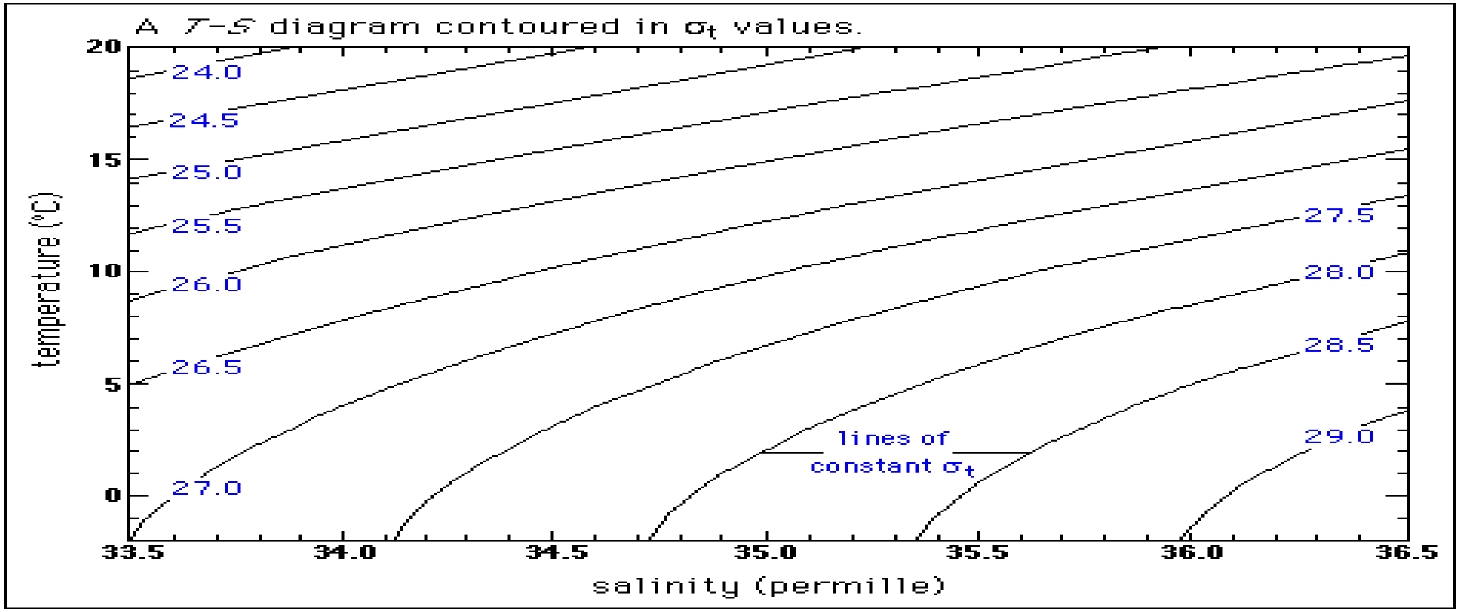
Diagrama T/S e Análise de Massas de Água

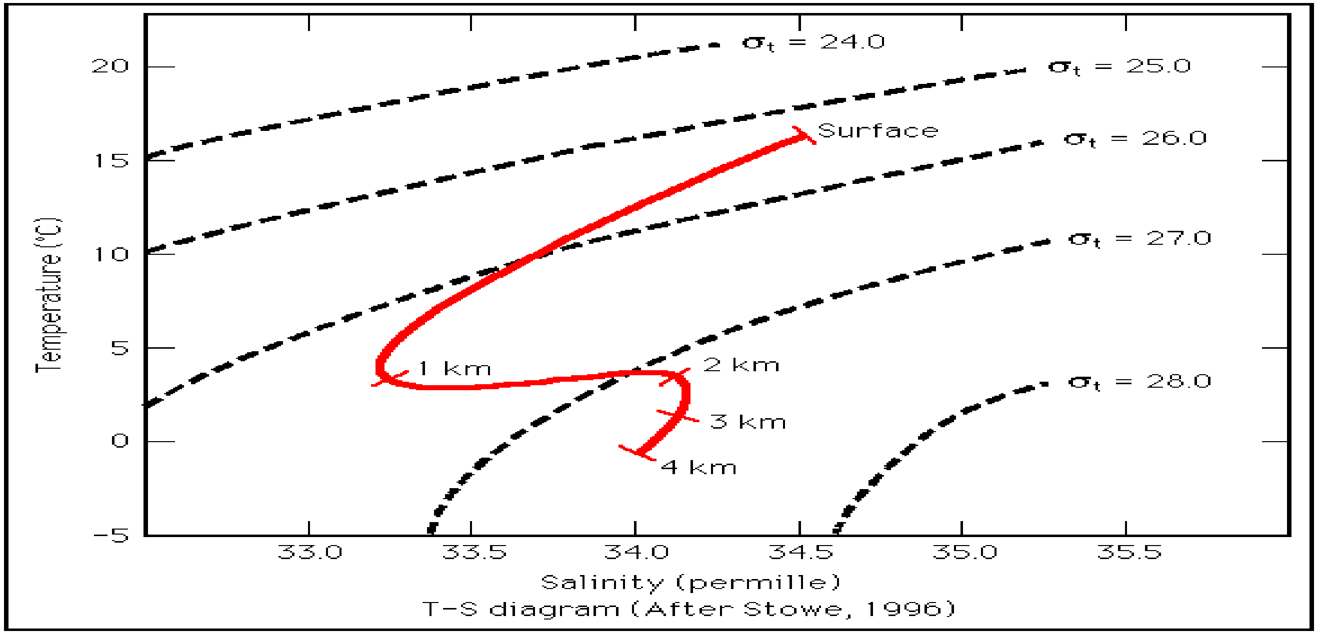
- Conceito de Massas de água
- O diagrama TS e seus usos

Diagrama TS

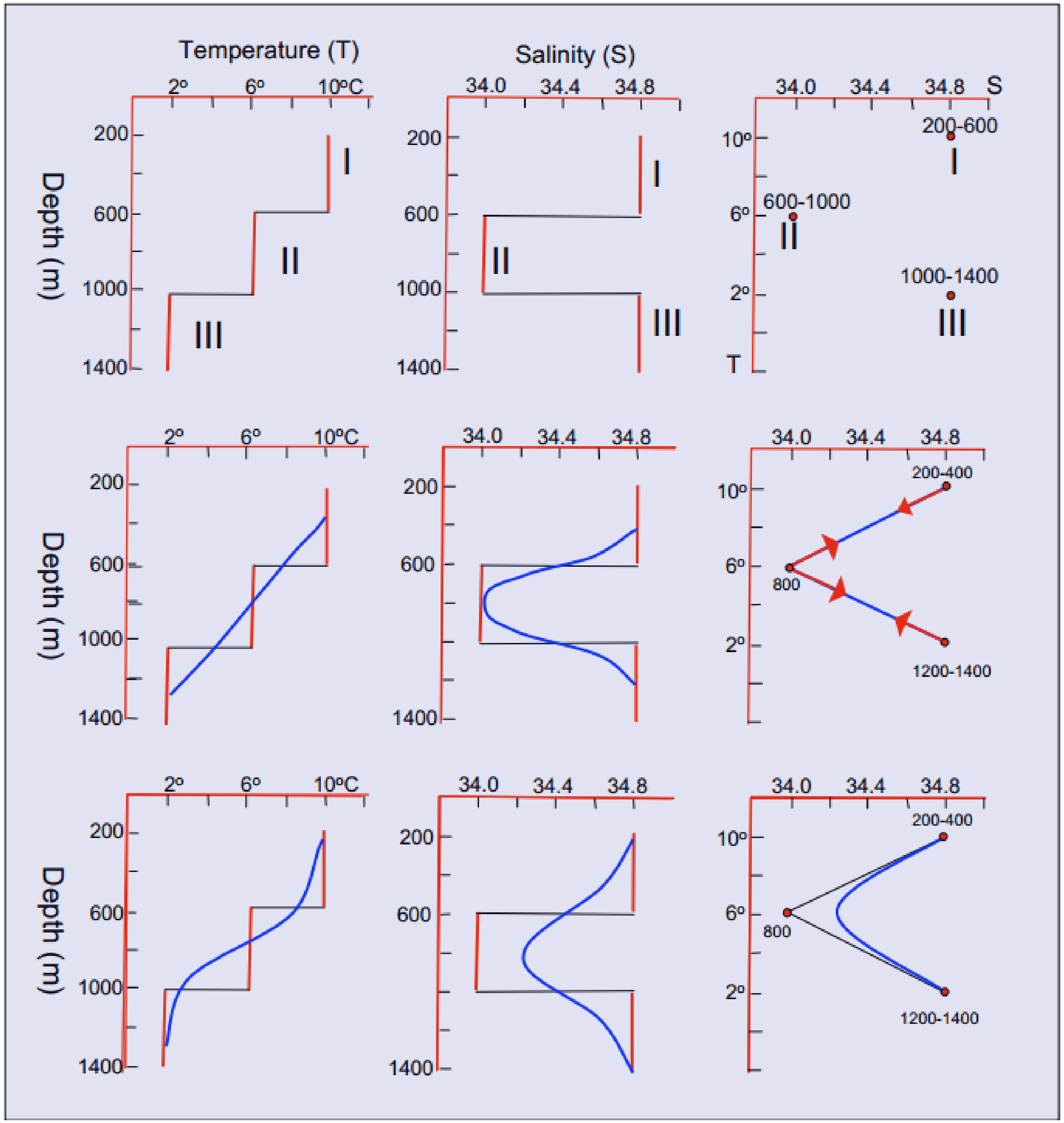
- Plots of salinity as a function of temperature, called *T-S* plots, are used to:
- delineate water masses and their geographical distribution;
- to describe mixing among water masses;
- and to infer motion of water in the deep ocean.
- Here's why the plots are so useful: water properties, such as temperature and salinity, are formed only when the water is at the surface or in the mixed layer. Heating, cooling, rain, and evaporation all contribute. Once the water sinks below the mixed layer, temperature and salinity can change only by mixing with adjacent water masses. Thus water from a particular region has a particular temperature associated with a particular salinity, and the relationship changes little as the water moves through the deep ocean.



Características básica de um T/S

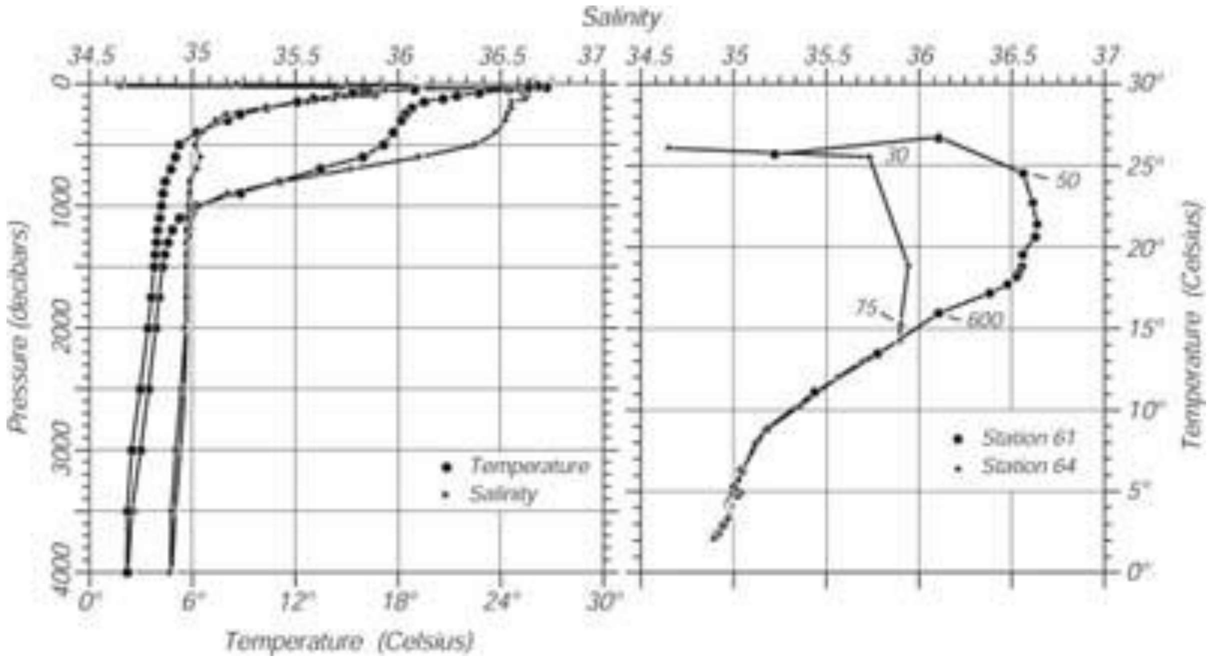


Exemplo de um T/S típico



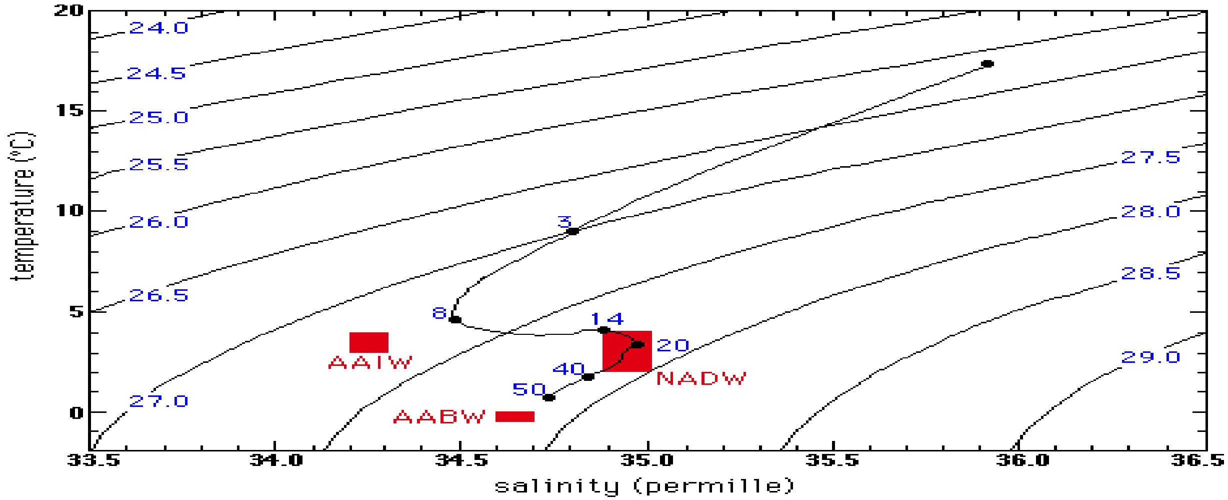
I, II, III – águas tipo

Linhas – massas de água

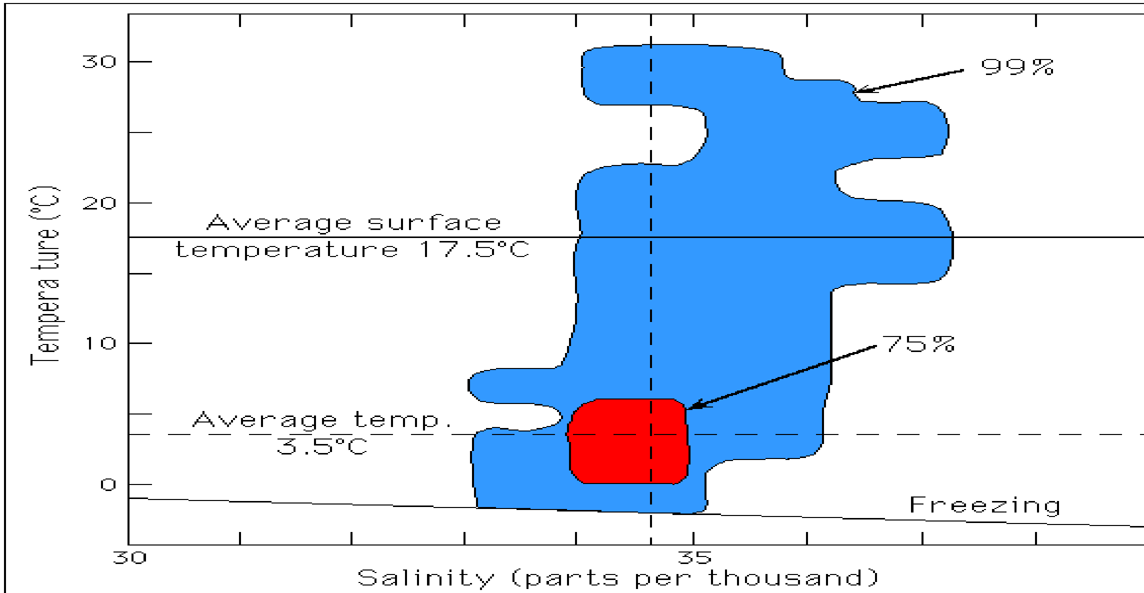


Temperature and salinity are not independent variables. For example, the temperature and salinity of the water at different depths below the Gulf Stream are uniquely related (figure right), indicating they came from the same source region, even though they do not appear related if temperature and salinity are plotted independently as a function of depth.

http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/chapter13_03.htm



An example of a T-S diagram for observations at depths from 150 m to 5,000 m at 9°S latitude in the Atlantic Ocean. Dots represent individual seawater samples; numbers indicate depths in hundreds of meters. Red boxes represent the major subsurface Atlantic water masses. AABW = Antarctic Bottom Water; NADW = North Atlantic Deep Water; AAIW = Antarctic Intermediate Water.



Temperature and salinity of 99% (75%) of the ocean water are represented by points within the blue (red) area. (After Gross, 1993).

Diagrama T/S Geral dos oceanos

Fonte: LDEO Oceanslides

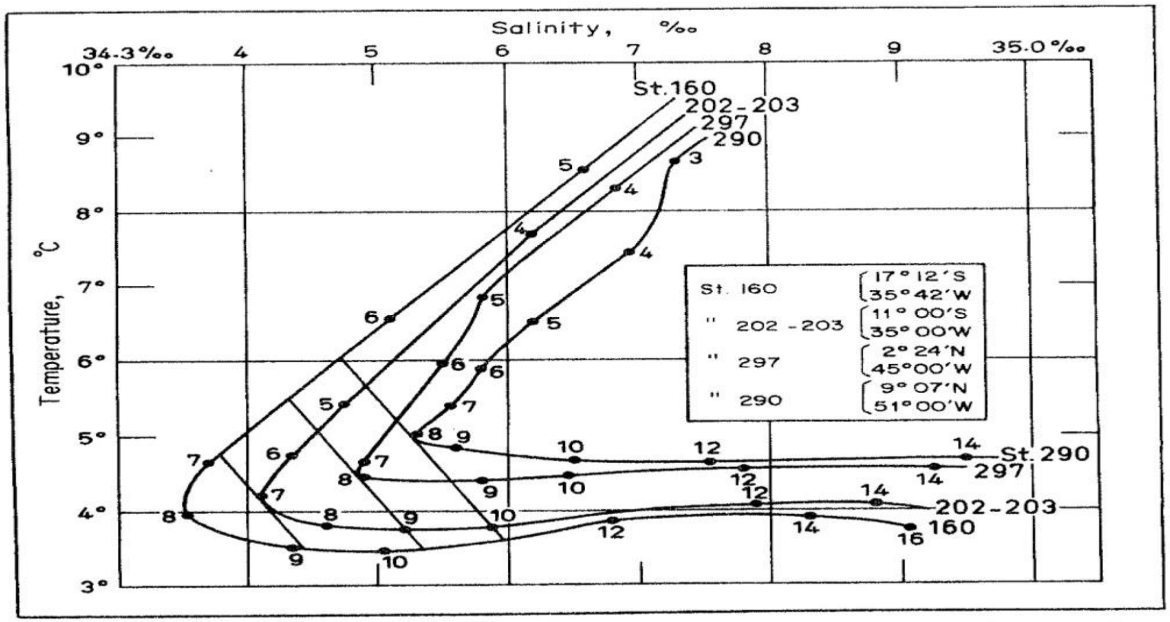
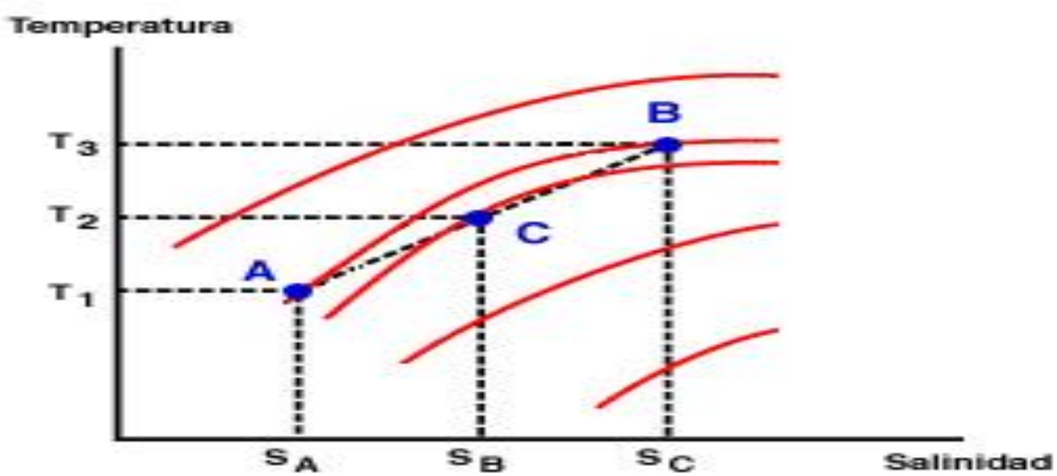


Fig. 5.34. Variations with latitude of the salinity minimum characterizing the Antarctic intermediate water between 17°S and 9°N in the Atlantic.



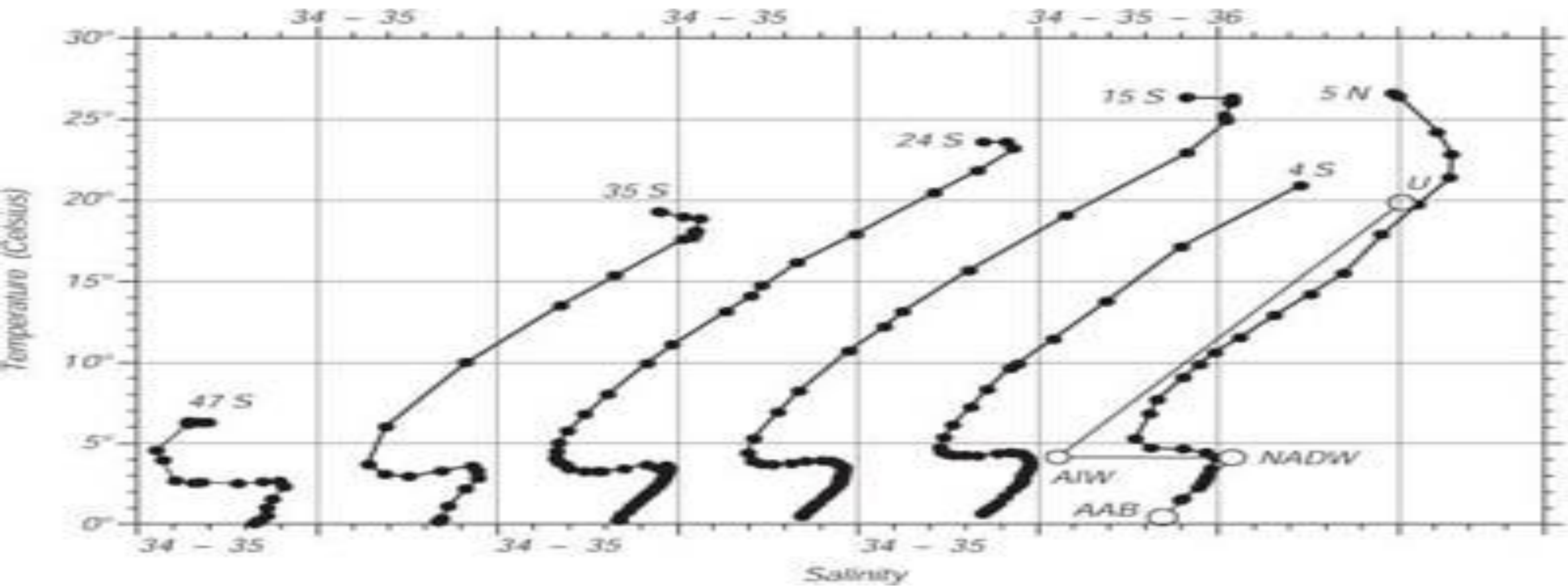


Figure 13.9 *T-S* plot of data collected at various latitudes in the western basins of the south Atlantic. Lines drawn through data from 5°N, showing possible mixing between water masses: NADW ? North Atlantic Deep Water, AIW ? Antarctic Intermediate Water, AAB - Antarctic Bottom Water, U - Subtropical Lower Water.

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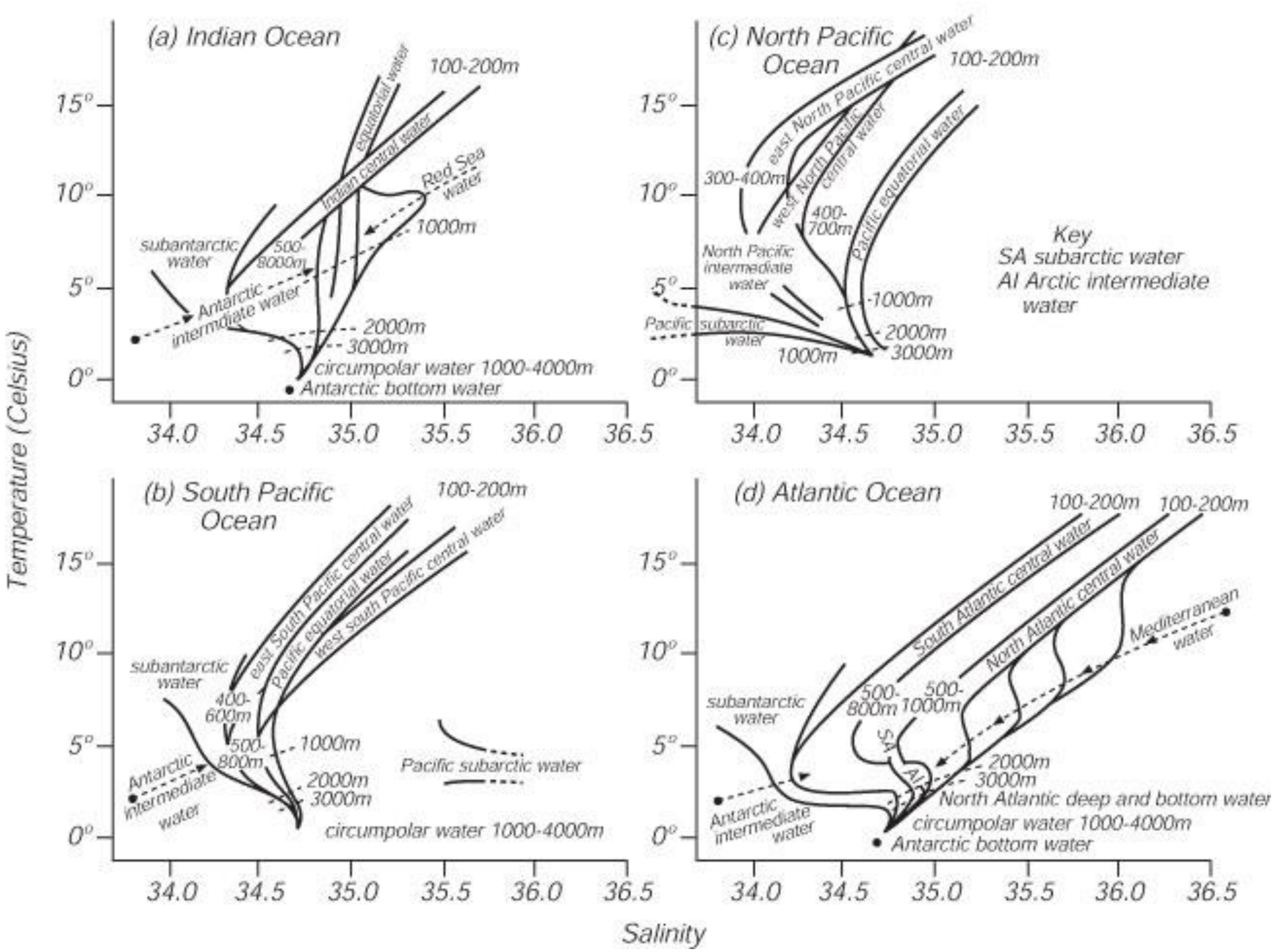


(a) Indian Ocean
100-200m
equatorial water
Indian central water
Red Sea water
1000m
subantarctic water
500-8000m
Antarctic intermediate water
2000m
3000m
circumpolar water 1000-4000m
Antarctic bottom water
(b) South Pacific Ocean
100-200m
east South Pacific central water
Pacific equatorial water
west South Pacific central water
subantarctic water
400-600m
500-800m
1000m
Antarctic intermediate water
2000m
3000m
circumpolar water 1000-4000m
Pacific subarctic water
(c) North Pacific Ocean
east North Pacific central water
100-200m
300-400m
west North Pacific central water
400-700m
Pacific equatorial water
North Pacific intermediate water
1000m
Pacific subarctic water
1000m
2000m
3000m
Key
SA subarctic water
AI Arctic intermediate water
(d) Atlantic Ocean
100-200m
100-200m
South Atlantic central water
North Atlantic central water
Mediterranean water
subantarctic water
500-800m
500-1000m
SA
AI
2000m
3000m
North Atlantic deep and bottom water
Antarctic intermediate water
circumpolar water 1000-4000m
Antarctic bottom water
Temperature (Celsius)
Salinity

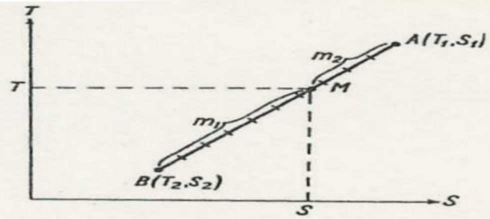


Fig. 24. The straight line of mixing of two water masses.

the mixture will then be determined by the formulae of mixing:

$$T = T_1 m_1 + T_2 m_2$$

$$S = S_1 m_1 + S_2 m_2$$

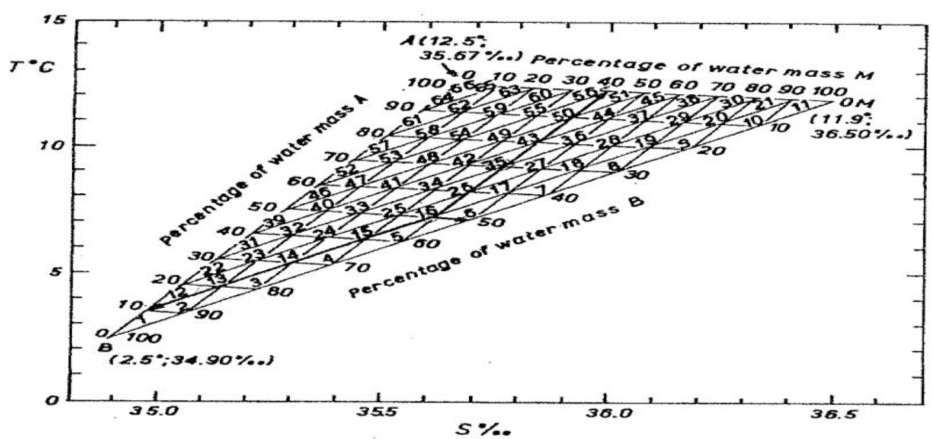
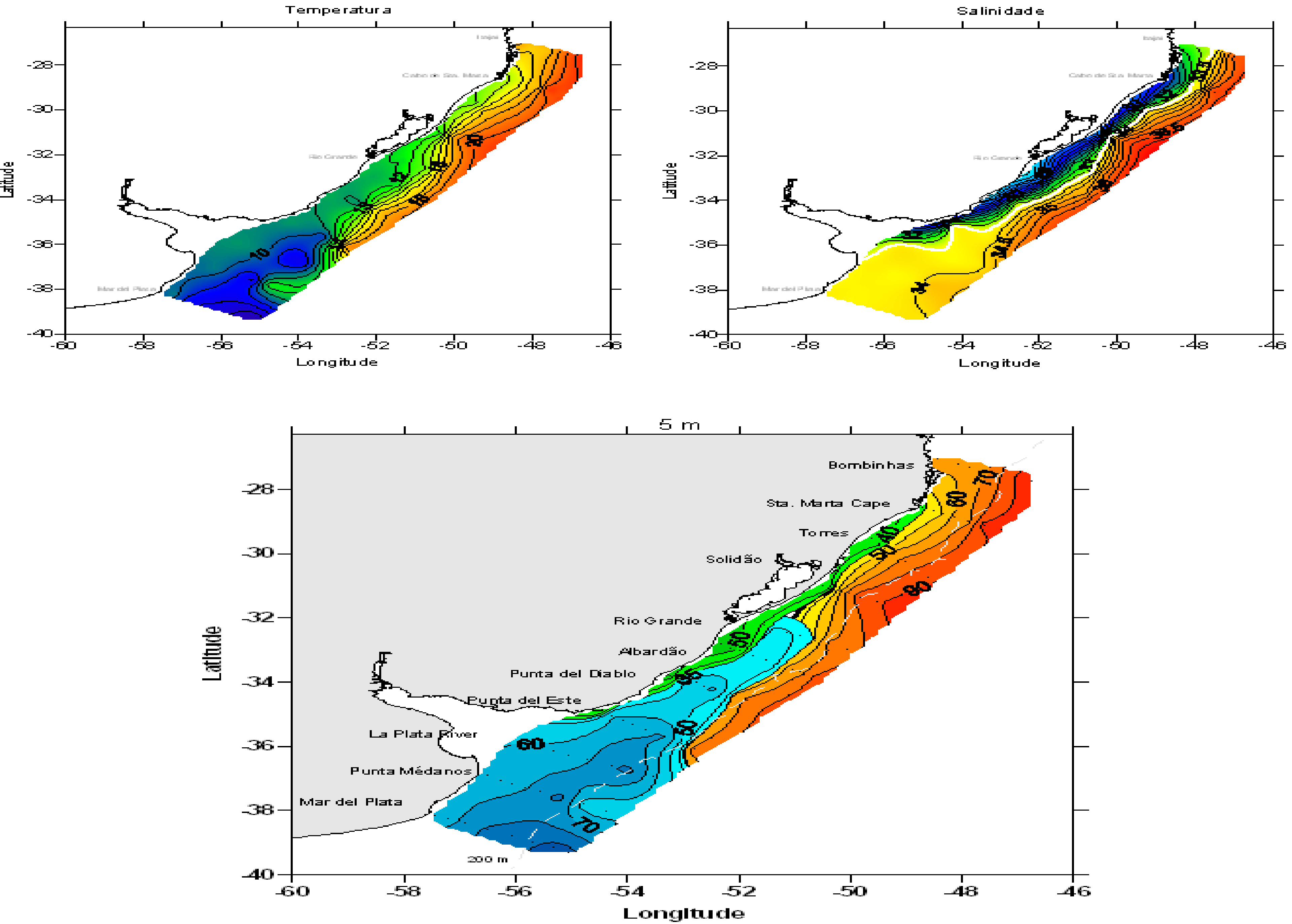
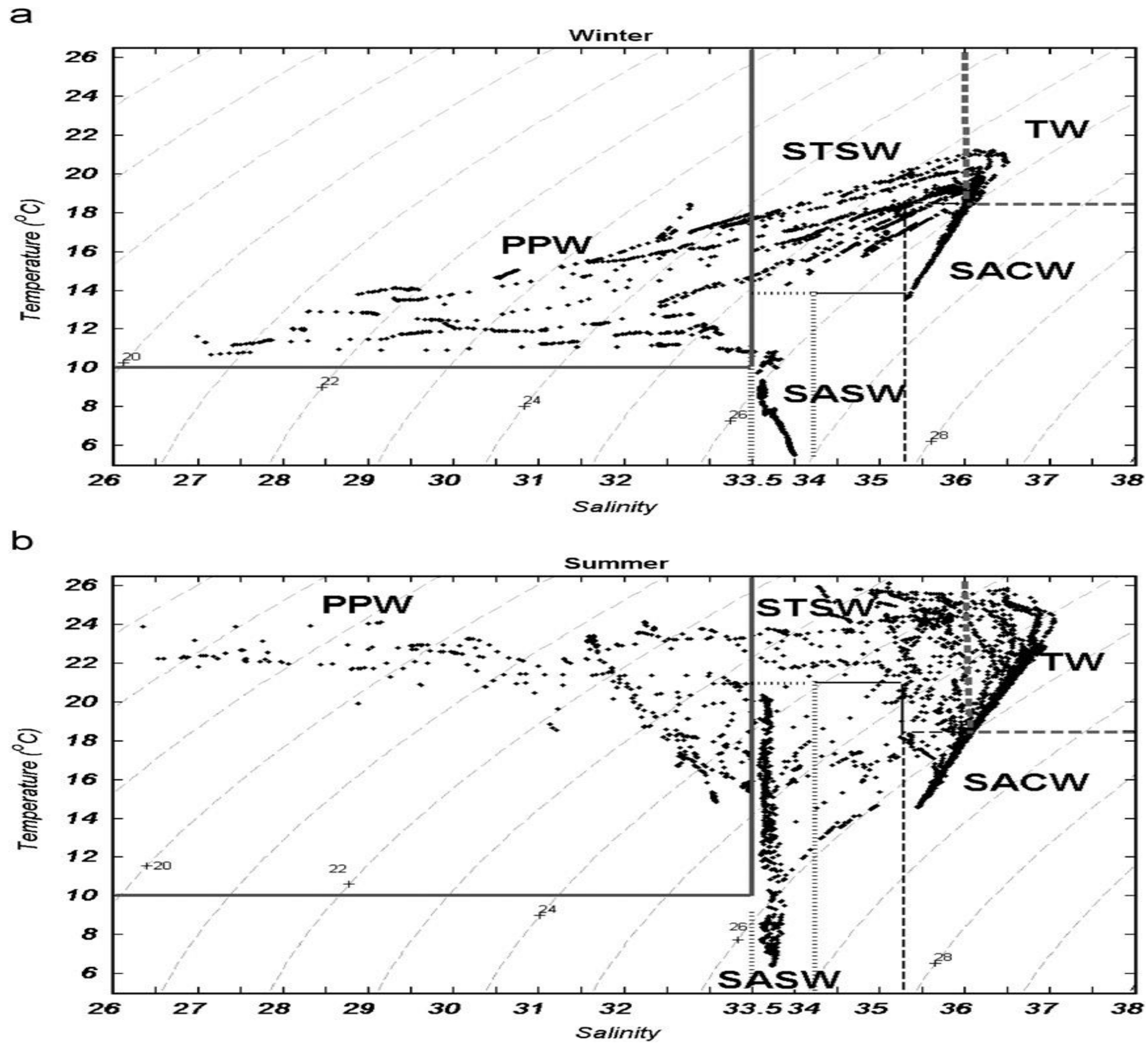


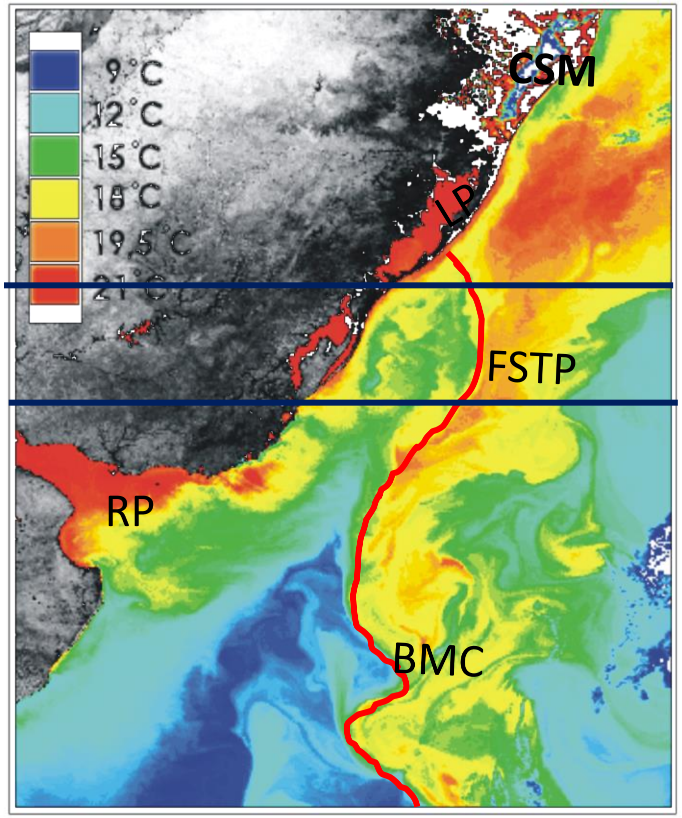
Fig. 25. Triangle of mixing (nomogram for the determination of the percentage content of water masses).

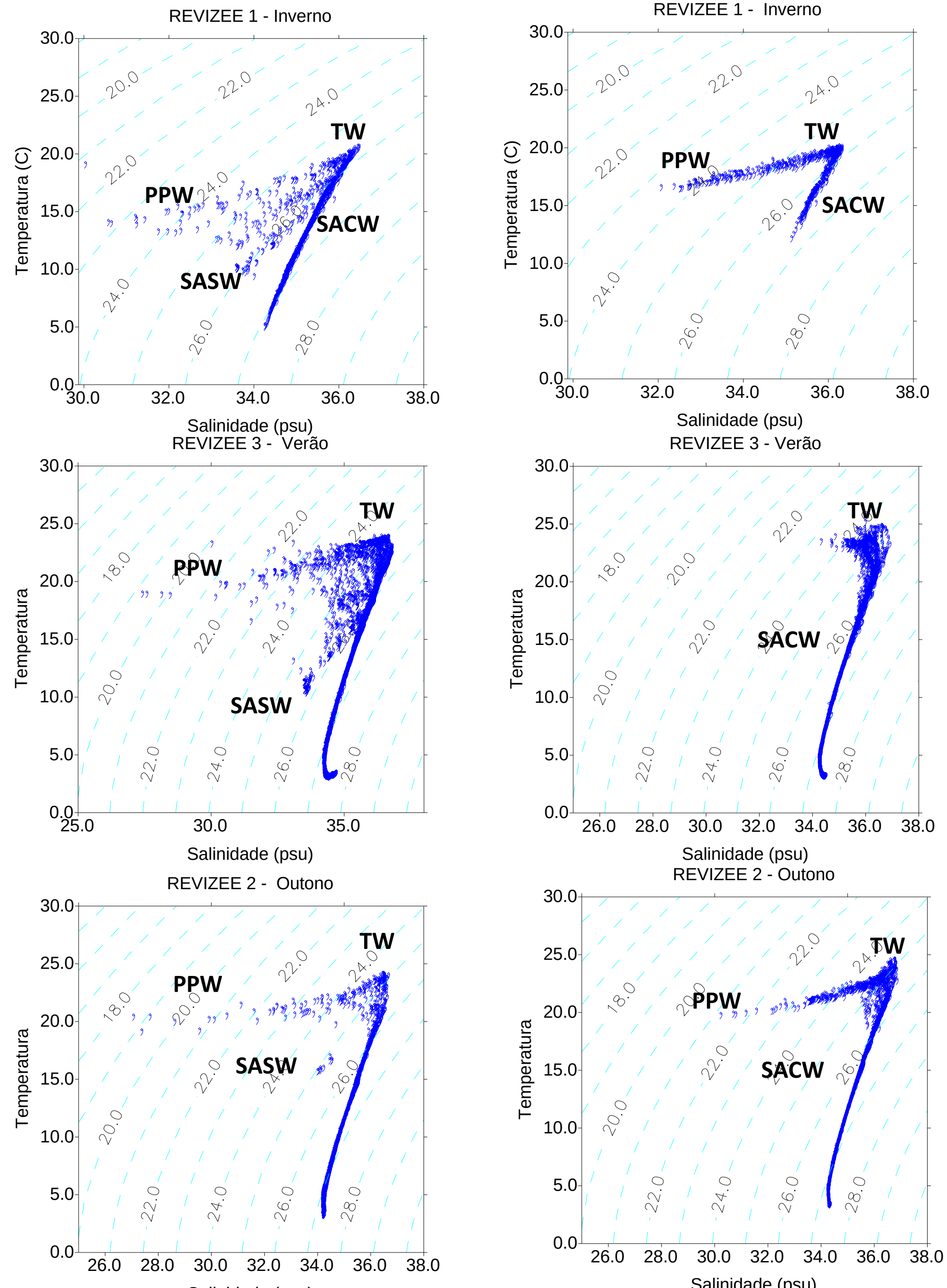


Temperatura
Salinidade
Latitude
Longitude
5 m
Bombinhas
Sta. Marta Cape
Torres
Solidão
Rio Grande
Albardão
Punta del Diablo
Punta del Este
La Plata River
Punta Médanos
Mar del Plata
200 m
Latitude
Longitude



Möller et al. (2008)

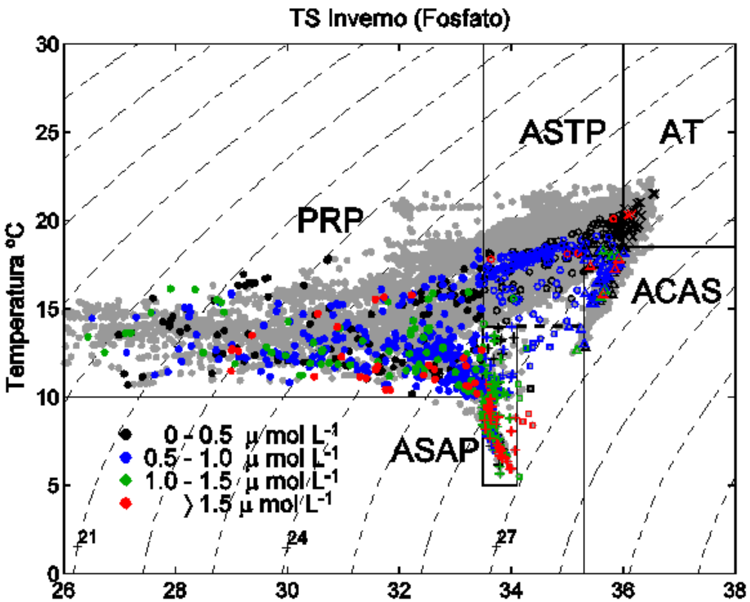


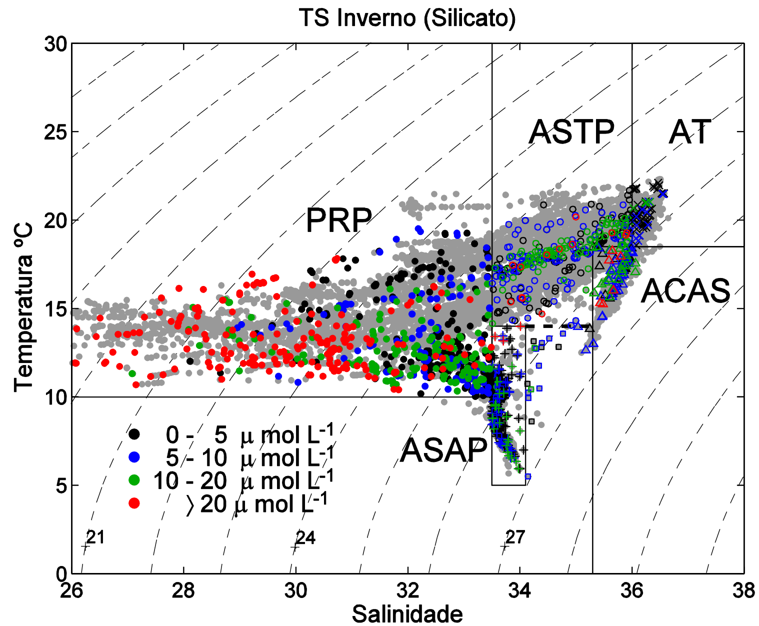


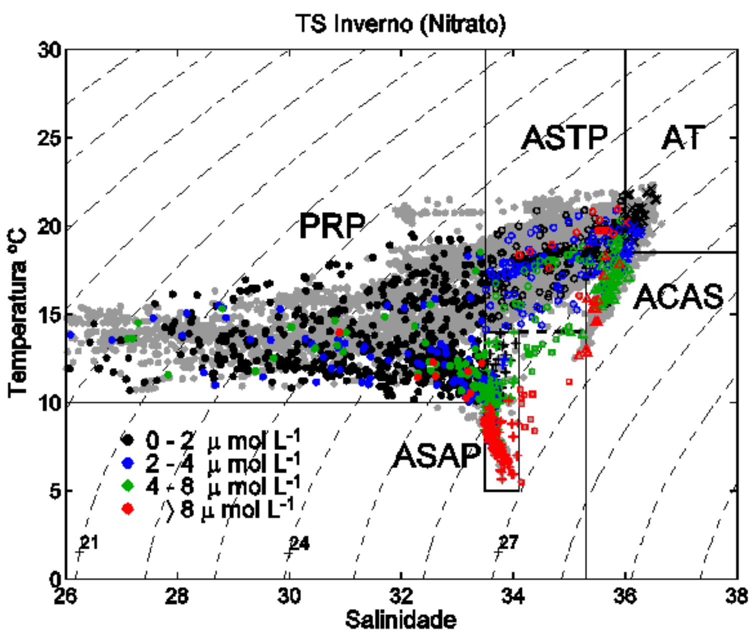
TS Diagrams REVIZEE - project

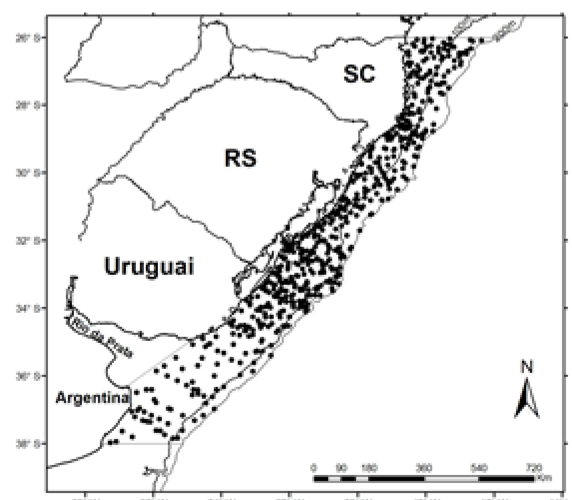
Prof. > 100 m

TS-Diagrams with nutrients for winter

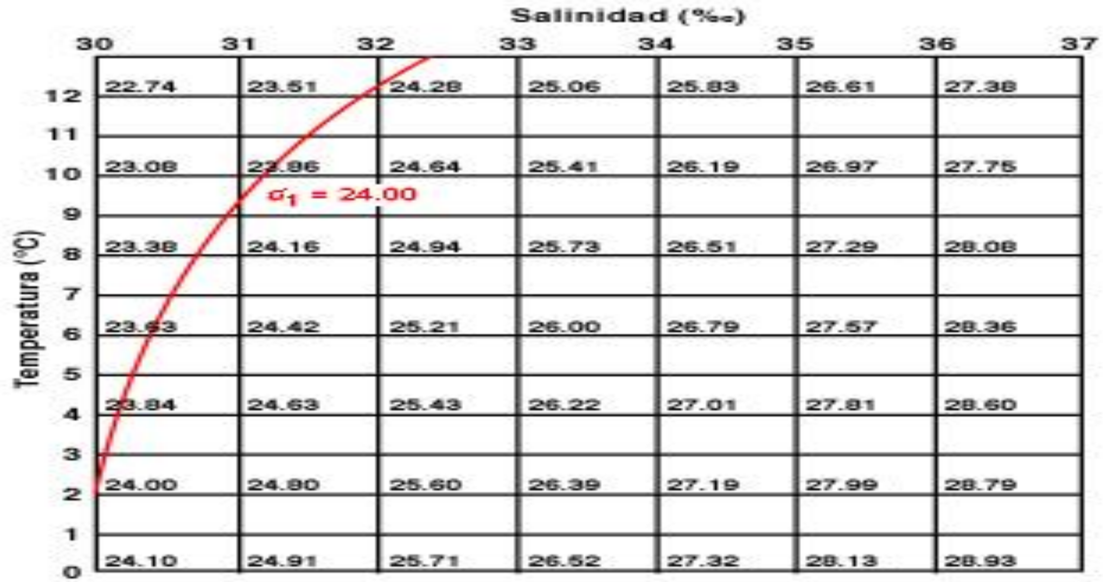


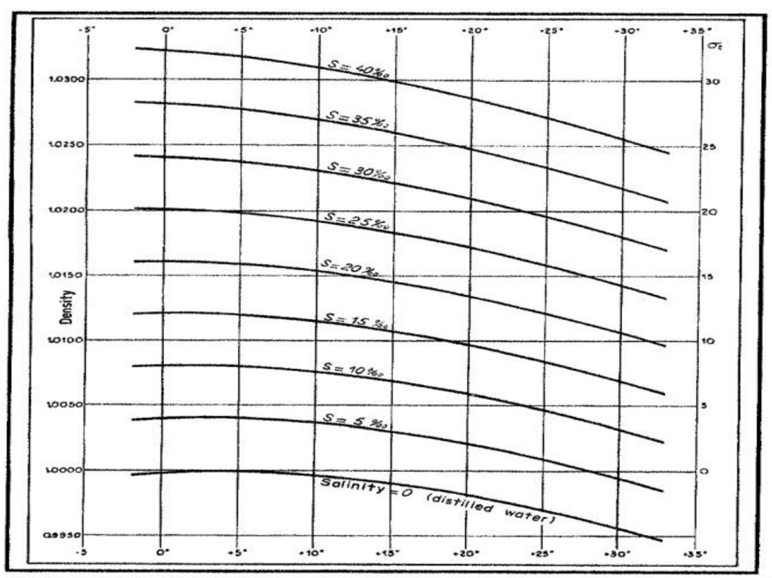




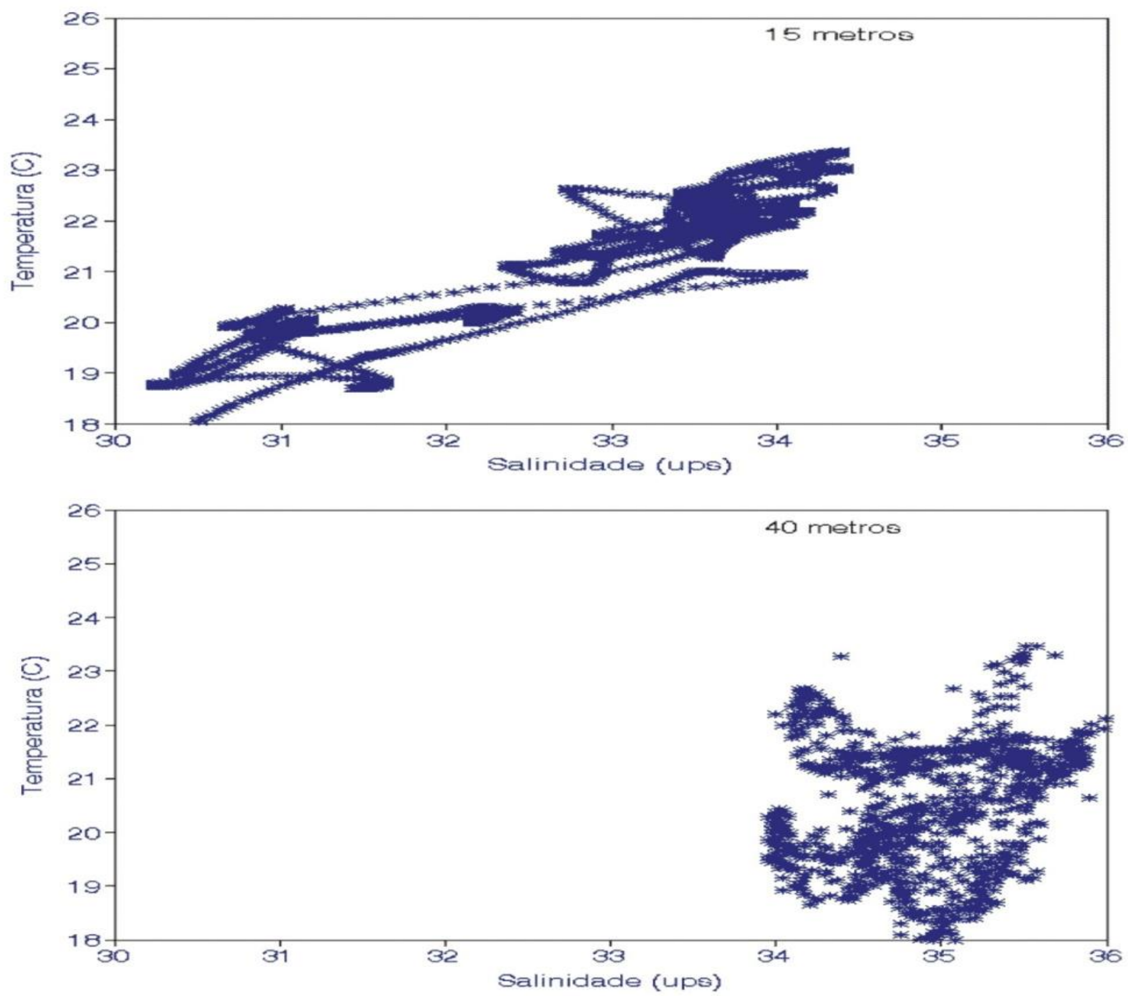


Aseff (2009)

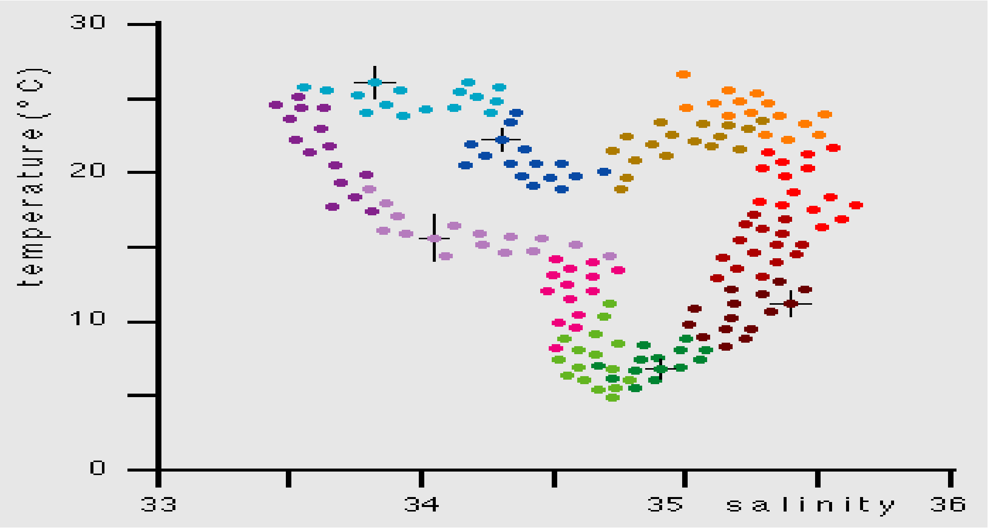




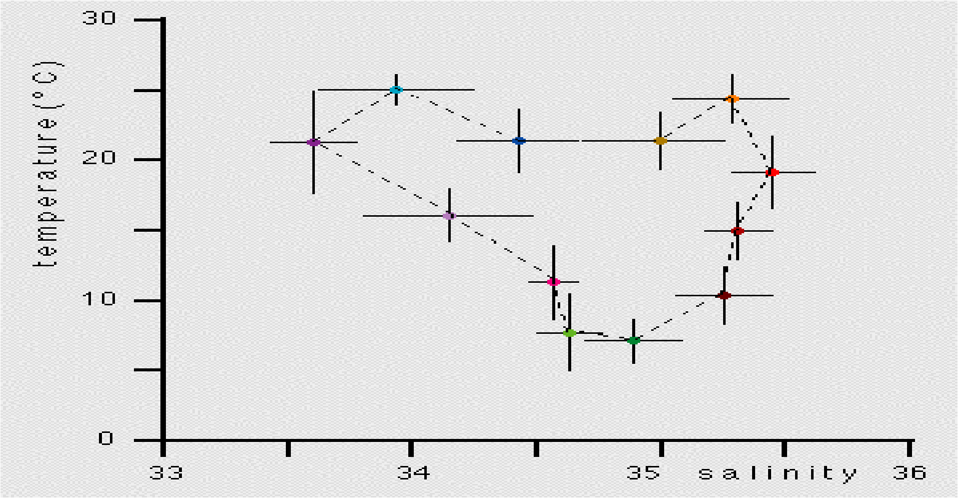
3.3. Density variations as a function of temperature for constant salinities. *T* on the abscissa, *d* and σ_t on the ordinate.


15 metros
Temperatura (C)
Salinidade (ups)
40 metros
Temperatura (C)
Salinidade (ups)

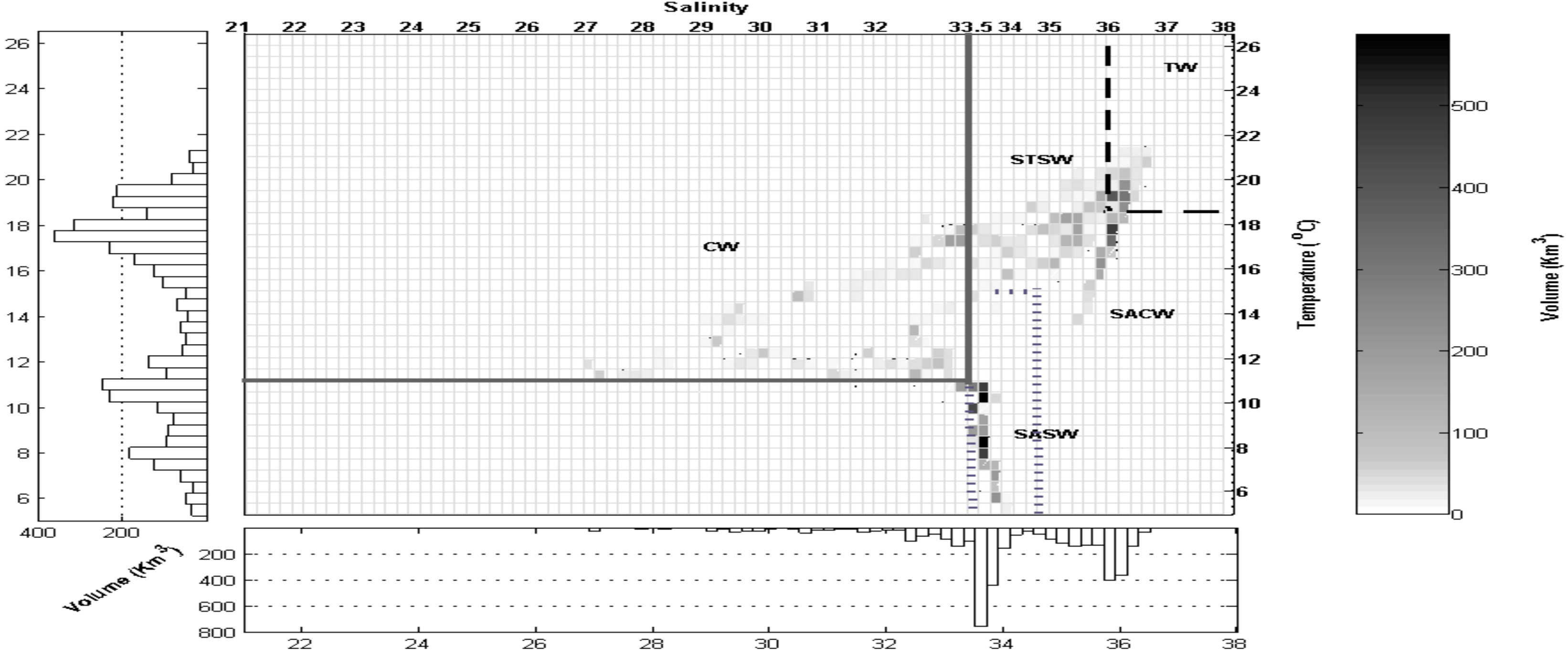
O diagrama TS-time

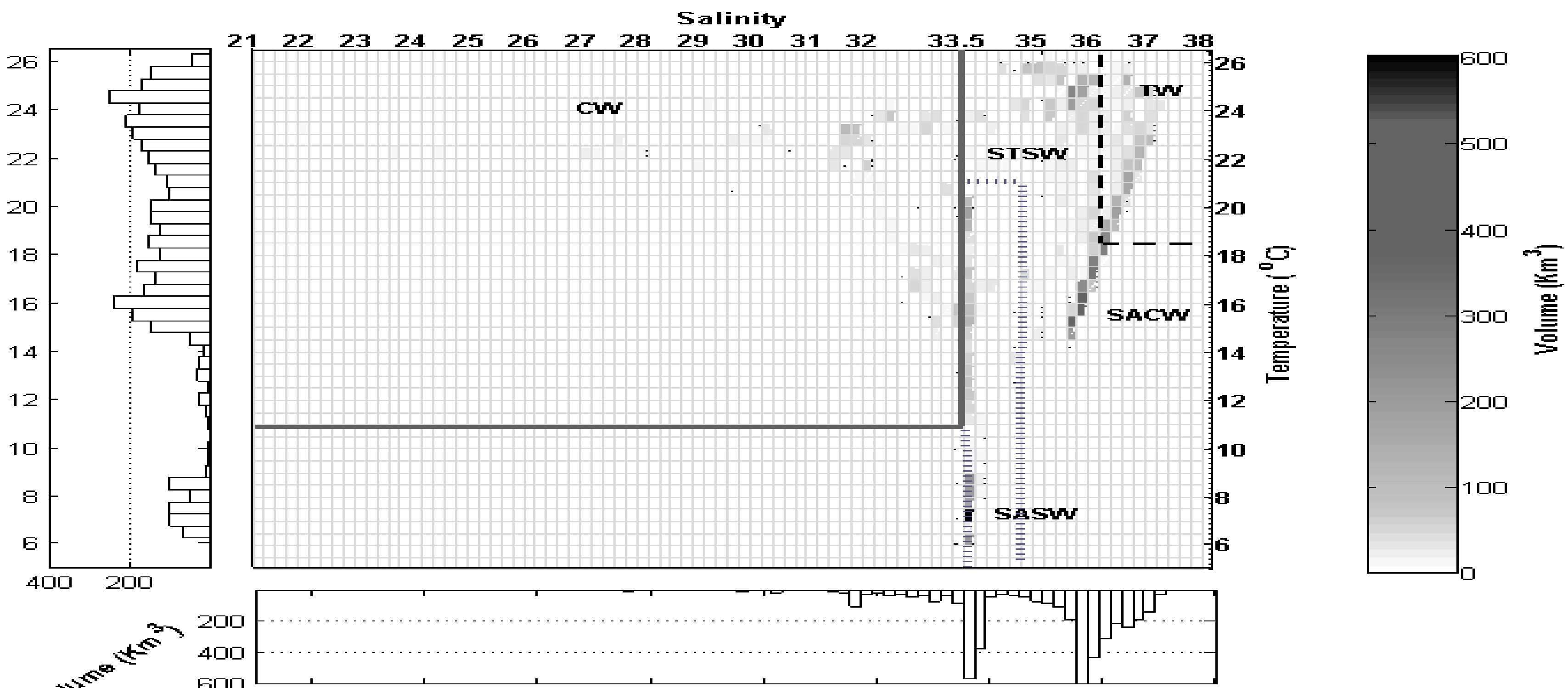


Medidas brutas. Cores indicam a variação temporal



Medias mensais e seus desvios


Salinity
TW
STSW
CW
SACW
SASW
Temperature (°C)
Volume (Km³)


Salinity
TW
CW
STSW
SACW
SASW
Temperature (°C)
Volume (Km³)

Water Mass	Winter		Summer	
	Termohaline Interval	% of Total Volume (*14.285 km³*)	Termohaline Interval	% of Total Volume (*14.338 km³*)
CW/PPW	T>11° C & S≤33.5	**23**	T>11° C & S≤33.5	**15**
TW	T ≥18.5°C & S≥36	**8**	T ≥18.5°C & S≥36	**21**
STSW	T >15°C & 33.5<S<35.5 T >18°C & 35.5<S<36	**25**	T >18°C & 34.5<S<36 T >21°C & 33.5<S<34.5	**22**
SASW	T≤14°C & 33.5<S≤34.5	**31**	T≤21°C & 33.5<S≤34.5	**23**
SACW	T≤18.5°C & S≥35.5	**13**	T≤18.5°C & S≥35.5	**19**

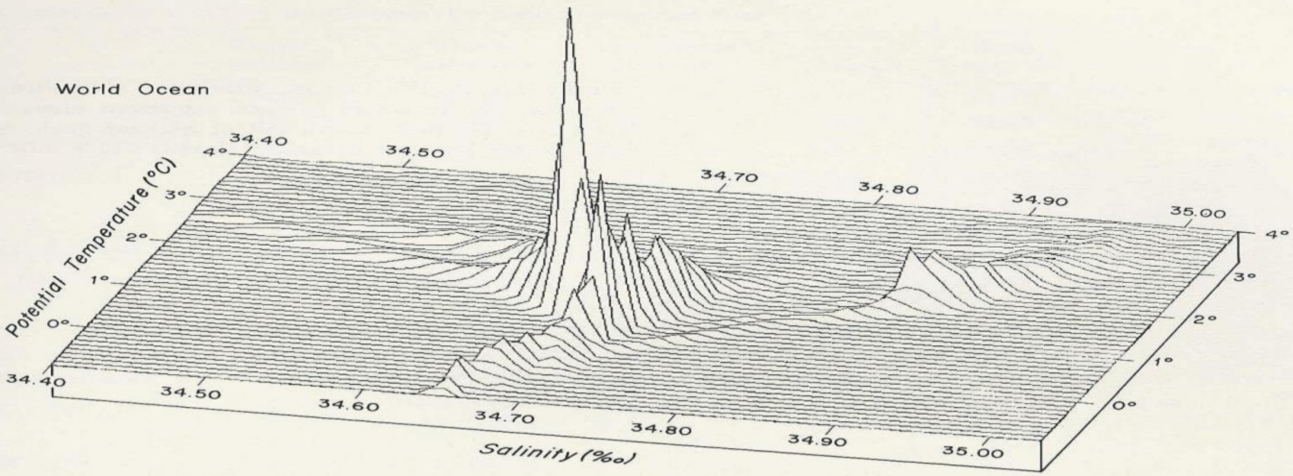


Figure 2.2 Simulated three-dimensional T–S diagram of the water masses of the world ocean. Apparent elevation is proportional to volume. Elevation of highest peak corresponds to 26.0×10^6 km^3 per bivariate class 0.1°C × 0.01‰.

Other Tracers

I have illustrated the core method using salinity as a tracer, but many other tracers are used. An ideal tracer is easy to measure even when its concentration is very small; it is conserved, which means that only mixing changes its concentration; it does not influence the density of the water; it exists in the water mass we wish to trace, but not in other adjacent water masses; and it does not influence marine organisms (we don't want to release toxic tracers).

Various tracers meet these criteria to a greater or lesser extent, and they are used to follow the deep and intermediate water in the ocean. Here are some of the most widely used tracers.

Salinity is conserved, and it influences density much less than temperature.

Oxygen is only partly conserved. Its concentration is reduced by the respiration by marine plants and animals and by oxidation of organic carbon.

Silicates are used by some marine organisms. They are conserved at depths below the sunlit zone.

Phosphates are used by all organisms, but they can provide additional information.

^3He is conserved, but there are few sources, mostly at deep-sea volcanic areas and hot springs.

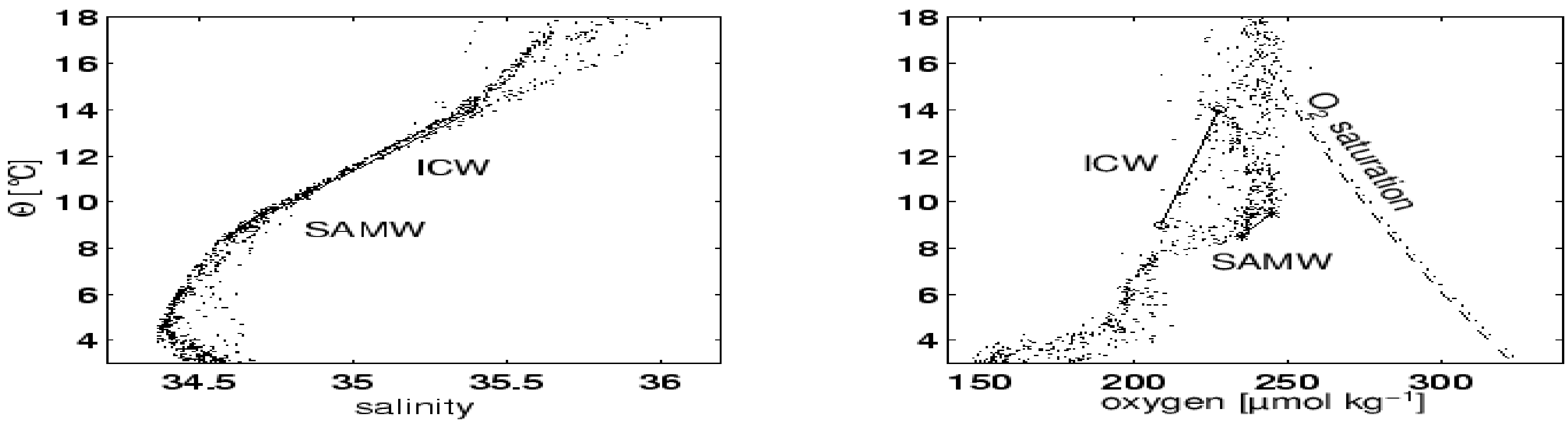
^3H (tritium) was produced by atomic bomb tests in the atmosphere in the 1950s. It enters the ocean through the mixed layer, and it is useful for tracing the formation of deep water. It decays with a half life of 12.3 yrs and it is slowly disappearing from the ocean. Figure 10.15shows the slow advection or perhaps mixing of the tracer into the deep north Atlantic. Note that after 25 years little tritium is found south of 30°N. This implies a mean velocity of less than a mm/s.

Fluorocarbons (Freon used in air conditioning) have been recently injected into atmosphere. They can be measured with very great sensitivity, and they are being used for tracing the sources of deep water.

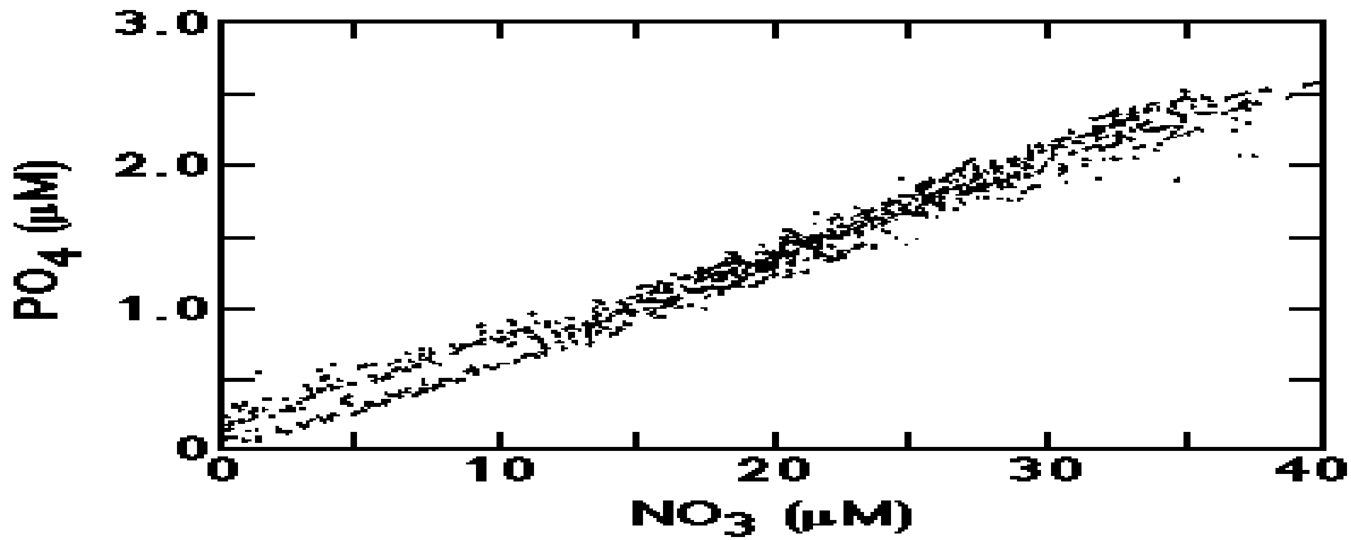
Sulphur hexafluoride SF_6 can be injected into sea water, and the concentration can be measured with great sensitivity for many months.

Each tracer has its usefulness, and each provides additional information about the flow.

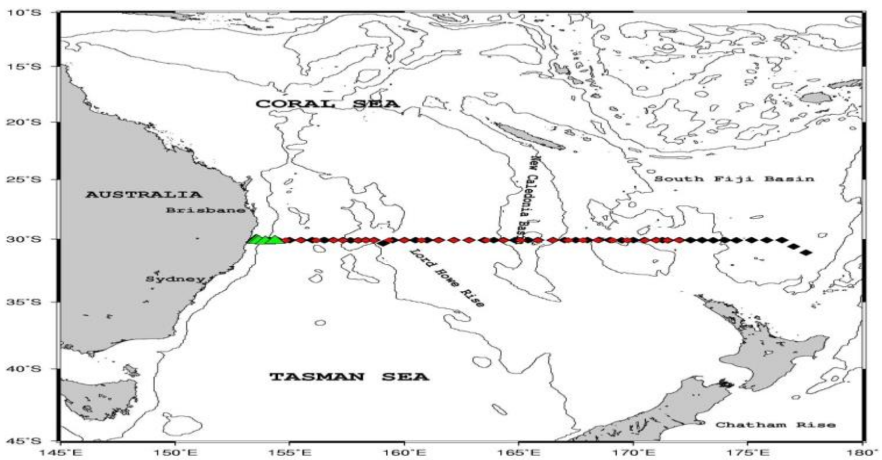
Outros diagramas de propriedades

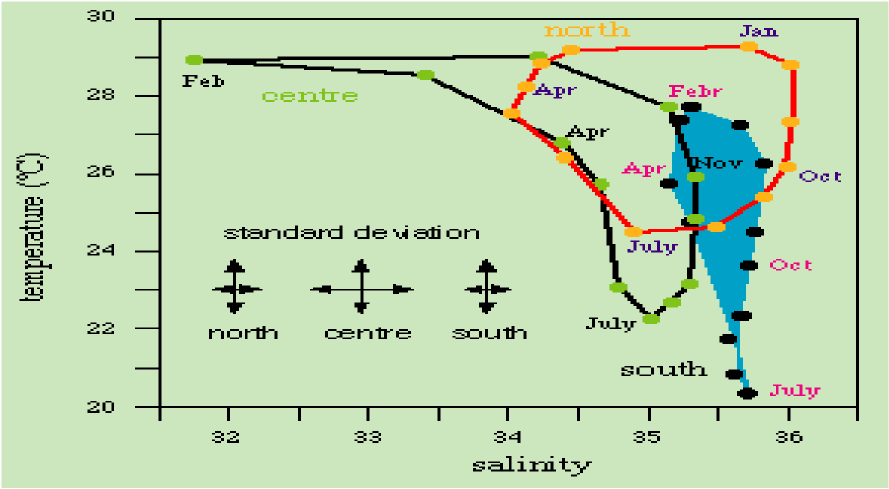


Fonte: Johannes Karstensen

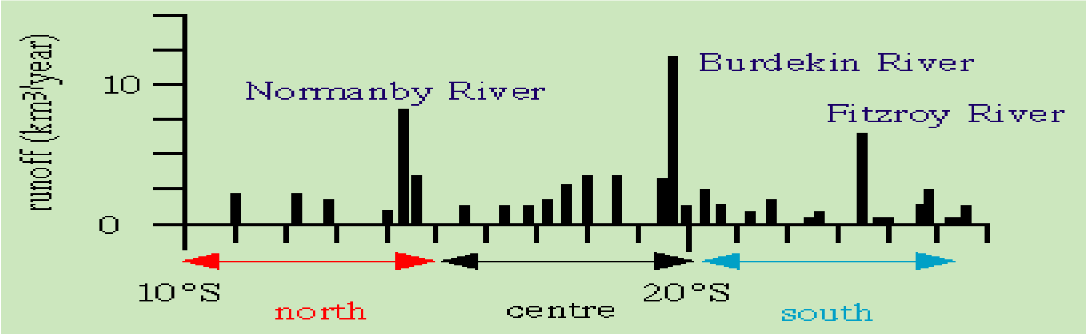


Estudo de caso utilizando um diagrama TS-time: da lagoa da Grande Barreira de Coral





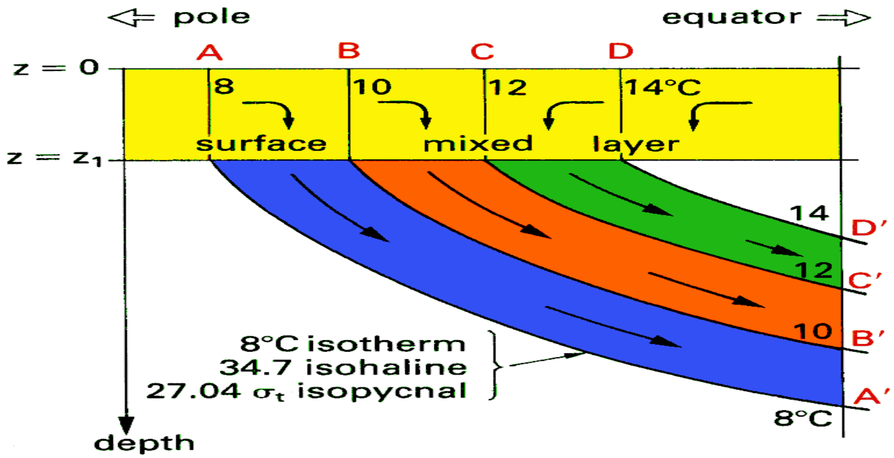
Water mass definitions (TS-time diagrams) for the southern, central and northern regions of the Great Barrier Reef lagoon. The regions are defined as north = 10 - 15°S, centre = 15 - 20°S, south = 20 - 25°S. Standard deviations are not given for every month but for the ensemble of TS-data in each region. Adapted from Pickard (1977).



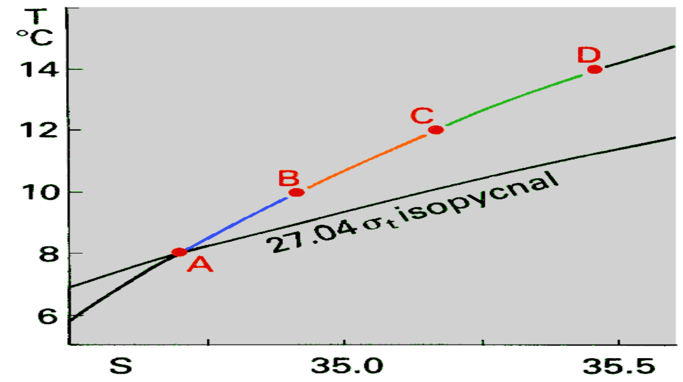
Mean freshwater input from land in the Great Barrier Reef lagoon. Adapted from Pickard (1977).

Formação de massas de água

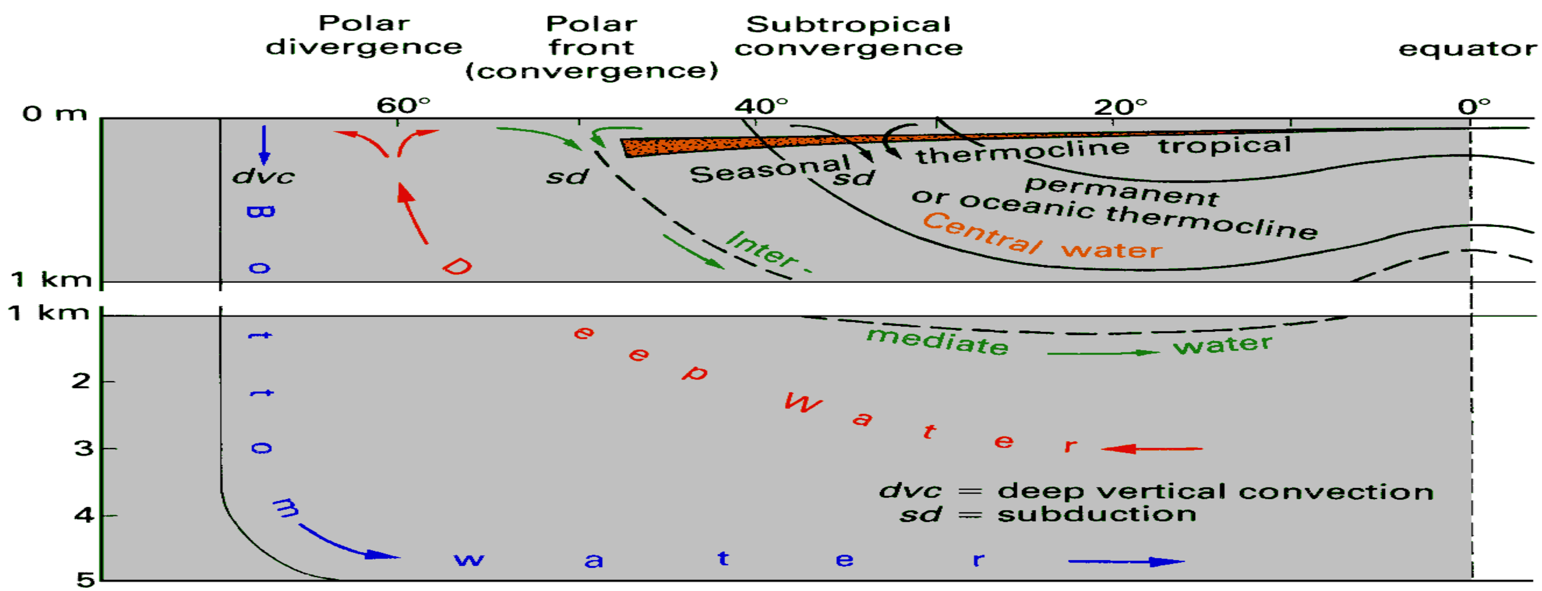
- Subducção: Águas Centrais e Águas intermediárias;
  - É o processo pelo qual as massas de água são injetadas em profundidades maiores <u>seguindo</u> as mesmas isopicnais da região da sua formação.
- Convecção profunda: Águas Profundas e Águas de Fundo
  - É resultado da formação, em camadas superficiais de uma água bem mais densa que a camada inferior favorecendo o desenvolvimento de forte circulação vertical.



pole
equator
A
B
C
D
z = 0
z = z1
8
10
12
14°C
surface
mixed
layer
14
D′
12
C′
10
B′
A′
8°C
8°C isotherm
34.7 isohaline
27.04 σt isopycnal
depth



T
°C
14
12
10
8
6
D
C
B
A
27.04 σt isopycnal
S
35.0
35.5



Polar
divergence
Polar
front
(convergence)
Subtropical
convergence
equator
0 m
60°
40°
20°
0°
dvc
sd
Seasonal
sd
thermocline
tropical
permanent
or oceanic thermocline
Central water
Inter-
mediate
water
1 km
1 km
2
3
4
5
Bottom
water
Deep Water
dvc = deep vertical convection
sd = subduction

PIRATAS DO TIETÊ - Laerte

Diagrama TS

- Plots of salinity as a function of temperature, called *T-S* plots, are used to:
- delineate water masses and their geographical distribution;
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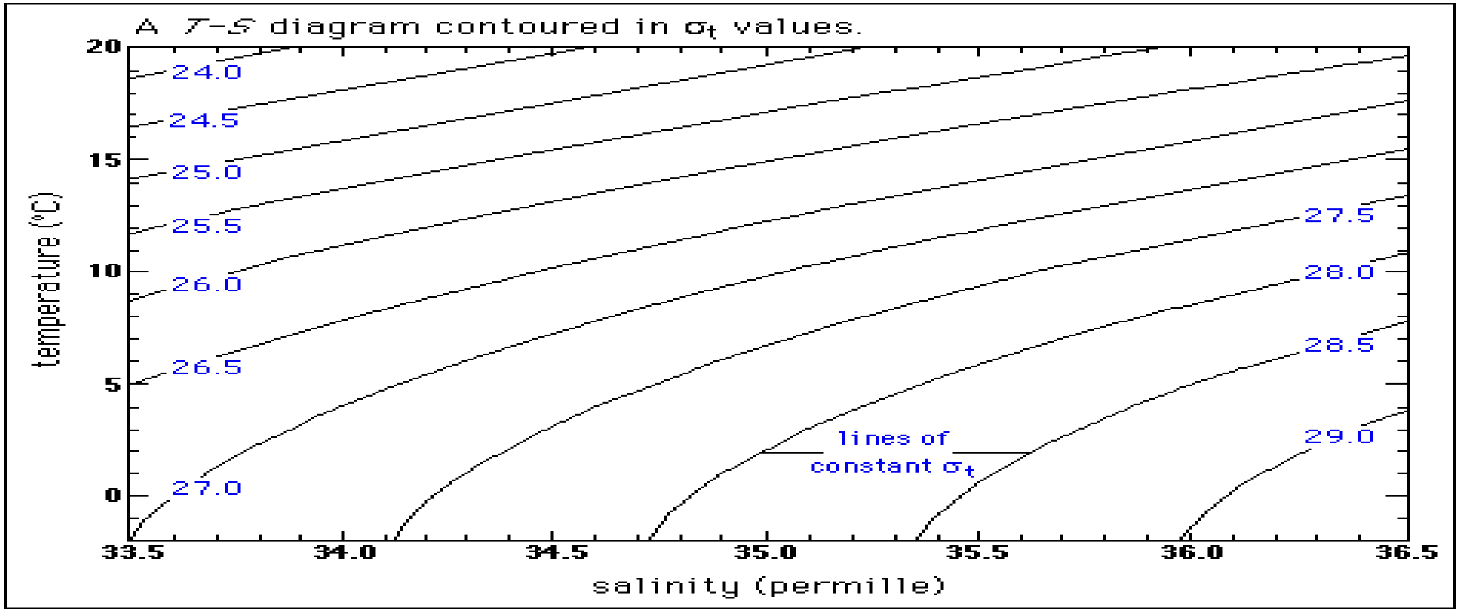
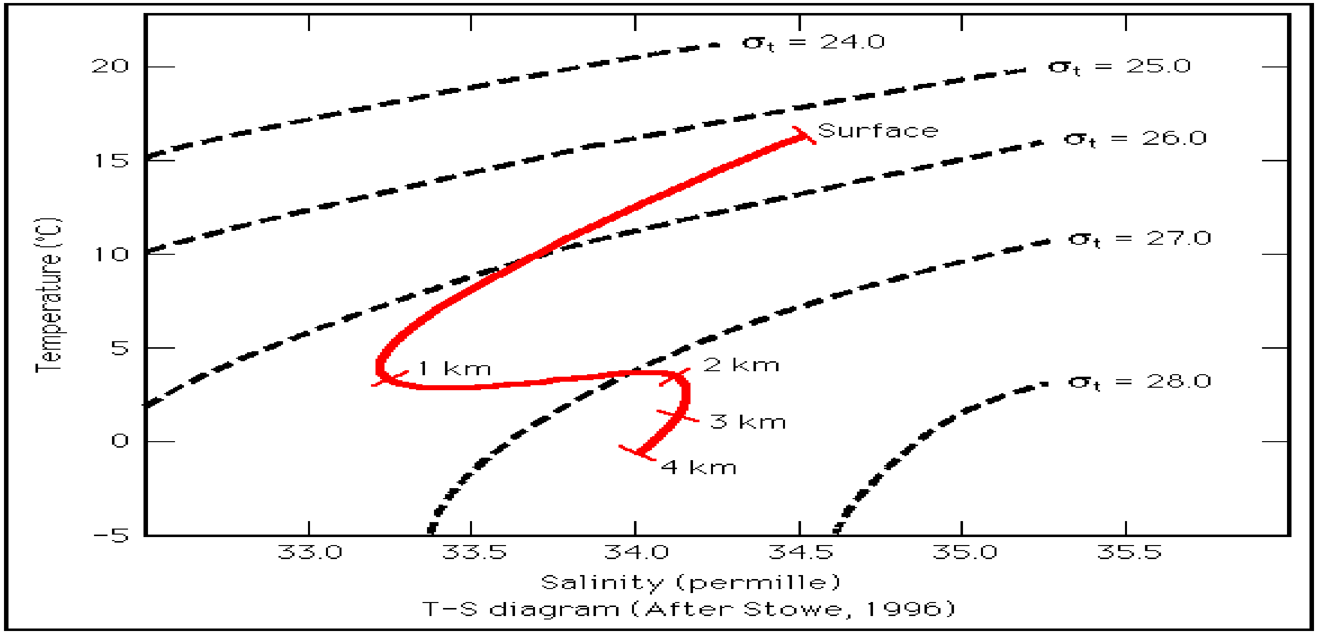
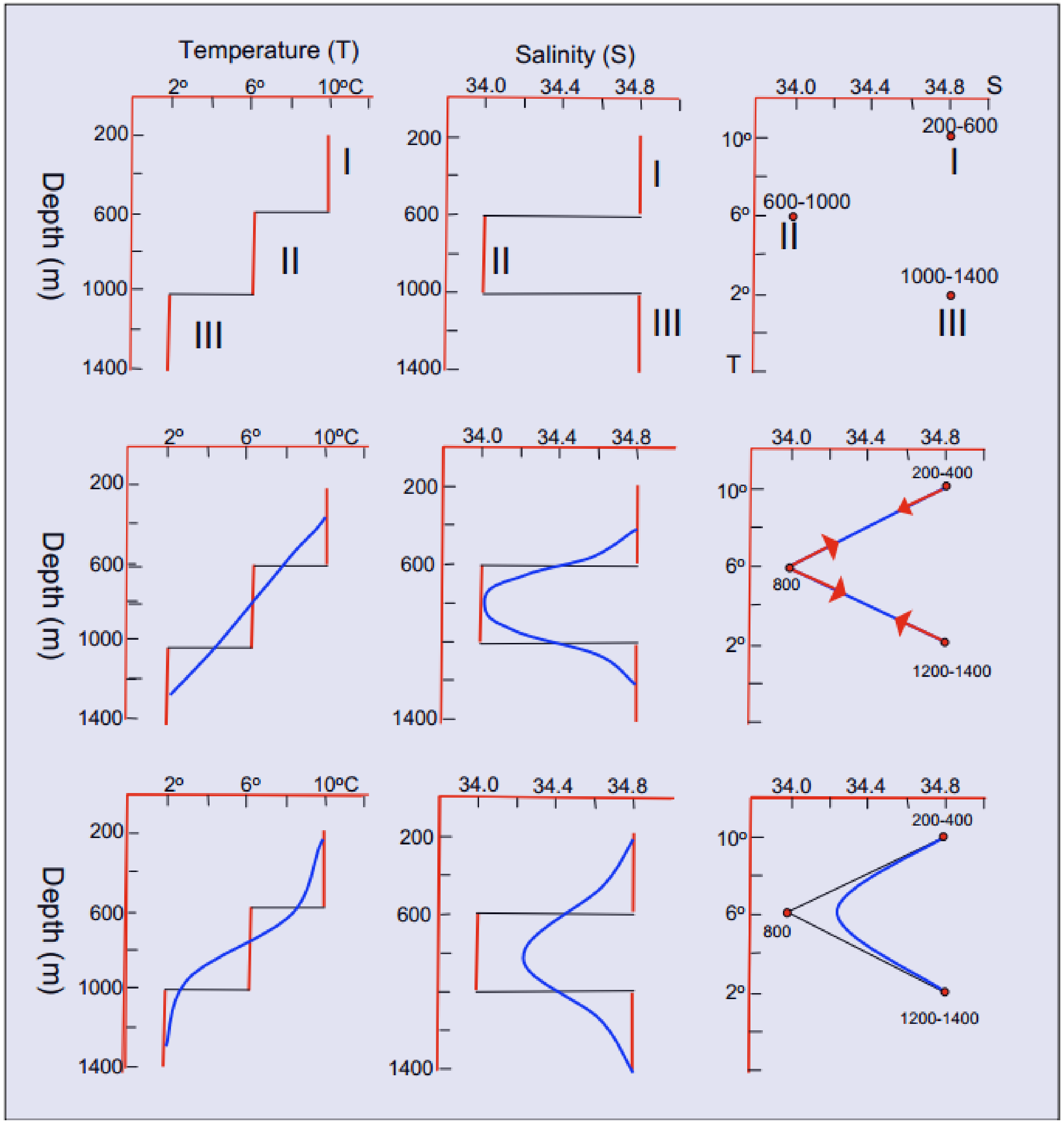


Características básica de um T/S

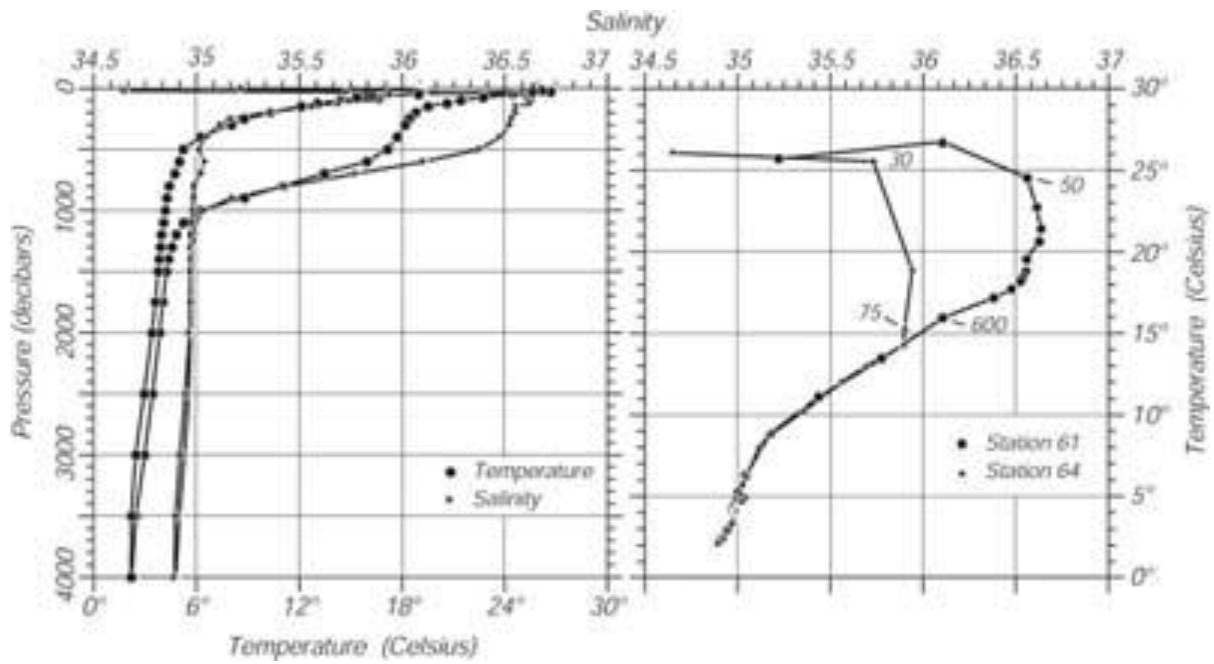


Exemplo de um T/S típico



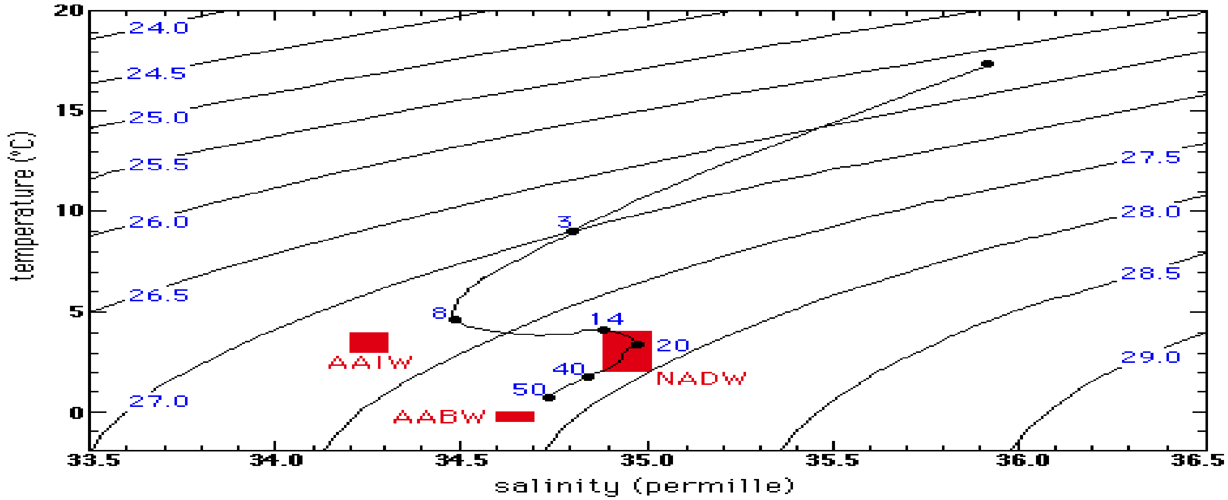
I, II, III – águas tipo

Linhas – massas de água

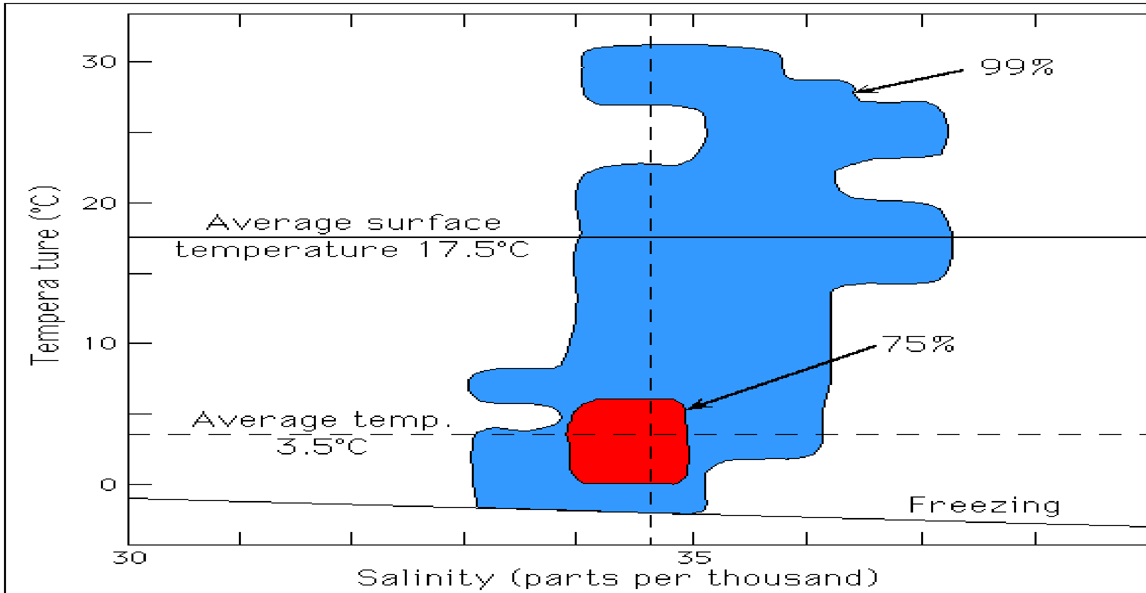


Temperature and salinity are not independent variables. For example, the temperature and salinity of the water at different depths below the Gulf Stream are uniquely related (figure right), indicating they came from the same source region, even though they do not appear related if temperature and salinity are plotted independently as a function of depth.

http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/chapter13_03.htm



An example of a T–S diagram for observations at depths from 150 m to 5,000 m at 9°S latitude in the Atlantic Ocean. Dots represent individual seawater samples; numbers indicate depths in hundreds of meters. Red boxes represent the major subsurface Atlantic water masses. AABW = Antarctic Bottom Water; NADW = North Atlantic Deep Water; AAIW = Antarctic Intermediate Water.



Temperature and salinity of 99% (75%) of the ocean water are represented by points within the blue (red) area. (After Gross, 1993).

Diagrama T/S Geral dos oceanos

Fonte: LDEO Oceanslides

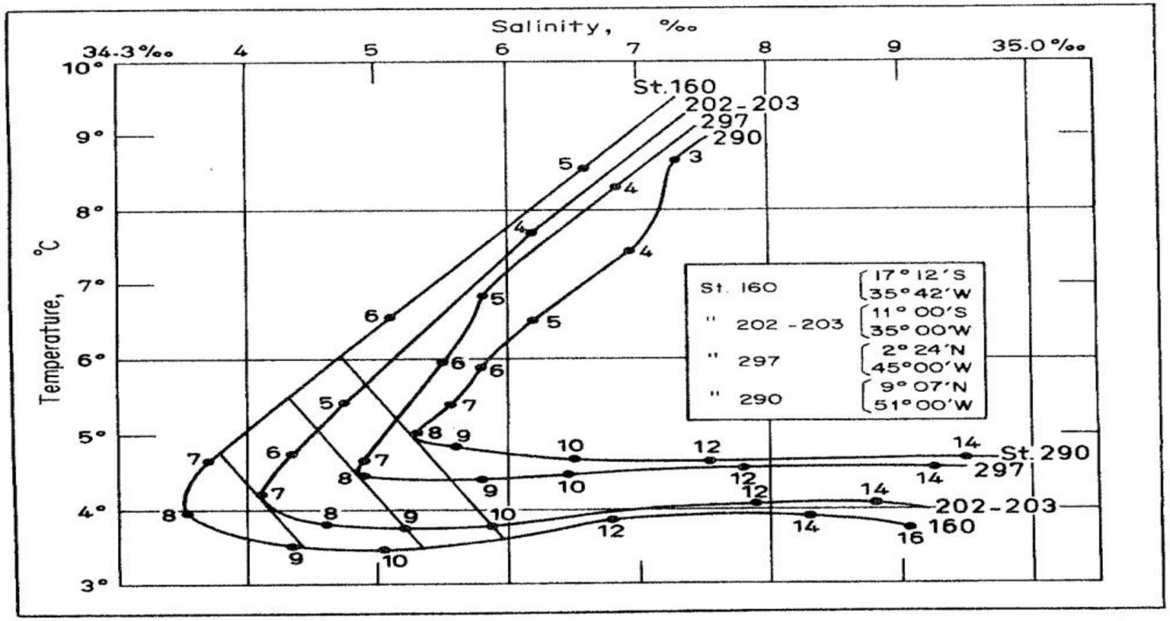
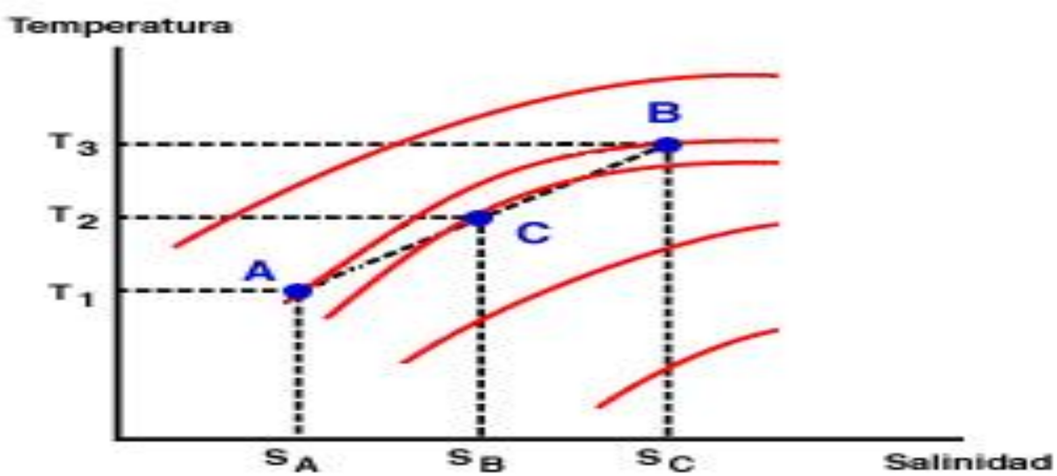


Fig. 5.34. Variations with latitude of the salinity minimum characterizing the Antarctic intermediate water between 17°S and 9°N in the Atlantic.



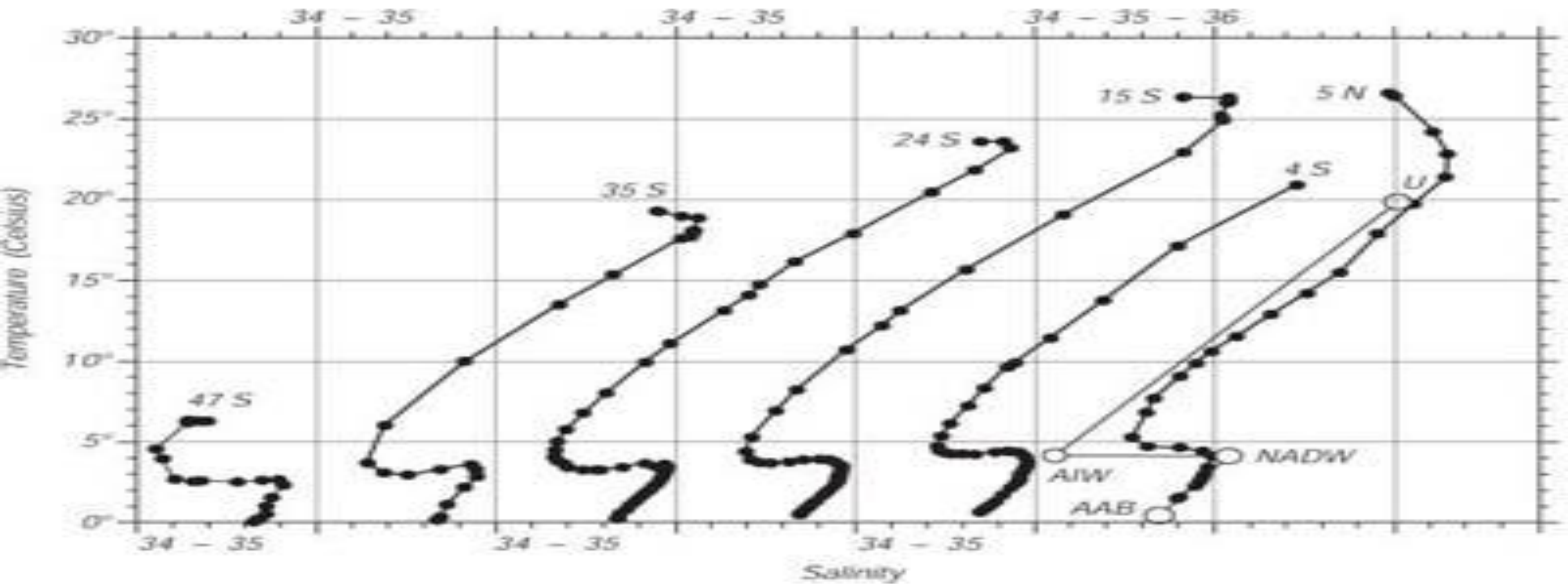
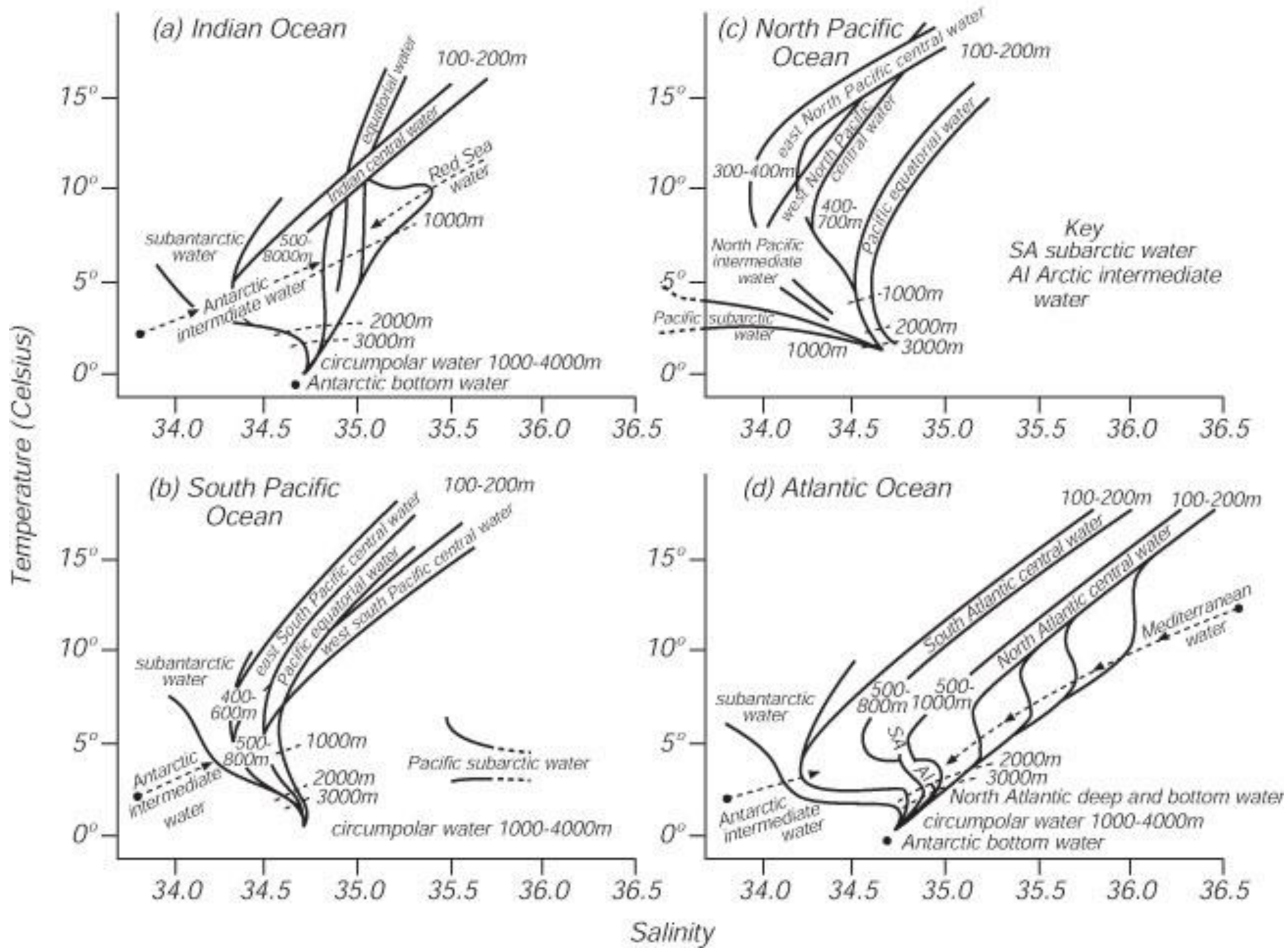


Figure 13.9 *T-S* plot of data collected at various latitudes in the western basins of the south Atlantic. Lines drawn through data from 5°N, showing possible mixing between water masses: NADW ? North Atlantic Deep Water, AIW ? Antarctic Intermediate Water, AAB - Antarctic Bottom Water, U - Subtropical Lower Water.

http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/chapter13_03.htm



(a) Indian Ocean
(b) South Pacific Ocean
(c) North Pacific Ocean
(d) Atlantic Ocean
Temperature (Celsius)
Salinity
100-200m
equatorial water
Indian central water
Red Sea water
1000m
subantarctic water
500-8000m
Antarctic intermediate water
2000m
3000m
circumpolar water 1000-4000m
Antarctic bottom water
east South Pacific central water
Pacific equatorial water
west South Pacific central water
400-600m
500-800m
Pacific subarctic water
east North Pacific central water
west North Pacific central water
Pacific equatorial water
300-400m
400-700m
North Pacific intermediate water
Pacific subarctic water
Key
SA subarctic water
AI Arctic intermediate water
South Atlantic central water
North Atlantic central water
Mediterranean water
500-1000m
SA
AI
North Atlantic deep and bottom water

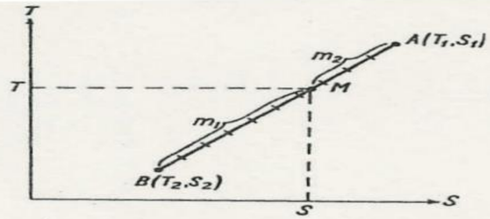


Fig. 24. The straight line of mixing of two water masses.

the mixture will then be determined by the formulae of mixing:

$$T = T_1 m_1 + T_2 m_2$$

$$S = S_1 m_1 + S_2 m_2$$

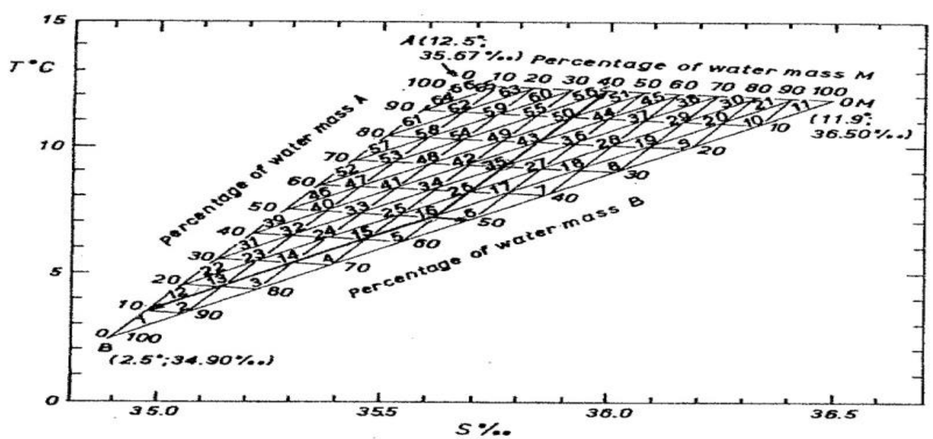
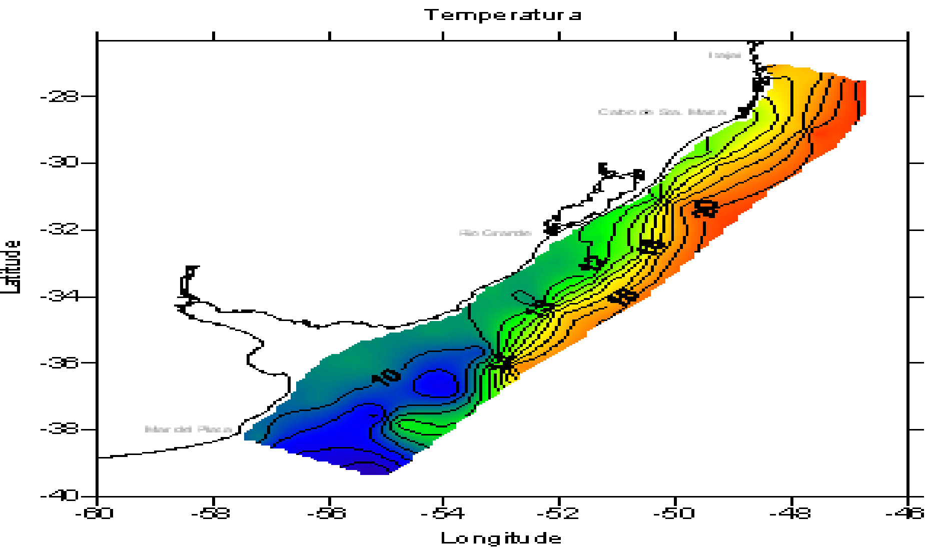
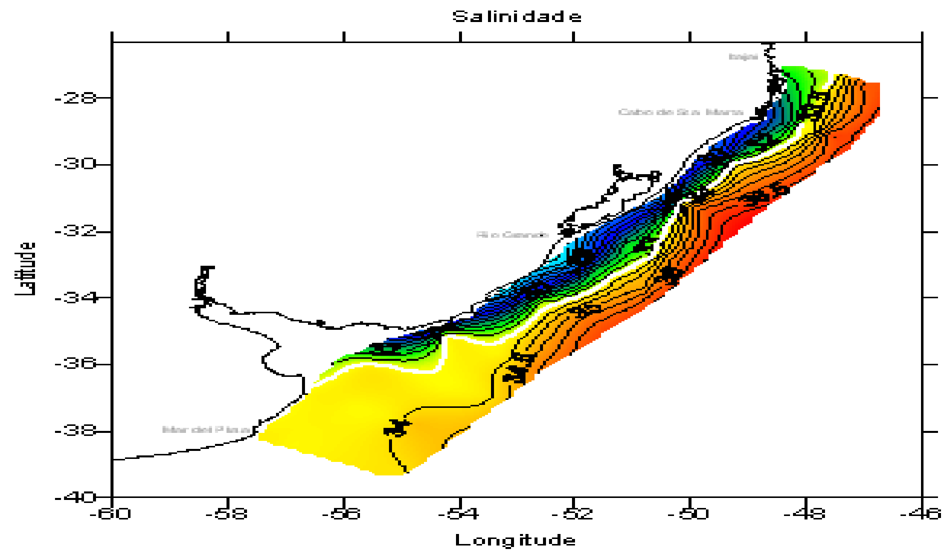
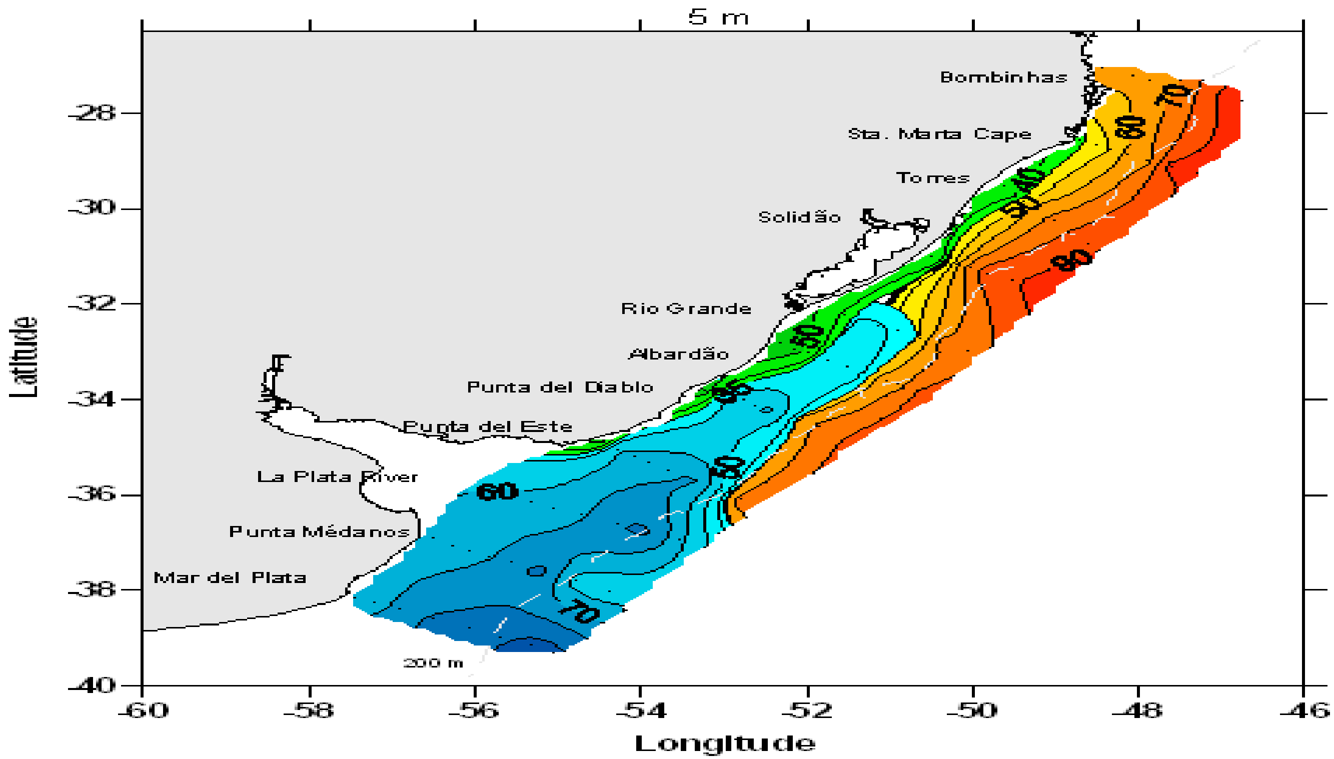
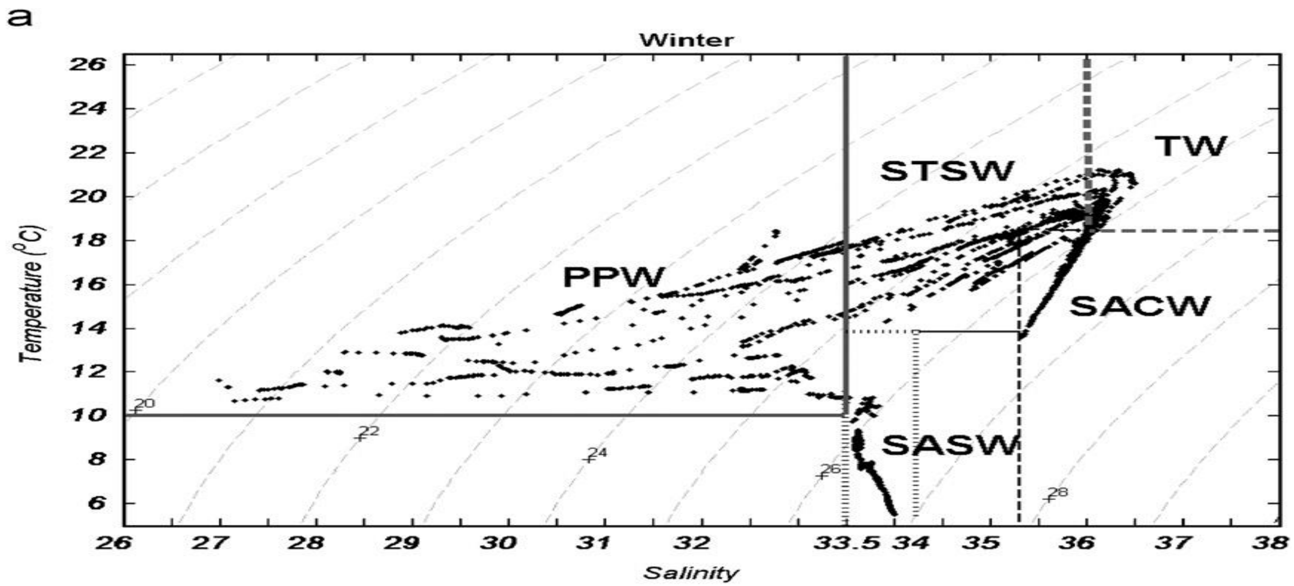


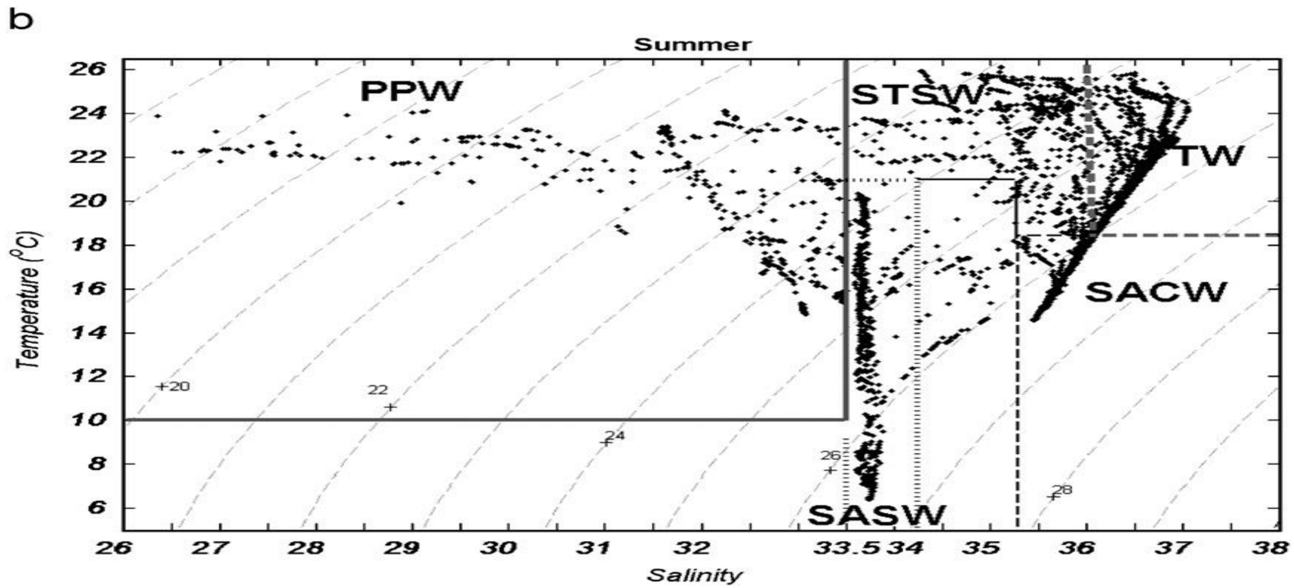
Fig. 25. Triangle of mixing (nomogram for the determination of the percentage content of water masses).


Temperatura
Latitude
Longitude
-28
-30
-32
-34
-36
-38
-40
-60
-58
-56
-54
-52
-50
-48
-46

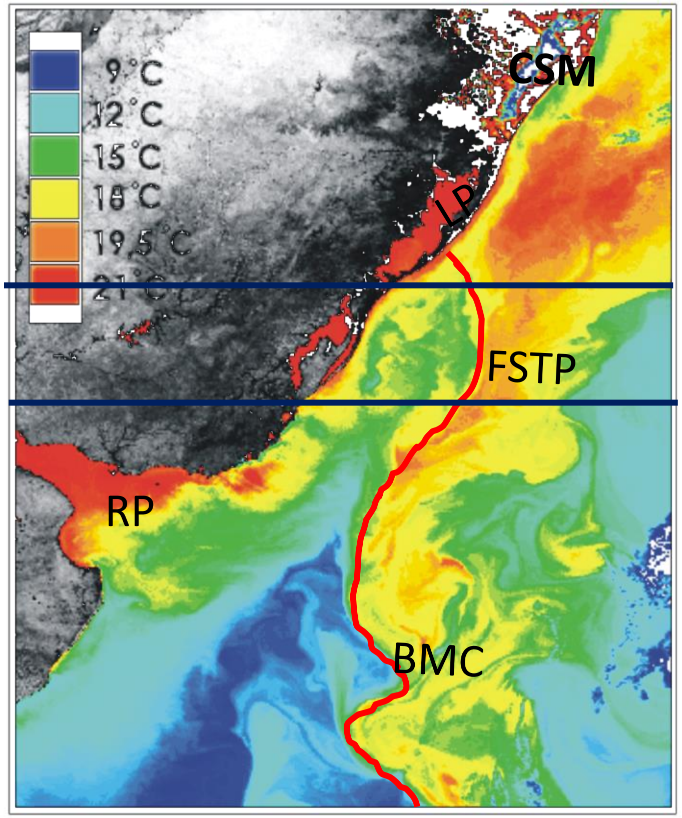

Salinidade
Latitude
Longitude
-28
-30
-32
-34
-36
-38
-40
-60
-58
-56
-54
-52
-50
-48
-46

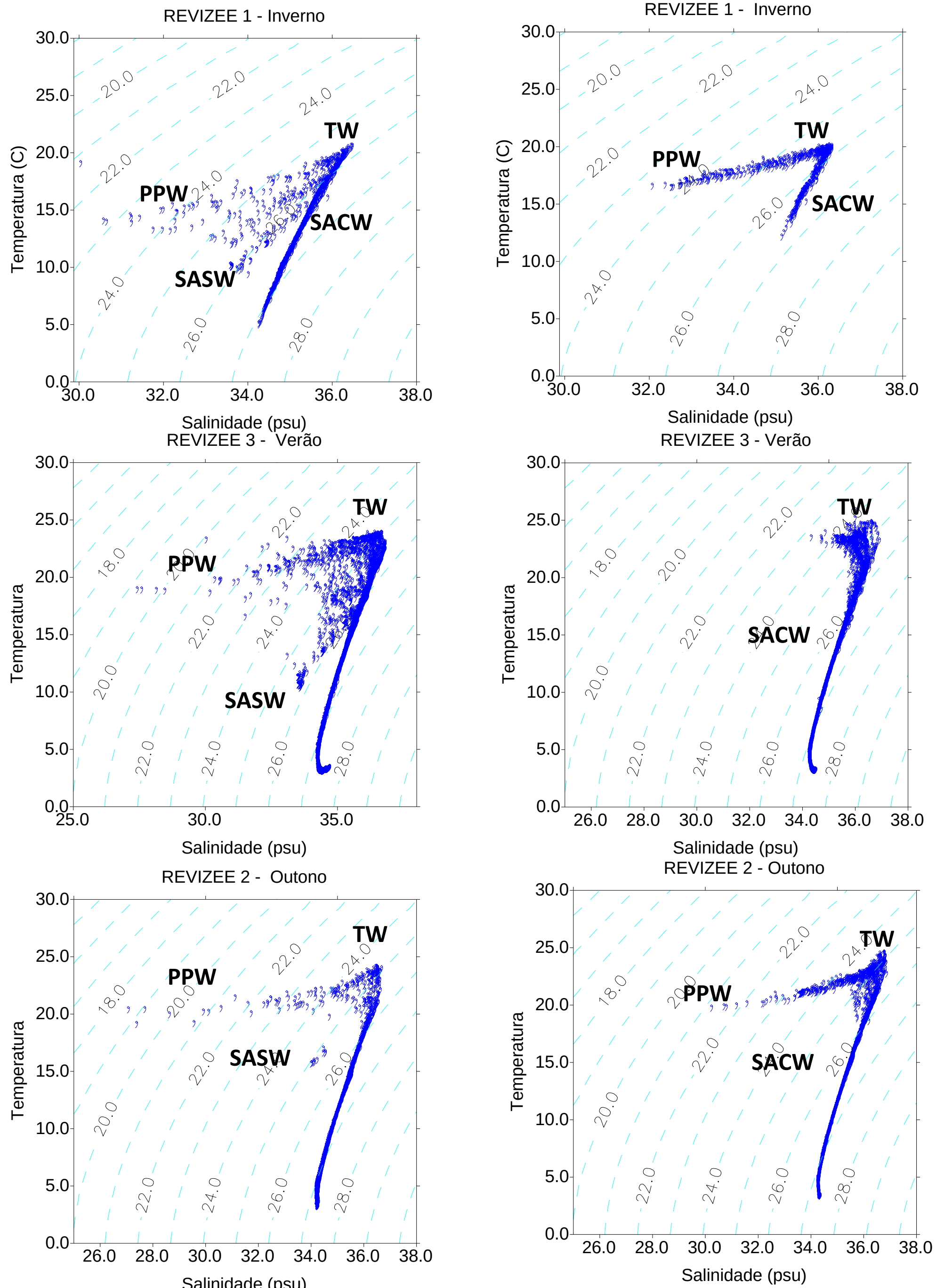

5 m
Bombinhas
Sta. Marta Cape
Torres
Solidão
Rio Grande
Albardão
Punta del Diablo
Punta del Este
La Plata River
Punta Médanos
Mar del Plata
200 m
70
60
40
50
80
50
65
60
50
70
Latitude
Longitude
-28
-30
-32
-34
-36
-38
-40
-60
-58
-56
-54
-52
-50
-48
-46





Möller et al. (2008)

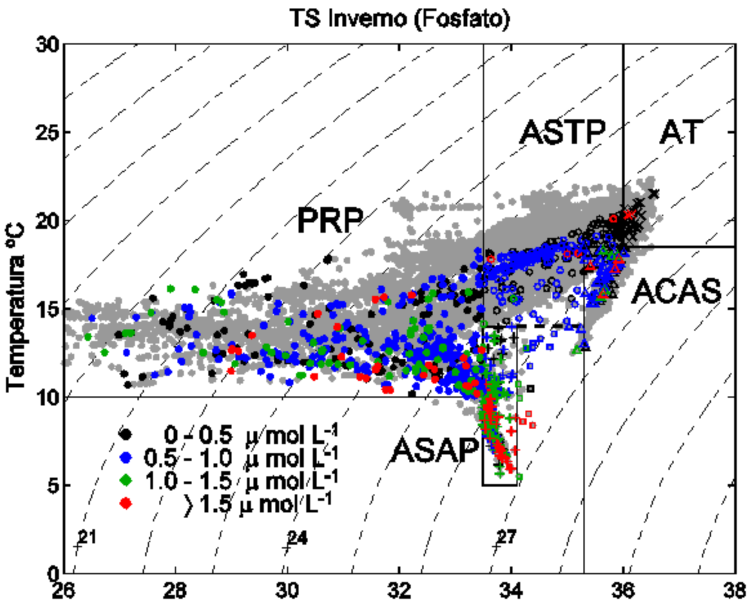


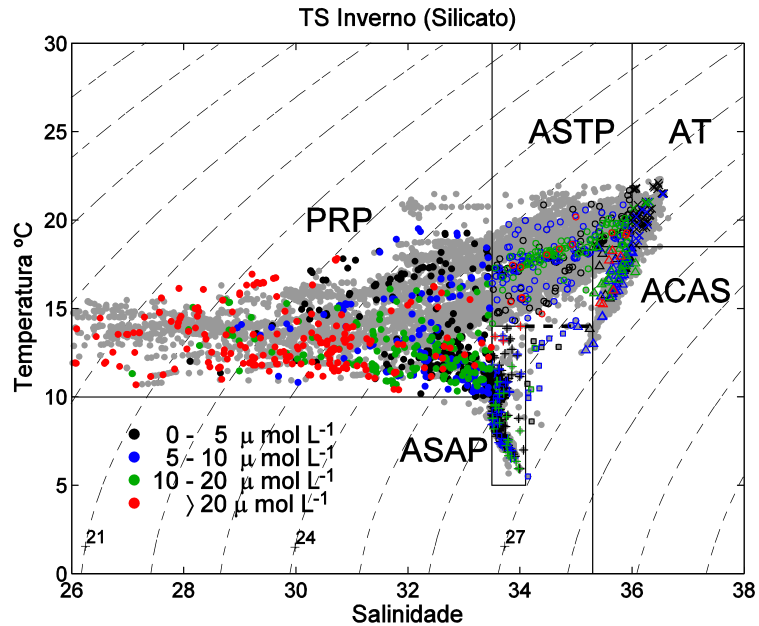


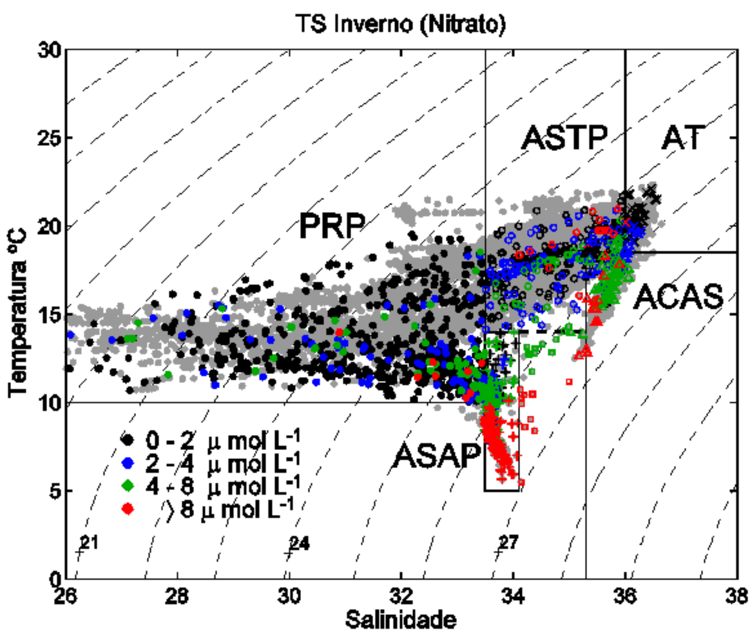
TS Diagrams REVIZEE - project

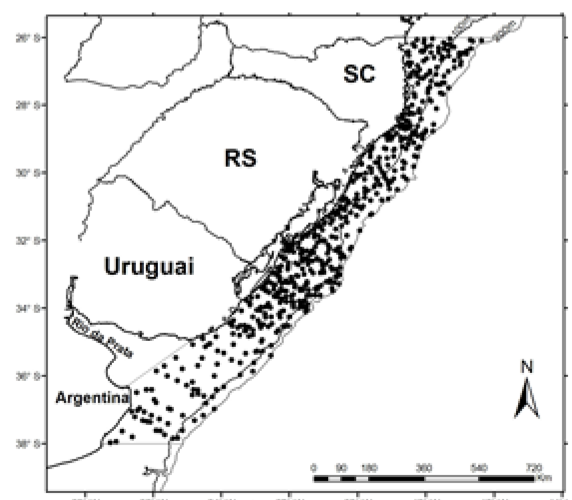
Prof. > 100 m

TS-Diagrams with nutrients for winter

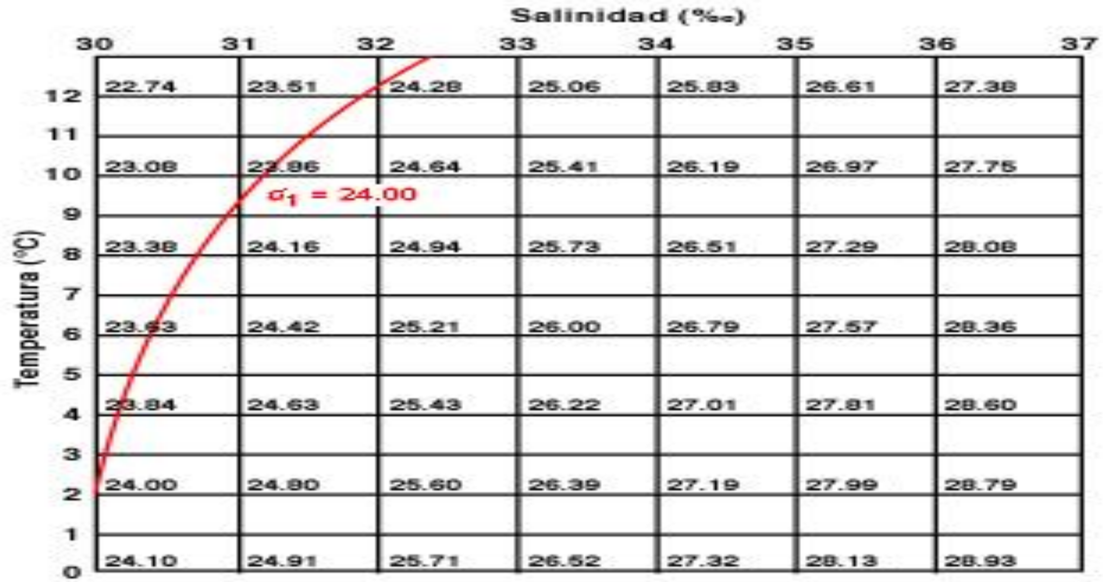


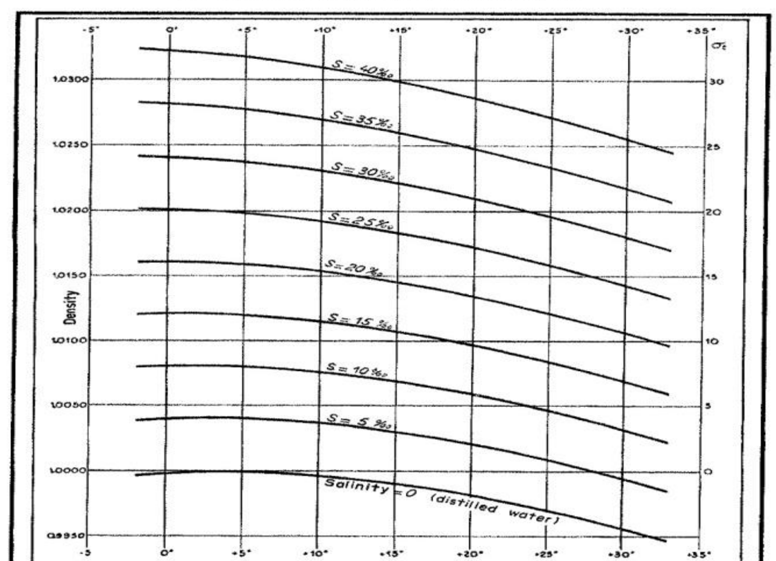




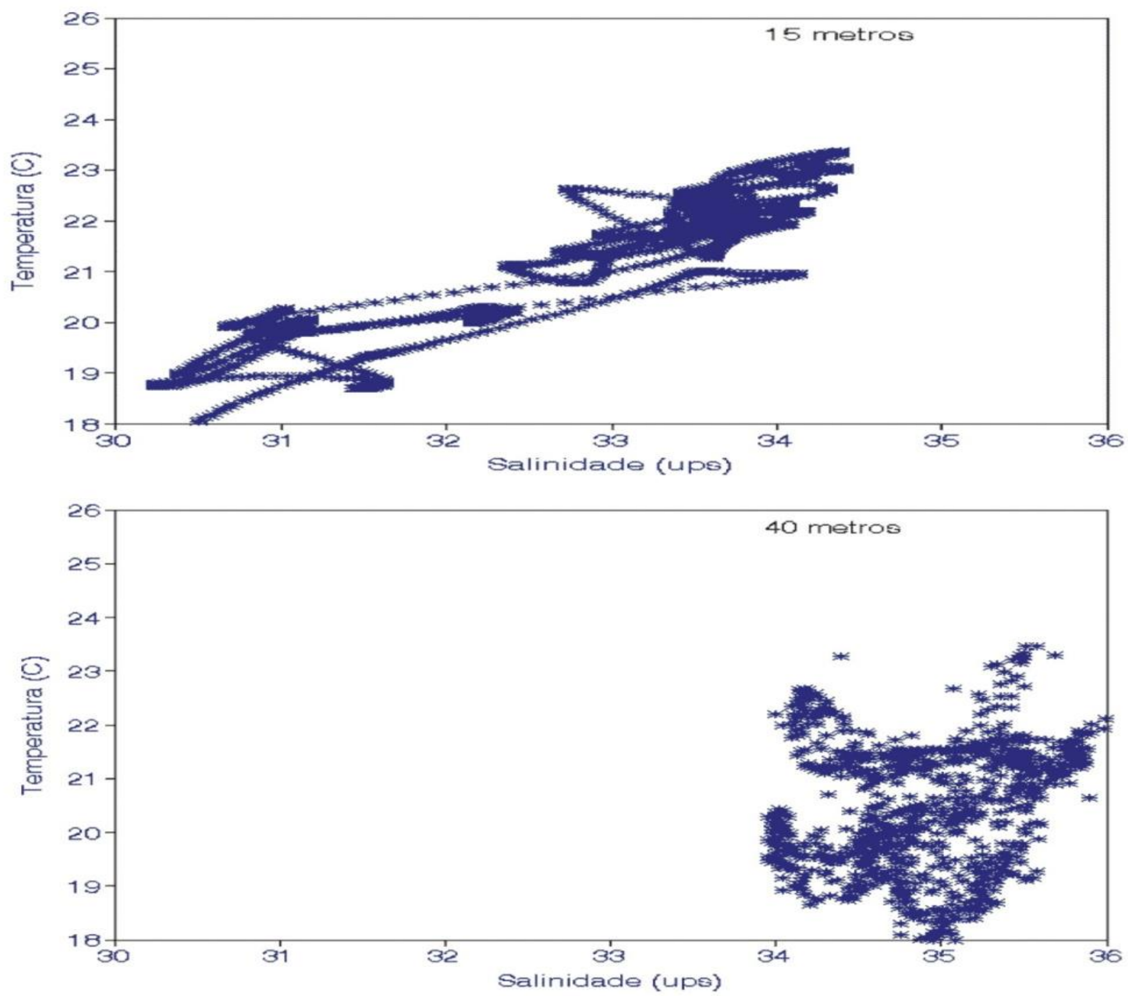


Aseff (2009)



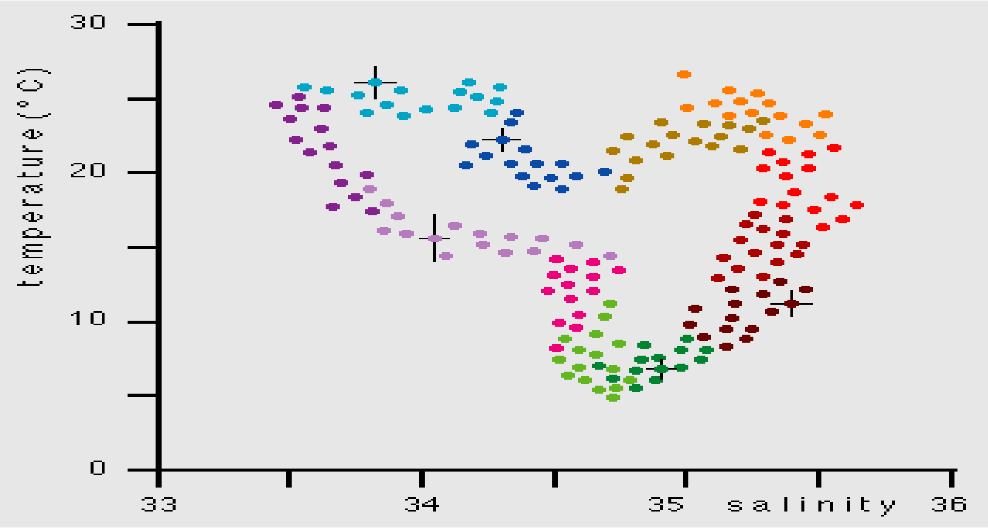


3.3. Density variations as a function of temperature for constant salinities. *T* on the abscissa, *d* and σ_t on the ordinate.

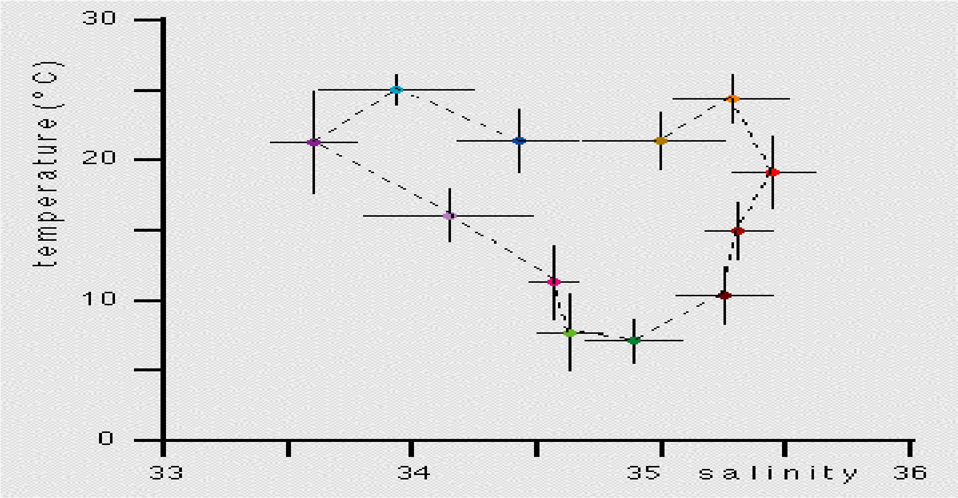


15 metros
Temperatura (C)
Salinidade (ups)
40 metros
Temperatura (C)
Salinidade (ups)

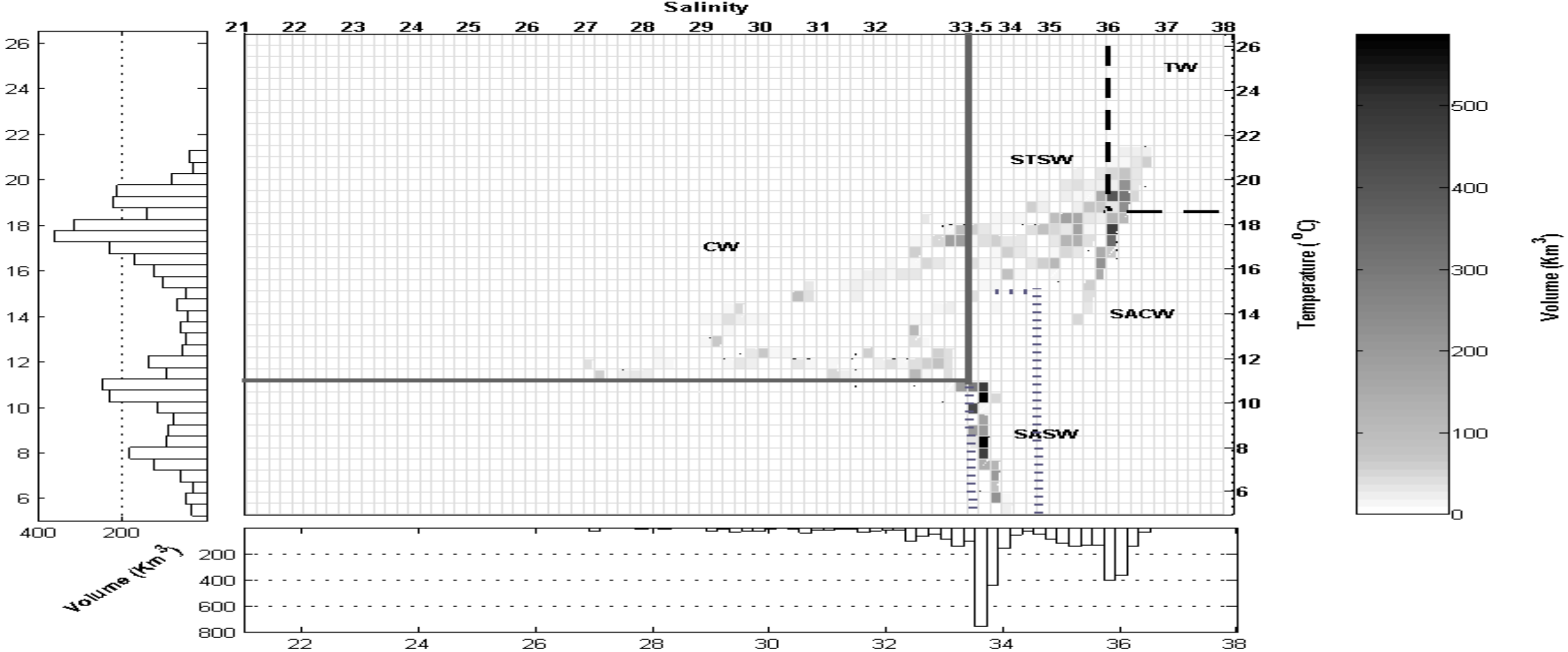
O diagrama TS-time

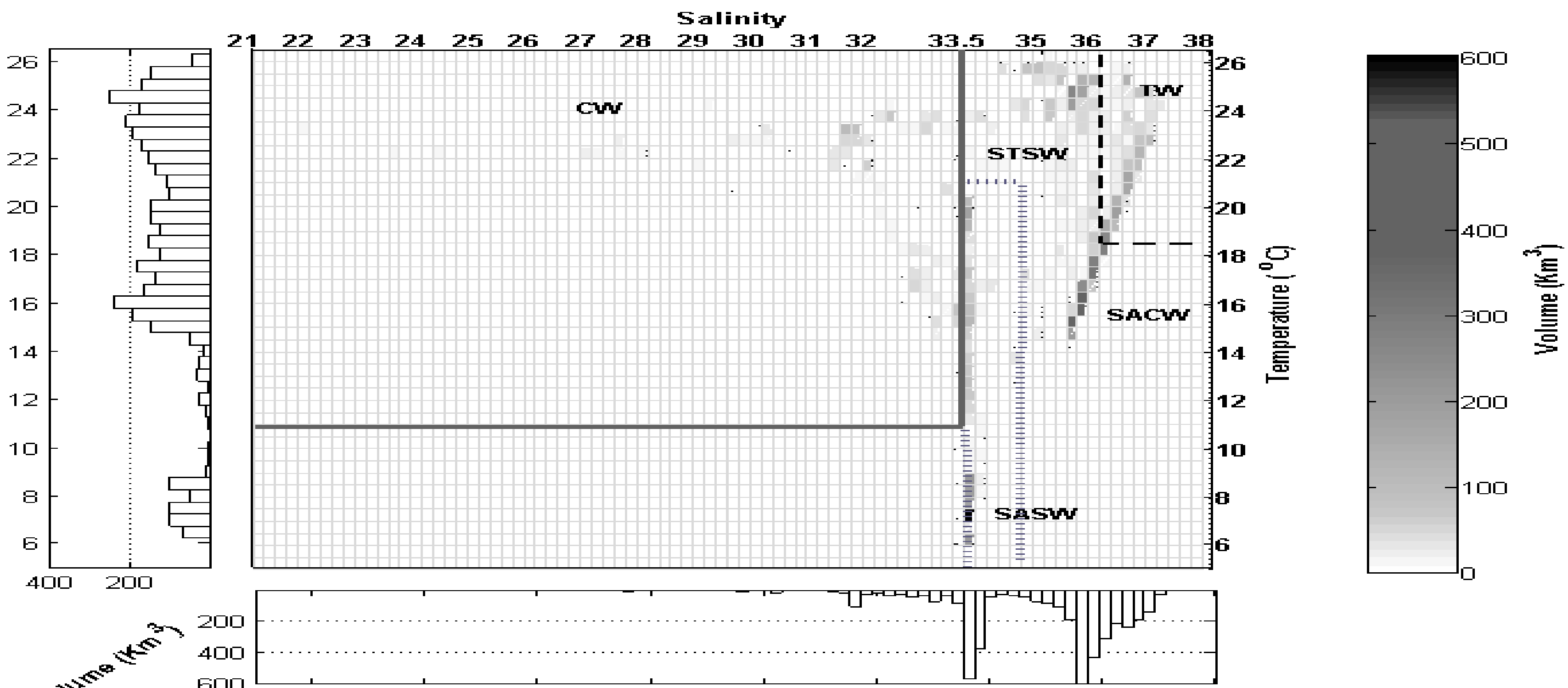


Medidas brutas. Cores indicam a variação temporal



Medias mensais e seus desvios


Salinity
Temperature (°C)
Volume (Km³)
TW
STSW
CW
SACW
SASW


Salinity
Temperature (°C)
Volume (Km³)
TW
CW
STSW
SACW
SASW

Water Mass	**Winter**		**Summer**	
	Termohaline Interval	% of Total Volume (*14.285 km³*)	Termohaline Interval	% of Total Volume (*14.338 km³*)
CW/PPW	T>11º C & S≤33.5	**23**	T>11º C & S≤33.5	**15**
TW	T ≥18.5ºC & S≥36	**8**	T ≥18.5ºC & S≥36	**21**
STSW	T >15ºC & 33.5<S<35.5 T >18ºC & 35.5<S<36	**25**	T >18ºC & 34.5<S<36 T >21ºC & 33.5<S<34.5	**22**
SASW	T≤14ºC & 33.5<S≤34.5	**31**	T≤21ºC & 33.5<S≤34.5	**23**
SACW	T≤18.5ºC & S≥35.5	**13**	T≤18.5ºC & S≥35.5	**19**

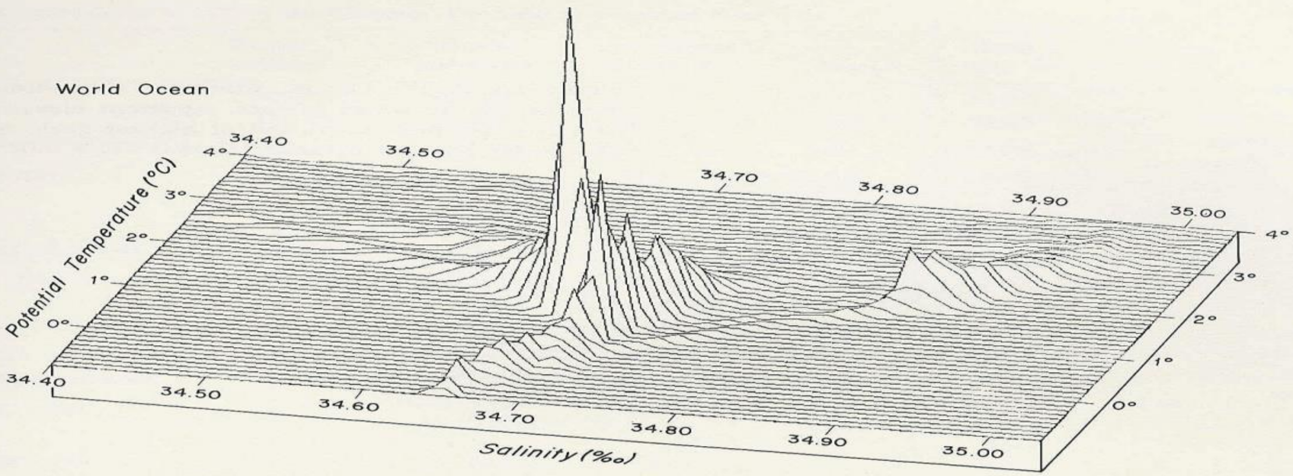


Figure 2.2 Simulated three-dimensional T–S diagram of the water masses of the world ocean. Apparent elevation is proportional to volume. Elevation of highest peak corresponds to 26.0×10^6 km^3 per bivariate class 0.1°C × 0.01‰.

Other Tracers

I have illustrated the core method using salinity as a tracer, but many other tracers are used. An ideal tracer is easy to measure even when its concentration is very small; it is conserved, which means that only mixing changes its concentration; it does not influence the density of the water; it exists in the water mass we wish to trace, but not in other adjacent water masses; and it does not influence marine organisms (we don't want to release toxic tracers).

Various tracers meet these criteria to a greater or lesser extent, and they are used to follow the deep and intermediate water in the ocean. Here are some of the most widely used tracers.

Salinity is conserved, and it influences density much less than temperature.

Oxygen is only partly conserved. Its concentration is reduced by the respiration by marine plants and animals and by oxidation of organic carbon.

Silicates are used by some marine organisms. They are conserved at depths below the sunlit zone.

Phosphates are used by all organisms, but they can provide additional information.

^3He is conserved, but there are few sources, mostly at deep-sea volcanic areas and hot springs.

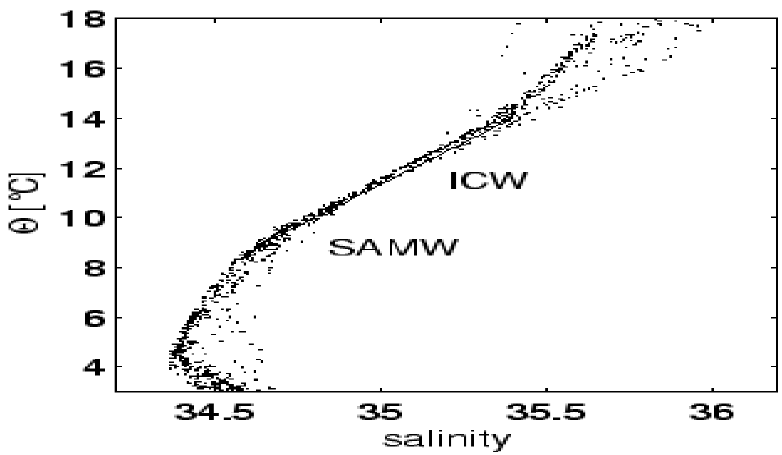
^3H (tritium) was produced by atomic bomb tests in the atmosphere in the 1950s. It enters the ocean through the mixed layer, and it is useful for tracing the formation of deep water. It decays with a half life of 12.3 yrs and it is slowly disappearing from the ocean. Figure 10.15shows the slow advection or perhaps mixing of the tracer into the deep north Atlantic. Note that after 25 years little tritium is found south of 30°N. This implies a mean velocity of less than a mm/s.

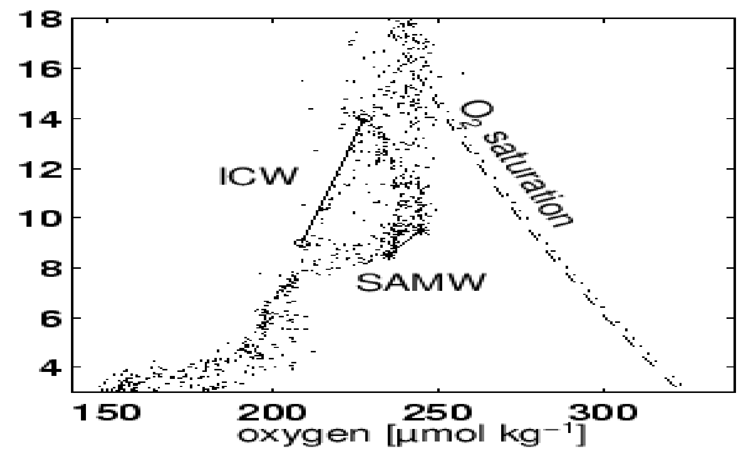
Fluorocarbons (Freon used in air conditioning) have been recently injected into atmosphere. They can be measured with very great sensitivity, and they are being used for tracing the sources of deep water.

Sulphur hexafluoride SF_6 can be injected into sea water, and the concentration can be measured with great sensitivity for many months.

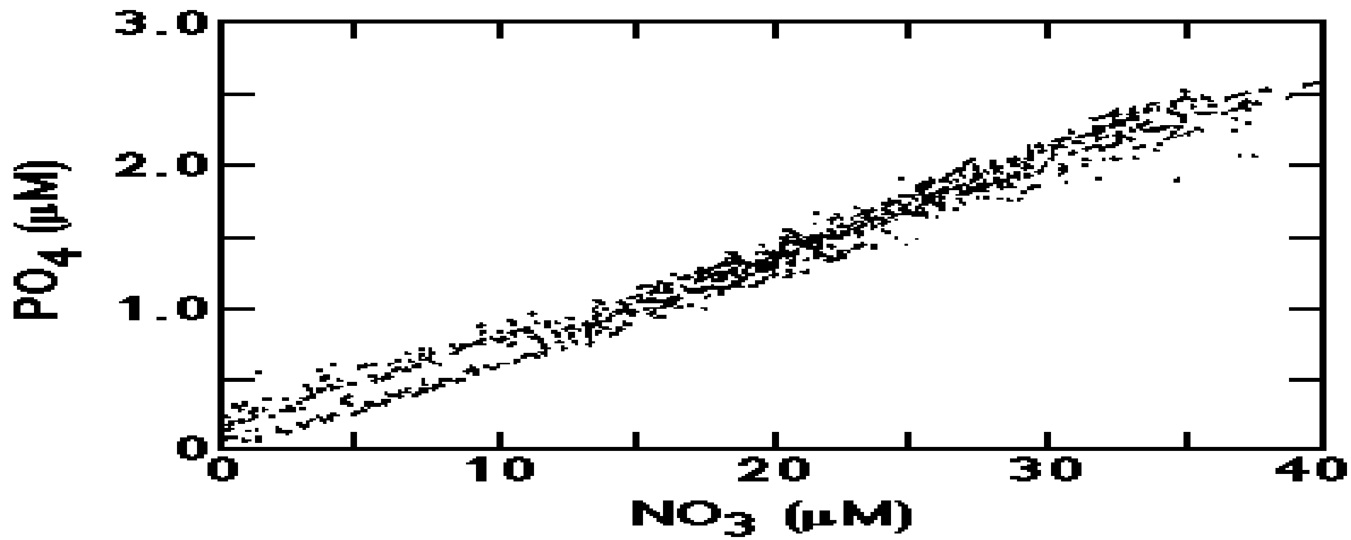
Each tracer has its usefulness, and each provides additional information about the flow.

Outros diagramas de propriedades

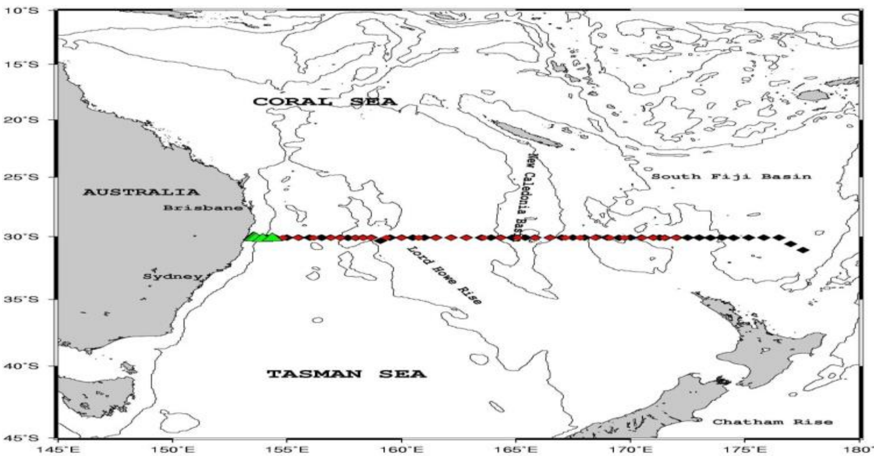


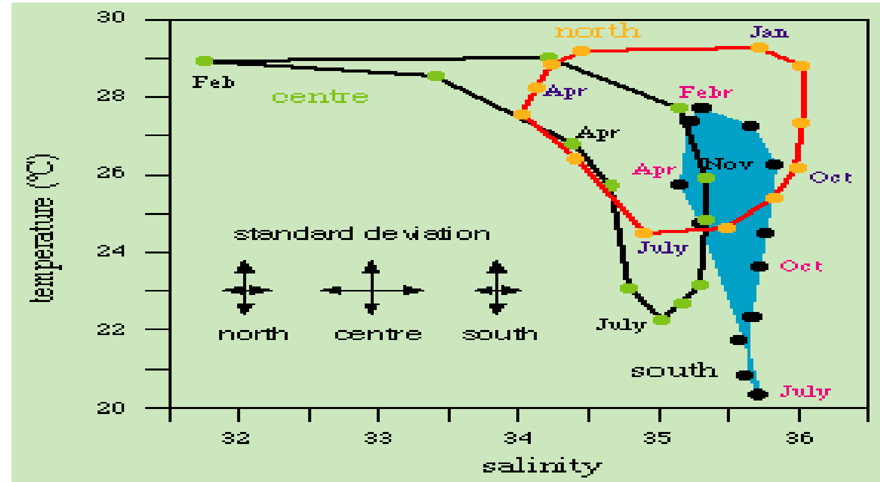


Fonte: Johannes Karstensen

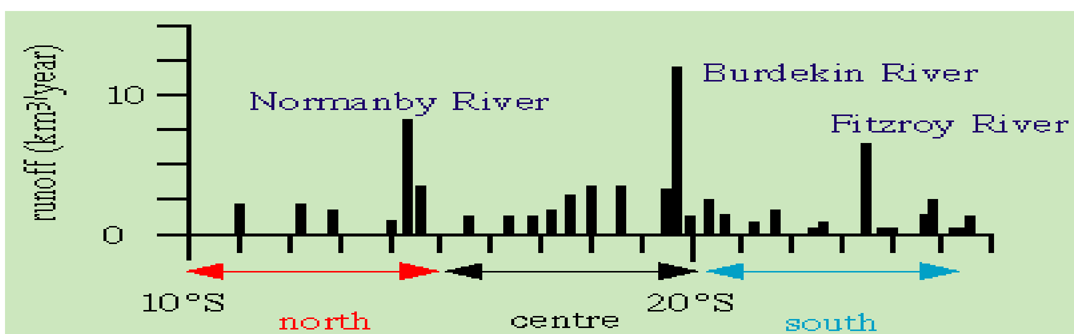


Estudo de caso utilizando um diagrama TS-time: da lagoa da Grande Barreira de Coral





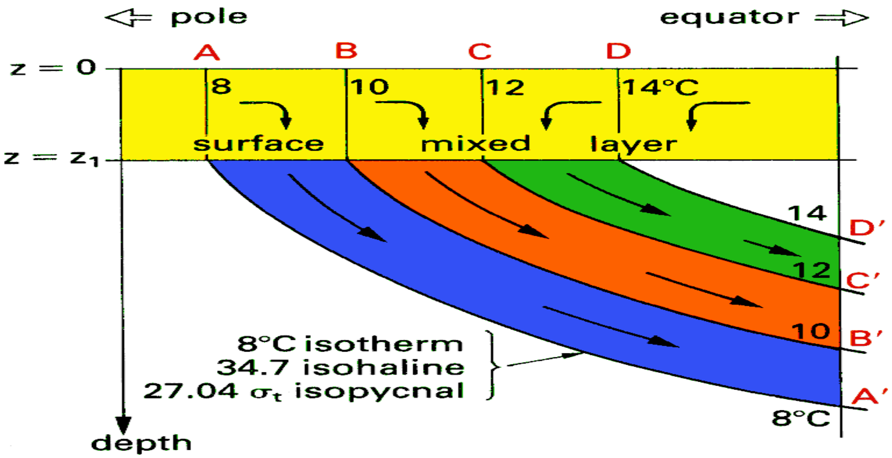
Water mass definitions (TS-time diagrams) for the southern, central and northern regions of the Great Barrier Reef lagoon. The regions are defined as north = 10 - 15°S, centre = 15 - 20°S, south = 20 - 25°S. Standard deviations are not given for every month but for the ensemble of TS-data in each region. Adapted from Pickard (1977).



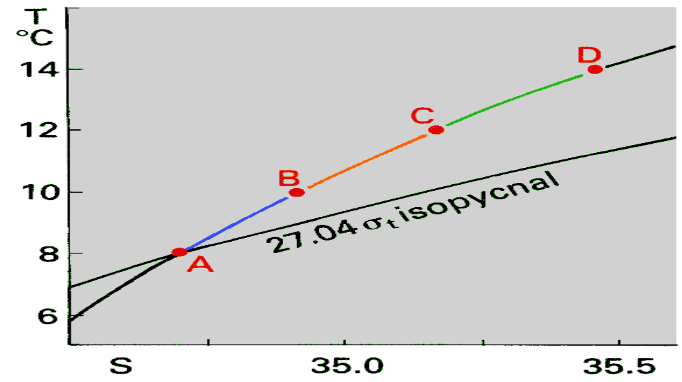
Mean freshwater input from land in the Great Barrier Reef lagoon. Adapted from Pickard (1977).

Formação de massas de água

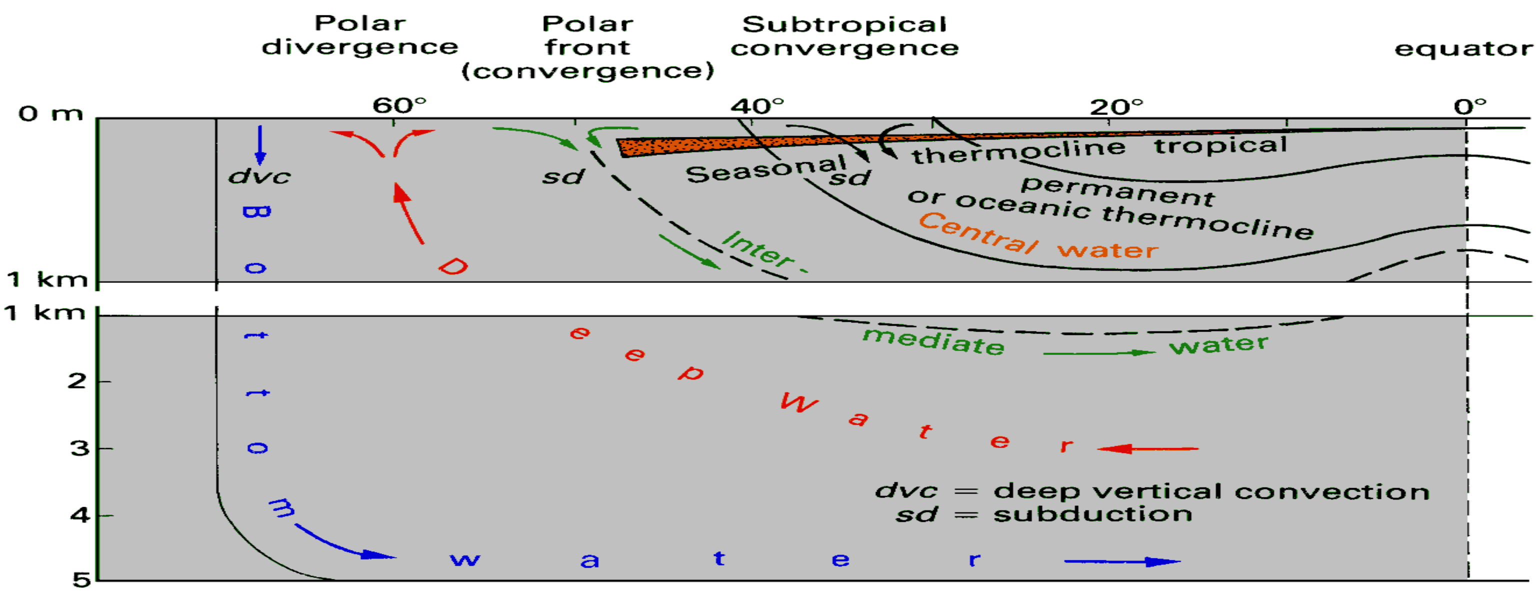
- Subducção: Águas Centrais e Águas intermediárias;
  - É o processo pelo qual as massas de água são injetadas em profundidades maiores <u>seguindo</u> as mesmas isopicnais da região da sua formação.
- Convecção profunda: Águas Profundas e Águas de Fundo
  - É resultado da formação, em camadas superficiais de uma água bem mais densa que a camada inferior favorecendo o desenvolvimento de forte circulação vertical.



pole
equator
A
B
C
D
z = 0
z = z1
8
10
12
14°C
surface
mixed
layer
14
D′
12
C′
10
B′
A′
8°C
8°C isotherm
34.7 isohaline
27.04 σt isopycnal
depth



T
°C
14
12
10
8
6
S
35.0
35.5
A
B
C
D
27.04 σt isopycnal



Polar divergence
Polar front (convergence)
Subtropical convergence
equator
0 m
60°
40°
20°
0°
1 km
1 km
2
3
4
5
dvc
sd
sd
Seasonal
thermocline
tropical
permanent or oceanic thermocline
Central water
Intermediate water
Deep Water
Bottom water
dvc = deep vertical convection
sd = subduction

PIRATAS DO TIETE - Laerte