Propriedades Físicas da Água do Mar

- Temperatura
  - Variação - amplitude
  - Métodos de determinação
  - Distribuição horizontal superficial
  - Distribuição vertical
  - Temperatura potencial
- Salinidade
  - Conceito
  - Variação - amplitude
  - Métodos de determinação
  - Distribuição horizontal superficial
  - Distribuição vertical
- Densidade
  - Conceito, anomalias, volume específico
  - Variação – amplitude
  - Métodos de determinação
  - Distribuição horizontal superficial
  - Distribuição vertical
  - Estabilidade/Instabilidade

Presença do sal na água do mar: impactos

- Altera:
  - Viscosidade
  - Compressibilidade – propagação do som
  - Índice de refração da luz
  - Densidade
  - Temperatura de máxima densidade
  - Ponto de congelamento

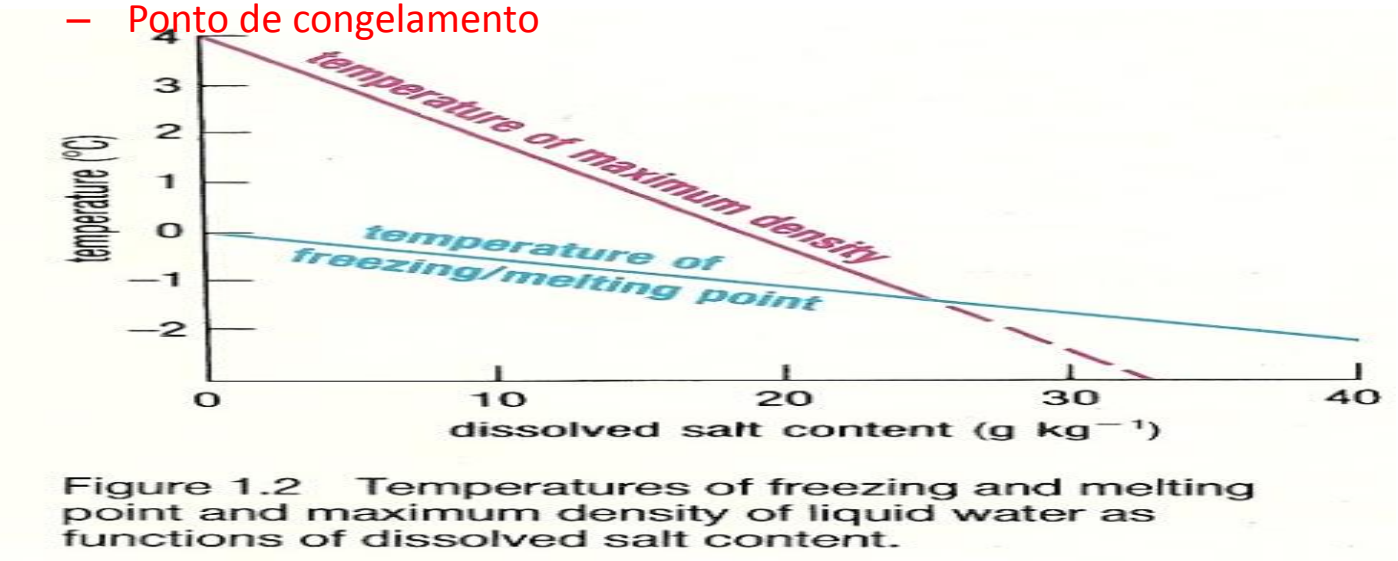
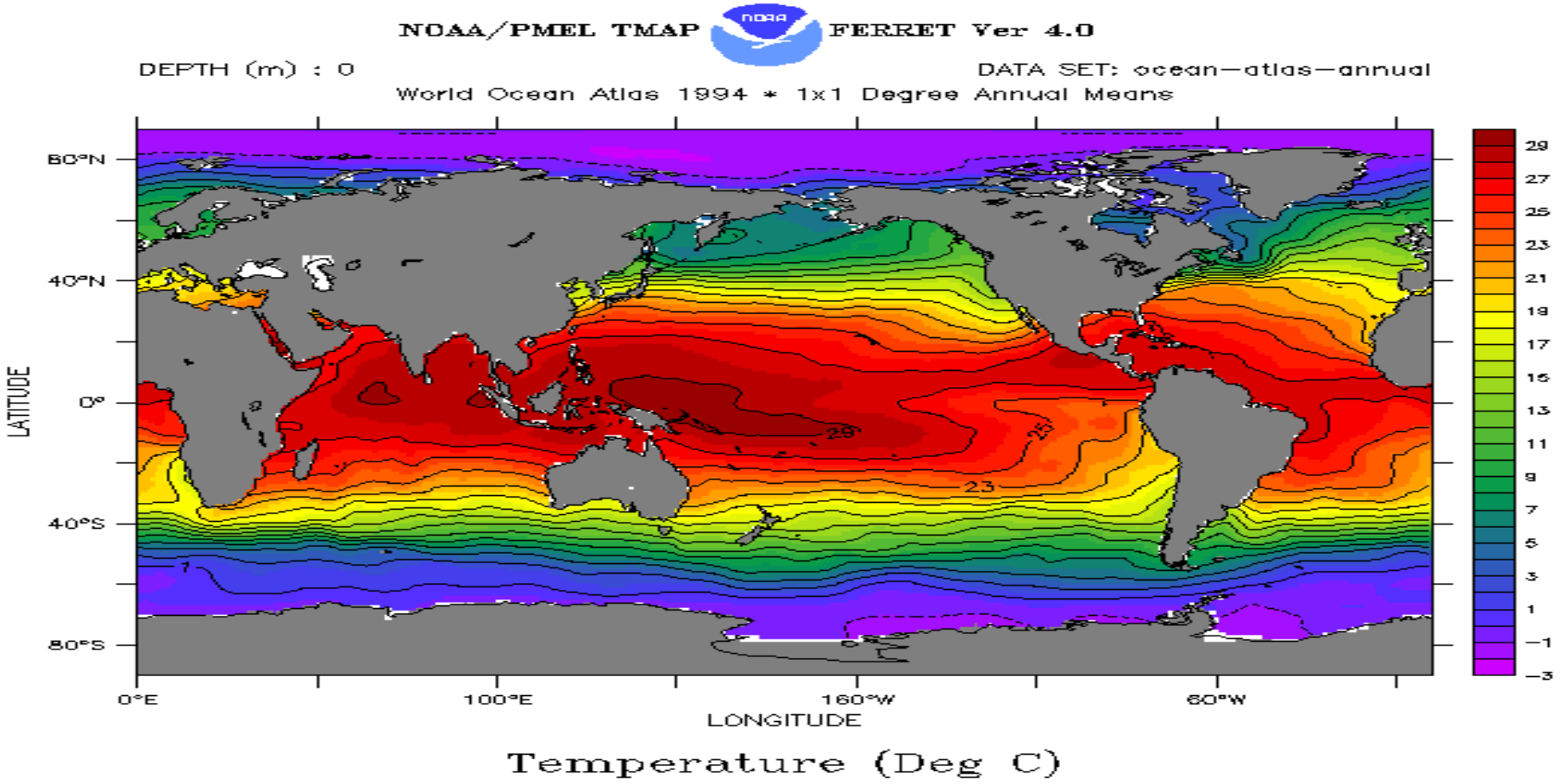


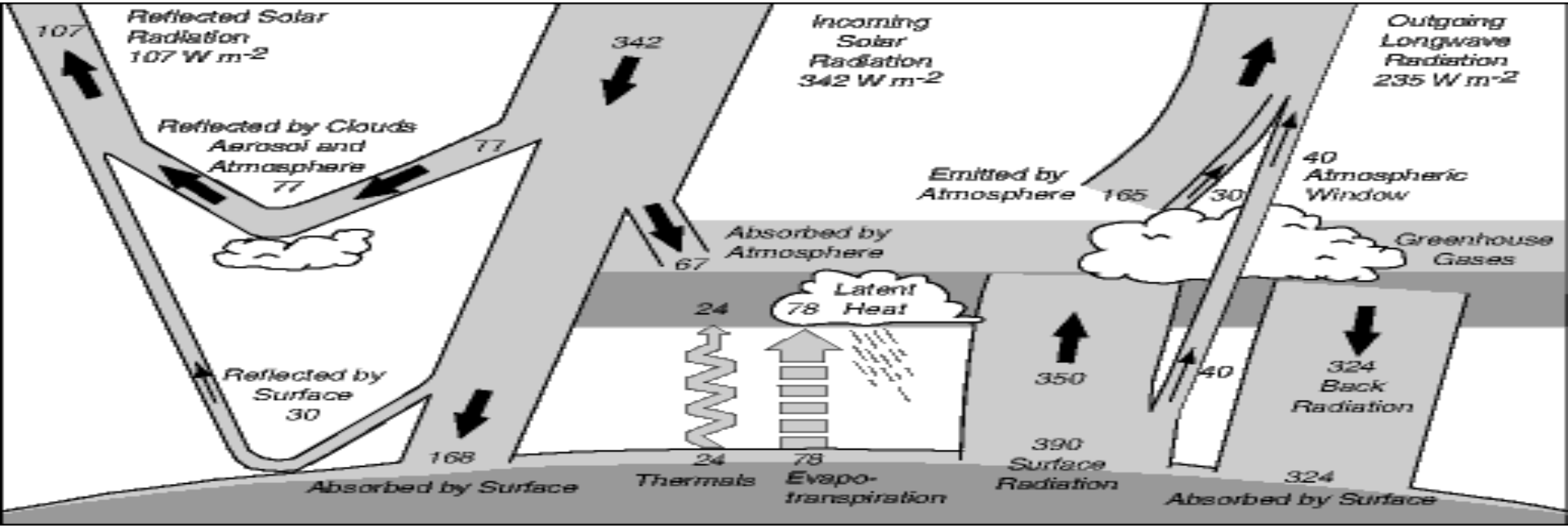
Figure 1.2 Temperatures of freezing and melting point and maximum density of liquid water as functions of dissolved salt content.

Temperatura da Água do Mar



Mean sea-surface temperature calculated from the optimal interpolation technique (Reynolds and Smith, 1995) using shipreports and AVHRR measurements of temperature. Contour interval is1° C with heavy contours every 5° C. Shaded areas exceed 29° C.

Balanço de Calor



The mean annual radiation and heatbalance of the earth. From Houghton et al. (1996: 58), which used data from Kiehl and Trenberth (1996).

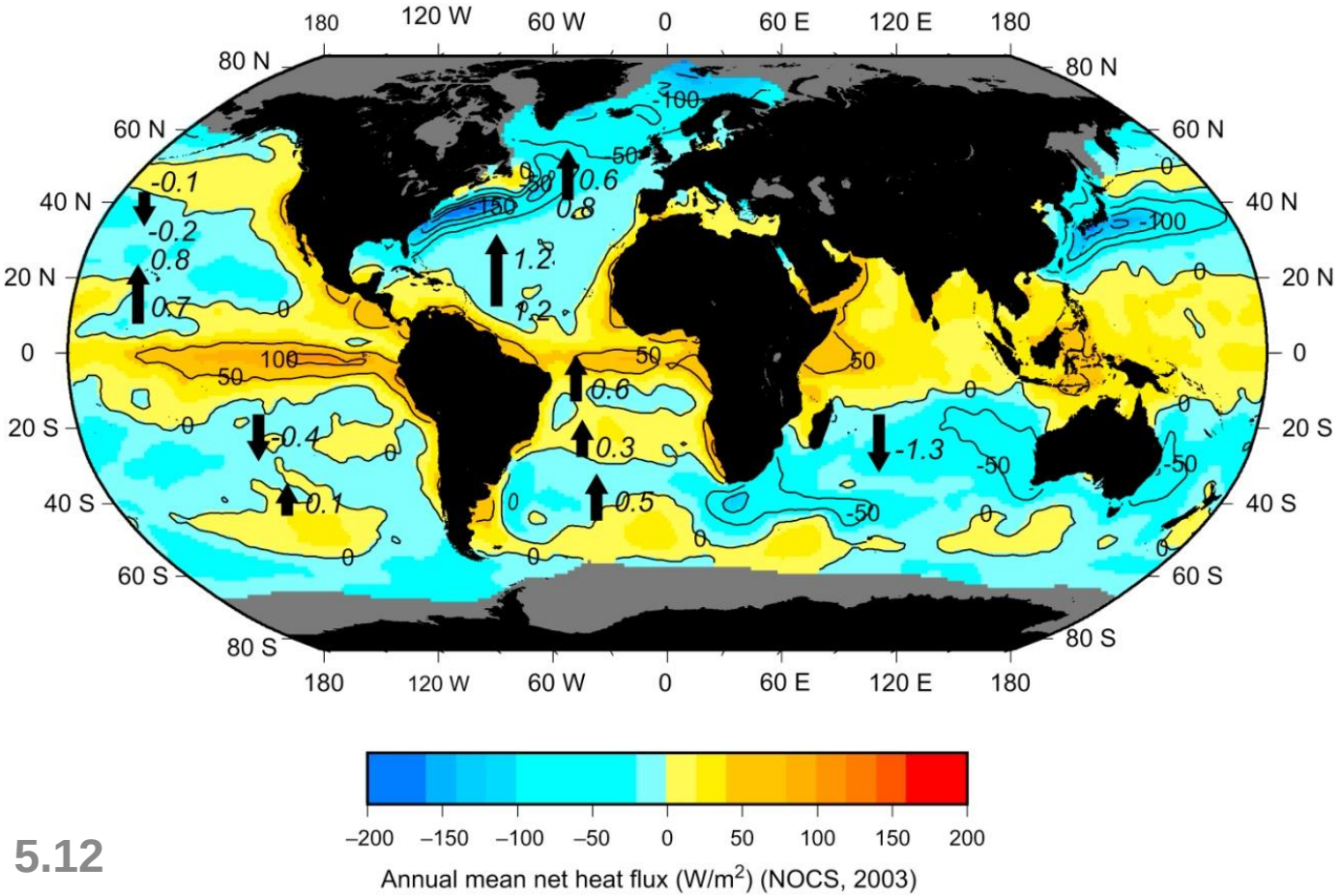


FIGURE 5.12

Annual average net heat flux (W/m^2). Positive: heat gain by the sea. Negative: heat loss by the sea. Data are from the NOCS climatology (*Grist and Josey, 2003*). Superimposed numbers and arrows are the meridional heat transports (PW) calculated from ocean velocities and temperatures, *based on Bryden and Imawaki (2001) and Talley (2003)*. Positive transports are northward. The online supplement to Chapter 5 (Figure S5.8) includes another version of the annual mean heat flux, from Large and Yeager (2009). This figure can also be found in the color insert.

Garrafas de Nansen e de Niskin

Nansen water bottles before (I), during (II), and after (III) reversing. (From Dietrich et al. 1980)

Fig. 6.16. Water sampling bottles (Nansen bottles), circa 1960 for mounting individually on a wire with reversing thermometer racks.

Fig. 6.17. Single Niskin bottle

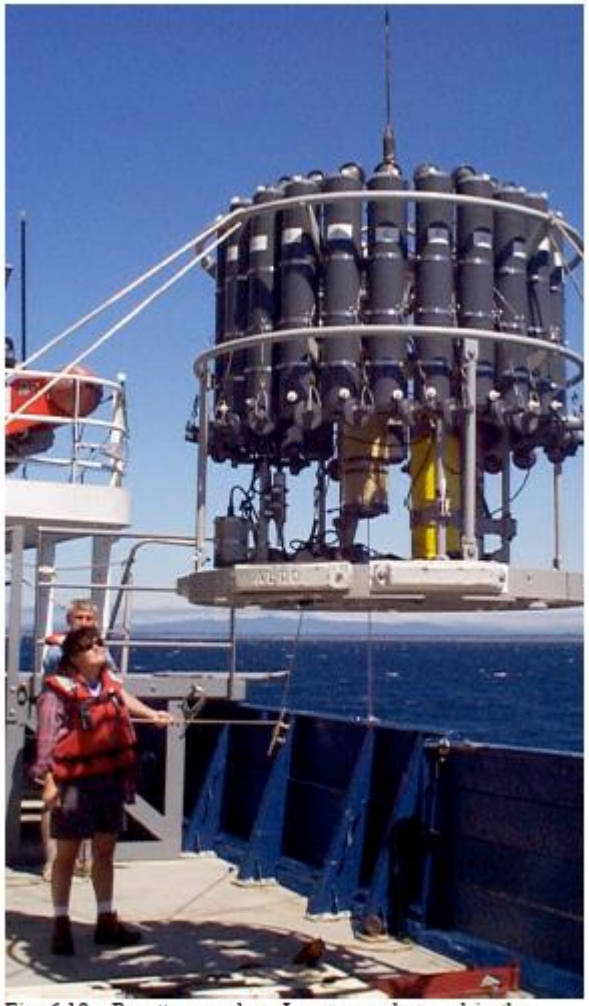


Fig. 6.18. Rosette sampler. Large sampler used in the World Ocean Circulation Experiment, with 36 10-liter Niskin bottles, an acoustic pinger (lower left), an LADCP (center, yellow long), a CTD (bottom, horizontal), and transmissometer (center, yellow short).

Termômetros de inversão

Nansen water bottles before (I), during (II), and after (III) reversing. (From Dietrich et al. 1980)

Fig. 6.16. Water sampling bottles (Nansen bottles), circa 1960 for mounting individually on a wire with reversing thermometer racks.

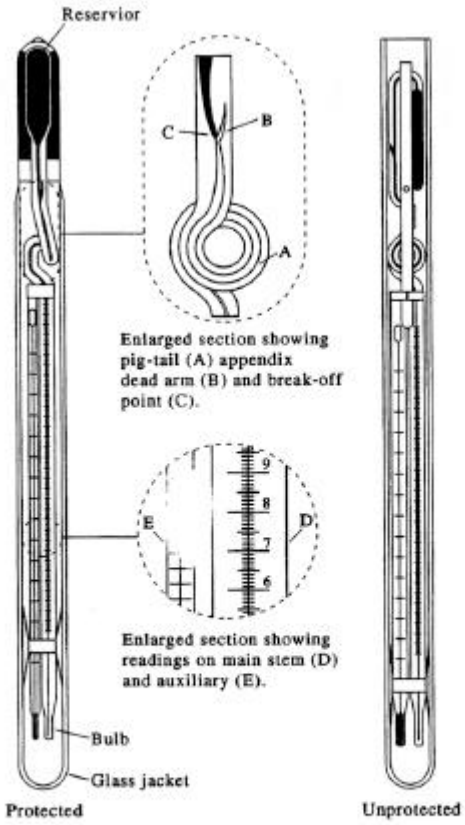


Fig. 6.21. Protected and unprotected reversing thermometers.

Fig. 6.22. Reading reversing thermometers

Métodos de medição

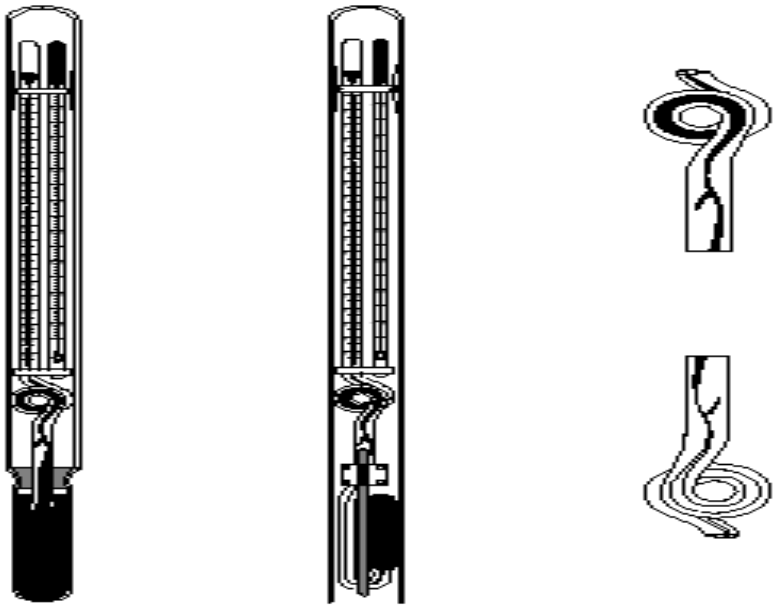
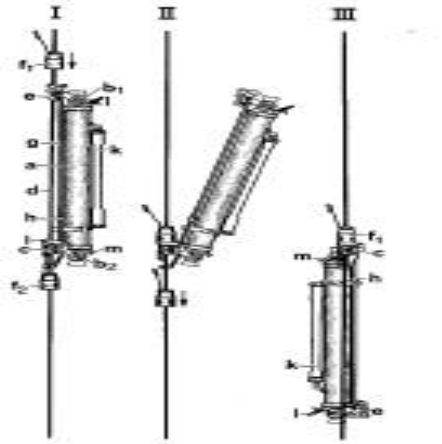
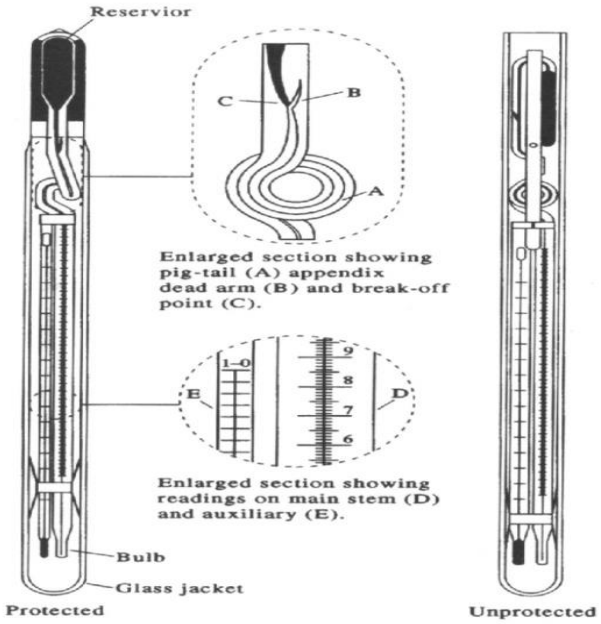


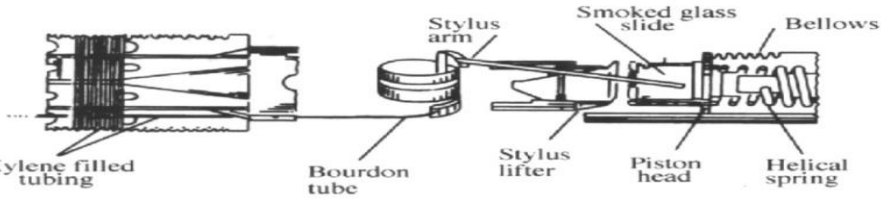
Figure 6.13 **Left**: Protected and unprotected reversing thermometers is set position, before reversal. **Right**: The constricted part of the capillary in set and reversed positions (From von Arx, 1962).

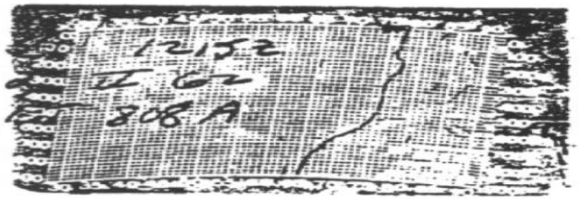




Temperature element

Pressure element





Bati-Termógrafo mecânico

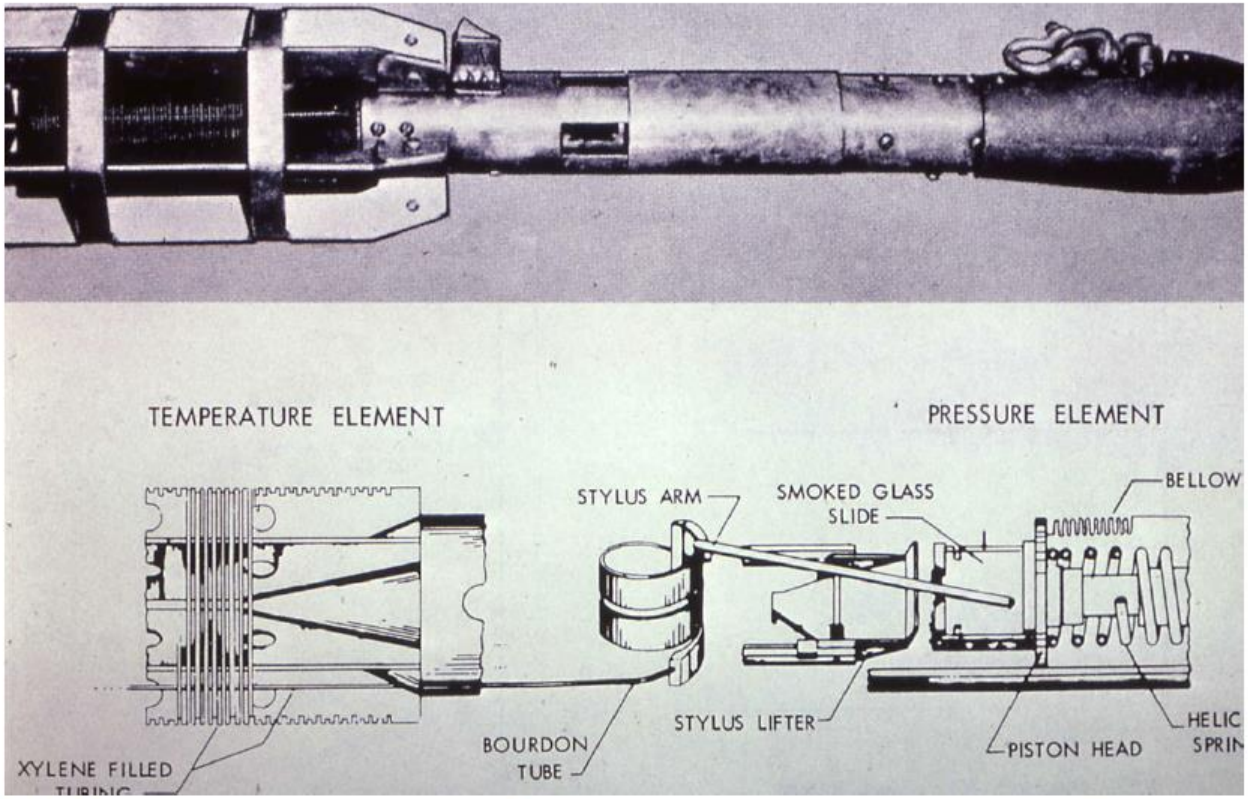
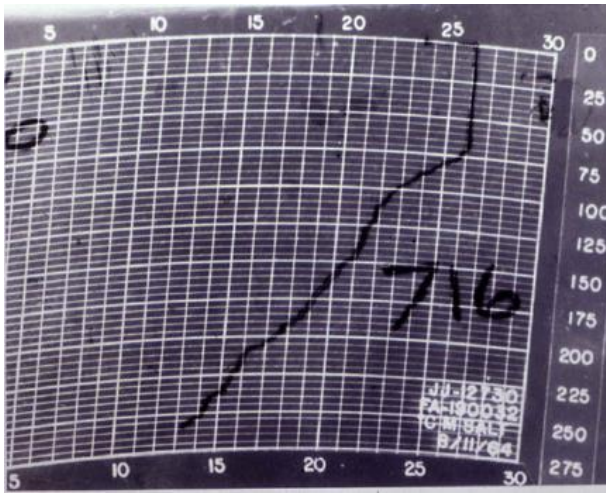
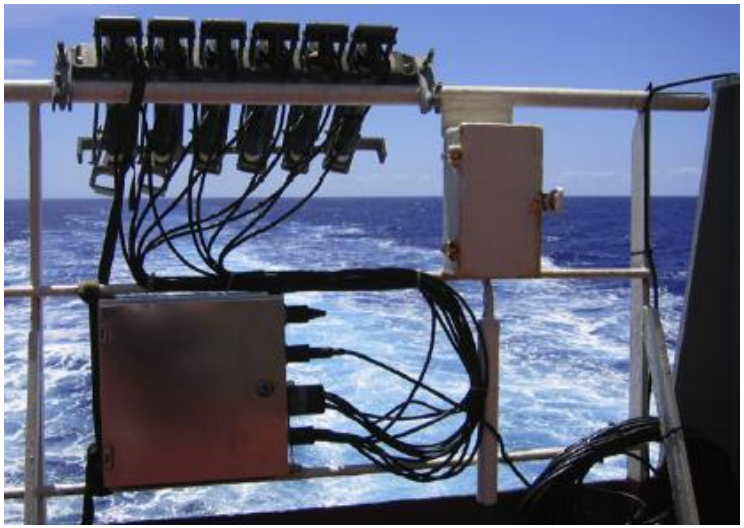
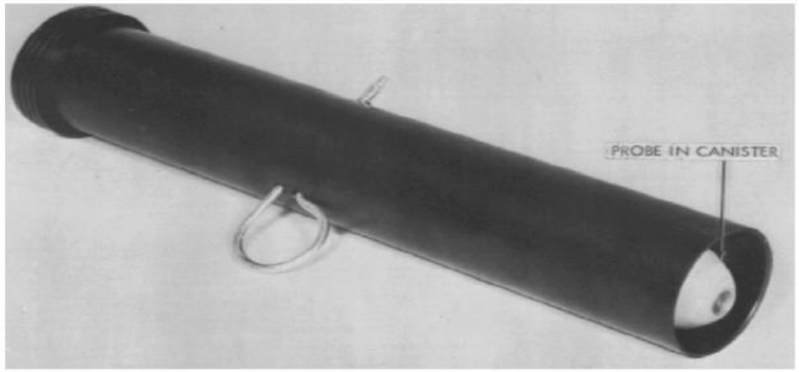
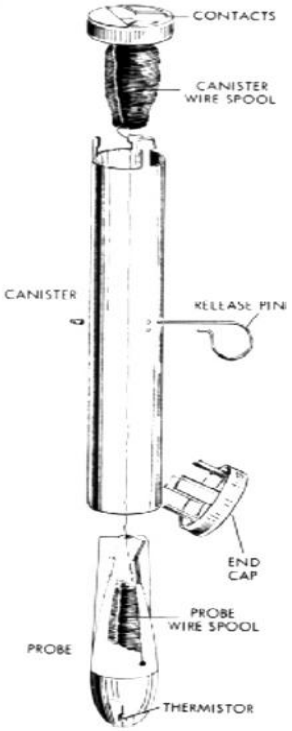


FIGURE S16.16 Mechanical bathythermograph (MBT), in use from 1951 to 1975. *Source: Neumann and Pierson (1966).*



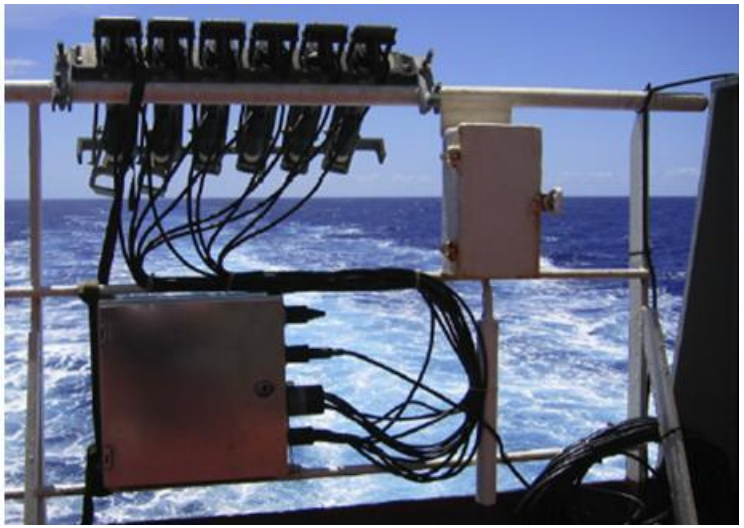


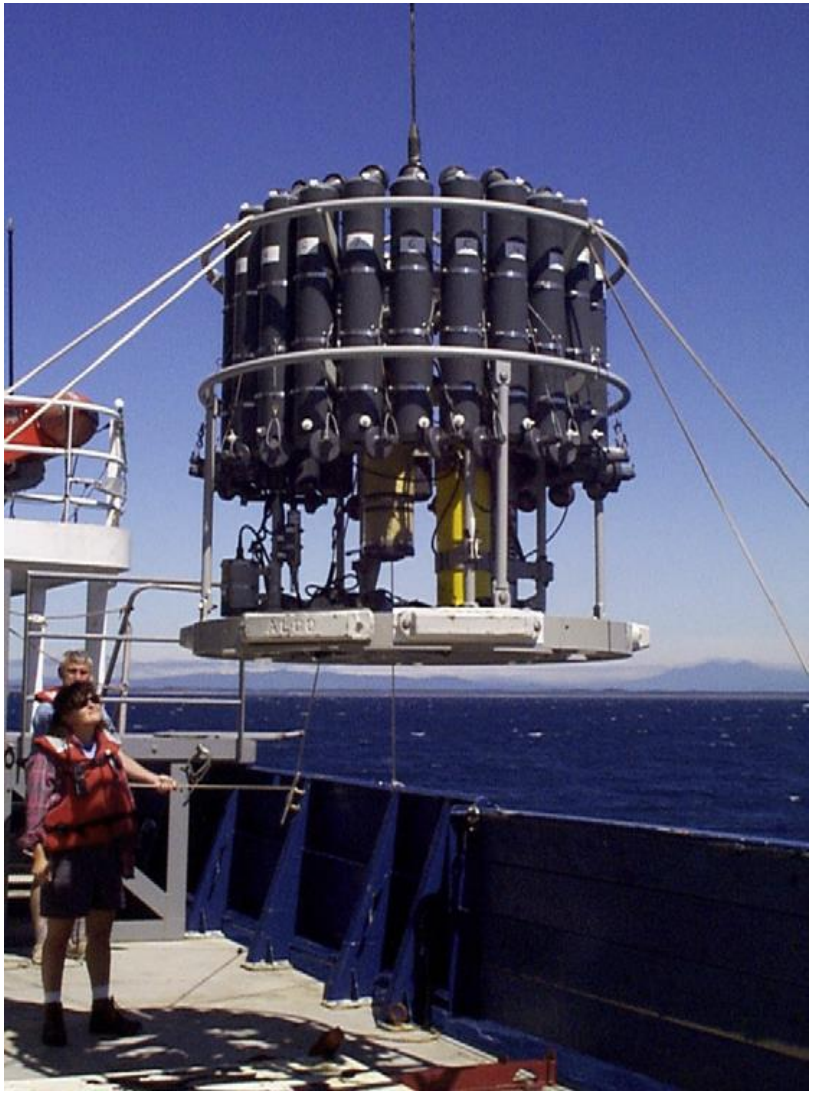




eXpendable-BT

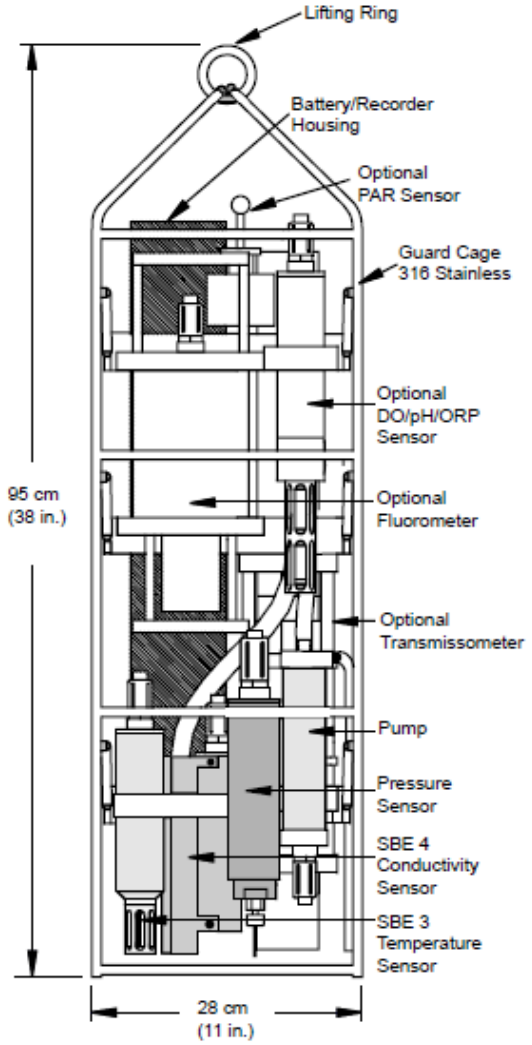
FIGURE S16.18 An expendable bathythermograph (XBT). *Source: From NOAA UOTC (2009).*



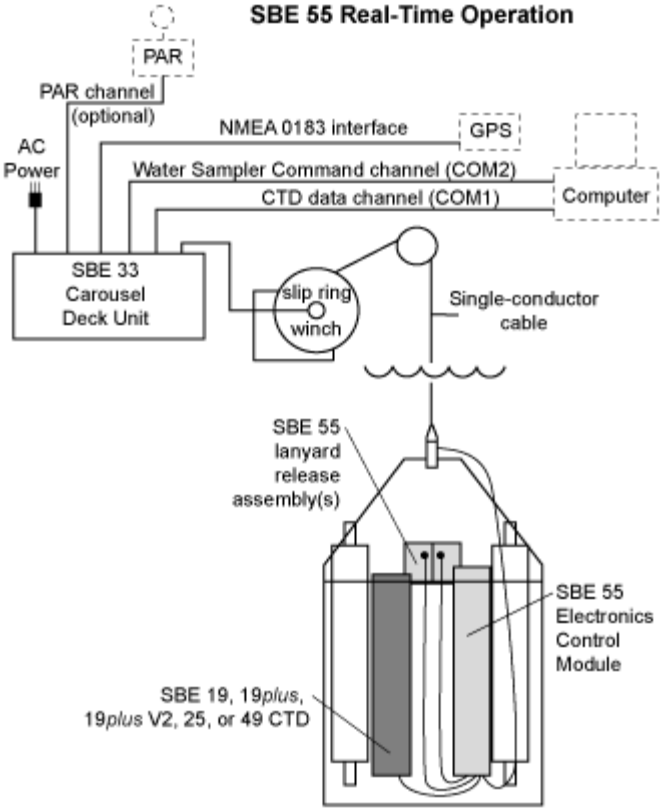


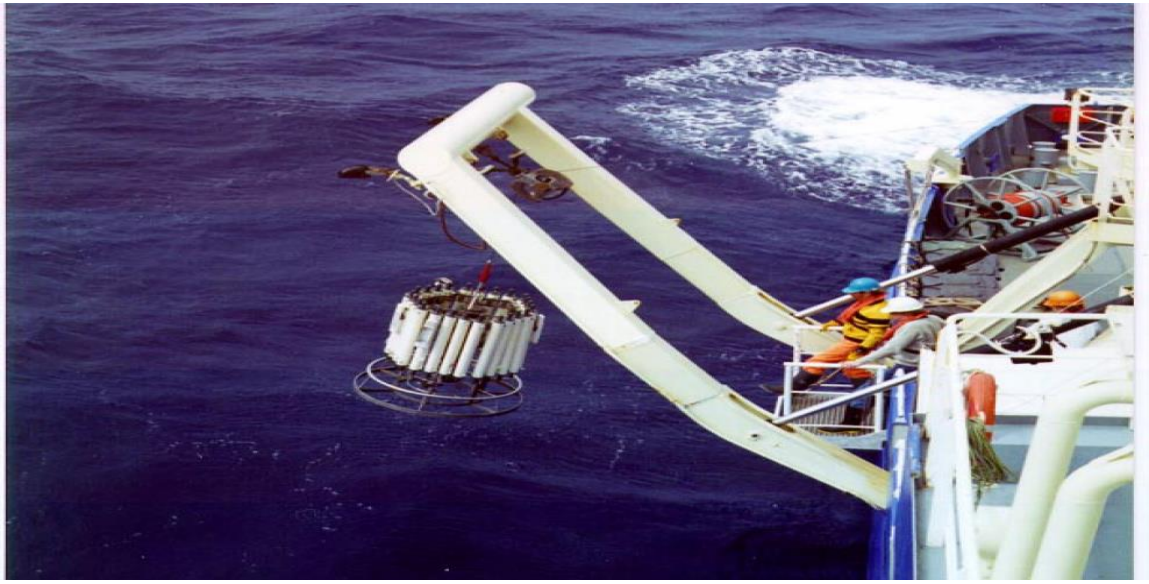
Condutividade Temperatura Depth
(Profundidade)

CTD

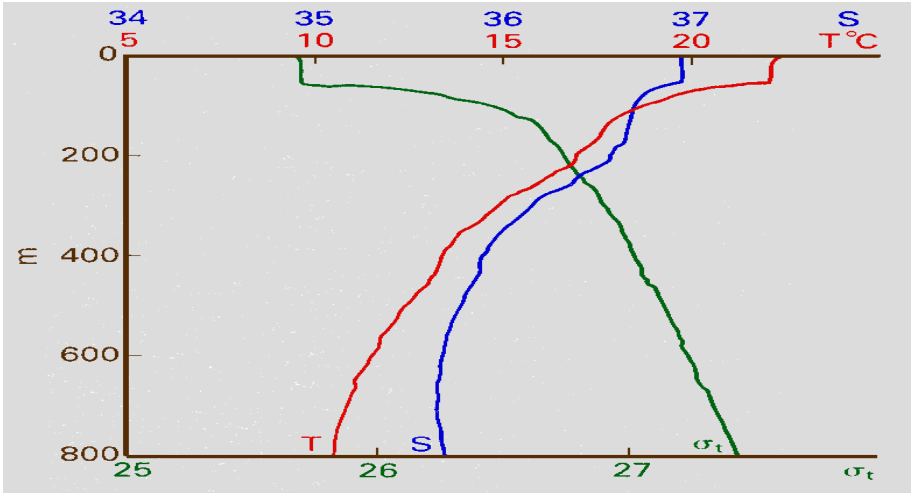

Lifting Ring
Battery/Recorder Housing
Optional PAR Sensor
Guard Cage 316 Stainless
Optional DO/pH/ORP Sensor
Optional Fluorometer
Optional Transmissometer
Pump
Pressure Sensor
SBE 4 Conductivity Sensor
SBE 3 Temperature Sensor
95 cm (38 in.)
28 cm (11 in.)


SBE


SBE 55 Real-Time Operation
PAR
PAR channel (optional)
NMEA 0183 interface
GPS
AC Power
Water Sampler Command channel (COM2)
CTD data channel (COM1)
Computer
SBE 33 Carousel Deck Unit
slip ring
winch
Single-conductor cable
SBE 55 lanyard release assembly(s)
SBE 55 Electronics Control Module
SBE 19, 19plus, 19plus V2, 25, or 49 CTD



A medida hidrografica : Roseta + CTD.



O perfil de T/S/Sigma-t resultante

Barcos de oportunidade

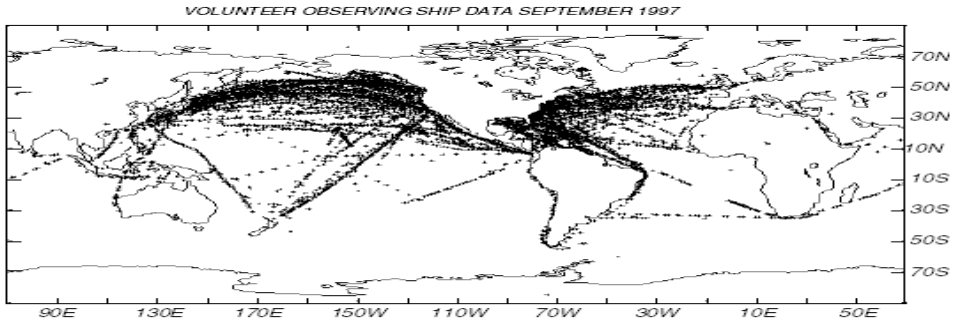
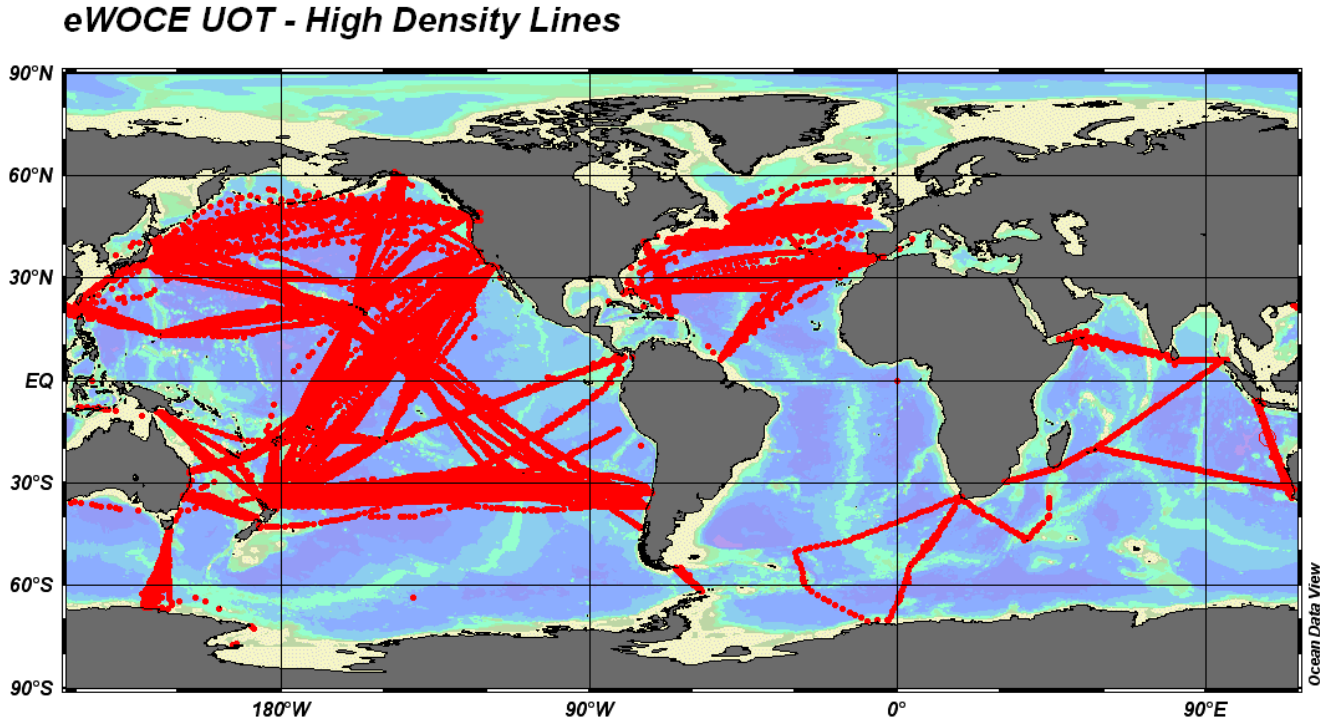
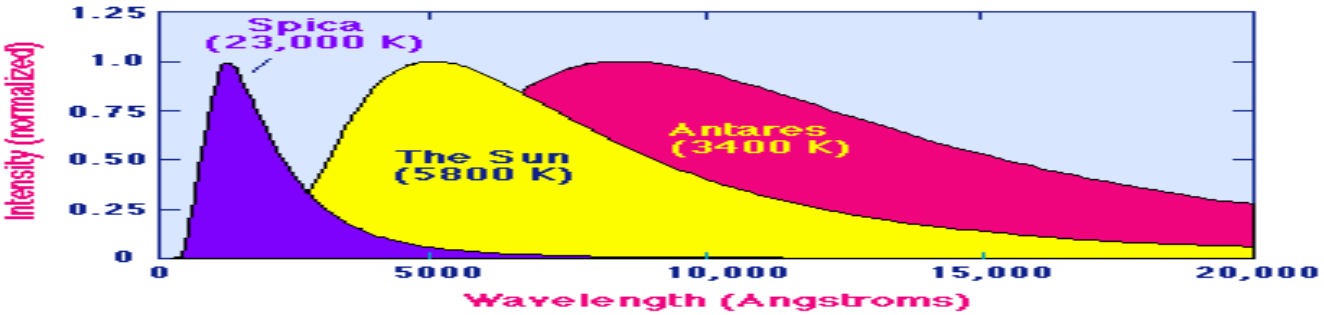


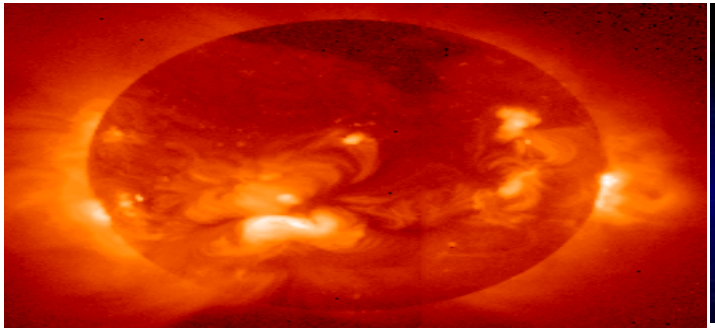
Figure 4.5 Location of surface observations made from volunteer observing ships and reported to national meteorological agencies. (From NOAA, National Ocean Service)



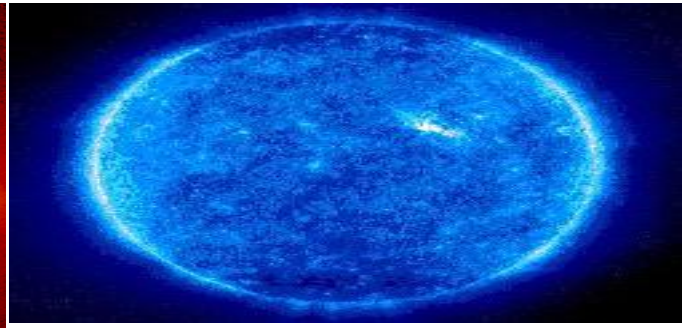
Sensoriamento Remoto Espectros de Radiação E.M.



Espectro Visivel: 4000 a 7000 Å ou 400 a 750 µm.

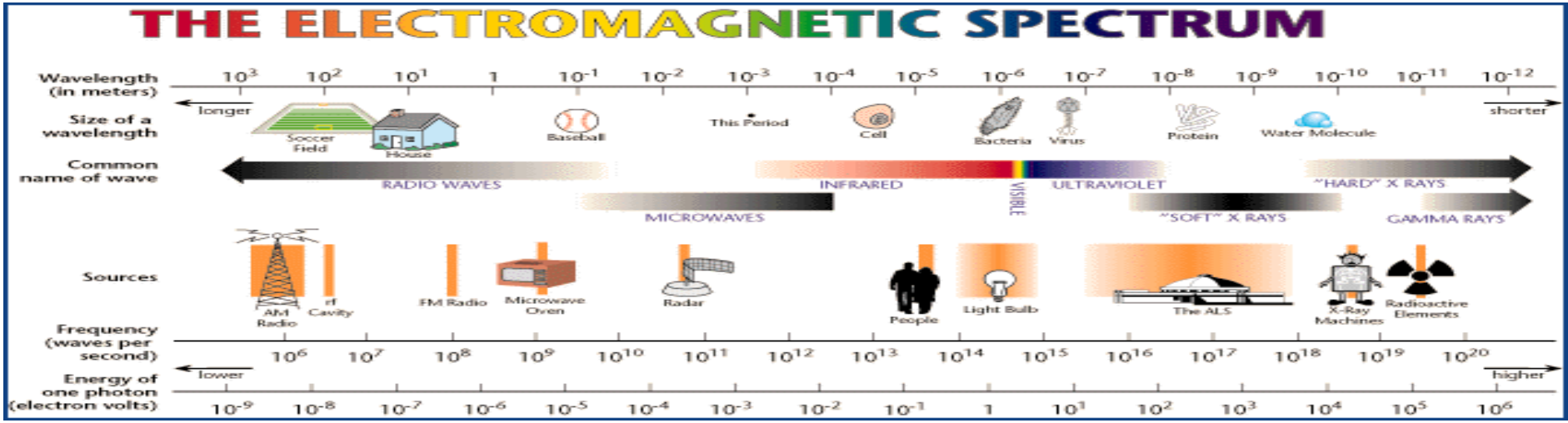


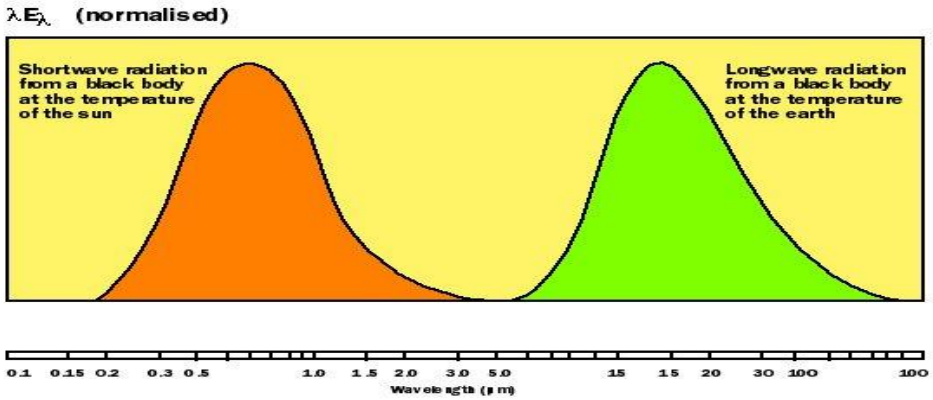
Sol (λ=raios-X)

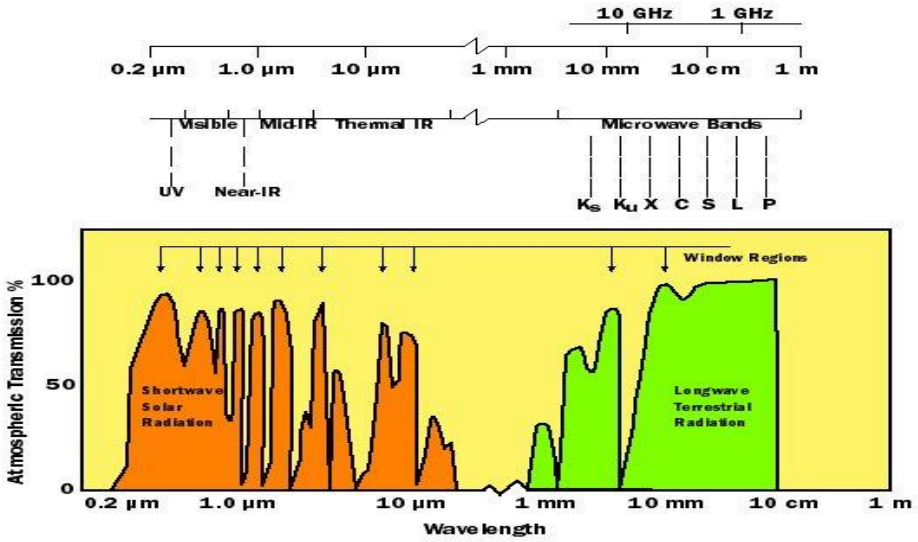


Sol (λ=UV)

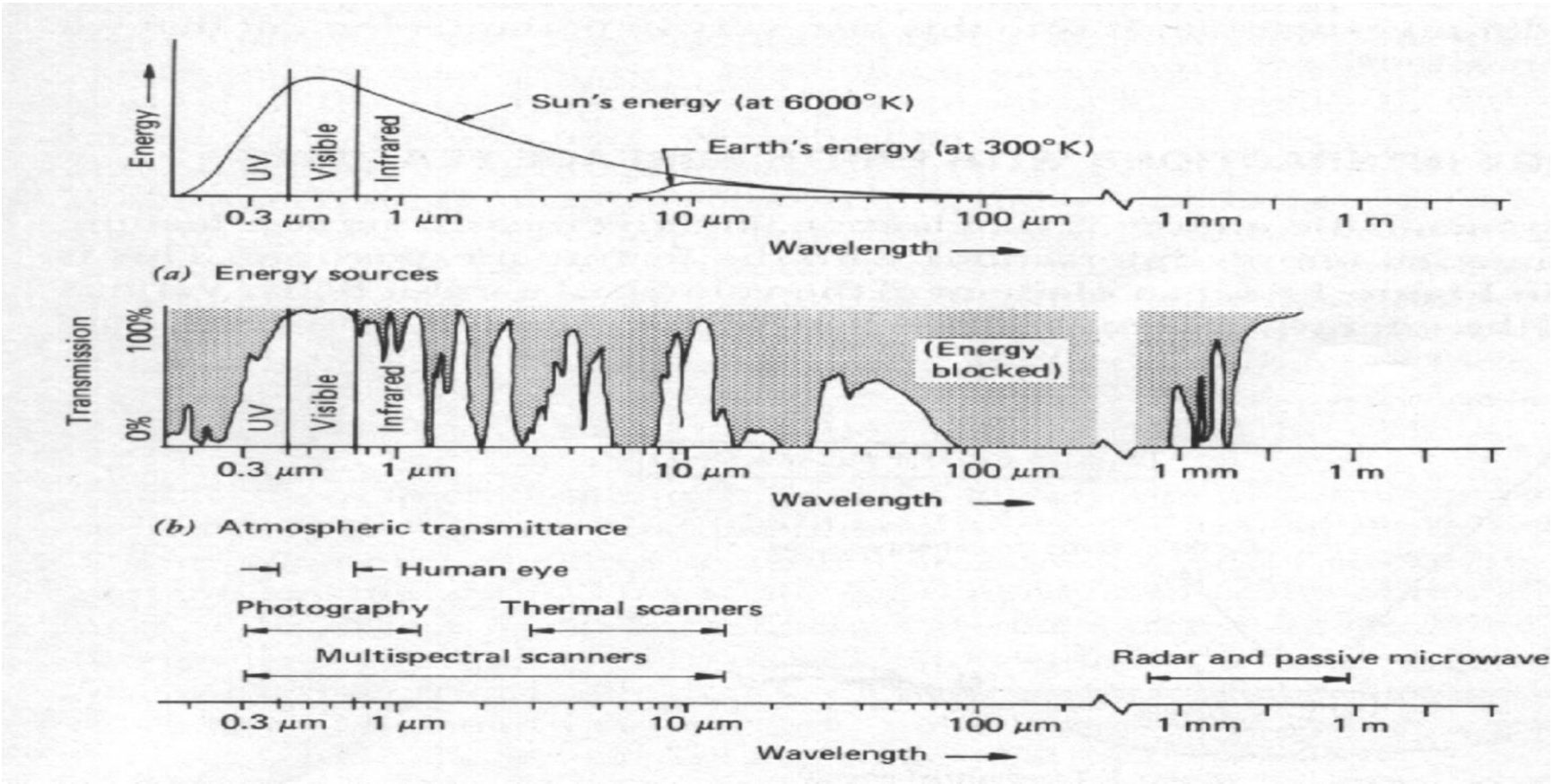
Fonte:http://csep10.phys.utk.edu/

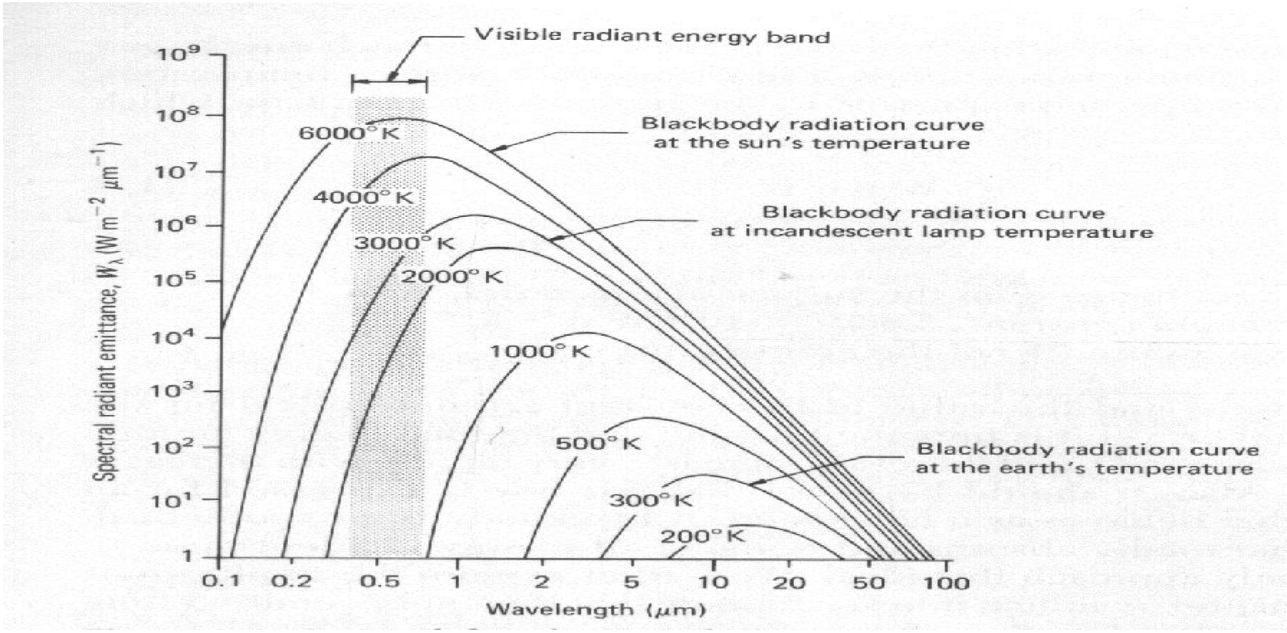


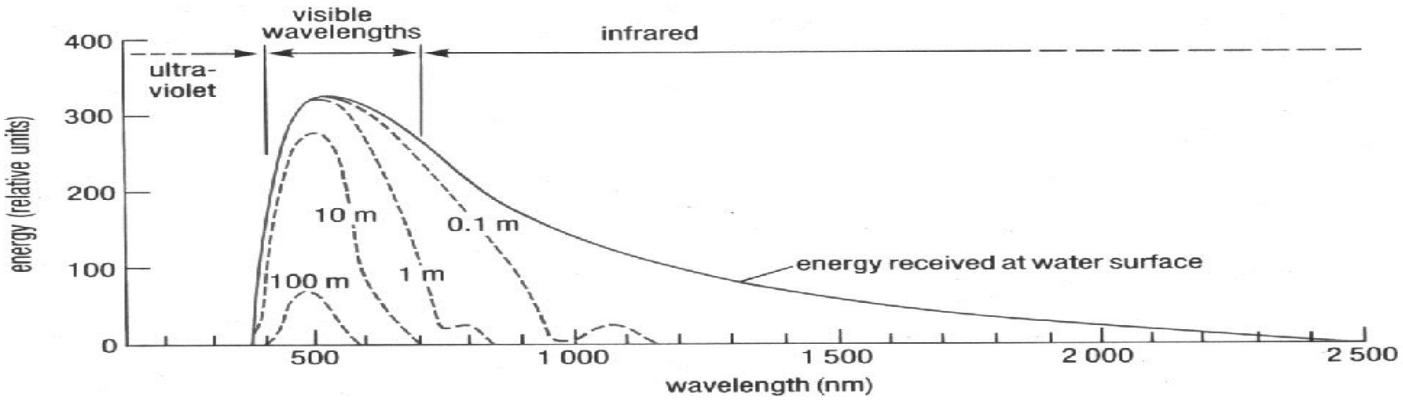




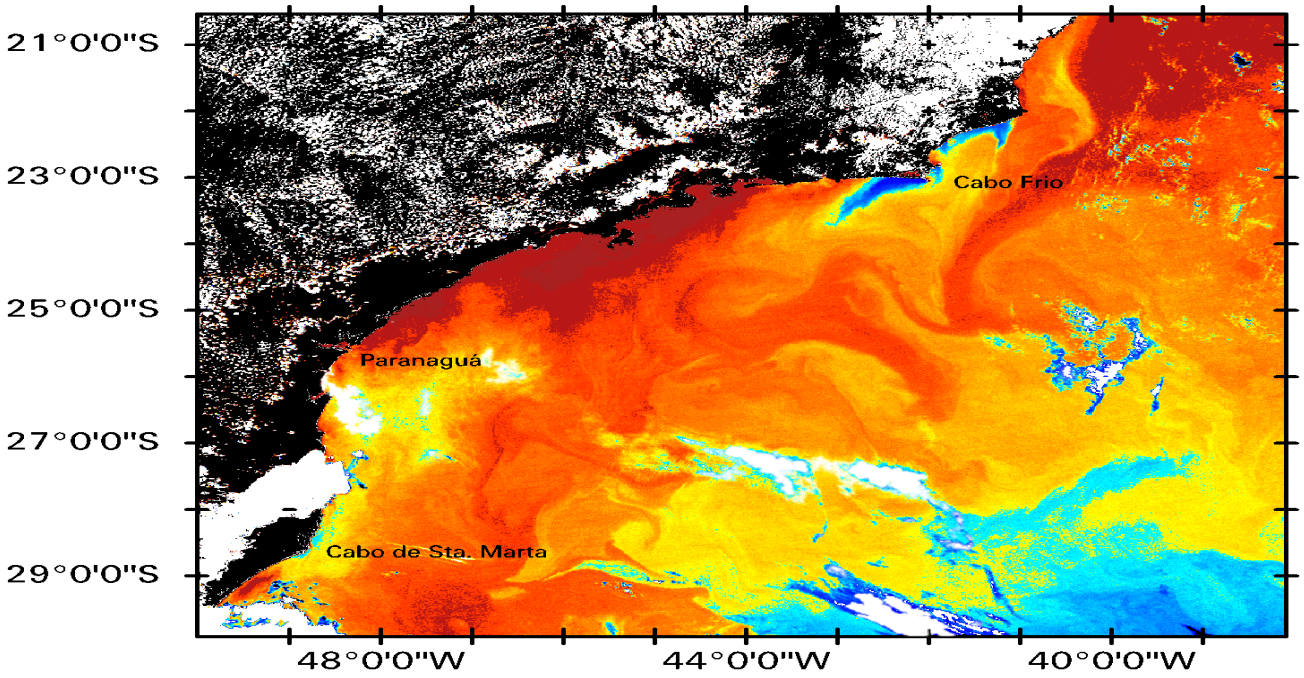
Fonte:http://www.electro-optical.com/


Energy
UV
Visible
Infrared
Sun's energy (at 6000°K)
Earth's energy (at 300°K)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(a) Energy sources
Transmission
100%
0%
(Energy blocked)
(b) Atmospheric transmittance
Human eye
Photography
Thermal scanners
Multispectral scanners
Radar and passive microwave


Visible radiant energy band
Blackbody radiation curve at the sun's temperature
Blackbody radiation curve at incandescent lamp temperature
Blackbody radiation curve at the earth's temperature
6000° K
4000° K
3000° K
2000° K
1000° K
500° K
300° K
200° K
Spectral radiant emittance, W_λ (W m^{-2} μm^{-1})
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
0.1 0.2 0.5 1 2 5 10 20 50 100
Wavelength (μm)


visible wavelengths
infrared
ultra-violet
energy (relative units)
400
300
200
100
0
10 m
0.1 m
1 m
100 m
energy received at water surface
500
1 000
1 500
2 000
2 500
wavelength (nm)

TEMPERATURA SUPERFICIAL DO MAR



TEMPERATURA (°C)

- Nuvens
- Terra
- 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24
- 25
- 26
- 27

Escala

100 0 km

SENSOR/SATÉLITE: AVHRR/NOAA-14

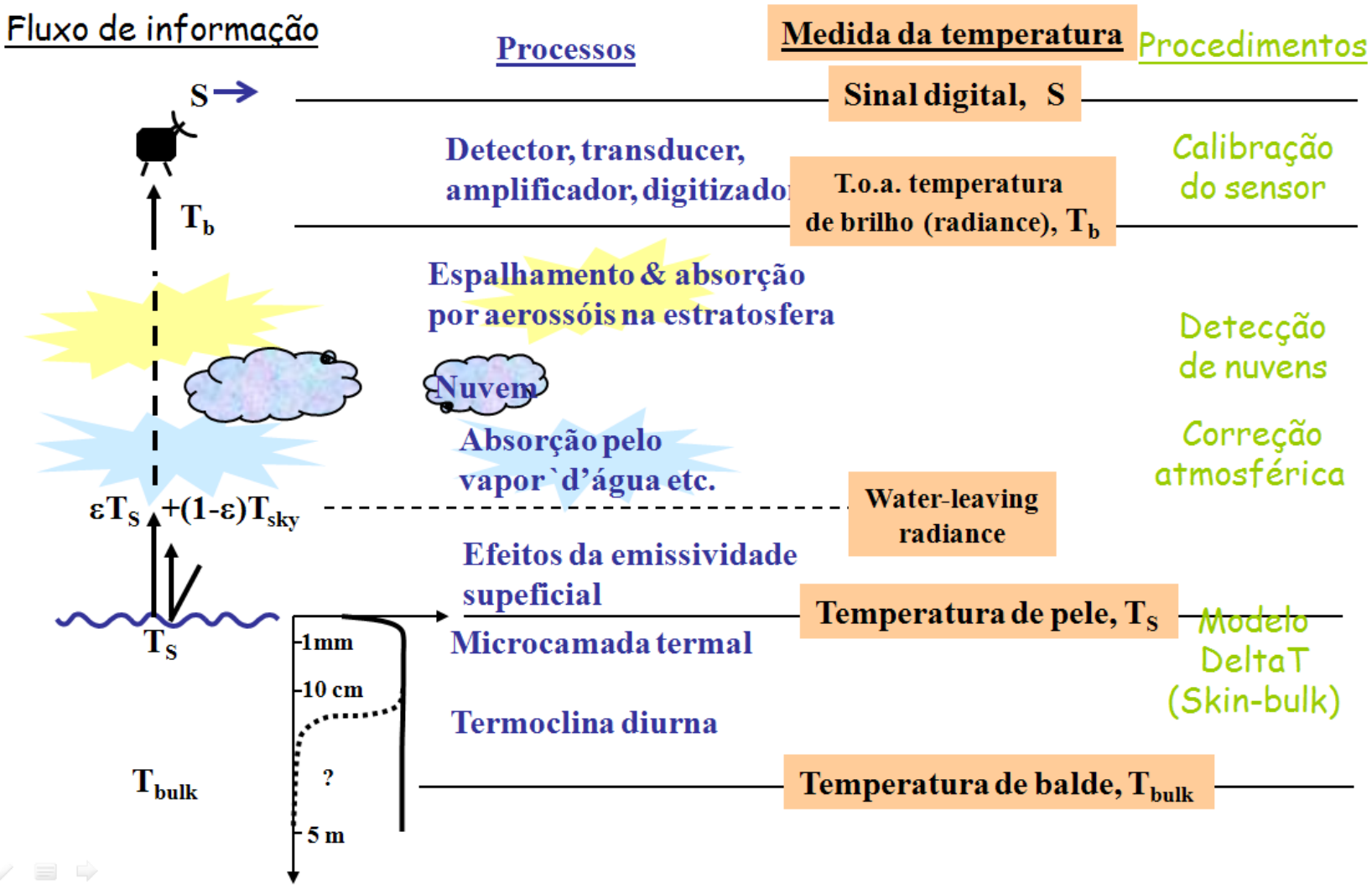
ALGORITMO: DAYTIME NLSST

AQUISIÇÃO: 07/11/95 - 16:54 GMT

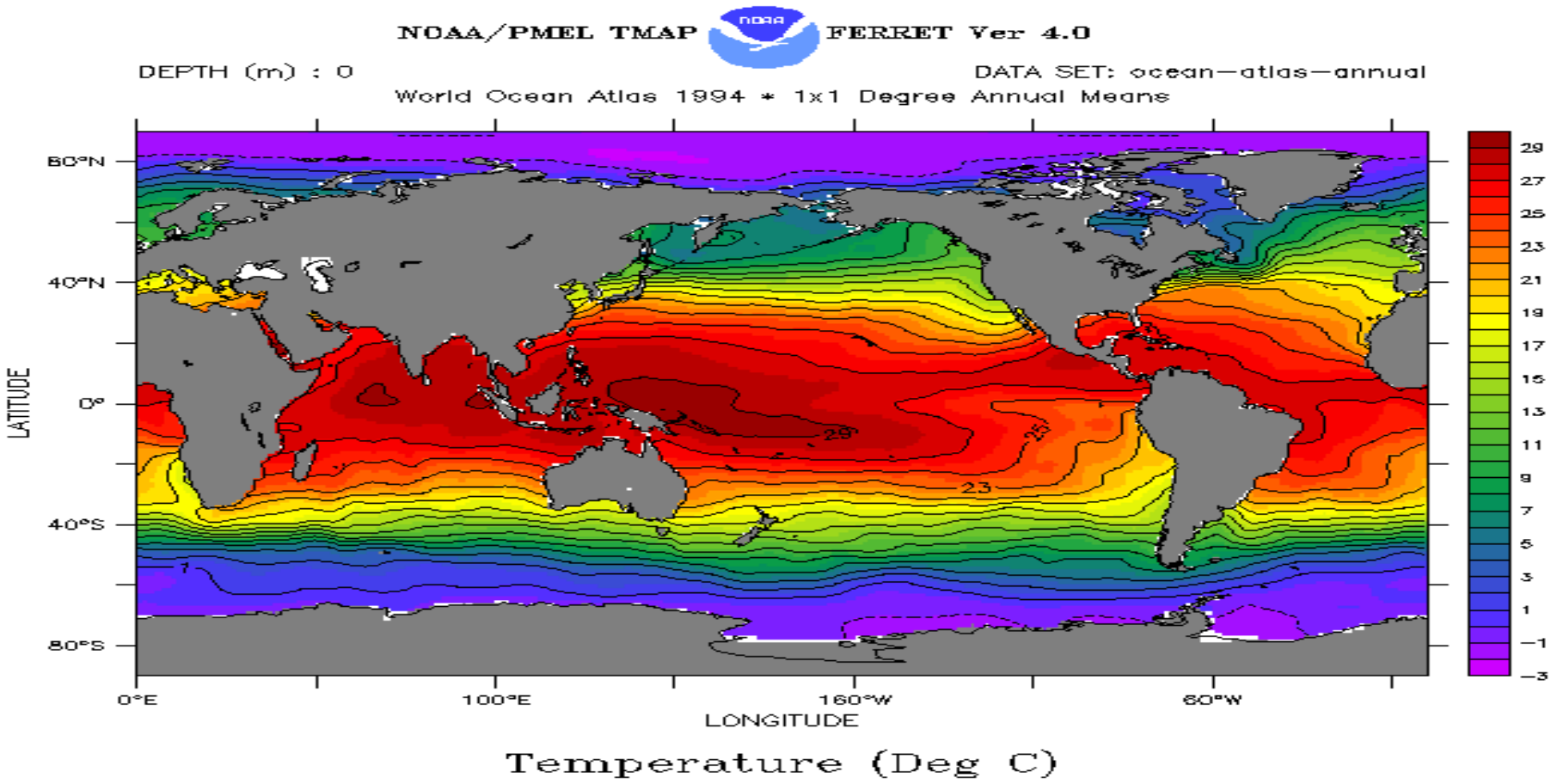
REGIÃO CENTRAL DA BACIA DE SANTOS

CONVÊNIO PETROBRÁS/FURG

Processos que afetam a medida de TSM

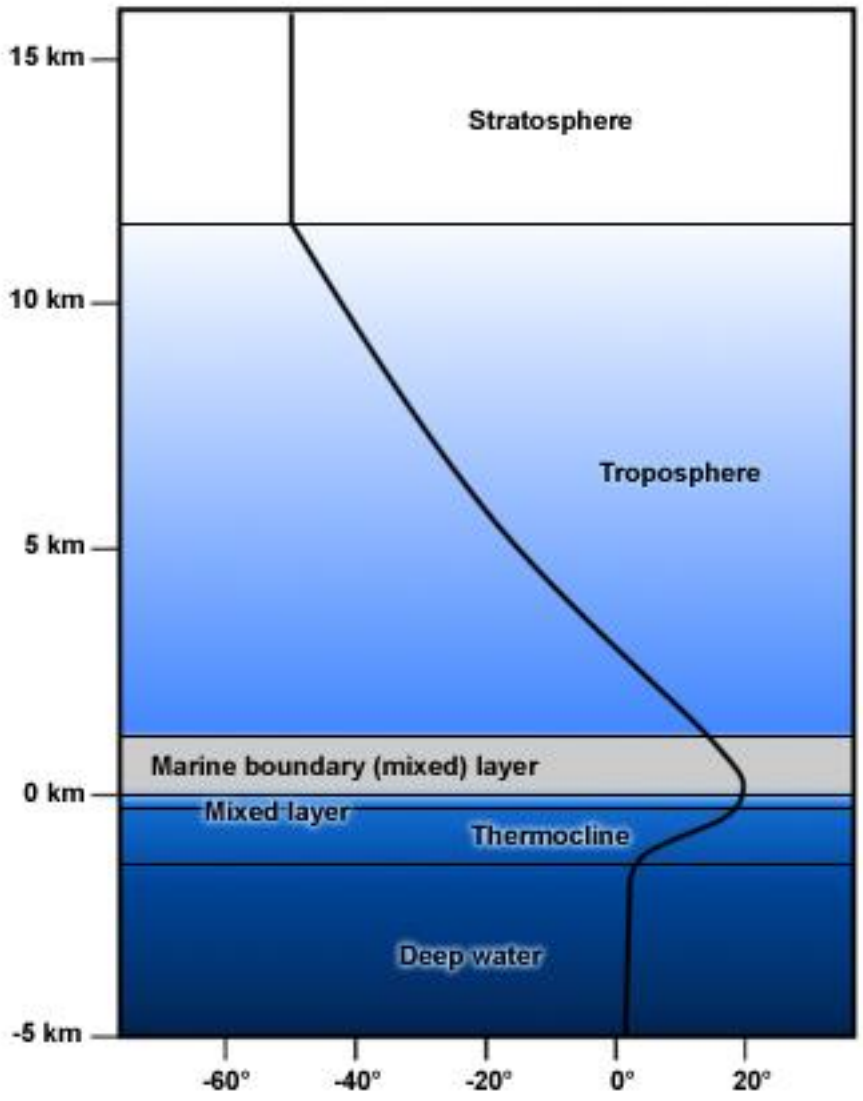


Distribuição horizontal –camada de mistura



Mean sea-surface temperature calculated from the optimal interpolation technique (Reynolds and Smith, 1995) using shipreports and AVHRR measurements of temperature. Contour interval is1° C with heavy contours every 5° C. Shaded areas exceed 29° C.

Temperature Profile from Seafloor to Stratosphere

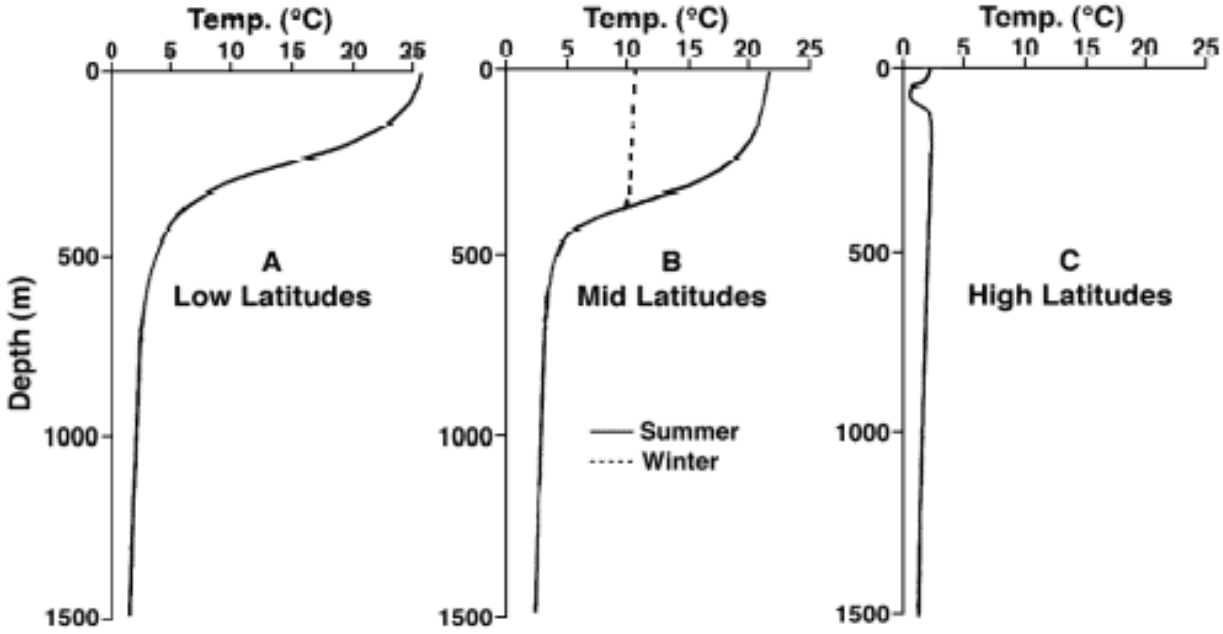


Distribuição Vertical da Temperatura entre 60 S e 60 N

Essa estrutura é alterada de acordo com a latitude. Em médias latitudes aparece, também, uma termoclina sazonal.

Em altas latitudes a camada de mistura vai, praticamente, até o fundo do oceano, com perfil com decréscimo suave da T até o fundo

Typical Temperature Profiles



Em função da latitude as zonas se dividem em:

Baixas latitudes Não existem ≠ significativas nas estações do ano

T das H2Os superficiais são sempre altas

Termoclina Permanente

Camada de mistura de pouca espessura.

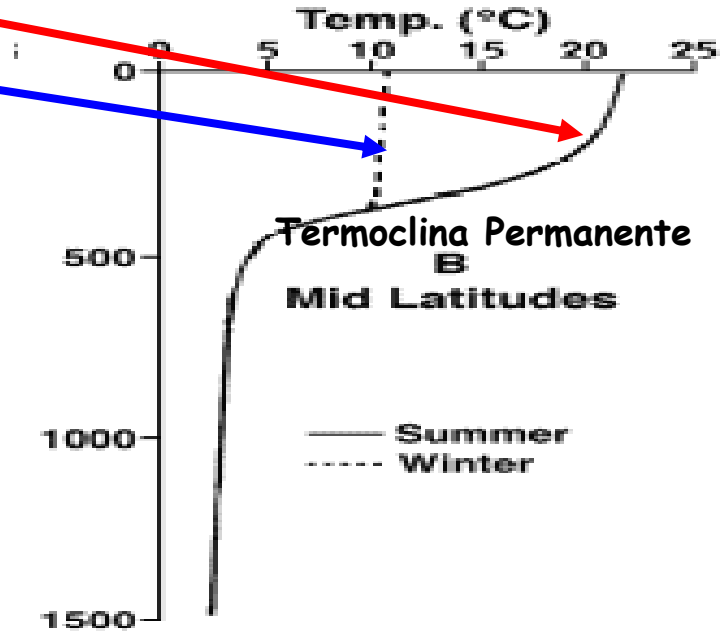
Divergência Equatorial

Médias latitudes

Termoclina Permanente & sazonal

Verão

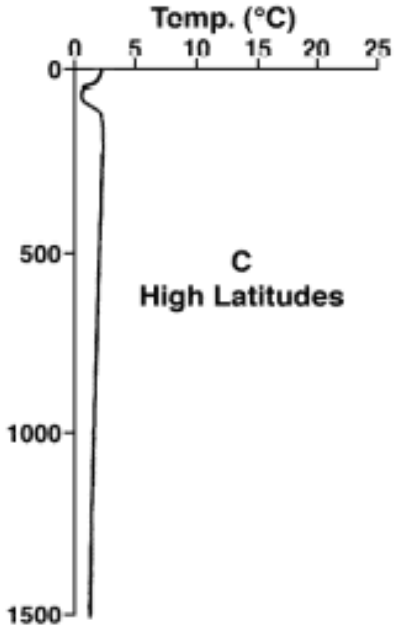
Inverno



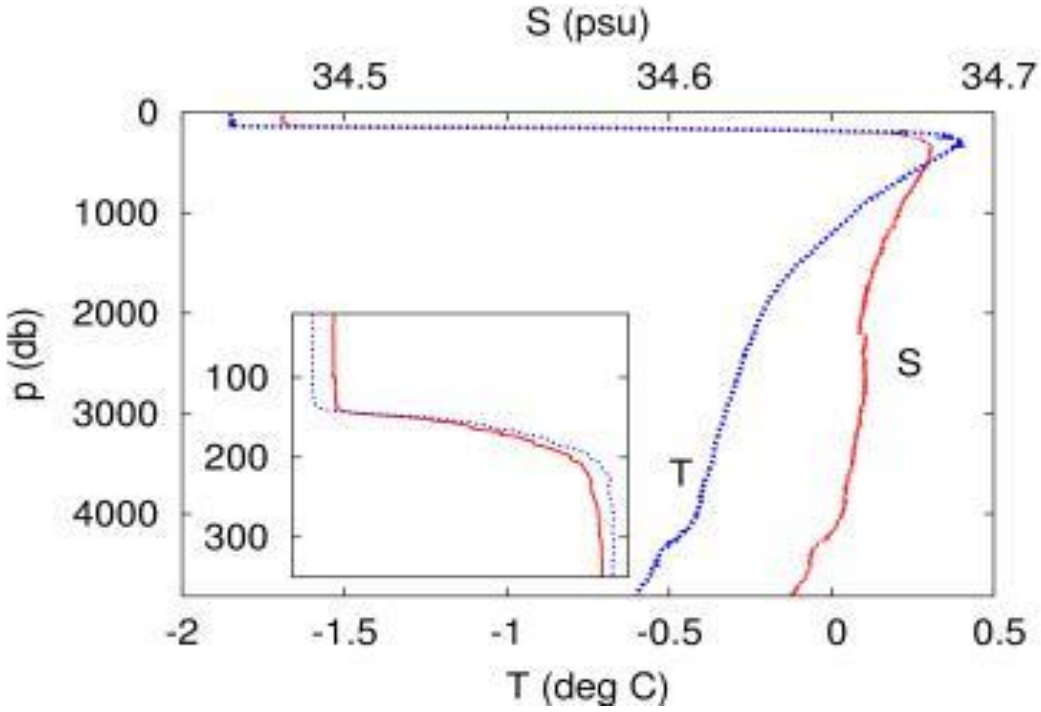
Altas latitudes

Inexistência da Termoclina Permanente

T quase Cte ao longo da coluna d´água

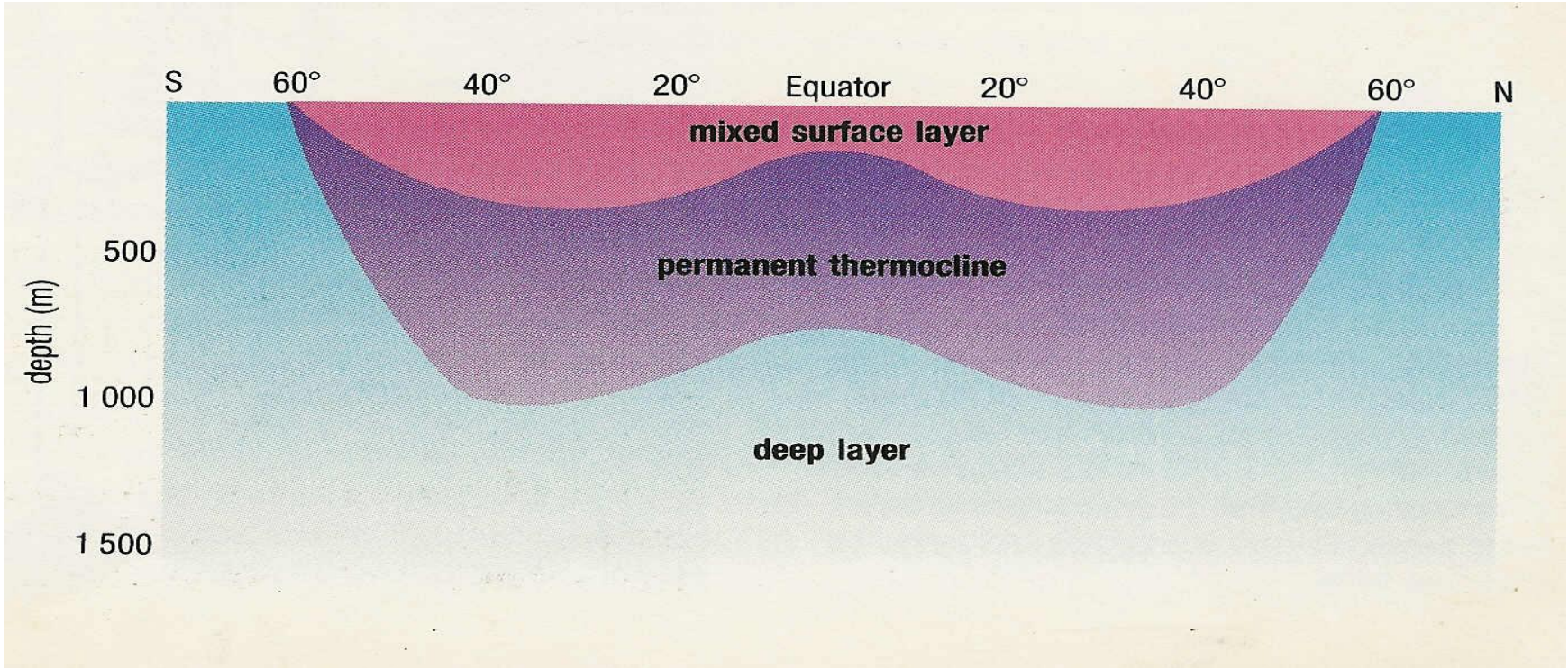


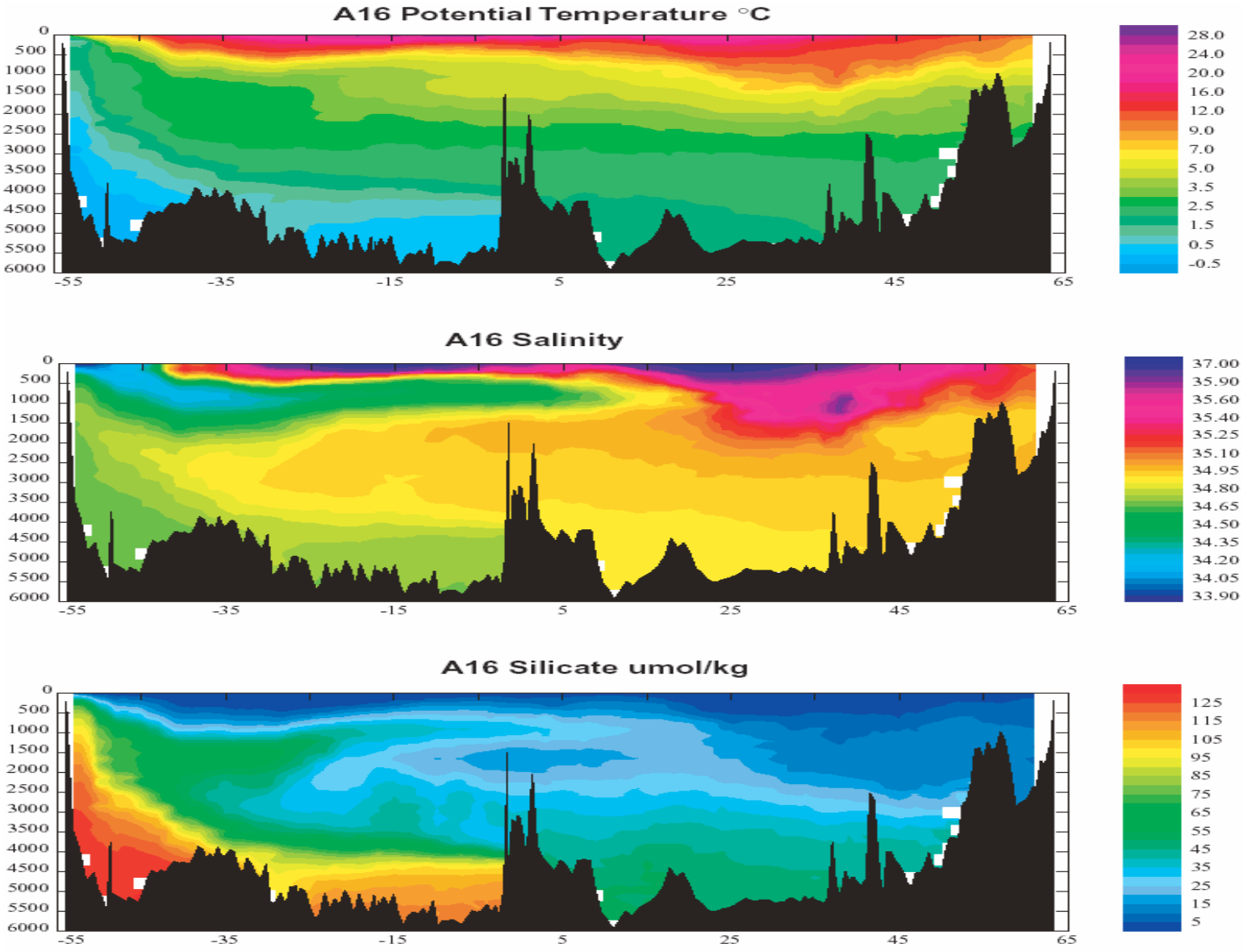
Região Subantártica



Mar de Weddell

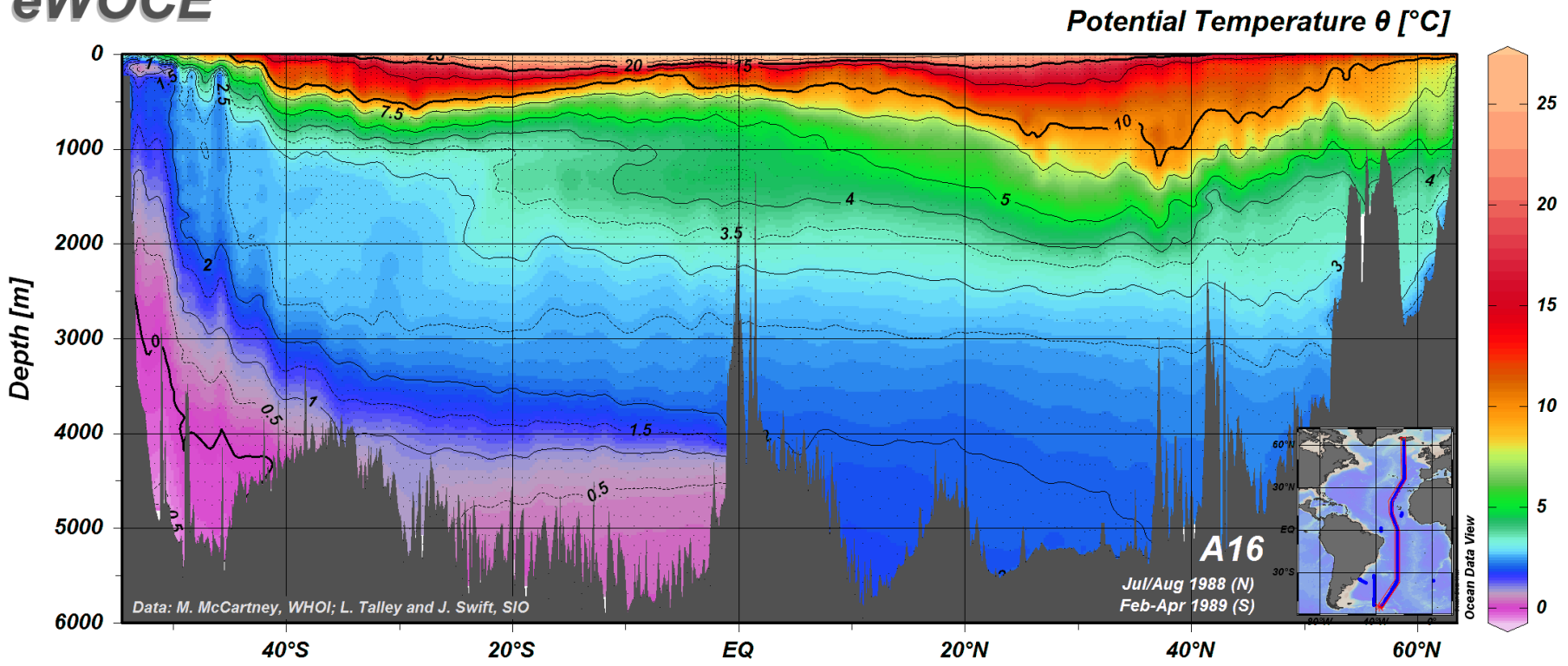
Resumo da distribuição latitudinal, em profundidade, da Temperatura

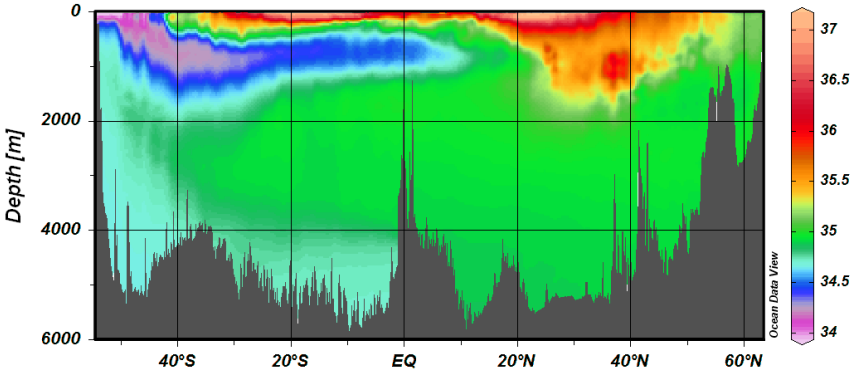


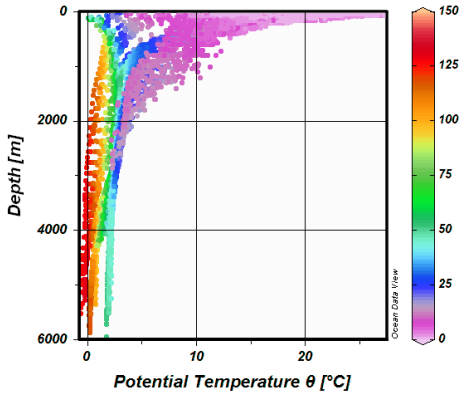


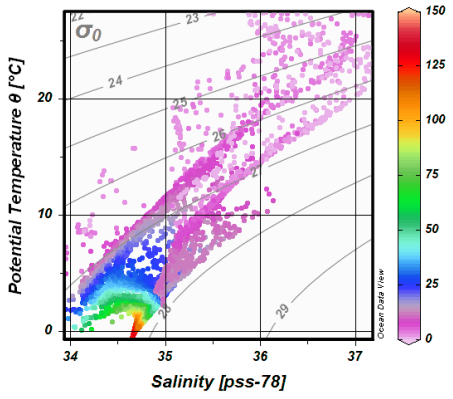
A16 - a WOCE mid Atlantic transect from south (left) to north.
(WOCE IPO)

eWOCE

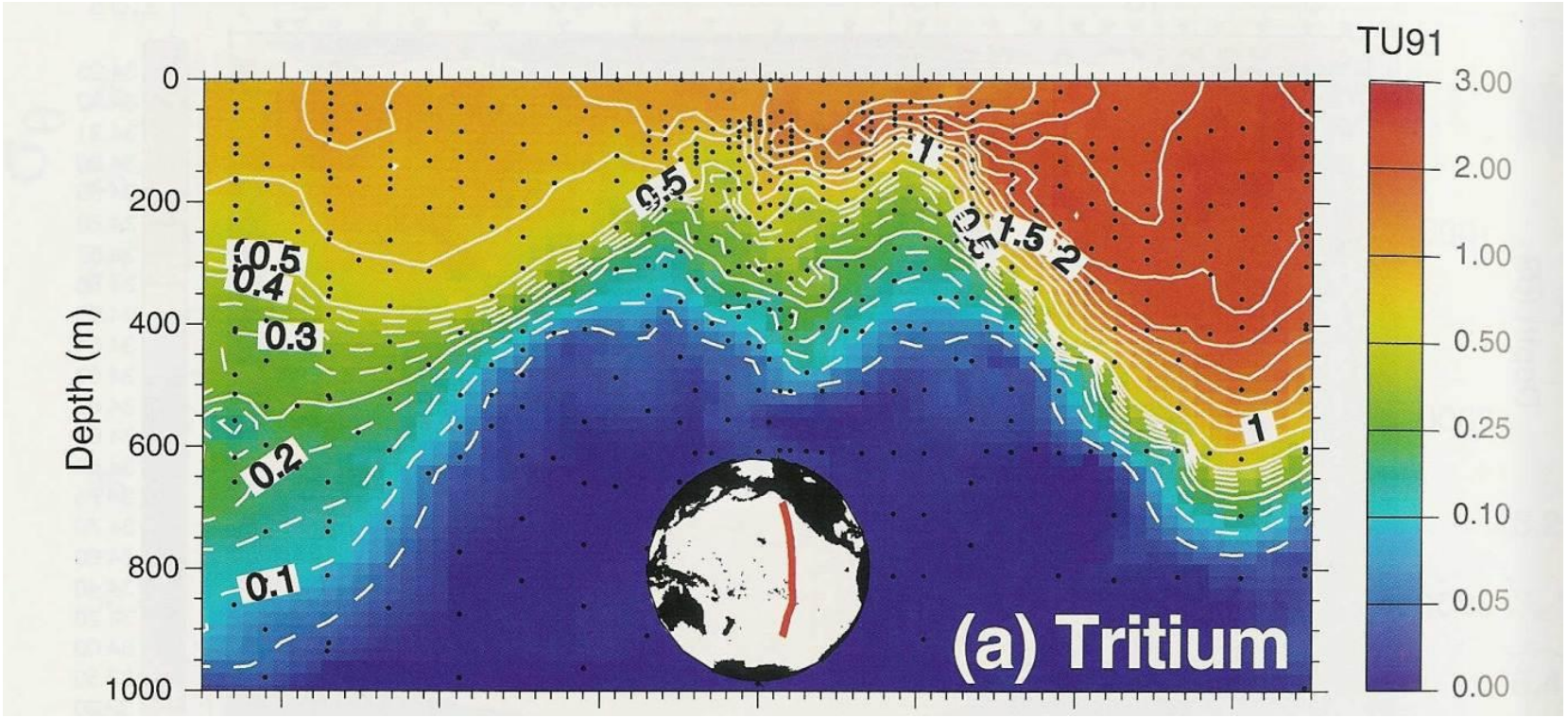

Potential Temperature θ [°C]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Data: M. McCartney, WHOI; L. Talley and J. Swift, SIO
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Ocean Data View
25
20
15
10
5
0


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

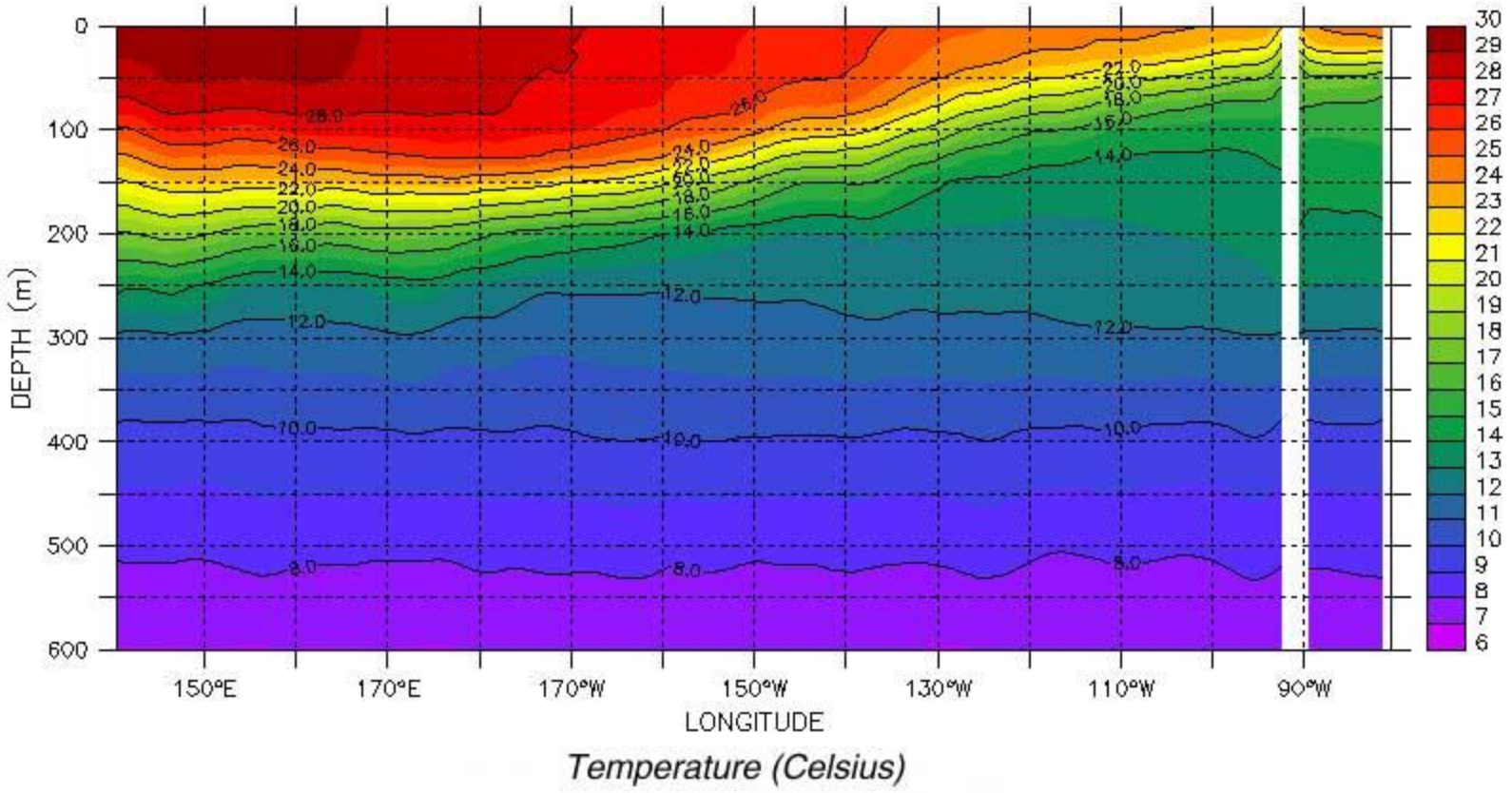

Silicate [µmol/kg]
Depth [m]
0
2000
4000
6000
0
10
20
Potential Temperature θ [°C]
150
125
100
75
50
25
0
Ocean Data View


Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
23
24
25
26
27
28
29
0
10
20
34
35
36
37
Salinity [pss-78]
150
125
100
75
50
25
0
Ocean Data View

Distribuição de Trítio no Pacífico



Secção transversal no Pacífico Equatorial: termoclina mais rasa na margem leste do oceano



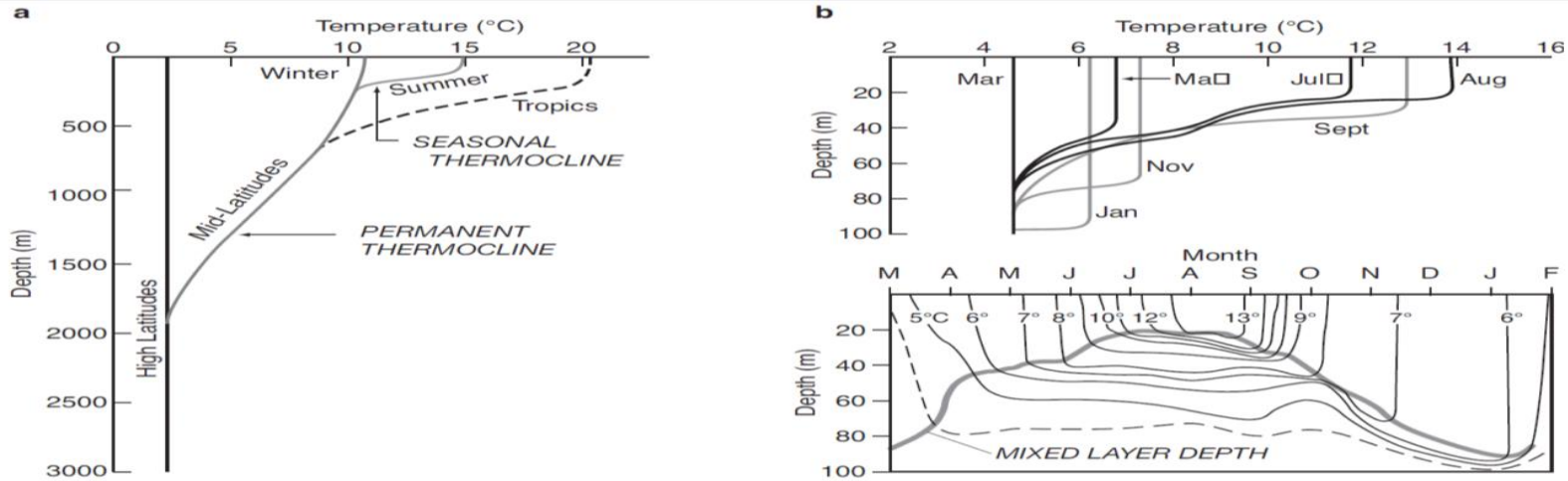
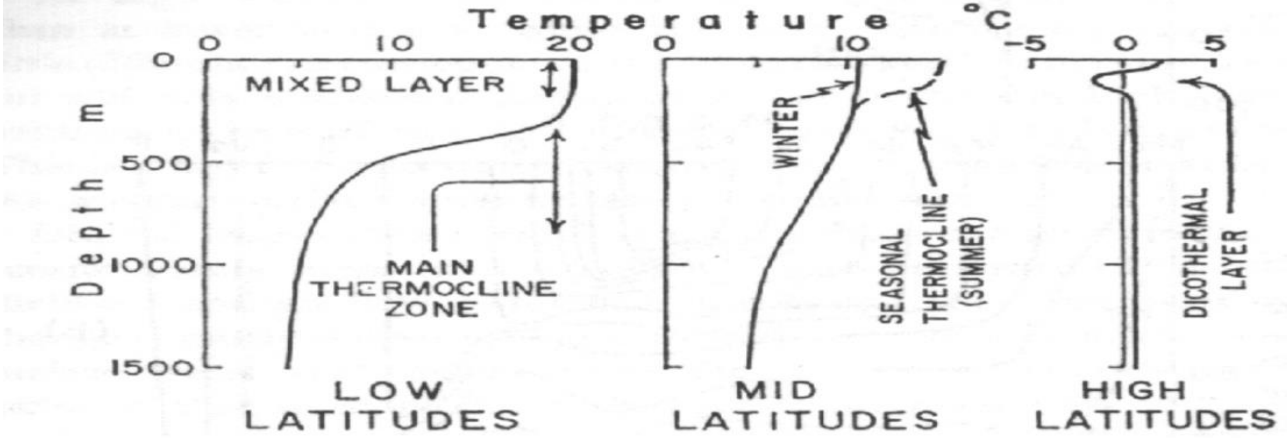
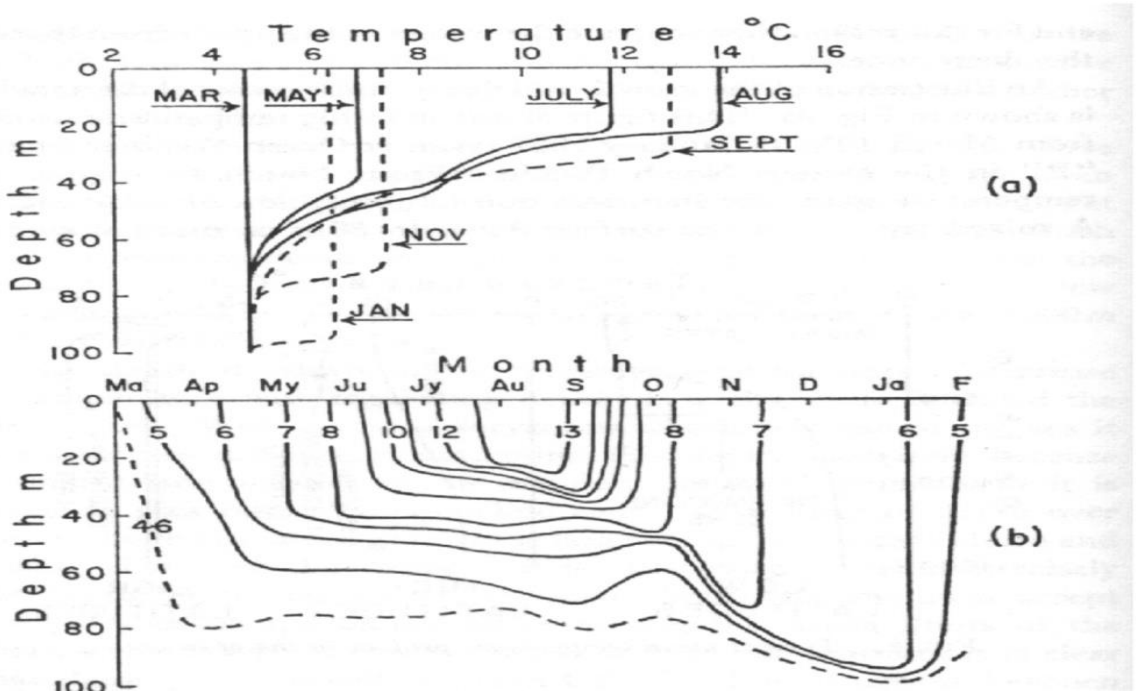


Figure 1.6: Schematic illustration of the vertical variation of temperature through the seasonal cycle (Figure from Sarmiento and Gruber, 2006).

Perfis Verticais de Temperatura



Formação da Termoclina Sazonal
Médias Latitudes



Temperatura potencial?

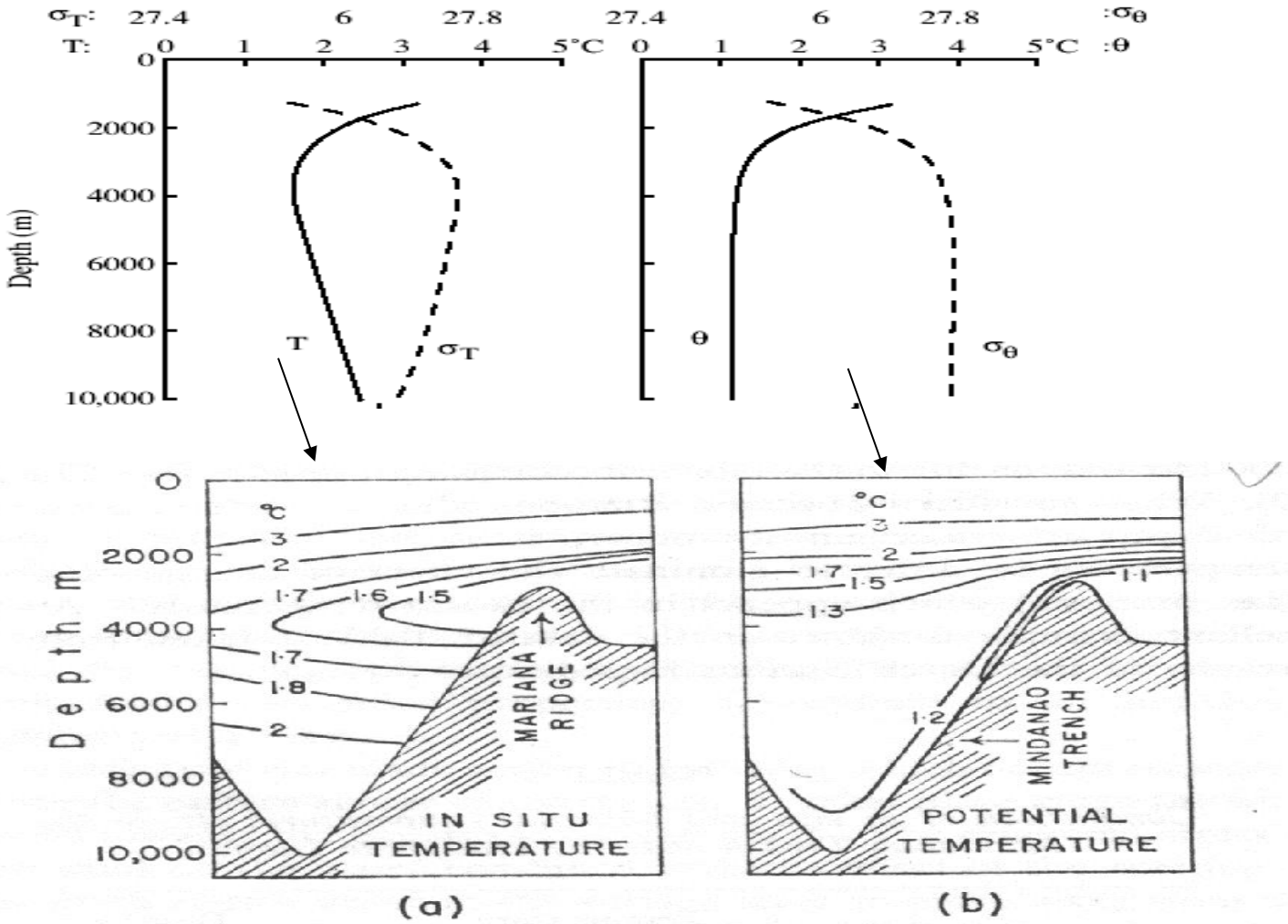
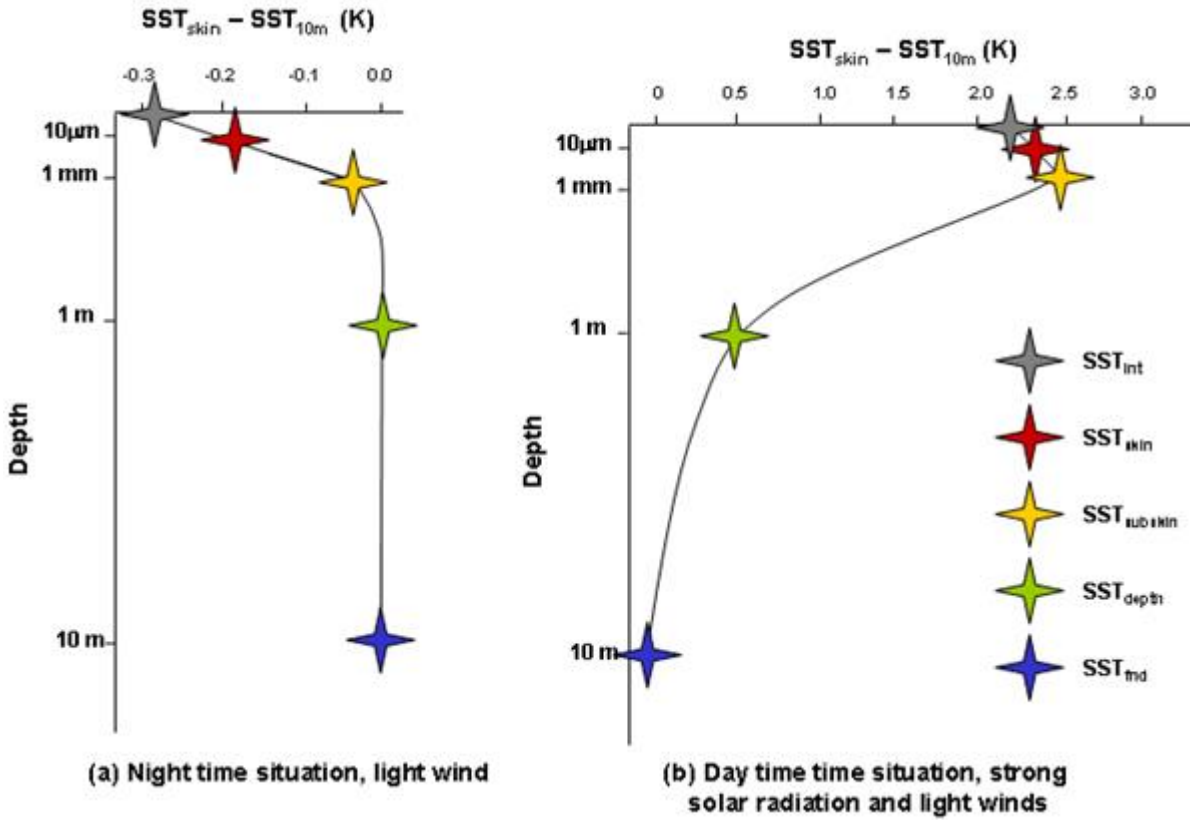


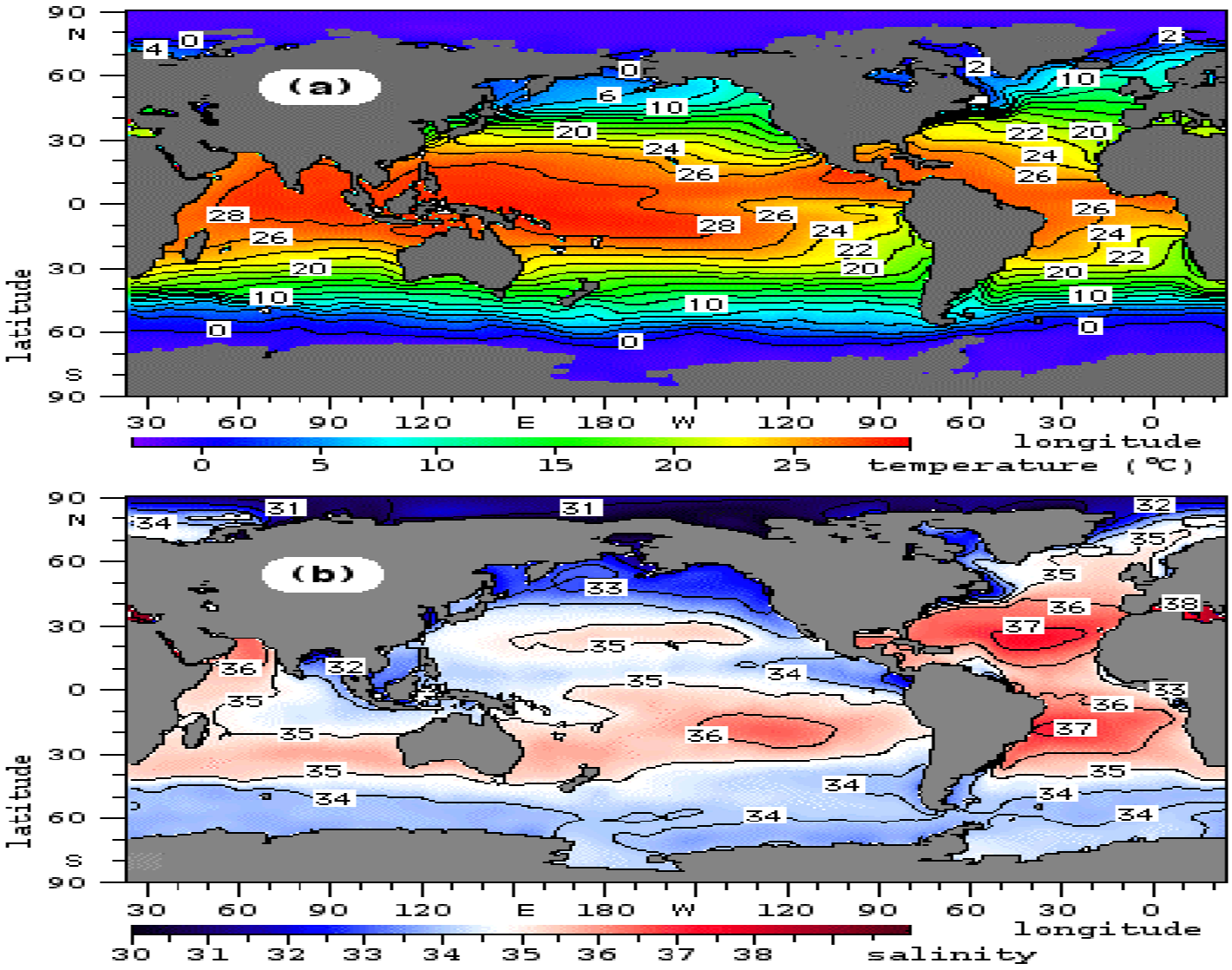
FIG. 10. In situ *and potential temperature distributions in the Mindanao Trench (after van Riel).*

É a T corrigida a partir da T *in situ* principalmente para grandes profundidades onde existe o efeito da pressão hidrostática.

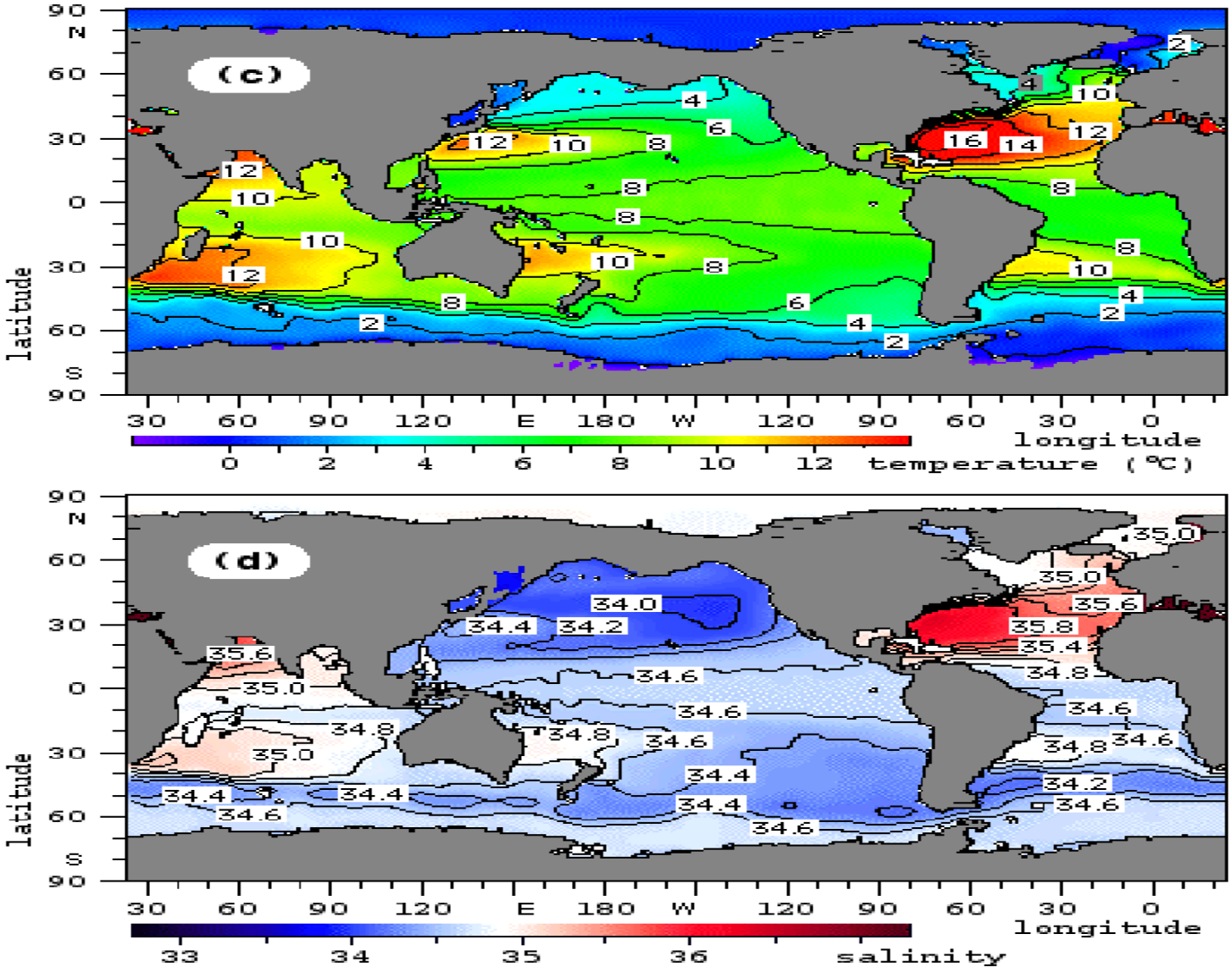


(a) Night time situation, light wind

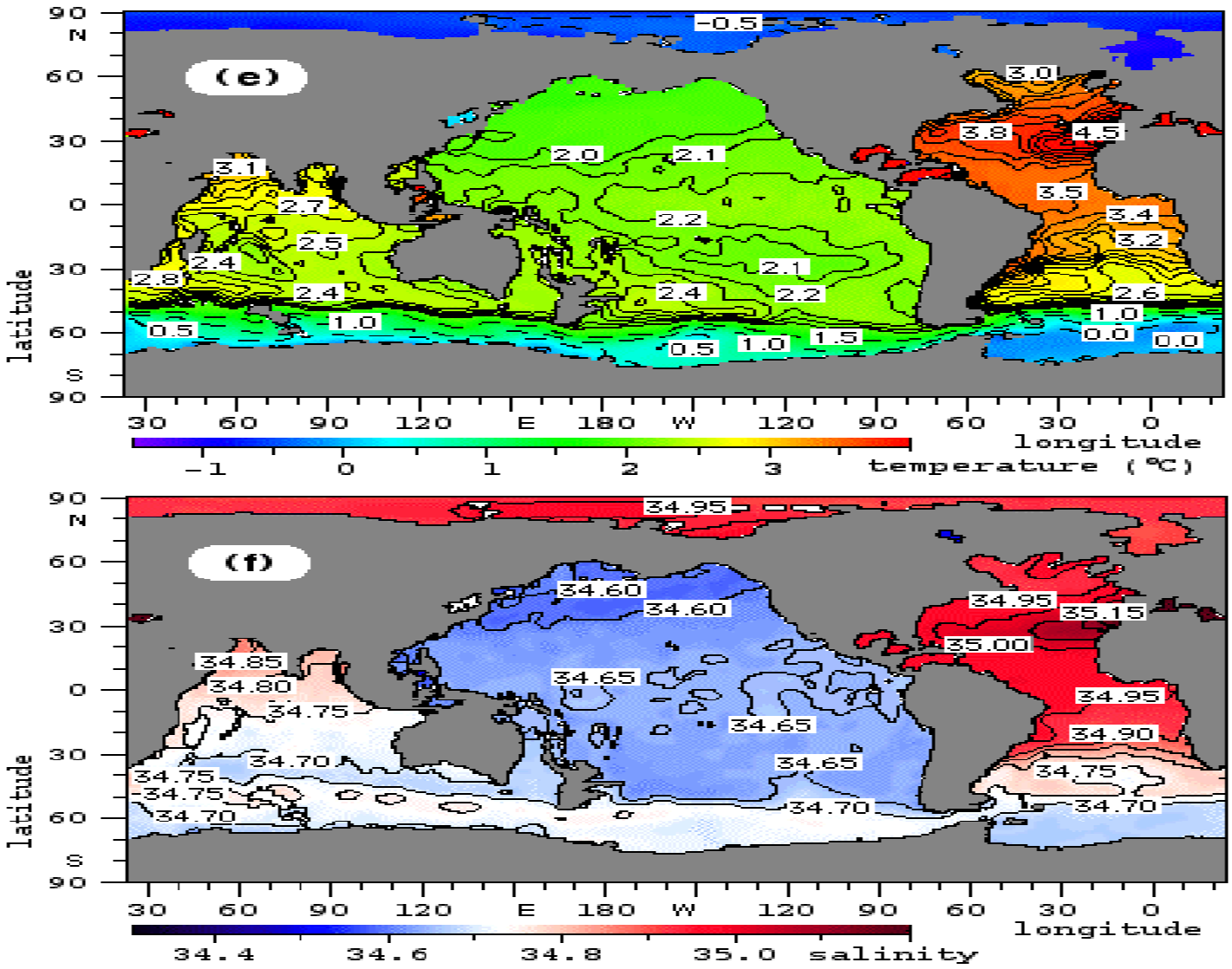
(b) Day time time situation, strong solar radiation and light winds


(a)
(b)
latitude
longitude
temperature (°C)
salinity
90 N 60 30 0 S 90
30 60 90 120 E 180 W 120 90 60 30 0
0 5 10 15 20 25
30 31 32 33 34 35 36 37 38

Z = 0 m

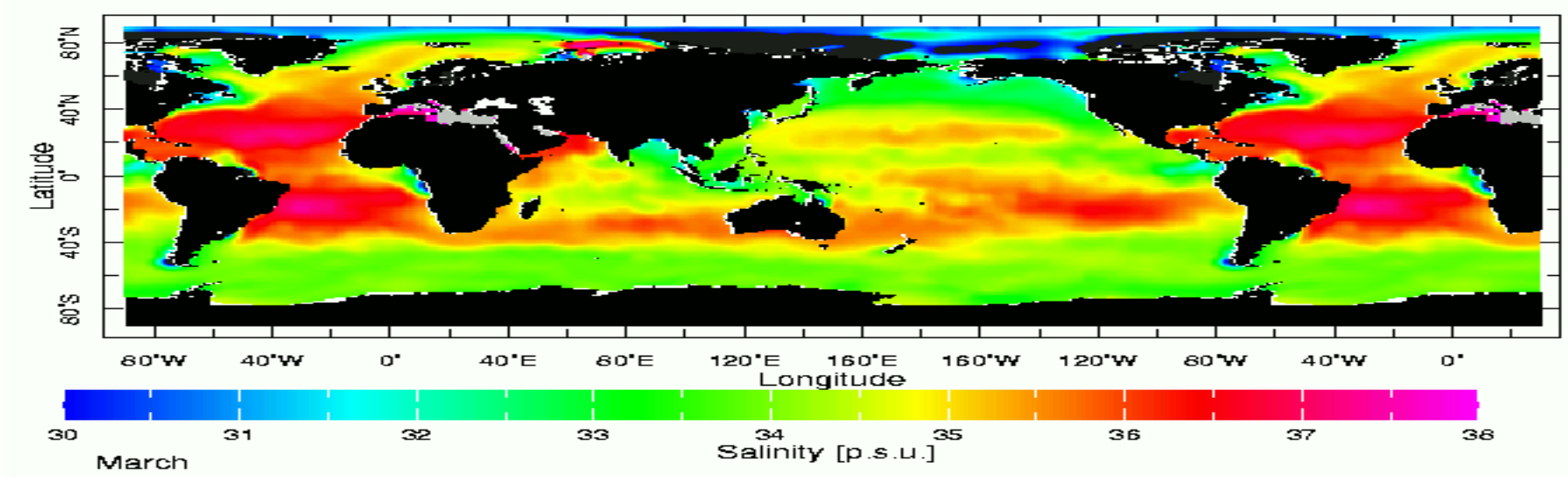

(c)
(d)
latitude
longitude
temperature (°C)
salinity
90 N
60
30
0
30 S
60 S
90 S
30 60 90 120 E 180 W 120 90 60 30 0
0 2 4 6 8 10 12
33 34 35 36

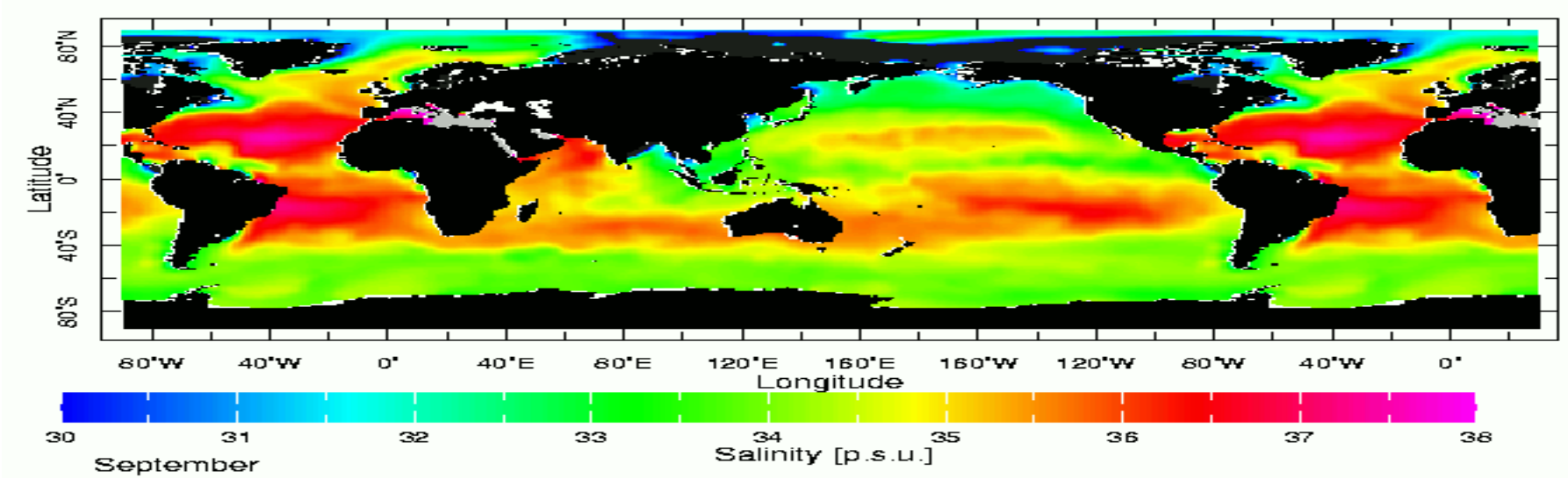
Z = 500 m


(e)
-0.5
3.0
3.8
4.5
3.5
3.4
3.2
2.6
1.0
0.0
0.0
3.1
2.7
2.5
2.4
2.8
2.4
1.0
0.5
2.0
2.1
2.2
2.1
2.4
2.2
0.5
1.0
1.5
90 N
60
30
0
30
60
90 S
30 60 90 120 E 180 W 120 90 60 30 0
longitude
-1 0 1 2 3
temperature (°C)
(f)
34.95
34.60
34.60
34.95
35.15
35.00
34.85
34.80
34.75
34.65
34.65
34.95
34.90
34.65
34.70
34.75
34.75
34.70
34.70
34.75
34.70
34.4 34.6 34.8 35.0
salinity
latitude

Z = 2000 m

Salinidade da Água do Mar





SALINIDADE????

É definida como o peso em gramas de material sólido dissolvido contido em 1 Kg de água do mar

qdo todos os carbonatos foram convertidos a óxidos, os brometos e iodetos em cloretos e todo material orgânico completamente oxidado.

MÉTODOS DE DETERMINAÇÃO

Salinidade = 1,80655 Cl.

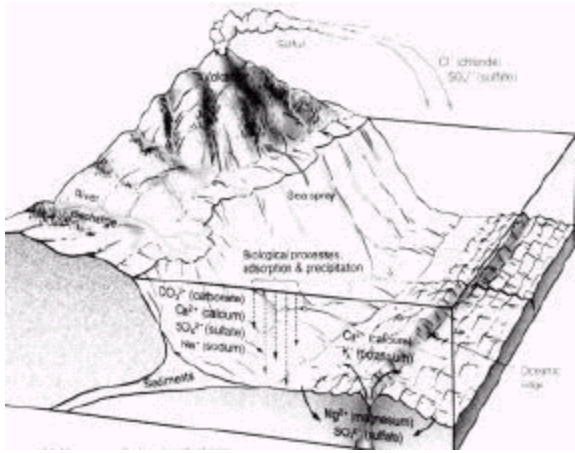
Evaporação [mat orgânica]

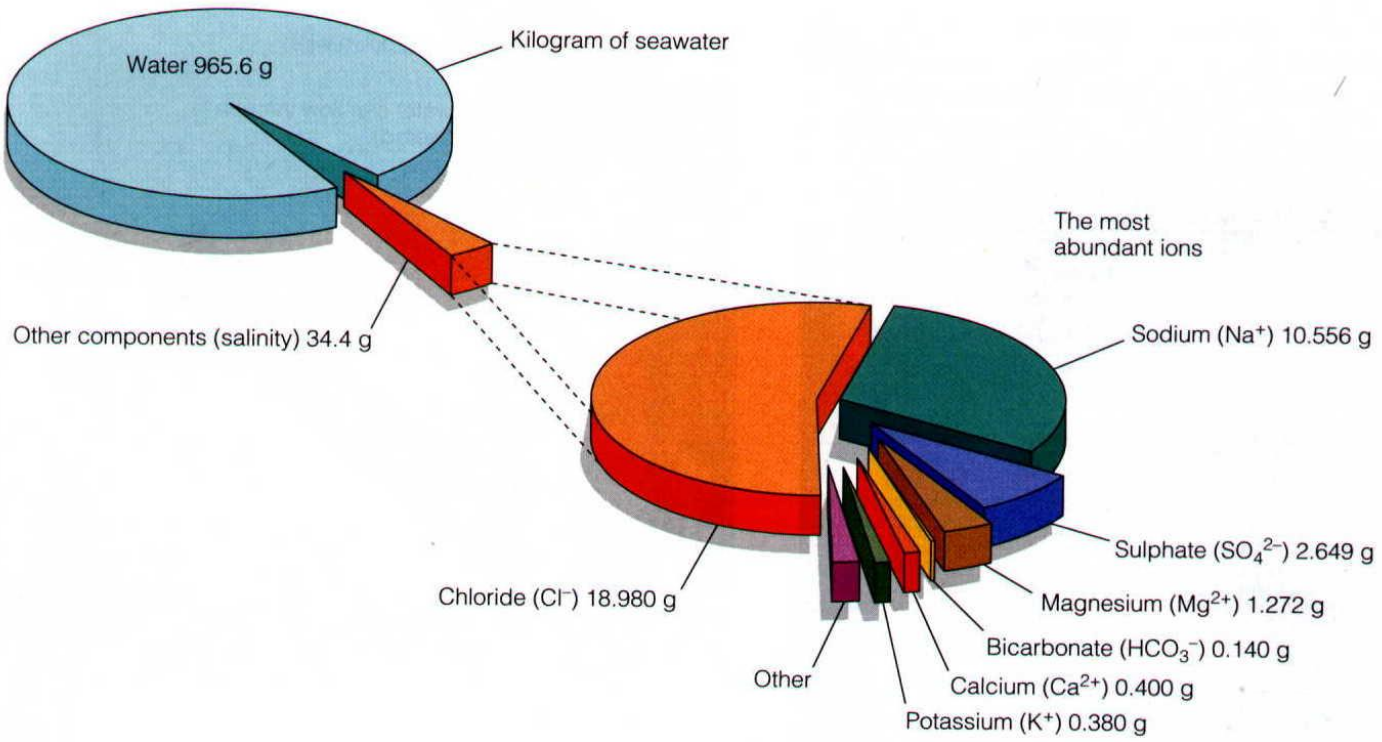
Titulação do íon cloro presente na água (clorinidade)

Atualmente condutividade elétrica

adicionados pelas erupções vulcânicas e descarga dos rios ao longo do tempo geológico.

1. Cl- com 55% do total de material dissolvido,
2. Na+ com 30,6%, sendo que o sal NaCl soma 86%,
3. SO4 - com 7,7%,
4. Mg++ com 3,7%,
5. K+ com 1,1%.




Kilogram of seawater
Water 965.6 g
Other components (salinity) 34.4 g
The most abundant ions
Sodium (Na^+) 10.556 g
Sulphate (SO_4^{2-}) 2.649 g
Magnesium (Mg^{2+}) 1.272 g
Bicarbonate (HCO_3^-) 0.140 g
Calcium (Ca^{2+}) 0.400 g
Potassium (K^+) 0.380 g
Chloride (Cl^-) 18.980 g
Other

Como determinar a salinidade ?

CLORINIDADE

$$S = 1.806\,55\,Cl$$

where *chlorinity Cl* is defined as “the mass of silver required to precipitate completely the halogens in 0.328 523 4 kg of the sea-water sample.”

$$S = -0.089\,96 + 28.297\,29\,R_{15} + 12.808\,32\,R_{15}^2 - 10.678\,69\,R_{15}^3 + 5.986\,24\,R_{15}^4 - 1.323\,11\,R_{15}^5 \qquad (6.3a)$$

$$R_{15} = C(S, 15, 0)/C(35, 15, 0) \qquad (6.3b)$$

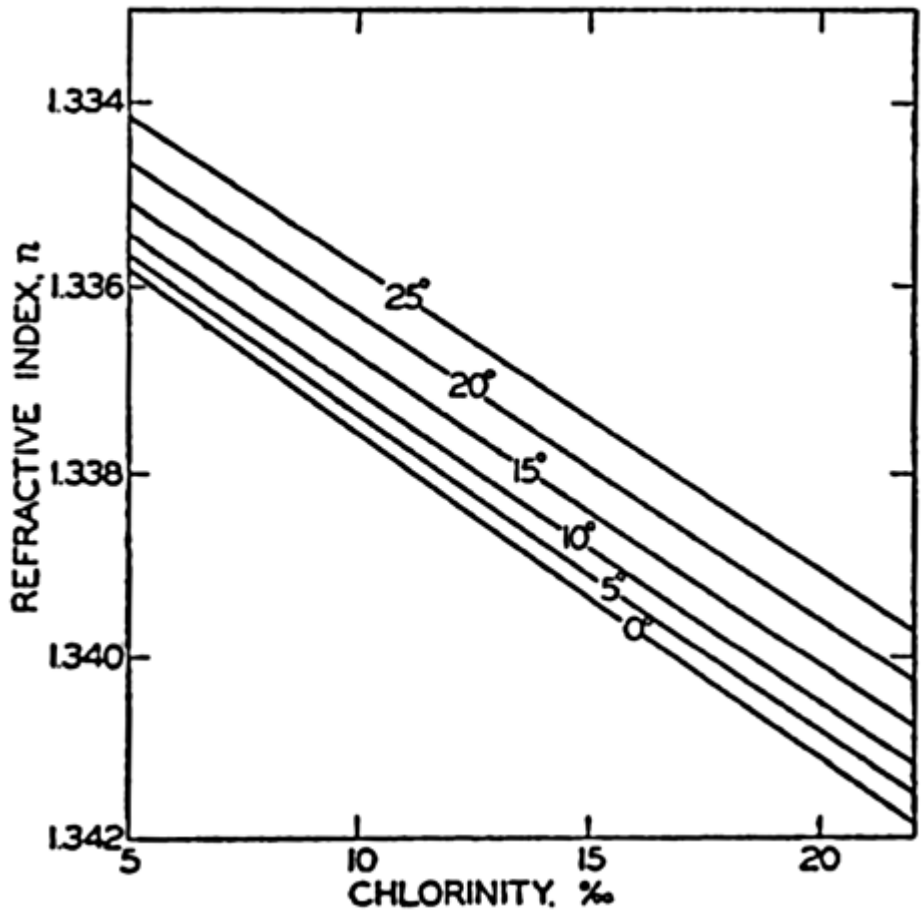
where $C(S, 15, 0)$ is the conductivity of the sea-water sample at 15°C and atmospheric pressure, having a salinity S derived from (6.4), and $C(35, 15, 0)$ is the conductivity of standard “Copenhagen” sea water. Millero (1996) points out that (6.3) is not a new definition of salinity, it merely gives chlorinity as a function of conductivity of seawater relative to standard seawater.

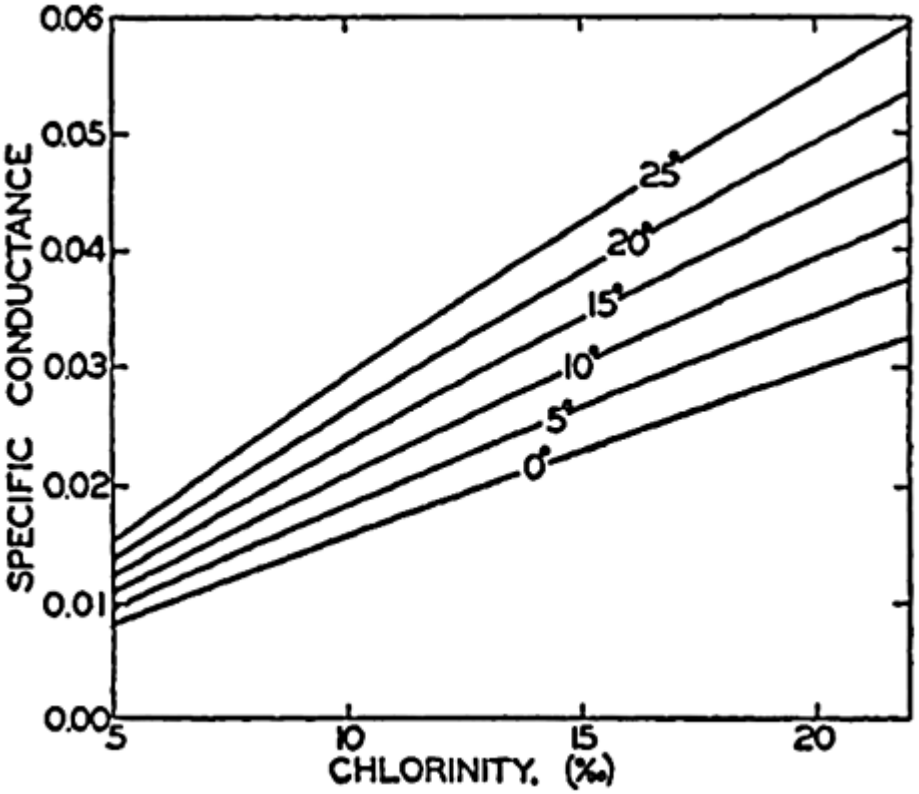
Practical Salinity Scale of 1978 By the early 1970s, accurate conductivity meters could be deployed from ships to measure conductivity at depth. The need to re-evaluate the salinity scale led the Joint Panel to recommend in 1978 that salinity be defined using only conductivity, breaking the link with chlorinity. All water samples with the same conductivity ratio have the same salinity.

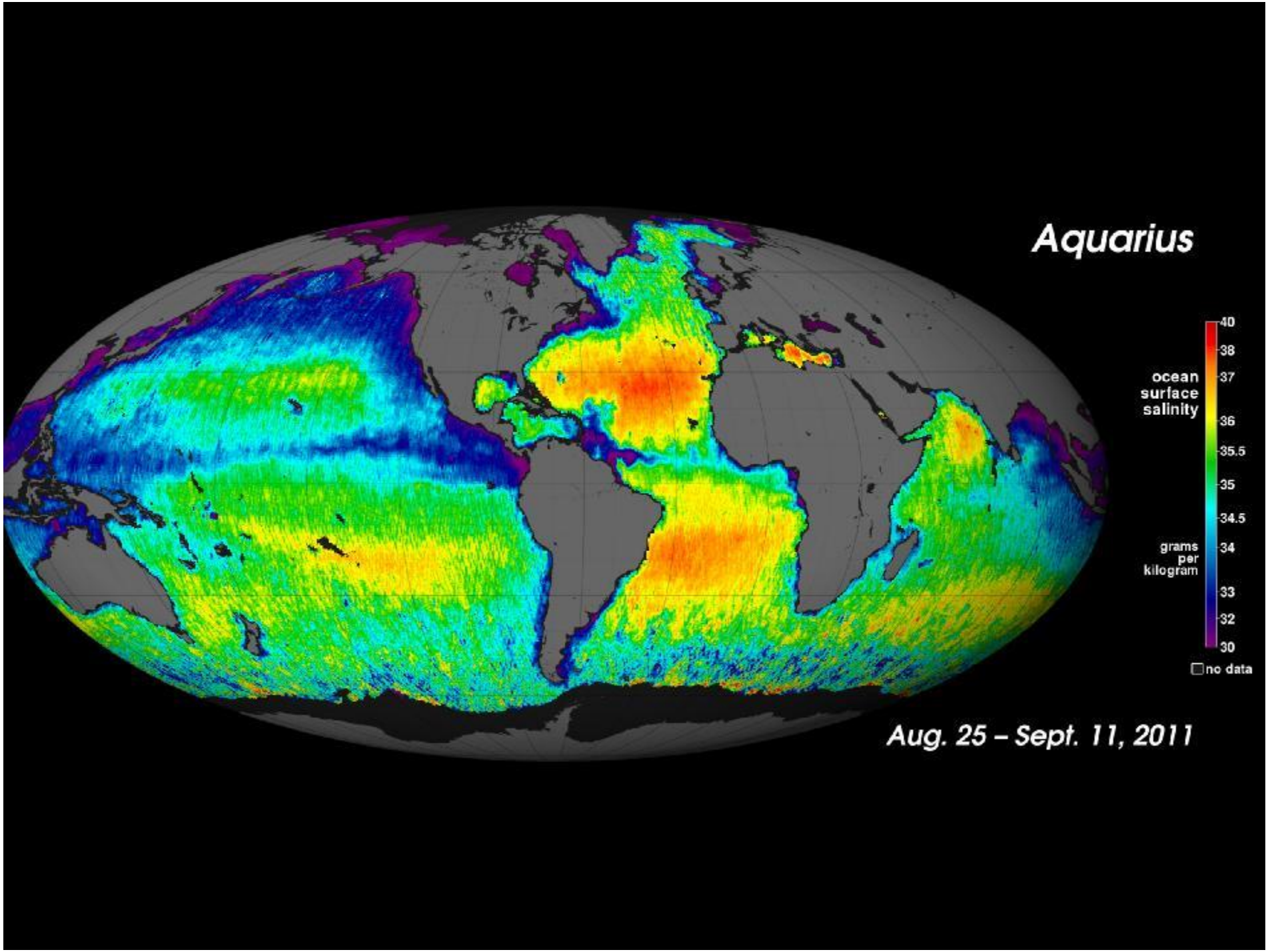
The *Practical Salinity Scale of 1978* is now the official definition:

$$\begin{aligned} S = {} & 0.0080 - 0.1692\, R_T^{1/2} + 25.3851\, R_T + 14.0941\, R_T^{3/2} \\ & - 7.0261\, R_T^2 + 2.7081\, R_T^{5/2} + \Delta S \qquad (6.4a) \\ R_T = {} & C(S,T,0)/C(KCl,T,0) \qquad (6.4b) \\ \Delta S = {} & \left[\frac{(T-15)}{1+0.0162\,(T-15)}\right] + 0.0005 - 0.0056\, R_T^{1/2} - 0.0066\, R_T \\ & - 0.0375\, R_T^{3/2} + 0.636\, R_T^2 - 0.0144\, R_T^{5/2} \qquad (6.4c) \\ 2 \le {} & S \le 42 \end{aligned}$$

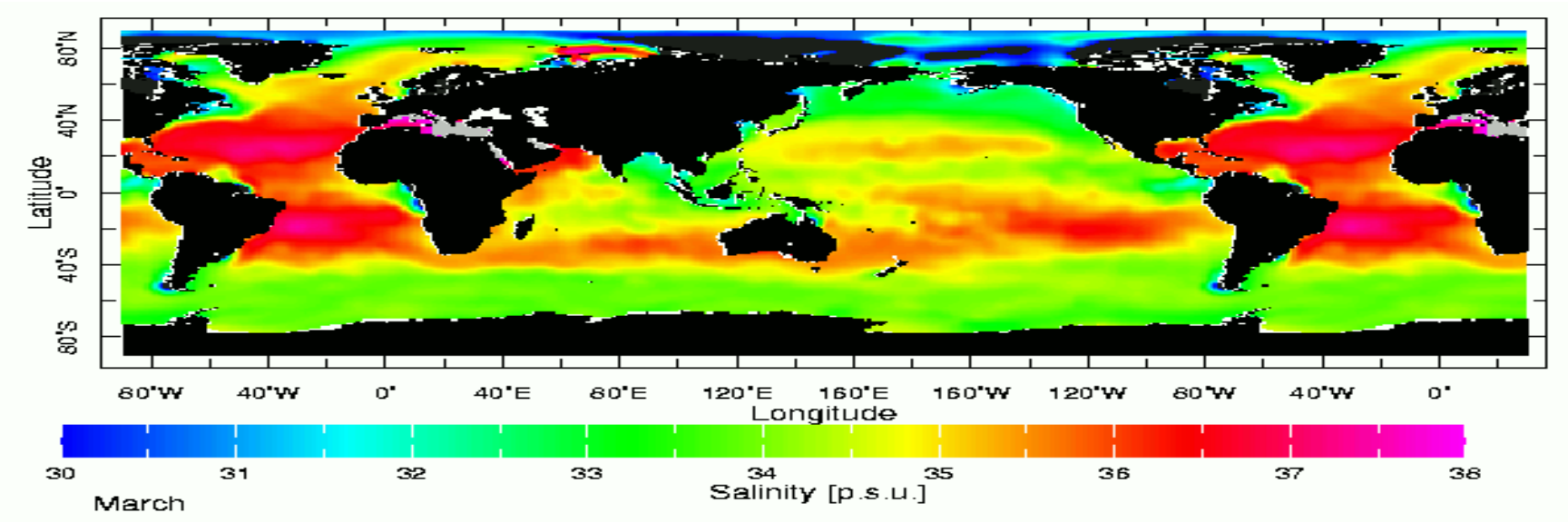
where $C(S,T,0)$ is the conductivity of the sea-water sample at temperature T and standard atmospheric pressure, and $C(KCl,T,0)$ is the conductivity of the standard potassium chloride (KCl) solution at temperature T and standard atmospheric pressure. The standard KCl solution contains a mass of 32.435 6 grams of KCl in a mass of 1.000 000 kg of solution. An extension of (6.4) gives salinity at any pressure (see Millero 1996: 72).

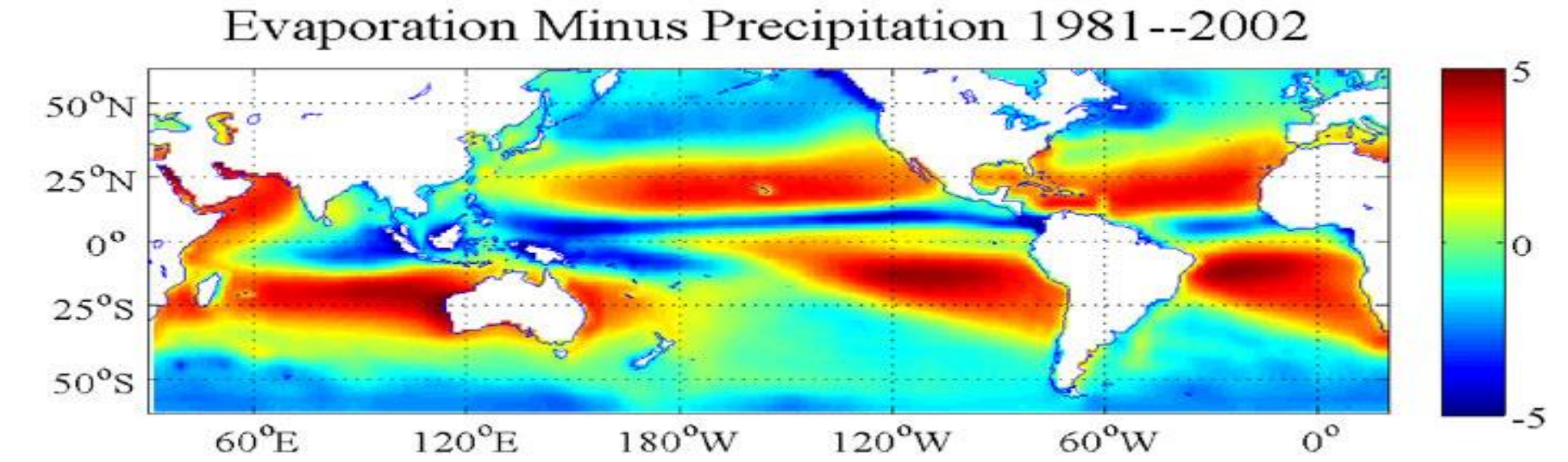

1.334
1.336
1.338
1.340
1.342
REFRACTIVE INDEX, n
25°
20°
15°
10°
5°
0°
5
10
15
20
CHLORINITY, ‰


0.06
0.05
0.04
0.03
0.02
0.01
0.00
SPECIFIC CONDUCTANCE
25°
20°
15°
10°
5°
0°
5
10
15
20
CHLORINITY, (‰)


Aquarius
ocean surface salinity
grams per kilogram
40
38
37
36
35.5
35
34.5
34
33
32
30
no data
Aug. 25 – Sept. 11, 2011

Variação superficial da salinidade: o que causa isso?



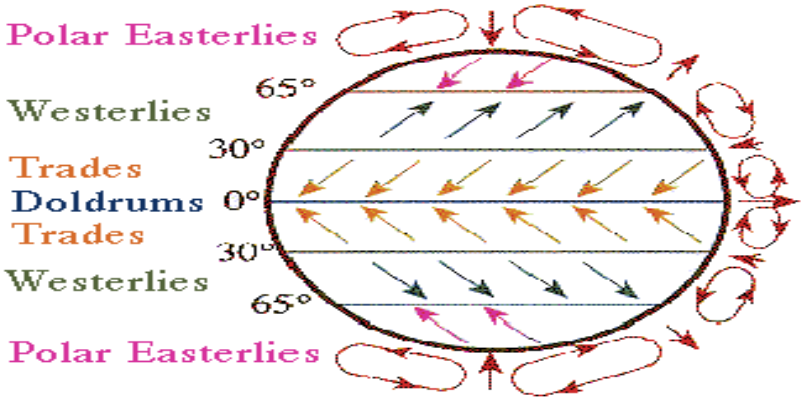


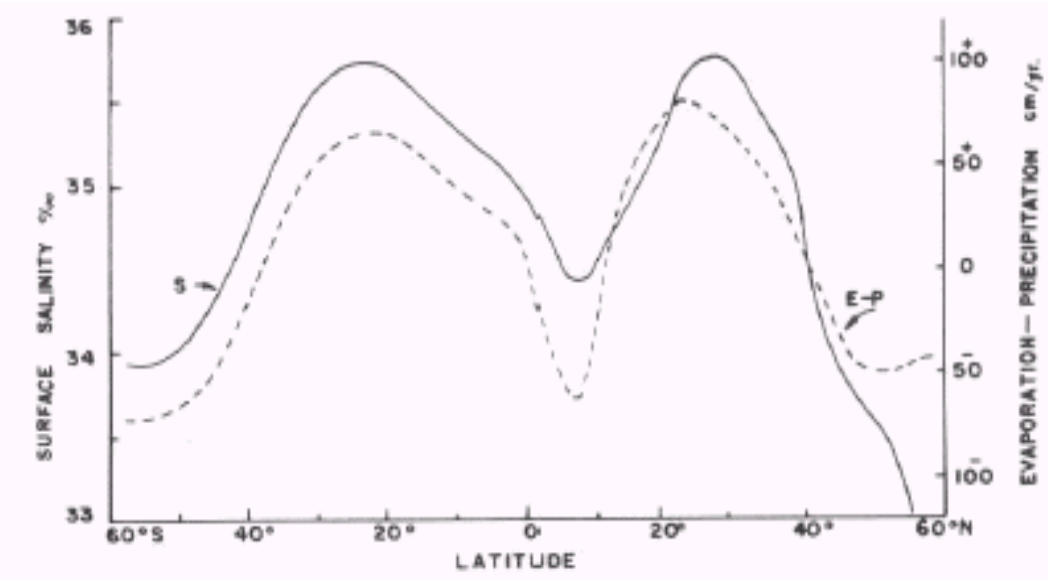
Variação da Salinidade

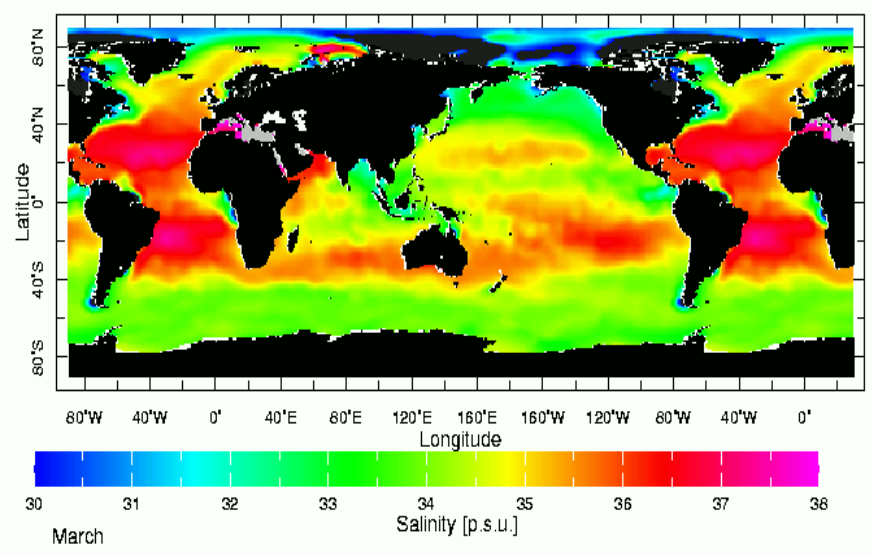
Evaporação, precipitação, aportes continentais, congelamento/degelo

DISTRIBUIÇÃO HORIZONTAL DA SALINIDADE

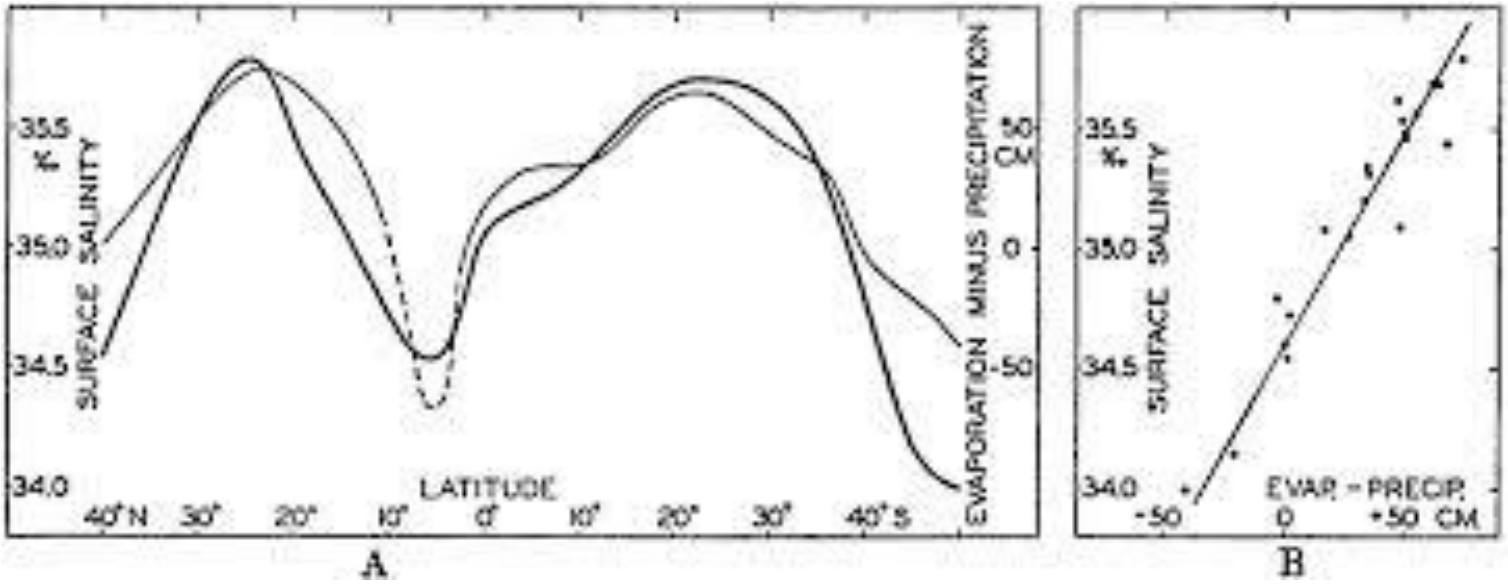
aproximadamente zonal
Depende do balanço E-P
Max ~20º E>P
Min Equador P>E
S média sup 33.8 e 37.5
Altas latitudes: congelamento/degelo

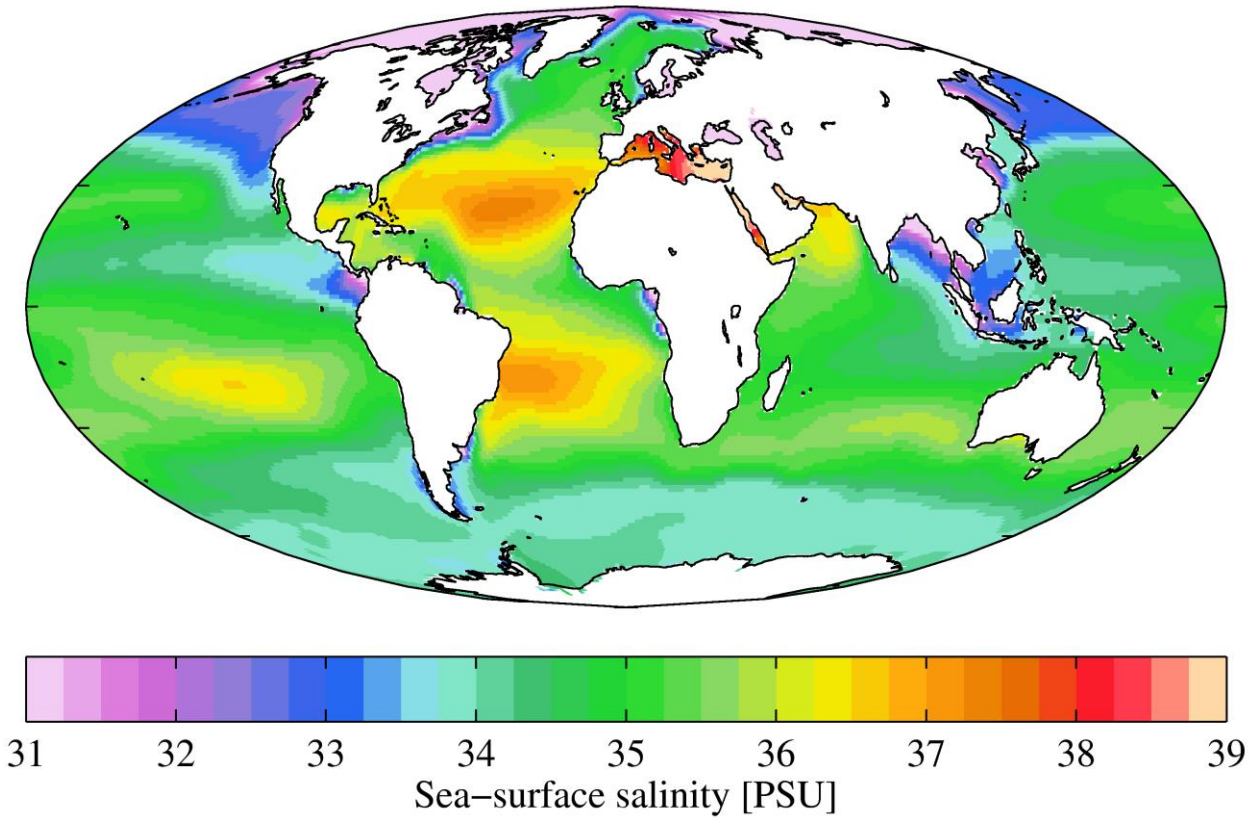


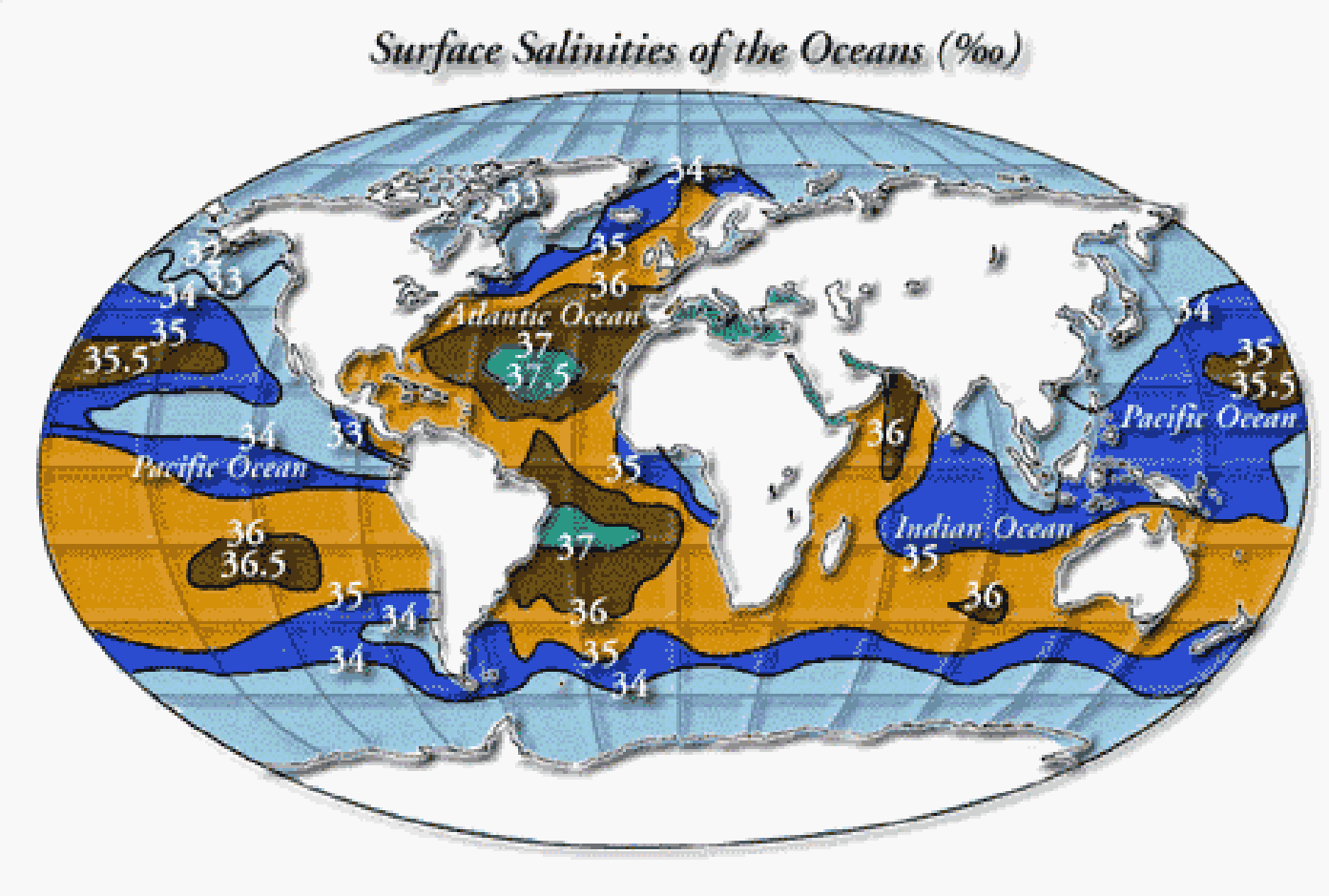


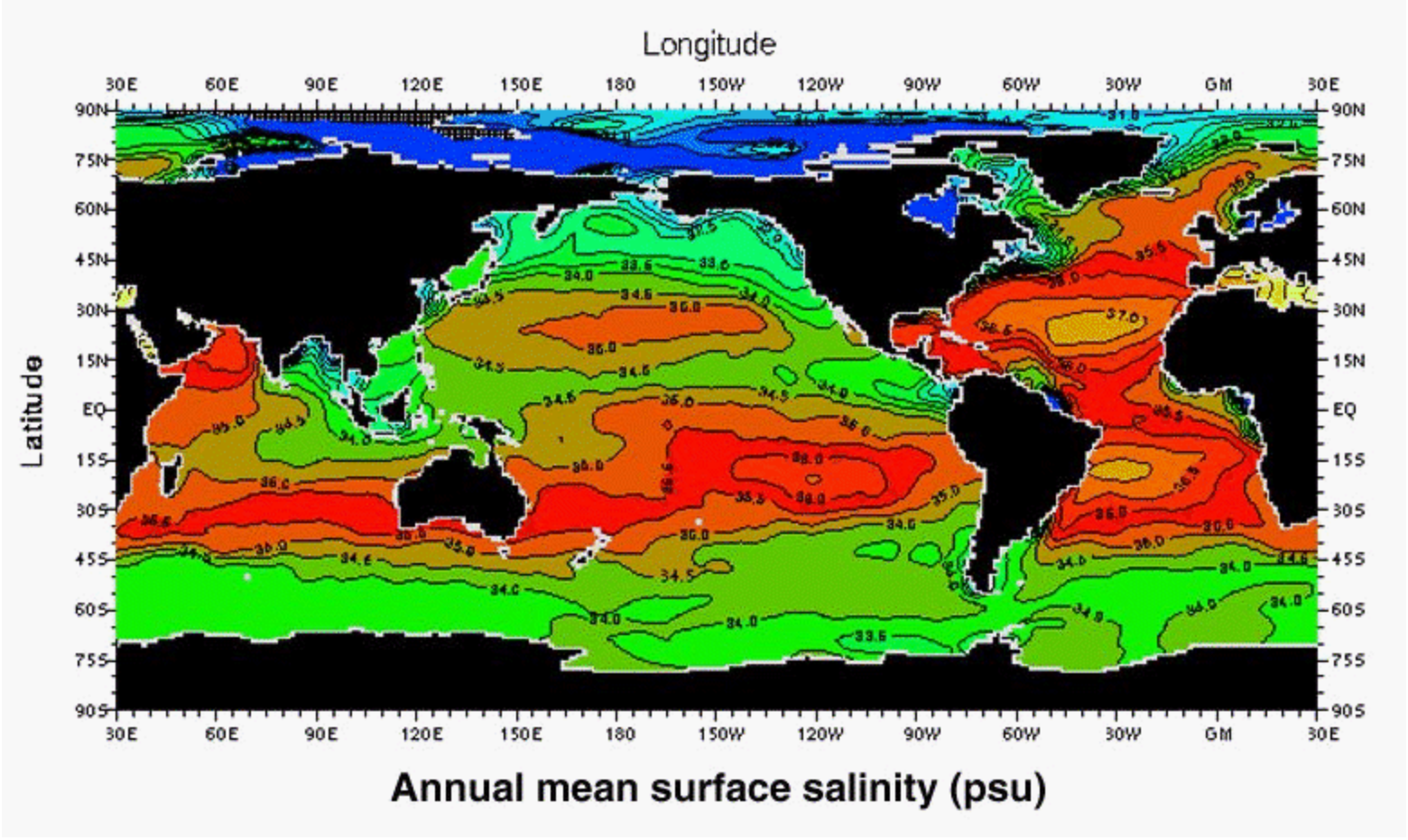


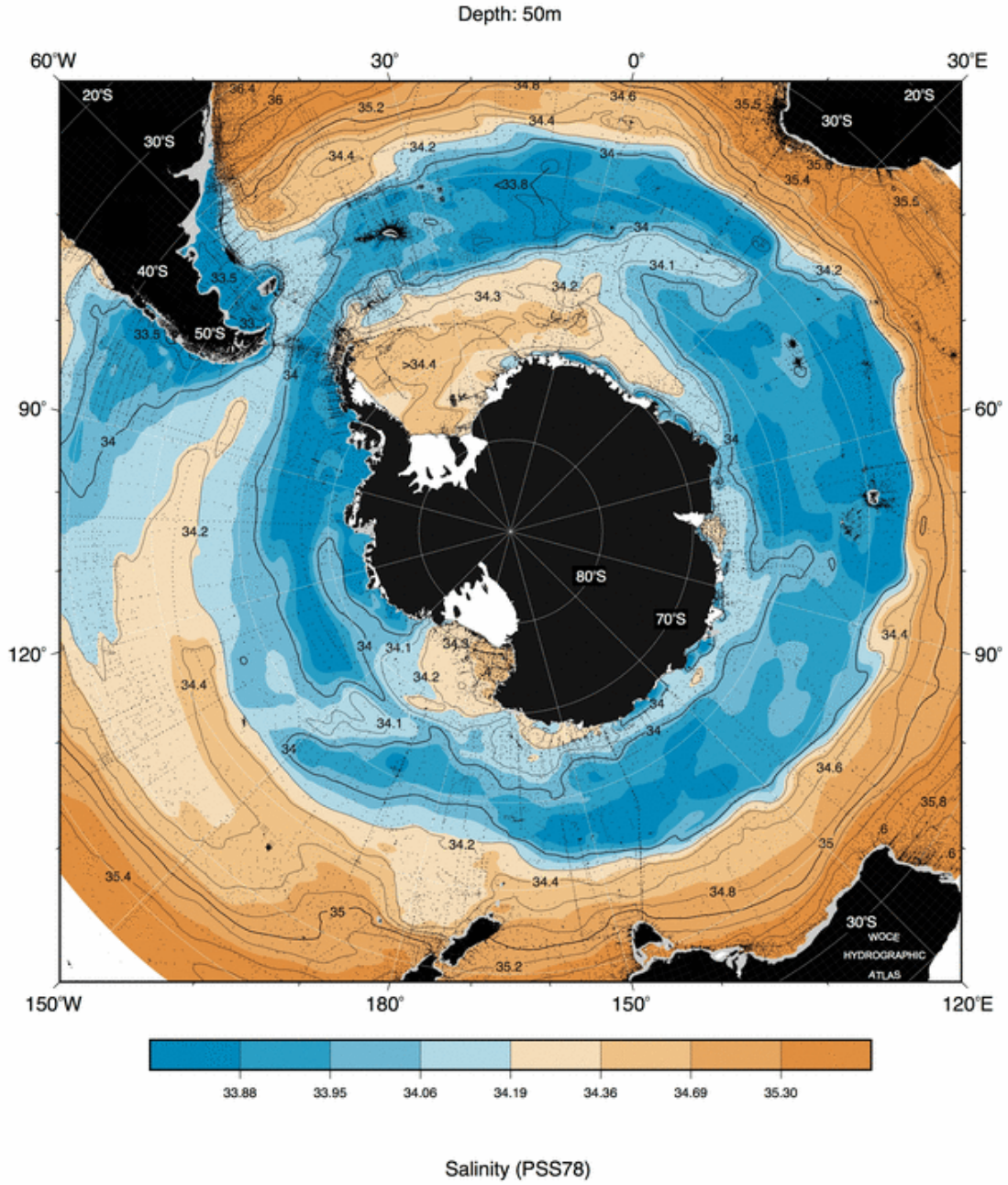
S superficial média para todos os oceanos e diferenças entre evaporação e precipitação (E-P) em função da latitude.


35.5
‰
35.0
34.5
34.0
SURFACE SALINITY
40°N
30°
20°
10°
0°
10°
20°
30°
40°S
LATITUDE
EVAPORATION MINUS PRECIPITATION
+50
CM
0
-50
A
35.5
‰
35.0
34.5
34.0
SURFACE SALINITY
-50
0
+50 CM
EVAP. - PRECIP.
B

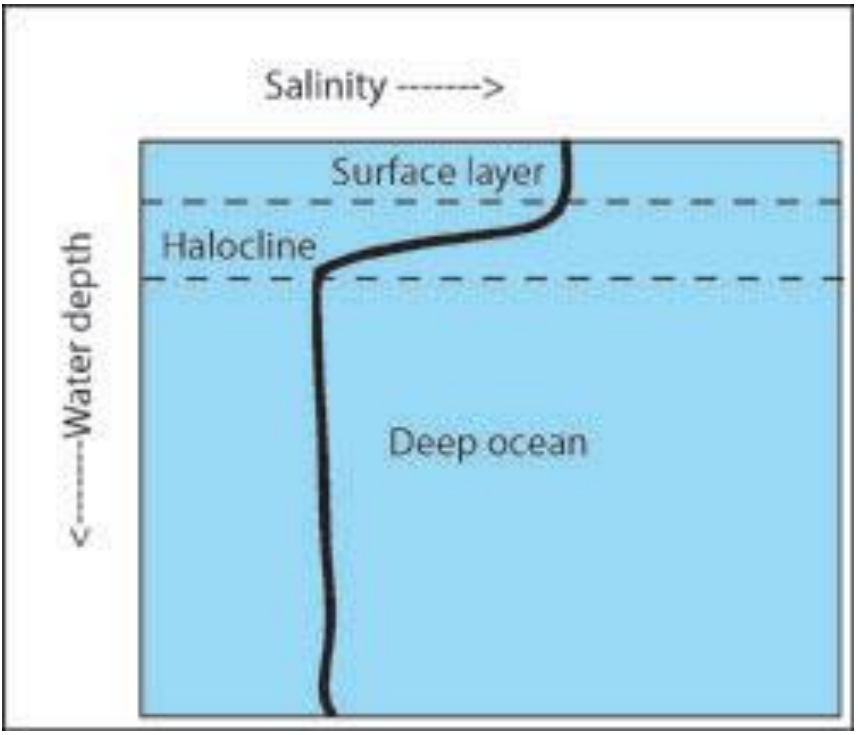

31
32
33
34
35
36
37
38
39
Sea−surface salinity [PSU]

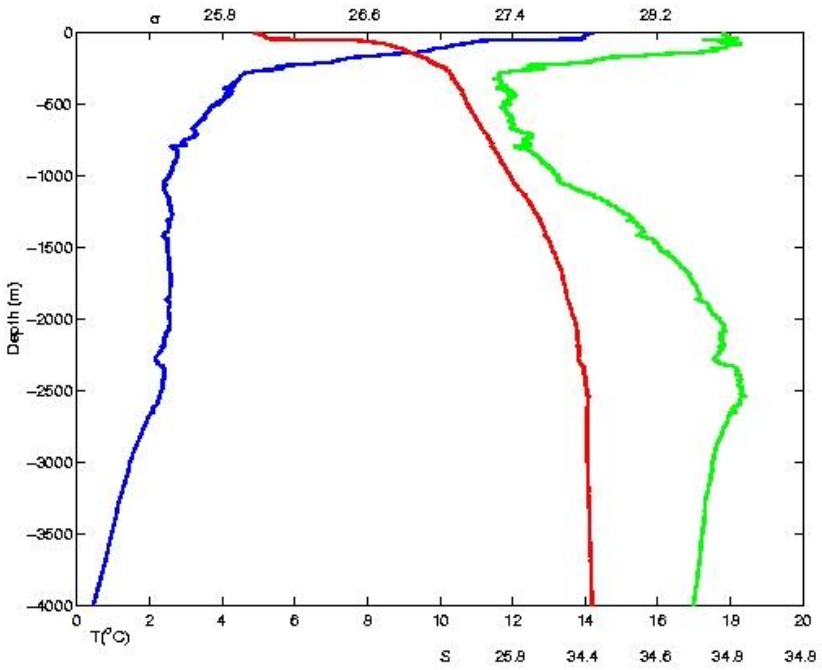

Surface Salinities of the Oceans (‰)
Atlantic Ocean
Pacific Ocean
Pacific Ocean
Indian Ocean
34
33
35
36
37
37.5
35.5
36.5


Longitude
30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W GM 30E
90N 75N 60N 45N 30N 15N EQ 15S 30S 45S 60S 75S 90S
Latitude
Annual mean surface salinity (psu)

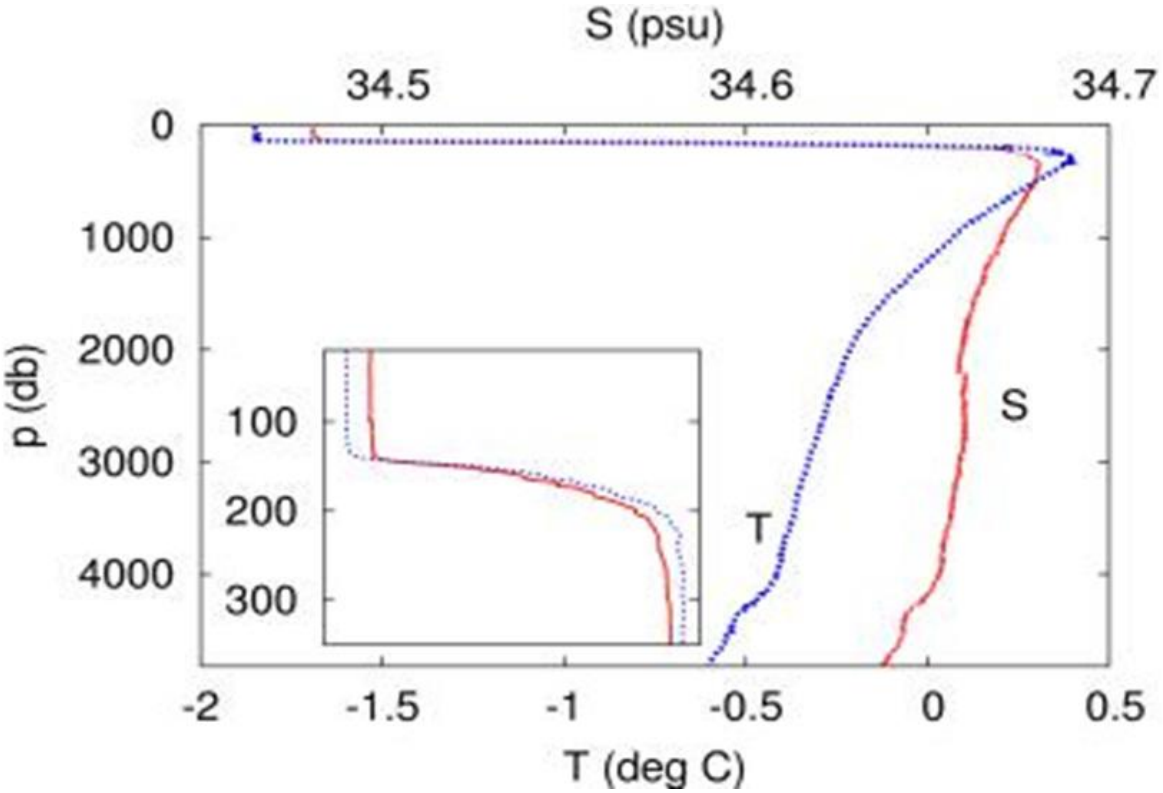

Depth: 50m
60°W
30°
0°
30°E
20°S
30°S
40°S
50°S
90°
60°
120°
90°
80°S
70°S
150°W
180°
150°
120°E
WOCE
HYDROGRAPHIC
ATLAS
33.88
33.95
34.06
34.19
34.36
34.69
35.30
Salinity (PSS78)

Distribuição Vertical da Salinidade entre 60 S e 60 N



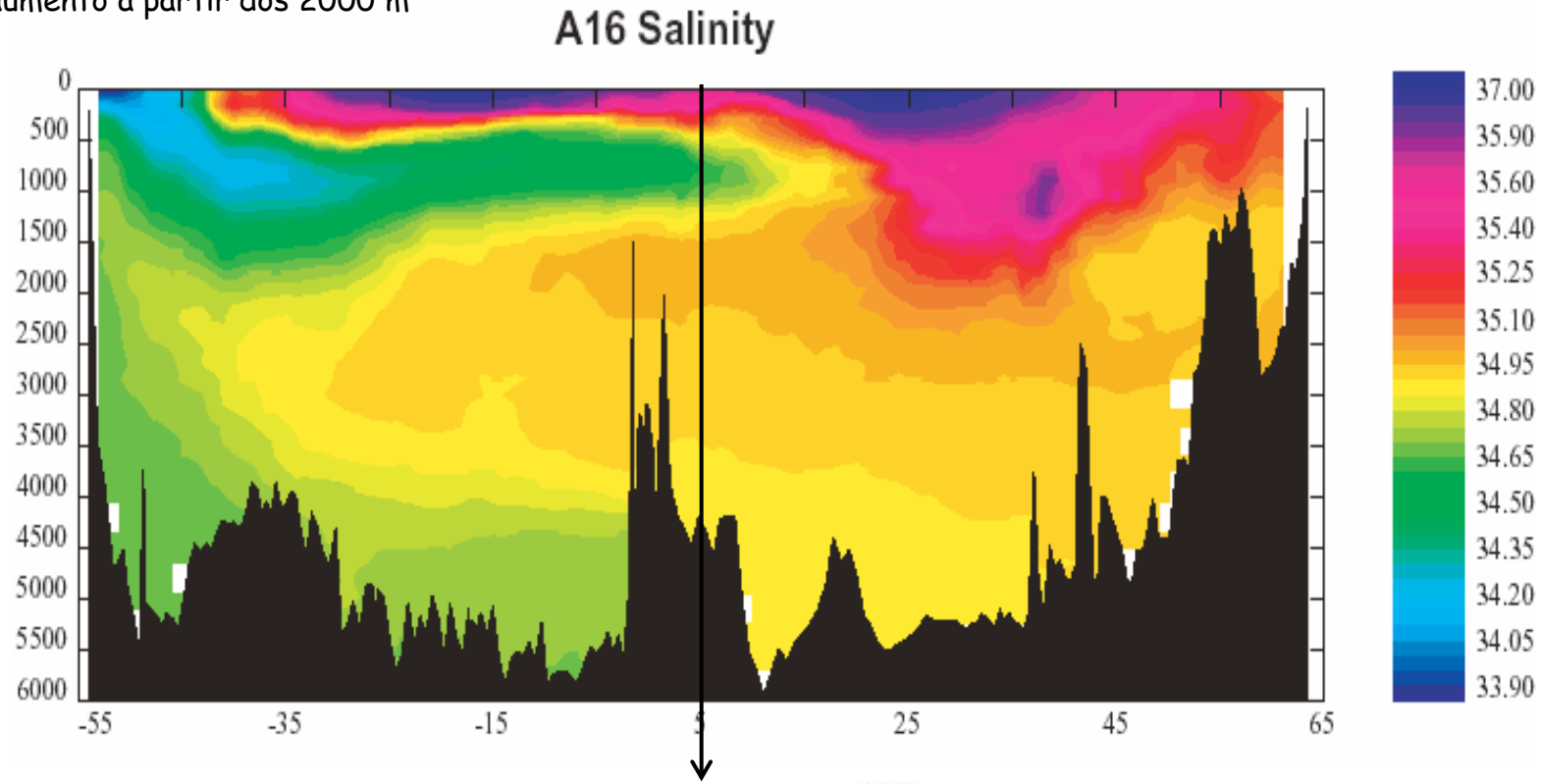


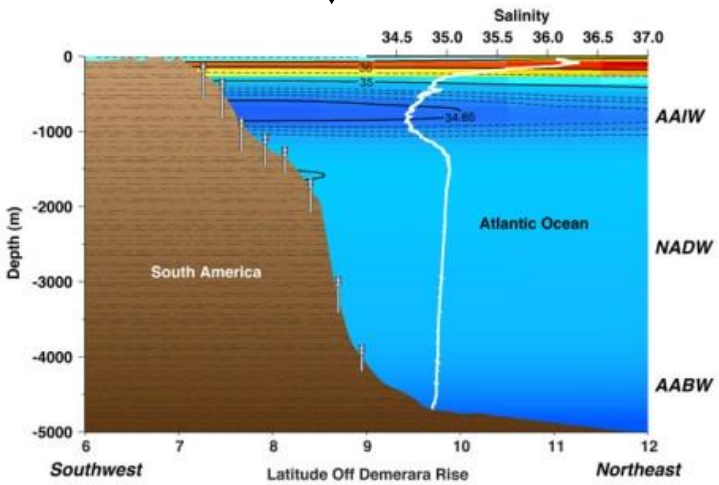
Distribuição Vertical da Salinidade em altas latitudes – Mar de Weddell



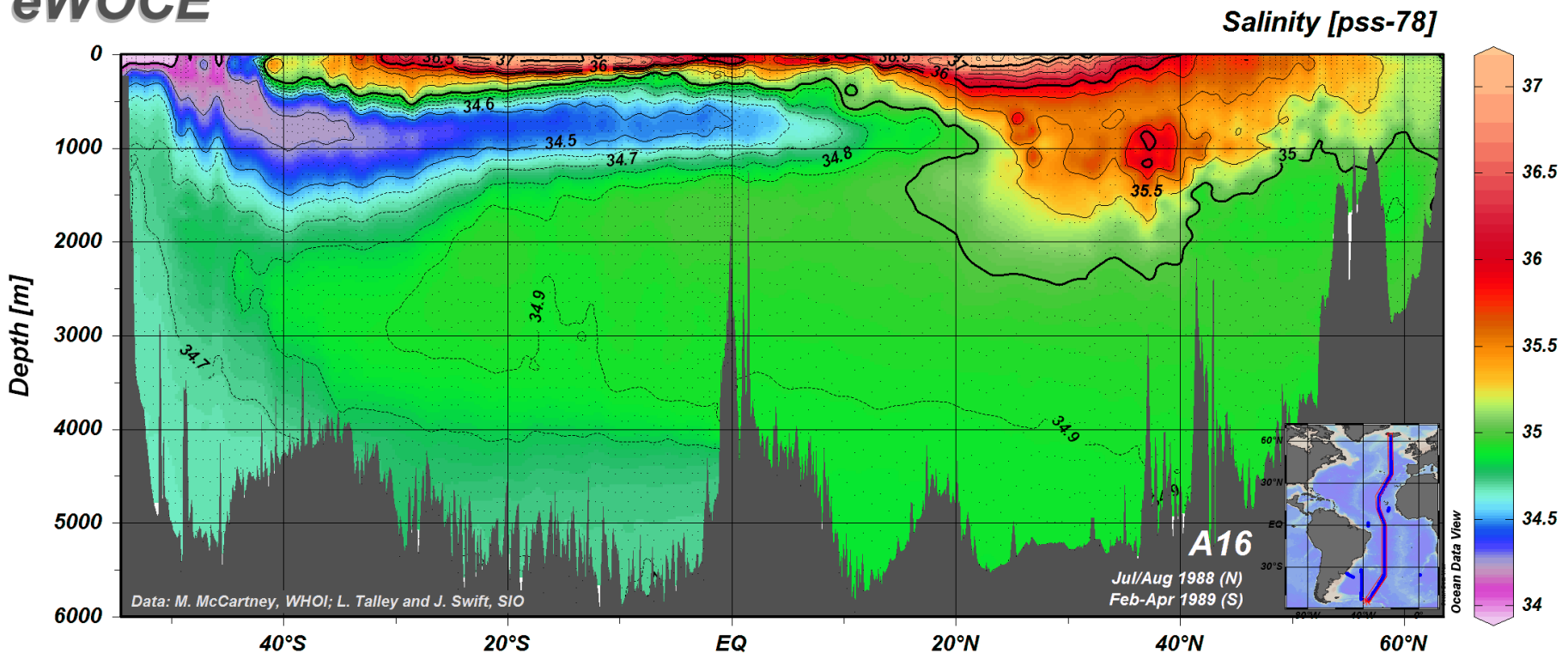
Distribuição vertical da Salinidade

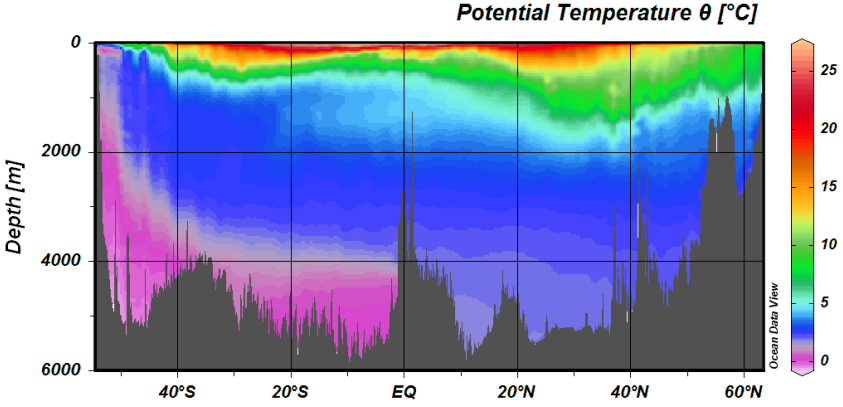
A distribuição vertical da S em baixas e médias lat é caracterizada por um mín de S entre 600 a 1000 m com um aumento a partir dos 2000 m

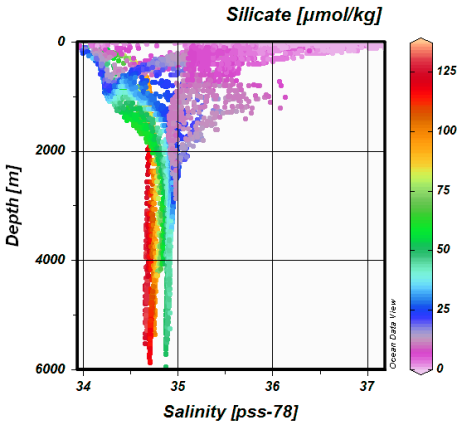


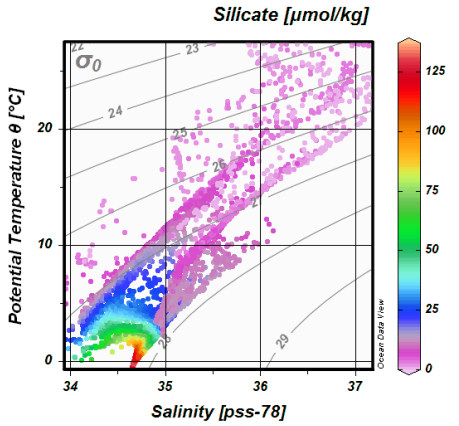


eWOCE

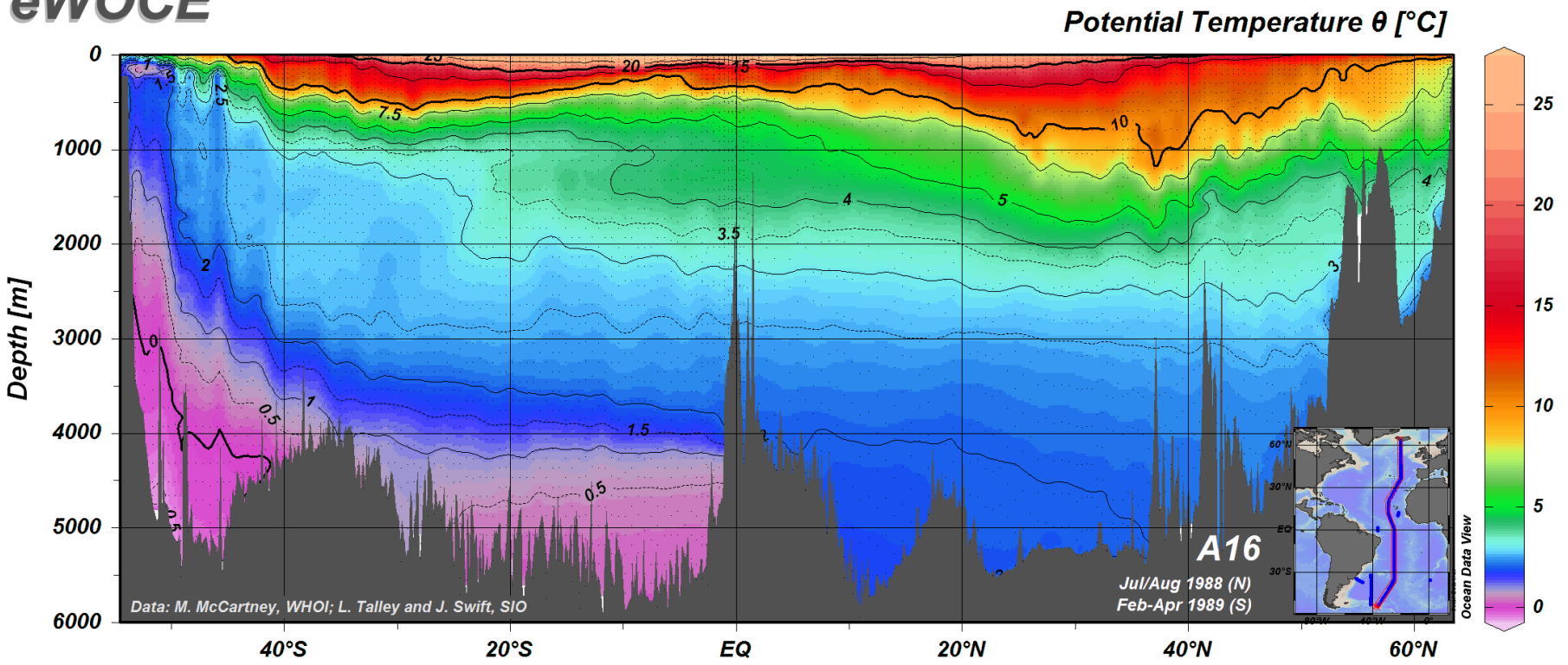

Salinity [pss-78]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
34.6
34.5
34.7
34.8
35.5
35
34.9
36
37
36.5
35
34.5
34
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Data: M. McCartney, WHOI; L. Talley and J. Swift, SIO
Ocean Data View

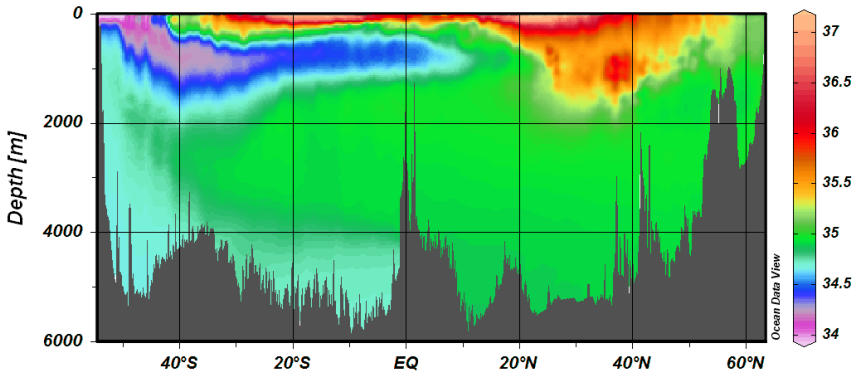

Potential Temperature θ [°C]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
25
20
15
10
5
0
Ocean Data View

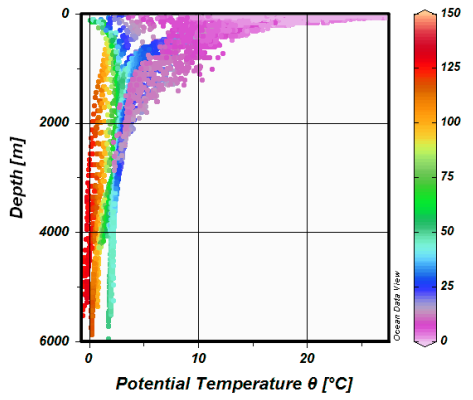

Silicate [µmol/kg]
Depth [m]
0
2000
4000
6000
34
35
36
37
Salinity [pss-78]
125
100
75
50
25
0
Ocean Data View

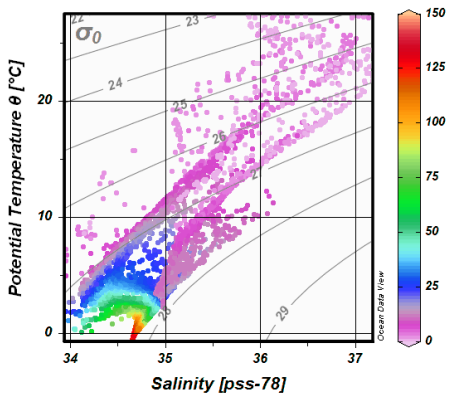

Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
23
24
25
26
27
28
29
0
10
20
34
35
36
37
Salinity [pss-78]
125
100
75
50
25
0
Ocean Data View

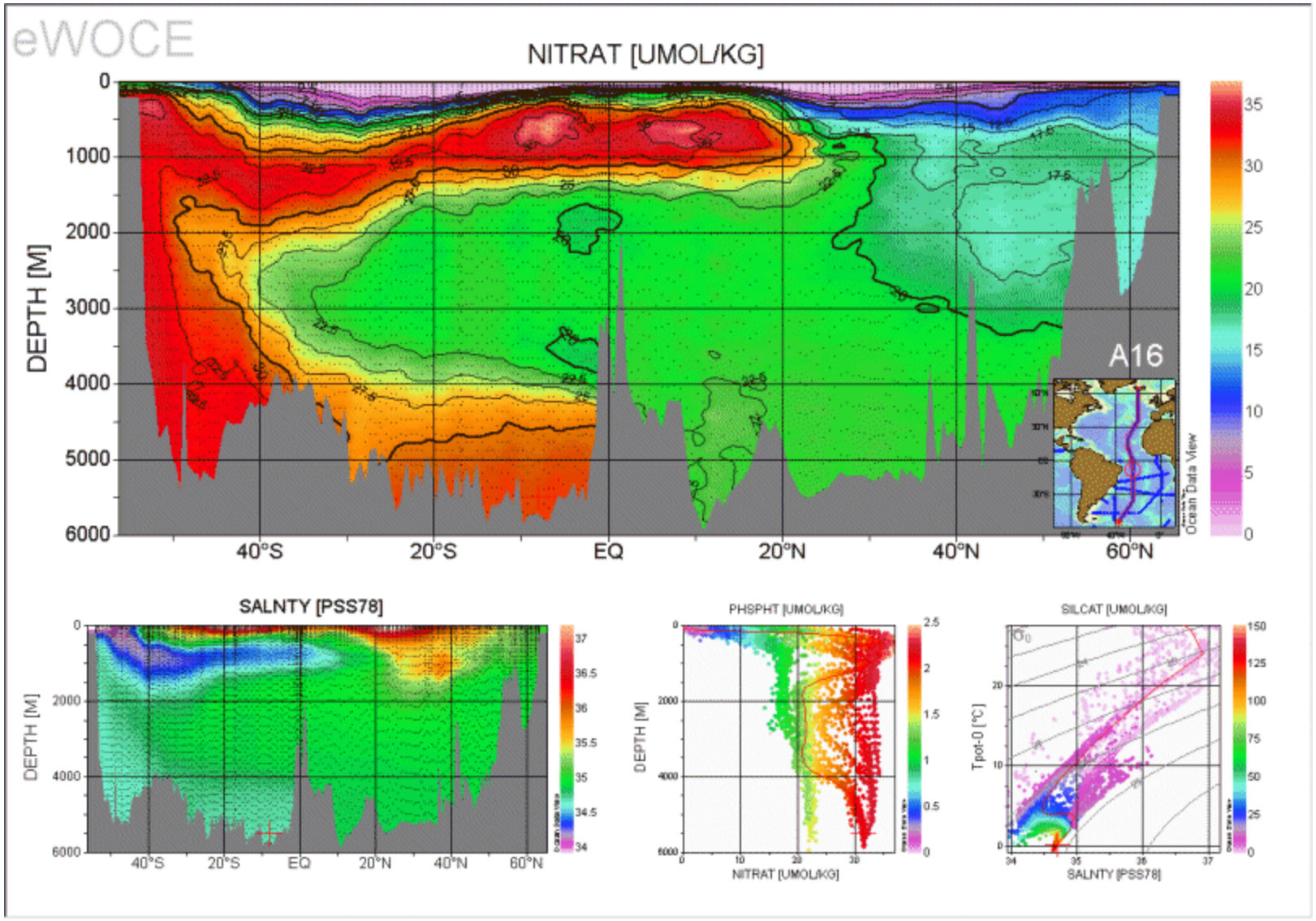
eWOCE


Potential Temperature θ [°C]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Data: M. McCartney, WHOI; L. Talley and J. Swift, SIO
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Ocean Data View
25
20
15
10
5
0

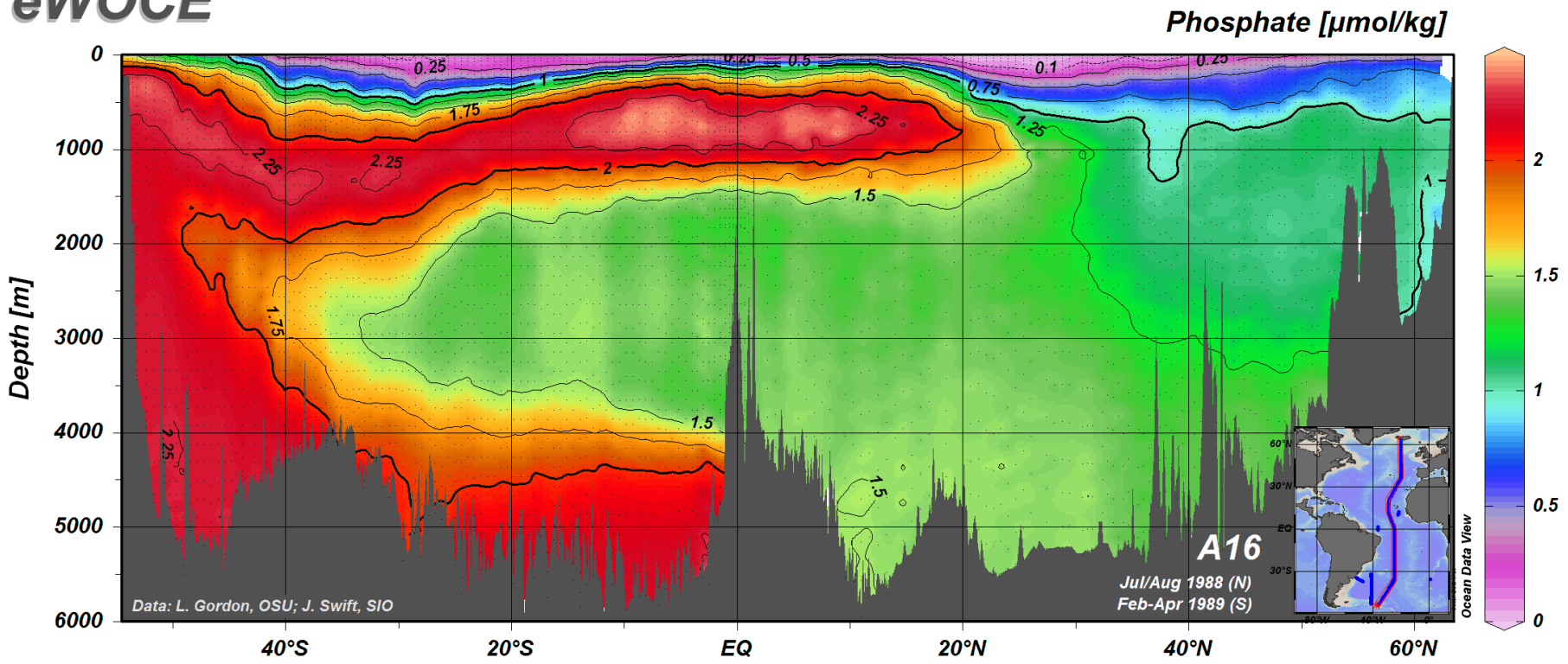

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Ocean Data View
37
36.5
36
35.5
35
34.5
34

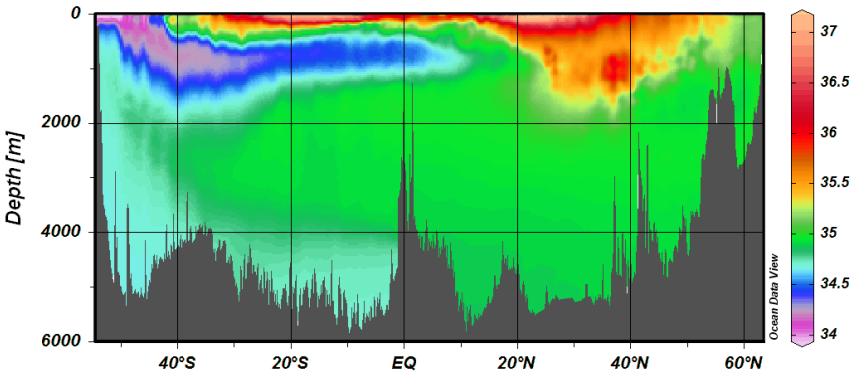

Silicate [µmol/kg]
Depth [m]
0
2000
4000
6000
0
10
20
Potential Temperature θ [°C]
Ocean Data View
150
125
100
75
50
25
0

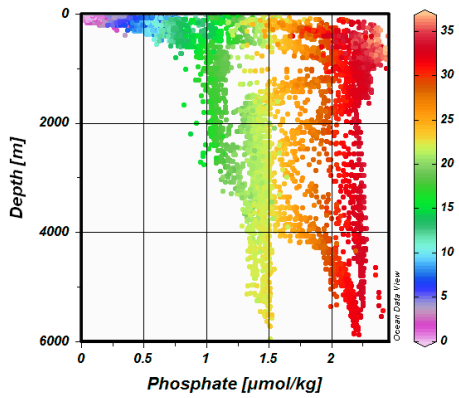

Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
20
10
0
34
35
36
37
Salinity [pss-78]
Ocean Data View
150
125
100
75
50
25
0

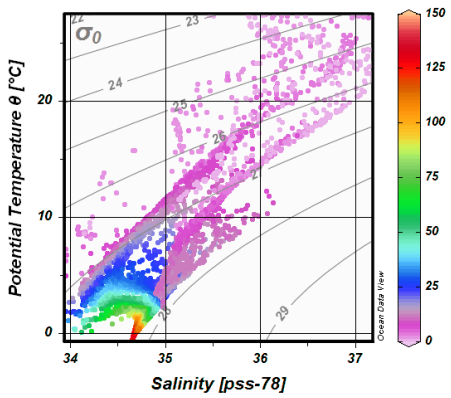

eWOCE
NITRAT [UMOL/KG]
DEPTH [M]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
A16
Ocean Data View
35
30
25
20
15
10
5
0
SALNTY [PSS78]
DEPTH [M]
37
36.5
36
35.5
35
34.5
34
PHSPHT [UMOL/KG]
NITRAT [UMOL/KG]
2.5
2
1.5
1
0.5
0
SILCAT [UMOL/KG]
Tpot-0 [°C]
SALNTY [PSS78]
150
125
100
75
50
25
0

eWOCE

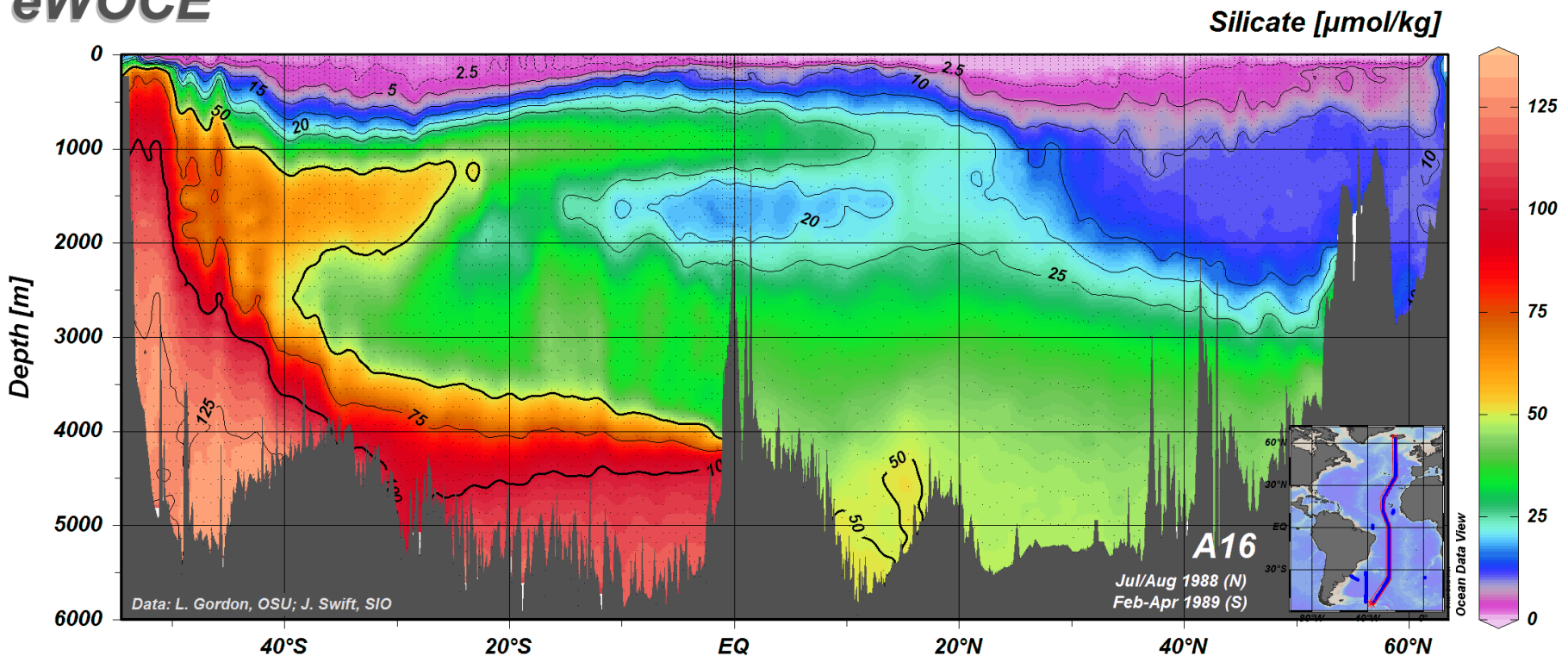

Phosphate [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
0.25
0.5
0.1
0.75
1
1.25
1.75
2
2.25
1.5
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Data: L. Gordon, OSU; J. Swift, SIO
Ocean Data View
2
1.5
1
0.5
0

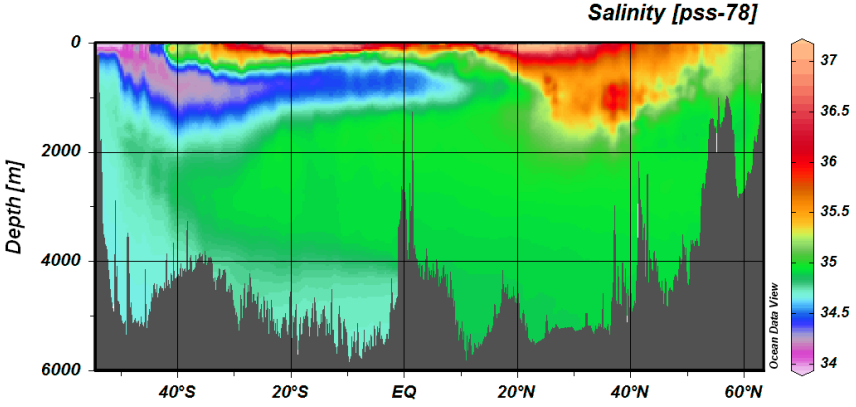

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
37
36.5
36
35.5
35
34.5
34
Ocean Data View

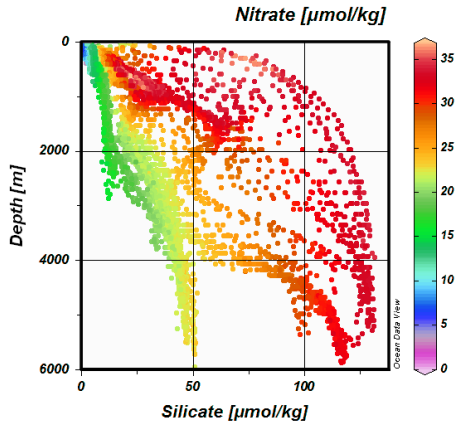

Nitrate [µmol/kg]
Depth [m]
0
2000
4000
6000
0
0.5
1
1.5
2
Phosphate [µmol/kg]
35
30
25
20
15
10
5
0
Ocean Data View

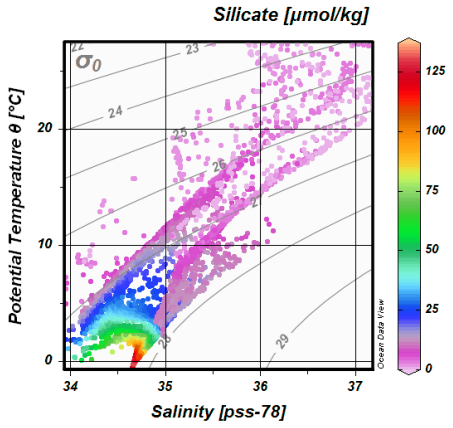

Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
23
24
25
26
27
28
29
0
10
20
34
35
36
37
Salinity [pss-78]
150
125
100
75
50
25
0
Ocean Data View

eWOCE

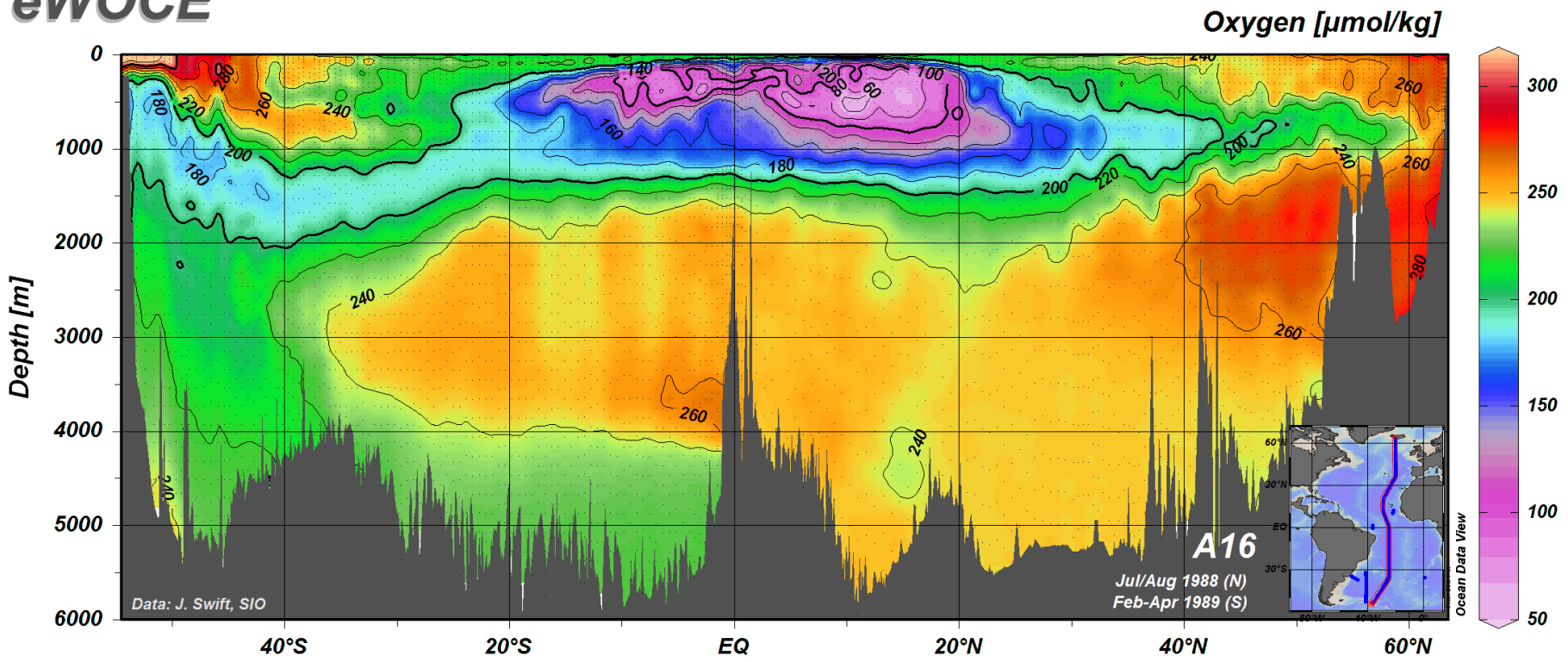

Silicate [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Data: L. Gordon, OSU; J. Swift, SIO
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Ocean Data View
125
100
75
50
25
0

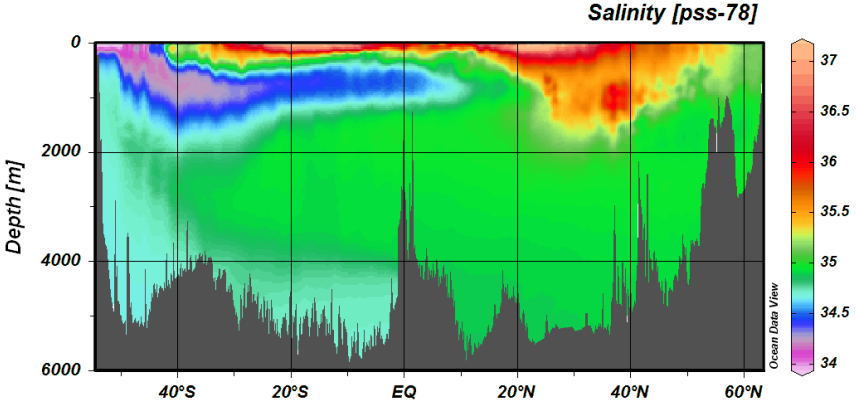

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Ocean Data View
37
36.5
36
35.5
35
34.5
34

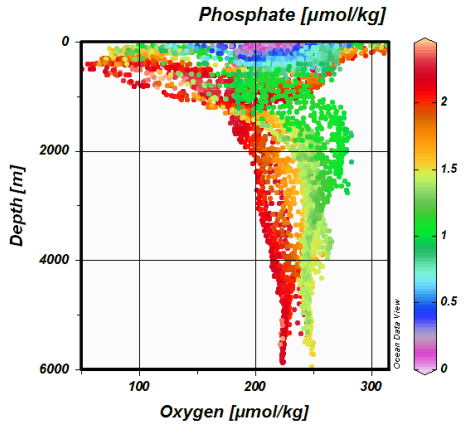

Nitrate [µmol/kg]
Depth [m]
0
2000
4000
6000
0
50
100
Silicate [µmol/kg]
Ocean Data View
35
30
25
20
15
10
5
0

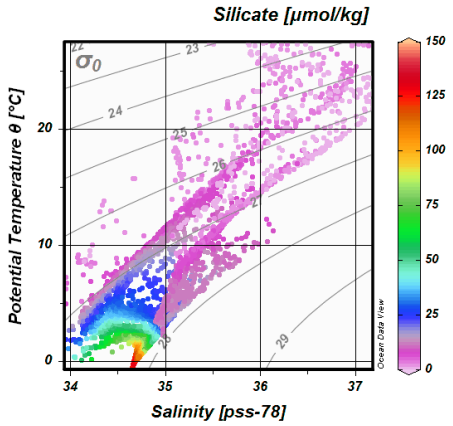

Silicate [µmol/kg]
σ0
Potential Temperature θ [°C]
0
10
20
34
35
36
37
Salinity [pss-78]
Ocean Data View
125
100
75
50
25
0

eWOCE

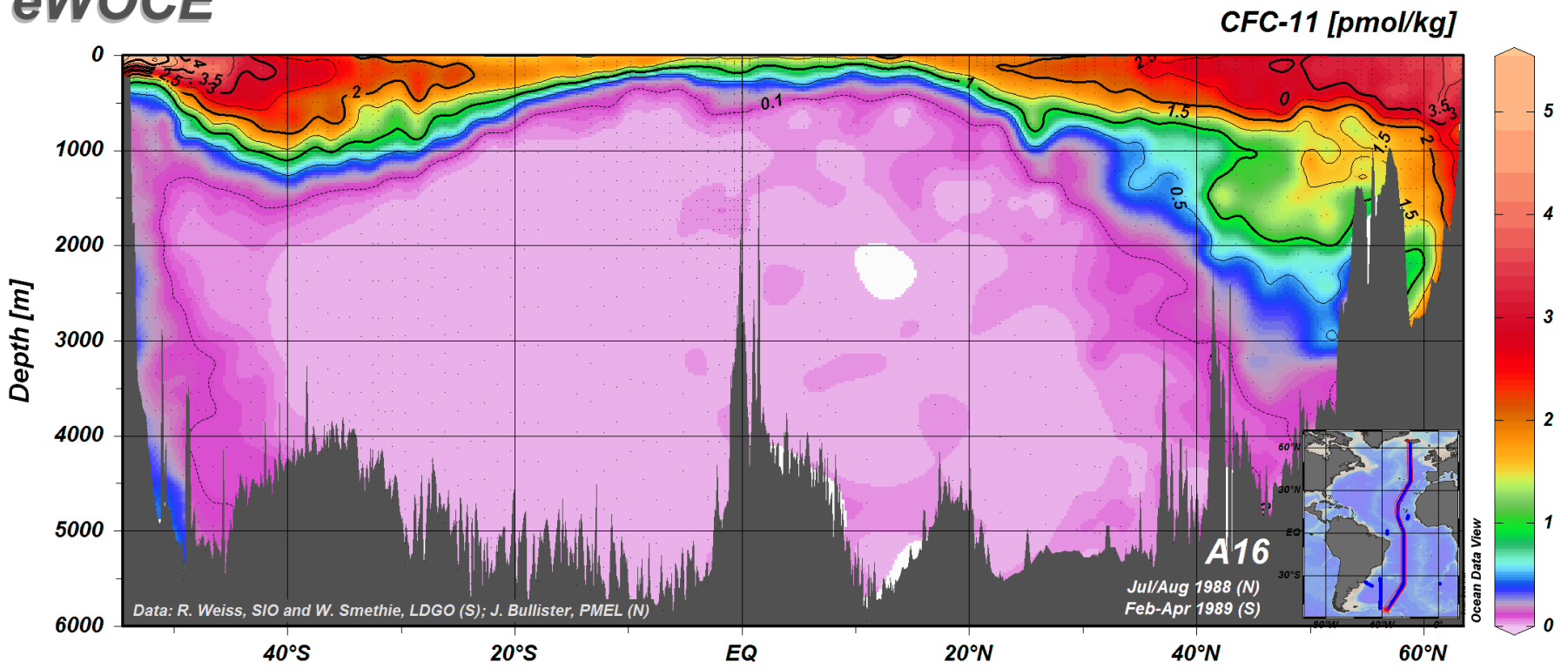

Oxygen [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Data: J. Swift, SIO
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Ocean Data View
300
250
200
150
100
50

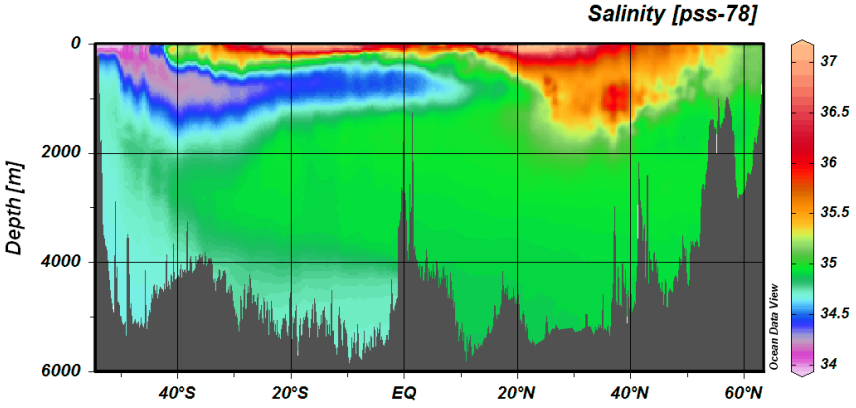

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
Ocean Data View
37
36.5
36
35.5
35
34.5
34

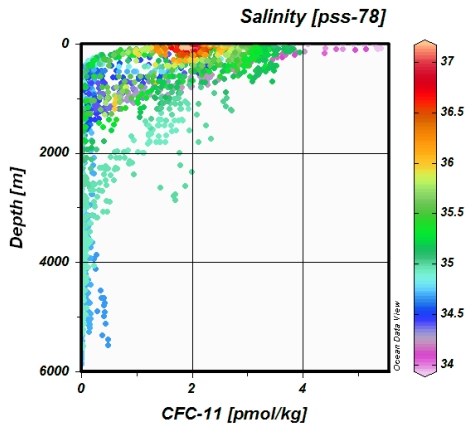

Phosphate [µmol/kg]
Depth [m]
0
2000
4000
6000
100
200
300
Oxygen [µmol/kg]
Ocean Data View
2
1.5
1
0.5
0

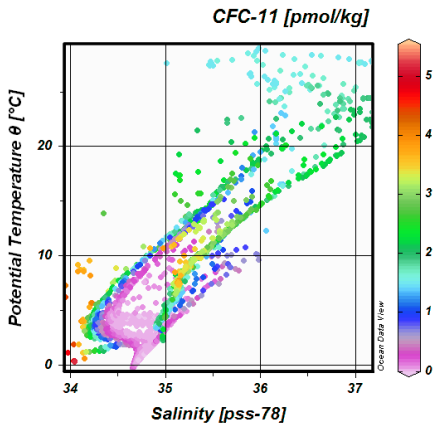

Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
0
10
20
34
35
36
37
Salinity [pss-78]
Ocean Data View
150
125
100
75
50
25
0

eWOCE


CFC-11 [pmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
0.1
0.5
1
1.5
2
2.5
3
3.5
4
0
5
4
3
2
1
0
A16
Jul/Aug 1988 (N)
Feb-Apr 1989 (S)
Data: R. Weiss, SIO and W. Smethie, LDGO (S); J. Bullister, PMEL (N)
Ocean Data View

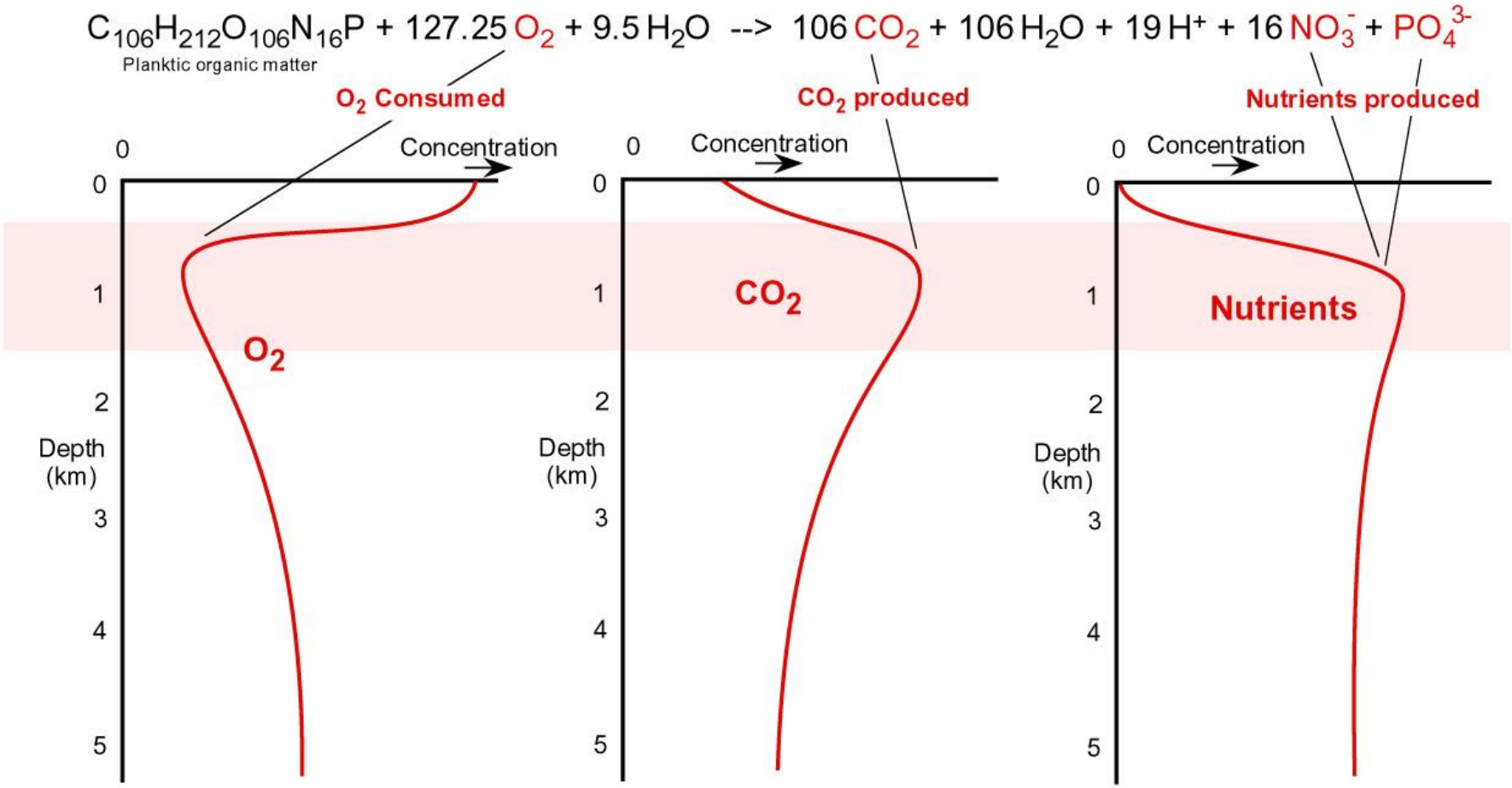

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
40°S
20°S
EQ
20°N
40°N
60°N
37
36.5
36
35.5
35
34.5
34
Ocean Data View

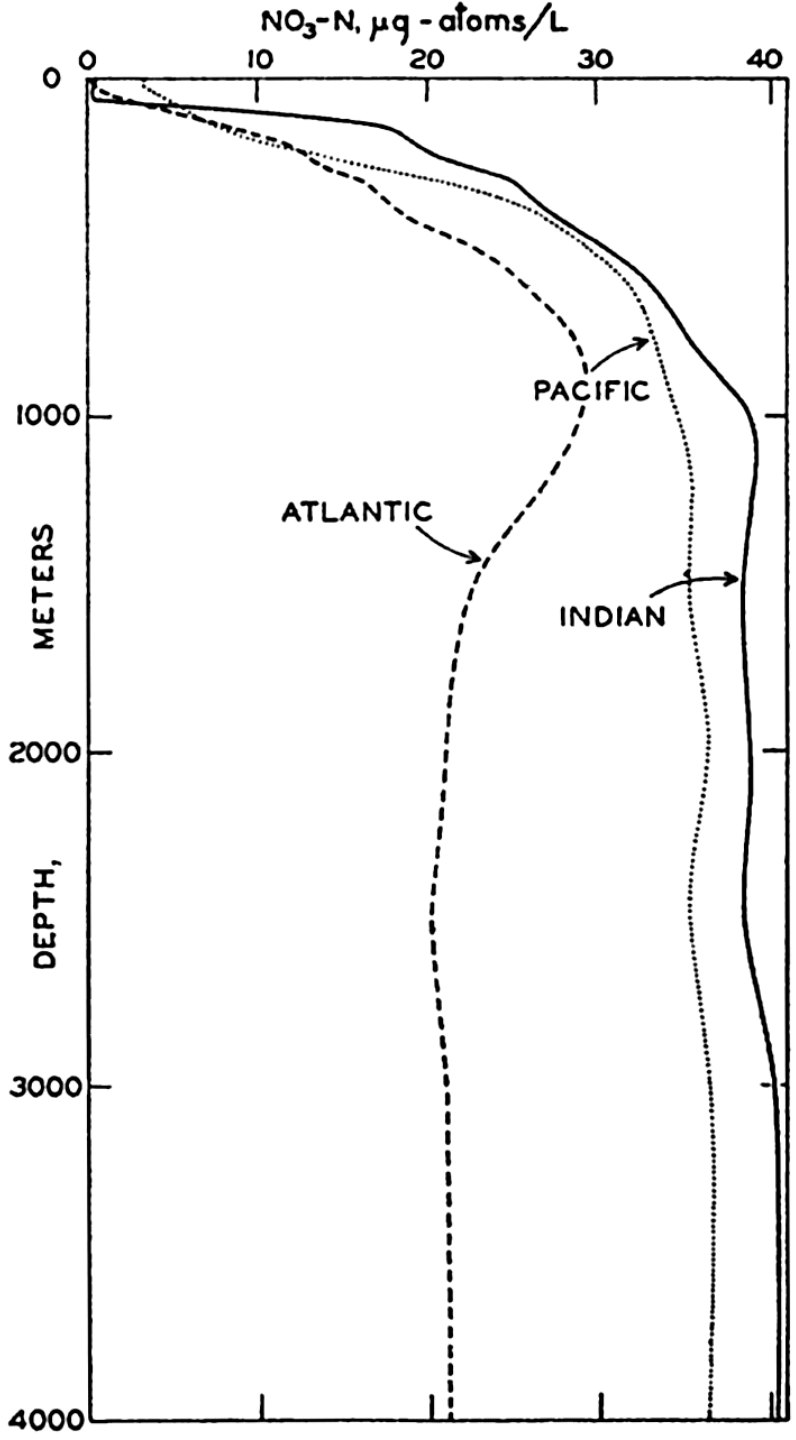

Salinity [pss-78]
Depth [m]
0
2000
4000
6000
0
2
4
CFC-11 [pmol/kg]
37
36.5
36
35.5
35
34.5
34
Ocean Data View

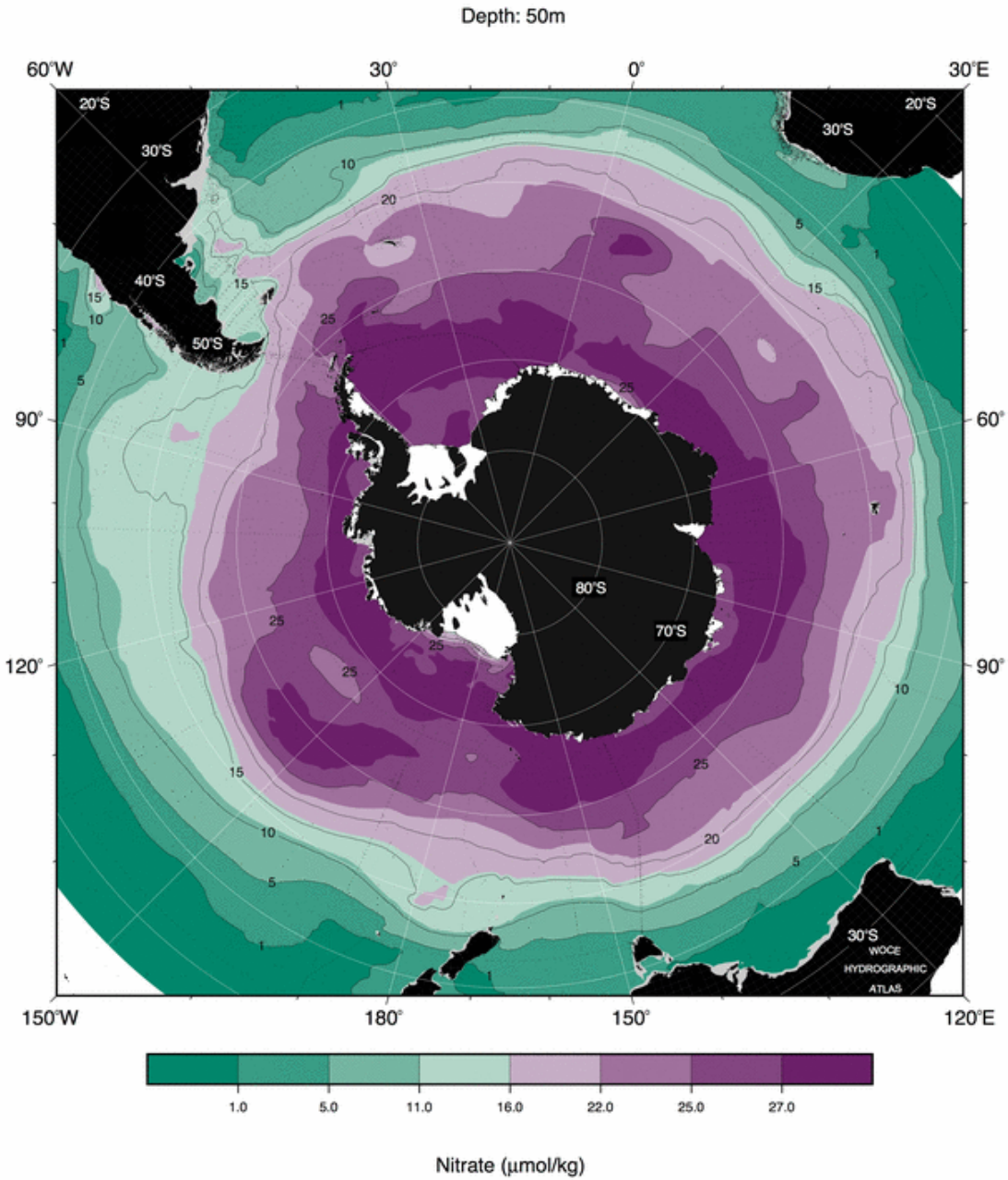

CFC-11 [pmol/kg]
Potential Temperature θ [°C]
0
10
20
34
35
36
37
Salinity [pss-78]
5
4
3
2
1
0
Ocean Data View

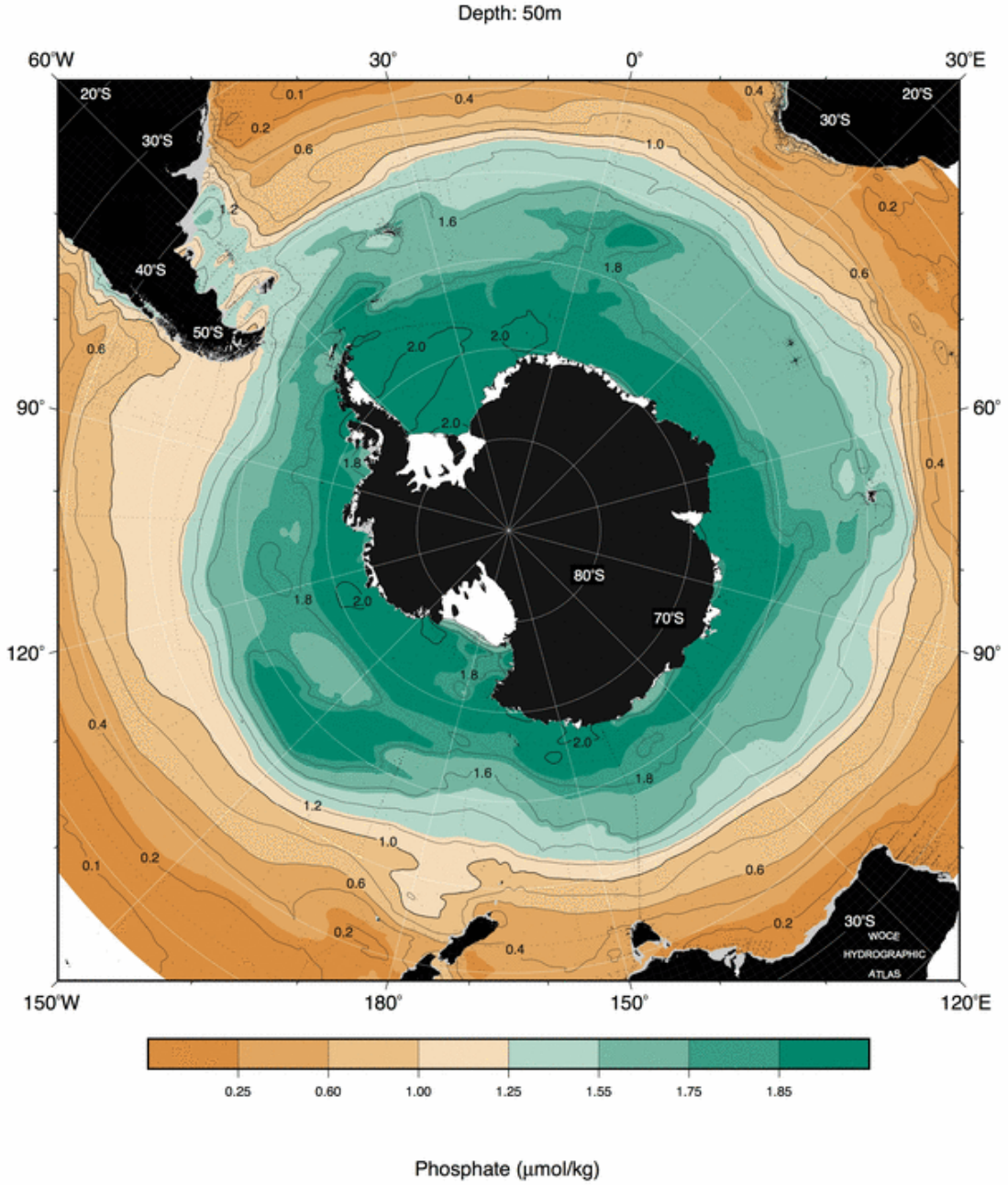
Variation in concentration of solutes in the oceans IV: oxidation of sinking organic particles - a summary

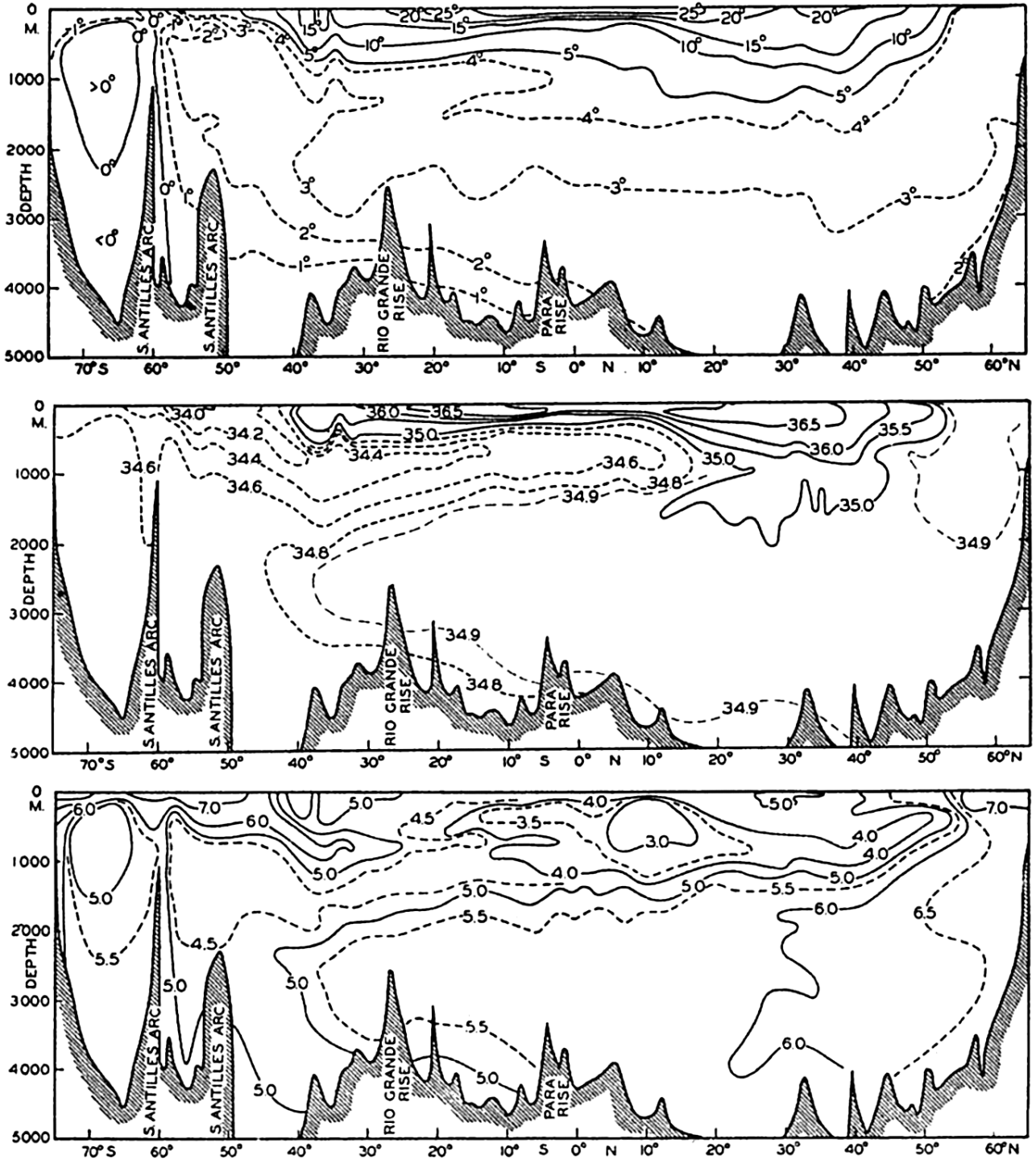
Parts I, II, and III of this series have shown how concentrations of dissolved nutrients, O_2, and CO_2 vary both vertically and laterally through the oceans. This page merely emphasizes the linkages among these distributions, all of which are greatly inlfuenced by oxidation of organic particles sinking from the photic zone through the thermocline and into the deeper ocean. As one can see below, this oxidation of organic matter consumes O_2 and releases CO_2 and the nutrients NO_3^- and PO_4^{3-}. In addition, oxidative (or other) decay of organic coatings on siliceous tests in the deep ocean allows dissolution of those siliceous tests, allowing release of a third critical nutrient, $SiO_{2(aq)}$, in the deep water.

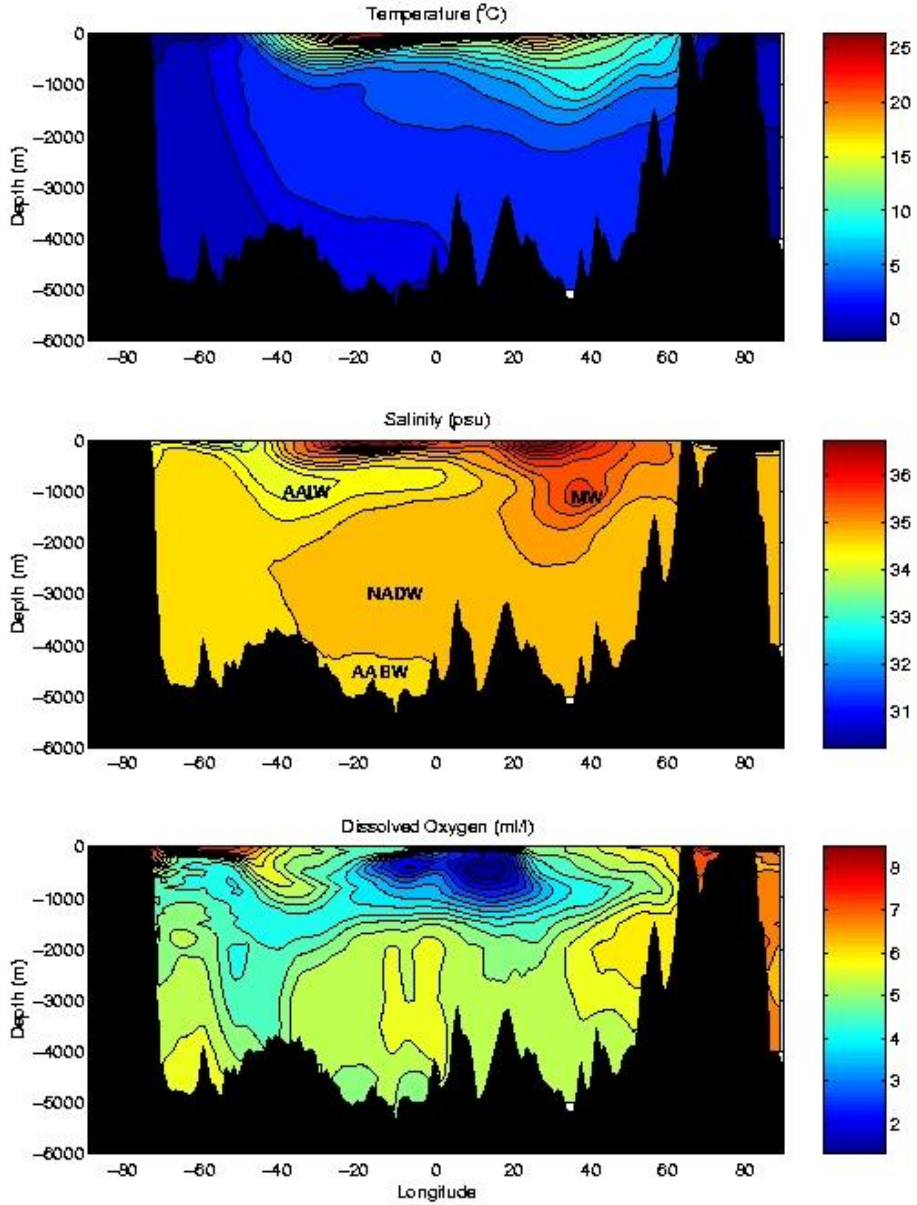



NO_3-N, µg - atoms/L
0
10
20
30
40
0
1000
2000
3000
4000
DEPTH, METERS
PACIFIC
ATLANTIC
INDIAN


Depth: 50m
60°W
30°
0°
30°E
20°S
30°S
40°S
50°S
90°
60°
120°
90°
80°S
70°S
150°W
180°
150°
120°E
30°S
WOCE
HYDROGRAPHIC
ATLAS
1.0
5.0
11.0
16.0
22.0
25.0
27.0
Nitrate (µmol/kg)


Depth: 50m
60°W
30°
0°
30°E
20°S
30°S
40°S
50°S
90°
120°
60°
150°W
180°
150°
120°E
80°S
70°S
0.1
0.2
0.4
0.6
1.0
1.2
1.6
1.8
2.0
WOCE
HYDROGRAPHIC
ATLAS
0.25
0.60
1.00
1.25
1.55
1.75
1.85
Phosphate (µmol/kg)


0
M.
1000
2000
3000
4000
5000
DEPTH
>0°
0°
<0°
S.ANTILLES ARC
S.ANTILLES ARC
RIO GRANDE RISE
PARA RISE
70°S
60°
50°
40°
30°
20°
10°
S
0°
N
10°
20°
30°
40°
50°
60°N
34.0
34.2
34.4
34.6
34.8
34.9
35.0
35.5
36.0
36.5
4.5
5.0
5.5
6.0
6.5
7.0


Temperature (°C)
Depth (m)
0
−1000
−2000
−3000
−4000
−5000
−6000
−80
−60
−40
−20
0
20
40
60
80
25
20
15
10
5
0
Salinity (psu)
AAIW
MW
NADW
AABW
36
35
34
33
32
31
Dissolved Oxygen (ml/l)
8
7
6
5
4
3
2
Longitude

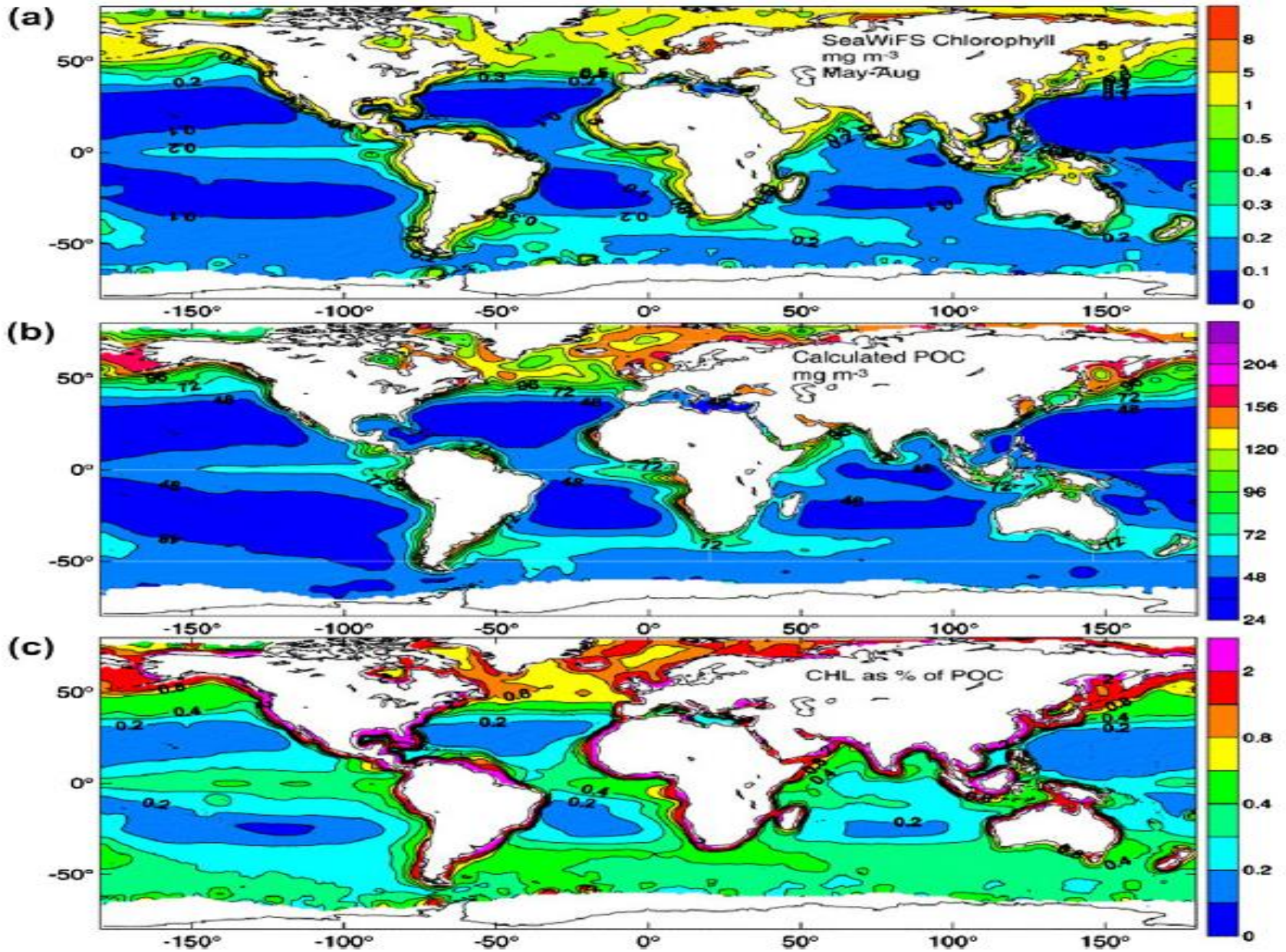
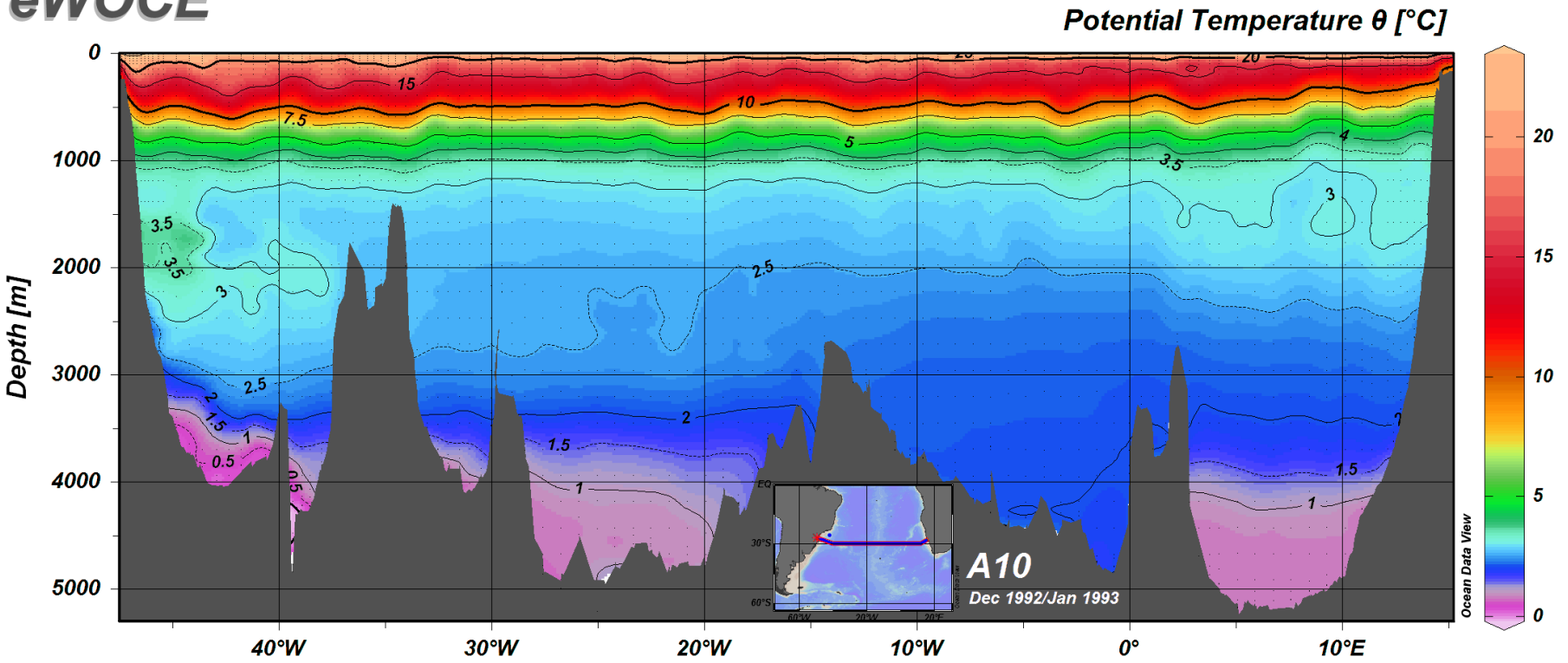
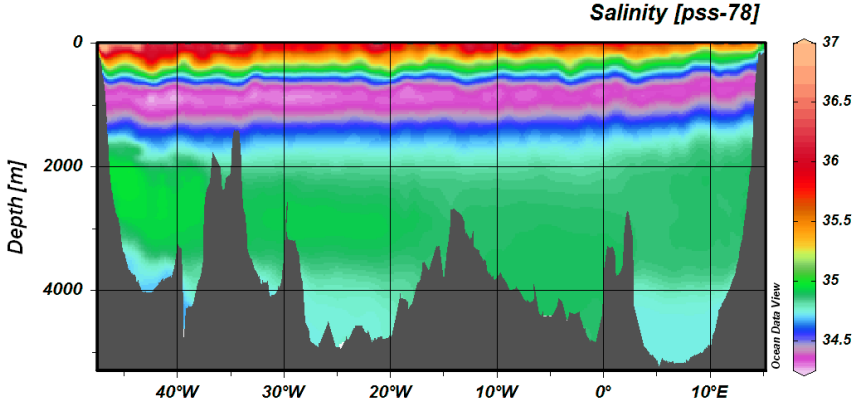
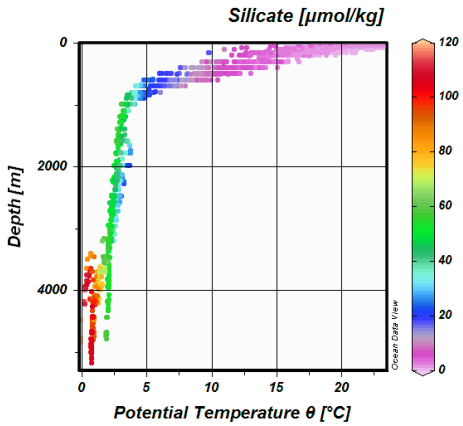


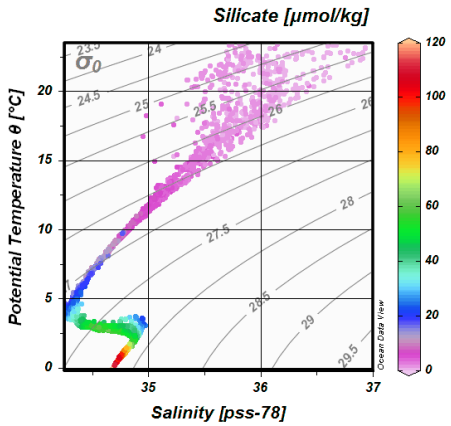
FIGURE S4.2 (a) Chlorophyll (mg m^{-3}), (b) particulate organic carbon (POC; mg m^{-3}), derived from SeaWiFS ocean color data, averaged May-August, 1997–2002, and (c) chlorophyll as % of POC. *Source: From Gardner, Mishonov, and Richardson, (2006).*

eWOCE

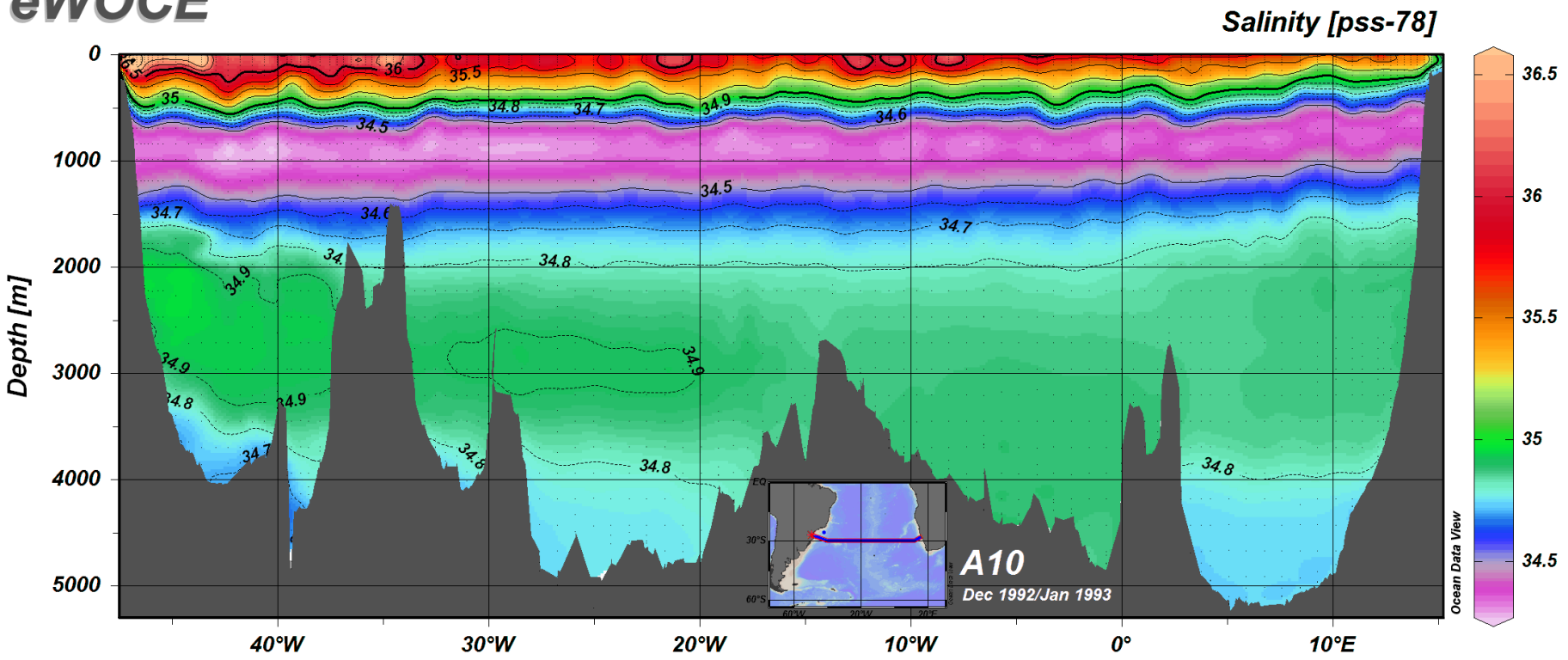

Potential Temperature θ [°C]
Depth [m]
0
1000
2000
3000
4000
5000
40°W
30°W
20°W
10°W
0°
10°E
A10
Dec 1992/Jan 1993
Ocean Data View

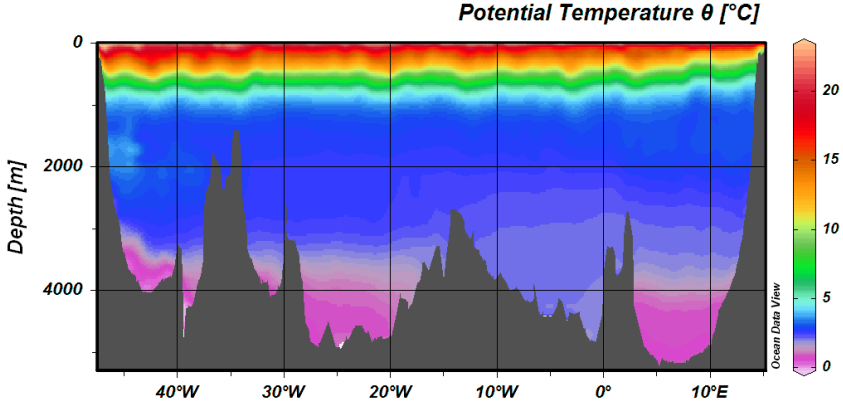

Salinity [pss-78]
Depth [m]
0
2000
4000
40°W
30°W
20°W
10°W
0°
10°E
Ocean Data View

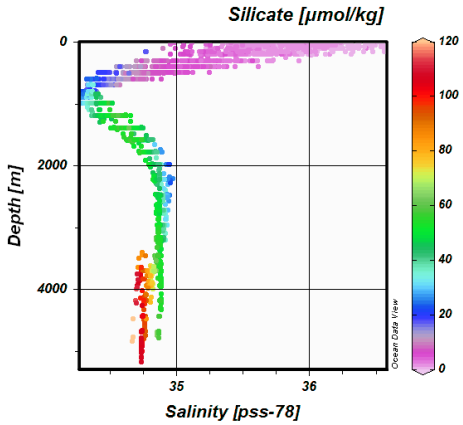

Silicate [µmol/kg]
Depth [m]
0
2000
4000
Potential Temperature θ [°C]
Ocean Data View

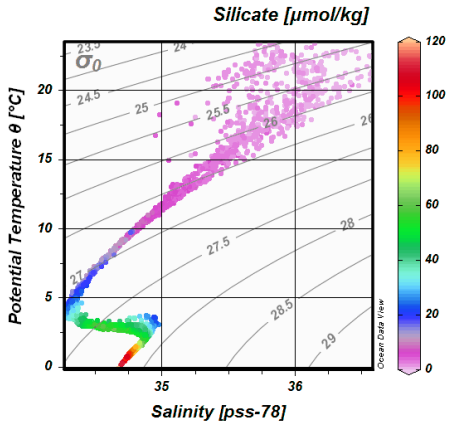

Silicate [µmol/kg]
Potential Temperature θ [°C]
Salinity [pss-78]
Ocean Data View

eWOCE

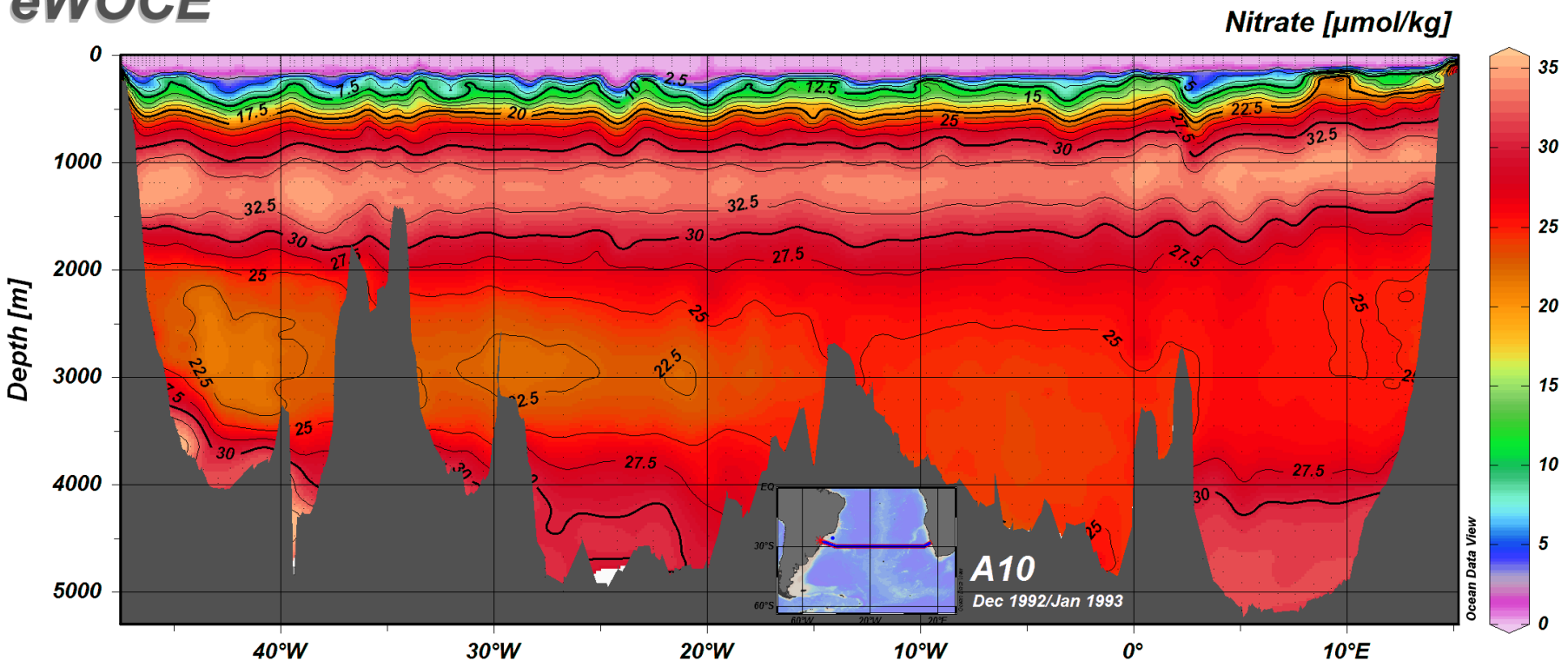

Salinity [pss-78]
Depth [m]
0
1000
2000
3000
4000
5000
40°W
30°W
20°W
10°W
0°
10°E
36.5
36
35.5
35
34.5
Ocean Data View
A10
Dec 1992/Jan 1993

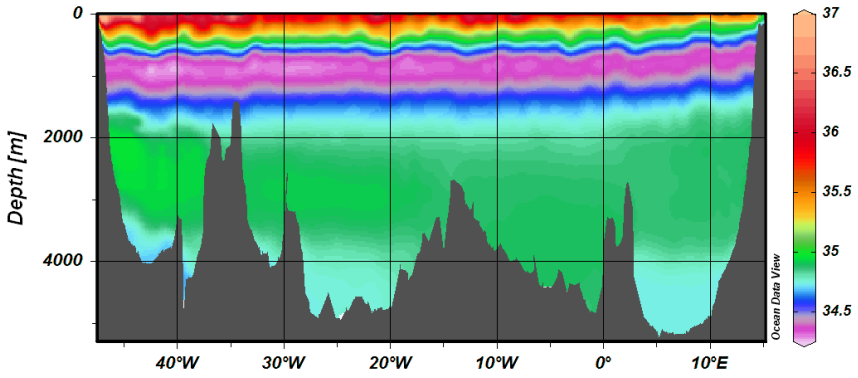

Potential Temperature θ [°C]
Depth [m]
0
2000
4000
40°W
30°W
20°W
10°W
0°
10°E
20
15
10
5
0
Ocean Data View

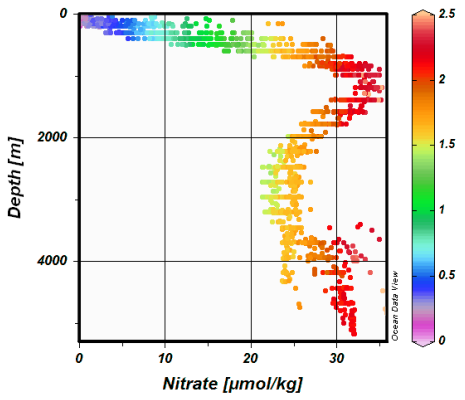

Silicate [µmol/kg]
Depth [m]
0
2000
4000
35
36
Salinity [pss-78]
120
100
80
60
40
20
0
Ocean Data View

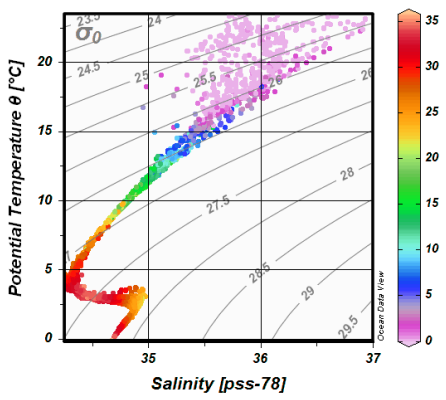

Silicate [µmol/kg]
Potential Temperature θ [°C]
σ0
0
5
10
15
20
35
36
Salinity [pss-78]
120
100
80
60
40
20
0
Ocean Data View

eWOCE

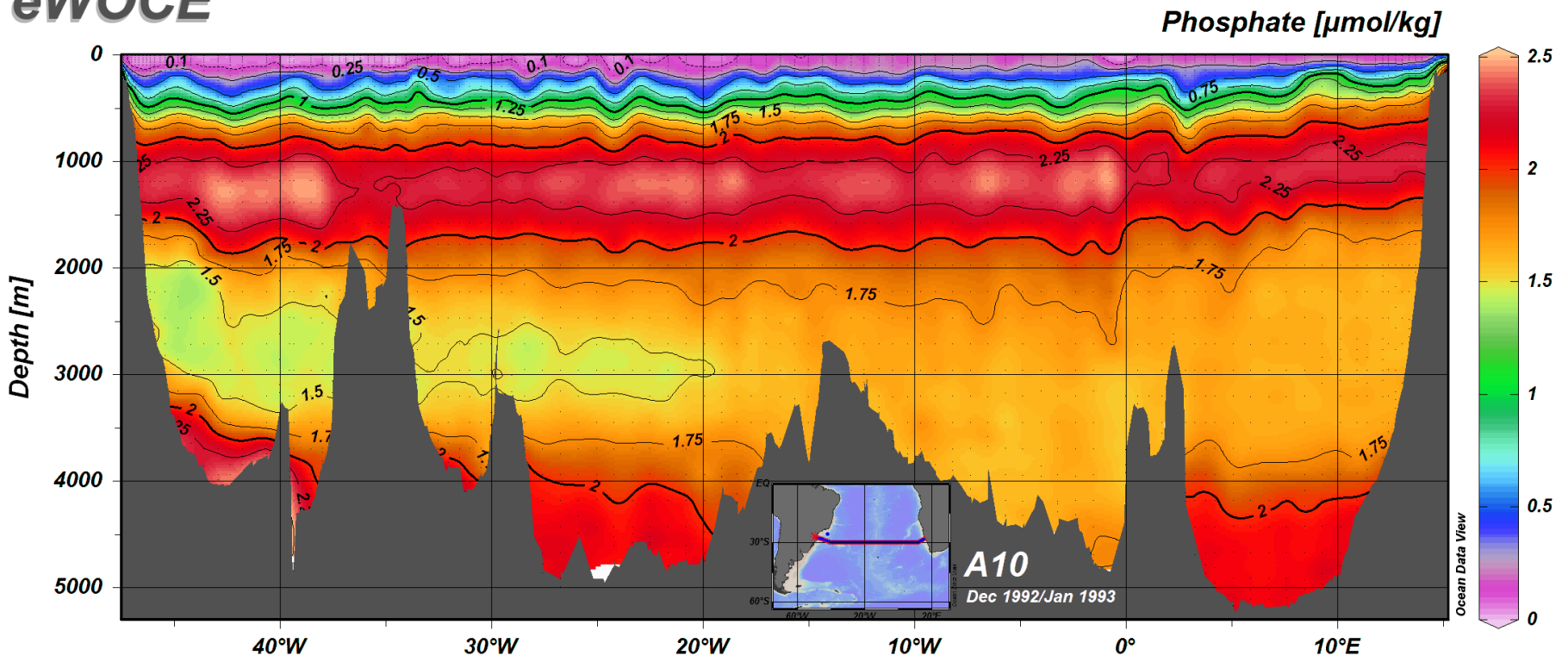

Nitrate [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
40°W
30°W
20°W
10°W
0°
10°E
A10
Dec 1992/Jan 1993
Ocean Data View
35
30
25
20
15
10
5
0

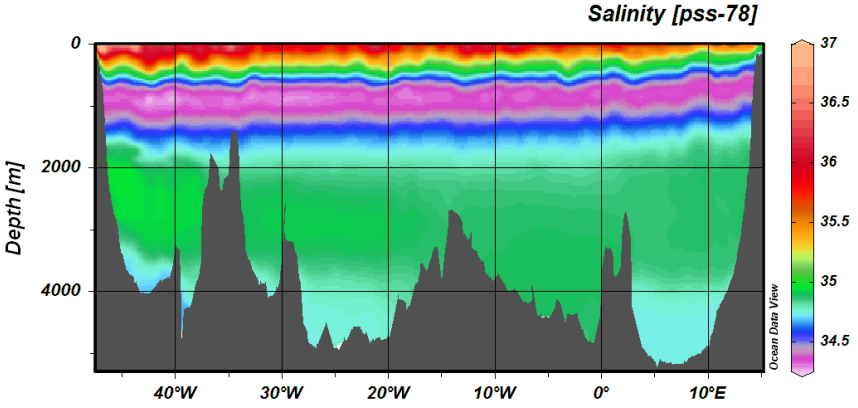

Salinity [pss-78]
Depth [m]
0
2000
4000
40°W
30°W
20°W
10°W
0°
10°E
Ocean Data View
37
36.5
36
35.5
35
34.5

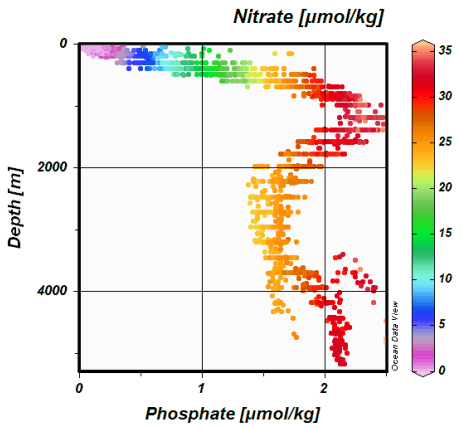

Phosphate [µmol/kg]
Depth [m]
0
2000
4000
0
10
20
30
Nitrate [µmol/kg]
Ocean Data View
2.5
2
1.5
1
0.5
0

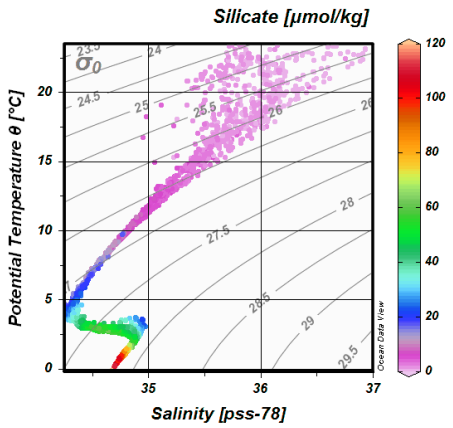

Nitrate [µmol/kg]
Potential Temperature θ [°C]
0
5
10
15
20
35
36
37
Salinity [pss-78]
Ocean Data View
35
30
25
20
15
10
5
0

eWOCE

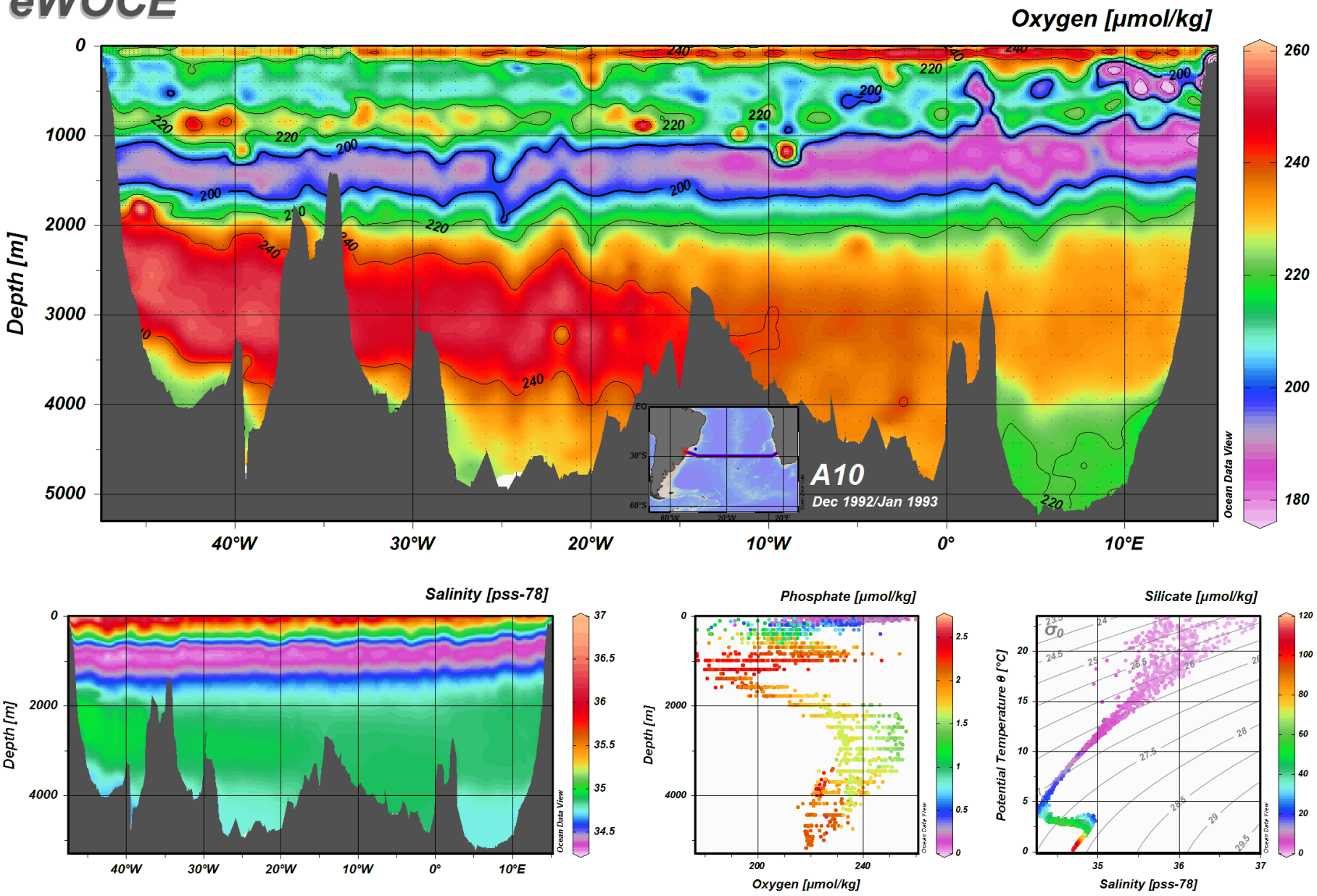

Phosphate [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
40°W
30°W
20°W
10°W
0°
10°E
A10
Dec 1992/Jan 1993
Ocean Data View
2.5
2
1.5
1
0.5
0


Salinity [pss-78]
Depth [m]
0
2000
4000
40°W
30°W
20°W
10°W
0°
10°E
Ocean Data View
37
36.5
36
35.5
35
34.5

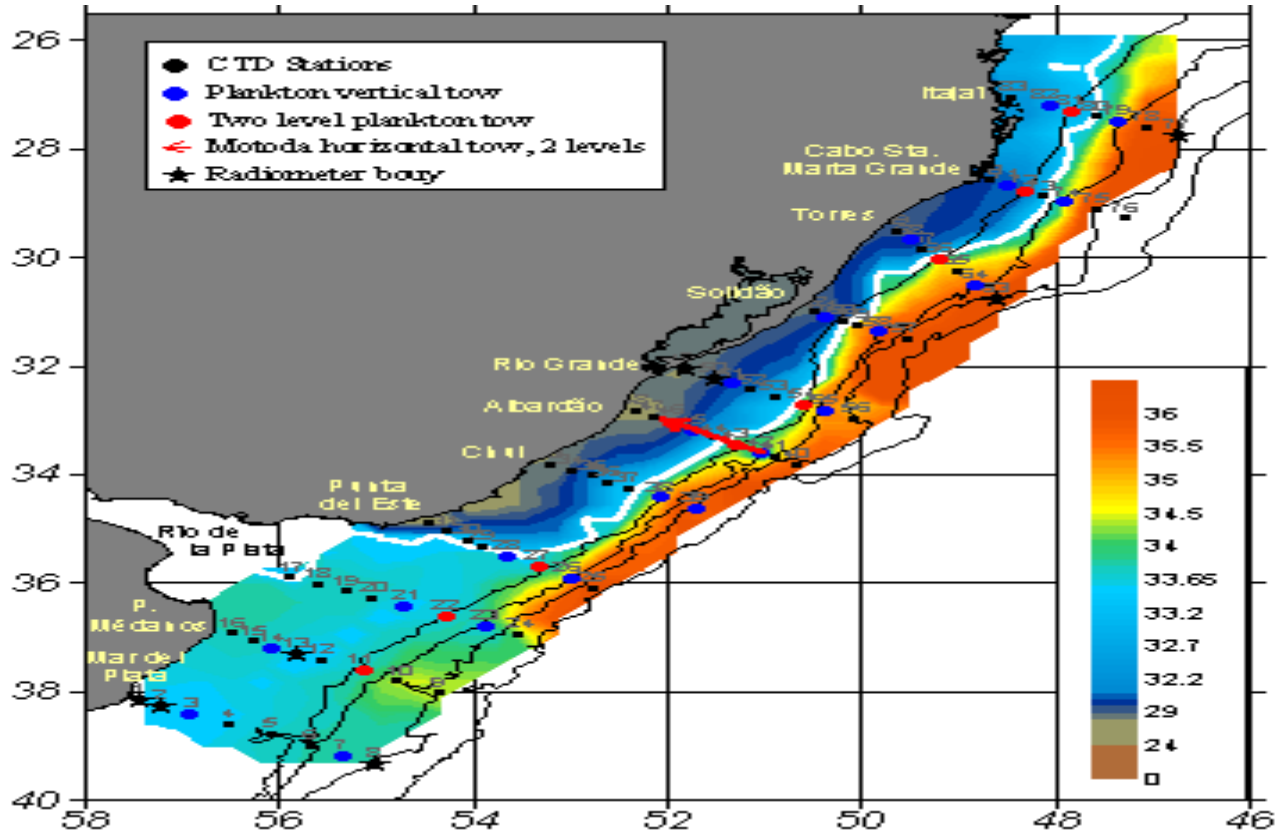

Nitrate [µmol/kg]
Depth [m]
0
2000
4000
0
1
2
Phosphate [µmol/kg]
Ocean Data View
35
30
25
20
15
10
5
0

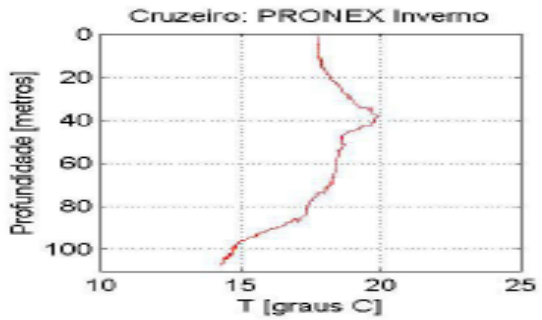

Silicate [µmol/kg]
Potential Temperature θ [°C]
0
5
10
15
20
35
36
37
Salinity [pss-78]
Ocean Data View
120
100
80
60
40
20
0

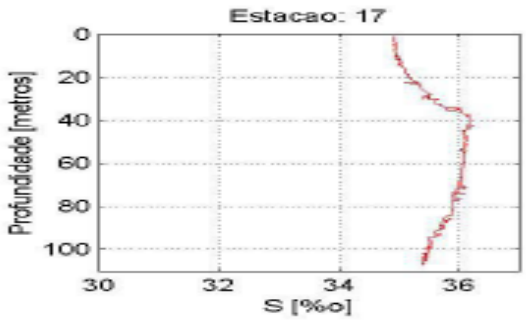
eWOCE

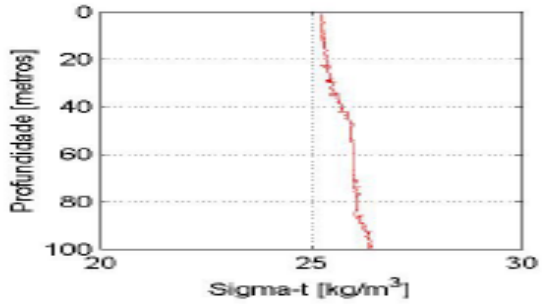

Oxygen [µmol/kg]
Depth [m]
0
1000
2000
3000
4000
5000
40°W
30°W
20°W
10°W
0°
10°E
260
240
220
200
180
Ocean Data View
A10
Dec 1992/Jan 1993
Salinity [pss-78]
37
36.5
36
35.5
35
34.5
Phosphate [µmol/kg]
2.5
2
1.5
1
0.5
0
Oxygen [µmol/kg]
Silicate [µmol/kg]
120
100
80
60
40
20
0
Potential Temperature θ [°C]
Salinity [pss-78]

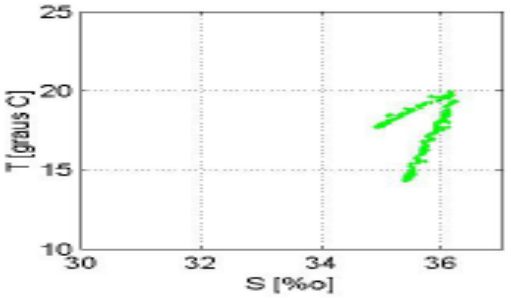
Regiões costeiras onde existe muita descarga fluvial ocorre geralmente uma camada de água superficial de baixa salinidade

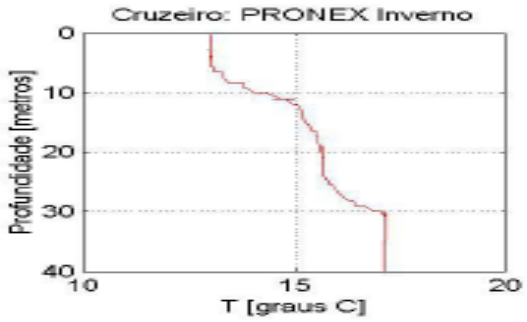


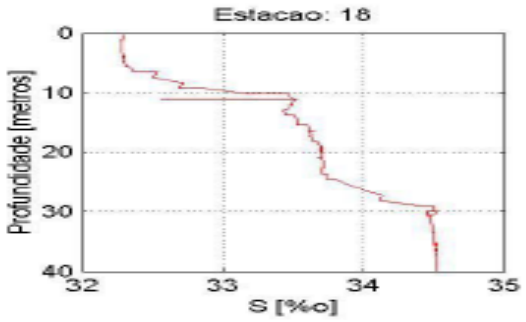

Cruzeiro: PRONEX Inverno
Profundidade [metros]
T [graus C]

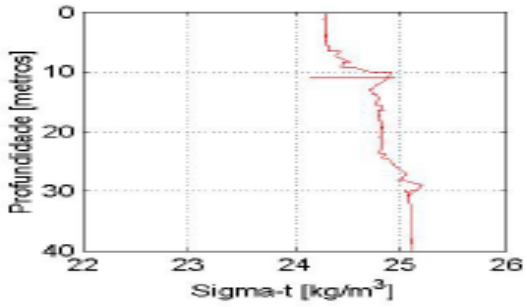

Estacao: 17
Profundidade [metros]
S [%o]

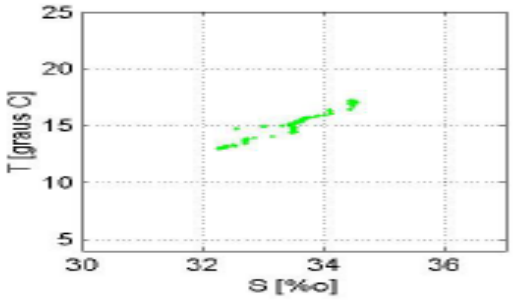

Profundidade [metros]
Sigma-t [kg/m3]


T [graus C]
S [%o]


Cruzeiro: PRONEX Inverno
Profundidade [metros]
T [graus C]


Estacao: 18
Profundidade [metros]
S [%o]


Profundidade [metros]
Sigma-t [kg/m3]


T [graus C]
S [%o]

DENSIDADE ??? relação entre a massa de qualquer substância e seu volume

Variação 1021 kg/m3 na superfície até 1070 kg/m3 no fundo

Conseqüência da Salinidade, Temperatura e Pressão ($\rho(S,T,p)$ é determinada pela equação de estado da água do mar)

A densidade vai determinar onde uma massa de água vai se estabelecer

Gde parte das correntes oceânicas pode ser adequadamente descrita conhecendo-se o campo de pressão.

A pressão em um determinado ponto do oceano é definida como o peso da água acima deste ponto. Este peso, por sua vez, é função da altura da coluna d'água em questão e da sua densidade.

Cálculo da densidade da água do mar

The density (ρ, kg/m^3) of seawater as a function of practical salinity (S), temperature (t, °C) and applied or gauge pressure (p, decibars) is given by

$$\rho(S,t,p) = \rho(S,t,0)/[1-p/K(S,t,p)] \quad (7)$$

where K(S,t,p) is the secant bulk modulus. The specific volume (V = 1/ρ m^3/kg) of seawater can be obtained from

$$V(S,t,p) = V(S,t,0)\cdot[1-p/K(S,t,p)] \quad (8)$$

$$\rho(S,t,0) = \rho_w + (b_0 + b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4)S + (c_0 + c_1 t + c_2 t^2)S^{3/2} + d_0 S^2 \quad (13)$$

$b_0 = + 8.24493E-1$ $\quad c_0 = - 5.72466E-3$

$b_1 = - 4.0899 E-3$ $\quad c_1 = + 1.0227 E-4$

$b_2 = + 7.6438 E-5$ $\quad c_2 = - 1.6546 E-6$

$b_3 = - 8.2467 E-7$

The density of the reference pure water (SMOW, Craig, 1961) is given by (IUPAC, 1976)

$$\rho_w = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \quad (14)$$

where

a_0* = + 999.842594 [-28.263737]

$a_1 = + 6.793952 E-2$

$a_2 = - 9.095290 E-3$

$a_3 = + 1.001685 E-4$

$a_4 = - 1.120083 E-6$

$a_5 = + 6.536332 E-9$

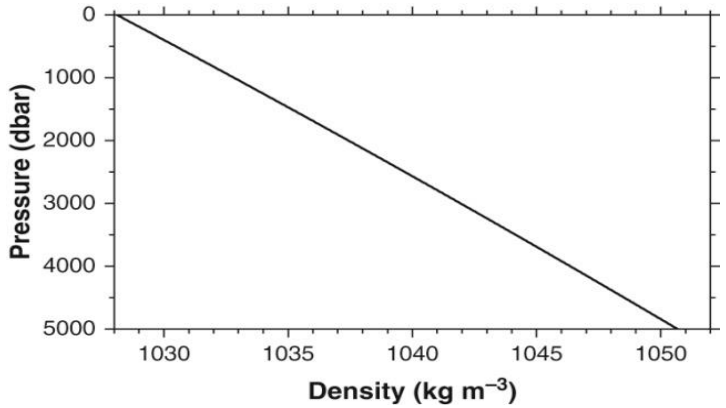
Distribuição horizontal da Densidade

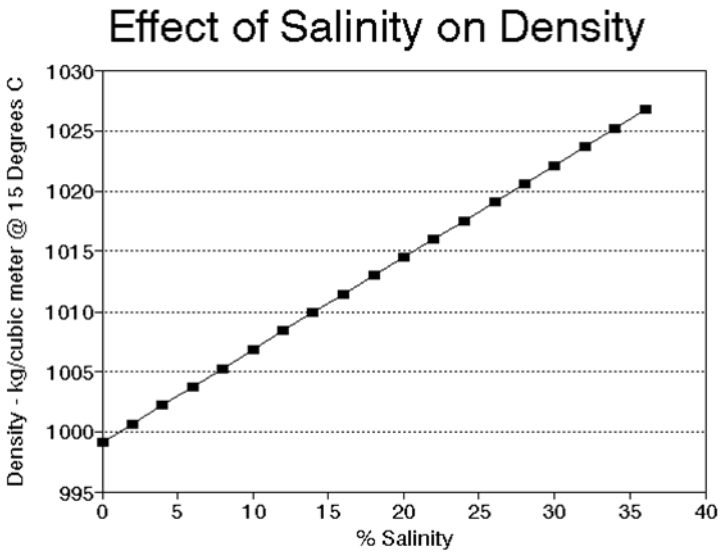
aumenta de 22 próximo do equador até 26-27 em 50° a 60° de latitude

Oceano aberto (Temperatura) águas com ↑ T, ↓densidade, são geralmente encontradas em camadas superficiais, e águas com ↓ T, ↑ densidade, em camadas profundas.

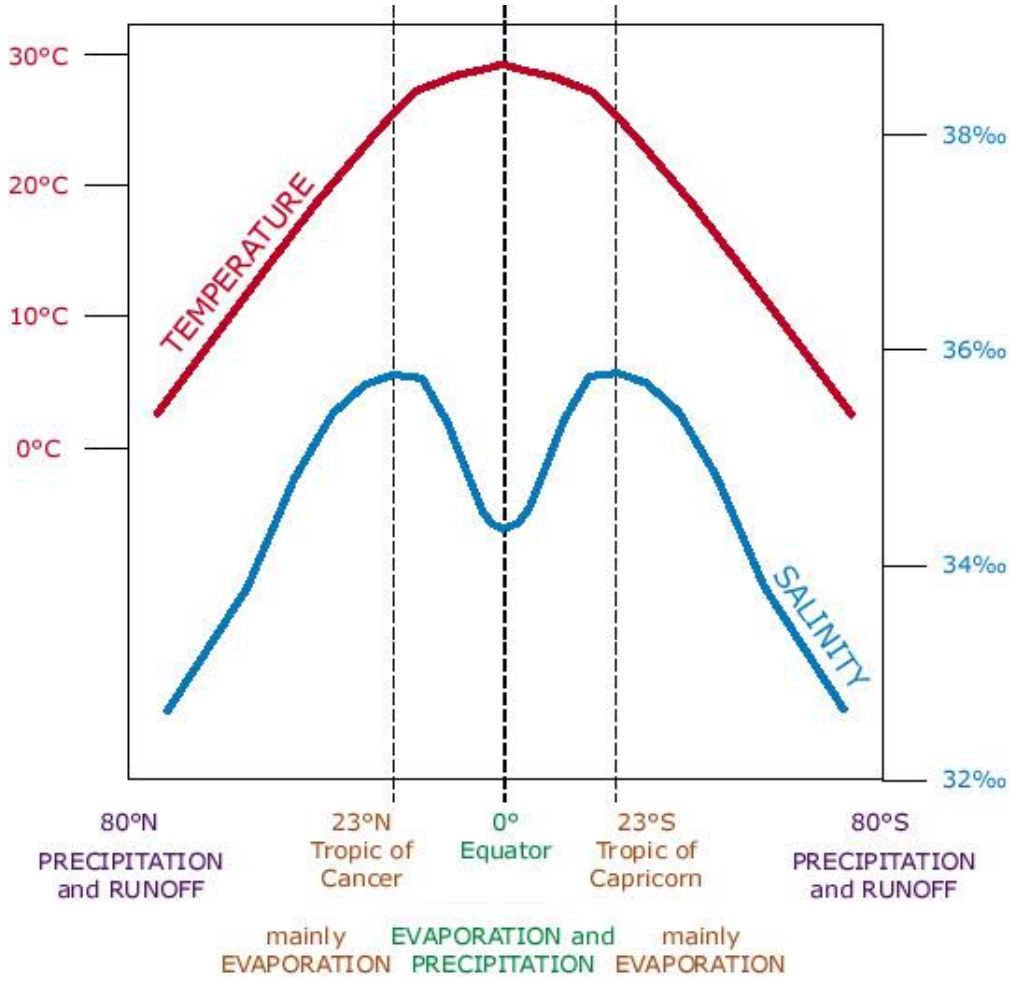
A Δ da S que ocorre em oceano aberto não tem efeitos suficientemente importantes para sobrepor-se ao efeito da temperatura na densidade.

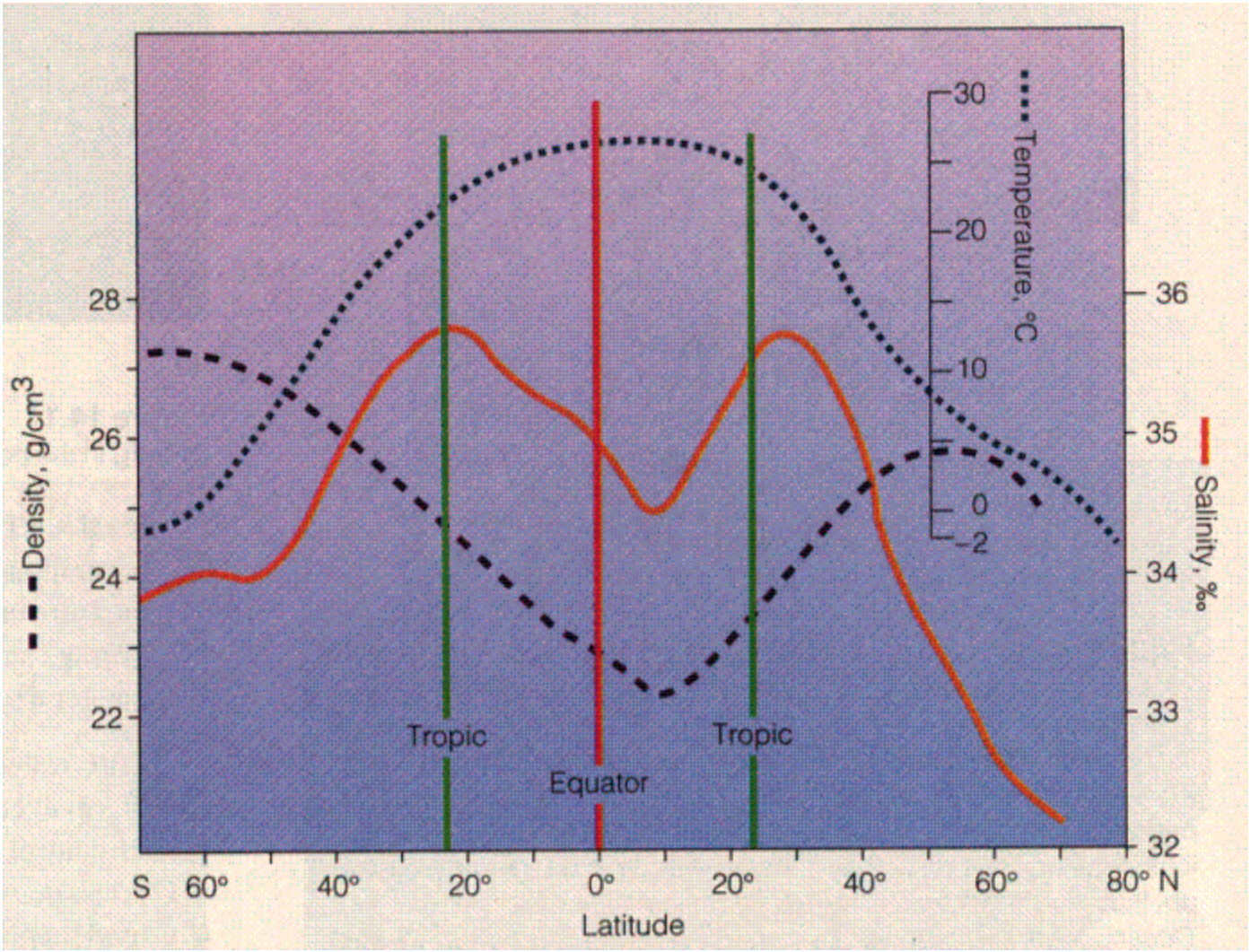
Em águas costeiras (fjords, lagoas e estuários), a S é sempre o fator controlador na determinação da densidade, em todas as profundidades.





Increase in density with pressure for a water parcel of temperature 0°C and salinity 35.0 at the sea surface.


30°C
20°C
10°C
0°C
TEMPERATURE
38‰
36‰
34‰
32‰
SALINITY
80°N
PRECIPITATION
and RUNOFF
23°N
Tropic of
Cancer
0°
Equator
23°S
Tropic of
Capricorn
80°S
PRECIPITATION
and RUNOFF
mainly
EVAPORATION
EVAPORATION and
PRECIPITATION
mainly
EVAPORATION

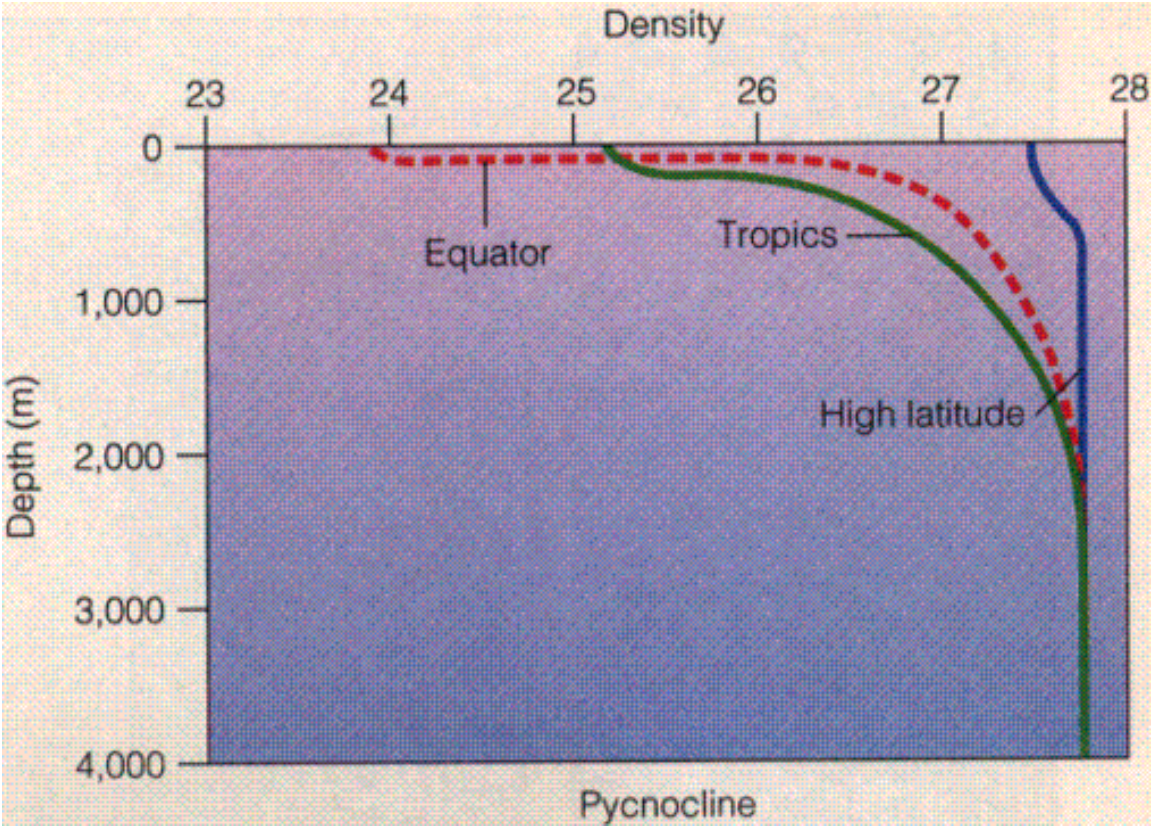

Density, g/cm3
28
26
24
22
Temperature, °C
30
20
10
0
-2
Salinity, ‰
36
35
34
33
32
Tropic
Equator
Tropic
S
60°
40°
20°
0°
20°
40°
60°
80° N
Latitude

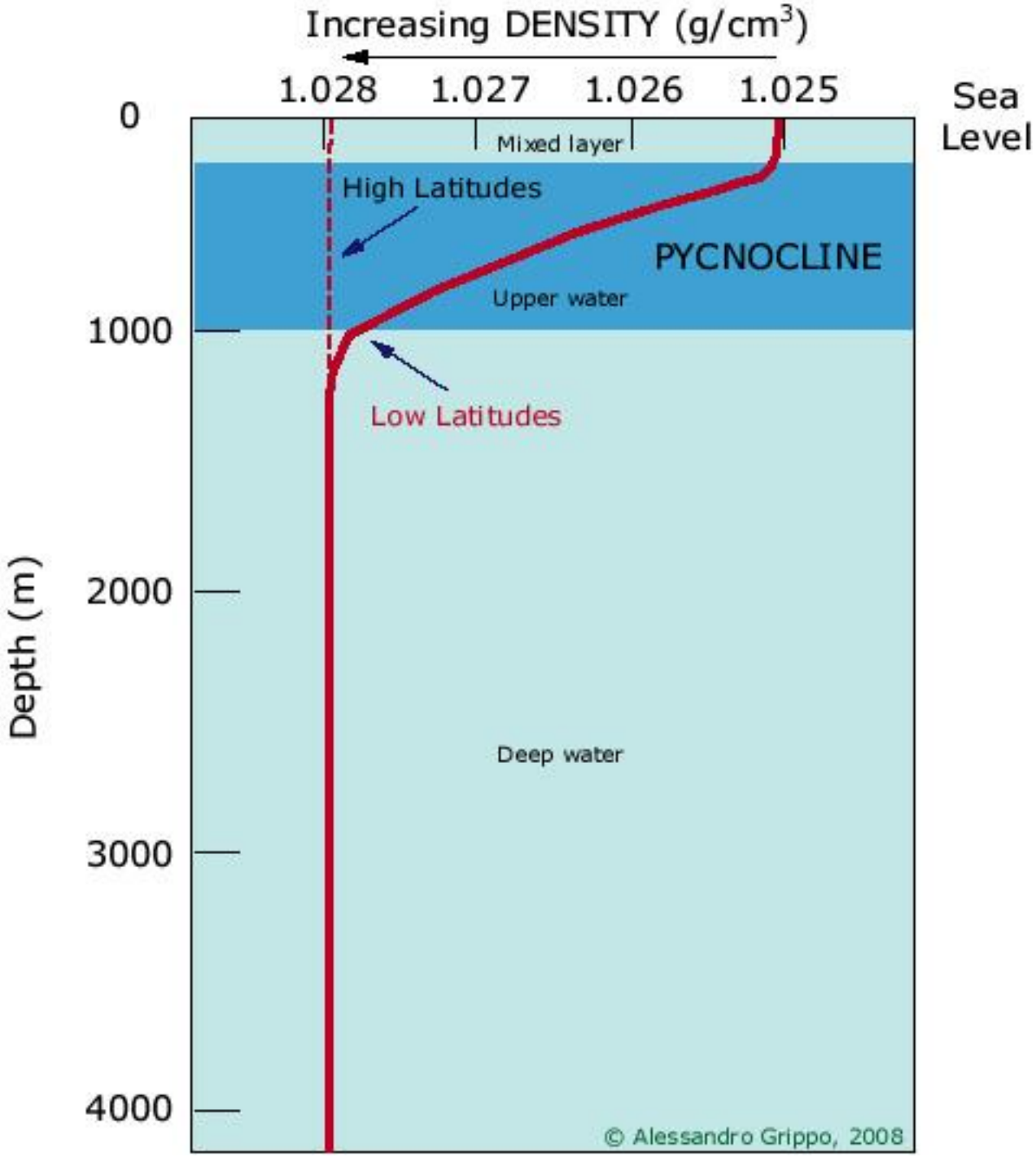
Distribuição vertical da Densidade

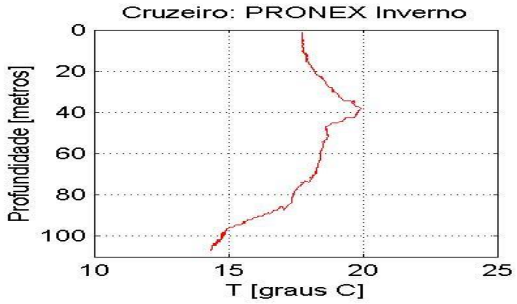
Equador: Picnoclina saliente/ camada de mistura peq

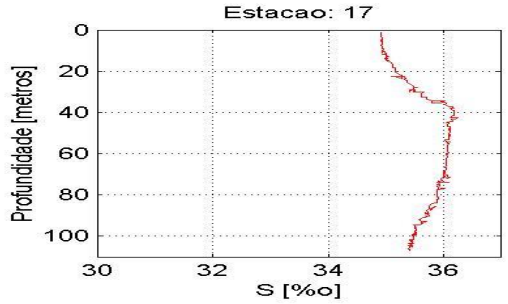
Trópicos: Camada de mistura maior/picnoclina pouco saliente

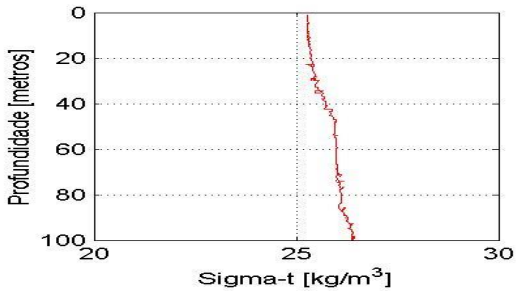
Pólos: Picnoclina muito peq (apenas devido às variações de S)

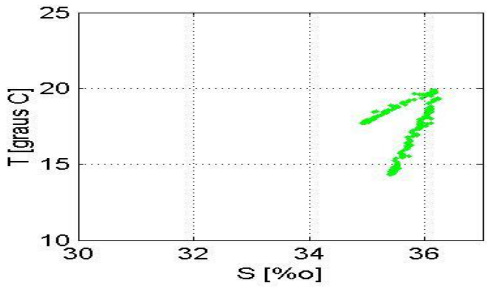


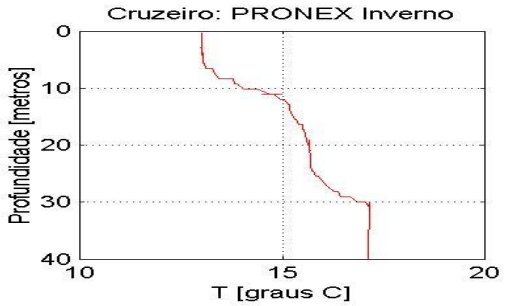

Increasing DENSITY (g/cm3)
1.028
1.027
1.026
1.025
Sea Level
0
Mixed layer
High Latitudes
PYCNOCLINE
Upper water
1000
Low Latitudes
Depth (m)
2000
Deep water
3000
4000
© Alessandro Grippo, 2008

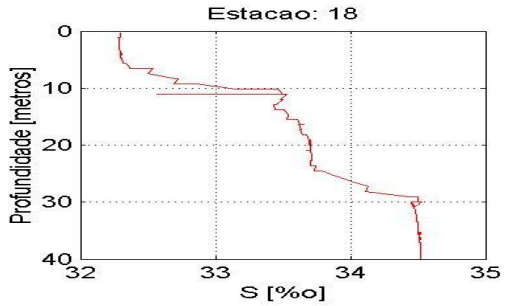

Cruzeiro: PRONEX Inverno
Profundidade [metros]
T [graus C]

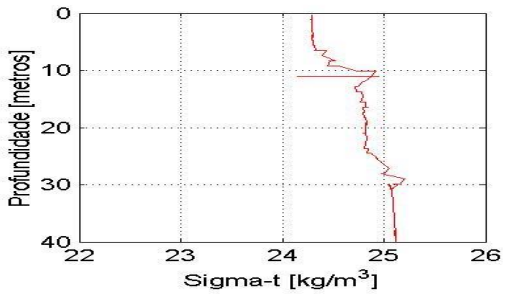

Estacao: 17
Profundidade [metros]
S [%o]

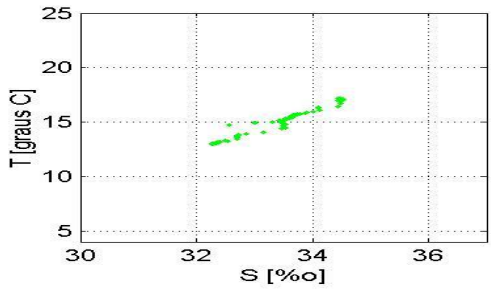

Profundidade [metros]
Sigma-t [kg/m3]


T [graus C]
S [%o]


Cruzeiro: PRONEX Inverno
Profundidade [metros]
T [graus C]


Estacao: 18
Profundidade [metros]
S [%o]


Profundidade [metros]
Sigma-t [kg/m3]


T [graus C]
S [%o]

Estabilidade/instabilidade na coluna de água

- Conceitos: estável, neutro, instável
- O número E – ondas internas – a frequência de Brünt-Väisälä
- Geração de instabilidade
- Processo de Dupla-difusão

A equação da estabilidade estática:

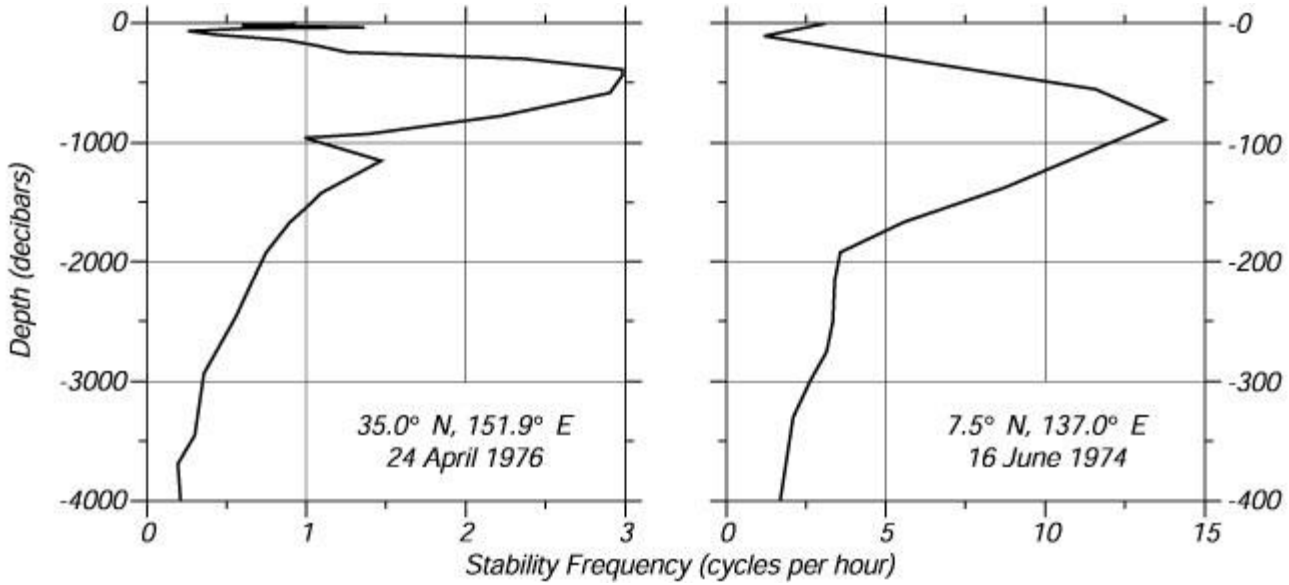
$$E \approx -\frac{1}{\rho}\frac{d\rho}{dz}$$

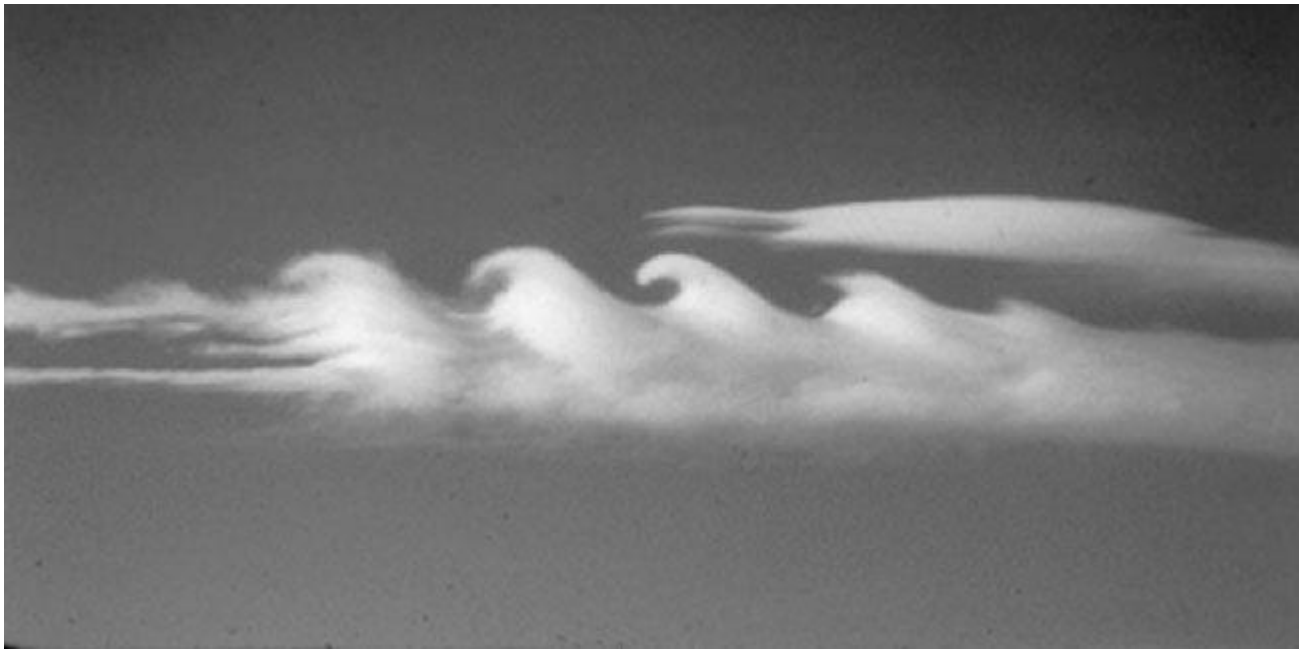
$E > 0$ Estável

$E = 0$ Neutro

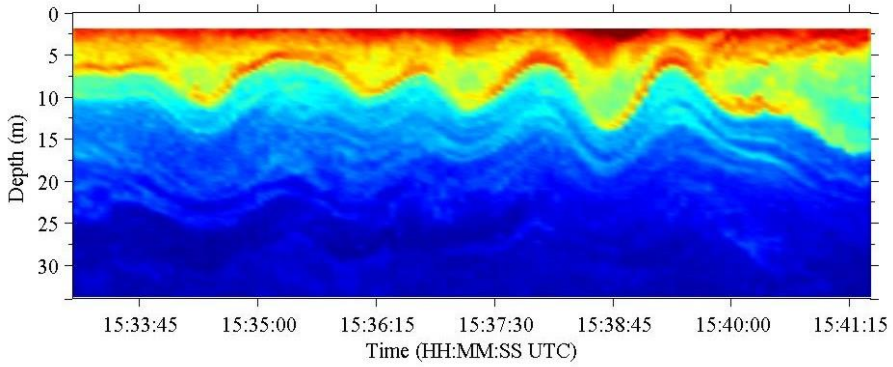
$E < 0$ Instável

In the upper kilometer of the ocean, $z < 1{,}000$m, $E = (50\text{-}1000)\times10^{-8}$/m, and in deep trenches where $z > 7{,}000$m, $E = 1\times10^{-8}$/m.

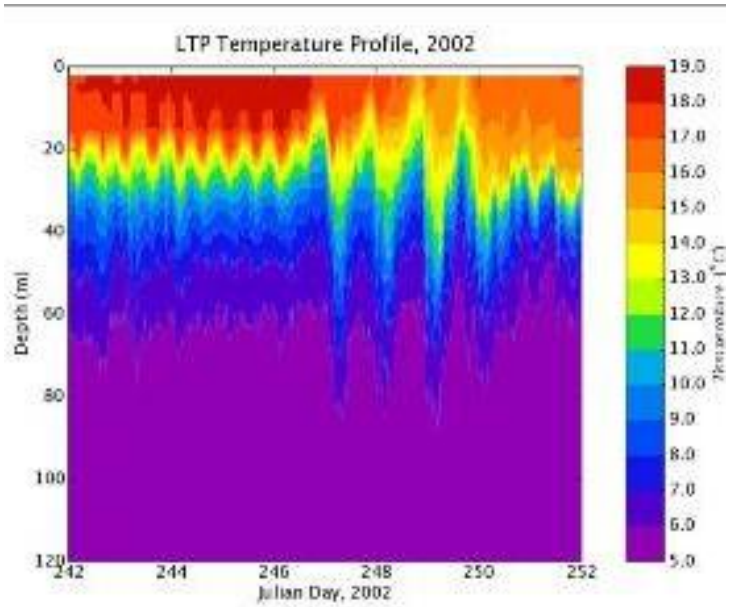




Billow clouds showing a Kelvin-Helmholtz instability at the top of a stable atmospheric boundary layer. Some billows can become large enough that more dense air overlies less dense air, and then the billows collapse into turbulence.



Ondas internas no Saint Lawrence Estuary:Large-amplitude internal waves (see image to the right) may be generated by stratified tidal flows over bottom topographic features. It is thought that such waves may be an important source of mixing in coastal waters, which means that they play a key role in coastal ecosystems, circulation, pollutant dispersal, etc.



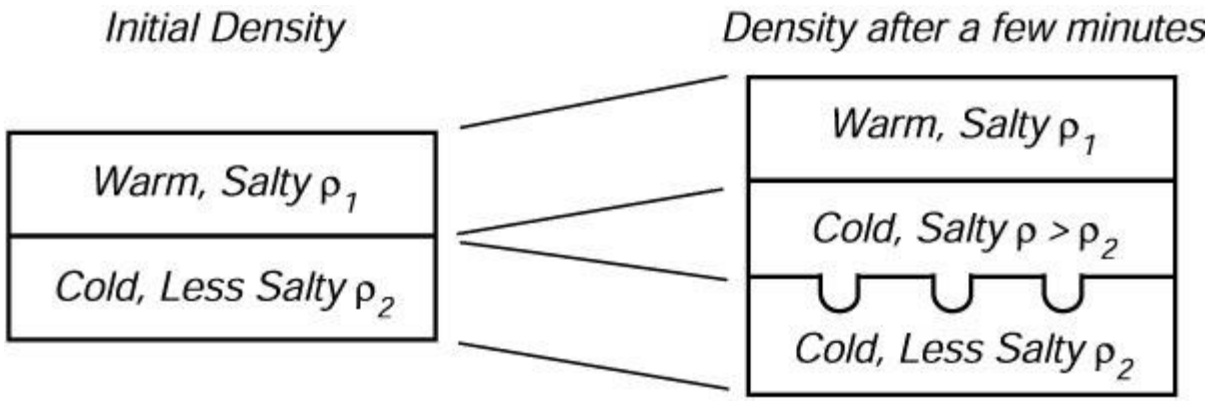
http://iod.ucsd.edu/research/iwaves/

http://www.es.flinders.edu.au/~mattom/IntroOc/notes/figures/animations/fig10a7c.html

Double Diffusion and Salt Fingers

In some regions of the ocean, less dense water overlies more dense water, yet the water column is unstable even if there are no currents. The instability occurs because the molecular diffusion of heat is about 100 times faster than the molecular diffusion of salt. The instability was first discovered by Melvin Stern in 1960 who quickly realized its importance in oceanography.

Consider two thin layers a few meters thick separated by a sharp interface. If the upper layer is warm and salty, and if the lower is colder and less salty than the upper layer, the interface becomes unstable even if the upper layer is less dense than the lower.



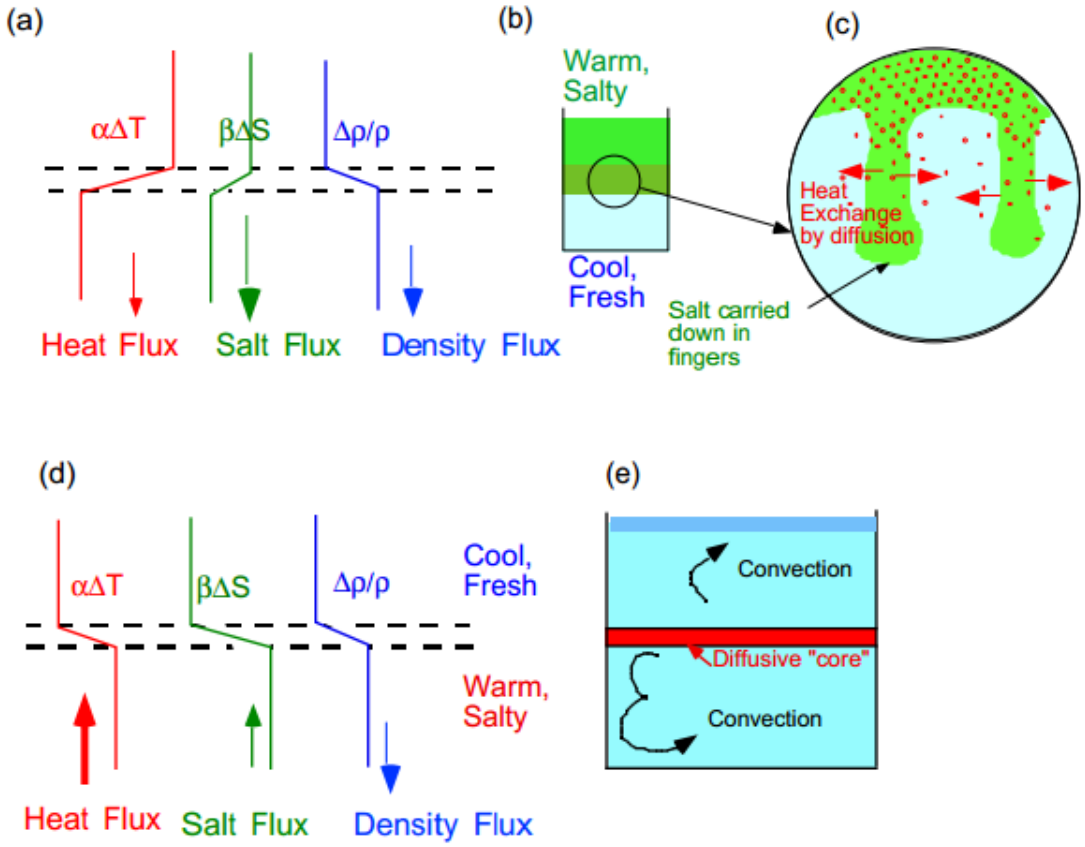
Warm salty over colder less salty. This process is called salt fingering It occurs in central waters of sub-tropical gyres, western tropical North Atlantic, and the North-east Atlantic beneath the out flow from the Mediterranean Sea. Salt fingering eventually leads to density increasing with depth in a series of steps. Layers of constant-density are separated by thin layers with large changes in density, and the profile of density as a function of depth looks like stair steps. Schmitt *et al.,* (1987) observed 5-30m thick steps in the western, tropical North Atlantic that were coherent over 200-400km and that lasted for at least eight months. Kerr (2002) reports a recent experiment by Raymond Schmitt, James Leswell, John Toole, and Kurt Polzin showed salt fingering o Barbados mixed water 10 times faster than turbulence.

Colder less salty over warm salty. This process is called diffusive convection. It is much less common than salt fingering, and it us mostly found at high latitudes. Diffusive convection also leads to a stair step of density as a function of depth. Here's what happens in this case. Double diffusion leads to a thin, warm, less-salty layer at the base of the upper, colder, less-salty layer. The thin layer of water rises and mixes with water in the upper layer. A similar processes occurs in the lower layer where a colder, salty layer forms at the interface. As a result of the convection in the upper and lower layers, the interface is sharpened; and any small gradients of density in either layer are reduced. Neal *et al*. (1969) observed 2-10m thick layers in the sea beneath the Arctic ice.

Cold salty over warmer less salty.

Warmer less salty over cold salty.

Salt Fingering e Cabelling



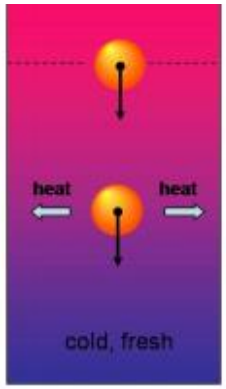


Figure 1: Schematic of the salt finger mechanism.

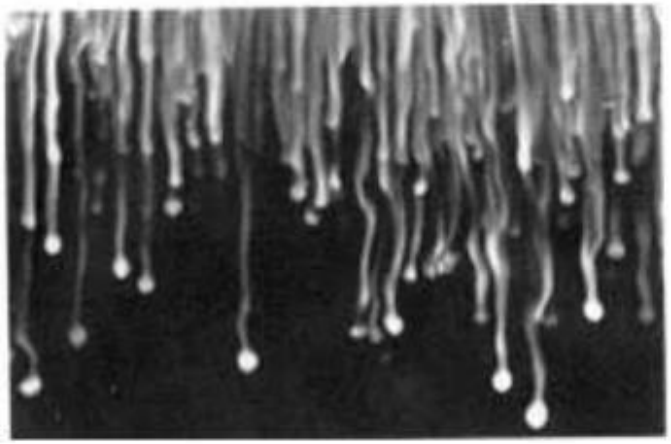


Figure 2: Salt fingers in a laboratory experiment [3].