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MEASUREMENTS OF SEA SURFACE TEMPERATURE FOR METEOROLOGICAL PURPOSES. RESULTS OF OBSERVATIONS FROM OCEAN WEATHER STATION M.

BY

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I. Introduction.

The temperature of the sea surface is of immediate interest to the daily forecaster in his dealings with the thermal interaction between the sea surface and the air. The theory of air masses, according to its relative classification, divides them in warm and cold masses, each with its characteristic weather. If we were interested only in the general level of temperature it would make little difference whether the sea were, say 7° or 8° C at a particular place and time. But, since we are interested in the relative sea vs. air temperature we want to know whether the water surface is colder or warmer than the air by even a small amount.

The Conference of Directors of the International Meteorological Organization (now World Meteorological Organization) voted in 1947 that:

> «In order to encourage accurate observing, the Conference recommends that sea and air temperatures should be read to 0.2°F or 0.1°C.»

To attain the required accuracy we must first get a sample representative of the sea surface, and then obtain its temperature. What is wanted is the temperature of the actual surface, that is in direct contact with the atmosphere. It is usually stated that when the surface is turbulent with breaking waves, any sample from the top 5 m or so will have essentially the same temperature. It is when the wind is insufficient to produce turbulence that a thermal stratification may occur. In the tropics and subtropics vertical gradients have the best chance to develop, owing to the intense sunshine and extended periods with little wind.

The present paper deals with observations from Ocean Weather Station M at 66°N 02°E, M/S «Polarfront I» and M/S «Polarfront II». In this latitude, near the arctic circle, the insolation is negligible in winter. In summer it may become important because of the long duration of insolation; compare the diagram Fig. 1, where the times of sunrise and sunset are calculated for the position 66°N 02°E.

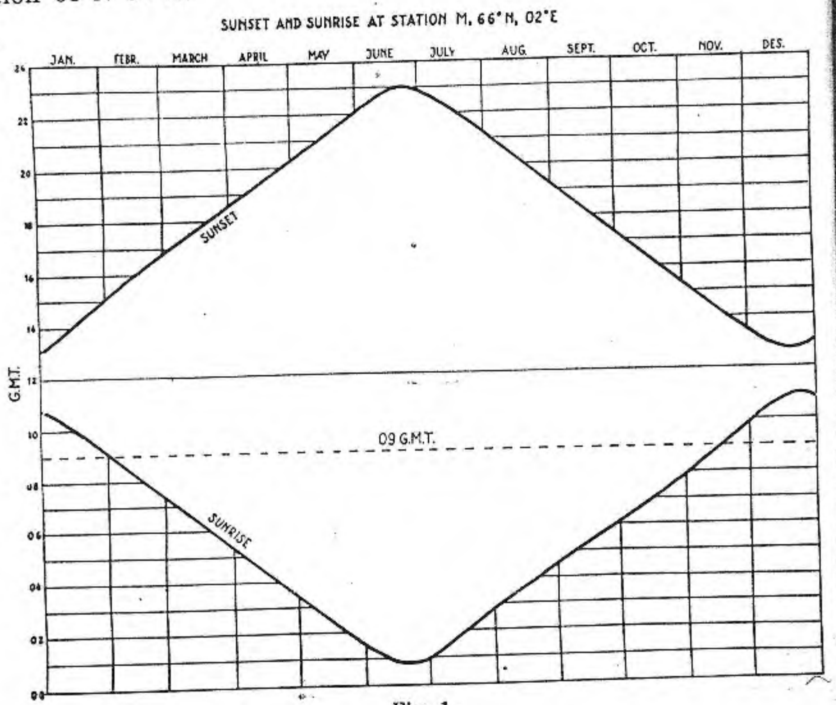

Fig. 1.

II. Measurements of Sea Surface and Intake Temperatures at Station M.

In order to compare the measurements of sea surface temperature obtained by the bucket method vs. reading of the sea thermograph (the intake method), special observations were made at Station M from February 1952 to January 1953. Measurements were made, when possible, every day at 09 GMT, and the following data were obtained:

1. The temperature of the sea at the depths of 0 m, 1 m, 2 m, 5 m and 10 m. The observations were made from starboard. The surface temperature was determined by the bucket method, the temperatures from the other depths by reversing thermometers. In the following we use the abbreviations T_0, T_1, T_2, T_5 and T_{10}.

2. Reading of the sea thermograph, T_T. The intake and output of water from the engine is on port, intake about 4 m below sea level and output at 0,5 m.

3. Four bucket readings, viz.:
   T_B = bow reading.
   T_{SB} = starboard reading.
   T_{SN} = stern reading.
   T_P = port reading.

4. Water samples were collected at 0 m, 1 m, 2 m, 5 m and 10 m. The salinity was determined, and the density value σ calculated.

Unfortunately all data from August 1952 are missing.

III. Direct Measurements at Different Depths.

Table I shows averages of temperature differences (depths minus surface) according to wind speed. We see that at a wind speed of 5 knots or more the stirring is so complete that the difference between surface and 5 m is negligible (0.01—0.04°C). Even at 10 m the differences are smaller than the error of reading. By wind less than 5 knots, i.e. 0 and 1 Beaufort, the differences are negligible down to 5 m. Only at 10 m it reaches a value of about 0.1°C. So for climatological purposes intake samples at this location would satisfactorily represent sea surface temperatures.

Table I.

Means of temperature differences according to wind speed.

No. of cases	Wind speed knots	T_1-T_0	T_2-T_0	T_5-T_0	$T_{10}-T_0$	T_2-T_1	T_5-T_1	$T_{10}-T_1$
28	00—04	—.03	—.04	—.05	—.12	.00	—.01	—.09
36	05—09	—.02	—.01	—.02	—.06	.01	.00	—.03
107	10—19	—.03	—.03	—.04	—.05	—.01	—.01	—.02
56	≧20	—.03	—.03	—.03	—.02	.00	.00	.00
227	All wind speeds	—.03	—.03	—.03	—.05	—.00	—.01	—.03

Table II.

Frequencies of temperature differences at different wind speeds. Cases within ± 0,05°, ± 0.10° and ± 0.20° (%).

± 0.05°.

Wind speed knots	T_1-T_0	T_2-T_0	T_5-T_0	$T_{10}-T_0$	T_2-T_1	T_5-T_1	$T_{10}-T_1$
00 - 04	46	46	29	18	96	82	64
05—09	47	54	33	30	91	94	78
10—19	55	51	50	47	93	94	90
≧20	63	53	60	57	98	100	91

± 0.10°.

	T_1-T_0	T_2-T_0	T_5-T_0	$T_{10}-T_0$	T_2-T_1	T_5-T_1	$T_{10}-T_1$
00—04	71	79	71	46	100	89	71
05—09	69	69	61	51	97	97	86
10—19	77	71	68	71	97	99	93
≧20	84	78	85	76	100	100	98

± 0.20°.

	T_1-T_0	T_2-T_0	T_5-T_0	$T_{10}-T_0$	T_2-T_1	T_5-T_1	$T_{10}-T_1$
00—04	96	96	93	82	100	100	86
05—09	88	89	89	86	100	100	94
10—19	96	94	95	91	99	100	97
≧20	96	96	96	97	100	100	100

The frequencies of differences not greater than ± 0.05°C, are a measure of the frequencies of active stirring to the depths indicated and, therefore, of the applicability of sampling at intake depths for daily weather analysis. Table II shows the frequencies of differences within the limits ± 0,05°C, ± 0.10°C, and ± 0.20°C. Even by strong wind (≧ 20 knots) usually more than 40 % of the differences are greater than ± 0.05°C. First with differences within the limits ± 0.20°C we meet frequencies near 100 %. We may thus conclude that except in calm, or almost calm weather, the temperature at intake depth equals the surface temperature within the limits ± 0.2°C.

Now, the surface temperature is measured by the bucket method, while the other temperature data are recorded by reversing thermometers. The difference in the technique of observation makes the material inhomogeneous, and it is possible that the recorded temperature difference between 0 and 1 m partly is due to this difference in the method of observation. The true difference may be far less, if not entirely insignificant.

In the right parts of table I and II are shown averages and frequencies of differences relative to the temperature at 1 m. We may here conclude that the temperature at the intake depth equals the temperature at 1 m within the limit ± 0.05°C, except in calm or almost calm weather.

IV. The Variation of the Sea Surface Temperature Relative to the Ship.

In order to investigate if there were any systematical difference between the different bucket readings, we have calculated the averages of $T_{SN}-T_{SB}$, T_P-T_{SB} and T_B-T_{SB} (table III), the meaning of the symbols given before. We see that the stern value is lower than the starboard reading, while the port and bow readings are higher. Even if the differences are small, the probability (P) that the differences occur by chance alone is less than one in thousand, except for the difference between port and bow reading. The lower value to the stern is probably caused by the upwelling of colder water by the propeller, and the warmer water at port by the output of warm water from the engine on the port side just below sea surface.

Table III.

A. Means of temperature differences between different bucket readings.

Number of cases	$T_{SN}-T_{SB}$	T_P-T_{SB}	T_B-T_{SB}
240	−.008	.019	.011

$P<0.001$ ($T_{SN}-T_{SB}$ vs. T_P-T_{SB}); $P=0.2$ (T_P-T_{SB} vs. T_B-T_{SB}); $P<0.001$ ($T_{SN}-T_{SB}$ vs. T_B-T_{SB})

B. Difference between highest and lowest bucket reading. Frequency distribution (%). Total number of observations 240.

Max.diff.	%
0.0—0.1	78.1
0.1—0.2	16.9
0.2—0.3	3.1
0.3—0.4	1.3
0.4—0.5	0.4
0.5—0.6	0.2

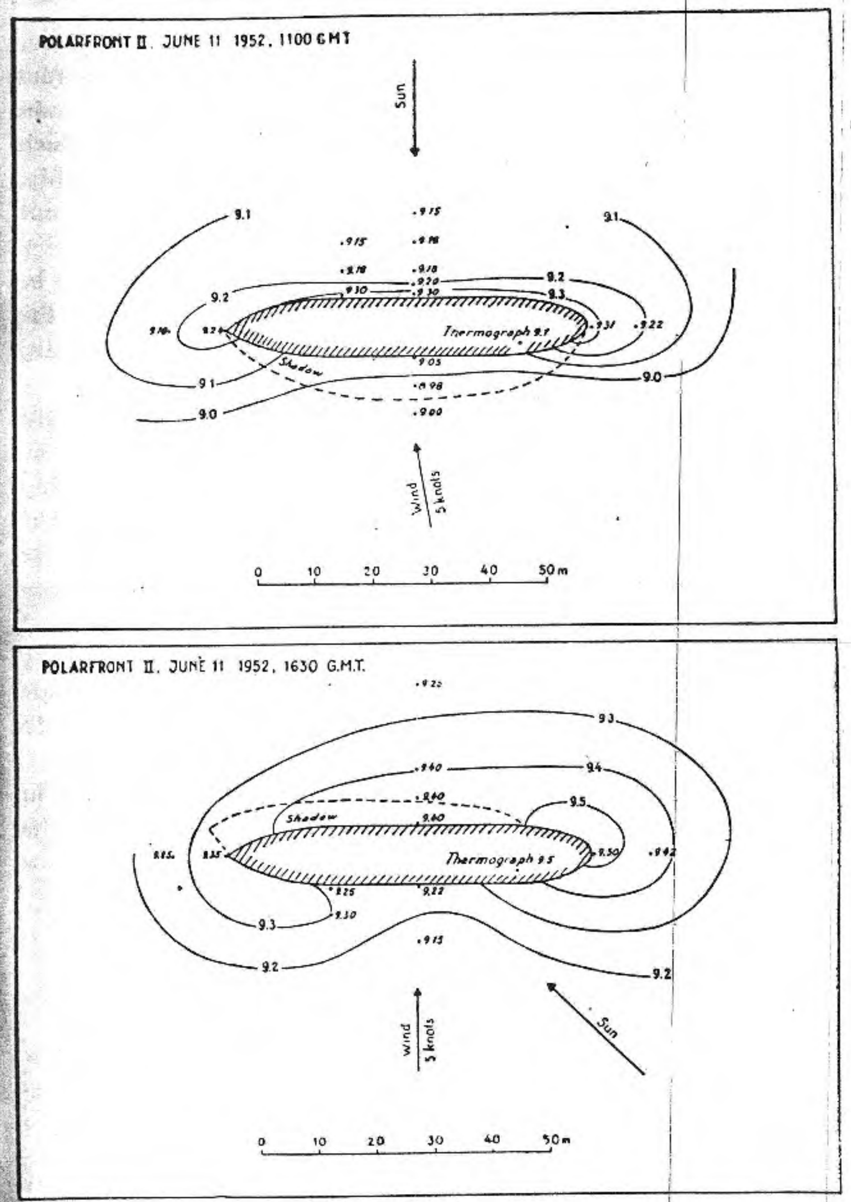

Fig. 2

In table III are also calculated the frequencies of differences between the highest and lowest bucket readings. The maximum difference is 0.5°C, and 78 % of the differences are less than 0.1°C. Consequently it is usually of less importance from which place on the ship the sample is taken, even on a stationary ship, but we ought to avoid taking samples from the stern or the side of output from the engine.

Now, on a moving ship the bucket samples usually have to be taken on the lee side, but the temperature variation round the ship is in this case probably much smaller than by a stationary ship.

On June 11th 1952 at 11 GMT and 1630 GMT, sea surface temperature measurements were made from «Polarfront II» by means of a rubber-dinghy at different distances from the ship (up to 25 m). The results of observations are shown in Fig. 2. The different temperature readings are plotted on the figure, and we have tried to draw possible isotherms for every 0.1°C.

The whole day had a clear sky, and the measurements at 11 GMT showed the highest temperatures on starboard. On the port side (in the shade) the temperature close to the ship's side was about 0.3°C lower. The temperature as a whole fell with increasing distance from the ship.

At 1630 GMT starboard was still the warmest, even if now in the shade. The heat absorbed by starboard ship's side during the morning was still affecting the sea surface temperature, and now apparently at a far greater distance from the ship.

V. The Sea Thermograph Readings.

As mentioned before the intake is at a depth of 4 m below sea level. By means of T_2 and T_5 we have calculated the temperature at 4 m, T_4 and the averages of $T_T - T_4$ for the two ships:

«Polarfront I»: 0.102°C.
«Polarfront II»: 0.079°C.

The readings of the sea thermograph are thus on an average 0.1°C higher than the recorded temperature at the intake depth (4 m), for either ship. It is not possible to read the sea thermograph closer than to the nearest 0.1°C. That both the thermographs get the same sign for the correction must be a coincidence. It serves no purpose to compare the readings of the sea thermograph with the sea surface temperature measured by bucket, as the errors in determining the temperature by the two methods probably are of the same order of magnitude as the true temperature difference between the two depths.

VI. Annual Variation of the Temperature Differences.

Table IV shows the monthly averages of the temperature differences, depth minus surface. The right part of the table refers to 1 m depth, and we see that there are no marked annual variation here. For January the left part of the table shows relatively great positive values, compared with the other months. The right part of the table shows no such peculiarity for January, and the explanation probably is that in January the surface thermometer

Table IV.

Means of temperature differences by month.

Month	T_1-T_0	T_2-T_0	T_5-T_0	$T_{10}-T_0$	T_2-T_1	T_5-T_1	$T_{10}-T_1$
Jan.	.09	.10	.11	.09	.01	.02	.01
Feb.	−.02	−.02	−.02	−.03	.00	.00	−.01
March	−.02	−.05	−.01	−.02	−.02	.01	.00
April	.01	.01	.00	.00	.00	−.01	−.01
May	−.05	−.04	−.05	−.03	.01	.00	.02
June	−.09	−.11	−.11	−.14	−.01	−.01	−.04
July	−.04	−.05	−.07	−.15	−.02	−.03	−.11
Aug.							
Sept.	−.03	−.03	−.04	−.05	.00	−.01	−.02
Oct.	−.05	−.04	−.06	−.06	.00	−.01	−.01
Nov.	−.04	−.02	−.04	−.05	.01	.00	−.02
Dec.	−.02	−.01	−.02	.00	.01	.00	.02

was damaged, and a reserve thermometer was used. We still see that the inhomogeneity of the material makes it impossible to draw any safe conclusion about the temperature difference of the uppermost metre of the water layer.

VII. The Vertical Distribution of Density.

Table V.

Means of σ differences according to wind speed.

Wind speed Knots	$\sigma_1-\sigma_0$	$\sigma_2-\sigma_0$	$\sigma_5-\sigma_0$	$\sigma_{10}-\sigma_0$	$\sigma_2-\sigma_1$	$\sigma_5-\sigma_1$	$\sigma_{10}-\sigma_1$
00—04	—.005	—.003	.004	.012	.000	.006	.014
05—09	—.031	—.035	—.032	—.028	.000	.003	.007
10—19	—.008	—.019	—.019	—.017	—.011	—.007	—.004
$\geqq$ 20	—.013	—.009	—.007	—.005	.006	.002	.007
All wind speeds	—.012	—.017	—.015	—.012	—.004	—.002	.003

Table VI.

Means of σ differences by month.

Month	$\sigma_1-\sigma_0$	$\sigma_2-\sigma_0$	$\sigma_5-\sigma_0$	$\sigma_{10}-\sigma_0$	$\sigma_2-\sigma_1$	$\sigma_5-\sigma_1$	$\sigma_{10}-\sigma_1$
Jan.	—.024	—.022	—.024	—.021	.003	.000	.002
Feb.	—.010	—.016	—.016	—.008	—.002	—.003	.001
March	—.041	—.049	—.038	—.049	—.007	.005	.015
April	—.005	—.006	—.010	—.014	—.001	—.005	—.009
May	—.008	—.011	—.006	.005	.001	.010	.018
June	.005	.008	.010	.012	.002	.003	.006
July	—.044	—.067	—.059	—.055	—.023	—.015	—.003
Aug.							
Sept.	—.001	—.005	.001	.003	—.005	.002	.003
Oct.	.003	.002	.001	.005	—.001	—.004	.001
Nov.	—.004	—.014	—.009	—.002	—.009	—.005	.001
Dec.	—.003	—.002	—.008	—.006	.000	—.001	—.004

Tables V and VI give the averages of the differences of σ, ($\sigma = 1000\ (\varrho - 1)$ where ϱ is the density). The right parts of the tables, as usually, refer to a depth of 1 m. We notice that

the right part of table V shows that at wind speed 10—19 knots the differences are of opposite sign compared with the other differences. It is impossible to find any reasonable physical explanation to this, and most likely the true differences in density are within the limits of error of the density determination. It is thus difficult to draw any conclusion from these tables, concerning the vertical distribution of density in the uppermost 10 m of the water, but it may be noticed that the right part of table V shows the greatest positive values of the density differences at 10 m and at small wind speeds.

VIII. Final Remarks.

During the last years special series of observations have been made by various countries, to investigate the methods of observing sea surface temperature. The chief results are published in the following paper:

Technical note No. 2 Methods of Observation at Sea. Part I-Sea Surface Temperature. WMO — No. 26. TP. 8., 1954, which is here referred to.

As the bucket method is impracticable in fast ships and in all ships often dangerous, the Norwegian ships doing weather observations use the condenser intake method for determining sea surface temperatures. It follows from the foregoing that the condenser intake method is satisfactory, and that the variations in depth of the condenser intake do not affect the accuracy of the observation to any appreciable extent.

Finally I want to express my sincere thanks to Mr. J. Huseklepp for assistance in preparing the material and to Mr. K. Knaus for drawing of the figures.

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