SEASONAL VARIATIONS IN THE SURFACE TEMPERATURE OF SEA-WATER AT MANDAPAM FROM JANUARY 1950 TO DECEMBER 1954

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Introduction

The information we have at present on the seasonal variations in the surface temperature of the sea-water around India, both offshore and coastal, is based mostly on short-term observations made in a few areas. There are, however, a few records of continuous long-time observations from certain regions. The data available, up to the end of the first quarter of this century, on surface temperature variations in Indian waters, both coastal and open ocean, have been incorporated in the work of Sewell (1928 and 1929) who himself has made extensive observations on the seasonal variations of surface temperatures. Some general data on the surface temperature conditions of coastal waters at restricted places along the coasts of India are also found in literature *q.v.*, Chidambaram and Menon (1945), Bal, Pradhan and Gupte (1946), George (1953) and Ramamurthy (1953). With the exception of the observations made at Calicut by Chidambaram and Menon (1945), which cover a period of five years, 1938–1942, and by George (1953) for about three years, from November 1948 to April 1951, the others are restricted to relatively short periods. Recently Chacko, Valsan and Malu Pillai (1954) have given an account of the meteorology and hydrography of the Kundugal Gut in the Gulf of Mannar which is approximately four and a half miles east of the place where the present observations have been made. Their observations relate to the period 1949 to 1952. Ganapati and Murthy (1954) have made observations on the temperature variations of the surface waters off Visakhapatanam Coast during October 1952 to March 1953.

At the Central Marine Fisheries Research Station, Mandapam Camp, regular records of the surface temperature have been maintained since January 1950. These data are gathered near the shore, on the Gulf of Mannar side, just outside the station, where readings are taken every morning at about 6 o'clock. As these temperatures are taken at a place where the sea-water is subject to vicissitudes of land heating and cooling, they are, at least in part, undoubtedly more extreme than those gathered at some distance from the shore. However, the main purpose of this study is to determine

the yearly and seasonal variations and fluctuations and to determine the thermal rhythm and long-time periodicities, if any. In addition an attempt is also made to study the possible relationship between the atmospheric and surface water temperatures.

The value of this type of work will be easily understood when we consider the fact that the seasonal as well as the general distribution, migration and relative abundance of organisms in the sea are to a very large extent regulated by temperature variations. Therefore, not only the mean temperatures of the various seasons are important but also the extremes.

Surface Temperature

The monthly average surface temperatures for the years 1950–1954 are shown in Fig. 1. We find from this that the average temperature was invariably low at the beginning of each calendar year and was at its lowest in January 1950, 1951 and 1952. In 1953 and 1954 the lowest was in December. The temperature steadily increased from this low level up to April when the highest mean temperature was reached. Following the summer maximum, the average temperature recorded a decrease in June or July but again showed a slight increase in July or August resulting in a secondary maximum in August, September or October. The temperature at the time of the secondary maximum was often, however, appreciably below that of the primary or summer maximum. An exception to this was noticed in 1951 when the mean monthly surface temperatures at the time of the primary and secondary maxima (April and September respectively) very closely approximated (Fig. 1). During June to November the average generally fluctuated around 27·0° C. and 28·5° C. By November the temperature registered a fall and a sharp decline was recorded in December. It is interesting to note, as will be seen from Fig. 1, that the annual temperature history apparently repeats itself on the same general pattern every year, at least this is true for the five years covered by this investigation.

The highest average surface temperature of 30·06° C. was recorded in 1953 and the lowest of 24·32° C. in January 1950. During the period of five years, 1950–1954, the lowest temperature of 23·50° C. was recorded twice, on January 2 and 16, 1950 and the highest, 32·30° C., on May 9, 1951. Chacko *et al.* (1954) recorded the highest surface temperature of 31° C. in May 1949 and the lowest, 24·1° C. in January 1951. The range in temperature varied considerably from month to month and also during the same month from year to year. The maximum difference, so far recorded, within a month was 4·8° C. in May 1951 and November 1952, and the minimum difference of 1·5° C. in January and June, 1950. Similarly, the difference

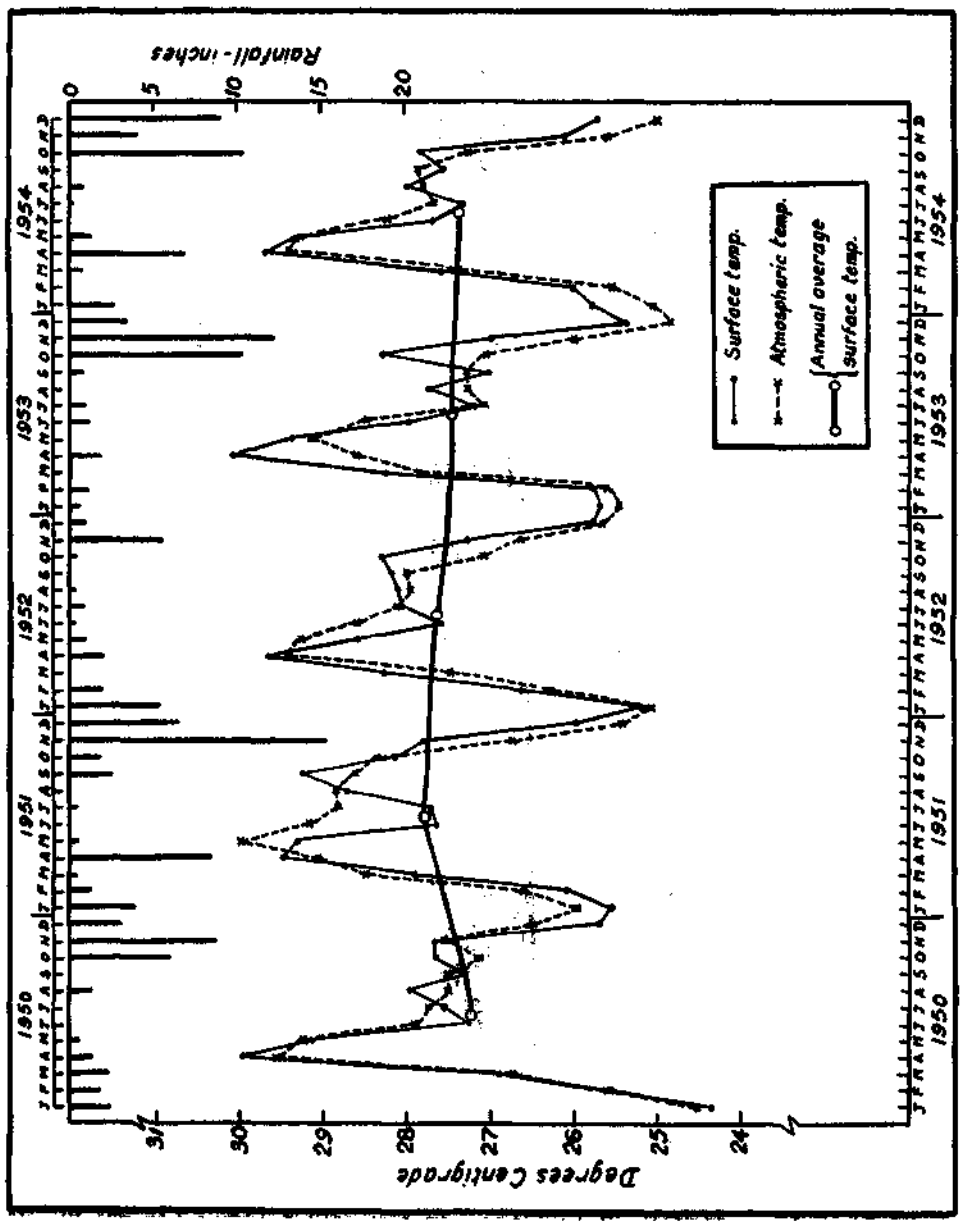

FIG. 1 showing the mean monthly surface and atmospheric temperatures, mean annual surface temperature and rainfall (represented by bars at the top of the figure).

between the highest and lowest temperatures varied from year to year. Thus, for 1950, 1951, 1952, 1953 and 1954 the respective values were 6·8° C., 7·9° C., 6·2° C., 6·5° C. and 6·8° C., the greatest difference being in 1951 (Table I). The difference between the highest and lowest temperatures recorded during the course of the entire five-year period was, however, 8·8° C.

TABLE I

Maximum and minimum temperatures (°C.) recorded during the period January 1950 to December 1954

Month	1950		1951		1952		1953		1954	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
January ..	25·0	23·5	26·8	24·6	26·2	24·5	26·8	24·5	27·0	24·0
February ..	27·5	24·5	27·3	25·3	27·4	25·2	27·5	24·5	28·8	24·5
March ..	28·4	25·5	30·0	26·4	30·0	27·0	29·4	27·2	29·5	25·0
April ..	30·3	28·5	30·6	28·0	30·7	28·2	31·0	28·4	30·8	28·0
May ..	30·3	26·5	32·3	27·5	30·2	26·5	30·5	28·0	30·8	28·2
June ..	27·9	26·4	29·8	26·4	28·7	27·0	29·8	26·0	29·0	26·8
July ..	28·5	25·3	29·6	25·5	30·0	26·4	29·0	25·3	29·0	25·7
August ..	29·6	26·8	30·5	26·4	29·2	26·5	30·0	26·0	30·0	25·5
September ..	29·5	25·8	30·3	26·9	29·5	27·0	29·6	26·5	29·0	26·5
October ..	28·7	26·2	29·5	26·8	29·8	26·4	29·6	27·0	29·2	26·0
November ..	29·1	25·5	29·8	26·4	29·8	25·0	28·8	25·1	28·0	25·0
December ..	26·7	25·0	28·0	24·4	26·8	25·0	26·1	24·5	27·5	24·0

The annual range in the mean monthly temperatures was highest, 5·63° C. in 1950 and lowest, 3·95° C. in 1951. The ranges were 4·43° C., 4·75° C. and 3·97° C. in 1952, 1953 and 1954 respectively. The range in the entire five-year period was 5·74° C. According to Sewell (1929) the annual range in the monthly mean temperature in the Gulf of Mannar is 3·42° C. but in the shallower waters the range is slightly greater, 3·9° C. He remarks: " In computing the average for the Gulf of Mannar I have made use of only

those observations that were taken by Pearson in deep water of over 100 fathoms; in this series at the commencement of the year the temperature is low, being 26·06° C. in January; it then steadily rises to 29·03° C. in April, but at the commencement of the south-west monsoon the temperature falls till it is as low as 25·61° C. in June, after which it again rises to 27·50° C. in November and finally falls again till January." Although in the locality under consideration a fall in temperature was noticed in June or July, the mean monthly temperature during this period was never observed to be the lowest as mentioned by Sewell (1929) for the Gulf of Mannar. The lowest temperatures were recorded always in December or January and further, the annual range in the monthly mean temperature observed in the present instance was also distinctly higher than that reported by Sewell (1929). This, as already mentioned earlier in this paper, might be due to the fact that the data were collected at a place by the shore where the temperature of the water might be affected to a large extent by land heating and cooling resulting in somewhat higher and lower values.

The deviations of average surface temperature in each month during the period 1950 to 1954 from the ' normal ' as represented by the total monthly averages during the five-year period is shown in Fig. 2. We find from this the interesting feature that the averages were neither entirely above nor entirely below the normal in any of the years but relatively warm and cold periods often alternated in a somewhat irregular manner. Thus, in 1950 except in April, November and December the averages were below normal, whereas in 1951 the values were above normal throughout. In the subsequent three years, 1952 to 1954, values below normal showed a gradual increase. In 1952 the averages were below normal in three months (April, May and June), in 1953 during six months (February, July to September, November and December) and finally in 1954 but for four months, January, May, June and December, the averages were below normal. Further, it will be noticed that there was a comparatively long warm period extending from November 1950 to December 1951 and after a few months a similar long spell of warm period was recorded. This was, however, only for seven months, from July 1952 to January 1953 when the averages were above normal (Fig. 2). Thus, during these five years we find that continuous periods of below normal averages were relatively short, not exceeding six months, compared to those of above normal averages and the magnitude of deviation was also greater in the positive direction (+ 1·38° C.) than in the negative side (— 1·07° C.).

The variations in the average yearly temperatures are shown in Fig. 1 by the smooth curve, the values being 27·23° C., 27·79° C., 27·61° C.,

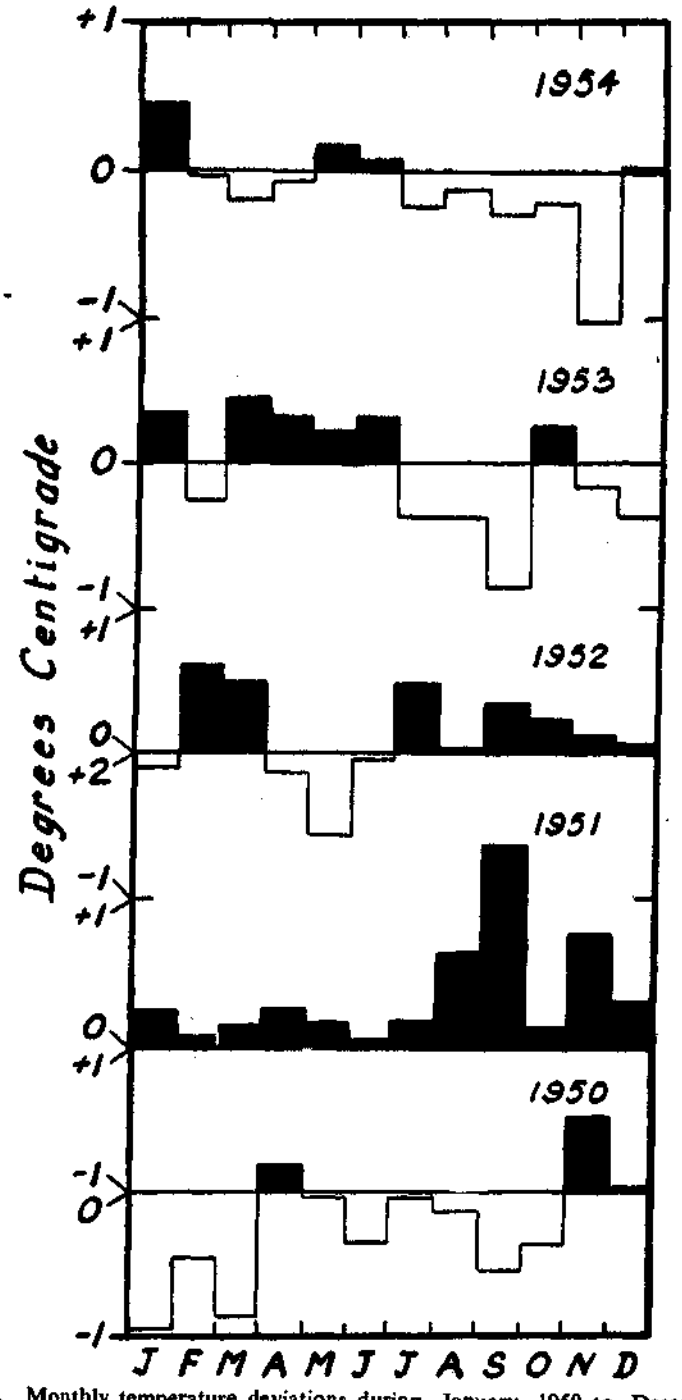

FIG. 2. Monthly temperature deviations during January 1950 to December 1954 from the 'normal' as represented by the total monthly averages during the period 1950–54.

27·44° C. and 27·36° C. for 1950, 1951, 1952, 1953 and 1954 respectively. From these values it will be seen that 1951 was relatively the warmest and 1950 the coolest years during the interval 1950–54. The variations, however, are only slight.

The surface temperature conditions of this locality may be said to show a double oscillation during the course of a year which is characteristic of many places in the seas around India. This, at least in the case of open waters, has been attributed to the influence of atmospheric temperature which over open waters of the Indian seas exhibits a double oscillation in the course of the year. Thus, Sewell (1929) has remarked in the case of surface waters of the Bay of Bengal and Andaman Sea that: "As I have already pointed out.... the air temperature over the open waters of the Indian seas exhibits a clear double oscillation in the course of the year, there being two maxima, one in April and the other in September-October, corresponding to the two dry hot seasons, and two minima during the periods of south-west and north-east monsoons respectively. One would naturally expect to find that the temperature of the surface water follows the same or at least a similar course and also exhibits a double oscillation, and all the available evidence shows clearly that this is actually the case." He also remarks that an exactly similar double oscillation during the course of the year is clearly evident in the temperature observations made by Pearson in the Gulf of Mannar off Ceylon. A similar double oscillation has been recorded by Chidambaram and Menon (1945) off West Hill, Calicut and is evident from the data given by Ramamurthy (1953) for the Madras Coast. The former authors have remarked that: "The lowering of temperature during the months of June, July and August is due to the rains that break with the south-west monsoon and to the consequent reduction in the number of hours of sunshine." Chacko *et al.* (1954) have noticed that the surface temperature in the Kundugal Gut showed a weak bimodal oscillation, the maximum being in April-May and the minimum in December-January. They have also noticed a tendency for the temperature to increase in September-October.

In the locality under consideration it was noticed that the lowest temperatures were always recorded soon after the north-east monsoon (Fig. 1),* which is the rain-bearing monsoon of this area, had reached its maximum. The appreciable reduction during this period, November to January, may be due primarily to two causes: (1) the effect of rains and the influx of rain-

* The data on rainfall are based on those collected at Pamban and published by the Regional Meteorological Department, Madras, in their "Regional Daily Weather Reports".

water as evidenced by the lowering of salinity, and (2) incidence of the cold season when the sun is at its maximum southerly declination and the effects of solar radiation at its minimum because of the many cloudy and rainy days. The relatively slight fall in the surface temperature (about 1·8° C. to 2·8° C. depending on the year) during June-July coincides with the period of south-west monsoon. Although there is no appreciable rainfall at the time of this monsoon, the strong winds prevailing during this period create turbulent conditions which prevent the stabilization of surface water and its consequent heating up by insolation and cause rapid evaporation which reduces the surface temperature.

From the data extending over a period of five years the general pattern of temperature conditions may be described as follows: At the beginning of the year the temperature is low, it then steadily rises until it reaches a maximum in April. By June-July the temperature falls, the drop varying from year to year but is usually between 1·8° C. and 2·8° C. Immediately after this drop the temperature rises again and finally starts declining in November and by December it almost reaches the same level as that of January. Figure 3 which is based on the 'normal' temperature as represented by the total monthly averages for the entire period 1950–54 shows the general pattern of temperature conditions.

In the classification of thermal conditions of particular areas for biological purposes Parr (1933) has suggested four different categories in preference to the conventional terminology differentiating only two categories of temperature conditions. According to his classification the present locality may be classified, because of its relative stability and almost uniform conditions, as homostenothermal, *i.e.*, a region of greatest stability where the regular difference between the seasonal temperature levels as well as the irregular fluctuations around the seasonal trends of the temperature curve are slight. This quadruple classification of temperature conditions, however, describes only conditions within a year and, therefore, the same author has proposed two more terms for the designation of secular stability or instability of temperatures for periods longer than a year. Based on the data available at present the temperature conditions in this locality may be classified as monimothermal, *i.e.*, temperature conditions remaining relatively constant from year to year, as against reothermal where the temperature conditions show great variations from year to year, whether of a periodic or non-periodic character.

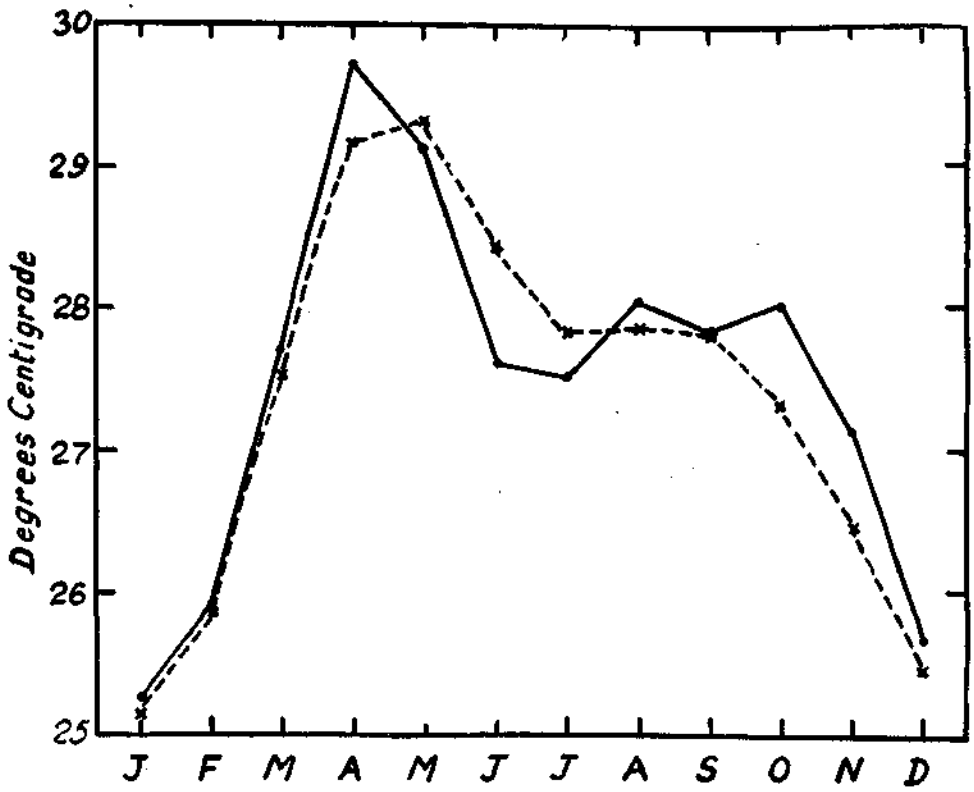

FIG. 3. Showing the general trend of surface and atmospheric temperatures based on the total monthly averages for 1950–54. Continuous and broken lines represent surface and atmospheric temperatures respectively.

RELATIONSHIP BETWEEN THE ATMOSPHERIC AND SURFACE TEMPERATURES

The atmospheric temperature was also recorded every morning at 6 o'clock along with the surface temperature readings. The variations in the monthly average atmospheric temperatures are shown in Fig. 1. We find that the curves for atmospheric and surface temperatures show very close similarities and except in twentythree months the mean monthly atmospheric temperature was below that of the surface waters (Table II). Further, while in all the five years the highest monthly mean surface temperatures were in the monthly average atmospheric temperatures were highest in April in 1950, April, 1952 and 1954 and in May in 1951 and 1953. Only continued observations for a number of years will establish whether this phenomenon of regular alternation is a characteristic of the thermal conditions of this area.†

† The year 1955, it has been noticed, has not been an exception to this case and, therefore, as is to be expected the mean monthly atmospheric temperature was higher in May (28·84° C.) than in April (28·48° C.).

TABLE II

Deviations of the monthly mean atmospheric temperature from the mean monthly surface temperature

Month	1950	1951	1952	1953	1954
January ..	+0·18	+1·27	−0·11	−0·24	−0·75
February ..	+0·02	+0·53	−0·36	−0·14	−0·45
March ..	−0·19	+0·57	−0·79	−0·36	−0·21
April ..	−0·40	−0·41	−0·19	−1·47	−0·29
May ..	+0·11	+0·62	+0·68	−0·23	−0·08
June ..	+0·63	+1·52	+0·99	+0·53	+0·51
July ..	+0·23	+1·08	+0·07	−0·13	+0·32
August ..	−0·41	+0·13	−0·15	−0·46	−0·17
September ..	+0·24	−0·61	−0·20	+0·28	+0·28
October ..	−0·55	+0·19	−1·19	−1·26	−0·60
November ..	−0·12	−1·10	−0·65	−0·98	−0·51
December ..	+0·80	−0·56	−0·09	−0·53	−0·77

The average atmospheric temperatures were above the mean surface temperatures mostly in the months of May, June and July. This was true in June in all the five years. They were above the mean surface temperatures in eight months in 1951, whereas in 1953 it was below for ten months. The longest continuous period when the atmospheric temperature was below the surface temperature was for ten months, from August 1952 to May 1953. Again there was a period of eight months from October 1953 to May 1954 when a similar situation existed. The atmospheric temperature was, however, never above the surface temperature continuously for more than four months. The range of deviation, both above and below, from the surface temperatures was almost similar, + 1·52° C. and − 1·47° C. The nature of relationship between the average atmospheric and surface temperatures, as can be seen from Table II, often varies considerably from

year to year and the available data do not suggest any definite pattern for these variations.

During the course of the five years, 1950–54, the greatest difference between the atmospheric and surface temperatures was observed twice, once on November 30, 1950 when the atmospheric temperature was 4·0° C. above the surface temperature, and then on April 20, 1953 when the former was 4·5° C. below the latter. The general trend in the atmospheric temperature, as represented by the averages for the five years, is shown in Fig. 3.

The surface temperature at the place where the present observations are made follow very closely the atmospheric temperature and it is quite reasonable to expect that it may considerably be influenced by the atmospheric temperature. But it will be noticed that such is not the case always. Thus, the fall in surface temperature recorded in June or July cannot be attributed to the effect of atmospheric temperature since during these months the atmospheric temperature has been, on the whole almost always, above the surface temperature (Figs. 1 and 3). This fact lends additional support to the suggestion made earlier in this paper that the observed decrease in the surface temperature in June-July is due (1) to the strong winds associated with the south-west monsoon causing turbulent conditions which prevent stabilization of the surface waters and consequent rise in temperature due to insolation, and (2) rapid evaporation resulting in the cooling of the surface waters.

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