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Scientific Paper No. 11

Some Calculations of Terms in the Energy Balance for Monthly Periods at the Ocean Weather Stations I and J in the North Atlantic

by H. C. SHELLARD, B.Sc.

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by H. C. Shellard, B.Sc.

INTRODUCTION

The ocean weather stations I and J have now provided almost continuous series of reliable and regular meteorological observations, made at more-or-less fixed points in the North Atlantic, for over 10 years. It is therefore possible to compute monthly mean values of the various meteorological elements with a quite high degree of accuracy, such means being based on eight observations a day throughout the month. It is worthwhile, therefore, to apply methods similar to those used by W. C. Jacobs[1]* to compute the various terms in the energy balance at the two stations on an individual monthly basis. The results obtained permit the relative importance of the different terms to be assessed for each station, and show how these terms varied throughout the year and from one year to another during the period 1948–56. A comparison with the results obtained by Jacobs for the eastern North Atlantic is also made.

PROCEDURE ADOPTED

The various terms which it is required to compute for each month are the following:

Q_s = net insolation reaching the sea surface.

Q_b = energy lost by back radiation to the sky.

$Q_r = Q_s(1-F) - Q_b$ = net energy penetrating the sea surface, where F is the fraction of Q_s lost by reflection.

Q_e = energy used for evaporation.

Q_h = sensible heat exchanged between sea and atmosphere.

$Q_a = Q_e + Q_h$ = total energy exchanged between sea and atmosphere.

$Q_c = Q_a - Q_r$ = net energy given up by the sea to atmosphere and sky.

Q_t = net gain in heat content of sea water column.

Q_v = net energy advected by ocean currents $= Q_c + Q_t$.

The procedure used for computing each of the above terms was as follows:

Net insolation reaching the sea surface (Q_s)

Values of $Q_{s_o} = Q\,(1-\alpha)$, the insolation reaching the sea surface with a cloudless sky, were first calculated. Values of Q, the insolation at the outer limit of the atmosphere, were interpolated from data due to Angot, taken from Brunt.[2] Mean values of α, the depletion

*The superscript figures refer to the bibliography on page 13.

of Q due to scattering and absorption, were computed from graphs of α against local apparent time (LAT) which had been drawn for each month, using altazimuth tables and figures for the percentage losses due to scattering and absorption for various solar altitudes, provided by Dr. G. D. Robinson. Values of Q_s were then computed from Kimball's[3] empirical formula

$$Q_s = Q_{s_0}\ (1-0{\cdot}071\ C_D),$$

where C_D is the mean total cloud amount in tenths during daylight hours. The value C_D was obtained from the mean monthly cloud amount for all hours, taken from the meteorological summaries for ocean weather stations I and J,[4] by applying a correction for diurnal variation; average curves for diurnal variation of cloud amount had been computed for another purpose. For the years 1955 onwards, however, mean total cloud amounts for each hour have been included in the annual summaries and these were used.

Energy lost by back radiation to the sky (Q_b)

Values of eff. Q_b, the effective back radiation to a clear sky, were computed, for day and night separately, using the graph given by Sverdrup[5] and based on Ångström's data, relating eff. Q_b to sea temperature and relative humidity. For the earlier years, 1948–49, the monthly means of relative humidity were computed from the monthly means of dry-bulb and wet-bulb temperature after correcting the latter for diurnal variation, but for 1950 onwards hourly mean values of dry-bulb temperature and dew-point were already available in the annual summaries and were used. The values in gm cal cm^{-2} min^{-1} taken from the graph were converted to gm cal cm^{-2} day^{-1} by multiplying by the appropriate average durations of day and night in minutes for the months concerned.

Values of Q_b were then computed from the following formula due to Asklöf[6] and Ångström[7]

$$Q_b = 0{\cdot}94\ [\text{eff. } Q_b\ (1-0{\cdot}083\ C)],$$

where C is the mean cloud amount in tenths for day or night hours, as appropriate. The total back radiation was obtained by addition of the day and night values.

Net energy penetrating the sea surface (Q_r)

First it was necessary to compute values of F, the fraction of Q_s that is lost by reflection from the sea surface. The values given by Sverdrup[5] for the fraction reflected on a clear day were increased by 25 per cent to allow for surface roughness, following Hay[8]. The resulting values, F_c, were then plotted against LAT, using altazimuth tables, for each month and each station position. Hence mean daily values of F_c were obtained for each month. Then, taking the fraction reflected on an overcast day to be 8 per cent (Sverdrup[5]), F was computed from

$$F = 0{\cdot}008\ C_D + F_c\ (1-0{\cdot}1\ C_D).$$

Hence mean values of Q_r, the net energy penetrating the sea surface were obtained from

$$Q_r = Q_s\ (1-F) - Q_b$$

Energy used for evaporation (Q_e)

It has been shown by Jacobs[1] that the mean evaporation from the sea surface can be computed from climatological data using the general relation

$$E = k\ (e_w - e_a)\ W_a,$$

where E is the rate of evaporation, e_w is the vapour pressure at the sea surface, e_a is the vapour pressure at height a, W_a is the wind speed at height a, and k is a constant, depending on the nature of the turbulence near the surface. He was able to find a value for k by also computing E by the energy balance method for selected areas. These areas were ones in which it could be assumed that the net amount of heat advected by ocean currents would be zero. A time interval of a year was employed so that the change in heat content could be assumed to be zero also. Jacobs' climatological data for $(e_w - e_a)$ and W_a were based on American ships' reports for the ocean areas concerned. He thus arrived at the relation

$$E = 0{\cdot}0736\,(e_w - e_a)\,W_a,$$

where E is in millimetres per day, e_w and e_a in millibars and W_a in knots.

More recently Privett[9] has carried out similar calculations using data from British selected ships and he found a value for k which was about 0·8 of that found by Jacobs. As it has been shown by Hay[10] that the agreement between the observations from ocean weather station J and those from British selected ships in the same locality is good, Privett's value for k has been used in this paper. A further small correction has been applied to allow for the fact that the wind speeds recorded by the weather ships relate to a height of about 55 feet, whereas those from merchant ships relate to 33 feet, being based on the Beaufort scale of wind force using the sea criterion. This involves multiplication of the observed mean wind speeds by 0·93, following Hay[11]. Thus the formula used was

$$E = 0{\cdot}0736 \times 0{\cdot}8 \times 0{\cdot}93\,(e_w - e_a)\,W_a$$
$$= 0{\cdot}0547\,(e_w - e_a)\,W_a \text{ mm day}^{-1}.$$

Since Q_e, the energy used for evaporation, is equal to $\frac{EL_t}{10}$ gm cal cm^{-2} day^{-1} where L_t is the latent heat of vaporization of water at the sea temperature in gm cal gm^{-1} we have

$$Q_e = 0{\cdot}00547\,(e_w - e_a)\,W_a L_t.$$

Here L_t was taken to be $605 - 0{\cdot}29 t_w$ gm cal gm^{-1}, where t_w is the sea surface temperature in degrees Fahrenheit. In computing e_w, 98 per cent of the saturation vapour pressure of water at temperature t_w was taken, in order to correct for salinity.

Sensible heat exchanged between sea and atmosphere (Q_h)

The sensible heat lost to the atmosphere through turbulent heat exchange was computed from

$$Q_h = RQ_e,$$

where R is the Bowen ratio $= 0{\cdot}363\,\frac{(t_w - t_a)}{(e_w - e_a)}$, where t_a is temperature at height a and the units are degrees Fahrenheit and millibars.

Hence $Q_h = 0{\cdot}00199\,(t_w - t_a) W_a L_t.$

Total energy exchanged between sea and atmosphere (Q_a)

The total heat exchanged between the sea and the atmosphere was obtained simply from

$$Q_a = Q_e + Q_h.$$

Net energy given up by the sea to atmosphere and sky (Q_c)

The net energy given up by the sea was computed from

$$Q_c = Q_a - Q_r.$$

Net gain in heat content of sea water column (Q_t)

It was possible to compute the energy used in local heating of the sea water for certain months in 1956 for which bathythermograph observations were available to a depth of 450 feet.

Net energy advected by ocean currents (Q_v)

For those months for which Q_t had been computed, values of Q_v, the net energy advected by ocean currents, were obtained, since

$$Q_v = Q_c + Q_t.$$

Values of Q_v for each year were obtained on the assumption that Q_t would be very nearly zero, taken over a complete year ending 31 December, in which case $Q_v = Q_c$.

MEAN VALUES FOR THE PERIOD 1948–56

Mean values of Q_s, Q_b, Q_r, Q_e, Q_h, Q_a and Q_c in gm cal cm^{-2} day^{-1} were computed for each station for each month of the period 1948–56. All these data are not presented here but the average monthly values, 1948–56, are shown graphically in Figures 1 and 2, which thus illustrate the annual variation of each term. The main features are as follows, the units used being gm cal cm^{-2} day^{-1} unless otherwise stated.

Net insolation reaching the sea surface (Q_s)

The net insolation reaching the sea surface has average monthly values ranging from 8 in December to 279 in June at station I and from 34 in December to 300 in May at station J. The reason for the May value being higher than that for June (288) at station J is that the mean cloud amount was appreciably smaller in May.

Energy lost by back radiation to the sky (Q_b)

Variations in the average amounts of energy lost by back radiation are relatively small, monthly values ranging from about 70 in June and July to about 90 in the winter months at both stations, the higher sea temperature in summer being more than compensated by the higher moisture content of the air and the increased cloudiness.

Net energy penetrating the sea surface (Q_r)

The net solar energy penetrating the sea surface has minimum values in December and maximum values in June, mean values for these months being -82 and 179 respectively at station I and -63 and 189 respectively at station J. Mean values are positive from March to September at station I and from March to October at station J, and negative in the remaining months.

Energy used for evaporation (Q_e)

The energy used in evaporation has average monthly values ranging from 110 in July to 293 in January at station I and from 111 in July to 274 in February at station J. The higher winter values are almost equally contributed to by the stronger winds and by stronger convection, that is higher values of $(e_w - e_a)$. The extreme monthly values were 64 (May 1951) and 363 (January 1949) at station I and 58 (July 1955) and 373 (January 1948) at station J. Generally speaking, mean values at the two stations are somewhat similar. Although in individual months they were sometimes very different, the coefficient of correlation between the computed values of Q_e at the two stations was found to be 0·70. For 108 pairs of values this is highly significant. A rather curious feature is that in every one of the nine Aprils Q_e was greater at station I than at station J (mean values 229 and 177 respectively), while in eight out of the nine Augusts Q_e was greater at station J than at station I (mean values 173 and 137 respectively). Q_e was also higher at station I than at station J in eight of the nine months of January (mean values 293 and 255 respectively).

Jacobs presented his results in the form of seasonal and annual maps showing the distribution of mean evaporation in centimetres per day over the North Atlantic and North Pacific. Values have been interpolated from these maps for the positions of stations I and J and are given in Table 1 with the corresponding mean values computed from the ocean weather ship data over the years 1948–56.

TABLE I. *Seasonal and annual values of evaporation in centimetres per day at ocean weather stations I and J with Jacobs' values for comparison*

	Winter	Spring	Summer	Autumn	Year
Ocean weather station I, 1948–56	0·45	0·34	0·20	0·36	0·34
Jacobs' values for 59°N 20°W	0·41	0·24	0.10	0·30	0·26
Ocean weather station J, 1948–56	0·44	0·29	0·23	0·38	0·34
Jacobs' values for 52½°N 20°W	0·36	0·18	0·07	0·24	0·21

It is clear from the table that in spite of the fact that a lower value of k than that found by Jacobs has been used, the values of E computed from reliable ocean weather ship data are still considerably larger than those computed by him for the same areas using climatological data from American ships. This suggests that all his values of E may be on the low side. The differences are greatest in summer but even over the whole year the weather ship data give values which are 60 per cent higher at station J and 30 per cent higher at station I.

It is of interest to note here that the computed monthly values of E for station J appear to vary in a similar way to the corresponding general monthly values of the rainfall over England and Wales. A highly significant correlation coefficient of 0·52 was found between the two sets of values. The relationship does not seem to be appreciably stronger if only the months of predominantly westerly flow are considered, however, and the following explanation is tentatively made. Values of the mean evaporation are high when the wind is stronger than normal and the air is drier than normal. Such conditions are likely to occur in months with disturbed weather and frequent incursions of polar air. This type of weather would be expected to give higher than average rainfall over the United Kingdom.

Sensible heat exchanged between sea and atmosphere (Q_h)

The energy used in turbulent heat exchange with the atmosphere was found to have average monthly values ranging from 20 in July to 153 in January at station I and from 9 in July to

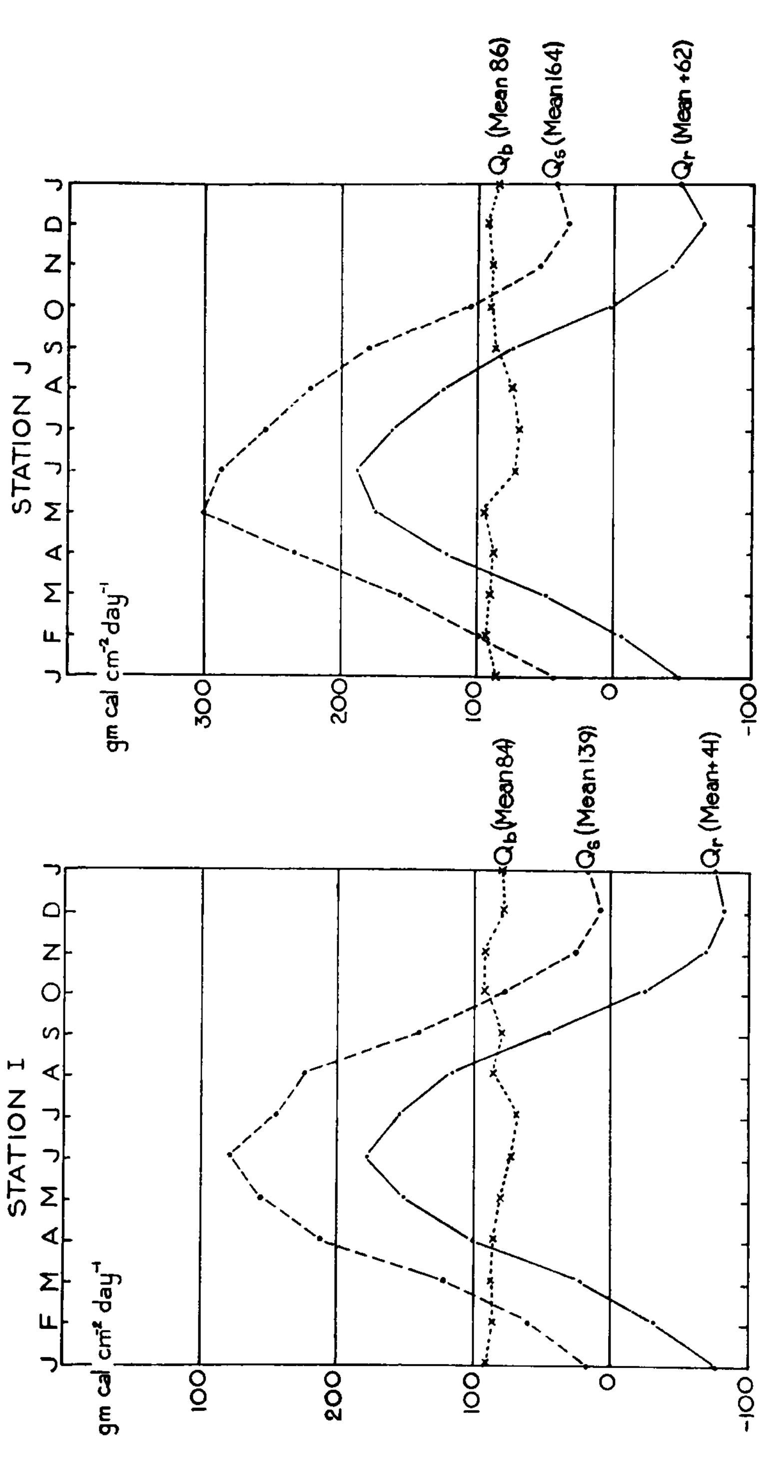

FIGURE 1. Annual variation of radiational terms Q_s, Q_b and Q_r at ocean weather stations I and J (mean values for the period 1948–56)

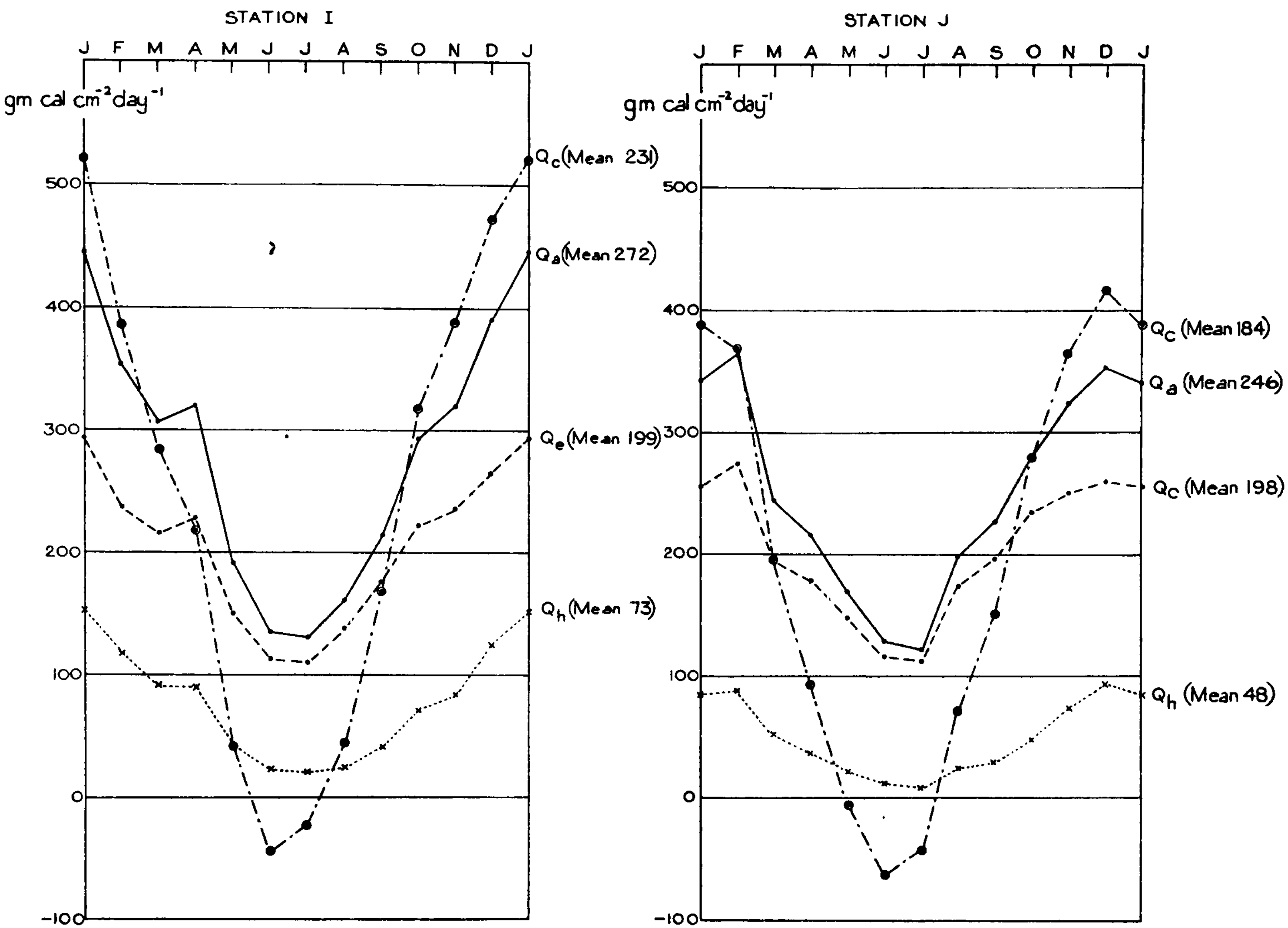

FIGURE 2. Annual variation of the terms Q_c, Q_h, Q_e and Q_a at ocean weather stations I and J (mean values for the period 1948–56)

[Erratum: for station J the dashed curve should be labelled Q_e (mean 198)]

94 in December at station J. Extreme values were 4 (June 1949) and 239 (January 1949) at station I and −11 (June 1950) and 155 (February 1951) at station J. Values are usually higher at station I than at station J but this is not always so in individual months. At station J the mean monthly values have been negative on three occasions, once each in May, June and July, because the mean sea temperature was lower than the mean air temperature in those months. This never happened at station I during the period reviewed, although in June 1949 the mean sea–air temperature difference was only 0·2°F.

Here again, comparison may be made with the seasonal values computed by Jacobs as shown in Table II.

TABLE II. *Seasonal and annual values of mean quantity of sensible heat exchanged between sea and atmosphere in gm cal cm⁻² day⁻¹ at ocean weather stations I and J, with Jacobs' values for comparison*

	Winter	Spring	Summer	Autumn	Year
Ocean weather station I, 1948–56	132	74	23	65	73
Jacobs' values for 59°N 20°W	120	15	−25	25	35
Ocean weather station J, 1948–56	89	37	15	51	48
Jacobs' values for 52½°N 20°W	60	0	−35	10	10

The weather ship data indicate appreciably higher values than those given by Jacobs; in particular his suggestion that Q_h is negative on the average in the eastern North Atlantic in summer is not supported. They confirm, however, that the amount by which the sea heats the atmosphere increases northwards north of latitude 50°N.

Total energy exchanged between sea and atmosphere (Q_a)

The total heat exchanged between the sea and the atmosphere has average monthly values ranging from 131 in July to 446 in January at station I and from 120 in July to 362 in February at station J. Extreme values were 69 (June 1949) and 602 (January 1949) at station I and 52 (July 1955) and 523 (December 1951) at station J. Values are usually higher at the more northern station in winter and spring although exceptions are quite common in individual months; in summer and autumn there are no marked differences between the mean values for the two stations.

Table III compares seasonal and annual values with those interpolated from Jacobs' maps of Q_a.

TABLE III. *Seasonal and annual values of mean total energy exchanged between sea and atmosphere at ocean weather stations I and J in gm cal cm⁻² day⁻¹, with Jacobs' values for comparison*

	Winter	Spring	Summer	Autumn	Year
Ocean weather station I, 1948–56	397	273	142	276	272
Jacobs' values for 59°N 20°W	360	155	35	205	190
Ocean weather station J, 1948–56	351	209	148	277	246
Jacobs' values for 52½°N 20°W	270	105	5	150	135

The differences between the values computed from ocean weather ship data and Jacobs' values are most marked in summer but over the year as a whole the computed values are greater than Jacobs' values by over 40 per cent for station I and over 80 per cent for station J.

Net energy given up by the sea to atmosphere and sky (Q_c)

The net energy given up by the ocean has average monthly values which are positive in all months except June and July, and reach their maximum values in winter. The mean values range from —44 in June to 521 in January at station I and from —62 in June to 416 in December at station J. In individual months, negative values have occurred from May to July at both stations; in these months there was thus a net gain of heat by the ocean. Over the year as a whole, however, the energy given up by the ocean is considerable, averaging 231 gm cal cm^{-2} day^{-1} at station I and 184 gm cal cm^{-2} day^{-1} at station J.

Net gain in heat content of sea water column (Q_t) *and net energy advected by ocean currents* (Q_v)

Mean monthly values of Q_t, the amount of heat stored in the water column, are not available for the period 1948–56 because regular bathythermograph soundings have been made by British ocean weather ships only since 1954. However, it can be assumed that over a period of several complete years the value of Q_t would be very small. Hence the average values for Q_c, the energy given up by the ocean, must represent the average amounts of energy advected into the areas by ocean currents and Q_v must therefore have an average value of about 231 gm cal cm^{-2} day^{-1} at station I and about 184 gm cal cm^{-2} day^{-1} at station J. Thus the average annual amounts of heat brought into the two areas by ocean currents amount to about 84,000 and 67,000 gm cal cm^{-2}, respectively. At station I the proportion of the total energy exchanged between the sea and the atmosphere, which is provided by advection of warmer water into the area, thus amounts on the average to about 85 per cent, the corresponding figure for station J being about 75 per cent. The remaining fraction is of course provided by the net solar radiation received by the ocean.

YEAR-TO-YEAR VARIATIONS

The following table shows the variations from year to year during the period 1948–56 of each of the terms Q_s, Q_b, Q_r, Q_e, Q_h, Q_a and Q_c, meaned over the calendar year January to December inclusive.

TABLE IV. *Mean annual values of terms in the energy balance for the years 1948–56 inclusive at ocean weather stations I and J, in gm cal cm^{-2} day^{-1}*

Year	Station I							Station J						
	Q_s	Q_b	Q_r	Q_e	Q_h	Q_a	Q_c	Q_s	Q_b	Q_r	Q_e	Q_h	Q_a	Q_c
1948	132	79	39	*173*	*61*	*234*	*195*	160	86	*58*	182	53	235	177
1949	*123*	*75*	35	200	*94*	*294*	*259*	*152*	*77*	59	193	57	250	191
1950	145	*89*	41	179	70	249	208	166	86	63	*181*	45	226	163
1951	147	88	43	202	85	287	244	166	86	62	*225*	*63*	*288*	*226*
1952	132	76	42	182	63	245	203	166	86	63	189	40	229	166
1953	141	86	41	214	69	283	242	164	84	64	186	37	*223*	*159*
1954	136	86	*35*	213	79	292	257	171	88	*65*	211	51	262	197
1955	147	87	44	202	65	267	223	*172*	*90*	64	196	*33*	229	165
1956	*150*	86	*45*	*218*	75	293	248	167	87	63	217	52	269	206

The variations in the average radiative terms Q_s, Q_b and Q_r from one year to another are relatively small, as might have been expected. Some of the variation that does occur is probably due to variation in the mean position of the stations. For example, the effect of the more northerly positions of both stations before April 1950 can be clearly seen. The remaining variations are due to changes in mean cloud amount, mean sea temperature and mean relative humidity. The annual amounts of heat used in evaporation and in directly heating the atmosphere, Q_e and Q_h (and hence those of Q_a and Q_c) do, however, show quite appreciable changes from one year to another. The variations are relatively the greatest in Q_h but the absolute variations of Q_a and Q_c are such that in one year they may be over 60 gm cal cm^{-2} day^{-1} greater than in another.

VARIATIONS IN *R*, THE BOWEN RATIO

The ratio between Q_h and Q_e is known as the Bowen ratio. Average monthly values were found to vary from 0·18 in July and August to 0·52 in January at station I and from 0·08 in July to 0·36 in December at station J. Extreme values were 0·06 (June 1949) and 0·67 (January 1956) at station I and —0·14 (June 1950) and 0·49 (December 1948) at station J. The overall mean values were 0·37 at station I and 0·24 at station J. The calculations thus support Jacobs' conclusion that *R* is a highly variable quantity, both seasonally and regionally, and is by no means a constant, as had earlier been assumed. They also suggest that *R* increases with increasing latitude.

Table V compares the computed mean seasonal values of *R* for the period 1948–56 at stations I and J with the corresponding values calculated from Jacobs' results, as given in Tables I and II.

There is good agreement between the winter values but those for the other seasons computed from the ocean weather ship data are less variable than those due to Jacobs, mainly because negative values of Q_h have been found to occur only in a few summer months at station J and are not general over the eastern North Atlantic in summer, as indicated by Jacobs' results.

TABLE V. *Seasonal and annual values of R at ocean weather stations I and J, with values derived from Jacobs' results for comparison*

	Winter	Spring	Summer	Autumn	Year
Ocean weather station I, 1948–56	0·50	0·37	0·19	0·31	0·37
Jacobs' values for 59°N 20°W	0·50	0·11	—0·42	0·14	0·23
Ocean weather station J, 1948–56	0·34	0·22	0·11	0·23	0·24
Jacobs' values for 52½°N 20°W	0·28	0·00	—0·85	0·07	0·08

USE OF BATHYTHERMOGRAPH DATA

Where bathythermograph observations are available it is possible to calculate Q_t, the change in heat storage in the water column. It is given by

$$Q_t = c\,\rho \int_0^\infty \delta T_w \, dz,$$

where c and ρ are the specific heat and density of sea water, which may be taken to be 0·93 gm cal gm^{-1} $°C^{-1}$ and 1·026 gm cm respectively, and T_w and z are water temperature and depth respectively. In practice the upper limit of the integral is the depth below which the annual temperature variation is negligible; this seems to be approximately achieved at about 450 feet at stations I and J. This is fortunate because the bathythermograph observations are normally made to a depth of only 450 feet. The integral is evaluated simply by measuring the area between the two relevant descent curves on a temperature–depth diagram. If this area is in °F ft and is denoted by A, and the measurements are made one month apart, then

$$Q_t = \frac{16{\cdot}9A}{n} \text{ gm cal cm}^{-2} \text{ day}^{-1},$$

where n is the number of days in the month.

To obtain some idea of the magnitude of the term Q_t some calculations have been made for the six months July to December 1956 at station J. Means of the soundings made during the two days centred on the beginning and end of each of these months are shown in Figure 3.

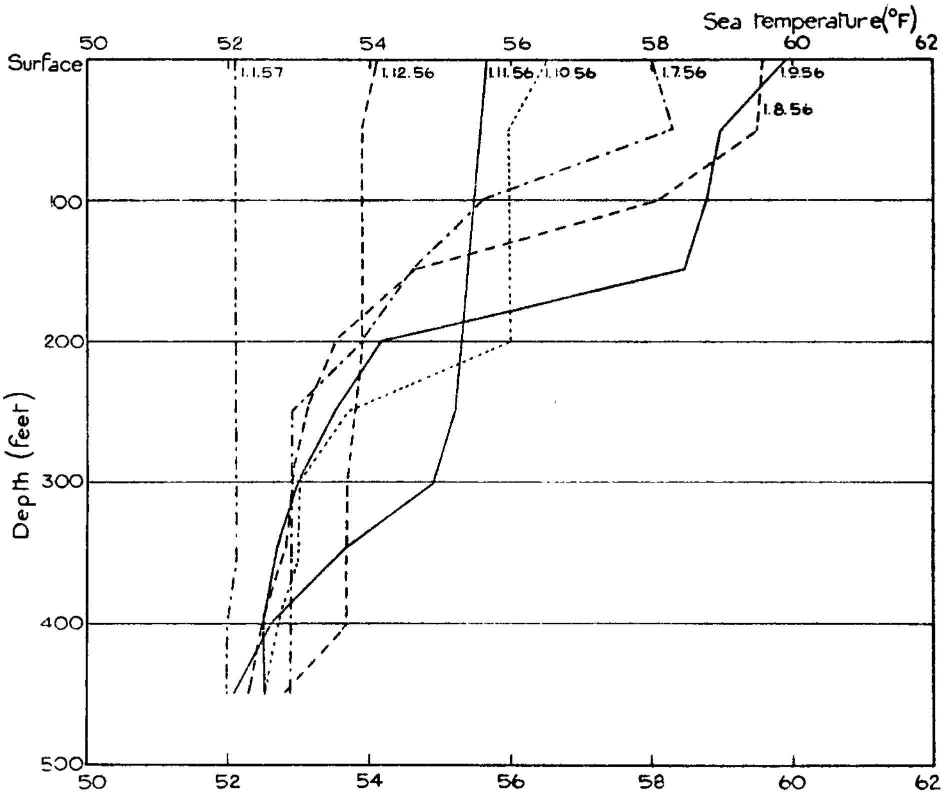

FIGURE 3. Bathythermograph observations at station J at monthly intervals. Each curve is the mean of four soundings taken at 0900 and 2100 GMT on the last day of one month and the first of the next.

The corresponding values of Q_t are as follows:

	July	Aug.	Sept.	Oct.	Nov.	Dec.
			gm cal cm⁻² day⁻¹			
Q_t	91	142	–202	29	–217	–396

It is evident from these figures that Q_t is an important term which must be taken into account when periods which are not a whole number of years are being considered.

It is of interest to examine the values of Q_v, the energy required to be advected by ocean currents in the same six months, using $Q_v = Q_c + Q_t$. They are

	July	Aug.	Sept.	Oct.	Nov.	Dec.
			$gm\ cal\ cm^{-2}\ day^{-1}$			
Q_v	40	269	5	276	132	84

Evidently Q_v varies over wide limits from month to month, although it is usually positive when averaged over such a period. This result suggests that the surface ocean currents in these areas are by no means steady.

SUMMARY AND CONCLUSIONS

(i) Following the general method adopted by Jacobs but using the regular and reliable meteorological observations from the ocean weather stations I and J over the period 1948–56, the magnitudes of various terms in the energy balance have been computed for each month for the two stations and the results summarized.

(ii) The annual variations of the various terms meaned over the nine-year period have been discussed.

(iii) A high correlation has been found between the computed monthly values of the evaporation term at the two stations. A smaller but still significant correlation has been found between the monthly evaporation at station J and the monthly rainfall over England and Wales and a possible explanation for this result has been suggested.

(iv) Comparison between mean seasonal and annual values of evaporation, sensible heat exchanged between sea and atmosphere and total energy exchanged between sea and atmosphere and the corresponding values found by Jacobs for the areas of stations I and J has shown:

(a) that Jacobs' evaporation values may be appreciably too low, especially at station J and in the summer,

(b) that his values for the sensible heat exchange are also too low over the eastern North Atlantic and that his suggestion that it is always negative in summer in this area is not supported,

(c) that seasonal and annual values for the total energy exchange in these areas are consequently considerably larger than suggested by Jacobs, particularly in the spring and summer.

(v) Values for the net energy given up by the ocean in an average year at the two stations have been computed and, on the assumption that all this energy is provided by advection of warmer water, it has been calculated that the average annual amounts of heat advected into the two areas are about 84,000 and 67,000 gm cal cm^{-2} at stations I and J respectively. Of the total energy which is exchanged between sea and atmosphere at stations I and J about 85 per cent and 75 per cent respectively is accounted for by advection.

(vi) Variations from year to year of the various terms in the energy balance during the period 1948–56 have been examined and it has been concluded that they may be considerable.

(vii) The variability of the Bowen ratio is confirmed, but the large negative values found by Jacobs for the eastern North Atlantic in summer have not been found at stations I and J.

(viii) Bathythermograph observations have been used to determine changes in the amount of heat stored in the water column over six periods of a month during 1956, and it has been shown that this is a very important term in the heat balance. Corresponding monthly values of the advection term have thus been obtained and it has been found that this may vary over wide limits.

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