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The Ross Shelf cavity water exchange variability during 1995-1998

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Summary. — This work aims at presenting an analysis of the evolution of the physical properties of a water column at the southern limit of the Ross Sea, Antarctica. Data has been collected over a four year period (from January 1995 to July 1998) by means of an oceanographic mooring (named mooring "F") berthed a few miles north of the Ross Ice Shelf at a depth of 600 m on the continental shelf. The velocity and temperature measurements have been investigated seeking for ISW (Ice Shelf Water) outflow footprints. These outflows are irregular massive injections of cold water from below the Ice Shelf, flowing mainly across the cavity floor into the Ross Sea bottom layers. The study evidenced a large number of DISW outflow events (Deep Ice Shelf Water, the coldest and densest fraction of the ISW, the actual main object of the present study), characterized by an interannual variability that could turn out to be an important co-factor in the variations of the planetary heat balance and climate instability. Differences in DISW outflow timings from biennium 1995-1996, during which a jet-like behaviour was dominating (each events was only a few days long), and 1997-1998 (with a few long and rather continous cold water outflows) have been detected. Moreover, in 1996 measurements evidenced a relatively long and warm period (about 110 days from March to July) characterized by the total absence of DISW outflow, this interval being more than twice longer with respect to any other similar ones registered during 1995, 1997 and 1998, and longer that any other warm period observed in the area during the early '80s. The estimates of cold water exchanged during the four years return a more complicated framework: 1996 behaviour seems to be closer to the 1997 than to the 1995 one, with high fluxes and high volumes. 1995 can probably be considered as the ignition of an interannual anomaly, which climax is the long warm period of spring 1996.

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PACS `93.30.Sq` – Polar regions.

1. – Introduction

The whole southern region of the Ross Sea area is covered by the Ross Ice Shelf (RIS), a wide and floating ice platform, with an area of half a million square kilometers and a thickness that ranges from 200 to 300 m at the marine edge up to 1000 m close to the continent(1) [1], topping a cavity (500–600 meters deep on average) in which Ross Sea waters freely circulate (see fig. 1). Ice shelves are known to be areas extremely active in water masses productions and transformations. The CDW (Circumpolar Deep Water), the water that the ACC (Antarctic Circumpolar Current) carries clockwise around the pole, is moved by the Ross Gyre into the Ross Sea, where it mixes with resident waters to form the MCDW (Modified Circumpolar Deep Water), an intermediate warm water characterized by a warm core (called WMCO) [2]. The WMCO temperature is $\approx -1°C$, approximately 2°C lower than the CDW and more than 1°C higher than the ISW (Ice Shelf Water) one(2). Close to the continental margin, along Victoria land (for geographic references see fig. 1), a second important process takes place: it is the brine release and the related sea ice production, which together lead to HSSW (High Salinity Shelf Water) formation [4, 5] and contributes to generate the ISW via basal melting below the RIS. Therefore near the edge of the Ross Ice Shelf two main fractions of the ISW can be identified according to the depth (and consequently to the water density) [6]: the Shallow Ice Shelf Water (SISW) and the Deep Ice Shelf Water (DISW). The Shallow ISW is mainly formed by melting of the near surface (between -50 m and -250 m [6]) edge of the RIS operated by the warm core of the CDW [7-9]. Because of its origin and its limited depth SISW will not be considered in this study.

DISW formation processes, in which HSSW plays an important role, take place below the RIS; forced in high-pressure conditions by the overhanging ice, the DISW originates from a transformation of HSSW by cooling and melting processes due to the contact with the RIS base and to the lowering of the freezing point related to the increasing pressure [10]. The ice presence gives the ISW not only a temperature lower than the surface freezing point (which is widely considered its distinctive characteristic) but also an increased dissolved oxigen concentration [6]. Not all the HSSW produced along the continental margin leads to ISW formation; HSSW major pathway is observed to be northward bound [11], but one of its branch moves south from its formation site (in the western sector of the Ross Sea) towards the Ross Island (see fig. 1) [11], flowing deeper under the RIS where eventually a depression in the sea floor (approximately 1000 m deep) stores it. The transformation in ISW takes place on that portion of the HSSW that moves out from that cavity and flows northward beneath the RIS (losing heat and gaining oxigen in the contact) and emerges near the date line area. It has been observed that the slow HSSW recirculation underneath the RIS triggers the DISW formation, supplying the salt that makes it highly dense in so compensating the buoyancy originated in the melting process [12-17].

The main focus of this work is the DISW (hereafter ISW) outflow dynamics and its variability, the latter already being identified as an important aspect in previous works [18, 19]. In fact the ISW plume seems to be rather discontinuous through months, with active periods (hereafter events) from a few days to almost one month long. Besides,

(1) http://visibleearth.nasa.gov/Oceans/Sea_Ice/Ice_Depth_Thickness.html.
(2) Cited temperatures refer to the depth of 300–400 m. For detailed temperatures profiles of the involved water types see [3].

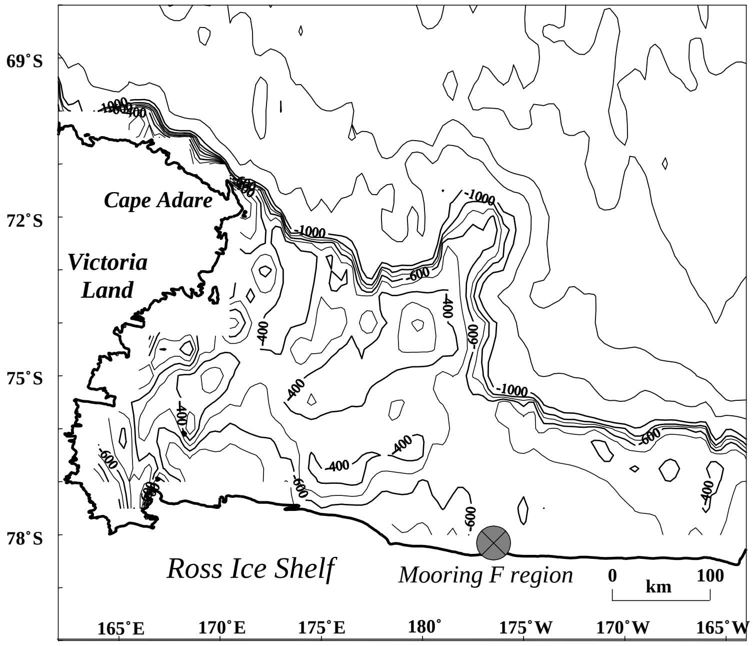

Fig. 1. – The Ross Sea area. At its southern border the RIS with mooring "F" position.

numerical modelling studies [20,21] confirmed the existance of the so-called "recirculation processes" in which together with the outflowing ISW plume an incoming (from the Ross Sea into the Ice Shelf Cavity) MCDW flow can be observed.

Recently new data became available that aimed at diminishing the uncertainties about the evolution and spreading of the water masses [22]; even if not being fully explanatory

TABLE I. – *Moorings' structures and characteristics.*

Year	Position – local depth (m)	Distance from RIS (km)	Currentmeters depth (m)			SBE depth (m)		Sampling interval (s)	Deploy date – Recovery date
1995	177°01′.623 W 77°59′.998 S 602	≈ 7	245	391	579	244	390	1800	27 Jan 95 21 Jan 96
1996	176°55′.560 W 77°57′.110 S 602	≈ 12	264	411	590	265	412	1800	21 Jan 96 24 Dec 96
1997-98	178°02′.274 W 77°58′.294 S 697	≈ 10	250	420	666	–	389	1800	26 Dec 96 08 Dec 98

in terms of measured width of the tongue and of the ISW behaviour because limited only to one mooring location, the data can contribute to better understand the dynamics. Despite previous efforts, an interannual analysis in the region was missing, as well as a thorough analysis of the link of the variability to other ongoing dynamical aspects. This paper aims to deepen some unsolved aspects by means of an accurate analysis of 1997-1998 data recently made available from the XIII expedition of the Italian National Programme for Antarctic Research (PNRA). The whole data set is now more than three years long and gives the possibility to make more reliable considerations about the temporal evolution of velocity and temperature signatures. In the paper the outflow activity is investigated by means of a detailed analysis of the interannual evolution of the water column and of the estimate of the outflow volumes of ISW events. The availability of this extended time series together with slight changes in mooring position through the years (see table I), offers the possibility to make some interesting inferences about the ISW interannual variability with regard to the long-term behaviour of the core during the four-year period. The outline of the paper is as follows: sect. **2** describes material and methods used, comments on velocity time series are given in sect. **3**, together with a description of progressive vectors meaning and results. Temperature analysis is the subject of sect. **4**, conclusions are given in sect. **5**.

2. – Materials and methods

During January 1995 after having performed a CTD section all along the RIS [2,23], a mooring named "F" was deployed where the signal of the ISW outflow was intense close to the edge of the RIS (77°59′.998 S; 177°1′.623 W) from January 28, 1995 to January 21, 1996, in a 600 m deep area [23]. The instrumental chain was recovered, maintained and re-deployed (77°57′.110 S; 176°55′.560 W) during the period from January 22, 1996 to December 24, 1996, in the framework of the XI expedition of the PNRA [24]. The new location was about 5 km north of the first one (at the center of the cold core, as in 1995 it had been placed in a slightly off-centred position with respect to the ISW core). During the XIII expedition of the PNRA carried out between December 26, 1996 and December 8, 1998 [25], the mooring was positioned (77°58′.294 S; 178°02′.274 W) at a depth of 697 meters, approximately 10 km north of the RIS edge, and more than 20 km further east than the two previous locations. The approximate position of mooring "F" within the Ross Sea can be seen in fig. 1. All moorings carried, among other devices, three currentmeters Aanderaa and two-temperature sensors SBE/Seacat. The upper (positioned ≈ 250 below the surface) and the intermediate (positioned at the assumed cold core depth, ≈ 400 m from sea level) currentmeters were coupled with a temperature sensor, while a low-resolution thermometer, embedded in every currentmeters, was used to monitor the water temperature at the third currentmeter depth (close to the sea floor, under the cold core), being this the minimal configuration required to monitor the termal and velocity gradients induced by the ISW cold-core. A more detailed description of the moorings arrays is given in table I.

An Acoustic Doppler Current Profiler (ADCP) was deployed as well at the top of the mooring during all the campaigns with the aim of investigating SISW behaviour; as this is not the focus of the present paper, we discuss here only the thermistors and currentmeters data, being the ISW masses not affected by the surface velocities.

Data gaps due to instrument failures occurred on September 3, and September 7, 1995, at 244 m and 579 m, respectively, and on October 10, 1995 at 390 m. In 1997-98 campaign currentmeters stopped working on May 13, 1998 at 250 m, on April 14, 1998

TABLE II. – *Tidal energy distribution, expressing the average fraction of the kinetic energy caused by tidal forcing. Column 2 expresses tidal energy fraction (in percentage) over the total energy, while columns from 3 to 9 show every components energy fraction (in percentage) of the total tidal energy.*

Year	Tidal energy	Diurnal components (with period (h))				Semidiurnal components (with period (h))			First 7 components sub-total
		K1 (23.9)	O1 (25.8)	P1 (24.1)	Q1 (26.9)	M2 (12.4)	N2 (12.7)	S2 (12.0)	
1995	18.3	38.3	18.4	3.7	1.1	0.4	0.3	0.4	62.6
1996	11.1	44.7	19.0	5.0	1.0	0.3	0.3	0.4	70.9
1997	18.4	49.2	22.1	5.9	0.8	0.6	0.8	0.8	80.2

at 420 m and on July 30, 1998 at 666 m, while the SBE/Seacat temperature recorder at 249 m was not completely operative. For this reason the 1998 data analysis ended in April: given the lack of a currentmeter centered on the ISW core, no reliable investigation on the vertical structure would have been possible from then on.

Because of the different mooring positions, all the available data were grouped into three data sets, years 1997-1998 being coupled in just one record. As first step the tidal signals have been identified and removed from currents data and temperature and salinity data have been daily averaged in order to remove the major cycle induced by tide. Results from tidal analysis will be discussed in the next section.

An objective analysis procedure was set up to reconstruct the water column evolution and to estimate the ISW core thickness.

3. – Analysis of velocity time series

In this section we provide a short background of the 1995-96 data analysis and present the evolution of temperature and velocity vertical structure for the 1997-98 time series. However, we remind that a detailed analysis of the 1995 and 1996 activity has been carried out in [22], where a similar tide removal procedure was carried out. An assessment of the contribution of the different harmonics to the total tidal signal is given in table II together with an estimation of the fraction of the total energy due to tide, the latter calcolated as the kinetic energy percentage due to tide induced currents. The tidal analysis points out how diurnal components (namely O_1 and K_1) are by far the most important, while the semidiurnal one turned out to be more than 10 times smaller, in agreement with other observation and modelling results [26, 27]. On average tide can be claimed responsable for around the 16% of the water kinetic energy.

Having a brief look at 1995 and 1996 behaviour (for a detailed analysis see [22]), we should remember here that during 1995 the along shelf velocity component (U), has been approximately 10% lower (on average) than during 1996, while the cross shelf component (V) was on average 6% higher. 1997 records show an average U similar to 1995 one (*i.e.* 10% lower than in 1996) while the V component is 20% lower than during 1995.

In fig. 2 the evolution of the vertical structure of both the U and V velocity components for 1997-98 is shown. In order to point out the scale of events, the period of

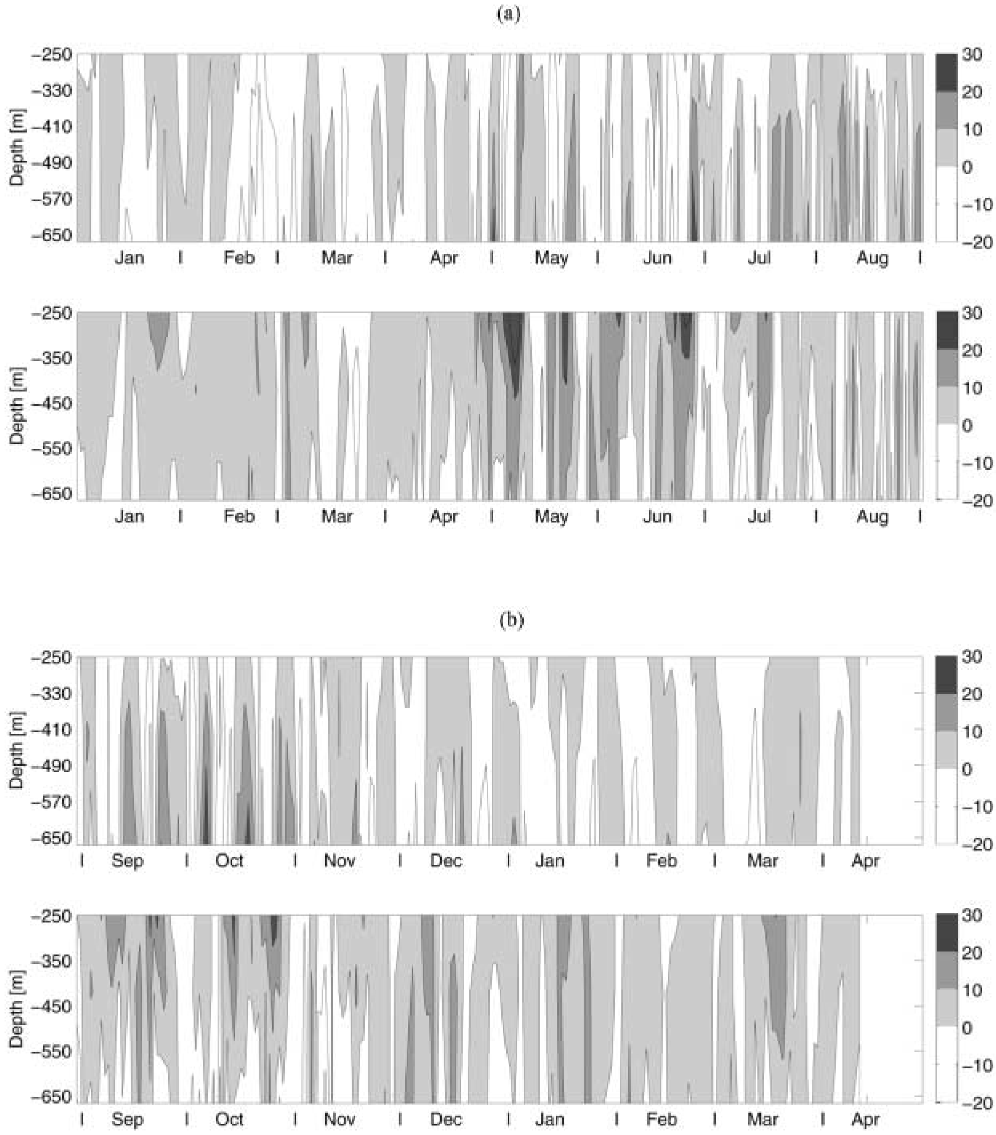

Fig. 2. – Velocity profiles in cm/s for 1997-1998. The record is shown split in two parts, a) from January 1997 to August 1997 and b) from September 1997 to April 1998. In each subfigure the top panels show the East-West velocity profiles (white areas refer to water moving from West to East toward the Victoria Land, same direction of the Antartic Circumpolar Current, while the grey ones the opposite). The lower panels show the North-South velocity profiles. Here the white areas represent water moving from north to south (*i.e.* water flowing from the ocean into the Ross Sea, while the grey areas refer to outflowing water from below the RIS).

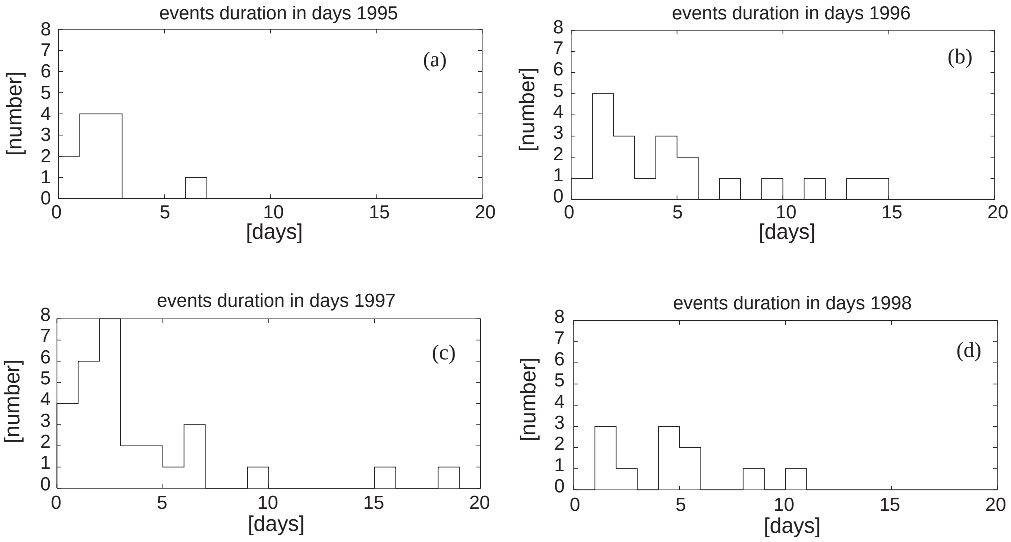

Fig. 3. – Distribution of the duration of events in a) 1995 (216 days long record); b) 1996 (335 days long record); c) 1997 (365 days long record); d) 1998 (103 days long record).

acquisition has been split into two parts: a) from January 1, 1997 to August 31, 1997 (fig. 2a), b) from September 1, 1997 to April 30, 1998 (fig. 2b). For north-south component white areas represent water moving from north to south (*i.e.* water flowing from the open Ross Sea toward the Ross Ice Shelf), while grey areas refer to outflowing water from below the RIS. For the U-component, white areas refer to water moving toward the Victoria Land, while grey areas to water moving on the opposite direction. The U-component behaviour seems to be rather regular compared to the V diagram, with similar lengths for white and grey sections. On the other hand, the north-south variability pattern not only is less regular through the 1997-1998 period, spanning from really short (less than a day) to long (up to twenty days) inversion time, but it is also quite different from the 1995-1996 one. Maximum (approximately 0.45 m/s) and both components typical velocities are similar to those of previous years. All velocities profile maps shown in fig. 2 have been obtained via a linear interpolation in space of the three current-meters (-250 m, -420 m and -666 m) daily averaged data. Time is shown along x-axis, while depth, expressed in meters, along y-axis. In fig. 3 are plotted the events duration histograms for the four years where the events (defined in the next section) lengths have been defined neglecting gaps smaller than an hour. It is rather evident how during the second biennium the events are on average longer than during the first couple of years; this is even more evident taking into account the different record length through years. A similar analysis (not shown here) has been performed for durations of gaps between events showing a clear difference between 1995 (with gaps durations almost uniformly distributed up to five weeks) and all the other years (with gaps mainly one week long).

Figure 4 shows the progressive vectors for the period from February to August of every year([3]), after tidal removal. These vectors can be thought of as an integration in

([3]) For 1998 only the period from February to April is available.

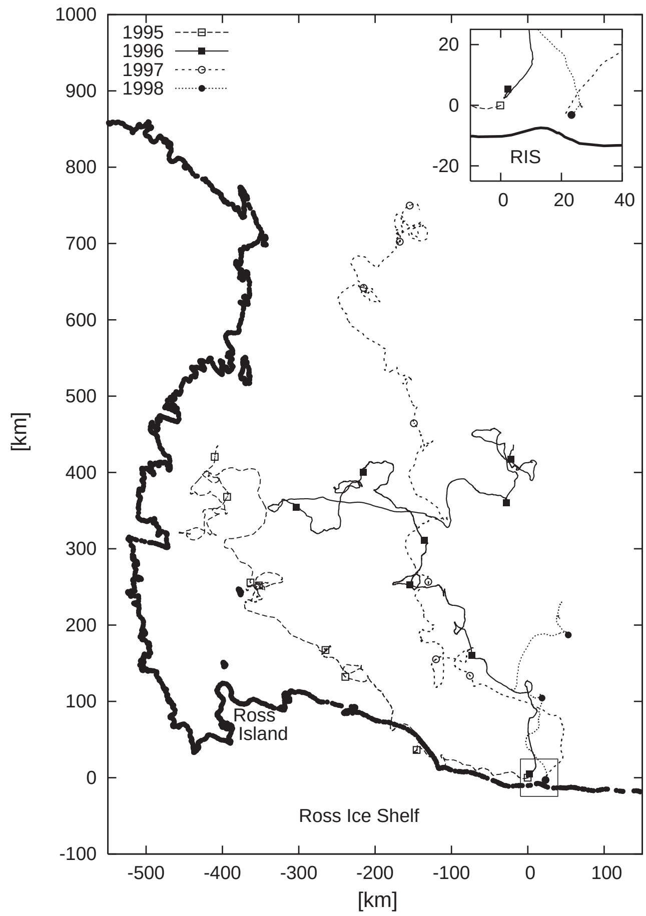

Fig. 4. – Progressive displacements calculated from velocity records, assuming as initial position the mooring location in each year. Note that what shown here is a Lagrangian representation, because all velocities refer to the same position. Nevertheless the paths give the idea of the differences of the records. The first day of each month has been marked.

time of the vectorial velocities. For a comparative analysis we choose the same period for all years. The positions of mooring "F", together with the distances relative to the RIS edge, during the three surveys considered, can be seen in fig. 4, or read in table I. We have considered the data acquired by the currentmeters at intermediate depth([4]) as representative of the ISW core plotting the first day of every month with a dot. During all years a dominant northward direction is evident, thus stating that a dominant outflow activity is present; nevertheless during 1995 the westward displacement is constantly comparable with the northward one (in seven months the total north-south displacement is about 500 km, with a east-west displacement up to 450 km). During 1996 the trend is less continuous: during the first four months the dominant direction is the northward one,

([4]) Intermediate current meters depths: −391 m for 1995, −411 m for 1996 and −420 m for 1997-98, for a complete representation of the moorings and the devices depths, see table I.

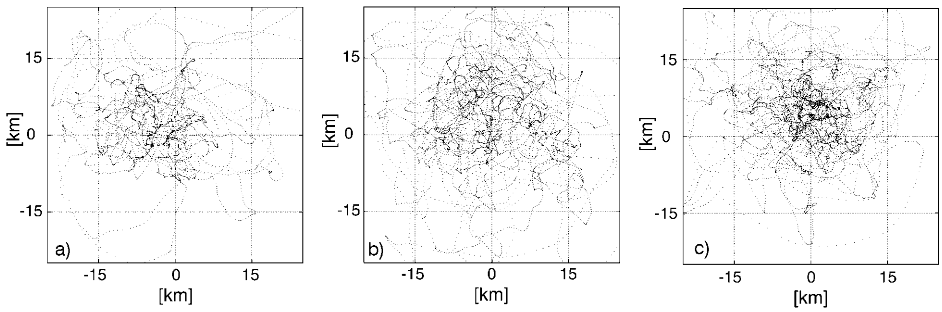

Fig. 5. – Plots of the distribution of the end points of the 36-hour progressive vectors. To obtain every plot a large number of displacements vectors have been computed; starting at every hour a 36 hours long subset (of both U and V components) is extracted, and a diplacement vector is computed. Only its final point is then plotted on the diagram. In a) 5147 end points (year 1995), in b) 8003 end points (year 1996) and in c) 8723 end points (year 1997) are shown. Because of the limited length of the record, no such a diagram has been done for year 1998.

while from June the displacement is mainly westward or eastward (July and August). The 1997-98 flow is once again different from the previous years ones, with an average dominant northward direction of 4.0 cm/s, almost twice that of the two previous years (2.3 cm/s). From 1995 to 1998 the cross-shelf drift gets less and less important. As already pointed out, during the three campaigns the mooring position has slightly been changed and we tried to address how relevant this was. The autocovariance analysis of the velocity data gave the same value for the e-folding decay (approximately 36 hours) for the three records. Using this value as the time span of a moving window we plotted (see fig. 5) the final points of the derived progessive vectors([5]). The spatial distribution of these final points can be considered as a test for the spatial correlation of the three mooring positions. The dense central areas of these diagrams give as significant spatial correlation between the records a range of about 20 km, larger than the mooring distances during years.

4. – Analysis of temperature time series

In fig. 6 the evolution of temperature profiles is shown. These profiles are based on the temperature records at three different depths. Upper and intermediate values come from SBE/Seacat temperature sensor([6]), while deeper ones come from the temperature sensor of the currentmeter (for displacement depths of all above cited sensor see table I). Integrating velocity and temperature information we can identify a large number of outflowing events, defined by the occurrence of positive V velocity values (northward flow from beneath the RIS to the Ross Sea) and temperature lower than $-1.90°$C. A peculiar class of events are the so-called recirculation episodes, defined by negative V velocity (southward flow from the Ross Sea toward the RIS) and the ISW signature. A general resume on outflow activity during the survey period can be seen in table III.

([5]) We computed a big number of 36 hours long progressive vector, everyone one hours shifted. This way two adjacent progressive vectors shares 68 of the 72 time record.

([6]) Since data from upper SBE record for year 1997-98 are not available (see table I) the current meter temperature sensor data have been used instead.

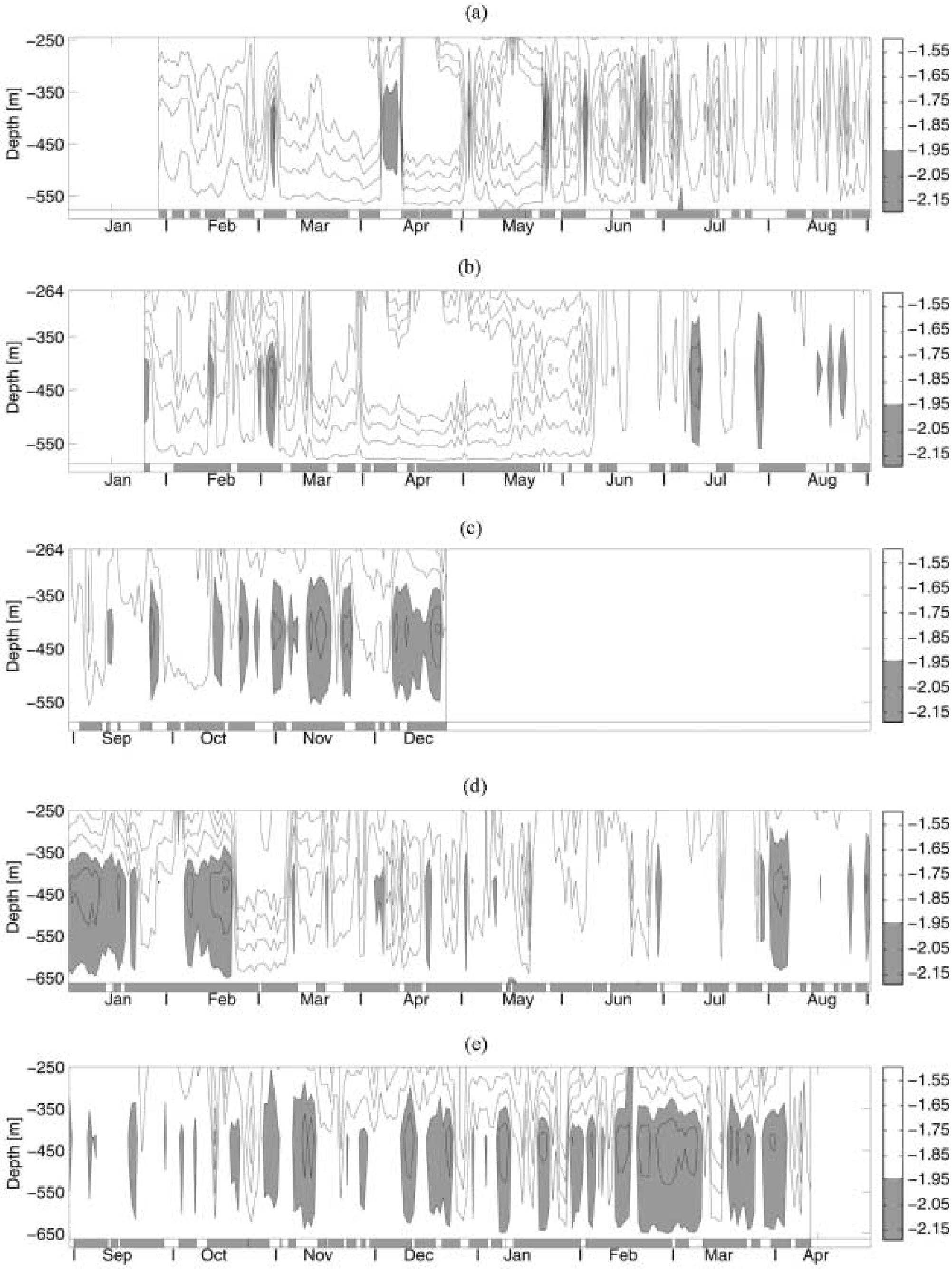

Fig. 6. – Daily averaged temperature profiles maps for period 1995-1998: a) from January 1995 to August 1995; b) from January 1996 to August 1996; c) from September 1996 to December 1996; d) from January 1997 to August 1997; e) from September 1997 to April 1998. These plots are a combination of temperature profile map (upper part in every diagram) together with velocity direction indication (small bar at the bottom). One countour line every 0.1°C has been drawn, and regions of temperature lower than −1.95°C are filled in dark grey.

TABLE III. – *Events characteristics over the 4 year period. Note that $\langle u \rangle$ over 1995-1996 events is larger than $\langle v \rangle$ during 1997-1998 ones.*

Year	Sampled time (days)	Number of events	Days with event	Outflow time (h)	$\frac{\text{Sampled t.}}{\text{Outflow t.}}$	Cold tongue properties $\langle u \rangle$ $\langle v \rangle$ (cm/s)	thickness (m)	center (m)
1995	216	11	21	609	8.5	9.3-2.4	388	-319
1996	335	20	95	2426	3.3	6.0-3.0	308	-335
1997	365	34	196	5298	1.7	2.0-4.5	336	-368
1998	103	13	72	2005	1.2	1.9-3.6	305	-392

Column 3 shows the number of events recorded every year, while column 4 counts the days in which at least half an hour or possibly longer events were found. No distinction between outflowing events and recirculation episodes has been made here. In column 5 the total time, in hours, of all events is given, while in column 6 the ratio Sampled time (in hours)/Outflow time (in hours) is computed. Last 3 columns give average velocities (the two components shown separated) during the events plus the estimated thickness and the estimated center depth of the cold core, the last two obtained interpolating the two depths of the threshold temperature.

With these derived measures we tried to evaluate the effectiveness of the outflows during years. Estimates of the fluxes (expressed in Sv) and overall outflowing volumes (expressed in 10^6 m^3) have been obtained as the product of: a) the average north-south components of velocity b) the ISW layer's thickness and c) its width, assumed to be 100 km. While a width of 25 km has been considered as representative of the cold core maximum signal ($T < -1.95$°C) in other studies [19,22,18], it is advisable to use a larger width (approximated in 100 km) when considering the whole water outflow and the related heat exchanges [28,2,23]. The obtained results for the cold water fluxes for years 1996 and 1997 (the only two actually comparable) were 1.4 Sv and 0.8 Sv, respectively. Note these are values averaged only on outflow events, so they cannot be intended as the average outflow of the whole year. We then integrated the instant flux values on the events to estimate the total volumes of cold water exchanged. Again only data for 1996 and 1997 are comparable, leading to approximately 1.5×10^7 million of m^3 in both years. Given the intrinsic discountinuous behaviour of the ISW outflows, the only reasonable way to include 1995 results in a comparative analysis, was to look at the two 1996 and 1997 chunks coinciding with the 1995 sampling interval (from January 27 to October 10). In that period 1995 fluxes were slightly smaller than 1997 ones, while the estimated volumes are around 10 times smaller than 1996 and 1997 ones. It turns out that during the period 1995-97 the outflow activity changed meaningfully: a) in 1995 short and mid-effective events led to a rather small overall outflow; b) in 1996 an almost stable number of events increased the outflowing volumes, being every event more powerful; c) in 1997 we registered a higher number of events, but in spite of this and their average longer durations, the total outflowing volume estimated turned out to be very similar to the 1996 one. A possible speculation could lie in a strong connection between the formation of ISW and HSSW production; with the different outflow dynamics having little effects on it and so turning in an almost constant amount of cold water produced (or at least a function of HSSW production).

In table III, it can be seen that the number of ISW events was basically the same during 1995 and 1996 (especially considering the shorter record of the 1995) but the 1996 episodes were longer, concentrated in a shorter period (almost missing during winter, when the presence of warmer outcoming water core ($T > -1.5°$C) was dominant) (see fig. 6a, b and c).

Figure 6a and fig. 6b show the water column structure from January 1997 to April 1998. The plots are a combination of temperature profile map (upper part in every diagram) together with velocity direction indication (small bar at the bottom). Temperature profiles are based on two SBE/Seacat T sensor and one currentmeter T sensor records. Data have been daily averaged and linearly interpolated on the vertical. Areas of temperature lower than $-1.95°$C are filled in dark grey. The velocity bar refers to the mid-depth currentmeters (centered on the cold water core) and shows the cross-RIS velocity direction: white when directed southward (refered to as negative in fig. 2) or grey when directed northward (refered to as positive in fig. 2). The ISW activity, present over the whole period considered, is characterized by the prevalence of outflows (only a short recirculation episode occurs on May). In general, the ISW outflows are marked by velocities lower than 10 cm/s and last from a maximum of 8 to a minimum of 2 days. The two longest events, respectively in January 1997 (about 20 days) and in February 1997 (about 10 days), are very intense in terms of the temperature minimum signature ($T < -2.1°$C). About the same number of cold events and recirculation processes are present during this period and the ISW activity is more intense with respect to the first semester, even though, in general, the events are shorter and more concentrated in time. The two most intense ISW events ($T < -2.1°$C) occur, respectively, in August (cold event) and in November (recirculation episode). The last 1997 ISW event (December) is about 15 days long and is characterized by an oscillation between positive and negative V velocity values, so it is difficult to label it as cold event or recirculation process. The 1998 ISW activity is practically continous and more intense than in the 1997 corresponding period (January-April). The cold water episodes are almost completely represented by long cold events (only two recirculation episodes are present at the beginning of January). From February to April the ISW outflow activity is persistent, characterized by a strong temperature signature ($T < -2.1°$C) and velocity values having generally order of 10 cm/s (fig. 2b, lower panel).

From the analysis of the average cross and along shelf velocities during the events, it appears as during 1995 and 1996 the along shelf component (column 7) was dominating, while during 1997-1998 the cross shelf component (column 8) was larger.

Some considerations about the temperature values corresponding to the ISW core depth may give an interesting insight on its interannual variability, and help us to better understand the previous issues. The temperature minimum ($T_{\rm MIN}$), which ranges from about $-2.1°$C to about $-2.2°$C, is representative of intense ISW plume formation; the corresponding V velocity component is almost always positive (flow from the RIS to the open Ross Sea) and decreasing from 1995 ($V = 8.0$ cm/s) to 1998 when it is almost zero ($V = 0.4$ cm/s). This feature, linked to the duration of the ISW events, confirms the variability of the ISW activity from a pulsing behaviour in 1995-96 to a much more persistent ISW outflow in 1997-98. In 1996 it is also detected the highest temperature maximum ($T = -0.865°$C).

5. – Conclusions

The main aim of this paper is the investigation of the variability of the ISW flow dynamics near the Ross Ice Shelf edge as observed at mooring "F" site during 1995-1998. The analysis of the temperature and velocity data acquired by the instrumental chain allows to reconstruct the evolution of the deeper part of the water column structure from 1995 to 1998 when the outflow is present and intense. Notwithstanding the different length of the acquisitions and the slightly different mooring array location, a sound comparison among the datasets is feasible. The ISW outflow process seems to be characterized by a discontinuous behaviour during 1995-96, exhibiting short and more frequent ISW injections, while the behaviour of 1997-98 appears as more regular and persistent. In spite of the limitation of having only one mooring site, the ISW outflow appears to be well localized in space, as certified by the fact that the phenomenon was captured during all the deployment years and by the correlation analysis too (see fig. 5). The number of events as well as the events total time appeared to increase from 1995 to 1997-1998, with the 1996 data being closer to 1995 than 1997 ones (especially considering the reduced length of 1995 record). The 1996 is then characterized by episodes concentrated in a shorter period of time and by the absence of ISW outflow during winter (for about 110 days), when an outcoming water core, defined by a temperature anomaly of about 0.5°C with respect to 1995. During 1997-98 events were generally longer than in the previous years, during which the duration was limited to two or three days on average and long episodes were quite unusual, and the overall outflow activity appeared to be stronger, being the 1997 number of days with episodes almost four times the 1995 and the 1996 ones. In 1998, even if the acquisitions are limited only to three months, the ISW activity is observed through all the period: the number of events per day of acquisition is twice the 1997 one. This is in agreement with the presence of a trend shifting from the impulsive behaviour of the ISW outflow process in 1995 to the persistent one in 1998 through the absence of ISW activity in 1996. Only part of the differences among the three record periods can be charged to the variations of the mooring positions (in 1997-98 more aligned with respect to the ISW core). The significant spatial correlation of the three datasets suggest an intrinsic variability of the outflow activity through the four years, confirmed by the results of volumes estimation which are in agreement with previous works.

The interesting behaviour registered during 1996 and leading to a warmer winter is actually preceding the El Niño Souther Oscillation by a few months. Still, further investigations are needed in order to better understand the links induced by the ISW outflow variability and large-scale climate connections.

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