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Michele Baques

University of Buenos Aires

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Michèle Baqués and Silvia Blanc

Naval Service of Research and Development (SENID), 327th Libertador Ave., 1638, Vicente López, Argentina. mbaques@yahoo.com, silblanc@yahoo.com

ABSTRACT

On December 2001 the Argentinean Naval Service of Research and Development participated in the LMG01-9 expedition to Antarctic Peninsula, which was part of the Antarctic Program of the National Science Foundation of the USA for 2001. The inclusion of a SENID researcher, in the role of scientific national observer, on board the icebreaker R/V Lawrence M. Gould enabled our institute access to additional at-sea measurements. The main purposes of the expedition were primarily focused in two research projects from foreign institutes which were out of the scope of local interests. However, *in-situ* measurements led also to valuable information on temperature, salinity, bathymetry, vectorial current velocity obtained with an Acoustic Doppler Current Profiler (ADCP) and planktonic organisms, along Drake Passage and in Antarctic Peninsula's adjacent waters. Oceanographic and acoustic measurements are being processed as input data for further computation of several acoustic parameters such as Volume Backscattering Strengths. Sound velocity profiles have been already calculated. Moreover, detection of Subantarctic and Polar fronts, eddies and jets could be achieved as a result of collected data analysis.

I. INTRODUCTION

At-sea controlled scientific measurements within the field of Ocean Acoustics require significant budgets to enable oceanographic vessels navigation, lodging of competent experienced personnel _technicians and researchers (oceanographers and acousticians)_ on board, as well as the acquisition of updated oceanographic and acoustic equipment. Undoubtedly, they imply a wide spectrum of strong investments in money, time and intellectual efforts. Currently, these facts are some of the reasons that lead to encourage joint international and multidisciplinary programs of *in-situ* measurements in the ocean instead of isolated scientific events exclusively restricted to regional or national interests.

Precisely, it is under this frame that the participation of the Argentinean Naval Service of Research and Development (SENID _ *Servicio Naval de Investigación y Desarrollo*_) in the LMG01-9 expedition to Antarctic Peninsula on board icebreaker R/V Lawrence M. Gould, took place on December 2001. This cruise was part of the Antarctic Project of the National Science Foundation (NSF) of the United States of America for 2001. The inclusion of a researcher with SENID in the role of scientific observer was suggested by the Argentinean Antarctic Institute as a reply to a request of the Ministry of Foreign Affairs, International Trade and Worship of the Argentinean Republic -National Protocol Bureau-.

This work represents an illustrative example of the utilisation of acoustic and oceanographic data collected during a cruise held with international resources.

The two main objectives that were pursued during the cruise [Baqués, 2003] were related to two abroad USA Projects whose principals investigators were researchers with Woods Hole Oceanographic Institute and the City University of New York/College of Staten Island. However, the cruise has finally contributed to increase Argentinean ocean-acoustics databases though its purposes were out of the scope of SENID's interests. Furthermore, data analysis of some of these oceanographic and acoustic measurements led to computation of sound velocity profiles along the north-south transect across the Drake Passage between 4^{th} and 7^{th} December 2001. Likewise, detection of the Subantarctic and Polar fronts, eddies and jets, as well as estimates of their respective locations could be held. An attempt to compute acoustic Volume Back-Scattering Strengths (in decibels) from at-sea ADCP's measurements has also been foreseen in this work. At this stage, their data processing is being currently carried out.

II. MATERIAL AND METHODS

Locations of the bathymetry, bathythermographic and acoustic stations along the track followed by the icebreaker L. M. Gould between 4^{th} and 7^{th} December 2001 are shown in FIG. 1.

Bathymetry Measurements. A hull-mounted Knudsen 320 B/R 3.5 kHz sonar was used to take bathymetry profiles. This rackmounted high power system (with 5/10 kW main transmitter and 2 kW second transmitter) that has probed to work well for full ocean depth surveys, also recorded GPS co-ordinates. Depth experimental data recordings were stored in the RVDAS (Research Vessel Data Acquisition System) installed on board. FIG. 2 shows the obtained track bathymetry over approximately the 65° W meridian.

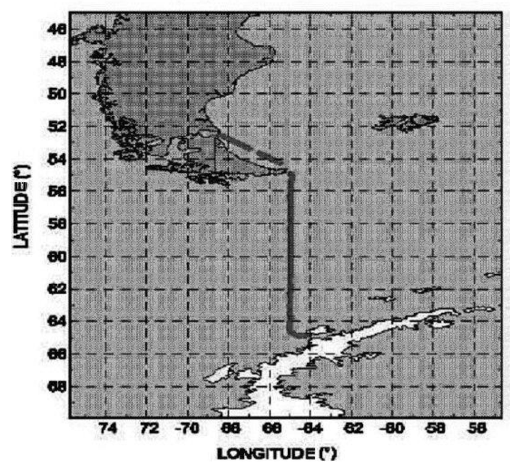

FIG.1. Locations of bathymetry, bathythermographic and ADCPs stations along the track followed by the icebreaker L. M. Gould during December 2001.

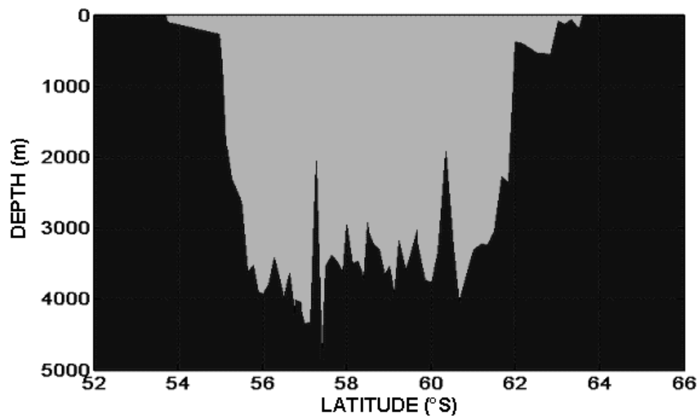

FIG. 2. Bathymetry of the track located over the 65° W meridian.

Bathythermographic Measurements were part of a high resolution XBT program initiated on September 1996 [Sprintall, 2003]. Crossing the Drake Passage during the north-south transect took about 4 days. In the meanwhile 82 XBTs were dropped across the SAF and PF. Sampling density ensured that measured temperature changes captured most of the variances associated to frontal systems and some other flow features. Only data coming from 8 XBTs droppings had to be depicted because of different errors associated to measurements techniques [Blanc *et al*., 2004]. Due to the slow ship speed (about 10 knots), the used XBTs (Sippican Blue probes) provided reliable temperature data mostly up to ~ 800 m enabling an adequate coverage of the upper ocean circulation within the Drake Passage.

Since for the authors investigation purposes, the main interest of having access to *in-situ* temperature measurements is their role of input data for further acoustic parameters computation, bathythermographic information presented here has been restricted to the first 500 m below sea level. FIG. 3 shows temperature distribution through a contour lines graphic in the depth-latitude plane for the first 500 m depth and the latitude interval 55.0°S-64.8°S, approximately along the 65°W meridian across the Drake Passage.

Salinity Measurements. Expendable conductivity-depth probes (XCTD) provided an insight into the vertical salinity structure. The six salinity profiles shown in FIG. 4 were obtained along the track with expendable probes of this type.

Current Velocity Measurements. Operating an acoustic Doppler current profiler (ADCP) from a research vessel is nowadays quite a widespread task for the entire oceanographic community (FIG. 5). They were originally designed for determining vector current velocities by measuring the Doppler shift of the backscattered signal from a narrow pulse of acoustic emitted energy. Moreover, it was sometimes considered as an eventual useful tool for bioacoustical studies (i.e. plankton behaviour, namely, numerical abundance and distribution) [Flagg *et al.*, 1989; Blanc *et al.*, 2004].

For a given ADCP whose acoustic transducer moves with the ship speed, $\mathbf{v_S}$, while emitting signals at f frequency and receiving their echoes at f_e, from the acoustic scatterers that "virtually" move with the oceanic current velocity, $\mathbf{v}$, it yields the detected Doppler shift [Emery *et al.*, 1997],

$$\Delta f = f - f_e = \frac{2\, v_{rel.}\, .\cos\theta\, .\, f}{c}, \tag{1}$$

where c is the sound velocity in seawater; $v_{rel.}$ is the absolute value of the relative current velocity vector, namely, $v_{rel.} = |\mathbf{v_{rel.}}| = |\mathbf{v_S} - \mathbf{v}|$; θ is the angle between the relative velocity vector and the line between the volume scatterers and the acoustic axis of the ADCP narrow beam.

During the LMG01-9 expedition a narrow band vessel mounted ADCP, manufactured by RD Instruments Inc. for oceanographic surveys, was used. Its operated at 150 kHz with continuous ensonification of a seawater column in the 26 m-200 m range depth. It consisted of four ceramic transducers, each of them pointing vertically downwards 30° off the geometric axis of the whole device. In fact, the used ADCP measured two physical quantities, namely, Doppler shifts, as set in Eq. (1), that lead to determine oceanic current velocities (as graphically illustrated in FIG. 6) and voltages from the so-called Automatic Gain Control which is an internal adjustment with the objective of keeping the transducer output constant. This latter measured quantity potentially enables estimates of relative backscattered acoustic intensities and consequently, gives rise to computed acoustic Volume Back-Scattering Strengths (in decibels).

Biological Samples. During the north-south crossing of the Drake Passage, researchers from Woods Hole Oceanographic Institute (WHOI) gathered phyto and zooplankton samples every 4 hours within the frame of a Project totally out of the scope of our Institute's interest [Baqués, 2003]. Nevertheless, a first analysis of the biological samples was performed with the purpose of identifying the possible organisms responsible for sound backscattering.

III. RESULTS

Sound velocity behaviour. Sound velocity profiles, c(z), were computed using Medwin's empirical equation [Medwin *et al*., 1998] for depths z measured in m, at each geographic position where a bathythermographic measurement was performed. Symbolically,

$$c(z) = 1449.2 + 4.6\,T - 0.055\,T^2 + 0.00029\,T^3 + (1.34-0.01\,T)\,(S-35) + 0.016\,z \qquad (2)$$

where T=T(z), temperature in °C, and S=S(z), salinity in ppm, are dependent on z.

Substitution of temperature and salinity measured profiles in Eq. (2), provides sound velocity distribution as a function of depth and latitude at Drake Passage on December 2001.

While 74 bathythermographic profiles were measured, only 5 salinity profiles were reliable within the amount of measurements held along the north-south transect. Therefore, with the aim of making compatible the bathythermographic information with the salinity one, the effect of the salinity variability in the determination of sound velocity profiles was analysed using extreme conditions, namely, (a) the bathythermographic profile at 60.524 °S and the salinity profile that shows the greatest variability in FIG. 4, at 60.500 °S; (b) the same temperature profile and an average constant salinity of 34.15 ppm. The maximum observed variation between both c(z) profiles, does not exceed 0.8 m/s, that means a 0.05 % of the average value of the sound velocity. Accordingly, S = 34.15 ppm was assumed to compute sound velocity profiles.

FIG. 7 shows sound velocity behaviour through a contour lines graphic in the depth-latitude plane for the first 500 m depth and the latitude interval 55.0° S-64.8° S, approximately along the 65° W meridian across the Drake Passage. When FIGS. 3 and 7 are simultaneously observed, it derives that c(z) is mainly governed by temperature distribution for nearly the first 200 m meanwhile for greater depths c increases with depth for any latitude.

Estimated location of fronts, eddies, Convergence and Divergence Antarctic zones. As it is well known the ACC (Antarctic Circumpolar Current) is characterised by continuous circumpolar fronts [Sprintall, 2003] that can be identified by the presence of strong temperature gradients. Distance interval between those fronts necessarily decreases along the Drake Passage since it is the narrowest zone crossed by the ACC (just ≈ 700 km). Fronts presence, namely, SAF (Subantarctic Front) and PF (Polar Front), could be detected during the expedition across the Drake Passage on December 2001.

Location of fronts, eddies and some other distinct characteristics in the area were preliminary estimated at SENID from XBT measurements (FIG. 3) during LMG01-9 oceanographic expedition. Salinity profiles and ADCP's current velocities measurements (as shown in FIG. 6[1]) contributed in general to reinforce the estimations derived from the observation of temperature behaviour. In particular, a sharp change in the sense of the vectorial current velocity appears in the estimated positions of the two warm eddies (FIG 6). Likewise, a rapid intensification of the current velocity (that means a significant increment in the module of the vector along a minimum latitude variation), can be observed near the estimated position of the Polar Front. Further results that were then reported [Sprintall, 2003] (including some results of satellite data processing held at the Scripps Institute of Oceanography to determine Sea Surface Height Anomalies _SSHA_ in the free sea surface) as well as personal communications with Dr. Teri Chereskin, constitutes a reasonable confirmation of the preliminary estimation whose definite version is shown in TABLE I.

TABLE I. Estimated location of distinct characteristics of the Drake Passage (December 2001), derived from at-sea measurements conducted during LMG01-9 cruise.

<table>
<tr><th colspan="2">Estimated Location for:</th><th>Estimated latitude (°S)</th><th>Observations</th></tr>
<tr><td colspan="2">Warm Jet</td><td>55.0</td><td>Estimated location with a precision of 0.2% .</td></tr>
<tr><td rowspan="6">AC (Antarctic Convergence zone)</td><td>SAF (Sub- Antarctic Front)</td><td>55.3</td><td>Estimated location with a precision of 0.2% .</td></tr>
<tr><td>Cold cyclonic Eddy</td><td>56.2</td><td rowspan="4">Estimated location for the eddy core. Meanders which separate northward from the PF are thought to develop into cold-core cyclonic eddies, containing cold water masses of Antarctic origin; while meanders which separate southward from the SAF, containing water masses originated in the Sub-Antarctic region, are thought to develop into warm-core anticyclonic eddies.</td></tr>
<tr><td>Warm anticyclonic eddy</td><td>56.8</td></tr>
<tr><td>Cold cyclonic eddy</td><td>57.8</td></tr>
<tr><td>Warm anticyclonic eddy</td><td>58.8</td></tr>
<tr><td>PF (Polar Front)</td><td>59.6</td><td>Estimated location with a precision of 0.2% .</td></tr>
<tr><td colspan="2">AD (Antarctic Divergence zone)</td><td>63.5</td><td>Estimated location with a precision of 0.2% .</td></tr>
</table>

[1] Kindly provided by Dr. T. Chereskin (Please, see acknowledgements).

FIG. 8 shows temperature data collected in the Drake Passage during LMG01-9 expedition on December 2001 for seven fix depths _ 0 m, 50 m, 100 m, 200 m, 300 m, 400 m and 500 m_.

Biological Samples. An on board first analysis of plankton samples made evident that copepods seemed to be the dominant constituents of plankton community in some stations (through personal communication from Dr. R. Scheltema), as shown in TABLE II. Size dimensions and physical properties of copepods suggest that these organisms might be responsible of sound volume backscattering responses to ADCP emissions at 150 kHz.

TABLE II. On board first analysis of plankton samples.

Station	**Date** (dd/mm/yy)	**South Latitude** (° : ' : ")	**West Longitude** (° : ' : ")	**SST** (ºC)	**Plankton Samples**	
					Zooplankton	**Phytoplankton**
LMG01-09-01	04/12/01	55:00:36	64:55:36	8.0	⊗	**X**
LMG01-09-02	04/12/01	55:39:54	64:58:06	5.0	∅	**X**
LMG01-09-03	04/12/01	56:19:54	65:01:24	5.8	**X**	
LMG01-09-04	04/12/01	57:00:42	64:58:48	6.0	**X**	
LMG01-09-05	05/12/01	57:39:54	64:54:54	3.8	∅	
LMG01-09-06	05/12/01	58:20:12	64:59:42	2.0	∅	
LMG01-09-07	05/12/01	59:02:24	64:57:36	3.7	∅	
LMG01-09-08	05/12/01	59:40:00	64:58:48	1.4	∅	**X**
LMG01-09-09	05/12/01	60:20:12	64:58:48	0.5	∅	**X**
LMG01-09-10	05/12/01	61:01:24	64:58:48	-0.2	**X**	**X**
LMG01-09-11	06/12/01	61:41:06	64:58:36	0.0	⊗	**X**
LMG01-09-12	06/12/01	62:19:24	65:01:24	0.1	∅	**X**
LMG01-09-13	06/12/01	63:00:06	65:00:54	-0.5	**X**	**X**
LMG01-09-14	06/12/01	63:40:54	64:59:24	0.9	**X**	**X**
LMG01-09-15	06/12/01	64:20:12	65:10:36	0.1	∅	**X**

References: **X**: Stations where plankton samples were obtained; ∅: Stations where copepods were observed; ⊗: Stations where a high density of phytoplankton was observed and nearly no copepods were found.

IV. DISCUSSION

As a summary, it has to be pointed out that the Argentinean Naval Service of Research and Development inserted participation in this foreign oceanographic expedition to Antarctica, carried out by researchers with prestigious institutions such as Woods Hole Oceanographic Institute or Scripps Institute of Oceanography, constituted an unique opportunity to have access to updated controlled at-sea measurements without any additional financial cost for our institute.

Data processing of the collected measurements of depth, temperature, salinity and Doppler frequency shifts across Drake Passage joint to further superposed analysis of the obtained results revealed interesting features about the upper ocean behaviour. Locations of the Subantarctic and Polar Fronts were estimated as well as eddies and jets were identified as it has been presented in Section III. On the other hand, sound velocity profiles could be computed. All these data were incorporated to local oceanographic Data Bases that could then be used as input data for the computation of other acoustic parameters currently included in acoustic information systems.

It might be added that as soon as it was noticed that vessel mounted ADCP operating at 150 kHz, would be available on board during the cruise, an attempt to compute acoustic Volume Backscattering Strengths from ADCP's automatically recorded voltages of acoustic backscattered signals, has been foreseen in this work. Although ADCP operation originally only pursued to accomplish an experimental study of the co-variability between currents and temperature including determinations of kinetic energy components of the Antarctic Circumpolar Current _ ACC_ within the Drake Passage, another alternative application of collected data is being encouraged. From that point of view, ADCP data processing has been only partially completed, namely, Doppler frequency shifts measurements already reported led to vector velocity currents[1] but recorded voltages corresponding to acoustic emitted and backscattered signals are still being processed. However, further analysis and consequent results about the acoustic response of the ensonified plankton along the track crossing Drake Passage, are considered out of the scope of this work.

ACKNOWLEDGMENTS

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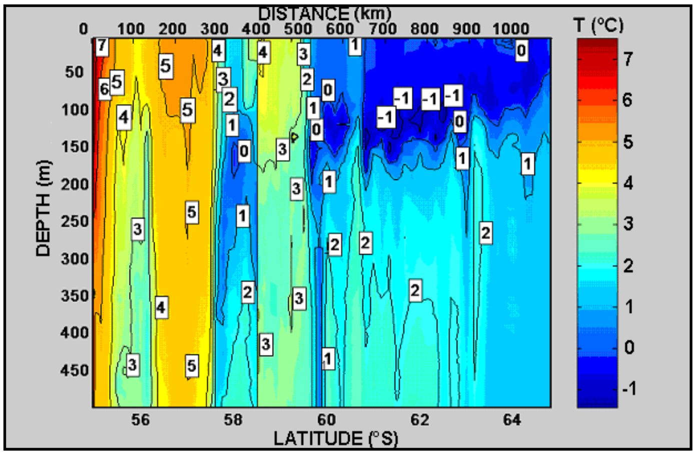

FIG. 3. Temperature Distribution in the first 500 m of the water column in the Drake Passage.

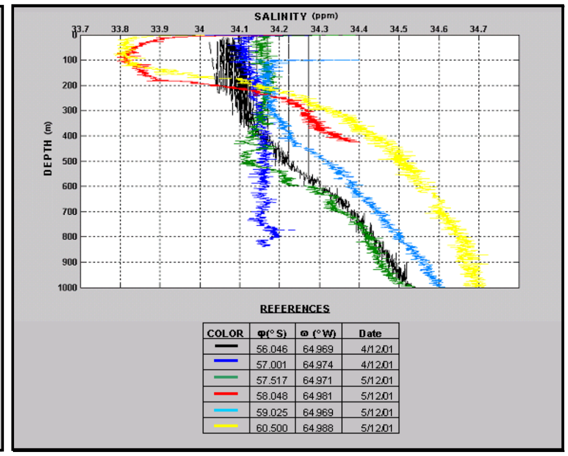

FIG. 4. Salinity Profiles obtained with XCTD.

FIG. 5. Acoustic Doppler Currents Profilers produced by *RD Instruments* Inc.

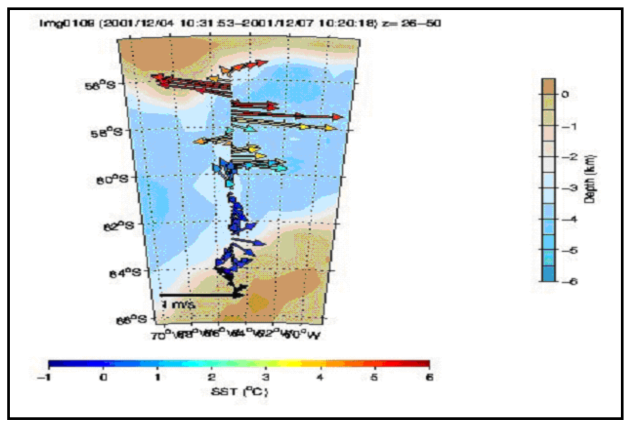

FIG. 6. Current Velocity Vector determined with ADCP for the 26 m - 50 m depths range.

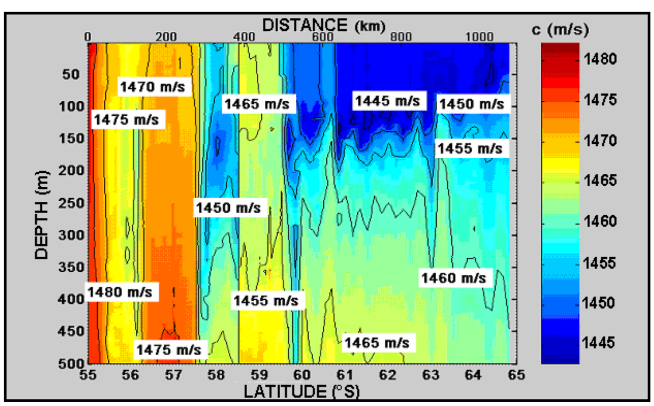

FIG. 7. Sound velocity (m/s) vs. depth (m) and latitude (ºS) derived from temperature, salinity and depth measurements, for the first 500 m of the water column in the Drake Passage.

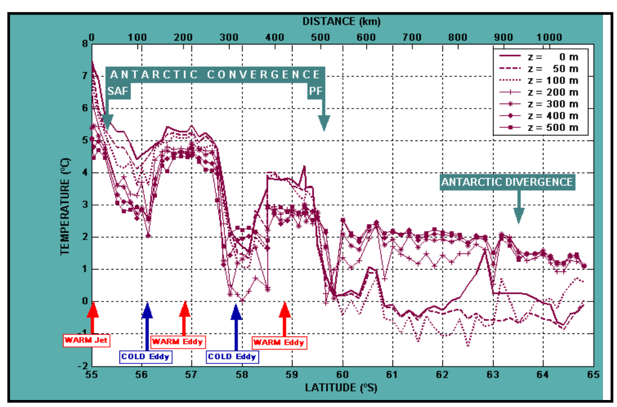

FIG. 8. Estimated location of the Antarctic Convergence and Antarctic Divergence Zones, from temperature (ºC) measurements vs. latitude (ºS) obtained for: 0 m, 50 m , 100 m, 200 m, 300 m, 400 m y 500 m.