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DUST-STORMS IN IRAQ

By F. E. COLES, B.Sc., D.I.C.

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DUST-STORMS IN IRAQ

By F. E. Coles, B.Sc., D.I.C.

In those parts of the world where the soil is dry and sandy and there is little vegetation, particles of sand or dust may be raised from the ground into the air by the action of a sufficiently strong wind. If the process continues, the air may be filled with sand or dust particles up to ten or fifteen thousand feet above the ground. In Iraq the desert character of the country favours this process, and the sand particles are very small and penetrating like dust, so that these sand-storms are termed dust-storms in Iraq. The criterion used to define a dust-storm is an obscuration due to sand or dust, with a wind of Beaufort force 4 or over, causing a decrease of visibility below 1,100 yards. The wall of sand which is often associated with Egyptian sand-storms or haboobs is relatively infrequent in Iraq. The first sign of the dust-storm in Iraq is often an abnormal glare or dazzle around the sun, then the dust may be seen to be rising in patches from the ground, so that the reduction of visibility is generally progressive. In some types of dust-storm however, particularly those associated with cold fronts or thunderstorms, the reduction of visibility is often sudden, and this type is therefore the most dangerous. They occur chiefly in the months October to November and March to June when thunderstorms are most frequent. (*See* Fig. 1.)

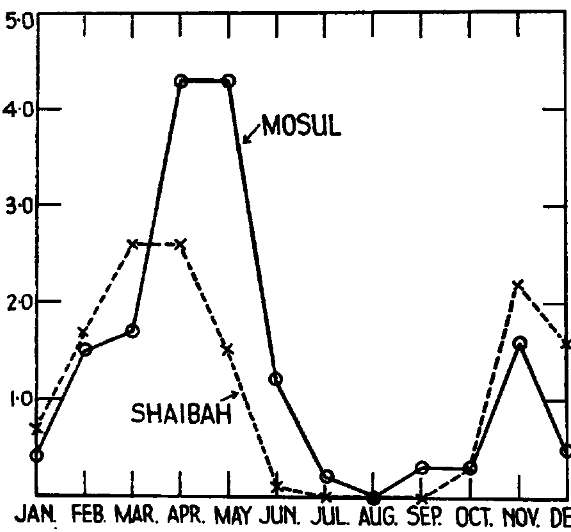

Fig. 1.—Average number of days of thunder per month, 1923–34.

General Types.—Dust-storms in Iraq may be classified according to two seasonal types, namely winter and summer storms.

Winter Storms.—In this category all storms in the period November to May are included. During the winter a branch of the anticyclone over central Asia extends across Iraq to the Mediterranean, so that pressure is generally high, decreasing southwards.

About three or four times a month, however, depressions move eastwards from the Mediterranean across Iraq causing rain, dust or thunderstorms. Depressions sometimes originate near the Jordan valley, forming as vigorous secondaries in the south-east quadrant of a large Mediterranean low. These secondaries often seem to form on the cold front of a Mediterranean depression, so the warm air of the secondary is probably desert air which has picked up moisture over the Red Sea or the Mediterranean. It is noteworthy that high temperatures with a warm S. wind or khamsin in Egypt are frequently followed in one to two days' time by a vigorous secondary over Iraq. An important characteristic of depressions moving across Iraq in winter is the large proportion which split into two components when the depression reaches eastern Iraq. This feature is no doubt due to the obstruction caused by the range of mountains along the Iraq-Persian frontier (the mountains in south-west Norway act in a similar way and often produce secondaries over the Skagerrak). Of the two components the northern one usually moves north-eastwards into Iran, while the southern moves south-eastwards down the Persian Gulf ; both systems may cause dust or thunderstorms. Generally dust rises over a wide area in advance of a depression as the wind freshens, and after the arrival of the cold front, sometimes with a squall and thick dust, there is usually a slow improvement in visibility. The wind may, however, freshen again from the north-west, and raise further dust.

Summer Storms.—All dust-storms occurring in the almost rainless period June to October are included in this class. During this period pressure is low over southern Iran and relatively high over western Iraq, causing a gradient for the strong NW. wind known locally as the " shamal." Fig. 2 shows the mean monthly pressure difference

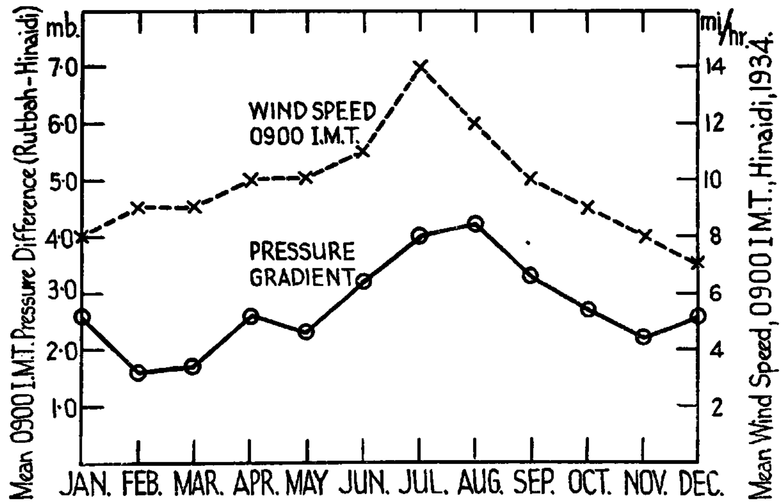

FIG. 2.—MONTHLY PRESSURE GRADIENT AND 0900 I.M.T. WIND SPEED AT HINAIDI.

at Rutbah and Hinaidi compared with the mean wind speed at Hinaidi at 0900 Iraq mean time (I.M.T.). It will be noted that the gradient is strongest in July and August. Summer dust-storms may be caused by small increases in the gradient, but often it appears that the influx of cooler air aloft causes dust by a steepening of the lapse. Unfortunately, there is insufficient upper air data to verify this theory. NW. winds persist for practically the whole of the period June to October, and all summer dust-storms are from this quarter. As might be expected, owing to the increased fetch of the NW. wind over the desert, summer dust-storms tend to increase in severity and frequency progressively from Hinaidi towards Basrah, and dust may be carried far down the Persian Gulf at this season.

Distribution of Dust-Storms.—In Fig. 3 is shown the average number of dust-storms per month at Rutbah, Mosul, Hinaidi, Diwaniyah and Shaibah during the period 1929 to 1935. The distribution of dust-storms is at first sight rather irregular, but points of similarity emerge between Rutbah and Mosul, and between Hinaidi, Diwaniyah and Shaibah. The first two stations represent western and northern Iraq, the others central and southern Iraq. In the latter areas there are evidently two maxima for dust, one in March the other in July. At Shaibah the March maximum is not so large as would be expected from comparison with Diwaniyah and Hinaidi, but this may be due to the fact that many storms occur with a SE. wind at this period; for Shaibah this wind blows from the Persian Gulf about 50 miles away, and generally produces little dust at Shaibah, although at Diwaniyah about 100 miles further north dense storms may occur owing to the greater wind fetch. At Rutbah and Mosul the chief points of similarity are maxima about May and minima in August. In April and May there is a maximum frequency of thunderstorms at Mosul as shown in Fig. 1, and it is probable that thundery squalls are responsible for the May maximum dust frequency in the north and west of Iraq. That this maximum is not apparent at Shaibah may be due to the fact that the frontal systems of depressions over the U.S.S.R. probably affect only northern Iraq, and also the mountains in this region must increase the frequency of thunderstorms. Fig. 1 shows that the frequency of thunderstorms at Shaibah in May is only about half that at Mosul. The low frequency of dust at Rutbah and Mosul from June to August compared with the maximum at Hinaidi and southwards is due to the pressure distribution. At this season northern and western Iraq are situated in a region of relatively high pressure just outside the influence of the Iranian low. Strong NW. winds and the majority of summer dust-storms are therefore confined to an area approximately south-east of a line from Ramadi to Kirkuk. (*See* Fig. 4.)

The distribution of dust-storms in Iraq during the winter is largely governed by rainfall. Table I shows the monthly rainfall in millimetres at Rutbah, Mosul, Hinaidi and Shaibah. Generally rainfall in Iraq decreases as the distance from the mountains along

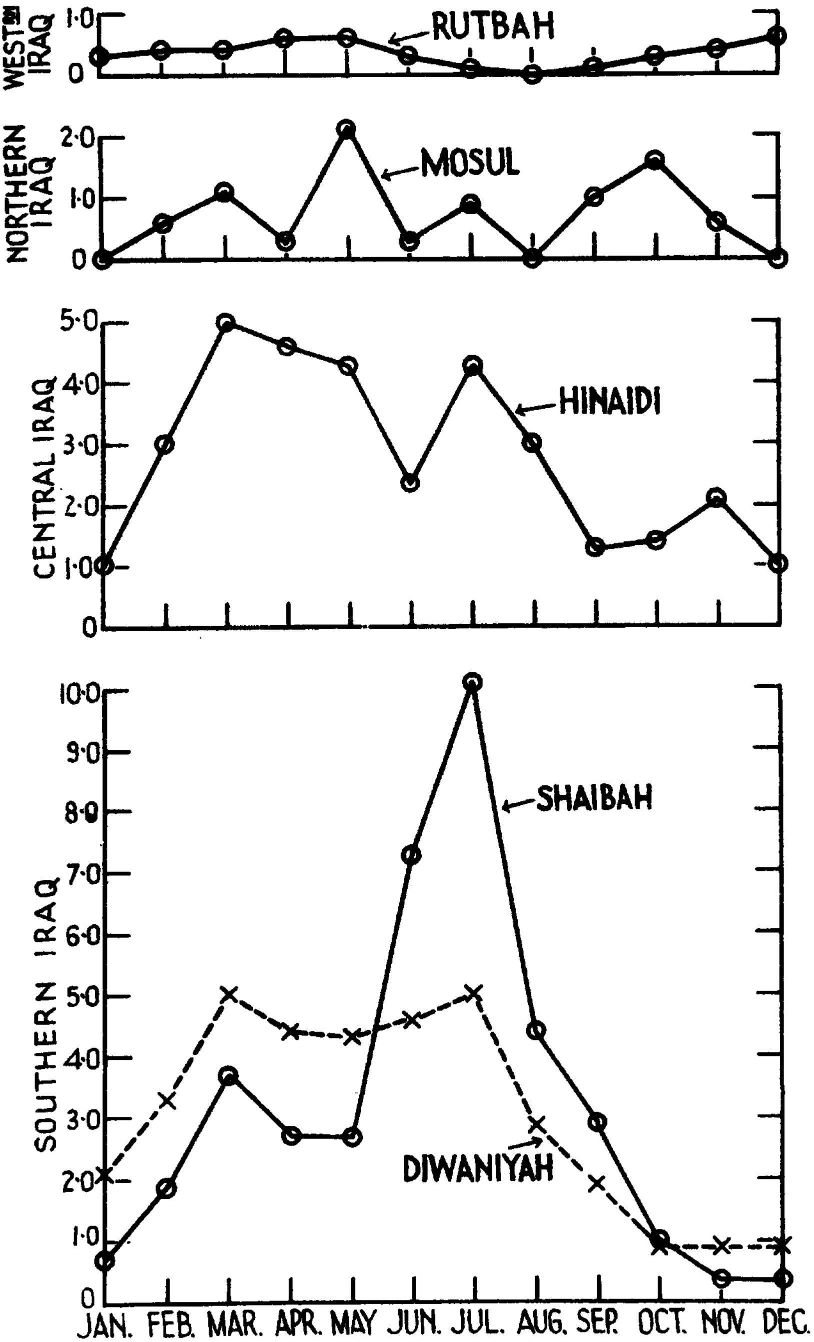

FIG. 3.—AVERAGE NUMBER OF DAYS OF DUST-STORM PER MONTH.

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the Iraq-Iran border increases. At all stations practically no rain occurs from June to September so that conditions become very favourable for dust development. From November to February, on the other hand, rainfall is considerable, and the ground becomes moist or muddy, so that even although it dries rapidly, dust-storms are infrequent.

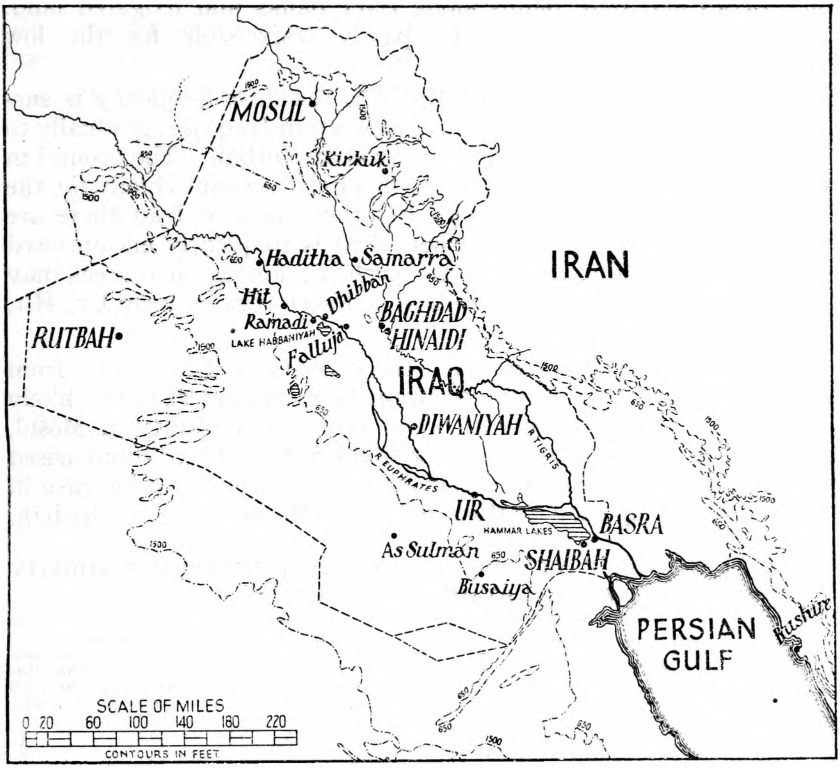

FIG. 4.

TABLE I.—MEAN MONTHLY RAINFALL AT VARIOUS STATIONS IN IRAQ

	Rutbah	*Mosul*	*Hinaidi*	*Shaibah*
	mm.	mm.	mm.	mm.
January	24·7	54·6	33·1	35·0
February	21·1	78·1	29·5	35·3
March	2·8	42·0	8·6	7·3
April	9·1	45·7	9·8	11·3
May	7·3	14·6	8·2	1·2
June	0·1	0·6	0·1	0·0
July	0·0	0·1	0·0	0·0
August	0·0	0·0	0·0	0·0
September	0·8	0·1	0·1	0·0
October	0·0	6·5	2·8	2·0
November	4·7	42·8	40·6	27·4
December	14·6	47·2	19·9	22·4

At Mosul in northern Iraq rainfall averages over 40 mm. in each month from November to April, and Fig. 3 shows the low frequency of dust during these months.

Another important factor in the development and distribution of dust-storms is vegetation, but in Iraq apart from camel-thorn there is no vegetation except in northern Iraq towards Mosul and the grasses and date palms along river banks and irrigated land. However, this factor must be partly responsible for the low frequencies at Mosul.

Despite the low rainfall at Rutbah, the dust frequency is surprisingly low. It should be noted that western Iraq rises gradually to a plateau about 2,000 ft. above sea level at Rutbah. The ground in this region is hard rock or basalt so this must account chiefly for the low dust frequency at Rutbah. In other parts of Iraq there are regions of soft powdery sand where dust is frequently encountered although surrounding regions may be clear ; among such areas may be mentioned the Falujah Plain, and desert regions near Ur, Hit, and north of Diwaniyah.

The Severity of Dust-Storms.—The severity of dust-storms from an aviation standpoint is judged from the minimum visibility likely to be encountered. Observations of minimum visibility at Mosul, Hinaidi and Shaibah for the period 1933–5 have been summarised in Table II. It will be seen that dust-storms generally increase in severity and frequency southwards from Mosul towards Shaibah.

TABLE II.—NUMBER OF DUST-STORMS WITH MINIMUM VISIBILITY BETWEEN CERTAIN LIMITS (1933–5)

	Mosul.					Hinaidi.					Shaibah.				
	<55 yds.	55–110 yds.	110–220 yds.	220–550 yds.	550–1,100 yds.	<55 yds.	55–110 yds.	110–220 yds.	220–550 yds.	550–1,100 yds.	<55 yds.	55–110 yds.	110–220 yds.	220–550 yds.	550–1,100 yds.
January	..	..	..	..	..	..	..	..	3	..	..	..	..	..	1
February	..	..	1	..	1	1	..	2	3	2	..	..	..	2	2
March	..	..	..	3	3	2	1	1	9	4	1	1	2	2	6
April	..	..	..	..	1	..	..	1	9	4	..	1	..	1	5
May	..	1	..	2	4	..	1	1	7	2	1	..	1	1	5
June	..	..	..	..	1	1	..	1	2	4	3	..	3	1	8
July	..	..	..	..	1	..	..	1	1	7	2	2	5	17	18
August	..	..	..	..	..	..	..	..	..	6	..	..	1	4	8
September	..	..	..	..	..	..	..	..	..	1	..	..	..	1	3
October	2	..	1	3	2	..	..	..	2	5	..	..	..	1	2
November	..	..	..	..	1	..	..	..	3	3	..	..	..	..	..
December	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1

The most severe storms occur at Hinaidi in March, at Shaibah in June and July, and at Mosul in October. In very severe storms the visibility may fall to 20 yds. The minimum visibility which will be experienced depends largely on the wind speed, so that early morning pilot balloon ascents may often serve as a useful criterion.

Fig. 5 is a graph of the wind speed at a level of 1,000 ft. at Shaibah, as measured in the early morning, plotted against the minimum visibility reached in dust-storms during the summer months. It is evident that the minimum visibility is approximately proportional to the wind speed at 1,000 ft., and therefore at Shaibah this wind speed measured by pilot balloon ascent about 0500 I.M.T. is a useful indication of the probable severity of dust. This criterion appears to be of value in central and southern Iraq, but at Mosul in northern Iraq no such criterion exists. In this area many severe dust-storms occur with cold fronts or thunderstorms, and frequently last only one or two hours, so the morning upper wind is of little prognostic value. As might be expected, the severity depends largely on the time of start of the dust-storm. Fig. 6 shows times of start at Shaibah

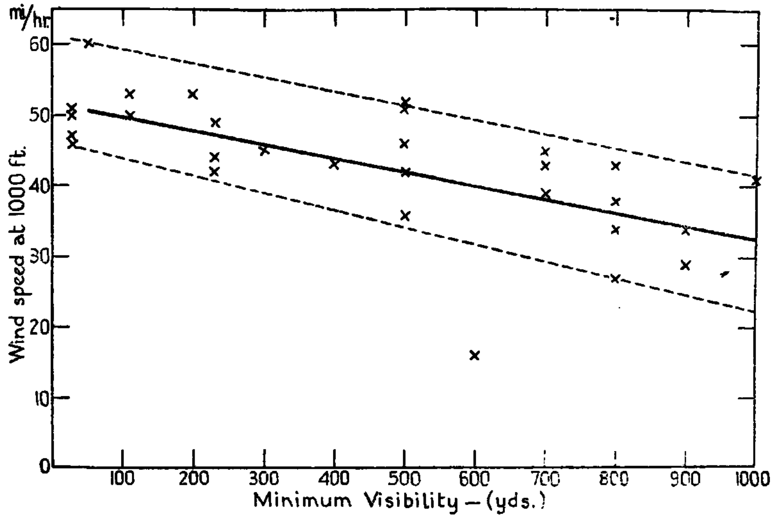

FIG. 5.—SHAIBAH, JUNE TO AUGUST, 1934.

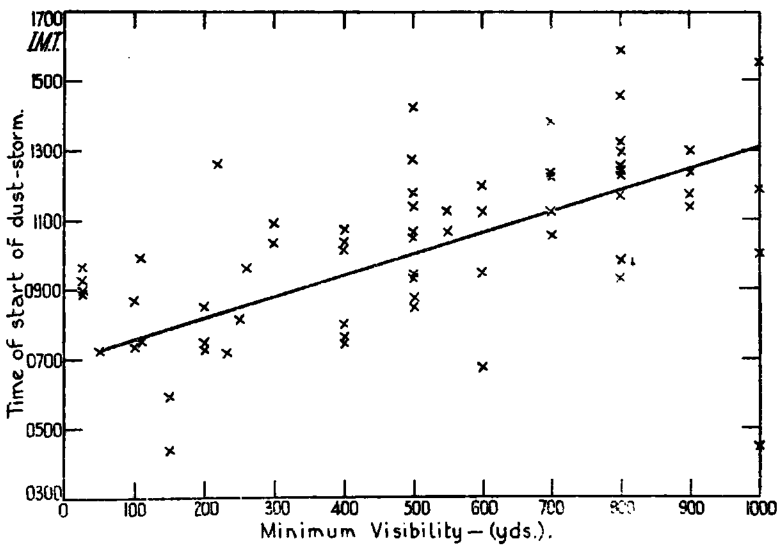

FIG. 6.—SHAIBAH, JUNE TO AUGUST, 1933–5.

during the summer plotted against minimum visibility, and generally speaking, the earlier the time of start the less the minimum visibility likely.

Times of Occurrence.—The times of start of dust-storms are largely influenced by diurnal changes of wind speed. Fig. 7 is a graph of wind speed at various hours at Hinaidi and Shaibah in January and July, 1934. At Shaibah the variation in summer has

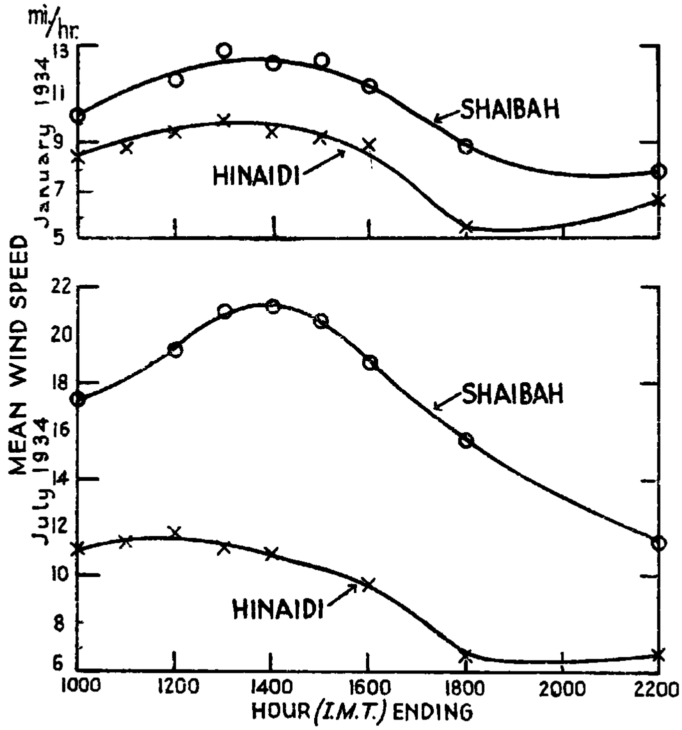

FIG. 7.—MEAN WIND SPEED AT HINAIDI AND SHAIBAH; DIURNAL CHANGE FOR JANUARY AND JULY, 1934.

almost twice the winter amplitude, and twice the summer amplitude at Hinaidi. During the night the surface wind is generally light, and free from convectional eddies owing to the presence of a large night inversion, as shown by Durst (1),* but as the inversion disappears one to two hours after sunrise, turbulence increases rapidly, and the eddy motion near the ground may raise dust.

It is to be expected then that dust-storms will occur chiefly during the day, when the surface wind and turbulence are strongest. At Hinaidi in the period 1931–4 only 13 per cent. of all dust-storms occurring commenced in the night period (1700 to 0400 I.M.T.); of these night storms 10 per cent. occurred in the months March to June. These months include those of greatest thunderstorm

* The numbers in brackets refer to the bibliography, on p. 14.

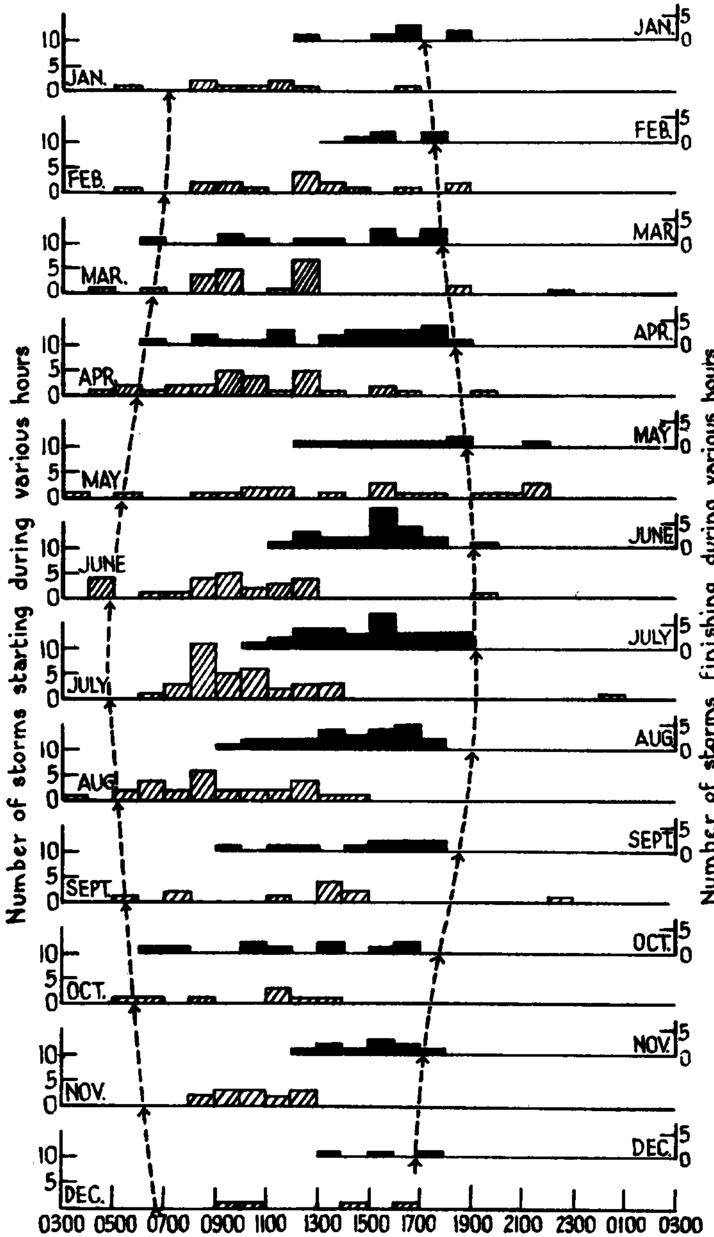

FIG. 8.—FREQUENCY SUMMARY OF TIMES OF START AND FINISH OF DUST-STORMS AT HINAIDI.

(NOTE:—Arrow-heads indicate times of sunrise and sunset for first day of each month.)

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frequency (*see* Fig. 2), and it seems probable that dust-storms at night are associated with thunderstorms. Frequency summaries of times of commencement and cessation of dust-storms have been compiled for Mosul, Hinaidi and Shaibah and that for Hinaidi is shown in Fig. 8. The following points are noteworthy :—

(1) Dust-storms most frequently start about 0800–0900 I.M.T. from June to August and finish about 1500–1600 I.M.T. in central and southern Iraq, while in other months they most frequently start one to three hours later. The later time of sunrise in the winter and slower dispersal of the night inversion no doubt explains this.

(2) Dust-storms starting in the afternoon or evening are most frequent at all stations in May. The favourite time of start is 1900–2000 I.M.T. at Mosul and 2100–2200 I.M.T. at Hinaidi.

(3) Dust-storms starting in the early morning, 0300–0500 I.M.T. are most frequent in June at Hinaidi and Shaibah, and in October at Mosul.

(4) Dust-storms persisting overnight are most frequent in March and July at Hinaidi.

(5) At Mosul storms rarely commence before 1200 I.M.T., except during September and October.

Dates of Maximum and Minimum Probability of Dust.—It is noteworthy that dust-storms in Iraq often occur about the same date in successive years. For example, at Hinaidi a dust-storm or thick dust haze occurred on March 29 in each year 1929 to 1935 ; the storm in 1935 was one of the most severe ever experienced. The dates on which the probability of dust is 40 per cent. or over are given in Table III(*a*), and for those marked with an asterisk the probability of dust is over 70 per cent. At Shaibah it will be noticed that there is a high probability of dust during the period June 15–25. It seems that this is the normal period for the onset of the " shamal " or strong NW. wind of Iraq in summer. Light or moderate NW. winds occur during most of the year, but the true " shamal " or strong NW. wind, which may blow for a period of anything up to ten days, apart from lulls at night, seems to favour the periods June 15–25, July 1–6, 12–16 and 20–26. In any year the " shamal " may occur only on two or three days in each period, but at Shaibah there is a high dust frequency during these periods. The " shamal " is generally stronger at Shaibah than elsewhere in Iraq, as shown in Fig. 7, and the severity of dust-storms is correspondingly greater, not only owing to the increased wind speed, but also to the long " fetch " of the wind over the desert.

Dates on which no dust-storms were observed during March to August 1929–35 are given in Table III(*b*). Generally September and October are the best months for aviation in Iraq owing to low dust, rain and thunderstorm frequencies.

TABLE III

(a) Dates of Maximum Dust-Storm Frequency.				(b) Dates of Minimum Dust Frequency.
Hinaidi.	*Diwaniyah.*	*Shaibah.*	*All Stations.*	*All Stations.*
Feb. 3	Feb. 3	..	Feb. 3	..
,, 23	,, 23		,, 23	
Mar. 29*	Mar. 19	Mar. 27	Mar. 29–30*	Mar. 13
,, 30	,, 26	,, 30*		,, 15
,, 31	,, 29*			,, 28
Apr. 11	Apr. 11*	..	Apr. 11	Apr. 23
,, 21	,, 20		,, 21	,, 29
	,, 21			
May —	May 12	..	..	May 5
				,, 10
				,, 16
..	June 18	June 15–17	June 23	June 7
	,, 23	,, 19–22		
	,, 30	,, 23–24		
July 26	July 3	July 3*	July 3	July 9
	,, 14	,, 6*		,, 10
		,, 13		
		,, 21		
		,, 25		
		,, 31		
Aug. 2	..	Aug. 14	..	Aug. 17
				,, 23–24
				,, 27–28
..	..	Sept. 18	..	..

Dust Suspensions.—On the day following a severe dust-storm visibility is often reduced below 1,100 yds. although the wind is insufficient to raise dust. This must be due to the gradual settlement of dust raised many hours before, and occurs frequently in the central region of a low which is filling up but which has caused dust to rise the previous day.

On the day after a dust-storm, the visibility about 0400 I.M.T. is often good, but later may deteriorate rapidly. It seems as if the normal night inversion may prevent the settlement of some of the smaller dust particles from high levels, and that these are precipitated only after the breakdown of the inversion soon after sunrise. An example of this effect occurred at Hinaidi on February 6, 1935. At 0500 I.M.T. the visibility was 6–12 miles, while at 0655 it had fallen to 2,000 yds. although the wind was almost calm.

Generally dust clears during the night in Iraq, but the time taken is very variable. Assuming that dust particles are carried up to 10,000 ft., which is probably the average ceiling of dust-storms in Iraq, then if the particles are all deposited in 10 hours the radius of the smallest particles would be about 1/60 mm., assuming that Stokes Law is valid for particles of this size. The result is probably about the right order, and accounts for the penetrating quality of Iraq dust-storms.

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[*Photo by Sqdn. Ldr. D. W. F. Bonham-Carter*

FIG. 9.—DUST-STORM NEAR SAMARRA, 1936.

Factors involved in the Development of Dust-Storms.—The chief difficulty in an investigation of the factors governing dust development, is to obtain upper air data during a storm, as pilot balloon or aeroplane ascents are impracticable. The raising of dust into the air may be expected to depend on three main factors :—

(1) The density and diameter of the sand or dust particles.
(2) The adhesion of the particles to the surface: this will again depend on such factors as rainfall and vegetation.
(3) The turbulence of the air near the ground.

As regards the first factor, there is not likely to be much variation in density of sand particles over Iraq, but the range of diameters must be wide. The smallest particles will be the first to rise and last to settle.

In the central plains of America the second factor has become increasingly important, as adhesion has been reduced by destruction of the native grasses and by ploughing, also possibly by decreasing rainfall. In Iraq a similar process may be occurring in those districts where the native camel-thorn is largely used for fuel. The adhesion of the soil is very variable with locality and season. There are large areas of soft sand, but much of the desert is firm and baked hard by the sun. The high plateau of western Iraq is of a hard basaltic type, hence the low frequency of dust at Rutbah. Rainfall is an important factor in increasing the adhesion of the sand particles, and is responsible for the low frequency of dust-storms during the winter months November to February. The third factor, turbulence, must be one of the chief factors in dust development, for it has been shown that dust-storms generally commence one or two hours after sunrise, when large scale convectional eddy motion begins, and cease by late afternoon when the night inversion forms again and damps down turbulence. C. Combier (2) has stated that for dust-storm development it seems to be essential that the air should be descending, so that it scrapes up the sand, so to speak, from the surface. This suggestion receives added weight from the observed frequent occurrence of dust-storms at the forward edge of thunderstorms and also behind cold fronts. There is little doubt that the raising of dust or sand particles into the air is generally due to a descending air current impinging on the sand surface, and by splashing eddies carrying sand upwards, if the current has sufficient speed. The process is probably analogous to that of a stone dropped into a pool of water, the detachment of water drops as spray being similar to the detachment and raising of sand particles. It seems probable then, that the raising of dust is associated with the gust fronts mentioned by Durst (3) in his theory of eddies, as in the first stages of an Iraq dust-storm belts of dust are often observed from the air at intervals of about a quarter of a mile, and are visible in the photo (Fig. 9) ; the belts are especially in evidence along dusty camel-tracks. If turbulence is of paramount importance in dust development, then it is to be expected that wind velocity, lapse rate, variation of wind velocity with height, horizontal temperature gradients and ground contours will be important subsidiary factors, and this is found to be the case.

Wind Velocity.—Best (4) has shown that the effect of wind velocity on gustiness is negligible for large lapses, but for small lapses and inversions gustiness near the ground increases with velocity. Once the night inversion is destroyed Best's results show that the extreme eddy velocity will increase in proportion to the wind velocity. If it is assumed that dust rises when the vertical component of eddy velocity reaches a critical value, then this value will correspond to a limiting mean wind speed at 40 ft. At Hinaidi the critical horizontal wind speed during the summer, when surface conditions are uniform, was found to be 18 mi./hr., although individual values varied by 4 mi./hr. on either side of the mean. For forecasting purposes it is found more useful to know the critical value of the wind at a height of 1,000 ft., and this is found to be about 30 mi./hr. In the year 1934 on 75 per cent. of occasions when upper winds at 1,000 or 2,000 ft. exceeded 30 mi./hr. at Hinaidi dust haze was reported in central or southern Iraq, but only on 20 per cent. of these occasions did dust-storms occur at Hinaidi, so the criterion must be used with caution. On some occasions velocities exceeding 22 mi./hr. have been recorded at Hinaidi by the anemograph and no dust has risen, and on these occasions it appears that the lapse rate and vertical wind gradient must be such as to cause a decrease of the vertical eddy component near the ground below the normal value, but there is insufficient upper air data to substantiate this theory.

Lapse Rate.—The lapse rate of temperature with height is of paramount importance in the growth of turbulence. In Iraq an inversion of 20° F. to 30° F. up to one or two thousand feet usually forms at night, and with such an inversion little surface turbulence is likely until the breakdown of the inversion by surface heating. Flowers (5) has shown that in Egypt zero lapse in the lower layers occurs roughly two hours after sunrise, and in Iraq it must occur about the same time. Fig. 8 shows the hours of greatest frequency of start of dust-storms at Hinaidi for each month, and the variation with time of sunrise is evident. The observed tendency for storms to cease or diminish in intensity in Iraq after 1500 I.M.T. suggests that the surface inversion forms again about this time in the layer close to the ground.

Flower (5) has shown the effect of lapse rate on the vertical gradient of wind velocity over the desert; generally the effect is such as to produce a decrease in wind gradient for an increase in the lapse. In Iraq in the early morning there is often a velocity of 40 mi./hr. recorded at 1,000 ft. while there may be a calm at the anemometer level, this large wind gradient gradually decreases as the night inversion disperses and the surface wind gradually increases in speed.

Best (4) has shown that for wind velocities less than about 4 m/sec. (9 mi./hr.) at a height of 2 m. (7 ft.) there is a marked increase in gustiness when the temperature gradient changes from inversion to lapse, but for larger wind velocities there is little change, so that the eddy velocity increases with wind velocity. The effect of an increasing lapse rate in dust development appears then to be an increase in the mean wind speed near the surface, and hence a corresponding increase in the extreme vertical eddy component up to the critical value when dust rises.

Wind Gradient.—The effect of wind gradient has been shown above to be intimately connected with the lapse rate of temperature. Other factors such as horizontal gradients of temperature which influence turbulence are no doubt important at the cold fronts of depressions, but the chief factors in dust development are apparently the wind velocity and the lapse rate near the ground.

Summary.—During the period June to September, dust-storms in Iraq occur with the " shamal " or strong north-westerly wind; during the remainder of the year dust-storms may occur with winds from any quarter, but especially from directions from south-east through south-west to north-west.

The periods of maximum frequency of dust-storms are May and October in northern Iraq, from March to July in central Iraq, and during June and July in southern Iraq. On the higher ground of western Iraq dust-storms are infrequent throughout the year owing to the hard rocky nature of the ground. Over the whole of Iraq dust-storms are infrequent during the months November to February when rainfall is greatest.

The most severe dust-storms occur in October in northern Iraq, in March in central Iraq, and during June and July in southern Iraq. The severity of dust-storms in central and southern Iraq in summer appears normally to be proportional to the wind velocity at 1,000 ft., and to the time of start of the storm. In winter the amount of recent rainfall largely influences the minimum visibility.

Storms normally start about 0800 I.M.T. and finish about 1500 I.M.T., but the time of start is generally later in winter than summer, and storms most frequently start about three hours after sunrise. Storms occasionally persist overnight, especially in March and July in central and southern Iraq. Dust-storms starting at night are most frequent during the period March to June, and there is little doubt that many night storms are associated with thunderstorms, which are most frequent at this time of year.

It is suggested that turbulence in descending air, as at Durst's " gust fronts", is an important factor in dust development; rainfall is also important in increasing the adhesion of dust or sand particles. Normally in summer it is found that dust-storms start when the surface wind (at 40 ft.) exceeds 18 mi./hr. (8 m./sec.). If a pilot balloon ascent is made about 0500 I.M.T. and the wind speed at 1,000 or 2,000 ft. is found to exceed 30 mi./hr. (13 m./sec.) pilots should note that this indicates a high probability of dust.

Dates of maximum and minimum probability of dust were compiled. The probability of dust was found to exceed 70 per cent. on March 29–30, April 11 and July 3.

BIBLIOGRAPHY

1. Durst, C. S.; Notes on the variations in the structure of wind over different surfaces. *London, Quart. J.R. Met. Soc.*, **59**, 1933, pp. 361–72.
2. Combier, C.; La climatologie de la Syrie et du Liban. *Paris, Rev. Géogr. phys.*, **6**, 1933, pp. 319–46.
3. Durst, C. S.; A theory of eddies. *London, Geophys. Mem.*, No. 54, Part III, 1932.
4. Best, A. C.; On the transfer of heat and momentum in the lowest layers of the atmosphere. *London, Geophys. Mem.*, No. 65, 1935.
5. Flower, W. D.; An investigation into the variation of the lapse rate of temperature in the atmosphere near the ground at Ismailia, Egypt. *London, Geophys. Mem.*, No. 71, 1937.

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