The Role of Western Boundaries in Wind-Driven Energetics
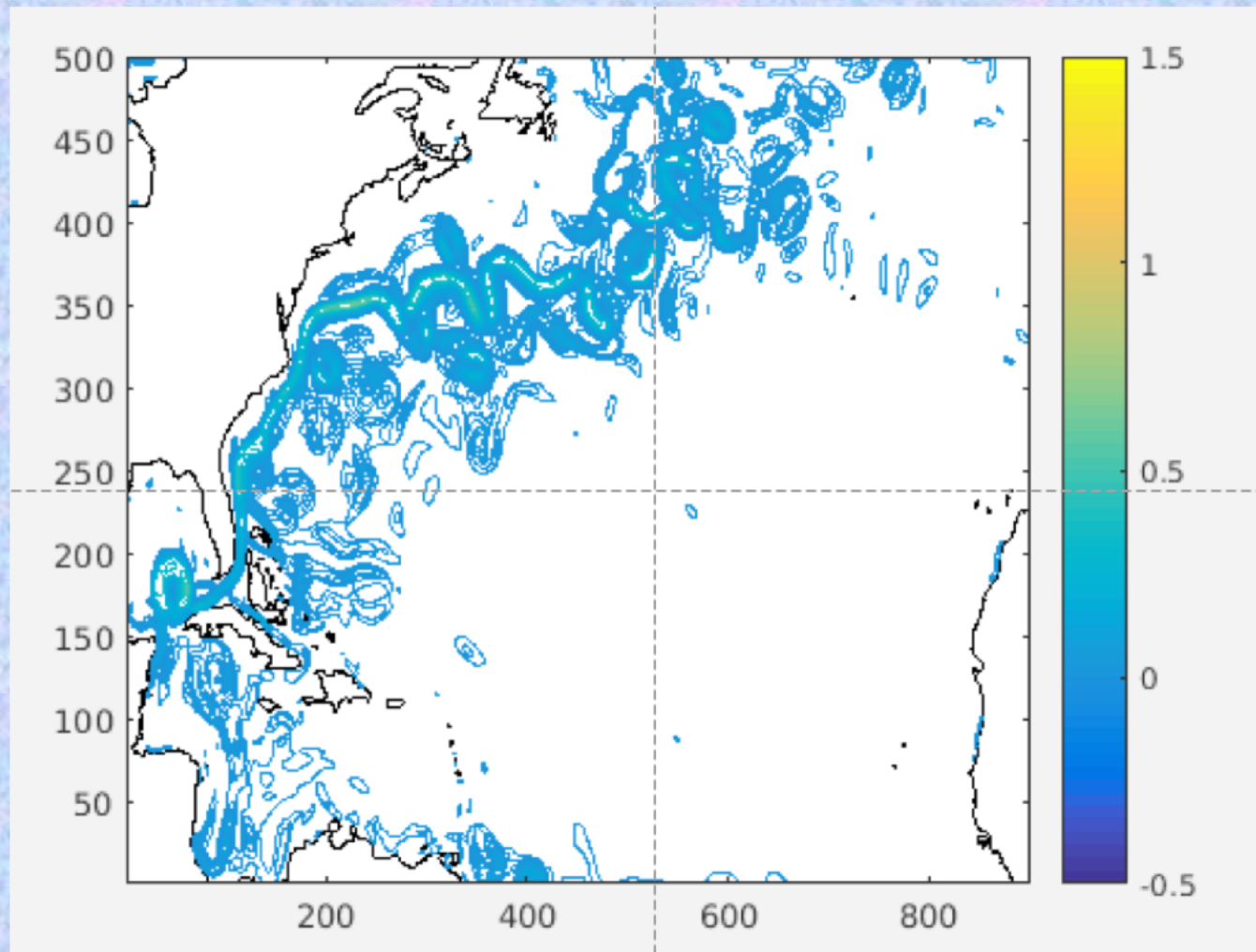
WK Dewar
EOAS
FSU/MEOM
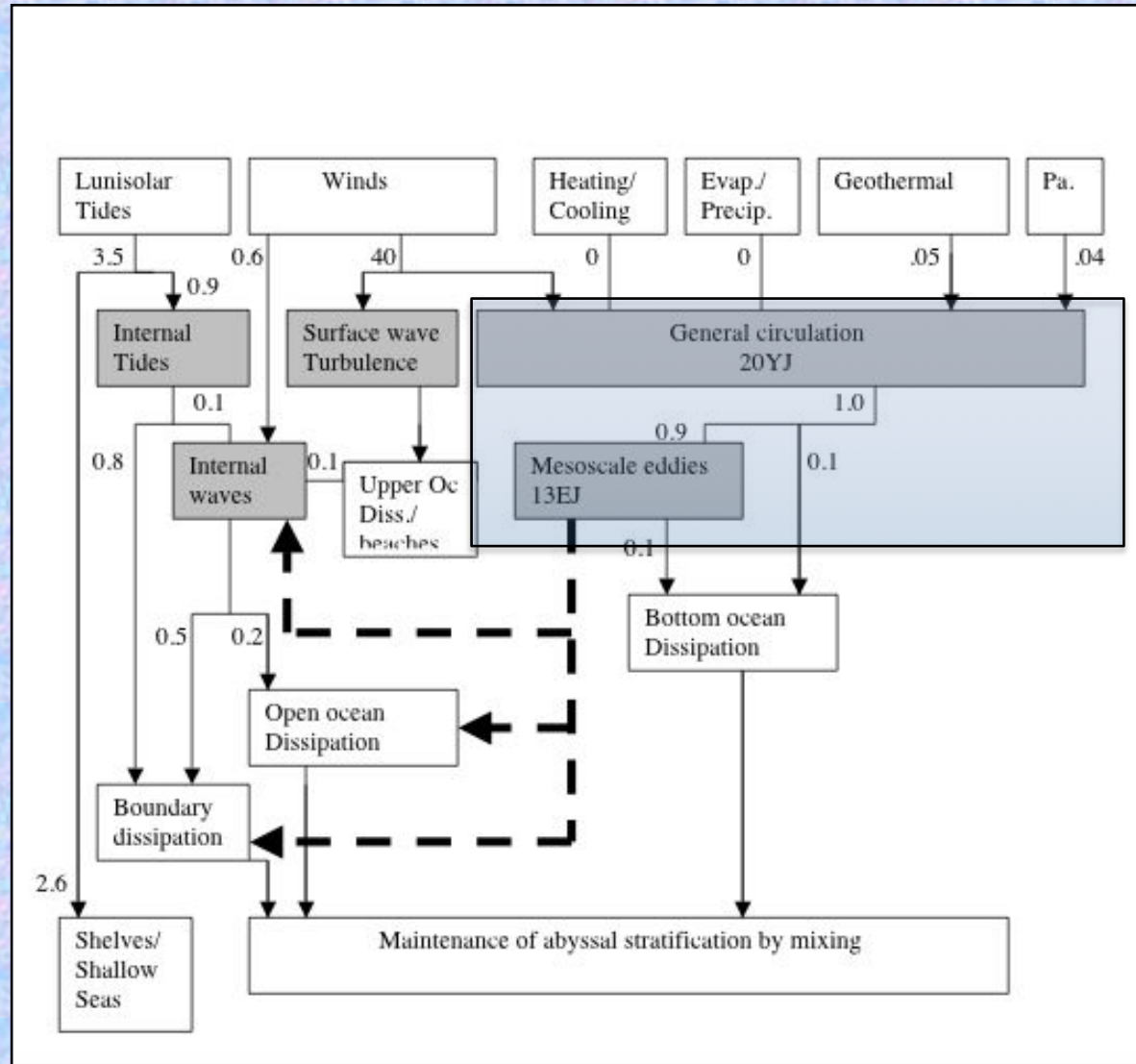with Q Jamet, B Deremble and N Wienders
EGU
Wednesday, May 6, 2020

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

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

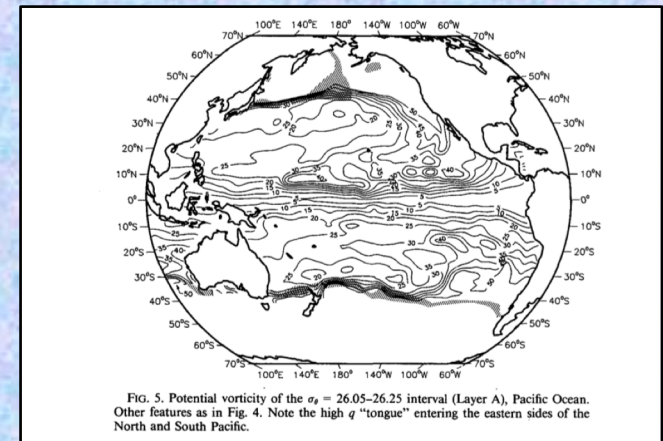$$\varepsilon = \frac{U}{fL} << 1, \ L \sim L_\beta, \ \frac{\delta h}{H} \sim 1$$

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
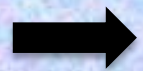value of these theories to the ocean.

Space and time scale separation

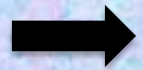$$T_{pg} = \frac{L_\beta}{\beta L_R^2} >> \frac{1}{\varepsilon f}$$

$$L_\beta >> L_R$$

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

$$\frac{\partial}{\partial t}q + \vec{\bar{u}}_o \cdot \nabla q + J(M_1, q) + \frac{(z_o)_b}{f}J(M_1, \frac{f}{(z_o)_b}) = 0$$ Quasi-geostrophy
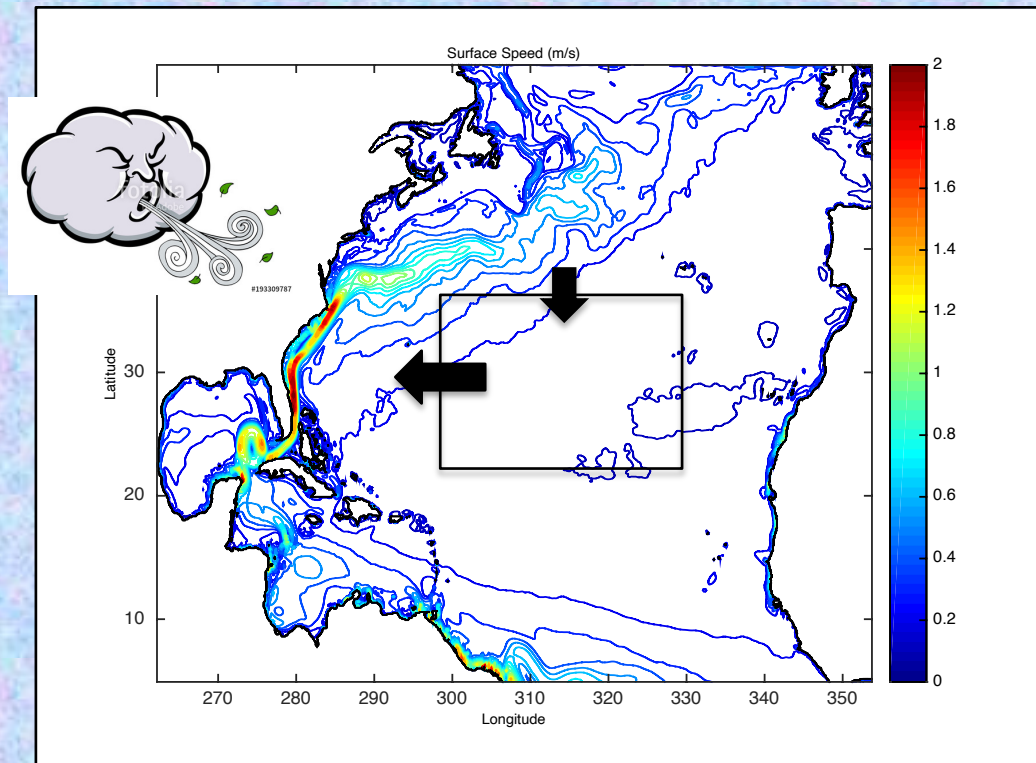
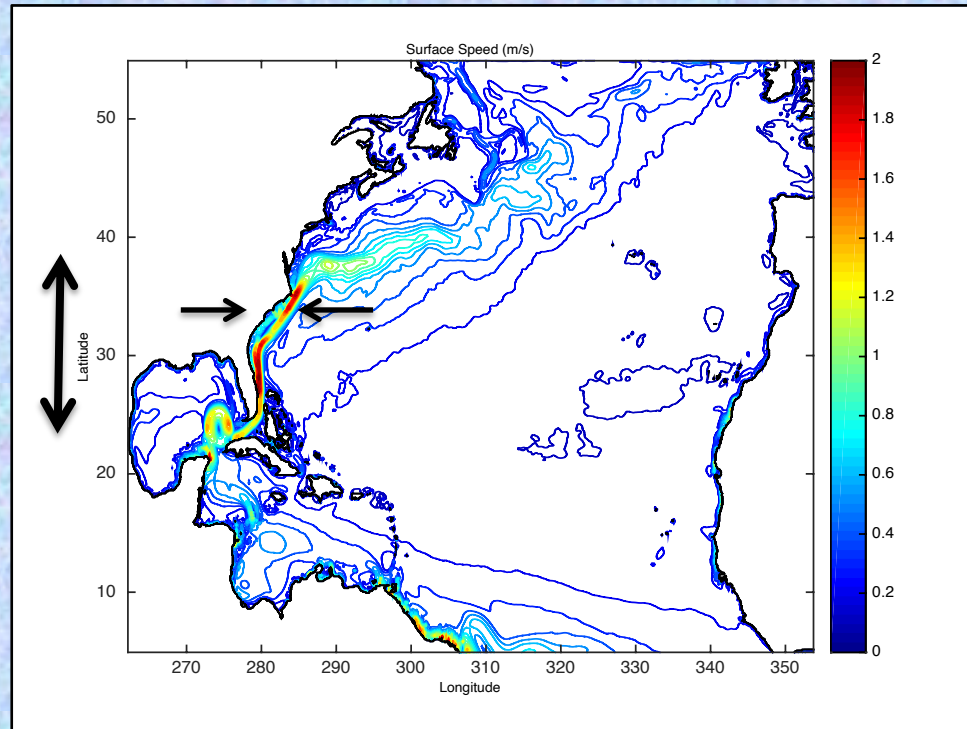$$q = \nabla^2 M_1 - f\frac{(M_1)_{bb}}{(z_o)_b}$$

Looks really good - BUT

Leaves us with an energetics problem
Ventilated Thermocline is forced, but not
dissipative

$$\oiint \vec{u}(p - bz) \cdot \vec{n}\, dS = \iint_A \vec{\tau}\, \vec{u}_o\, dA$$
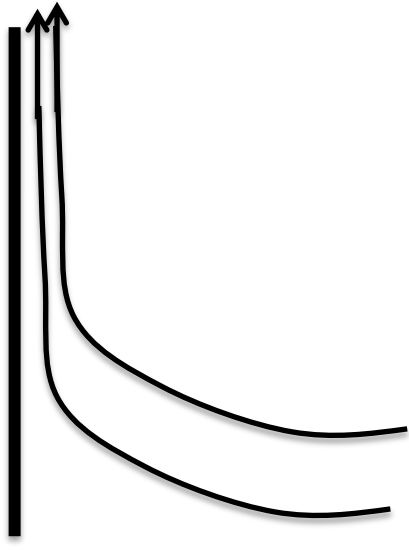
It's natural to look to western boundary layers for a solution

Surface Speed (m/s)

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

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

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

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

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

Looks really good - BUT

Leaves us with an energetics problem
Energy is conservative.

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

$\vec{u}(-bz + p)$

$\vec{u}K$

Both boundary
conditions are steady

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

Surface Speed (m/s)
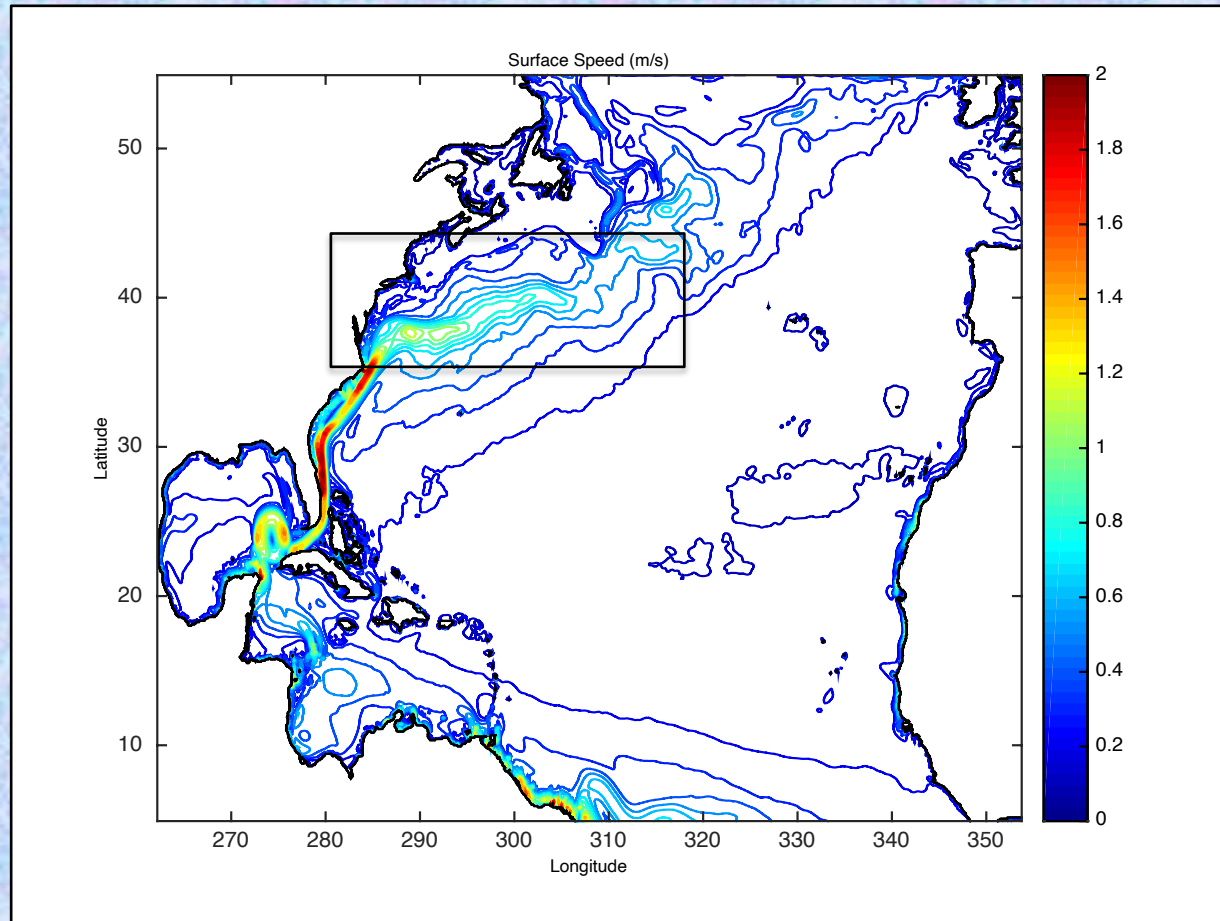
Full PE dynamics are required

So, where does this leave us?
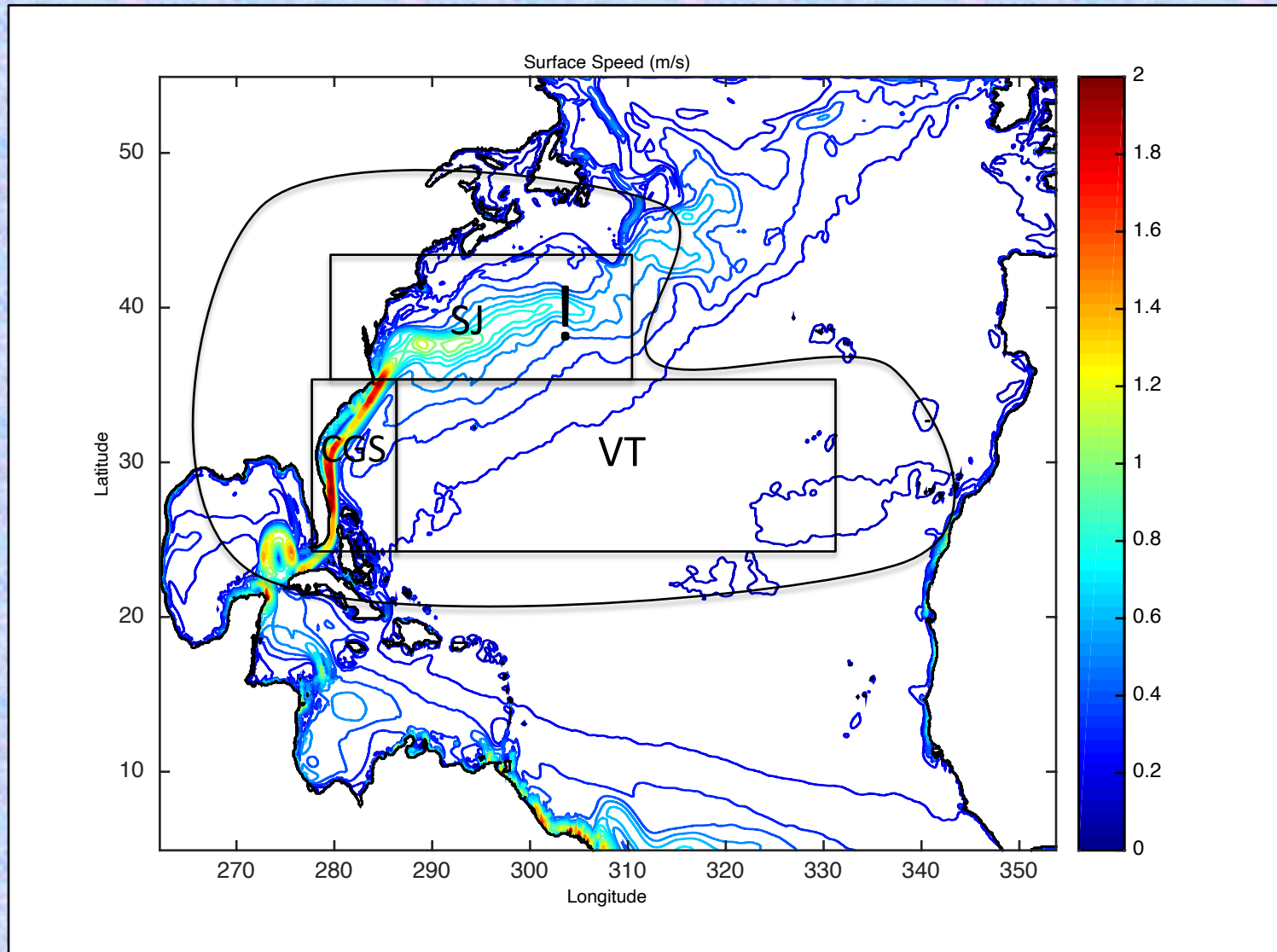
How to test in a realistic GCM?

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

$$\longrightarrow$$

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

MKEF   PW   VIS   MEC

WW+KEDISS
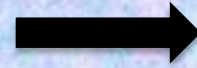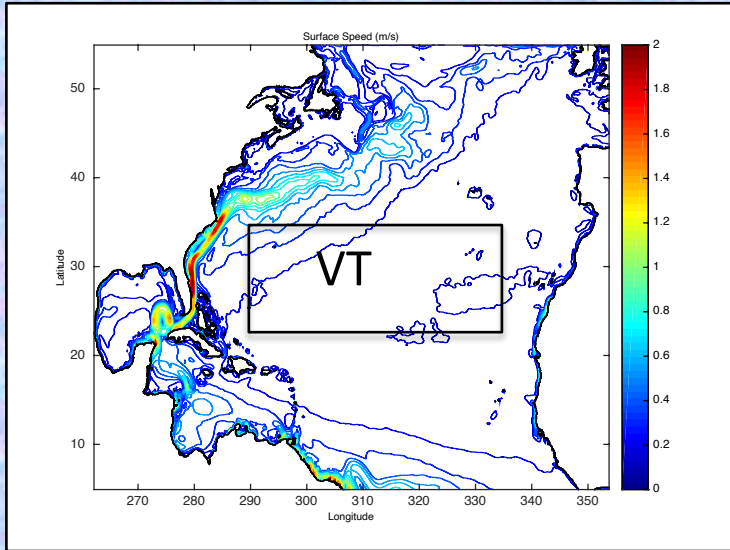
DKEF = .01 GW
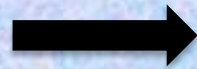
PW = 3.5 GW

WW = 4.9 GW

KEDISS = .01 GW

MEC = -1.3 GW
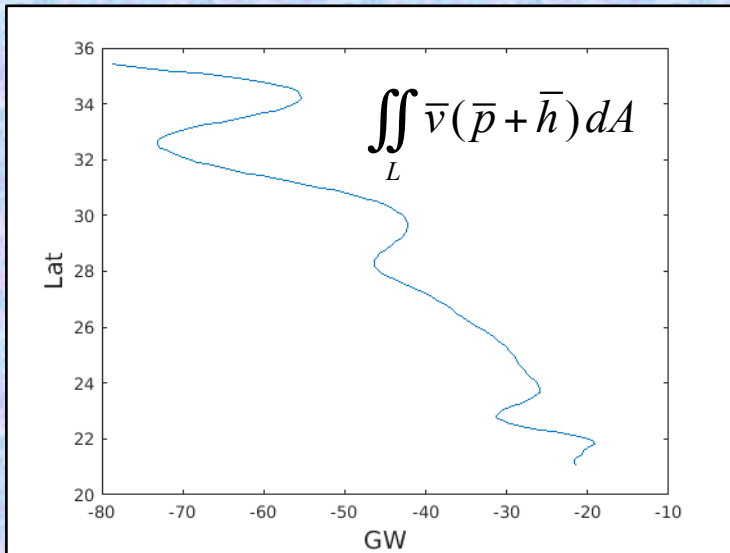
Something of a surprise
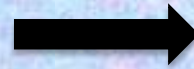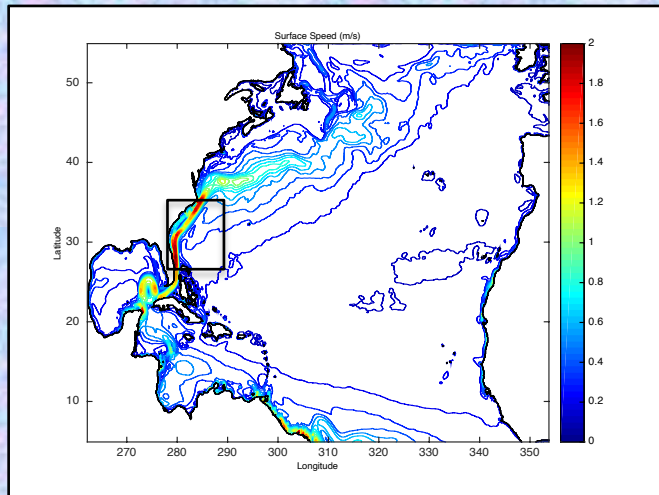
DKEF = 21 GW
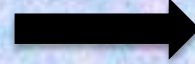
PW = -39 GW

WW = -0.7 GW

KEDISS = -7 GW
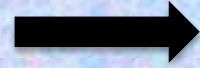
MEC = -11 GW

Leading order balance - Potential energy to kinetic Energy conversion

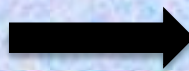Dissipation and eddies are not negligible, the latter due to Charleston Bump
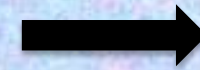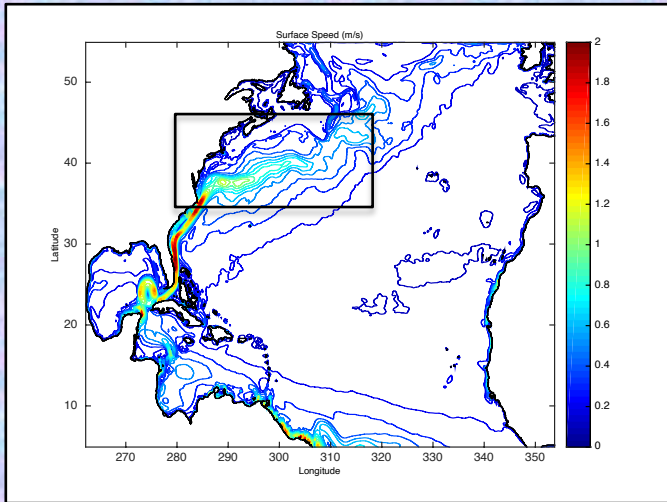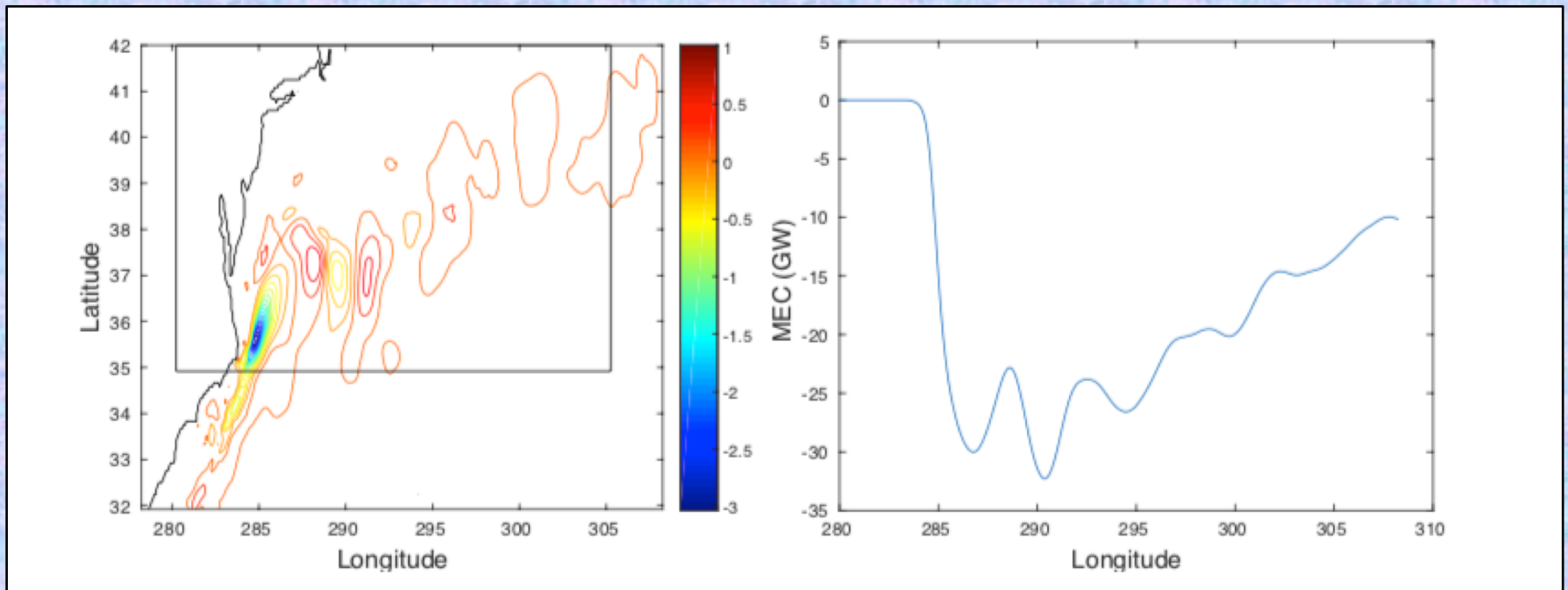
DKEF = -28 GW

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?