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SEA-BREEZES ALONG THE YORKSHIRE COAST IN THE SUMMER OF 1959

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The invigorating qualities of the climate along the Yorkshire coast have been discussed for generations. Modifying adjectives include rigorous, vigorous, bracing, stimulating, healthful; along with an occasional "bitter", or just plain "cold" from the lesser enthusiast. The inhabitants of this remarkably picturesque part of the English coast are generally quite proud of "their" climate. Indeed, many of them who trace their Yorkshire ancestry back for several generations boast that the health and longevity of the inhabitants are due to the extremes of temperature and wind.

Certainly the Yorkshireman is, for the most, a hardy, happy, healthy individual, who enjoys the sting of a "nor'easter" and the enveloping dampness of the spring "roke". As for myself, having lived for several enjoyable months among these wonderfully kind people, I am not necessarily convinced of the correlation between health, longevity, and the bracing "north-east breezes". Be that as it may, the coastal climate of Yorkshire is one of great interest to those concerned with relating climatic effects to water temperature distribution. It was for this purpose that I spent five months during the summer of 1959 investigating the nearshore oceanography and various meteorological parameters between Flamborough Head and Whitby.

The setting.—Adjacent to the coast and extending from Flamborough Head to north of Aberdeen, a turbulent tide stream results in an almost total mixing of the sea. Because of the configuration of the coast and the sea floor topography, the width of the mixed water varies from 7 to 10 nautical miles at Flamborough Head to 15 to 20 miles in the north. Throughout all of the year the water is nearly isothermal with depth (Dietrich[1]). In the warmer months a distinct increase in the temperature gradient is developed seaward of the mixed area because of surface heating, but in the tide stream, heat is more evenly distributed throughout the water column. This results in the surface water nearshore being considerably cooler than that offshore. As a matter of side interest, bottom water temperatures are higher in the tidally mixed water than they are farther to sea.

Air flowing from the east, originating either over land or sea and passing over the cool nearshore water, is interestingly, and often dramatically, affected in both temperature and moisture content. In order that information might be gained on the rate at which the air cools, it was desirable that temperature and humidity measurements should be made before and after the air passed over the area of cool water. Winds with a local origin were more useful than easterly gradient winds because of the greater ease in determining the entering characteristics of the air. Thus it was, during the summer, that I looked for and eagerly awaited days of land- and sea-breezes.

With the assistance of the Meteorological Office, a weather station was established on Flamborough Head. Records were obtained of the wind velocity and direction, temperature, and relative humidity. During the several days spent at sea to learn the distribution of water temperature, measurements were made every half hour of wind direction and velocity, and wet- and dry-bulb temperatures. From these data, a reasonably complete analysis of the winds is possible for the months of May to September, 1959.

The 1959 summer.—The summer of 1959 in Britain was the warmest and driest for several decades. In some parts of the British Isles, the increased evaporation and lack of rainfall resulted in serious water shortages. Yorkshire, too, experienced a summer far warmer and drier than normal. To exemplify the conditions, let us look at the mean air temperatures for August in several north-east towns.

At Durham, the mean temperature for August 1959 was 61·7°F. It is necessary to go back to the year 1947 before an August mean reached or exceeded this figure. At Scarborough, directly on the shore, the August mean in 1959 was 62·1°F; a temperature that had not been exceeded since the year 1933. At Tynemouth the August mean temperature in 1959 was 60·9°F. This had been equalled in 1954, but had not previously risen to 60·9°F since 1933. In August, Hull had a mean temperature of 64·1°F. This had not been exceeded since the year 1947. So we see that not only inland, but along the coast, too, the temperatures in the summer of 1959 were considerably higher than they had been for a number of years.

It is interesting in this respect to look at the mean air temperatures for Flamborough Head. My hygrothermograph was so located as to record temperatures as near as possible to those of the air over the immediately adjacent sea. Whereas all towns along the Yorkshire coast and inland recorded mean temperatures higher than 60° in August, at Flamborough Head the mean was 59·3°F. This was 1·5°F lower than at Tynemouth and more than 5°F lower than the mean air temperature at York. The same was true throughout all of the summer months. Because the temperatures at Flamborough Head are representative of the air temperature over the nearby sea, the difference between the mean air temperature over water and that over the land is easily noted. This is true regardless of whether the location is taken near the shore, as at Scarborough, Tynemouth, or Spurn Head, or several tens of miles inland, as at York or Durham.

The general synoptic situation over the British Isles during the summer of 1959 was one of higher-than-normal pressure. Throughout all of the warm months, the Azores high pressure area extended well into northern Europe with pressure anomalies as high as +8 millibars. At the same time, the Icelandic low pressure trough exhibited negative pressure anomalies and was displaced somewhat to the west of its normal position. There was, therefore, a decrease in the westerly air transport, and fewer cyclonic passages. Rainfall and cloudiness from frontal activity were minor over the Yorkshire coast. Rain fell at Flamborough Head on only four occasions from May to September. Three of the storms were the result of orographic clouds which had built up over the Pennines and moved across the coastal area.

As can be imagined the winds along the Yorkshire coast varied from the normal. Usually winds with westerly components dominate, with gradient winds from the north-east mainly in the late spring and early autumn months. Wind roses from Spurn Head and Tynemouth exemplify this condition (Figure 1). At Spurn Head, 20 per cent of the winds are from the west, 15 per cent from the south-west, and 17 per cent from the north-west. Less than 10 per cent blow from the east or south-east. North-east winds are present 8 per cent of the time. At Tynemouth, westerly winds are even more common. Here they occur nearly 40 per cent of the time: from the south-west, 20 per cent of the time; and from the north-west, 10 per cent of the time.

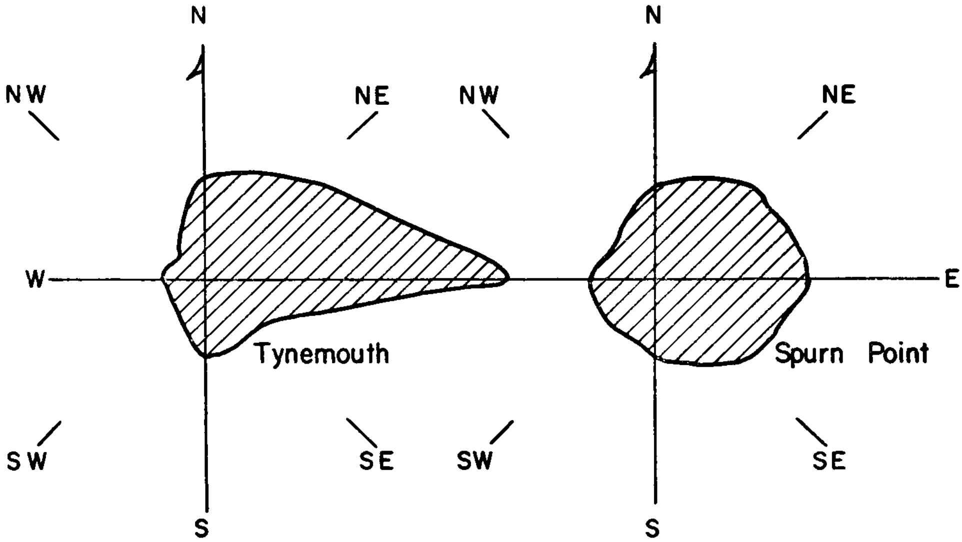

FIGURE 1—DIRECTION OF ANNUAL WIND AT 1300 GMT

At Flamborough Head during the summer of 1959, wind roses show a rather dramatic change from the average (Figure 2). In May more than 20 per cent of the winds came from the north-east with velocities generally higher than 15 knots. Winds were also common from the north, from the east and from the south. This is a distinct change from the normal wind system for the month of May. In June we again see a tendency for the winds to blow from the north. In this month, however, the dominant direction was north-west (25 per cent), but more than 10 per cent still came from the north.

In the month of July there was a definite change from the general northerly flow. Although more than 10 per cent of the winds came from the north-east, winds from the south-west and south blew 22 per cent and 21 per cent of the time, respectively. This change brought in warm southerly air.

In August, the air flow returned to a more normal pattern. Most of the winds were from the north-west, west or south-west, but still with a considerable percentage from north-north-west and north. Easterly winds were minor. In September another change occurred, as the dominant air flow was from the north-east.

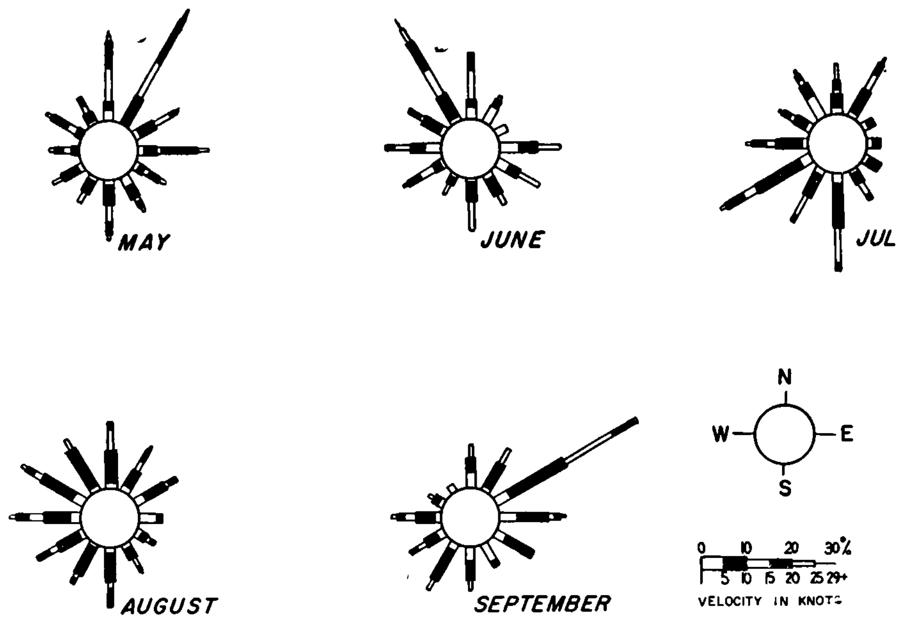

FIGURE 2—MONTHLY WIND ROSES FOR FLAMBOROUGH HEAD, 1959

The sea-breezes.—Local winds along sea coasts, and shores of other large bodies of water, have been studied by many workers and from many points of view. Balkema[2] discussed in considerable detail the sea-breeze phenomenon along the Dutch coast, and reviewed many theoretical papers as they related to his findings. Defant[3] has given a good summary and a good bibliography. The effect of the winds on health has been noted by Bilham,[4] and Stevenson[5] has shown the effect on nearshore waters. These papers, although few in number and not necessarily chosen for their importance, indicate the range of study that has been involved. The interested reader may refer to the bibliography in Defant's report for more articles, both theoretical and empirical.

In many areas, where geographical conditions are similar, land- and sea-breezes are also similar in their occurrence and characteristics. However, frequently one notes that workers investigating more or less the same area have quite dissimilar views and/or results. Such situations are difficult to understand, even though the studies might have been carried out at considerable intervals of time. Despite the fact that north-western Europe has experienced a secular climatic change in the past few decades, it is not realistic to assume that such a variation would drastically effect a local condition. I must assume, therefore, that many of the differences indicated in land- and sea-breeze occurrences, longevity and frequency, must be a matter of definition.

To be sure that all understand which winds I included in the category of land- and sea-breezes, I give this explanation. If in any 24-hour period there occurred a definite diurnal change in wind direction, from land–sea–land, this wind system was considered as a "land–sea" breeze. Occasions when an easterly wind was blowing and the velocity increased during the time of maximum insolation were classed as a "sea-breeze tendency", but not as a sea-breeze. These latter conditions were quite common in May and September when north-east gradient winds blew for several days at a time. These cannot be called "sea-breezes" for the air moves with the general pressure gradient as the motive force, and not due to any local thermal displacement of air.

Those days from 1 May till the end of September when a diurnal wind shift occurred numbered thirteen in all. These, to me, are incredibly few occurrences along a coast which is renowned for its winds from the sea, and it seems especially surprising in view of the nature of the 1959 summer. During these months, a minor cloud-cover allowed maximum insolation, so that there were many days when strong convective currents occurred inland. Differences in air temperature over the land and sea along the Yorkshire coast were often of the magnitude of 15–30°F. Yet, on few of these days did a sea-breeze occur, and on no consecutive days during the five-month period was there a "land–sea" breeze sequence. I do not in this report attempt to explain this apparent anomaly, but rather to relate the synoptic conditions when a sea-breeze was active.

The synoptic situation during the occurrences of sea-breezes.—The days during which a diurnal reversal of winds resulted from local heating were most common in June and July. A land- and sea-breeze system was evident on two days in May, one day in August, and on five days each in June and July. Such a distribution of occurrences is in itself somewhat surprising, in view of the fact that higher temperatures were recorded on certain days in August and September than in the other months. The lack of the phenomenon in September and the few days in May, can be accounted for by the constancy of strong gradient winds. To some degree, therefore, the absence of dominant pressure gradients in June and July may explain the greater number of local winds.

As I have mentioned previously, the general synoptic situation over Britain during the summer was one of domination by the Azores high pressure system. Despite this, high pressures were not uniformly constant over the British Isles. Many minor variations in the synoptic pattern occurred, but we can note that certain conditions existed on each day when there was a sea-breeze. In every instance the isobars were oriented so as to extend in either a north-west to south-east, or a north to south direction along the coast, and they were widely spaced so as to present a negligible pressure gradient. Each day was mainly cloudless; the humidity was 70 per cent or less prior to the beginning of the sea-breeze; and the coast had been unaffected by gradient winds for 24 hours or more preceding the sea-breeze. In this last respect, it is of interest to note the common existence of an inversion layer overlying the nearshore water and the coast on all days of low wind velocity, regardless of the direction of air flow.

At this point I must say that the conditions just noted were not necessarily restricted to days when land- and sea-breezes occurred. Let us examine the synoptic situation from 14 June to 19 June to exemplify the varying patterns. Sea-breezes blew on the 14th, the 16th and the 19th.

On 14 June (Figure 3), an ellipsoidal high pressure area, centred more or less over Ireland, extended across England. A shallow pressure gradient existed over the central North Sea, but there was little or no gradient over the Yorkshire coast. A sea-breeze began to blow at about 1100 GMT, with a consequent drop of air temperature from 64°F to 54°F in two hours, and a concurrent rise in relative humidity from 60 to 94 per cent. The barometric pressure began to decrease at 1200 GMT from 1042 millibars and levelled off at about 0000 GMT at 1032 millibars.

The following day saw the low pressure system to the north move over the Baltic Sea with a north-west to south-east oriented cold front extending through the central North Sea and across Scotland. Again isobars were north to south

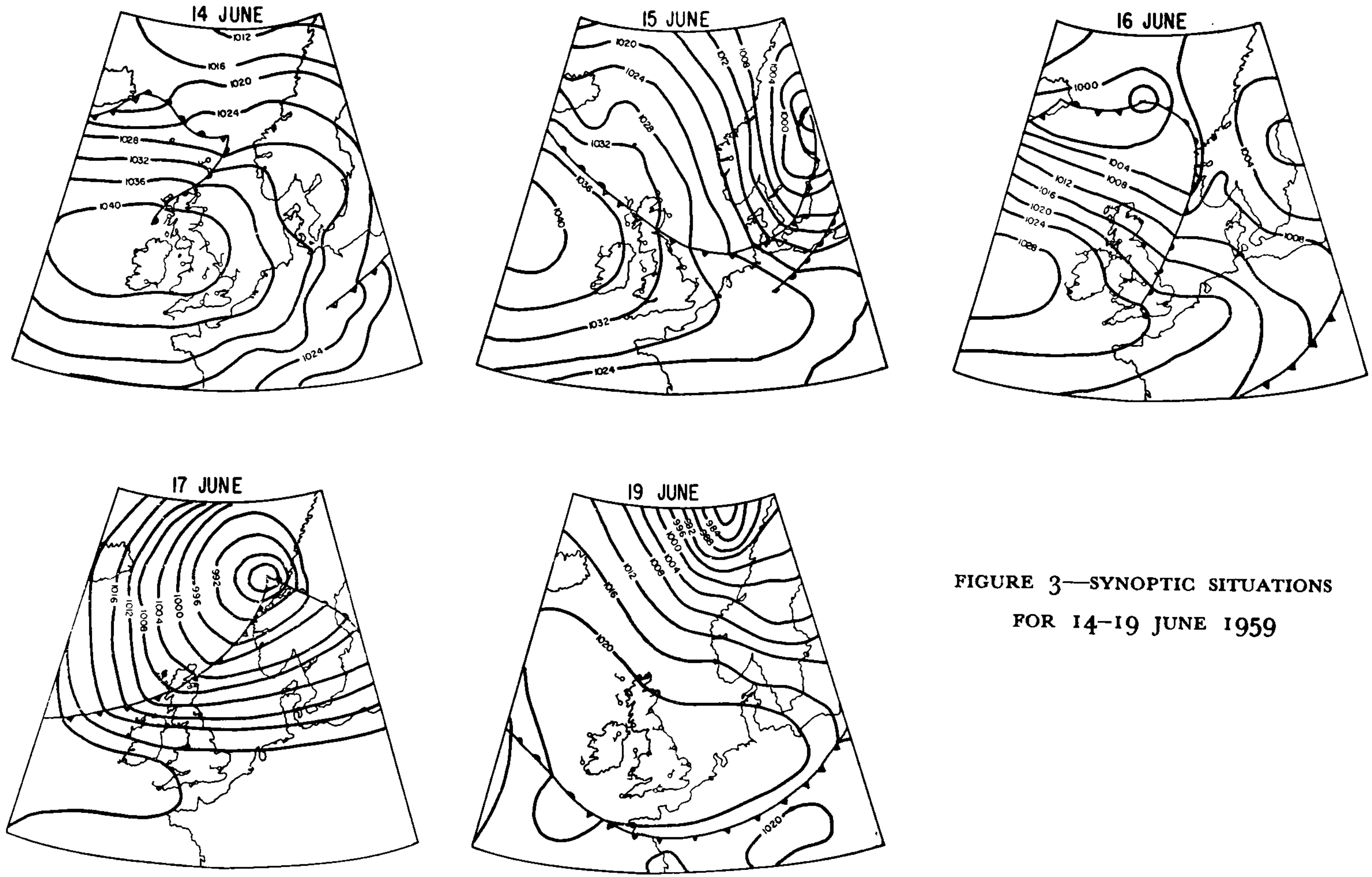

FIGURE 3—SYNOPTIC SITUATIONS
FOR 14–19 JUNE 1959

along the Yorkshire coast and rather widely spaced. North-west winds blew throughout the day. The barometric pressure continued to decrease and had reached 1026 millibars by midnight.

At midday, 16 June, a sea-breeze had been blowing for one hour and continued until about 1500 GMT. The air temperature dropped from 65°F to 58°F during this period, and the relative humidity rose from 55 to 80 per cent. The synoptic chart for this time shows a minor warm front crossing the coast. However, the barographic trace, although continuing to register a pressure decrease at Flamborough Head, gives no indication of a frontal passage. The rather rapid fall of pressure during this period is indicative of the approaching low pressure area north of Britain and the southerly course of the high pressure system south-west of Ireland.

By 1200 GMT on the 17th a strong pattern of westerly air flow, associated with the north-east to south-west oriented cold front, came over central and northern England. The air temperature rose to 72°F at Flamborough Head, and relative humidity dropped to 40 per cent. Each indicates the effects of the land mass on the air. The gradient flow easily dominated the winds on this day. On the 18th the frontal system continued to move south-eastwards and the following air flow, mainly from the north-west, brought low temperatures throughout the day. The pressure gradient was still strong and north-westerly winds occurred.

Pressures continued to rise irregularly on Friday, 19 June, and had reached 1023·5 millibars by 1000 GMT at which time a light breeze began from the sea. A high pressure system was centred over central England with ridges extending over north-east Europe and Iceland. This high pressure area continued to build during the following day, when the centre crossed the Yorkshire coast between 0900 and 1500 GMT. On this day, the 20th, however, no sea-breeze occurred.

Within this short period of six days in June there was a considerably varied series of cyclonic and anticyclonic activities affecting the Yorkshire coast. Yet, during these days there were the most closely spaced occurrences of land- and sea-breezes during the 1959 summer. They blew at times when one might have expected them to be precluded by the synoptic situation. Also there was a day (the 20th) when, with scattered clouds and no appreciable pressure gradient, the sea-breeze was absent. This latter condition, anomalous as it seems, was to occur with great frequency throughout the summer.

A high pressure sequence in July.—I believe at this time that the anomalous situation I have just mentioned deserves further elucidation. I have, then, chosen a period of 15 days in July when the pressure remained rather constant along the Yorkshire coast as a result of a continued series of high pressure areas. This was a period of maximum daytime temperatures above 60°F over the water (70°F on two days), and with night minima only once going below 54°F. Inland, some of the highest temperatures of the summer were recorded. A sequence of minor fronts occurred until the 18th, but from that day until the 25th a high pressure centre remained over England. Skies over the coastal area were mainly cloudless. Nevertheless, despite what seemed to be a condition when daily sea-breezes might blow, they occurred on only four days: the 14th, 19th, 21st and 24th. This last day nearly closed the activity for the summer, for it was not until 26 August that another sequence was to occur, and this, indeed, was the finale for the summer.

On 14 July the barometric pressure reached 1021 millibars at 0900 GMT. There were gradual falls and rises with a range of 5 millibars until the 19th, followed by a steady rise to 1024 millibars on the 20th. Pressures remained about 1020 millibars until the 25th when a steady fall preceded a frontal crossing on the 27th. Pressure gradients accompanying the passages of the minor fronts were gentle and not so disposed as to result in even moderate winds (Figure 4, 21 July). Between the fronts, gradients were negligible (as on the 19th). Conditions were such that one might have expected a complementary sequence of sea-breeze. Such was not the case.

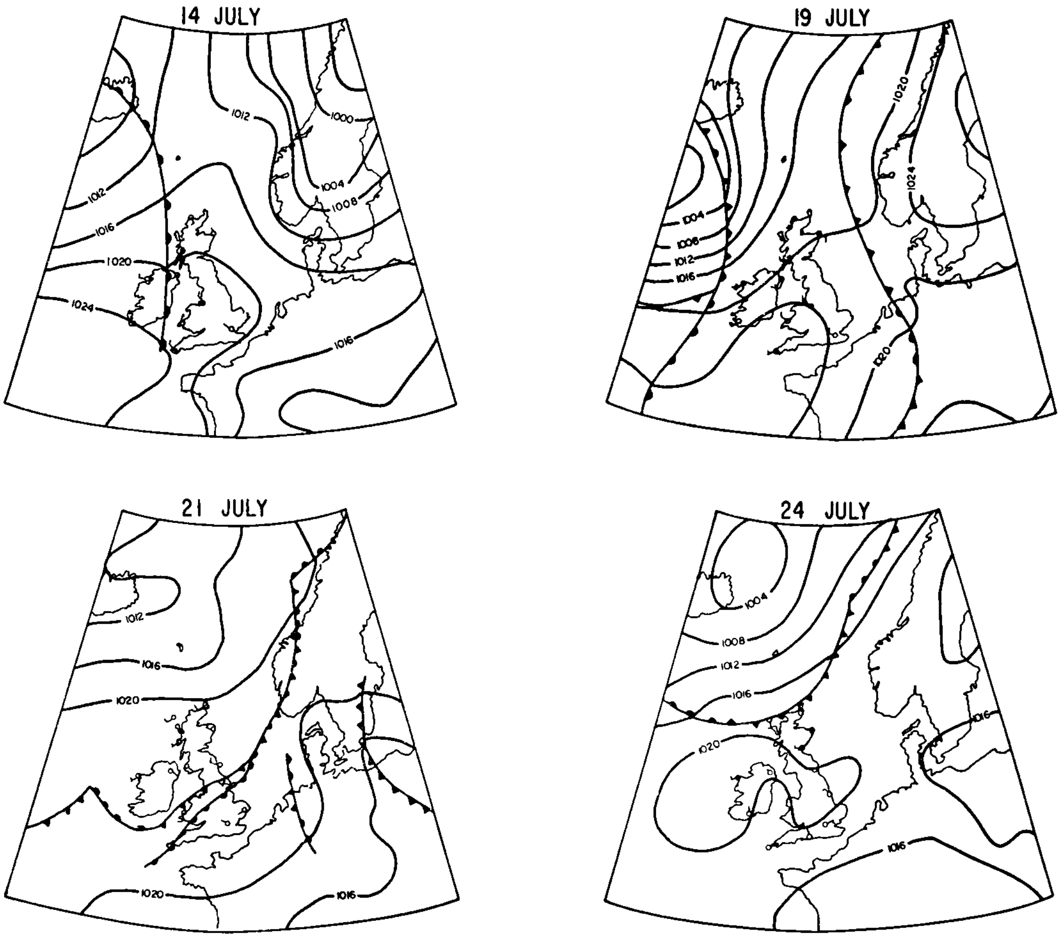

FIGURE 4—SYNOPTIC SITUATIONS FOR 14–24 JULY 1959

Of the sea-breezes that blew in July, that on the 19th was the only system that had any dramatic cooling effect, velocities greater than six knots, and a longevity of more than four hours. On this day the breeze began at about 1100 GMT, and continued to blow until 2000 GMT. Temperatures at the coast decreased by 4°F in a matter of minutes, and then continued their fall more gradually till 2000 GMT. The range was from 70° to 56°F at Flamborough Head and from 73·5° to 66°F some 10 miles inland. The breeze blew from the east-south-east, with a maximum velocity of 12 knots. At 1500 GMT it reached its greatest intrusion landward of 15 miles (Figure 5). At the boundary, a dramatic rise in temperature of some 5°F occurred in a distance of 200 yards where the easterly air flow met the general westerly flow from inland areas.

I shall not here go into further descriptions of the synoptic situations which might have been expected to result in sea-breezes, but there were many others, particularly a fortnight in August when a breeze blew only on the 26th. The examples described are, I believe, adequate at this time to illustrate the rather interesting lack of such local winds in the summer of 1959.

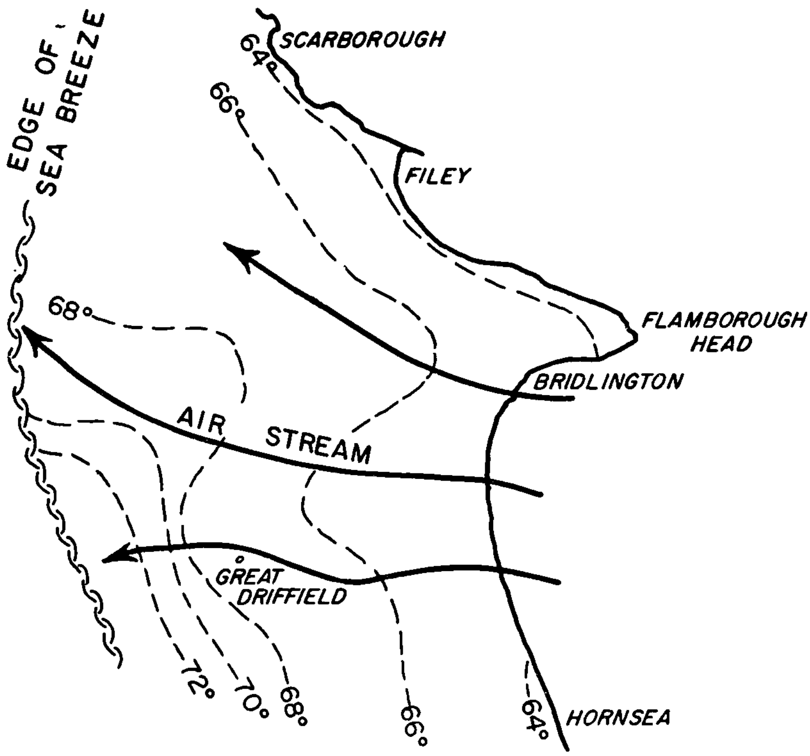

FIGURE 5—TEMPERATURE DISTRIBUTION FROM 1000–2100 GMT, 19 JULY 1959

Résumé.—It would be a presumption were I to conclude from the data gathered in 1959 that sea-breezes represent merely 8 per cent of the winds blowing over the Yorkshire coast in the summer months. Certainly there were several periods of consecutive days with north-easterly winds. On many such days the velocity of the wind rose appreciably (often to 20 knots) during the warmer hours. This must indeed be indicative of vertical air displacement inland allowing for augmentation of the easterly gradient flow. Again, there were many days, especially in August, when south-westerly or westerly winds blew night and day with a minor but distinct decrease in velocity beginning near midday. This, too, must be indicative of a sea-breeze tendency.

In this respect, I feel we must be definitive in those winds included in the category of land- and sea-breezes. An augmentation and/or retardation of velocity must not be compared, or confused, with the regularity of the diurnal reversals along tropical coasts; nor can they be analysed along with the less regular, but quite continuous, occurrence of the sea-breeze in the more temperate Mediterranean areas.

The summer of 1959 in England, one of the warmest and driest on record, would have been, it would seem, an ideal period for the maximum development of local coastal winds. A diurnal reversal, attributable to local heating and cooling, occurred on 13 days at Flamborough Head. (Two of these occasions might actually be suspected to be the result of passages of minor fronts. On one of these days, however, when two fronts were indicated on synoptic charts as crossing the area, the depression of pressure by merely one millibar might cause one to suspect frontal existence.) Such a number seems to be low indeed, for an area which has been previously described as one where sea-breezes blow for "days on end". I must admit, therefore, that my feelings are more disposed towards the belief that gradient winds are far more important here than land- and sea-breezes.

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VARIATIONS IN 200-MILLIBAR FLOW IN THE TROPICS

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Introduction.—In a recent note Murray[1] drew attention to the unusually strong westerly winds over Aden at 200 millibars in January 1958, and pointed out that such large variations of monthly mean flow could be accounted for by displacements of a few degrees latitude in the mean position of the subtropical westerly or equatorial easterly jet streams, without regard to changes in their average intensity. Upper wind observations in the east Indian Ocean area suggested that abnormally strong westerlies or weaker easterlies prevailed in low latitudes during this month, and it was thought of interest to examine the data for other stations to see over how wide an area this was the case, since widespread variations in upper flow are probably connected with variations in the north-east and north-west monsoons. Since data were available for three stations in the one longitude (at and on either side of the equator) it was also of interest to see to what extent shifts of position or changes in intensity of the equatorial easterly maximum contributed to the variations of the flow as observed at one station.

Data sources.—The data used in this study have been taken from a number of sources. Daily data are provided in: *Daily Weather Report,* Overseas Supplement; Malayan Meteorological Service, *Pilot Balloon Data* and *Radar Wind Data;* New Zealand Meteorological Service, *Pacific Islands Bulletin;* and the microcards of the International Geophysical Year data published by the World Meteorological Organization. For some stations under Australian control, manuscript data were kindly provided by the Director of Meteorology, Commonwealth Bureau of Meteorology. Monthly and seasonal means have been computed from the above, or taken from the values given in: *Upper air data for stations maintained by the Meteorological Office;* United States Weather Bureau, *Monthly climatic data for the world* and *Climatic Data,* National Summary; and from publications by Clarkson[2], Phillpot[3], Ramage[4], Joint Task Force Seven[5], and Crutcher[6].

Distribution of anomalies in the 200-millibar zonal flow.—Only the zonal component of the flow will be considered here, since this is the relevant quantity for consideration of the north – south displacements of the mean jet stream (although this component is also affected by other factors). The changes in meridional component would reflect to a greater extent east – west movements of the mean troughs and ridges, and also, if averaged over large areas, the changes in the mean meridional circulation; for an understanding of the dynamics of the process it would be necessary to consider this component as well.

In Figure 1 are shown mean zonal components at 200 millibars for January 1958 and their departures from the average value over several years for a number of stations in the East Asian and Pacific region. West components are positive, and departures are positive (westerly anomaly) when the west component is stronger, or the east component weaker, than average. Except for Christmas Island, Lae and Majuro, all averages are for five or more years' data.

It can be seen from Figure 1 that a marked westerly anomaly greater than 10 knots extends over East Asia and the east Indian Ocean to about 120° E and at least twenty degrees of latitude on each side of the equator. There is a marked easterly anomaly over the equatorial central Pacific. Strong upper westerlies also occurred over India (not shown); the mean zonal component over Madras (0001 GMT) was 40 knots. Rawin averages for India have not been published, but available cross-sections for winter[7,8] suggest an average of 20 knots for the latitude of this station, 13° N. It thus appears that the westerlies were stronger or easterlies weaker than usual over almost a quadrant of the tropics. The anomaly at Aden is the largest one observed.

Since means are computed by calendar months, it could be that the anomaly for January 1958 is in a sense an accident; similar periods occurring partly in one month and partly in another would be averaged out or reduced. However it appears that the anomaly is an intensification of a general trend; seasonal (December – February) averages for the period December 1957 to February 1960 show similar behaviour to the averages for January 1958 when compared with averages for an earlier period centred around 1953. Values for several stations are set out in Table I.

TABLE I—DECEMBER – FEBRUARY AVERAGES OF THE 200 MB ZONAL COMPONENT AND DIFFERENCES FROM THESE FOR THE PERIOD DECEMBER 1957 – FEBRUARY 1960

Station	Period	Zonal component *knots*	Difference for Dec. 57 – Feb. 60 *knots*
Nairobi	Dec. 1949 – Feb. 1954	—15·8	+10·6*
Aden	Dec. 1948 – Feb. 1955	+20·0	+ 6·5
Singapore	Dec. 1951 – Feb. 1955	—21·2	+ 6·3
Koror	Dec. 1950 – Feb. 1957	—19·4	+ 2·2†
Darwin	Dec. 1952 – Feb. 1957	— 5·1	+ 3·3
Guam	Dec. 1949 – Feb. 1957	— 2·1	+ 1·8‡
Wake Is.	Dec. 1949 – Feb. 1957	+26·8	+ 1·7
Truk	Dec. 1951 – Feb. 1956	—11·2	— 0·9
Canton Is.	Dec. 1949 – Feb. 1957	+ 8·4	— 9·2
Johnston Is.	Jan. 1950 – Dec. 1956	+31·1	+ 3·3
Hilo	Dec. 1950 – Feb. 1957	+43·3	+ 5·4 §

Westerly zonal components are positive, easterlies negative.
*Dec. 1958 – Feb. 1960 only.
†Feb. 1959 not included.
‡Jan. 1959 not included.
§200 mb value for Feb. 1959 extrapolated from 250 mb value.

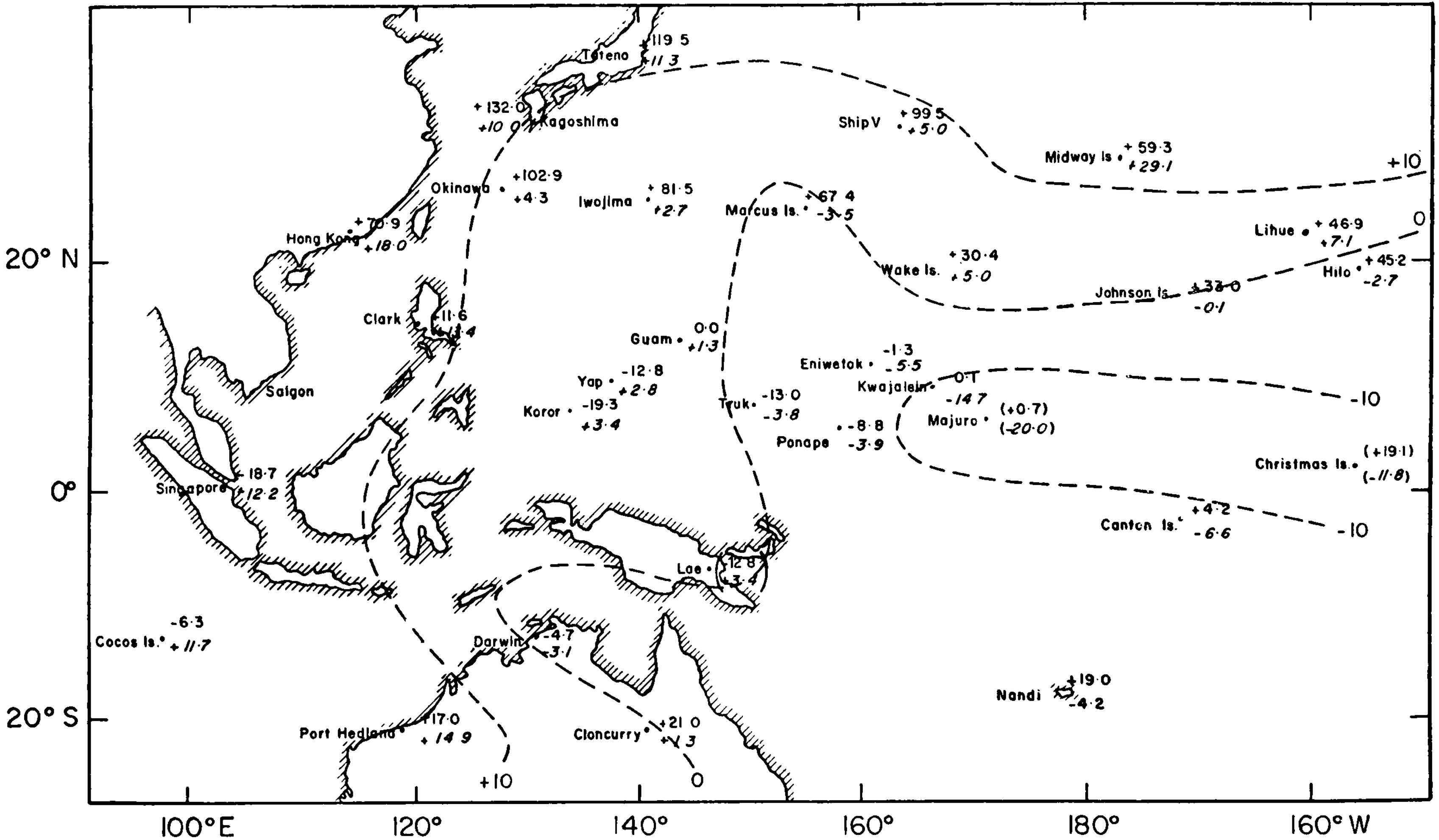


FIGURE 1—200 MB MEAN ZONAL WIND AND DEPARTURE FROM AVERAGE OVER EAST ASIA AND THE WEST PACIFIC, JANUARY 1958

Upper figures represent the 200 mb mean zonal wind in knots (westerlies positive) and the lower figures and isopleths the departures from average.

It can be seen that in particular the westerlies are stronger or easterlies weaker over the Indian Ocean region (Nairobi, Aden, Singapore) in the later period, while in the equatorial central Pacific (Canton Island) there is an opposite tendency. Where monthly averages are available the differences given in Table I are computed from monthly means; from these it appears that over the North Pacific the differences between earlier and later periods are most marked in December, but in the other regions any or all months can contribute. Some part of this effect at the higher-latitude stations is probably due to improvement in observing techniques, with fewer losses due to strong winds at high levels, particularly in connexion with the International Geophysical Year. However this would not apply at the lower-latitude stations where the upper winds are not as strong, nor where (as at Singapore) the effect is in the opposite sense to the direction of the strong mean winds.

Relative significance of speed changes and displacements in equatorial regions.—Climatologically, the strong upper easterlies over Asia during northern summer later weaken and move southwards, while the westerlies to the north increase, until in January – February the easterly maximum is located just south of the equator. The observations in January 1958 at 100° – 120° E indicate that in this region at least the anomaly is not due to southward displacement of the northern hemisphere westerly jet and a concomitant displacement of the equatorial easterlies, since one would then expect an easterly anomaly at Cocos Island. Nor is it due to the occurrence of the easterly jet at a higher level than usual, since the easterly at Singapore at 50,000 feet was weaker than at 40,000 feet. It rather appears that symmetry with respect to the equator tends to be preserved; the jet streams of both hemispheres were displaced equatorwards, with weakening of the intervening easterlies. This might imply as a synoptic process alternate north – south shifts of the easterly maximum combined with a general decrease in its strength; but inspection of the daily values shows that the variations can be in the same sense on both sides of the equator. In Figure 2 daily values (0001 GMT) of the 200-millibar zonal wind components are plotted for Saigon, Singapore and Cocos Island (in approximately the same longitude) from November 1957 to March 1958. The Aden values are also given for comparison. It will be seen that on several occasions major variations are in the same sense, at or about the same time. Note, for instance, the change at all three stations at the end of November and beginning of December, and the westerly flow at the beginning of January.

Quantitatively, this common variation may be expressed by correlation coefficients; these (together with their significance levels) are, for the period December 1957 to February 1958, Cocos Island – Singapore +0·40 (10 per cent), Singapore – Saigon +0·64 (1 per cent) and Saigon – Cocos Island +0·29 (above 10 per cent). The significance levels have been computed taking into account the values of auto-correlation coefficients for Singapore, which indicate that 90 days' observations correspond only to 18 independent ones. In view of the fact that the easterly maximum lies close to Singapore during this season, the existence of positive correlations at this station with stations both north and south of it indicates that overall changes of flow intensity at this time of year predominate over north – south shifts of the speed maximum. On some occasions the easterly stream is entirely disrupted, presumably by extended troughs[9] reaching the equator in both hemispheres at or about the same

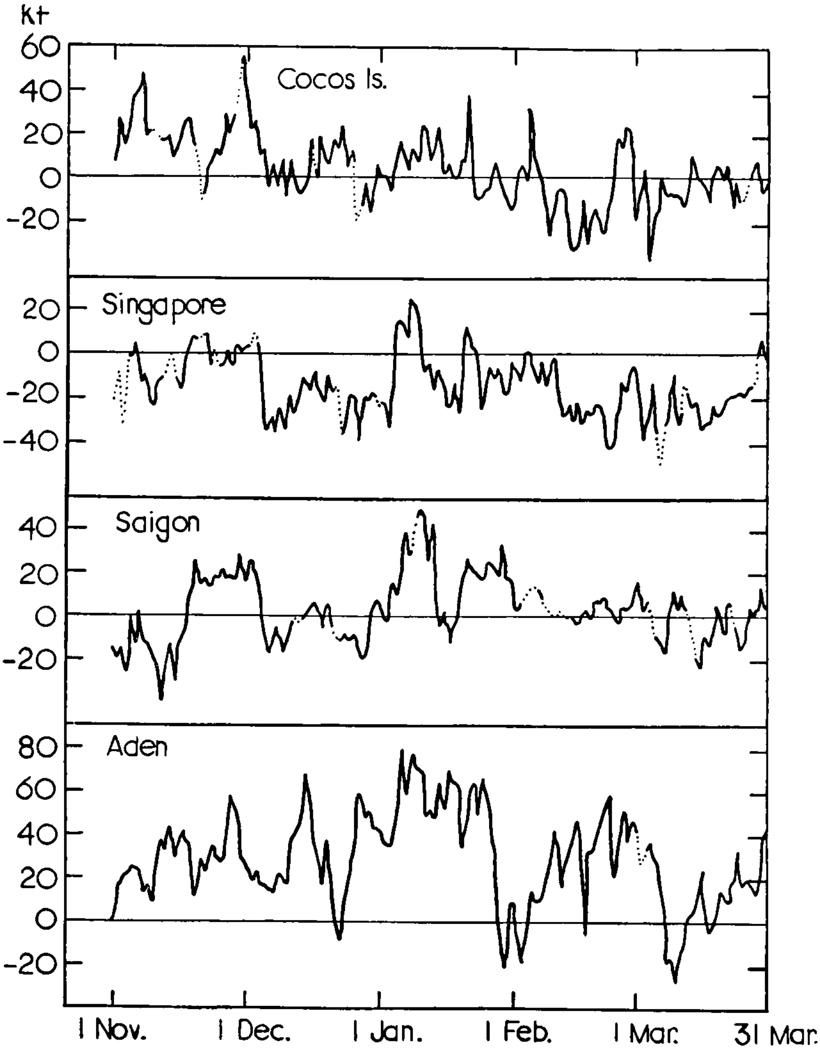
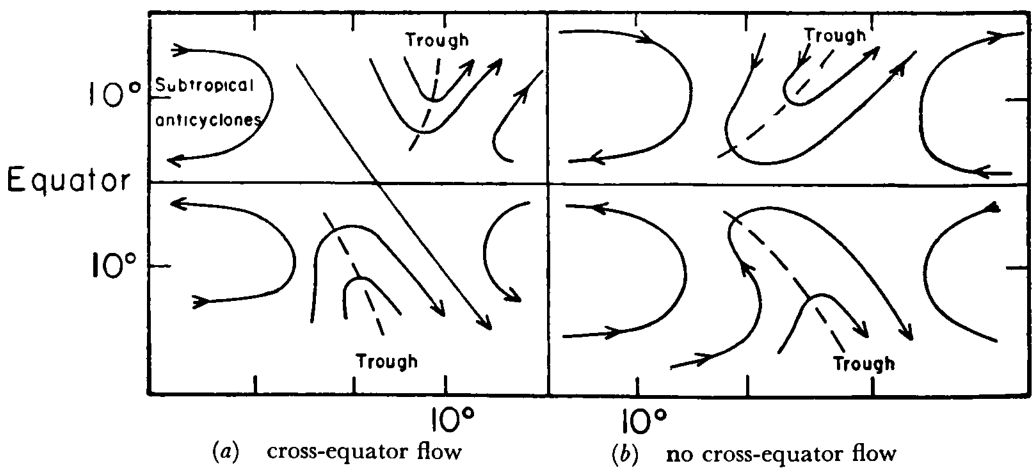


FIGURE 2—200 MB ZONAL COMPONENTS IN KNOTS, 0001 GMT, NOVEMBER 1957 – MARCH 1958

Westerly components are positive, easterlies negative. Dotted lines indicate interpolated values; for Cocos Island and Singapore they were interpolated from 1200 GMT observations when available.



(*a*) cross-equator flow (*b*) no cross-equator flow

FIGURE 3—STREAMLINE PATTERNS WITH EQUATORIAL WESTERLY ANOMALY

longitude, as in the suggested streamlines given in Figures 3(*a*) (cross-equator flow) and 3(*b*) (no cross-equator flow). Such situations are common over the central Pacific at certain seasons, appearing even in the monthly means[7]; they are presumably much less common in the Asian region.

Similar correspondence in the fluctuations at Cocos Island and Singapore has been observed in other years, though not in all, and also an almost simultaneous formation and dissipation of westerlies in low latitudes extending to the equator in both hemispheres at this longitude. The correspondence extends to the monthly means if the seasonal trend is excluded; for example, the departures from the monthly means for December to February are given in Table II for Singapore and Cocos Island for the five years of common rawin observations. Departures of the same sign occur in nearly all months; if this is expressed as a correlation coefficient, the value is +0·81.

TABLE II—DEPARTURES FROM MONTHLY MEAN AT 40,000 FEET AT SINGAPORE AND COCOS ISLAND

Dec.	Singapore	Cocos Is.	Jan.	Singapore	Cocos Is.	Feb.	Singapore	Cocos Is.
	kt	*kt*		*kt*	*kt*		*kt*	*kt*
1955	− 1·8	− 3·4	1956	− 7·9	−10·0	1956	− 6·5	− 7·8
1956	− 5·1	− 5·4	1957	+ 4·6	− 3·3	1957	− 0·7	− 3·6
1957	+ 1·5	+ 6·2	1958	+ 9·4	+11·6	1958	+ 3·3	+ 3·6
1958	+ 5·5	+ 7·4	1959	+ 0·4	+ 0·9	1959	+ 5·1	+11·5
1959	− 5·2	− 4·6	1960	− 6·5	+ 1·0	1960	− 1·3	− 3·2
Mean	−20·5	− 1·2		−15·9	− 6·2		−20·9	− 9·6

Conclusions.—The strong westerlies in January 1958 observed at Aden are part of an anomaly that extended over the Indian Ocean area, apparently being most marked in the west of the region. This was an intensification of a general tendency for the upper tropical easterlies to be weaker during the latter part of the decade 1950 – 60 than in the earlier part. In low latitudes, changes in intensity dominated shifts of the climatological jet streams in producing this result.

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VISIBILITY IN PRECIPITATION

By G. J. JEFFERSON, M.Sc.

Many forecasts of horizontal surface visibility contain phrases such as "reduced in precipitation to" or "falling in rain to", preceded and followed by forecast visibilities out of and in precipitation respectively. Such subjective estimates may vary widely as to how much visibility is reduced by precipitation of various kinds.

The reduction of visibility by precipitation depends on the size, number and nature of the elements of which it is composed and their uniformity over the area around the observer containing the visibility points. It also depends to some extent on the increase of humidity due to evaporation from the precipitation itself.

It is stated in the *Handbook of aviation meteorology*[1] that light rain has little effect, moderate rain usually gives a visibility of 2–6 miles, while heavy rain (as the term is used in temperate latitudes) reduces visibility below 1000 yards. In drizzle it varies from two miles to 500 yards and is commonly below 1000 yards in moderate snow and from 200 to below 50 yards in heavy snow.

In an appendix to a study of atmospheric opacity, Wright[2] calculates the reduction of visibility to be expected in moderate rain. He suggests that a reduction from code figure 8 (old International Code 12½–30 miles) to 6 (2½–6¼ miles) and from 6 to 5 (2200 yards—2½ miles) is to be expected.

Recent work in the U.S.S.R. indicates more precise relationships between visibility and precipitation. Poljakova[3] derives the following formula connecting rainfall intensity and visibility:

$$S = 14 I^{-0 \cdot 74},$$

where S is the visibility in kilometres and I the intensity of rainfall in millimetres per hour. This relation is based on 59 observations of the micro-structure of rain, 40 at Leningrad and 19 at Čakvi, near Batumi on the Black Sea. The coefficient of diminution of light and the intensity of rainfall were in each case calculated from the measured drop-size spectrum, using equations previously derived and described in an earlier paper. Visibility S in kilometres is taken as being related to α the coefficient of diminution of light per kilometre by the relation $\alpha = 3/S$. The observations gave a correlation coefficient of 0·95 between log α and log I. Using Poljakova's formula, the visibilities for the upper limits of slight rain (0·5 millimetres per hour) and moderate rain (4 millimetres per hour) are 12·6 and 2·7 nautical miles respectively.

In another paper, Poljakova and Tret'jakov[4] describe experiments to ascertain the visibility to be expected in falling snow. Using cone-shaped collecting funnels of carefully computed shapes and dimensions, the rate of snowfall was measured and recorded and is expressed as an equivalent rate of rainfall in millimetres per hour. The transparency was measured by a light and a photo-electric cell over a base line of about 200 metres. Using 68 observations at Leningrad they derived for snow the formula

$$S = 0 \cdot 94\, I^{-0 \cdot 91}$$

where S is again the visibility in kilometres and I is the intensity of snowfall equivalent to rainfall in millimetres per hour. The correlation coefficient between log α and log I is in this case 0·91. An approximate form of the formula is the very simple relation

$$S \simeq \frac{1}{I}.$$

Assuming the depth of snow to be ten times the equivalent depth of rainfall, this formula gives visibilities of 0·95 nautical miles (1940 yards) and 0·14 nautical miles (286 yards) for the upper limits of slight snow (0·5 centimetres per hour) and moderate snow (4 centimetres per hour) respectively.

Richards[5], being concerned to provide a method of forecasting the hourly rate of accumulation of snowfall from observed visibilities, has approached the subject from a different viewpoint. He used 193 cases at Malton Airport, Canada, from the months of December to March in the years 1941–52. Observed visibility is plotted against measured hourly snowfall accumulation. Although the scatter is rather wide, he has drawn a smooth curve based on average rates of accumulation computed for certain ranges of visibility. This curve is reproduced in Figure 1 together with a curve derived from the formula of Poljakova and Tret'jakov and it is evident that there is fairly good agreement between them. Richards' curve gives a slightly greater visibility for 0·5 centimetres of snow per hour than Poljakova and Tret'jakov, but his curve does not extend above the rate of fall of 1·6 centimetres per hour.

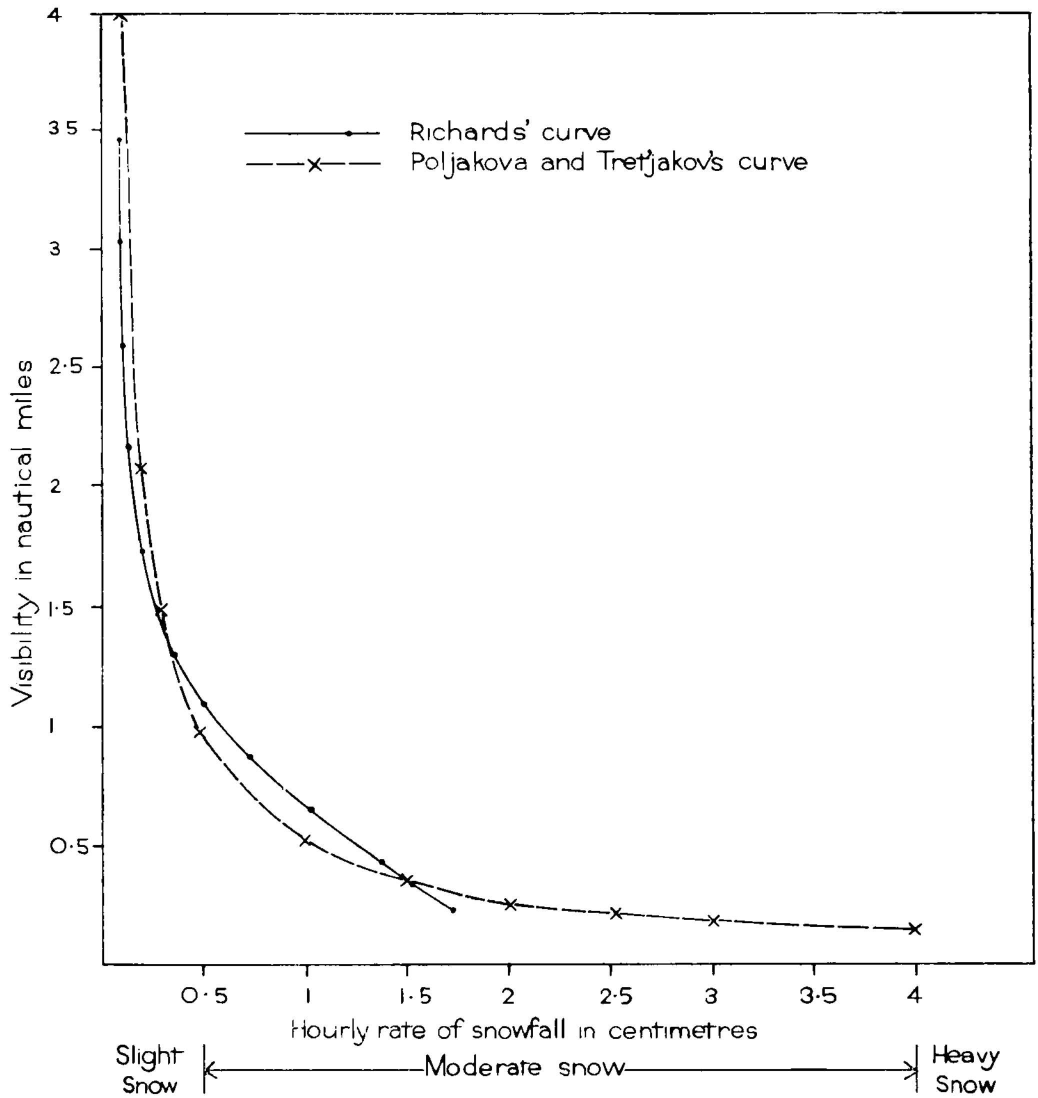

FIGURE I—CURVES RELATING VISIBILITY AND RATE OF SNOWFALL

A short investigation of a different kind has been made into the relation between visibility and the different types of slight or moderate precipitation. It is important to distinguish as far as possible between actual reduction of visibility by the falling elements of precipitation and any reduction by pre-existing fog, or fog (such as frontal fog) formed by the precipitation itself. The use of ocean weather station observations on the eastern North Atlantic has probably fulfilled these conditions as well as possible. Radiation and up-slope fogs and smoke pollution are eliminated whilst the data themselves show that other forms of fog are not common in precipitation. The use of ocean weather station data has also had the additional advantage that most of the required observations are available in punched card form.

The estimation of visibility at sea is handicapped by the absence of fixed objects which are used at a land station and visibility is reported in only one figure. Visibility is reported by ocean weather ships in the International Code figures 90–99[6] in which the ranges of visibility expressed as the second code figure are those of the old International (before 1949) Code. American weather ships at ocean weather stations "A" and "C" reported in the American ship code until approximately 1954 and 1956 respectively. The change-over was gradual, as some American ships commenced to use the International 90–99 Code before others, and no precise date can be given. The observations have, however, been analysed so that the differences are small. The only limits derived from the American code which are significantly different are:

Code figure	American	International
91	0·1 n. miles	>55 yds.<0·1 n. miles
92	0·2 n. miles	0·1 n. miles

This, affecting poor visibility, makes little difference to the results here presented.

The stations considered in the investigation were ocean weather stations "A", "C", "J", "I" and "M" and the observations used were for 1500 GMT for the first two and 1200 GMT for the others. This choice ensured that so far as possible all the observations were made in full daylight, although ocean weather station "M" lying just south of the Arctic Circle experiences almost total darkness for a short period centred on the winter solstice. The periods of observation used are shown in Table I.

TABLE I—PARTICULARS OF STATIONS FROM WHICH DATA WERE USED

Ocean weather stations	*Position*	*Period of observations used*	*Remarks*
"A"	62°N, 33°W	Jan. 1953–Dec. 1959	American ship's visibility code used for some observations until December 1954.
"C"	52°45′N, 35°30′W	Jan. 1953–Dec. 1958	American ship's visibility code used until about 1956–57. The change-over was gradual.
"J"	52°30′N, 20°W	Jan. 1953–Dec. 1959	Ocean weather stations "J" and "I" were at one time in slightly different positions.
"I"	59°N, 19°W	Jan. 1953–Dec. 1959	
"M"	66°N, 02°E	June 1948–Nov. 1958 Jan.—July 1959	
Manchester Airport		Jan. 1949–Dec. 1958	

Counts were made of the number of occasions of visibility in the ten ranges for all code figures of present weather from 00 to 49 together and for each separate code figure from 50 to 99. An examination of the number of occurrences within each range of visibility showed that all stations experienced similar frequencies with each kind of precipitation and without precipitation. The data for all stations have, therefore, been combined to produce the histograms of Figure 2, showing percentage frequencies of occurrence for each type of precipitation for which there were at least ten observations. This eliminates precipitation reported as heavy, which is rare over the sea.

Whilst these histograms largely speak for themselves, there are certain interesting conclusions which may be drawn. Showers have less effect than precipitation of a more continuous type due to their smaller horizontal extent. Objects at a distance are more clearly visible by the observer in a shower which obscures only a portion of the distance between him and the object viewed than in continuous precipitation which obscures the whole distance even though the intensity at the place of observation is the same. Furthermore, since showers over the sea normally occur in cold air which is being warmed from beneath, their histograms show no poor visibility whereas the histogram for no precipitation includes cases of fog over the sea.

The effect of slight rain, slight snow showers and moderate rain showers is, in general, to reduce visibility by one code figure, the histograms in each case closely resembling those for no precipitation but displaced one step to the left. The effect of slight rain showers is even less, merely raising the percentage of code figure 97 above that of code figure 98. Moderate snow showers show a similar reduction of one code figure but can also cause poor visibility at times as shown by the appreciable percentages of code figures below 95. With slight drizzle and moderate rain the effect is to decrease the visibility by two code figures. This is in good agreement with the calculations by Wright[2]. Slight showers of sleet show a fairly even distribution between code figures 96, 97 and 98, with an appreciable percentage of occasions of very good visibility. With moderate drizzle, the spread is much wider with a maximum frequency in code figures 95 and 96 but quite appreciable percentages of 97, 94 and 92.

It is interesting to note that the visibility given by Poljakova's formula for the upper limit of moderate rain (2·7 nautical miles) lies just within the lower end of the range of visibility on the histogram occurring most frequently in moderate rain. On the other hand, the visibility for the upper limit of slight rain (12·6 nautical miles) lies just above the range of visibility (code figure 97, 6–12 nautical miles) occurring most frequently on the histogram for slight rain. The upper limit for slight snow from Poljakova and Tret'jakov's formula (0·95 nautical miles) lies just below the lower limit of visibility code figure 95. As can be seen on the histogram only eight per cent of occurrences of slight snow showed a visibility below this.

For purposes of comparison with a typical station where smoke pollution is common, similar data for Manchester Airport are included (Figure 3). The effect of smoke is evident from a comparison of the histogram for conditions of no precipitation in Figure 3 with the corresponding histogram of Figure 2, code figure 96 being the most common as opposed to code figure 98 for the ocean weather stations.

A general comparison of the histograms of Figures 2 and 3 for each kind of precipitation suggests that the amount of reduction is about the same as that experienced at sea but when the visibility is already only moderate due to other causes such as smoke haze, no further reduction is to be expected.

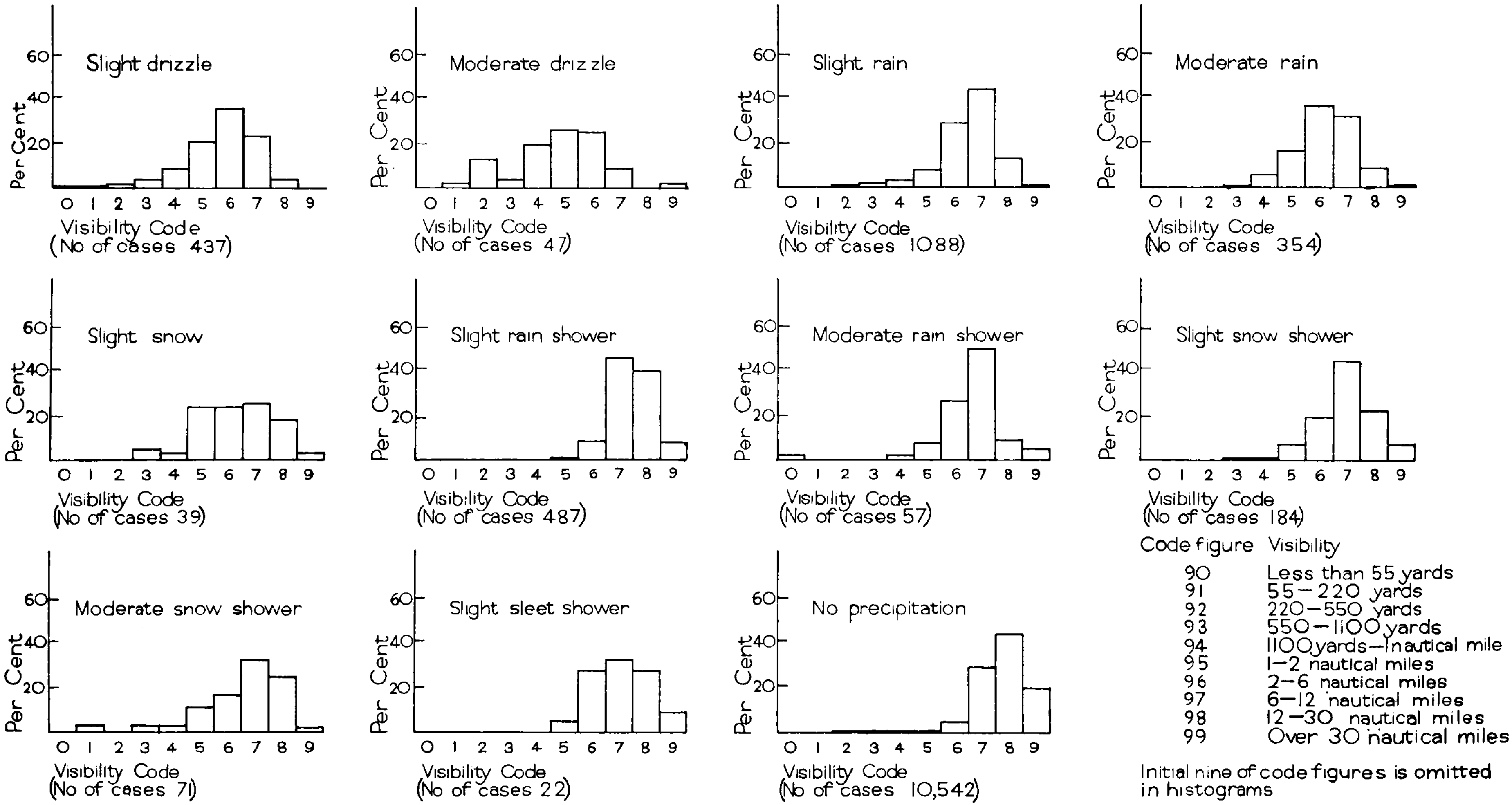

FIGURE 2—PERCENTAGE FREQUENCIES OF VISIBILITY DURING VARIOUS FORMS OF PRECIPITATION AT OCEAN WEATHER STATIONS "A", "C", "J", "I" AND "M"

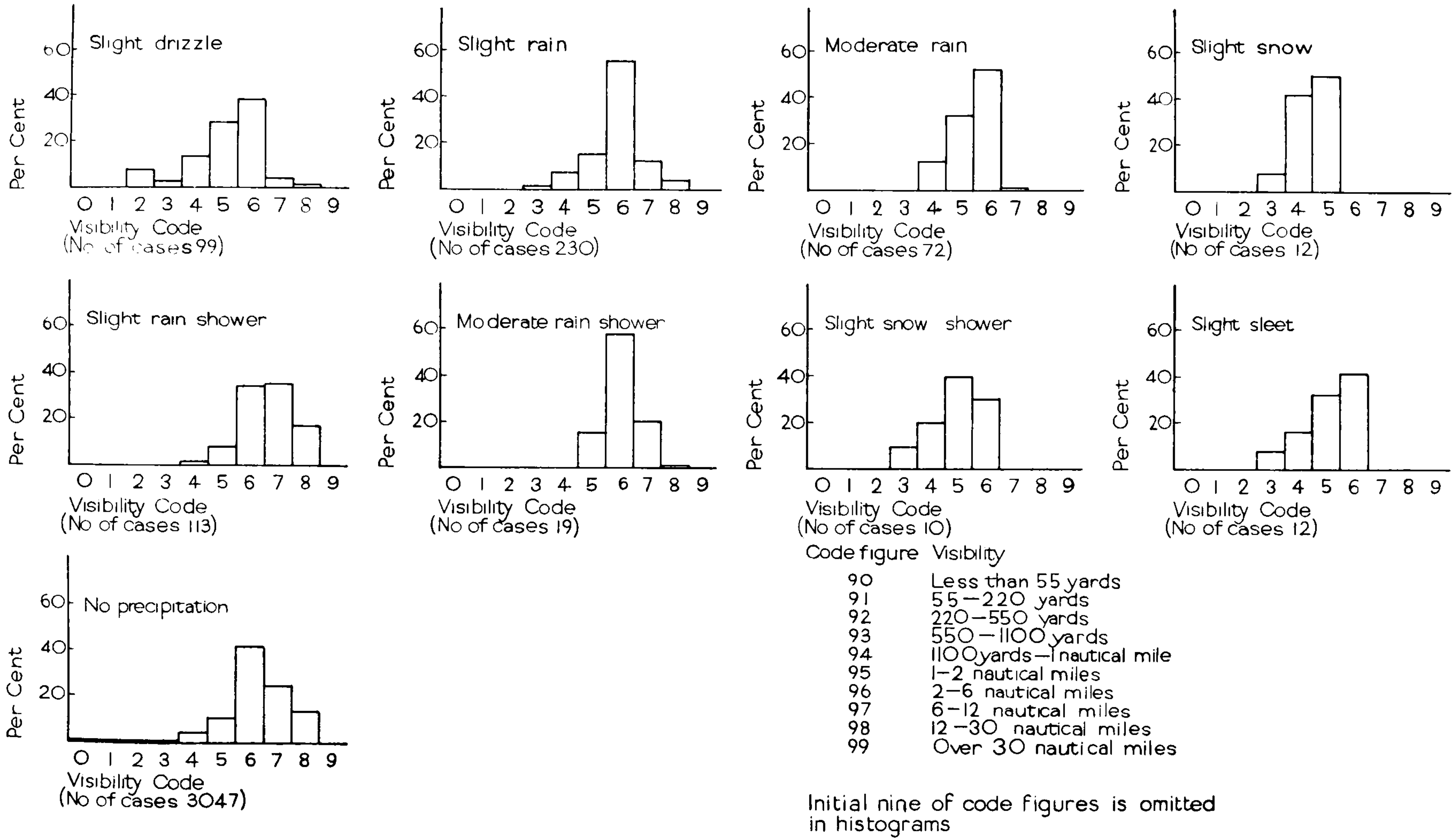

FIGURE 3—PERCENTAGE FREQUENCIES OF VISIBILITY DURING VARIOUS FORMS OF PRECIPITATION AT MANCHESTER AIRPORT

With slight rain showers, the percentage frequency of good visibilities is greater than with no precipitation. This is to be expected since showers are most commonly associated with cold air and often with moderate or strong northwesterly winds, while all wind directions and speeds are included in the "no precipitation" figures. The same tendency is evident with moderate rain showers, though in this case it is mainly confined to an absence of visibilities below 95. It is evident that with rain showers of moderate intensity, visibility is, on nearly 50 per cent of occasions, between two and six nautical miles and at almost all other times between one and two or between six and twelve nautical miles.

In general, it appears that no very great reductions of visibility are to be expected with slight or moderate precipitation and that really poor visibility is rare with most types. It is also worthy of note that with many types of precipitation, especially of the instability kind, visibility is often more than six miles and not infrequently over twelve miles.

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THE DURATION OF SURFACE WETNESS

By J. M. HEARN, B.Sc.

Introduction.—The weather has a pronounced effect on the incidence of plant disease. If weather data could be used to create a system of disease forecasting this would be of immense value to agriculture and horticulture. In the past, the process has been difficult, because there was insufficient knowledge of the significant elements. Methods are now being developed by meteorologists and pathologists which involve not only the use of new meteorological instruments but also the new use of standard meteorological observations. At the same time the experience so gained points the way to a new approach in the representation of humidity climate, which may prove useful not only in the problems of plant pathology but also in questions of barn hay-drying, grain storage and so on. This new approach was presented to the XVth International Horticultural Congress at Nice by Mr. L. P. Smith in 1958.[1] Research into apple scab and the weather is the subject of an article to be published in *Plant Pathology*[2] which reviews the progress made during the last ten years in which agricultural meteorologists have had a major role to play.

The surface wetness recorder.—The surface wetness recorder was produced as a result of close co-operation between plant pathologists at the Rothamsted Experimental Station and members of the Meteorological Office at Harrow.[3, 4] The instrument is similar in nature to a dew-balance and it records the length of time that a polystyrene block retains surface moisture when exposed in the open air. A full deflexion on the instrument is approximately equivalent to a heavy dewfall or the minimum rainfall observed in a rain-gauge.

During the summer of 1957 one of these instruments was exposed in an orchard at Sudbury, Suffolk. The nearest meteorological station that records hourly humidity is Felixstowe, which lies on the coast some twenty miles distant to the east-south-east. The hours of surface wetness recorded at Sudbury were compared with the number of hours when the relative humidity at Felixstowe was 90 per cent or more. The results are given in Table I.

TABLE I—COMPARISON BETWEEN HOURS OF SURFACE WETNESS AT SUDBURY AND HOURS OF RELATIVE HUMIDITY ⩾ 90 PER CENT AT FELIXSTOWE

Date of ending of period of 10 days	10-day means of duration of (a) surface wetness *hours*	(b) high humidity *hours*
28 March	11·3	10·7
7 April	8·1	10·9
17 April	4·7	3·8
27 April	1·7	1·1
7 May	3·3	2·8
17 May	6·0	4·0
27 May	4·2	4·0
6 June	3·7	2·8
16 June	6·2	4·5
26 June	5·7	3·8
6 July	5·9	7·0
16 July	6·2	4·5
27 July	7·6	7·2

(Record for 18 July missing)

The correlation coefficient between these two sets of figures is 0·90. This is extremely high when one considers that one station is inland and the other coastal and that they are twenty miles apart. Furthermore, during the period under consideration there were several days when weather conditions differed in the two places. There were six days in all when coastal fog prevailed at Felixstowe and not at Sudbury (1–5 April and 5 July) and six other days when showers fell inland and not on the coast (10 April, 8, 12 and 26 June, 1 and 10 July). If these days are disregarded the coefficient becomes 0·97. The close

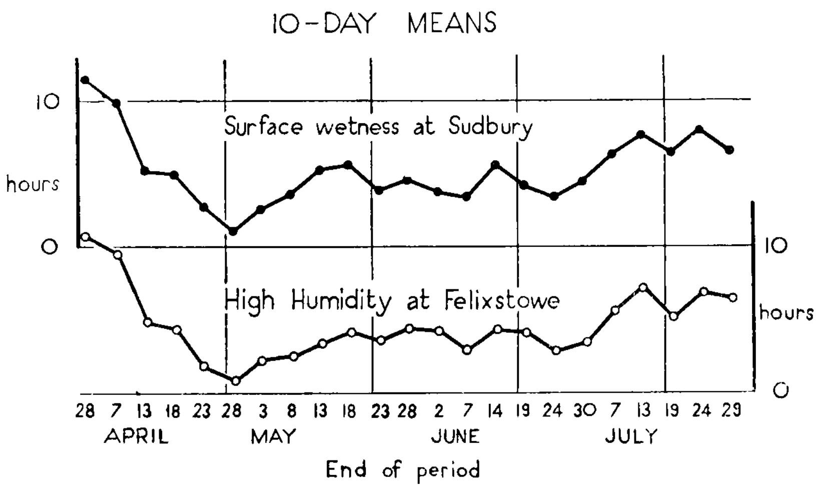

FIGURE 1—COMPARISON OF HIGH-HUMIDITY HOURS WITH SURFACE-WETNESS HOURS

similarity between the records is illustrated by the running 10-day means plotted in Figure 1.

The relationship between leaf wetness and relative humidity was also confirmed by observations taken by Mr. J. P. Jay of the Meteorological Office, Kehelland near Camborne. In a communication dated 22 October 1958 regarding the conditions in his own garden in Cornwall, he stated that "89–91 per cent (relative humidity) still seems to be the average drying point, the odd case not fully drying out until 85 per cent is reached. None dried out with relative humidity at 92 per cent or more".

Operational use.—The duration of surface wetness is of prime importance in the incidence of certain fungus diseases of crops. This is because the development and germination of spores and their infection of susceptible host tissues takes place only under specific conditions of temperature and wetness. These conditions vary with the disease but the criteria required for two of the most fully investigated diseases, namely potato blight and apple scab, are given by Beaumont periods and Mills periods respectively. In considering these it must be remembered that their criteria differ in that screen temperature and humidity records are used for the assessment of Beaumont periods whereas in isolating Mills periods macro-temperatures are used in conjunction with wetness recorded on a micro-scale, that is the surface of a leaf, if observations are taken visually, and the polystyrene block of a wetness recorder, if obtained instrumentally.

From 1956 onwards surface wetness recorders were used with considerable success to provide data from which the occurrence of Mills periods could be ascertained. But at the same time the use of humidity criteria for the definition of critical conditions was also being investigated.[5, 6] Field work and observation showed that leaf surfaces tended to remain wet only if the relative humidity of the air, as measured under standard meteorological conditions, did not fall below 90 per cent. The validity of equating 90 per cent relative humidities with wetness was substantiated by the close similarity observed between the Sudbury surface wetness recorder and the Felixstowe humidity records and this idea was tested further when Mills periods, derived from surface wetness recorder data for the years 1956–59, were compared with periods which use 90 per cent relative humidity following rain as a threshold of wetness (now called Smith periods). A marked correlation was found to exist between these.

Examples for the year 1959 are given in Figure 2, which have been extracted

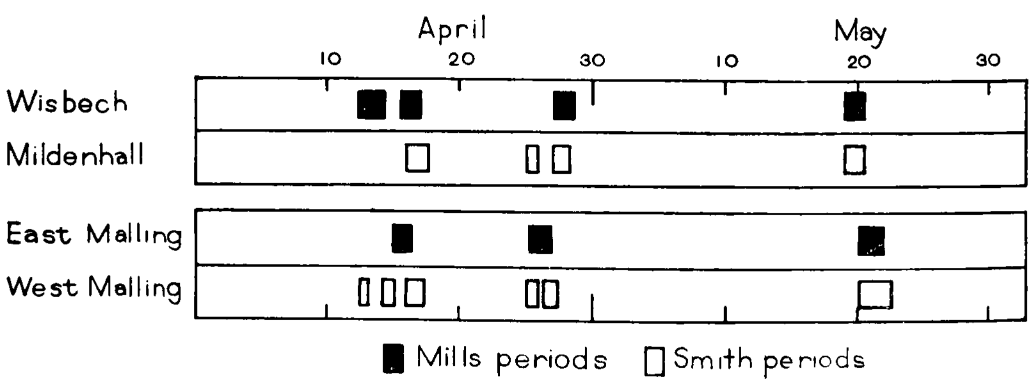

FIGURE 2—MILLS AND SMITH PERIODS, 1959

from charts showing the incidence of Mills periods at some fifteen stations using wetness recorders, and the Smith periods extracted from the hourly records of a similar number of synoptic stations in the same general area. Wisbech and Mildenhall are some thirty miles apart inland in East Anglia. East and West Malling are within a few miles of each other in Kent but the latter station is higher by nearly 200 feet.

Having established a relationship between high humidity and surface wetness it seemed clear that a network of stations reporting relative humidities of 90 per cent or more after the occurrence of rain or heavy drizzle could be used to provide substantiating evidence for the data already received from the surface wetness recorders. During 1960 this surmise was tested on an operational basis and found to be correct. Indeed the standard meteorological observations were, on the whole, the more reliable indicators of critical weather conditions. However, it is clear that the most satisfactory results come from the combination of data from both networks and that the information so gained can form a sound basis for the recognition of weather critical to the incidence of plant diseases and hence play a vital role in their prevention.

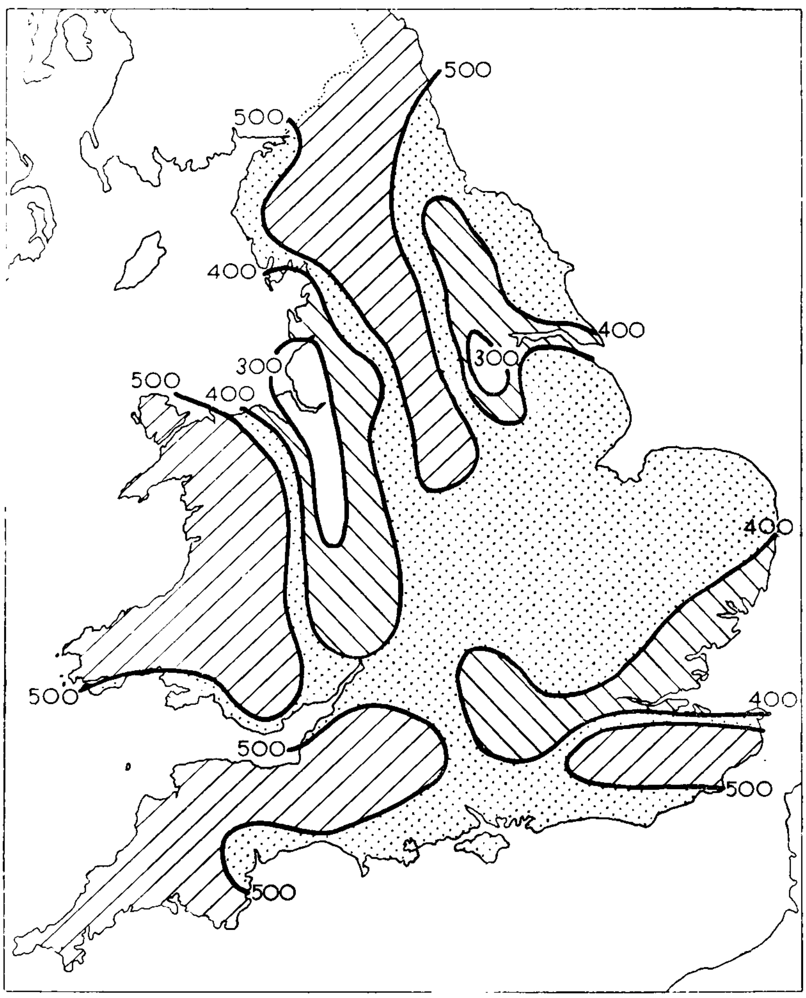

FIGURE 3—AVERAGE DURATION OF HIGH HUMIDITY (HOURS) DURING JUNE AND JULY (1950–54)

Climatological use.—Climatological maps showing the average duration of high humidities will obviously give a very good representation of the average duration of surface wetness. Figure 3 shows the average map for June and July. The areas with the least number of hours of high humidity are not those with the lowest average humidity or those with the lowest daytime humidities. The area with the least number of humid hours lies in the Wirral Peninsula and south-west Lancashire in the "shadow" of the Welsh mountains. A similar area exists behind the Pennines. Other factors which affect the parameter are

(*a*) height above sea level,

(*b*) nearness of the sea,

(*c*) local topography and liability to frost or fog.

In confirmation of the existence of a non-humid area in north-west England, it is interesting to note that barn hay-drying has been unusually successful in the lowlands of Lancashire and Cheshire. It is also an area of relatively high potential transpiration.

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OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 5—An experiment in numerical forecasting, by E. Knighting, B.Sc., G. A. Corby, B.Sc., F. H. Bushby, B.Sc., and C. E. Wallington, M.Sc.

A report is made on the first two numerical forecasting experiments carried out in the Meteorological Office. The theoretical and practical details are given and then the numerical forecasts are compared with the conventional forecasts made by the Central Forecasting Office (C.F.O.) using certain statistical measures of success. Some examples of the numerical forecasts are compared with their C.F.O. counterparts.

The results show that:

(*a*) objectively analysed charts form a suitable basis for making numerical forecasts;

(*b*) the statistical measures indicate that the numerical forecasts are of similar quality to the C.F.O. forecasts;

(*c*) the errors in the numerical forecasts are mainly due to over-development of high-pressure systems and to the assumptions made regarding the changes at the boundary of the forecasting area.

Cumulus dynamics (Proceedings of the first conference on cumulus convection). Edited by Charles E. Anderson. 9¾ in. × 7 in., pp. ix+211, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1960. Price: 70*s.*

In May 1959, 45 meteorologists met at Portsmouth, New Hampshire, U.S.A., to hold a week's conference on convection and cumulus cloud physics. *Cumulus dynamics* is a nicely produced report of the proceedings.

The 23 papers written into the book range from purely observational studies using laboratory models, photogrammetric methods and research aircraft to numerical studies tackled with the aid of high-speed computers. These papers include contributions by M. A. Estoque on the convective heat flux near the earth's surface, by L. Berkofsky on the inclusion of the latent heat of condensation in a numerical forecasting model, by T. Fujita on tornado development and by R. H. Douglas on hailstorms in Alberta. V. J. Schaeffer describes simple laboratory apparatus for the study of clouds and C. S. Downie broaches the interesting subject of cloud modification with carbon black.

It would be too lengthy to list all the papers and authors in the book, and indeed the papers themselves appear to be considerably condensed from the versions presented verbally at the conference itself. But this condensation is acceptable if the book is considered as a digest of the methods rather than the results of the research work described by the participants at the conference. As such the book is stimulating rather than profound. It is well produced with clear diagrams and attractive photographs, but the price seems to be rather high if it is intended to reach the student or young research worker in the field.

C.E.W.

A history of the United States Weather Bureau. By D. R. Whitnah. 9¼ in. × 6¼ in., pp. xii+267, *illus.*, University of Illinois Press, Urbana, Illinois, U.S.A., 1961. Price: $6.00.

It is not easy to review a book about the history of a government agency of a foreign country and one can only assume that domestic and national details have been reflected accurately. If this is so, then the author has not been as careful in his references to international meteorology and international events, such as World War II. Pages 203 and 210 contain some startling inaccuracies and naïve references to World War II and to the World Meteorological Organization. It is a shock to be told that that United Nations specialized agency is affiliated to UNESCO, a sister agency. Co-operation there is, of course, but certainly not affiliation.

One is left with the impression that the author at no time realized that meteorology provides an outstanding example of international collaboration on a big scale and this fact is most inadequately treated. It is true that before World War II, the new world considered that Europe exercised an unhealthy hegemony over international meteorological affairs, but this situation has changed radically since 1942. More attention could well have been paid to the contributions made by the United States Weather Bureau, notably by its Chief, Dr. F. W. Reichelderfer, which helped so much to create the truly international atmosphere which today exists in meteorological organizations such as WMO.

A reference is made to three-day forecasts for the North Atlantic begun in 1901 and to the benefits derived therefrom by European nations. The author says warnings were cabled to London and fog was forecast whenever possible!

No remark or amplification is made except a footnote to say that the period of validity of these forecasts had decreased to 36 hours in 1958—not altogether a surprise.

This reviewer cannot but conclude that the task of writing the history of a major State Meteorological Service ought not to be undertaken by a historian unless he has the help of advisers, both inside and outside that Service, who can and do ensure that all facets of the history can be and are carefully checked and edited. It would be difficult enough for a professional member of such a Service, but for a layman it is formidable indeed. C.W.G.D.

Introduction to theoretical meteorology. By S. L. Hess. $9\frac{1}{4}$in. × 6in., pp. xiv + 362, *illus.*, Constable and Company Ltd., 10 Orange St., London, W.C.2, 1961. Price: 60*s.*

It is often said, in an effort to attract recruits to a career in meteorology, that the atmosphere offers a wonderful natural laboratory for the young scientist who wishes to continue with his studies in physics. It is not so often said that the science of meteorology offers a vast and exciting field in which the budding mathematical physicist can employ his ingenuity. Almost every aspect of theoretical physics is brought to play in one form or another by the atmosphere, the whole extent of which is gradually being encompassed and digested by the meteorologist. The latter theme has not been developed as well as it might have been. Books on meteorology have tended either to fall in the popular class for the layman reader, and contain no mathematics at all, or in the specialist class for the advanced reader or experienced research worker in meteorology or one of its allied subjects, and contain mathematics which no one else can attempt to understand. There has been practically nothing to lead the way gently for the theoretically minded young scientists fresh from their undergraduate studies.

Professor Hess has gone a long way towards filling the gap in his *Introduction to theoretical meteorology.* He leads gently indeed and never tugs at the rein—yet at the end the initiate has followed every inch of the way and emerges with a sound and adequate basic background and, we hope, with an affection for the science which can store so many opportunities for theoretical exploration.

It is claimed that the book assumes no more than second-year mathematics and physics at the American University Level. This is probably about the standard of Advanced Level General Certificate of Education in this country. Actually certain methods included, as, for example, complex numbers and partial differential equations, go beyond the second or American sophomore year. To this Professor Hess says ". . . the reader need not comprehend their solutions, merely verifying by substitution that the alleged solution satisfies the governing equation". This apology can perhaps well be applied to students in this country for whom Advanced Level represents the goal of academic attainment. But the undergraduate student would be studying more advanced mathematics concomitantly.

Professor Hess expresses the opinion that ". . . however aesthetically satisfying such methods as vector analysis may be to the accomplished theoretician, my teaching experience indicates that the majority of beginners are confused by unfamiliar mathematical language"—a well established but not always accepted truth.

The book contains the usual material in classical dynamical meteorology which will not be listed here. It concludes with a brief account of numerical prediction, followed by a concise chapter on the general circulation.

The book is beautifully produced; the paper and type are excellent. There are the usual few misprints in the mathematics which seem almost unavoidable in most books. The table of symbols on the cover is of great help. Finally the inclusion of problems is a very helpful asset. In Hess' words ". . . the student must learn to apply theory by solving challenging problems"—a principle that has not been used as thoroughly in teaching meteorology as it has in mathematics or physics.

A.H.G.

Aerodynamic capture of particles, edited by E. G. Richardson. 10 in. $\times 6\frac{1}{2}$ in., pp. 200, *illus.*, Pergamon Press, Oxford, 1960. Price: 50*s.*

This is another in the series of symposium reports in which these publishers specialize, being the proceedings of a symposium held at the British Coal Utilisation Research Association, Leatherhead, in January 1960. The proceedings are also reported in identical form in the *International Journal of Air Pollution*[1], and the papers are certainly more appropriate to a journal than to this more durable form of presentation.

The symposium performed the useful function of bringing together some of those in different fields of research to whom the mechanism and efficiency of capture of particles in a gas or liquid are of importance. In meteorology this interest is aroused by theoretical studies of the coalescence of droplets to form raindrops and by studies of the scavenging effect of raindrops in clearing the air of the particulate matter which is the most obvious constituent of atmospheric pollution. The use of water sprays to suppress dust in mines is the artificial analogue of this, while the dry deposition of particles is of interest in the design of filters, in the curing of fish by smokes, in coal mines and in the radioactive fall-out problem. The capture of water drops by moving surfaces has long been of interest in aircraft design because of its application to ice formation when the drops are supercooled, but new problems of erosion have arisen when the surface is moving at high speed. Collection efficiencies in all applications may be affected by electric charges on the particles or by the nature of their surface (for example wettable or non-wettable).

Papers on all these diverse interests were presented at the symposium and are reproduced in this book with a more-than-usually informative discussion of the theoretical papers. Some of the papers are brief surveys while others report results of original research. There is no really comprehensive and authoritative survey, however, such as would make the book of lasting value, but many will find something of interest to them here and there.

R. F. JONES

REFERENCE

1. RICHARDSON, E. G. (Editor); Aerodynamic capture of particles. *Int. J. air Poll., Oxford,* **3,** Nos. 1-3, 1960.