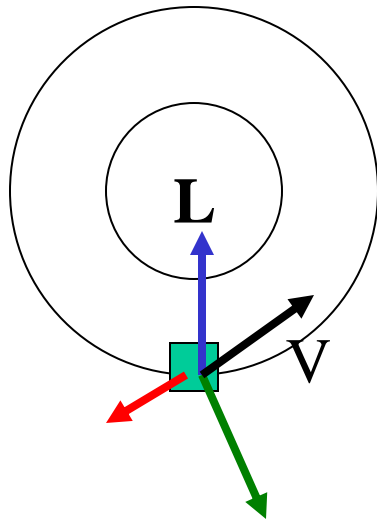


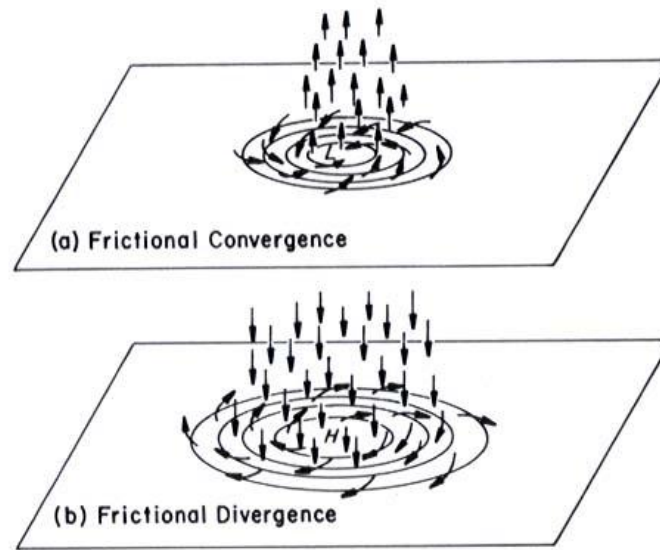
Ekman pumping, upwelling and the global SSTs

Recall the role of friction

- Makes the motion non-geostrophic



Net inflow



First some predictions...

What happens if we mix this water?

- a) Nothing, water stay clear as it spins
- b) Water will turn completely purple
- c) Water will flow into the middle and up
- d) Water will flow to the sides an up
- e) Water will flow up everywhere

Key result!

- If the flow is geostrophic, there is no vertical motion!
- Only get convergence or divergence if not geostrophic
- Thus vertical motion requires more than 2 forces!

First some predictions...

What happens if we mix this water?

- a) Nothing, water stay clear as it spins
- b) Water will turn completely purple
- c) Water will flow into the middle and up
- d) Water will flow to the sides an up
- e) Water will flow up everywhere

Which of the following is FALSE

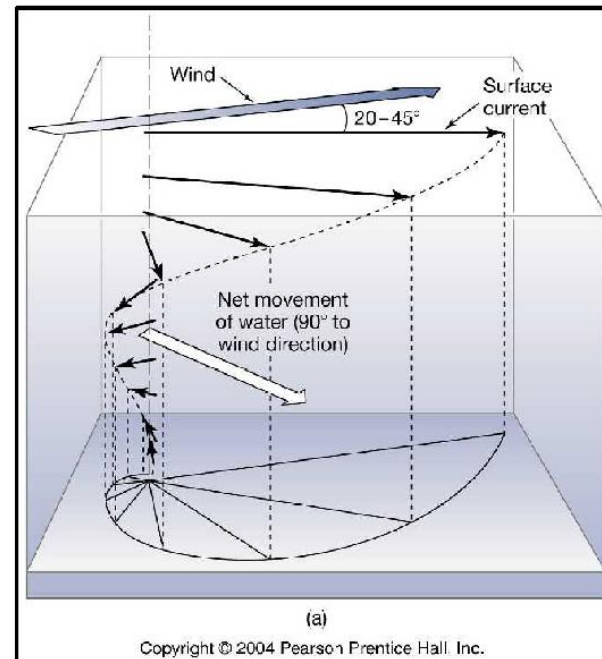
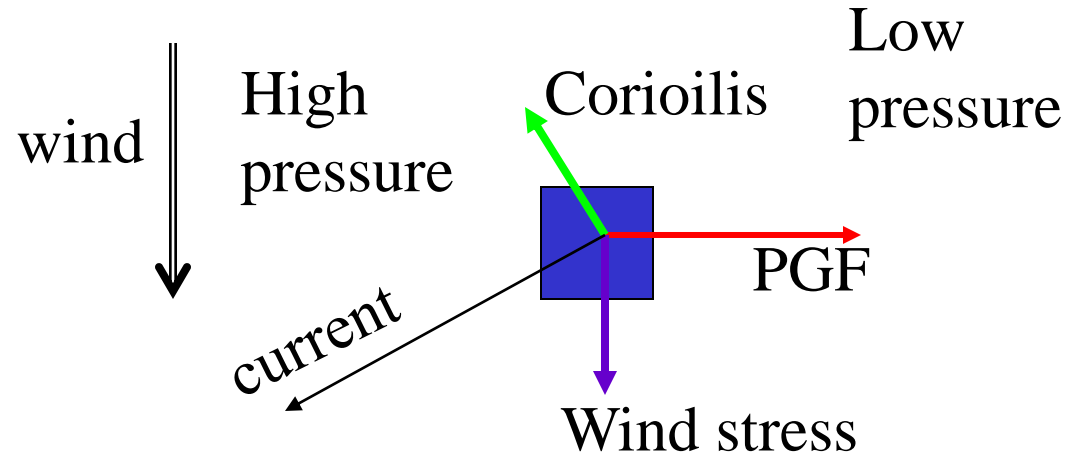
- A. Upwelling occurs on eastern sides of the oceans
- B. Western boundaries of the ocean are warmer than the eastern sides
- C. Surface currents are about the same direction as the wind
- D. The ocean gyres are in approximate geostrophic balance
- E. Temperature and salinity changes are the main cause of deep ocean circulation

Which forces are important for Ekman layers in the ocean?

- A. Coriolis, pressure gradient, friction
- B. Coriolis, pressure gradient, wind stress
- C. Centrifugal, Coriolis, pressure gradient
- D. Coriolis, pressure gradient
- E. Pressure gradient, wind stress, friction

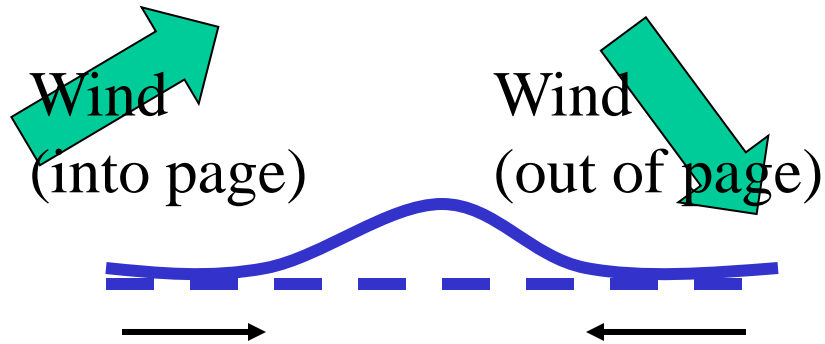
Surface ocean currents and transport

- Coriolis force has to balance BOTH pressure gradient and wind stress means
- So surface current must move to the right (in the NH) of the wind
- This surface water pushes on the water below, which again turns to the right, and so on downward
- The net water transport over this layer is exactly 90 degrees to the right of the wind.
- *Thanks Ekman!*



Ekman pumping

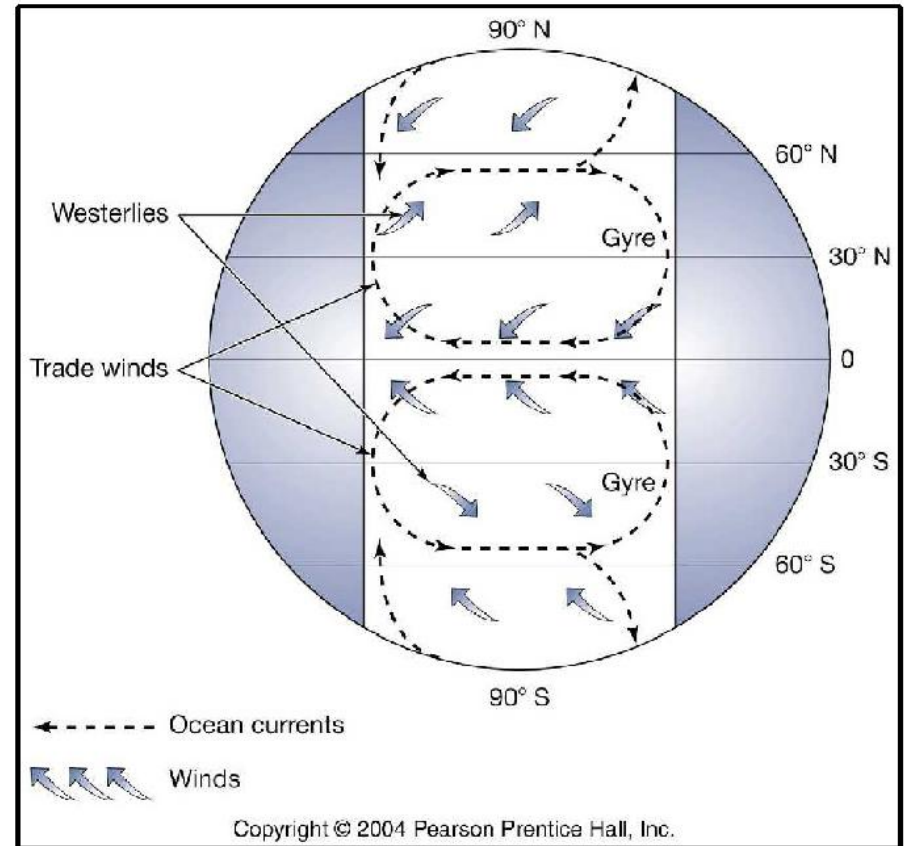
Since water moves to the right of the wind, the water in the subtropics is pushed to the middle



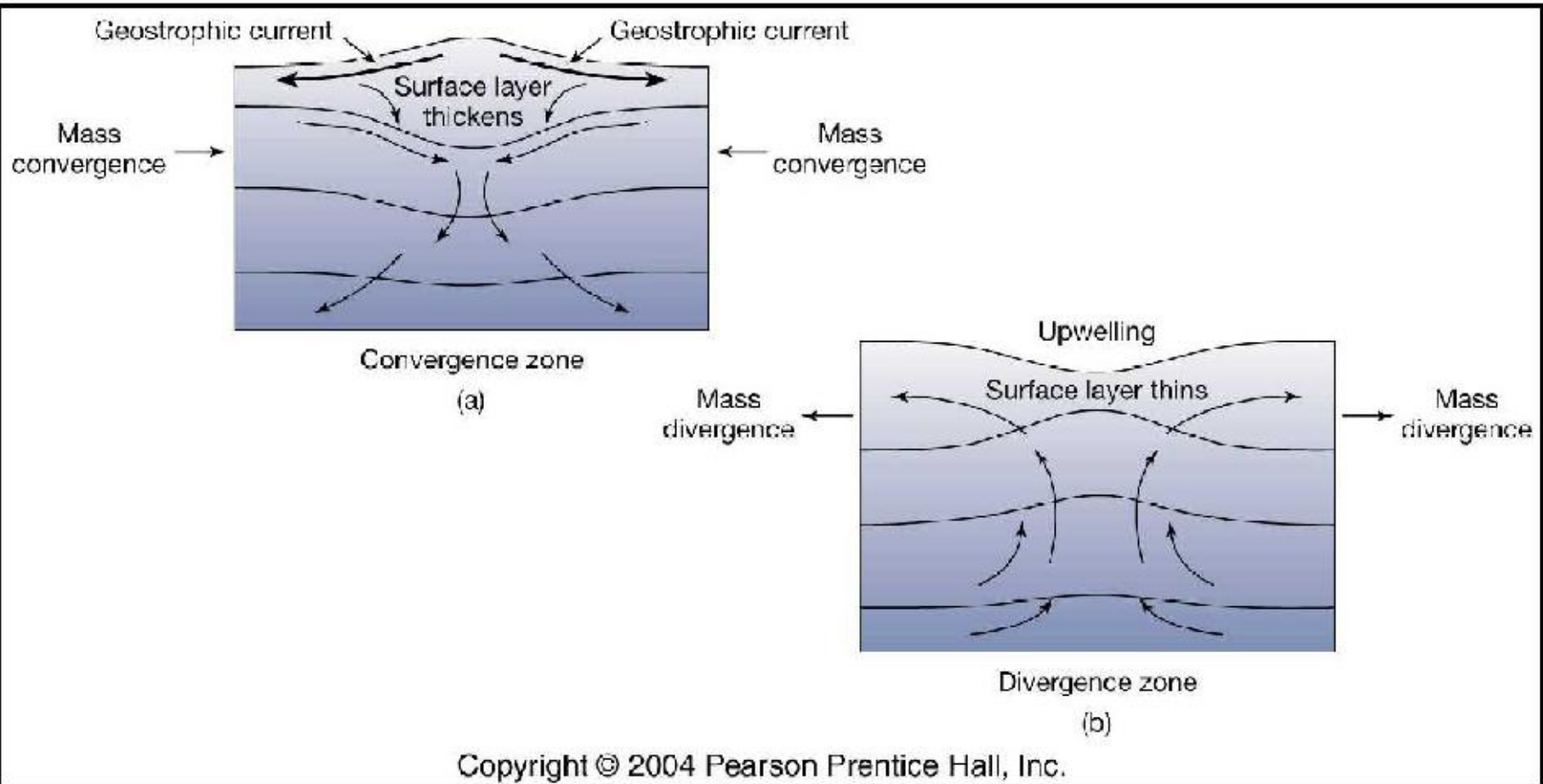
Ekman pumping pushes water to the right

Water piled up means high pressure

So ocean surface currents in geostrophic balance



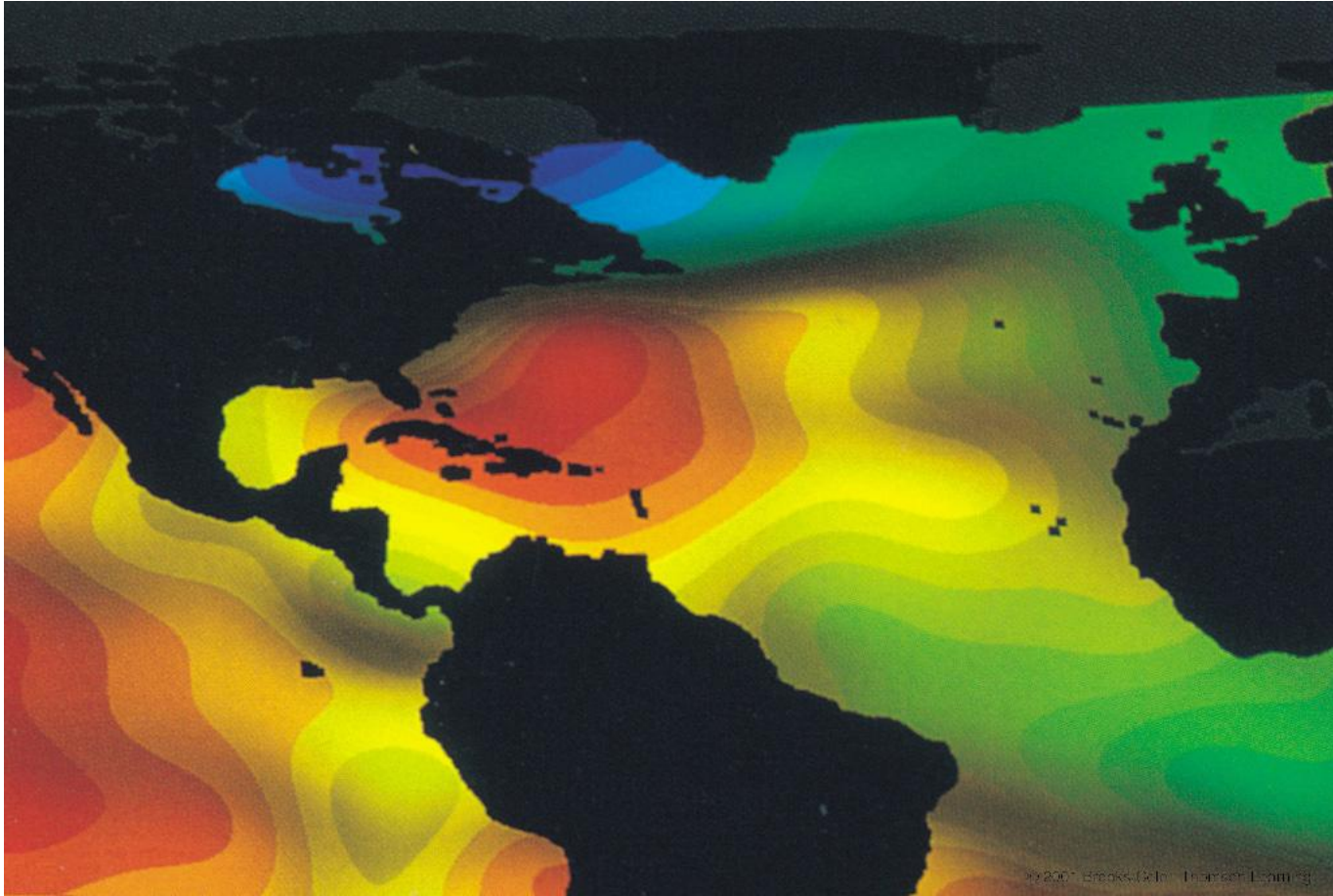
Upwelling and downwelling



Lumpy water

How do you make high pressure in a tank?!

Average sea level elevation seen from space



Ekman transport allows water to “pile up” in center of ocean basin

This forces geostrophic currents on the large scale

These are the anticyclonic ocean gyres

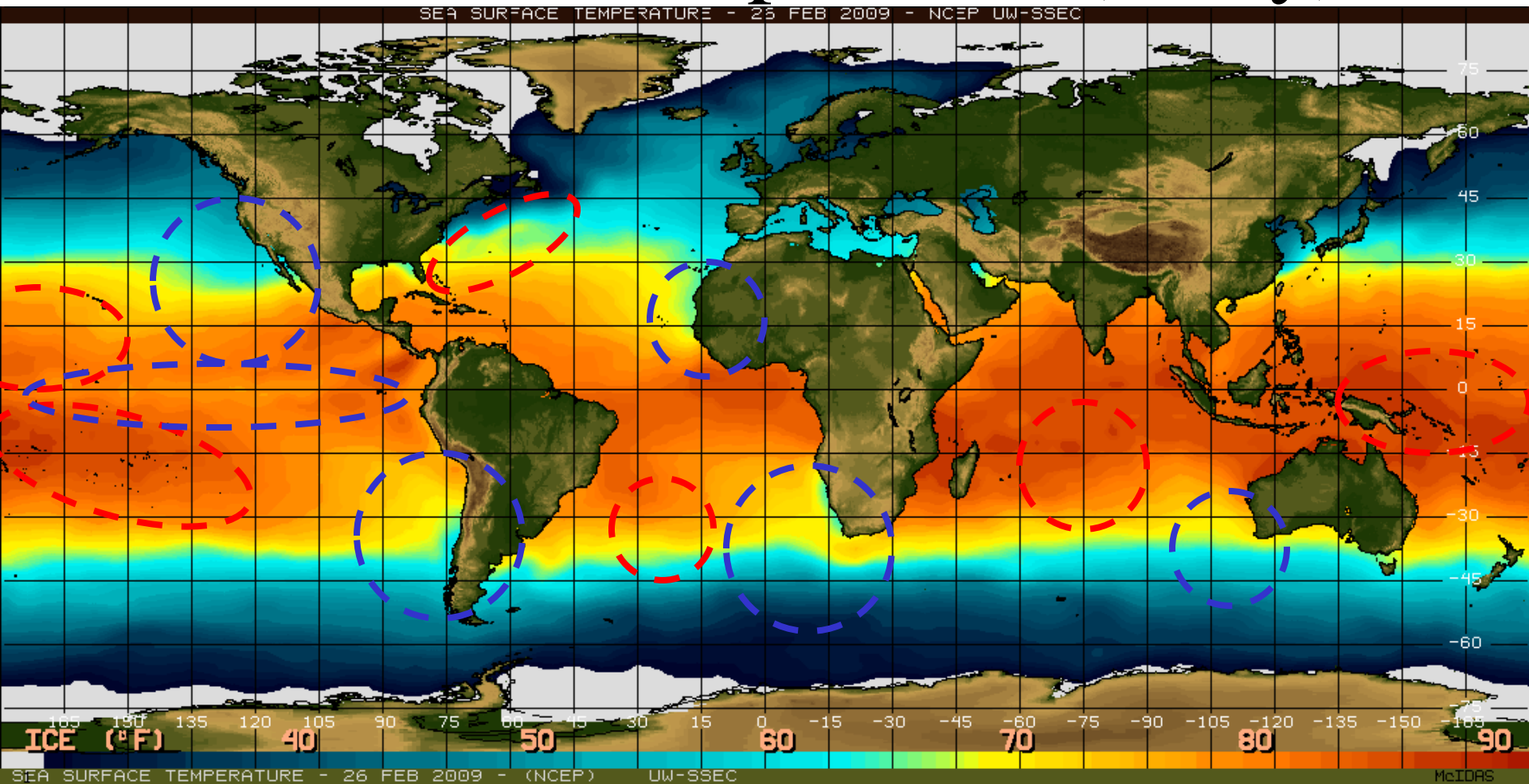
Which forces are important for Ekman layers in the ocean?

- A. Coriolis, pressure gradient, friction
- B. Coriolis, pressure gradient, wind stress
- C. Centrifugal, Coriolis, pressure gradient
- D. Coriolis, pressure gradient
- E. Pressure gradient, wind stress, friction

Which of the following is TRUE

- A. Upwelling only occurs when the wind is weaker than normal
- B. Upwelling only occurs when the wind is stronger than normal
- C. Downwelling only occurs in the center of subtropical gyres
- D. El Nino is linked to weaker than normal easterly winds
- E. El Nino occurs when upwelling is stronger than normal

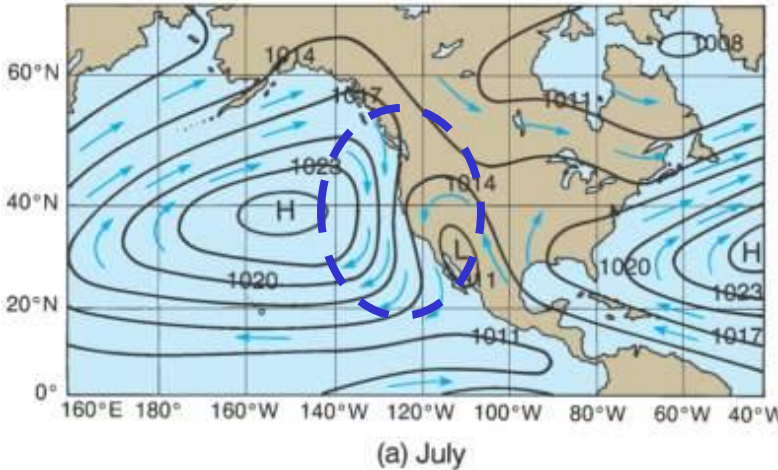
Sea surface temperature (today)



How can we measure this from satellites?

West Coast Upwelling and Downwelling

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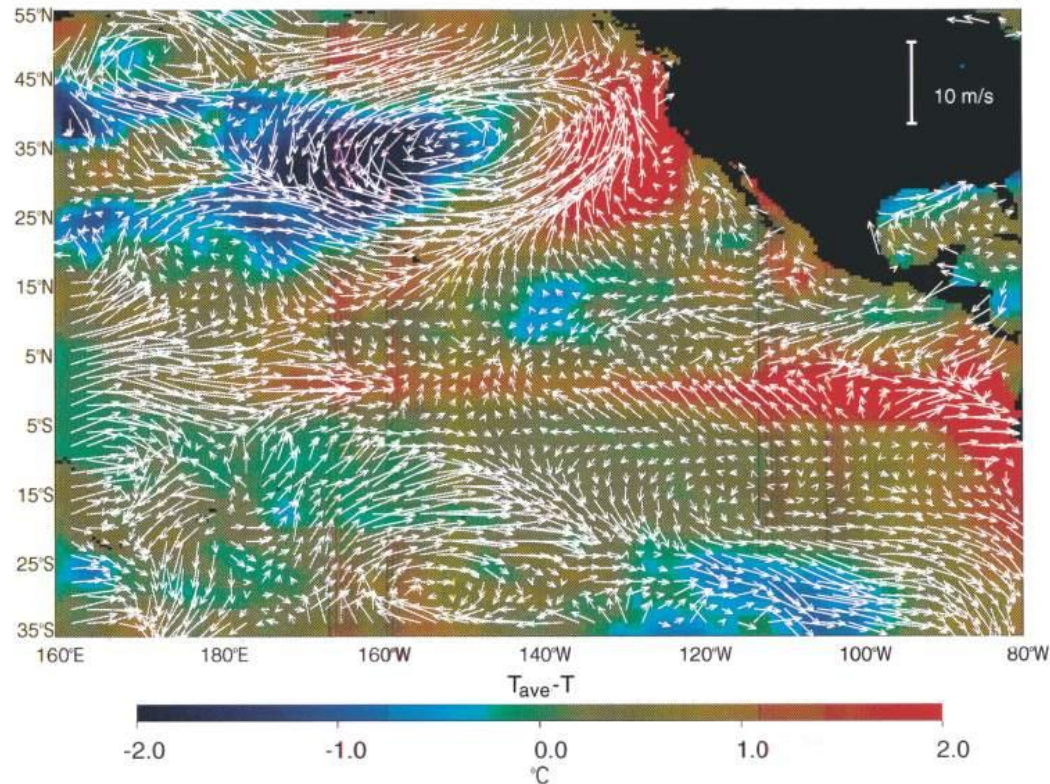


(a) July

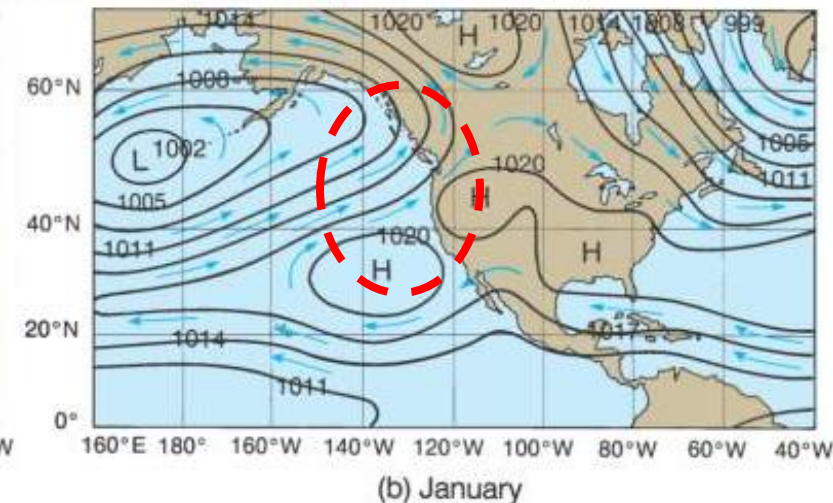
Certainly upwelling in Summer, but also changes with season!

This is because the atmospheric circulation is very different in different seasons.

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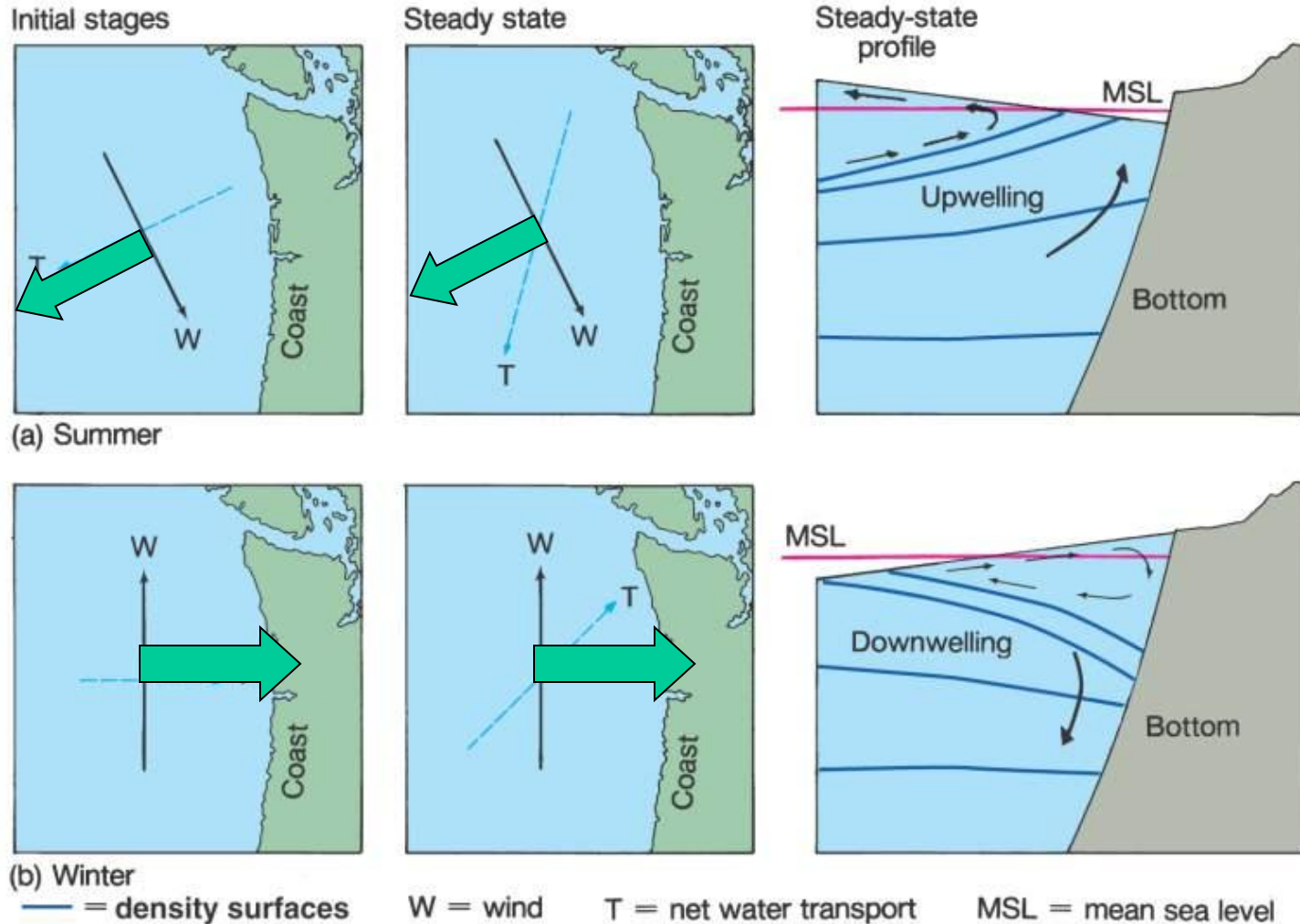


(b) January

-2.0 -1.0 0.0 1.0 2.0
°C

Coastal upwelling and downwelling is promoted by Ekman transport associated with alongshore winds

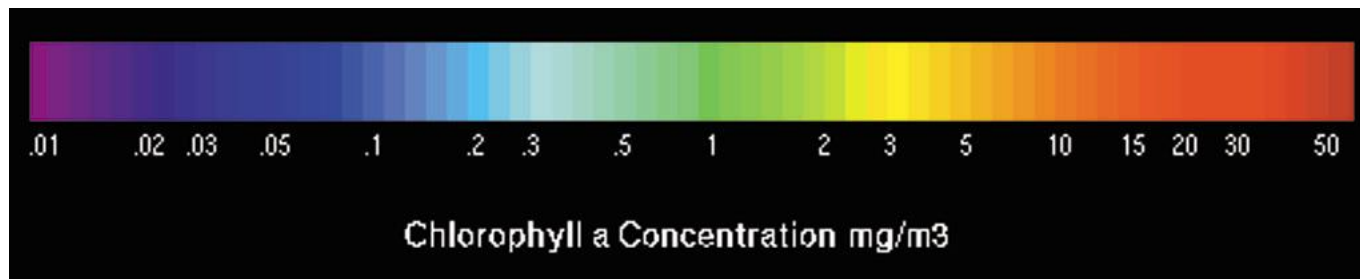
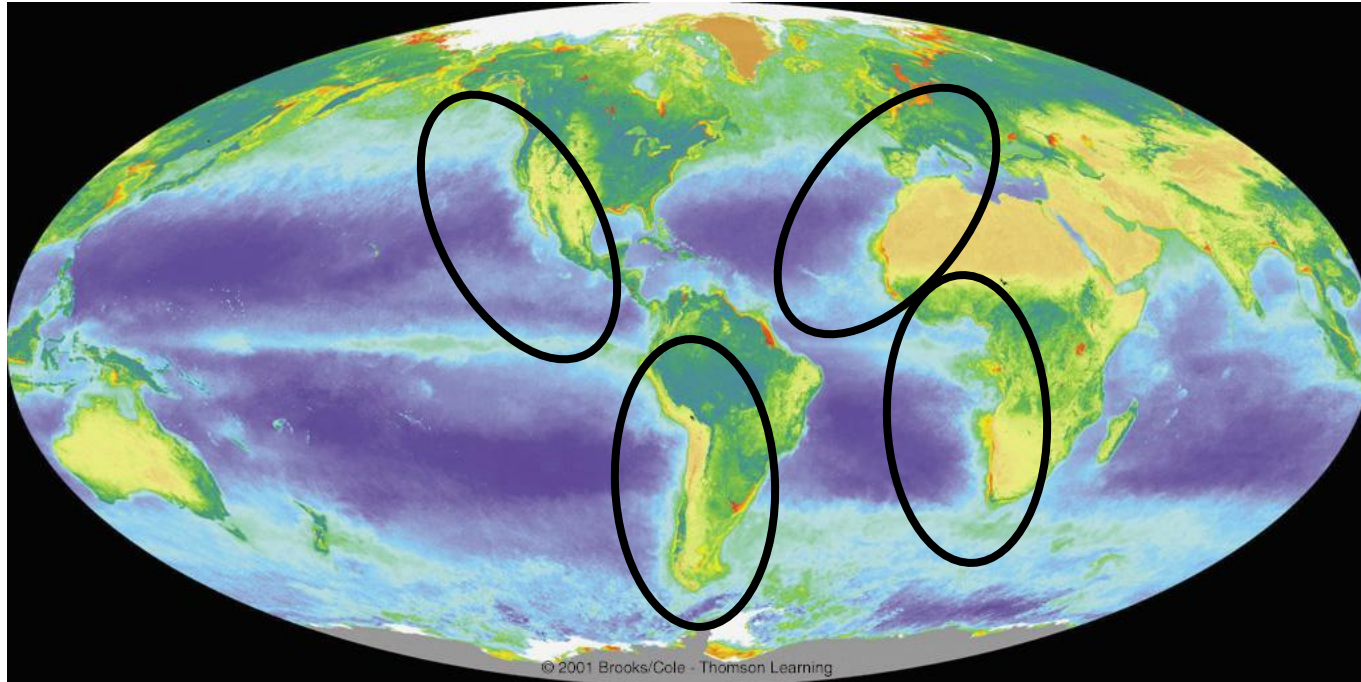
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Upwelling means biological productivity!

- Upwelled water is rich in nutrients.
(including oxygen)
- When the nutrients enter the upper 100m or so, there is available sunlight, and photosynthesis can occur.
(This is called the Euphotic Zone.)
- Upwelling regions are therefore biologically rich and diverse.
- Very active marine ecosystems.
- Also active fishing!

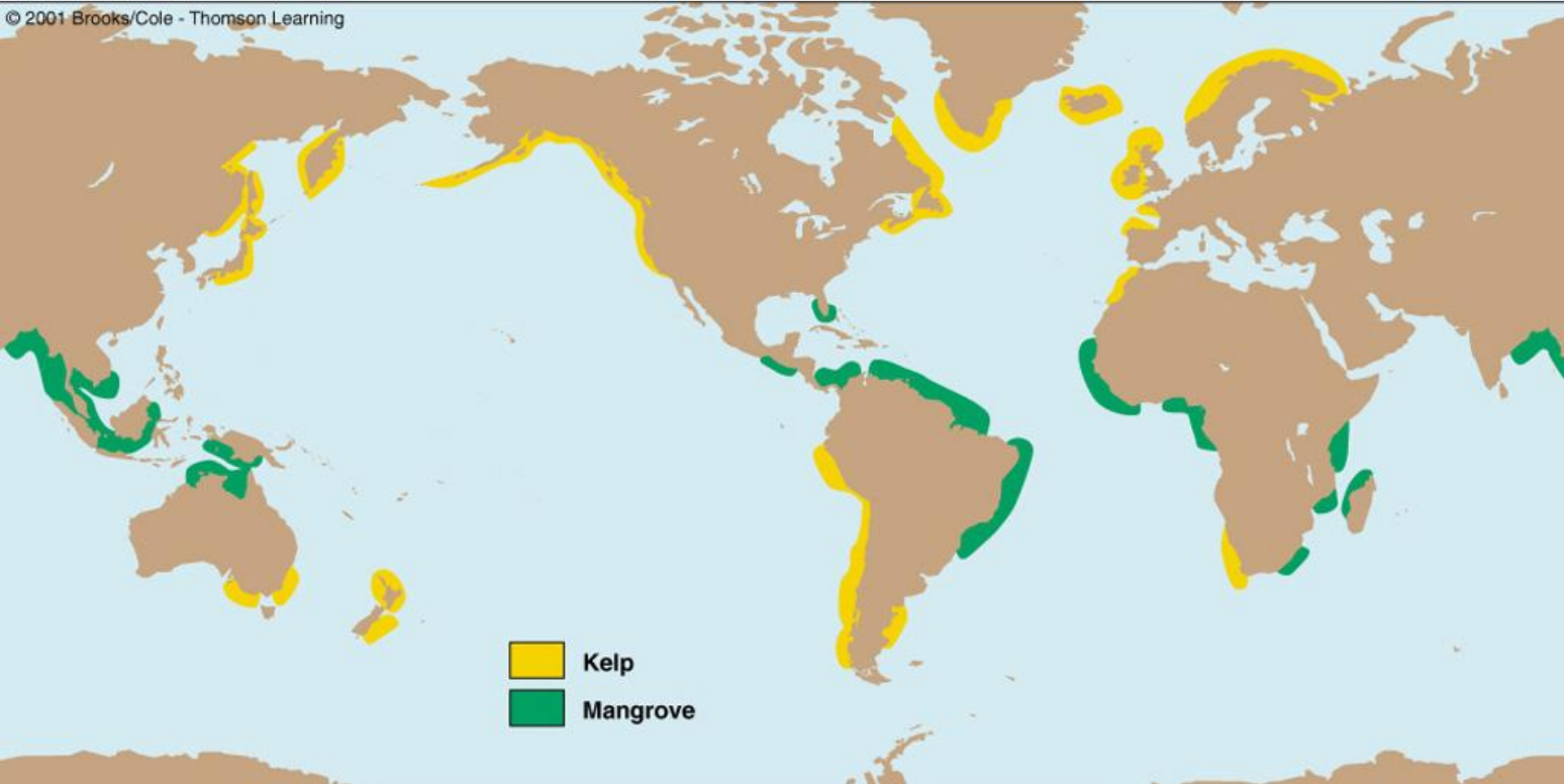
Ocean Chlorophyll and Major Coastal Upwelling Regions



“Greenness” measured by satellite.
(Chlorophyll absorbs specific wavelengths, which can be measured)

Marine vegetation linked to upwelling

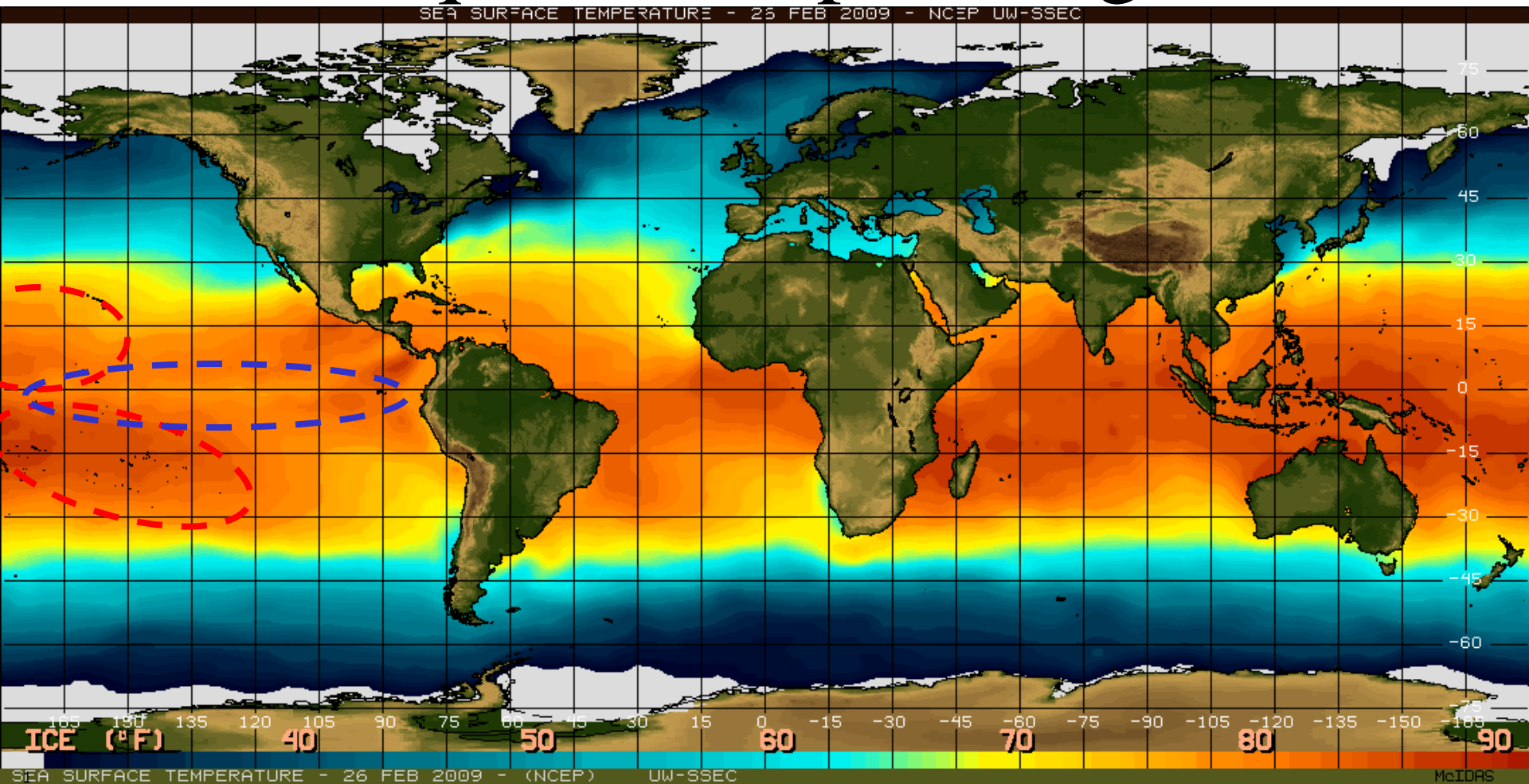
© 2001 Brooks/Cole - Thomson Learning



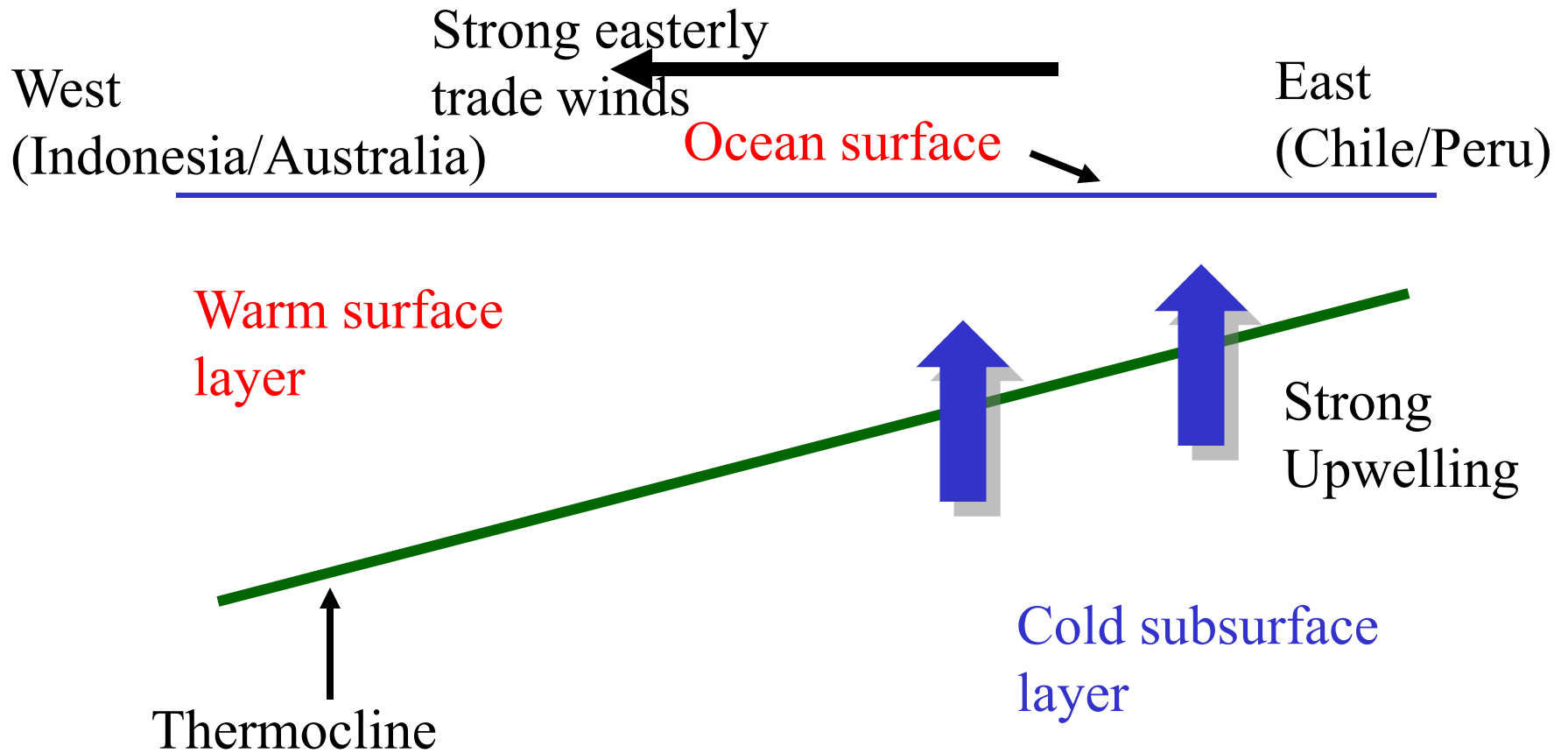
Kelp is very active with high amounts of nutrients and light

Mangrove swamps where limited oxygen (and other nutrients)

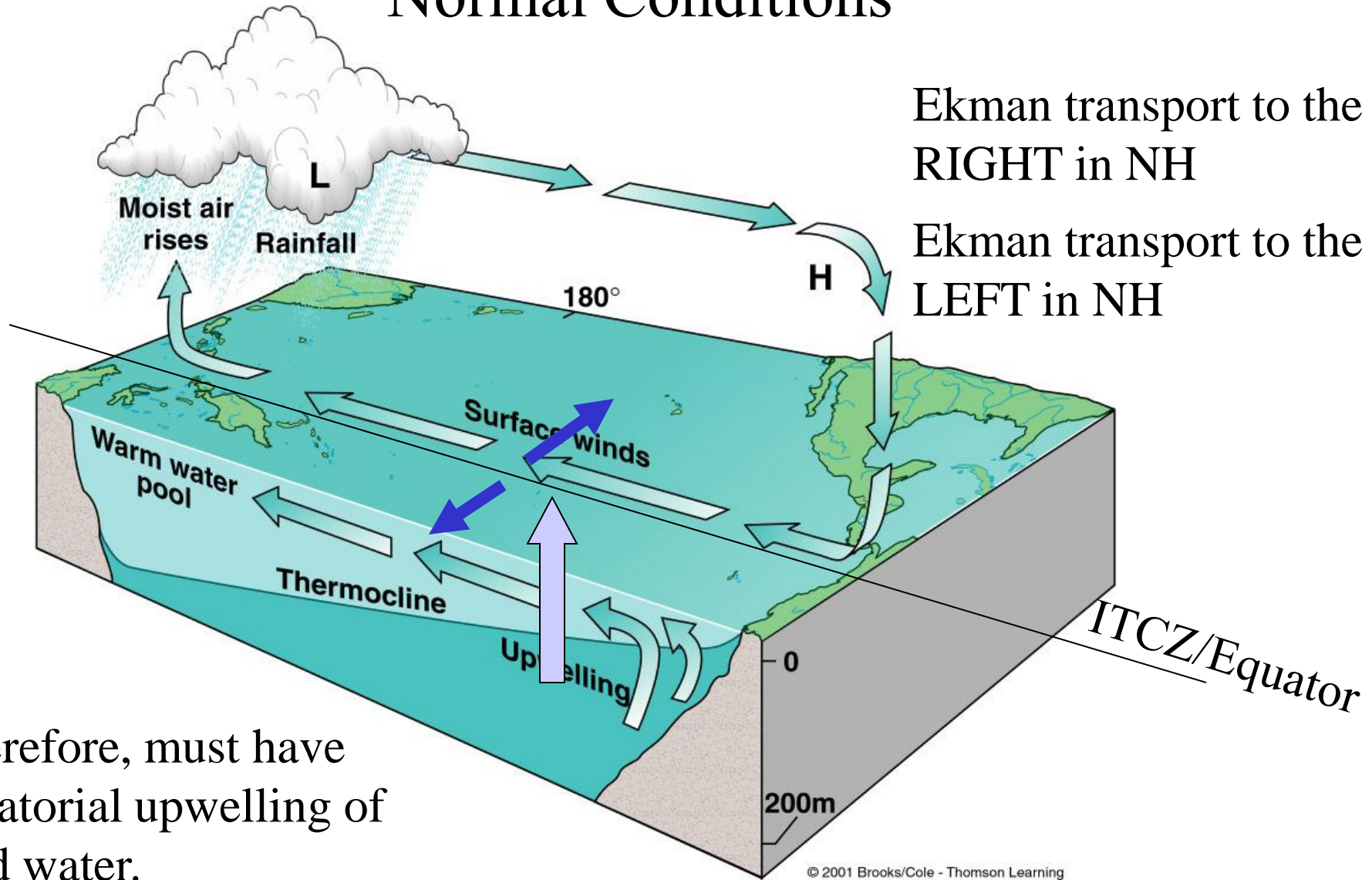
Equatorial upwelling



Idealized Vertical Section at Equator (Normal Year)

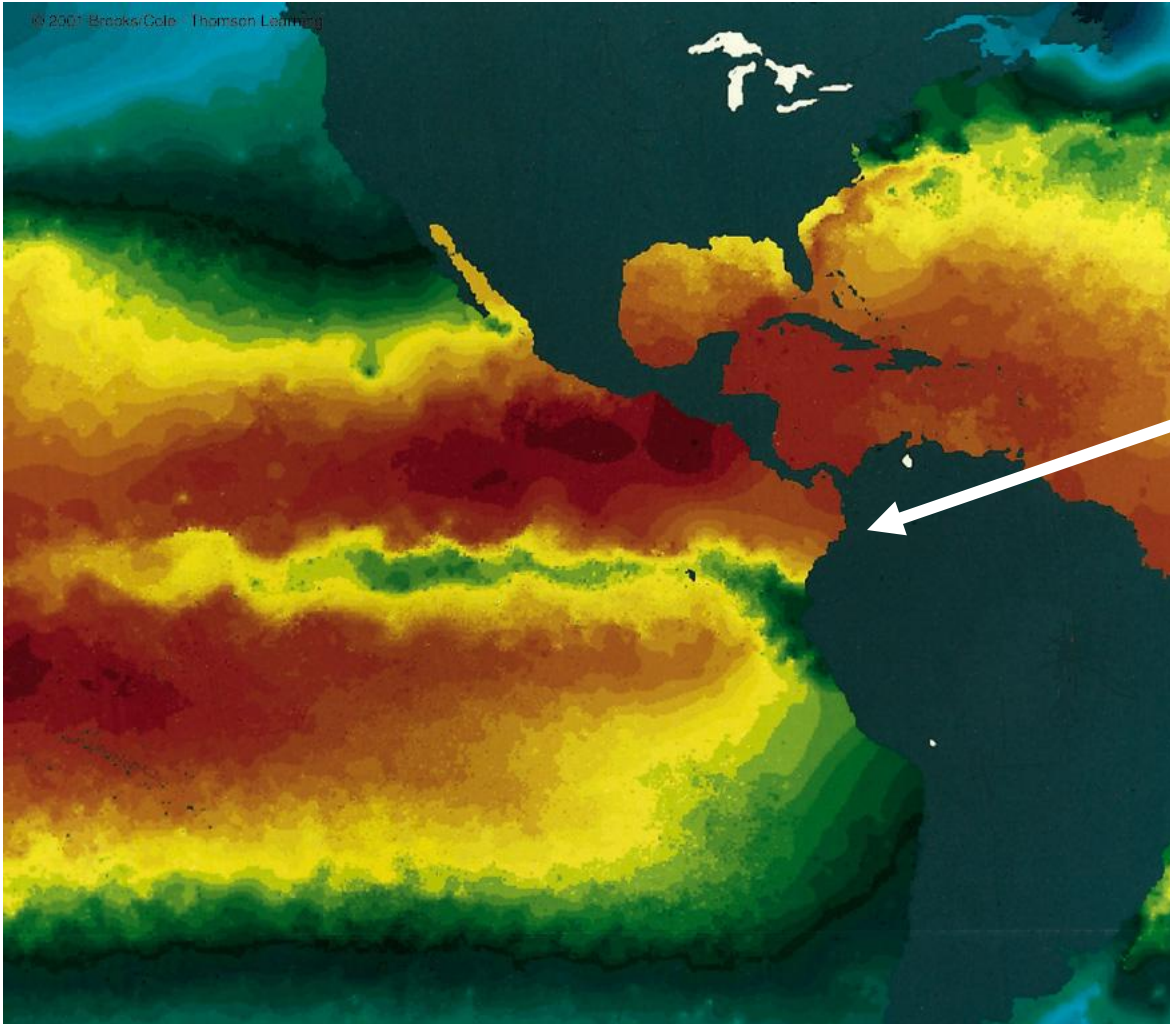


Normal Conditions

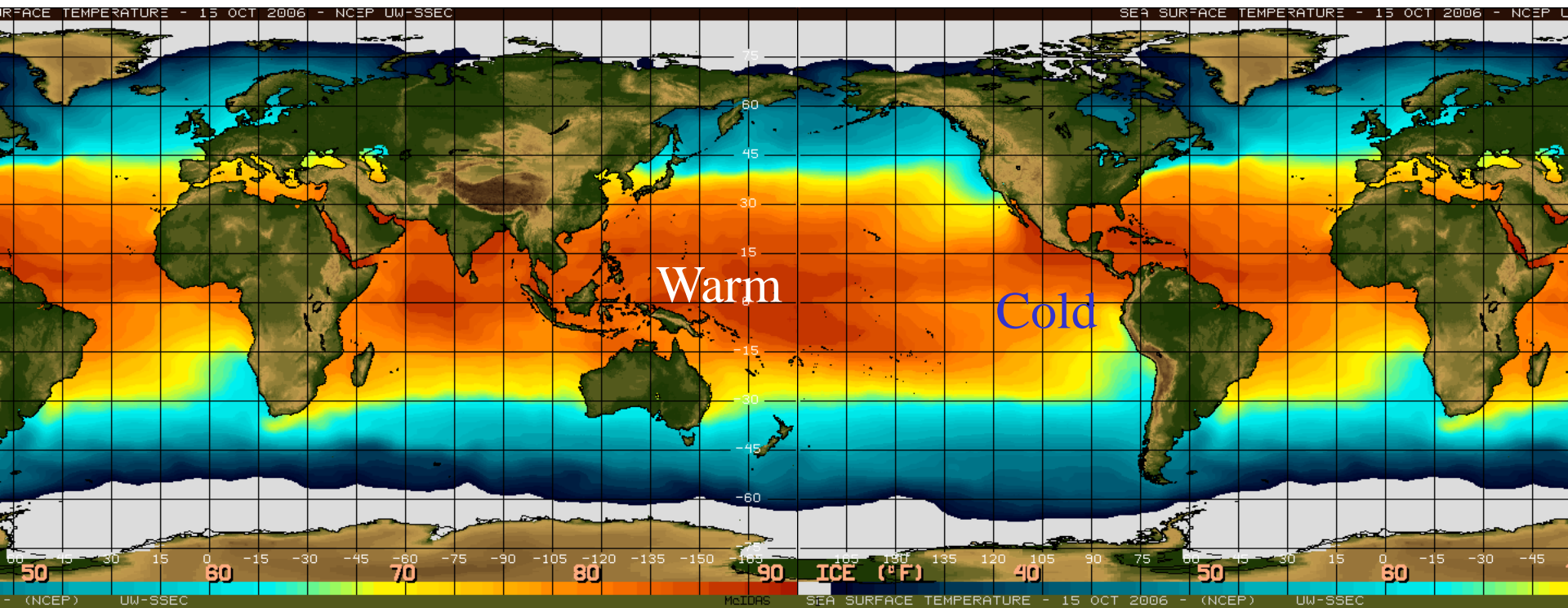


Therefore, must have equatorial upwelling of cold water.

Equatorial Upwelling – Normal Year



Notice wave like
pattern
(see next lecture)



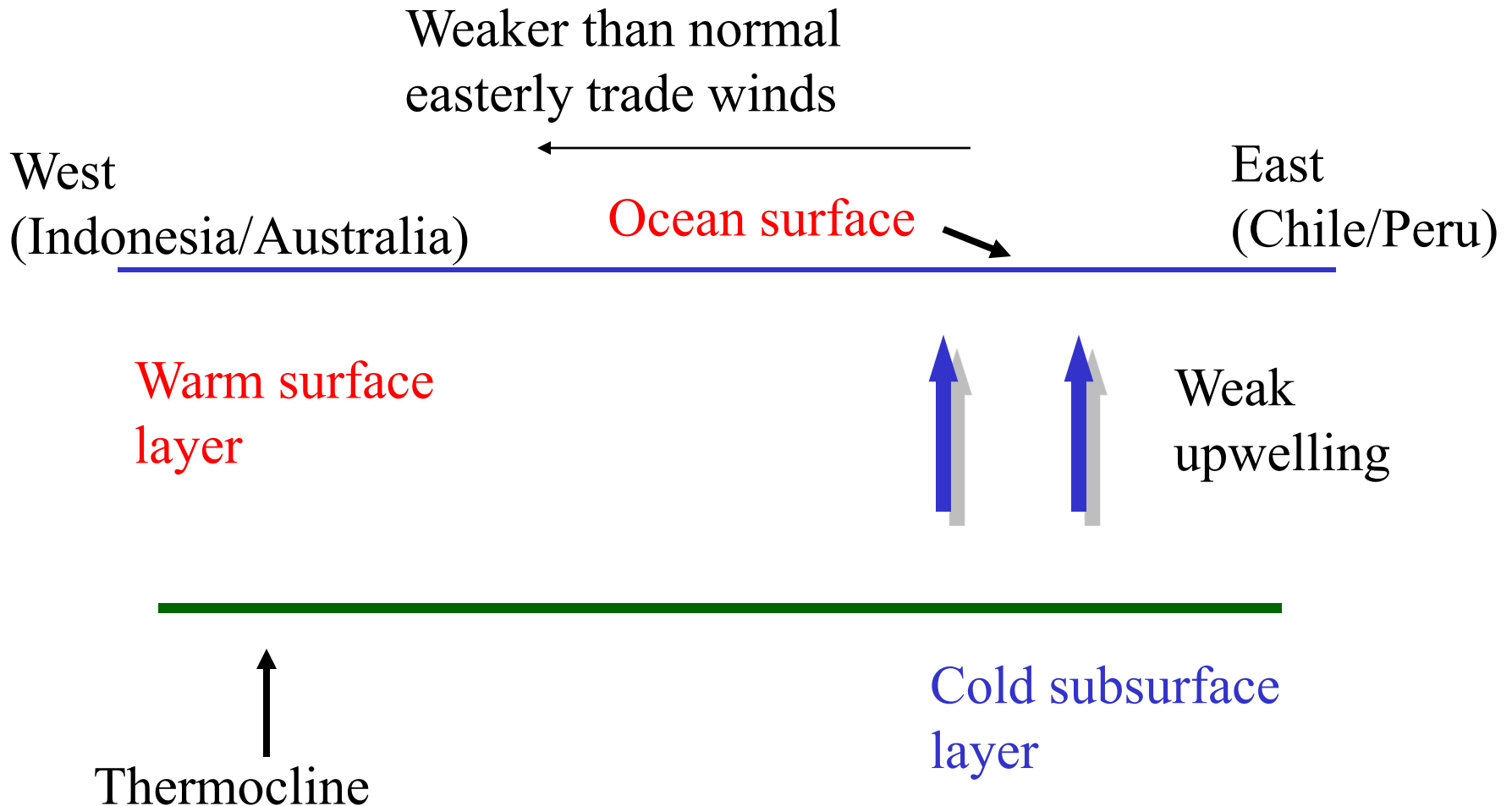
Upwelling explains many aspects of why ocean temperature varies from east to west

But what happens if, for some reason, the Equatorial easterly wind was weaker than normal?

Less Ekman transport. Less upwelling of cold water.

So SST would be warmer than normal!

Idealized vertical section at equator (El Nino Year)



El Nino Sea Level Changes

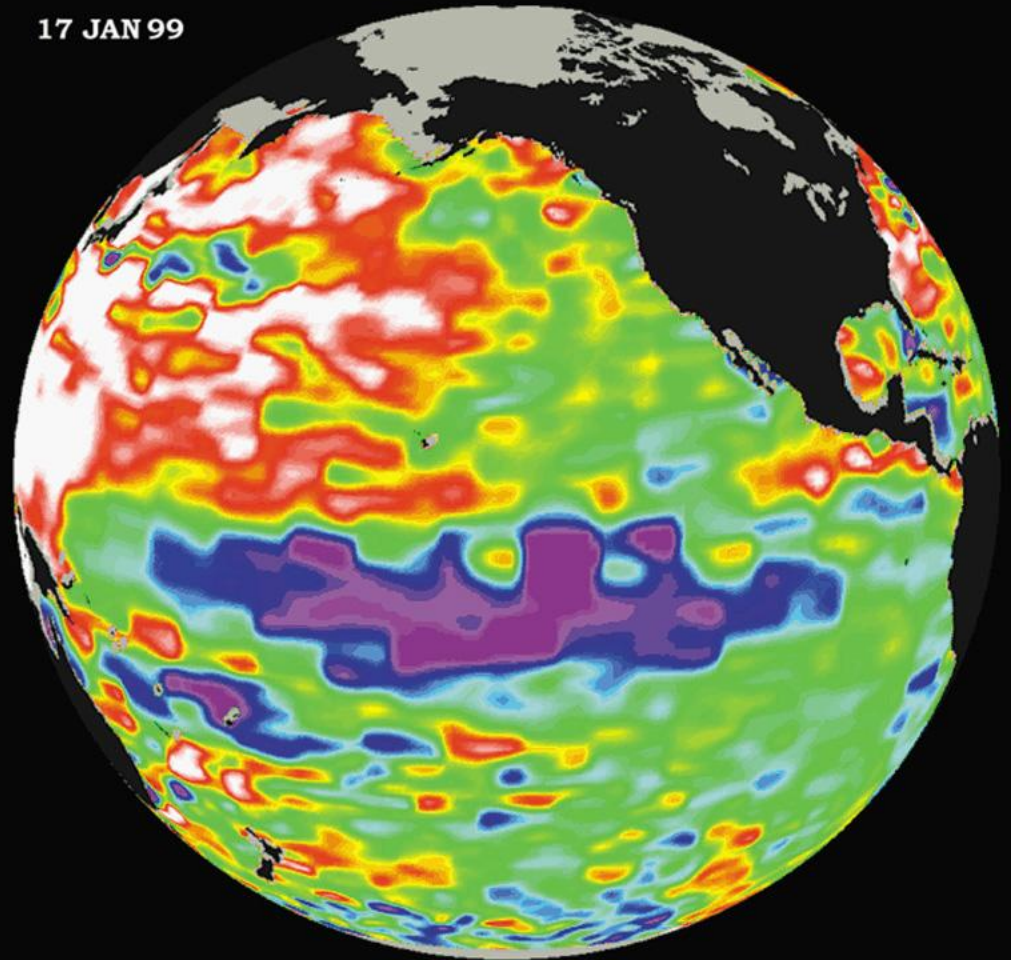
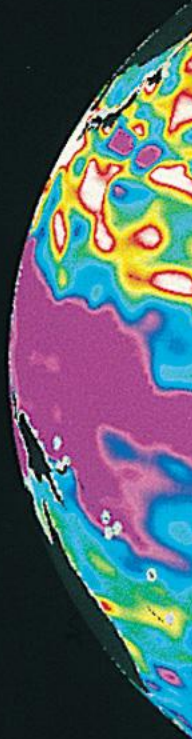
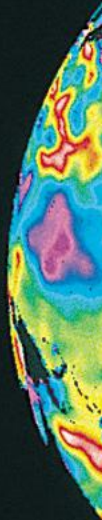
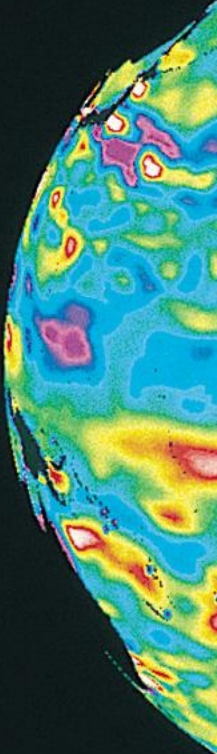
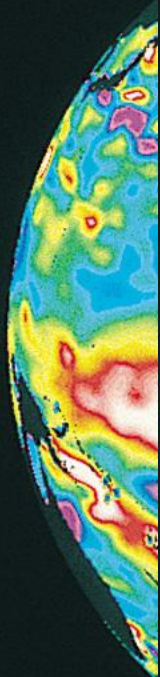
25 MAR 97

25 APR 97

25 MAY 97

23 OCT 97

17 JAN 99



Which of the following is TRUE

- A. Upwelling only occurs when the wind is weaker than normal
- B. Upwelling only occurs when the wind is stronger than normal
- C. Downwelling only occurs in the center of subtropical gyres
- D. El Nino (warm SST) is linked to weaker than normal easterly winds
- E. El Nino (warm SST) occurs when upwelling is stronger than normal

Key points

- Vertical motion occurs in BOTH the atmosphere and ocean when the flow is not geostrophic (friction for the atmosphere, wind stress for the ocean)
- Wind pushing on surface of the ocean can cause **divergence** (and **upwelling**) or **convergence** (and **downwelling**)
- Upwelling can occur at the coasts, especially the eastern sides but also can occur at the equator
- **Upwelled water is full of nutrients**, **downwelled** water has been sitting at the surface for a long time, and has very **little nutrients left**.
- As such, upwelling links the biology and marine ecosystems to climate

- *Changes in wind change the upwelling conditions.*
- Day-to-day, seasons, or year-to-year, or with climate change!
- At the equator, this is linked to **El Nino** and **La Nina** events (more of this in later lectures)

