NEAR SURFACE CURRENT DETERMINED FROM INPE's SATELLITE-TRACKED BUOY, DURING 6-26 NOVEMBER, 1985

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ABSTRACT

A field experiment was made to test INPE's drifting, oceanographic buoy during 6-26 November, 1985. Buoy measurements obtained during 10-20 November were made from the Brazilian hydrographic ship Alte. Saldanha, near 24°8'S, 45°13'W. Within the buoy, a UHF transmitter compatible with System ARGOS, transmitted sensor data via an omnidirectional antenna within the buoy. The System ARGOS aboard polar orbiting satellites e.g., NOAA-7 and NOAA-9, received, recorded and retransmitted the buoy's signals, as the satellites passed over the local horizon of the buoy. Geographic fixes are determined from the doppler frequency of the buoy's transmissions, in combination with the known orbital characteristics of the satellite receiving the signals . The first part of the experiment obtained positional data when the buoy was stationary on land; the second part obtained positional data while the buoy was adrift at sea. There were five times when the buoy was stationary. Positional accuracy of the buoy was estimated by determining positional differences with respect to the five mean positions, and then combining these differences to make an overall estimate of the positional error (1σ). Based on 46 ARGOS positions, the latitude was determined to be known to within ±0.003° (±285m) and the longitude to within ±0.008° (±810m). During the drifting buoy part of the experiment, the positions of the buoy were determined by ship's radar and by System ARGOS. The mean velocity of the buoy drift was 13.0cm s^{-1} toward 273° from the radar measurements and 14.1cm s^{-1} toward 273° from the radar measurements and 14.1cm s^{-1} toward 274° based on ARGOS data, and are not considered statistically different. This experiment suggests that INPE's drifting buoy is capable of obtaining useful measurements of near surface currents.

1. INTRODUCTION

INPE recently designed and built a drifting oceanographic buoy that is tracked via satellite, for use in Antarctica and national waters. This buoy was tested during a brief experiment aboard the *Almirante Saldanha*, one of Brazil's hydrographic ships. The experiment occurred during 6-26 November 1985, although actual measurements with the buoy in the water occurred during 19-20 November, near 24° 10'S, 45° 15'W.

The principal objective of the experiment was to test the buoy's ability to determine sea surface currents (0-10 m) through sequential displacements of the buoy in local waters. In order to evaluate these data, it was also necessary to determine the positional accuracy of the buoy when it was stationary, that is when the buoy was at a fixed and known location. To determine whether the satellite-tracked buoy positions provided realistic estimates of ocean currents, a series of radar measurements was made concurrently.

Detailed information about the buoy's structure, etc. has been reported elsewhere (Stevenson and Alonso 1985), so only a general description will be given here. The buoy is bi-conic in shape (Figure 1), with the greatest dimension (1.87 m) in the vertical. When in the water, the buoy floats with only the widest part above the waterline. The buoy is fabricated from fiber glass, using modern composite technology. A rectangular sail (2m X 3m) is set 10m below the buoy, using a strong steel cable.

Two thermistors set into a sensor cable determine water temperature below the buoy; a third thermistor determines air temperature from atop the buoy. When used at sea, the buoy provides temperature as well as positional data. Only the positional data will be considered in this report.

2. DATA AND METHODOLOGY

Buoy positions were determined from the ship at hourly intervals with the ship's radar. The relative positions of the buoy were then converted to latitude and longitude by referencing the ship's position to nearby land points. Positional errors of 50-200 m are common with radar observations, depending on how the measurements are made. Times of measurement are given in hours (GMT).

The drifting buoy's positions, as determined by satellite, are more complicated to determine when compared to the radar measurements. The number of observations that can be obtained from the satellite system ARGOS depends on the latitude of the buoy. The frequency of satellite coverage for this global system is seen in Figure 2. Note that for the latitude of our experiment (24°S), the average number of positional fixes is 6 in a 24 hour period when two satellites are in operation.

Details of System ARGOS are given in the literature e.g., ARGOS Users Guide (1984), so only a simple review is given here. Each time the buoy transmits data from its sensors, the UHF signal itself can also be used to locate the buoy. The data collection platform (DCP) within the buoy transmits the data at about one minute intervals, so that any satellite in polar orbit equipped with the System ARGOS can receive these data. Because the satellite is travelling at high velocity in its orbit, the incoming signal suffers a change in its transmitted frequency, called a doppler shift. It is this doppler shift, together with information known about the satellite's orbit, that makes it possible to determine the position of various drifting buoys.

The quality of these positional data are directly related to the stability of the DCP oscillator within the buoy. Service ARGOS, which processes all positional buoy data, considers positions known to within 350m to be of good quality.

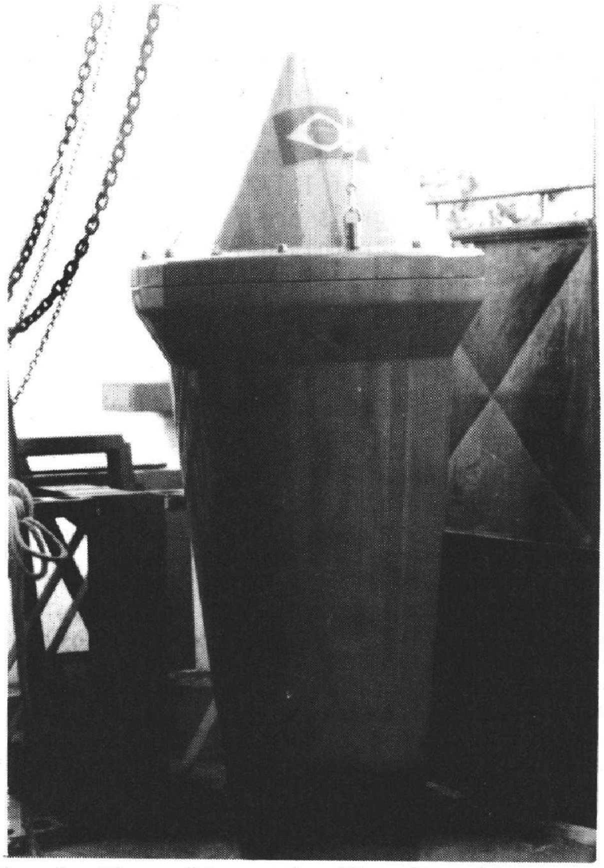

Fig. 1 - View of buoy shortly after its construction. The antenna is located inside the top cone, the transmitter is just inside the widest part of the hull, and the power supply is in the bottom of the buoy.

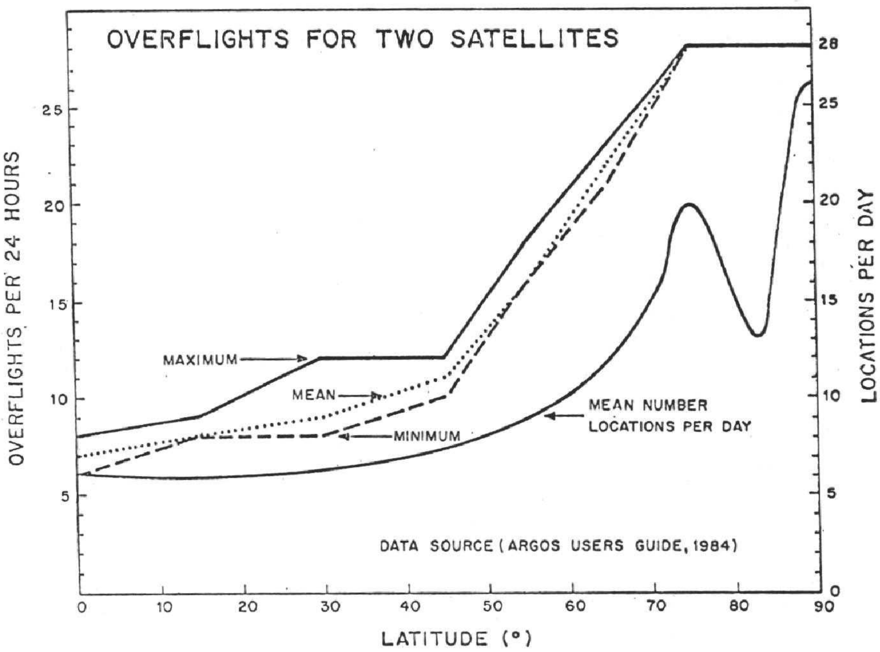

Fig. 2 - Frequency of overflights and positional locations per day for NOAA-n type satellites.

There is a time delay associated with the ARGOS buoy data. Because the orbital period of the satellites is about 101 minutes, the total time to receive the data and to process the doppler signals to obtain positional data produces a delay of 1 1/2 - 4 1/2 hours, from the time the signals are first received by the satellites. After this delay the data are in the ARGOS Center's distribution computer in Toulouse, France, listed by experiment number, country, etc. These data can then be obtained via Telex, direct from Service ARGOS, or later by computer listing and magnetic tape.

A time series of consecutive buoy positions can be used to determine a resulting set of mean velocities or an overall mean velocity for the time series. The assumption normally made is that the buoy's movements are not appreciably affected by wind friction on the buoy and that the buoy is effectively coupled with the surrounding water. While the latter assumption is usually valid if a subsurface sail or drogue is used, there is always a small amount of error introduced into the drifter trajectory since the buoy is a solid, while the water consists of fluid particles.

The method used to obtain the mean current based on the radar data was to treat the latitude and longitude observations as separate time series. A linear regression was made using latitude and longitude respectively, against time. The resulting equation for latitude;

$$Lat = aT + b \quad , \qquad (1)$$

is obtained where the slope coefficient (a) is the mean velocity $\overline{u}$ or $\overline{v}$. The resulting mean velocity of the drifter, and hence the current is determined by combining the $\overline{u}$ and $\overline{v}$ values,

$$\overline{V} = (\overline{u}^2 + \overline{v}^2)^{1/2} \quad . \qquad (2)$$

The direction of the mean current (θ) is normally determined by

$$\theta = \tan^{-1} (\overline{v}/\overline{u}) \quad , \qquad (3)$$

and the conventional definition of compass angles. The above procedure was first used on the radar data, followed by the same treatment with the ARGOS positional data.

Wind measurements were made during the experiment at hourly intervals. The directional sense of these observations was changed by adding 180° to each observation. This is normally done so that the wind velocities can be directly compared with current measurements.

3. RESULTS

As noted in the previous Section, buoy positions obtained via Service ARGOS were first used to evaluate the positional accuracy of these data. Prior to leaving INPE (São Jose dos Campos) for the field work, the buoy DCP was turned on, and we began receiving sensor and positional data via Service ARGOS. There was a several day period when the buoy and related equipment were in transit to the embarkation port (Paranagua, Parana), and also after the cruise, when the equipment was being returned to INPE. There were 5 occasions when the buoy was in a fixed location during these two periods of time. The positional data corresponding to the stationary buoy positions were used to determine the positional accuracy of the buoy data.

The data were individually processed for the 5 time intervals and also combined into one general data set. Since the results are similar for both methods, only the general result is shown here. The positional errors for the 46 observations are seen in Figure 3.

It is apparent from Figure 3 that there are differences in the magnitude of error for latitude and longitude. The latitudinal uncertainty is less than half of that for longitudinal values. This result is explained by the fact that the satellites are in nearly polar orbits (orbital inclination ~ 9°) and hence most of the velocity vcetor is directed north/south. The doppler shift is determined along the satellite path sith greater precision therefore than to either side of the subtrack of the satellite. Since the buoy is often to one side or the other of the subtrack, component of the doppler shift available to determine the longitudinal component is necessarily less.

The two elliptical envelopes in Figure 3 represent 1σ and longitudinal directions. The majority of the time ($1\sigma \sim 63\%$), latitudinal and longitudinal errors were 285 m and 810 m, respectively. This corresponds to an error of ± 0.003° and ± 0.008° in latitude and longitude. Since 2σ represents about 95% of a normal sample population, almost all of the positional fixes were within this envelope (within 600 m for latitude and about 1600 m for longitude). Determination of mean currents, etc. must be considered in terms of these uncertainties.

As previously mentioned, the more stable the DCP oscillator the smaller the positional errors. As presently formatted by Service ARGOS, there are practical limits. The positional data are given to the nearest 0.001°, which corresponds to about all 111 m increments in latitude. This represents the positional limits of the ARGOS system, at least for the present.

The general movement of the drifting buoy is illustrated in Figure 4. After launching the buoy it remained in the same general area for some hours. Then it gradually accelerated in movement toward the west and continued in this direction until the end of the experiment.

Note that there were 4 ARGOS position fixes during the experiment. The dashed line indicates a lack of radar data for some hours before resuming radar position again. In all cases the positions obtained from ARGOD appear to be very close to those determined by radar.

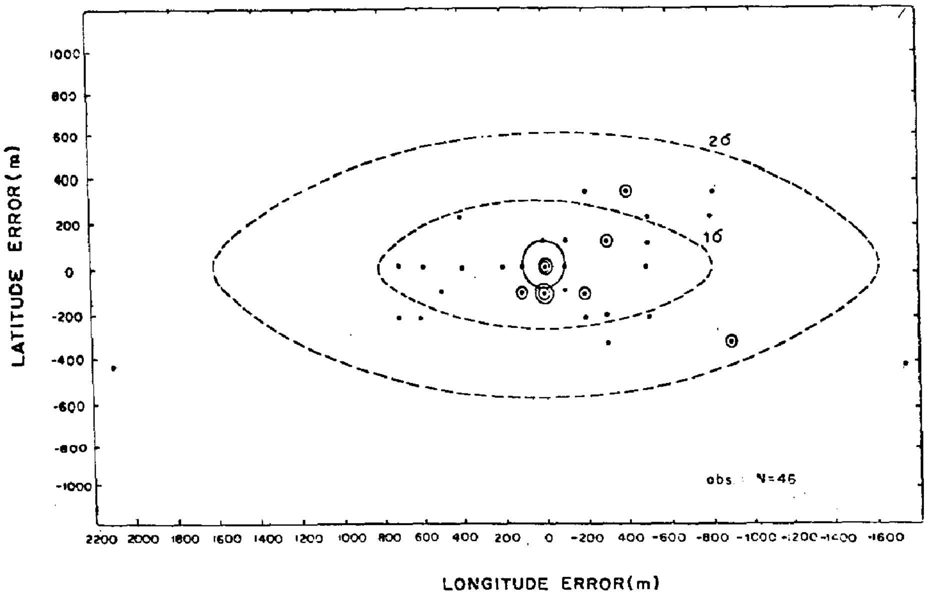

Fig. 3 - Positional errors for the INPE buoy used in the experiment. Multiple observations with same positional errors are shown by small circles. Ellipses represent 1σ and 2σ magnitude of error.

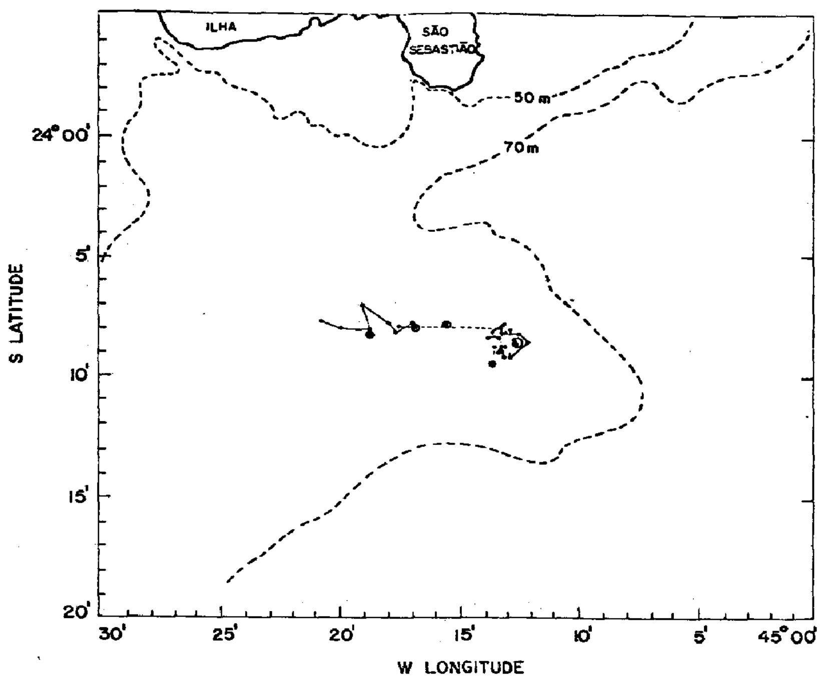

Fig. 4 - Displacement of drifting buoy. Asterisk (*) marks start of buoy motion. Small circles represent buoy positions determined by Service ARGOS.

Details of the buoy motion and hence surface currents, are best in Figure 5 and 6. Figure 6 illustrates the latitudinal aspect of buoy drift. Here we see more clearly that the ARGOS positions are close to those of the radar determinations. The distance scale in the figure shows that the ARGOS positions are well within the 2σ error. This is good, considering that the radar measurements themselves possess smaller but definite positioning errors. It is apparent that the overall displacement during the experiment was small, hence the velocity in this direction wil be small.

The longitudinal displacement of the drifter is seen in Figure 6. The ARGOS positions are again close to those determined by radar, and within the 2σ error limit. Visual comparison of Figures 5 and 6 shows that the buoys overall velocity was much greater in the east/west direction (zonal) than for the meridional direction.

Estimates of the mean current strenght and direction were obtained from numerical treatment of the time series show in Figures 5 and 6. The meridional velocity component based on the linear regression of the radar data was 0.7 cm s^{-1} toward the north and for the ARGOS data was 0.9 cm s^{-1} toward the north. The mean zonal current for the radar data was 13.0 cm s^{-1} toward the west and 14.1 cm s^{-1} toward the west for ARGOS data. The resulting mean velocity estimates were 13.0 cm s^{-1} toward 273 from radar observations and 14.1 cm s^{-1} toward 274 from ARGOS measurements. A simple comparison indicates the two estimates to be the same, since the directional accuracy of radar measurements is 1-2^{o} under the best of conditions. For the duration of the time series and the buoy displacement the mean speed has an uncertainty of about 1 cm s^{-1}.

Whether or not the mean current velocity is realistic, that is represents the actual mean current during the same period is a different question. Various studies have attempted to answer this question (e. g., Vachon 1973); and most of them have indicated that the smaller and lower the buoy profile in the water, the more accurately the buoy will indicate actual current conditions. Also the size of the subsurface sail in comparison to the size and geometry of the surface drifter are important. In this report we will only briefly consider the aspect of the wind.

The shipboard wind measurements are illustrated in Figure 7. The lenght of an individual wind stick is proportional to the wind intensity; and the destination of the wind is considered to be outward, along the axis of a stick. Winds were weak and toward the NW during the first 4 hours of 19 November. For the next 16 hours the wind direction changed toward the SW and then returned to the W and NW. By 22 hours (LT), the wind had changed again and blew persistently and strongly toward the SW until the end of 20 November.

The possible influence of the wind on the bouy can be estimated by a comparison of the buoy trajectory with the wind time series (Figures 5 and 6 with 7). During the period of 11-15 hours (GMT) and 11-16:30 hours on 19 November, the buoy moved northward and eastward. During this period the wind destination was first toward the SW them changed toward WNW. From about 15-17:30 hours, the buoy reversed its direction of movement, before continuing toward the NE. From 21 hours of the same day until 18 hours on 20 November, however, the bouy's northward motion further decreased while the buoy's westward movement increased markedly. During the same time the wind continued strongly toward the SW.

Although both the buoy and wind registered northward motion during the first few hours after launch of the buoy, the northward wind movement was weak and any resulting wind friction on the buoy would have been very small. Later when the wind was strongly toward the south, the buoy continued its northward movement. During the first several hours of the experiment, the buoy's eastward motion bore no relation to the westward wind. After 22 hours (GMT), both wind and buoy movement were toward the west.

The authors interpretation of these motions is that if the bouy was being materially affected by the wind, there should be an immediate and noticeable change in the buoy's trajectory in the same general direction as for the wind. Much of the time the drifter, however, was moving in opposition to the wind direction.

To improve the detectability of the buoy on the ship's radar, a small surface raft was attached to the bouy at about 11 hours (GMT) on 20 November. While this additional float undoubtedly increased the effect of the wind friction on the buoy, the magnitude of this influence is not readily detected in the time series.

4. CONCLUSIONS

Several conclusions may be drawn from this experiment. Among them are:

1. Positional accuracy of the buoy was determined to be good to within ±810 m for latitude and ±285 m for longitude (±1σ), using the buoy on the land and at fixed locations.
2. The mean surface current (0-10) was 13.0 cm s^{-1} toward 273^{o} from radar data and 14.1 cm s^{-1} toward 274^{o} based on ARGOS data. Considering the length of the time series and the observational errors (number one above), these values are not considered significantly different from each other.
3. While difficult to verify from such a short time series, it appears that the wind friction on the bouy was negligible during the experiment. This is to say that for wind velocities up to 12 kts there does not appear to be a noticeable influence (< 1 cm s^{-1}) on buoy movement.

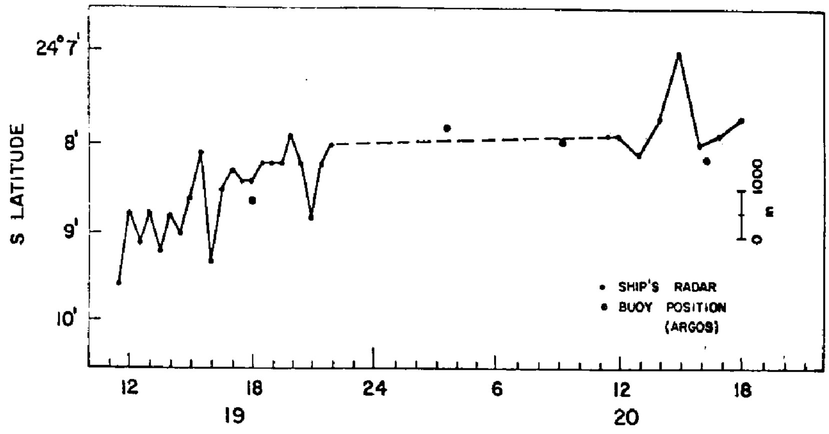

Fig. 5 - Latitudinal displacement of drifting buoy with time. Broken line indicates lack of observations.

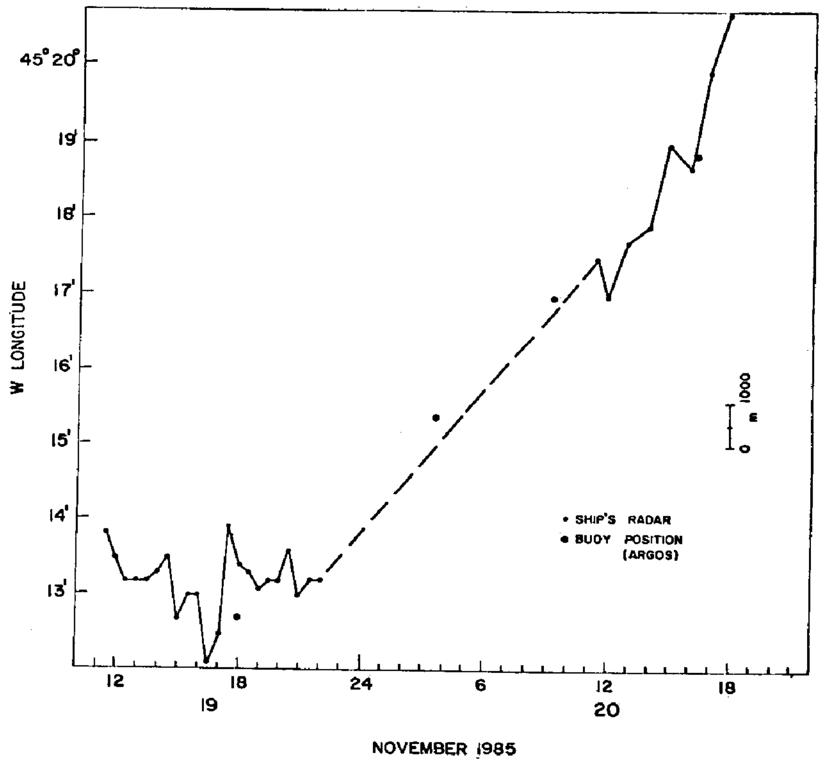

Fig. 6 - Longitudinal displacement of drifting buoy with time. Broken line indicates lack of radar observations.

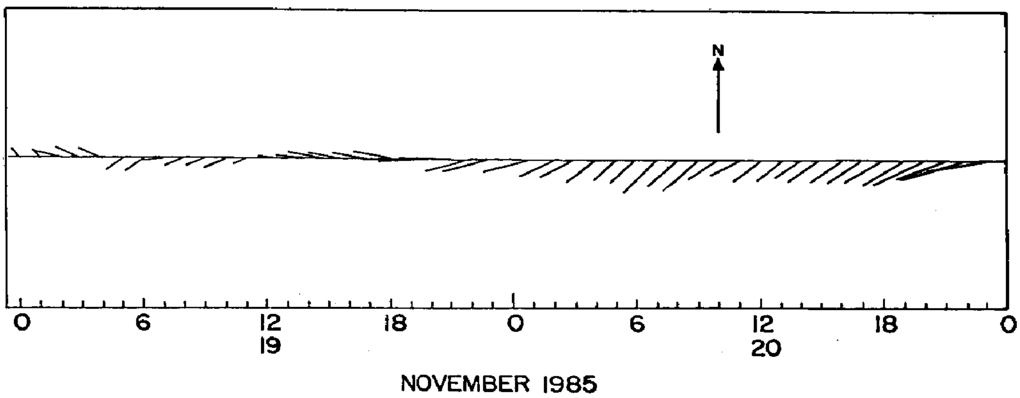

Fig. 7 - Wind stick diagram for shipboard winds. Length of stick indicates intensity: North arrow equals 20 kts. Wind destination is taken outward from the reference line, along a stick. Time scale is converted to GMT by adding 2 hours to the times of observations.

5. REFERÊNCES

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