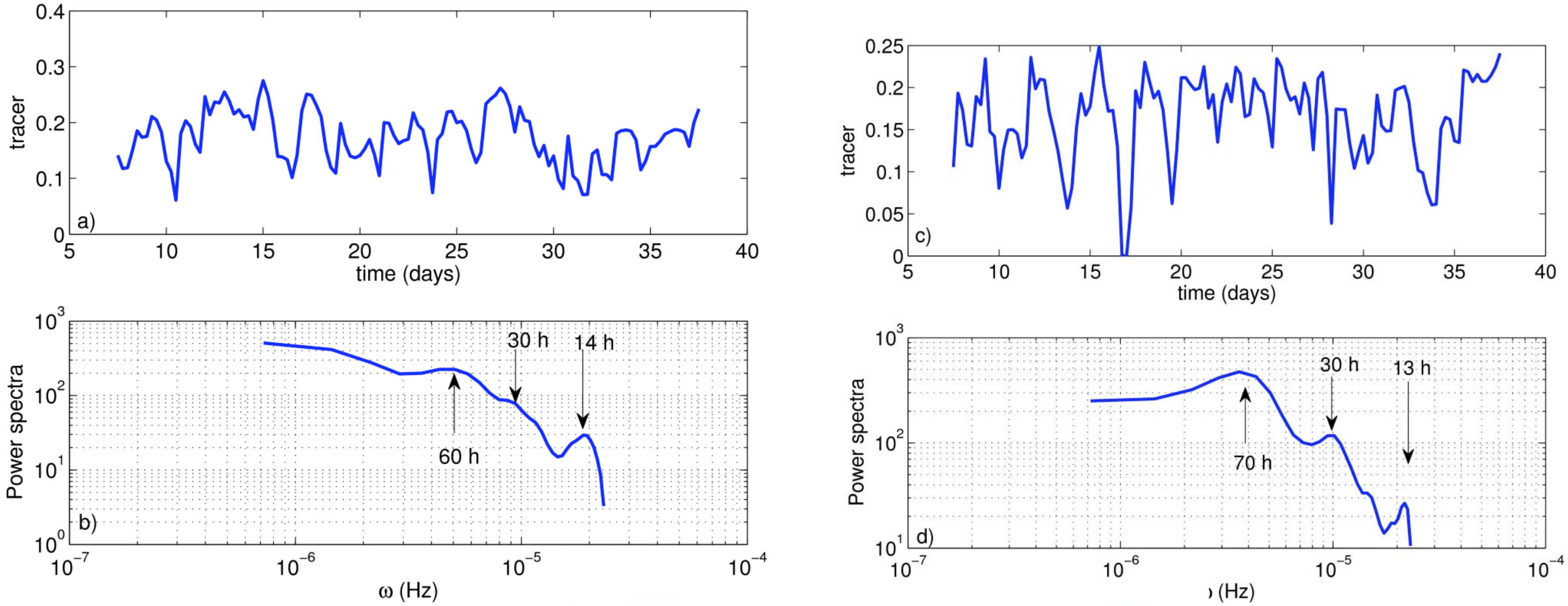
No-corrugation case

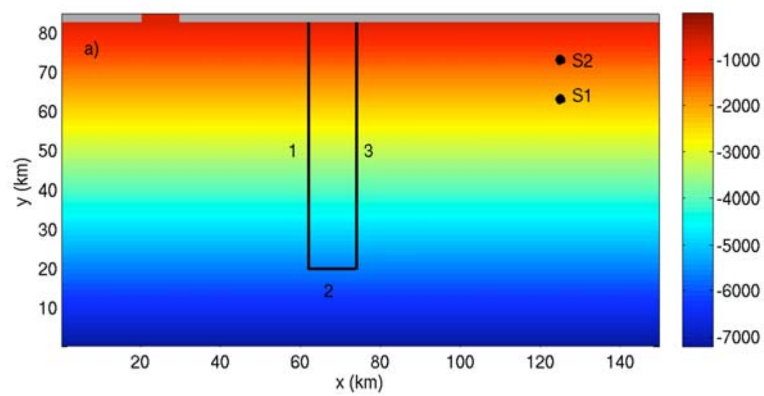


Tracer weighted overflow thickness

Power Spectra

S1 S2





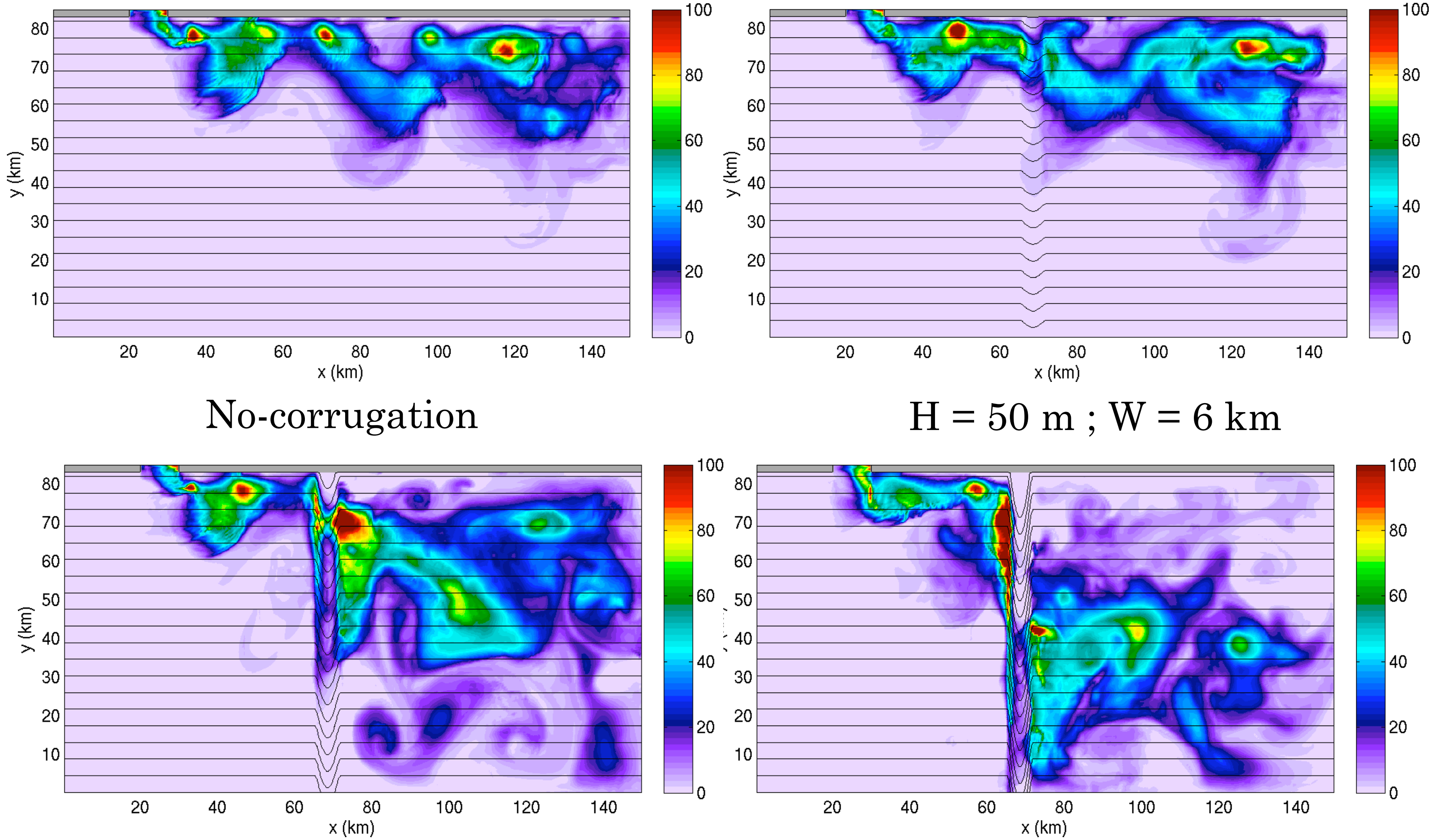
Experiments

Exp	H [m]	W [m]	H/W
1	50	2000	0.025
2	150	2000	0.075
3	300	2000	0.15
4	600	2000	0.3
5	800	2000	0.4
6	1000	2000	0.5
7	1200	2000	0.6
8	50	4000	0.0125
9	150	4000	0.0375
10	300	4000	0.075
11	600	4000	0.15

Exp	H [m]	W [m]	H/W
12	800	4000	0.2
13	1000	4000	0.25
14	1200	4000	0.3
15	50	6000	0.00833
16	150	6000	0.025
17	300	6000	0.05
18	600	6000	0.1
19	800	6000	0.1333
20	1000	6000	0.1666
21	12	6000	0.2

slope = 0.08 ; $f = -1.4\times10^{-3}\ s^{-1}$; $\Delta\rho = 2\ kgm^{-3}$; $g' = 1.9\times10^{-3}\ m^2/s$; $h_{in} = 150$ m

Effect of a ridge; overflow thickness [m]



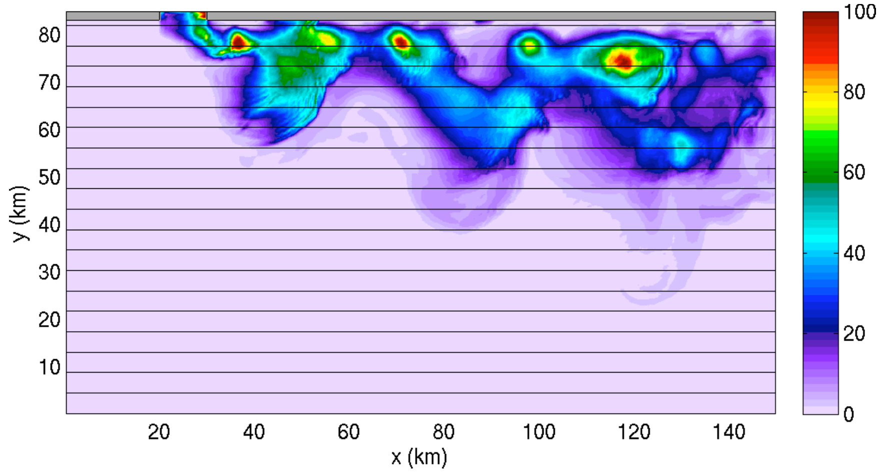
No-corrugation

H = 50 m ; W = 6 km

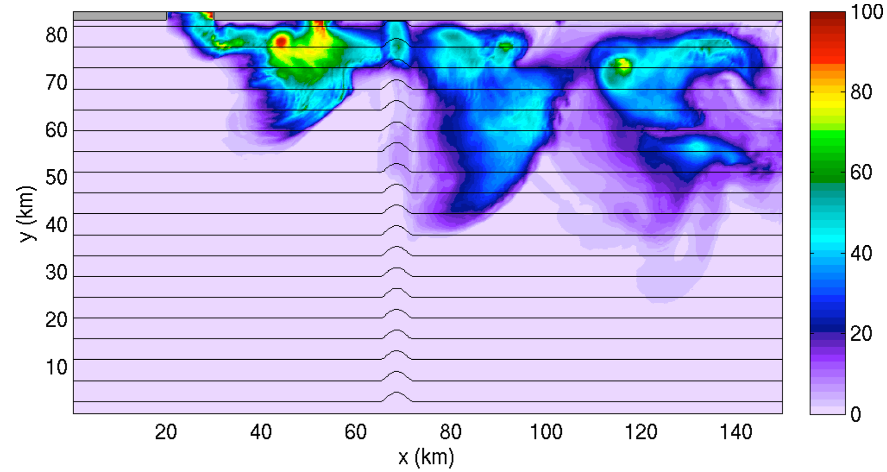
H = 600 m ; W = 6 km

H = 1200 m ; W = 6 km

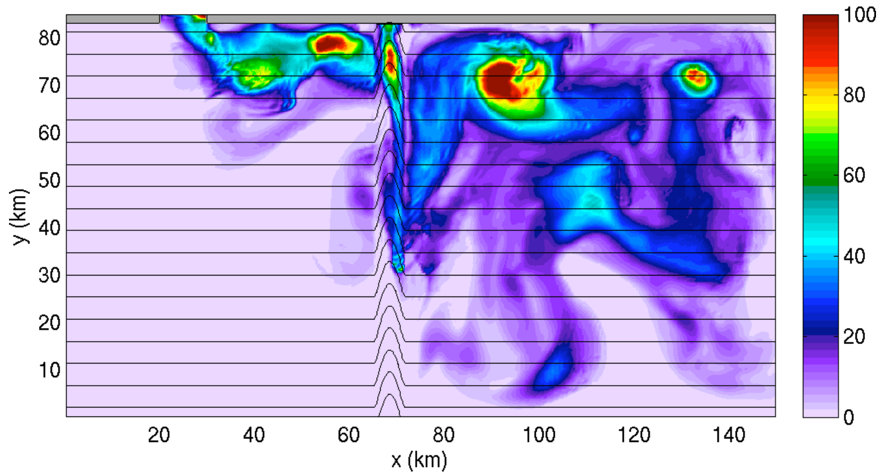
Effect of a canyon; overflow thickness [m]



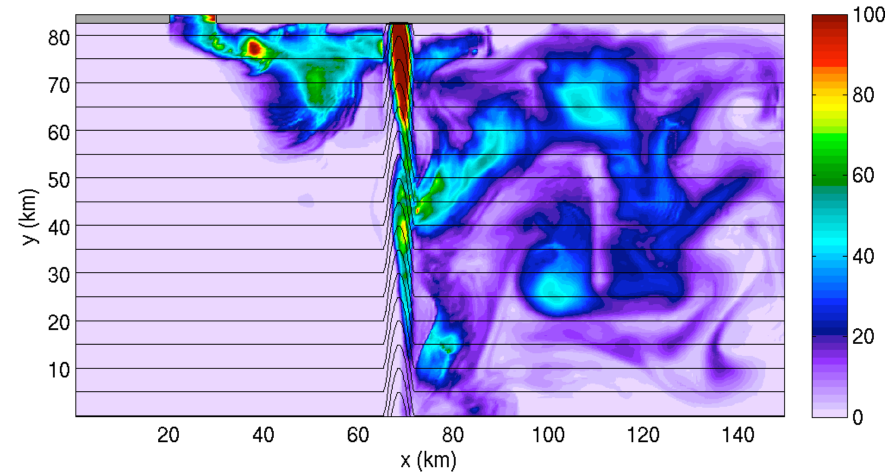
No-corrugation



H = 50 m ; W = 6 km



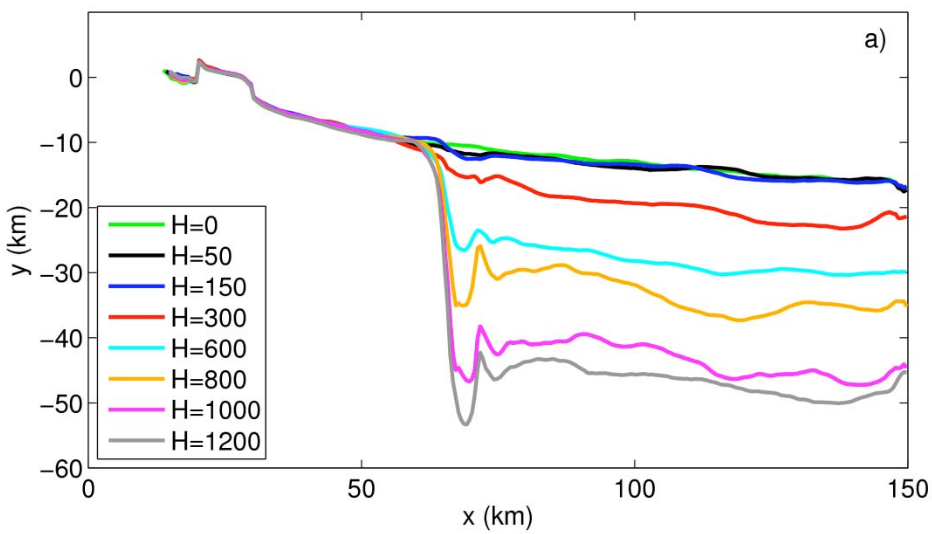
H = 600 m ; W = 6 km



H = 1200 m ; W = 6 km

Mean path in y-direction

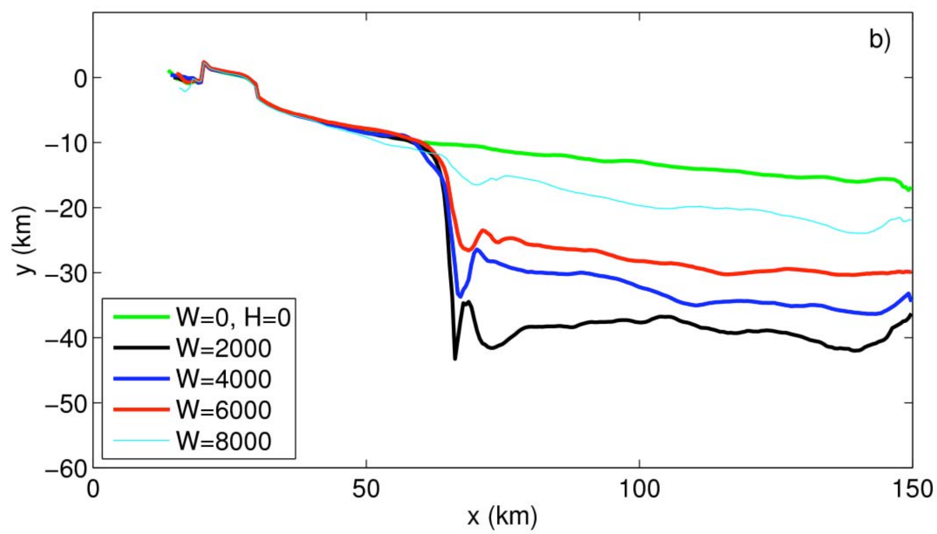
$\overline{Y^{\tau}}$



W = 6 km

H $\nearrow$

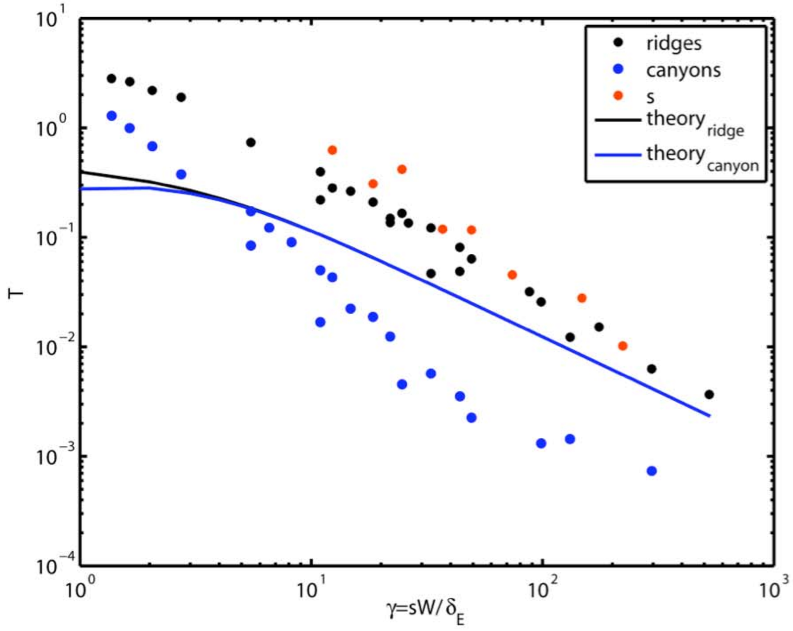
$\overline{Y^{\tau}}$

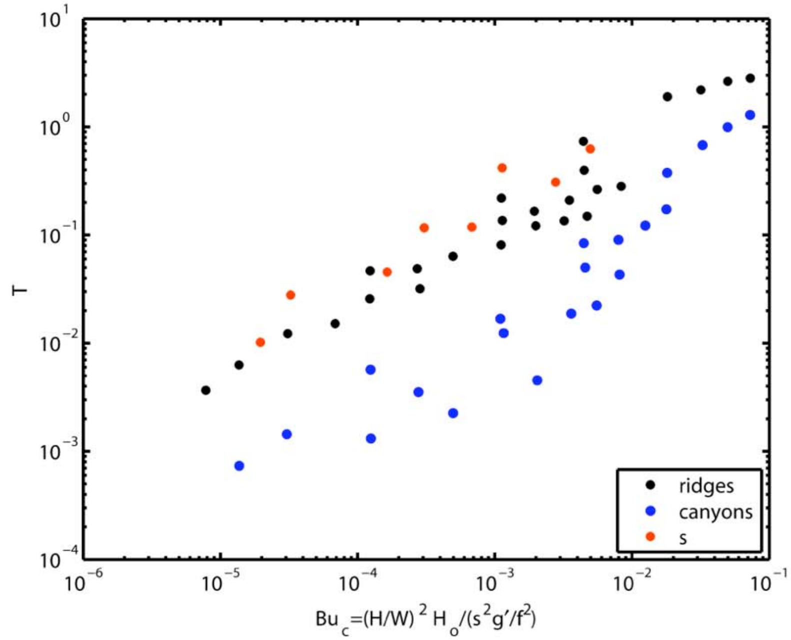


H = 600 m

W $\nearrow$

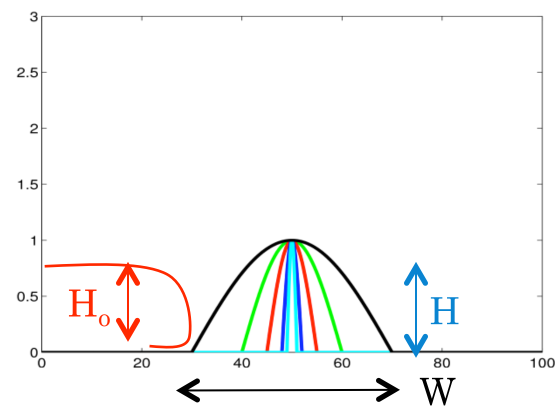
Transport sensitivity to H, W and s





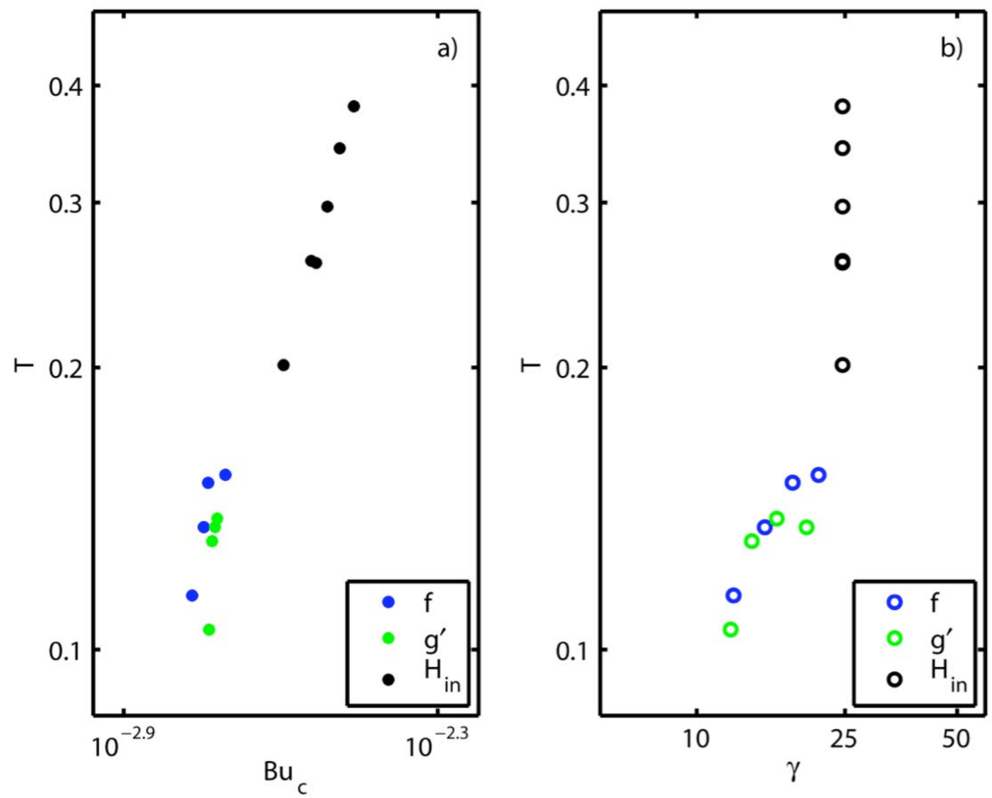
$$\gamma = \frac{sW}{C_d \frac{g'}{f^2}\sqrt{s^2 + (H/W)^2}}$$

$$Bu_c = \left(\frac{H}{W}\right)^2 \frac{H_o}{s^2 g' f^2}$$



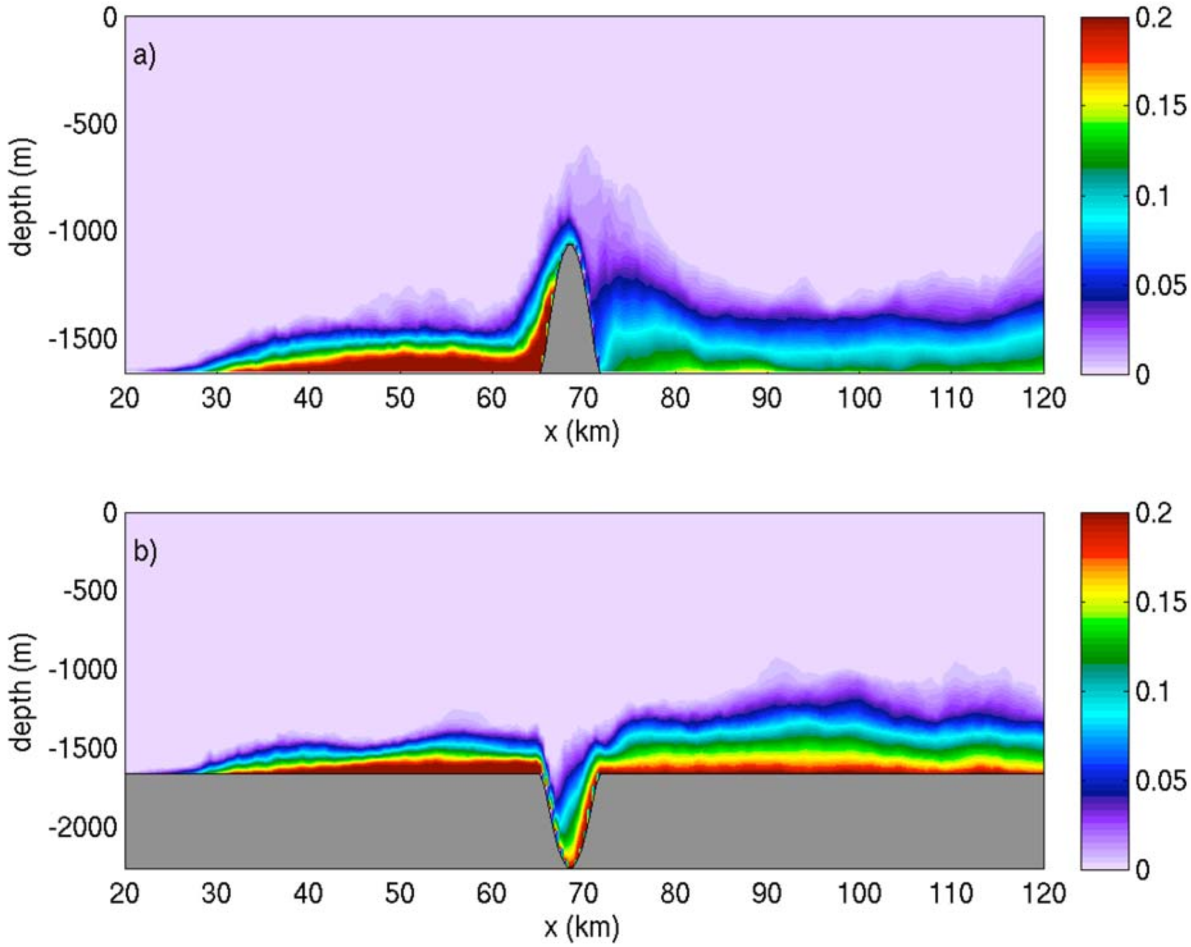
Transport sensitivity to f, g', h_{in}

$$Bu_c = \left(\frac{H}{W}\right)^2 \frac{H_o}{s^2 g' f^2}$$

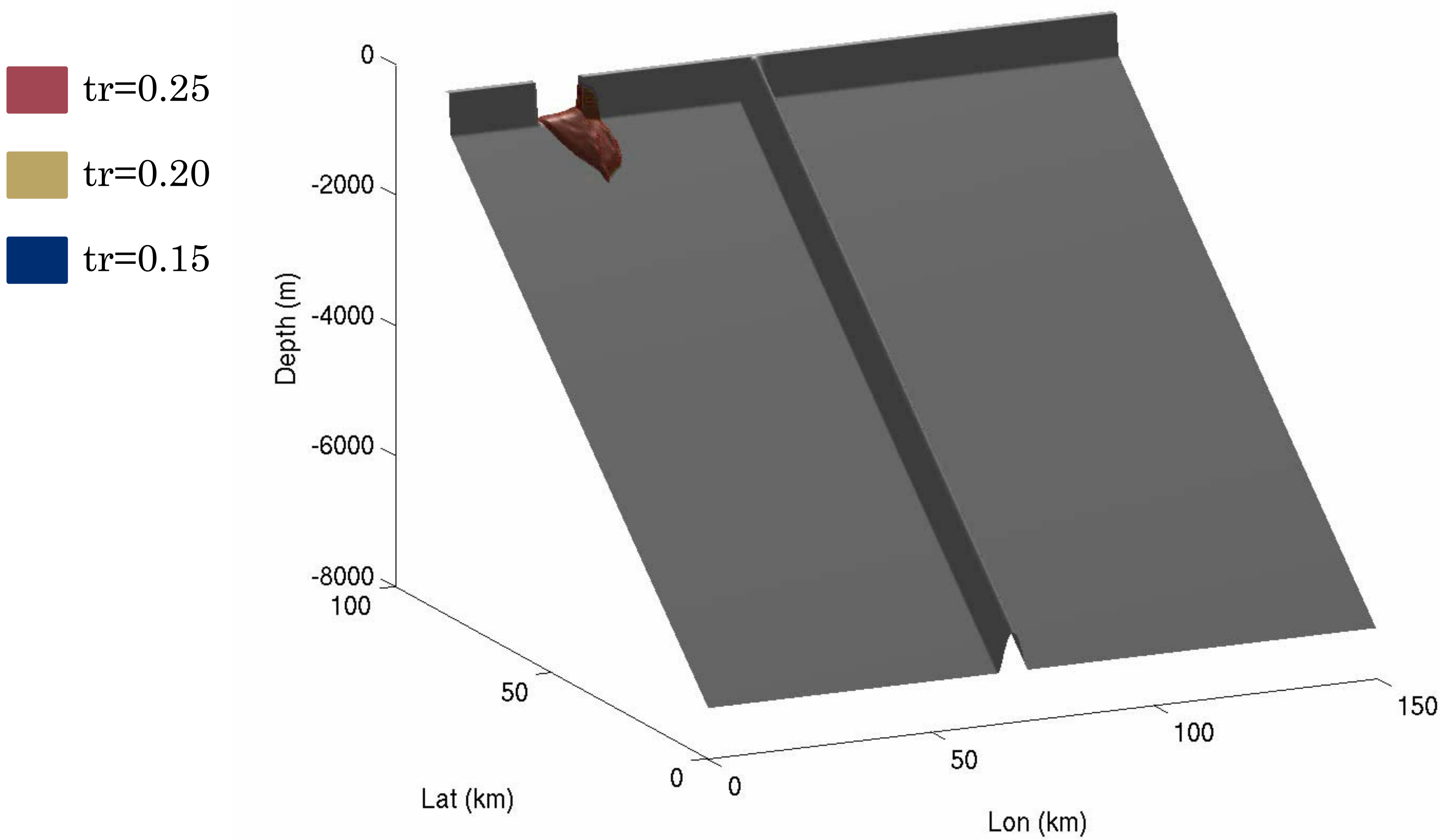


$$\gamma = \frac{sW}{C_d \frac{g'}{f^2}\sqrt{s^2 + (H/W)^2}}$$

Vertical Section at y = 70 km

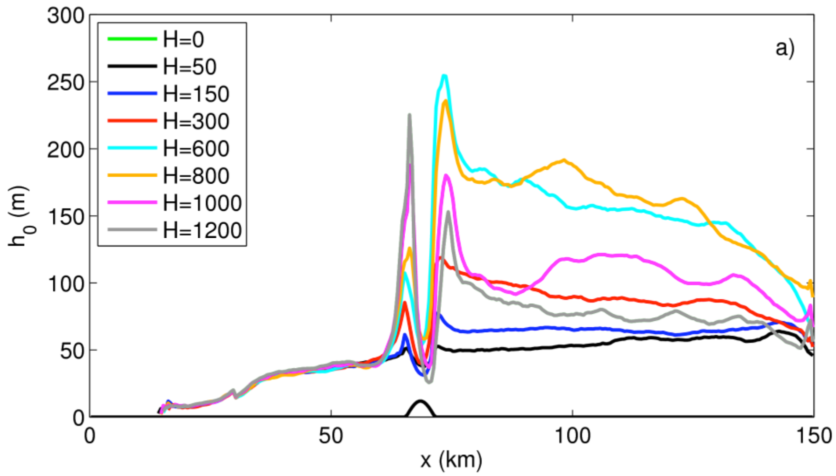


3D Iso-surfaces with H=600m;W=6 km

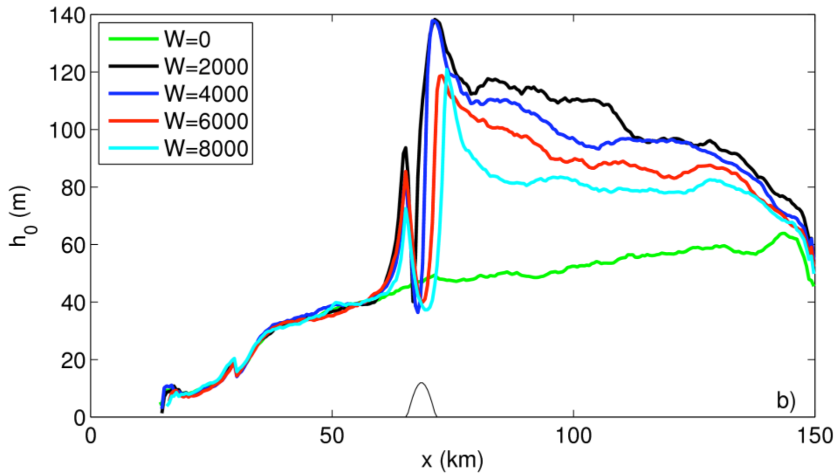


Overflow thickness

$h_0(x)$



$h_0(x)$



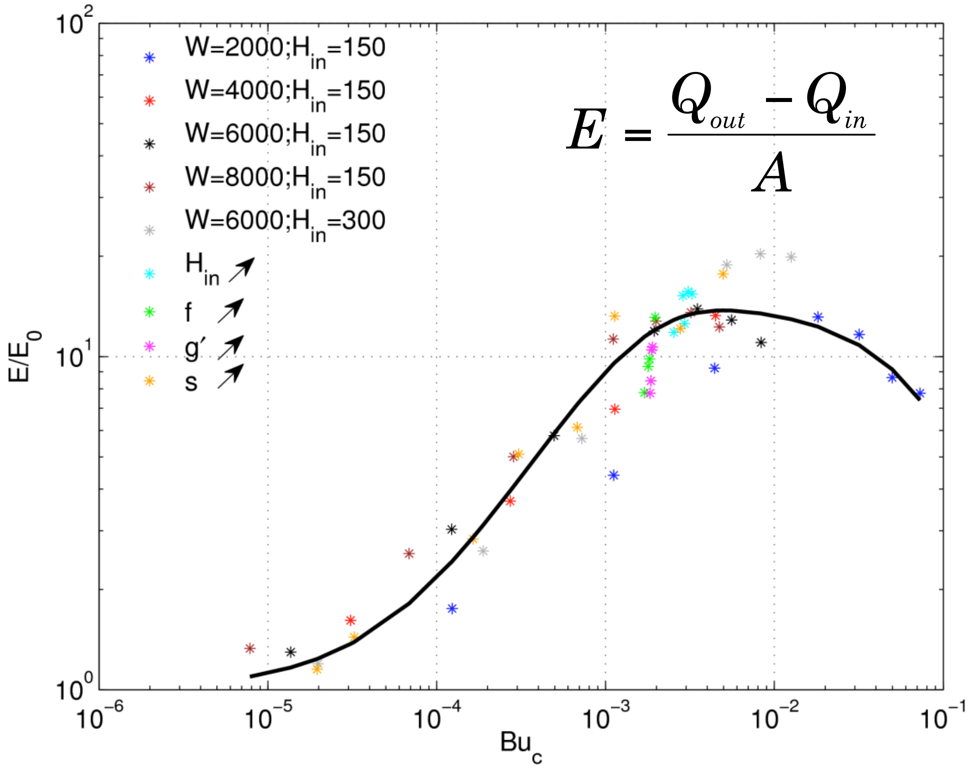
W = 6 km

H ↗

H = 600 m

W ↗

Entrainment



$$\frac{E}{E_0} = f(Bu_c) = ae^{(-bBu_c)} + ce^{(-dBu_c)}$$

$$a = 14.55; \quad b = 9.2961; \quad c = -13.55; \quad d = 914.7$$

Jackson et al. (2008) parameterization

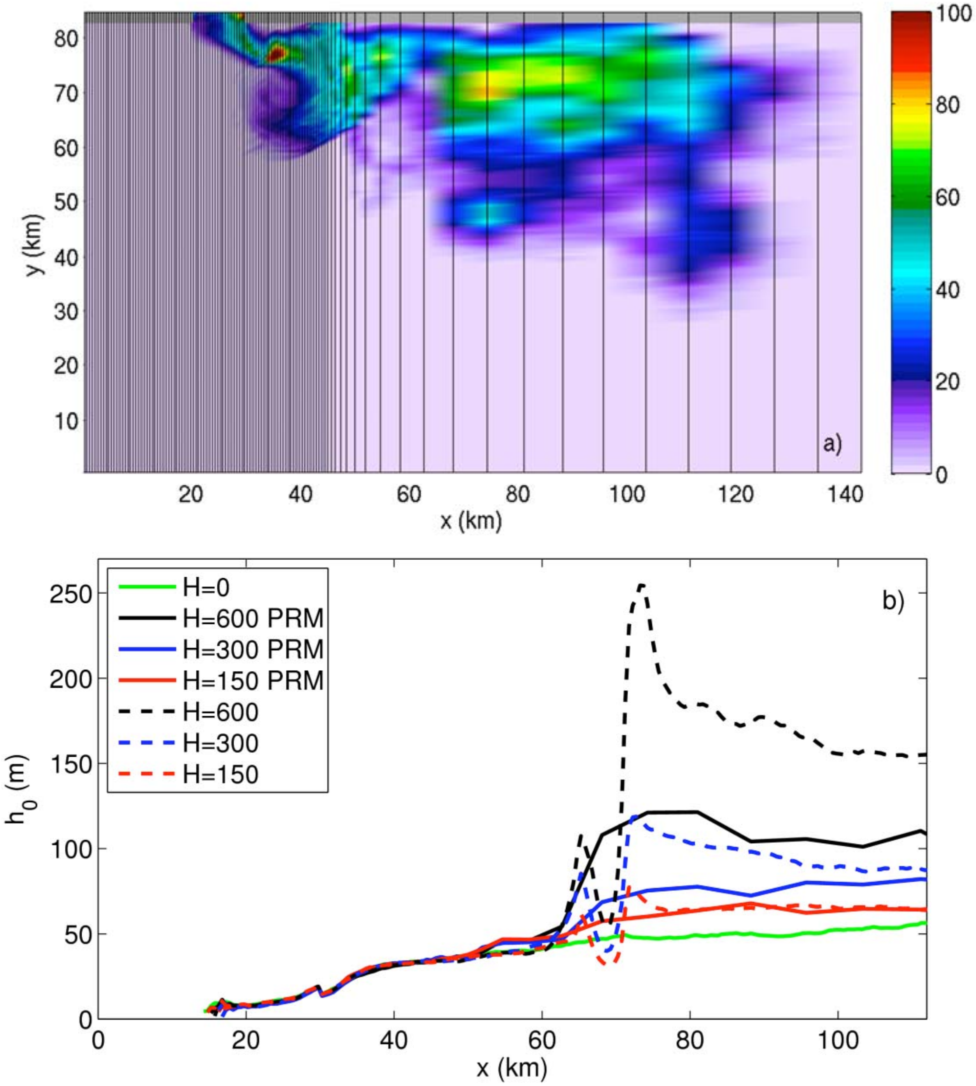
$$\boxed{\frac{\partial^2 \kappa}{\partial z^2} - \frac{\kappa}{L_d^2} = -2SF(Ri)}$$

$$\frac{\kappa}{\kappa_o} \sim \frac{E}{E_o} = f(Bu_c)$$

New parameterization

$$\boxed{\begin{aligned} &\frac{\partial^2 \kappa}{\partial z^2} - \frac{\kappa}{L_d^2} = -2\overline{S}F(\widetilde{Ri}) \\ &\overline{S} = Sf(Bu_c) \end{aligned}}$$

New Parameterization



- Upstream conditions kept constant (i.e. Δx=500 till x=45 km).
- Try to reproduce a ridge with a 6 km width and a height of H = 150, 300 and 600 m.
- The new parameterization increases the mixing around the ridge location.
- Since the new parameterization effects only the vertical shear, there is no downslope transport unlike the resolved cases.

Summary and Conclusion

✓ Power spectra of the tracer field indicate that the variability in the Weddell Sea overflow is due to eddies.

! Eddies occur because of PV stretching. What sets the frequency?

✓ Ridges transport the gravity current downslope more effectively then canyons.

✓ Bu_c can be used as a single parameter that governs the flow.

✓ A new parameterization is introduced to represent unresolved shear in coarse resolution models.

‼ This is the first step to reproduce the effects of a very complex problem.