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COURSE ON CLIMATE VARIABILITY STUDIES IN THE OCEAN
"Tracing & Modelling the Ocean Variability"
16 - 27 June 2003

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Tracing and Modelling the Ocean Variability -II

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Tracing and modeling ocean variability

ICTP – June 2003

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variability {
- Ocean's 'weather'
- Geostrophic eddies

Discuss:

1. Eddies: are they important for climate?

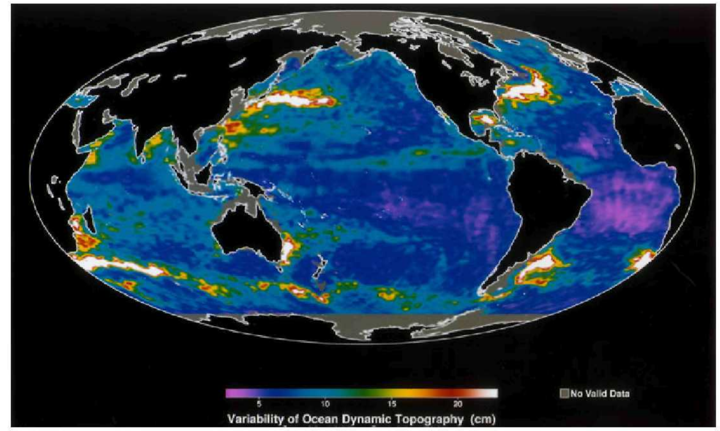
2. Eddies and their role in setting structure of thermocline, mixing….

Eddies, mixing and large-scale ocean circulation

1. Role of geostrophic eddies in diabatic processes

2. Maintenance of the thermocline in a turbulent ocean

1 Eddies and diabatic processes



Eulerian mean

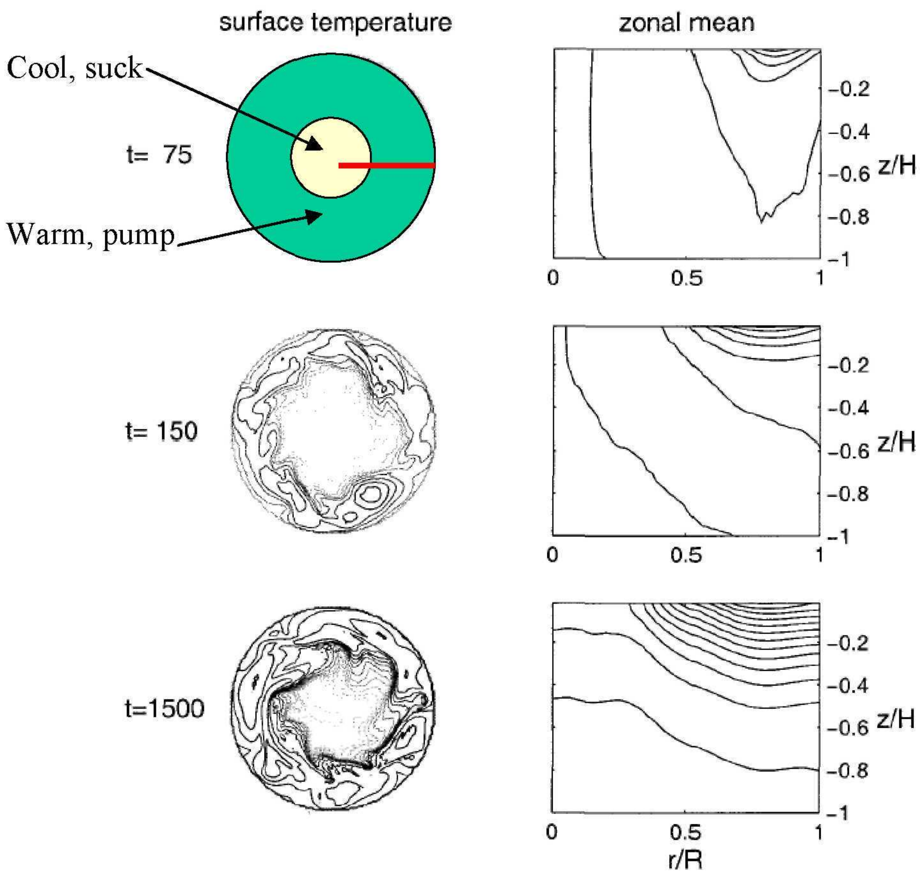
$$\overline{\mathbf{v}} \cdot \nabla \overline{b} = \frac{\partial}{\partial z}\left(k_v \frac{\partial \overline{b}}{\partial z}\right) - \nabla \cdot \left(\overline{\mathbf{v}'b'}\right)$$

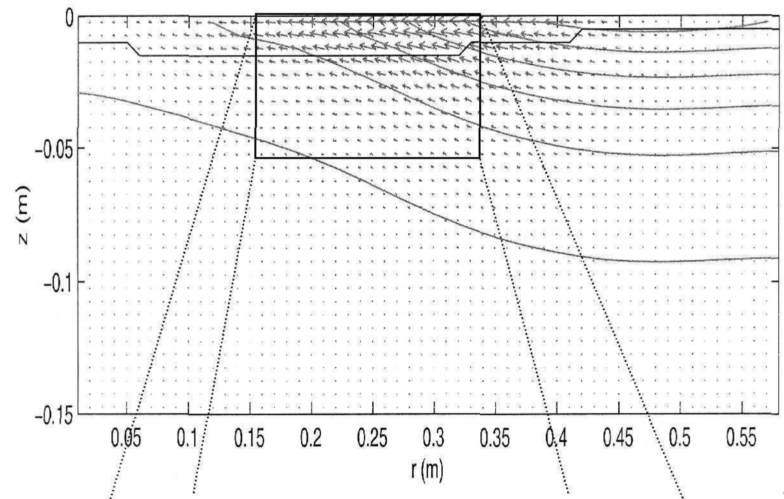
usually ignored because

- eddy fluxes are only large in boundary currents and jets. $\nabla \cdot \left(\overline{\mathbf{v}'b'}\right) \rightarrow 0$ over most of ocean most of the time.
- eddy fluxes are adiabatic anyway, aren't they? $\nabla \cdot \left(\overline{\mathbf{v}'b'}\right)$ can then be written entirely as an *advective* flux.

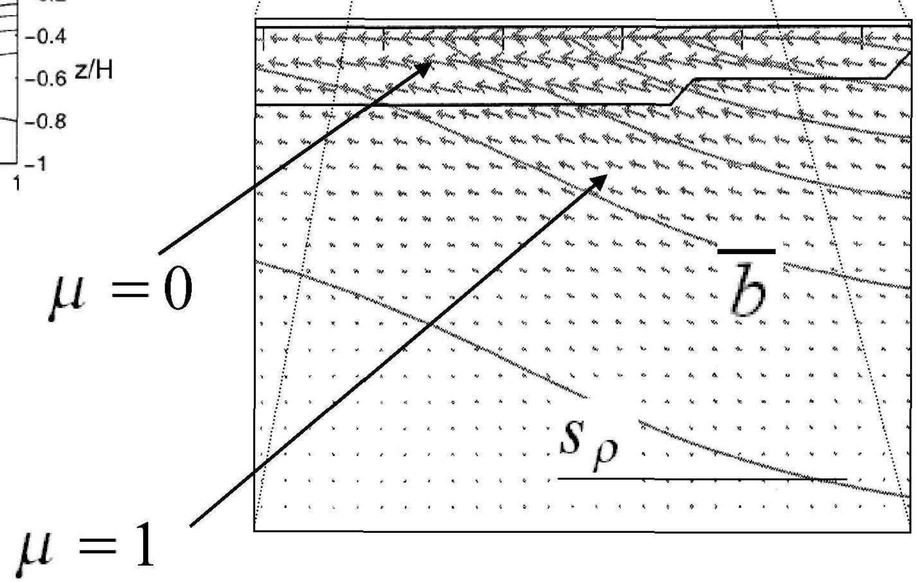
Diapycnal eddy fluxes

Karsten and Marshall, 2002



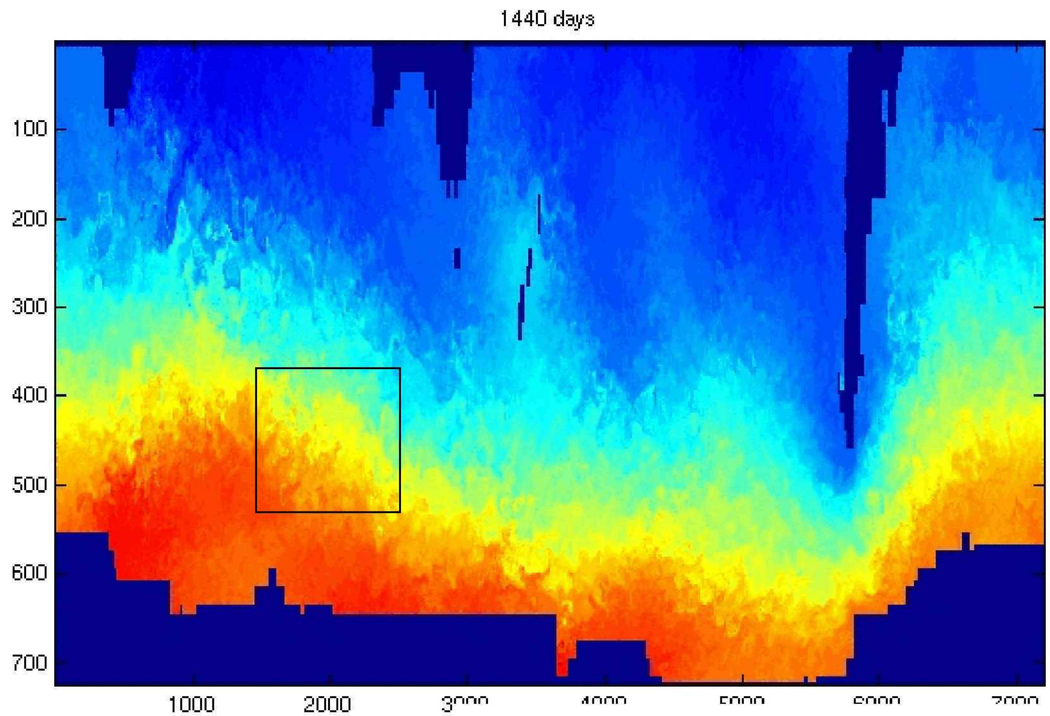


$$\overline{\mathbf{v}'b'} = (\overline{v'b'}, \overline{w'b'})$$

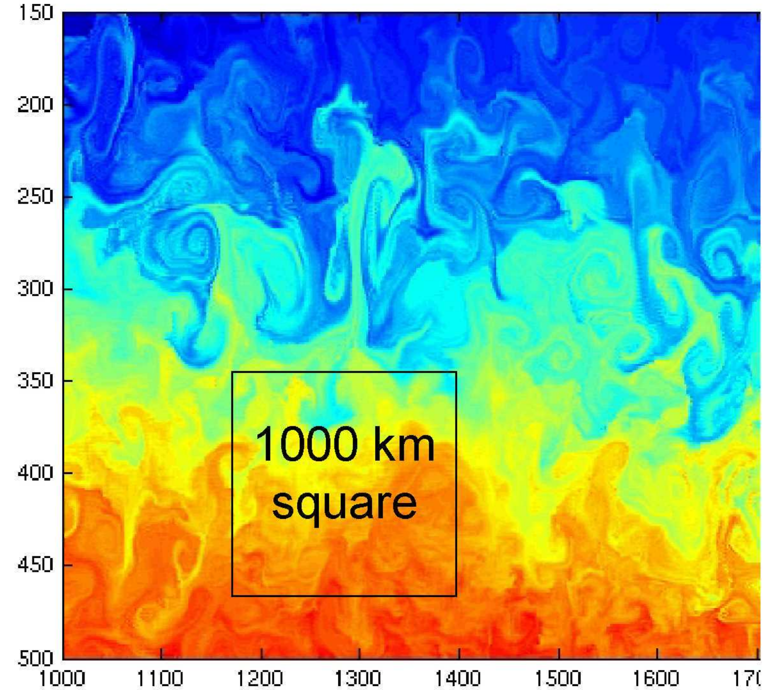


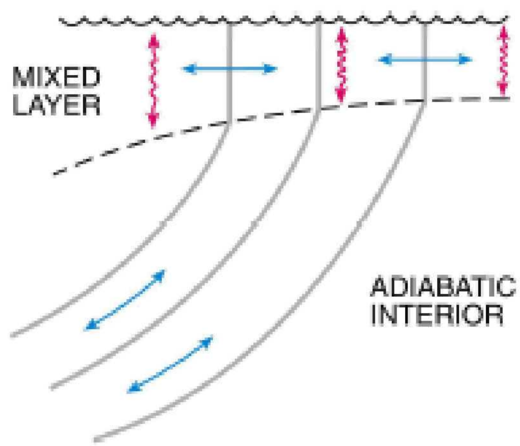
$$\mu = \left(\frac{\overline{w'b'}}{\overline{v'b'}} \right) \left(\frac{1}{s_\rho} \right)$$

Evolution of passive tracer

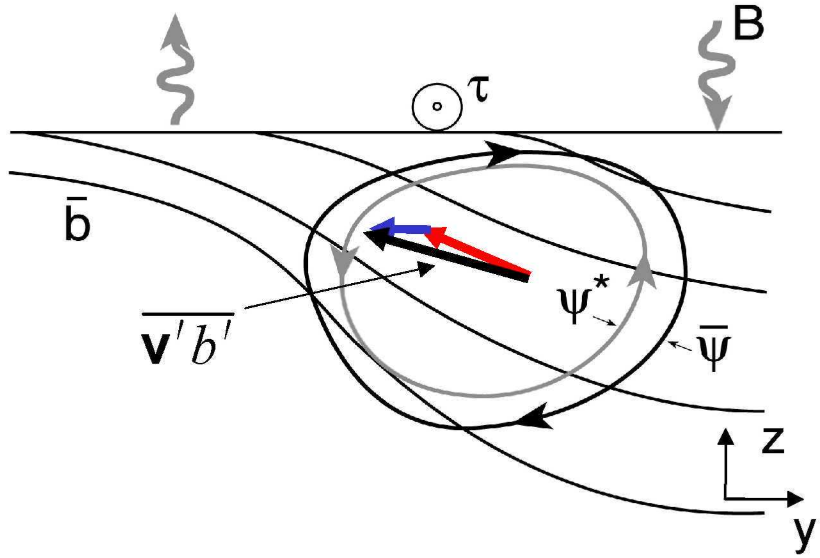


Idealized tracer driven by surface currents in ACC





Residual mean



$$\mathbf{v}_R \cdot \nabla \overline{b} = \frac{\partial}{\partial z}\left(k_v \frac{\partial \overline{b}}{\partial z}\right) - (1-\mu)\nabla \cdot \left(\overline{\mathbf{v}'_h b'}\right)$$

where $\mathbf{v}_R = \overline{\mathbf{v}} + \mathbf{v}^*$

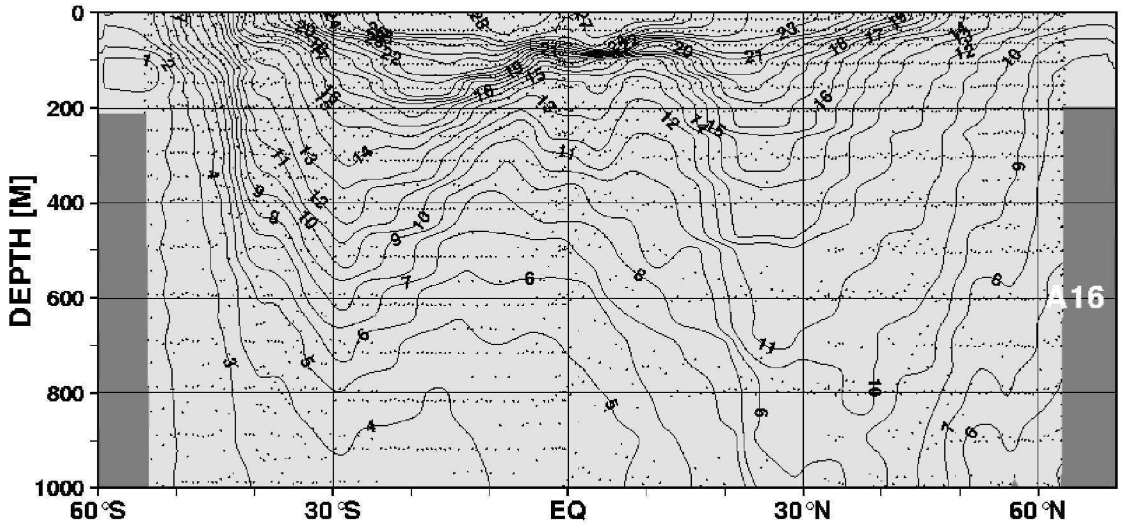
Diapycnal eddy flux

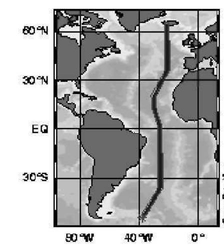
Diabatic parameter

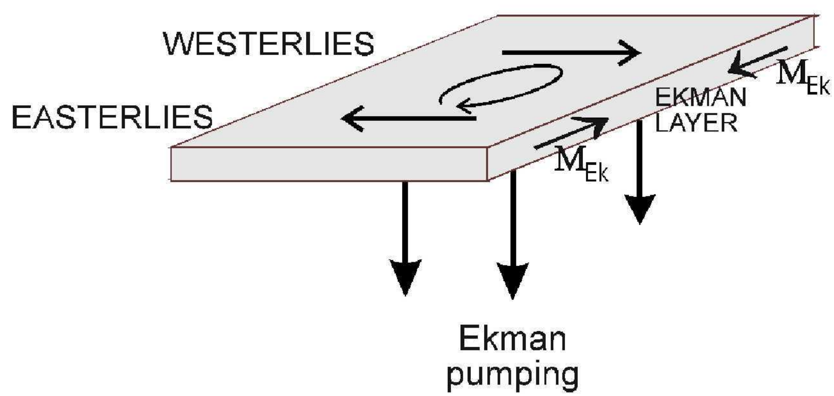
Held & Schneider

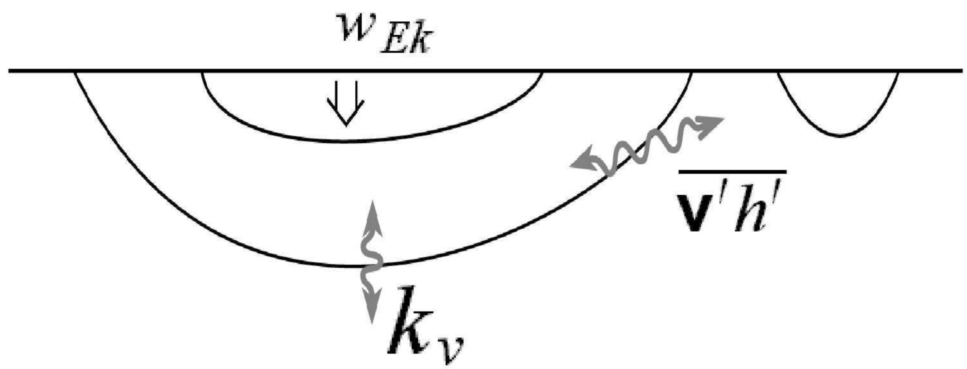
2

Maintenance of the thermocline









Prevailing view:

heat gets diffused away by 'small-scale' mixing

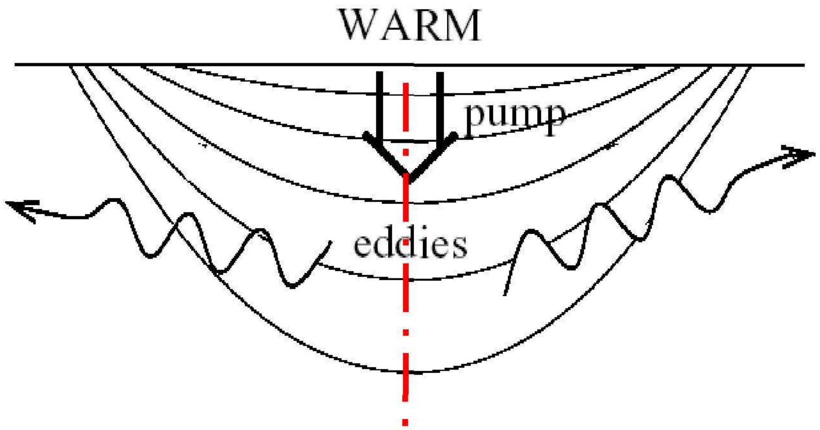
Alternative hypothesis:

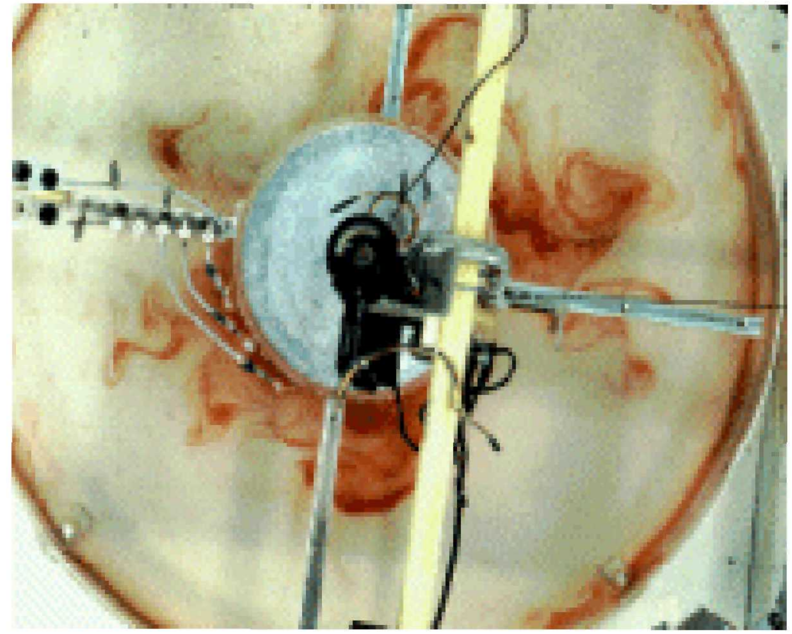
eddies play a central diabatic role, fluxing heat laterally

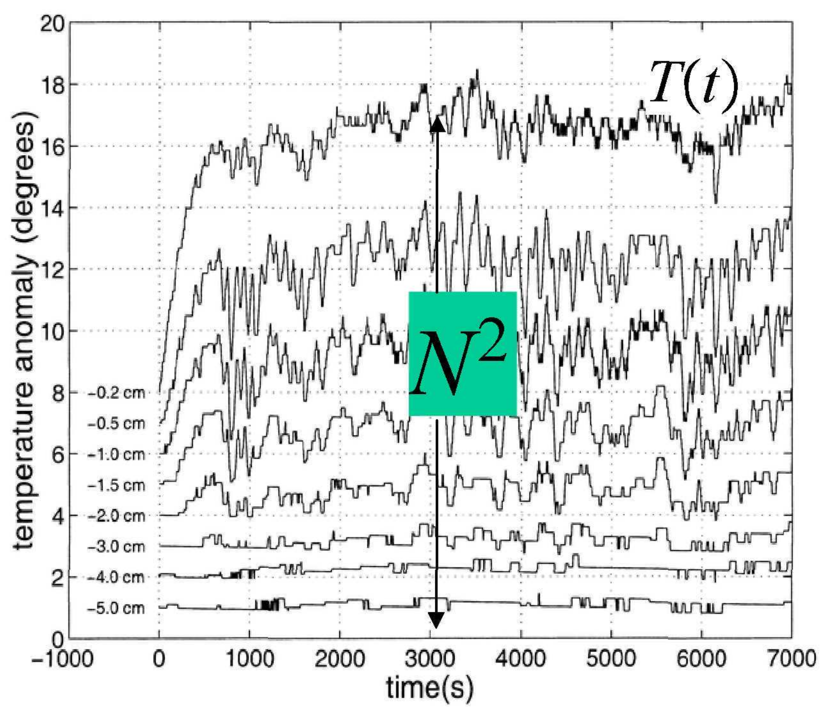
Laboratory abstraction:

warm pumped lenses

'f'-plane







Marshall et al. (2002)

Theory

$$Q = 2\pi r_o \overline{v'h'}$$

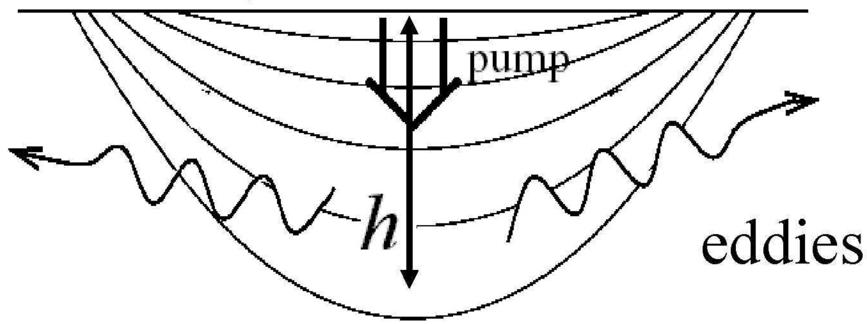
$$\overline{v'h'} = cuh$$

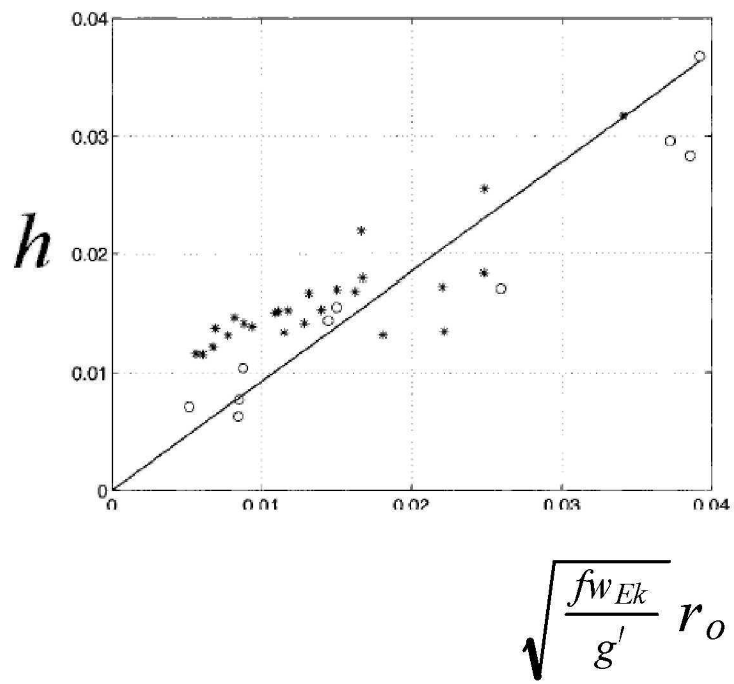
$$u = \frac{g'h}{fr_o}$$

$$h \sim \sqrt{\frac{f w_{Ek}}{g'}}\, r_o$$

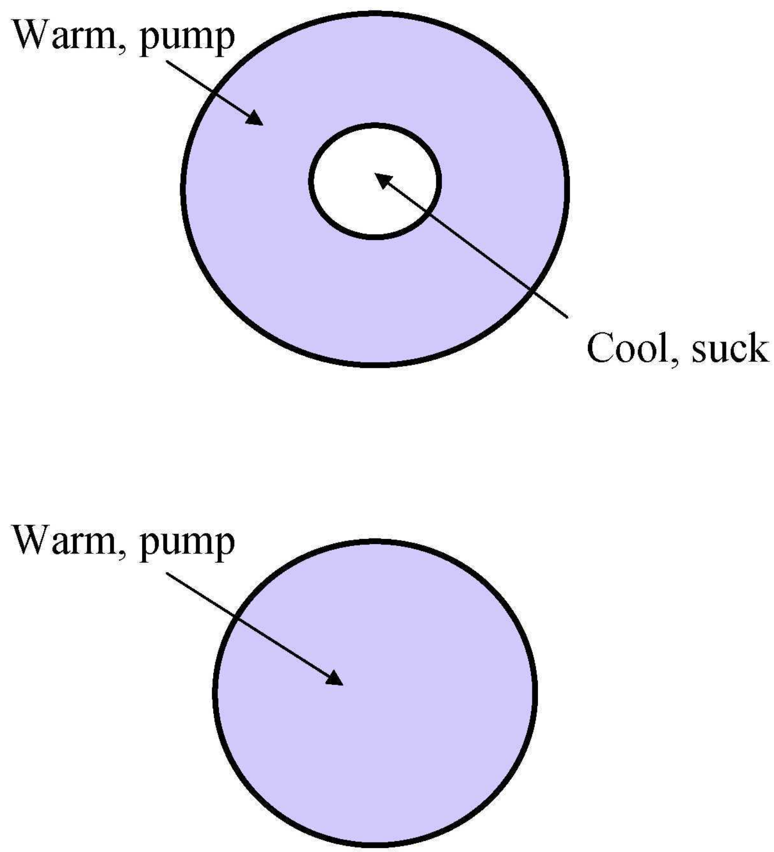
$$u \sim \sqrt{\frac{g' w_{Ek}}{f}}$$

$$Q = \pi r_o^2 w_{Ek}$$

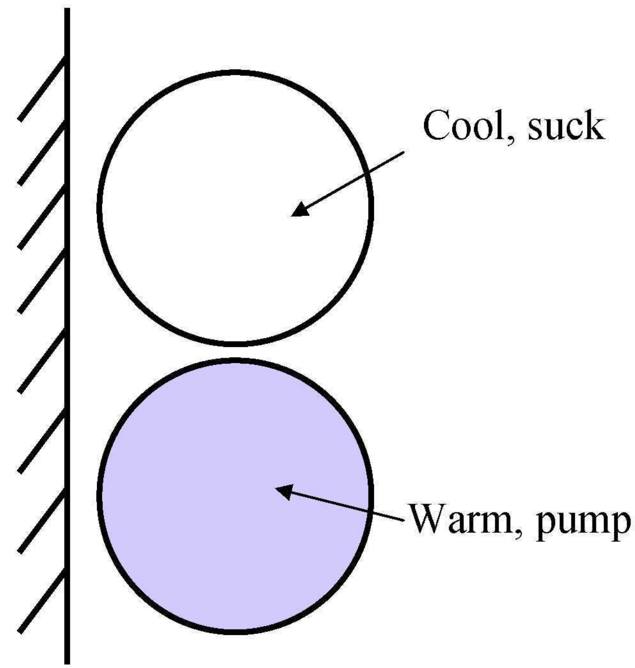




Variations on the theme



‘f’-plane



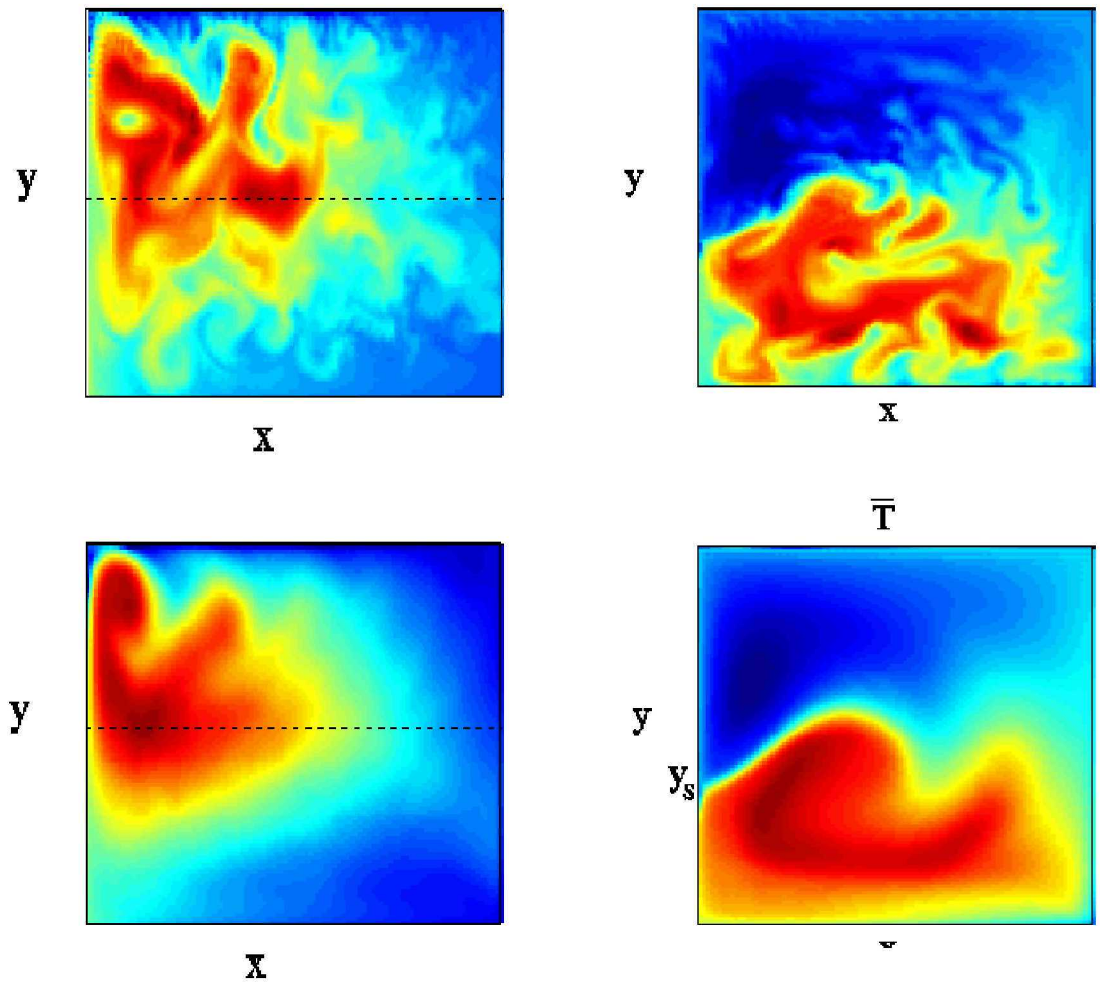
β -plane gyres

β -plane gyres

In collaboration with
Timour Radko

Single

Double



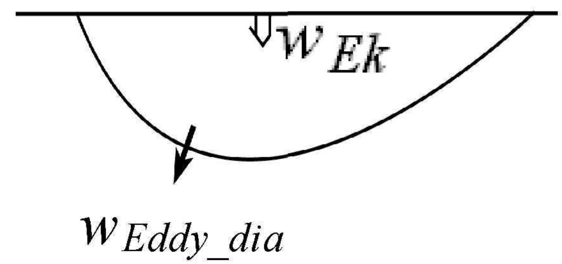
Diagnostic framework

Buoyancy

$$\nabla . (\mathbf{v}\,\overline{b}) = D_{Eddy} + D_{smallscale}$$

where

$$D_{Eddy} = -\nabla . \left(\overline{\mathbf{v}' b'}\right)$$



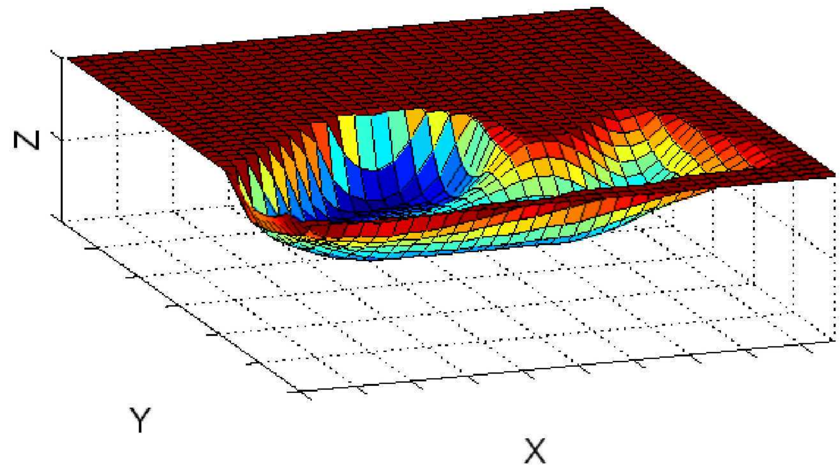
Define

$$w_{Eddy\_dia} = \frac{D_{Eddy}}{\overline{b}_z}$$

Evaluate

$$\alpha = \frac{w_{Eddy\_dia}}{w_{Ek}}$$

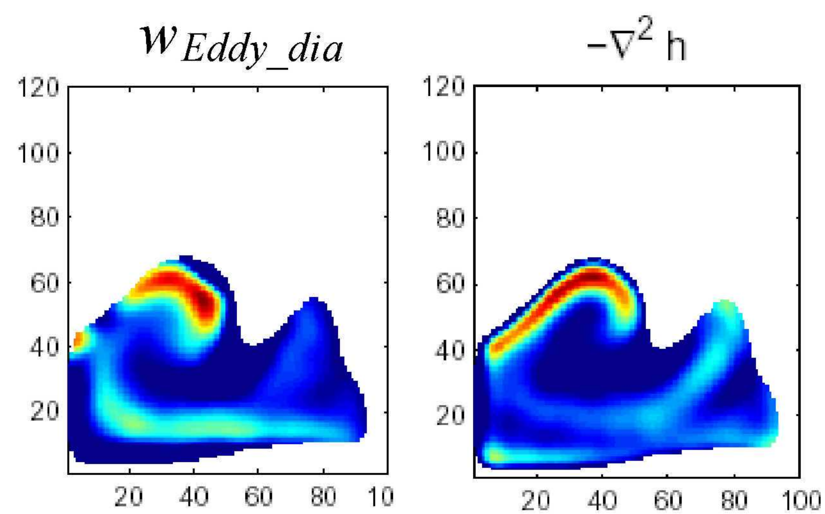
How is the volume balanced?



$$\alpha = \frac{w_{Eddy\_dia}}{w_{Ek}}$$

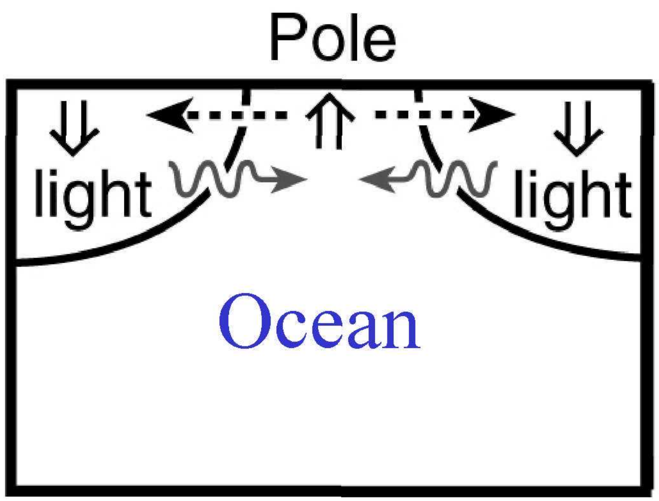
$$\alpha = 0.87$$

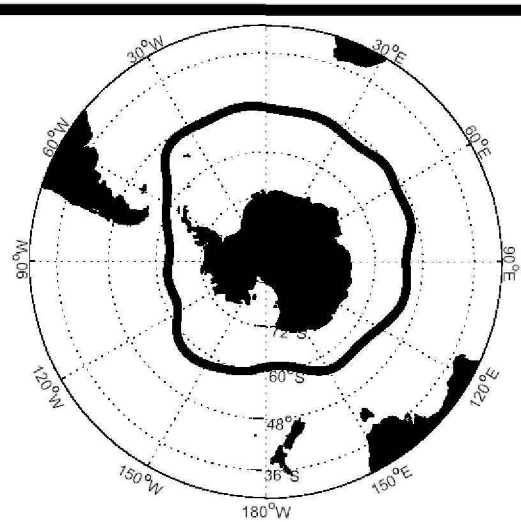
T	α
21	0.88
19	0.86
18	0.85
17	0.78
15	0.73
13	0.61

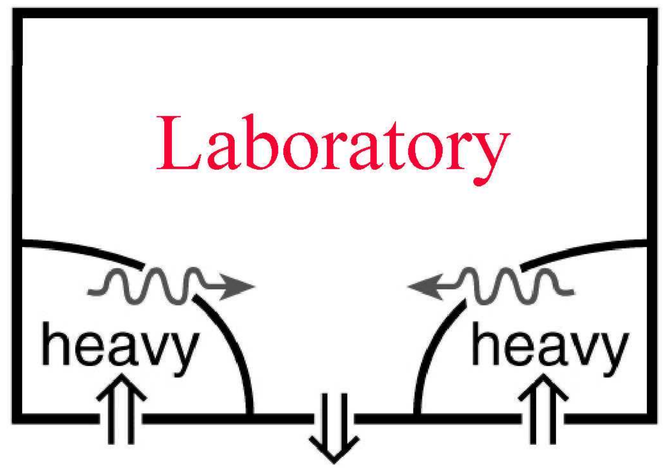


another example

Laboratory Model of Circumpolar Current

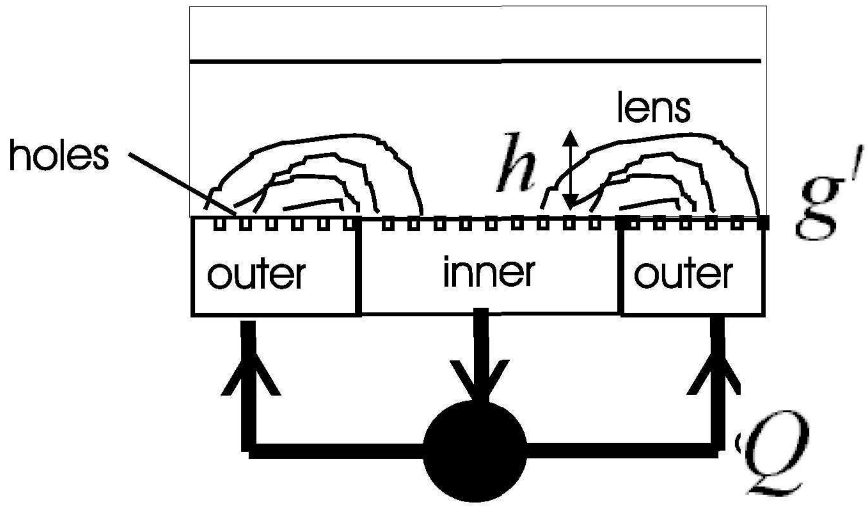


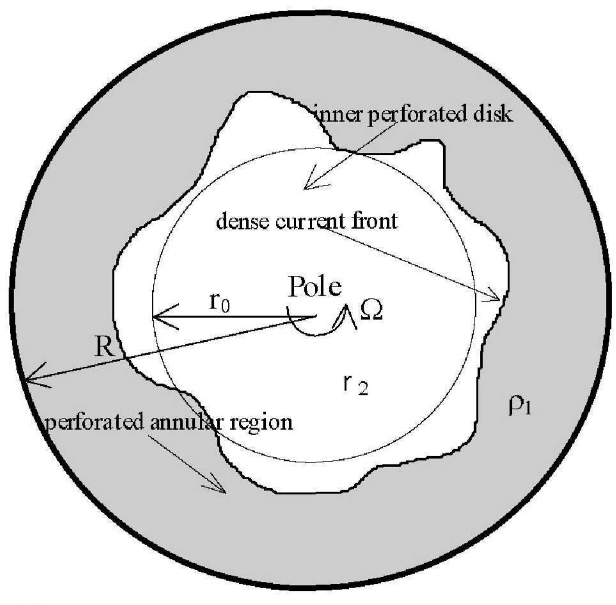




Apparatus

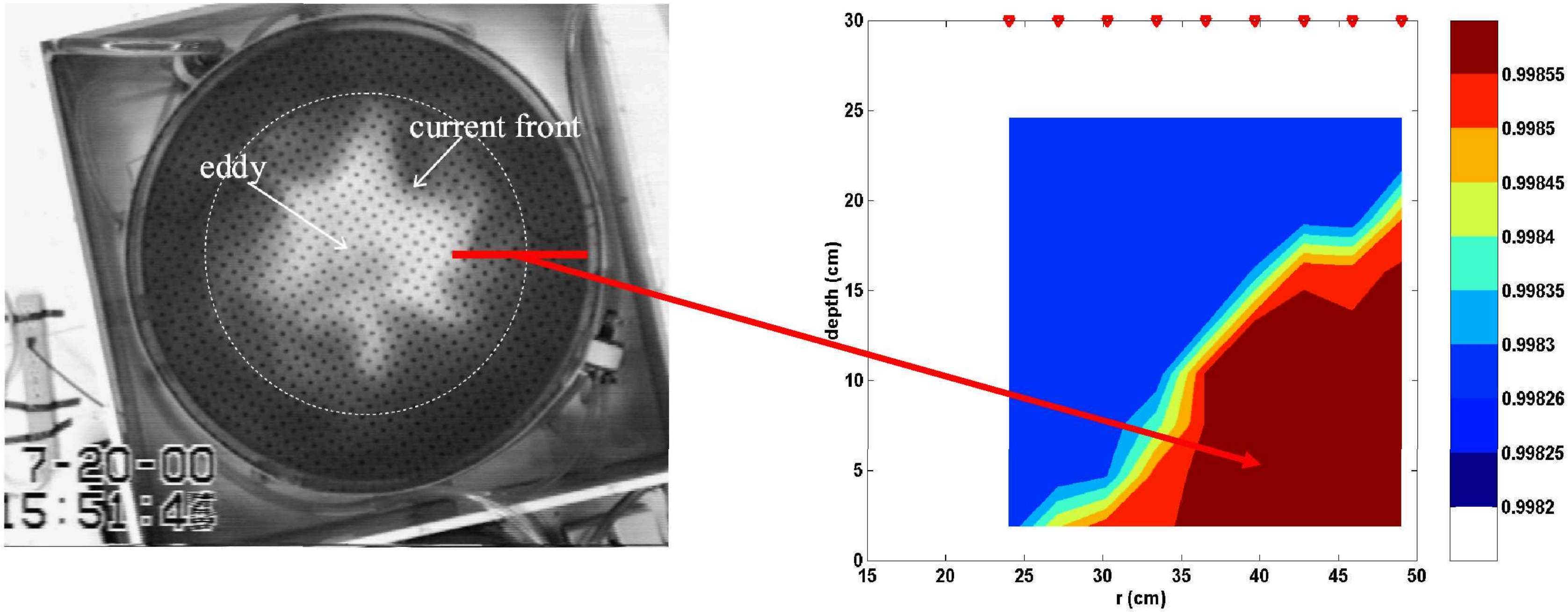
$$f = 2\Omega$$



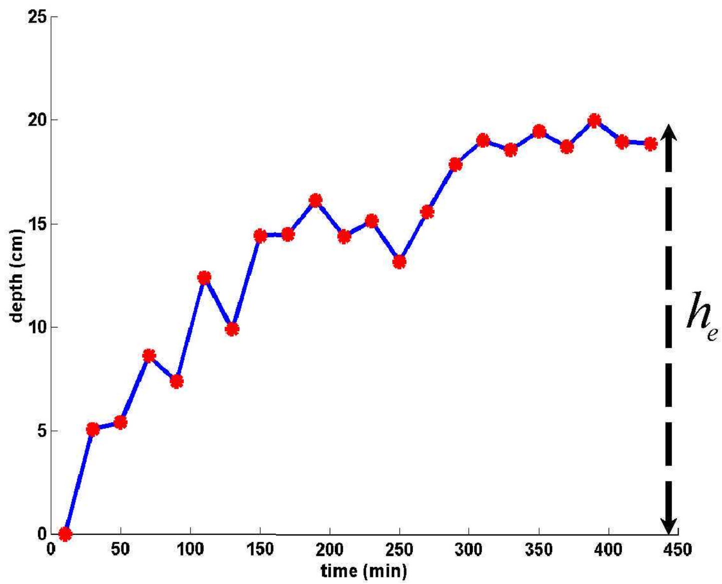


Claudia Cenedese
Jack Whitehead

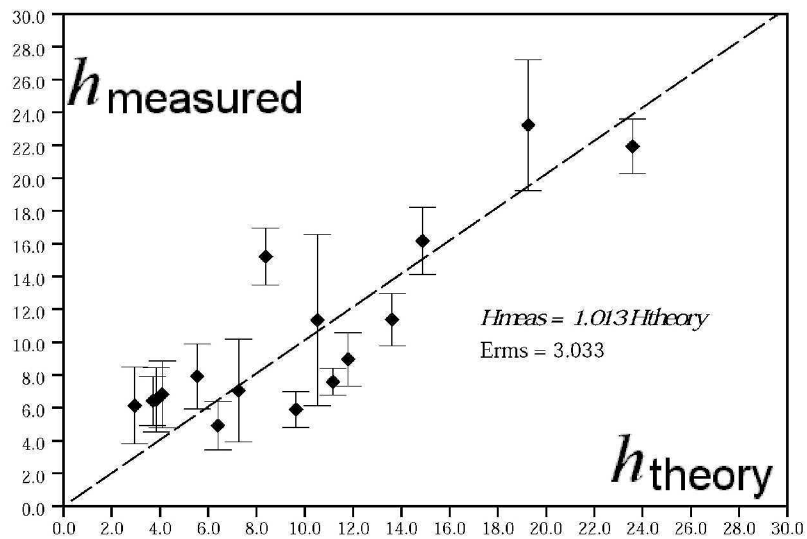
b)



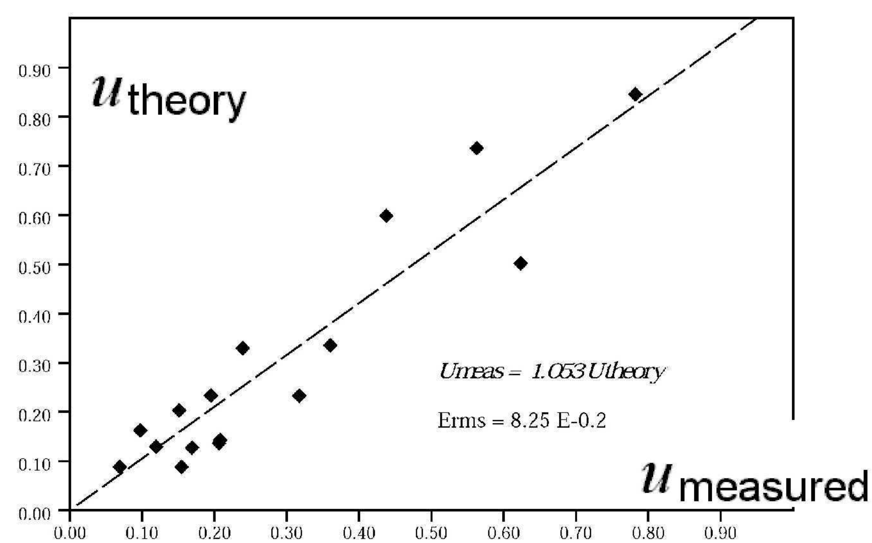
interface depth



$$h \sim \sqrt{\frac{f w_{Ek}}{g'}}\, r_o$$

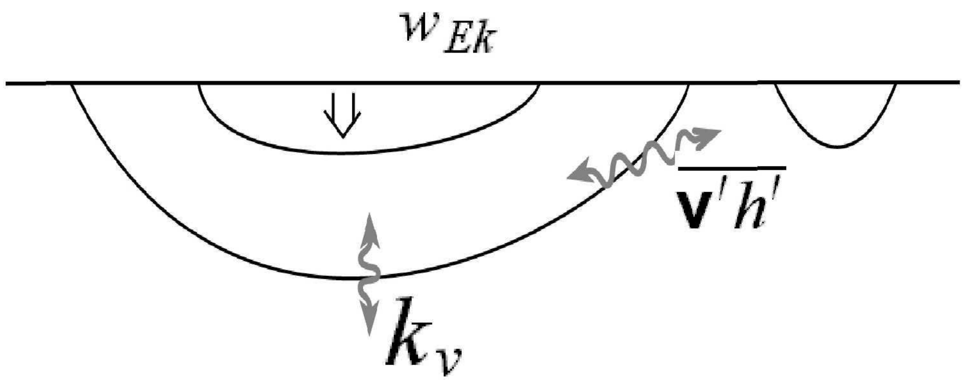


h measured
h theory
Hmeas = 1.013 Htheory
Erms = 3.033



u theory
u measured
Umeas = 1.053 Utheory
Erms = 8.25 E-0.2

Conclusions



Geostrophic eddy transfer is often erroneously neglected in favor of small scale mixing in discussions of large scale buoyancy balances.

Numerical and laboratory experiments suggest that eddy transfer, rather than small-scale mixing, may play a central role in maintaining the structure of the thermocline, particularly in the southern ocean, but also in subtropical ocean gyres.

Geostrophic eddies are likely to play a key role in diabatic processes, particularly near the upper surface, where eddy fluxes inevitably have a diapycnal component.