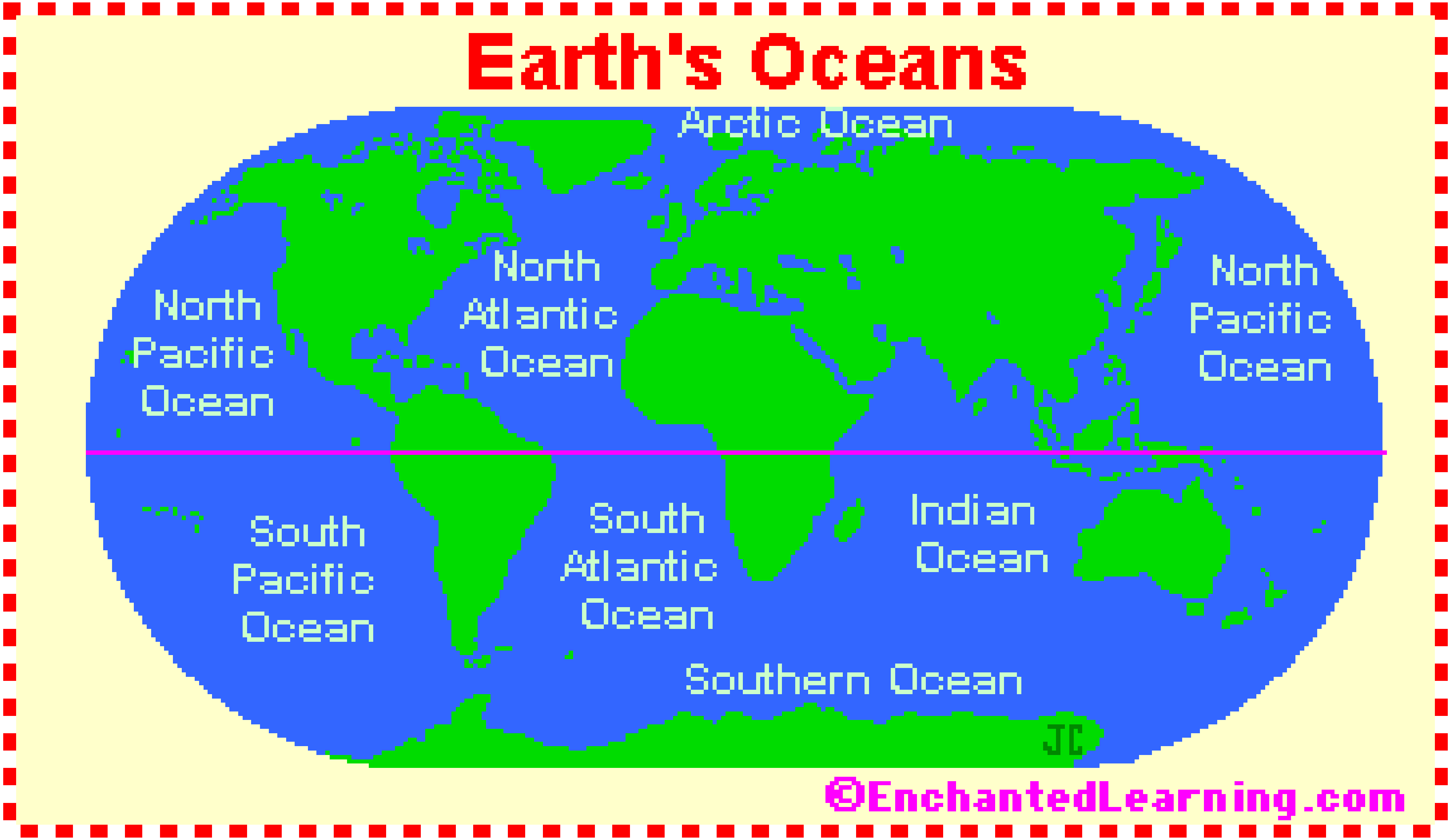
Oceans and the climate



70.8% surface is ocean, 29.2% is land.

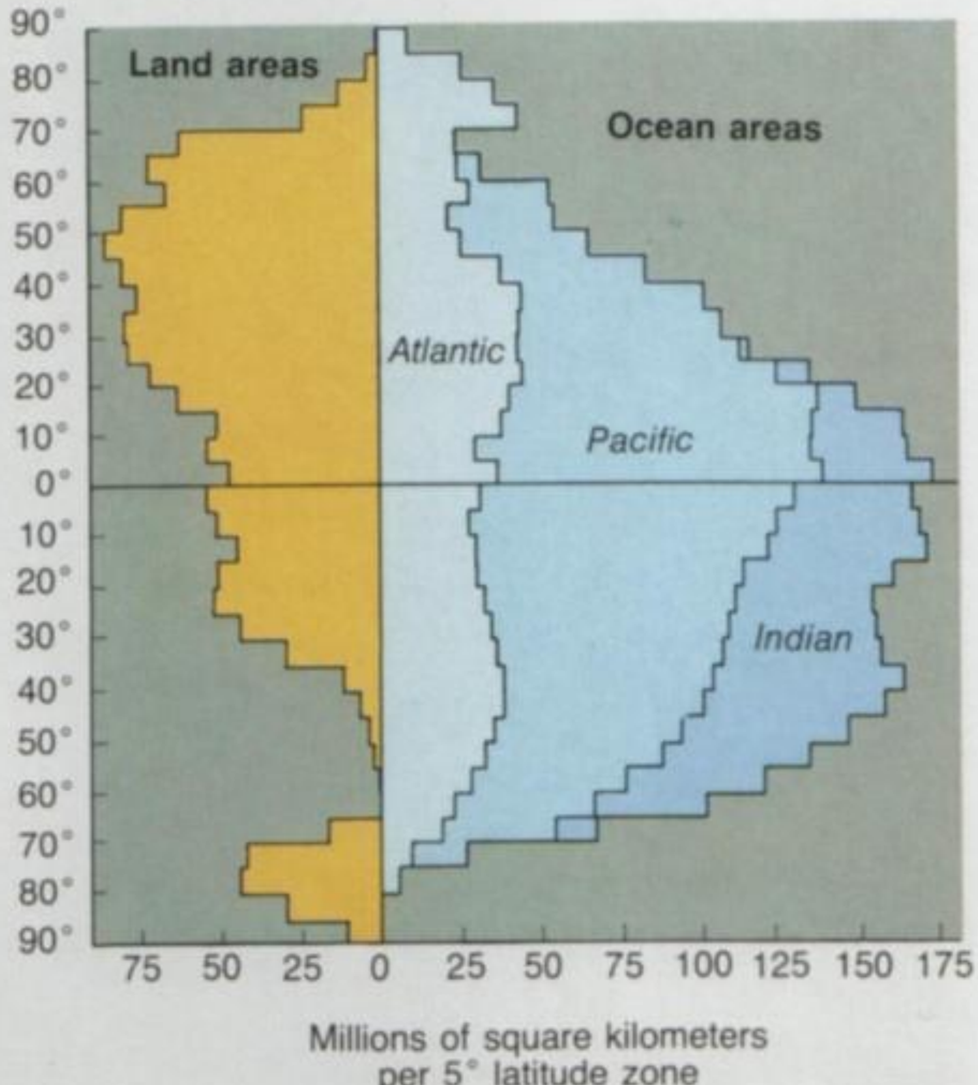
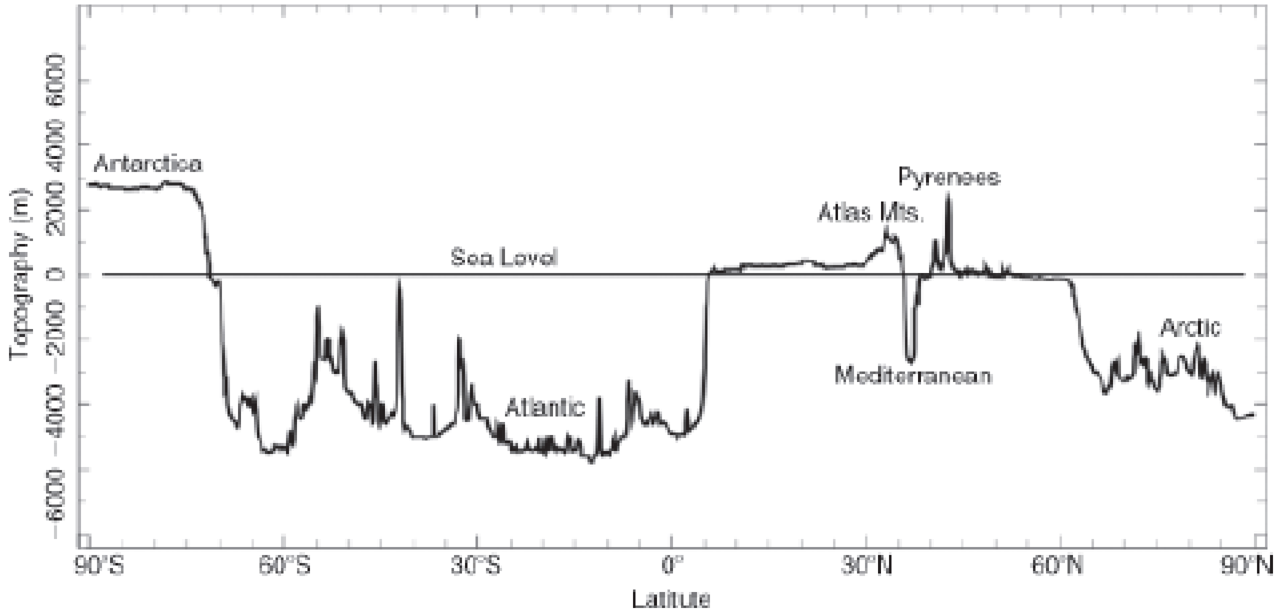


FIGURE 10.1
Distribution of land and water in each 5-degree latitude belt. (After M. Grant Gross, *Oceanography: A View of the Earth*, 2nd ed., Englewood Cliffs, N.J.: Prentice Hall, 1977; and M. Grant Gross, *Oceanogra-*



GURE 1.2. A north-south section of topography relative to sea level (in meters) along the Greenwich meridian longitude) cutting through Fig. 9.1. Antarctica is over 2 km high, whereas the Arctic Ocean and the south antic basin are about 5 km deep. Note how smooth the relief of the land is compared to that of the ocean floor.

מה מניע את האוקינוסים?

הפרשי צפיפויות

רוחות אטמוספריות

צפיפות: תלויה בטמפרטורה ובמליחות

הפרשים קטנים (לעומת האטמוספירה מאד) אבל הבדלים קטנים יכולים להניע הרבה

טמפרטורה קרה ומליחות גבוהה מעלים את הצפיפות

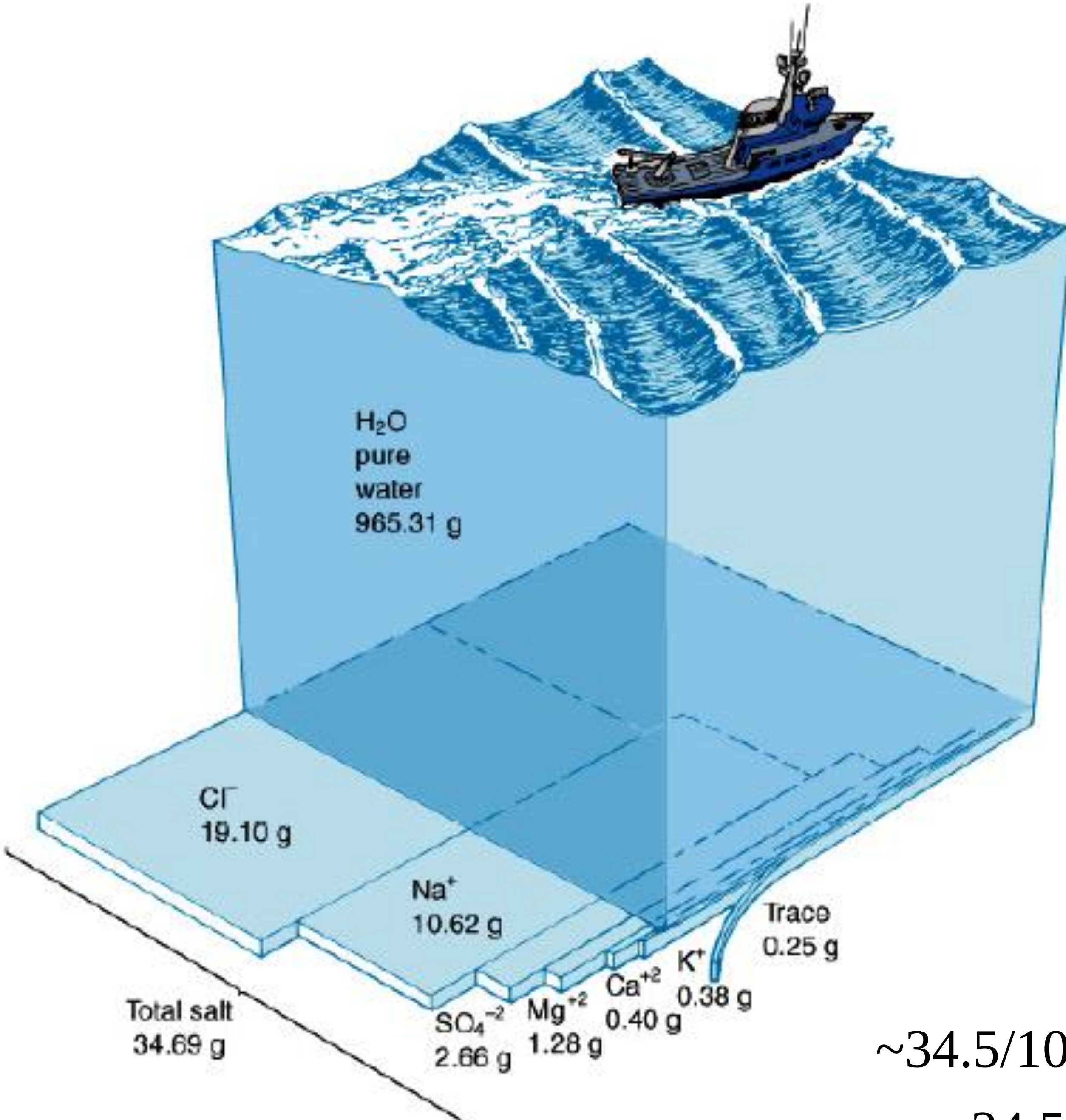
מליחות: נמדדת ביחידות של הולכה יחסית, הנקראות:

PSU – practical salinity units ושוות בקרוב טוב ליחס המסות בגרם לקילוגרם:

1 PSU= gr salt/ kg sea water

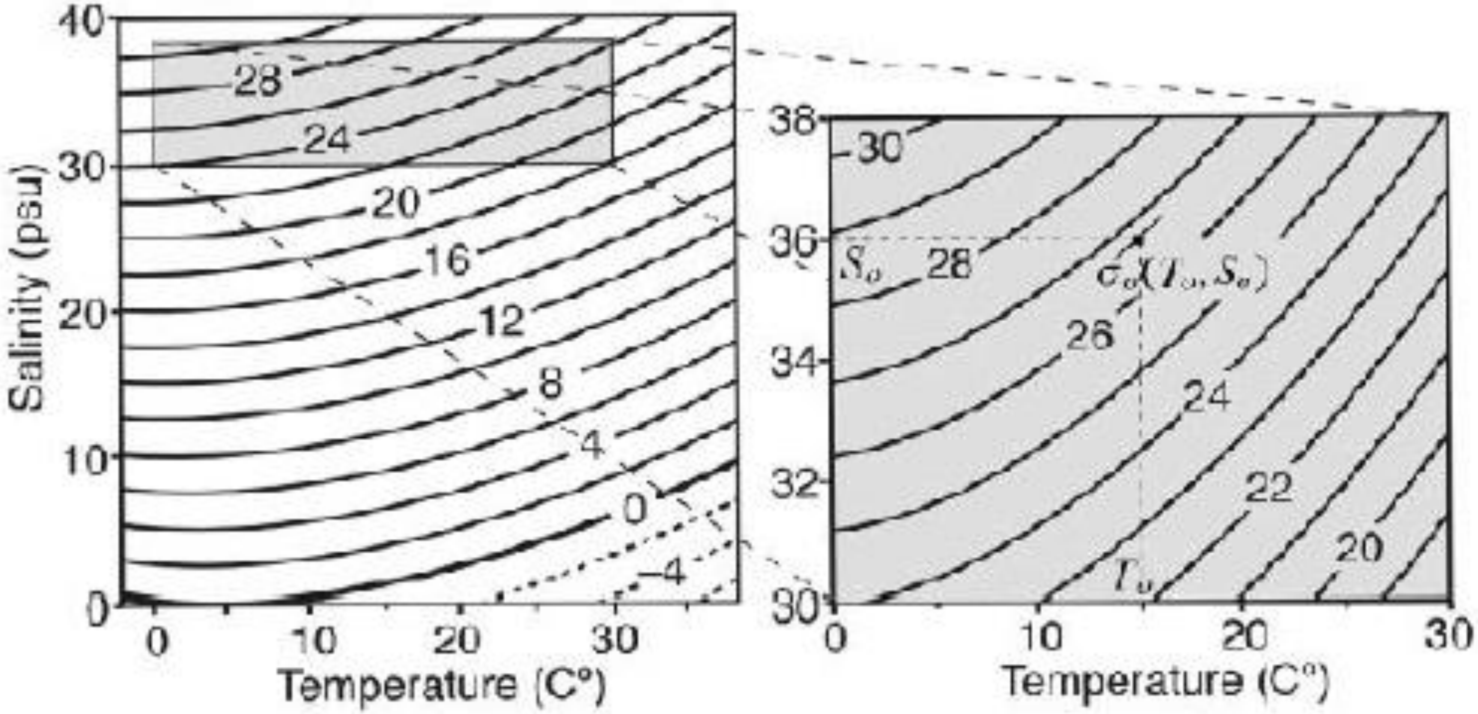
מליחות ממוצעת באוקינוסים : 34.5psu

Salinity



~34.5/1000 = 34.5‰

34.5 per mil



Density anomaly (kg/m^3), relative to a reference density of 1000 kg/m^3

שימו לב- קרח של מים מתוקים יותר קל ממים (האנומליה של המים)

קרח של מים מלוחים כמו ים לא יותר קל ממי ים. מדוע עם כך הקרחונים צפים?

Marshal and Plumb, “Atmosphere, Ocean and Climate dynamics”, 2008, Academic press

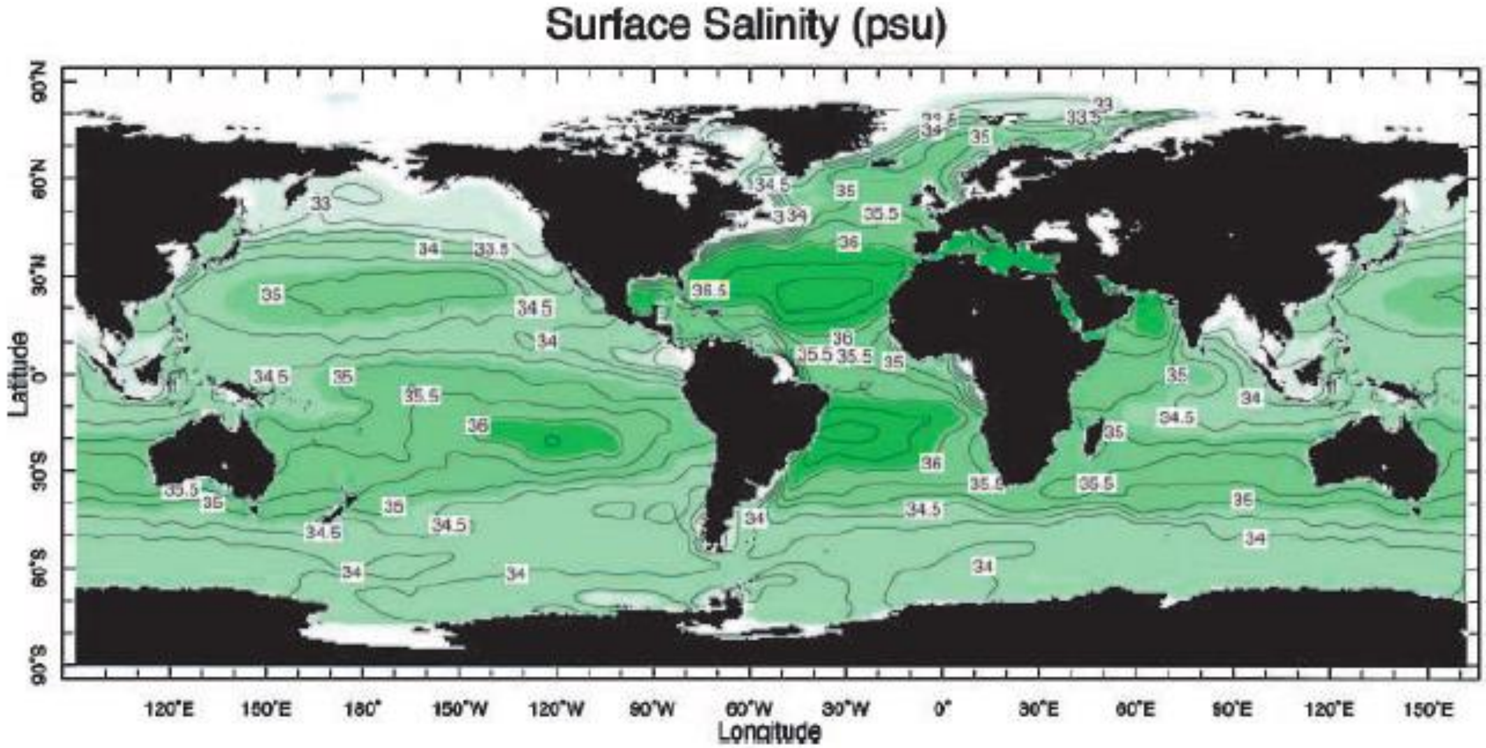


FIGURE 9.4. The annual mean salinity distribution at the surface of the ocean (in psu). Darker green represents salty fluid. Data from Levitus World Ocean Atlas (1994).

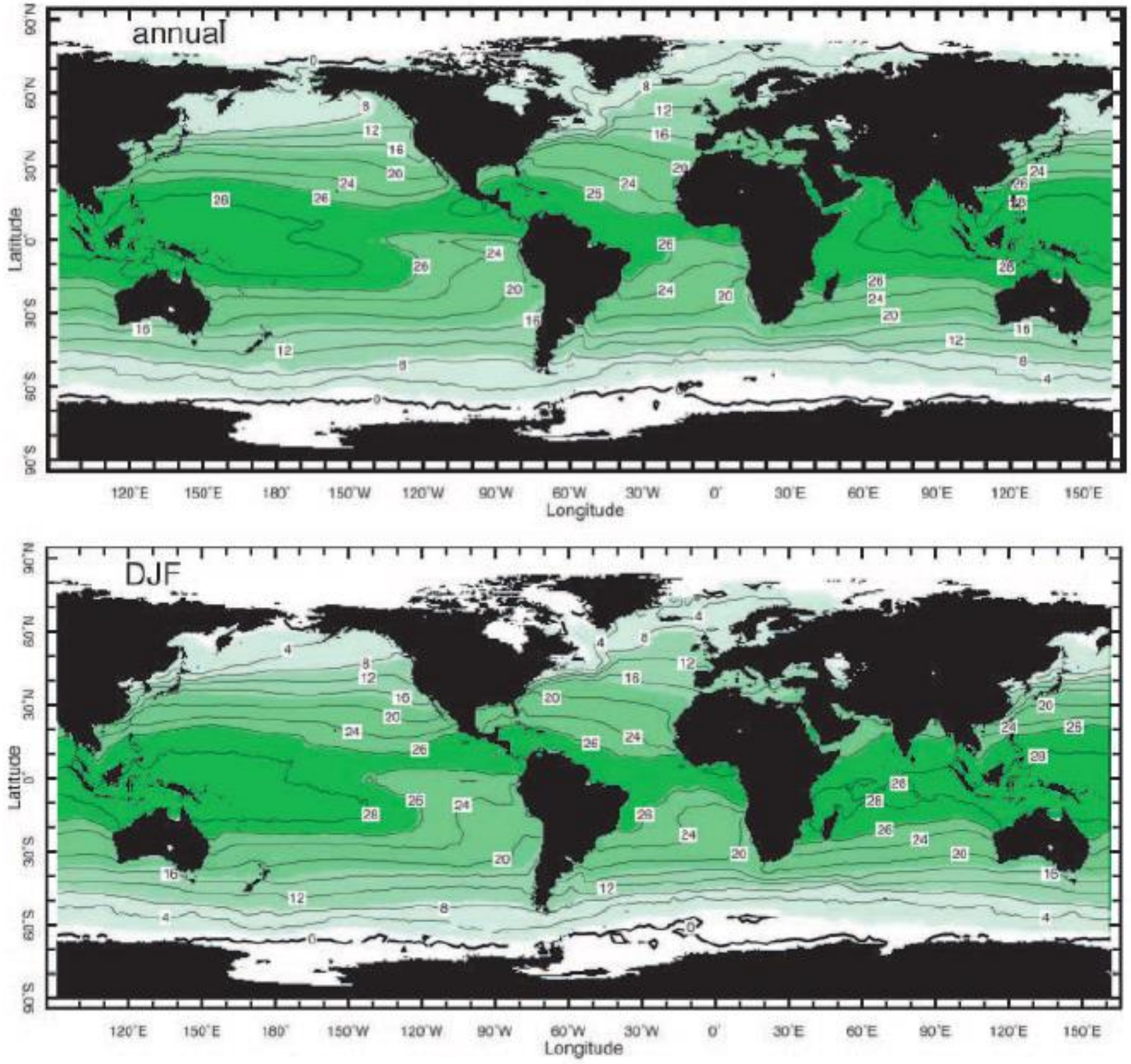
תהליכים שמשפיעים על המליחות:

התאידות וקפיאת מים – מגדילים

גשם, המסת קרחונים, נחלים, מקטינים

Marshal and Plumb 2008

Sea Surface Temperature (ºC)



Marshal and Plumb 2008

Potential temperature (degrees C)

First 1000 meters

Deep ocean- very cold

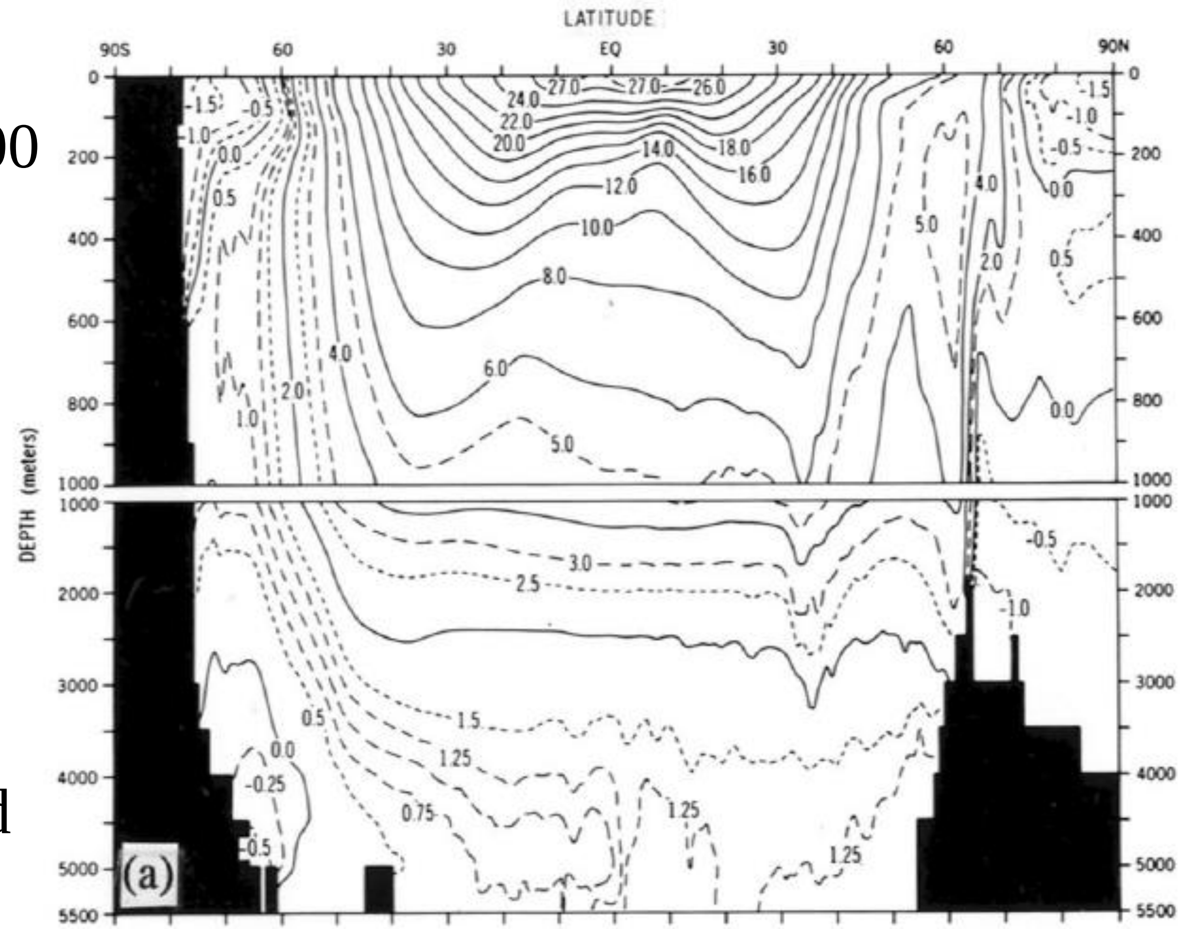


Figure 7.1a from Hartmann's book, taken from Levitus (1982)

Salinity (parts per thousand °/oo)

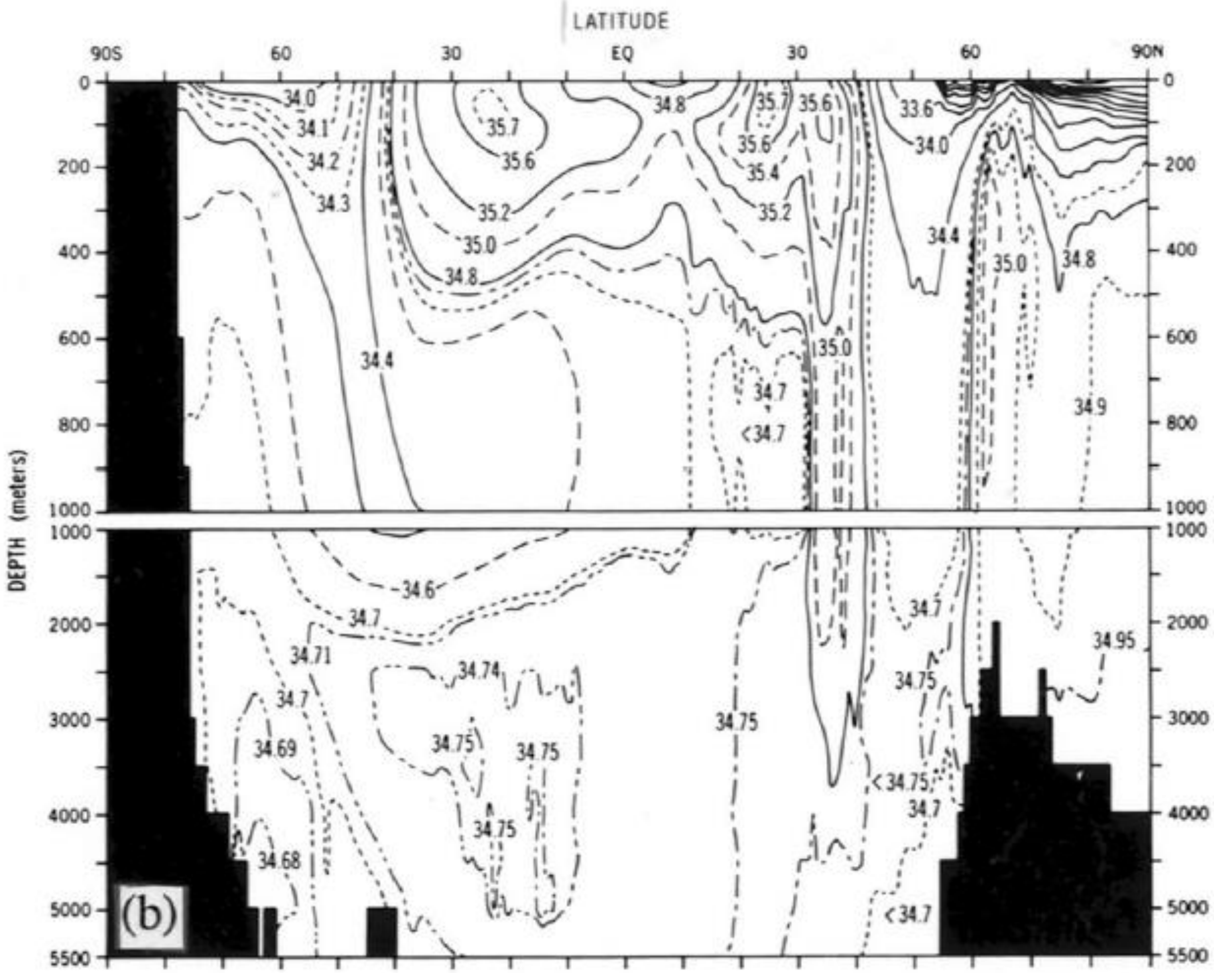
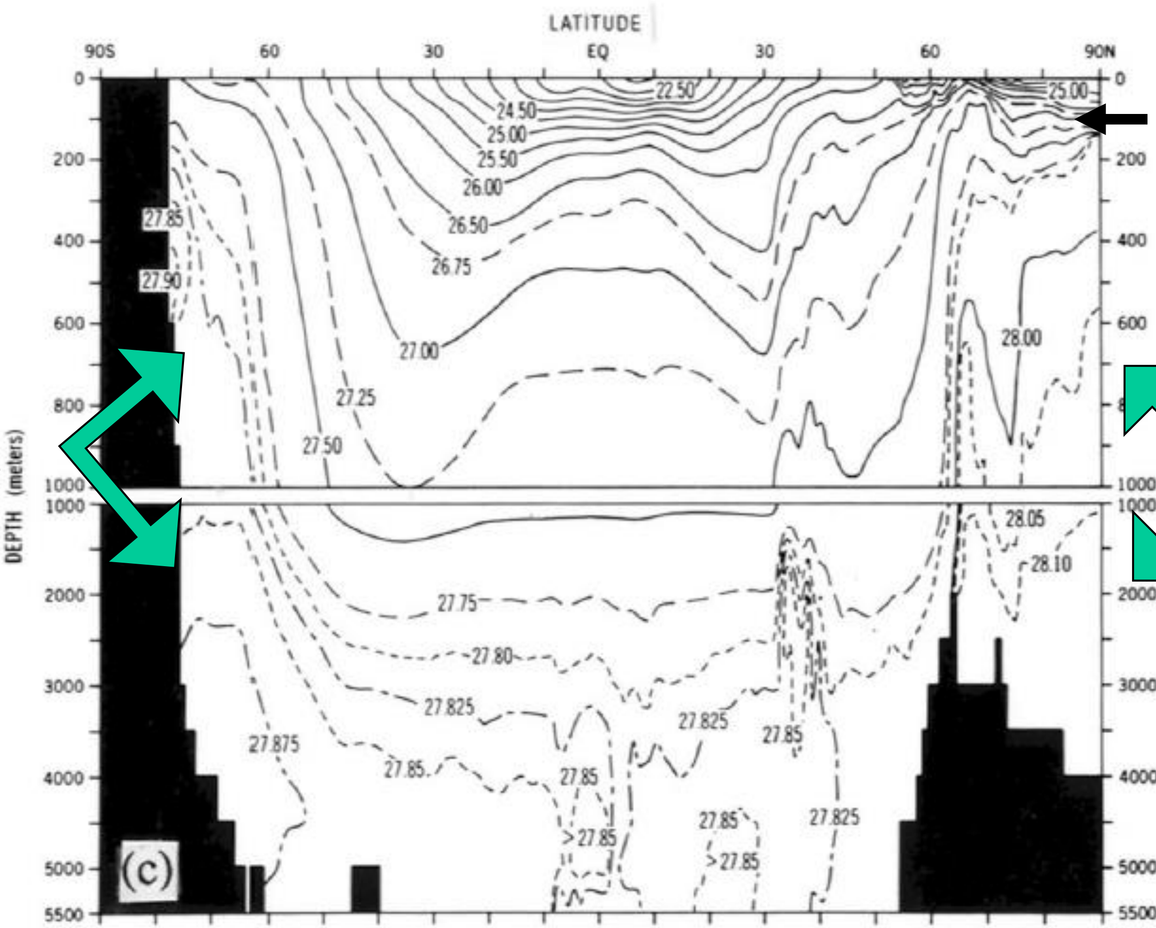


Figure 7.1b from Hartmann's book, taken from Levitus (1982)

Potential density (the density this water would have at sea surface pressure) ρ_t-1000 kg/m^3

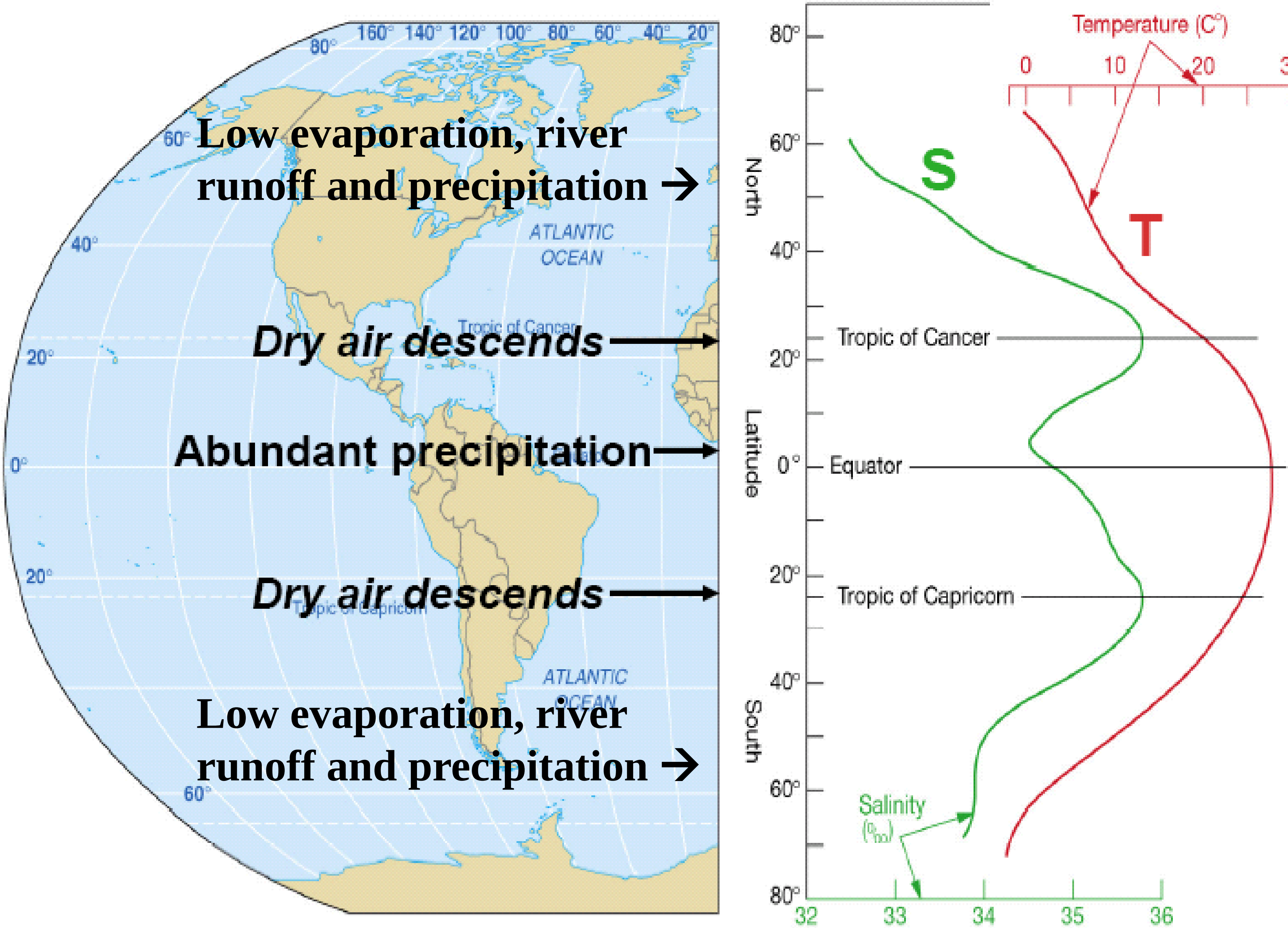


The low density here allows freezing only at top

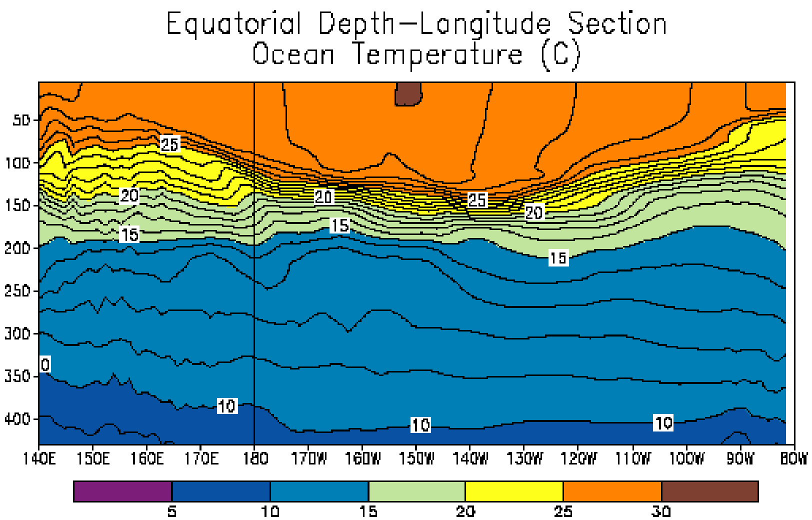
Vertical mixing

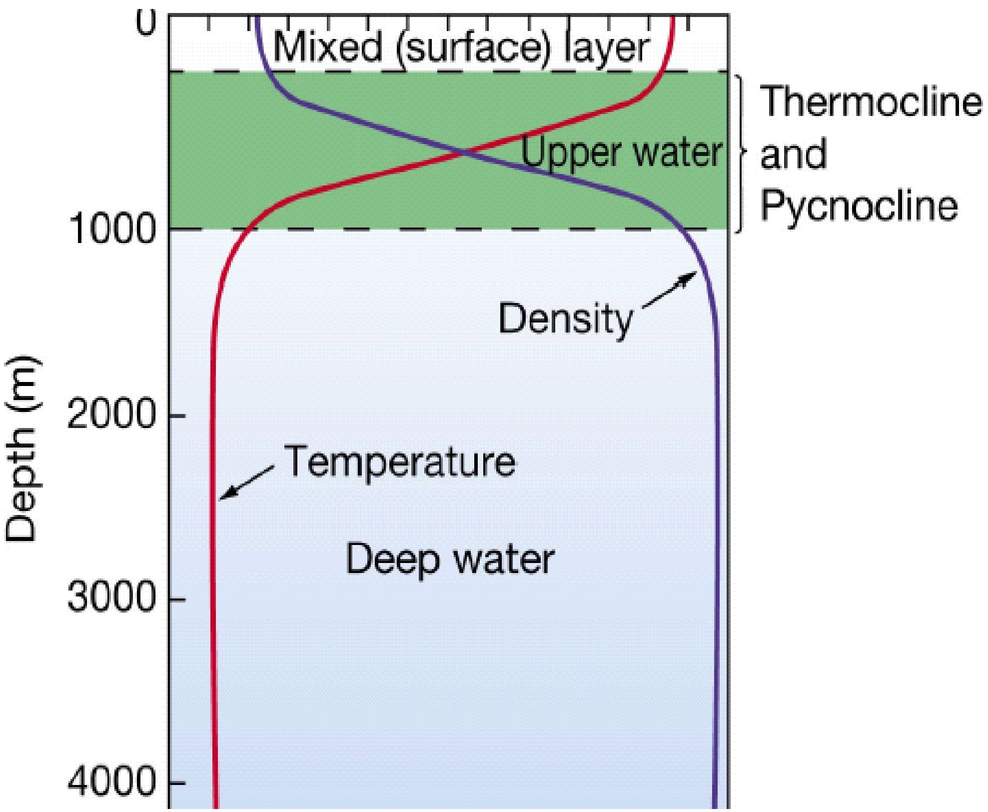
Vertical mixing

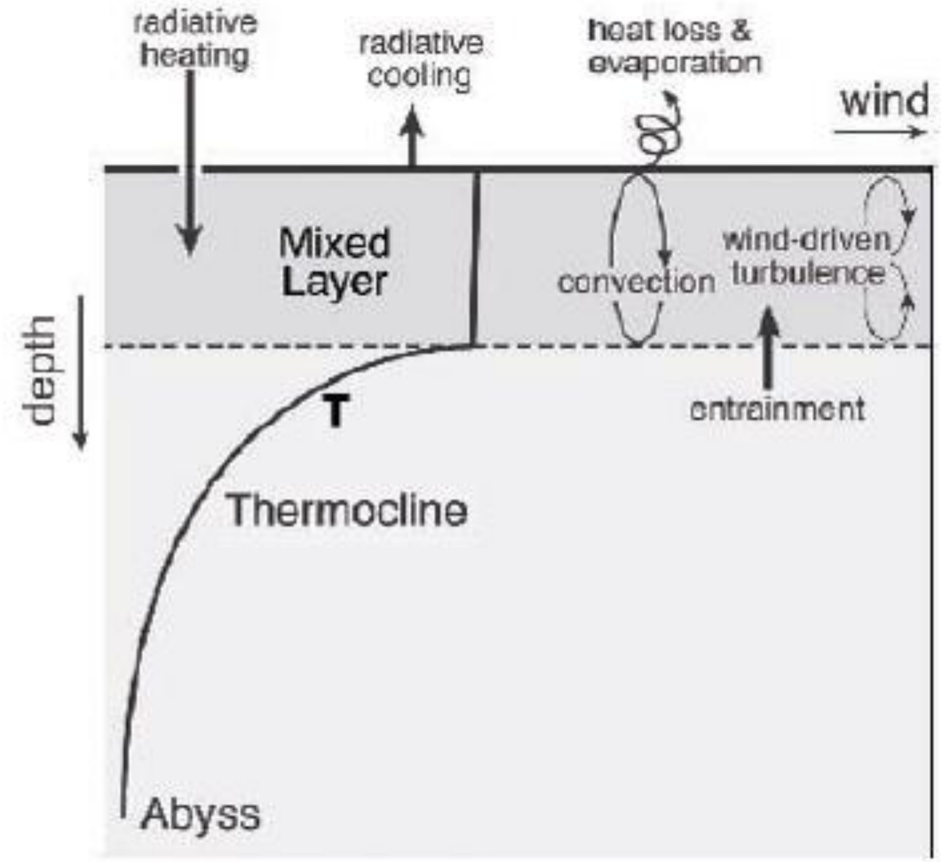
Figure 7.1c from Hartmann's book, taken from Levitus (1982)

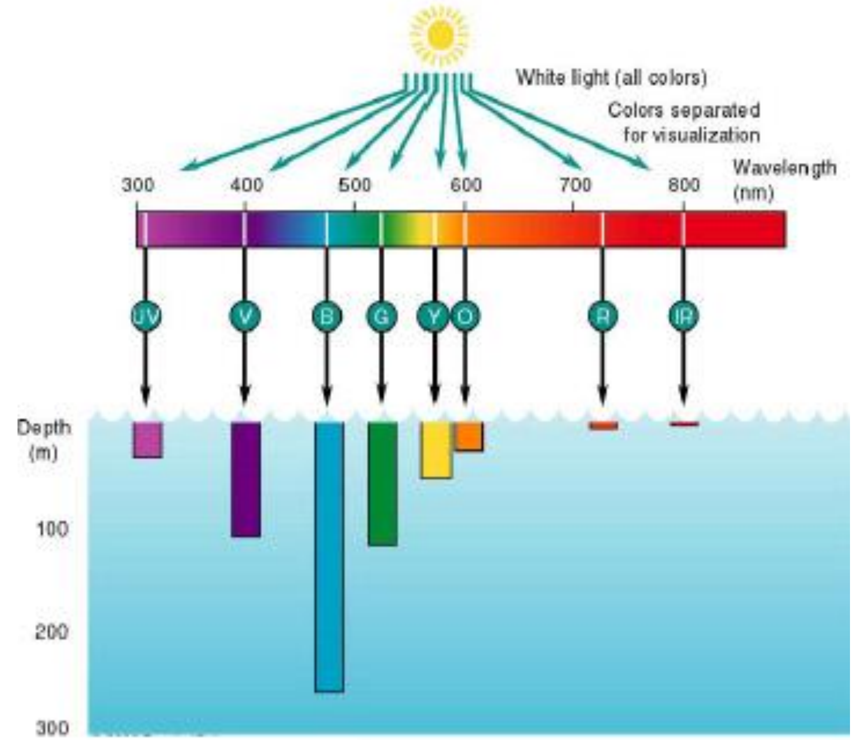


Low evaporation, river runoff and precipitation →
Dry air descends
Abundant precipitation
Dry air descends
Low evaporation, river runoff and precipitation →
ATLANTIC OCEAN
Tropic of Cancer
Tropic of Capricorn
ATLANTIC OCEAN
160° 140° 120° 100° 80° 60° 40° 20°
80°
60°
40°
20°
0°
20°
60°
Temperature (C°)
0 10 20
S
T
North
Latitude
South
80°
60°
40°
20°
0°
20°
40°
60°
80°
Tropic of Cancer
Equator
Tropic of Capricorn
Salinity (‰)
32 33 34 35 36


Equatorial Depth–Longitude Section
Ocean Temperature (C)
50
100
150
200
250
300
350
400
140E
150E
160E
170E
180
170W
160W
150W
140W
130W
120W
110W
100W
90W
80W
5
10
15
20
25
30

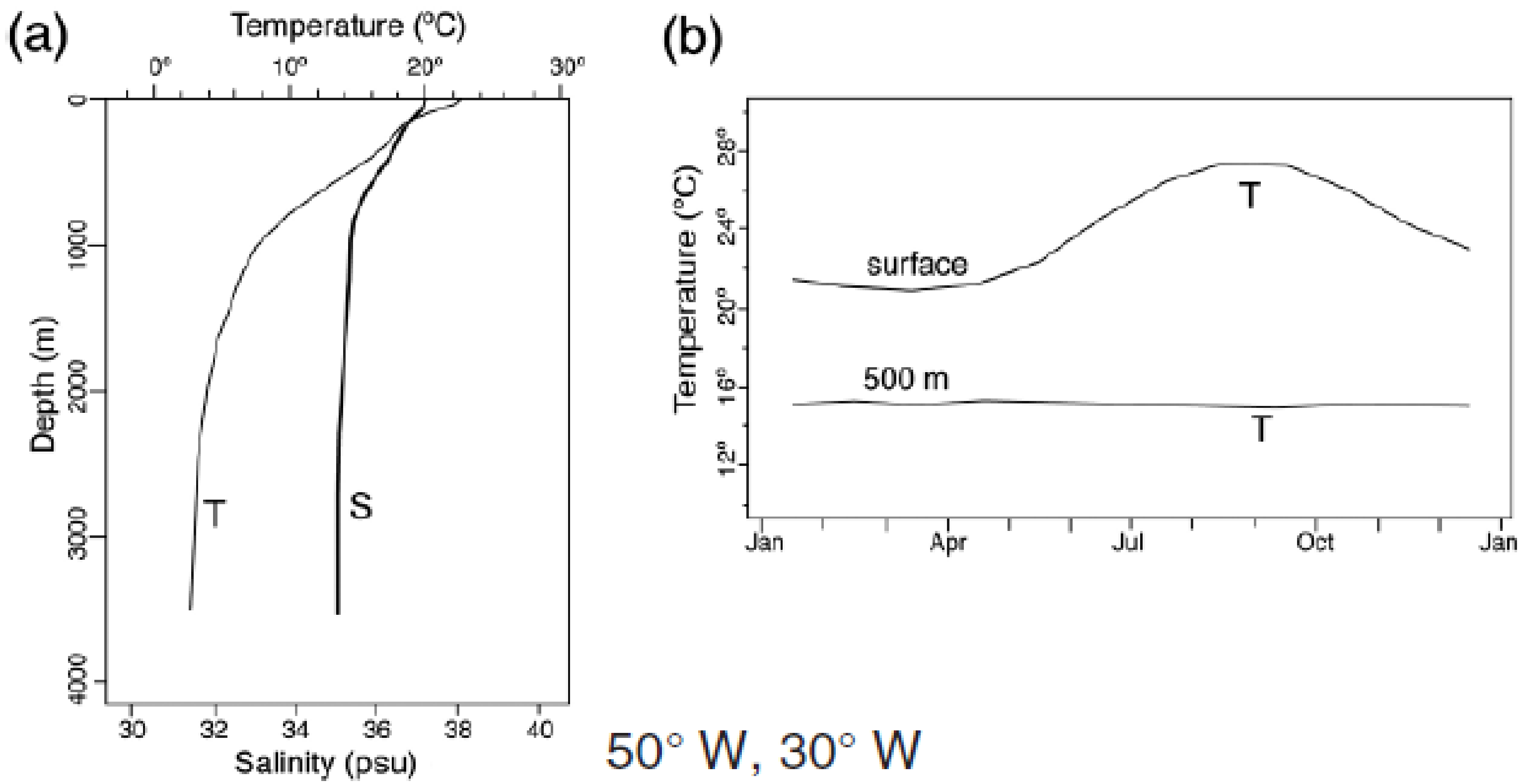

Mixed (surface) layer
Upper water
Thermocline
and
Pycnocline
Density
Temperature
Deep water
Depth (m)
0
1000
2000
3000
4000





שכבת הערבוב: משתנה עונתית וממקום למקום. בממוצע כמאה מטרים, יכולה להגיע גם לקילומטר באזורים הכי צפוניים בהם הקרור חזק

אמנם השמש מחממת מלמעלה, אבל היא מחממת שכבה, בעוד הקרור קורה מפני השטח. ערבוב מכני על ידי הרוחות גם תורם.



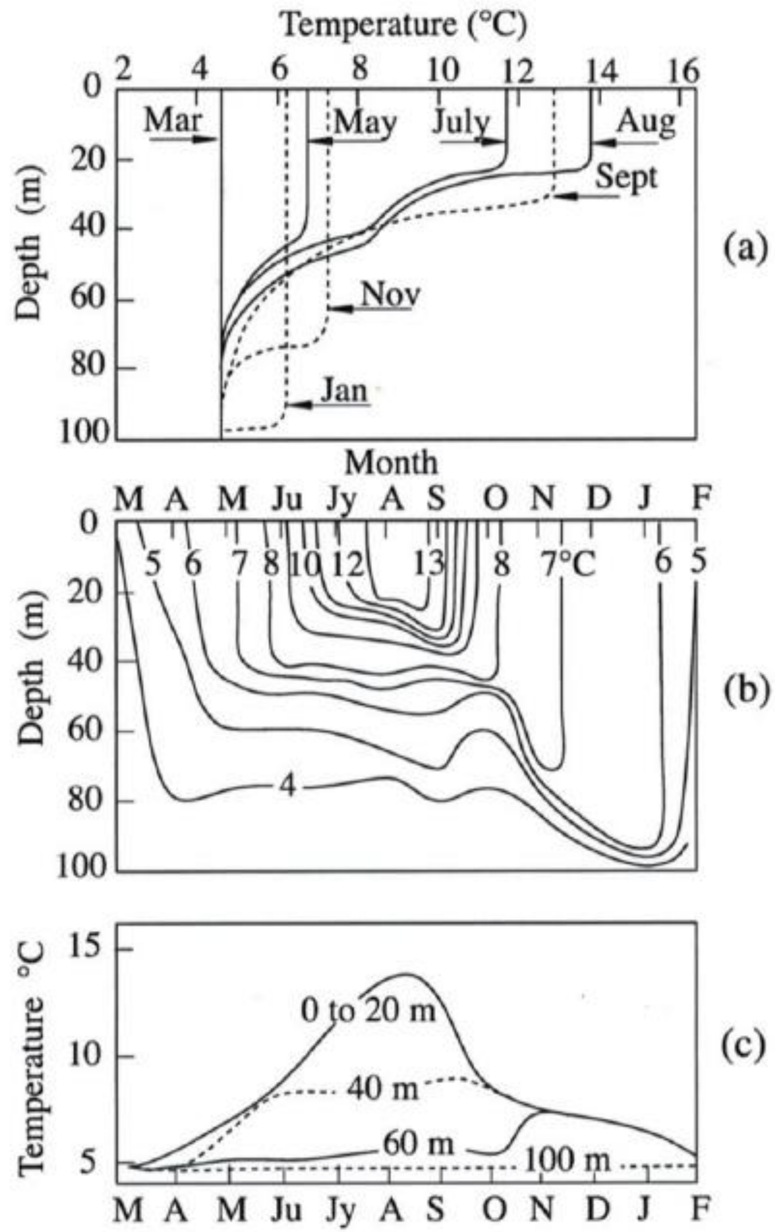
50° W, 30° W

FIGURE 9.12. (a) Annual mean *T* and *S* profile at 50° W, 30° N in the Atlantic Ocean. The thermocline is clearly evident. The *T* scale is at the top, the *S* scale at the bottom. (b) The cycle of *T* at 50° W, 30° N in the Atlantic Ocean in the Levitus monthly mean climatology. The strong seasonal cycle at the surface has vanished at a depth of 500 m. Data from the Levitus World Ocean Atlas (1994).

ככל שמעמיקים, השנויים יותר איטיים. שינויים יומיים מרגשים בשכבת
הערבוב. מחזור עונתי מורגש בתרמוקלינה, אבל לא במעמקים

Seasonal evolution of the mixed layer temperature at 50N, 145W (Eastern North Pacific).

Figure 7.6 from Hartmann's book, taken from Pickard and Emry (1990)



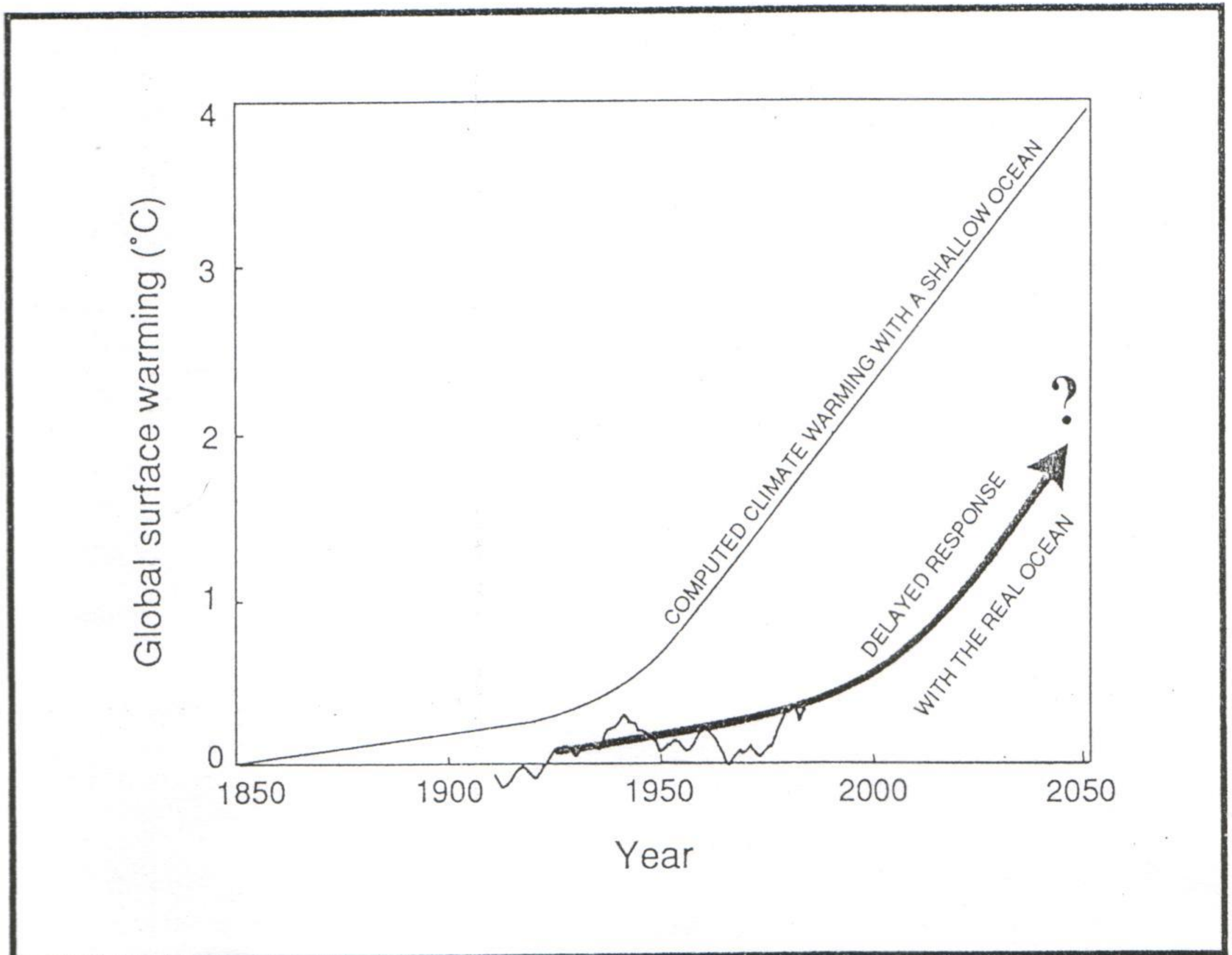


Figure 7. A possible climate warming scenario for the global atmosphere only (black line) and the complete earth climate system (coloured line). The observed global temperature record is shown on the same scale (Morel, personal communication).

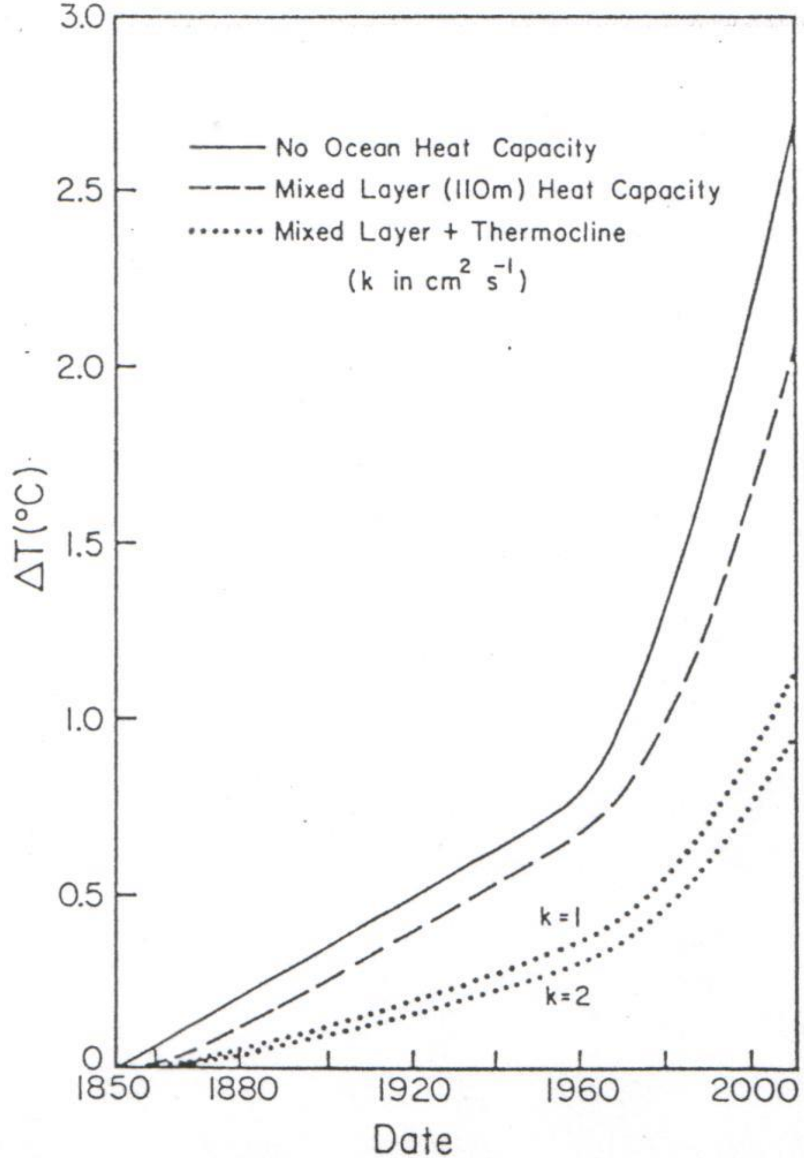
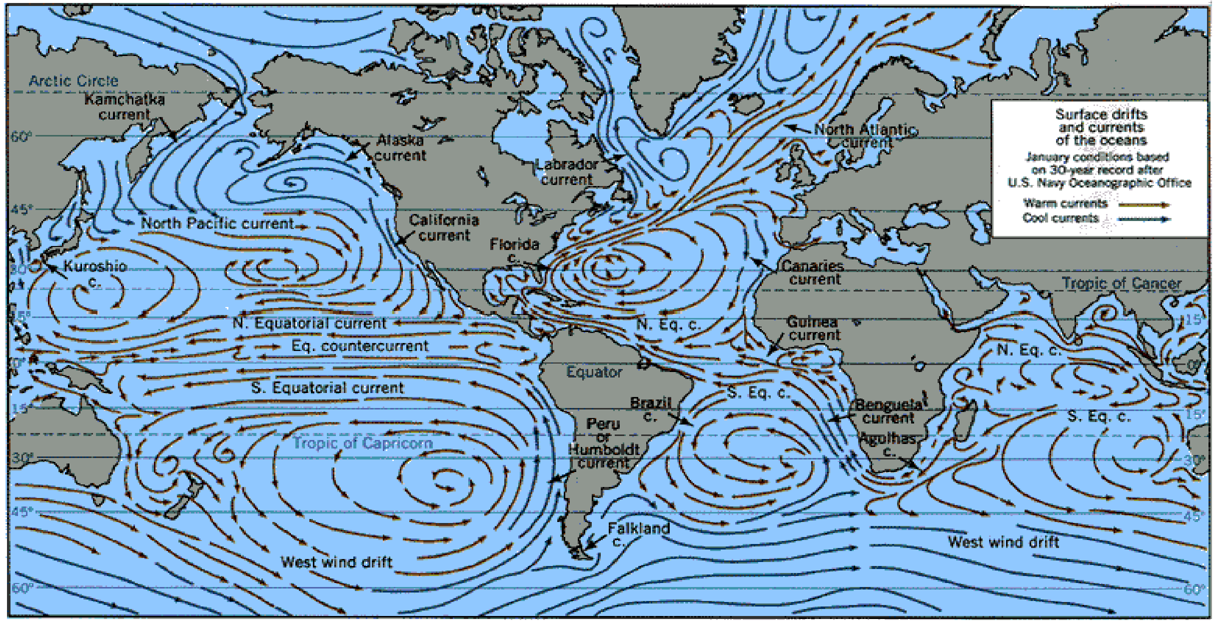
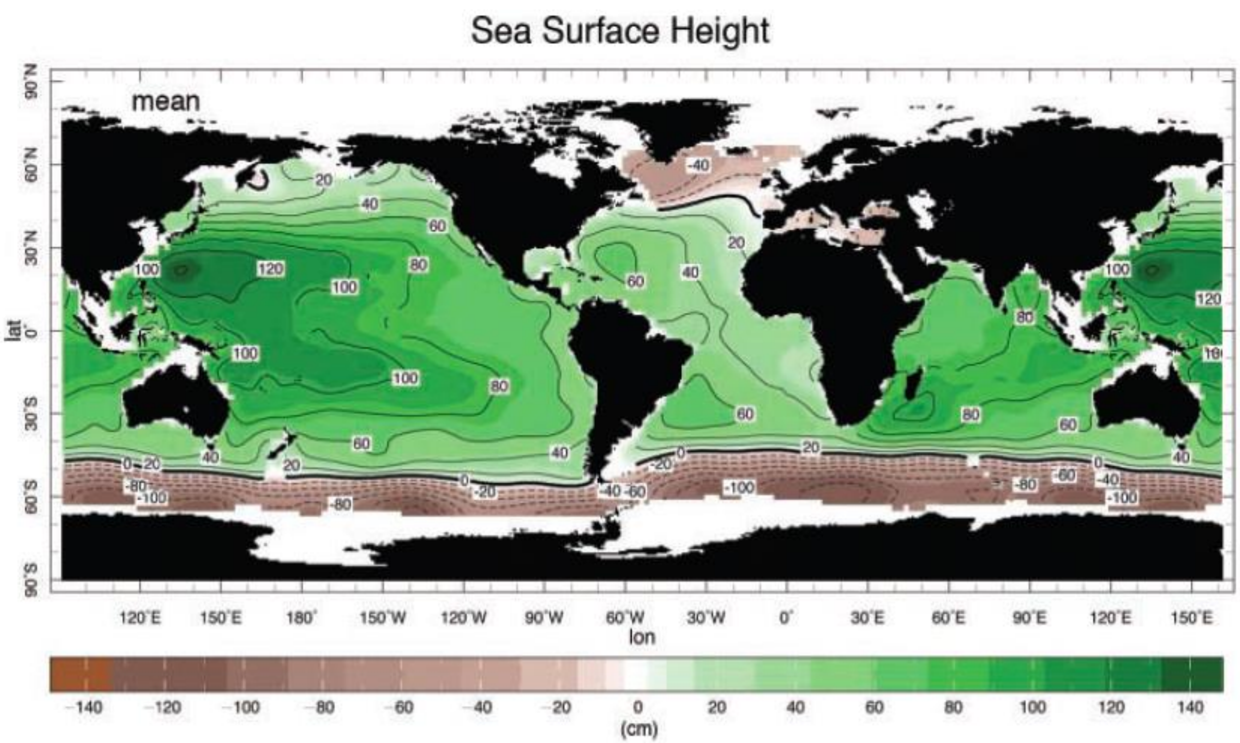
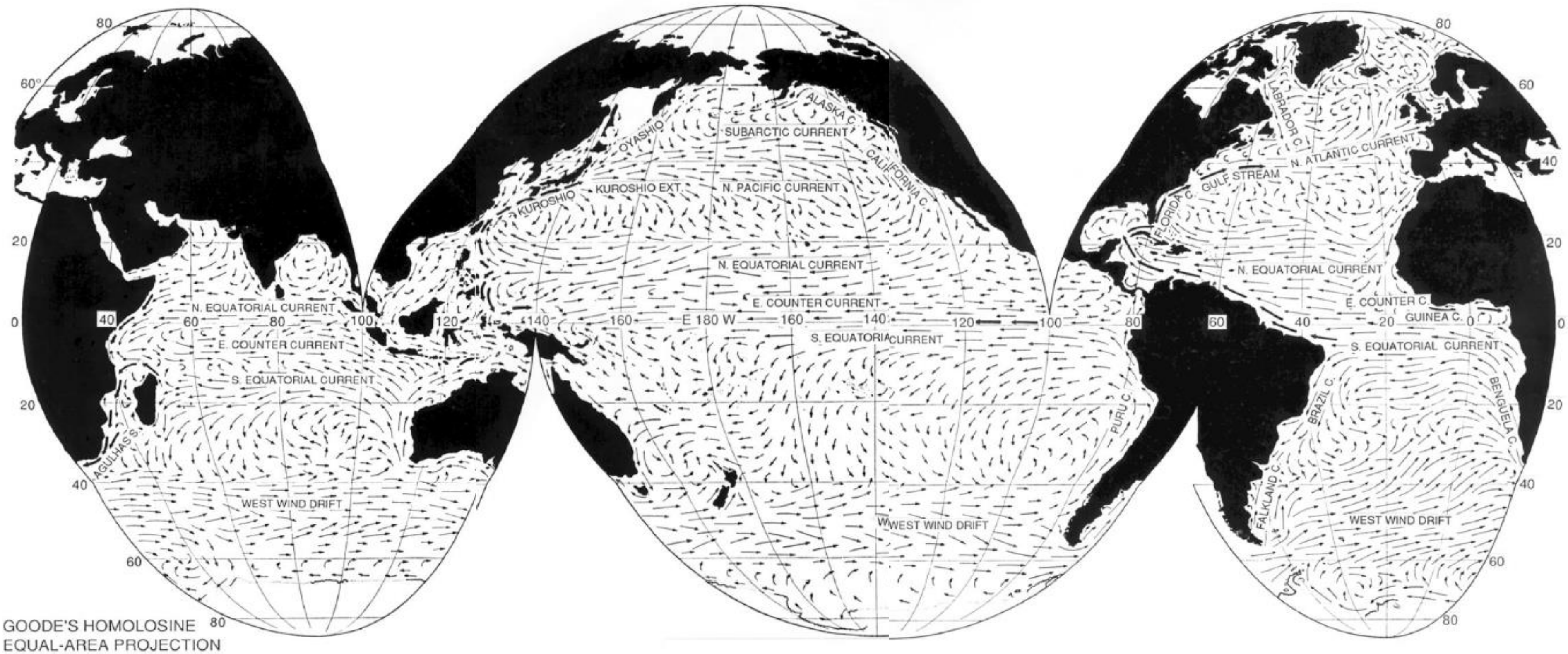


Fig. 18. Global mean warming computed for the CO_2 and trace gas scenarios in Table 4.

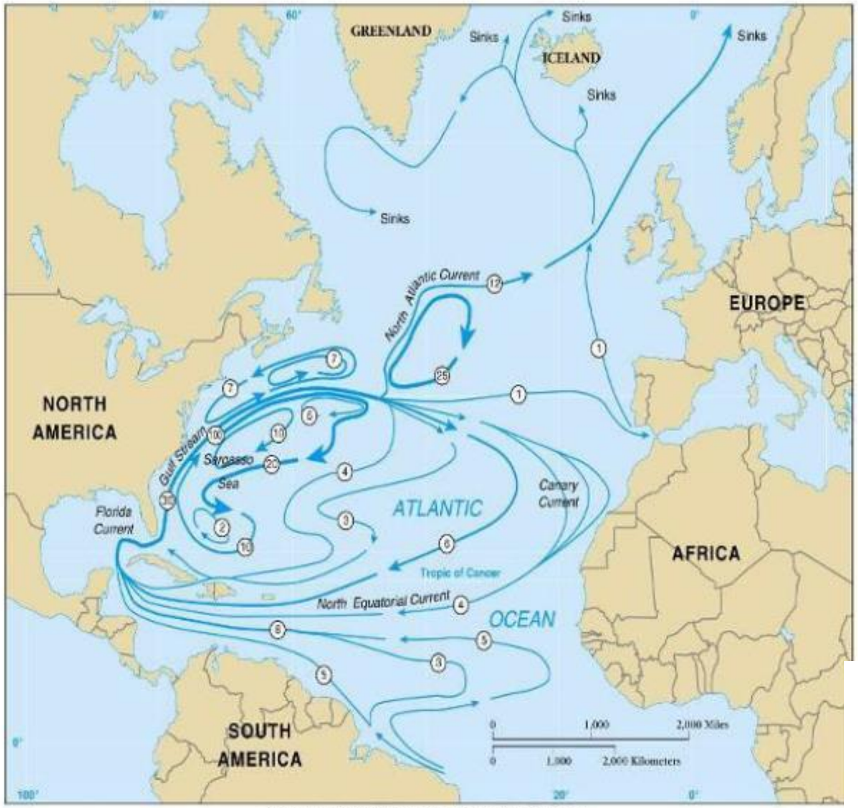


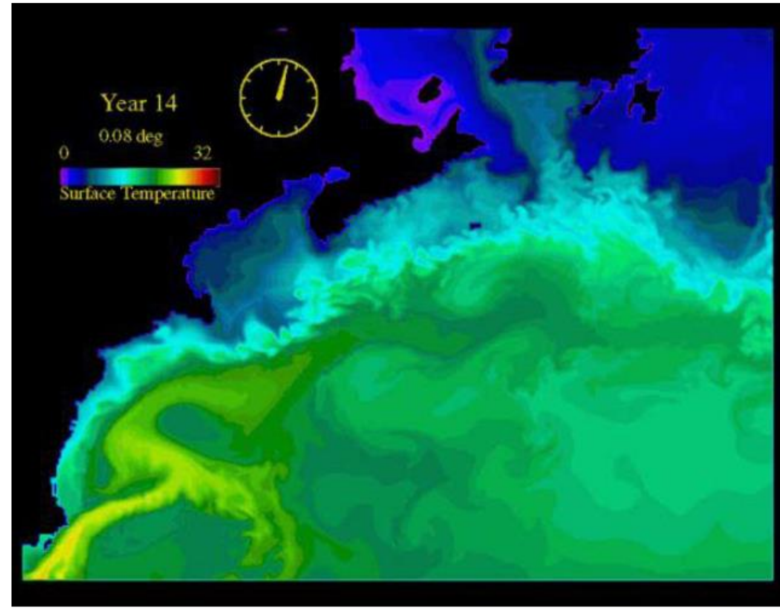
הזרימה גיאוסטרופית

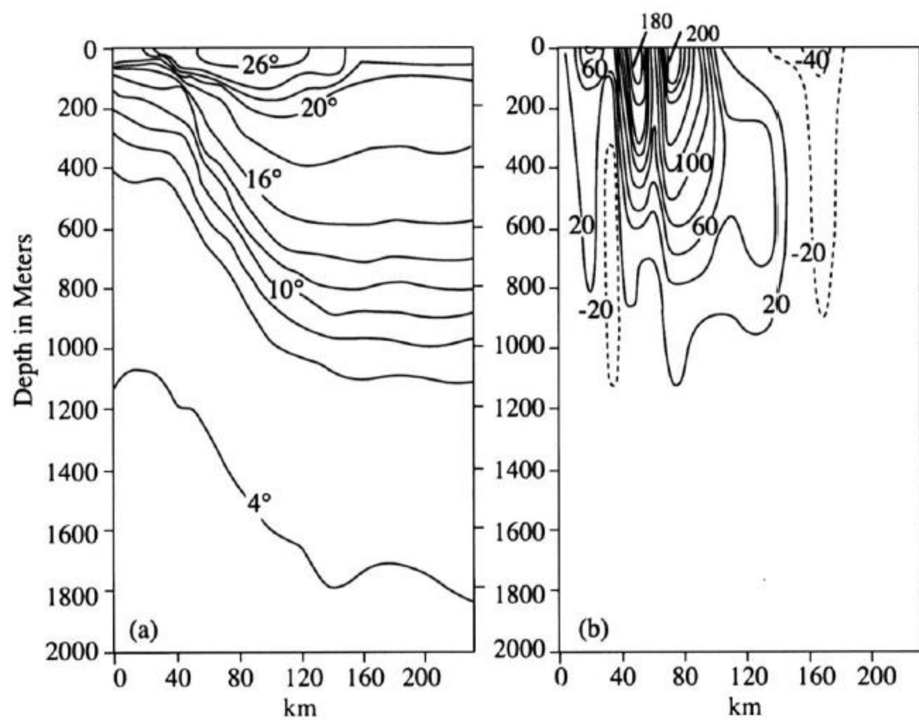




Western boundary currents- poleward flowing
Eastern Boundary currents- subtropical, equatorward flowing
Weak return flows for both
Antarctic circumpolar current
Equatorial currents







The gulf stream
A bit like the atmospheric jet stream, in thermal wind balance, with eddies developing on it

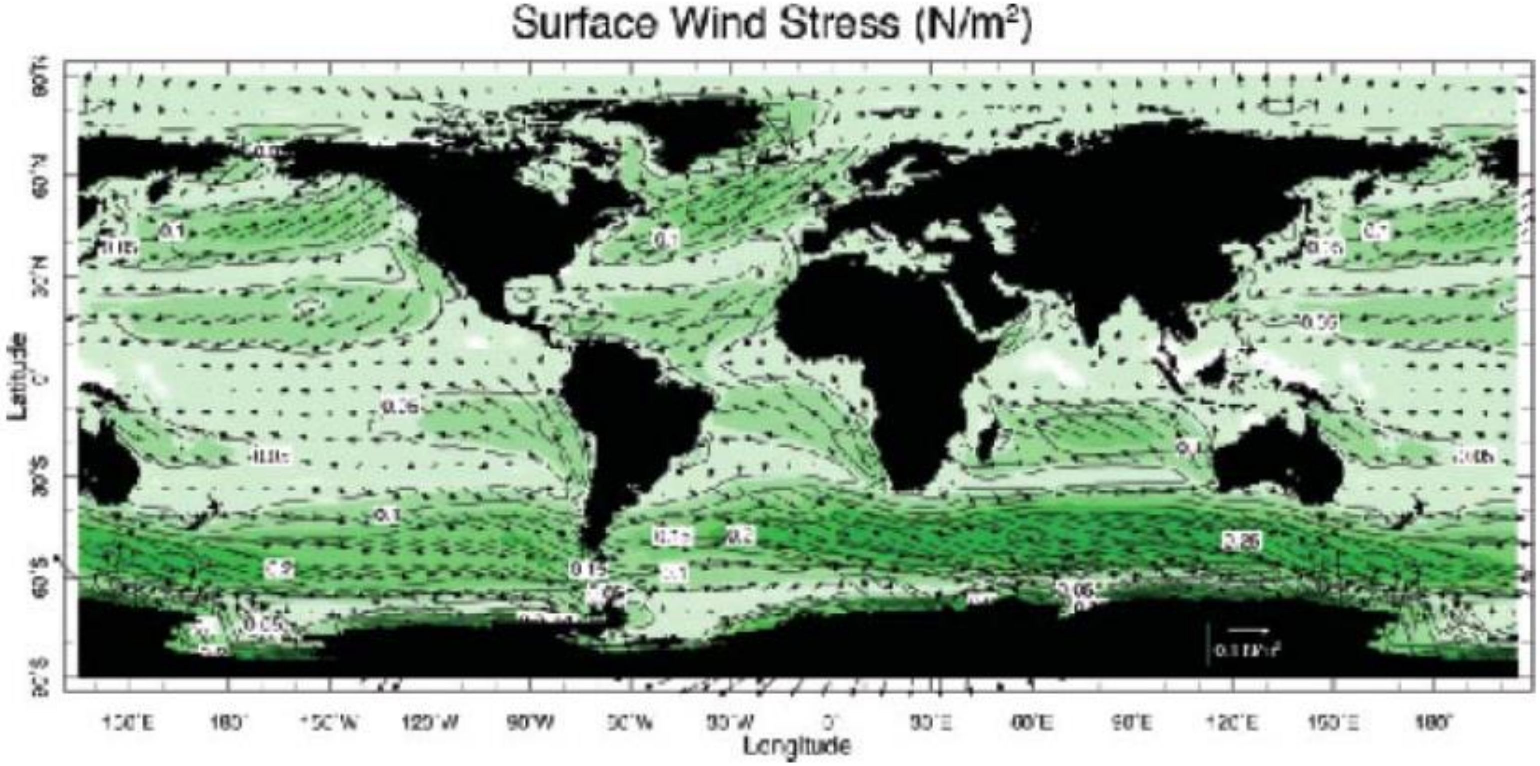


FIGURE 10.2. Annual mean wind stress on the ocean. The green shading and contours represent the magnitude of the stress. Stresses reach values of 0.1 to 0.2 $N\,m^{-2}$ under the middle-latitude westerlies, and are particularly strong in the southern hemisphere. The arrow is a vector of length 0.1 $N\,m^{-2}$. Note that the stress vectors circulate around the high and low pressure centers shown in Fig. 7.27, as one would expect if the surface wind, on which the stress depends, has a strong geostrophic component.

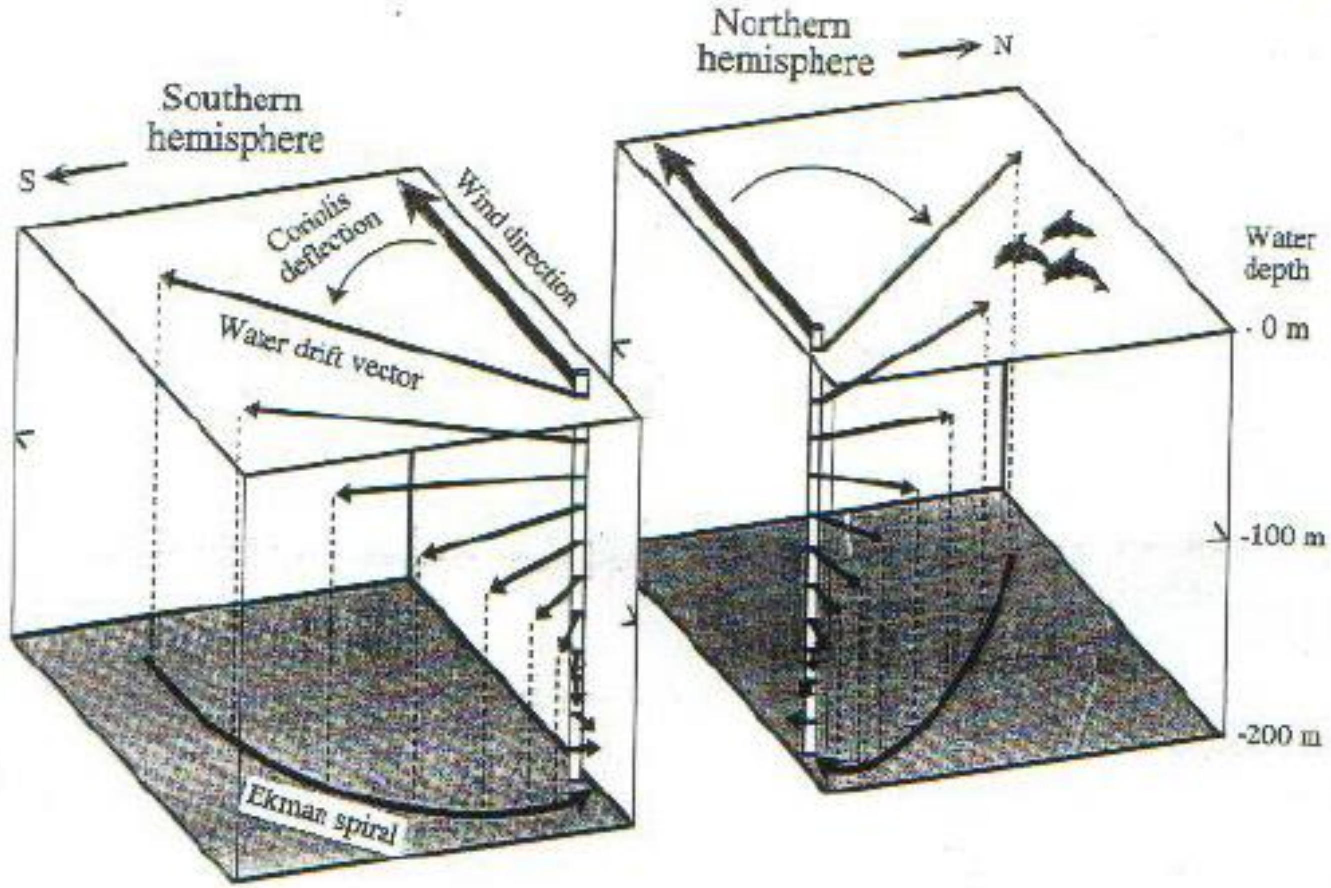
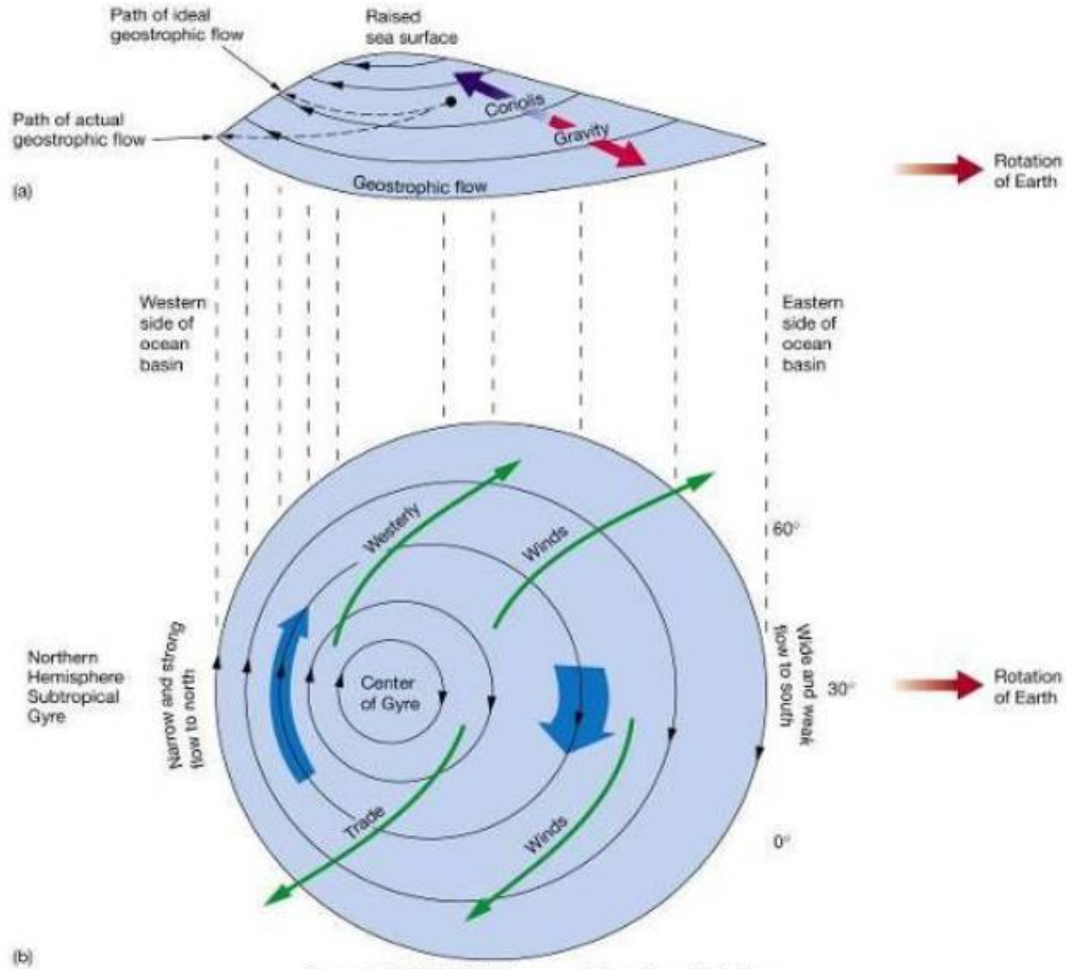
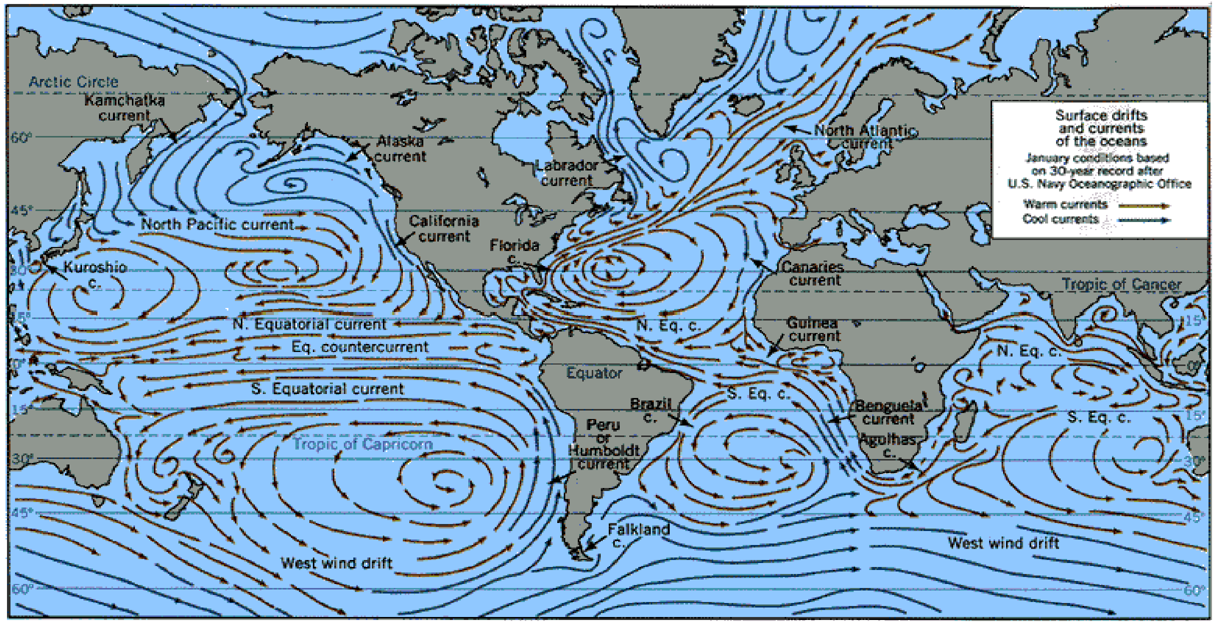


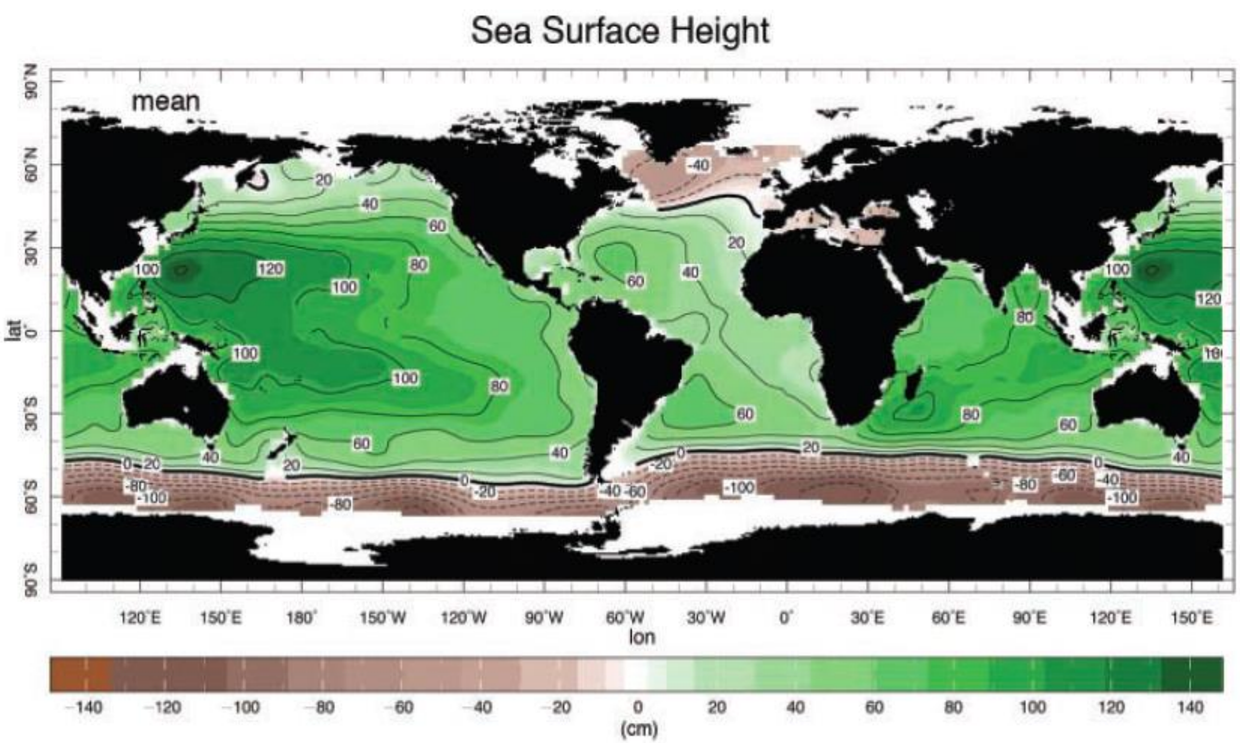
Figure 4.2 Schema of Ekman transport in a water column for both hemispheres (based on Beer, 1983).

The implication to large scale ocean circulation

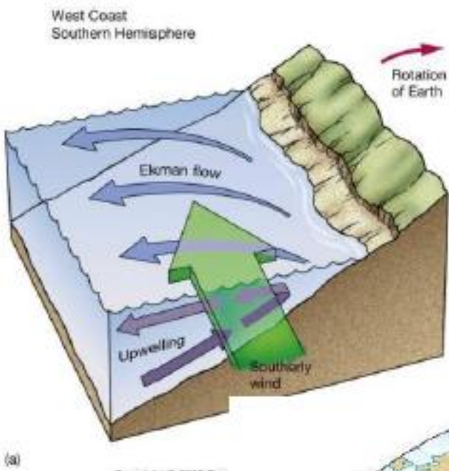




הזרימה גיאוסטרופית

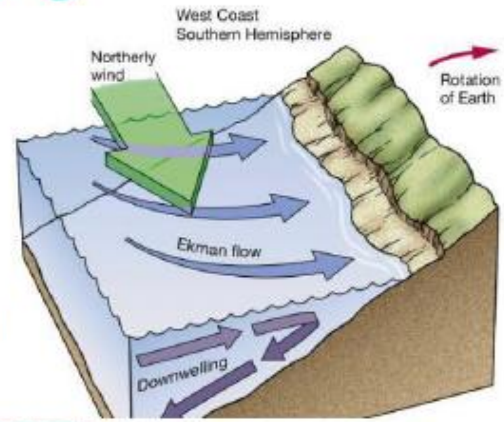


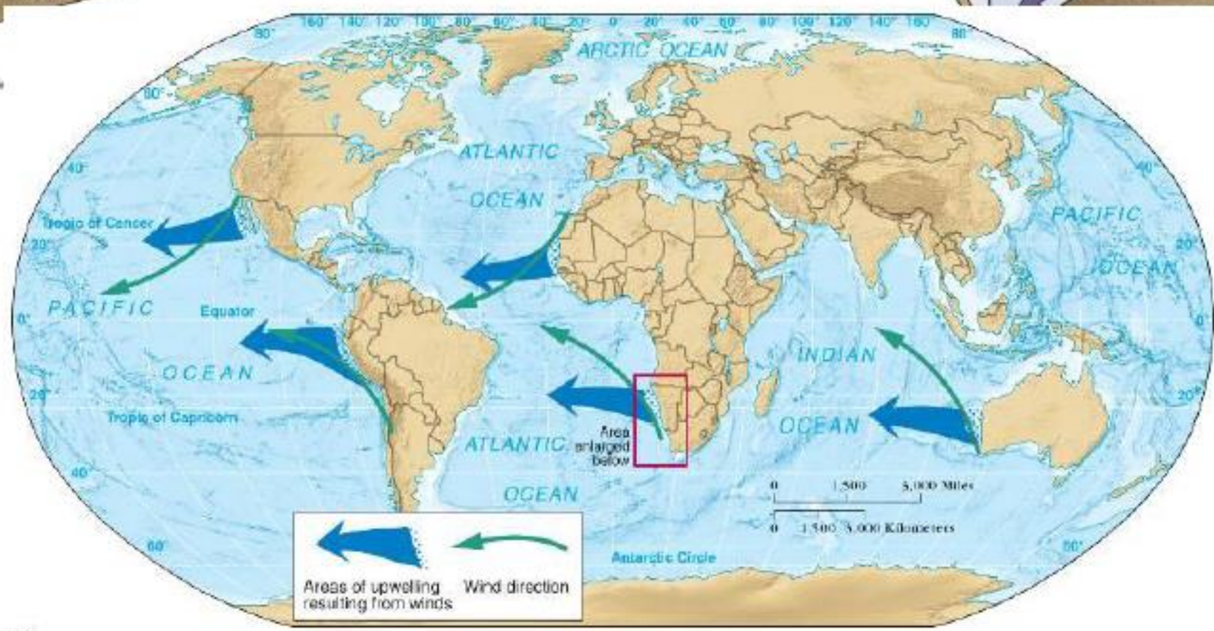
Coastal upwelling



Upwelling

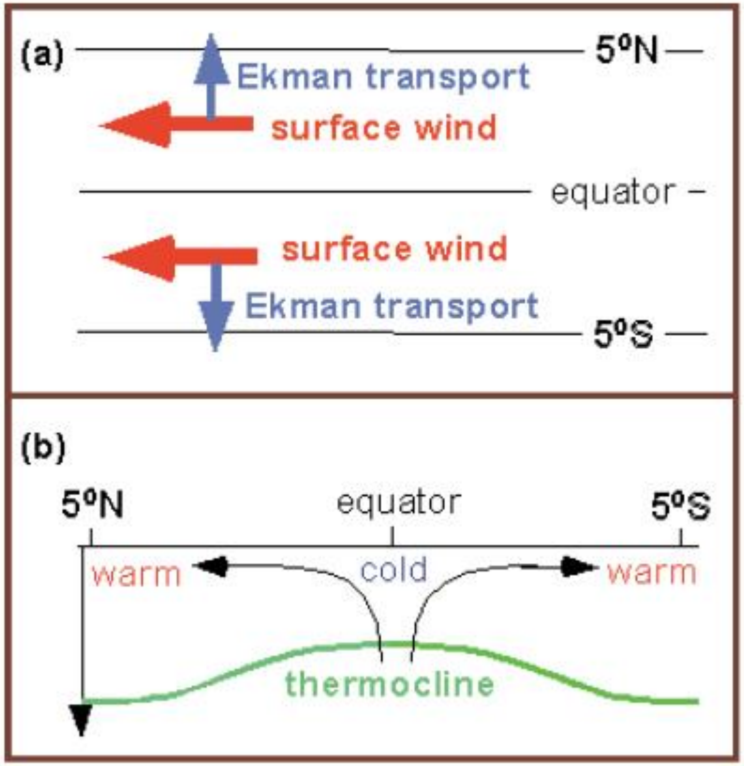
Downwelling

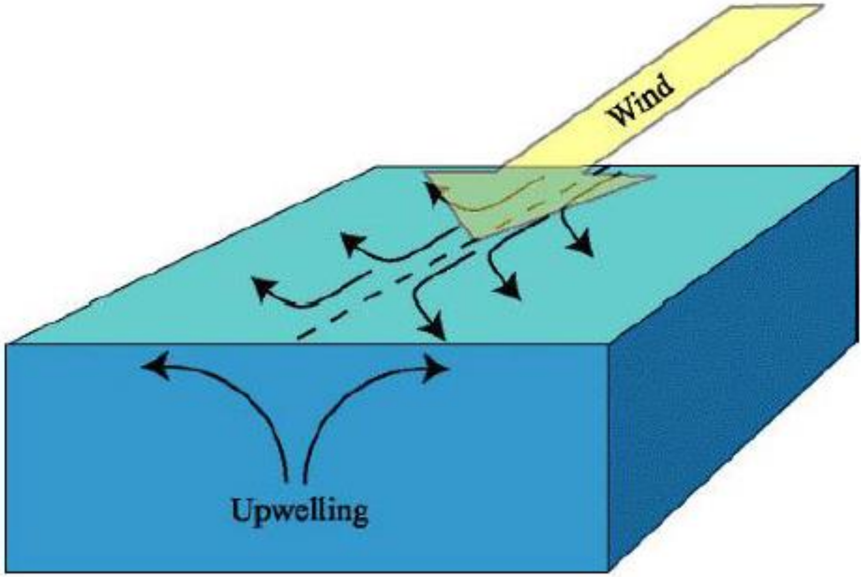




(a)

Equatorial upwelling





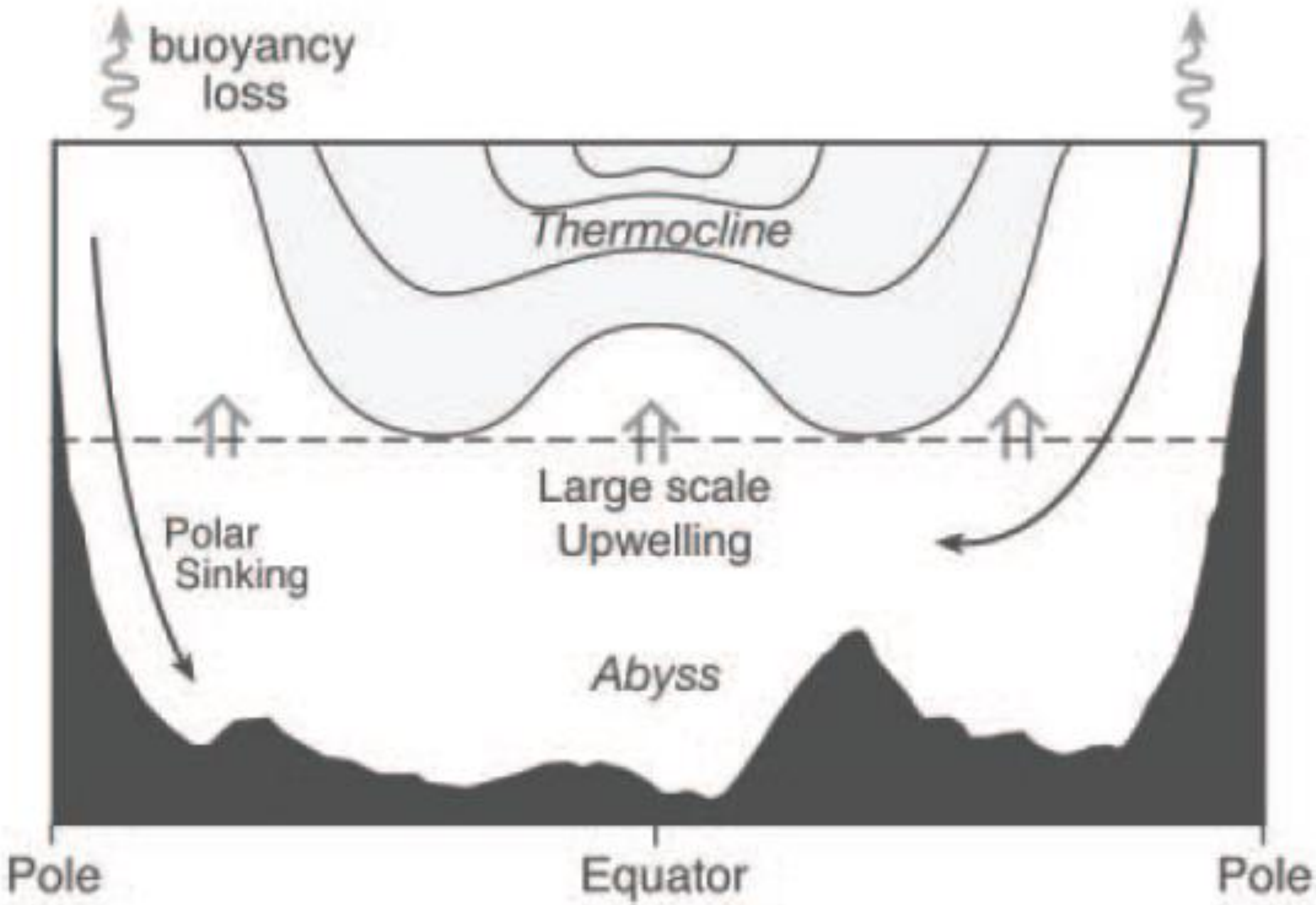
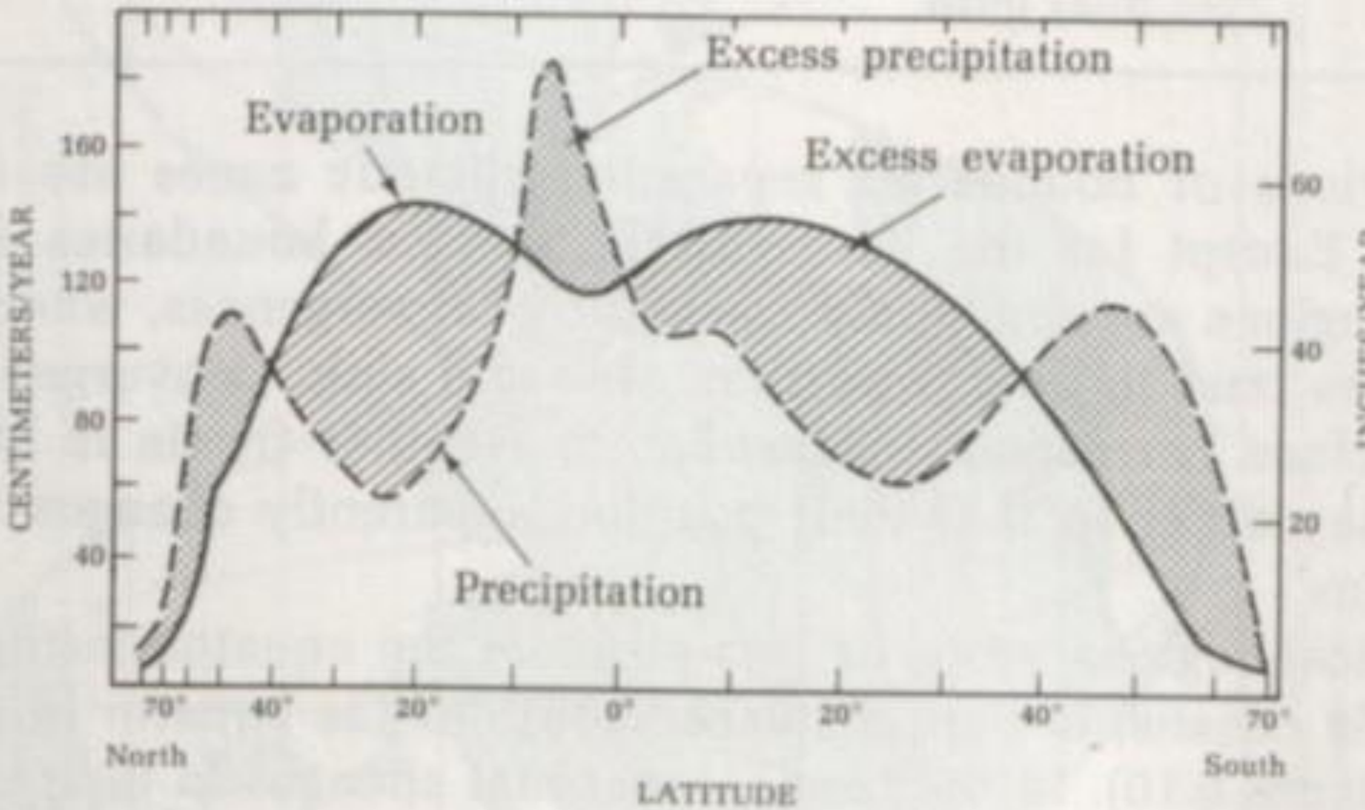

buoyancy
loss
Thermocline
Large scale
Upwelling
Polar
Sinking
Abyss
Pole
Equator
Pole

FIGURE 6.9 *Distribution of evaporation and precipitation over the ocean. (Data from G. Wüst, W. Brogmus, and E. Noodt, "Die zonale Verteilung von Salzgehalt, Niederschlag, Verdunstung, Temperatur und Dichte an der Oberfläche der Ozeane,"* Kieler Meeresforschungen, *Band V [1954], p. 146.)*



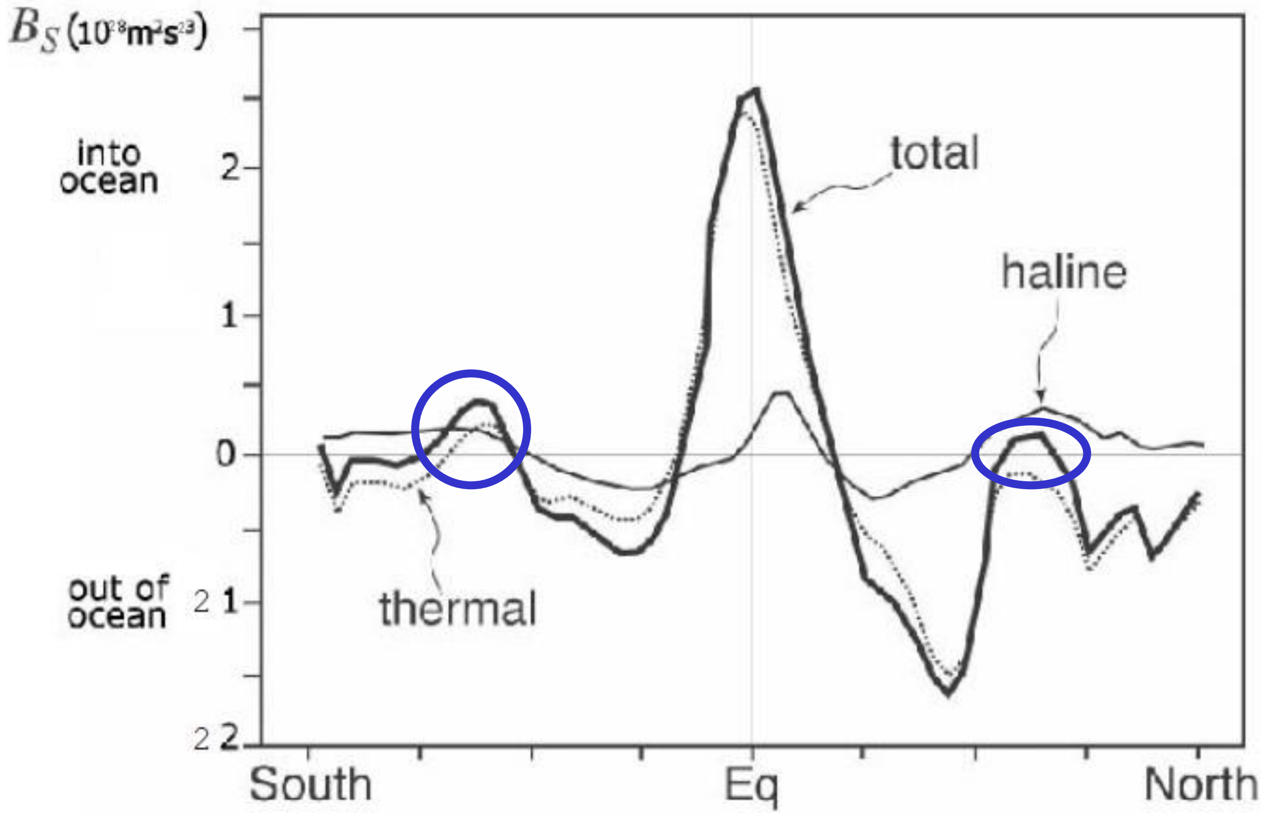
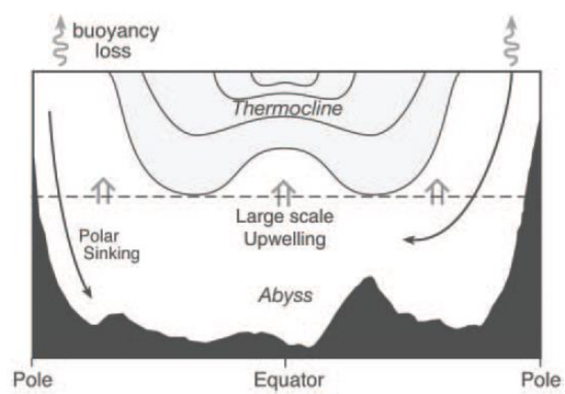
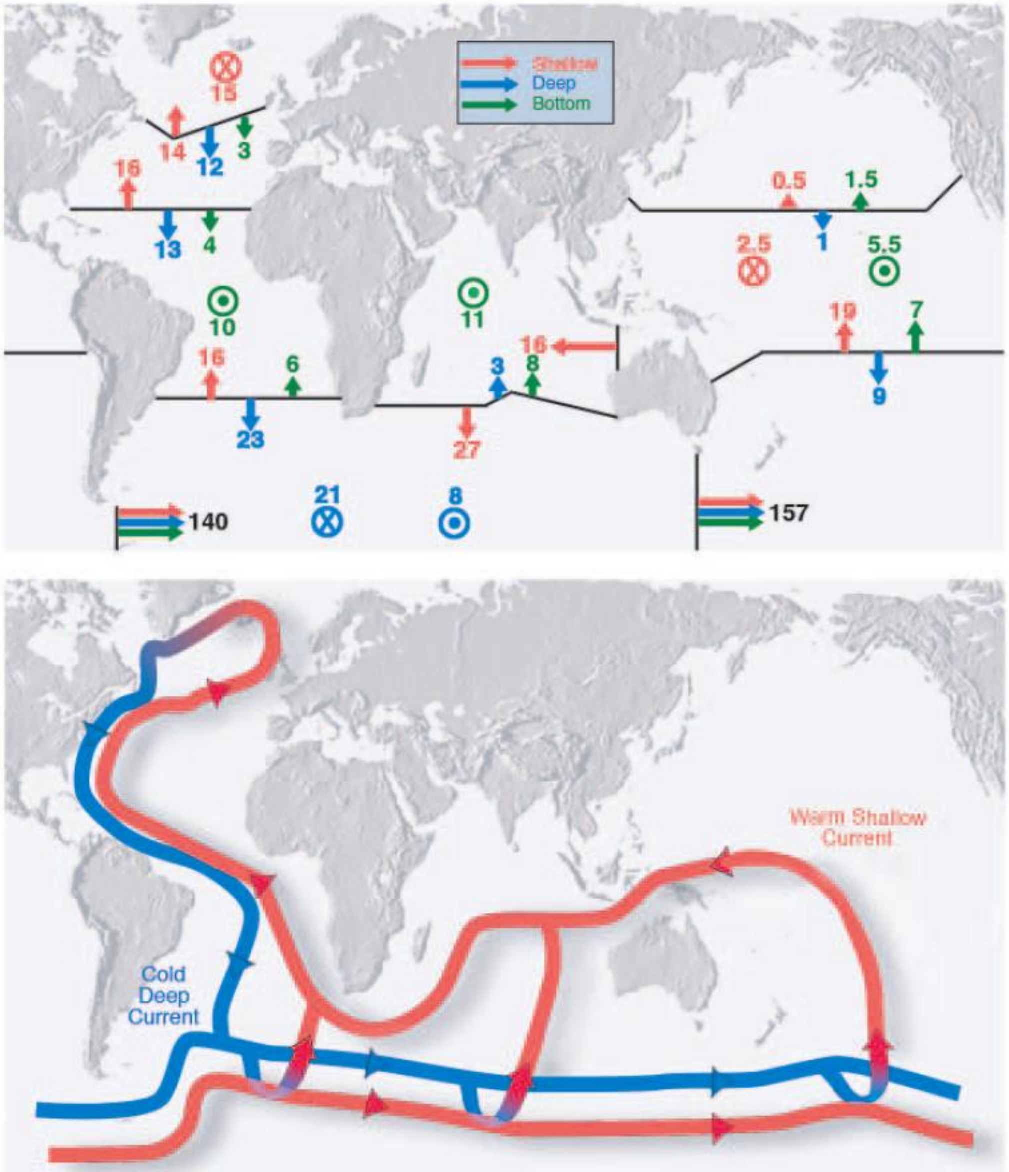


FIGURE 11.7. The zonally-averaged buoyancy forcing (thick black line) and the thermal (dotted line) and haline (thin line) components that make it up, Eq. 11-4 in units of $m^2\,s^{-3}$. Courtesy of Arnaud Czaja (Imperial College). Note that a heat flux of $50\ W\,m^{-2}$ is (roughly) equal to a buoyancy flux of $2 \times 10^{-8}\ m^2\,s^{-3}$. Data from Kalnay et al. (1996).



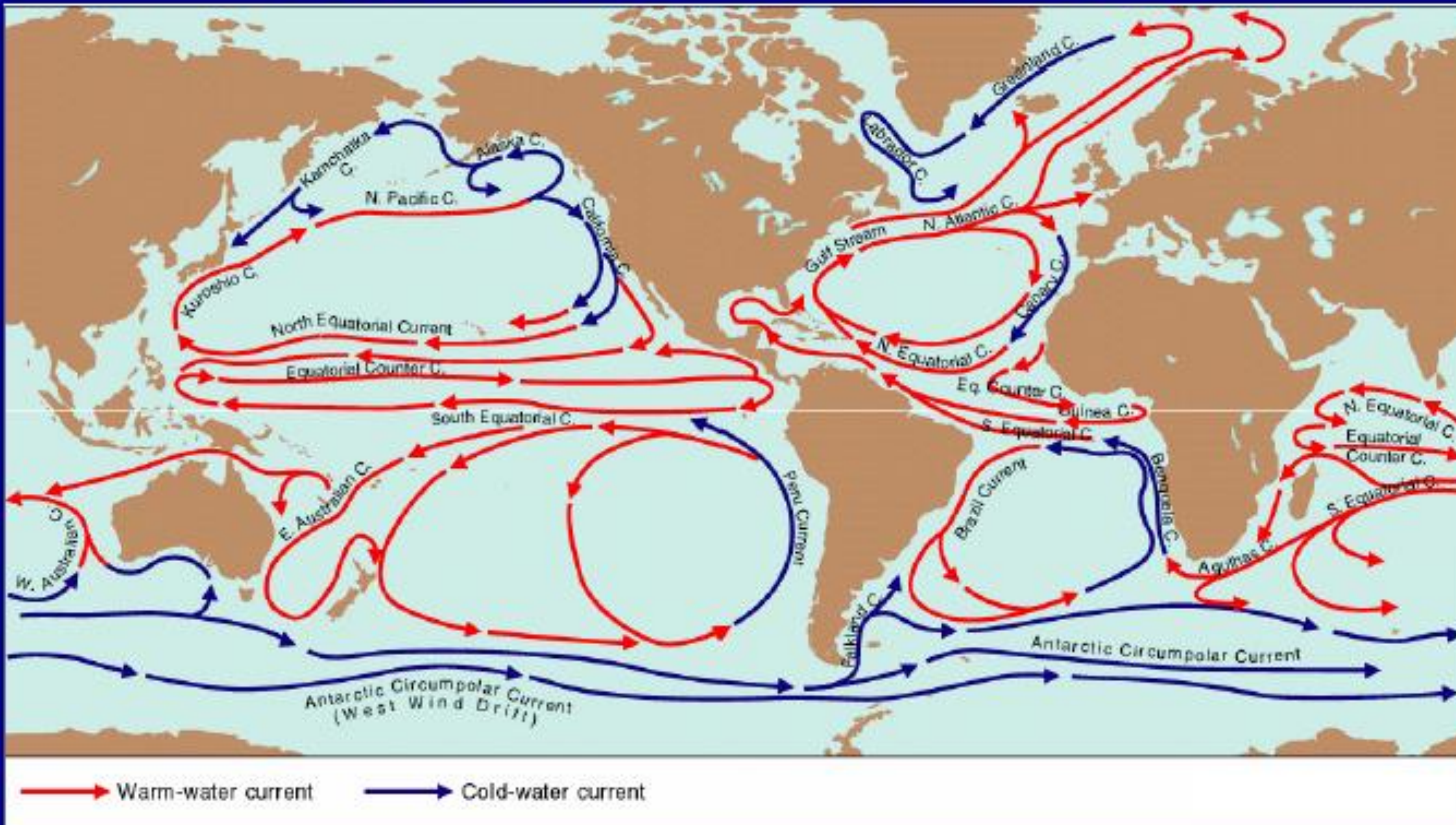


The thermohaline circulation

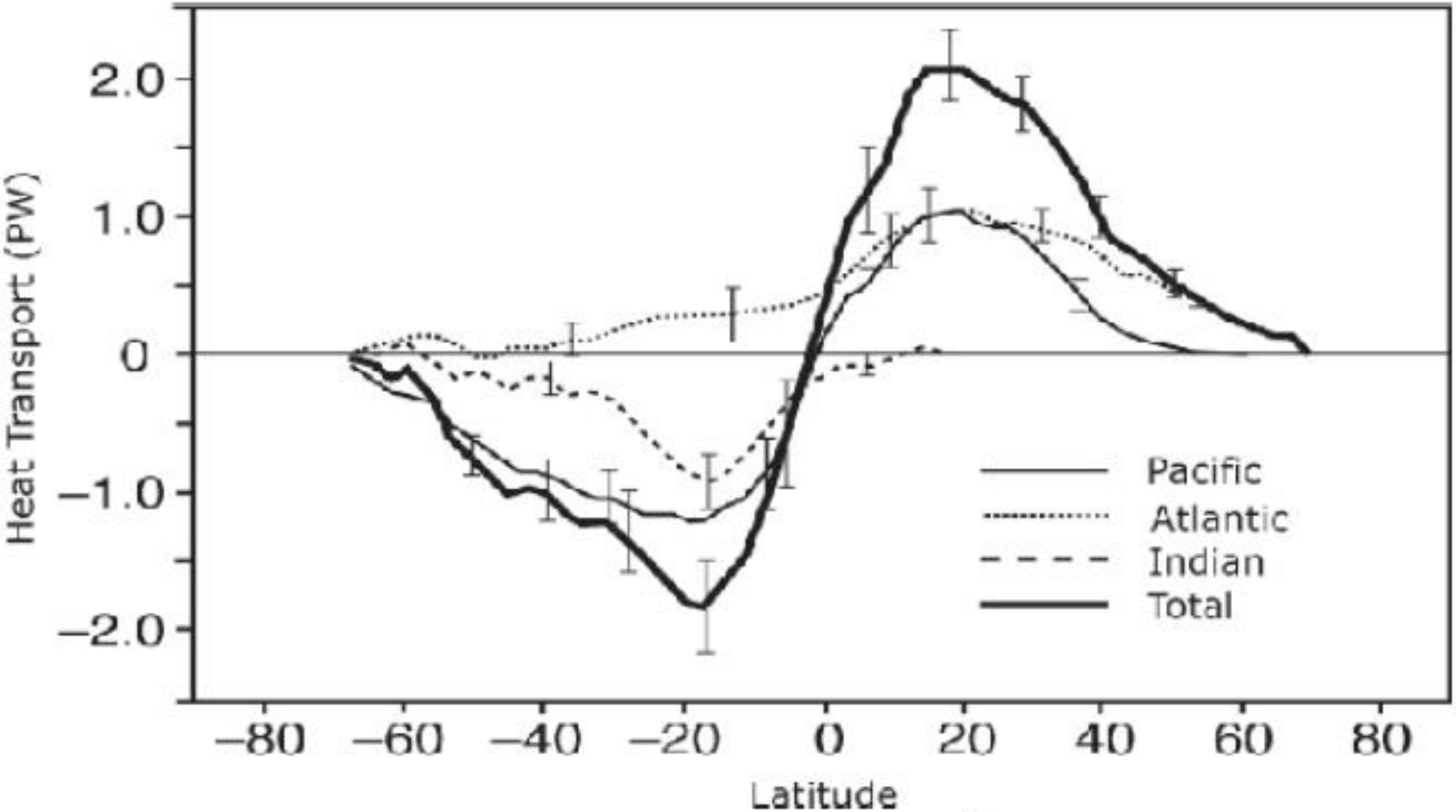
The conveyor belt

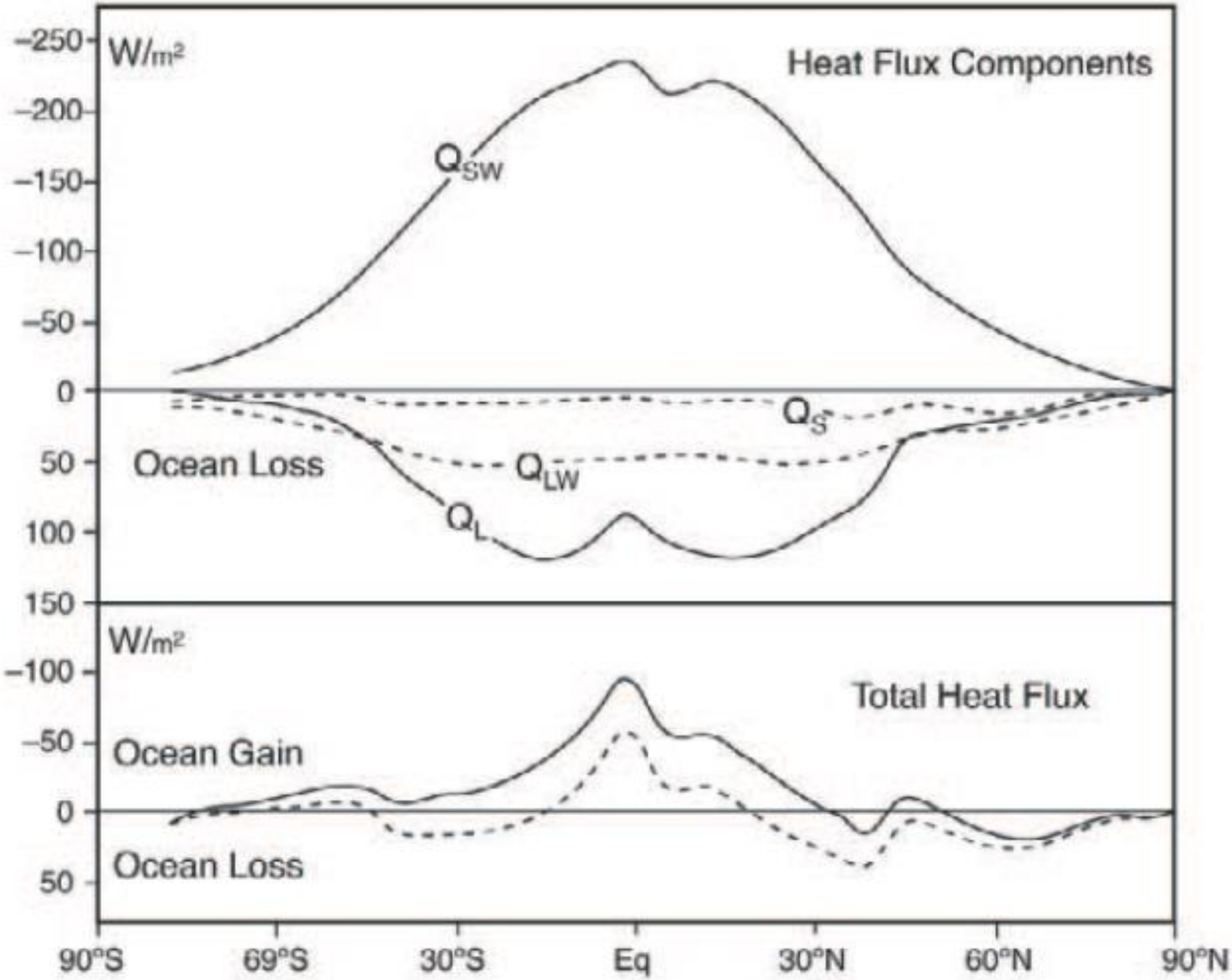
FIGURE 11.28. Top: Estimate of global ocean circulation patterns based on Ganachaud and Wunsch (2000) modified from Alley et al. (2002). The circulation is separated into 3 layers: shallow (red, < 2 km), deep (blue, 2–4 km), and bottom (green, > 4 km). Horizontal arrows across the marked sections represent the volume transport in Sv. Circles (⊙ for upwelling, ⊗ for downwelling) represent the vertical transport out of the layer in question in Sv. Bottom: A cartoon, based on the quantitative estimates shown above, of the ocean's 'shallow to deep' overturning circulation illustrating the asymmetry between the Atlantic and Pacific basins and between northern and southern hemispheres. Blue represents deep flow (2–4 km, red shallow flow (< 2 km). Transitions between shallow and

World Surface Current Gyres



Notice the pattern of the world's surface current gyres: clockwise flow in the N Hemisphere; counter-clockwise flow in the S Hemisphere

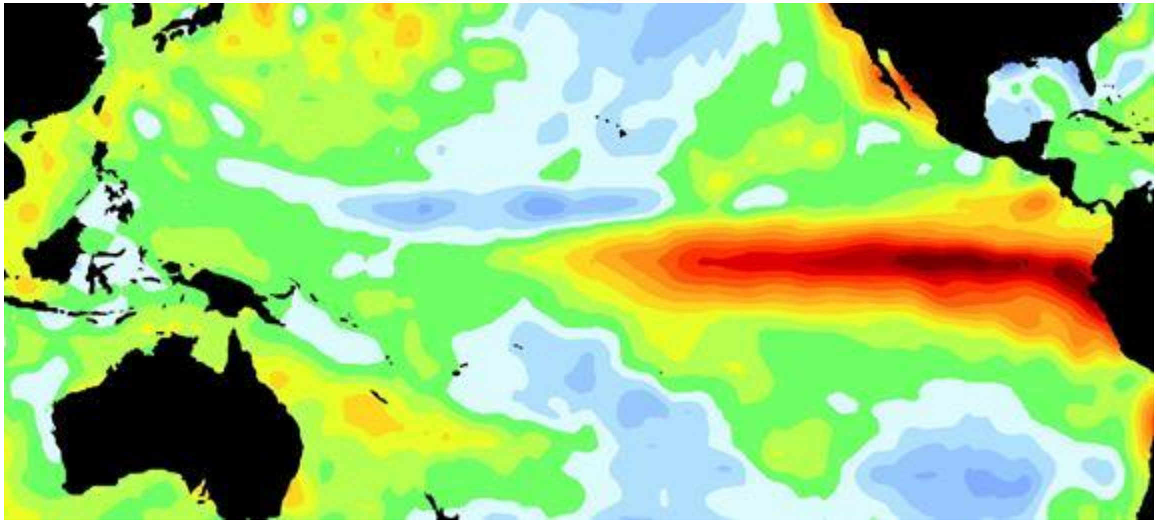

Heat Transport (PW)
2.0
1.0
0
−1.0
−2.0
−80
−60
−40
−20
0
20
40
60
80
Latitude
Pacific
Atlantic
Indian
Total



W/m²
Heat Flux Components
Q_SW
Q_S
Q_LW
Q_L
Ocean Loss
–250
–200
–150
–100
–50
0
50
100
150
W/m²
Total Heat Flux
Ocean Gain
Ocean Loss
–100
–50
0
50
90°S
69°S
30°S
Eq
30°N
60°N
90°N

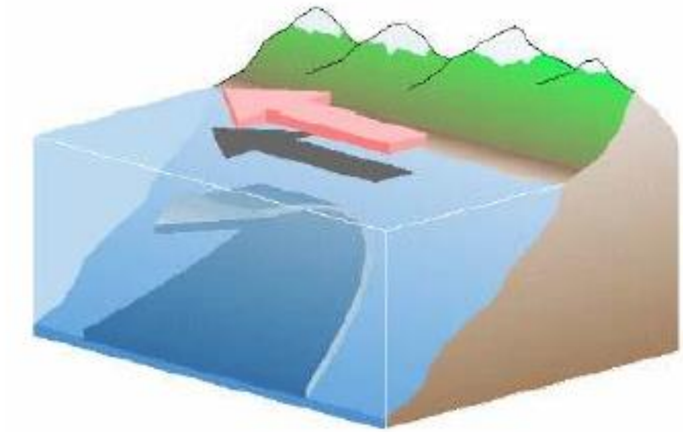
El Nino – Southern Oscillation (ENSO)

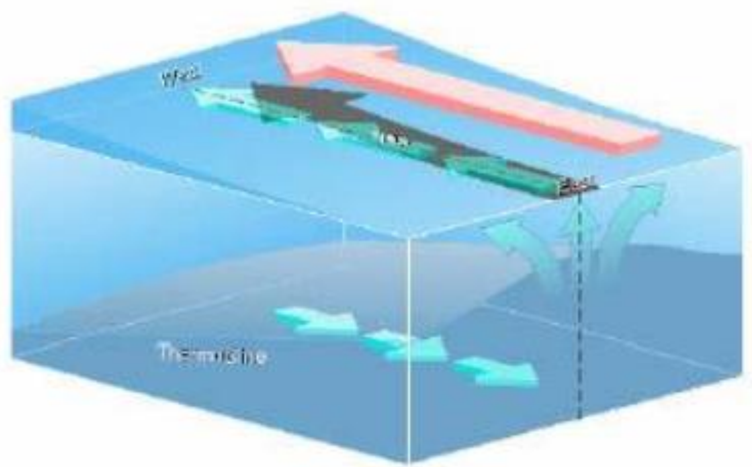
El Nino: A tropical phenomenon which occurs naturally every few years, in which the waters off the coast of Peru are anomalously warm for a period of 6 months or more. During this time there are no fish. Fishermen used to call it El Nino since it usually occurred around Christmas time.

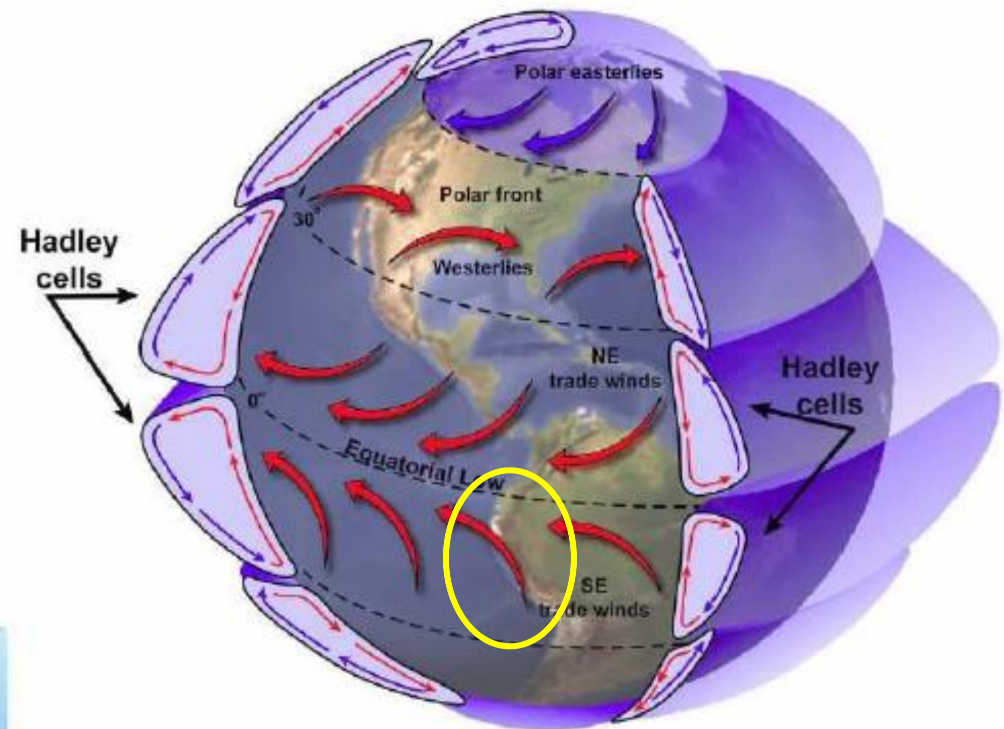


El Nino1997/8 SST anomalies
Red / yellow - warm
Blues - cold

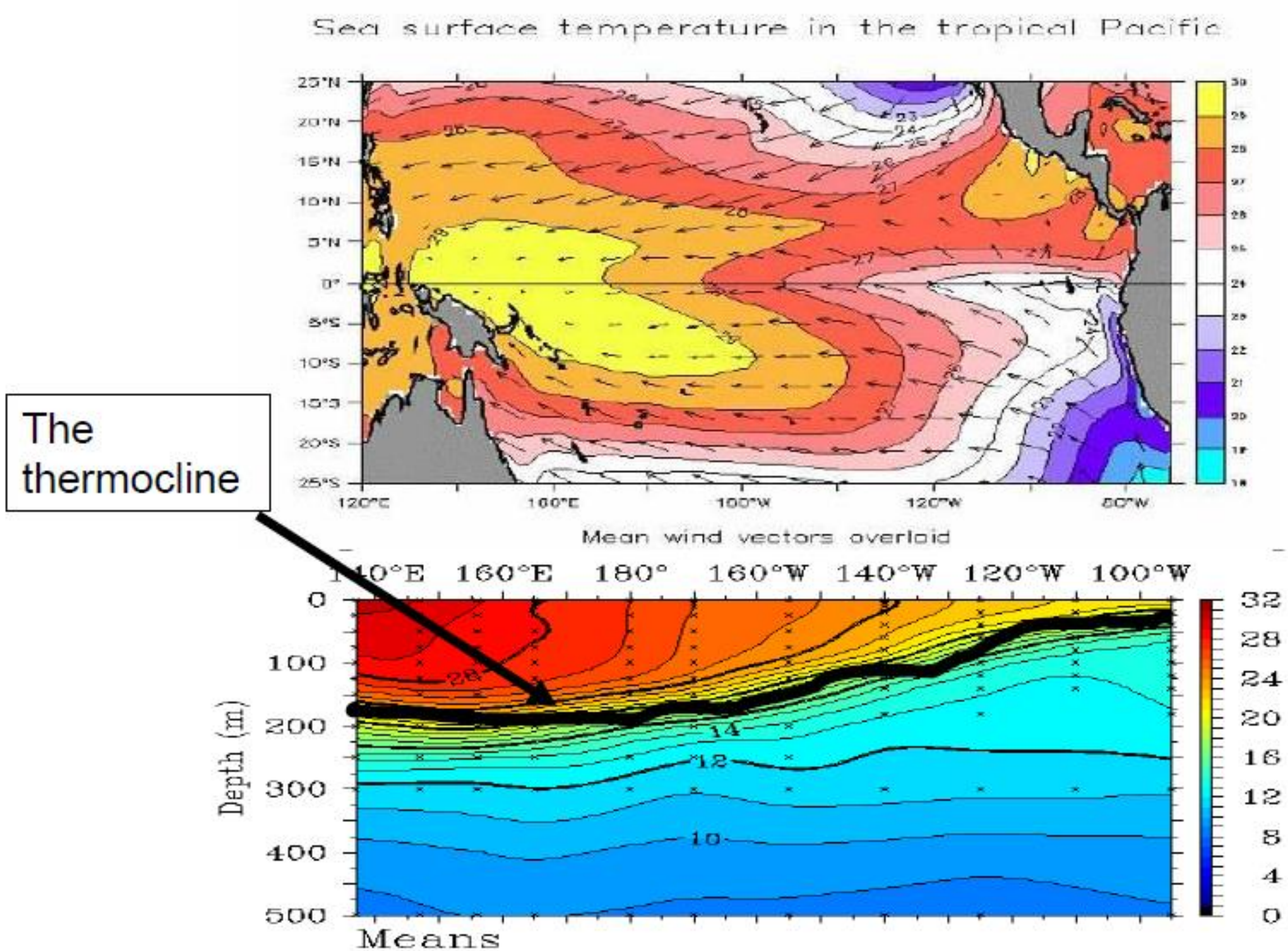
The trade winds and resulting currents

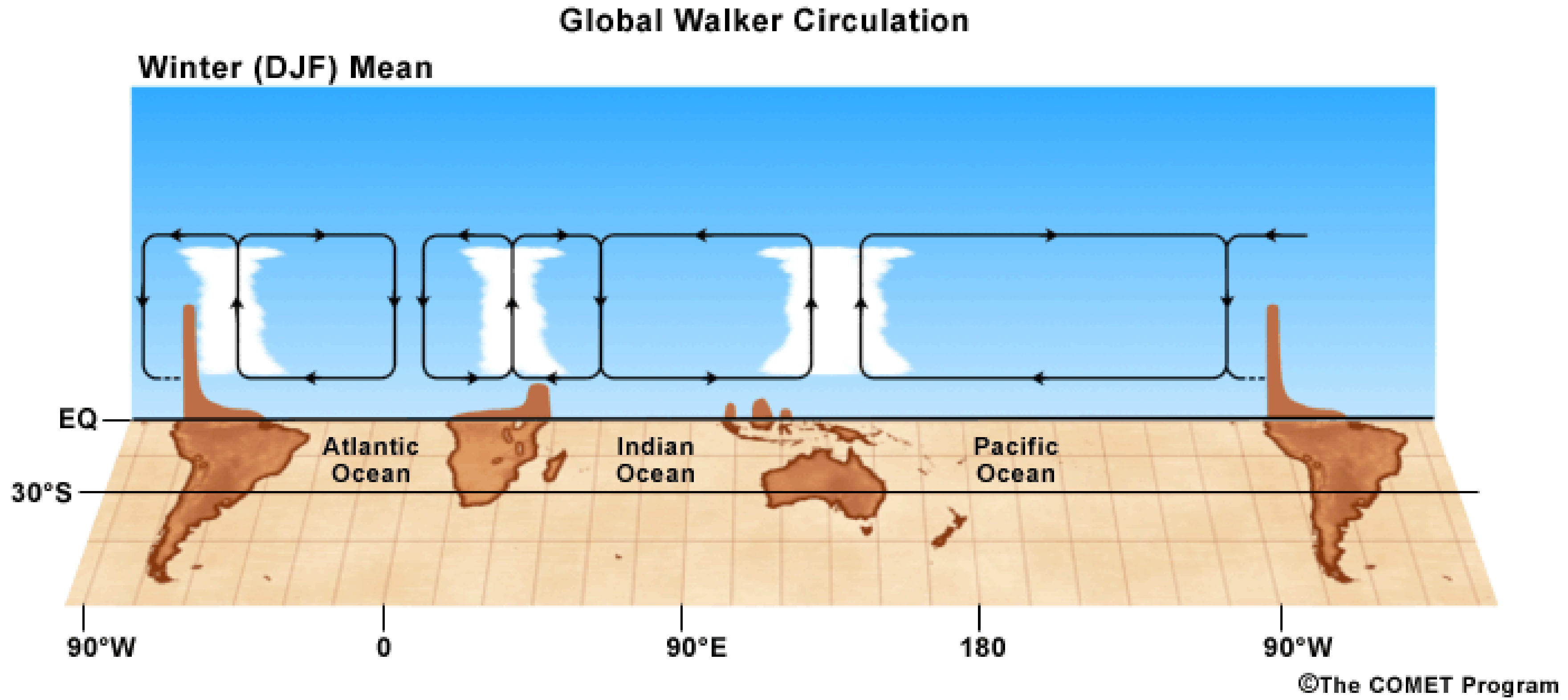


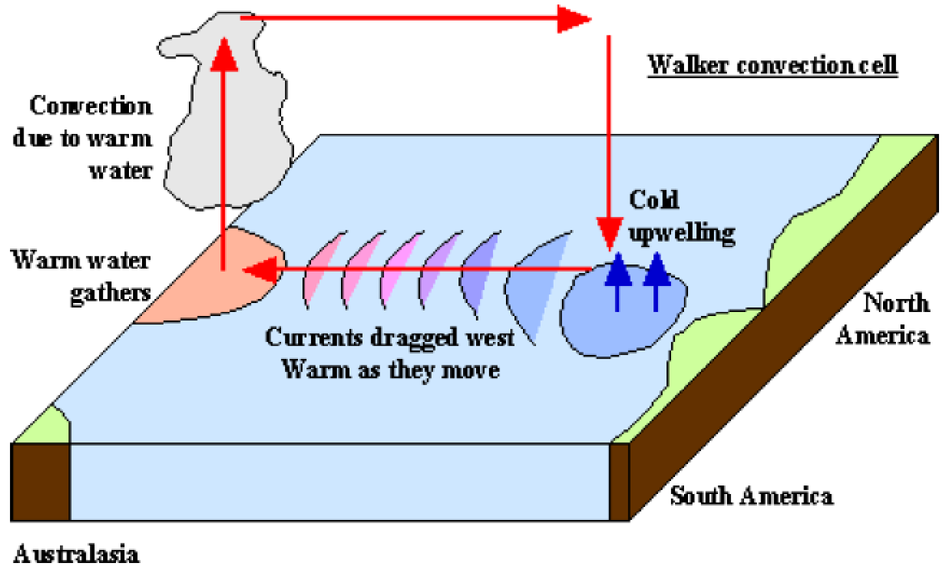




באזור פרו הרוחות במקביל לקו החוף

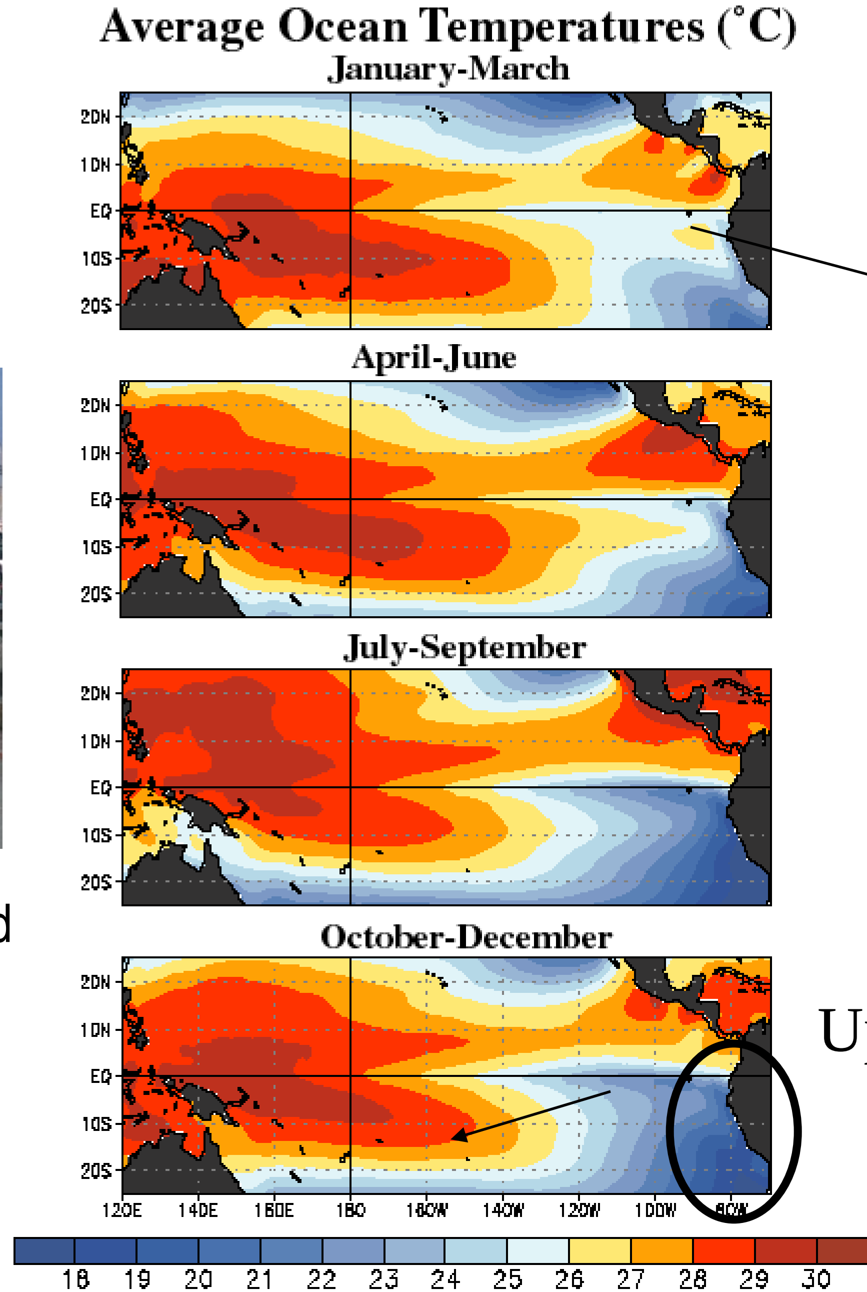

The thermocline
Sea surface temperature in the tropical Pacific
Mean wind vectors overlaid
160°E
180°
160°W
140°W
120°W
100°W
Depth (m)
0
100
200
300
400
500
28
14
12
10
32
28
24
20
16
12
8
4
0
Means


Global Walker Circulation
Winter (DJF) Mean
EQ
30°S
Atlantic Ocean
Indian Ocean
Pacific Ocean
90°W
0
90°E
180
90°W
©The COMET Program


Walker convection cell
Convection due to warm water
Cold upwelling
Warm water gathers
Currents dragged west
Warm as they move
North America
South America
Australasia

מחזור הרוחות העונתי גורם
להפוגה עונתית בבצבוץ
בסביבות חג המולד. בשנות אל
ניניו ההפוגה מתארכת מאד.

Fishermen along the coasts of Peru and Ecuador in the 1800s to describe the warm southward ocean current that appears around Christmas time and lasts a few months (“la corriente del Niño”)



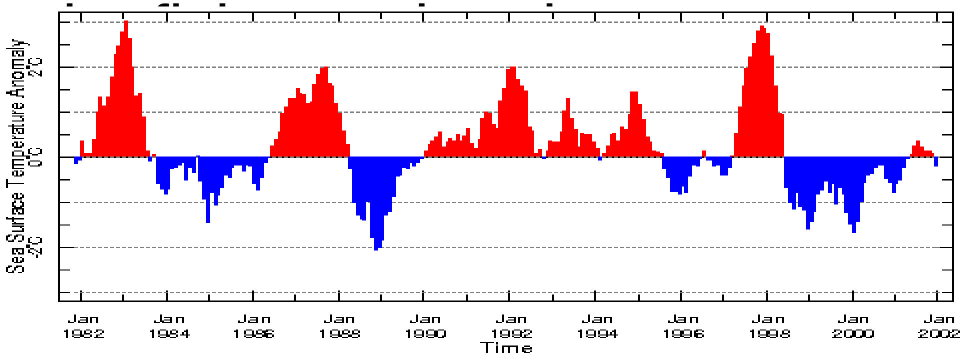
הפוגה
בבצבוץ

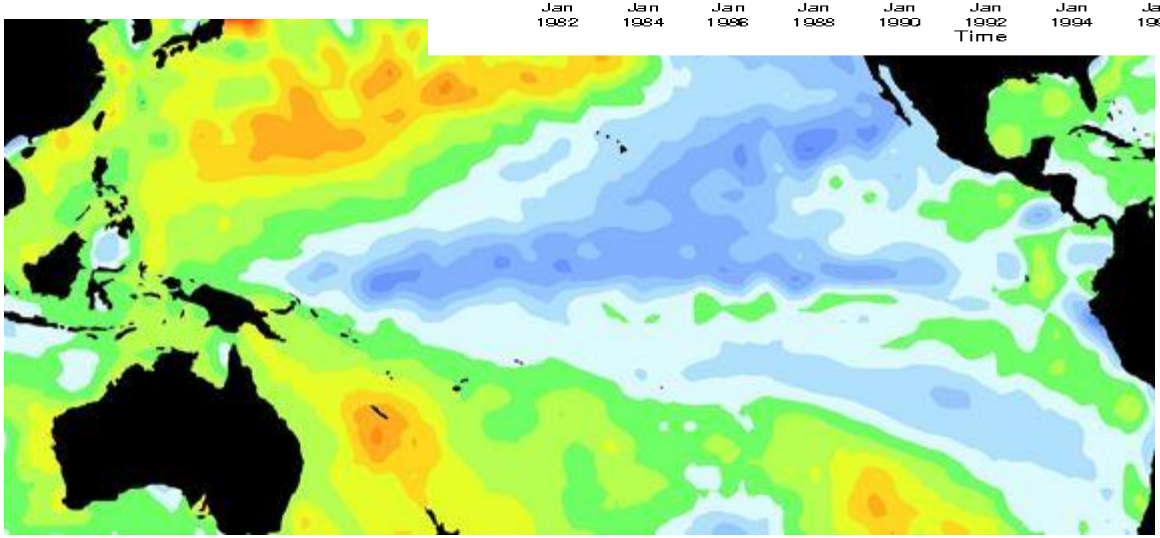
Upwelling
ביצבוץ

La Niña

The opposite phenomenon

A large pool of cold water forms off the coast, at around Christmas tim

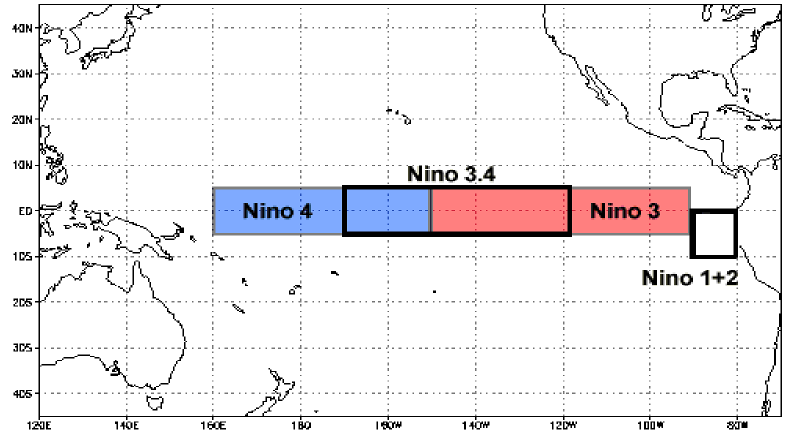




La Nina1998/9 SST anomalies
Red / yellow - warm
Blues - cold

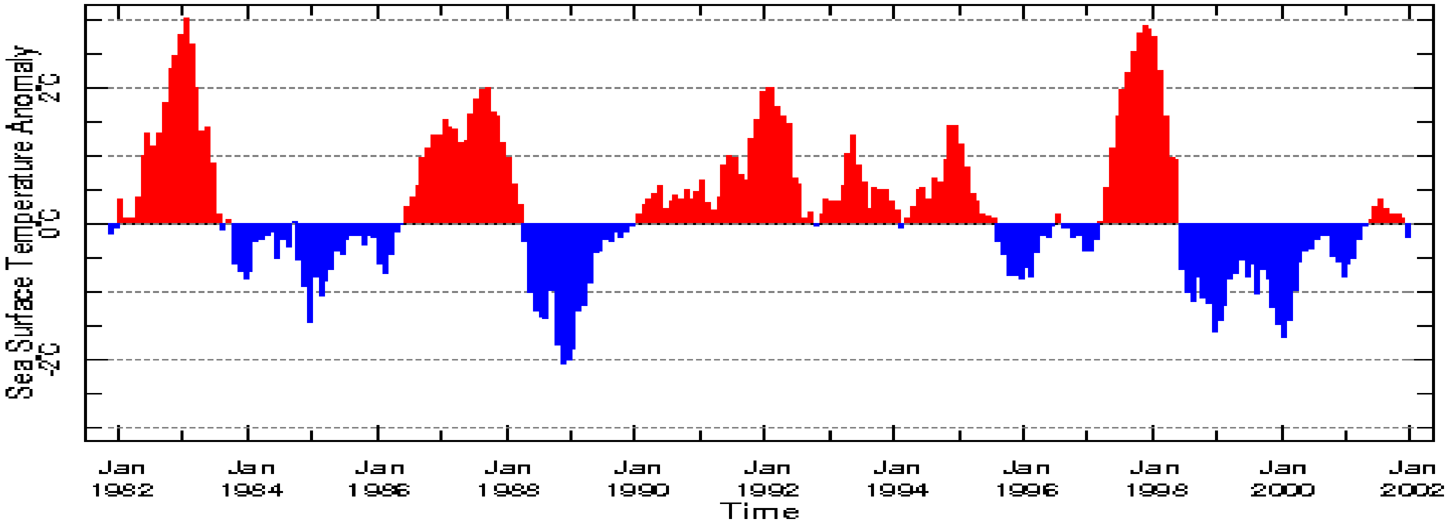
El Nino indices – mean seas surface temperature in a defined box

Nino SST indices



Nino 3 – largest SST variability
Nino 4 – most important for changes in convection and precipitation
Nino 3.4 – optimal index

Nino 3.4 index

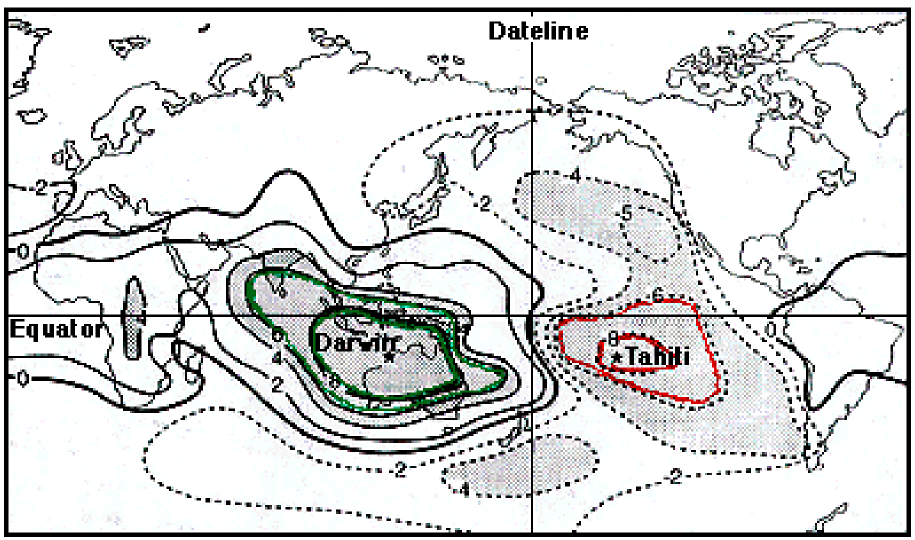


Southern Oscillation

Discovered by Sir Gilbert Walker (1868-1958) while trying to find out why the Indian Monsoon failed and caused a famine (in 1899-1900).

A pressure oscillation between Darwin and Tahiti

SOI: Tahiti and Darwin as "centers of action", msIp correlations between two locations

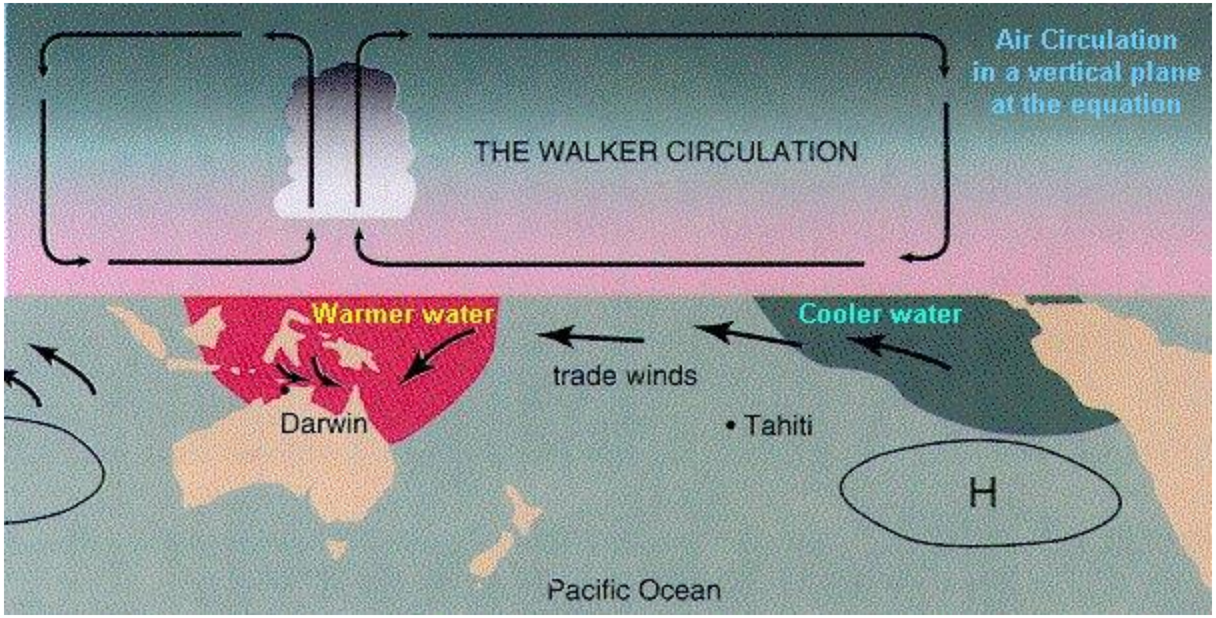


Tahiti and Darwin are at opposite ends of the Southern Oscillation's seesaw, and so the difference in pressure between them is used to measure the Southern Oscillation. The numbers represent a statistical measure called the correlation coefficient. The figure shows that the pressure variation at Tahiti is as closely related to Darwin as are locations near to Darwin, but with the opposite sign (i.e., if the Pressure is high at Darwin, it is low at Tahiti and vice versa). (After Rasmusson, 1984.)

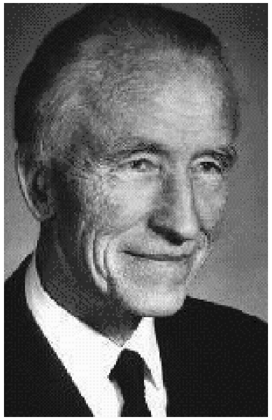
Southern Oscillation

Discovered by Sir Gilbert Walker (1868-1958) while trying to find out why the Indian Monsoon failed and caused a famine (in 1899-1900).

It is part of the longitudinal-vertical circulation pattern in the tropics, which responds to surface heating patterns, and involves deep convection

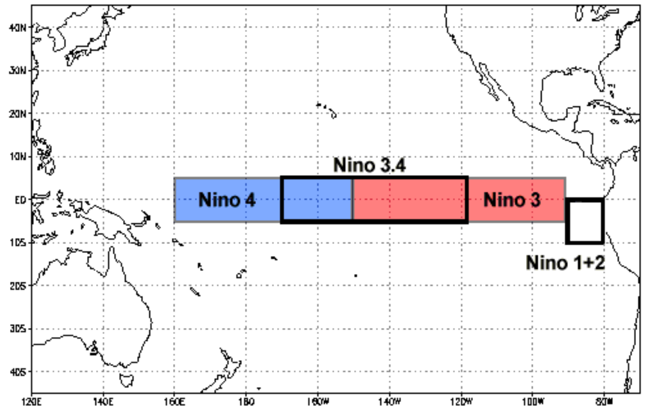


The two seem to oscillate together: Southern Oscillation and Niño



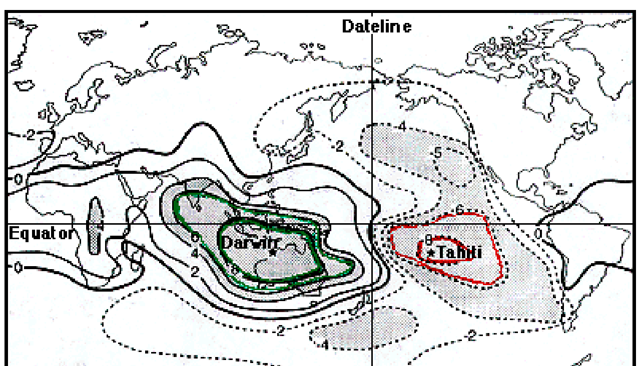
Jacob Bjerknes

Nino SST indices

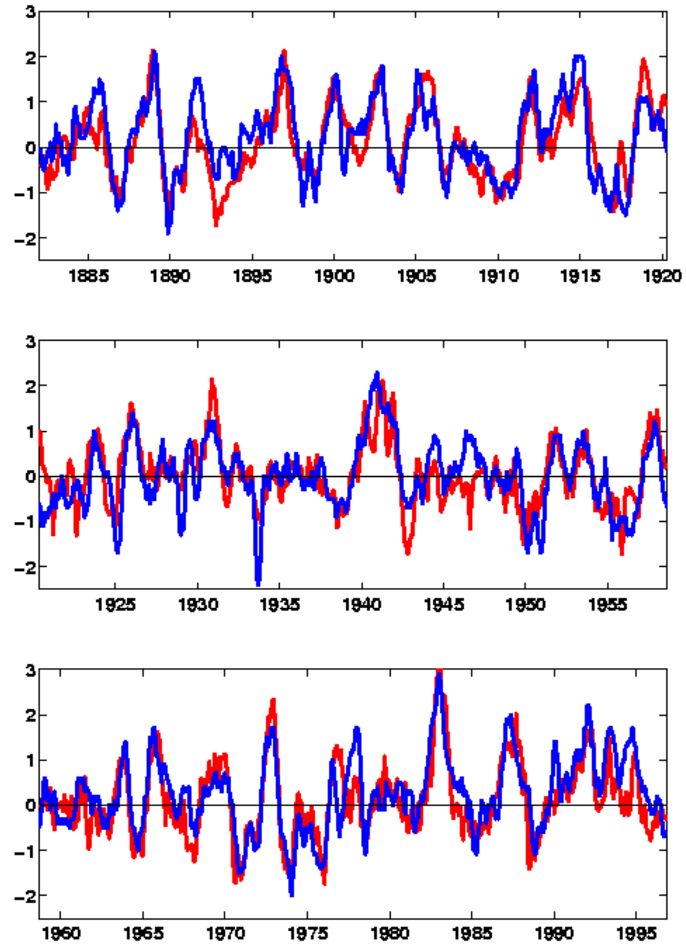


Southern Oscillation sea level pressure index

SOI: Tahiti and Darwin as "centers of action", mslp correlations between two locations



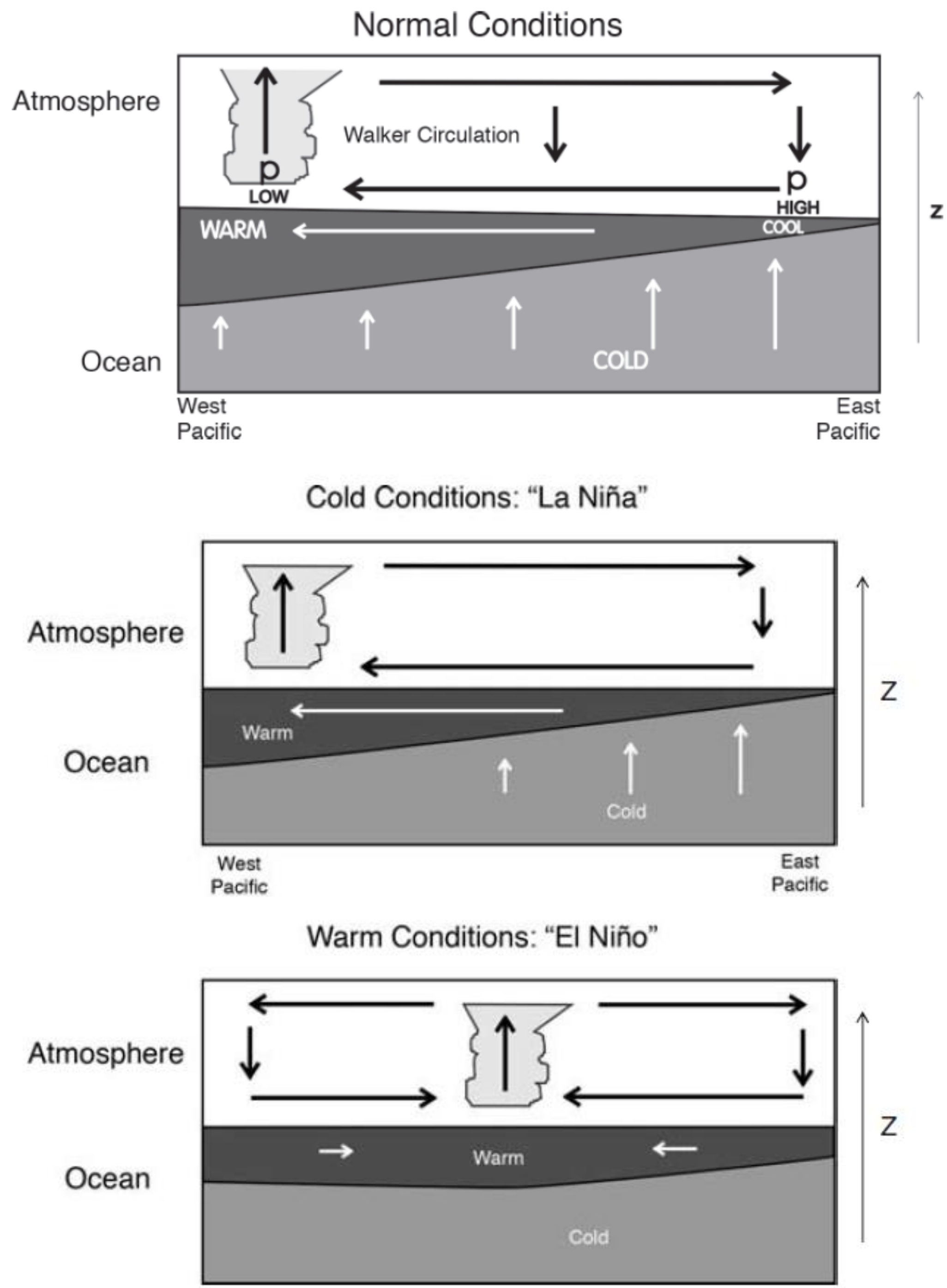
Darwin SLP NINO3 SST 1882 – 1996



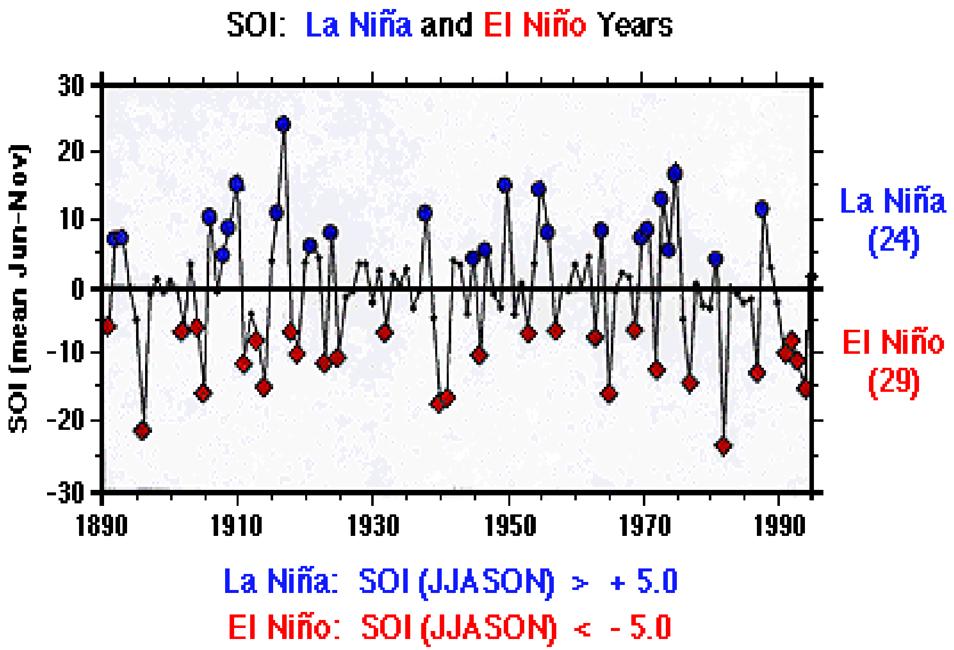
A positive feedback between the atmospheric an oceanic circulations

During El Niño:
•Weaker trade winds
•Thermocline deeper in east Pacific, lower boundary less sloped
→Upwelling weakens
→Eastern Pacific ocean warms
•Convection shifts eastwards
→Trade winds weaken

What stops it? Complex ocean dynamics- wavey perturbations on thermocline carry the “signal” of eastern shallowing to the west, then back again. When the signal reaches which propagate across Pacific ocean on thermocline from east to west then back



ENSO is a relatively frequent phenomenon.

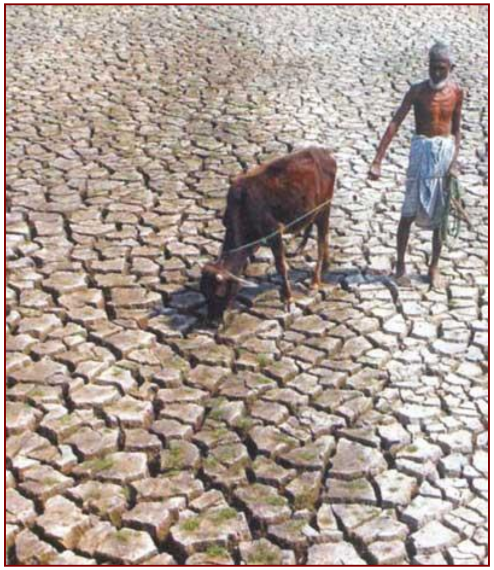


Out of 100 years, around 25% were El Niño and 25% La Niña

ENSO is responsible for most of our skill in seasonal forecasting, for the tropics and midlatitudes.

Know to cause all sorts of calamities:

Drought and wildfires



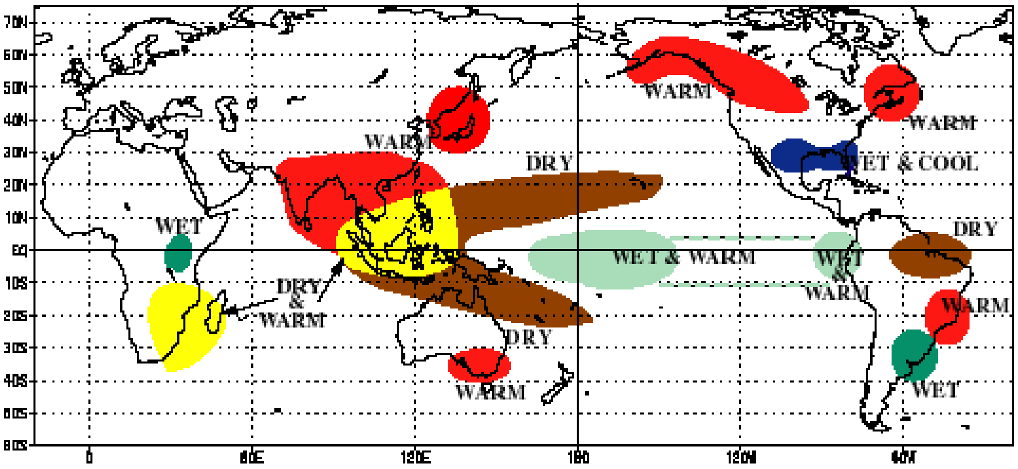
Drought in India, during El Nino (1987)

Fires rage in Indonesia before the 1997 El Niño.

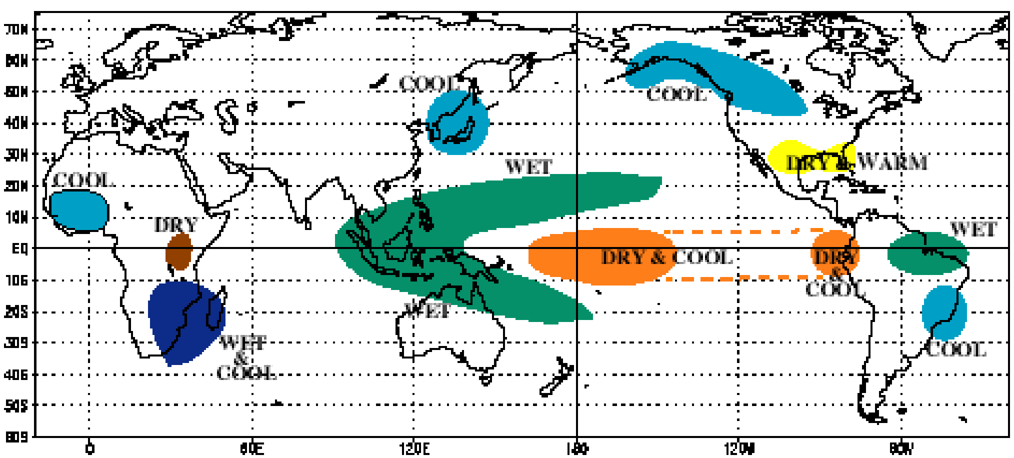
Floods

El Nino storms flood Russian River, California, March 1998

WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



From the climate prediction center monthly ocean briefing: current El Nino – maybe big one in the making