SHORT COMMUNICATIONS

SEA SURFACE TEMPERATURES*

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Introduction

The surface of the sea is losing heat by evaporation and by long-wave radiation exchange with the sky, both of these rates being of the order of 10^{-2} W cm^{-2} in clear weather. Heat lost in this way must be provided by conduction upward from the water beneath and downward from the air above. Short-wave radiation need not be considered since it is not absorbed at the surface. It seems possible therefore that on days of light wind the "skin" temperature of the sea might be appreciably less than the temperature of the layers beneath. Now sea surface temperatures are usually measured by means of a dip bucket and it is clear that water entering the bucket is derived in varying amounts from various depths below the surface, so that the temperature of the mixture will not generally be equal to the skin temperature of the sea. In view of these considerations an experiment was carried out with the object of determining the skin temperature by measuring the long-wave radiation emitted from the sea and comparing it with the dip bucket temperature.

Method

The observations were taken from the end of Mordialloc pier during the late summer and autumn of 1953. The pier is approximately 300 yd long and the depth of the water at the end is about 16 ft. All measurements were made in clear weather with light winds, partly to obtain steady conditions and partly to reduce the number of variables in the experiment. Furthermore if a cool skin does exist it will reach its maximum development in these circumstances. A Linke Feussner actinometer placed about 6 ft above the water was used to measure the radiation. The instrument was inclined at about 10° to the downward vertical so that the supporting timbers of the pier were not in its field of view. The galvanometer used in conjunction with the actinometer was housed in a large box with a slot at one end for viewing the scale. Despite all precautions taken to reduce the effect of vibration caused by sea and wind it was at times not possible to take reliable measurements. Considerable fluctuation in reading could also be caused by specular reflection of sunlight from the oscillating sea surface.

In steady conditions the galvanometer can be read to the nearest 0·5 mm, which corresponds to a temperature difference between instrument and sea of

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about 0·15 °C. This small deflexion is produced by a temperature difference between the thermojunctions of the actinometer of the order of 0·01 °C. In spite of its thick copper casing there are almost always temperature gradients within the instrument which can produce much bigger temperature differences and correspondingly larger spurious deflexions. If the spurious deflexion produced in this way were to remain constant during the course of an observation then it would be of no importance. However, the temperature field within the instrument is unfortunately never quite steady, especially when the instrument is in use in the open air, and the spurious or " zero " deflexion may change by several millimetres in the 30 sec necessary to take an observation. This means that it is necessary to take an observation several times until one is fortunate enough to obtain one during which the zero deflexion changes only by 1 mm or less. Deflexions can usually only be obtained to the nearest millimetre because of this, and consequently temperature differences can only be measured to about 0·3 °C. This inaccuracy is inherent in the instrument itself and cannot be reduced by increasing the sensitivity of the galvanometer.

The Linke Feussner measurements of long-wave radiation from the sea surface do not give its temperature directly, firstly because the sea is not a perfect black body and secondly because the air between instrument and sea absorbs and emits long-wave radiation. It is possible to allow for these effects in the following manner. Suppose the reflection coefficient of the sea is α and the transmissivity of the air between instrument and sea is $1-\beta$. If the temperature of the sea surface is T_1, the incoming radiation from the sky is R, and a representative temperature of the air is T_2 then the apparent temperature of the surface as measured with the Linke Feussner actinometer, T say, is given by

$$\sigma T^4 = [(1-\alpha)\sigma T_1^4 + \alpha R][1-\beta] + \beta\sigma T_2^4, \quad \ldots\ldots\ldots\ldots \quad (1)$$

where σ is the Stefan-Boltzmann constant. Now R is approximately equal to $4\sigma T_1{}^4/5$, so

$$T^4 \approx T_1^4\left(1-\frac{\alpha}{5}\right) - \beta(T_1^4 - T_2^4),$$

therefore

$$T \approx T_1\left(1-\frac{\alpha}{20}\right) - \beta(T_1 - T_2). \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

The coefficient β depends on the vapour pressure of the air and can be estimated from an Assman psychrometer reading taken at the level of the instrument. T_2 was put equal to the dry-bulb temperature at instrument height, the temperature gradient being accounted for by taking only 170 cm air path instead of 200 cm. The reflection coefficient of water at normal incidence is given by Brunt (1939, p. 121, Fig. 35) for wavelengths up to 18 μ. The average value weighted according to Planck's law for a temperature of 300 °K, is about 0·03. This does not contradict the value of 0·06 usually quoted in the literature since this was calculated from Fresnel's formulae (Ångström 1915) on the assumption that the refractive index is 4/3. It is a weighted mean over all angles of incidence taking account of variation of both reflection coefficient and quantity of incident radiation. At angles of incidence from 0° to 30° Fresnel's formulae give 0·02 for the reflection coefficient. It will be assumed here that the reflection coefficient at an angle of incidence of 10° is 0·03.

Results

The data obtained are shown in Table 1. The differences between the actual surface temperature and the dip bucket temperature have a mean value of —0·25 °C. The standard deviation is 0·32 °C, which is consistent with the accuracy of the observations. Since there are 12 observations the difference is significant at the 5 per cent. level. On only one occasion (February 19) was there an appreciable warm skin and that was also the only occasion when the air was appreciably warmer than the water. These results are in substantial agreement with those of Bruch (1940). The experiment was carried out in conditions favourable for the development of a cool skin, i.e. conditions of clear sky and light wind. In general therefore the temperature difference will be less than 0·25 °C but in very favourable circumstances may be higher. It is unlikely that any serious errors will be made if surface temperatures are quoted to the nearest 1 °F when measured with dip buckets suitably designed to minimize other sources of error.

TABLE 1

RESULTS OF SEA SURFACE TEMPERATURE MEASUREMENTS

Date	Time	$T_2—T_1$ (°C)	$\beta \times 10^2$	δ* (mb)	ΔT† (°C)
1953					
Feb. 19	1530	+4·15	13·5	10·0	+0·35
„ 26	1412	—2·0	15	9·7	—0·2
„ „	1427	—1·65	15	9·5	—0·4
„ „	1536	—2·25	15	9·3	+0·15
Mar. 4	2140	—4·1	13	9·3	0·0
„ „	2146	—4·2	13	9·5	—0·2
Apr. 7	1305	—2·1	10·5	9·7	—0·45
„ „	1407	—2·0	11	9·6	—0·15
„ 10	1508	—1·3	14	5·1	—0·75
„ 15	1457	+0·5	16·5	3·3	—0·45
„ „	1507	+0·5	16·5	3·3	—0·55
May 29	1520	—3·1	11·5	3·5	—0·5

* δ is the difference between the saturation vapour pressure at the sea surface and the vapour pressure at instrument height.

† ΔT is the difference between surface temperature and dip bucket temperature.

Stability of the Cool Skin

If the rate of loss of heat from the surface is 10^{-2} W cm^{-2} then the temperature gradient in the subsurface laminar layer is 1·7 °C cm^{-1}. This will produce a temperature difference of 0·25 °C in 0·15 cm which is therefore the approximate thickness of the laminar layer. Rayleigh (1916) has shown that it is possible for a fluid to remain " unstably " stratified provided the following inequality holds

$$\frac{\rho_1-\rho_0}{\rho_0}<\frac{27\pi^4 k\nu}{4gh^3},$$

where k is the diffusibility for heat and ν is the kinematic viscosity, ρ_1 the density at the top and ρ_0 the density at the bottom of the layer whose thickness is h. In the present case the condition becomes

$$\Delta T<13\ ^{\circ}\mathrm{C}.$$

Thus on this basis at any rate there is no reason to doubt the existence of a laminar layer.

References

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