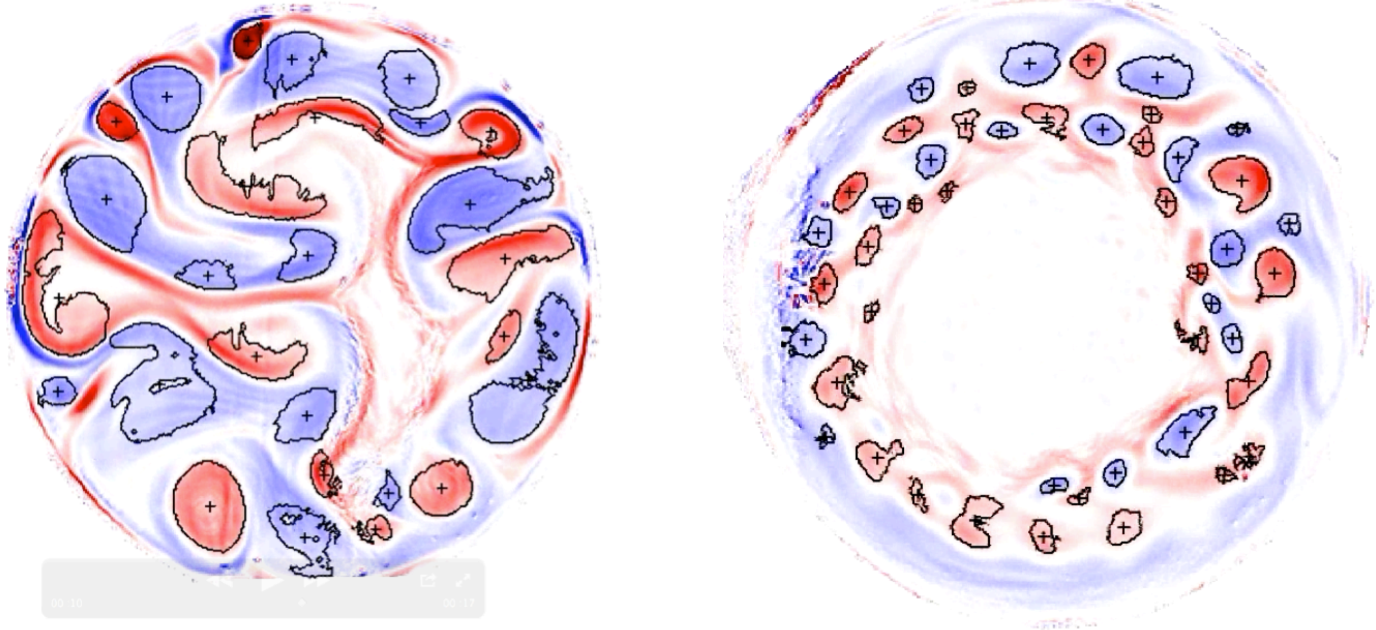
SYNBIOS Workshop *Paris July 2015*

Meso and sub meso scale dynamics of coastal current along steep shelf bathymetry



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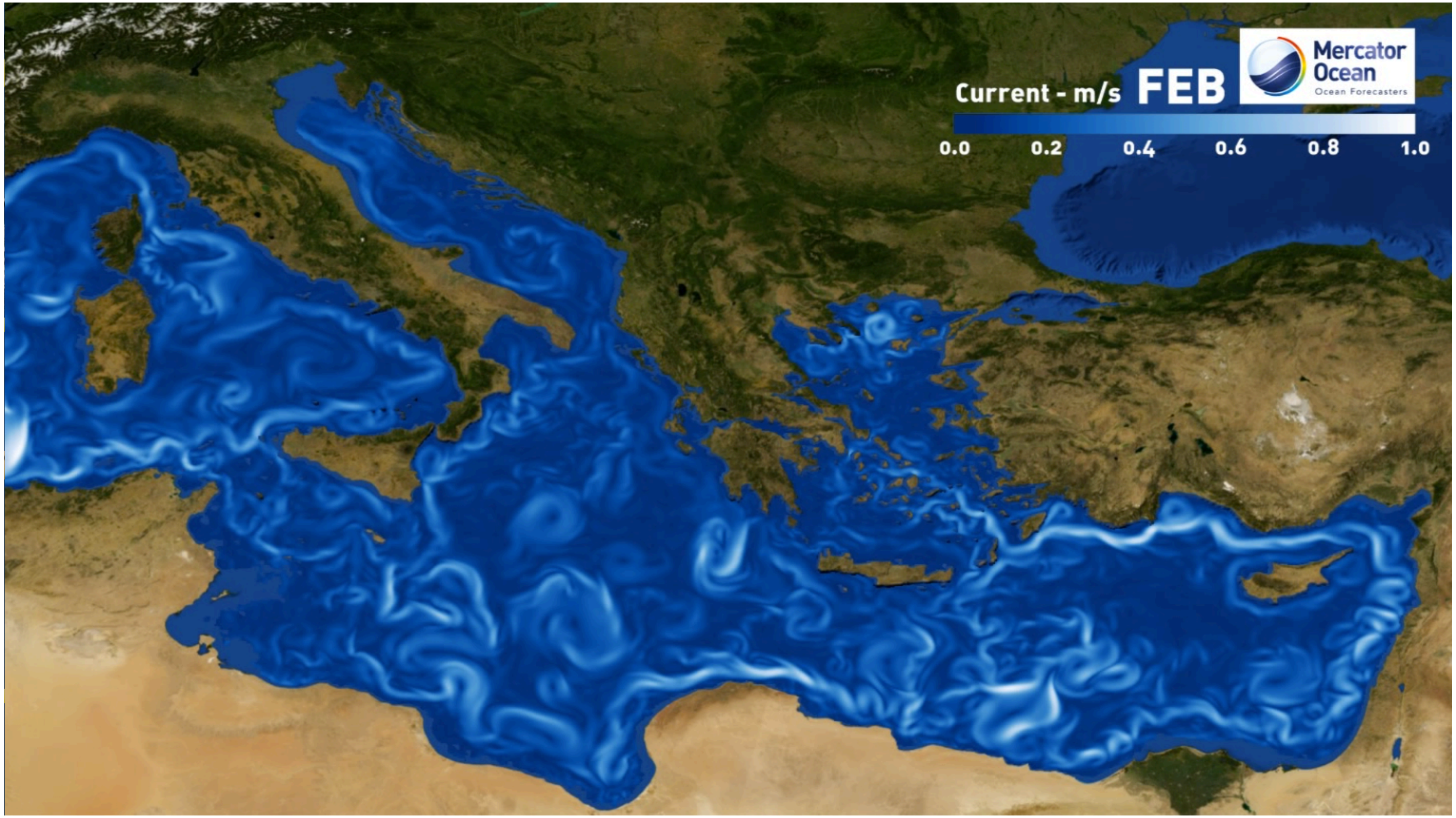
(4) Waterloo University, Canada.

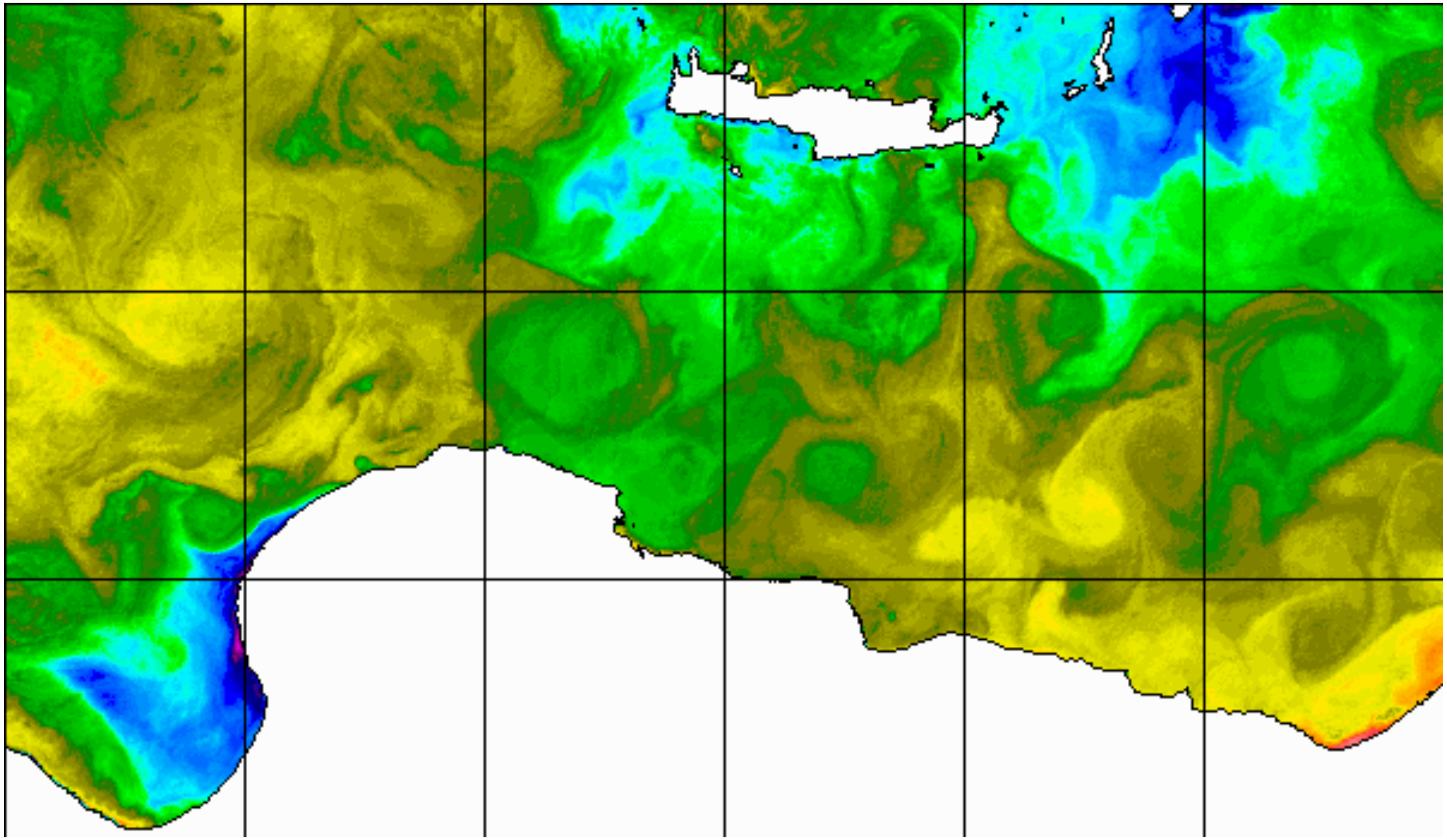
Coastal current along steep shelf bathymetry

Motivations: 1/36° Eastern Mediterranean basin



Coastal current along steep shelf bathymetry

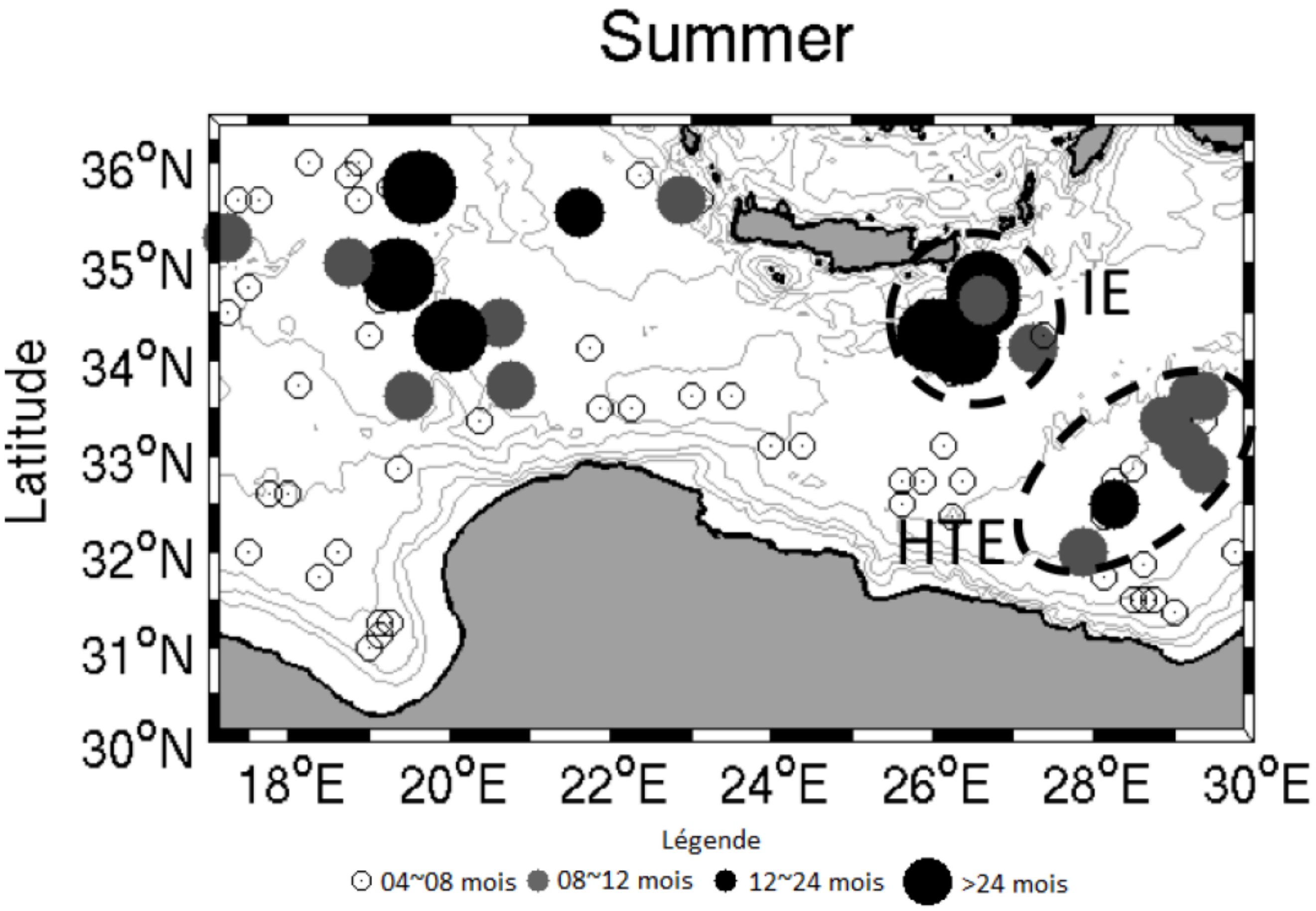
Motivations: formation of coastal eddies Mediterranean Sea



SST 18 June 2006

Coastal current along steep shelf bathymetry

Motivations: formation area over steep or smooth shelf slope ?



Mkhinini *et al.* JGR (2014)

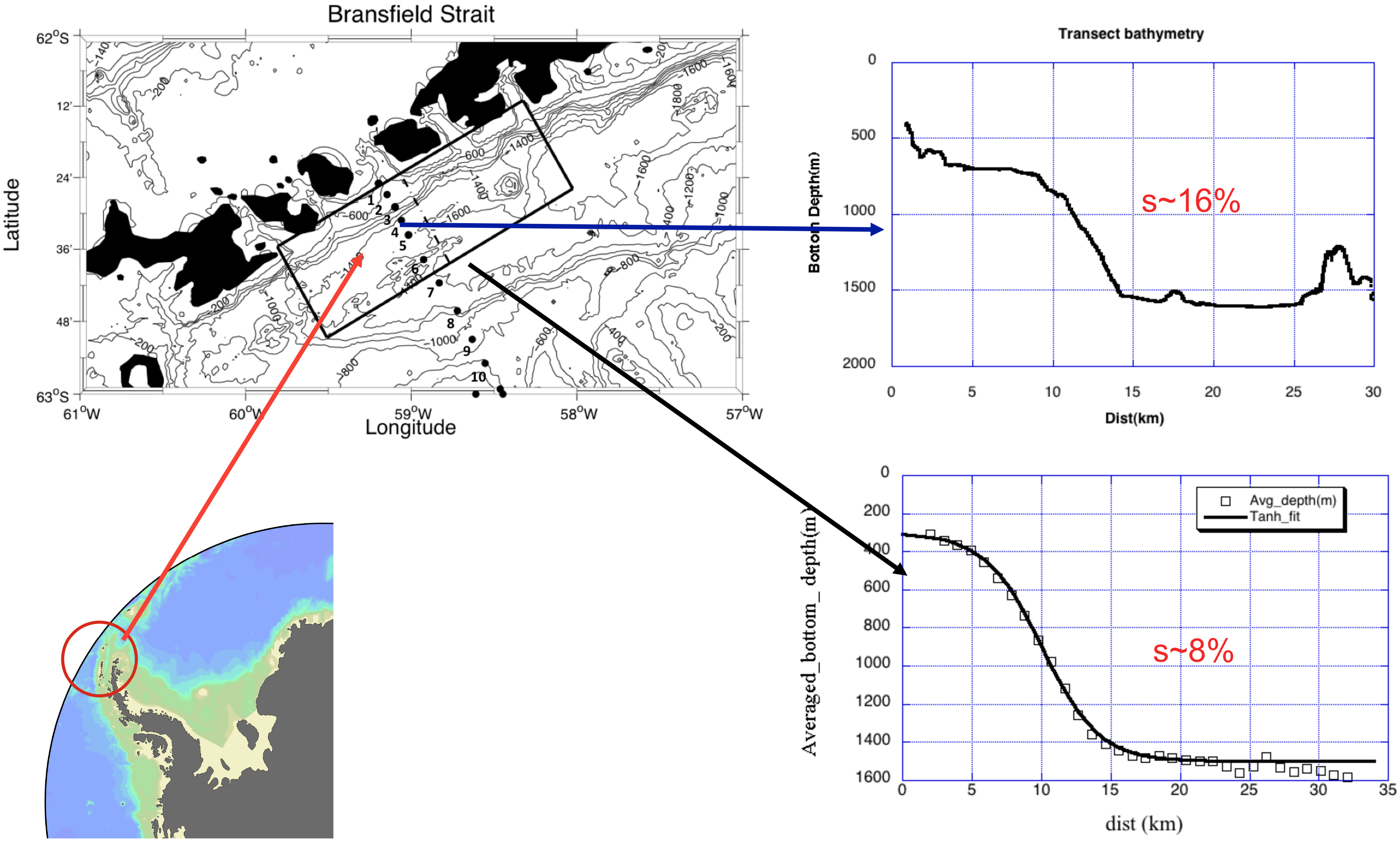
Coastal current along steep shelf bathymetry

Motivations: Bransfield Current (Antarctica)

COUPLING in-situ survey 2010

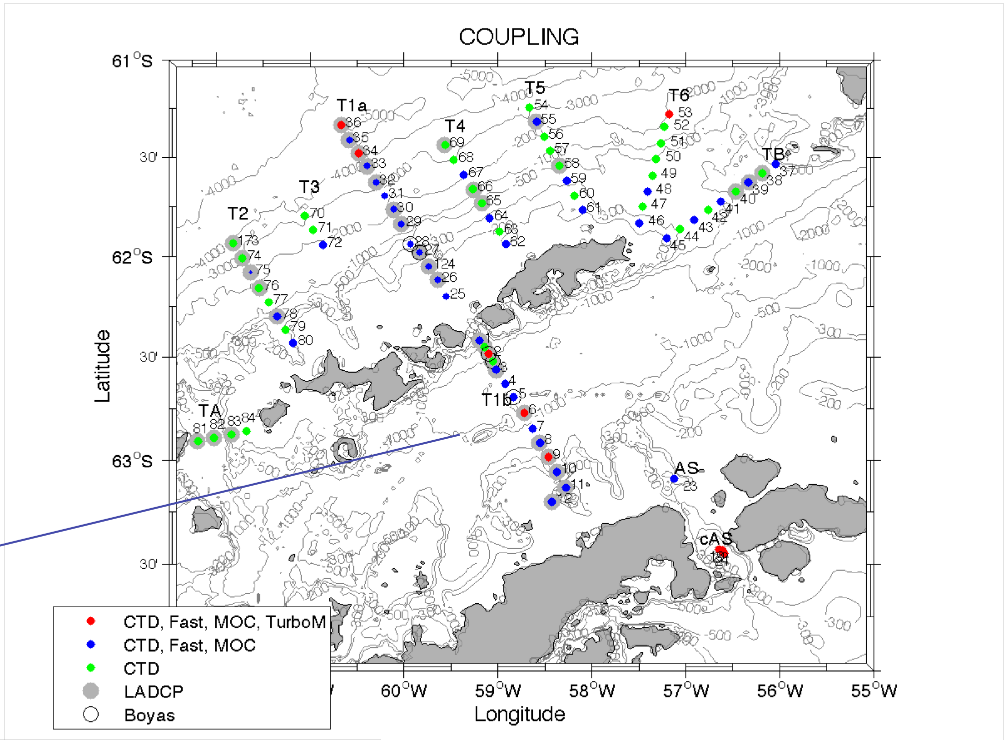
Coastal current along steep shelf bathymetry

Buoyant coastal current : Bransfield strait bathymetry (Antarctica)



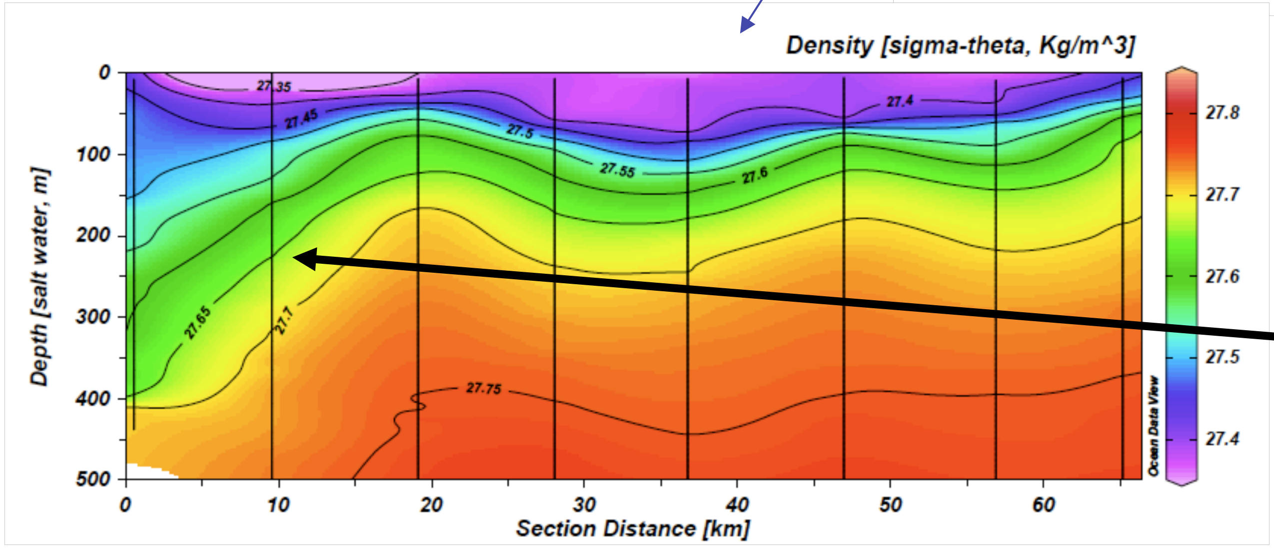
Coastal current along steep shelf bathymetry

Buoyant coastal current :
Bransfield current (Antarctica)



COUPLING Campaign 2010

CTD Transect 1b

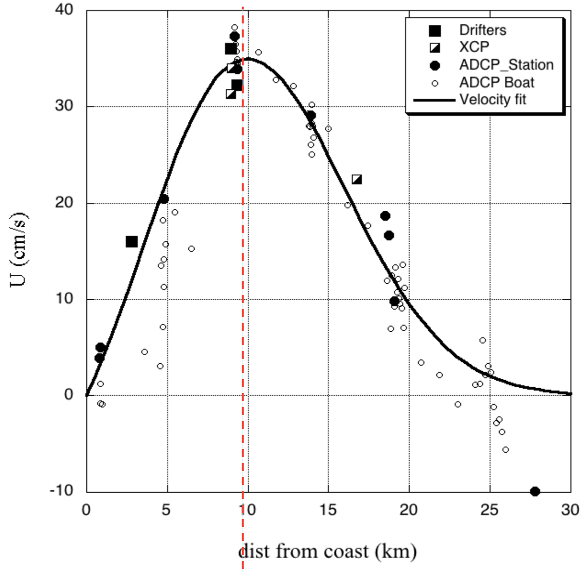


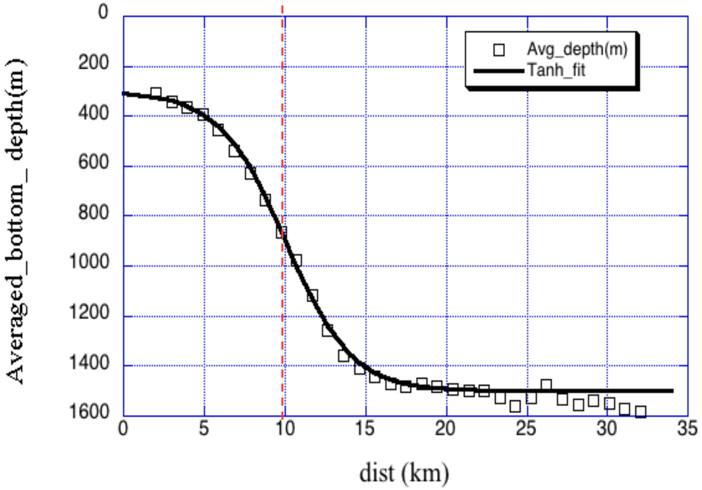
isopycnal slope $\alpha \sim 1\ \%$

Coastal current along steep shelf bathymetry

Buoyant coastal current : stable Bransfield current (Antarctica)

VELOCITY PROFILE



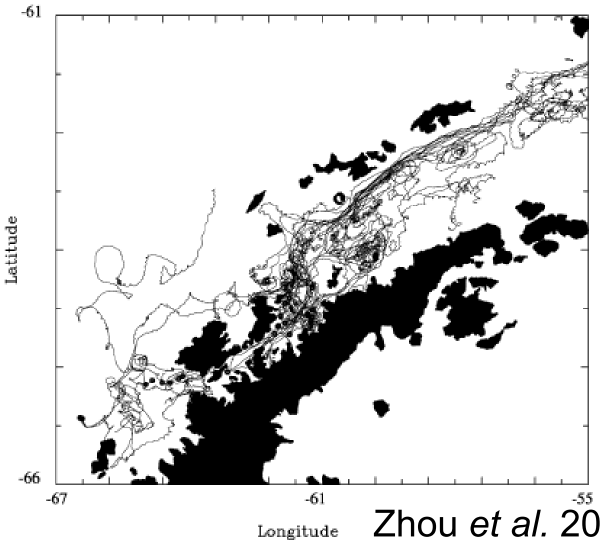


$$Ro = \frac{U}{f\,L} \approx 0.2 - 0.3$$

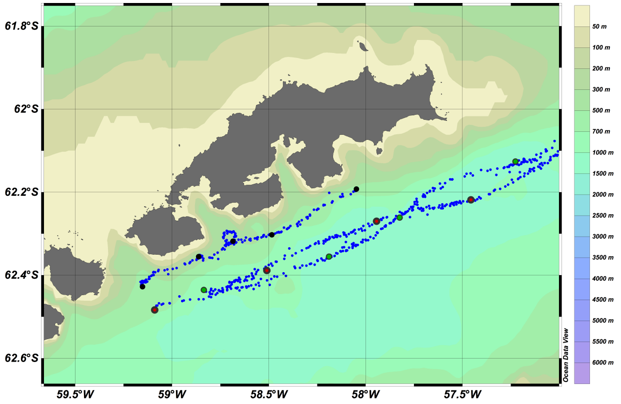
$$Bu = \left(\frac{R_d}{L}\right)^2 \approx 1$$

GEOSTROPHIC CURRENT

DRIFTERS TRAJECTORIES



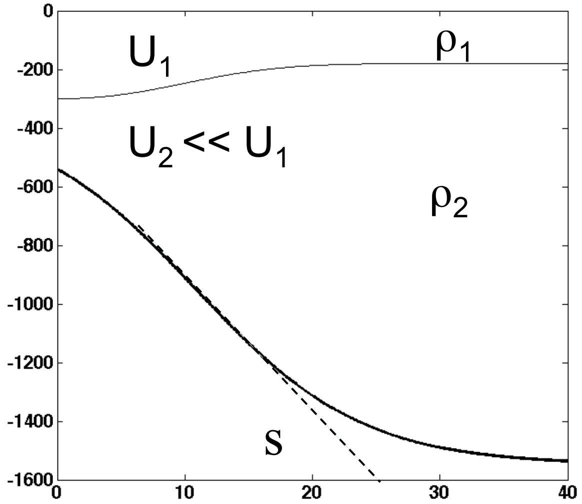
Zhou *et al.* 2002



Sangra et al. DSR 2011, Poulin *et al.* JPO 2014

Coastal current along step shelf bathymetry

Simple configuration



Surface intensified current

Ro $Bu=(R_d/L)^2$

Vertical stratification

$\gamma=H_1/H_2$

Shelf bathymetry

S

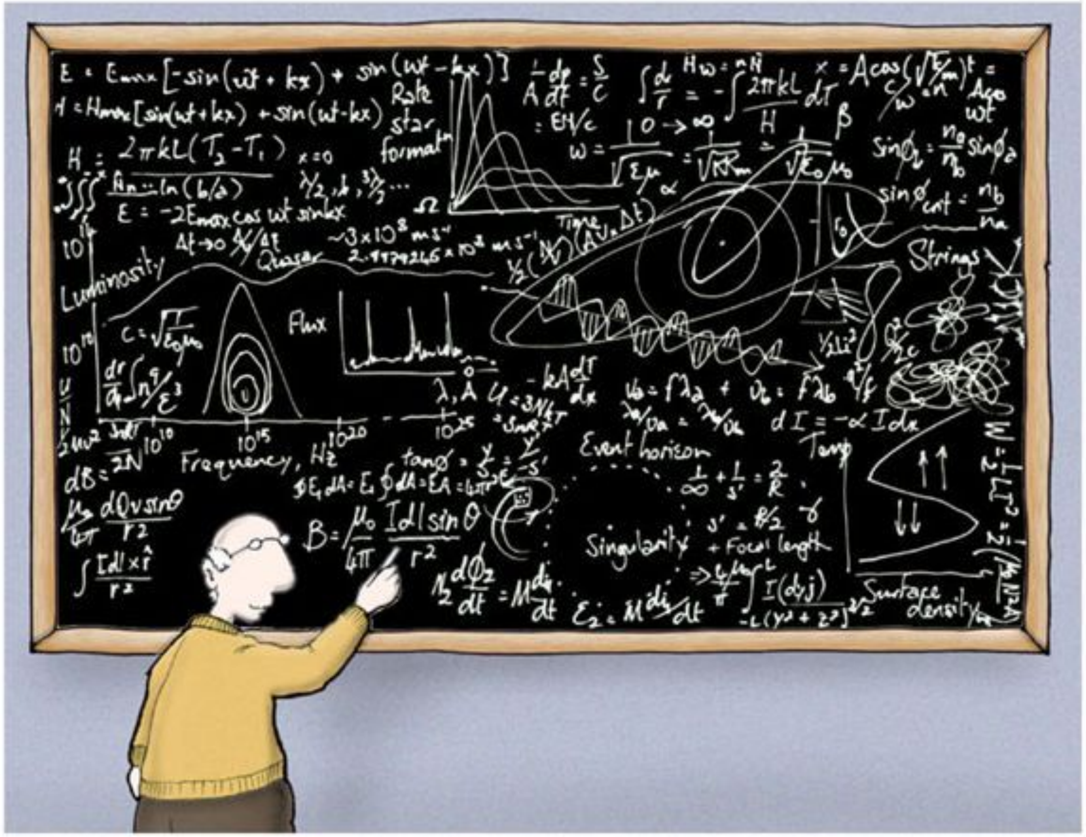
Simple questions: impact of the coastal shelf

- stabilize / destabilize ?
- unstable wavelength selection ?
- Size and vertical structure of detached eddies ?

Surprisingly… no clear answers

Coastal current along steep shelf bathymetry

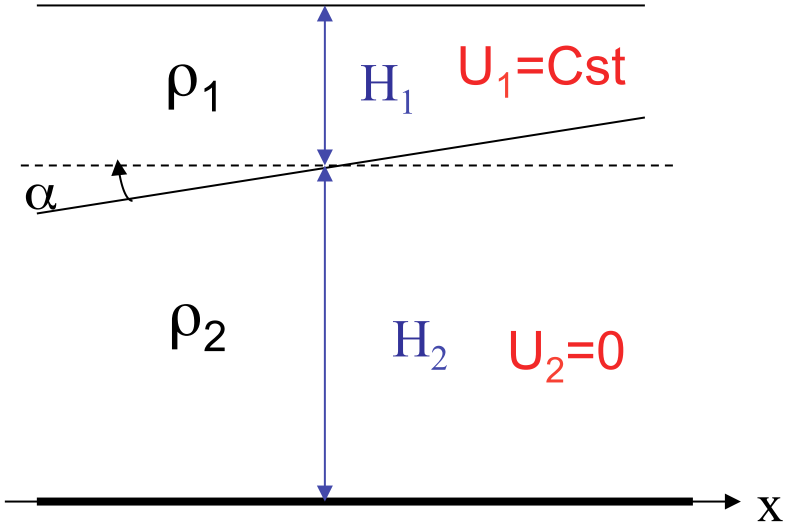
What do we learn from linear stability analysis ?



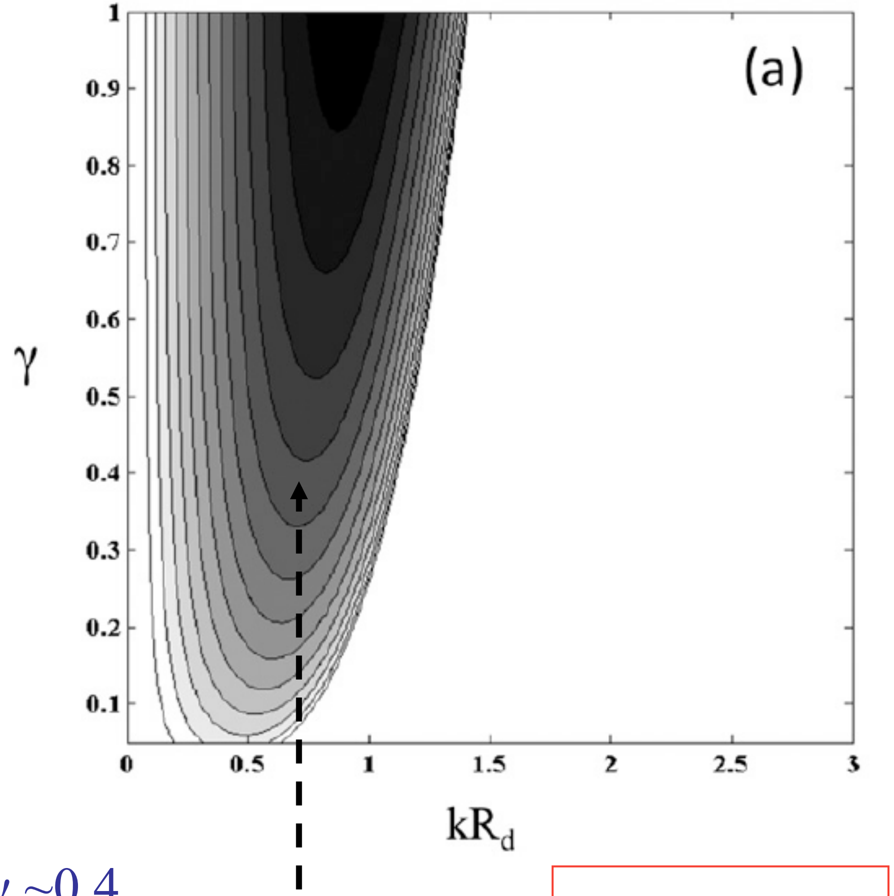
Coastal current along steep shelf bathymetry

What do we learn from simple models ?

Phillips model, QG two layers



Growth rates



$\boxed{\gamma = H_1/H_2}$

$h_2 \sim 2.5\ h_1 \quad \gamma \sim 0.4$

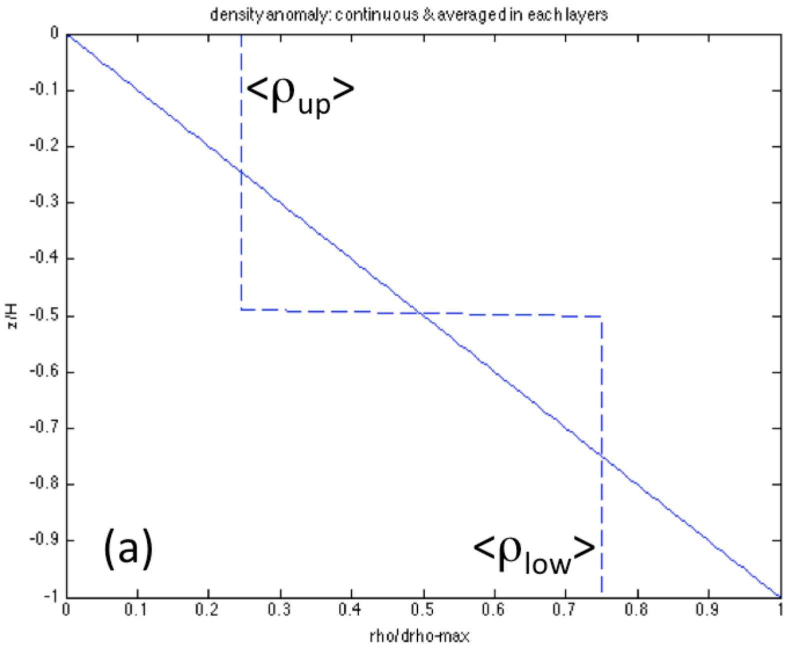
Bransfield current

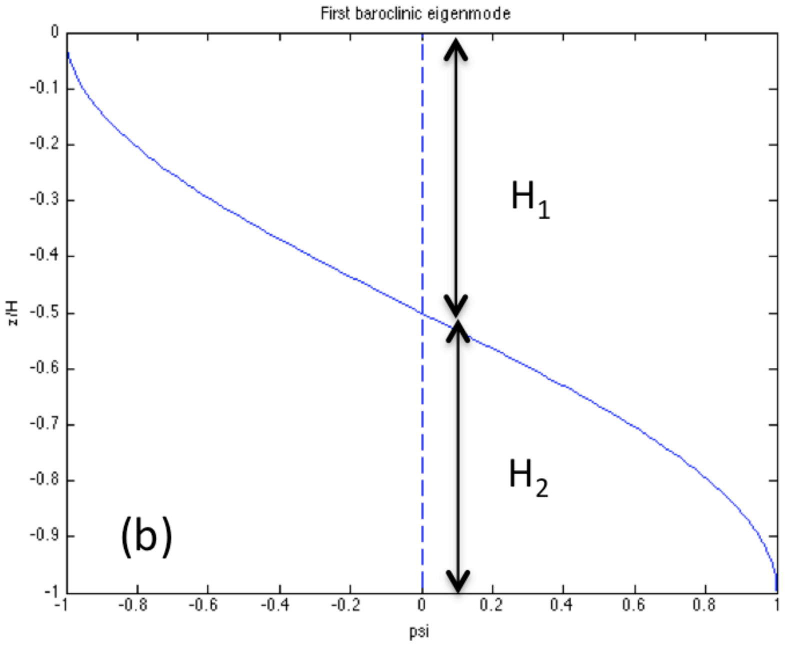
$kR_d \sim 0.65 \Rightarrow \boxed{\lambda_{max} \sim 9\ R_d}$

What do we learn from simple models ?

linear stratification

Stratification parameter $\gamma = H_1/H_2 = 1$ ⟺ $N = \mathrm{Cst}$

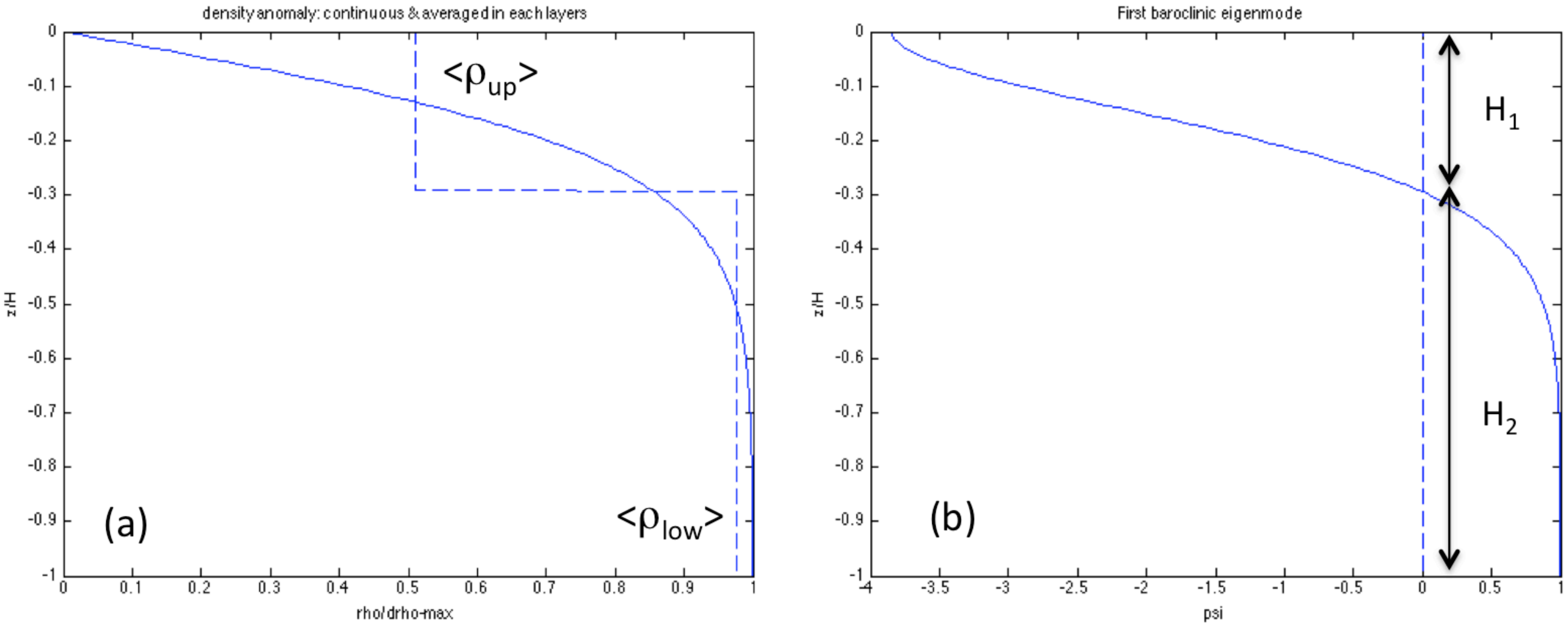




What do we learn from simple models ?

Stratification parameter $\gamma = H_1/H_2 < 1$ ⟺ *Stratification amplified at the surface*

$N \neq \mathrm{Cst}$

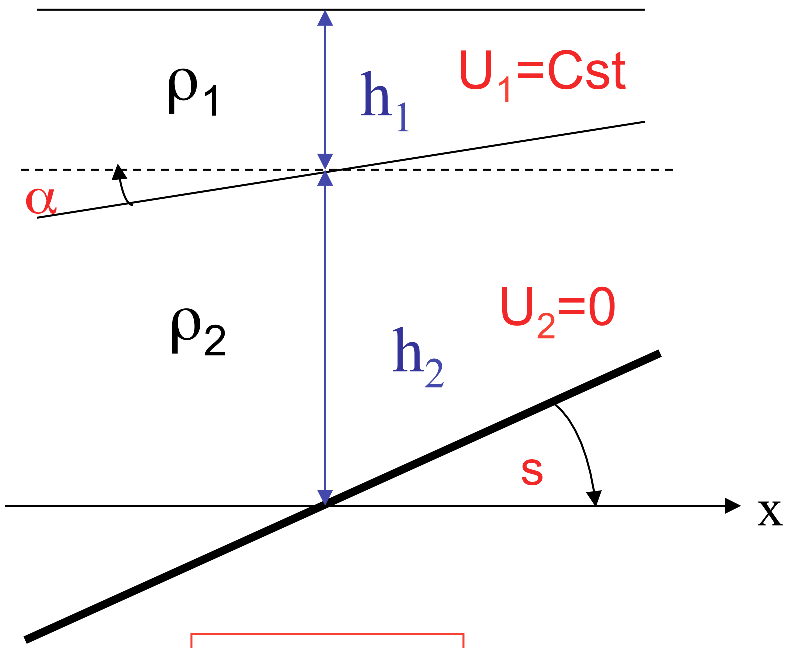


$\gamma = 0.4$

Coastal current along steep shelf bathymetry

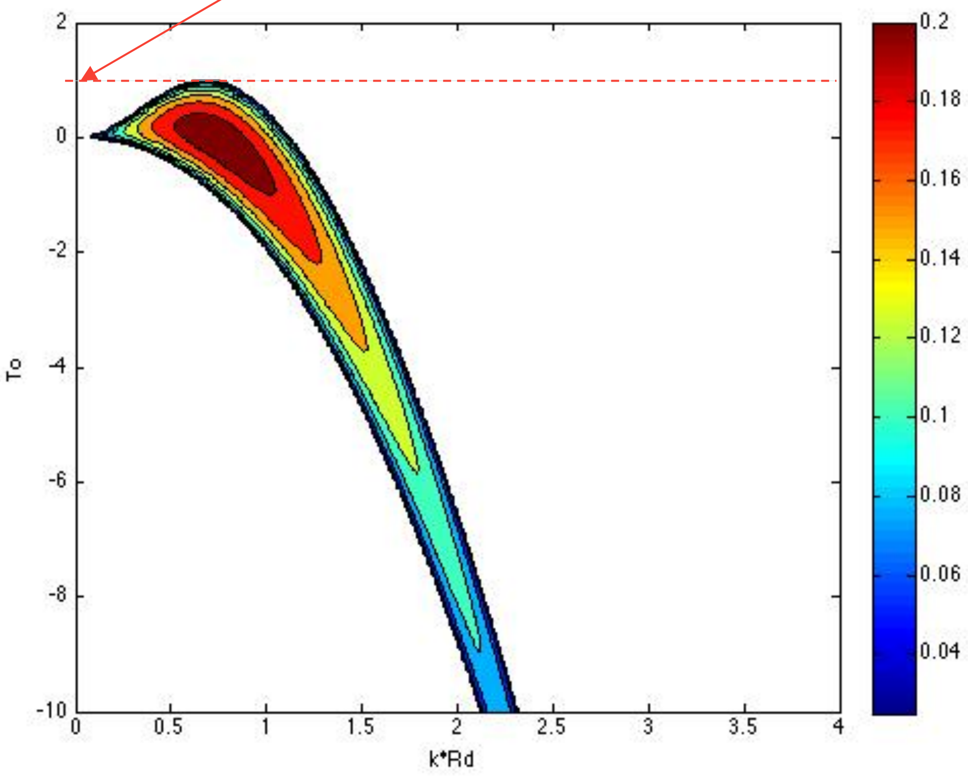
What do we learn from simple models ?

Phillips two layers QG model



$$To = \frac{s}{\alpha} \geq 0$$

To = 1

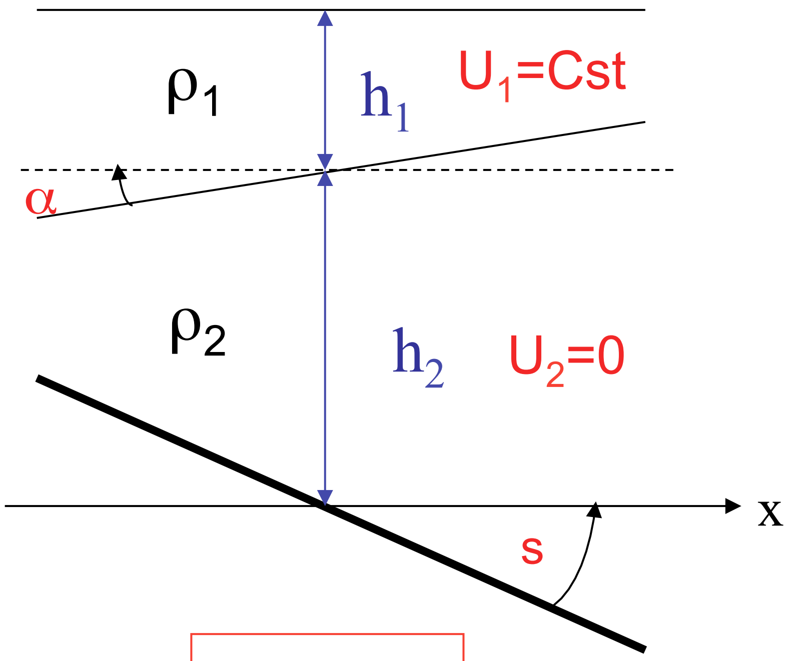


To > 1 → STABLE

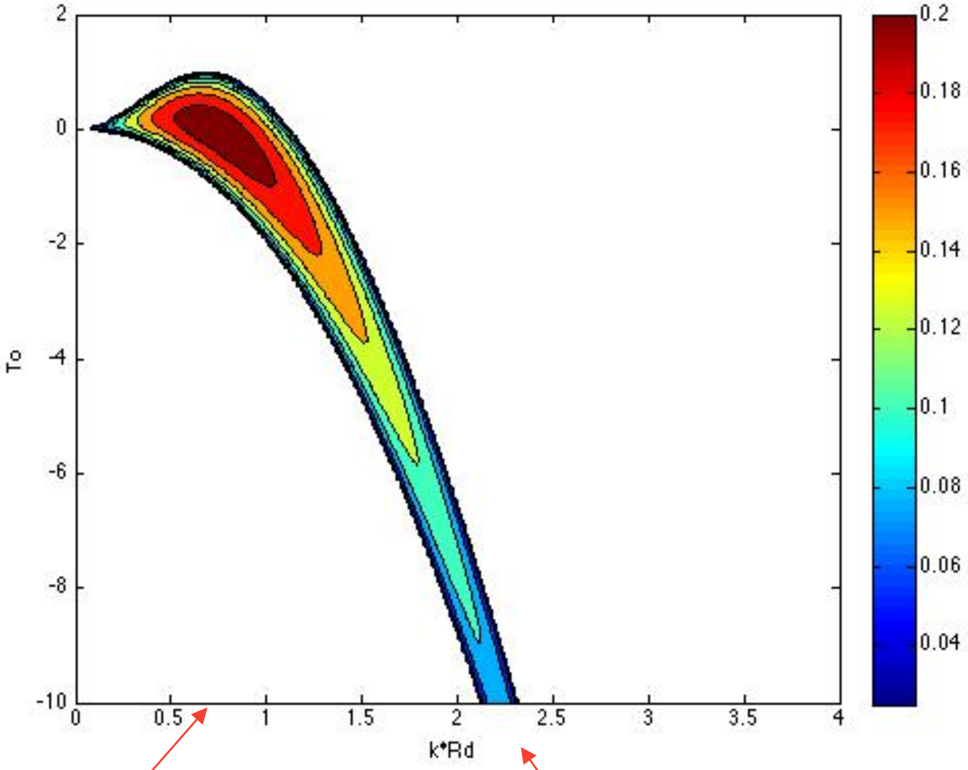
Coastal current along steep shelf bathymetry

What do we learn from simple models ?

Phillips two layers QG model



$$\boxed{To = \frac{s}{\alpha} \le 0}$$



Long wavelength cutoff

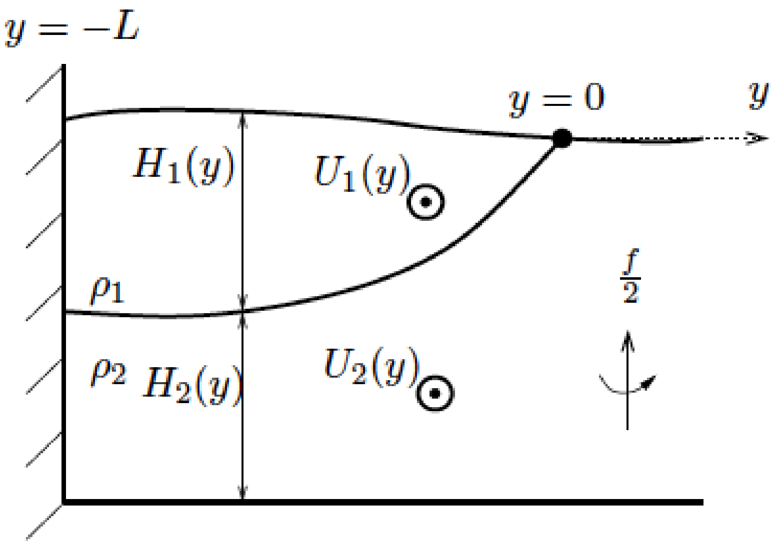
Small wavelength selection & STABILIZATION

Coastal current along steep shelf bathymetry

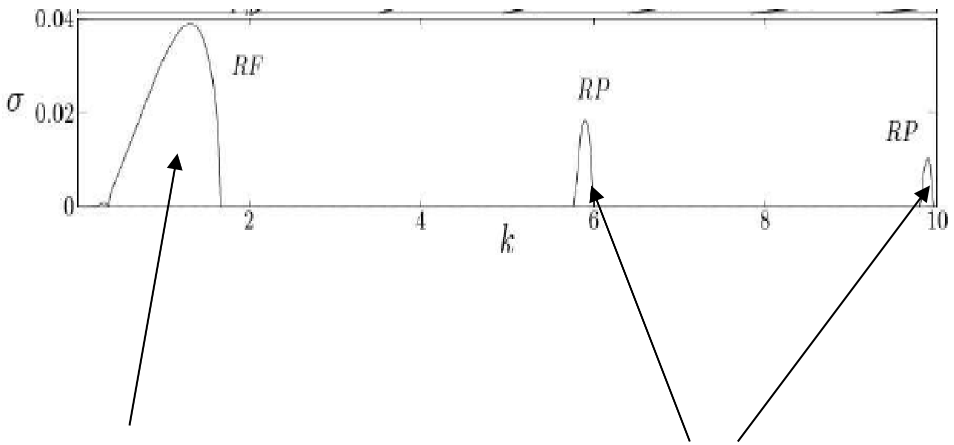
What do we learn from RSW models ?

Buoyant coastal front, flat bottom

Surface advected $\gamma = H_1/H_2 \sim 0.1$



$L = R_d$ $Bu = 1$



Frontal-Rossby modes
(i.e. Rossby-Rossby)

Geostrophic instability

$kR_d \sim 1.5$

Poincarré-Rossby modes

Ageostrophic instability

$kR_d \sim 6$

Boss, *et al*. (1996)

Gula, Zeitlin & Bouchut, *J. Fluid Mech.* (2010)

Coastal current along steep shelf bathymetry

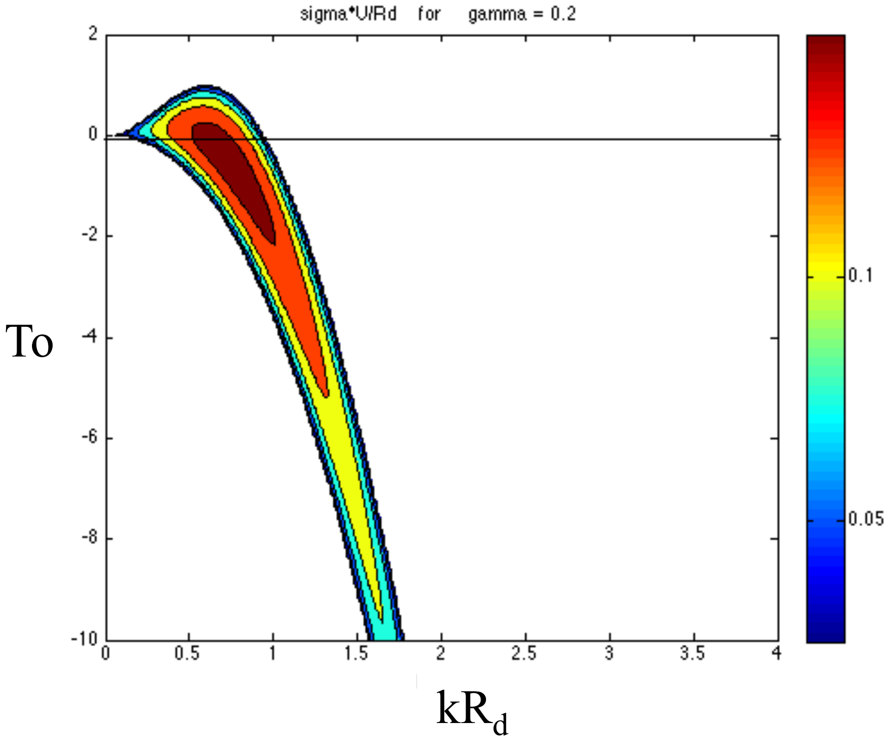
Impact of bottom slope (two-layer models)

Topographic parameter

$$\boxed{To = \frac{s}{\alpha}}$$

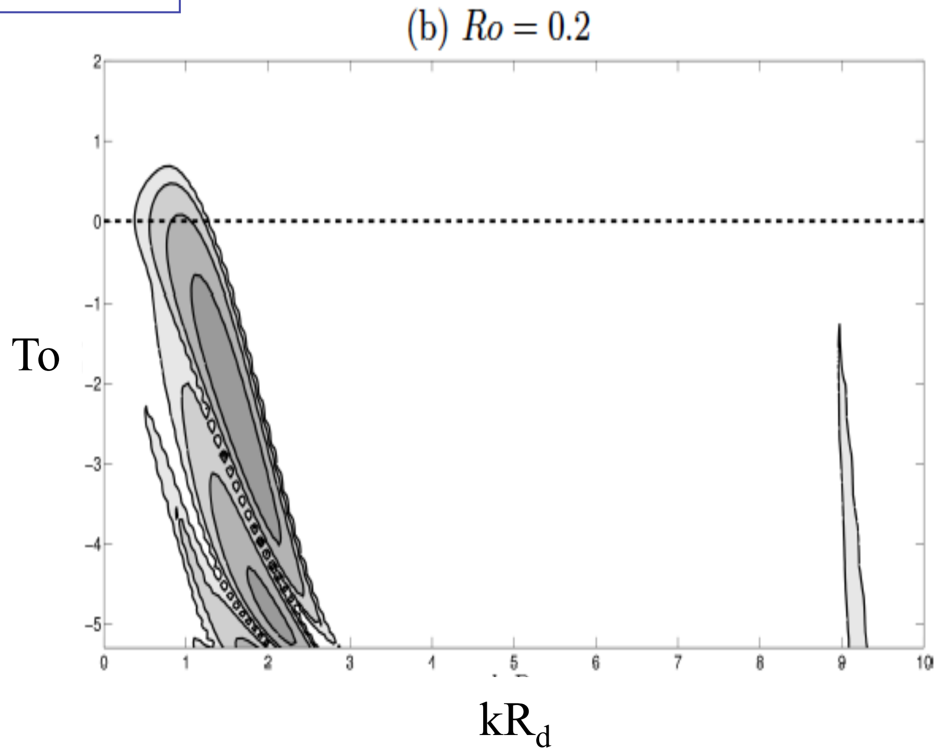
Phillips QG model

Coastal current (no outcropping)



RSW model

Coastal front (with outcropping)



Mysak JPO (1977)
Pennel PhD (2012)

$To < 0$ ↘ ➡ kR_d ↗ σ_{max} ↘

Gula & Zeitlin (2014)

Impact of bottom slope: topographic parameter

Upper layer jet velocity

$$V_{\text{current}} = \frac{g^*}{f}\partial_x h_1 = \frac{g^*}{f}\alpha$$

Phase speed of Topographic Rossby Waves

$$V_{\text{TRW}} \approx -s\frac{f}{Hk^2}$$

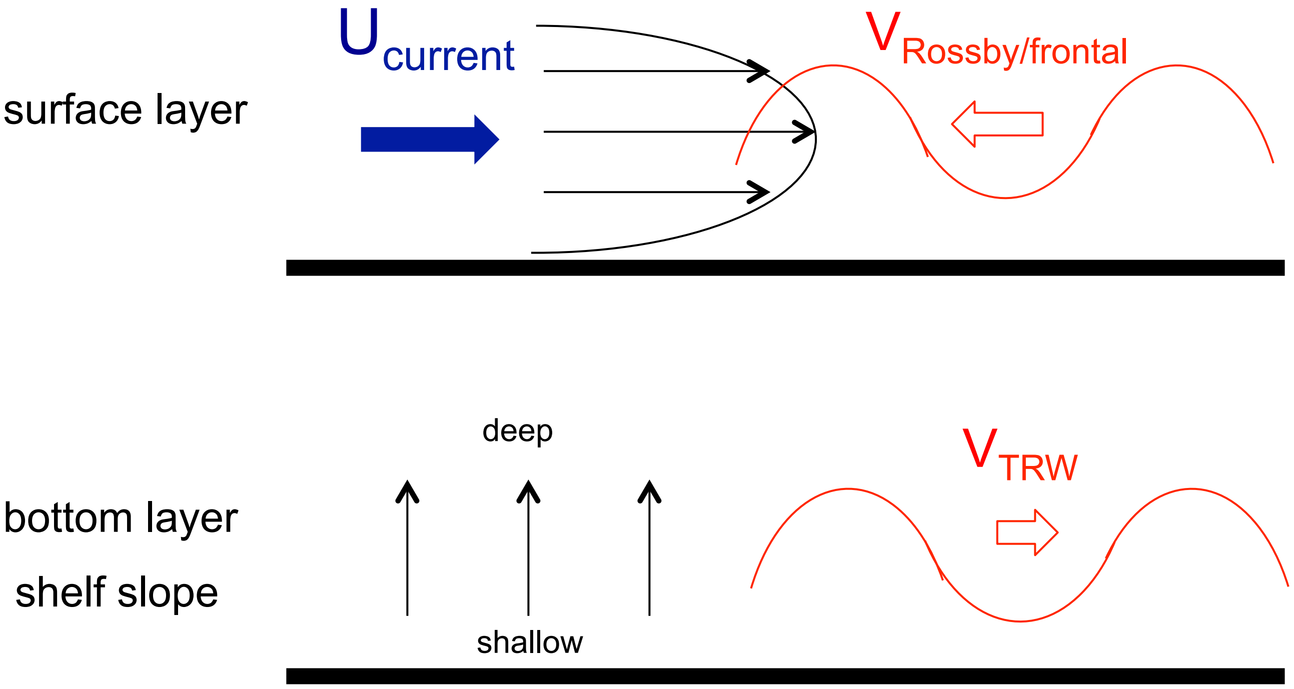
$$\frac{V_{\text{TRW}}}{V_{\text{current}}} = -\frac{s}{\alpha}\frac{f^2}{g^* Hk^2}$$

$$\boxed{To = \frac{s}{\alpha} = -\frac{V_{\text{TRW}}}{V_{\text{current}}}k^2R_d^2 \approx -\frac{V_{\text{TRW}}}{V_{\text{current}}}}$$

when $kR_d \sim 1$

$To < 0$	$V_{\text{jet}} V_{\text{TRW}} > 0$	*prograde* topography
$To > 0$	$V_{\text{jet}} V_{\text{TRW}} < 0$	*retrograde* topography

Impact of bottom slope: simple mechanism



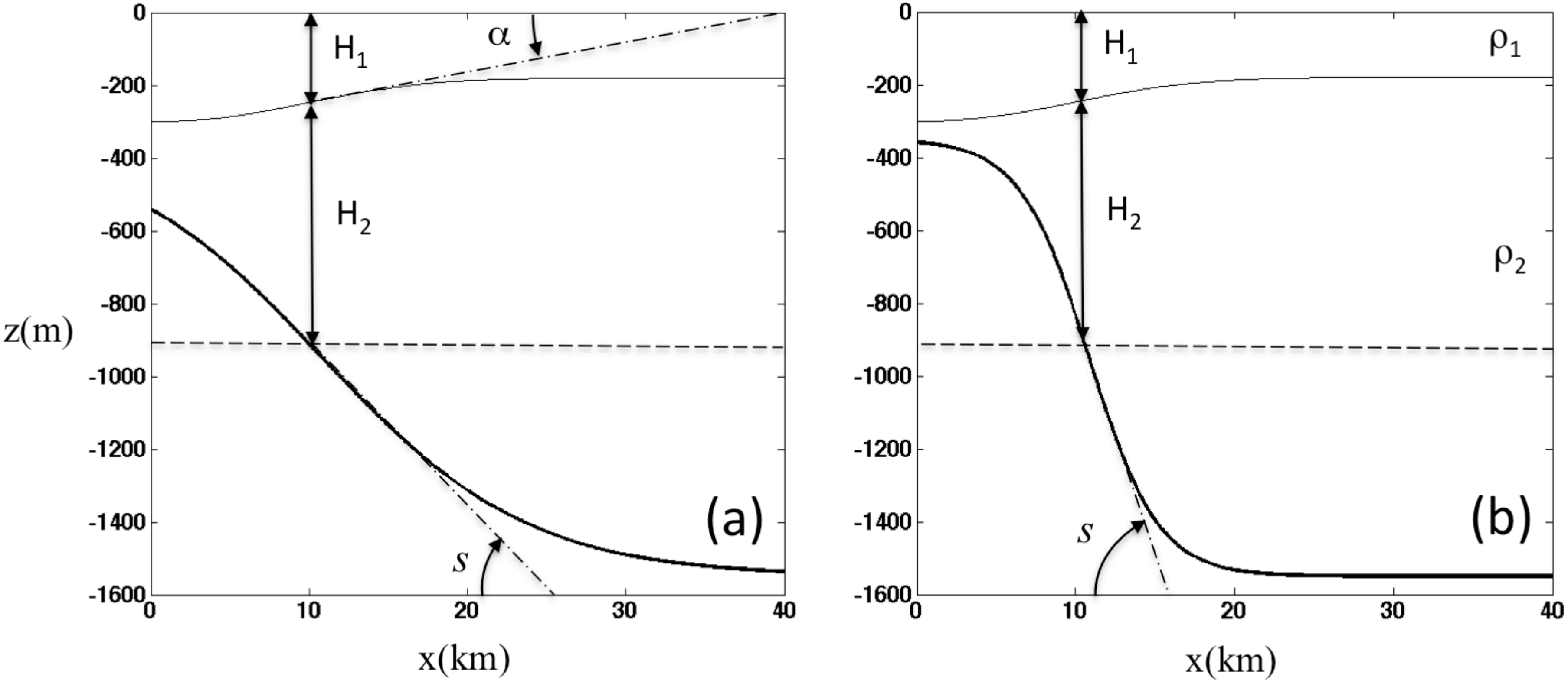
Topographic Rossby Waves

$$V_{TRW} \approx -s\frac{f}{Hk^2}$$

Phase speed locking

$$\boxed{U_{current} - V_R = V_{TRW} + \gamma V_R} \Rightarrow \quad s<0 \searrow \qquad kR_d \nearrow$$

Shallow-water model: idealized two layers configuration



Vertical stratification parameter

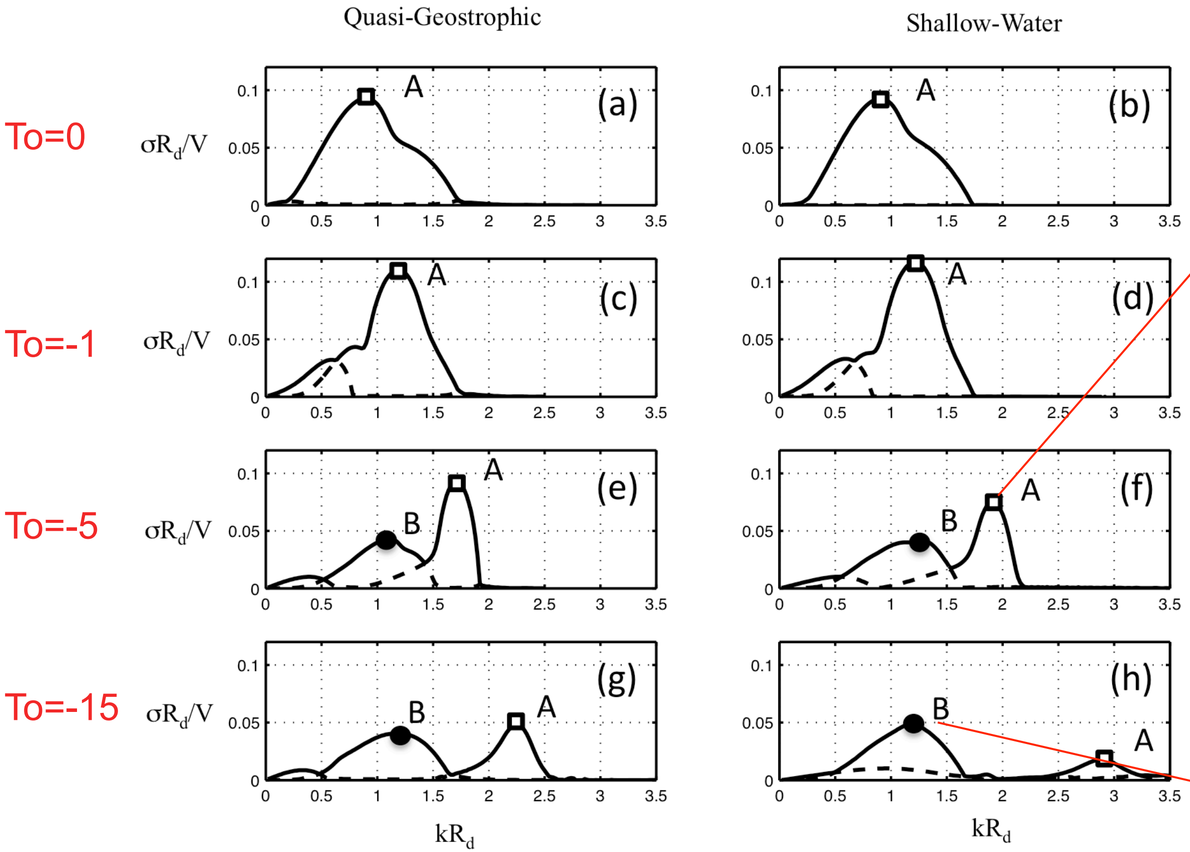
$$\boxed{\gamma = H_1 / H_2 = 0.4}$$

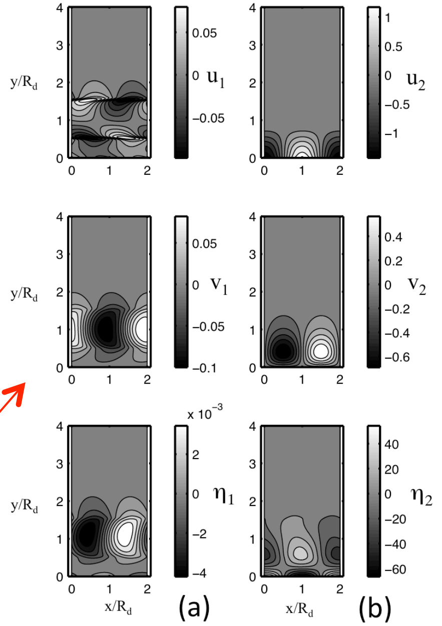
Topographic parameter

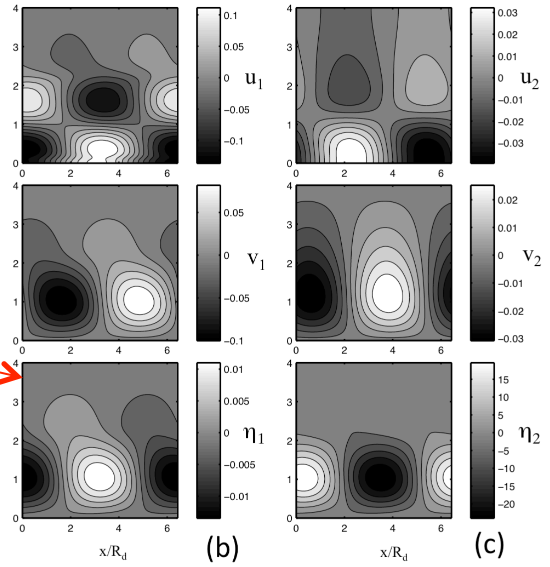
$$\boxed{To = s / \alpha < 0}$$

Coastal current along steep shelf bathymetry

Shallow-water model:
idealized two layers configuration







Two unstable modes: A,B

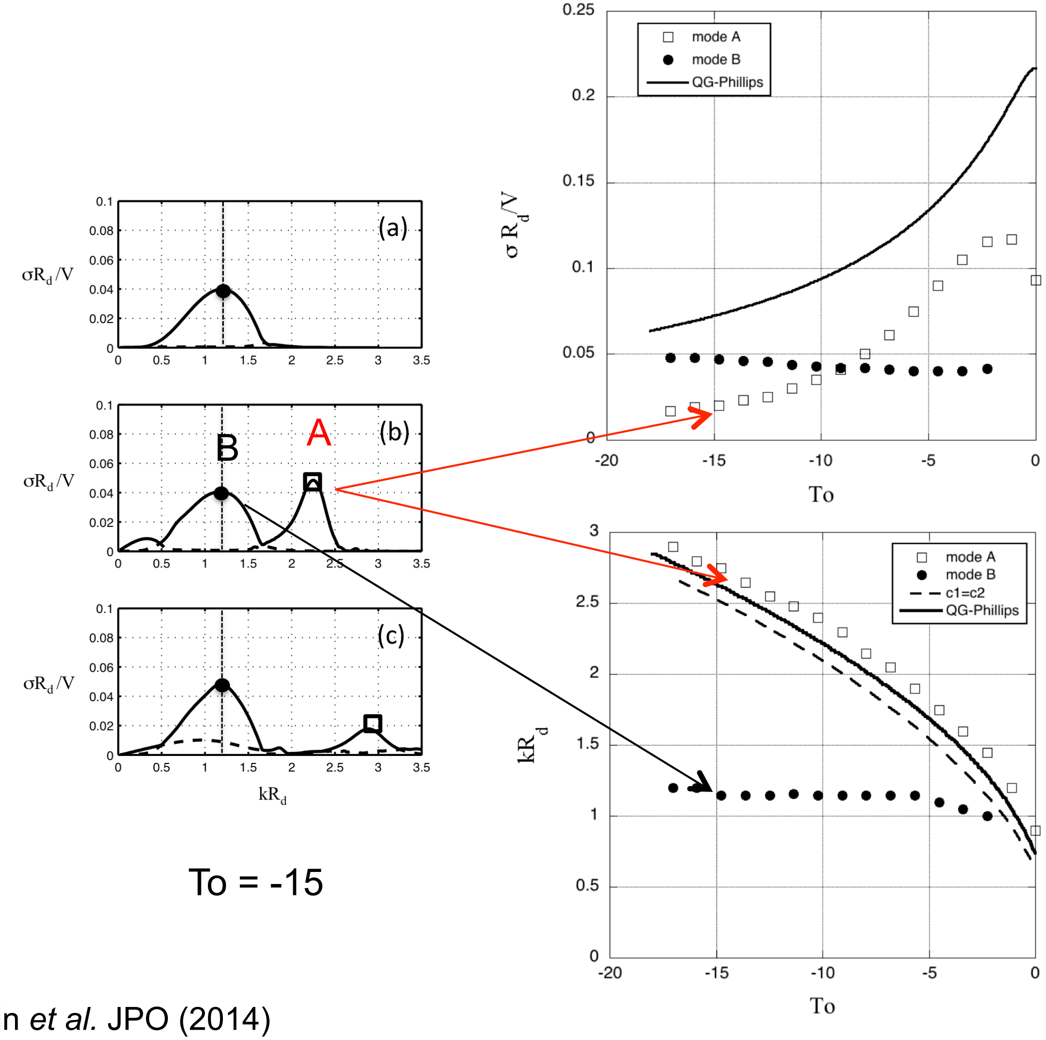
Coastal current along steep shelf bathymetry

Shallow-water model:
idealized two layers configuration

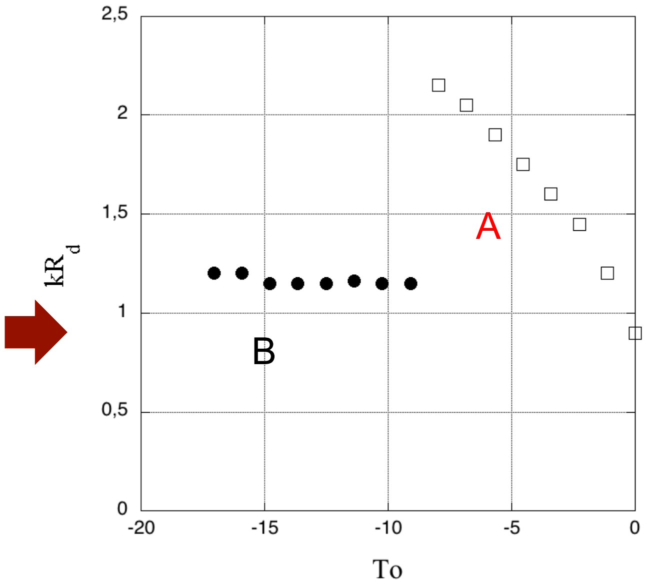
QG
1 layer

QG
2 layers

RSW
2 layers



To = -15

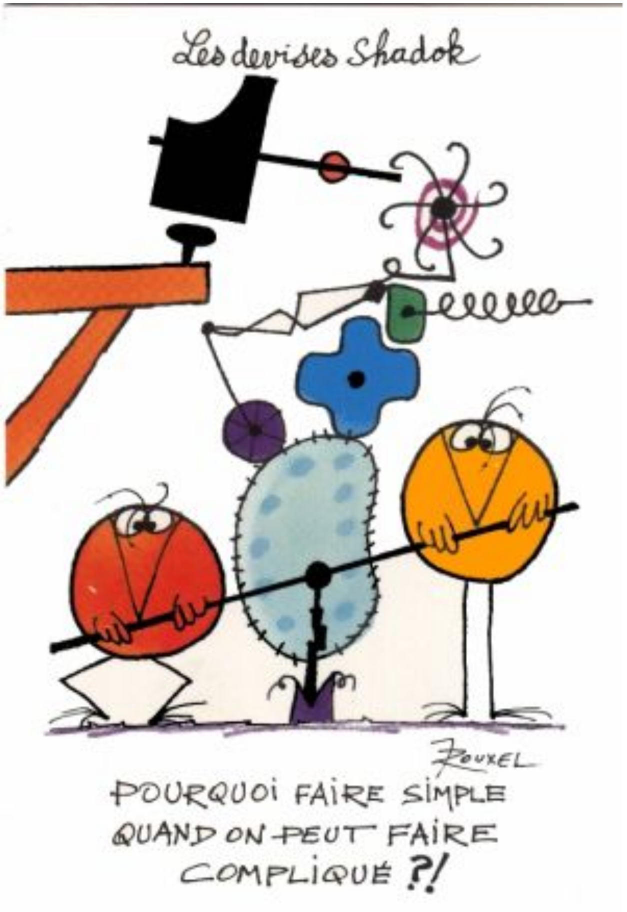


mode B
barotropic
shear
instability

mode A
baroclinic
instability

Poulin *et al.* JPO (2014)

What do we learn from laboratory experiments ?

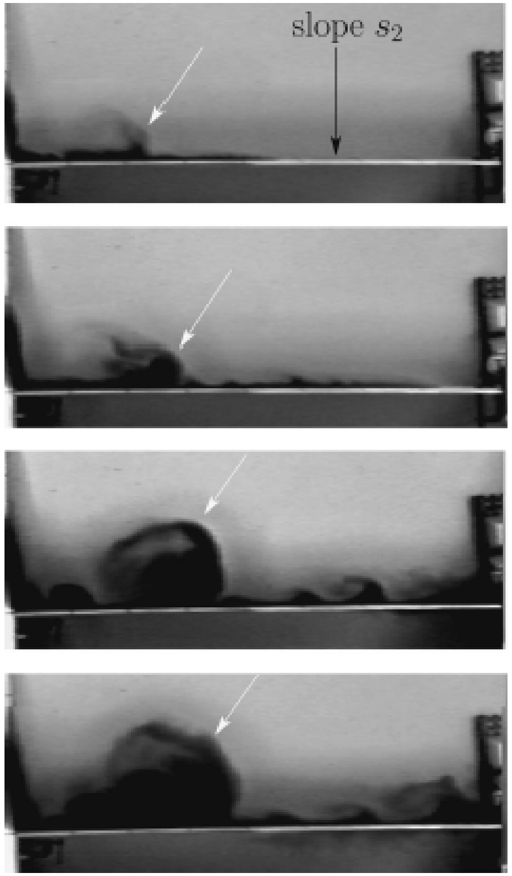


Coastal current along steep shelf bathymetry

What do we learn from previous studies ?

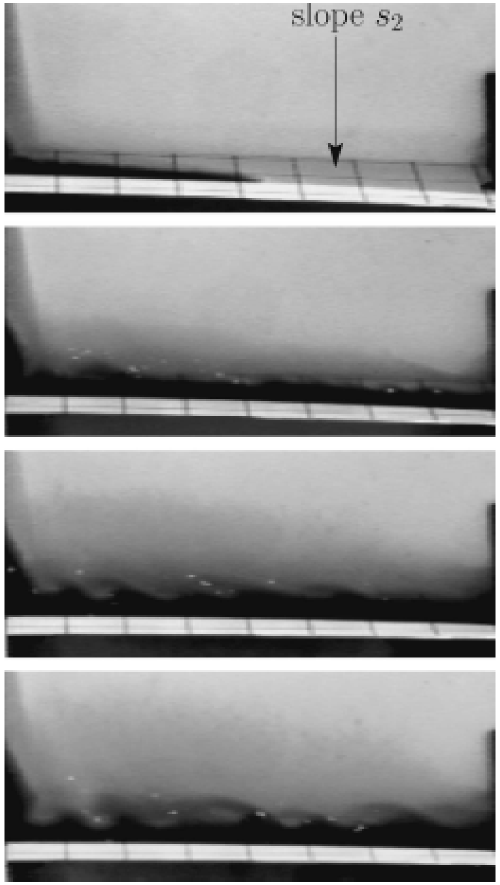
Surface advected configuration

$$H_1 \sim H_2/2$$



$s_2 = 0$

formation of large eddy



$s_2 \sim 370\%$

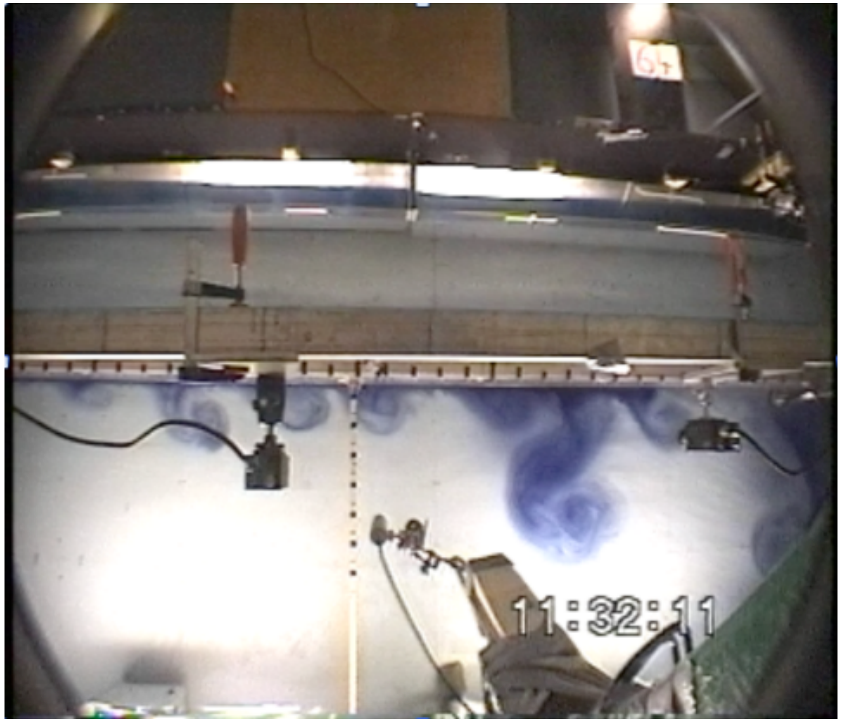
smaller meanders

Wolf & Cenedese,
J. Phys. Oceanogr.(2006)

Coastal current along steep shelf bathymetry

What do we learn from laboratory studies ?

Coastal gravity current in the Trondheim rotating platform (5m diameter)



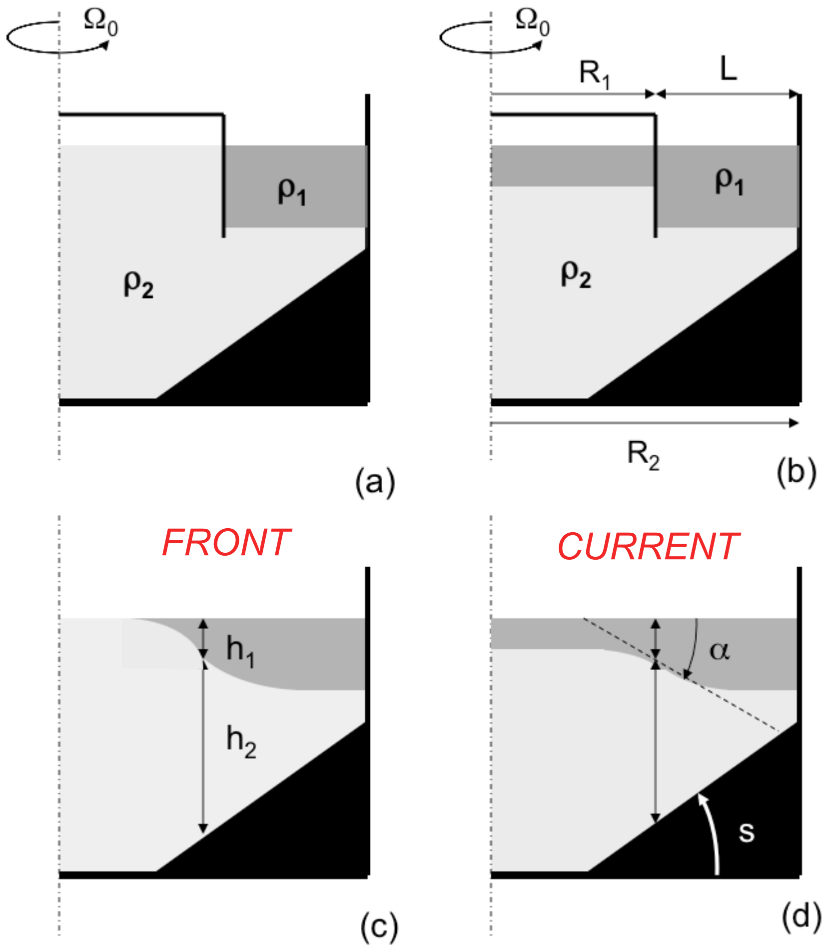
Flat bottom s=0

Steep slope s=50%

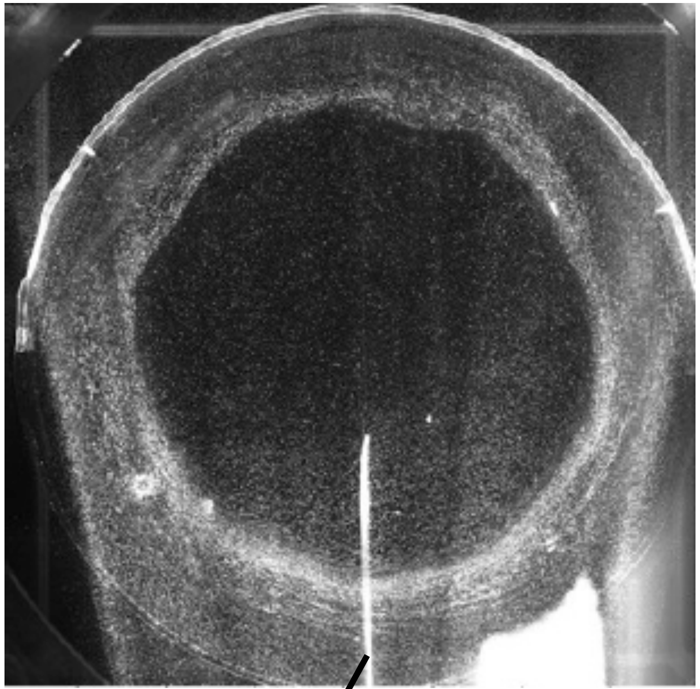
© Sandy Gregorio

Coastal current along steep shelf bathymetry

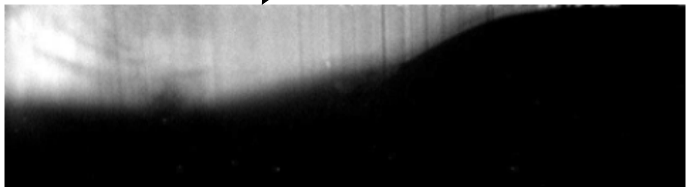
Idealized configuration: experimental setup



Initial and adjusted configurations
side view of the two layer salt stratifications



top view with PIV particles



side view LIF visualization

Coastal current along steep shelf bathymetry

High resolution
PIV measurements:
4800x3200
pixels camera

COASTAL FRONT
FLAT BOTTOM CASE

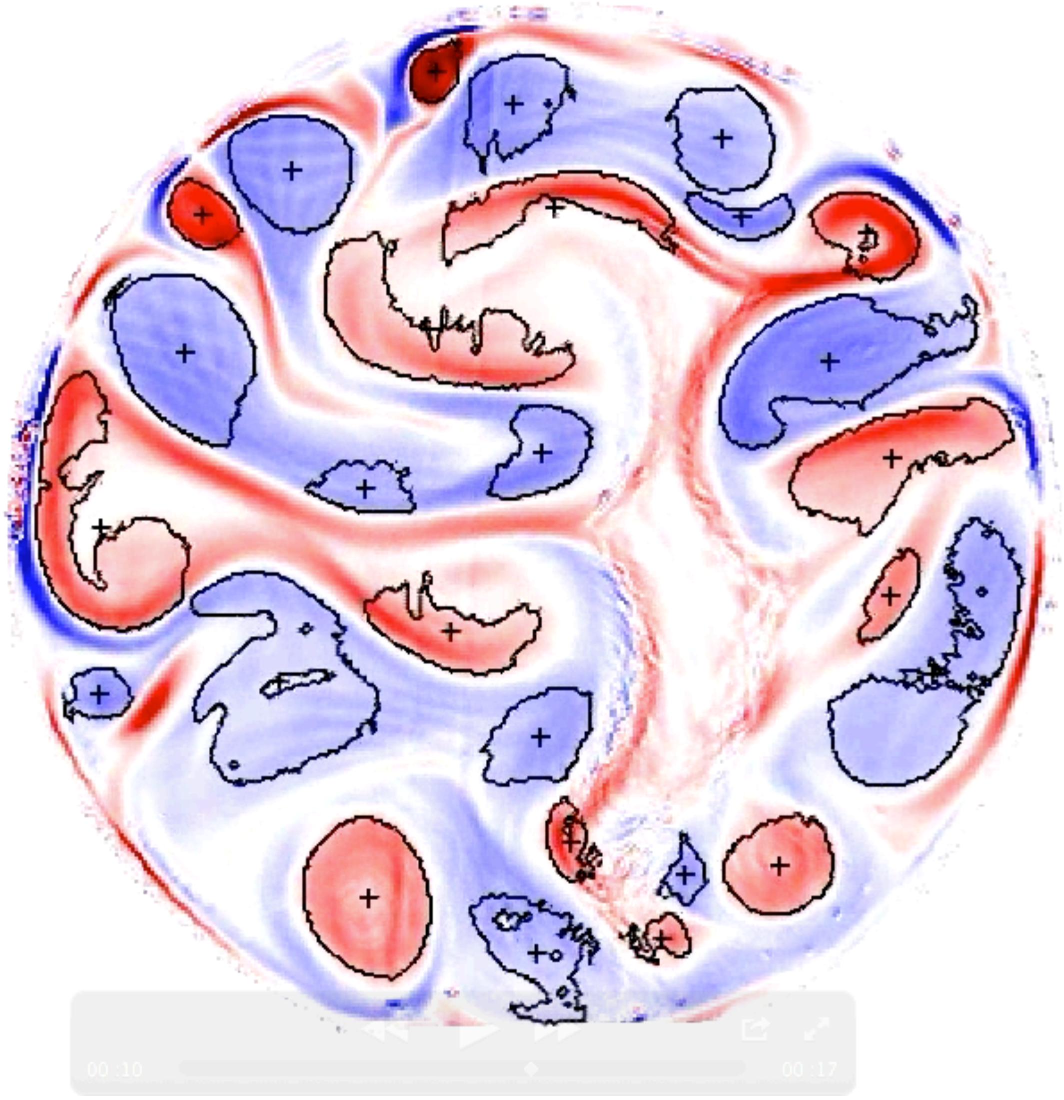
Coastal current along steep shelf bathymetry

High resolution
PIV measurements:
surface vorticity

blue: anticyclonic
red: cyclonic

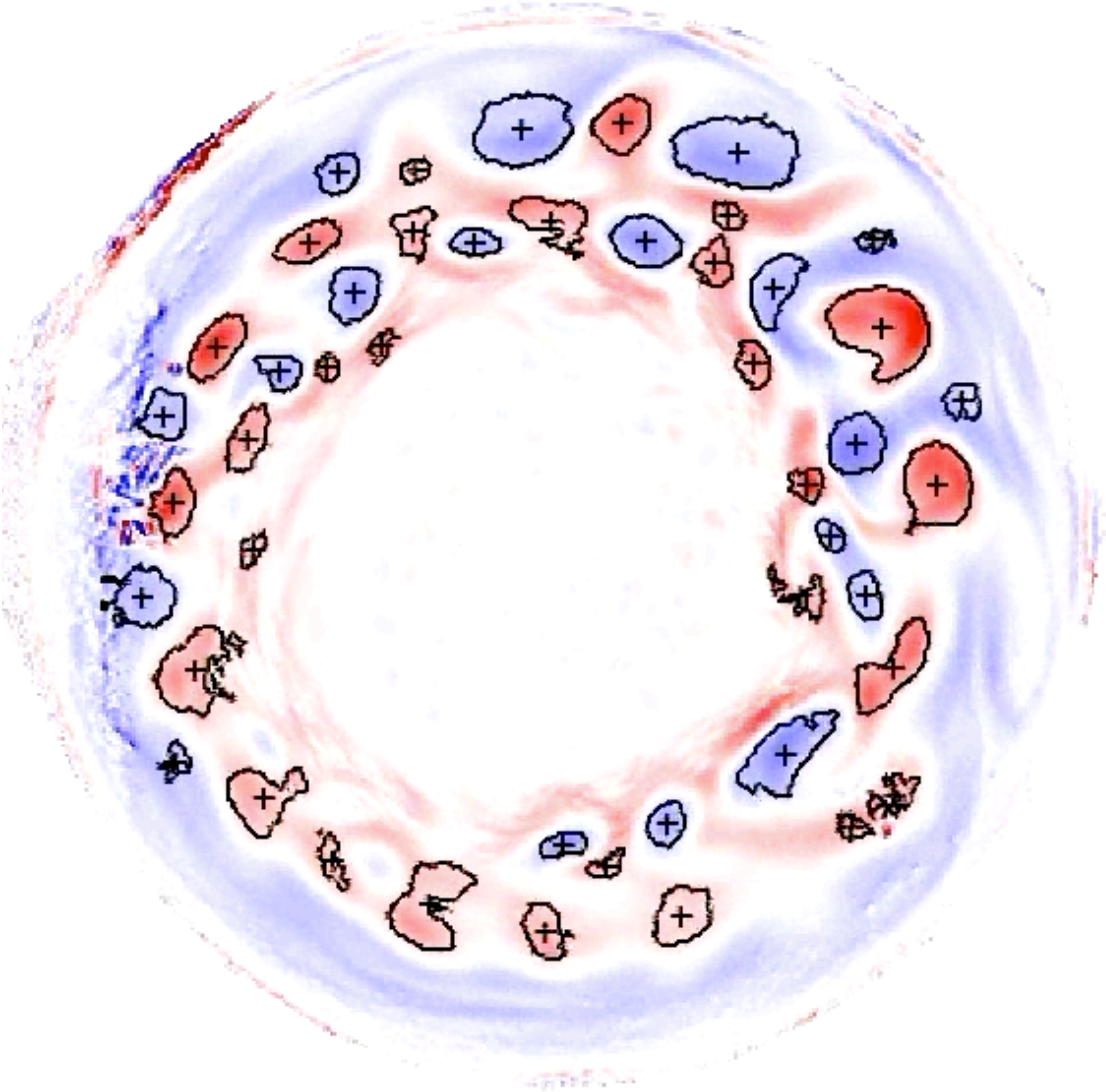
COASTAL FRONT
FLAT BOTTOM CASE

Black contours Okubo-Weiss criterion
(Isern-Fontanet et al. 2003)



Coastal current along steep shelf bathymetry

High resolution
PIV measurements:
surface vorticity



blue: anticyclonic
red: cyclonic

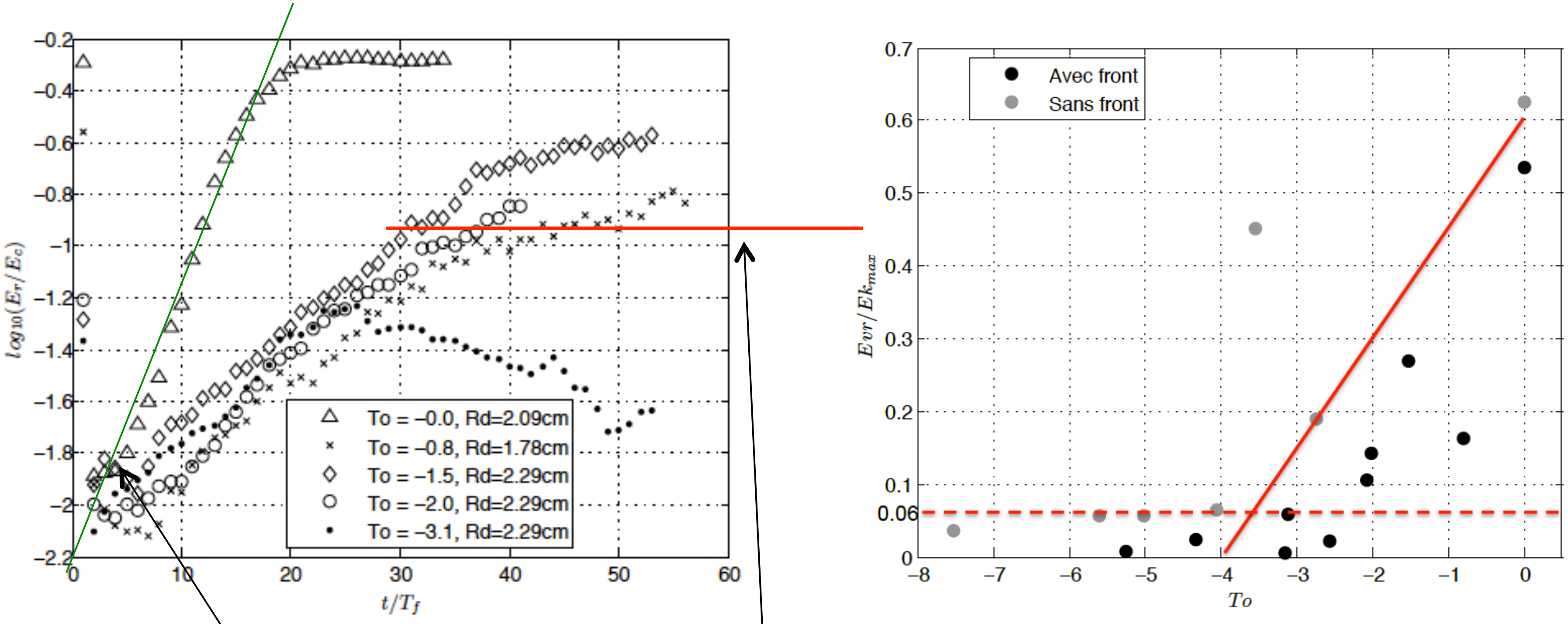
LINEAR SHELF

Topographic parameter

$$To = \frac{s}{\alpha} = -1.3$$

Coastal current along steep shelf bathymetry

Evolution of cross shore KE/KE_{Tot}



Estimation of unstable growth rates
(flat bottom case s=0)

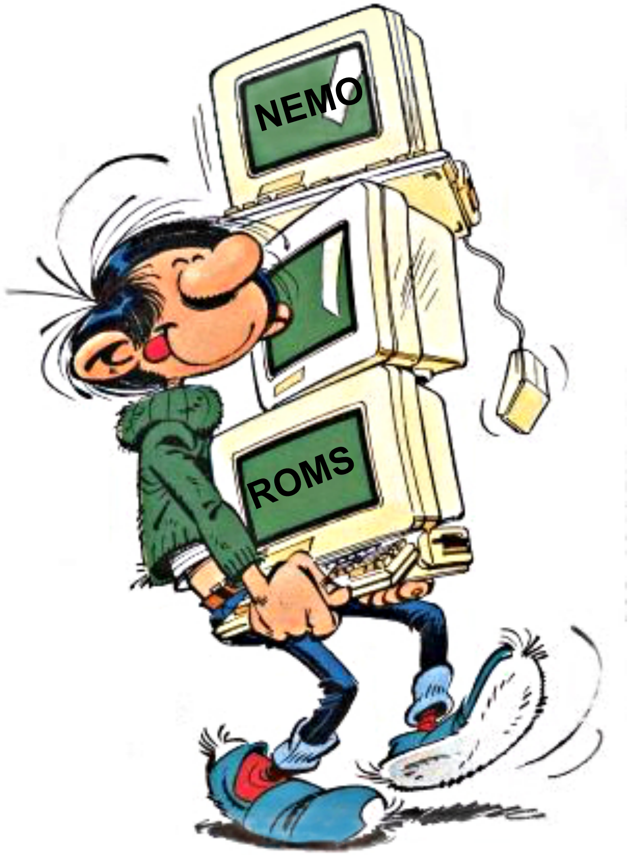
Level of non-linear saturation

$To_c \sim -3.5$

Géhéniau *et al.* (to be submitted)

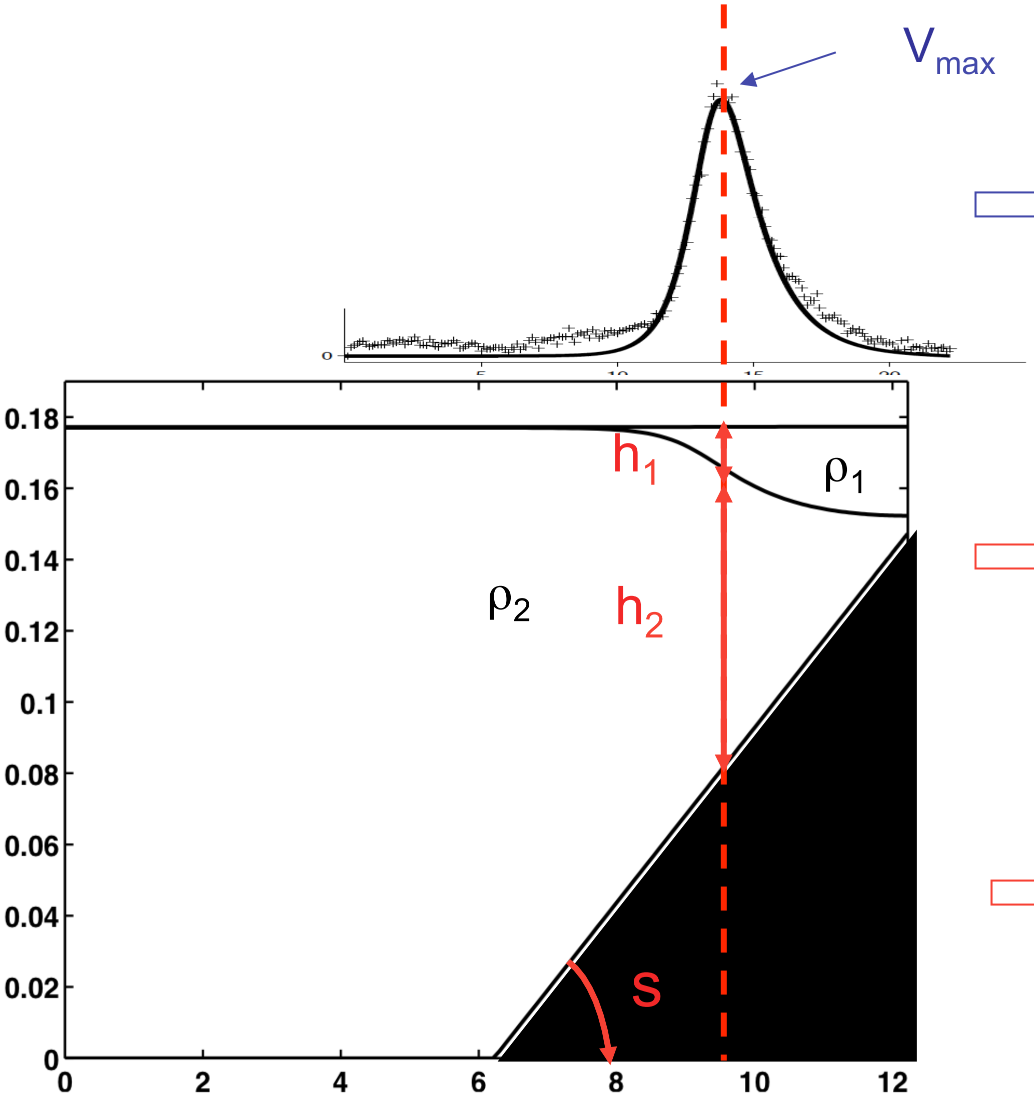
Coastal current along steep shelf bathymetry

What do we learn from numerical simulations ?



Coastal current along steep shelf bathymetry

Topographic impact: NEMO simulations / lab configuration



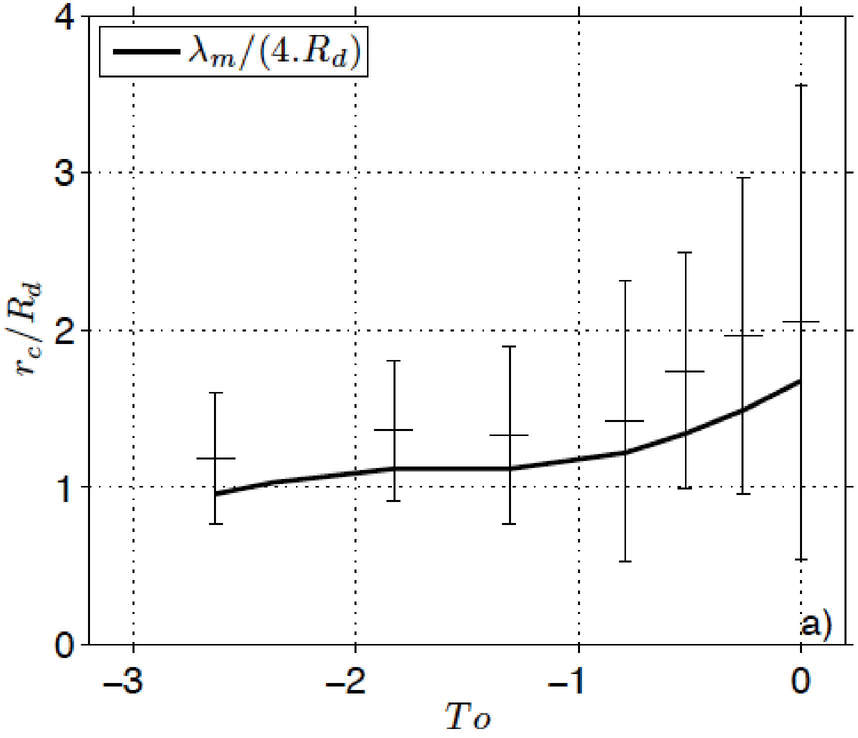
⇨ Ro= $V_{max}/(f R_d)$=0.35

⇨ $\gamma = h_1/h_2 = 0.3$

⇨ To= s/α

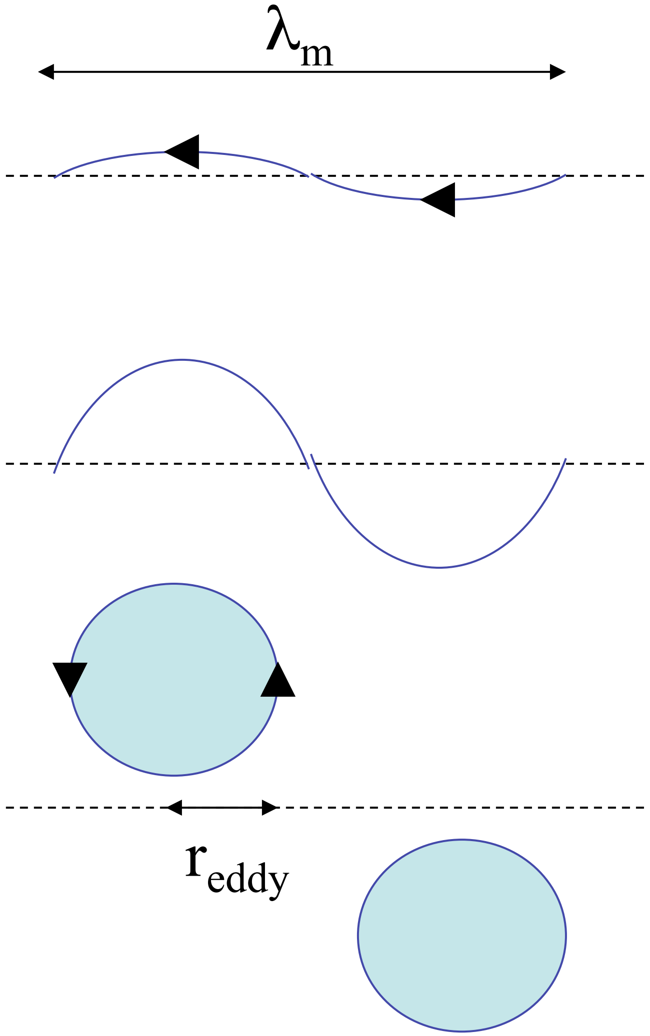
Coastal current along steep shelf bathymetry

Topographic impact on: eddy size



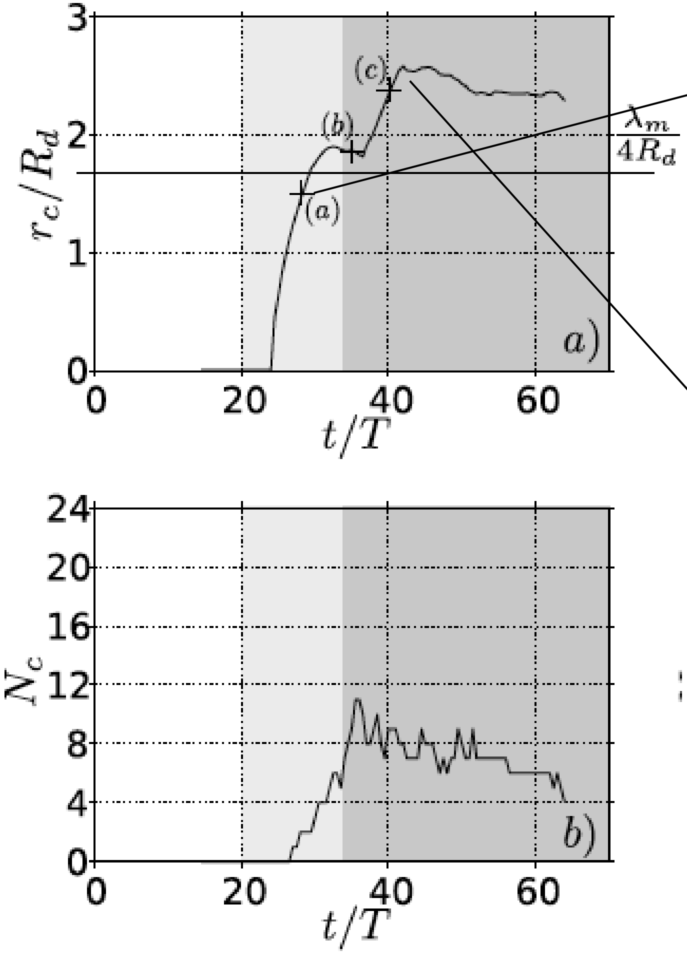
non-linear saturation

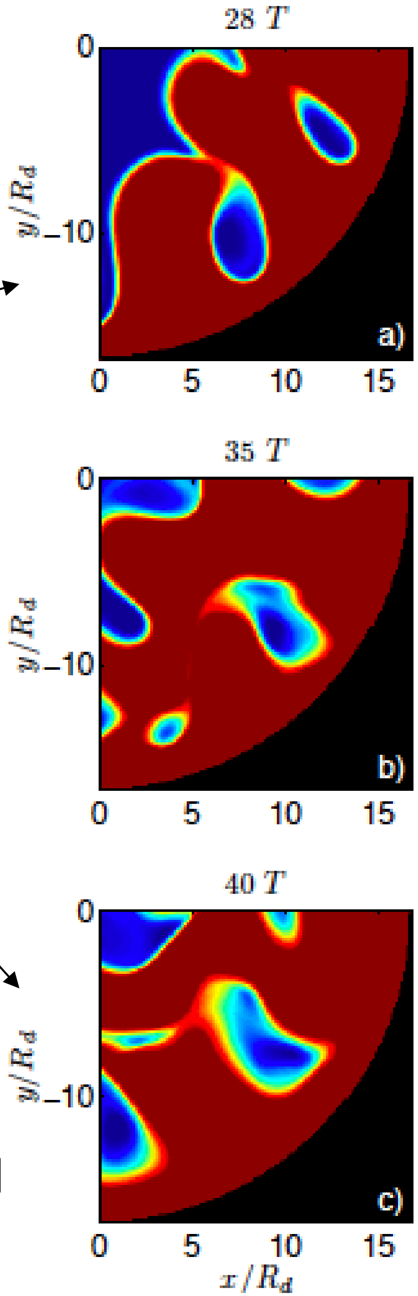
$r_{eddy} \sim \lambda/4$



Coastal current along steep shelf bathymetry

Secondary linear process: flat bottom To=0





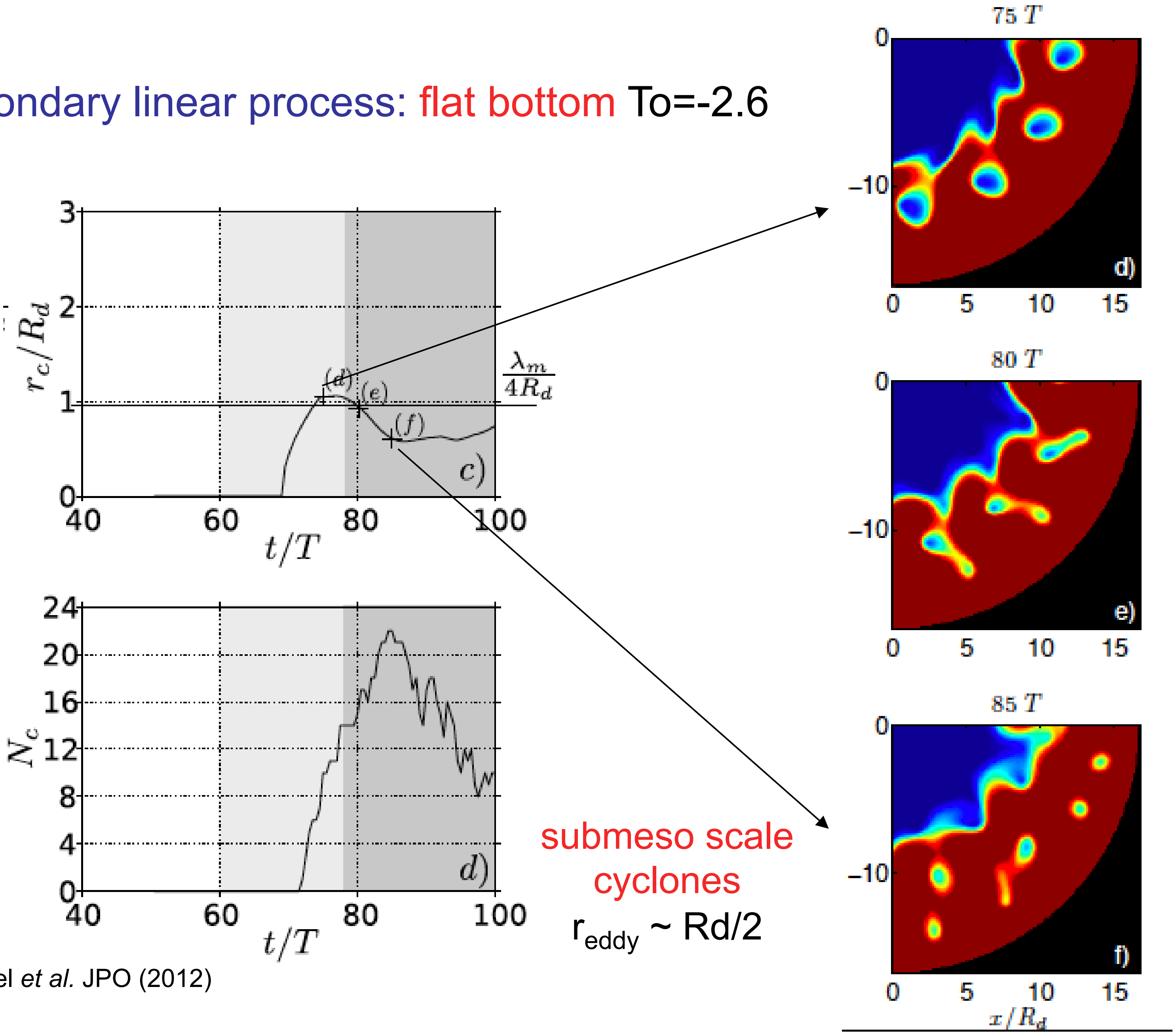
meso scale cyclones

r_{eddy} ~ 2.5 Rd

Pennel *et al.* JPO (2012)

Coastal current along steep shelf bathymetry

Secondary linear process: flat bottom To=-2.6



submeso scale cyclones

r_{eddy} ~ Rd/2

Pennel *et al.* JPO (2012)

CONCLUSIONS

Linear stability is not enough, non-linear shelf stabilization is crucial

Various dynamical regimes

1- Standard baroclinic instability, meso-scale anticyclones
strong cross-shelf exchanges

2- Rossby-TRW instability, Trapped Coastal Instability
reduced cross-shelf exchanges, small-scale trapped eddies

Direct cascade towards sub meso-scale eddies may occurs !

3- Strong non-linear stabilization, weak barotropic shear disturbances
no cross-shelf exchanges, strong along shore transport

Next step… next talk: fully stratified configuration (Bu, γ, T_p)