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FLUCTUATION OF TEMPERATURE IN THE WATERS OF THE OPEN ADRIATIC

KOLEBANJE TEMPERATURE VODE OTVORENOG JADRANA

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The purpose pursued by the present paper has been the making of a survey of temperature conditions for the Adriatic as a whole which would provide data referring to various seasons and to a series of years. The task was accepted by the author in absence of a surwey of this kind covering the Adriatic Sea. It is necessary, therefore, to emphasize in this connection that neither the attempt to find out all the causes of these variations nor the thorough study of their dynamics has been within the range of the author's scope. He has tried, however, to give some rational explanations of a number of events described in the present paper.

It is required from the data to be processed for this purpose that they should reflect a comprehensive view of all the investigated area arrived at either at the same time or, at least, within the shortest time span that can be realized.

The data should , moreover, result from a systematic and relatively frequent collecting. Of all the hydrographic investigations which have hitherto taken place in the Adriatic area (for particulars, see Buljan's paper, 1953), only those collected by the expeditions »Najade« and »Ciclope« during their cruises lasting from March 1911 till February 1914 can meet these requirements.

The two expeditions, particularly the »Najade« one, have collected such a plenty of hydrographic material during the mentioned period that the Adriatic, owing to this fact, has become one of the most investigated seas of the whole Mediterranean region.

Unless otherwise stated, all the data and conclusions contained herein refer to the period of investigations from 1911 to 1914.

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*) A part of the present paper, as far as the South Adriatic Pit area is concerned, was reported to the General Assembly of the International Commission for Scientific Investigation of the Mediterranean, held in Istanbul in September, 1956.

In order to obtain a comprehensive picture of the conditions with respect to fluctuations of temperature in space and time, the method of processing only the minimum and maximum temperature values for each processed station (leaving untouched all other data) was applied in the present paper.

This from what we know as yet unemployed method has the advantage of giving the limits of the temperature range, thus comprising actually all the cases in the surveyed area occurring within those limits. The method appears to represent an economical way of getting the first and rough idea of temperature conditions of an area.

Two outstanding Adriatic areas have been given particular attention in the present paper: the Jabuka Pit and the South Adriatic Pit. The marginal parts of the Adriatic, as well as its shallow parts, have not always been considered. The advantage of this method consists therein (1) that it deals with the main body of the Adriatic water, and (2) that it neglects various influences of limited local importance which tend to disturb the results e.g., the influence exerted by the coast or land in shallow areas. All these marginal effects, taken together, reflect themselves in the ultimate water character of the two pits, so they too have been included in the survey.

Table 1. *The Material Collected at the Stations of the »Najade« and »Ciclope« Expeditions Utilized in the Survey of the South Adriatic Pit.*

Time of Collecting	»Najade« Stations	»Ciclope« Stations
III. 1911.	A 28, A 30	———
V.	A 28	T 35, T 39, T 43, T 45, T 52, T 54
VIII.	A 28, A 29, A 30	T 36, T 38, T 40, T 42, T 44
XI.	A 27, A 28, A 29, A 30	———
II. 1912	A 27, A 28, A 29, A 30	———
V.	A 27, A 28, A 29, A 30	———
VIII.	A 27, A 28, A 29, A 30	T 20, T 22, T 24, T 26
III. 1913	A 28, A 30	T 34, T 36, T 38, T 40, T 42
V.	A 28, A 29, A 30	T 15, T 17, T 19, T 21
VIII.	A 27, A 28, A 29, A 30	T 29, T 31, T 33, T 35, T 37
XI.	A 27, A 28, A 29, A 30	T 32, T 34, T 36, T 38
II. 1914	A 28, A 29, A 30	T 35, T 37, T 39, T 41

In order to reduce to a minimum degree the influence of local variations on the problem of arranging the characteristic maxima according to depths, the author's attention was centred on the stations lying around the middle of the basins (Fig. 1), i.e. on those stations only where the depth exceeded 600 m in the South Adriatic (Table 1.), and 150 m in the Jabuka Pit (Table 2.). All the data, therefore, which are given below, as well as the conclusions drawn, refer to the core, to the major part of the Adriatic waters. The author has sometimes availed himself of some other data referring to the coastal regions. When the minimum and maximum temperatures (absolute values) were determined,

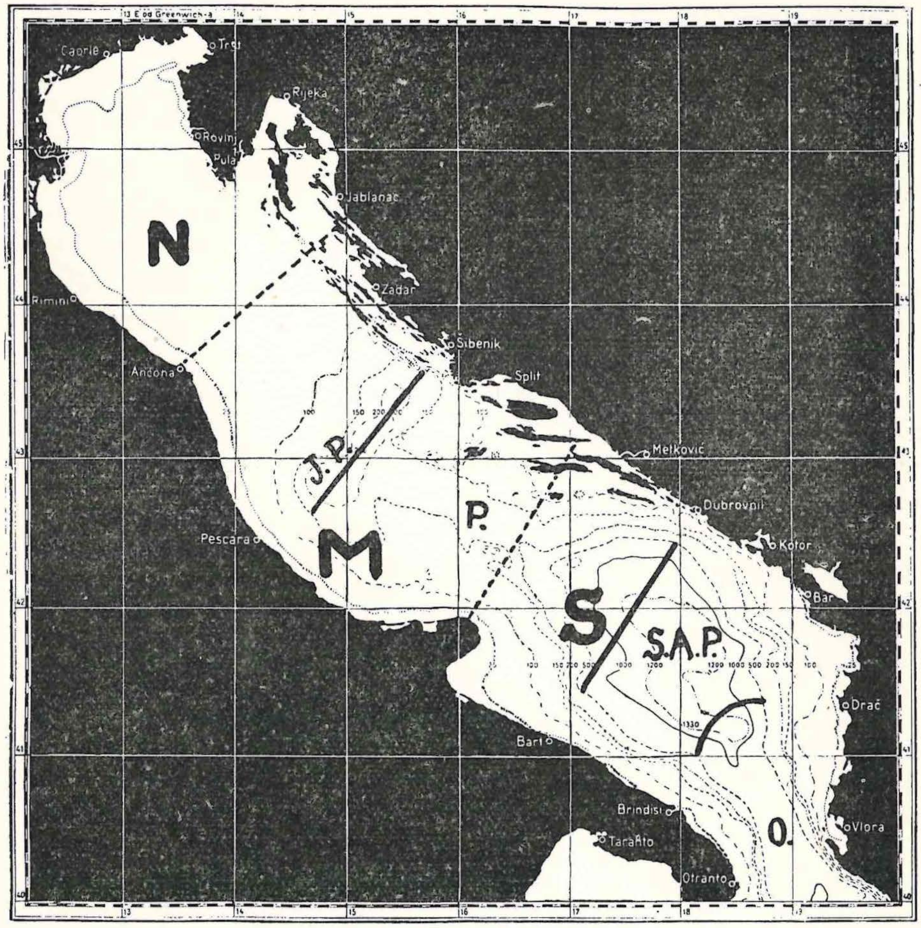


Fig. 1.

The Adriatic Sea. The upper transversal full line in the direction of Šibenik illustrates the position of the »N a j a d e« stations in the Jabuka Pit area, processed in this paper. The middle full line lying between Dubrovnik and Bari shows the positions of the »C i c l o p e« stations across the South Adriatic Pit area, which was also used for the purposes of the present paper. The lower bow-shaped curve covers the position of the used »Najade« stations in the mentioned Pit.

N, M, S, — North, Middle, and South Andriatic respectively.
J. P. — Jabuka Pit.
P. — Palagruža Sill.
S. A. P. — South Adriatic Pit.
O. — Otranto Sill.

all the available temperature data were then taken into consideration, even those referring to the shallow coastal waters of the North Adriatic (Tab. 5.).

It should be pointed out here that the material obtained by the two expeditions was successfully collected almost at the same time, and that the cruises, spread over a period of four years, were repeated on nearly the same dates each year. Out of the total twenty stations covering the area of the South Adriatic Pit and done in the course of four winters, eighteen ones were visited during the period between February 21st and March 4th, i.e. within a twelve day span (two stations differ for additional three weeks). Where there are discrepancies between the dates of observations made at the spring, summer, and autumn stations, they do not exceed the span of 10, 9 or 7 days respectively in any single case during the four years of investigations performed by the two expeditions. It is not unlike with the material referring to the Jabuka Pit.

The time coincidence of this twosome material collecting is then most satisfactory, particularly if considered that the whole of the Adriatic was the objective of the two expeditions organized by two governments, and lasting for several years.

Table 2. *Stations Taken for the Study of Temperature Variations in the Jabuka Pit. (The data were taken from the »N a j a d e« material only).*

Collecting Time of							
III. 1911	A 10,	A 11,	A 12,	A 13,	A 15		
V.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
VIII.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
XI.	A 11,	A 12,	A 13,	A 14,	A 15,	A 16	
II. 1912	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
V.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
VIII.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15	
III. 1913	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
V.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
VIII.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
XI.	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16
II. 1914	A 10,	A 11,	A 12,	A 13,	A 14,	A 15,	A 16

The winter temperature data have been much more used for the purpose of the present paper than the ones referring to other seasons. It was mainly through the winter data that the conclusions, given in the present paper, were reached.

This can be explained by the fact that the principal inflow of Ionian waters into the Adriatic basin takes place just in winter, as stated by

M. Z o r é (1956). In this way, the temperature data referring to the two Adriatic pits provide the opportunity of finding out both the degree of cooling of this basin as a consequence of the winter season and the extent of the water inflow from the south.

The meaning of symbols used in this paper:

$\bar{t}^0_m$ = Average of minimum aemperatures for the processed stations regardless of depth of the layer.

$\bar{t}^0_M$ = Average of maximum temperatures for the processed stations regardless of depth of the layer.

$\Delta\bar{t}^0$ = $\bar{t}^0_M - \bar{t}^0_m$

t^0_m = The lowest temperature for all processed stations regardless of depth of the layer.

t^0_M = The highest temperature for all processed stations regardless of the depth of the layer.

Δt^0 = $t^0_M - t^0_m$

$\bar{D}_m$ = Average depth in metres of minimum temperature layers for all processed stations.

$\bar{D}_M$ = Average depth in metres of maximum temperature layers for all processed stations.

Δt^0_m = Temperature span within the t^0_m during an interval of time.

Δt^0_M = Temperature span within the t^0_M during an interval of time

$\Delta\bar{t}^0_m$ = Temperature span within the $\bar{t}^0_m$ during an interval of time.

$\Delta\bar{t}^0_M$ = Temperature span within the $\bar{t}^0_M$ during an interval of time.

TEMPERATURE FOUND IN THE JABUKA PIT

The processed data referring to this area are given in Table 3.

The minimum temperature (t^0_m) for the period between March 1911 and February 1914 was found in May 1913 (10,53°C), and the maximum one (t^0_M) in August 1912 (26,31°C). The mean of the minima ($\bar{t}^0_m$) for individual cruises ranged between 11,10°C in August 1913 and 11,89°C in November 1911, the temperature span being 0,79°C.

The absolute minima (t^0_m) ranged between 10,53°C in May 1913 and 11,49°C in August 1912, the temperature span being 0,96°C.

The mean maxima ($\bar{t}^0_M$) for the period between March 1911 and February 1914 extended from 12,02°C in March 1911 to 24,61°C in August 1912, the temperature span being 12,59°C.

Table 3. *Temperature Conditions in the Jabuka Pit During the Period Between March 1911 and February 1914.*

1	2	3	4	5	6	7	8	9
	$\bar{t}'_m$	$\bar{t}^0_M$	$\Delta\bar{t}^0$	t^0_m	t^0_M	Δt^0	$\bar{D}_m$	$\bar{D}_M$
III. 1911	11.50	12.02	0.52	11.17	12.12	0.95	149	12
V.	11.61	17.83	6.22	10.83	18.38	7.55	171	2
VIII.	11.62	24.30	12.68	10.76	25.50	14.74	171	0
XI.	11.89	16.23	4.34	10.94	18.02	7.08	174	6
II. 1912	11.78	13.01	1.23	11.29	13.46	2.17	189	24
V.	11.84	17.18	5.34	11.44	17.47	6.03	201	0
VIII.	11.72	24.61	12.89	11.49	26.31	14.82	217	0
III. 1913	11.65	13.23	1.58	10.65	13.46	2.81	207	0
V.	11.78	17.85	6.07	10.53	18.37	7.84	209	0
IIIV.	11.10	22.40	11.30	10.62	23.15	12.53	204	0
XI.	11.26	17.38	6.12	10.68	18.36	7.68	206	2
II. 1914	11.63	13.42	1.79	10.76	13.70	2.94	208	9

The absolute maxima (t^0_M) during the four years of investigations ranged between 12,12°C in March 1911 and 26,31°C in August 1912, the temperature span being 14,19°C.

During the four winter seasons covered by the investigations either the Δt° or the $\Delta\bar{t}'$ manifested an upward trend in wintertime. (See Table 4).

Table 4. *Span Growth Between the Winter Minimum and Maximum Temperatures, Referring to Both the Absolute Values and the Mean Temperature Values for the Jabuka Pit Area During the Period of Four Years.*

(The temperature values are given in degrees Centrigrade)

	Δt^0	$\Delta\bar{t}^0$
1911	0,95	0,52
1912	2,17	1,23
1913	2,81	1,58
1914	2,94	1,79

Since the values of minimum temperatures, the absolute ones as well as the average ones, have manifested a great stability, it would mean that the increase of winter maximum temperatures during the years of investigation was responsible for the above growth of the Δt° and $\Delta\bar{t}^0$. There were no mild winters in the Adriatic area during that period, certainly not in 1912/13, on the contrary, the latter was the coldest winter of the entire period from 1911 to 1914, as follows from the study of Table 3 (Data on minimum temperatures — the absolute, and the average ones: column. 5 and 2)*) Low minima prevailing in the Adriatic waters during the whole of 1913 are due to that severe winter. It is evident, then, that the inflow into the Jabuka Pit of warmer water coming from the south — practically in 1912 and 1913 — was responsible for the increase of Δt° spans. This is in agreement with the previously established ingression of Mediterranean water of a higher salinity which occurred during the same period (B u l j a n, 1953) — a conclusion drawn from the examination of salinity fluctuations observed in the Adriatic.

It would be instructive in this connection to extend our survey for a while also to the absolute minimum and maximum temperatures found for the whole of the Adriatic during the winter cruises of both expeditions in the period between 1911 and 1914.

Table 5. *Absolute Minimum and Maximum Temperatures Found in the Adriatic as a Whole During the Winter Months 1911 — 1914.*

	$t^{0}{}_{m}$	$t^{0}{}_{M}$	Δt^{0} Span
1911	6.18	13.80	7.62
1912	6.60	15.60	9.00
1913	6.14	15.90	9.76
1914	4.10	16.19	12.09

In the Table 5 the spans are given between the maxima and minima of the recorded temperatures which occurred during the winter cruises. It is evident from the Table that the temperature span for the Adriatic as a whole grew larger toward 1914, not only as a consequence of the inflow warmer water from the south (increase of maxima), but also owing to severe colds prevailing in the Adriatic area, particularly in the North Adriatic during the winters 1912/13 and 1913/14 (decrease of minima).

The span between the absolute minima ($\Delta t^{\circ}m$), as resulting from Table 6, was rather insignificant:

Table 6. *Annual Spans of Minimum Temperatures Found in the Jabuka Pit Area During the Years of Investigations.*

	$\Delta t^{0}{}_{m}$
1911	0,41⁰
1912	0,20⁰
1913	0,15⁰

*) Compare also the temperatures found in the North Adriatic, e.g. the isotherms 9⁰, 10⁰ and 11⁰ in Graphs 5 and 6; the isotherms 9⁰, 10⁰, 11⁰ in Graphs 9 and 10.

A decrease of the Δt^0_M (span between the maximum temperatures) of this basin is encountered on the other hand (see Table 7) which may be taken as a sign of the declining continental character of the waters of this area.

Table 7. *Annual Spans of Maximum Temperatures Found in the Jabuka Pit Area.*

	Δt^0_M
1911	13,38⁰
1912	12,85⁰
1913	9,69⁰

Only further studies may reveal to what extent the decrease of the Δt^0_M is the result of growing currents in this basin during the years concerned or of some other factors too.

Table 8. *Limits of Variations of the $\Delta \bar{t}^0_m$ and $\Delta \bar{t}^0_M$ of the Water of Jabuka Pit Area.*

	$\Delta \bar{t}^0_m$	$\Delta \bar{t}^0_M$
1911	0,39	12,28
1912	0,06	11,60
1913	0,68	9,17
1911/14	0,79	12,59

The spans between the mean temperature minima ($\Delta \bar{t}^0_m$) and maxima ($\Delta \bar{t}^0_M$) in the Jabuka Pit area in a year's time are shown in Table 8. It is evident from the values in this Table that the variations of temperature maxima are by far more pronounced than those of temperature minima. This is characteristic for the behaviour of sea water temperatures in general. The variations of the mean temperature maxima in the Jabuka Pit area during the period of investigations manifest a downward trend of values, which is in agreement with what was said before.

By comparing the $\Delta \bar{t}^o$ variations with respect to the seasons of the year, we find that the lowest one occured in wintertime (below 1,79°) and the highest (up to 12,89°) in summer as evident from Table 9.

Similar seasonal variations of the Δt^o of absolute temperature values referring to this basin are given in Table 10, from which we find that the values are somewhat higher than those given in Table 9, amounting to less than 2,94° in winter and up to 14,82° in summer.

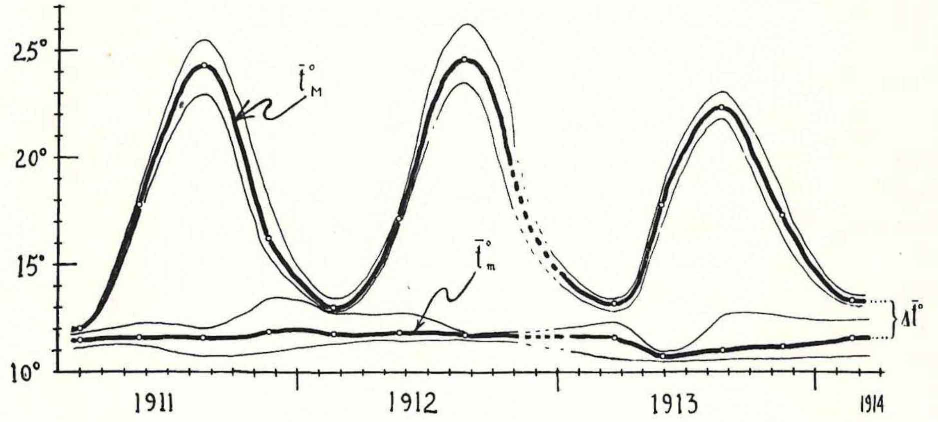
In spring and autumn, the spans between the temperature maxima and minima — taken both the absolute values and the mean values — are intermediate and approximatively of the same order of values.

Table 9. *Variations of Span Between the Mean Maximum and Minimum Temperatures Prevailing in the Jabuka Pit Area in Various Seasons.*

$$\bar{t}^0_M - \bar{t}^0_m = \Delta\bar{t}^0$$

	Winter	Spring	Summer	Autumn
1911	0,52	6,22	12,68	4,34
1912	1,53	5,34	12,89	—
1913	1,58	6,07	11,30	6,12
1914	1,79	—	—	—

The fluctuation of temperature minima and maxima in the Jabuka Pit area for the three year period is concisely shown in Graph 2, from which it is evident that, from 1911 on, the winter maxima were growing higher. The means of winter minima did not show any remarkable change except in the spring 1913, when the cooling took place as a result of the severe winter and of the amassing of cool water of North Adriatic origin at the bottom of the Jabuka Pit.



Figs. 2.

Fluctuation of temperature maxima (the upper bundle of curves) and minima (the lower bundle of curves) of the sea water in the Jabuka Pit area. Bolder curves represent the concerned mean temperatures ($\bar{t}^0_m$ and $\bar{t}^0_M$) found in a series of stations. Thinner curves on both sides of the intermediate curves represent individual extreme deviations of the temperature value. For the construction of the graph the »Najade« data deriving from the stations involving depths over 150 m were used. The parts of the curves lying in the intervals marked by blank dots have mostly been arbitrarily and schematically traced.

Table 10. *Variations of Span Between the Absolute extreme Temperatures Prevailing in the Jabuka Pit Area in Various Seasons.* (Δt^0).

$$t^0_M - t^0_m = \Delta t^0$$

1911	0,95	7,55	14,74	7,08
1912	2,17	6,03	14,82	—
1913	2,81	7,84	12,53	7,68
1914	2,94	—	—	—

TEMPERATURES FOUND IN THE SOUTH ADRIATIC PIT

The processed data for this area are shown in Table 11. The minimum absolute temperature for the period between March 1911 and February 1914 was found in February 1912 (12,47°C), and the maximum one fell in August 1911 (27,08°C).

Table 11. *Temperature Conditions Found in the South Adriatic Pit.*

1	2	3	4	5	6	7	8	9
	$\overline{t^0_m}$	$\overline{t^0_M}$	$\overline{\Delta t^0}$	t^0_m	t^0_M	Δt^0	$\overline{D_m}$ metres	$\overline{D_M}$ metres
III. 1911	12,83	13,14	0,41	12,78	13,21	0,43	2	650
V.	13,02	17,59	4,57	12,58	17,83	5,25	635	2
VIII.	13,06	25,50	12,44	12,55	27,08	14,53	539	3
XI.	12,56	16,34	3,78	12,54	16,73	4,19	1042	5
II. 1912	12,61	13,36	0,75	12,47	13,44	0,97	510	225
V.	12,66	17,77	5,11	12,59	18,38	5,79	993	0
VIII.	12,92	23,92	11,00	12,58	24,55	11,97	828	8
II. 1913	12,75	13,74	0,99	12,57	14,82	2,25	755	74
V.	12,66	17,77	5,11	12,59	18,38	5,79	993	0
VIII.	12,72	23,01	10,29	12,60	23,52	10,92	954	3
XI.	12,81	16,71	3,90	12,56	17,91	5,35	959	8
II. 1914	12,92	14,22	1,30	12,67	14,63	1,96	917	10

The mean temperature minima ($\overline{t^0_m}$) referring to individual cruises ranged between 12,56°C in November 1911 and 13,06°C in August 1911 (see column 2), so the span amounted to 0,50°C, being lower than the corresponding span value for the smaller Jabuka Pit area (0,79°C).

The values of absolute temperature minima (t^0_m) ranged between 12,47°C in February 1912 and 12,78°C in March 1911, the span amounting to 0,31°, being again lower than the corresponding value for the Jabuka Pit area (0,96°C).

The mean temperature maxima ($\overline{t^0_M}$) during the period of investigations ranged between 13,14°C in March 1911 and 25,50°C in August 1911, the span being 12,36°C. The corresponding value for the Jabuka Pit area resulted higher, i.e. 12,59°C.

The values of absolute temperature maxima (t^0_M) during the same period ranged between 13,21°C in March 1911 and 27,08°C in August 1911 (see column 6), with the resulting span of 13,87°C (14,19°C for the Jabuka Pit area).

During the 1911—1914 period an upward trend of the Δt^o and $\Delta \overline{t_0}$ can be observed in this basin too, as shown in Table 12.

Since the values of absolute temperature minima are marked by stability in this basin too (they vary mostly for 0,31° C), the constantly increasing spans in Table 12, as in the case of the Jabuka Pit area, can be explained by the inflow into the Adriatic basin of warmer water from the Mediterranean, which inflow grew more intense from 1911 on.

Table 12. *Showing the Growth of the Span Between the Extreme Temperatures (Absolute Values and Mean Values) in the South Adriatic Pit Area During the Winter Period. The Values are C°.*

	Δt^0	$\Delta \overline{t^0}$
1911	0,43	0,41
1912	0,97	0,75
1913	2,25	0,92
1914	1,96	1,30

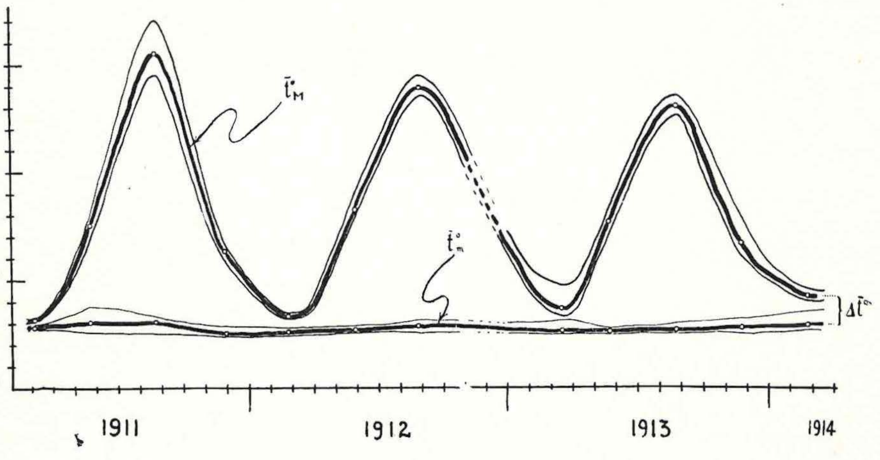
It is evident from Table 12 (Column 2) that the Adriatic basin was particularly exposed to warm water inflow in the winter 1913, while we can observe from Column 3 that the inflow of warmer water into the area continued also in the winter 1914.

The span between the absolute minima was dwindling here too, as in the case of the Jabuka Pit area (Table 13).

Table 13. *Span of Temperature Minima and Maxima (Absolute Values) in the South Adriatic Pit Area During the Period of Investigations.*

	Δt^0_m	Δt^0_M
1911	0,24°	13,87°
1912	0,11°	11,11°
1913	0,04	8,70

The spans between the temperature maxima are also decreasing in the area of this basin during the years of investigations (Table 13). This can be taken as an indication of the decline of »continental« properities of the basin owing to the current in it growing more intense, and perhaps to the meteorogical influences too. (It should be mentioned here that the water of this basin displayed a definitely higher salinity in the summer 1913 than in the summers 1911 and 1912 (Bulјan, 1953)). The fluctuation of extreme temperatures referring to this area and covering a period of four consecutive winters is shown in Graph 3.



Figs. 3.

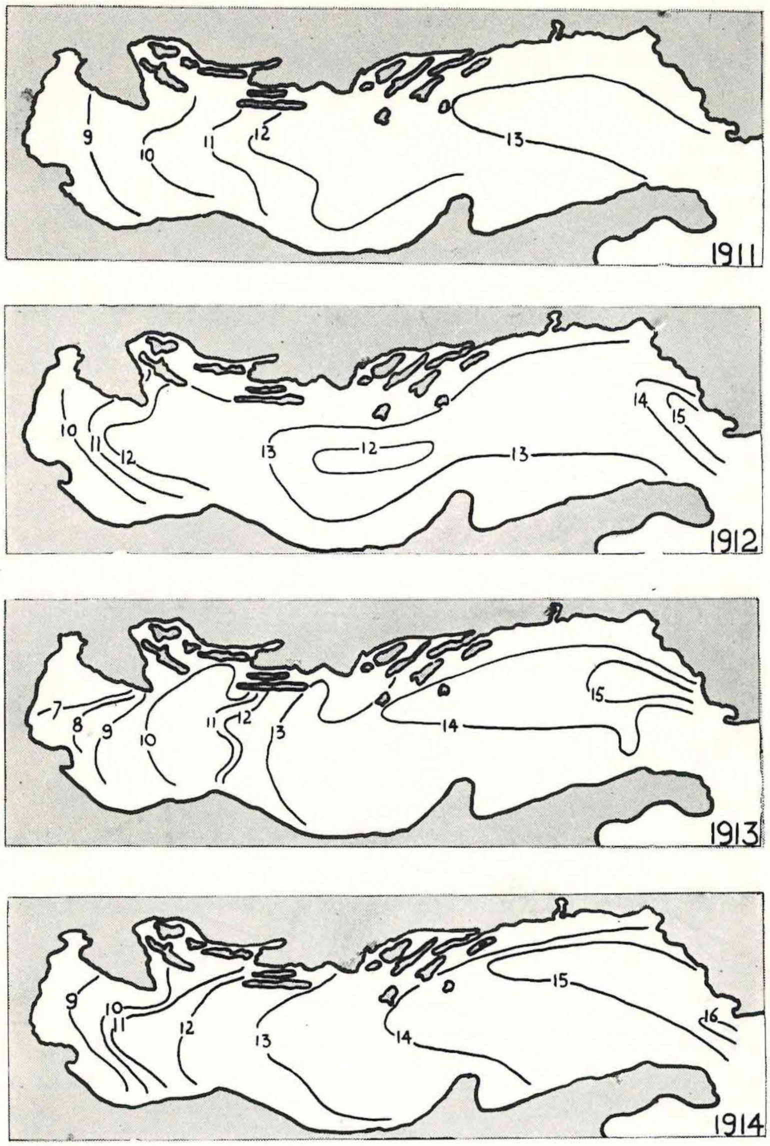
Fluctuation of temperature maxima (the upper bundle of curves) and minima (the lower bundle of curves) of the sea water in the South Adriatic Pit area over a series of years. Bolder curves represent the concerning mean temperatures ($\bar{t}^0_m$ and $\bar{t}^0_M$) for series of stations. Thinner curves on both sides of the intermediate curves represent individual extreme deviations of the temperature value. For the construction of the graph the data collected by the expeditions »Najade« and »Ciclope« stations involving depths over 600 m were used. The parts of the curve lying in the intervals marked by blank dots have been schematically and arbitrarily traced.

In order to sum up in a few lines the temperature characteristics of the two Adriatic basins, Table 15 is given here as it contains the most important data.

Table 14. *Temperature Characteristics of the Two Adriatic Pits For the Period Between 1911 and 1914.*

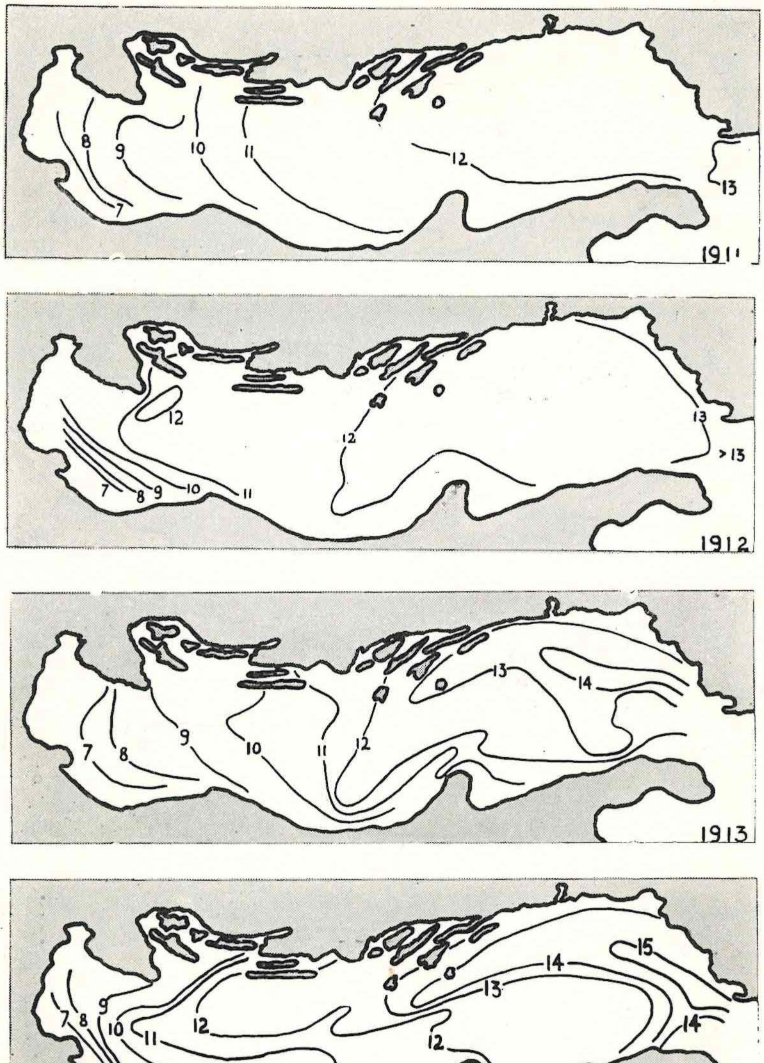
	$\Delta\bar{t}^0_m$	$\Delta\bar{t}^0_M$	Δt^0_m	Δt^0_M
Jabuka Pit	0,79	12,59	0,96	14,19
South Adriatic Pit	0,50	12,36	0,31	13,89

The above Tables show that the difference between the highest and the lowest absolute temperatures of the sea water during the three year-



Figs. 4, 5, 6, 7.

Maximum temperatures of sea water in the Adriatic area shown in a horizontal arrangement regardless of the level of their occurrence during the four successive winter seasons (1911 — 1914). It is evident from the graphs that the Adriatic waters were getting warmer during the period of investigations, particularly in the southern and middle part of the basin. The construction of the graph, basing on the data collected by the »N a j a d e« and »C i c l o p e« expeditions, comprised the data from all stations regardless of their depths. Note the southward push of isotherms from 9^0, 10^0 and 11^0 in 1913, compared with 1912, as a result of the severe winter in 1913.



Figs. 8, 9, 10, 11.

Minimum temperatures of sea water in the Adriatic area snown in a horizontal arrangement regardless of the level of their occurrence during the four successive winter sasons (1911 — 1914). It is evident from the graphs that the Adriatic waters were getting warmer during the period of investigations, particularly in the southern and middle part of the basin. The construction of the graphs, basing on the data collected by the »N a j a d e« and »C i c l o p e« expeditions, comprised all the stations regardless of their depths.

Note the southward push of isotherms from 9^0, 10^0, and 11^0 in 1913, compared with 1912, as a result of the severe winter in 1913.

long investigations amounted to 15,78°C for the Jabuka Pit area (table 2.), and 14,61°C for the South Adriatic Pit area (table 11.). It is evident, then, that this amplitude too, like the others exposed on preceding pages, shows a lower value in the larger and deeper South Adriatic Pit (depth 1330 m) than in the Jabuka Pit, which is considerably smaller in area and less deep (depth 265 m) than the former.

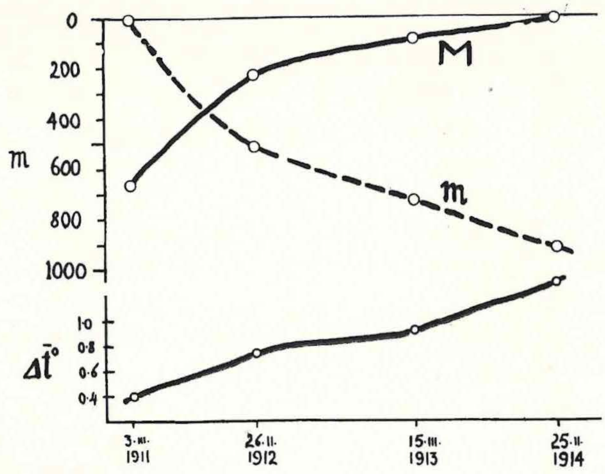
Finally, if both areas are taken together as an unbroken whole — the Adriatic Sea — but leaving the marginal strips apart as already suggested in the introductory part of the present paper — then the amplitude between the highest and the lowest temperatures found during the period of investigations amounted to 16,55°C.

Figures 4—7, showing the horizontal distribution of temperature maxima of the Adriatic waters regardless of the depth of layers where te maxima were found during the winter months from 1911 till 1914, offer additional evidence for the illustration of the growing inflow into the Adriatic of warmer water coming from the south during the period of investigations. They give a picture of fluctuation of the thermic regime in the Adriatic in general.

By showing the gradual growth of temperature minima in the Adriatic basin during the winter seasons from 1911 till 1914 (this being in good agreement with the contents of the present paper), the set of graphs Nos. 8—11 serves to the same purpose.

DISTRIBUTION OF EXTREME OF TEMPERATURES IN THE SOUTH ADRIATIC PIT IN RELATION TO DEPTH

The data brought out and processed in the present paper make it possible for us to disclose a phenomenon which seems to be characteristic for the Adriatic Sea. It consists in the shifting of the position of temperature maxima and minima in the water layers of the basin during the period of investigations, as the data given in Table 15 allow to conclude. (Fig. 12.). The layers where the temperature minima were found during the winter vertical stirring of layers in 1911, were situated at the very surface, but they descended deeper and deeper in each of the following three winters (Fig. 13, 14, 15, 16). The layers where the temperature maxima were found in the winter 1911, were mostly situated, on the contrary, in the depths of the basin (Fig. 17, 18, 19, 20), but they rose higher and higher toward the surface during the succeeding winters, to reach the very surface in the winter 1914. As evident from Fig. 12, the



Figs. 12.

Temperature conditions in the South Adriatic Pit area during the winter seasons from 1911 till 1914.

a) The upper graph. Contrary shifting of sea water layers wherein the maximum (M) and minimum (m) temperatures were found in winter.

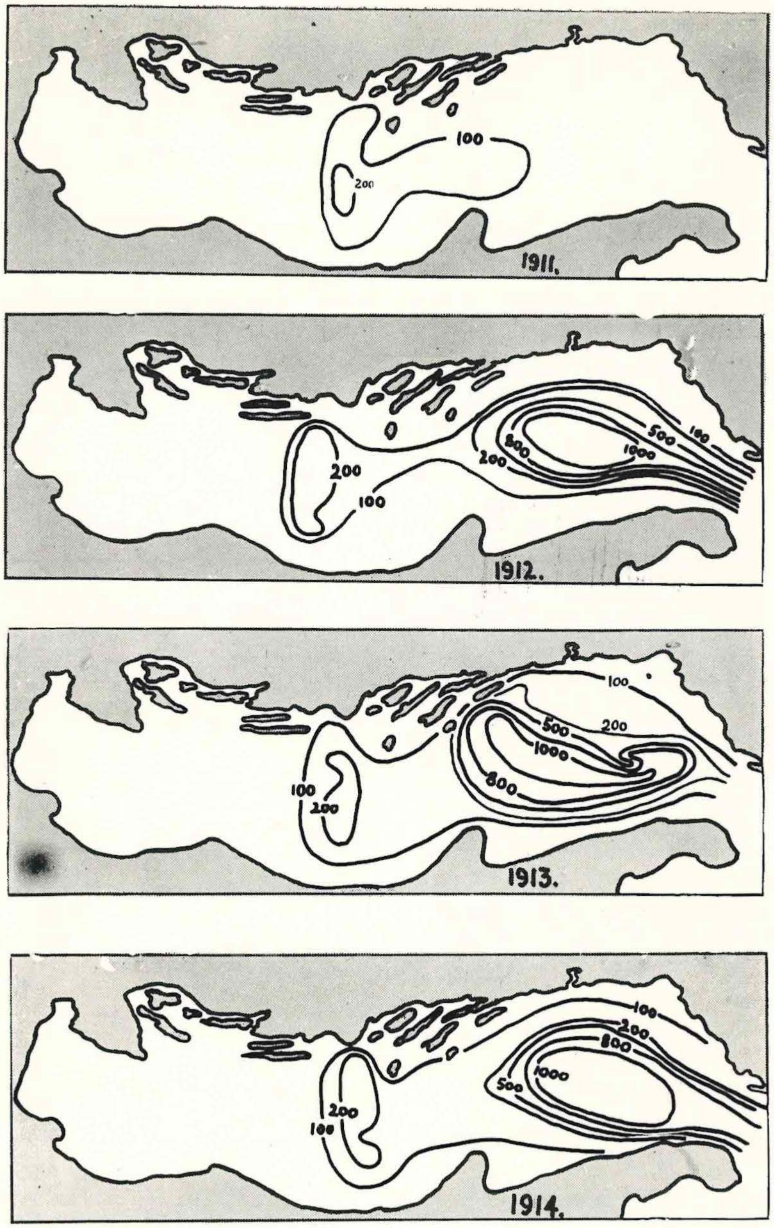
b) The lower graph. Increase of the temperature span of the water in the Pit area. It is evident therefrom that the rise of this curve is followed by the shifting of layers with the maximum temperature toward the surface. The action of convective vertical displacements of water is manifest on the left hand side of the above graphs, while the impact of advective water displacements is displayed on the right hand side. Since the graph aims at illustrating the conditions prevailing in wintertime only, the data referring to other seasons have intentionally been neglected.

phenomenon goes hand in hand with the increase of the span between the mean values of temperature maxima and minima ($\triangle \bar{t}^o$). (See Table 15). This gradual descending of layers where the temperature minima were situated in the winters 1911—1914, occurred also in the Jabuka Pit area, although not in so pronounced a way as it was the case with the South Adriatic Pit area.

The 1911—1914 minimum temperatures of the sea water in the Jabuka Pit area were always found in the deeper layers of the basin,

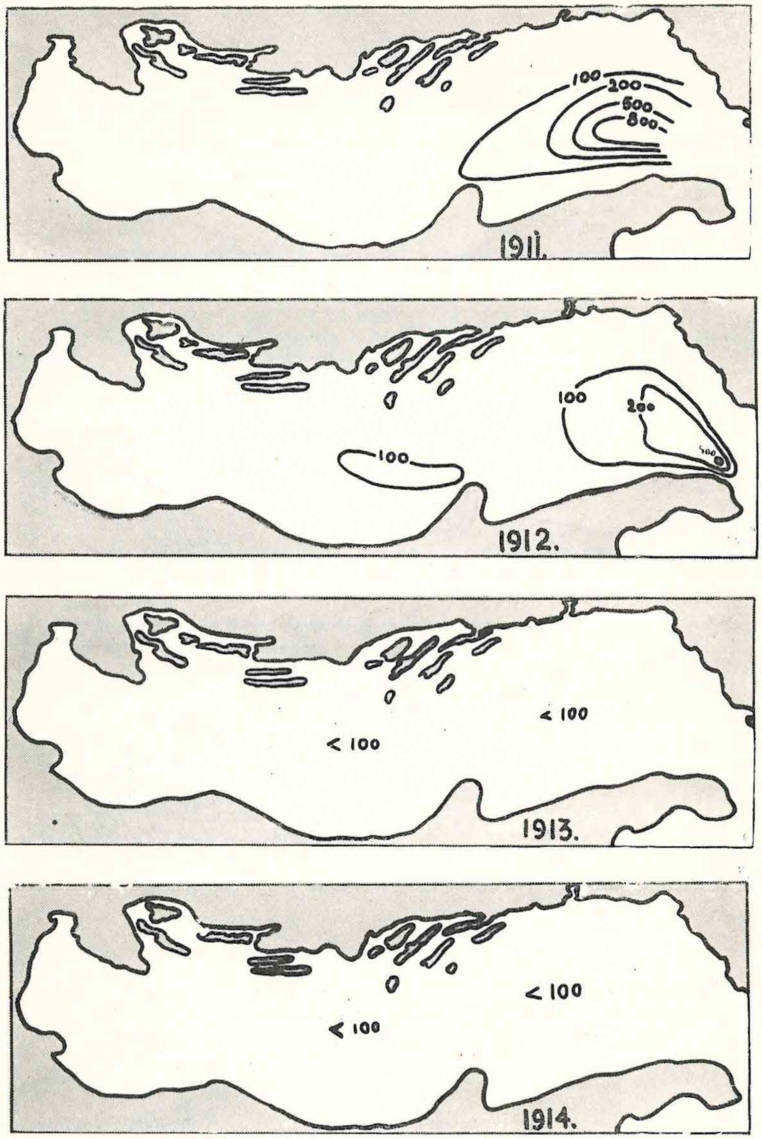
Table 15. *Distributions of Layers According to Depths Where the Temperature Minima and Maxima Were Found in the South Adriatic Pit Area During the Winter Seasons.*

	Average Depth (m)		
	$\bar{D}_m$	$\bar{D}_M$	$\triangle \bar{t}^0$
1911	2	650	0,41
1912	510	225	0,75
1913	727	84	0,92
1914	917	10	1,30



Figs. 13, 14, 15, 16.

Distribution of isobaths with regard to the position of water temperature minima in the areas of the two Adriatic Pits during the winter seasons 1911 — 1914. The advective current in the deeper layers of cooler water bodies coming from the North Adriatic, caused the layers with the temperature minima to descend after 1911.



Figs. 17, 18, 19, 20.

Distribution of isobaths with regard to the position of water temperature maxima in the areas of the two Adriatic Pits during the winter seasons 1911 — 1914. The warmest layers are seen rising toward the surface during the four successive winters. This occurrence was recorded in spite of the fact that the winter 1912/13 had been the coolest winter season in the Adriatic area during the period of investigations. It looks like that the rising of warmest layers takes place under the influence of advective currents in the upper layers of warmer water bodies coming from the south.

lying between 150 and 217 m, while the maximum ones occurred in layers lying closer to thé surface, between 0 and 24 m. The actual depths, however, were distributed over a wider range. The layer with the minimum temperature tended to descend deeper and deeper all the time from 1911 on (see Table 3, column 8).

In the area of the Southern open Adriatic, the water layers where the maximum temperatures occurred, occupied a deep position in the winters 1911 and 1912, and the temperatures never went beyond the 13,5°C level, while in the winters 1913 and 1914 some of the absolute temperature maxima kept above the 14,6°C level and were situated near the surface.

This rising of layers where the temperature maxima were found was, in the author's opinion, connected with the advective inflow of warmer water from the south which was more pronounced during the winter 1912 and onward (especially in the winter 1913) than in the winter 1911. The higher temperature of the inflowing water caused the water density to decrease and made such water keep to the surface layers in spite of surface cooling as a result of winter in general and particularly of the winter 1912/13, recorded as severe above average in the Adriatic area.

In 1912 and the succeeding years, in the same way, the water layers where the minimum temperatures were found, occupied the deepest positions, not owing to convective (vertical) water displacements in winter (as proved by the fact that the warmer water was situated in the upper layers), but as consequence of an advective inflow of cold water from the North Adriatic in quantities considerably larger than during some other years, e.g. in the winter 1911.

The convective (vertical) displacement of water, caused by the process of cooling on the spot is a normal occurrence in the Adriatic in winter. The data given in this paper disclose that the advective (horizontal) displacements of water bodies start to be more and more pronounced during the periods of ingressions in the Adriatic. These displacements include both cold water coming from the NorthAdriatic area along the bottom and warmer water from the Ionian Sea flowing nordwards in the surface layers.

The peculiarity of the presence of warmer waters in the subsurface layers and the most intensively cooled water bodies in the depths of the Adriatic Pit d u r i n g t h e w i n t e r s e a s o n could be considered one of the indicators of the occurrence of the ingression period in the Adriatic.

SUMMARY

Condensed data on temperature fluctuation in the Adriatic area during the period extending from 1911 till 1914 are given in the present paper.

It folows from the survey that warmer bodies of water coming from the Mediterranean were flowing into the Adriatic at an increasing rate during the mentioned period which caused a gradual rising of winter temperature of the Adriatic waters in the open areas, in spite of the very severe winter recorded in the Adriatic area in 1912/1913.

This occurrence is in good agreement with the Adriatic ingressions which phenomenon was earlier found by the same author while processing the data on salinity fluctuation in the same area, particularly for the period from 1912 till 1914 (Buljan, 1953). The Adriatic ingression is the phenomenon consisting in the rising of salinity of the Adriatic water because of a growing inflow of Mediterranean water into the Adriatic basin.

As shown by the data given in the present paper, the amplitude of annual temperature fluctuation of the waters of the open Adriatic — including both the South Adriatic Pit and the Jabuka Pit — dwindles when ingressions make their appearance.

The conclusion can also be drawn now that temperature of the waters of the open and middle Adriatic areas is increasing during the ingression periods.

It has been established that the amplitudes of variations — both of average and absolute temperatures, and both of minimum and maximum ones — reach higher values in the Jabuka Pit area than in the South Adriatic Pit area. The span between the absolute temperature minima and maxima found in the Jabuka Pit area over a series of years amounted to 15,78°C, while it did not go beyond 14,61°C in the South Adriatic Pit area.

By pooling of data on the two areas, we find that the common span between the absolute temperature maxima and minima over a series of years reached 16,55°C.

There is also another phenomenom established by the author, namely that whenever the inflow of Mediterranean water into the Adriatic grows more intense, i.e. with the occurrence of ingressions, the layers where

the temperature maxima are found in winter are situated at the sea surface whereas such layers tend to descend whenever the influence of the Mediterranean waters upon the Adriatic basin lessens.

The sea water layers where the minimum temperature is found in winter shows the opposite behaviour.

The opinion has been expressed that the vertical convective thermohaline displacements of water bodies normally play an important part in the Adriatic area during the winter season. It seems, however, that the importance of the advective displacements of water bodies is increasing during the periods of ingression in winter in the Adriatic Sea, not only as regards the surface layers, but with respect to the deeper layers of this basin as well.

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KOLEBANJE TEMPERATURE VODE OTVORENOG JADRANA

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Kratak sadržaj

U radu su izneseni sažeti podaci o kolebanju temperatura u Jadranskom moru u toku godina 1911.—1914.

Iz pregleda izlazi, da je u toku tog razdoblja u Jadran ulazila toplija voda iz Mediterana u sve znatnijoj mjeri, što je izazvalo postepeni porast zimskih temperatura ovog mora u otvorenim područjima, nekada usprkos veoma hladnih zima kao na pr. 1912./1913. god. koja je vladala nad Jadranskim područjem, posebno u Sjevernom Jadranu.

To je u skladu sa pojavom Jadranskih ingresija, čije je postojanje autor ranije utvrdio na temelju proučavanja podataka saliniteta za ovo more, posebno za razdoblje 1912.—1914. (Buljan, 1953.).

Doba ingresija je razdoblje pojačanog ulijevanja Mediteranske vode u Jadranski bazen, čime se povisuje slanost Jadranskog mora.

Kako to proizlazi iz podataka, koji se donose u ovom radu u to doba se također smanjuje amplituda godišnjih kolebanja temperature mora u otvorenom dijelu Jadrana, tako u južnoj kotlini, tako i u Jabučkoj kotlini.

Isto tako se sada može izvesti zaključak, da se u doba ingresije vrši i ugrijavanje vode otvorenoga Južnog i Srednjeg Jadrana.

Utvrđeno je, da su amplitude oscilacija kako prosječnih tako i apsolutnih, minimalnih kao i maksimalnih temperatura u Jabučkoj kotlini više od onih u Južnoj Jadranskoj kotlini. Razlike između apsolutnih minima i maksima temperature nađenih u pojedinom bazenu kao cijelini u toku višegodišnjih mjerenja su bile utvrđene: 15,78° za Jabučku kotlinu i 14,61° za Južnu Jadransku kotlinu. Uzevši obje kotline skupa otvoreni Jadran je u toku nekoliko godina pokazao razliku između apsolutnih maksimalnih i minimalnih temperatura od 16,55°.

Nadalje je utvrđena pojava da se u doba jačeg strujanja Mediteranske vode u Jadran, dakle u doba ingresije, smještaj slojeva sa maksi-

malnom temperaturom u zimskom razdoblju nalazi uz površinu mora, a u doba oslabljenog upliva Mediterana na Jadran sloj sa maksimalnom temperaturom se spušta u dubinu. Sloj sa minimalnom temperaturom u moru, također u zimskom razdoblju, ponaša se obrnuto.

Izneseno je mišljenje da u Jadranskom moru normalno zimi igraju znatnu ulogu vertikalni konvekcijski termohalini pokreti vodenih masa. U doba ingresije čini se, dobivaju posebno značenje advektivna pokretanja vodenih masa, kako u površinskim, tako i u dubinskim nivoima ovoga mora.

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