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엘리펀트섬 인근 해역에서 관측된 ADCP 유속과 지형류의 비교분석; 1996년 하계 정선 관측치에 나타난 결과

Comparison Study for Flow Velocities Observed by ADCP and Geostrophic Currents; Results obtained from a Hydrographic Section in the Weddell Sea During 1996 Field Season

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한국해양연구소

제출문

한국해양연구소장 귀하

본보고서를 "엘리펀트섬 인근 해역에서 관측된 ADCP 유속과 지형류의 비교분석" 과제의 최종보고서로 제출합니다.

1998년 2월

연구책임자: 이 형 모
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요 약 문

I. 제목

엘리펀트섬 인근 해역에서 관측된 ADCP 유속과 지형류의 비교분석;
1996년 하계 정선 관측치에 나타난 결과

II. 연구 개발의 목적 및 중요성

1. 목표
   Acoustic Doppler Current Profiler (ADCP)에 의해 관측된 유속과 지형류의 비교분석.

2. 중요성
   ADCP에 의해 관측된 유속과 지형류의 상관관계가 클 경우, 무류점에서의 절대 유속 산정법이 개발가능하고, 이를 이용하여 산정될 수 있을 절대유속장은 부유퇴적물이나 표영생물의 오랜 기간에 걸친 운송량 산정에 사용될 수 있음.

III. 연구 내용

1. 1996년 하계 정선 관측치에 나타난 수괴의 확인 및 특성 파악
2. 정선 관측치가 내포하고 있는 현상의 파악
3. ADCP에 의해 관측된 유속과 지형류의 비교분석.

IV. 결과

1996년 하계 정선 관측 결과로 확인된 수괴는 Antarctic Surface Water, Winter Water, Lower Circumpolar Deep Water, 그리고 저염의 Antarctic Slope Front Water이다. 그 중 저염의 Antarctic Slope Front Water는 shelf break의 북쪽, 수심 약 300 m인 곳에서 V자 형태를 띈 이중전선의 모양을 갖는 특성을 보였다. ADCP에 의해 관측된 유속과 지형류를 비교한 결과, 관측된 유속장은 비선형 현상의 영향이 큰 것으로 나타났다.

V. 차후 연구 방향에 대한 제언

제 10차 남극과학연구단에 의해 1996년 남극 하계기간 중에 수행된 정선 관측은 생물의 분포상 및 그의 변화에 초점을 맞춘 것으로 대다수의 정점들이 표층 200 m까지만 관측되었다. 그러나 생물의 변화 양상도 물리적 환경의 지배를 받으므로, 관측해역의 종합적인 이해가 근본 개념으로서, 모든 실험 및 관측을 계획할 때에 고려되어야 한다.

한 예로써, 확인된 V자 형태를 띈 이중전선은 생물, 지질, 화학의 변수 분포에 대한 이해가 중요하고, 또한 이에 대한 역학적 해석은 아직 충분히 연구되지 않은 중요한 현상이다. 이를 위하여, 정점의 간격을 좁게한 세밀한 관측을 물리, 생물, 지질, 화학의 변수에 대하여 수행하도록 지원되어야 한다. 또한, 장기간에 걸친 여러 정점에서의 유속계의 계류는 현상의 시간적 변화특성을 파악하기위한 필수적인 요소이다.

SUMMARY

1. Title

Comparison Study for Flow Velocities Observed by ADCP and Geostrophic Currents; Results obtained from a Hydrographic Section in the Weddell Sea During 1996 Field Season

II. Purpose and Significance of the Study

1. Purpose

To compare flow velocities observed by an acoustic Doppler current profiler (ADCP) with calculated geostrophic currents

2. Significance

It has been one of the crucial problems in the community of physical oceanography to develop methods of finding the velocity at level of no motion. If geostrophic currents and the current field observed by ADCP are highly correlated in some situation, then it will be possible to develop methods of finding the velocity at level of no motion. The absolute velocity obtained by the method can be utilized in other studies, for example, transport estimations of suspended sediments, plankton, etc.

III. Contents

1. Water-masses over the Antarctic continental shelf and slope
2. Temperature and salinity fields
3. A comparison between flow velocities observed by an ADCP and calculated geostrophic currents

IV. Results

From temperature and salinity fields observed during the 1996 field season, identified water masses are Antarctic Surface Water, Winter Water, Lower Circumpolar Deep Water, and Antarctic Slope Front Water with low salinity. The presence of V-shaped double front is also identified. The front is located north of the shelf break. As revealed by flow fields observed by an ADCP, strongly nonlinear processes dominated the observed currents, which were represented by fronts and eddy-like features embedded in the density field.

V. Proposals for future researches

In general, we need to have oceanographic data set for the whole water column in the three-dimensional structure, in order to make progress toward the full description of the phenomena mentioned above and to try dynamical interpretation further. Especially for the V-shaped double front identified, we additionally need to map the front with horizontally finer resolution than the present one in the cross-shelf direction and current meter moorings at several depths.

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1. Introduction

Antarctic Bottom Water (AABW) has been known to play an essential role in the abyssal circulation of the world ocean. The AABW occupies the bottom portion of water column and is generally colder than 0° C, though somewhat arbitrary (Gordon, 1971). Reported two major varieties of the AABW are the type of cold and less-saline water originating in the Weddell Sea and the warmer and more-saline type forming in the Ross Sea (Carmack, 1986). Other types are observed in the Davis Sea (Treshnikov et al., 1973), the eastern margin of the Weddell-Enderby basin (Jacobs and Georgi, 1977), the Bransfield Strait (Gordon and Nowlin, 1978), and from off the Adelie coast (Gordon and Tchernia, 1972). There are suggested loadings to the pool of bottom water which do not reach to the bottom of the sea (Carmack and Killworth, 1978; Gordon, 1978, 1981). Carmack and Foster (1975) estimated the rate of production of bottom water at approximately 2-5 X 10^6 m^3/sec in the Weddell Sea.

The AABW is formed in the region near the edge of continental shelf break around Antarctica by mixing of near-surface water with Circumpolar Deep Water. This mixing and other related processes are revealed as strong subsurface gradients of water properties. The subsurface gradients are called as Antarctic Slope Front (ASF) (Jacobs, 1986, 1989, 1991). Jacobs (1991) reviewed its hydrography, currents, processes, and biological productivity. The shape of the front is affected by shelf width. For narrow or relatively shallow shelves, this topographic front becomes shallow and flattens towards the north, merging with the pycnocline beneath the thick and deep temperature minimum. However, for wide shelves, V-shaped double front appears with the minimum salinity in its middle part. The slope front is weaker where shelf water and adjacent deep-water salinities are roughly equal. If nearly undiluted tongs of Circumpolar Deep Water floods the continental shelf, the front is less pronounced, as observed in the Bellingshausen Sea (Potter and Pareon, 1985). Temporal changes of the slope front would be mainly also subject to that of shelf water. Other studies for Antarctic coastal circulation and the slope front include Gill (1973), Carmack (1974), Foster and Carmack (1976), Carmack and Foster (1977), Foldvik et al. (1985a, b), Fahrbach et al. (1992), Ohshima et al. (1996), Kim (1995), and Hofmann and Klinck (1997).

This report is for hydrographic survey carried out during the 10-th Korean Antarctic Research Program, 25-28 December 1996 (Fig. 1). A CTD section was mainly along the 55° W meridian north and south of Elephant Island. Its southern stations located over continental shelf were slightly shifted to the east. The edge of sea ice was located close to the southernmost station. Because this survey was mainly for surface biological research, CTD casts were performed up to the water depth of 200 m, except stations 10, 13, and 14. Locations of stations and other information are listed in Table 1.

In the following section, properties of water masses are summarized, which are identifiable in the study area. Using the properties, observed fields of temperature and salinity are described at sampled stations and along the section. Discussion is in the final section.

2. Water-masses over the Antarctic continental shelf and slope

Summarized below and in Table 2 are properties of water masses found over the Antarctic continental shelf and slope (Carmack, 1986; Kim, 1995).

(a) Antarctic Surface Water (AASW) and Winter Water (WW)

AASW is found from the surface to approximately 300 m depth in the oceanic regime. Its salinity range varies with space and time from approximately 34.35 to 34.45 ppt. In winter its density range is in approximate range of sigma-0 = 27.65 to 27.70 kg/m^3. In summer, due to precipitation, surface heating, and ice melting, the upper layer of AASW becomes warmer and fresher than the lower layer, resulting to the presence of Winter Water (WW). The WW is thought to be a remnant of wintertime convection, which is represented by temperature minimum layer.

Toole (1981) has discussed the seasonal maintenance of the temperature minimum layer. Near the continental margin, and in the central Weddell and Ross gyres, the WW has temperatures near the freezing point and salinities approaching the critical value for the onset of the cabelling instability (Fofonoff, 1956).

(b) Shelf Water (SW)

It is defined as water over the Antarctic shelf regime with salinity greater than the cut-off salinity and potential temperature less than -1.7° C. The cut-off salinity is defined to that at the base of the potential temperature minimum layer of the AASW in the oceanic regime, whose value is from approximately 34.35 to 34.45 ppt, and is 34.40 ppt on the average

(Kim, 1995). Low-salinity Shelf Water is distinguished from high-salinity Shelf Water by the maximum potential density of Lower Circumpolar Deep Water (sigma-0 = 27.87 kg/m^3).

(c) Lower Circumpolar Deep Water (LCDW)

LCDW shows potential temperature greater than 0° C and salinity greater than 34.66 ppt. It is observed with almost no change in characteristics everywhere around Antarctica.

(d) Antarctic Slope Front Water (ASFW)

According to Kim (1995), ASFW is characterized by potential temperature between -1.7° C and about 0.2° C, and salinity greater than the cut-off salinity. The ASFW is observed everywhere around Antarctica except in the Bellingshausen-Amundsen sector between 63° and 155° W along the Antarctic continental slope. Low-salinity ASFW is produced by isopycnal mixing of LCDW with low-salinity Shelf Water. High-salinity ASFW is produced by diapycnal mixing of low-salinity ASFW with high-salinity Shelf Water, which has densities greater than the maximum density of LCDW.

3. Temperature and salinity fields

In this section observed properties of temperature and salinity are described, while referring the properties of water masses described in the last section. Vertical profiles of temperature, salinity, and density are shown at stations north and south of Elephant Island, and the northernmost station over the continental shelf (Fig. 2).

At Station 7, the northernmost station, the temperature minimum of -0.15° C is located at the depth of 80 m within the WW. Temperature minimum of -0.5° C appears at the depth of 100 m at Station 10 within the thicker layer of WW than that of Station 7. It also shows temperature maximum of 1.935° C at the depth of 290 m. The LCDW is identifiable based on its water properties below the WW. At these two stations mixed layer depths are slightly shallower than those of temperature minimum.

However, the WW is not observed at stations south of Elephant Island. At Station 13 temperature profile decrease with depth, except some signals of interleaving waters at depths centered at 150 m and 240 m. There is no mixed layer at this station. It is observed that temperature at the depth of 200 m is warmer than that of the upper layer of 50 m thick at Station 17 which is the northernmost station over the continental shelf. At Station 17 the upper layer almost coincides with the mixed layer which is not present at Station 13.

Temperature contours are shown in Fig. 3. The WW is observed at stations north of Elephant Island. Its core depth becomes deeper at stations 10 and 11 than other stations further north. Isotherms are almost vertical around the Elephant Island. South of the Elephant Island, it is likely that southward heat flux in the upper 100 m is represented by the shape of 0° C isotherm, for example. The presence of sea ice edge plays a role as the cold reservoir.

As shown in Fig. 4, just south of the island, there appears a core of less-saline water which can be bounded by the contour of 34.30 ppt contour.

The core approximately resemble the contour representing the southward heat flux. Salinity contours spreading from the top of Station 23 support the role of the cold reservoir as buoyancy source of less-saline water due to ice melting.

In contrast to the almost vertical isotherms south of the island, isohalines below 200 m depth can be connected to those over the shelf and form V-shaped ones (Figure 4). The pattern of sigma-t distribution is almost similar to that of salinity due to the fact that, in polar regions, salinity controls seawater density more strongly than temperature (Fig. 5). The feature can be identified as the V-shaped double front (Gill, 1973; Jacob, 1986, 1989, 1991) by ranges of temperature and salinity for the ASFW (Kim, 1995). As can be inferred from water masses marked in Figure 5, the observed ASFW turns out to be the low-salinity ASFW which was produced by the isopycnal mixing of LCDW with low-salinity SW.

4. A comparison between flow velocities observed by an acoustic Doppler current profiler and calculated geostrophic currents

Acoustic Doppler Current Profiler (ADCP) was also used to measure instantaneous current profiles at the CTD stations. In order to compare the baroclinic flow field obtained by geostrophic calculations, the ADCP currents are rotated into the direction of the geostrophic current between two neighboring stations. The rotated currents at the level of no motion are subtracted and then interpolated to get the modified current speed in order to obtain the baroclinic flow corresponding the geostrophic flows at the mid-point between two stations. We call it modified ADCP flow field. The level of no motion utilized are at depths of 200 m and 100 m as shown in Figures 6 and 7, respectively. In the two figures the top and middle frames are the geostrophic and modified ADCP flows. The bottom frame is for the difference flow field which is obtained by subtracting the modified ADCP flow from the geostrophic flow. The baroclinic geostrophic flow fields show almost barotropic patterns, but the modified ADCP flow fields show baroclinic pattern. Comparison of magnitudes of the two flow fields reveal the difference of an order of magnitude: the modified ADCP flow fields are, roughly speaking, ten-times faster than those of the geostrophic flow fields. This could be because of the front-like feature in the depth range marked by the WW north of the Elephant Island (Fig. 5). Two features present in the south of the island could also contribute to the difference flow fields: two eddy-like features representing the southward heat-flux and the cold reservoir due to the presence of the sea-ice edge (Fig. 5).

Geostrophic flow is calculated under the assumption that the Coriolis term is in balance with the pressure-gradient term in governing equations of motion. However, the ADCP flow shows the instantaneous total flow field even including nonlinear terms. In this respects, the contribution of nonlinear phenomena is dominant to the total flow field observed at the times of measurements along this hydrographic section. In other words, the Rossby number is greater than one. This is the reason why the middle and bottom frames look very similar, even after taking the differences from the geostrophic flow field.

5. Summary and discussion

As reported in other studies, followings were identified from the CTD section mainly along the 55° W meridian north and south of Elephant Island during the 10-th Korean Antarctic Research Program, 25-28 December 1996.

(1) Winter water was observed at stations north of Elephant Island. The depth of temperature minimum in the winter water is deeper than the bottom depth of mixed layer.

(2) Lower Circumpolar Deep Water was identified from the temperature and salinity profiles at Station 10.

(3) There was the signal of southward flux of heat captured in the upper 100 m layer at stations south of Elephant Island.

(4) Sea ice located further south provided buoyancy forcing to the study area.

(5) The V-shaped double front was identified in the subsurface water north of the continental shelf break and coexisted with Antarctic Slope Front Water.

(6) The flow fields were dominated by strongly nonlinear processes which were represented by fronts and eddy-like features.

Six items listed above are just for qualitative description. There were several phenomena we could not describe further due to lack of proper data. Those are as follows.

(1) Stations 7 and 10, mixed layer depths were slightly shallower than those of temperature minimum. This could be due to, at the time of observation, wind-stirring effect was less-effective than that of net

incoming radiation.

(2) Vertical isotherms north and south of Elephant Island could serve as a barrier for the possible heat flux. Or those could represent phenomena related to the topography around the island.

(3) There are interleaving signals at Station 13

(4) The core of less-saline water in the upper layer south of Elephant Island could be due to surface process, for example, meandering currents, which would need three-dimensional data for process identification.

In general, we need to have oceanographic data set for the whole water column in the three-dimensional structure, in order to make progress toward the full description of the phenomena mentioned above and to try dynamical interpretation further. Especially for V-shaped double front identified, we additionally need to map the front with horizontally finer resolution than the present one at least in the cross-shelf direction. Current meter moorings are also required at several depths.

With the available data set, following can be mentioned for the V-shaped double front. Salinity distribution over the continental shelf was strongly affected by sea-ice melting. The sea-ice melting is definitely caused by the net incoming radiation and could contribute to the formation of V-shaped isohalines representing the Antarctic slope front through mixing precesses. The V-shaped feature would indicate the presence of a conduit next to and along the shelf break for the fluxes of relevant tracers, as mentioned in other studies. As Jacob emphasized in his 1991 paper, it is believed that the study area could be one of sites where descended water from the near-surface is on its way to the deep ocean through bottom boundary layers beneath the Antarctic Slope Front.

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Table 1. Information on CTD observations

Station	Observation Time / (Local time)	Cast used	Casted Depth (m)	Latitude & Longitude
7	Dec. 26 1996 / (18:25)	up	200	60° 04.26′ S 54° 58.19′ W
8	Dec. 26 1996 / (22:15)	up	200	60° 12.98′ S 55° 01.85′ W
9	Dec. 27 1996 / (05:25)	up	200	60° 31.98′ S 55° 02.40′ W
10	Dec. 27 1996 / (13:10)	up	728	60° 46.37′ S 55° 03.38′ W
11	Dec 27 1996 / (15:15)	up	307	60° 58.95′ S 54° 56.71′ W
12	Dec. 27 1996 / (21:10)	up	199	61° 17.31′ S 55° 01.25′ W
13	Dec. 28 1996 / (00:06)	up	748	61° 29.11′ S 54° 55.86′ W
14	Dec. 28 1996 / (06:30)	down	748	61° 44.72′ S 55° 04.45′ W
17	Dec. 26 1996 / (00:55)	up	200	62° 30.17′ S 54° 04.11′ W
19	Dec. 25 1996 / (20:20)	up	202	62° 59.97′ S 53° 57.40′ W
21	Dec. 25 1996 / (14:05)	up	203	63° 29.77′ S 54° 05.14′ W
22	Dec. 25 1996 / (11:30)	up	205	63° 44.49′ S 54° 01.12′ W
23	Dec. 25 1996 / (07:30)	up	202	64° 00.00′ S 54° 03.00′ W

Table 2. Generalized characteristics of water masses in the subpolar regime. S at θ_{min} is for the salinity at the base of the potential temperature minimum layer of Antarctic Surface Water in the oceanic regime. *s* and *w* with AASW are for summer and winter seasons, respectively. *ℓ* and *h* with SW and ASFW are to indicate low- and high-salinity, respectively. From Kim (1995).

Water Mass	Potential Temperature (℃)	Salinity	Oxygen (mℓ/ℓ)	Potential Density
AASW(*s*)	θ>-1.7	S<34.35	O_2>7.5	σ_0<27.65
AASW(*w*)	-1.9<θ<-1.7	34.35<S< S at θ_{min}	7.0<O_2<7.5	27.65<σ_0<27.70
LCDW	θ>0	S>34.66	4.0<O_2<5.5	27.77<σ_0<27.87
SW(ℓ)	θ<-1.7	S at θ_{min}< S<34.60	O_2<7.0	27.70<σ_0<27.87
SW(*h*)	θ<-1.7	S>34.60	O_2<7.0	σ_0>27.87
ASFW(ℓ)	-1.7<θ<0	S at θ_{min}< S< 34.60	5.5<O_2<7.0	27.70<σ_0<27.87
ASFW(*h*)	-1.7<θ<0	S>34.60	5.5<O_2<7.0	σ_0>27.87

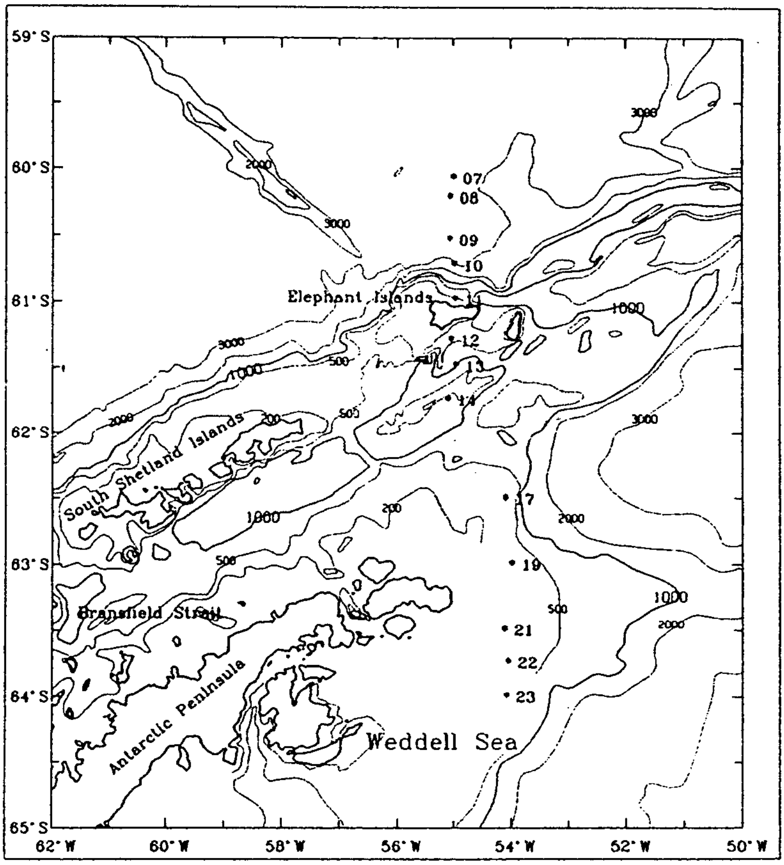

Figure 1. Bathymetry and station locations for the 10th Korea Antarctic Research program, 1996

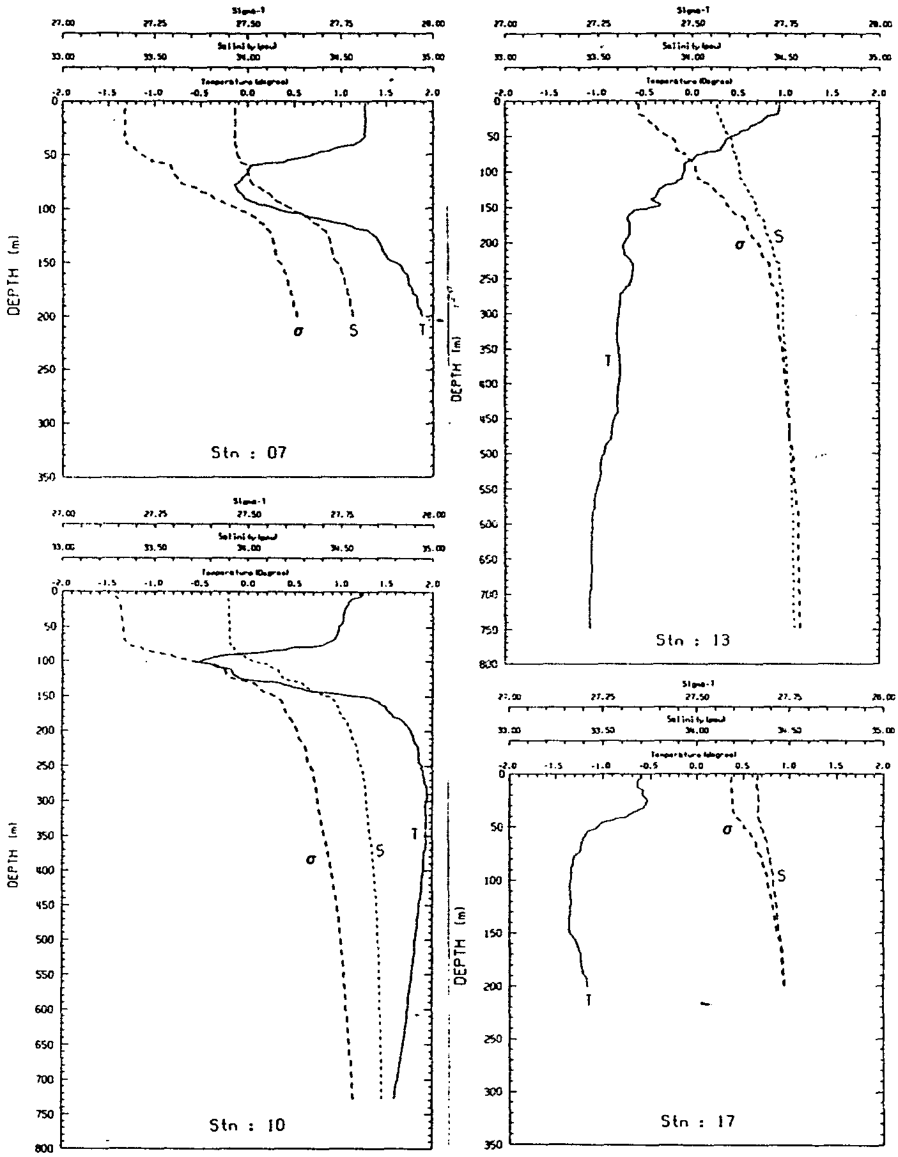

Figure 2. Temperature, salinity, and density profiles at sample stations

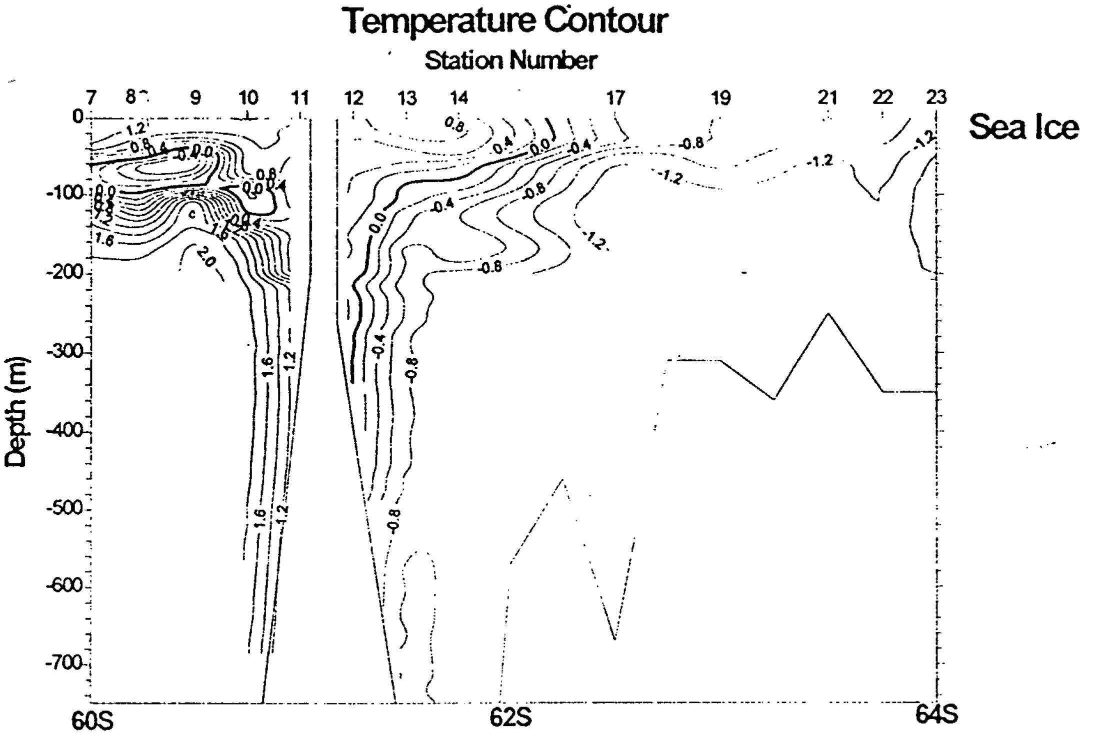

Figure 3. Contoured temperature field

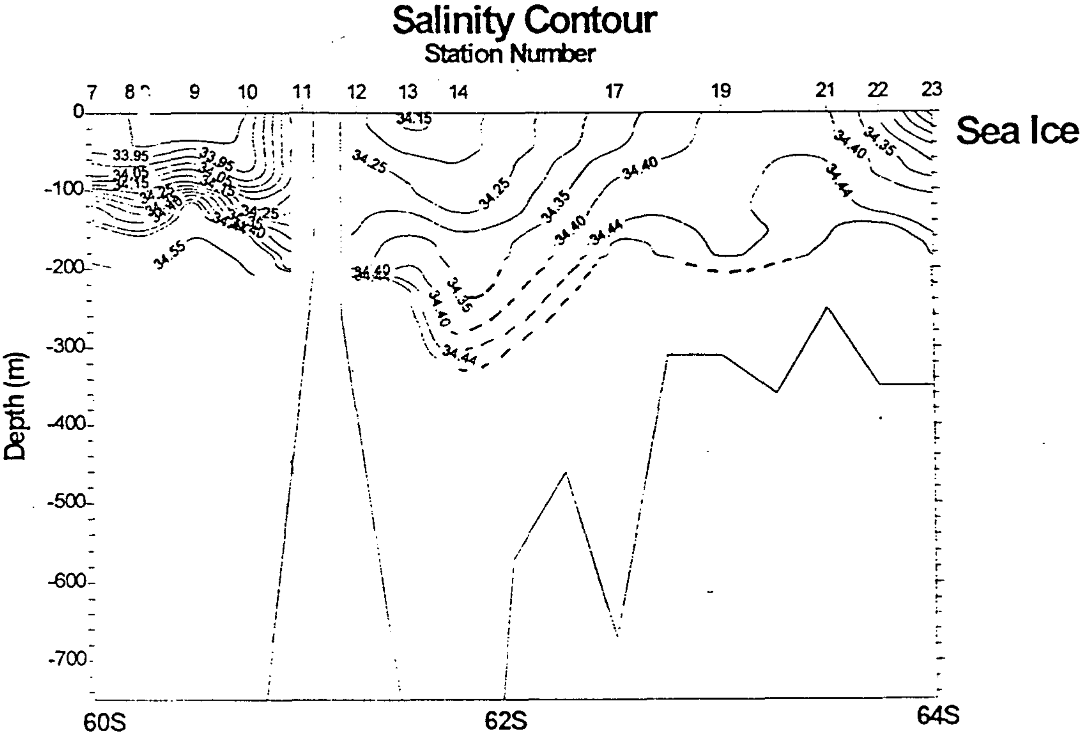

Figure 4. Contoured salinity field

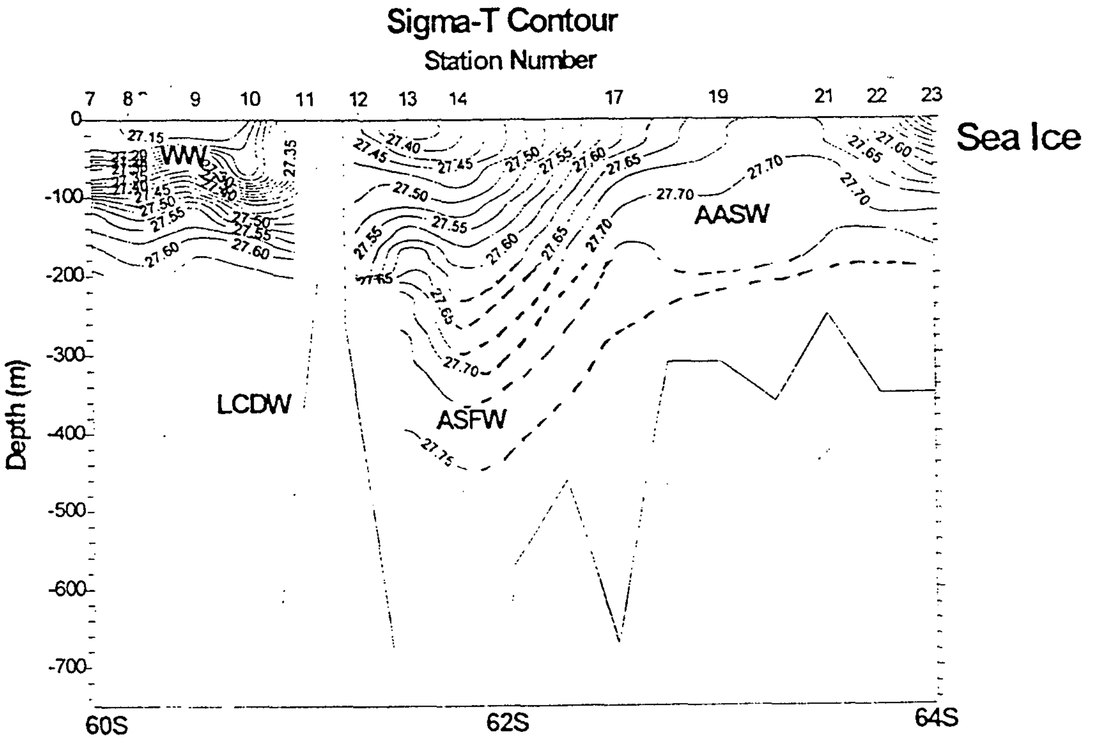

Figure 5. Contoured density field

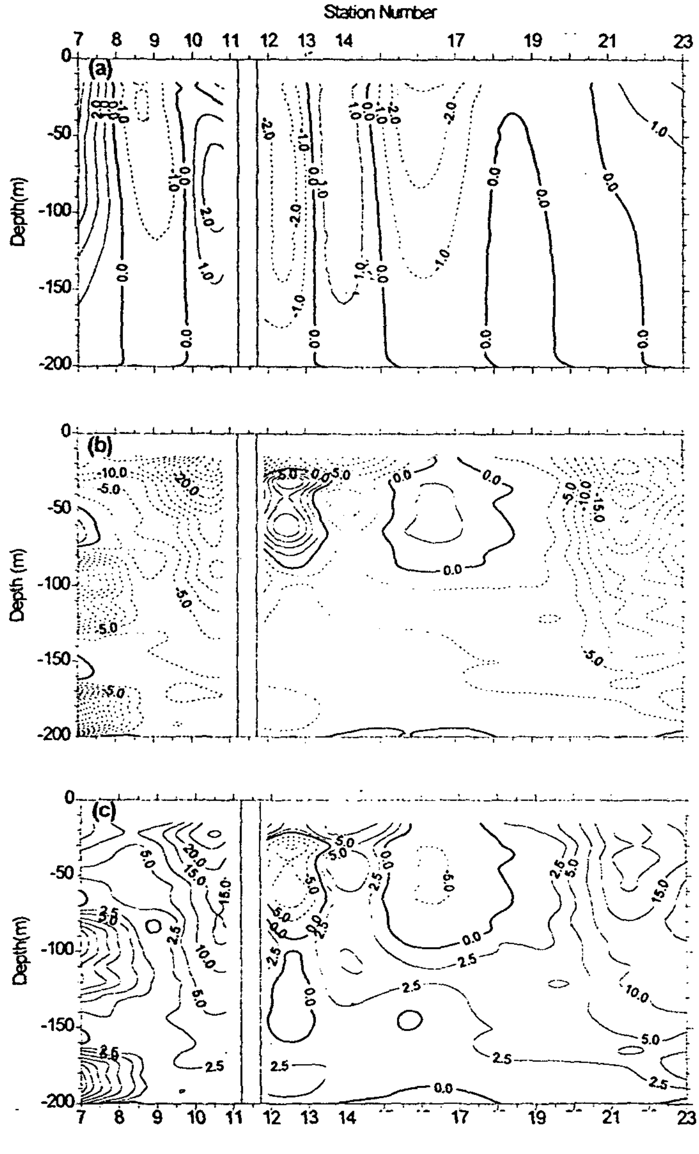

Figure 6. (a) Geostrophic flow field computed with the level of no motion at the depth of 200 m. (b) Modified ADCP flow field (c) Flow field of the difference obtained by subtracting the modified flow field from the geostrophic flow field.

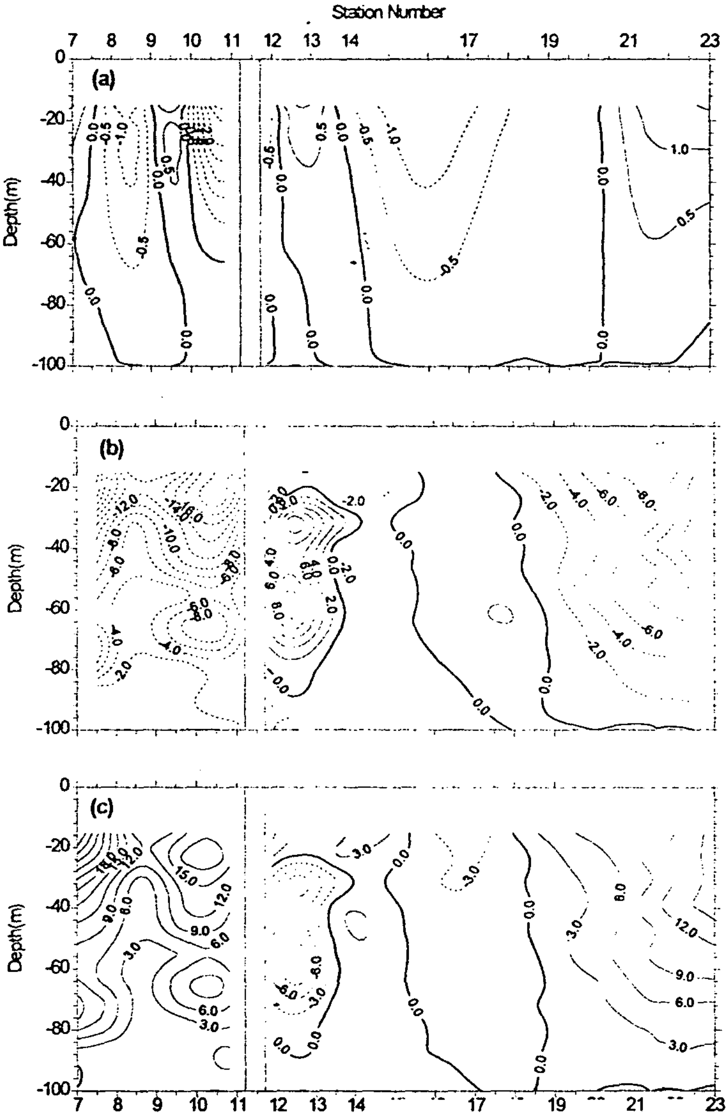

Figure 7. Same as Figure 6 except the level of no motion at the depth of 100 m