Parameterizing Submesoscale Eddies for Global Ocean Models

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University of Colorado and CIRES

Collaborators:
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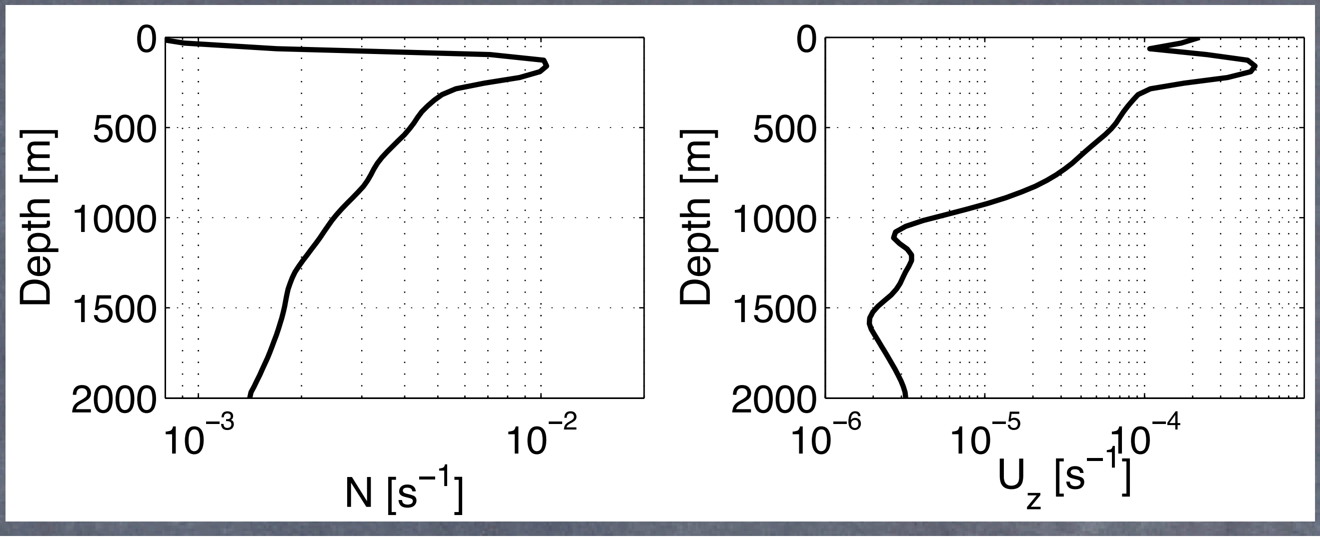
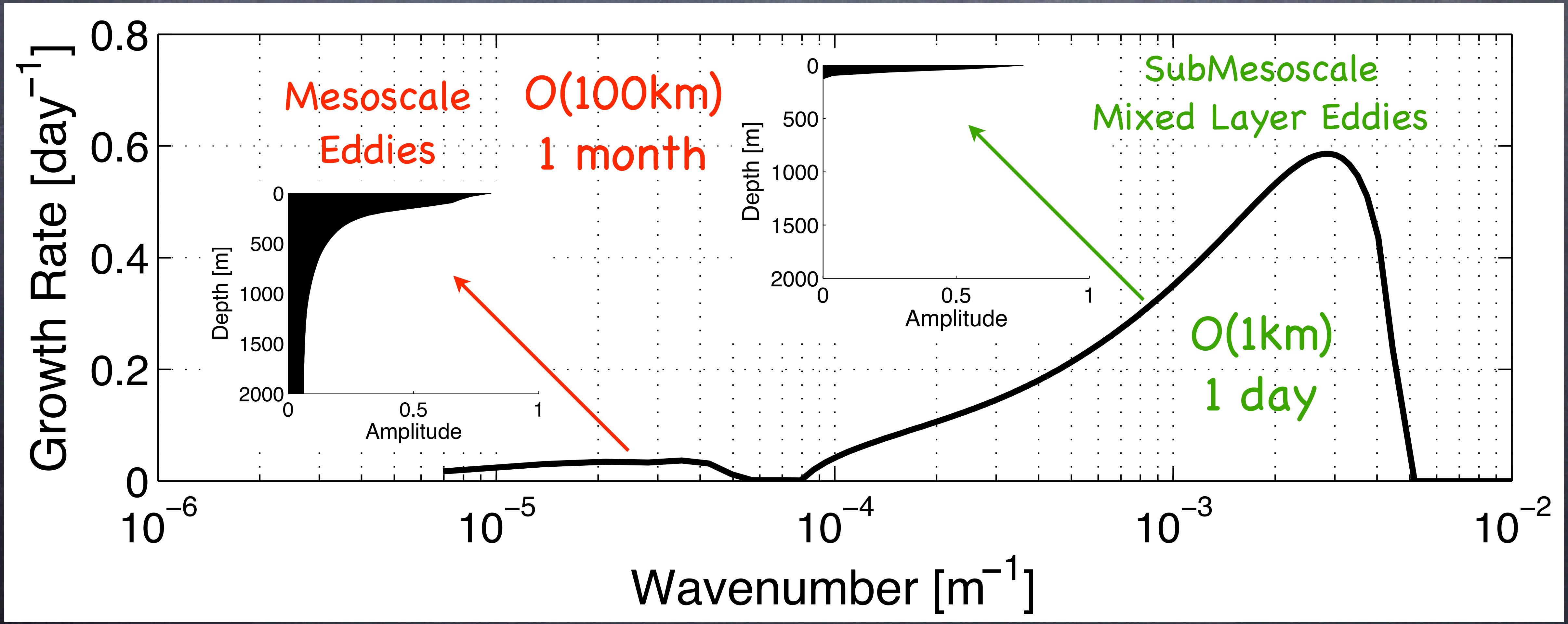
NCAR Geophysical Turbulence Phenomena
IMAGe Theme of the Year: Turbulent Theory and Modeling
Boulder, CO; Wednesday 2/27/08, 12:15-12:30

Typical Ocean Stratification Permits
Two Types of Baroclinic Instability:

Mesoscale and SubMesoscale (Boccaletti et al., 2006)





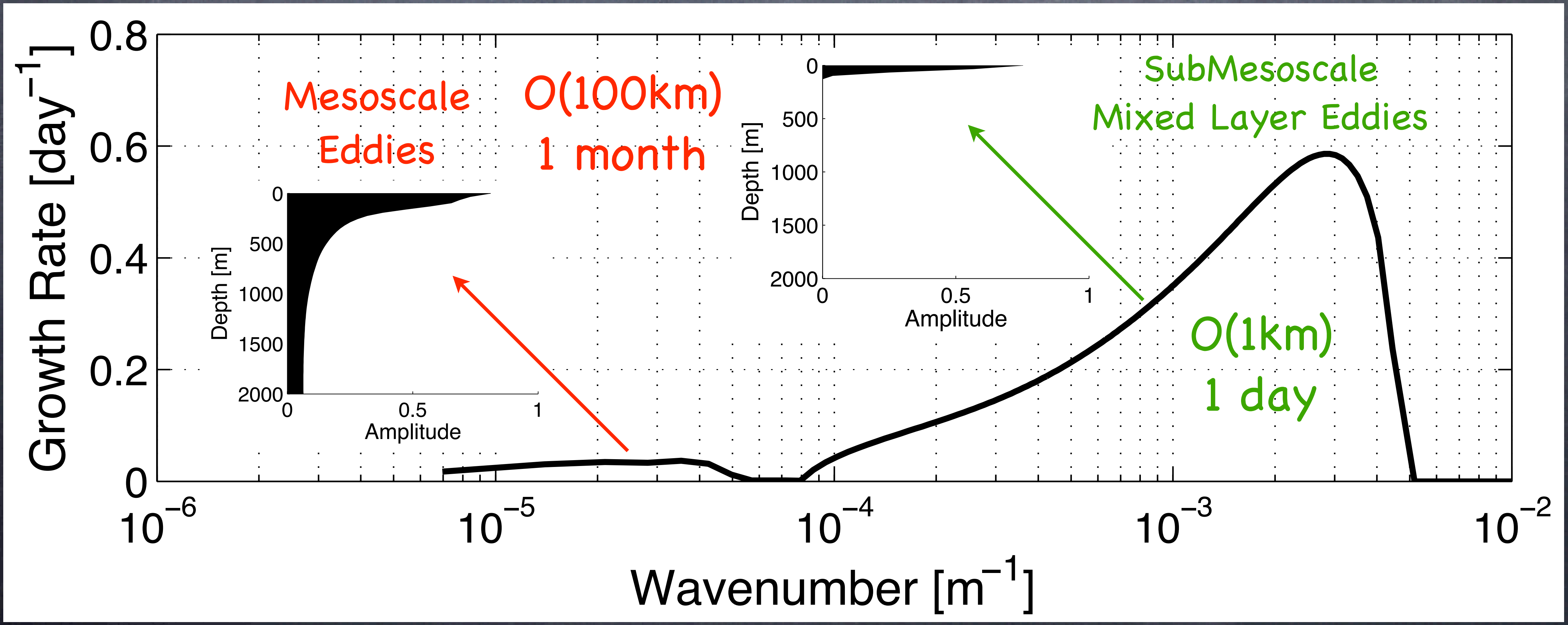
Typical Ocean Stratification Permits

Two Types of Baroclinic Instability:

Mesoscale and SubMesoscale (Boccaletti et al., 2006)

Vertical fluxes are Submesoscale
and tend to restratify

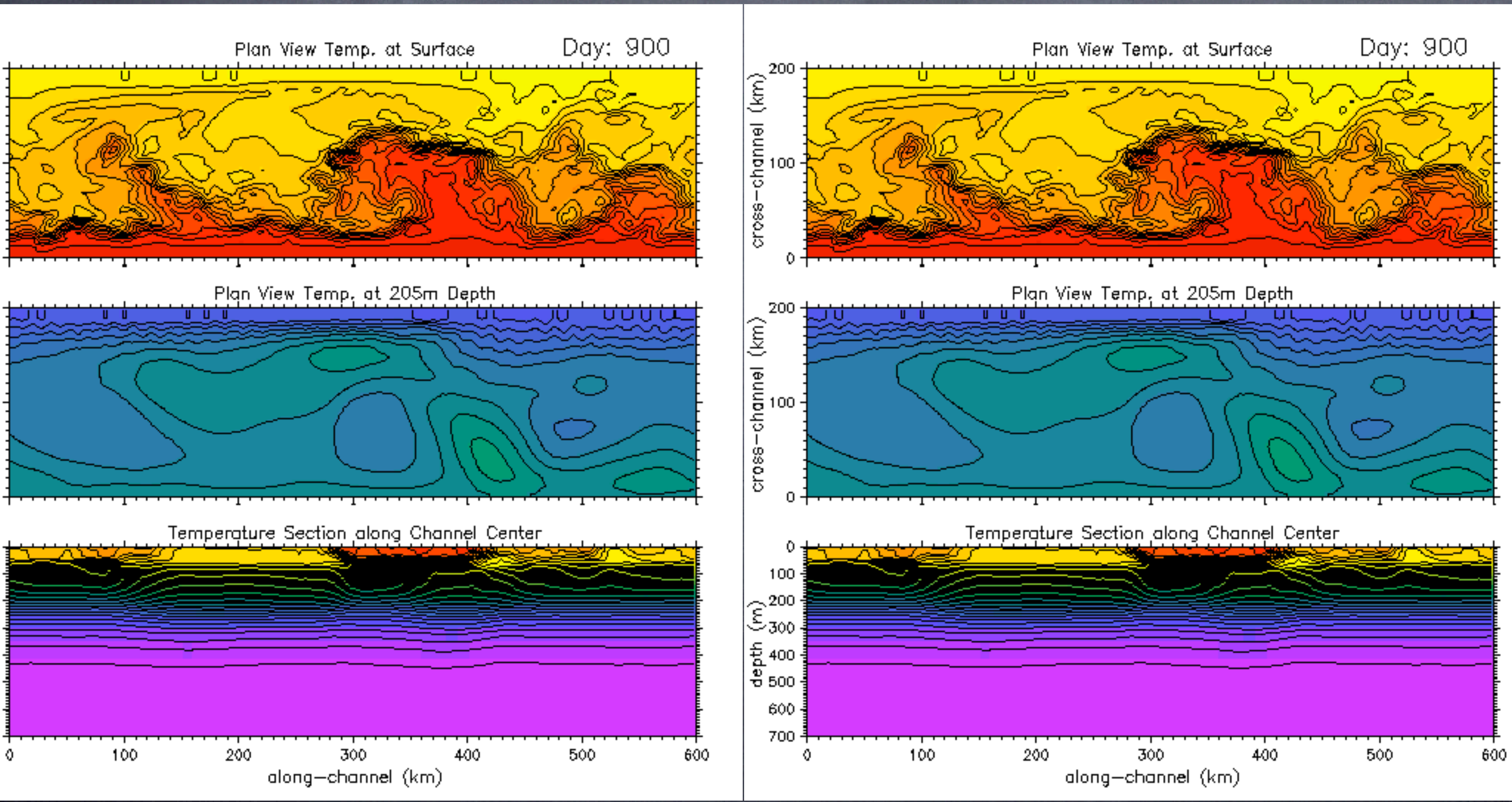
Horizontal fluxes are Mesoscale
and tend to stir



Having a Mixed Layer Counts!

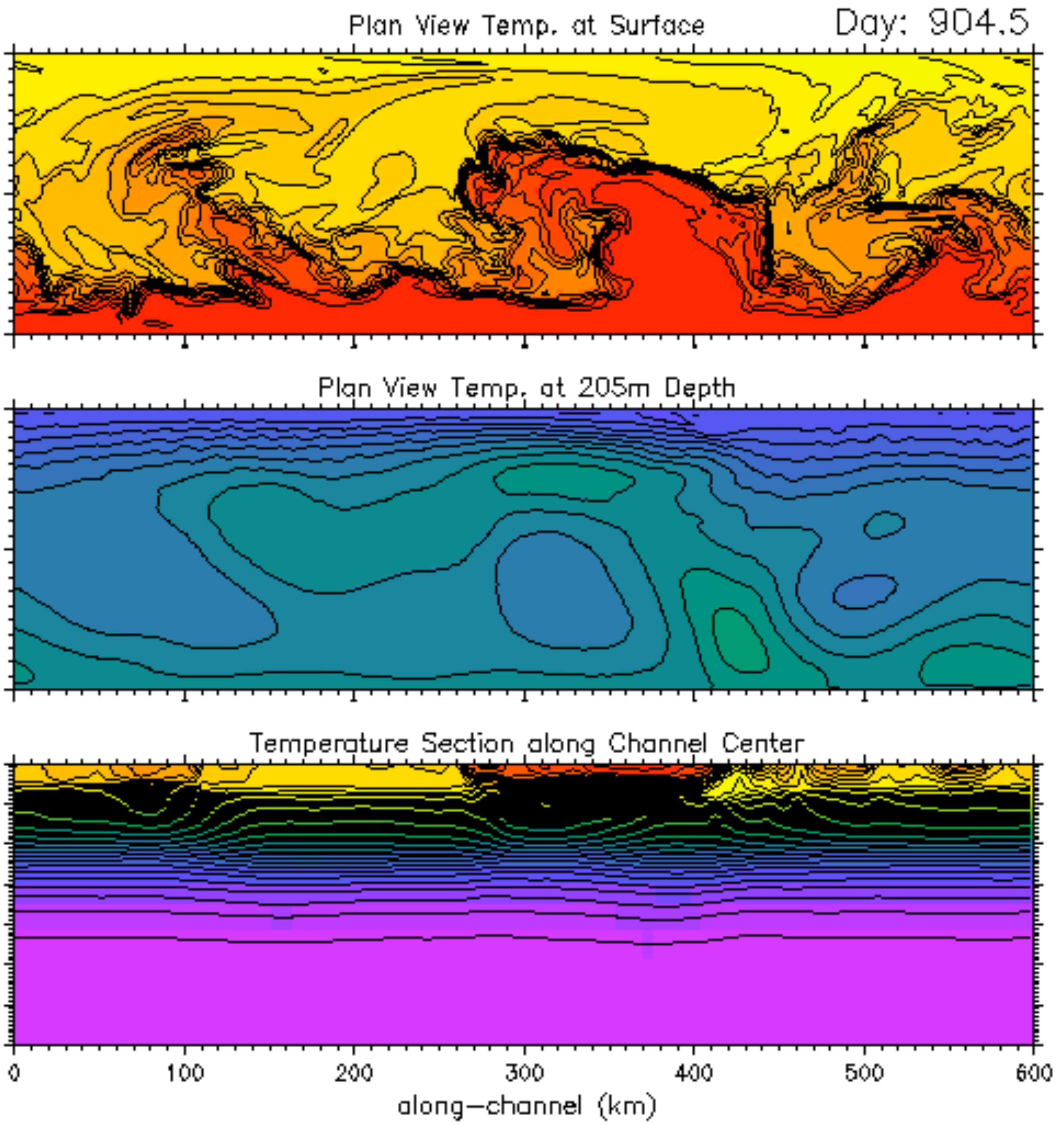
The vertical buoyancy flux in the ML (<w'b'>)

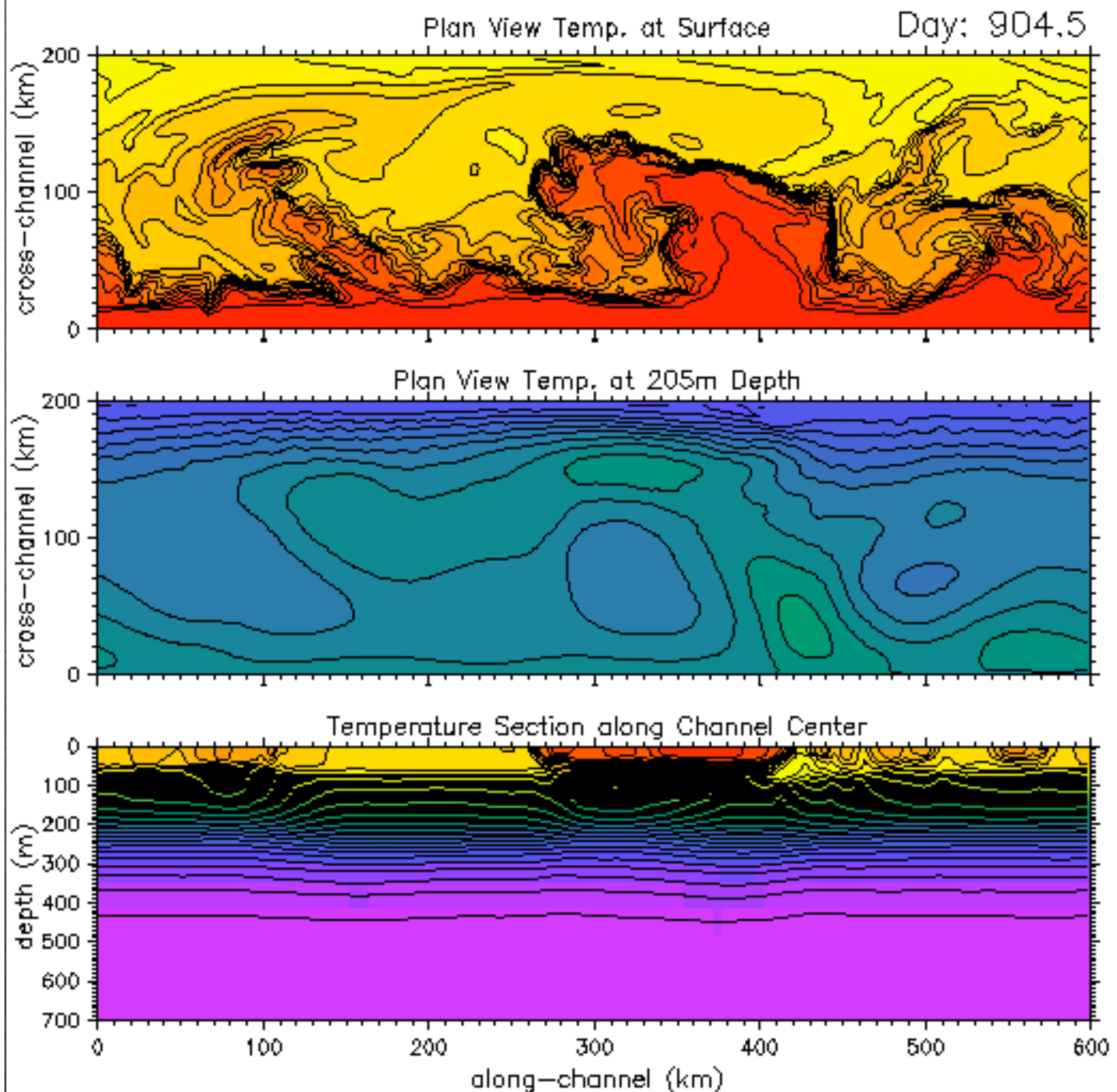
without diurnal cycle is notless than with cycle (ML)



Having a Mixed Layer Counts!

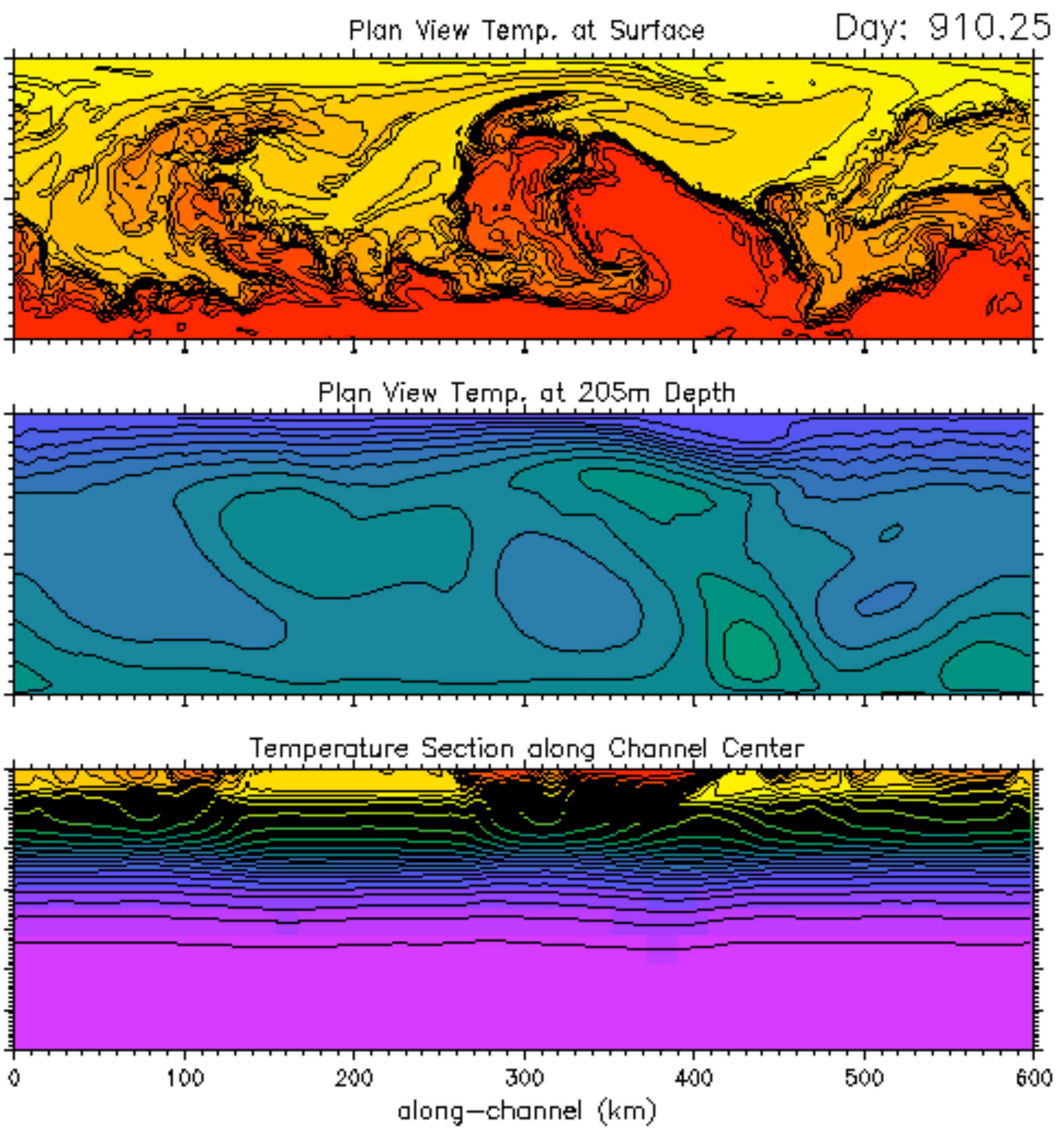
The vertical buoyancy flux in the ML (<w′b′>) without diurnal cycle is less than with cycle (ML)

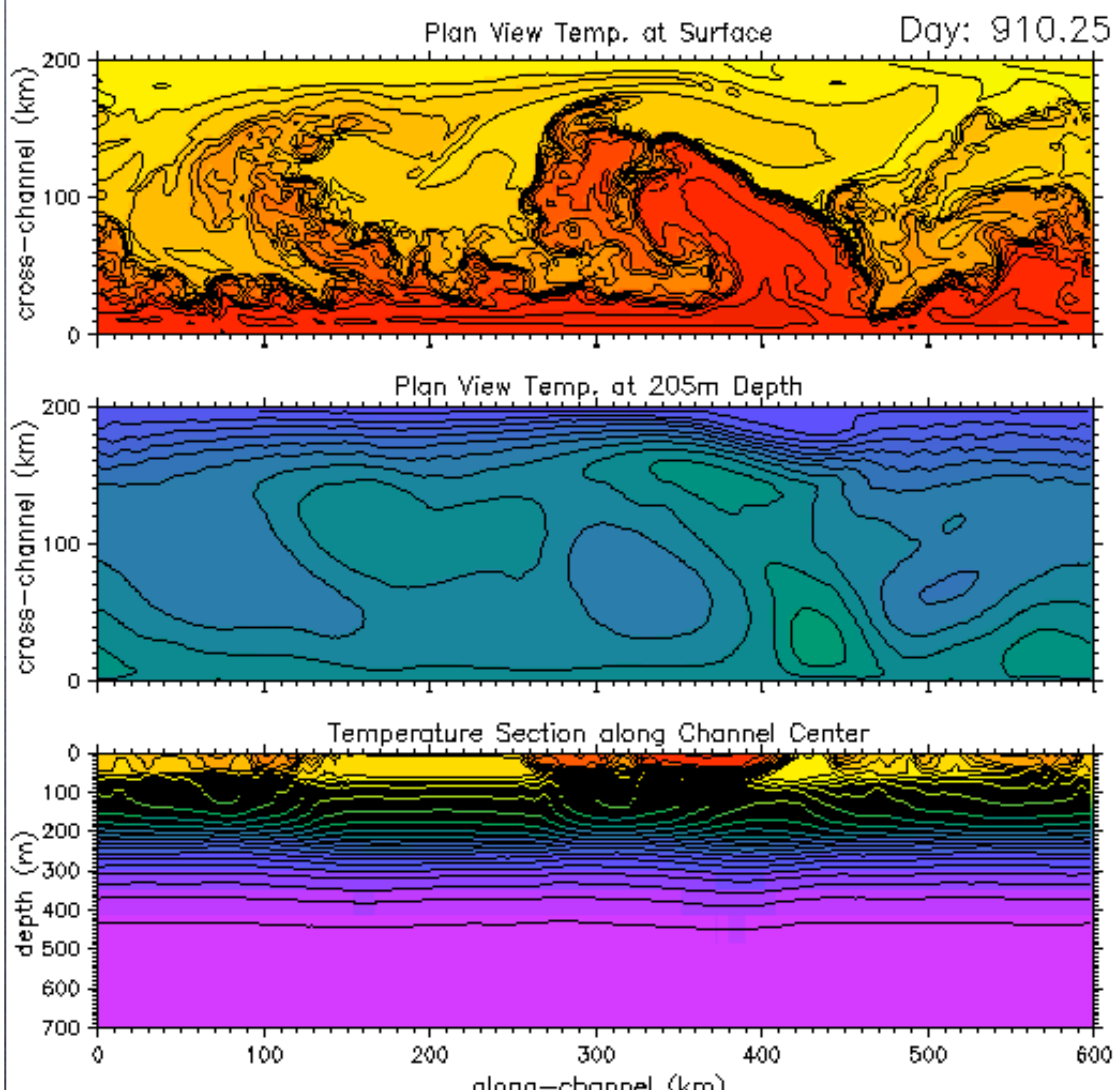




Having a Mixed Layer Counts!

The vertical buoyancy flux in the ML (<w'b'>) without diurnal cycle is 2x less than with cycle (ML)





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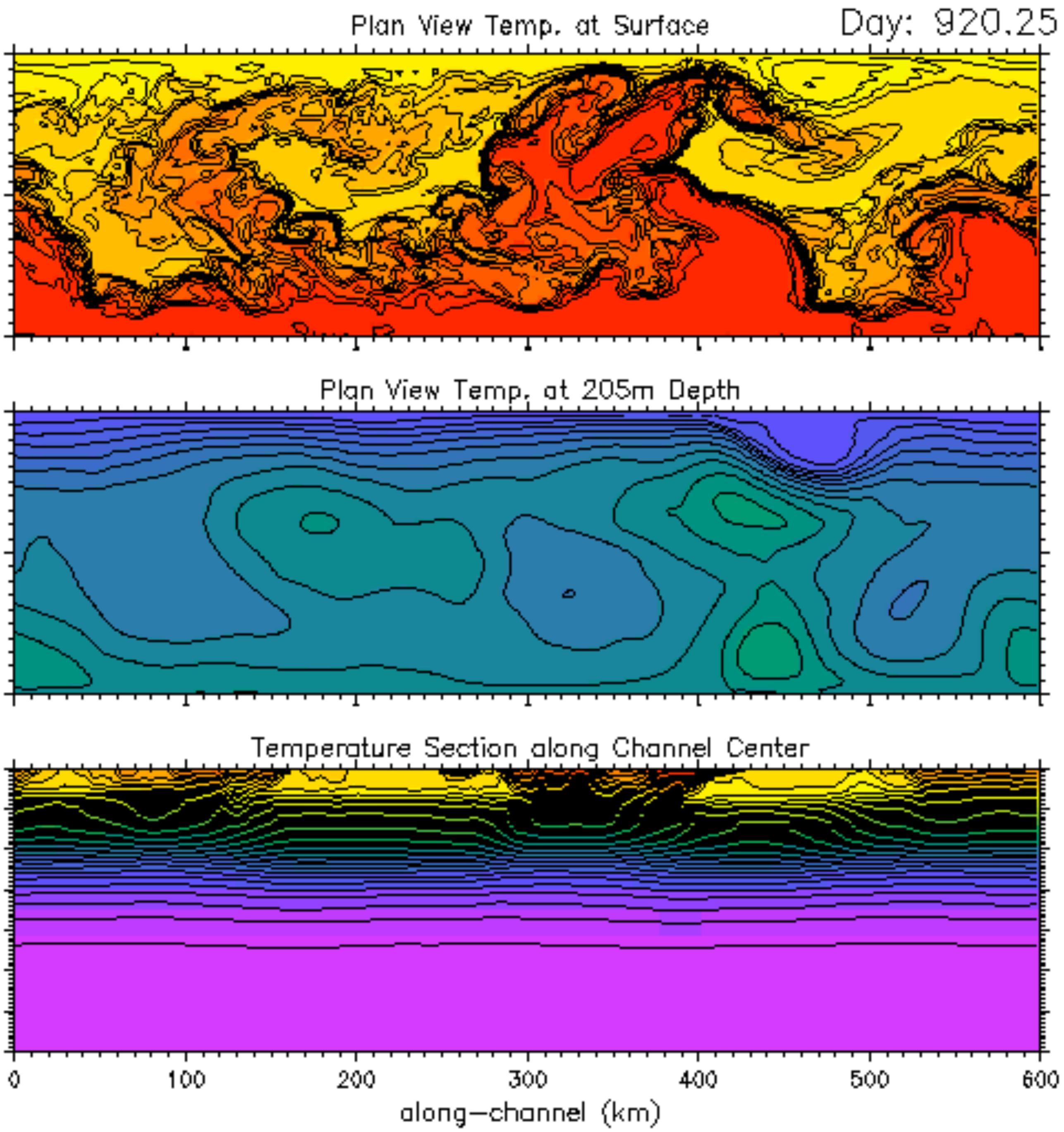
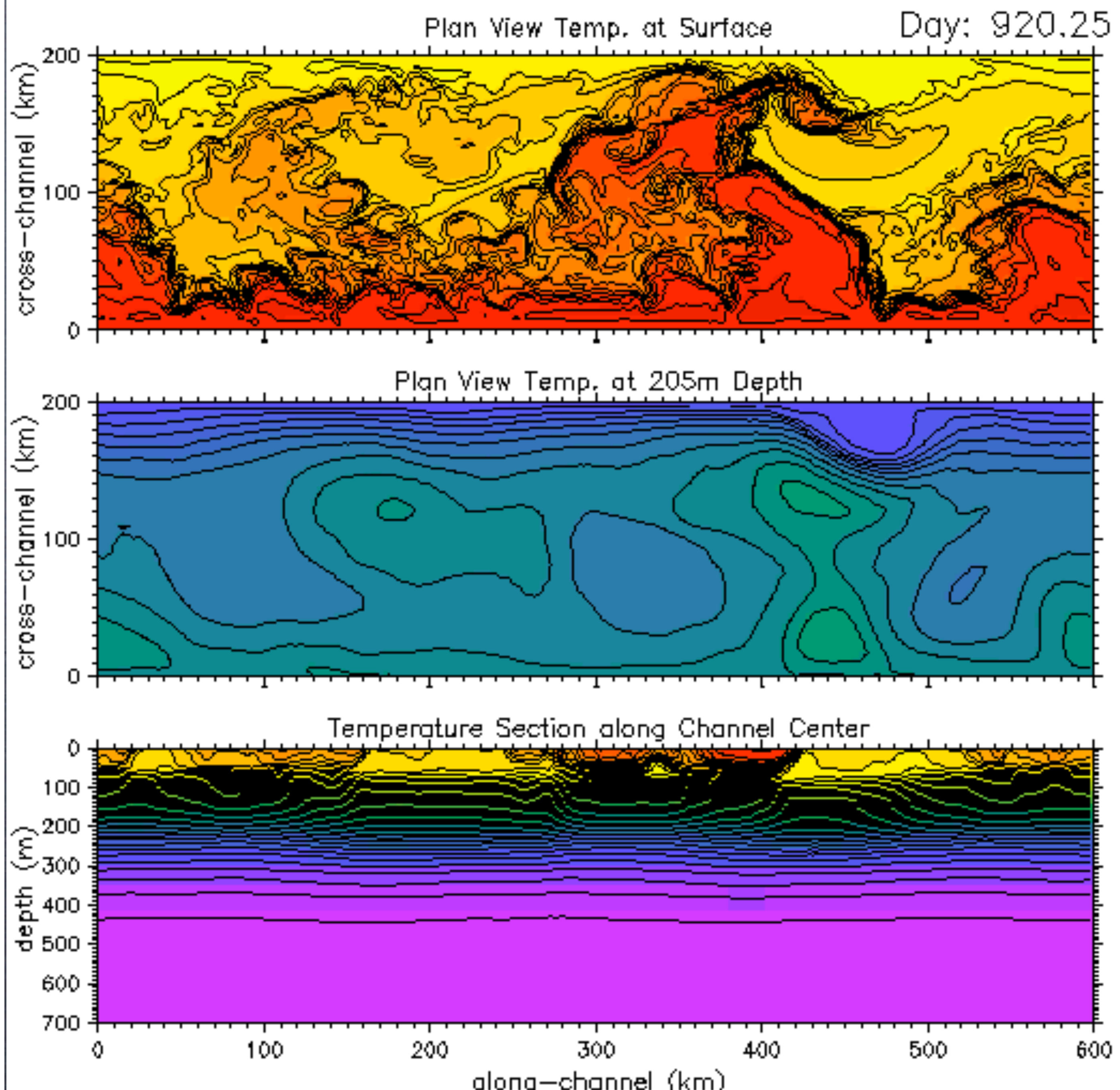
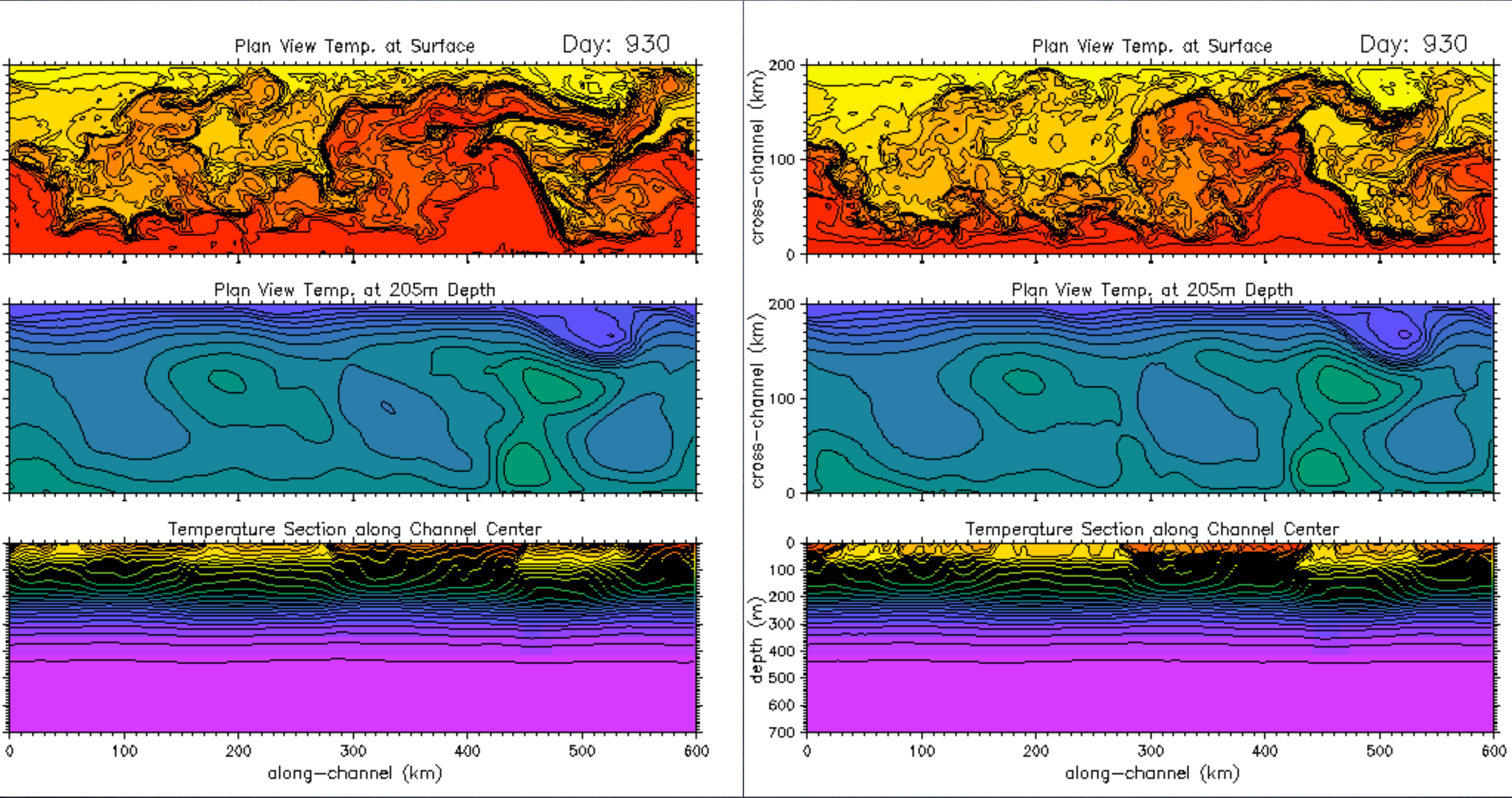




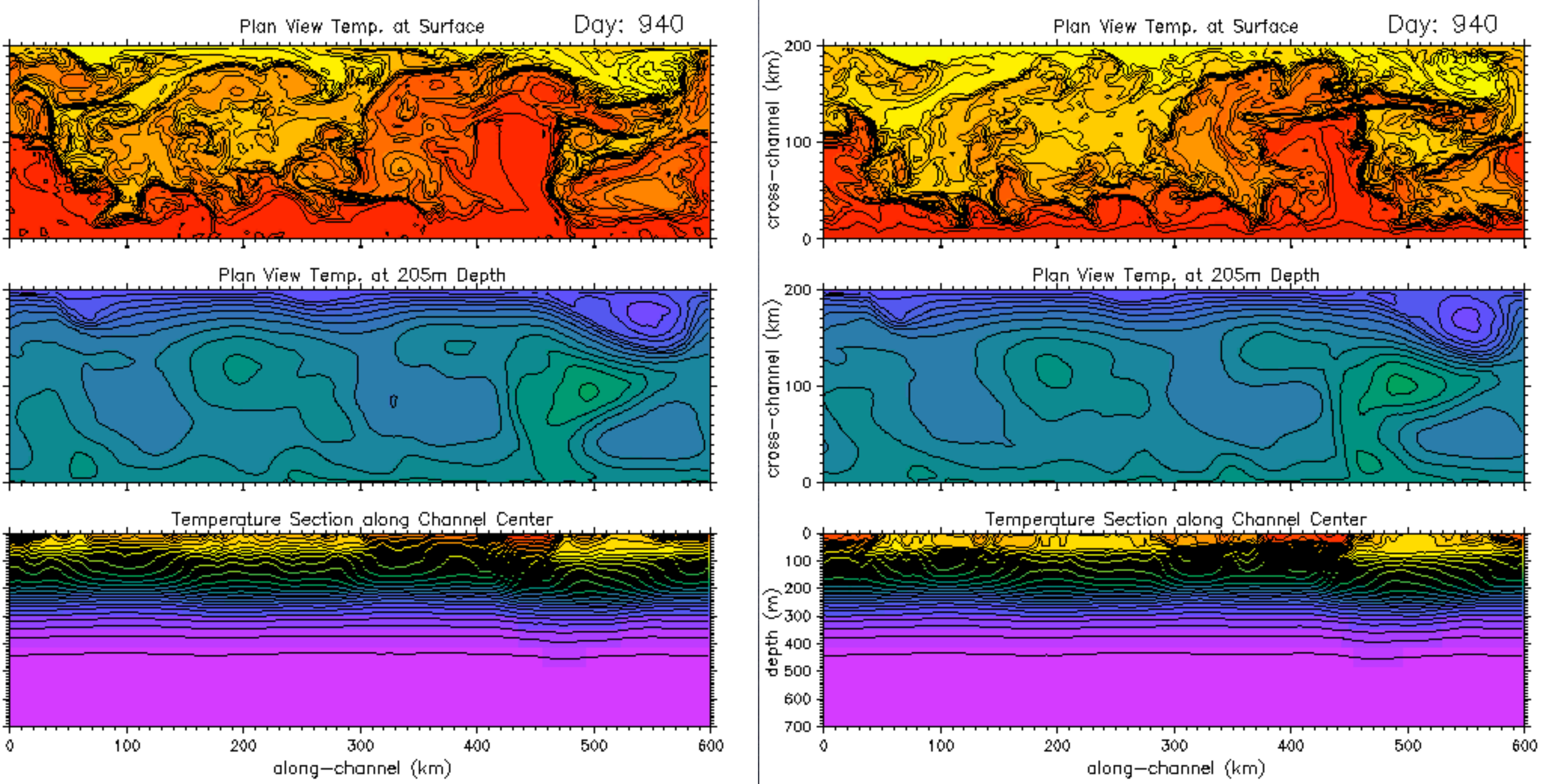
Having a Mixed Layer Counts!

The vertical buoyancy flux in the ML (<w'b'>) without diurnal cycle is 3x less than with cycle (ML)

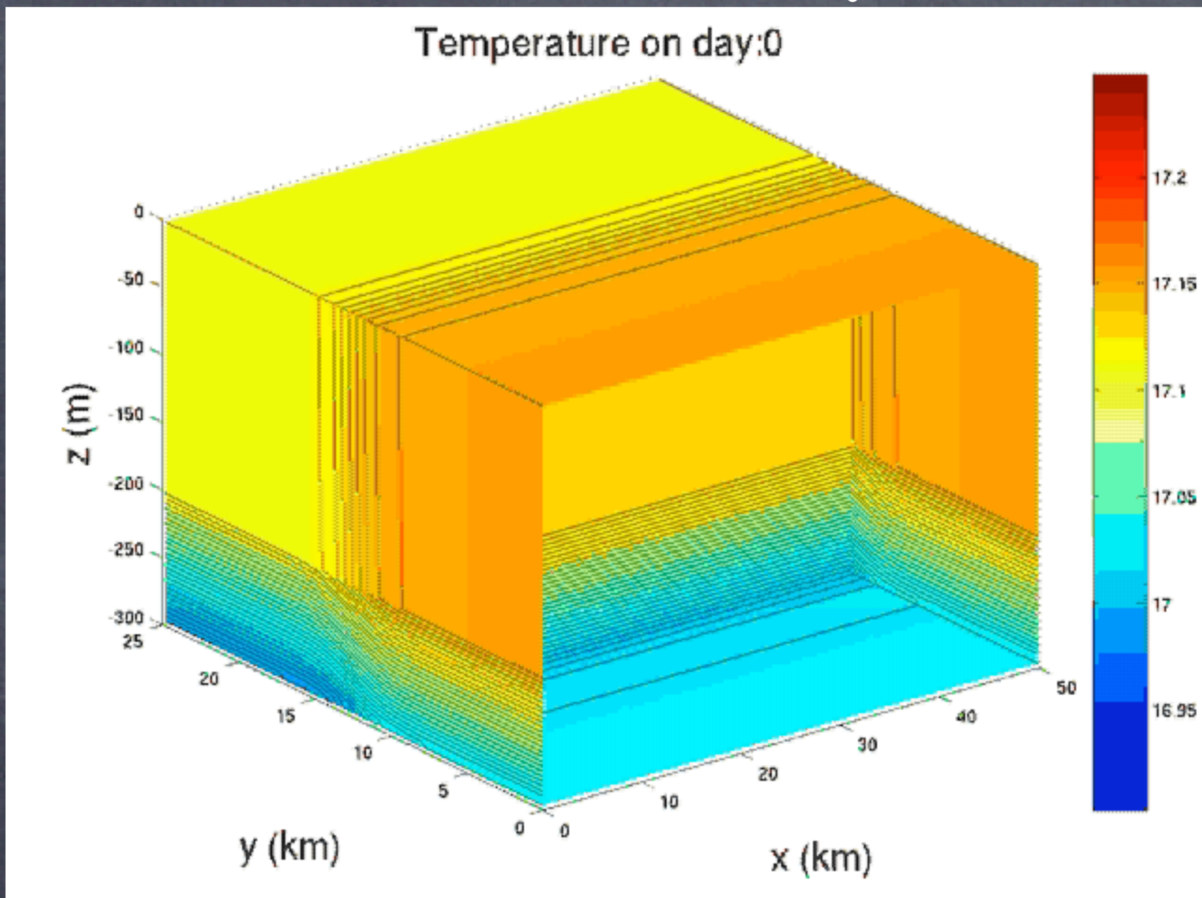


Having a Mixed Layer Counts!

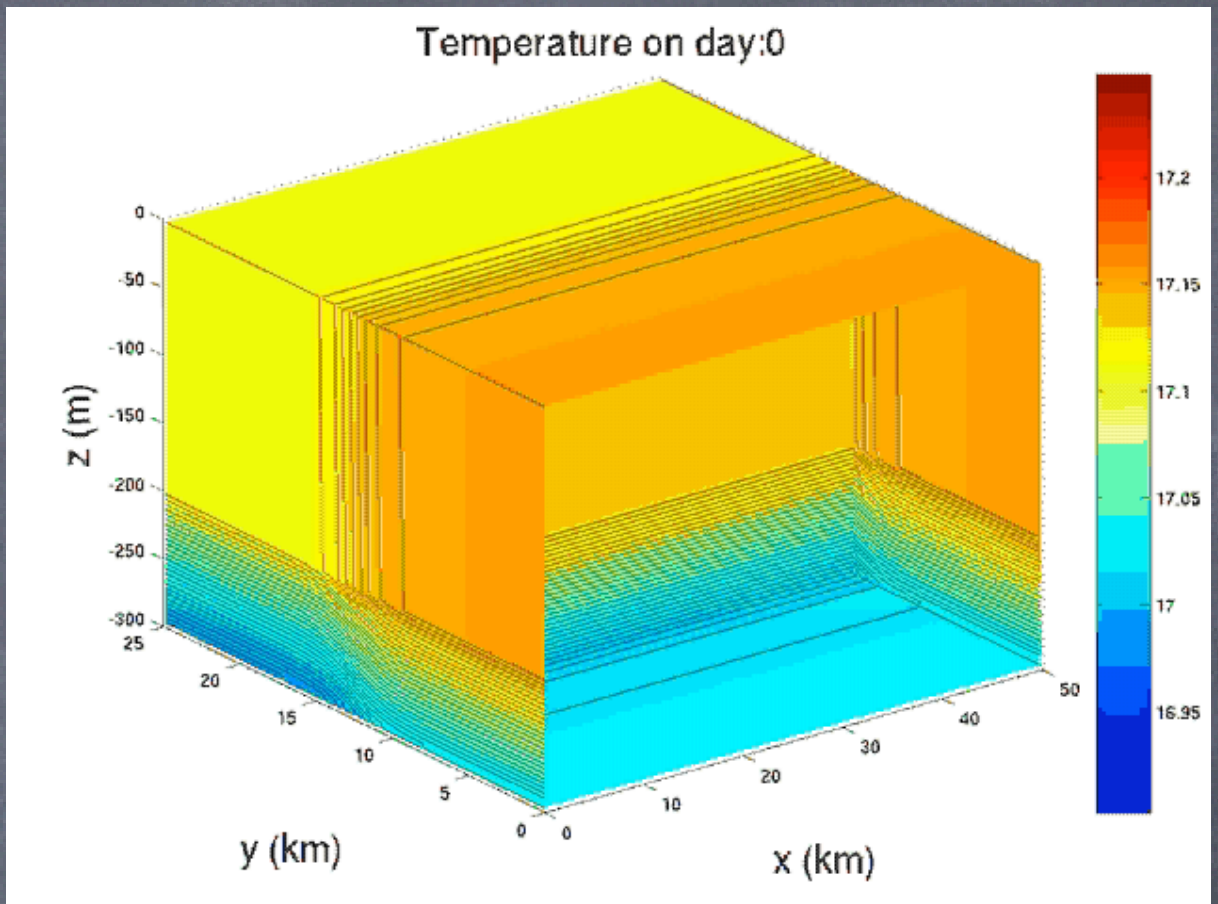
The vertical buoyancy flux in the ML (<w'b'>) without diurnal cycle is 4x less than with cycle (ML)



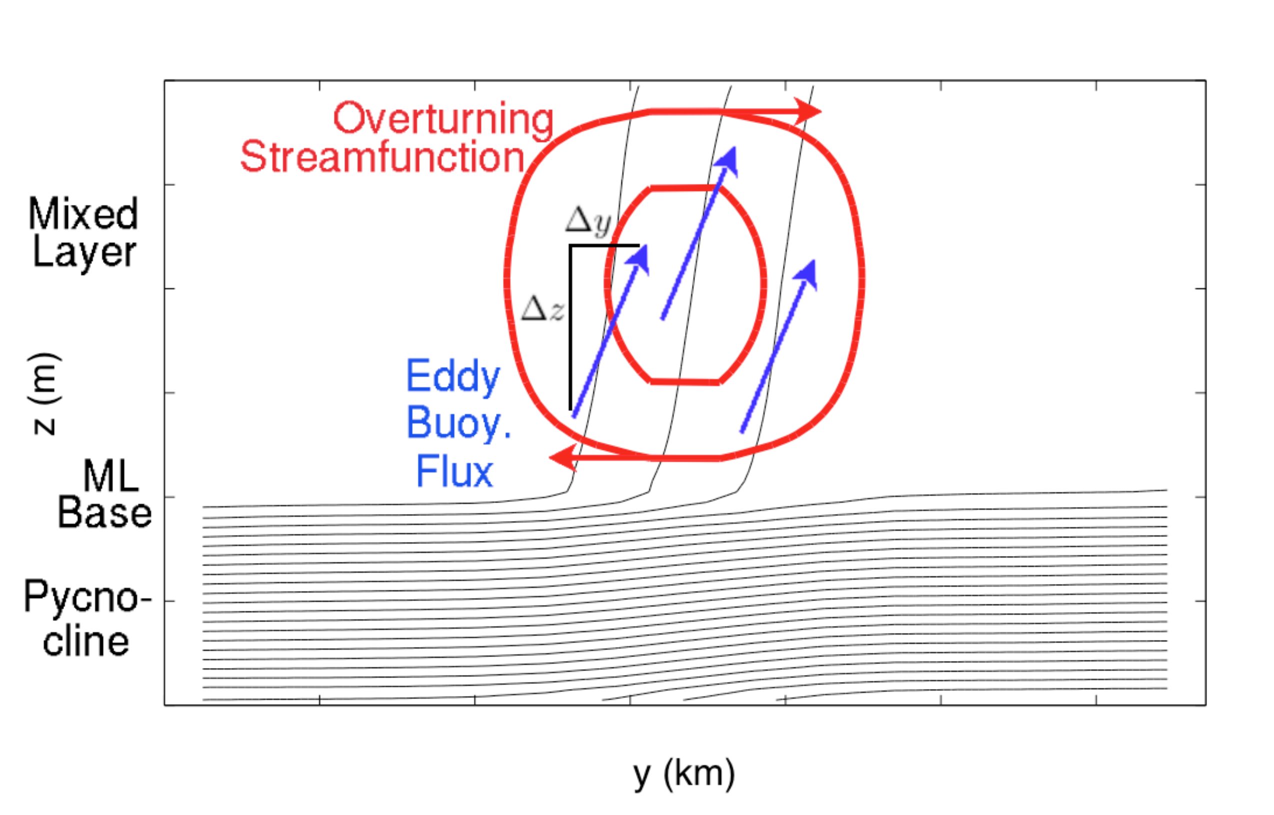
Prototype: Mixed Layer Front



Simple Spindown



Plus, Diurnal Cycle and KPP



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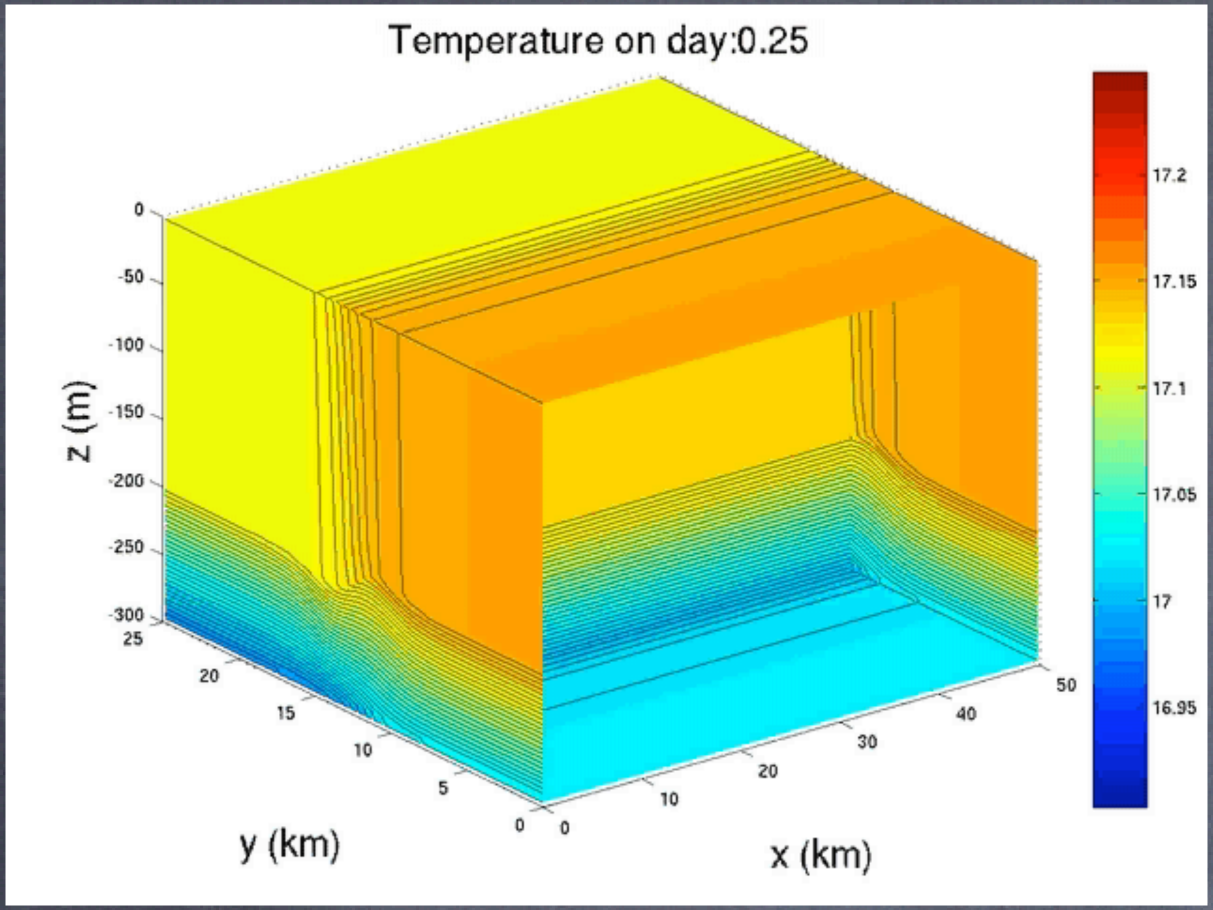

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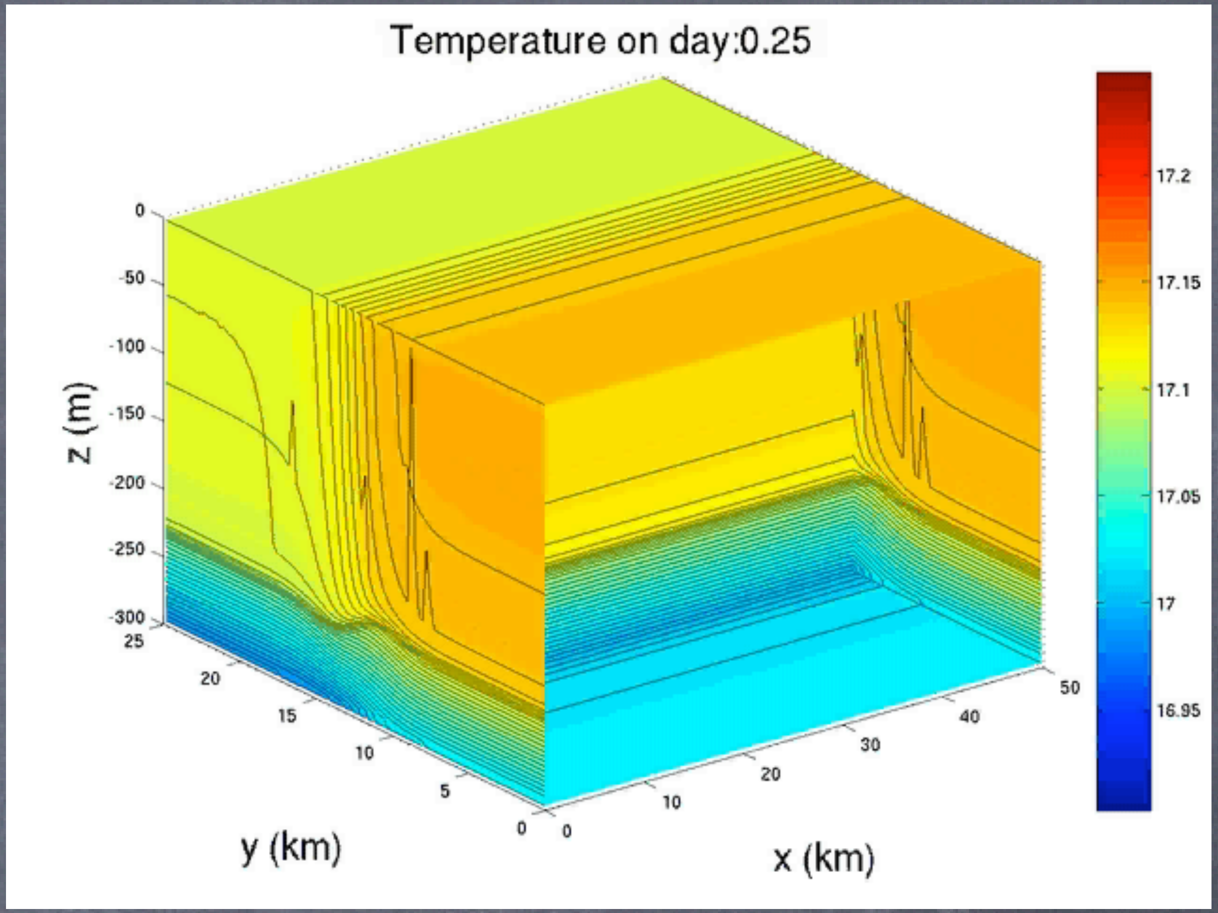

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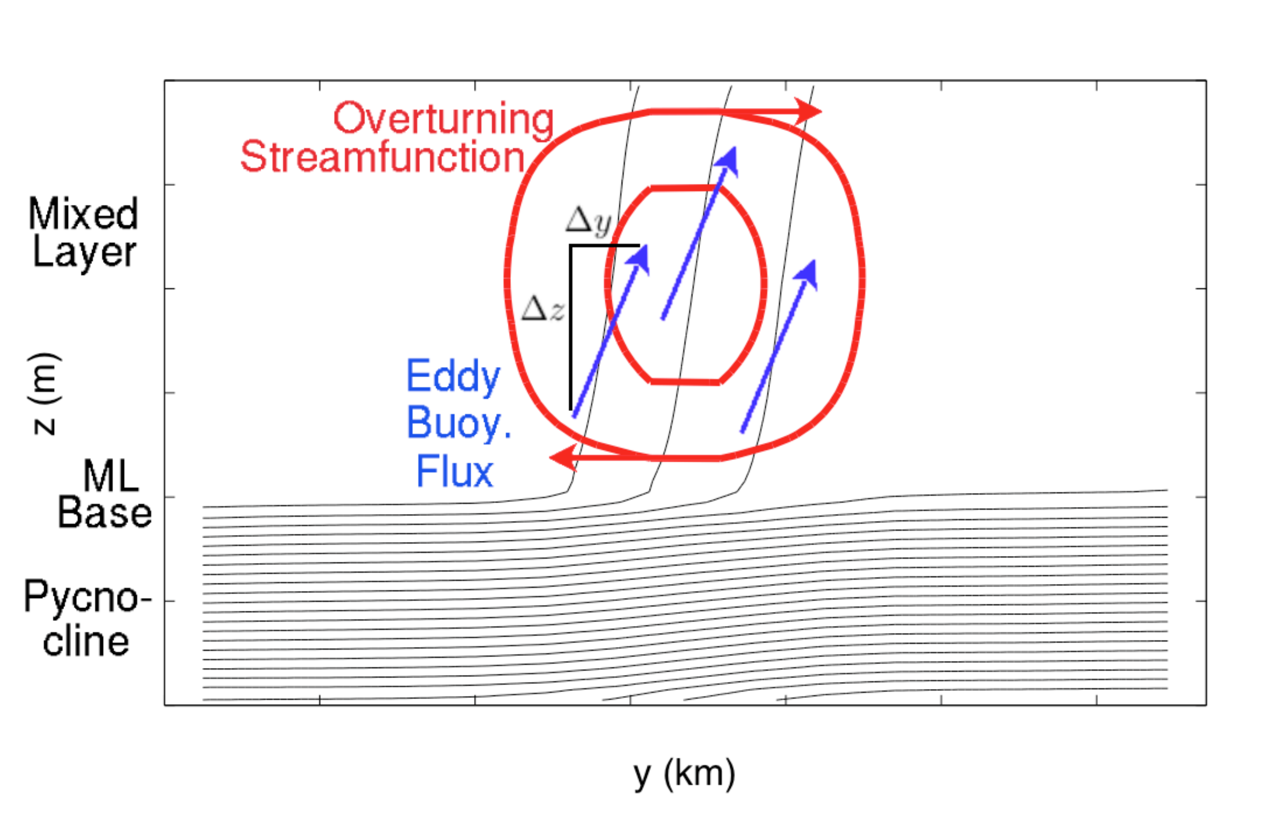

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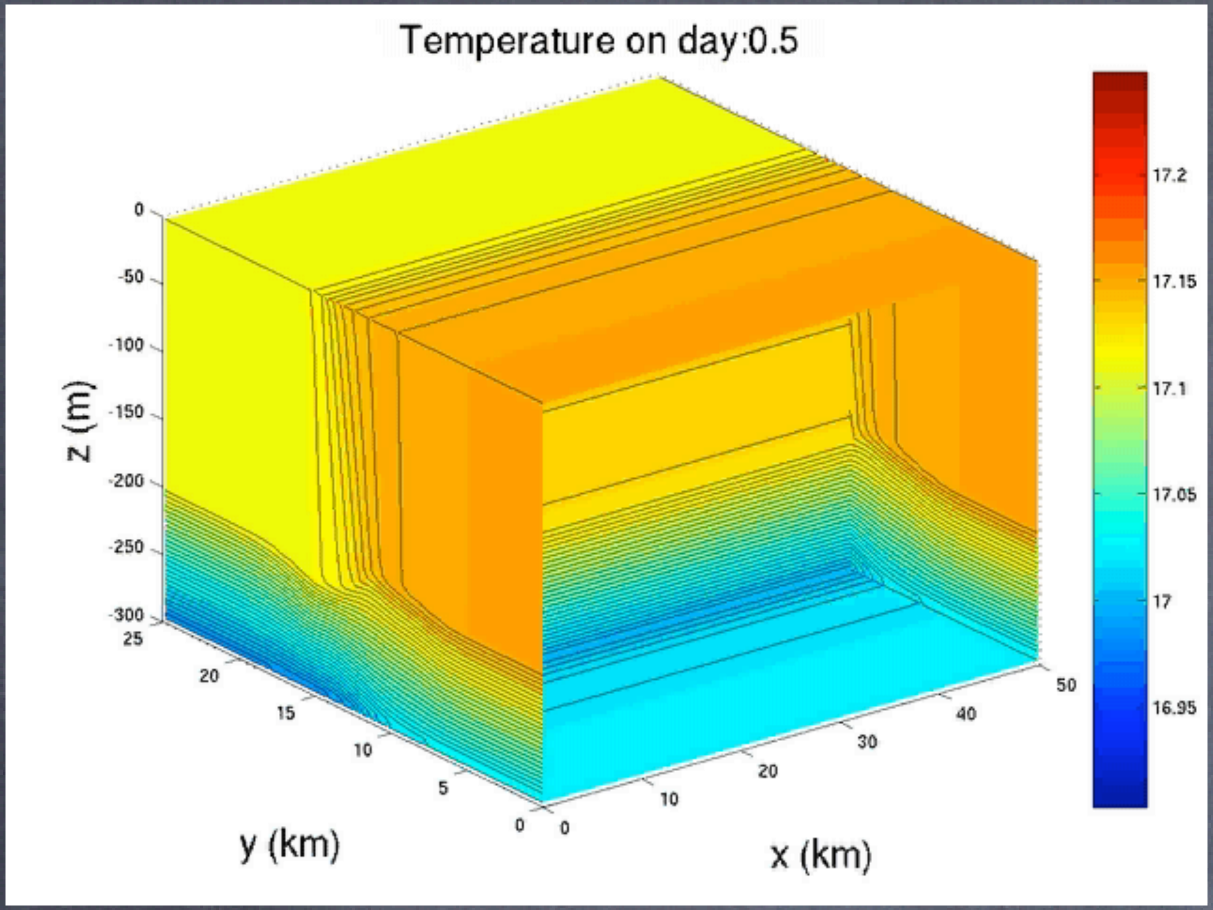

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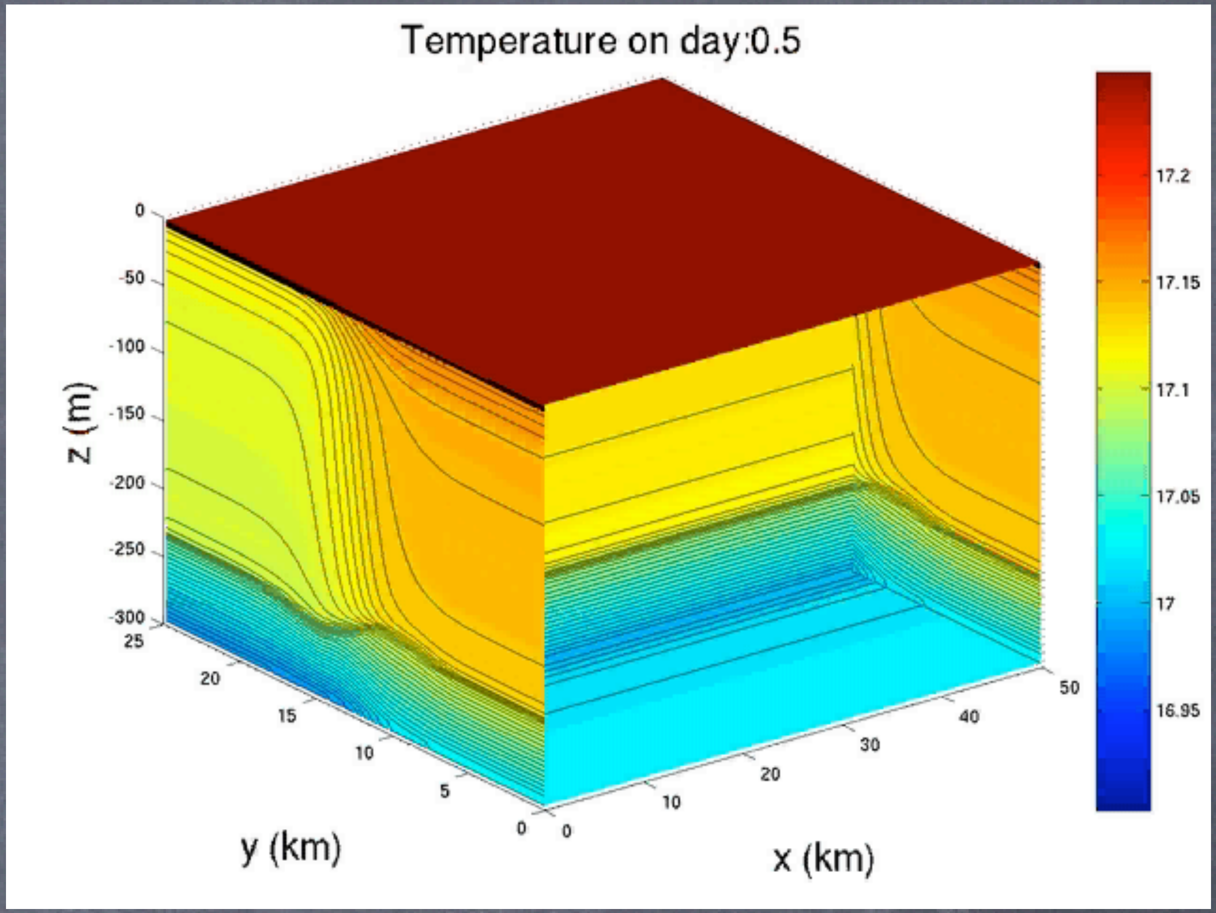

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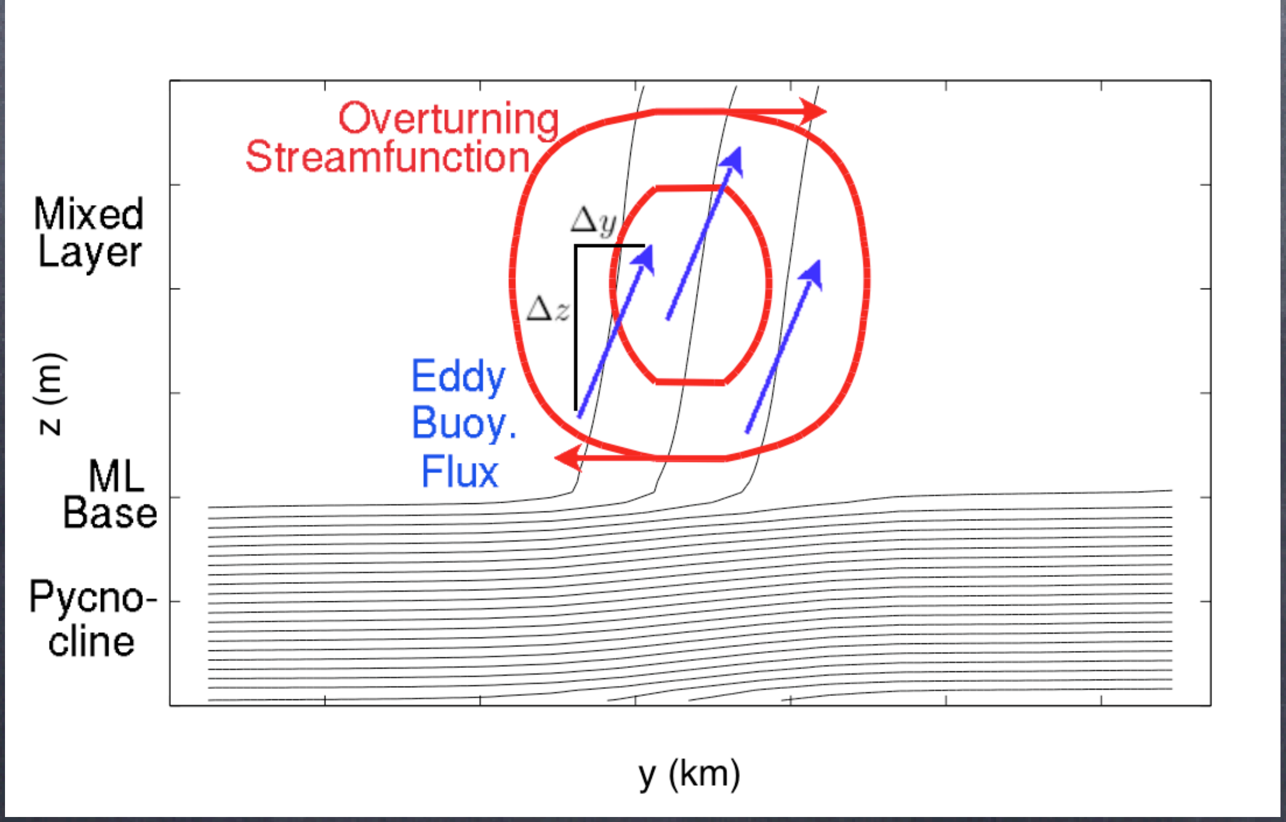

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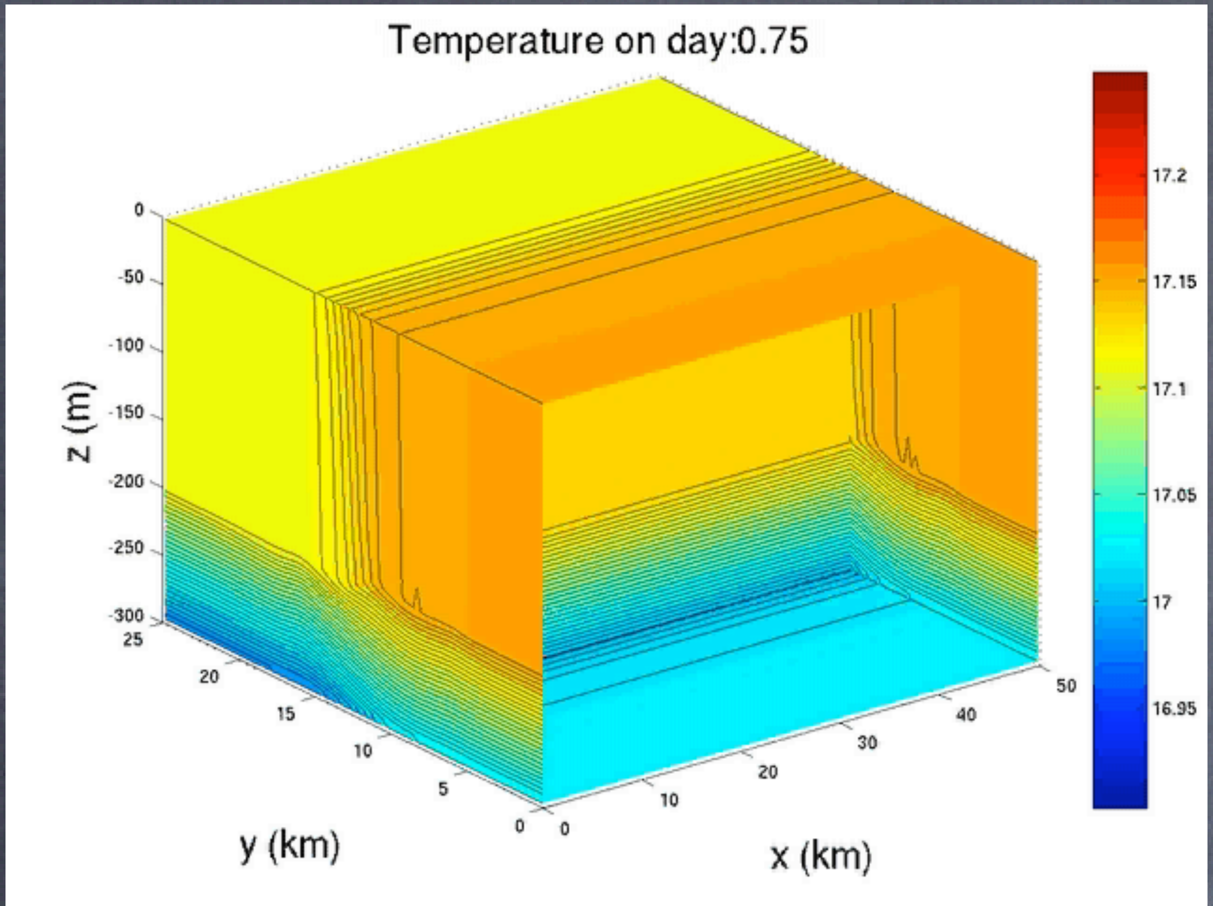

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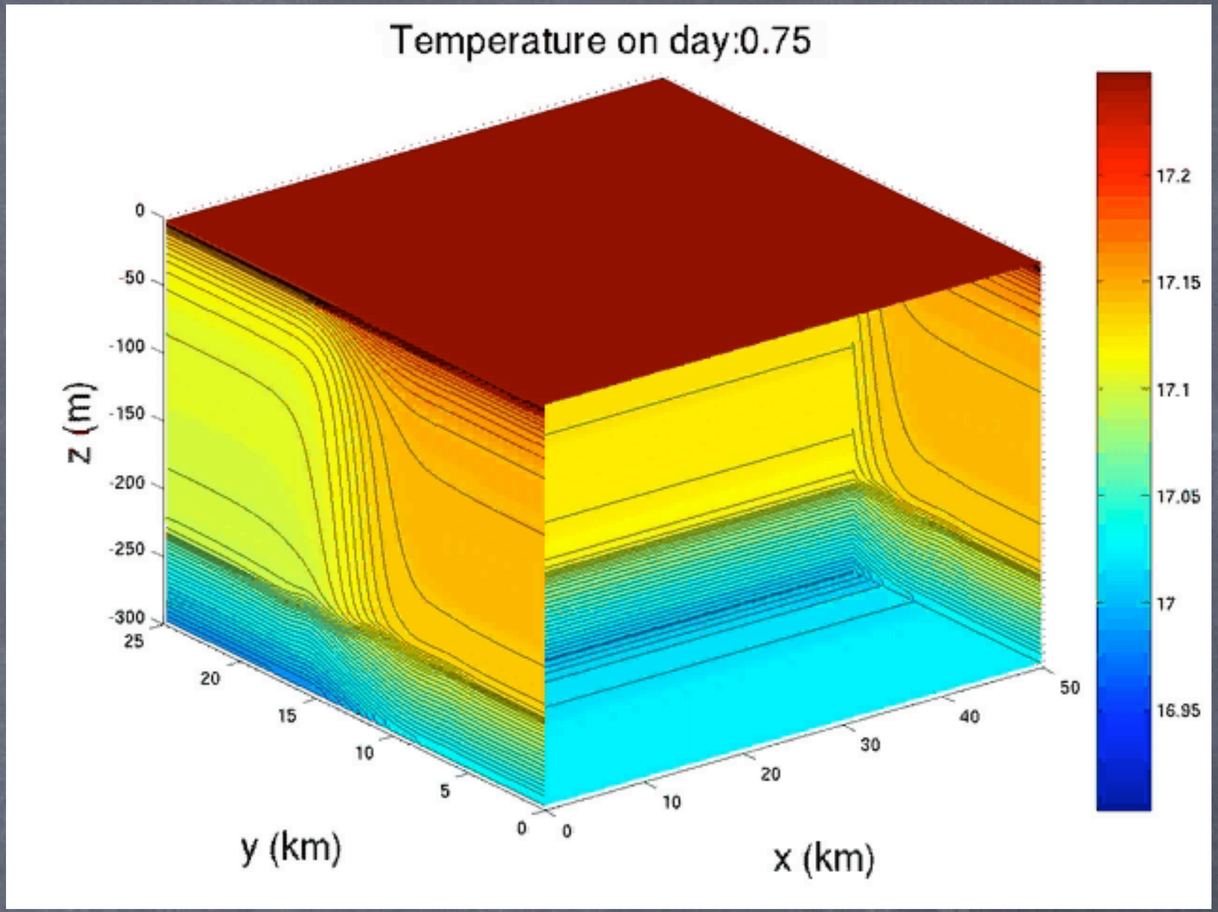

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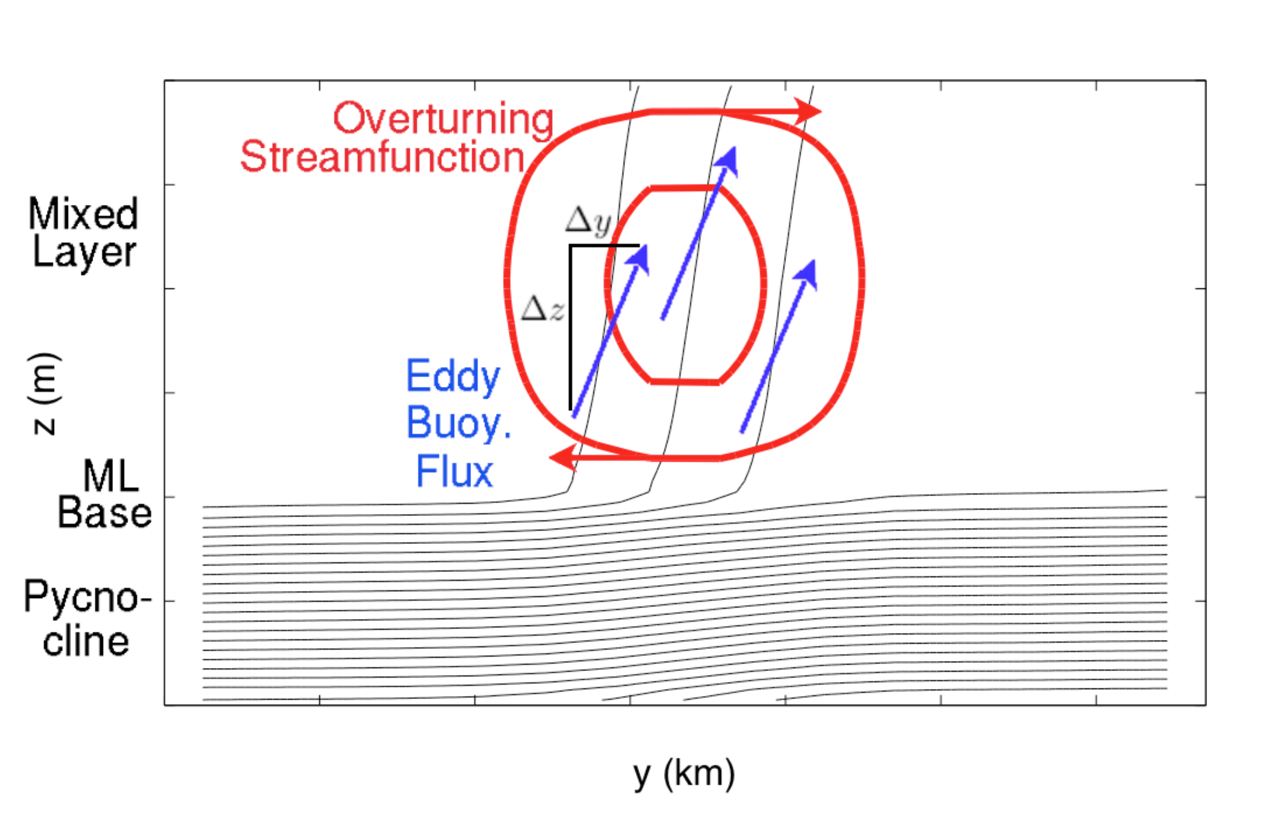

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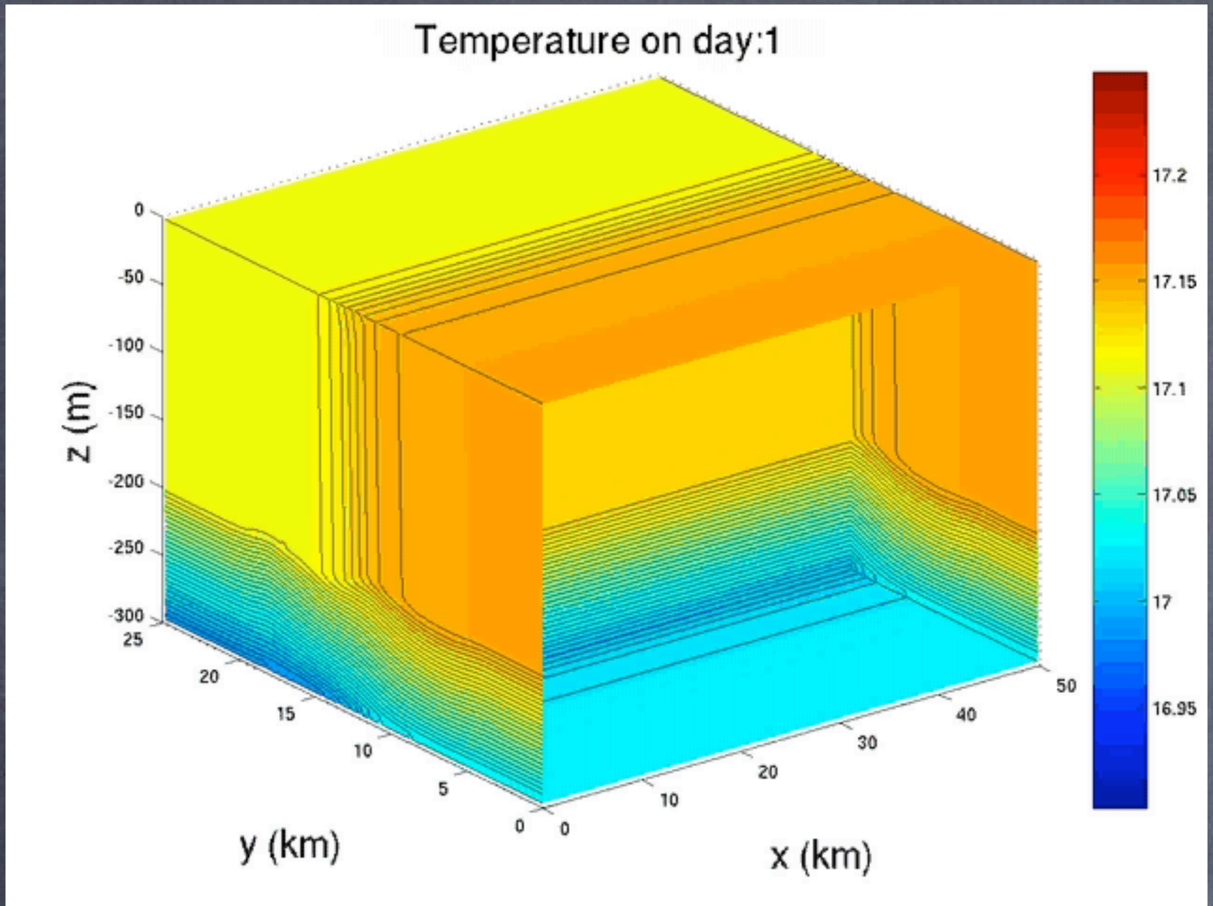

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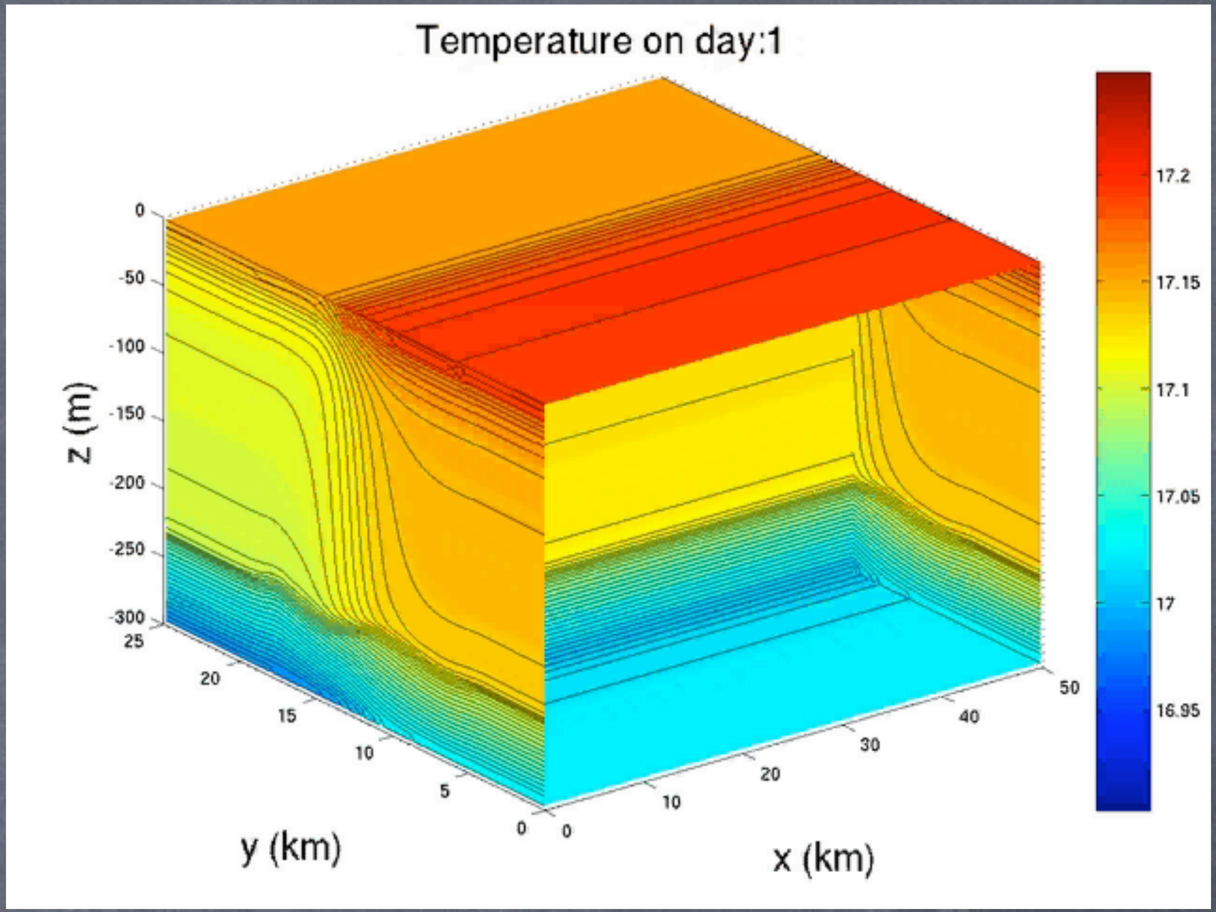

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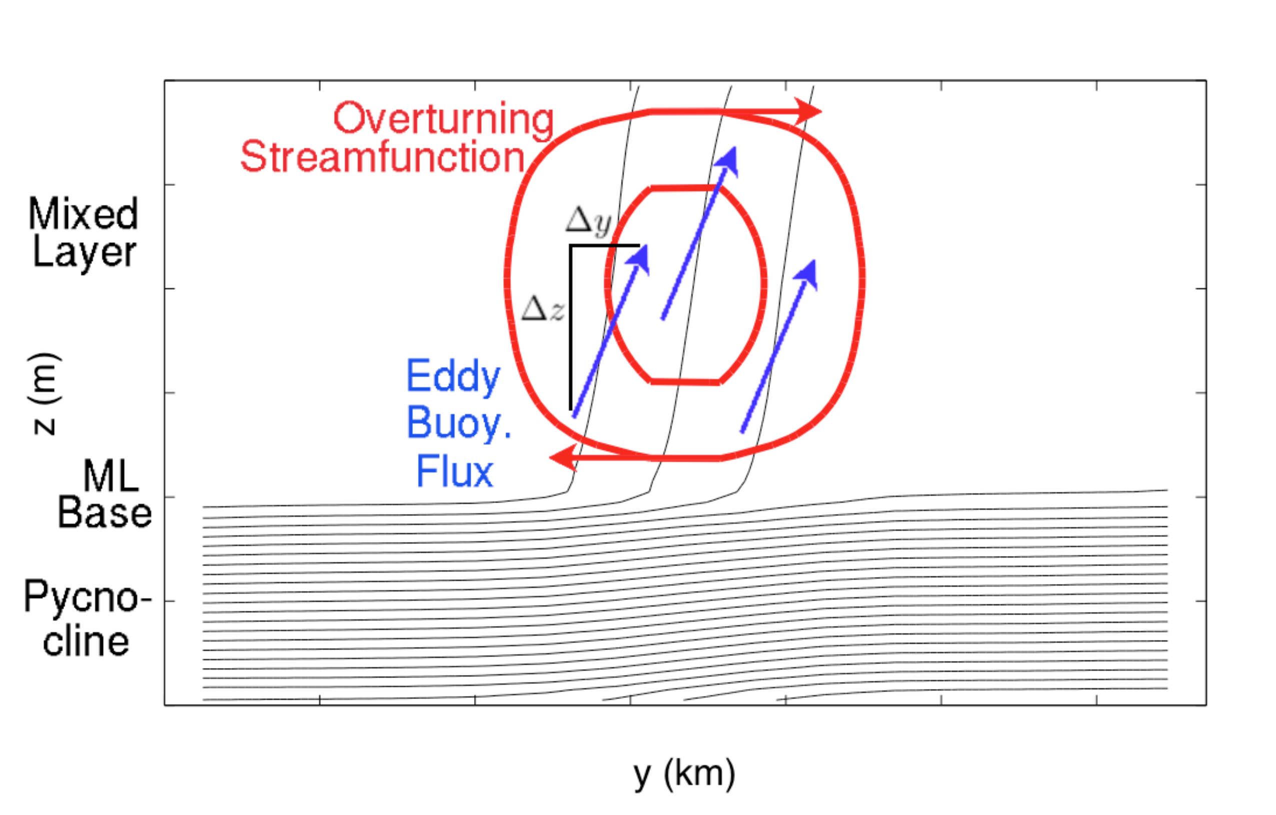

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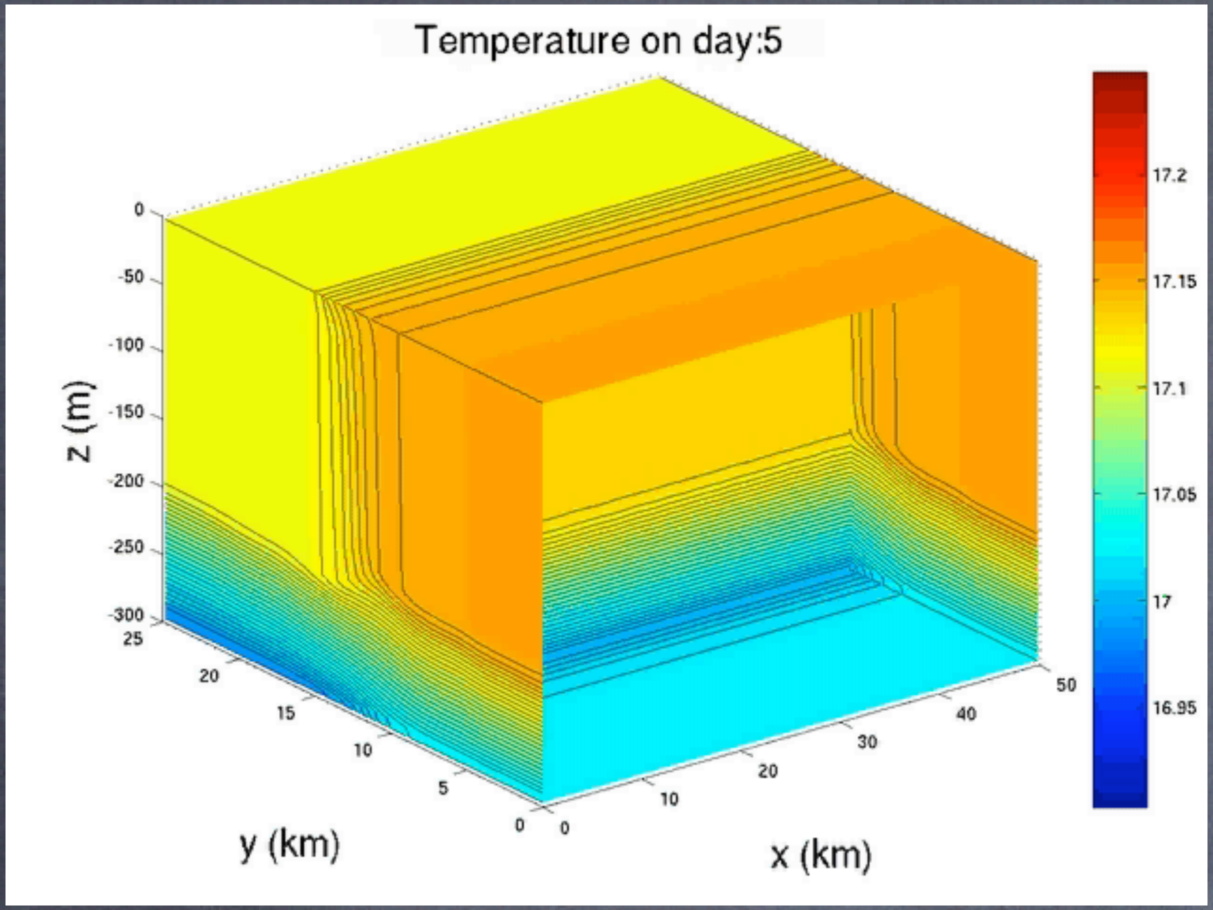

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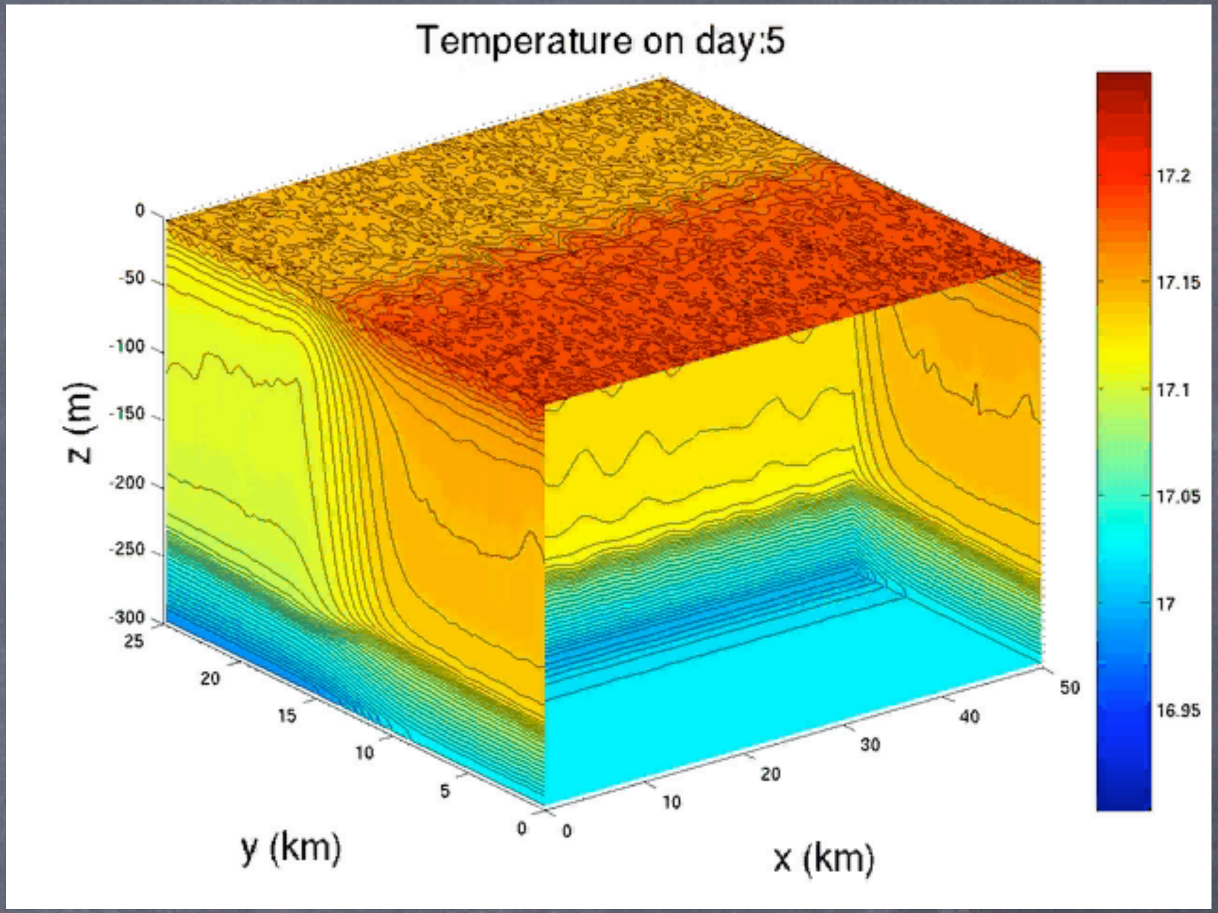

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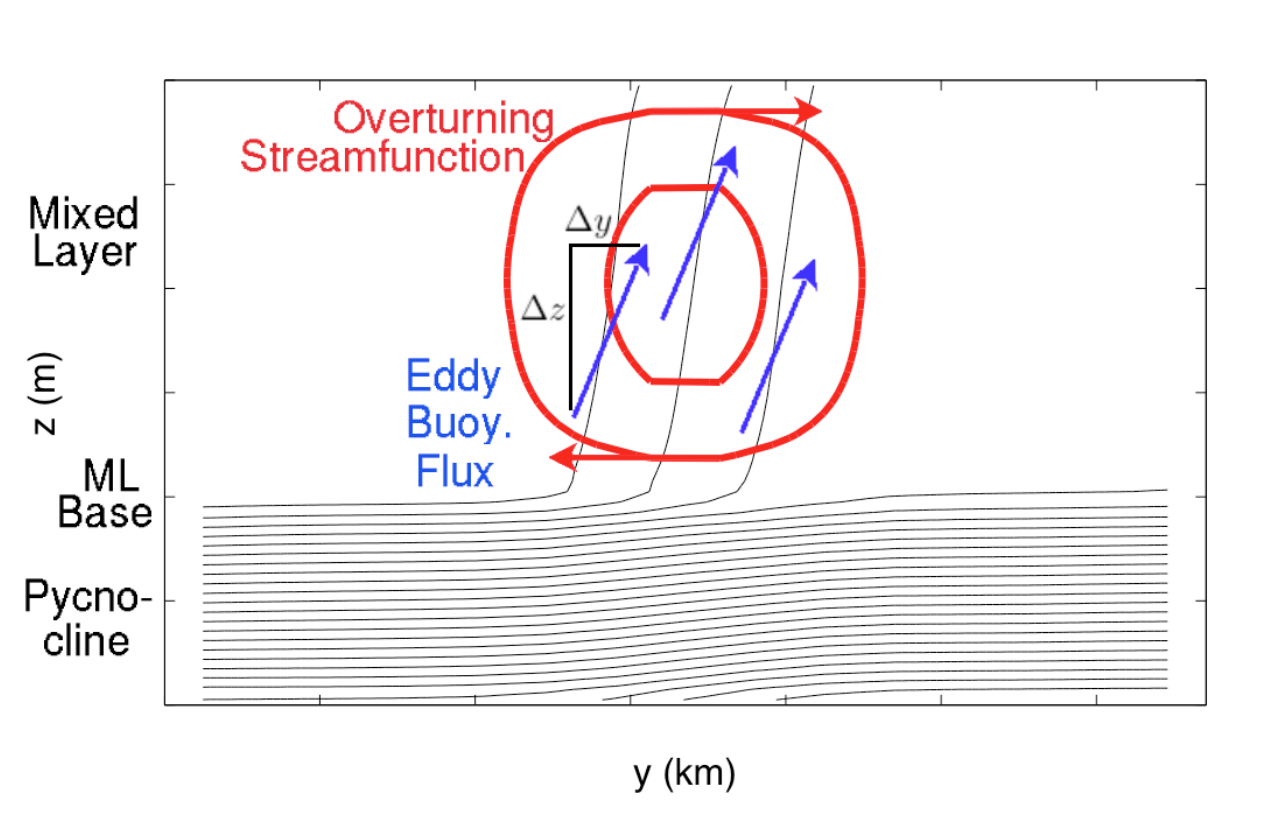

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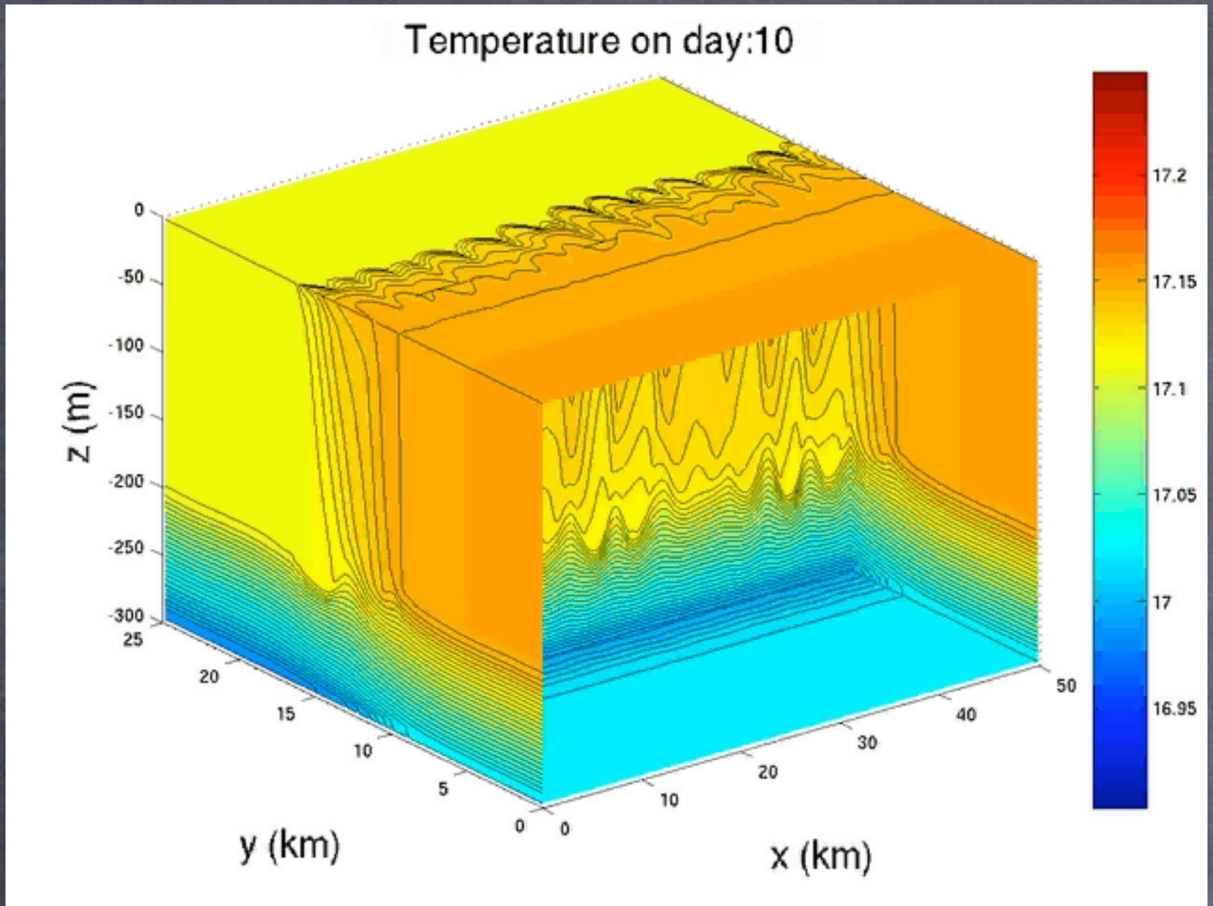

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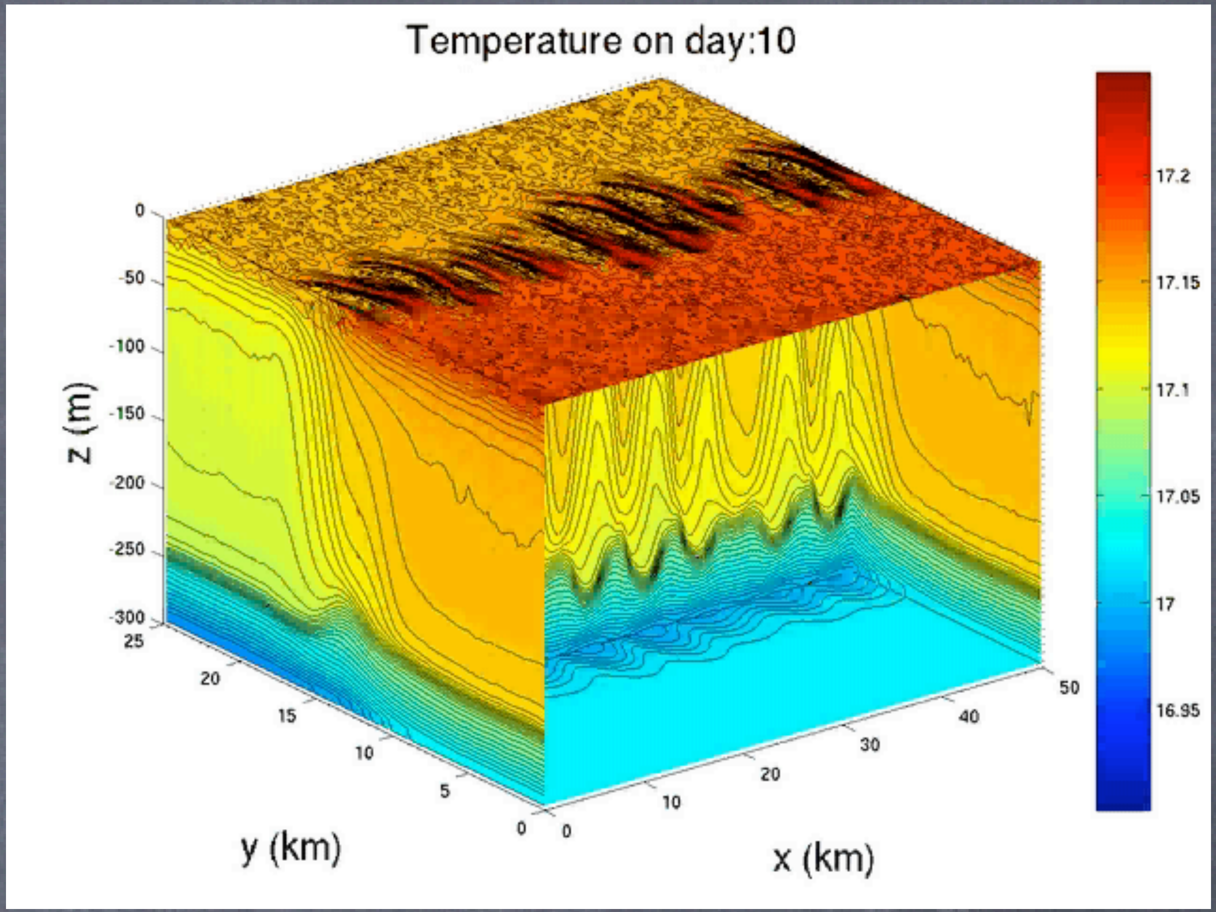

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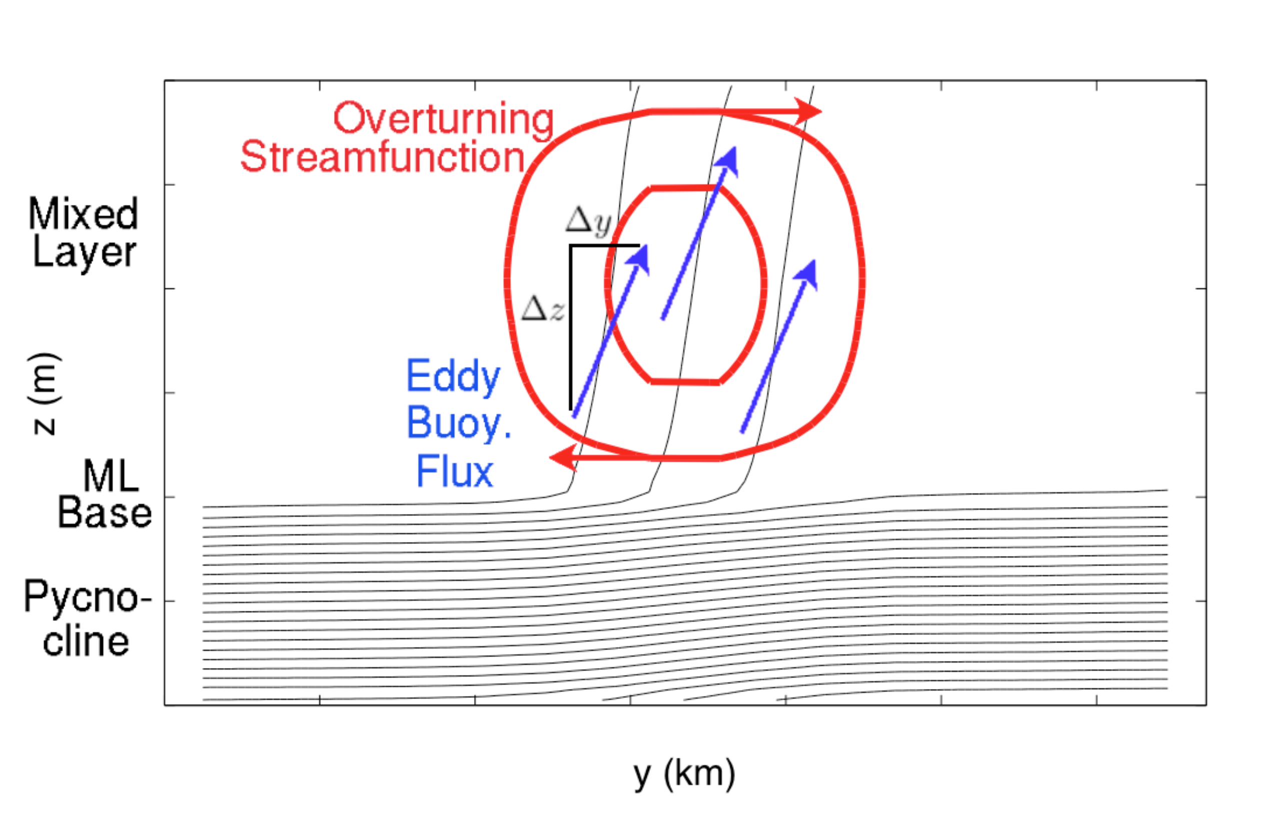

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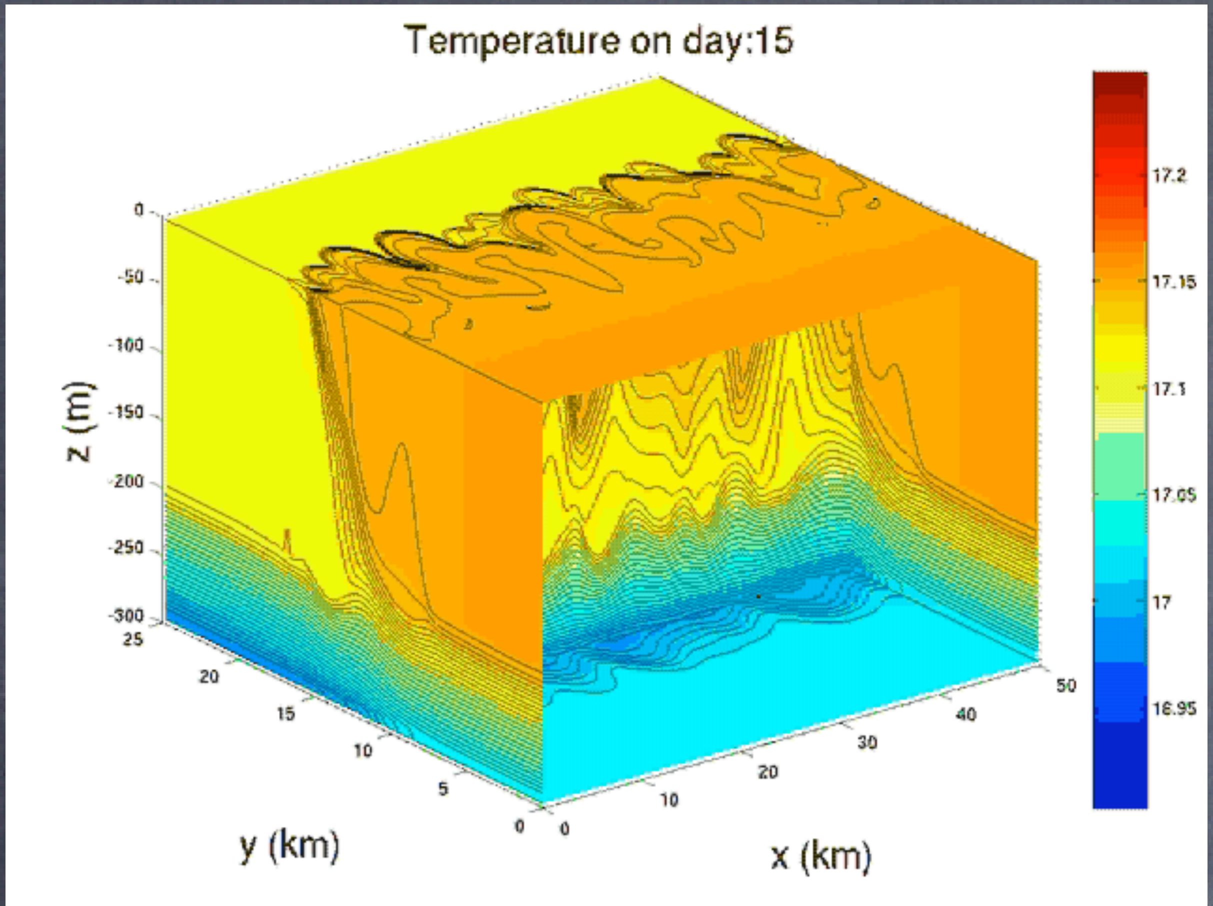

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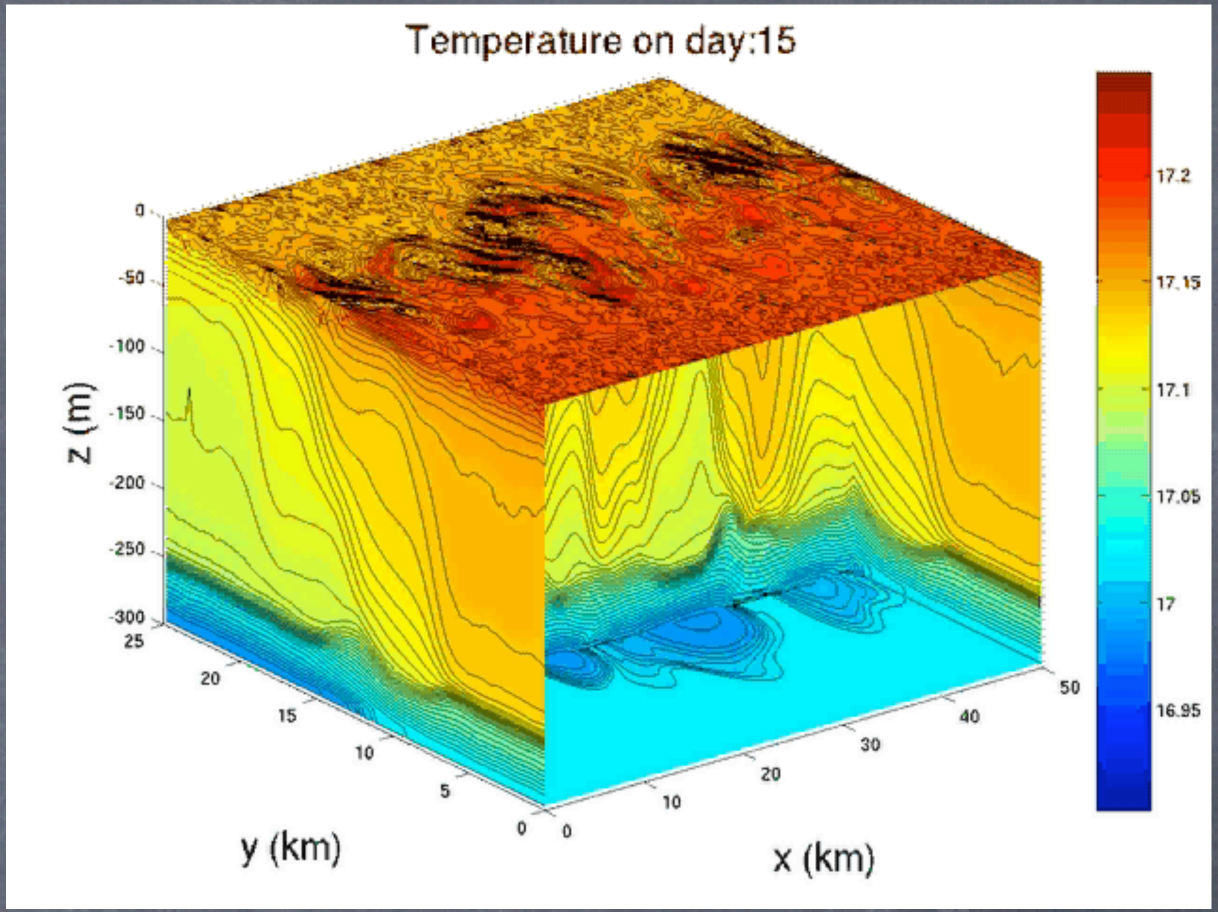

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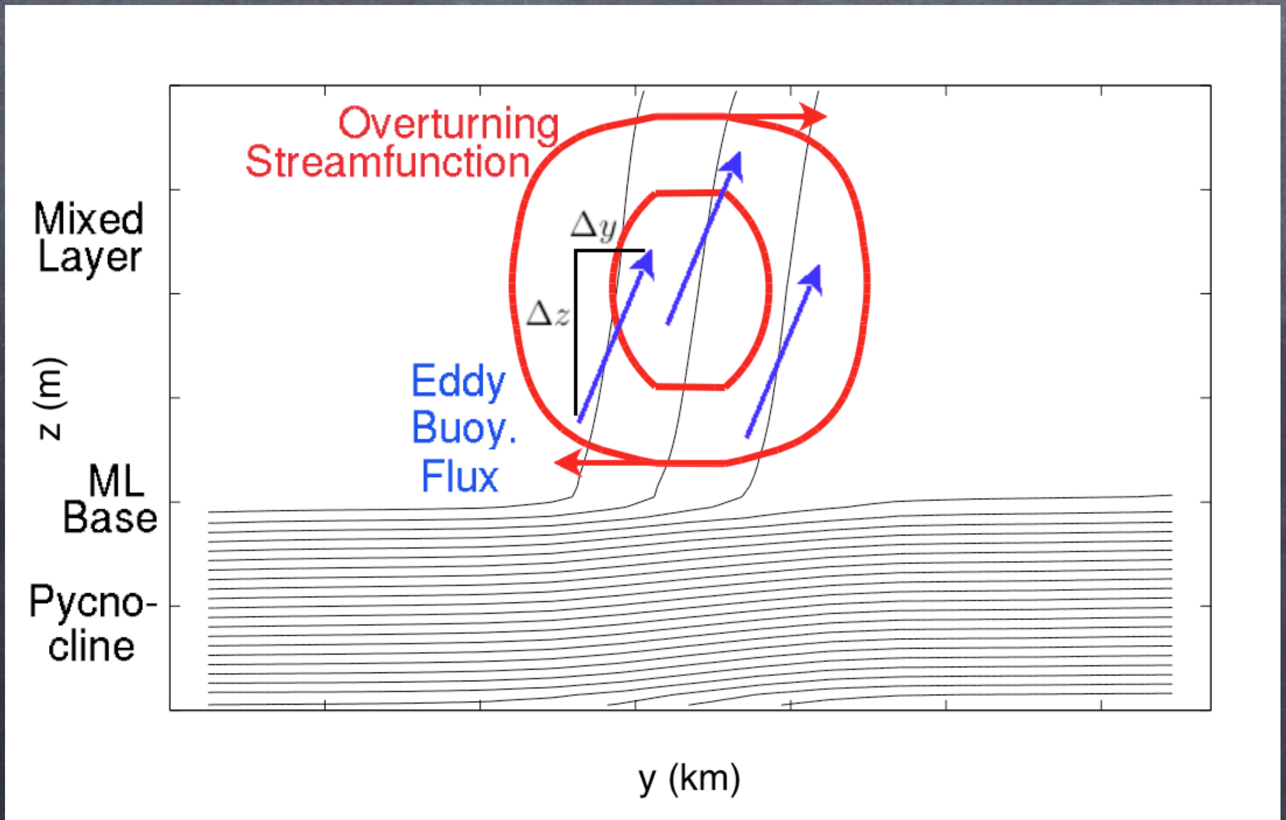

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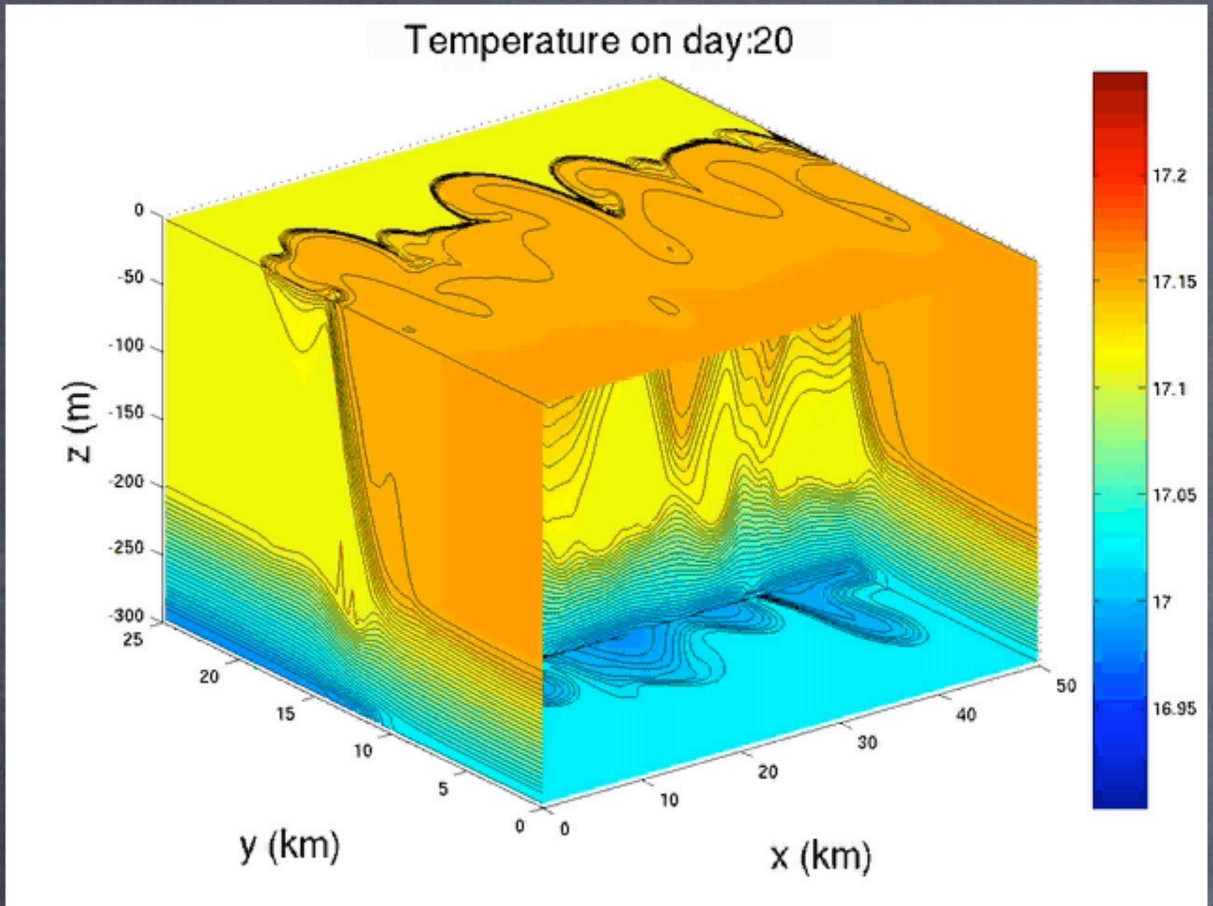

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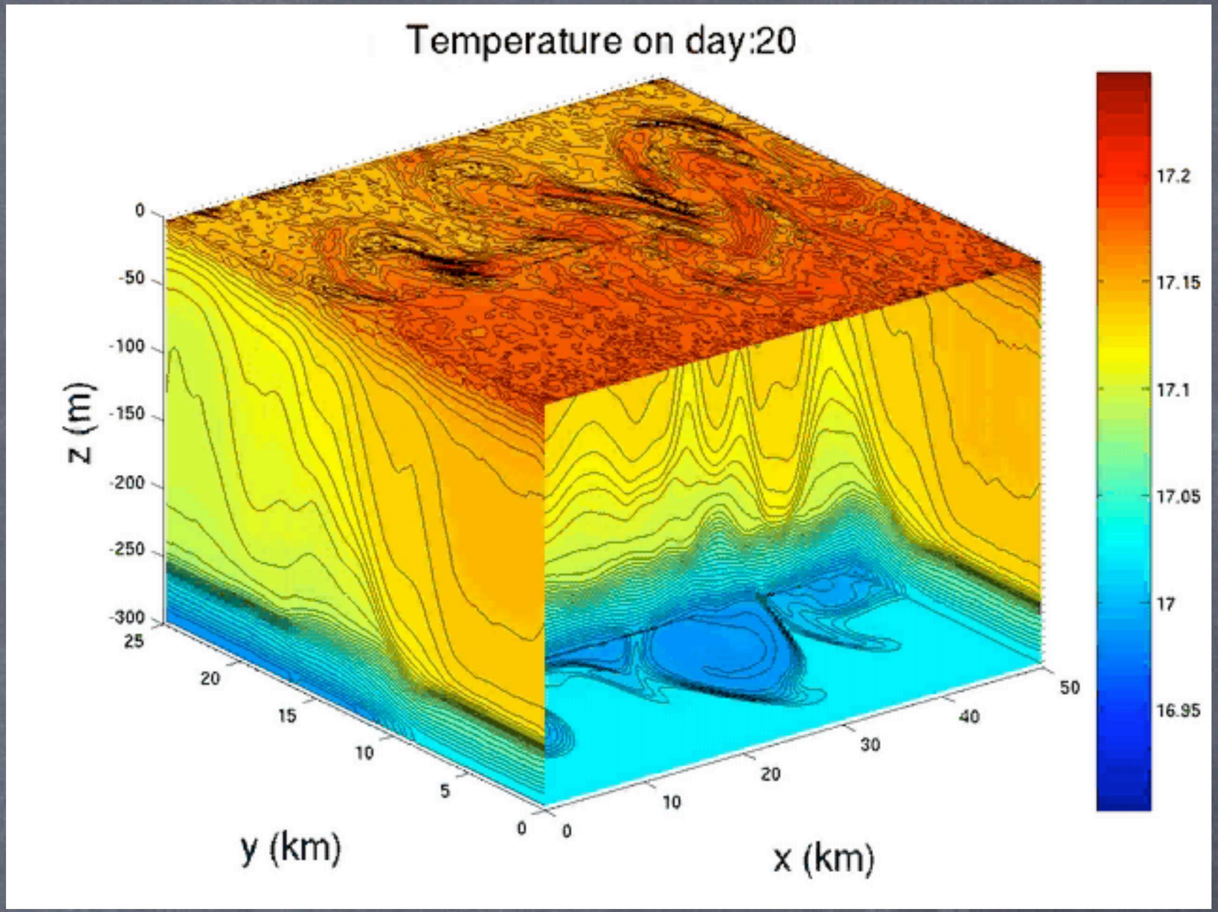

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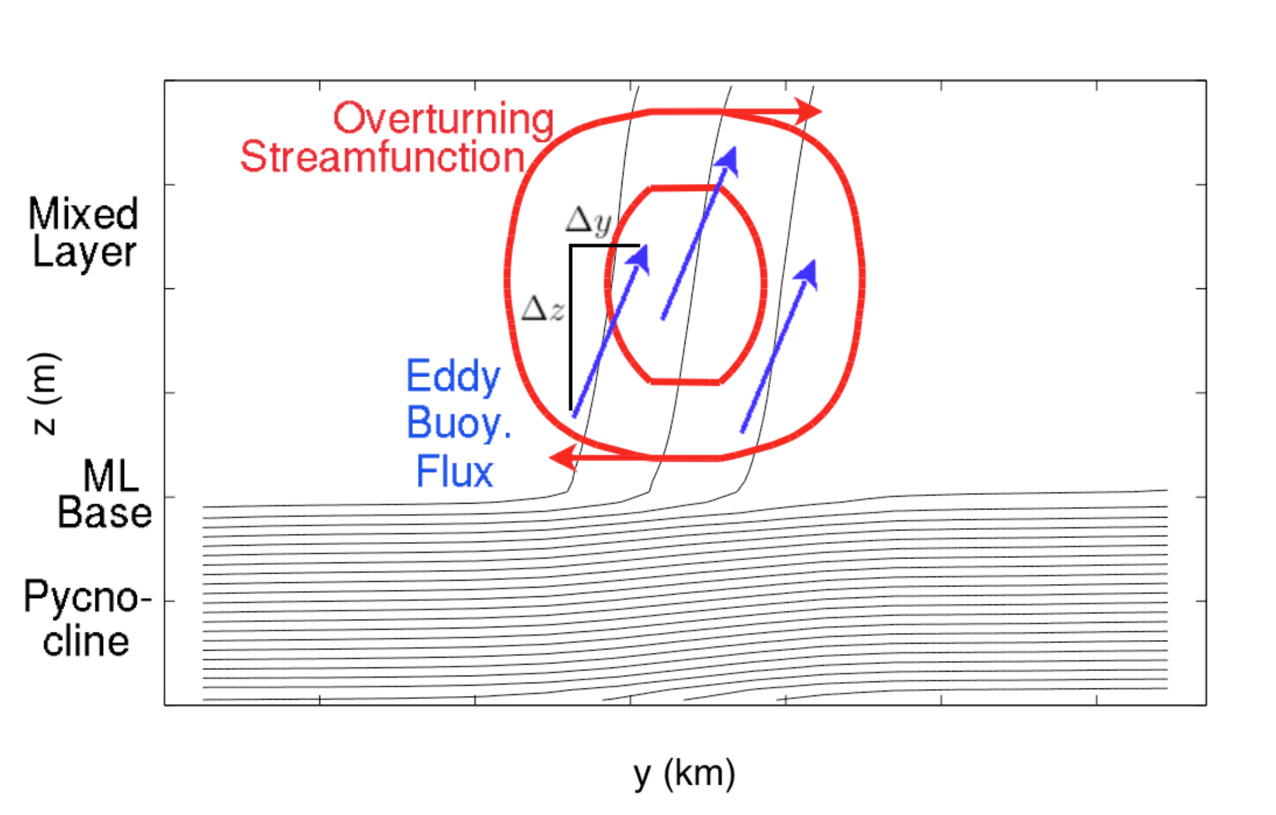
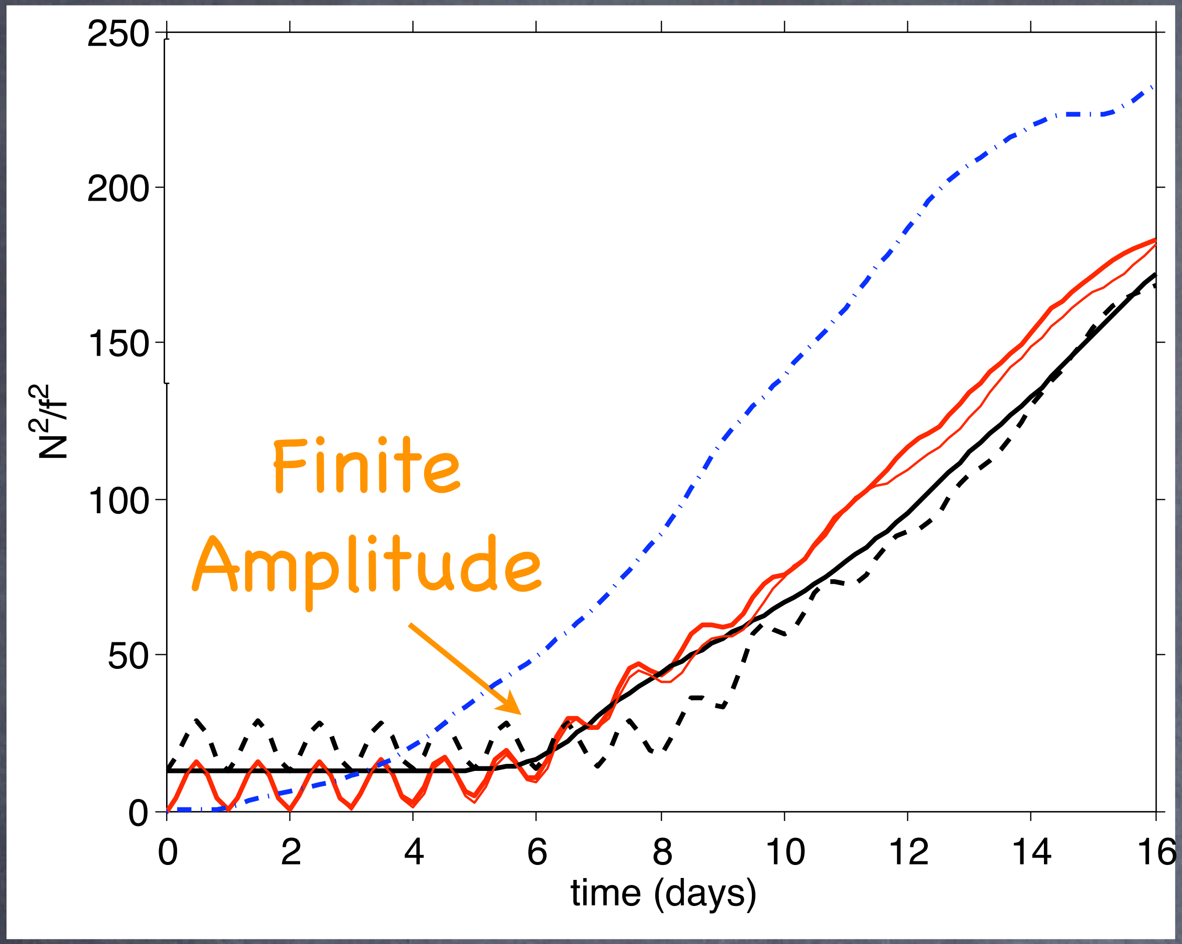


Parameterization of Finite Amp. Eddies: Ingredients



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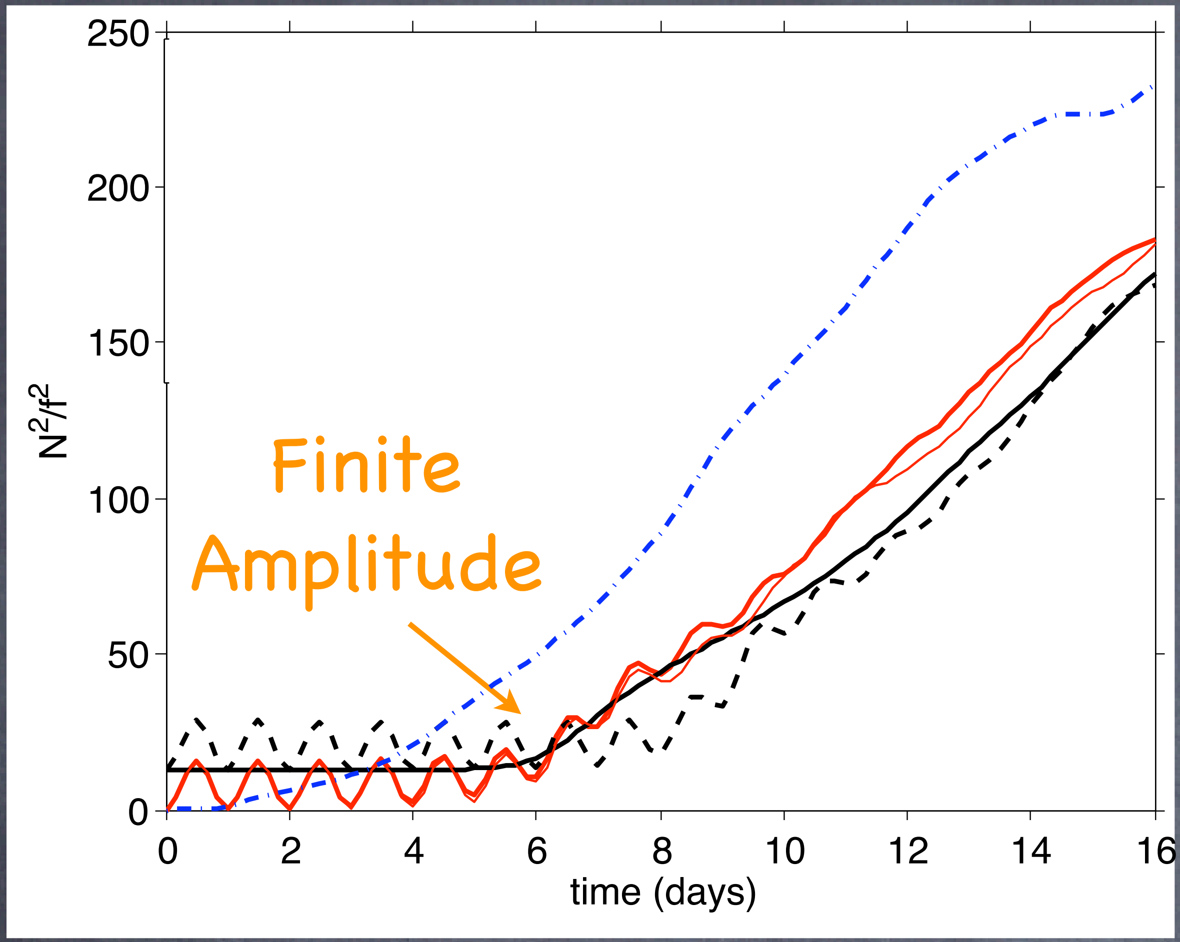

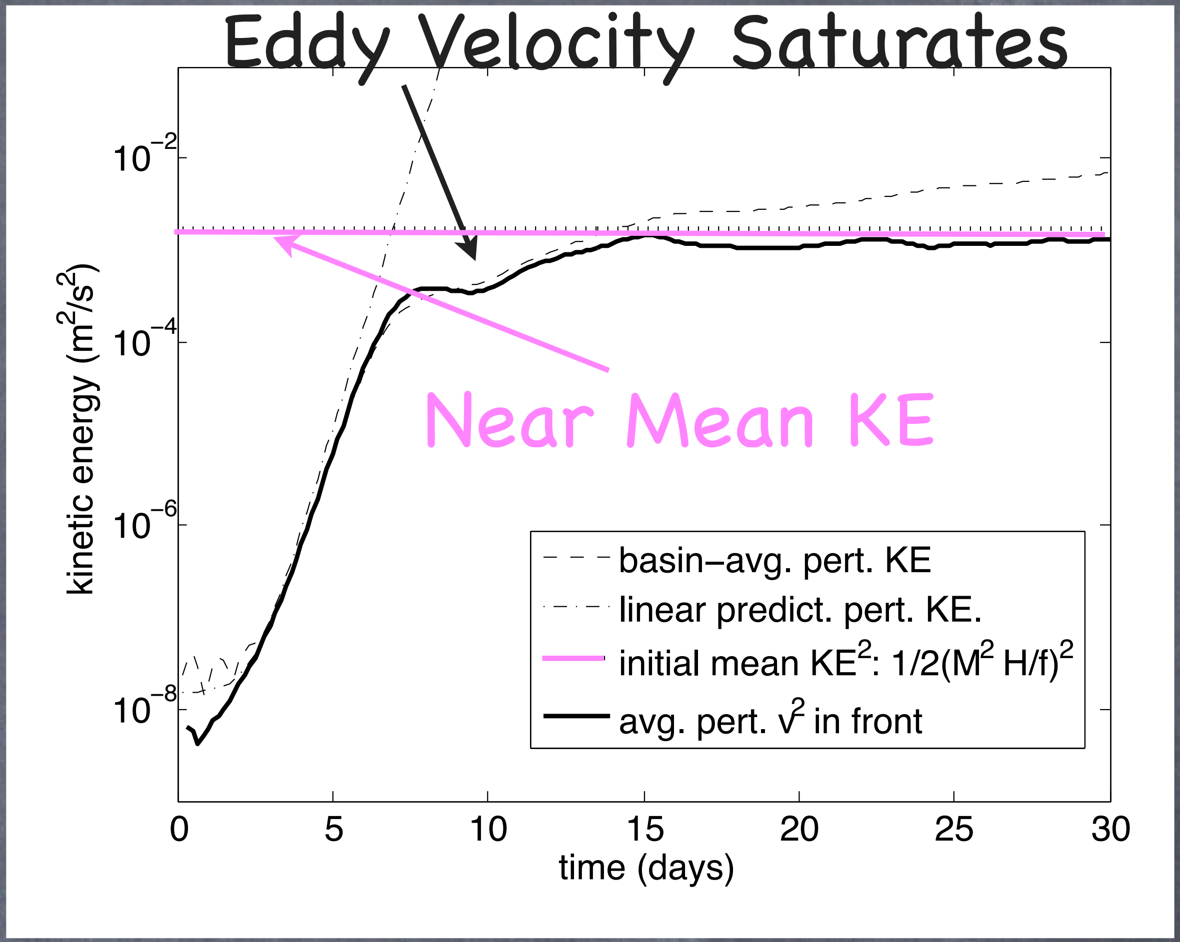

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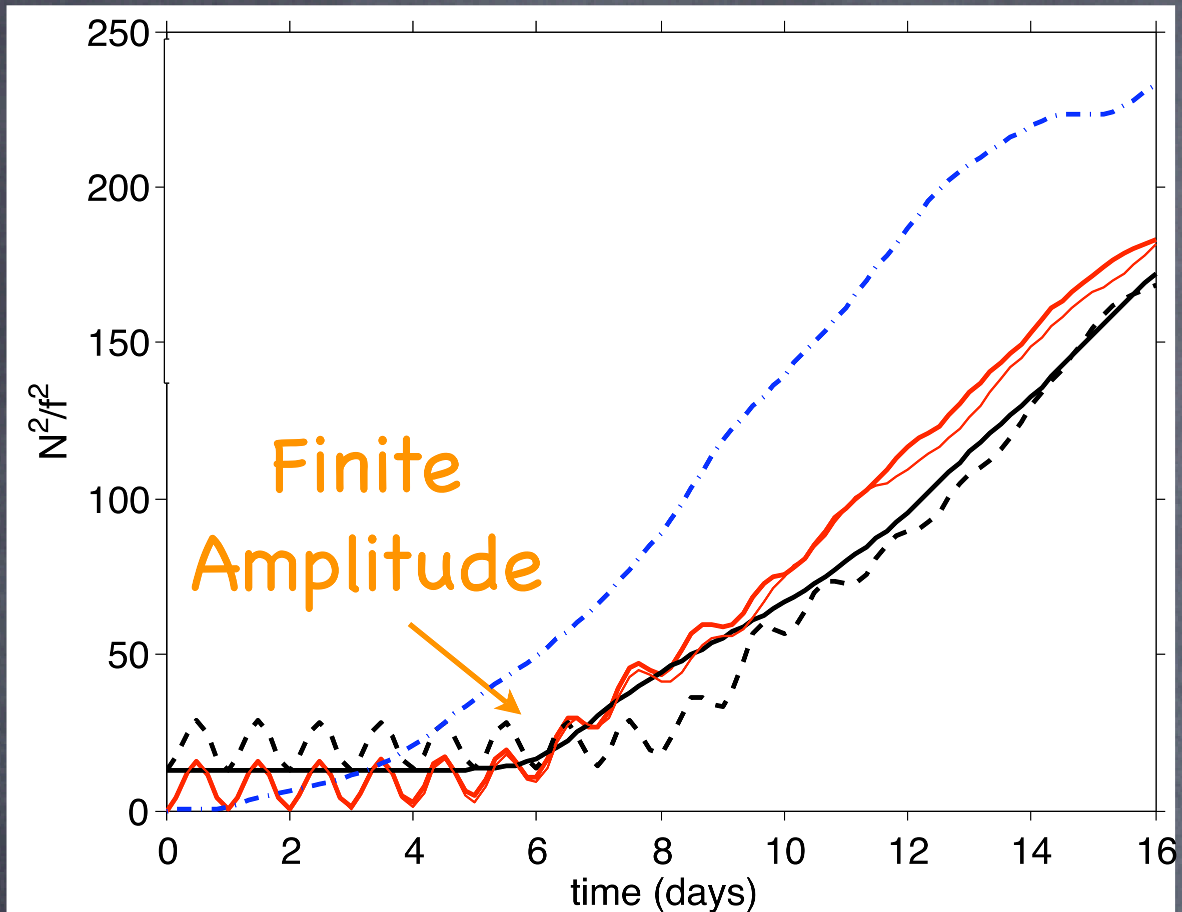

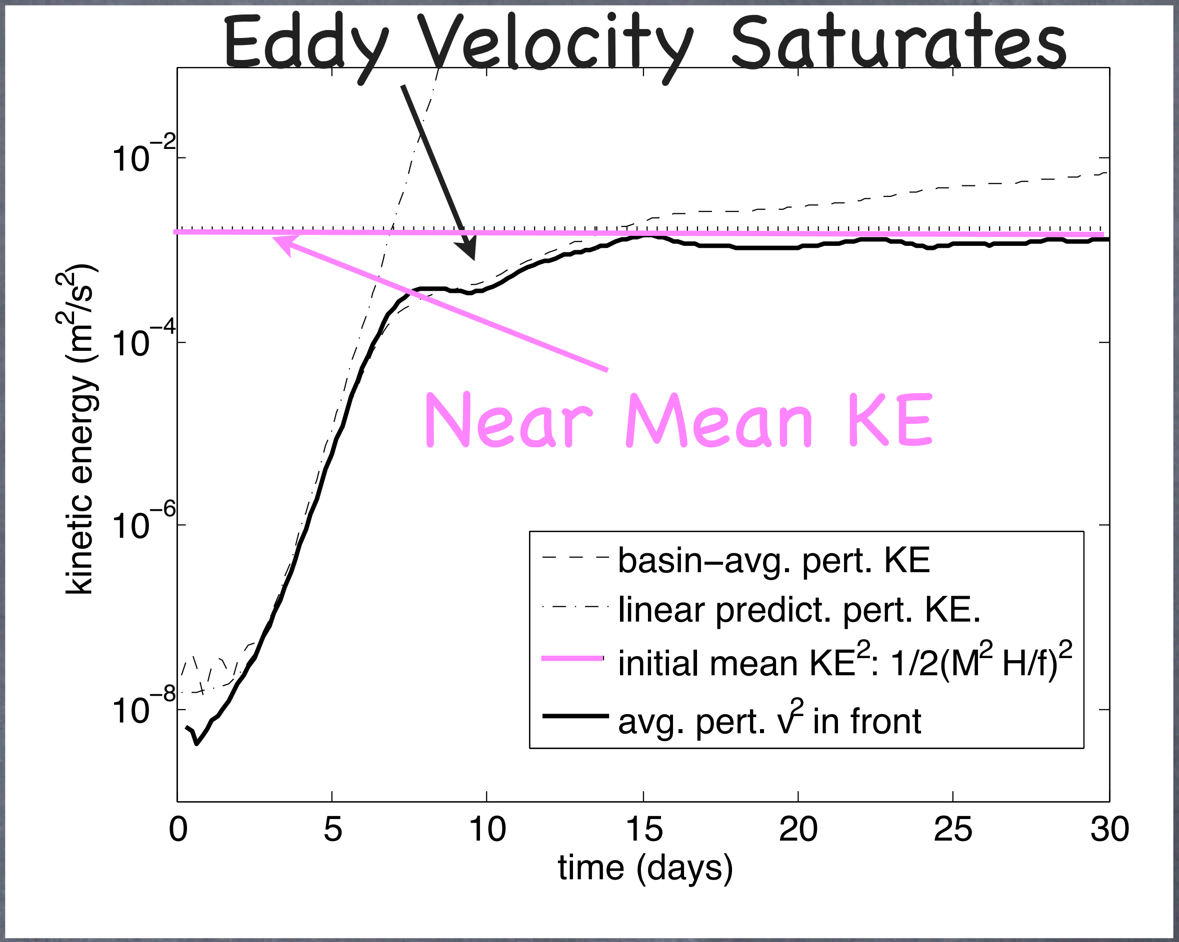

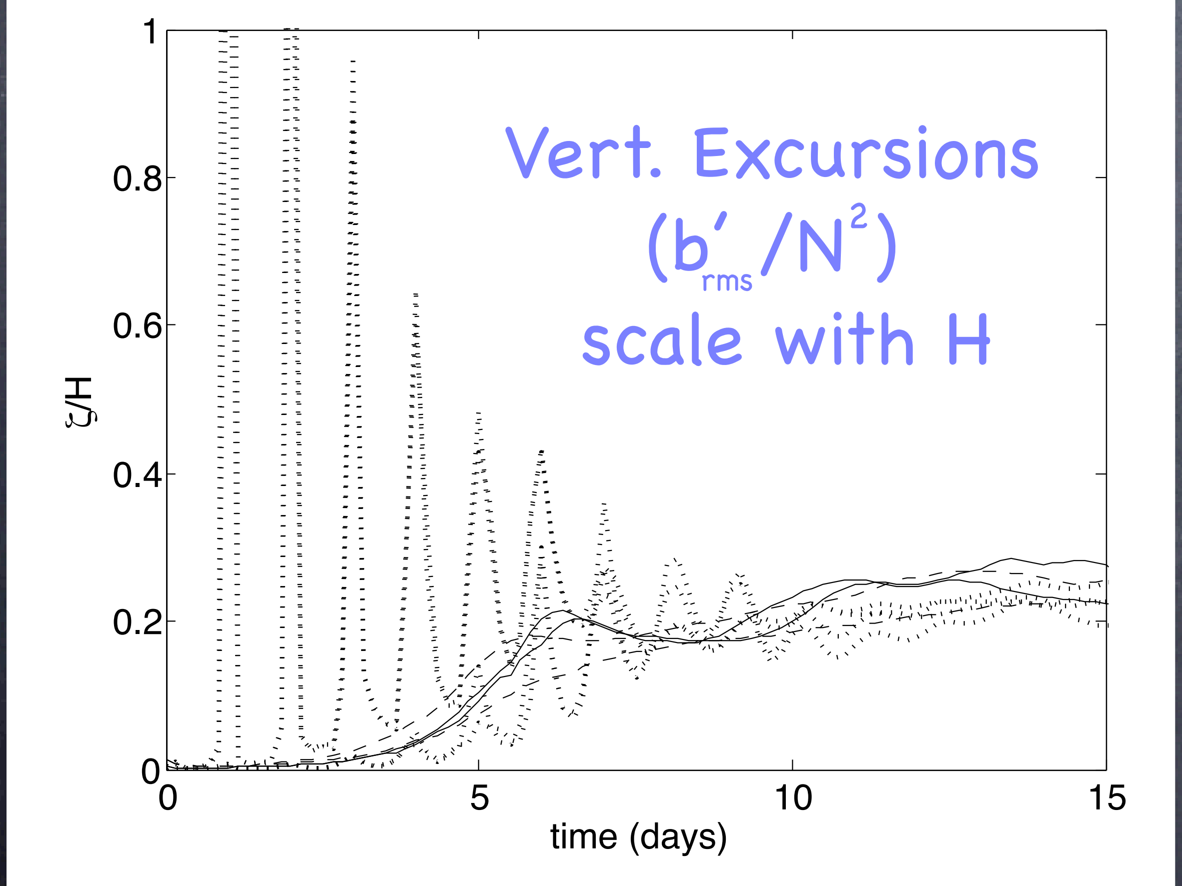

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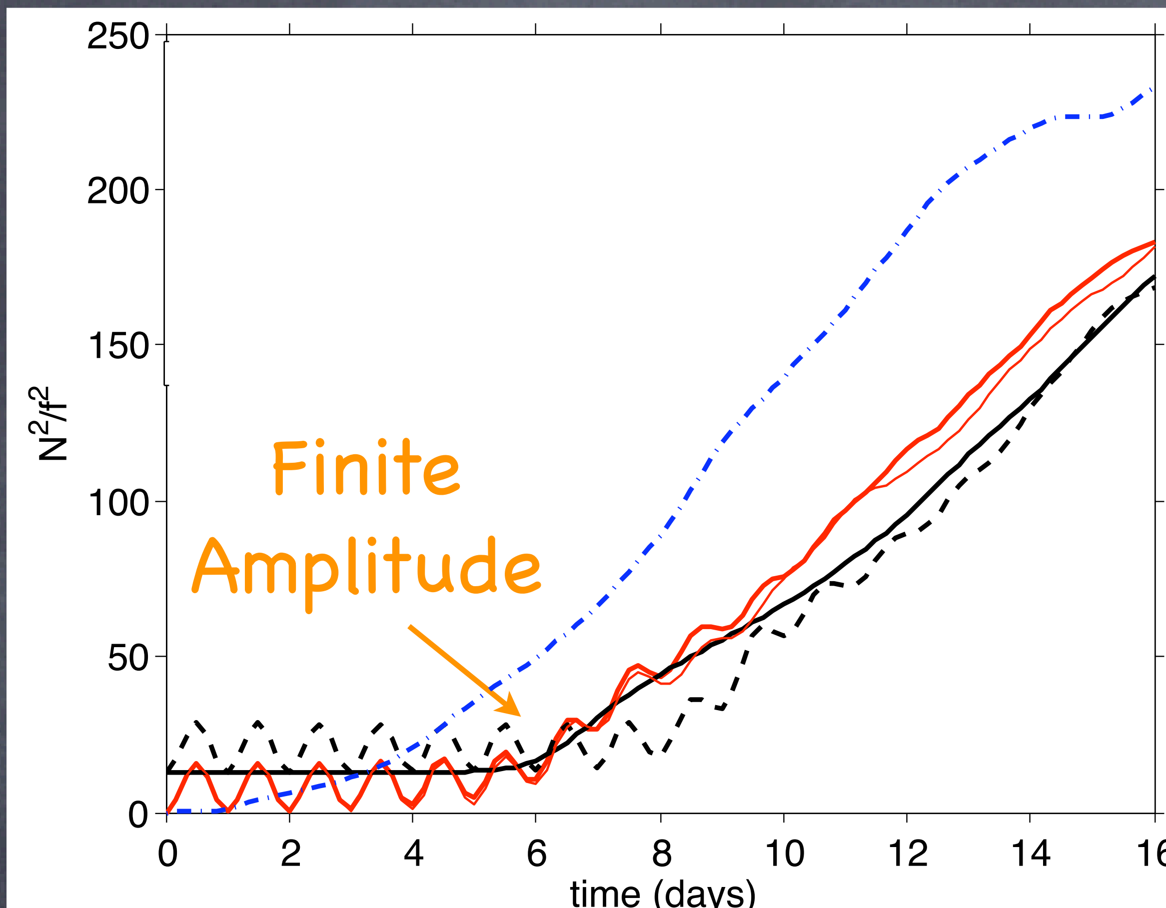

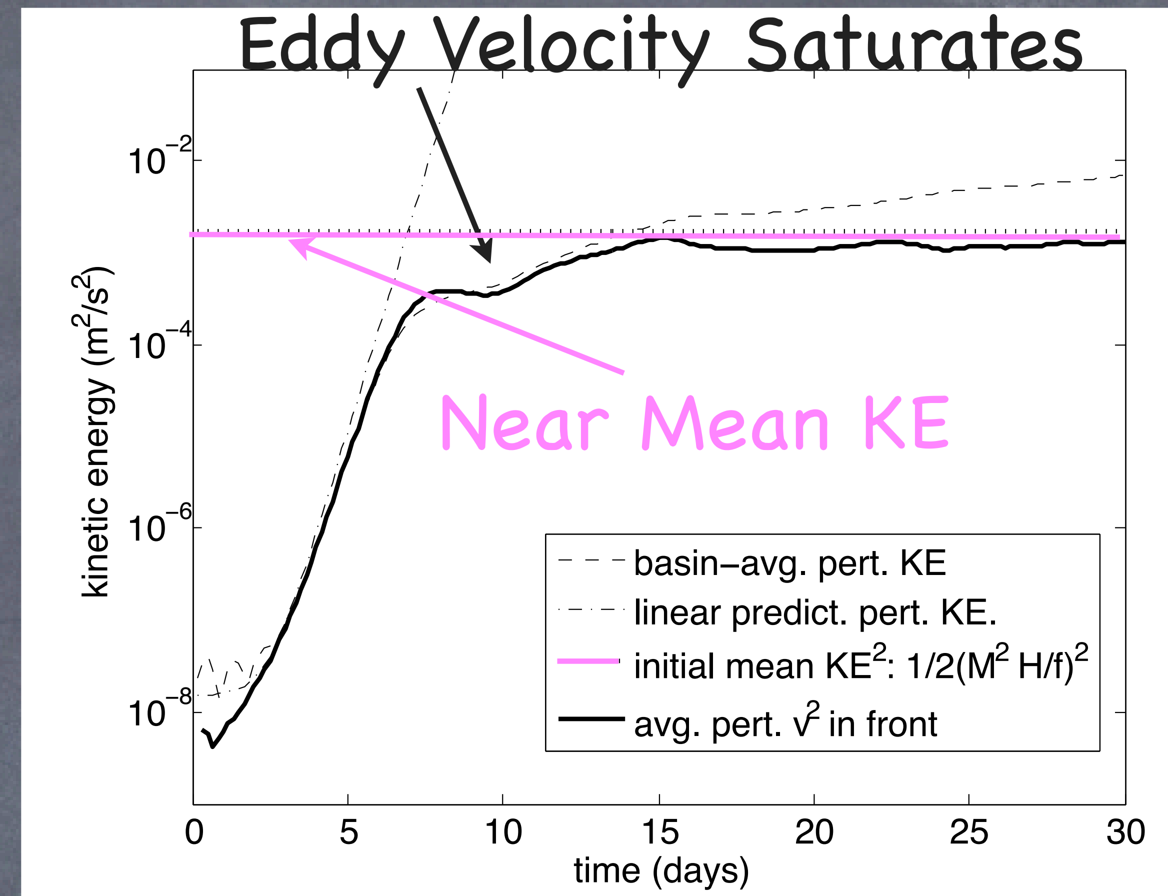

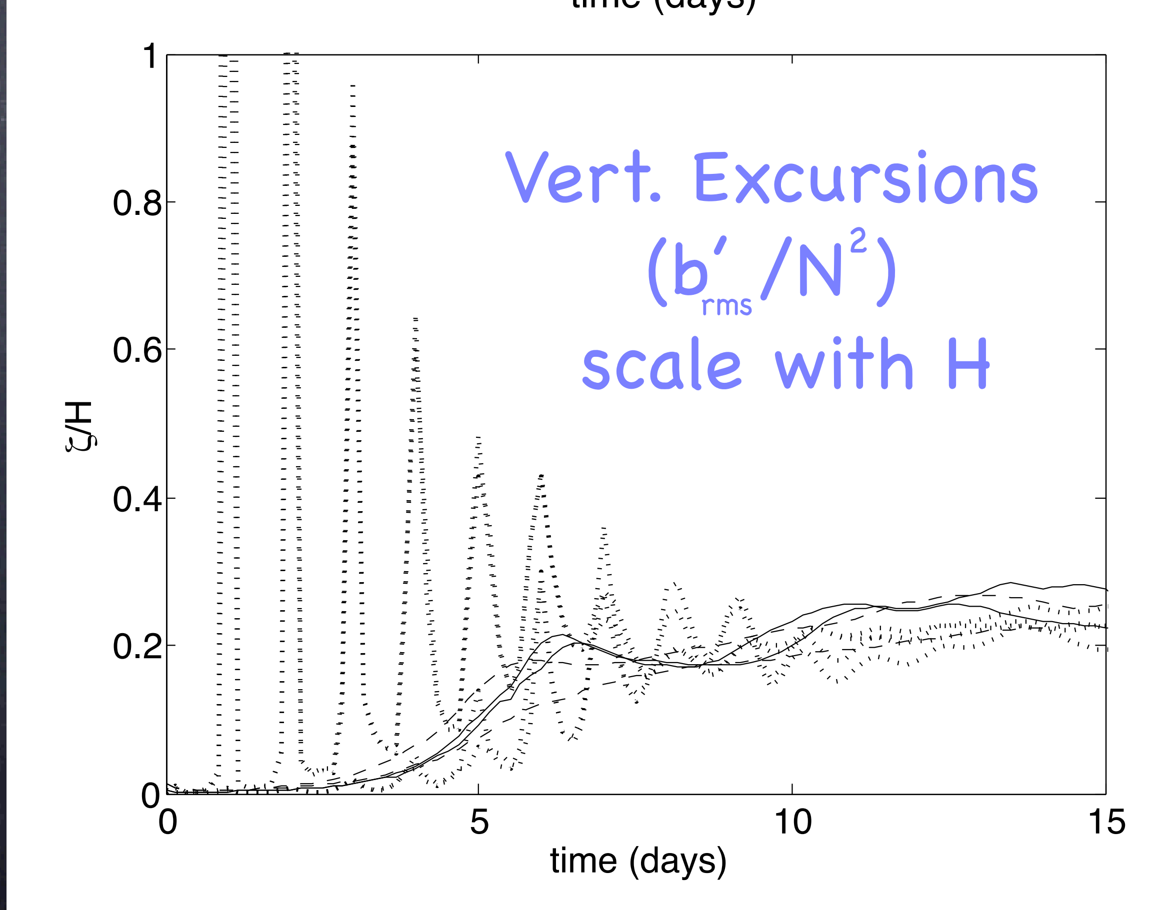

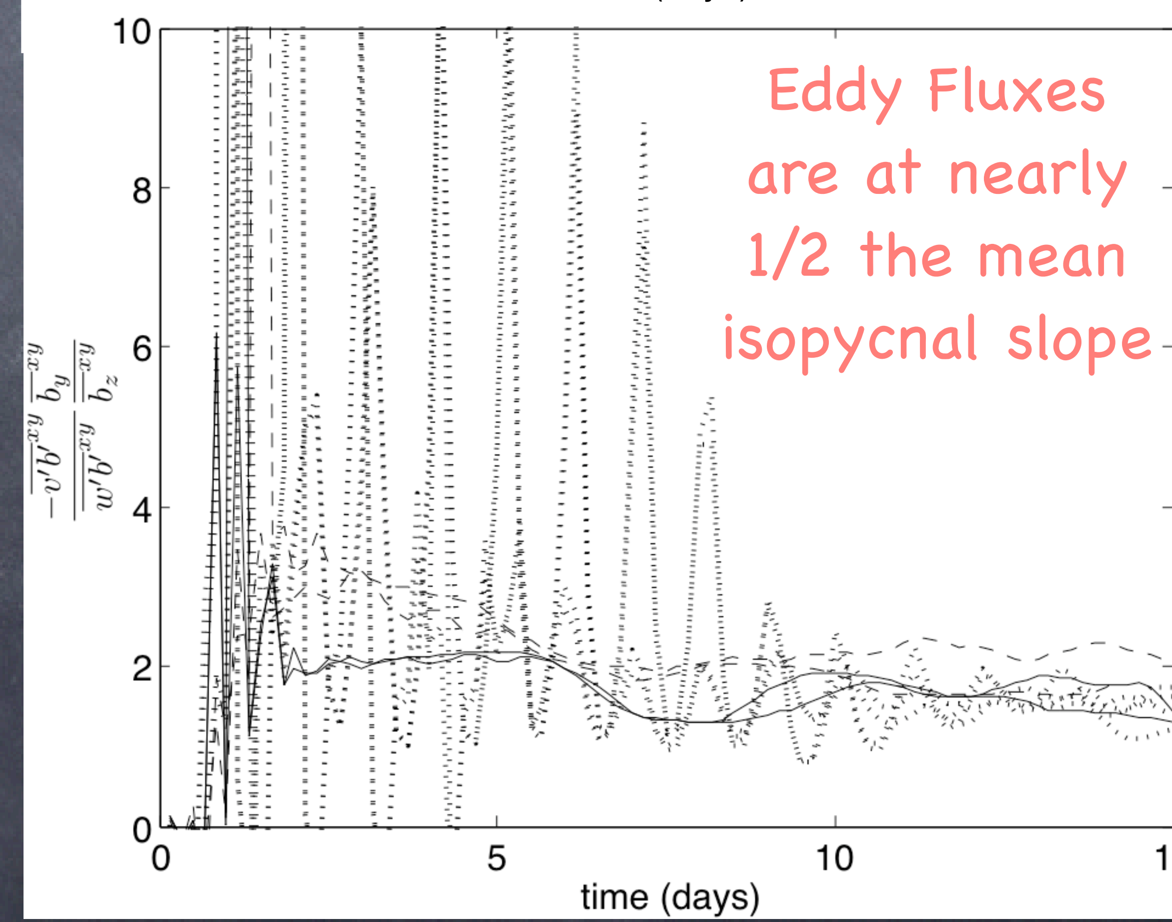

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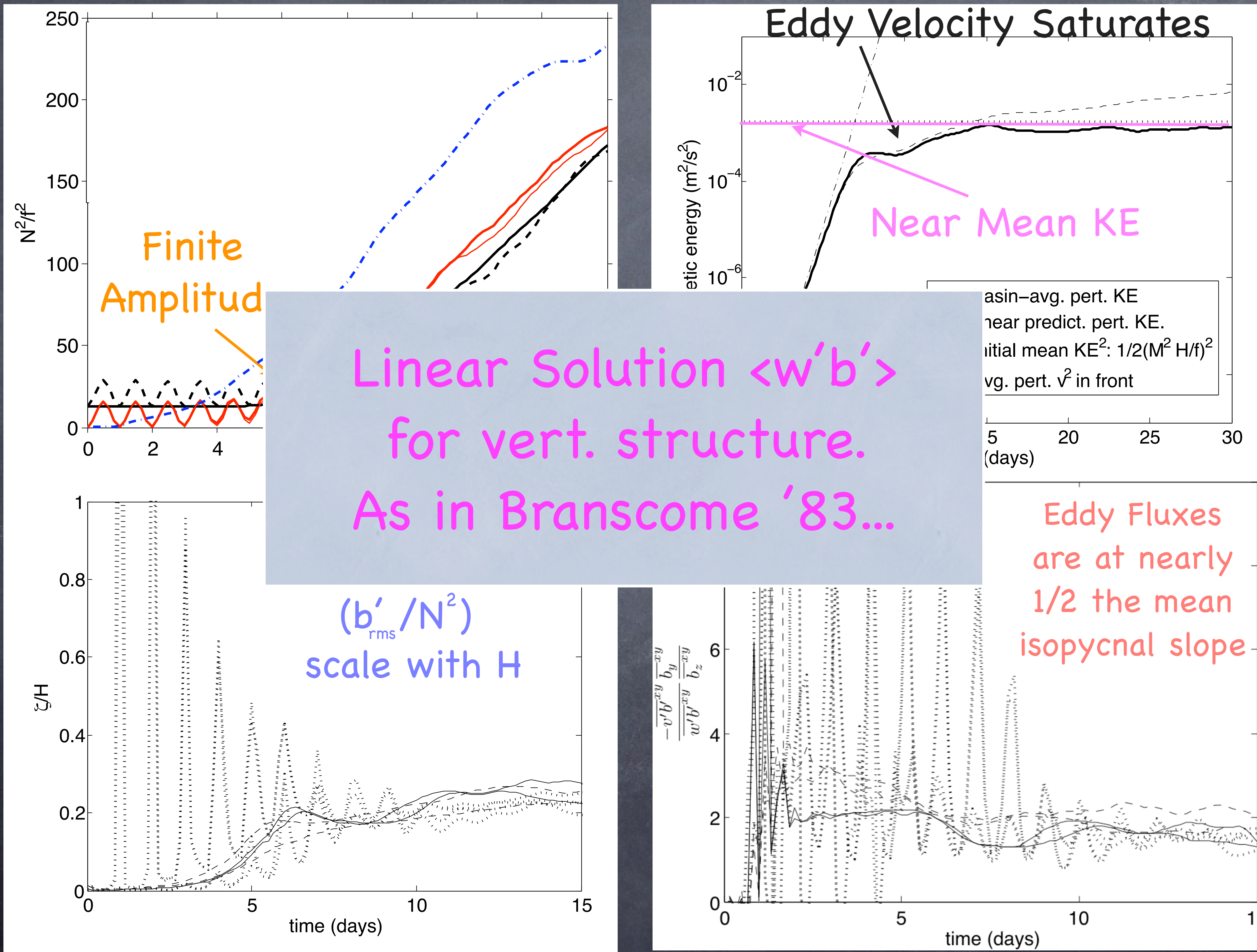


Linear Solution <w'b'>

for vert. structure.

As in Branscome '83...

The Parameterization:

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

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

Fox-Kemper et al. (08)

- The horizontal fluxes are downgradient:

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

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

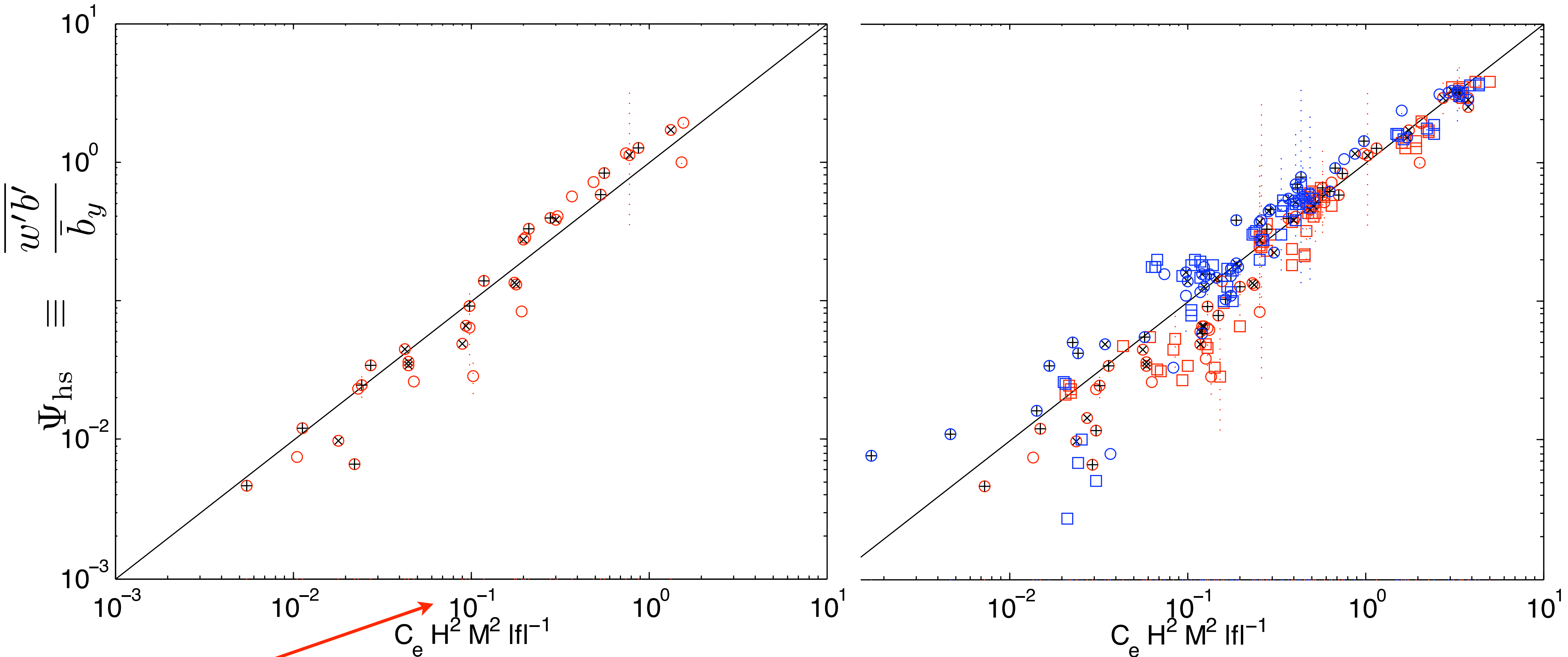
$$\boxed{\overline{w' b'} = \frac{C_e H^2 \mu(z)}{|f|} |\nabla \bar{b}|^2}$$

-

It works for Prototype Sims:

Red: No Diurnal

Blue: With Diurnal



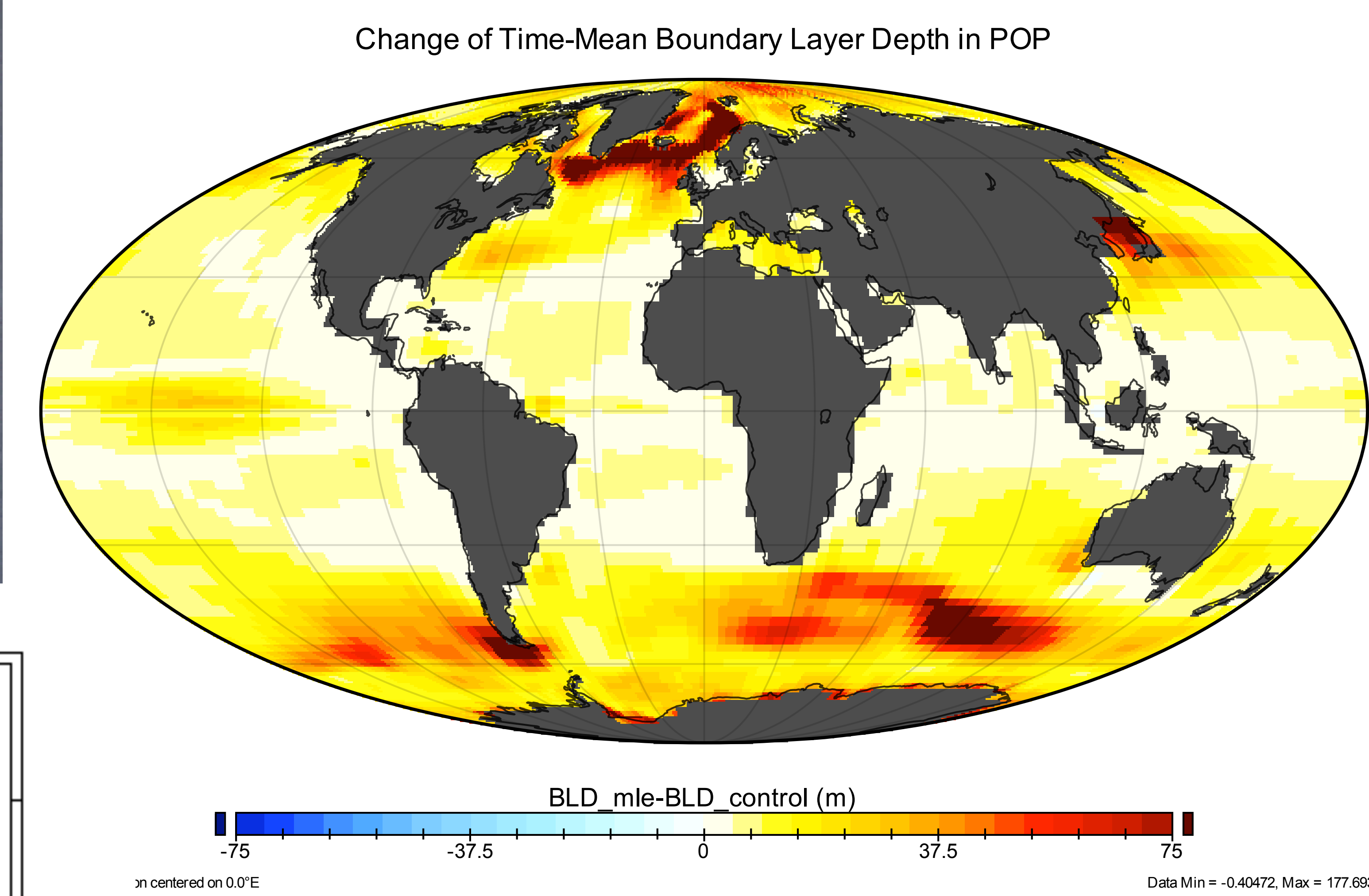
>2 orders of magnitude!

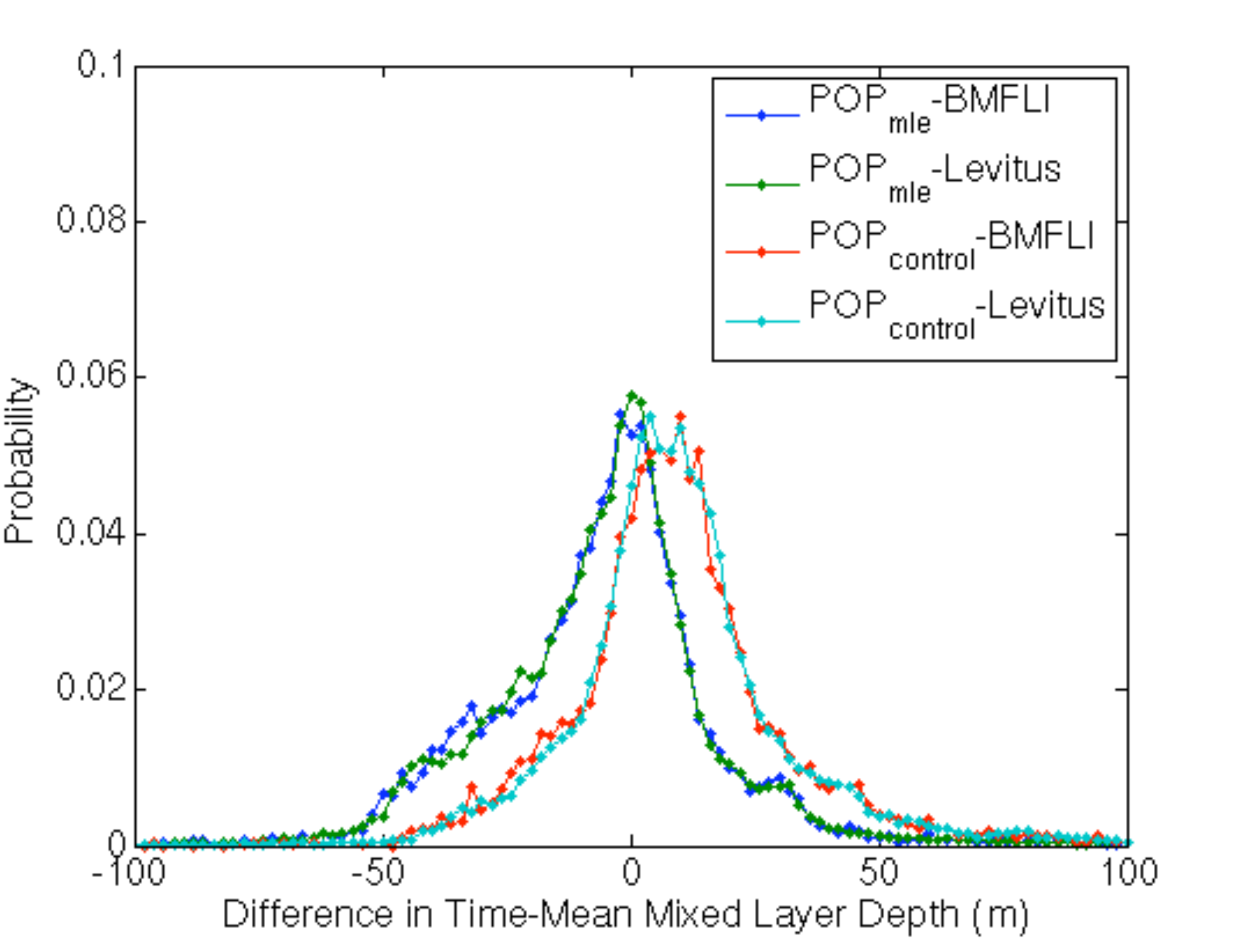
Circles: Balanced Initial Cond.

Squares: Unbalanced Initial Cond.

Works In 'Real' Models!

- HIM/GOLD and CCSM/POP
- Soon to be in MITgcm & MOM





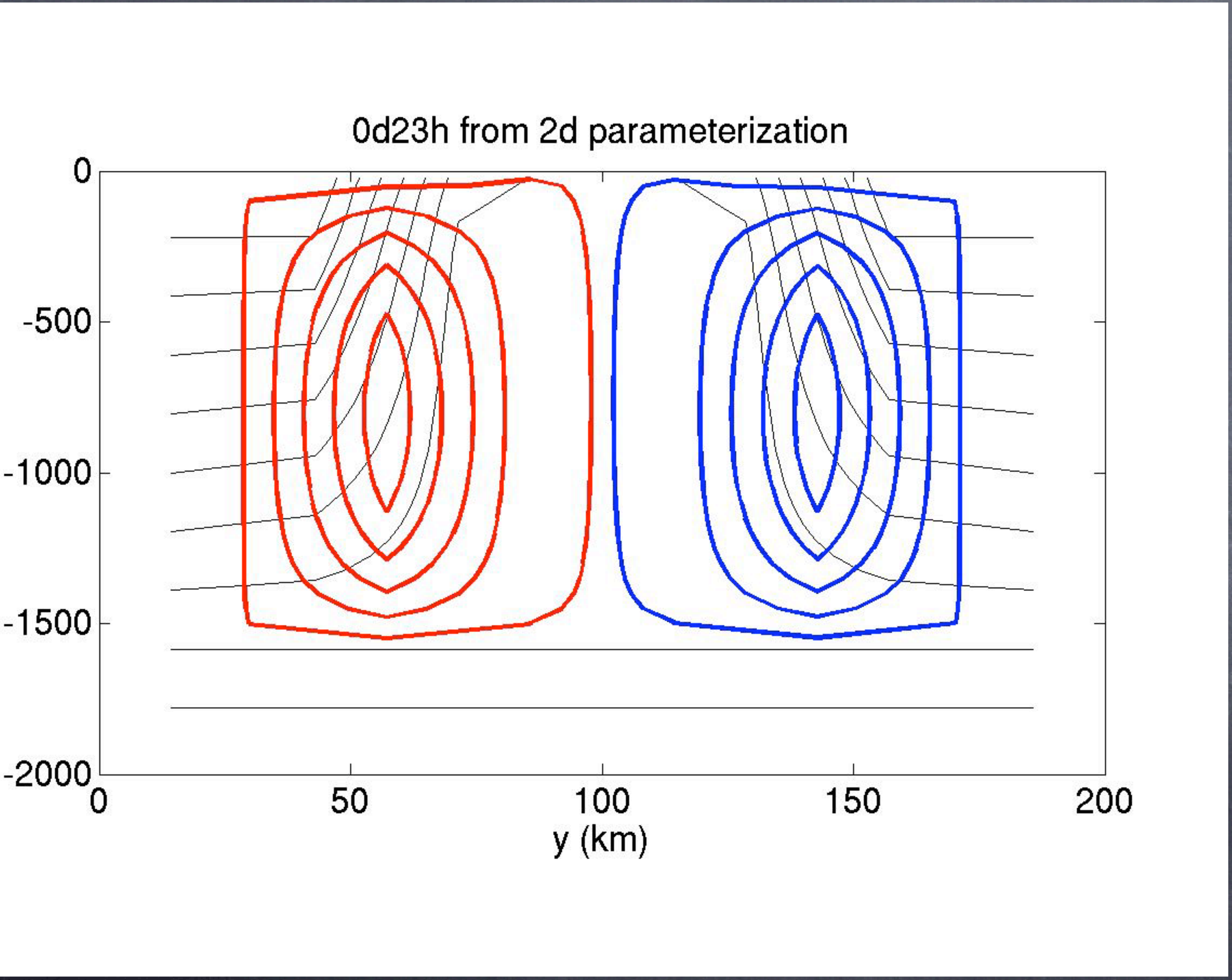
- RMS: 16m->8m, Skew 2.4->0.6

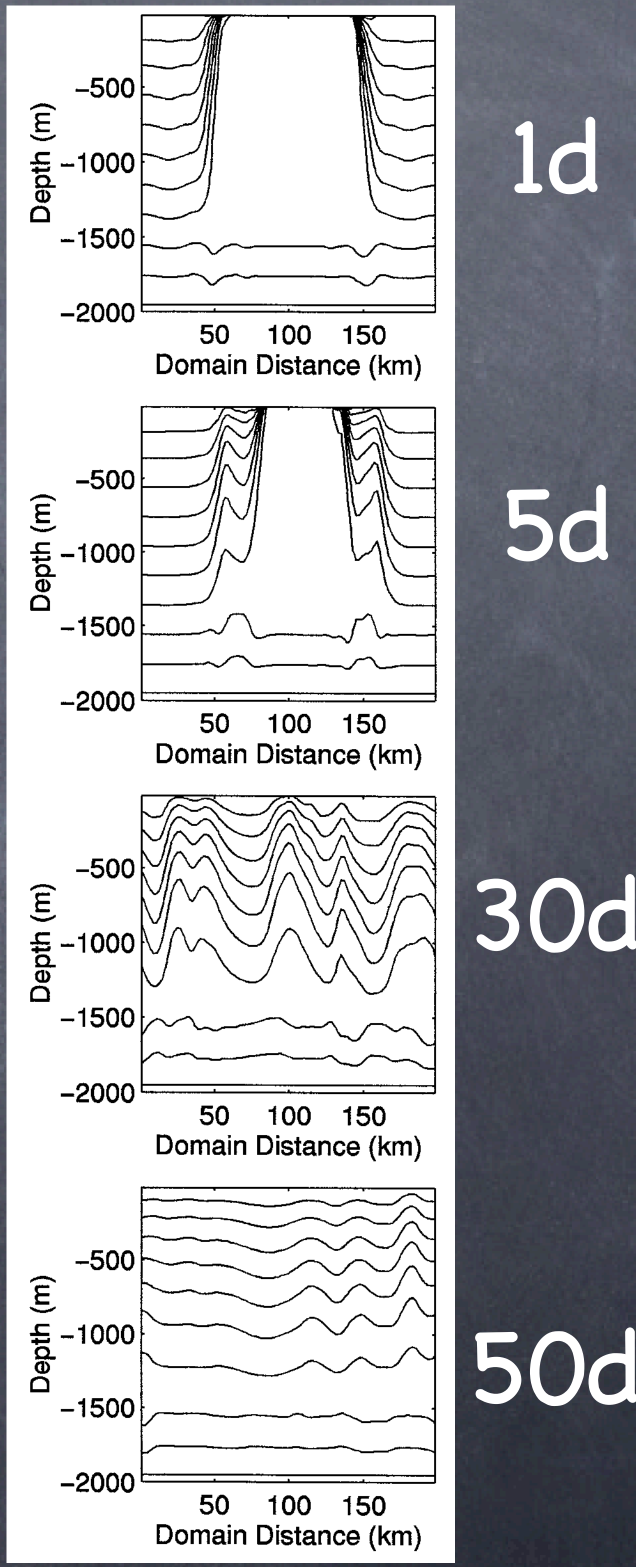
Summary I:

- Submesoscale features, and mixed layer eddies in particular, exhibit large vertical fluxes of buoyancy often ignored in climate models.
- A parameterization of mixed layer eddy fluxes as an overturning streamfunction is proposed. The magnitude comes from extraction rate of potential energy.
- Many observations are consistent, and model biases are reduced. Biogeochemical effects are likely, as vertical fluxes and mixed layer depth are changed.
- In HIM & CCSM, soon to be in MITgcm and MOM.
- 4 Papers so far... fox-kemper.com/research

What if it's not a Surface Mixed Layer?

e.g., Deep Convection (versus Jones & Marshall)





Param gives same scaling, but...

Jones & Marshall 97

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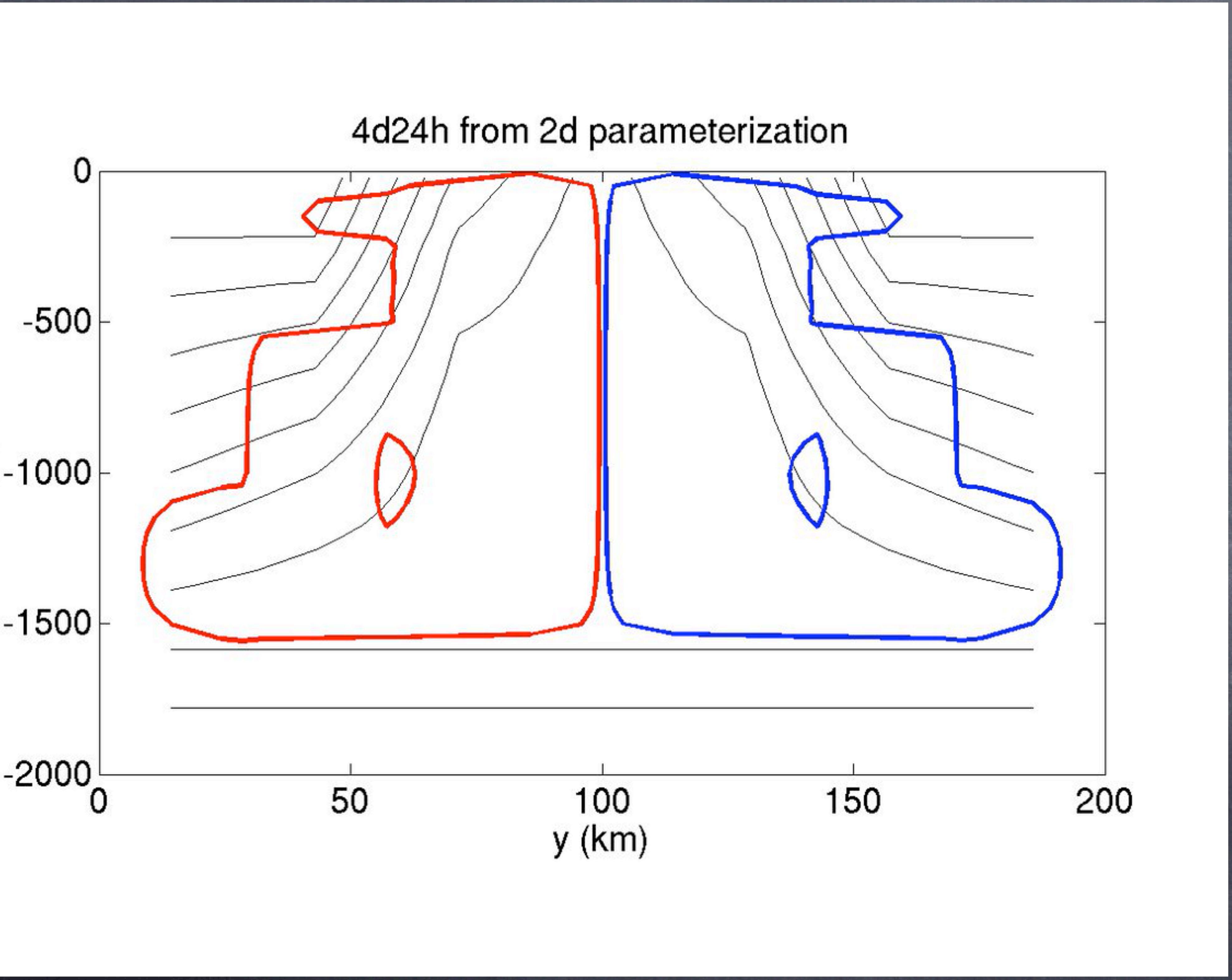

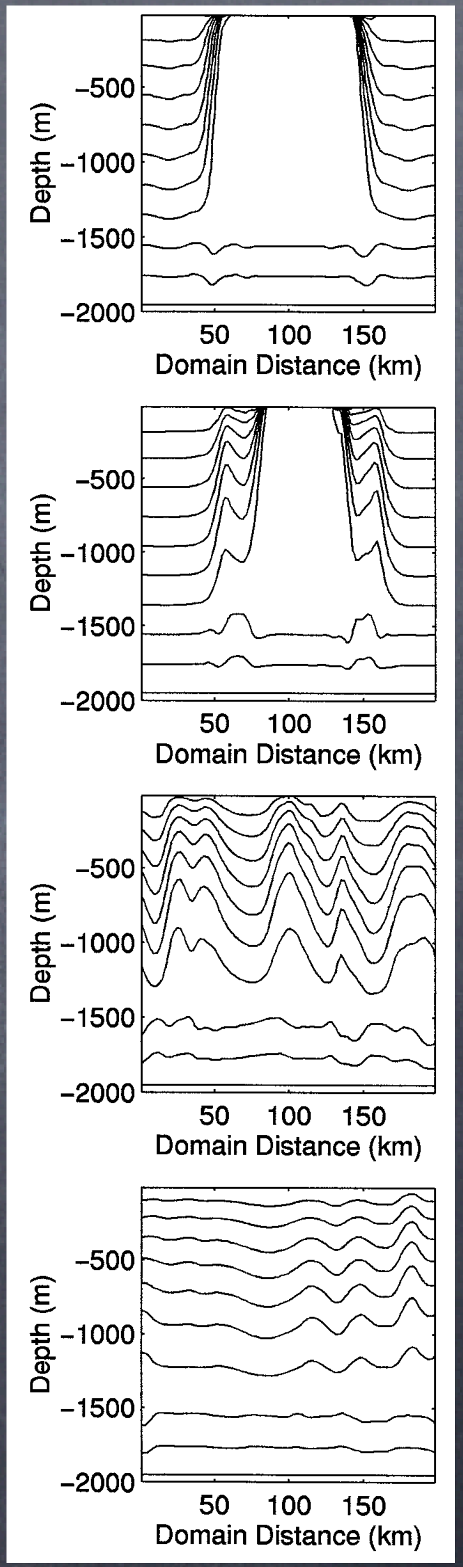

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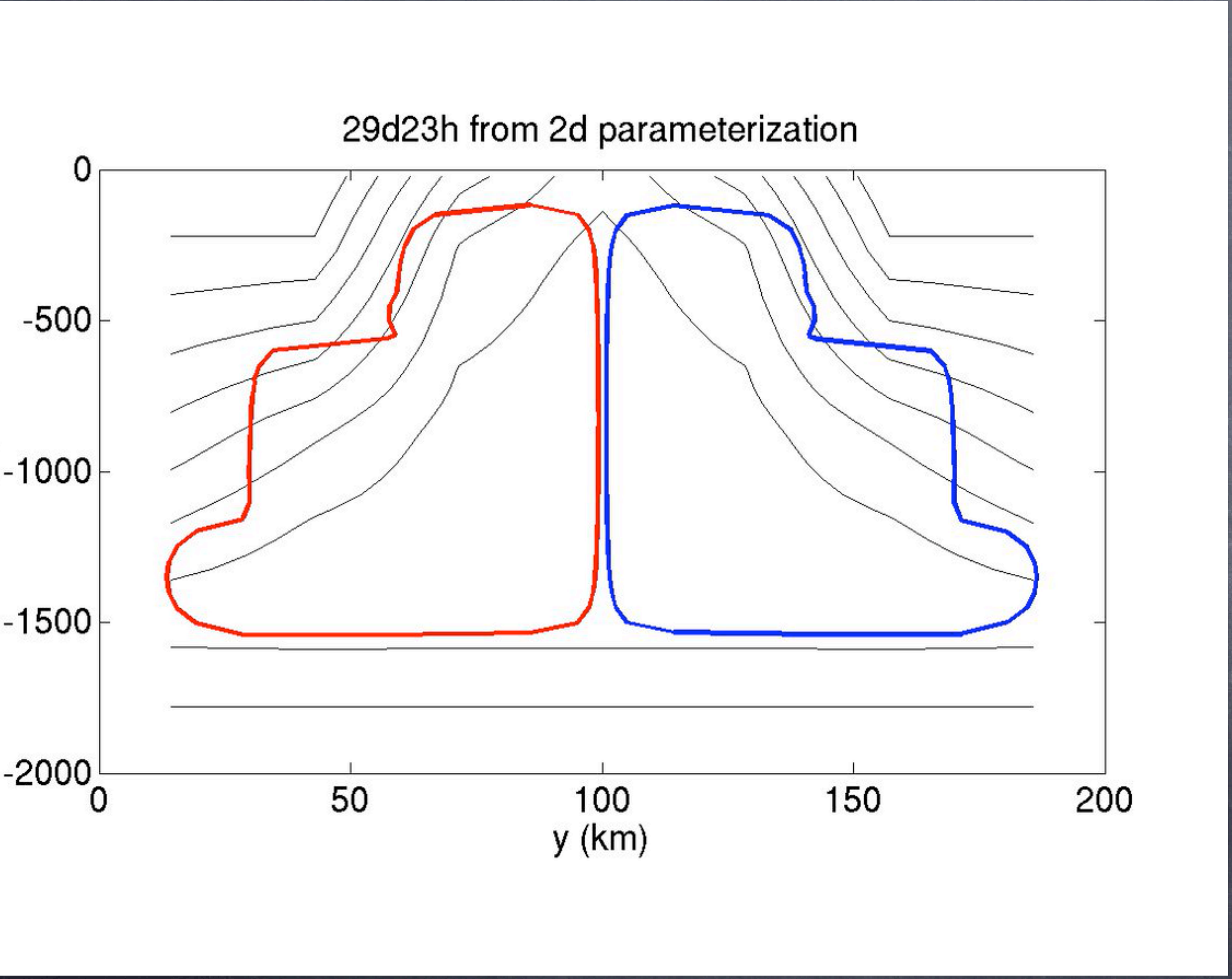

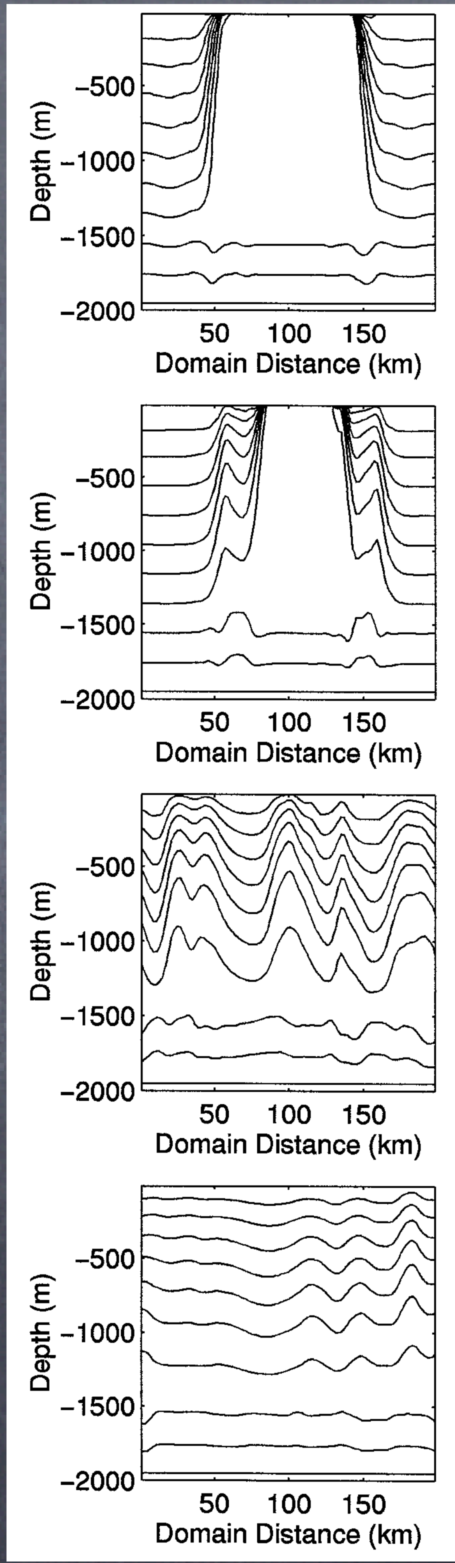

1d

5d

30d

50d

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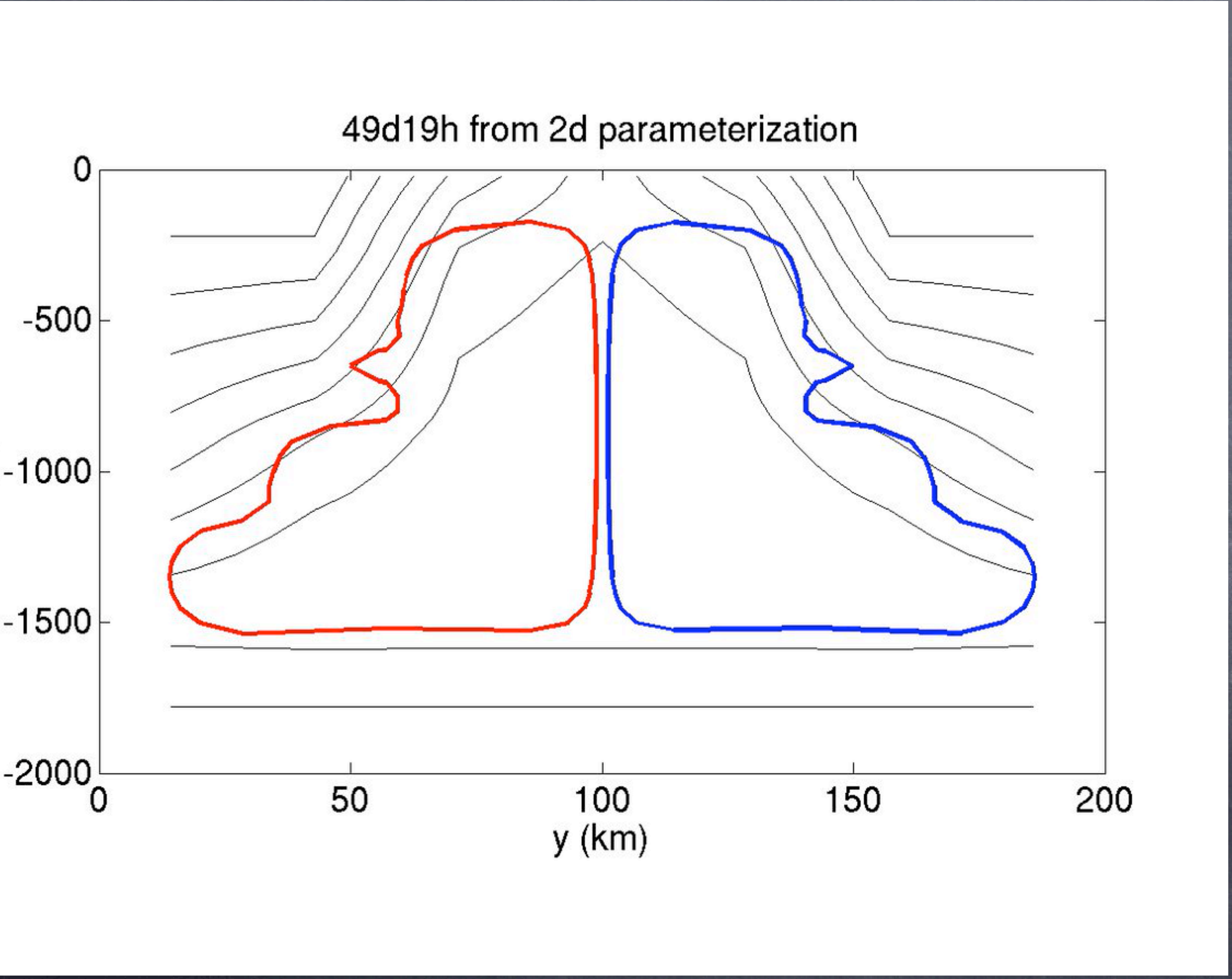

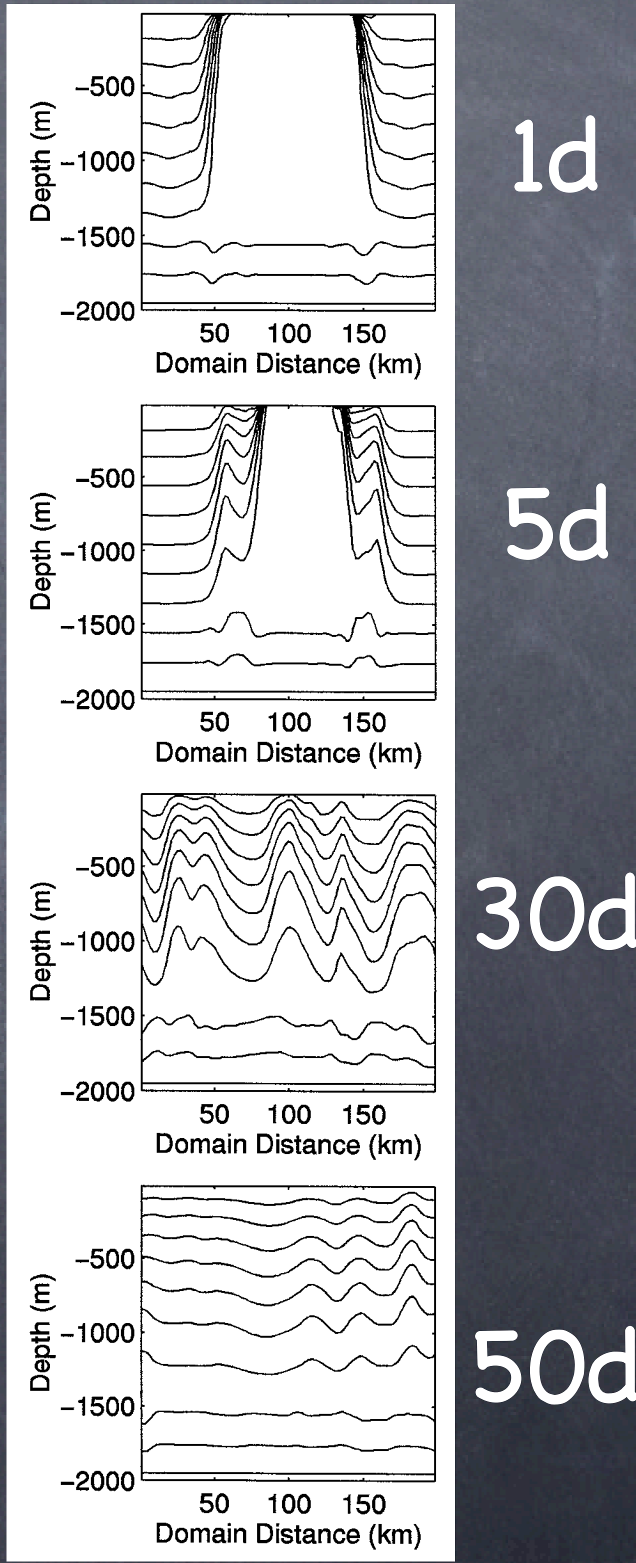

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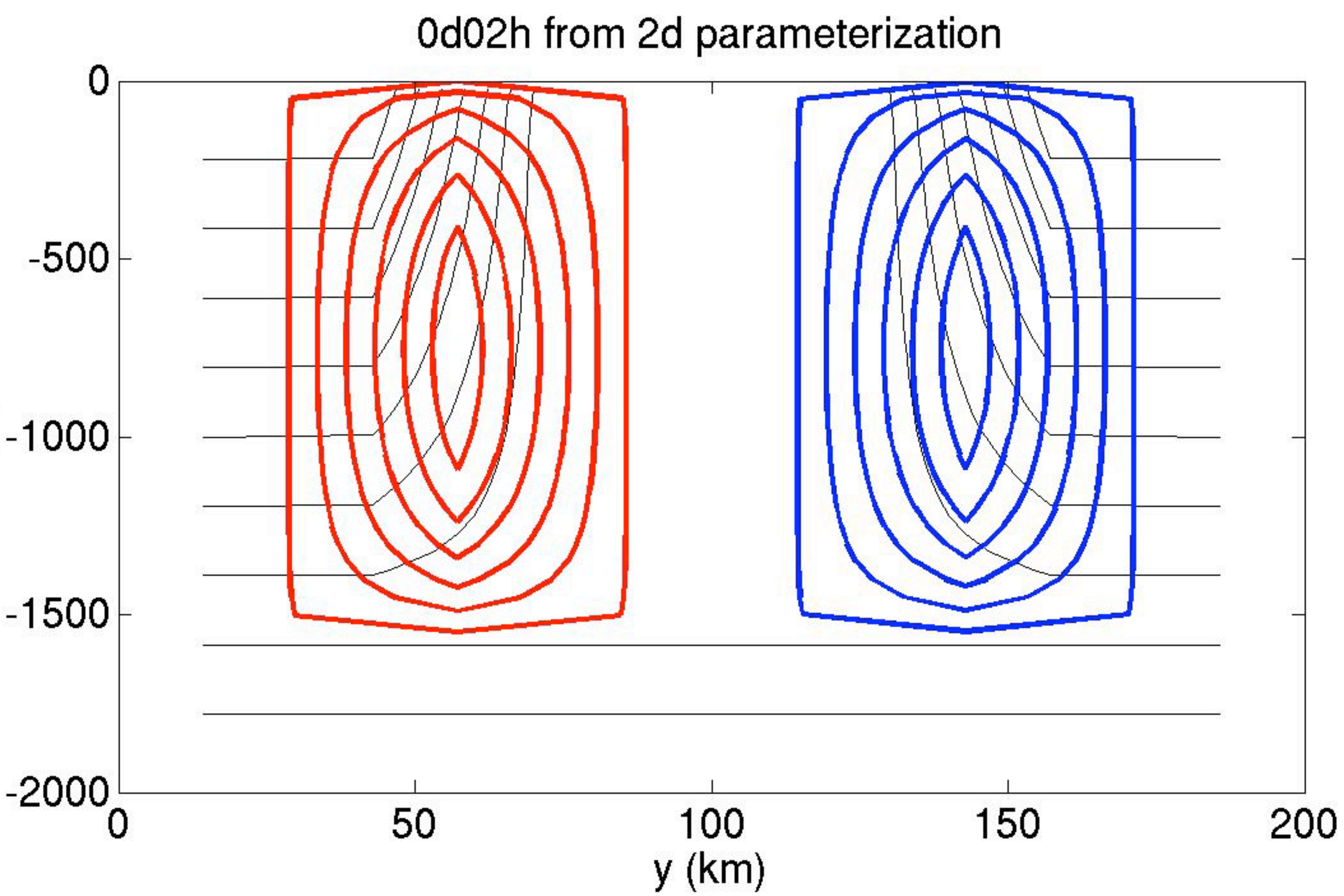

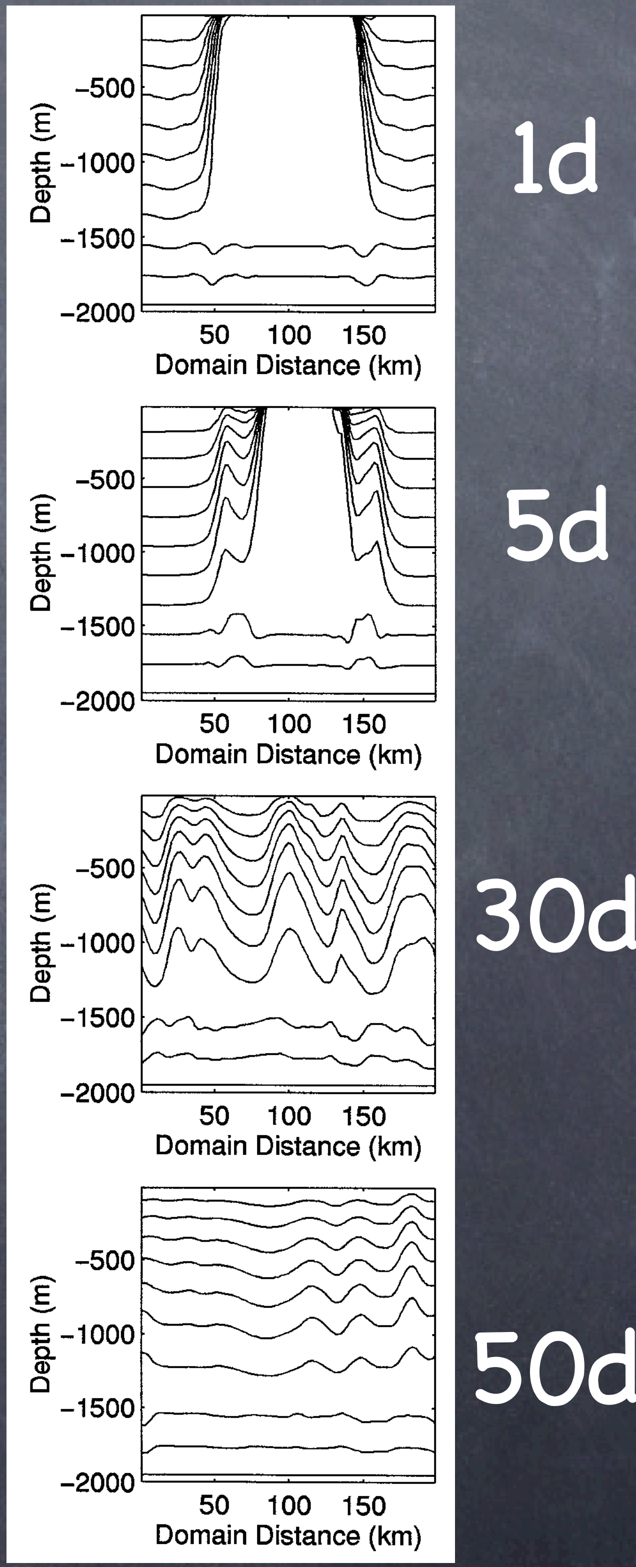

Vertical structure is different...

Jones & Marshall 97

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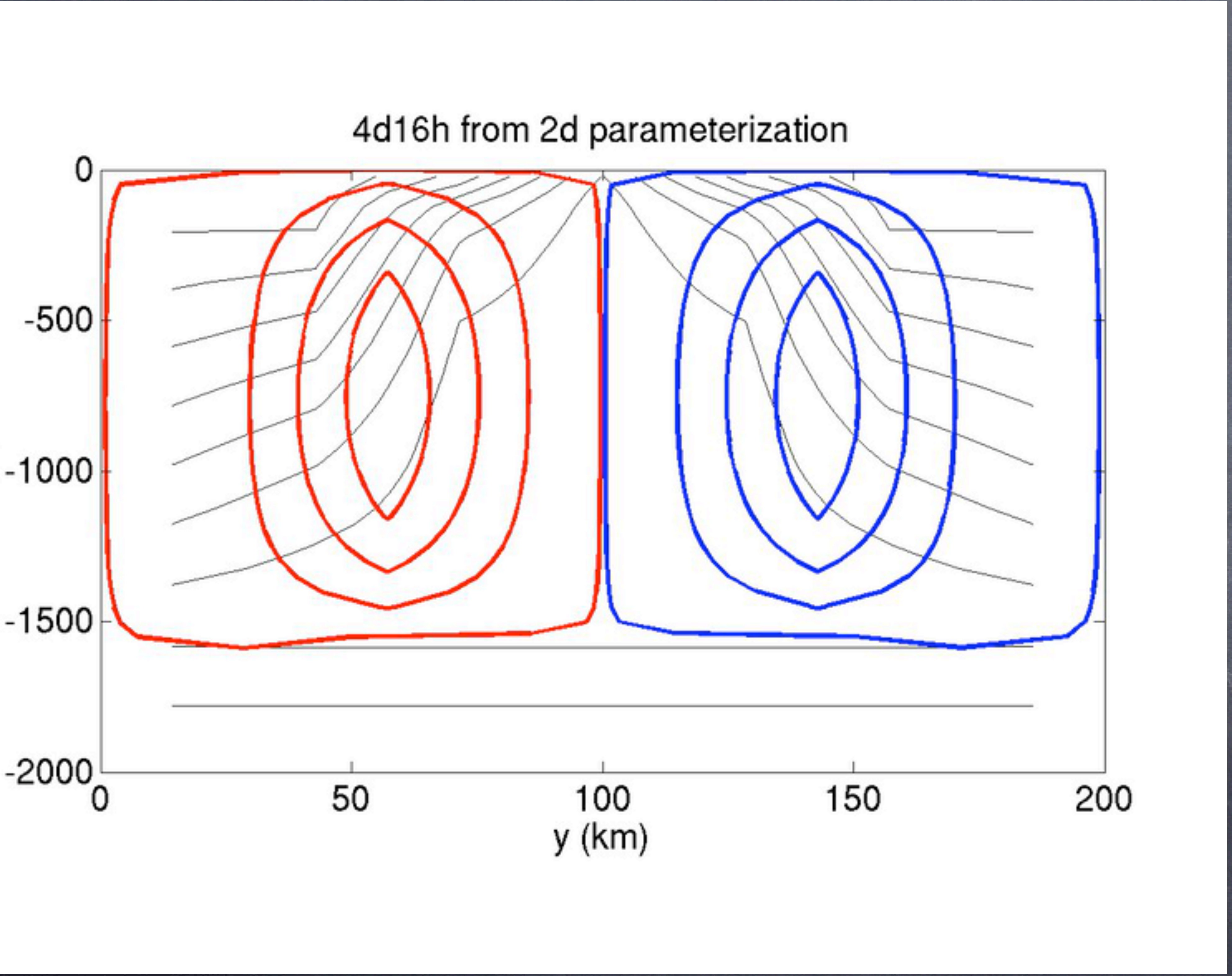
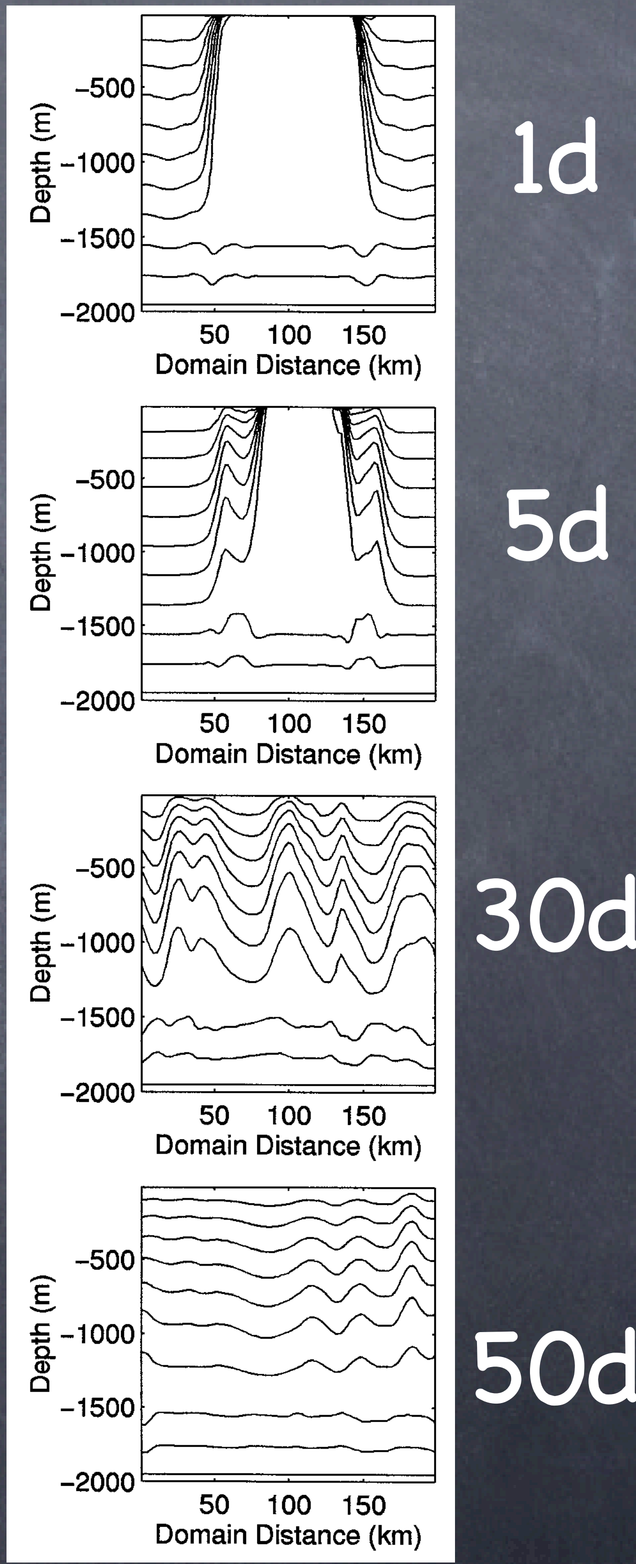


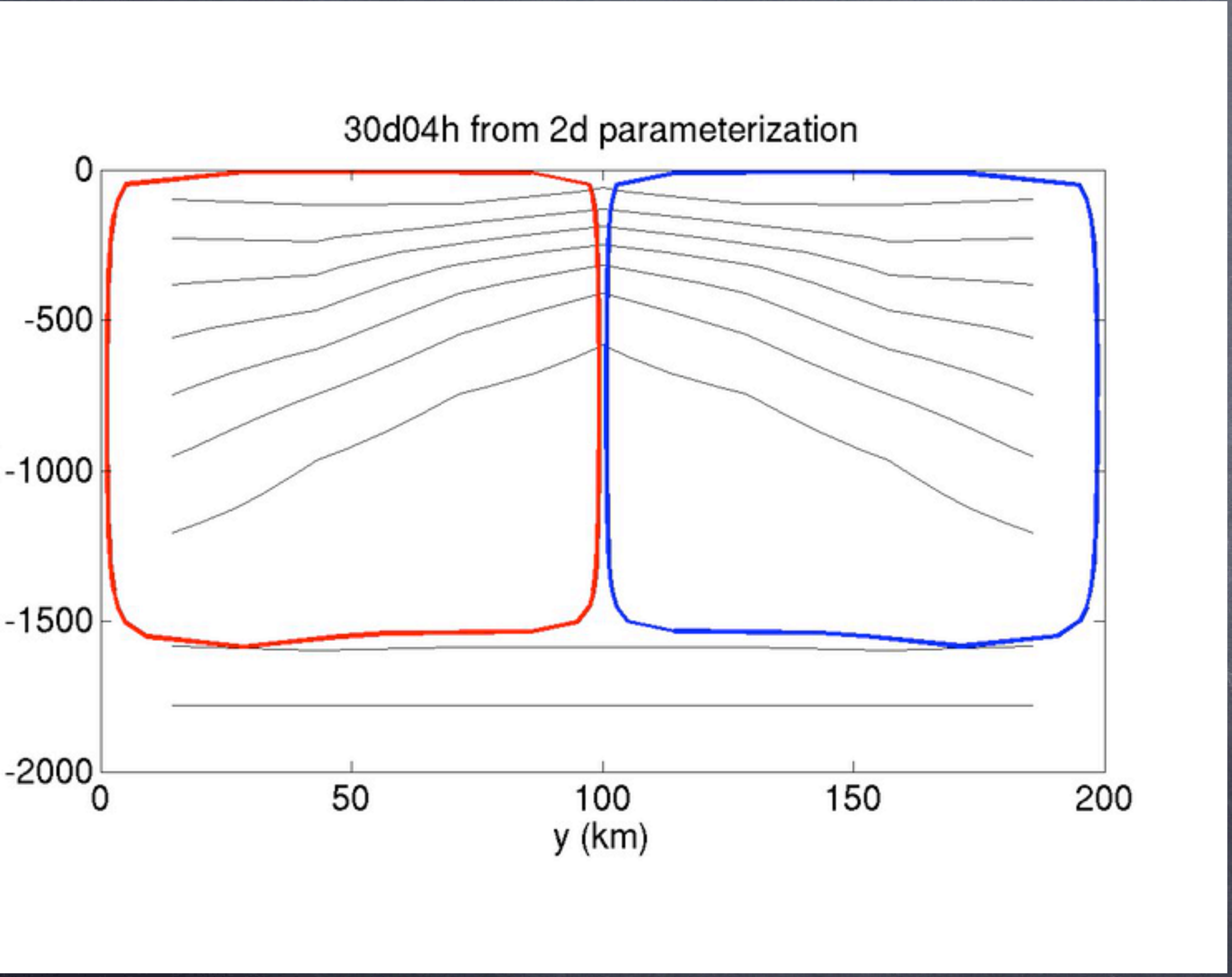


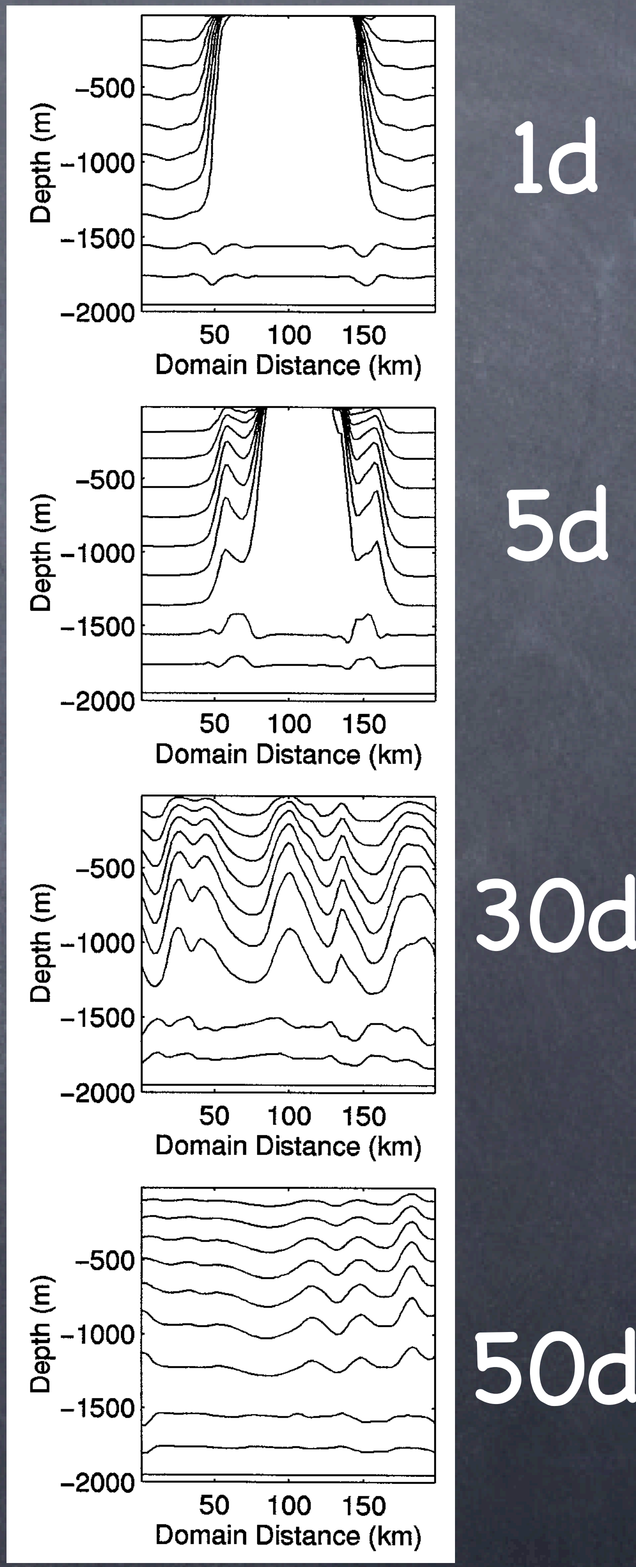
Vertical structure is different...

Jones & Marshall 97

What if it's not a Surface Mixed Layer?

e.g., Deep Convection (versus Jones & Marshall)





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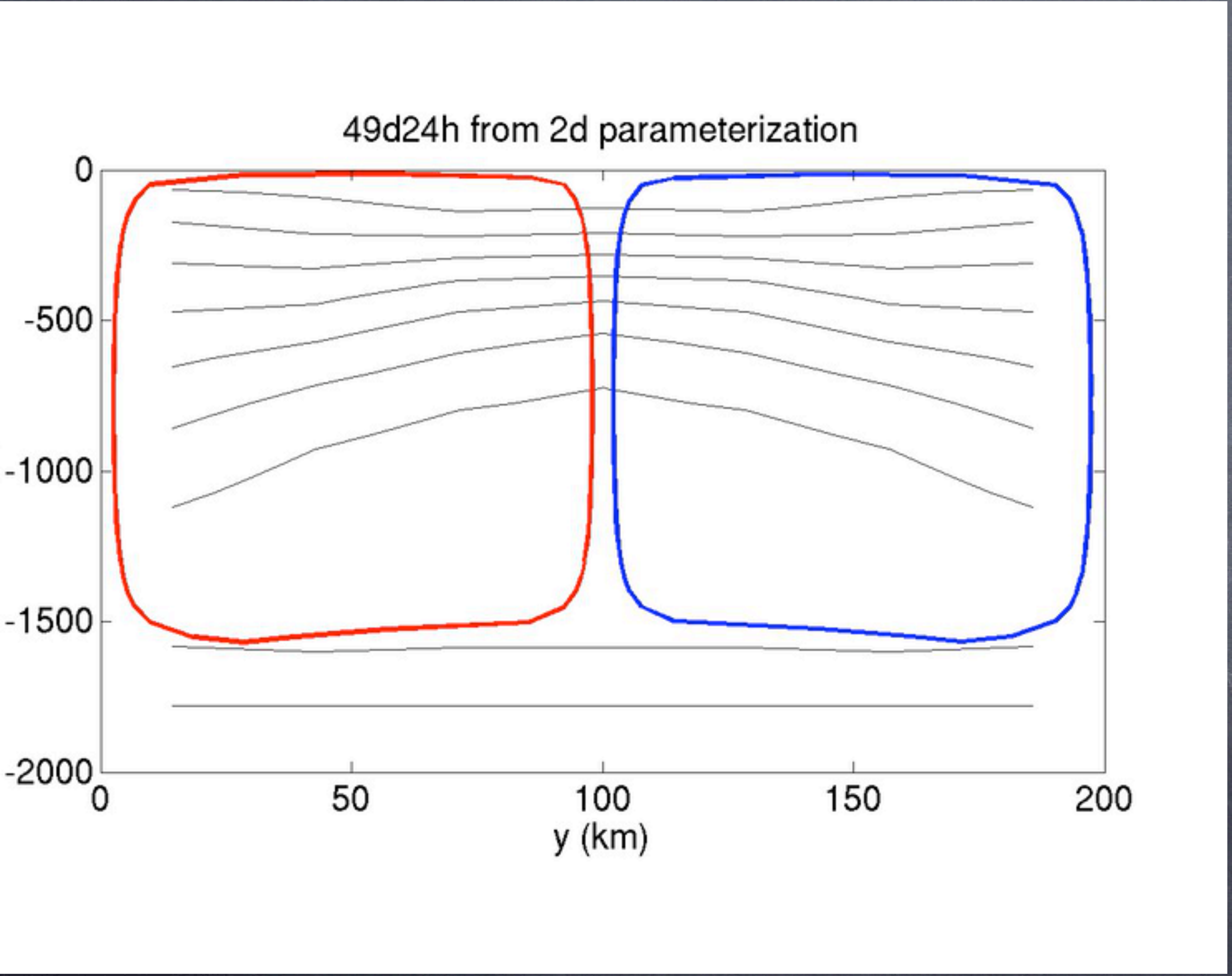

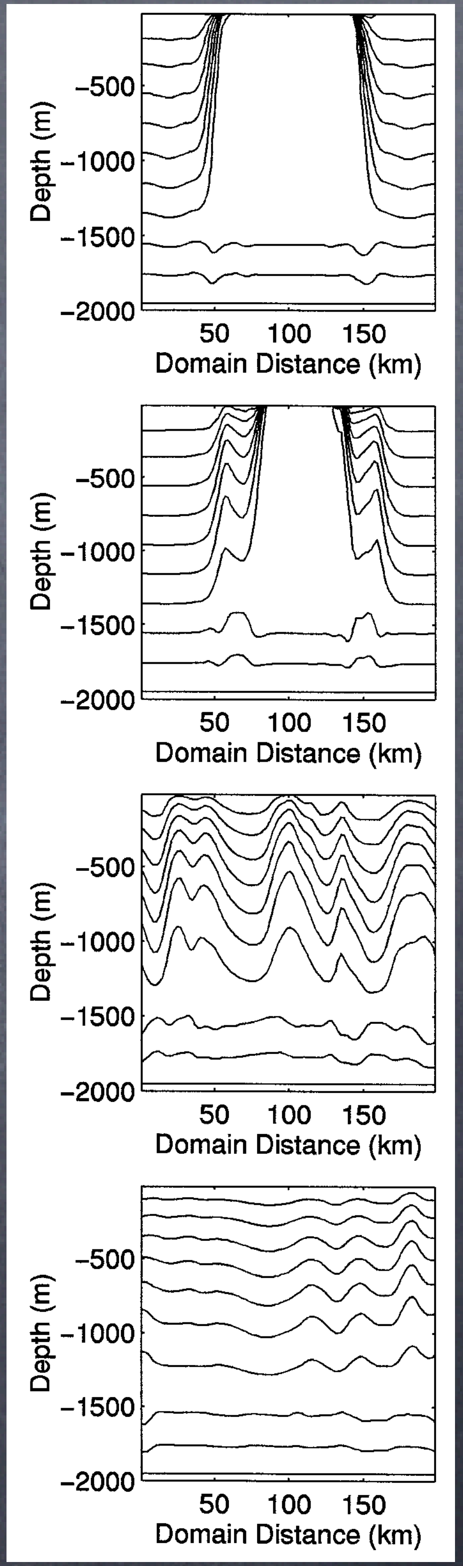

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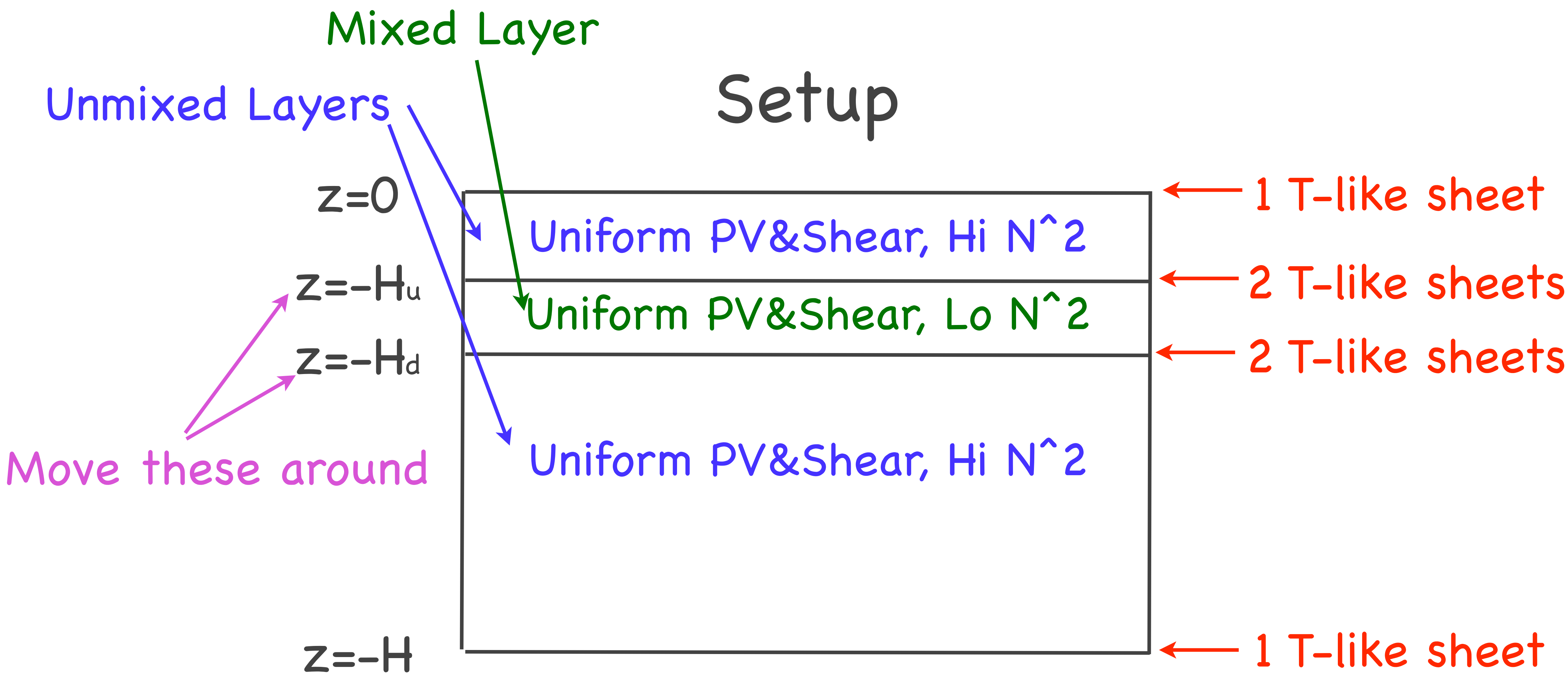
Consider SQG Eady + Mix

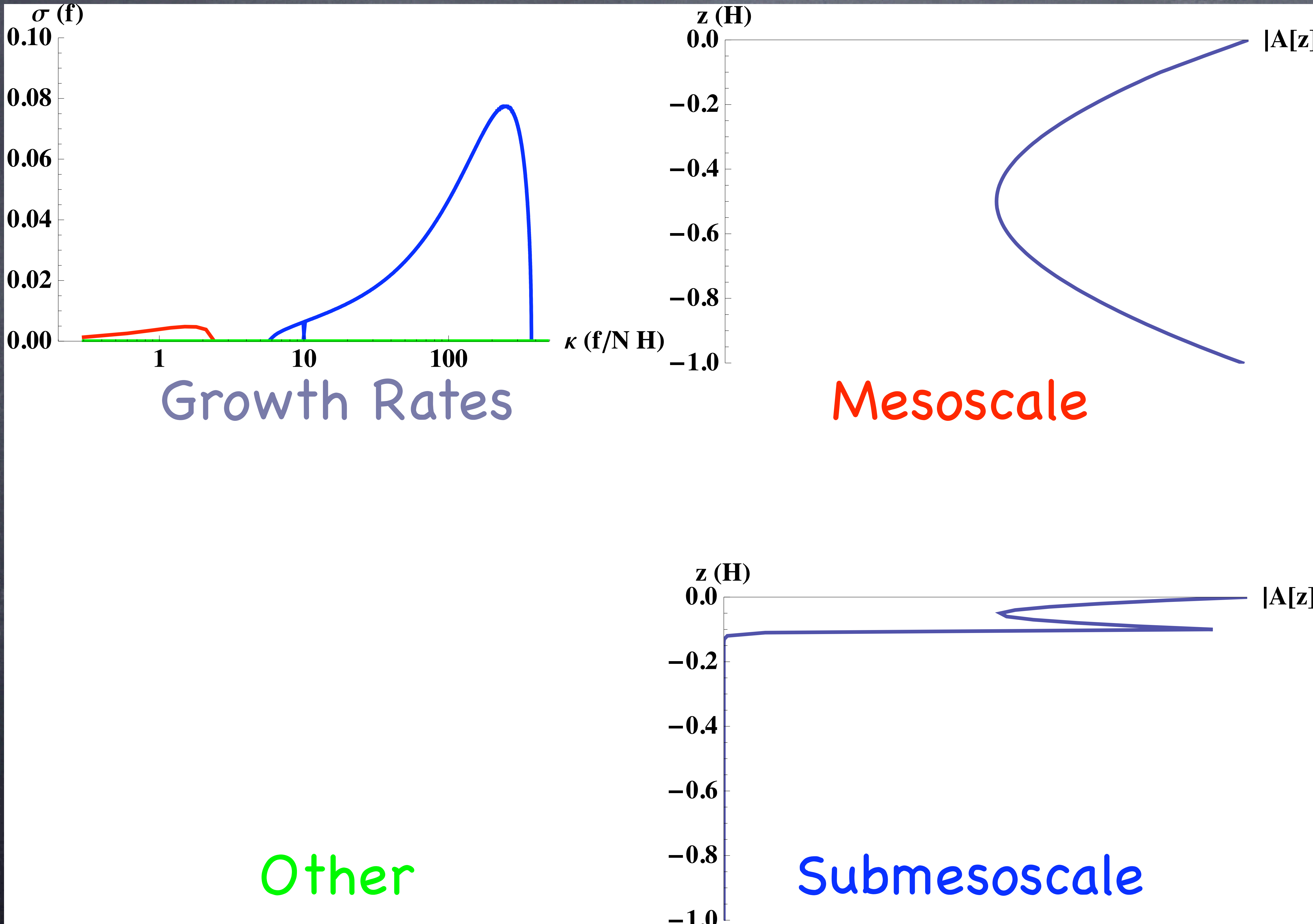


Could make mix as cooling or stirring.

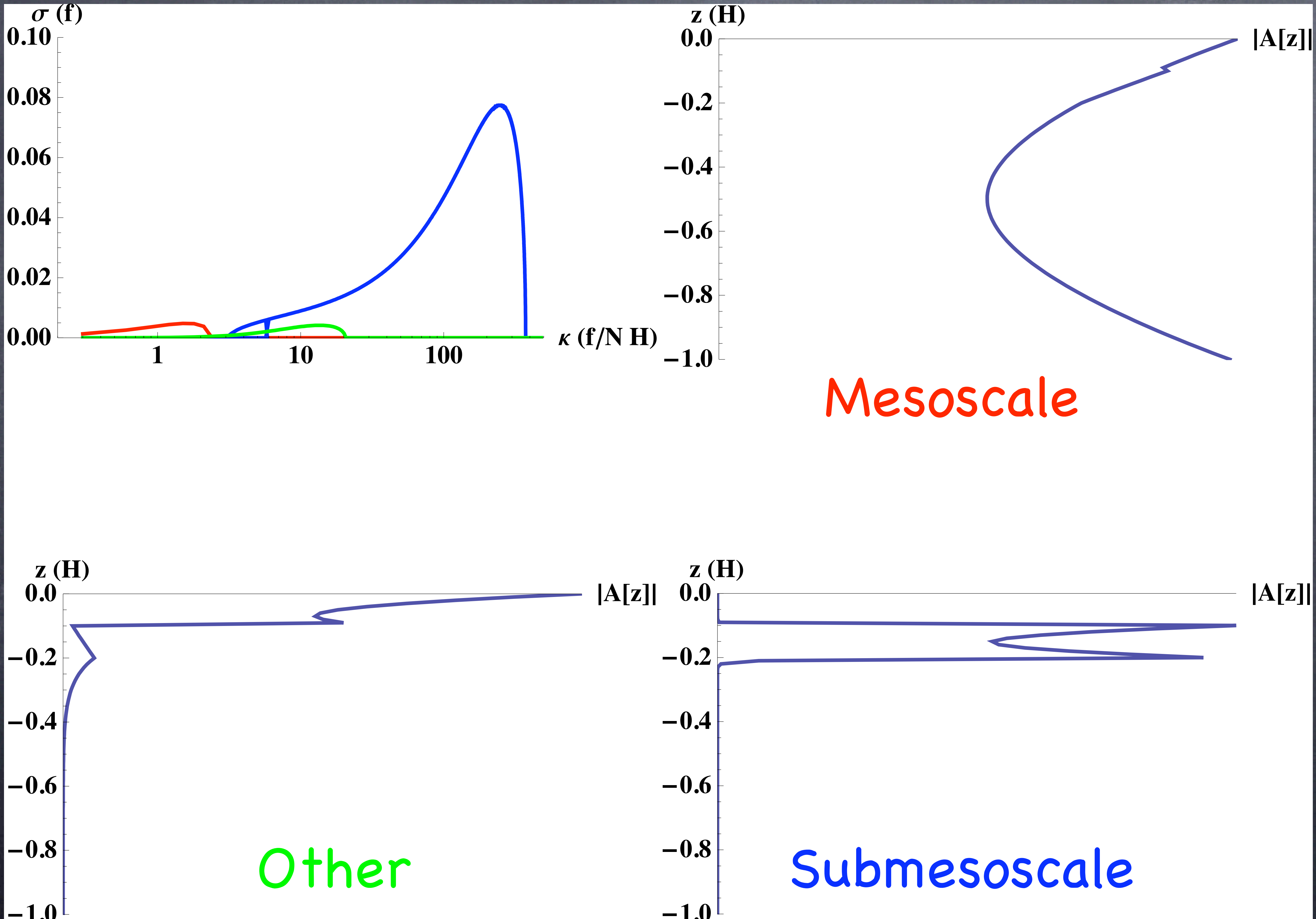
Instability amounts to 6th order poly...

Possibly 3 growing modes and 3 decaying.

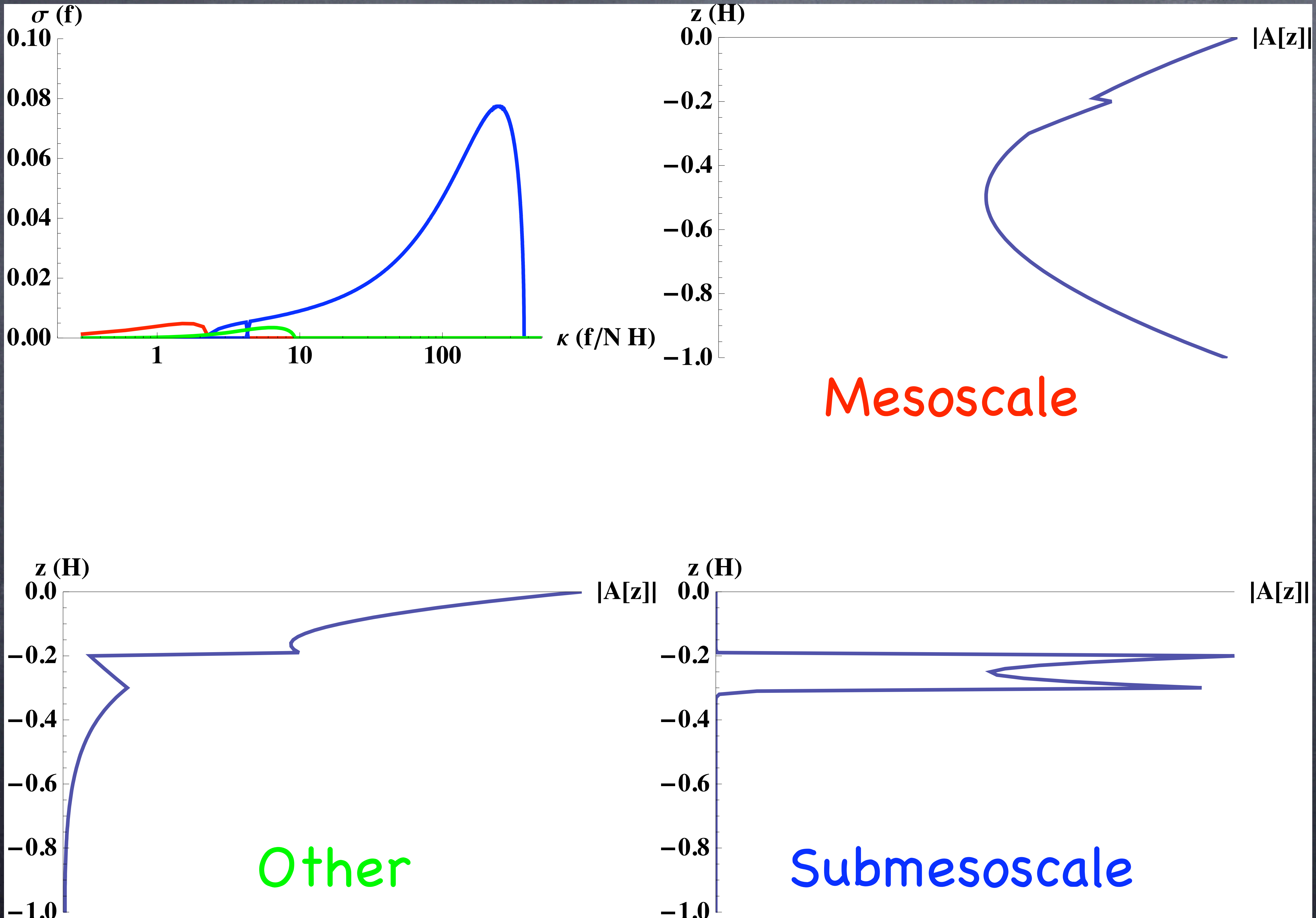
Consider SQG Eady + Cool 0-100m



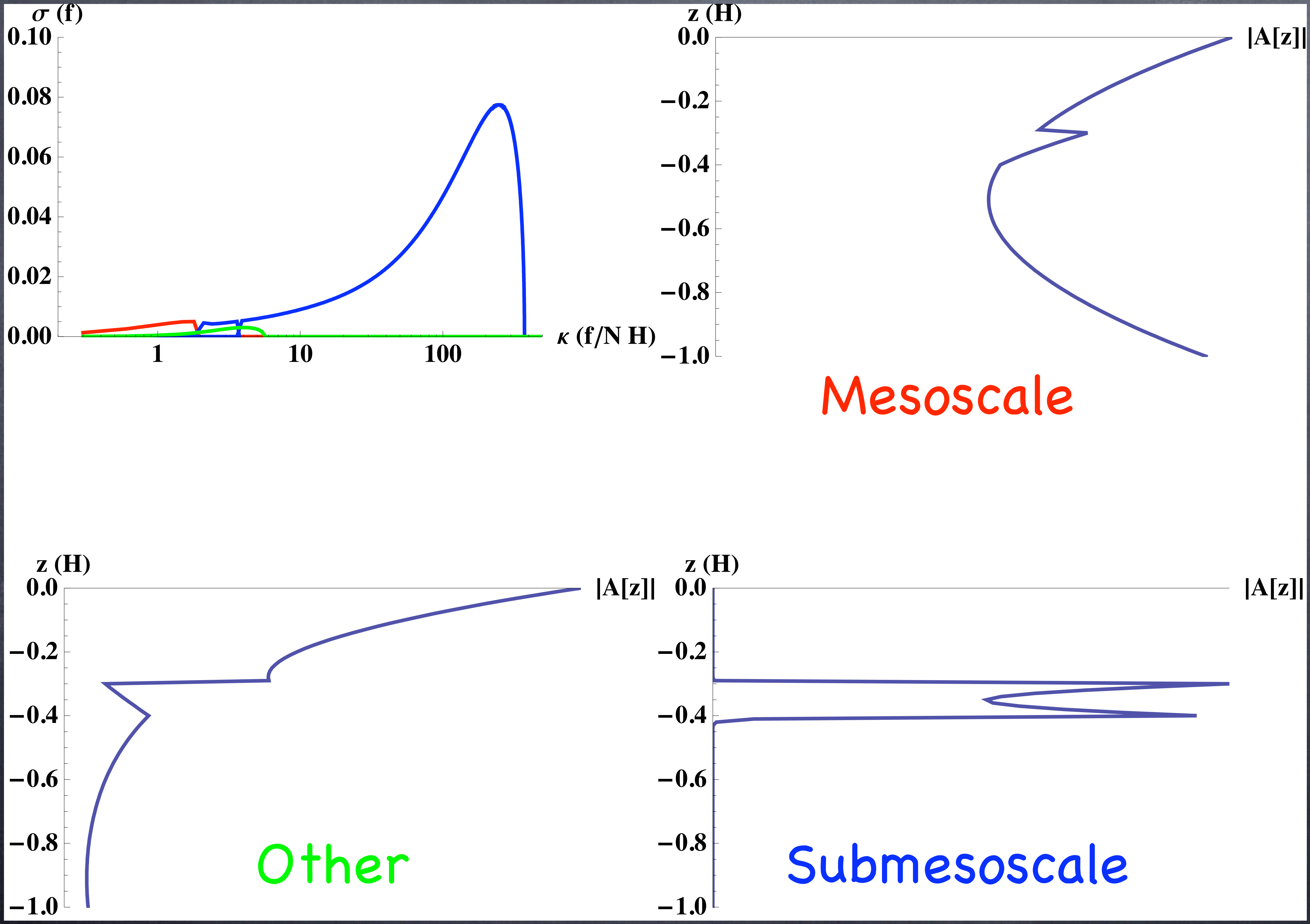
Consider SQG Eady + Cool 100-200m



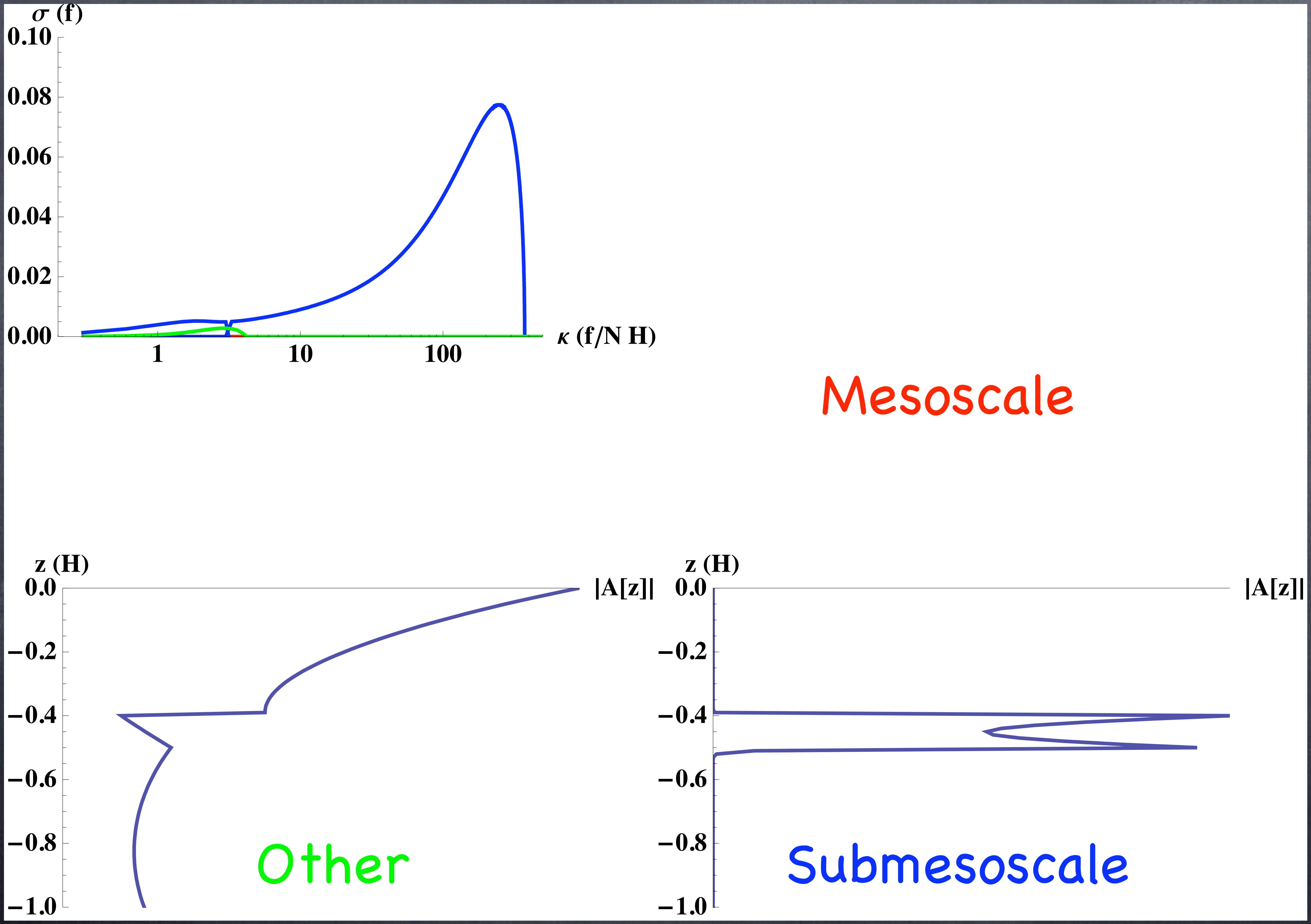
Consider SQG Eady + Cool 200-300m



Consider SQG Eady + Cool 300-400m



Consider SQG Eady + Cool 400-500m



Summary II:

- A parameterization of mixed layer eddy fluxes as an overturning streamfunction is proposed.
- The parameterization reduces model bias in GOLD and POP.
- However, difficulties arise in parameterization of submesoscale features if restratification isolates reduced stratification away from boundaries.
- Preliminary testing/linear instability analysis reveals that extending submesoscale may be relatively easy, but preventing mesoscale double-counting will not.
- 4 Papers so far... fox-kemper.com/research

The Global Parameterization:

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

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

Account for equator by going to subinertial ML approx (Young 94)

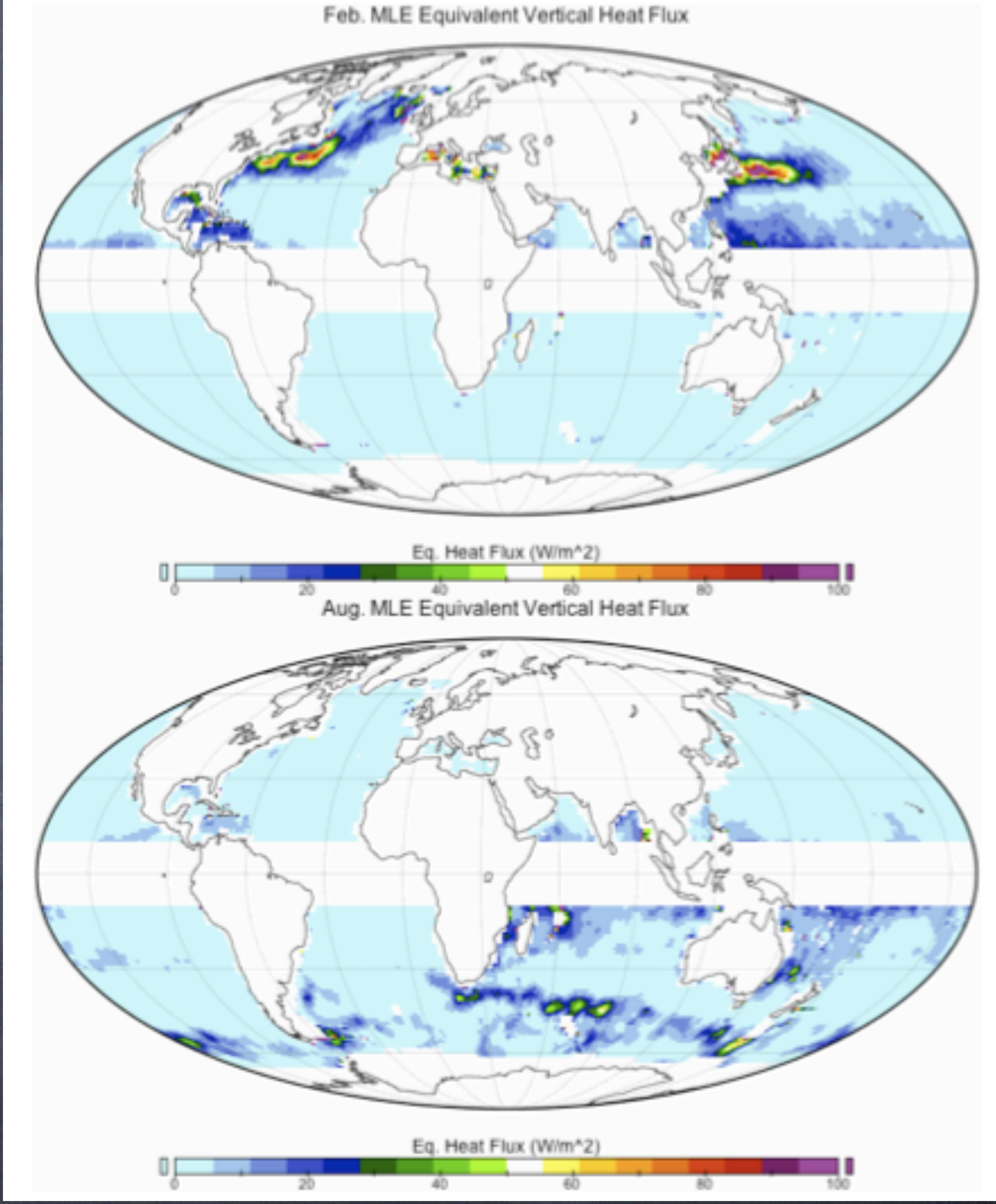
$$\mathbf{\Psi} = \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$

Account for coarse res. by assuming

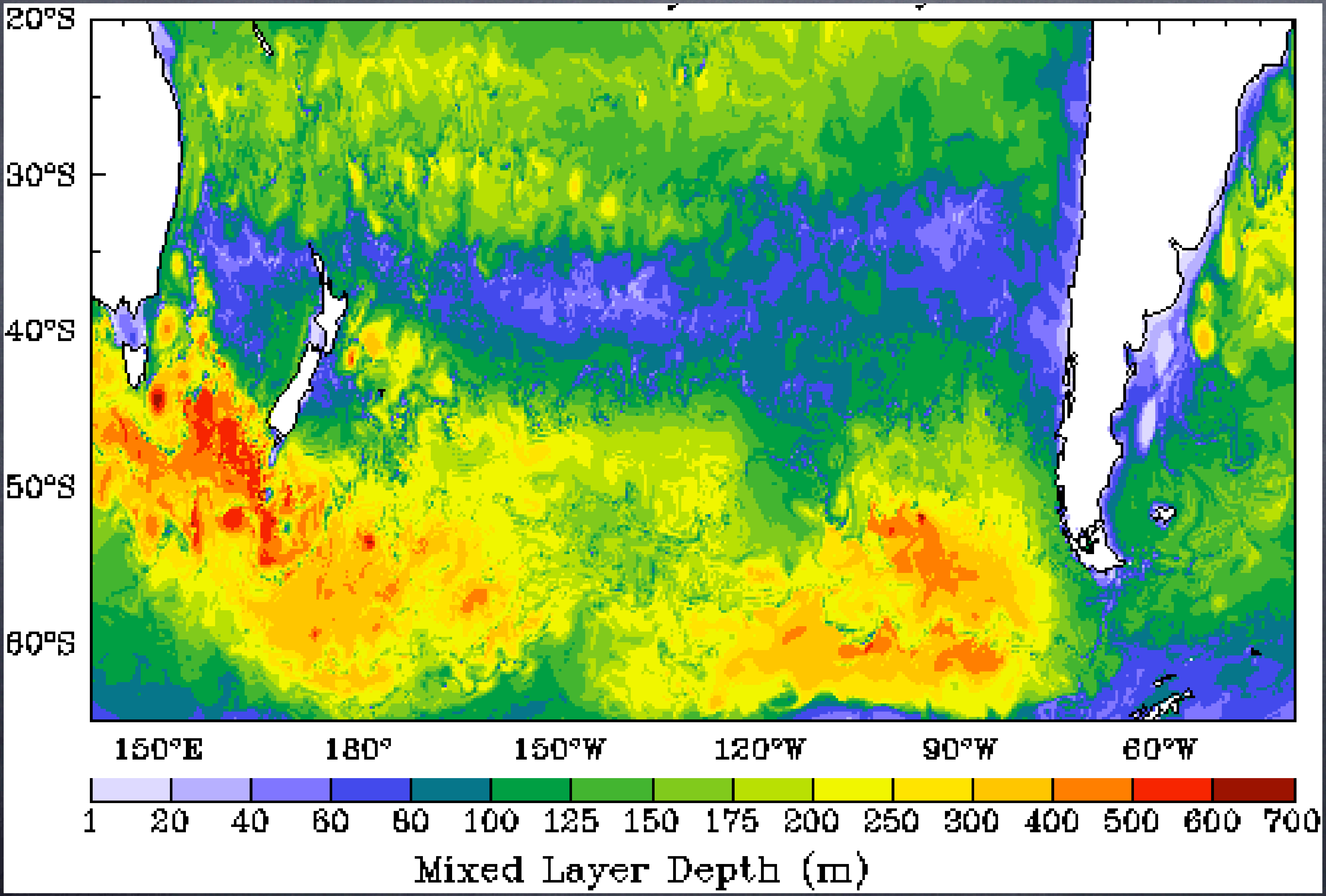
$$E_b(k) \sim k^{-2} \rightarrow \mathbf{\Psi} = \left[\frac{L_f}{\Delta x}\right] \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{\mathbf{z}}$$

Obs. reveal $L_f \sim R_d$

Estimate of Vert. Heat Flux from satellite data agrees



Changes To Mixing Layer Depth in Eddy-Resolving Southern Ocean Model



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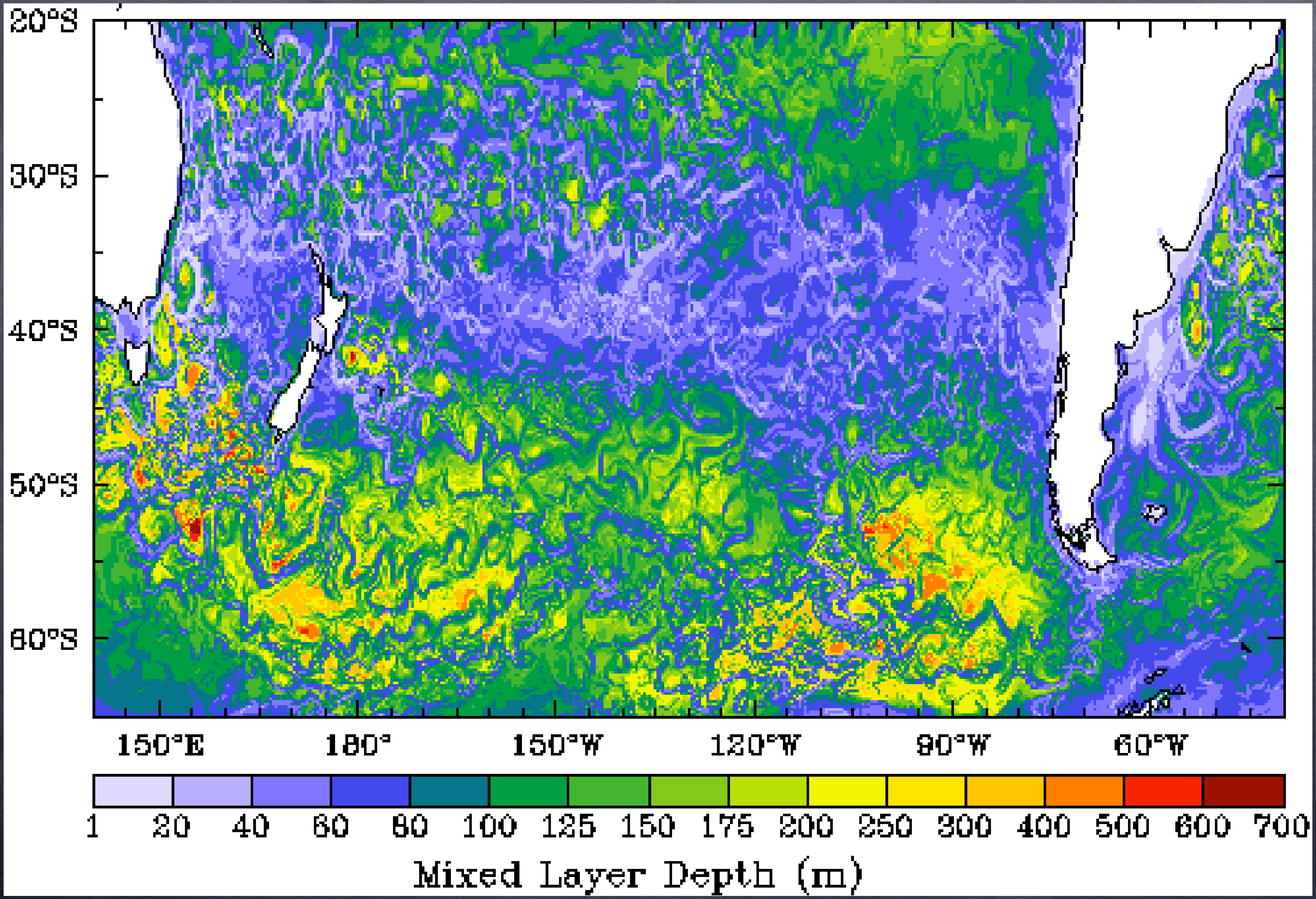
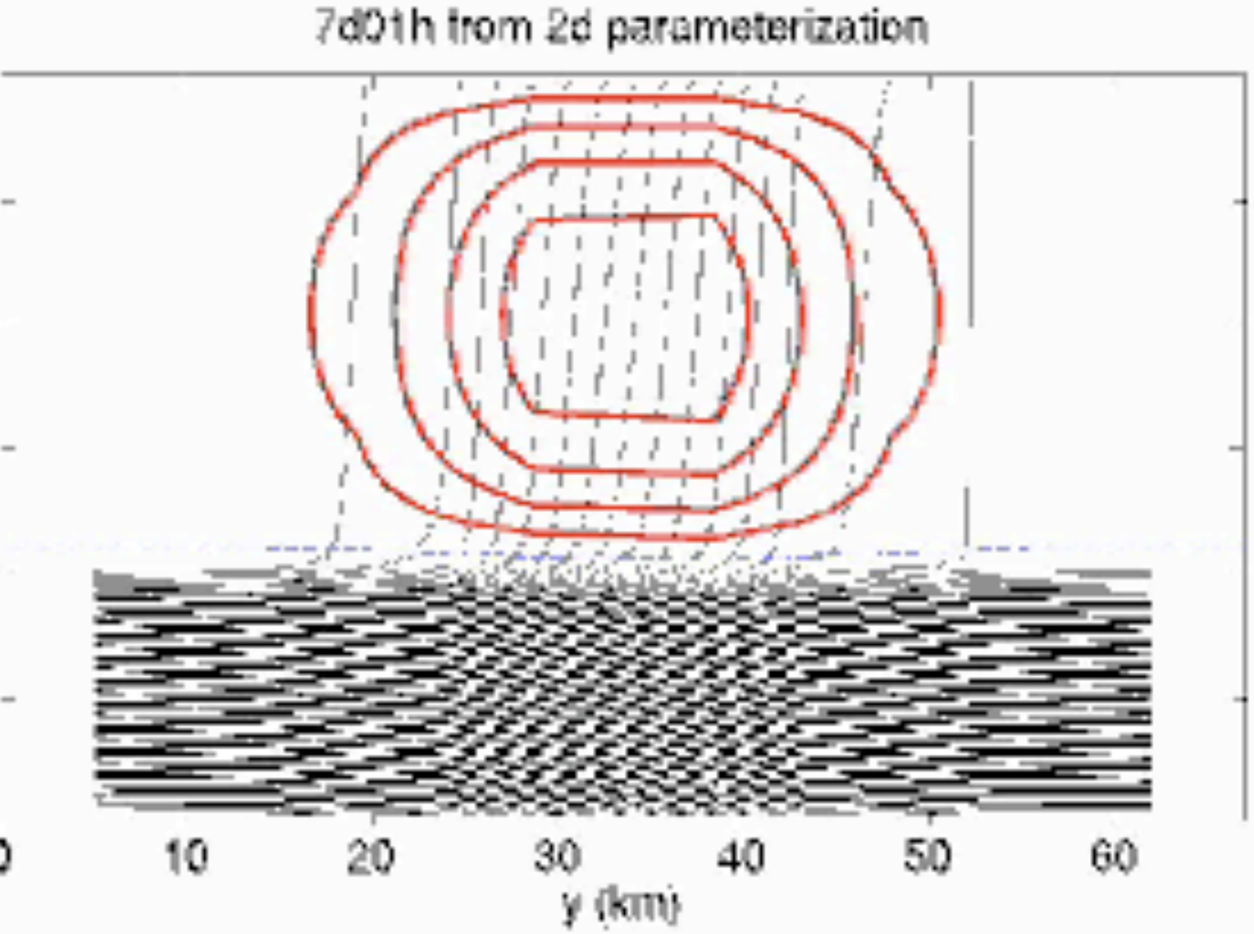
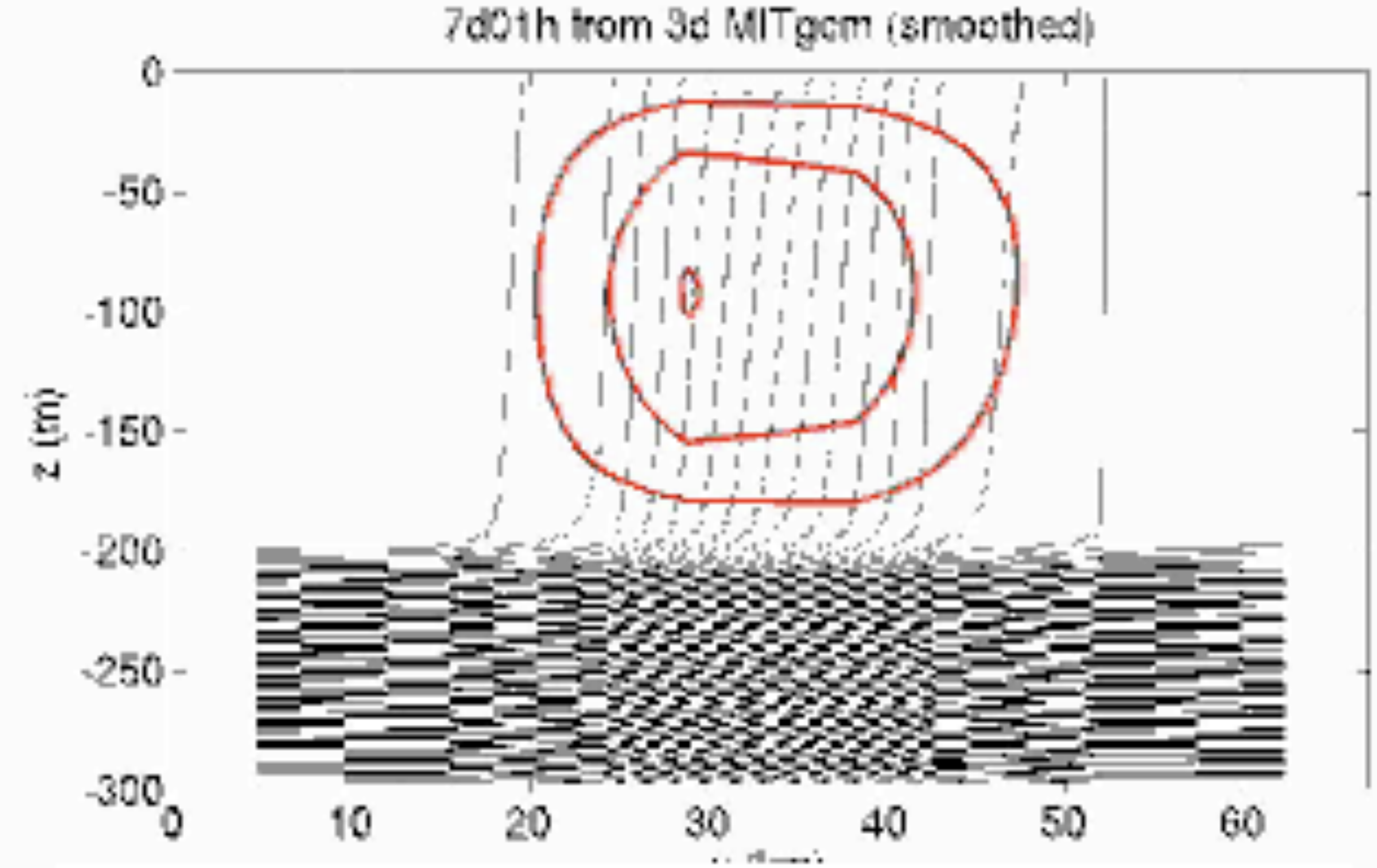


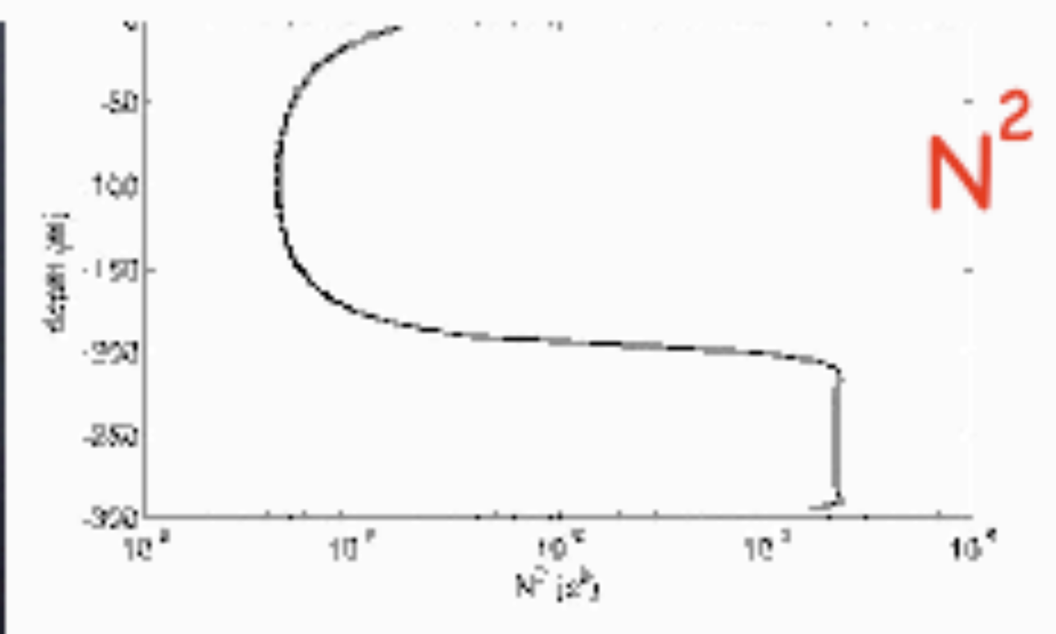
What does it look like?

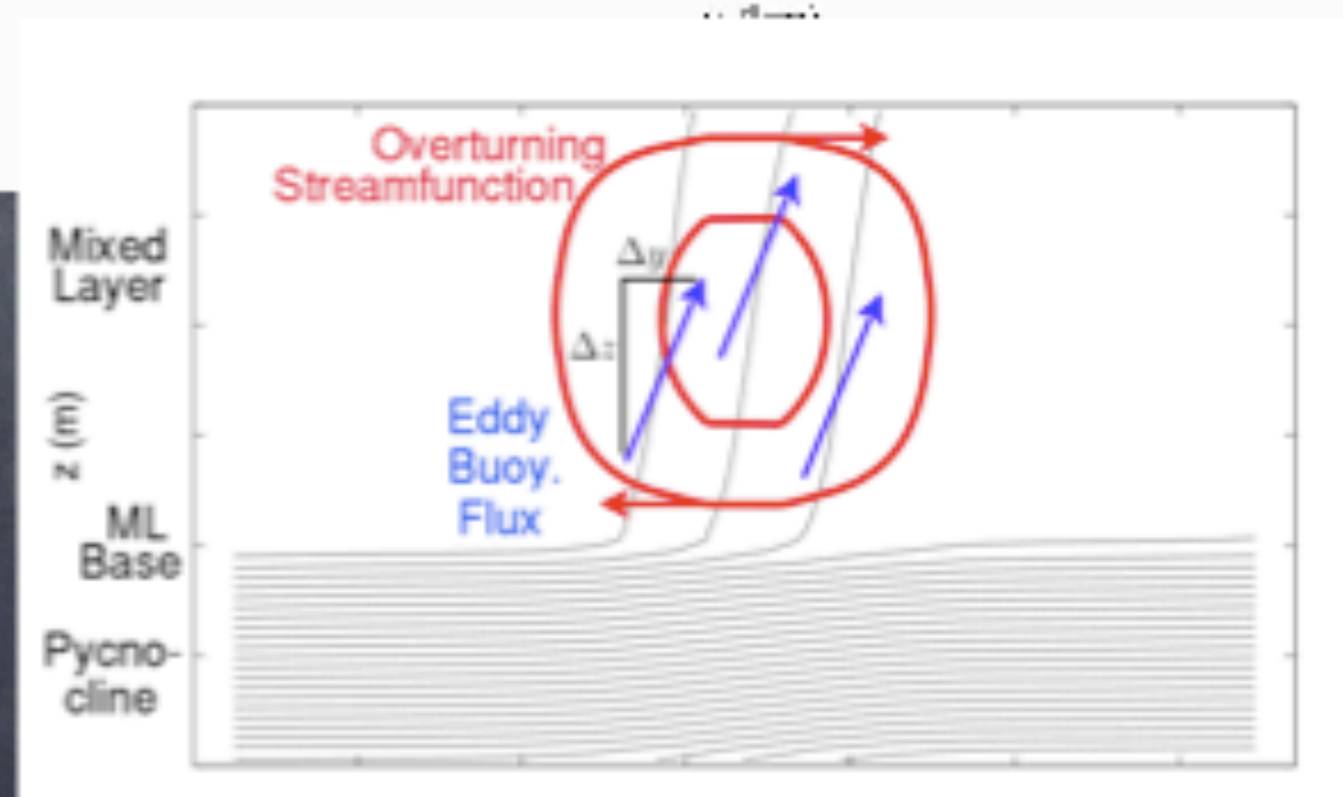
Parameterization (2d, 10km grid)



Submesoscale-Resolving (3d,500m grid)







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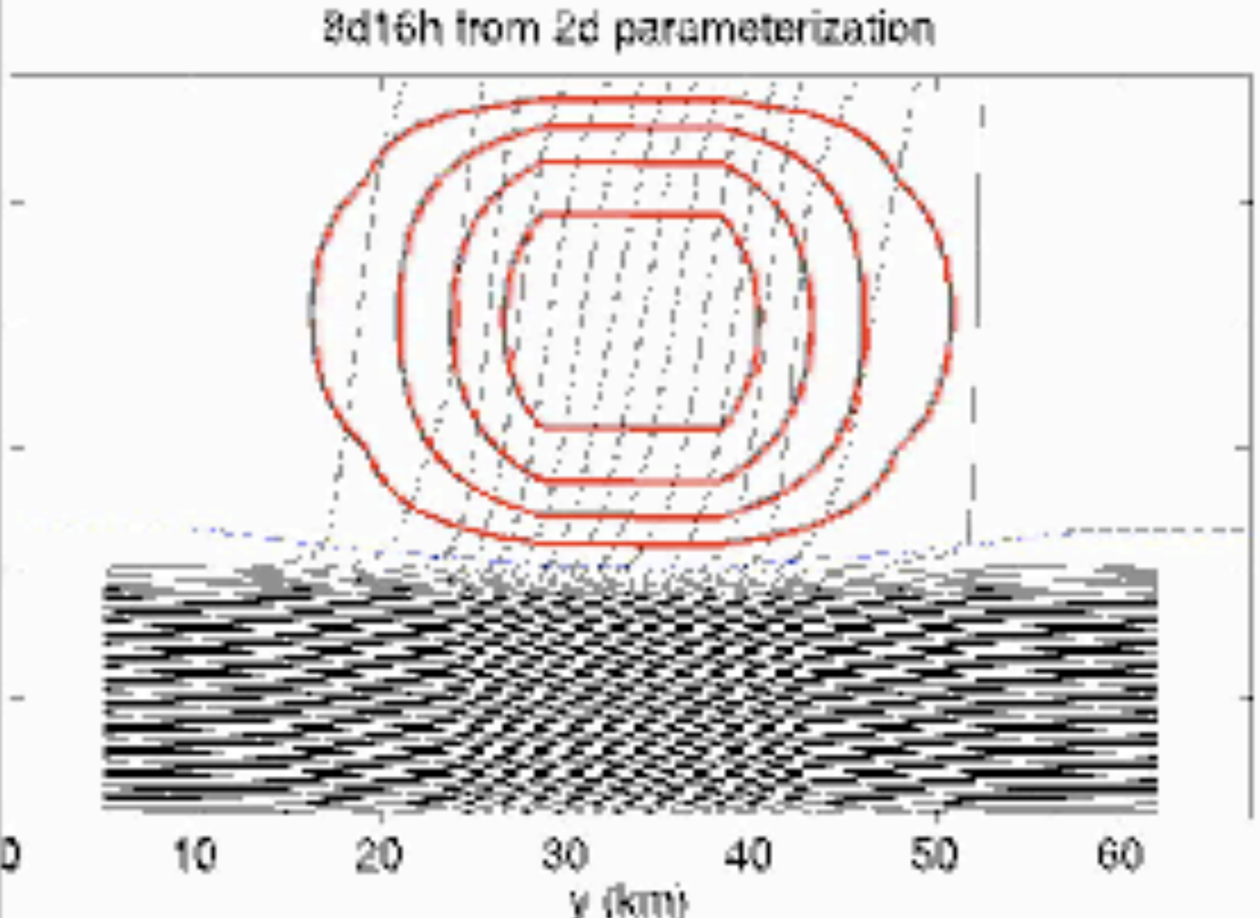

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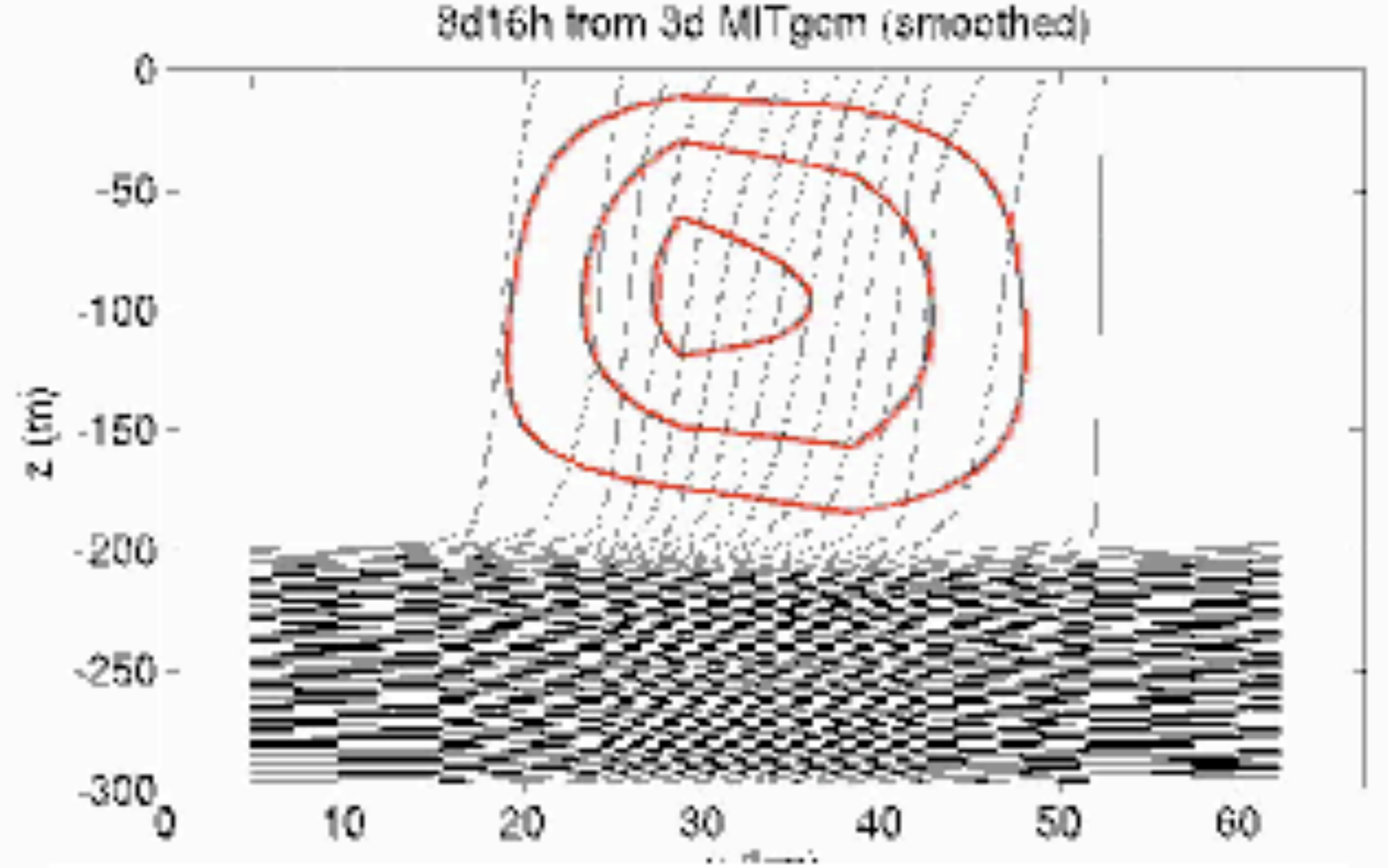
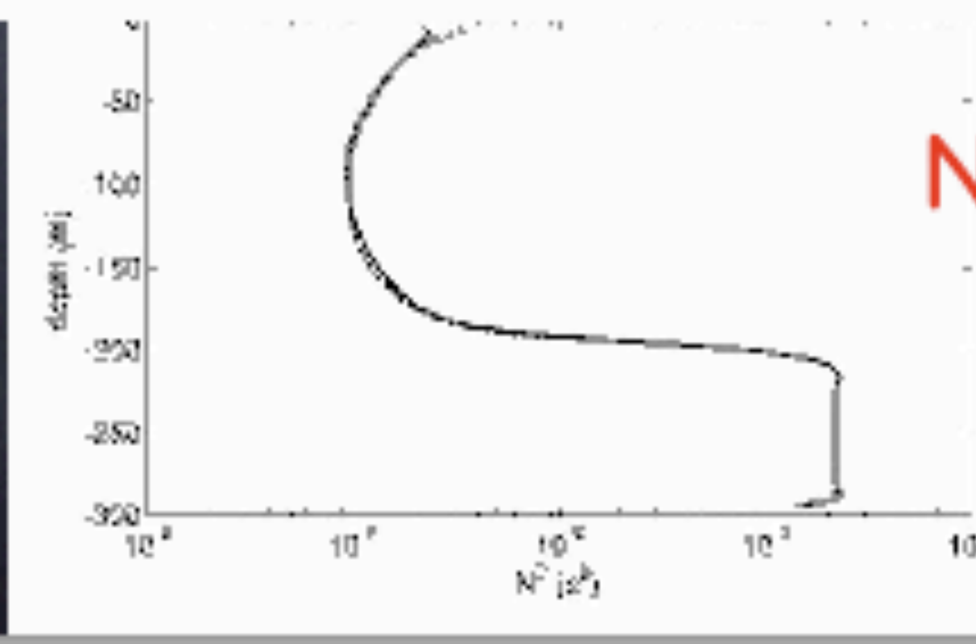
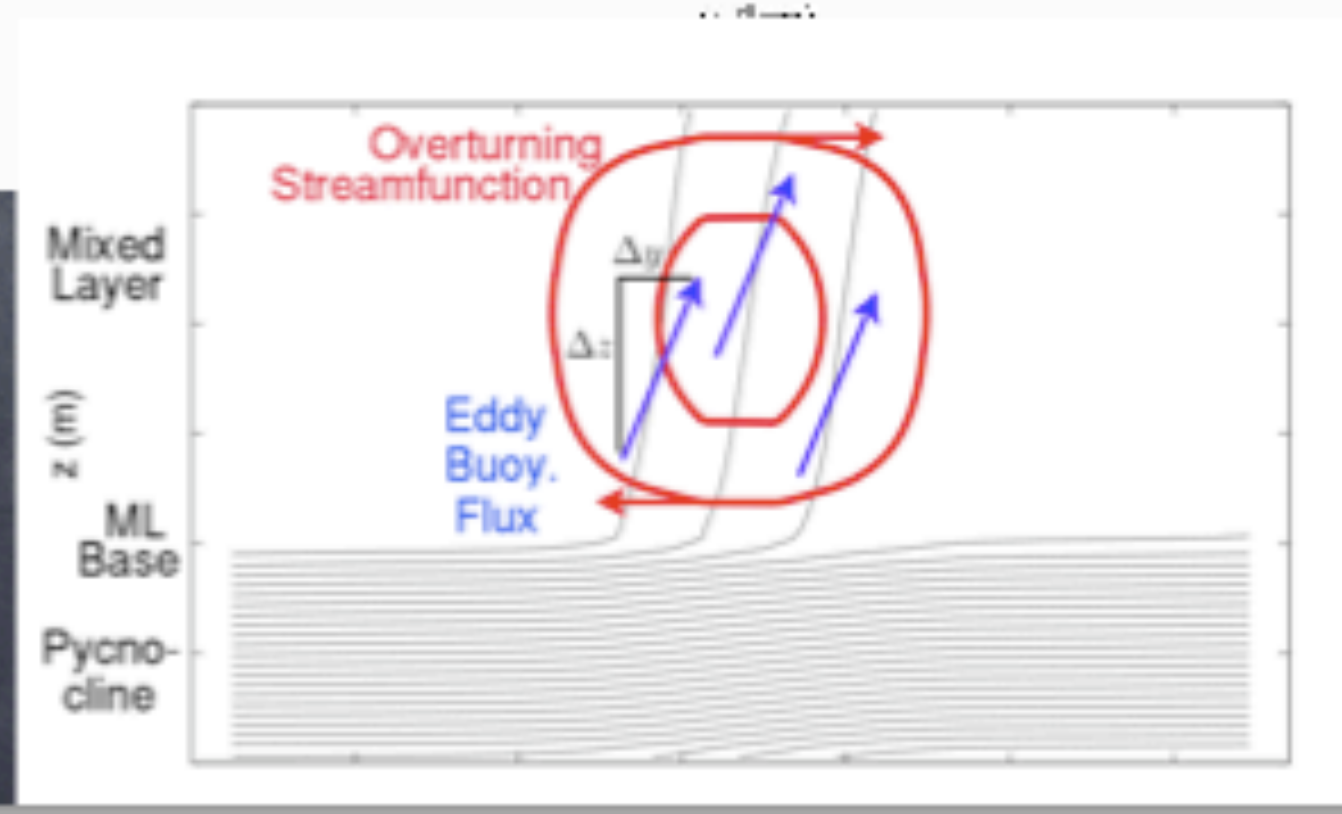




N^2



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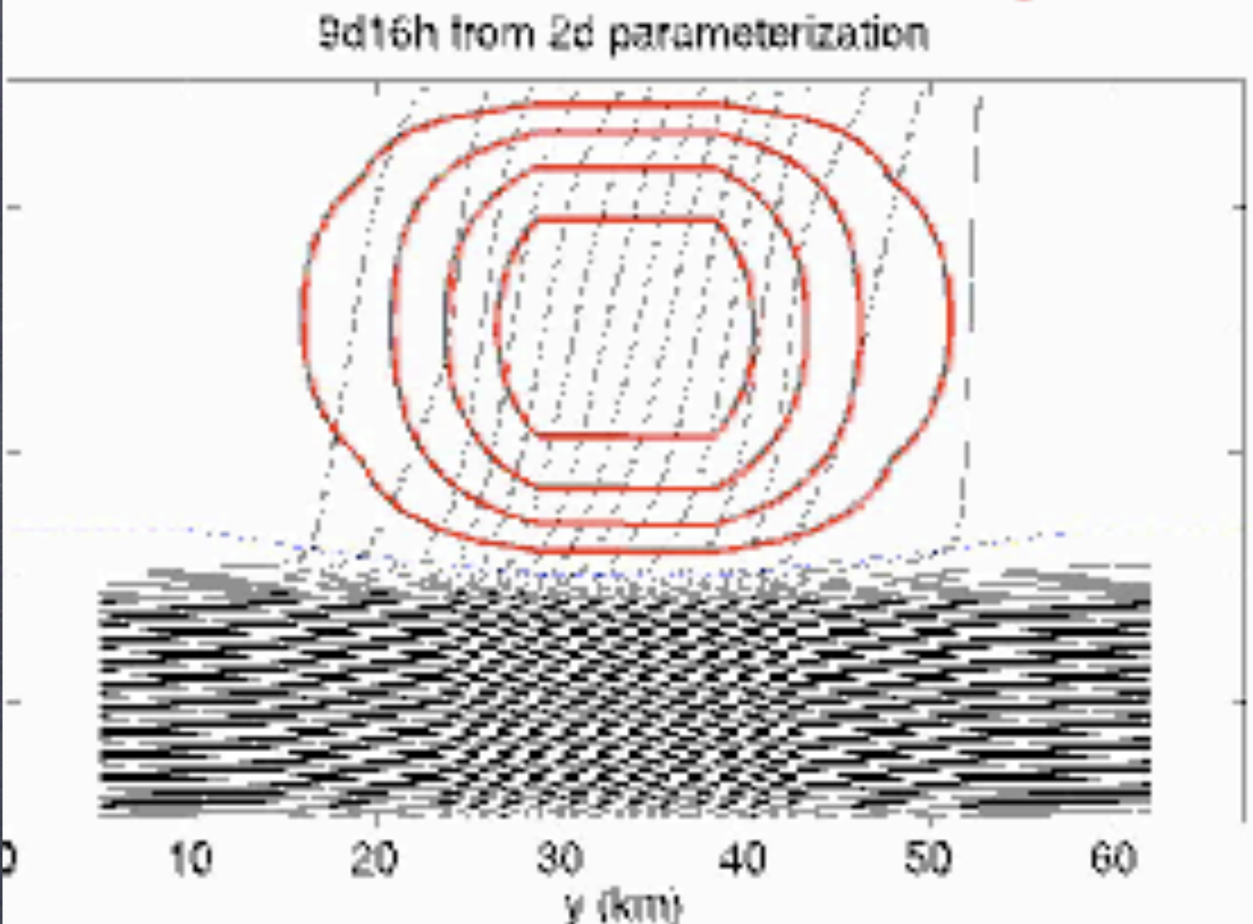

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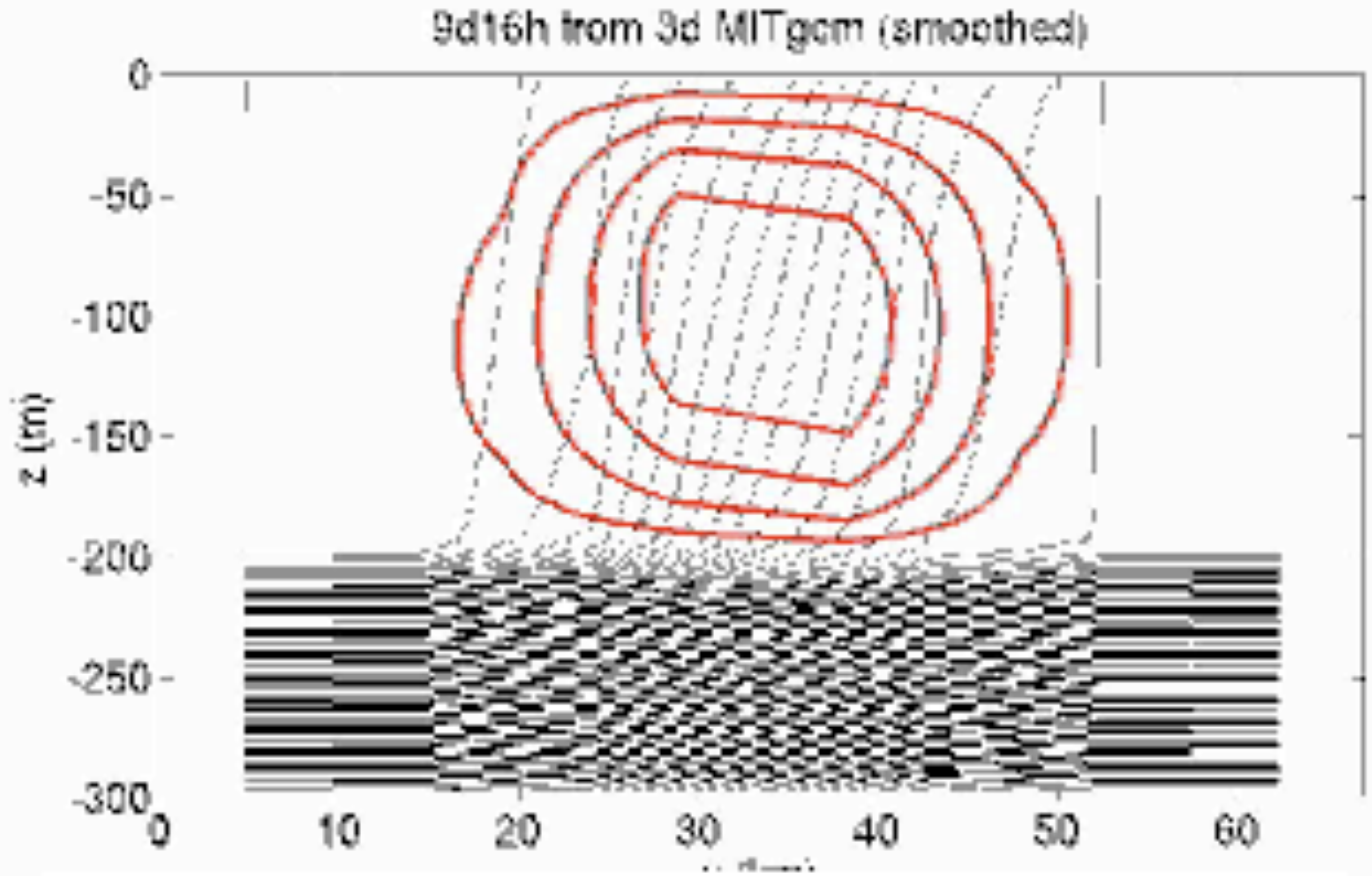

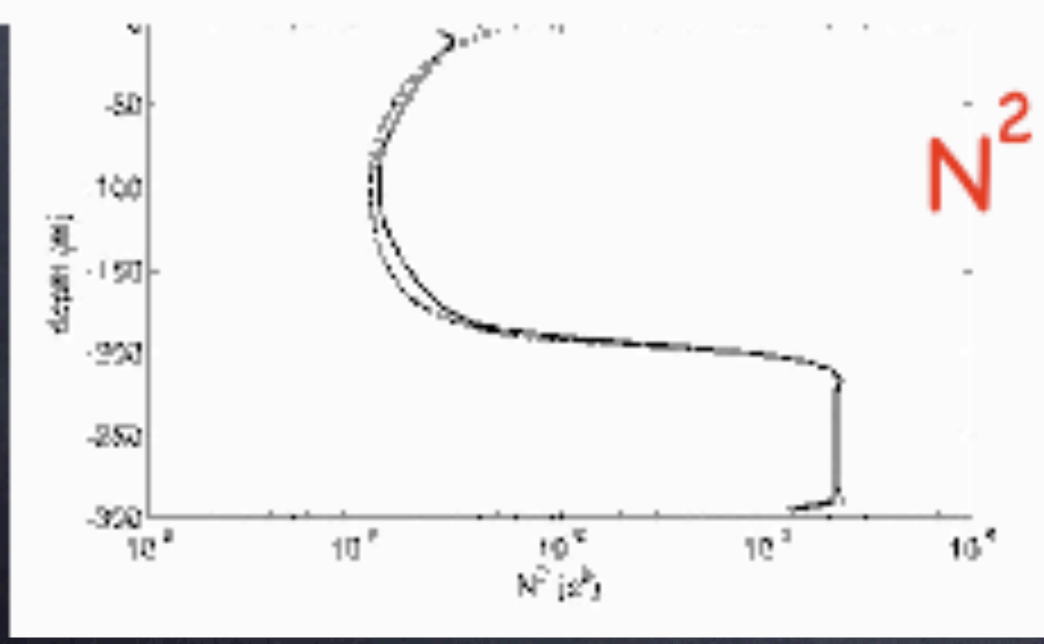

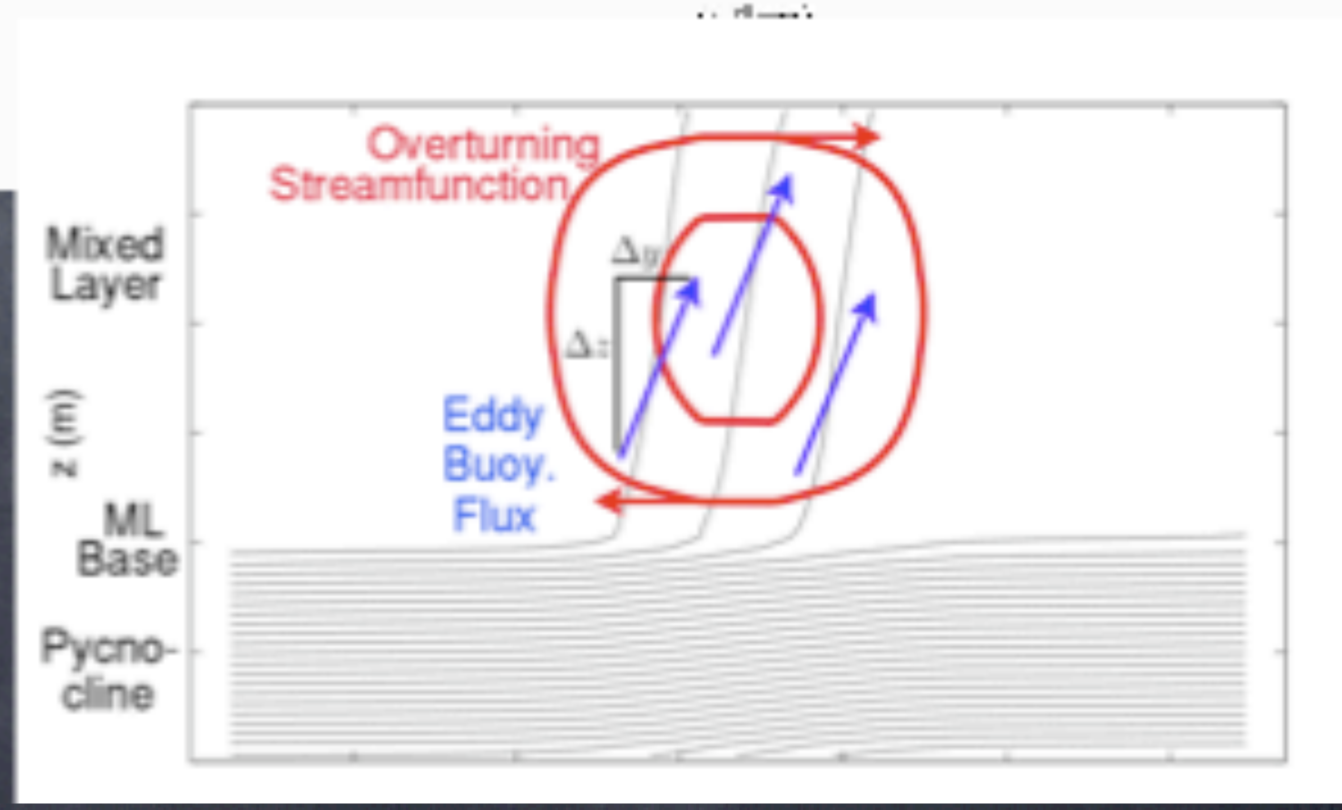

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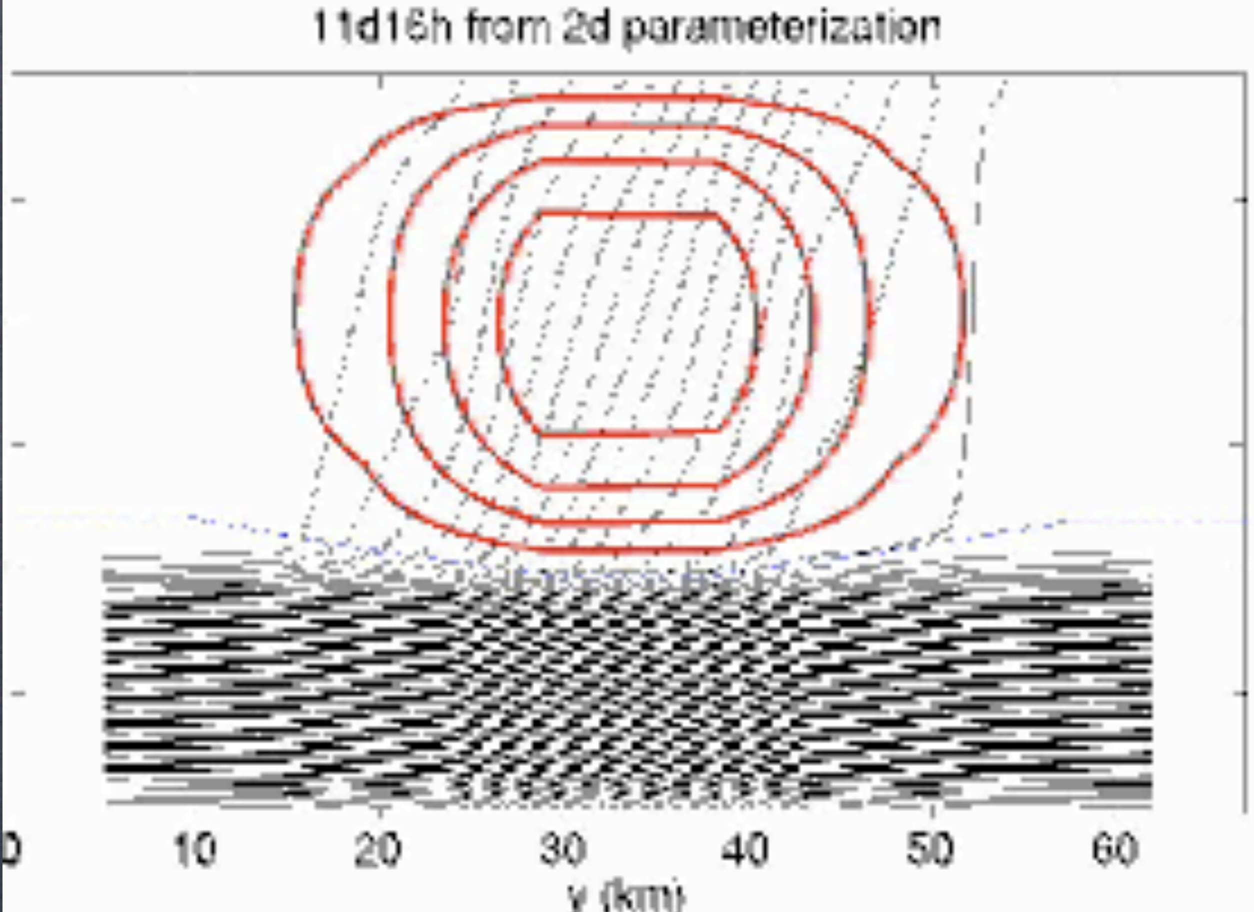

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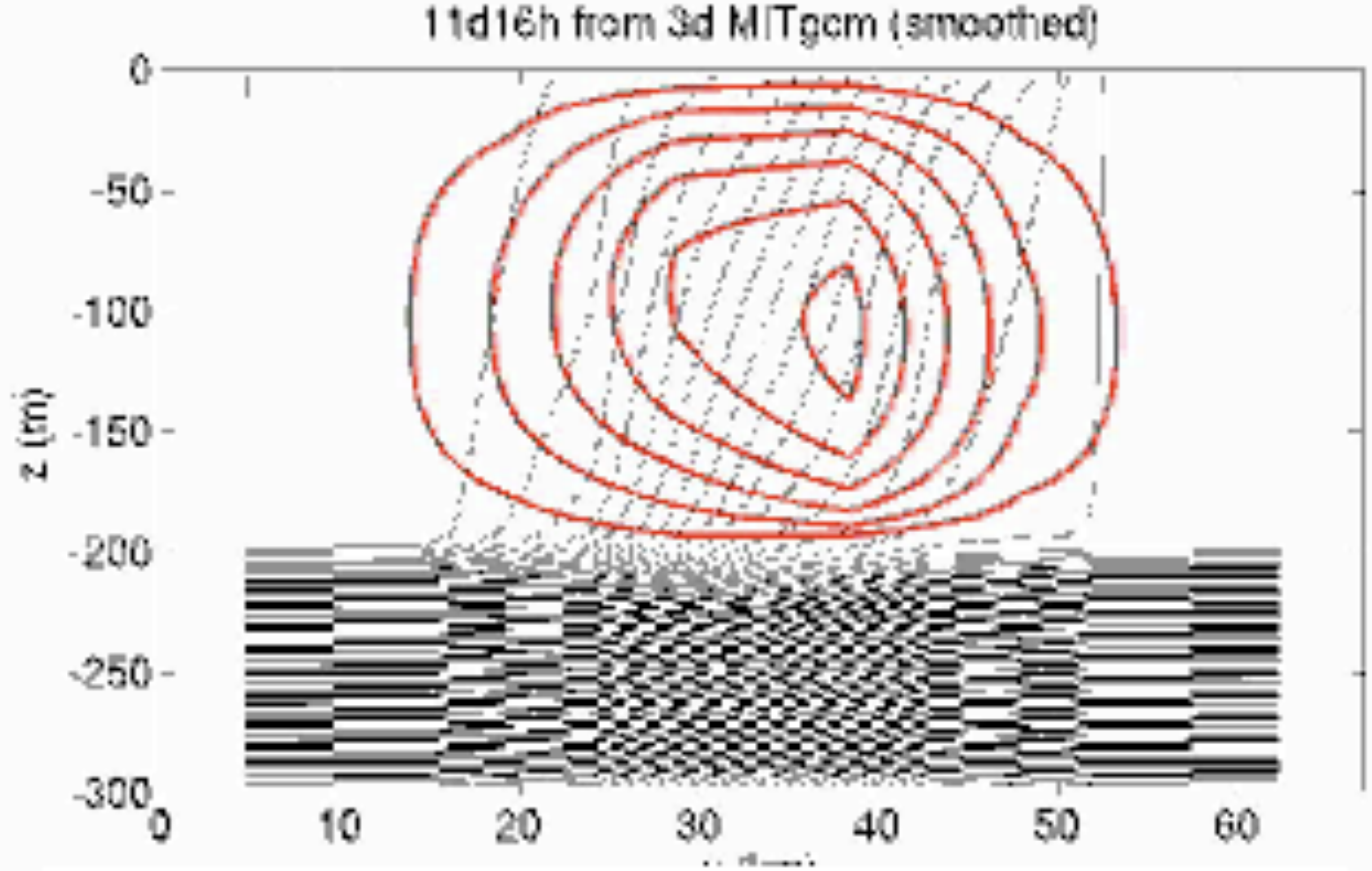

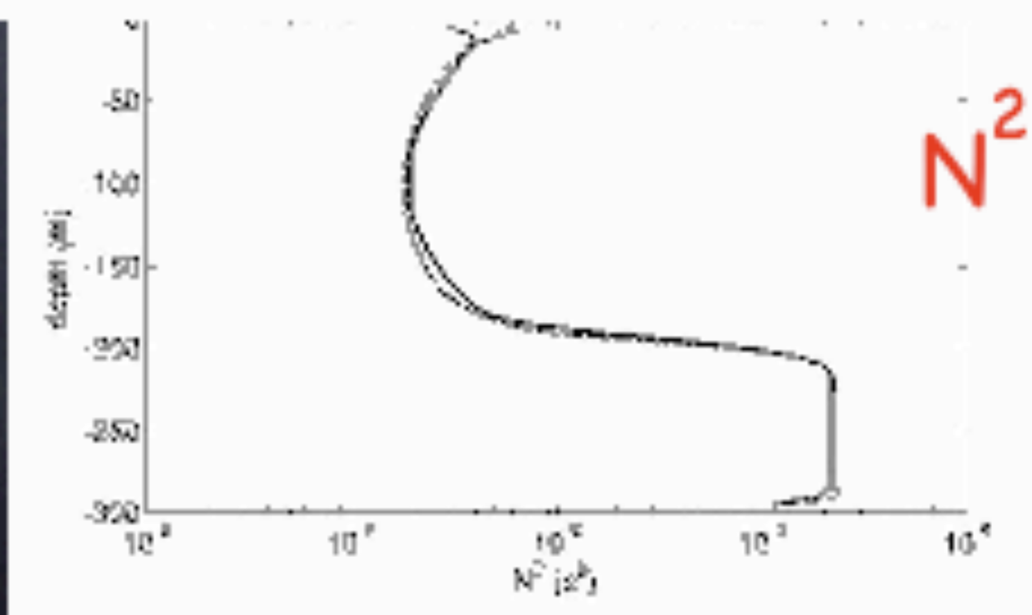

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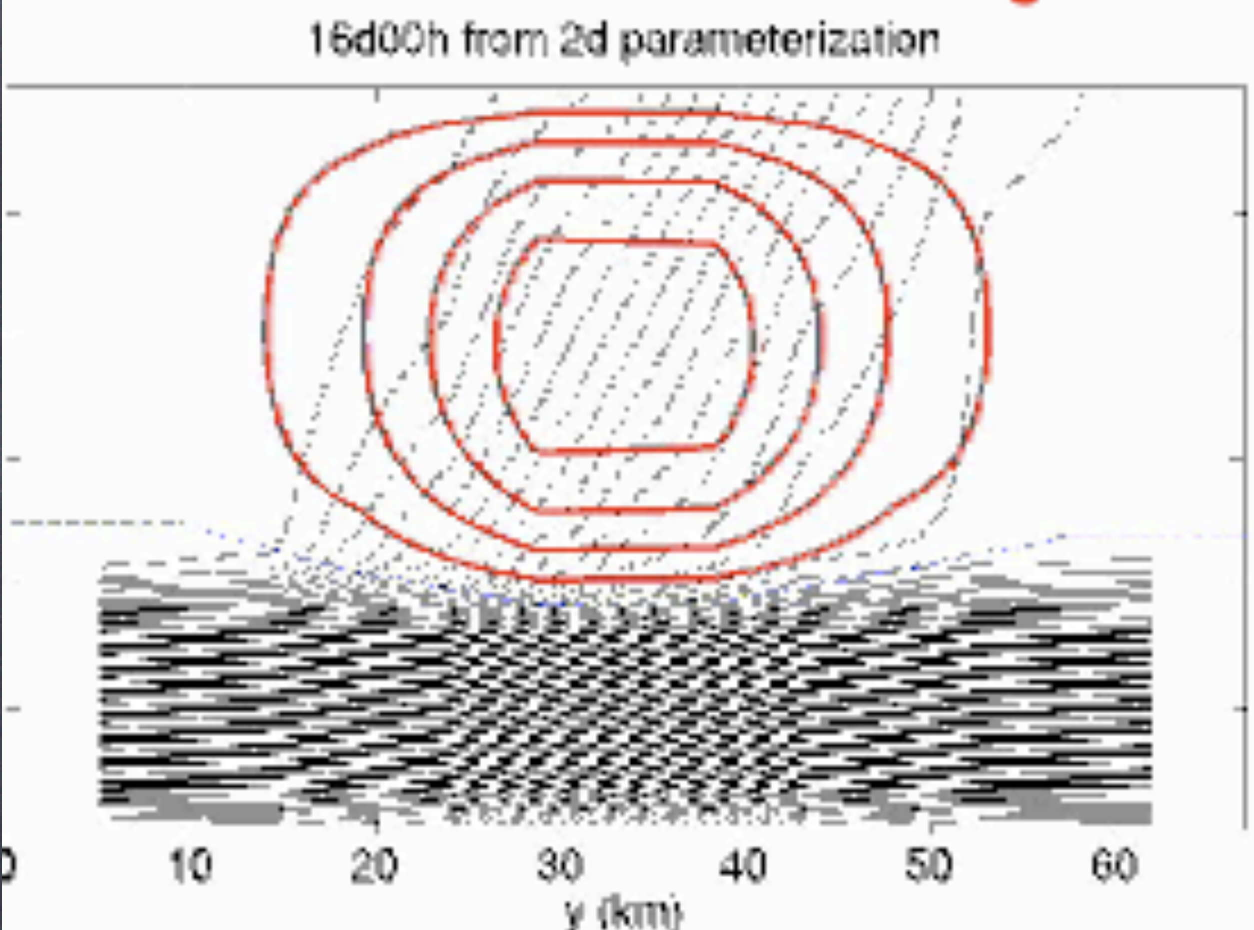

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