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THE COMPARATIVE MEASUREMENTS OF SEA-SURFACE TEMPERATURE IN THE U.S.S.R.

Report to the fifth session of CMM, WMO

by

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At present, a great variety of methods and devices for SST measurements - from radiation thermometers and remote electrical instruments to the old "method of bucket" and "the condenser intake method" - is used in the world network of ships' hydrometeorological stations. The latter method, which consists of SST determination from measurements in the kingston of the cooling pipe of the vessel's engine-room especially is in wide use.

For the reasons mentioned above, the SST vessel data have different errors and are qualitatively unhomogeneous. It makes the synoptic analyses of the results of SST observation difficult, and also their use for practical purposes (fisheries and weather forecasting) and for scientific investigations (ocean-atmosphere interaction, general circulation of the atmosphere, heat balance of ocean and maritime climate).

Having this in mind, the fourth session of CMM, in Resolution 3 and Recommendation 1, called upon its members to pay serious attention to the problem of SST measurements and to develop the most simple, reliable and cheap method that will give identical results on vessels of various types and tonnages.

Now we have the new problem of arriving at a more correct definition of SST, because, concurrently with the old methods, the new methods (radiation thermometer) are used, which results in the SST measurements being made in different sea-surface layers-- from an upper-surface film, a few microns in thickness, to a depth of 2-3 metres. At the same time, it is known that in certain stratifications at different depths the temperature can differ greatly, which results in heterogeneity of the information obtained.

According to Resolution 3 and Recommendation 1 (CMM-IV), comparative investigations of different methods of SST measurements were made by the Soviet Union in 1967 and 1968. These measurements were made on research vessels "Academician Shirshov" (displacement of 6,800 tons), "A. J. Woeikof" and "J. M. Shokalsky" (each 3,600 tons) in different climatic areas of the Pacific and the Indian oceans and also on small vessels of the "trawler" type (400 tons) in the Black Sea and in the Sea of Asov. The observations were made under different hydrometeorological conditions from April 1967 to February 1968 between latitudes 40°N and 60°S. They were made with the vessel in motion and drifting in a calm sea and in moderate and high seas. During this period, the minimum temperature was -0.5°C, maximum temperature 30.5°C; the corresponding air temperatures were -0.4°C and 29.5°C, respectively.

The comparative measurements were made under the unified programme developed in the State Oceanographic Institution, and they were tabulated in a unified form. The programme and the form of recording are very similar to those that we obtained later from the Panel for the Study of Methods and Instruments for Measuring Sea-Surface Temperature established within the CMM Working Group on Technical Problems.

Simultaneous readings of the following instruments were used for comparative analysis:

Mercury thermometers in standard mounting (the type of Spindler's mounting) overboard and in a bucket;

Electrical resistance thermometer (VRS) placed in a special recess in the hull of the vessel at a depth of 1.8 metres;

Electrical resistance thermometers and thermistor lowered overboard with recording at a potentiometer;

Mercury thermometer in the engine-room.

On the research vessel "Academician Shirshov" the prototype of bucket ABC, constructed according to the working drawings presented to us by Mr. Crowford, was also used.

The measurements were carried out on the port and starboard sides of the vessel, on the foredeck, on the stern, and amidships. The air temperature, cloud amount and state of sea were recorded at the same time.

Altogether, 420 complete observations were carried out on these vessels.

Processing and analysis of observations

In order to detect errors arising from the above methods of SST measurement, all series of comparative observations were subjected to statistical processing. This consists of determining the difference (ΔT) between readings of reverse deep-sea (Nansen - Peterson) thermometers, taken as standard, and the results of measurements of all the instruments. Thus, the most accurate instrument, after the deep-sea thermometer, was found, and this could then be used as a subsidiary standard for processing all data obtained. This step was found to be necessary as the deep-sea thermometers were used while drifting only.

As can be seen from Tables 1 and 2, on r/v "Academician Shirshov" the bucket ABC was found to be suitable as a subsidiary standard, while on other vessels the electrical resistance thermometer VRS was found to be suitable. Subsequent processing consisted in comparing subsidiary standards with readings of all other tested instruments. The results showing different values of ΔT are set out in Tables 1 and 2. Moreover, an analysis of observational data was made to determine the effect of different factors (sea waves, the values of water-air temperature difference, insolation) and also location of observations on the accuracy of the readings of specific instruments.

The results of comparison

Analysis of the data of comparative investigations enables us to come to the following conclusions:

Table 1

Frequency (%) of differences (ΔT) between the readings of the electrical thermometer VRS and other instruments

T	$T_{vrs}-T_{dst}$	$T_{vrs}-T_{etf}$	$T_{vrs}-T_{ets}$	$T_{vrs}-T_{b}$	$T_{vrs}-T_{m}$	$T_{vrs}-T_{er}$
0.0	28	37	-	30	34	-
0.1	51	43	7	46	44	-
0.2	19	17	40	18	16	-
0.3	2	3	30	5	4	-
0.5	-	-	13	1	1	2
0.6	-	-	10	-	1	-
0.7	-	-	-	-	-	-
1.0-1.2	-	-	-	-	-	10
1.3-1.5	-	-	-	-	-	37
1.6-2.0	-	-	-	-	-	37
2.1 and more						
Total	100%	100%	100%	100%	100%	100%

T_{vrs} - Electrical thermometer VRS.
T_{dst} - Deep-sea reverse thermometer.
T_{etf} - Electrical thermometer on foredeck.
T_{ets} - Electrical thermometer on stern.
T_{b} - Thermometer in mounting in the bucket.
T_{m} - Thermometer in mounting overboard.
T_{er} - Thermometer in engine-room.

Table 2

Frequency (%) of differences (T) between the readings of the bucket ABC and other instruments

T	$T_{abc}-T_{dst}$	$T_{abc}-T_{vrs}$	$T_{abc}-T_{b}$	$T_{abc}-T_{m(m)}$	$T_{abc}-T_{M(p)}$	$T_{abc}-T_{er}$
0.1	99	65	55	58	10	-
0.2	1	22	18	8	7	-
0.3	-	8	9	25	7	2
0.4	-	5	9	6	6	-
0.5	-	-	-	3	-	8
0.6	-	-	-	-	12	13
0.7	-	-	9	-	6	7
0.8	-	-	-	-	-	11
0.9	-	-	-	-	10	11
1.0-1.2	-	-	-	-	13	16
1.3-1.5	-	-	-	-	18	9
1.6-2.0	-	-	-	-	8	14
2.1 and more	-	-	-	-	3	9
Total	100%	100%	100%	100%	100%	100%

T_{abc} - The bucket ABC.
T_{dst} - Deep-sea reverse thermometer.
T_{vrs} - Resistance thermometer VRS.
T_{b} - Thermometer in mounting (in bucket).
$T_{m(m)}$- Thermometer in mounting (metal glass) overboard.
$T_{m(p)}$- Thermometer in mounting (polyethylene glass) overboard.
T_{er} - Thermometer in engine-room.

1. The most representative place for SST measurements is the foredeck of a vessel, on the side where the ship's exhaust-water is not substantial.

   It was found that measuring on a deck near an exhaust-water outlet results in an apparent increase in the actual water temperature amounting on average to 0.2°C, and measurements on the stern result in an increase of 0.3-0.4°C.

2. The remote electrothermometer mounted in the bows or amidships is the most accurate and convenient to use. To obtain data representative of the temperature of the surface layer, it is advisable to mount this thermometer not lower than 1 metre below the draft line. The reading scale should be placed in the chart-house; and this will reduce the work of the navigator on watch in making SST measurements, and will provide the most reliable data.

   Therefore, it seems desirable to adopt the recommendation of CMM addressed to maritime countries, and when designing new vessels or over-hauling old ones, it is necessary to allow for the mounting of the above-mentioned instruments as a part of the navigational equipment of the vessel.

3. When remote thermometers are not available, the SST measurements on vessels should be made by water sampling overboard. For this purpose, the ABC bucket-type instrument is the most accurate and convenient of all the instruments we have tested.

   According to the results of tests on r/v "Academician Shirshov" the ABC bucket-type instrument has the following characteristics:

   Readings of the instrument are extremely close to those of reversing thermometers. Comparison of our data shows that differences between the readings of the two instruments are, on average, 0.1°C in 99% of the cases. However, these data are not sufficient for the final evaluation of the accuracy of the instrument.

   Constructional features of the instrument decreases the errors due to evaporation and the effects of external factors (heating and cooling) on the temperature of isolated water samples.

   The test of cooling made on r/v "Academician Shirshov" showed that with a difference of 3-4°C between water and air temperatures, the water temperature in the bucket decreased by 0.2°C in three minutes, and by 1.2°C in 20 minutes.

   The same results have been obtained by Mr. G. Campbell in the testing of heating under conditions of greater differences between water and air temperature up to 10°C.

   The construction of the instrument permits water to circulate freely during the sampling. It is very important that the thermometer and its mounting, while sampling, should be in the environment, the temperature of which it is intended to measure. In this connexion, it should be noted that with the bucket method, these are often errors of measurement because the thermometer mounting may have been previously heated inside or by the sun or, conversely, it may have been cooled, due to low air temperatures.

   Attaching the instrument to a rope by the "bridle" method with a line 2 metres long to ensure a horizontal position and sliding over the water surface without sinking appreciably.

   The instrument can be used on vessels moving at high speed, which is very important since other methods of water sampling are practically limited to speeds of not more than 8-10 knots.

   The instrument is easy to manufacture and is convenient to use during severe hydrometeorological conditions.

4. While drifting and at low speeds of the vessel (up to 6-8 knots) the bucket method and method of direct measurement overboard with thermometer in mounting can be used for SST measurements.

Comparison with bucket ABC and VRS shows that using these methods errors are less than 0.2°C in 70-80% of cases. With greater differences between water and air temperatures, however, and with high seas and winds (which result in increased evaporation) measurements with a thermometer in a mounting give rise to greater errors and, therefore, its use in these cases cannot be justified. This refers especially to thermometers in mountings of light polyethylene glass.

5. Comparative observations show that the SST data obtained from the engine-room of a vessel contain larger errors and are not, therefore, representative of the actual water-surface temperature. On r/v "Academician Shirshov" errors of more than 0.5°C have occurred in 98% of the observations, while on the other vessels the measurements have shown readings which were too high by 1.2 to 2.3°C in 83% of cases. It is important to note that the values of the error do not follow any marked pattern and mainly depend on the operating conditions of the cooling system in the engine-room.

While drifting with the engines stopped, the inflow of water into the cooling system decreases or ceases, which results in a sharp increase in the error of up to 8-10°C.

The values of errors in measurements in engine-rooms depend on the type and size of the vessel, which determine the depth of water intake and the length of pipeline inside the vessel between the intake and the thermometer. The quality of the thermometer, its scale, its place of mounting in the pipeline, and the degree of the possible influence of hot and cold neighbouring water-mains on its readings are of great importance.

All this shows that data relating to SST measurements from the engine-room are unreliable and that the use of a condenser intake method is unreliable and impracticable for a ship making hydrometeorological observations.

Definition of the term SST

While considering the problem of methods for improving water-surface temperature measurements, it is necessary to define SST more precisely. We must recognize as correct the opinion of the Panel for the Study of Methods and Instruments for Measuring SST (Working Group on Technical Problems) concerning the necessity for a definition of the term SST, since, being based on the results of the study of the thermal structure of the surface of the water, we can now more critically interpret the significance of the data obtained, depending on the methods used.

Present theoretical and experimental investigations show that processes of heat and water exchange between sea surface and atmosphere result in the formation of a thin cooled surface layer which freely transmits solar radiation to the lower layers, where it is absorbed.

Presence of a cold surface layer results in negative gradients of temperature in this layer having a thickness of about 1-2 cm. Therefore, the sea-surface temperature can differ considerably from the temperature of lower layers.

According to the observations on r/v "Iceberg" in the North Atlantic, negative temperature gradients in this layer occurred in 83% of the cases, and only in 8% of cases were there positive gradients. The mean value of gradients in the daytime was -0.43°C and at night -0.34°C. In some cases, the gradient reached a value of -2.0°C.

Similar gradient values were obtained for different latitudes of the Pacific. On the average, the gradient is -0.5°C, varying from -0.1° to -0.8°C.

The cooled surface layer called "a cold film" was experimentally found to be extremely stable for different conditions; and the layer persists even in sea conditions up to force 6 on the Beaufort scale.

From this short review, one can see that the term SST, which is well established in the practice of marine observations and investigations, can actually be related only to a very thin surface-layer, the temperature of which is to some degree of approximation given by radiation thermometer readings.

This definition is not applied to the results of measurements with standard ship instruments, as they measure the temperature, not of the water surface, but at some depth under the surface layer. The depth of measurement depends on the extent to which the instrument is submerged, and with methods available at present this varies between wide limits, from 0.5 m to 2-3 m. Considering mixing of water due to the ship's motion and the inertia of mercury thermometers, it will be more exact to speak not of the temperature at a certain depth, but of the quasi-integral temperature characteristic of a subsurface water layer. Naturally, to obtain the most homogeneous observational data it is necessary to endeavour to limit the thickness of this layer, taking it now as 1 metre. The value is proposed on the basis of practical possibilities of using existing instruments, and on the basis of actual data of water temperature changes in this layer, which do not exceed the required limits of accuracy of measurement.

Thus, it becomes necessary to introduce a new concept - that of TSSL (temperature in surface-sea-water layer) as applied to the results of water temperature measurements with standard ships' instruments and methods.

Summarizing, it is possible to suggest the following terminological definitions:

SST - Sea-water surface temperature, representative of a thin surface layer of water (from a few microns to 1-2 cm) being measured with a ship's or airborne radiation thermometer.

TSSL - Temperature in surface-sea-water layer having a thickness of not more than 1 metre, being measured with standard ships' instruments and methods.

Application of these concepts can be justified in that they give a clear idea of the physical meaning of the sea-water temperature data which is obtained.

In this report, there is no discussion of the question of possible and required accuracy of temperature measurements at the surface of the sea for research and practical purposes. One can suppose a priori that there is a considerable effect due to the space-time variability of temperature as the measurements are not generally made at a point, nor are they made instantaneously but over a certain distance, depending on the speed of the vessel and inertia of the instrument.

In this connexion, it is desirable to recommend investigations into the effect of this factor on accuracy of water-temperature measurements (SST and TSSL) in seas and in oceans.

REFERENCES

See page 140 of this volume.