I. General Circulation

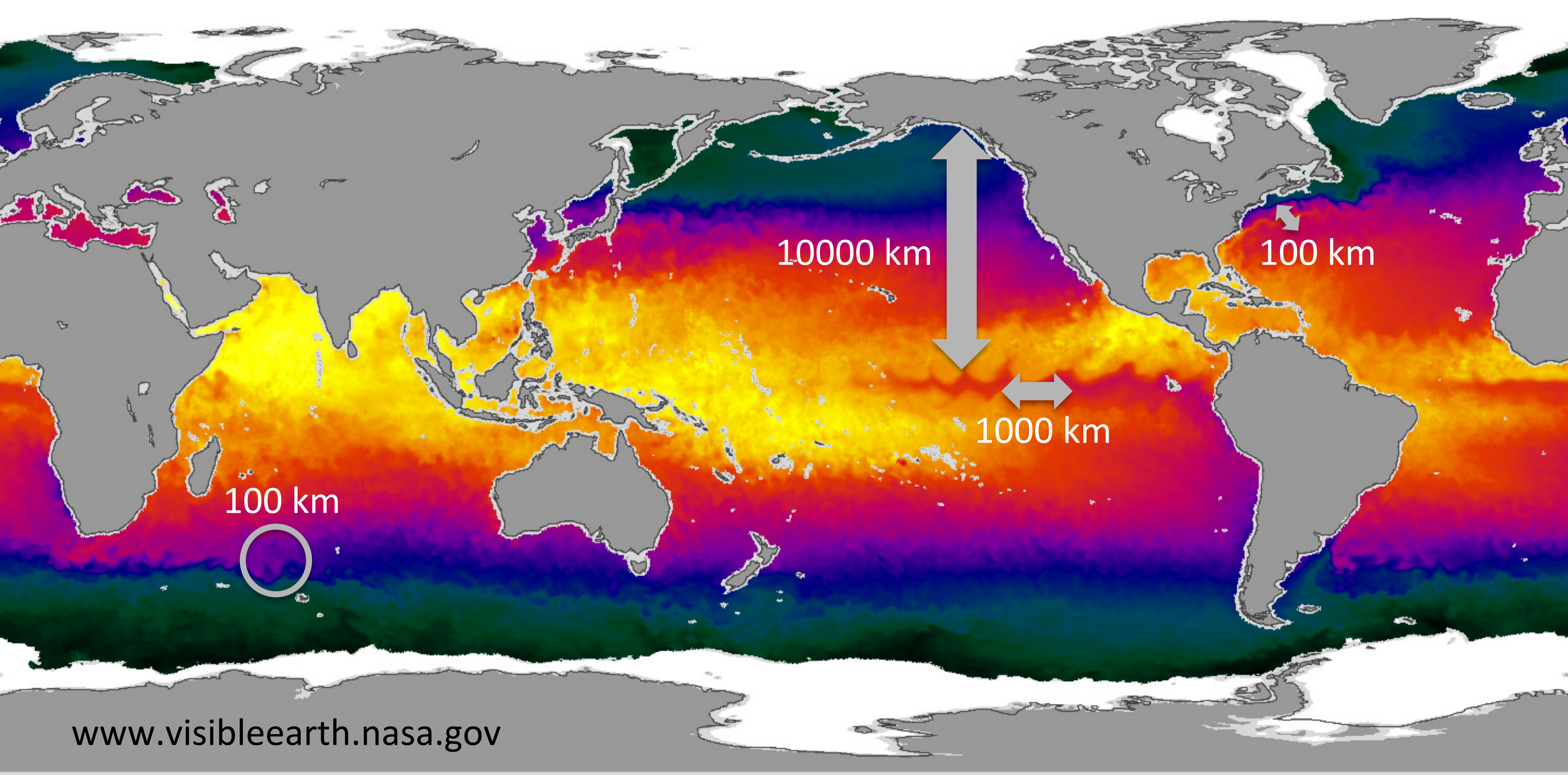
Emily Shroyer, Oregon State University

II. Coastal Processes

Stephan Howden, University of Southern Mississippi

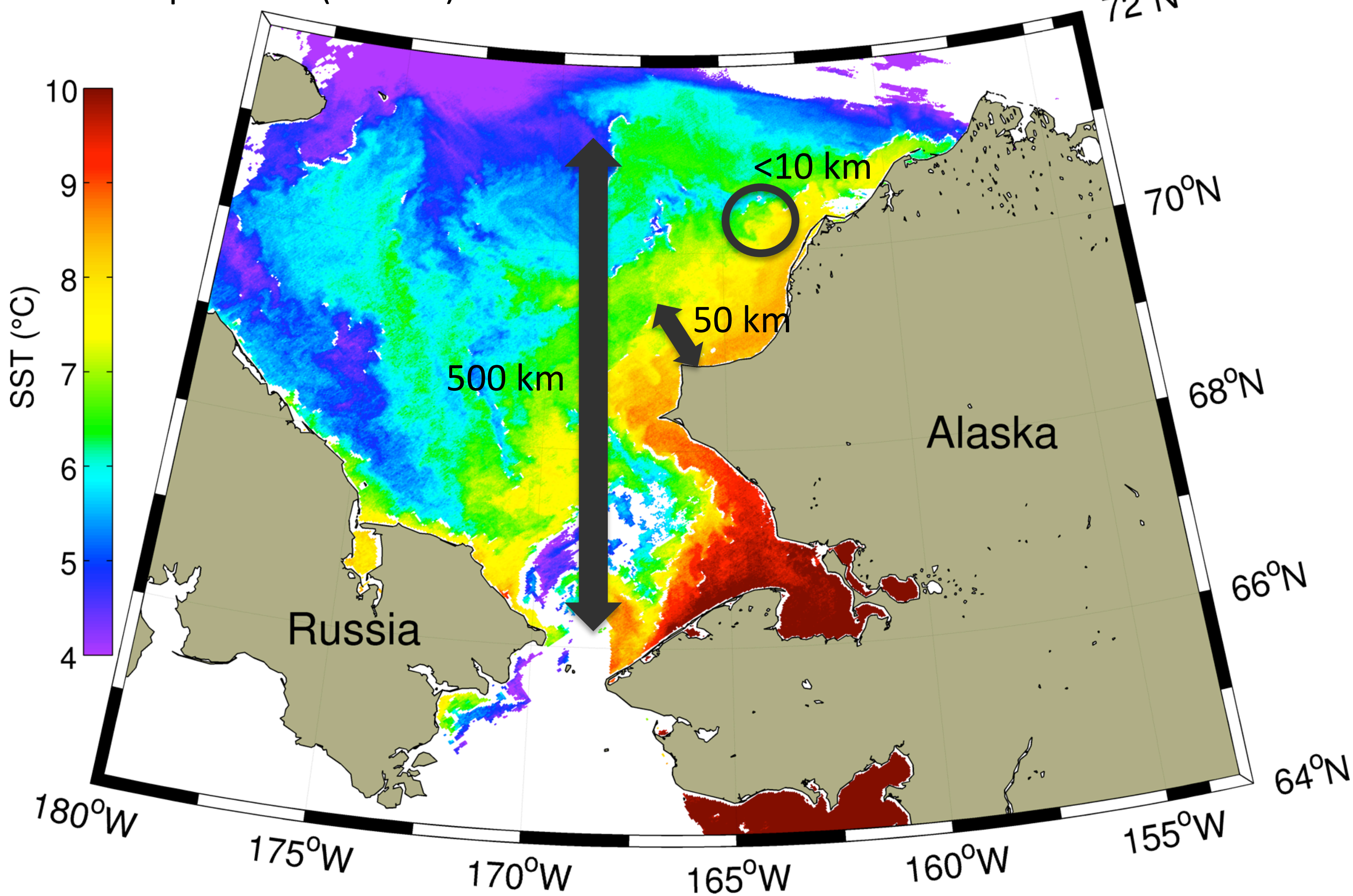
Variability in the Ocean

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



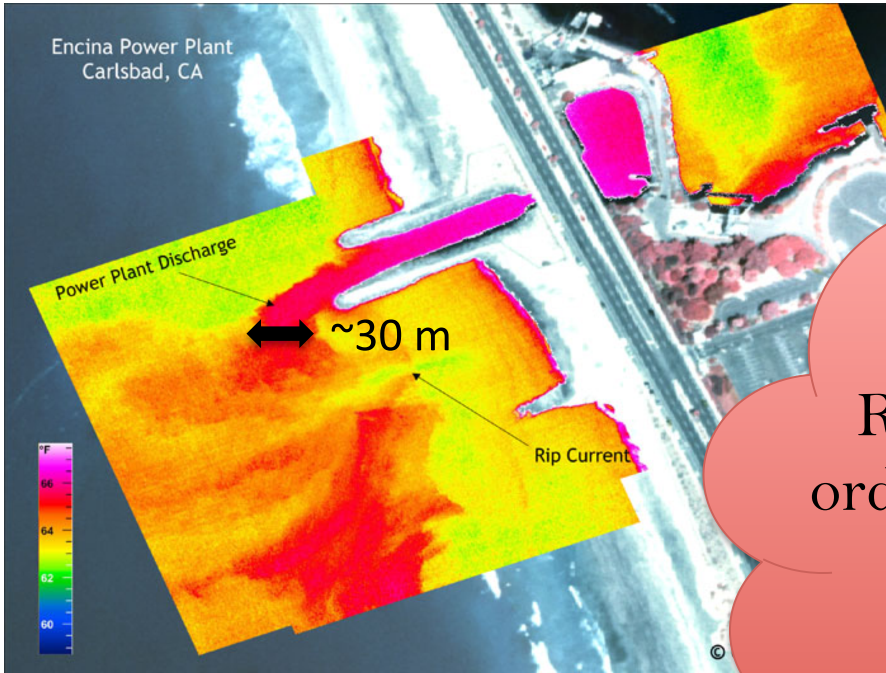
Variability in the Ocean

Sea Surface Temperature (MODIS)

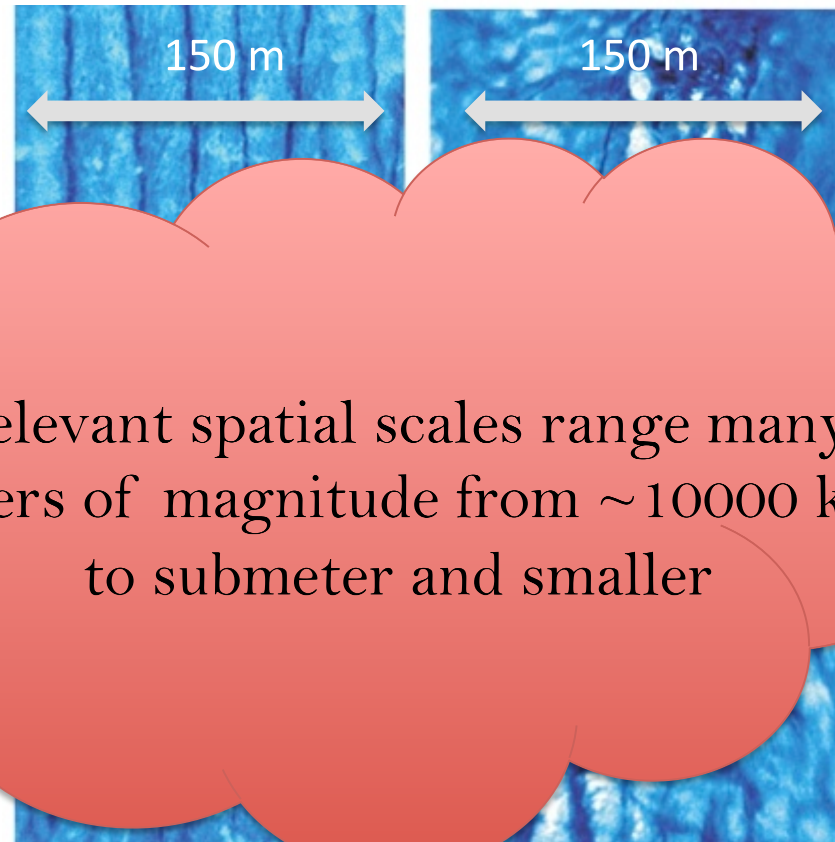


Variability in the Ocean

Sea Surface Temperature (Field Infrared Imagery)

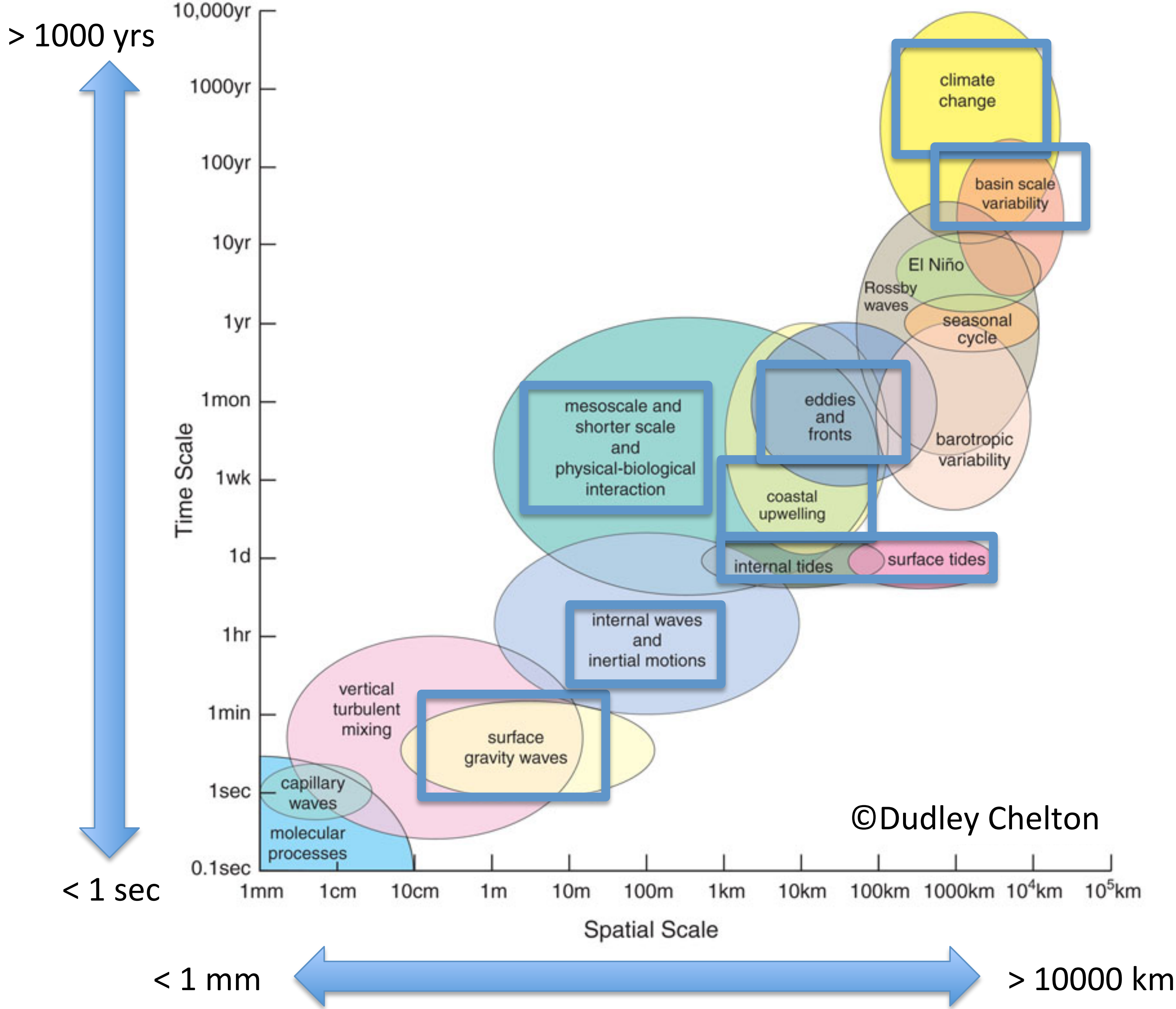


Plant Discharge, Ocean Imaging



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

Langmuir and Internal Waves, NRL



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

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*

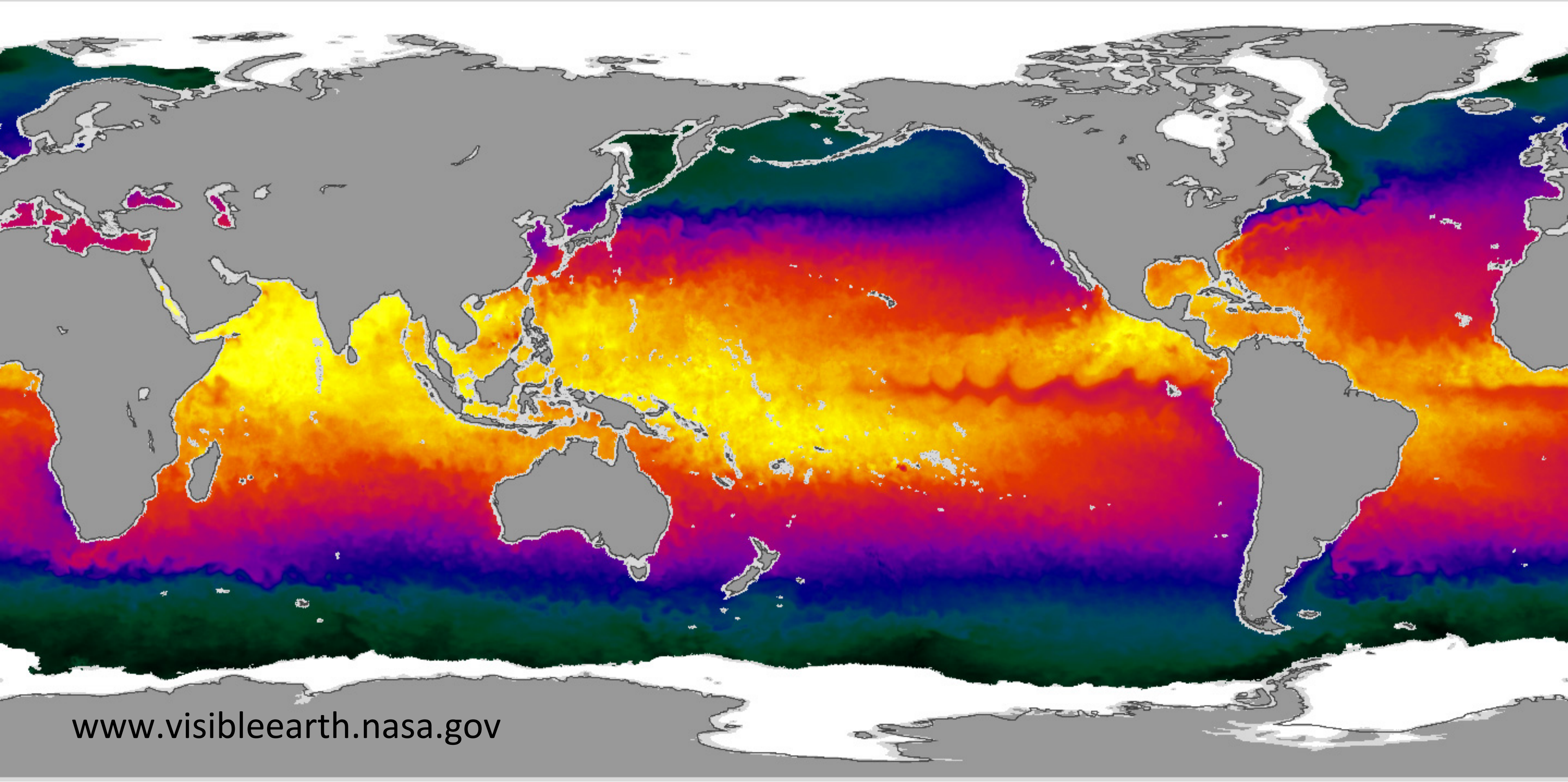
need to describe both the *mass* and *volume* when dealing with fluids

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

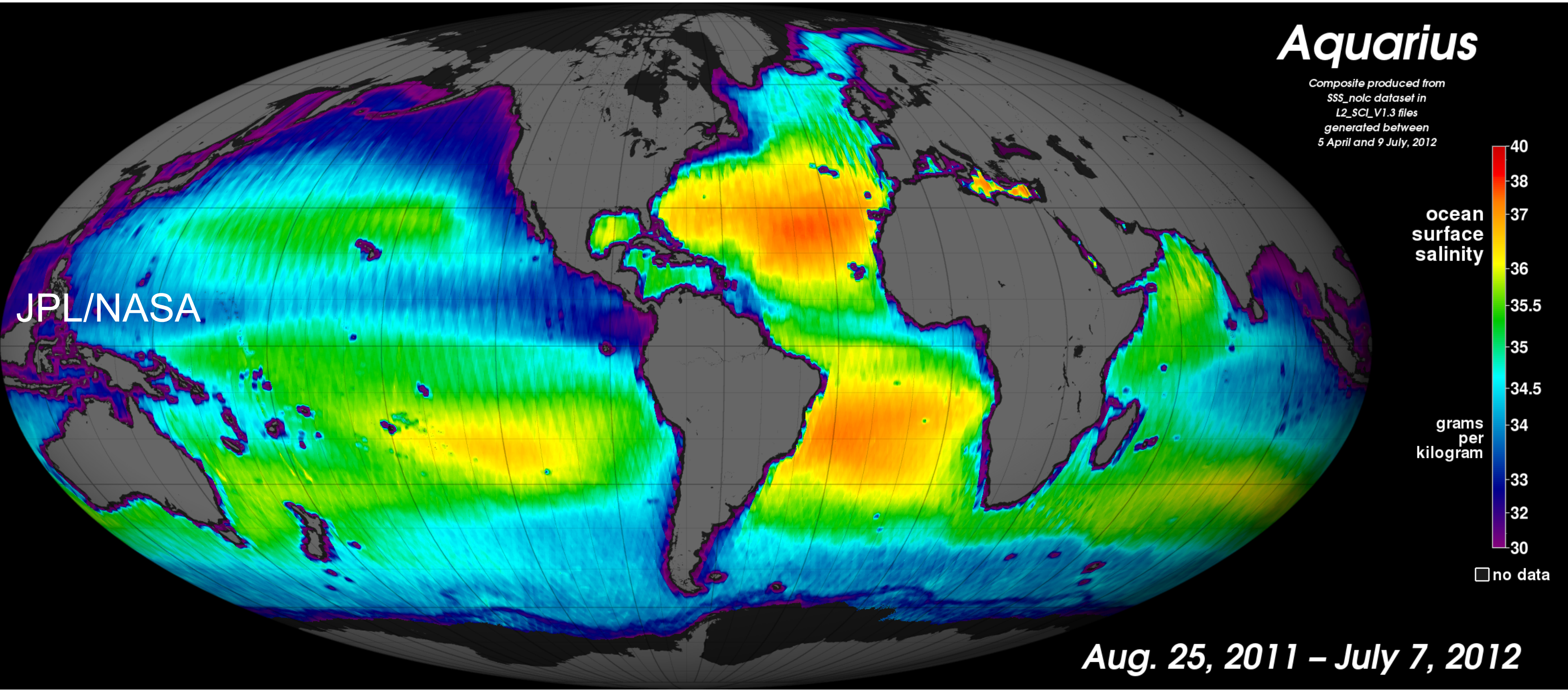
Temperature, Salinity, & Pressure

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

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



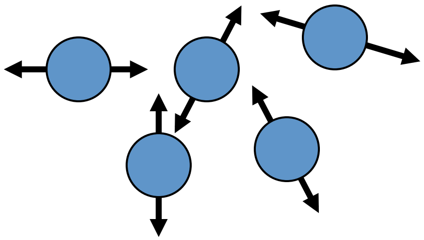
Surface *Salinity*: Precipitation & Evaporation



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.

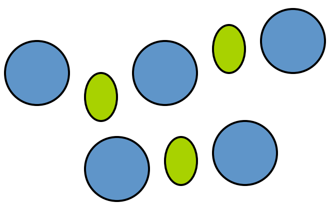
How do T, S, and P influence density (ρ)?

<u>Seawater's density is a function of T, P and S</u>



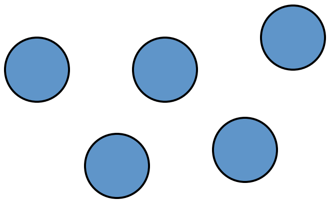
As Temperature ↑

ρ↓



As Salinity ↑

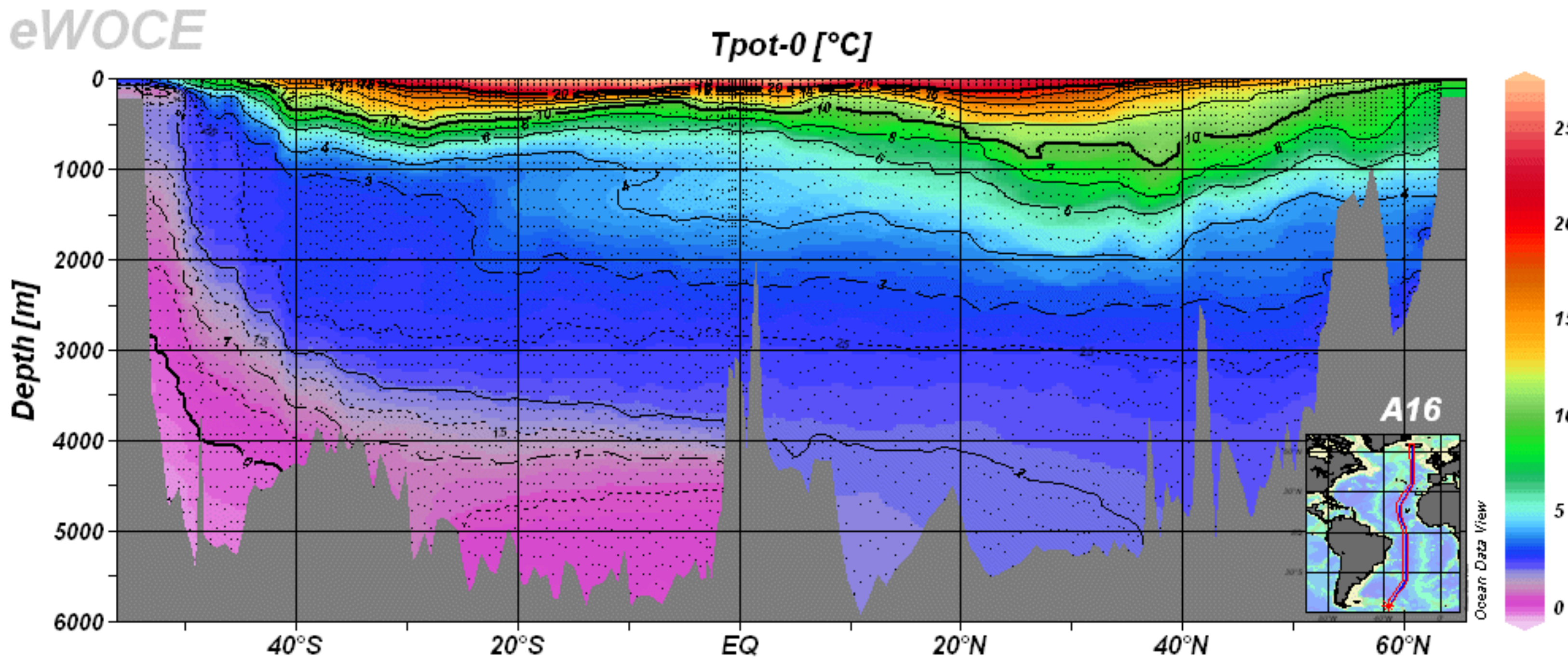
ρ ↑

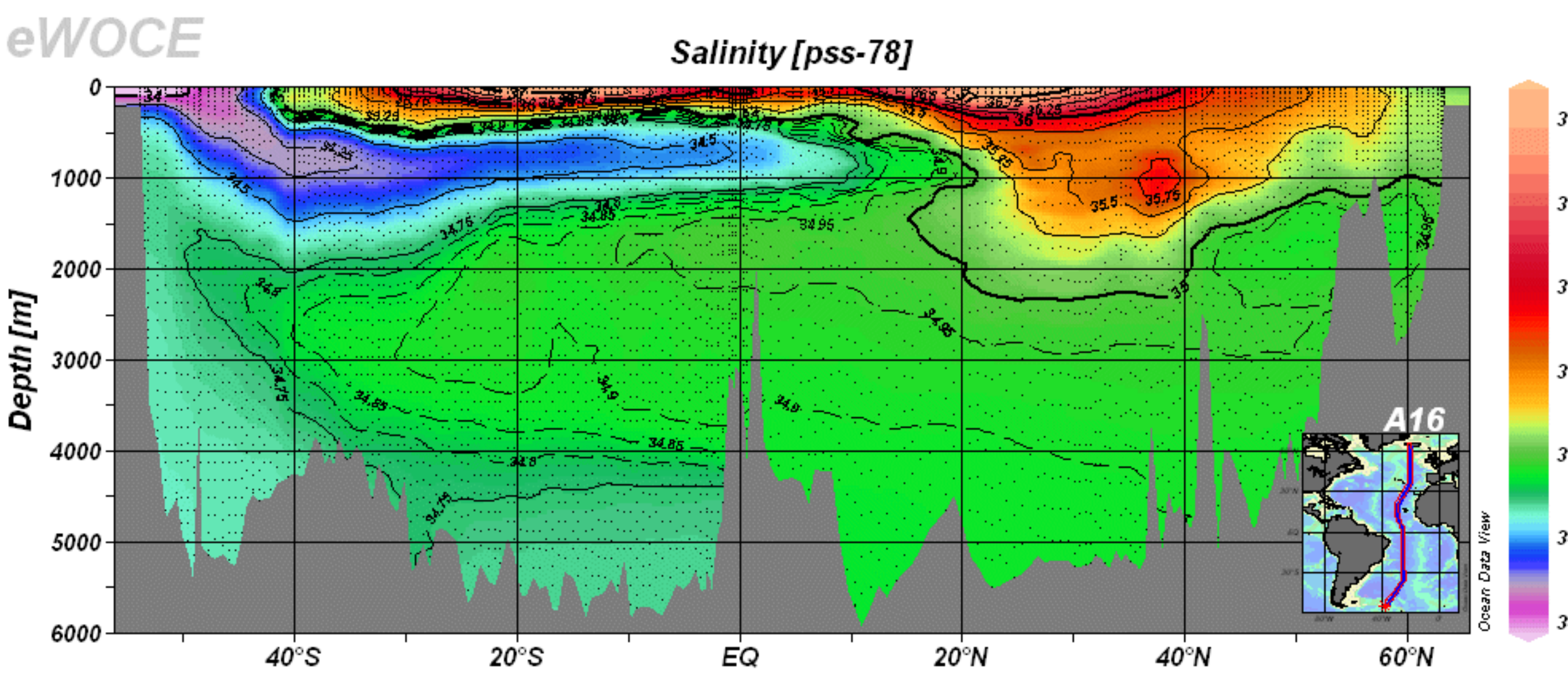


As Pressure ↑

ρ ↑

(note: seawater is only a little compressible…6% change)


eWOCE
Tpot-0 [°C]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
A16
Ocean Data View
25
20
15
10
5
0


eWOCE
Salinity [pss-78]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
A16
Ocean Data View
37
36.5
36
35.5
35
34.5
34

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

Estimating the Circulation and Climate of the Ocean- Dimitris Menemenlis

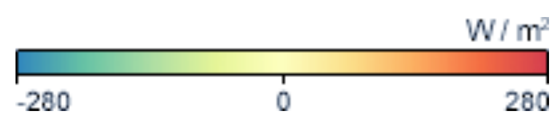
What leads to the general circulation in our oceans and the distribution of scalars like temperature and salt?

Why study Fluid Dynamics?

Atmosphere and Ocean regulate our climate.

Act as natural heat engines removing heat from one place and depositing it in another.

Net Radiation January 2015 (NASA)



Why study Fluid Dynamics?

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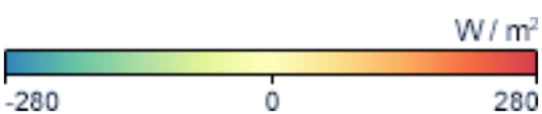
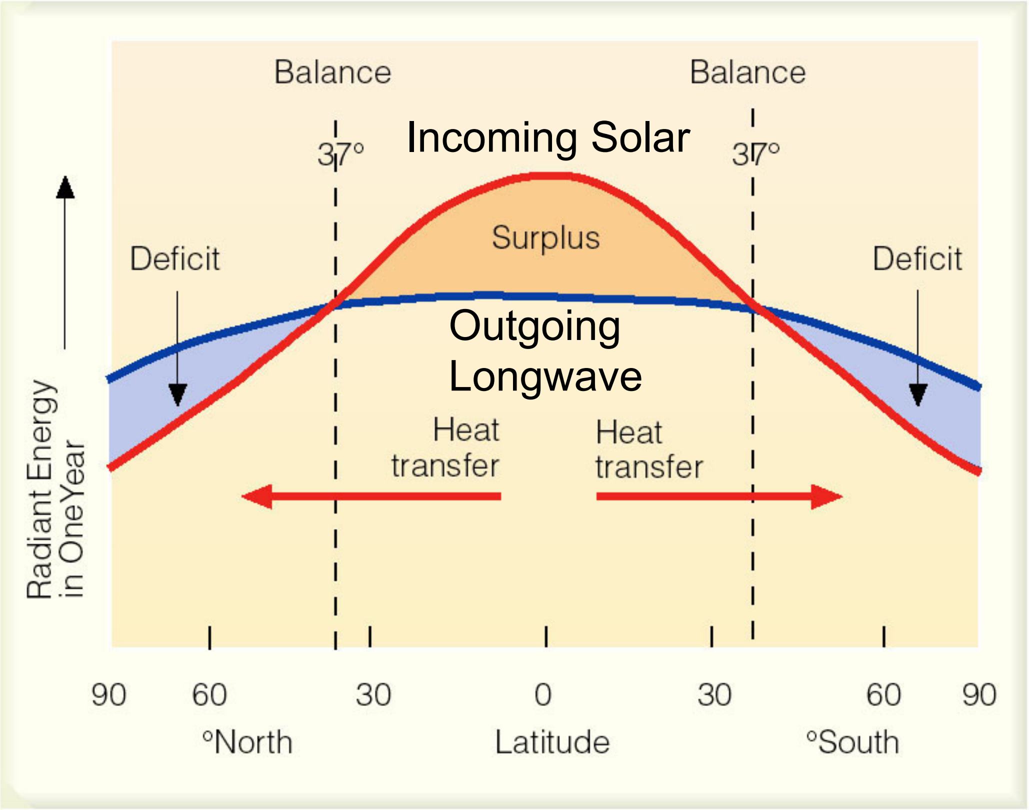
Net Radiation June 2015 (NASA)



Add Latitudinal Dependence→

Top-of-Atmosphere Energy Balance:

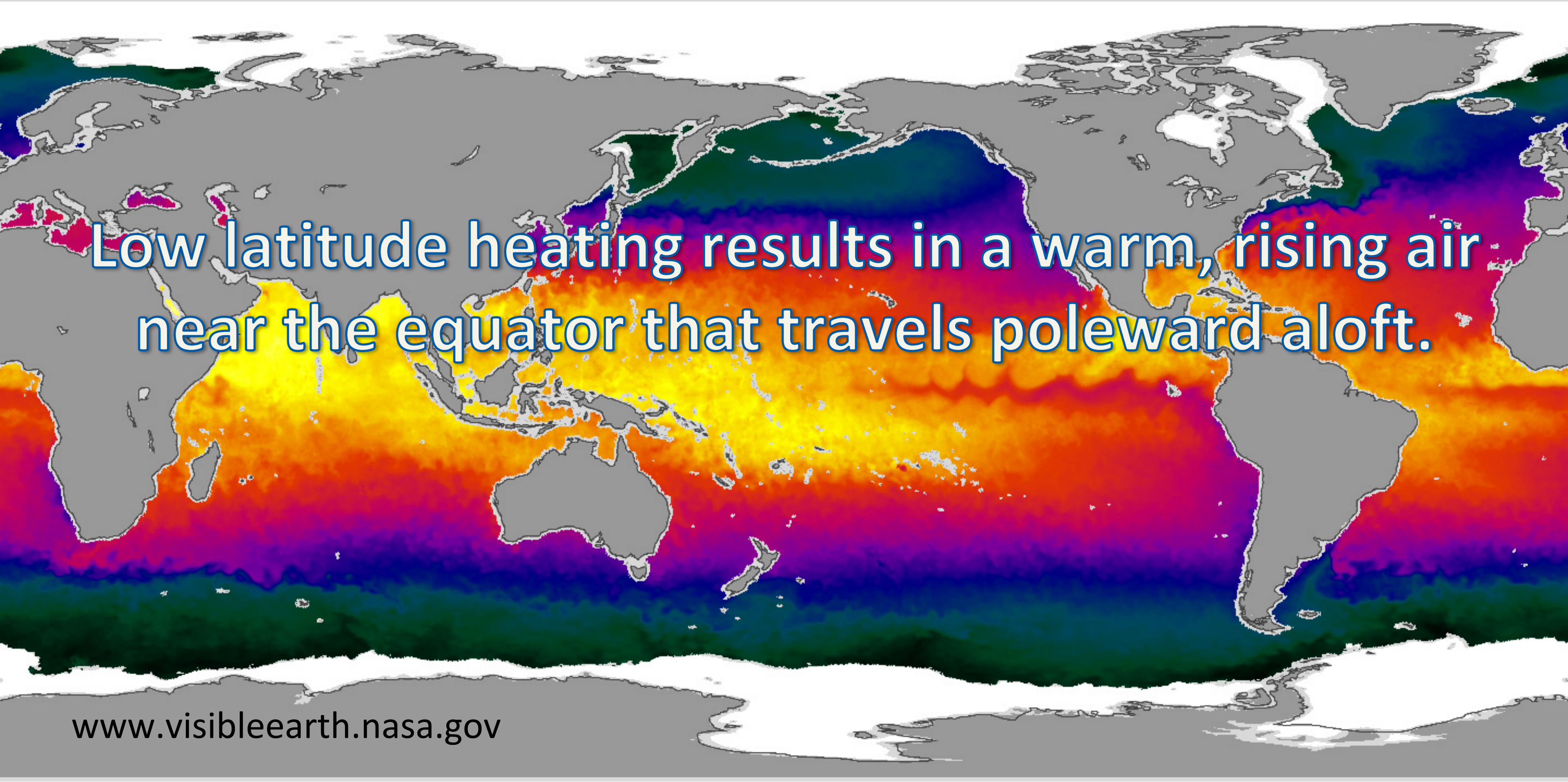


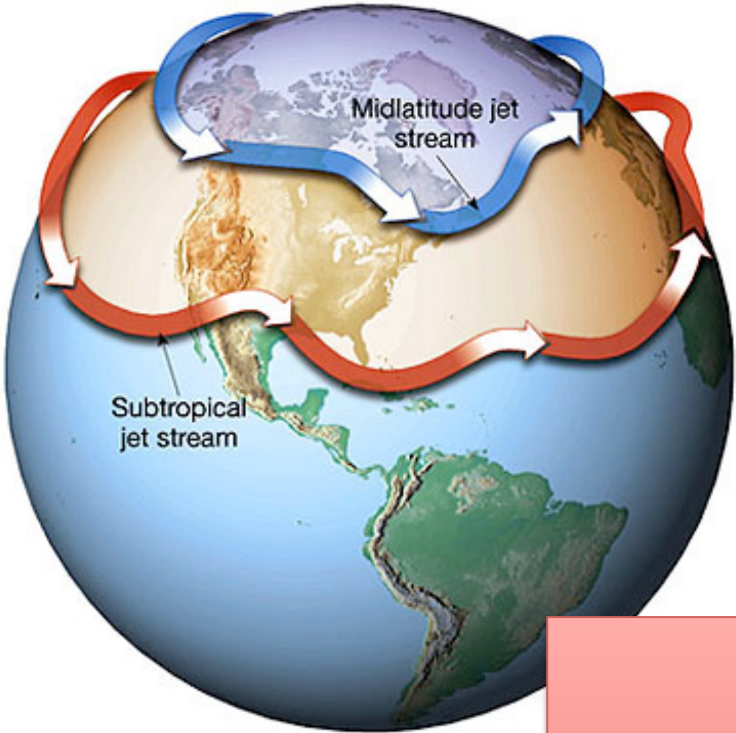
There is a net ***radiative*** heating at the equator when averaged over a year. Incoming solar ***radiation*** in the tropics exceeds outgoing longwave ***radiation***.

Yet, this can't be the complete long-term solution (tropics boil, poles → absolute 0).

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

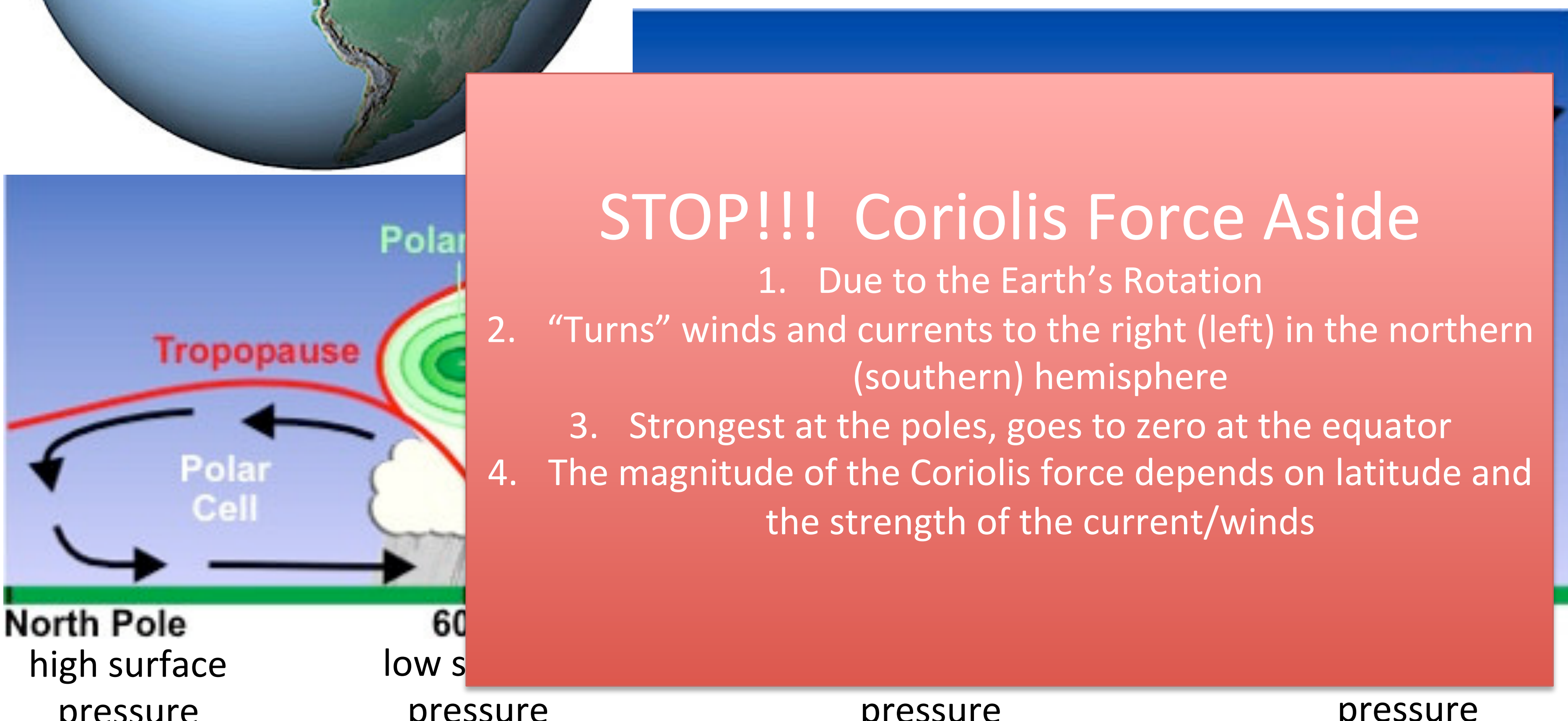
Sea Surface Temperature from NASA's Aqua Satellite (AMSR-E)





The ***Polar and Hadley Cells*** are thermally direct cells, i.e., they are associated with the rising of warm air and sinking of cool air.

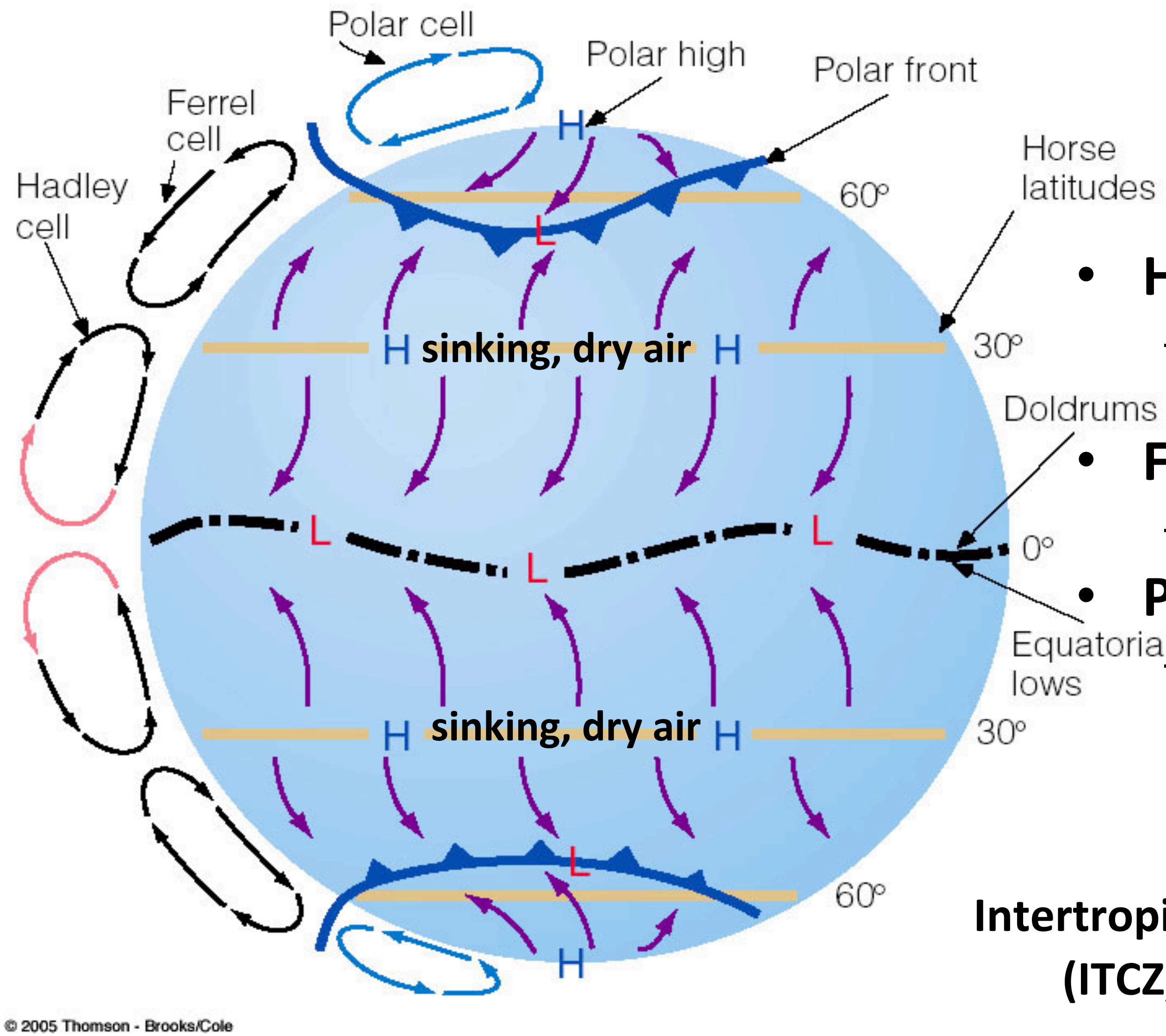
The ***Ferrel Cell*** is thermally indirect cell that is dominated by eddies and instabilities (mid-latitude storms).



STOP!!! Coriolis Force Aside

1. Due to the Earth's Rotation
2. "Turns" winds and currents to the right (left) in the northern (southern) hemisphere
3. Strongest at the poles, goes to zero at the equator
4. The magnitude of the Coriolis force depends on latitude and the strength of the current/winds

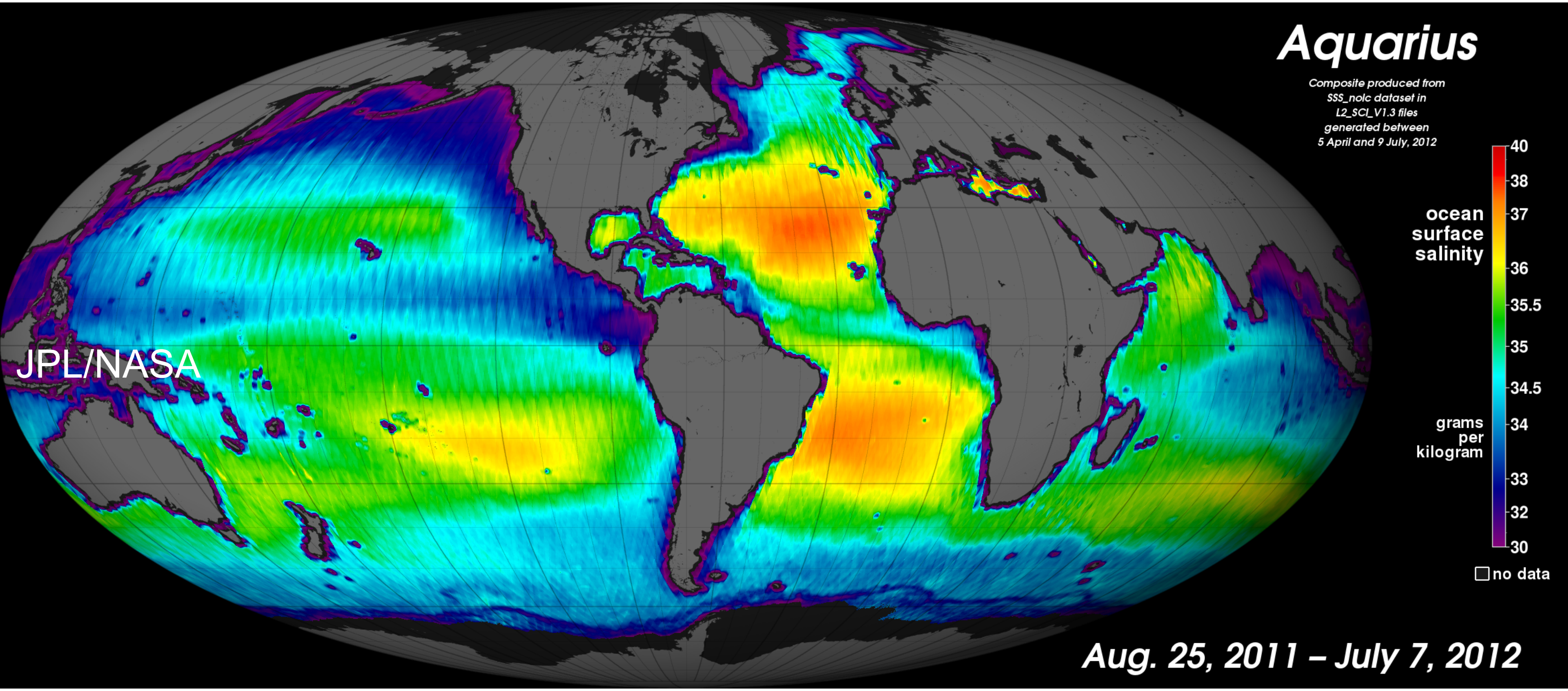
The Net Result for Circulations at the Surface (Particularly if There Were No Land Masses)



- **Hadley**
  - *northeasterly and southeasterly tradewinds*
- **Ferrel**
  - *midlatitude westerlies*
- **Polar**
  - *polar easterlies*

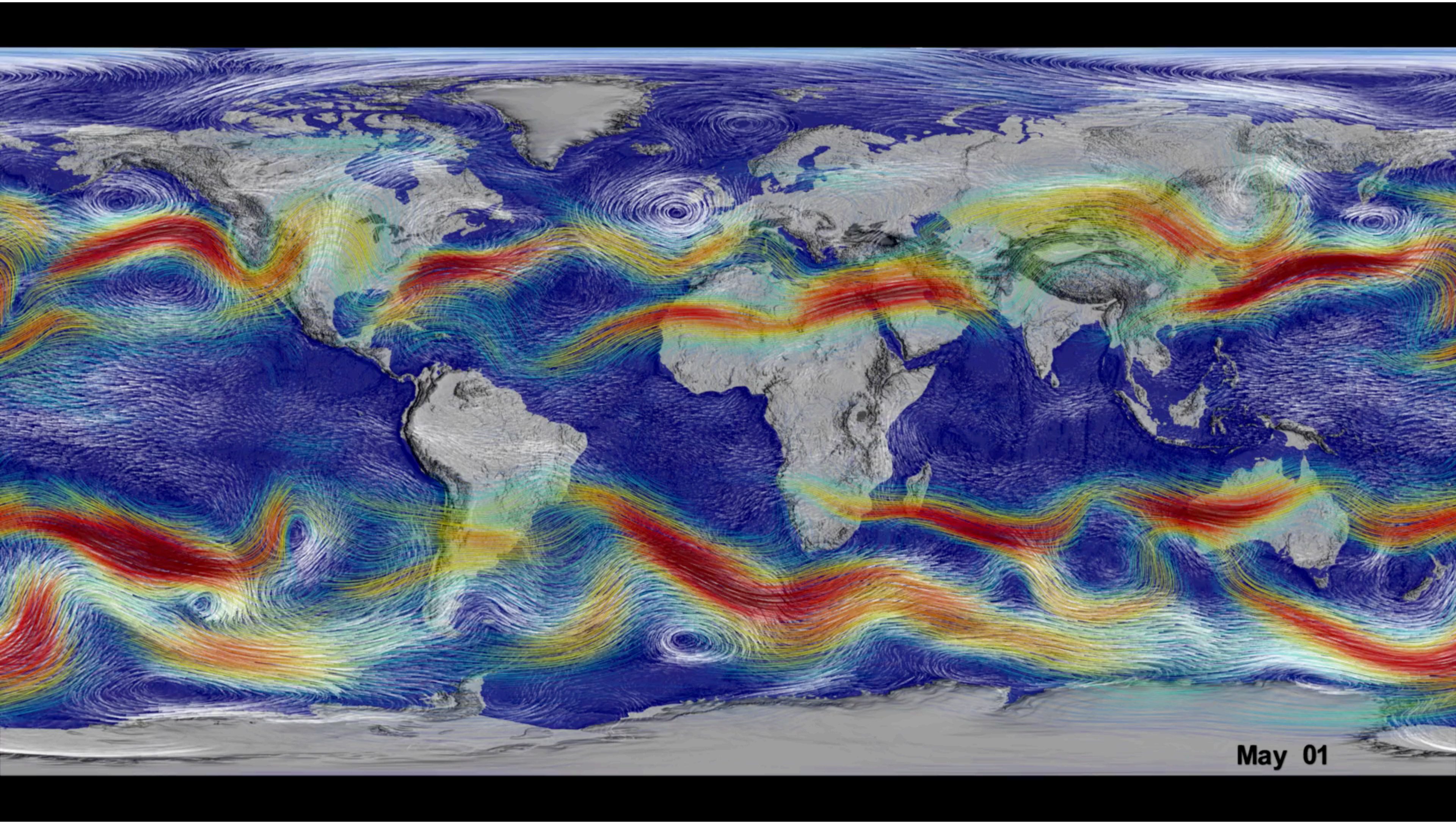
Intertropical Convergence Zone (ITCZ, low pressure)

Surface *Salinity*: Precipitation & Evaporation

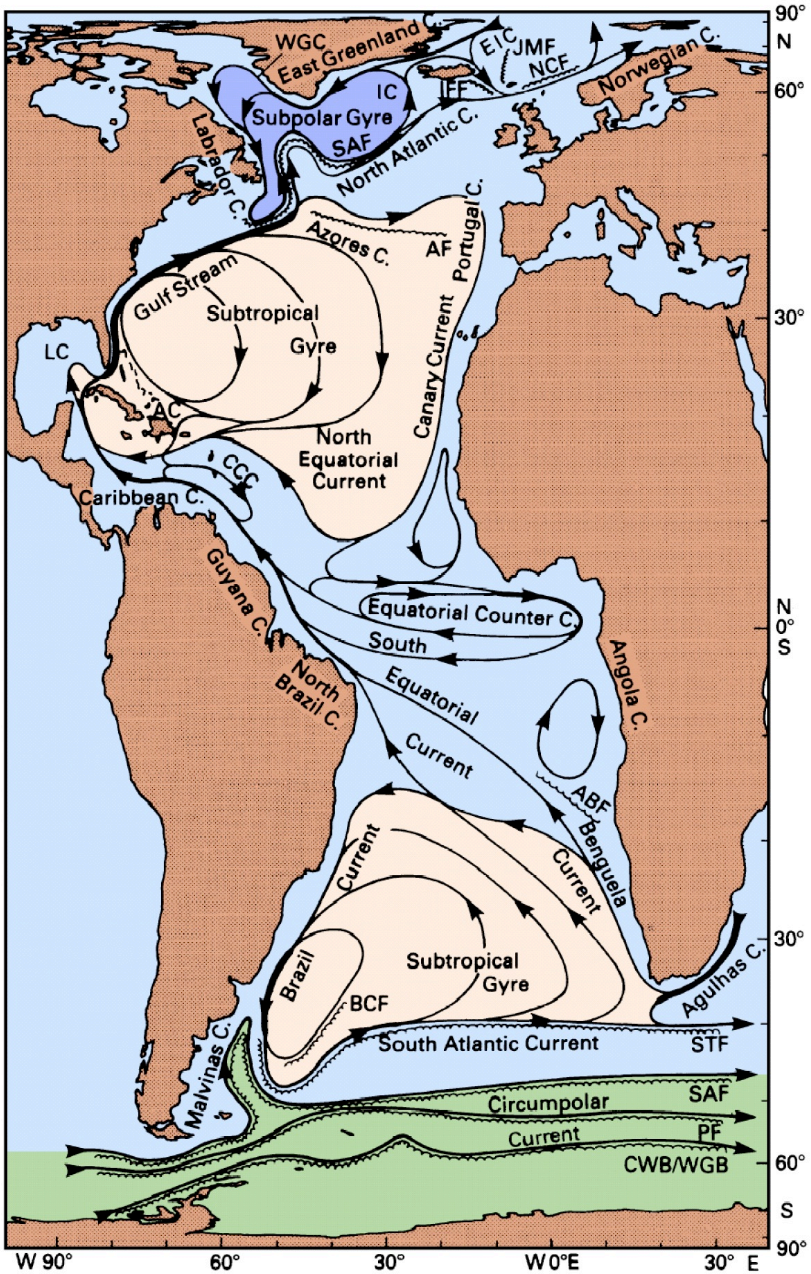


Where precipitation exceeds evaporation and river input is low, salinity is high and vice versa. Areas of high evaporation and low precipitation are found along the downwelling branch of the Hadley Cell.

NASA's MERRA



Reality is more complicated… but generalities in prevailing winds are consistent with an idealized 'water world'.



Surface currents of the Atlantic Ocean

Abbreviations are used for the East Iceland (EIC), Irminger (IC), West Greenland (WGC), and Antilles (AC) Currents and the Caribbean Countercurrent (CCC). Other Abbreviations refer to fronts: JMF: Jan Mayen Front, NCF: Norwegian Current Front, IFF: Iceland - Faroe Front, SAF: Subarctic Front, AF: Azores Front, ABF: Angola - Benguela Front, BCF: Brazil Current Front, STF: Subtropical Front, SAF: Subantarctic Front, PF: Polar Front, CWB/WGB: Continental Water Boundary / Weddell Gyre Boundary. Adapted from Duncan *et al.* (1982), Krauss (1986) and Peterson and Stramma (1991).

Tomczak and Godfrey (2003)

How do the winds cause these current systems?

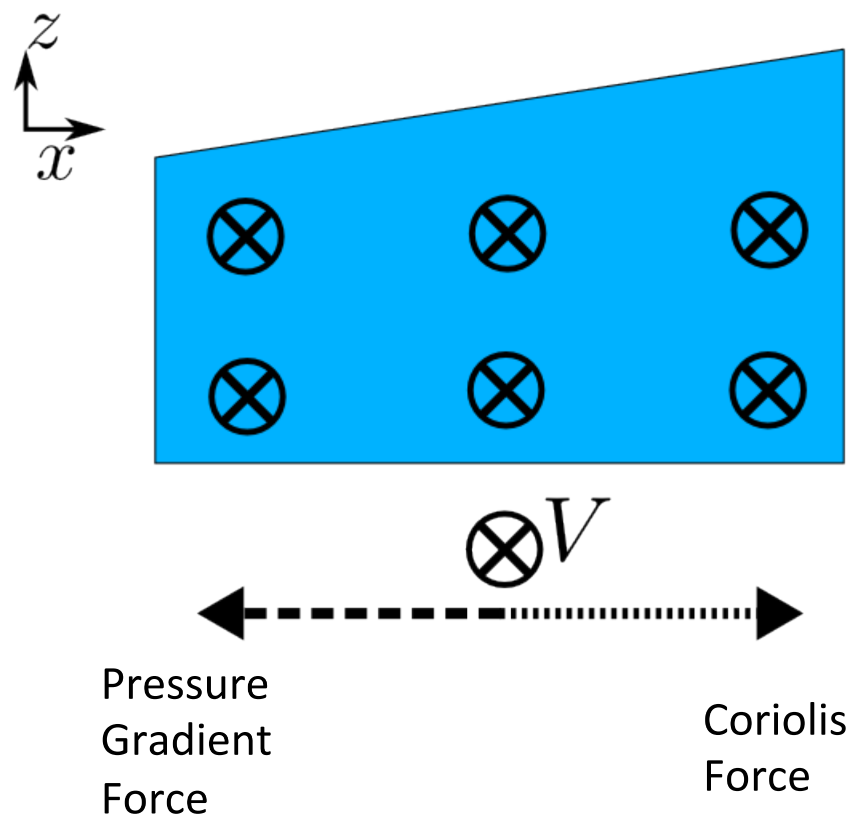
BIG CONCEPT #1 → Geostrophic Balance

#1

Large-scale motions are often in geostrophic balance, in which a steady current is associated with a force balance between the pressure gradient and the ***Coriolis*** force

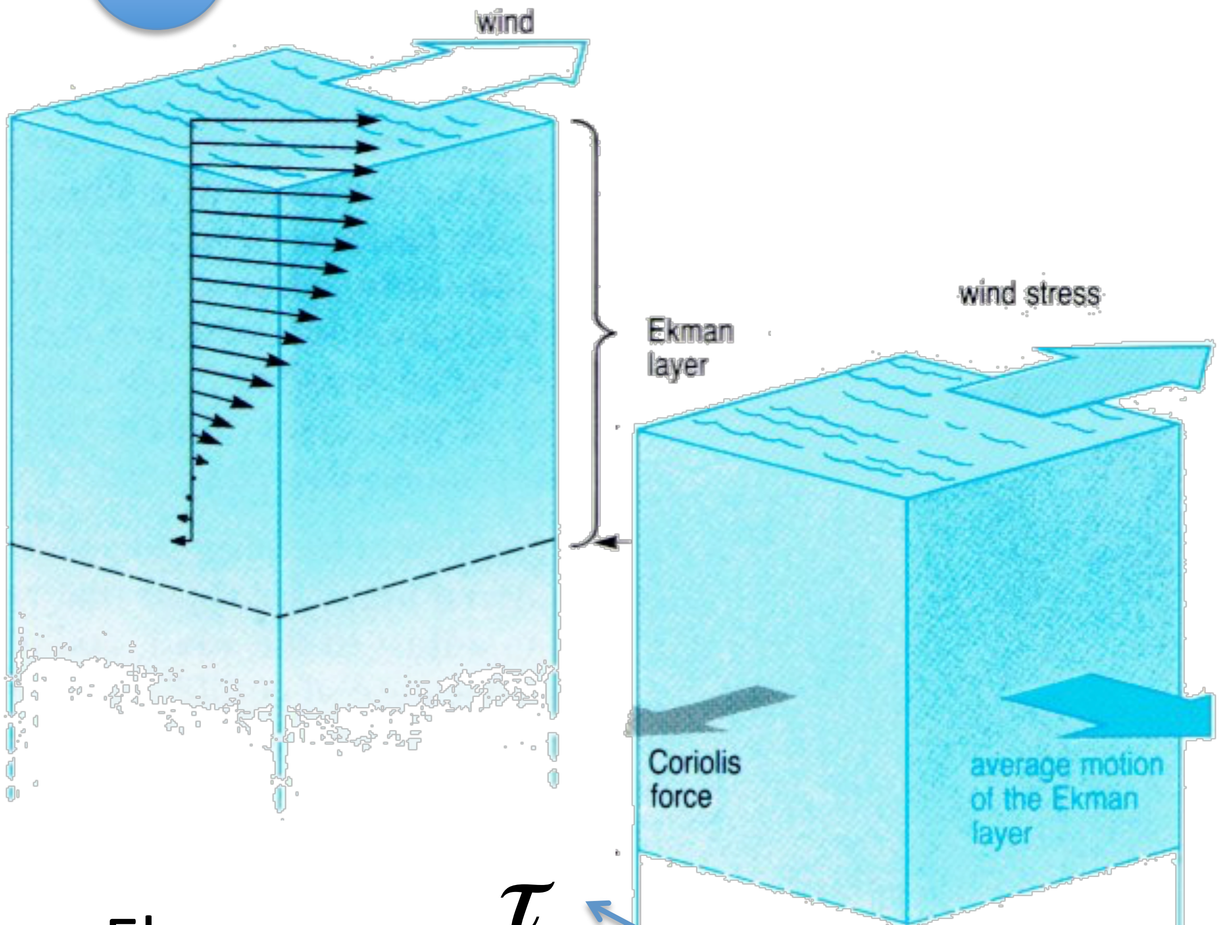
Drawn for the northern hemisphere, how would this change in the southern?

Barotropic Pressure Gradient



BIG CONCEPT #2 → Ekman transport

#2



Ekman Transport:

Due to wind stress and the Earth's rotation:

water in the surface layer is transported to the right *(left)* of the winds in the northern *(southern)* hemisphere

Ekman (1905)

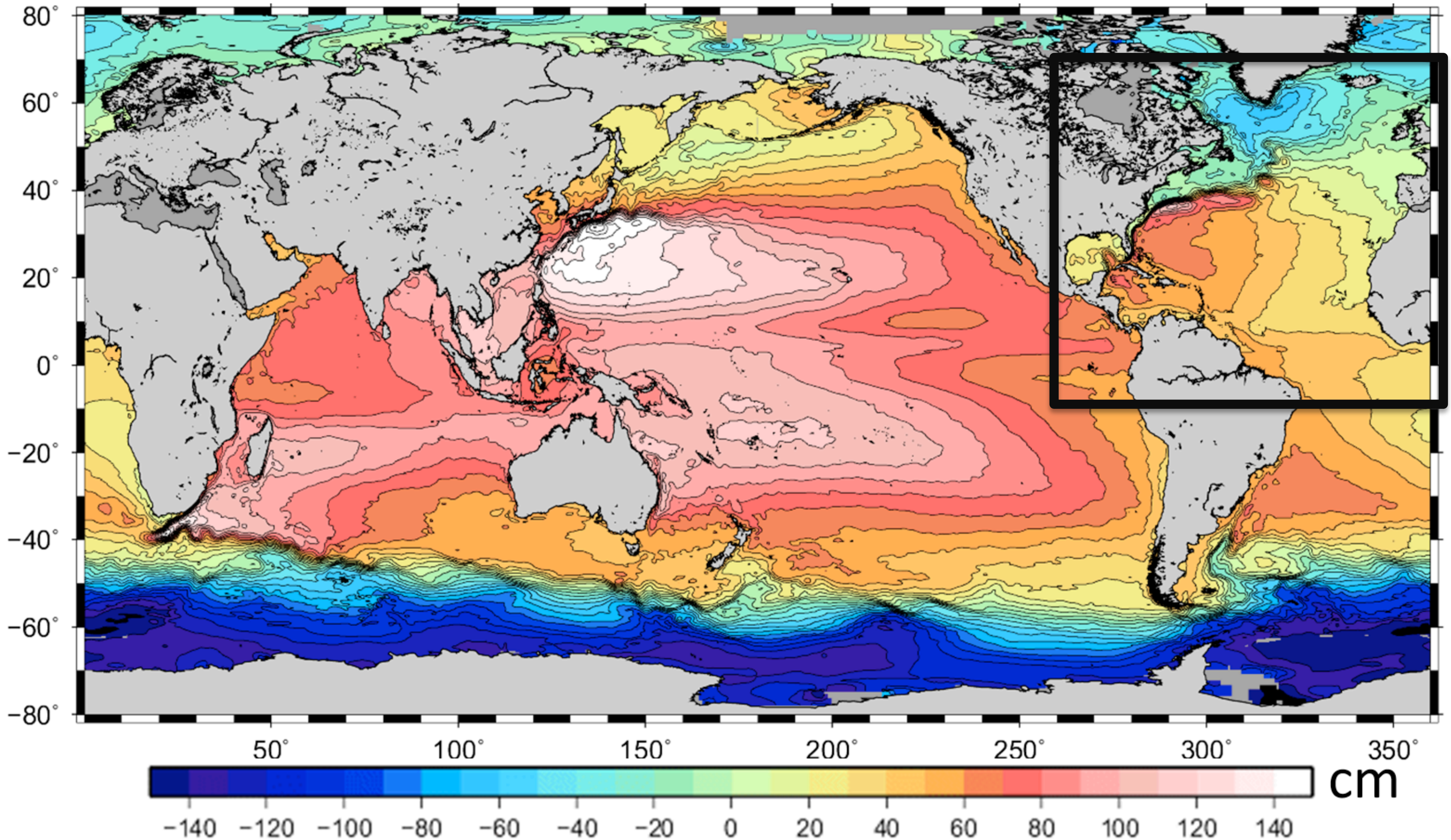
$$\text{Ekman Transport} = \frac{\tau}{\rho f}$$

wind stress (N/m^2)

Coriolis parameter(1/s)

seawater density (kg/m^3)

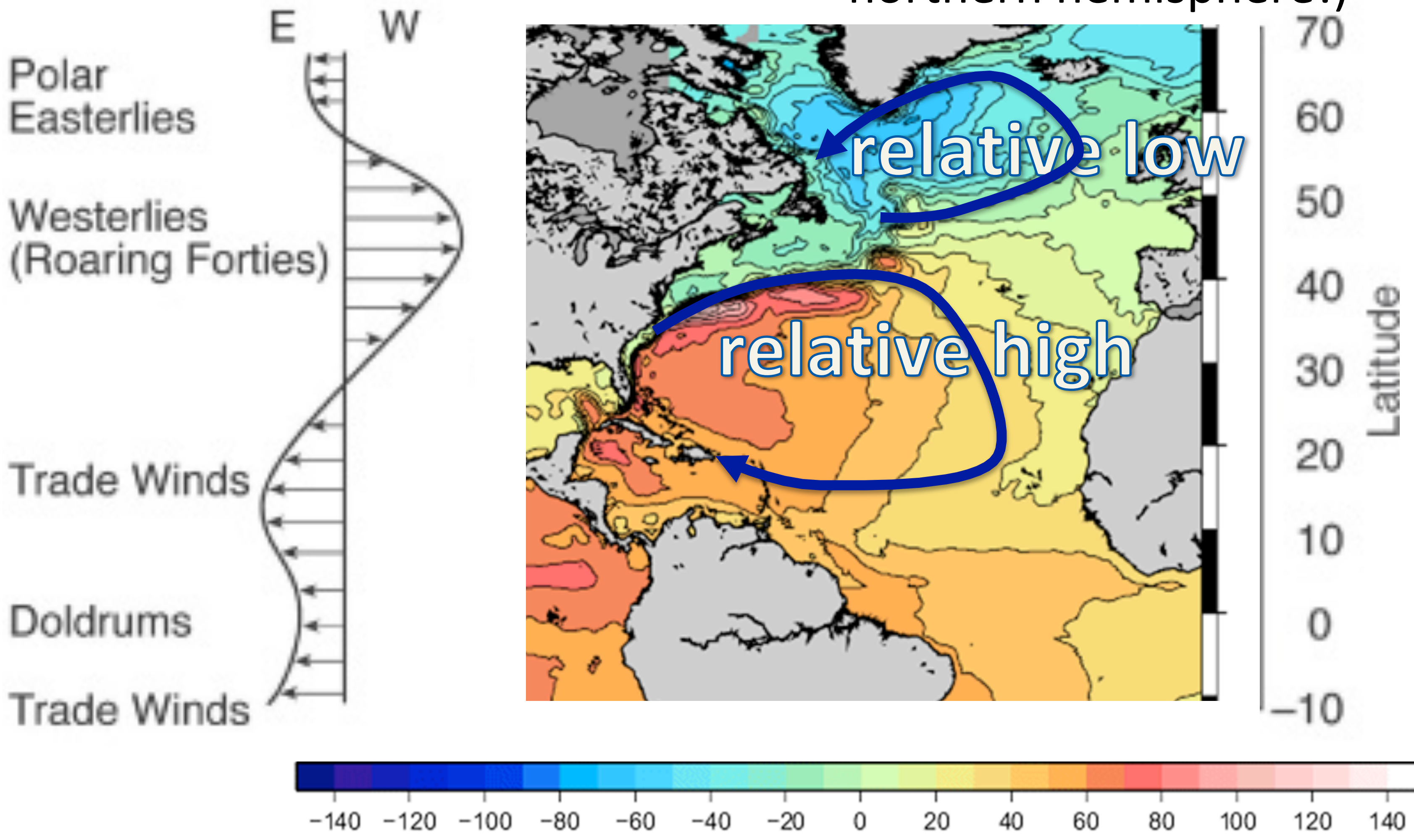
Resulting Ocean Circulation (Geostrophy + Ekman)



http://www.aviso.altimetry.fr

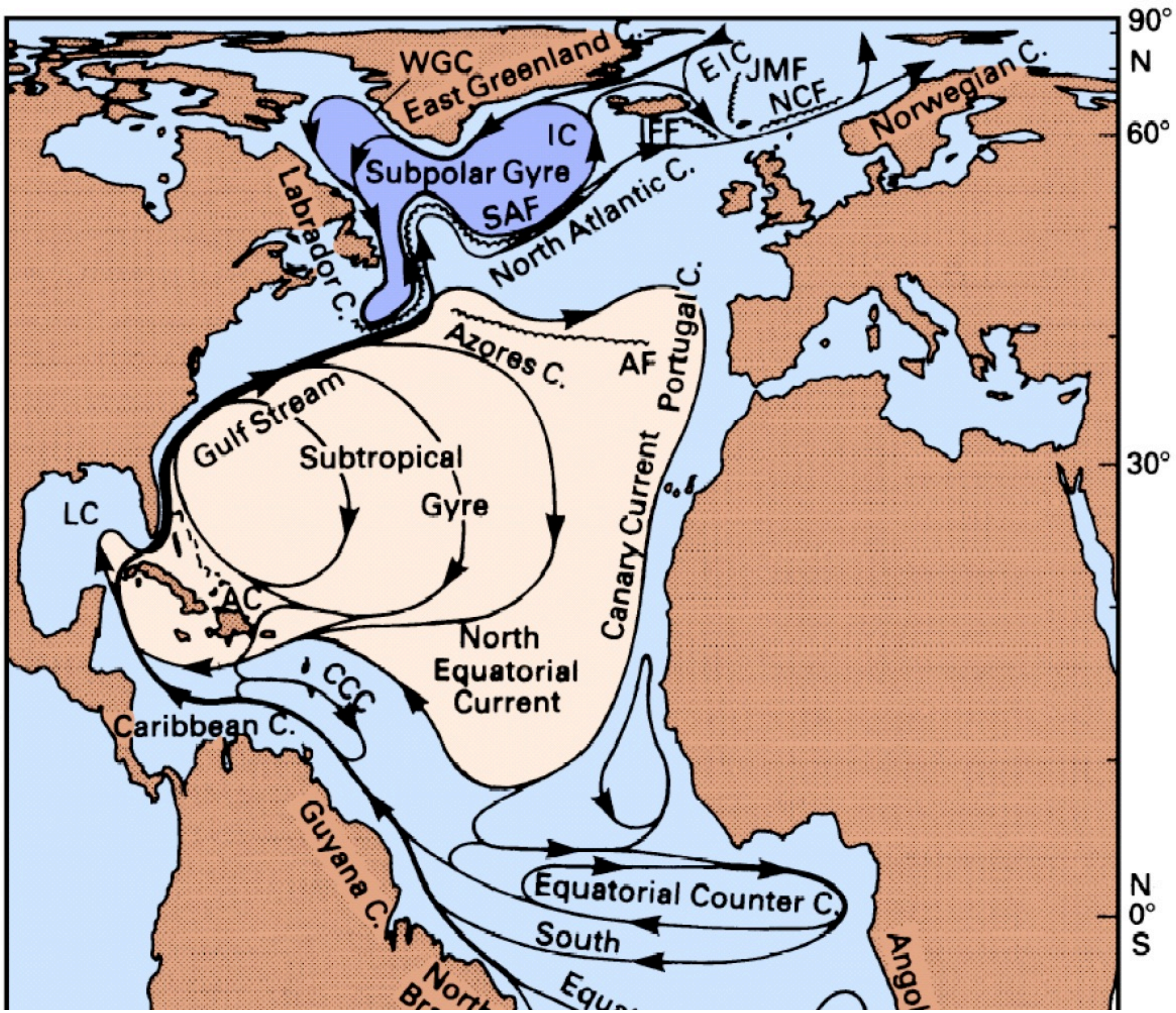
Resulting Ocean Circulation (Geostrophy + Ekman)

“high to the right”, “low to the left” (in the northern hemisphere!)



http://www.aviso.altimetry.fr

Resulting Ocean Circulation (Geostrophy + Ekman)

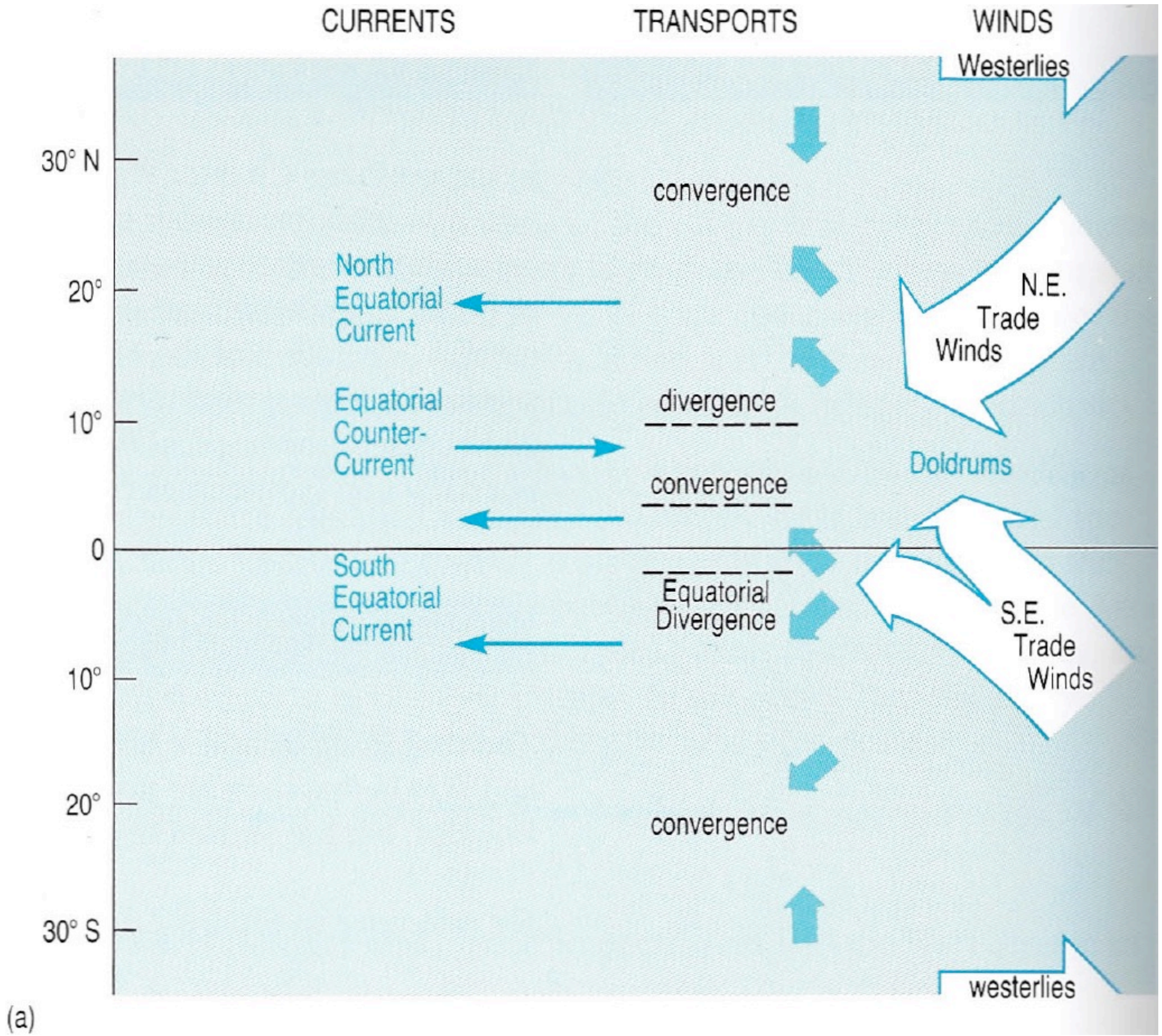


"high to the right"

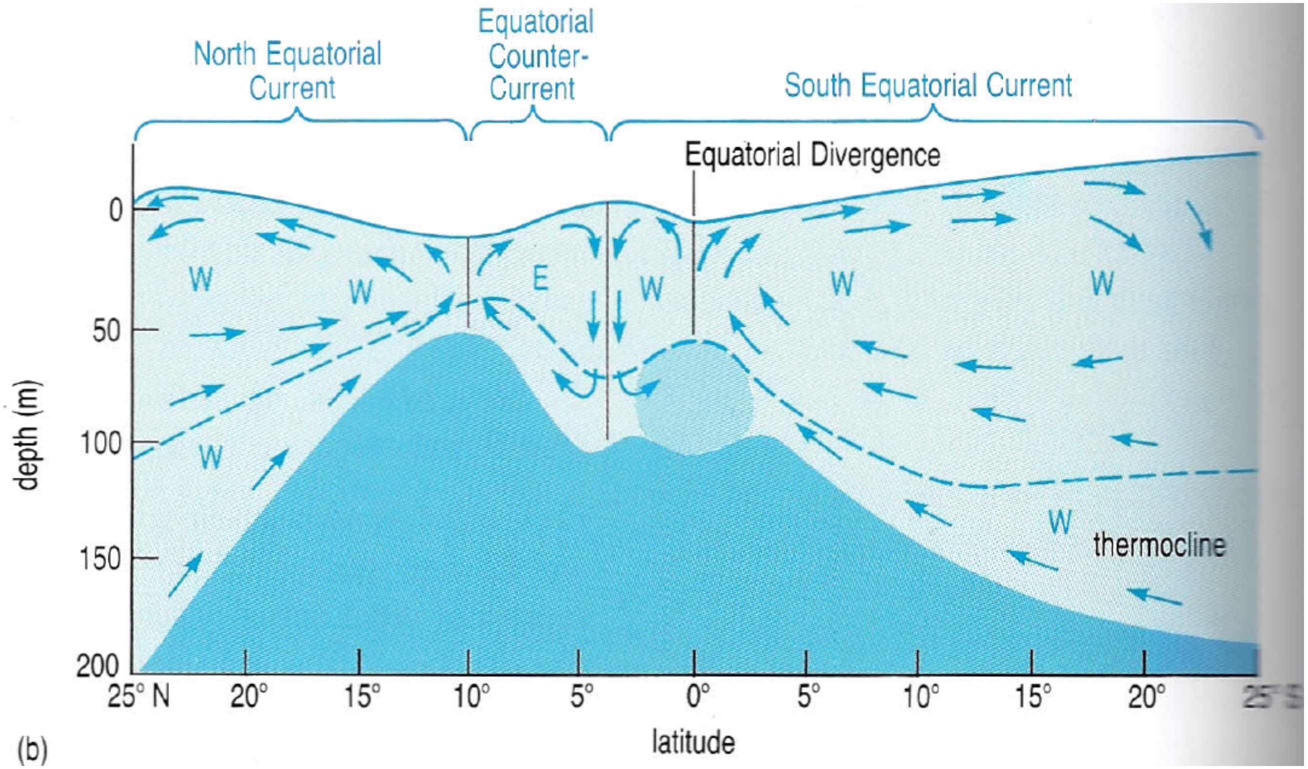
"low to the left"

(in the northern hemisphere!)

What happens at the Equator?

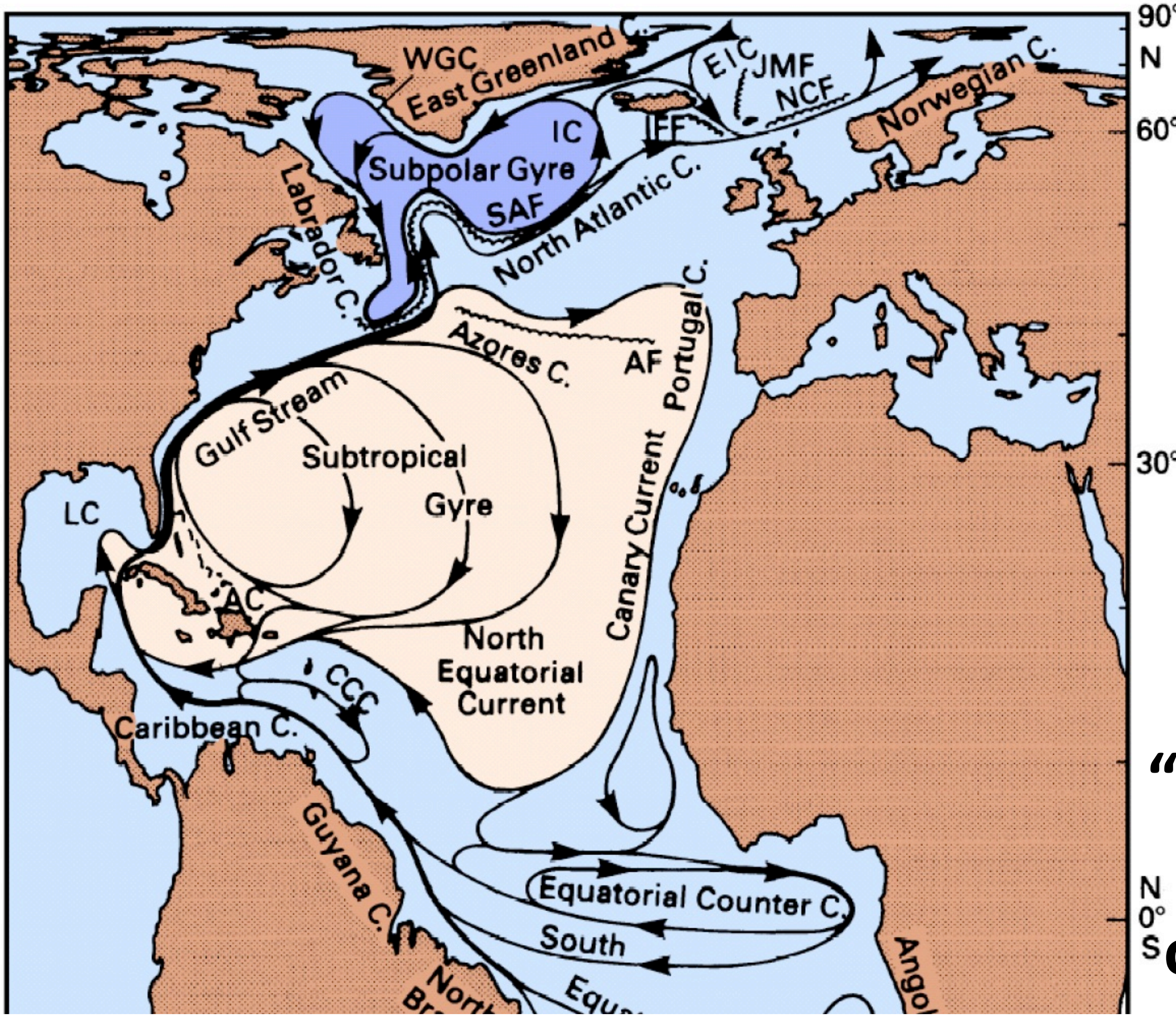


The relationships between the wind direction, the surface current and the Ekman transport (short blue arrows), in equatorial latitudes. Note the Doldrum belt between about 5°and10°N.



North-south diagrammatic section showing the vertical and meridional circulation in equatorial latitudes, and the shape of the sea surface and thermocline. Regions of eastward and westward flow are indicated by the letters E and W. The darker blue region (in which geostrophic current is assumed to be zero) is the deep water below the thermocline. The blue oval at about 100 m depth at the Equator represents the Equatorial Undercurrent

Resulting Ocean Circulation (Geostrophy + Ekman)

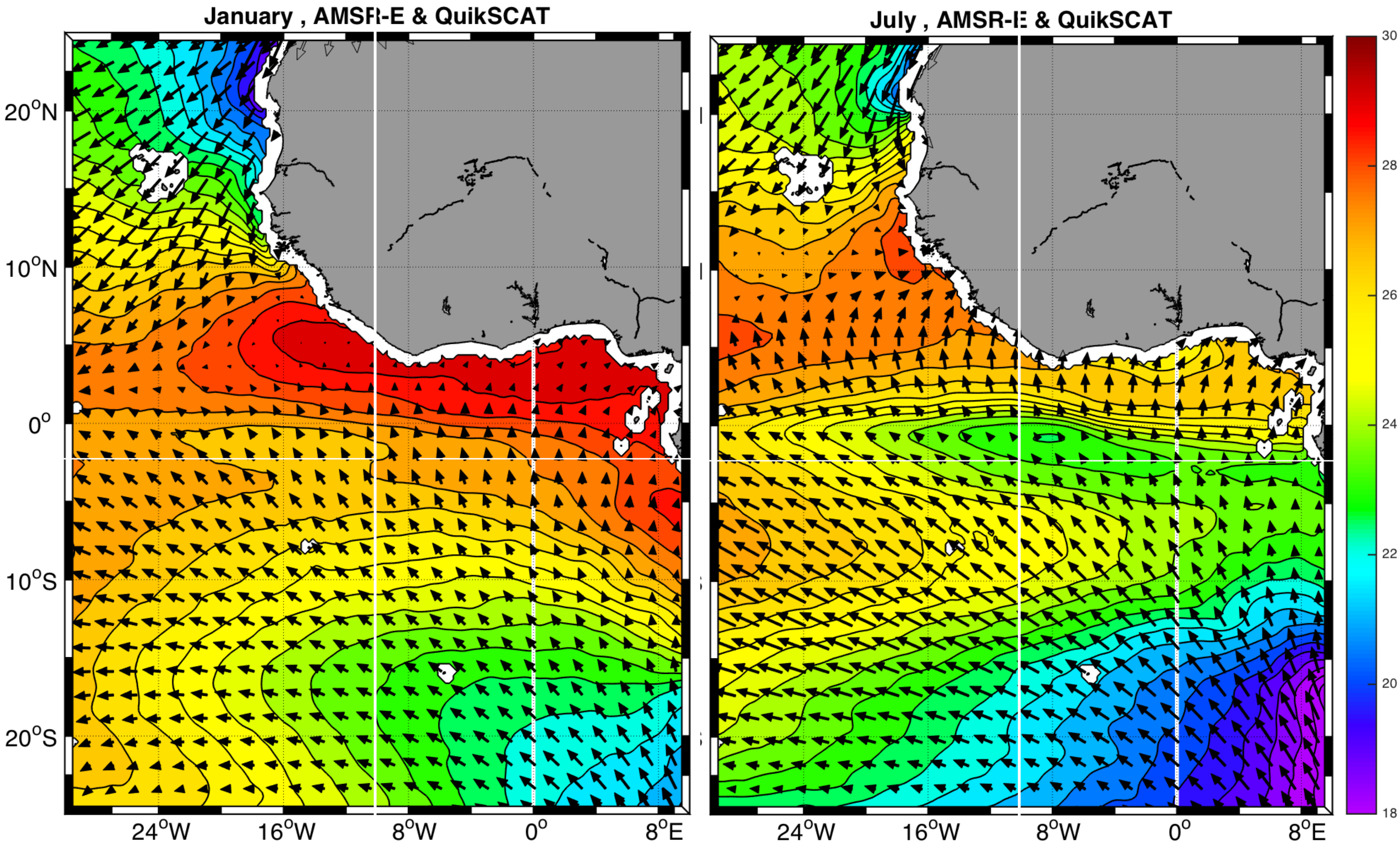


"high to the right"

"low to the left"

(in the northern hemisphere!)

"Steady" view of the system, variability occurs at a range of time scales!!


January , AMSR-E & QuikSCAT
July , AMSR-E & QuikSCAT
20°N
10°N
0°
10°S
20°S
24°W
16°W
8°W
0°
8°E
30
28
26
24
22
20
18

Winds and Coastal Upwelling/Downwelling

Equatorward winds

Offshore Ekman transport

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

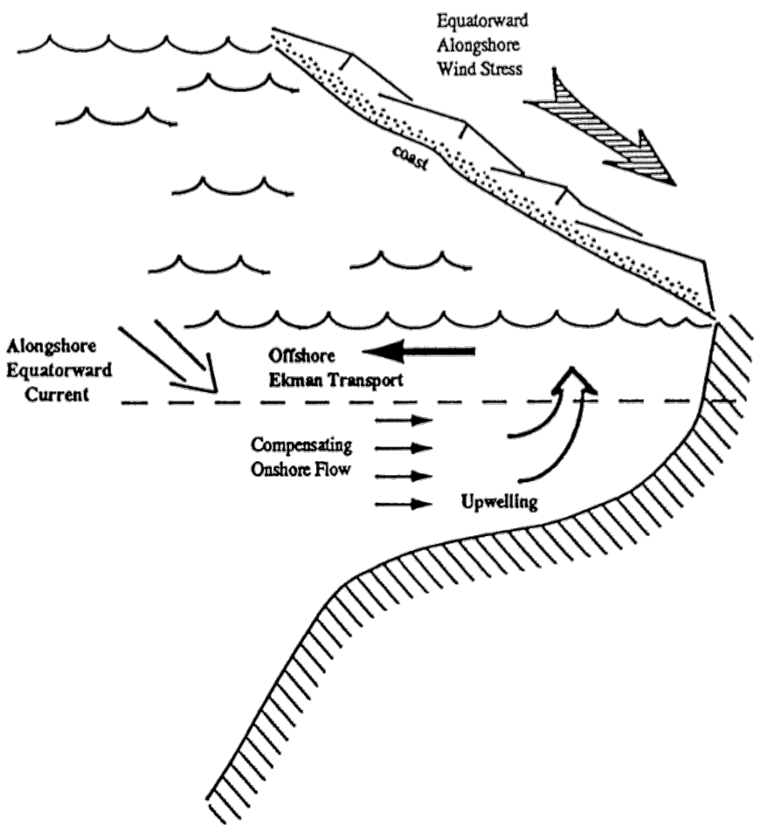
Strong equatorward along-shelf flow

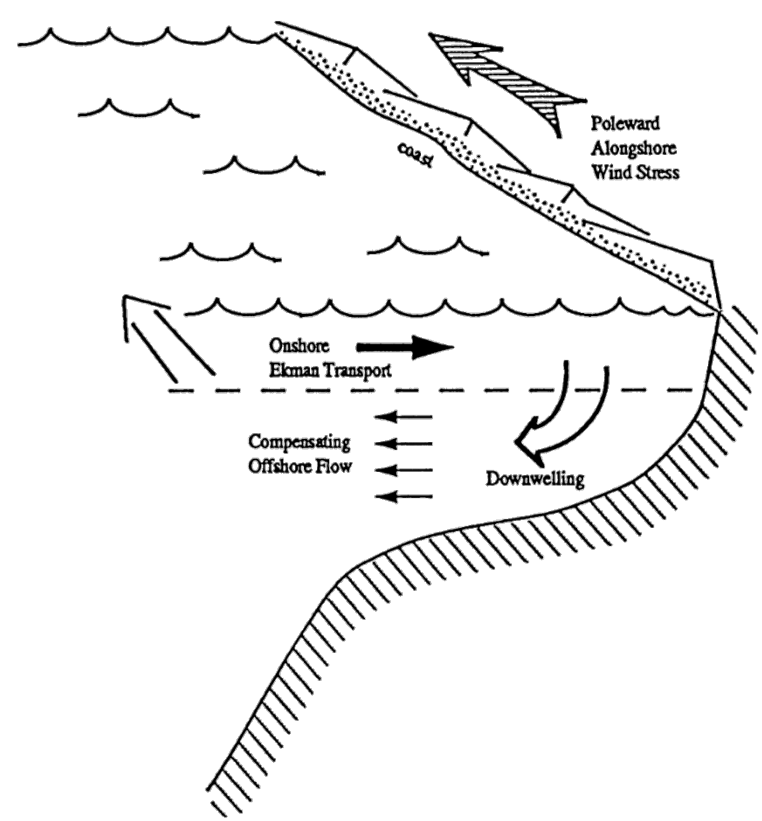
Poleward winds

Onshore Ekman transport

Downwelling traps warm, nutrient poor surface water near the coast

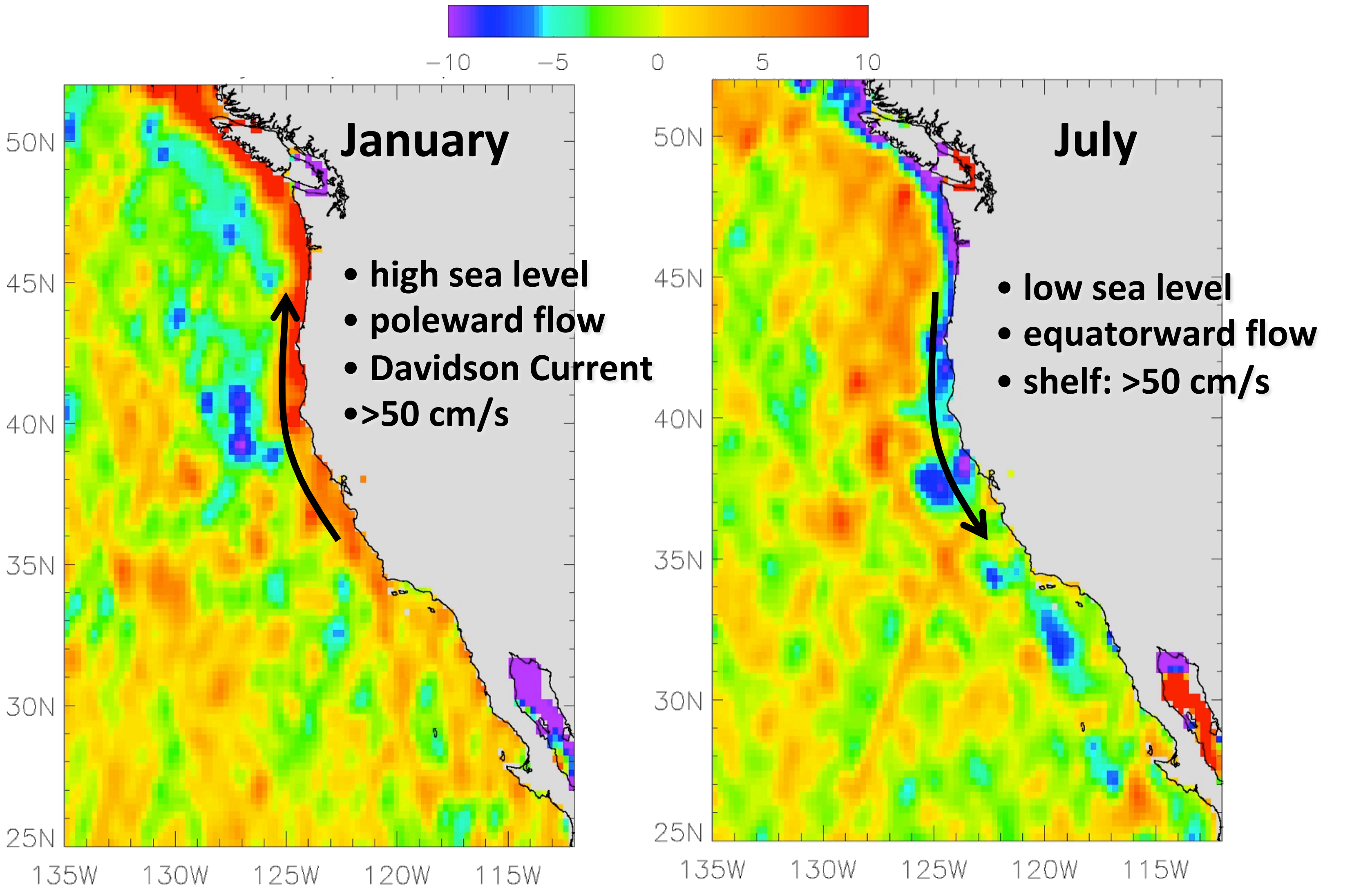
Strong poleward along-shelf flow



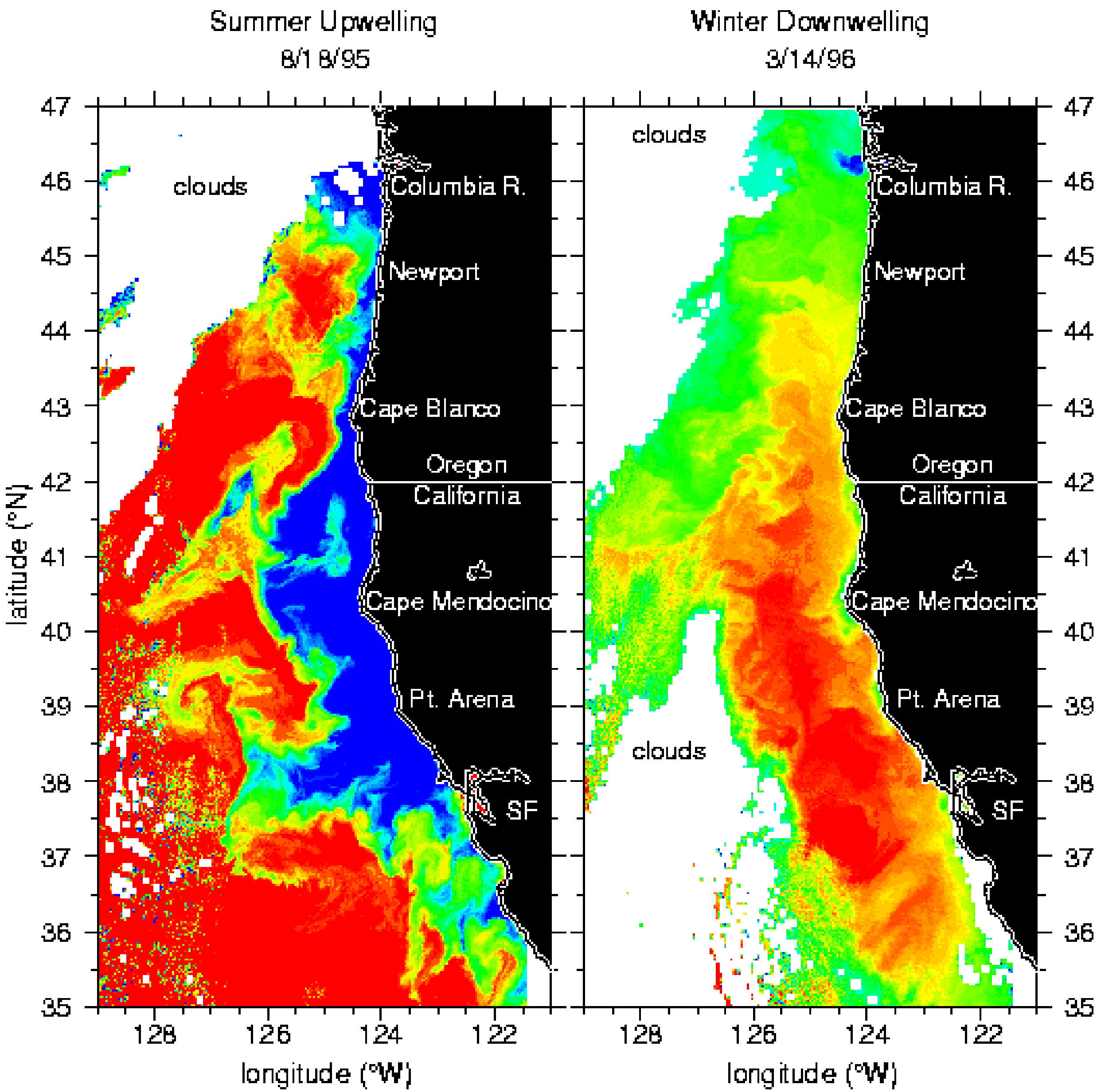


Flow Over the Shelf: Winter vs. Summer

(from 10 years of Altimeter Data)



Upwelling and Downwelling along the US west coast

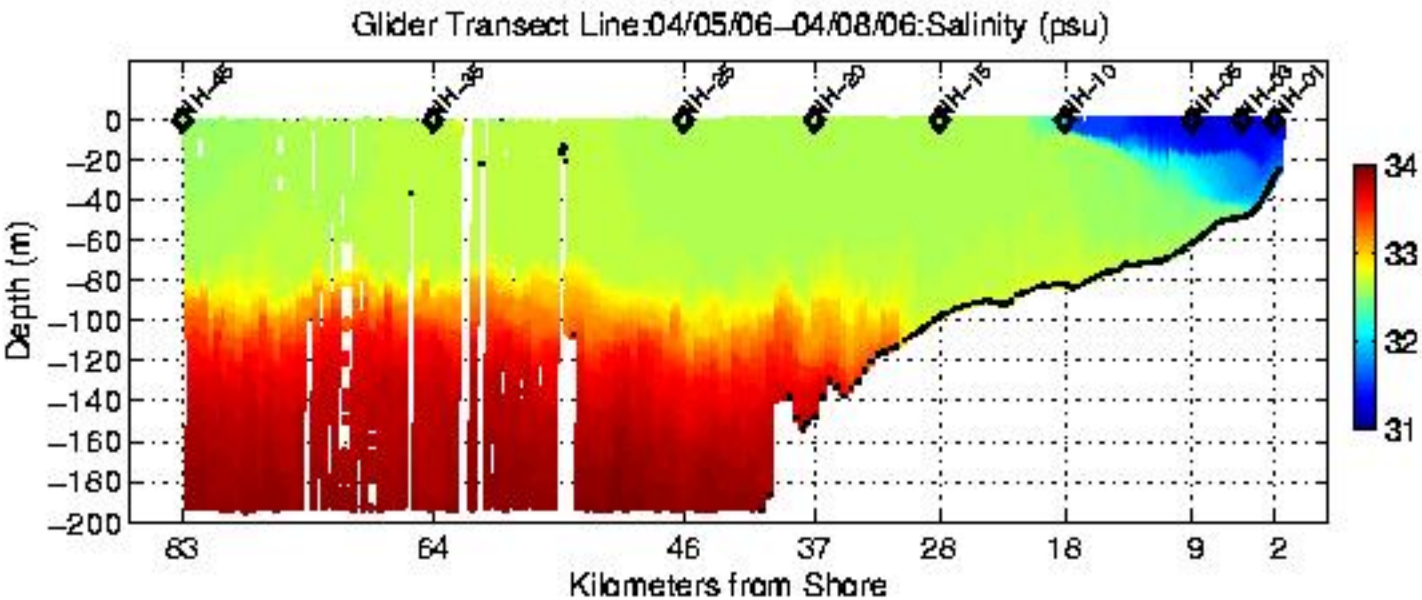


blue = cold

red = warm

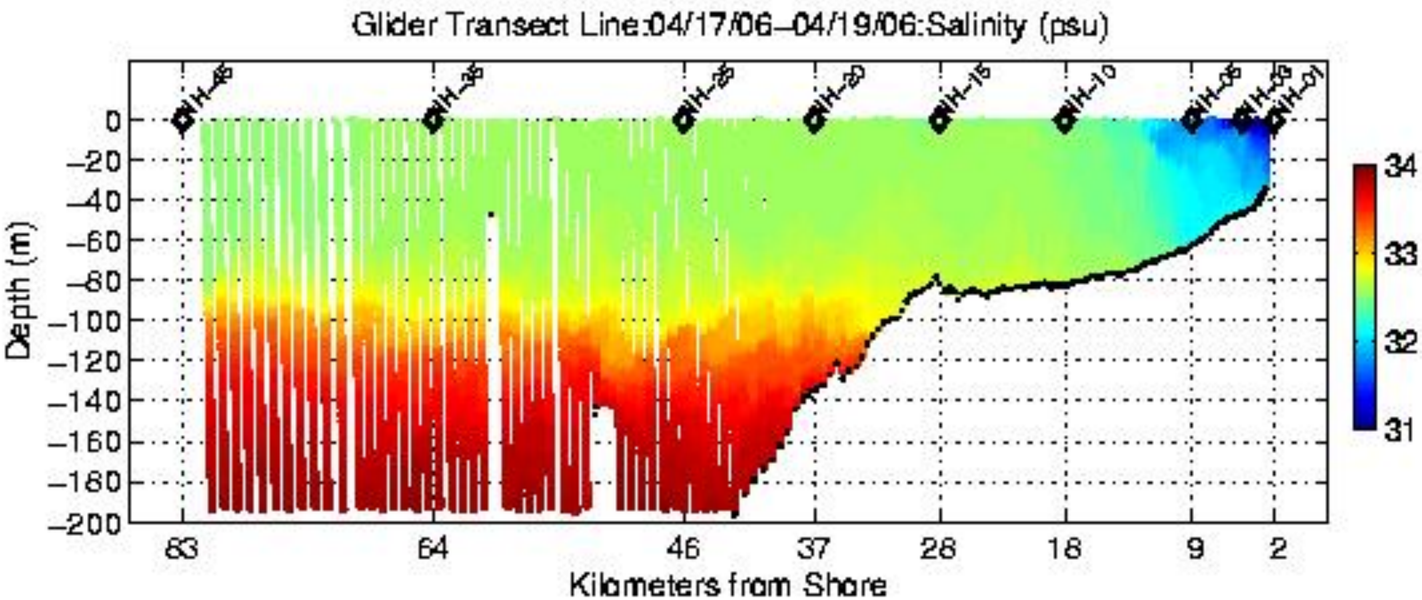
The Oregonian
July 25, 1996

April 5-8



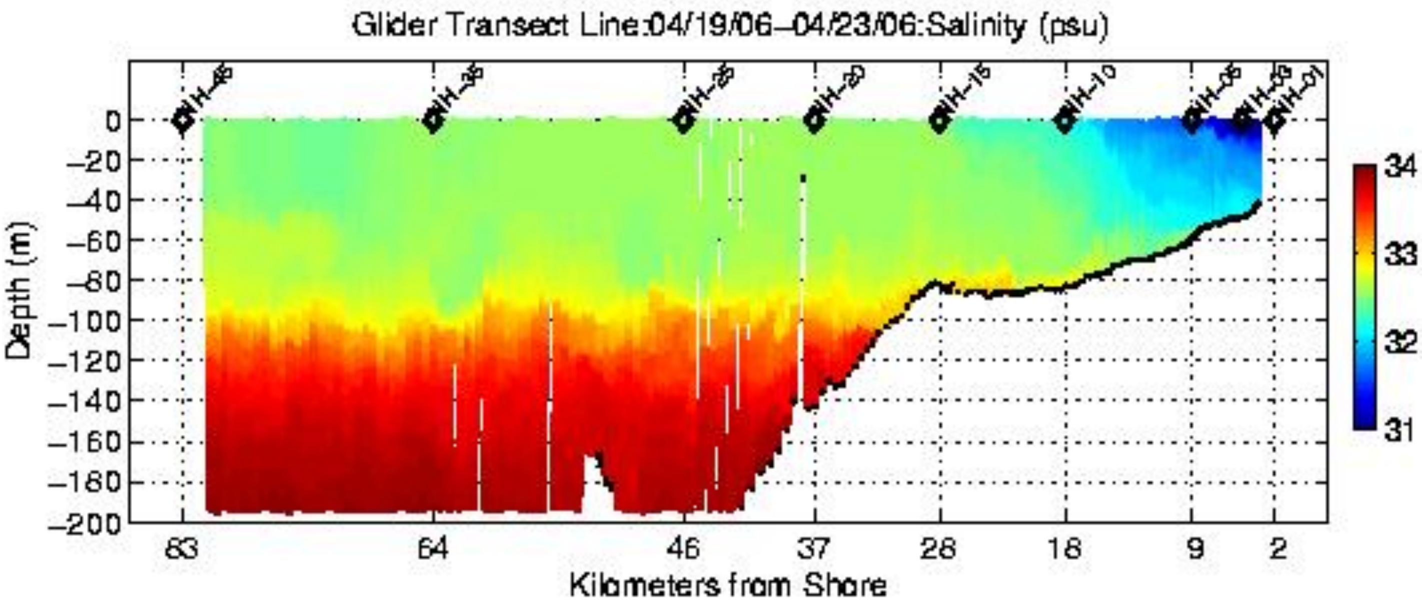
down

April 17-19



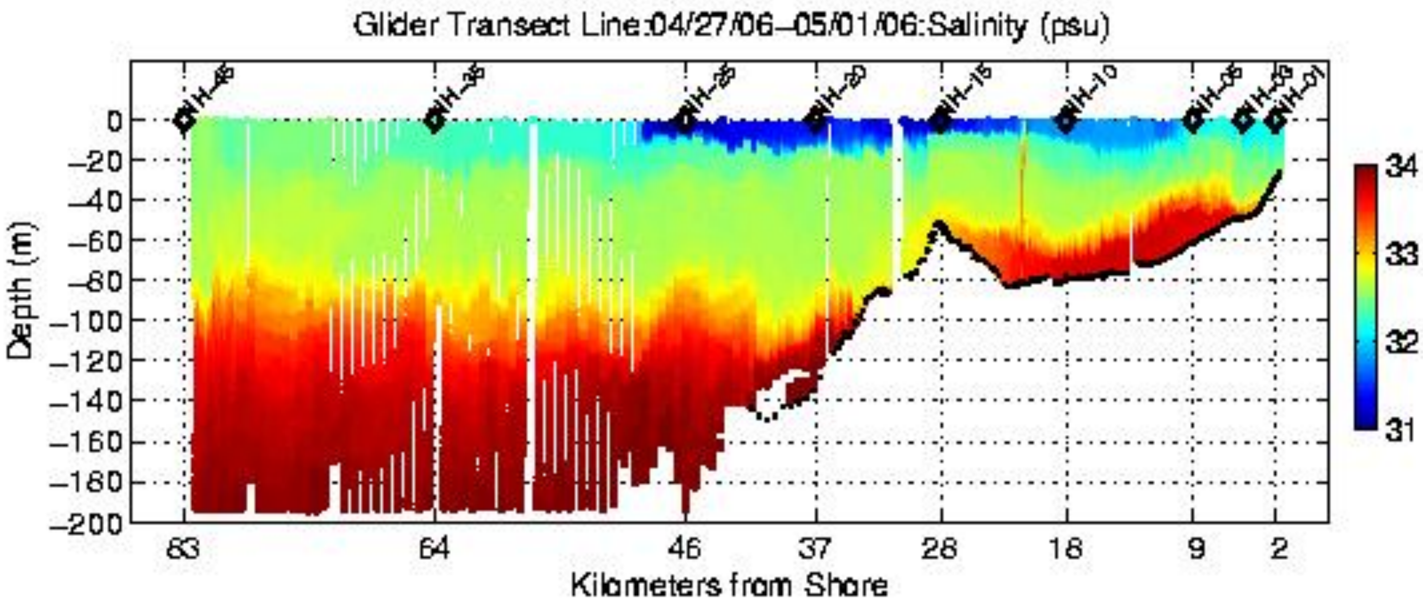
down

April 19-23



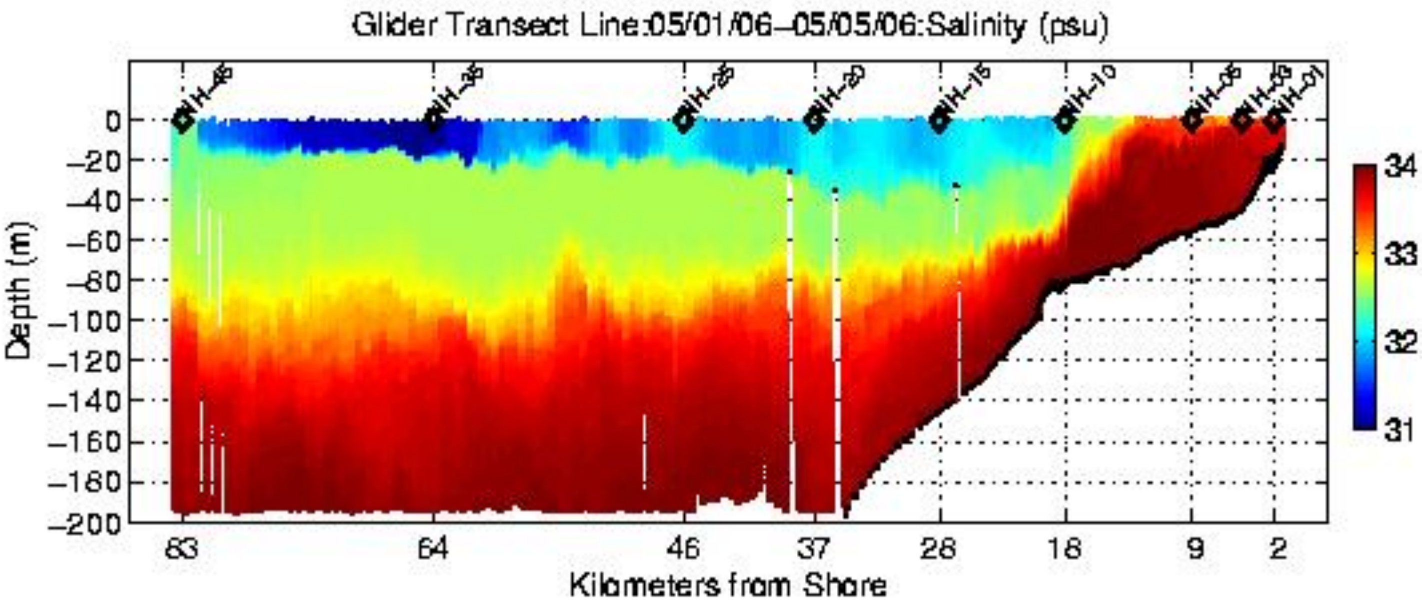
down

April 27-May 1



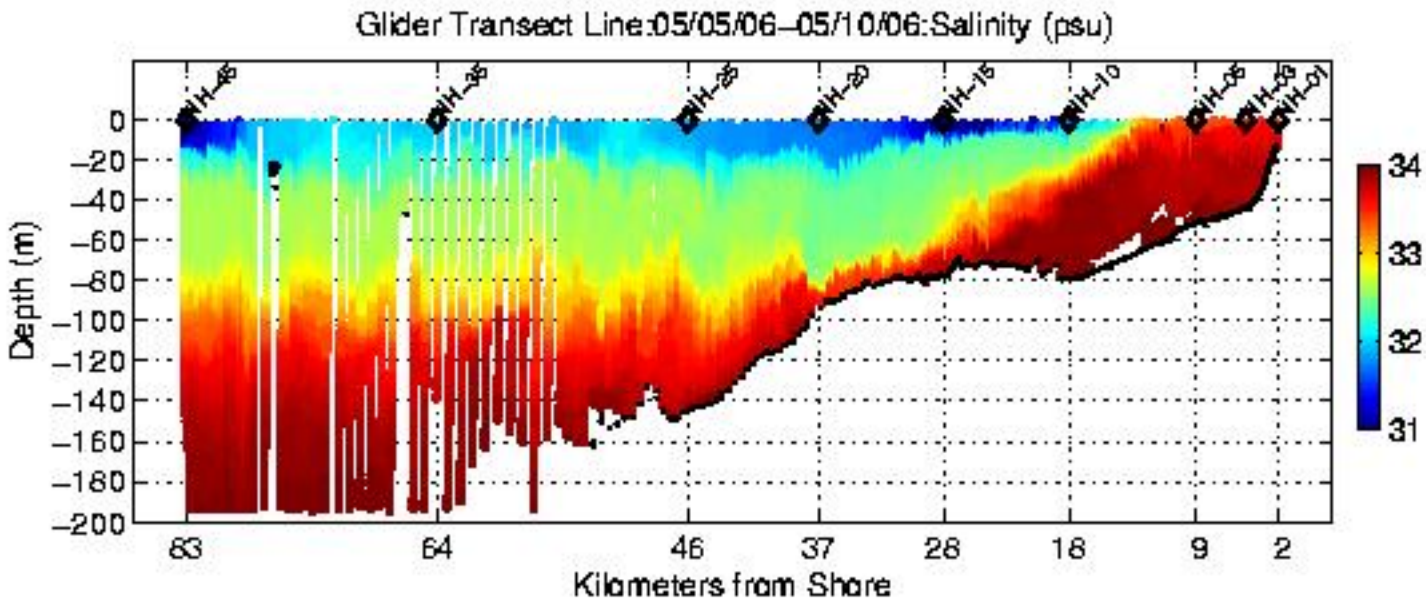
up

May 1-5


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

down

Winds, Ekman Transport and Coastal Upwelling/Downwelling

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Offshore Ekman transport

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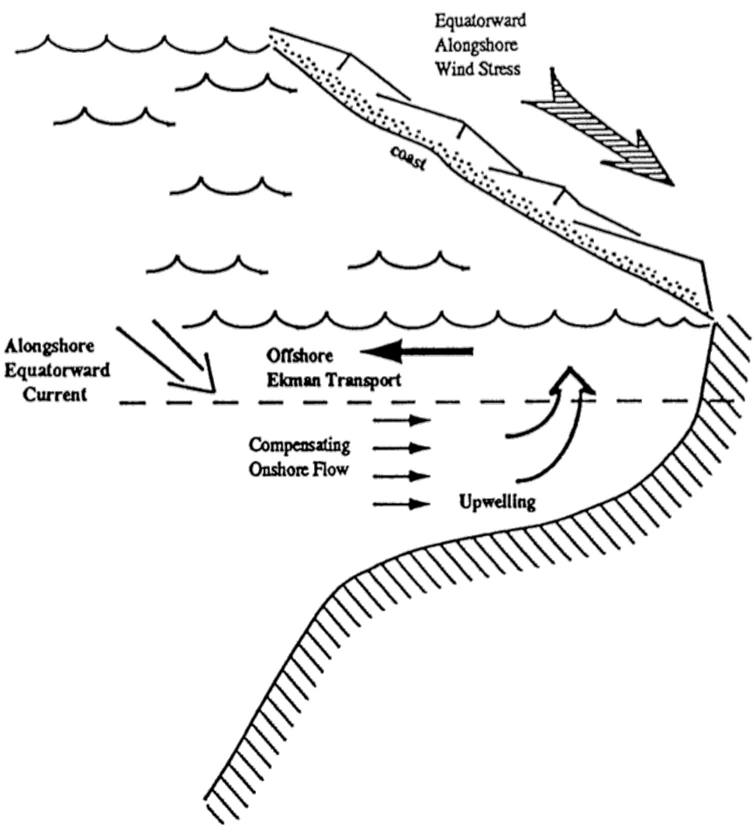

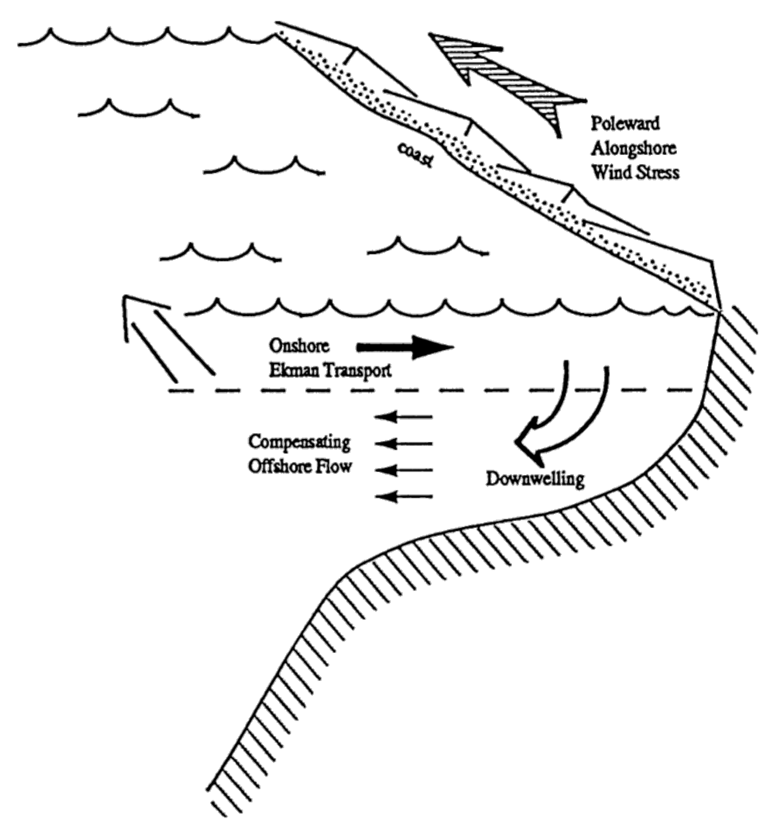

Satellite Observations of Upwelling in the Gulf of Guinea

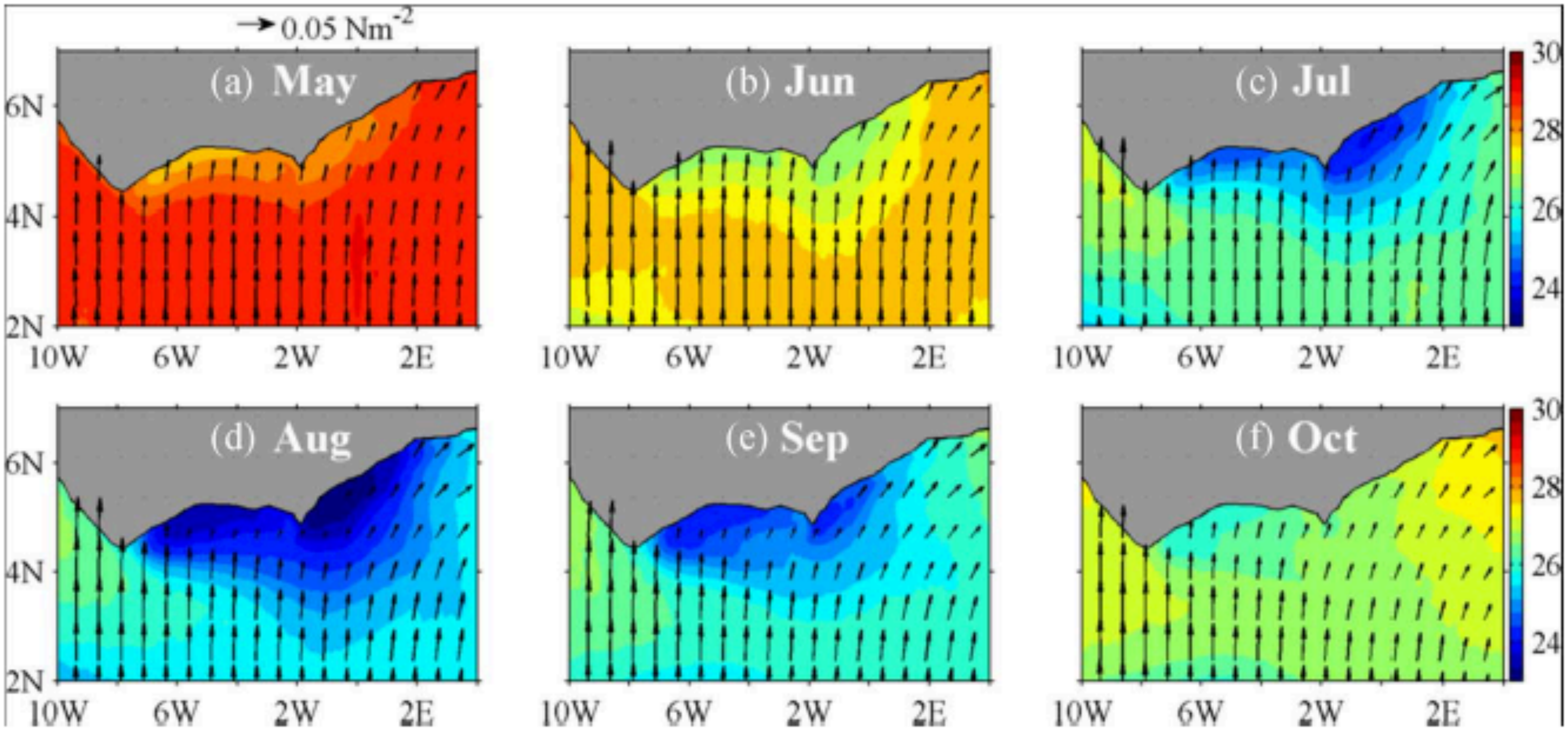

Fig. 2. Monthly mean SST (color shaded; in degrees Celsius) in the northwestern GoG region. Arrow vectors show mean wind stress ($N{\cdot}m^{-2}$).

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