Dynamical Influences on Observation Impacts for Ocean Data Assimilation

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Outline

Balance and partitioning of energy at different scales
Some pontification
A little speculation
A sprinkle of some hard results for good measure and credibi

Observation Impacts

The "analysis equation":

$$\boldsymbol{x}_a = \boldsymbol{x_b} + \boldsymbol{B}\,\boldsymbol{H}^T \left(\boldsymbol{H}\,\boldsymbol{B}\,\boldsymbol{H}^T + \boldsymbol{R} \right)^{-1} \left(\boldsymbol{y_o} - H\left(\boldsymbol{x_b} \right) \right)$$

The Kalman gain matrix:

$$\boldsymbol{K} = \boldsymbol{B}\,\boldsymbol{H}^T \left(\boldsymbol{H}\boldsymbol{B}\,\boldsymbol{H}^T + \boldsymbol{R} \right)^{-1}$$

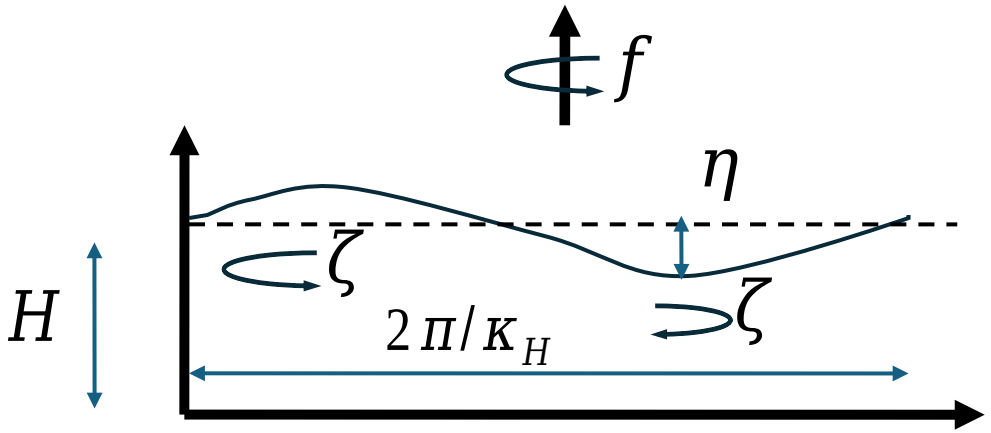
common approach to quantifying observation impact involves

In 4D-Var and ensemble-based approaches contains the model dynamics.

The impact of the obs will depend the underlying dynamics, even if *B* and *R* are known perfectly.

Setting aside the practical challenges and issues of DA let's revisit how the underlying dynamics of the ocean circulation

Energy Partitioning



Based on Gill (1982)

Vorticity conservation:

PV and energy conserved

Energy partitioning ratio:

where is the horizontal wave number and Rossby radius of deformation (Burger number,)

For scales Rossby radius, so stretching relative vorticity mass field dominates

For scales Rossby radius, so relative vorticity stretching velocity field dominates

For scales ~ Rossby radius, so (energy is equipartioned)

Can generalize to a continuously stratified ocean by summing the vertical modes

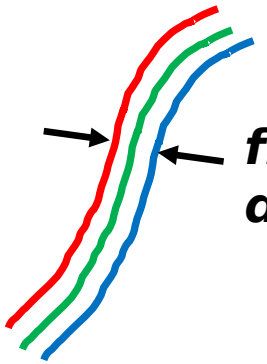
Geostrophic Adjustment

Temperton (1973) building on Washington (1964) offers a more general DA perspective:

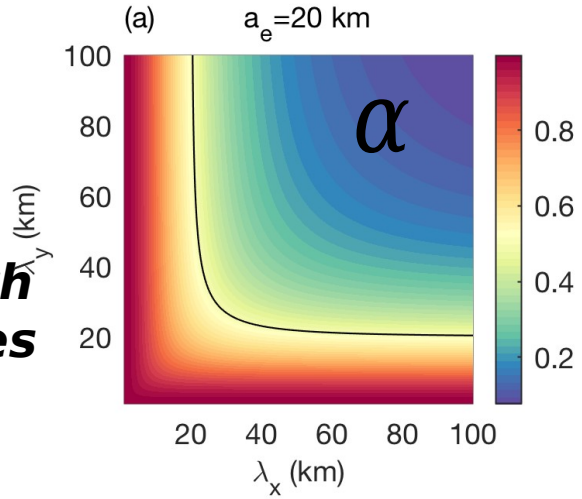
$$\left(\begin{array}{c}\textbf{final}\\ \textbf{velocity field}\end{array}\right) = \left(\begin{array}{c}\textbf{initial}\\ \textbf{velocity field}\end{array}\right) + (1-\alpha)\left(\begin{array}{c}\textbf{initial}\\ \textbf{mass field}\end{array}\right)$$

$$\alpha = \kappa_H^2 a^2 / \left(\kappa_H^2 a^2 + 1\right)$$

For scales Rossby radius, , velocity adjusts to mass field
For scales Rossby radius, , mass field adjusts to velocity field



front width determines



$$\kappa_H^2 = k^2 + l^2 = \left(2\pi/\lambda_x\right)^2 + \left(2\pi/\lambda_y\right)^2$$

The smallest scale determines !

The Importance of Balance

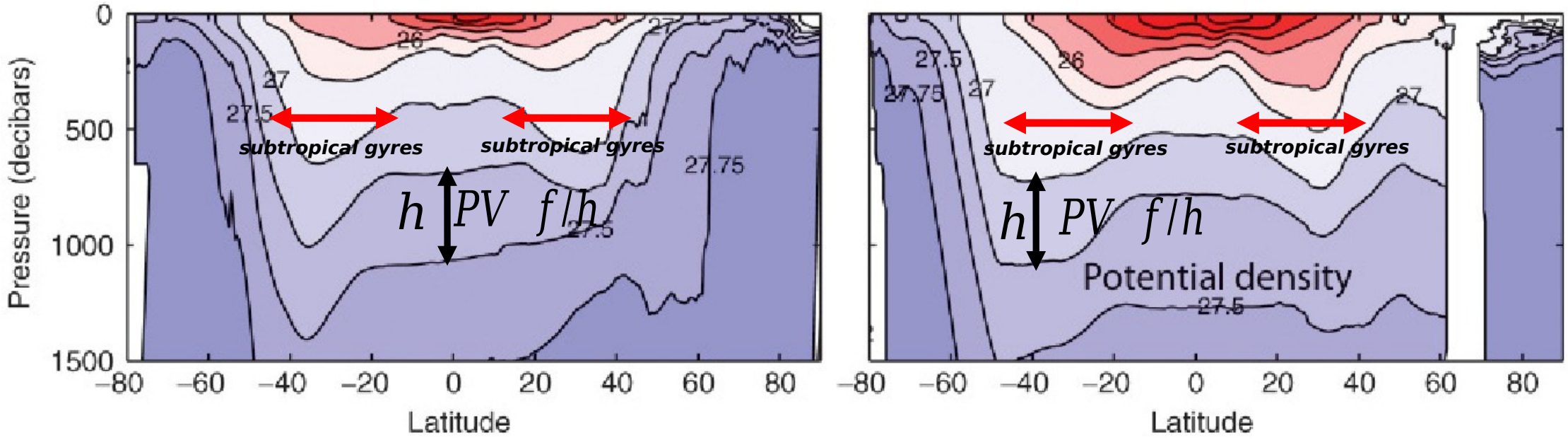
- The Rossby number implies that rotation dominates and the flow is quasigeostrophic.
- Quasigeostrophy provides a diagnostic relation between the mass and velocity field.
- Thus, the extent to which is small (or smallish) is very handy for DA.
- The nature of the balance is important and the question then becomes one of energy partitioning (*i.e.* where is most of the information?)

Let's think about the large scales first…

Zonal average ocean density $Ro \;\; U/fL \ll 1, Fr \;\; U/NH \ll 1$ ¿¿¿

(*rotation important*)(*stratification important*)

Atlantic Ocean ***Pacific Ocean***



Stratification controls:

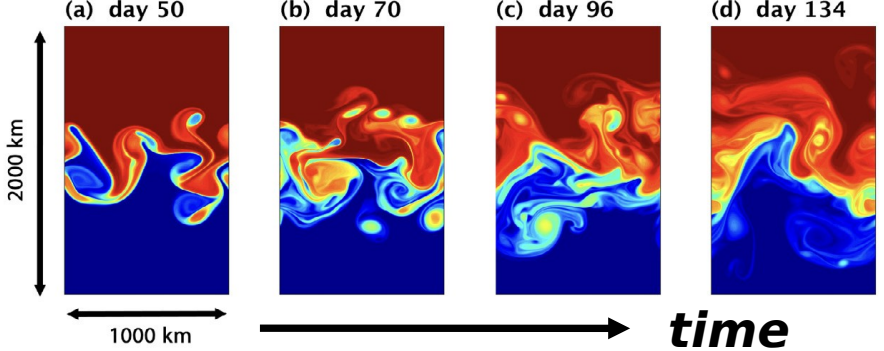
- **Modal structure**
- **Thermal wind and vertical shear**
- **Ventilation, subduction and thermocline structure**

(LPS)

Mass field (T & S) observations provide critical information, and velocity will adjust accordingly.

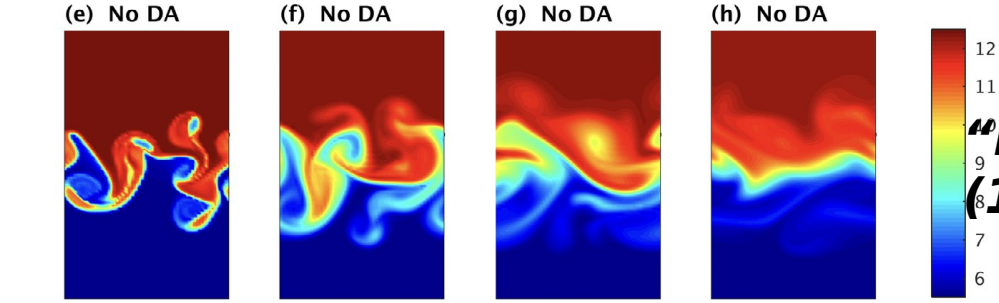
For steady state surface density (SST+SSS) determines full 3D density field solution of nonlinear PV equa

What about intermediate scales..

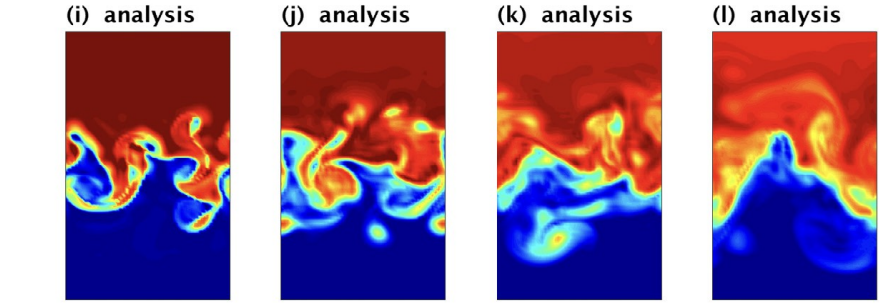


"Nature run"
(2km resolution)

$f < 0$

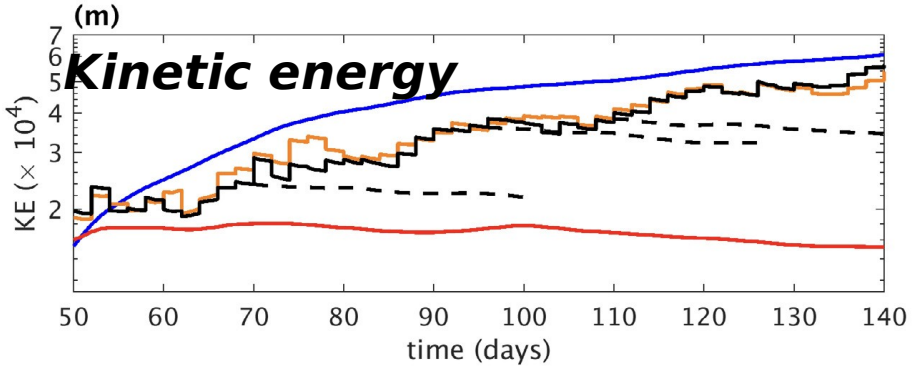


"Forecast model"
(10km resolution)



OSSE

"Forecast model"
(10km resolution)



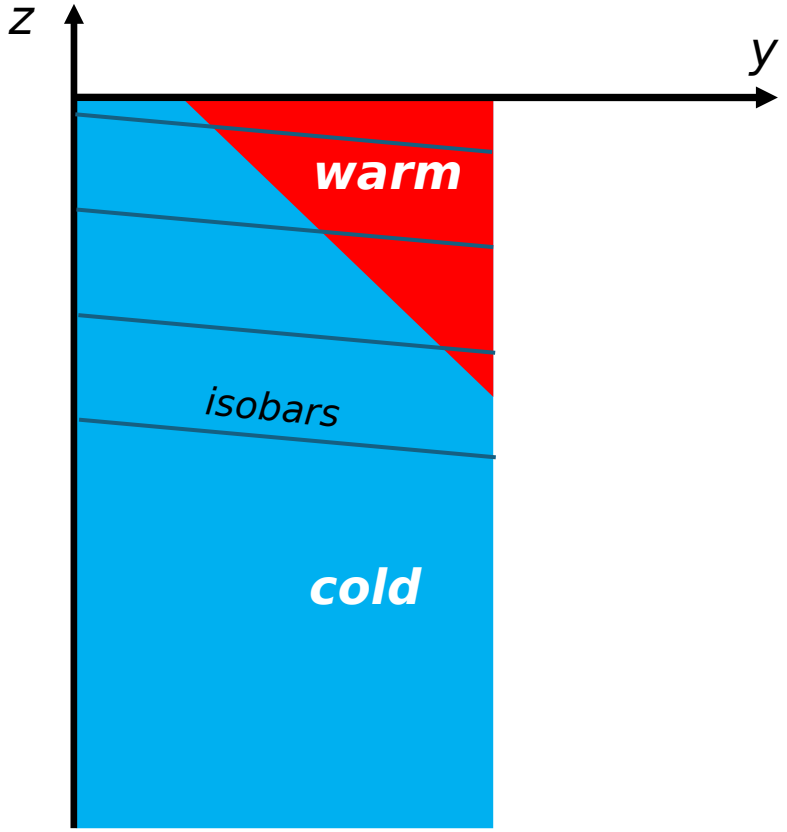
nature run

no DA

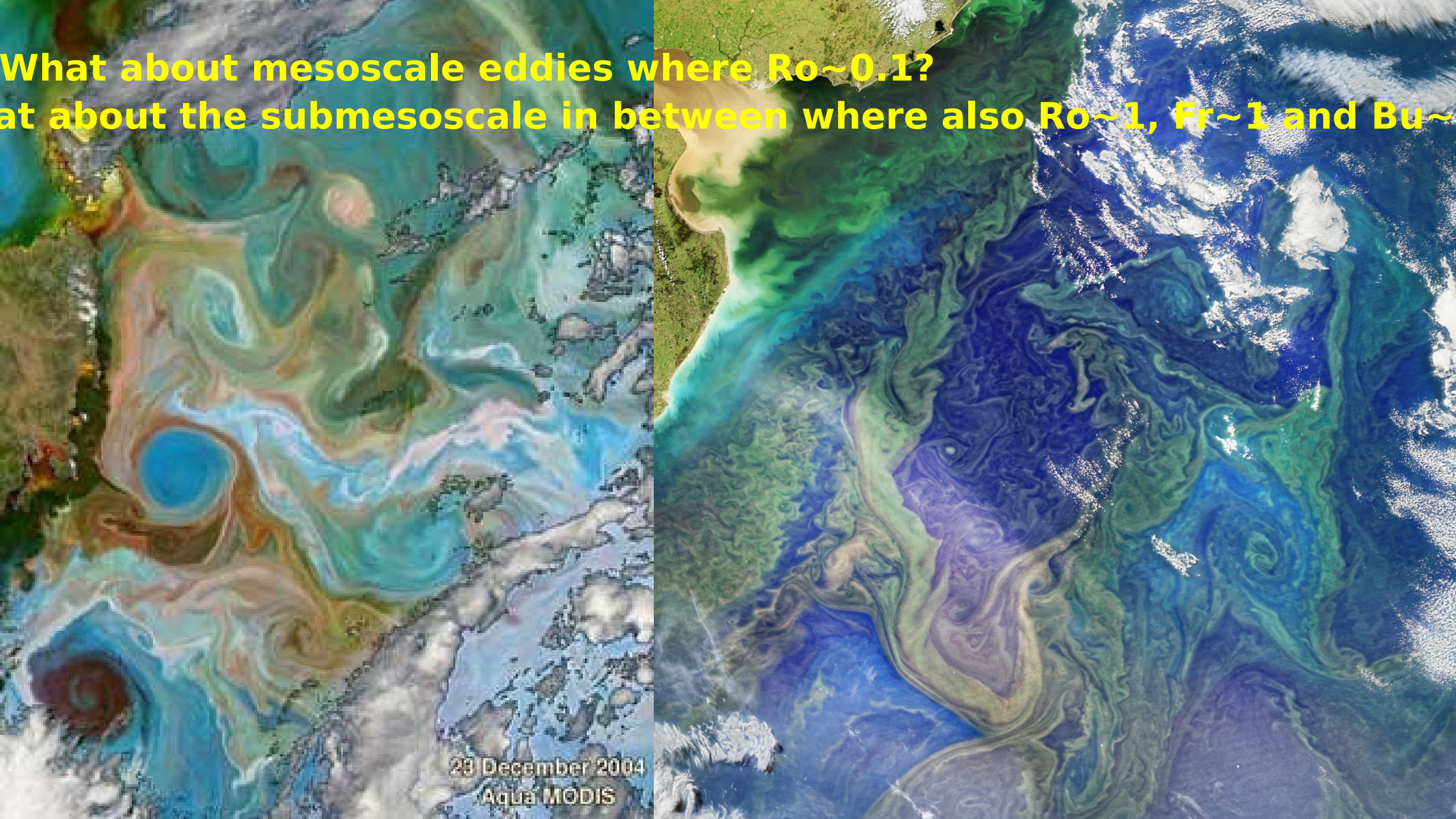
DA (T obs)

Baroclinic instability:

arguably the major source of mesoscale eddies

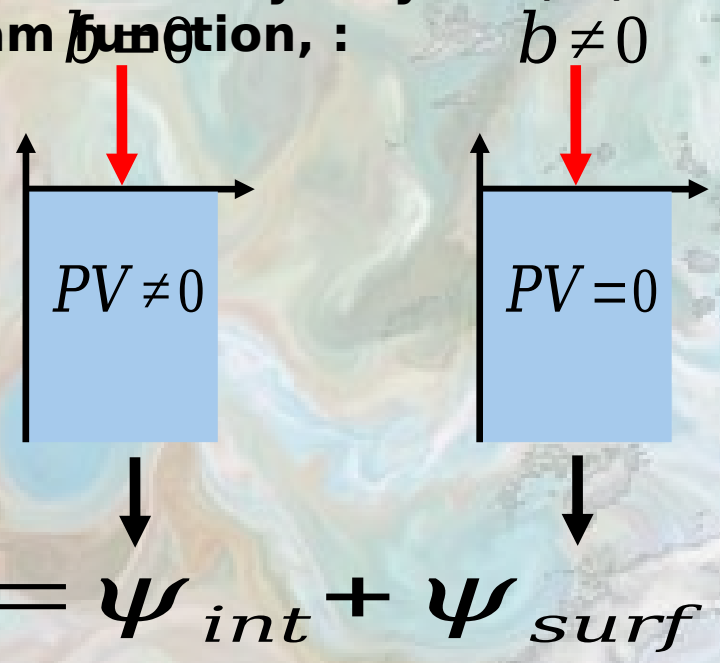


Assimilation of mass field obs continually props up the isopycnals and fuels baroclinic


What about mesoscale eddies where Ro~0.1?
at about the submesoscale in between where also Ro~1, Fr~1 and Bu~
23 December 2004
Aqua MODIS

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Solutions of QG PV equation forced by surface buoyancy flux, *b*, for stream function, :



classical QG solution mesoscale eddies via baroclinic instability

Mesoscale

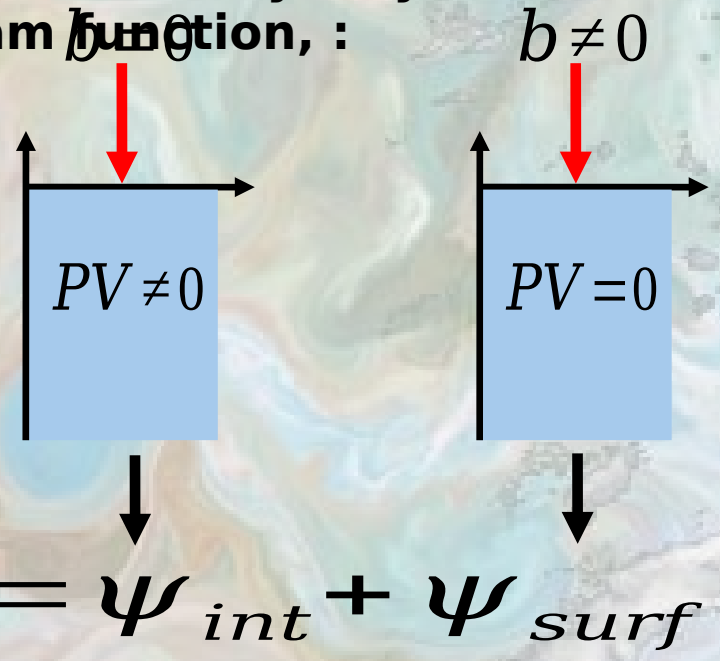
surface QG frontogenesis adding ML leads to instabilities ← ***not AI*** ☺

Submesoscale

(Blumen, 1978; Held et al, 1995; Lapeyre and

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$$\psi = \psi_{int} + \psi_{surf}$$

classical QG solution mesoscale eddies via baroclinic instability *Mesoscale*

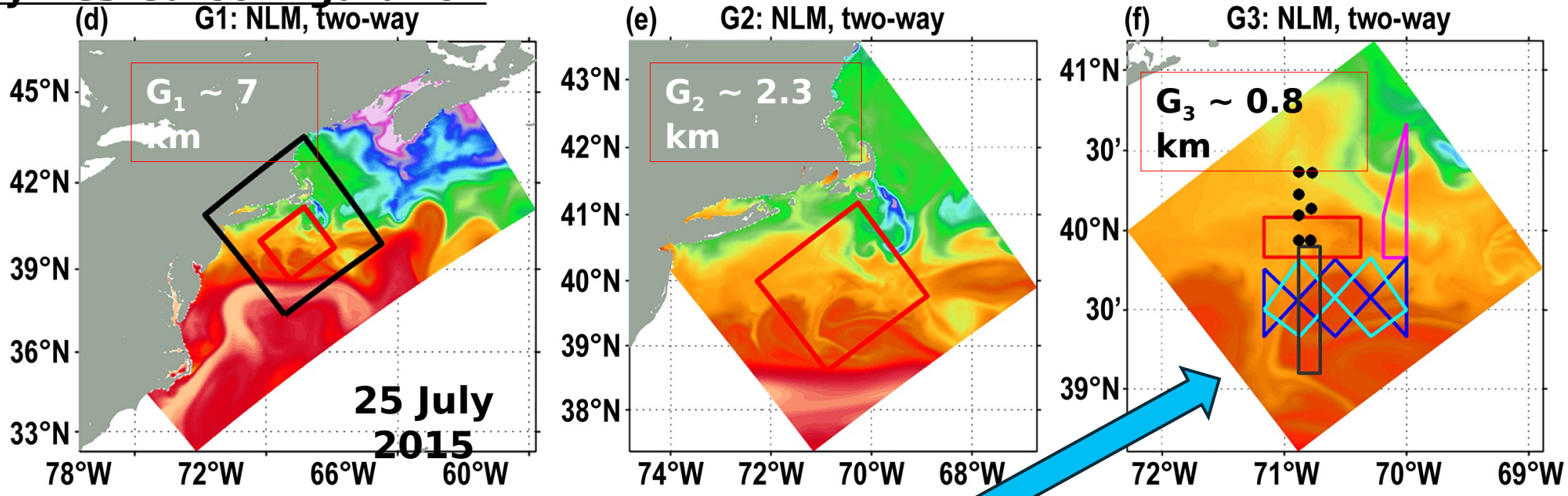
surface QG frontogenesis adding ML leads to instabilities *Submesoscale*

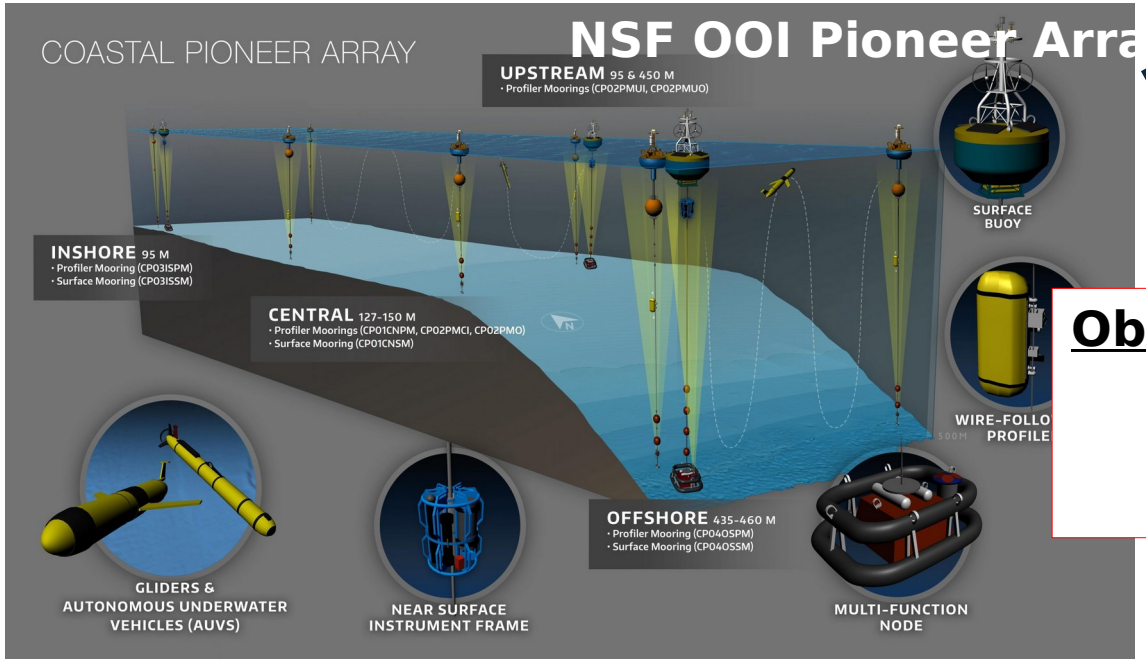
(Blumen, 1978; Held et al, 1995; Lapeyre and

Interdependent scales:

- **the submesoscale is conditioned on the mesoscale**
- **the mesoscale is conditioned on the gyre scale**
- **energy cascades are scale dependent which means we need to get a lot of things right!**

OMS Triply Nested Configuration

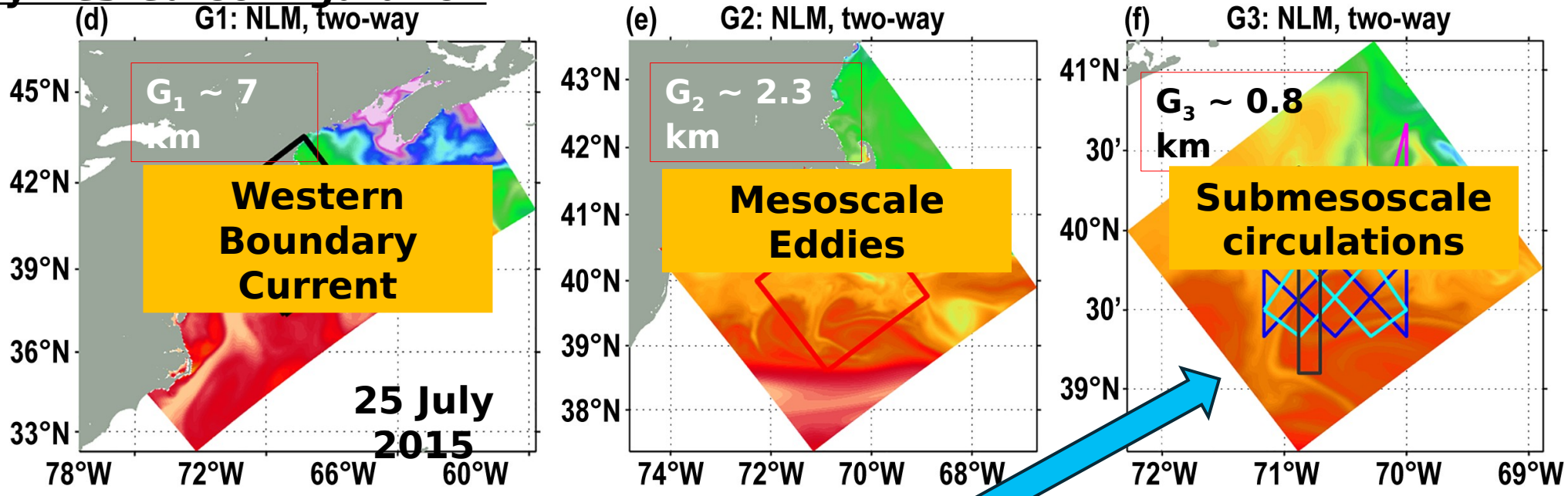


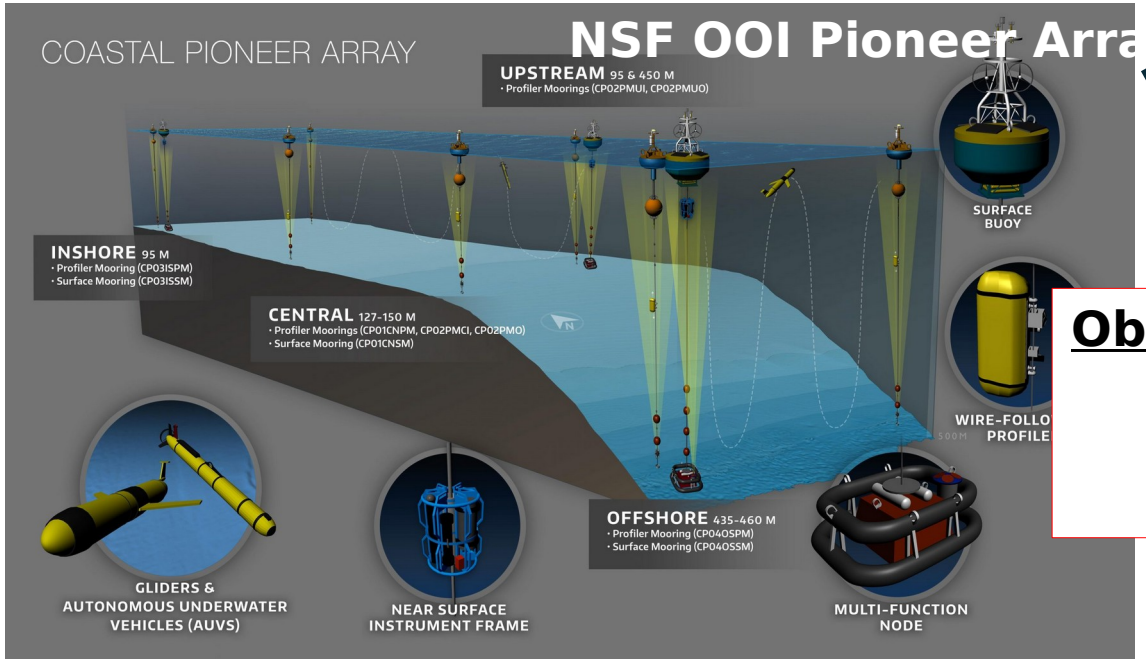


Simultaneous 4D-Var DA across all three nested grids (1- & 2-way nesting)

Obs: SST (AVHRR, GOES, TRMM, AMSR2, WindSat)
SSH (Jason, AltiKa, CryoSat)
in situ T,S (NDBC buoys, Argo, XBT, drifters, glide
in situ u,v (moorings, HF radars)

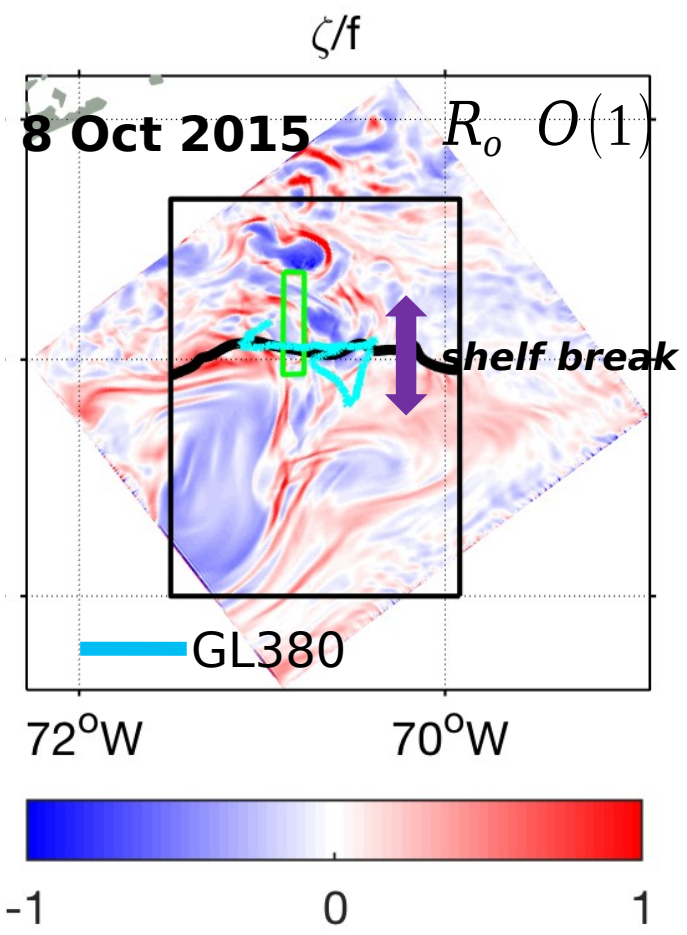
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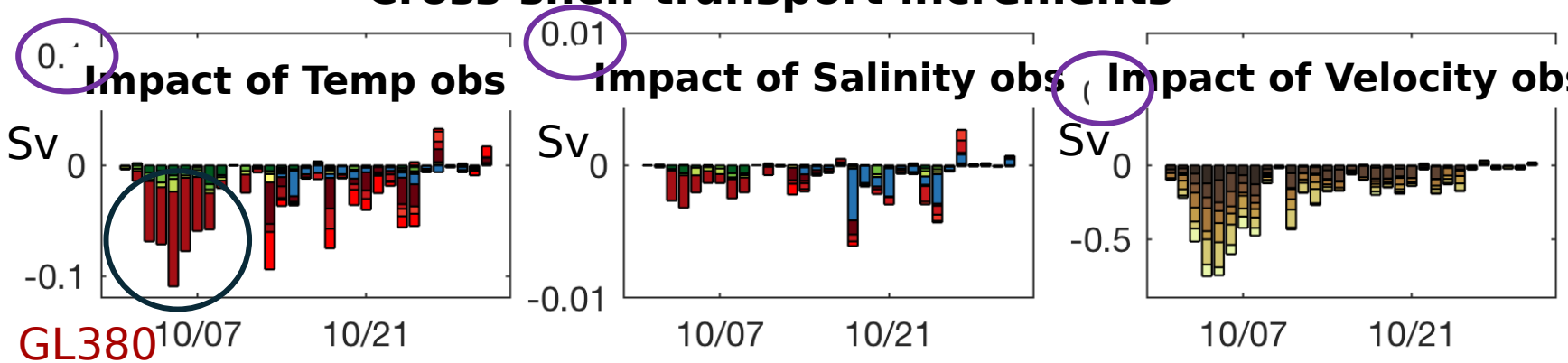


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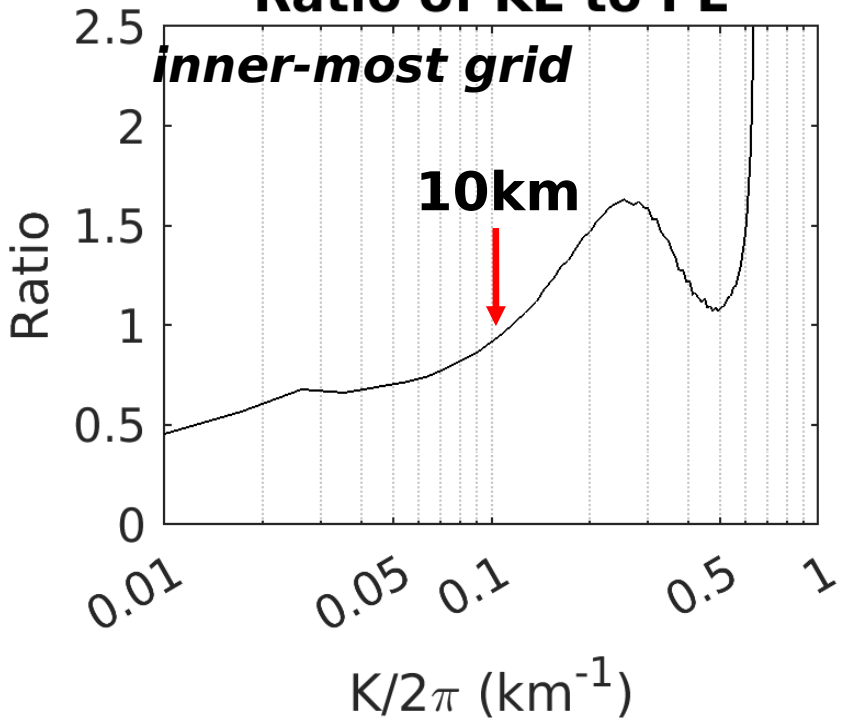


Cross-shelf transport increments

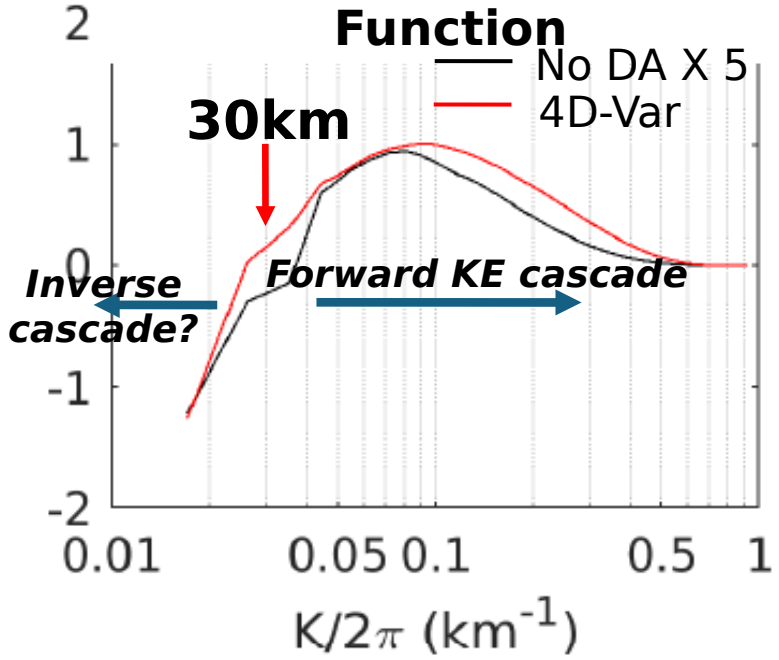


6 gliders & 7 moorings

Ratio of KE to PE



G3 Spectral Transfer Function



Final Thoughts and Reflections

- **The primary balances in the ocean can provide a useful guide as to which type of observations will be most impactful.**
- **Similarly, they can help us to understand the impact of the observations that we already have in hand.**
- **More broadly, these balances can guide our choice of balance operators for *B*.**
- **Perhaps with if we pay closer attention to the underlying dynamics of the circulation regimes that we are attempting to recover we can make make better use of existing observations.**