Geophysics

Academician V. V. SHULEIKIN

1958

SovietRxiv

Abstract

Full Text

Geophysics

Academician V. V. SHULEIKIN

TELLURIC CURRENTS IN THE OCEAN AND MAGNETIC DECLINATION

In 1956, Yu. G. Ryzhkov and F. A. Gubin, lowering electrodes from the side of the diesel-electric ship *Ob'* , discovered in the Indian Ocean a sharp increase in the density of telluric currents at depth ([1]). In connection with this, the question again arose of the role that telluric currents may play in the origin and variations of magnetic declination ([2]). Of special interest is the measurement of the density of telluric currents at various depths in the Atlantic Ocean between Africa and South America, where the distance between the continents is the smallest. Here, according to the investigations of L. A. Korneva ([2]), on the map of the latitudinal component of the intensity of the Earth' s magnetic field there appears a most interesting region within the closed isoline $H_\varphi > 10\,000\ \gamma$. During the oceanographic-geophysical expedition on the vessel *Sedov* in the last quarter of 1957, we succeeded in making measurements both in this region and to the north of it.

Special lead electrodes, cast from a single crucible and protected from washing by seawater, had their own potential difference, which could be reduced to 0.5 mV. They were lowered from "Emit" * winches, one of which was installed on the forecastle and the other on the quarterdeck, at a distance of 100 m from one another. The wires were connected to the electronic-tube potentiometer of the same "Emit" installation for recording the potential differences between the electrodes; the recording was made by a pen on paper.

The potential difference between points on the very surface of the sea was measured by means of ordinary floating "Emit" electrodes, placed one at 50 m and the other at 150 m from the ship' s stern, in order to avoid the influence of its metal hull.

A completely reliable recording of the potential differences between electrodes was obtained on 10 XI 1957 at latitude 17°05′N and longitude 31°57′W. In the surface layer the gradient reached about 30 mV/km and was directed along the meridian from north to south. At a depth of 250 m the potential difference between electrodes located in one horizontal plane at a distance of 100 m from one another behaved as shown in the copy of the recording in Fig. 1. The vessel, lying in drift, predominantly with a heading angle of 163°, was sometimes brought into the meridian. This caused a certain increase in the potential difference and showed that the potential gradient there, just as at the ocean surface, was directed from north to south. Introducing a correction for the residual inherent potential difference between the electrodes, it was possible to consider that at a depth of 250 m the potential gradient along the meridian was about 80 mV/km. The temperature was $\upsilon = 14.7^\circ$, the salinity $S = 36.0‰$. Thus, from the tables, the electrical conductivity was $\sigma = 0.0437\ (\Omega \cdot \mathrm{cm})^{-1}$. With the measured value of the potential gradient, the current density at a depth of 250 m should have reached $3.57 \cdot 10^{-4}$ a/m^2.

Both the upper portion of the curve in Fig. 1 and direct observations by the needle of the potentiometer showed that, with the simultaneous raising

* Apparatus for measuring current velocities by the electromagnetic method. In the region studied, the current velocities were negligible, and the values of the vertical component of the Earth' s magnetic field were small; therefore the induction currents generated in the water by the Faraday effect did not distort the field of telluric currents.

electrodes, the difference of potentials between them decreases according to a simple linear law. Extending the straight line to the ocean bottom, one can approximately extrapolate the values of the potential gradient at depth and estimate the order of magnitude of the entire current flowing along the meridian in the investigated region of the Atlantic Ocean. Such a rough estimate shows that through a "gate" 1 m wide and 5000 m high (from the surface to the bottom) there flows along the meridian a current of about 10 a. According to the calculations of L. A. Korneva ([3]), the existing value of the latitudinal component of the geomagnetic-field intensity and, consequently, the existing magnetic inclination at the studied point in the ocean is provided by a current of 15 a in these "gates." The missing part of the field intensity is, by all indications, provided by currents in the ionosphere. There is reason to suppose that future investigations will reveal approximately equal shares of both of the factors mentioned in producing the latitudinal component (and producing the inclination).

Equally reliable registration of telluric currents at depth was carried out by us aboard the *Sedov* on 24 XI 1957 during work at a daily oceanographic station with coordinates $\varphi = 34^\circ 02'$N, $\lambda = 35^\circ 54'$W. Here the electrodes were lowered to a depth of 700 m, where a potential gradient of about 150 mV/km was found. Taking into account a temperature of 10.4° and a salinity of 35.55‰, the electrical conductivity of the water was determined, and from it and the gradient—the current density at a depth of 700 m; it proved to be equal to $6 \cdot 10^{-4}$ a/m^2.

Again a linear law of increase of current density with depth was revealed, and extrapolation to the bottom showed that the total current in the ocean should amount to about half of the value which, according to Korneva, would be sufficient to produce the latitudinal component of the intensity existing here

Fig. 1

Fig. 1

Figure 1: Fig. 1

of the geomagnetic field and the existing declination. It is interesting that the recording of potential differences on the potentiometer showed that, at the point under study, the gradient is directed at an angle of 115° to the meridian. This value is only 12° less than that computed theoretically by L. A. Korneva.

The striking phenomenon—the sharp increase in the density of telluric currents at depth—was also confirmed by V. I. Lopatnikov on the third research vessel, the expedition ship *Mikhail Lomonosov*, in the Atlantic Ocean on 25 October 1957 at latitude 59°06′ N, longitude 16°20′ W, and on 26 October 1957 at latitude 58°30′ N, longitude 16°00′ W.

The absence of systematic errors due to some effect of water pressure on the electrodes at depth is confirmed already by the fact that electrodes of similar material, lowered by P. A. Vinogradov (4) to 1100 m in Lake Baikal, detected in this freshwater enclosed basin a decrease in the density of telluric currents by several percent. Additional verification was carried out by us under laboratory conditions: together with E. T. Krenkel and other colleagues of the Institute of Instrument Engineering of the Hydrometeorological Service, we observed the behavior of our electrodes in a steel cylinder filled with water of salinity 35‰ under a pressure of 40 atm. No increase in the intrinsic potential difference between the electrodes occurred; indeed, even some decrease of this insignificant quantity was observed.

In the future it will be necessary to construct an exact theory of telluric currents increasing with depth in the ocean. At present it is still too early to speak of constructing it, since even simpler and long-known phenomena in the field of the Earth' s magnetic and terrestrial electric fields are still the subject of international discussion. It can only be asserted that telluric currents in the ocean are connected with corpuscular radiation from the Sun. The reason for the increase of their density with depth can only be explained schematically.

On the basis of observations, let us adopt a simple linear law for the increase of current density with increasing coordinate y, measured downward from the surface of the ocean, whose depth is H:

$$i = i_1 + i_2 y/H. \tag{1}$$

Here i_1 and i_2 vary only very weakly with change in x. Let the specific resistance of water be equal to ρ. If the electric field in its thickness is regarded as purely potential, then for the potential V one may write the equation

$$\partial V/\partial x = \rho(i_1 + i_2 y/H)$$

and, consequently,

$$V = \rho i_1 x + \rho i_2 xy/H + \text{const.} \tag{2}$$

In such a case one would have to admit that

$$\partial V/\partial y = \rho i_2 x/H. \tag{3}$$

But on the basis of (3) the vertical component of the potential gradient could reach enormous values with practically unlimited increase of x (up to thousands of kilometers in the ocean). In reality such enormous vertical potential gradients do not exist in the ocean. Hence the actual picture of the phenomenon can be explained only by the superposition of certain vortex currents on a field of currents possessing a potential. An analogous superposition of fields has long been known in alternating-current technology in the occurrence of the so-called skin effect (5) in thick conductors: the current density changes sharply from the axis of the conductor to the periphery, without giving rise to any radial component of the potential gradient. Usually the skin effect is described by direct integration of Maxwell' s equations within the space occupied by the conductor. The physical picture of the phenomenon is well represented as a system of Foucault vortex currents, penetrating-

covering this space; the radial components of the eddy currents mutually cancel out ([6]), and only the axial components remain. The latter are directed either along the gradient of the potential field or opposite to it, in accordance with which the current density changes within the live cross-section of the conductor.

Of course, the planetary effect described in the present article is immeasurably more complex. One can only suppose that here the hypothetical eddy currents are directed opposite to the principal telluric currents near the surface of the water and in the same direction as the principal currents at the bottom of the ocean. The vertical components of the eddy currents cancel one another out.*

It must be assumed that the generation of eddy currents in the ocean against the background of the principal—potential—field is caused by the rotation of the principal current lines about the Earth' s axis with cyclic frequency $\omega = 7.3 \cdot 10^{-5}$ sec^{-1}. Precisely as a consequence of such rotation, the principal currents, which are constant for an observer on the Earth, lead to periodic oscillations of the magnetic field at a point not rotating together with our planet: this point is continuously swept by the moving lines of force of the magnetic dipole created by currents in the Atlantic and Pacific Oceans ([3]).

Quantitatively, such a hypothesis is plausible. Indeed, the criterion for the influence of eddy currents in engineering, as is known, is the dimensionless quantity

$D\sqrt{\mu\omega/\rho}$. Here D is the thickness of the layer encompassed by the electromagnetic field, μ is the magnetic permeability of the medium, ω is the cyclic frequency, and ρ is the specific resistance of the medium. In our problem the numerical value of ω/ρ is very small in comparison with engineering problems, but the value of D is extremely large; moreover, D stands before the radical, while ω/ρ is under the radical sign. Consequently, the probable value of the criterion does not exclude the possibility of a noticeable role for eddy currents, although, understandably, it still does not prove their existence.

What is now needed is a careful measurement of the magnetic declination at the bottom of the oceans. This applies especially to that region of the Atlantic Ocean which was discussed at the beginning of the present article.

For their active assistance in arranging the experiments on the expeditionary oceanographic vessel *Sedov*, I express my gratitude to P. S. Mitrofanov and V. N. Dolgopolov.

Received15 I 1958

CITED LITERATURE

1. Yu. G. Ryzhkov, DAN, **113**, No. 4, 787 (1957).
2. V. V. Shuleikin, DAN, **76**, No. 1 (1951).
3. L. A. Korneva, Tr. Morsk. gidrofiz. inst., **7**, 32 (1956); DAN, **107**, No. 5, 679 (1956).
4. P. A. Vinogradov, DAN, **113**, No. 6, 1255 (1957).
5. L. R. Neiman, P. L. Kalantarov, *Theoretical Foundations of Electrical Engineering*, 3, Moscow, 1954, p. 211.
6. *Physical Dictionary*, 4, Moscow, 1938, p. 891.

* A good scheme of the mutual cancellation of the normal components is given in ([6]).

Note: Figure translations are in progress. See original paper for figures.