Introduction to
Observational Physical Oceanography
12.808

Class 2, 9 September, 2008

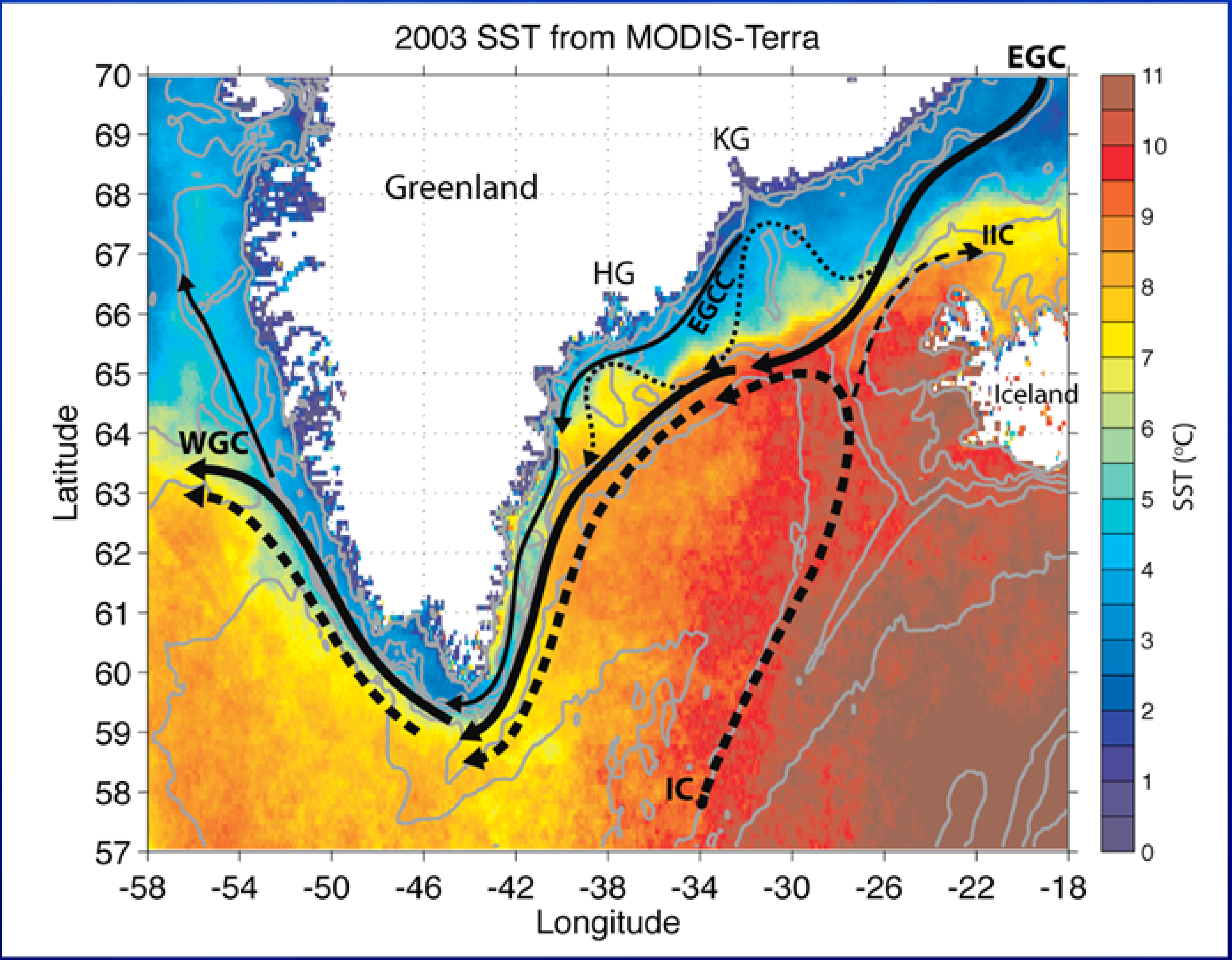
Seawater – its properties and their distribution

1:00 to 2:00

these slides are online at

http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class2_9Sep08.ppt

http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class2_9Sep08.pdf



2003 SST from MODIS-Terra
EGC
KG
Greenland
HG
EGCC
IIC
Iceland
WGC
IC
Latitude
Longitude
SST (°C)
70
69
68
67
66
65
64
63
62
61
60
59
58
57
-58
-54
-50
-46
-42
-38
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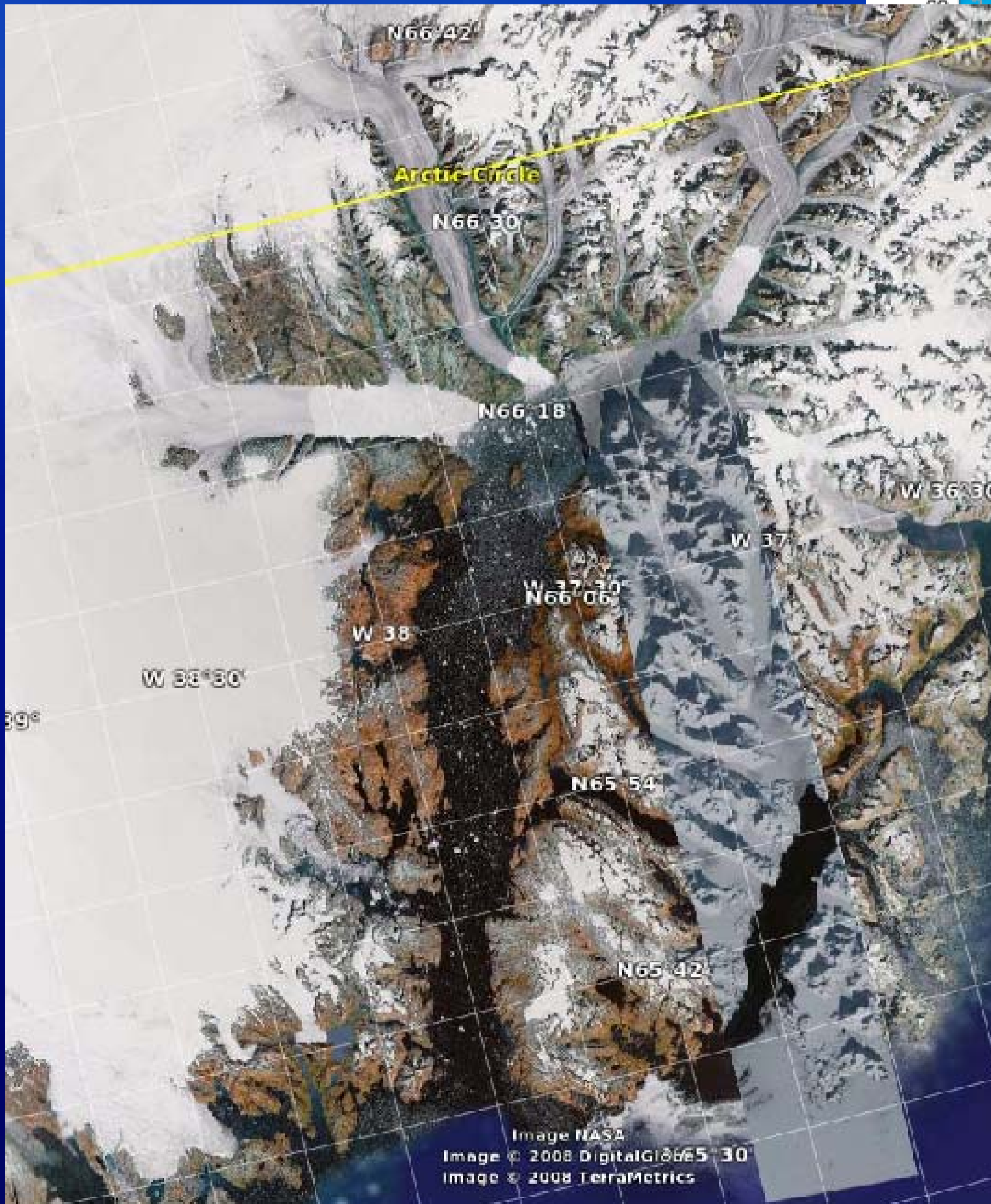
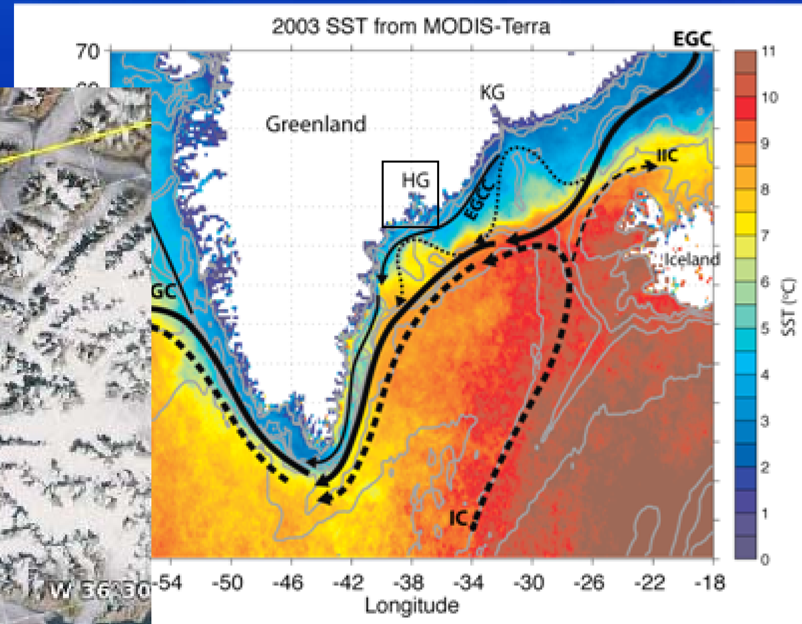
4
3
2
1
0


N66°42'
Arctic Circle
N66°30'
N66°18'
W 36°30'
W 37
W 37°30'
N66°06'
W 38
W 38°30'
39°
N65°54'
N65°42'
Image NASA
Image © 2008 DigitalGlobe
65°30'
Image © 2008 TerraMetrics


2003 SST from MODIS-Terra
70
EGC
KG
Greenland
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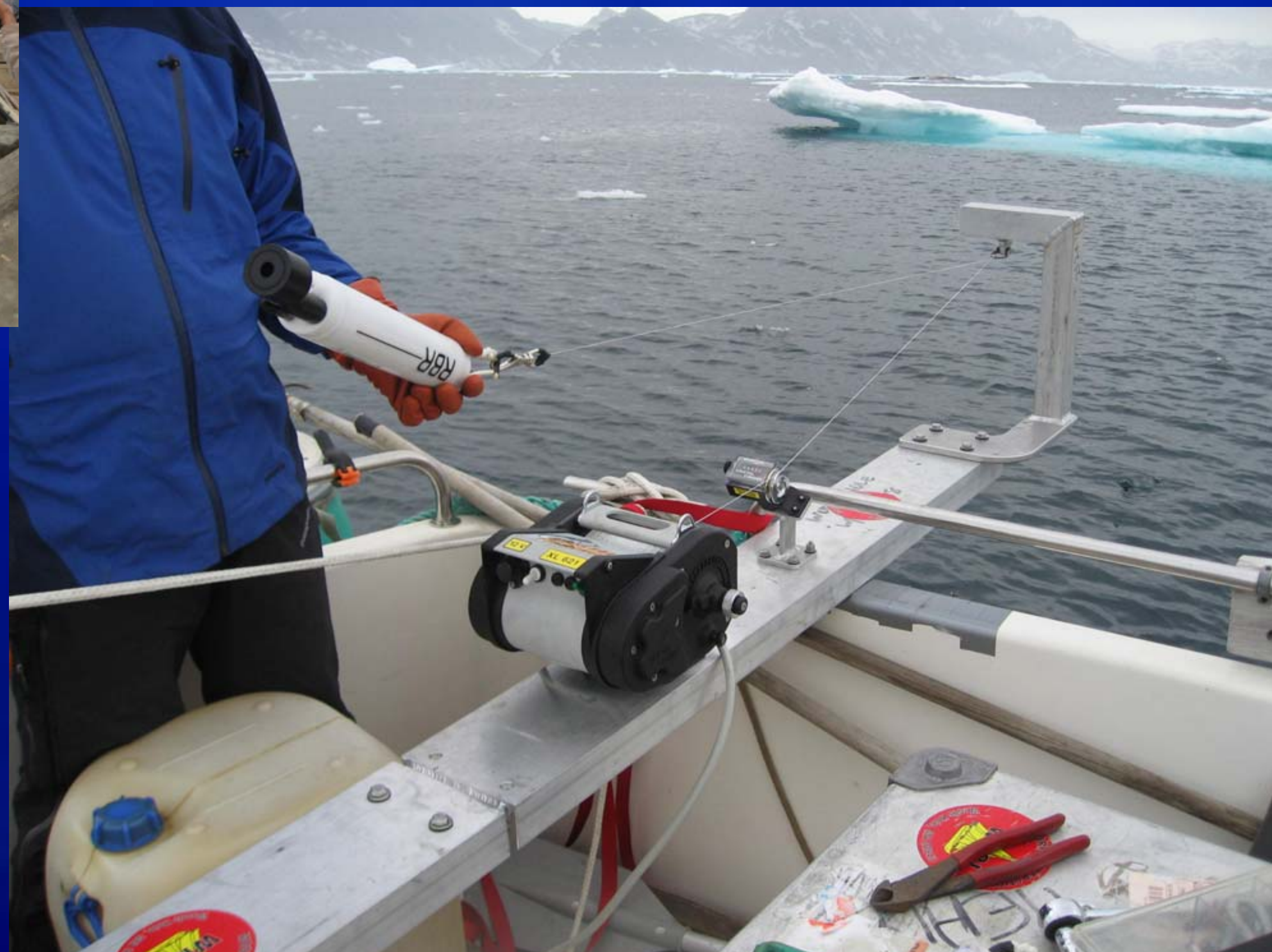
IIC
Iceland
GC
IC
-54 -50 -46 -42 -38 -34 -30 -26 -22 -18
Longitude
SST (°C)
0 1 2 3 4 5 6 7 8 9 10 11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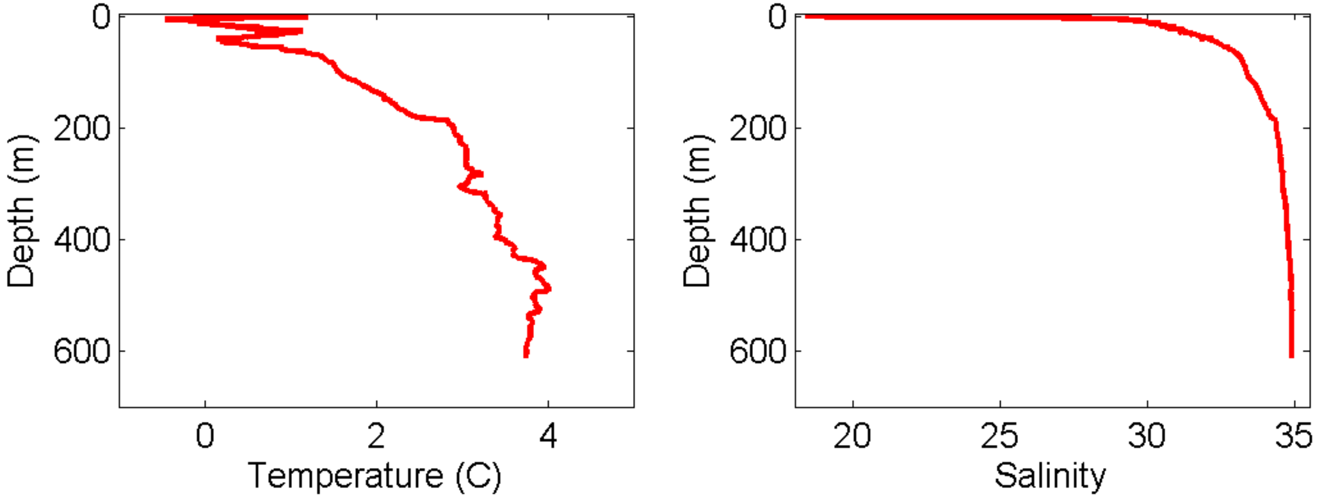


Temperature and Salinity in Sermilik Fjord

September 2nd 2008

Class 2

Seawater: its properties and their distribution

- temperature
- salinity

} Class 2

- pressure
- density (equation of state)
- potential temperature/density
- static stability

} Class 3

- T/S diagrams
- water types and masses

} Class 4

Reading: Knauss 2005, Ch 1 and 2.

Annual Mean Sea Surface Temperature, SST

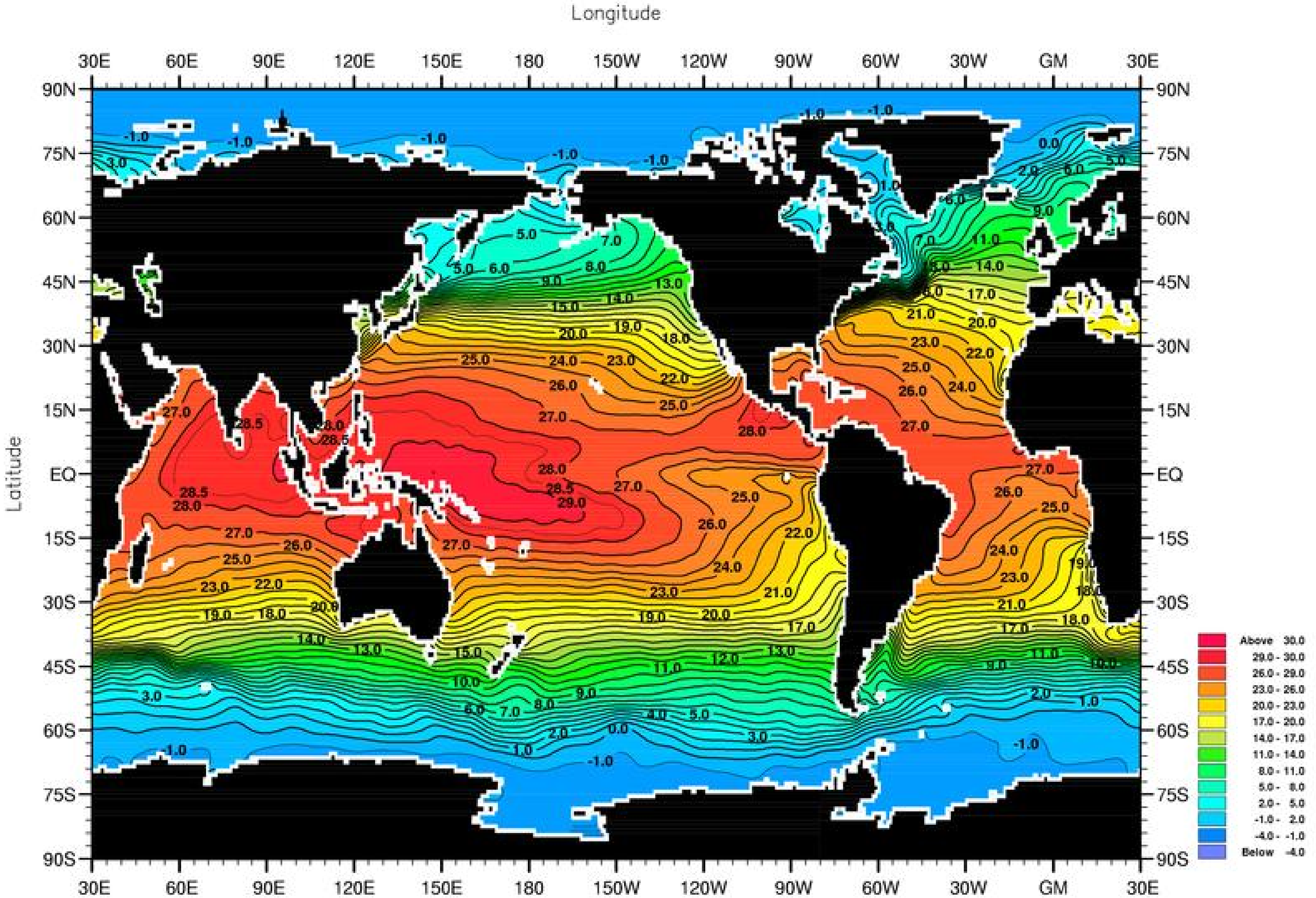


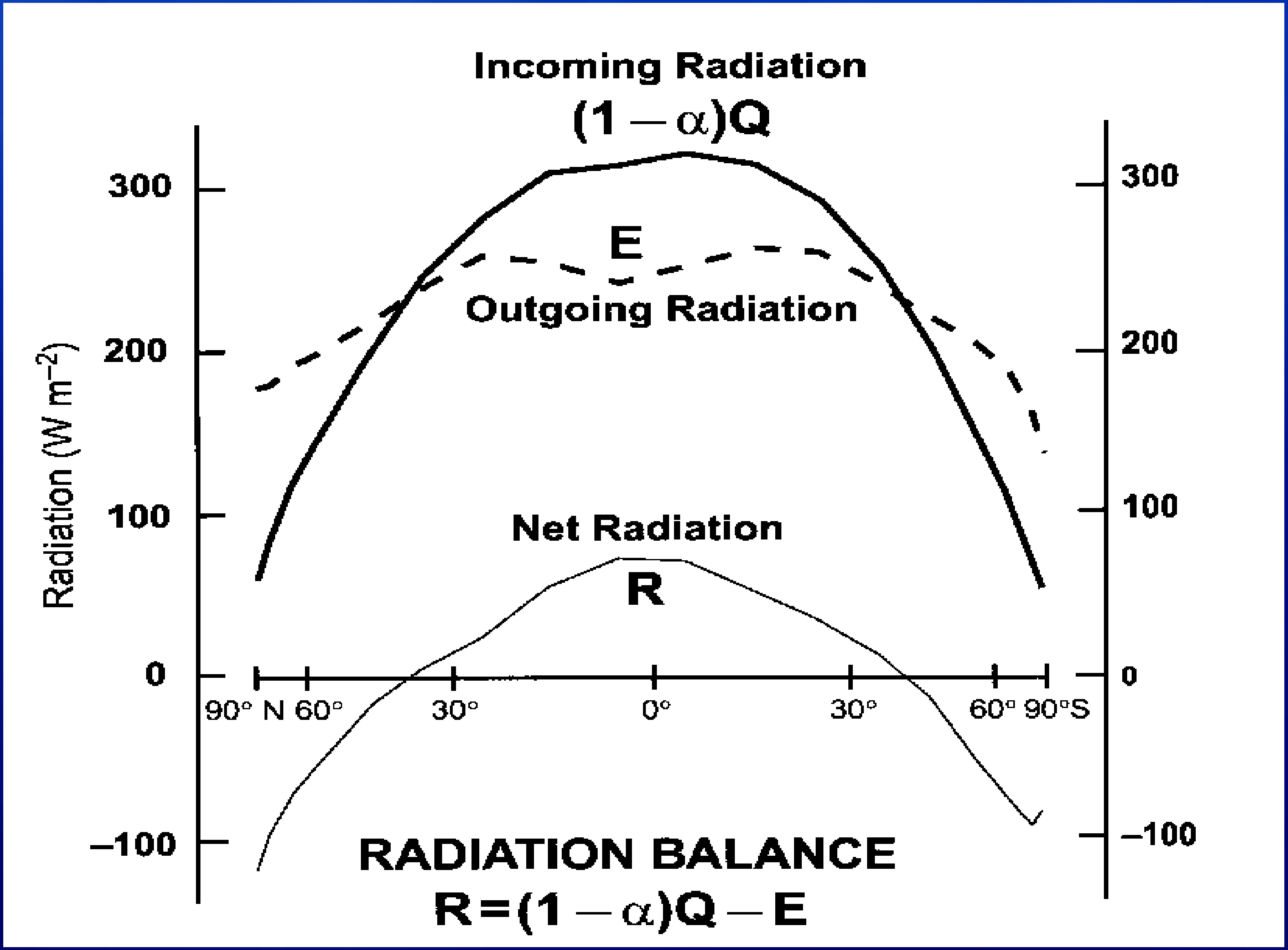
Fig. A2-1. Annual mean temperature (°C) at the surface.

Minimum Value= -1.93 Maximum Value= 29.93 Contour Interval: 1.00

made from about 5 million hydro casts

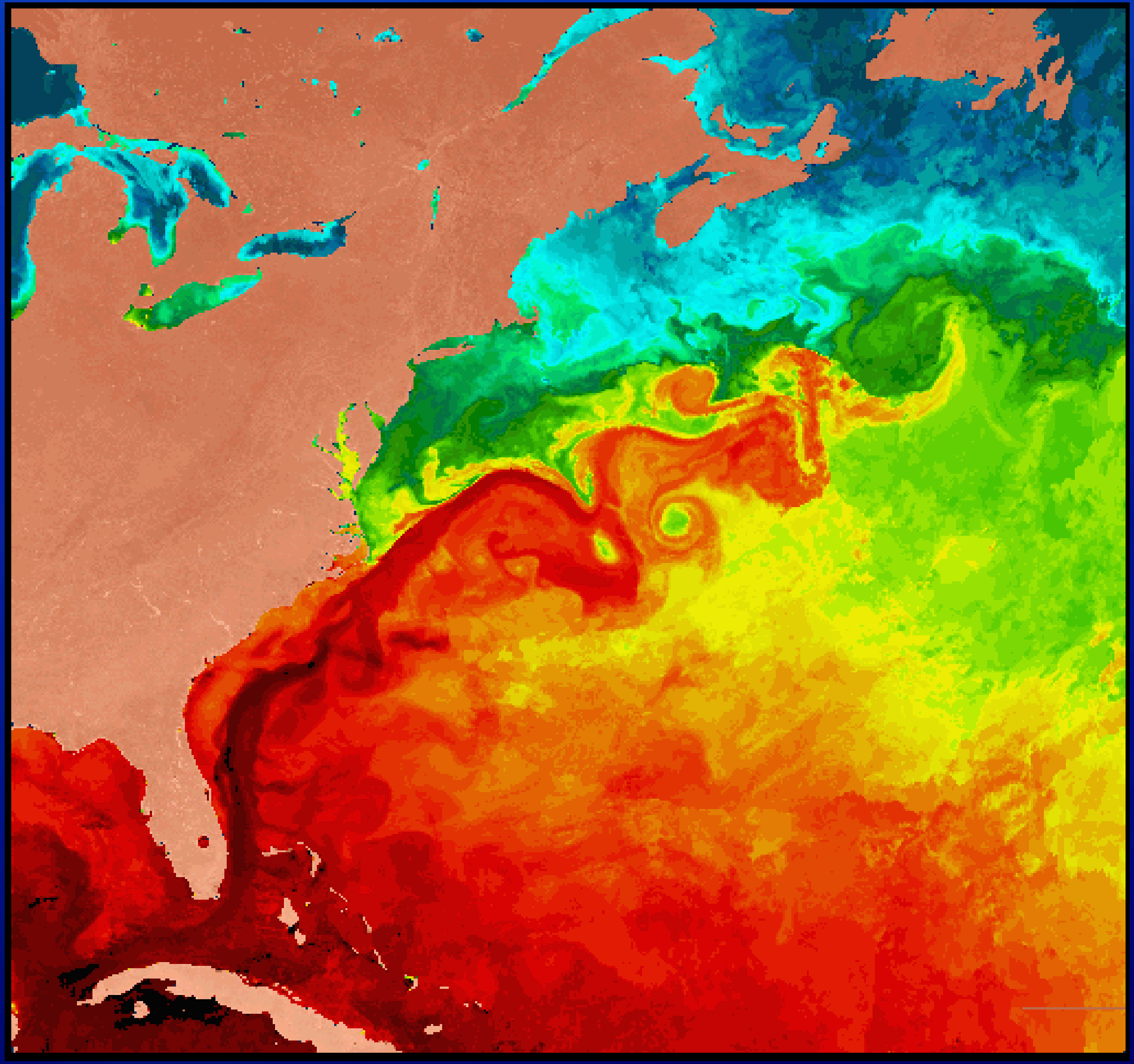
World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

Q is strongly dependent upon latitude; E is much less so



from Bryden, 2001

Deviations from latitudinal bands due to ocean circulation



Infrared Radiometry: high horizontal coverage, accuracy of ~0.5 C.
Surface only.

Why does temperature matter ?

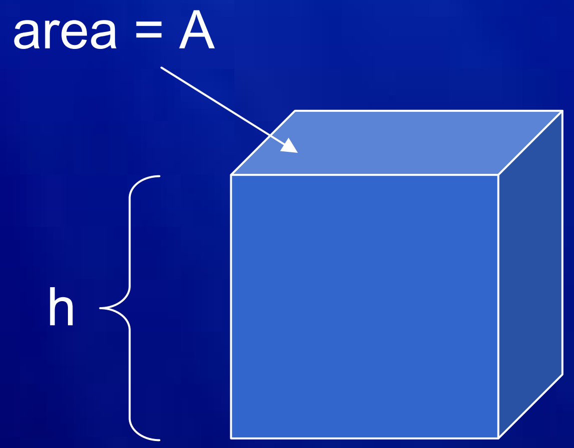
- Influences the chemistry and biology of the ocean
- Regulates the phase transitions (water vapour, sea-ice)
- Regulates the exchange of heat with the atmosphere
- Tends to dominate the density of seawater
- Impact on sea-level

Temperature and Heat

Consider a column of ocean of area A and thickness h

$$H = \text{Heat Content} = \rho\, C_p\, T\, A\, h$$

Units of heat content = Joules (J)



Cp - specific heat capacity of sea water
~ 4000 J/(kg C)

ρ - density ~ 1025 kg/m^3

Temperature and Heat

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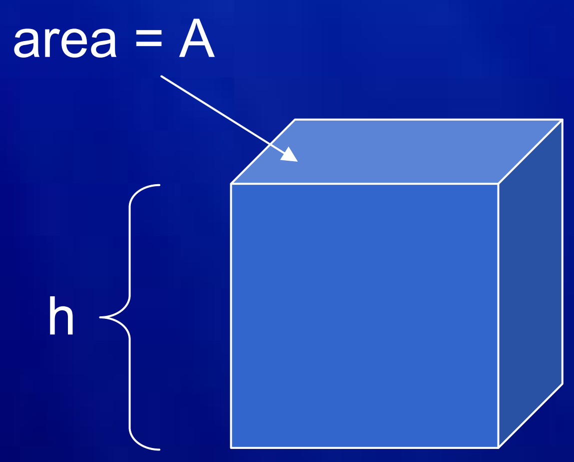


Cp - specific heat capacity of sea water
~ 4000 J/(kg C)

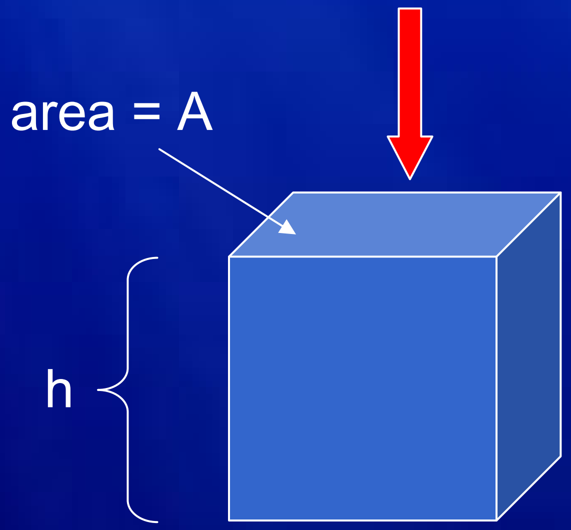
ρ - density ~ 1025 kg/m^3

Temperature units – degree Celsius (ºC or C)

T in ºK (or Kelvin) = T in ºC – 273.15

Changes in Heat Content and Temperature

Consider a box at the sea-surface - its heat content can change due to transfer of heat through its `ocean walls' or through exchange of heat with atmosphere above it - assuming no exchange through the 'ocean walls':



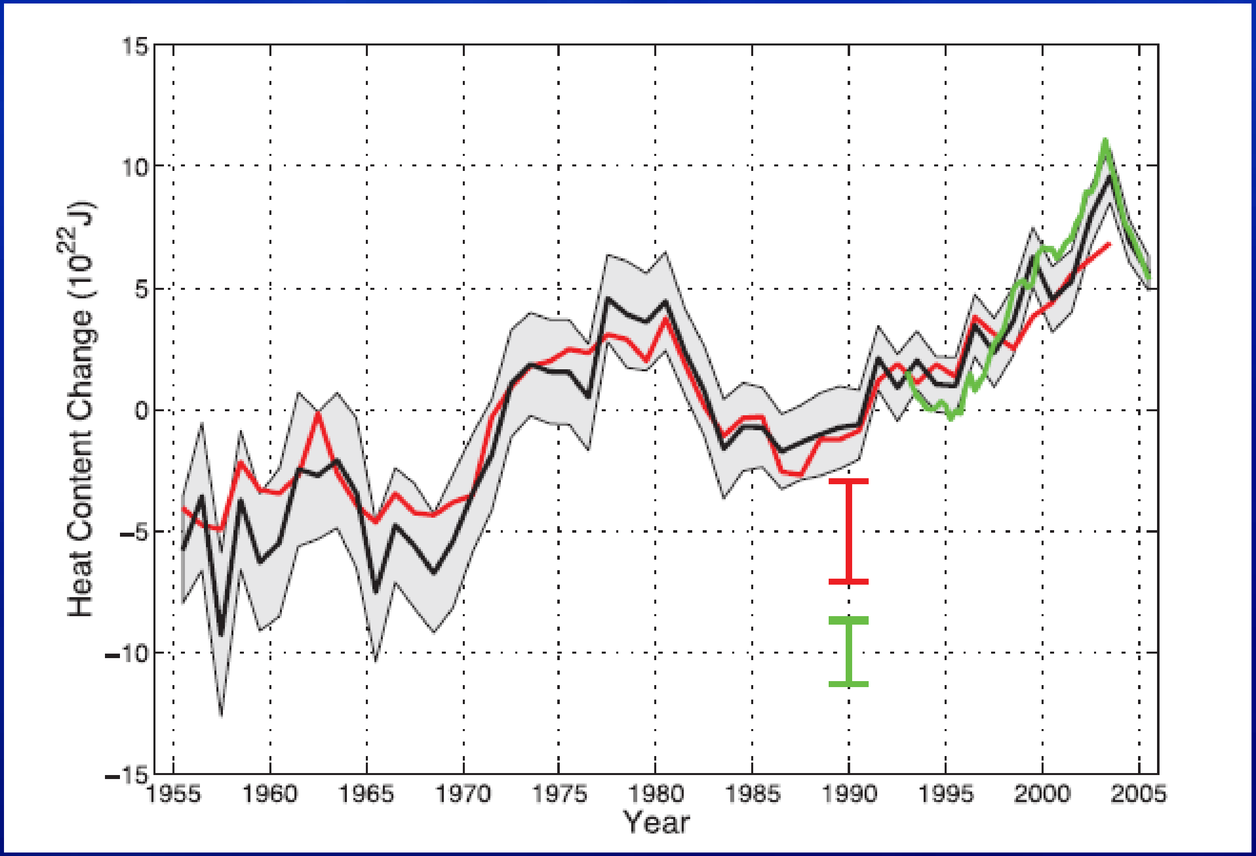
Q, a heat flux; Q = [Watts m^{-2}] = [J s^{-1} m^{-2}]

$$\Delta H = \Delta (h A \rho Cp T) = A Q \Delta t$$

$$\Delta T = Q /(Cp h \rho) \Delta t$$

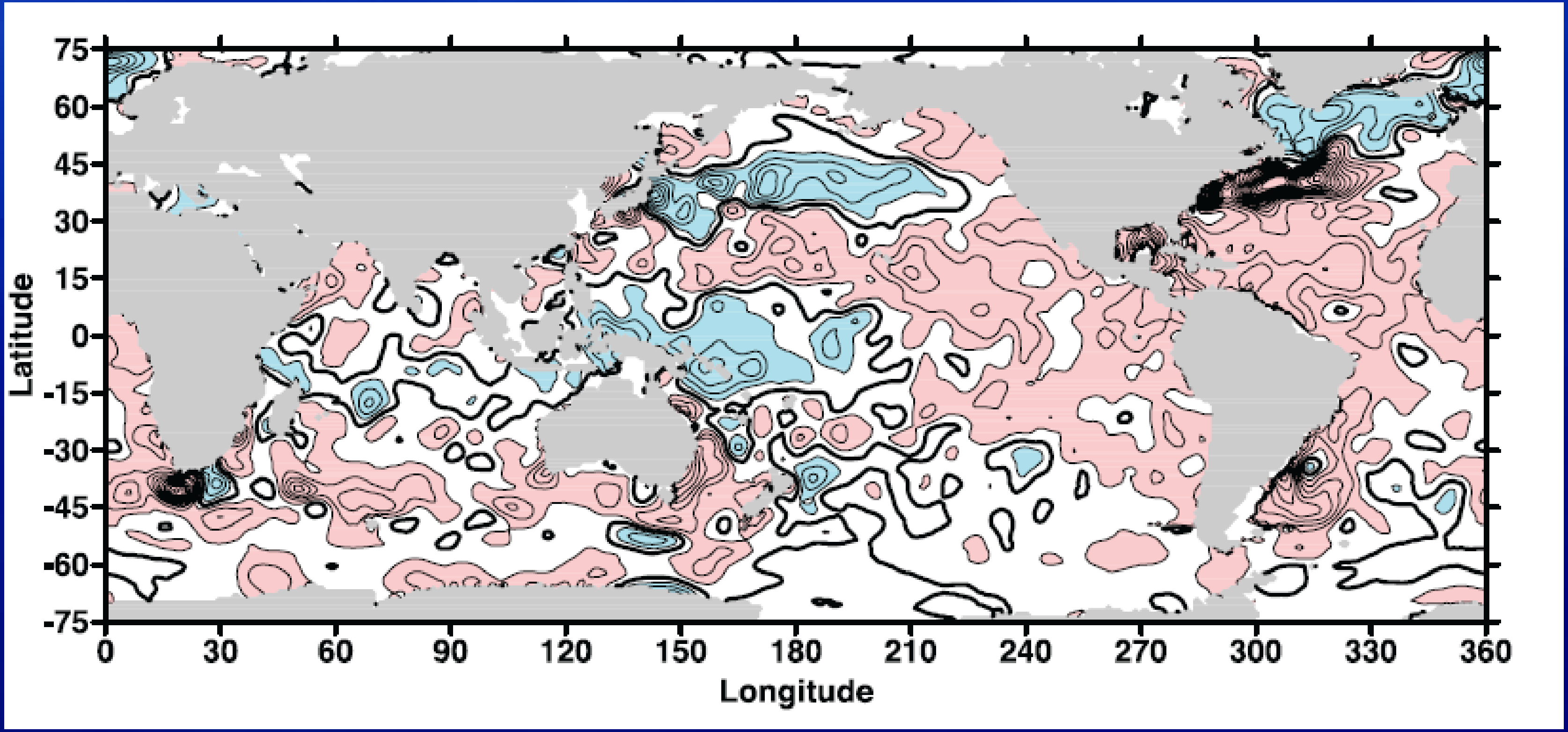
$$dT/dt = Q/(Cp h \rho)$$

Time series of global annual heat content change of the upper 700m

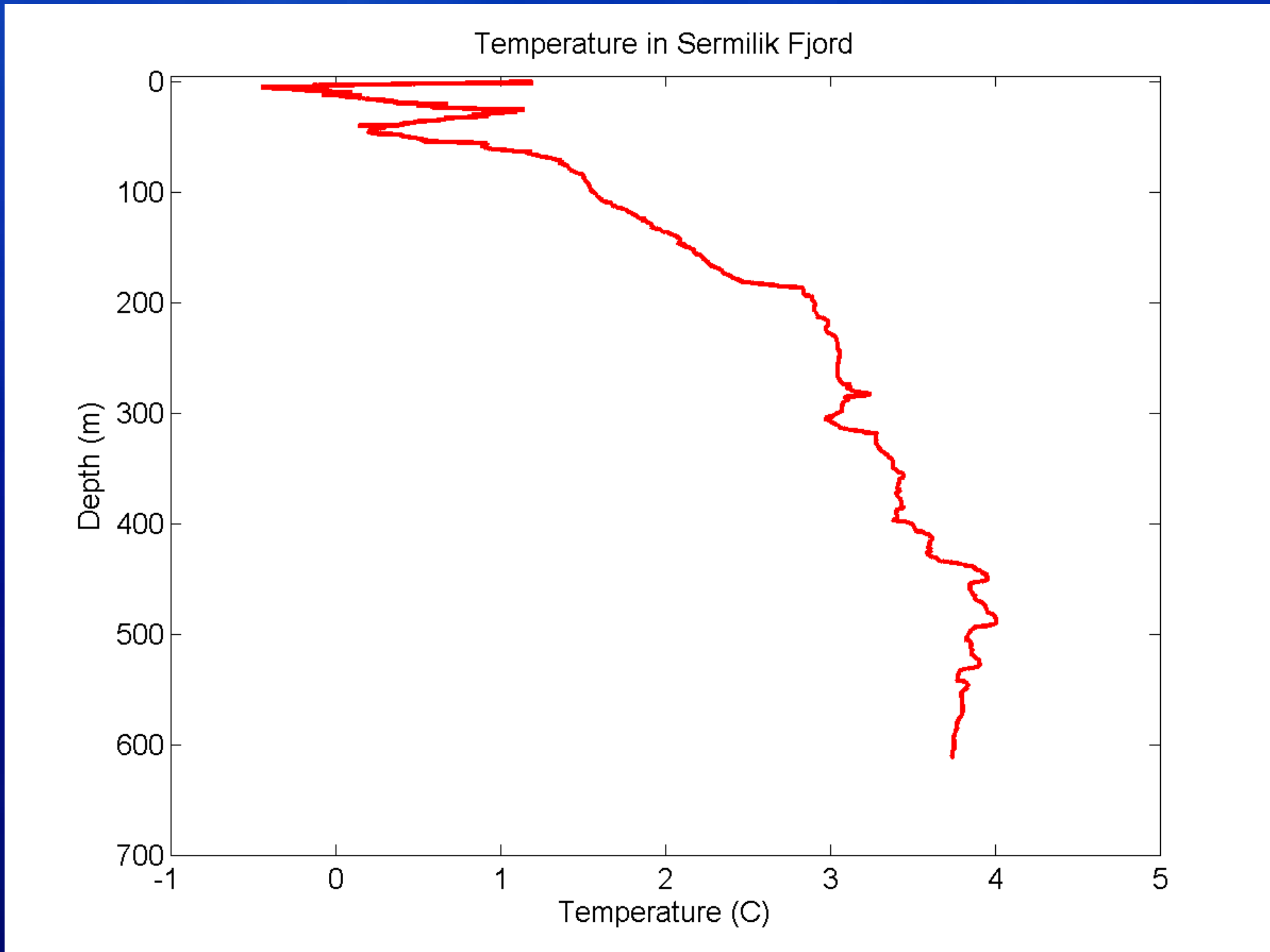


IPCC 2007 p. 390

Linear trend 1955-2003 of change in heat content per unit area of the upper 700m (W/m²) – contour interval is 0.25 W/m²



IPCC 2007 p. 391


Temperature in Sermilik Fjord
Depth (m)
0
100
200
300
400
500
600
700
-1
0
1
2
3
4
5
Temperature (C)

Measuring temperature (sub-surface)

-you need to go, or send an instrument, at the location
-you need an instrument

1880 - 1970
Reversing Thermometers
(expansion/contraction of a fluid as it warms/cools)

accurate to ~ 0.01 C

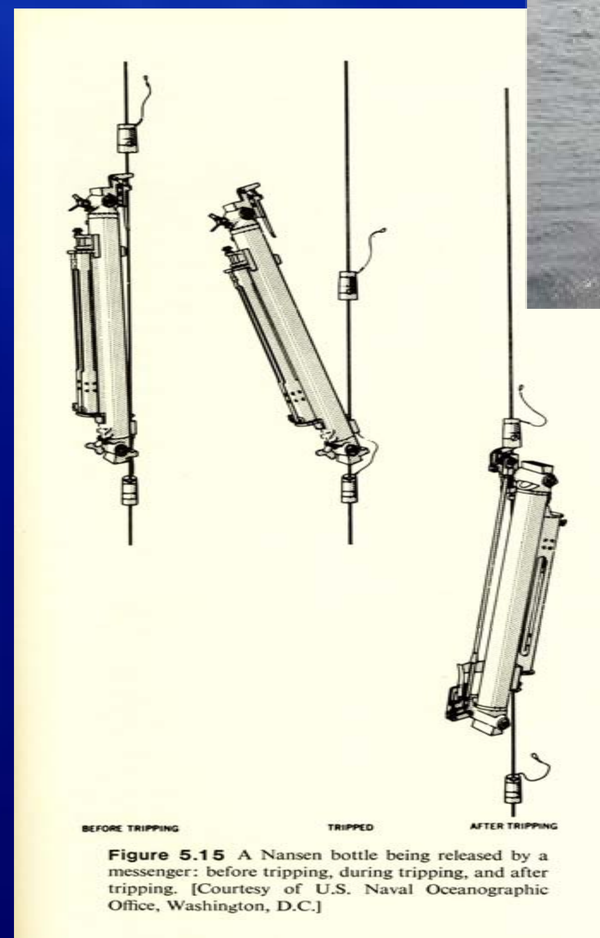


Figure 5.15 A Nansen bottle being released by a messenger: before tripping, during tripping, and after tripping. [Courtesy of U.S. Naval Oceanographic Office, Washington, D.C.]

photo from SEA

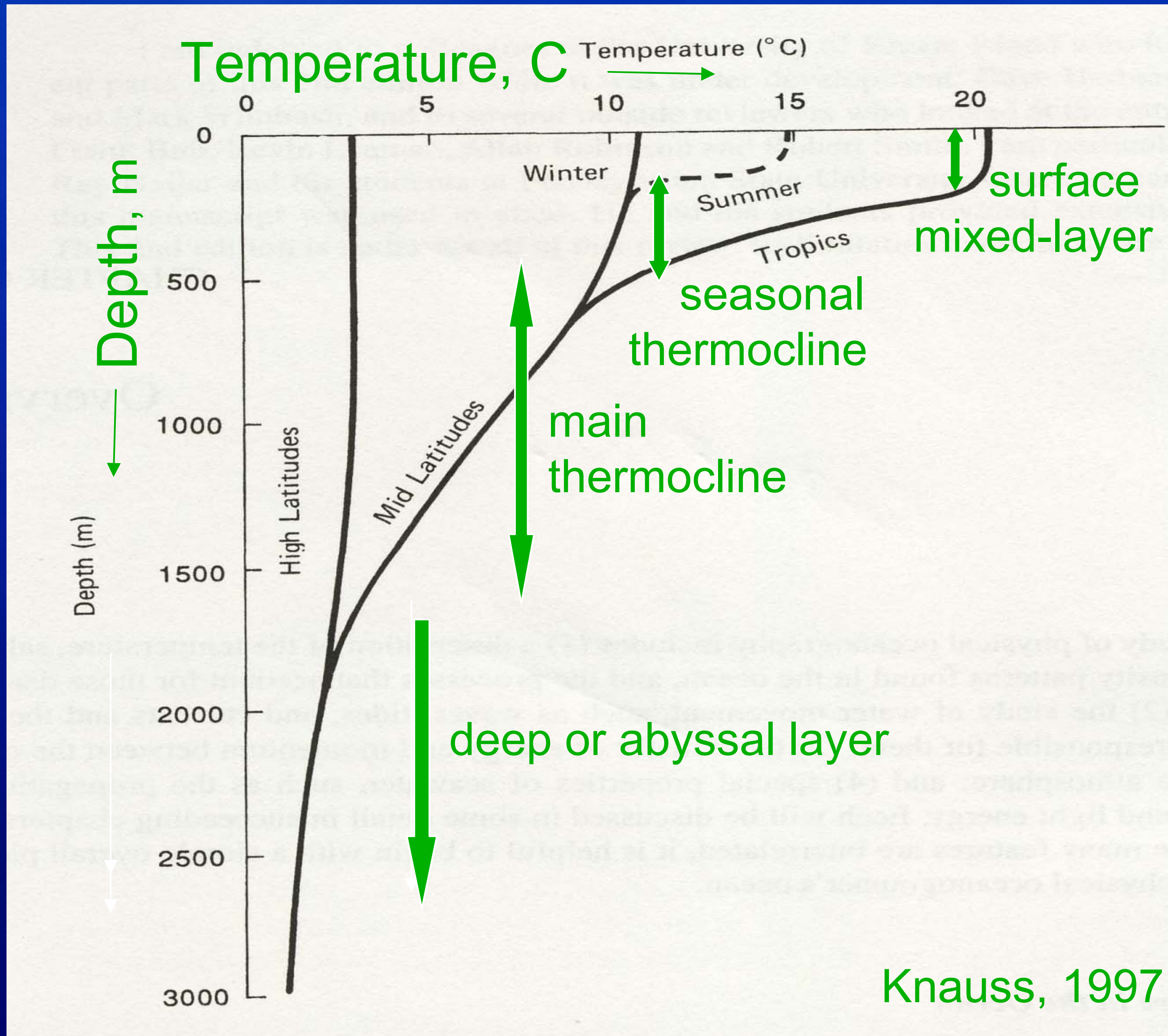
Measuring temperature (sub-surface)

-you need to go, or send an instrument, at the location
-you need an instrument

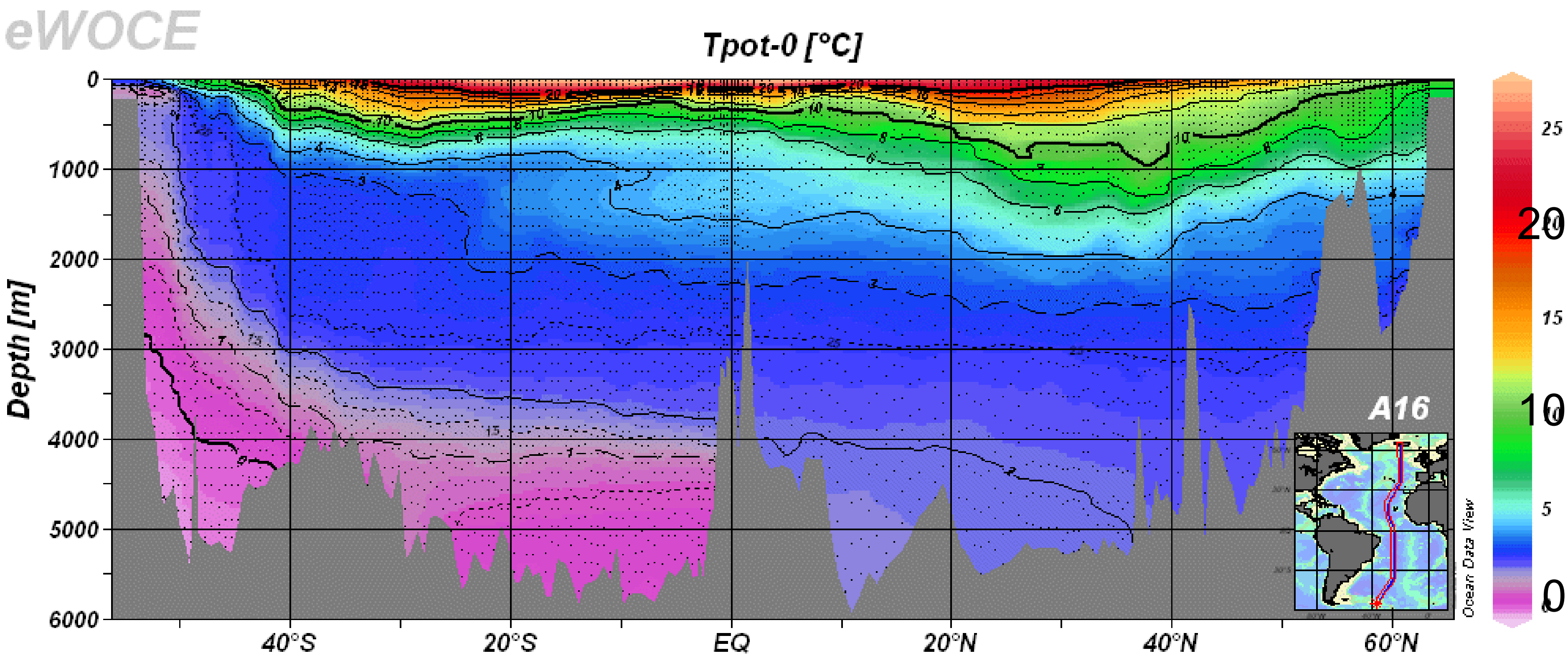
From ~ 1960
Thermistor: use the relation between the conductivity of metals/semiconductors and temperature. Accuracy 0.001 C

photo by R. Pickart

a typical vertical profile of temperature



a north to south section (z, y) of Potential Temperature, C

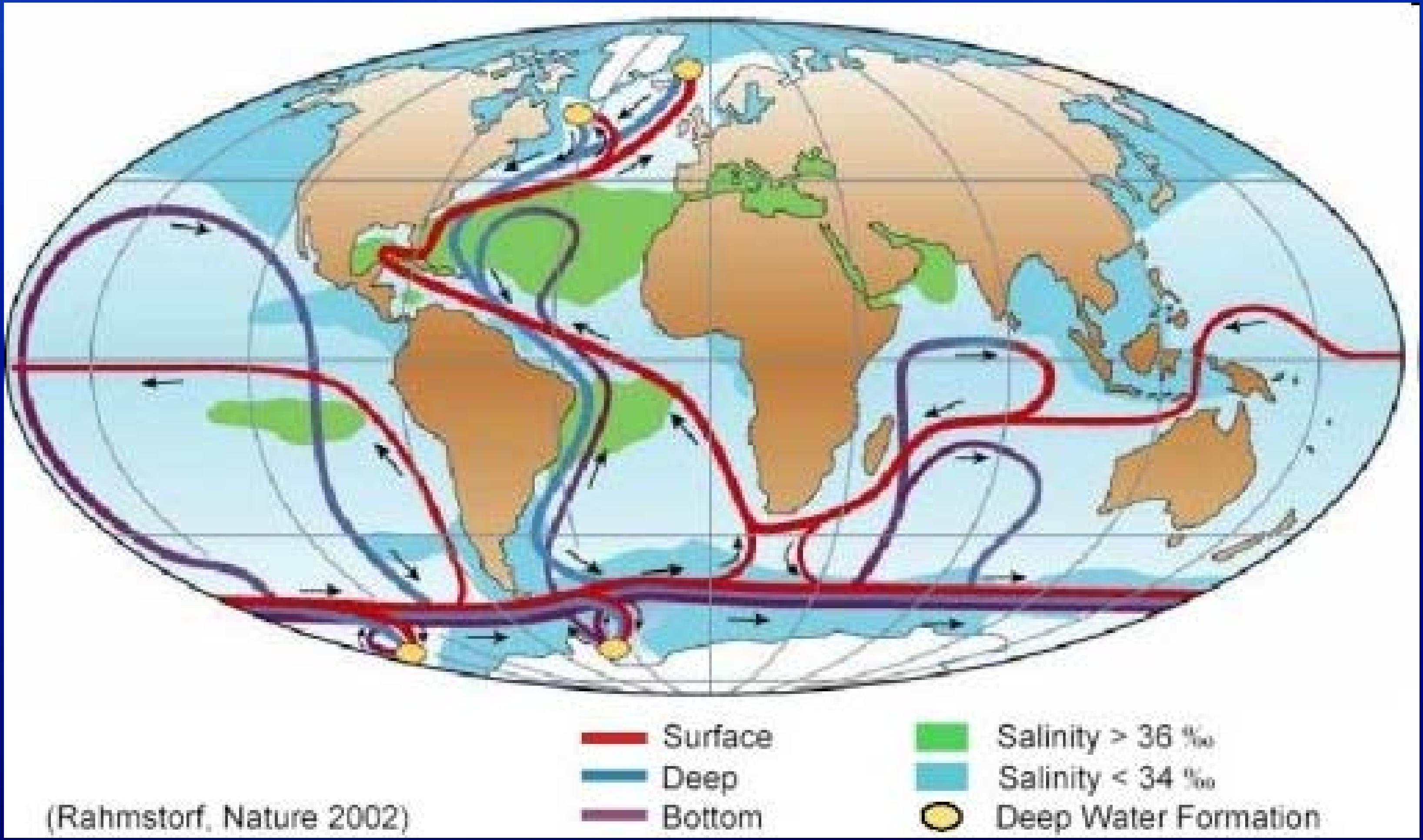


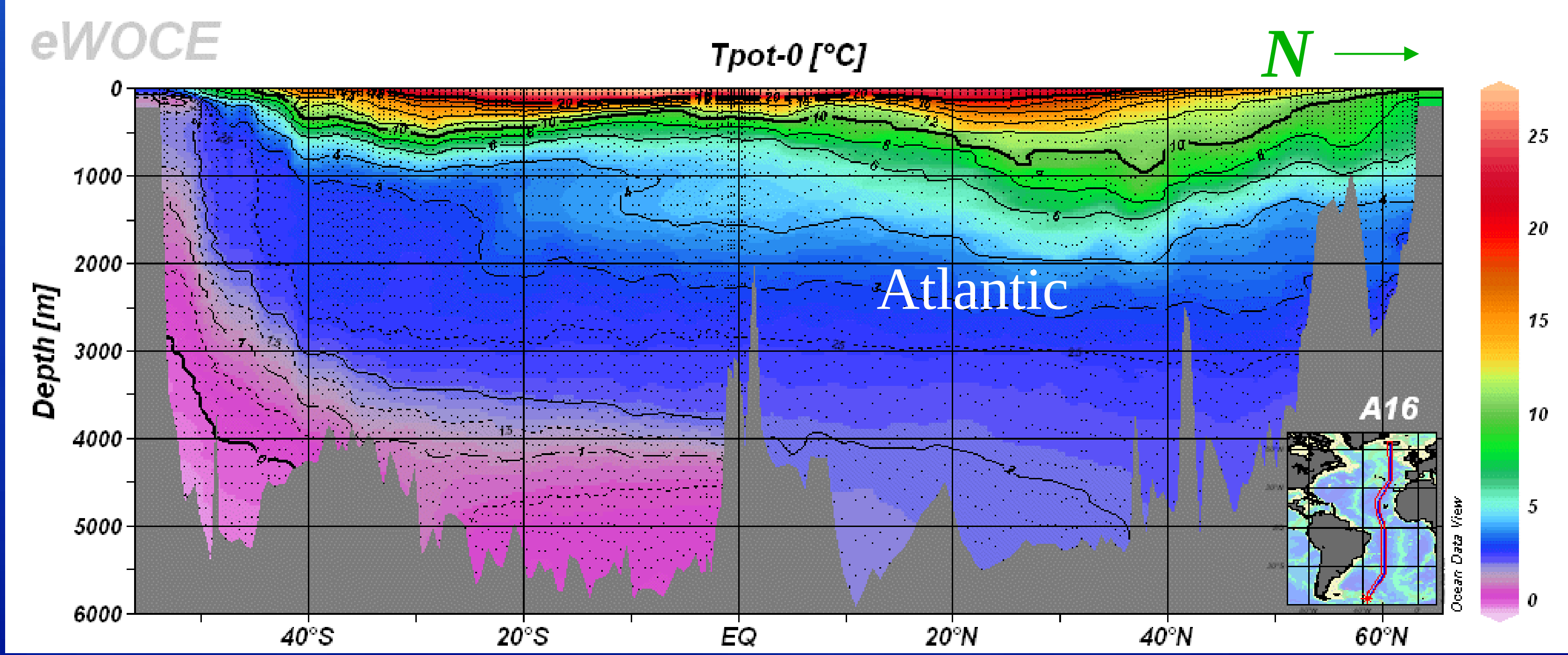
-1 C < T < 30 C at the surface

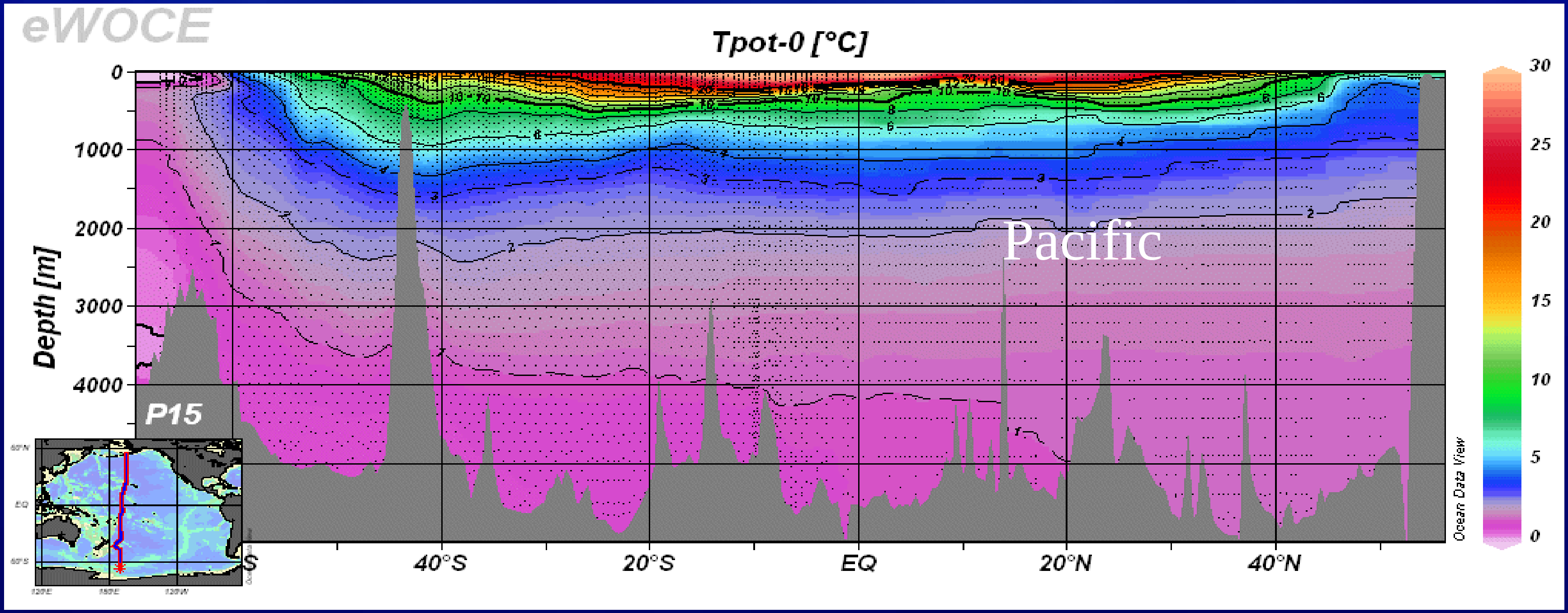
T < 3 C for depths > 1500 m

e-woce gallery

Thermohaline Circulation/Overturning Circulation







e-woce gallery

Salinity:

Measure of the amount of dissolved salts present in seawater

(note while the amount varies the relative concentrations are almost constant throughout the ocean).

Table 3.1 Average concentrations of the principal ions in seawater, in parts per thousand by weight.

Ion	‰ by weight		
chloride, Cl^-	18.980	negative ions (anions) total	= 21.861‰
sulphate, SO_4^{2-}	2.649		
bicarbonate, HCO_3^-	0.140		
bromide, Br^-	0.065		
borate, $H_2BO_3^-$	0.026		
fluoride, F^-	0.001		
sodium, Na^+	10.556	positive ions (cations) total	= 12.621‰
magnesium, Mg^{2+}	1.272		
calcium, Ca^{2+}	0.400		
potassium, K^+	0.380		
strontium, Sr^{2+}	0.013		
		overall total salinity	= 34.482‰

From Seawater, Its Composition ..

Surface Salinity Distribution Annual Mean

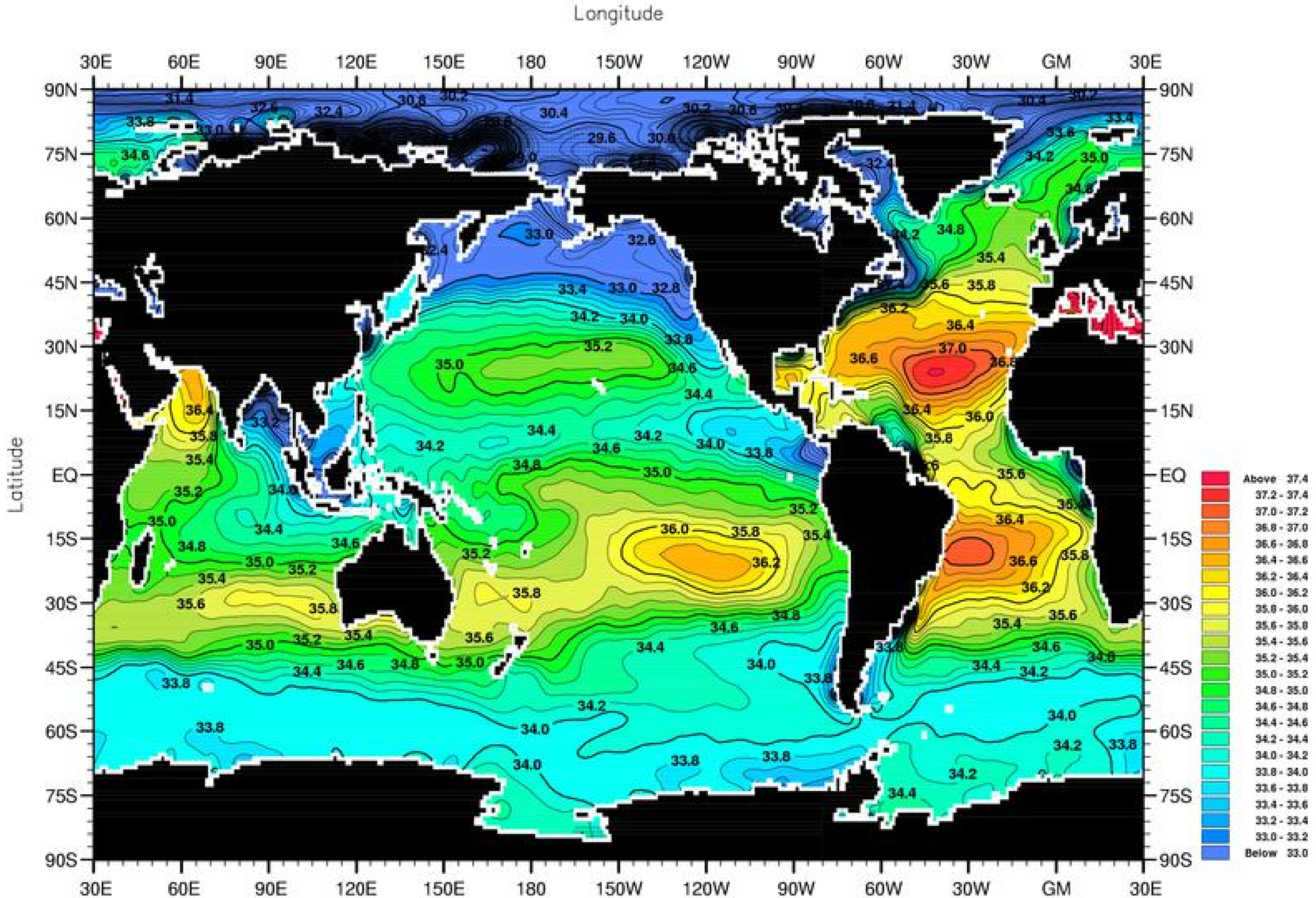


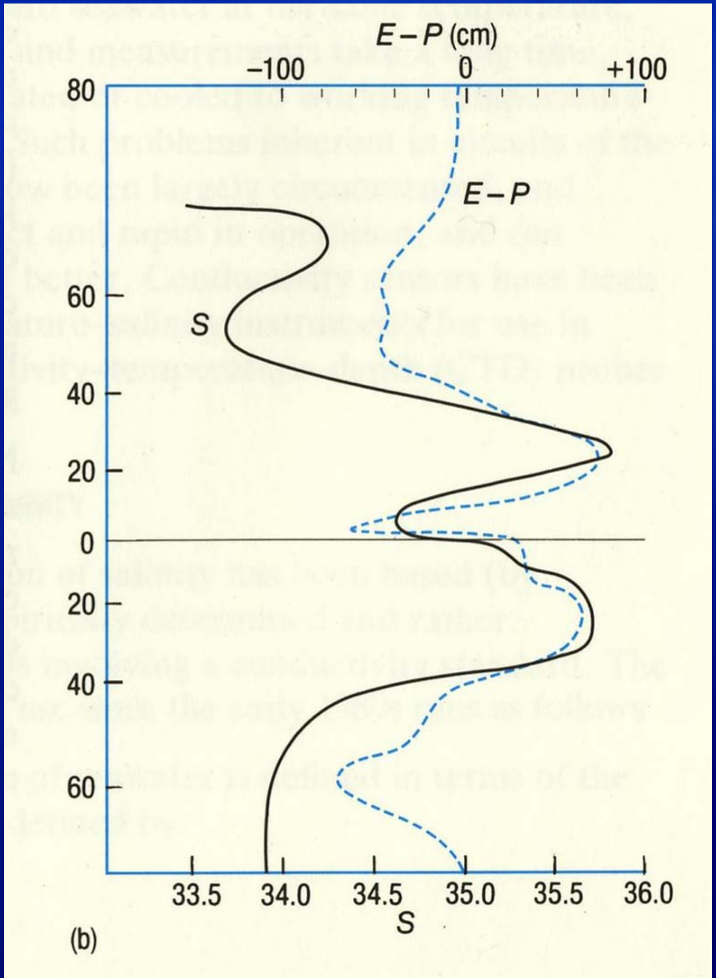
Fig. A2-1. Annual mean salinity (PSS) at the surface.

Minimum Value= 2.37 Maximum Value= 40.37 Contour Interval: 0.20

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

Distribution of sea surface salinity

Salinity variations are mainly due to fresh water subtracted or added at the the surface by evaporation and precipitation, E - P, and continental runoff.

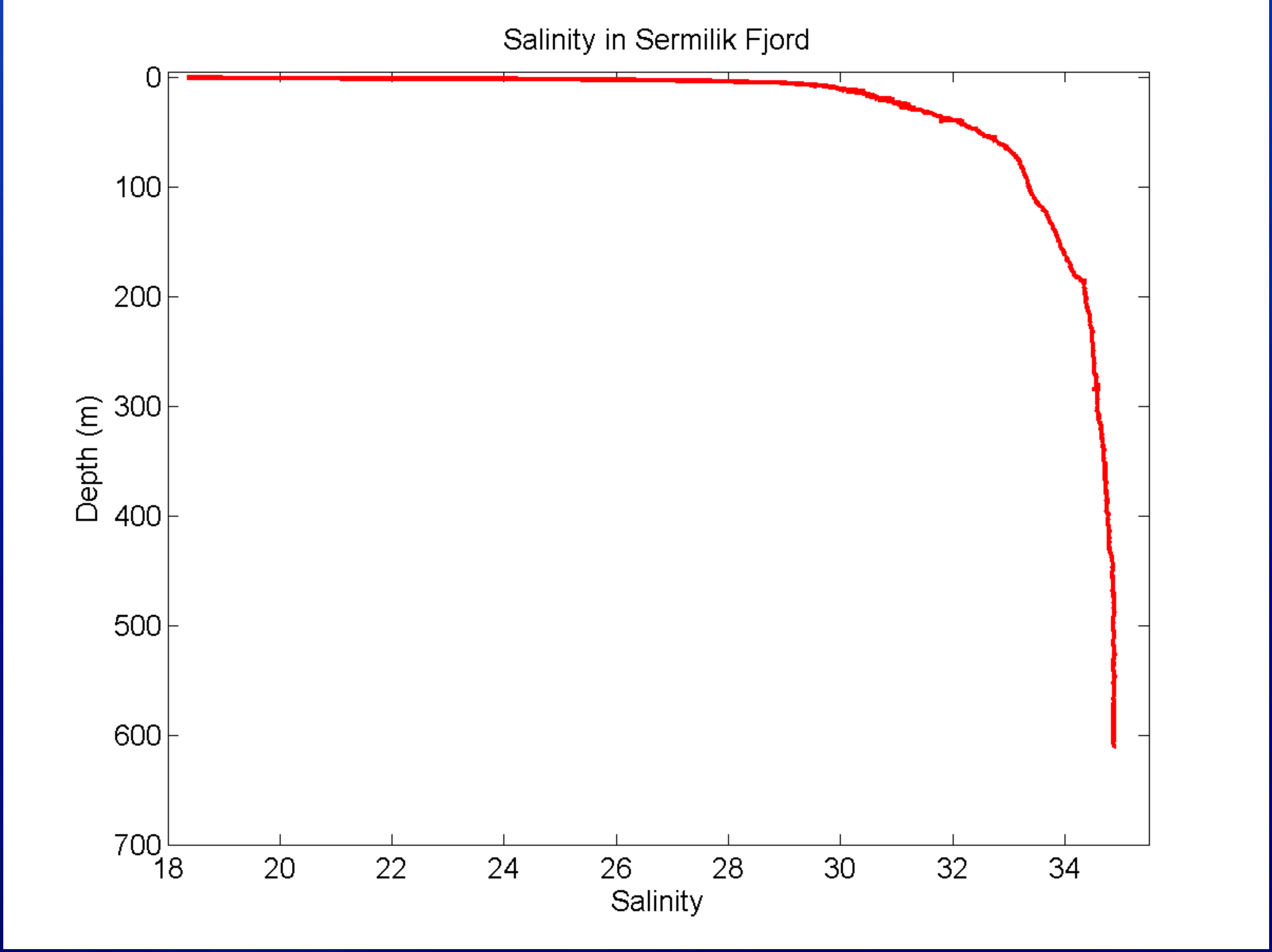


from Seawater: Its Composition ..

Why does salinity matter?

- Influence on density (dynamics, stability)

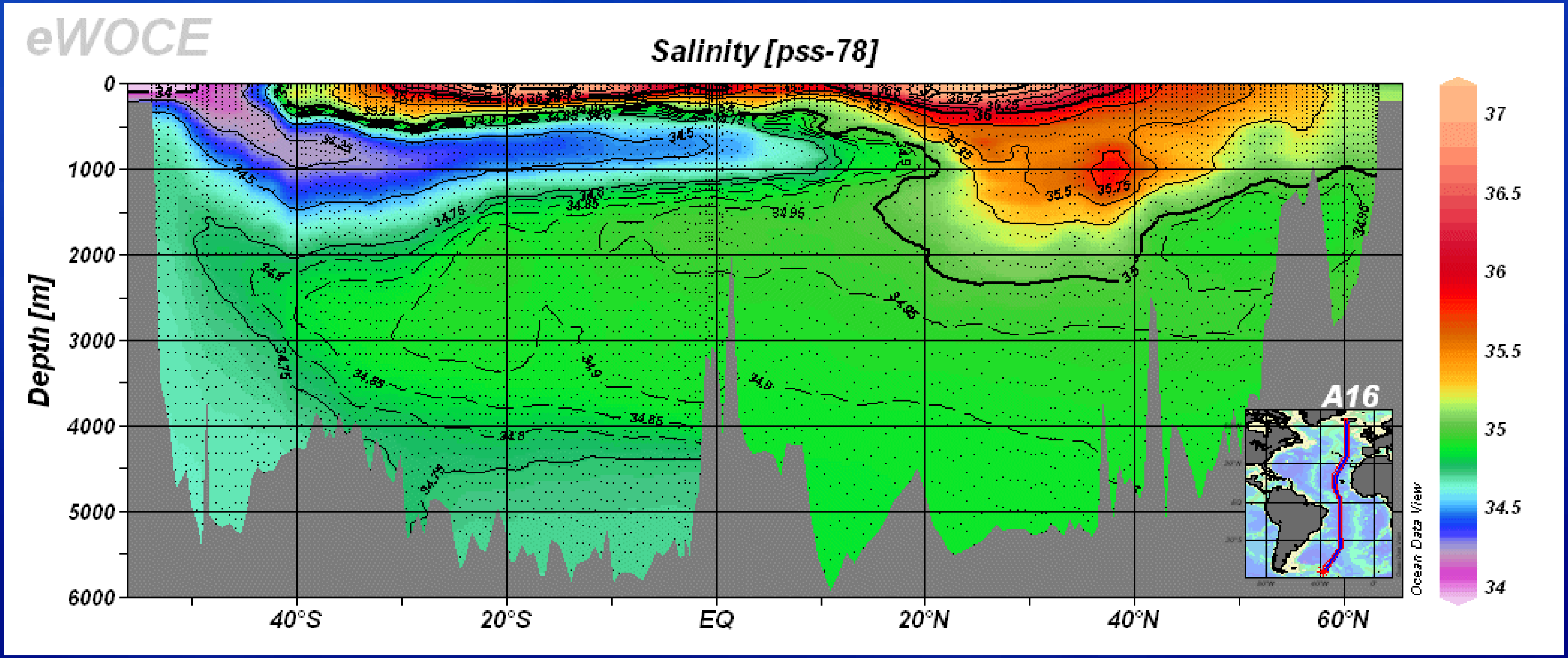
- Some influence on life in the ocean
(especially in extreme environments such as estuaries)

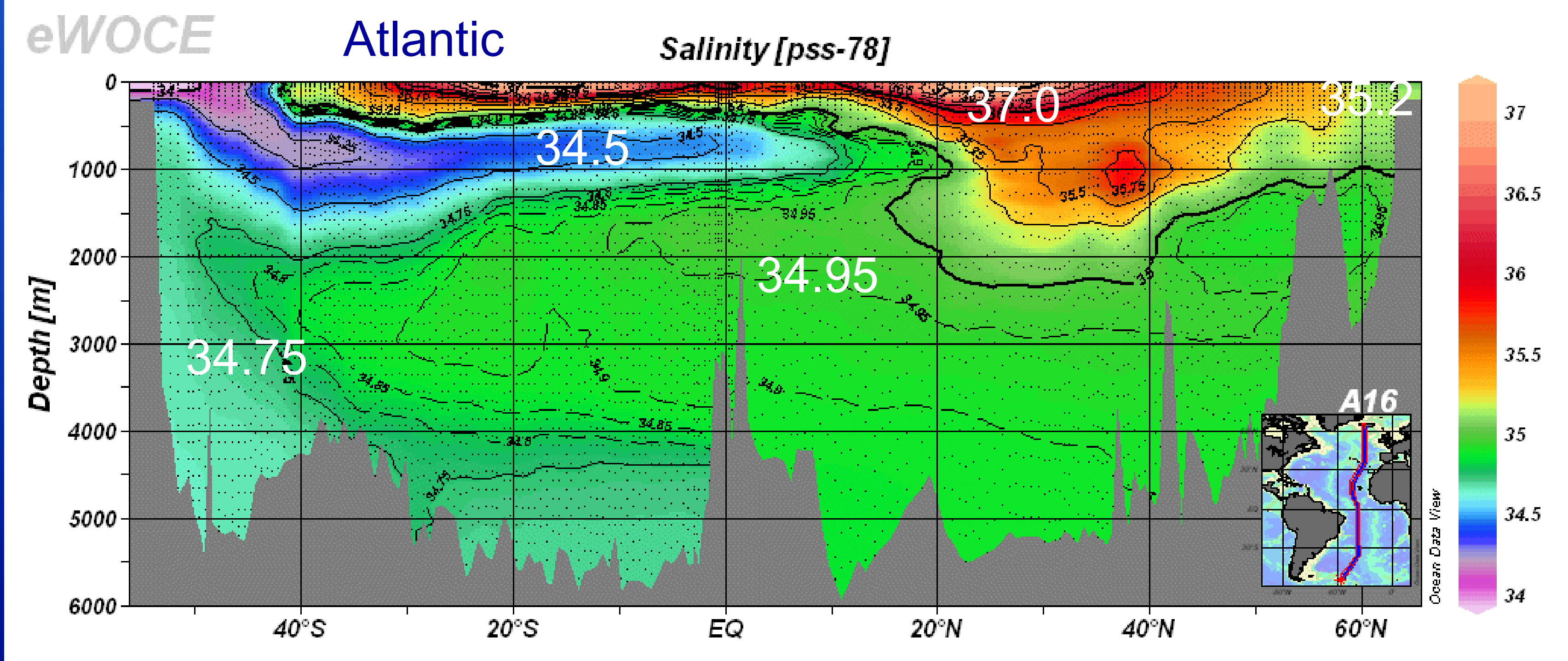


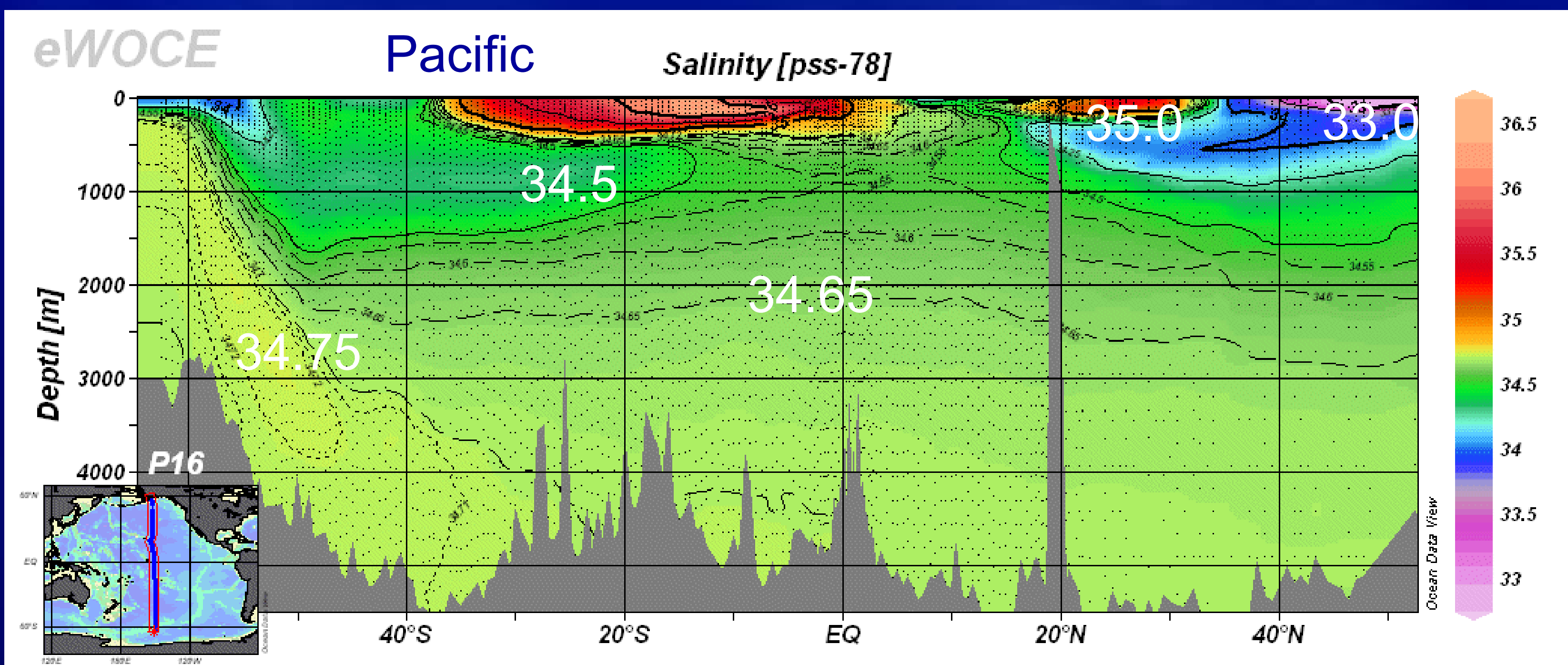
Salinity in Sermilik Fjord
Depth (m)
0
100
200
300
400
500
600
700
18
20
22
24
26
28
30
32
34
Salinity

North Atlantic

N →







(color scale is different)

How do we measure salinity:

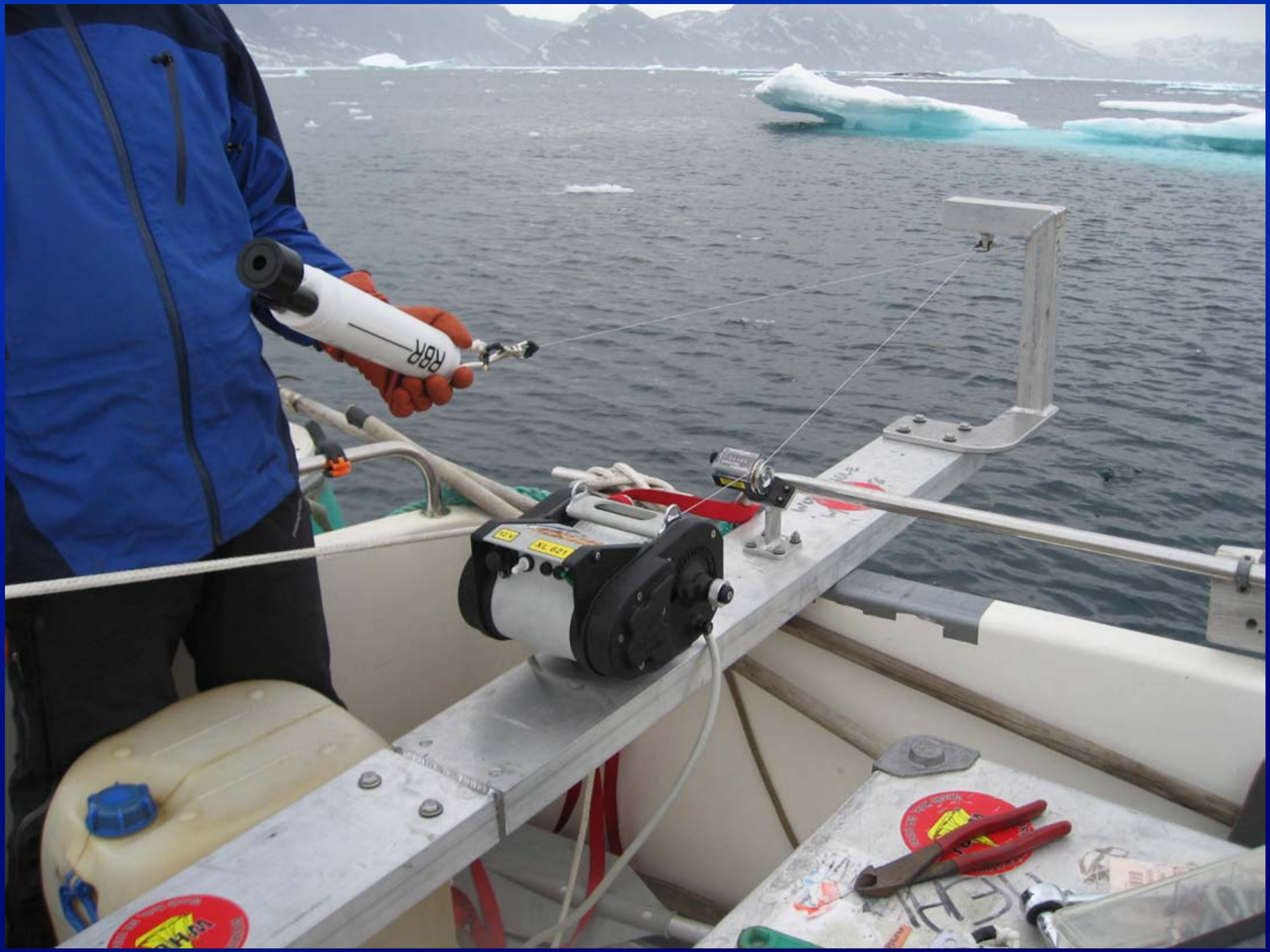
Historically: fresh water was evaporated to determine the mass of the salts (slow, inaccurate)

More Recently: titrate to find the amount of chlorine (labor intensive and expensive)

Current: Measure conductivity and use the relation between S and the conductivity of seawater, removing the effect of T. Carefully calibrated CTDs can achieve accuracy of about 0.002.

Salinity has non-dimensional units e.g., S = 36.4 , but it is not unusual to see 36.4 psu (practical salinity units).

Salinity Measurements in Sermilik Fjord



How does salinity change?

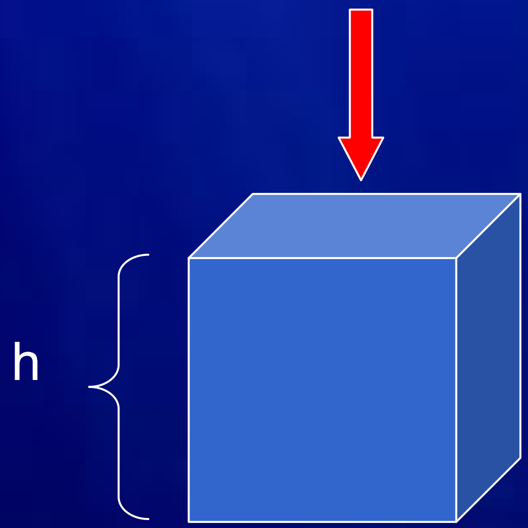
Changes in salinity are primarily governed by the addition/removal of fresh water instead of the addition/removal of salt

Fresh water changes are primarily due to

1) E-P, evaporation minus precipitation,
2) sea-ice formation and melt,
3) river-run off and glacial melt

Fresh water addition/removal is expressed as a:

F_{fw} = volume flux [volume/(time area)] = [length/time].



E nonzero means water loss

P nonzero means water gain

E – P can have either sign;

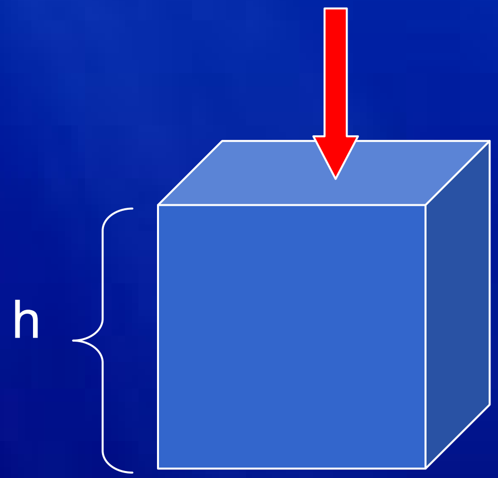
E - P > 0 is an excess of evaporation

significant values are 1 m/year

How does salinity change?

The addition/removal of fresh water will change the volume (i.e. the thickness h, assuming A is constan

$$dh/dt = F_{fw}$$



But the amount of salt must be conserved:

$$d(hS)/dt = S\,dh/dt + h\,dS/dt = 0, \text{ or}$$

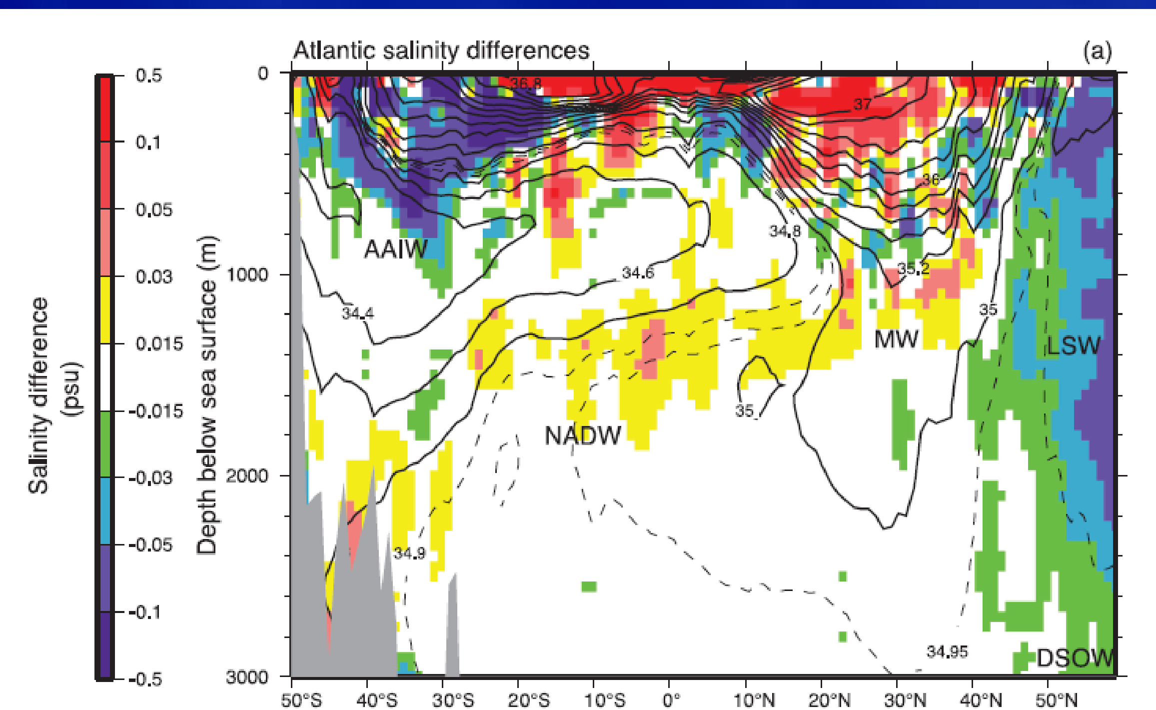
$$dS/dt = -(S/h)dh/dt = -(S/h)\,F_{fw}$$

For example – if $F_{fw} = -(E-P)$

Net Evaporation will cause an increase in salinity,
Net Precipitation will cause a decrease in salinity.

Large-scale, coherent trends of salinity are observed for 1955 to 1998, and are characterised by a global freshening in subpolar latitudes and a salinification of shallower parts of the tropical and subtropical oceans. Freshening is pronounced in the Pacific while increasing salinities prevail over most of Atlantic and Indian Oceans. These trends are consistent with changes in precipitation and inferred larger water transport in the atmosphere from low latitudes to high latitudes and from the Atlantic to the Pacific. Observations do not allow for a reliable estimate of the global average change in salinity in the oceans.

IPCC 2007 – p. 387



Salinity Difference

between mean

1985-1999 minus 1955-1969

IPCC 2007 – p. 395 (redrawn from Curry et al. 2003)

The first homework project.

1) Assuming the area of the ocean of 361 million square kilometers and given the global heat content change curve from the IPCC report, what is the associated mean global temperature change of the upper 700m?

2) How large would the net mean surface flux over the ocean have to be to induce this change?

3) Given the global ocean's average salinity of 35, how would it change if all of the Greenland Ice Sheet melted?