I. Wind-driven Coastal Dynamics

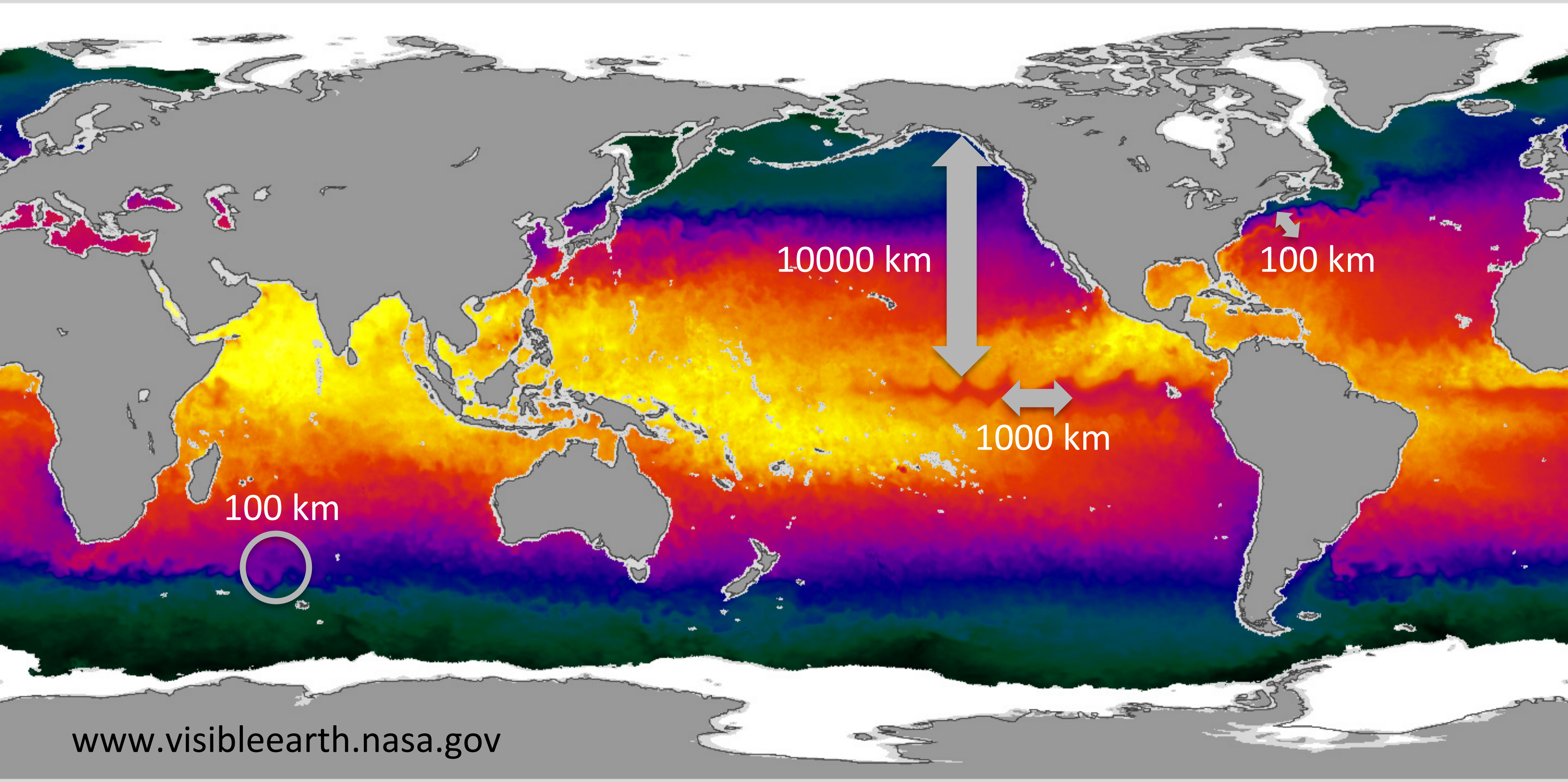
Emily Shroyer, Oregon State University

II. Estuarine Processes

Andrew Lucas, Scripps Institution of Oceanography

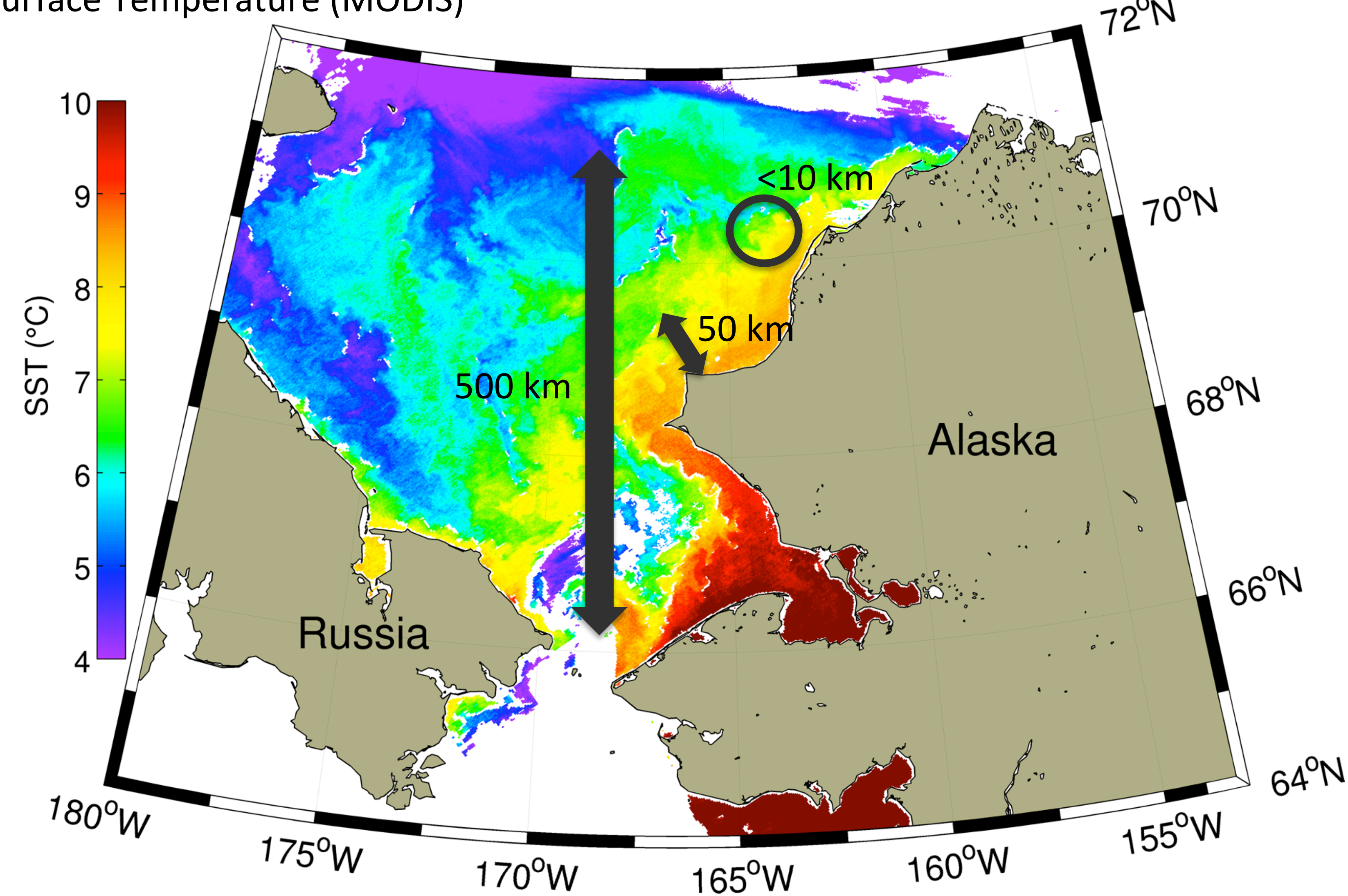
Variability in the Ocean

Sea Surface Temperature from NASA's Aqua Satellite (AMSR-E)



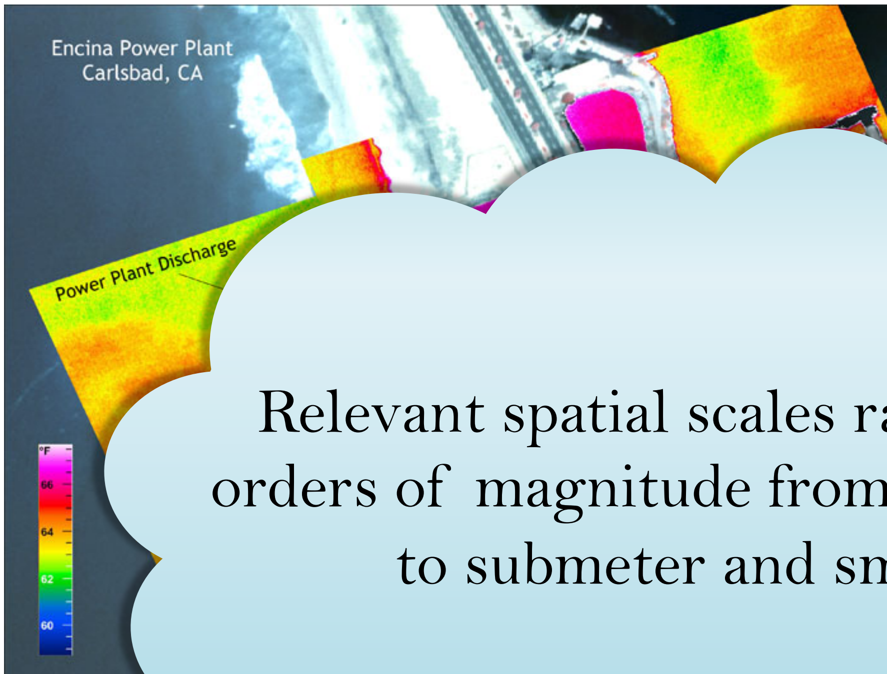
Variability in the Ocean

Sea Surface Temperature (MODIS)

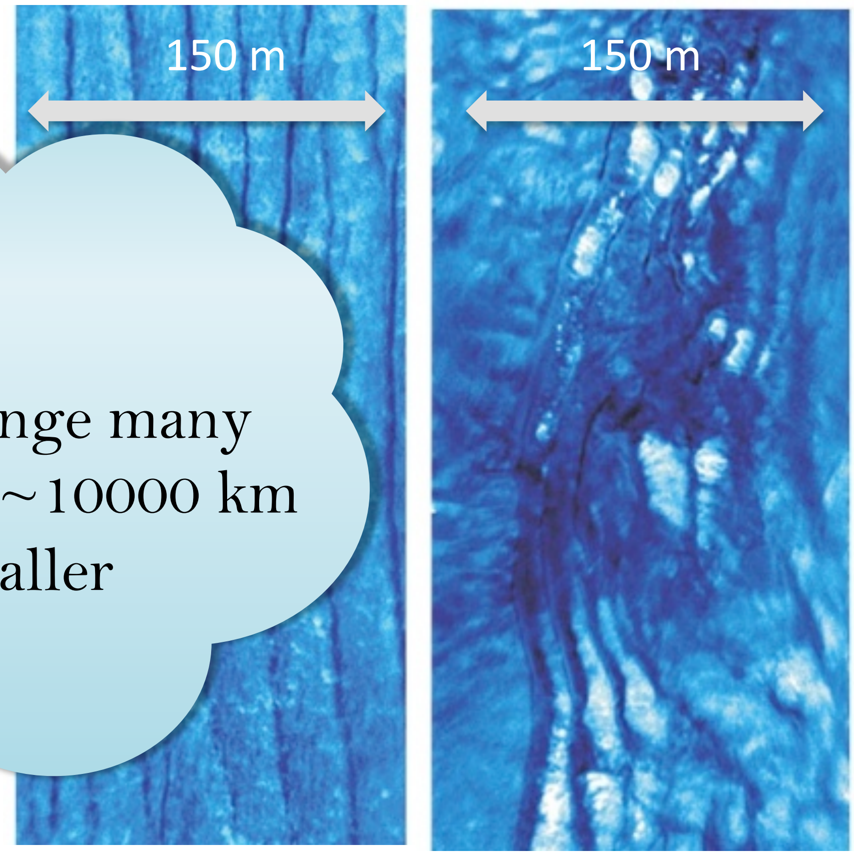


Variability in the Ocean

Sea Surface Temperature (Field Infrared Imagery)

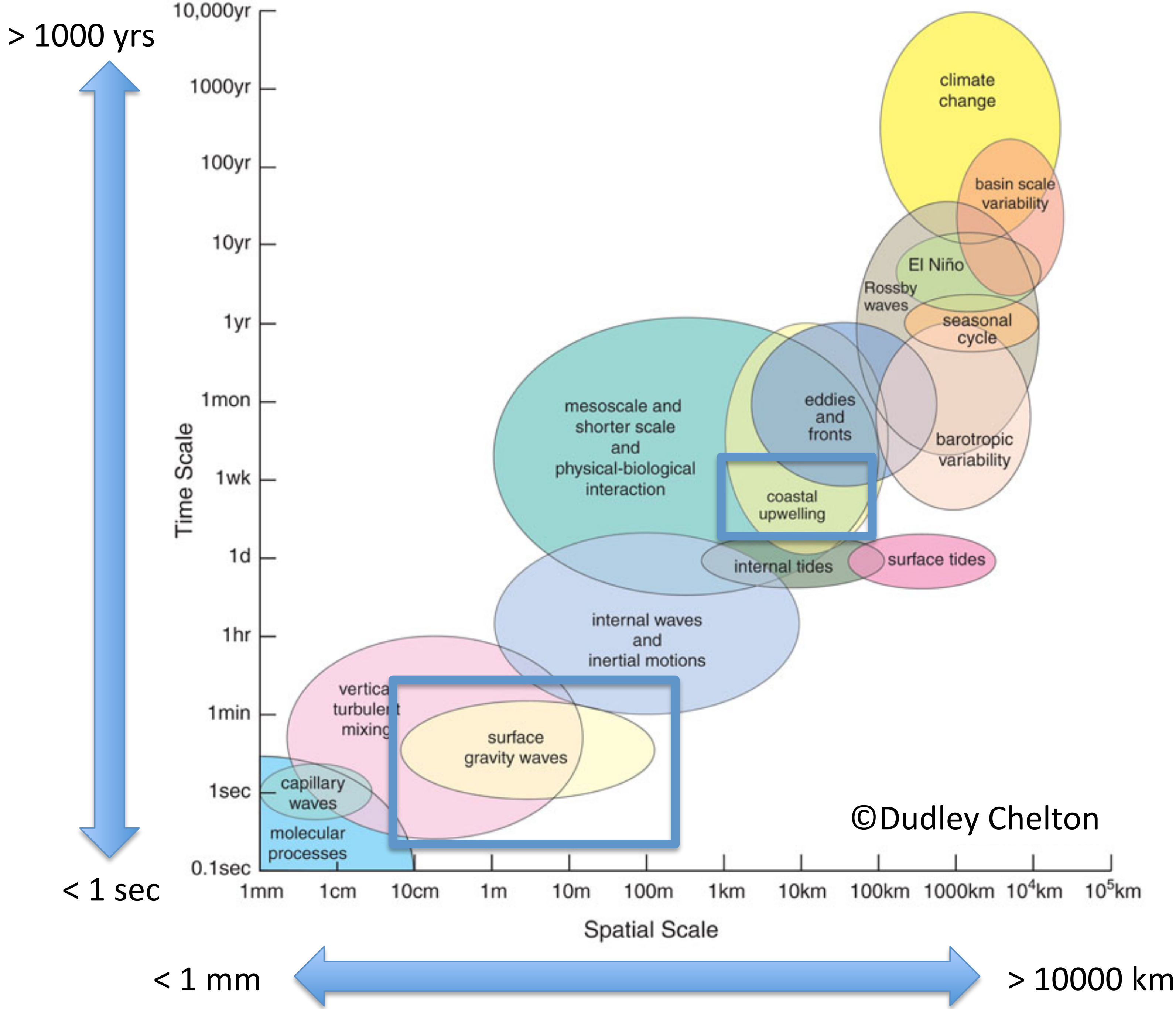


Plant Di



Langmuir and Internal Waves, NRL

Relevant spatial scales range many orders of magnitude from ~10000 km to submeter and smaller



> 1000 yrs
< 1 sec
10,000yr
1000yr
100yr
10yr
1yr
1mon
1wk
1d
1hr
1min
1sec
0.1sec
Time Scale
climate change
basin scale variability
El Niño
Rossby waves
seasonal cycle
mesoscale and shorter scale and physical-biological interaction
eddies and fronts
barotropic variability
coastal upwelling
internal tides
surface tides
internal waves and inertial motions
vertical turbulent mixing
surface gravity waves
capillary waves
molecular processes
©Dudley Chelton
1mm
1cm
10cm
1m
10m
100m
1km
10km
100km
1000km
10^4km
10^5km
Spatial Scale
< 1 mm
> 10000 km

What does a physical oceanographer want to know in order to understand ocean processes?

From Merriam-Webster

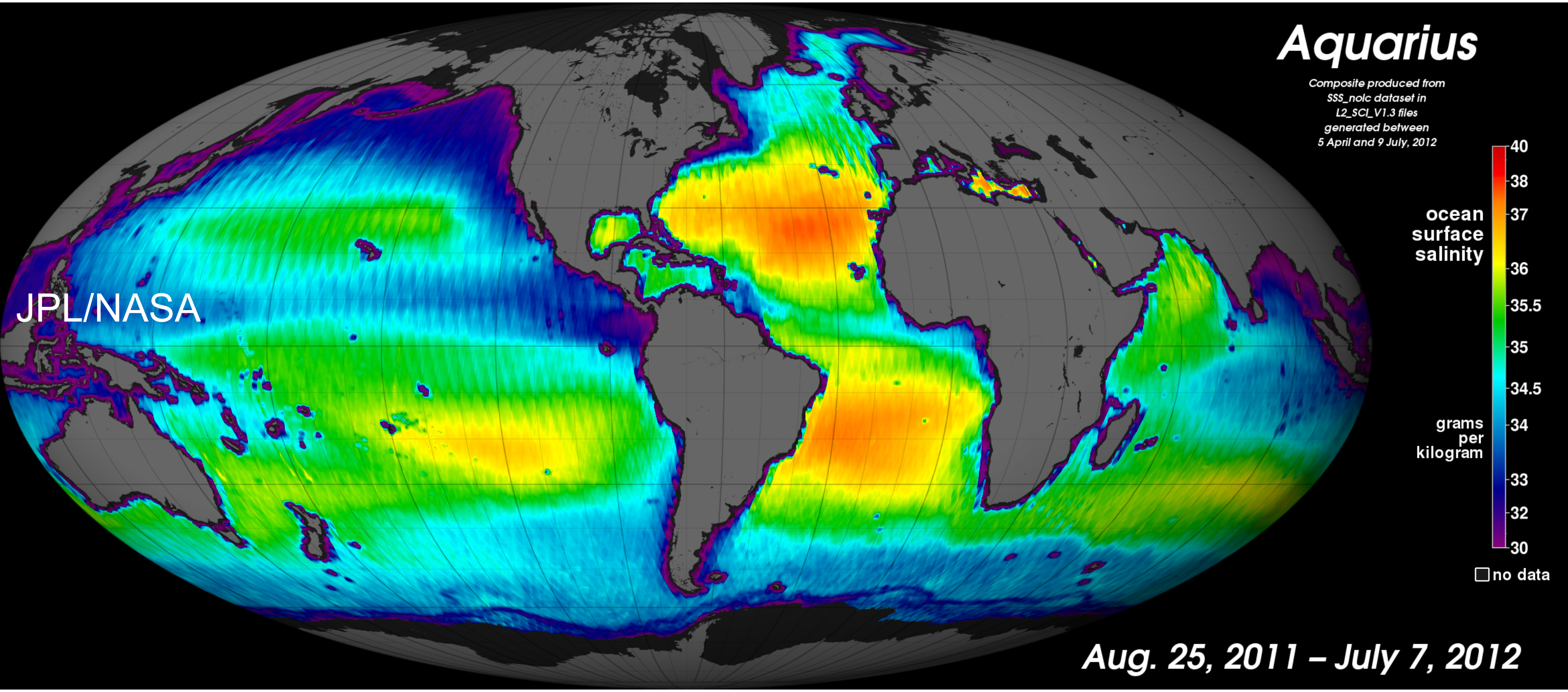
Fluid (noun) : a *substance* (as a liquid or gas) tending to flow or *conform to* the outline of *its container*

need to describe both the *mass* and *volume* when dealing with fluids

Enter→ density (ρ) = mass per unit volume = M/V

Salinity, Temperature, & Pressure

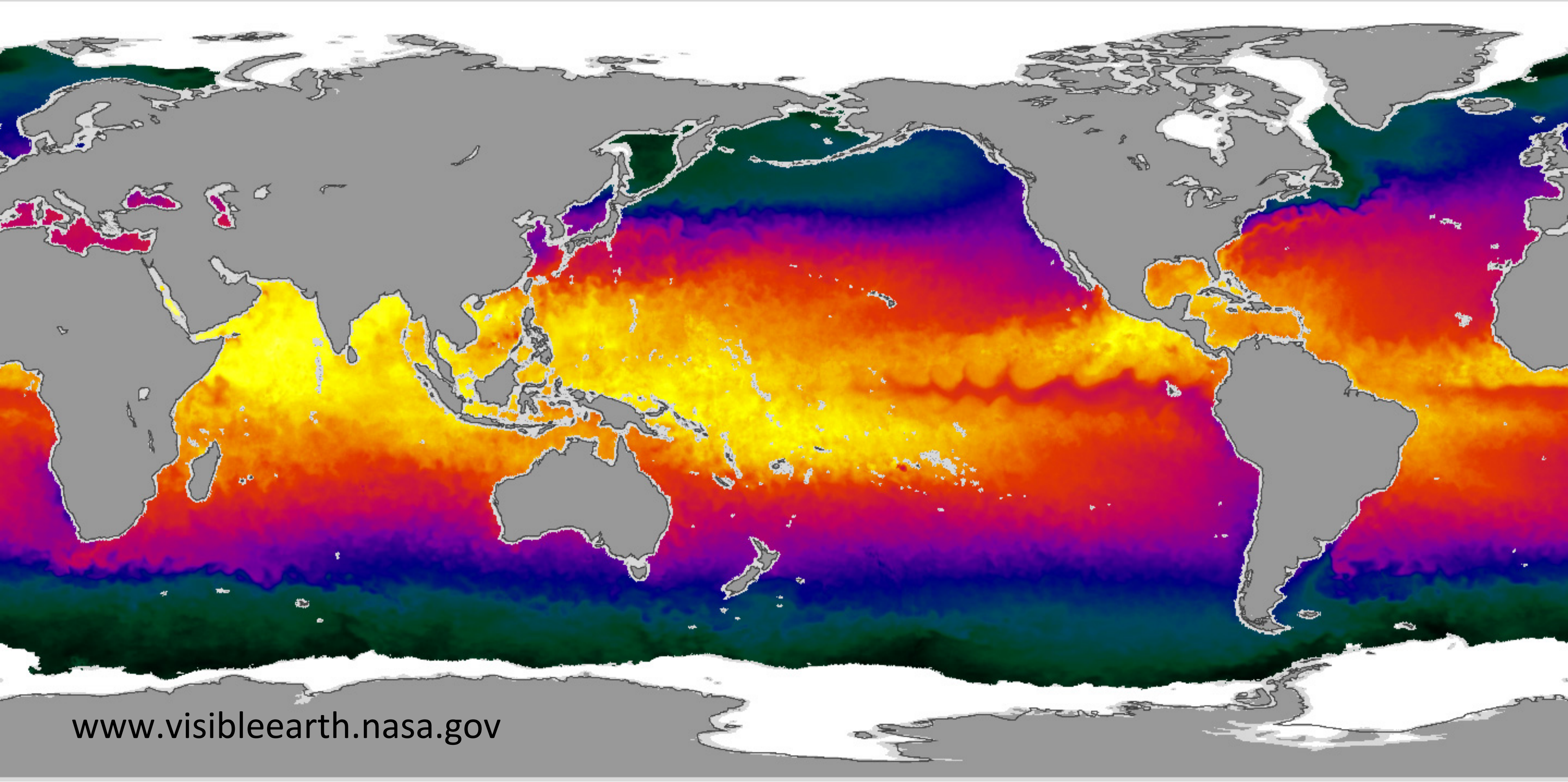
Surface *Salinity*: Precipitation & Evaporation



Where precipitation exceeds evaporation and river input is low, salinity is increased and vice versa. Note: coastal variations are not evident on this coarse scale map.

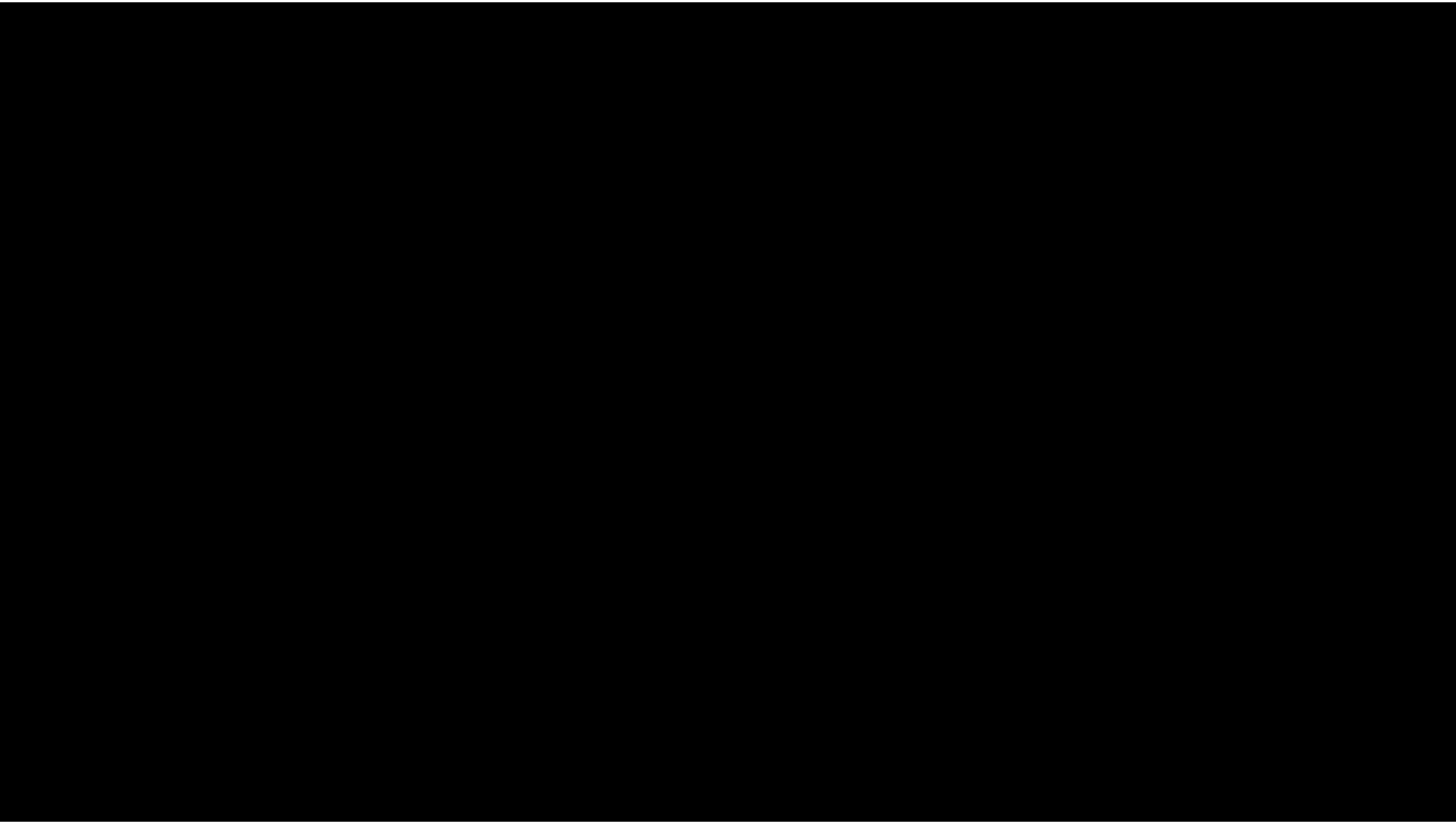
Surface *Temperature*- Net warming at low latitudes and cooling at high latitudes. → Need *Transport*

Sea Surface Temperature from NASA's Aqua Satellite (AMSR-E)



Perpetual Ocean http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=3827

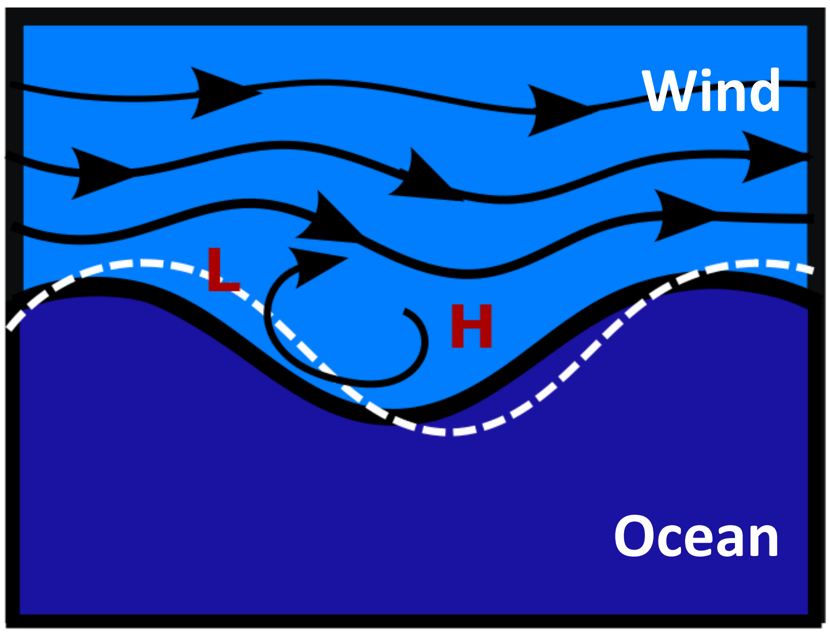
Estimating the Circulation and Climate of the Ocean- Dimitris Menemenlis



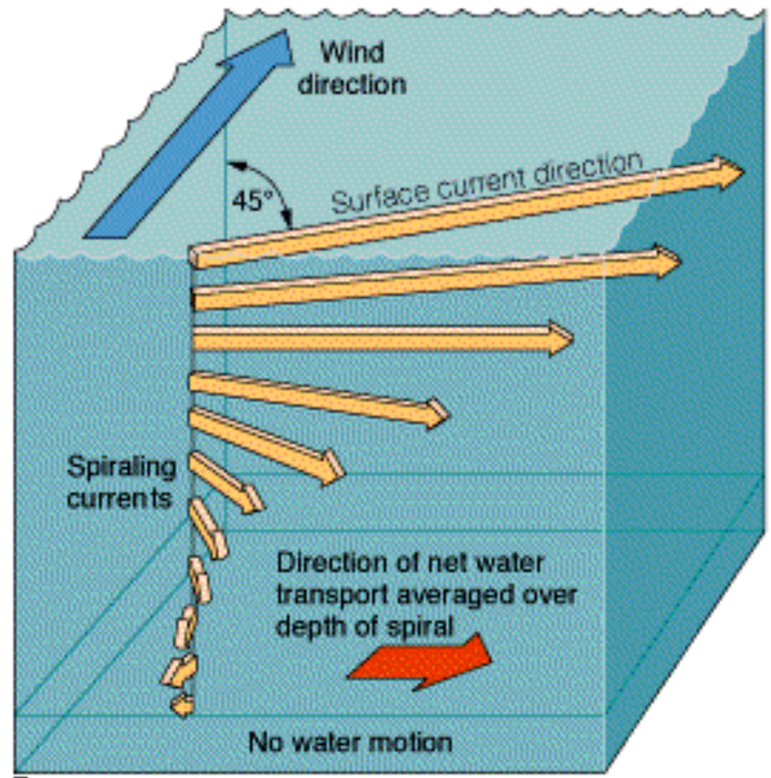
Coastal Circulation

What happens when the wind blows on the surface of the ocean???

1. Surface Waves
Swell & Wind Waves



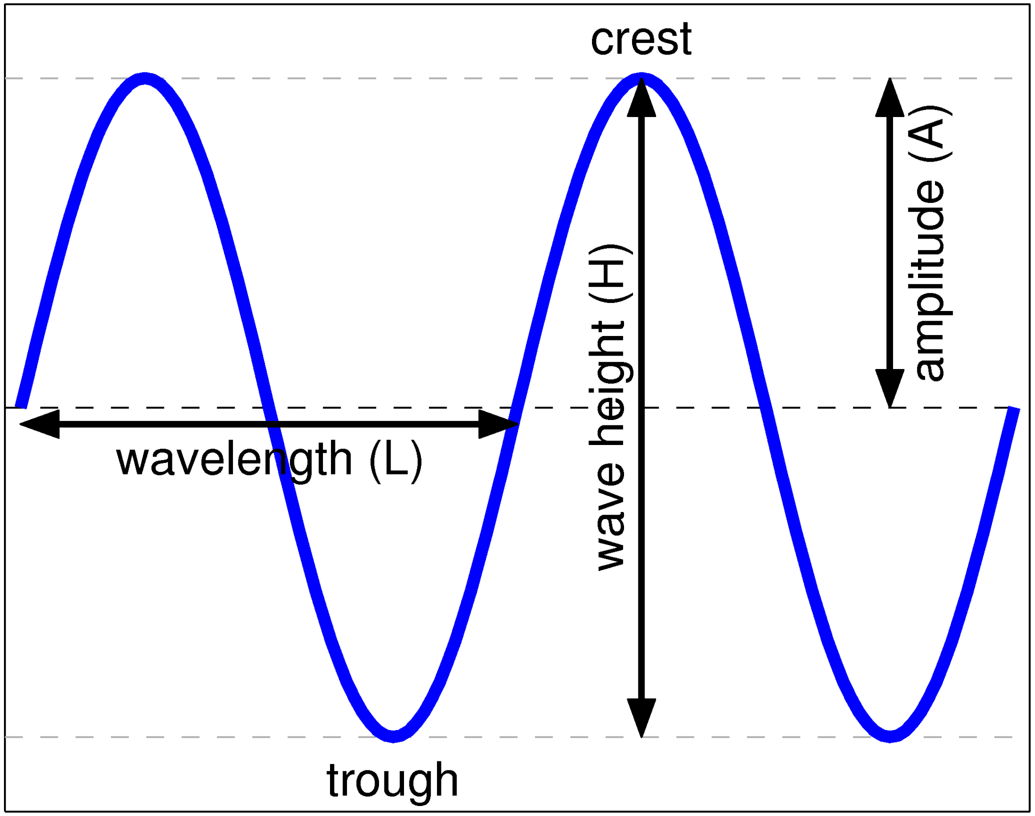
2. Ekman Transport:
Coastal Upwelling



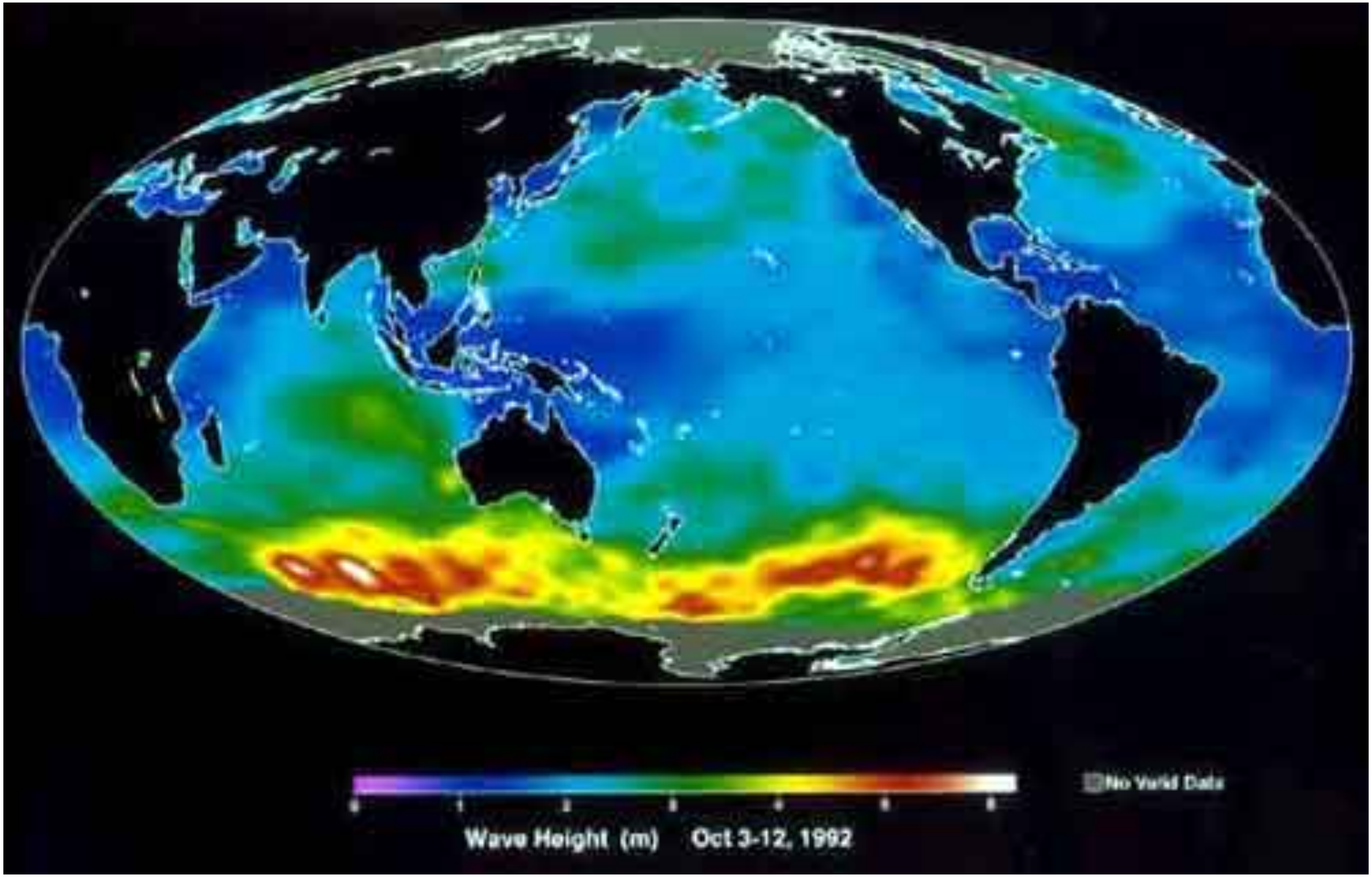
Waves in the Ocean

Properties of a Wave

Wave Height
Amplitude
Wavelength
Wave Steepness

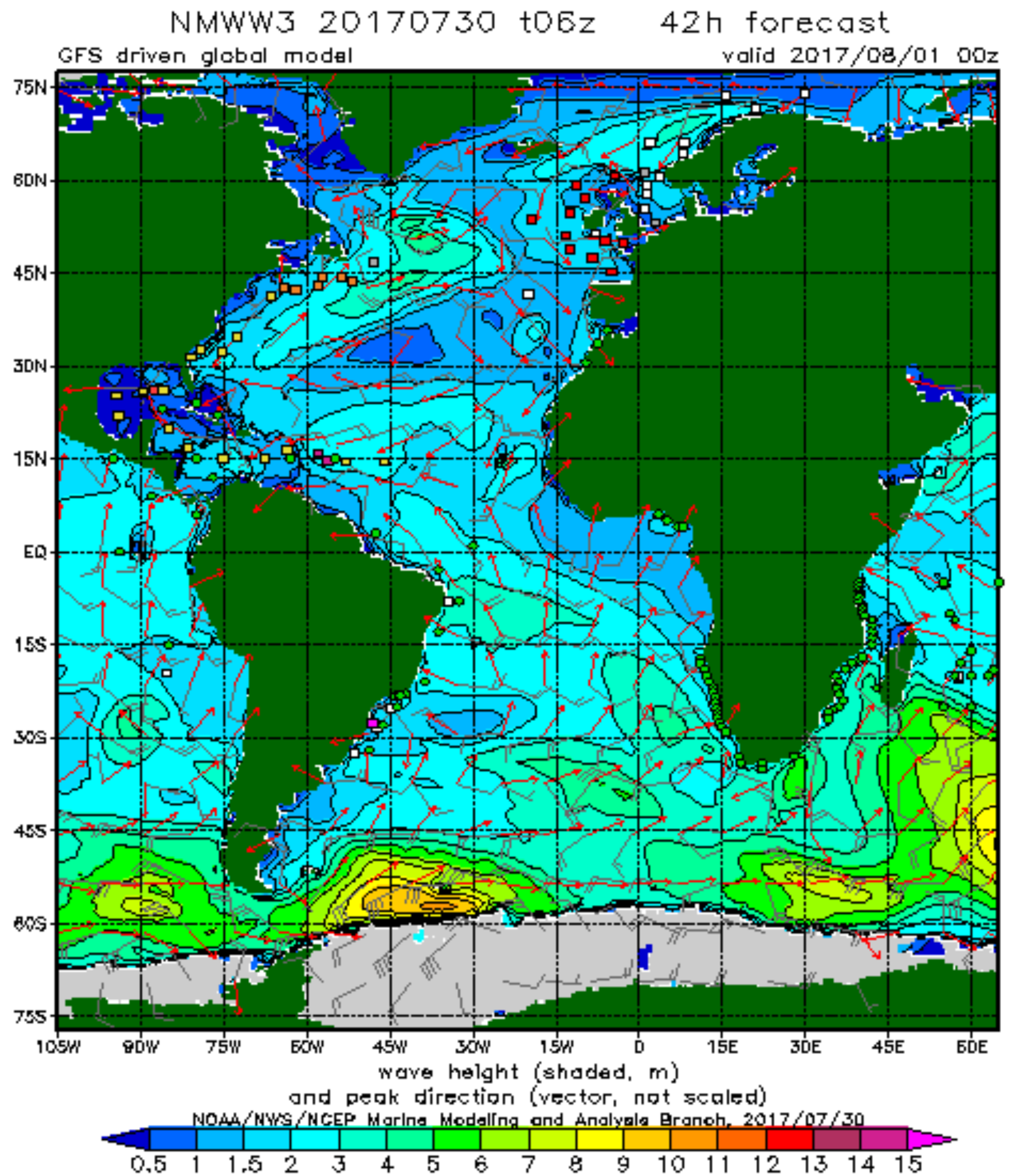


Wind Generation of Surface Gravity Waves



Wavewatch III- Surface Wave Forecast

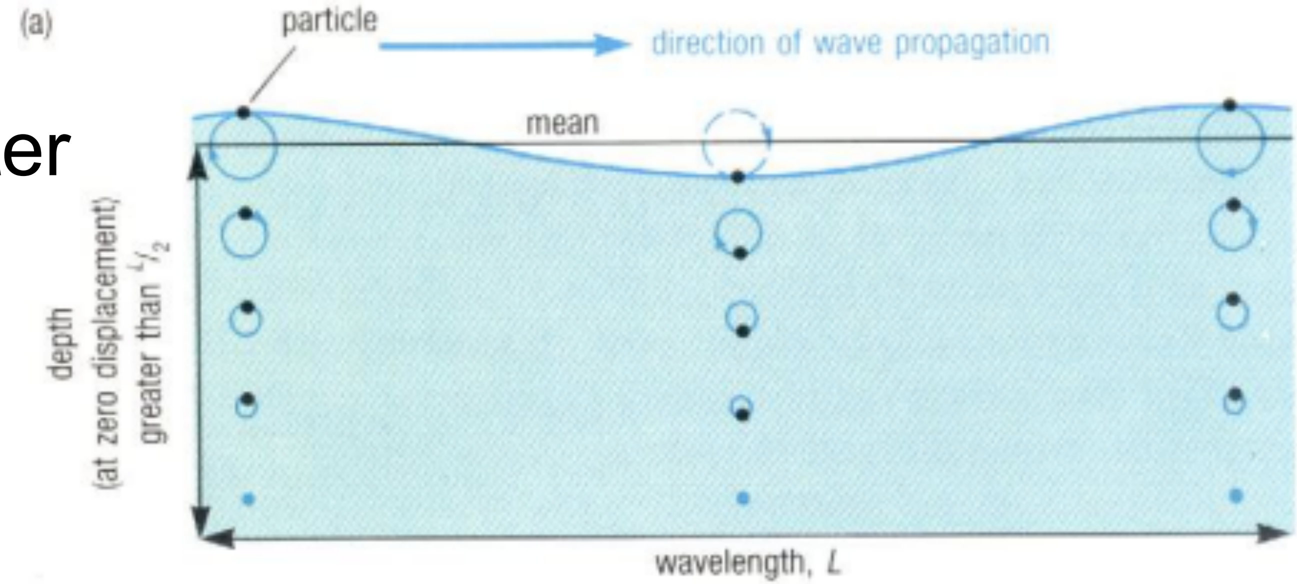
- SO storms very energetic
- swell versus wind waves
- swell- long waves arrive first



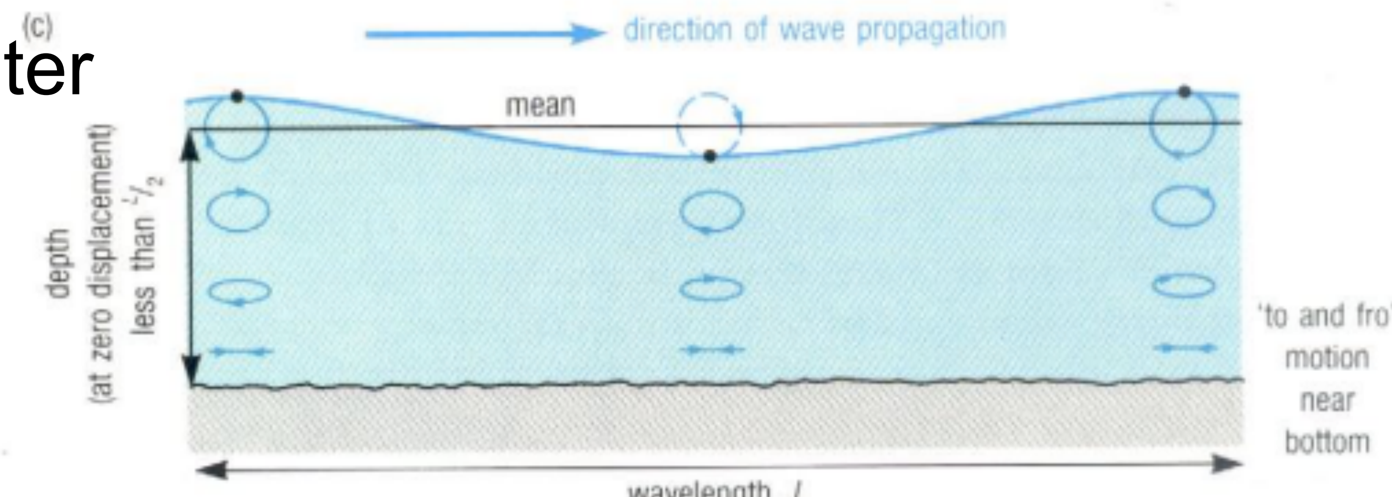
http://polar.ncep.noaa.gov/waves/

Surface Gravity Waves

Deep Water Waves



Shallow Water Waves



Surface Gravity Waves-- Wave Speed ($c=L/T$)

$$c = \sqrt{\frac{gL}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)}$$

water depth

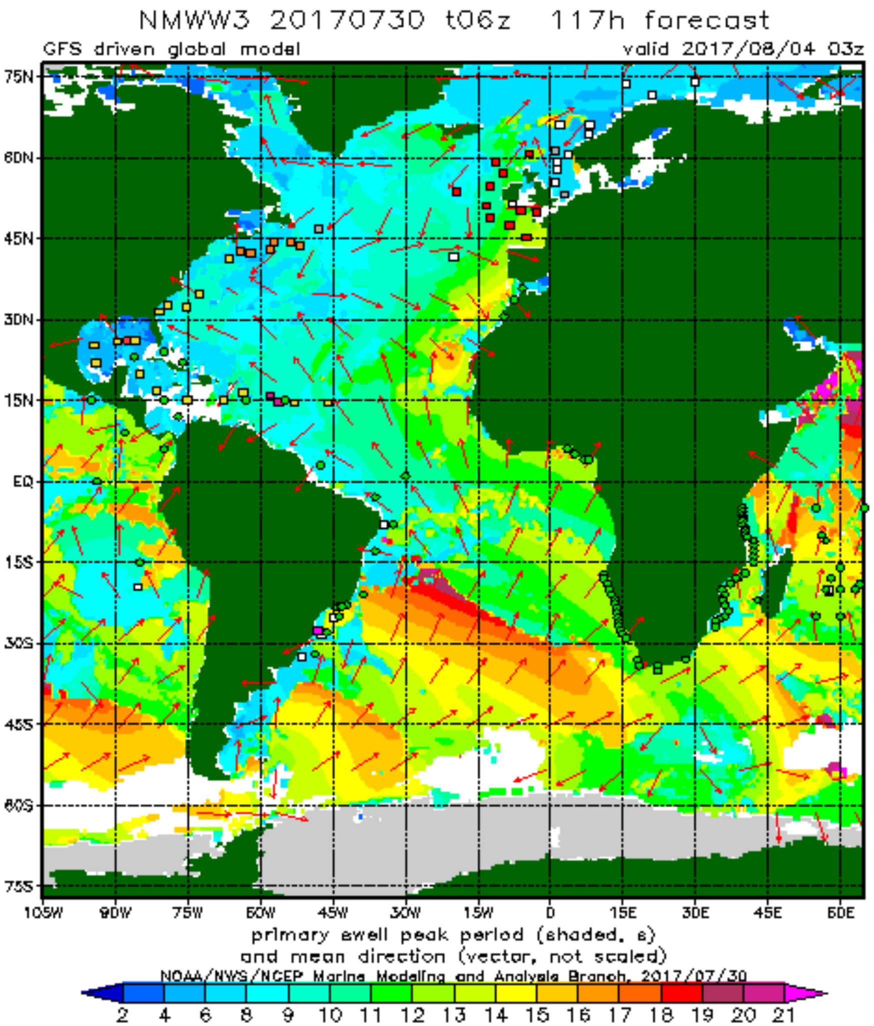
Shallow Water Waves

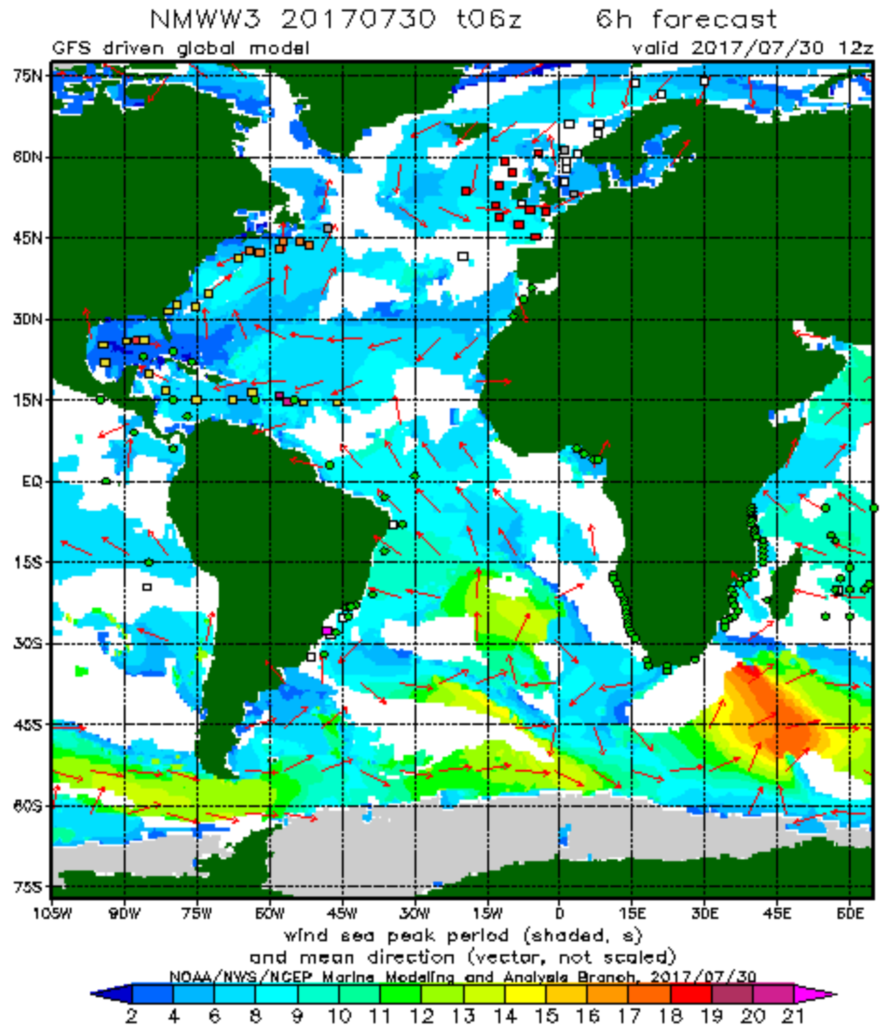
$$\tanh\left(\frac{2\pi d}{L}\right) \rightarrow \frac{2\pi d}{L}; c = \sqrt{\frac{gL \times 2\pi d}{2\pi L}} = \sqrt{gd}$$

Deep Water Waves

$$\tanh\left(\frac{2\pi d}{L}\right) \rightarrow 1; c = \sqrt{\frac{gL}{2\pi}} = \frac{gT}{2\pi}$$

Dispersion



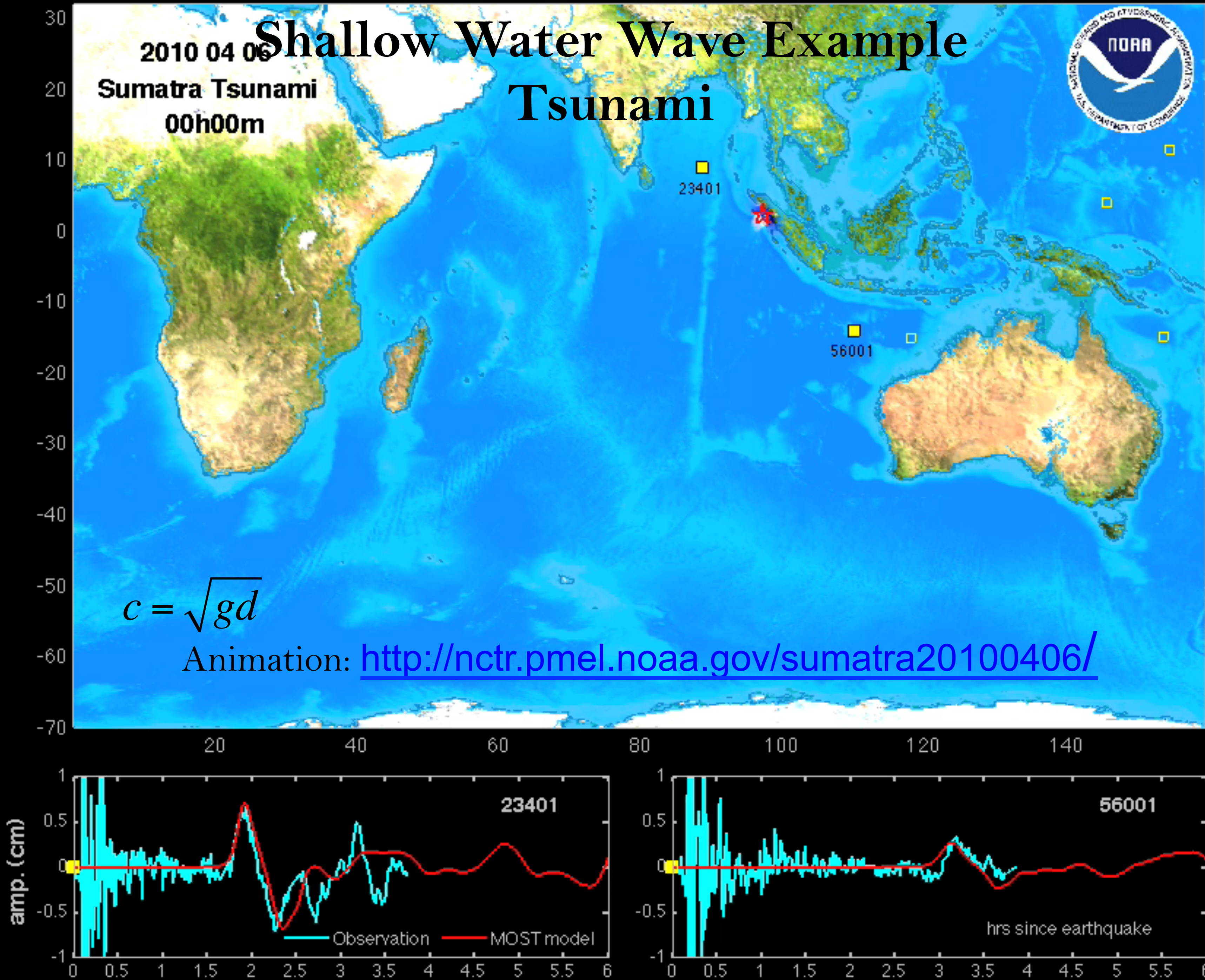


Deep Water Waves

$$c = \sqrt{\frac{gL}{2\pi}} = \frac{gT}{2\pi}$$

Swell Period (left)
Sea Period (right)

Shallow Water Wave Example Tsunami

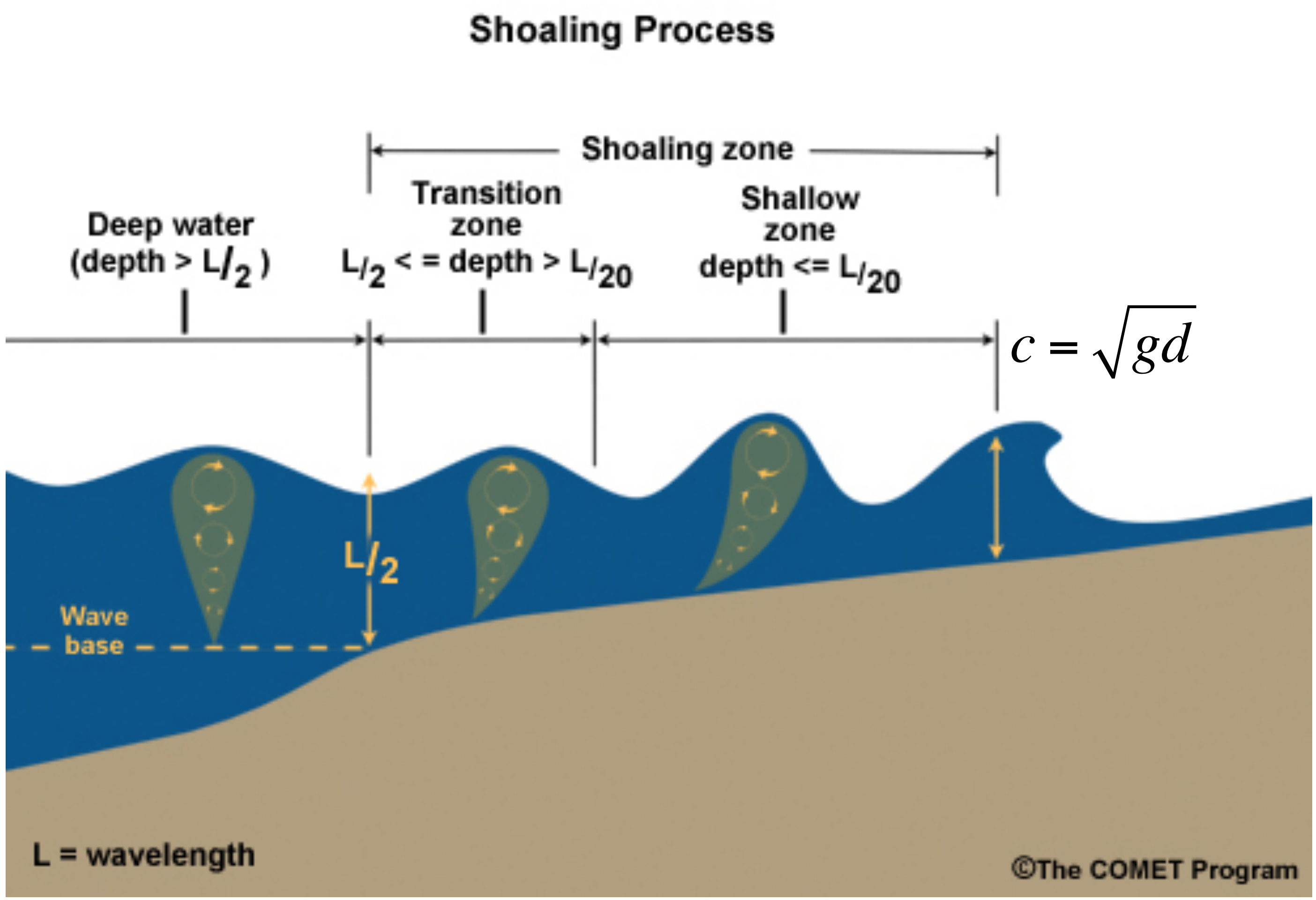


$$c = \sqrt{gd}$$

Animation: http://nctr.pmel.noaa.gov/sumatra20100406/

Wave Shoaling

$$c = \sqrt{\frac{gL}{2\pi}}$$

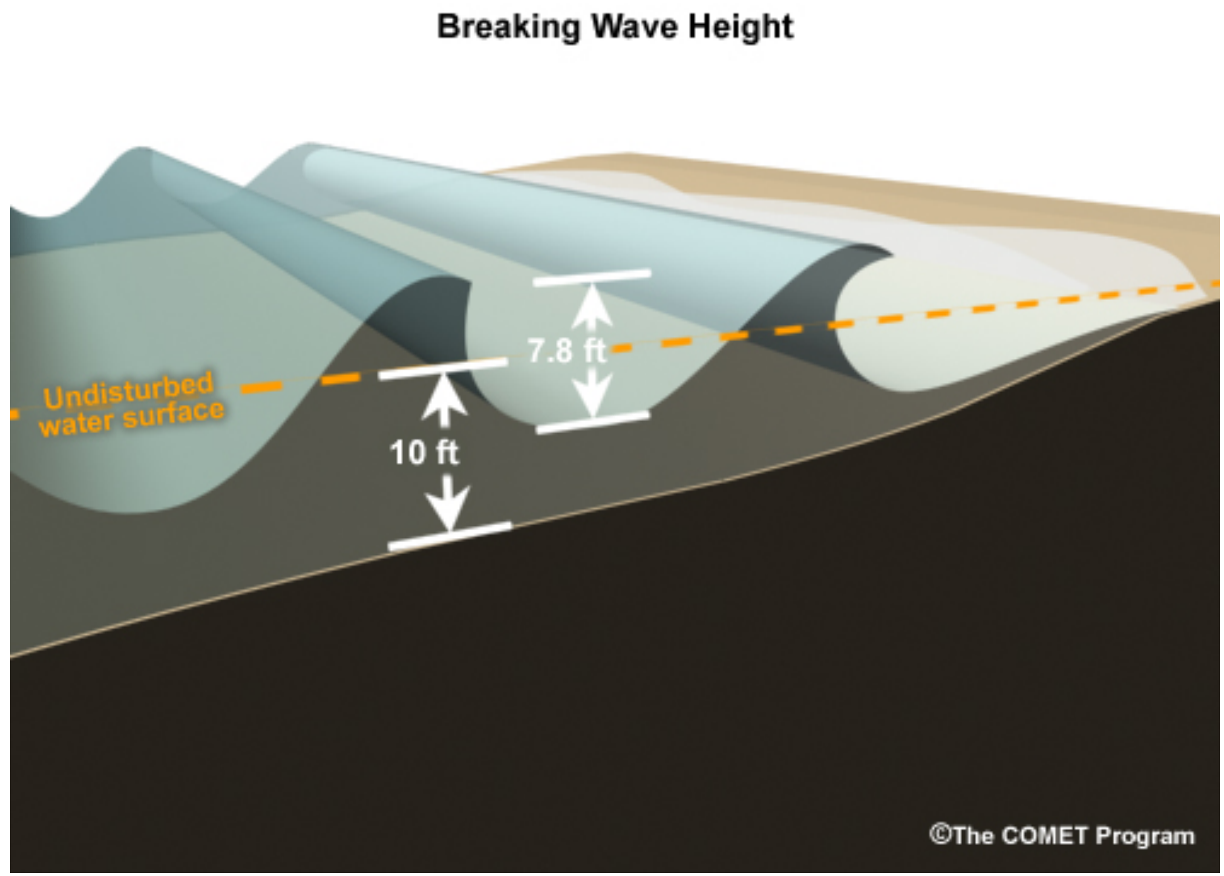


$$c = \sqrt{gd}$$

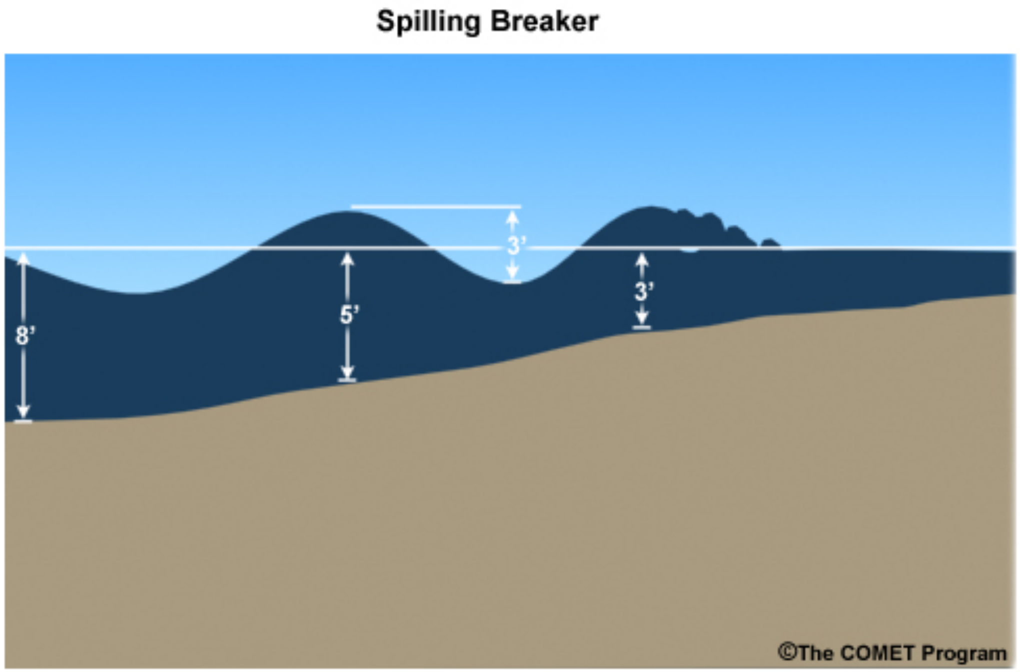
Breaking

surface waves break when the wave height is greater than 0.78 times the water depth

$H > 0.78h$



Spilling Breakers

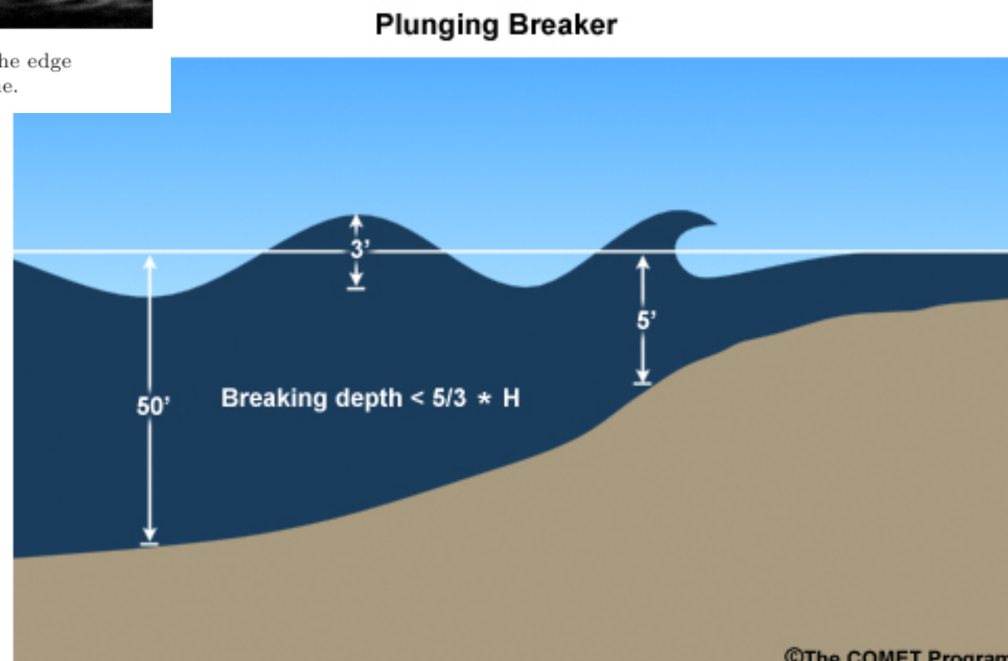


- foam,turbulence at crest
- gently sloping beach
- starts some distance from shore

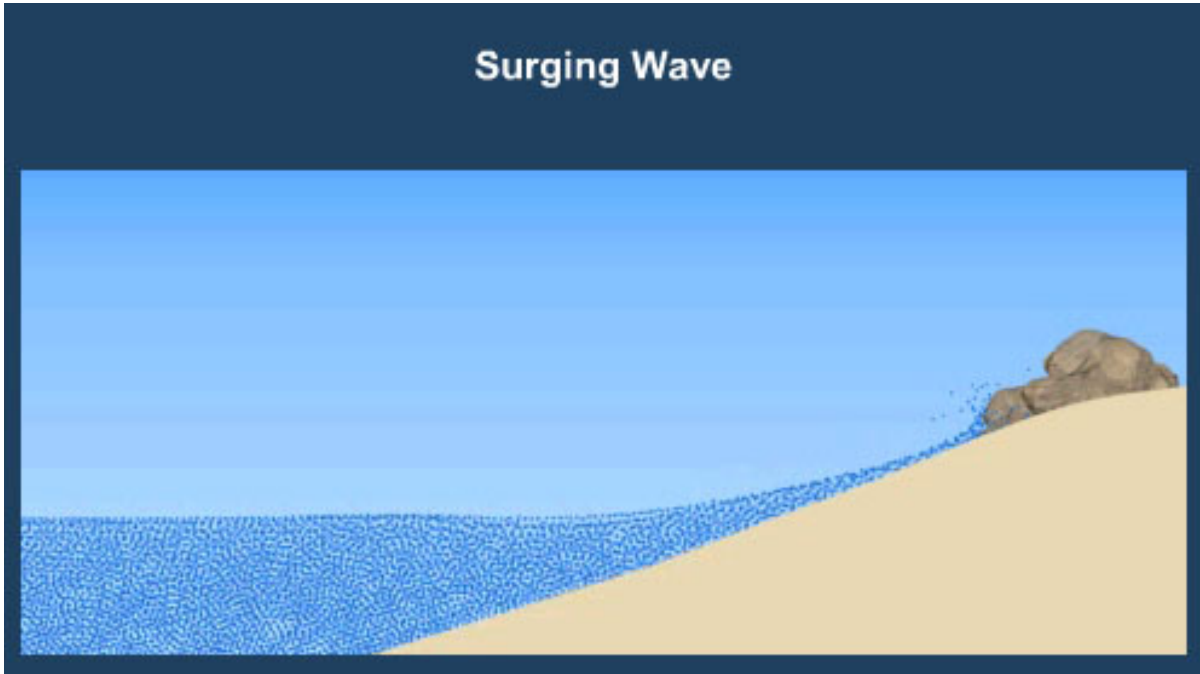
Plunging Breakers

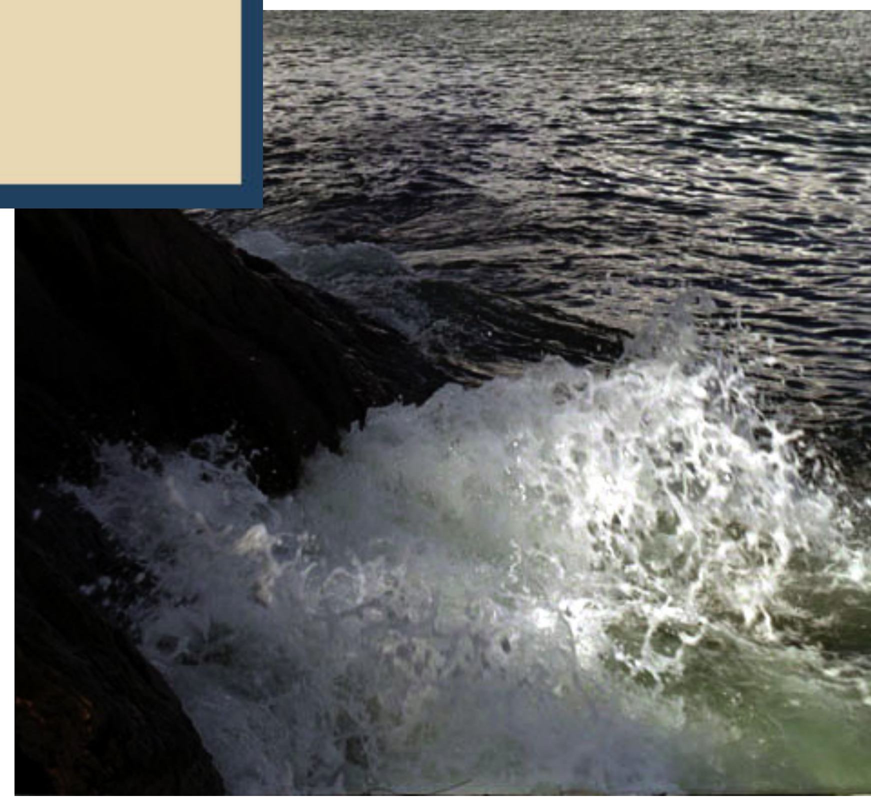
Figure 17.4 Steep, plunging breakers are the archetypical breaker. The edge of such breakers are ideal for surfing. From photo by Jeff Devine.

- dissipated over short distance
- variable slopes
- shallower slopes/distant swell
- wind-- collapsing breaker



Surging Breakers



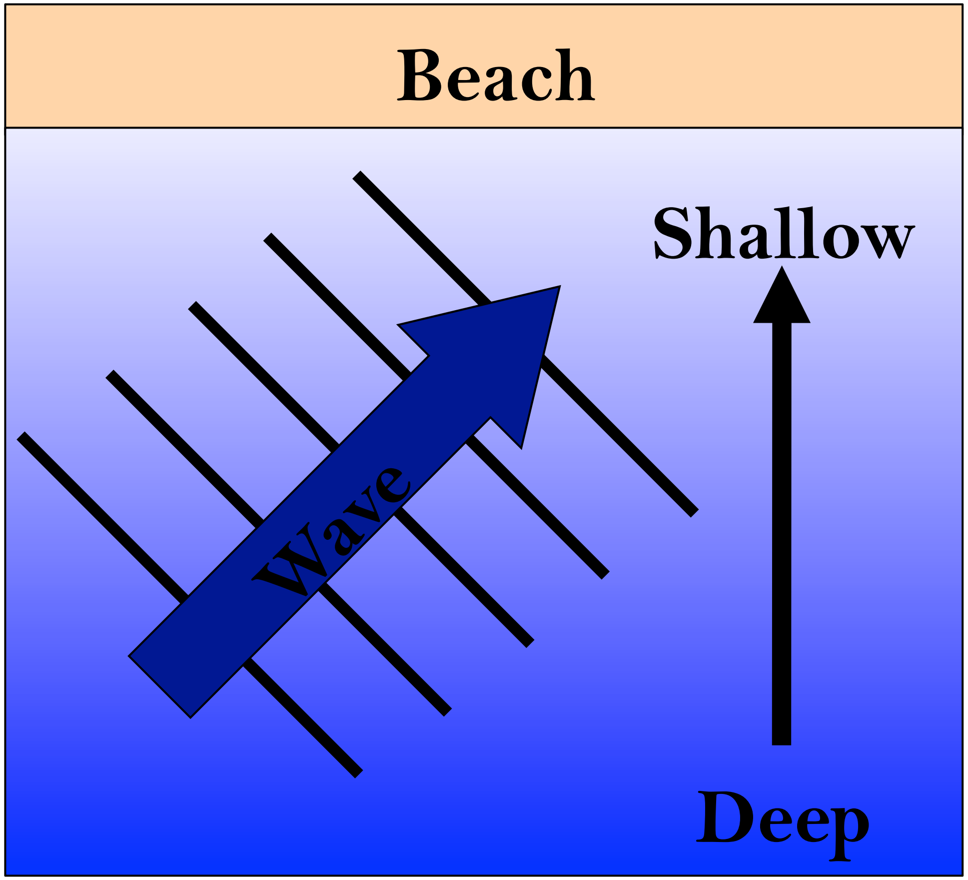


- unbroken
- steep slopes
- waves run-up beach

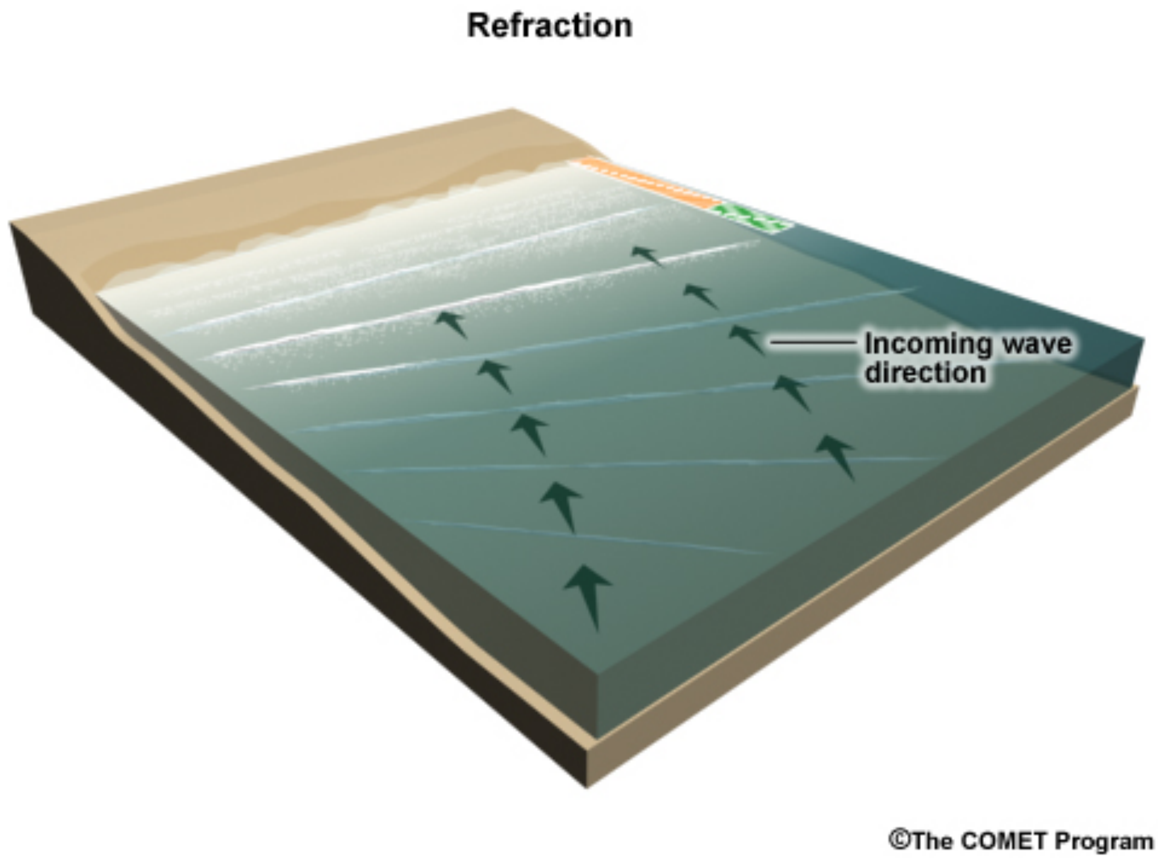
Refraction

What happens if a wave is incident at an angle to the shore (or the shore bends)?

$$c = \sqrt{gd}$$



Refraction



What happens if a wave is incident at an angle to the shore (or the shore bends)?

$$\boxed{c = \sqrt{gd}}$$

Refraction

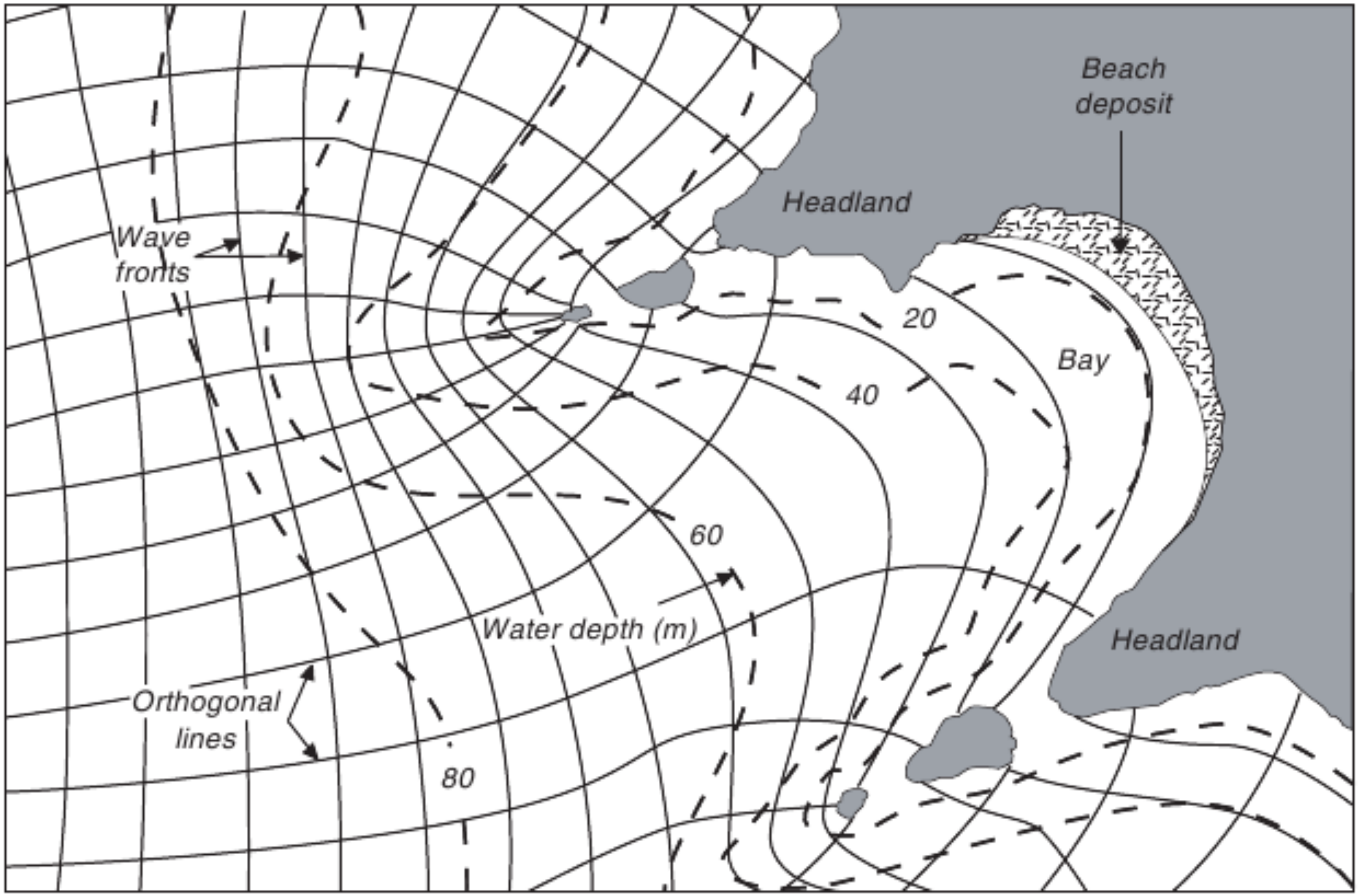
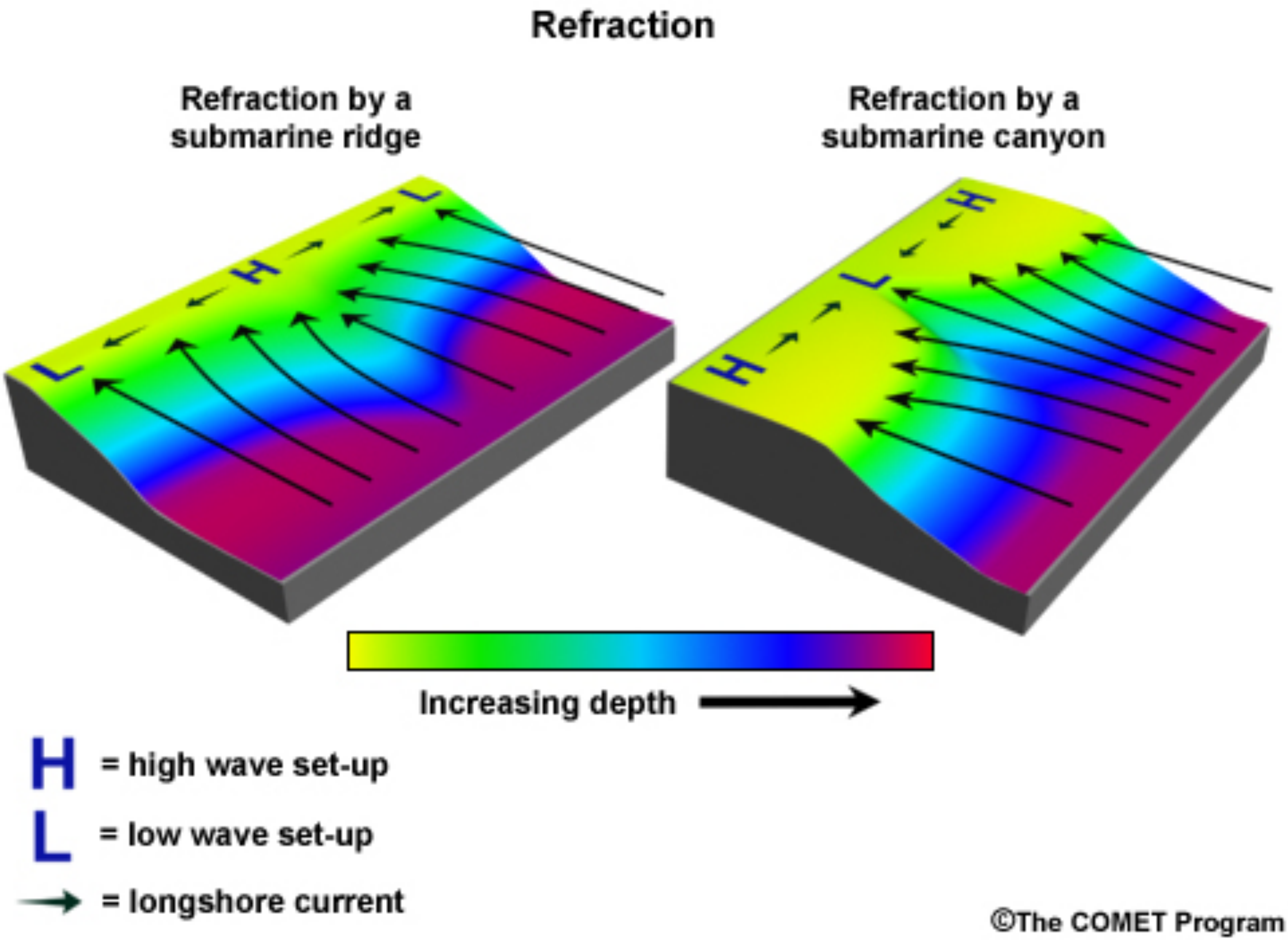


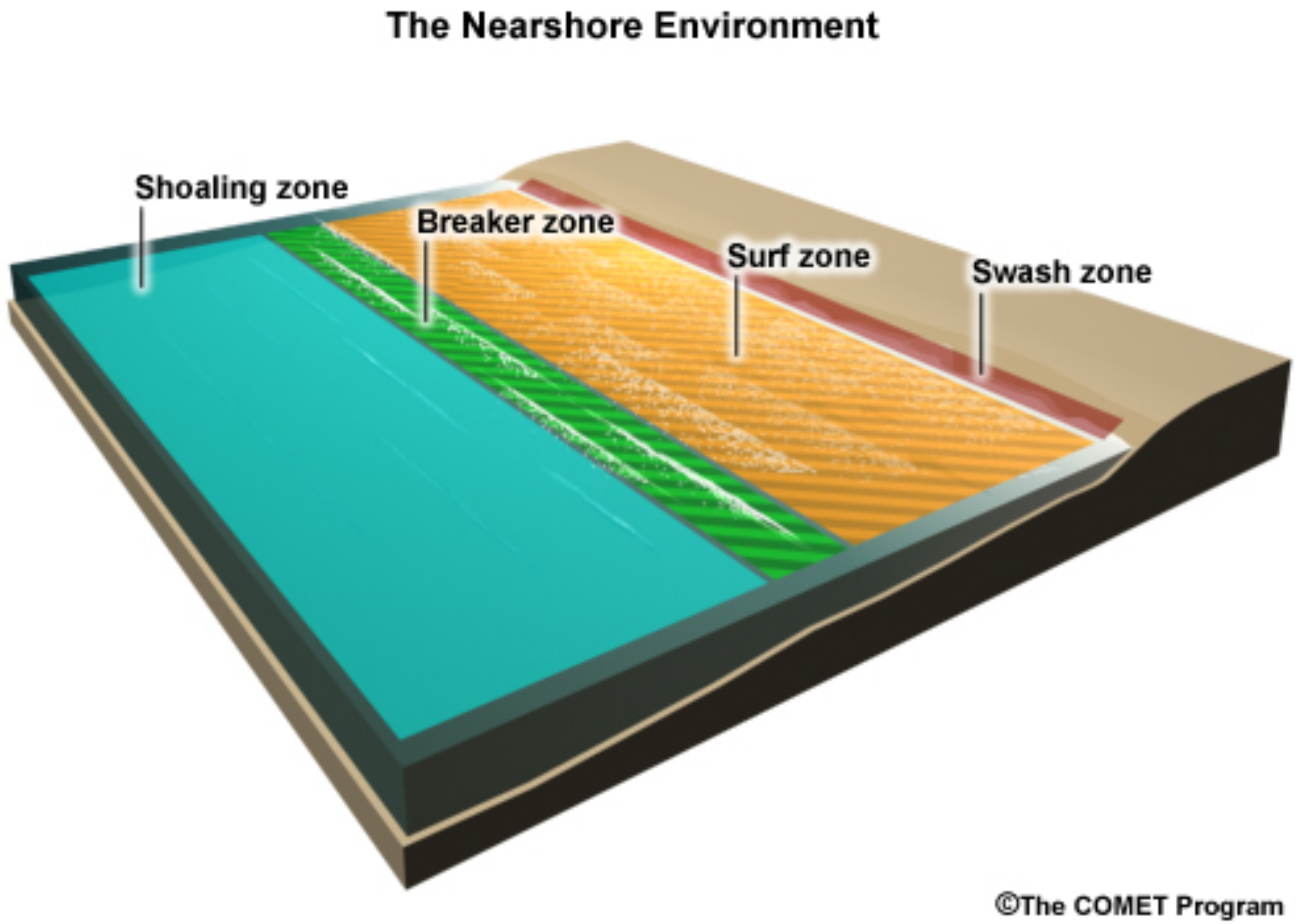
Figure 17.2 sub-sea features, such as submarine canyons and ridges, offshore of coasts can greatly influence the height of breakers inshore of the features. After Thurman (1985: 229).

Refraction



Refraction
Refraction by a submarine ridge
Refraction by a submarine canyon
L
H
L
H
L
H
Increasing depth
H = high wave set-up
L = low wave set-up
= longshore current
©The COMET Program

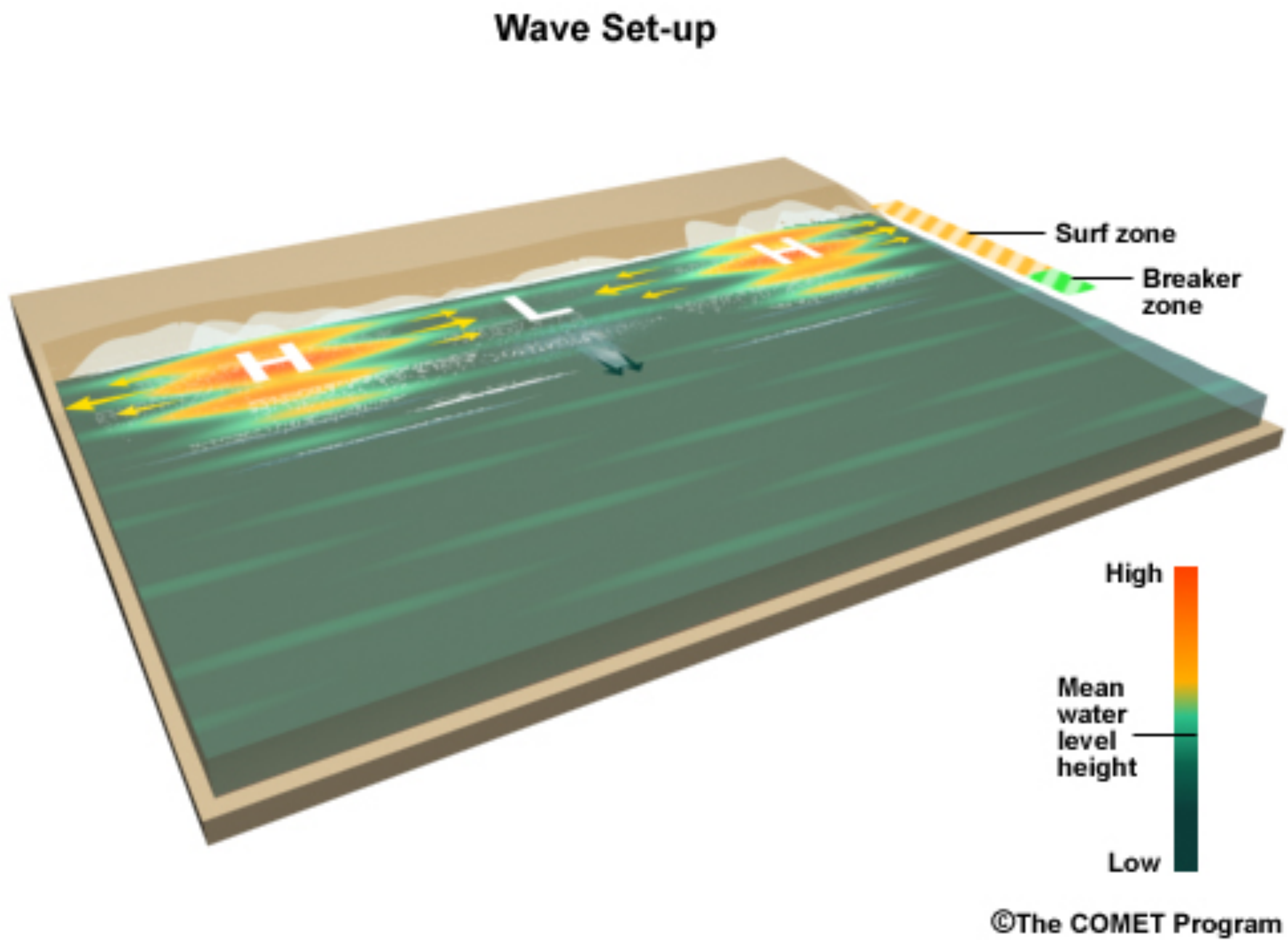
Rip Currents



waves steepen → begins to break → rolling bores

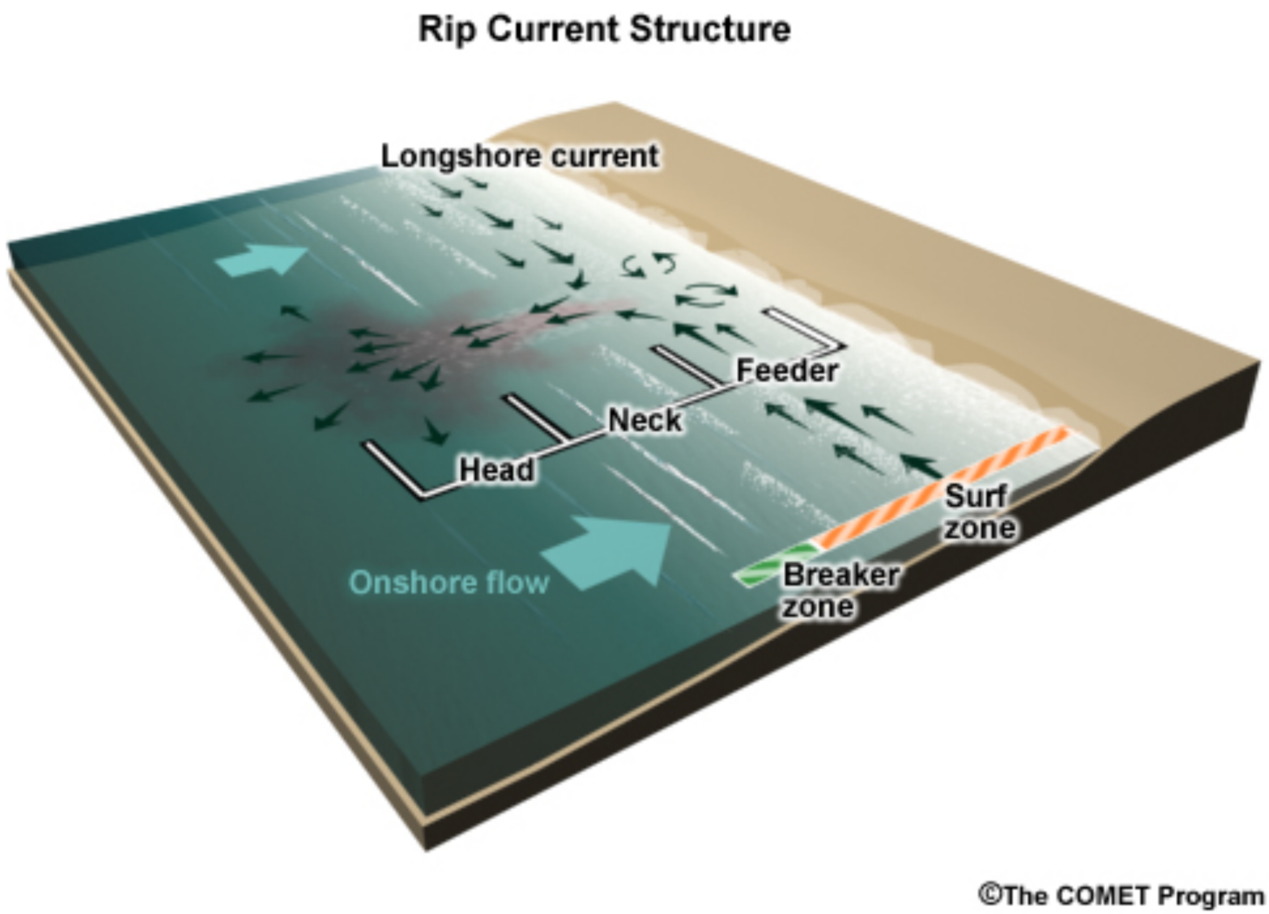
What happen to wave speed and height as waves shoal?

Rip Currents→Wave Set-Up



Variability in Breaking Zone will result in variability of the alongshore pressure gradient.

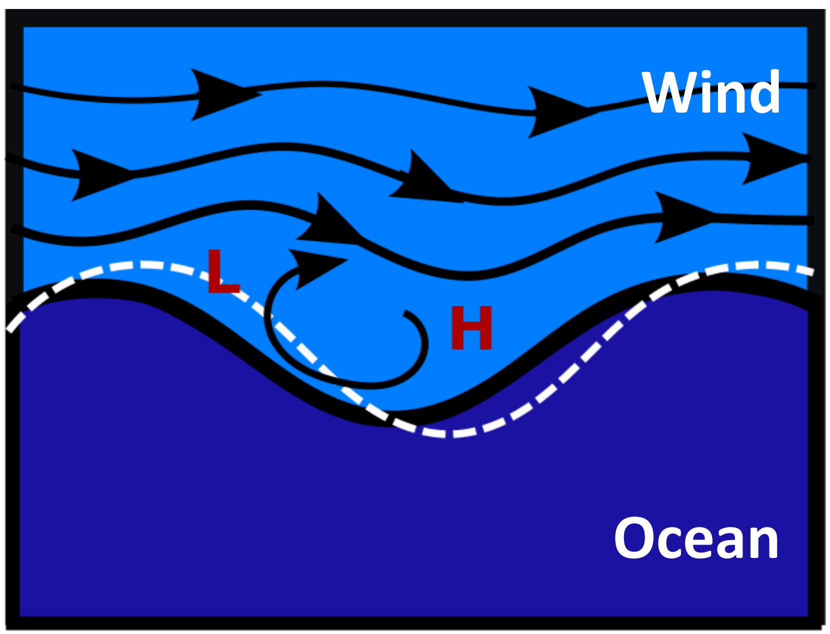
Rip Currents



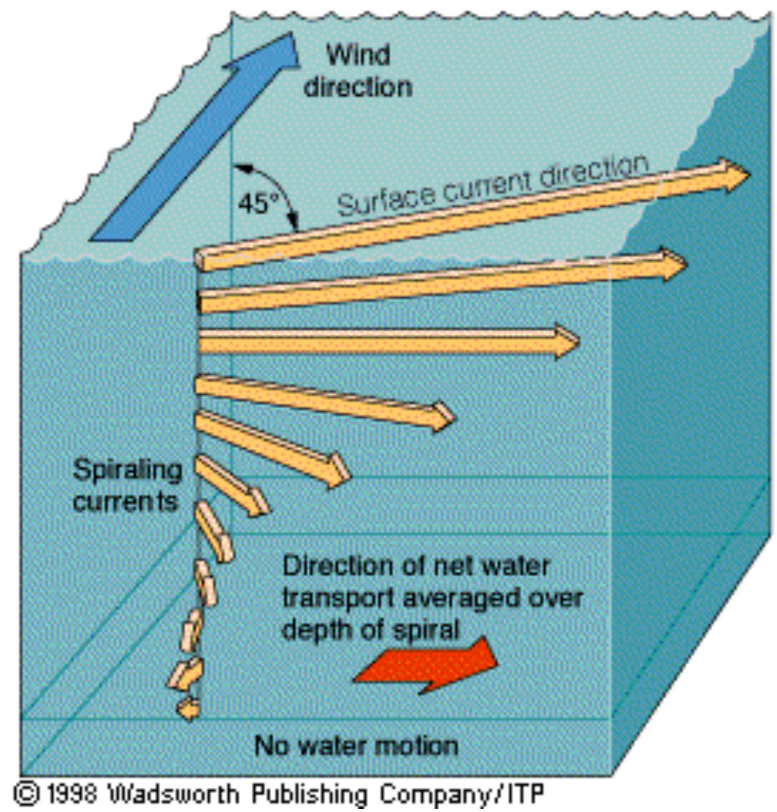
manmade & natural structures, topography, character of incident wave field, slope of the beach (steep=small surf zone= weak longshore currents)

What happens when the wind blows on the surface of the ocean???

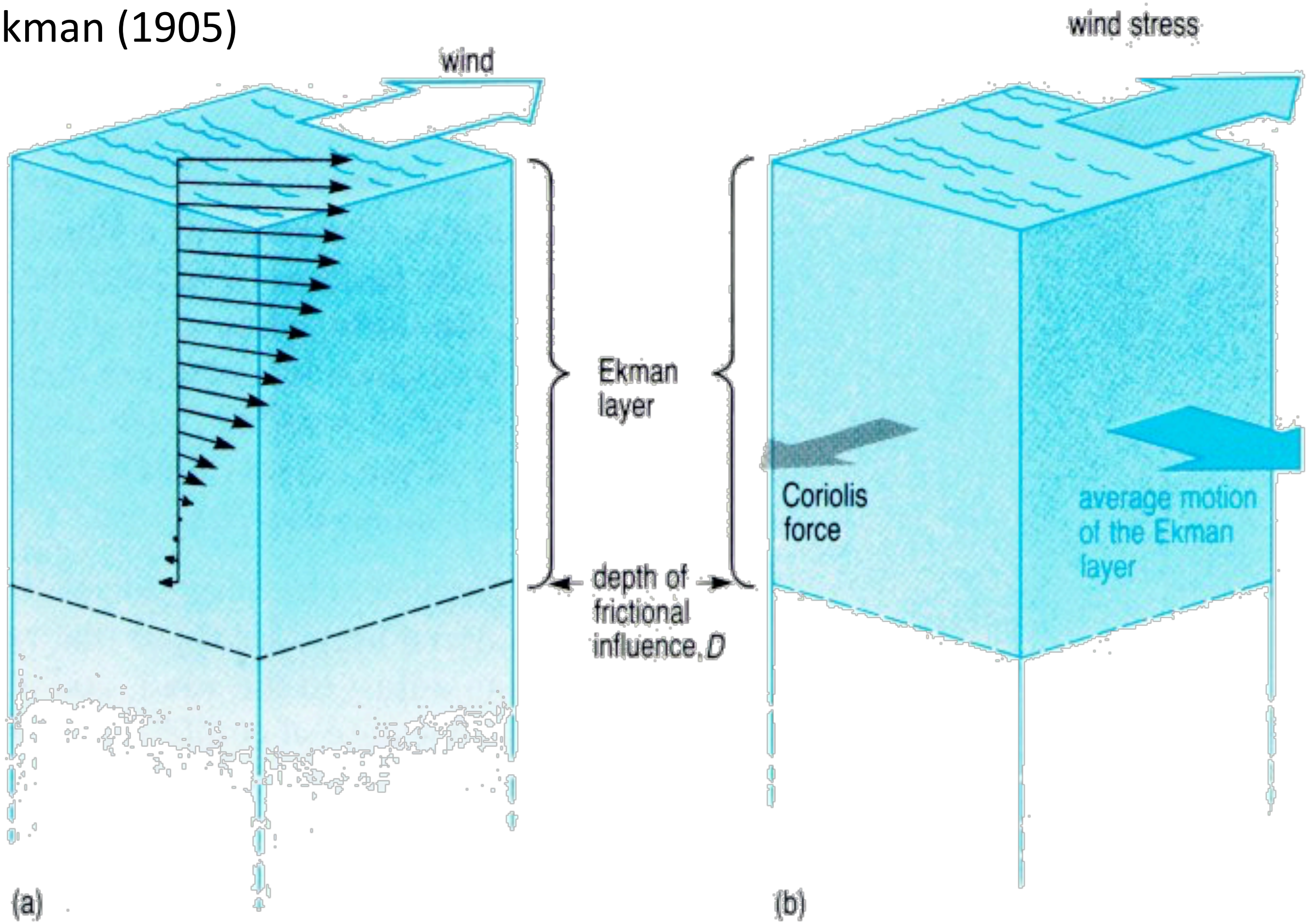
1. Surface Waves Swell & Wind Waves



2. Ekman Transport: Coastal Upwelling



Ekman (1905)



<u>Ekman Transport:</u>

Due to wind and the Earth's rotation

Always to the right of the wind

$$\text{Ekman Transport} = \frac{\tau}{\rho f}$$

τ = Wind Stress (proportional to wind speed squared)

ρ = Density of Sea Water

f = Coriolis parameter (Earth rotation rate)

Winds, Ekman Transport and Coastal Upwelling/Downwelling

Equatorward winds

Offshore Ekman transport

Upwelling brings deep, cold, nutrient rich water to the surface near the coast

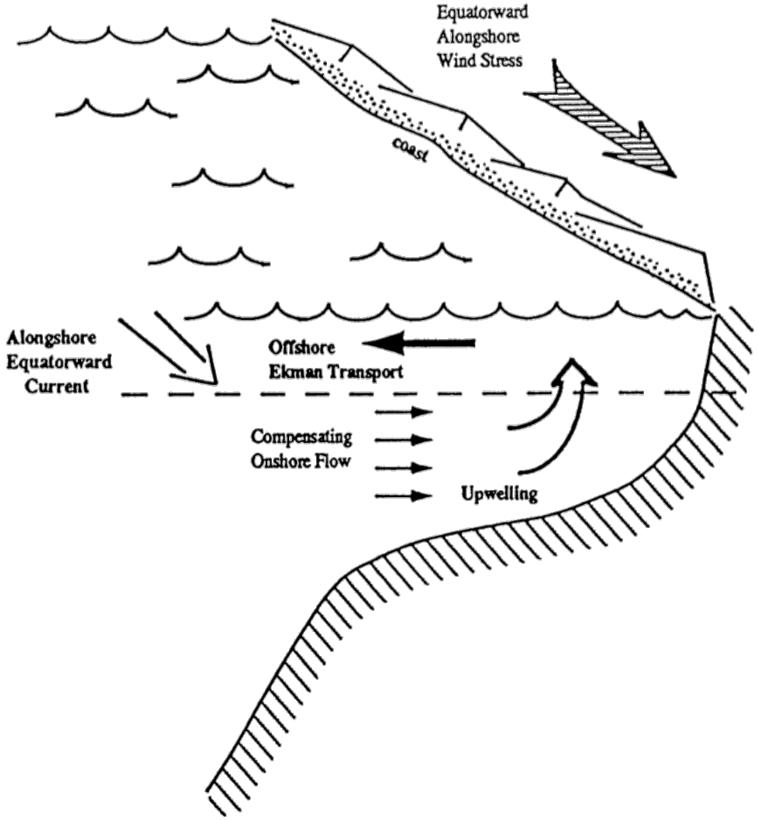
Strong equatorward along-shelf flow

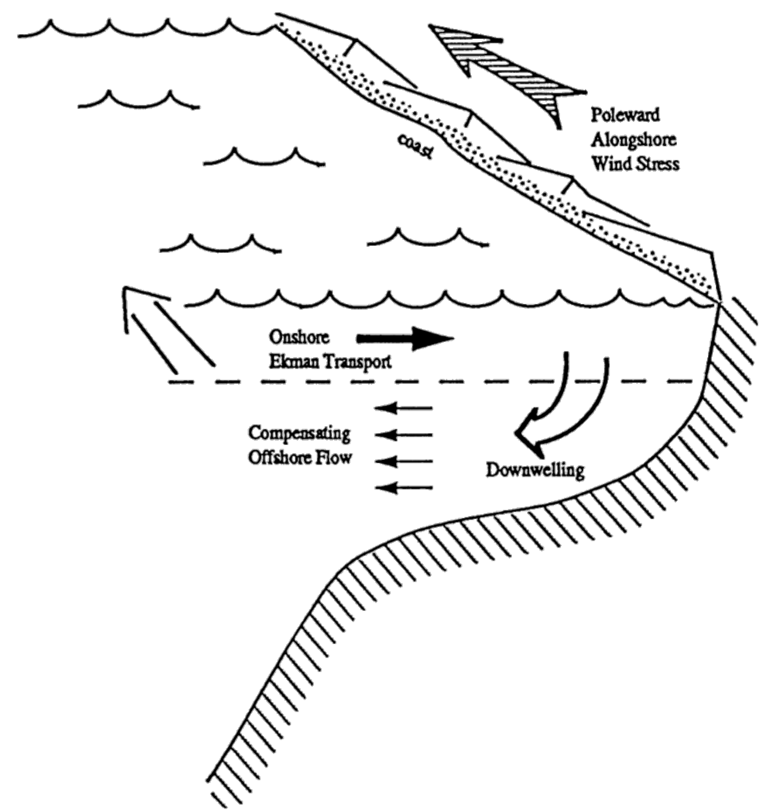
Poleward winds

Onshore Ekman transport

Downwelling traps warm, nutrient poor surface water near the coast

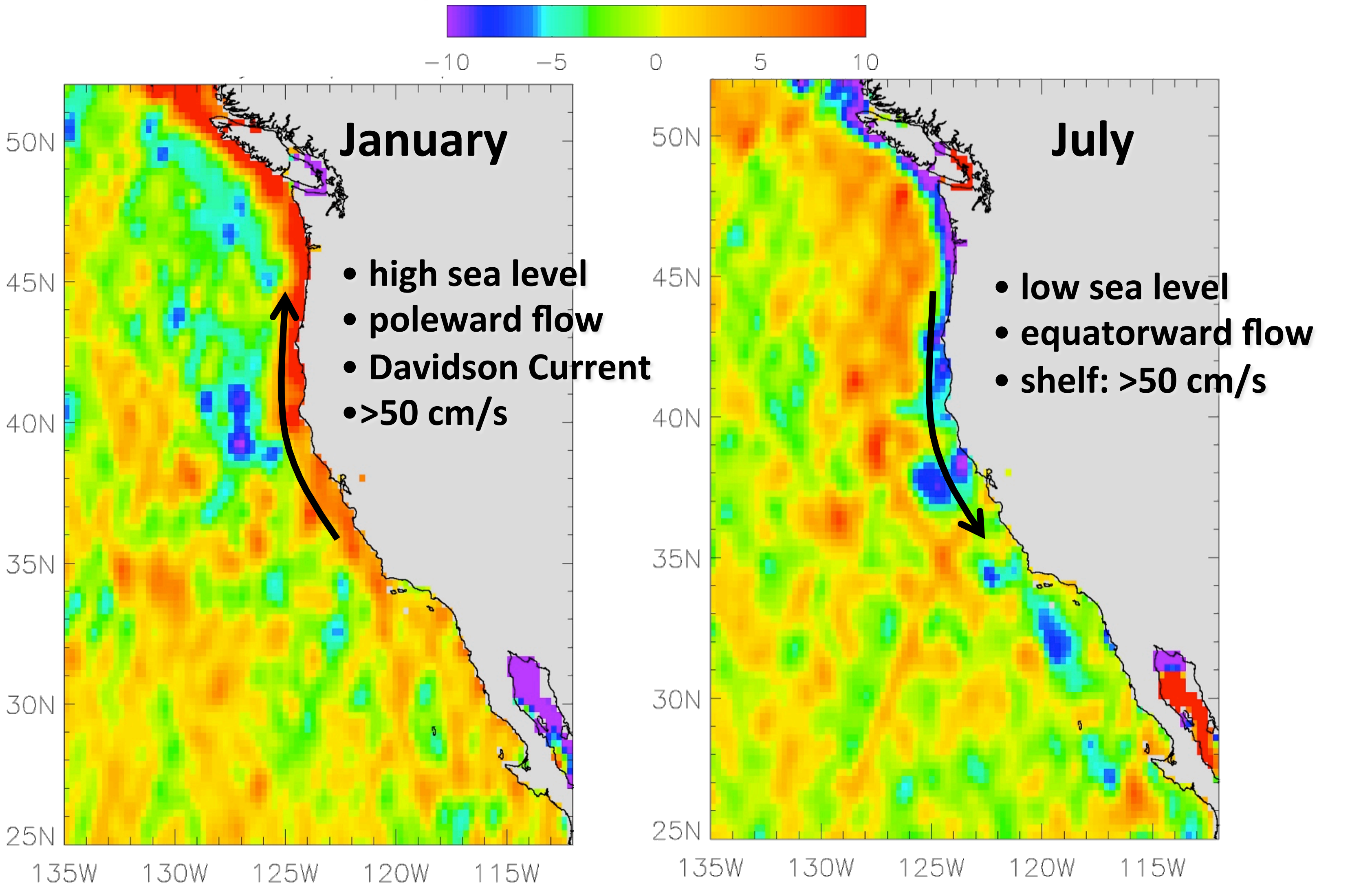
Strong poleward along-shelf flow



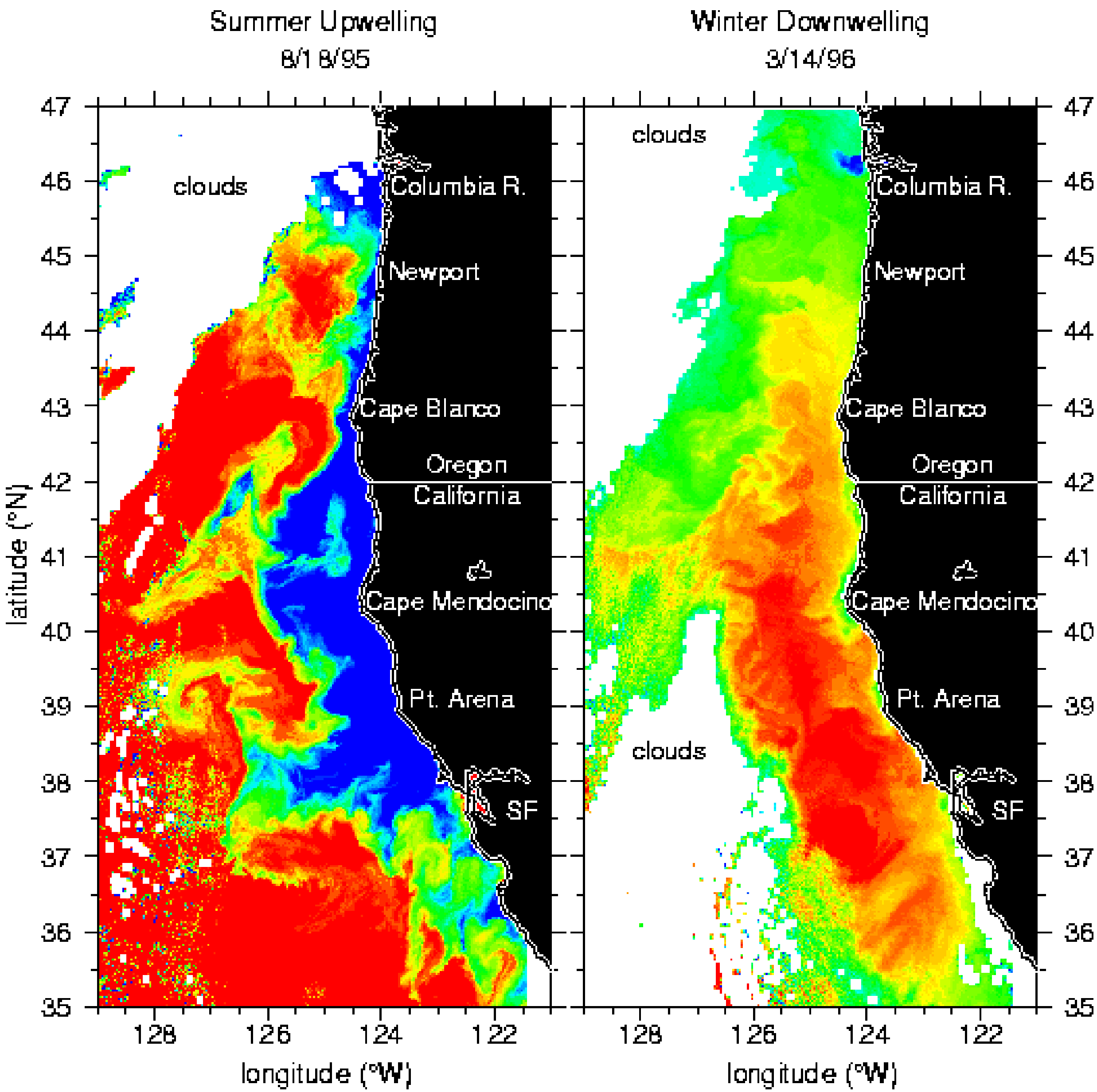


Flow Over the Shelf: Winter vs. Summer

(from 10 years of Altimeter Data)



Upwelling and Downwelling along the US west coast

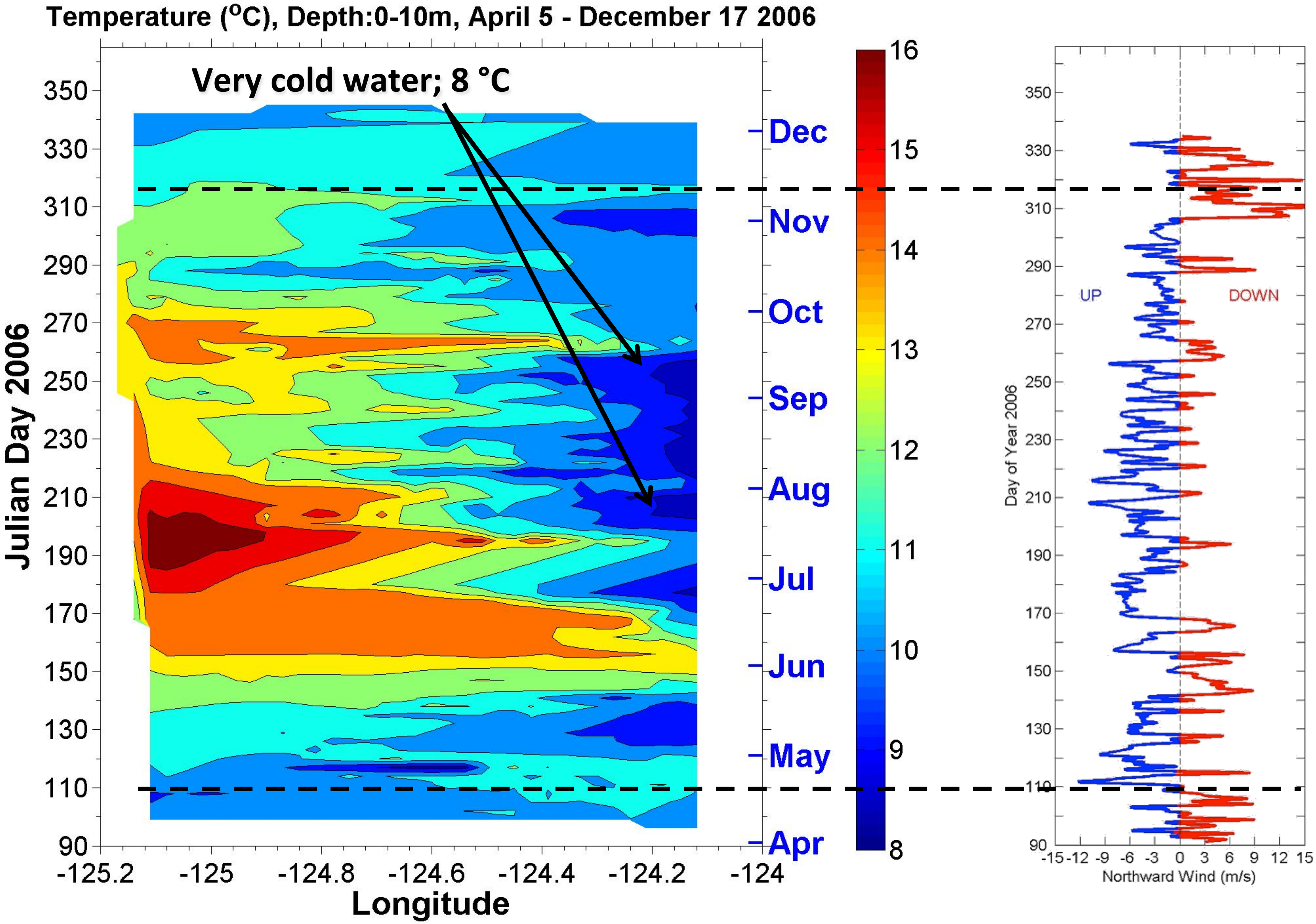


blue = cold

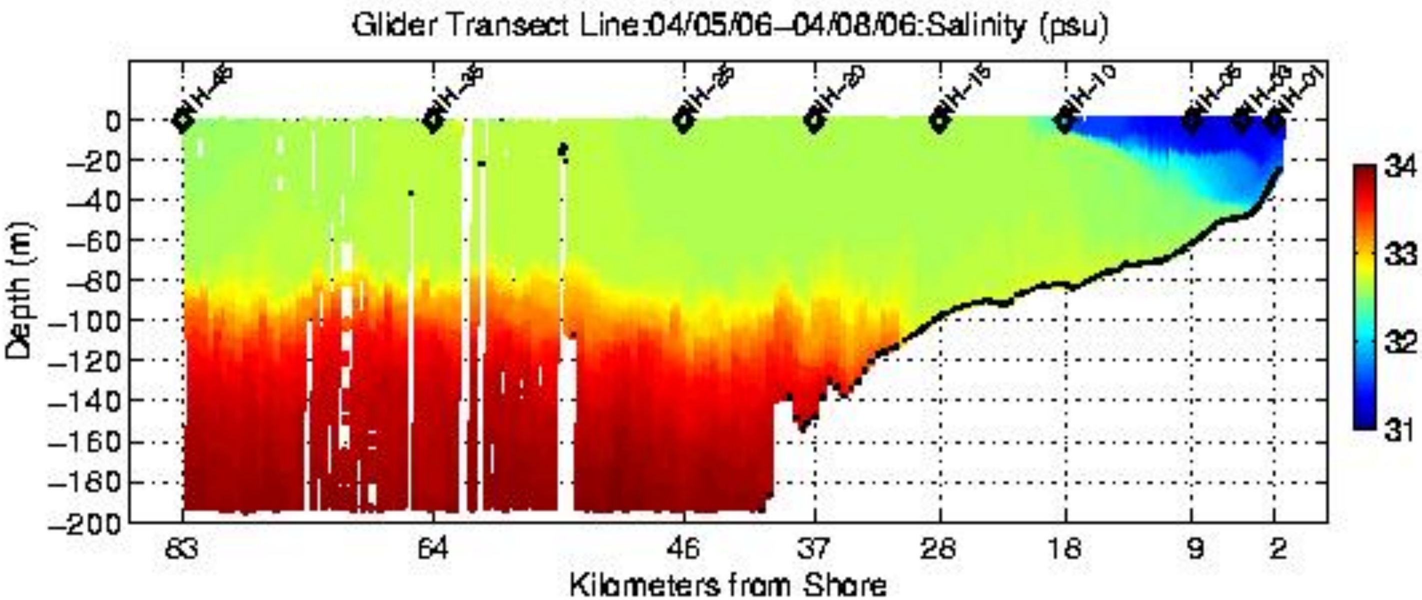
red = warm

The Oregonian
July 25, 1996

Glider Observations of Upwelling

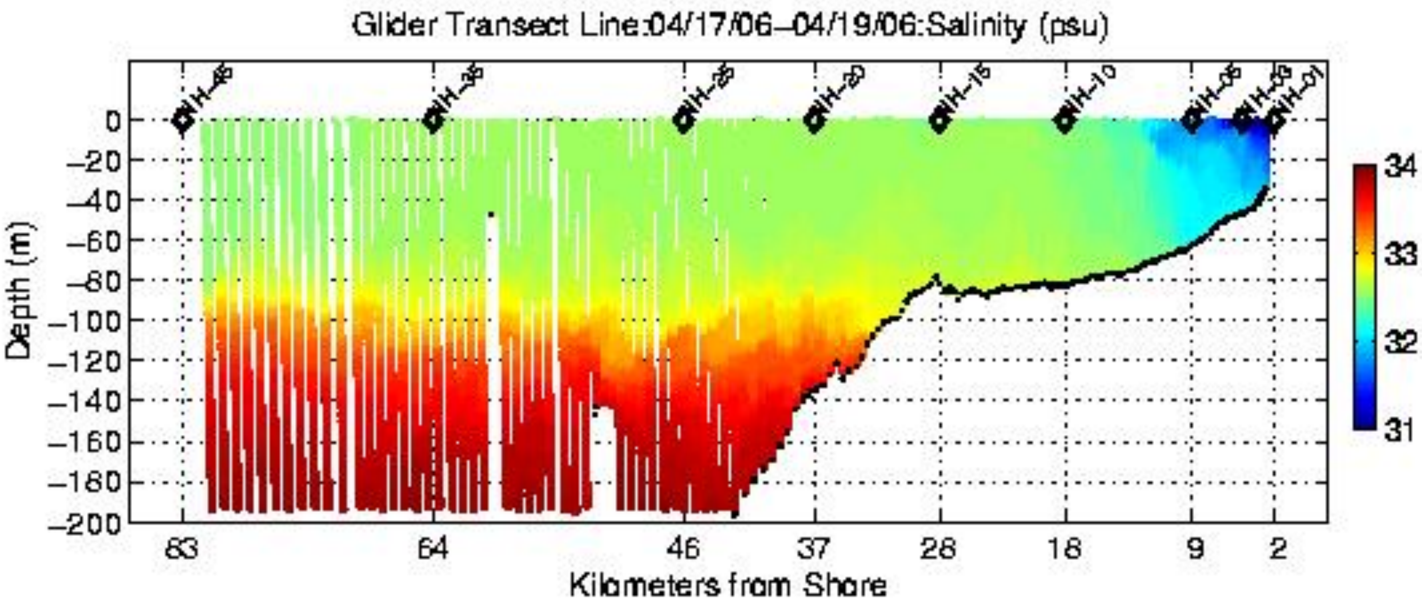


April 5-8



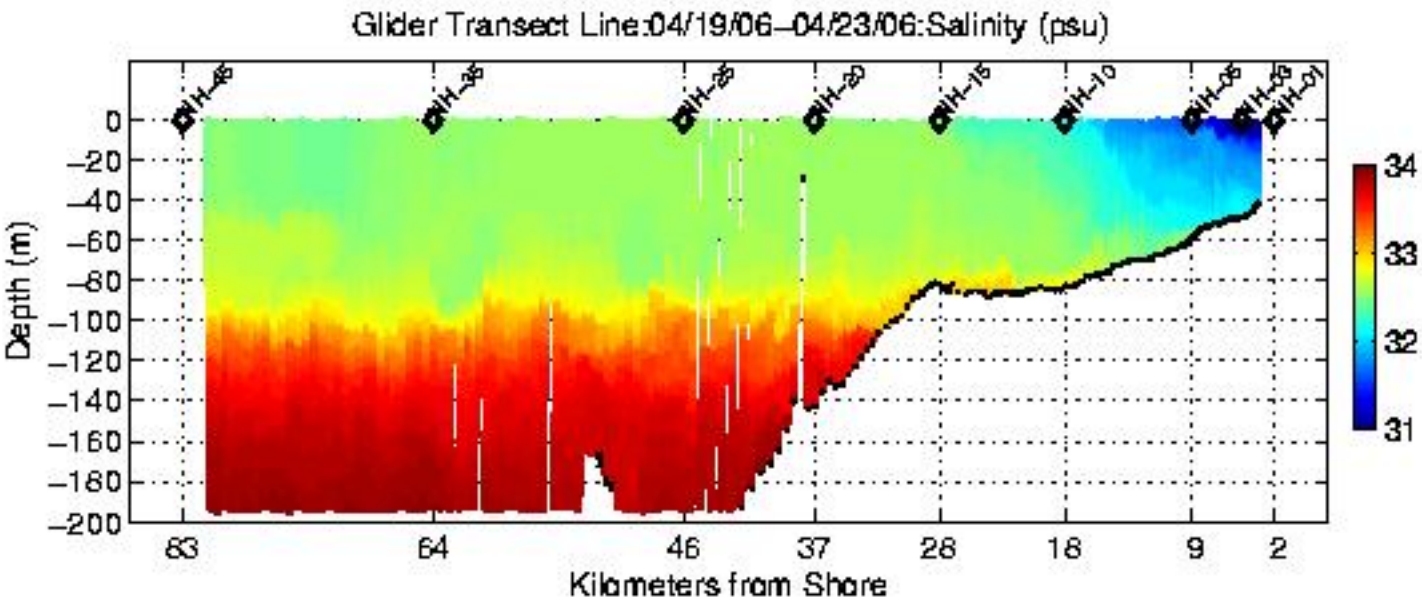
down

April 17-19



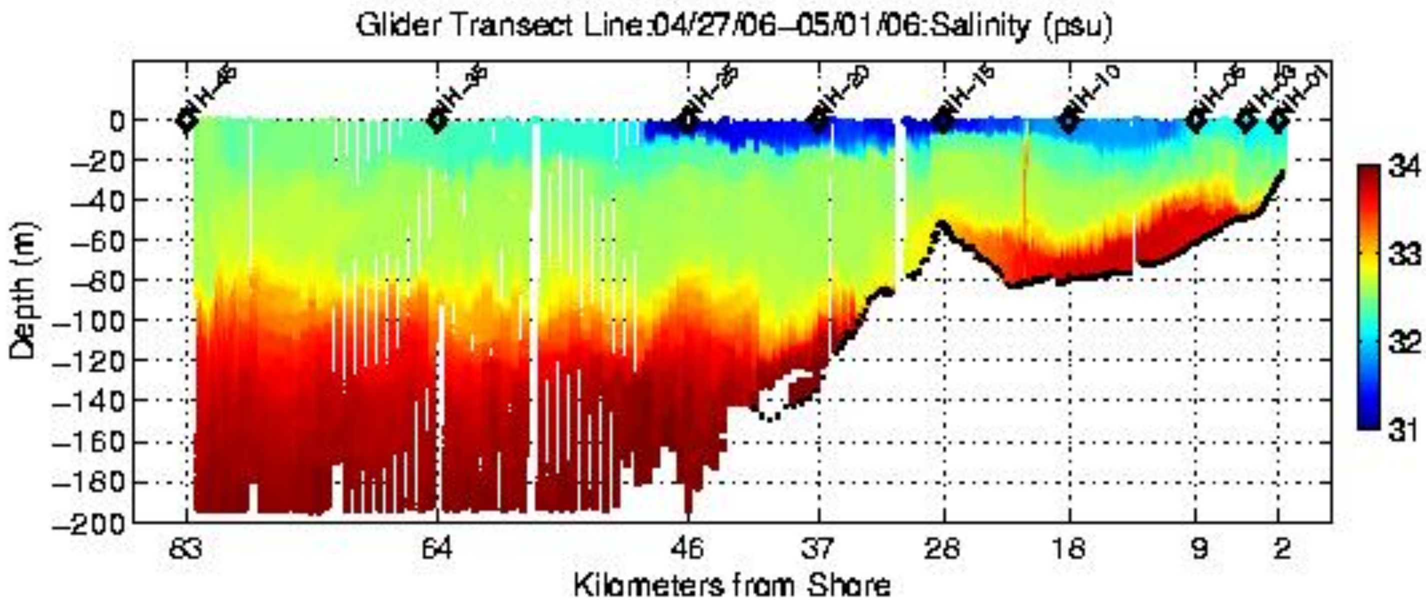
down

April 19-23



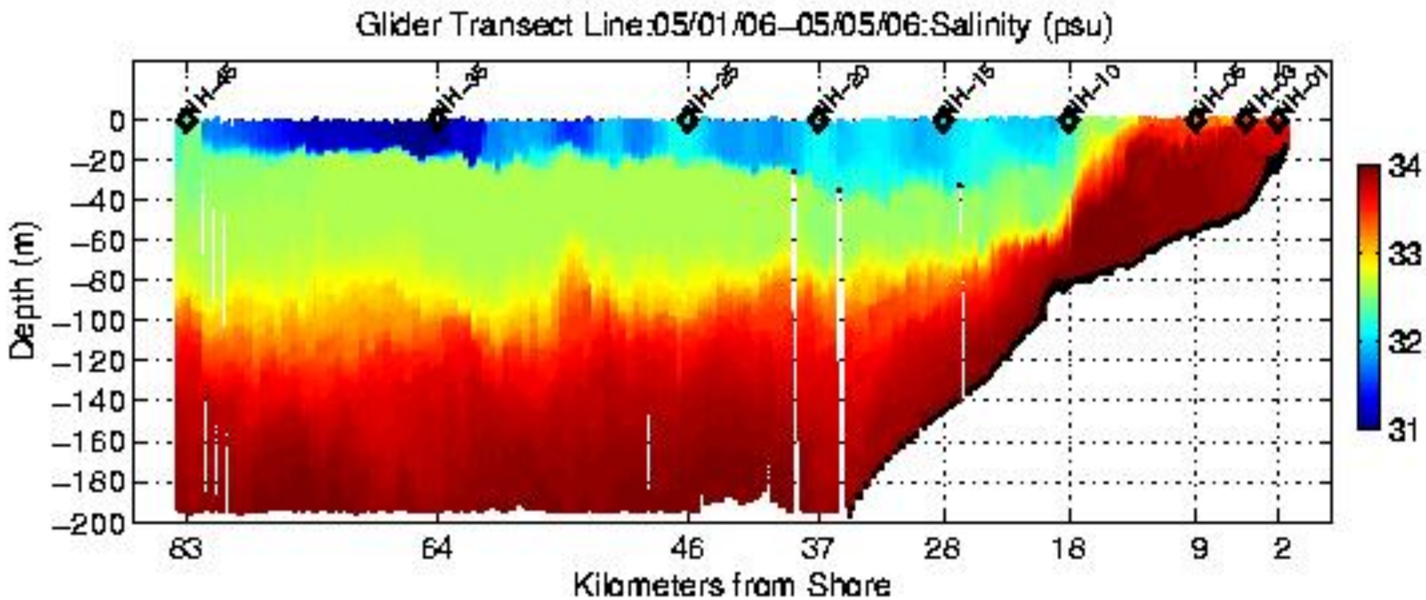
down

April 27-May 1



up

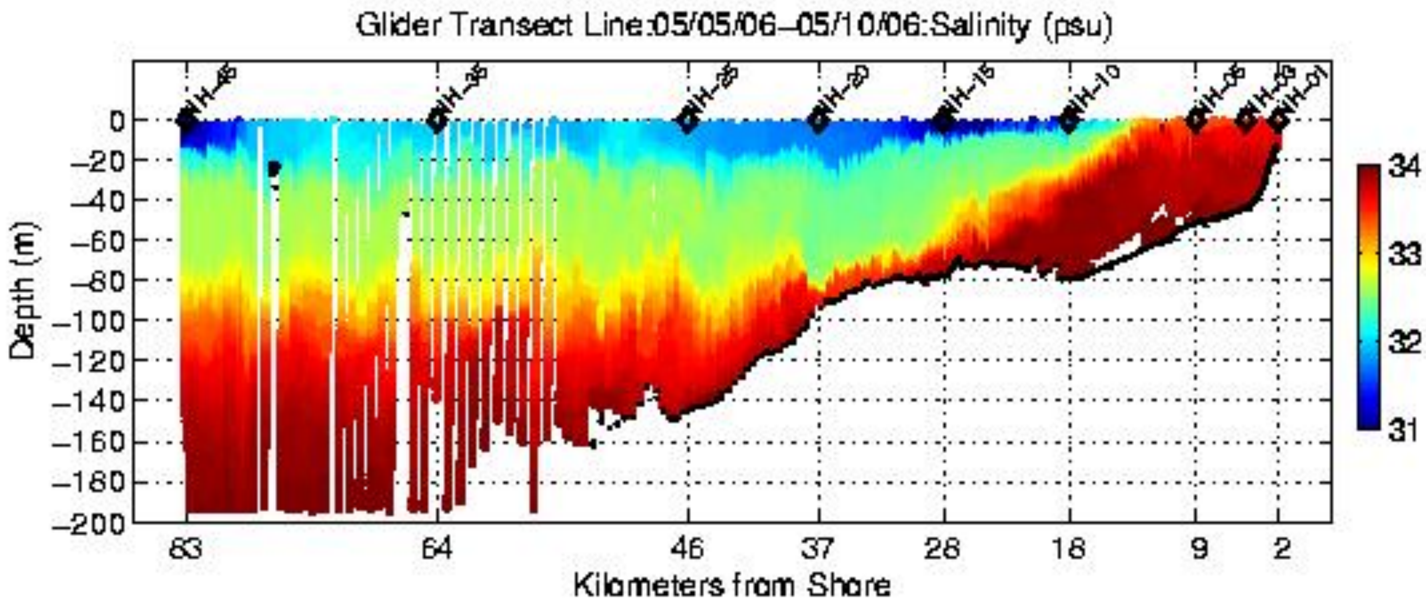
May 1-5



Glider Transect Line:05/01/06–05/05/06:Salinity (psu)
NH-20
NH-15
NH-10
NH-01
Depth (m)
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
83
64
46
37
28
18
9
2
Kilometers from Shore
34
33
32
31

up

May 5-10


Glider Transect Line:05/05/06–05/10/06:Salinity (psu)
NH-45
NH-35
NH-25
NH-20
NH-15
NH-10
NH-05
NH-03
NH-01
Depth (m)
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
83
64
46
37
28
18
9
2
Kilometers from Shore
34
33
32
31

down

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Equatorward winds

Offshore Ekman transport

Upwelling brings deep, cold, nutrient rich water to the surface near the coast

Strong equatorward along-shelf flow

Poleward winds

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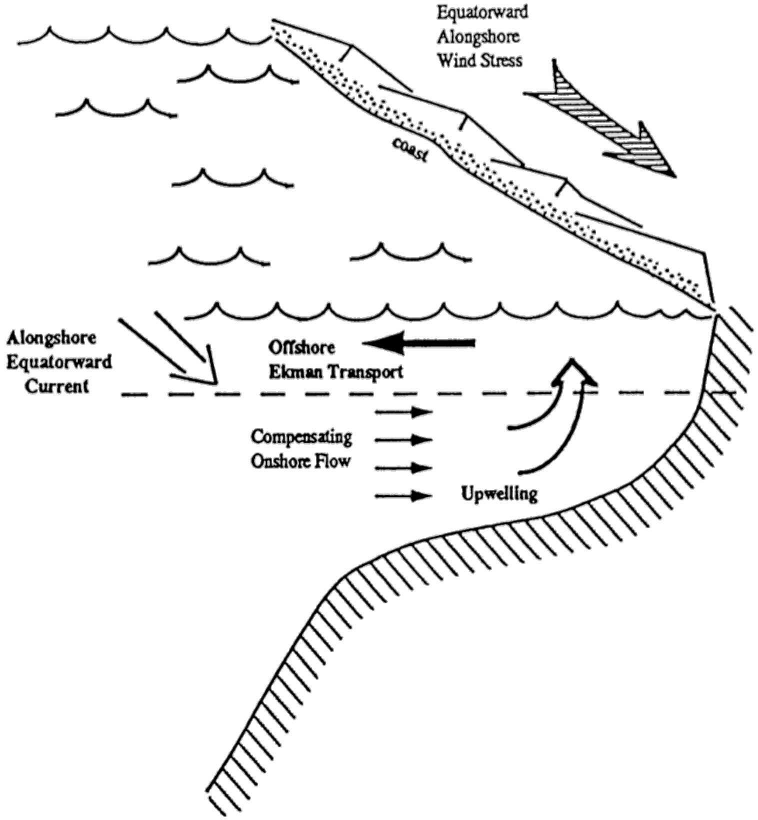
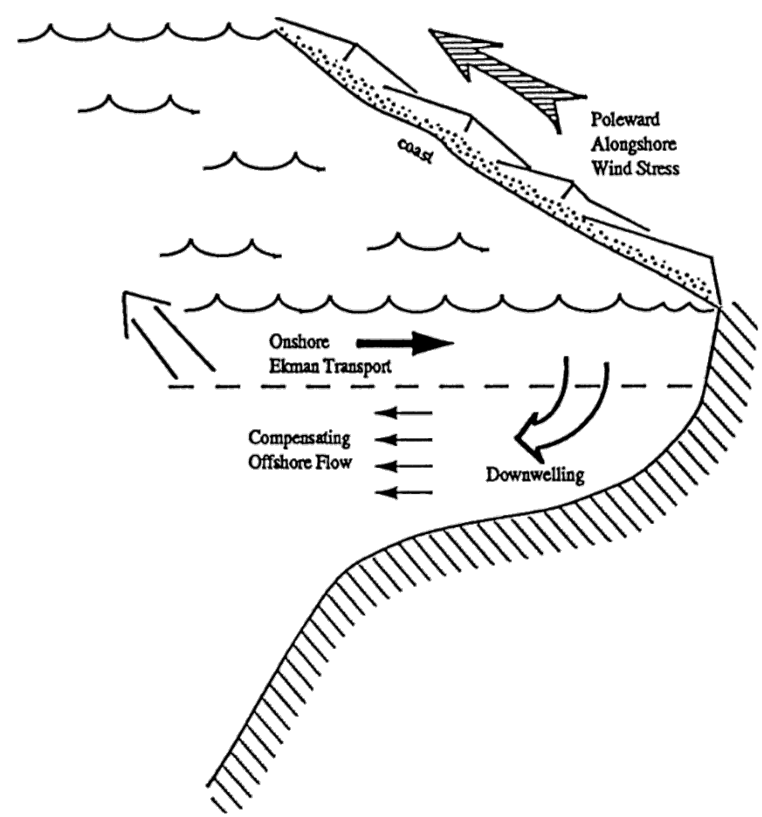
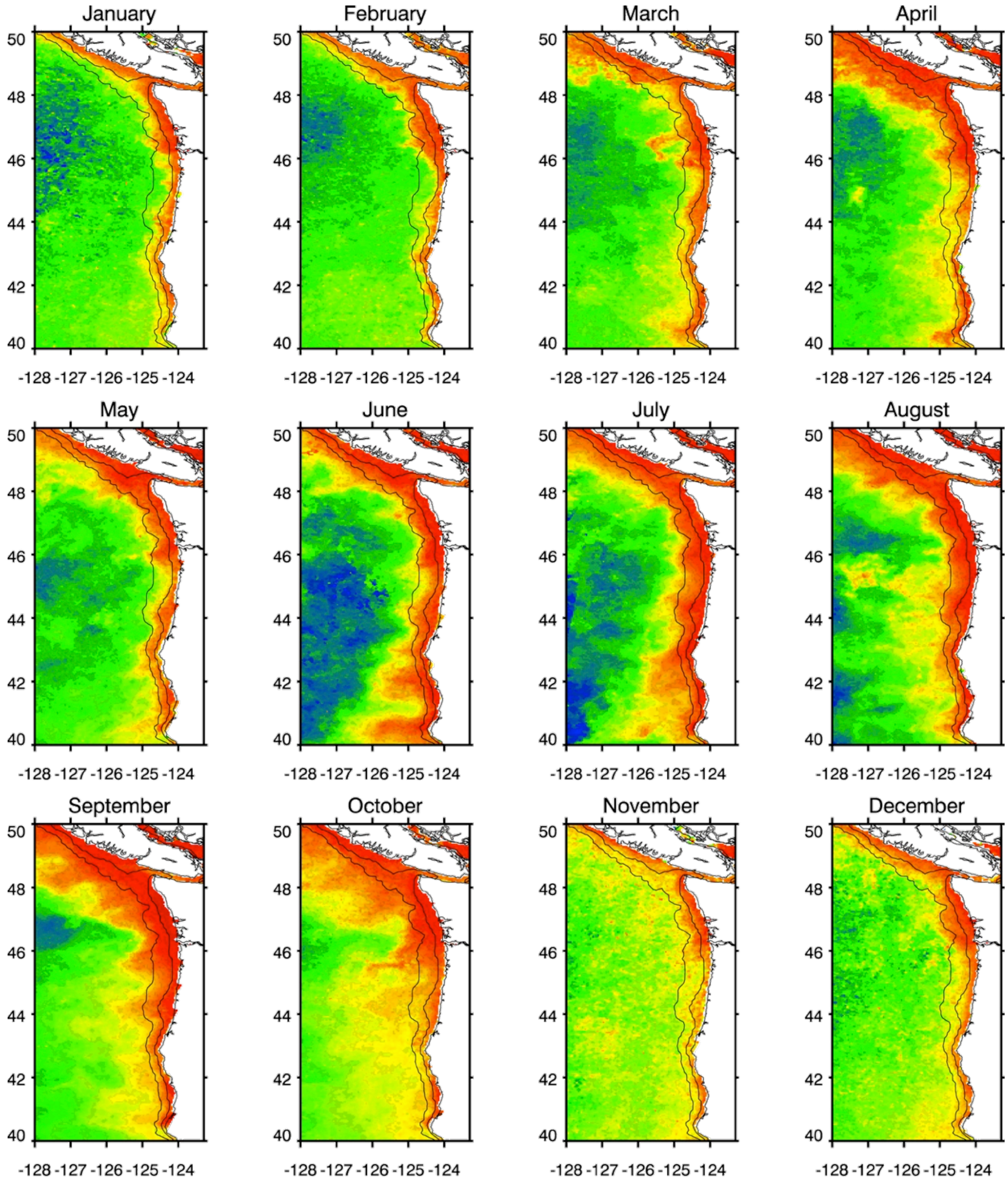
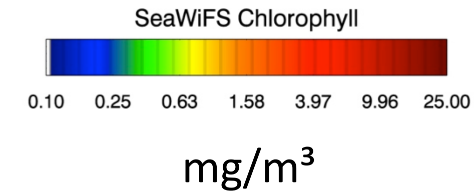
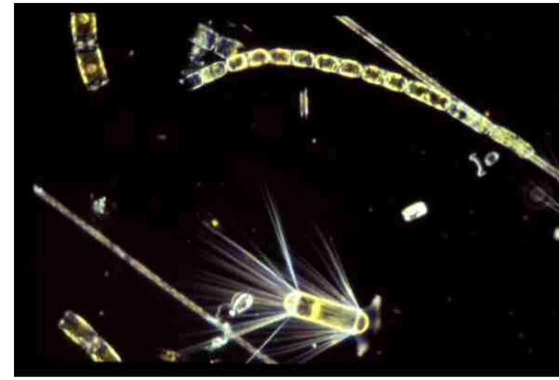








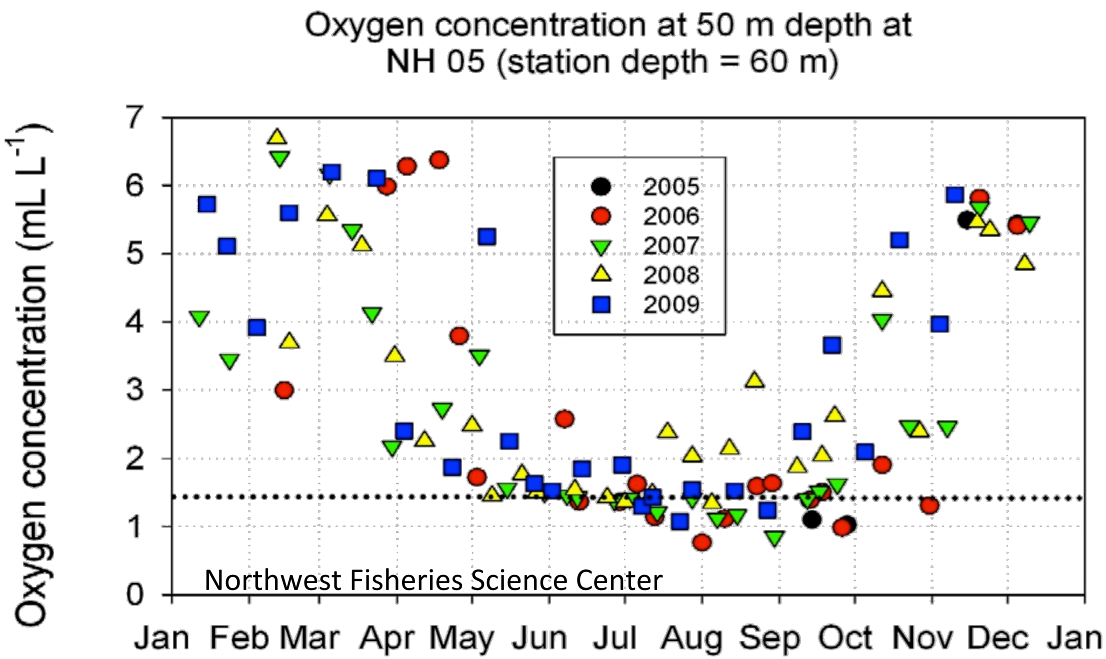


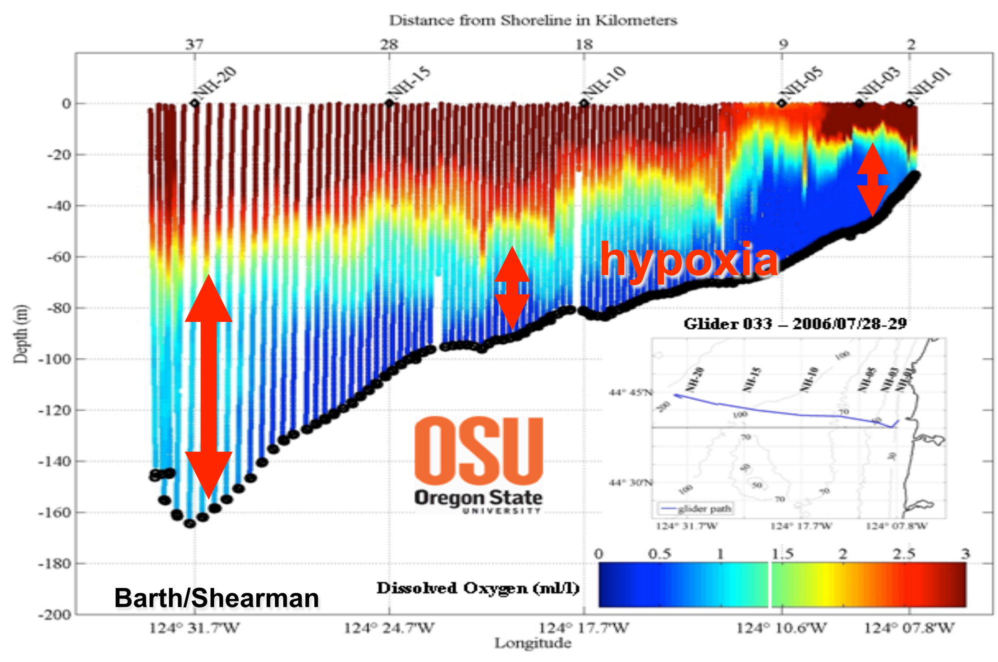
upwelled nutrients
feed phytoplankton

courtesy of
Andy Thomas (U Maine)

Seasonal Hypoxia

- **Summertime low oxygen levels**
- **Physical-Biological Intereraction**
- **Upwelled water low in oxygen, high in nutrients**
- **Biological processes drive the oxygen lower**





Satellite Observations of Upwelling in the Gulf of Guinea

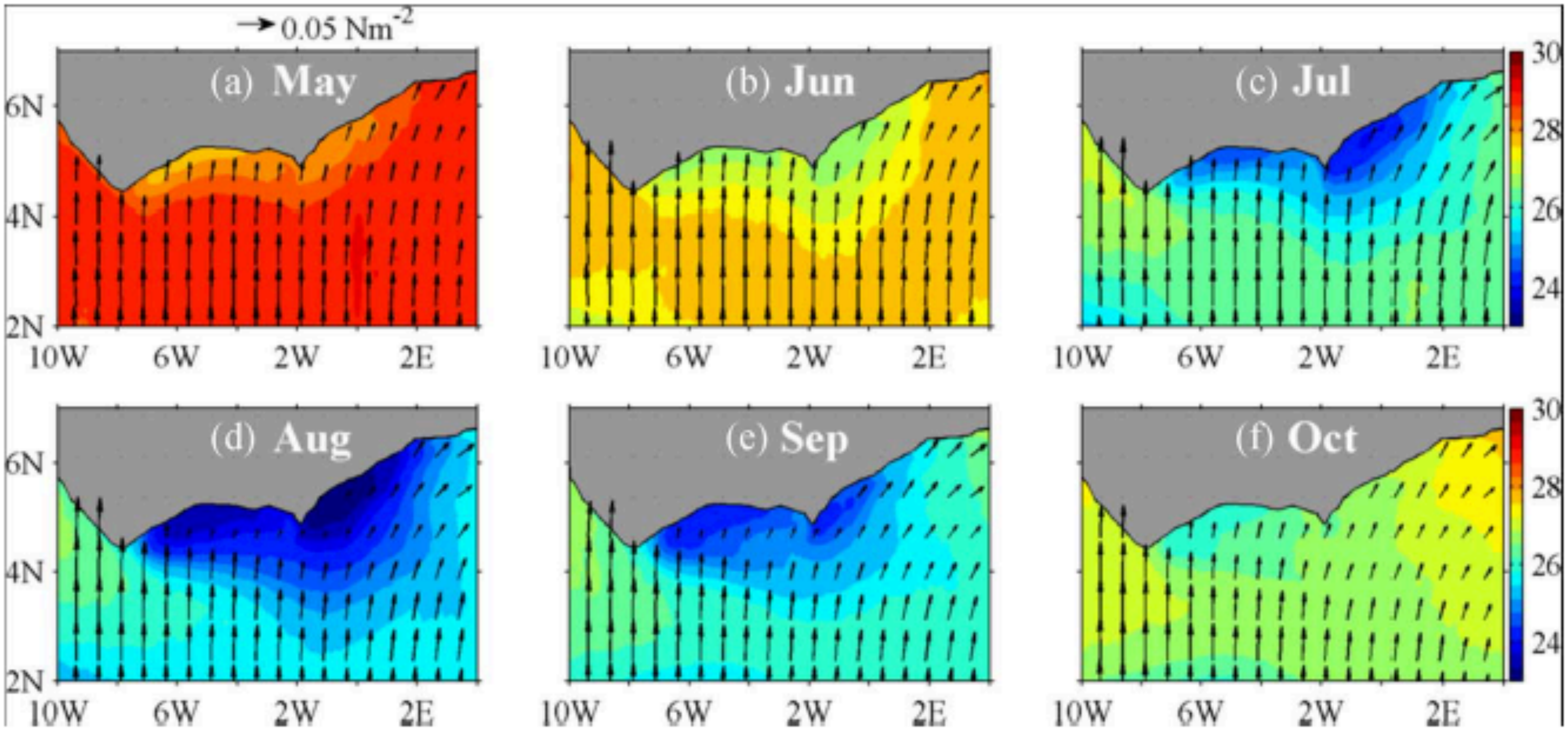


Fig. 2. Monthly mean SST (color shaded; in degrees Celsius) in the north-western GoG region. Arrow vectors show mean wind stress (N·m^{-2}).

George Wiafe

Dept. of Marine & Fisheries Sci., Univ. of Ghana, Accra, Ghana

Ebenezer S. Nyadjro

Nat. Oceanic & Atmos. Adm. Pacific Marine Environ. Lab., Seattle, WA, USA