CHAPTER 5

The African Dust Plume: Its Characteristics and Propagation Across West Africa in Winter

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ABSTRACT

The south-westward advection of Saharan Dust in Winter from the Bilma–Faya Largeau source area across Nigeria into the Gulf of Guinea has been discussed. The African Dust Plume has been defined and described. Three distinct phases of the Saharan dust transport have been identified and discussed. And finally some meteorological factors controlling the emission, transport, persistence and dispersion of the African Dust Plume have been outlined.

5.1 INTRODUCTION

Observation shows that each year between November and March large quantities of dust particles are transported from the Sahara desert towards the Gulf of Guinea across Nigeria. The agency of such dust transport is the harmattan, a cold dry wind which therefore produces one of the severest winter weather conditions in West Africa – the harmattan dust haze.

The harmattan dust particles are very fine opalescent particles which are so minute that they can remain air-borne for a considerable length of time. The dust which subsequently arrives in West Africa as the harmattan dust haze according to measurements by El-Fandy (1953) has a diameter range of 1.3–2.0 μm and concentration of about 300–500 cm^{-3}.

The presence of these harmattan dust particles constitutes a dusty atmosphere and in this paper a dusty atmosphere is defined as an atmosphere in which obstruction to vision is brought about by the presence of extremely dry and minute dust particles in the air with visibility reduced to less than 1 kilometre by natural dust.

It is known that the dust which affects a greater part of West Africa in winter south of latitude 15°N, particularly the Nigerian zone, comes mainly from the northeastern Sahara usually along the alluvian plain of Bilma (18°N, 12°E) (in

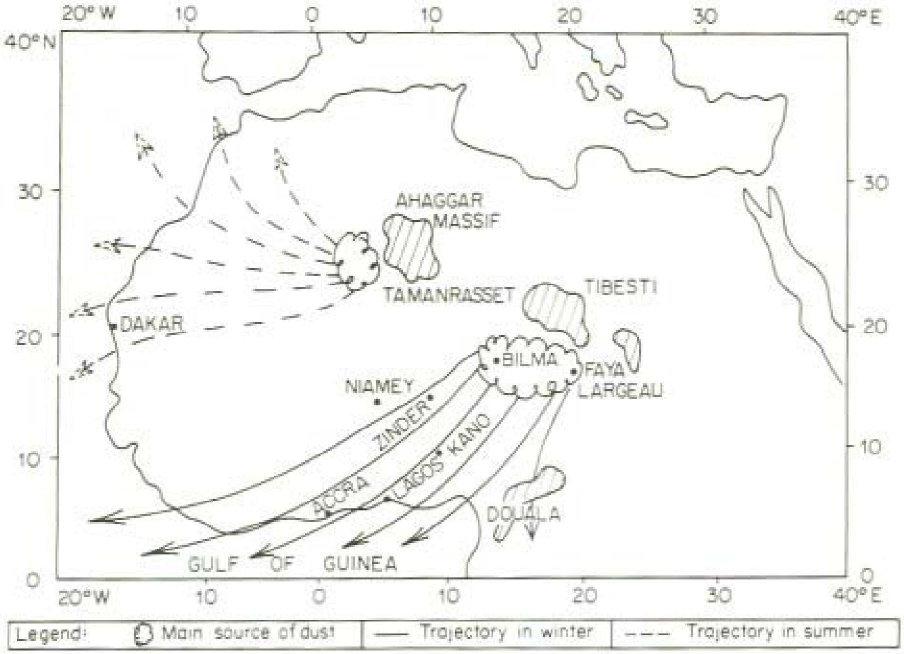


Figure 5.1 Saharan dust trajectories across West Africa

Southern Niger) and Faya Largeau (18°N, 19°E) (Chad) off the western slope of the Tibesti massif (Wilson, 1971; Kalu, 1975) (see Figure 5.1).

According to Wilson (1971) there are several source areas for the Saharan dust, but the one which is responsible for the existence of the dusty atmosphere over Nigeria and adjoining West African countries is the Bilma – Faya Largeau area. This source region is in conformity with the observed south-westerly dust trajectory over West Africa and the north-easterly direction of the mean low-level winds during this season.

The dust particles are then transported down wind from the source region in a 'plume' form towards the Gulf of Guinea by the strong north-easterly winds mainly at the 900 and 850 mb levels particularly north of the Intertropical Discontinuity (ITD), taking a south-westerly trajectory over Nigeria. On the average it takes about 24 hours for the dust to reach the northern border of Nigeria with the dust front moving at 15 knots (Aina, 1972).

In a thick harmattan dust haze which is synonymous with dusty atmosphere as defined above, visibility at the surface can be as low as 200 metres or less as a result of high dust concentration and 3–4 days spell of dusty atmosphere is never unusual particularly in the northern parts of Nigeria. The intensity of atmospheric dustiness defined in terms of dust concentration in West Africa has been found to decrease southwards probably as a result of increasing moisture content of the atmosphere towards the coast.

The occurrence of dusty atmosphere is usually accompanied by an extremely cold weather condition as a result of intrusion of cold air from the middle latitudes into the tropical latitudes across the Mediterranean. This is additive to the characteristic cloudless sky as a result of low humidity values which favours unrestricted loss of terrestial radiation resulting consequently in large diurnal temperature range.

5.2 PREVIOUS WORK

Much has been written about the transport of the Saharan dust in various parts of Africa. Wilson (1971) deals with the deposition and movement of the Saharan dust over Eastern Sahara. El-Fandy (1953) discusses the structure and concentration of the Saharan dust over the Sudan. Carlson and Prospero (1972) have by means of aircraft observations documented the transport of the Saharan dust in summer from North Africa to the Caribbean across the Atlantic.

In West Africa, however, the published materials have concentrated on evolving forecasting techniques for the onset and dispersion of the harmattan dust primarily for civil aviation purposes (Hamilton and Archbold, 1945; Burns, 1961). Their method for forecasting the arrival of the Saharan dust over West Africa depended primarily on first visible evidence of dust emission in the desert source region. This method is unreliable because dust has on many occasions been raised in the desert without being reported because of the scanty network of stations in the desert.

The most recent works on the dust problem are by Adefolalu (1968) and Aina (1972). The principal credit of this approach which is relevant to the Saharan dust transport problem is the introduction of the 'low level jet' technique for the forecasting of the emission and subsequent south-westward advection of the dust. Kalu (1975) also discussed the existence and characteristics of the African Dust Plume and produced a synoptic model for the successful forecasting of the development, persistence and dispersion of dusty atmosphere with or without evidence of air-borne dust in the desert source region.

The present paper discusses the development and transport of the Saharan dust across West Africa in winter. Relevant background information necessary for the understanding of the transport of a dust haze plume has been included.

5.3 THE SOURCE REGION CHARACTERISTICS

There are several source areas for Saharan dust. The dust which eventually affects any area outside the Sahara itself depends on the particular source region and the associated circulation patterns at the lower layers of the atmosphere which are evidenced by the direction of the prevailing winds.

From observation it is believed that the Saharan dust affecting some parts of West Africa in winter comes originally from the alluvian plain of Bilma (Niger) – Faya Largeau (Chad) off the western slope of the Tibesti massif of North Africa. The choice of the plain of Bilma and Faya Largeau is without prejudice to any other existing source areas for the Saharan dust in other parts of the Sahara desert. Our present interest lies on the source and the meteorological factors favourable for the emission, movement and deposition of the Saharan dust particles which subsequently affect Nigeria as the harmattan dust haze.

It is necessary to point out that the Saharan dust also affects other parts of northern Africa during different periods of the year. During summer, for example, when the dust is essentially absent in West Africa south of the surface position of the ITD, the trajectory of the Saharan dust changes to a westward direction to affect southern Algeria, Morocco, the Spanish Sahara, etc. and further west to the Caribbean Islands across the Atlantic (Martin, 1975; Prospero, 1968).

A lot of studies on the composition of the Saharan dust have been made by many workers, for example, the mineralogical analysis of the Saharan dust samples collected on mesh at Barbados by Prospero and Carlson (1970), a microscopical analysis of the harmattan dust at the Imperial Institute, London (Hamilton and Archbold, 1945), the mechanical sifting analysis by the Agricultural Chemistry of Ibadan (Hamilton and Archbold, 1945).

Wilson (1971) has shown that the subsoil in the alluvian plain of Bilma – Faya Largeau consists mainly of light fine and loose clay particles also of alluvian type which have settled in the area as a result of denudational action from the mountainous Tibesti east of the plain (Figure 5.1 above).

The study also indicates that the neighbouring areas of the Bilma – Faya Largeau has a hilly topography and therefore contains mainly sand or rock debris which by their nature are heavy and not easily raked up by the wind excepting of course some denudational weathering process which collects sand and feeds into the Bilma – Faya Largeau plain.

In order to understand the behaviour of the Saharan dust it is necessary for us to explain the following situations namely (1) the preferential deposition of dust in the Bilma–Faya Largeau source area and (2) the periodic emission of the dust into the atmosphere.

To explain the first case we shall examine the wind pattern over the Bilma–Faya Largeau areas. It has been found that the wind field in the Bilma–Faya Largeau plain on the mean is convergent and bi-directional below 1500 m, with one stream north of the Tibesti mountain and the other from the southern slope of the mountain (Figure 5.2). This pattern is also reflected from the sand flow patterns of the Sahara (Figure 5.3) if we regard sand flow direction as identical to wind direction. A major factor responsible for the observed large-scale deposition of sandy ergs is the resulting velocity convergence as a result of decrease of the katabatically funnelling wind stream down the western slope of the Tibesti massif on arrival at the plain (Samways, 1976). This typical wind field creates a favourable condition for the formation of ergs as a result of the deceleration or convergence of the air streams which diverge from the northern and southern slopes of the Tibesti mountain into the plain of Bilma–Faya Largeau (Figure 5.2).

The fact that dust continues to be raised from the source region every year only

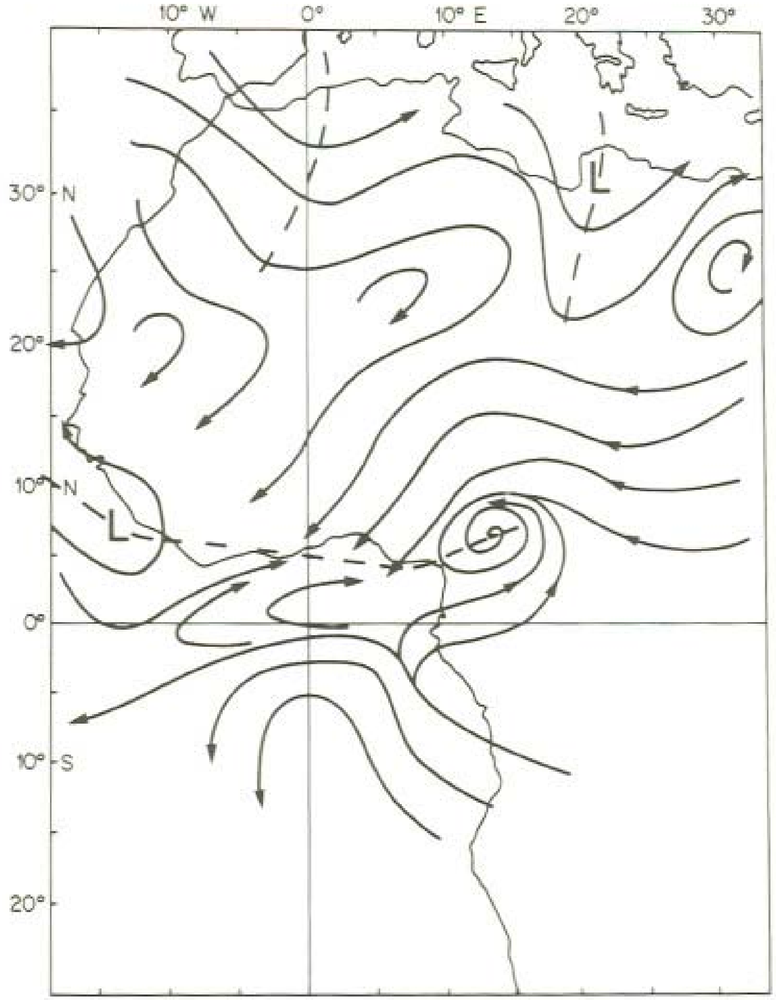


Figure 5.2 Typical midwinter streamlines (850 mb)

implies that there must be an efficient resupply mechanism or feed back system, otherwise, with time as a result of continued deflation process, there would be no longer dust deposits in the source region and so no harmattan dust would occur over West Africa. Since we know that this does not happen, it therefore means that the deflation rate in this region is usually exceeded by a resupply of dust into the plain.

Available dust particles are constantly fed into the wind at the western slope of the Tibesti and, when blowing through the plain the air becomes gradually filled with dust. Deposition occurs under favourable meteorological conditions such as

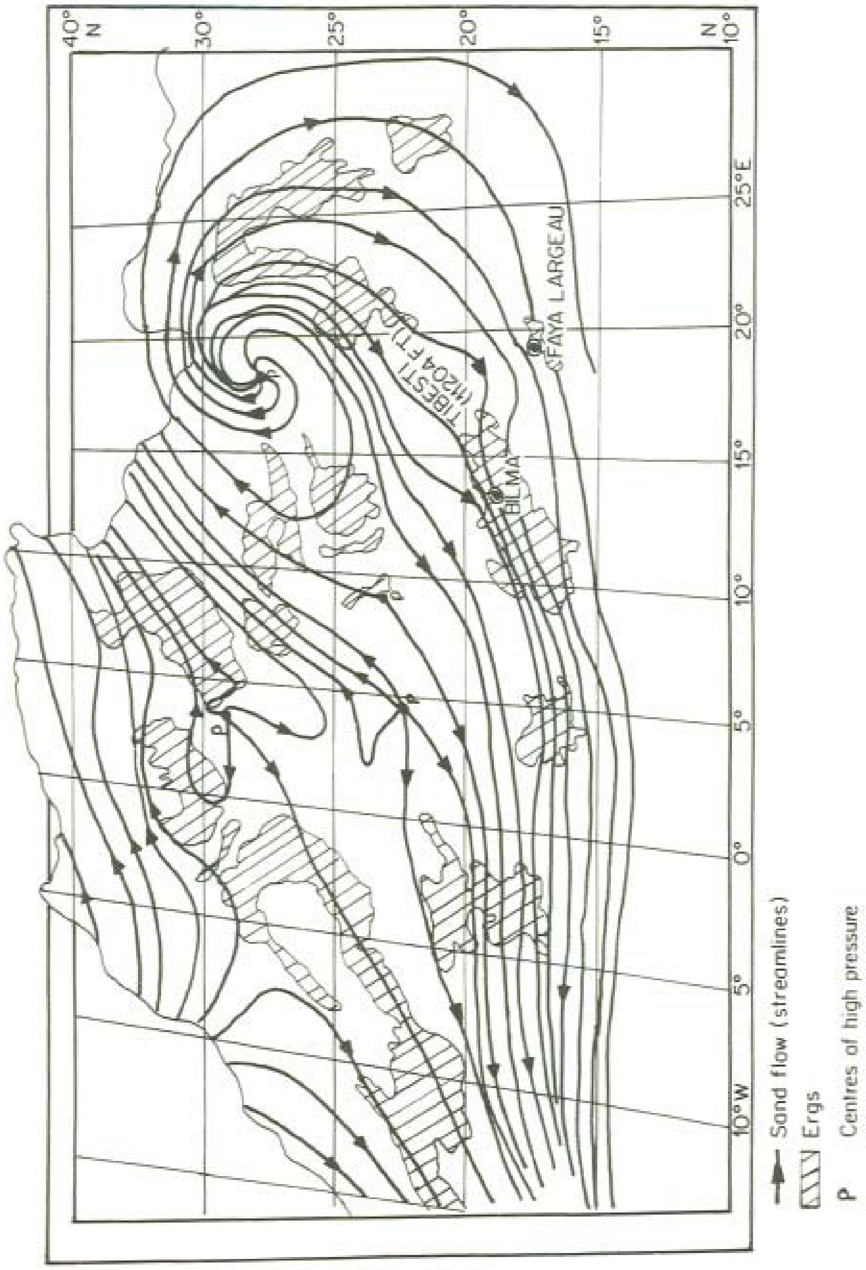


Figure 5.3 Sand-flow in the Sahara 1925–60 (after Wilson, 1971)

convergence or deceleration of the wind stream. The reverse process can also occur, i.e. no ergs in places characterized by accelerating divergent wind system.

Resupply of dust may come from fluvial action from the Tibesti massif east of the alluvian Bilma–Faya Largeau lowland. From Figure 5.3 one thing is clear – that the Bilma–Faya Largeau source area is constantly being resupplied with fresh dust deposit from the east. In fact the dust may have a history further east than we know.

The second explanation we shall consider is the periodic emission of dust from the source region. Dusty atmosphere in West Africa during the winter period results usually from a large-scale discharge into the atmosphere of dust particles. This does not occur every time, only when certain synoptic features must have been established over the source region.

One of such conditions is the development of high wind speed at the surface to create the necessary turbulence and instability as has been discussed by Adefolalu (1968) which will keep the dust air-borne for a considerable length of time. A study by the author (Kalu, 1975) shows that such atmospheric situation is created by the development of an induced meso-scale phenomenon of pressure surge arising from intense low level anticyclogenesis west of the intruding mid-latitude trough. This has been known to be associated with large scale intrusion of 'cold outbreaks' from the middle latitudes into the tropical atmosphere in winter in the form of upper troughs, moving usually eastward along the Mediterranean latitudes (Adefolalu, 1976). This is depicted in Figure 5.4.

Intensification of the subtropical anticyclone at lower levels produces a state of

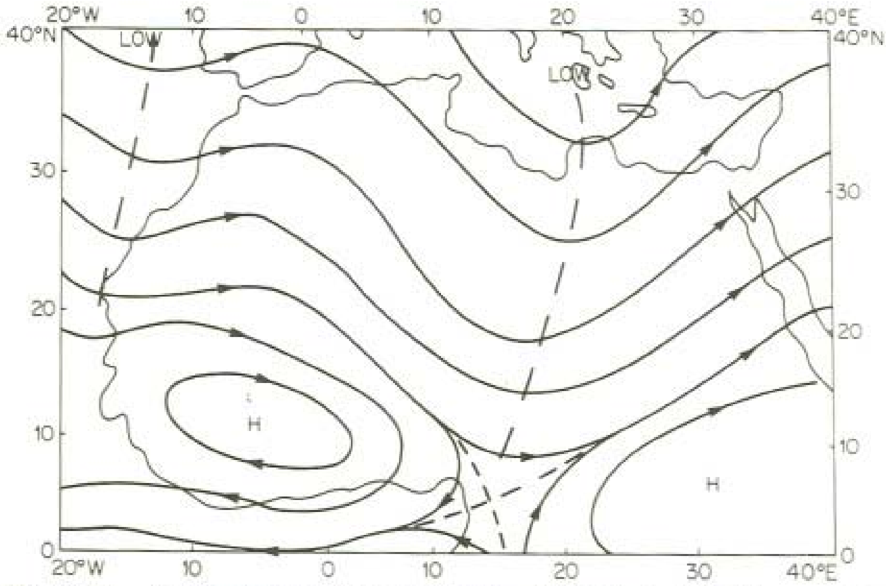


Figure 5.4 An intrusion of an upper level trough (200 mb, 9th February 1974)

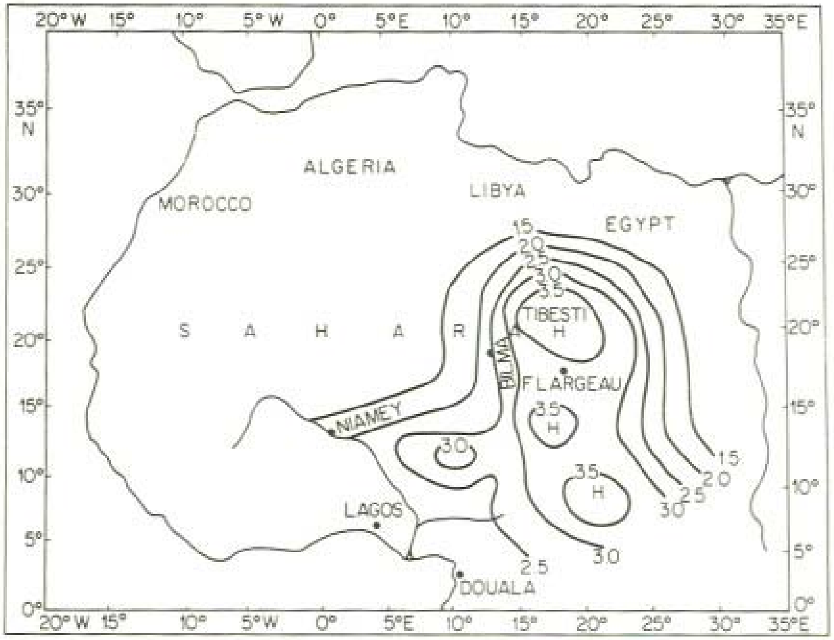


Figure 5.5 Pressure surge indicated by isollobaric high centre (24 hour tendencies)

pressure surge (Figure 5.5) which is associated with strong low level winds particularly at the surface where wind speed of about 30 knots or more can be observed (winds of 40 knots or even 50 knots are not unusual (Figure 5.6). Whenever such synoptic features as described above are evident on weather charts at the appropriate season dust is usually raised at the source region. In Nigeria this has been a useful forecasting tool for the development of the harmattan dust haze in West Africa from the Bilma–Faya Largeau source area.

The peculiar thing about duststorms is that it is not always that such a high wind velocity as about 30 knots or more is needed so as to raise the dust particles from the ground surface and keep them air-borne for some time (Figure 5.7). The meteorological conditions must first be satisfied before there can be a reasonable and sustained discharge of particulate substance into the atmosphere. Thus the periodic development of strong surface wind which arises as a result of low level anticyclogenesis with its associated pressure surge and instability causes the periodic emission of dust into the atmosphere and hence the periodic occurrence of dusty atmosphere down wind of the source of dust (Figure 5.8).

It is to be remarked that the velocity of 30 knots or more is based on observational evidence and has been successfully used in Nigeria to forecast the development of dusty atmosphere from the Bilma–Faya Largeau source area. With such a wind speed enough instability will be generated to keep the dust particles air-borne for a considerable length of time.

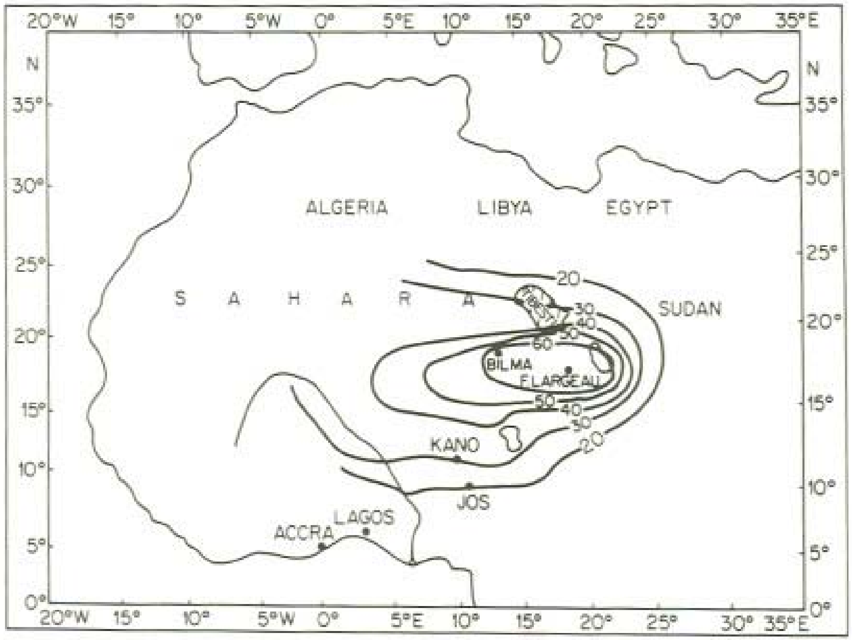


Figure 5.6 Low-level 'jet' 900 m on 31st January 1975, 12^h GMT (isotachs in knots)

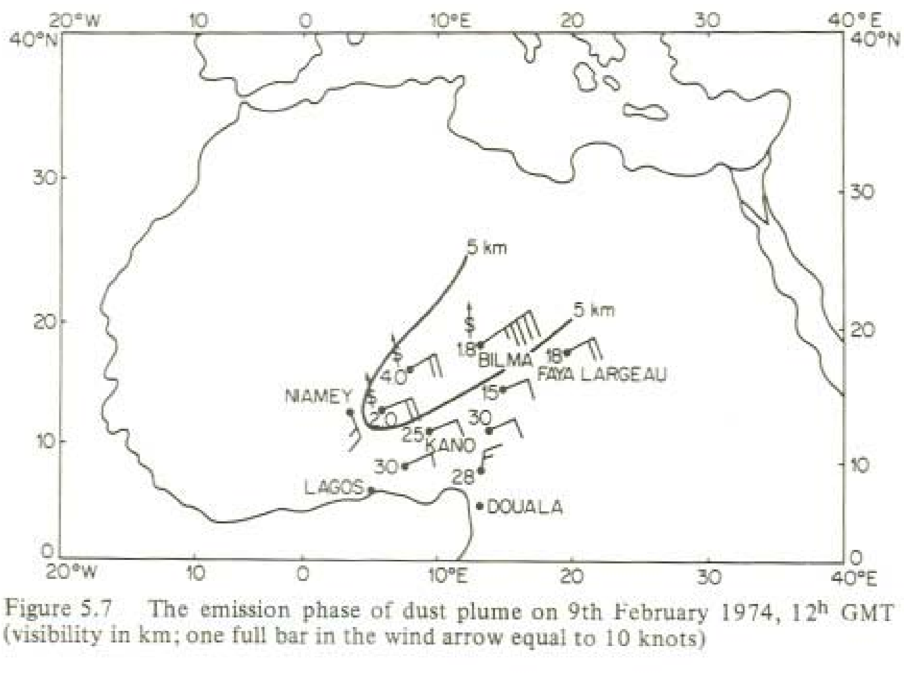


Figure 5.7 The emission phase of dust plume on 9th February 1974, 12^h GMT (visibility in km; one full bar in the wind arrow equal to 10 knots)

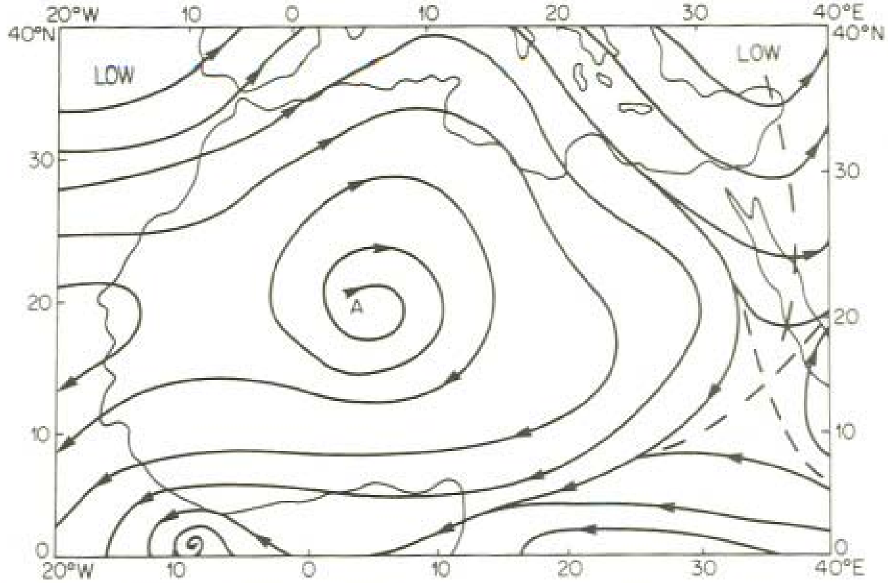


Figure 5.8 Low-level anticyclone with pronounced cyclonic shear at its eastern periphery on 11th February 1974, 12^h GMT (850 mb)

5.4 THE AFRICAN DUST PLUME

The harmattan dust haze is a synoptic scale system which has been observed to affect simultaneously a large area of the West African sub-region as a particulate body. The minute Saharan dust particles which in essence constitute a dusty atmosphere have been quantized into an idealized entity which we call 'The African Dust Plume' (ADP) (Carlson and Prospero, 1972) with certain distinct physical structure and properties. The plume concept has been construed and upheld in this paper because it has been observed that the Saharan dust propagates across West Africa in this form. It is not the atomistic conception of dusty atmosphere that is of great interest to us, but in a group because it is in this plume form that the harmattan dust affects us as a significant weather element during the dry winter months in West Africa.

Martin (1975) in his detection of overland and overwater dust in visible and infrared pictures of the Synchronous Meteorological Satellite (SMS) during GATE in 1974 observed and concluded that dust clouds over-land appeared as 'tongues' and as 'plumes' with the forward edge 'bending cyclonically and sometimes forming a hook' (Figure 5.9). In the present discussion of the transport of the Saharan dust across West Africa in winter, a plume model as envisaged by the author's own observations of the harmattan dust over Nigeria at aircraft altitudes below 700 mb, corroborated with resports from several pilots at the Kano International Airport, seems to confirm the 'Plume' concept of dust propagation. A dust plume as

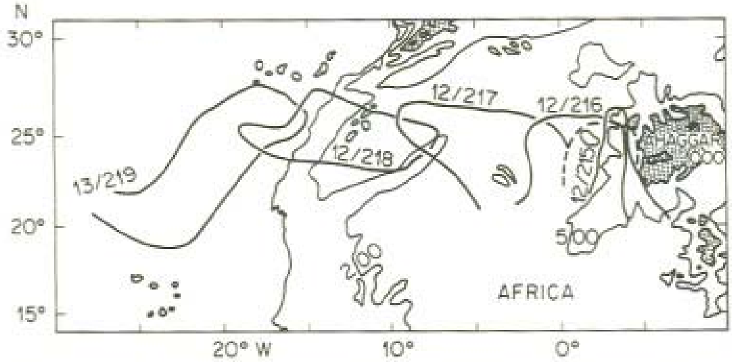


Figure 5.9 Path of a typical outbreak of dust haze in the Western Sahara (after Martin, 1975)

Note 12/215 . . . . . . 3rd August 1974, 12^h GMT
12/216 . . . . . . 4th August 1974, 12^h GMT
12/217 . . . . . . 5th August 1974, 12^h GMT
12/218 . . . . . . 6th August 1974, 12^h GMT
13/219 . . . . . . 7th August 1974, 13^h GMT

construed here is defined as an aerodynamic enclosure in space containing dust particles in addition to the normal constituents of the air in such a mixture that both dust particles and air molecules are indistinguishable by an unaided vision.

For such a model the concentration of dust particles varies both in the horizontal direction as well as in the vertical and has the singular advantage of illustrating the 3-dimensional structure of dust extent in the atmosphere (Figure 5.10). Observations show that in a dusty atmosphere improvement in visibility usually starts from the source region of a particular dust plume and progresses down-wind and never the reverse unless of course if another spell has started before clearance begins upstream. This suggests that the forward edge of the plume may have the highest dust concentration and lowest concentration restricted to the rear of the plume as has been actually observed (Aina, 1972; Kalu, 1975).

Secondly the fact that dust is propagated by the agency of the upper winds implies that concentration would be maximum at levels where the wind is strongest. This level corresponds to 900 mb at Kano, although the dust top may be at higher levels. (See Figure 5.11).

In an effort to define an aerodynamic three-dimensional configuration which would conform to the observed plume characteristics as outlined above, a careful analysis of the visibility distribution at the surface was made and the results showed that the 1 kilometre isopleth or less is approximately ellipsoidal (Figure 5.12). This result is also evident in the work by Aina (1972) and Samways (1976). Also satellite observations confirm a possible ellipsoidal shape of the Saharan dust plume as can be noticed from Figure 5.13 which shows some Application Technology Satellite (ATS) pictures of tracks of a dust cloud from Africa to the Caribbean in July 1969.

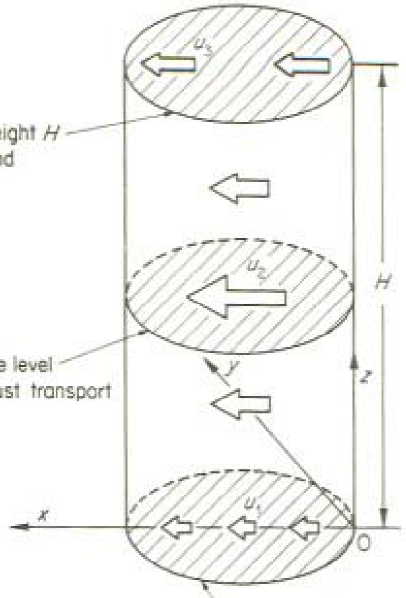


Figure 5.10 A schematic hypothetical model of a dust column showing the ellipsoidal dust fronts at various levels of the atmosphere ($u_2 > u_3 > u_1$)

Since I had no facility to measure dust concentrations at heights above the earth's surface, I depended on aircraft reports all of which seemed to confirm one thing – that the concentration of dust decreased with height particularly within an atmospheric layer which is thermally mixed with a possible discontinuity at the level of maximum wind speed.

If however the atmospheric column is not thermally mixed as usually the case during the night when temperature inversion may exist below 700 mb, the inversion layer will show a greater dust concentration as a result of the dust-trapping characteristic of an inversion layer. Insolation usually destroys such a temperature inversion resulting in a thermal mixing of the atmospheric column which may set-up vigorous convective current whereby the upper part of the layer is rapidly brought down to lower layers and the lower part taken up.

The above accounts would explain why visibility in a dusty atmosphere usually deteriorates in the morning hours around 0900 GMT (Figure 5.14). In most cases it is observed that dust first arrives at a station at higher levels and when mixing occurs within the atmospheric column as described above, dust is then brought down to lower levels through subsidence and turbulent mixing.

The forward edge of a dust plume is anvil-shaped as schematically depicted in Figure 5.15. This is in agreement with the dust 'tongue' as observed by Martin (1975) from satellite dust imagery (Figure 5.16).

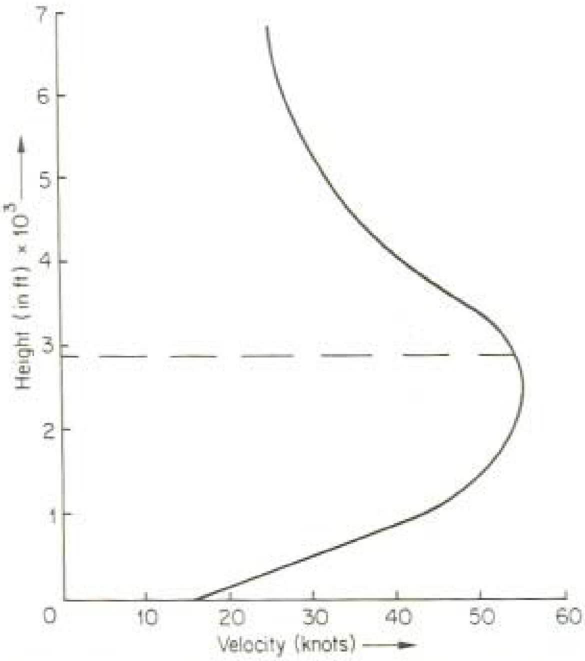


Figure 5.11 The mean velocity profile over Faya Largeau

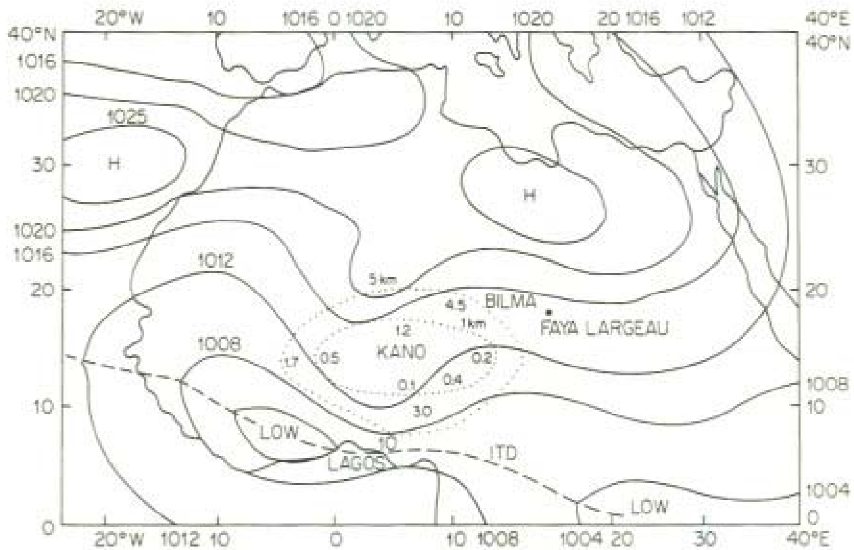
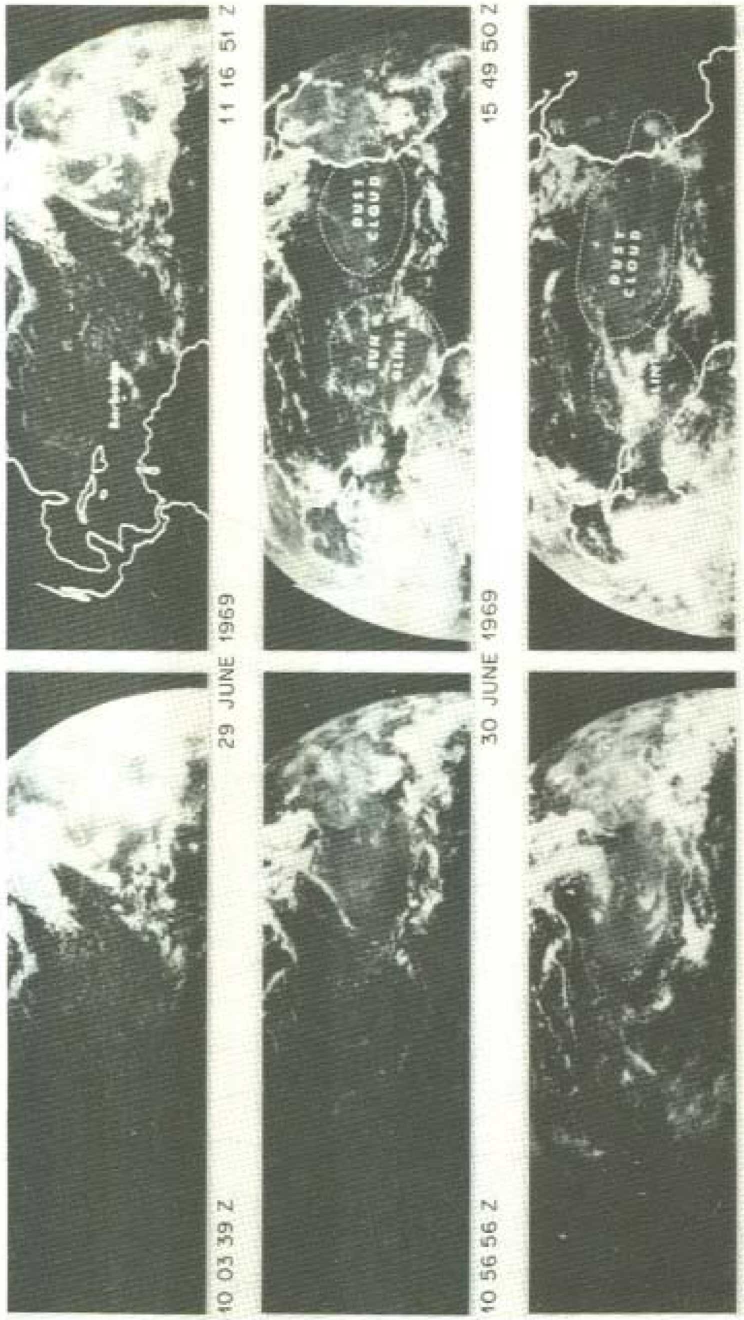


Figure 5.12 Visibility distribution. Surface 0900 GMT, 11th February 1974 (Visibility in km)


29 JUNE 1969
10 03 39 Z
11 16 51 Z
30 JUNE 1969
10 56 56 Z
15 49 50 Z
DUST CLOUD
1 JULY 1969
11 34 31 Z
17 49 50 Z
DUST CLOUD

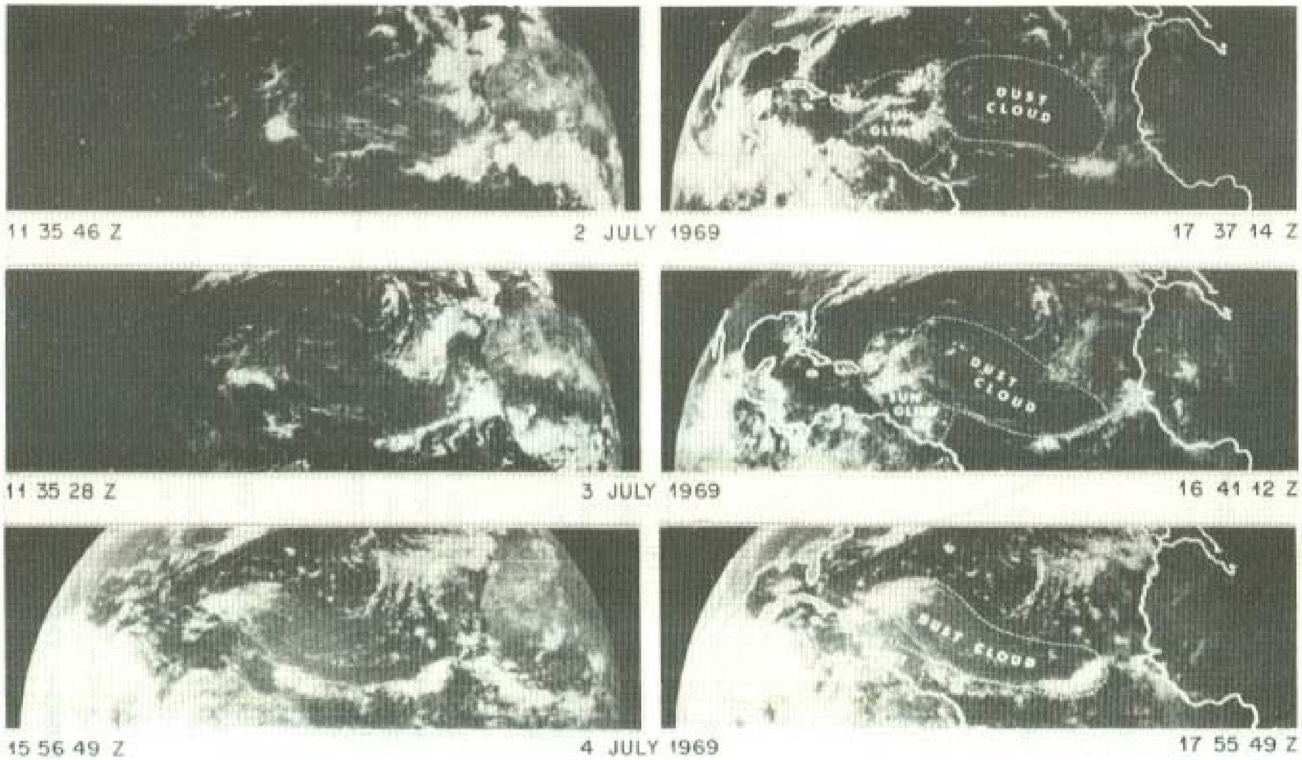


Figure 5.13 ATS III tracks a dust cloud from Africa to the Caribbean.
Abnormally high dust counts were recorded on 3, 5, 6, and 11 July 1969 at Barbados in the Lesser Antilles. The dust source is the Sahara, as these Application Technology Satellite (ATS) III pictures indicate. Dust clouds can significantly increase the normal amount of incoming solar radiation absorbed in the atmosphere; consequently less solar energy reaches the surface. All dust cloud effects on weather are not known. The ATS III camera should help clarify dust cloud/weather interrelationships

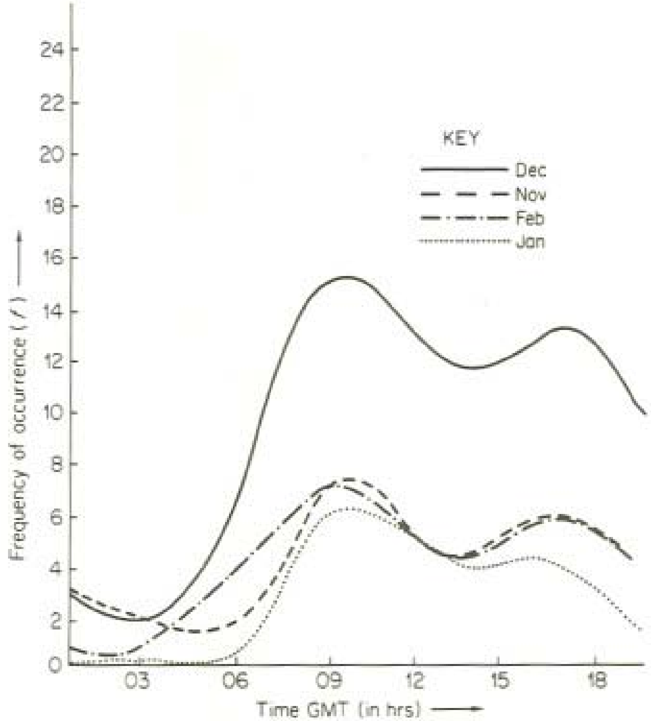


Figure 5.14 The diurnal frequency of occurrence of Harmattan dust storm (visibility 200–1000 m over Kano (1971))

The ellipsoidal configuration of the harmattan dust plume is still highly hypothetical. It needs further research before final conclusions can be made on the actual shape of the African Dust Plume. Meanwhile we shall apply the plume model in our present discussions on the propagation of the harmattan dust across West Africa.

5.5 PHASES OF DUST PROPAGATION

The propagation of the Saharan dust from the desert source regions to the time it arrives in the West African subregion as the harmattan dust haze may be discussed under three distinct phases.

5.5.1 The Instantaneous Phase

This is the emission stage and marks the beginning of what may constitute the history of the African Dust Plume. The phase marks the period when dust particles

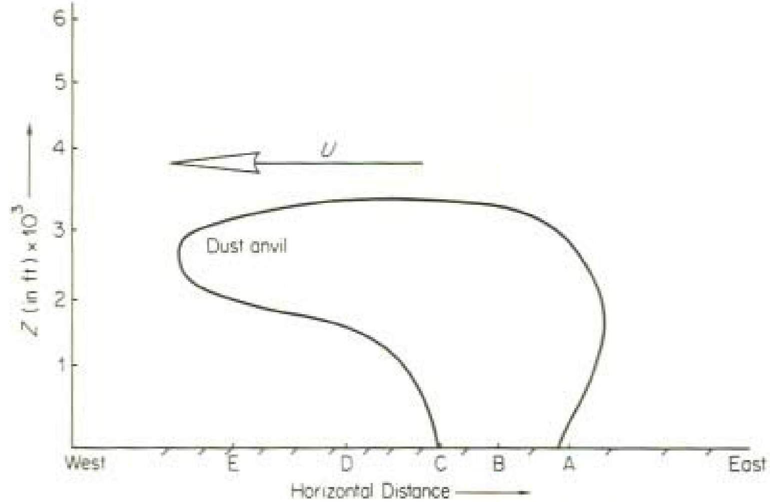


Figure 5.15 Propagation of dusty atmosphere
A: Onset of clearance at station A
B: Station under dusty atmosphere
C: Dust front just reaching station C
D: } Good visibility at night with a chance for
E: } deterioration by mid-morning owing to turbulent mixing

are violently raised from the ground usually in the form of duststorms as a result of very strong surface wind. One important characteristic of the Instantaneous Phase is that it is highly unstable and depending on the degree of instability in the atmosphere. The phase may occur in pulses with very short time intervals and a corresponding fluctuation in visibility. It is more eddy fluctuations, created principally by the low-level pressure surge as discussed in Section 5.3 than normal thermal convection that are responsible for the state of instability and turbulence that has been found to be associated with the emission stage of the dust plume.

The plume of dust during this phase is diffused upward by turbulence and there is pronounced buoyancy and no spreading in the horizontal direction as the mean motion during this phase is directed upwards.

5.5.2 The Spreading Phase

When the dust has been raised from the ground as discussed above and diffused upwards by turbulence to the level where the wind is strong enough, transportation starts in the horizontal direction. This marks the Spreading Phase. During this stage the dust particles within the plume can be assumed homogeneous in terms of grain size as the heavier particles must have sedimented out of the plume body during the first phase as a result of gravity.

It is observed that with time the wind which raised up the dust particles

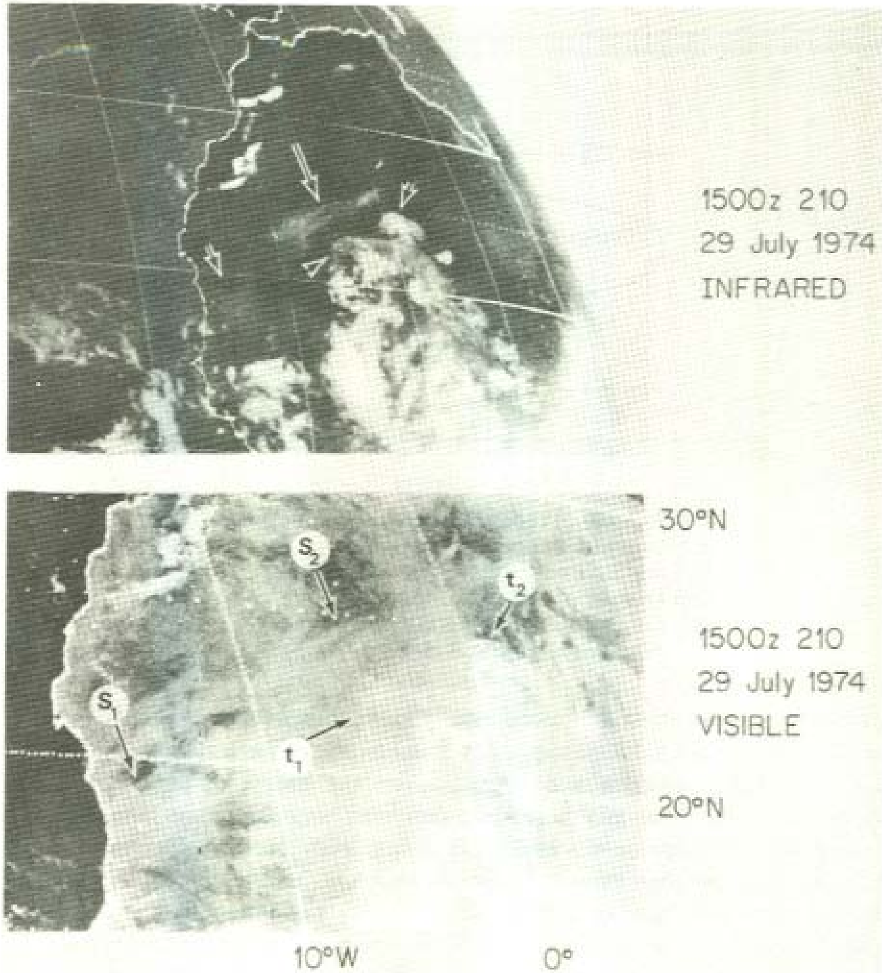


Figure 5.16 Dust tongues (t_1 and t_2) and dust streaks (S_1 and S_2) in simultaneous SMS infrared and visible pictures covering the western Sahara (after Martin, 1975)

gradually weakens and this suggests that the plume also gradually loses its vertical momentum and the eddies developed during the instantaneous phase become less powerful. The overall result of this attenuation in the surface wind strength is a general spreading motion of the dust plume. Whereas the first phase relates to the area of dust emission (i.e. the source region), the second phase usually starts some few kilometres downwind.

5.5.3 The Equilibrium Phase

The Equilibrium Phase is the most stable of the three phases of motion of the dust haze plume. It sets in as soon as the Spreading Phase has been completed. It is assumed that at this stage the plume has finally lost independence and moves entirely under the influence of the prevailing winds.

In West Africa and Nigeria in particular this stage is usually marked by a gradual reduction in visibility from, say 30 km (under normal weather) to about 5 km (in dust haze) within, say 6 hours. Thereafter the visibility deteriorates rapidly becoming poorest when perhaps the core of the dust plume comes over the station. The significant thing about the Equilibrium Phase is that it usually takes place some hundreds of kilometres downwind. For example the harmattan dust haze which affects the entire Northern States of Nigeria arrives there at its Equilibrium Phase.

5.6 SOME METEOROLOGICAL FACTORS CONTROLLING DUST TRANSPORT

5.6.1 The Prevailing Wind

Among the meteorological factors that control the propagation of the Saharan dust, the wind comes readily to mind. The prevailing wind therefore plays the greatest role in the movement of the Saharan dust right from the emission stage to the propagation stage. This is associated with the circulation patterns in the Saharan air layer where dust is usually propagated. Upper jets have sometimes been associated with dust transport (Obasi, 1965).

Dust in general is propagated through the atmosphere by the agency of the upper level winds depending on the vertical extent of the dust layer. It is observed that the Saharan Air Layer (SAL) over West Africa in winter does not usually exceed the 700 mb level particularly north of the ITD, but in the more humid part of West Africa south of the ITD the SAL may be found as high up as at the 600 mb level (Carlson and Prospero, 1972).

The fact that the upper winds are directly responsible for the dust transport implies that the concentration of dust at any place and at any level of the atmosphere depends on the quantitative removal (depletion) of dust by wind. If the wind is strong within the SAL, the concentration of dust over any given location on the earth's surface will decrease as the rate of movement of dust aloft across such a surface is large. The reverse is the case for weak winds resulting in high dust concentration.

Over Kano (12°N, 8°E) in Nigeria the 900 mb level was found to constitute on the mean the level of maximum dust transport. This is because in the light of the above discussions the 900 mb level coincides with the level of maximum vertical wind shear. An examination of the velocity profile of various stations in West

Africa shows that there is always a characteristic zone of max. wind (see Figure 5.15 above).

In West Africa during the northern winter, the dominant synoptic feature is the subtropical anticyclone which generates the strong north-easterly winds which have been associated with the transport of the Saharan dust, (Figure 5.2). The persistence of a dusty atmosphere over any location therefore depends on the magnitude of these north-easterly winds.

Wind speed affects the rate of deposition of air-borne dust particles and so while velocity divergence is favourable for faster dust movement, velocity convergence enhances dust accumulation and deposition on the surface. Characteristically light wind and calm conditions are very conducive for longer persistence periods for a dusty atmosphere than stronger winds.

During the first two weeks of March 1977, West Africa experienced one of the severest harmattan spells that have ever been observed in the territory. The contributory synoptic feature was a southward shift and stagnation of the subtropical anticyclone over West Africa such that a greater portion of the subregion was under the influence of the dry continental north-easterly winds. The blocking effect of the anticyclone over West Africa is so pronounced that the dry season seems to be cutting into the rainy period particularly in the southern part of the region with the result that an unusually dry weather is presently being experienced in West Africa. The northward advance of the ITD has been greatly checked by the dominating influence of the blocking anticyclone.

Characteristically the mean flow at lower levels of the troposphere has continued to be the north-easterlies which therefore advect the dry dusty Saharan air across West Africa into the Equatorial Trough.

The amount of dust transported across any given locality is directly proportional to the mean wind velocity over the area. Thus the stronger the wind the faster and greater the volume of dust transported across a given place. The wind is therefore one of the most important meteorological factors controlling the transport of the Saharan dust.

5.6.2 Vertical motion

Another important characteristic of the atmosphere which affects dust transport is the state of air motion in the atmosphere – whether convective upward motion or subsiding downward motion is taking place. The former results in an upward transport as is usually the case for pressure systems such as the low pressure areas and troughs where an upward and convective motion is usually pronounced. One advantage of an upward motion in a dusty atmosphere is that much of the available dust is pushed upwards into the atmosphere and eventually removed by the stronger upper winds to other areas downwind. This process results in a decrease in the concentration of dust particles at the surface and lower levels.

Subsident motion, on the other hand, is associated with the descent of dust particles and usually results in higher concentration of dust at lower levels of the atmosphere. Pronounced large-scale subsidence results generally in a greater persistence of a dusty atmosphere. It is usually an effective instrument for forecasting the persistence of the harmattan dust haze in West Africa.

5.6.3 Thermal stratification of the atmosphere

Temperature variation particularly in the vertical direction affects the transport of particulates in various ways and the harmattan dust is not an exception. Thermal stratification of the atmosphere is therefore an important parameter that controls to a large extent the transport of the Saharan dust.

Thermal mixing of the atmosphere is most pronounced when the temperature lapse rate attains or nears the dry adiabatic value and as Pasquill (1971) has observed strong lapse enhances vertical mixing of the atmosphere.

Observations in Nigeria show that a low level temperature inversion of limited depth develops during the night usually somewhere below 700 mb when the atmosphere is stable, and when this occurs in a dusty atmosphere dust is usually trapped within the inversion layer. It is known that an inversion temperature profile of the atmosphere suppresses vertical mixing and this goes to explain the reason for the existence of high concentration of dust within an inversion layer.

However when insolation becomes strong in the morning with the lapse rate becoming steeper the transfer of dust particles from one layer to another increases reaching maximum when the temperature profile attains or nears the dry adiabatic value. This results in a rapid free up-and-down motion within the atmosphere and under such conditions the inversion is destroyed leading to the redistribution of the dust to lower layers of the atmosphere. The overall result of thermal mixing in a dusty atmosphere is usually the occurrence of poor surface visibility. The author's observation in Kano (Kalu, 1975) shows that this happens around 0900 G.M.T. (Figure 5.14).

This temperature stratification of the atmosphere affects the diurnal cycle of dust in the atmosphere and by this we mean the increasing concentration of dust (poor visibility) at the surface and adjoining layers of the atmosphere in the morning when insolation results in the mixing of the atmospheric column and the decreasing concentration (good visibility) when dust is trapped within the inversion layer as a result of suppressed vertical mixing of the atmospheric column.

5.6.4 Moisture Content

The moisture content of the atmosphere or humidity is perhaps one of the most important factors controlling dust transport in the atmosphere. Characteristically the tiny dust particles behave as condensation nuclei which have a great affinity for water and by absorbing water they grow becoming heavier and sediment out of the atmosphere. Thus if the Saharan dust plume comes over to a section of the

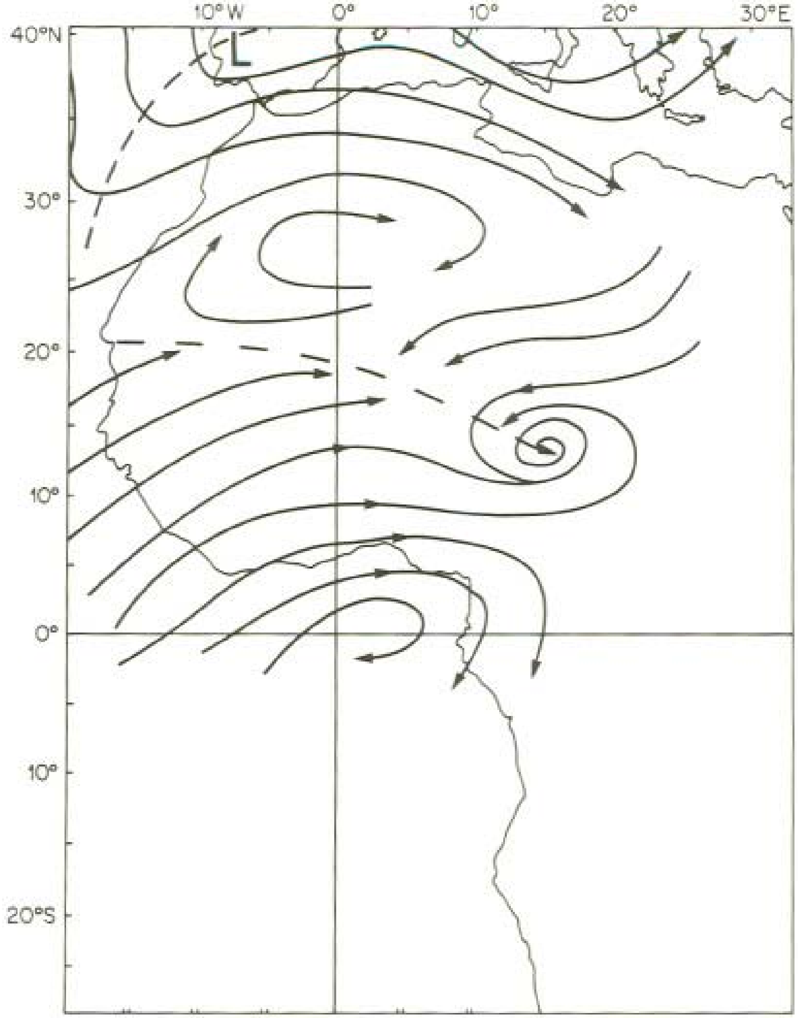


Figure 5.17 Typical midsummer streamlines (850 mb)

atmosphere where the moisture content is high, the immediate result will be that a large amount of it would sediment out giving rise to improved visibility.

In West Africa the intensity of the harmattan dust has been found to decrease south of the surface position of the ITD and this decrease has been associated with increasing moisture content of the atmosphere towards the coast during the winter period when the Saharan dust is observed over the southern part of West Africa.

One significant thing about the Saharan dust transport in West Africa is that in northern summer when the position of the ITD shifts northwards over the southern part of the Sahara, the trajectory of the Saharan dust across West Africa also shifts to the north-western part of Africa over Mauritania and Morocco. Dust clouds have been frequently observed off the Atlantic coast of North-west Africa and the Caribbean Islands in summer. These have been documented by Carlson and Prospero (1972) and recently by Martin (1975) (Figure 5.9).

During the northern summer a greater part of the West African subregion does not experience any dusty atmosphere because the humid and penetrating south-west – monsoon winds do not allow whatever dust that is available to be transported across West Africa particularly the Nigerian area as the influence of the dry north-easterlies is restricted to Central Sahara during this period (see Figure 5.17).

5.7 CONCLUSION

The Saharan dust is propagated in a plume form across West Africa at about the same speed as the African Easterly Waves and takes on the average about one to two days to advect to the northern Saharan border of West Africa, for example the northern parts of Nigeria, after emission from the Bilma–Faya Largeau source region.

The African Dust Plume (ADP) arises as a result of a state of pronounced atmospheric instability associated with a pressure surge at low levels of the atmosphere resulting from an intense low-level anticyclogenesis and upper convergence.

The dust is transported by the low-level continental north-easterly winds below 700 mb particularly the 900 mb where wind speeds of 30 knots or more are observed. The Saharan air layer is found at lower levels of the atmosphere during winter particularly north of the ITD, but at higher levels in summer (750–600 mb) south of the convergence zone because the Saharan air characteristically overrides the more humid and denser tropical maritime air mass south of the ITD.

While the dust plume maintains a south-westerly trajectory across West Africa in winter with the dust originating from the north-eastern part of the Sahara, in summer, as a result of the penetrating south-westerly monsoon winds, the dust disappears south of latitude 15°N and is then mainly restricted to the north-western part of Africa with possibly a different source history from that which affects Nigeria in winter (Figure 5.1).

Whatever dust that eventually arrives in West Africa from the Sahara depends on the direction and strength of the low-level winds below 700 mb, especially the 900 mb flow as well as the thermodynamic characteristics of the lower tropical troposphere such as thermal stratification and moisture content.

Some aspects of the African dust plume are still hypothetical, for example the three-dimensional aerodynamic structure of the plume. It is however hoped that the proposed West African Monsoon Experiment (WAMEX) will throw more light on the characteristics of the African dust plume.

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