The Role of Western Boundaries in Wind-Driven Energetics

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Sources and Sinks of Ocean Mesoscale Eddy Energy
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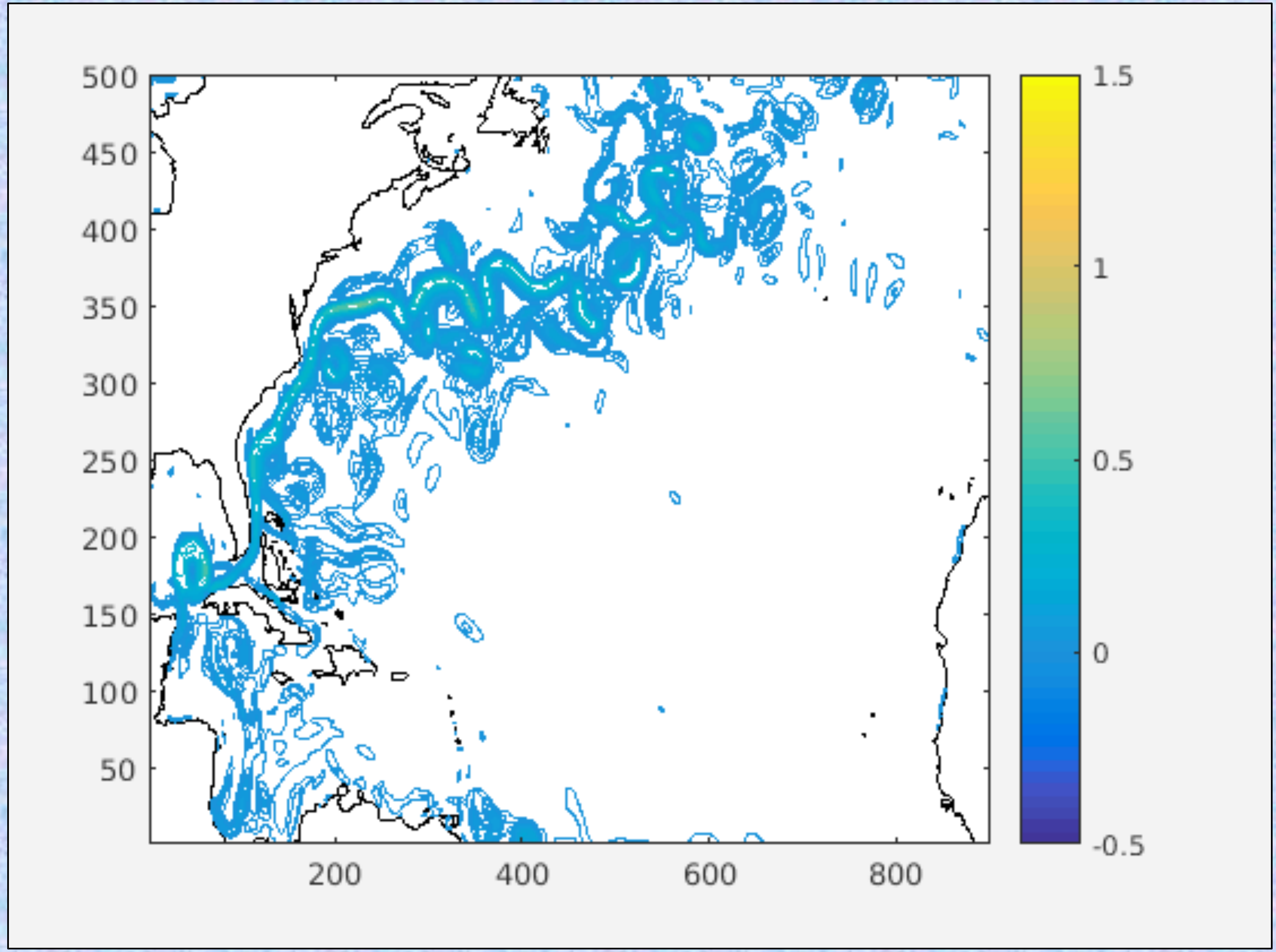
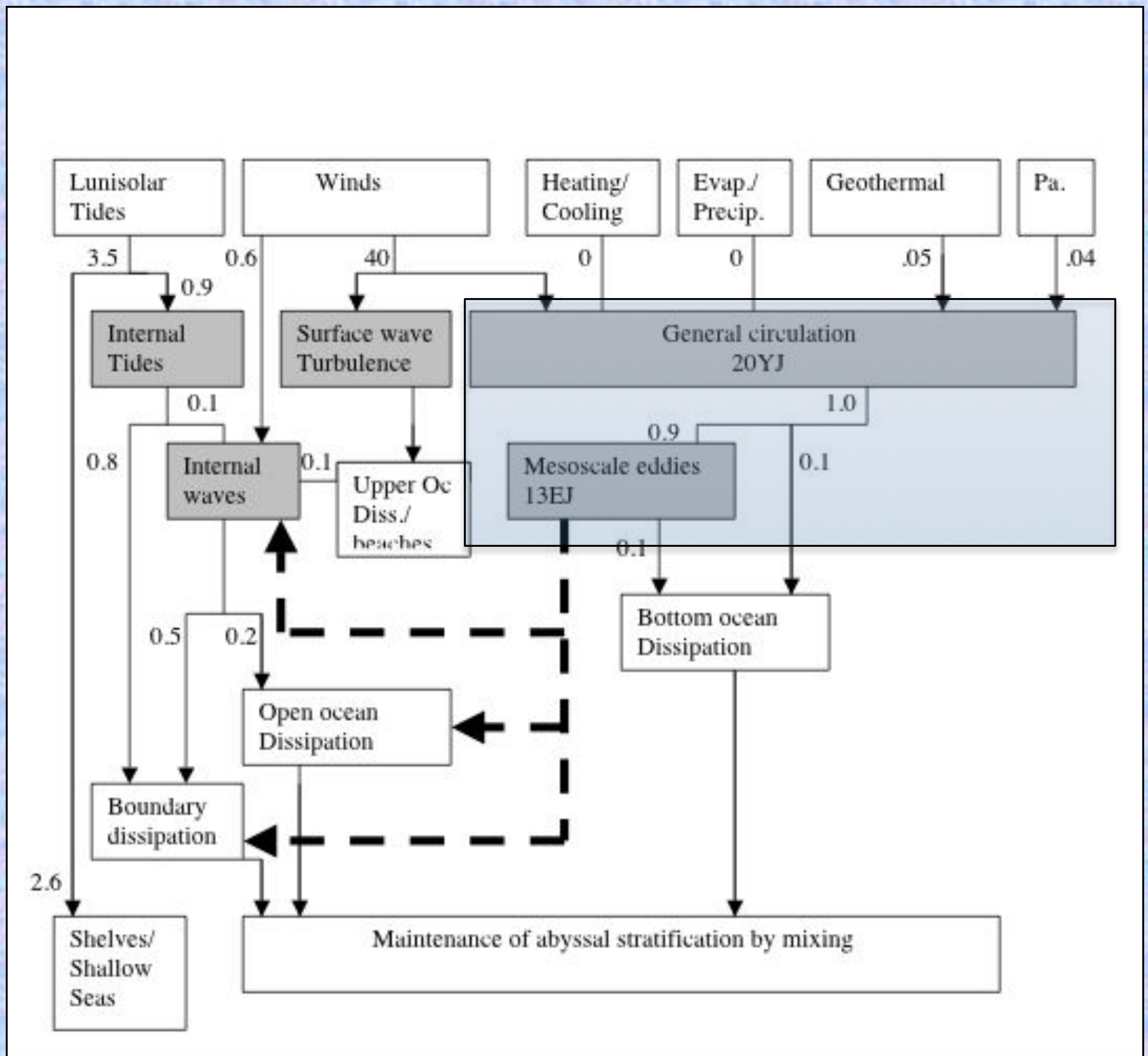
Surface Speed (m/s) from 1/12 North Atlantic Model



A recent view of the Ocean Energy Budget



The leading theoretical views of the General Circulation and eddies come from

$$\beta v = f\frac{\partial}{\partial z}w;\ \ \vec{u}\cdot\nabla f N^2 = 0$$

$$\varepsilon = \frac{U}{fL} << 1,\ \ L \sim L_\beta,\ \ \frac{\delta h}{H} \sim 1$$

Ventilated Thermocline Theory

geostrophic, hydrostatic, steady

$$\frac{d}{dt}q = 0;\ \ q = \nabla^2 p + \frac{\partial}{\partial z}\frac{f}{N^2}\frac{\partial}{\partial z}p + \beta y$$

$$\varepsilon = \frac{U}{fL} << 1,\ \ L \sim L_R,\ \ \frac{\delta h}{H} \sim \varepsilon$$

Homogenization Theory

mildly ageostrophic

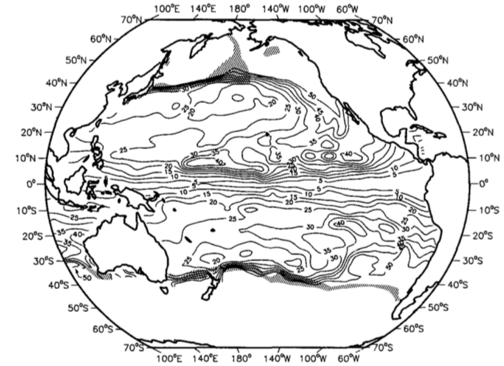


FIG. 5. Potential vorticity of the σ_θ = 26.05–26.25 interval (Layer A), Pacific Ocean. Other features as in Fig. 4. Note the high q "tongue" entering the eastern sides of the North and South Pacific.

Many Studies have supported the explanatory value of these theories to the ocean.

Space and time scale separation

$$T_{pg} = \frac{L_\beta}{\beta L_R^2} >> \frac{1}{\varepsilon f}$$

$$L_\beta >> L_R$$

Pedlosky 1984
The Equations for Geostrophic Motion in the Ocean

$$\frac{\partial}{\partial T}\frac{(z_o)_b}{f} + \frac{1}{f}\bar{J}(M_o, \frac{(z_o)_b}{f}) = 0$$

The Ventilated Thermocline

$$\frac{\partial}{\partial t}q + \underline{\vec{\bar{u}}_o \cdot \nabla q} + J(M_1, q) + \underline{\frac{(z_o)_b}{f} J(M_1, \frac{f}{(z_o)_b})} = 0$$

$$q = \nabla^2 M_1 - f\frac{(M_1)_{bb}}{(z_o)_b}$$

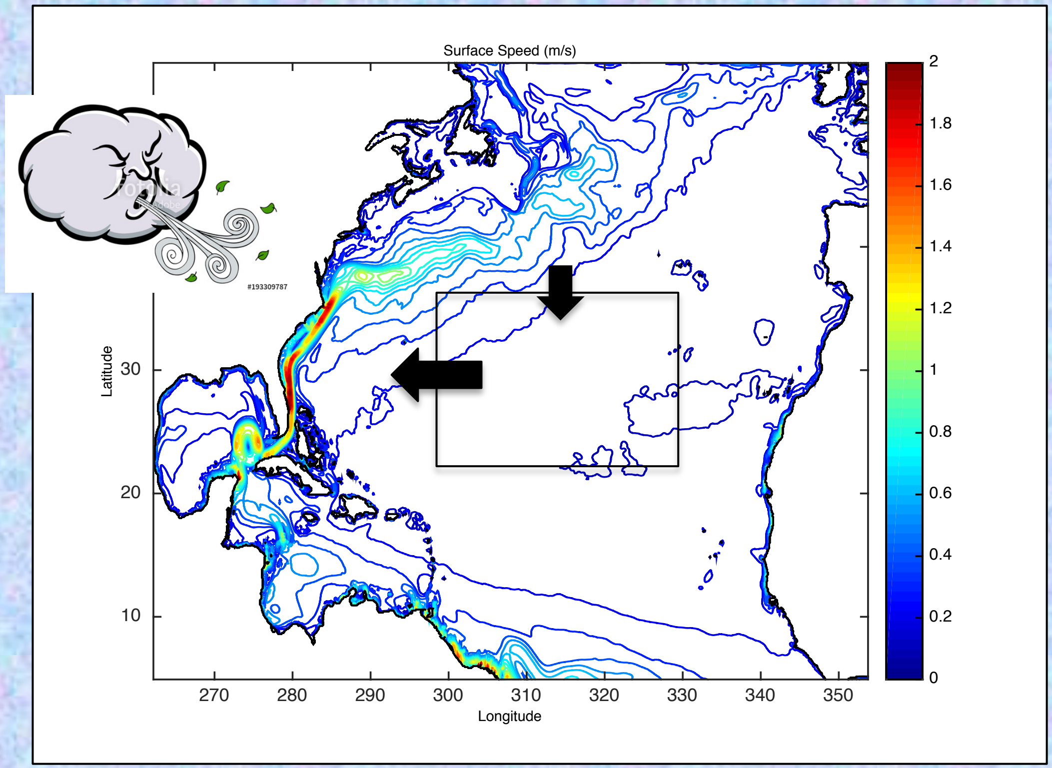
Quasi-geostrophy

Looks really good - BUT

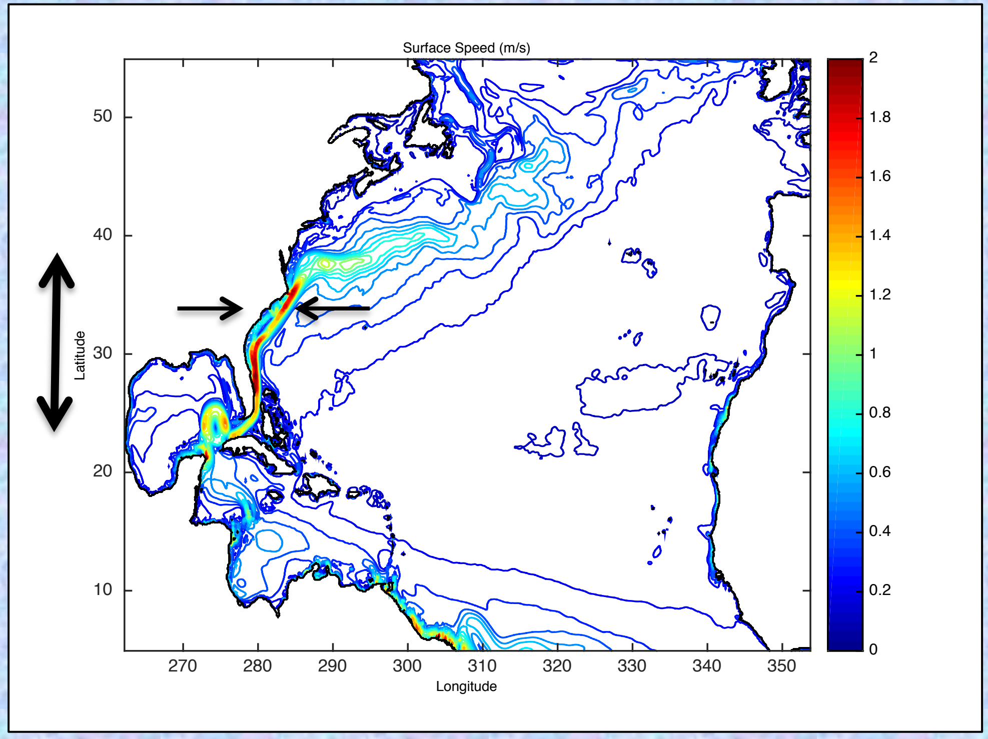
Leaves us with an energetics problem

Ventilated Thermocline is forced, but not dissipative

$$\oiint \vec{u}(p-bz)\cdot\vec{n}\,dS = \iint_A \vec{\tau}\cdot\vec{u}_o\,dA$$



It’s natural to look to western boundary layers for a solution



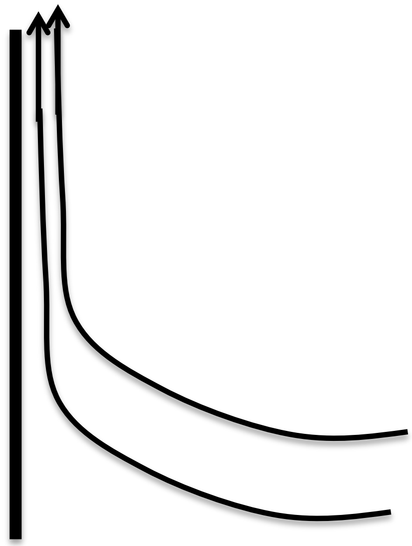
Instead of X,Y ~ L_β, x,y ~ L_R

Examine x~ L_R , y ~ L_β

Grooms, et al DAO, 2011

After much sweating and grinding of teeth, bl pv equation emerges that connects to the pg interior

$$M_{ox}^{2} = -M_{o}$$



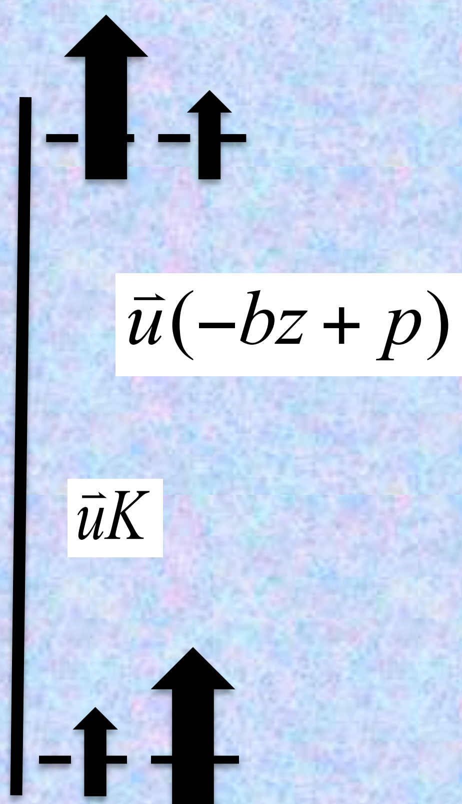
$$\hat{q} \rightarrow \frac{(z_o)_b}{f} \quad x \rightarrow \infty$$

$$u_o \hat{q}_x + \hat{v}_o \hat{q}_y = 0;$$

$$\hat{q} = \frac{\dfrac{M_{oxx}}{f} + f}{(M_o)_{bb}}$$

Looks really good - BUT

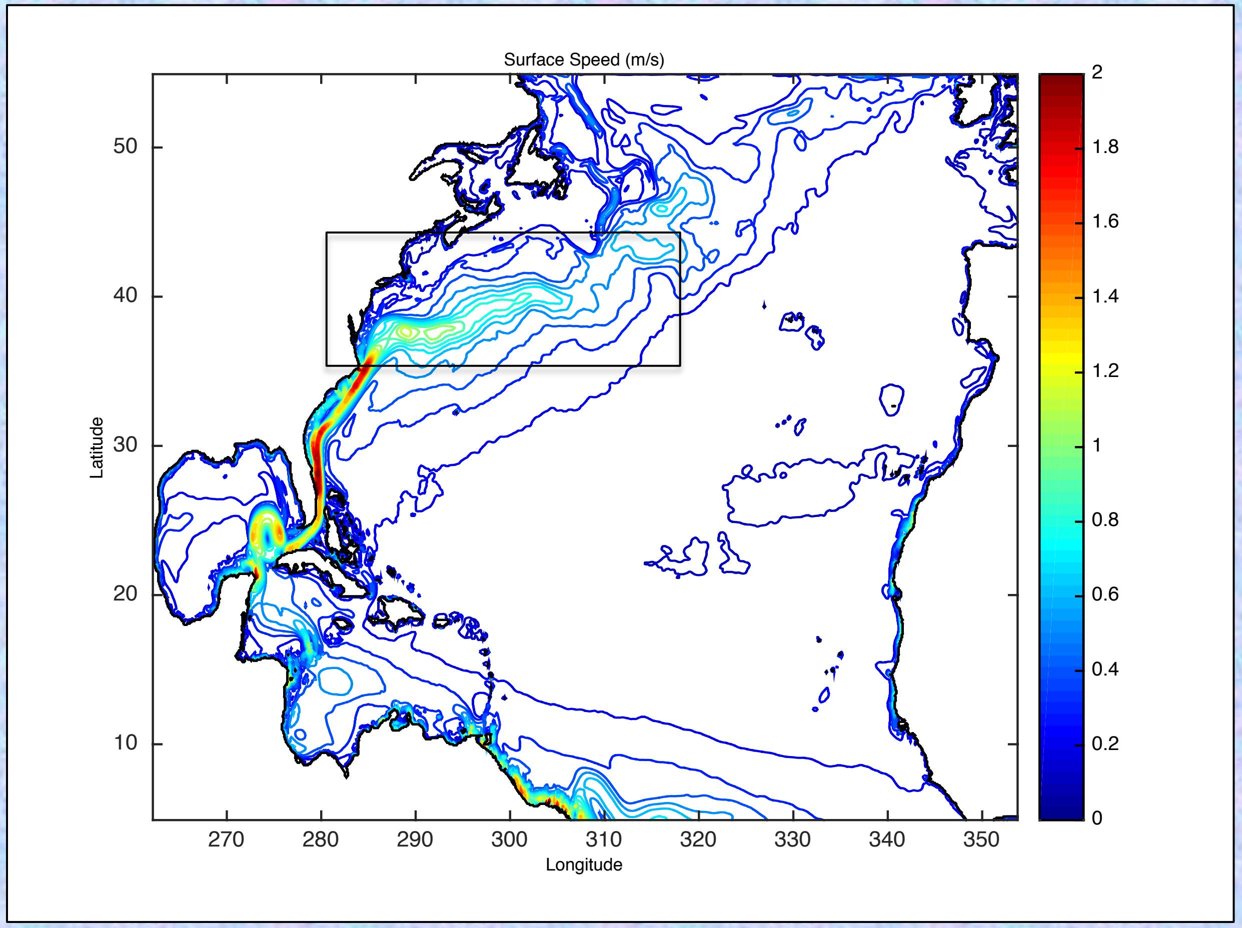
Leaves us with an energetics problem
Energy is conservative.



$$\oiint_S \vec{u}(K - bz + p)\cdot\vec{n}\, dS = 0$$

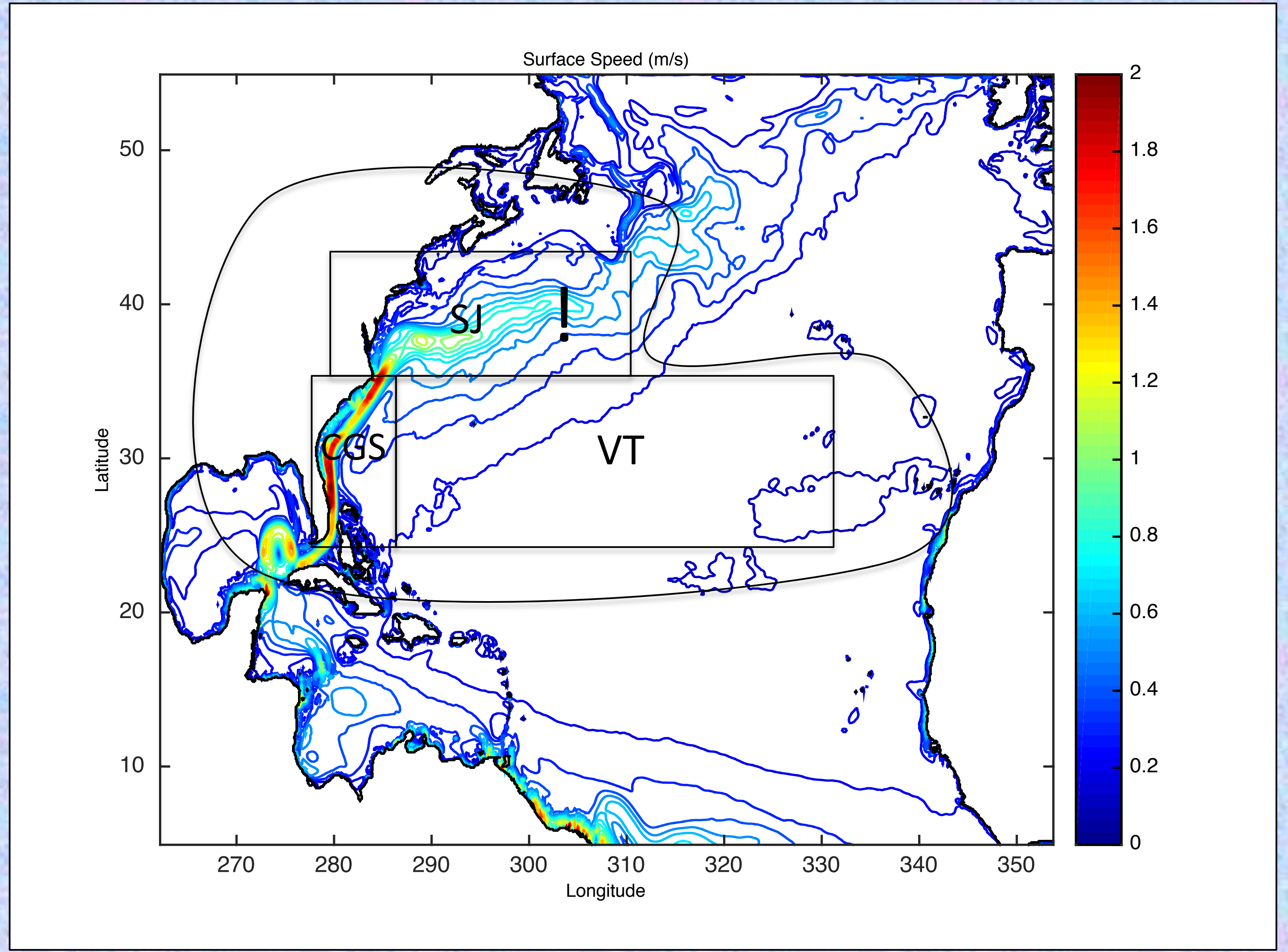
Both boundary conditions are steady

So – What's Next?
Continuing around the gyre, we come to the separated jet



Full PE dynamics are required

So, where does this leave us?



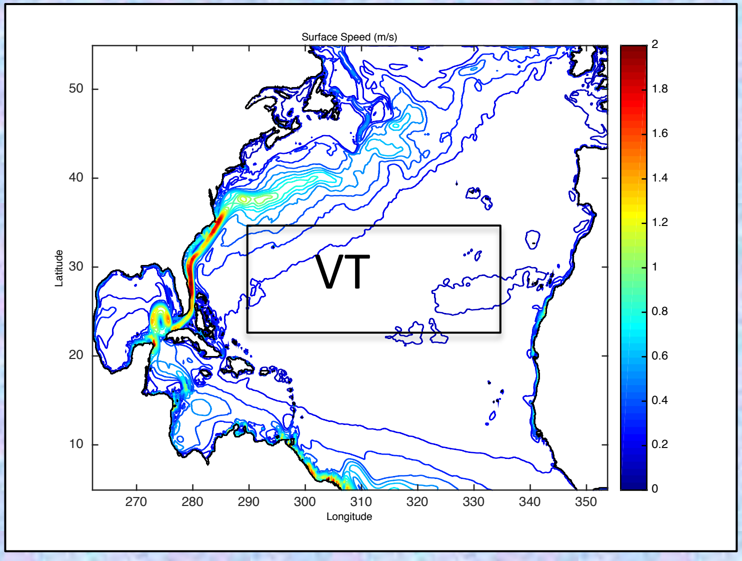
How to test in a realistic GCM?

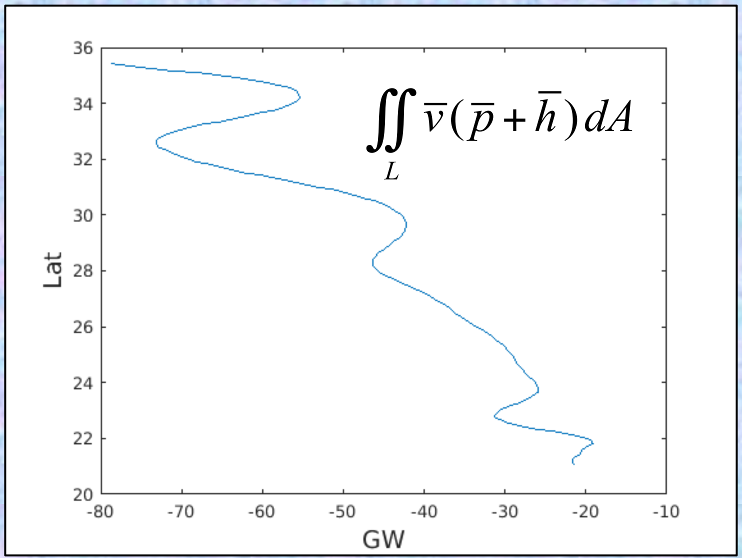
$$\overline{\vec{u}} \cdot \nabla \overline{\vec{u}}_h + \vec{f} x \overline{u}_h = -\nabla_h \overline{p} - \nabla \cdot \overline{\vec{F}} - \nabla \cdot \overline{\vec{u}' \vec{u}'_h}$$

$$\Longrightarrow$$

$$\nabla \cdot \overline{\vec{u}} K = -\underline{\overline{\vec{u}}_h \cdot \nabla \overline{p}} - \overline{\vec{u}}_h \cdot \nabla \cdot \overline{\vec{F}} - \overline{\vec{u}}_h \nabla \cdot \overline{\vec{u}' \vec{u}'_h}$$

MKEF | PW | VIS WW+KEDISS | MEC





DKEF = .01 GW

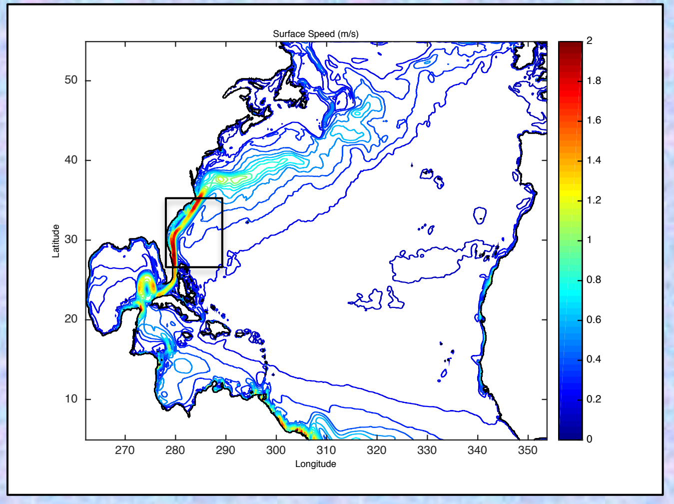
PW = 3.5 GW

WW = 4.9 GW

KEDISS = .01 GW

MEC = -1.3 GW

Something of a surprise



DKEF = 21 GW

PW = -39 GW

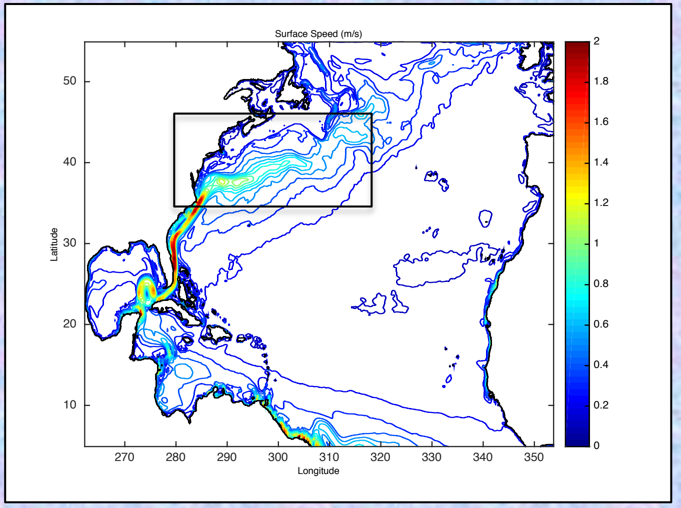
WW = -0.7 GW

KEDISS = -7 GW

MEC = -11 GW

Leading order balance - Potential energy to kinetic Energy conversion

Dissipation and eddies are not negligible, the latter due to Charleston Bump



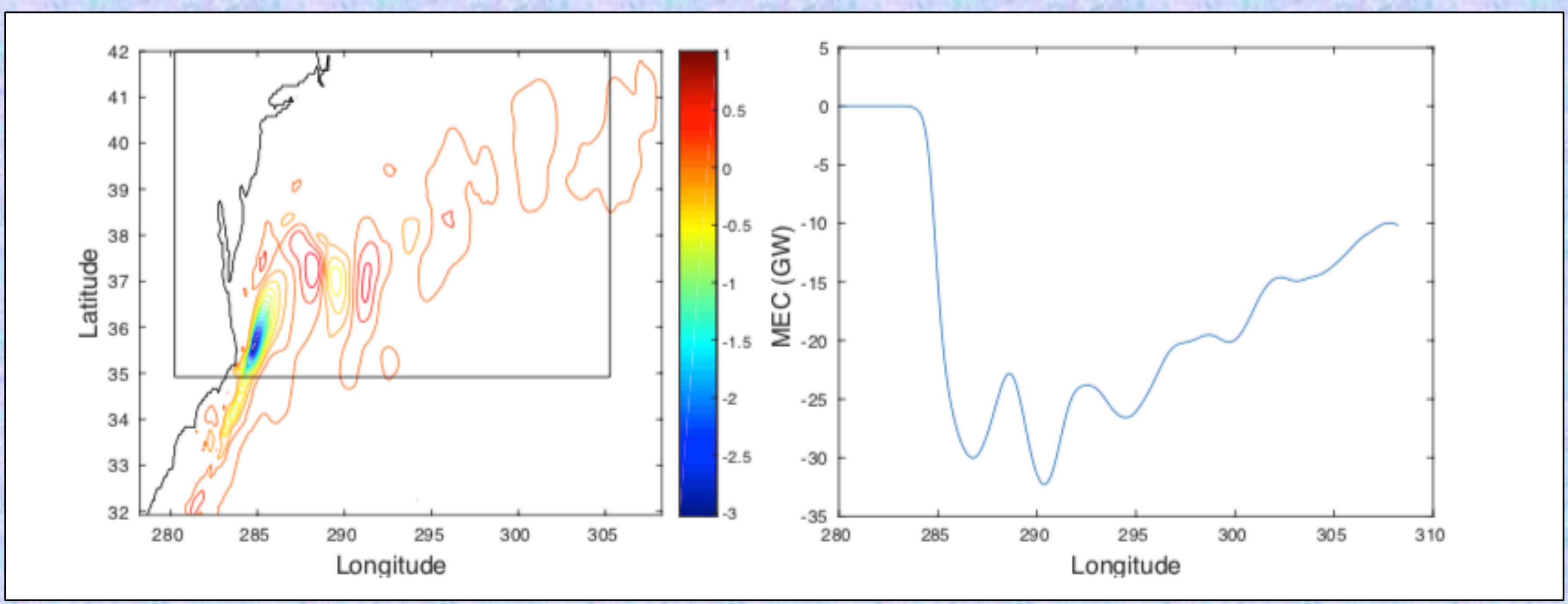
DKEF = -28 GW

PW = 17 GW

WW = 3.6 GW

KEDISS = -0.7 GW

MEC = -14 GW



Summary:

A straightforward dynamical division of subtropical gyres suggested by theory seems consistent with a realistic 1/12 model

Mesoscale is powered up primarily in the separated jet extension (not obviously qg)

Is the ventilated thermocline inertial?