Energetics of quasi-horizontal stirring and mixing

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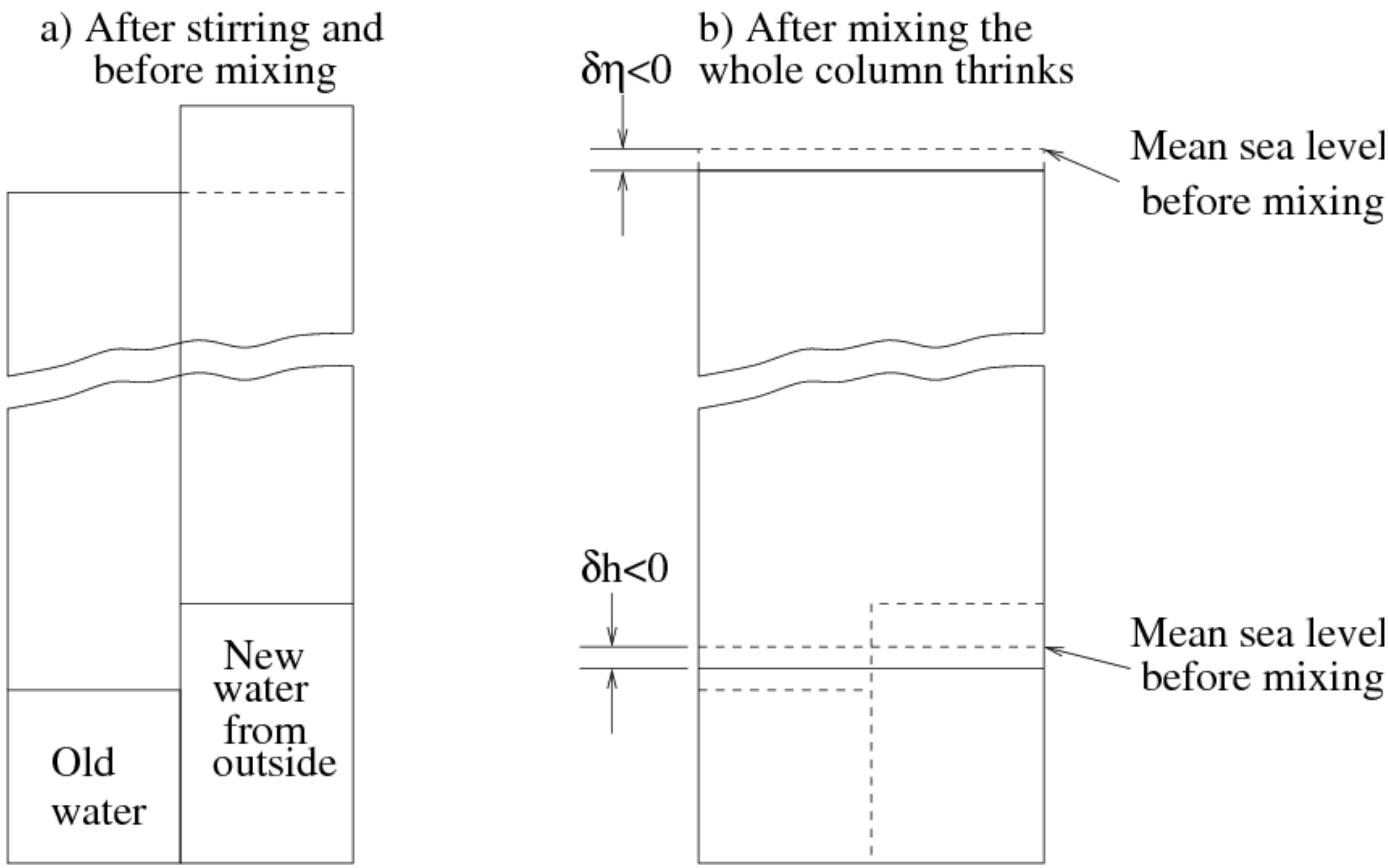
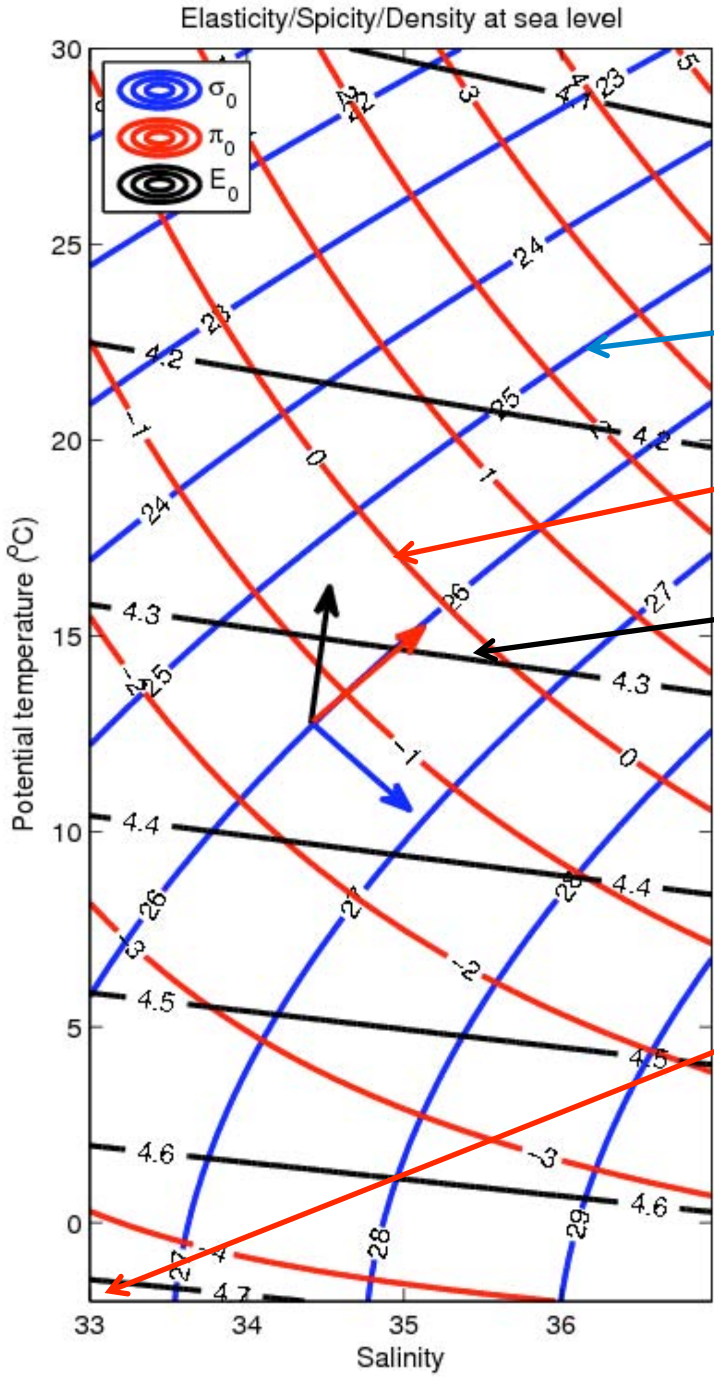
Major points

- What really matters is eddy diffusion, not molecular diffusion
- Eddy diffusion consists of Stirring and Mixing
- Isopycnal exchange of watermass is no free lunch
- Cabbeling is always a sink of GPE
- A new type of meso-scale instability

  supported by energy released in connection with the non-constant elasticity of seawater.

Eddy diffusion is separated into 2 steps: stirring & mixing





Density

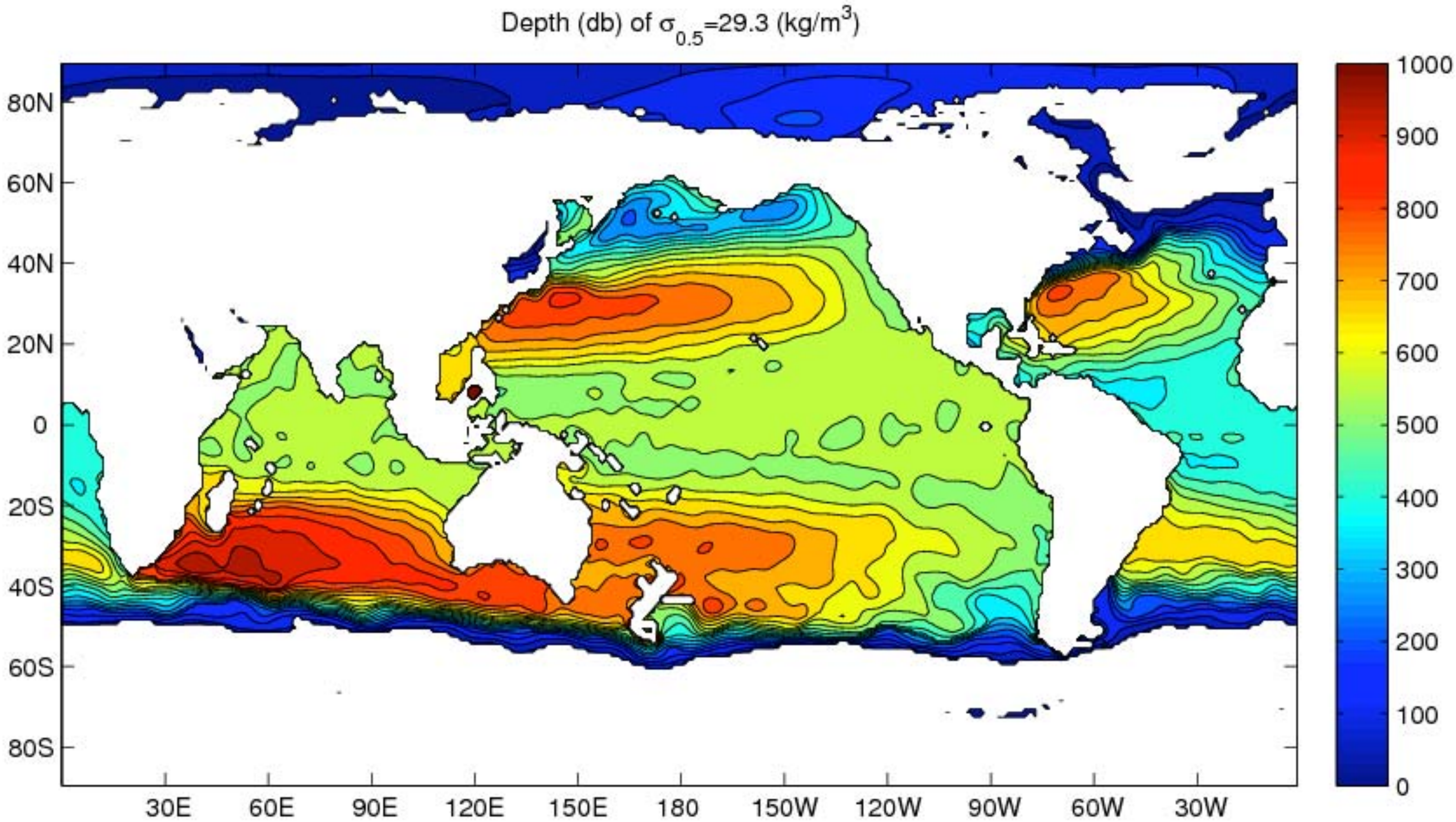
spicity

elasticity

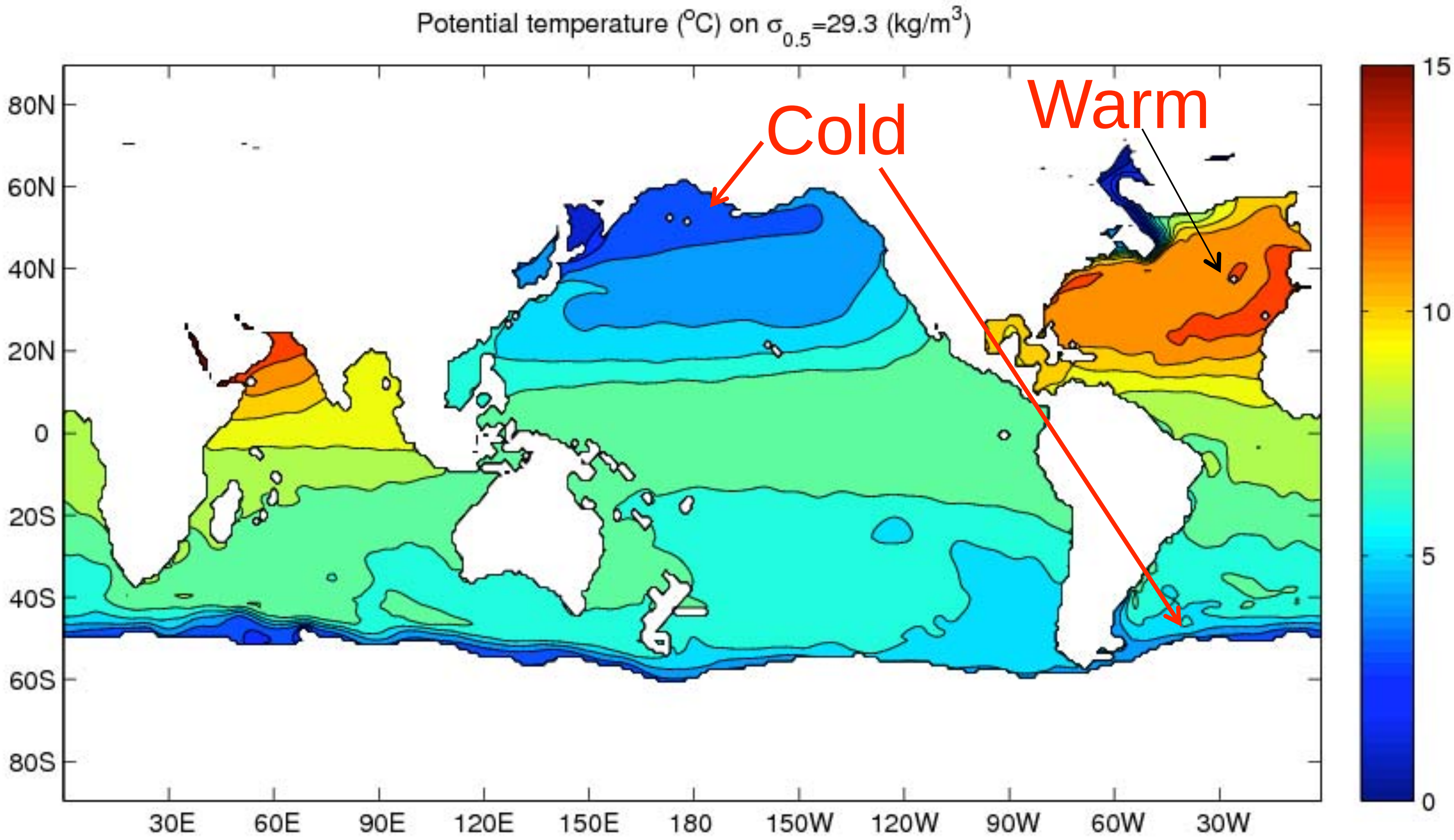
$$E = 1000 db \rho K_\eta \left(kg / m^3 \right)$$

Cold & fresh water is more compressible

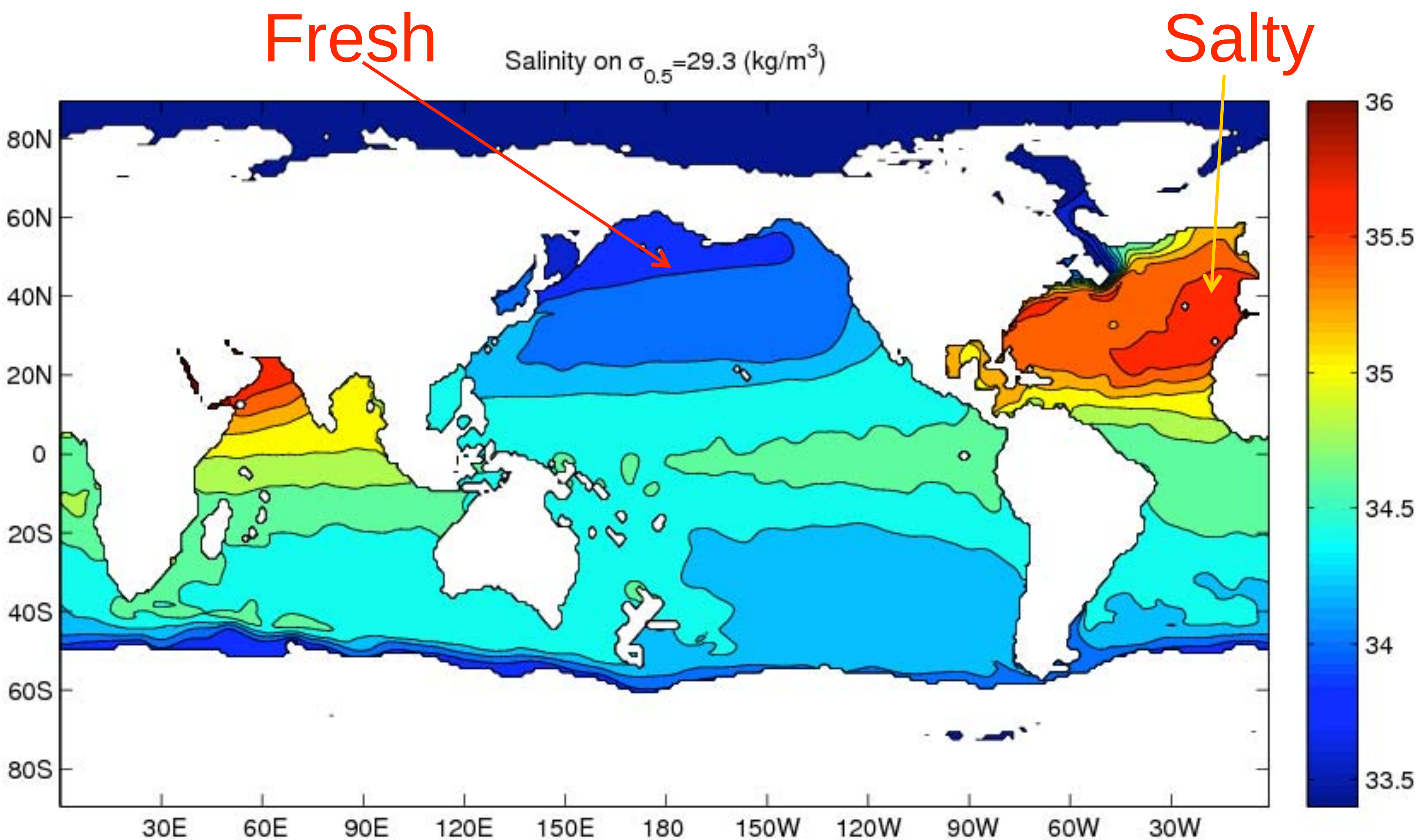
Depth of $\sigma_{0.5} = 29.3(kg/m^3)$



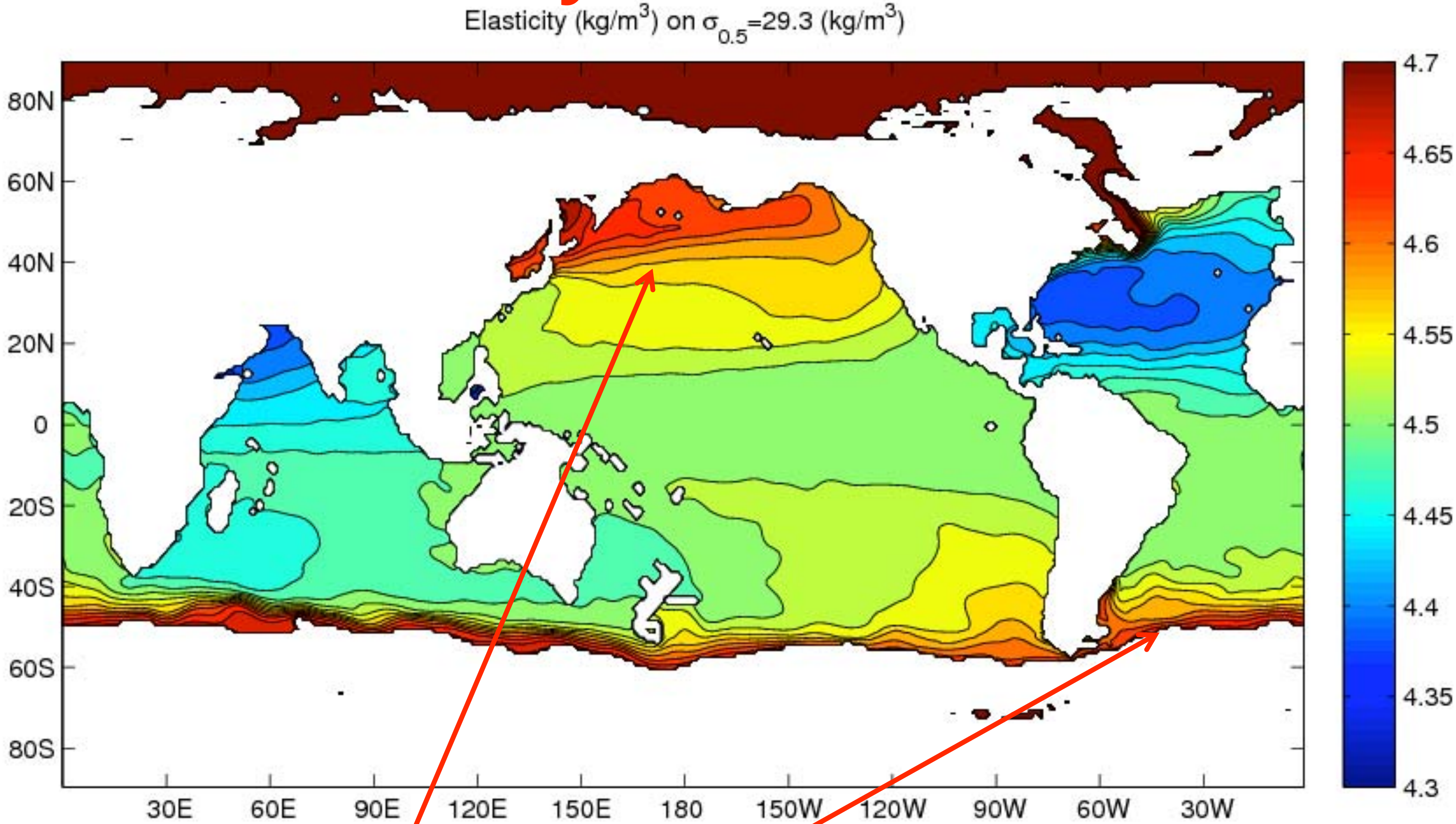
Potential temperature on $\sigma_{0.5} = 29.3(kg/m^3)$



Salinity on $\sigma_{0.5} = 29.3(kg/m^3)$



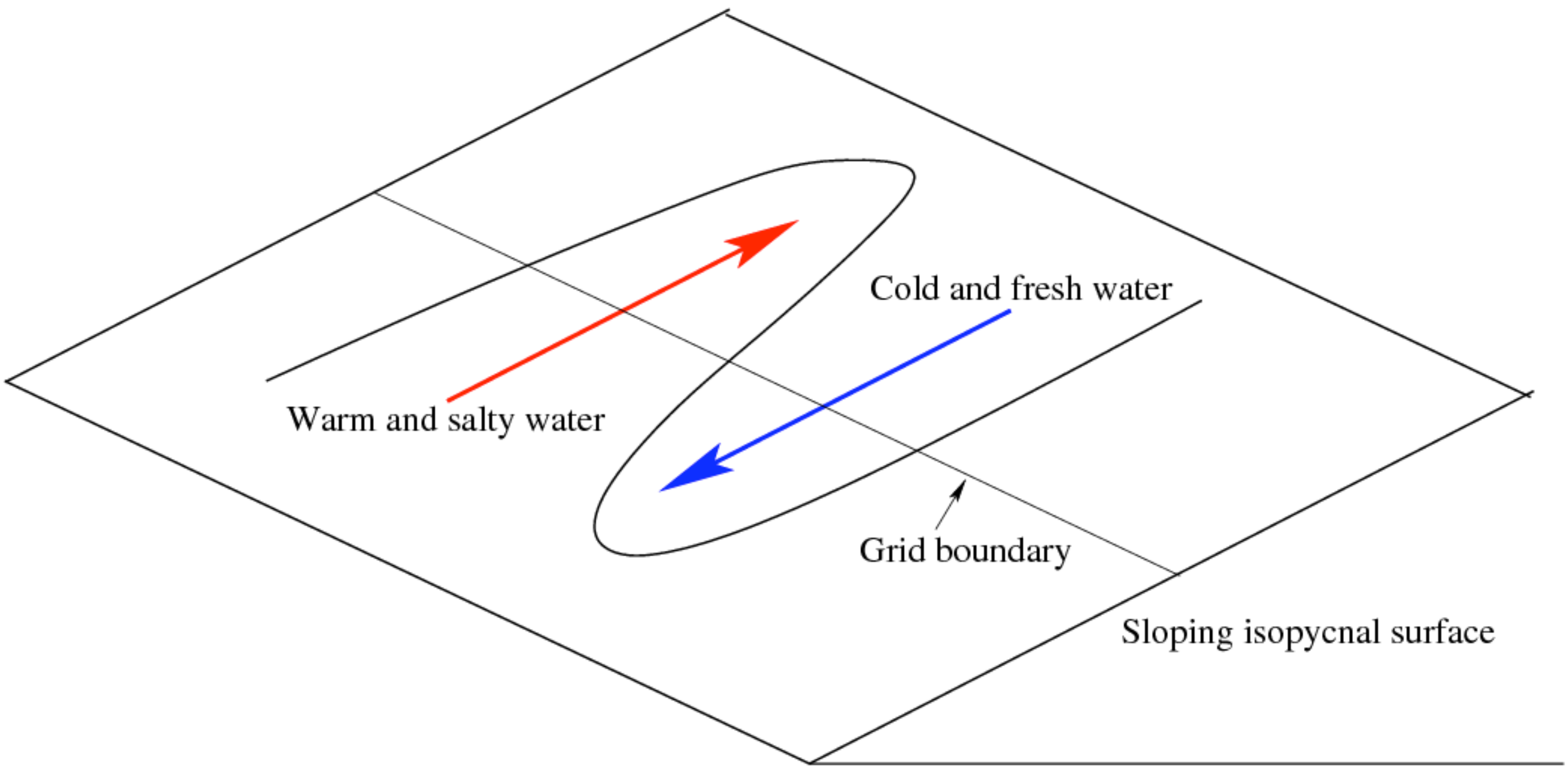
Elasticity on $\sigma_{0.5} = 29.3(kg/m^3)$



Meaning of the high gradient?

Pole-pole difference in Elasticity controls the bottom water formation

On eddy scales: Can perturbations on isopycnal surfaces grow ?

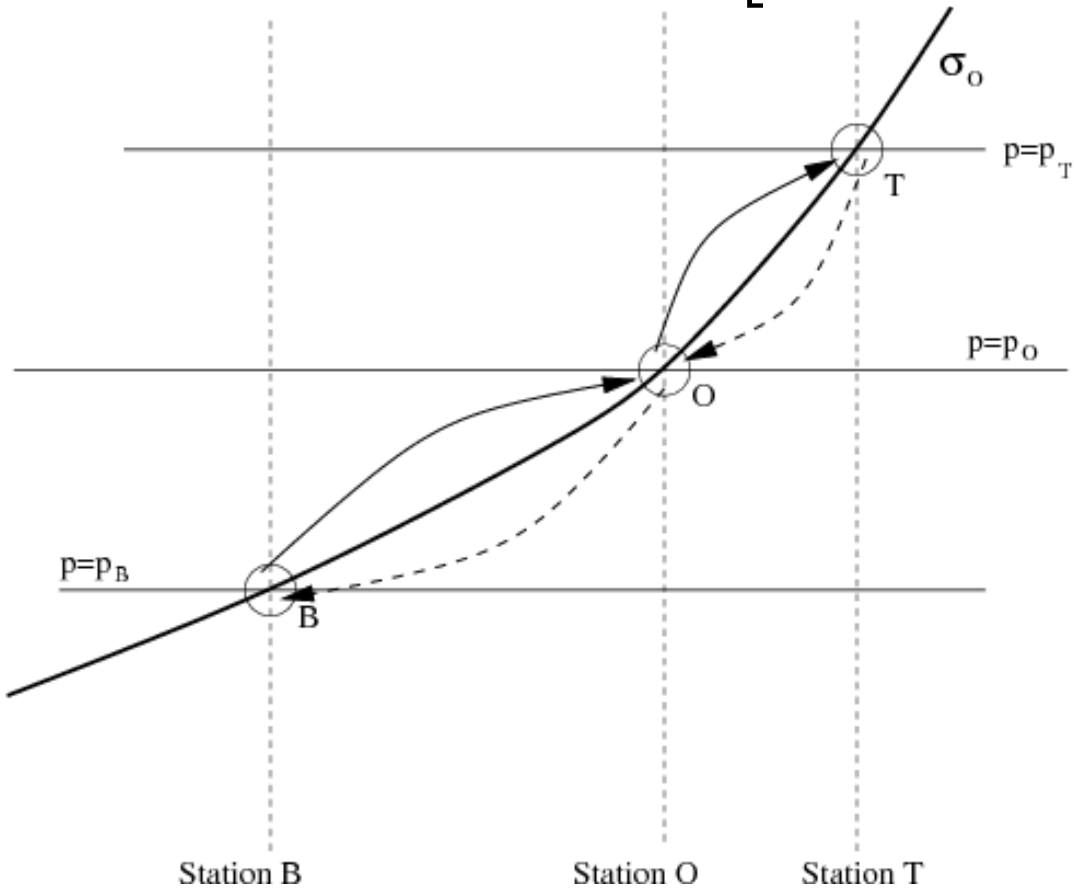


Stirring along isopycnal surface

induces density anomaly and GPE changes

$$\rho(B \to T) - \rho(T) = [E(T,O) - E(B,O)]\,\Delta p / 2000$$

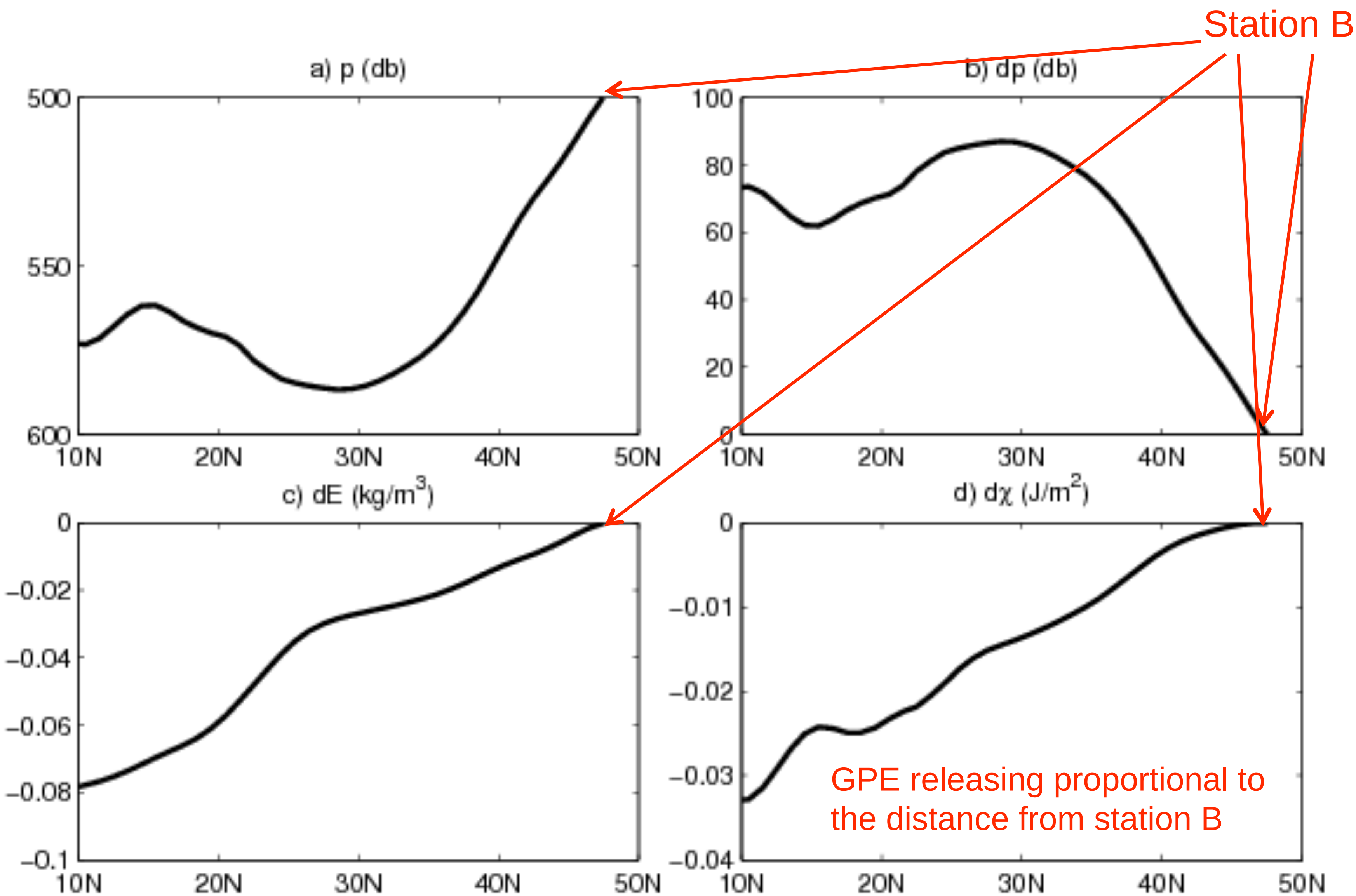
$$\rho(T \to B) - \rho(B) = [E(T,O) - E(B,O)]\,\Delta p / 2000$$



Density anomaly at both stations is non-zero.

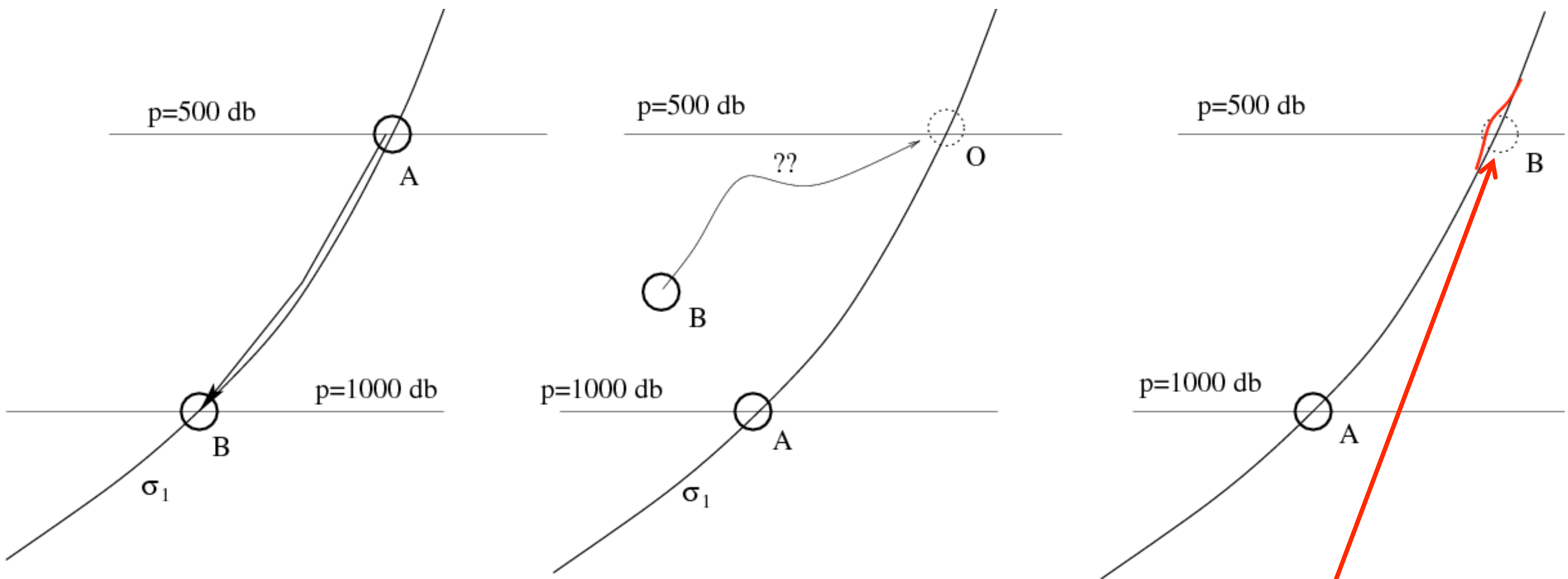
They have the same value

Amplitude of perturbations



Isopycnal exchange is no free lunch

To count GPE changes, at least two parcels should be included

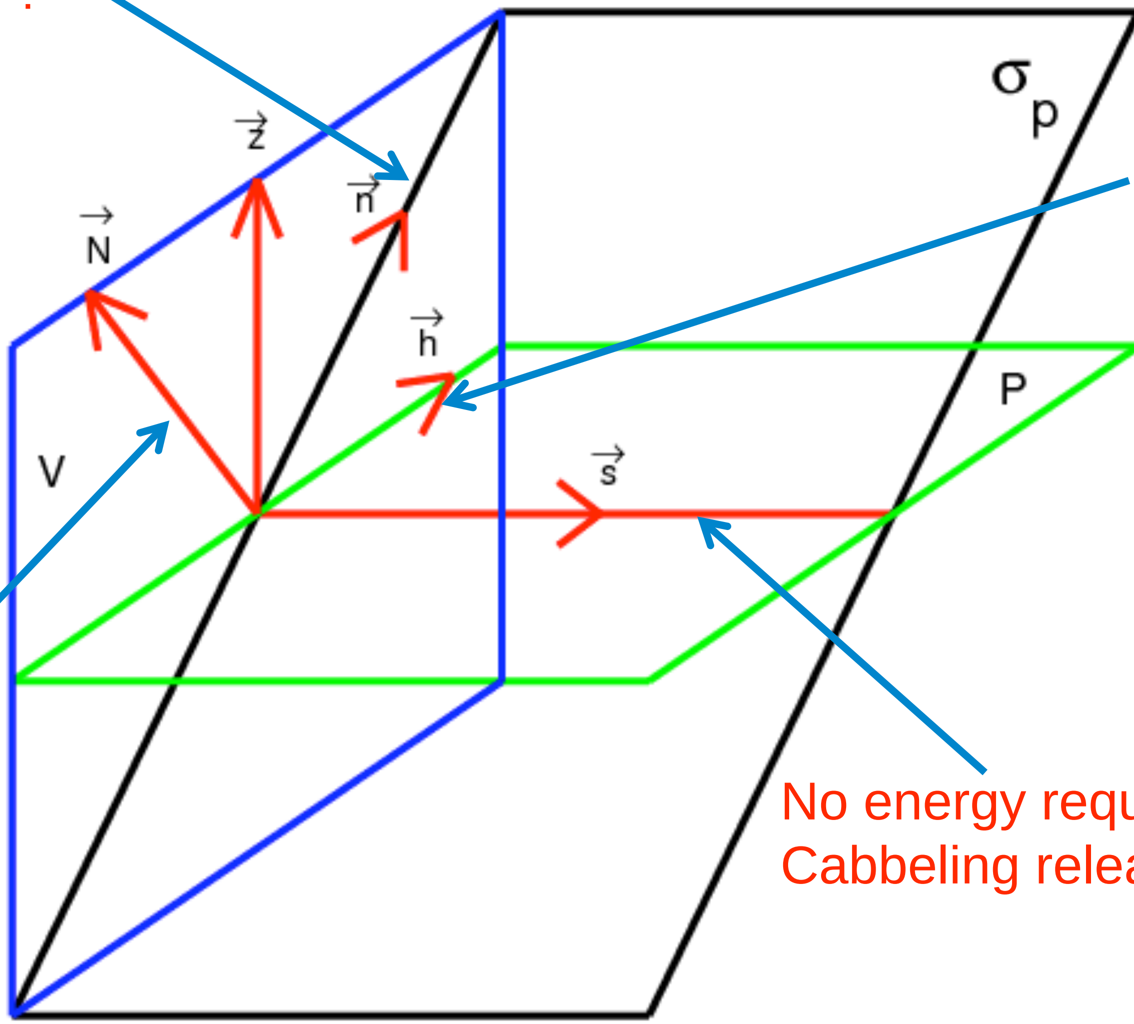


a) Two parcels before switch
b) Parcel positions after moving A
c) Density surface adjusted

Isopycnal surface may be distorted after water parcel exchange

Sketch of three surfaces and basic vectors

No energy required for isopycnal stirring ?



Horizontal diffusion changes GPE

Diapycnal diffusion requires energy for supporting

No energy required for stirring; Cabbeling releases GPE

Optimization of mixing energy for isopycnal mixing

- The optimal wedge of mixing

  It is defined by the potential density surface and the adiabatic density surface

- Within the mixing wedge, the mixing energy is optimized:

  1) When energy is released, it is maximal

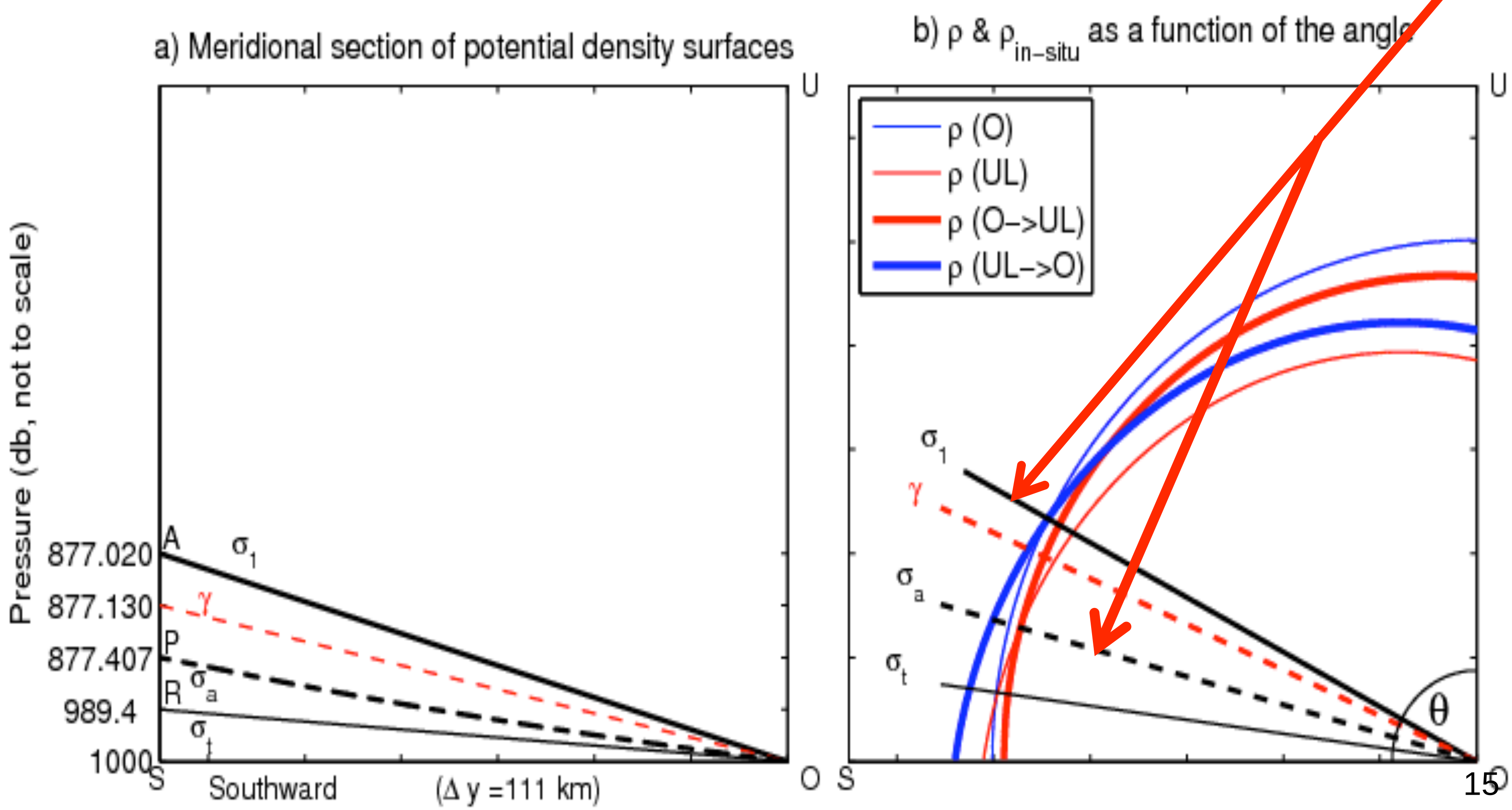
  2) When energy is required, it is minimal

- Using the mean local isopycnal slope is adequate for isopycnal mixing

A meridional section through 30.5ºW at 49.5ºS and 48.5ºS

(WOA01)

Within this wedge, GPE is released after exchange

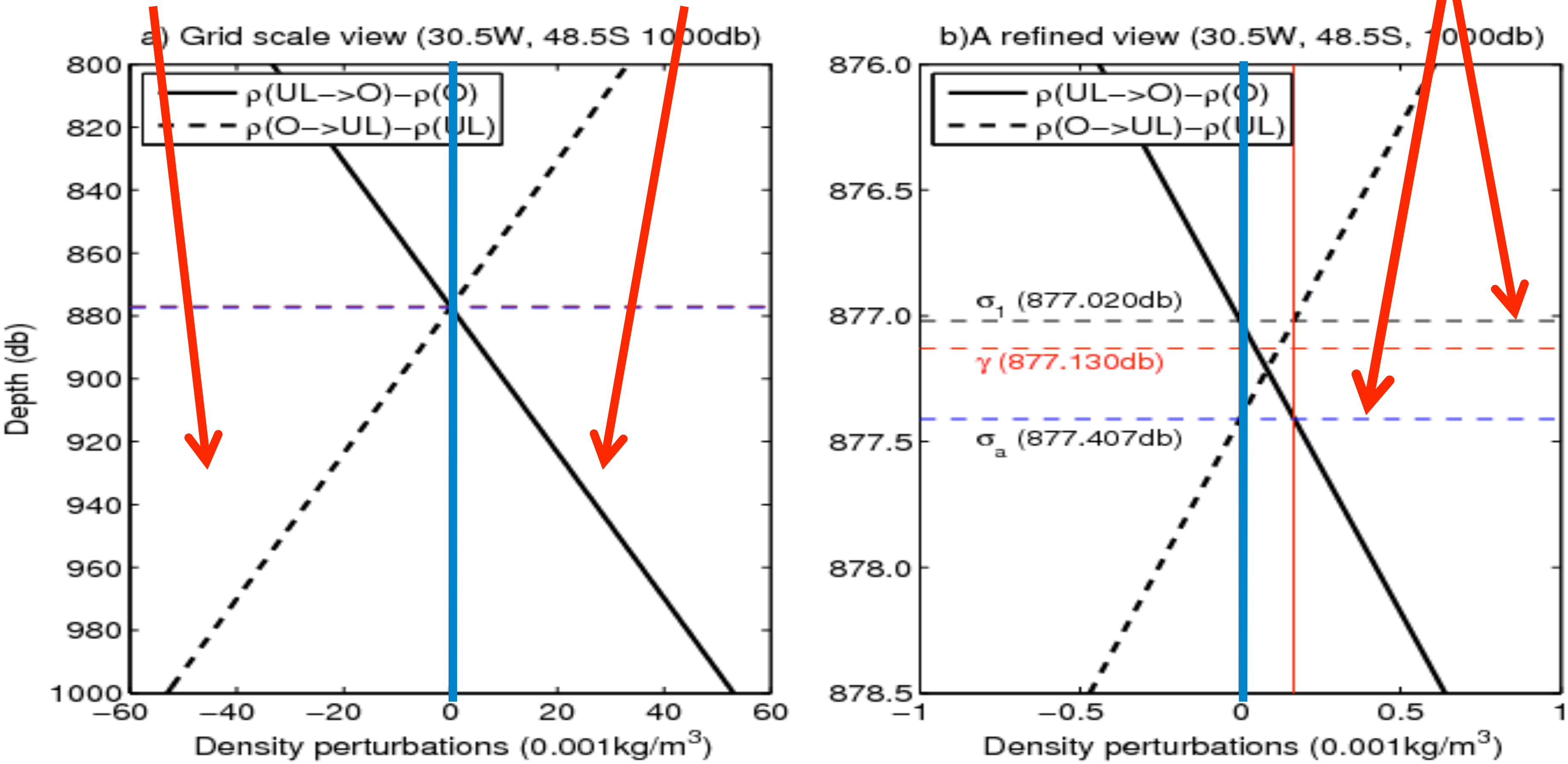


A meridional section through 30.5°W at 49.5°S and 48.5°S

Density declines
→GPE is increased

Density increases
→GPE is released

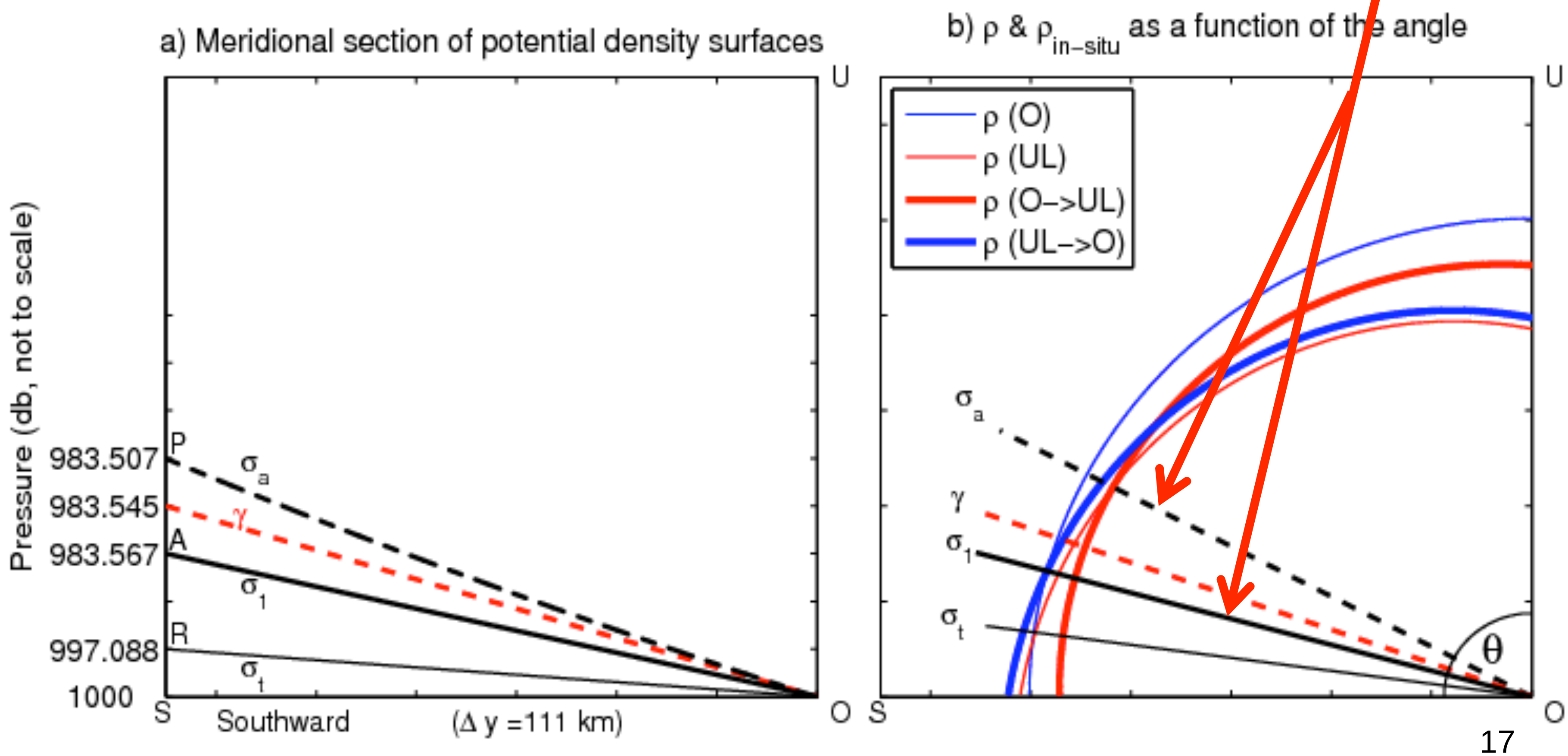
Within this wedge, GPE is
released after exchange



A **meridional section through 149.5^{o}E at 19.5^{o}N and 20.5^{o}N**

(WOA01)

Within this wedge, GPE is increased after exchange
→mechanical energy is required for supporting

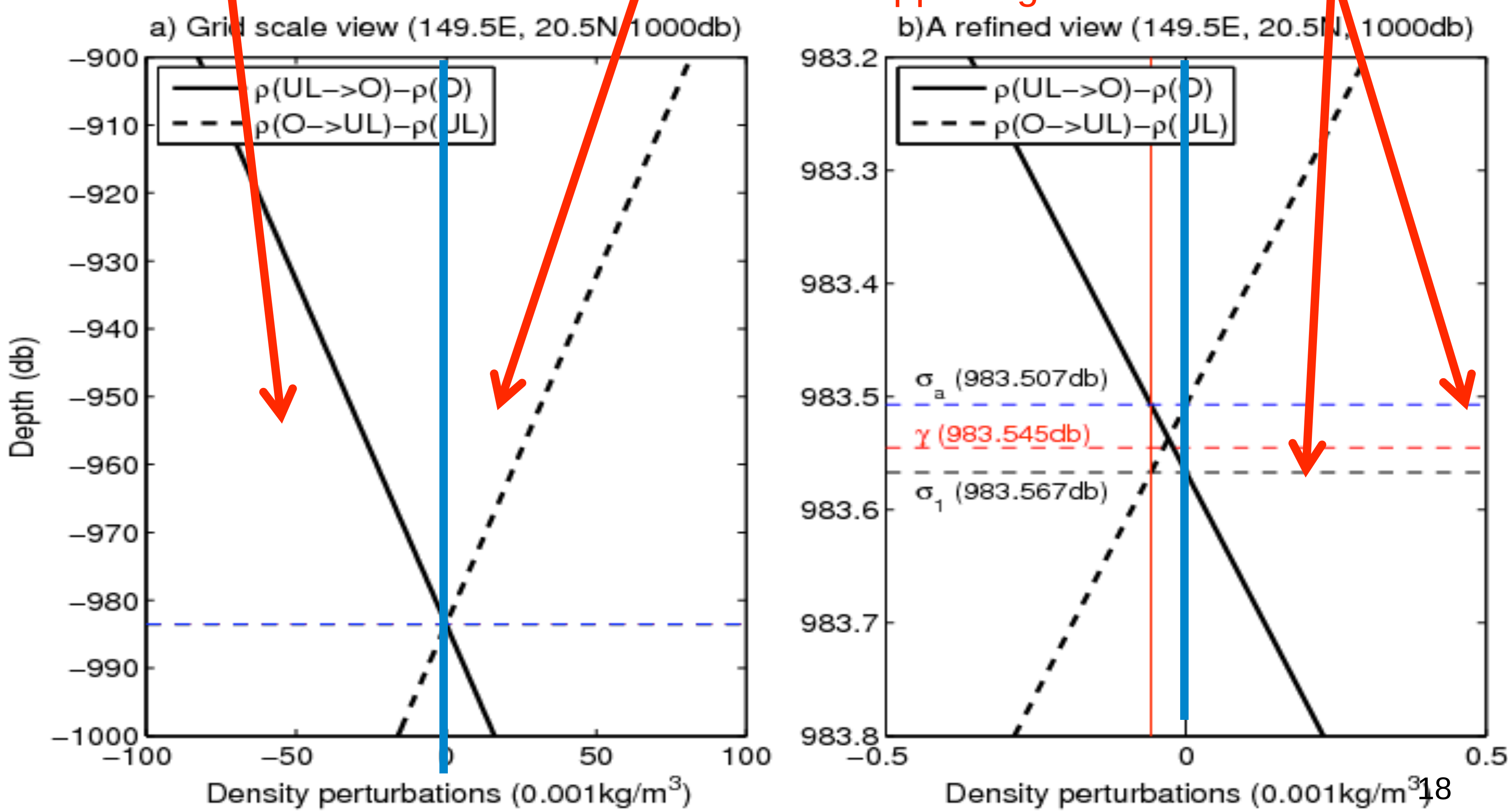


A **meridional section through 149.5ºE at 19.5ºN and 20.5ºN**

Density declines
→GPE is increased

Density increases
→GPE is released

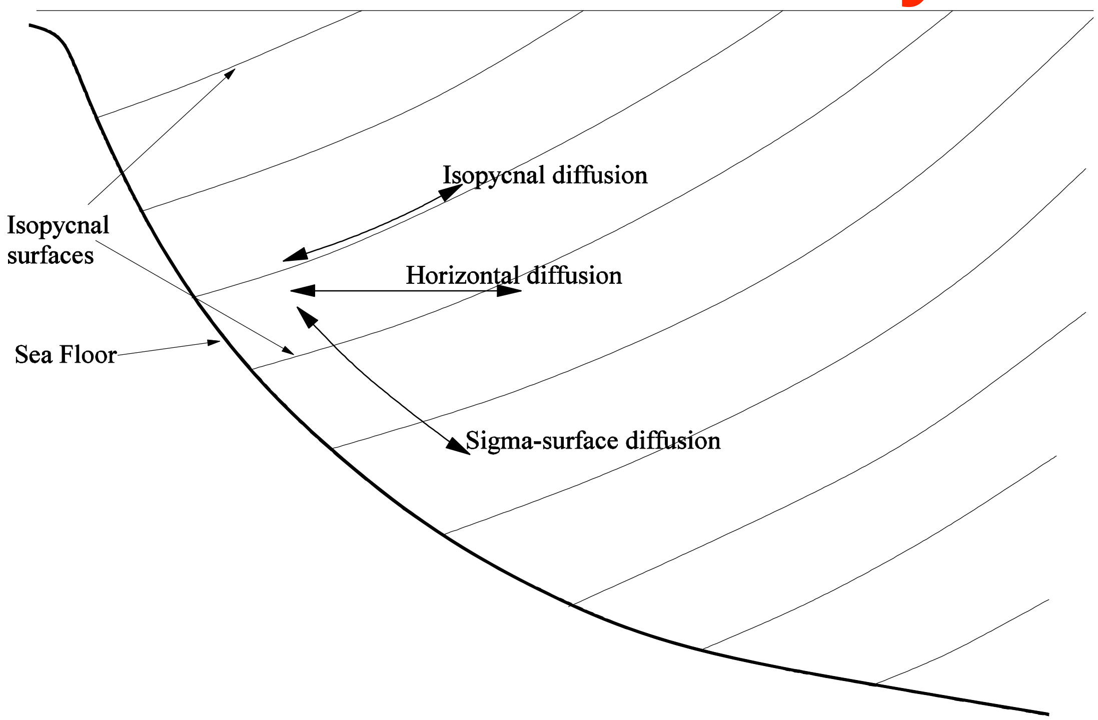
Within this wedge, GPE is increased after exchange
→mechanical energy is required for supporting



Energy source/sink associated with eddy diffusion

- Energy released during diffusion cannot be very efficiently used to sustaining diffusion when energy is required.
- For the station at (30.5W, 48.5S), exchange within this wedge leads to release of GPE (self energized).
- Exchanging outside this wedge requires mechanical energy for supporting.
- Isopycnal surface can be treated as the surface where “horizontal stirring” requires the least amount of GPE, so it is the preferred surface for “horizontal diffusion”.

Isopycnal, horizontal and sigma-surface eddy diffusion

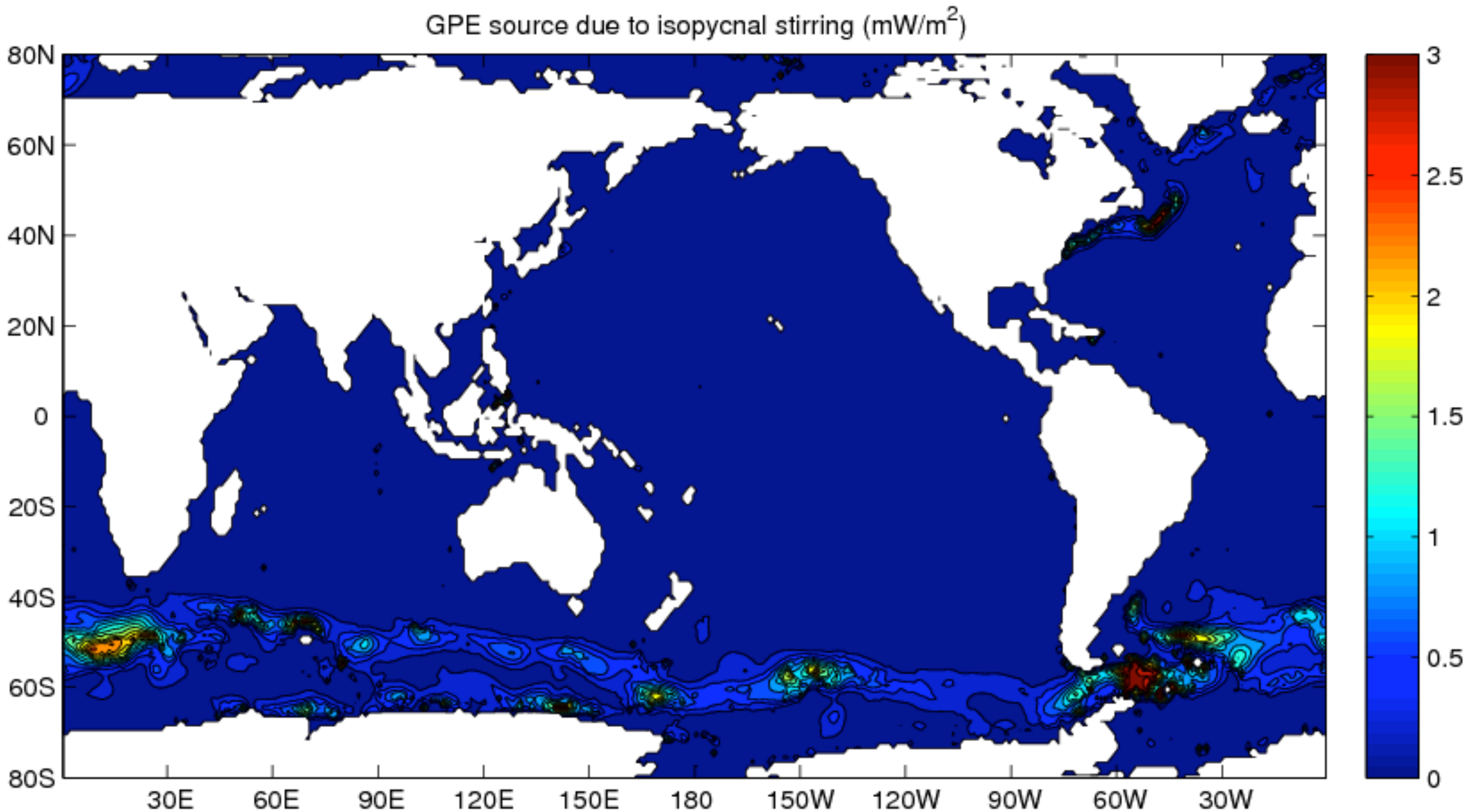


GPE source/sink (TW)

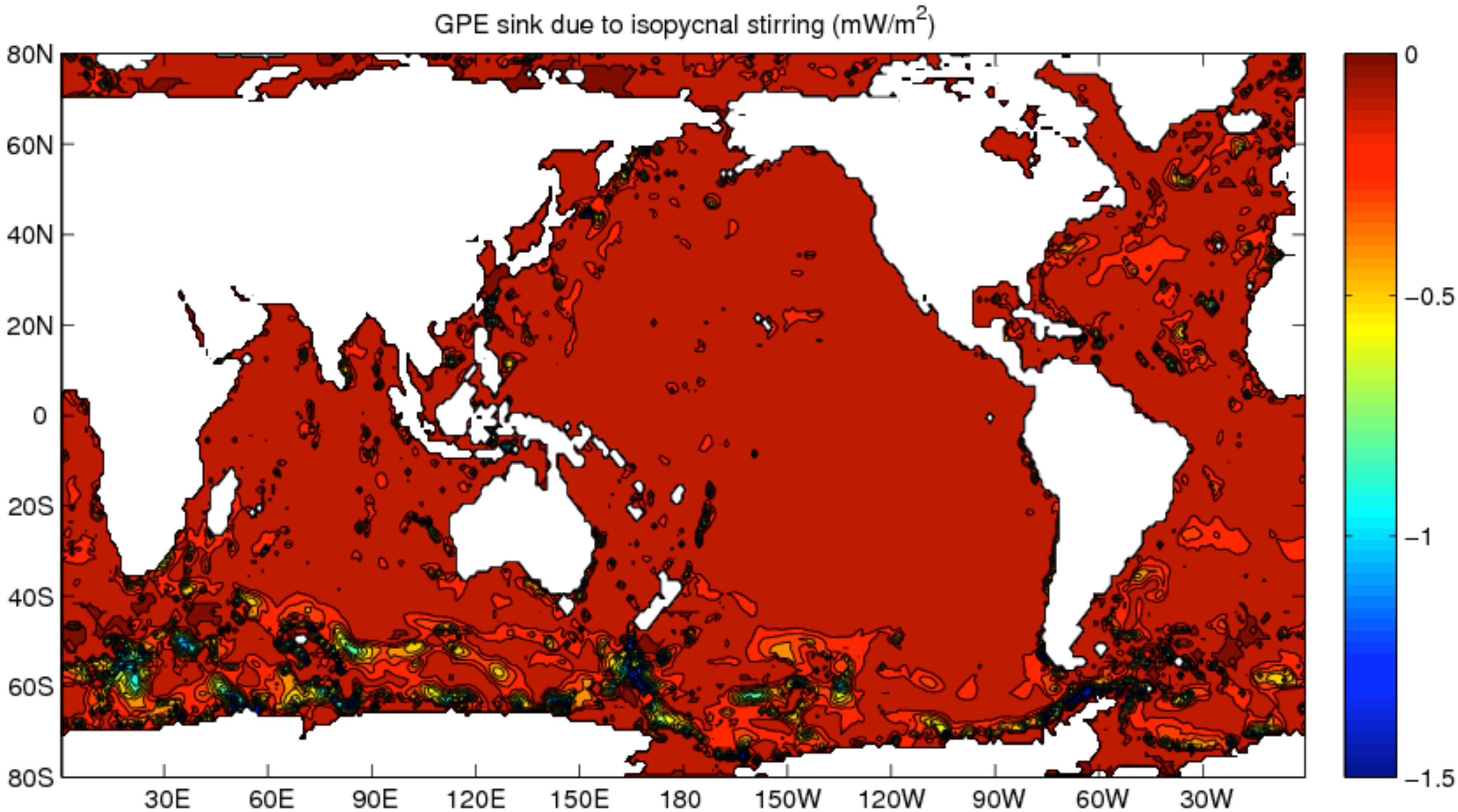
Sink means perturbations are locally seft-energized

Type of eddy diffusion	Stirring		cabbeling due to mixing	Sum of the absolute values
	Source	Sink	Sink	
Horizontal	3.8	-3.8	-0.21	7.8 ?
Sigma	150	-58	-17	225 ??
Isopycnal	0.031	0.025	-0.052	0.108

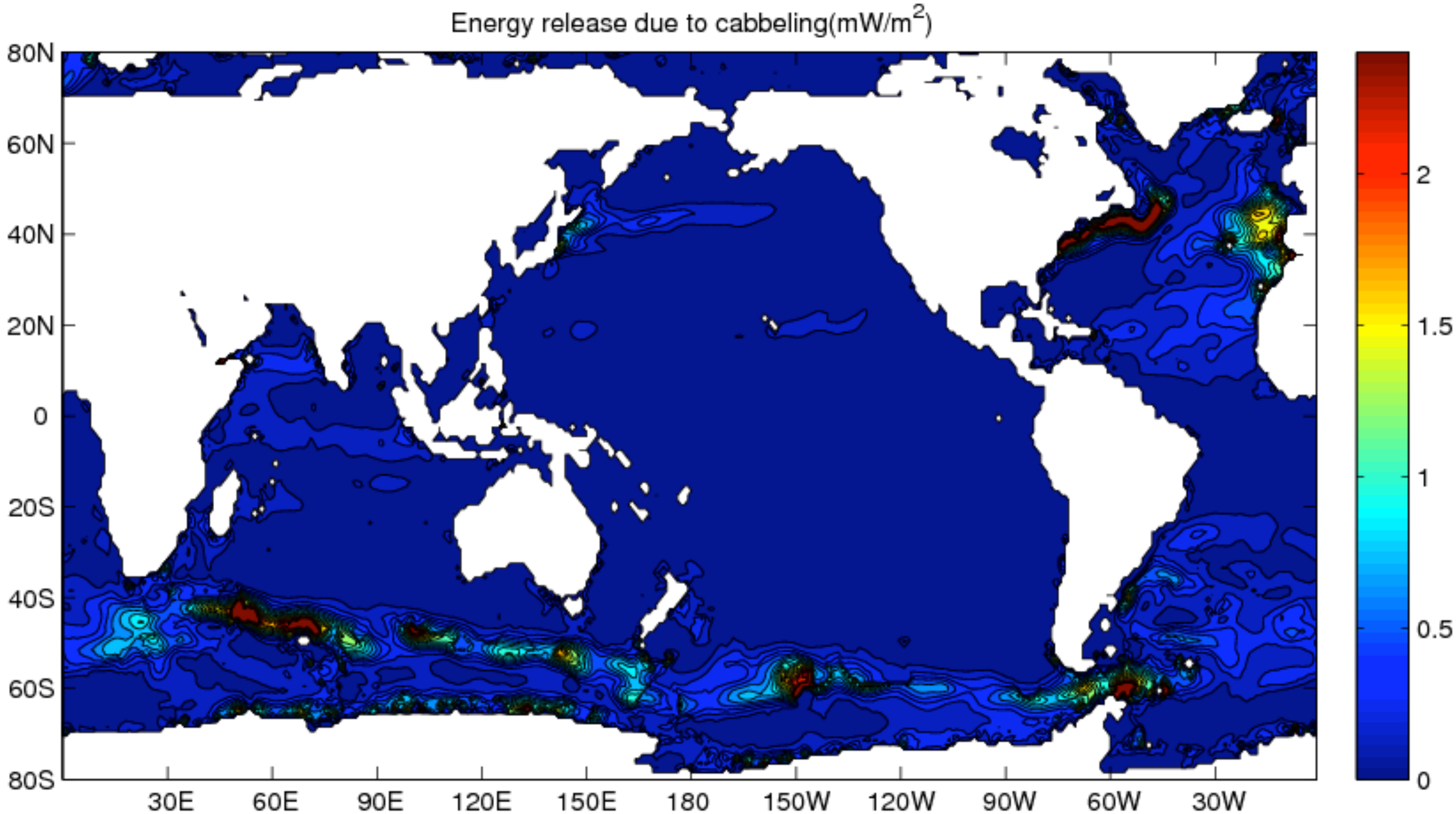
GPE source due to isopycnal stirring (stirring takes external energy)



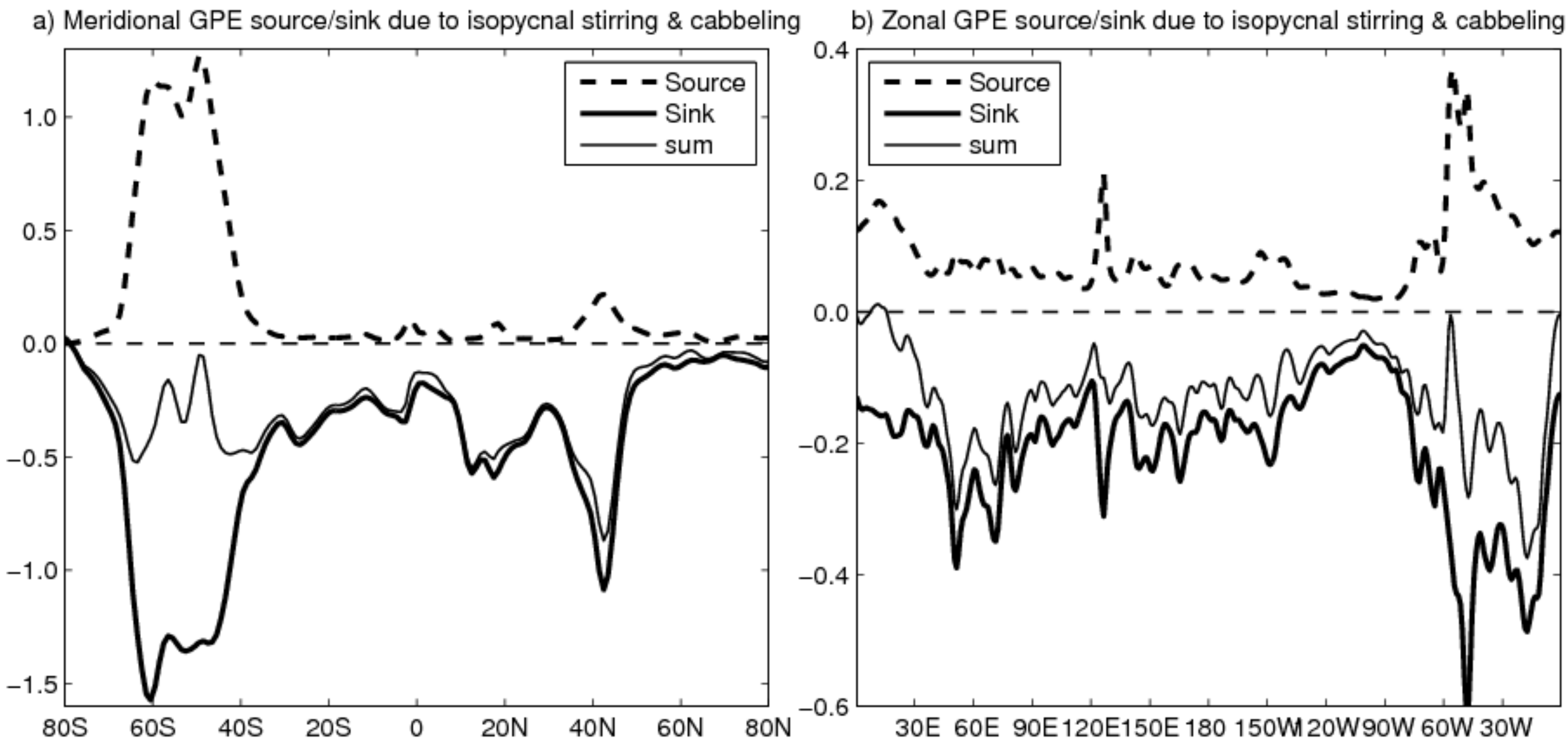
GPE sink due to isopycnal stirring (stirring is self-energized)



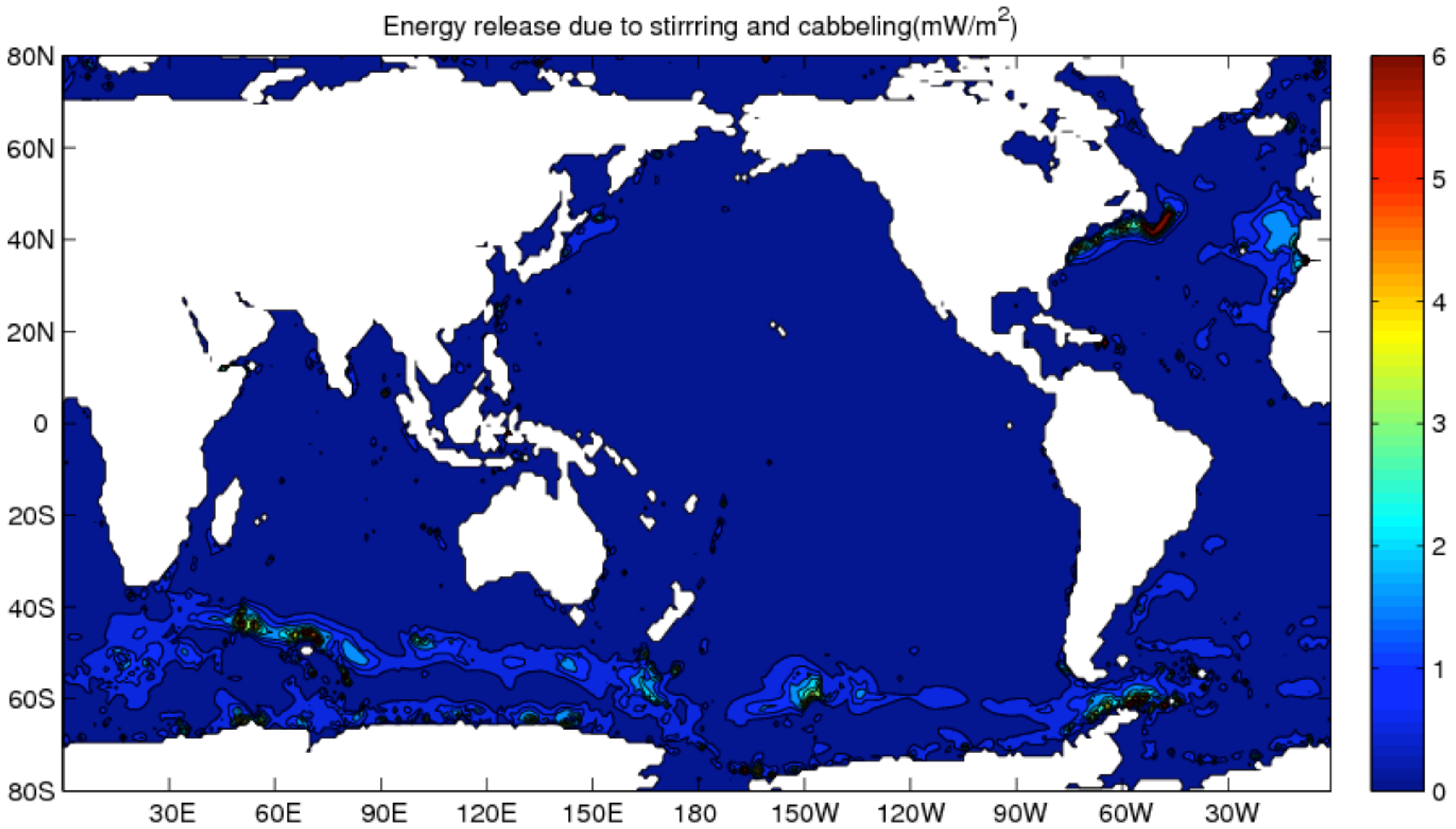
GPE sink due to cabbeling in connection with isopycnal mixing



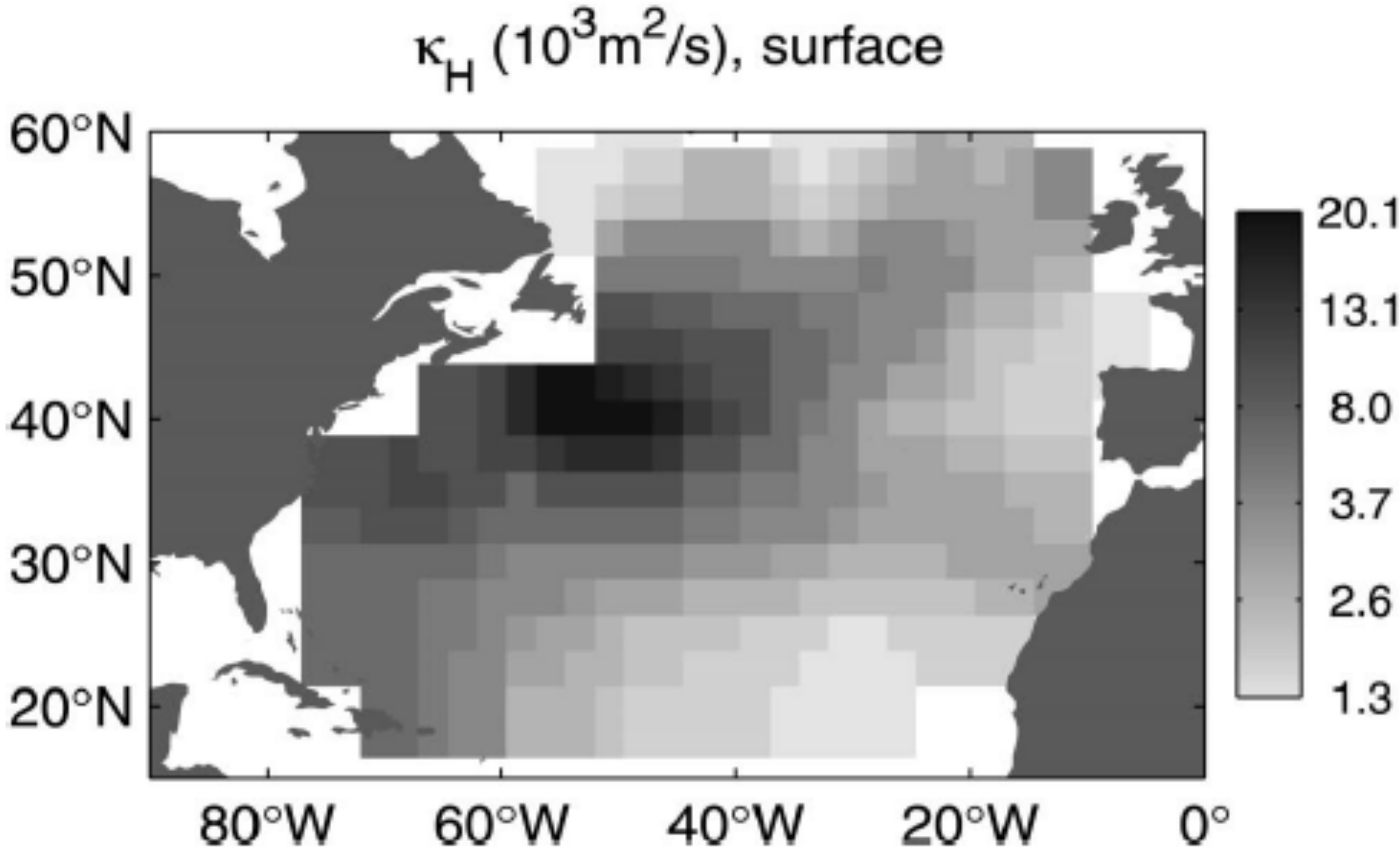
Net GPE source & sink due to isopycnal stirring/mixing



GPE sink due to isopycnal stirring and cabbeling

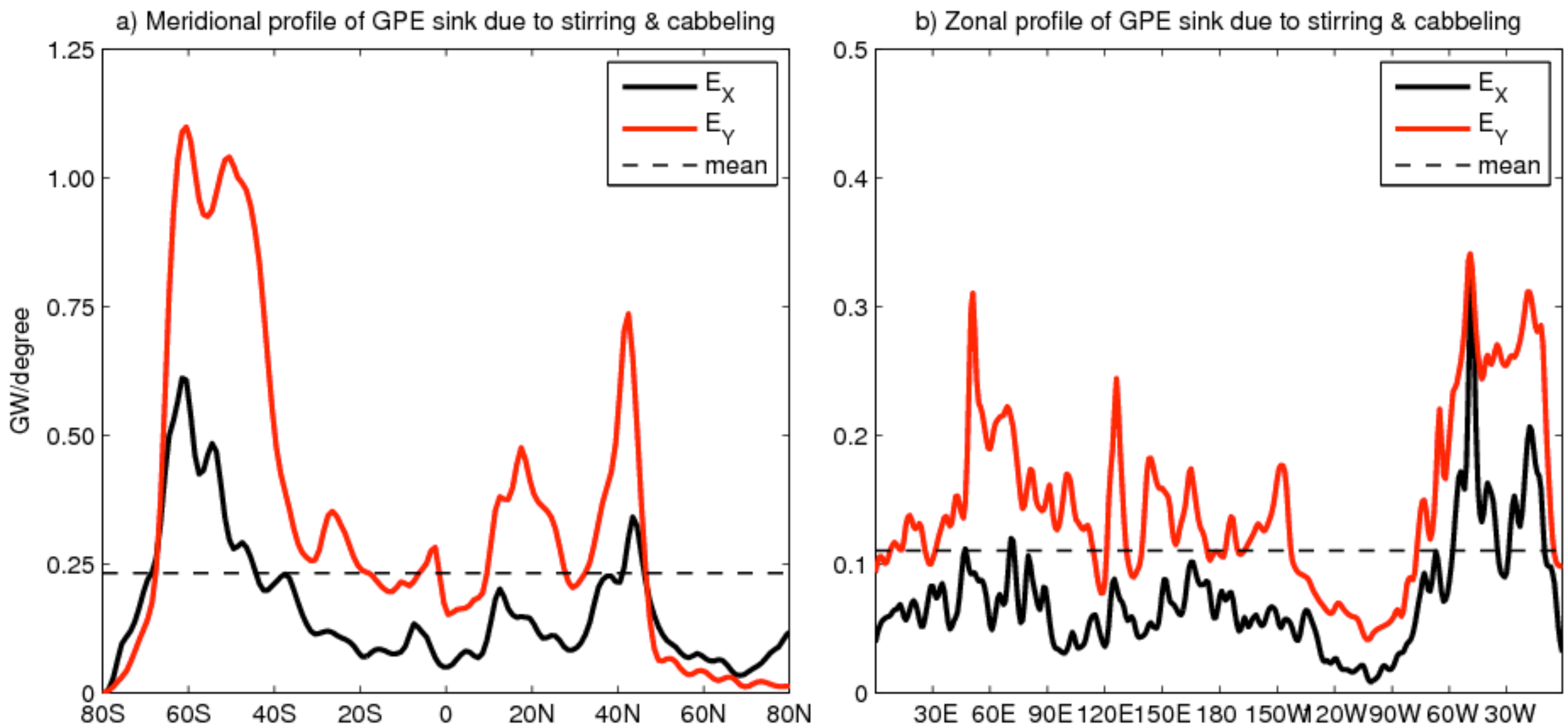


Eddy diffusivity inferred from drifter trajectories (Lumpkin et al., 2002)



GPE sink due to isopycnal stirring/cabbeling

Diffusion is not homogeneous or isotropic



Conclusion

- Quasi-horizontal tracer diffusion changes GPE:

  1) Isopycnal surface diffusion may be the best choice. Diffusion is non-uniform and an-isotropic

  2) Horizontal diffusion is no good, sigma surface diffusion is completely non-physical
- Thermohaline perturbations on isopycnal surfaces may grow with energy released from mean state --- this is a new type of instability.
- Our analysis may suggest where to observe such instability.