COMPARISON OF GEOSTROPHIC CIRCULATION WITH TRAJECTORY MEASUREMENTS OF SATELLITE TRACKED BUOYS IN THE EASTERN BELLINGSHAUSEN SEA, ANTARCTICA

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RESUMO

Bóias rastreadas por satélite oferecem ao cientista marinho uma ferramenta poderosa para a medida direta das correntes superficiais, através o deslocamento progressivo desses derivadores com tempo. Este estudo compara estimativa da corrente superficial obtida das duas bóias brasileiras, com a circulação geostrófica indireta, para aquela região do Mar de Bellingshausen, à oeste da península antártica. Correntes médias para as bóias perto e afastada da costa foram 13cm/s à 201° e 2cm/s a 101°, respectivamente, estimada usando regressão linear com as trajetórias. Dois mapas da circulação geostrófica, um do início do experimento, o outro do fim do experimento, foram comparados com as trajetórias. Inspeção das trajetórias das bóias indicaram a presença de um ou mais vórtices no campo de fluxo, o maior tendo um período de mais ou menos 17 dias. Movimento, semelhante a vórtices, para a trajetória afastada da costa, constituiu 33-88% da trajetória em geral, em comparação a 3-4% para a trajetória perto da costa. Estimativos da energia causada pelo movimento de vorticidade indicaram que a trajetória afastada da costa contém 6-18 vezes mais vorticidade do que para a trajetória perto da costa.

ABSTRACT

Satellite-tracked drifting buoys offer the marine scientist a powerful tool for the direct measurement of surface currents, through the progressive displacement of these drifters with time. This study compares estimates of the surface current obtained from two Brazilian buoys, with the indirect geostrophic circulation, for that region of the Bellingshausen Sea just West of the Antarctic Penninsula. Mean currents for the nearshore and offshore buoys were 13cm/s toward 201° and 2cm/s toward 101°, respectively, estimated from linear regression of the trajectories. Two maps of geostrophic circulation, one from the start of the experiment, the other from the end of the experiment, were compared with the trajectories. Inspection of the buoy trajectories showed the presence of one or more eddies in the flow field, the largest one having a period of about 17 days. Eddy like motion for the offshore trajectory contributed 33-38% to the overall trajectory, compared to 3-4% for the nearshore trajectory. Estimates of the energy due to eddy motion showed the offshore trajectory to contain 6-18 times more eddy motion than for the nearshore trajectory.

1. INTRODUCTION

Oceanic circulation in the Bellingshausen Sea, located on the western side of the Antarctic Penninsula, is still known only in terms of its large scale clockwise gyre, (Gordon and Molinelli, 1982), a southwesterly surface coastal current along the East side of the Sea (Gordon, 1971); and a westerly bottom current, Gordon (1966).

Details about the mesoscale circulation and physical exchange processes in the central and eastern parts of the Bellingshausen are not represented in the literature. Because of our limited knowledge about water exchange between this Sea and the Strait of Bransfield, an experiment was made in the eastern extremity of the Bellingshausen during the austral summer of 1987. A previous report by Stevenson and Stech (1989) described features of the surface circulation in the central and eastern parts of the Sea. Their study was based on 1987 Brazilian buoy data and 1979 FGGE (First GARP Global Experiment) buoy data. Our study is a continuation of that work, and makes a comparison of Brazilian buoy and geostrophic circulation data, in the Bellingshausen Sea.

The area of our study was determined by both the location of the drifter trajectories and the associated hydrographic stations, used during the Vth Brazilian Antarctic Expedition, in the Eastern Bellingshausen Sea (Figure 1). The overall surface circulation experiment was completed during the period of 17 January to 15 April, 1987, although the data used in this report were limited to the interval 17 January to 03 March, 1987, when the buoys were still in the vicinity of the station grid. The field work was conducted aboard the Brazilian Oceanographic Support ship, Barão de Teffé.

2. DATA AND METHODS

Hydrographic Data

Hydrographic data were collected at 13 stations, divided into two sets. The first set of 8 stations was completed just after launching the two buoys; the second set of 5 stations was completed just after recovery of one of the buoys. The locations of these stations and the buoy deployment positions, together with the regional bathymetry, are shown in Figure 2.

At each station a STD (Salinity, Temperature, Depth) instrument was lowered to a depth of 1000m to obtain vertical profiles of these two properties. Meteorological observations were routinely made at each station to obtain various measurements, such as wind speed and direction.

After data processing, the final measurements of temperature and salinity are considered known to within 0.01C and 0.01PSS (Practical Salinity Scale), respectively. These data formed the basis for the determination of the density field and subsequently the geostrophic circulation field.

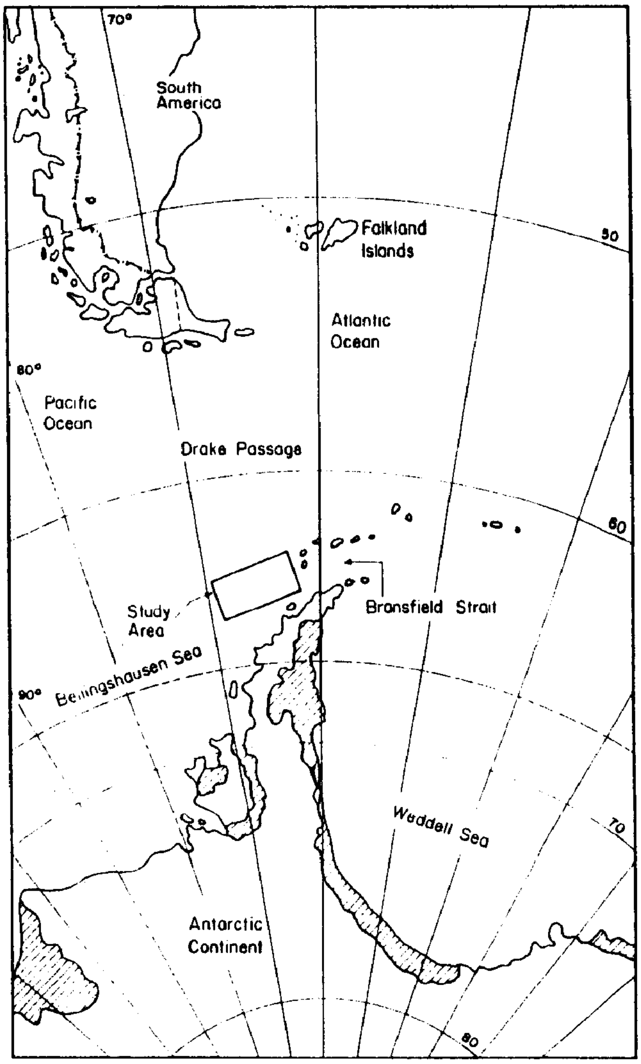

Figure 1 - Study region is shown in rectangle, West of Antarctic Penninsula.

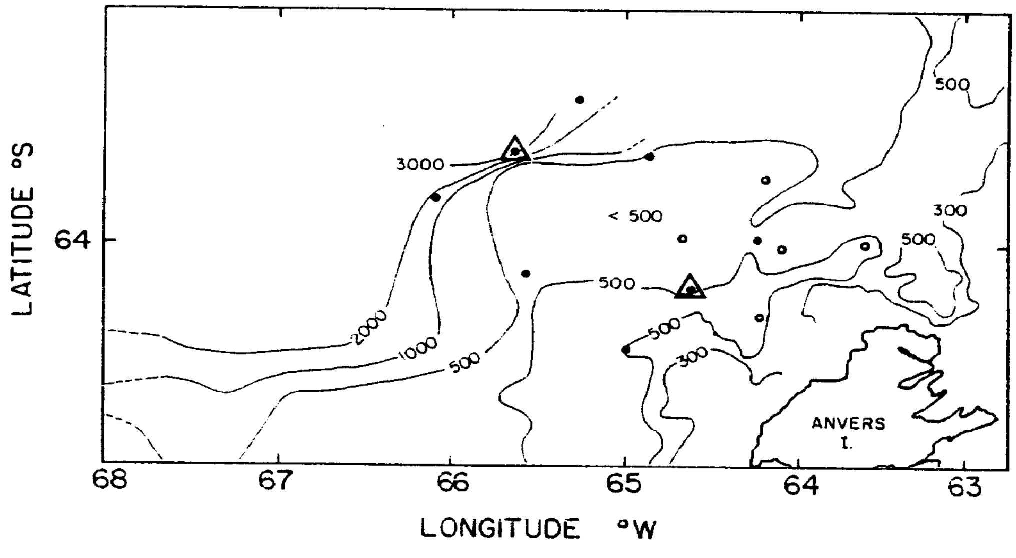

Figure 2 - Solid and open circles represent initial and final sets of oceanographic stations, respectively; buoys launched at triangles. Bottom bathimetry is in meters.

Because the maximum depth of the STD casts varied from a few hundred meters to more than 1,000m, 500 decibars was selected as the reference level for the geostrophic field. This level offered the advantage of having a number of station depths close to or greater than 500m. Those stations with STD depths greater than 500m provided a basis for extrapolation of the remaining shallower station data to this reference level. The method used has been described by da Silva Jr. (1989).

Wind Measurements

Wind measurements were made at each of the STD stations. Anemometers, located atop the vessel, about 12m above the waterline, provided data to the nearest m/s and degree.

Wind observations were first put into (u,v) component form. Mean zonal and meridional wind components were then determined for each set of oceanographic stations.

Buoy Trajectories

While the drifting buoys transmit their data to satellites passing overhead in polar orbits, the buoy data for this study were obtained in quasi real-time during the first several weeks of the experiment, by using the ship's telex to access our data base archived at CLS ARGOS in Toulouse, France. The remainder of the data were obtained after the experiment, in the form of computerized listings received from ARGOS.

The precision of the buoy positions is defined by ARGOS, while the accuracy is dependent upon the stability of the master crystal within each of the buoys transmitters. Because ARGOS provides buoy positional data to within 0.001 degree of latitude (111m), this is the precision routinely available. Previous experience, with our buoys in Brazilian waters, indicates that the positions of our buoys are known to within 0.0026 degrees latitude (285m), for 1 standard deviation (Stevenson and Alonso, 1986).

The frequency of available positional data varies with latitude, with more data being collected at the higher latitudes, due to convergence of satellite orbits. When the data were obtained by ship telex, up to 4 positions were obtained per day; from the ARGOS data archive, it was possible to obtain up to 11 positions per buoy per day.

How well the buoy follows a specific parcel of water, or to what extent its trajectory represents the actual current is not easily determined. In general, one can expect better results if the ratio of the cross-sectional area of the drag element to the surface float is large. Niiler et al (1987) suggested that ratios as large as 50:1 are desirable. Since the actual drag is related to the hydrodynamic coefficient of drag of these frontal areas, it is probably more accurate to include drag coefficients in this ratio. The effective drag ratio of the area of the subsurface drag element (Ad) to the area of the surface buoy or float (Af) is determined by the following equation

$$R = (AdxCdd)/(AfxCdf) , \qquad (1)$$

where Cdd and Cdf represent the hydrodynamic drag coefficients for the drag element and the buoy, respectively.

A large ratio (R) indicates greater efficiency in following the water. A small ratio suggests that the drifter will be more sensitive to effects of windage, that is, the wind friction on the exposed parts of the buoy. For technical and economical reasons, it is not always practical to construct or use buoys with large drag ratios. The effective frontal area ratio for our buoys is 8.9. When the drag coefficients are included, this ratio increases to 13:1. Our buoys fall within the range $10 < R < 50$ indicated for most drifters (Niiler et al, 1987). A more recent report by Mackas et al (1989) noted a difference of only 0.10cm/s in mean velocity, estimated by three types of drogued drifters, whose frontal area ratios varied from 10:1 to 50:1 (for the referenced drifter). Based on results by Krauss et al, (1989) for drogued buoys similar to ours, we estimate that the slippage of our buoys in the water, due to wind effects on the exposed parts of the buoy, is negligible for winds up to 15m/s. This slippage may approach 2cm/s for winds of 20m/s (gale conditions).

3. RESULTS AND DISCUSSION

The trajectories of the two drifters are shown in Figure 3. From the figure it can be seen that the buoys were launched along a line perpendicular to the axis of the coast.

The mean currents estimated from the two drifting buoys are shown in Table 1. The mean offshore current was 1.9cm/s toward 101 deg., while the nearshore current had a mean speed of 13.2cm/s toward 201 deg. It is important to remenber that the same number of observations was not used for the two trajectories, due to the fact that the nearshore buoy left the region after about 6 days.

The mean surface wind based on the initial STD stations was 4.9m/s toward 191 deg and 8.9m/s toward 243 deg for the stations at the end of the experiment, respectively. The mean nearshore current was 2.7% of the magnitude of the mean wind speed.

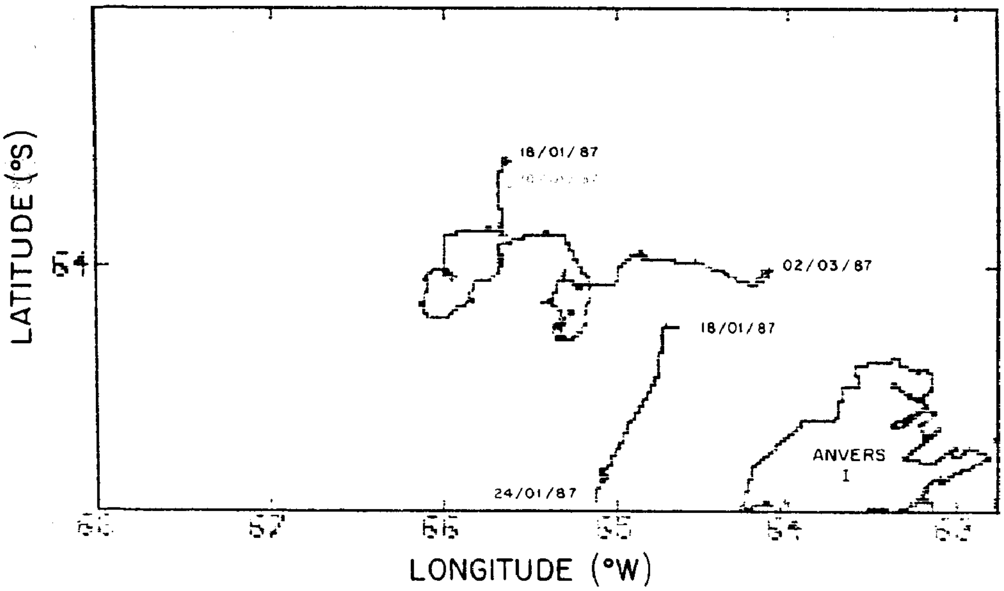

Fig. 3 - Trajectories for nearshore and offshore buoys launched on 18 January, 1987, along a transect tangent to Anvers Island. Nearshore buoy moved out of the study area after 6 days.

TABLE 1

MEAN CURRENT AND WIND VELOCITIES

BUOY	Nº OBS	u CM/S	v CM/S	V CM/S	DIR DEG	WIND DATE	V M/S	DIR DEG
OFFSHORE	79	1.9	0.4	1.9	101	17-19/01/87	4.9	191
NEARSHORE	13	-12.3	-4.7	13.2	201	02-03/03/87	8.9	243

Characteristics of the trajectories for the two buoys were substantially different. The component trajectories for the offshore buoy contained large eddy like motions, with periods of 16-18 days (Figures 4, 5), while variations in the trajectory of the nearshore buoy (Figures 6, 7) were only about 10% as large. The variation of the current along each trajectory is indicated by the goodness of fit estimates (R^2) noted in Table 2. For the nearshore trajectory, only 3-4% of its variation is due to eddies, while for the offshore buoy this value increases to 32-88%. The magnitudes of the variances reversed between the components of the offshore and onshore trajectories. This reversal indicates the presence of substantially more eddy like motion along the east/west direction for the offshore trajectory, compared with more eddy like motion in the latitudinal direction for the nearshore trajectory. A more quantitative estimate of the energy contained in the eddy like motions along each trajectory was calculated from the relation

$$E(x,y) = \sum (x', y')^2/t \qquad (2)$$

where x', y' are the longitudinal and latitudinal displacement components for the normalized series, and t is the elapsed time of the series. A comparison of these values (Table 2) shows the offshore trajectory to contain 6-18 times more energy than the nearshore trajectory.

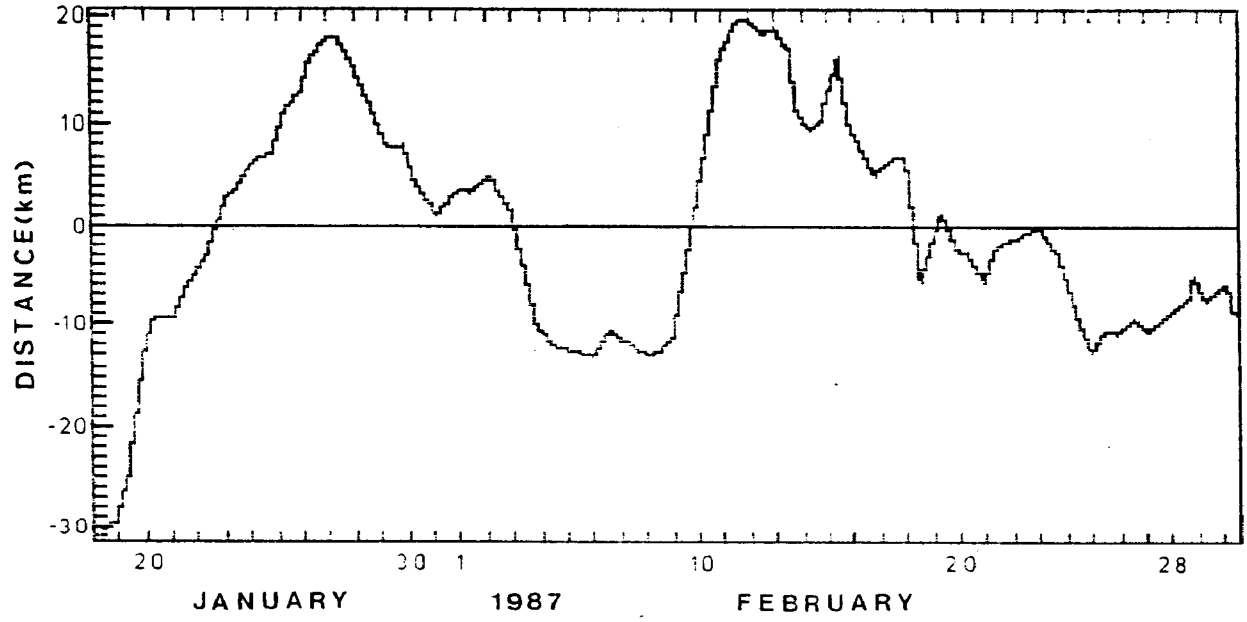

Fig. 4 - Latitudinal displacement of offshore buoy from the mean latitudinal velocity, with time.

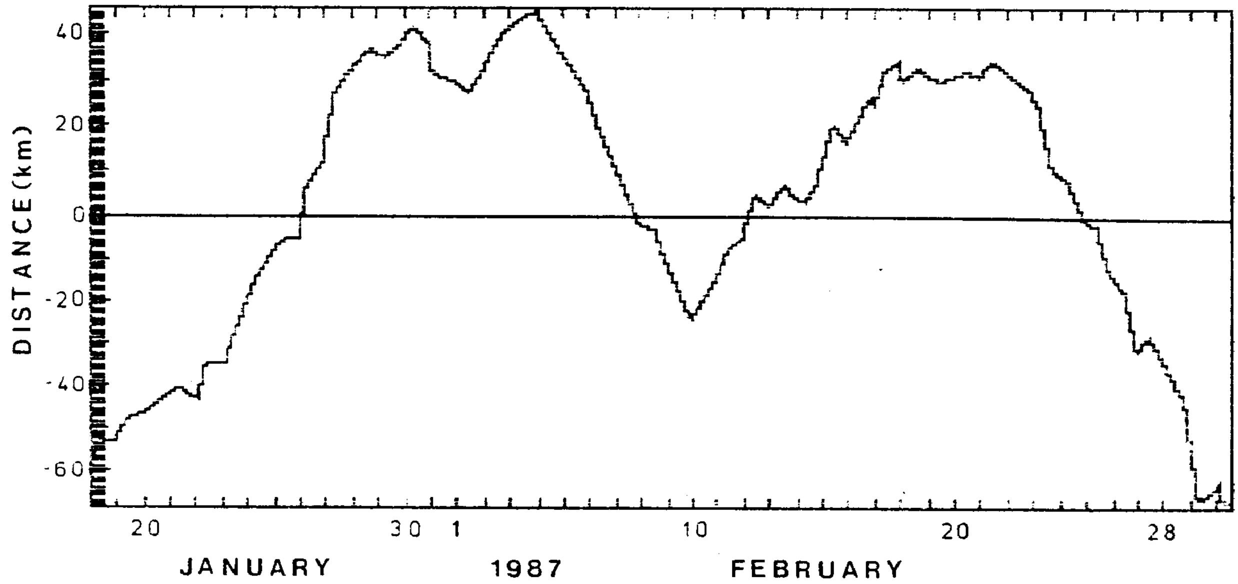

Fig. 5 - Longitudinal displacement of offshore buoy from the mean longitudinal velocity, with time.

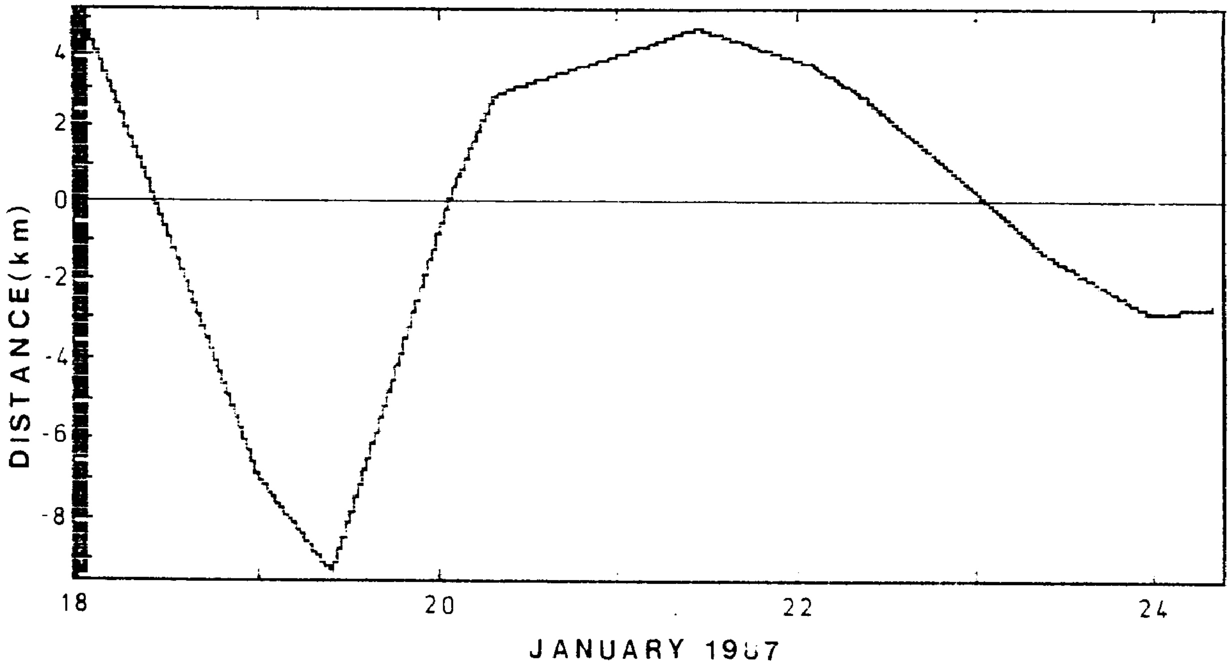

Fig. 6 - Latitudinal displacement of nearshore buoy from the mean latitudinal velocity, with time.

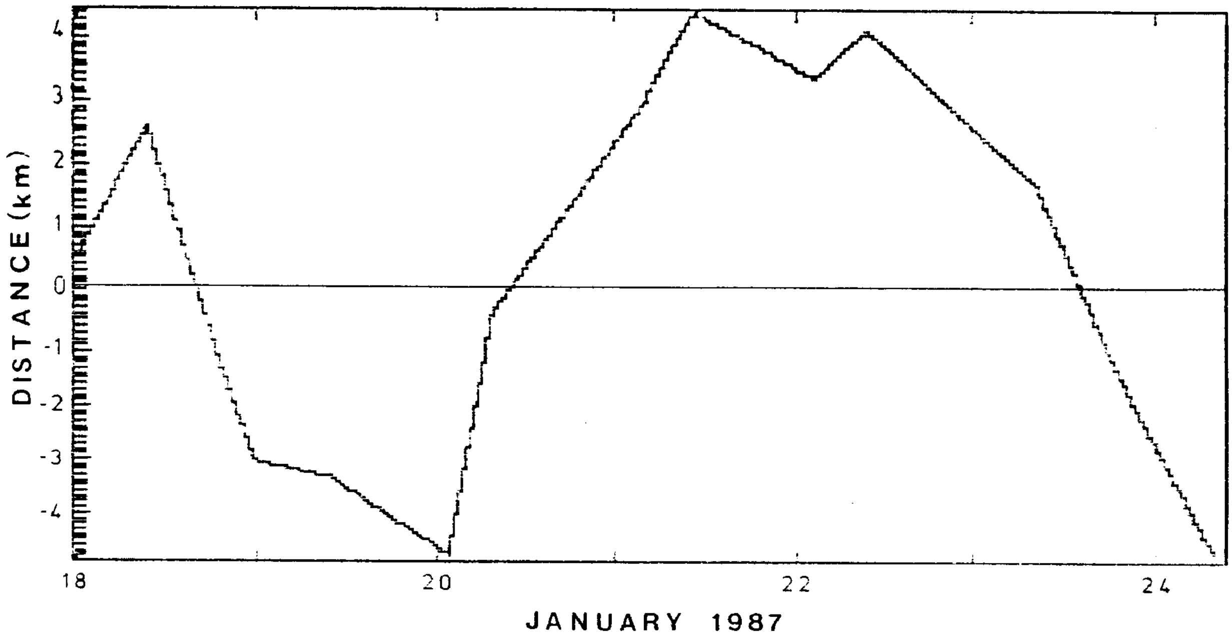

Fig. 7 - Longitudinal displacement of nearshore buoy from the mean longitudinal velocity, with time.

TABLE II

VARIABILITY IN BUOY TRAJECTORIES

BUOY	VARIANCE ($m^2 \times 10^8$)		(R^2)		E (m^2/s)	
	long.	lat.	long.	lat.	long.	lat.
OFFSHORE	6.881	1.576	0.68	0.12	4.544	2.842
NEARSHORE	1.809	5.118	0.97	0.96	252	461

The relative geostrophic circulation at 10m depth for the two data sets is shown in Figures 8 and 9. It can be seen that the velocity fields varied at the start from 8 to 22cm/s for 17-18 January and from 5 to 7cm/s, at the end of the experiment (2-3 March). A large eddy is apparently embedded in the local circulation at the start of the experiment (Figure 8). An eddy like circulation is also present at the end of the experiment (Figure 9). From these two isolated data sets, we cannot say that these figures show the same eddy.

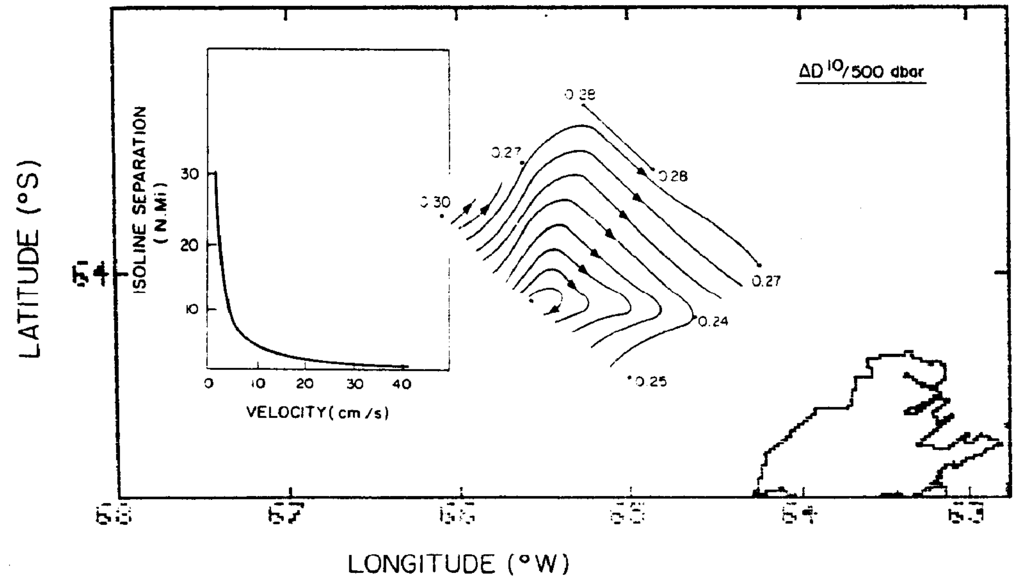

Fig. 8 - Relative geostrophic circulation at 10m, referenced to 500 decibar level, for the initial set of oceanographic stations. Speed is determined from the separation distance between adjacent isolines (inset graph).

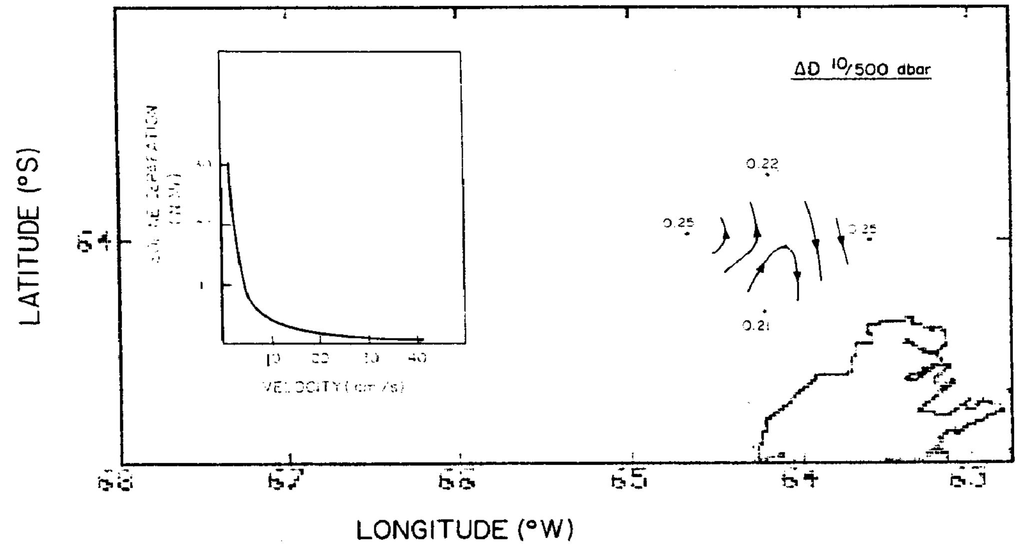

Fig. 9 - Relative geostrophic circulation at 10m, referenced to 500 decibar level, for the final set of oceanographic stations. Speed determination is same as for Figure 4.

A qualitative comparison of the two drifter trajectories (Figure 3) with the geostrophic circulation at the beginning and end of the experiment (Figures 8-9) shows both similarities and differences. The geostrophic circulation, while a convenient approximation to the actual circulation, suffers from a number of well known limitations. The geostrophic current speeds are also relative, in that the current speed is assumed to be zero at the chosen reference level (500 dbars), when in fact the current may be greater than zero at that level.

A comparison of the current speed obtained from the buoy trajectories and geostrophy provides a ratio of 0.3-.6:1. Published ratios (Kirwan et al, 1978; McNally, 1981; da Silva Jr., 1989) indicate a range of 2-3:1, 4-5:1 and 4:1, respectively. This variation in current speed may be sometimes explained by the presence of an Ekman current that hasn't yet come into equilibrium with the geostrophic flow. Velocity errors may also be due to the integrated displacement effect of large surface waves on the surface buoy, wind drag or "slippage" errors, etc. For our experiment, however, the sets of oceanographic stations required only 2-3 days time, while the offshore trajectory covered a period of more than 40 days. This large time interval for the offshore buoy is considered sufficient to average out larger velocities that may have been present for a few day's time. Comparison of the 6-day nearshore trajectory with the 2--day geostrophic field yields a ratio of about 1-1.5:1, closer to the published literature.

The presence of the large eddy registered by the offshore buoy trajectory is readily apparent from the initial geostrophic circulation field (Figure 8). The fact that the same buoy was recovered within the area of the final geostrophic field, supports the idea that the eddy present at the start of the experiment was, in fact, the same eddy 40 days later.

4. CONCLUSIONS

From the two satellite tracked drifter trajectories and geostrophic circulation fields, it was possible to improve our understanding of the mesoscale circulation in the eastern part of the Bellingshausen Sea.

The nearsurface current within 50km of the Penninsula was slightly South of East, at about 2cm/s. At the same time on the continental shelf, the current was alongshore and southward at 13cm/s.

The offshore buoy trajectory indicated the presence of a large eddy or vortice, whose period was on the order of 17 days. This variation in the trajectory accounted for 32-88% of its total variation. The geostrophic circulation field for the same area showed the presence of this large eddy. Because the nearshore trajectory included only 6 days time, variations in its time series could not effectively confirm this large eddy, although smaller scale variations were present and accounted for 3-4% of the trajectory's variation. The geostrophic circulation field at the end of the experiment suggested the presence of an eddy. Because the satellite tracked drifter trajectory provided continuity in time and space between the two geostrophic fields, we conclude that the eddy observed at the start and end of the experiment are the same

An index of the eddy like energy contained in the trajectories was determined for each trajectory. The offshore trajectory contained 6-18 times more energy than for the nearshore trajectory. It must be remembered, however, that the eddy was apparently mostly offshore during the time when the nearshore buoy was in the study area. This could explain the much smaller energy indicated for the nearshore trajectory.

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