# Deep layer variability in the Eastern North Atlantic: the EDYLOC experiment

Current meter array
Dynamics
Bottom nepheloid layer
Variability
Porcupine abyssal plain

Mouillages de courantomètres
Dynamique
Couche néphéloïde profonde
Variabilité
Plaine abyssale Porcupine

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ABSTRACT

The ÉDYLOC ("Étude DYnamique LOCale") experiment was carried out by IFREMER-Centre de Brest in 1981-1982 in order to describe the dynamics and evaluate the space and time scales of current variability in the deep layer of the Porcupine abyssal plain (North East Atlantic). Six moorings separated by 11 to 73 km were deployed in a flat bottom area near 47°N, 14°30'W. The water depth was 4780 m. The results are described here.

A hydrological survey, with nephelometry profiles, shows that a nepheloid layer exists at each station with the strongest signal associated with the only observed bottom mixed layer in the north-western part of the array; it is also there that the currents are the strongest throughout the measurement period.

Over the 11 months of record (data return: 96.2%), the horizontally averaged mean speed is 1.26 cm/s at 4000 m and 1.50 cm/s at 10 m above the bottom with a predominancy of the westward-component. The correlation between the two levels is very high, which means that the deepest level dynamics is not influenced by the bottom effect to the extent that one might expect in a bottom boundary layer. A bottom intensification is observed on KM (kinetic energy of the mean flow) and on KE (eddy kinetic energy) and, for both levels, the currents appear more energetic than for other previous experiments.

The zero-crossing of the auto-correlation functions is 20 days for the U-component at both levels and 66 and 33 days for the V-component at 4000 and 10 m above the bottom respectively.

At both levels, the zero-crossing of the transverse velocity correlation function is 27 km.

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RÉSUMÉ

Variabilité dans la couche profonde de l'Atlantique Nord-Est : l'expérience ÉDYLOC

L'expérience ÉDYLOC (Étude DYnamique LOCale) a eu lieu en 1981-1982 dans le but de décrire la dynamique et évaluer les échelles spatiales et temporelles de la variabilité du courant dans la couche profonde de la plaine abyssale Porcupine dans l'Atlantique Nord-Est. Six mouillages séparés de 11 à 73 km ont été installés dans une région à fond plat autour de 47°N, 14°30'W sur une profondeur d'eau de 4780 m. Les résultats en sont décrits ici.

Une reconnaissance hydrologique, avec des profils de néphélométrie, a montré l'existence d'une couche néphéloïde à chaque station, la plus intense étant associée à l'unique couche mélangée de fond observée dans la partie nord-ouest de la zone; c'est également à cet endroit que les courants ont été les plus forts pendant toute la période de mesures.

Sur les onze mois de mesures (retour des données : 96,2%), la vitesse moyenne, moyennée horizontalement, est de 1,26 cm/s à 4000 m et 1,50 cm/s près du fond, avec une prédominance pour la composante Est-Ouest. La corrélation entre les deux niveaux est très élevée, ce qui indique que l'effet de couche limite n'est pas si important.

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Une intensification est observée sur KM, énergie cinétique moyenne et sur KE, énergie cinétique turbulente, et aux deux niveaux, les courants sont plus énergétiques que lors d'expériences précédentes.

Le premier passage à zéro de la fonction d'autocorrélation moyenne est à 20 jours aux deux niveaux pour la composante U et à 66 et 33 jours pour la composante V à 4000 m et au fond, respectivement.

Aux deux niveaux, le premier passage à zéro de la fonction de corrélation transverse est 27 km.

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## INTRODUCTION

The EDYLOC Experiment ("Étude Dynamique Locale"), was conducted in order to evaluate spatial and temporal scales of deep current variability in the eastern North Atlantic Porcupine abyssal plain. Long-term current measurements were carried out with the deployment of six moorings, with two levels of measurements each (4000 and 10 m above the bottom); a CTD survey was performed during the moorings recovery cruise. The two level results will allow a comparison of the ocean interior dynamics with that of the benthic boundary layer.

Briefly, the characteristics of the benthic boundary layer will be reviewed. Theoretically, in close proximity to the bottom, a "logarithmic layer" must be found, where the current speed is assumed to decrease as a logarithmic function to reach zero on the bottom; this theory supposes that shear is constant in the layer and that the Coriolis forces may be neglected compared with viscosity. Above this layer, the Coriolis forces cannot be neglected and the Ekman theory is relevant; the current describes an "Ekman spiral" with its characteristic veering. In the oceans, all the Ekman layers are turbulent. The logarithmic layer is the one-tenth deepest part of the Ekman layer. In deep oceans, the order of the Ekman layer thickness is 10 m and that of the logarithmic layer is 1 m (for a velocity of 4 cm/s and a friction velocity $u^*$ of 0.2 cm/s). The theoretical difficulty is to link these two layers mathematically.

It is more difficult to observe these layers in the oceans, particularly in deep oceans. In fact, the logarithmic profile has been observed, but the existence of an Ekman layer with its associated veering has been less well established (Bowden, 1978). This is probably due to the non-stationary currents (tidal oscillations) encountered in the areas of observations. In the logarithmic layer, the time scale (of the order of $z/u^*$ which is around 10 minutes) is small compared with the tidal period which allows the establishment of the logarithmic profile. The time scale of the Ekman layer is of the order of the inertial period which is comparable to the tidal periods. Then, the tidal or inertial oscillations disturb the establishment of the Ekman layer.

In our experiment, the deepest level (10 m off the bottom) is quite surely above the logarithmic layer but could be in the upper level of the Ekman layer if it exists. Comparison with the 4000 m results will allow us to determine whether this is the case.

Another approach to the characterization of the influence of the bottom in the deep layer is to examine its hydrological fine structure and the existence of a nepheloid layer. As a result of homogenization due to turbulence above the bottom, a bottom mixed layer (BML) appears in the lower part of the water column, its thickness depending on the strength of this dynamic activity. It cannot be directly related to the theoretical Ekman layer because a BML may be the result of superposition of local old and recent BMLs and advected BMLs. Armi and Millard (1976) studied the BMLs over the Hatteras abyssal plain; they found that the BML thickness was correlated with the daily mean speed of the current and its vertical extension was around 6 times the theoretical Ekman layer thickness. Nevertheless, the existence of a BML is the signature of a mixing activity on the bottom which makes this layer dynamically different from the upper layer.

The bottom mixed layer is usually associated with an intense particle resuspension whose vertical extent may sometimes be much larger than that of the BML itself. This layer above the bottom, where the suspended particle concentration is higher due to the presence of the bottom, is the "bottom nepheloid layer" (BNL). As for the BML, it may result from the superposition of locally resuspended particles and advected particles. The different aspects of nepheloid layers are reviewed by McCave (1986).

It was with the aim of describing this environment that a CTD survey (with nephelometry) was planned during the moorings recovery cruise.

The moorings were launched during the "EDYLOC 81" cruise, in May 1981, aboard the R/V *Le Noroit* and recovered in April 1982 during "EDYLOC 82" aboard the same ship.

To exclude local topographic effects, the region selected was a deep abyssal area (4780 m) over the Porcupine abyssal plain around 47°N, 14°30W, where the Tourbillon experiment took place in 1979 (Fig. 1).

The moorings array was designed as a cross, the branches of which were respectively parallel and normal to the continental margin. To obtain a maximum of mooring pairs to compute the spatial correlations, the moorings were separated with increasing distances, the smallest being 11 km and the largest 73 km. A similar experiment was conducted elsewhere during the same period by I.O.S. (Institute of Oceanographic Science, UK), the results of which (Saunders, 1983) will be compared with ours.

Each mooring carried two Aanderaa current-meters, the deeper at 10 m off the bottom and the shallower at 4000 m depth, *i.e.* around 800 m off the bottom. This level was chosen as representative of the ocean interior and will be used in a comparison with the near-bottom level; furthermore, this depth is a common level with previous experiments in this area: Neads, Tourbillon 79...

During the recovery cruise, CTD profiles were carried out in order to describe the hydrological environment. The Neil-Brown CTD was equipped with a nephelometer, a prototype built at IFREMER-Centre de Brest whose first tests on this cruise were satisfactory.

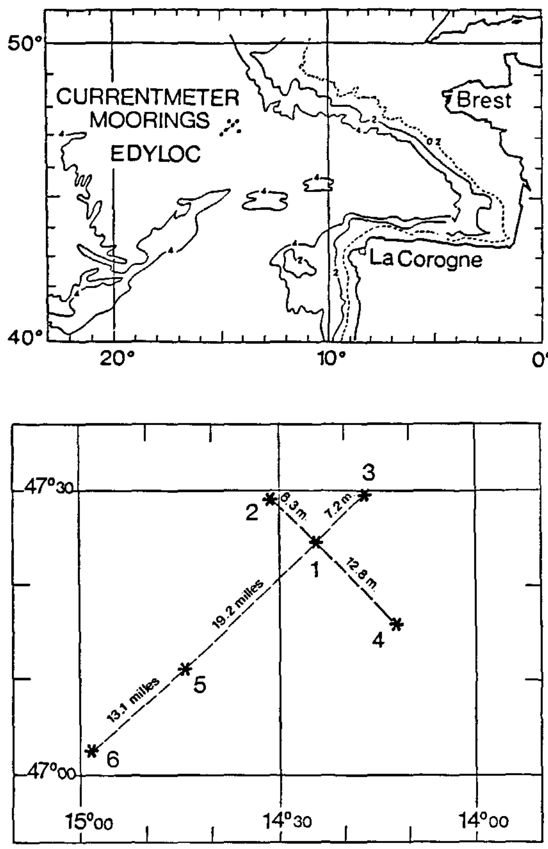


Figure 1

*Location and schema of the moorings array of the EDYLOC 81-82 experiment.*

This device (Fig. 2) has been developed at IFREMER by Gouillou as a sensor dependent on the CTD both for its power supply and its data acquisition system; its measurements are recorded simultaneously to those of temperature, salinity and oxygen. It is an adaptation, for deep pressures, of a shallow-water instrument built by Prieur at the Laboratoire de Physique et Chimie Marines of Villefranche-sur-Mer (France). It measures the optical scattering, by suspended matter, of a beam near an angle of 4°. The ratio of scattered light over direct light is linearly related to the optical scattering coefficient and to the particle concentration. The calibration versus diffusion coefficient (metres-1) has been obtained by comparison with the Prieur's instrument (Vangriesheim, Gouillou, 1987). To obtain the relationship with particle concentrations, a delicate *in situ* calibration is needed with dry weight. Because of the low concentrations encountered in the deep ocean, this relation is not yet obtained. Thus, the nephelometry data will be presented here as nondimensional values which are those of the scattered light/direct light ratio.

## RESULTS

### Hydrological environment

The hydrological structure can be studied from the CTD stations carried out around the moorings. Figure 3 shows, as an example, profiles of potential temperature, salinity, and oxygen at station 19 which reached the bottom. This figure enables the different water masses to be identified:

– a surface layer affected by seasonal fluctuations of some tens of metres;

– Northeast Atlantic central water down to around 500 m;

– Mediterranean water characterized by a salinity maximum and small temperature inversions around 1000 m;

– Labrador Sea water around 1700 m with its minimum of salinity;

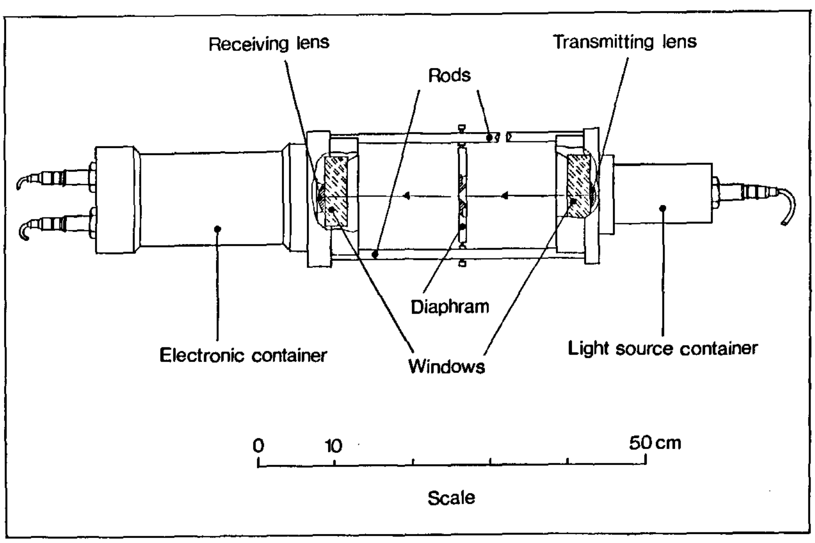


Figure 2

*The nephelometer built at IFREMER which was installed on the CTD.*

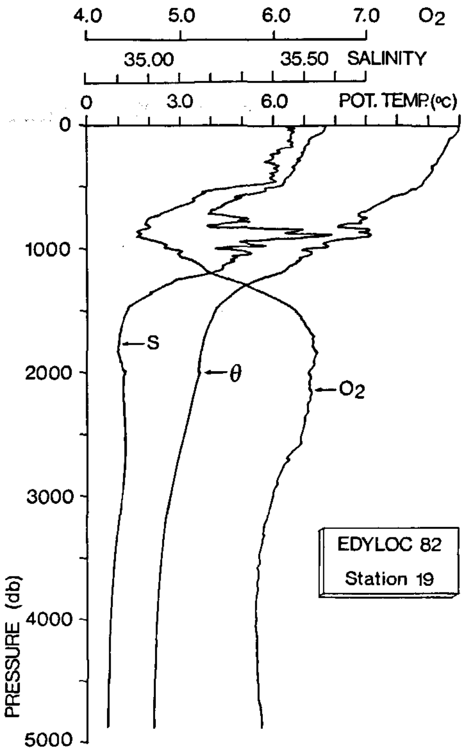


Figure 3
*Vertical profiles of potential temperature, salinity and oxygen concentration at station* 19 (47°34.43′ *N*, 14°07.52′ *W*).

– a layer with a slight deep salinity maximum around 2300 m which is usually attributed to Norwegian Sea water influence but which could be due to that of Mediterranean water according to Harvey and Glynn (1985);

– the Northeast Atlantic bottom water of Antarctic origin where salinity and temperature decrease slowly to the bottom.

During the CTD survey, only 6 stations with nephelometry measurements were carried out down to the bottom (the other CTD casts stopped at 4 000 m). The vertical profiles for this parameter are drawn on Figure 4; the upper part has been truncated because of the very high values at the surface. As the nephelometer has been developed in order to measure low particle concentrations in the deep ocean, its response in the high concentrations of the euphotic layer is non-linear; consequently, the high surface values should not be compared to the remaining profile. The strong peaks which sometimes appear are due to large particles which saturate the scattering signal.

Besides the upper layers, the scattering signal is rather homogeneous, except near the bottom where an increase of the signal is observed. This reveals the presence of a nepheloid layer, the top of which lies between 4100 and 4400 dbar (thickness of 750 to 500 m) except at station 16 where the layer top is at 4700 dbar and where a strong signal is observed close to the bottom; at this station, the nepheloid layer is then the thinnest (200 m) but the strongest and it is the only station where a bottom mixed layer (around 90 m thick) appears on the potential temperature and salinity profiles (*see* expanded deep profiles on Fig. 5). At the other stations, no bottom mixed layers appear; potential temperature and salinity decrease slowly down to the bottom. This absence of bottom mixed layer linked with a weaker signal of nephelometry at these stations could indicate that the boundary effect on the dynamics is weaker than at station 16 where the effect of the bottom is well-marked.

After these observations, it is evident that the uppermost current-meter (4000 m) is above the nepheloid layer which is, itself, thicker than the slight and thin bottom mixed layer observed at only one station. The deepest current-meter (10 m off the bottom) is in the nepheloid layer and in the BML when it exists. We may thus expect some differences between the dynamics of the two levels.

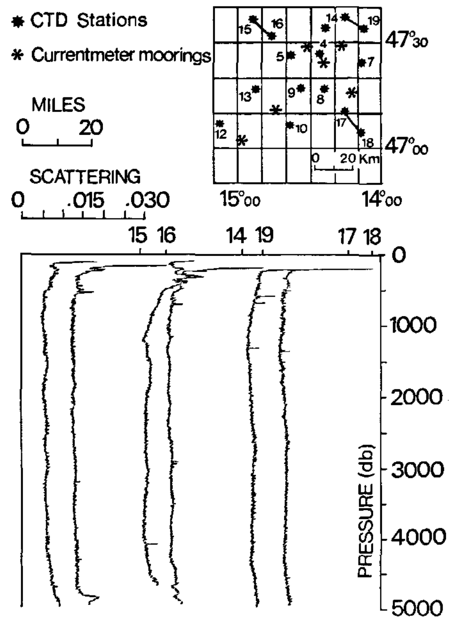


Figure 4
*Vertical profiles of nephelometry at stations* 15, 16, 14, 19, 17, 18.

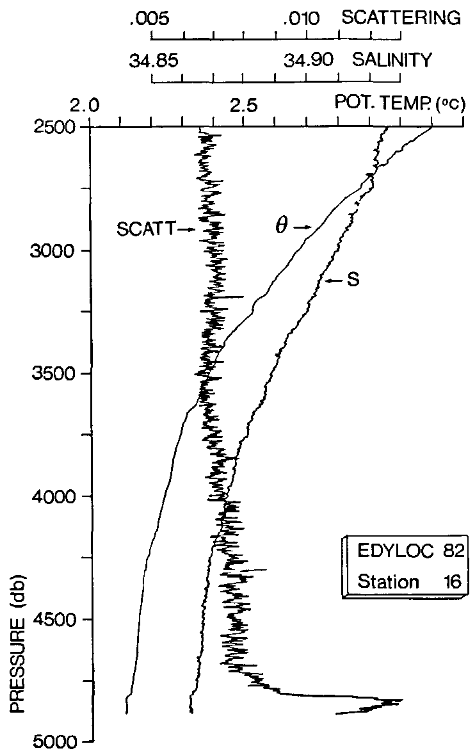


Figure 5
*Expanded deep vertical profiles of nephelometry, potential temperature and salinity at station* 16 (47°31.50′ *N*, 14°45.80′ *W*).

## Currents

### *The data set*

Current and temperature data were collected with Aanderaa RCM5 current-meters. Rotor, compass and temperature sensors were calibrated at IFREMER before deployment. All instruments were equipped with an expanded temperature scale whose resolution is 8 m°C. Currentmetres, at 4000 m, had a pressure sensor to measure the mooring line excursions which were, in fact, insignificant.

The data return was very good. Measurements lasted from 19, 20, or 21 May 1981 to 6, 7 or 8 April 1982. Only 2 of the 12 data series have short gaps: at mooring M3, speed data at 4000 m starts only on 19 July, and at mooring 6, temperature data at 4000 m stop on 9 January. Thus, the data return is 98.5% for speed data and 97.7% for temperature data *i. e.* 96.2% to have the two parameters simultaneously. The data sample interval was 1 hour.

The data have been processed and presented either unfiltered or filtered, depending on the calculation concerned. To remove high frequency oscillations, such as tide and inertial oscillations, a Lanczos filter with a cut-off period of 2 days has been used.

### *General description of the circulation*

A data report (Vangriesheim, 1986) presents all the results by means of graphics such as speed, east and north components (U and V), temperature versus time, stick-plots, progressive vector diagrams, energy spectra and different statistical values. It may be consulted for complementary details.

To give an insight of the pattern of the circulation deduced from our measurements, Figure 6 shows the PVDs at 4000 m and 10 m off the bottom on maps where the starting point of each PVD coincides with the location of the mooring concerned. Except at mooring 3 where measurements at 4000 m start two months later than the others, these fictitious trajectories show a strong correlation between the two levels. At moorings 1, 2, 3, which are the nearest, the westward component is predominant throughout the duration of the measurements. At M4, the northward component is always predominant. For moorings 5 and 6, no predominance appears.

The stick-plots of Figure 7 show the time-fluctuations of the current at moorings M2 and M5, where it was respectively the strongest and the weakest. For these two extreme cases, the correlation between the two levels is evident. Evident also but not so strong is the correlation between the north components at the two locations, in spite of the dominance of the west component at M2.

It should be noted that it is only near the location of the highest current speed (station 16 is the closest to mooring 2) that a bottom mixed layer associated with the strongest nepheloid layer was encountered. Thus, these observed BML and BNL are partly related to the local higher current. The hydrological measurements took place during a short interval compared with the duration of the current measurements; as the correlation between high currents and existence of BML and BNL is strong at the end of these measurements, it may be supposed that this deep structure lasted throughout the period where M2 currents were high, *i. e.* throughout the 7 months of measurements.

### *Statistics*

From the unfiltered data, the maximum speed encountered lies between 12.4 and 14.4 cm/s at 4000 m and between 14.4 and 16.3 cm/s at 10 m off the bottom, thus indicating higher maximum speeds near the bottom. For U-components, values at 4000 m vary from −12.9 to 12.7 cm/s and from −15 to 14.6 cm/s at 10 m off the bottom; for V-components, the values lie

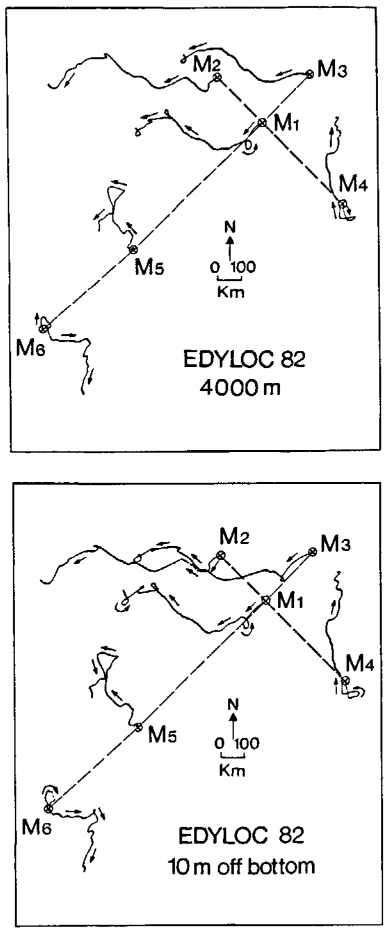


**Figure 6**

***Progressive vector diagrams obtained for the 6 moorings at 4000 m and at 10 m above the bottom.***

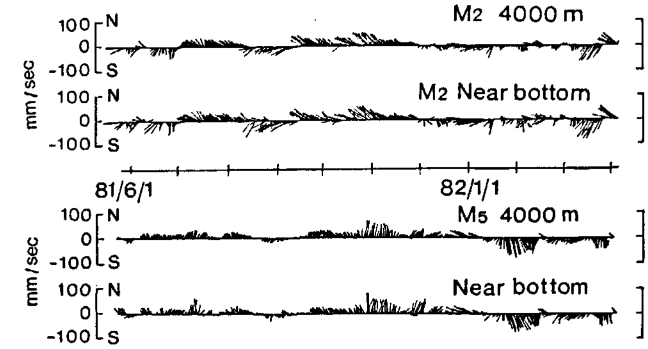


**Figure 7**

***Stick-plots of the currents at moorings M2 and M5.***

between −14.1 and 12.5 cm/s at 4000 m and between −12.8 and 14.1 cm/s at 10 m off the bottom. Thus, the two components seem to reach maximum values of the same order.

Figure 8 presents mean velocities, for both levels, at the six points of measurements. As in Figure 6, the westward-component appears to be predominant at both levels for M1, M2, M3, as does the northward-component at M4. The slight veerings (1° to 10°) between the two levels seem to have no significance in terms of Ekman veering: when the two vector directions are distinct, the veering is twice on the right and twice on the left (at M2 and M3 where the currents are the highest).

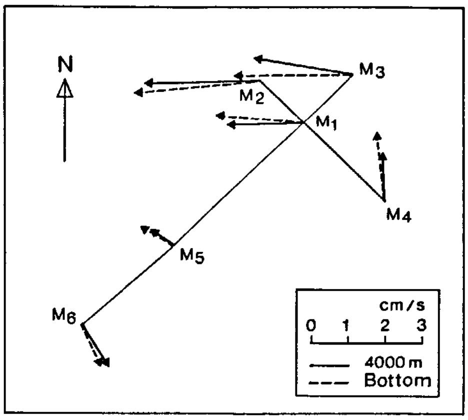


Figure 8
*The 11-month mean velocity field at 4000 m and 10 m above the bottom.*

The lowest mean velocities are 0.7 and 0.9 cm/s (4000 m and bottom respectively) at M5 and the highest are reached at M2 with 3.1 and 3.3 cm/s (4000 m and bottom respectively) which shows, as for maximum speeds, higher values near the bottom.

Figure 9 summarizes, on a grid resembling the mooring array, the mean values for U- and V-components, KM and KE for each filtered data serie as well as their averages (with errors). An estimation of the error has been obtained based on $\overline{U'^2}$, $\overline{V'^2}$, the time scales found for U and V at each level (*see* section concerned with autocorrelations) and considering that, as the horizontal correlation length is 27 km, the average is made with 3 independent data sets: M1-M2-M3-M4, M5 and M6. The method used for this estimation is taken from Bendat and Piersol (1971).

At both levels, the error is higher for the V-component due to the fact that the integral time scale is longer for this component.

From Figure 9, it may be deduced that the horizontal average speed is 1.26 cm/s at 4000 m and 1.50 cm/s near the bottom.

The values of $\overline{U'^2}$, $\overline{V'^2}$ and $\overline{U' * V'}$ have been used to determine the principal axes of the fluctuations. At 4000 m, the principal axis is oriented along 003° *i.e.* almost northward, and 57% of the energy is in this direction. At 10 m above the bottom, the direction is 018°, *i.e.* slightly most eastward and the energy is not more polarized in this direction (57% also). Such a

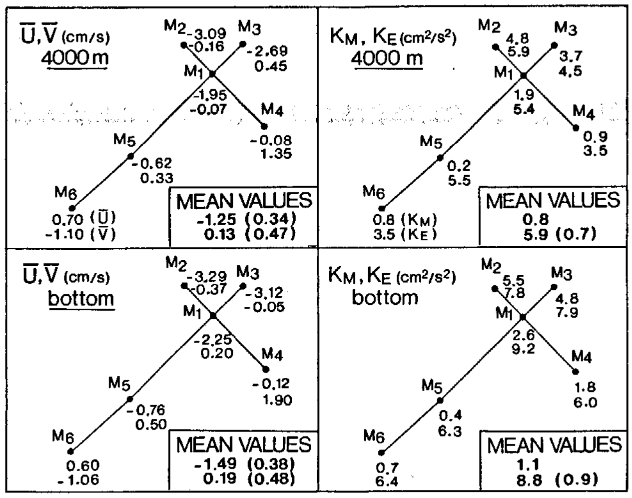


Figure 9
*Ū, V̄ and KM, KE for each mooring at 4000 m and 10 m above the bottom and mean values (i.e. averaged over the 6 moorings) with errors.*

calculation has been made also within frequency bands; it shows that no higher polarization appears at any frequency band and that all the energy is concentrated in the low frequency range with almost the same polarization as in the mean signal (Mercier, pers. comm.).

*Frequency analysis*

As regards to the energy content of the data, Figure 10 shows, as an example, the kinetic energy spectrum obtained from unfiltered data at both levels for M1. Strong signals can be identified at semi-diurnal and diurnal frequencies and at inertial frequency (inertial period in this area is around 16 h 30). At both levels, the energy associated with semi-diurnal tide is higher

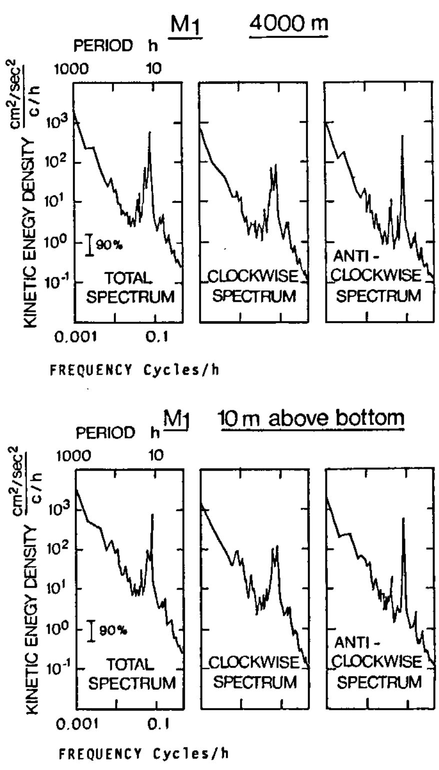


Figure 10
*Total, clockwise and anti-clockwise spectra obtained from unfiltered data at mooring 1 (4000 m and 10 m above the bottom).*

Table 1

*Confidence levels (at 90%) and numbers of degrees of freedom for the energy spectra of Figure* 11.

| | 4000 m | | | 10 m above bottom | | |
|---|---|---|---|---|---|---|
| Period band days | $f*$KE | limits (cm/s) 2 | N | $f*$KE | limits (cm/s) 2 | N |
| 626 to 208 | 2.43 | 1.15 to 8.91 | 6 | 3.08 | 1.47 to 11.31 | 6 |
| 208 to 125 | 4.07 | 1.94 to 14.9 | 6 | 5.24 | 2.50 to 19.23 | 6 |
| 125 to 69 | 2.64 | 1.51 to 6.08 | 12 | 3.53 | 2.01 to 8.10 | 12 |
| 69 to 48 | 2.54 | 1.45 to 5.84 | 12 | 3.61 | 2.06 to 8.29 | 12 |
| 48 to 30 | 1.63 | 1.08 to 2.83 | 24 | 2.39 | 1.57 to 4.14 | 24 |
| 30 to 19 | 0.81 | 0.57 to 1.25 | 36 | 1.66 | 1.17 to 2.57 | 36 |
| 19 to 12 | 0.68 | 0.51 to 0.94 | 60 | 1.37 | 1.04 to 1.91 | 60 |
| 12 to 6 | 0.55 | 0.46 to 0.67 | 156 | 1.51 | 1.27 to 1.84 | 156 |
| 6 to 2 | 0.43 | 0.40 to 0.48 | 576 | 1.39 | 1.27 to 1.54 | 576 |

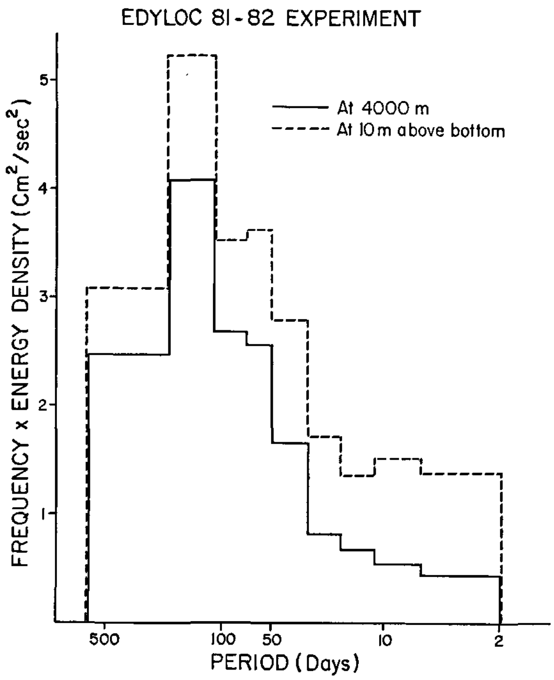


Figure 11

*Average kinetic energy at* 4000 *m and* 10 *m above the bottom in energy preserving form (obtained from filtered data).*

than that of inertial oscillations. For all moorings, tidal energy at 4000 m is lower than near the bottom but no such significant tendency appears for inertial oscillation energy.

To examine low-frequency fluctuations, horizontally averaged energy spectra have been calculated at each level from filtered data. The spectra at both level are presented in Figure 11 in variance preserving form. Frequency averaging has been made over several adjacent frequency bands to obtain a better estimation of the result. Table 1 shows the limits of these averaged bands as well as their $f*$KE content, the confidence levels (at 90%) and the number of degrees of freedom in each period band.

It may be noticed that the energy is higher for the bottom at all frequencies; this intensification is greater for periods less than 30 days where the bottom energy exceeds by a factor of two the 4000 m level energy. This is statistically significant because, as shown in Table 1, there is no overlap between the confidence limits of the two levels due to the high number of degrees of freedom at these periods.

A broad maximum appears at both levels between 208 and 48 days, particularly between 208 and 125 days. This peak is in the period band affected by the eddies

Table 2

*First zero crossing, integral time scale, square integral time scale from averaged autocorrelations for U, V, T.*

| | | First zero crossing (days) | Integral time scale (days) | Square integral time scale (days) |
|---|---|---|---|---|
| U | 4000 m | 20 | 9 | 8 |
| | Bottom | 19 | 8 | 5 |
| V | 4000 m | 66 | 17 | 14 |
| | Bottom | 33 | 12 | 10 |
| T | 4000 m | 47 | 14 | 19 |
| | Bottom | 23 | 9 | 6 |

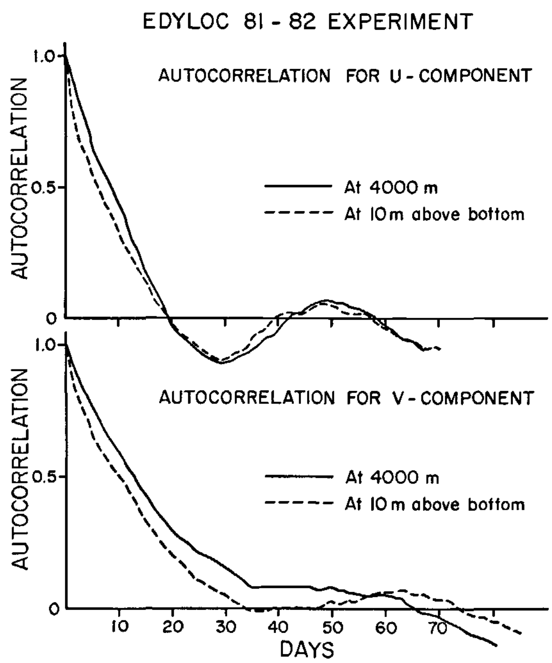


Figure 12

*Autocorrelation functions for U- and V-components at* 4000 *m and* 10 *m above the bottom.*

or some seasonal signal and is now a rather usual feature.

*Time and space scales*

Averaged autocorrelation functions have been calculated for U- and V-components at both levels. In Figure 12, which presents the results, it appears that the time scale for the V-component is much longer than for the U-component. This is shown more precisely on the Table 2, which summarizes the values of the first zero crossing, the integral time scale and the square integral time scale for U, V and T at each level. The autocorrelations have been calculated with a maximum time lag of 150 days. The integral time scales were evaluated over the interval bounded by the first zero crossing, and the square integral time scale was calculated up to 150 days. From this table, it may also be noticed that for the 3 parameters, the time scales are less at 10 m off the bottom than at 4000 m. This is the same feature as that previously observed on the spectra where the bottom intensification was higher for short periods.

At the opposite, at Tourbillon (Mercier, Colin de Verdière, 1985), the time scales increase with the depth down to 3000-4000 m (the two levels were averaged in the calculations), where the square integral time scale is 11 days for both U- and V-components which is an intermediate value between those found for U and V at EDYLOC.

The horizontal scales of the low-frequency currents have been obtained by computation of the transverse and longitudinal correlations for all the pairs of data series at each level. Then, the results have been averaged in each band of 5 km; the results are shown in Figure 13. The transverse correlation had its first zero crossing at 27 km at both levels and, as is usually found, the longitudinal correlation never reaches zero. This horizontal scale lies between those found at 3000 m for Tourbillon (32 km) and on Madeira abyssal plain (Saunders, 1983) at 10 m above bottom (22 km).

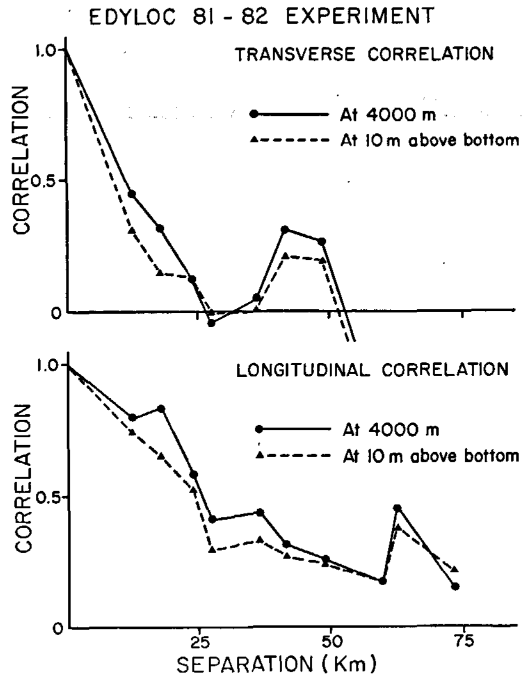


Figure 13

*Transverse and longitudinal correlation functions calculated at 4000 m and 10 m above the bottom.*

## DISCUSSION AND CONCLUSIONS

### Hydrological environment and suspended particle

The CTD survey performed around the moorings array revealed that, despite a very flat bottom topography, a nepheloid layer appears on all the vertical profiles. Nepheloid layers have been observed for a long time in the West Atlantic (Eittreim, Ewing, 1972) and in the whole Atlantic (Biscaye, Eittreim, 1977), where they are closely linked to the Antarctic bottom water flow. In the Northeast Atlantic, they were observed more recently, particularly over rough topographies or slopes (Vangriesheim, 1985, Fig. 4; Dickson, McCave, 1986; Nyffeler, Godet, 1986) but they had never been observed over the Porcupine abyssal plain. In these cases, they are not directly linked with a water mass flow but are caused by dynamical processes over the bottom. The feature found here over the plain is rather different from that observed over a slope. On the EDYLOC profiles, the nepheloid layer is marked by a smooth increase of the signal down to the bottom; it is only in the last tens of metres that a stronger signal appears. On the slope (Vangriesheim, 1985, Fig. 4), it is characterized by a more homogeneous layer separated from the upper one by a strong gradient and which coincides with a well-marked bottom mixed layer. This set of data is too small to understand the behaviour of the bottom nepheloid layers over EDYLOC area; it is yet enough to know that the uppermost current meter of the moorings is above the nepheloid layer.

The important point to be noted is the fact that the area where the only BML has been observed linked with the strongest nepheloid layer is that where the currents were the strongest (station 16); at this station, this observation might support the idea of a local process of generation of the BML and BNL. At the other stations of the area, the thicker observed nepheloid layer is more likely a stack of discrete BNLs generated elsewhere and advected along density surface. According to one reviewer of this paper, this generation mode would prevail also for the station 16, considering that the observed nepheloid layer thickness (200 m) is too high compared with the average thickness (50 m) of locally generated BNLs deduced by bottom Rn-222 profiles (Gurbutt, Dickson, 1986). In this case, the origin of the BNL observed at station 16 must be due to a topography outside the array at a depth corresponding to that of the maximum light scattering measured at this station. More data would be needed to confirm this assertion.

### Mean circulation

Concerning the current measurement results, it appears that the mean current is more westward than usually found in this area.

As for the current measurement results at 4000 m, the westward component is higher than in most of the previous experiments conducted in the Eastern North Atlantic (Dickson *et al.*, 1985); this is not the case for the northward component which is less in our experiment. The resultant at 4000 m at EDYLOC is towards west-north-west, whereas it was north-east at Tourbillon in the same area in 1979-1980 (Mercier, Colin de Verdière, 1985). This discrepancy between two consecutive experiments made in the same place shows again that a one year time-average of the current is not enough to be statistically significant. Nevertheless, the existence of a northward component is consistent with the Antarctic origin of the bottom water. The only southward weaker mean current observed at mooring 6 could be explained by the influence of topography to the south-west of this mooring.

The near-bottom values may be compared also to other results: in most experiments in the same area, the U-component is not so intense at 10 or 50 m above the bottom as in the present case.

**Mean flow kinetic energy and eddy kinetic energy**

In order to compare the values of KE and KM with those of other experiments, Tables 3 and 4 summarize some previous results obtained in almost the same conditions *i. e.* over an abyssal plain with at least the same depth, excluding experiments conducted further north than EDYLOC or conducted over topography. From these tables, the EDYLOC values are in agreement with the energy decrease toward the south already noticed by Dickson *et al.* (1985).

Nevertheless, KE values at 4000 m are higher at EDYLOC than in previous experiments in the same basin and, in addition, higher than those obtained at the same place during Tourbillon 79-80; as for KM, the EDYLOC values at 4000 m are also the highest except for the mooring 0 (MAFF) data.

Concerning the near-bottom results, EDYLOC KE values are of the same order as those obtained at the same place during Tourbillon but are higher than those obtained elsewhere in the same basin.

**Bottom intensification**

Concerning kinetic energies, it may be seen on Figure 9 that KM is higher on the bottom than at 4000 m for all the moorings but M6, and that bottom KE is higher for the six moorings. On averaged values, it is clear that this intensification is statistically significant for KE; concerning KM, though it is not statistically

Table 3

*Comparison of 4000 m KE and KM EDYLOC values with other experiments carried out over at least the same depth in the North-East Atlantic.*

| Experiment | Water depth (m) | KE $cm^2/s^2$ | KM $cm^2/s^2$ | Source |
|---|---|---|---|---|
| EDYLOC | 4780 | 5.9 | 0.8 | – |
| Same area | | | | |
| Tourbillon | 4800 | 3.3 | 0.3 | Colin de Verdière and Mercier (IFREMER) |
| Same basin | | | | |
| Mooring O | 4820 | 5.62 | 2.61 | Dickson |
| 49 10.4 N 15 44.6 W | | | | (MAFF*) |
| Neads 7 | 4995 | 2.1 | 0.12 | Maillard |
| 47 00 N 10 00 W | | | | (IFREMER) |
| Neads 5 | 4760 | 1.02 | 0.50 | Dickson |
| 46 06 N 17 09 W | | | | (MAFF*) |

* MAFF: Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, Suffolk, UK.

Table 4

*Comparison of near-bottom KE and KM EDYLOC values with other experiments carried out over at least the same depth in the North-East Atlantic.*

| Experiment | Water depth (m) | KE $cm^2/s^2$ | KM $cm^2/s^2$ | Source |
|---|---|---|---|---|
| EDYLOC | 4780 | 8.8 | 1.1 | – |
| Same area | | | | |
| Tourbillon M10 | 4775 | – | – | Vangriesheim |
| 20 m off bottom | – | 9.6 | 0.3 | (IFREMER) |
| 50 m off bottom | – | 9.6 | 0.3 | |
| Same basin | | | | |
| Mooring O | 4820 | 5.63 | 2.41 | Dickson |
| 50 m off bottom | | | | (MAFF) |
| 49 10.4 N 15 44.6 W | | | | |
| Madeira abyssal plain | | | | |
| 33 N 22 W | 5300 | 3.6 | 0.01 | Saunders |
| 10 m off bottom | | | | (IOS**) |
| 81-14 50 m off bottom | 4912 | 2.83 | 1.12 | Dickson |
| 81-16 50 m off bottom | 5296 | 2.05 | 1.78 | (MAFF) |
| 81-17 50 m off bottom | 5027 | 2.38 | 0.04 | |
| Canary abyssal plain | | | | |
| CV1 | 5200 | 1.76 | 0.46 | Vangriesheim |
| 10 m off bottom | | | | (IFREMER) |
| 24 49.6 N 25 02.9 W | | | | |
| CV2 | 4885 | 1.17 | 1.12 | – |
| 10 m off bottom | | | | |
| 19 14 N 29 47.7 W | | | | |

** IOS: Institute of Oceanographic Sciences, Wormley, Godalming, Surrey, UK.

significant, this increase from 4000 m to the bottom for almost all the moorings is worth pointing out.

A bottom intensification has been already observed in other places and at Tourbillon between 3000 and 4000 m (Mercier, Colin de Verdière, 1985). However, there is no evidence that the one observed here is due to the same processes. It would be interesting to know up to which level the downward intensification observed at EDYLOC and at Tourbillon could be found; better vertical resolution is needed between 3000 m and the bottom to determine this. Besides, here, this intensification seems to be slightly higher for the V-component than for the U-component.

The average ratios KE/KM are almost identical near the bottom (7.8) and at 4000 m (7.4), which means that KE and KM seem to be intensified in the same proportion. The intensification of KE, which is the most significant, is rather high compared to that observed during Tourbillon (Mercier, 1983): the ratio KE (bottom)/KE (4000 m) is 1.5 at EDYLOC while KE (4000 m)/KE (3000 m) was 1.3 during Tourbillon (for a greater level difference).

Energy frequency analysis shows that the intensification is greater for high frequencies. The hypothesis of topographic Rossby waves to explain this does not hold: firstly, no slope appears on the local topography and secondly, horizontal coherences show that only low frequency oscillations are coherent while those of high frequency, where topographic Rossby waves are expected, are not coherent (Mercier, pers. comm.).

Thus, the explanation for this intensification must be sought elsewhere, and further comparisons with models will be made. Particularly, a non-linear model taking account of the topography (Treguier, 1987), without boundary layer, predicts a KM deep layer intensification. Thus, the bottom intensification encountered in our experiment would not necessarily be due to a boundary layer effect and there is not enough data to determine whether our deepest level of measurement is or not in the boundary layer.

**Time and space scales**

As for the time scales, they are consistent with other North-East Atlantic results but an interesting feature is the difference between U and V time scales (Tab. 2). The V time scale is much longer than the U one which was not the case for the Tourbillon experiment. No satisfying explanation can be given.

This set of data allowed the evaluation of the horizontal scales in the deep layer of the Porcupine abyssal plain, a task not done before employing current measurements. The horizontal scale (27 km) is found to be the same at both levels. The deep spatial scale appears to be the same as that of upper levels or that of the southern area. An attempt was made to find assymetries in the spatial correlation. To this end, horizontal correlations were calculated separately with the set of moorings deployed along the line parallel to the continental slope and with the moorings installed along the line normal to the slope. No significant differences appear in the results which could permit any assertion about a polarization by the slope except that it seems to be small.

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