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Benthic observations on the Madeira Abyssal Plain

Benthic
Currents
Temperature
Camera
Benthos
Courants
Température
Caméra

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ABSTRACT

A free-fall tripod has been used to obtain measurements of the near-bottom currents and temperature on the Madeira Abyssal Plain in a water depth of more than 5,000 m. A demodulation technique was used to separate the flow into tidal, inertial and low frequency components, giving mean amplitudes of about 3 cm/sec., 2 cm/sec. and 1 cm/sec. respectively; the peak current during the 64 day experiment was only 7.5 cm/sec. The temperature increased by about 10 millidegrees with occasional oscillations of 2-3 millidegrees. These are interpreted as narrow thermal "fronts" which had a horizontal thickness of only a few hundred metres, the temperature oscillations resulting from their advection past the sensor by the fluctuating currents. No sediment movement due to the action of the currents could be detected in the record from a time-lapse camera, and only one biological excavation event was recorded on the film.

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RÉSUMÉ

Observations benthiques dans la plaine abyssale de Madère

Les courants et la température ont été mesurés au voisinage du fond dans la plaine abyssale de Madère, à plus de 5000 m de profondeur, à l'aide d'un tripode à chute libre. Les composantes du flux, séparées par une technique de démodulation, ont des amplitudes moyennes de 3 cm/s pour la marée, 2 cm/s pour l'inertie et 1 cm/s pour la basse fréquence. La température a présenté sur la durée de l'observation une élévation d'environ 10 millidegrés, avec des oscillations occasionnelles de 2 à 3 millidegrés. Ces résultats s'interprètent par la présence de « fronts » thermiques étroits dont l'épaisseur horizontale n'est que de quelques centaines de mètres, les oscillations de température résultant de l'advection due aux fluctuations de courants. Aucun mouvement de sédiment sous l'action des courants n'a pu être décelé sur l'enregistrement de la caméra, et un seul phénomène biologique a été enregistré sur le film.

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INTRODUCTION

As part of a study into the character and properties of the benthic boundary layer, a free-fall tripod has been used to make current and temperature measurements close to the sea floor. The purpose of the instrument is to measure the current and temperature variability over time scales of the order of hours to months. The tripod, which was similar to those described by Butman and Folger (1979) and Wimbush and Lesht (1979), consisted of a framework made from aluminium tubing and was about 2.5 m high with a distance between the feet of approximately 4.5 m. The tripod carried a standard VACM (Vector Averaging Current Meter), arranged vertically so that the centre of its rotor was 1 m above the sea bed. A 16 mm camera was attached to the body of the current meter with the lens 2 m above the sea floor and inclined at an angle of about 20° to the vertical, thus photographing an area of the sea bed 65 × 95 cm in size. The smallest feature that can be resolved on the photographs has a diameter of about 0.5 cm. A flash unit was attached beneath the rotor cage to give a low angle of illumination. The camera took a single exposure every 64 minutes which, with a

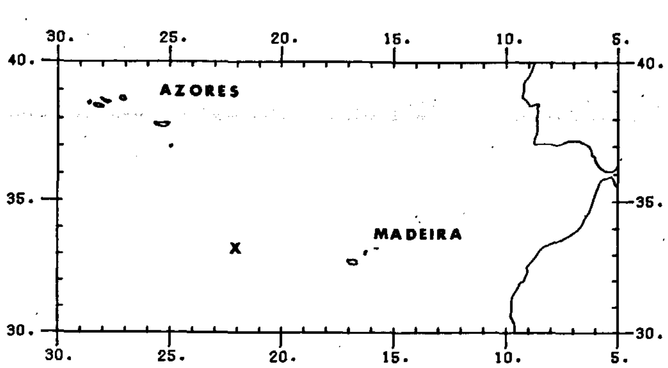

Figure 1
Location of the observations.

film capacity of 2,000 frames, permits a maximum deployment time of around 88 days. The site selected for the test deployment was near the NEADS (North East Atlantic Dynamics Experiment) 1 mooring at 33°10'N, 21°50'W in water approximately 5,300 m deep, at a location 450 km to the west of Madeira on the Madeira Abyssal Plain (Fig. 1). The tripod was launched on November 26, 1980, and recovered on January 30, 1981.

RESULTS

Currents

The current data, recorded at 30 minute intervals, were calibrated using the low speed formula given by Spencer, D'Asaro and Armi (1980). The current speed was below the threshold of the rotor for a substantial proportion of the record, and the corresponding gaps in the current components were treated as missing data (Fig. 2). The time series were analysed by a simple demodulation technique in which the east and north components of the flow were each considered to be of the form

$$u(t) = a_1 + a_2 \cos(2\pi\omega_1 t + a_3) + a_4 \cos(2\pi\omega_2 t + a_5).$$

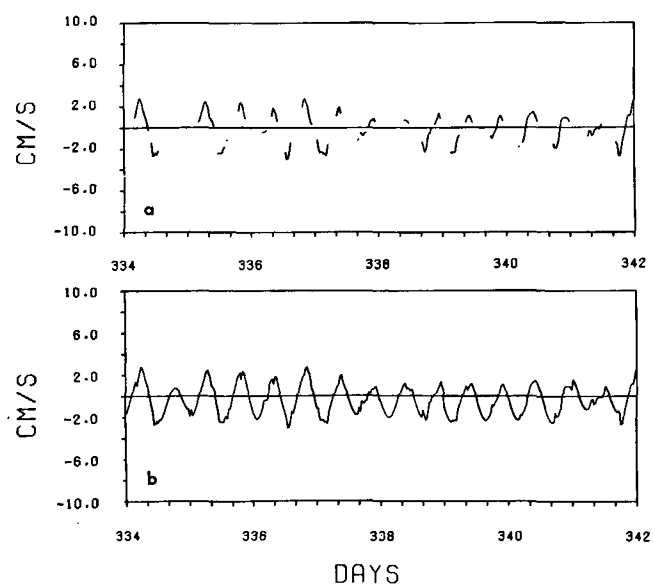

Figure 2
North component of the current during days 334-342 (days of the year during 1980): a) original data containing gaps due to the stalled rotor; b) gaps filled by the demodulation method.

where a_1 is the mean flow and ω_1 and ω_2 are the dominant tidal and the inertial frequency. The coefficients a_1 to a_5 were estimated by least squares within non-overlapping two-day long blocks of data. The time variable was adjusted to have its origin coincident with a maximum of the equilibrium constituent at the Greenwich meridian so that the computed tidal phases could be compared with known cotidal charts. The frequencies ω_1 and ω_2 were taken as 1.93 cycles/day (cpd) corresponding to the M_2 tidal component, and as 1.095 cpd which is the expected local inertial frequency. Spectral analysis of a portion of the original record that contained relatively few stalled periods, which could be filled by linear interpolation, showed these to be the dominant frequencies, although the inertial peak was observed to be shifted by 3% towards higher frequencies (the demodulation results were not sensitive to small changes in the value chosen for ω_2). A shift in the observed frequency has been reported in other measurements of inertial signals (Perkins, 1972; Millot, Crepon, 1981). Following the demodulation analysis, the data gaps within each 2-day block could be filled using expression (1) and continuous current records constructed (Fig. 2).

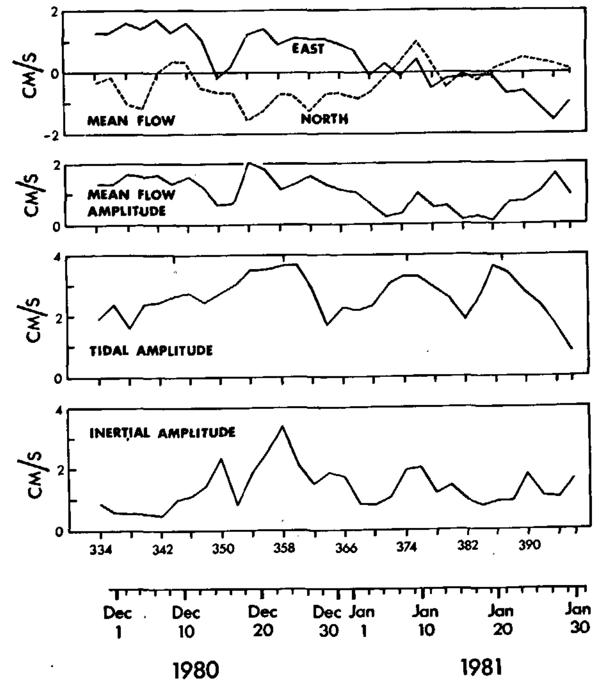

Figure 3
Results of the demodulation analysis.

Figure 3 shows the components and amplitude of the low frequency (2-day mean) flow, and the tidal and inertial amplitudes (calculated by combining the results from the east and north components). The residual sums of squares from the least squares analysis (an indicator of the goodness of fit between the original data and the constructed currents) were used to estimate error bars. This gave estimated errors of 0.32 cm/sec. for the components of the mean flow, 0.45 cm/sec. for the current amplitudes, 9° for the tidal phases and 18° for the inertial phases.

The components of the mean flow showed low frequency fluctuations with amplitudes of about 1 cm/sec. and periods longer than 30 days; these were superimposed on a mean flow of about 1 cm/sec. directed towards the Southeast. The progressive vector diagram, Figure 4, showed a mean flow towards the Southeast at about 1 km/day from the start of the record until day 370. The mean flow was then near-zero until day 386 when it began to move westwards at about 1 km/day, maintaining this general speed and direction until the end of the record. The peak strength of the low frequency flow, reached on day 354, was about 2 cm/sec.

The tidal amplitude showed a pronounced spring/neaps character with the amplitude varying between 2-4 cm/sec. The tick marks along the upper axis of the tidal amplitude plot, Figure 3, show the approximate times of the high water spring tides predicted by tide tables for Funchal, Madeira. It is clear that the peak benthic tidal currents occurred near to the time of the surface spring tides. The amplitude of the inertial flow was around 2-3 cm/sec. and was comparable with the amplitude of the tidal flow. The peak instantaneous current speed, of about 7.5 cm/sec., was recorded near the start of day 358 and was due to the alignment of tidal and inertial flows, each having a speed of about 3.0 cm/sec.

The tidal phases of the East and North components had mean values of about 10° and were approximately equal, suggesting that the tide was essentially rectilinear. The mean ratio of the East and North tidal amplitudes was 0.72 so that the major axis of the (degenerate) tidal ellipse was directed approximately SW-NE. The 10° phase angle implies that the benthic current lead the surface tide by about 50°, or 1.75 hours, at the M_2 frequency since numerical models of the surface tide show that the surface elevation lags the Greenwich transit by about 40° (Huthnance, Baines, 1982).

Temperature

The temperature increased during the first part of the observations, rising by about 10 millidegrees in 30 days, and then remained relatively steady after day 365 (Fig. 5). Abrupt temperature changes of 2-3 millidegrees, often accompanied by oscillations, were common throughout the record. One of the clearest examples occurred during day 375.

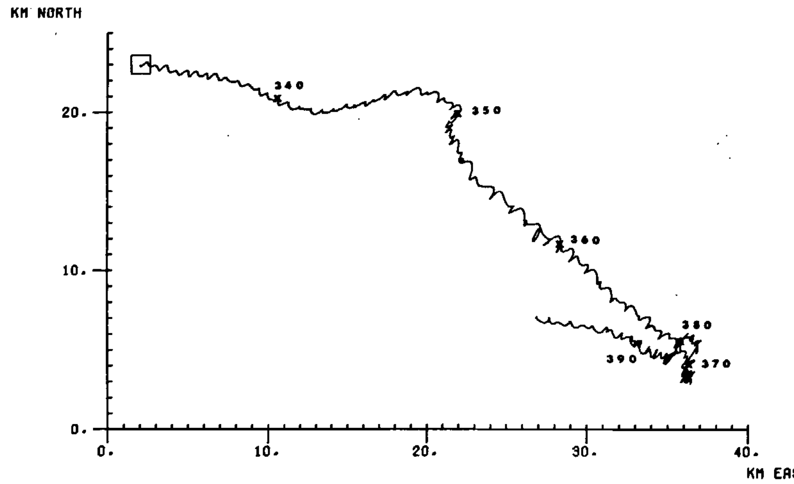

Figure 4
Progressive vector diagram of the currents, gaps interpolated by the demodulation method.

It is possible to reconstruct the local contours of these features if we assume that:

1) the near bottom temperature field was simply advected by the horizontal flow during the periods in which the features are apparent (1-2 days); and that

2) the currents were locally uniform in the horizontal plane over the corresponding advective length scales (typically 2 days × 3 cm/sec. ≈ 6 km).

The latter is the familiar assumption by which the progressive vector diagram, shown in Figure 4, is a valid representation of particle movement, and implies that there was no vertical motion leading to horizontal convergence or divergence. The first assumption allows us to assign temperatures to positions on the progressive vector diagram, which can then be contoured. The features at days 343, 361 and 375 have been analysed in this way. In each case the observed fluctuations could be ascribed to thermal fronts, with roughly E-W orientations, having temperature changes of 2-3 millidegrees across their widths of about 300 m, being advected back and forth across the position of the current meter by the fluctuating currents. The horizontal scales of the fronts were somewhat greater than the typical boundary layer thicknesses reported by Armi and D'Asaro (1980). The fronts were not always associated with changes in the mean flow. The latter would be necessary to maintain geostrophic balance if the temperature variations were associated with density changes.

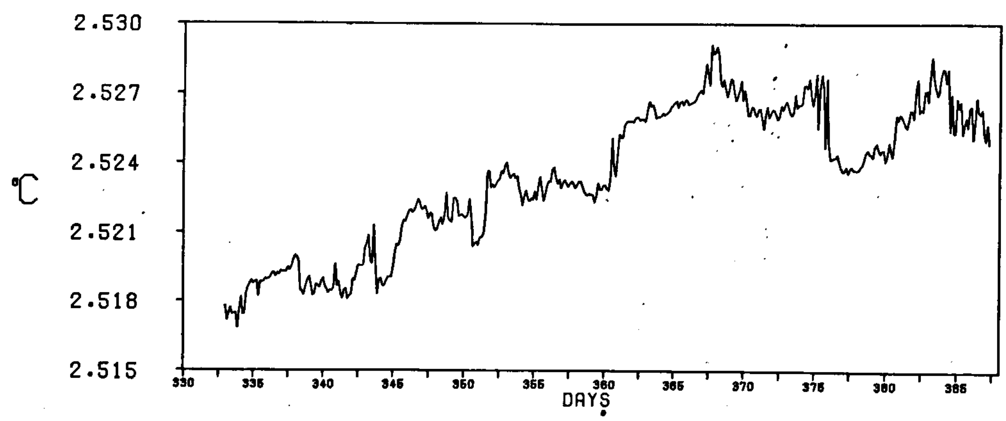

Figure 5
Benthic temperature record.

Figure 6
Exposure of the sea bed showing the shadow of a holothurian and evidence of bioturbation in the surface sediments, the area shown is approximately 65 × 95 cm.

Camera

The camera system exposed about 1,450 frames while the tripod was on the bottom, each image covering the same 65 × 95 cm area of the sea floor. They showed the sea bed to be composed of a calcareous ooze, typical of the sediments throughout this abyssal area (Fig. 6). There was no evidence of ripple marks or other indications of the previous action of strong current flow, and the film, when played at speeds of 2-24 frames/sec. through a projector showed no sign of sediment movement during the 64 days of the observations; this is consistent with the weak currents recorded by the current meter. There were, however, numerous mounds and markings that are characteristic of the reworking of the sediments by biological activity. The images showed several rounded bumps, each about 5 cm in diameter and 2-3 cm high (deduced from the shadows), that closely resembled the cone shaped mounds made by burrowing animals. Figure 6 presents the only frame to show direct evidence of an animal, a holothurian (sea cucumber) 25 cm in length swimming at a height of about 25 cm above the sea floor (it is the shadow of the holothurian that is most obvious, the animal itself is largely transparent but can be seen on the original colour film as a faint pink image at the bottom centre of the frame). Only one observable excavation event occurred during the time lapse exposures. This took place on day 382 and appeared as a flat circular impression 10 cm across. The circular patch elongated slightly after about 3 days and then remained unchanged for the final 11 days of the film.

Acknowledgements

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