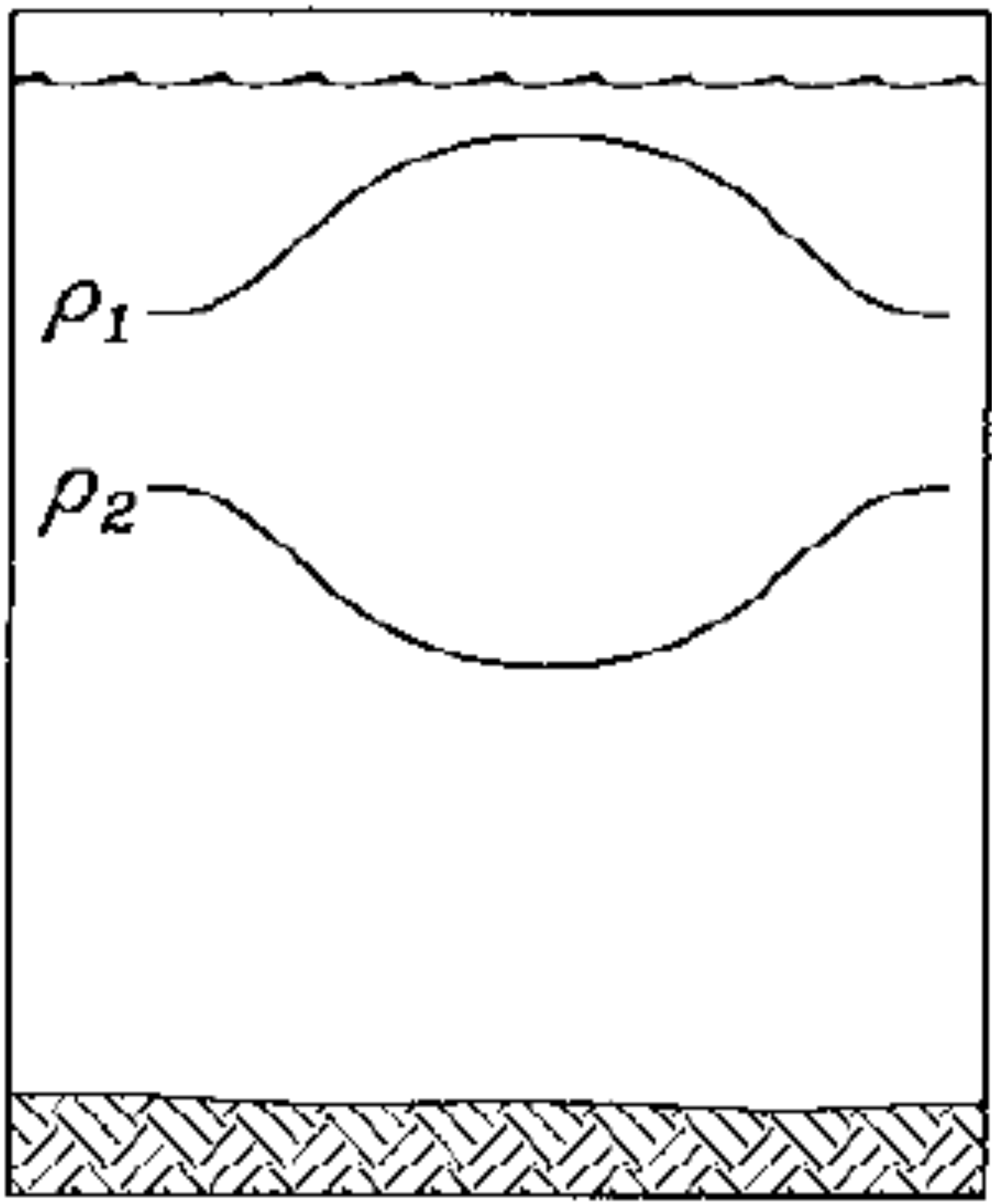
AOS 103

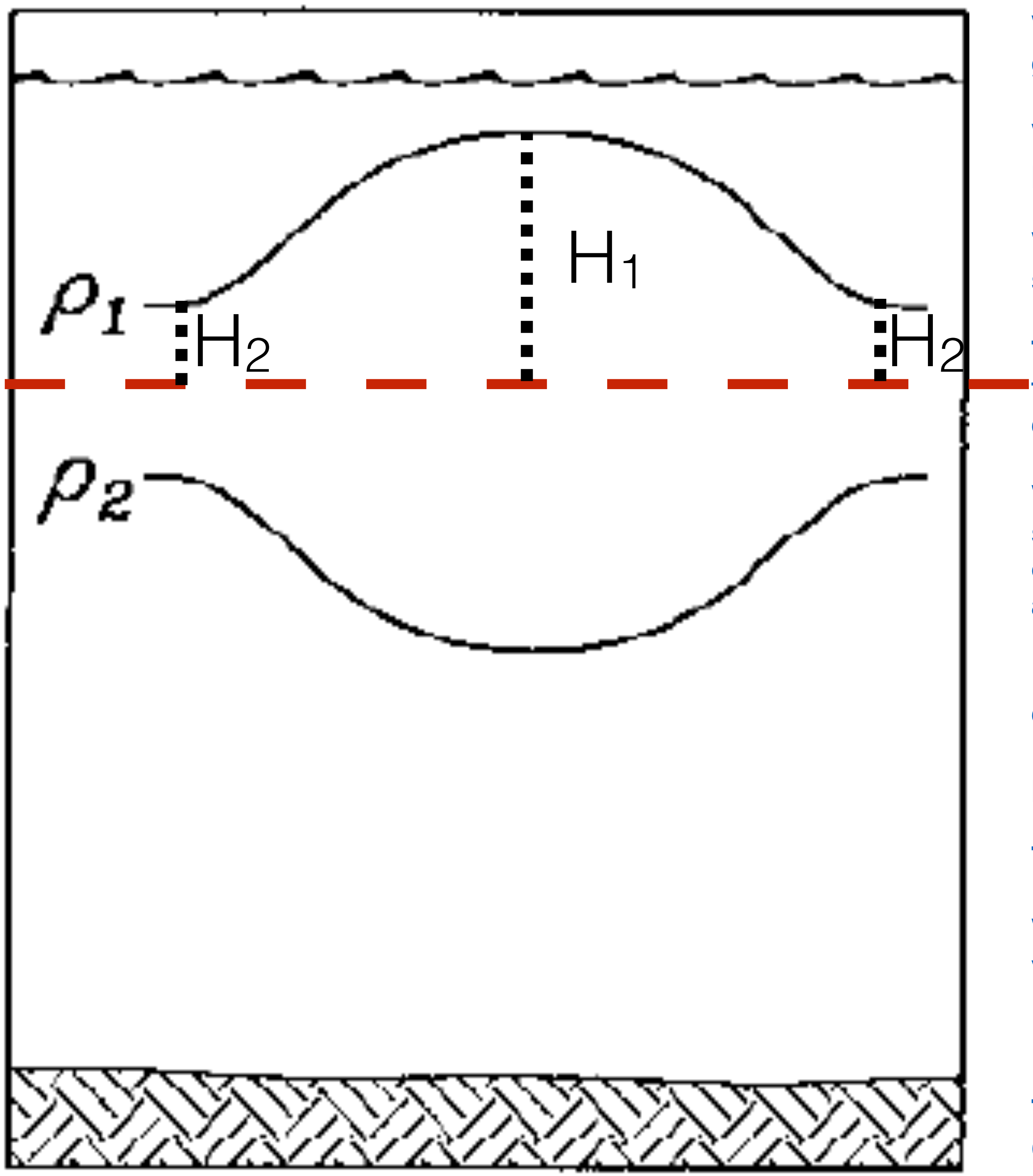
Week 7 Discussion

Mode Water Eddy



- Flat sea surface
- Isopycnal structure drawn
- Deduce the flow

Mode Water Eddy



We need to get to a statement of the horizontal pressure gradient force

We can do this by using hydrostatic balance at different points in the horizontal (along the red-dashed line)

We can interpret the space in between the 2 contour lines as a space of constant density

Therefore the hydrostatic pressure variation will be related to the thickness of the space between the 2 contour lines (black dashed lines).

We can make the above assumption b/c we know that the sea surface is flat, so the hydrostatic pressure is not dependent on sea surface height b/c it is constant along the horizontal axis.

In the middle, the thickness of the water column relative tot he density contour is larger ($H_1 > H_2$) This implies that at the intersection of the black dashed line and red line, the pressure is higher than at the sides.

The pressure gradient force points outwards from the middle

We are in the Northern Hemisphere, so the geostrophic velocity flows to the right of the pressure gradient force which is into the page on the right side and out of the page on the left side

The velocity structure is indicative of anticylonic (counterclockwise) circulation

Observations/Modeling

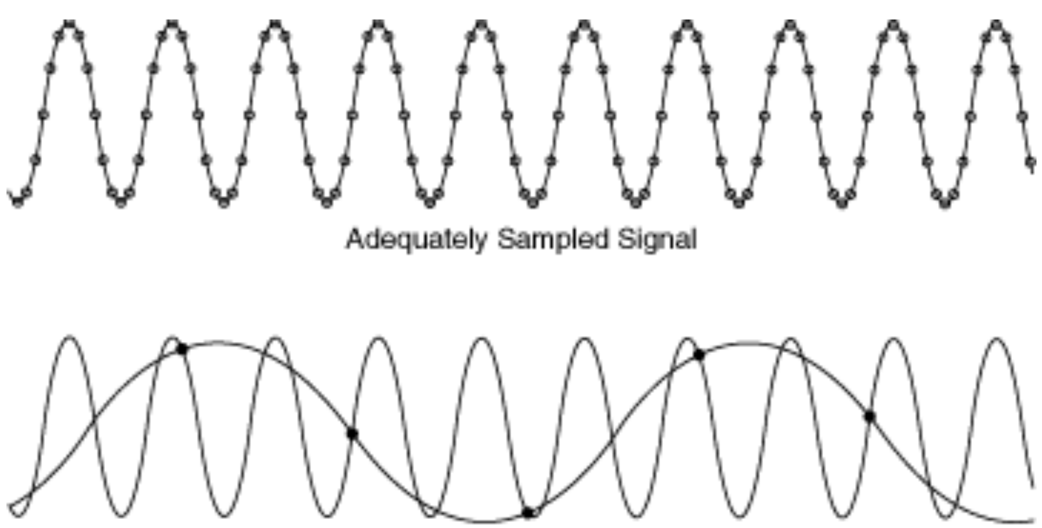
1) Explain aliasing with a sketch of made up data (actual and aliased data)

2) What type of spatio-temporal resolution would you want for a model to simulate the following:

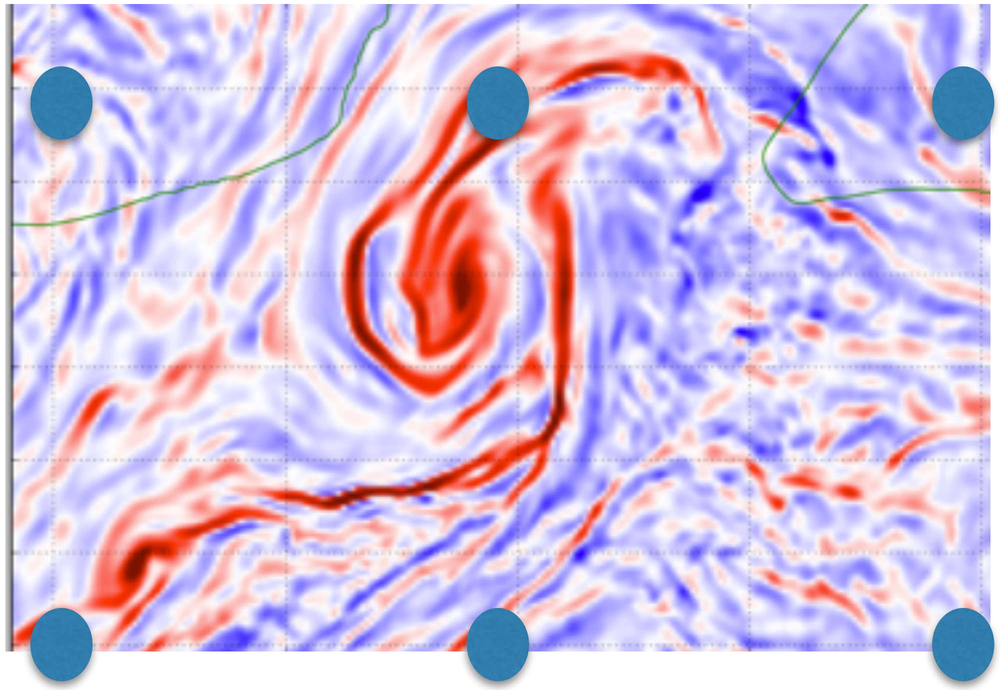
- -climate
- - fronts,eddies, and filaments
- - Langmuir cells
- - internal tides
- - molecular processes

3) Do you think it is possible to capture all those processes in one model (why or why not)?

1) Explain aliasing with a sketch of made up data (actual and aliased data)



Example of Spatial Aliasing



if we took measurements at only the blue dots, we would miss all of the finer detail that is occurring

Aliasing is the misrepresentation of a signal because it is under sampled. Which means that the measurements of the signal (in space or time) are not frequent enough to fully capture the true signal (e.g. one measurement every day or one measurement every 100km)

2) What type of spatio-temporal resolution would you want for a model to simulate the following:

- climate
- fronts,eddies, and filaments
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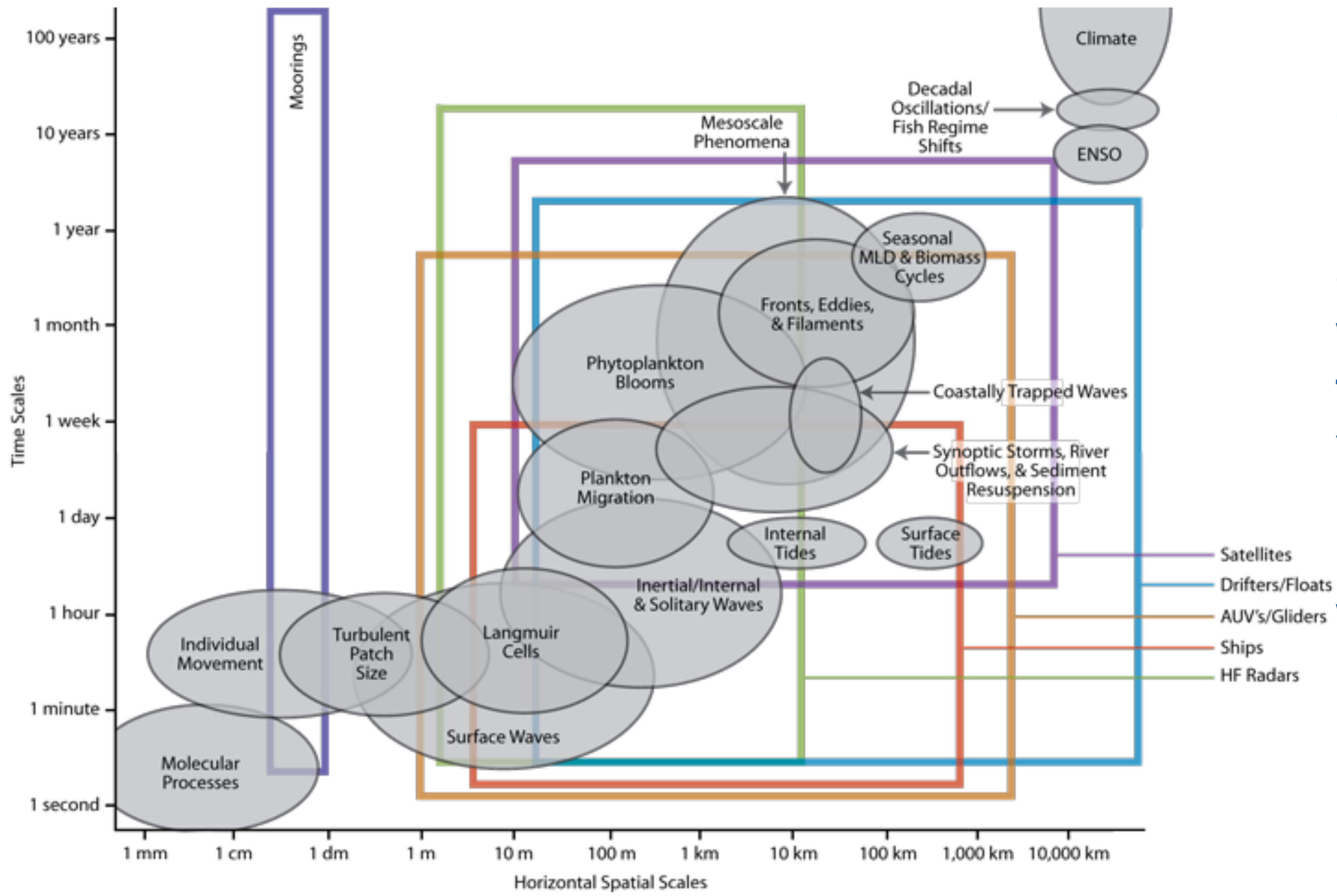


Each of the processes listed above has a specific space and time scale shown in this figure.

If you wanted to accurately model any of those physical processes you would have to choose a space and time scale that applies to the physics you are interested in

For example: for internal tides, you would want a spatial resolution at least O(10km) and a temporal resolution at least O(~1day)

3) Do you think it is possible to capture all those processes in one model (why or why not)?

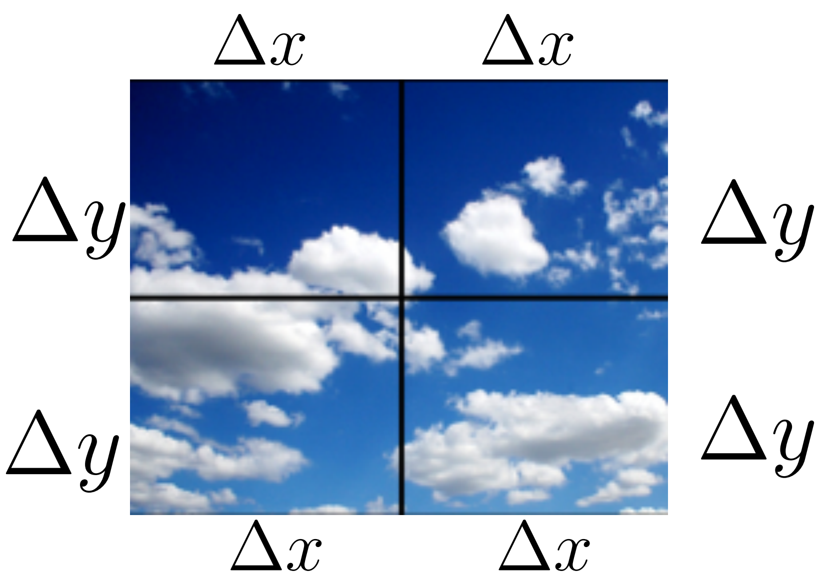
The short answer is no, essentially because it would require massive computing power and time that is not feasible.

At this point in time, it is essentially impossible to capture molecular processes (the smallest space and time scales) AND climate in the same simulation because they are at opposite ends of the spatio-temporal spectrum.

That is, climate acts on the largest space and time scales and molecular processes act on the smallest space and time scales.

To capture both of these processes in a model is essentially impossible because the computing power/speed is not good enough (for the calculation to happen in a reasonable amount of time)

However, models can cope with this dichotomy, by using *parameterizations* which can emulate processes that happen sub-grid scale (e.g., clouds in a climate model, or molecular mixing).



A common problem in atmospheric models is that clouds cannot be explicitly resolved b/c they are usually much smaller than the grid-boxes. However, cloud effects are very important to larger scale atmospheric dynamics and heat and moisture budgets, thus their effect must be quantified via a parameterization.

Eddies

1) Why do eddies exist (why do they form)?

2) What processes can lead to their formation

3) What dynamical balance dictates eddy velocities?

4) What is the statistical definition of an eddy (write an equation and explain it)

5) Explain the difference between the paradigms for 3D and 2D turbulence

6) Explain 3 effects eddies have on the ocean

1) Why do eddies exist (why do they form)?

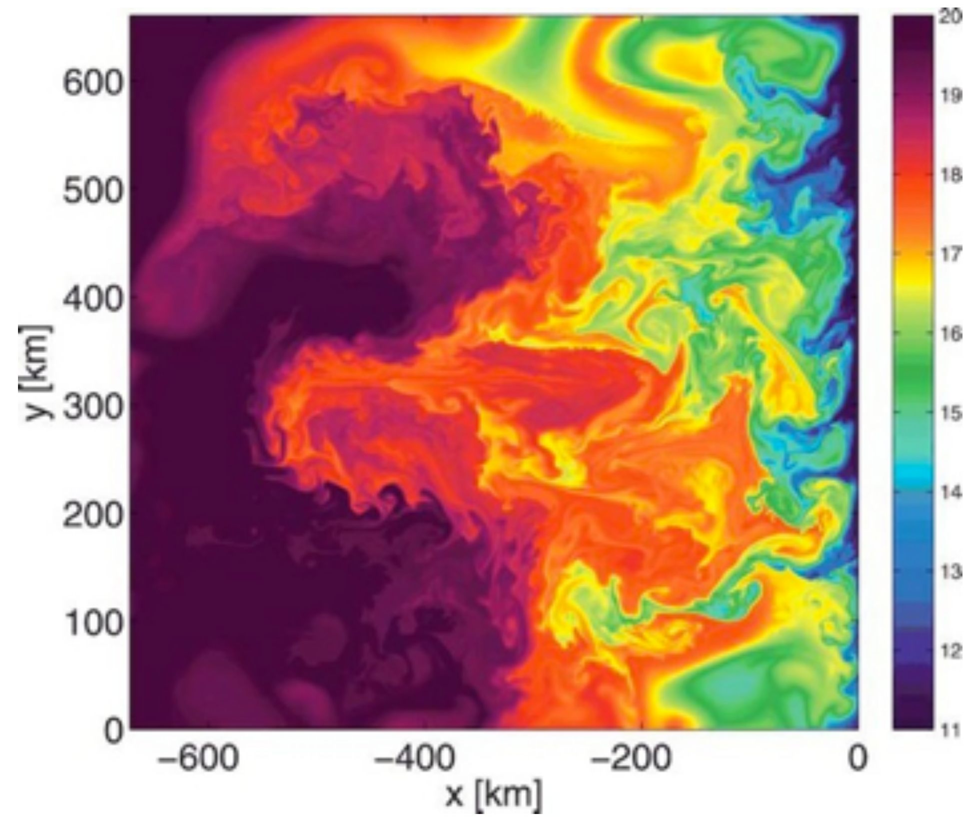
The ocean is a turbulent place

-The ocean is a very turbulent place: this means that the actual, real, flows are not perfect steady-state balances (like geostrophic or Ekman) and they exhibit seemingly chaotic tendencies (lots of 'wiggles'…the smaller the spatial scale you look, the more wiggles for the most part)

-The turbulent phenomena in the ocean can result from flow instabilities

-Despite this chaos, we can determine what causes the instabilities and through some somewhat laborious mathematical analysis that we won't get into in this course we can determine the mean effects of classes of turbulent flows

-Eddies are one type of phenomena that are a consequence of instability and they have been studied a great deal b/c their effects are so important to describing the full spectrum of ocean physics (i.e how does heat get transported to the poles, how is energy transferred, how does the ocean 'nudge' itself toward a dynamical equilibrium)



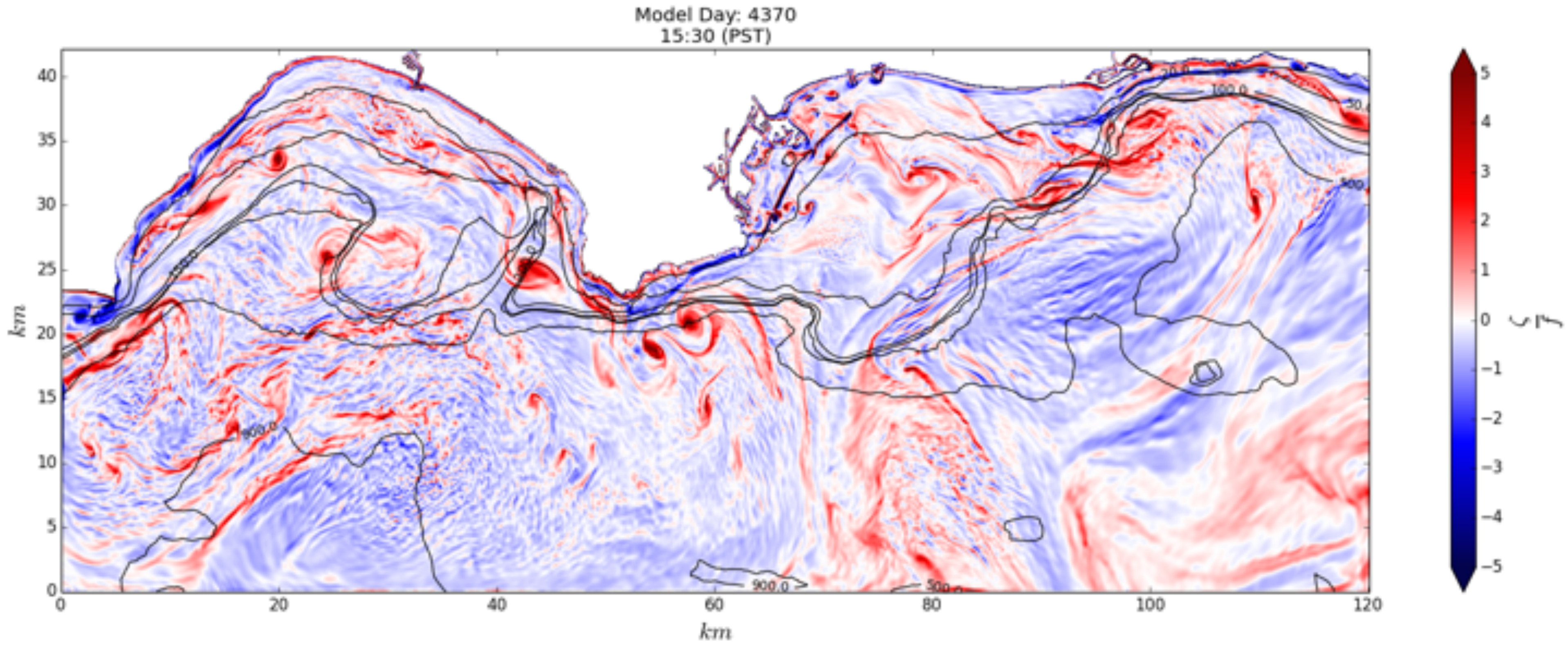
1) Why do eddies exist (why do they form)?

- Eddies form because ocean flows will develop instabilities

- You can think of the instability (and resulting eddy) as the way in which the flow keeps itself in check

- If instabilities did not form in flows ocean velocities would go to infinity, but nature does not allow this and thus eddies and other instability induced phenomena occur that are nature's way of keeping the system from getting out of control (i.e. velocities that go to infinity)

- It turns out that the resulting phenomena from these instabilities (eddies are one example) actually have very important roles in the energy budget and maintaining overall equilibrium in the system (which is what the atmospheric and ocean systems are constantly trying to get to…again, that's why fluid moves: to balance out gradients of things and achieve equilibrium…which is another word for balance…and every STEADY-STATE (i.e. stable) ocean current is part of some balance: geostrophic, ekman, etc.)

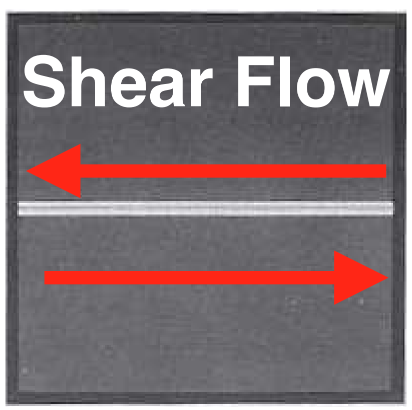


2) What processes can lead to their formation

Barotropic Instability

Barotropic instabilities occur in 2D (x,y) shear flows

Perturbations (i.e., something that will disrupt the satiate of the flow) can amplify exponentially and lead to eddy (vortex) formation by “rolling up” of the shear layer



Step forward in time

Baroclinic Instability

Baroclinic instabilities occur for baroclinic flows (one of the relevant dimensions is the vertical)

In these instabilities, vertical shear and the density gradient are the energy source for the eddy

Vertical shear

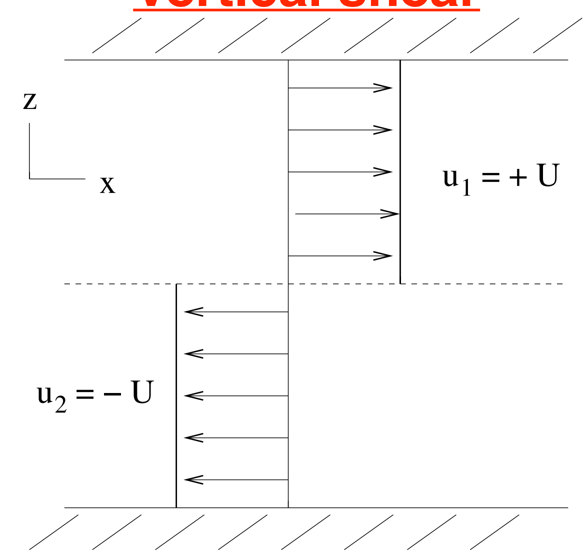
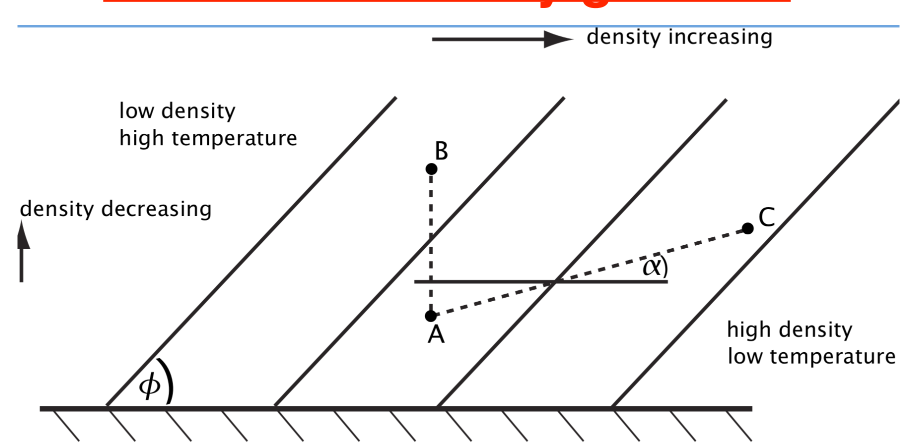
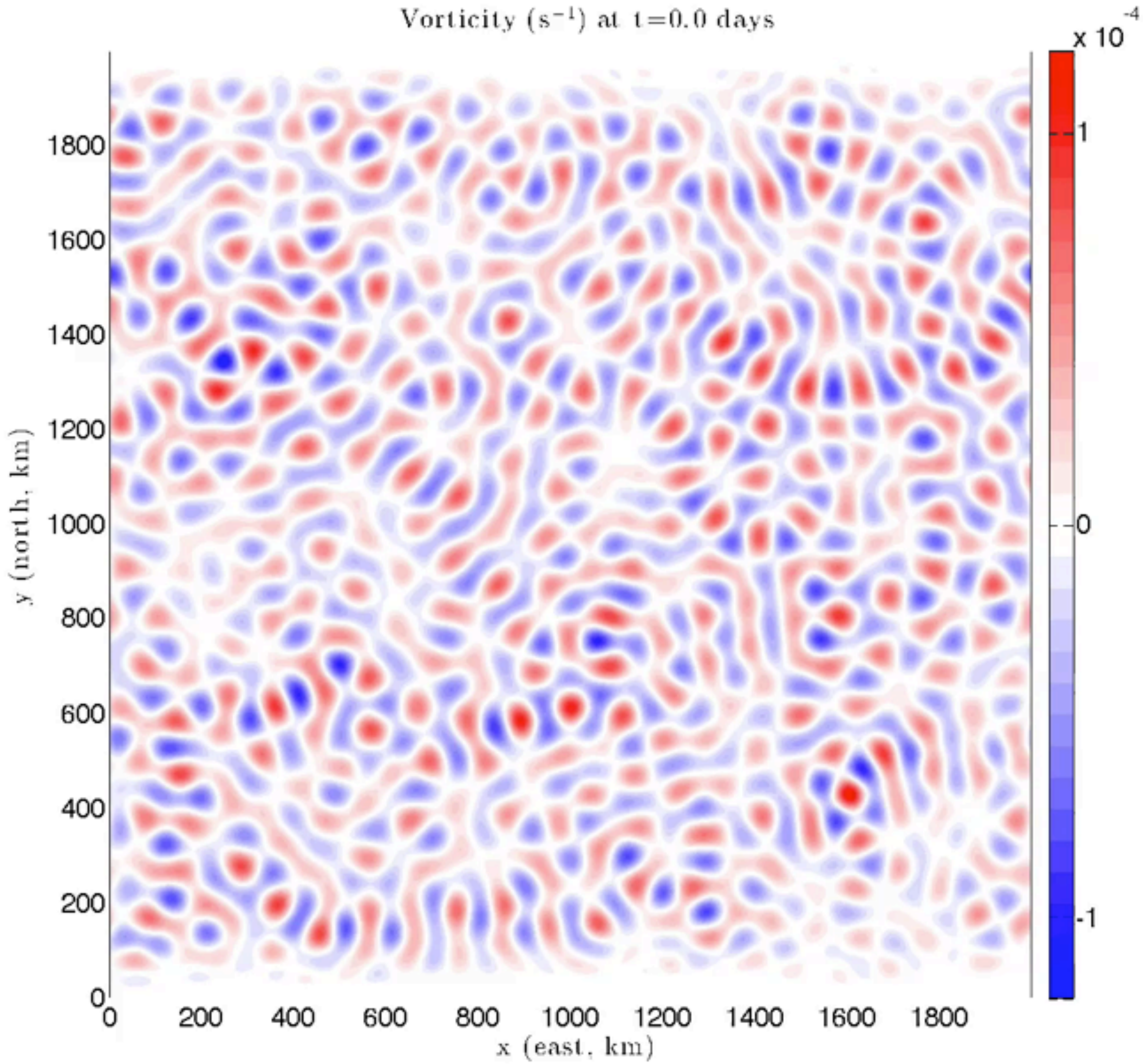


Fig. 5.4. Mean zonal baroclinic flow in a 2-layer fluid.

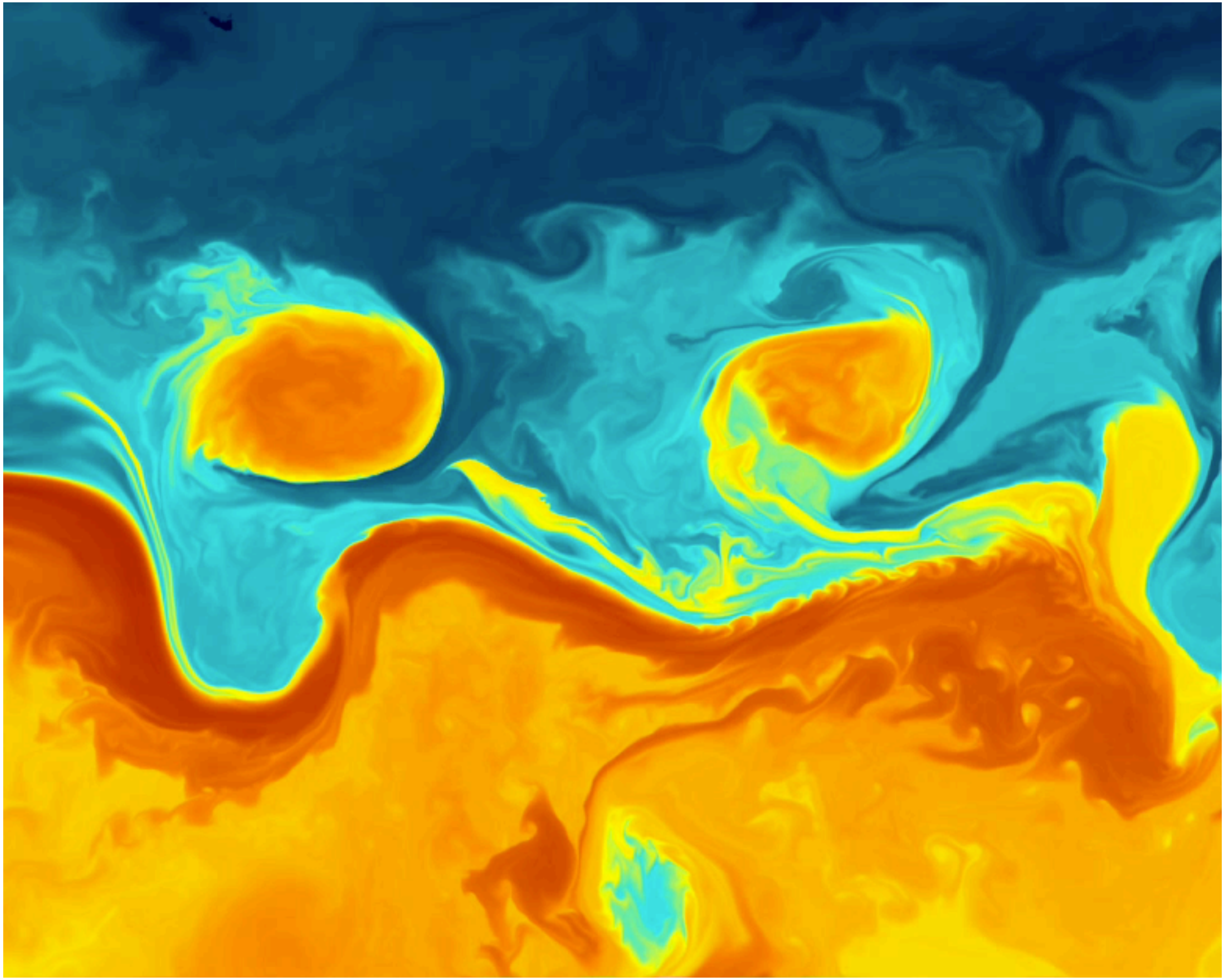
Horizontal density gradient



Inverse Energy Cascade (Movie)

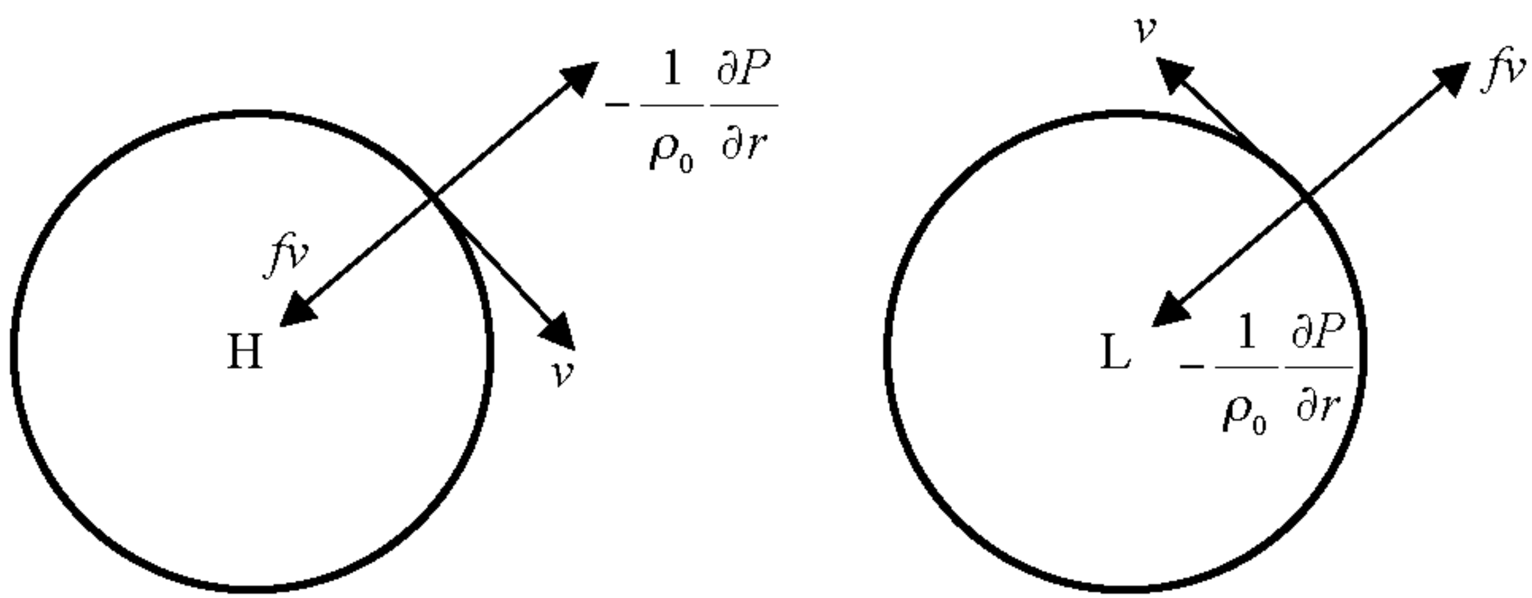


Gulf Stream Eddies

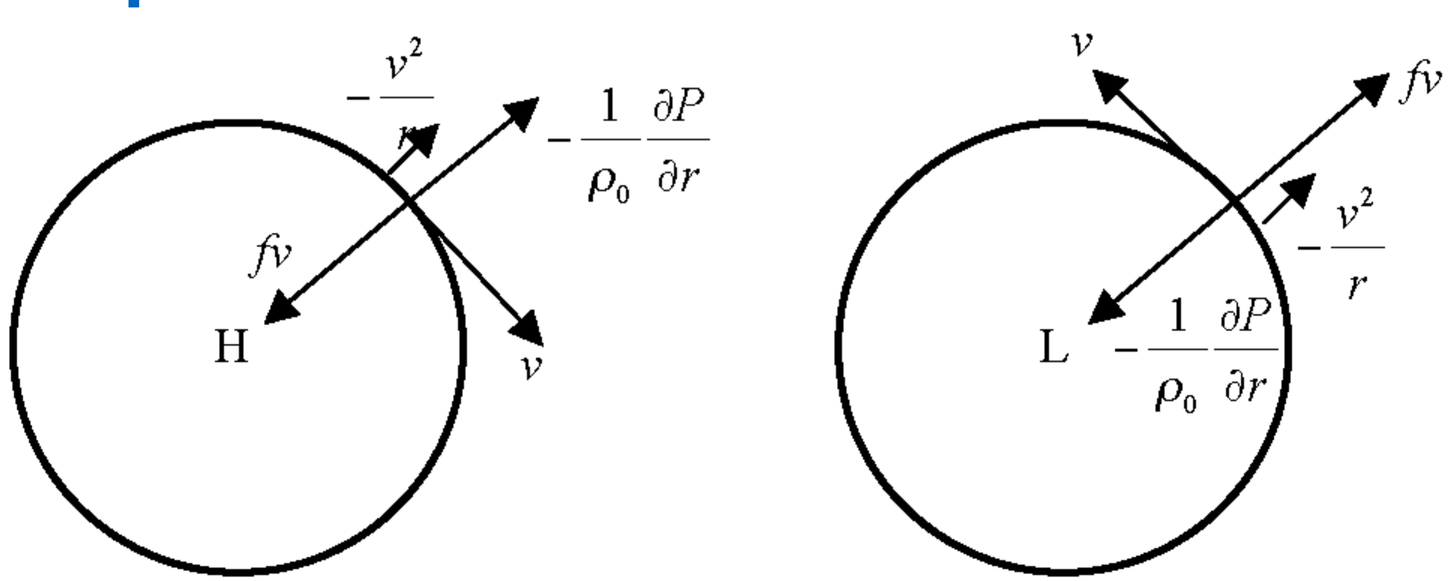


3) What dynamical balance dictates eddy velocities?

Eddies are typically in geostrophic balance



If the eddy is relatively small (<10km), the centrifugal force can become non-negligible, and the eddy is said to be in cyclogeostrophic balance



4) What is the statistical definition of an eddy (write an equation and explain it)

Take a field and decompose it into 2 components:

1) Mean (average)
2) Fluctuations about the mean ("eddy")

$$v = \langle v \rangle + v'$$

Field (for this example, velocity)

Mean (time or space)

Eddy component (deviation from the mean)

$$\langle v' \rangle = 0$$

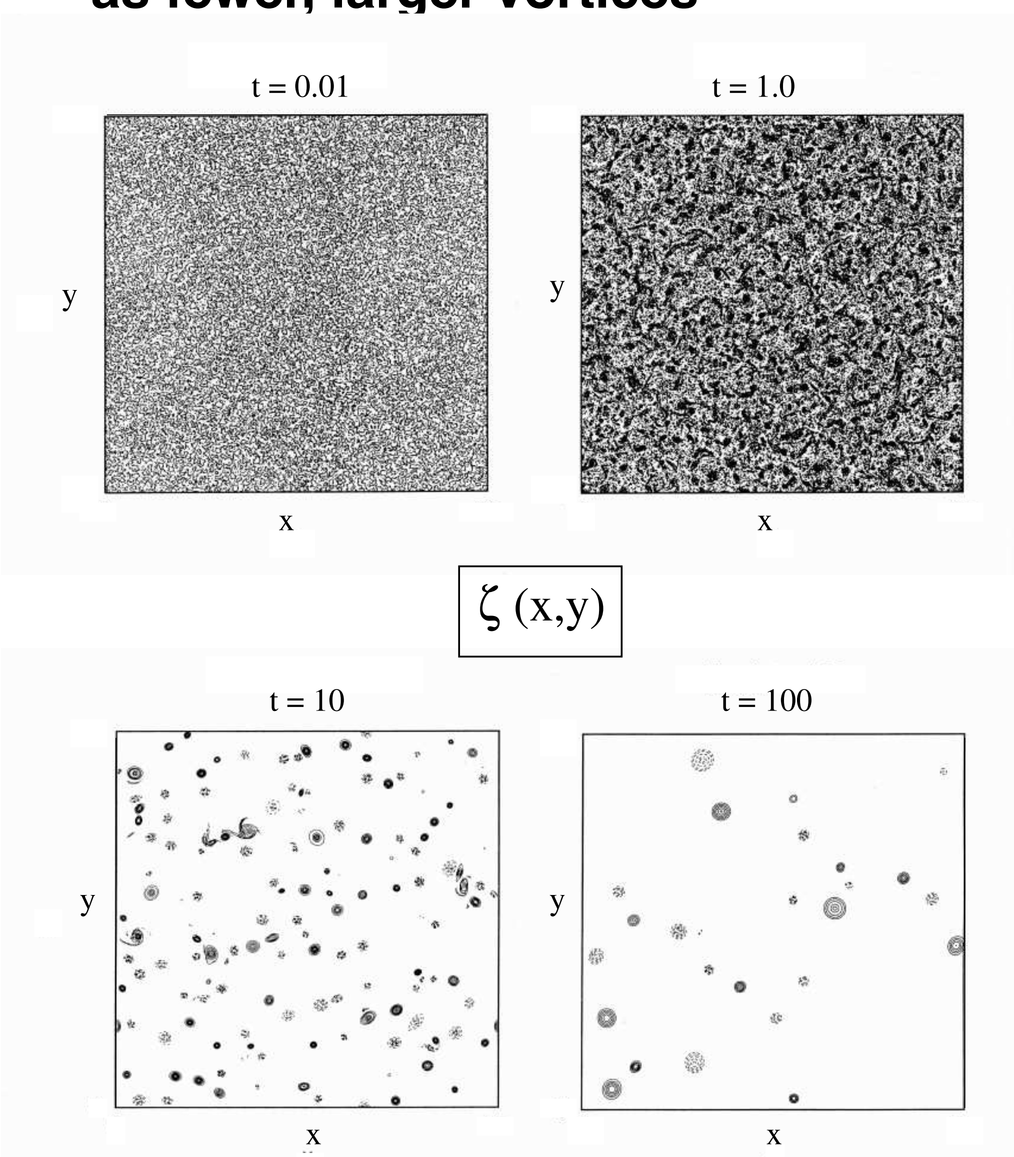
By definition, the mean(average) of a fluctuation (eddy) is zero

5) Explain the difference between the paradigms for 3D and 2D turbulence

2D turbulence

Inverse energy cascade

- 2D(barotropic) turbulence has **energy that is transferred to larger and larger scales** as time goes on
- An initial state of small scale vorticity (many vortices) will ultimately end up as fewer, larger vortices



3D turbulence

Forward energy cascade

- 3D stirring leads to smaller and smaller scales of tracer gradients
- **The transfer of energy is to smaller and smaller scales**

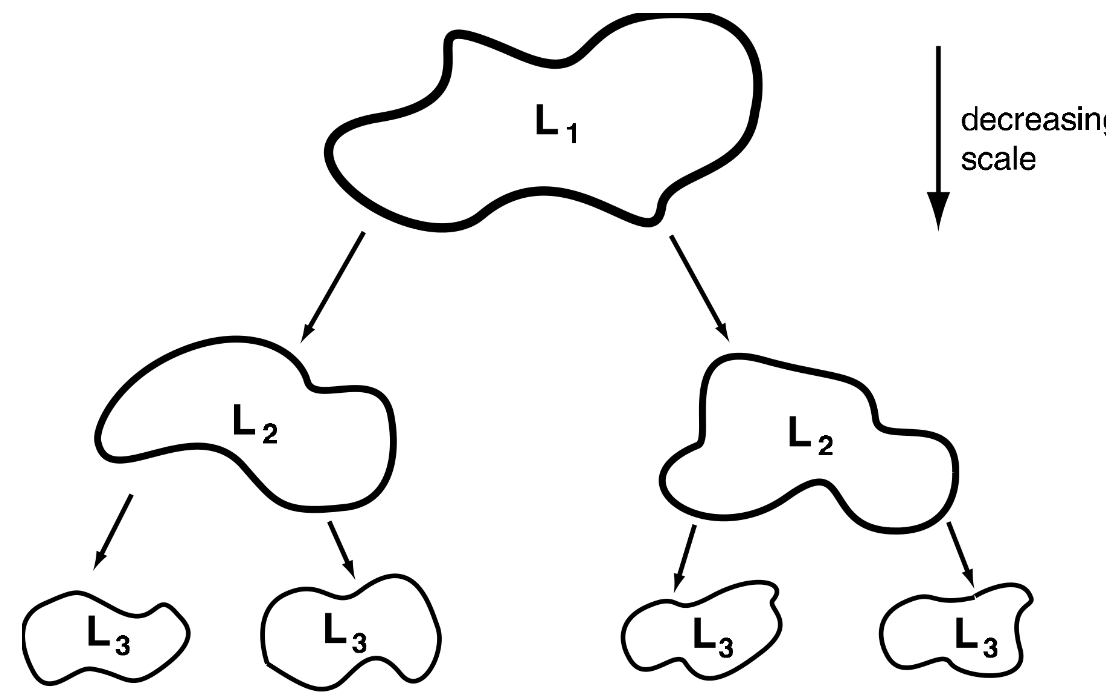


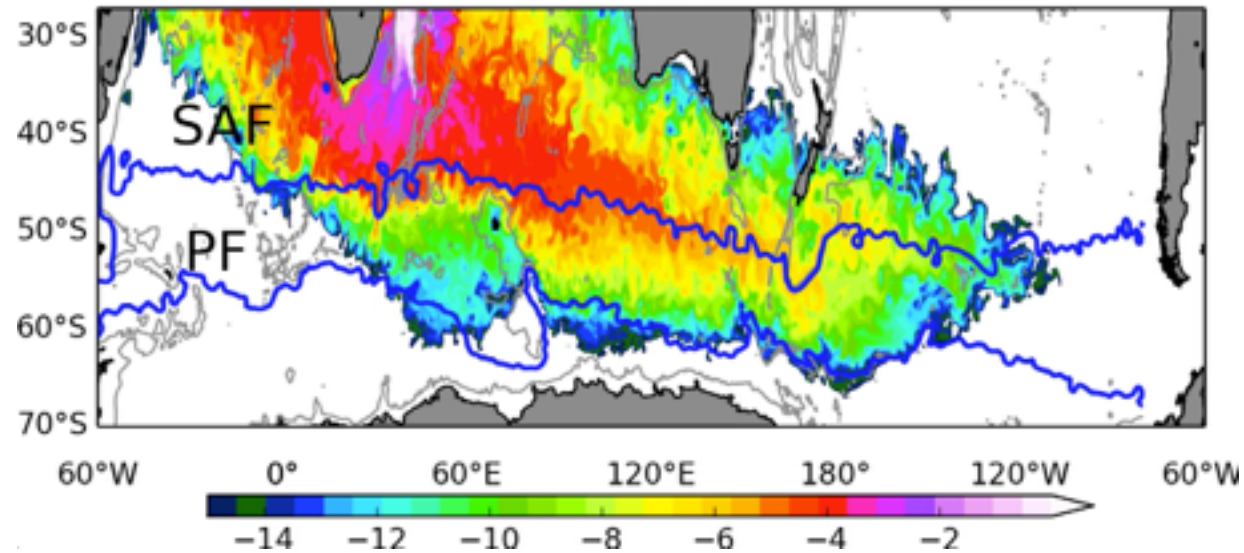
Fig. 8.2 Schema of the passage of energy to smaller scales: eddies at a large scale break up into smaller scale eddies, thereby transferring energy to smaller scales. If the passage occurs between eddies of similar sizes (i.e., if it is spectrally local) the transfer is said to be a cascade. The eddies in reality are embedded within each other

6) Explain 3 effects eddies have on the ocean

1) Eddy diffusion of tracers

-eddies transport tracers from places of high concentration to places of low concentration
-in the ACC, heat transport to the south is primarily done by this eddy diffusion process

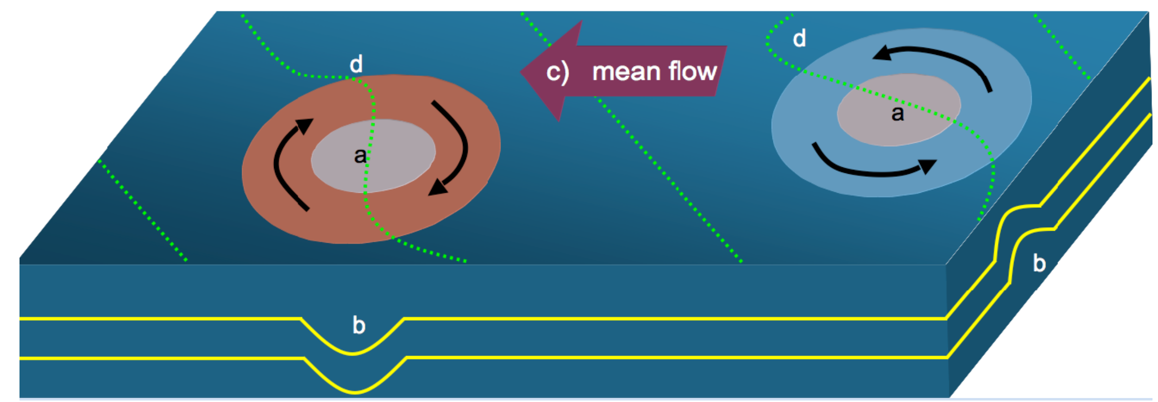
(1)



2) Bolus Transport

- eddy induced contraction of isopycnals causes transport through the isopycnal surfaces

(2)

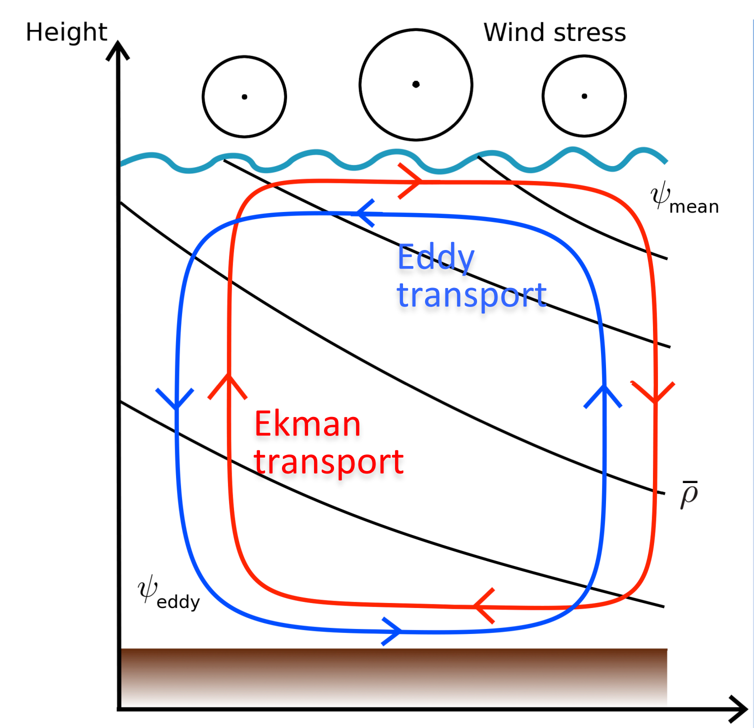


3) Isopycnal un-steepening

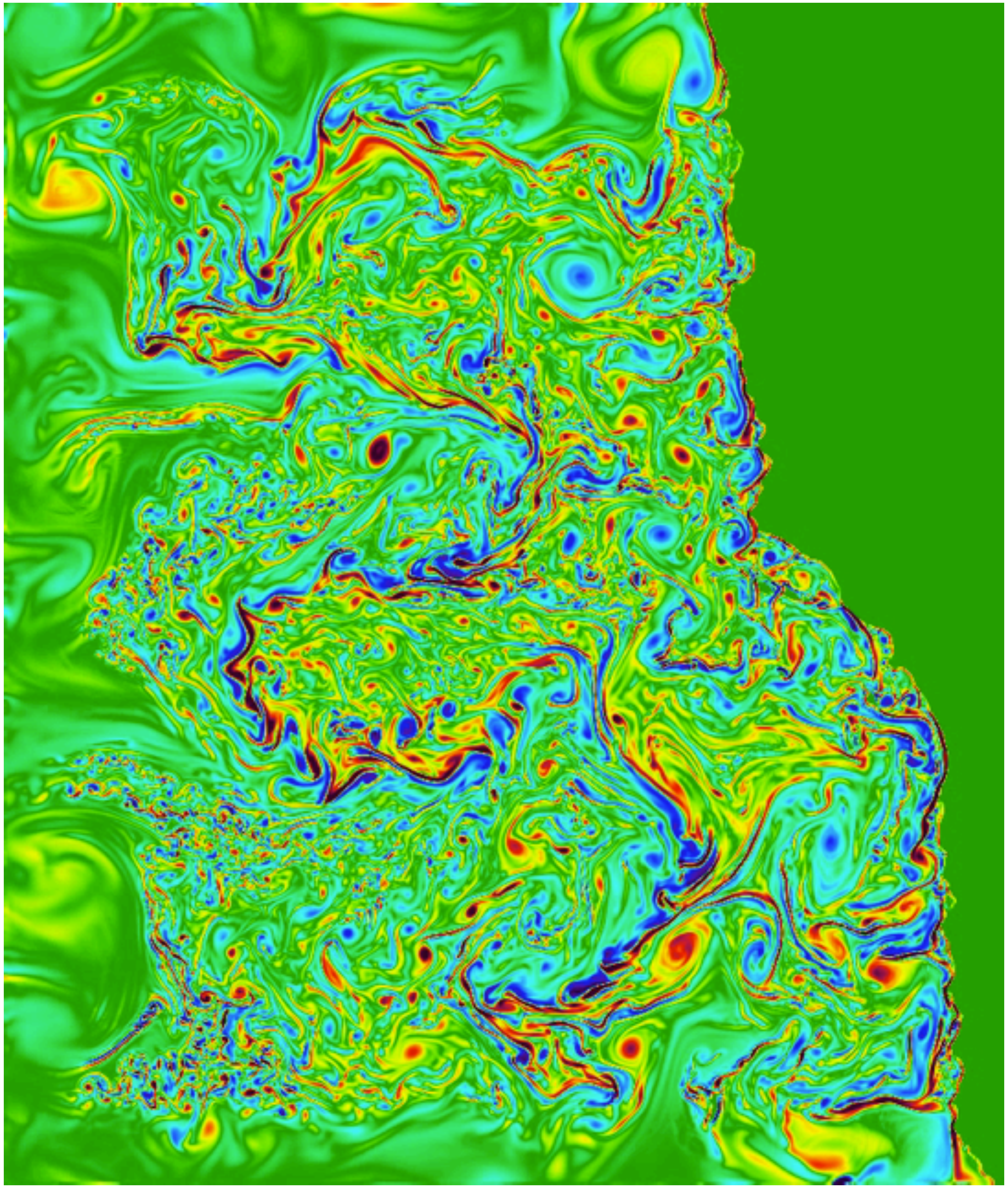
-potential energy is released due to eddies 'un-steepening' isopycnals (i.e. force the isopycnals to become more flat in the horizontal)

ACC: eddies act to flatten the isopycnals, ekman transport acts to steepen the isopycnals—-> the balance between the 2 determines how baroclinic the ACC is

(3)



U.S West Coast Models



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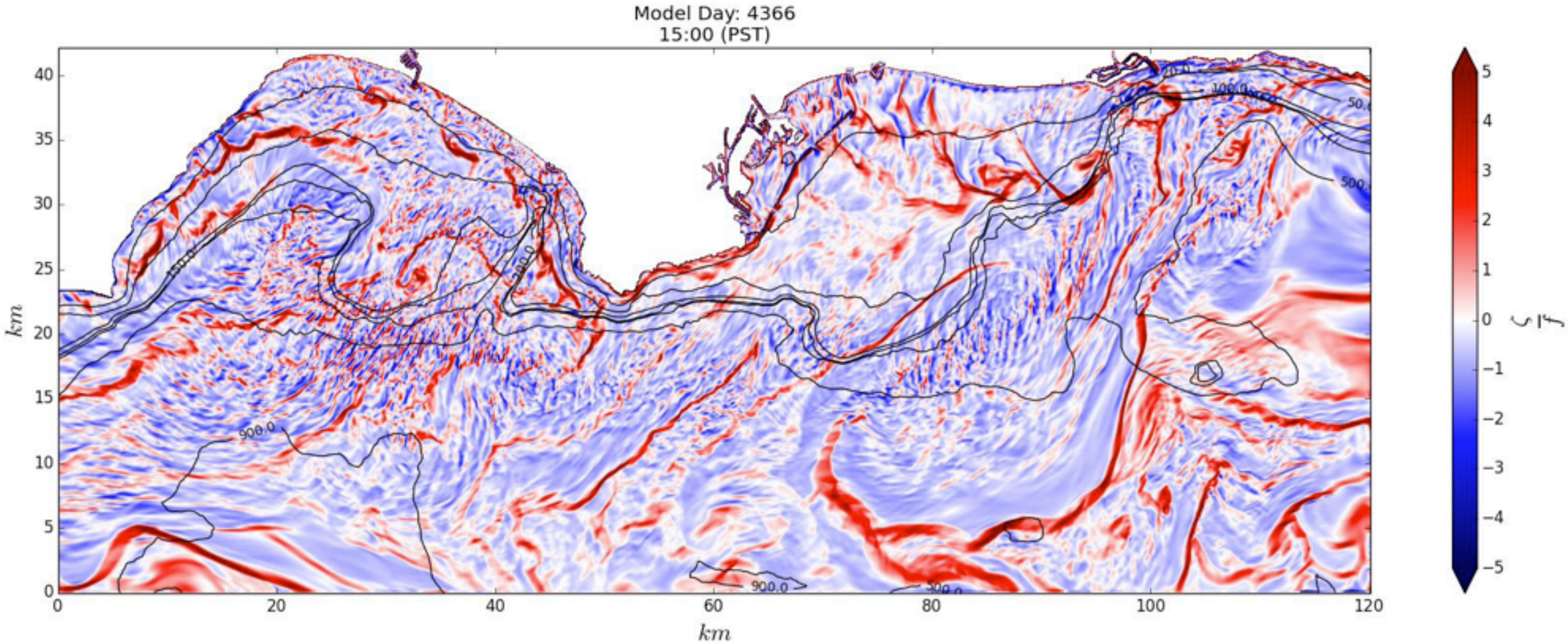

U.S West Coast Models