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ON GRADIENT CURRENTS IN THE ADRIATIC SEA

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I.

Differences in sea water density cause the sloping of the isobaric surfaces towards the level ones, and thus on the latter a pressure gradient acting vertically upon the isobars of the level surfaces is formed. The Coriolis' force causes in the Northern Hemisphere a deflection to the right of every body in motion. Thus with the gradient and Coriolis' forces mutually balanced, a circulation ensues in the direction of the geopotential contours of the isobaric surfaces. Geopotential topographies can, then, be conceived as a system of streamlines of gradient currents, i.e. of currents caused by the distribution of mass in the sea. Currents of this kind are component part of the general circulation occurring in the sea.

Investigations of currents prevailing in the Adriatic go back to the middle of the XIX century (Lorenz, 1863). More extensive researches, by Wolf and Luksch, followed later (1881). The authors made also direct measurements of currents, but their chart of currents is based, for the most part, on conclusions based on the distributions of temperature and salinity, and on the data known from experience. The chart possesses all the qualitative characteristics of the later published ones. Two oceanographic expeditions covering the whole of the Adriatic area took place between 1911 and 1914, the Austrian »Najade« and the Italian »Ciclope«. During the expeditions currents were also studied by means of drift bottles thrown overboard. Nine series of bottles were thrown by the Italian expedition, covering the whole of the Adriatic during various seasons. A total of 584 drift bottles was released by the Austrians in a year's time (Mazelle, 1914). The data, obtained from recaptured bottles, were analyzed by Feruglio (1920), and these analyses, together with the qualitative analyses of temperature and salinity distribution obtained from the material collected by the expeditions, served as a basis for the drawing of the chart of currents in the Adriatic (Strömungskarte der Adria, 1915), which does not display a qualitative difference from the chart drawn by Wolf and Luksch, but, in addition, contains quantitative data also. Charts of currents, however, obtained by means of such analyses only, cannot give correct quantitative data. The chart drawn by J. Krčmar, and published by the Hydrographic Bureau of the Yugoslav Navy (1928) has probably completed the preceding charts, but the way the entries of details were made is not known.

It should be mentioned that another expedition took place at the time of the »Najade« and »Ciclope«, viz. the Croatian expedition »Vila Velebita«, covering the Bay of Kvarner and investigating the currents occurring in that bay (Gavazzi, 1915). Since no computation has been ever made with regard to gradient currents in the Adriatic area, this paper represents an attempt to give the first geopotential topographies for the Adriatic.

I take this opportunity to record my thanks to dr. M. Buljan, Chief of the Department of Physiography at the Institute of Oceanography and Fisheries, Split, who suggested the study and whose advices were helpful in the course of my work. My special thanks are due to Professor Josip Goldberg, Ph. D., the Academician, head of the Geophysical Institute at the Zagreb University, for his kind attention and stimulative suggestions.

II.

To compute the geopotential topographies for the Adriatic, the author availed herself of the data obtained by the »Najade« and »Ciclope« expeditions. These expeditions had been jointly collecting hydrographic data four times a year during a 3 years' period (1911—1914) along eight transversal profiles (»Najade«, 4 profiles; »Ciclope«, 4 profiles). Out of a total of 12 »Najade« and 10 »Ciclope« cruises, 7 simultaneous cruises were performed by both expeditions. Geopotential anomalies were computed for 5 simultaneous cruises made by both expeditions, and separately for one »Najade« cruise. The remaining material, being short of profiles, which are of particular interest here (Otranto Strait), was of no avail. Thermometers Richter & Wiese and Negretti & Zambra were used by the two expeditions to measure the sea temperature, but no corrections were made. Salinity values were determined by means of Copenhagen normal water. Samples were taken, almost on all cruises, at the same stations and at the same levels. As the »Najade« samples were taken from more levels than those of »Ciclope«, standard levels of the »Ciclope« Expedition (0, 5, 10, 20, 50, 100, 200, 500 m) were applied during the elaboration. Owing to the fact that both expeditions performed their simultaneous cruises along the eight profiles within an interval of about three weeks, the data may be considered roughly synoptic for the purpose of our computations.

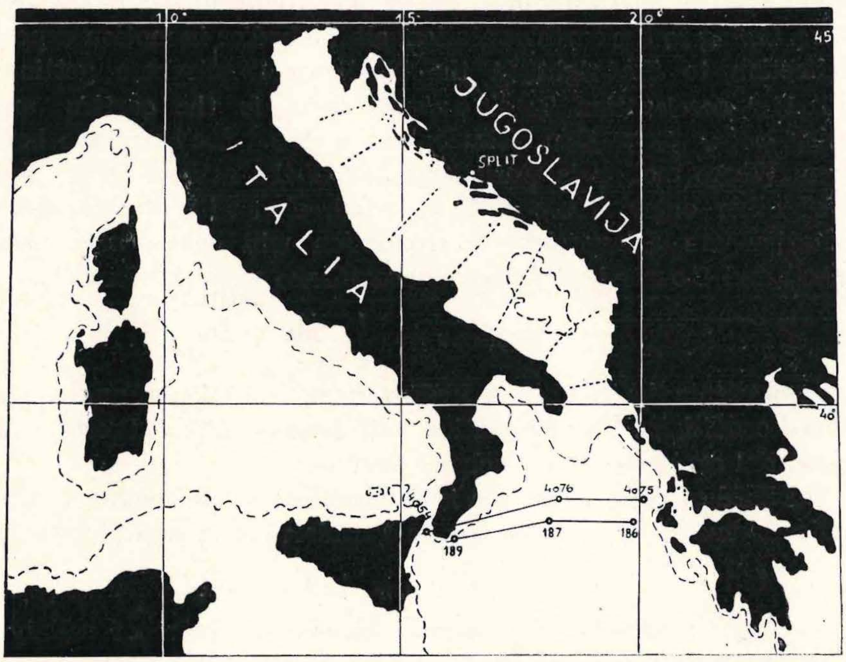

Fig. 1. The Adriatic and Sicily—Peloponnesus profiles for which the geopotential anomalies have been computed.

In order to have a look into the conditions of circulation in the adjoining part of the Mediterranean, the computation was made for the Sicily-Peloponnesus profile, for which the temperature and salinity data at three stations were provided by the Danish expeditions »Thor« (1908—1910) and »Dana« (1928—1930). The time of these two expeditions, unfortunately, did not coincide with that of the »Najade« and »Ciclope«.

III.

The geopotential anomalies and current velocities were computed from the temperature and salinity data by applying the Bjerknes' theorem of circulation and the Helland-Hansen (1903) formula respectively. If an increase or decrease of sea water density in some place results in the sloping of the isobaric surfaces toward the level surfaces, a pressure gradient $\frac{1}{\varrho}\frac{dp}{dn}$ is then formed on the level surfaces, where ϱ stands for density, p for pressure, and n for direction in which the gradient acts, i.e. vertically upon the geopotential contours of the isobaric surface. Owing to the earth's rotation, all the bodies in motion experience a deflection to the right in the Northern Hemisphere getting the Coriolis' acceleration $2\,\omega \sin \varphi\, v$, where ω is the earth's angular velocity, φ the geographic latitude, and v the velocity of the body in motion. Where motion is stationary, and if the actions of the friction and of other outer forces such as wind, etc., with the exception of gravitation are disregarded, a circulation will ensue with balanced gradient and Coriolis' forces in accordance with the formula

$$2\omega \sin \varphi v = \frac{1}{\varrho}\frac{dp}{dn} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1),$$

which represents the Euler's hydrodynamic equation of motion applied to these conditions. The circulation will develop in the direction of the geopotential contours of the isobaric surface.

The field of mass in the sea is determined by the distribution of the specific volume $\alpha_{s,\,t,\,p}$ which can be considered as a sum of two factors

$$\alpha_{s,\,t,\,p} = \alpha_{35,0,p} + \delta,$$

where $\alpha_{35,0,p}$ represents the specific volume of water of saliniy 35‰ and temperature 0°C, at the pressure p in decibars, and δ the anomaly of the specific volume. The member $\alpha_{35,0,p}$ being determined by its geometric position and pressure, the field of pressure can be shown by the distribution of the anomalies of the specific volume δ.

The total field of pressure consists of a slope field which is determined by the rising of the sea surface owing to some actual piling up of mass at some place and of the relative field of pressure developing in dependence on the field of mass, and it can be determined, provided the field of mass is known, by means of the basic hydrostatic equation

$$dD = \alpha\, dp \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2),$$

where dD is the interval of the gravity potential or the difference of the dynamic depth at a distance dz $(dD = gdz)$. For the practical reckoning by integration and introduction of anomalies of the specific volume, instead of α, we obtain (Sverdrup, 1952. pp. 409)

$$\Delta D = \int_{p_1}^{p_2} \delta dp \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3),$$

where ΔD represents the anomaly of the geopotential distance between the isobaric surfaces p_1 and p_2 or, in short, the geopotential anomaly. Since we can assume, by diverging insignificantly, that the pressure is only a function of depth, and besides, since the unit for the measurement of pressure (decibar) numerically corresponds to geometric metres, the respective geometric surfaces are taken for the isobaric surfaces p_1 and p_2.

The knowledge of the actual level surfaces of gravity and isobaric surfaces determined by means of the geometric depth is necessary to find out the geopotential topographies of an area. The level surfaces can be determined by applying the equation (3), if at least one level surface is known. This being not the case, we assume that somewhere in the depth of the sea there is an isobaric surface identical with the level surface, and it is taken for the computation of geopotential anomalies for the next isobaric surface. The assumed surface is the reference surface for our computation.

It results from formula (1) that

$$v = \frac{1}{2\omega \sin \varphi} \frac{dp}{dn} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

that is adapted to practical needs for the computation of velocity (Sverdrup, op. cit. pp. 448),

$$v_1 - v_2 = \frac{10}{2\omega \sin \varphi \; n} (\Delta D_A - \Delta D_B) \quad \ldots\ldots\ldots\ldots (5),$$

where ΔD_A and ΔD_B are the geopotential anomalies in two chosen places, and n the distance between them. This is actually the known Helland-Hansen's formula for the computation of velocity of gradient currents.

The anomalies of the specific volume in situ were computed, for the purposes of this paper, by means of Sverdrup's tables (La Fond, 1951), and from the data of σ_t, temperature, and salinity. The geopotential anomalies for each vertical series of data in each of the places were obtained by multiplying the layer thickness by the average anomaly of the specific volume for each layer (δdp); the values thus obtained were added from the surface to the isobaric surfaces whose geopotential anomaly were required $(\int \delta dp)$. Beside the errors amounting to 0.02°C in temperature, and 0,01‰ in chlorinity, and the probable one in the measured

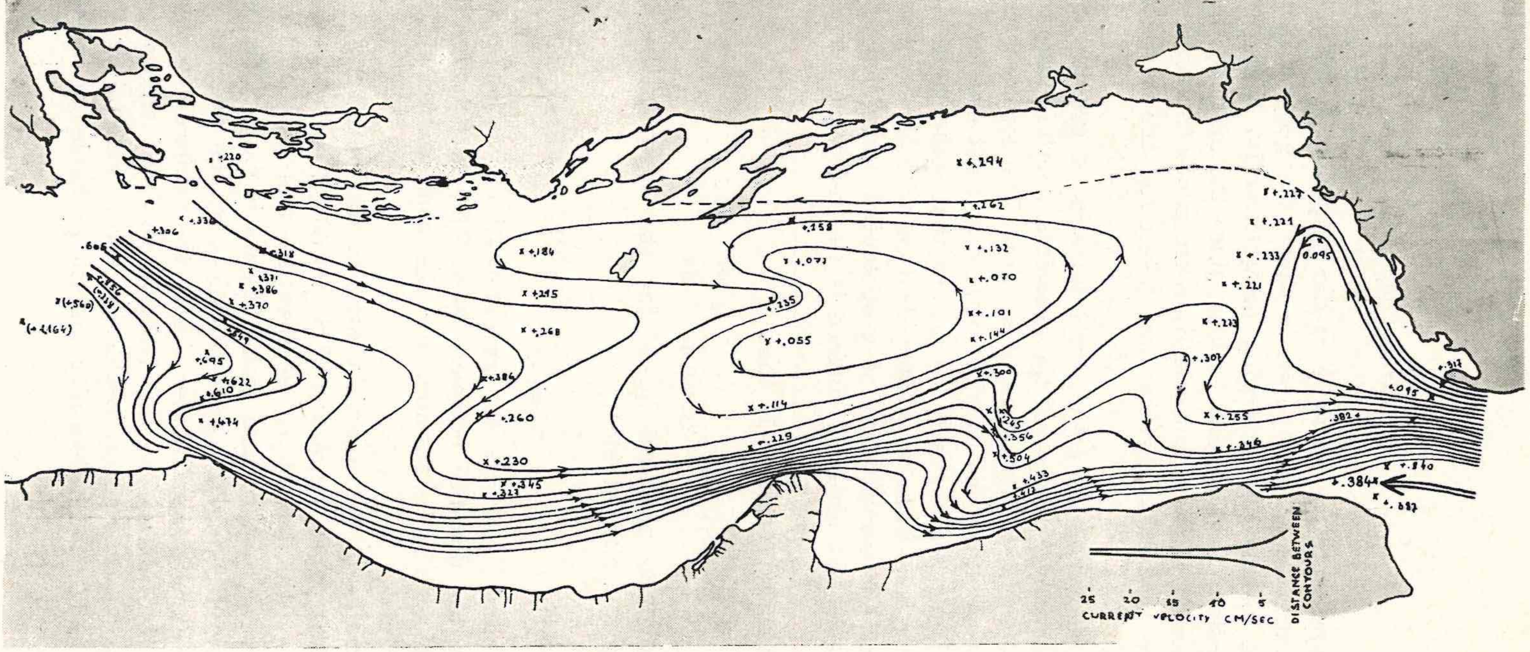

Fig. 2 A. Geopotential topography of the sea surface in dynamic decimetres relative to the 50 m decibar surface for the period between 16. VIII. and 6. IX. 1911 (the stations are marked by an »x«).

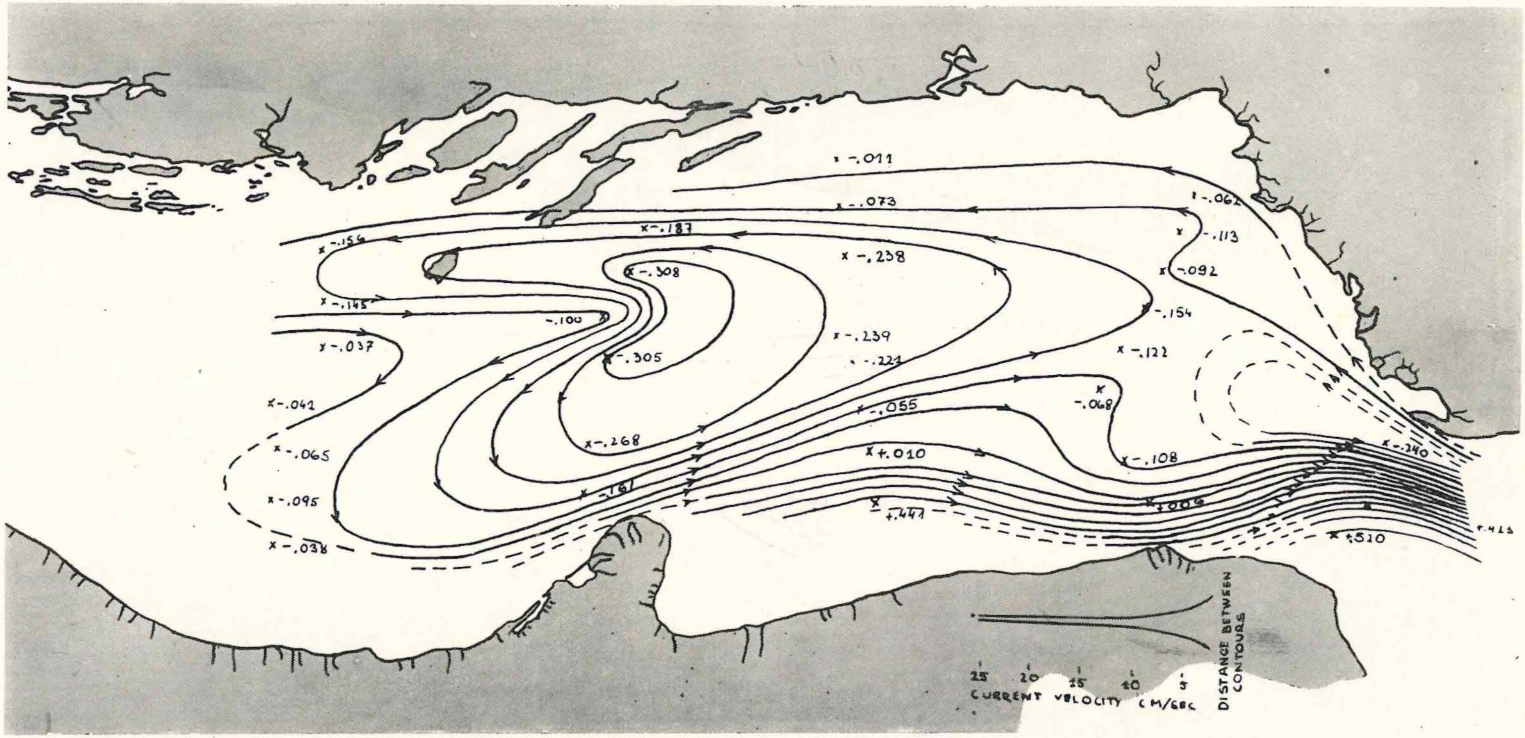

Fig. 2 B. Geopotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. VIII. and 6. IX. 1911.

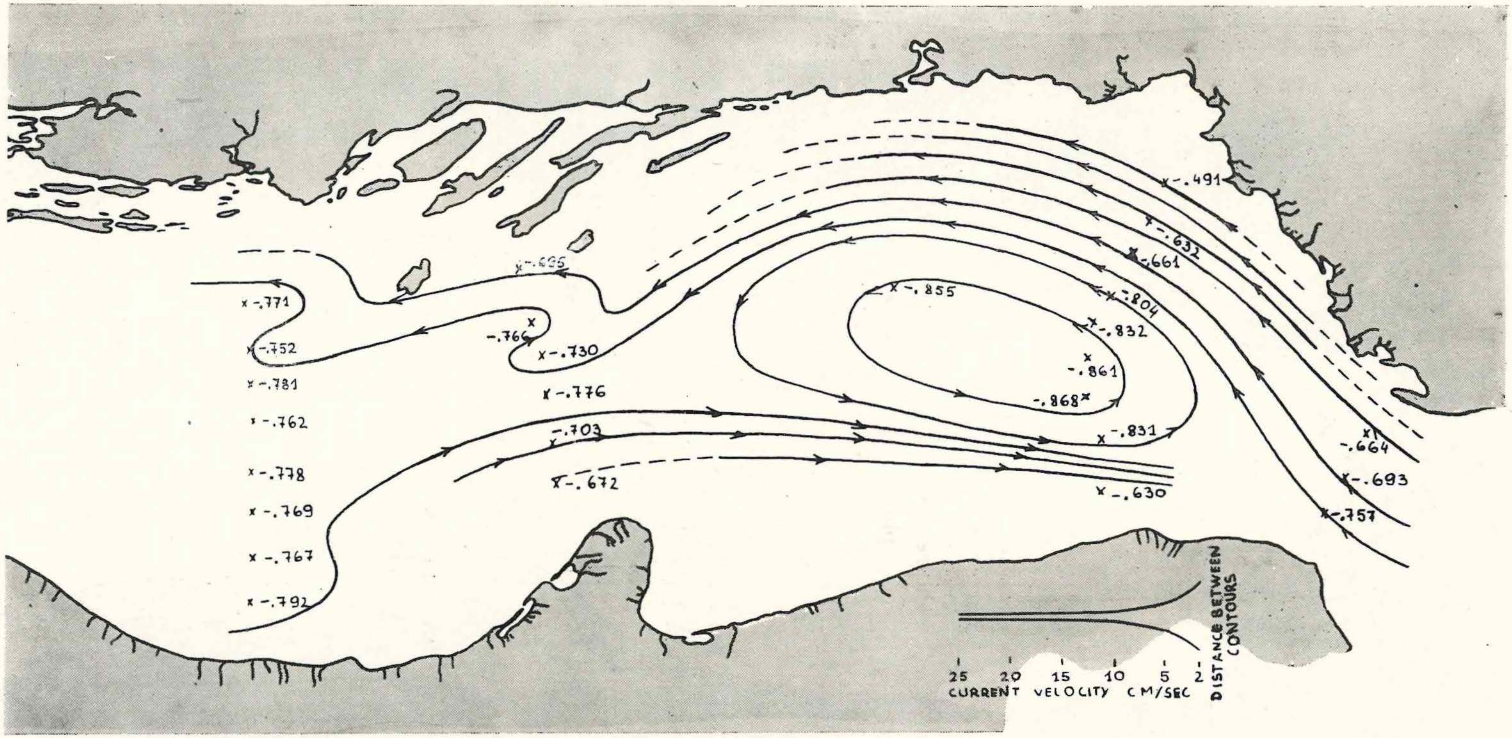

Fig. 3 Geopotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. II. and 11. III. 1912.

depth from which the sample was obtained, the correct value for the geopotential anomaly can be arrived at in the fourth digit of the dynamic metre when a reference surface up to 100 m was used. By diverging to the same extent in temperature, chlorinity, and measured depth, we can obtain the correct value in the third digit of the dynamic metre (Barnes & Thompson, 1938) by applying a reference surface of 100—1000 m. As the data, used for this purpose, lie within these limits of accuracy, the geopotential anomalies up to the fourth digit of the dynamic decimetre were entered on topographies by using 50 and 100 m reference depths, while topographies according to 200 and 500 m reference depths contain such anomalies up to the third digit of the dynamic metre. The contour lines were drawn on the former topographies for intervals of 5 dynamic mm, and on the latter ones for intervals of 10 dynamic mm.

The choice of the reference depth is limited by the depths of the basin as a whole and of the places where samples are taken. The 50 m depth covers the south, the middle and a part of the north Adriatic. The 100 m depth comprises the south and the middle Adriatic, but the data are generally too scanty for computations by means of the 500 m reference depth. The topographies made according to the above reference depths, however, do not essentially differ from one another in qualitative respect. An example is given in Fig. 6 A,B,C,D, where the topographies according to four reference depths are drawn for one situation, together with the respective isobaths.

The depths of 1000 m and 500 m respectively were taken as reference depths for the profile Sicily — Peloponnesus. Current velocities were computed from the data obtained for geopotential anomalies by applying the Helland-Hansen's formula. The velocities were then entered in the profile, and the lines of equal current velocities were drawn for intervals of each 0,5 cm/sec of the velocity.

IV.

Six different situations were covered by the computation of dynamic topographies for the Adriatic area: 16. VIII.—6. IX. 1911., 16. II.—11, III. 1912., 16. V.—9. VI. 1913., 16. VIII.—1. IX. 1913., 16.—24. XI. 1913. and 16. II.—9. III. 1914.

Most of the topographies given here were made according to reference

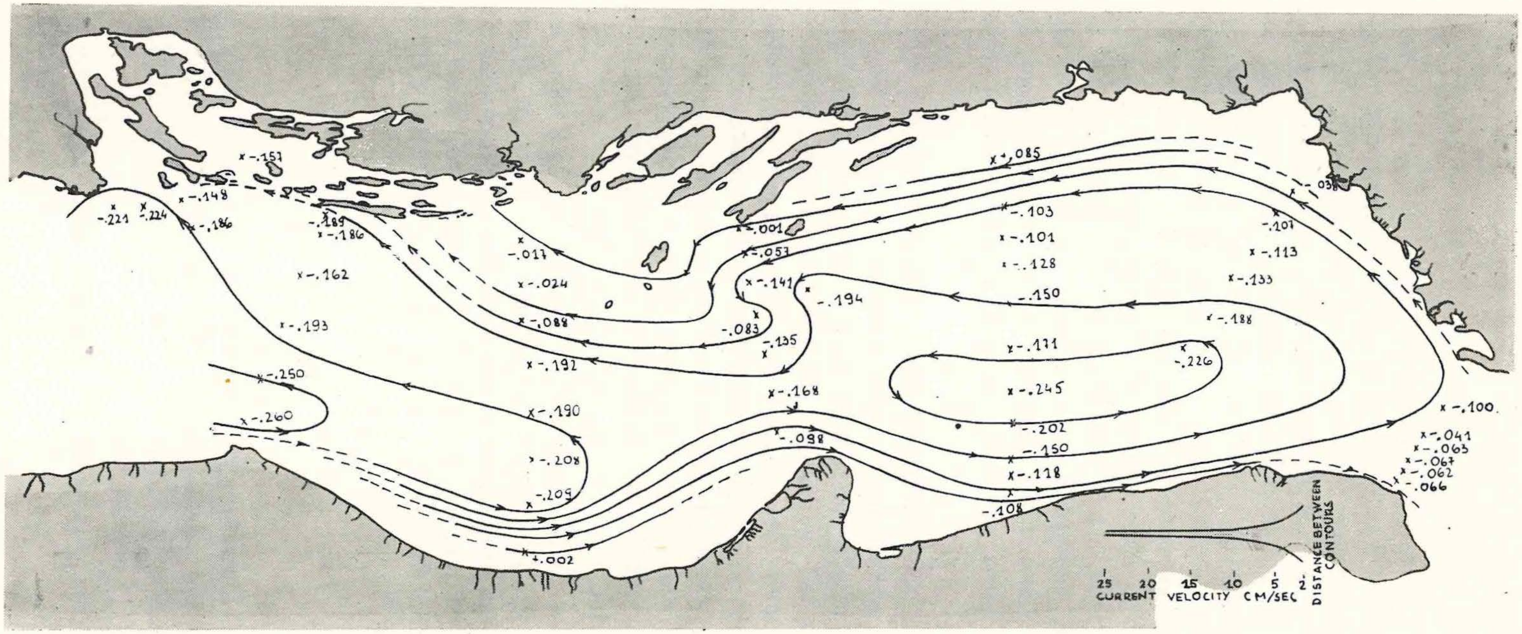

Fig. 4 A. Geopotential topography of the sea surface in dynamic decimetres relative to the 50 m decibar surface for the period between 16. V. and 9. VI. 1913.

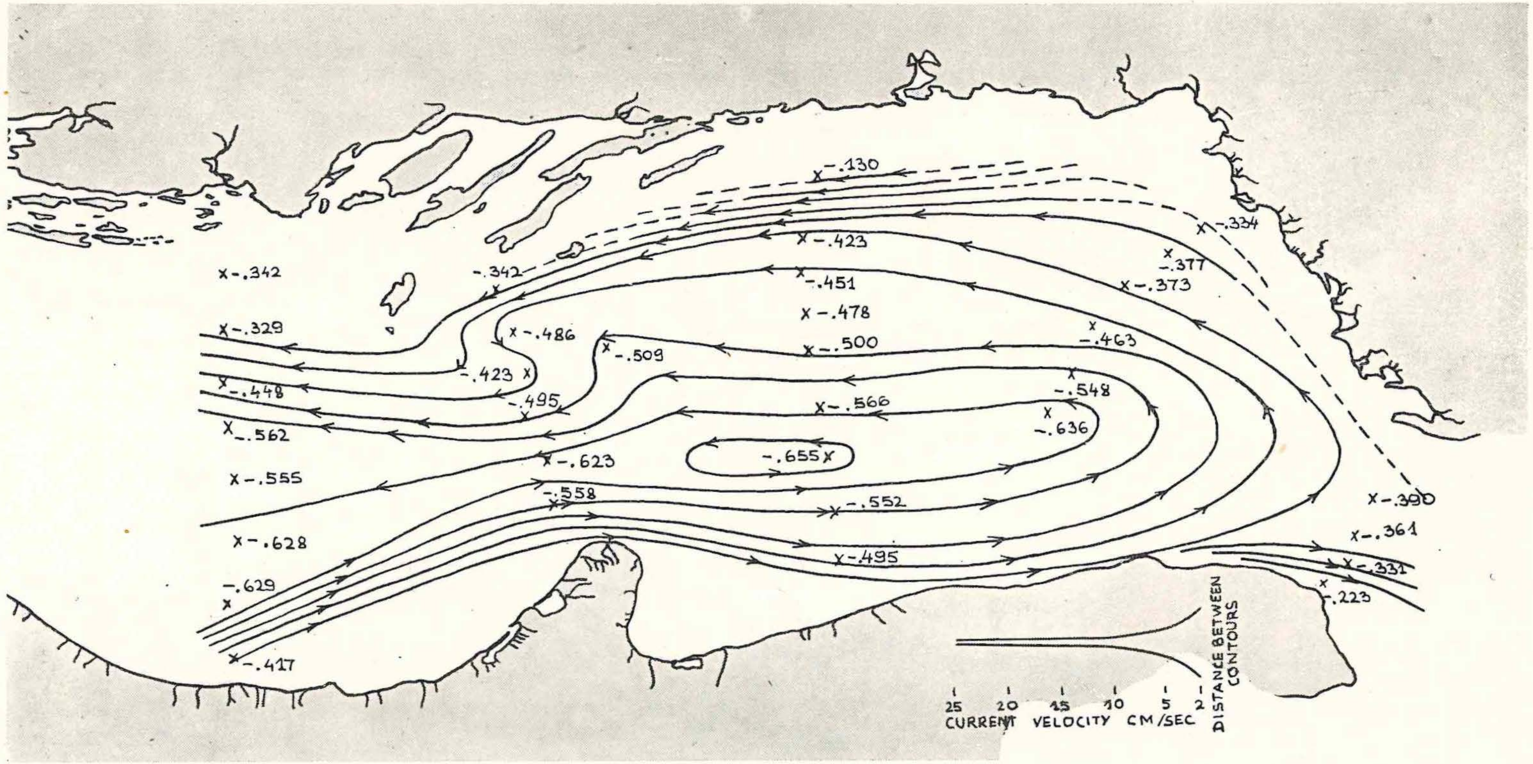

Fig. 4 B. Geopotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. V. and 9. VI. 1913.

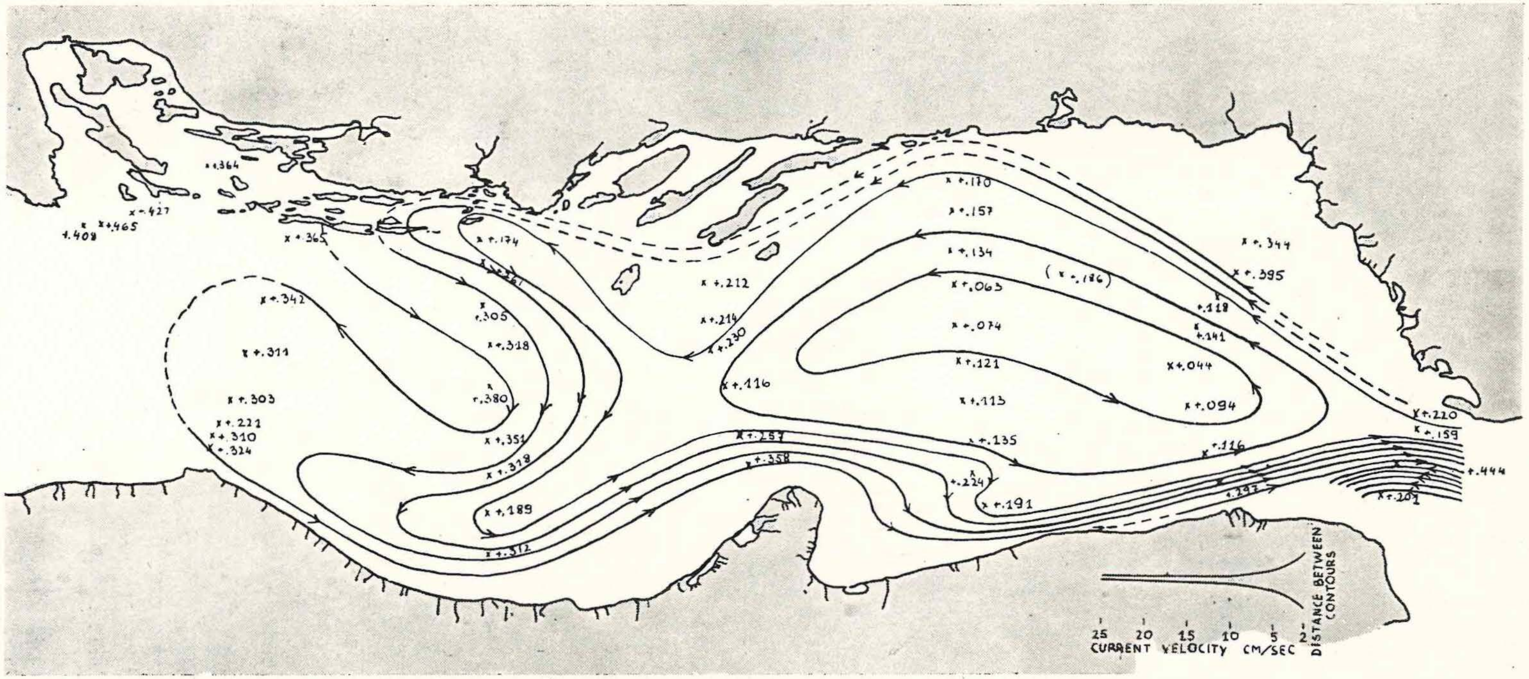

Fig. 5 A. Geopotential topography of the sea surface in dynamic decimetres relative to the 50 m decibar surface for the period between 16. VIII. and 1. IX. 1913.

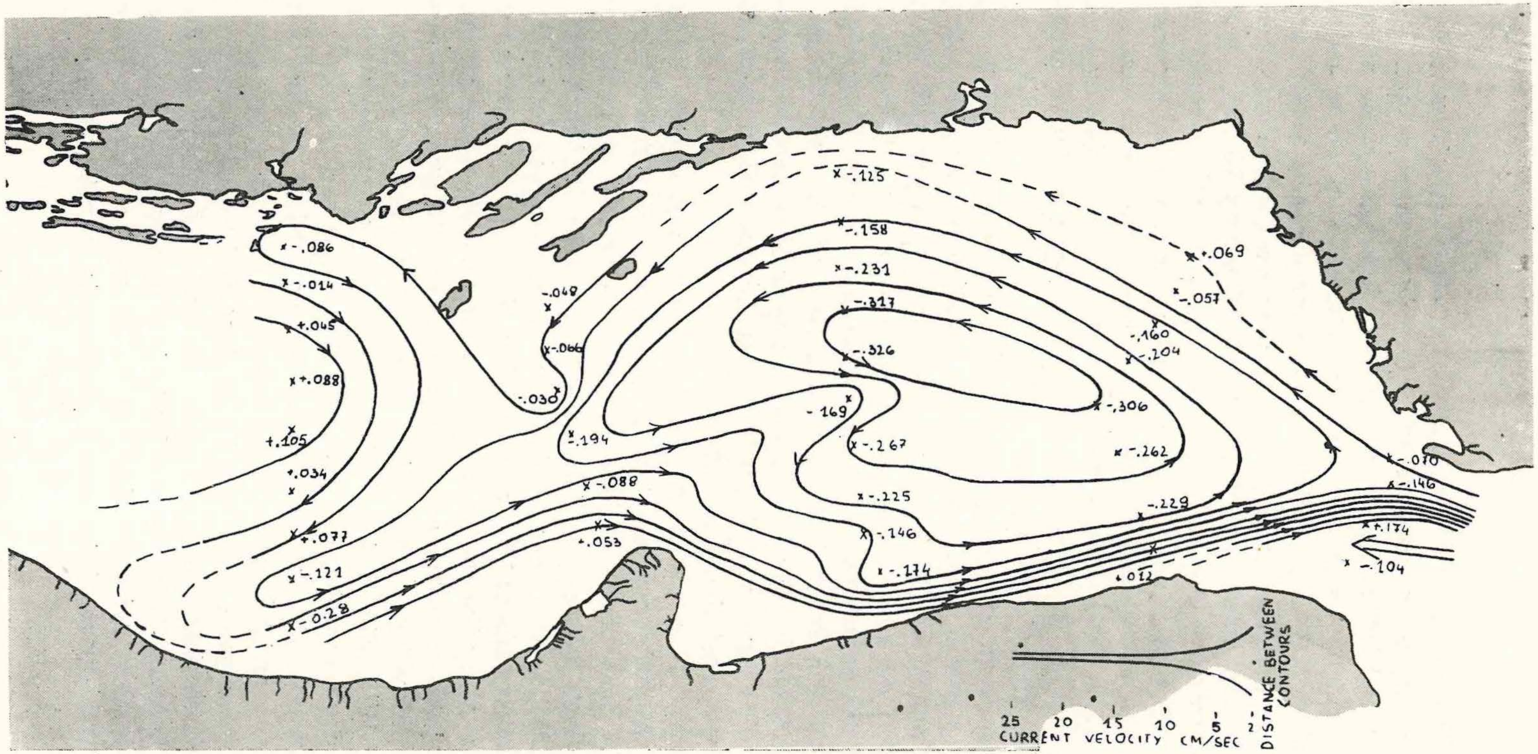

Fig. 5 B. Geopotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. VIII. and 1. IX. 1913.

surfaces which seemed more probable, while for some situations topographies were made according to the reference surfaces of 50 m and 100 m, or 100 m and 200 m respectively. The topographies made in summer time (August-September) according to references of 50 m or 100 m (Fig. 2 A,B; 5 A,B) hardly differed one from another, so we can draw the conclusion that the current is rather near the surface in that season. In topographies made in winter-time (February-March), however, coherent lines according to the 50 m reference surface could not be drawn with certainty and they differ a little more from the topographies made according to the 100 m reference surface. The reason thereof may be found in the fact that a thicker water layer is involved in the circulation during the winter, and that the depth of 50 m cannot be considered a surface of no motion.

Streamlines in all charts have a cyclonic course, i.e. the current enters the Adriatic along the eastern coast, and leaves it along the western (Italian) one. This kind of circulation was generally found by Wolf and Luksch (1874—1880) as a result of their qualitative analysis of the distribution of temperature and salinity. That course of currents was also determined by the analysis of the data obtained by means of drift bottles and by a detailed analysis of surface isotherms and isohalines (Feruglio, 1920). The current generally flows more closely along the west coast than along the east coast.

It is easy to see that the distribution of streamlines undergoes changes in the different seasons of the year, and some regularity can also be traced in these changes. Thus an obviously swifter outgoing current took place along the west coast in August-September 1911 and 1913 (Fig. 2 A,B; 5 A,B), while a reverse picture of circulation was found there in winter (February-March 1912 and 1914, Fig. 3; 7 A), i.e. a current grown less stronger along the west coast and gaining in velocity along the east coast. There was no characteristically swifter circulation in one direction in spring (May-June 1913, Fig. 4A,B), and the November chart (November 1913, Fig. 6 A) displays a swifter current along the east coast, but also a considerable one along the west coast.

So, rhythmic changes take place in the system of the Adriatic currents, i.e. a swifter and a more developed current occurs along the west coast in summer and along the east coast in winter, while equally developed circulations are found along the east and west coasts both in spring and autumn. The current velocity is generally more pronounced in August-September and November (up to 30 cm/sec) than in February when the development of the current reaches its lowest point.

In spring in the region of north Adriatic the Alpine rivers start to bring larger quantities of freshwater. This gives a new impulse to circulation, and as in spring, and particularly in summer, in this region is found the water which is relatively fresh and warm (Fig. 8 A,B, ~~5~~ 11 A,B), it is considerably lighter than the one with which it comes into contact in the southern Adriatic. In this way the circulation along the west coast comes into being, as the lighter water flows by the right side of the heavier one. A circulation along the east coast is more developed in winter. Warmer water with a higher salinity value flows from the southern Adriatic into northern Adriatic during that season. The difference in temperature being more striking (up to 8^{0} C) than that in salinity (2‰), the water, flowing from the southern to the northern Adriatic, is nevertheless lighter, and it runs along the east coast, leaving the heavier water at the right side. The difference in density is, however, not so acute at this time of the year as it happens in summer, owing to the influence of salinity and temperature changes upon the density being a variable one. The current, therefore, does not flow so distinctly close by the coast as it does along the west coast in summer.

The lighter the water mass coming from the place of origin, the closer to the coast will the current flow. Thus it happened that a more developed and coastwise current occurred along the west coast in August-September 1911 than during the same time interval in 1913 (Fig. 2 A,B; 5 A,B). Charts of surface isohalines and isotherms (Fig. 8 A,B; 11 A,B) show that the water masses of the Adriatic (particularly in its northern part) were generally warmer and less saline in August-September 1911 than during the same period in 1913. A similar case was observed for February-March 1914, when the current had been more pronounced along the east coast than during the same time interval in 1912 (Fig. 3; 7 A,B), while it is seen from surface isotherms that the waters in the southern Adriatic were warmer in 1914.

Beside the aforsaid seasonal differences in circulation, we could also notice the shifting of the places of the maximum and minimum of the dynamic depths in the different seasons of the year. Thus in summer (August-September) a distinct maximum is found in the northern Adriatic, and around it a corresponding anticyclonic circulation, which was more pronounced in summer 1913 than in 1911, although the 1911 maximum had been a higher one. In winter (February-March), however, a minimum is observed in the northern Adriatic, and it is more distinct in the 1914 topography than in the 1912 one, where only a secondary

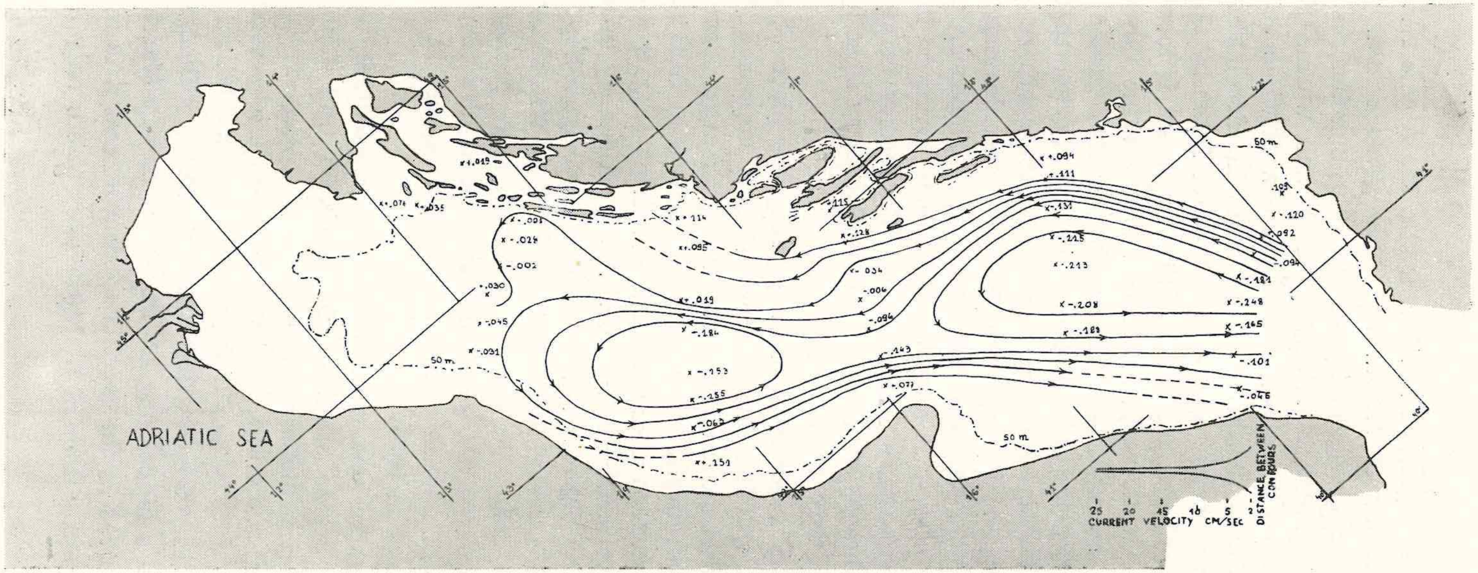

Fig. 6 A. Geopotential tvopography of the sea surface in dynamic decimetres relative to the 50 m decibar surface for the period between 16. and 24. XI. 1913. The broken line stands for the 50 m isobath.

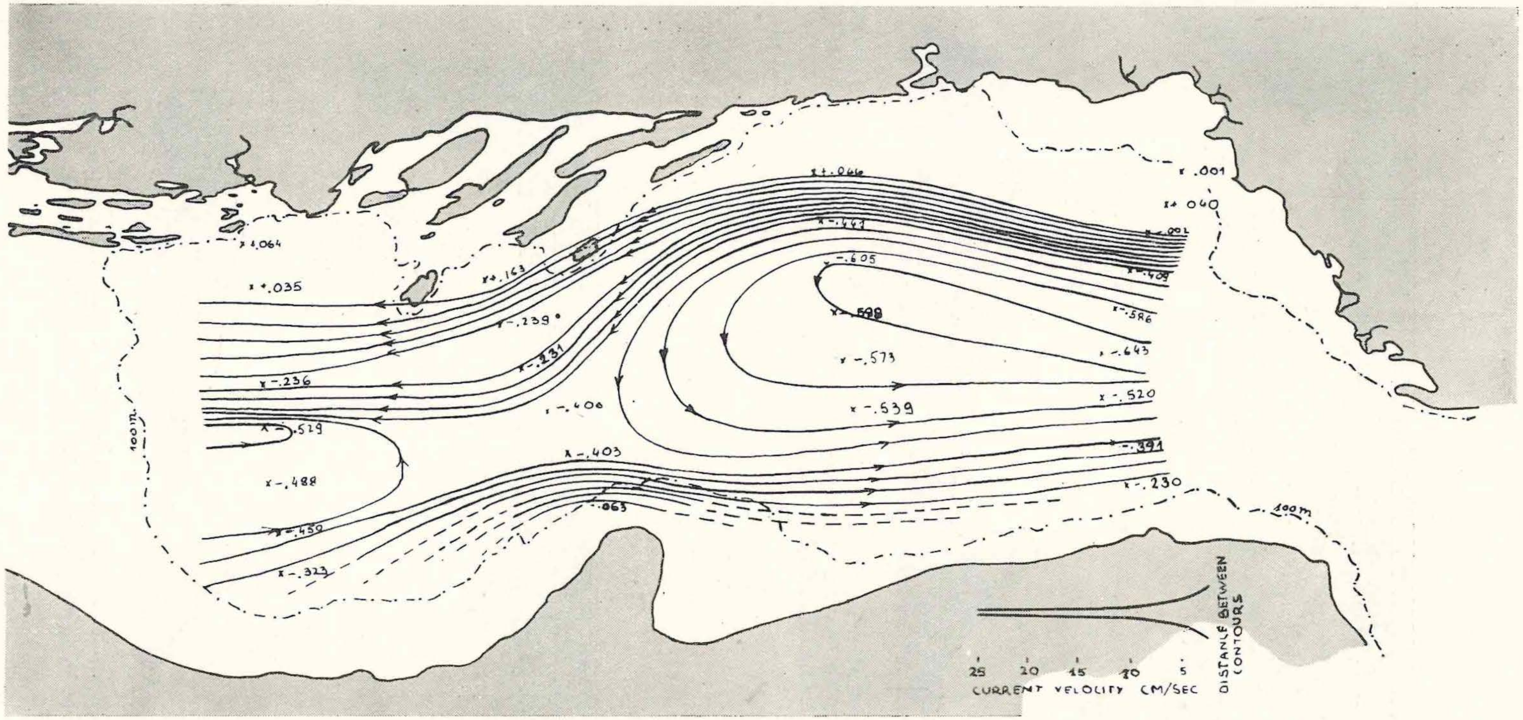

Fig. 6 B. Geopotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. and 24. XI. 1913. The broken line stands for the 100 m isobath.

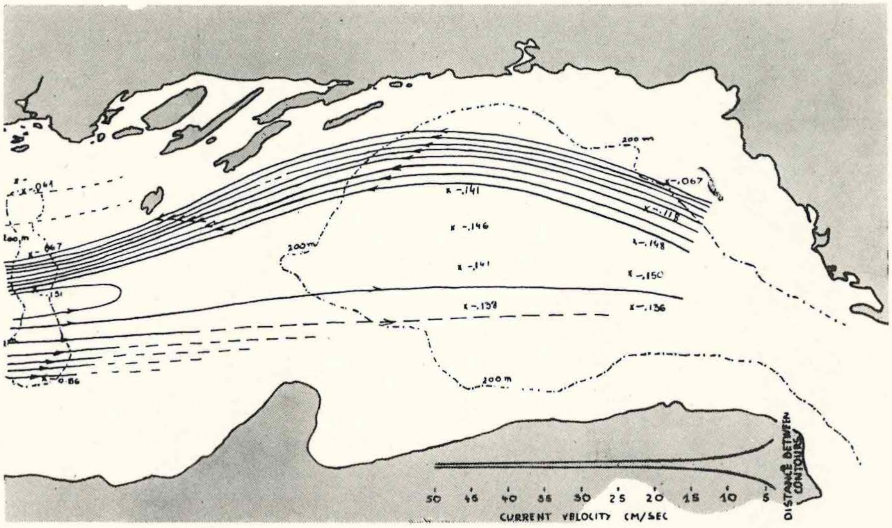

Fig. 6 C. Geopotential topography of the sea surface in dynamic metres relative to the 200 m decibar surface for the period between 16. and 24. XI. 1913. The broken line stands for the 200 m isobath.

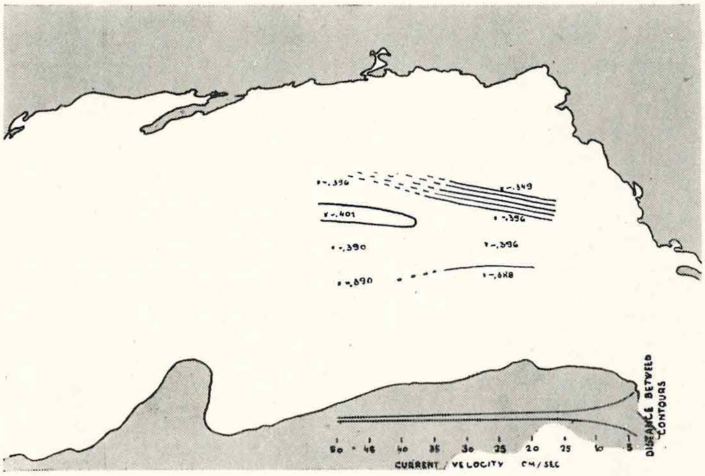

Fig. 6 D. Geopotential topography of the sea surface in dynamic metres relative to the 500 m decibar surface for the period between 16. and 24. XI. 1913.

minimum is found, while the main minimum appears in the waters of the South Adriatic Pit. It is sure, that the locations of the maximum and minimum are in connection with the summer heating and winter cooling of the shallow north Adriatic basin, where the annual temperature fluctuation (up to 20°C) is considerably higher than in the southern Adriatic or Mediterranean (about 10°C). If the greater freshwater inflow in the north Adriatic region in spring and summer helps the heating of the sea water during that period, it is evident that — in comparison with the south Adriatic — a lighter water mass is formed here, and, vice versely, during the autumn and winter a heavier water mass, as the temperature here can be lower by 10°C than in the southern Adriatic.

Between the lighter water mass of the northern Adriatic and the heavier one of the southern Adriatic, a transversal circulation toward the west coast is found in summer, and we can assume that the course of this circulation, influenced by coastline, or by the prevailed summer NW wind, is caused to deviate along the coast, toward the south Adriatic. A distinct outgoing current along the west coast of the Adriatic, at any rate, appears at the same time when a maximum occurs in the northern part of the sea. Less saline water of north Adriatic origin is brought along with this current, and it is evident from the surface isohalines that the lowest salinity value for the Adriatic as a whole is found in August-September.

A heavier water mass is formed, as already mentioned, in the northern part of the Adriatic during the autumn and winter, than in its southern part and Mediterranean. A transversal circulation between the different water masses toward the east coast, however, is not evident, but it is probably caused to deviate along the coast as a result of its influence. An incoming current appears, anyhow, along the east coast of the Adriatic at the same time when a minimum occurs in the northern part of the sea. Since the streamlines in the Otranto Strait are sure to extend further into the Mediterranean, a more saline and warmer Mediterranean water is then brought to the Adriatic along with such incoming current. As evident from the surface isohalines, the Adriatic is generally more saline during the autumn and winter than during the summer. But this phenomenon, of course, may be the outcome of a factor other than a more intensive inflow of Mediterranean water at that time, as e.g. an increased evaporation during the winter months. It seems, however, that the Adriatic waters are much more affected by the more saline Mediterranean during the autumn and winter than during the spring and summer. We

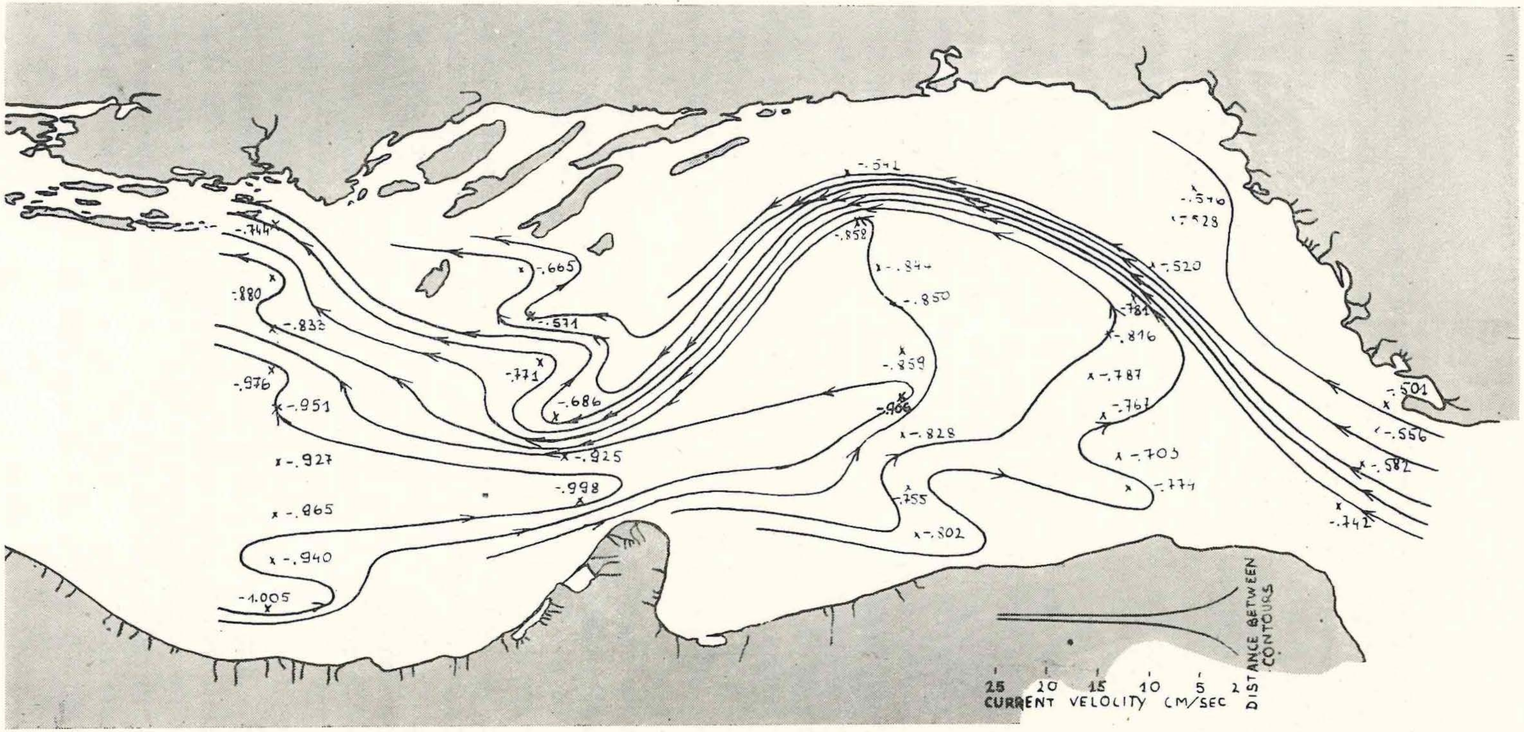

Fig. 7 A. Gecpotential topography of the sea surface in dynamic decimetres relative to the 100 m decibar surface for the period between 16. II. and 9. III. 1914.

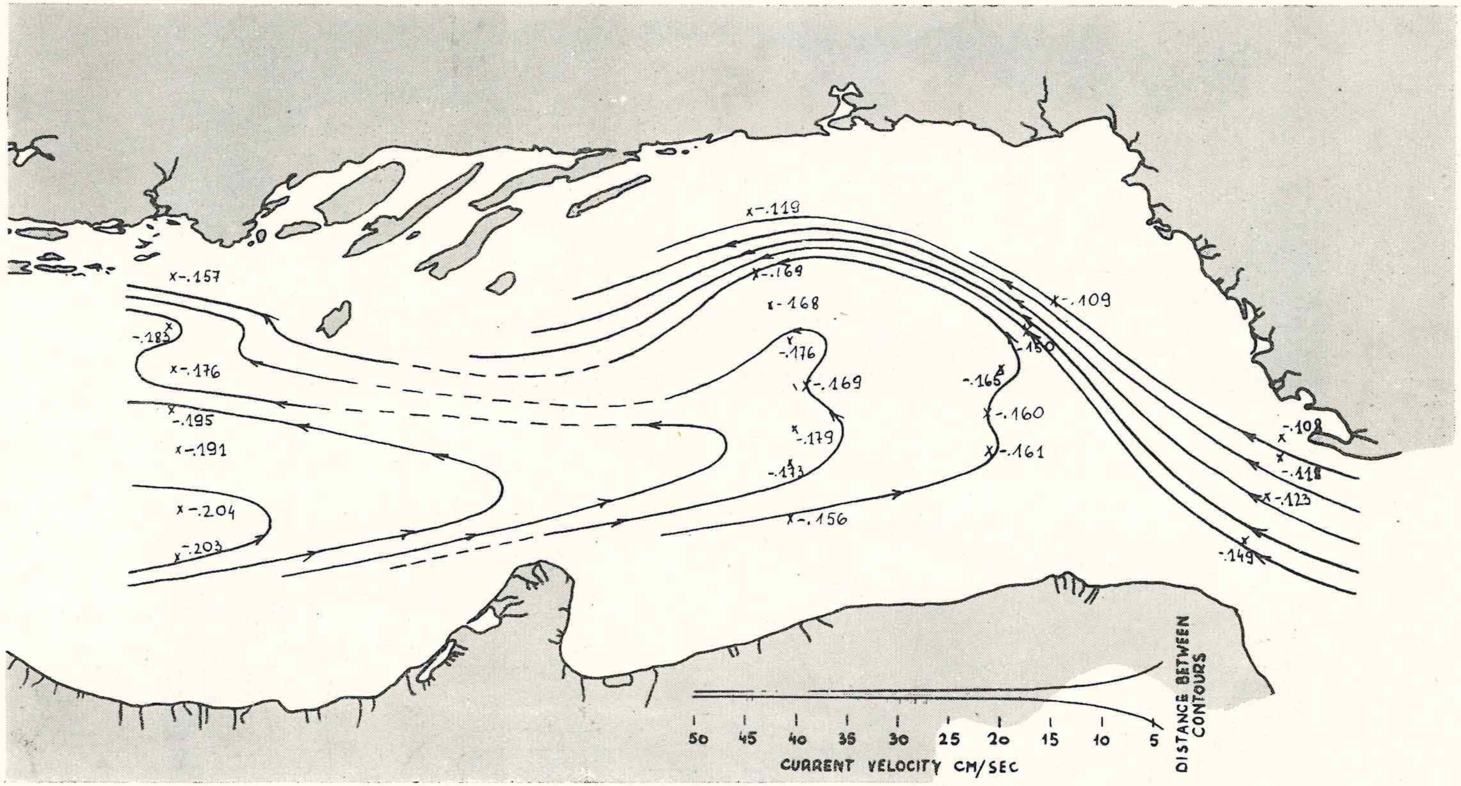

Fig. 7 B. Geopotential topography of the sea surface in dynamic metres relative to the 200 m decibar surface for the period between 16. II. and 9. III. 1914.

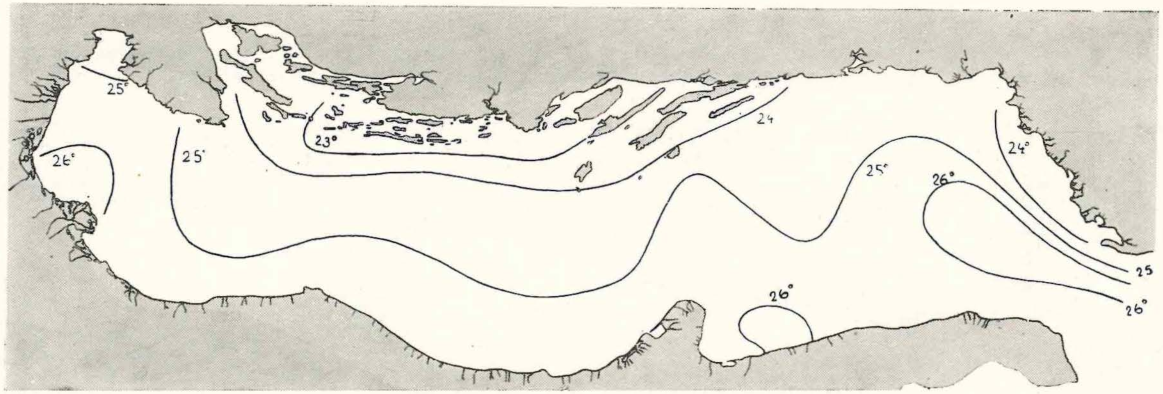

Fig. 8 A. Isotherms of the sea surface for the period between 16. VIII. and 6. IX. 1911. (Orig.)

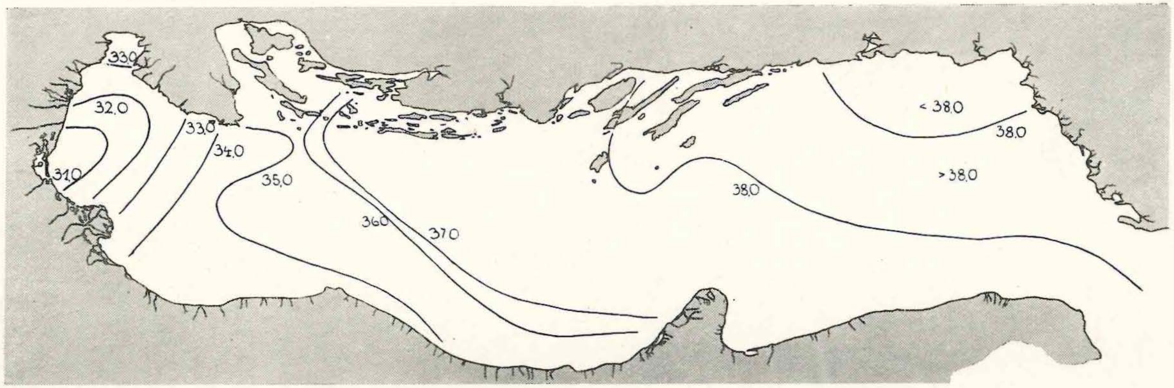

Fig. 8 B. Isohalines of the sea surface for the period between 16. VIII. and 6. IX. 1911. (Orig.)

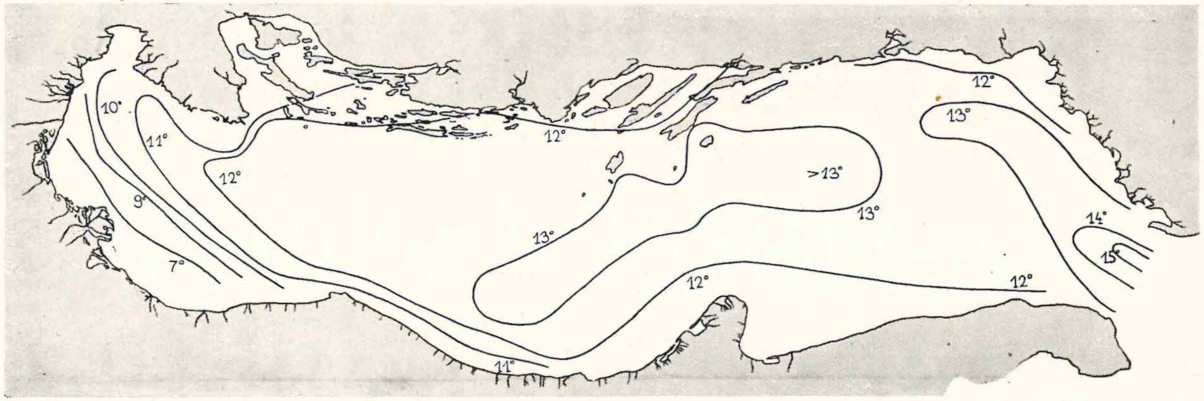

Fig. 9 A. Isotherms of the sea surface for the period between 16. II. and 11. III. 1912. (Orig. M. Buljan).

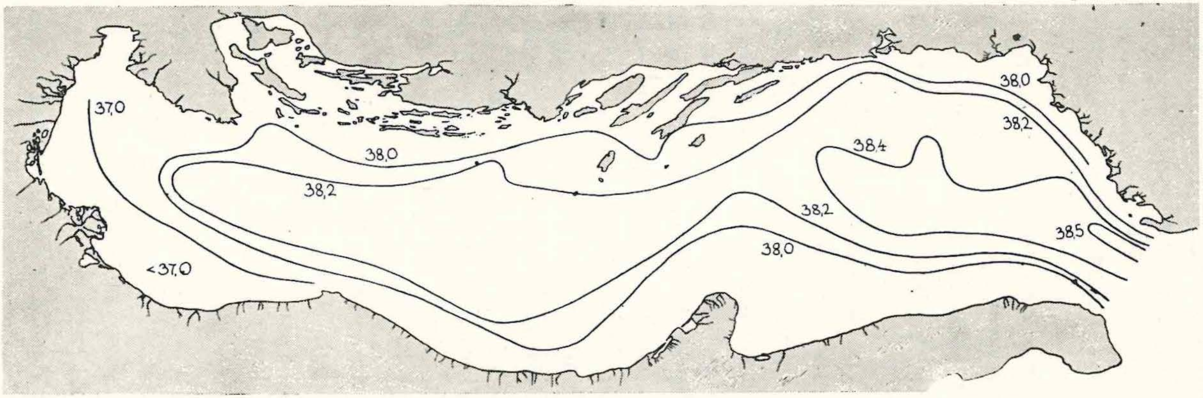

Fig. 9 B. Isohalines of the sea surface for the period between 16. II. and 11. III. 1912. (Orig. M. Buljan).

can substantiate this statement by the fact that the maximum occurrence of the Peridiniales group of phytoplankton, which is characteristic for warm waters, takes place in the eastern middle Adriatic inshore waters in autumn (E r c e g o v i ć, 1936). A considerable inflow of Mediterranean water, rich in plankton, may be the cause thereof.

The existence of a connection between the appearance of minima or maxima in the northern part of the Adriatic and the occurrence of incoming and outgoing currents respectively is evident from the coincidence of a lower minimum with a well developed incoming current. This results from a comparison of the topographies covering February-March 1912 with the 1914 ones. During that period in 1914 the minimum was for 15 dyn. mm lower in the middle Adriatic than during the same period in 1912, and the outgoing current in 1914 had an increased velocity and was generally more developed. We also find that the salinity of the south Adriatic was higher in February-March 1914 than during the same period in 1912, which shows the presence of a connection existing between the incoming current in winter and the increase of salinity in the Adriatic basin caused by the influence of the Mediterranean. A connection of this kind has already been suggested by M. B u l j a n (1953), in his paper on the fluctuations of salinity in the Adriatic.

Similarly in August-September 1911 the maximum was for 25 dyn. mm higher than during the same period in 1913, and the 1911 outgoing current was swifter and more developed. It results from the surface isohalines and isotherms that a higher maximum in 1911 was caused by the fact that the water of the north Adriatic had a higher temperature and lower salinity than in 1913.

It is evident, however, that the circulations occurring in the Adriatic are not the same every year, and that they vary not only from one season of the year to another, but from year to year as well, this being in connection with the varying conditions of hydrographic factors in the northern part of the Adriatic as compared with its southern part and Mediterranean. Basing on his observations of salinity fluctuations in the Adriatic for a number of years, M. B u l j a n (op. cit.) drew similar conclusions as to the occurrence of fluctuations of current velocity in the Otranto region.

Since the relative topographies of the Adriatic are in agreement with the already known data on circulation in that basin, we can infer that the currents in the Adriatic are for the most part gradient ones, so much the more as generally there are no constant winds blowing in the area.

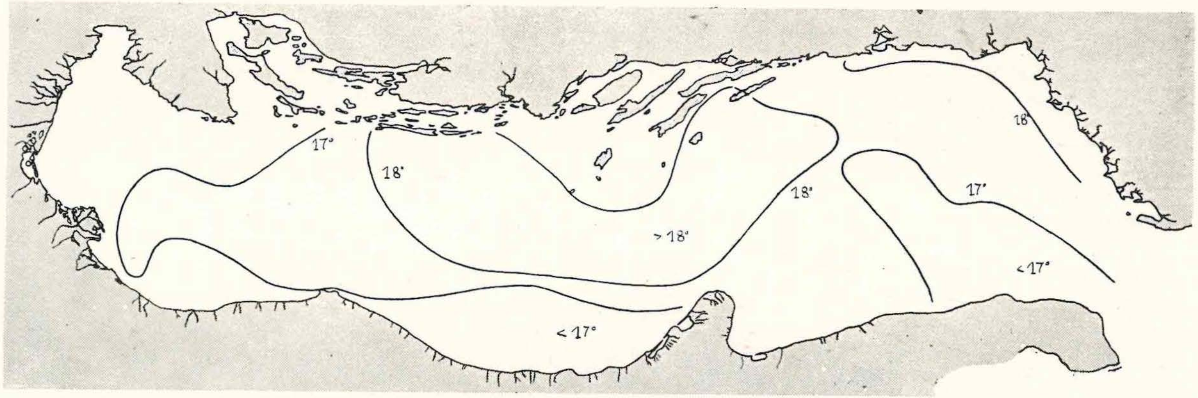

Fig. 10 A. Isotherms of the sea surface for the period between 16. V. and 9. VI. 1913. (Orig.)

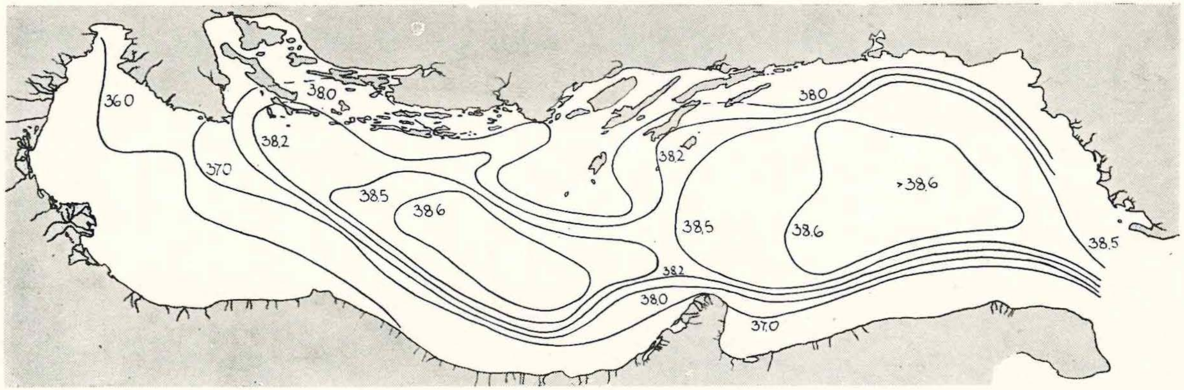

Fig. 10 B. Isohalines of the sea surface for the period between 16. V. and 9. VI. 1913. (Orig.)

Fig. 11 A. Isotherms of the sea surface for the period between 16. VIII. and. 1. IX. 1913. (Orig.)

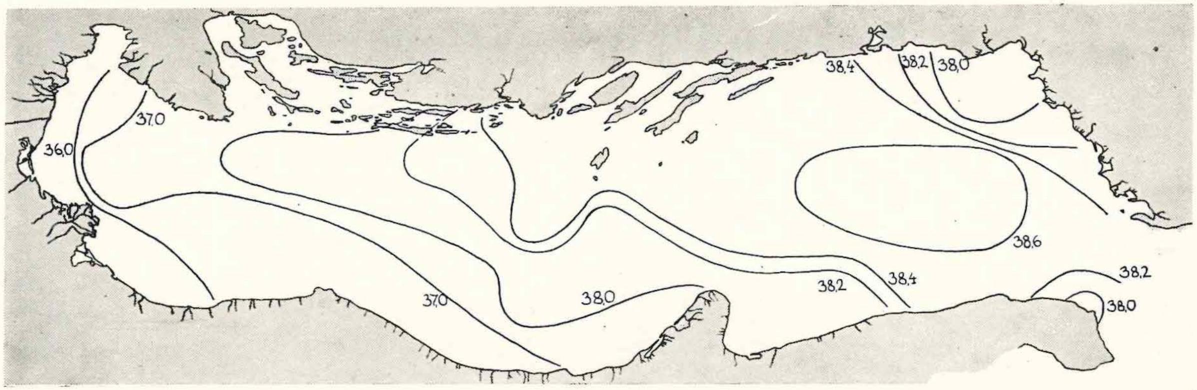

Fig. 11 B. Isohalines of the sea surface for the period between 16. VIII. and 1. IX. 1913. (Orig.).

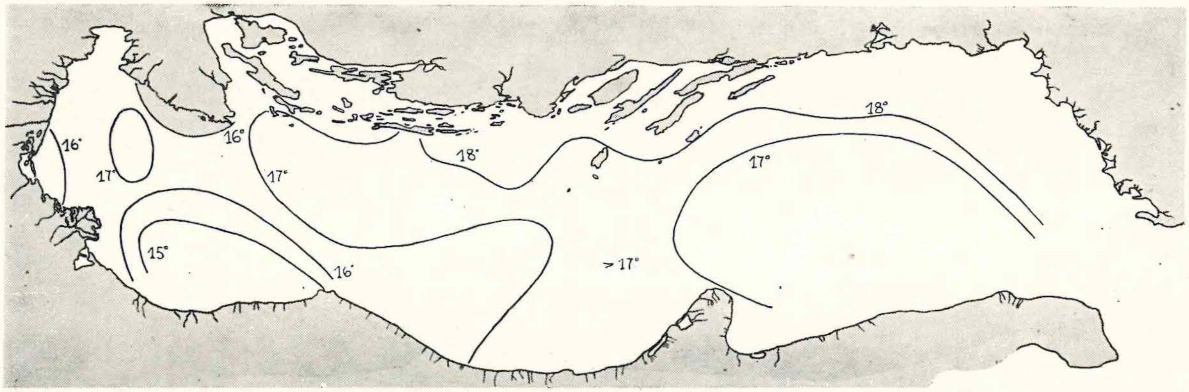

Fig. 12. A. Isotherms of the sea surface for the period between 16. and 24. XI. 1913. (Orig. M. B u l j a n).

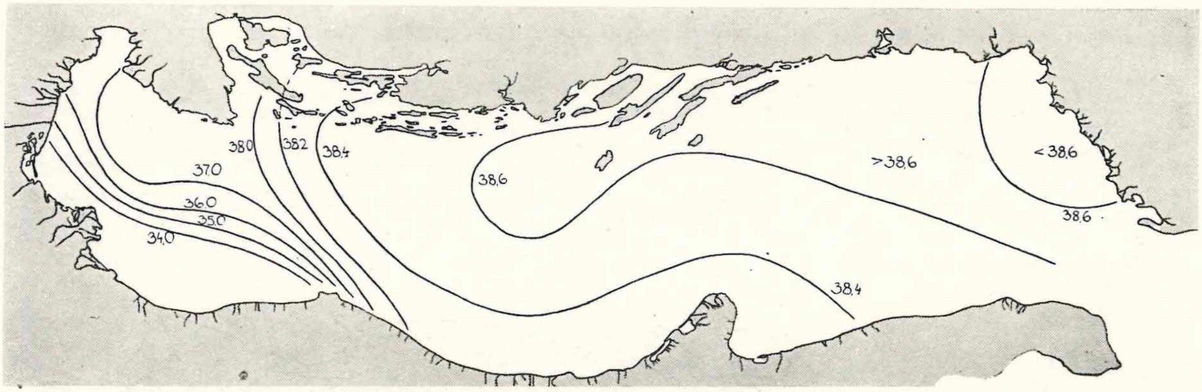

Fig. 12 B. Isohalines of the sea surface for the period between 16. and 24. XI. 1913. (Orig. M. B u l j a n).

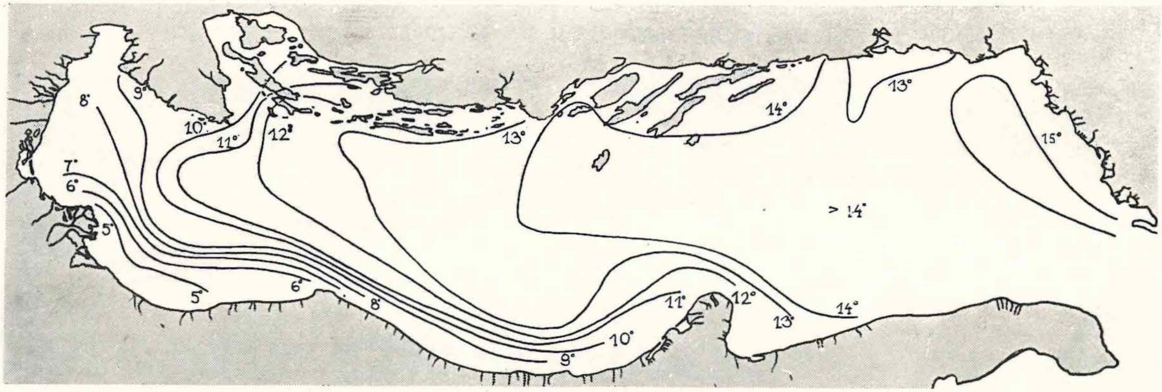

Fig. 13 A. Isotherms of the sea surface for the period between 16. II. and 9. III. 1914. (Orig. M. Buljan).

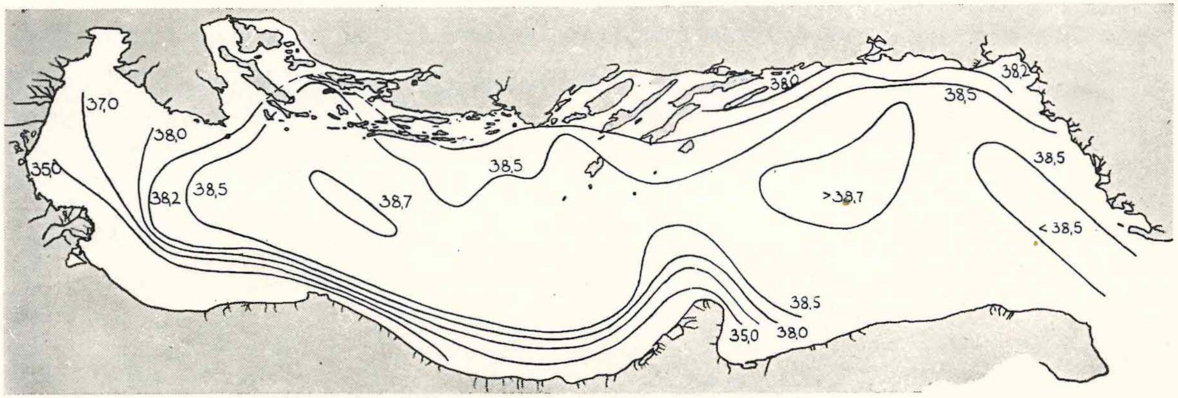

Fig. 13 B. Isohalines of the sea surface for the period between 16. II. and 9. III. 1914. (Orig. M. Buljan.)

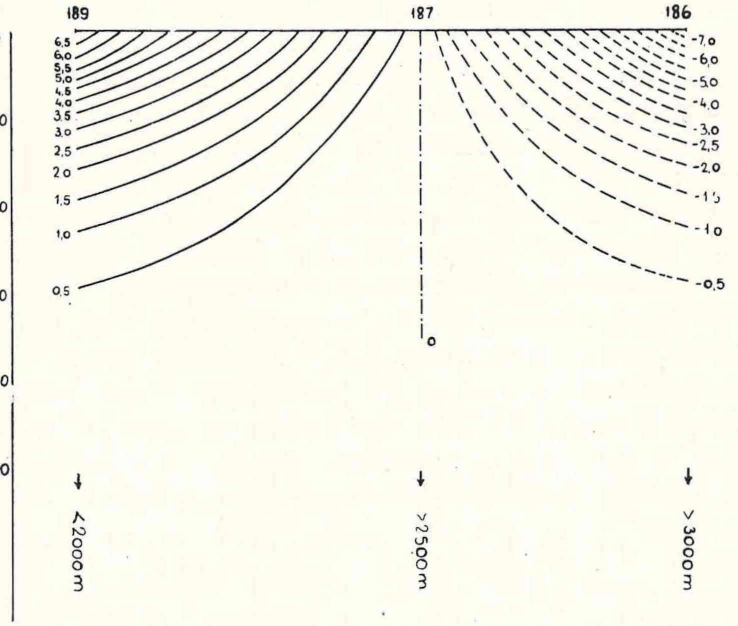

Fig. 14. Components of velocity (cm/sec), positive toward N, in the profile between Sicily and Peloponnesus, according to the data obtained by the »THOR« Expedition.

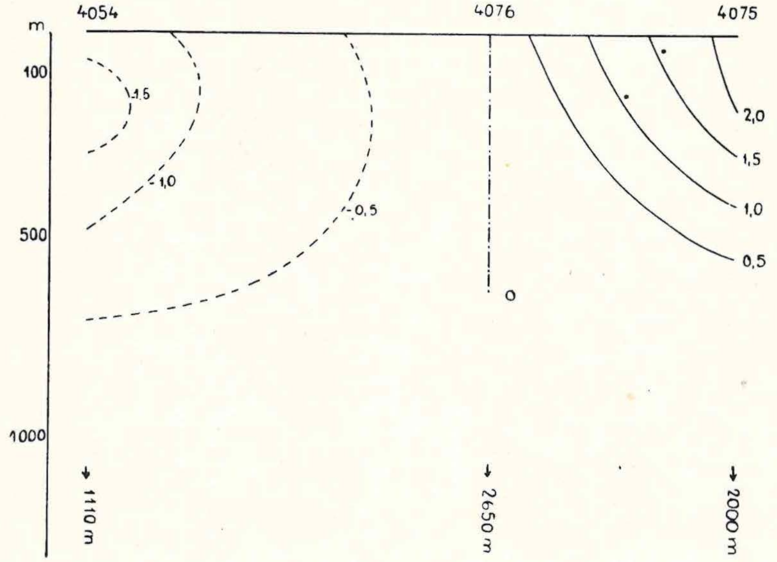

Fig. 15. Components of velocity (cm/sec), positive toward N, in the profile between Sicily and Peloponnesus, according to the data obtained by the »DANA« Expedition.

The vertical distribution of velocities in the profile Sicily—Peloponnesus (Fig. 14, 15) presents a reverse picture in August 1910 (17.—19. VIII.) in comparison with the May 1930 one (5.—22.V.), suggesting that the circulation does not retain a constant direction in the Mediterranean either. According to Platania's (19~~40~~23) finding there were no constant currents in the most of the Mediterranean. The distribution of currents in the mentioned profile in August would perhaps agree with the circulation occurring in the Adriatic during the same month if we realize that the outgoing current is displaced along the east coast of the Otranto Strait, and that an incoming current flows along the west coast of the Otranto Strait (Fig. 2 A; 5 B), which may be the extension of the circulation going along the Italian side of the Ionian Sea. The distribution of currents in May would be in agreement with the cyclonic circulation in the Adriatic. The Sicily—Peloponnesus profile too displays currents running more swiftly in August than in May.

SUMMARY

To calculate the geopotential topographies for the region of the Adriatic Sea, the material collected by the NAJADE and CICLOPE Expeditions (1911—1914) was used, and to obtain the vertical distribution of current velocities in the section from Sicily to Peloponnesus, the data collected by the THOR (1910) and DANA (1930) Expeditions were applied.

The geopotential anomalies and current velocities were calculated from temperature and salinity data by applying the Bjerknes' Theorem and the Helland-Hansen formula respectively, and by taking — as reference depths — the isobaric depths of 50, 100 and 200 m for the Adriatic area, and the 500 and 1000 m ones for the Sicily to Peloponnesus profile.

The calculation of dynamic topographies for the Adriatic region covered six distinct situations: 16. VIII.—6. IX. 1911., 16. II.—11. III. 1912., 16. V.—9. VI. 1913., 16. VIII.—1. IX. 1913., 16.—24. XI. 1913. and 16. II.—9. III. 1914.

The presence of a cyclonic course of streamlines has been proved in the Adriatic.

Seasonal rhytmic changes have been found to occur in the system of Adriatic currents, i.e. swifter and more developed currents appear along the west coast in summer, and along the east coast in winter, while the spring and autumn circulations reach equal intensity along both the coasts. The currents are generally swifter in August-September and November (up to 30 cm/sec) than in February, when they are the weakest.

The course of the cyclonic streamlines in the Adriatic is connected with the character of gradient currents in that basin. Lighter water flows along both the coasts during the occurrence of a developed circulation, since a lighter water mass is formed during the spring — summer period in the northern Adriatic, and during the autumn — winter period in the southern Adriatic.

The author deals with the seasonal fluctuations of the positions of both the maximum and minimum of dynamic depths. The occurrence of a

maximum in summer and a minimum in winter has been found in the northern part of the Adriatic. Great annual amplitudes in sea water temperature in the northern Adriatic and a considerable inflow of fresh water to that region in spring are held responsible for these changes. A connection has been found to exist between the appearance of the northern Adriatic maximum and the forming of the outgoing current, and between the appearance of the northern Adriatic minimum and the forming of the incoming current.

It has also been found that swifter incoming current coincides with a lower minimum in the northern part of the Adriatic, and that a swifter outgoing current concurs with a higher maximum. Since the current, entering the Adriatic in winter, flows from the Mediterranean which shows a higher degree of salinity, the author supposes that the salinity rise, occurring in the Adriatic basin in winter is caused by such a current, while the summer outgoing current produces the opposite result as the water mass of the north Adriatic origin has lower salinity in that period.

It has been established, that the annual variations in the circulation of Adriatic waters are in connection with the different stages of the hydrographic factors in that basin.

The conclusion has been drawn that the geopotential topographies show to a great deal a real picture of Adriatic currents.

A short survey of the distribution of currents in the Sicily—Peloponnesus profile as related to the circulation occurring in the Otranto Strait is also given.

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O GRADIJENTSKIM STRUJAMA JADRANSKOG MORA

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Kratak sadržaj

Za izračunavanje geopotencijalnih topografija za područje Jadranskog mora upotrebljen je materijal ekspedicija NAJADE i CICLOPE (1911.—1914. g.), a za dobivanje vertikalnog rasporeda brzina struja na profilu Sicilija—Peloponez korišten je materijal ekspedicija THOR (1910) i DANA (1930).

Geopotencijalne anomalije i brzine struja računate su iz podataka za temperaturu i salinitet Bjerknesovom metodom, odnosno Helland-Hansenovom formulom, a kao dubine referencije uzete su izobaričke dubine od 50, 100 i 200 m za područje Jadrana, a 500 i 1000 m za profil Sicilija— Peloponez.

Izračunate su dinamičke topografije za područje Jadrana za 6 različitih situacija: 16. VIII.—6, IX. 1911. g., 16. II.—11. III. 1912. g., 16. V.—9. VI. 1913. g., 16. VIII.—1. IX. 1913. g., 16.—24. XI. 1913. g. i 16. II.—9. III. 1914. g.

Utvrđeno je, da strujnice u Jadranu imaju ciklonalan tok.

Ustanovljene su ritmičke promjene u režimu jadranskih struja, t. j. ljeti nalazimo brže i razvijenije strujanje uz zapadnu obalu, a zimi uz istočnu, dok je u proljeće i jesen strujanje uz obe obale jednako razvijeno. Općenito su u mjesecima augustu-septembru i novembru struje brže (do 30 cm/sec) nego u februaru, kada su najslabije izražene.

Razmatran je ciklonalni tok strujnica u Jadranu, koji je doveden u vezu s karakterom gradijentskih struja u tom basenu. Naime, uz obe obale u periodu izrazitog strujanja, struji lakša voda, jer se u proljetno-ljetnom periodu oblikuje u sjevernom Jadranu lakša vodena masa, a u jesensko-zimskom u južnom Jadranu.

Tretirane su sezonske razlike u smještaju maksimuma i minimuma dinamičkih dubina. Nađeno je, da se ljeti u području sjevernog i srednjeg

Jadrana nalazi maksimum, a zimi minimum. Ovo je protumačeno velikim godišnjim amplitudama temperature mora u sjevernom Jadranu, kao i prilivom slatke vode u proljeće u tom području. Ukazano je na vezu pojavljivanje maksimuma u sjevernom Jadranu i stvaranja izlazne struje, kao i pojavljivanja minimuma u istom području i stvaranja ulazne struje u Jadran.

Nađeno je, također, da se uz niži minimum u sjevernom Jadranu oblikuje i brža ulazna struja, a uz viši maksimum brža izlazna struja. Kako ulazna struja u Jadran struji zimi iz slanijeg Mediterana, pretpostavljeno je da takva struja uvjetuje zimsko zaslanjenje jadranskog basena, dok ga ljetna izlazna struja sa slađom vodom u izvornom području zaslađuje.

Utvrđeno je, da strujanja u Jadranu nisu svake godine jednaka, a da su te razlike u vezi s različitim stanjem hidrografskih faktora u tom basenu.

Izveden je zaključak, da relativne struje u Jadranu imaju važan udio u općem strujanju.

Kratko je razmatran odnos rasporeda struja na profilu Socilija—Peloponez prema strujanju u Otrantskim vratima.