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WATERMASSES, CURRENTS AND TIDES AT THE SOFALA BANK, NOVEMBER 1987

by

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RESUMO

Investigou-se a zona sul do Banco de Sofala. Esta zona foi coberta com uma densa rede de estações hidrográficas e tendo sido ancorado um conjunto de dois correntómetros e um medidor de pressão. Observou-se água com salinidade elevada perto da costa, com um valor máximo superior a 36,6 partes por mil. Discutem-se tanto as correntes médias como as de marés. A direccção das correntes médias é determinada pelo talude continental e parecem serem influenciadas pelo vento. As marés possuem, a 60 metros de profundidade, uma componente semi-diurna muito forte cujo eixo principal, com cerca de 53 cm/s, é perpendicular à linha da costa. Considera-se a possibilidade das correntes de marés contribuirem para o transporte, por alguns kilometros por dia, de seres planctónicos com migrações verticais diurnas.

ABSTRACT

The southern part of the Sofala Bank was investigated. A net of closely spaced hydrographic stations were obtained and a current meter mooring consisting of two current meters and a bottom pressure recorder was deployed. High salinity shelf water was observed near shore with a maximum salinity above 36.6 ppt. Both average and tidal currents are discussed. The mean currents are steered by the continental slope and seem to be influenced by the wind. The tides have strong semidiurnal components, with a major axis of 53 cm/s perpendicular to the coast at 60m depth. The possibility that the tides may transport passive drifters with a diurnal vertical migration pattern up to a few kilometres a day is considered.

1. INTRODUCTION

The Sofala Bank, central Mozambique, is an important fishing area. It has previously been documented (Jorge da Silva,1986, Gammelsrød,1992) that variations in the environmental conditions have a major impact on the shrimp fishery in the area. A cruise was therefore designed to study small-scale processes and time variations of the oceanic conditions.

At the Sofala Bank the salinity of the water masses has a large variability. In the central and northern part low salinities are found due to the influence of the Zambezi River. In the dry season the rivers in the southern part some times dry out, and very high salinities are occasionally observed (Brinca et al., 1981, Brinca et al. 1983). As the cruise took place in the end of the dry season, we concentrated on the southern part to verify the existence of this high salinity shelf water (HSSW).

The general circulation in the area is dominated by the southbound Mozambique current off the shelf (Sætre and Silva, 1984), and with a countercurrent upon the shelf, thus giving rise to cyclonic eddies. Jorge da Silva(1984) have studied the Sofala Bank circulation in some detail, and discussed the occurrence of cyclonic eddies on the shelf. This cruise was exclusively designed for the physical oceanography program, so we had the advantage to obtain quasi synoptic sections. For the first time direct current measurements were obtained in the area, and the structure and amplitudes of both average and tidal currents are discussed.

For more recent observations from the area, see Paula e Silva and Hoguane (1989), Steen and Hoguane (1990a,b).

2. WATER MASSES

Following Jorge da Silva (1984) we have distinguished between three water masses in the area:

i) Low Salinity Shelf Water (LSSW) is defined as water with salinity below 34.8. Close off the river mouths in the rainy season the salinity goes down to about 20. The Zambezi river is the most important source of fresh water with an average annual runoff of about 100 km^3, compared to the total for the central Mozambique of about 127 km^3 (Sætre and Jorge da Silva, 1982).

ii) Oceanic water ($34.8<S<35.4$), is the name denoted to a mixture of Equatorial Surface Water and Subtropical Water transported by the Mozambique Current.

iii) High Salinity Shelf Water (HSSW) is defined to have salinities above 35.4, occasionally salinities above 37.2 is observed in the nearshore zone. Jorge da Silva (1984) indicated that this water is formed through evaporation in the mangrove zones.

3. INSTRUMENTS AND METHODS

The Russian research vessel "Sevastopolski Rybak" was used as our observation platform. For hydrographic work we used Nansen bottles equipped with reversing thermometers. The water samples were analyzed for salinity onboard using an Australian salinometer, model GM-65. Four sections perpendicular to the coast were taken, see Fig.1 for positions.

The current meter mooring were anchored at the shelf break at 200m depth in position 20° 13'S, 036° 09.1'E (see Fig.1). The mooring consisted of 2 Aanderaa RCM-7 currentmeters and a WLR-7 bottom pressure recorder. The sampling intervals were set to 5 min. The currentmeters were deployed at 60m and 170m respectively, and they were both equipped with temperature and conductivity sensors. The mooring was operating for a period of about 8 days, but the upper currentmeter failed after 5 days due to a failure in the electronic memory. The currentmeters were also equipped with pressure sensors which gave an indication of the actual depth of the recorders.

After about 4 days the surface buoy, equipped with a pole and a flash light, punctuated, yielding a much poorer buoyancy. Combined with the strong current at the end of the observation series, the upper current meter initially at 60m, was dislocated to about 90m depth, and the lower currentmeter from 170m to 176m. This may probably have not influenced the results of the lower current meter, and the upper meter failed when this problem occurred. For more details of the observation methods and the instrumentation, including the design of the rig, see Hoguane (1990).

4. RESULTS

4.1 Horizontal structures.

Horizontal distribution of temperature and salinity at the surface and at the bottom are shown in Fig. 2. The shallow shelf is dominated by HSSW. Salinity above 36 is observed in the near shore zone at the three northernmost sections with a maximum above 36.6 at 20°10'S.

Outside the shelf break oceanic water occurs. The temperature is decreasing smoothly towards the open ocean, but the salinity picture is more confusing, showing patches of both high and low salinity water.

The density distribution at 10m depth is shown in Fig. 2e. Because of the relative small variations of the salinity the large scale density structure is dominated by the temperature. However, the small scale vortices are due to the patchiness of the salinity. The influence of the HSSW on the density is also readily seen.

4.2 Vertical sections.

Figs. 3 - 6 show the vertical distribution of temperature and salinity at the four E-W sections. The sections are numbered from S1 to S4, indicating the order they were taken. The positions of the sections are shown on Fig.1.

We notice that on the shallow shelf the water is weakly stratified, with the tendency of maximum temperatures at the surface and maximum salinities at the bottom, thus giving rise to opposite tilt of the isotherms and isohalines.

A thermocline is found at the shelf break between 50 and 150m depth where the temperature decreases from 25°C to 17°C. The isotherms (and therefore the density) have a dome shape, indicating a cyclonic circulation with a north going current adjacent to the slope and a south going current some 30 km outside.

The dome shape extends below 200m in sections S2 and S3, while in section S1 the isotherms are descending out from the coast below 200m, and in section S4 the temperature gradient is opposite. These variations below 200m are probably not true variations in space, but rather a time variation; Considered as a time series the temperature characteristics below 200m changes from a smooth temperature gradient off the coast (S1), through a dome shape (S2 and S3), and, finally, a smooth temperature gradient towards the coast (S4). In terms of geostrophic circulation this will mean a current towards the south in the beginning, changing to a penetration of the cyclonic eddy down below 200m, to end up with a northward deep current at the end of the observation period.

4.3 Time series - Nansen casts.

At the position of the current meter mooring, Nansen casts were taken for a period of about 9 hours shortly after the deployment of the mooring, see Fig.7. The temperature was constant or slowly rising in the beginning, but at about 08GMT a marked decrease took place. The amplitudes are most clearly revealed between 50m and 150m, where the thermocline is situated. The temperature variations are therefore most likely associated with vertical displacement of water masses with amplitudes up to more than 50m.

As expected the salinity picture is more confusing, but a negative trend seems to take place at the end of this time-series.

4.4 Results from the moorings

Before presentation the data from the recorders were filtered using a 3 hour low-pass filter and resampled every hour.

a) Current measurements

Progressive vector diagrams are shown in Fig.8. The currents at both 170m and 60m are rather unidirectional parallel to the coast, indicating that the topography steers the current. At 170m the prevailing current was weak (in average about 10cm/s) towards SW the first 4 days. Around November 11 the current turned towards NE and the speed increased to an average of 20cm/s.

At 60m the influence of the slope is also obvious, but cross-slope currents occur to a larger extent than at 170m. In general the current is NE, and in average about 30cm/s.

The velocity components, the temperature and salinity registrations from the current meters, and the water level measurements are shown in Figs 9 - 12. We have chosen to rotate the coordinate system 40° clockwise, so the components shown are cross slope (positive off-shore, i.e. SE) and along slope (positive NE).

At 60m the current component along the slope (Fig.9b) is the strongest, and reflects the average current, (compare Fig. 8a). Although there is no net current in the cross-slope direction, the cross slope speed is occasionally relatively strong with amplitudes up to 40 cm/s (Fig.9a). A semi-diurnal signal is clearly seen in the cross slope component.

At 170m (Fig.11) the cross-slope current remains small (<10cm/s). In the component parallel to the slope we recognise the SW weak average current in the first few days, turning NE and becoming much stronger at the end of the observation period. A semidiurnal variation may be observed in the first part of the record.

b) Bottom pressure registrations

The pressure registrations (Fig.13a), obtained close to the bottom, are dominated by a semi-diurnal signal with a maximum amplitude of about 1.6m in the beginning of the series. Full moon occurred November 5, so the spring tide amplitudes are even higher.

c) Temperature and salinity registrations

The temperature and salinity records from the mooring are shown in Figs. 10, 12 and 13. In accordance with the hydrographic observations (Figs 4 - 7) the temperature at the bottom (220m) is about 1°C colder than at 170m, while the temperature at 60m is about 5°C higher.

The registrations at 60m indicate salinities between 35.2 and 35.3, which compare well with the hydrographic sections. However, the registrations at 170m (Fig.12b) indicate salinities above the values found by the Nansen casts. This is obviously due to a calibration problem of the current meter at 170m depth, so the absolute salinity values in Fig.12b should not be taken too seriously, but the amplitude of the variations are believed to be correct.

d) The tides.

The tidal ellipses for the major constituents are shown in Fig.14. We notice that at 60m the dominating M_2 component indeed has its major axis oriented perpendicular to the slope. The major tidal constituents are given in Table I.

The temperature registrations at 60m also have a very clear tidal signal, lagging the off-shore current about 90 degrees (Fig.10a), as the maximum temperature is obtained just before the current turn inshore and starts to bring in the colder off-shore water.

Even at 170m (Fig.12) both temperature and salinity seem to vary with the tides. We note that the fluctuations are relative small during the period when sections S2 and S3 were taken, see Fig.13) i.e. when the cyclonic circulation was deep, so it likely that the 170m current meter was situated near the center of the cyclone in this period and thus near the extremal points for both the isohalines and isotherms.

5. DISCUSSION

5.1 General circulation and water masses.

If we compare the Nansen casts time series (Fig.7) with the current measurements at 60m (Fig.9), we notice that the general warming throughout the water column is associated with an off-shore current, and the cooling starts when the current turns bringing the colder lower layer water up-slope.

The upper layer geostrophic cyclonic circulation at the shelf break, as revealed from the temperature sections (Fig.3 - 6), does not fit quite with earlier observations (Jorge da Silva (1984), because the cyclonic eddy is usually found more to the west upon the shelf.

The shift in the lower layer density field from a shoreward density gradient through a dome shape structure to end up with an off shore density gradient compares well with the current at 170m, which was undulating SW-NE with a net SW when S1 was taken, shifting to a very weak net flow during S2 and S3 to a uni-directional NW current when S4 was occupied.

5.2 The influence of the wind.

Wind observations from Vilanculos (see Fig.1 for location) are shown in Fig.15. These observations are believed to be representative for the study area. A comparison of on-board wind observations with observations from Vilanculos and Beira is done by Hoguane (1990).

The wind was rather weak during the first 3 days of the survey, but on November 10 the speed picked up to gale force in N or NW direction. The shift in the current regimes occurring both at 60m and 170m is consonant with the increase in the wind speed. At 60m the speed towards NE increased around November 10, see Fig.9, and a couple of days later even at 170m the current increased towards NE along the slope. As the shift in the current at 60m occurred almost simultaneously with the change in the wind it looks like the current may be directly influenced by the wind through friction. However, it is somewhat surprising that the direct effect of friction comes so fast and is so strong at 60m depth. The frictional surface current will cause a change in the density structure, which in turn give rise to change in the horizontal pressure forces and therefore the geostrophic velocities, compare the development of the temperature, and therefore the density structure in Figs 3-6. Thus the influence of the wind on the current at 170m is eventually indirect through geostrophic adjustment. This may be the case even for the current at 60m depth.

5.3 The tides

At the 60m level the on-shore off-shore strong tidal signal has the characteristics of a standing wave, as zero velocity coincides with the extreme water levels, see Fig. 13b. Amphidromic M2 maps indicate that this is a region where two tidal systems interfere, and may thus set up standing waves in the M2 band.

5.4 Transport of larvae.

It is believed that penaeid prawns, like the common and valuable *P.indicus*, and maybe other species use the protected inshore mangrove swamps as nursery areas. But it is yet not understood how the larvae are transported from the open ocean to the nursery areas. The fact that the tidal currents have the major axis oriented perpendicular to the shore provides us with a possible explanation: The larvae are passive drifters, but have the capability to migrate vertically. Thus if the diurnal vertical migration patterns are tuned in with the tides, a net transport over long distances may take place (Rothlisberg et al. 1983). We also expect that the tidal currents are stronger upon the shallow Bank.

The maximum distance the shrimp may be transported by the tides may be calculated as follows: If the vertical migration is tuned such that the shrimp are drifting only when currents are onshore, (and during off-shore currents they are deposited at the bottom) they will in average be transported a distance D during a tidal cycle T according to the formula:

$$D = U \times T/p$$

where U is the value of the major half-axis of the tidal ellipsoid (53 cm/s) see Fig.14. As the semi-diurnal period is dominating, T ~6 hours, so D ~ 3km per day.

6. RECOMMENDATIONS AND FUTURE WORK

This investigation has clearly demonstrated that the time-variability at the Sofala Bank is considerable, and the interpretation of quasi synoptic sections should be done with care.

The shrimp fishery at the Sofala Bank is of great importance, and joint cruises with biologists should be planned in order to testing the theory that larvae are transported to the nursery areas with the tides.

7. ACKNOWLEDGEMENTS

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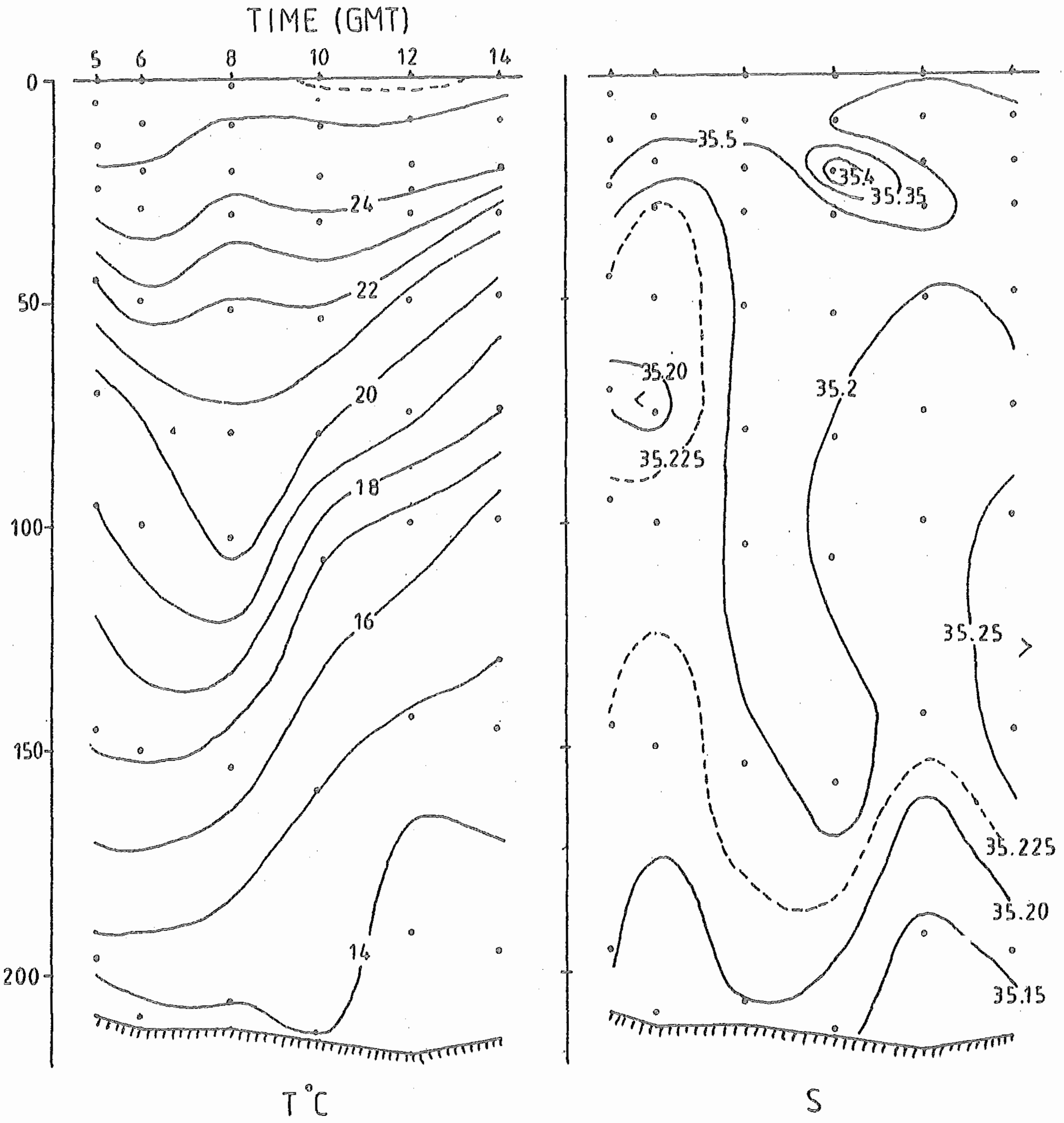

Fig.7. Time series of the vertical distribution of temperature and salinity as obtained from a repeated station of Nansen casts near the current meter mooring.

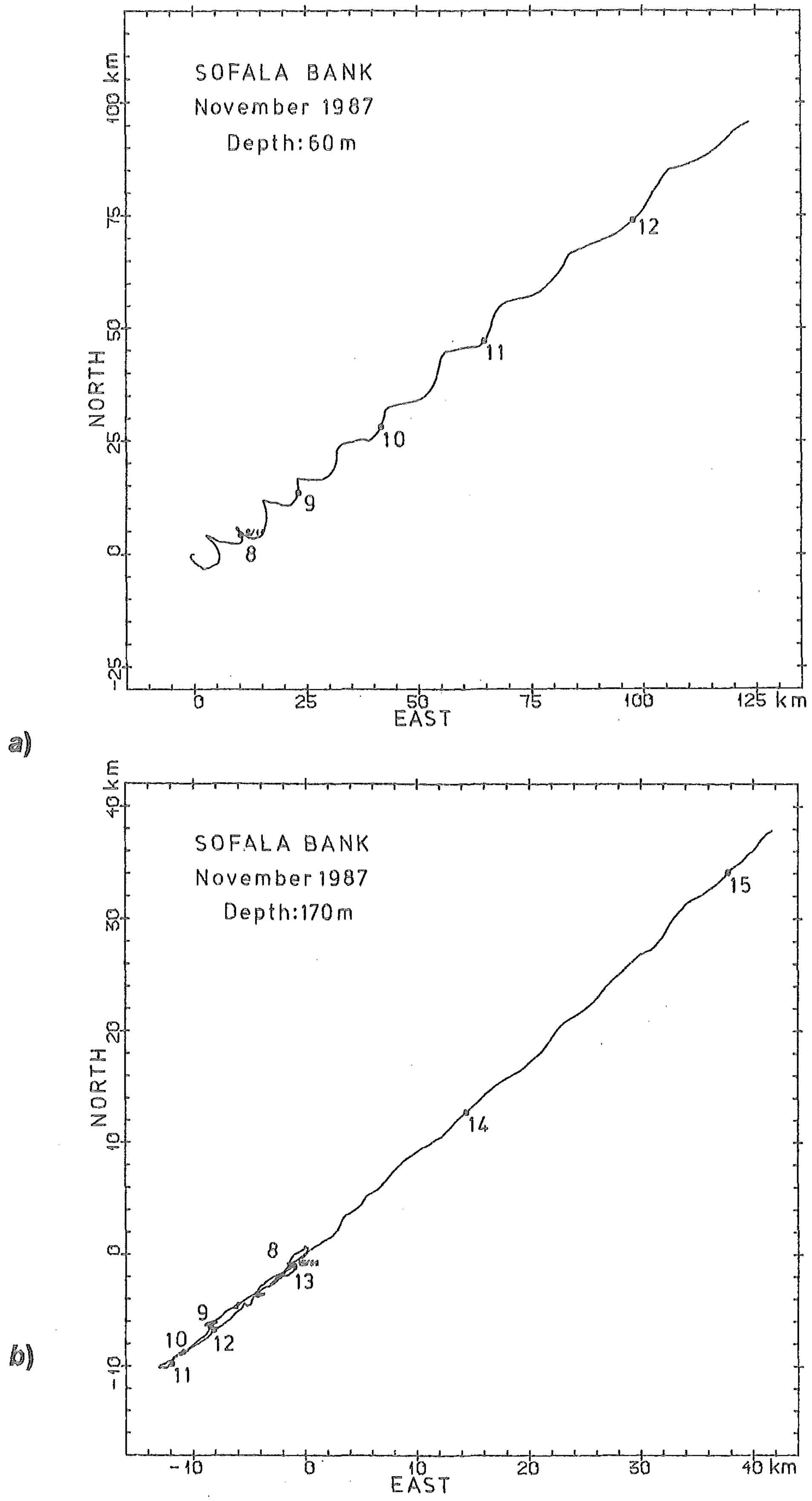

Fig.8. Progressive vector-diagrams at a) 60m and b) 170m. Note the different scales of the two plots. Also note that the time spans are different as the upper meter failed after about 6 days.

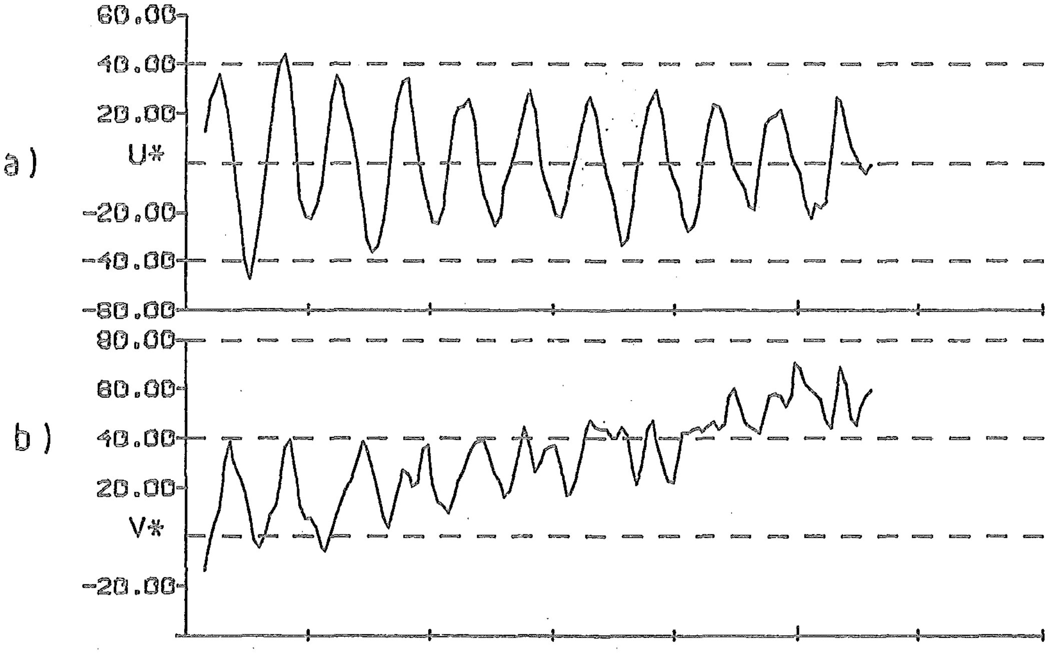

Fig.9. Current at 60m depth given as a) Cross slope (140°), and b) Along slope (50°) components.

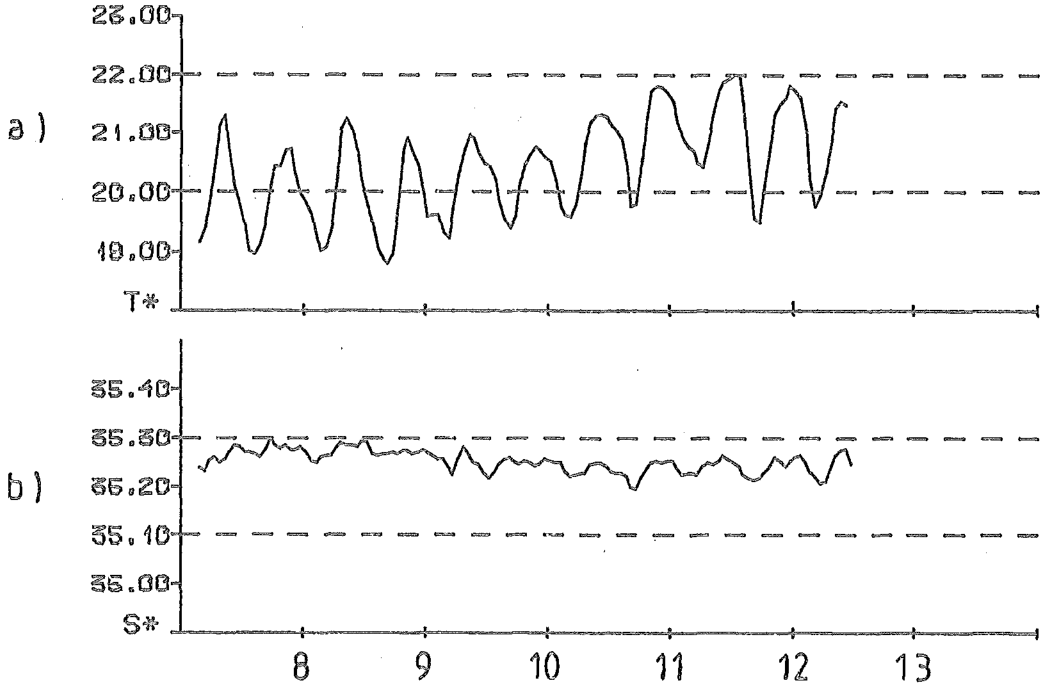

Fig.10. Registrations at 60m depth of a) Temperature and b) Salinity.

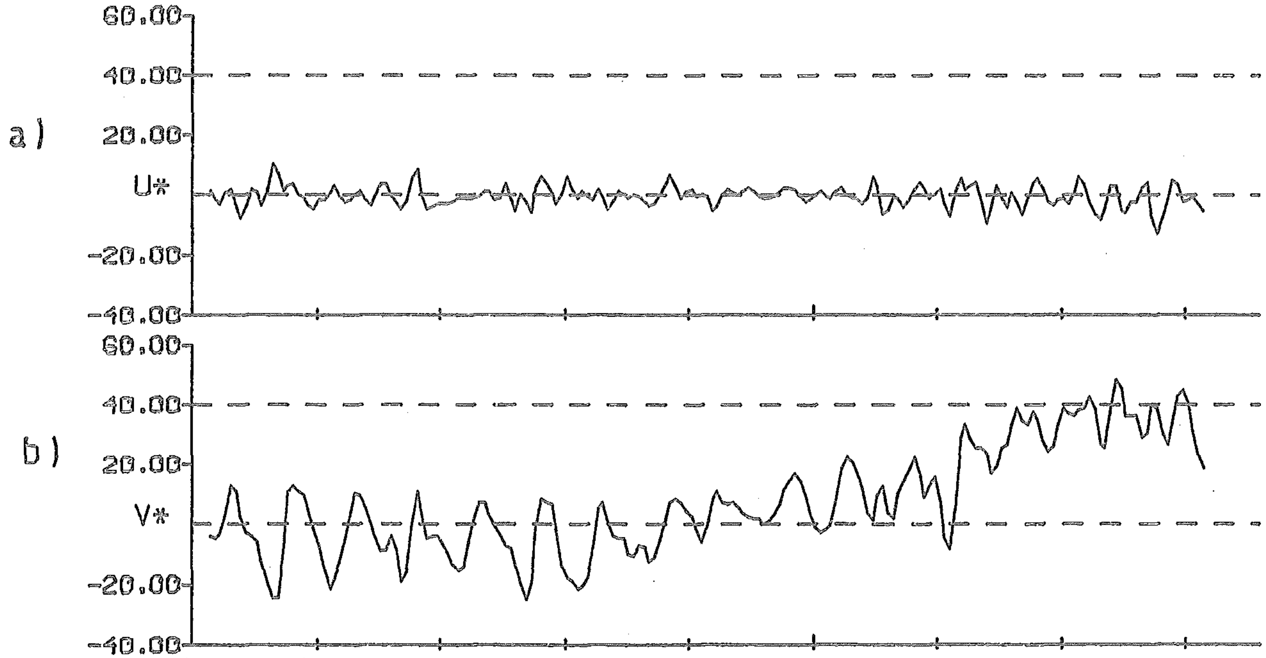

Fig.11. Current at 170m depth given as a) Cross slope (140°) and b) Along slope (50°) components.

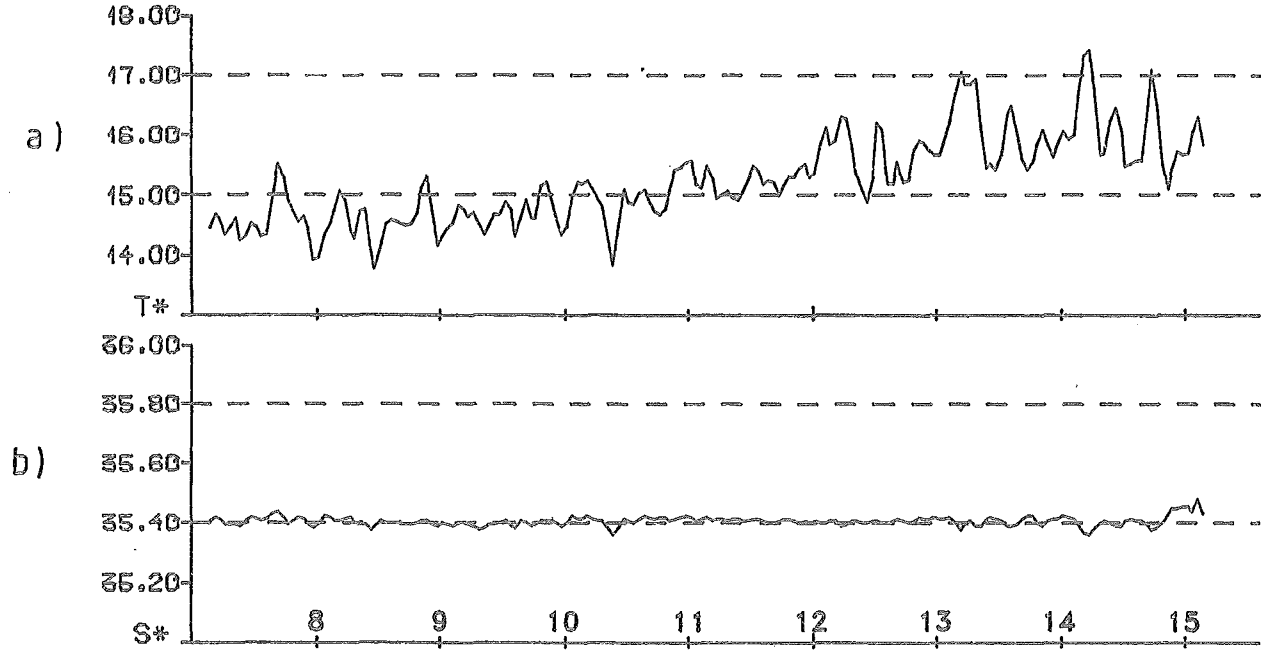

Fig.12. Registrations at 170m depth of a) Temperature and b) Salinity.

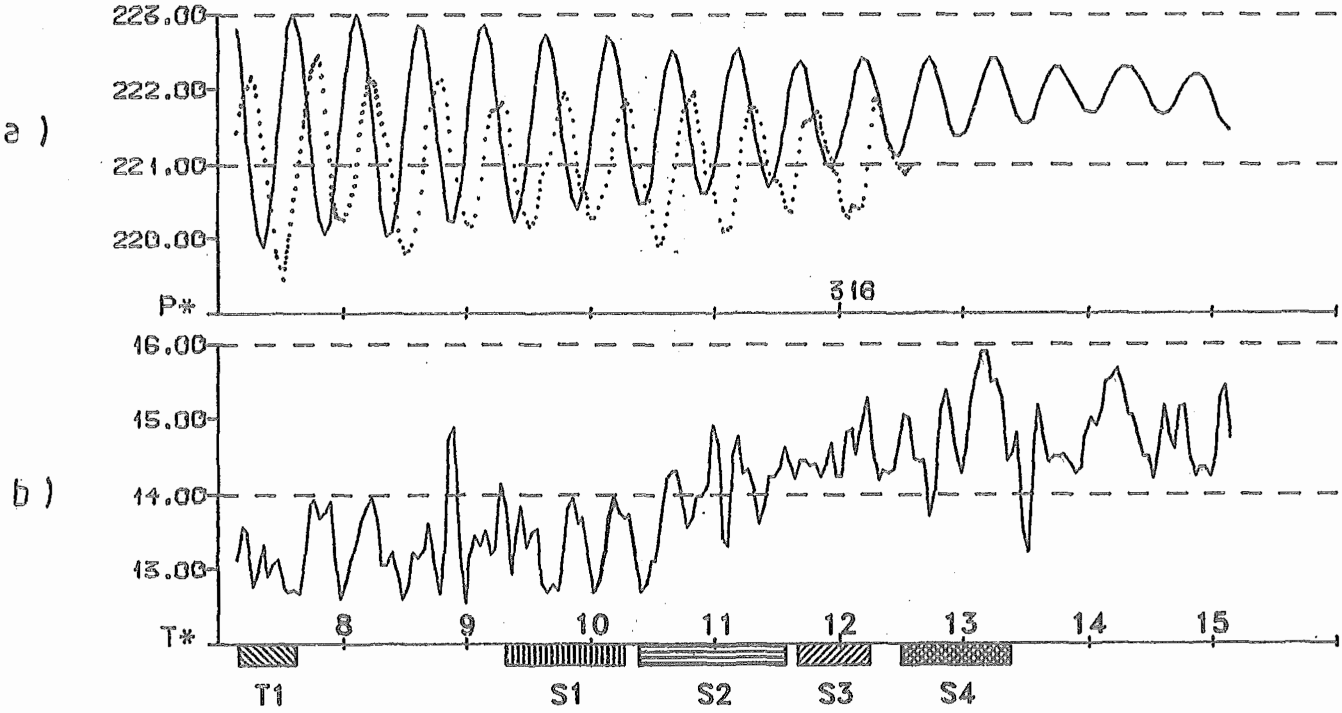

Fig.13. a) Bottom pressure and b) Bottom temperature. The cross slope current at 60m (Fig.9a) is shown as a dotted curve. The time-spans when the hydrographic sections were taken are also indicated.

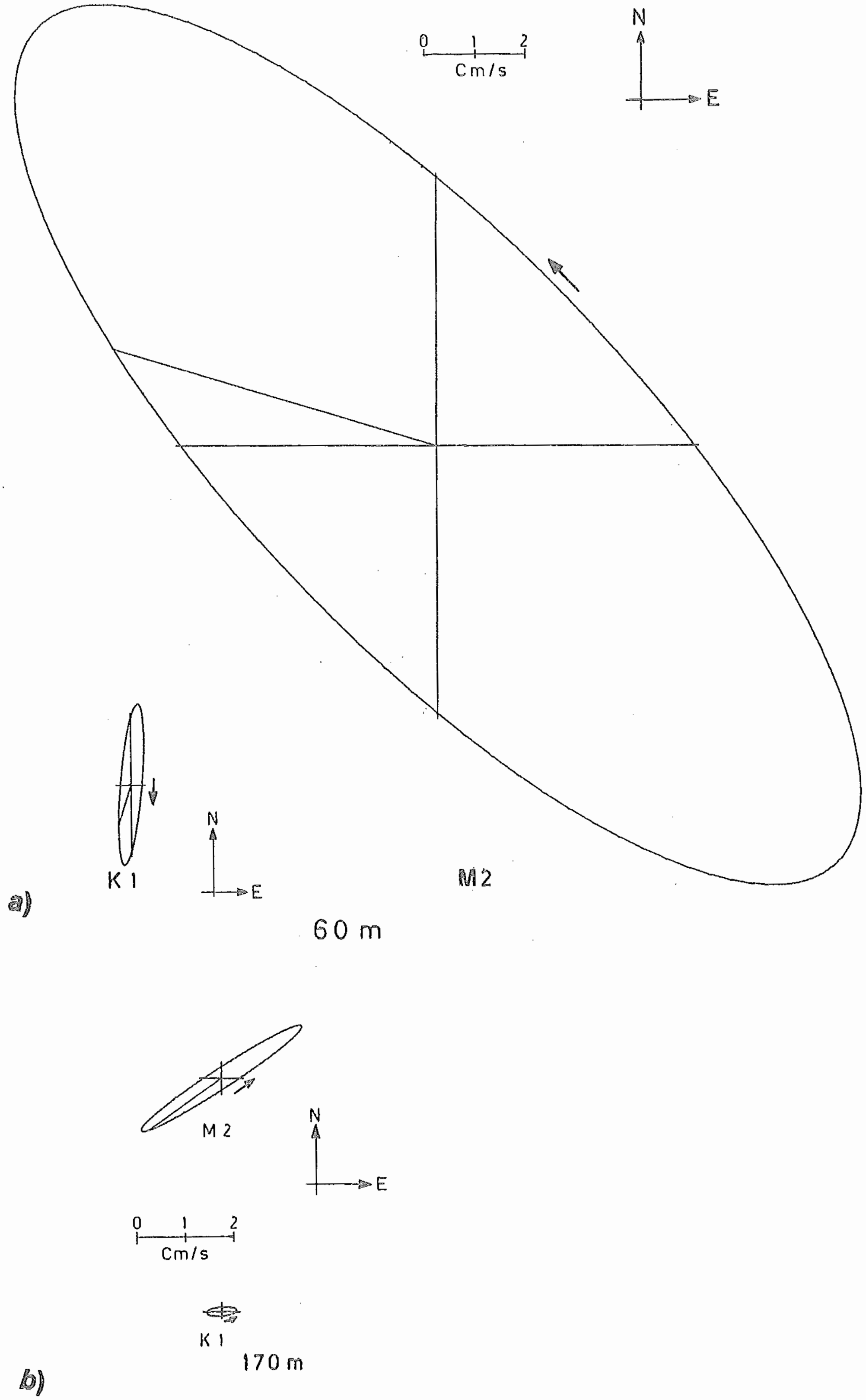

Fig.14. Tidal ellipses for the major constituents (M2 and K1) at a) 60m, and b) 170m. The direction of rotation is indicated.

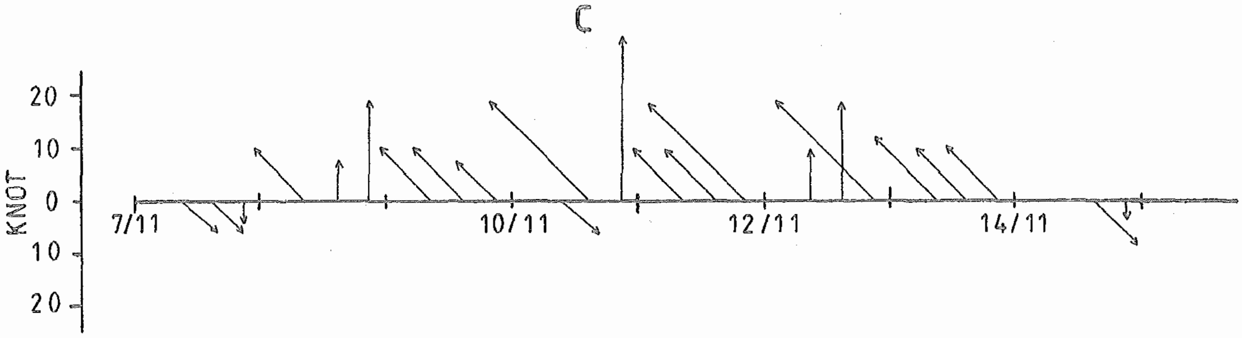

Fig.15. Wind observations at Vilanculus (for location see Fig.1) during the period of the survey.