Submesoscale Dynamics and Parameterization:

Potential Implications for Mesoscale Parameterization?

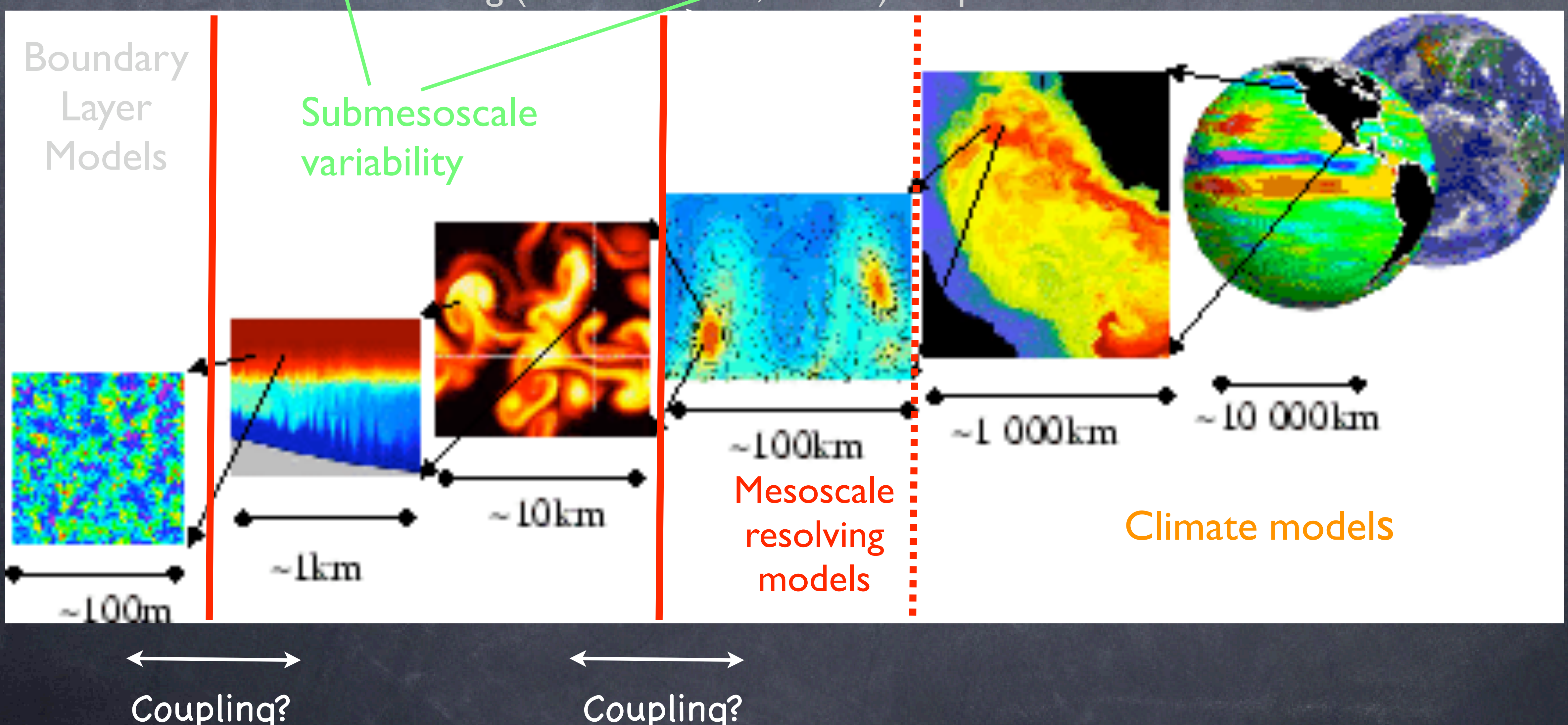
Baylor Fox-Kemper
University of Colorado at Boulder

CLIVAR WGOMD Workshop on Ocean Mesoscale Eddies

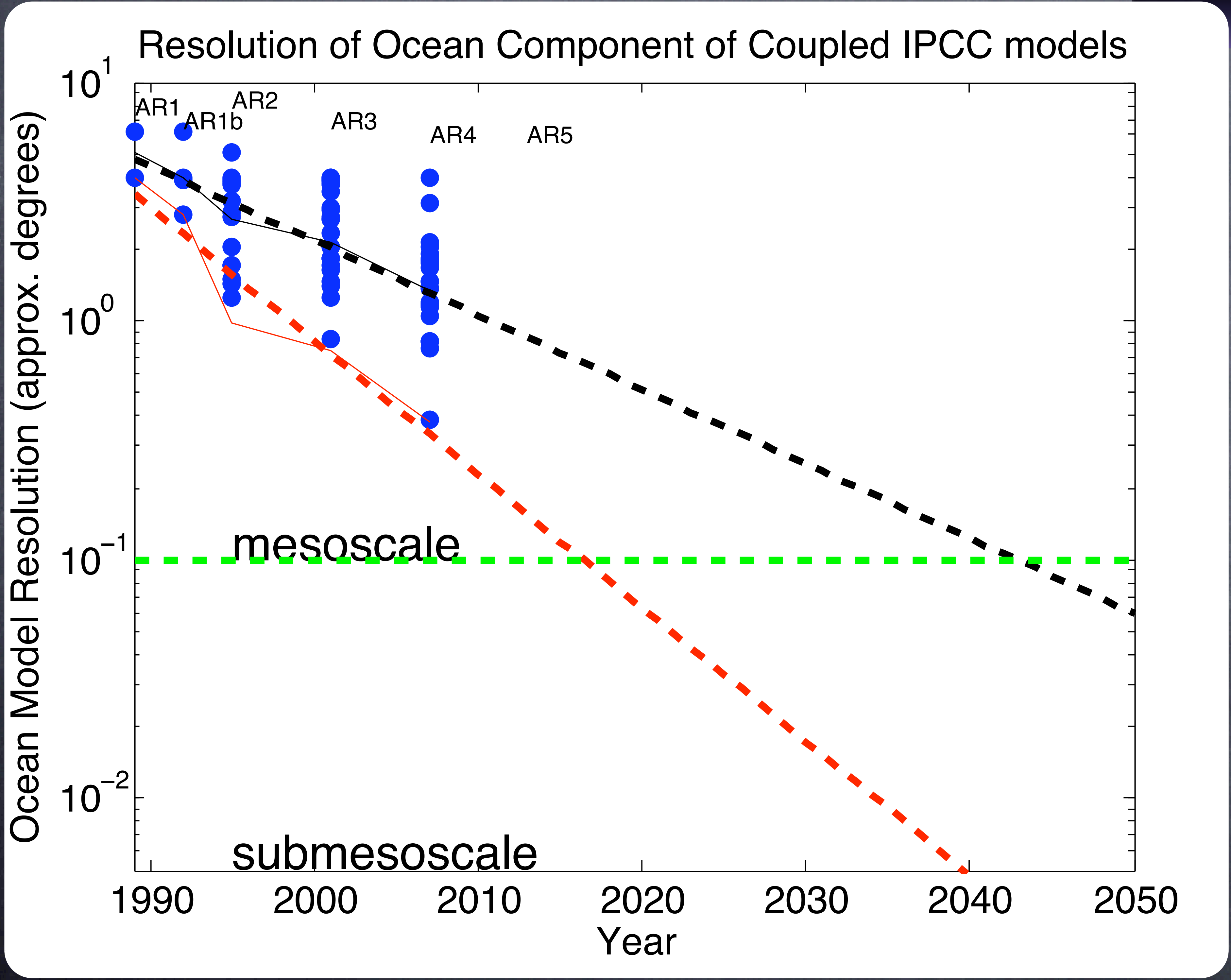
Collaborations with: R. Ferrari, G. Boccaletti, G. Danabasoglu, R. Hallberg, F. Bryan, J. Dennis

Upper Ocean in Climate Models

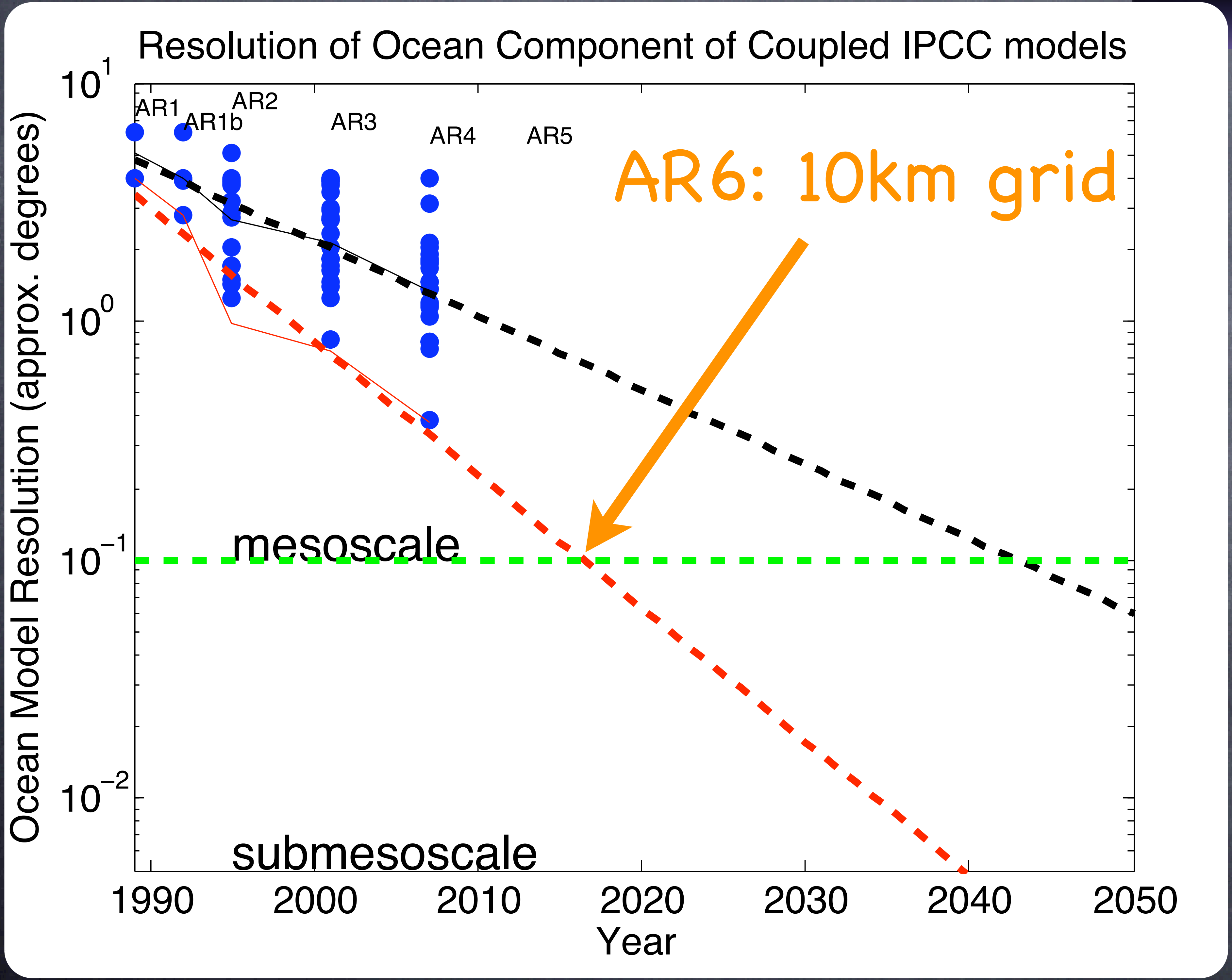
- Large-scale ocean circulation (100 - 10,000 km, yrs->centuries) => resolved
- Mesoscale variability (10 - 100 km, mo -> yrs) => resolved or parameterized
- Submesoscale variability (100 m - 10 km, d -> mo) => ignored until recently
- Internal waves & Langmuir circulations (10-100m, hr -> day) => crudely param.
- Turbulent mixing (10 cm - 100 m, s -> hr) => parameterized



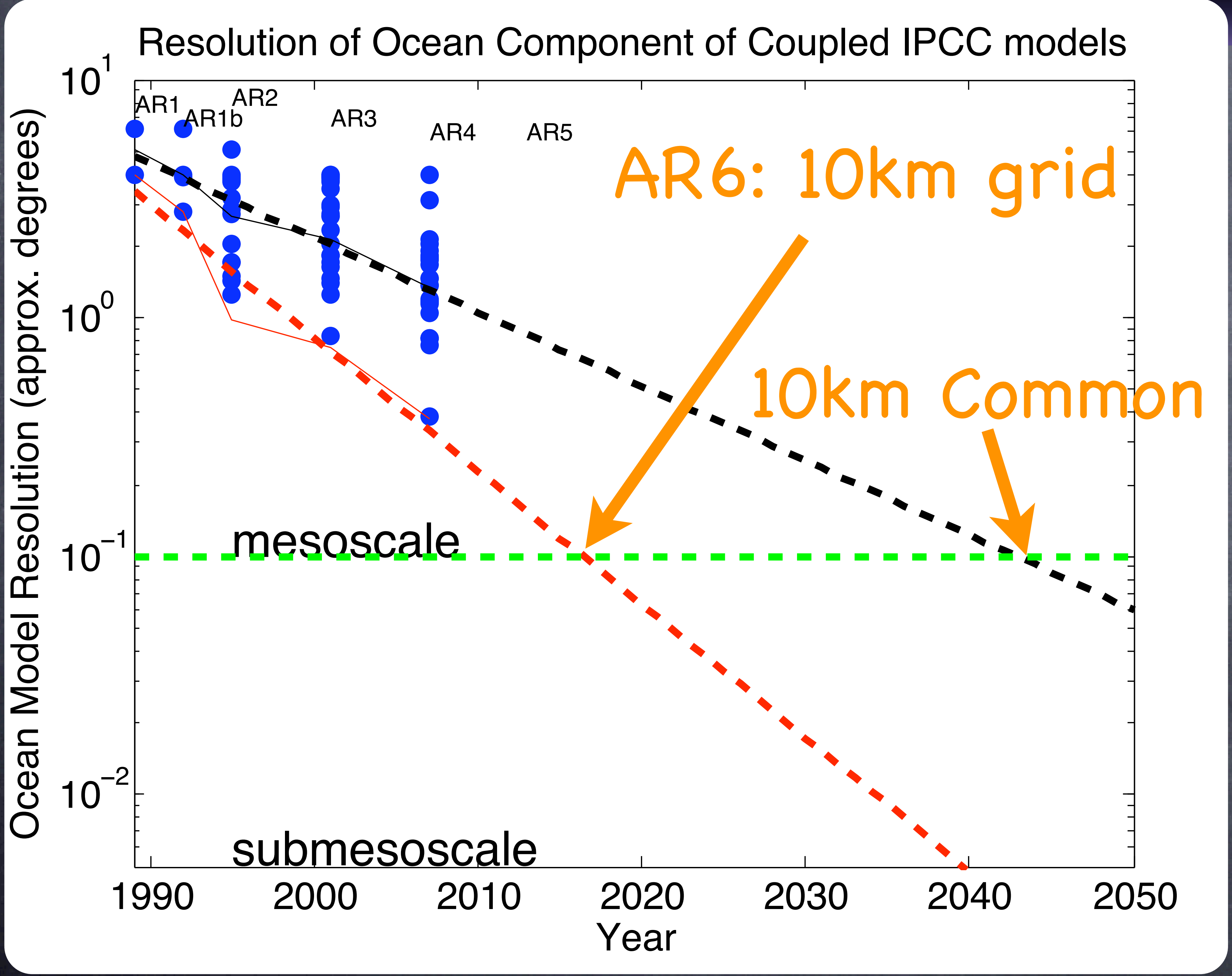
The Future of Resolution



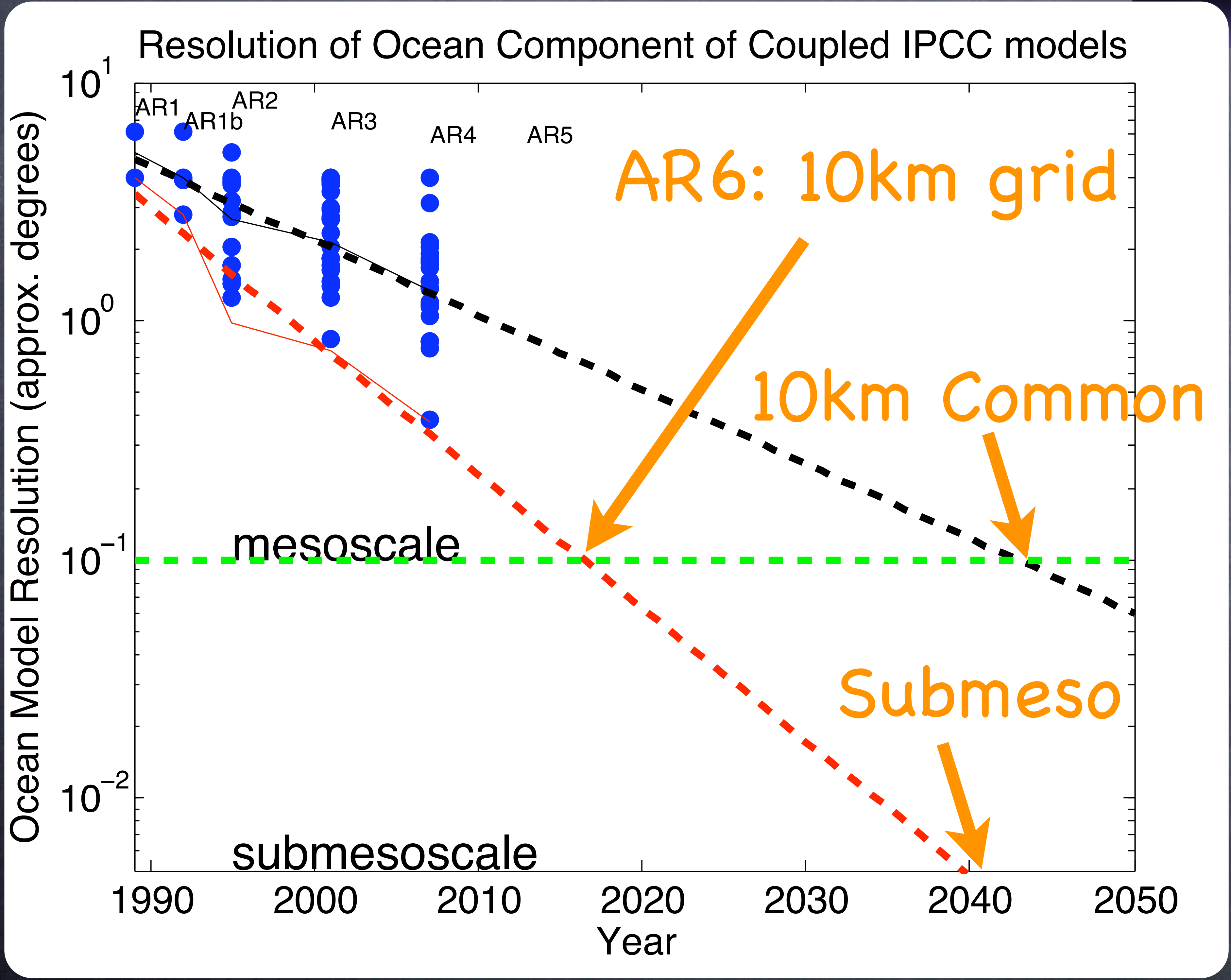
The Future of Resolution



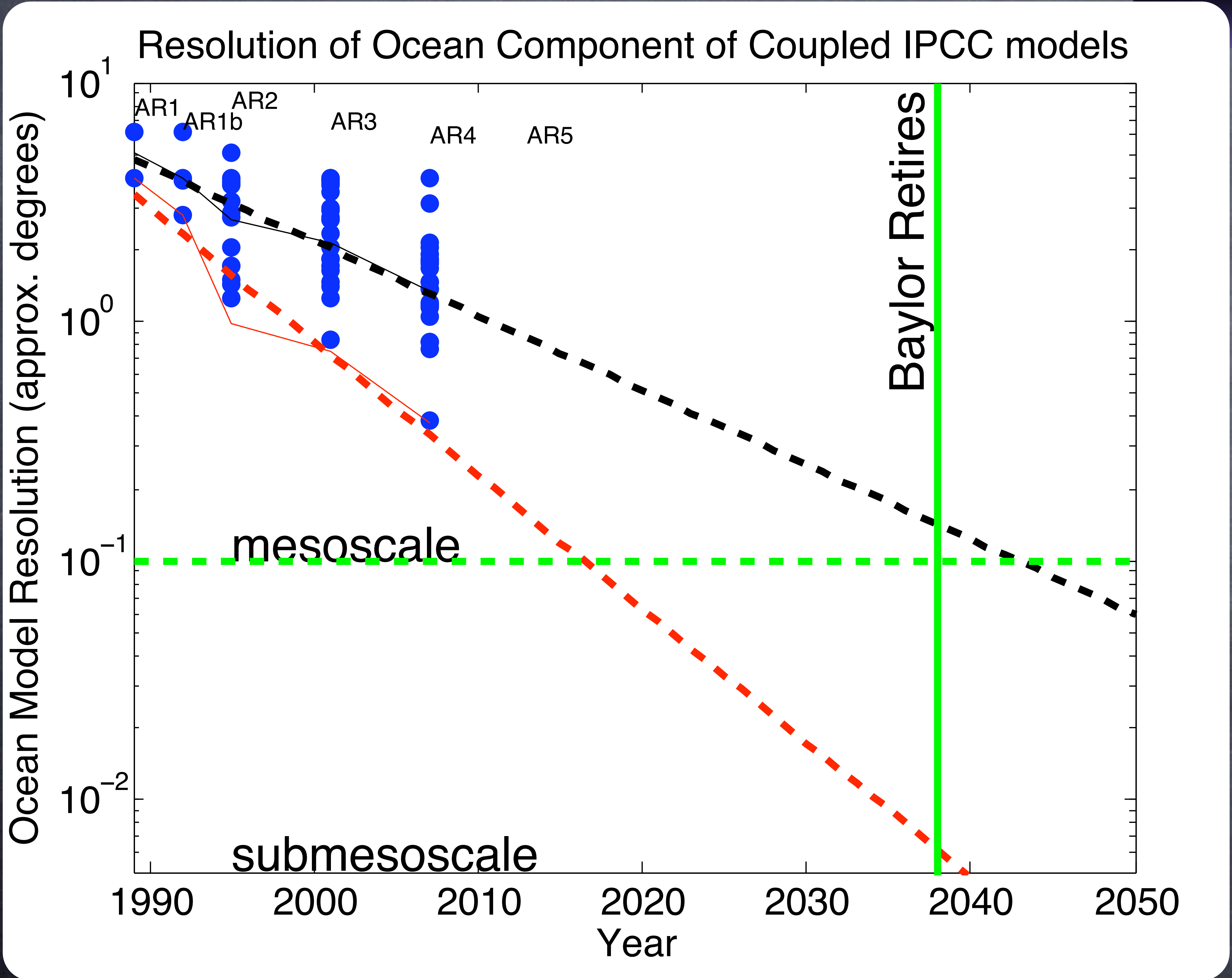
The Future of Resolution



The Future of Resolution



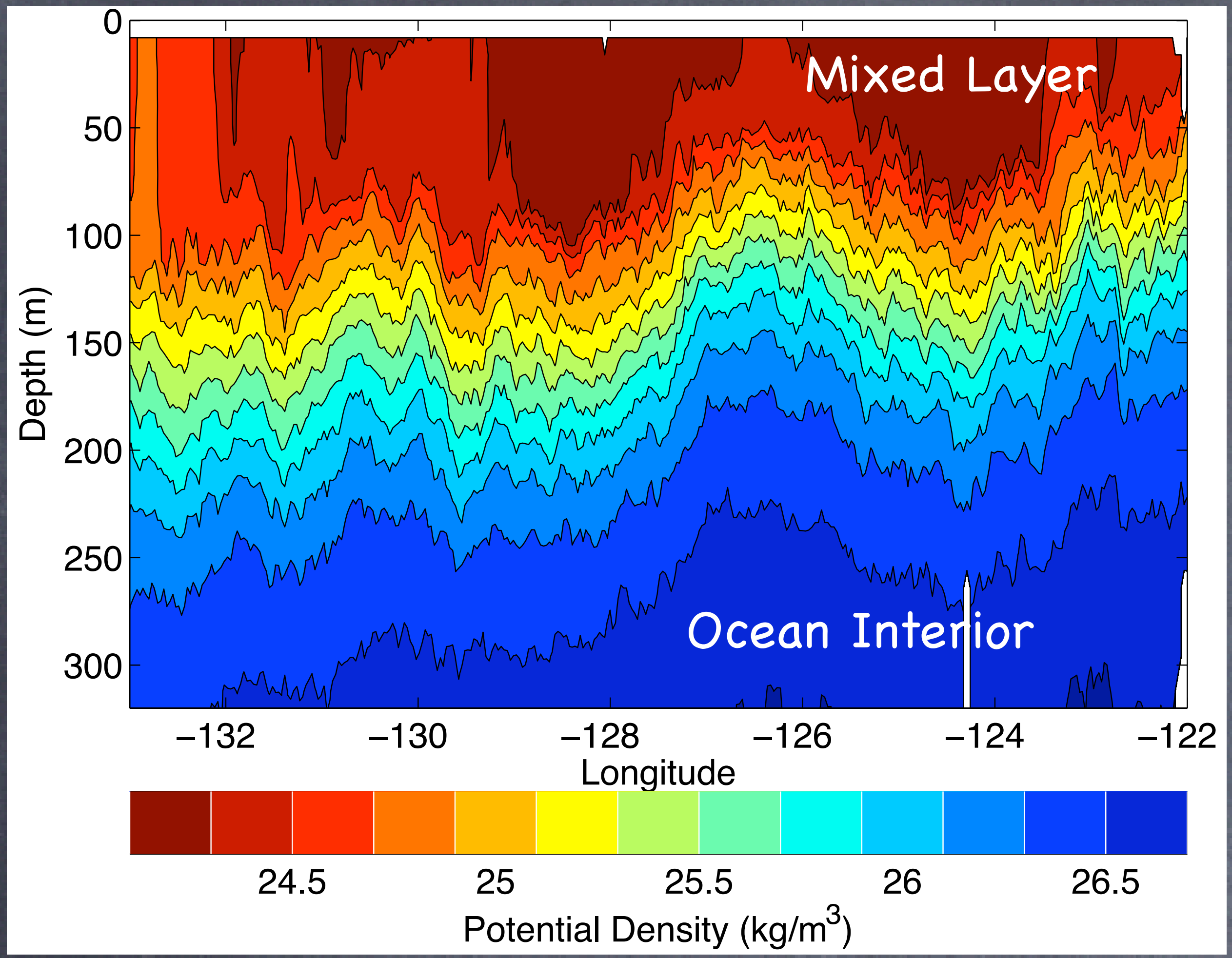
The Future of Resolution



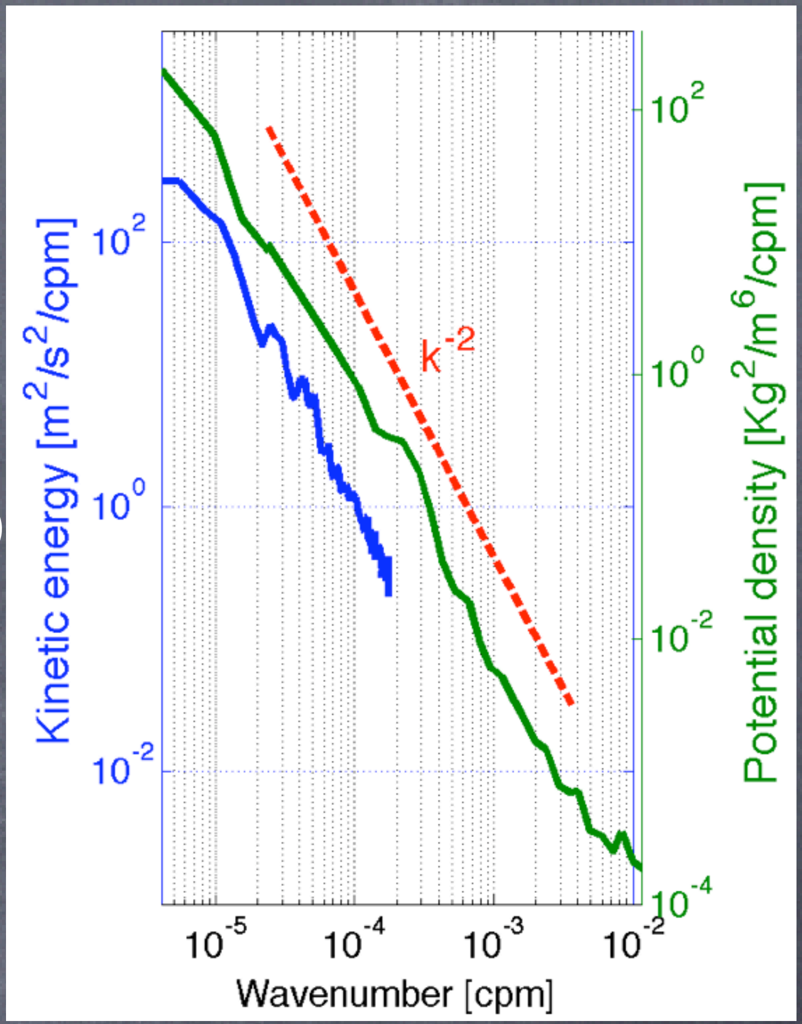
Surface Submesoscale Characteristics

- Ro=O(1), Ri=O(1) (Post-Rossby adjustment after mixing events or frontogenesis).
- Frontogenesis: Capet, McWilliams et al.; Klein, Lapeyre et al.
- Eddies and Instabilities? Fox-Kemper, Ferrari et al.; Molemaker, McW. et al.
- Climate Significance: The Ocean and Atmosphere 'Talk' through the Mixed Layer, and Phytoplankton live there
- Why focus on the mixed layer? Next slides.

Upper Ocean: Mixed Layer



Pot'l Density measured by Seasoar towyo along a straight section from (32.5N, 122W) to (35N, 132W) between the CA current and the subtropical gyre.
(as in Ferrari & Rudnick, 2000)

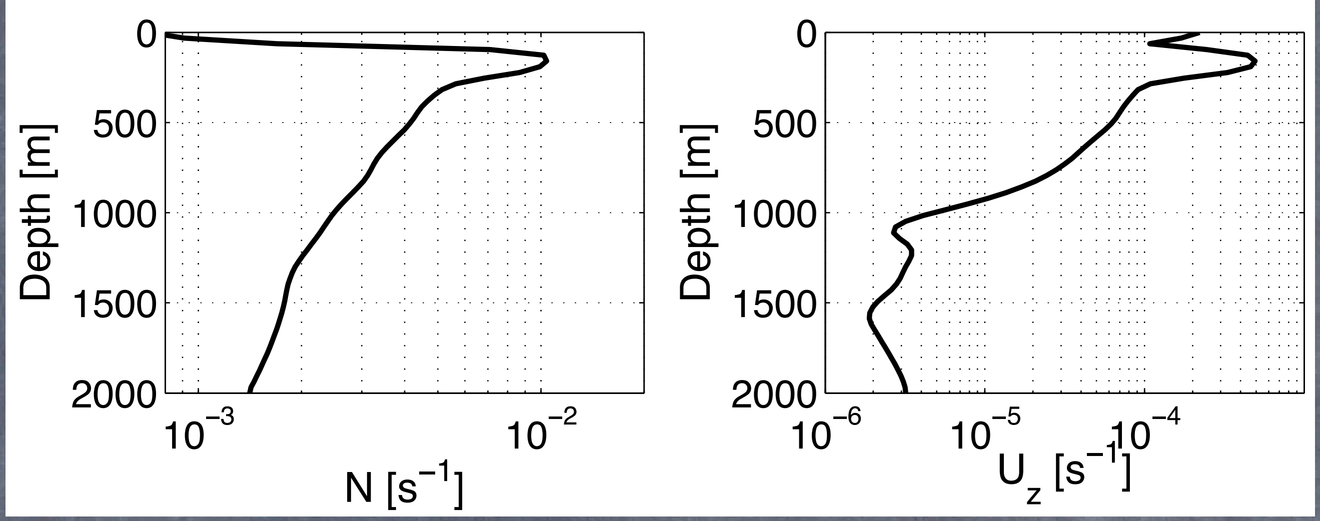


The mixed layer is not TOTALLY mixed.
Fronts are common.

This weakly-stratified, fairly rapidly mixed region is active at the submesoscale...

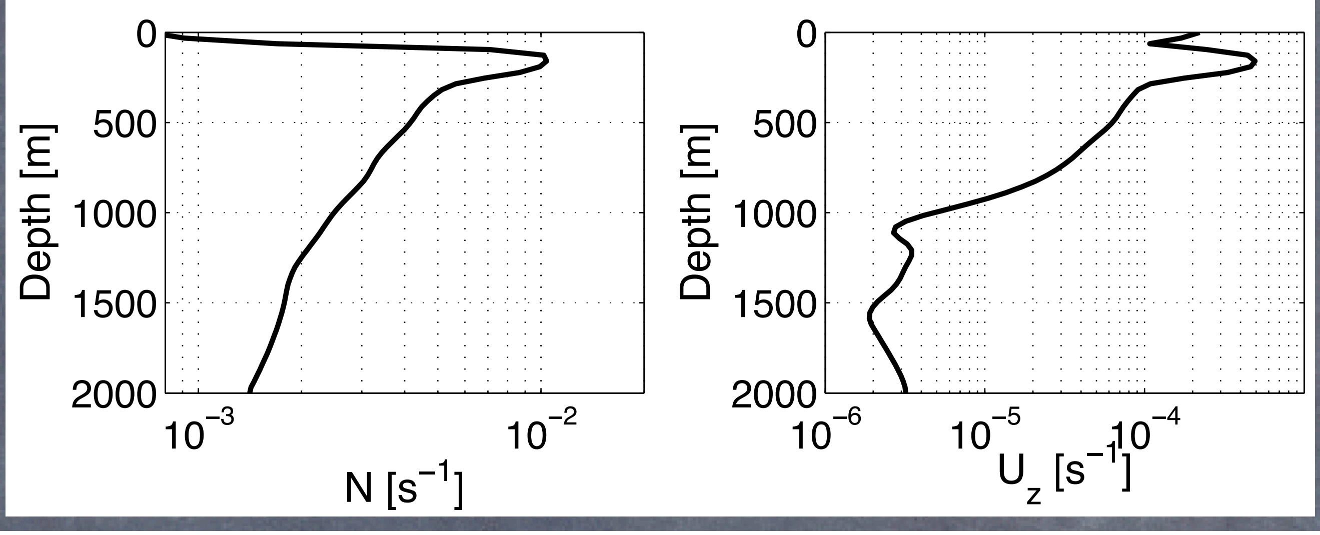
Typical Stratification Permits Two Types of Baroclinic Instability:

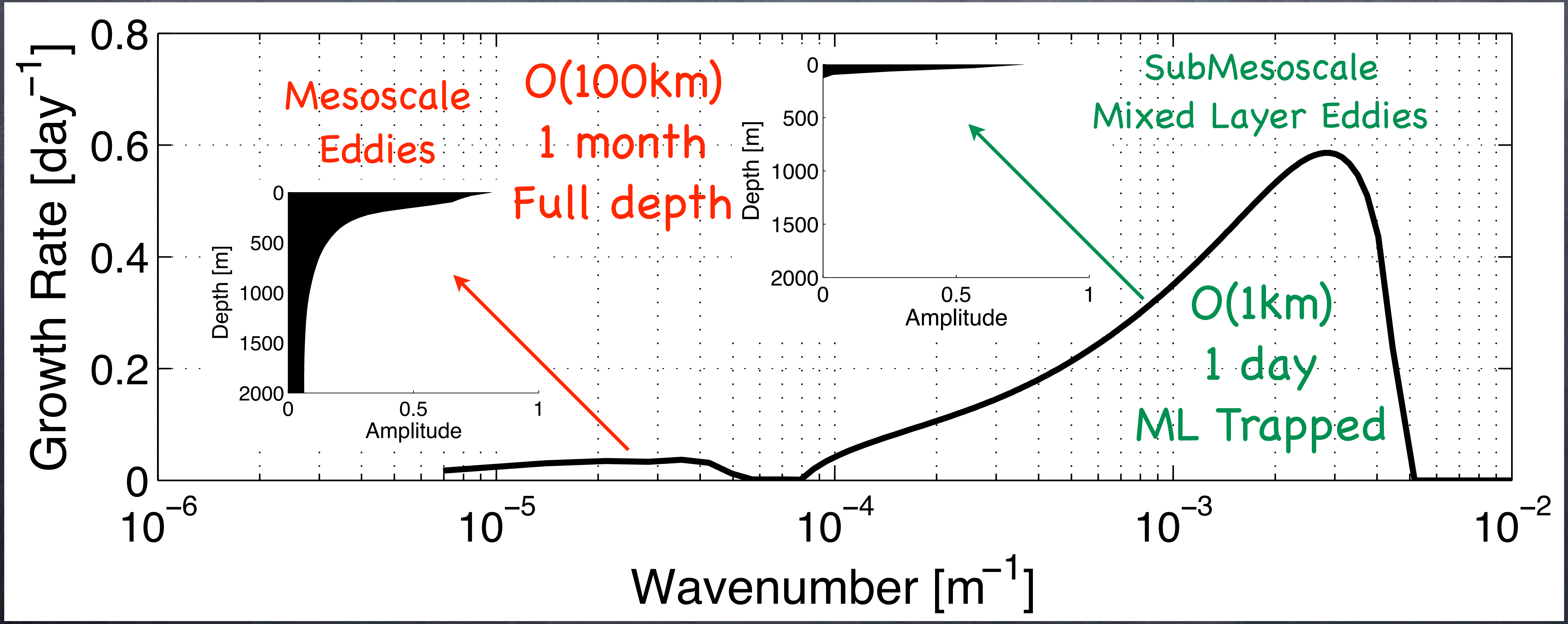
Mesoscale and SubMesoscale Eddies (Boccaletti et al., 2006)



Typical Stratification Permits Two Types of Baroclinic Instability:

Mesoscale and SubMesoscale Eddies (Boccaletti et al., 2006)

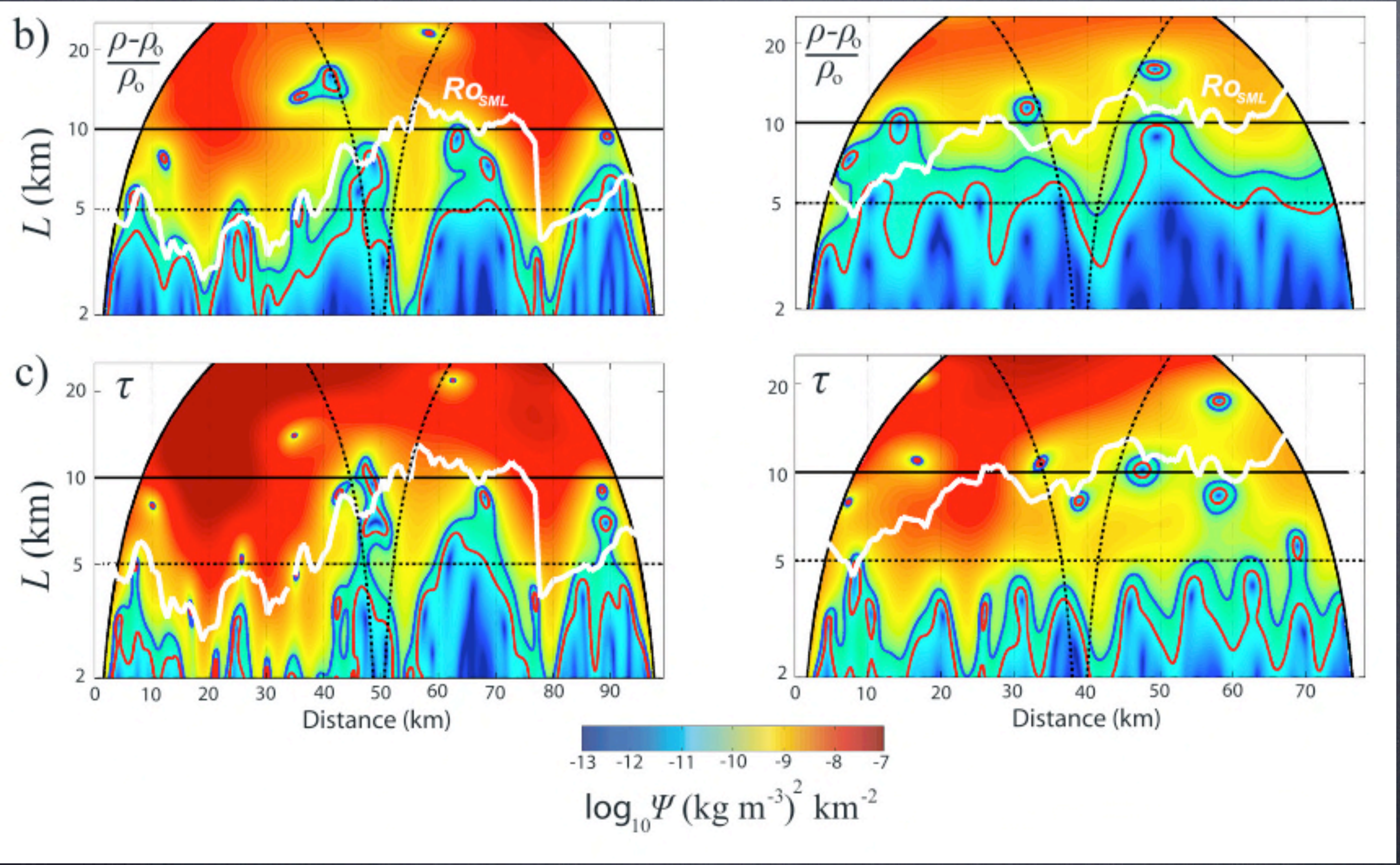




Also, Mixed Layer Fronts are Submesoscale:

Density variability at larger scale than ML Def. Radius

(Hosegood et al., 2006)

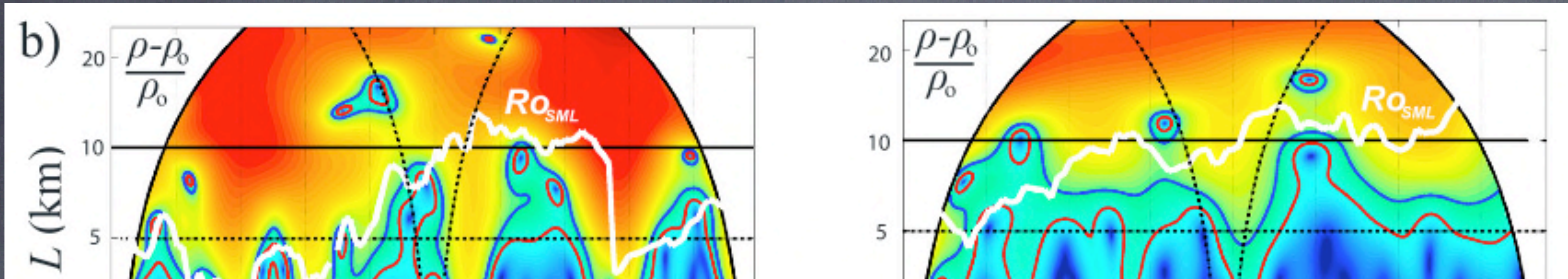


Wavelet Scalograms of Seasoar Towyos of N. Pacific Subtropical Front.

Also, Mixed Layer Fronts are Submesoscale:

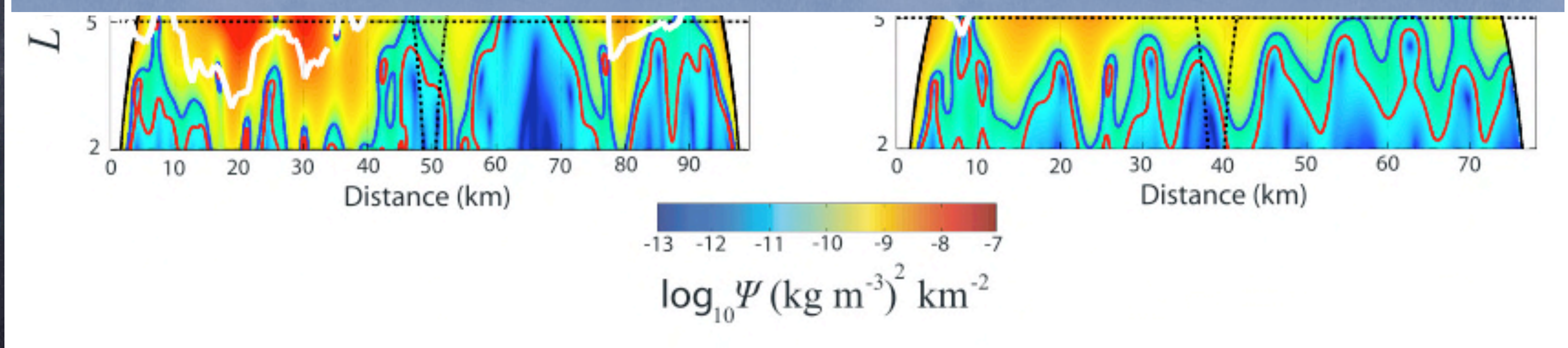
Density variability at larger scale than ML Def. Radius

(Hosegood et al., 2006)



Regarding First BC mode def. radius motion:

'The Ocean has a great deal more variability than that' -C. Wunsch

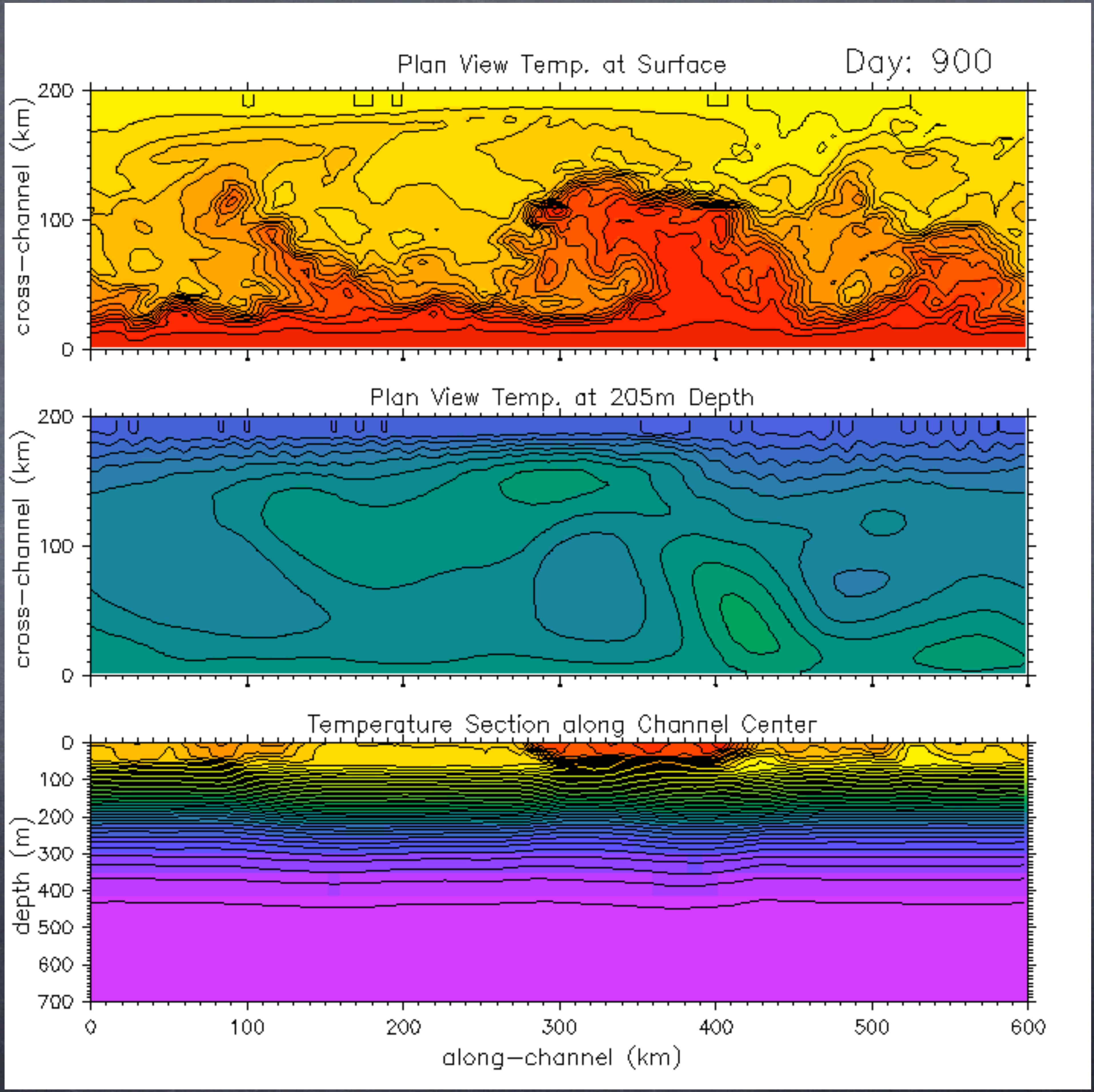


Wavelet Scalograms of Seasoar Towyos of N. Pacific Subtropical Front.

Mesoscale and SubMesoscale are Coupled Together:

ML Fronts are formed by Mesoscale Straining.

Submesoscale eddies remove PE from those fronts.



The Character of the Submesoscale

(Capet et al., 2008)

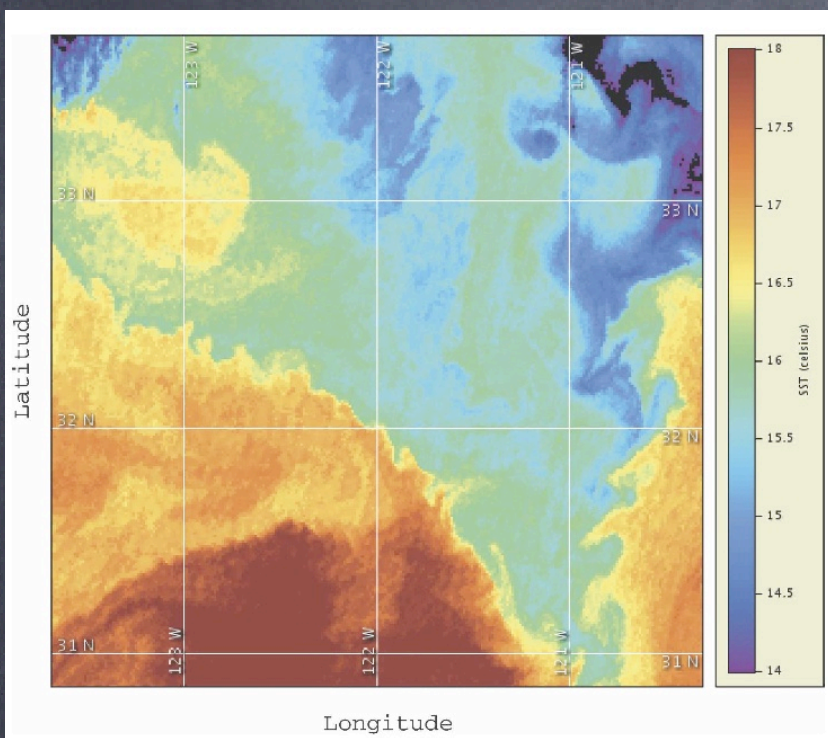
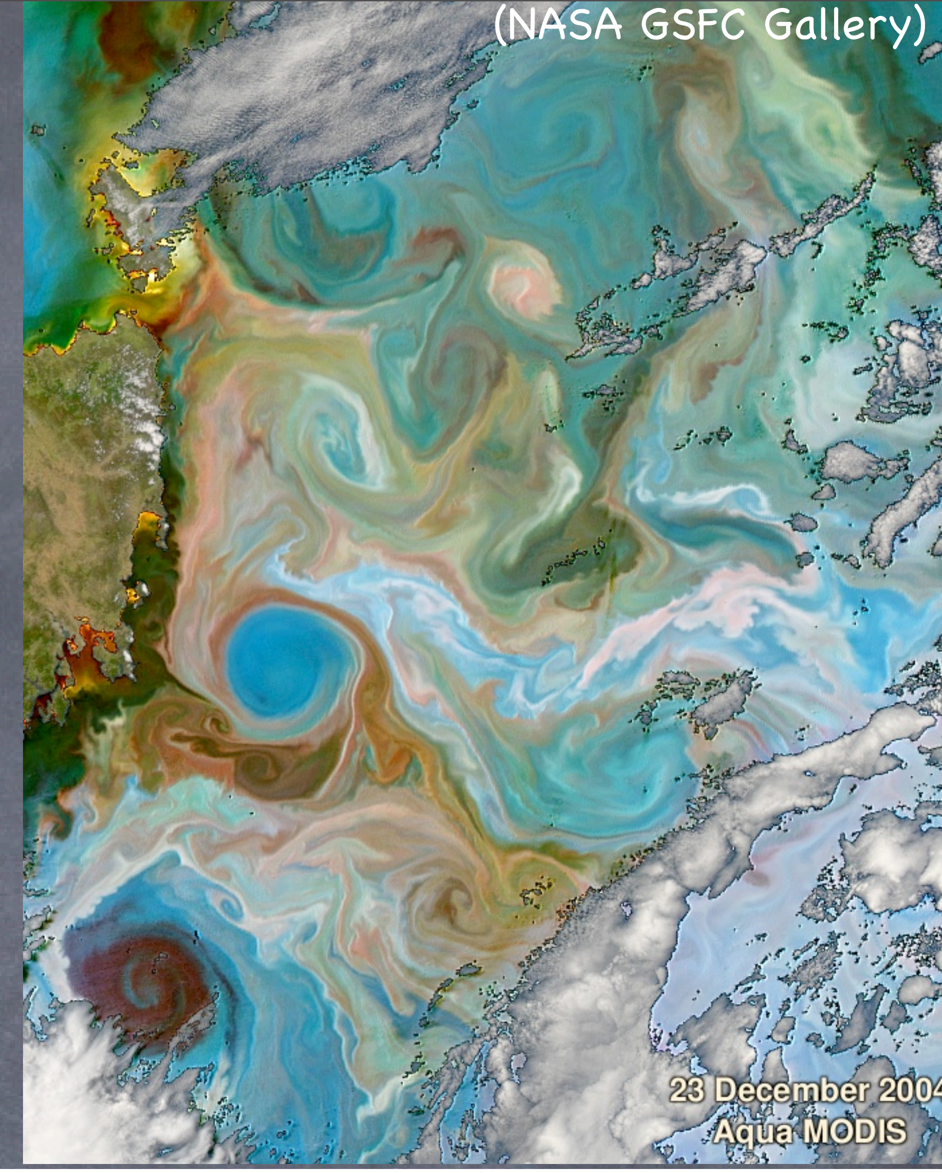


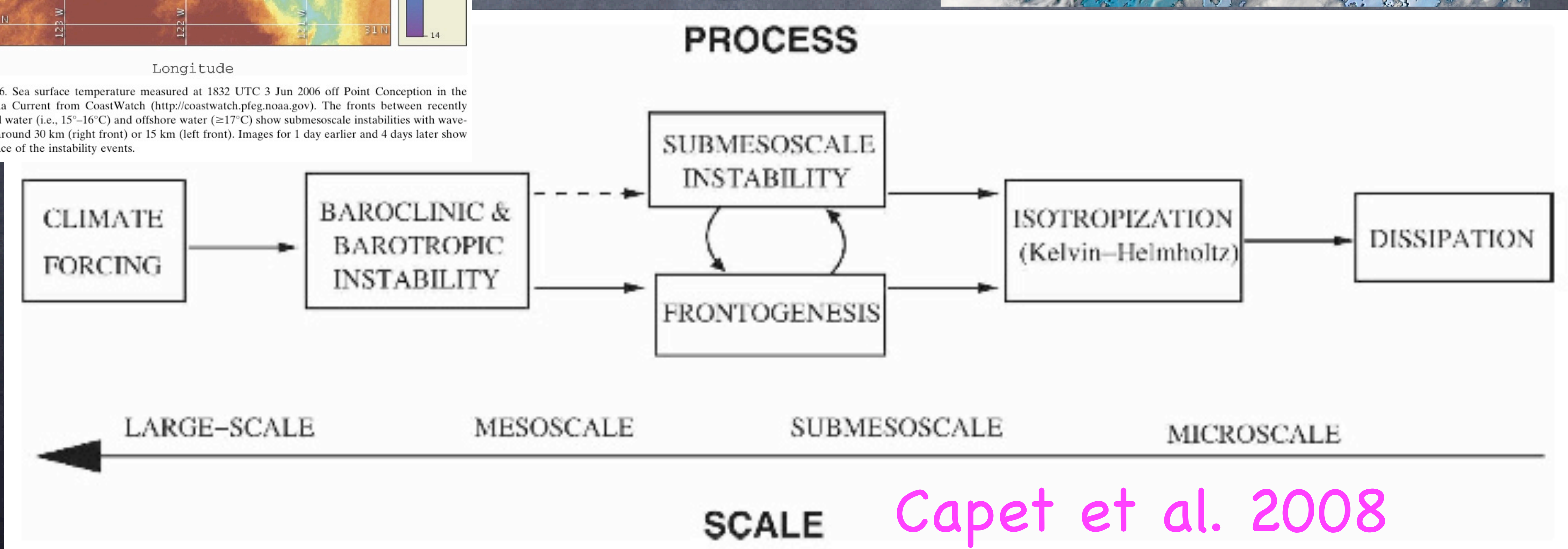
FIG. 16. Sea surface temperature measured at 1832 UTC 3 Jun 2006 off Point Conception in the California Current from CoastWatch (http://coastwatch.pfeg.noaa.gov). The fronts between recently upwelled water (i.e., 15°–16°C) and offshore water (≥17°C) show submesoscale instabilities with wavelengths around 30 km (right front) or 15 km (left front). Images for 1 day earlier and 4 days later show persistence of the instability events.

- Fronts
- Eddies
- Ro=O(1)
- Ri=O(1)

100 km

(NASA GSFC Gallery)





Capet et al. 2008

Vertical fluxes are Submesoscale and tend to restratify

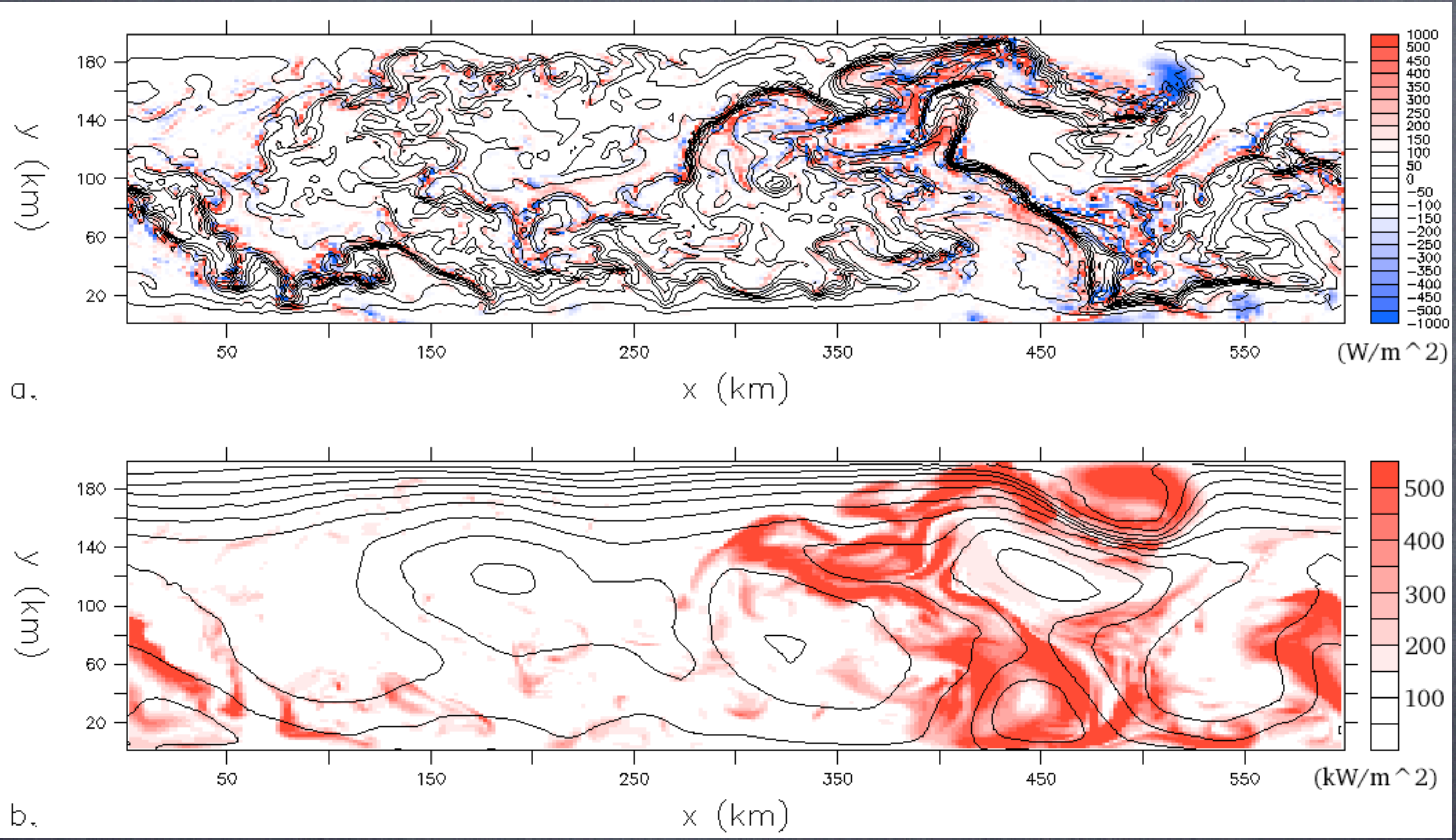
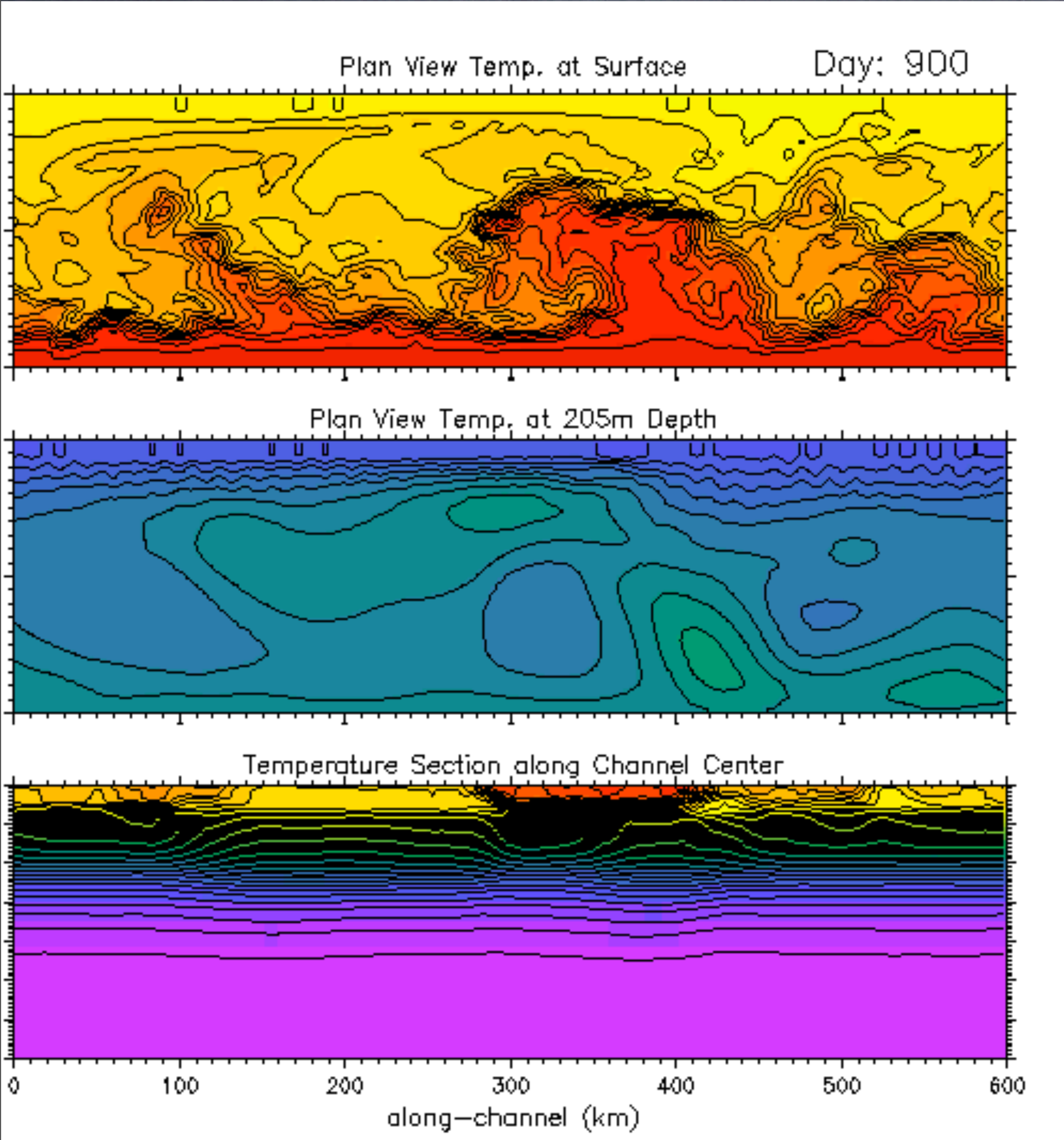


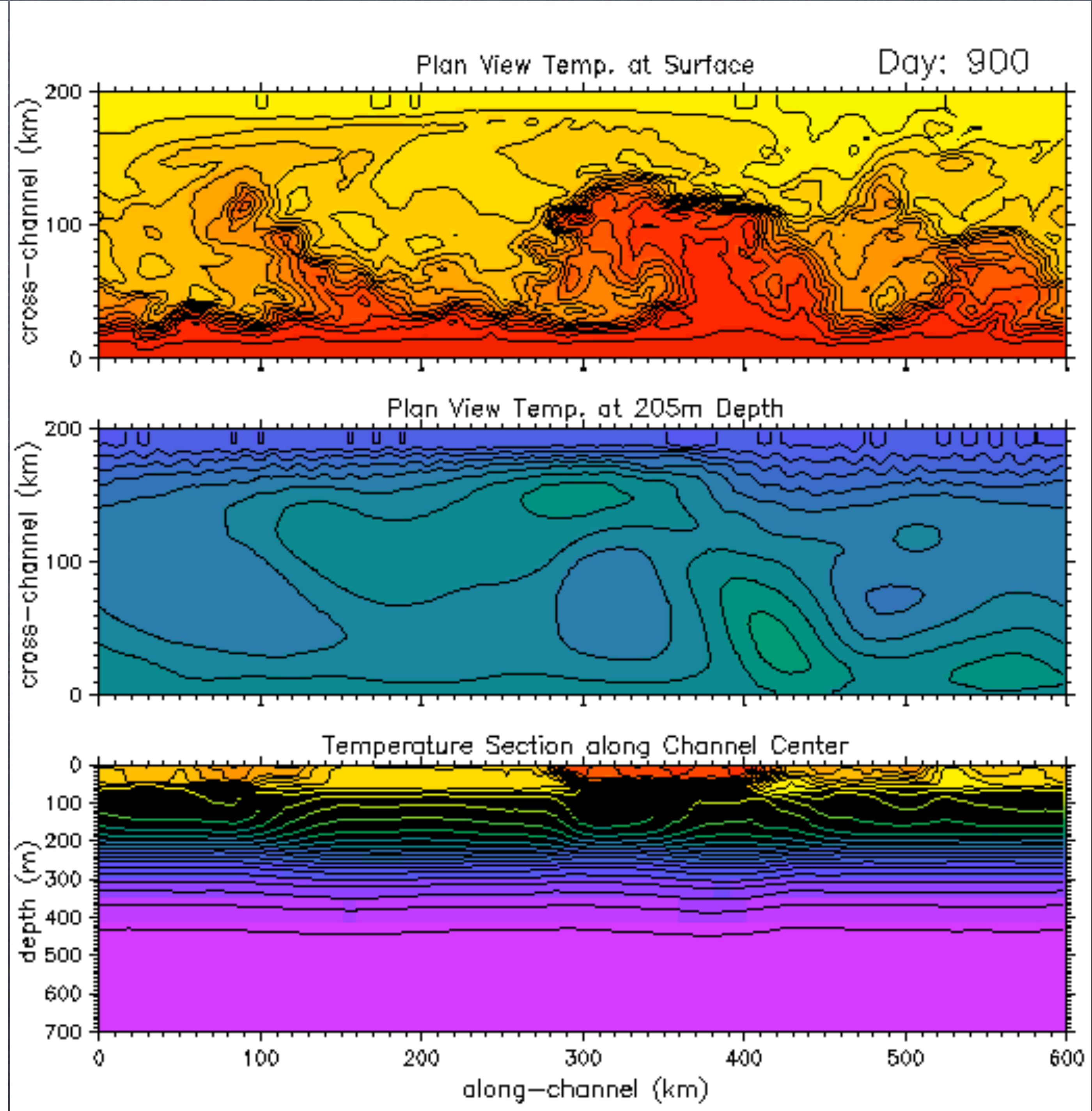
FIGURE 1: Contours of temperature at the a) surface and b) below the mixed layer base in a simulation with both mesoscale eddies and MLEs ($0.2°C$ contour intervals). Shading indicates the value at the depth where $\overline{w'b'}$ (upper panel) and $|\overline{\mathbf{u}'_H b'}|$ (lower panel) take the largest magnitude.

Horizontal fluxes are Mesoscale and tend to stir

Remixing the Mixed Layer Counts!

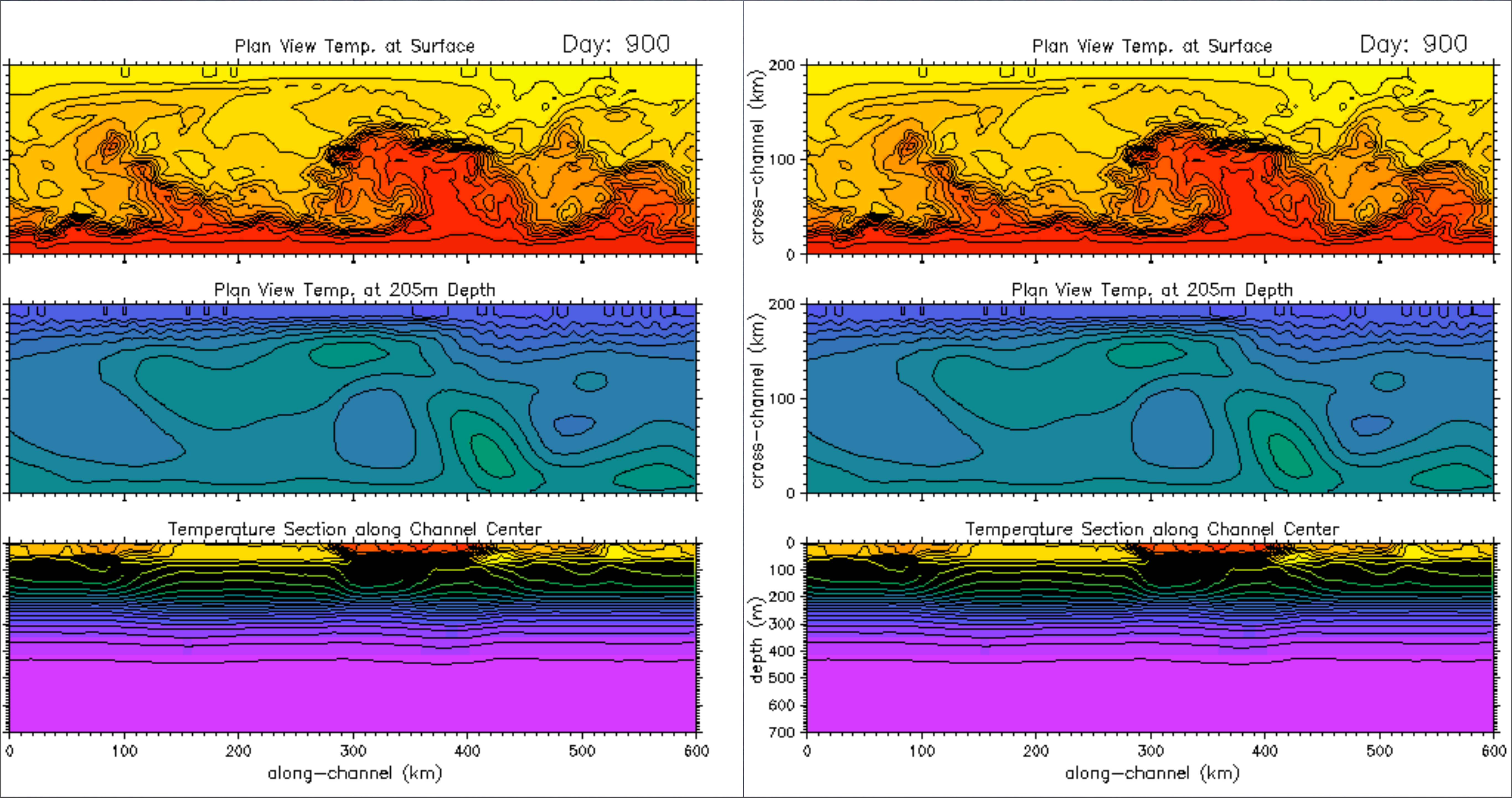
The vertical buoyancy flux in the ML (<w'b'>) without diurnal cycle is notless than with cycle (ML)



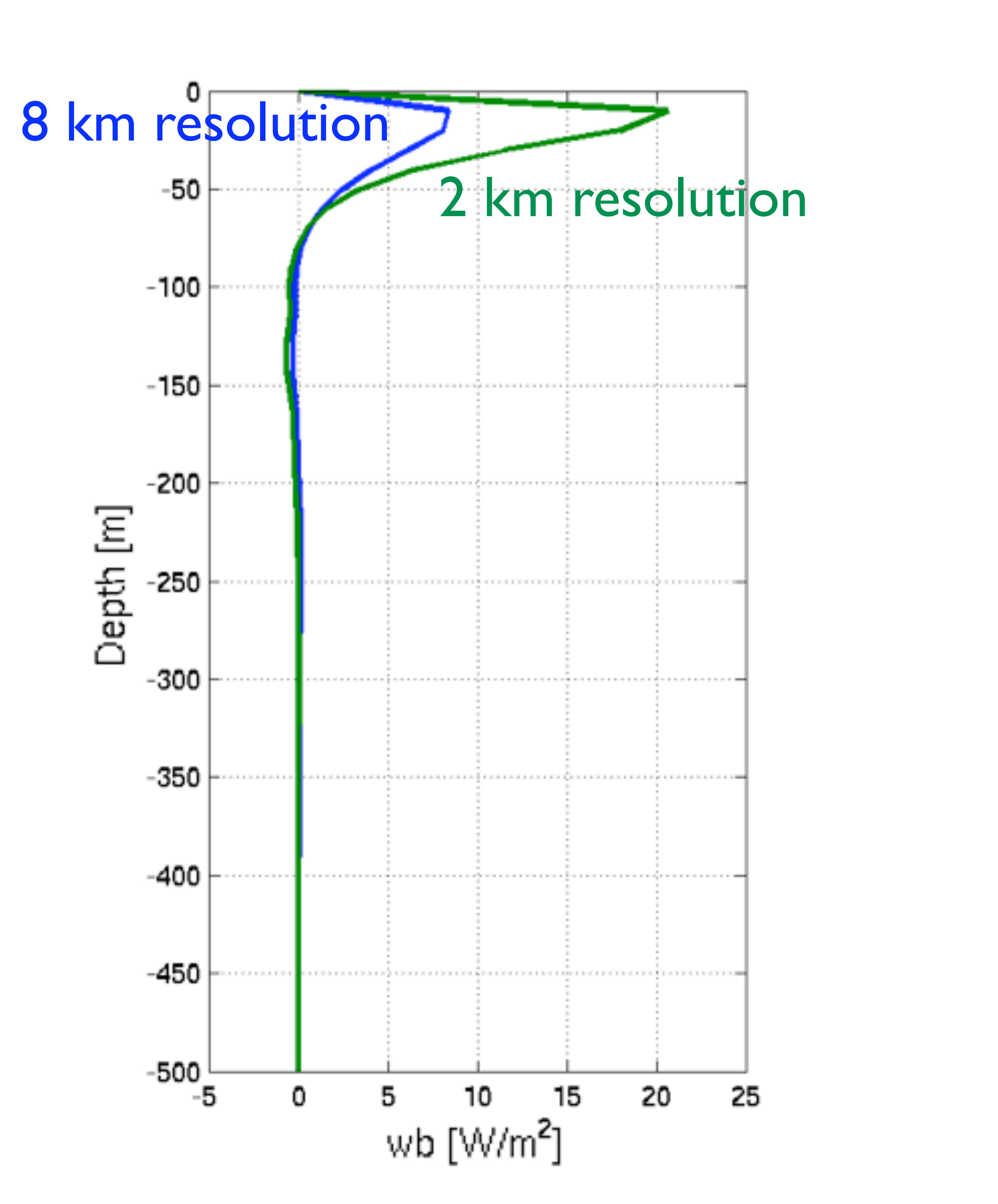


Remixing the Mixed Layer Counts!

The vertical buoyancy flux in the ML (<w'b'>) without diurnal cycle is 4x less than with cycle (ML)



Vertical buoyancy fluxes increase as submeso becomes resolved

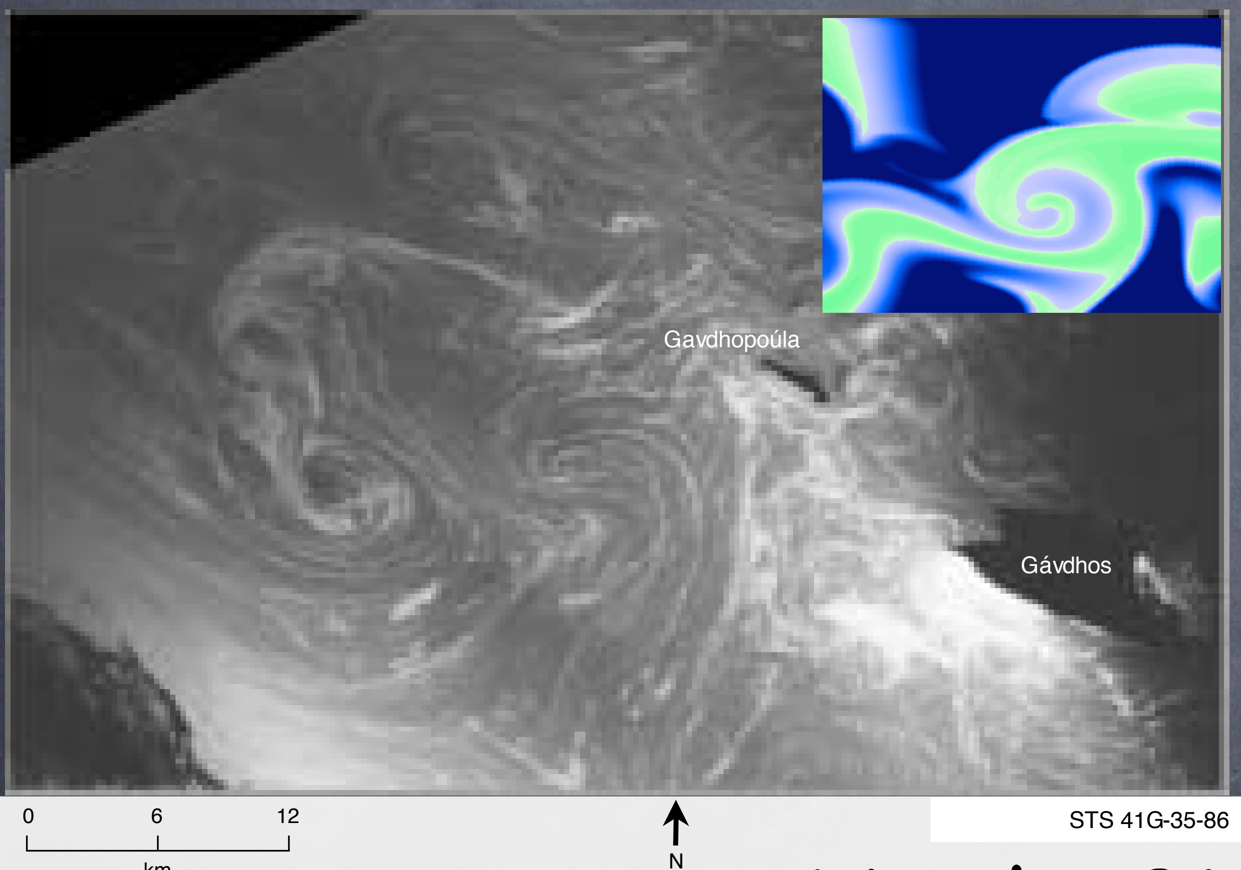


- Comparison of vertical buoyancy fluxes at two different resolutions
- Fourfold enhancement of fluxes critically depends on presence of a mixed layer
- The fluxes are such as to rapidly restratify the surface mixed layer

Known since Oschlies, '02

Observed:

Strongest Mixed Layer Eddies= Spirals on the Sea?



Munk, 01

Figure 1. A pair of interconnected spirals in the Mediterranean Sea south of Crete. This vortex pair has a clearly visible stagnation point between the two spirals, the cores of which are aligned with the preconditioning wind field. 7 October 1984.

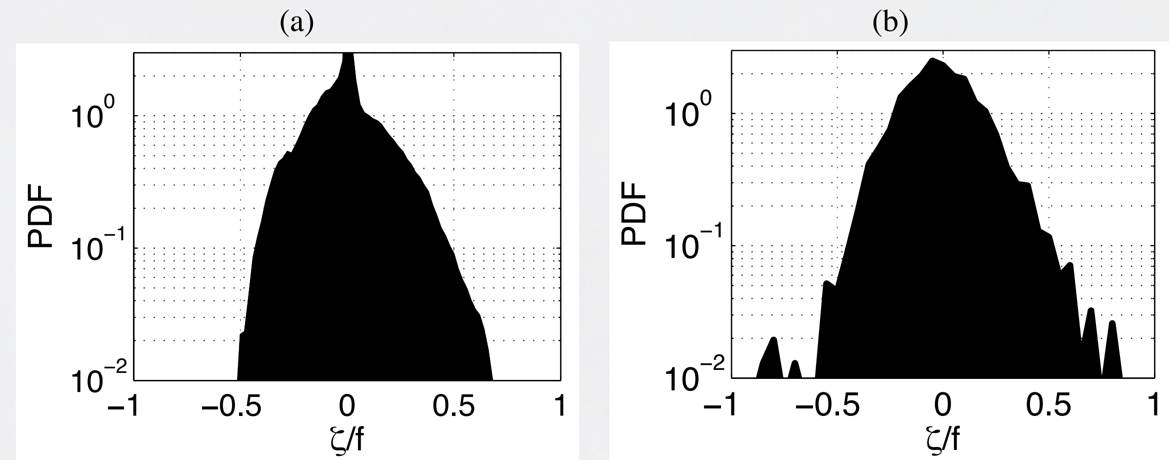


Figure 12: Probability density function of relative vorticity divided by Coriolis parameter. (a) Results from the numerical simulation of a slumping horizontal density front. ($z > 100$ only to exclude bottom Ekman layer.) The PDF is estimated using surface velocity measurements at day 25 (see also Fig. 11). A positive skewness appears as soon as the baroclinic instability enters in the nonlinear stage, and it continues to grow. Note that the peak at $\zeta/f = 0$ is due to the model's initial resting condition; that fluid has not yet been contacted by the MLI. (b) Results from ADCP measurements in the North Pacific. The PDF is calculated in bins of width 0.02.

Mixed Layer Eddies are predominantly cyclonic, as are obs.
(Boccaletti et al., 2007)

Other submesoscale features... not yet parameterized.

- Front-Wind interactions & Intrathermocline Eddies--Thomas, Thomas & Ferrari (08)
- Meddies and other SCVs--McW. (85), Lilly et al. (03)
- Coastal Submesoscale Eddies & Shelfbreak Front Eddies--Gawarkiewicz et al., Capet et al. (08)
- Submesoscale and Energy Cascade--Capet et al (08, pt. III)
- SQG and the Submesoscale--LaCasce, Klein, Lapeyre
- Review--Thomas, Tandon, Mahadevan (08)

First: Mixed Layer Eddy Parameterization

A Global Parameterization of Mixed Layer Eddy Restratification

$$\mathbf{\Psi} = \left[\frac{\Delta x}{L_f}\right] \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$

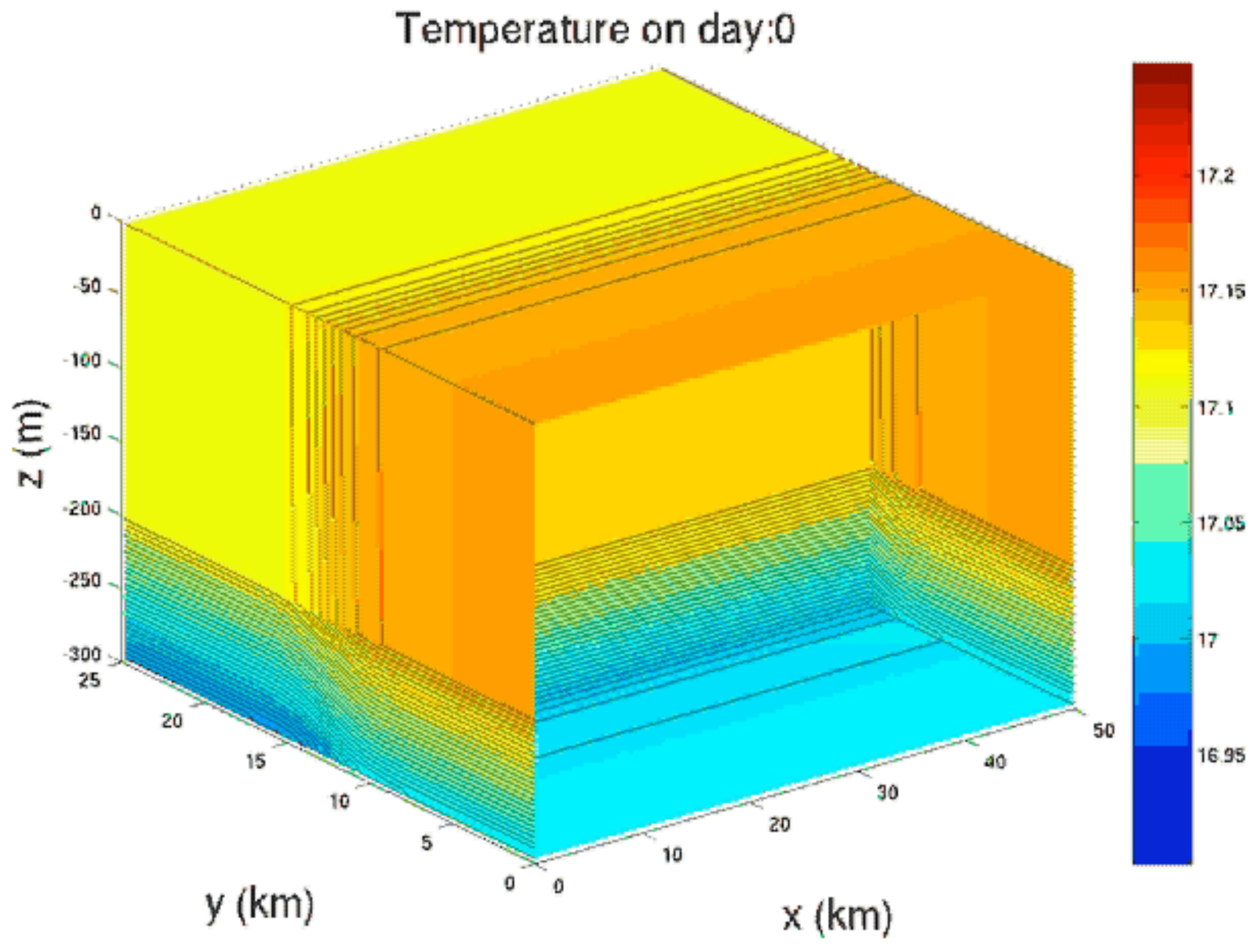
$$\mu(z) = \left[1 - \left(\frac{2z}{H} + 1\right)^2\right]\left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]$$

Which parameterizes eddy-induced velocity and buoyancy fluxes

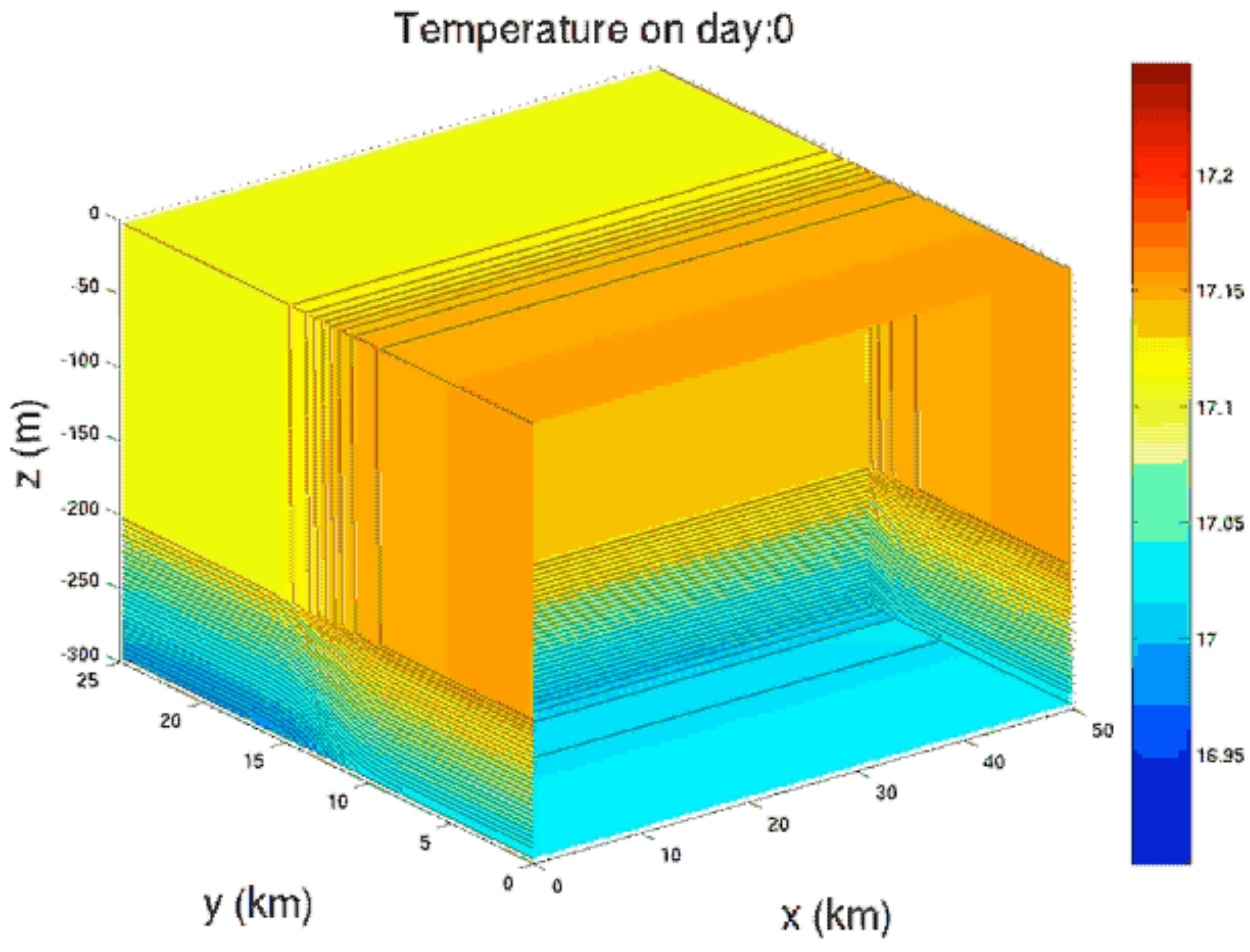
$$\mathbf{v}^\dagger = \nabla \times \mathbf{\Psi} \qquad \overline{\mathbf{v}'b'} \approx \mathbf{\Psi} \times \nabla \bar{b}$$

Where does this parameterization come from, and what can be applied to the mesoscale?

Prototype: Mixed Layer Front Adjustment



Simple Spindown

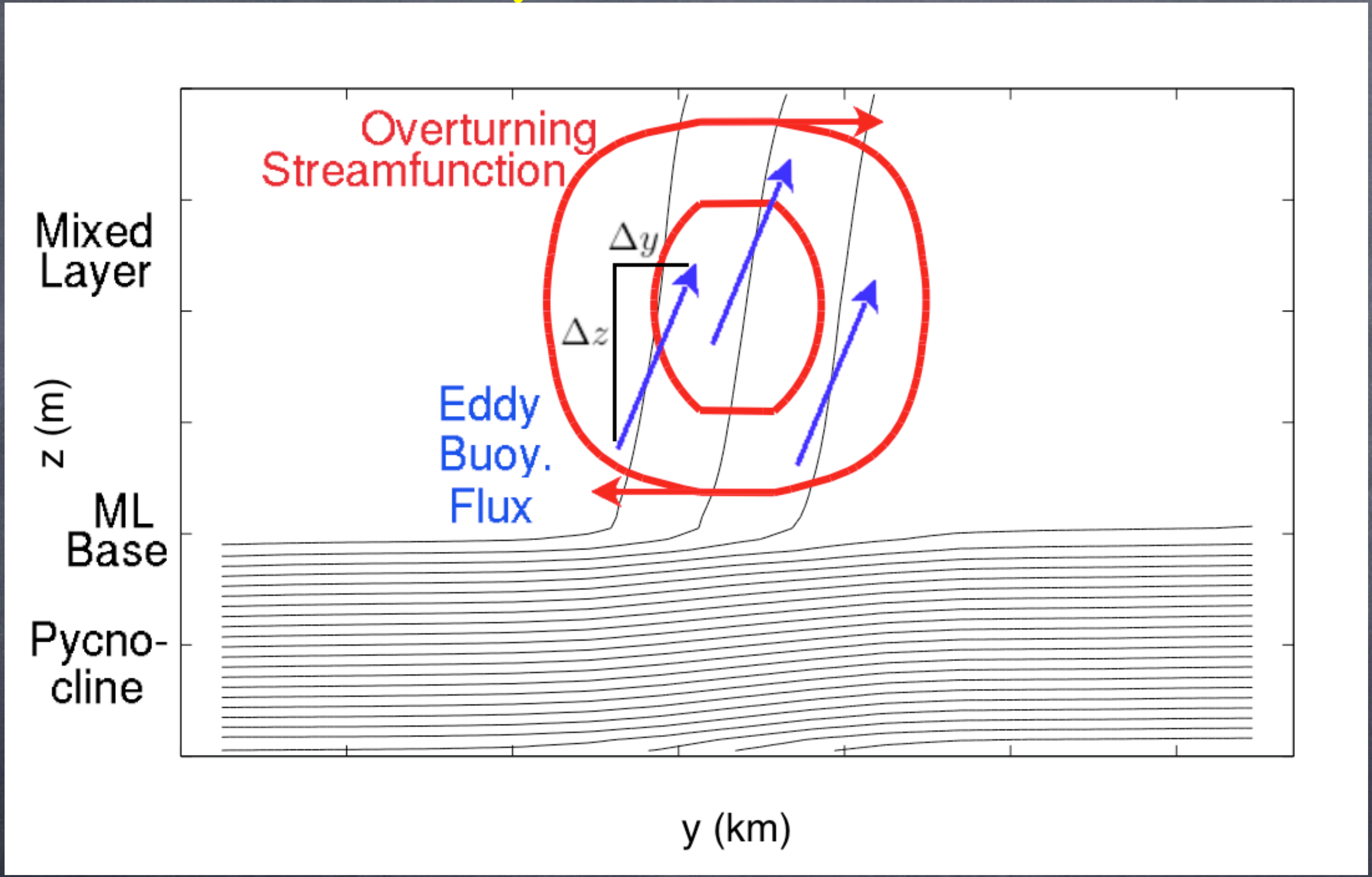


Plus, Diurnal Cycle and KPP

Note: initial geostrophic adjustment overwhelmed by eddy restratification: Ri>1 is our focus

Overturning Schematic:

An Eady-like Problem



Horizontal scale of overturning = scale of front

Vertical structure of overturning = ?

The Scaling of MLIs

Mixed Layer Eddies (MLEs) begin as ageostrophic baroclinic instability of a front in the Mixed Layer: the Mixed Layer Instability (MLI)

MLI=infinitesimal

MLE=finite amplitude

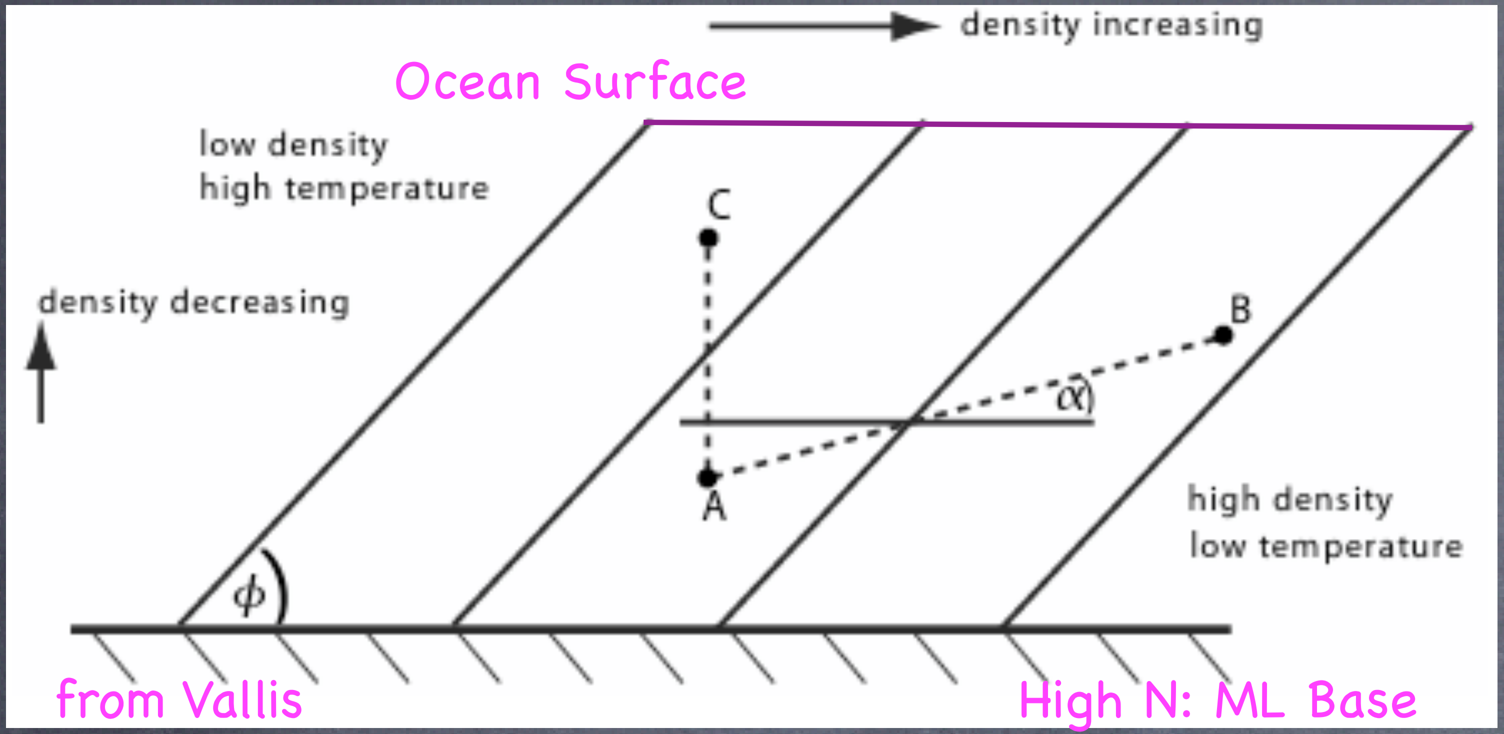
$$L_s = \frac{2\pi U}{|f|}\sqrt{\frac{1+Ri}{5/2}} \approx 5.6\frac{NH}{|f|}$$

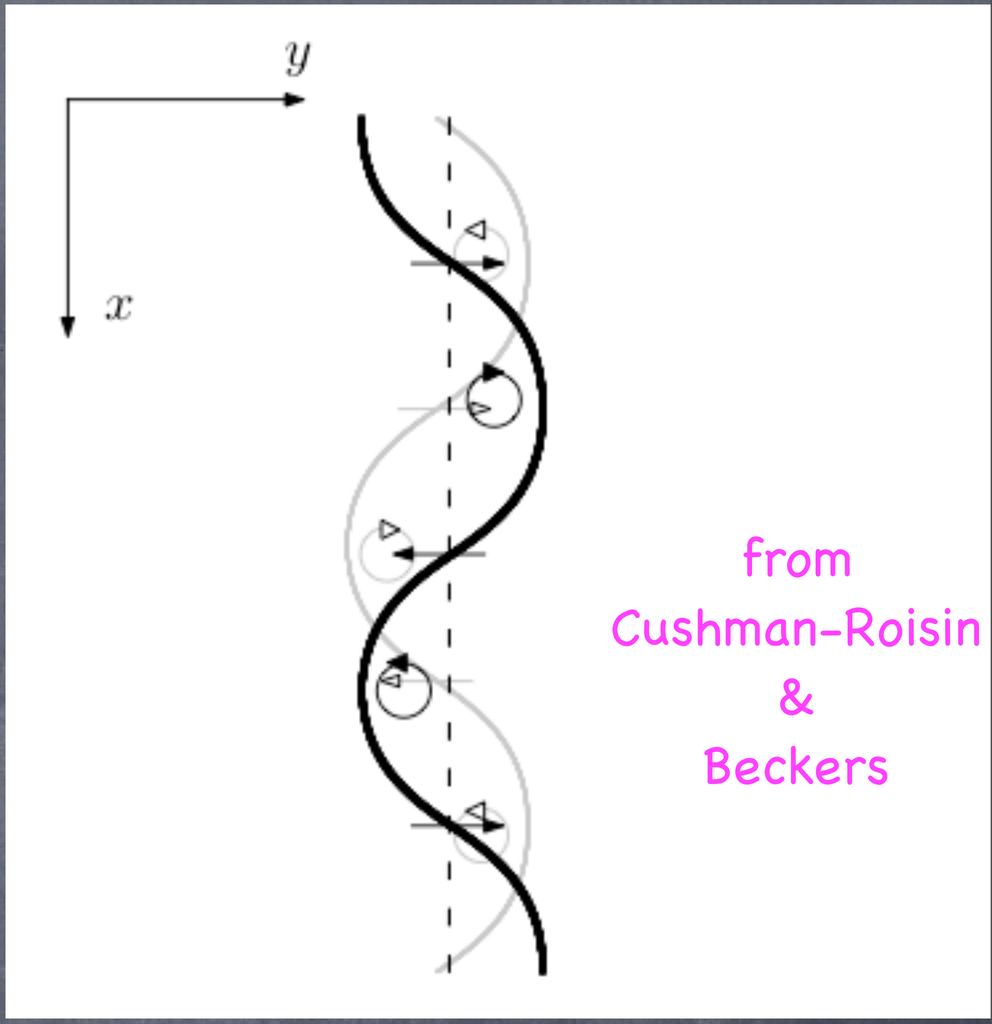
$$\tau_s = \sqrt{\frac{54}{5}}\frac{\sqrt{1+Ri}}{|f|} \approx \frac{4.6}{|f|}$$

(Fastest growing modes of Stone 66, 70, 72)

See Boccaletti et al 07,
Fox-Kemper et al 08
& Hosegood et al 06

MLI selected by Eady edge wave interaction





from
Cushman-Roisin
&
Beckers

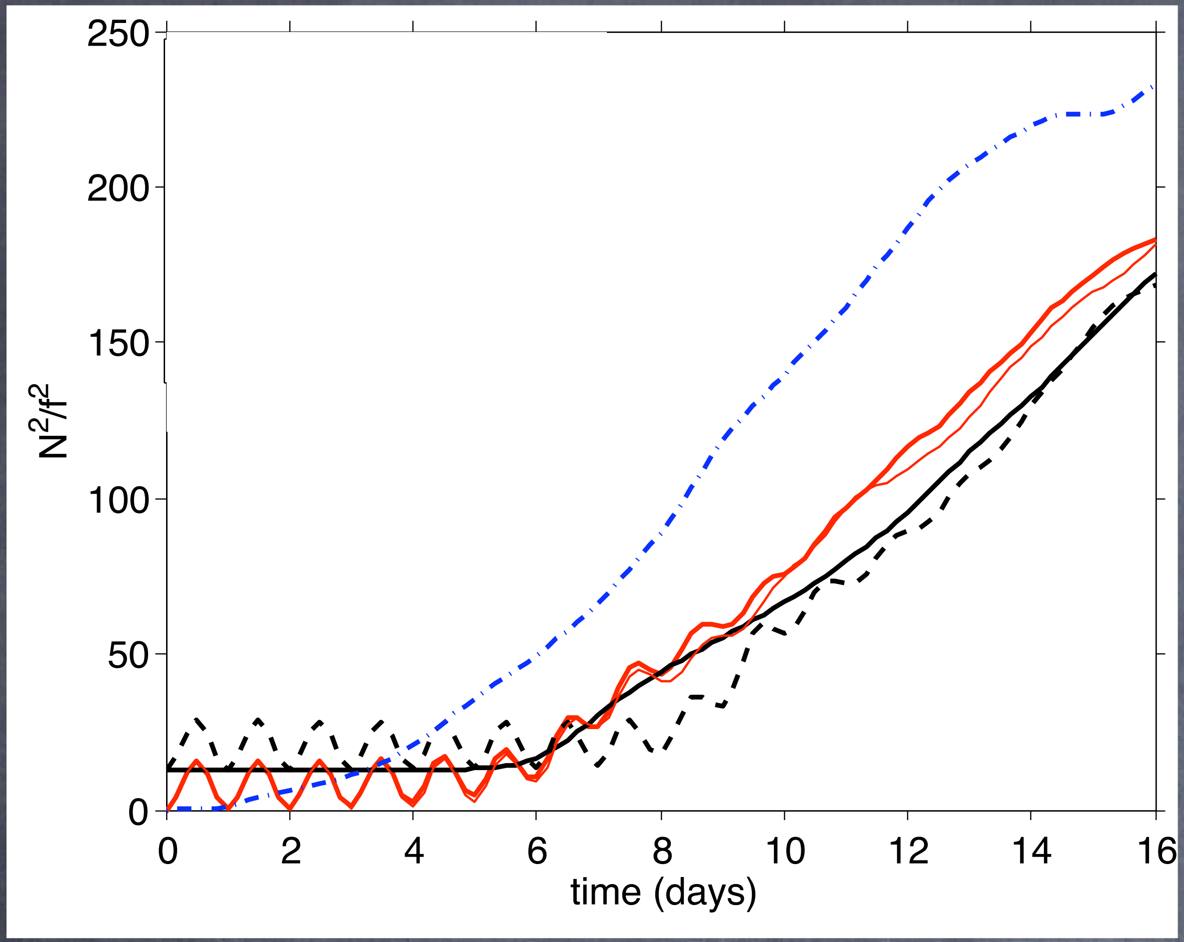
Eady,
SQG-like
Problem:

$$PV = 0 = f - (k^2 + l^2)\Psi + \frac{\partial}{\partial z}\frac{f^2}{N^2}\frac{\partial \Psi}{\partial z}$$

Vertical decay scale set by horizontal length-scale,
Growing lengthscale matches edge wave phase.

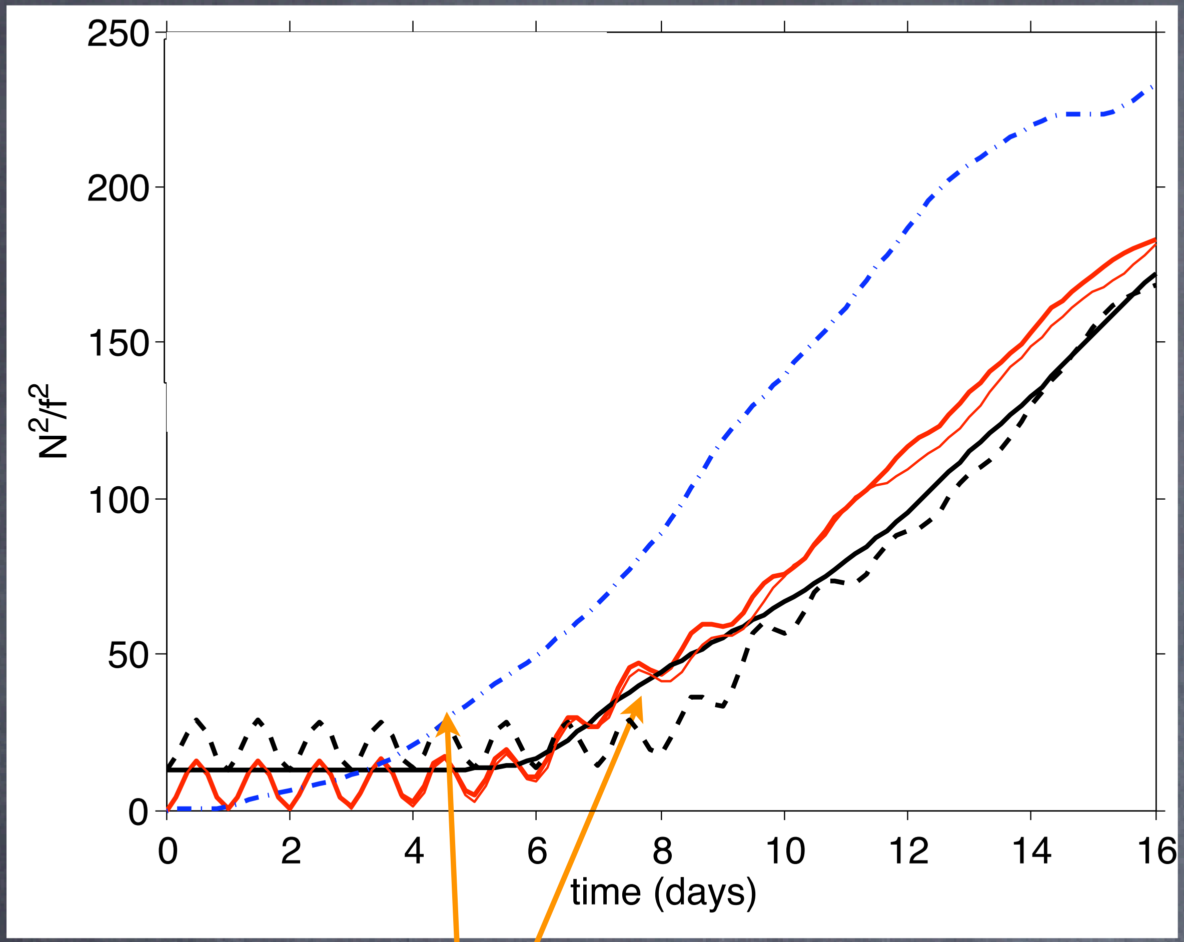
Parameterization of MLEs: Ingredients

Restratifying ->



Parameterization of MLEs: Ingredients

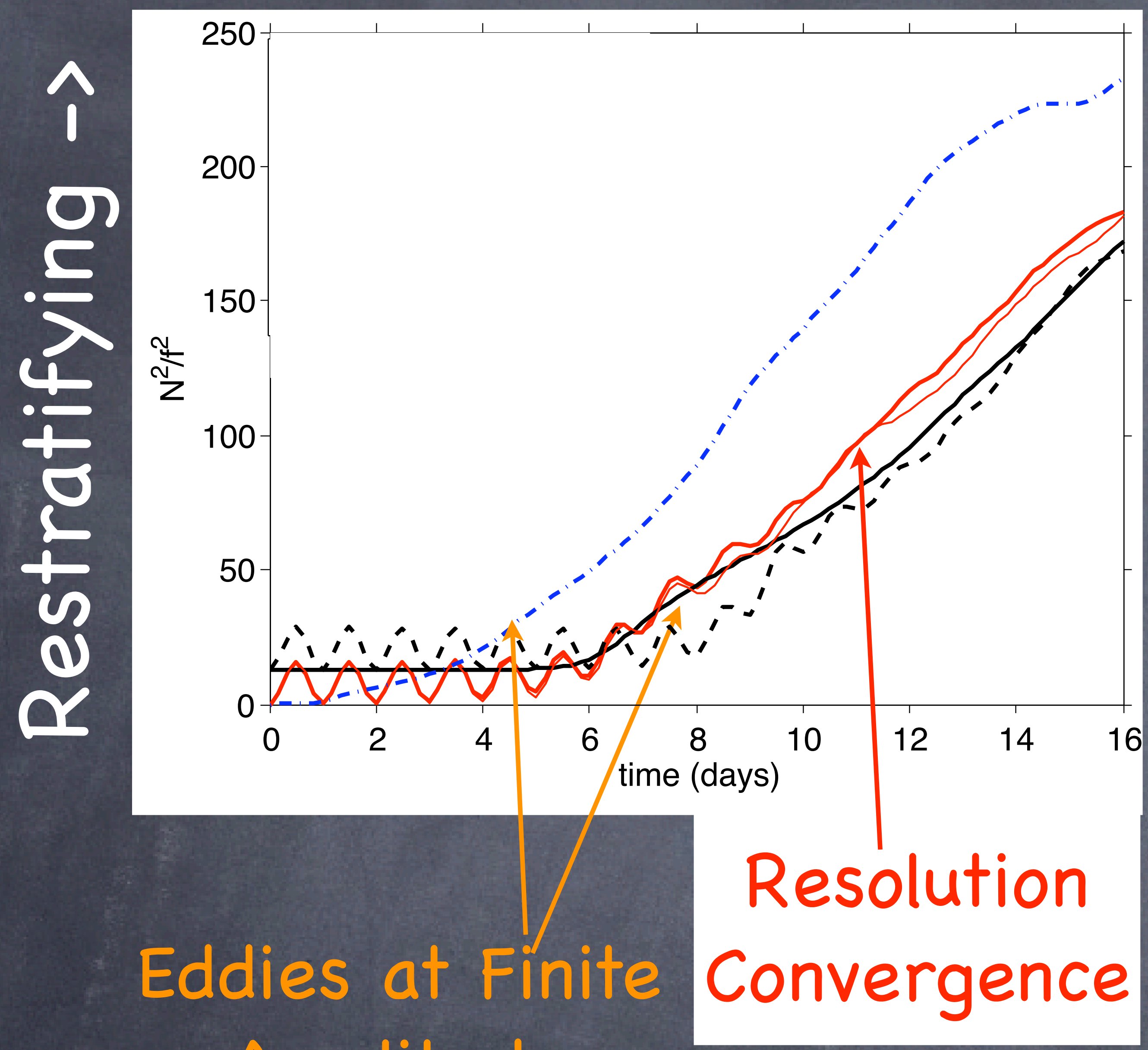
Restratifying ->



Eddies at Finite Amplitude

Restratification occurs with *finite* MLEs

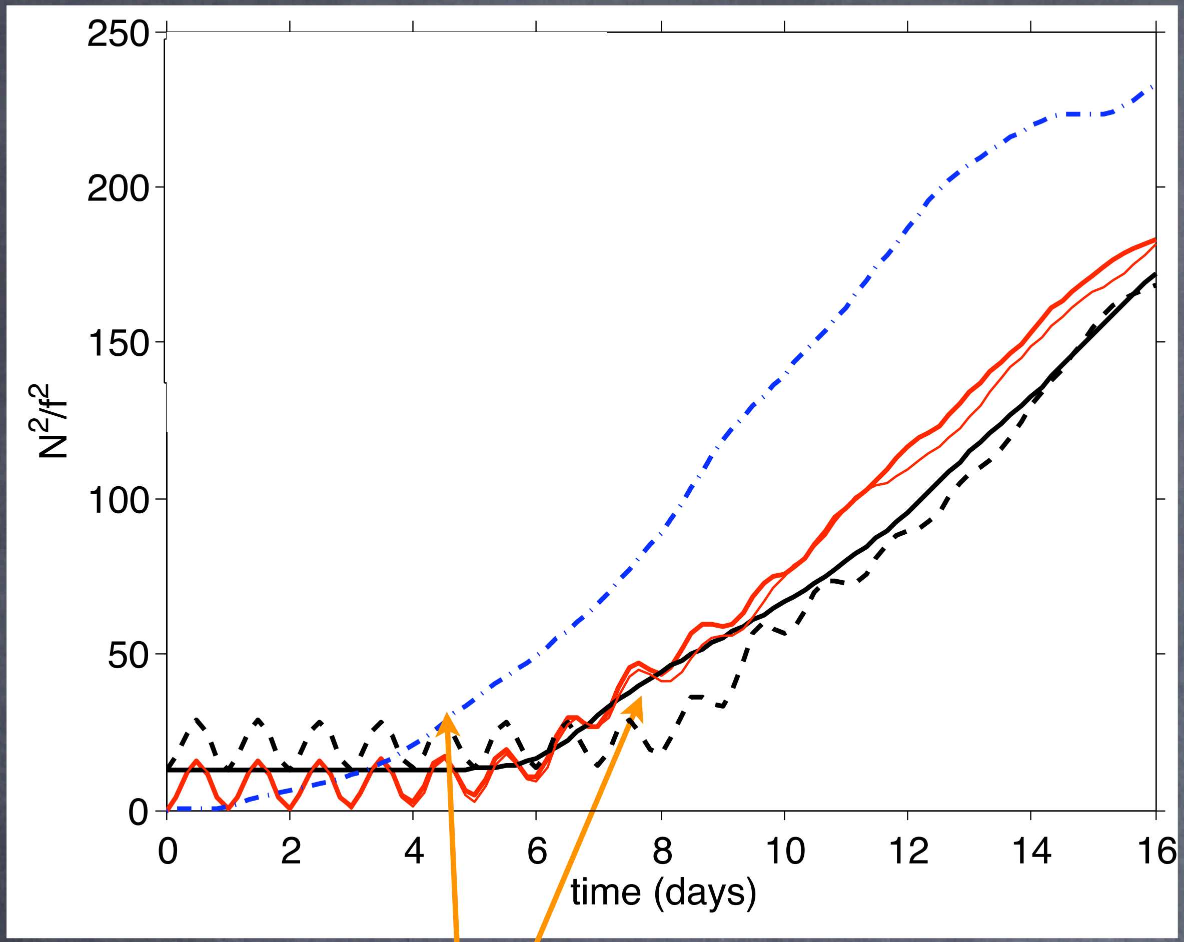
Parameterization of MLEs: Ingredients



Restratification occurs with *finite* MLEs

Parameterization of MLEs: Ingredients

Restratifying ->



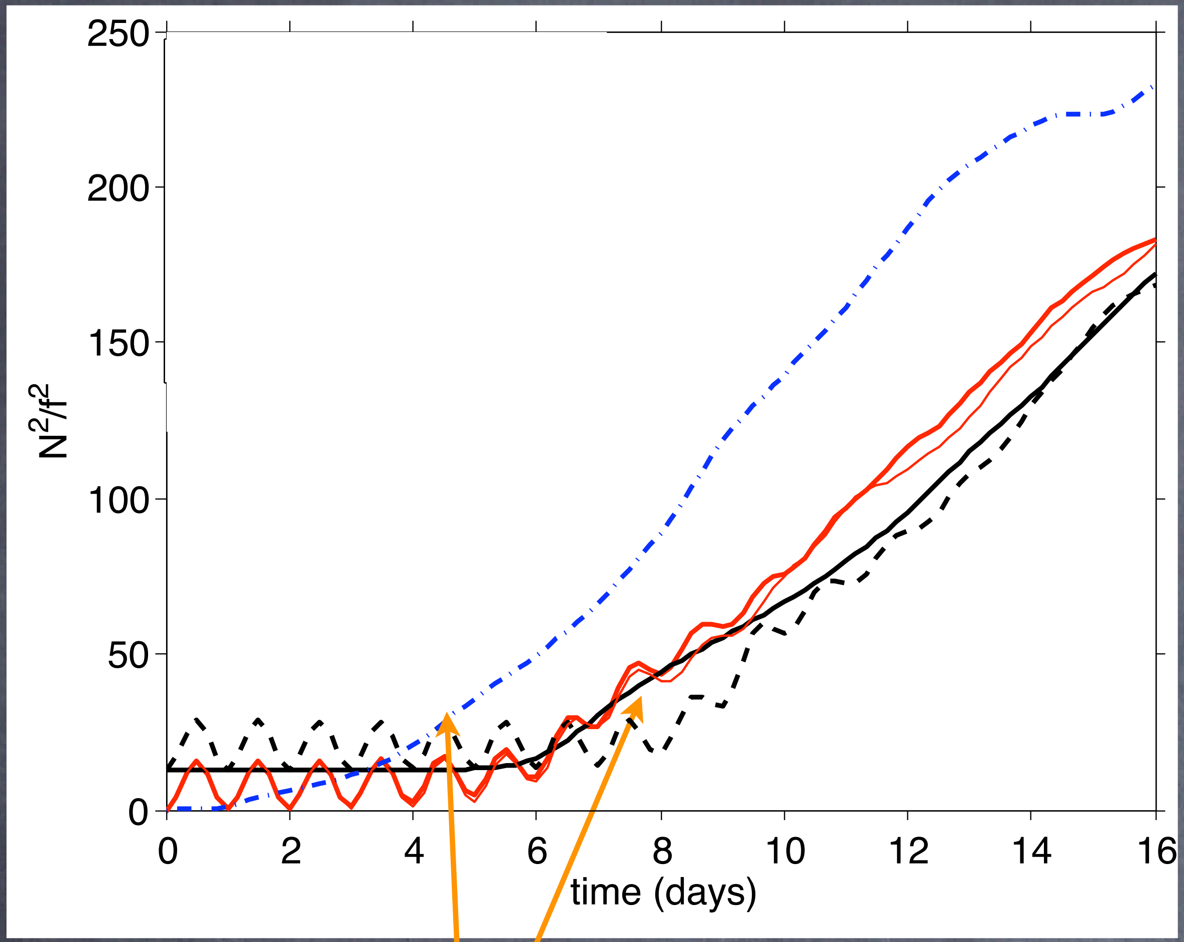
Eddies at Finite Amplitude

Restratification occurs with *finite* MLEs

Power Spectrum of KE

Parameterization of MLEs: Ingredients

Restratifying ->

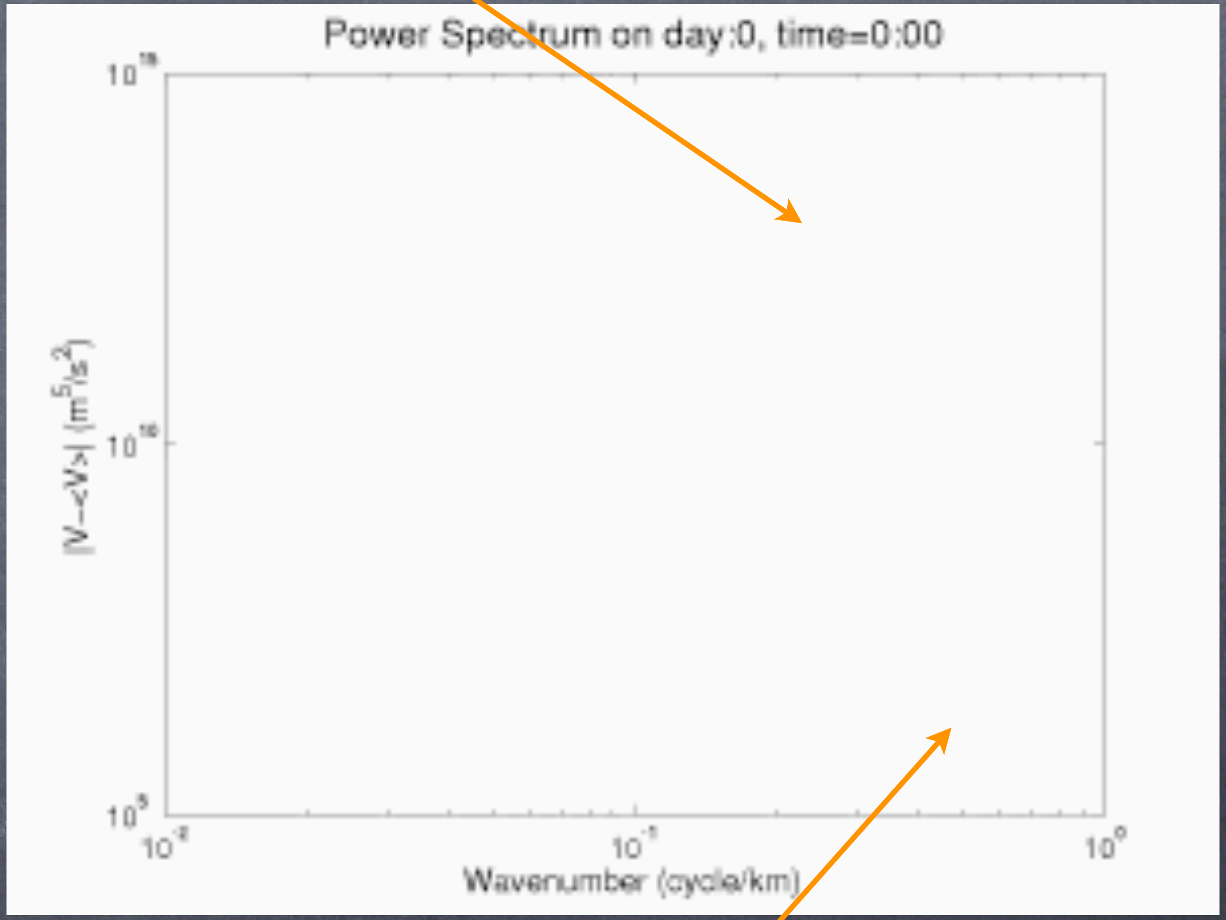


Eddies at Finite Amplitude

Restratification occurs with *finite* MLEs

Power Spectrum of KE

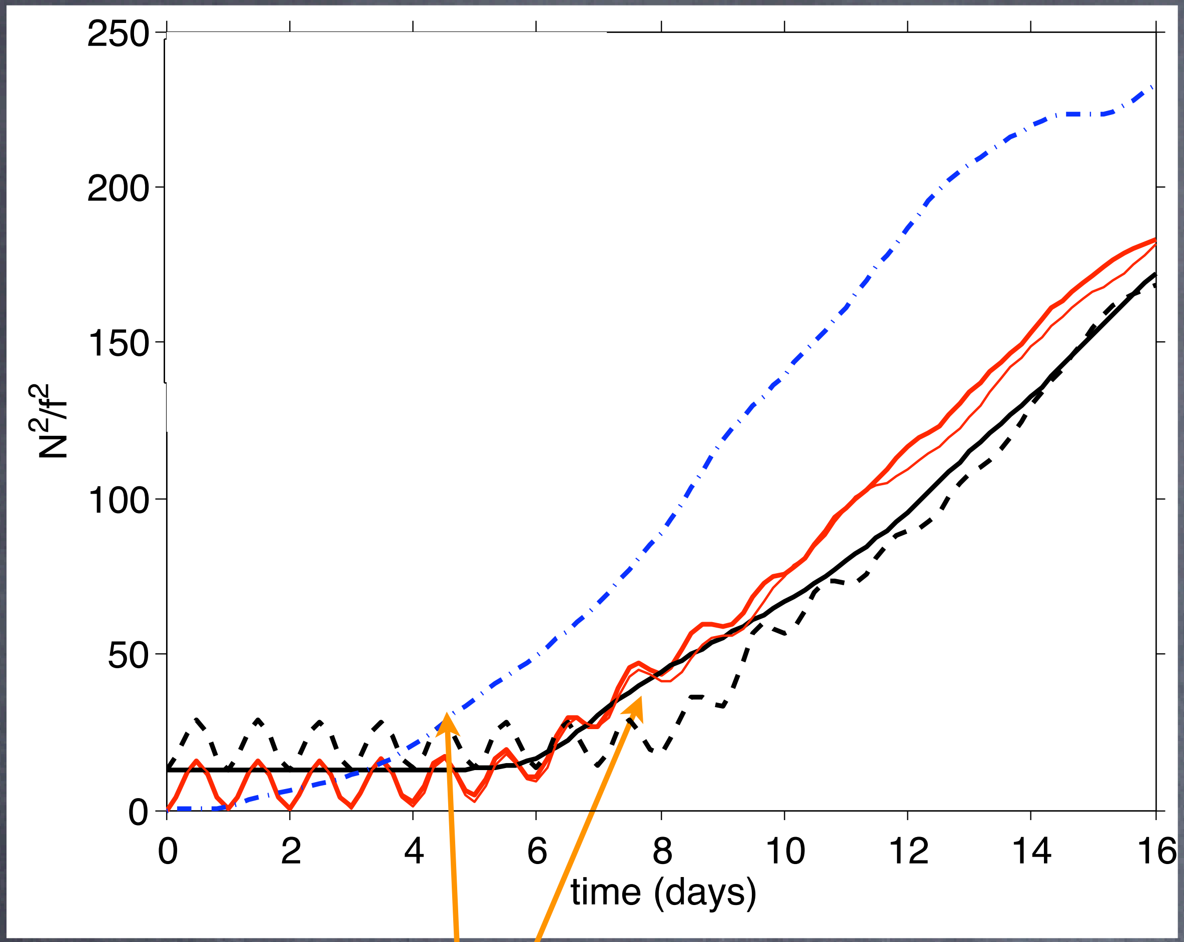
At Finite Amplitude
Larger Horizontal Scale



Initially, Linear Prediction of Lengthscale good

Parameterization of MLEs: Ingredients

Restratifying ->

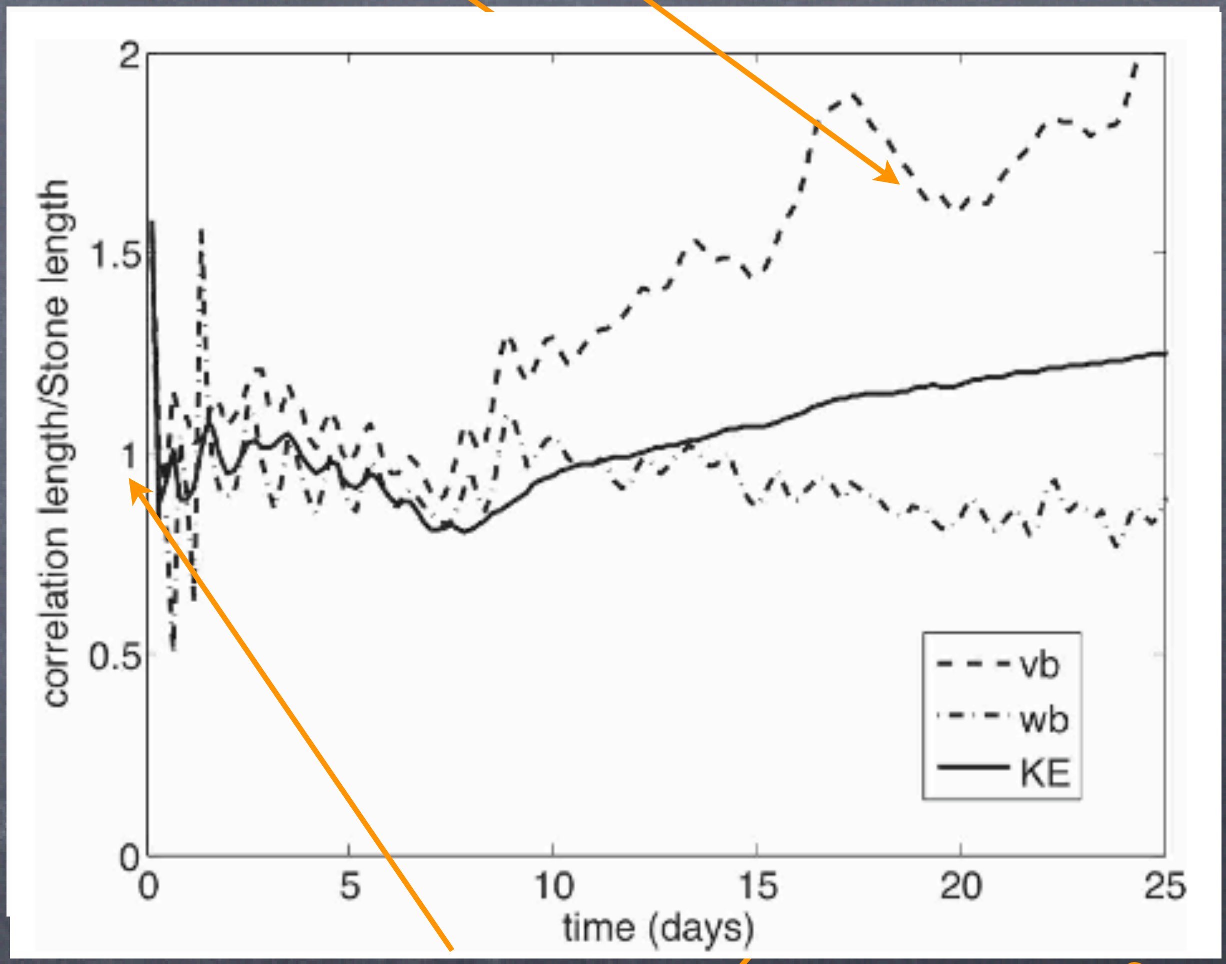


Eddies at Finite Amplitude

Restratification occurs with *finite* MLEs

Power Spectrum of KE

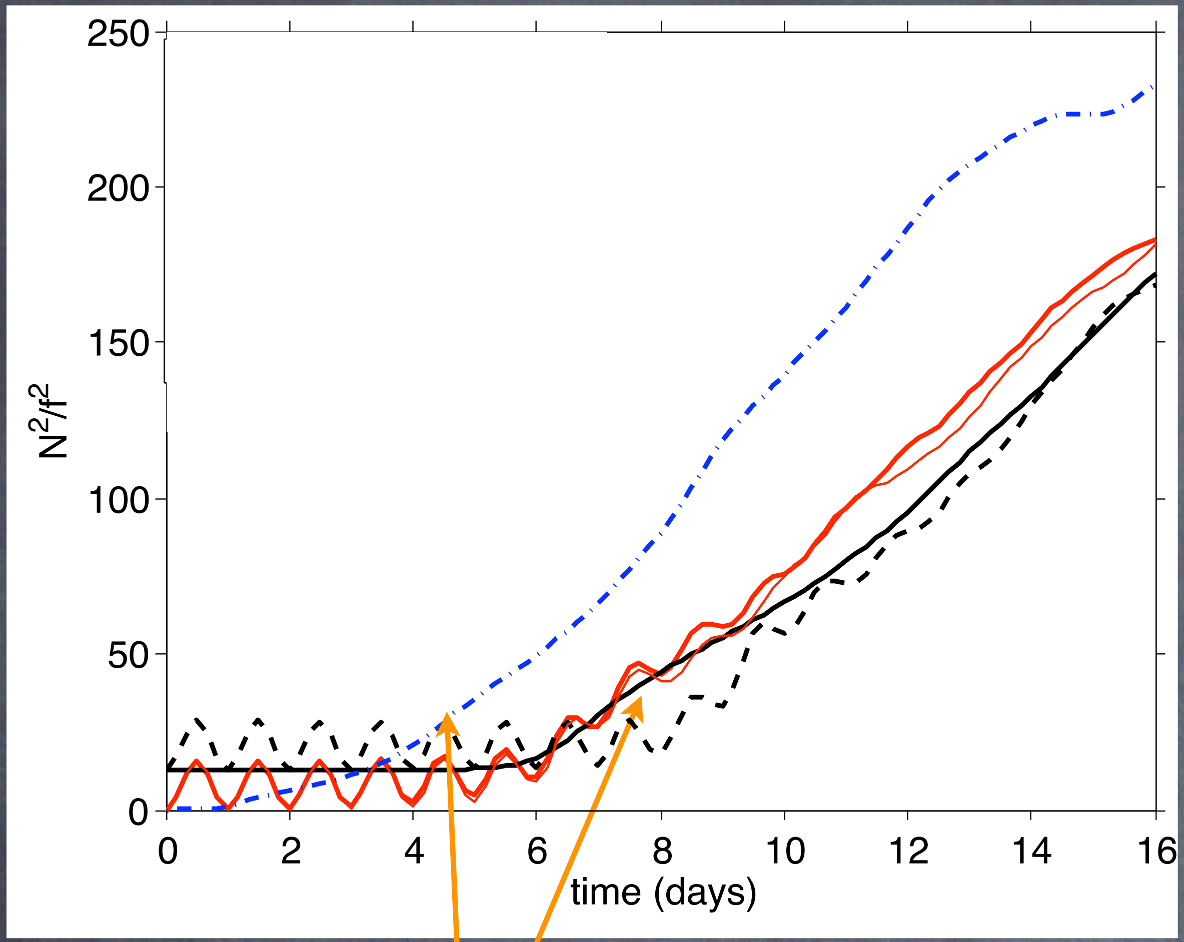
At Finite Amplitude Larger Horizontal Scale



Initially, Linear Prediction of Lengthscale good

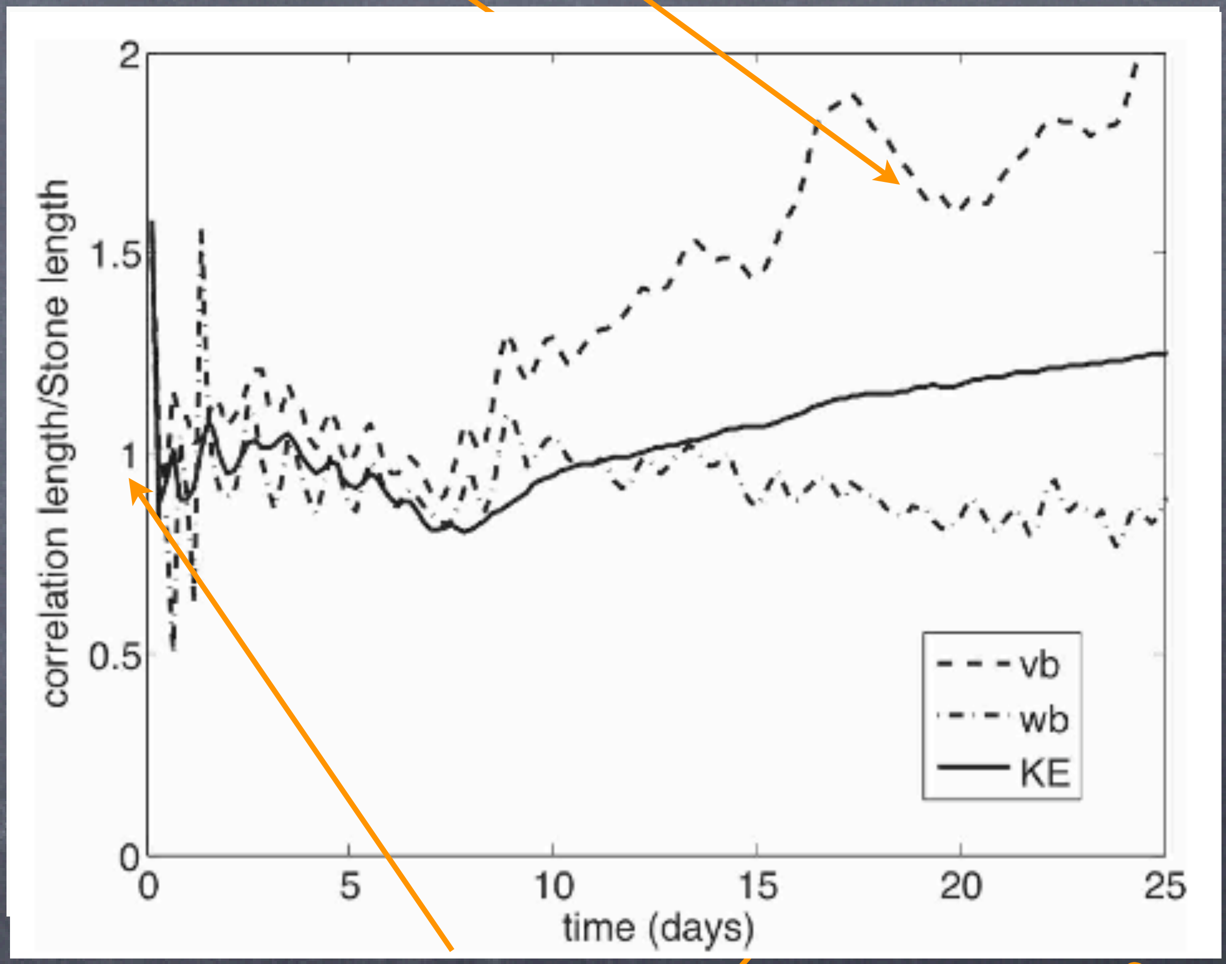
Parameterization of MLEs: Ingredients

Restratifying ->



Power Spectrum of KE

At Finite Amplitude
Larger Horizontal Scale



Eddies at Finite Amplitude

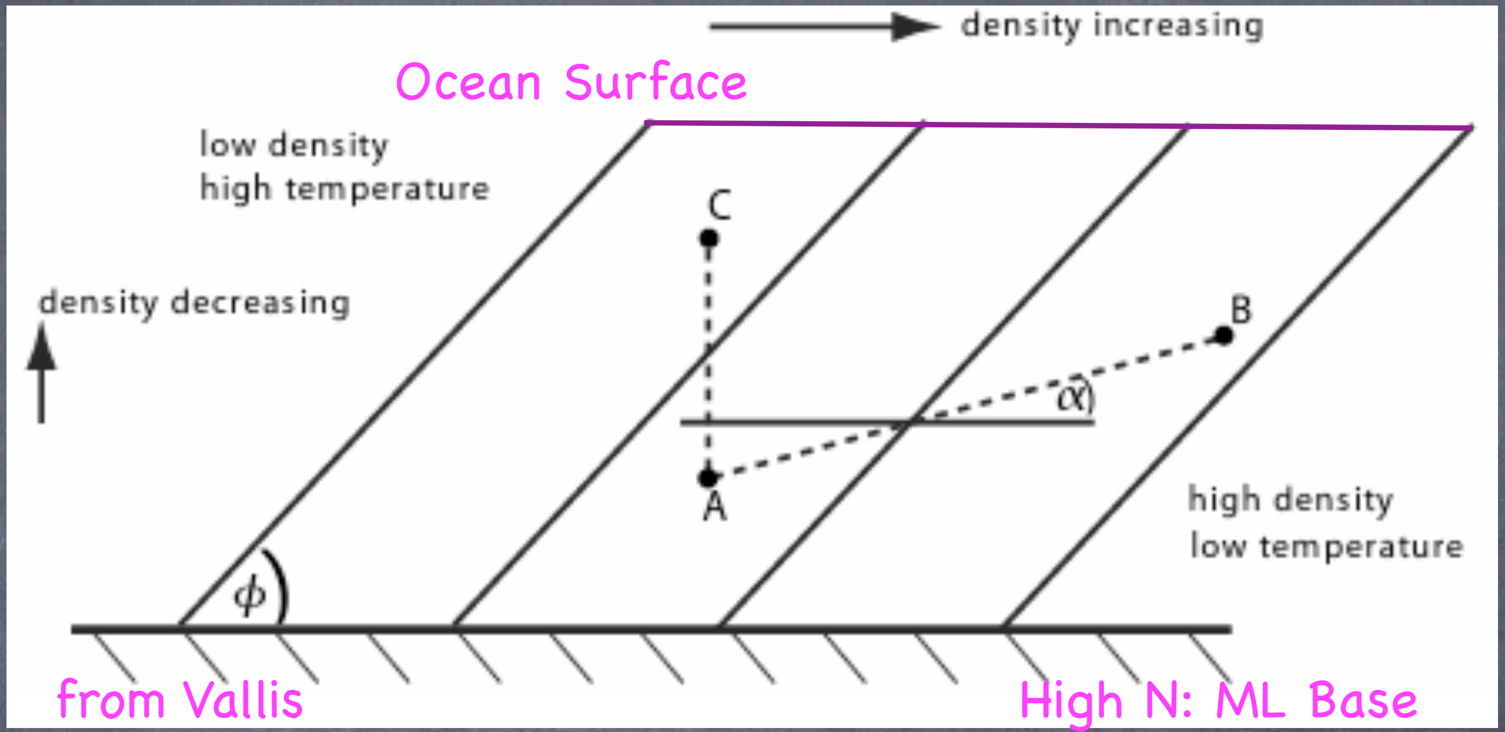
Restratification occurs with *finite* MLEs

Initially, Linear Prediction of Lengthscale good

Inverse Cascade => Different Scaling from Linear Instability

The Scaling of MLEs

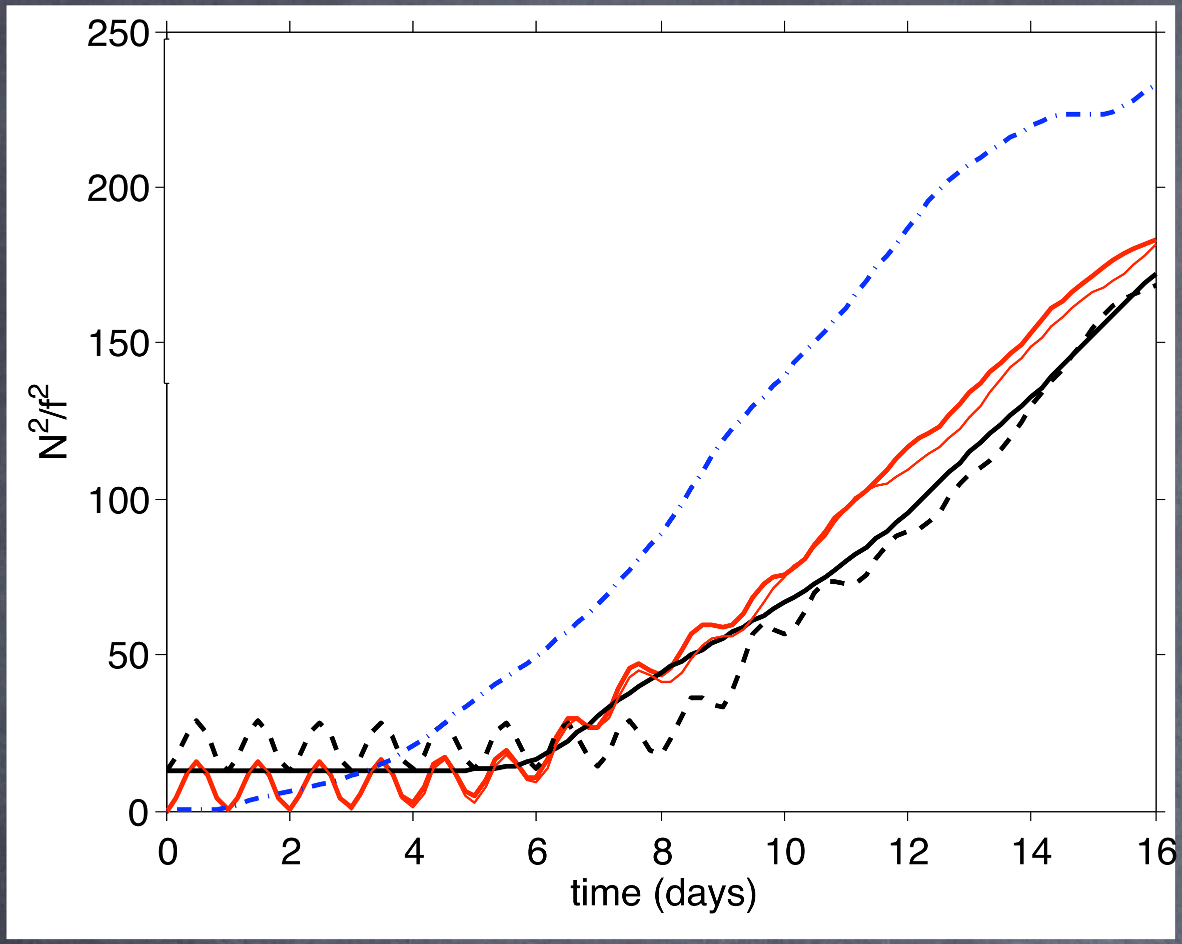
MLEs form from MLIs, but scale differently due to this inverse cascade.



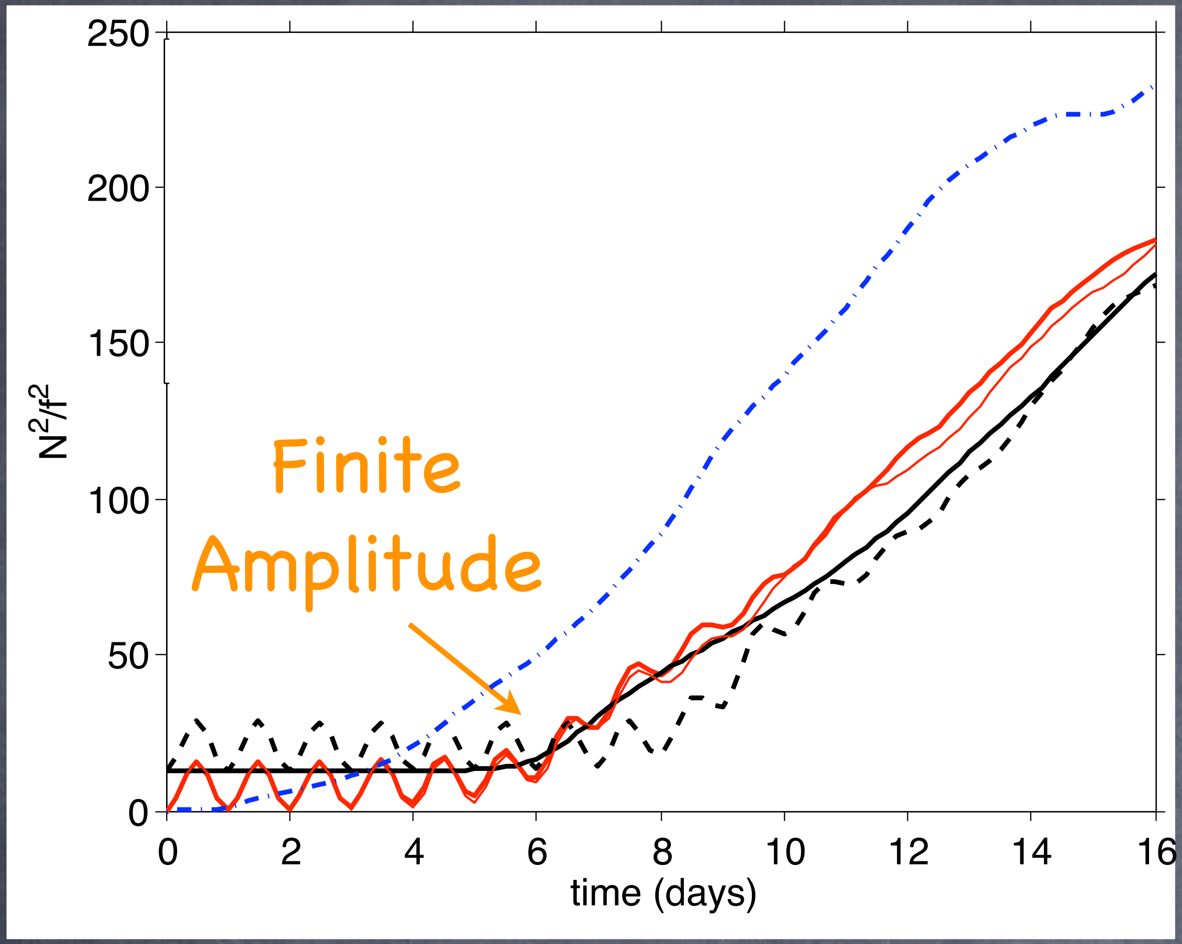
- Advective, not instability, Timescale
- Saturated, not exponentially growing, EKE
- Inverse Cascade, not unstable lengthscale

See Fox-Kemper et al 08

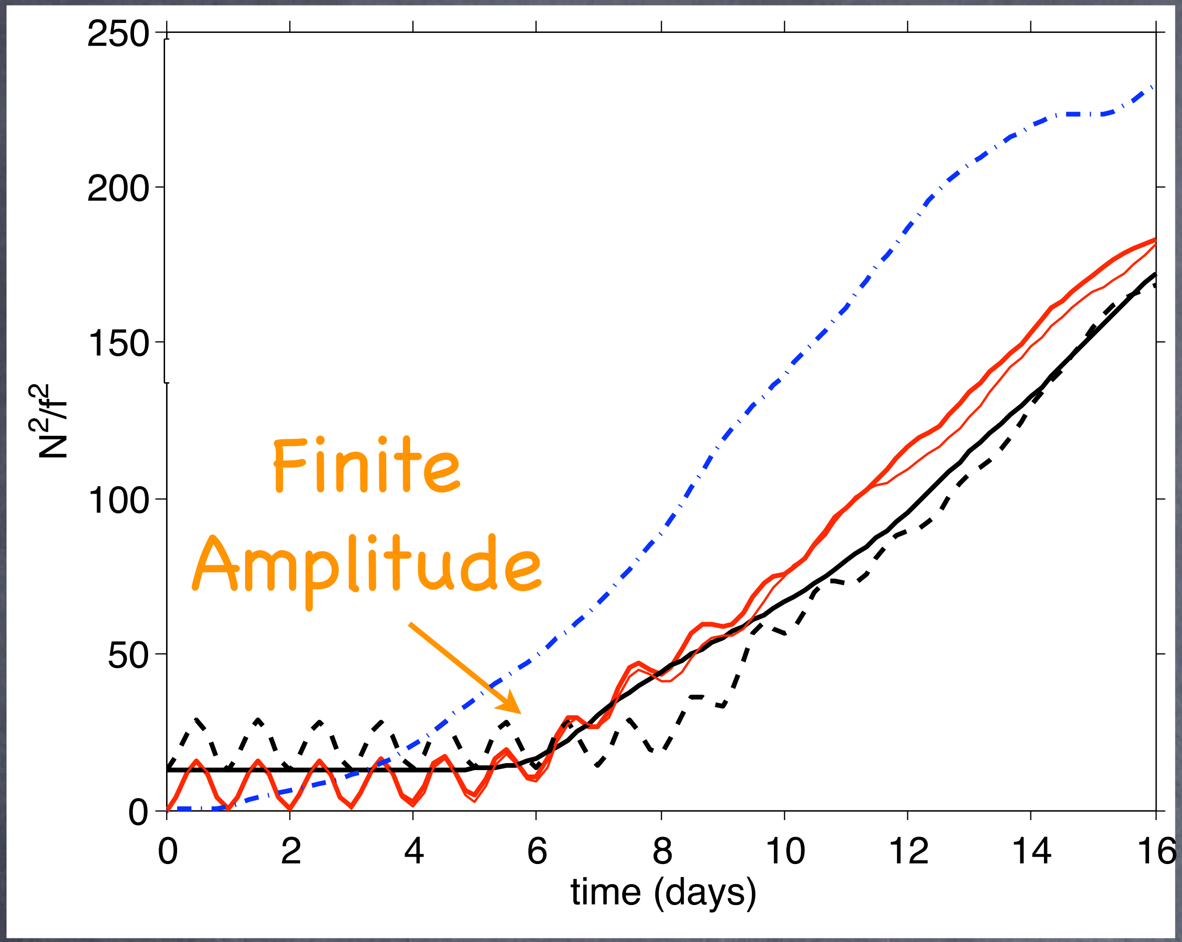
Scaling of MLEs: Ingredients

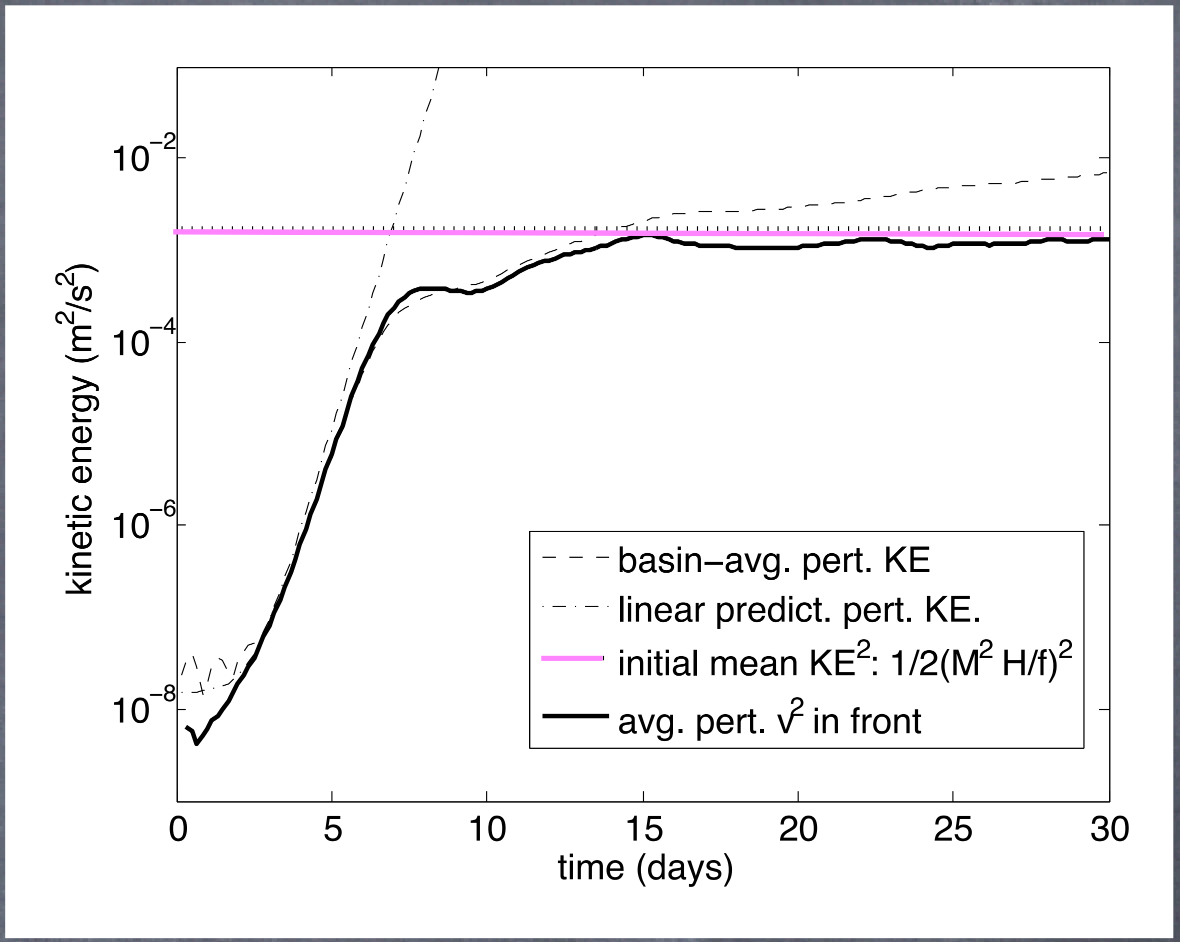


Scaling of MLEs: Ingredients

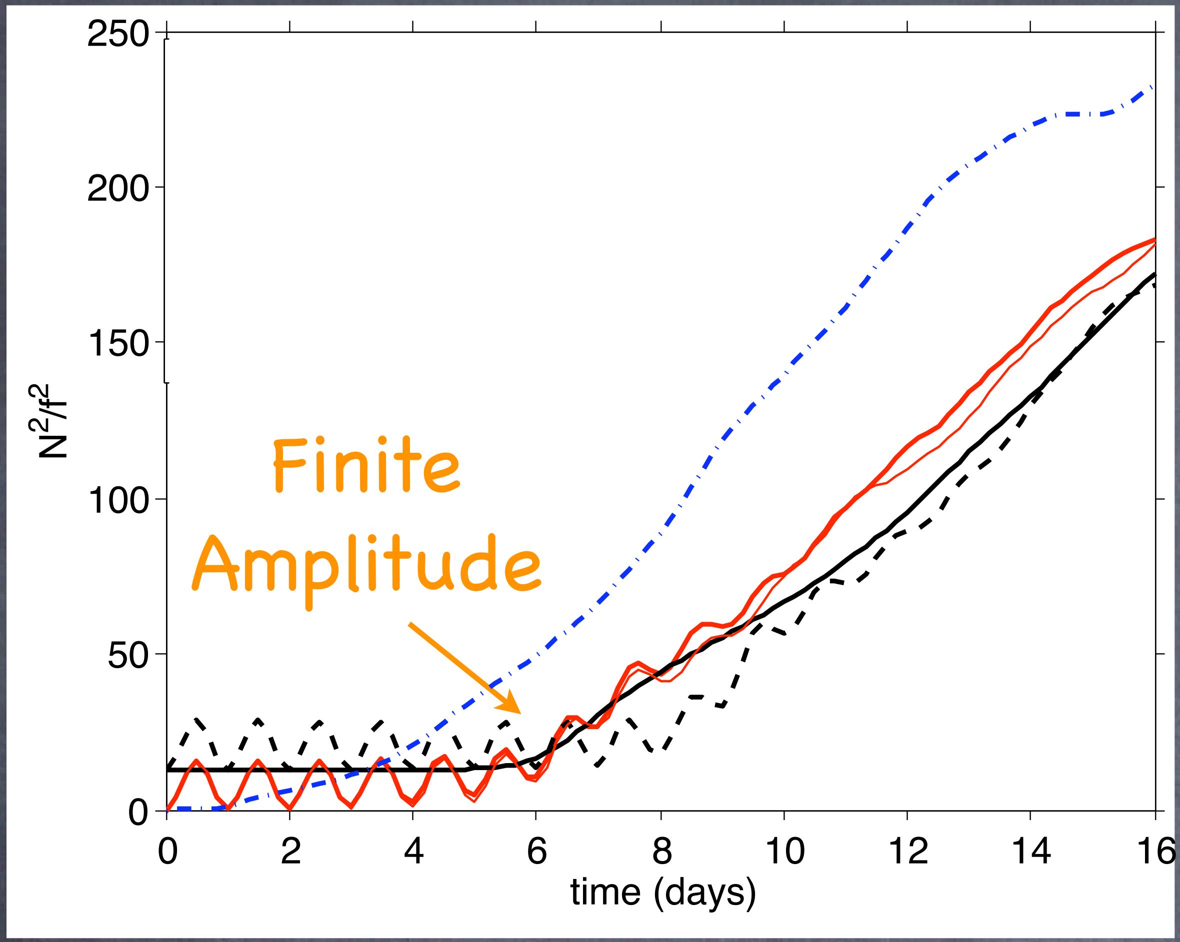


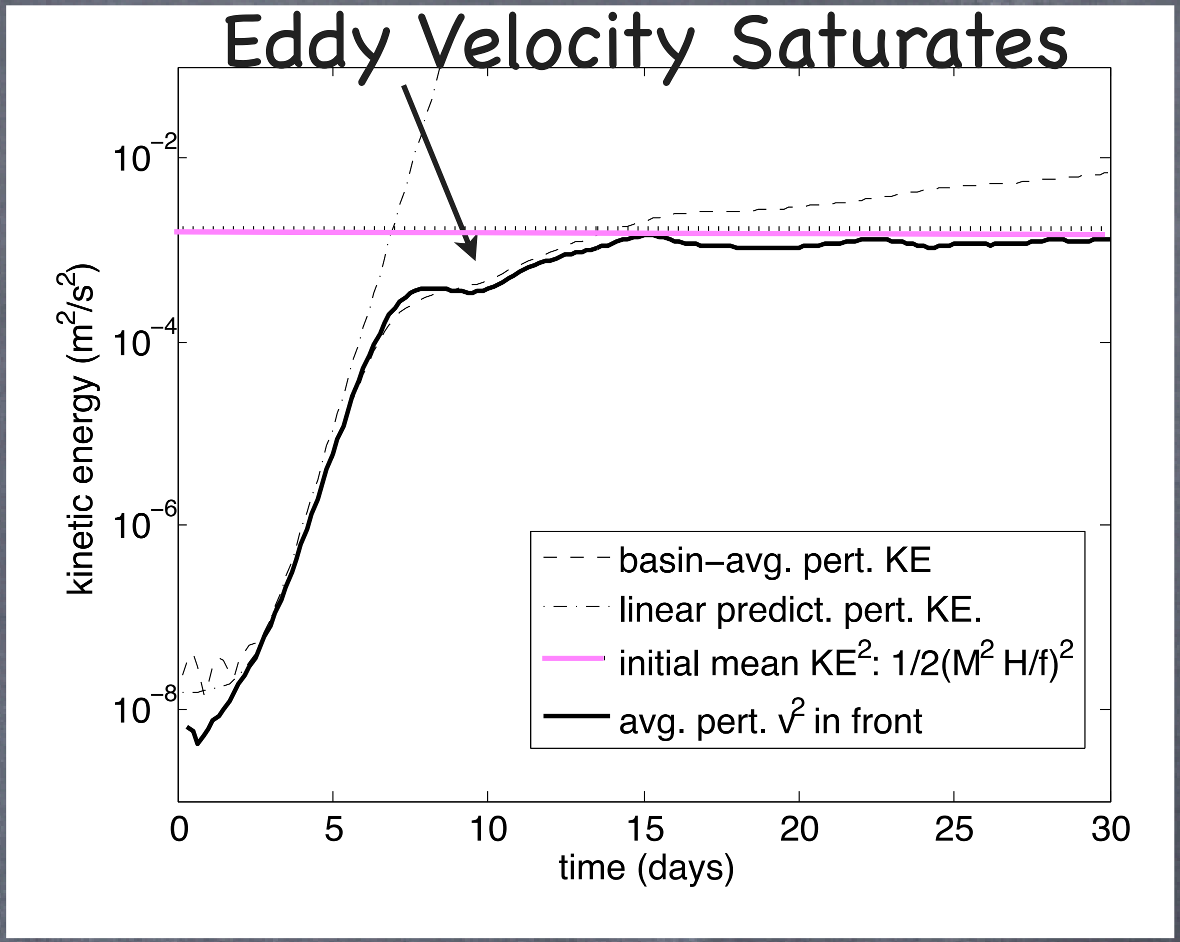
Scaling of MLEs: Ingredients



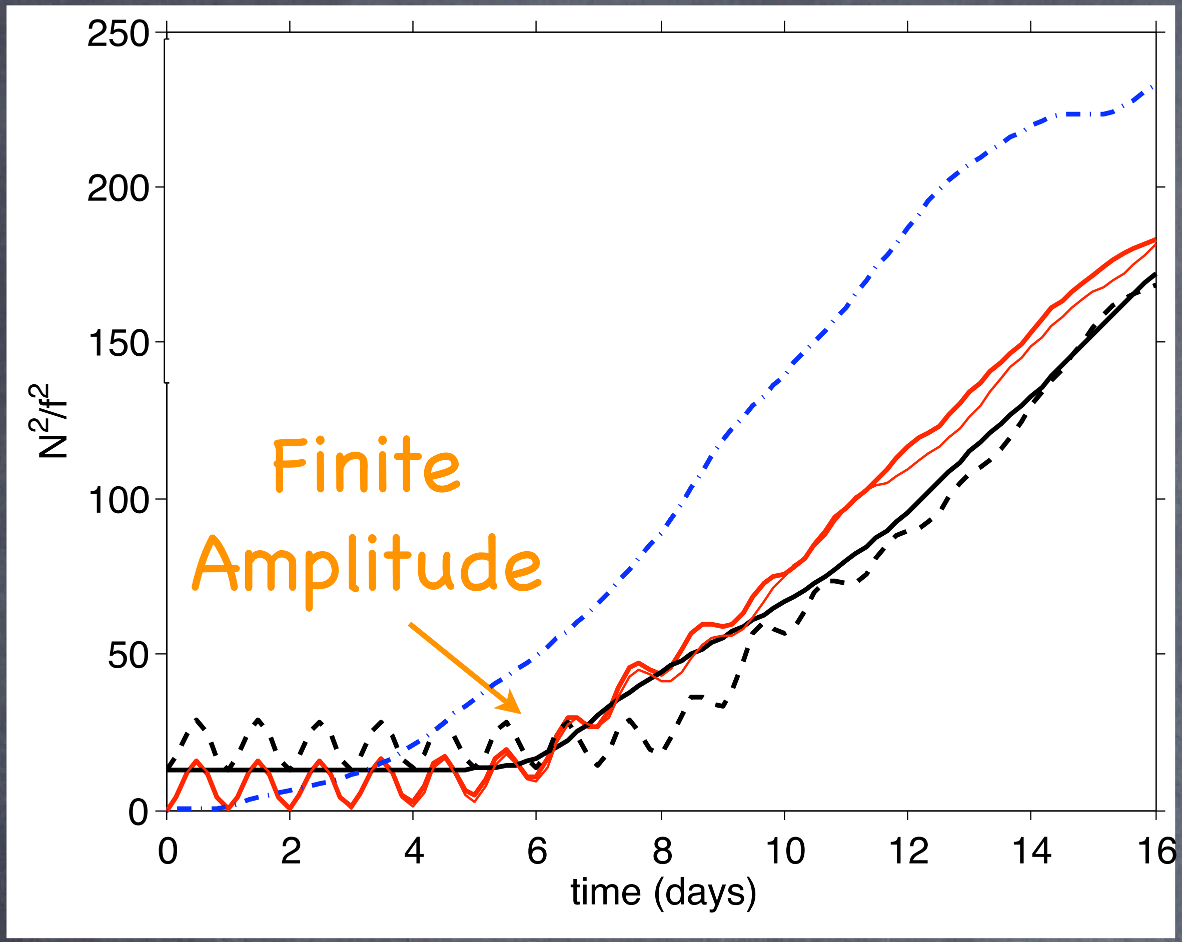


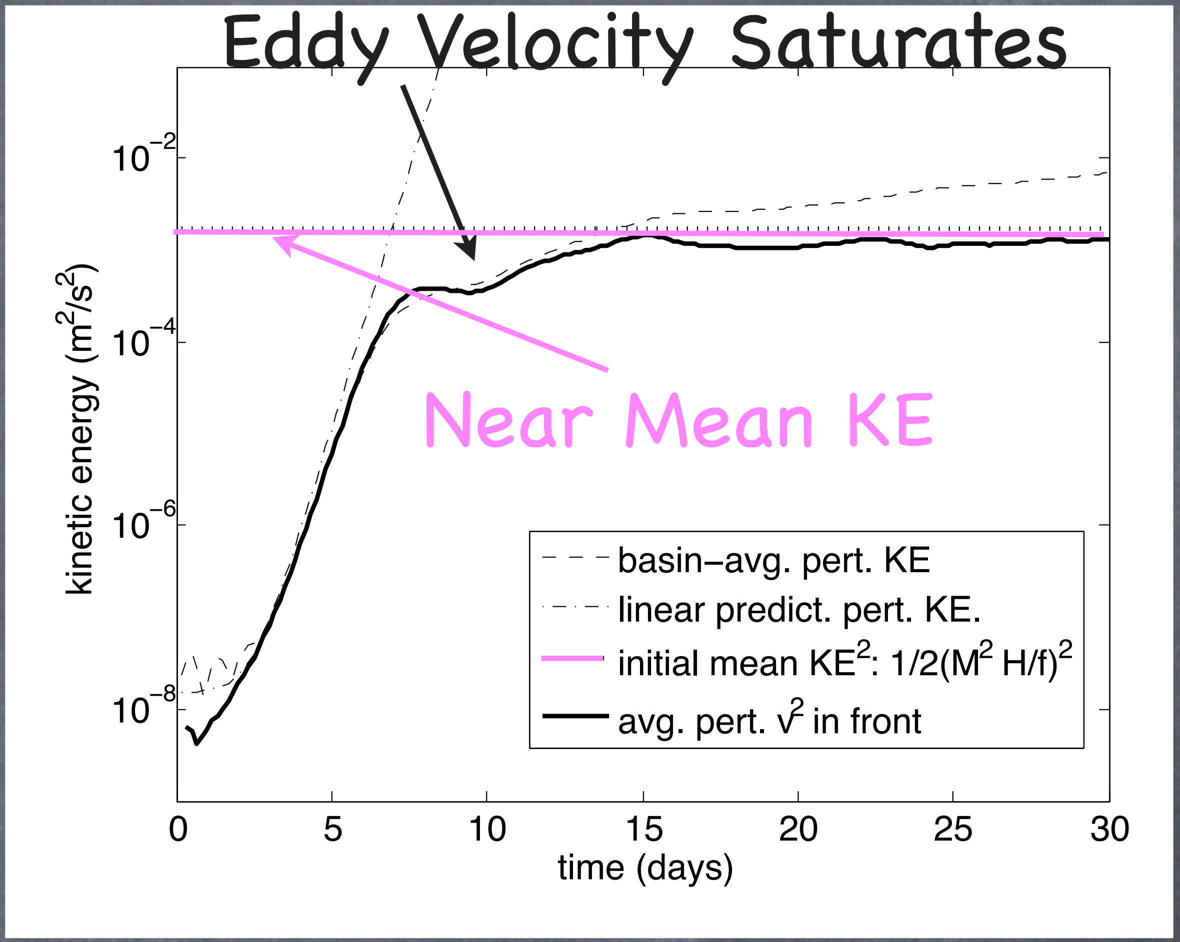
Scaling of MLEs: Ingredients



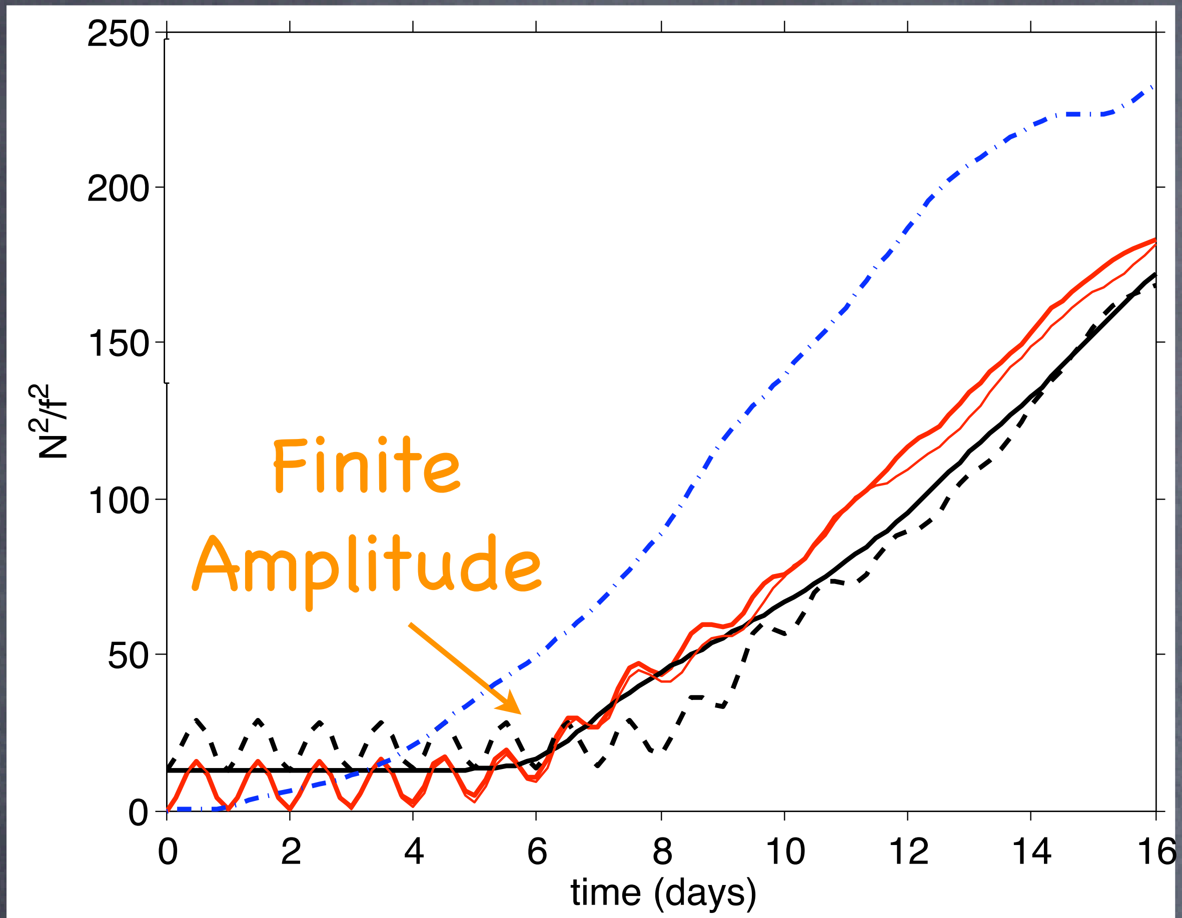


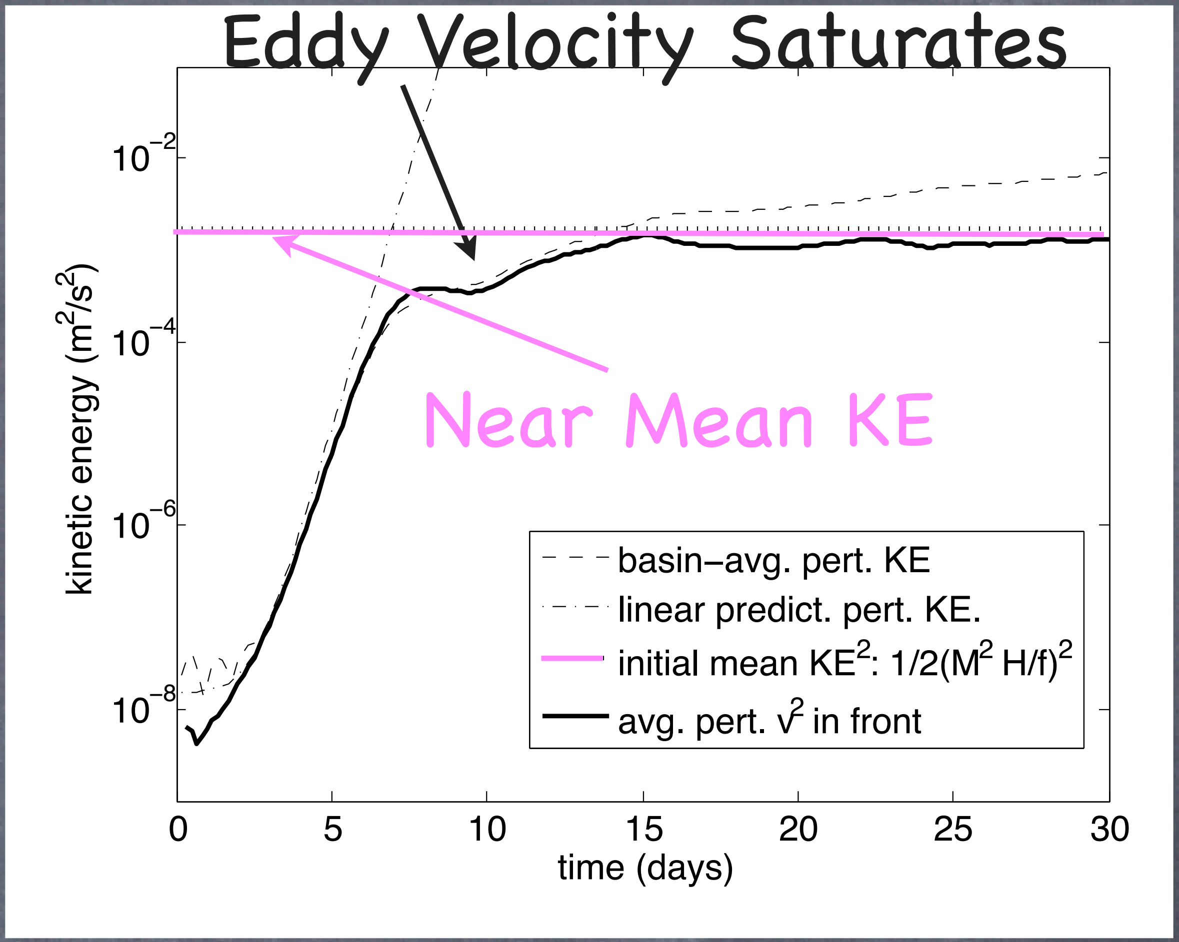
Scaling of MLEs: Ingredients

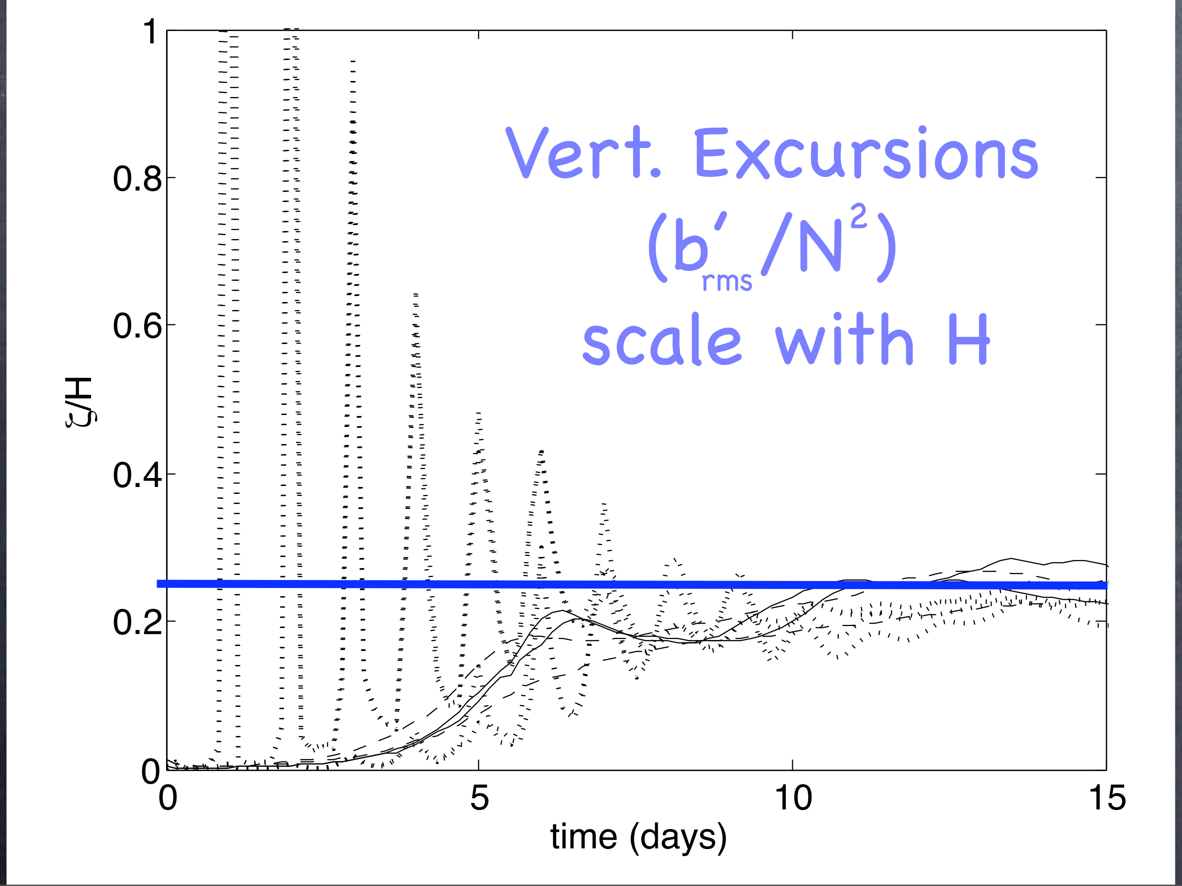




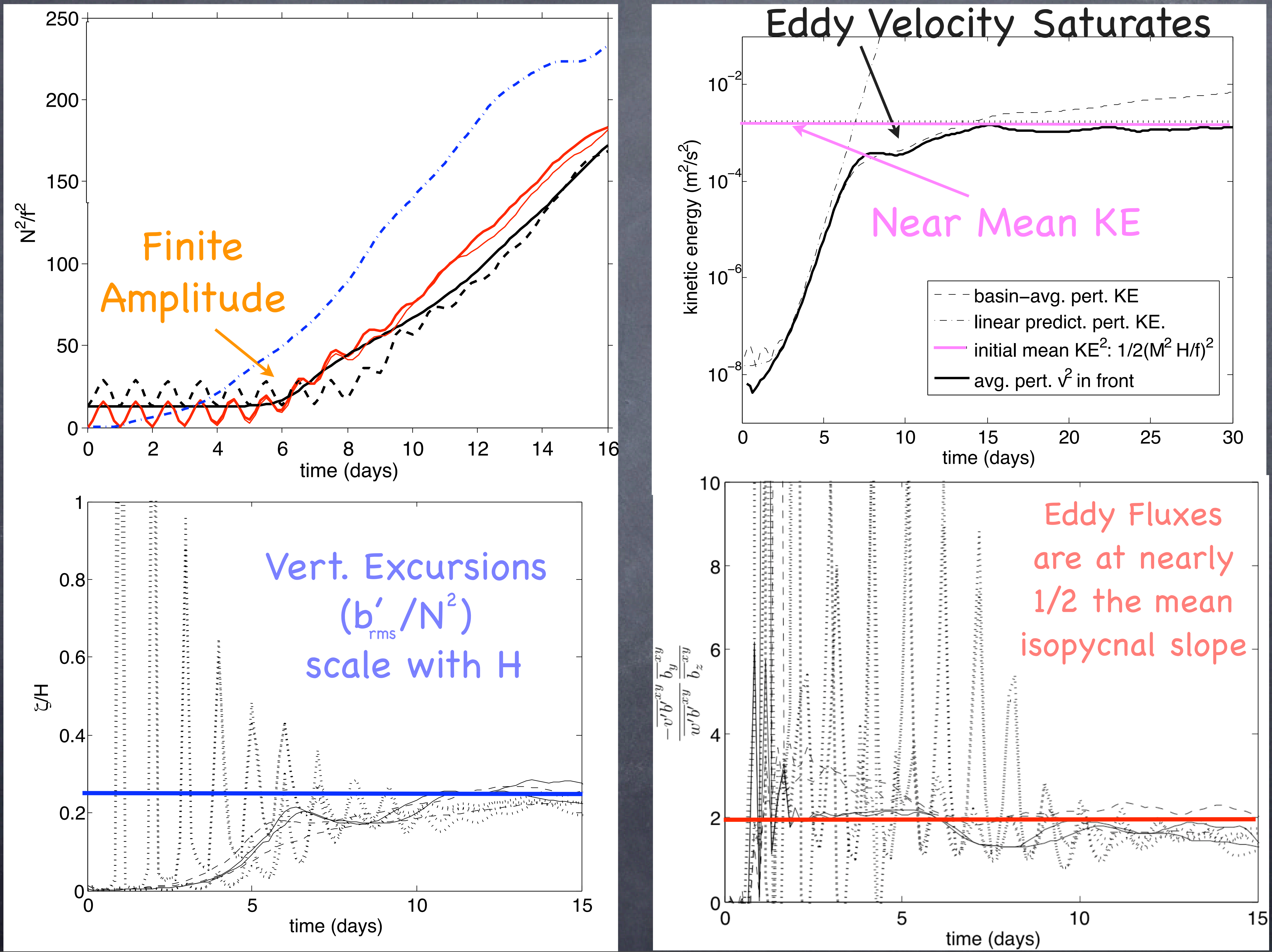
Scaling of MLEs: Ingredients







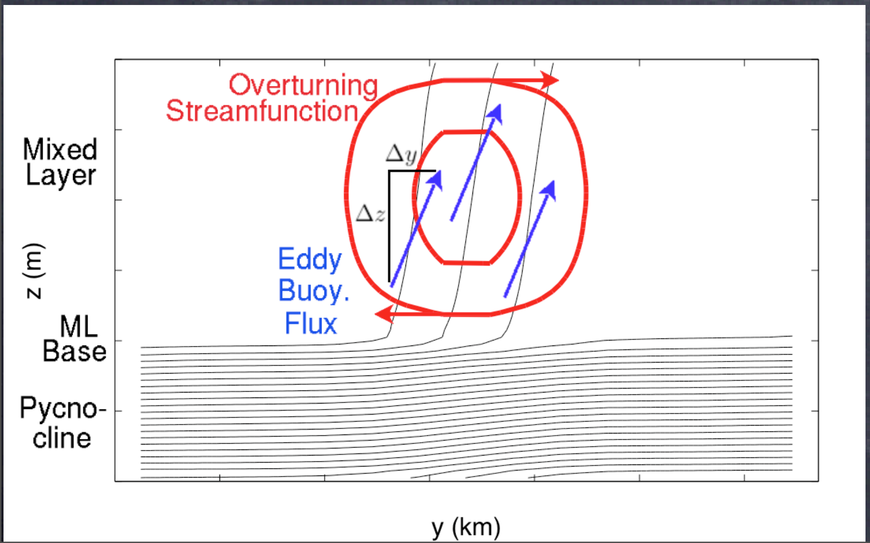
Scaling of MLEs: Ingredients



Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$



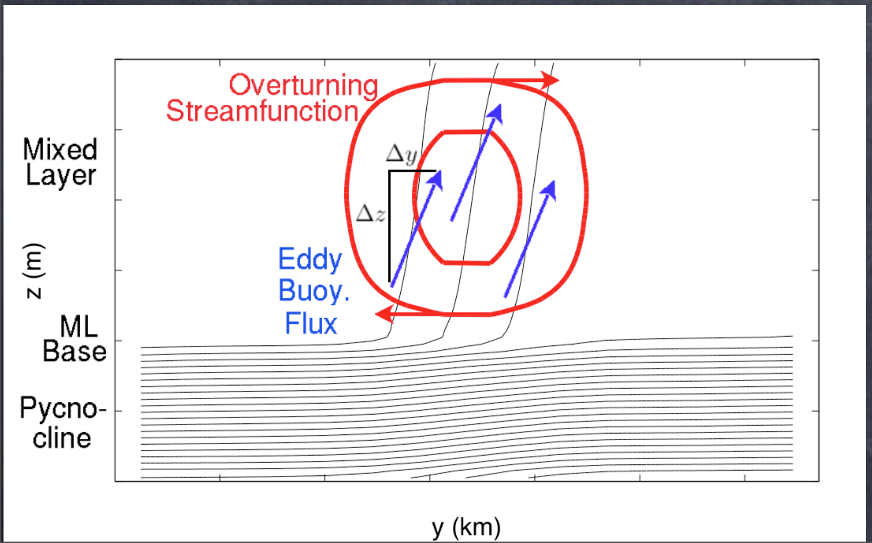
$$\langle wb \rangle \propto \frac{-\Delta z \Delta b}{\Delta t}$$

Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.



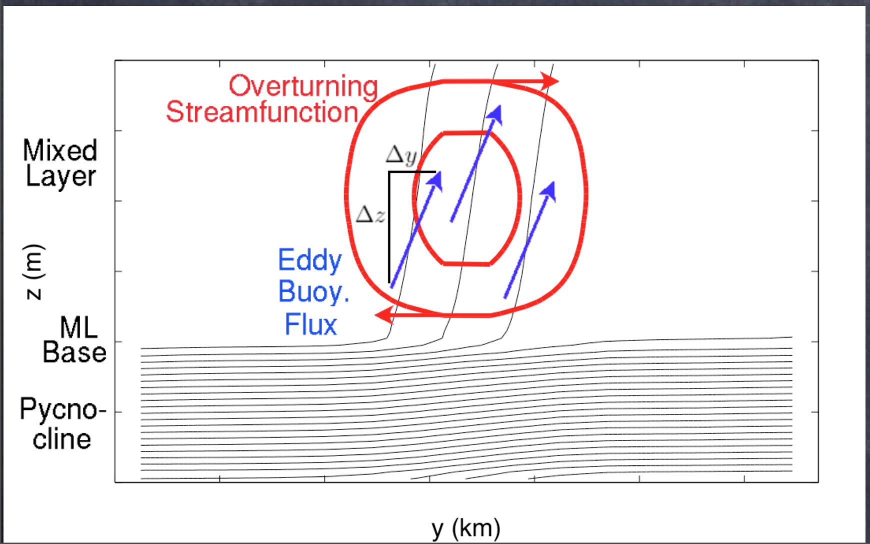
$$\langle wb \rangle \propto \frac{-\Delta z \Delta b}{\Delta t}$$

Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.



$$\langle wb \rangle \propto \frac{-\Delta z \left(\Delta y \frac{\partial \bar{b}}{\partial y} + \Delta z \frac{\partial \bar{b}}{\partial z} \right)}{\Delta t}$$

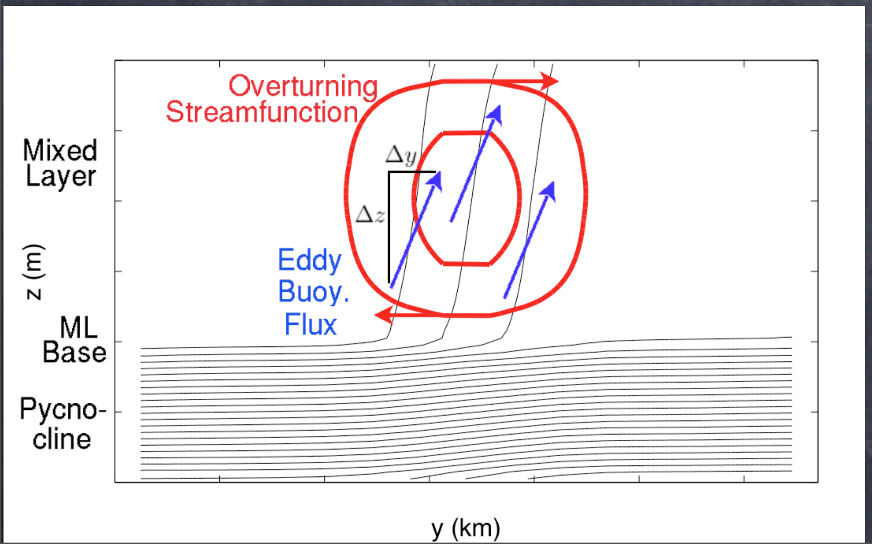
Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

$$-\langle wb\rangle = \frac{\partial\langle PE\rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$



$$\langle wb\rangle \propto \frac{-\Delta z\left(\Delta y \frac{\partial \bar{b}}{\partial y} + \Delta z \frac{\partial \bar{b}}{\partial z}\right)}{\Delta t}$$

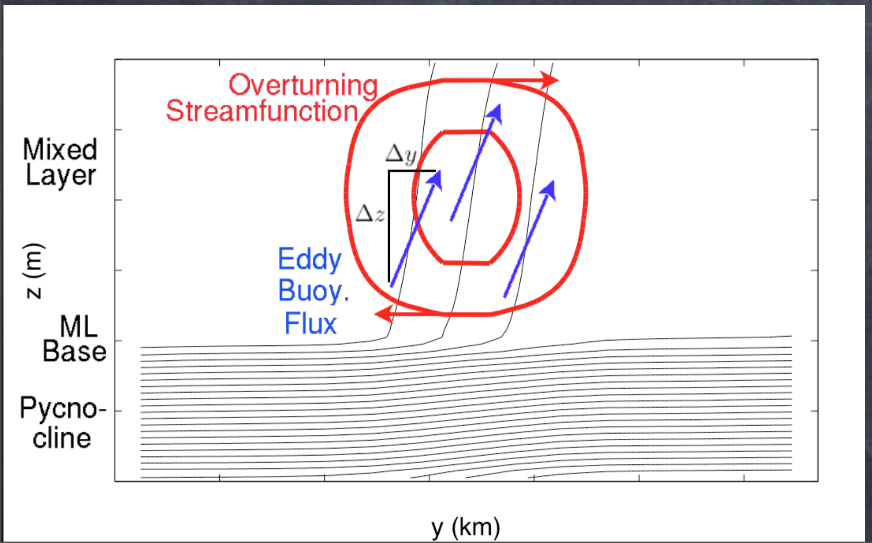
Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$



$$\langle wb \rangle \propto \frac{\Delta z \Delta y \frac{\partial \bar{b}}{\partial y}}{\Delta t}$$

Magnitude Analysis: Vert. Fluxes

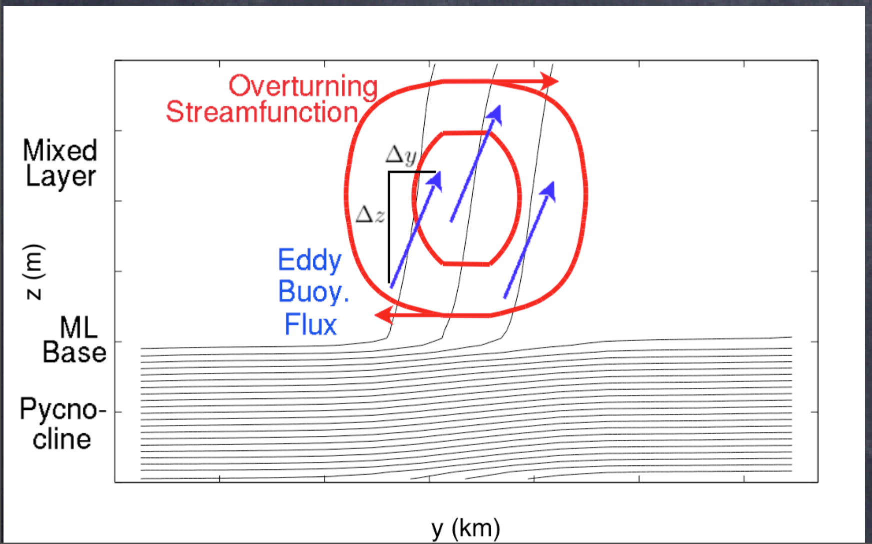
Extraction of potential energy by submesoscale eddies:

$$-\langle wb\rangle = \frac{\partial\langle PE\rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$

Time scale is turnover time



$$\langle wb\rangle \propto \frac{\Delta z \Delta y \frac{\partial \bar{b}}{\partial y}}{\Delta t}$$

Magnitude Analysis: Vert. Fluxes

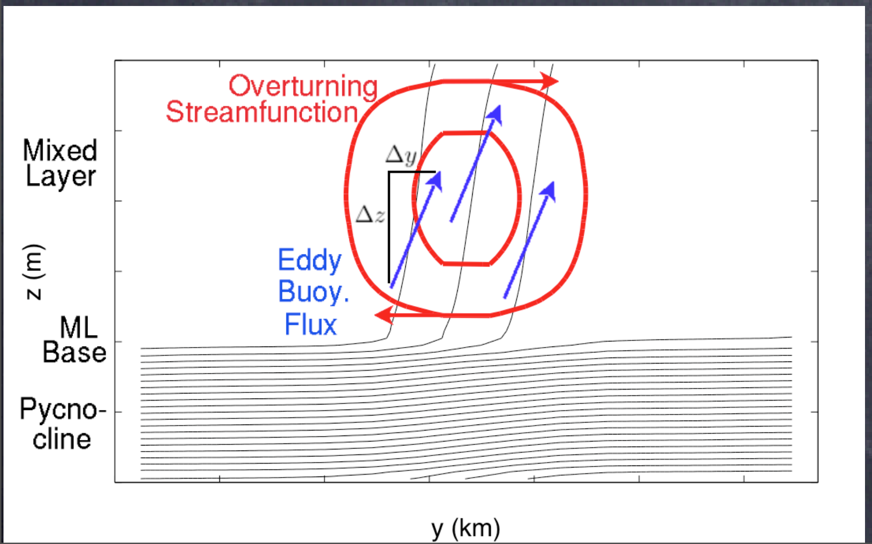
Extraction of potential energy by submesoscale eddies:

$$-\langle wb\rangle = \frac{\partial\langle PE\rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$

Time scale is turnover time



$$\langle wb\rangle \propto \frac{\Delta z \Delta y \frac{\partial \bar{b}}{\partial y}}{\Delta y / V}$$

Magnitude Analysis: Vert. Fluxes

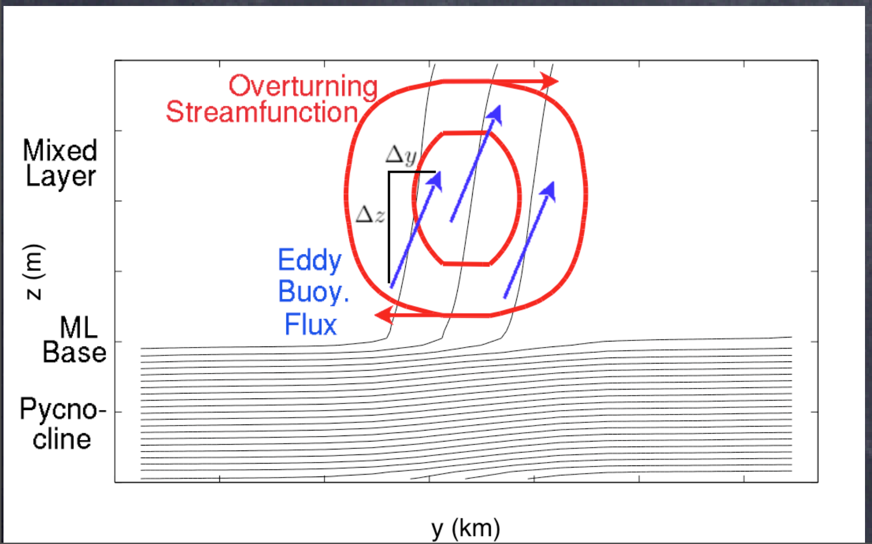
Extraction of potential energy by submesoscale eddies:

$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$

Time scale is turnover time from mean thermal wind:



$$\langle wb \rangle \propto \frac{\Delta z H}{|f|} \left[\frac{\partial \bar{b}}{\partial y} \right]^2$$

Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

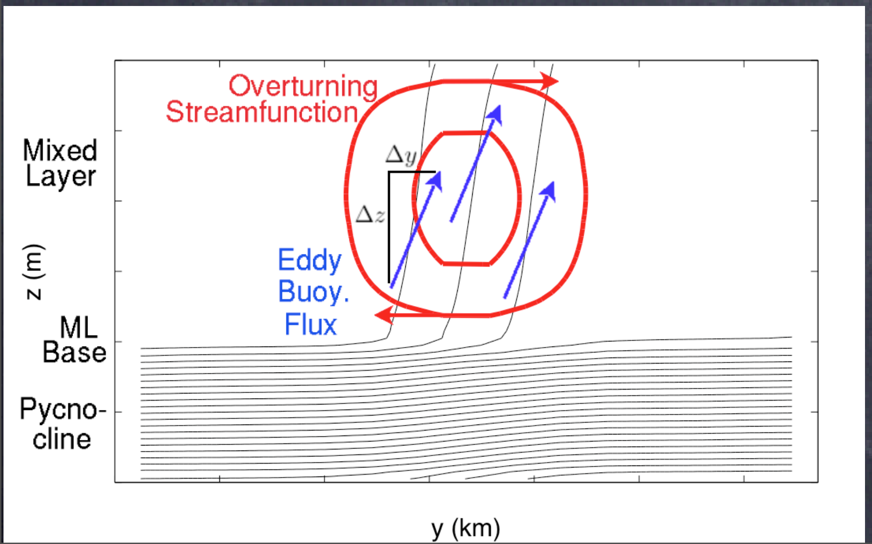
$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$

Time scale is turnover time from mean thermal wind:

Vertical scale known: $\Delta z \propto H$



$$\langle wb \rangle \propto \frac{\Delta z H}{|f|} \left[\frac{\partial \bar{b}}{\partial y} \right]^2$$

Magnitude Analysis: Vert. Fluxes

Extraction of potential energy by submesoscale eddies:

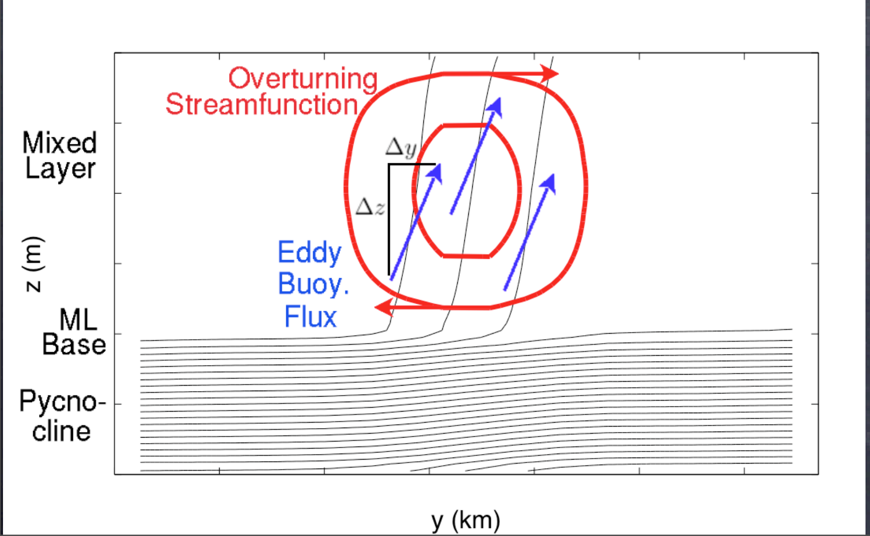
$$-\langle wb \rangle = \frac{\partial \langle PE \rangle}{\partial t} \approx \frac{\Delta PE}{\Delta t} \propto \frac{\Delta z \Delta b}{\Delta t}$$

Buoy. diff just parcel exchange of large-scale buoy.

Flux slope scales with the buoy. slope: $\frac{\Delta y}{\Delta z} \propto \frac{-\frac{\partial \bar{b}}{\partial z}}{\frac{\partial \bar{b}}{\partial y}}$

Time scale is turnover time from mean thermal wind:

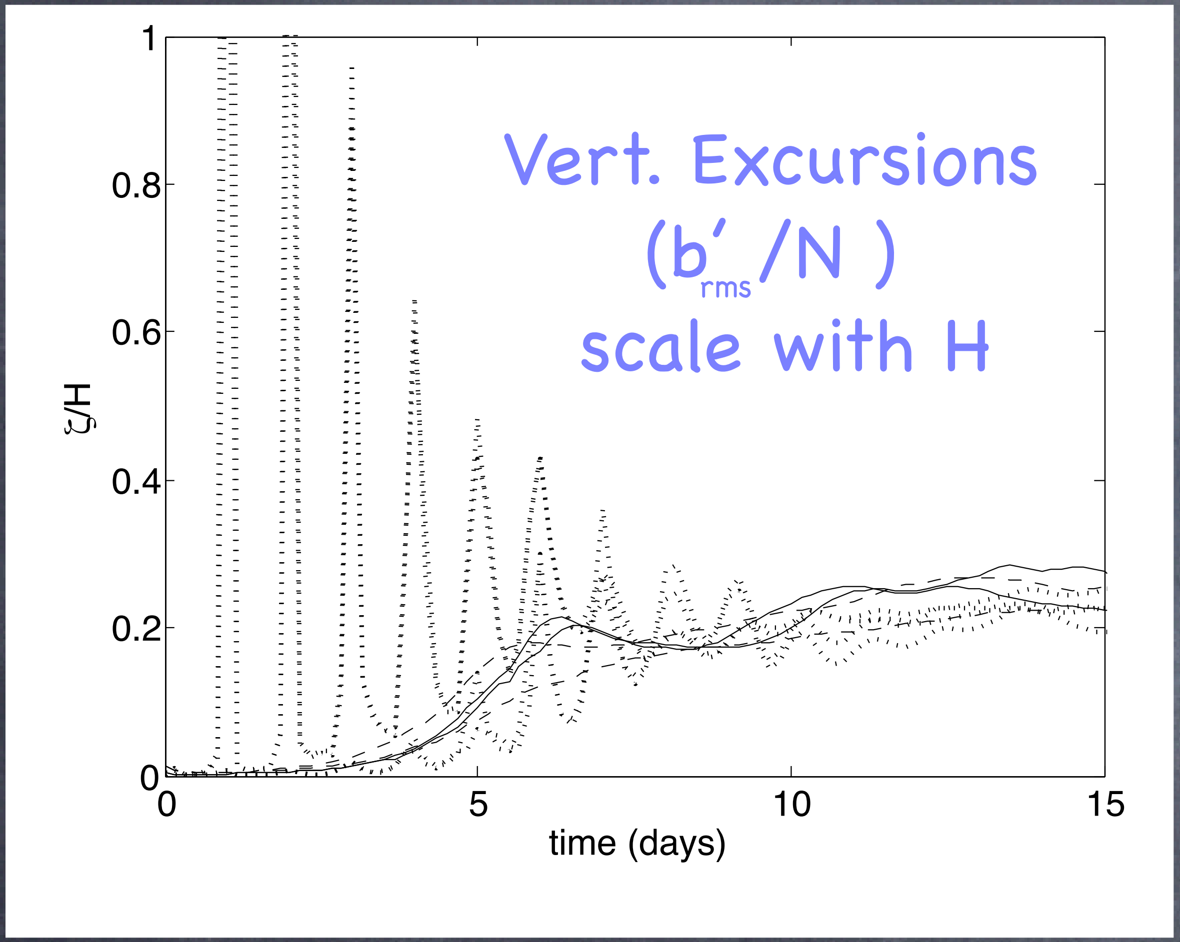
Vertical scale known: $\Delta z \propto H$



$$\langle wb \rangle \propto \frac{H^2}{|f|} \left[\frac{\partial \bar{b}}{\partial y} \right]^2$$

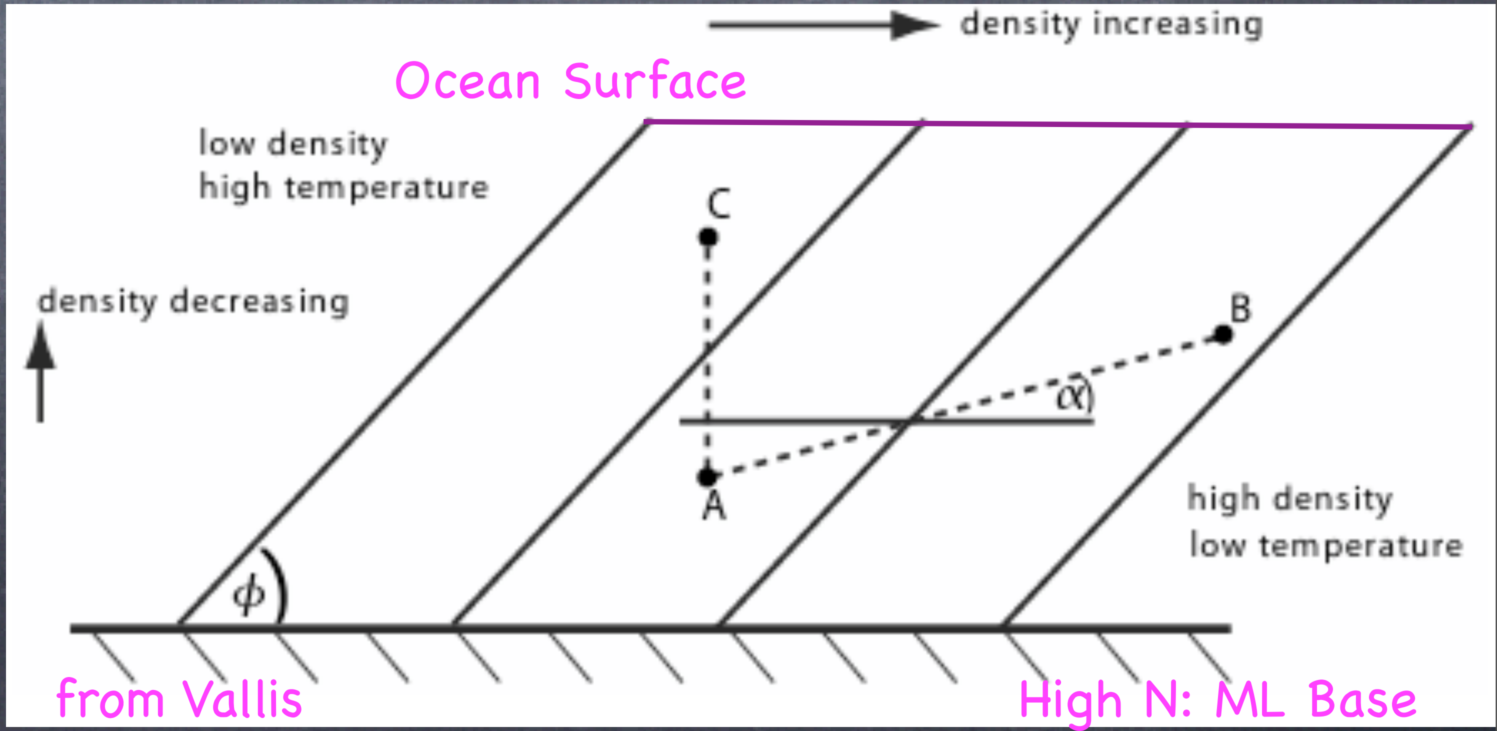
Fox-Kemper et al., 2007

MLE halted by vertical constraint and fluxes along isopycnal slope



Still Eady or SQG-like problem, but horiz. scale linked to vertical scale by PE extraction slope;

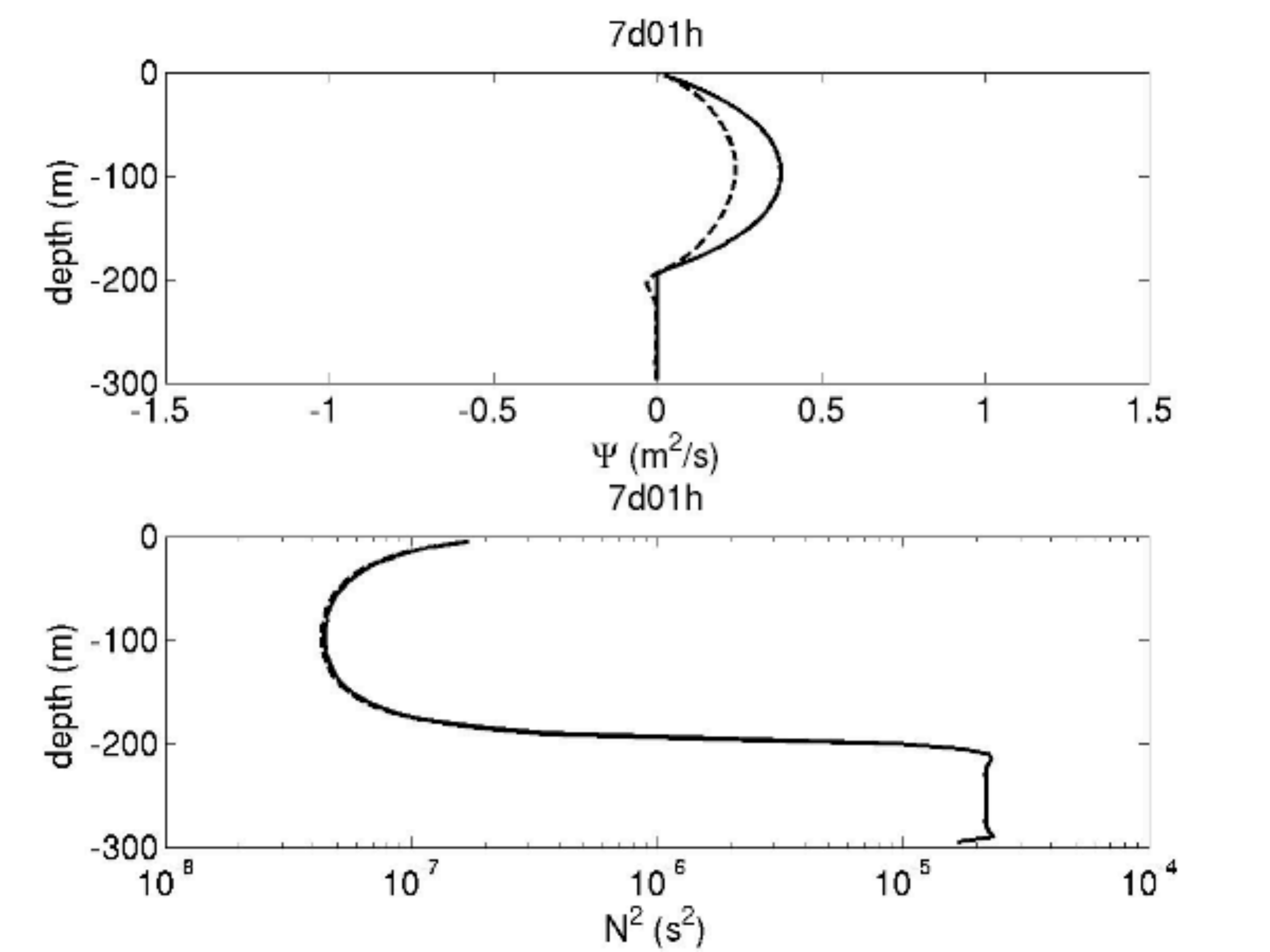
Vertical scale limited by ML depth.



Linear Solution <w'b'> Shape for vertical structure.

As in Branscome '83...

MLE are trapped within the Mixed Layer!



Stone Solution to $O(Ro^2)$

$$\mu(z) = \left[1 - \left(\frac{2z}{H} + 1\right)^2\right]\left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]$$

The Parameterization:

$$\mathbf{\Psi} = \frac{C_e H^2 \mu(z)}{|f|} \nabla \bar{b} \times \hat{\mathbf{z}}$$

$$\mu(z) = \left[1 - \left(\frac{2z}{H} + 1\right)^2\right]\left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]$$

- The horizontal fluxes are downgradient:

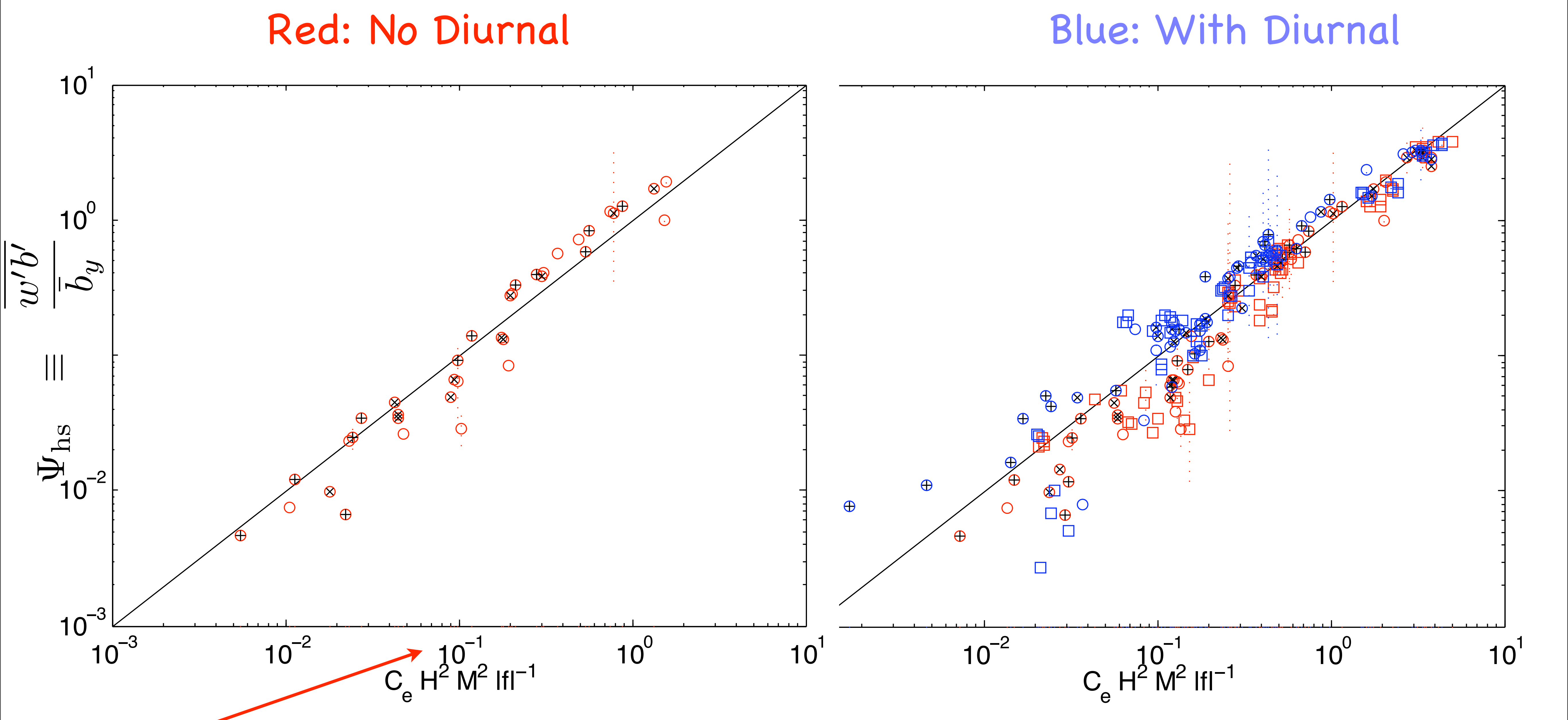
$$\overline{\mathbf{u}_\mathbf{H}' b'} = -\frac{C_e H^2 \mu(z) \frac{\partial \bar{b}}{\partial z}}{|f|} \nabla_H \bar{b}$$

- Vertical fluxes always upward to restratify with correct extraction rate of potential energy:

$$\overline{w' b'} = \frac{C_e H^2 \mu(z)}{|f|} |\nabla \bar{b}|^2$$

- Just like it has to be... at least according to Peter G.

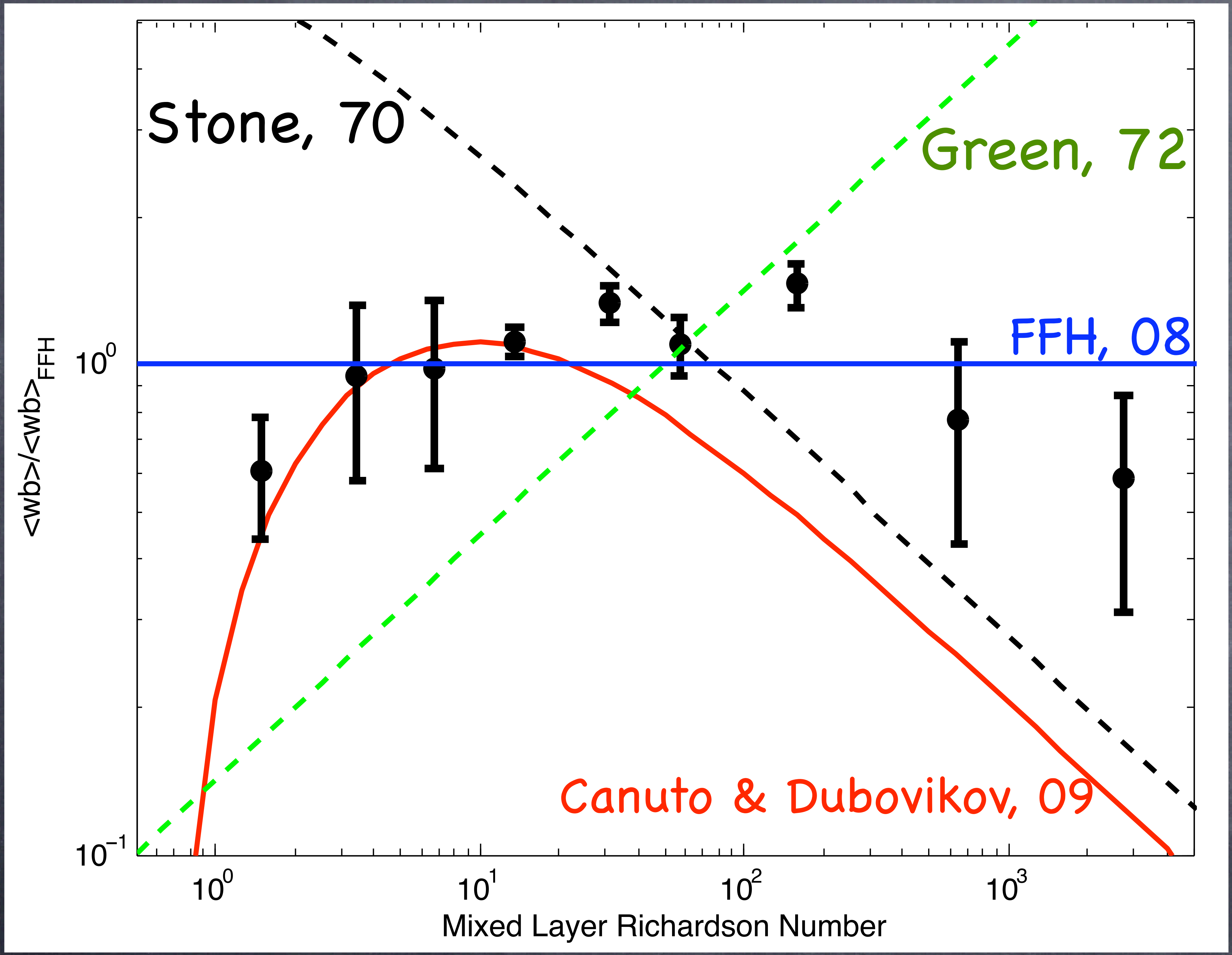
It works for Prototype front slumping



>2 orders of magnitude!

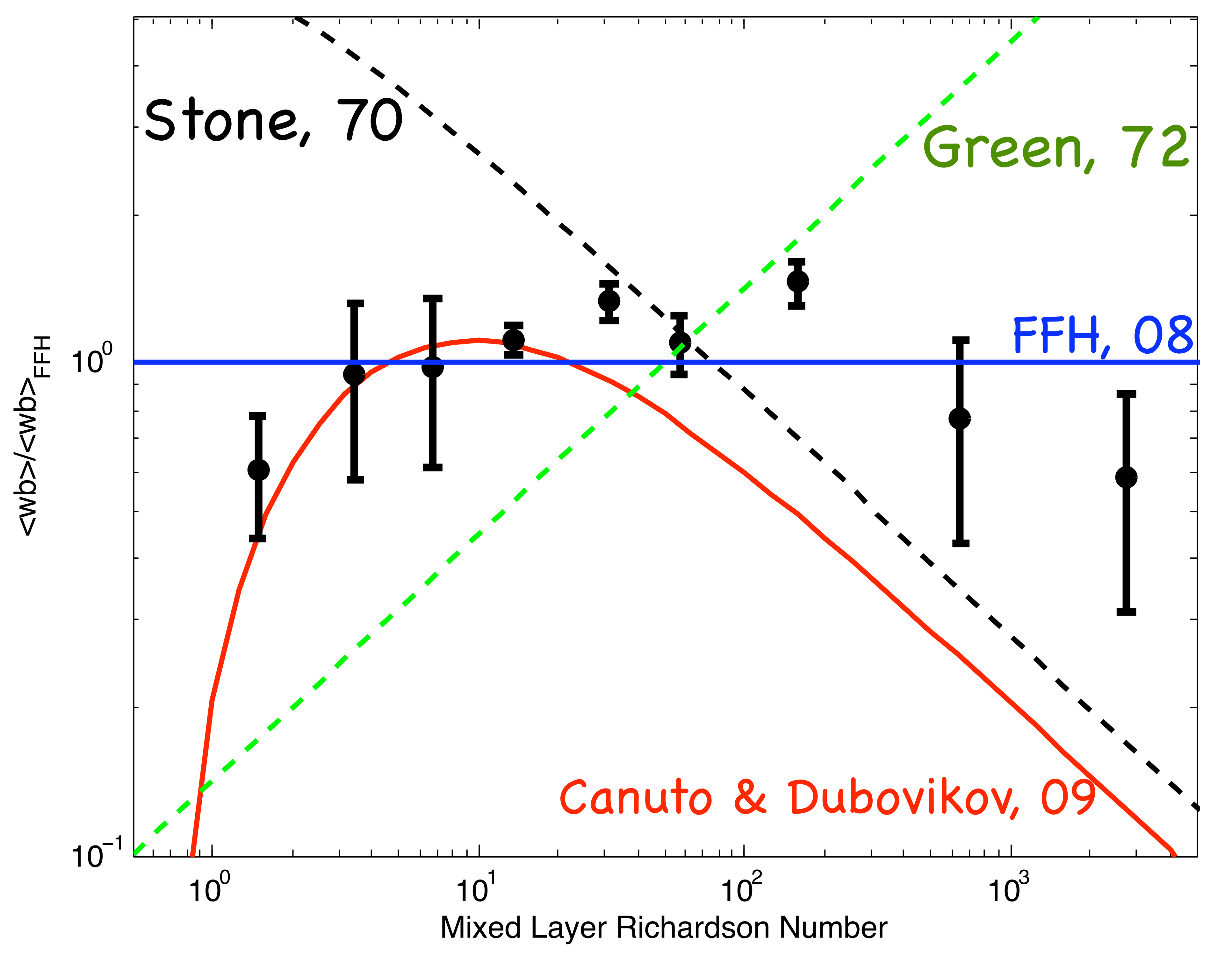
Circles: Balanced Initial Cond.
Squares: Unbalanced Initial Cond.

Better than the Competition:



Extends over Ri more mesoscale (9000) than submesoscale (1)

Better than the Competition:

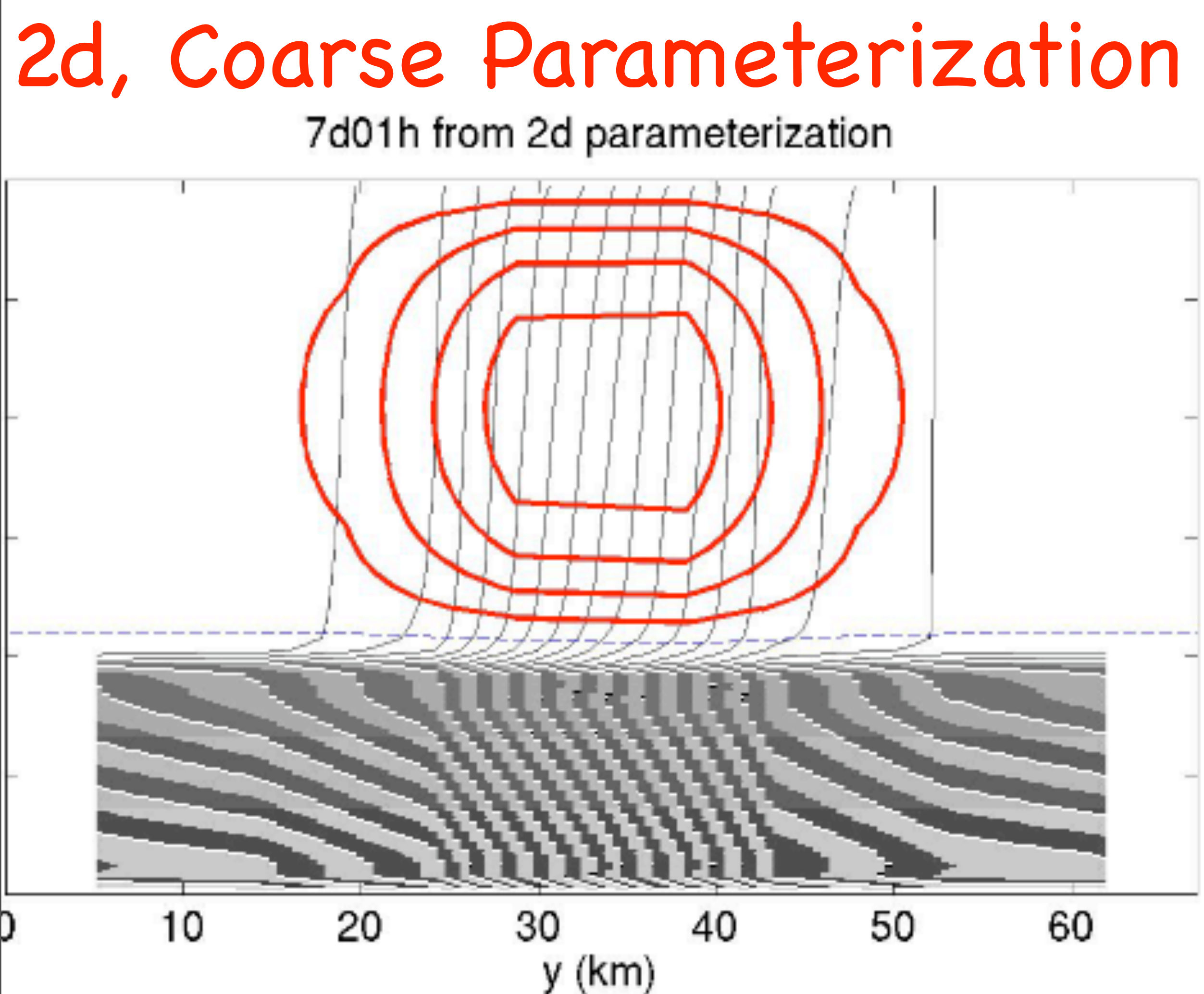


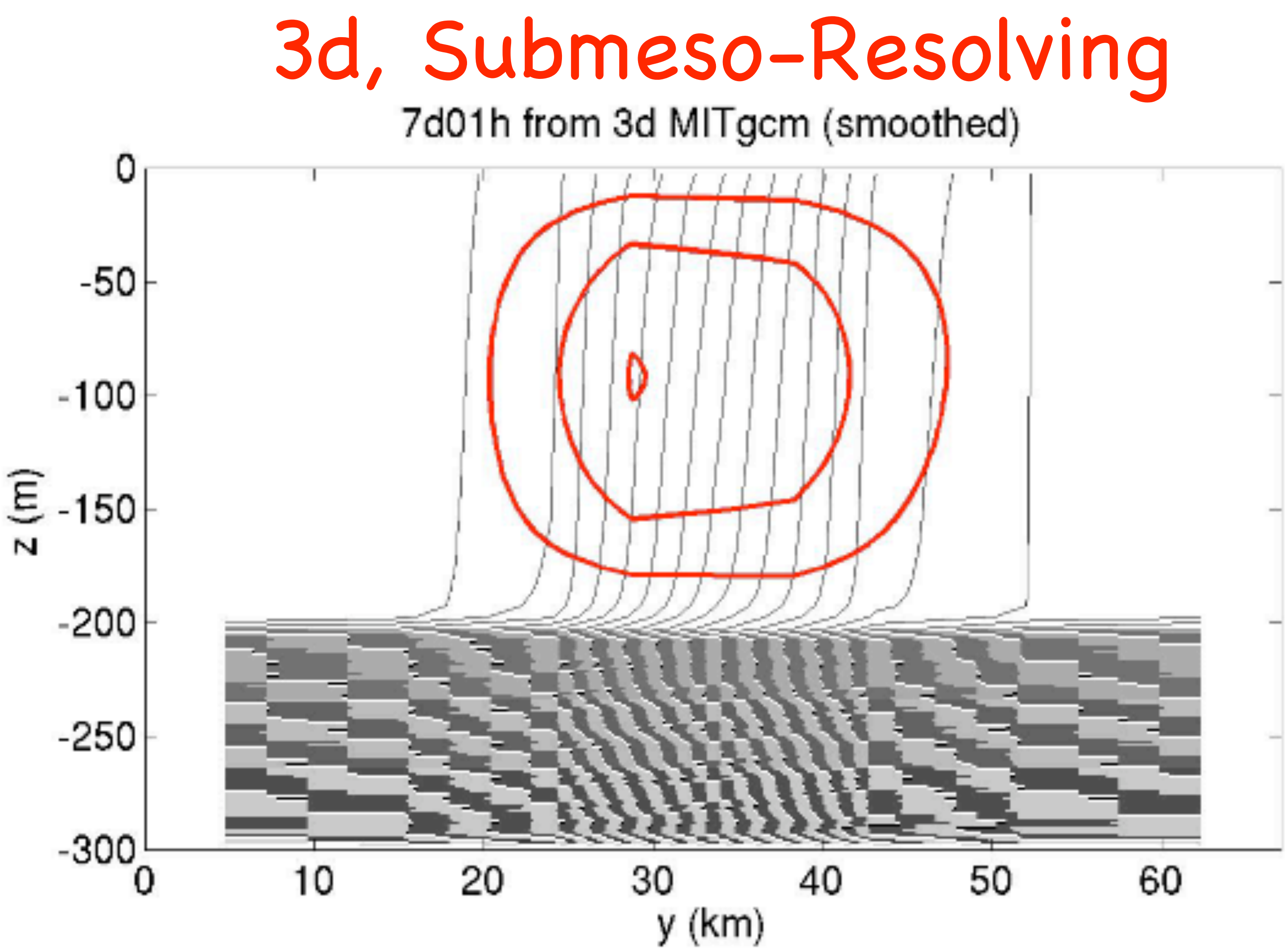
Green equals Visbeck (97) Held & Larichev (95)

Extends over Ri more mesoscale (9000) than submesoscale (1)

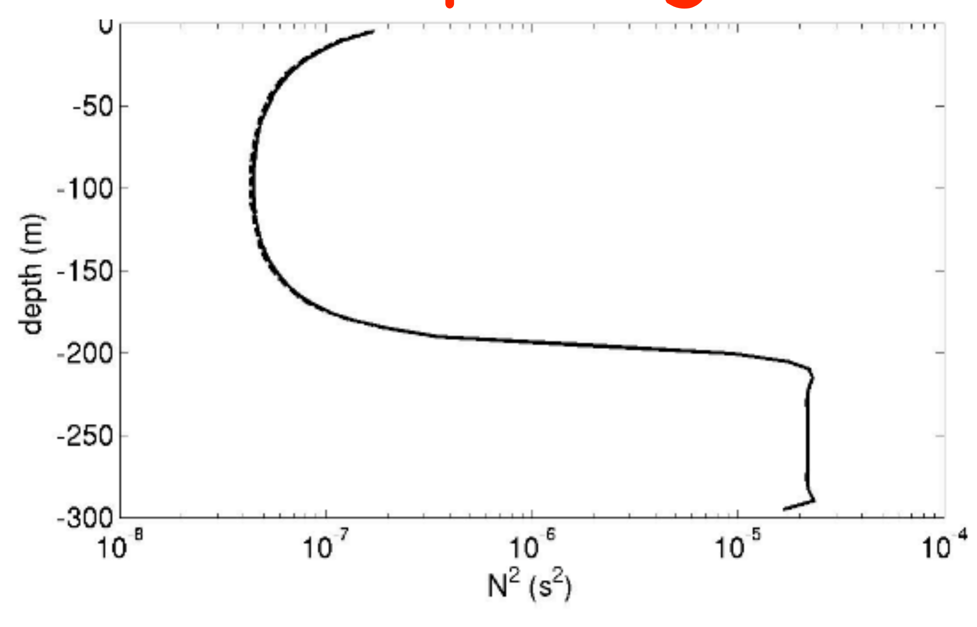
And Agrees with Deep Convection Studies: Jones & Marshall (93,97), Haine & Marshall (98)

What does it look like?





Comparing N^2



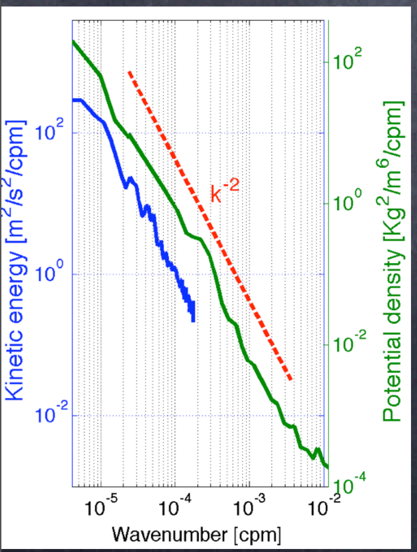
The Global Parameterization:

$$\mathbf{\Psi} = \frac{C_e H^2 \mu(z)}{|f|} \nabla \bar{b} \times \hat{\mathbf{z}}$$

$$\mu(z) = \left[1 - \left(\frac{2z}{H} + 1\right)^2\right]\left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]$$

At equator, go frictional! to (Young 94)

$$\mathbf{\Psi} = \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$



Account for coarse res. by scaleup

$$E_b(k) \sim k^{-2} \rightarrow \mathbf{\Psi} = \left[\frac{\Delta x}{L_f}\right] \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$

Obs. reveal (Hosegood et al., 2006): $L_f \sim R_d$

A Global Parameterization of Mixed Layer Eddy Restratification

$$\boldsymbol{\Psi} = \left[\frac{\Delta x}{L_f}\right] \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$

$$\mu(z) = \left[1 - \left(\frac{2z}{H} + 1\right)^2\right] \left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]$$

Which parameterizes eddy-induced velocity and buoyancy fluxes

$$\mathbf{v}^{\dagger} = \nabla \times \boldsymbol{\Psi} \qquad \overline{\mathbf{v}'b'} \approx \boldsymbol{\Psi} \times \nabla \bar{b}$$

Now, What Does it Do Globally?

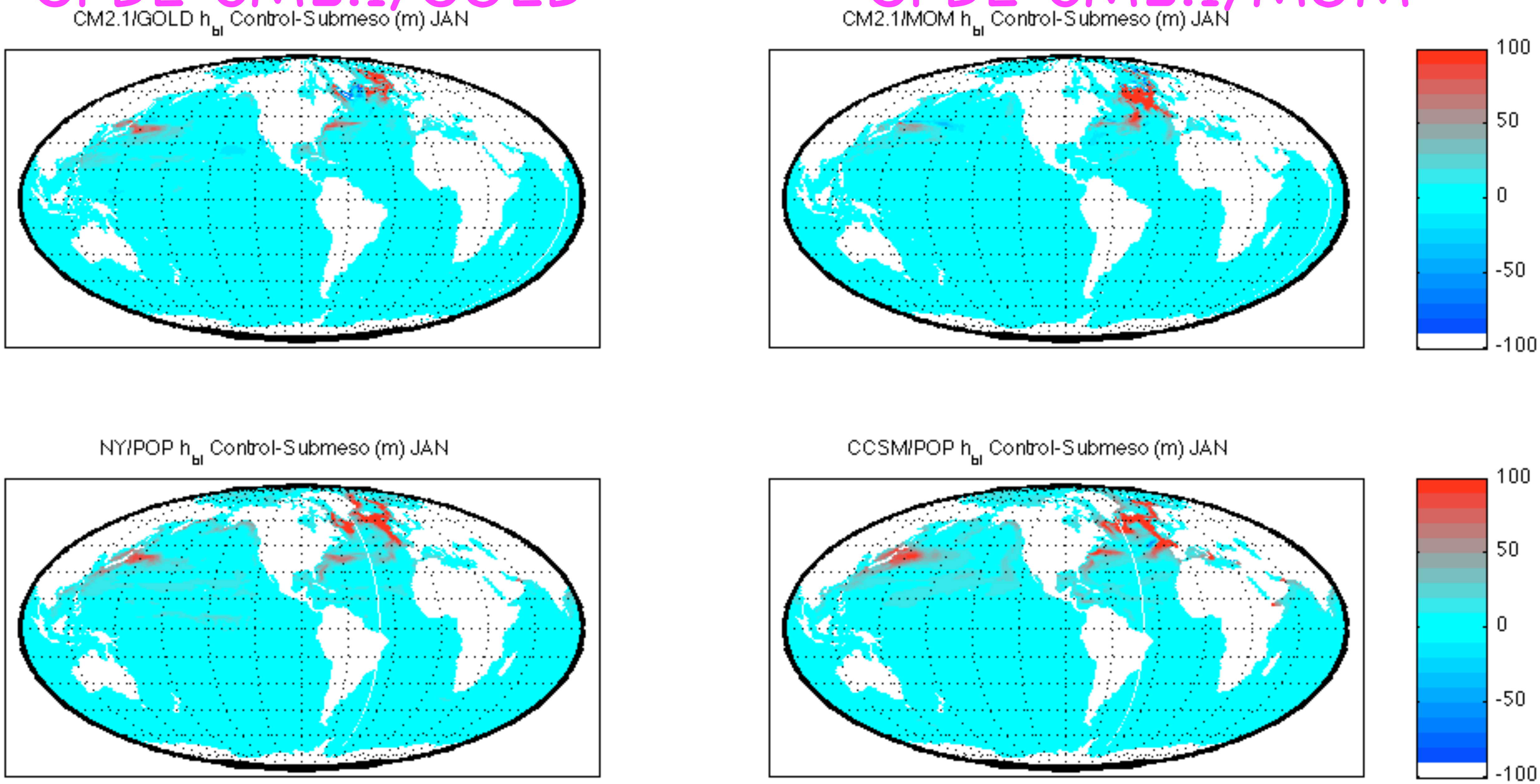
Improves Restratification after Deep Convection

Note: param. reproduces Haine&Marshall (98) and Jones&Marshall (93,97)

& generally **shallower boundary layers**

GFDL CM2.1/GOLD

GFDL CM2.1/MOM



NCAR Normal Year/POP

NCAR CCSM/POP

MLE-Control:Climatologies at end of > 100yr simulation

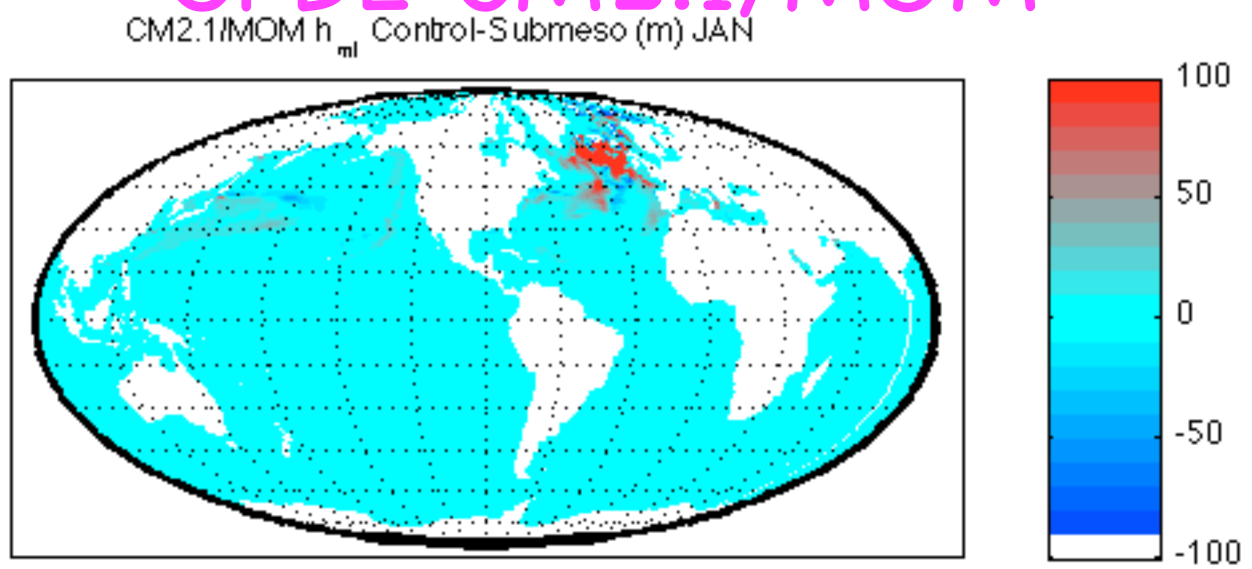
Improves Restratification after Deep Convection

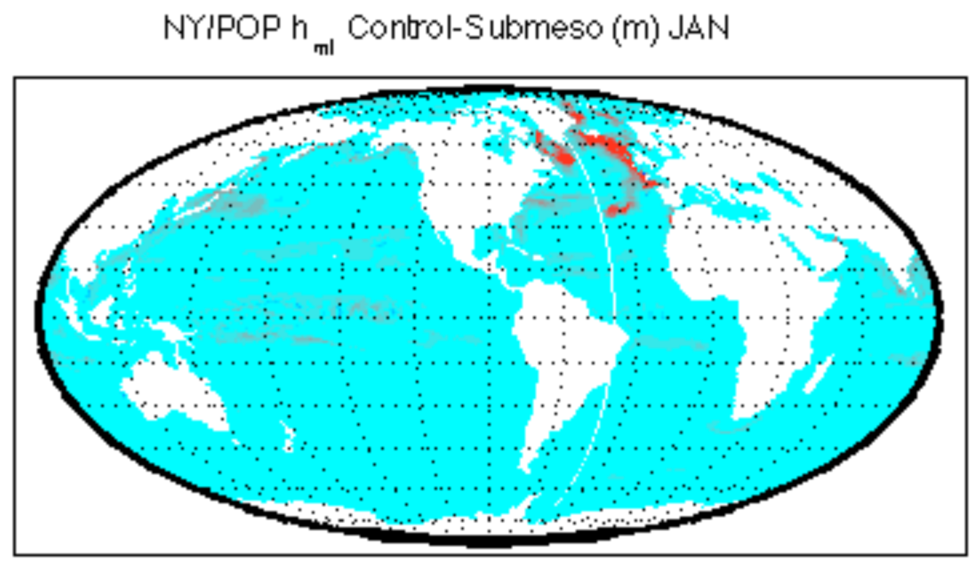
Note: param. reproduces Haine&Marshall (98) and Jones&Marshall (93,97)

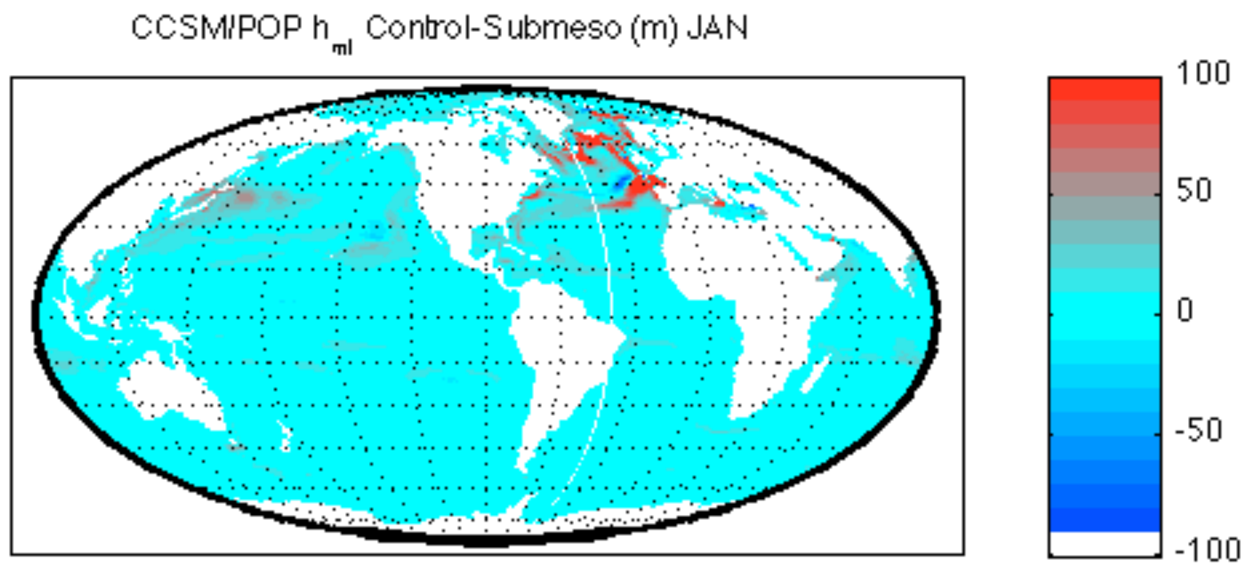
& generally shallower mixed layers

(nonzonal structure as in obs: Rintoul)

GFDL CM2.1/MOM





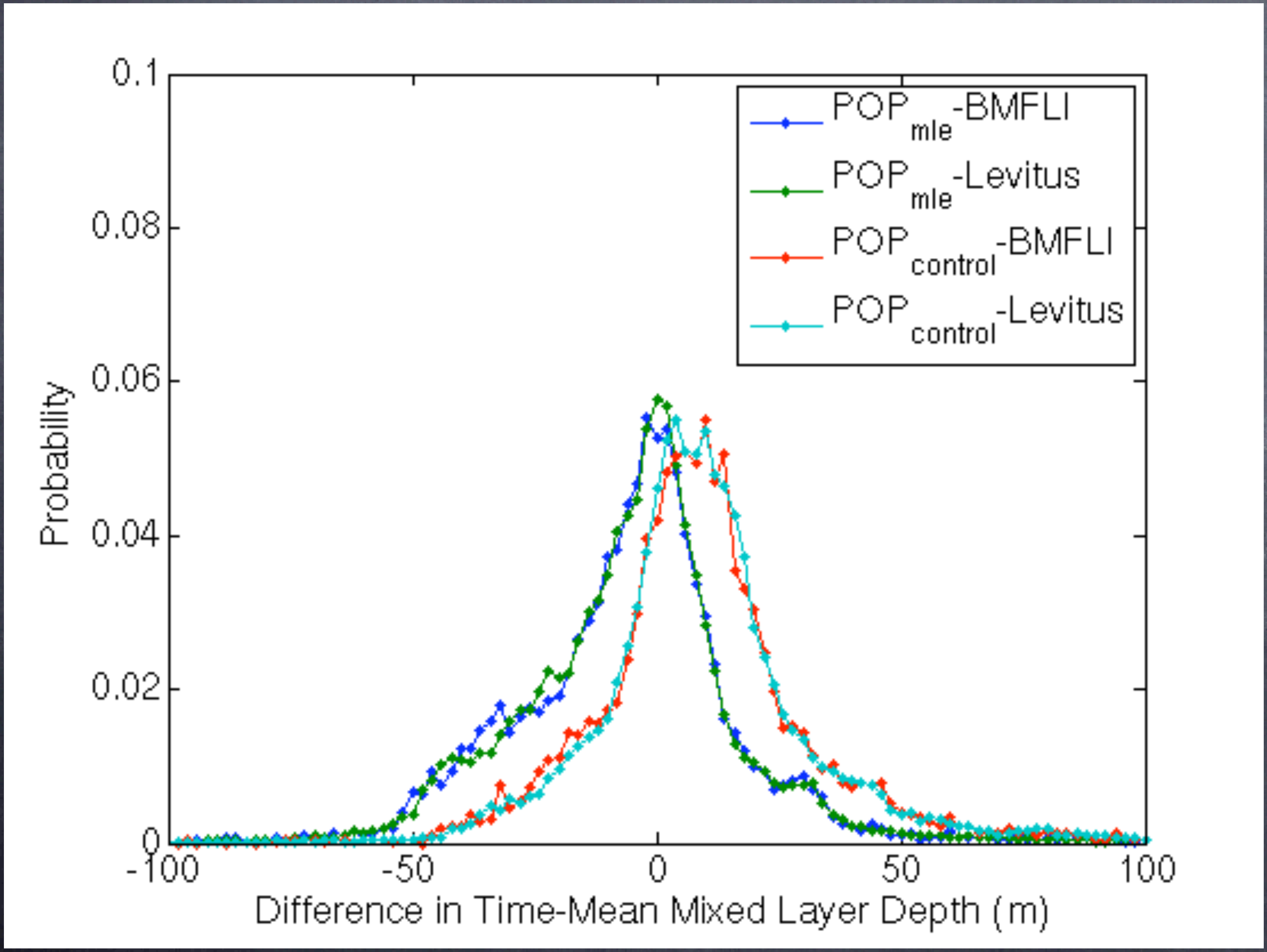


NCAR Normal Year/POP

NCAR CCSM/POP

MLE-Control:Climatologies at end of > 100yr simulation

Bias Reduction in POP Mixed Layer Depth

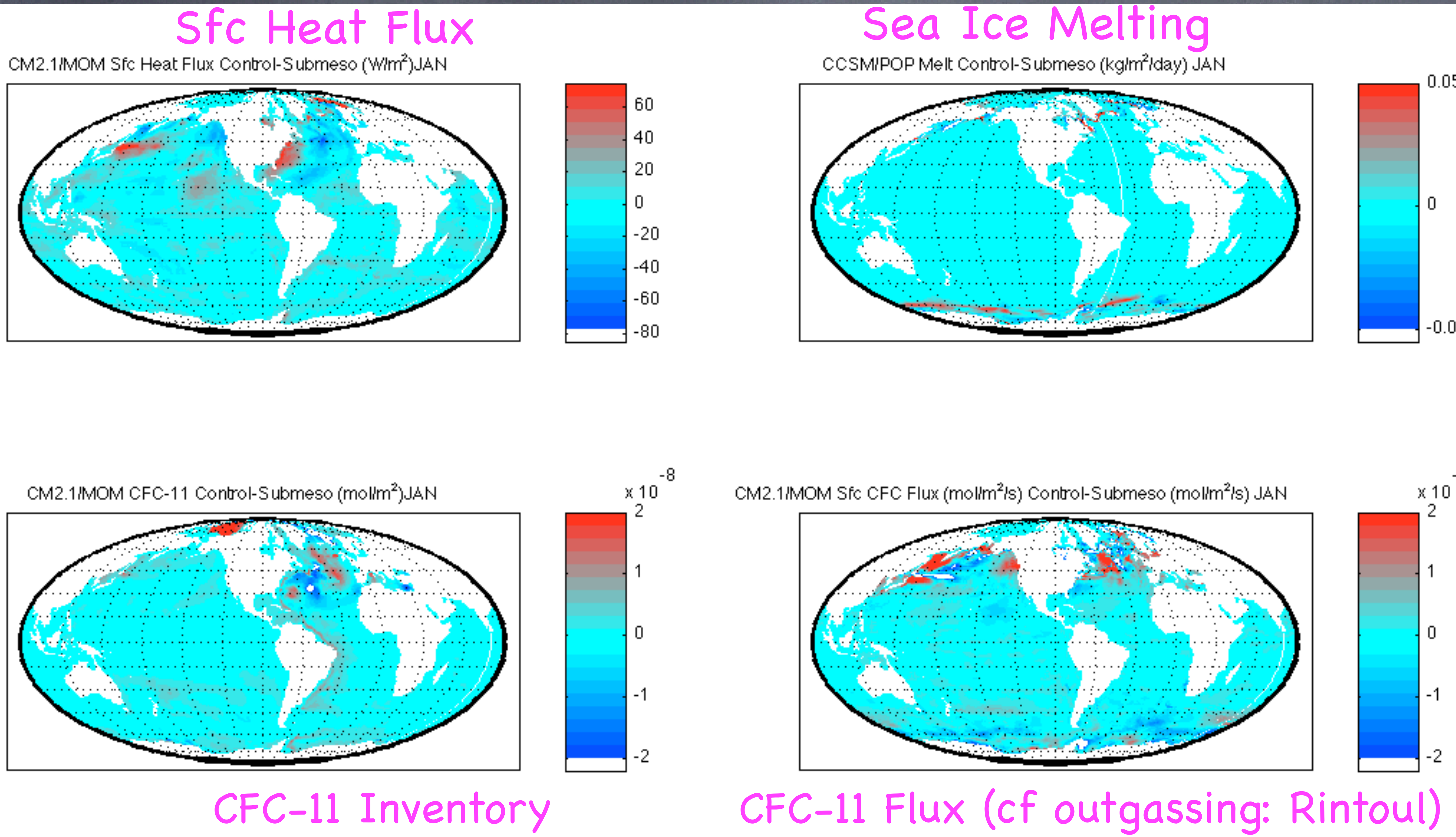


RMS error: 16m reduced to 8m

Skewness: 2.4 reduced to 0.6

Fox-Kemper, Danabasoglu, Ferrari, Hallberg '08.

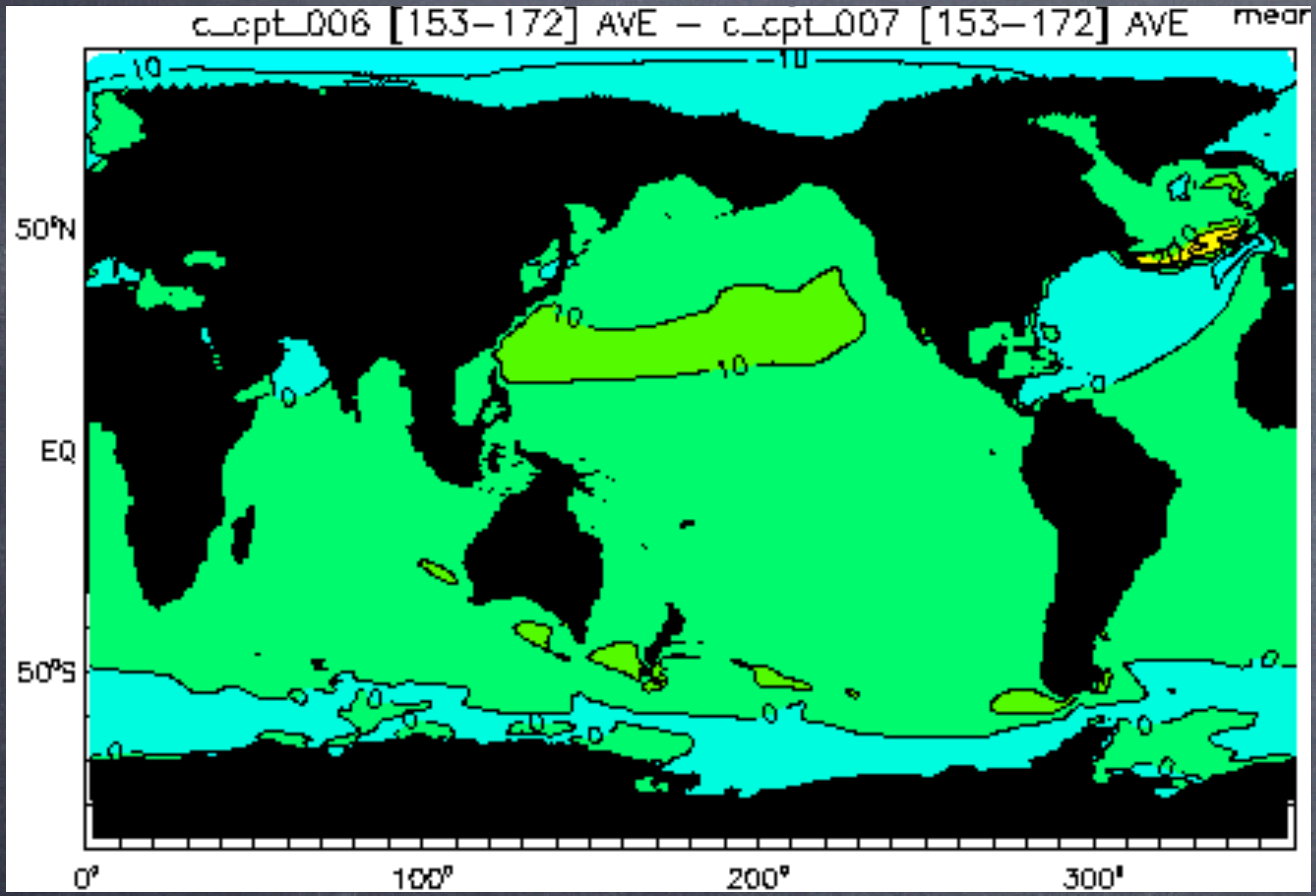
Changes other variables we care about...



MLE-Control:Climatologies at end of > 100yr simulation

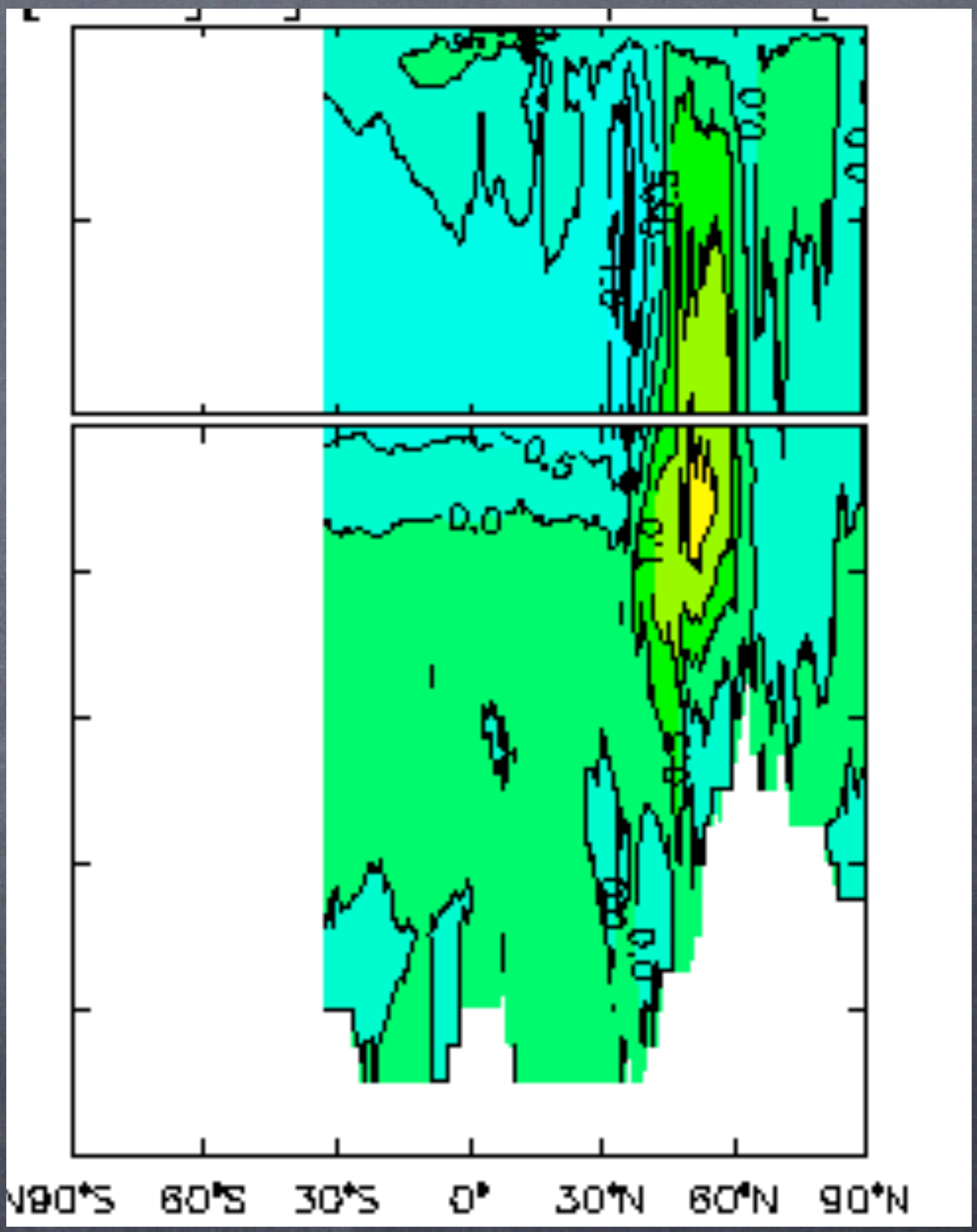
Changes other variables we care about...

Avg. Ideal Age 4 yrs older at 500m with MLE (up to 30%)



(as big as coarse vs 10km, Frank)

MOC 10% greater with MLE



MLE-Control:Climatologies at end of > 100yr simulation

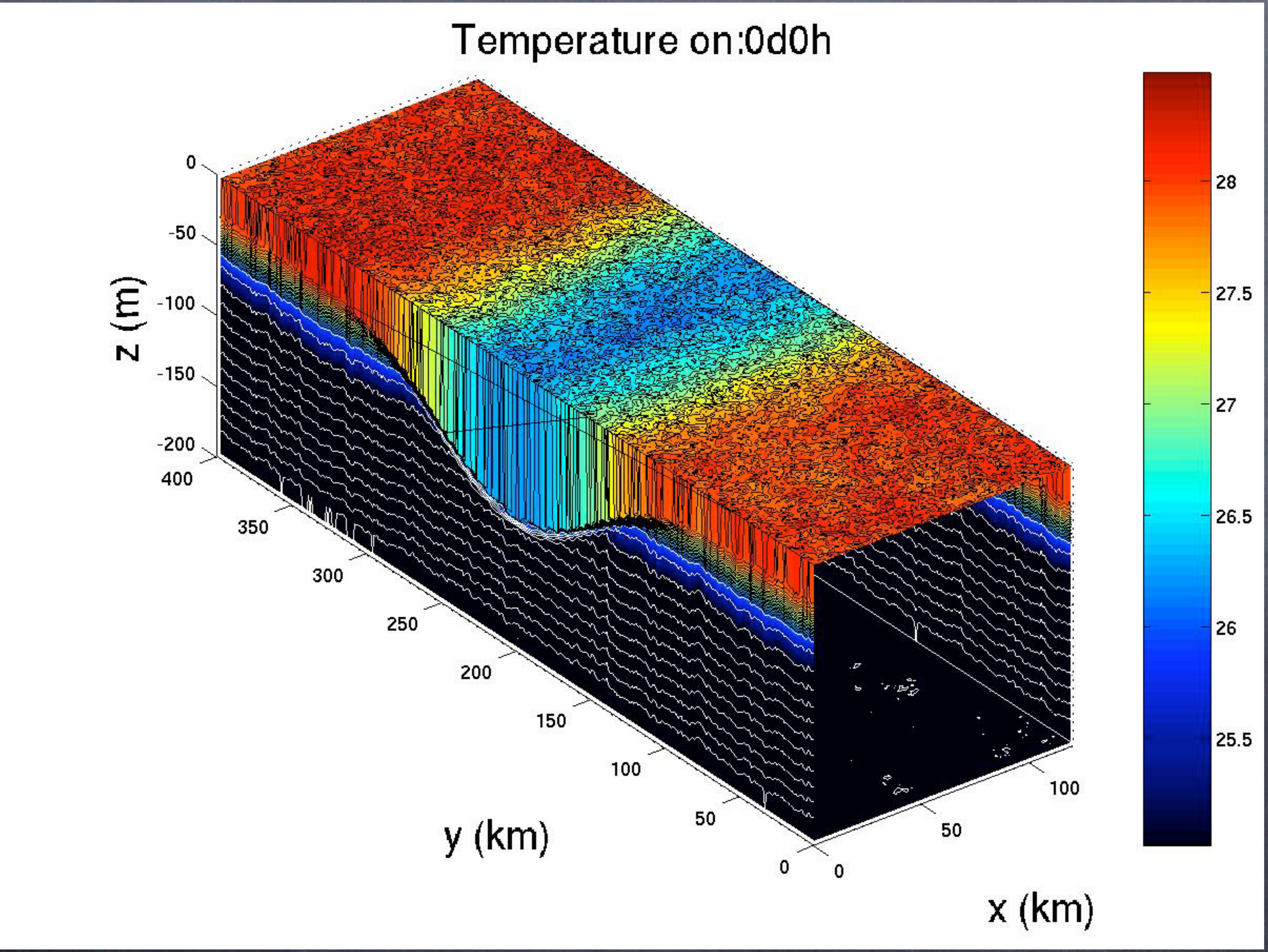
MLE Parameterization Conclusions

- A restratification parameterization based on nonlinear Mixed Layer Eddies has been formulated
- It outperforms other scalings in prototype simulations, and new evidence shows that it applies in more general settings including wind (Capet 08, Mahadevan et al. 09)
- It has now been implemented in a number of global models--producing nontrivial improvements of mixed layer properties

Mesoscale Implications?
Mesoscale Connections?

- MLE parameterization blends naturally with GM, etc.: Just add together the streamfunctions
- But, shouldn't we be able to provide a similar scaling for Mesoscale GM coefficient, a la Visbeck?
- After all, MLE are quasibalanced, and scaling works up to at least Ri=9000
- But, the real difficulty is illustrated by cases where the surface MLEs become subsurface SCVs...

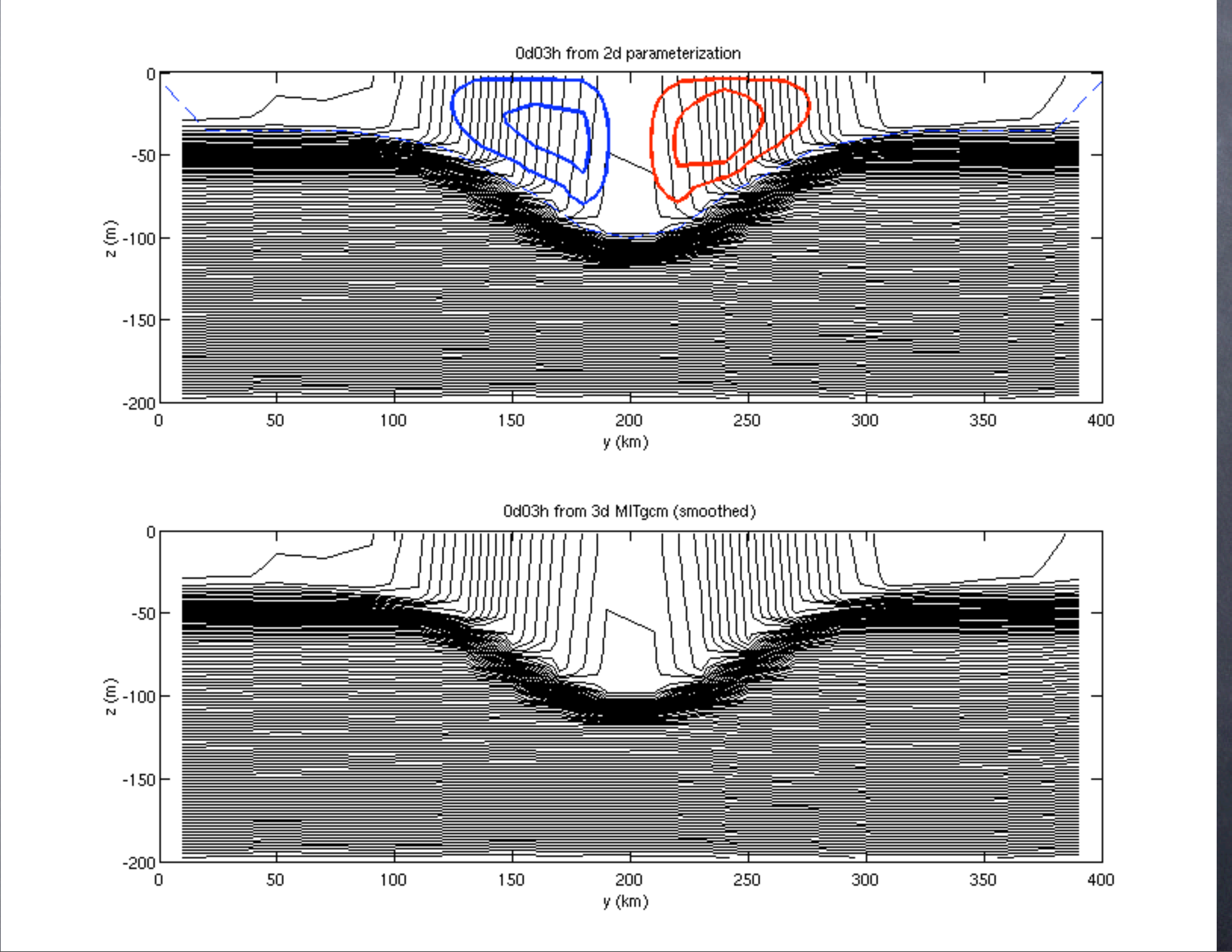
An Example of MLE Becomes Subsurface SCV: Hurricane Wake Recovery



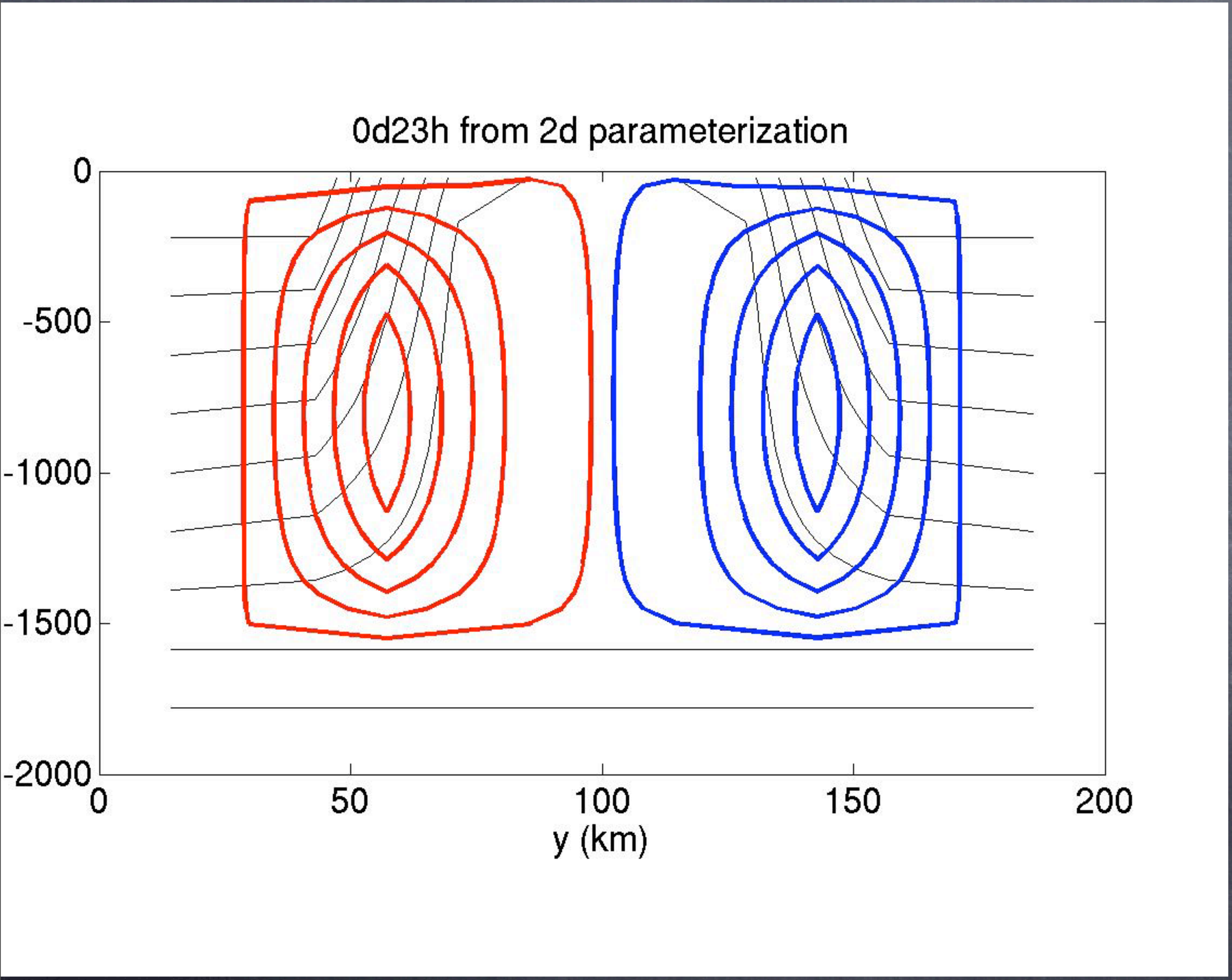
An Example of MLE Becomes Subsurface SCV: Hurricane Wake Recovery

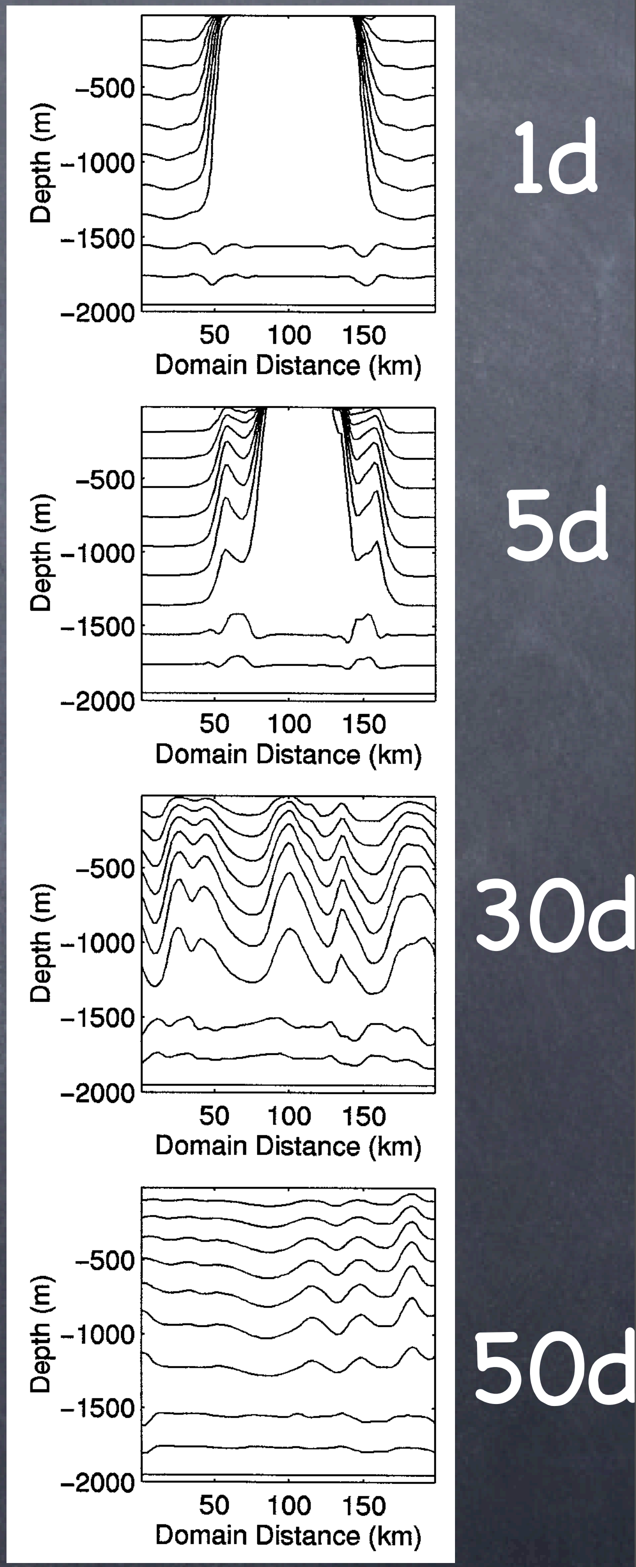
MLE Param.

3d Model, (no wind or solar)



An Example of MLE Becomes Subsurface SCV: Deep Convection (vs. Jones & Marshall '97)

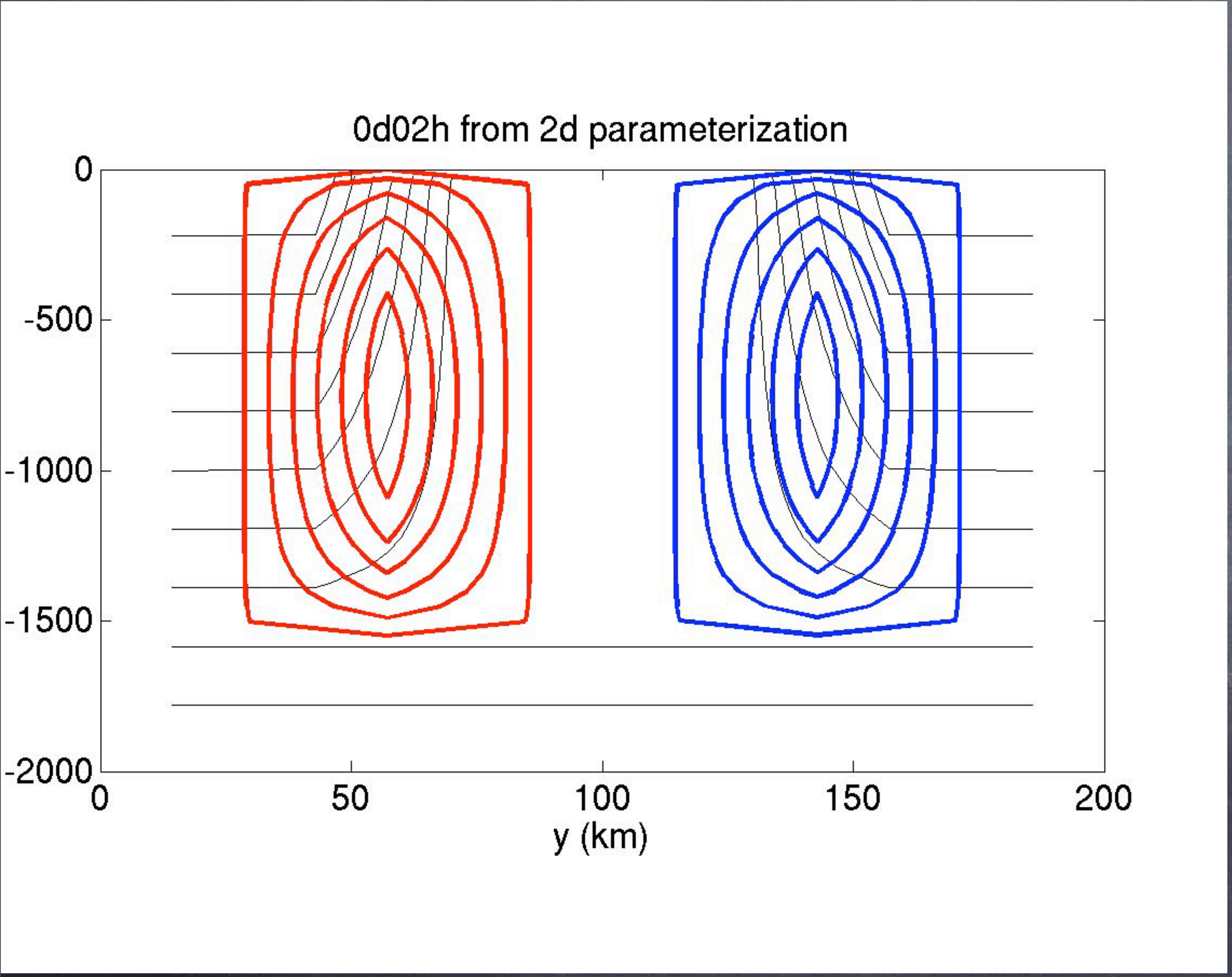


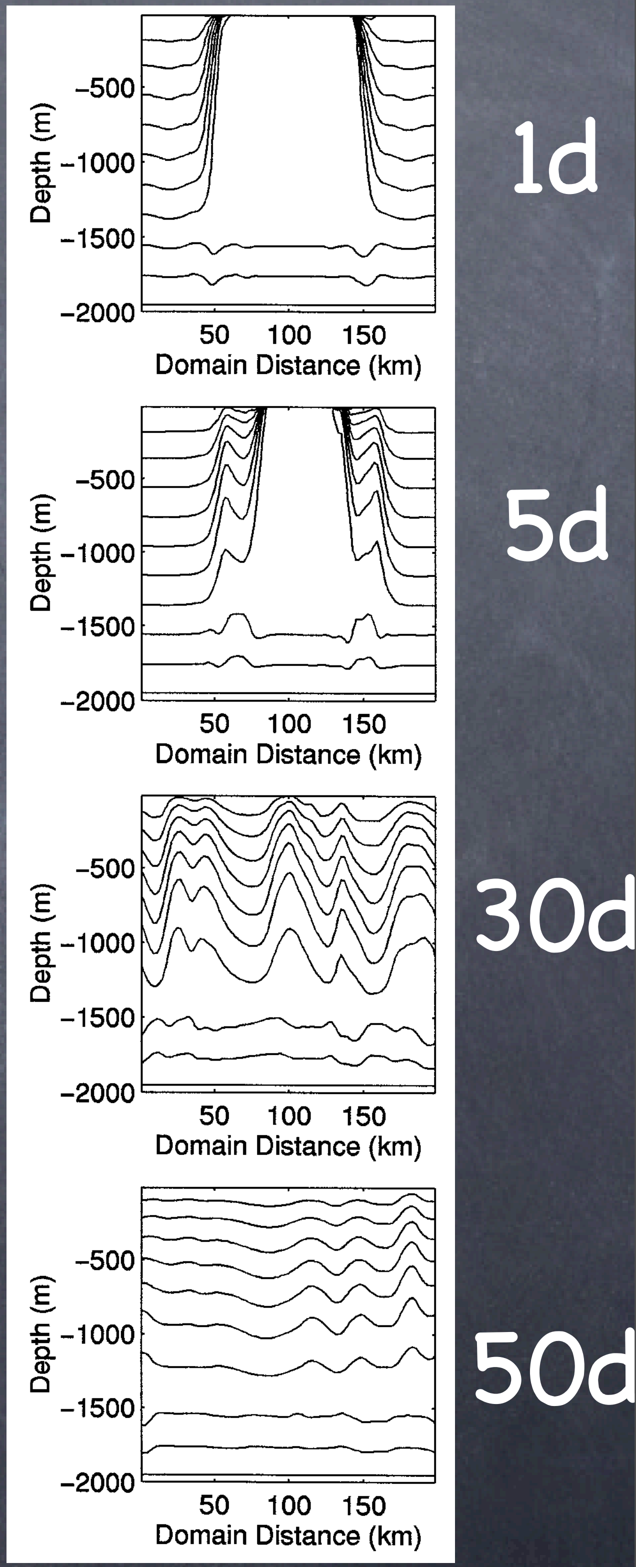


Param gives same scaling, but...

Jones & Marshall 97

An Example of MLE Becomes Subsurface SCV: Deep Convection (vs. Jones & Marshall '97)





Vertical structure is different...

Jones & Marshall 97

The Problem is:

The mesoscale equivalent isn't rEady

- Clearly, MLE parameterization is challenged by situations where medium-sized interior PV grads; Big PV grads are equivalent to rigid surfaces and are OK, just medium-sized fail.
- Smith (07) shows Phillips-type (interior PV grads) dominate the energy extraction

The Problem is:

The mesoscale equivalent isn't rEady

- Clearly, MLE parameterization is challenged by situations where medium-sized interior PV grads; Big PV grads are equivalent to rigid surfaces and are OK, just medium-sized fail.
- Smith (07) shows Phillips-type (interior PV grads) dominate the energy extraction

What to do?

Parameterization Challenge Suite

- The needed stratification, shear, strain, etc. are in the global model Frank presented
- Will extract 'typical' eddy configurations by EOF or SOM
- Will simulate individually: O(2000) simulations
- Global run analog of mesoscale-submesoscale channel;
- Parameterization suite -> Analog of protype sim here