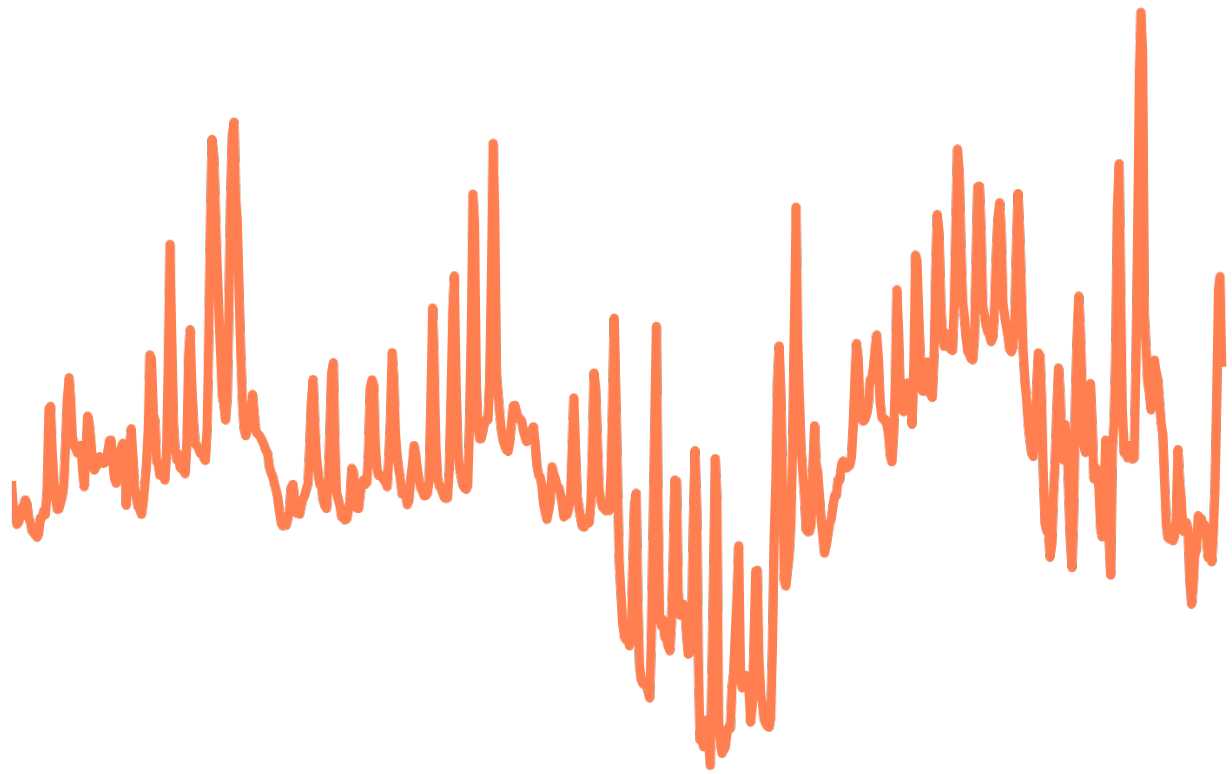
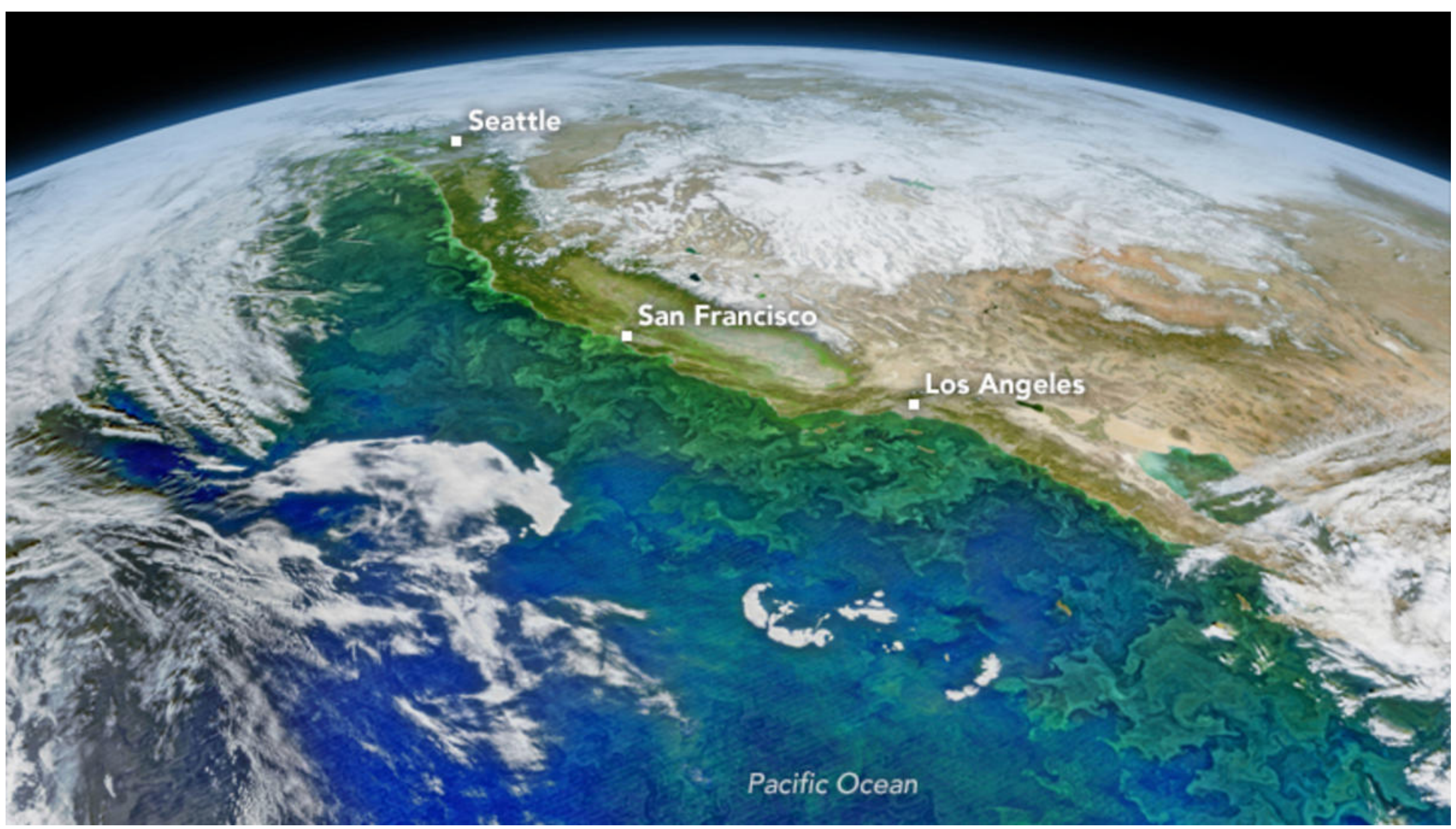
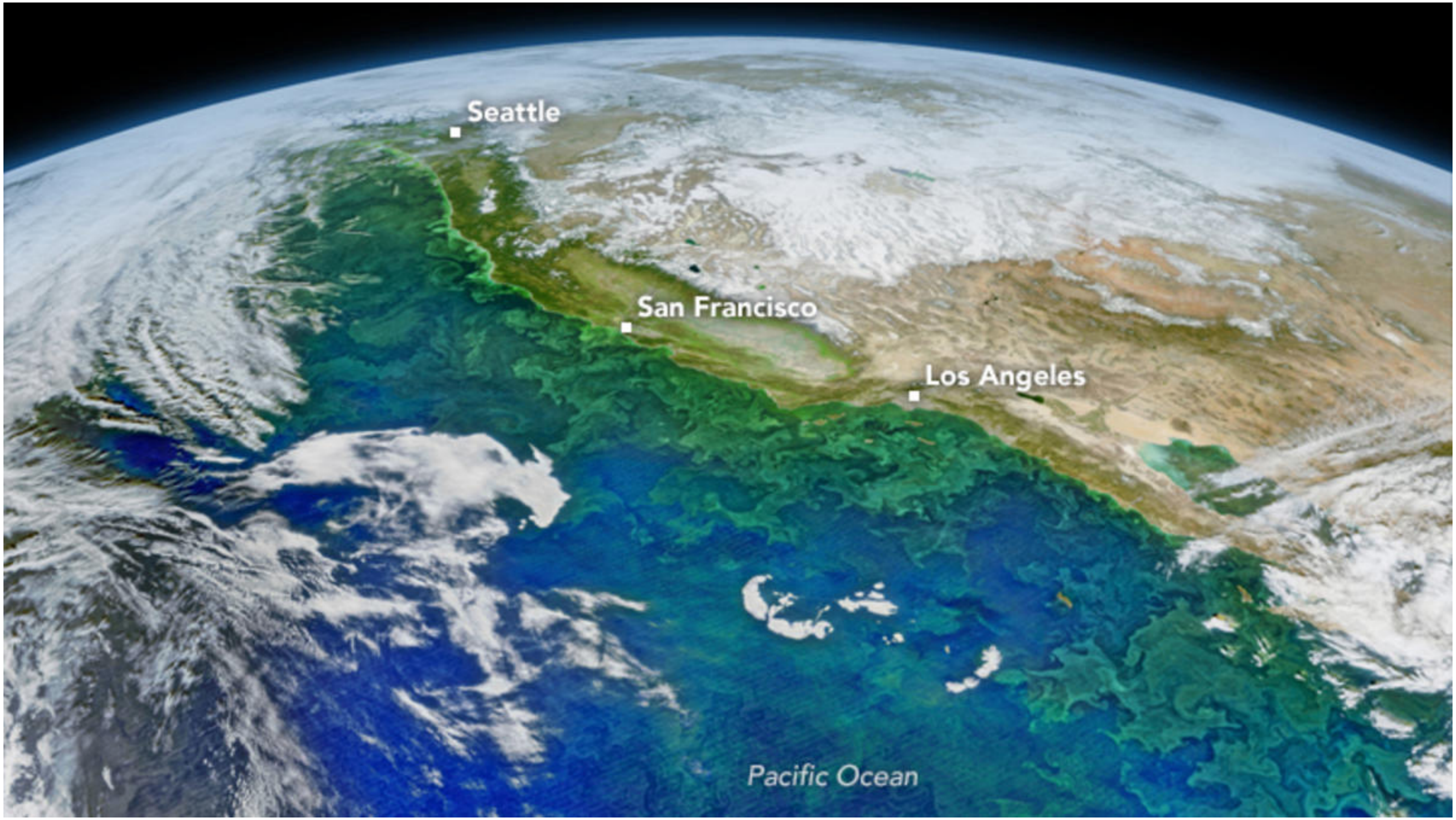
Variability in the Ocean: Physical conceptions of California's coastal ocean



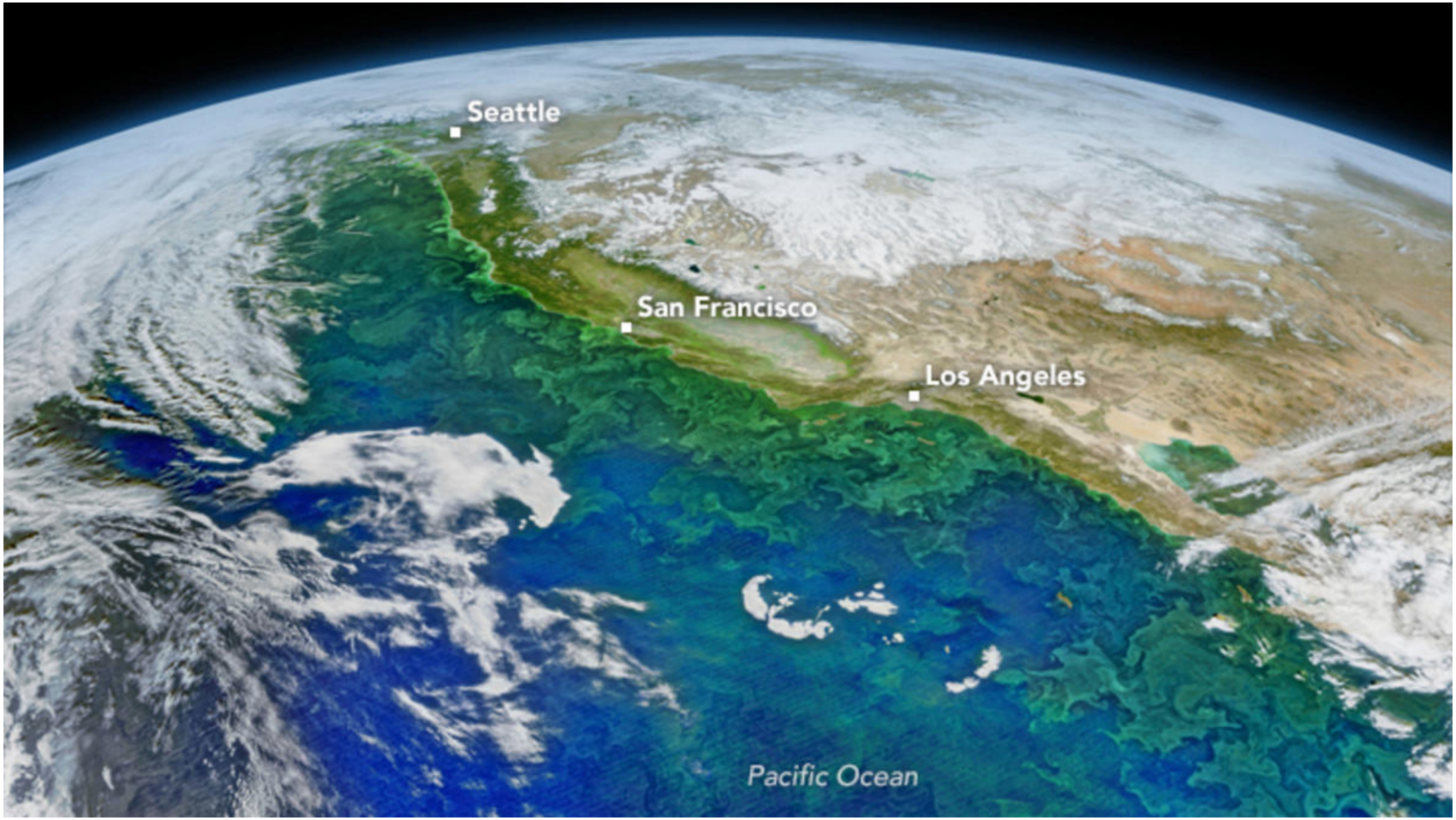


AOS 130 Lecture
May 9, 2017
Daniel Dauhajre

Why does the ocean look like this?



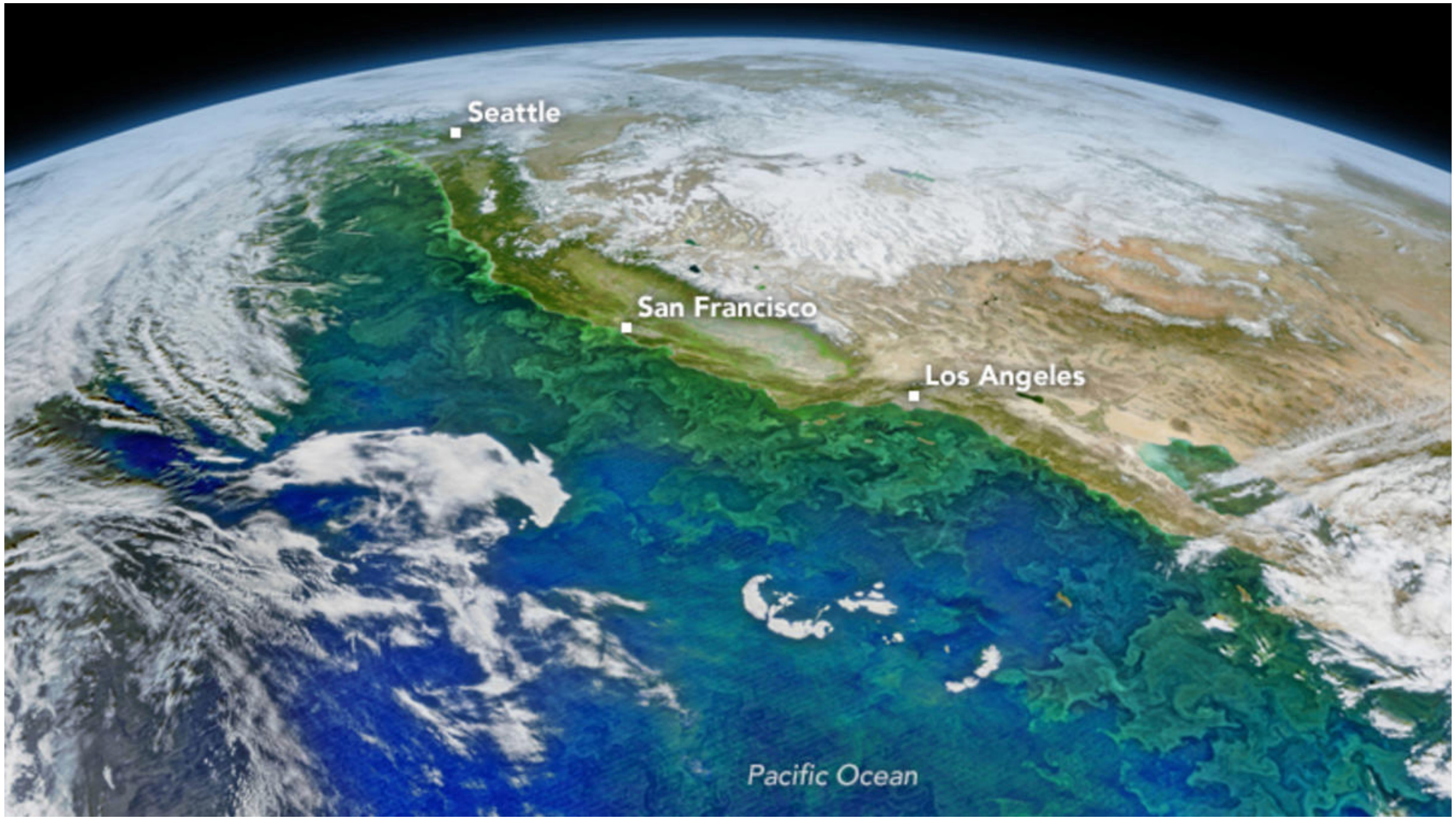
Why ask this question?



1) Because the ocean exists and looks the way it does
2) Because that green stuff is food

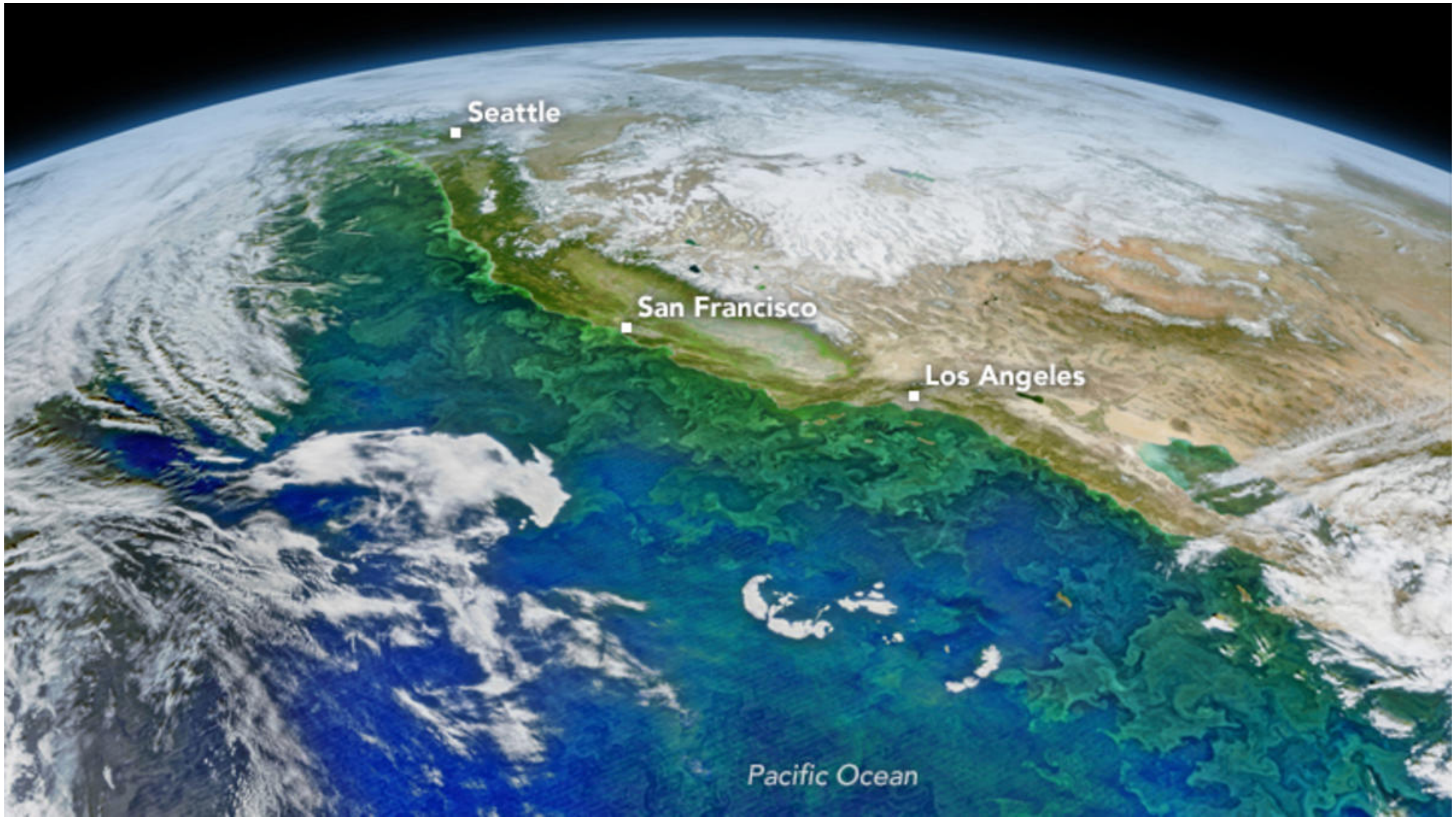
What does it "look like"?

Pretend you know nothing about oceanography…describe what you see



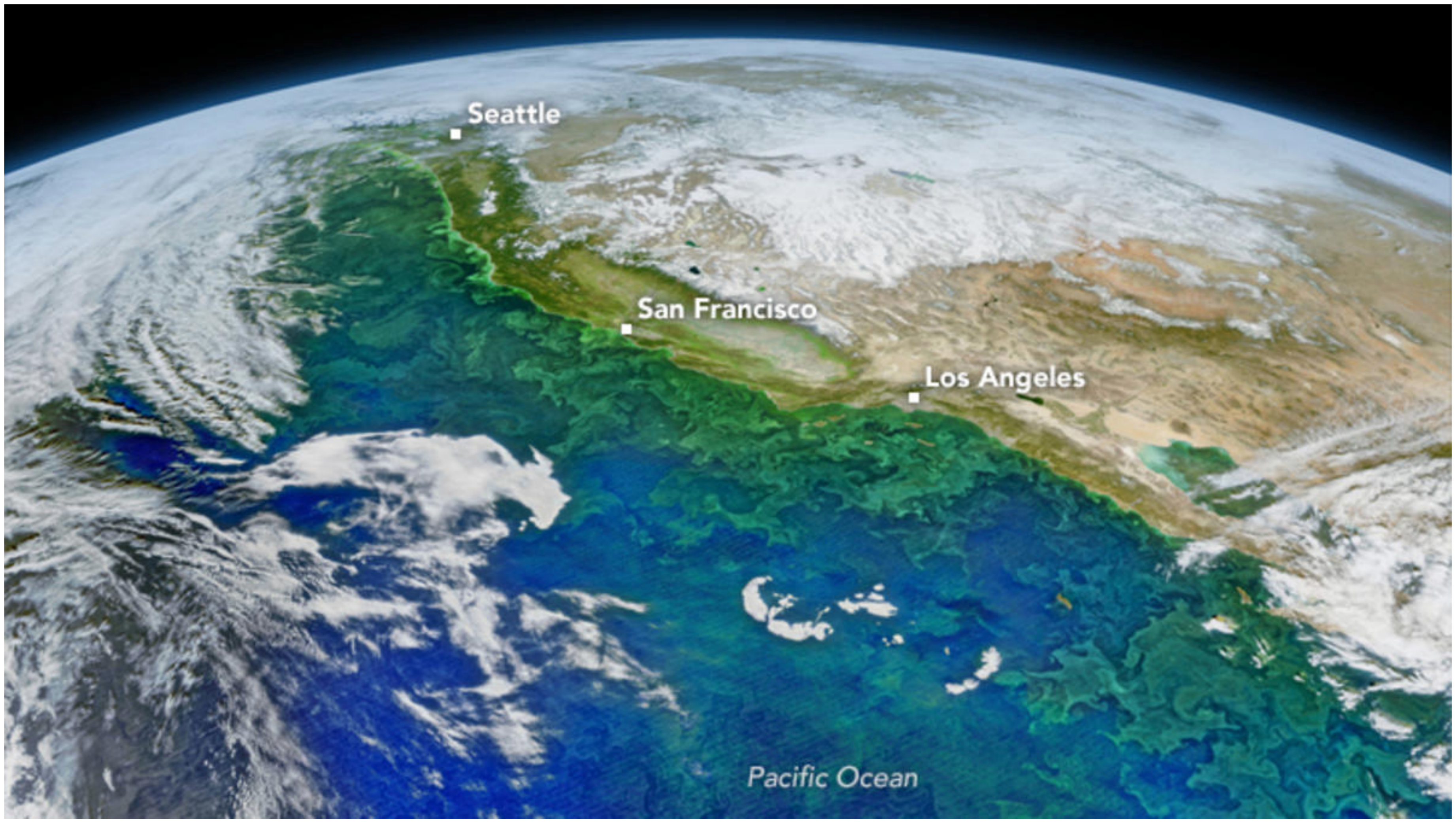
- There's green and blue colors
- The green 'stuff' is not uniformly distributed
  - It is closer to the coast and brighter to the north of San Francisco
  - While it is clumped together close to the coast, it is comprised of many wiggles.
  - These wiggles look to sit on the edges of places where the color changes (light to dark green or green to blue)

Now we have some basic questions we can ask



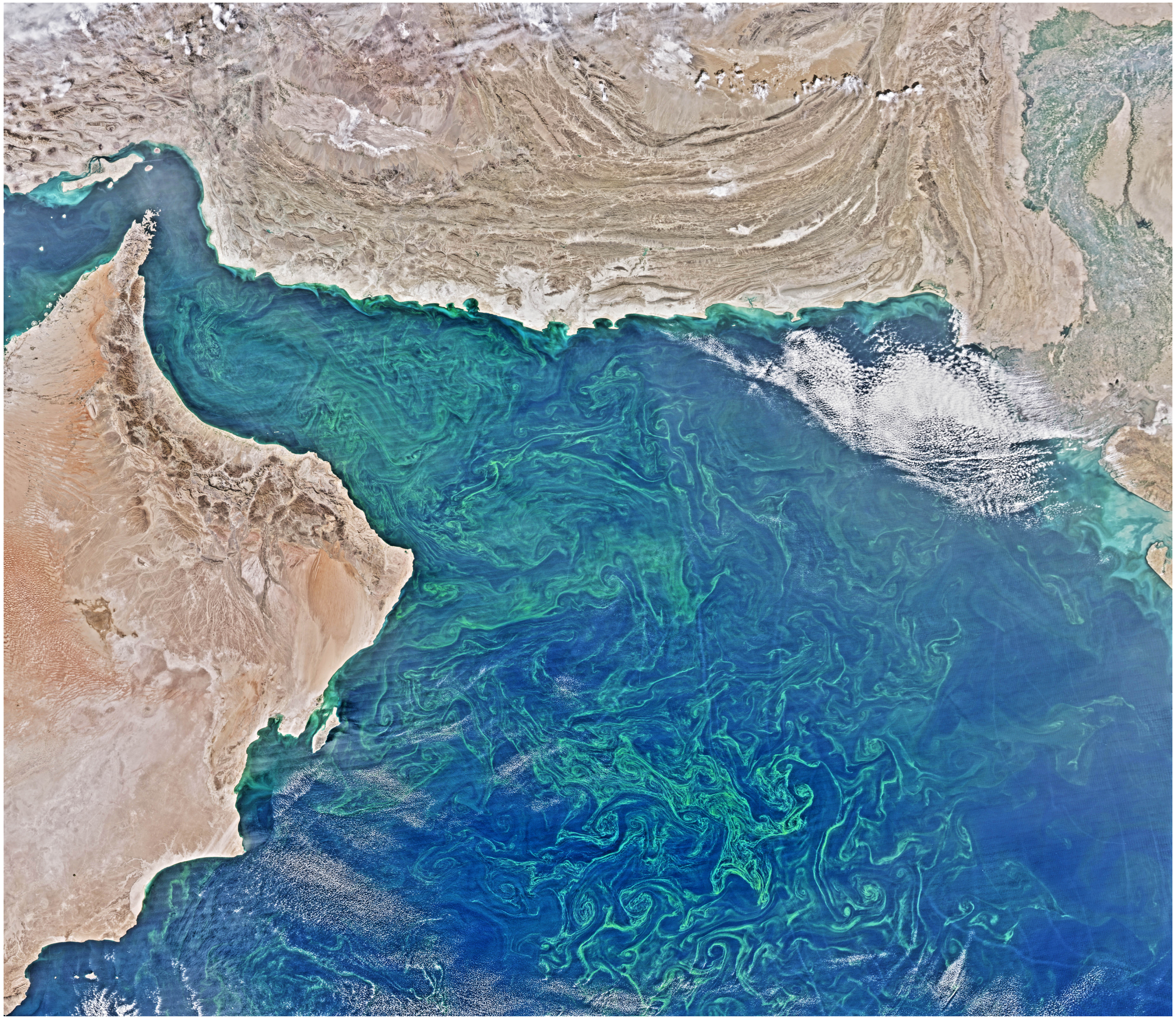
- Why are there blue and green colors?
- To what extent are these colors mixed?
- Why is the green concentrated near the coast?
- Why do those wiggles exist?
  - Why do they only appear to exist in places where the colors change?

And the deeper questions…



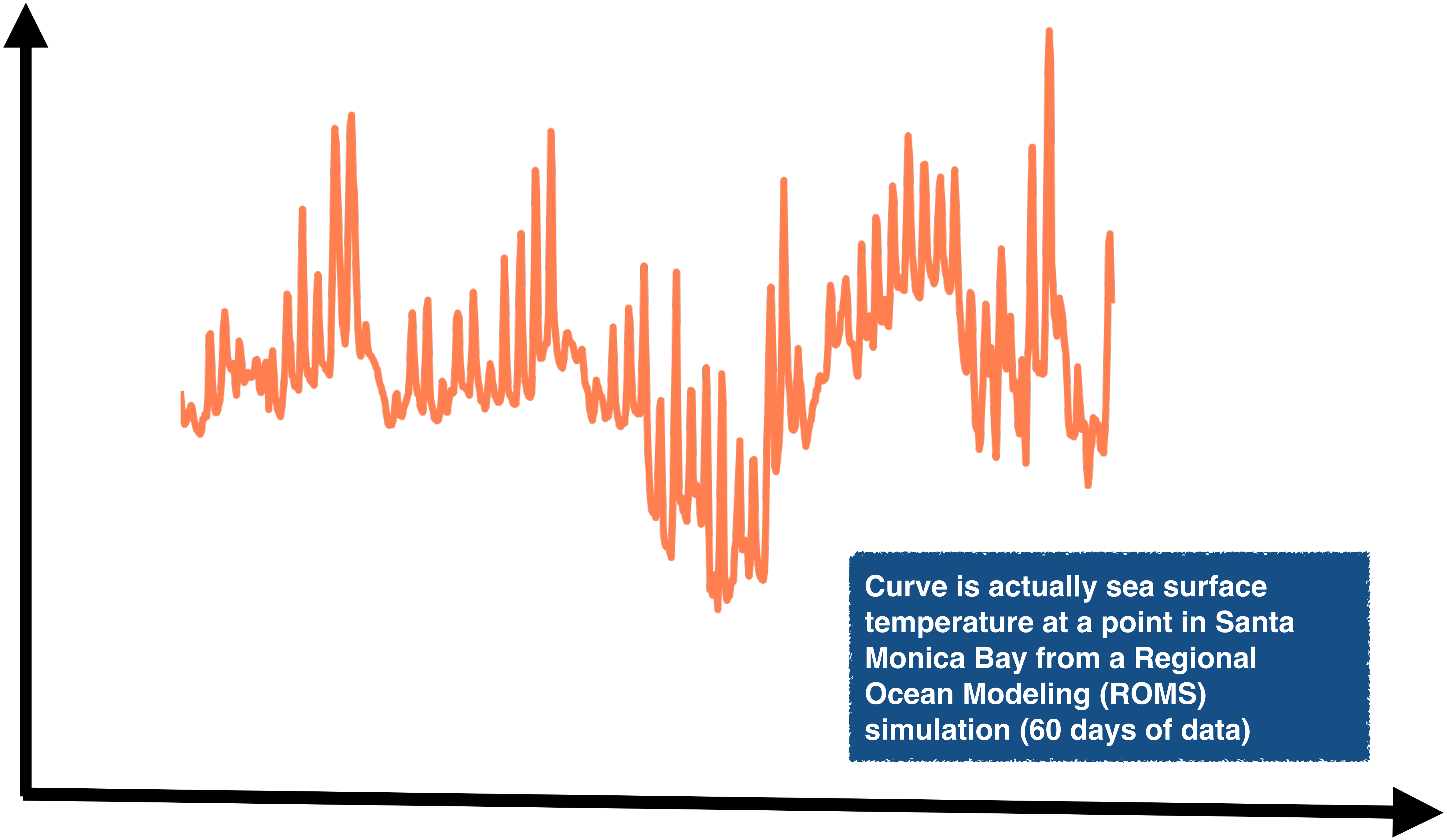
- Does one or a variety of processes in the ocean control this distribution of color?
  - What would this picture look like if only one of these processes was active?
  - How do these processes interact with each other to produce the picture we are looking at?

If we understand the processes governing the colors in previous picture can we similarly understand what's going on here as well?



Variability

WHAT PROCESSES DRAW THIS CURVE?



TIME OR SPACE

Curve is actually sea surface temperature at a point in Santa Monica Bay from a Regional Ocean Modeling (ROMS) simulation (60 days of data)

Let's imagine this curve represents the temperature of the ocean at the end of Santa Monica Pier.

Say you were extremely curious about the water temperature here and so you continued making these measurements for 100 years at the same location with the same frequency (e.g., every hour) and thus you extended this curve 100 years into the future.

After 100 years, you may be able to very confidently predict that the water at night is colder than during the day and that the water in September will be warmer than in December.

Which approach is more valuable to understanding the temperature of the ocean?

Now say that on the first day you went out to continue your measurements, you noticed that your skin got very warm during the day and you were very cold at night…you realized that the sun was heating you up during the day and the lack of sun made it colder at night.

You wonder if the sun has an analogous effect on the seawater…

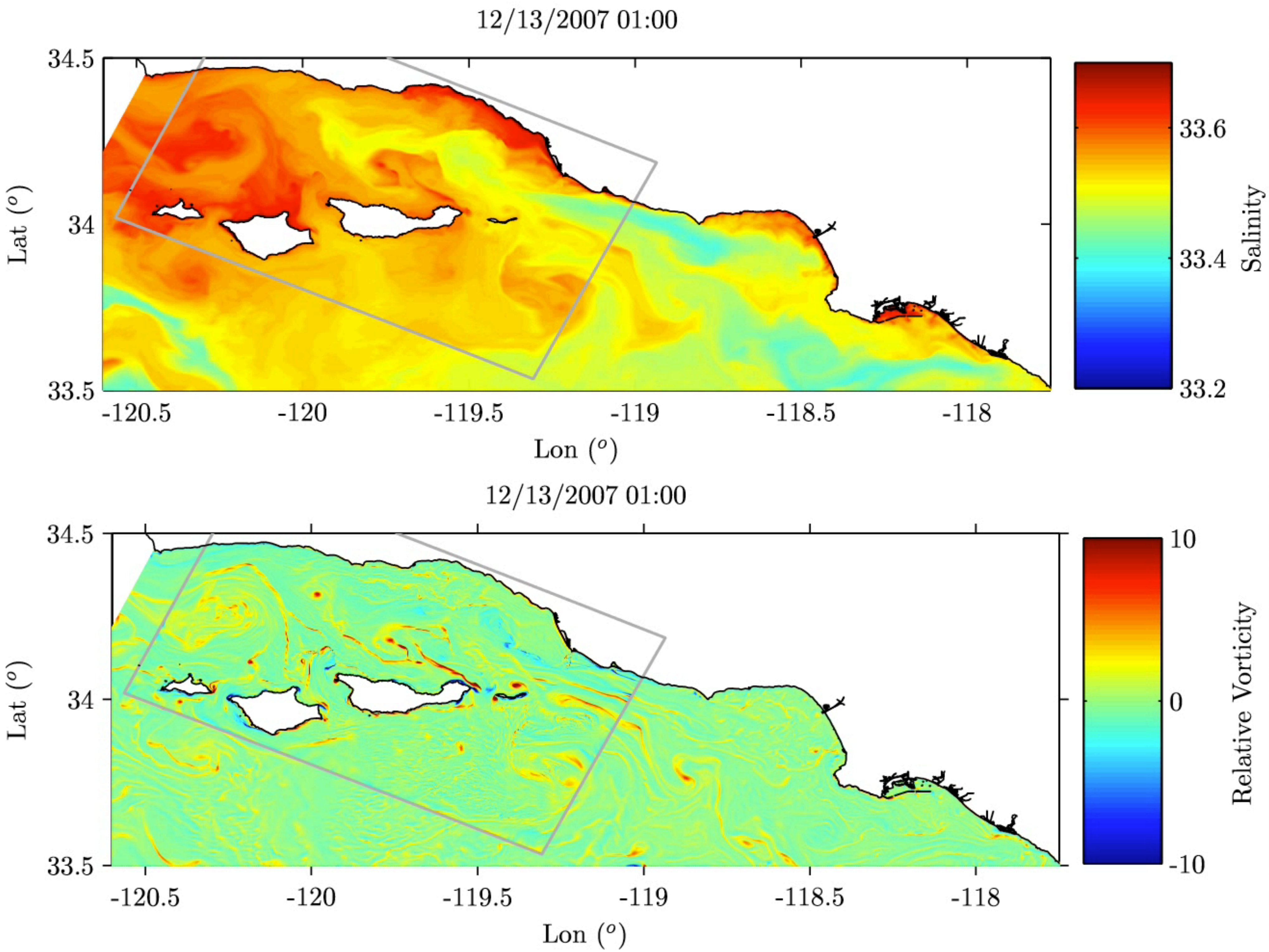
You then decide to abandon your plans for measurements and attempt to obtain a <u>mechanistic</u> understanding of the role of sunlight on temperature of seawater.

How is obsessing over the types of wiggles in a curve applicable to oceanography?

This is an ocean with no variability….

There's variability (wiggles) all over the ocean…

and different processes that contribute to each of them

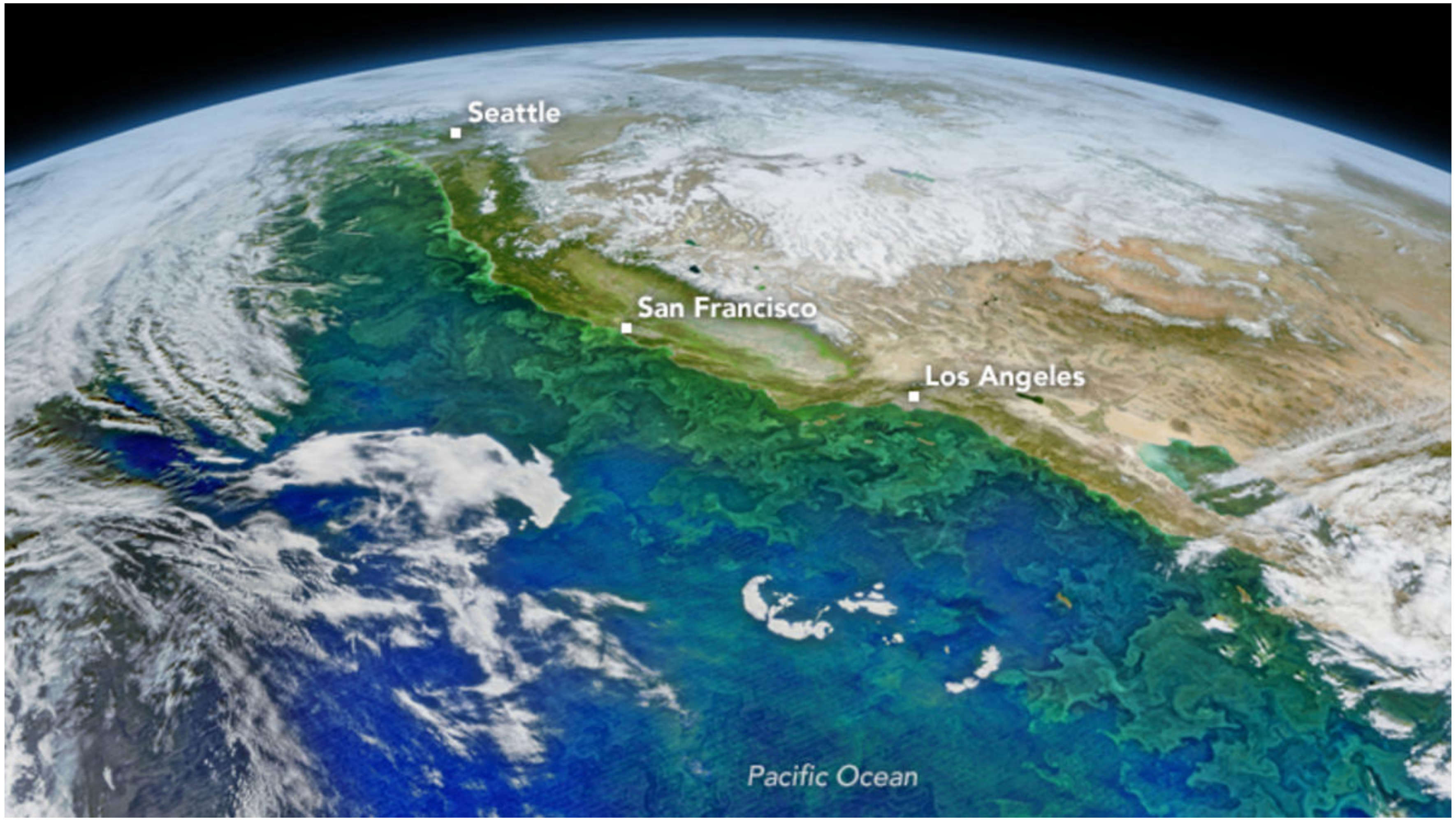


ROMS hindcast of the SouthernCalifornia Bight (Leonel Romero, UCSB)

A list of the different types of ocean variability you saw in that realization of the surface of the Southern California Bight

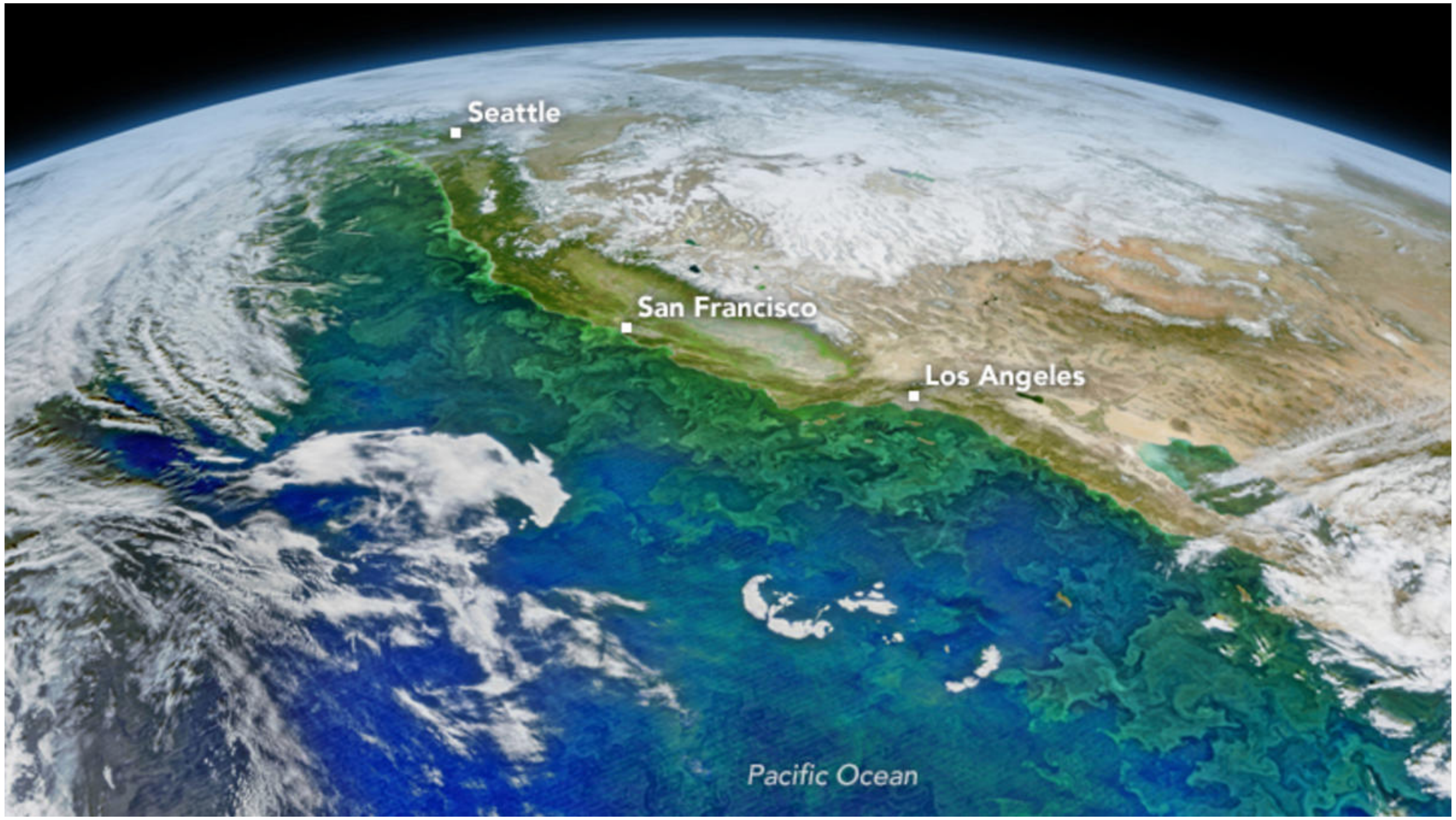
- Surface heating / cooling (daily flashing)
- Tides (daily onshore/offshore ‘jiggle’ of water mass)
- Geostrophic currents (flow parallel to surface density contours, e.g., large scale upcoast flow)
- Locally wind-driven currents (…not exactly visible to the eye in that movie)
- Coastal trapped waves (pulses of along-shore flow, also not obvious to the eye)
- Mesoscale eddies (vortexes ~ O(10 km))
- Submesoscale fronts and filaments (small scale (<O(1km)) wiggles of strong horizontal gradients in surface density and surface velocity)
- Topographic wakes (vortical structures flowing off tips of headlands and islands)
- Freshwater plumes (low salinity water masses originating at rivers and inlets at the coastline)

What <u>processes</u> draw this ocean?



- Does one or a variety of processes in the ocean control this distribution of color?
  - What would this picture look like if only one of these processes was active?
  - How do these processes interact with each other to give the picture we are looking at?

For brevity…let's give ourselves a shortcut...



- The green color is representative of phytoplankton
- Phytoplankton blooms occur during 'optimal' conditions that depend on light, nutrient availability, and the temperature of the seawater
- Generally, there's more nutrients in deeper, colder waters (because when plankton die they sink and get converted back to nutrients)

A toolbox

Inventory of (dynamical) ingredients

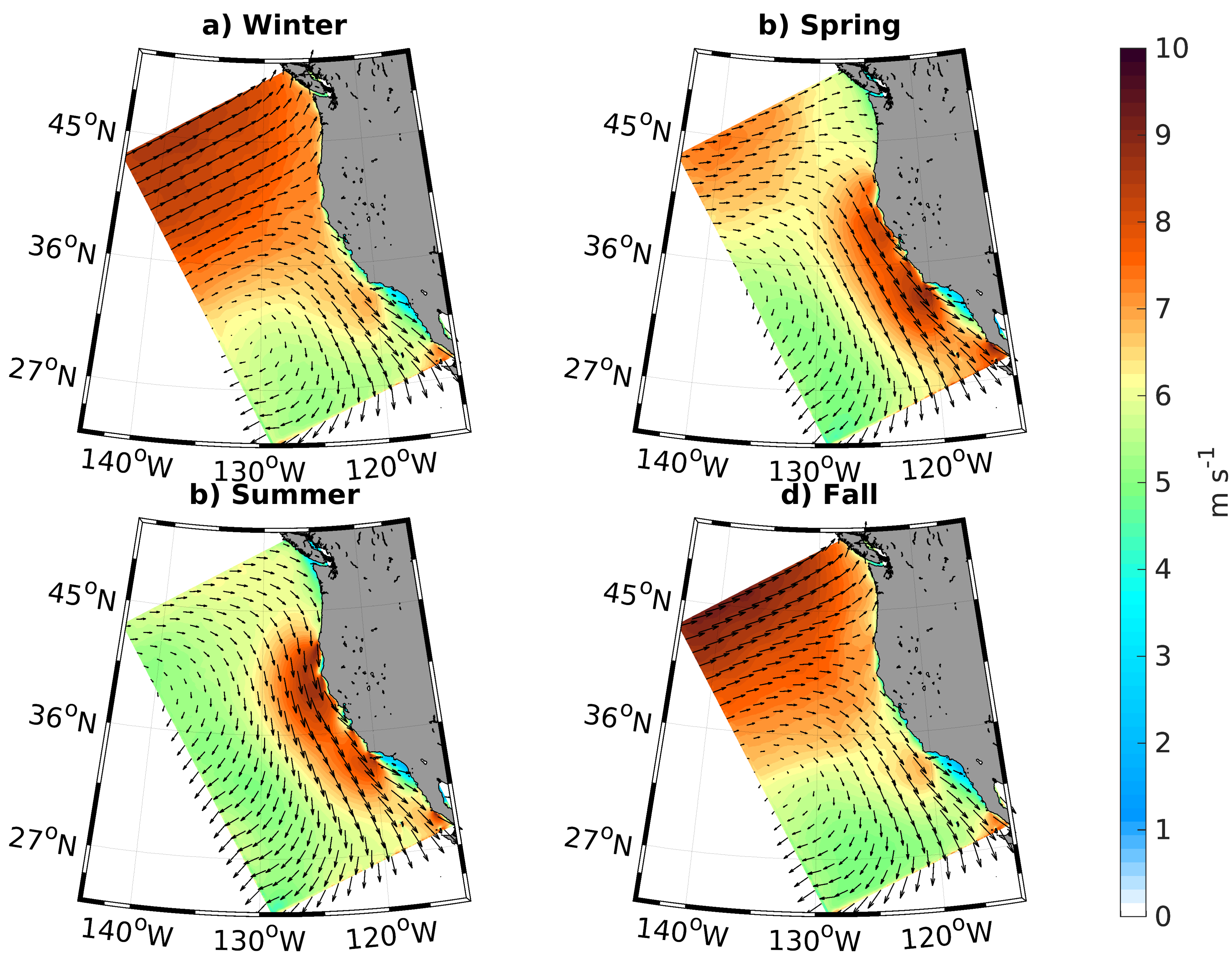
- Coastline
- Continental slope / shelf
- Rotation of earth
- Atmospheric forcing (wind, heat flux)
- Pressure gradient force

This is a simple, not exhaustive list

Inventory of 'truths'

- Things (mass, volume) are conserved
- forces drive movement (F = ma)
- pressure felt at depth = weight of water above
- Turbulence (seemingly chaotic stuff) is a thing

Wind is always a good place to start…

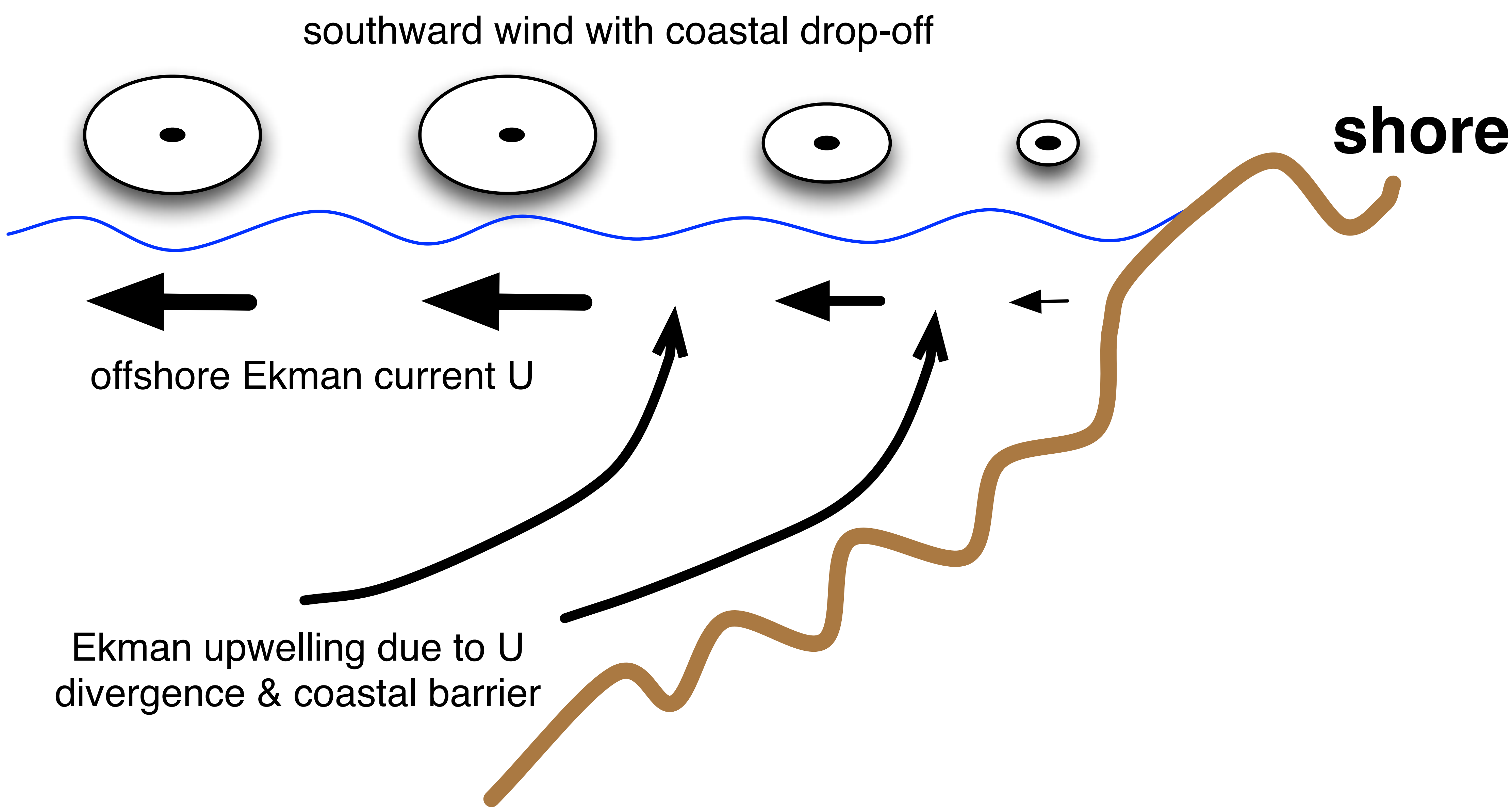


Ingredients: solar heating, earth's rotation, pressure gradient force

Truths: F =ma

What currents will the wind drive?

Ekman currents



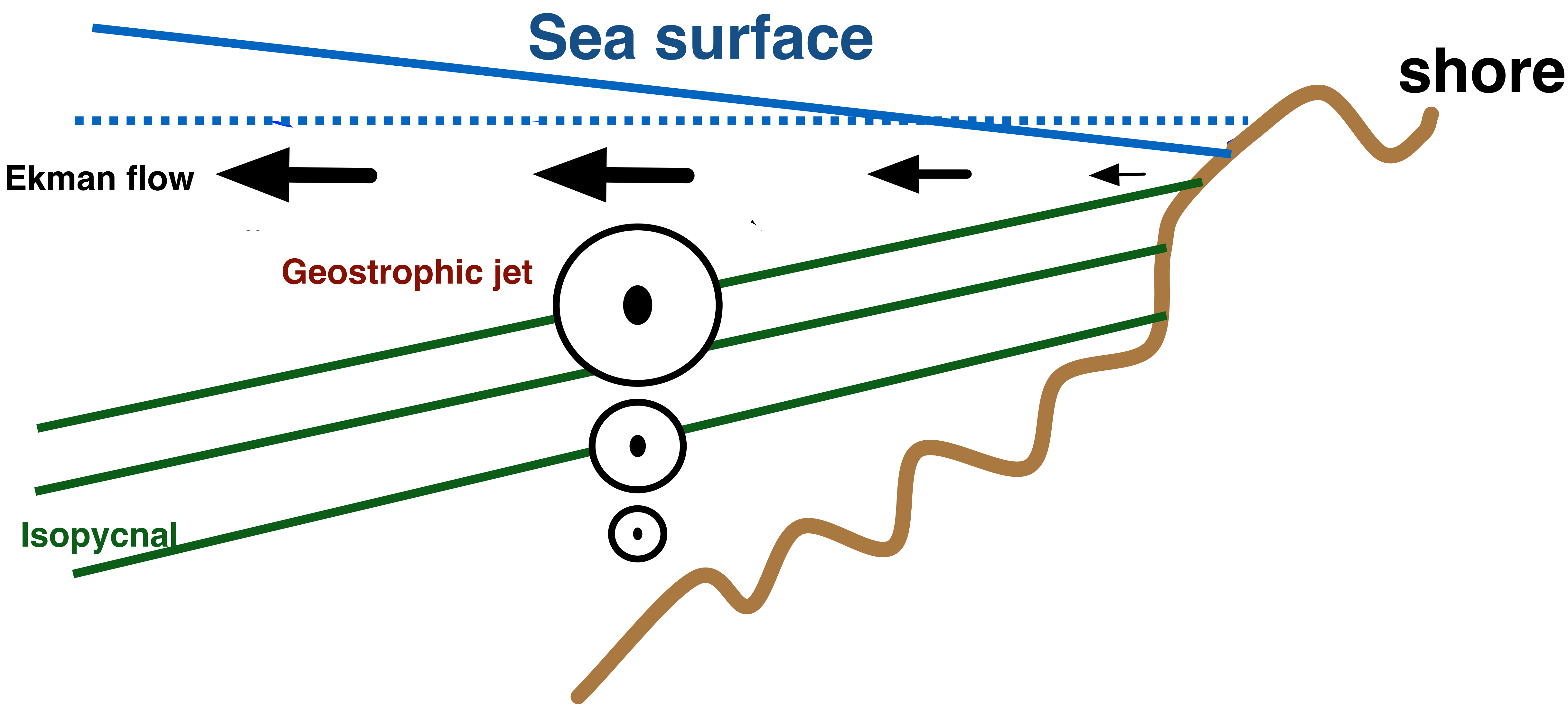
Ingredients: coastline, wind, earth's rotation

Truths: conservation of mass, F=ma

Artwork by Jim McWilliams

What currents will the wind drive?

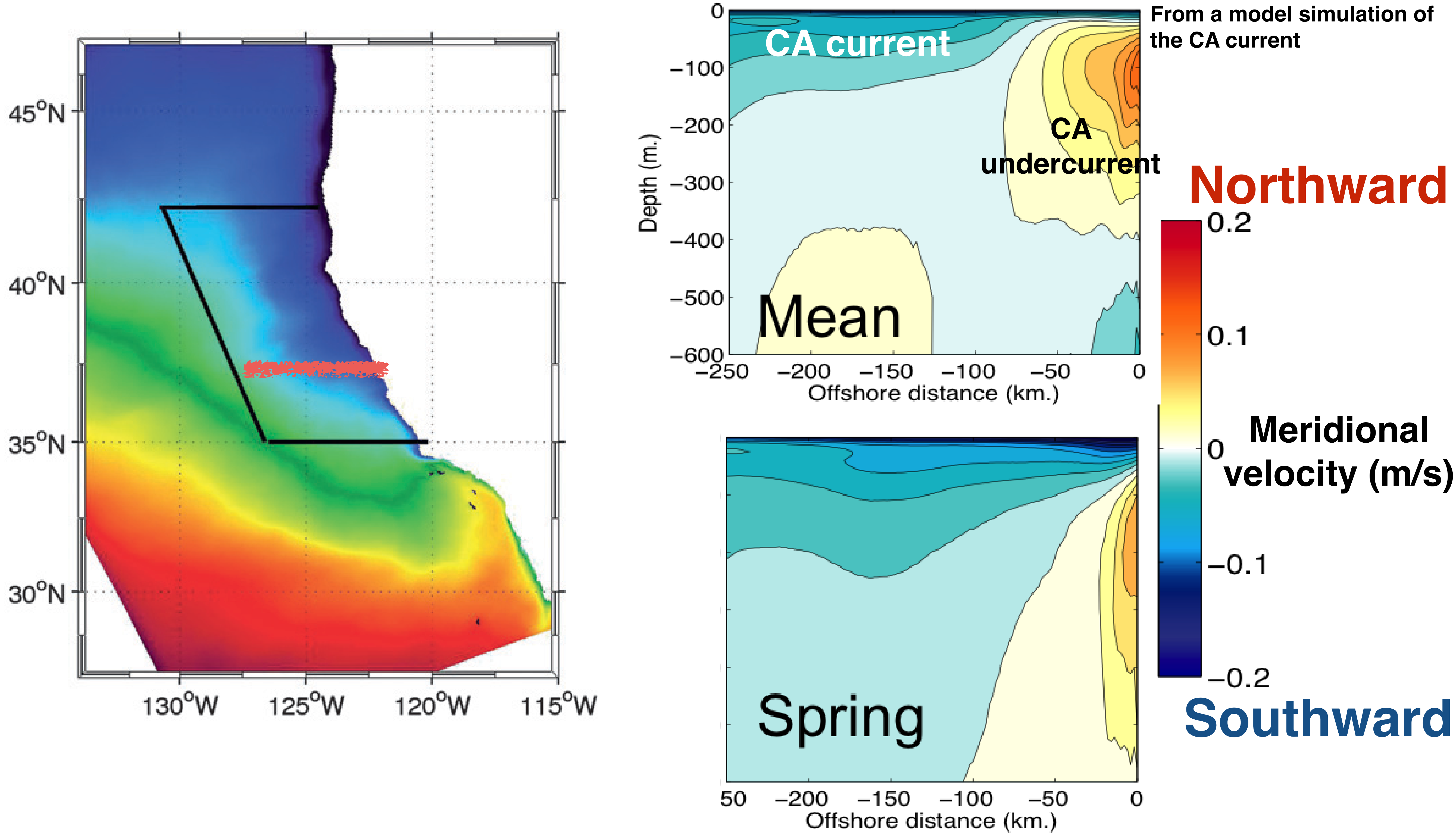
Ekman currents set up conditions for geostrophic currents



Ingredients: coastline, earth's rotation, pressure gradient force

Truths: conservation of mass, hydrostatic balance

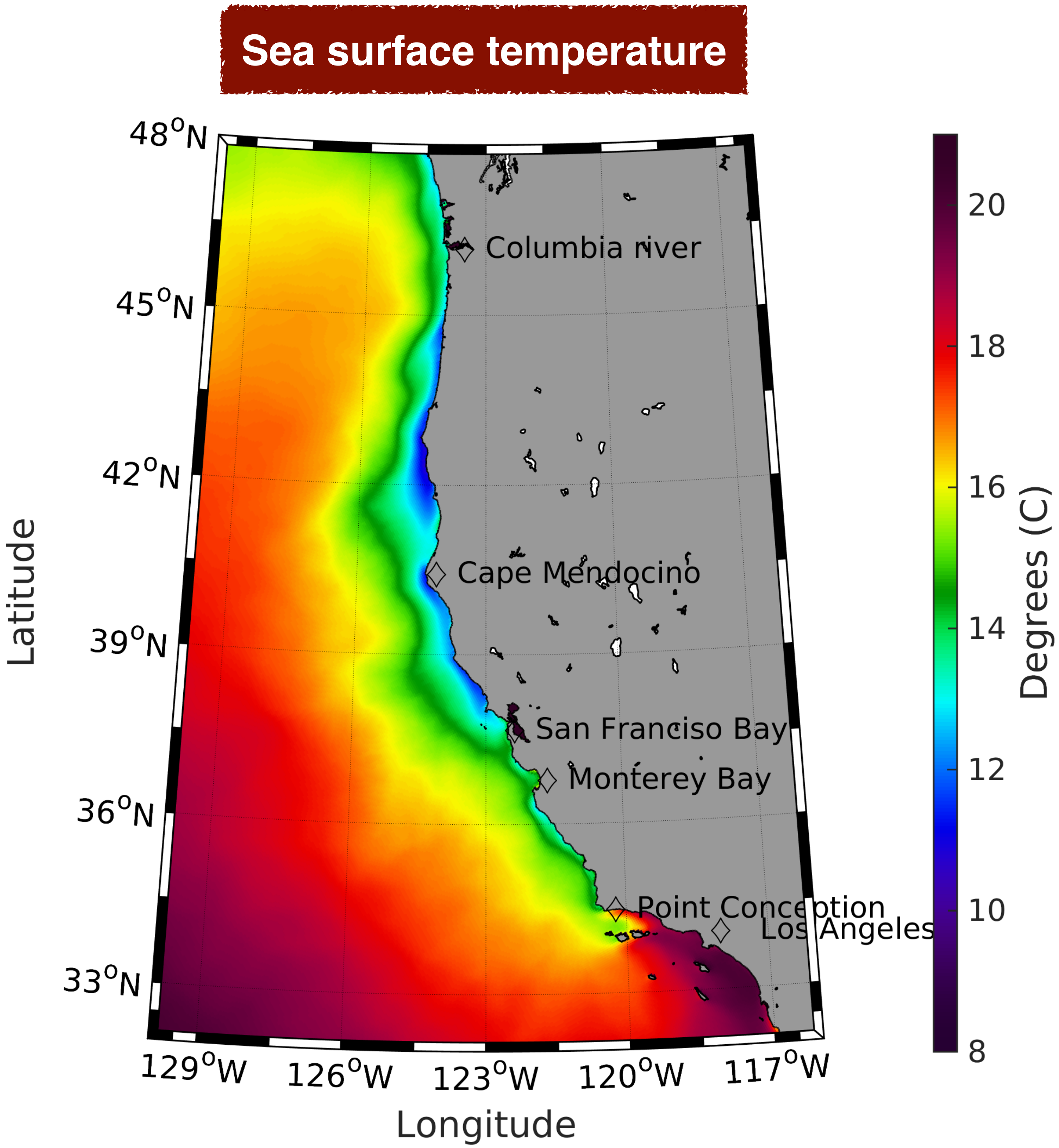
CA current geostrophic velocity



Ingredients: coastline, earth's rotation, pressure gradient force

Truths: conservation of mass, hydrostatic balance, F=ma

How does the CA coastal ocean look if only wind-forced (Ekman) and pressure-gradient forced (gestrophic) currents existed?



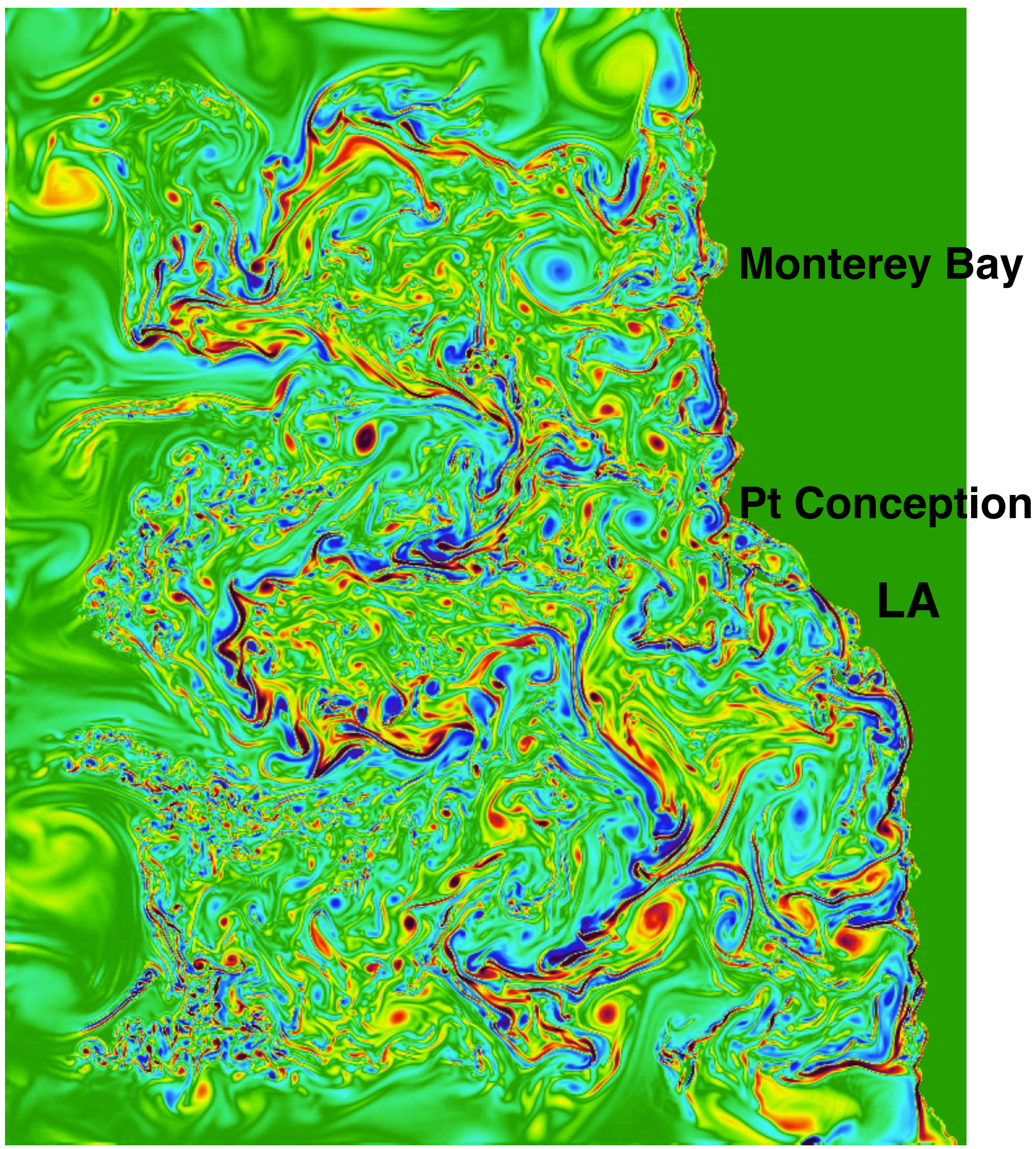
Ingredients: coastline, earth's rotation, pressure gradient force, solar heating

Truths: conservation of mass, hydrostatic balance, F=ma

But…it really looks like this (why?)

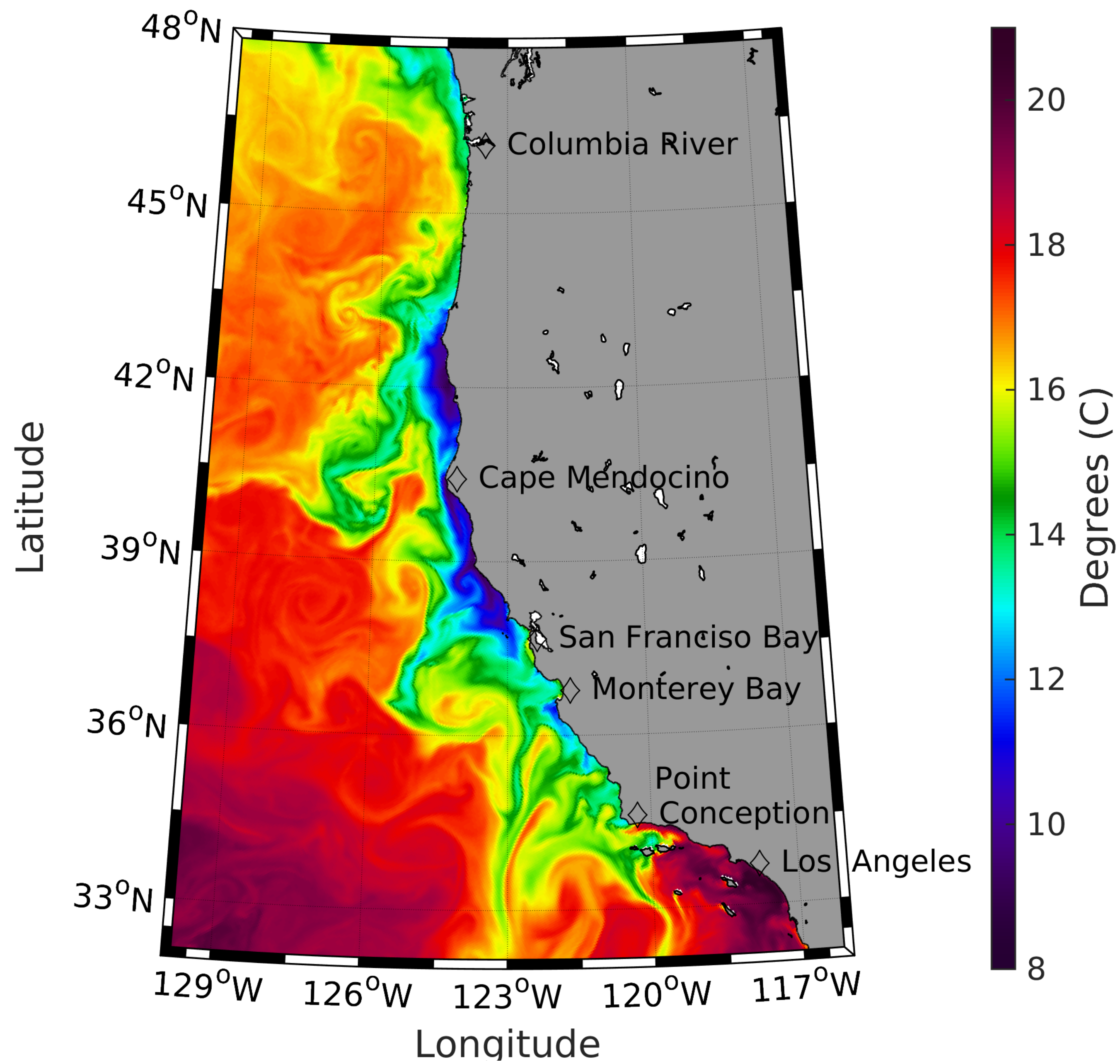
Turbulence is a thing

Surface relative vorticity



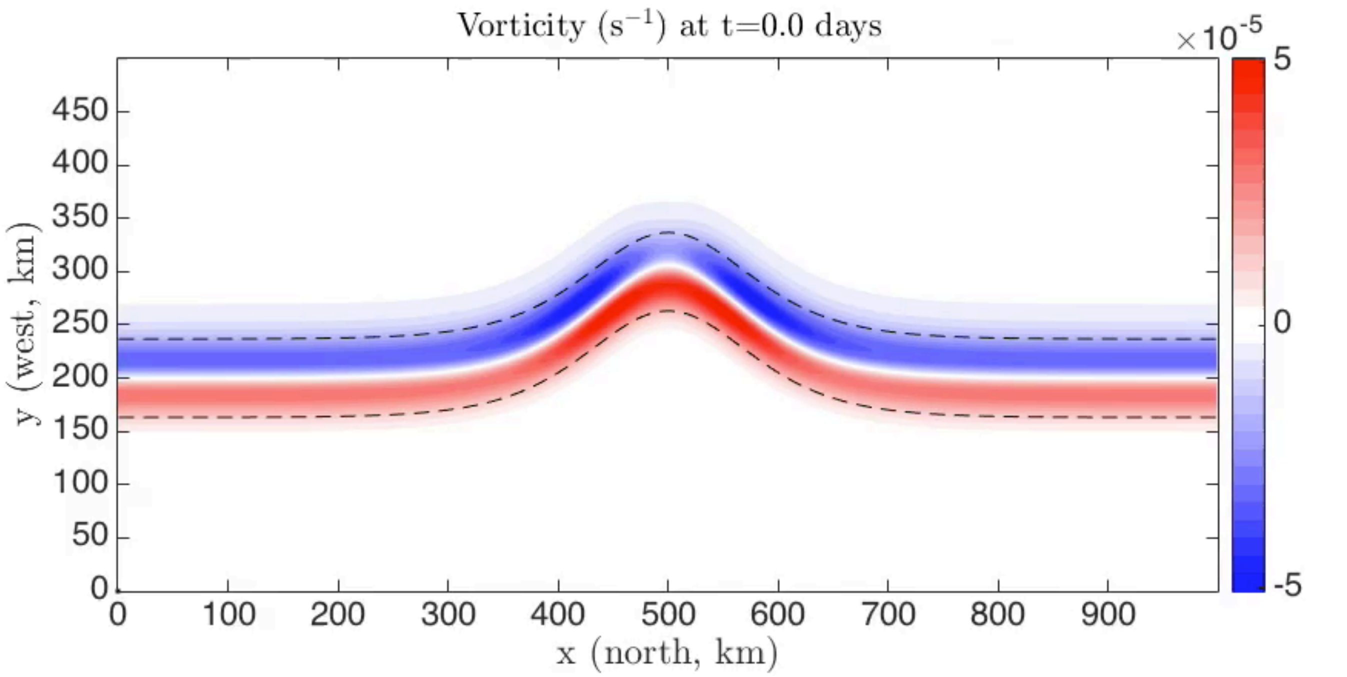
ROMS simulation (1.5 km horizontal resolution)

Sea surface temperature

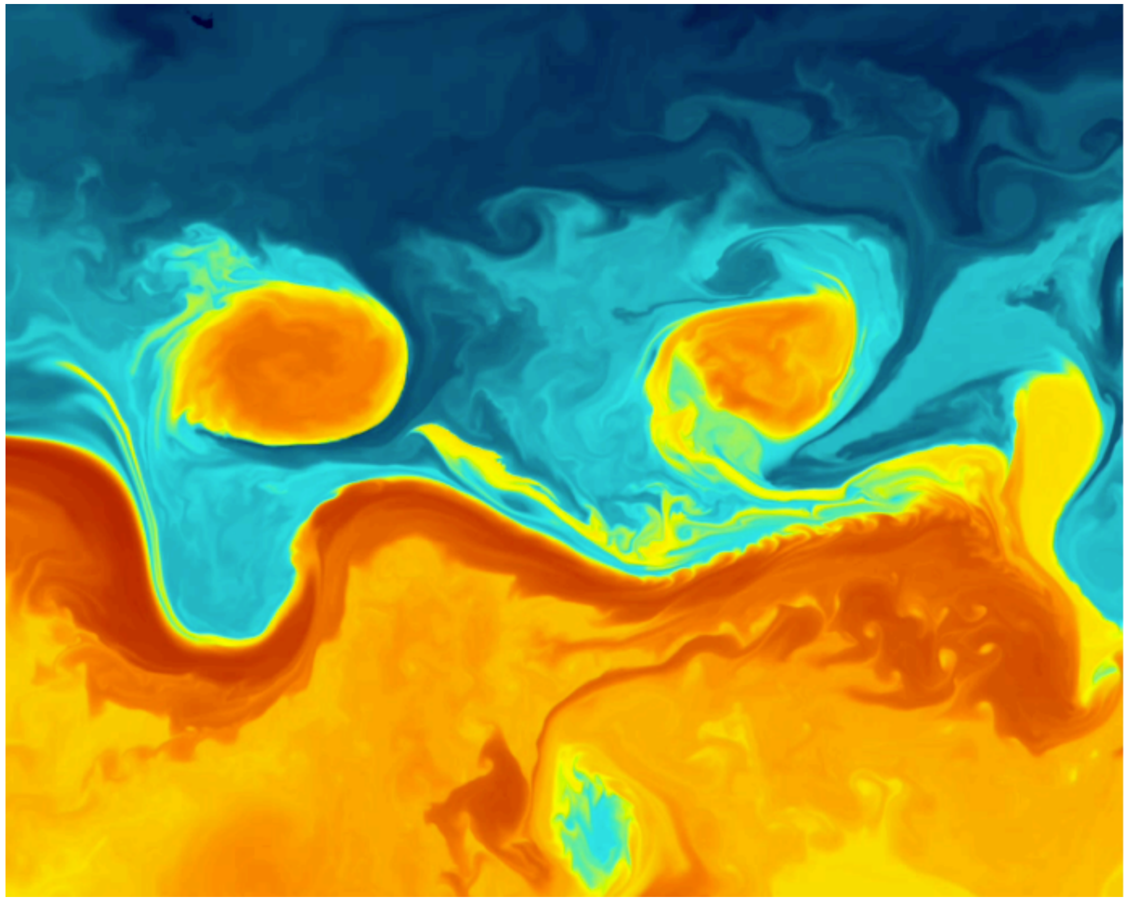


Why is turbulence a thing in this case?

Geostrophic currents can be prone to <u>instabilities</u> that produce <u>eddies</u>



Your HW assignment, coded by Prof. Stewart



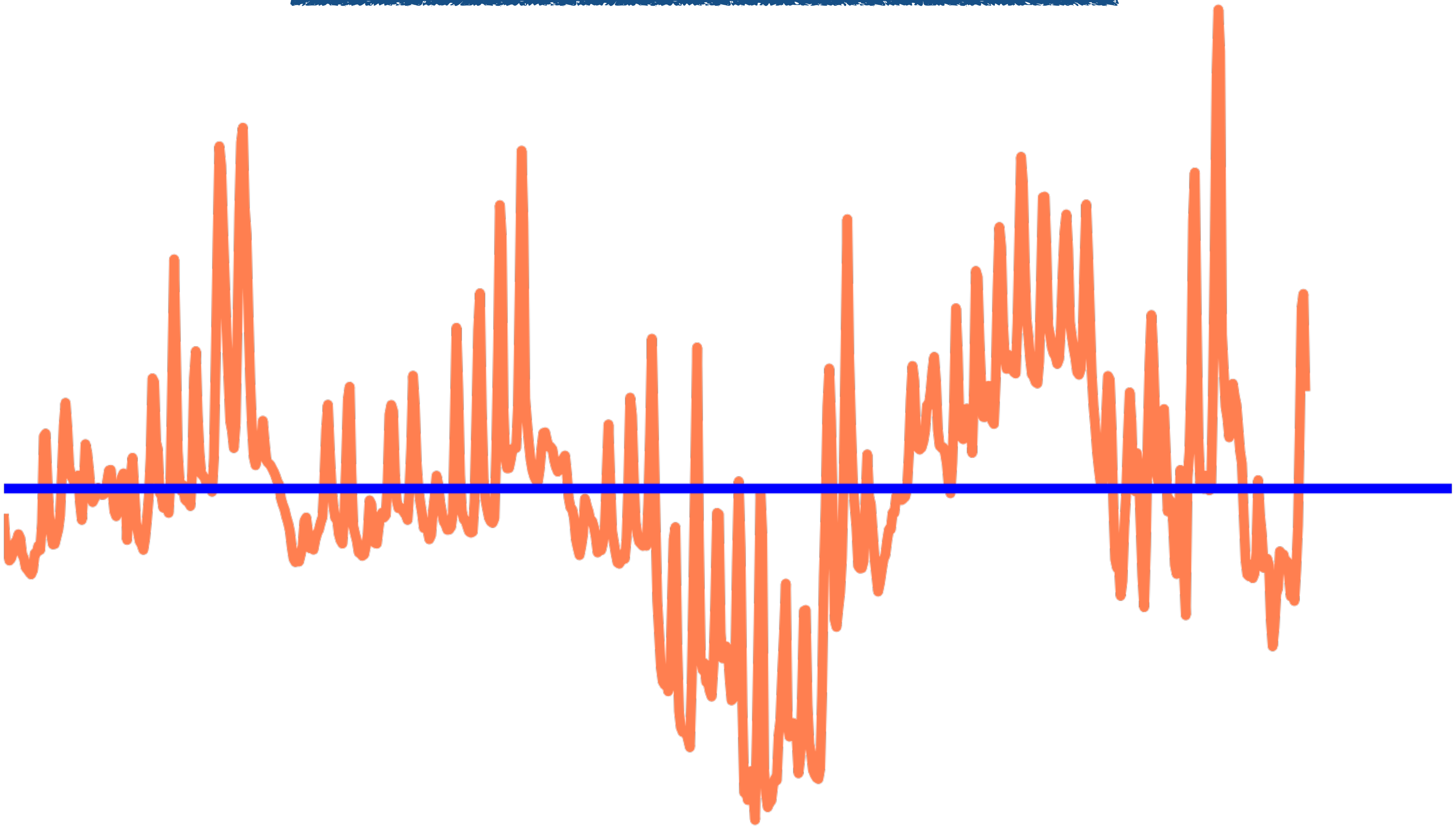
ROMS Gulf Stream eddies (simulation and figure by Jon Gula)

Ingredients: earth's rotation, pressure gradient force

Truths: turbulence, F=ma, conservation of volume, hydrostatic balance

Defining eddies

eddy = anything that is not the mean



$$a = \overline{a} + a'$$

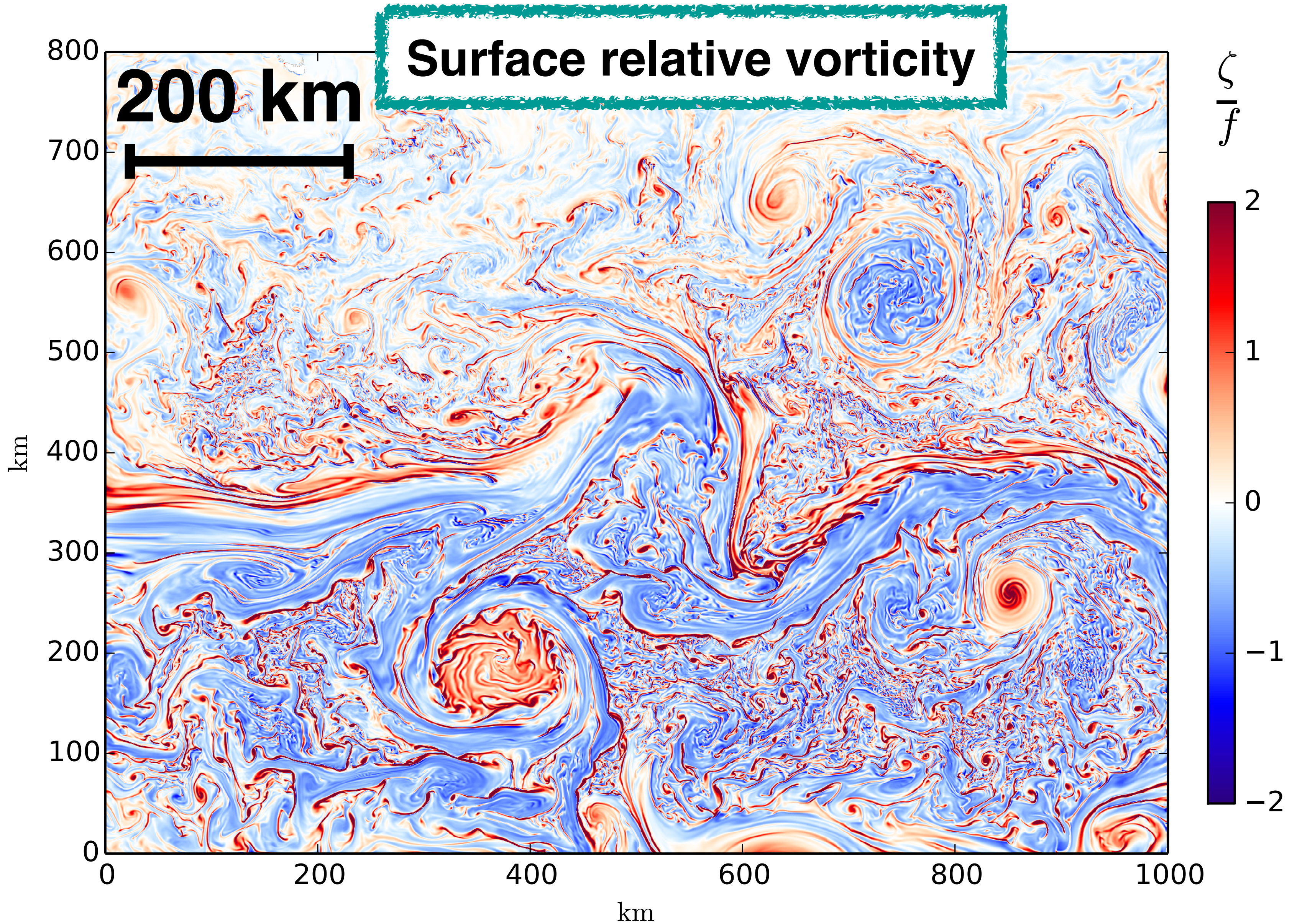
mean eddy

Defining eddies

eddy ~ repeatedly arising preferred spatial pattern (“coherent structure”)

mesoscale eddy = coherent vortex O(10-100 km) in spatial scale that lives for O(months)

submesoscale eddy = coherent structure O(10 m - 1km) in spatial scale that lasts for O(days)



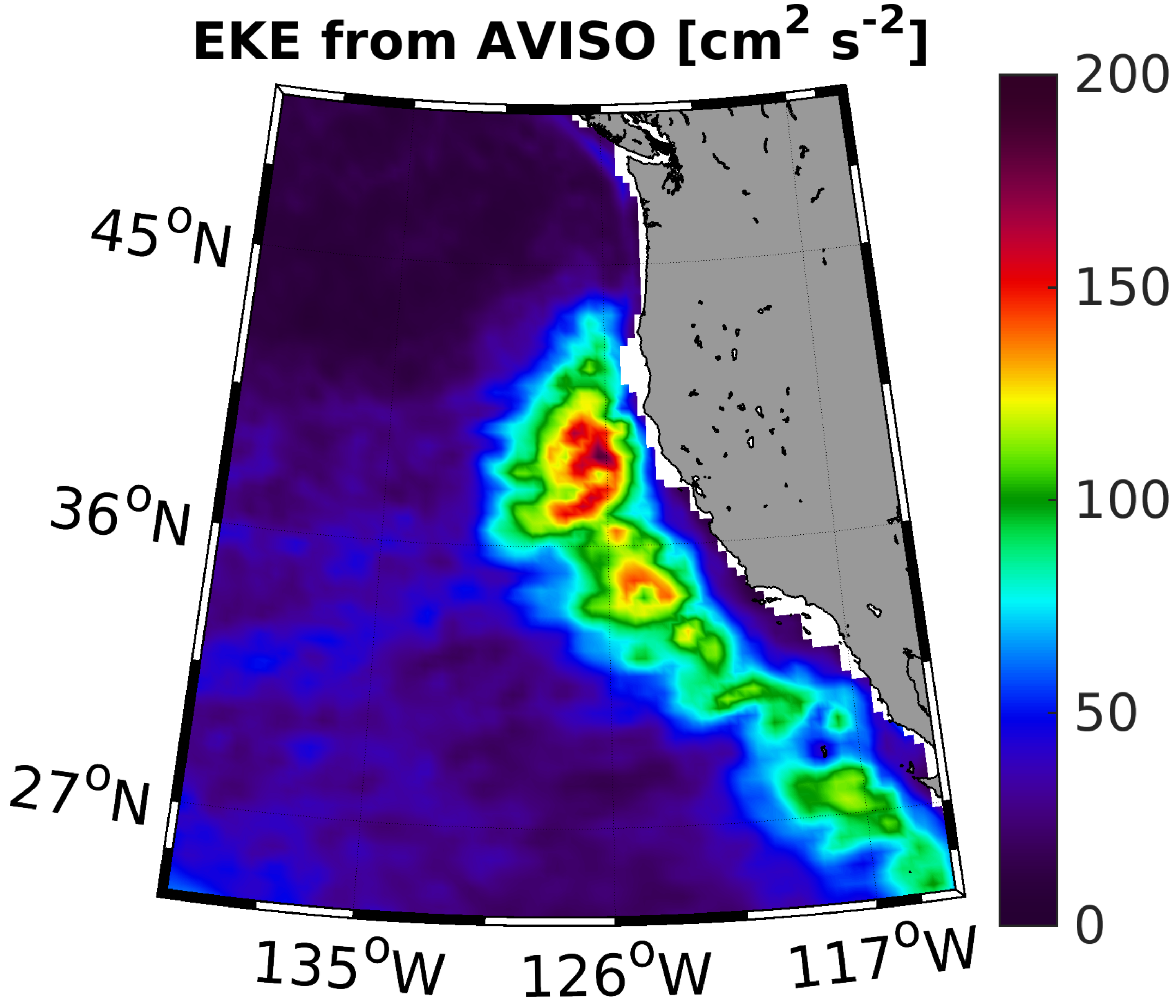
ROMS simulation of the Gulf Stream with a horizontal resolution of 250m (Jon Gula)

McWilliams (2016)

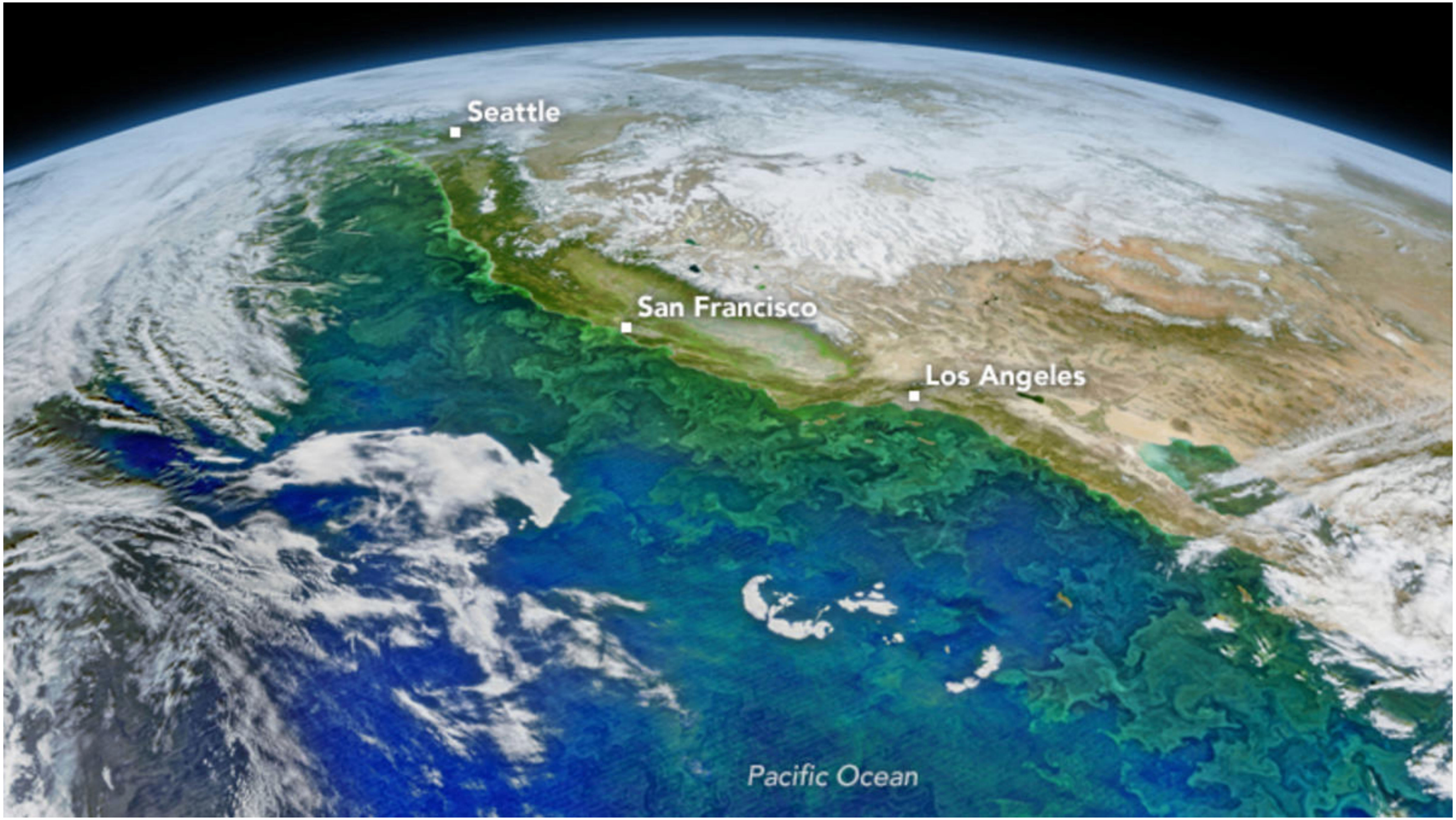
Diagnosing eddy activity in the CA current

Eddy Kinetic Energy (EKE)

$$\mathrm{EKE} = \frac{1}{2}\left(\mathrm{u}'^2 + \mathrm{v}'^2\right)$$



Do the eddies affect the CA current in a systematic way?



Isolating eddy effects

Method 1

$$a = \overline{a} + a'$$

Theoretical approach: plug this relation into equations of fluid motion and isolate eddy terms

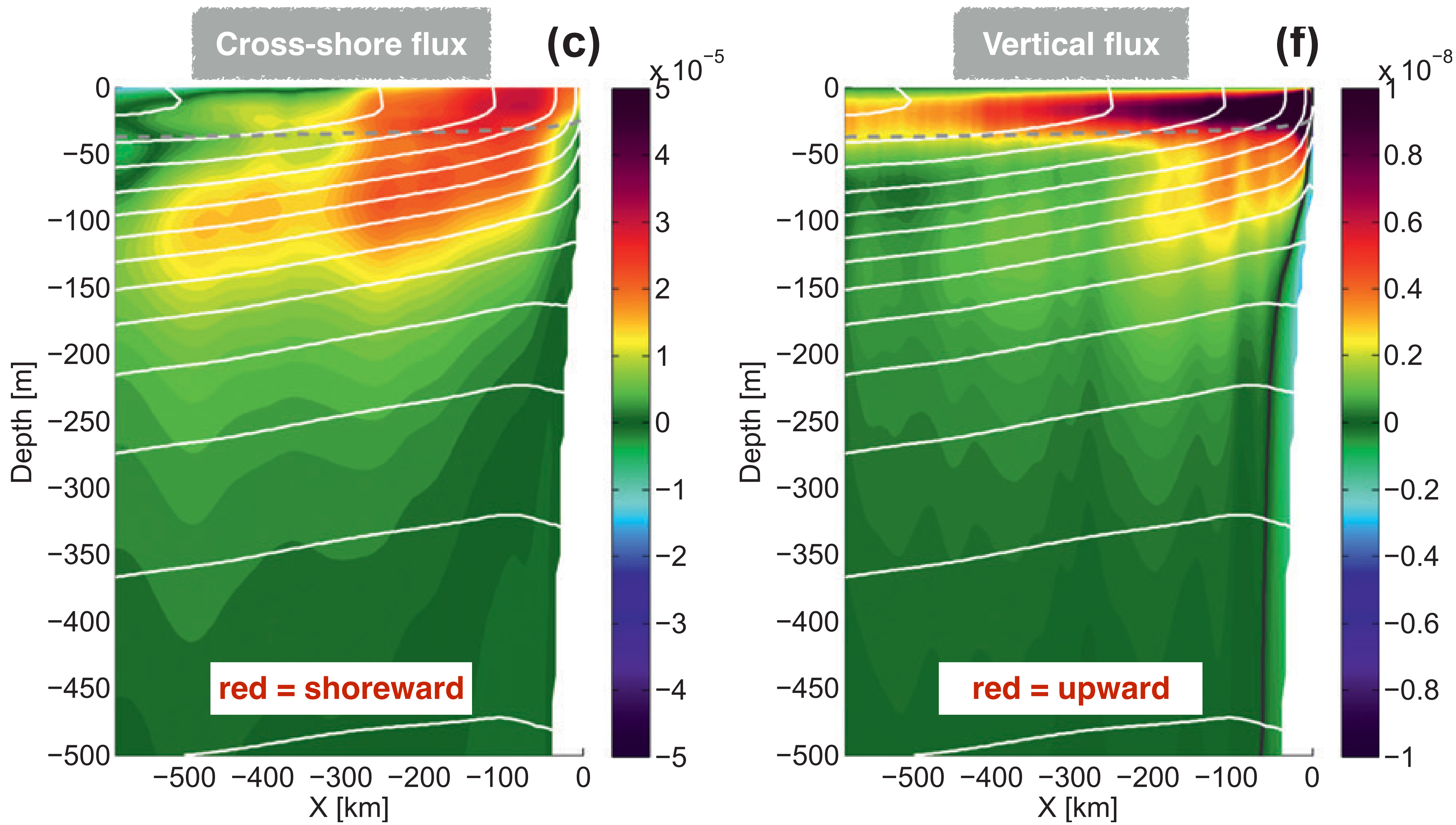
Observational approach: subtract mean from observations to get eddies

Method 2

Numerical modeling approach: Turn off term in equations of fluid motion that cause turbulence (eddies)

Do the eddies affect the CA current in a systematic way?

Eddy fluxes of buoyancy (m²/s³)



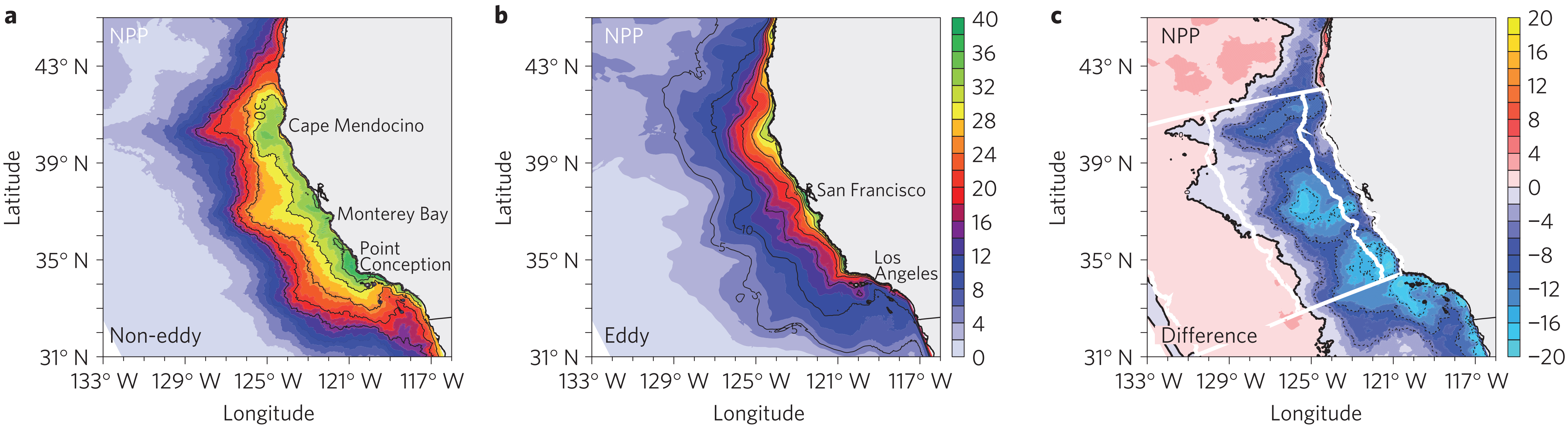
CA current eddies will flux heat upwards and towards the shore (opposing the mean upwelling circulation)

Colas et al. 2013

Do the eddies affect the CA current in a systematic way?

Eddy impact on net primary production (NPP)

No eddies | **eddies** | **eddy minus no eddy**

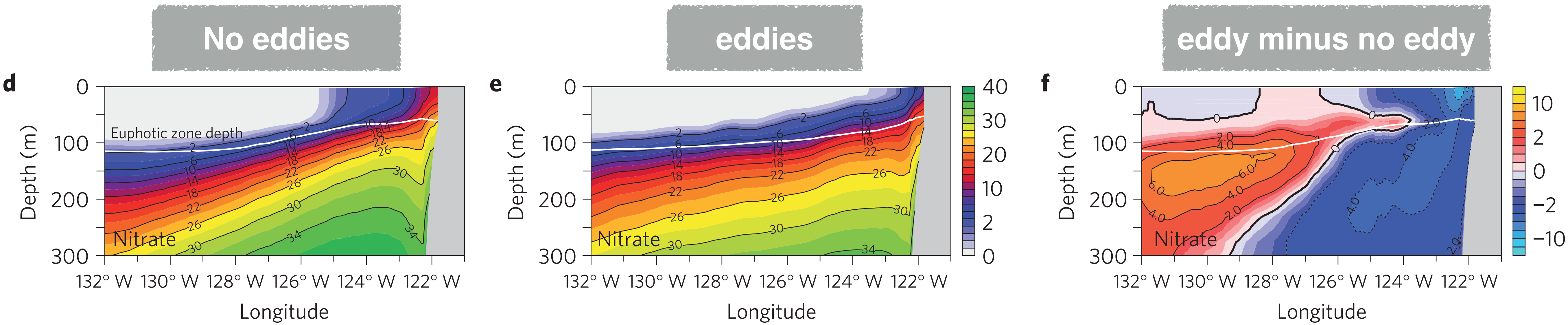


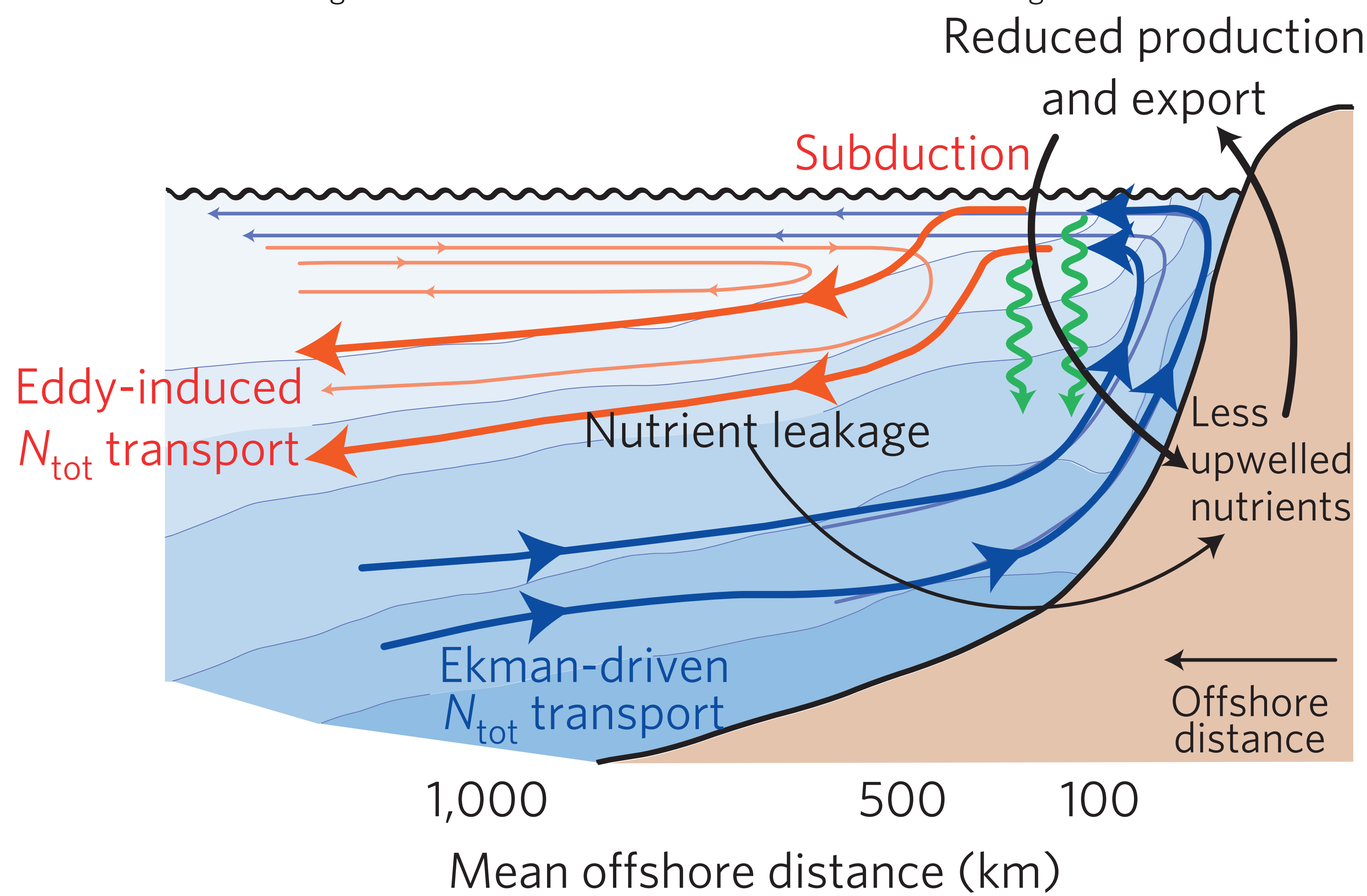
NPP reduced in an CA current system with eddies

Gruber et al. 2011

Do the eddies affect the CA current in a systematic way?

Eddy impact on nitrate

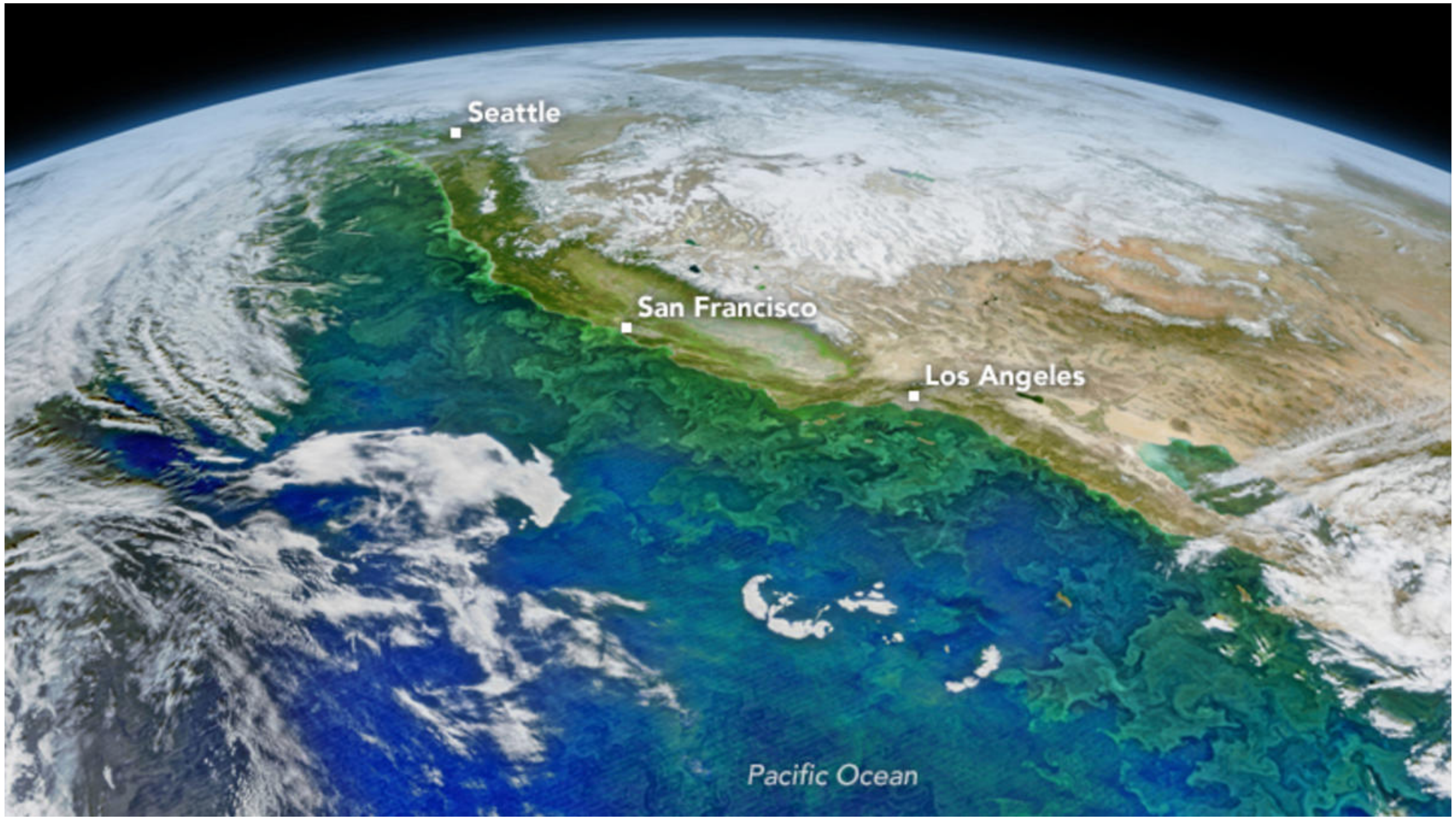




Reason eddies reduce NPP: the eddies remove a nutrient needed for photosynthesis (nitrogen) from the place where photosynthesis happens (euphotic zone)

Gruber et al. 2011

WHAT PROCESSES DRAW THIS OCEAN?



- Does one or a variety of processes in the ocean control this distribution of color?
  - What would this picture look like if only one of these processes was active?
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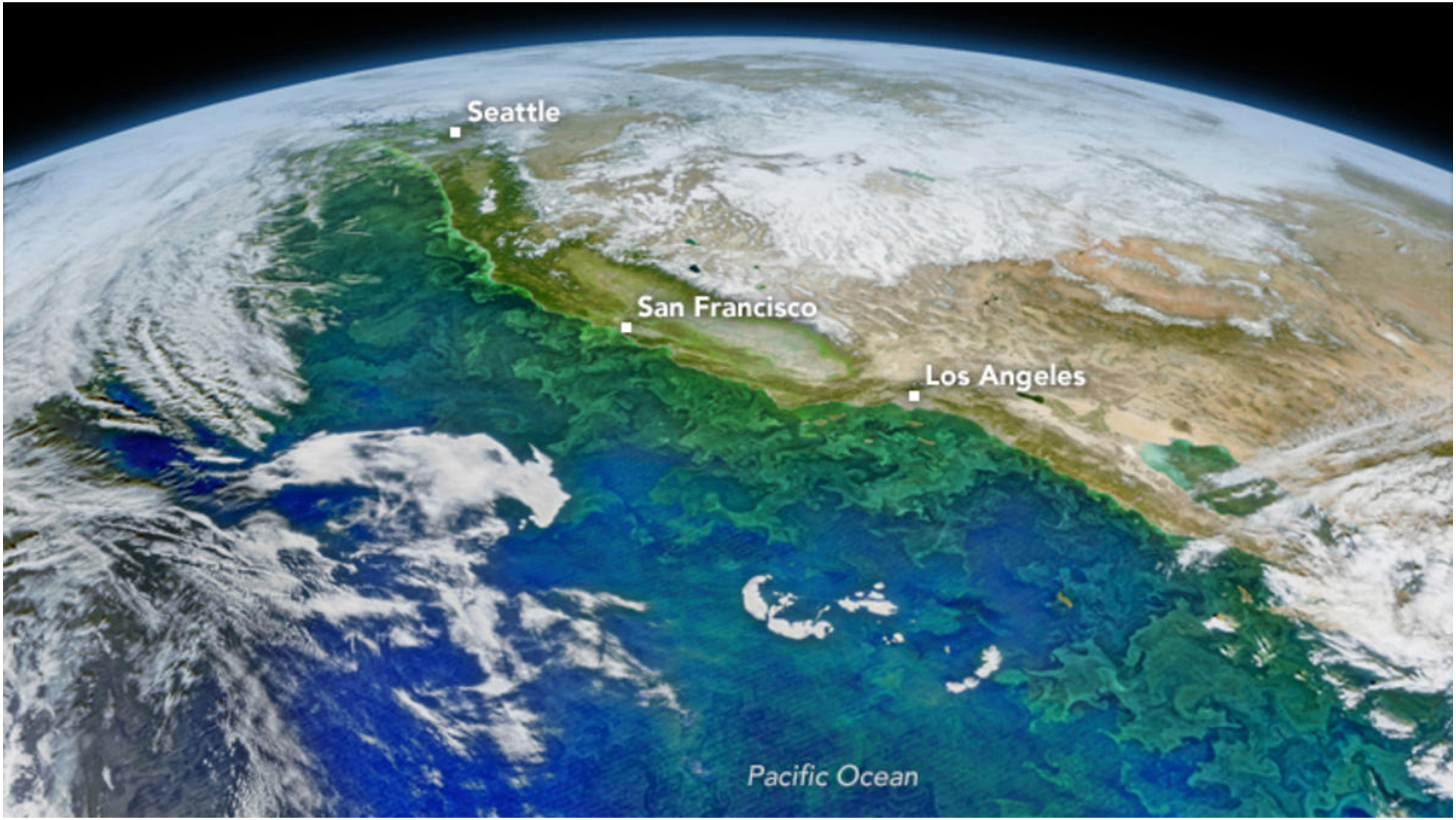
Have we talked about all the variability?



What happens when you have a finer-scale view of things?

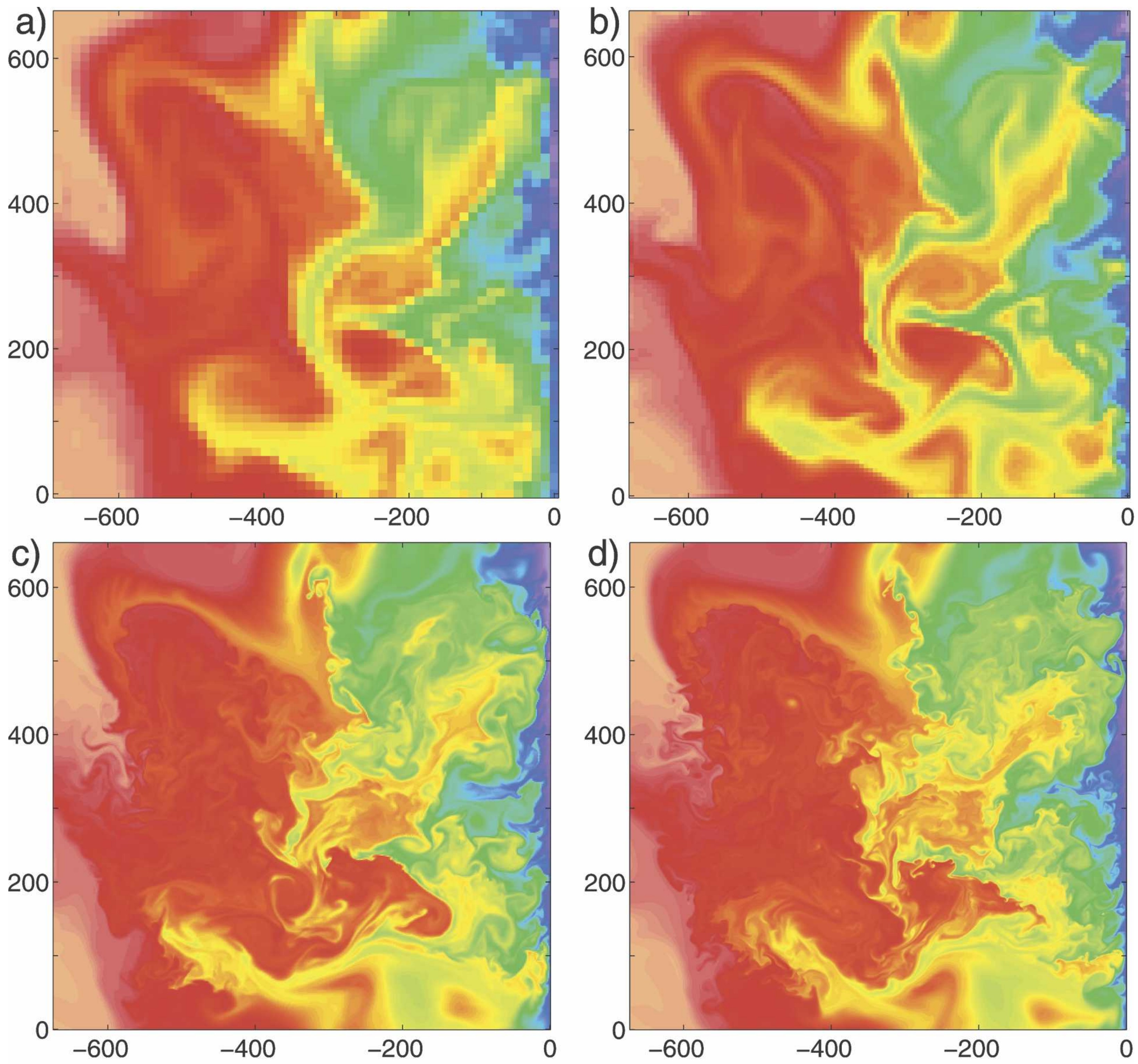
Sea surface temperature in an idealized eastern boundary current upwelling system (analogous to the CA current system) at different horizontal resolutions

12 km

6 km

1.5 km

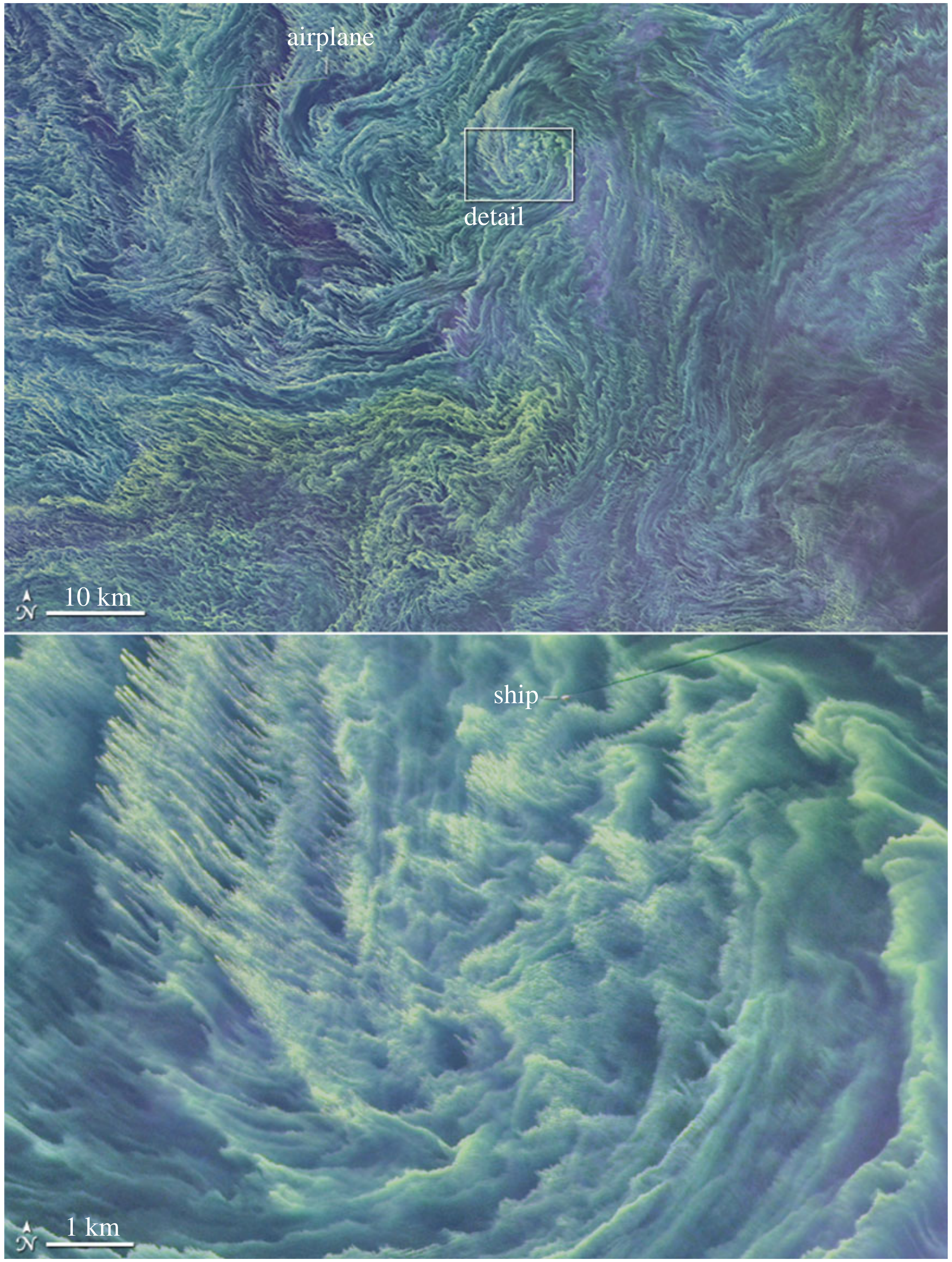
0.75 km



Capet et al. 2008a

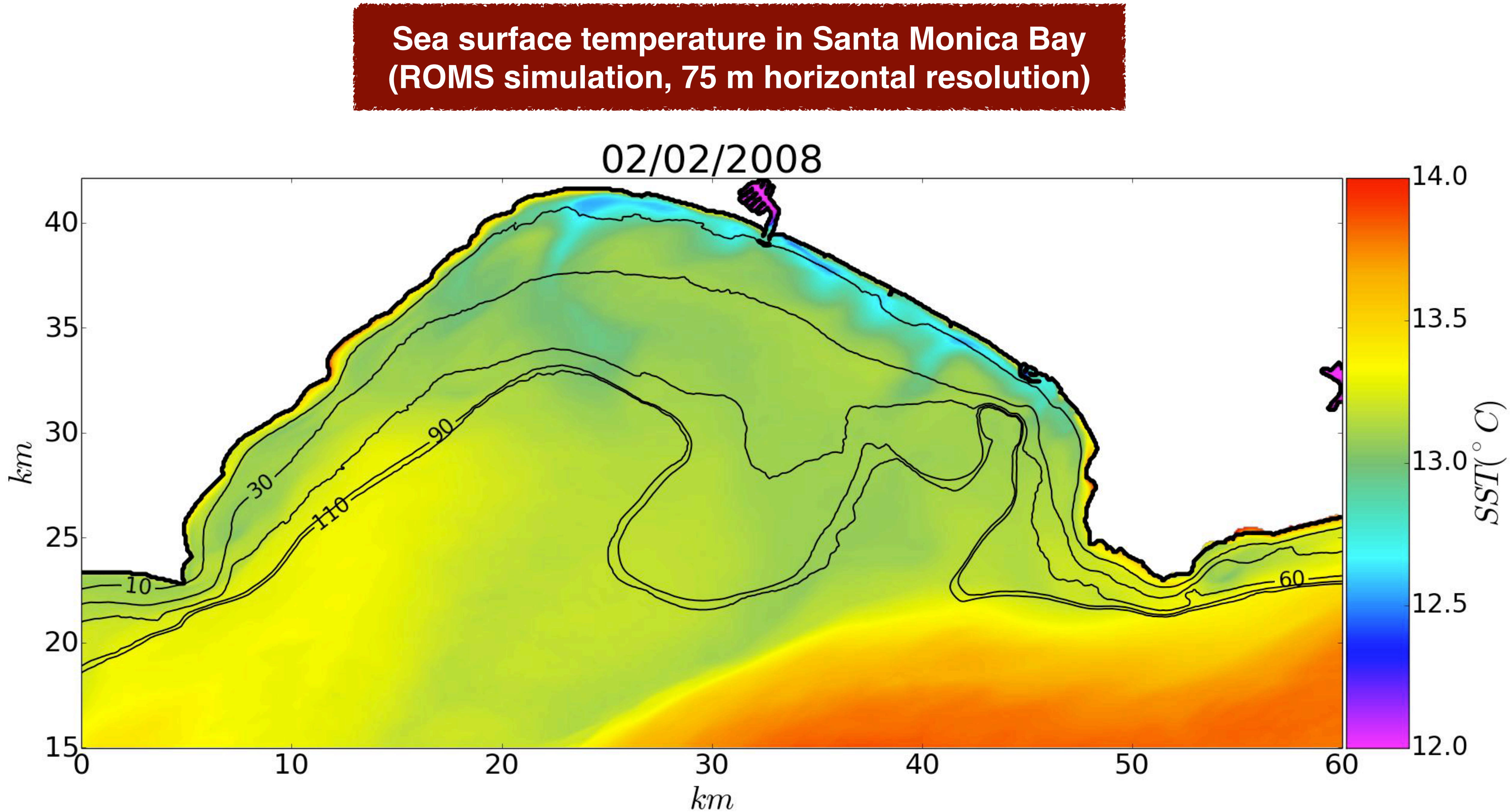
What happens when you have a finer-scale view of things?

Bloom of cyanobacteria in Baltic Sea



McWilliams (2016)

Submesoscale Currents



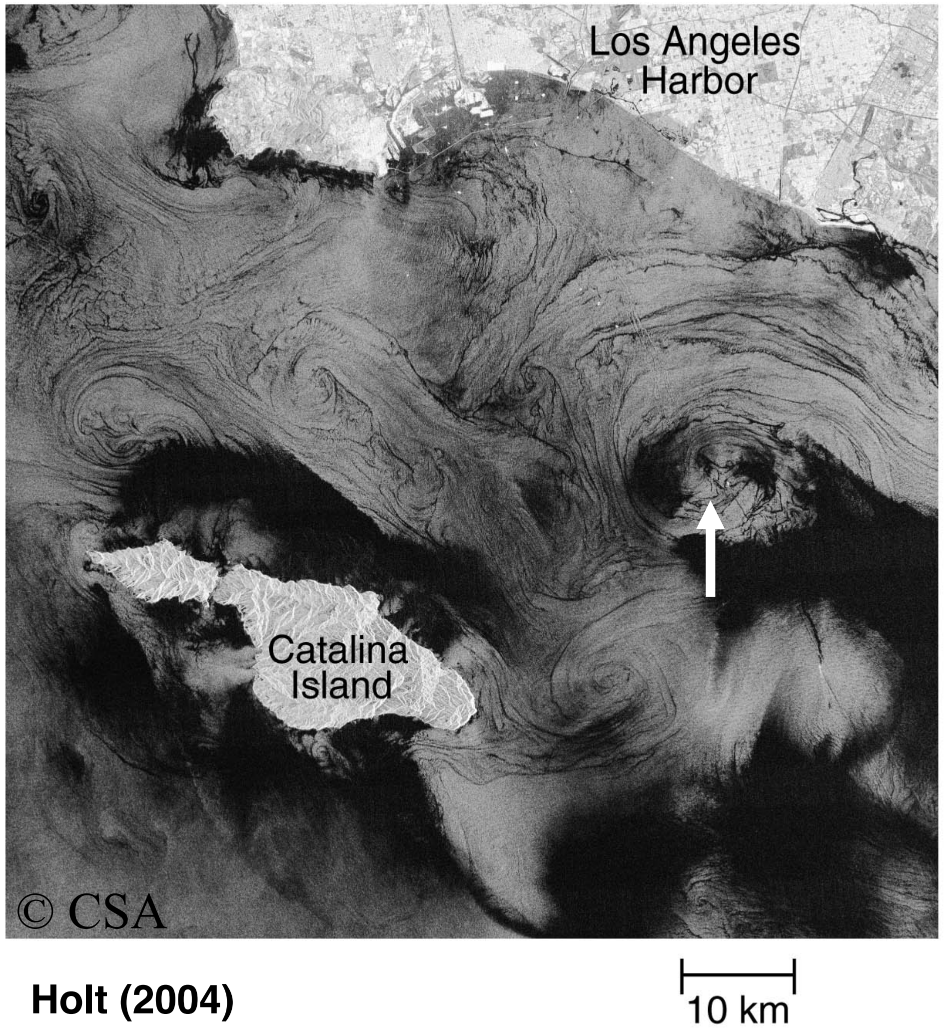
Ingredients: earth's rotation, pressure gradient force ,vertical mixing, straining flows

Truths: turbulence, F=ma, conservation of volume, hydrostatic balance(?)

Submesoscale currents are seemingly everywhere at the ocean surface

Synthetic Aperture Radar (30 m resolution), San Pedro Bay

RADARSAT - December 26, 1998



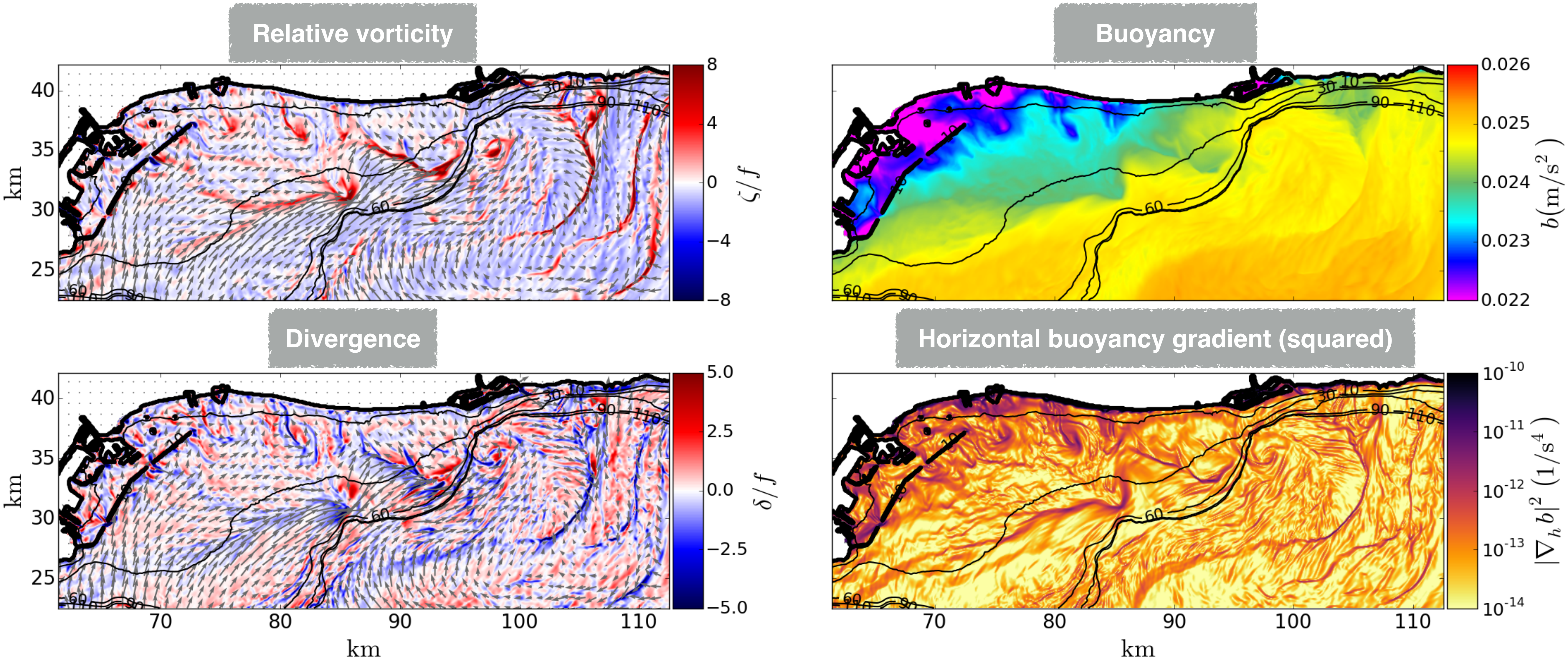
Holt (2004)

Sun-glint off the Mediterranean coast of Africa

Munk et al (2000)

Deepwater horizon oil spill, Gulf of Mexico

Surface fields in San Pedro Bay (ROMS simulation, 75m horizontal resolution)



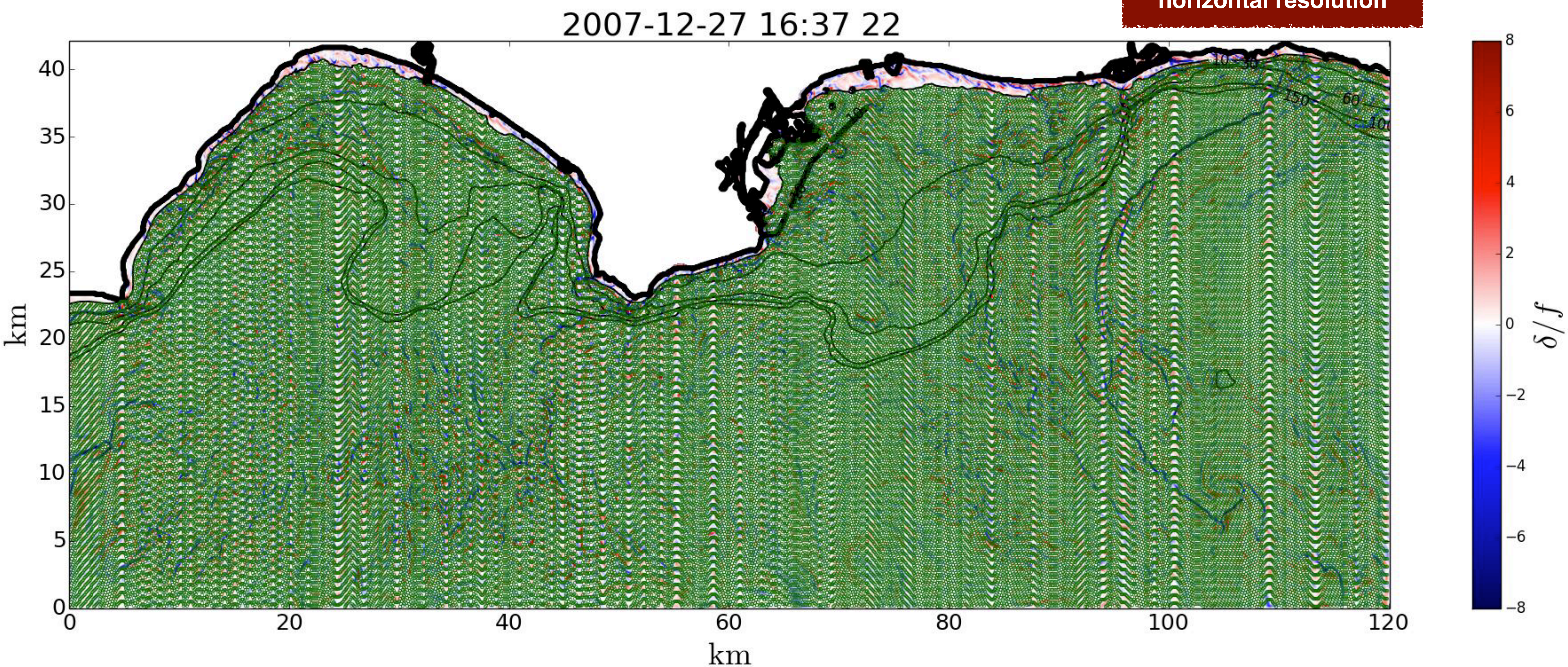
Submesoscale coherent structures are small-scale (<1km), short-lived (days) , and relatively ubiquitous at the ocean surface

These currents are a mixture of geostrophic (rotation = pgf) and ageostrophic (not geostrophic) dynamics and exhibit very strong surface convergence (i.e., they trap stuff) and localized downwelling

Dauhajre et al. 2017 (In Rev.)

Now…let's throw some green stuff into Santa Monica and San Pedro Bays

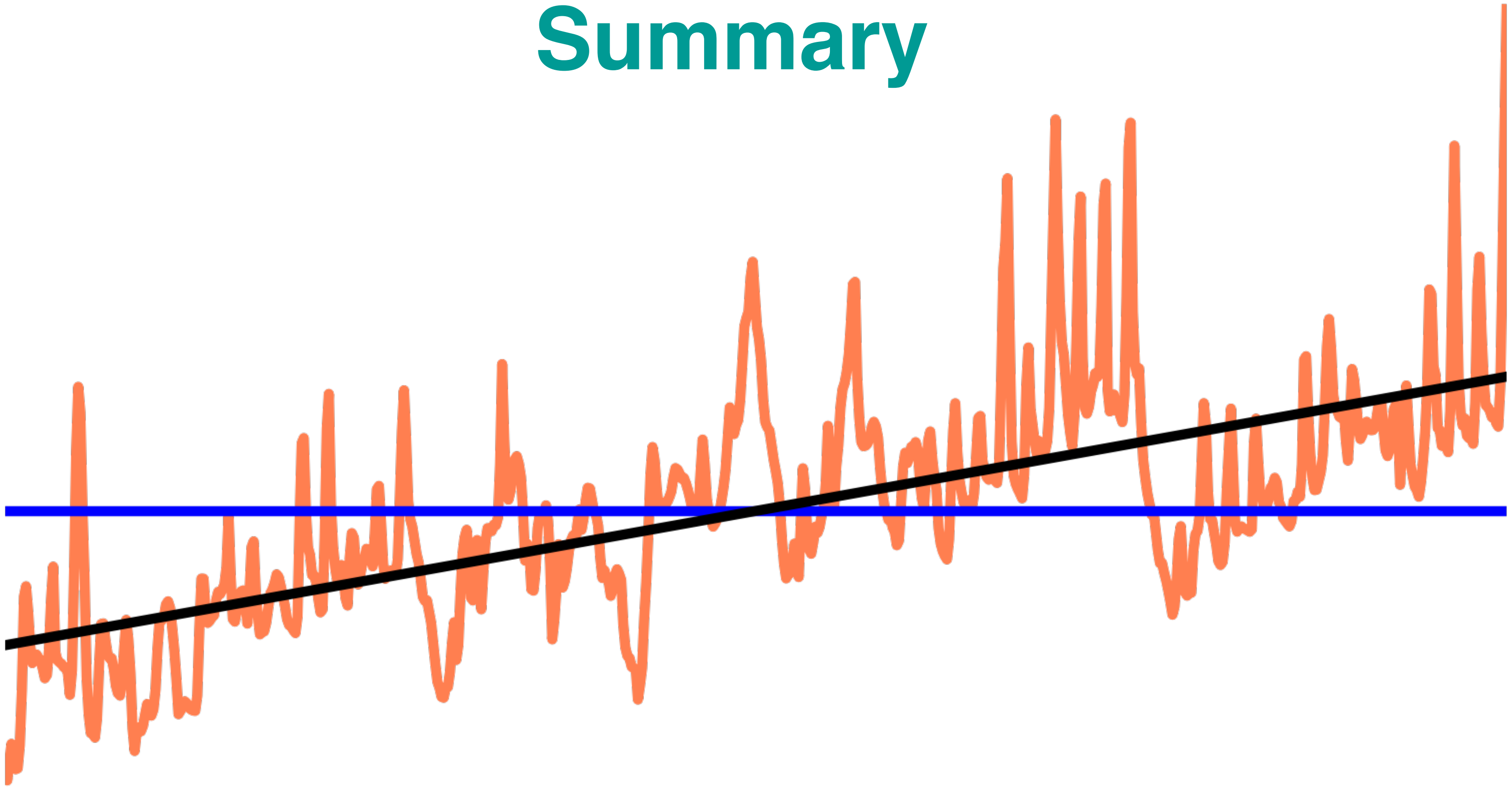
ROMS simulation, 75m horizontal resolution

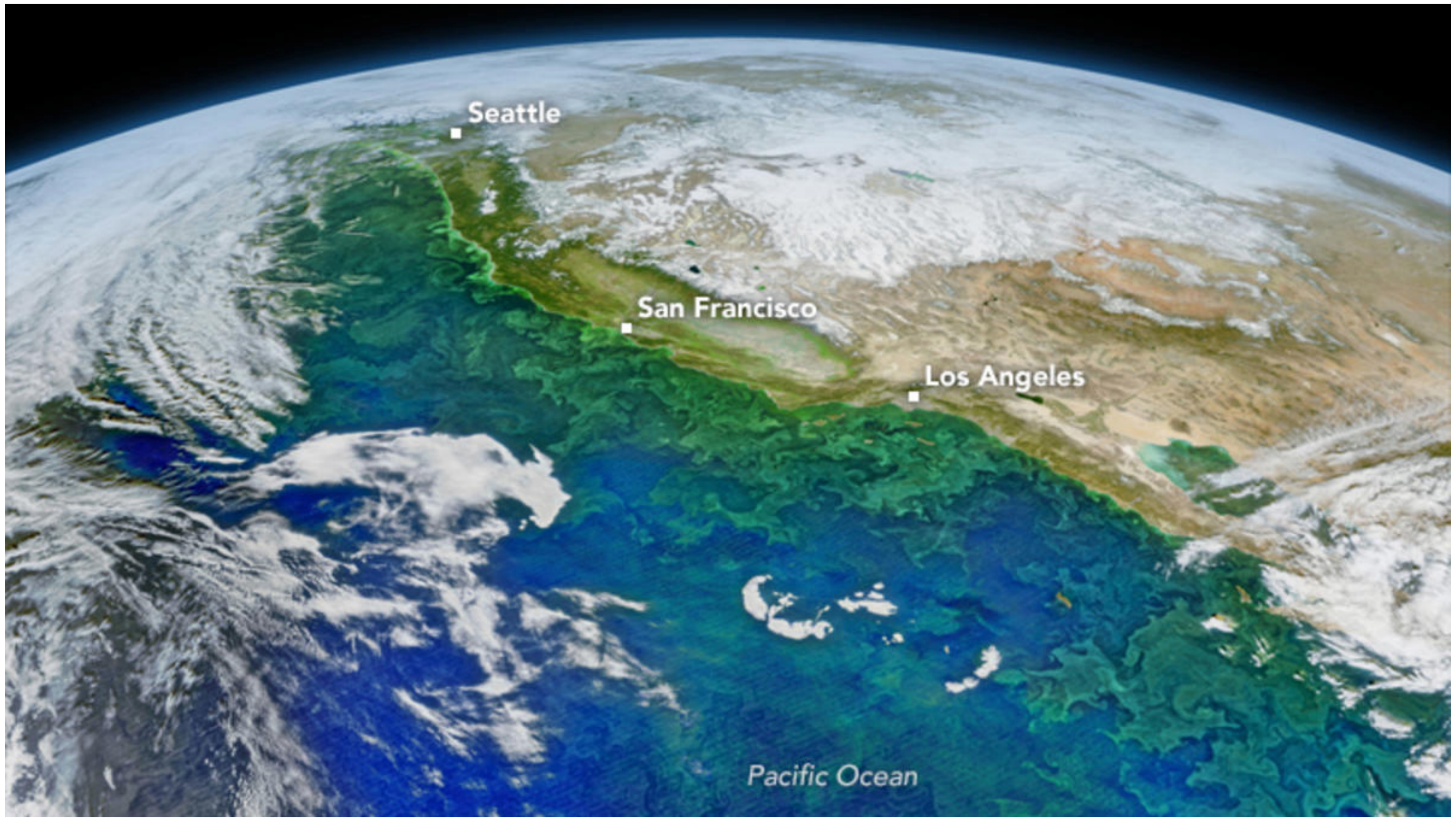


Green dots are simulated 'Lagrangian' particles that are moved around by the surface currents. Blue/red colors indicate surface divergence

After seeing that…what questions do you think we would need to answer to "properly" design a Marine Protected Area (MPA) in the coastal ocean?

Summary





Some movies of ocean models doing their thing

Entire world (GFDL)

https://www.youtube.com/watch?v=wq12nIQ5SuE

Southern Ocean (ANU)

https://www.youtube.com/watch?v=UhVCtJfLMB4&t=19s

Montery Bay (UCLA ROMS)

https://www.youtube.com/watch?v=BM0In7MZ4Ig

San Pedro Bay (UCLA ROMS)

https://www.youtube.com/watch?v=STJ4PMKUj5g