Turbulence and layering surrounding an anticyclonic vortex: seismic observations and high resolution simulations

Claire Ménesguen, *(LPO-Ifremer)*

Sylvie Le Gentil, Richard Schopp, Thomas Meunier, Ana Aguiar *(LPO-Ifremer)*

Louis Géli, Bruno Marsset *(LGG-Ifremer)*

Nori Aiki *(JAMSTEC, Japan)*

Lien Hua

Outline

- Observations of submesoscales surrounding an interior anticyclonic vortex

- High resolution simulations:

    - instability and balanced turbulence of an idealized Meddy

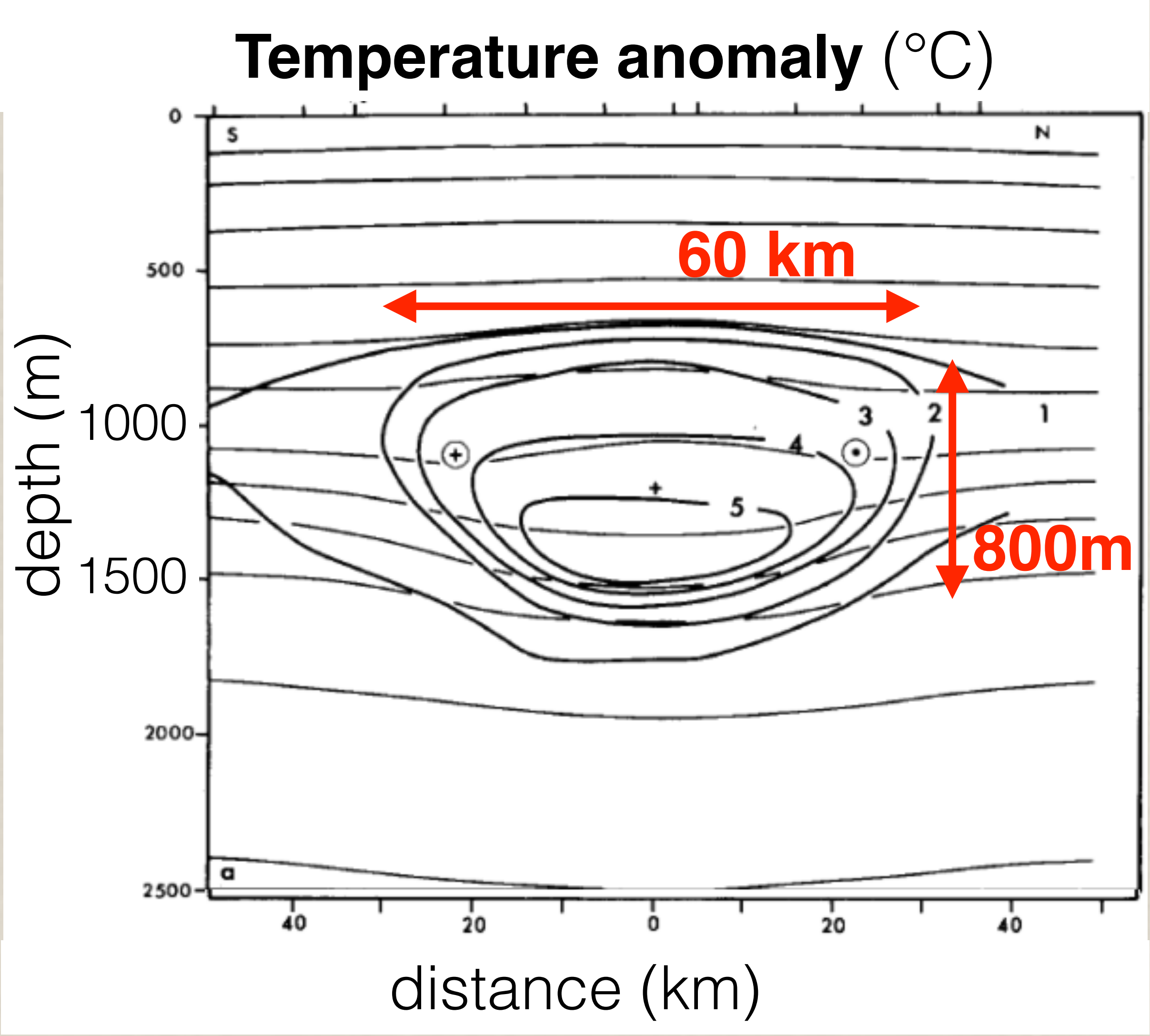
    - temperature and salinity stirring

    - possible implication for a direct cascade of energy to dissipation

Outline

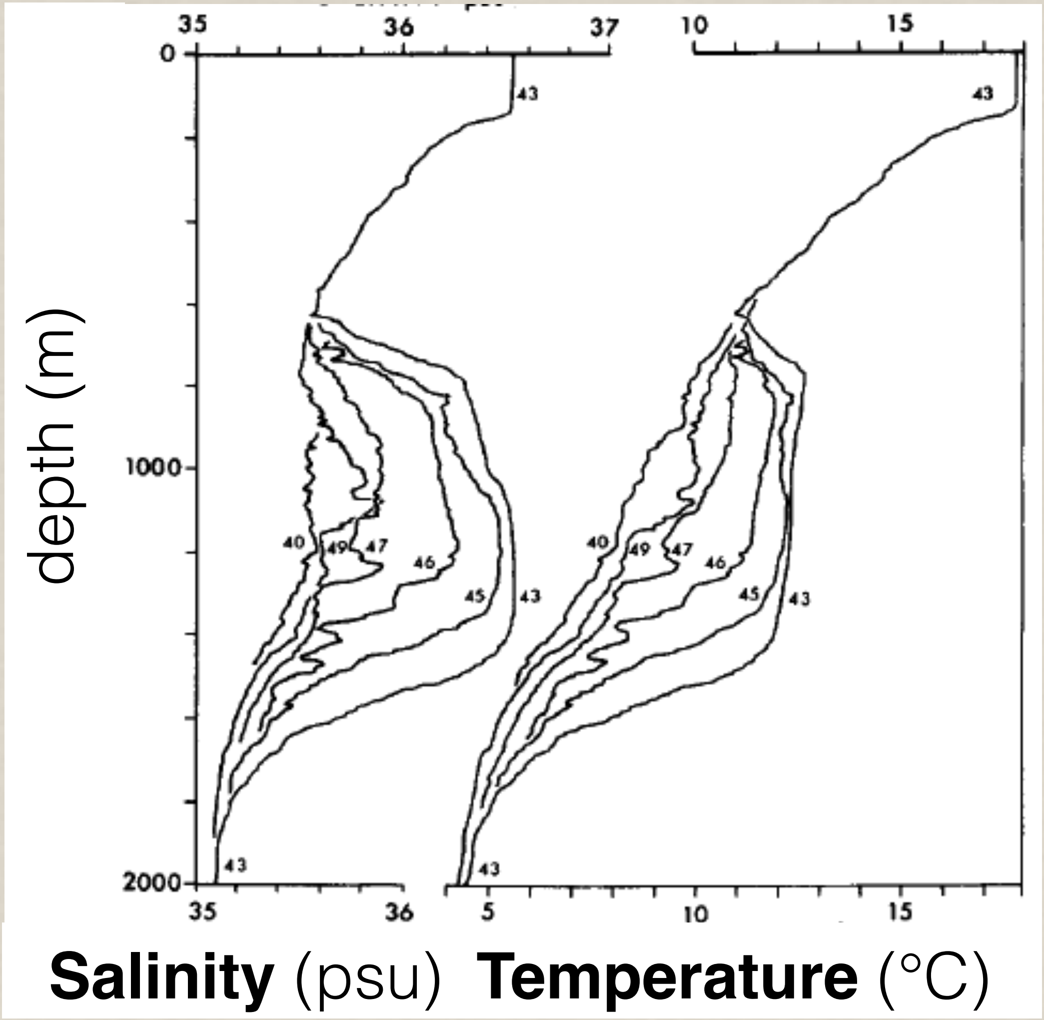
- Observations of submesoscales surrounding an interior anticyclonic vortex
- High resolution simulations:
    - instability and balanced turbulence of an idealized Meddy
    - temperature and salinity stirring
    - possible implication for a direct cascade of energy to dissipation

Historical observations of mesoscale coherent vortex in the Gulf of Cadiz



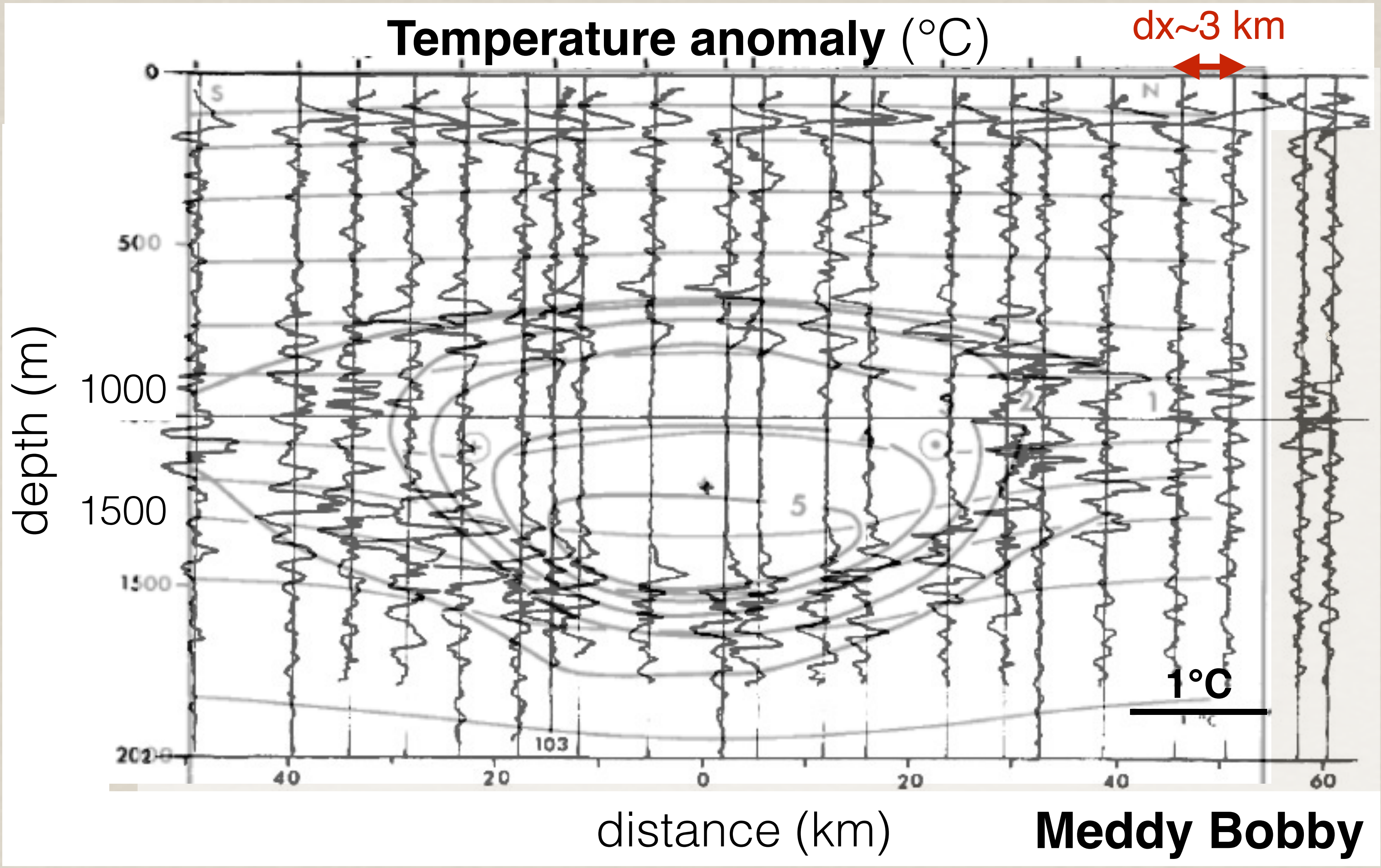
Meddy Bobby

(Pingree&Le Cann,1993)



☞ Meddies are vortices in geostrophic balance of hot and salty mediterranean water

Historical observations of mesoscale coherent vortex in the Gulf of Cadiz

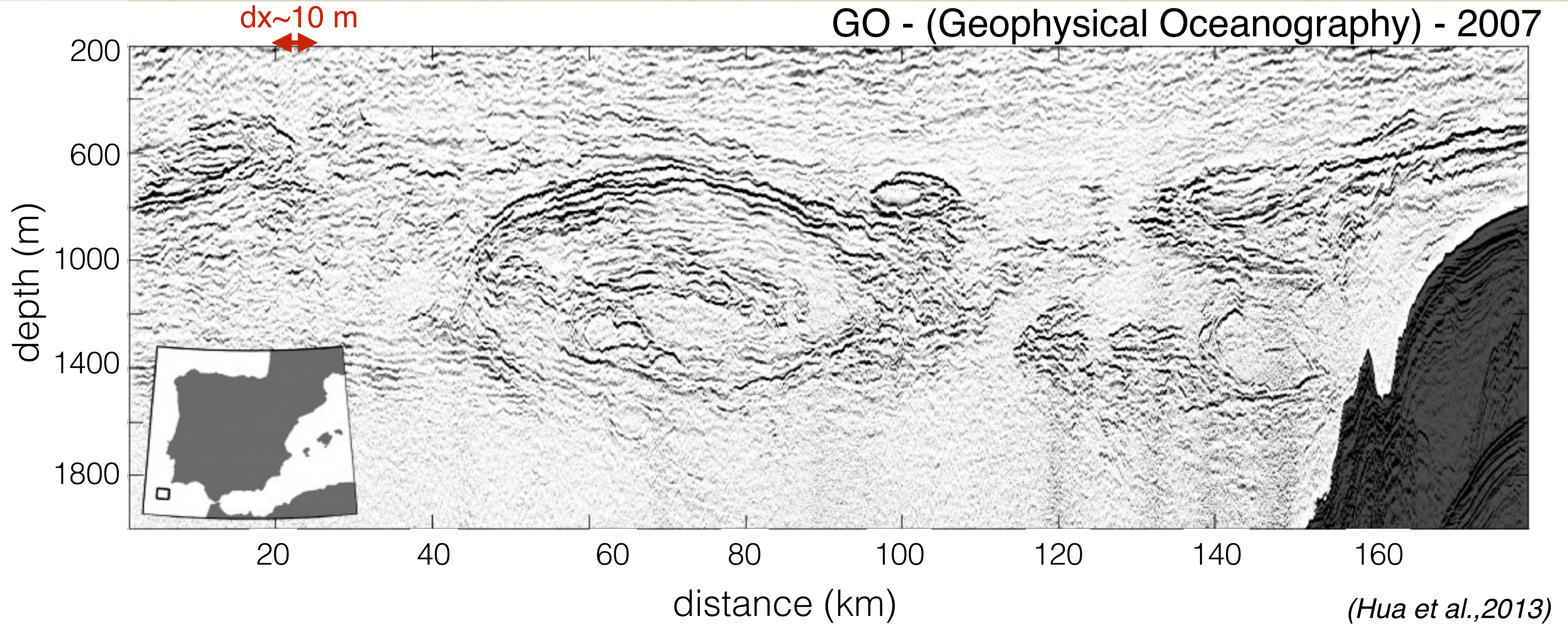


(Pingree&Le Cann,1993)

☞ **Small scale structures surround the mesoscale vortex**

☞ **Small scale structures are located where the mean gradient is maximum**

Small scale structures surrounding the mesoscale vortex

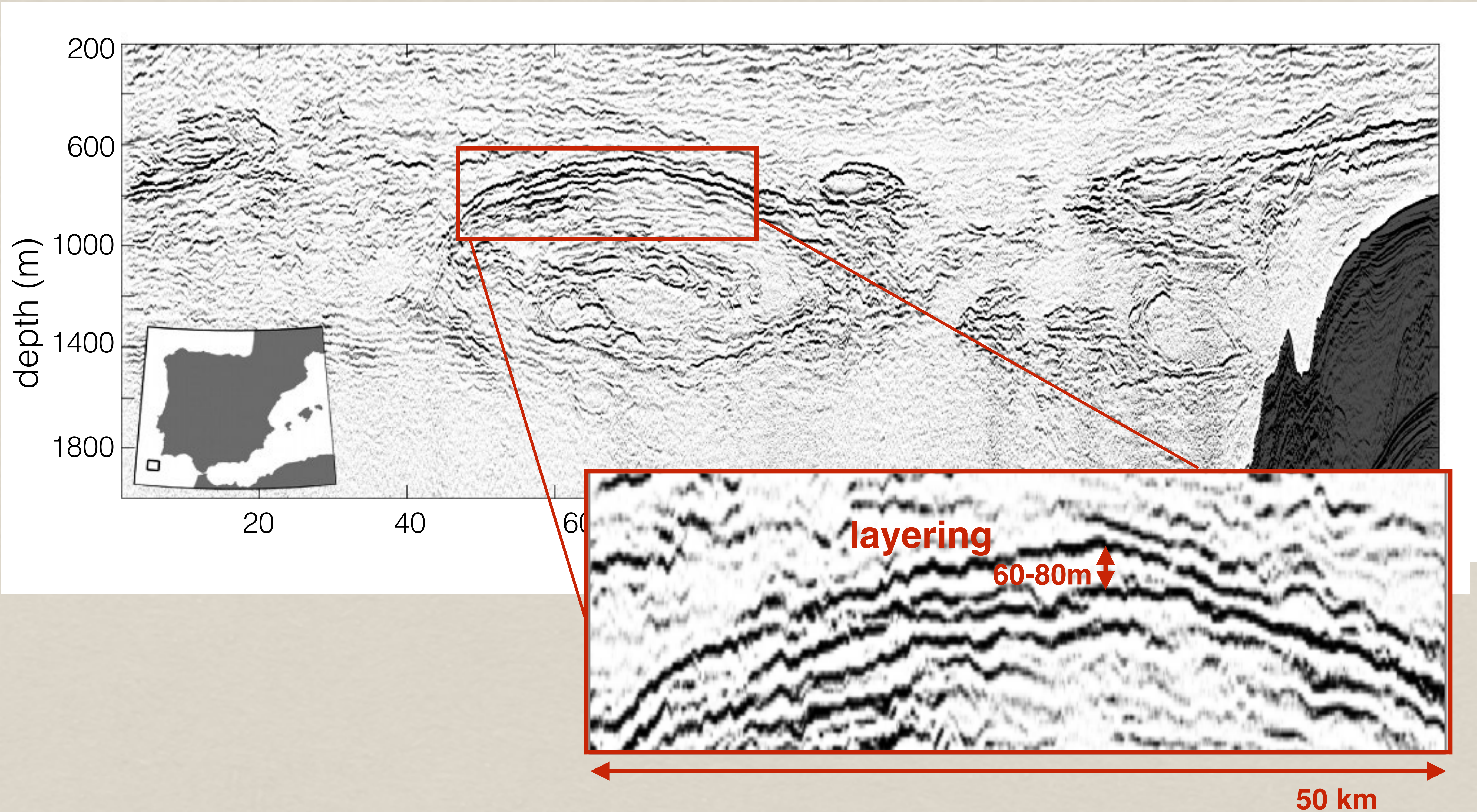


(Hua et al.,2013)

Acoustic reflectivity: $r = \dfrac{\partial(\rho c)}{\partial z} \otimes Source \sim \dfrac{\partial}{\partial z} T'$

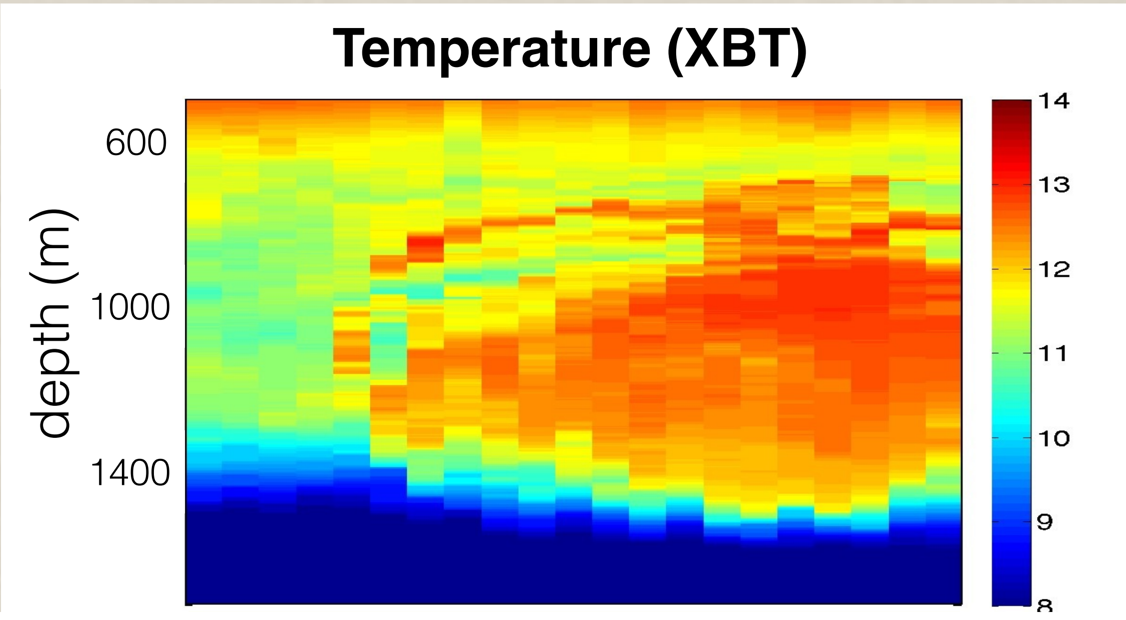
☞ **Seismic sections reveal the lateral continuity (over ~50km) of small scale structures surrounding the meddy**

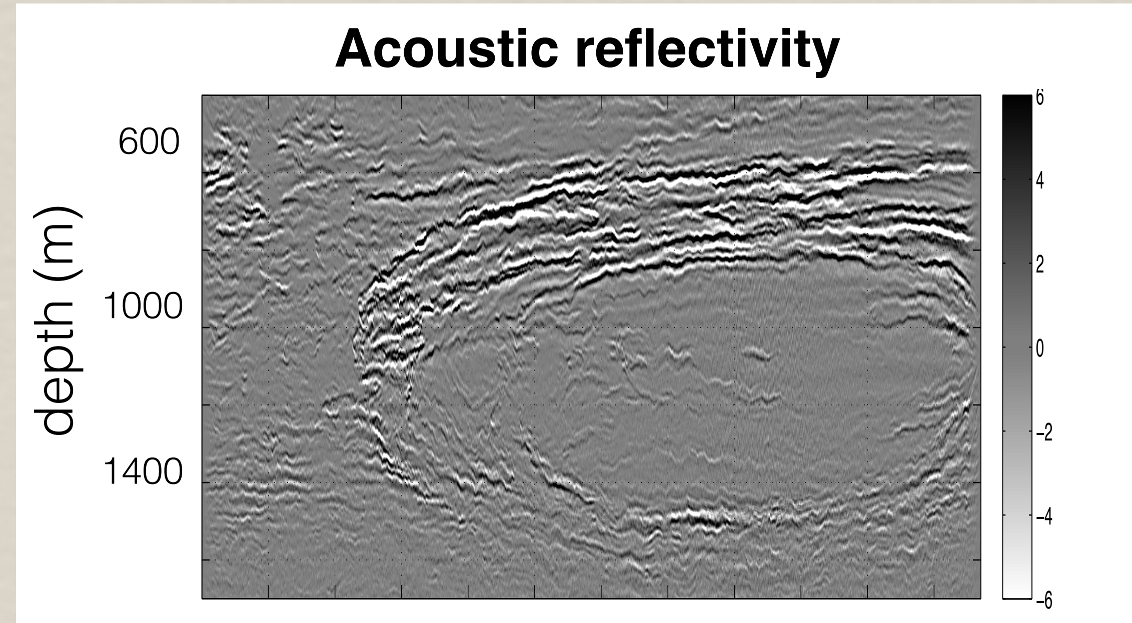
Small scale structures surrounding the mesoscale vortex



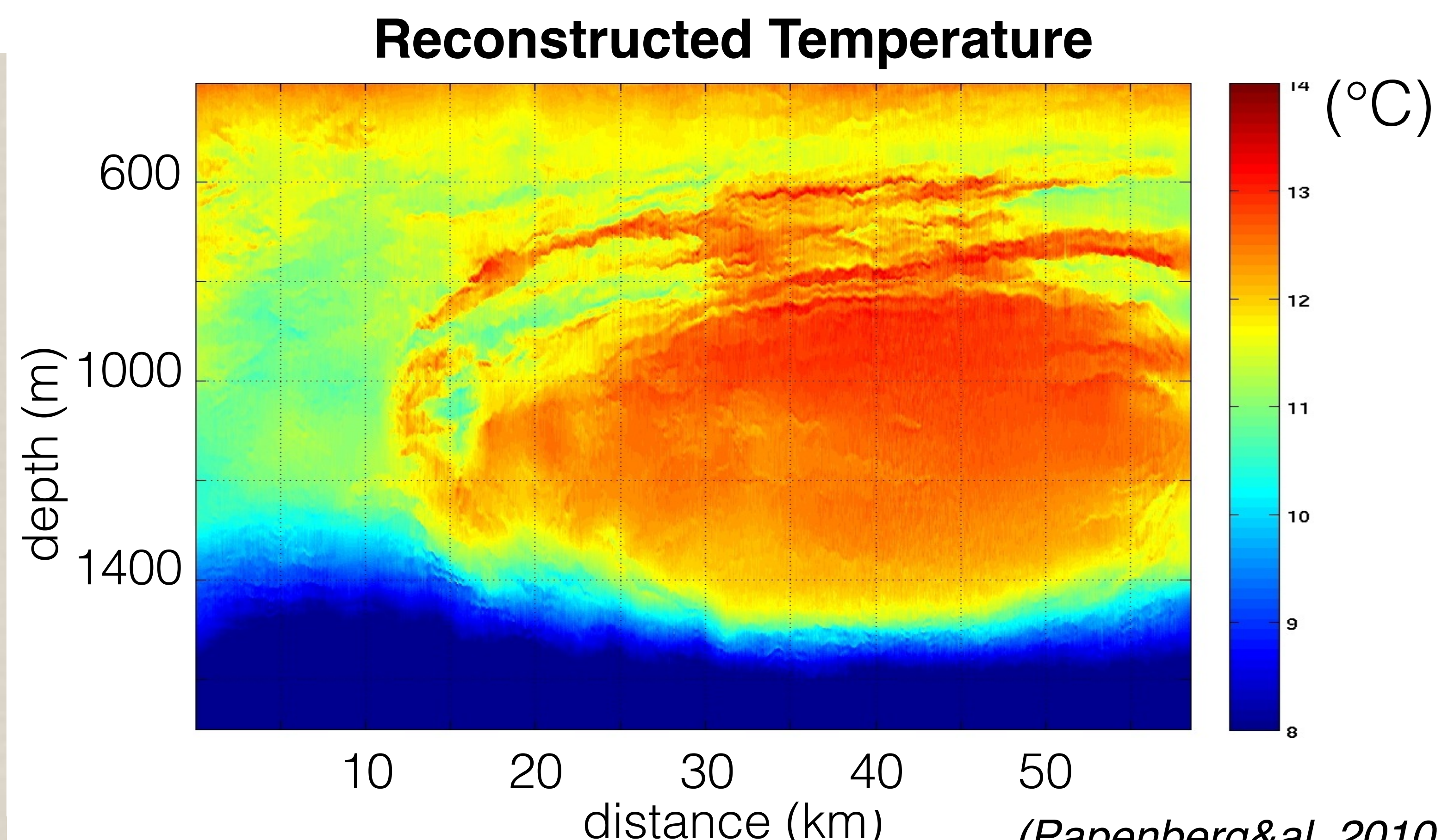
☞ **Small scales features are stacked over the vertical (60-80m): layering**

Progress in oceanographic observations due to seismic data





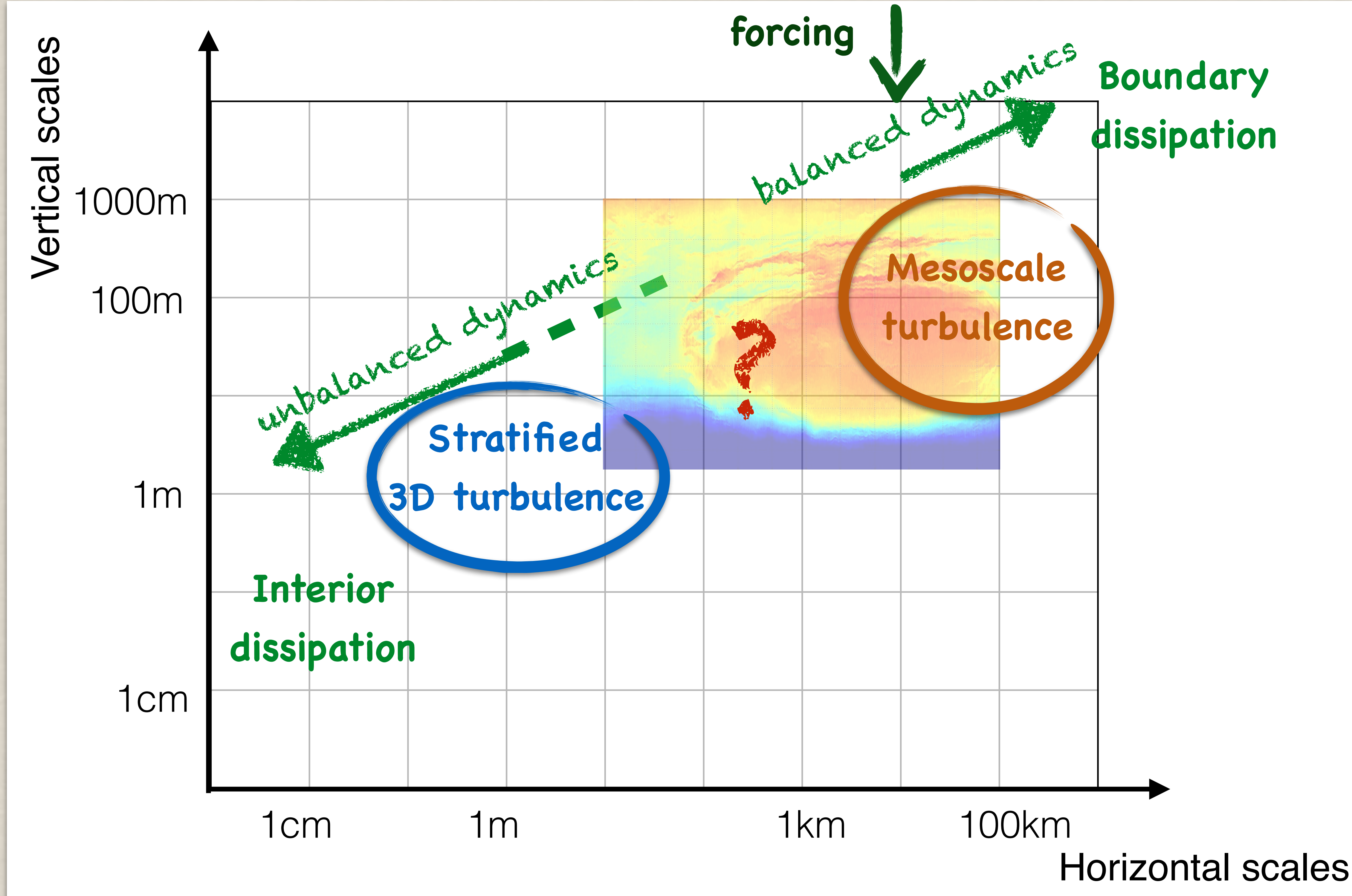
GO, Gulf of Cadiz, 2007



(Papenberg&al.,2010)

☞ **2D high resolution temperature&salinity fields reconstructed from the reflectivity signal and XBT casts**

Context



☞ **Does mesoscale feature produce such small scale layering?**

Does it lead to an interior route to dissipation?

Outline

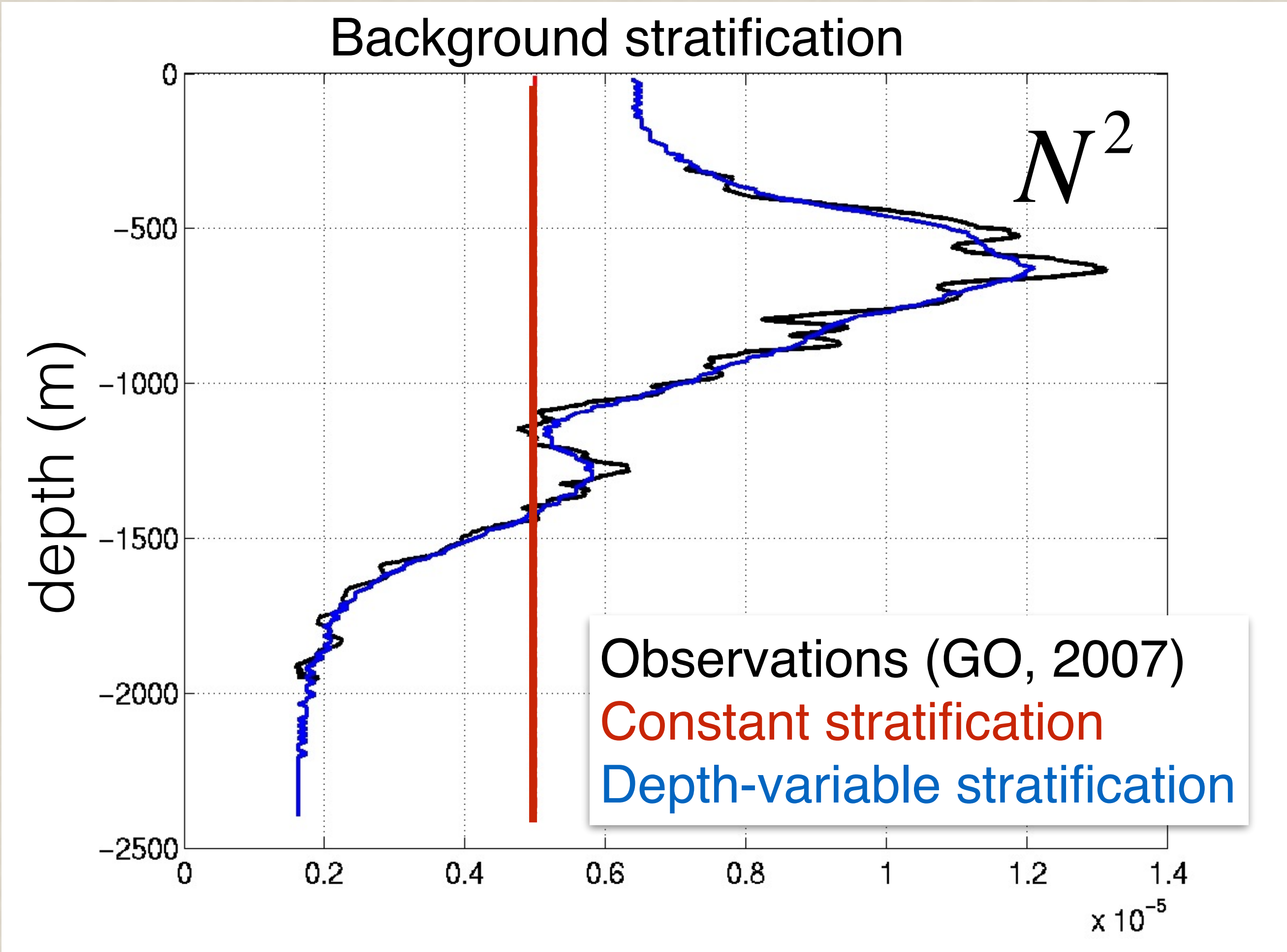
- Observations of submesoscales surrounding an interior anticyclonic vortex
- High resolution simulations:
    - instability and balanced turbulence of an idealized Meddy
    - temperature and salinity stirring
    - possible implication for a direct cascade of energy to dissipation

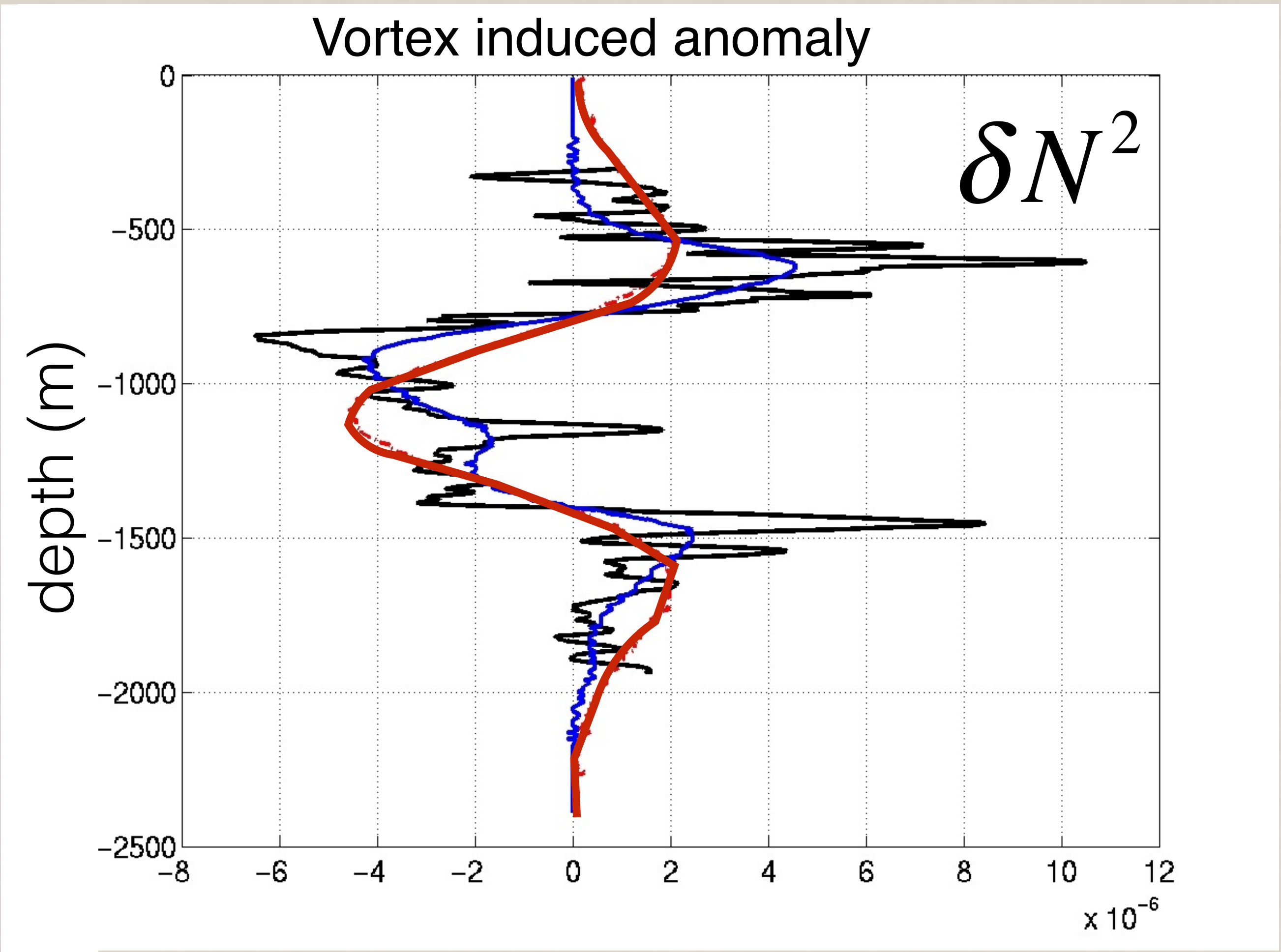
Our idealized meddy

QG spectral model *(Hua&Haidvogel 87)*,

on an f-plane, with density as the only thermodynamic tracer.

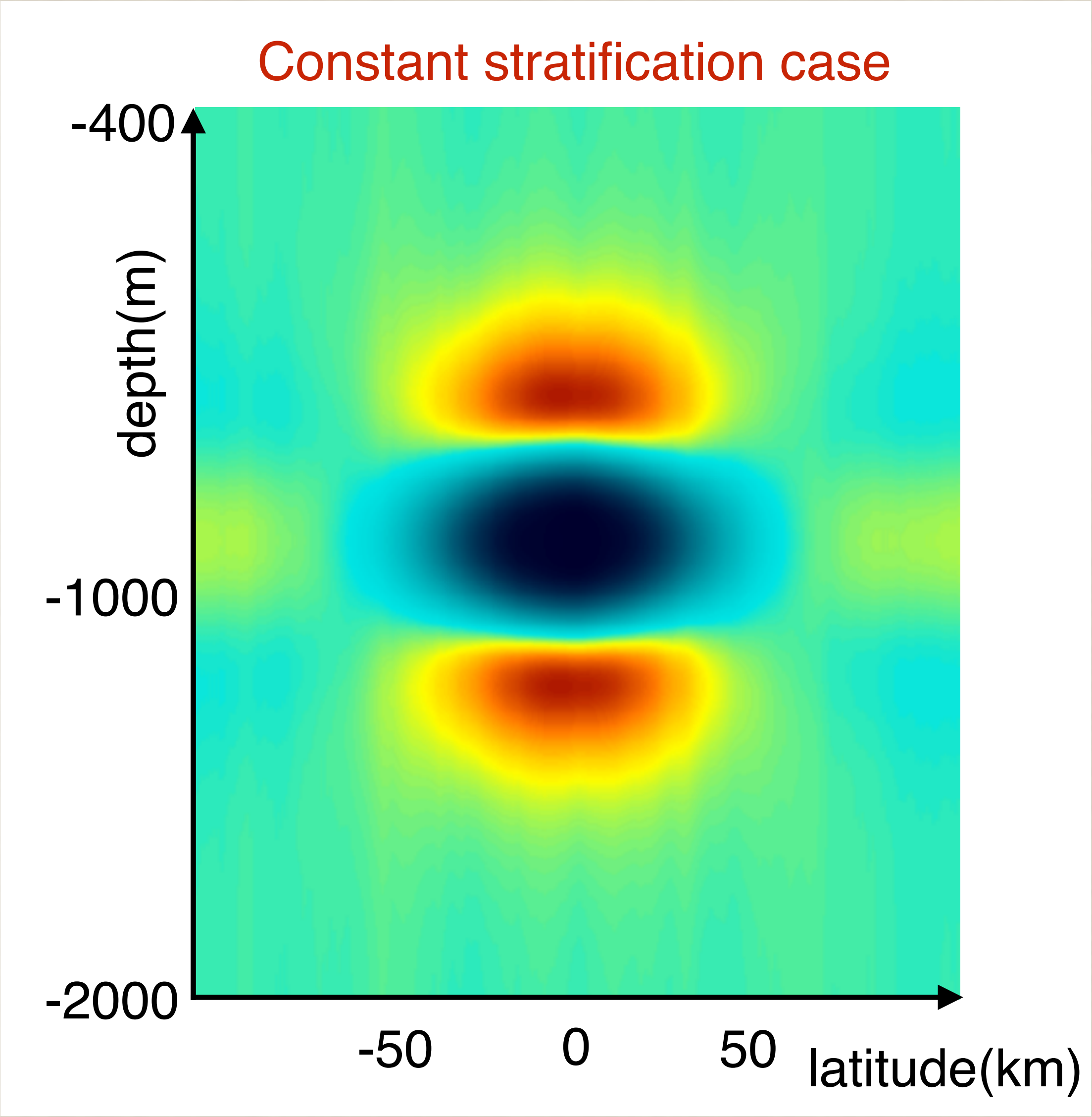
Vortex initialization: Bu=0.15 (flat lens), Ro=0.3





(Hua & al., 2013)

Initialization of QG-PV



☞ In both cases, vortices will be destabilized by baroclinic instability

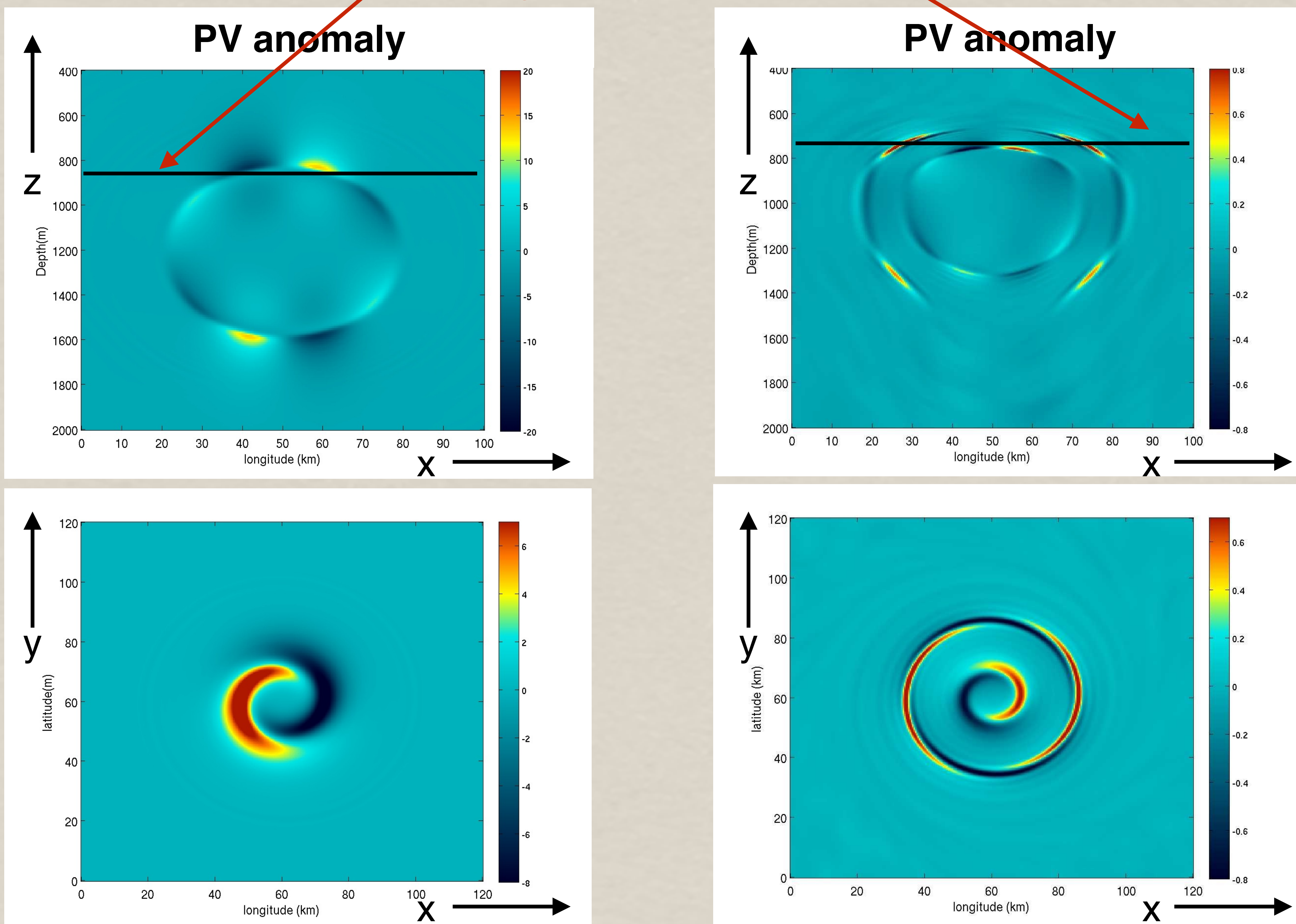
Linear baroclinic unstable modes and critical levels

(Nguyen, Hua &al., 2012)
(Hua & al., 2013)

critical levels of the most unstable eigenmodes (m=1or2)

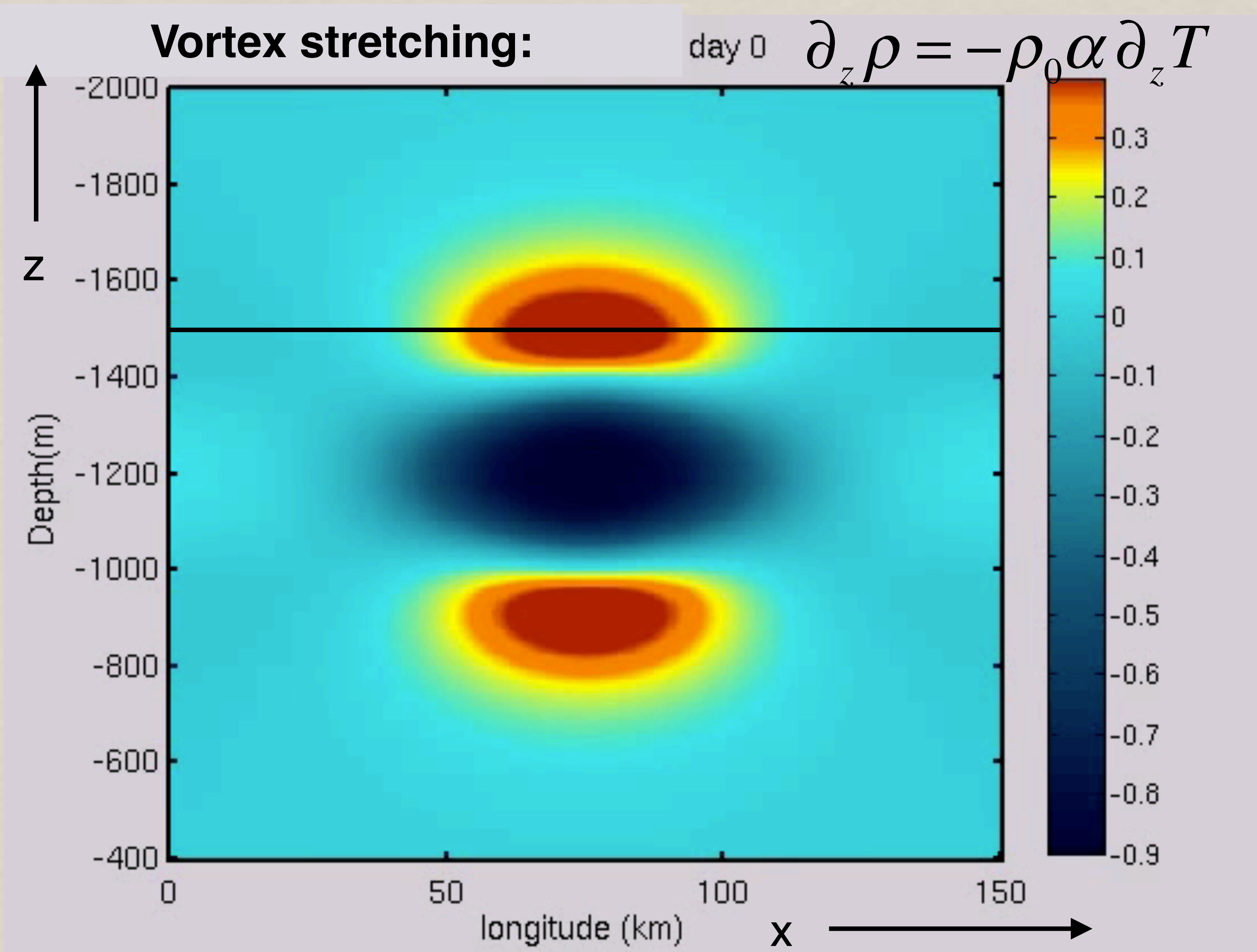
Constant stratification

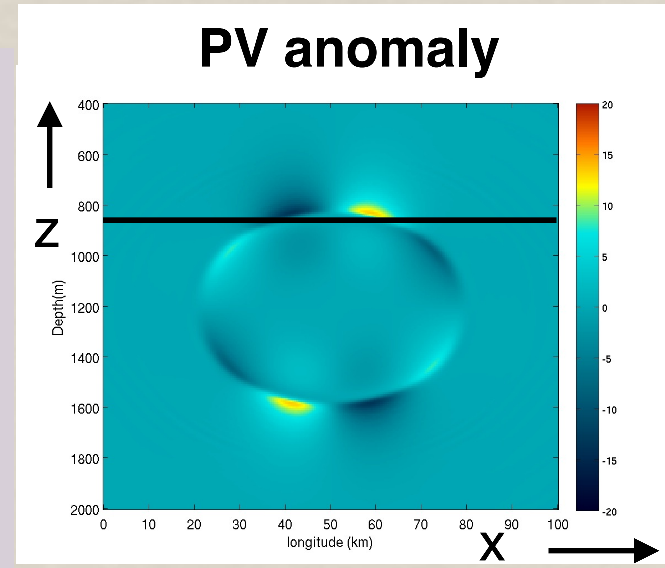
Depth-variable stratification

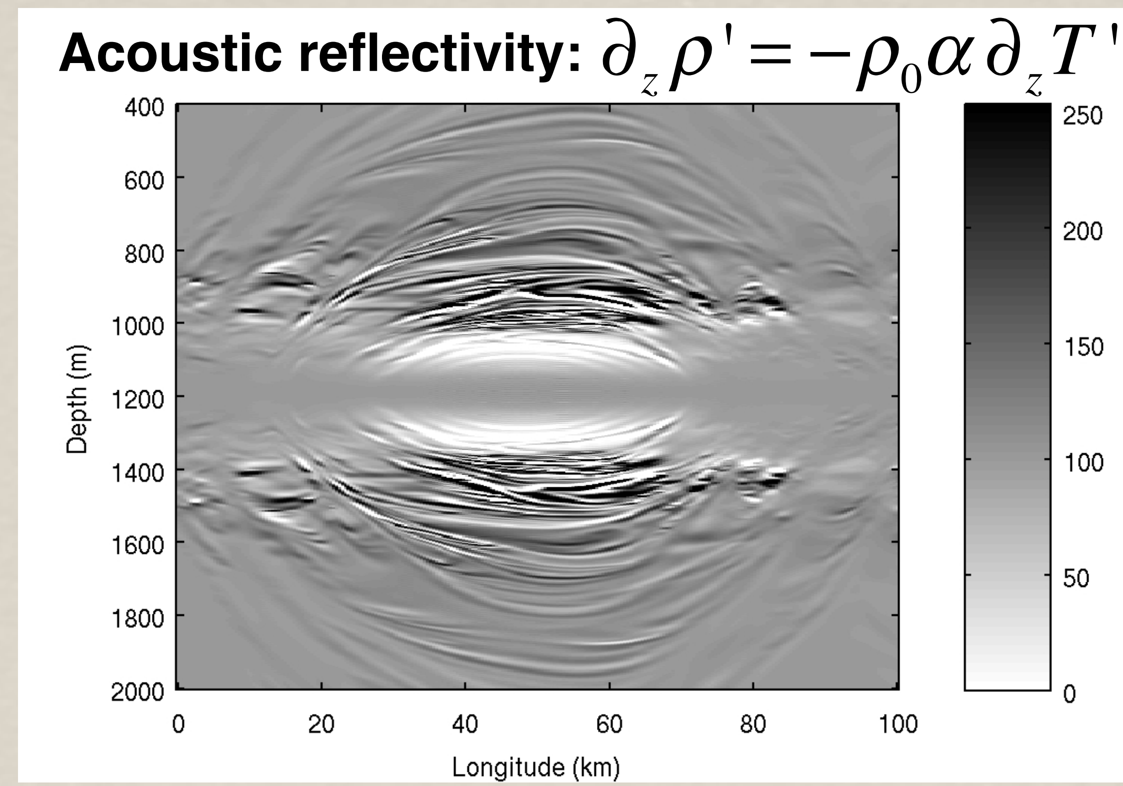


☞ **Eigenmodes of the mix barotropic/baroclinic instability confine PV perturbation on critical layers**

Non-linear evolution: layering formation at critical levels



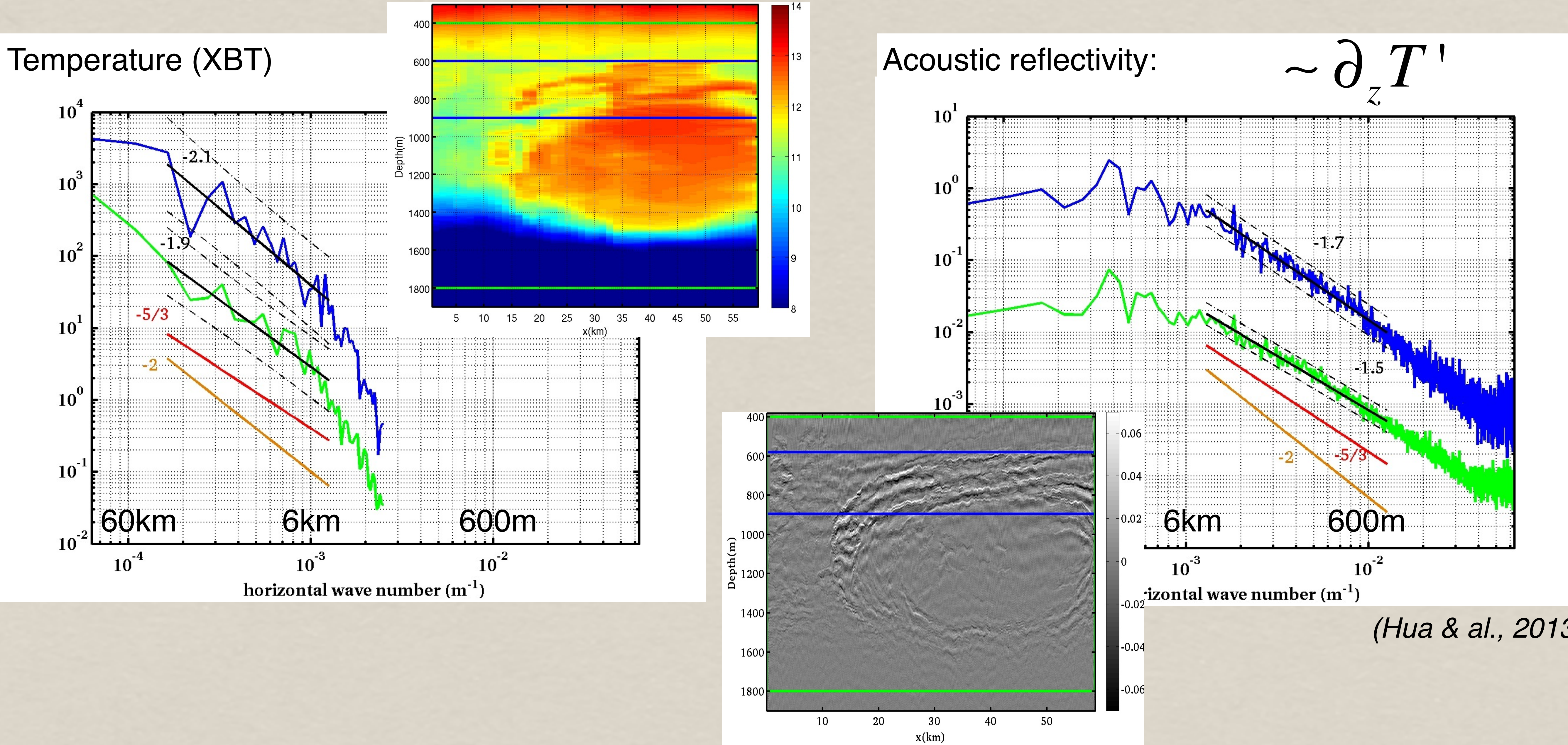




(Hua & al., 2013)

- ☞ **Wind up of PV anomalies at critical levels**
- ☞ **Acoustic reflectivity deduced from the model leads to the same type of layering signal than the one observed in seismic data**

Layering characteristics: from observations

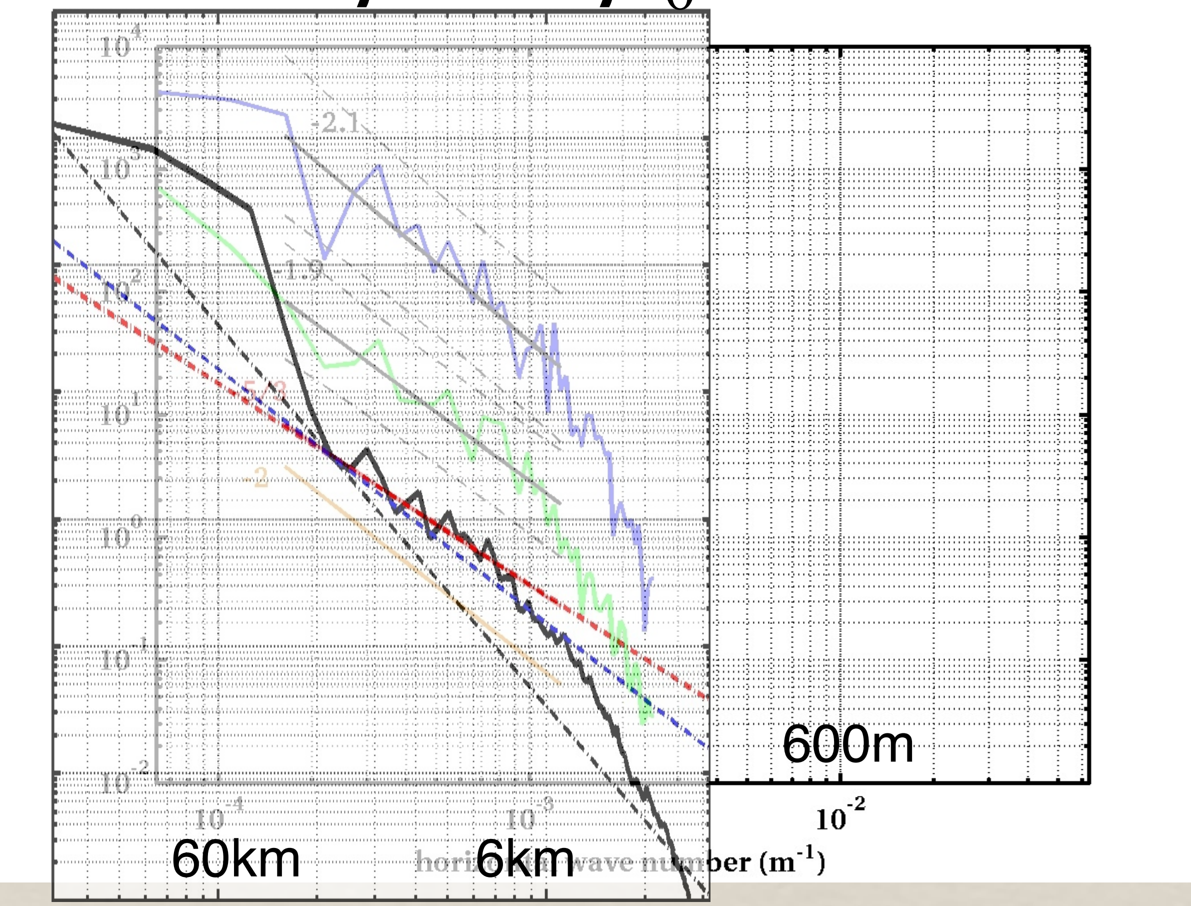


(Hua & al., 2013)

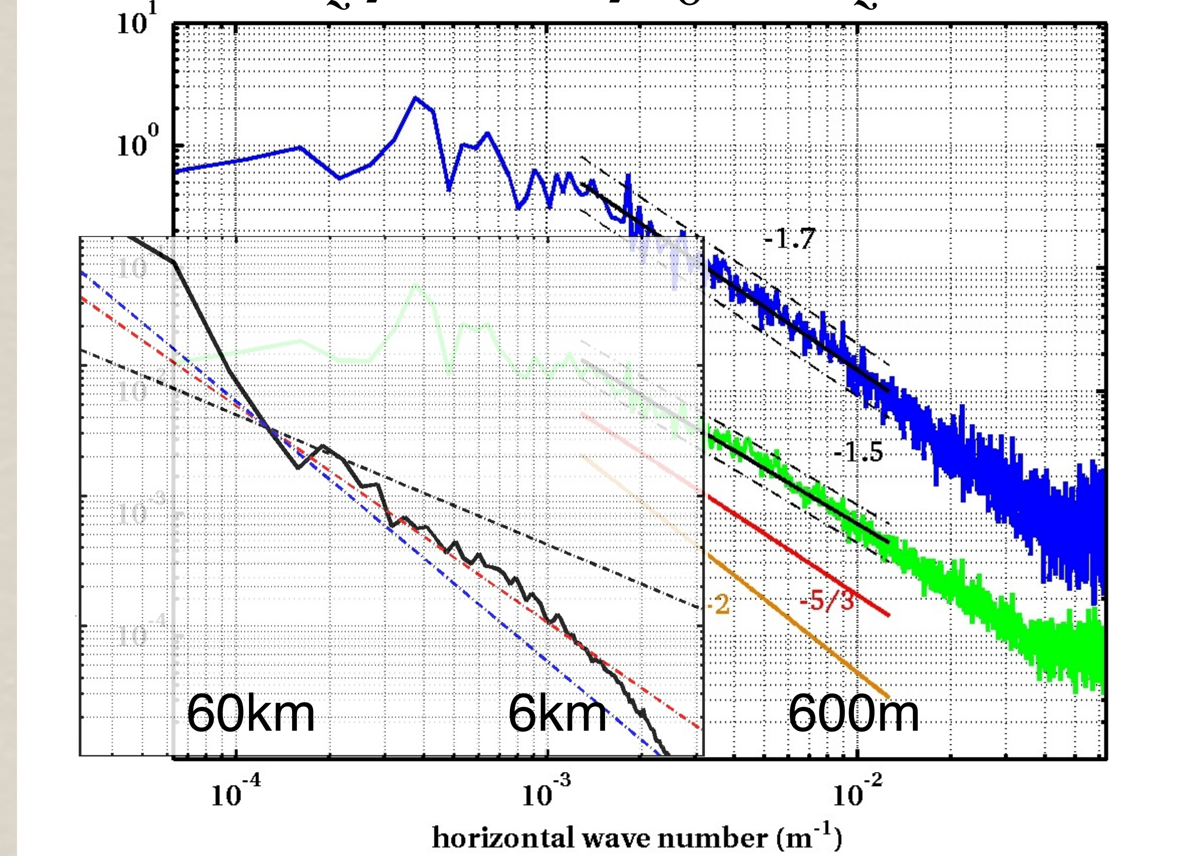
☞ **Temperature and $\dfrac{\partial T'}{\partial z}$ exhibit horizontal spectral laws between -2 and -5/3**

Layering characteristics: as reproduced by the QG model

$$\rho = -\rho_0 \alpha T$$



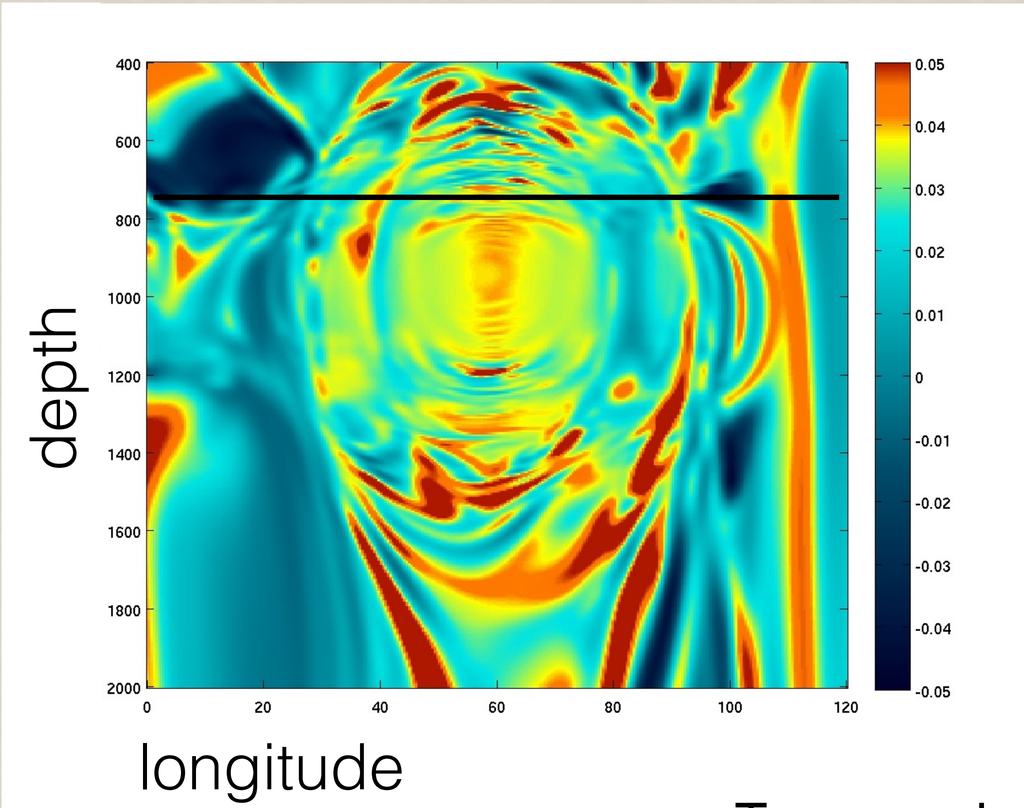
$$\partial_z \rho = -\rho_0 \alpha \, \partial_z T$$

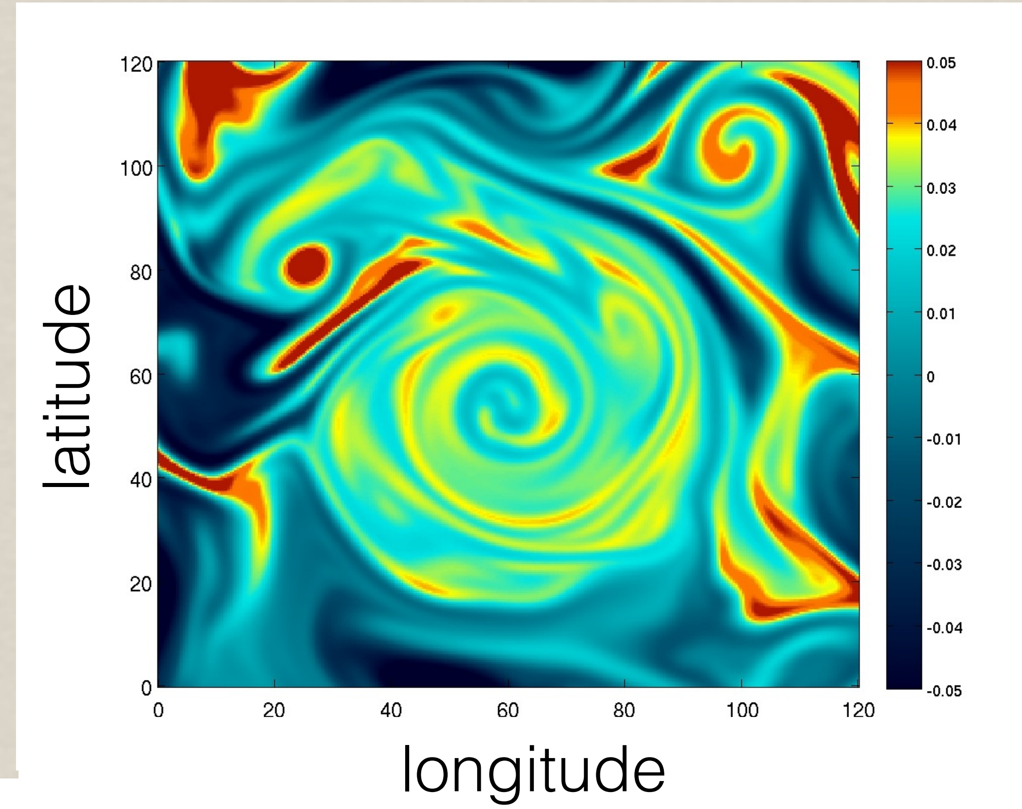


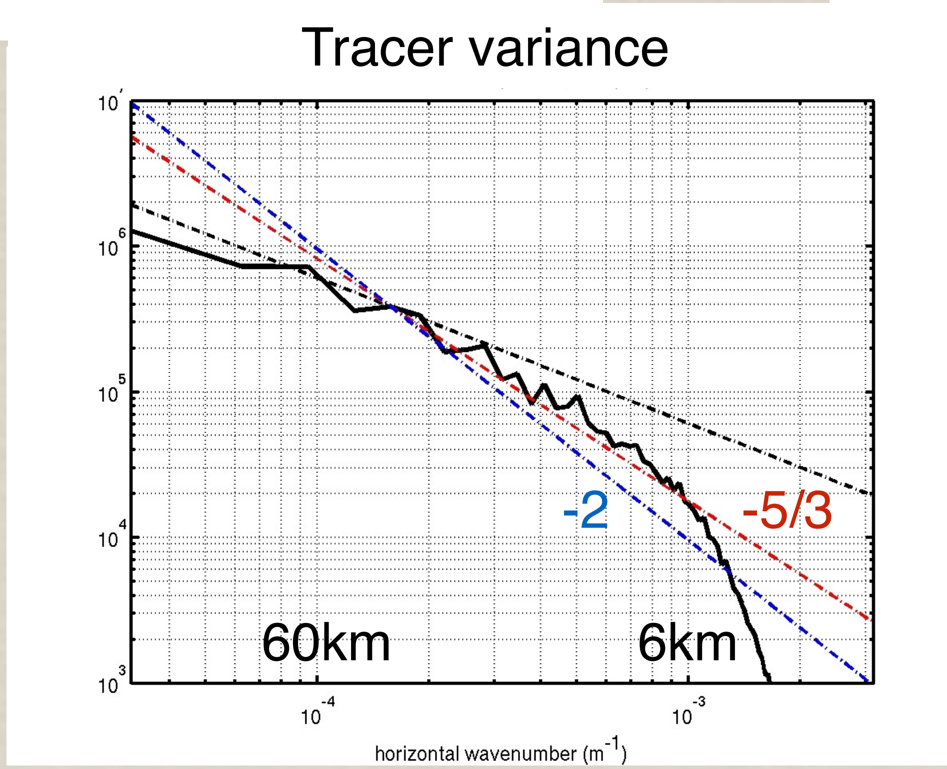
(Hua & al., 2013)

☞ **we reproduce, in the QG model,**
horizontal spectral laws between -2 and -5/3 for T and $\partial_z T$

Passive tracer shows spiraling structures in the layering area







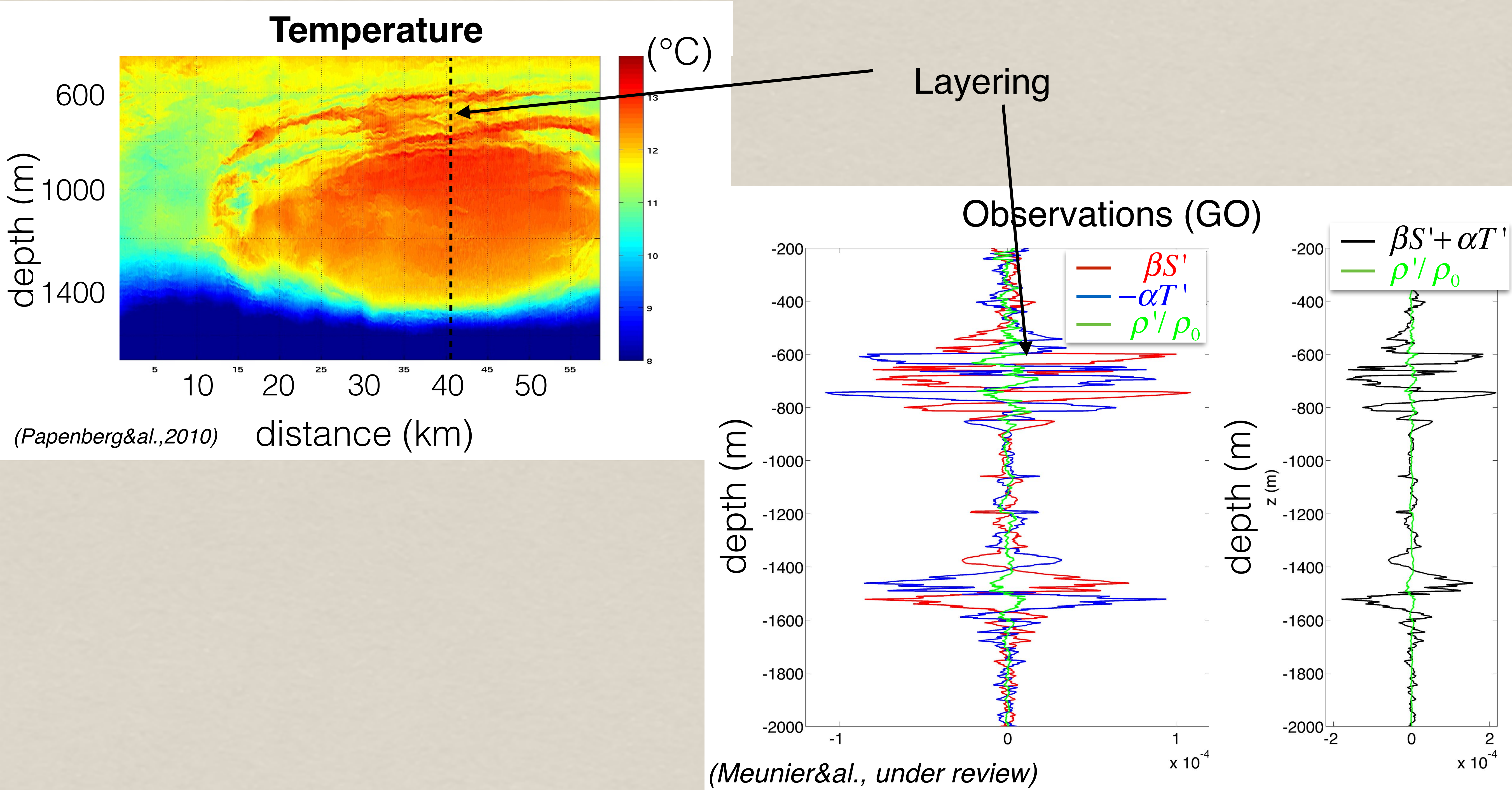
(Hua & al., 2013)

☞ **Geometric effect of 2D spiral structures *(Gilbert, 1988 and Lundgren, 1982)***

Outline

- Observations of submesoscales surrounding an interior anticyclonic vortex
- High resolution simulations:
    - instability and balanced turbulence of an idealized Meddy
    - temperature and salinity stirring
    - possible implication for a direct cascade of energy to dissipation

Isopycnal stirring of temperature and salinity



(Papenberg&al.,2010)

(Meunier&al., under review)

!!!see in poster session!!!

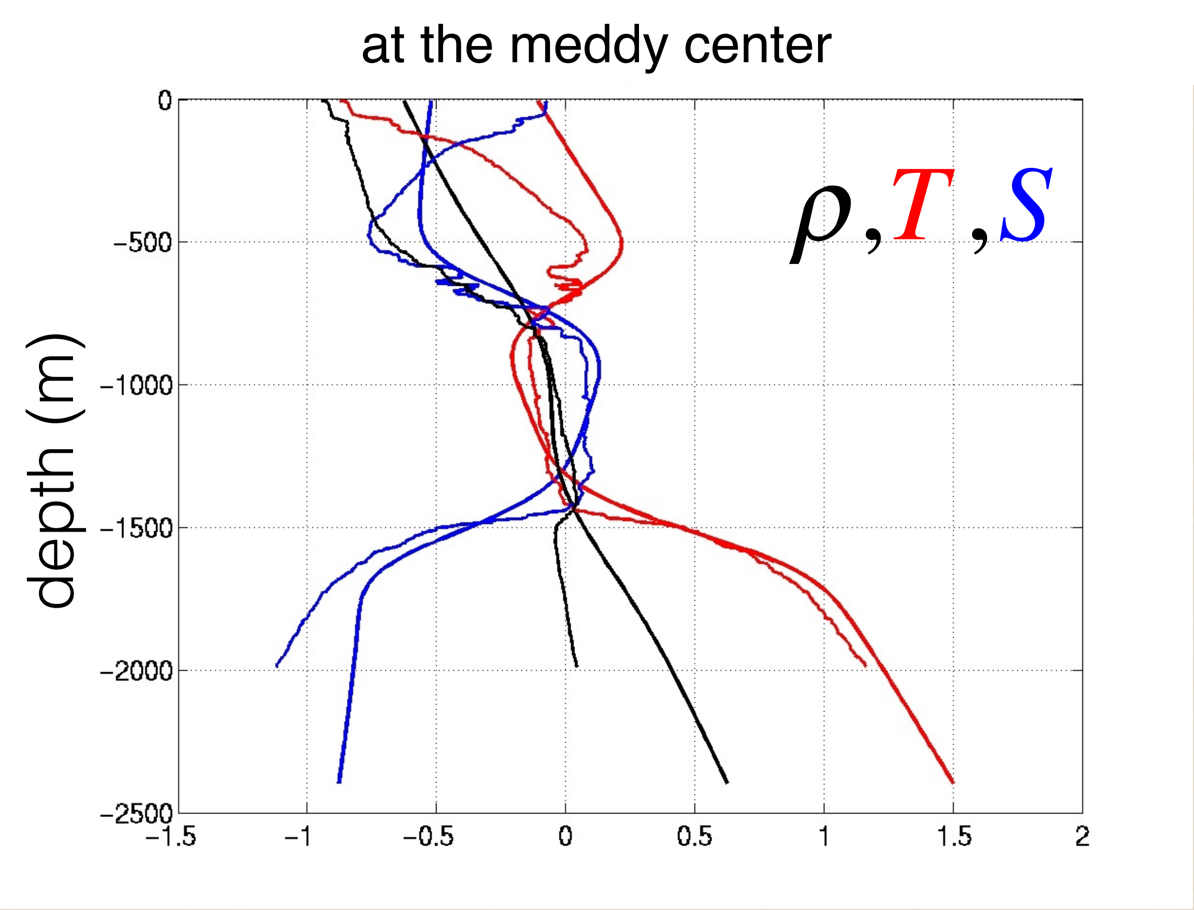
☞ **The 60-80m vertical scale is mostly due to isopycnal stirring of T and S**

(88% of T, S anomalies are compensated in density)

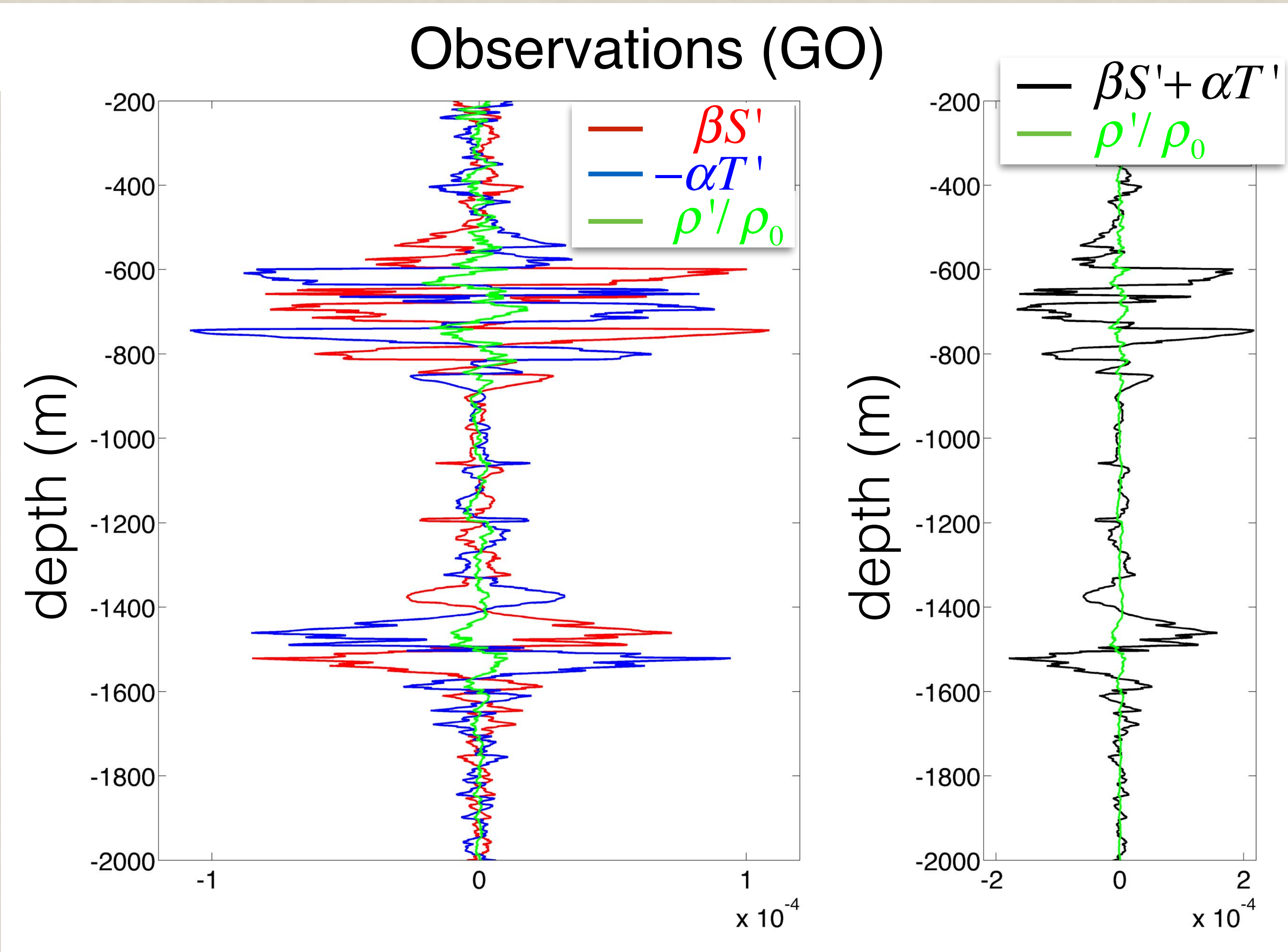
Isopycnal stirring of temperature and salinity

Primitive Equations/NonHydrostatic model: NHOES (H. Aiki)
with a f-plane approximation

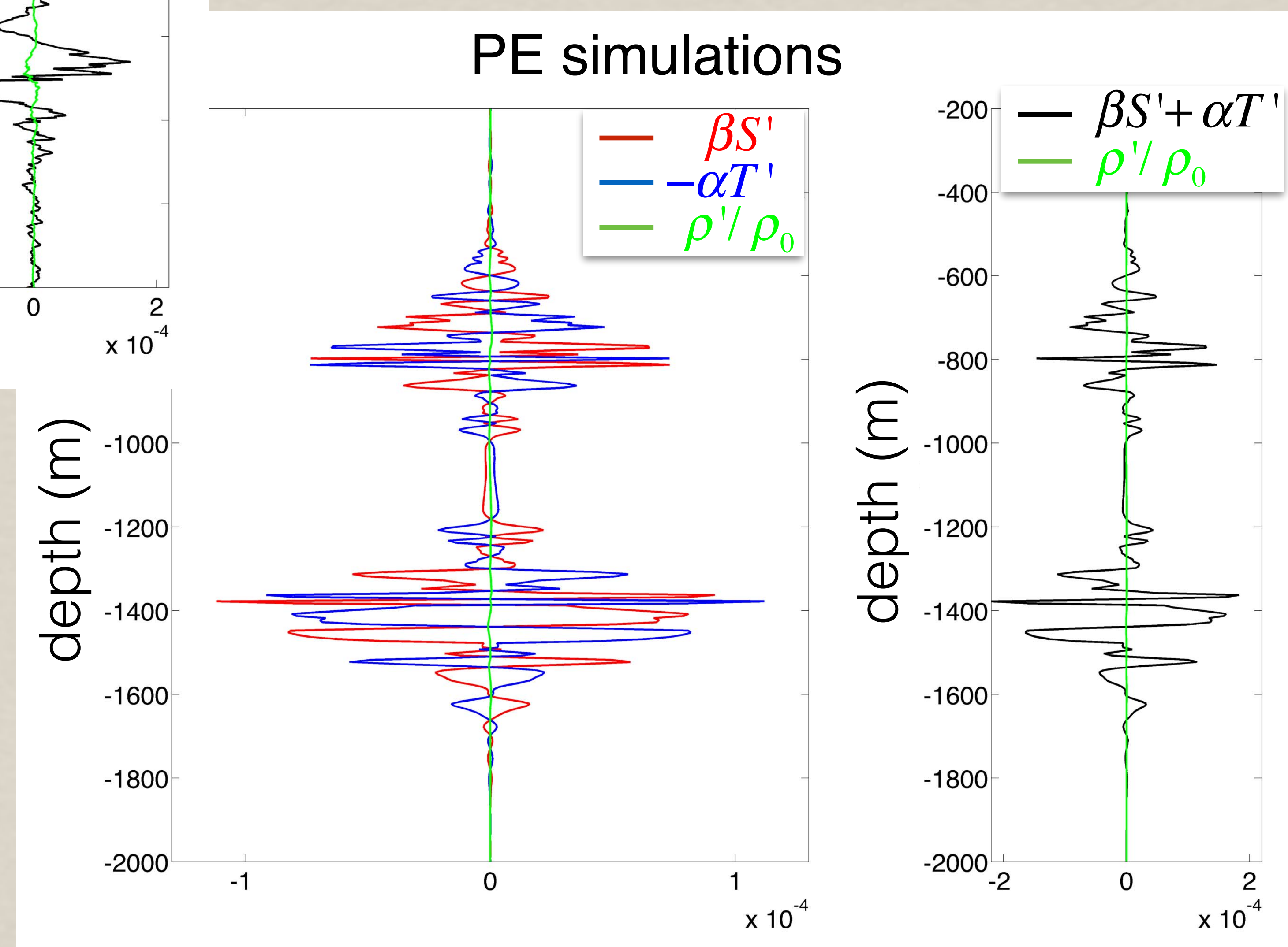
The equation of state depends on temperature and salinity: $\rho = \rho_0(1 - \alpha_0 T + \beta_0 S)$
- to include stirring of tracers
- $\kappa_T = \kappa_S$ that excludes double diffusive effects



Isopycnal stirring of temperature and salinity

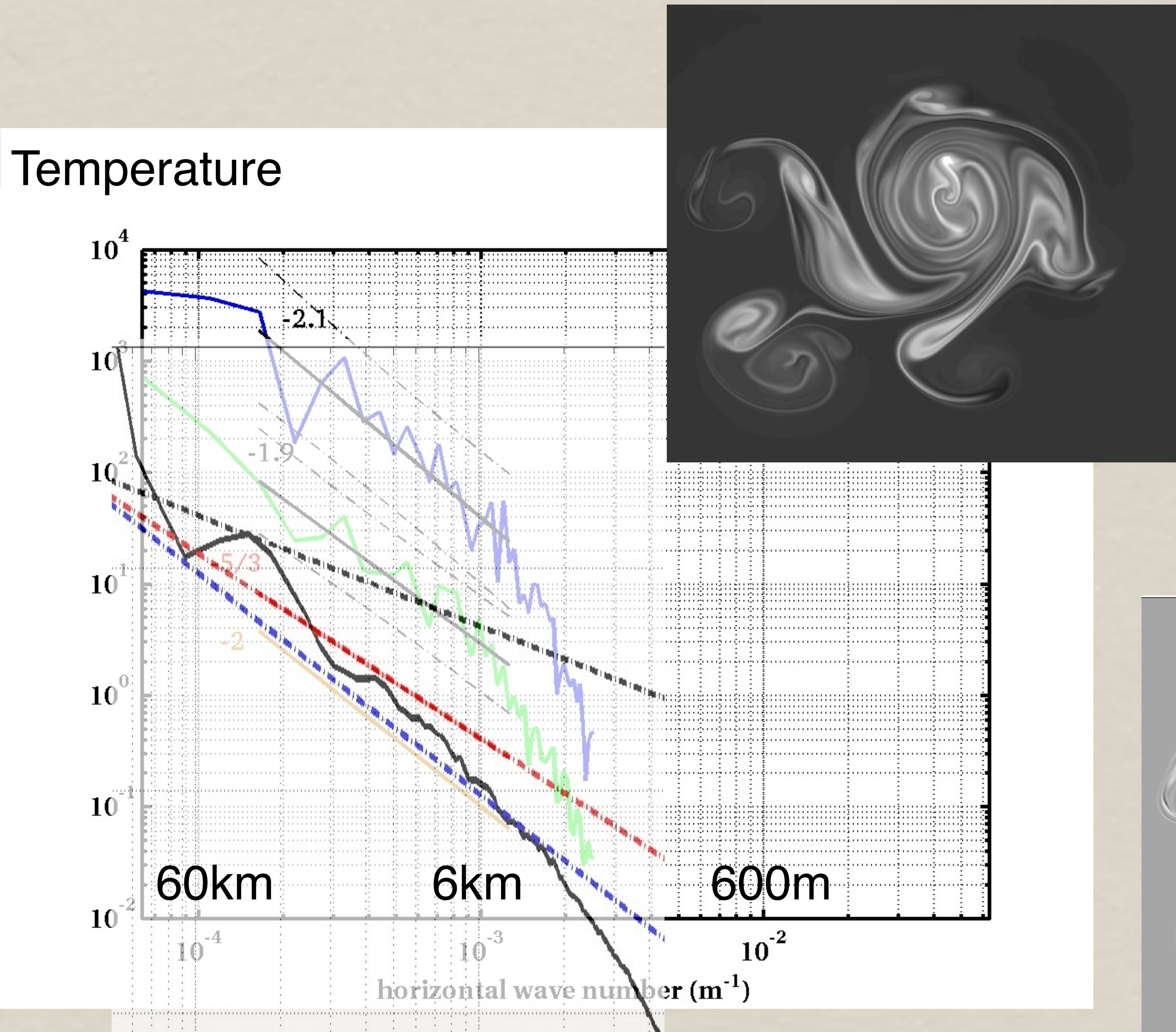


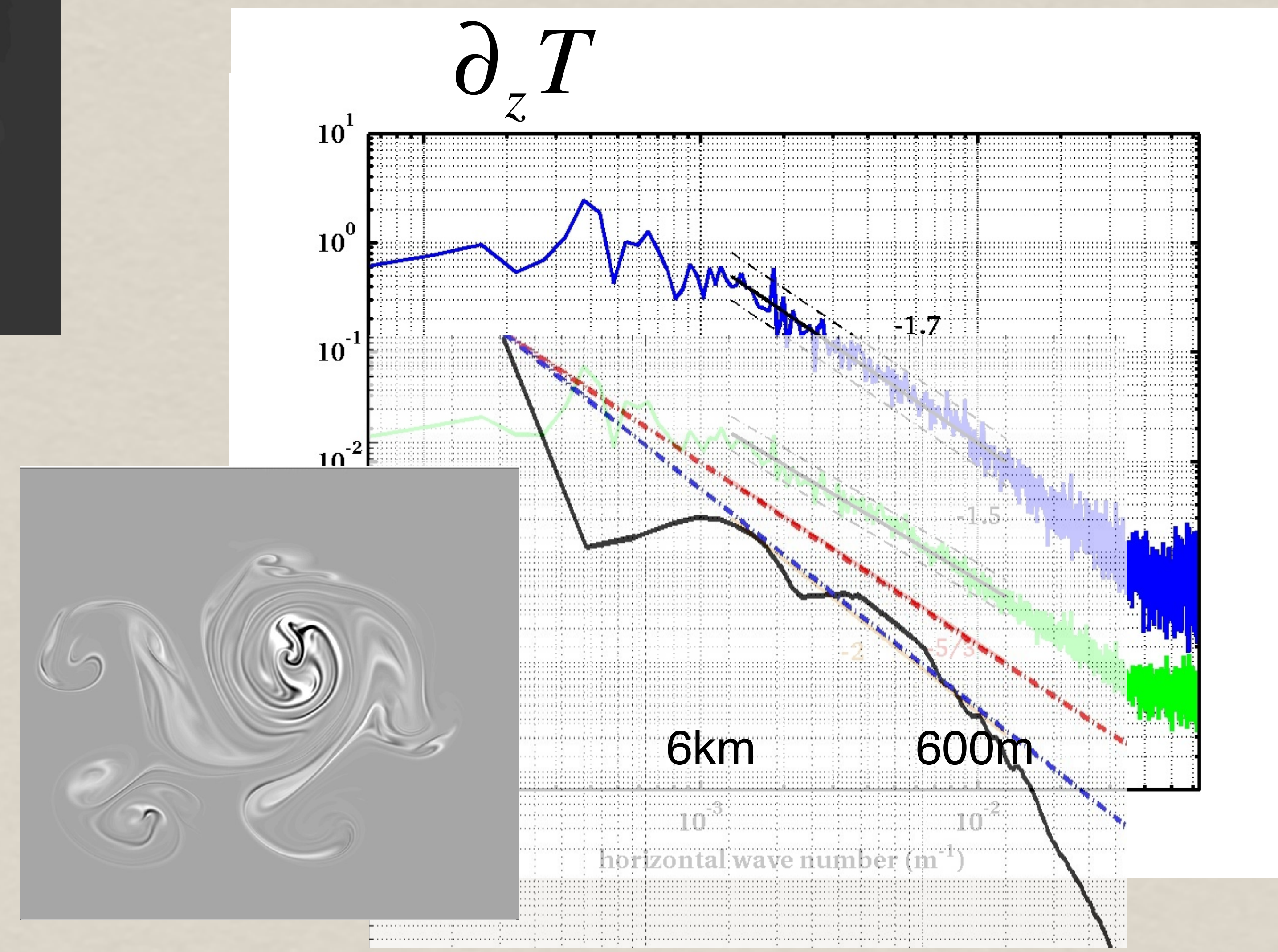
(Meunier&al., under review)



- ☞ **PE model well reproduces the stirring of compensated tracers.**
- ☞ **a slight layering signature grows in density (ongoing work)**

Layering characteristics: as reproduced by a PE model, with T and S





☞ **T and $\partial_z T$ from the high resolution PE model (1000³) present the same horizontal spectral laws between -2 and -5/3 (typical of 2D spiral structures) than the one obtained in observations**

Outline

- Observations of submesoscales surrounding an interior anticyclonic vortex

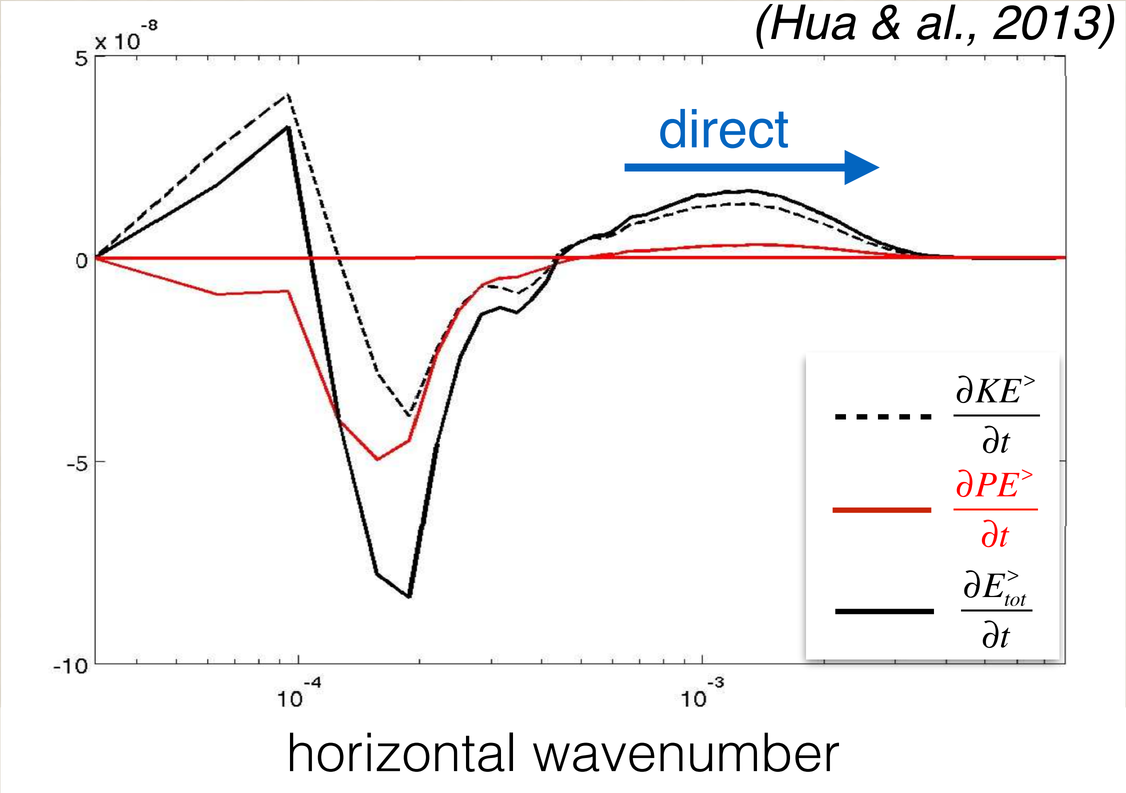
- High resolution simulations:

    - instability and balanced turbulence of an idealized Meddy

    - temperature and salinity stirring

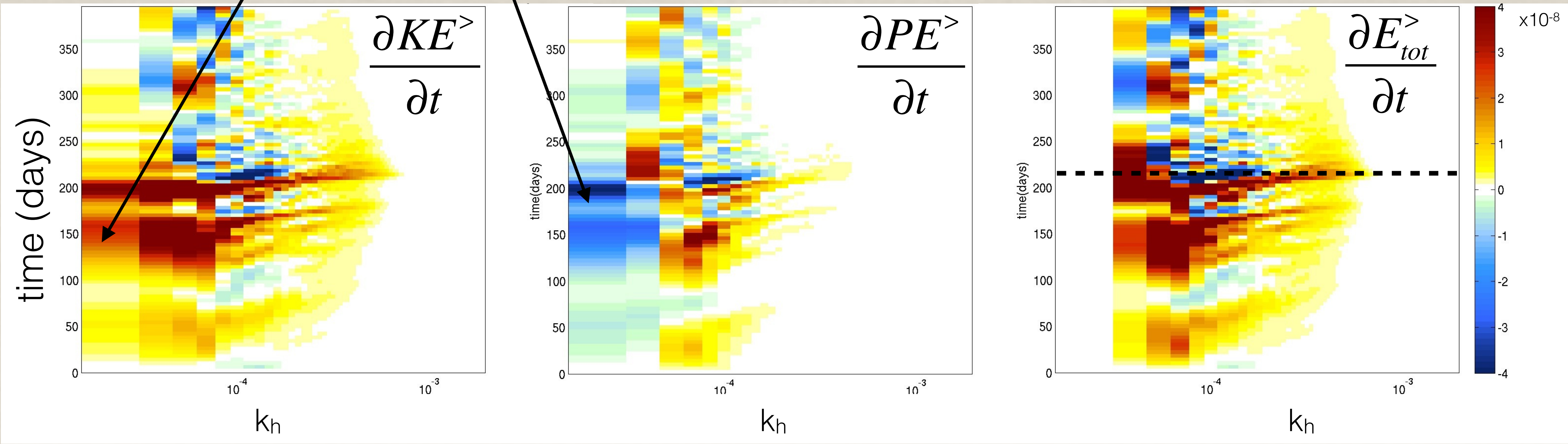
    - possible implication for a direct cascade of energy to dissipation

QG cumulated energy fluxes

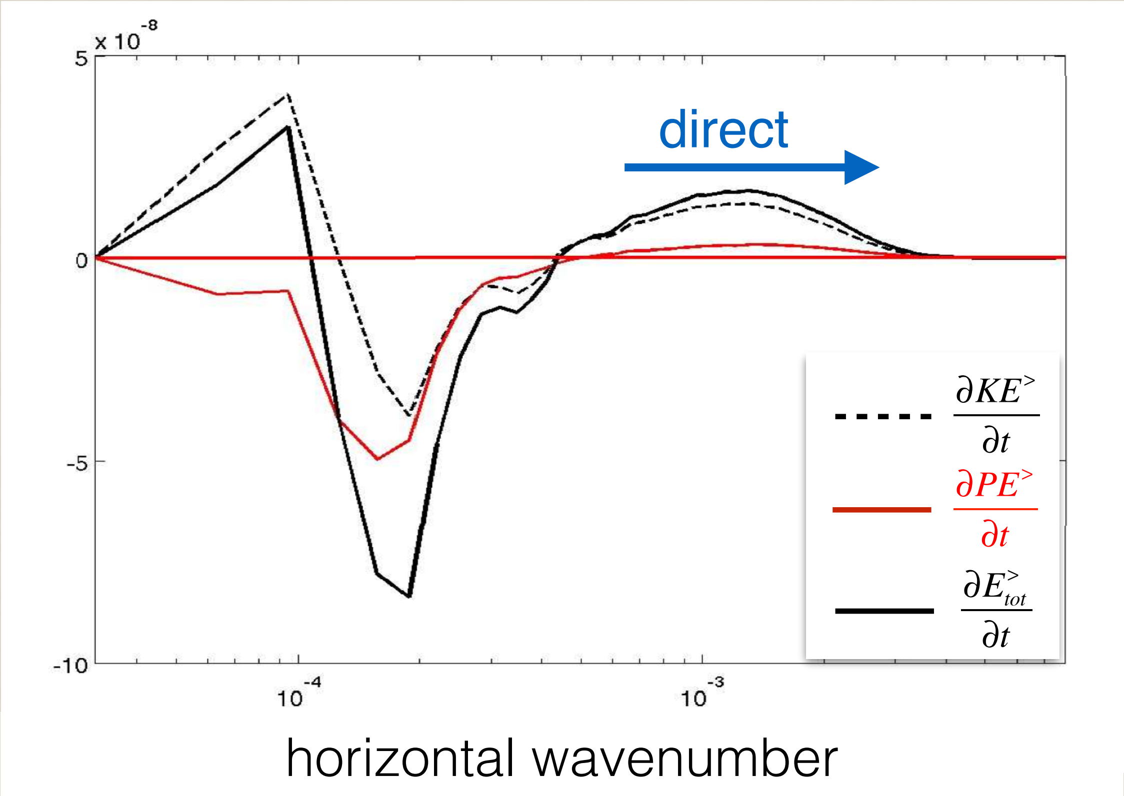


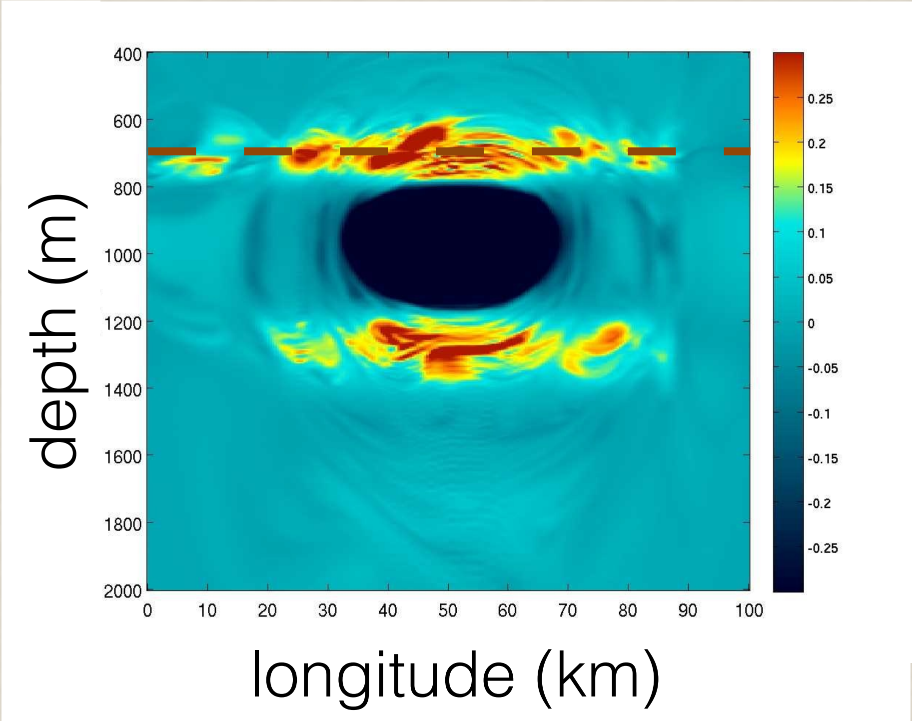
Baroclinic instability:

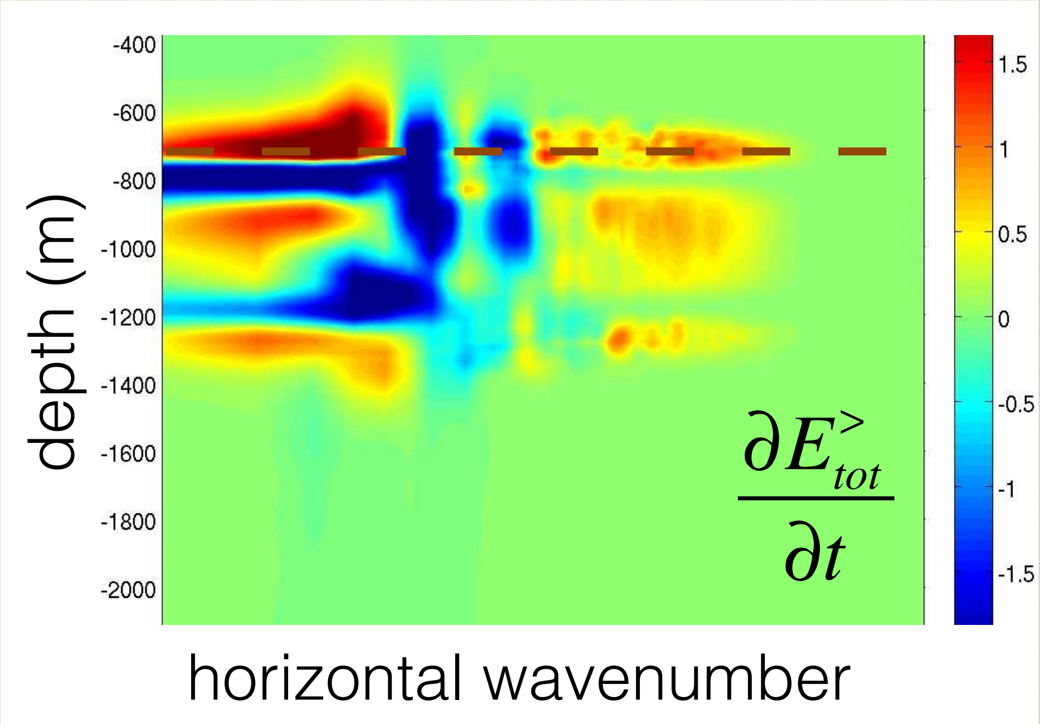
PE to KE transfer



QG cumulated energy fluxes

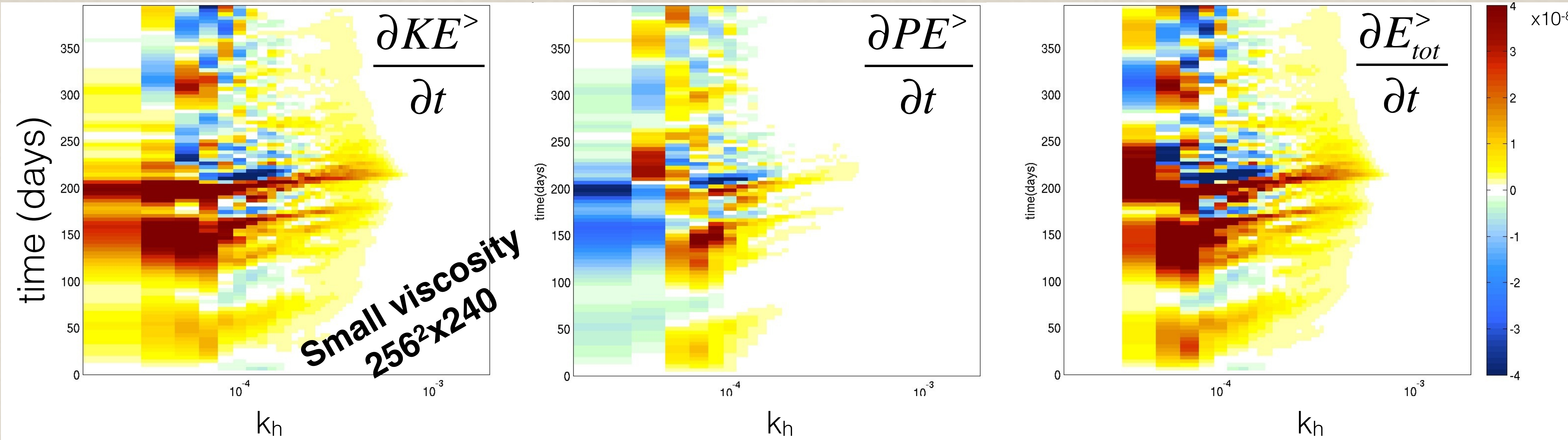




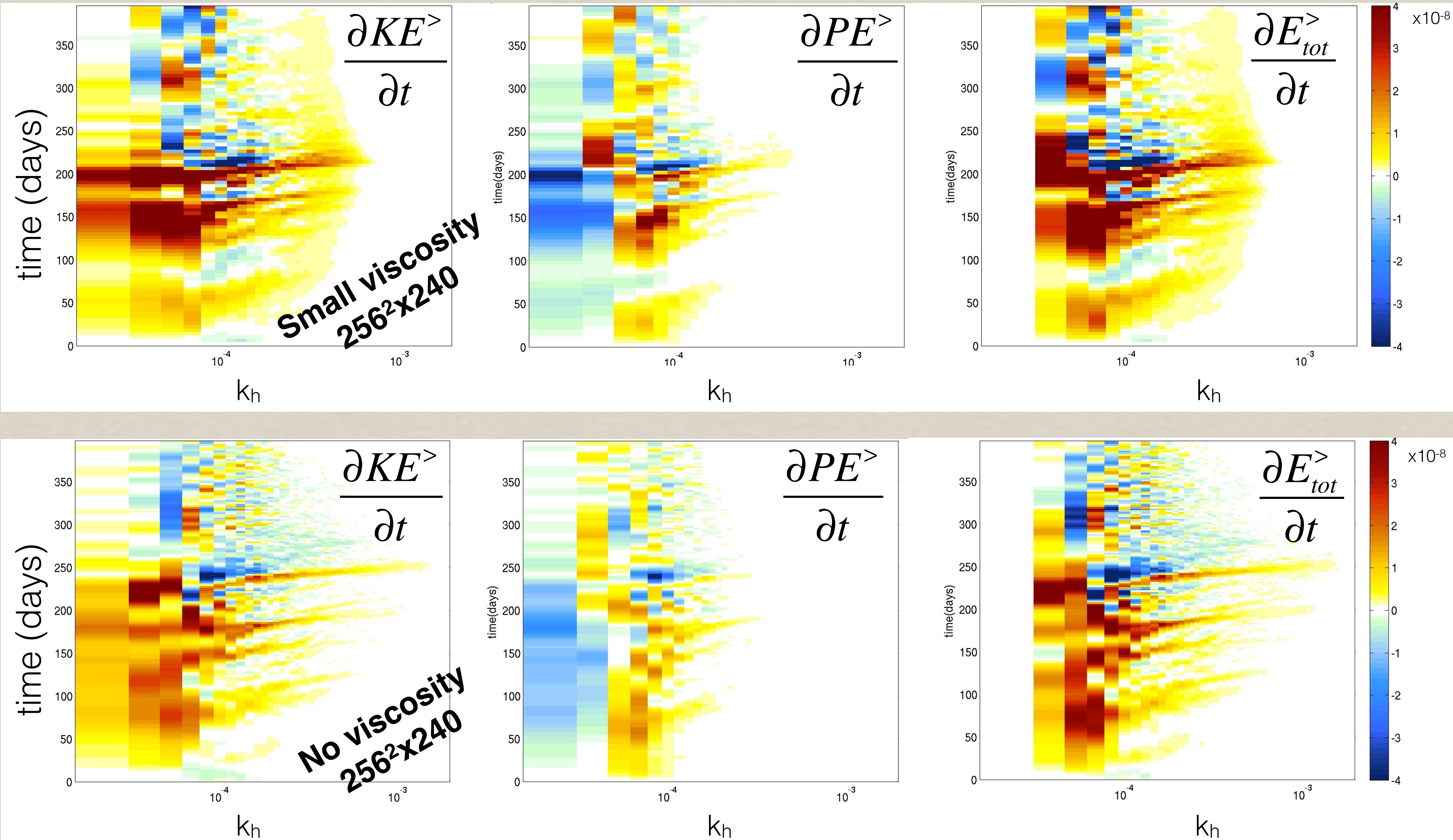


☞ **Inside the layering = preferred localization of direct transfer of energy (kinetic and potential).**

QG cumulated energy fluxes



QG cumulated energy fluxes



☞ **The direct cascade is function of the model viscosity (and the model resolution - *Arbic et al. 2013*)**

☞ **What are the next mechanism in PE that could lead to dissipation in the layering?**

Summary

Observations :

- persistent vertical stacked coherent layers (~80m height, 50km long) around meddies:
88% of the signal in temperature and salinity are density compensated,
but there is still density layers observed.

- [-2 -5/3] horizontal spectral laws for T and T_Z

High resolution 3D simulations :

- layering in PV and ρ_Z is produced in a QG model by the destabilization of a lens shape vortex (baroclinic instability, strong on critical levels)

- layering in Temperature and Salinity is mainly produced by the isopycnal winding up of small scales around the vortex.

- tracers have dominant spiraling patterns and they give similar [-2 -5/3] horizontal spectral laws (ρ, ρ_Z and a passive tracer in QG, T and T_Z in PE)

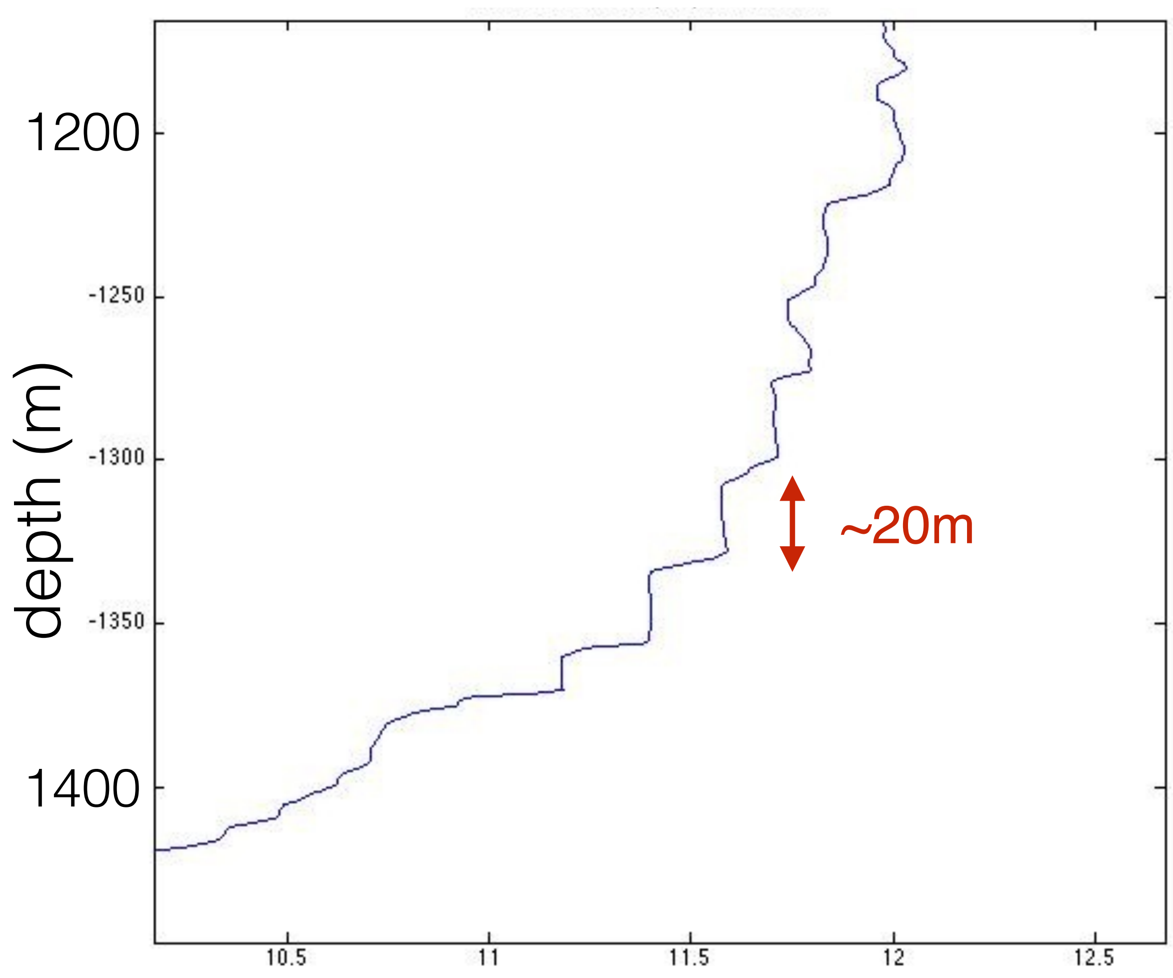
- energy is produced in QG at the submesoscales range where the layering is formed but the production seems to depend on the viscosity&resolution of the model *(Arbic & al 2013)*.

What limits vertical scales of layering? (~80m)

The isopycnal winding up of tracers can not explain the arrest of a vertical scale.

What is an unbalanced mechanism that leads to dissipation of energy in the layering area?

Staircases below the meddy
(observations, GO)



Potential temperature

Secondary instability:
double-diffusive effects (often invoked) or other process?

Work in progress with high resolution QG, PE & NH models