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THE STANDARD ERROR OF A SEA SURFACE TEMPERATURE AS MEASURED USING A CANVAS BUCKET

By M. W. STUBBS

Summary.—From 492 canvas bucket observations of sea temperature obtained on voyage six of *Weather Surveyor* in 1962, the standard error of a single observation was deduced, with 95 per cent confidence limits to be 0.202±0.013°F (0.112±0.007°C). This is an upper limit to the instrumental error since it was impossible from the data to separate the instrumental error from the small spatial and temporal fluctuations of the sea temperature; a complete programme of paired observations is required before these latter errors may be separated from the instrumental errors.

Introduction.—The measurement of sea surface temperature from the British Ocean Weather Ships is by means of a canvas bucket when the ship is 'on station' and an insulated bucket when she is 'under-way.' An estimate of the accuracy of the measurements using the canvas bucket is desirable. Provided the errors are normally distributed, the root mean square error or the standard error is a convenient measure of the accuracy since two-thirds of the errors lie in the range plus or minus the standard error. Sufficient data were obtained on voyage six of *Weather Surveyor* in 1962 to define an upper limit to the standard error; *Weather Surveyor* was on station 'Juliet' during voyage six.

Errors in the measurement of the sea surface temperature.—The sea surface temperature is obtained by lowering the canvas bucket into the water over the stern of the ship; it is hauled back on board and the thermometer is placed in the water in the bucket; after about half a minute the thermometer is read.

Ashford[1] has discussed the errors that can arise in this temperature due to the ambient wet-bulb temperature being different from the sea temperature. During voyage six the wet-bulb temperature was, on average, 2.27°C lower than the observed sea temperature; from Ashford's results this deficit would result in an average fall of temperature of water in the bucket of 0.01°C per minute, whilst the largest deficit of 6.9°C would have resulted in a fall of 0.04°C before the thermometer was read. These values are an order of magnitude lower than the standard error found below but may be regarded as a systematic error in the bucket temperature if no correction is applied to the readings.

4°F

0.1°C

Although the instrumental error is of interest in this note, local temporal and spatial fluctuations of sea surface temperature can result in the observed value not being a true representation of the sea surface temperature. Åmot[2], for example, has discussed the heating effect of the hull of the ship, especially when the sun is shining; he found that the sea temperature can be raised in such conditions by 0.1° to 0.3°C from its initial value up to a distance of 10 metres from the hull of the vessel.

Stevenson[3] has described how the bucket temperature may be lower than its representative value because of the effect of wind on the hull of a ship; the wind can cause upwelling of water from the region of the keel of the vessel on the lee side. This effect is most marked if there is a definite temperature gradient in the upper layer of the sea. According to Stevenson the fall of temperature associated with this effect can amount to 0.5°F (0.3°C).

Marked inhomogeneities of temperature also exist in the open sea. These can be caused by several factors, changing winds, turbulent overturning and the effect of ocean currents being a few possible causes. The standard error deduced below includes all these errors and may therefore be considered as an upper limit to the instrumental standard error of the method.

The standard error of a bucket observation.—The bucket temperature θ_n measured at hour n may be written in the form:

$$\theta_n = T_n + F_n + e_n \qquad \ldots (1)$$

where T_n is the representative temperature of the water, F_n is the magnitude of the errors due to the small local fluctuations of temperature and e_n is the magnitude of the errors due to the instrumental errors. The observed temperature j hours later, θ_{n+j}, can be written as:

$$\theta_{n+j} = T_{n+j} + F_{n+j} + e_{n+j}. \qquad \ldots (2)$$

On subtracting (1) from (2) and squaring both sides of the new equation, then summing over all the pairs of temperature measurements j hours apart:

$$\Sigma(\theta_{n+j} - \theta_n)^2 = \Sigma(T_{n+j} - T_n)^2 + \Sigma F^2_{n+j} + F_n^2 + \Sigma e^2_{n+j} + \Sigma e^2_n + \ldots\text{. cross terms} \qquad \ldots (3)$$

Now $\Sigma F^2_{n+j} \simeq \Sigma F^2_n$ and $\Sigma e^2_{n+j} \simeq \Sigma e^2_n$. It can also be shown that there is little or no relation between T, F and e, thus the cross terms may be neglected. Dividing (3) by N_j, the number of pairs of observation j hours apart, gives

$$\frac{\Sigma(\theta_{n+j} - \theta_n)^2}{N_j} = \frac{\Sigma(T_{n+j} - T_n)^2}{N_j} + 2s^2 \qquad \ldots (4)$$

$$\text{where } s^2 = \frac{\Sigma F_n^2 + \Sigma e_n^2}{N_j}$$

Now $N_j = N - j$ where N is the number of observations, so that when $j = 0$;

$$s^2 = \frac{\Sigma F_n^2 + \Sigma e_n^2}{N}$$

i.e. s^2 is the variance due to local spatial fluctuations of the sea temperature and the instrumental errors.

In equation (4) when $j = 0$ the term $(T_{n+j} - T_n)^2/N_j$ vanishes and

$$\left[\frac{\Sigma(\theta_{n+j} - \theta_n)^2}{N_j}\right]_{j=0} = 2s^2 \qquad \ldots (5)$$

The term on the left cannot easily be measured and, in fact, pairs of observations were not made but the graph of $\Sigma(\theta_{n+j} - \theta_n)^2/N_j$ against j can be constructed, and a value for the left-hand term obtained by extrapolation assuming that the graph is linear. In equation (4) the differences between pairs of temperatures may be expected to increase with increasing values of j whilst the term in s^2 is likely to remain almost constant.

Results.—On voyage six, 492 hourly observations of sea surface temperature were obtained between 1200 GMT on 27 August and 0000 GMT on 17 September 1962. The term $Y = \Sigma(\theta_{n+j} - \theta_n)^2/N_j$ was computed for the values of j from one to six, and the straight line which best fits the observations is shown in Figure 1. The equation of the line was found (the regression of Y on j) and the calculated intercept on the Y-axis was 0.08166, this being the estimate of $2s^2$ (see equation (5)). Thus the standard error s of a bucket observation was found to be 0.202°F (0.112°C). The 95 per cent confidence limits of this standard error were ± 0.013°F (0.007°C).

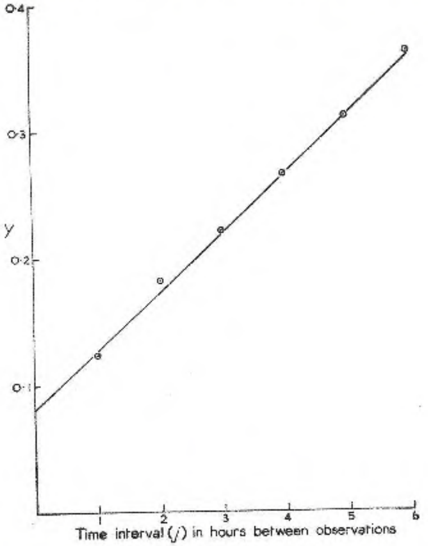

FIGURE 1—GRAPH OF Y AGAINST j

Graph of $Y = \Sigma(\theta_{n+j} - \theta_n)^2/N_j$ as a function of j.

The accuracy of a bucket temperature is thus sufficient to reveal fluctuations of sea surface temperature of 1° or 2°F over periods of one or two days. Fluctuations of this magnitude do occur as can be seen in Figure 2 which shows some of the hourly values of sea temperature on voyage six. These fluctuations may be caused by several factors; the cloudiness, the speed, direction and fetch of the wind are a few possible causes.

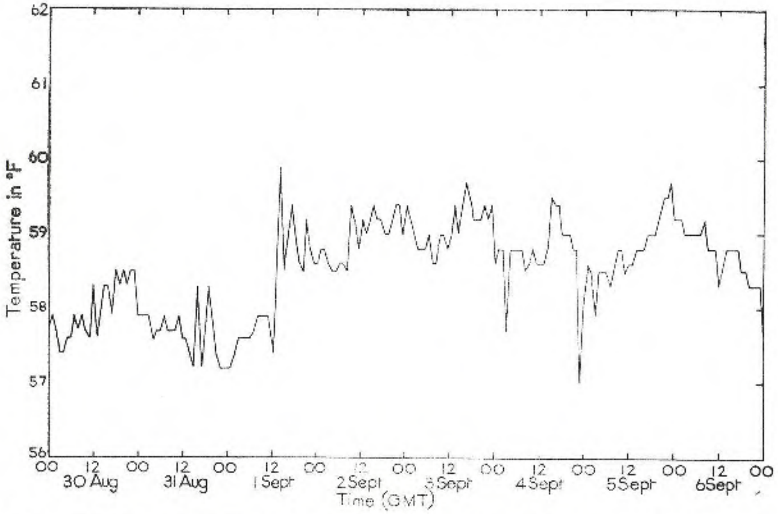

FIGURE 2—SEA SURFACE BUCKET TEMPERATURES MEASURED AT HOURLY INTERVALS BETWEEN 0000 GMT ON 30 AUGUST AND 0000 GMT ON 7 SEPTEMBER DURING VOYAGE SIX OF WEATHER SURVEYOR IN 1962

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