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Mesoscale eddies in the Arabian and Oman Seas and their impact on the Persian Gulf Water outflow

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Outline

1) Introduction – presentation of the domain

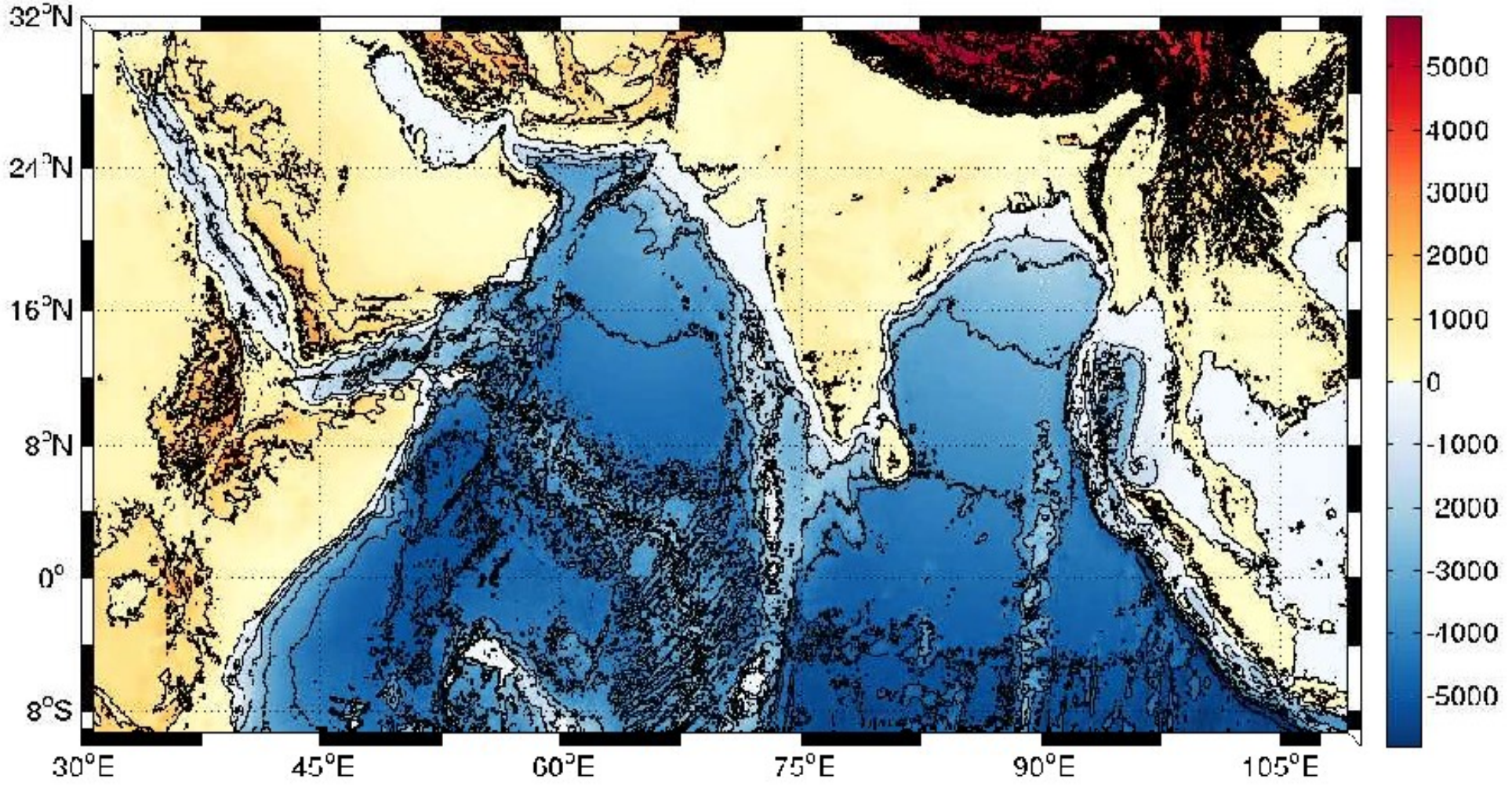
2) The mesoscale circulation in the Arabian Sea and Sea of Oman

3) Impact on the Persian Gulf Water outflow

4) Conclusion

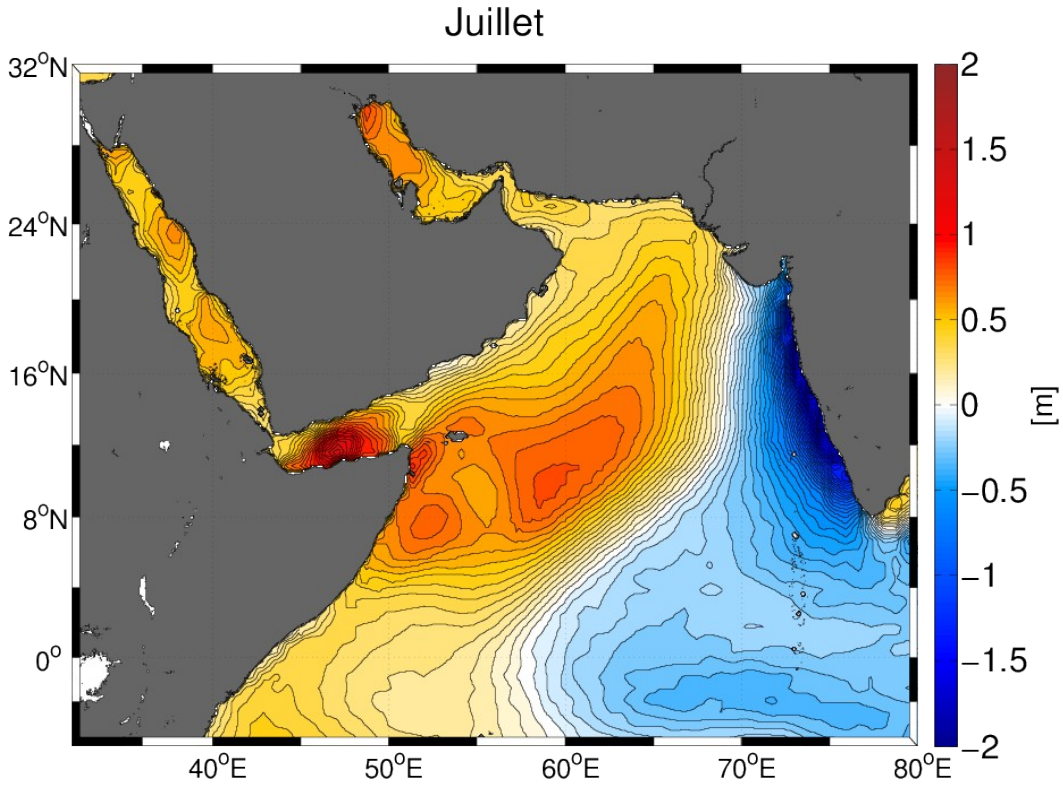
1) Introduction – Presentation of the domain

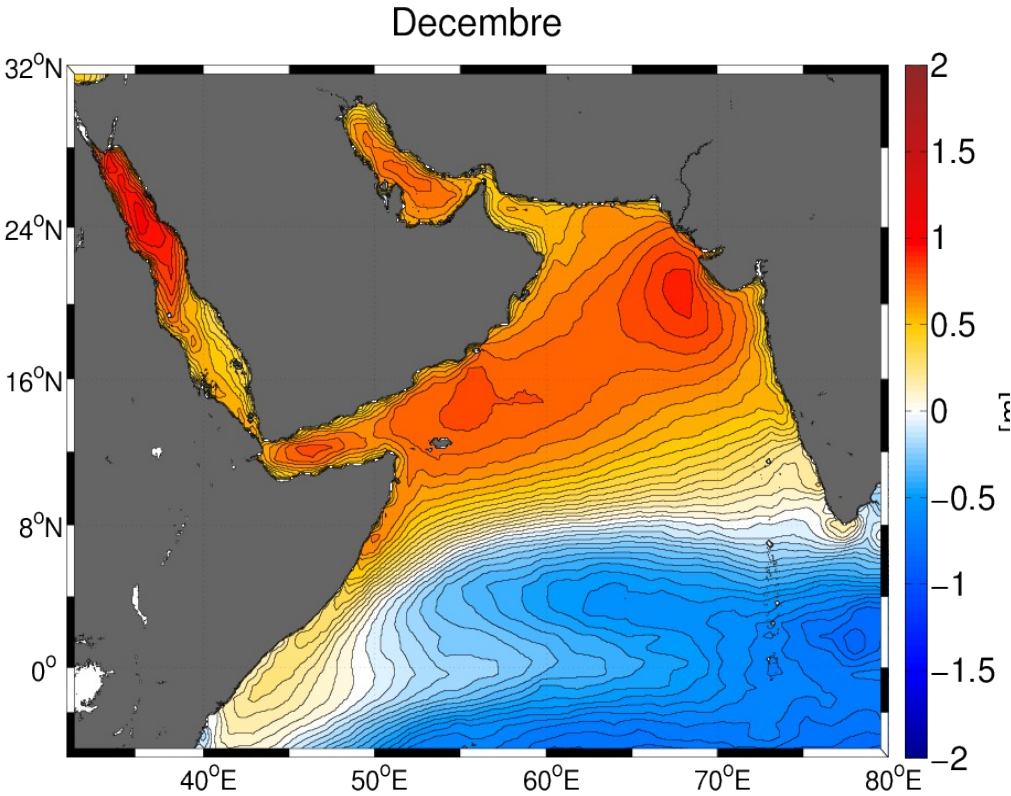
Region of complex topography



1) Introduction – Presentation of the domain

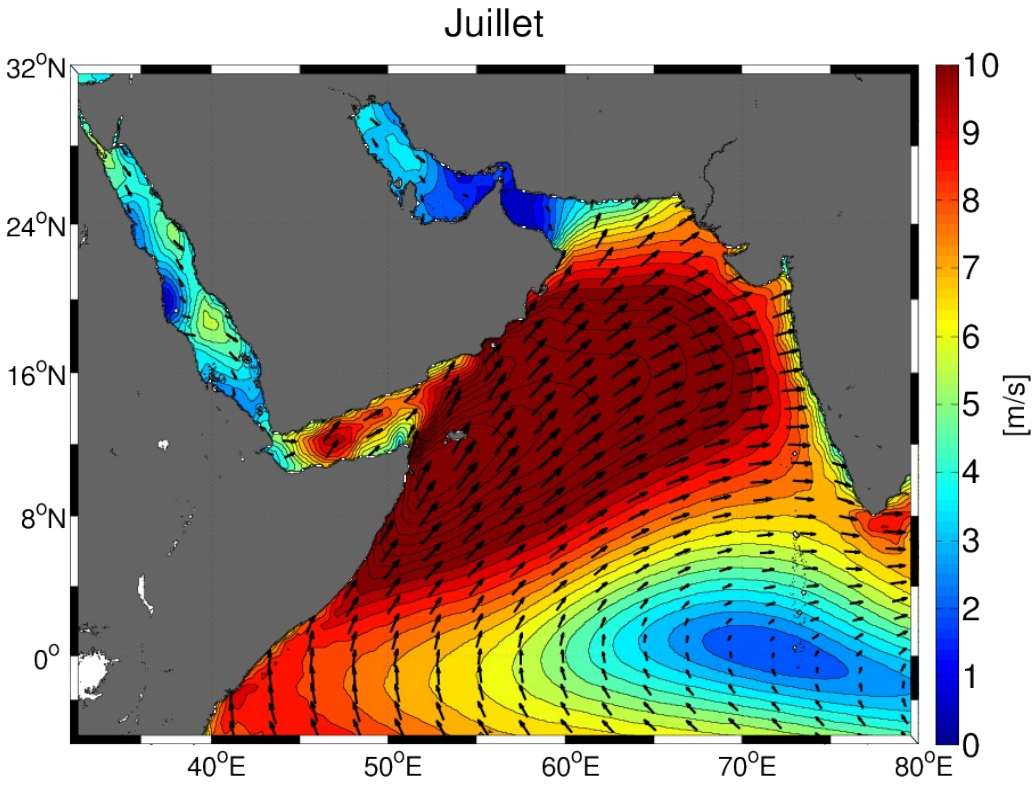
Region of strong evaporation
(monsoon rainfall in summer
along the west coast of India)

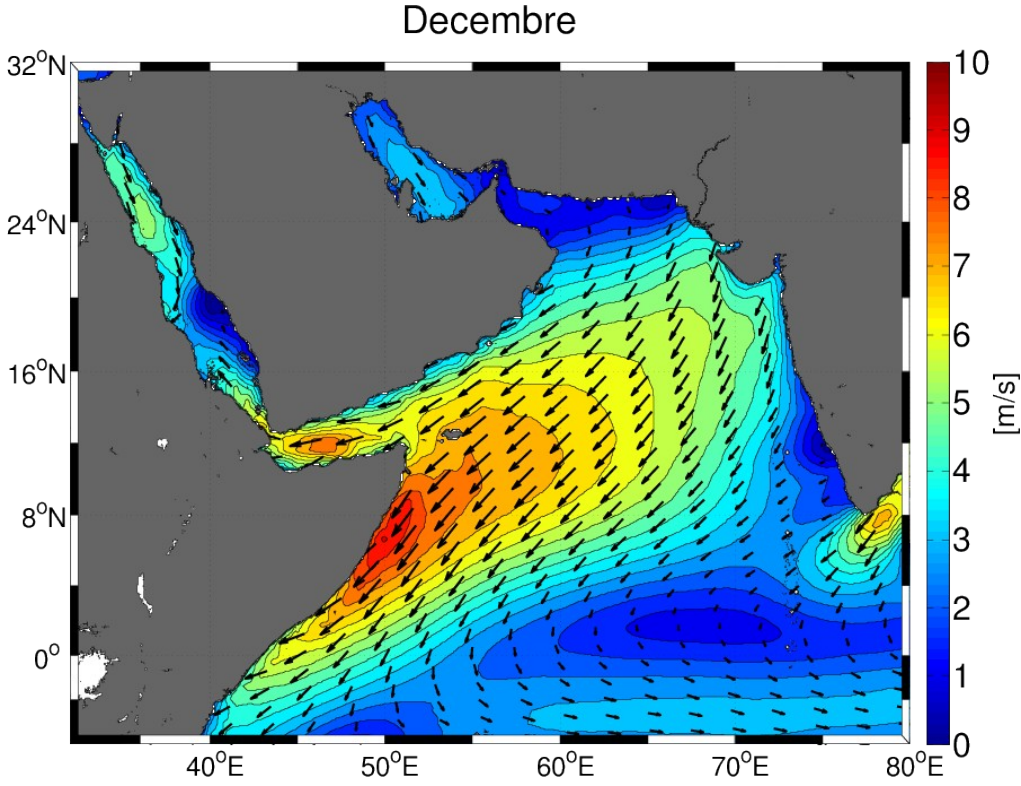




1) Introduction – Presentation of the domain

Region of intense monsoon winds in summer (and a little less so in winter)



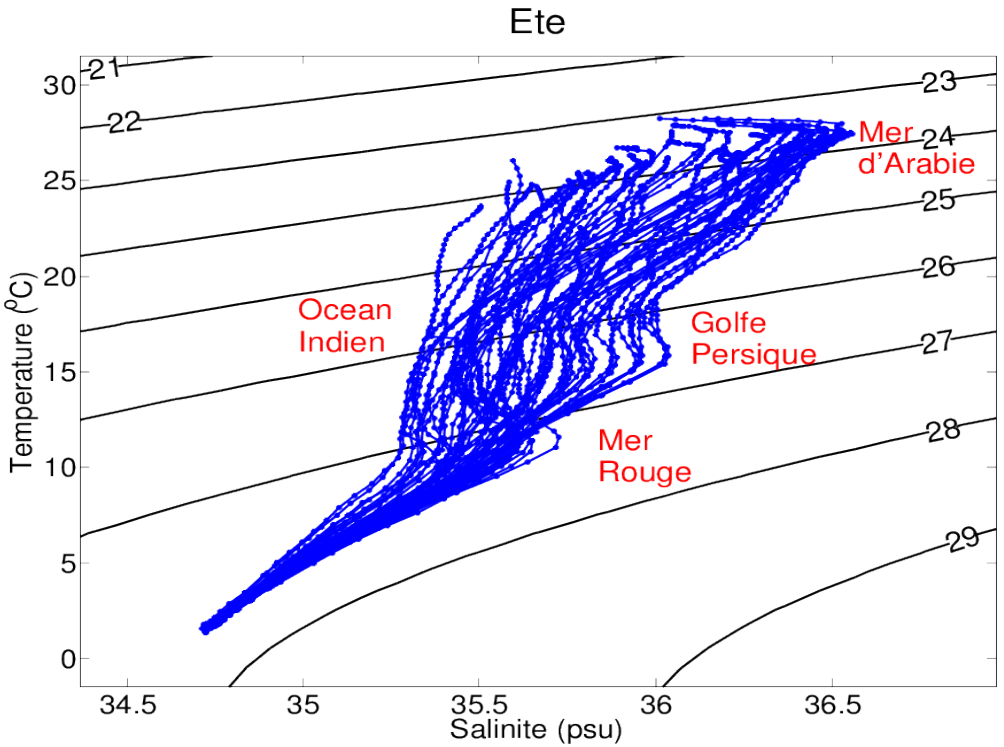


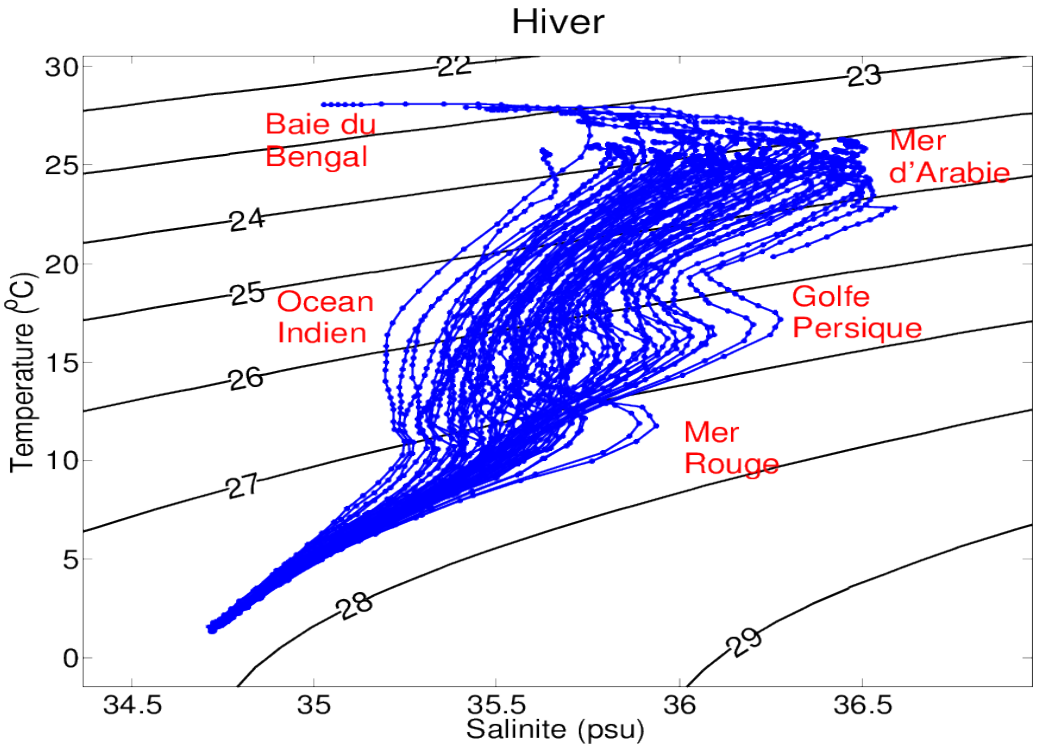
1) Introduction – Presentation of the domain

Formation of very salty water (S > 40) in marginal seas (Red Sea, Persian Gulf)
Outflow of these salty waters into the Arabian Sea via Bab el Mandeb and Hormuz

Summer

Winter



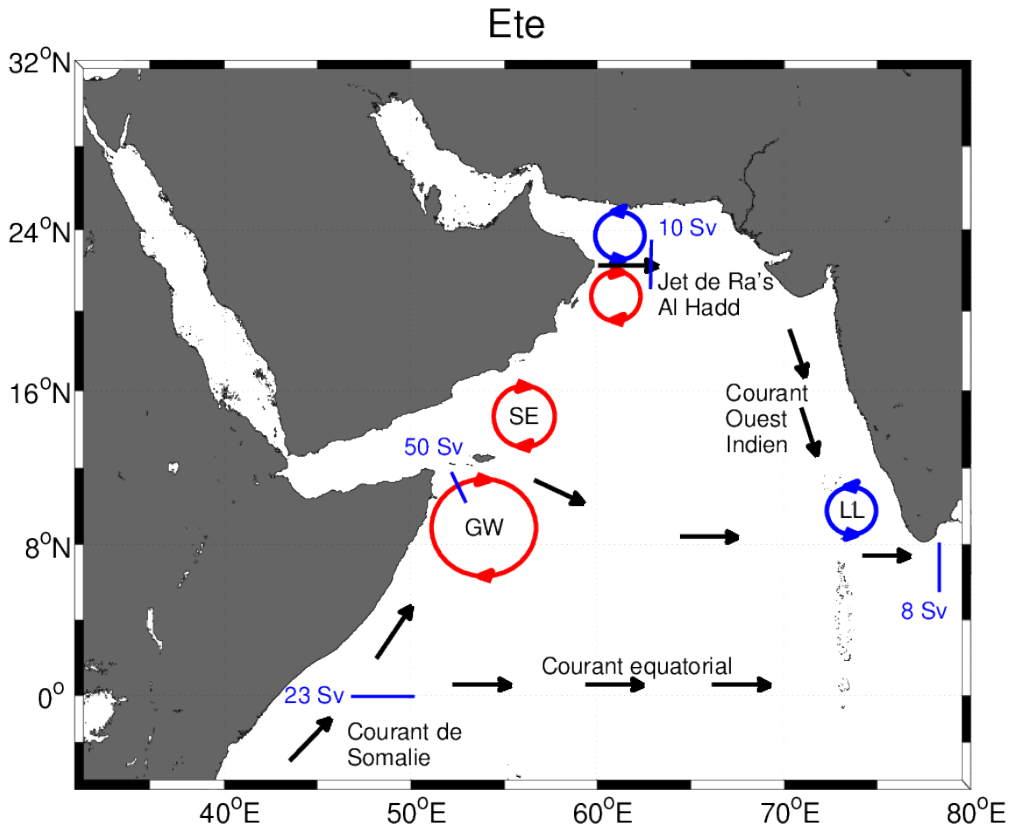


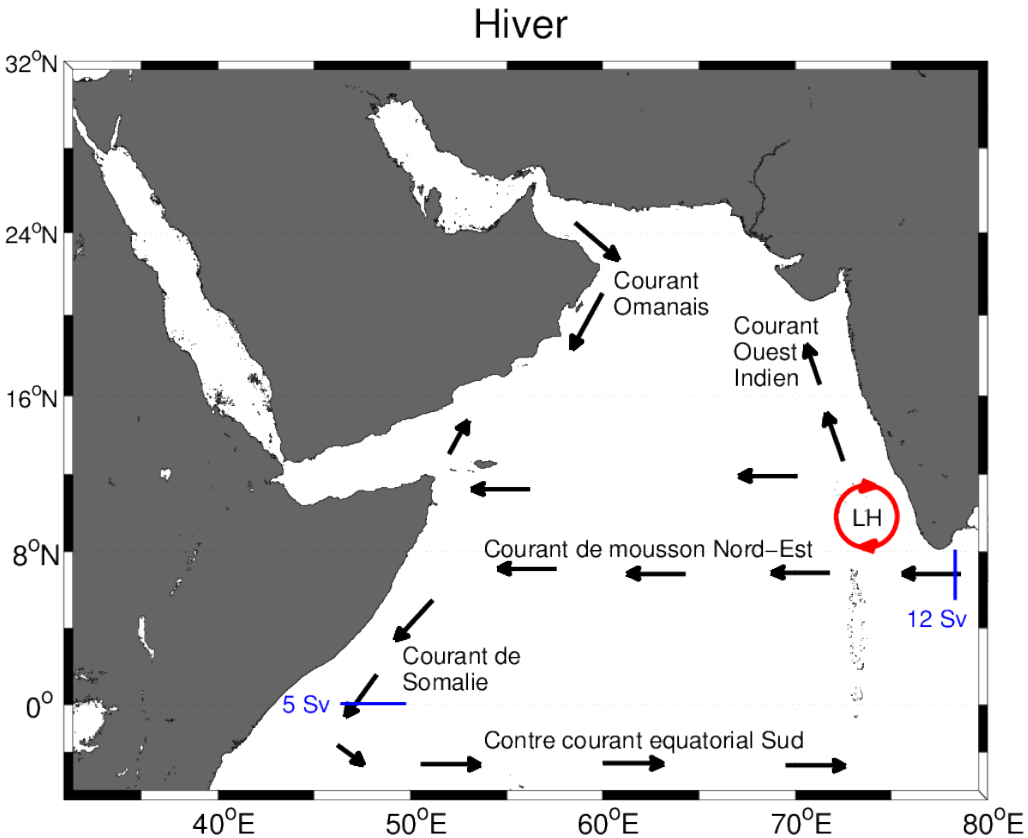
1) Introduction – Presentation of the domain

Regional circulation : from historical measurements - LL Laccadive Low, LH Laccadive High, GW Great Whirl, SE Socotra Eddy

Summer

Winter





1) Introduction – Presentation of the domain

Previous studies of the region :

- Numerical models of Red Sea, Red Sea outflow, Persian Gulf (and more rarely PG outflow) – more recently HR model of whole region (HYCOM, SHOM, L'Hegaret et al., 2015, subm) and of Arabian Sea (ROMS, Vic 2014)

- experiments at sea : MtMichell Expt (PG 1991), JGOFS (AS 1994), GOGP (SO 1999), REDSOX (GA 2001), Physindien (AS, SO and PG, 2011-2014)

- Available here : meteorological data, in-situ data (ARGO, CTD from Coriolis database), and HYCOM output (climatol. forcing, 5 km, 32 levels)

Objectives

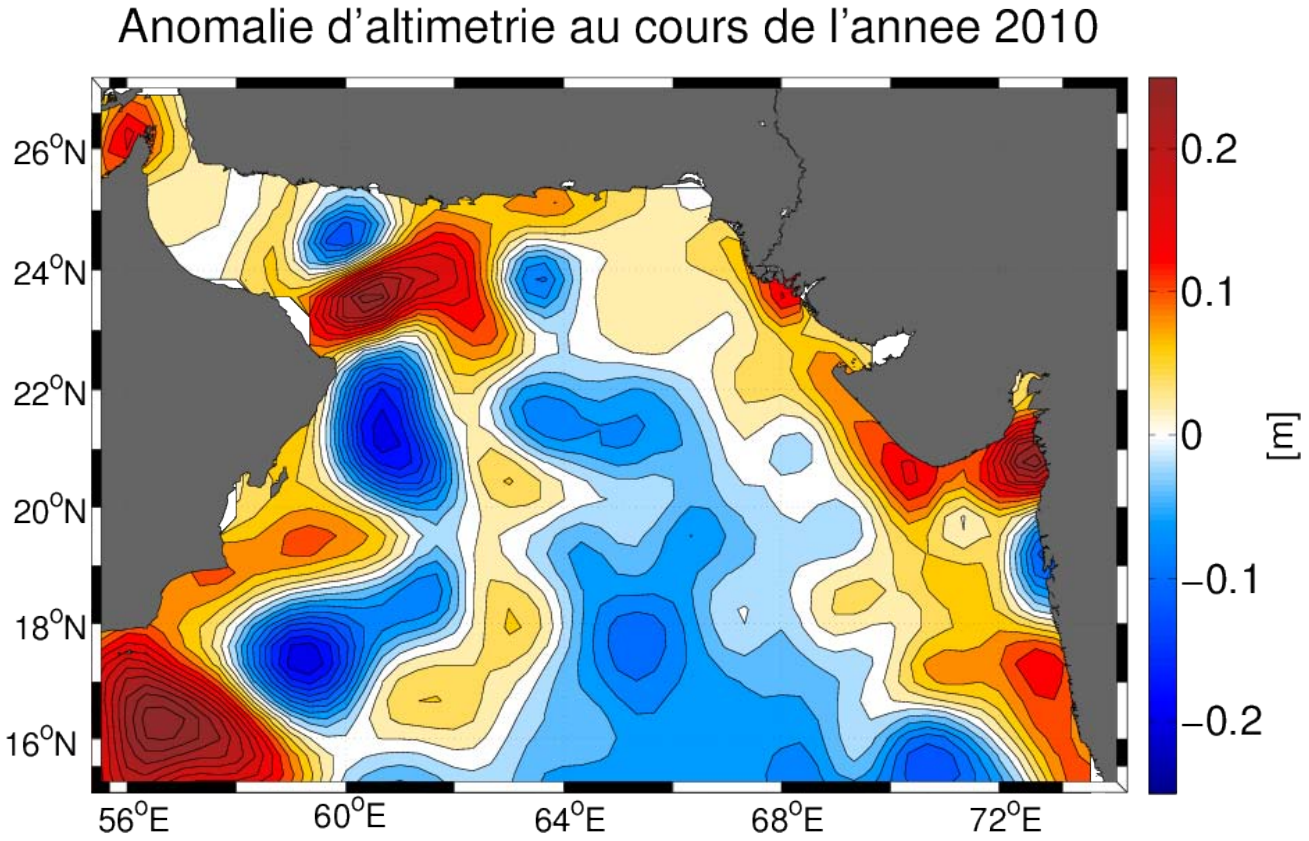
- Characterize mesoscale activity in the Arabian Sea and Sea of Oman

- Study its influence on PGW outflow

2) Mesoscale dynamics

Altimetric data → mesoscale features
and seasonal variability.

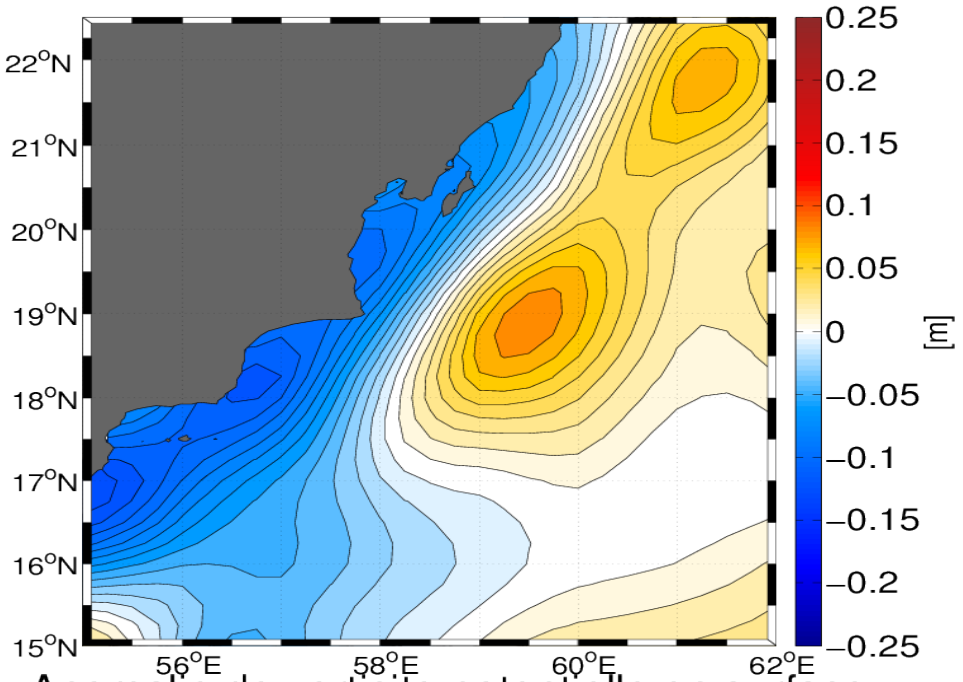
<u>Three main features :</u>
- coastal current (strip of >0 or <0 SLA),
- eddies near the coast
- RW offshore



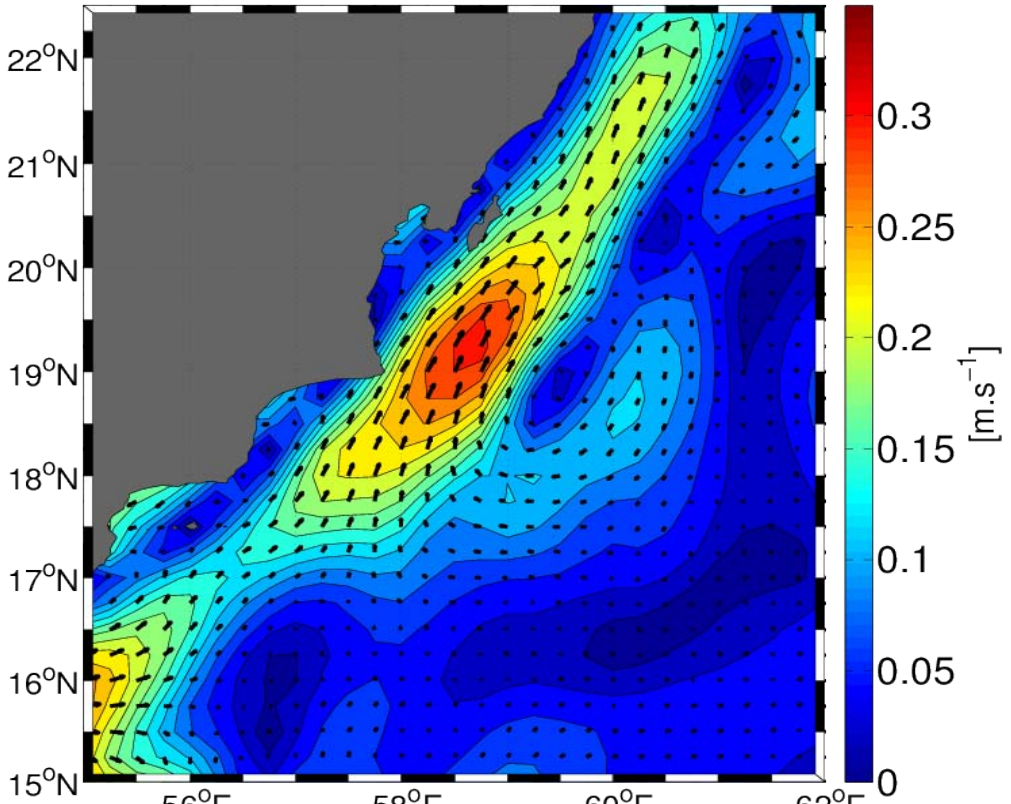
2) Mesoscale dynamics - coastal current

Present in summer and in winter ;
forced by offshore or shoreward Ekman transport (from data)

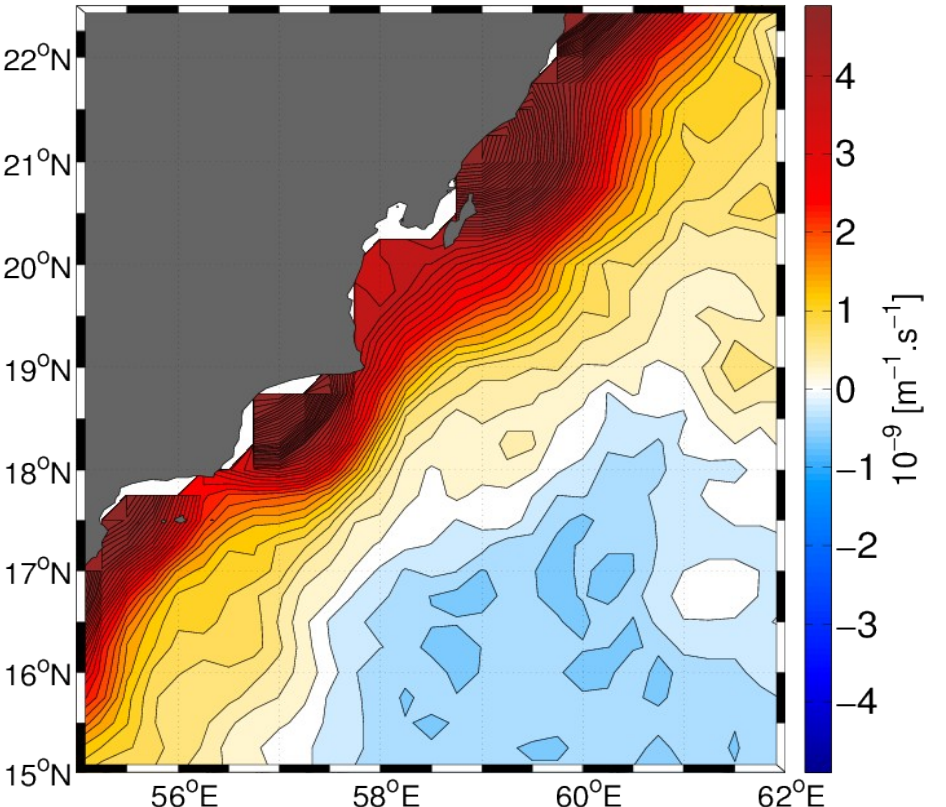
Anomalie d'altimetrie issue d'AVISO



Vitesses de surface issues d'AVISO

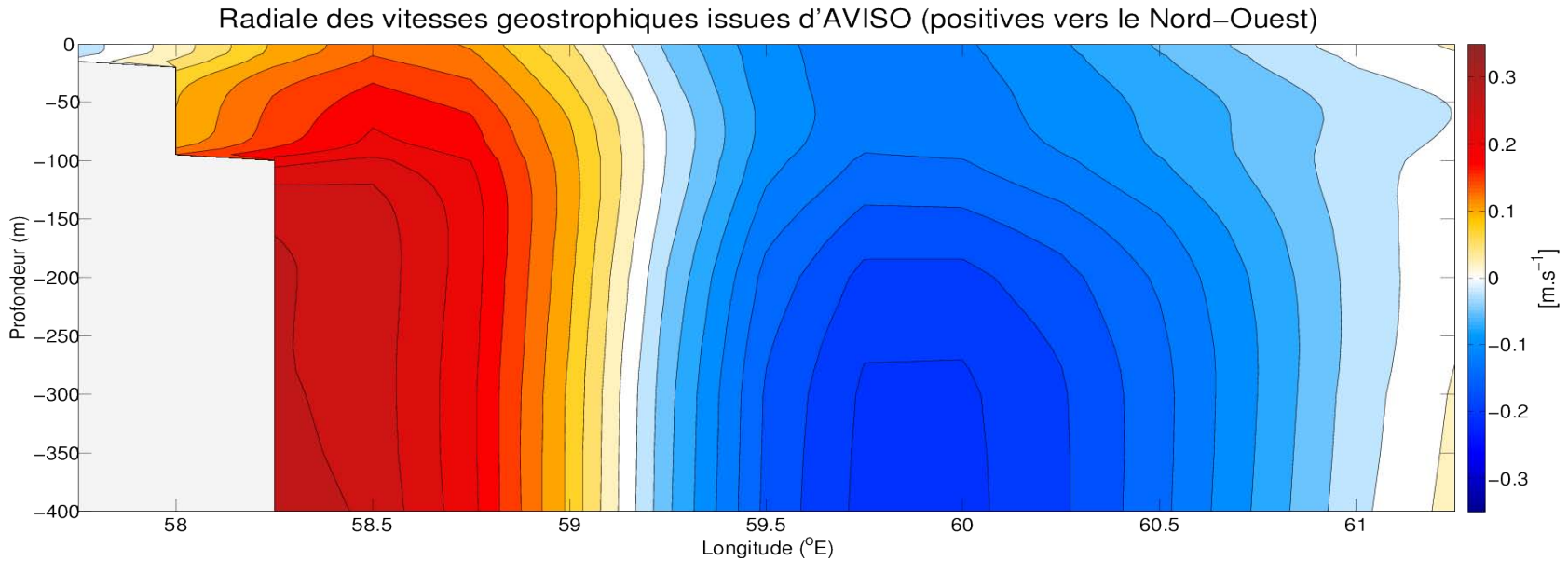


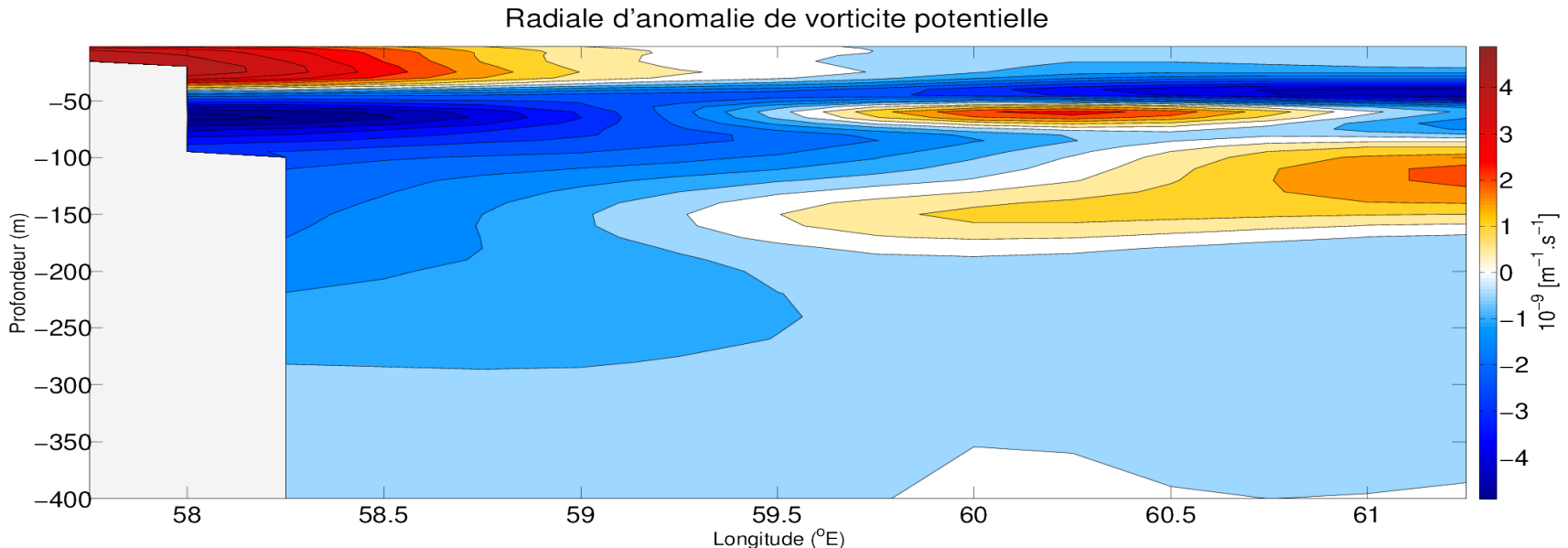
Anomalie de vorticite potentielle en surface



2) Mesoscale dynamics - coastal current

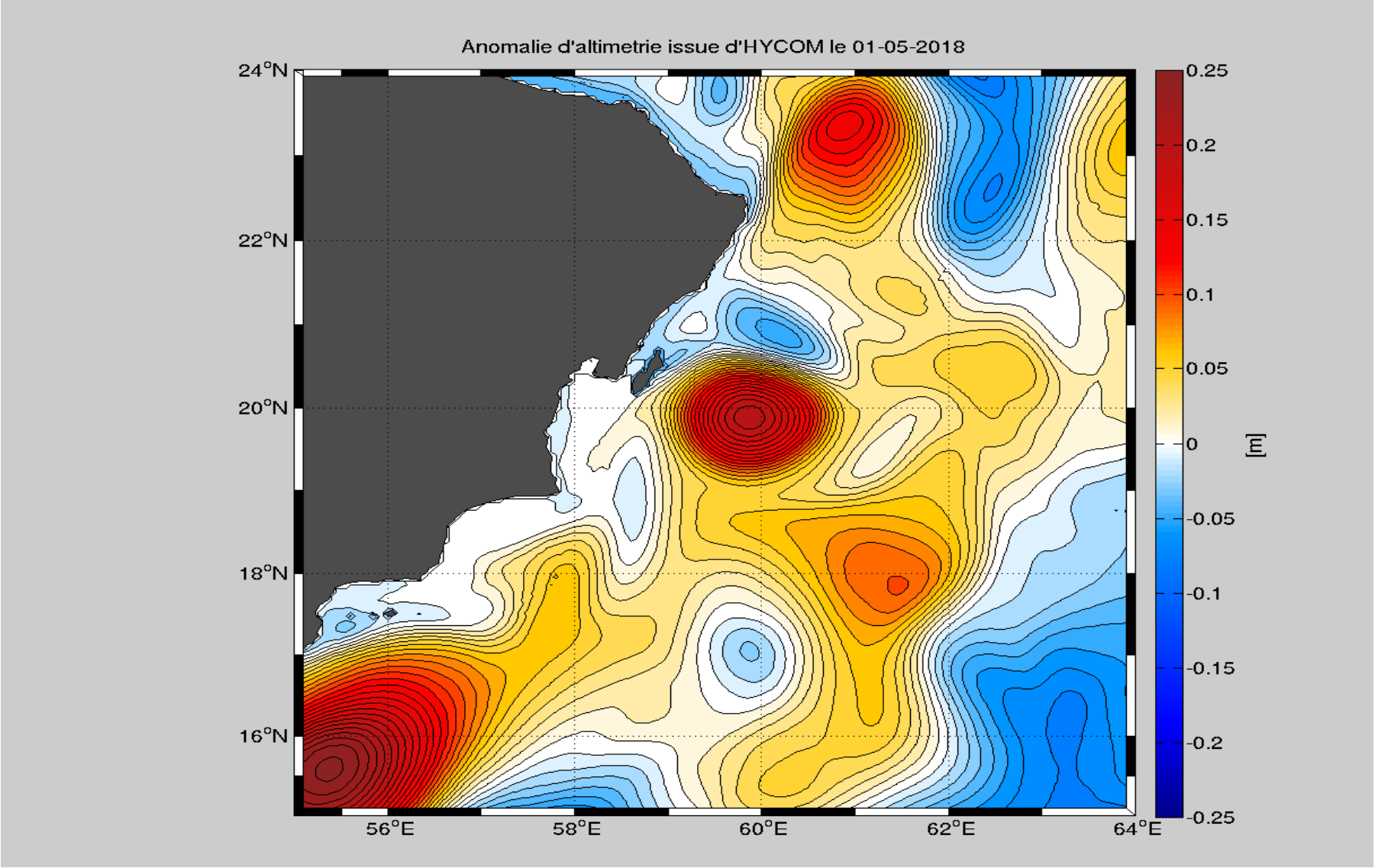
Can be barotropically or baroclinically unstable (from data)





2) Mesoscale dynamics - coastal current and eddies

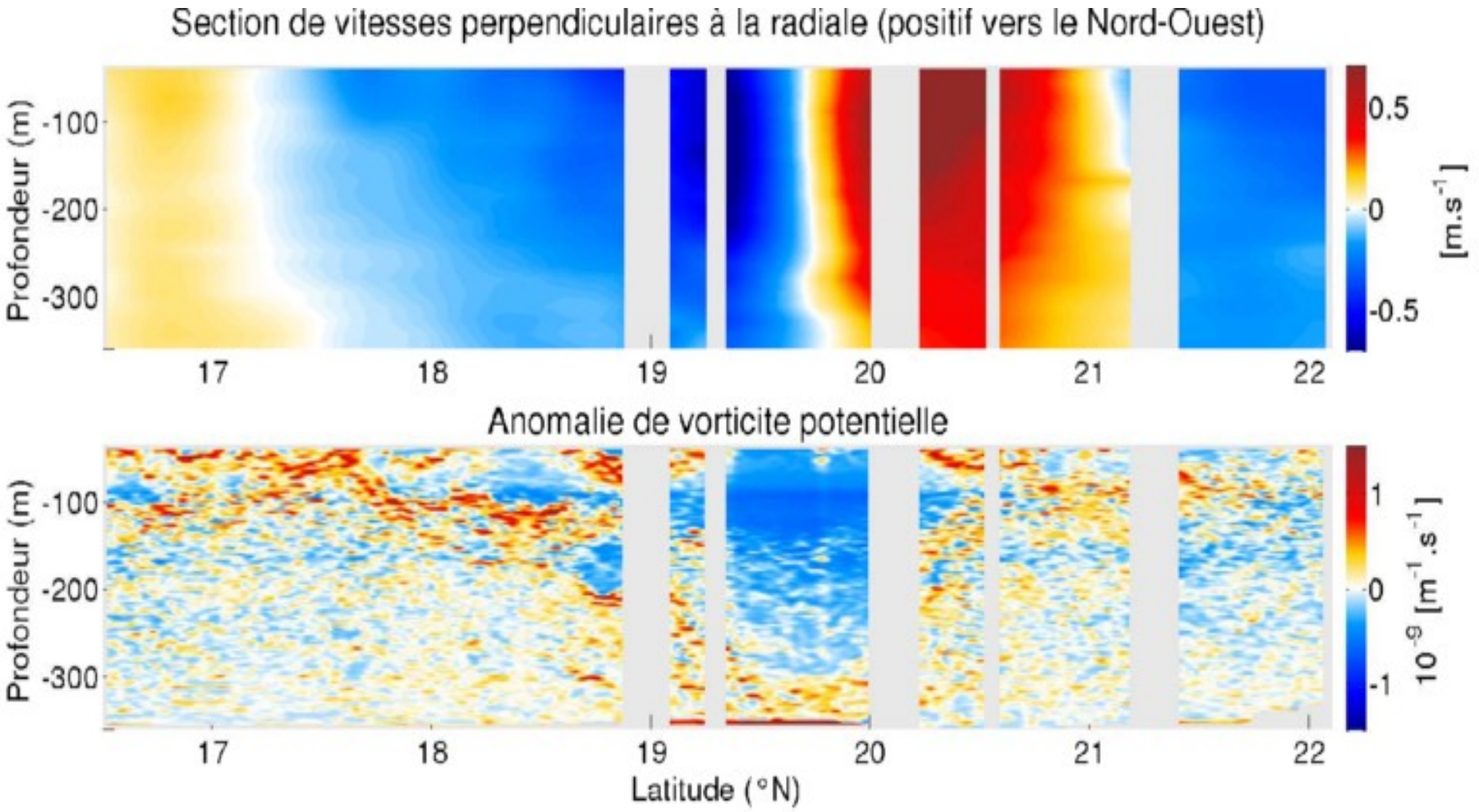
The instability of the coastal current leads to meanders and eddies (HYCOM)



2) Mesoscale dynamics - eddies

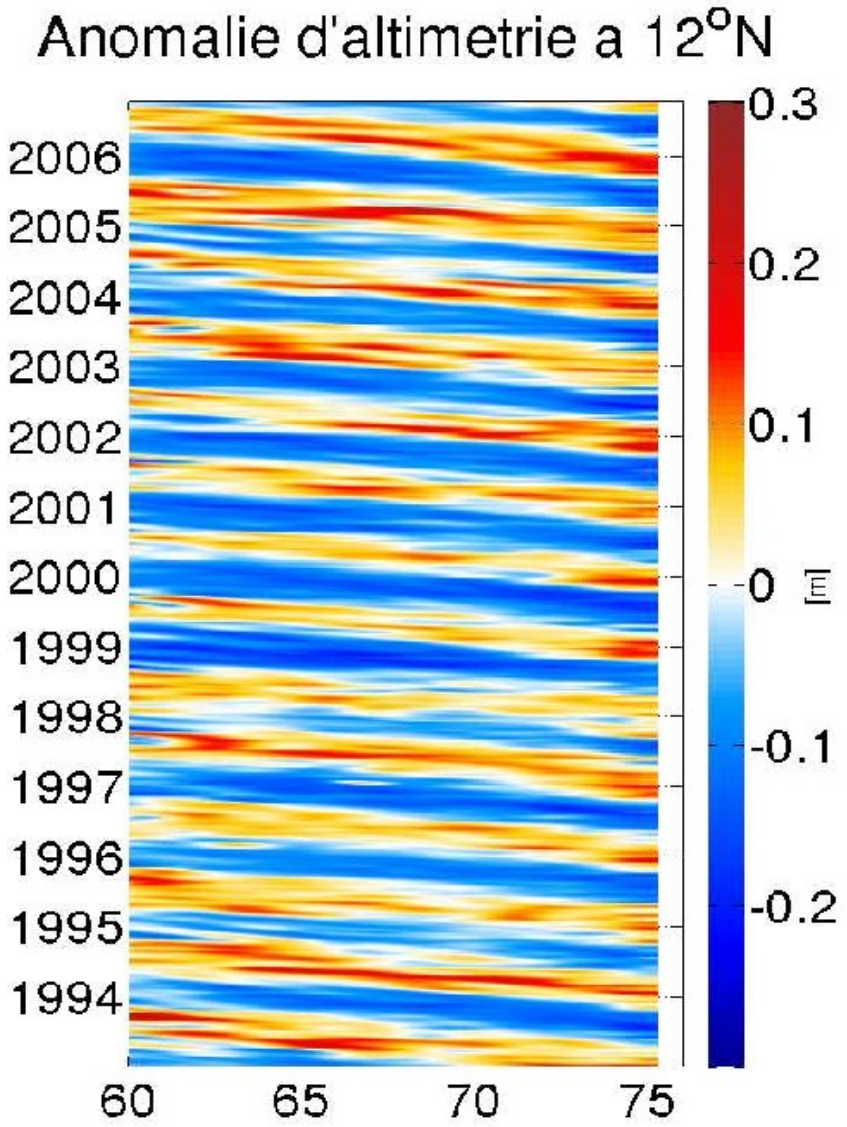
Eddies near the coast have 150-200 km diameter, > 200m deep (T,S) core and a deep dynamical influence (V : 0.7 → 0.2 m/s, surface → 700m depth)

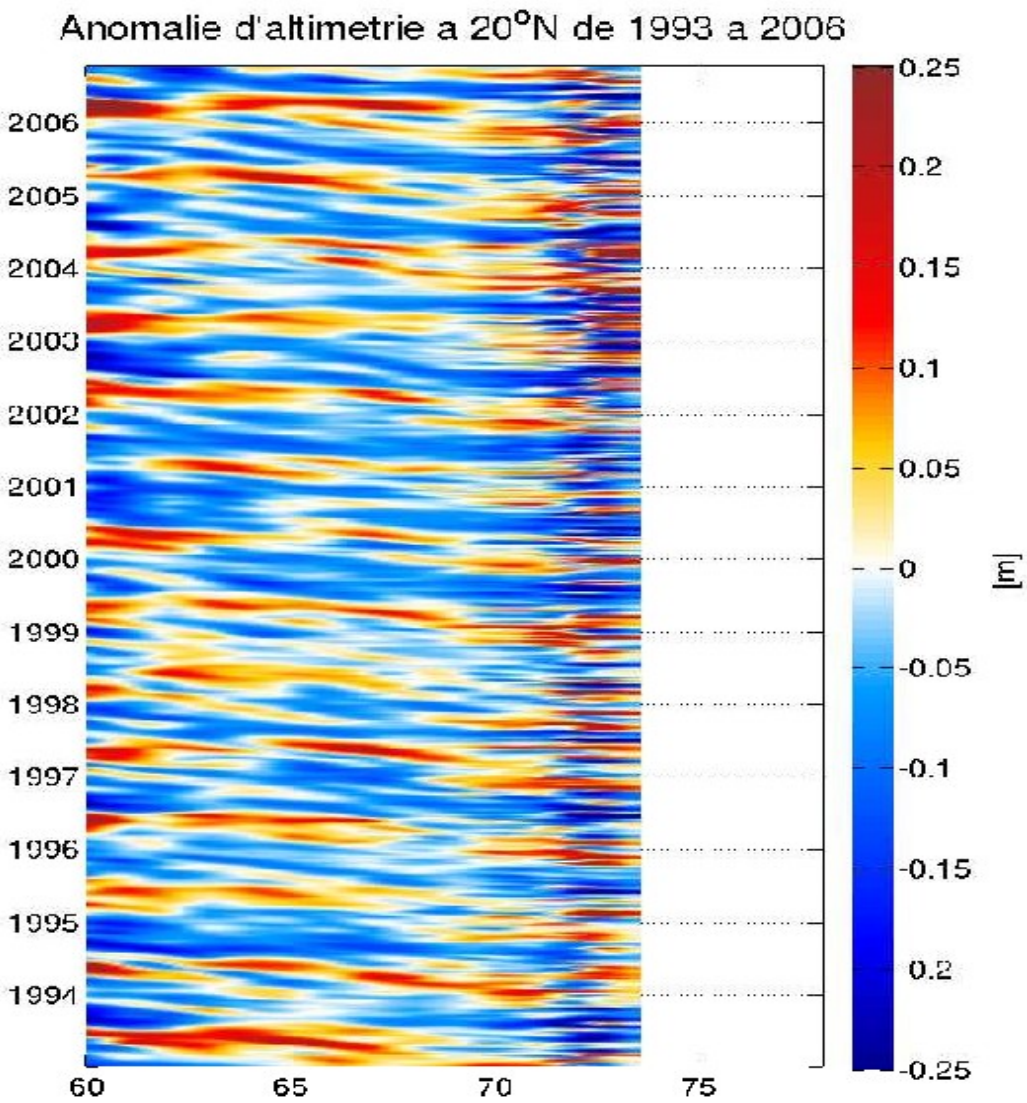
Meridional section across C, AC, C at RAH (Physindien 2011)



2) Mesoscale dynamics – Rossby Waves

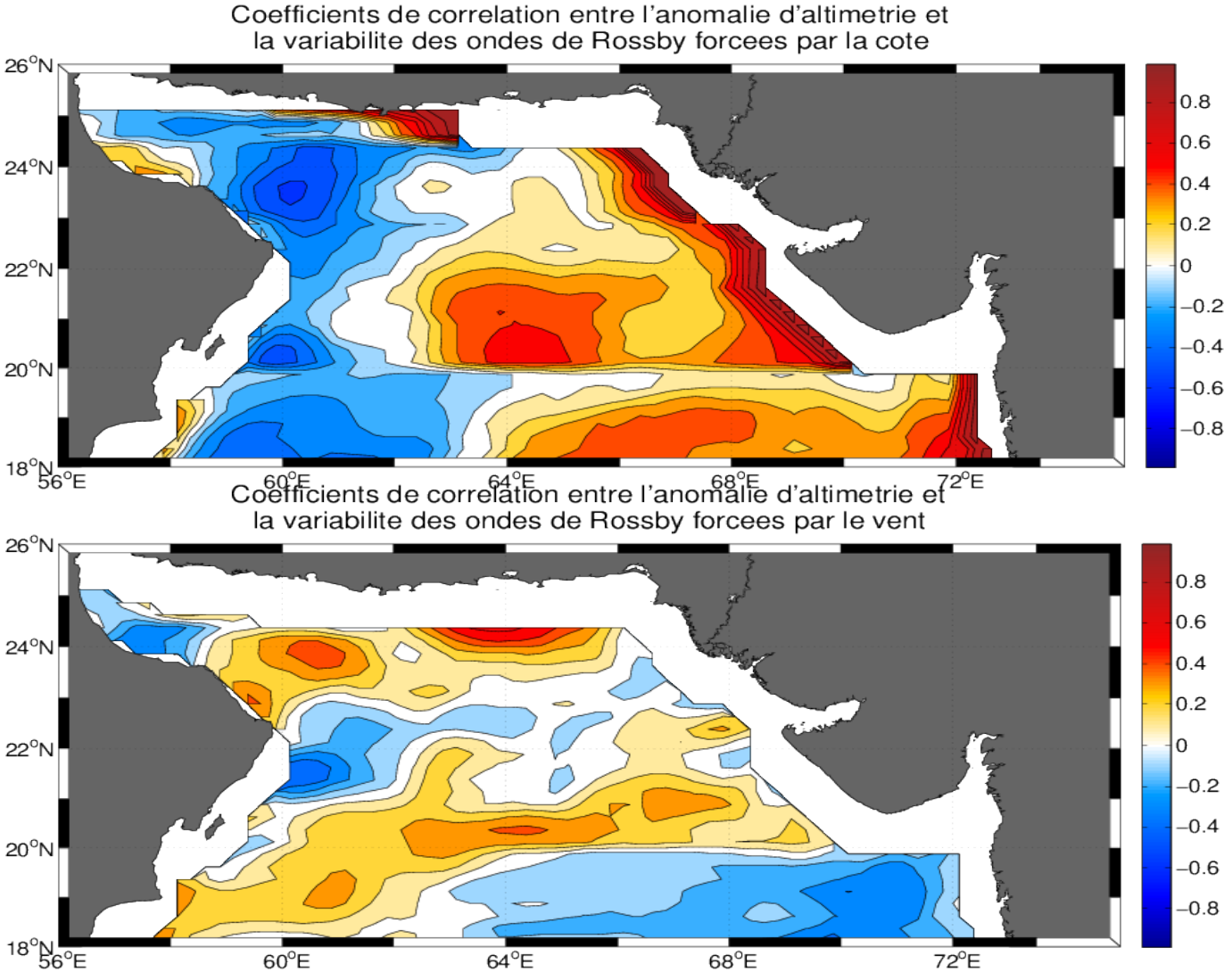
V_p = -3.5 cm/s at 20N, close to baroclinic phase speed (Hovmoller diagram)





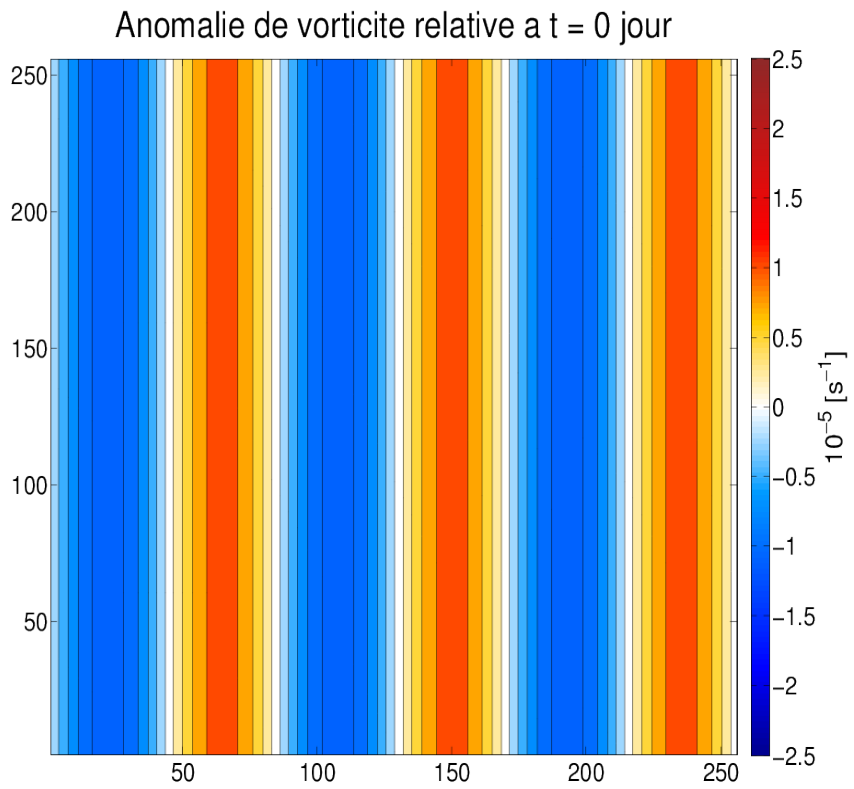
2) Mesoscale dynamics – Rossby Waves

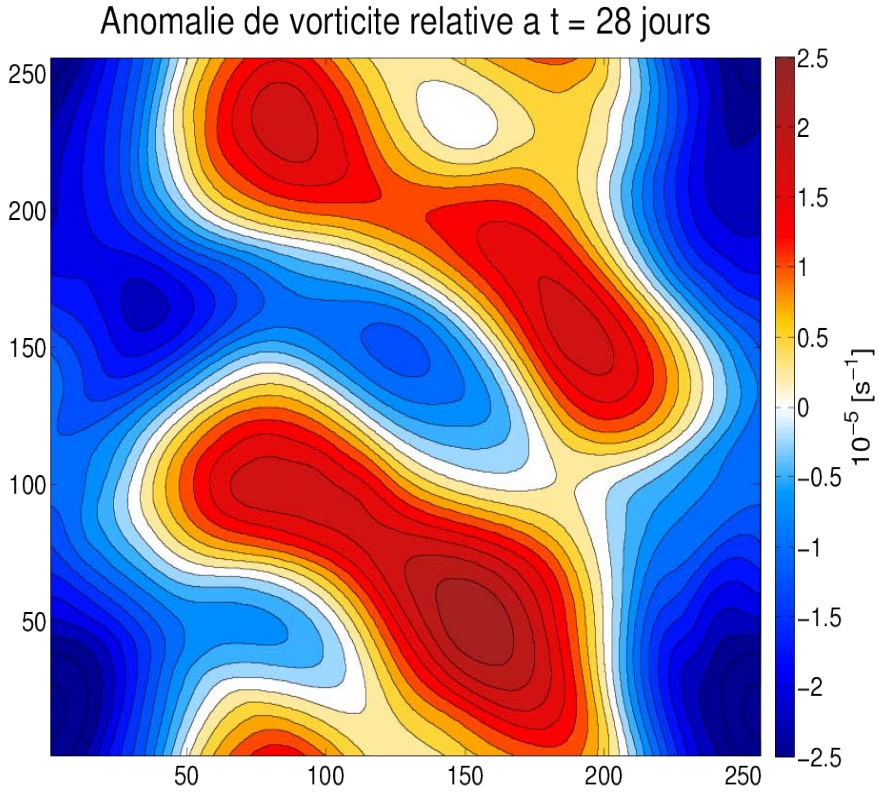
Up to 16N good correlation with Kelvin waves coming from Bay of Bengal (not shown), to the north, influence of the wind ; Fu and Qiu (2002) two-layer wind forced model → surface propagating signal decomposed into waves forced at the eastern boundary, and waves forced by the wind → compute correlations



2) Mesoscale dynamics – Interactions

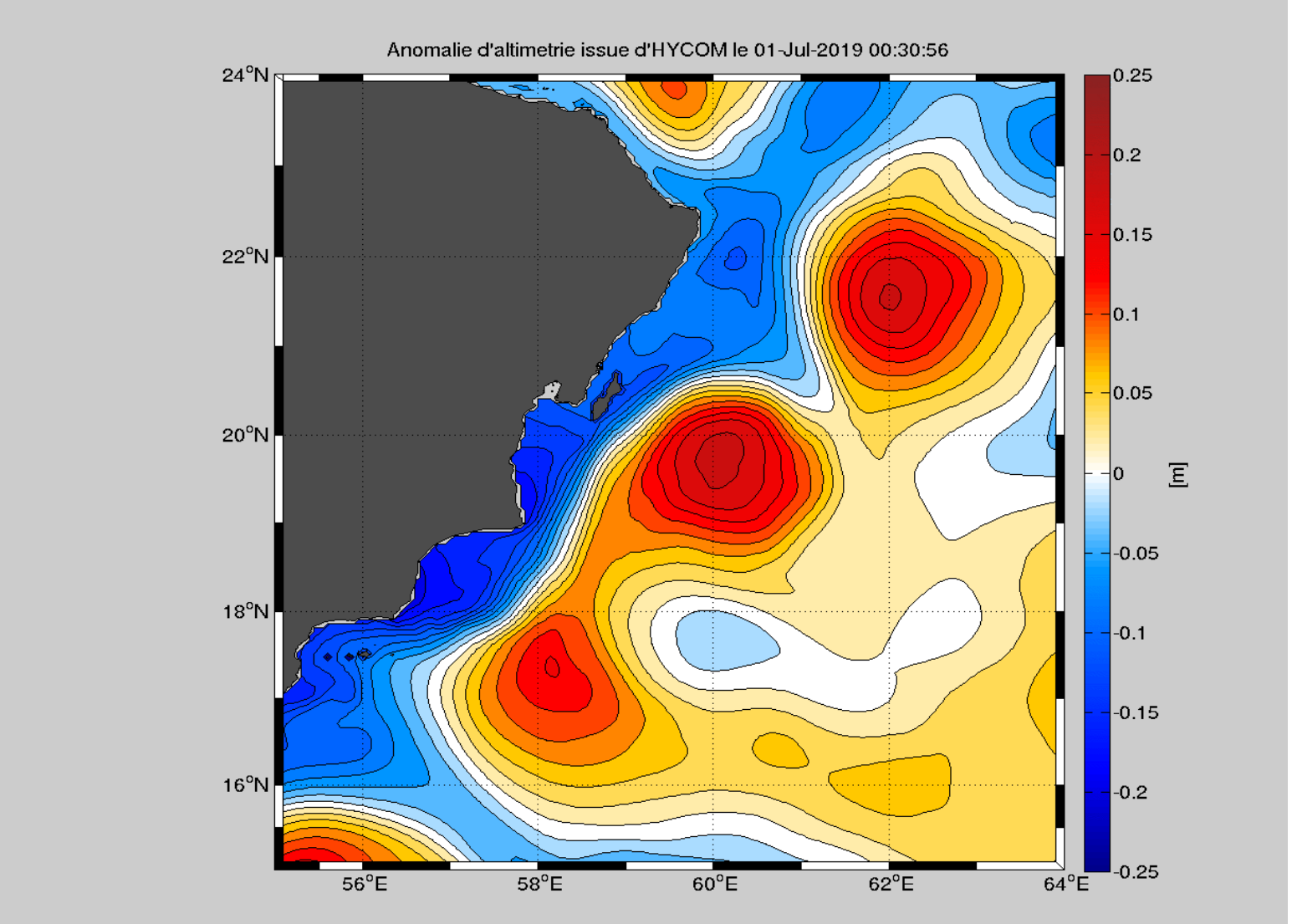
Rossby-wave seamount interaction (2D vorticity model) : seamount is at the center of the domain → formation of complex SSH patterns (closed streamlines) also seen in Hovmoller diagrams . These isolated structures then interact with the coastal eddies and reinforce them.





2) Mesoscale dynamics – Interactions

Vortex-vortex interaction near the coast (from HYCOM)



2) Mesoscale dynamics – Interactions

Eddies can also be reinforced by the wind (and they can then deepen)

Eddies near the coast are long lasting (lifetime of several months)

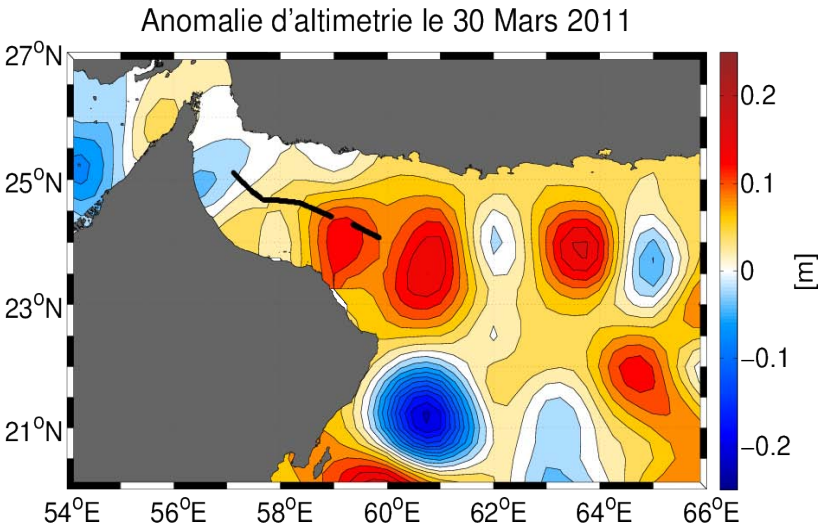
They are also fairly deep reaching dynamically

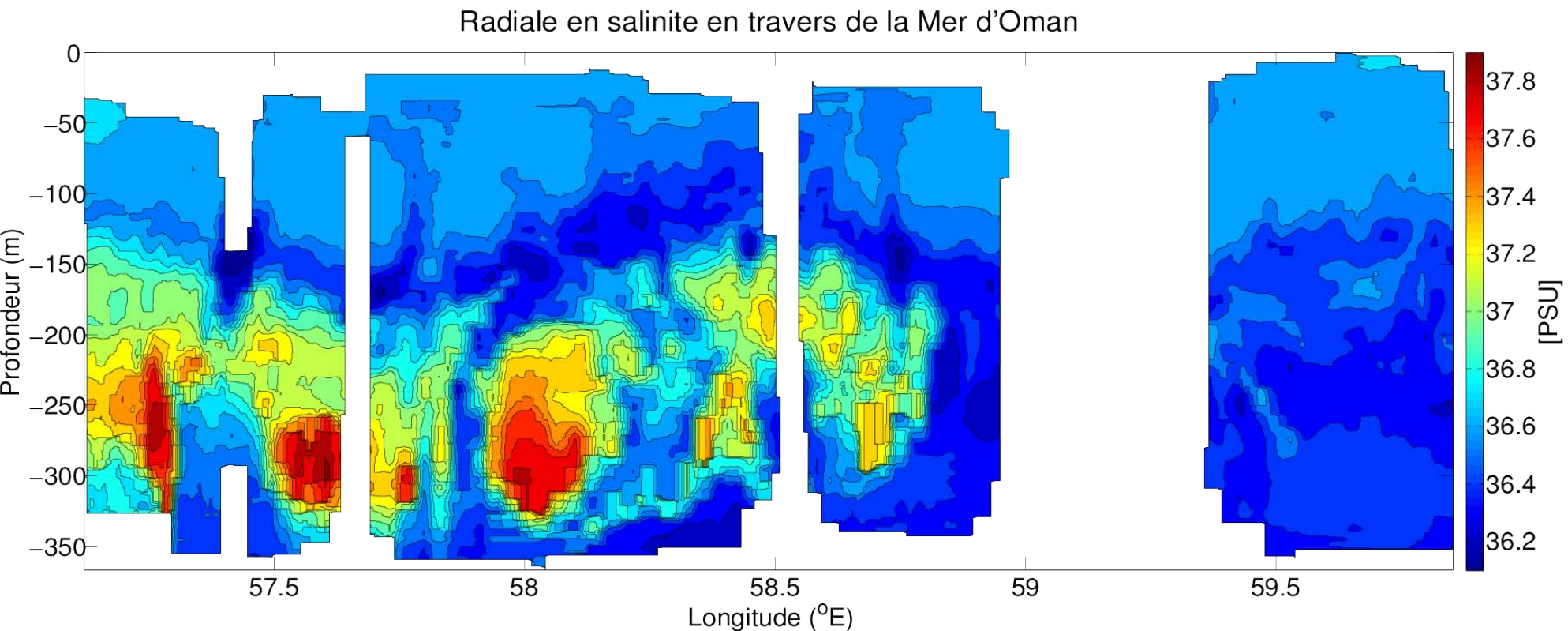
Therefore they must influence the outflows and in particular the shallow PGW outflow (250-350 m depth)

3) Influence of eddies on the PGW outflow

Deep reaching eddies advect, deform and fragment the PGW outflow into filaments, small eddies, layers and turbulent patches

<u>Sea of Oman</u>

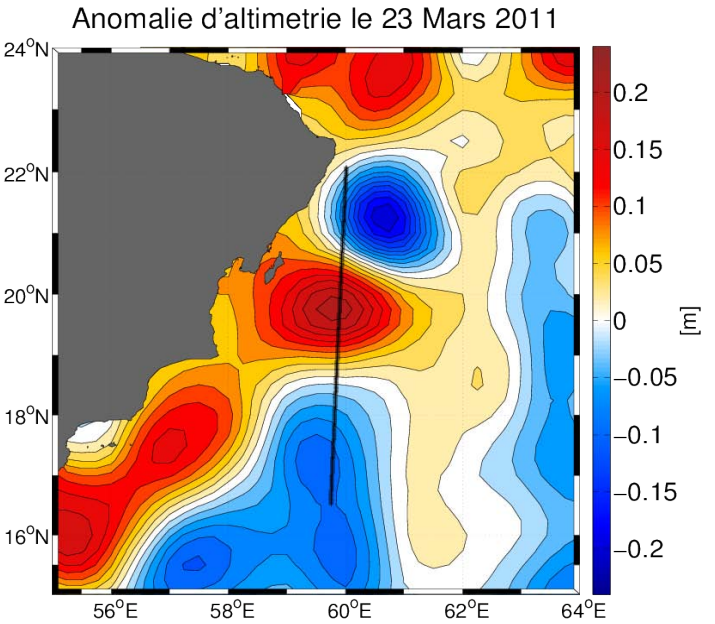


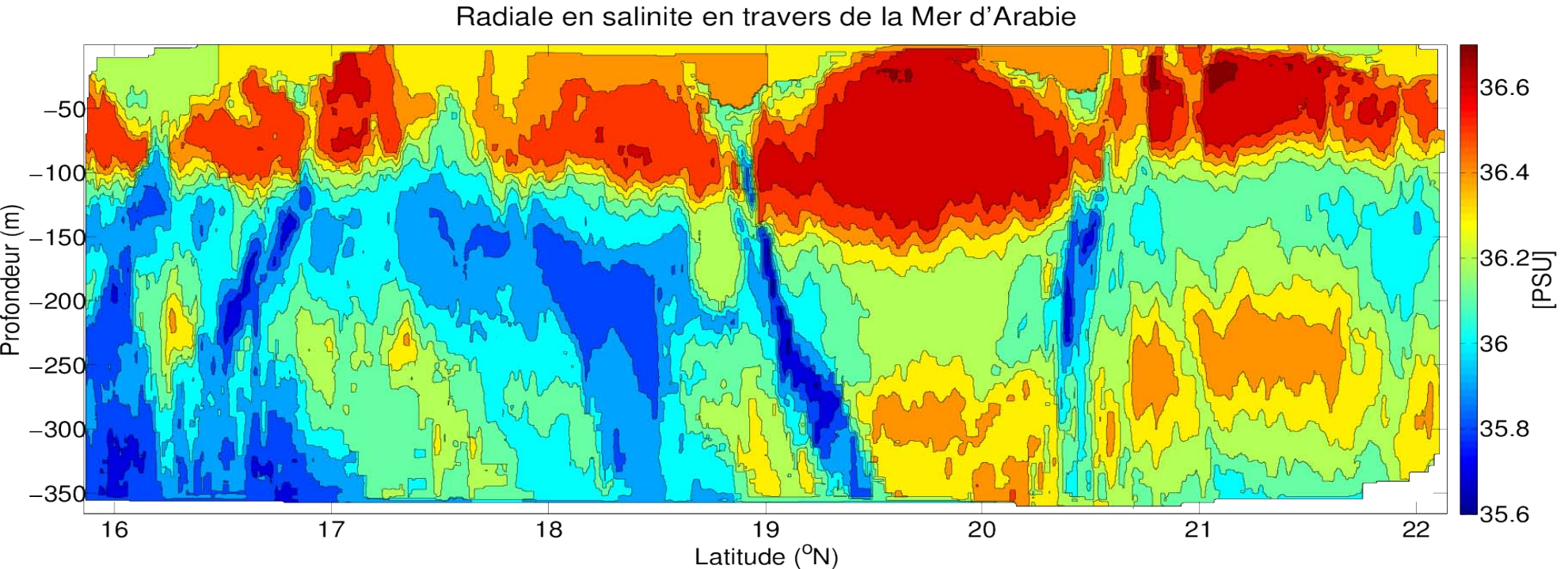


3) Influence of eddies on the PGW outflow

Deep reaching eddies advect, deform and fragment the PGW outflow into filaments, small eddies, layers and turbulent patches

<u>South of Ras al Hadd – Arabian Sea</u>

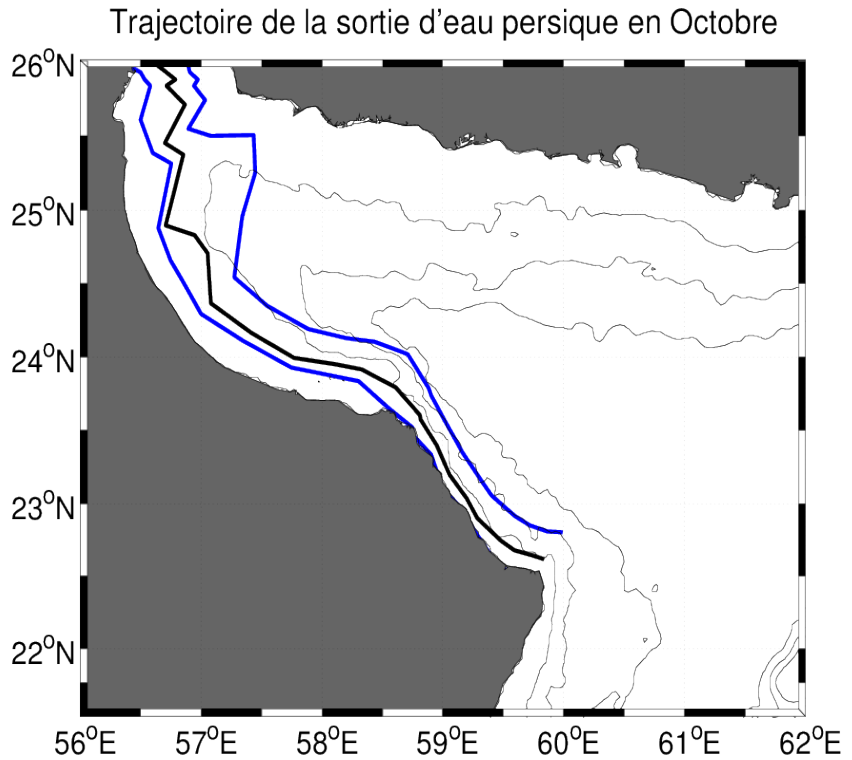


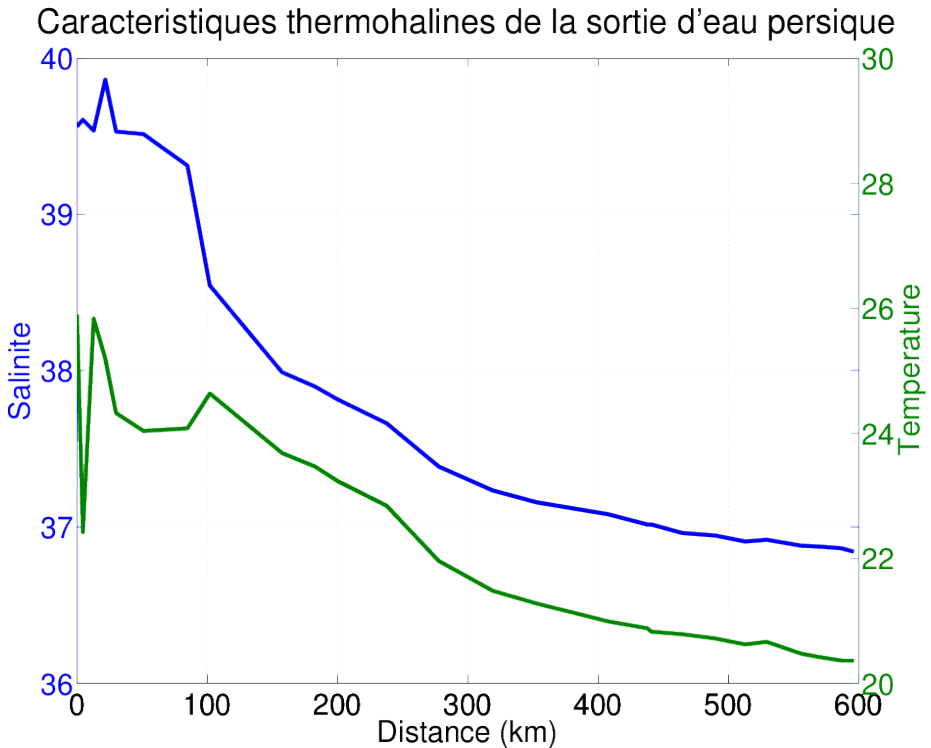


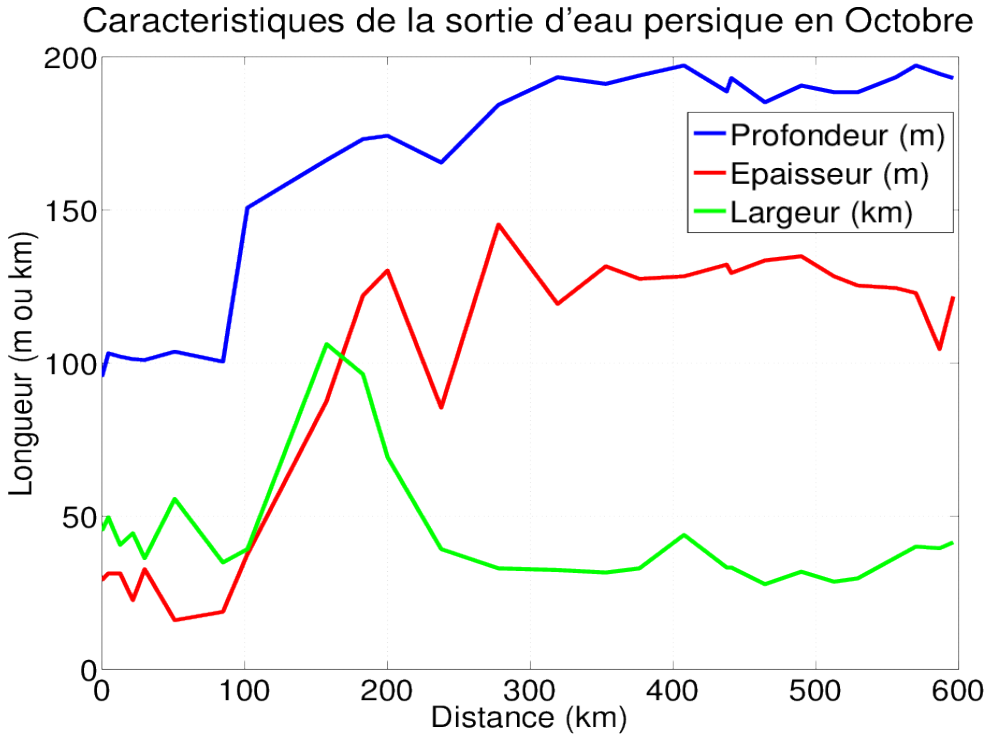
3) PGW outflow in October

Similar to GOGP99 experiment results

Few eddies (essentially cyclonic circulation in the Sea of Oman)

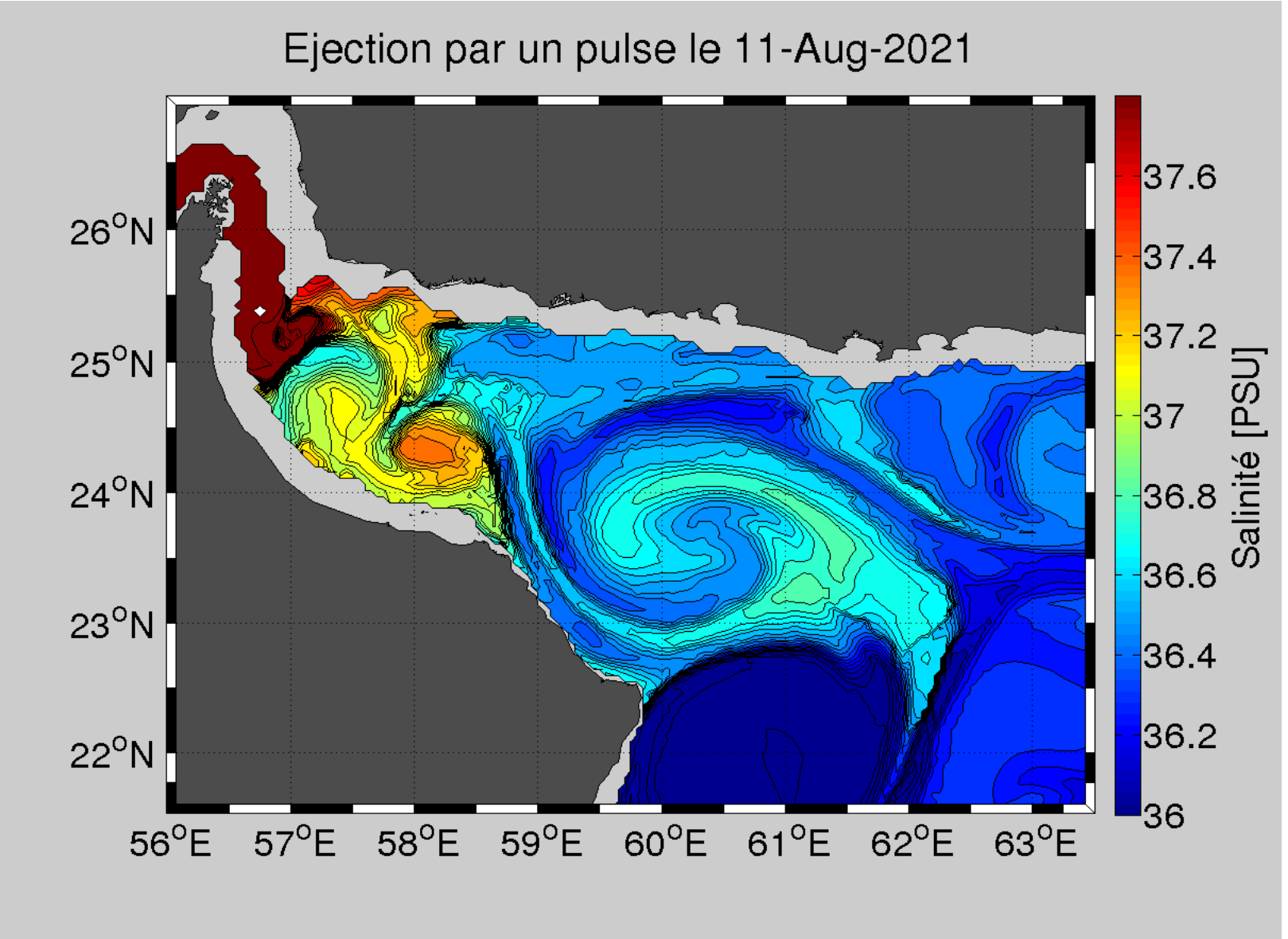






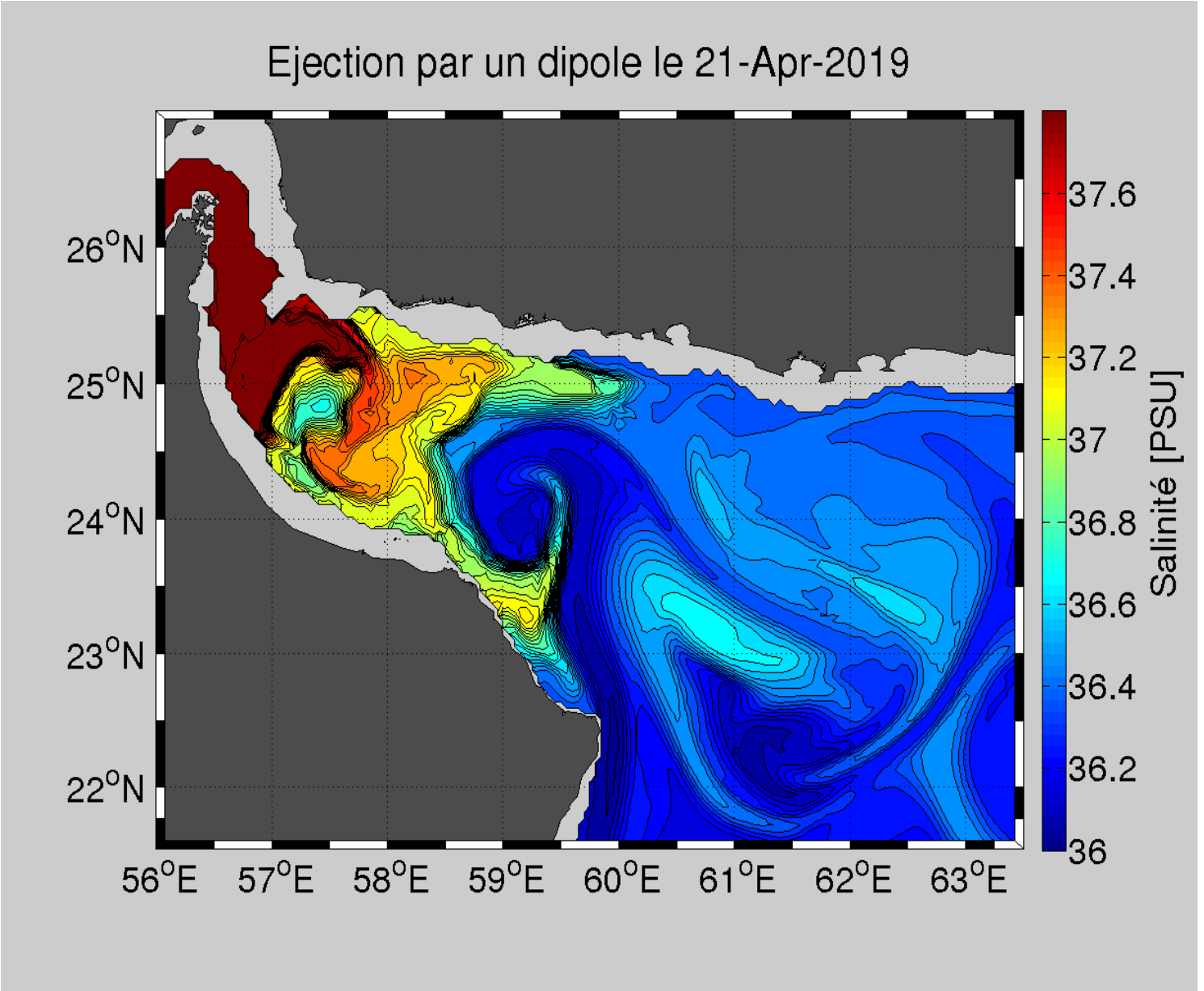
3) PGW ejection from the coast

Pulse of salinity from Hormuz (HYCOM): summer and fall
wrapping of PGW around eddy core, then insertion (-0.4 psu from the outflow)



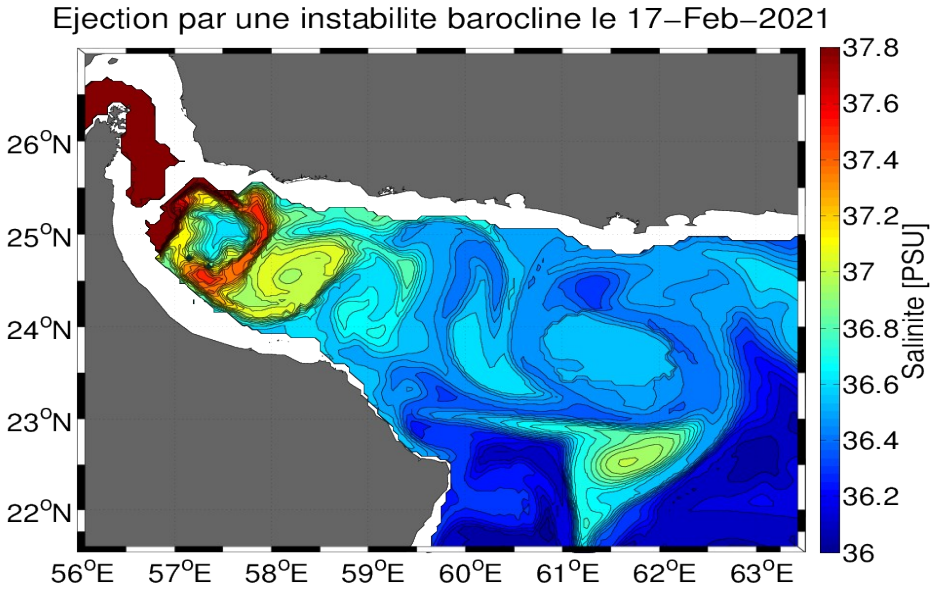
3) PGW ejection from the coast

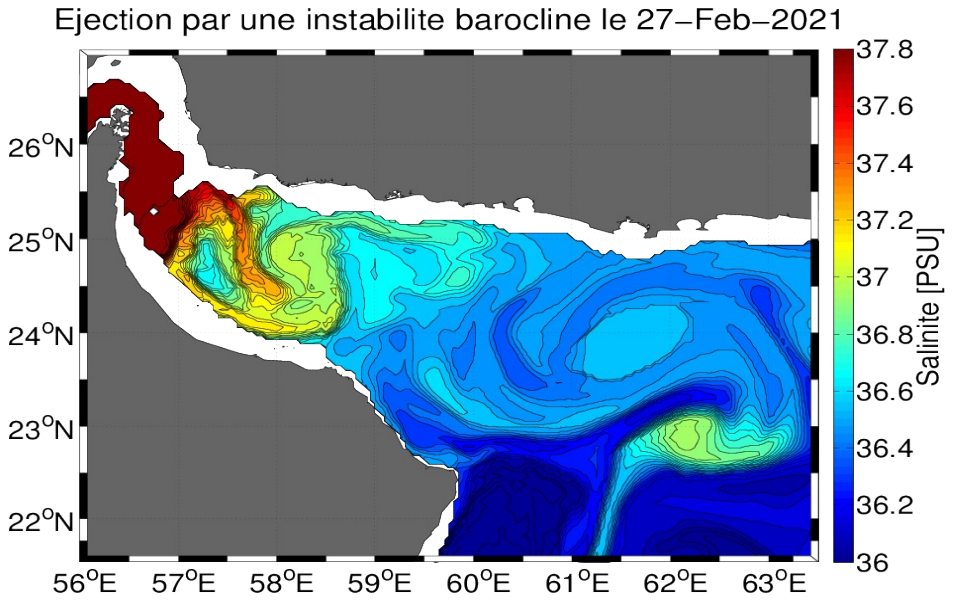
Dipole formation (HYCOM) : spring intermonsoon, outflow fragmented, E and W recirculation along Iranian coast

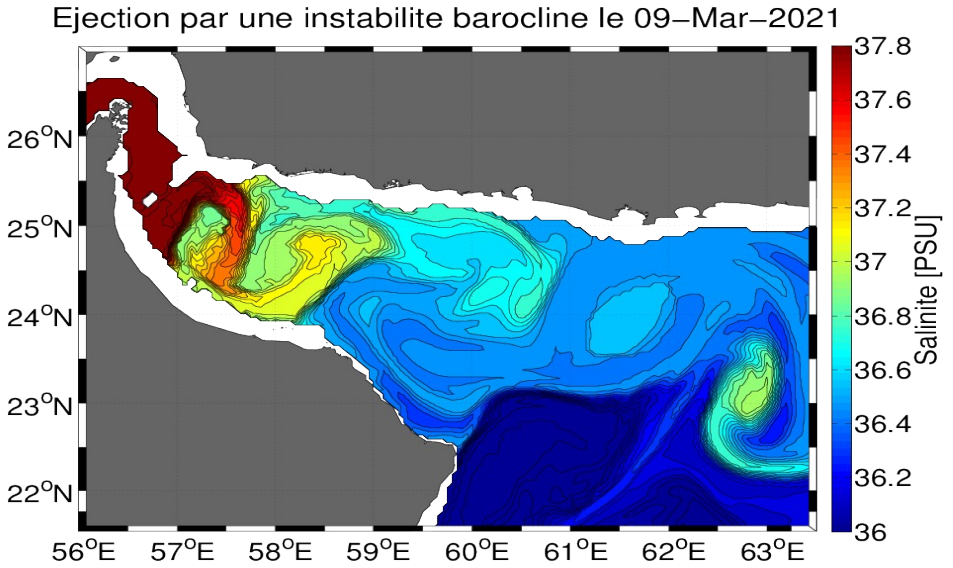


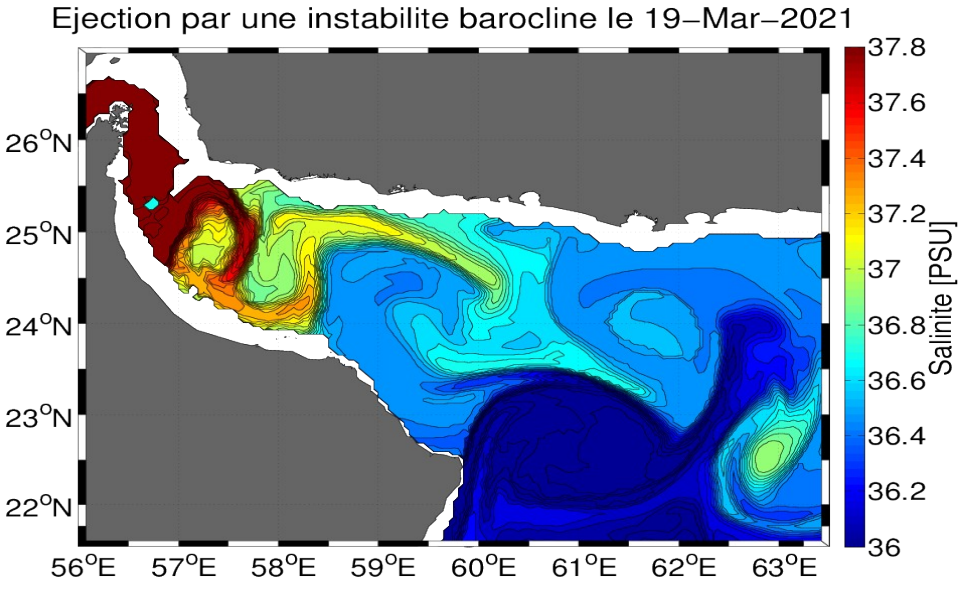
3) PGW ejection from the coast

Baroclinic instability of coastal outflow (HYCOM)



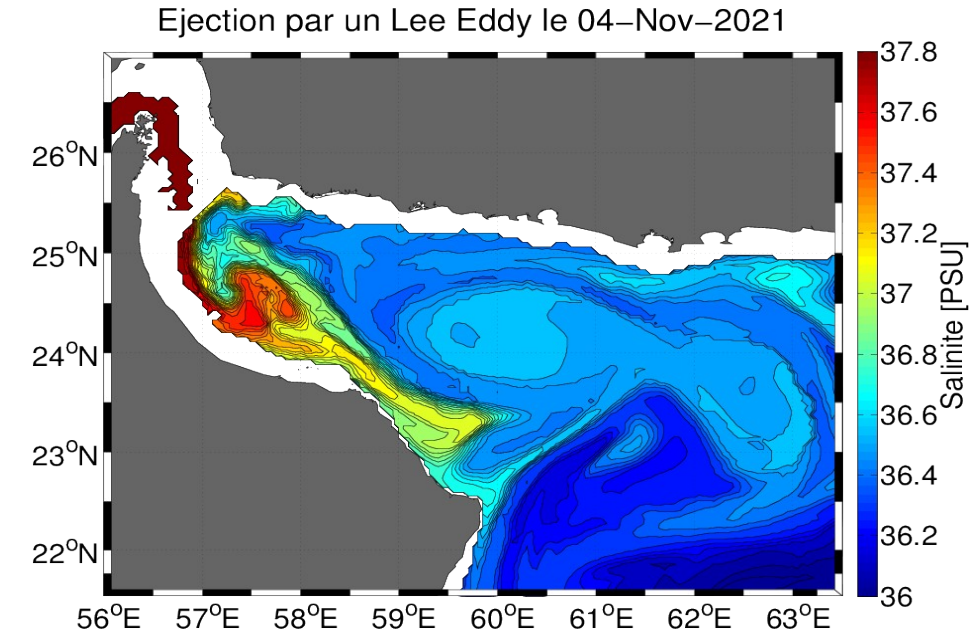


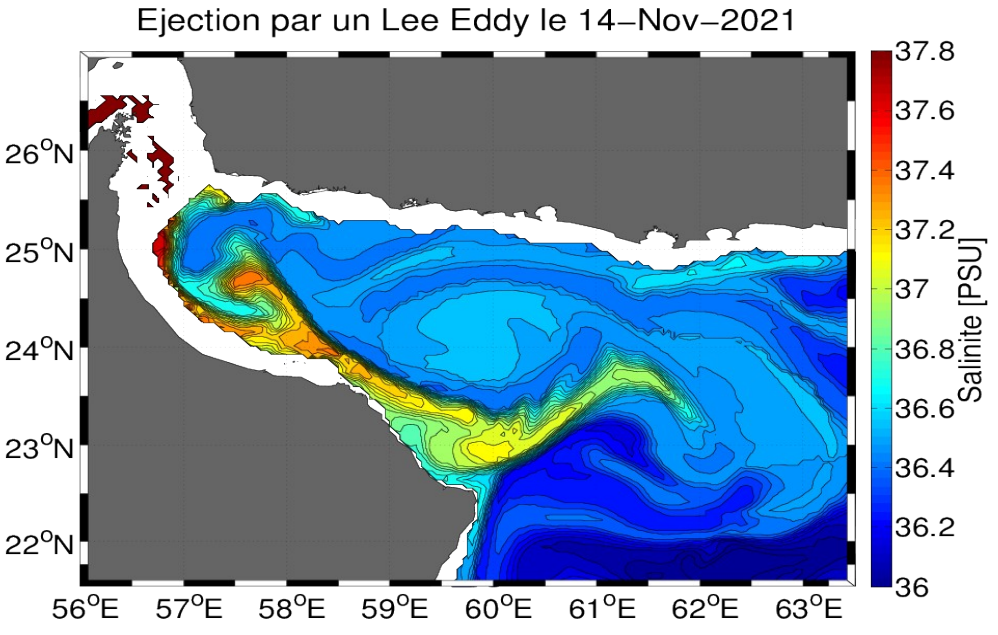


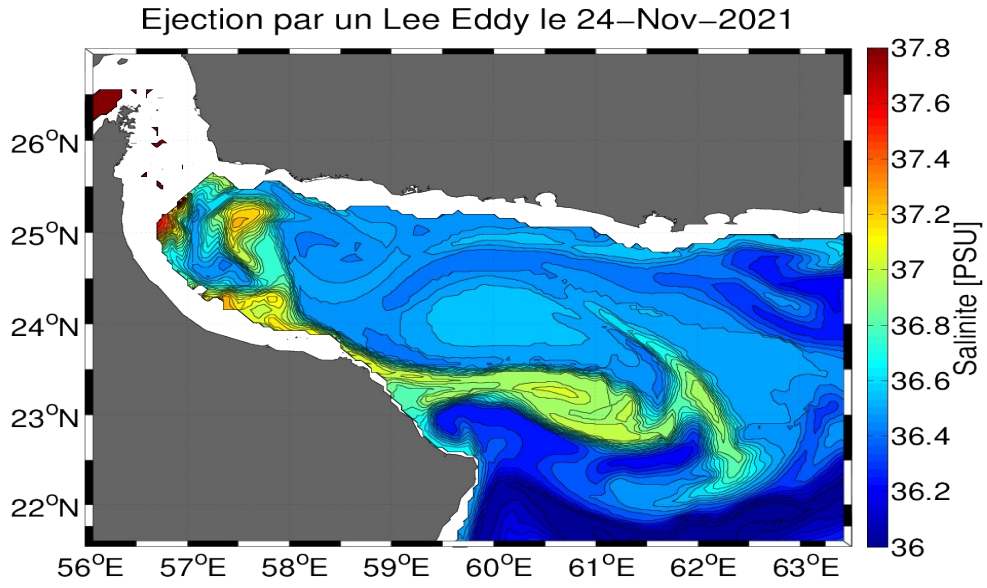


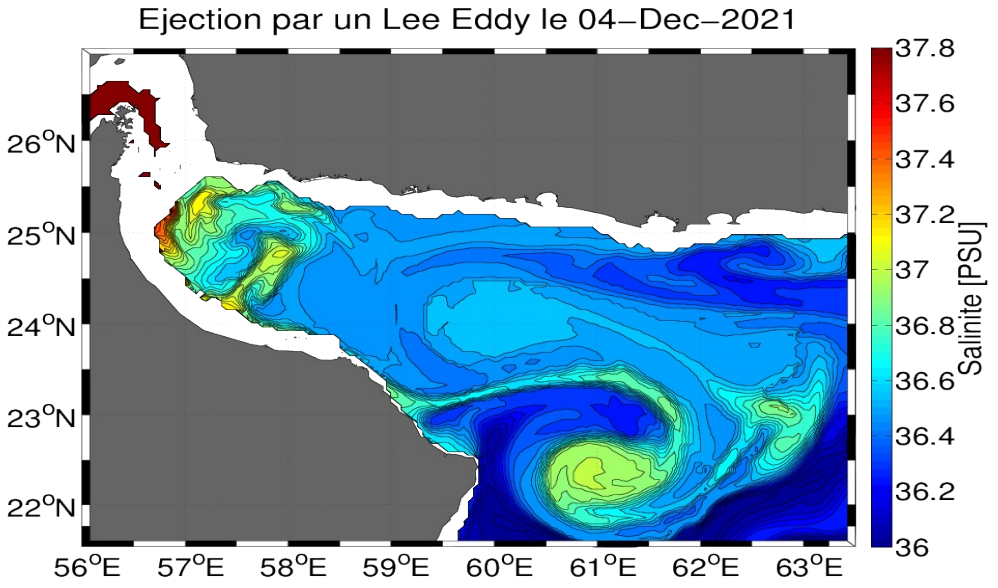
3) PGW ejection from the coast

Lee eddy formation at Ras al Hamra and detachment (HYCOM)









3) PGW ejection from the coast

Lee eddy formation at Ras al Hamra and detachment (HYCOM)

→ during winter monsoon

→ high salinity eddies (core -0.2 psu from PGW outflow) with long Lifetime (Several months)

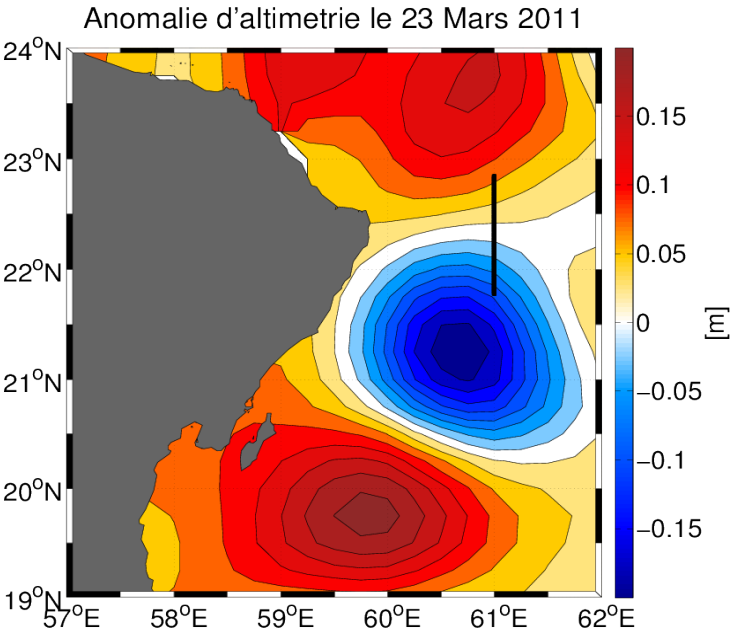
3) a lens of PGW

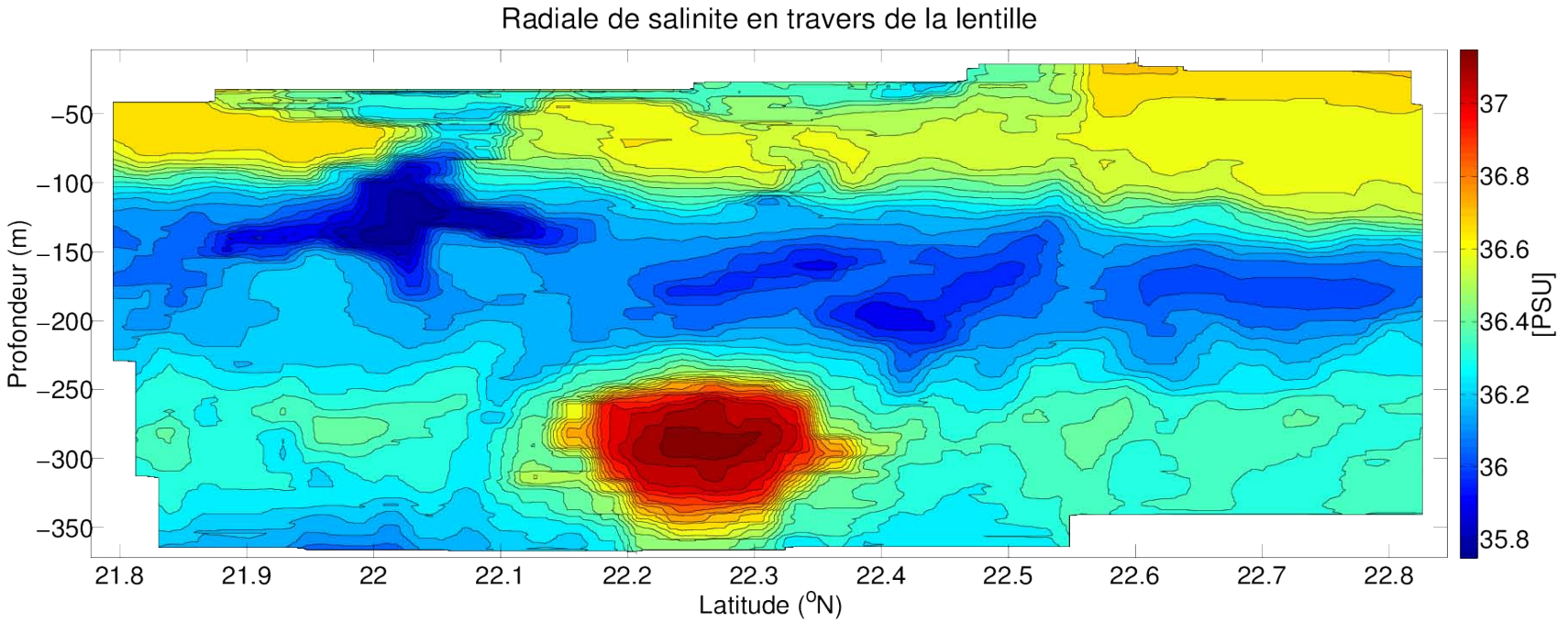
<u>Characteristics (observed during Physindien 2011)</u>

→ at the periphery of mesoscale eddies

→ major axis 15 km, minor axis 11 km

→ high salinity in the core





3) a lens of PGW

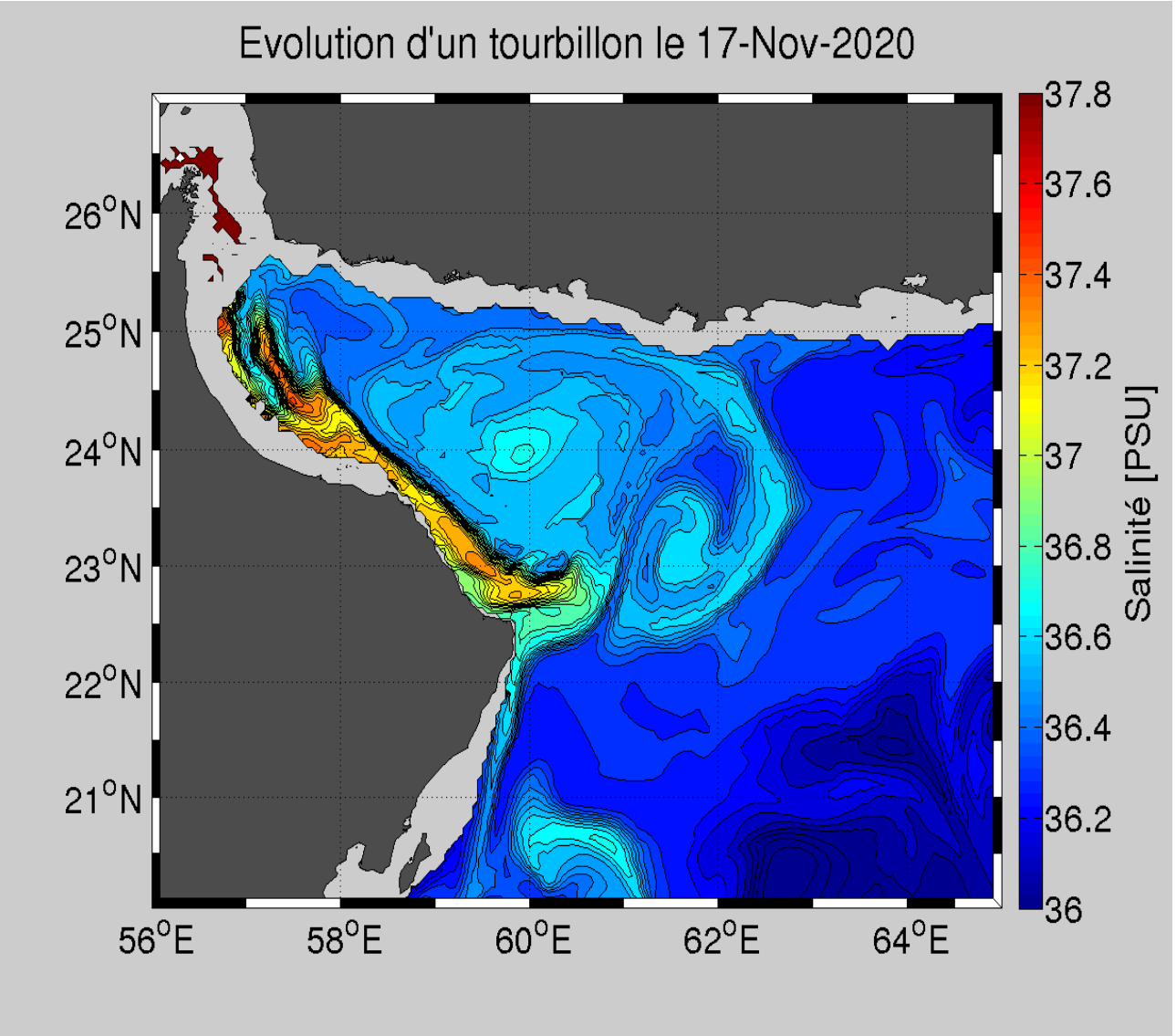
<u>Possible origin</u>

→ ejection from Ras al Hamra, 15 days prior to sampling

→ ejection south of Ras al Hadd, 10 days before

→ remnant of a lee eddy formed in winter and then slowly eroding

Difficult to track (strong signature of mesoscale eddies ; floats/buoys ejected but show other fragments nearby)



4) Conclusions

Mesoscale dynamics

-eddies formed by the instability of the surface coastal currents and by destabilized Rossby waves ; they have a deep dynamical signature

- interactions between eddies strengthen them

- large seasonal variability

Impact on PGW

- important rôle of eddies in advecting, tearing, stirring and mixing PGW in the Sea of Oman (and in the Arabian Sea)

- modification of PGW outflow trajectory and characteristics in the Sea of Oman

- formation of submesoscale structures (filaments, lenses)

- inclusion of PGW below mesoscale eddies or in lee eddies