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Synoptic conditions and field of the vertical component of drift current speed in the north-eastern part of the Tropical Atlantic

By

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Summary

The atmosphere and the ocean can be considered as a single system with processes of interaction. All changes occurring in the atmosphere must certainly be reflected in changes of the physical state of the ocean and somehow in changes of the vertical component of drift speed which dominates in the formation of the vertical speed field in the upper layers of the ocean.

We examine the influence of changes of the synoptic situation upon the changes of the field of the vertical component of the drift speed on the basis of the material of two hydrometeorological surveys conducted in the area to the south of the Arquipelago de Cabo Verde. We come to the conclusion that the intensity of vertical movements in summer is connected with the existence of a tropical depression region and with the local cyclonic vortexes on its axis.

With the filling up of the region of reduced pressure on the axis of the tropical depression a weakening of the cyclonic vortexes in the atmosphere occurs which leads to a remarkable decrease of vertical movements.

The connection of tuna distribution with the character of vertical movements was examined. It was pointed out that tuna catches decreased with the weakening of vertical circulation.

Introduction

Since the atmosphere and the ocean can be considered as a single system with processes of interaction all the changes occurring in the atmosphere must certainly be reflected in changes of the physical state of the ocean.

Particularly, we are interested in the question of variations in the vertical component of the speed of the drift current as a function of the synoptic conditions.

We tried to conduct such an investigation for the area of the Tropical Atlantic situated south of the Arquipelago de Capo Verde.

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The analysis of hydrological data available in AtlantNIRO made it possible to find out that the most characteristic peculiarity of the part of the ocean to be investigated is the presence of intensive vertical water movements which are subject to significant variations in time and space.

The different aspects of the influence of upwelling and sinking have been discussed many times, therefore we'll not dwell upon this question.

However, it is necessary to indicate that in some cases these processes influence the life development in the sea.

The vertical movements are closely connected with divergence and convergence of the surface currents because of the condition of liquid indissolubility.

The basic reasons for the occurrence of this phenomenon can be different, but the dissimilarity of the wind field is considered the main reason. By means of tangential tension this dissimilarity is transferred to the surface giving an effect of divergence and convergence.

One of the authors who take up this subject for study is K. Hidaka who discusses the distribution of areas of divergence of surface currents and their seasonal variation in a number of papers (3,4). As was already mentioned not only the wind influences the rise of vertical movements. There are a number of other reasons.

In particular, while approaching the Equator the value of the vertical component of the Coriolis parameter, and some other factors, increase. However, there is a seasonal variation of vertical movements which can be compared only with great seasonal variations of wind conditions forming fields of both wind and gradient-convection current. Thus, it can be suspected that currents of the upper layer of the ocean and hence the vertical component of their speed are the reflection of wind conditions having a considerable influence down to depths of 200-300 meters.

The quantitative estimation of the vertical component of drift current speed contribution to the total vertical speed will be discussed later on.

Initial materials and method of calculation of the vertical component of drift current speed

The basis of our investigation is the material of two hydrometeorological surveys made by the AtlantNIRO vessel SRTR-9006 "Olekma" in summer (August-September) and autumn (October) 1964 in the ocean area situated southward to the Archipelago de Cabo Verde. From these data two charts of the surface baric field which corresponds to the surveys in time and also two charts of the distribution of the vertical component of the drift current speed were plotted.

Since the initial value for the estimation of the drift component of the vertical speed is the tangential tension of the wind we will shortly dwell upon the method of its calculation.

It turned out that it was impossible to estimate the geostrophic wind from gradients of atmospheric pressure.

Speed of this wind calculated by the formula:

$$U_g = \frac{1}{2\omega\varrho\sin\varphi}\,\frac{\delta p}{\delta n}$$

appeared to be too high.

Furthermore, the direction of the pressure gradient does not seem to be very reliable because of the small values of its components on parallel and meridian.

For these circumstances the ship's investigations were used for estimation of the tangential tension.

The estimations of the tangential tension of the wind were made by means of the formula: $T_a = c\varrho V_o^2$ where

T_a is the tangential tension of wind

c a dimensionless factor

ϱ air density

V_o speed of the surface wind

The values of the dimensionless factor c depend on the state of the atmosphere (1). Since this during the surveys can be characterized as equiponderant and weekly unstable (t of water - t of air > 0) the values of c is equal to 0.0035.

For estimation of the vertical component of the drift current the formula proposed by Chekotillo (2) was used:

$$W_h = -\frac{1}{\varrho f}(\mathrm{curl}\, T_a + \frac{\beta}{f} T_{ax})$$

where W_h is the vertical speed of drift current

h depth of friction (according to Ekman)

β Rossby parameter

f Coriolis parameter

T_{ax} projection of the tangential tension of wind on the X-axis.

It seems necessary to make a quantitative deposit to the common vertical component of the current speed which can be considered as a sum of drift and gradient-convectional components.

An estimation for the upper layer of the ocean down to the depth of real penetration of wind current will be made.

According to (2) the characteristic expressions for the drift currents are:

$$W'_d = \frac{T_a}{\varrho f L} \quad \text{and} \quad W''_d = \frac{F T_a}{\varrho f},$$

for the gradient-convectional:

$$W'_g = FhV_g \quad \text{and} \quad W''_g = \frac{\xi \Delta p_a}{\varrho f L}$$

Here L is the characteristical scale of eddies with intensive vertical water movements

T_a tangentional tension of wind

f Coriolis parameter

V_g speed of gradient-convectional current

ξ excess of troubled sea surface above the zero plane

Δp_a gradient of atmospheric pressure

h characteristic depth of drift current penetration.

Taking:

$L = 10^7$ cm, $h = 10^3$ cm, $\xi = 10^2$ cm, $f = 10^{-5} \sec^{-1}$, $F = 10^{-8} \mathrm{cm}^{-1}$,

$\varrho = 1\ \mathrm{g\,cm}^{-3}$, $p_a = 10^{-5}\ \mathrm{g\,cm}^{-2} \sec^{-2}$, $U_g = 10\ \mathrm{cm} \sec^{-1}$, $T_a = 1\ \mathrm{dyn\,cm}^{-2}$

Then:

$$W'_d = 10^{-2}\ \mathrm{cm} \sec^{-1}, \quad W''_d = 10^{-3}\ \mathrm{cm} \sec^{-1},$$

$$W'_g = 10^{-4}\ \mathrm{cm} \sec^{-1}, \quad W''_g = 10^{-5}\ \mathrm{cm} \sec^{-1}.$$

This means that the drift component of vertical speed penetrates much deeper than does the gradient-convectional component.

Returning to the method of calculation of the vertical speed we can say that this operation was carried out by means of usual methods of number differentiation.

Estimated data were connected with the middle points of 1-degree squares. The area of investigation was divided into such squares.

Discussion of the data obtained

Let us study the mean chart of the surface baric field (Fig. 1) which was plotted for the period of August-September 1964. This period of averaging was chosen because the wind conditions in August-September were almost stable. The speed and direction of wind changed insignificantly.

The baric field during the said months had the following peculiarities. The general direction of isobars is characterized by a clearly expressed latitude orientation. The axis of tropical depression is situated in the region of 10°-15°N. In our opinion its limits are represented quite well by the 1013 mb isobar. Near the African coast the axis of depression takes the direction of the coast and in the west (30°W) it follows the meridian. All over the area the depression edges are bordered by zones of increased pressure.

The interesting peculiarity of the investigated baric field is the presence of local regions of reduced pressure that have diameters of several hundred kilometers. The question can be raised whether these regions exist or their appearence in the chart is a result of errors of methodical character being introduced in averaging the initial data. It seems that we can prove the truth of such baric formation by the following.

1. All the centres of reduced pressure are situated on the axis of baric depression.

2. The existence of local deepening of the baric field must give rise to local cyclonic vortexes of wind field which can lead to upwelling and reducing of the surface layer temperature.

Distribution of water temperature at the depth of 50 m in August-September 1964 can prove it. Thus for example, a reduced pressure region centred at 10°N, 30°W corresponds to the tongue of cold water with temperature below 16°, the region of reduced pressure at 10°-12°N, 21°-25°W corresponds to the large patch of cold water below 16°. It should be noticed that the last region of reduced pressure has the larger area, hence the area of cold water is also larger. It seems that it is not necessary to prove further the reality of the existence of local regions of reduced pressure, since also in October they are not situated randomly, but on the axis of depression. Moreover, these local deepenings of the baric field have probably great seasonal stability which can be observed in the multi-years plan.

To discover the position of upwelling and sinking we calculated the values of the divergence of surface current speed for the Eastern Atlantic from the multi-years average data.

Comparing the charts of the baric field for August-September 1964 with the distribution chart of current speed divergence for the summer period it turned out that the region of reduced pressure at 10°-12°N, 20°-25°W corresponds to the region, of corresponding size, of great numerical values of positive divergence, i.e. intensive upwelling. We don't give the chart of the distribution of current speed divergence because of the limited size of the article.

The coincidence of the zone of great values of the divergence with the region of reduced pressure does not seem to be accidental. Since the surface currents of the Eastern Atlantic are caused by the wind it is clear that the high multi-years' mean values of positive divergence of current speed reflect great cyclonic vortexes of the wind field, proving somehow the existence of local baric deepenings on the axis of tropical depression.

Another interesting peculiarity of the baric field is the clearly expressed influence of orographic conditions on the isobar configuration. For instance, near the Arquipelago de Cabo Verde the form of isobars has a waving character which can be explained by the influence of the large air warming over these islands. Near Cabo Verde the 1014 mb isobar repeats the configuration of the coast line. Undoubtedly, such local disturbances of the pressure field must somehow influence local hydrological conditions.

Now we start to examine the distribution of vertical speed in the summer period (Fig. 3).

Let us take into account that the centres of areas with intensive rising movements are connected with the above mentioned cyclonic formation on the axis of the tropical depression and also with the zones of reduced atmospheric pressure branching from the depression. However, the main region of large upwelling is connected with the position of the depression axis.

The locations of sinking water are connected with the increased pressure. The most intensive sinking movements can be observed near Cabo Verde to the east and west of the Arquipelago de Cabo Verde, at the extreme south-east of the area examined.

It should be pointed out that in the eastern part of the zone (to the east of 25°W) the ocean area occupied by water upwelling is much more extensive than in the west, though in this part upwelling is quite intensive. As a matter of fact, here (area 9°N, 31°W) we have the greatest speed of upwelling water current ($-1265 \cdot 10^{-5}$ cm sec^{-1}).

To the north-west and south-west from Dakar there are two regions of water upwelling with maximum speeds of $-520 \cdot 10^{-5}$cm sec^{-1} and $-918 \cdot 10^{-5}$cm sec^{-1} respectively.

Maximum sinking speeds are observed to the west of the Arquipelago de Capo Verde ($+618 \cdot 10^{-5}$cm sec^{-1}) and at the extreme south-east ($+802 \cdot 10^{-5}$cm sec^{-1}). The last figure also confirms the fact that the vertical movements are mostly developed to the east of 25° W.

It is known that water temperature is a rather good indicator of vertical movements. In the given chart of water temperature distribution at the depth of 50 m (Fig. 2) upwelling zones correspond to lower water temperature, and sinking zones correspond to higher temperature. Thus, there is probably coincidence between the peculiarities of the structure of the baric field, the vertical speed distribution and the distribution of water temperature.

Let us begin to analyse autumn conditions. In October the size of tropical depression (the area limited by the 1013 mb isobar) decreases strongly (Fig. 4). The tendency of isobaric extension in the meridional direction leads to the breaking down of the zonal circulation, to the filling up of cyclonic formations in the axis of tropical depression, and to the weakening of monsoon winds blowing towards the continent.

The trade-wind systems of both hemispheres approach each others too. There were remarkable changes in the distribution of the vertical component of drift current speed in October (Fig. 5). A sharp weakening of the intensity of the vertical movements can be noticed. Judging from the maximum speed values these movements decreased at least by 2-3 times in the eastern region. In the west the intensity decreased too, though near 8°N, 27°W the maximum speed of upwelling ($-764 \cdot 10^{-5}$ cm sec^{-1}) is being observed.

It is interesting to note that the orientation of isobars has generally a latitudinal direction in summer and the zone of water upwelling and sinking has a meridional direction.

In autumn isobars are inclined to follow a meridional direction, and zones of upwelling and sinking a latitudinal direction. Examining the field changes of drift current speed we notice that they follow the changes of the baric field in the near-land atmospheric layer. At the same time the characteristic regions of water upwelling and sinking are closely connected with the characteristic atmospheric centres which are the centres with increased and reduced atmospheric pressure.

Vertical Circulation and Tuna Distribution

At the present moment we can surely affirm that tunas in the high seas usually occur in the areas where for dynamic reasons deep waters bring nutritives to the upper layers providing the high biological productivity of the area. Vertical movements which form the feeding conditions influence the physical structure of water, particularly the water temperature distribution. Changes in temperature are well felt by tuna.

Therefore, one can suggest that changes in the field of vertical speed influence the tuna distribution. In August-September 1964 (Fig.3) the catches of tuna were significant during well-developed upwelling movements of water. It is interesting to point out that the main part of the catches takes place on the periphery of the zones of upwelling.

The size of the catches seems to be connected with the intensity of vertical movements. In the eastern part of the region where the rising movements are more significant in this period of the year and occupy the larger area the catches of tuna are somewhat higher. Probably larger fish occur here. When the vertical circulation weakens in October (Fig. 5) the catches of tuna decrease. One can see the lack of big specimens. The centre of higher catches is displacing to the south-west; this allows the conclusion that larger tunas migrate towards south-west.

Conclusions

In the Tropical Atlantic, to the south of the Arquipelago de Capo Verde, the connection between the structure of the surface baric field of the atmosphere and the field of the vertical component of the drift current is observed.

In summer the maximum upwelling speed is connected with the regions of cyclonic vortexes of wind field situated on the axis of depression.

When the region of reduced pressure in autumn is filled up on the axis of depression a weakening of cyclonic vortexes in the atmosphere occurs and leads to a remarkable decrease of vertical water movements.

The distribution of tuna is connected with the character of changes of the field of vertical component of drift current speed.

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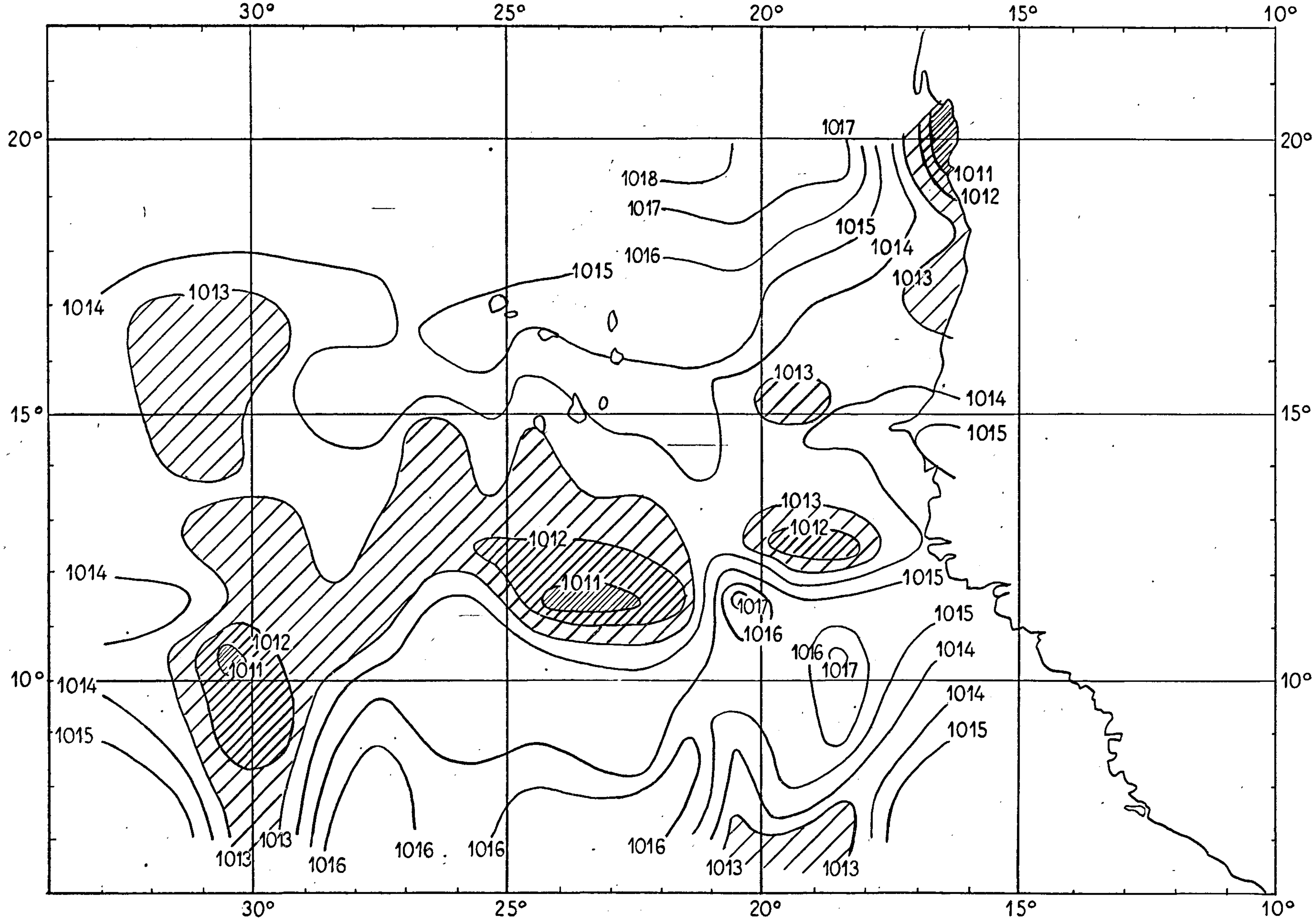

Fig. 1. Chart of average surface baric field for August-September, 1964

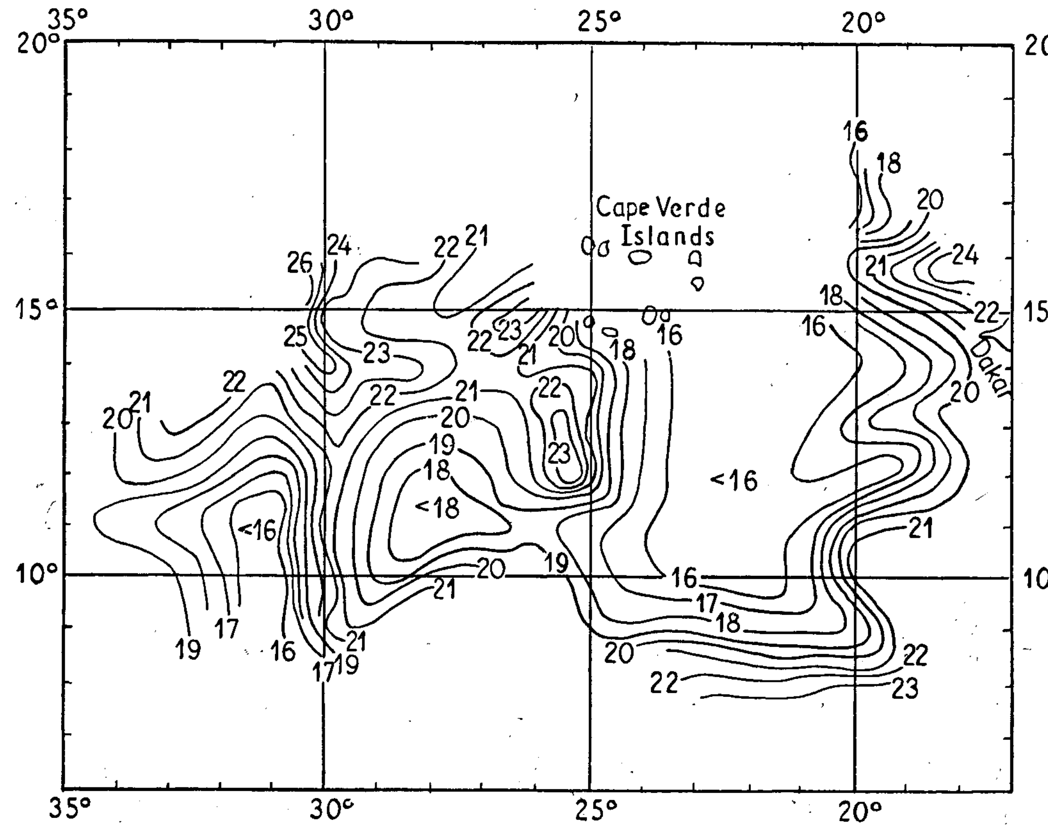

Fig. 2. Water temperature distribution at the depth of 50 m in August-September, 1964

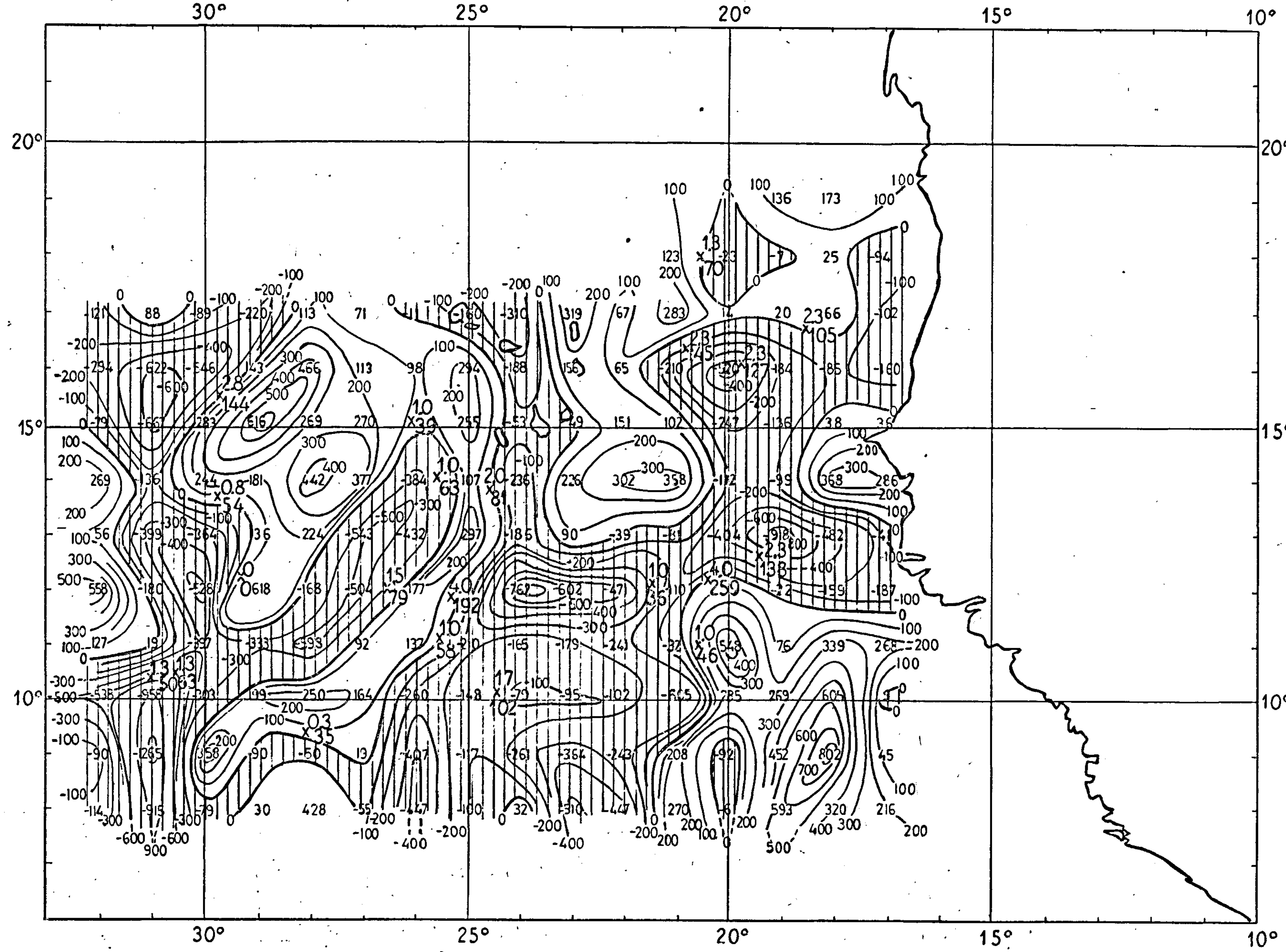

Fig. 3. Distribution of vertical component of drift current speed ($10^{-5} cm sec^{-1}$) and tuna catches in August-September, 1964. Regions of upwelling are hatched. Catch for 100 long-line hooks is given by two figures: the upper one indicates the number of tuna caught, the lower one the total tuna weight in kg.

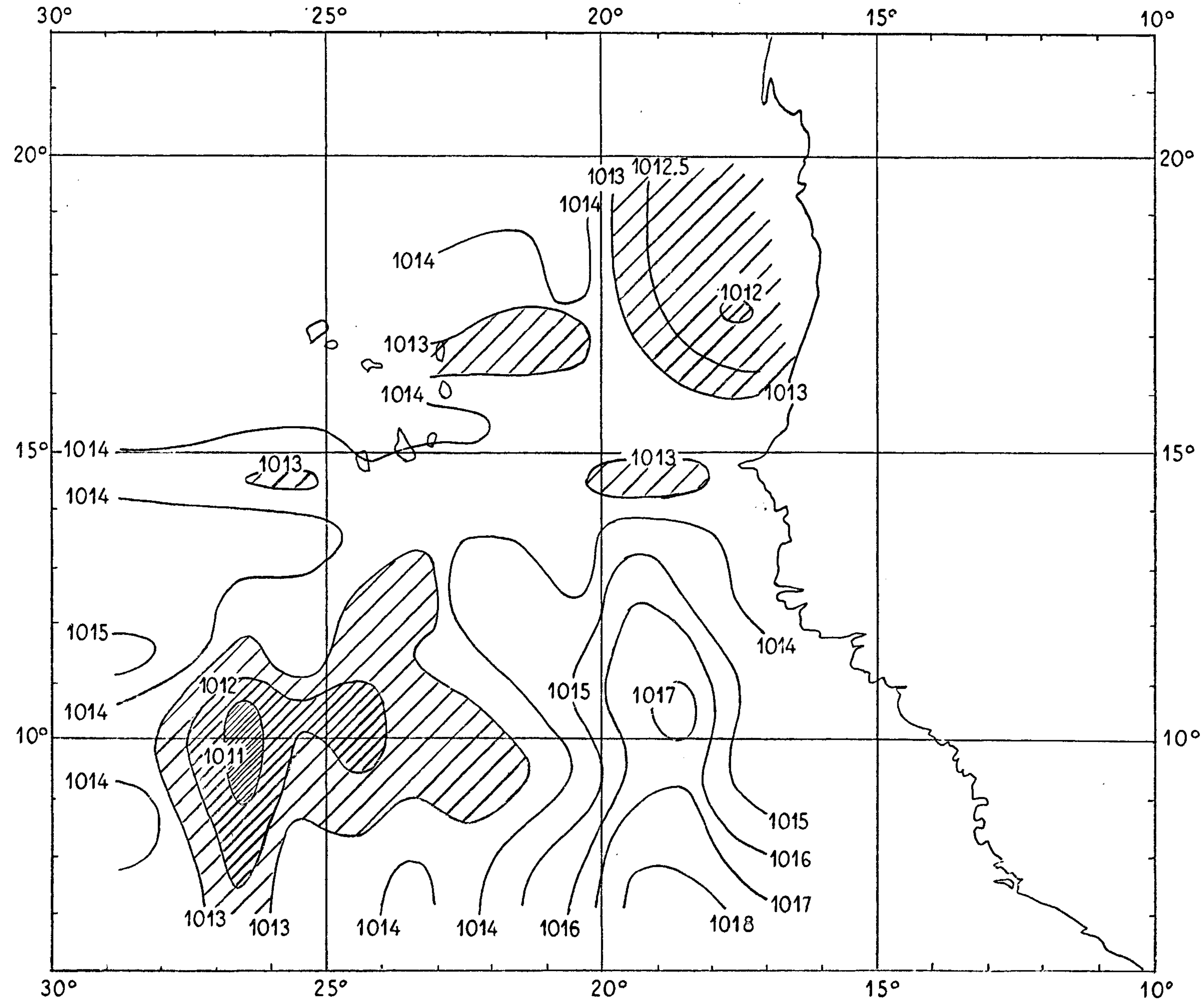

Fig. 4. Chart of average surface baric field for October, 1964

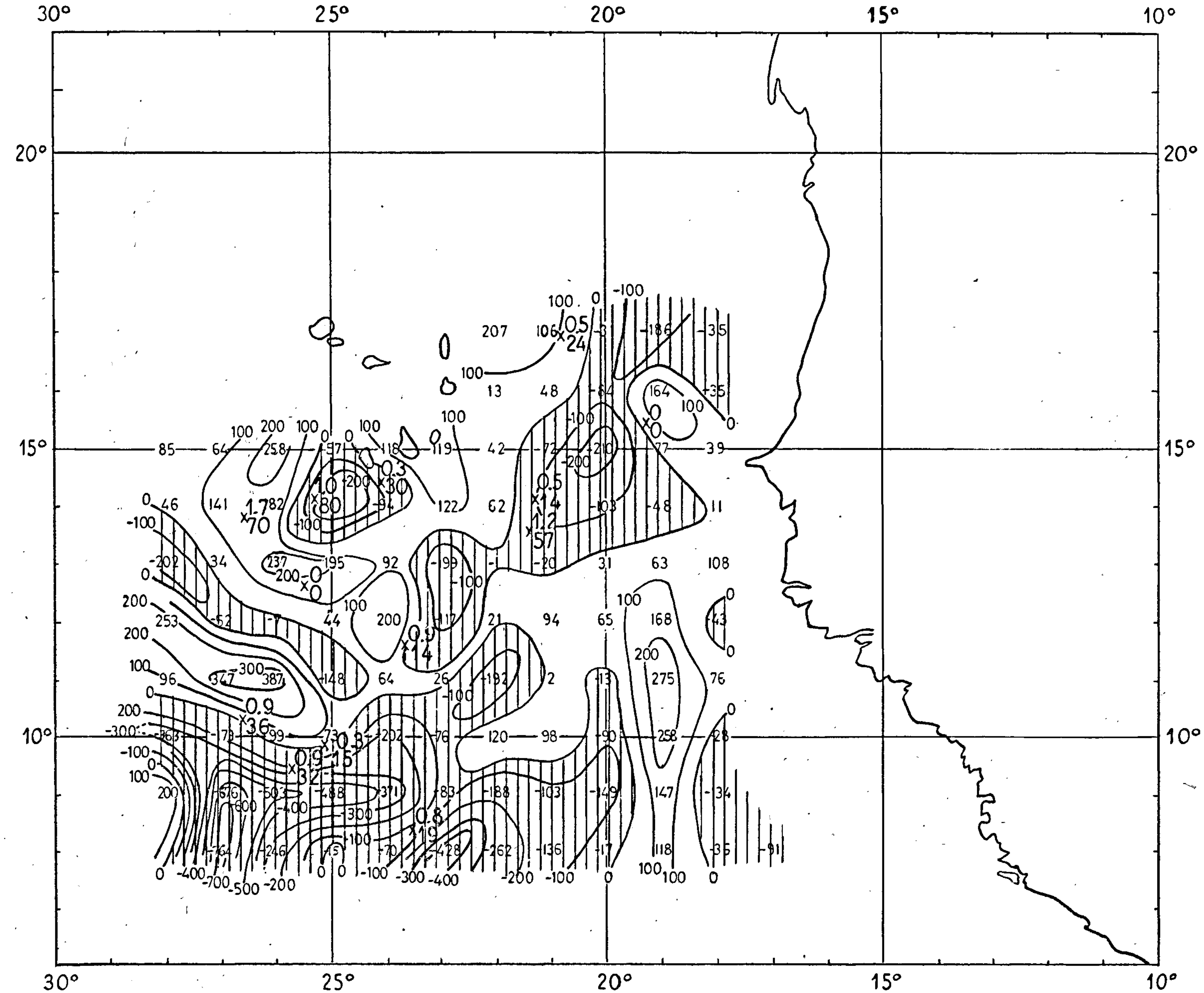

Fig. 5. Distribution of vertical component of drift current speed (10^{-5} cm sec^{-1}) and tuna catches in October, 1964. Regions of upwelling are hatched. Catch for 100 long-line hooks is given by two figures: the upper one indicates the number of tuna caught, the lower one the total tuna weight in kg.