OCEANOGRAPHIC CONDITIONS AT THE SOUTHERN END OF THE ARGENTINE CONTINENTAL SLOPE*

by

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RESUMEN

Condiciones oceanográficas en el extremo austral del talud continental argentino. Se analizan las características del estrato superior del Agua Intermedia Antártica entrante al Atlántico Sur, sobre la base de datos oceanográficos observados en cuatro períodos de fines de invierno (1978, 1980, 1994 y 1995). Se analiza el régimen de los primeros 500 metros de la columna de agua a lo largo del talud continental y alrededor de las Islas Malvinas, entre 48° y 55°S. Con el objeto de mostrar los patrones de distribución de temperatura, salinidad y densidad se presentan mapas de distribución horizontal de dichos parámetros observados en 1994. Se describen también, para los años 1994 y 1995, tres secciones de salinidad ubicadas estratégicamente en el canal de Malvinas mostrando la estratificación de las aguas entrantes y circulantes al sur de las islas. La distribución horizontal y vertical de clorofila 'a' observada en 1995 es presentada con el objeto de dar mediciones de referencia de este parámetro. Por último se discute la variabilidad inter-anual del contenido de calor para dos áreas de 5°x 5°, al Este y al Oeste de las islas, mediante la comparación del valor medio de la temperatura superficial de mar de los cuatro años. El invierno de 1995 resultó ser el más frío con anomalías térmicas mayores a -0.4 °C en relación a los otros tres años.

SUMMARY

The characteristics of the upper Antartic Intermediate water (AAIW) entering the Southern Atlantic are described on the base of oceanographic data collected from four late austral winters (1978-1980-1994-1995). The upper 500 meters regime along the shelf break and around Malvinas Islands (48º to 55º S) is analyzed. In particular, the 1994 horizontal distribution of temperature, salinity and density was mapped in order to show the extreme winter pattern of these parameters. Three salinity sections crossing the water flow direction in the Malvinas Channel (South to the islands) were selected to

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describe the vertical stratification 1995 and 1995. Horizontal and vertical distribution of chlorophyll a from the 1995 cruise is presented as reference data, considering the lack of information on this parameter for the area. Finally, the inter-annual variability of the heat content in two 5º x 5º areas (East and West to the islands) is discussed by comparing the Sea Surface Temperature (SST) data between the four sampled years. From this information, 1995 resulted in the coolest winter, presenting a temperature anomaly around -4º C respect to the other winters.

Key words: Antarctic intermediate water, Argentine shelf break, South Western Atlantic.
Palabras claves: Agua intermedia antártica, talud continental argentino, Atlántico Sudoccidental.

INTRODUCTION

A cool and low salinity layer originated at subpolar regions characterises water masses at intermediate levels of southern oceans (Wüst, 1935; Deacon, 1933, 1937; Sverdrup, 1934, 1940). This water mass is commonly identified as Antarctic Intermediate Water (AAIW). It is formed at the Antarctic Polar Front of the southeast Pacific, Drake Passage, southwest Atlantic and surrounding regions (McCartney, 1977; Molinelli, 1978; Molinelli, 1981). Starting from this zone, it is carried northward by the Malvinas Current along the South America Continental slope. At its origin, the Malvinas Current is a 400 m thick layer with temperature ranging from 3.5 to 5° C and an almost constant salinity of 34.2 PSU (Gordon *et al.* 1977; Jacobs and Georgi, 1977; Molinelli, 1978, 1981; Piola and Gordon, 1989). This water flows out of the Scotia Basin through two major openings in the Scotia Ridge, west and east to the Burdwood Bank. Due to its shallowness, the western channel allows waters from the upper layer (density range 27.05 to 27.15 kg m^{-3}) to come in the Malvinas Channel. The eastern channel is deeper and permits also the heavier type of the AAIW (density range 27.15 to 27.3 kg m^{-3}) to enter. After entering the Malvinas Channel it surrounds the east side of the Malvinas Islands, following the sloping edge of the Argentine Continental Shelf (200 to 1000 m isobaths). North to the islands, it flows northward along the continental slope until it encounters the Brazil Current, defining the subtropical confluence. Piola and Gordon (1989) indicated that Antarctic Intermediate Waters undergo modifications of the lighter type (27.05 to 27.20 kg m^{-3}) by winter air-sea interaction on its northward flowing to the Argentine Basin. In particular, they associate the 27.0/27.1 σ_t range to the upper 300 m in the surroundings of Burdwood Bank and Malvinas Islands for the winter period.

In this paper, the winter conditions for the upper stratum of the AAIW passing through the Malvinas Channel in the south east region of the Argentine Continental shelf, are described. The thermohaline conditions for the upper 500 m under cool vertical convection, is discussed.

Geomorphology of the area

Figure 1 presents the main topographic characteristics of the studied area. The 200 m isobath defines four emerging morphologic features: Malvinas Islands, Burdwood Bank, Isla de los Estados and the Argentine Continental Shelf. The Malvinas Channel extends in a west-east direction, separating the Malvinas Plateau and the Northern Scotia Ridge, both extending eastward. The bathimetry increases toward the east in the channel, with depths from 400 m at the west margin to 3000 m at 56° W. Along the Scotia Ridge and between Isla de los Estados and Burdwood Bank an 80 km wide and 400 m deep channel connects the Scotia Basin with the Malvinas Channel. Another opening along the Scotia Ridge connects the Malvinas Channel and the Scotia Basin, east to Burdwood Bank. Centered at 55° W, this channel is 130 km wide and as deep as 1800 m. Both channels, west and east to Burdwood Bank, are the entrance for the Malvinas Current that drives AAIW northwards in the upper 800 m (Piola and Gordon, 1989). The shallow western channel allows the passage of the lighter type of this water mass formed at subantarctic regions. This waters were identified as Subantarctic Mode Water (SAMW) (McCartney, 1977, 1982), or the warmer thermocline isohaline water defined by Molinelli (1978). The eastern channel is the entry of the heavier type of AAIW formed at the Polar Front under a stronger antarctic influence (Jacobs and Georgi, 1977; Molinelli, 1981; Georgi, 1979; Piola and Georgi, 1982).

West to the 200 m isobath, the continental shelf

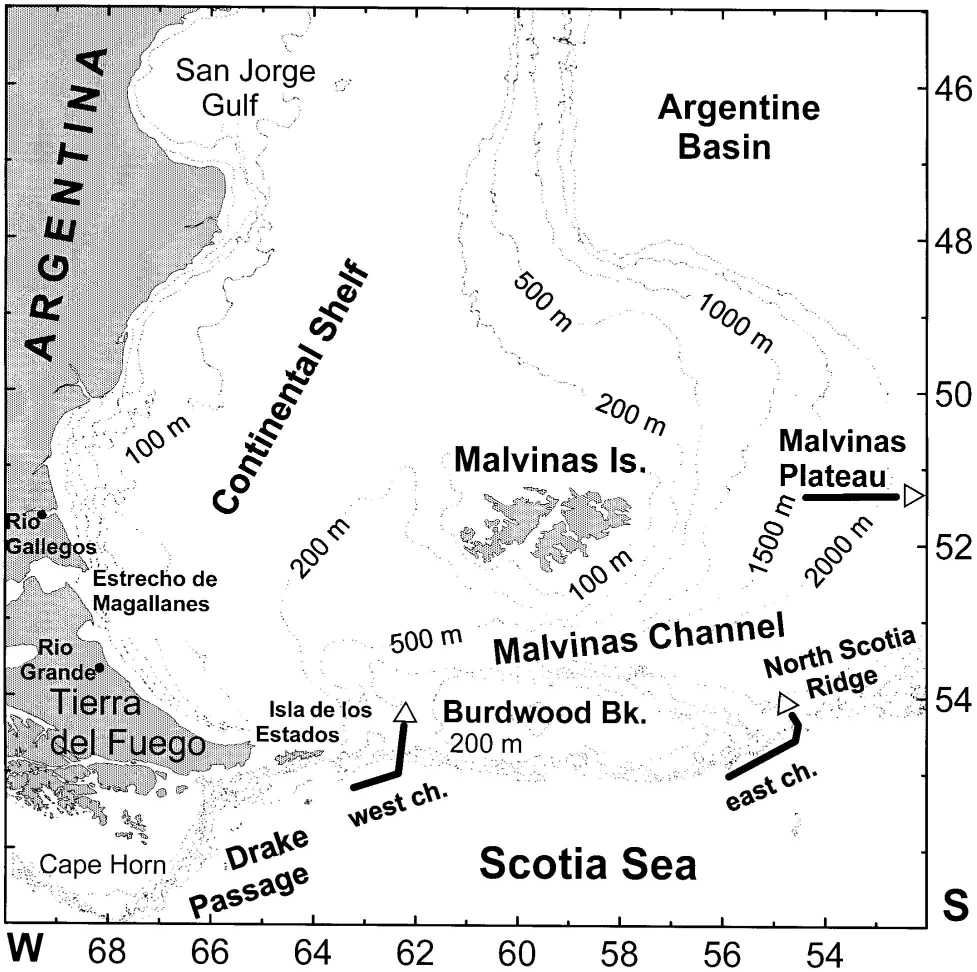

Figure 1. Main topographic features in the studied area.
Figura 1. Caraterísticas topográficas principales del área de estudio.

can be divided into a 100 km band along the coast where depth increases down to 100 m (1 m/km tilt) and a wide plain (250 to 450 km) with a smoother increase in depth towards the 200 m isobath, where slope decreases in the order of 2.5 to 4.5 m/km.

DATA AND METHODS

In order to characterise the winter and late winter conditions and its variability in the area, several cruises during this period were analyzed. Table I summarized the employed data and figure 2 shows the stations distribution.

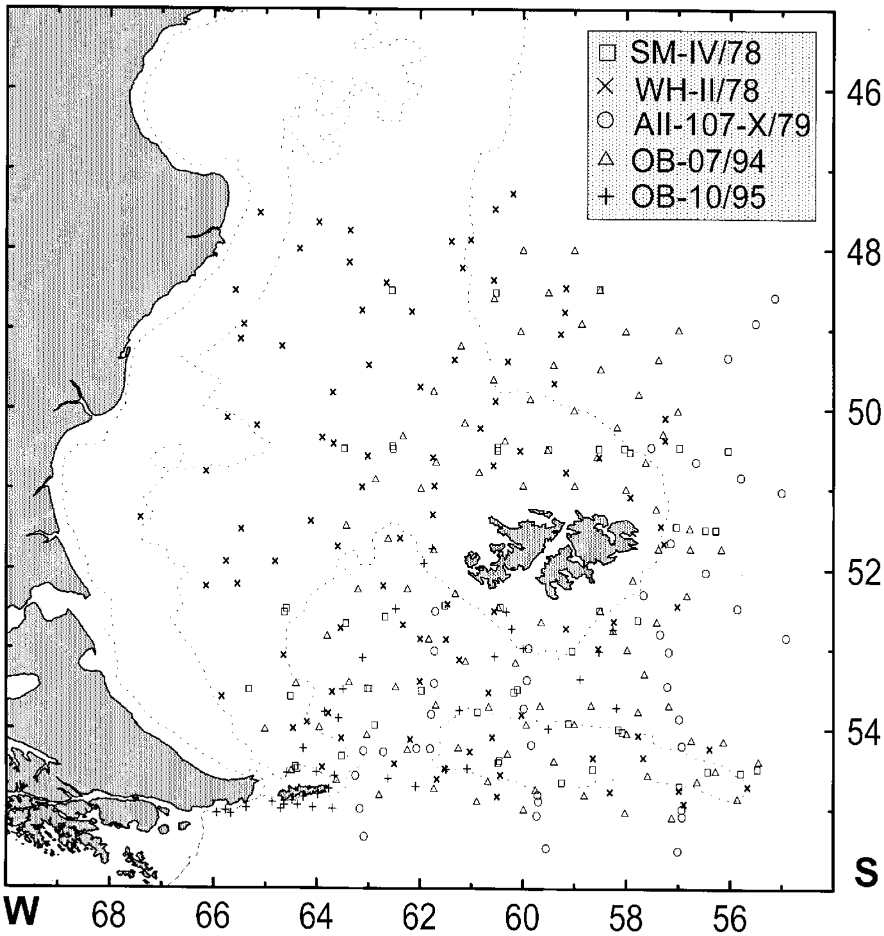

Figure 2. Station distribution for cruises SM-IV/78: Shinkai Maru, leg IV (August, 1978), WH-II/78: Walther Herwig, leg II (August, 1978), AII-107-X/79: Atlantis II-107. Leg X (August, 1979), OB-07/94: Oca Balda, leg 07 (September, 1994) and OB-10/95: Oca Balda, leg 10 (September, 1995).

Figura 2. Distribución de estaciones de las campañas SM-IV/78: Shinkai Maru, pierna IV (Agosto de 1978), WH-II/78: Walther Herwig, pierna II (Agosto de 1978), AII-107-X/79: Atlantis II-107. Pierna X (Agosto de 1979), OB-07/94: Oca Balda, pierna 07 (Septiembre de 1994) y OB-10/95: Oca Balda, pierna 10 (Septiembre de 1995).

Oceanographic data were collected with Nansen bottles at standard levels in cruises SM-IV/78 and WH-II/78. Additionally, sea surface temperatures (SST) from each trawl stations of the Shinkai Maru cruise were used. Conductivity-Temperature-Depth profilers (CTD) were the data source in the other cruises. A Neil Brown MKIII CTD was used in Cruise AII-107/X (Georgi *et al.*, 1981), while data in OB cruises were collected with a ME Kiel Multisonde CTD. Not reported yet, data from the latter two cruises are preliminary, with a precision of ± 0.015°C in temperature and ± 0.009 UPS in salinity.

Temperature, salinity and density isopleths charts for the surface and 500 m levels from cruise OB-07/94 were analyzed. The 500 m level was constructed with data from this level and bottom values when depth was less than 500 m. In order to describe the vertical stratification of the water column, three vertical sections from cruises OB-07/94 y OB-10/95 (Figure 7 and 8) were also studied.

Light penetration was measured with a LI-192 SB Lambda Licor underwater quantum sensor. Water samples for pigments analysis were obtained with 5 liter. Niskin bottles or a clean plastic bucket (surface). Sampling depths were selected according to light penetration, using the 1%, 10%, 25%, 50% and 100% (surface) of the light coming to the surface. 1 liter. sub-samples were filtered through Whatman GF/F glass fiber filters, and chlorophyll "a" was measured by fluorescence with a Perkin-Elmer LS-3 spectrofluorometer (Holm-Hansen, *et al.* 1965).

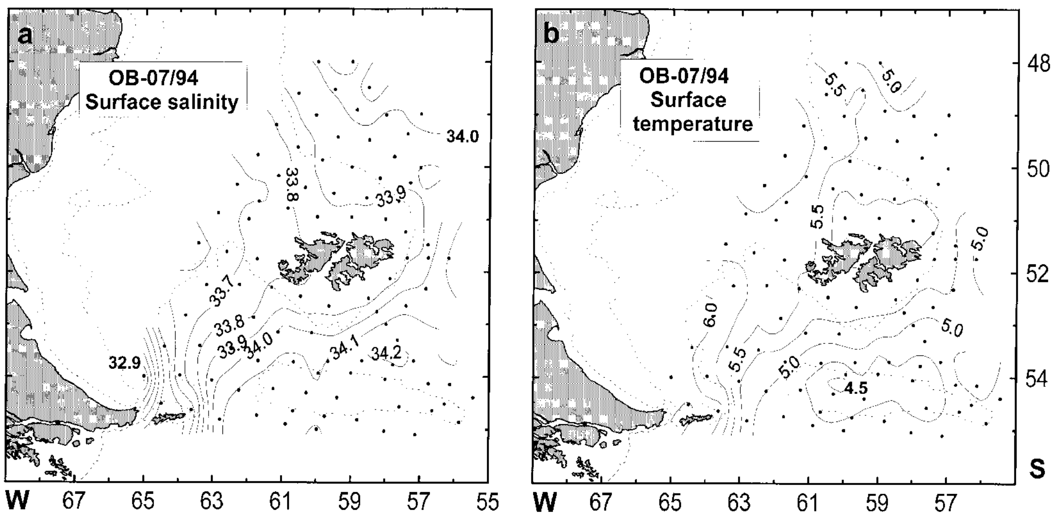

Figure 3. Surface salinity (a) and temperature (b) field from cruise OB-07/94, characterizing the late winter condition (September).

Figura 3. Campo de salinidad (a) y temperatura (b) de superficie durante la campaña OB-07/94, caracterizando la condición de fines de invierno (Septiembre).

RESULTS

Properties distribution on 1994

Figure 3a, shows the salinity surface distribution of the water entering the Malvinas Channel, between Tierra del Fuego and Burdwood Bank. It spreads into two branches, one with salinity below 33.8 UPS that moves northward, west to Malvinas Islands and a second branch with salinity above 33.9 UPS, that runs eastward, around the islands, following the bathimetry. Horizontal gradients are strong east and north to Isla de los Estados, as a result of the mix of slope water and fresh water from Beagle Channel and Cape Horn continental shelf (Krepper, 1977; Krepper and Rivas, 1979; Bianchi *et al.*, 1982). The rest of the area is characterised by a weak horizontal gradient, presenting the east branch around the islands, slightly stronger gradients. Centered at the 34.0 PSU, this gradient follows the 500 m isobaths (Figure 1 and 3a), crossing the Malvinas Channel, leaving the shallower part of the channel westward (depths lower that 500 m).

The surface temperature field shows a maximum horizontal gradient east to Isla de los Estados, as a result of the convergence of the shelf and slope waters described before. The rest of the area has weak gradients, with less than 1°C differences (figure 3b). Water that goes west to the Malvinas Islands are warmer than 5.5°C and the east branch around the islands is cooler than 5.25°C. The coolest surface temperature is located in correspondence with Burdwood Bank (around 4.5°C).

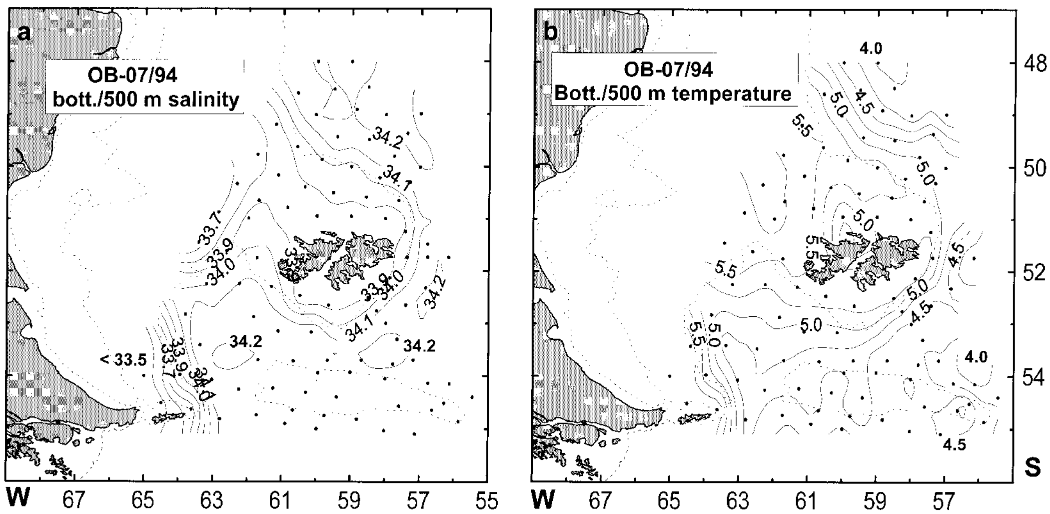

Figure 4. Bottom/500m salinity (a) and temperature (b) field from cruise OB-07/94, characterizing the late winter condition (September).

Figura 4. Campo de salinidad (a) y temperatura (b) de fondo/500m durante la campaña OB-07/94, caracterizando la condición de fines de invierno (Septiembre).

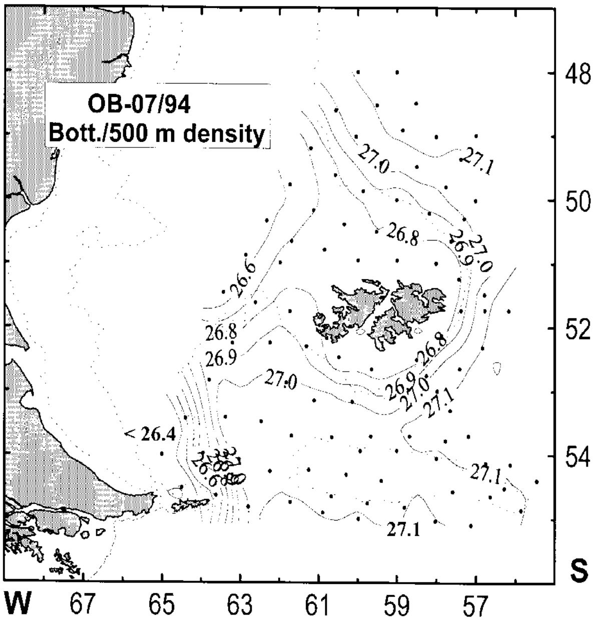

Figure 5. Bottom/500m density field (st) from cruise OB-07/94, characterizing the late winter condition (September).

Figura 5. Campo de densidad (st) de fondo/500m durante la campaña OB-07/94, caracterizando la condición de fines de invierno (Septiembre).

The bottom/500 m isopleths show strong horizontal gradients separating the shelf waters (σt < 26.8) from pure upper AAIW waters (σt from 27.05 to 27.15). A front is defined by T, S and σt following the 200 m isobath (figures 4a, 4b and 5). Maximum gradients are centered at 5°C, 34 PSU and 26.9 in density. Shelf bottom waters are warmer, fresher and lighter, while the heavy, salty and cooler waters define the lighter AAIW (Piola and Gordon, 1989). The property fields show the strongest gradients, east and north to Isla de los Estados, forced by the presence of fresher water from the continental shelf. The front continues northward and clockwise along the slope, following the west end of the Malvinas Channel. At the southern extreme of the Malvinas shelf the maximum gradient turns north and describes an anticyclonic gyre around Malvinas Islands, reaching the western boundary of the Argentine Basin. The whole Malvinas Channel and Burdwood Bank are dominated by the lighter AAIW water mass with S greater than 34.1 PSU and σt ranging from 27.0 to 27.1 kg m^{-3}. Piola and Gordon (1989) found the western side of the Malvinas Channel mainly occupied by the lighter type of AAIW in the depth range from 0 to 300 m (figure 3, from Piola and Gordon, 1989). This density stratum intersects the surface to the east and forms a wedge towards the west side of Malvinas Channel. At its deeper level (300 m), the extent of this wedge is observed as an arc connecting the two tips that close the west sector of the channel. The southern tip is located east to Isla de los Estados and the northern one at the southern shelf break of Malvinas Island. Both references are coincident with the maximum T and S horizontal gradients (figure 4a, 4b, 6 and 7). This density range is mainly supported by the water formed over and around the Burdwood Bank, Scotia Sea and eastern South Pacific (McCartney 1977, 1982; Molinelli, 1978; Molinelli, 1981).

Vertical stratification on 1994 and 1995

In order to describe the vertical stratification of the water column at the area, three sections, from cruises in 1994 and 1995, were analyzed. The section I extends from Isla de los Estados to Burdwood Bank, and shows the incoming flux from the Scotia Sea (figure 6a and 7a). Section II crosses the west end of the Malvinas Channel, from Islas de los Estados to the west side of Malvinas Island (figure 6b and 7b); and section III from Burdwood Bank to the continental shelf break south to Malvinas Island (figures 6c and 7c). Only the salinity field is shown as isolines and mean values for temperature and density are written on each layer.

Section I (figure 6a and 7a) presents the salinity distribution across the west channel in the south end of the area. This channel connects the Scotia Sea

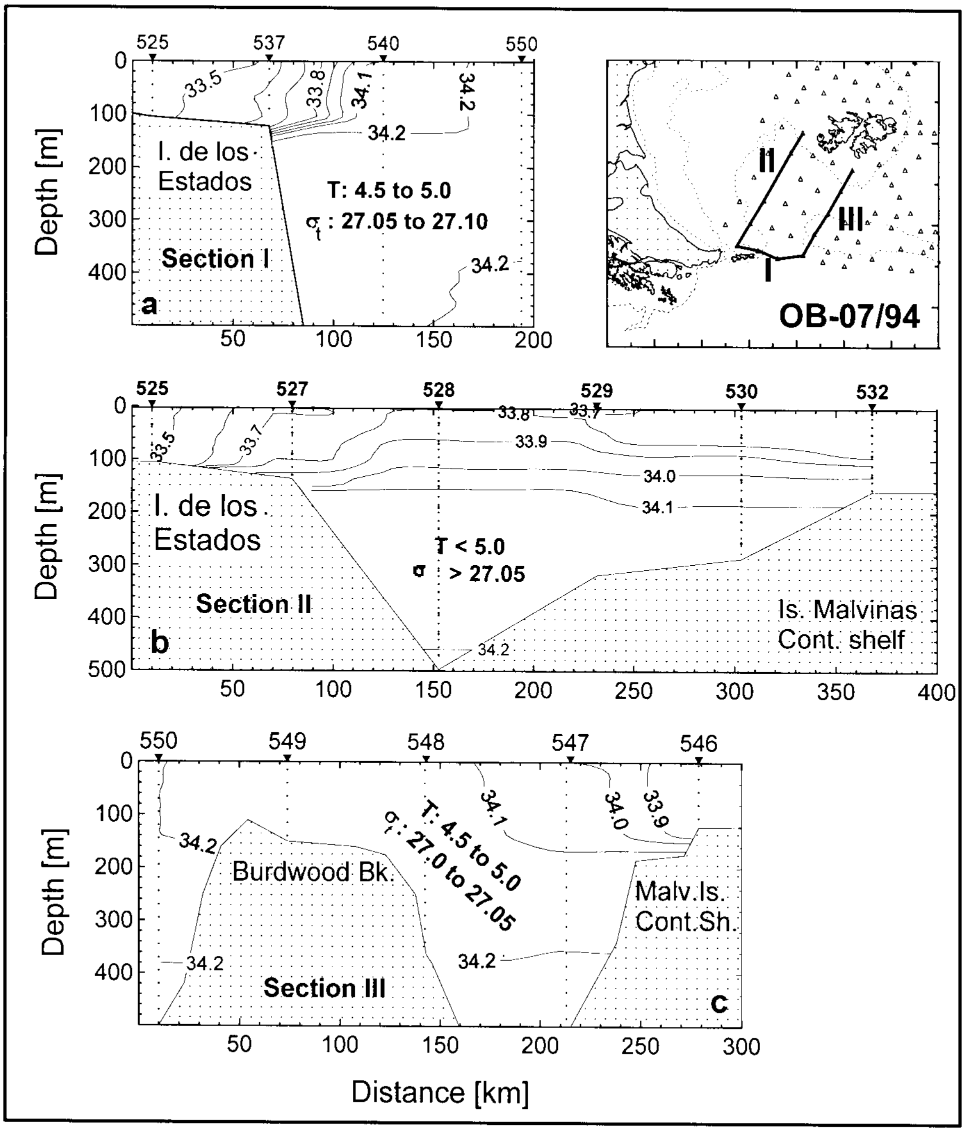

Figure 6. Salinity sections for cruise OB-07/94. a) Isla de los Estados - Burdwood Bank. b) Isla de los Estados - Malvinas Is. Continental shelf. c) Burdwood Bank - Malvinas Is. continental shelf. Temperature (T) and density (st) mean values are included.

Figura 6. Secciones de salinidad para la campaña OB-07/94. a) Isla de los Estados - Banco Burdwood. b) Isla de los Estados - plataforma continental de las Islas Malvinas. c) Banco Burdwood - plataforma continental de las Islas Mavinas. Se incluyen los valores medios de temperatura (T) y densidad (st).

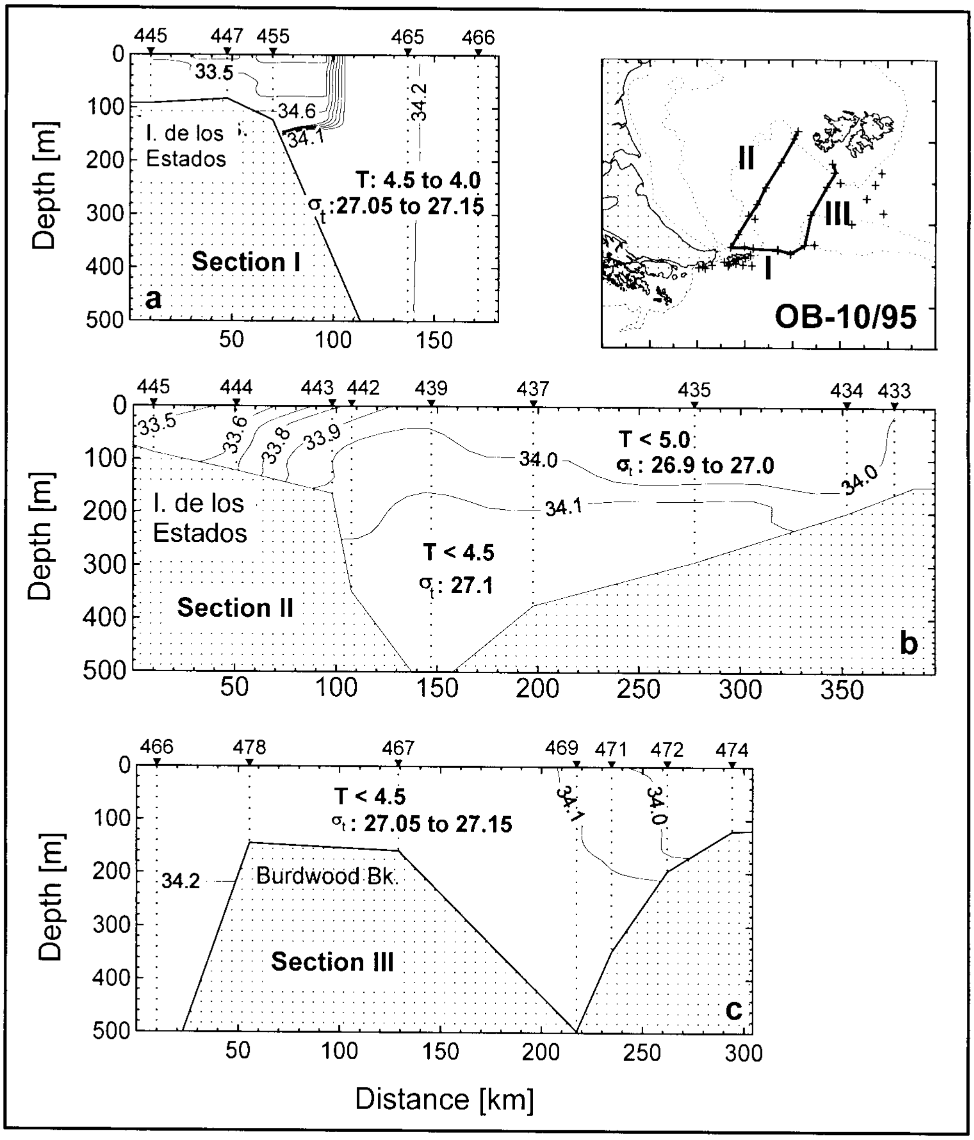

Figure 7. Salinity sections for cruise OB-10/95. a) Isla de los Estados - Burdwood Bank. b) Isla de los Estados - Malvinas Is. Continental shelf. c) Burdwood Bank - Malvinas Is. continental shelf. Temperature (T) and density (st) mean values are included.

Figura 7. Secciones de salinidad para la campaña OB-10/95. a) Islas de los Estados - Banco Burdwood. b) Isla de los Estados - plataforma continental de las Isla Malvinas. c) Banco Burdwood - plataforma continental de las Islas Mavinas. Se incluyen los valores medios de temperatura (T) y densidad (st).

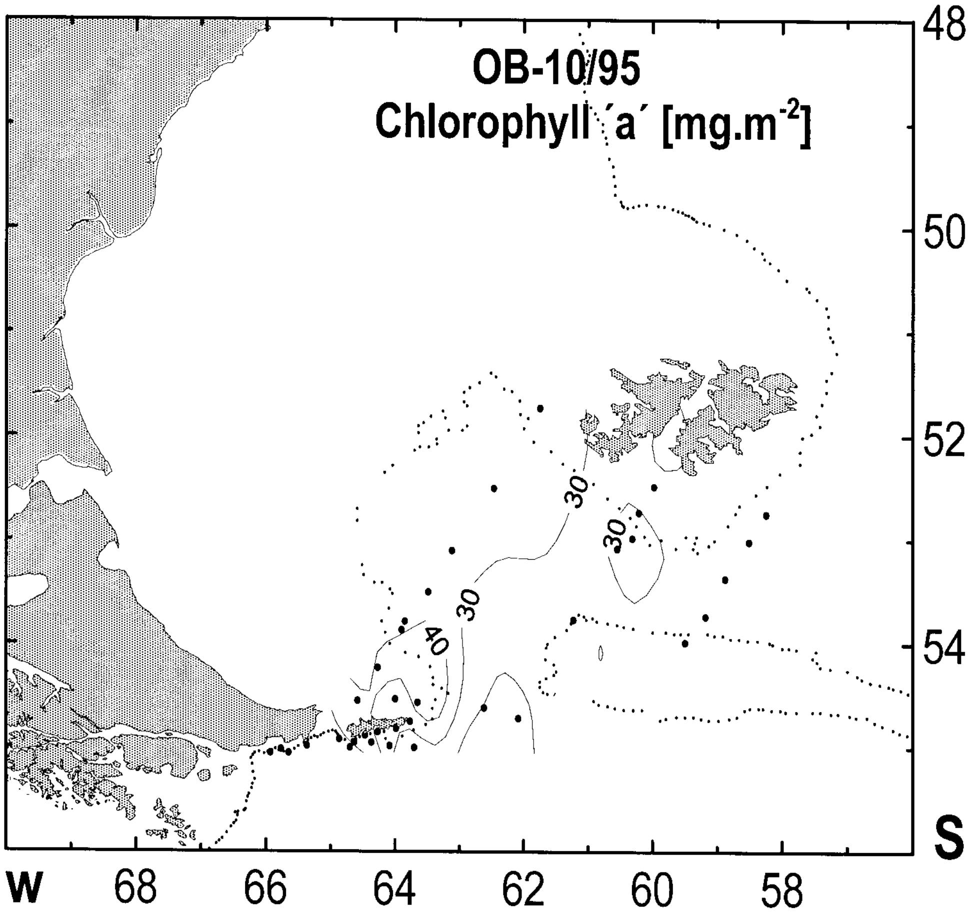

Figure 8. Chlorophyll 'a' (mg. m^{-2}) horizontal distribution integrated over the photic zone sampled on cruise OB-10/95.
Figura 8. Distribución horizontal de clorofila 'a' (mg. m^{-2}) integrada para toda la zona fótica medida en la campaña OB-10/95.

with the Malvinas Channel and is the area of origin of the Malvinas Current. This current transports the lighter AAIW that enters the Malvinas Channel west to Burdwood Bank. A strong contrast in the physical properties is found between these open ocean waters and the shelf waters, highly diluted by the Beagle Channel outflow and shelf waters from the Cape Horn. The fronts defined at the shoal areas (also seen in figures 3a and 4a) are mainly controlled by salinity. Temperature of the incoming waters is cooler than that of the shelf waters (T < 5.0°C), and much heavier (σ_t greater than 27.0). This is a 400 m thick layer, fed with the heavy, cool and salty water from the upper stratum of the Malvinas Current.

Section II shows, an upper low density and warmer layer, characterised by a low salinity content; and a heavier bottom layer with higher salinity and lower temperature (figures 6b and 7b). Density values of this bottom layer are close to the upper

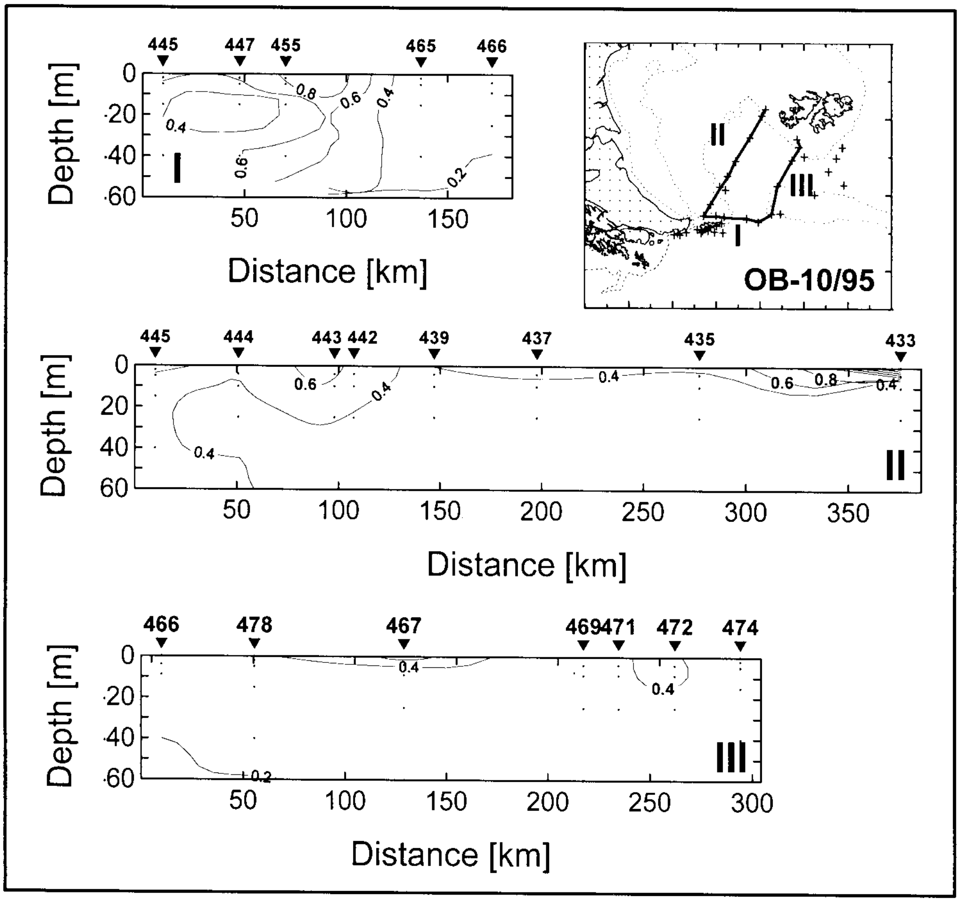

Figure 9. Vertical distribution of chlorophyll 'a' (M) observed on cruise OB-10/95. a) Isla de los Estados - Burdwood Bank. b) Isla de los Estados - Malvinas Is. Continental shelf. c) Burdwood Bank - Malvinas Is. continental shelf.

Figura 9. Distribución vertical de Clorofila 'a' (M) observada durante la campaña OB-10/95. a) Isla de los Estados - Banco Burdwood. b) Isla de los Estados - plataforma continental de las Islas Malvinas. c) Banco Burdwood - plataforma continental de las Islas Mavinas.

mode water defined by Molinelli (1978) or the SAMW proposed by McCartney (1977, 1981). The upper layer water mass resulted from the mixture of water incoming through section I with shelf diluted water. The picnocline is located between 100 and 200 meter depth and intersects the rising slope at the edge of the basin. This intersection defines the bottom front observed in figure 4a. A stronger front is observed at the southern end of this section (Isla de los Estados shelf) when the low salinity water coming from the shelf converges with the water from Scotia Sea, generating a surface front at the edge of the continental slope (100 to 200 m water depth).

Section III (figure 6c and 7c), crosses the outcoming flow from the western Malvinas Channel. It shows the weakest horizontal and vertical stratification, due to the homogeneity of the incoming AAIW, and also because water formed in the surrounding of Burdwood Bank has the same type. A salinity front is observed at the northern end of this section. This front results from the convergence of open ocean water with shelf waters at depths from 100 to 200 m (station 547 and 546, OB-07/94 and 471 and 472, OB-10/95). The shelf around the islands is occupied by low salinity water, as is also observed in figures 3a and 4a. Data from the OB-07/94 cruise show lighter water densities than those from the OB-10/95.

Chlorophyll 'a' distribution

In particular for the cruise OB-10/95, the distribution of phytoplankton biomass in the area was estimated through the concentration of chlorophyll "a", as a preliminary survey, considering the lack of information for the area. Figure 8 presents the horizontal distribution of chlorophyll "a" (mg chl.a.m^{-2}) integrated over the photic layer (≈ 60 m depth). In general, the measured concentrations were low, as can be expected for the winter period in high latitudes. Values ranged from 17.13 to 55.39 mg chl.a.m^{-2}, and a soft increase was noted towards the Argentine continental shelf. The highest chlorophyll "a" integrated concentration was measured west to the Isla de los Estados (64.44 mg chl.a.m^{-2}), close to the mouth of the Beagle Channel; and a very low concentration area (less than 20 mg chl.a.m-2) was located in the Malvinas Channel, corresponding with the entrance of the AAIW.

Figure 10 presents the vertical distribution of chlorophyll (µM) in the three sections analyzed for this cruise. In all of them the low chlorophyll values distribution reflected the marked vertical homogeneity of the water column showed by the physical

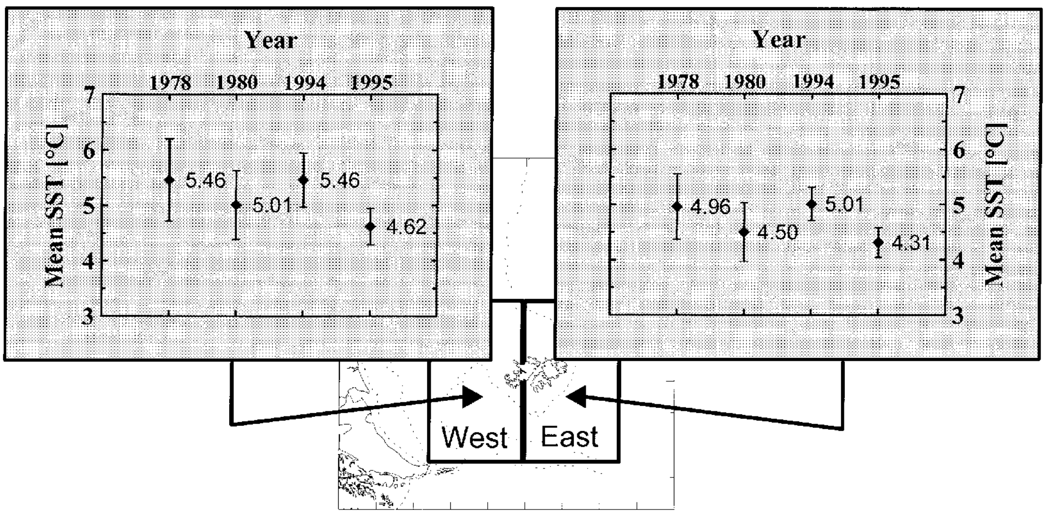

Figure 10. Mean sea surface temperature (SSTm) for 1978, 1980, 1994 and 1995 in two sectors of 5° latitude x 5° longitude, showing the inter-annual variability, of heat content at east and west sector of the studied area.

Figura 10. Temperatura media superfical del mar (SSTm) para los años 1978, 1980, 1994 y 1995, mostrando las variaciones interanuales en el contenido de calor para dos sectores de 5° de latitud x 5° de longitud al Oeste y Este del área de estudio.

data. As the only significant observations, it can be mentioned the correspondence of the surface maximum (1.0 µM) in section I (Figure 10a) with the saline front located at the shelf break close to Islas de los Estados (Figure 8a), and the highest chlorophyll concentration (1.9 µM) located over the shelf break west to the Malvinas Islands (Figure 10b). This latter was restricted to a very shallow surface layer and masked by the integration over the photic layer. It can also be noted in section III (Figure 10c) that the only increase in the chlorophyll concentration was related to the northern edge of Burdwood Bank and to the shelf break south to Malvinas Islands.

Variability in water properties

An evident difference in the salt and heat content between cruises 07/94 and 10/95 is noted in sections I, II and III. Changes in water properties may be expected as a result of different forcing conditions in the formation of the water mass. Anomalous advective or convective processes at the formation zone could result in changes in the T and S fields for different years. In order to evaluate the possible inter-annual variation, temperature from four cruises performed at the same season (Table 1) and a bathythermograph (BT) data base were analyzed and compared.

Table 2 shows the mean Sea Surface Temperature (SSTm) calculated from each cruise data for two different sectors of 5° lat. x 5° long west and east to Malvinas Islands (Figure 10). The east sector was located at 55° to 60° W - 50° to 55° S, and the west sector at 60° to 65° W - 50° to 55° S. Historical BT data from the SHN (1973) for this period and for the same sectors indicate a 300 m mixed layer with temperatures of 4.3 and 5.3 °C for the east and west sectors respectively.

Table 2 (also Figure 10) shows a SSTm amplitude close to 1° C, denoting the 1995 winter as the coolest (OB-10/95). This period also showed a saltier water column relative to the other cruises. Both conditions would indicate a stronger signal of the AAIW with formation of heavier water in that winter period. The weakest (warmer and fresher) signal for the 1978 period corresponded to Shinkai Maru cruise. Temperatures from the AII-107/X cruise were also cooler and saltier in 1980, while those of the OB-07/94 cruise seemed to be relatively warmer and fresher. As no statistical analysis was performed on the data and only the surface layer were compared, the results are relative and does not enable to define a conclusive anomalous climatic condition at the upper water column in these winter periods.

DISCUSSION

The circulation pattern and characteristic water masses in the study area are mainly controlled by the advection and local convection of the lighter type of AAIW, in the density range from 27.05 to 27.15 kg m-3 (Piola and Gortdon, 1989). The main core of this water type enters the area through the west channel between Islas de los Estados and Burdwood Bank, permanently interacting with diluted shelf water of continental origin, and generating a slope front along the 200 m isobath. Mixed waters, resulting from the interaction between shelf and open ocean water, feed the upper 200 m of the western end of the Malvinas Channel and advect without a topographic constrain along the continental shelf. This 200 m mixed water column occupies the whole continental shelf around the Malvinas Islands. Eastward to the front and around the islands, the water column defines the upper core of the Malvinas Current, with a strong vertical homogeneity induced by surface cooling, characteristic of the winter period (McCartney, 1977, 1981; Piola and Gordon,

Table 1. Oceanographic cruises analyzed in this study. Also shown are sampling methods, number of stations and date of the cruises.
Tabla 1. Campaña oceanográficas analizadas en este estudio. Se muestra también, para cada campaña, el método de muestreo empleado, numero de estaciones realizadas y fechas correspondientes.

Cruise	RV	Instrum.	# Of Stations	Date
OB-07/94	Cap. Oca Balda	ME-CTD	97	Sept.9 to Oct.2
OB-10/95	Cap. Oca Balda	ME-CTD	40	Sept.3 to Sept.25
AII-107X/80	Atlantis II	NBIS-CTD	37	Aug.14 to Aug.31
SM-IV/78	Shinkai Maru	Nan.Bot. + SST	16 + 37	Jul.28 to Aug.14
WH-II/78	Walther Herwig	Nansen bottles	97	Aug.8 to Sept.3

Table 2. Statistical information from the analyzed cruises on Sea Surface Temperature (SST) for 1978, 1980, 1994 and 1995 at the winter period. Historical bathytermograph data are also included.
Tabla 2. Datos estadísticos del período de invierno de la temperatura superficial del mar para los años 1978, 1980, 1994 y 1995. Se incluyen también datos históricos batimétricos del área.

Period	1978 August	1980 August	1994 Sept.	1995 Sept.	BT-base Jul. to Sept.	Sector
SSTm	5.46	5.01	5.46	4.62	5.3	
s	0.74	0.62	0.49	0.33	-	West
N	61	10	35	29	21	
SSTm	4.96	4.50	5.01	4.31	4.3	
s	0.59	0.53	0.30	0.27	-	East
N	40	20	43	6	13	

1989). The area of the Burdwood Bank is defined as an AAIW formation zone, induced by the decrease in depth and the mixing of surface water by wind stress, that drives down the atmospheric cooling at the sea-air interface. The density difference between frontal mixed water and pure AAIW at the western side of the Malvinas Channel induces the entrance of a dense wedge below the lighter surface stratum. At the bottom stratum, the whole area is dominated by the AAIW lighter type with a weak dilution.

Significant inter-annual changes in temperature were observed between the analysed periods. The 1995 winter period was the coolest, indicating a year with stronger formation of AAIW, either by advection of heavier water or a more intense local convection in the area. Additionally both processes could have induced a salinity increase in this year, as observed comparing figures 7 and 8. This condition also contributed in the formation of denser water in 1995. The differences observed for the 1995 period respect to that of 1994 were above 0.05 to 0.1 in σt, 0.8°C cooler and ±0.05 psu saltier.

CONCLUSIONS

The study area is divided into two regimes: a) A shelf regime just above the continental slope, characterised by a mixture of continental run off and open ocean surface waters. b) An open ocean regime defined by the Malvinas Current upper stratum carring the lighter AAIW core. The limit between these regimes follows the 200 m isobath and is controlled by the density distribution and topography.

The western side of the Malvinas Channel is characterised by a two layer system directly associated with the above described horizontal stratification. The upper layer is dominated by mixed shelf waters and the bottom layer by the AAIW lighter core advected and mixed underneath the upper layer.

The Burdwood Bank is the formation and modification region for the AAIW mass depending on the characteristics of the incoming waters and on local cooling. For both 1994 and 1995 cruises the outcropping of sub-surface waters indicates a vertical convection. This water type formed in the 1994 period had density values from 27.0 to 27.05 kg m^{-3}, while that formed in the 1995 period was denser (27.05 to 27.15 kg m^{-3}). The latter seems to be an anomalously cooler and saltier period, relative to the available historical data for the same period of the year.

An oceanic front is well defined at the continental slope east to Isla de los Estados, formed by the convergence of shelf diluted water and the lighter core of AAIW. This front follows the topography, maintaining a line of sharp horizontal gradients at the south-west border of the Malvinas Channel. A much weaker front is formed by the isopicnals convergence south to the Malvinas Islands, where water is forced to move along the continental slope following the 200 m isobath. It is noteworthy that this two fronts coincide with the areas where the major reproductive concentrations of blue whiting were observed in both cruises (Acoustic Survey, in this volume).

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