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'Andhi', the convective duststorm of northwest India

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ABSTRACT. The convective duststorm occurring over Northwest India during the pre-monsoon season is called '*Andhi*'. In this paper a study is made on *Andhi* of Delhi using available meteorological records of recent years. From records of horizontal visibility and surface wind speed variations associated with them, *Andhi* has been classified into 4 types. Radar PPI photographs studied shows that the distance between the cumulonimbus cloud or squall line as seen in the radar and the ground level position of the duststorm (or gust-front) can be as large as 30 kilometres. The paper also gives a review of the existing knowledge on the phenomenon of convective duststorm (*Andhi* and *Haboob*).

1. Introduction

1.1. During the months of April, May and June, duststorms occur frequently in Punjab, Haryana, North Rajasthan and adjoining west Uttar Pradesh. When dust raised by strong wind reduces horizontal visiblity to less than 1000 metres we call the phenomenon a duststorm. There are three classes of duststorms according to their intensities light, moderate and severe duststorms, as per the classification adopted by India Meteorological Department. (detals are given in Table 1).

TABLE 1

Classification of duststorm according to intensity

Intensity of dust-storm	Wind force (on Beaufort scale)	Visibility
LIGHT	4 to 6	Less than 1000 metres upto 500 metres.
MODERATE	6 to 8	Less than 500 metres upto 200 metres.
SEVERE	9 or more	Less than 200 metres.

1.2. There are two types of duststorms-the 'pressure gradient' type and the 'convective' type. In the convective type of duststorm, dust is raised by the down-draft of a thunder storm cloud (cumulonimbus) or a squall line. '*Andhi*' is the local (Indian) name for the convective type of duststorm, a name possibly given because of the darkness created by the dust-wall as it passes over a station. Most of the duststorms that occur at Delhi are of the '*Andhi*' type. The frequency of duststorms at Delhi (Safdarjung) is 1 in April and 3 each in May and June as given in "*Climatological Tables of Observatories in India* 1931 *to* 1960"; for the whole year the average number of duststorms is 8.

1.3. We have only very little knowledge about '*Andhi*' except about its climatology. The earliest study available on *Andhi* is that by Hankin (1921) who gave a visual description of *Andhi* dust-wall and the associated cumulonimbus cloud. Srinivasiah and Sur (1938) have given climatological information regarding occurrence of duststorms at Agra. According to Bhalotra (1954) there is no difference in the atmospheric humidity content between a day of duststorm and a day of thunderstorm.

1.4. Convective type of duststorms also occur in the region extending west-wards of the Indian *Andhi* belt across Pakistan and Arabia to the arid regions of Africa like Sudan, Chad etc. In Africa and Arabia the phenomenon is called Haboob because of the strong wind associated with it. On Haboobs some elementary descriptive accounts are available in the literature (Sutton 1925, Lawson 1971) etc. The average speed of advance of the Khartoum Haboob is 32 m.p.h. With the arrival of a Haboob there is invariably a fall in temperature and rise in relative humidity. In a severe case the temperature drop may be as great at 15° C. Idso *et al.* (1972) report that in the arid regions of southwestern United

States duststorms of a very similar nature occur, although much less frequently than in Sudan (2 or 3 per year at Phoenix as compared to about 24 at Khartoum). Minimum visibility in an American duststorm average about 0.25 miles and it usually takes about 1 hour for visibility to return to 6 km. However, this return to 6 km has been as short as 12 minutes and as long as 3 hours. Dustwalls are found to reach upwards to 8000 feet as reported by aircraft.

1.5. Idso *et al.* (1972) has also presented a descriptive account with photographs of the dustwall of the severe duststorm of 16 July 1971; they called it an *'American Haboob'*. Relative humidity jumped from 33 per cent to 74 per cent with the passage of the duststorm's gust-front and the temperature dropped over 13° C. The average time required for these humidity and temperative changes was 7 minutes. Photographs of the duststorm showed that the boundry of the dust-wall was having the shape assumed by a current of dense fluid under cutting a less dense fluid (density currents as they are called) also characteristic of the Haboobs of Sudan as reported by Lawson (1971). A comparison between Laboratory and atmospheric density currents can be found in Simpson (1969).

1.6. WMO technical report No. 78 (1966) gives a brief note on duststorms as seen in radar displays. The echoes appear very similar on the PPI, to thunderstorm echoes. On the RHI the precipitation aloft with none of it reaching the ground can clearly be seen. The echoes are mostly cellular in structure, the height of the cells often reaching 12 km ; the average height is about 8 kilometres. Squall line type of duststorms with length over 300 km and width between 8 and 24 km have also been observed.

2. Meteorological instruments used in this study

2.1. A skopograph (transmissometer) for the continuous recording of horizontal visibility at a height of about 2.8 metres above ground is located near the threshold of runway 28 at Delhi airport. The distance between the projector and receiver of the skopograph (base-line) is 150 metres. Surface wind measurements are obtained from two anemographs, one an electrical cup-generator anemograph with its sensors located very close to the skopograph site, which has open ground (without wind obstructions) all around and the other a Dines' pressure tube anemograph located on the roof of a building close to the Air Traffic Control building. The sensors of the electrical anemograph are at a height of about 6 metres above ground. The Dines' P.T. anemograph is surrounded by building and its wind sensors are located at a height of about 16 metres above ground level. The distance of the Dines' P.T. anemograph from the skopograph site is 400 to 450 metres. Approximately midway between the skopograph site and the Dines' P.T. anemograph is the surface observatory where self-recording raingauge, thermograph and hygrograph are installed (the latter two are installed in Stevenson screens at a height of 4 feet above ground). Raingauge, thermograph, hygrograph and a Dines' P.T. anemograph are also located at Safdarjung airport which is about 10 km east-northeast of Delhi airport. Data from all these instruments are used in this study.

2.2. A weather radar working on 3 cm wave length was located close to Safdarjung airport during the period covered by this study (it has since been shifted and installed at Delhi airport). It has a useful range of 300 km in PPI and with RHI. Beam width is 1° conical.

3. Classification of Andhi using visibility and wind records

3.1. Raipal and Joseph (1978) made a preliminary study of the visibility variations in 40 *Andhis* which occurred at Delhi (Palam) airport during the period June 1972 to June 1977 for which complete records were available. From the nature of variation of visibility and wind speed it was found that 4 types of *Andhi* occur. Type 1 and 2 are associated with well defined squalls with the wind speed shooting to the maximum at the beginning itself and they have similar features. In all there were 20 such cases, 14 under type 1 and 6 under type 2. Type 1 cases have occurred during day time particularly afternoon and evening (The 14 cases of type 1 duststorms have occurred during the period 1207 IST to 2102 IST. Out of these 11 cases occurred during the period 1500 IST to 2000 IST). Type 2 cases occurred during night and morning hours (2107 IST to 1054 IST). In type 3 the downdraft winds from the associated cumulonimbus or squall line have lasted 1 to 2 hours as in type 1 and 2, but they did not have a sharp squall to begin with. In type 3 there were 14 cases. Type 4 is associated with individual sharp gusts of wind from convective clouds lasting for a few minutes, where the visibility reduction is also short-lived.

3.2. A few detailed case studies of *Andhis* of types 1, 2 and 3 (which accounted for 85 per cent of the *Andhis*) using data from all available surface Meteorological instruments at Delhi airport and the weather radar are presented in this paper.

4. Type-1 Andhi

4.1. *Andhi of* 13 *May* 1973

4.1.1. Fig. 1 gives the records of visibility and surface wind speed at Delhi airport associated with this duststorm. The prevailing visibility before the duststorm was about 3 km which is characteristic of the season. With the onset of the duststorm there was a sudden fall of visibility which began at 1515 IST and in 2 to 3 minutes the lowest visibility in this duststorm of 110 metres was reached. This may be called phase A. The visibility remained below 200 metres for

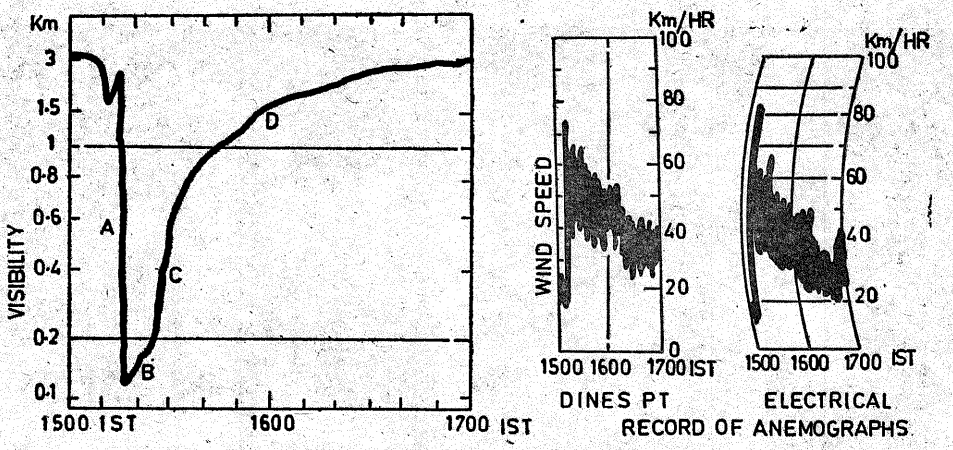

Fig. 1. Visibility and wind speed variations in type-1 Andhi of 13 May 1973

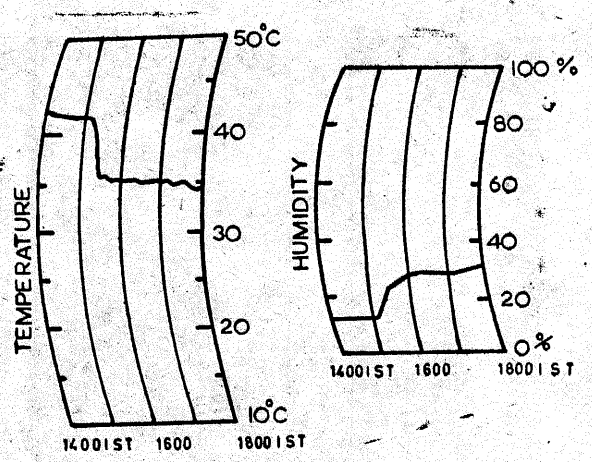

Fig. 2. Temperature and humidity variations in the type-1 Andhi of 13 May 1973

about 8 minutes (*i.e.*, till 1525 IST) which may be called phase B. Thereafter there was rapid improvement of visibility (phase C) followed by slow improvement of visibility (phase D). Visibility remained below 1,000 metres in this severe duststorm for about 28 minutes which is the duration of the dustorm. Visibility improved to 3 km by 1650 IST.

4.1.2. Wind records show that the duststorm was associated with a squall of speed 84 km.p.h. at the site of the skopograph (recorded by the electrical anemograph) and a speed of 74 km. p.h., recorded by the Dines' P. T. Anemograph. The squall was from the direction west. In the squall the maximum wind speed was reached within 1 to 2 minutes after the beginning of the wind increase. From the records of visibility and wind variations it is seen that the time of the sudden decrease of visibility and the time of the sudden increase in wind speed were very nearly the same (If there is a lag of a few minutes, one from the other, it is however not possible to know it precisely from the records, as time resolution in the chart is low). One feature of interest is that in the phase of rapid improvement of visibility, surface wind associated with the duststorm was still very strong.

4.1.3. Safdarjung airport also had a duststorm that day. The squall and duststorm set in at Safdarjung airport at about 1525 IST. The squall had a sharp wind maximum of 66 km at the beginning itself as at Delhi airport and it was from west-south-west direction. The squall and duststorm, therefore, covered the distance from Delhi airport to Safdarjung airport in 10 minutes and so the speed of movement of the duststorm was about 60 km. p.h.

4.1.4. At Delhi airport there was a temperature drop of 6°C due to this duststorm (from 41 C° to 35°C) and a rise in relative humidity through 16 per cent (from 12 per cent to 28 per cent). These changes may be seen in Fig. 2. The major portion of the temperature fall took place in the first 2 minutes whereas the major portion of the humidity increase took place more slowly in about 8 minutes from the beginning of the duststorm. The changes in Safdarjung airport were similar.

4.1.5. The available radar PPI/RHI photographs of the convective clouds associated with this duststorm are given in Fig. 3. The PPI picture taken at 1442 IST (3a) with radar in range 400 km shows a squall line about 300 km long

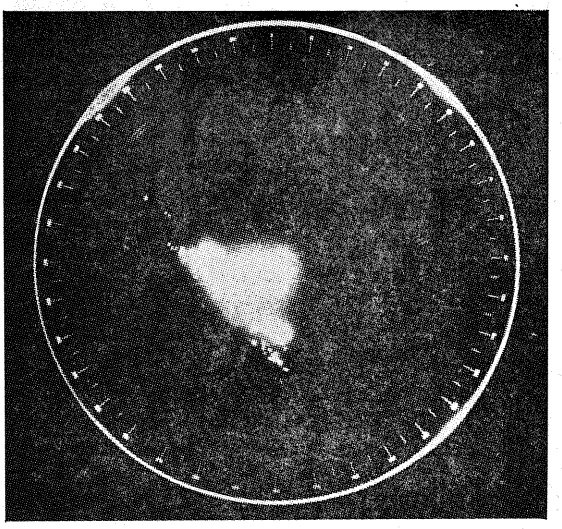

Fig. 3(*a*). PPI picture at 1442 IST, range 400 km, elevation 0·5° of 13 May 1973

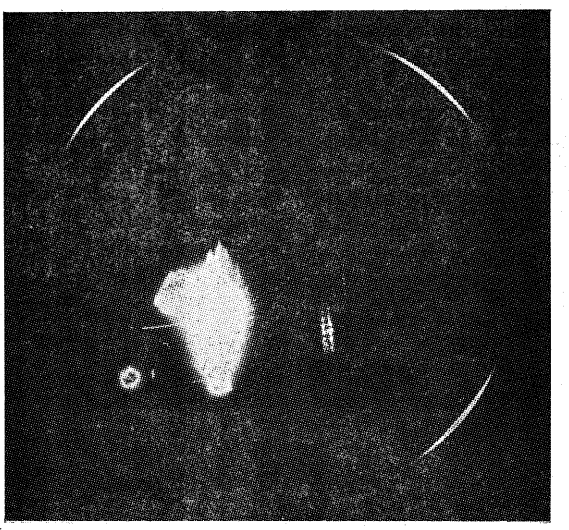

Fig. 3(*b*). RHI picture at 1443 IST, range 200 km, direction 250° of 13 May 1973

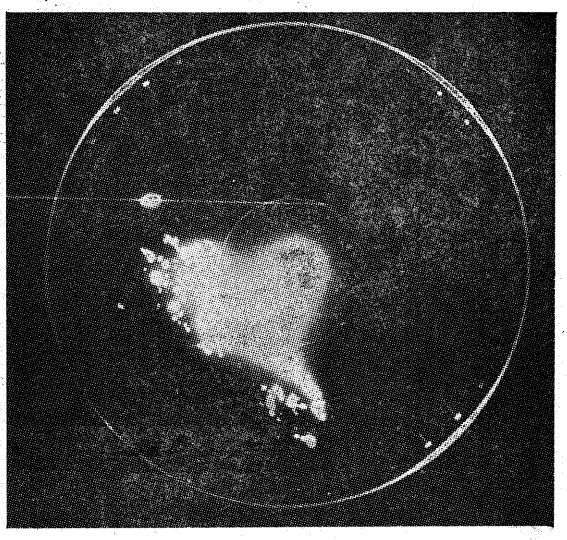

Fig. 3(*c*). PPT picture at 1541 IST, range 300 km, elevation 0.5° of 13 May 1973

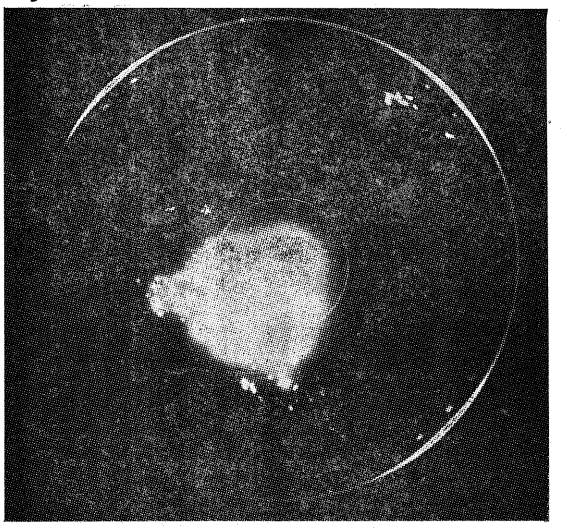

Fig. 3(*d*). PPI picture at 1632 IST, range 300 km, elevation 0.5° of 13 May 1973

and of considerable width in the south to north-west sector, about 100 km away from the radar located at Safdarjung airport premises. There is another cloud mass between the squall line and the radar. The RHI picture at 1443 IST in the direction of 250° (3b) shows vertical structure similar to a thunderstorm of the humid regions. The heights of the echo in RHI was 13 km and it was at a distance of about 70 km from the radar. The cloud seen in the RHI is possibly the cloud mass seen in the PPI between the squall line and the ground echo around Safdarjung. Delhi airport is at a distance of 10 km in about 250° direction from the radar at Safdarjung and so at 1443 IST this cloud seen in RHI was at a distance of about 60 km from Delhi airport. The duststorm occurred at Delhi airport about half an hour after this RHI picture time *i.e.*, at 1515 IST. The PPI picture at 1541 IST (3-c) shows that this cloud echo was still to the west of Delhi airport. It may be inferred that the dust-storm was at a distance of more than 30 km away from the convective cloud echo.

4.1.6. There was no precipitation associated with this severe duststorm either at Delhi or Safdarjung airports.

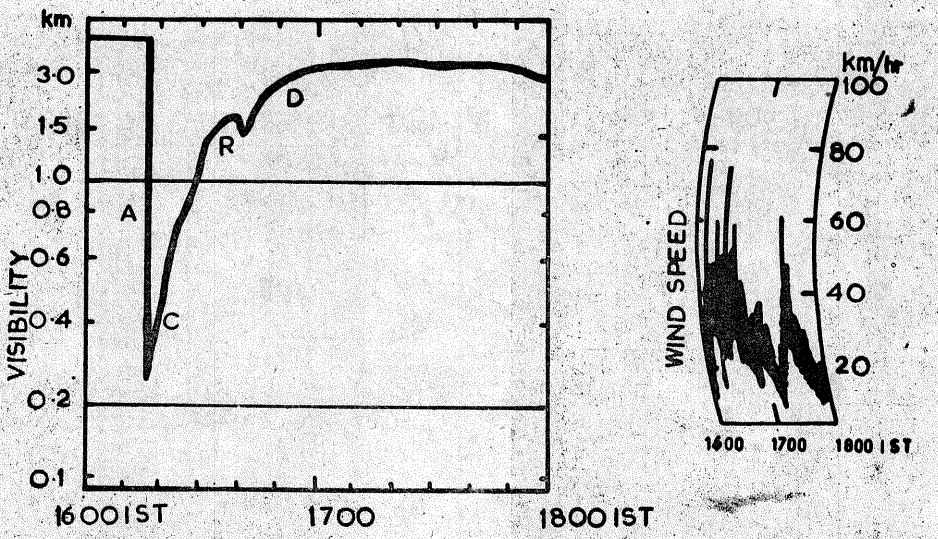

Fig. 4. Visibility and wind speed variations in type-1 Andhi of 20 May 1976

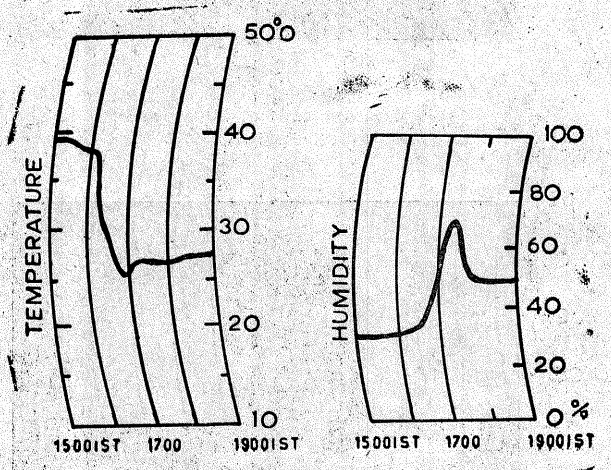

Fig. 5. Temperature & humidity variations in type-1 Andhi of 20 May 1976

4.2. *Andhi of* 20 *May* 1976

4.2.1. Fig. 4 gives visibility and wind variations in this duststorm as recorded at Delhi airport. It is a typical record of a type-1 duststorm in which phase B is absent. It is a moderate duststorm. Visibility fall began at 1617 IST and in one to two minutes the visibility reached the lowest value of 280 metres. Soon thereafter visibility began improving at first rapidly and thereafter more slowly. Visibility was below 1000 metres (duration of duststorm) for 14 minutes. Wind records show that the duststorm was associated with a sharp squall of speed 73 km. p. h. at the Dines' P.T. Anemograph and a speed of 80 km. p. h. at the site of the skopograph. The squall was from north-north-east direction.

4.2.2. This duststorm was associated with about 0.3 mm of rainfall at Delhi airport which occurred for a few minutes from 1635 IST (*i.e*, 18 minutes after the beginning of the duststorm). The variation of visibility marked R in the figure may be due to this rainfall. The rainfall has not significantly affected the rate of improvement of visibility. Safdarjung airport recorded 2.2 mm rainfall between 1630 and 1645 IST. The duststorm had hit Safdarjung airport at 1613 IST.

4.2.3. The temperature and humidity variations in this duststorm may be seen from Fig. 5. There was considerable fall in temperature (fall of 13°C at Delhi airport from 38°C to 25°C) and also considerable rise in relative humidity (from 31 to 70 per cent). The fall in temperature associated with phase A of the duststorm is only 6.5°C at Delhi airport which is comparable to the fall in temperature in the case of the duststorm of 13 May 1973. The change in humidity is gradual here also as in the case of the duststorm of 13 May 1973.

4.2.4. Fig. 6 (a, b, c, d) show the PPI pictures of the convective cloud associated with this duststorm. At 1411 IST there was a cloud mass to the northwest of the radar at a distance of 150 km. It became a squall line and reached a location 90 km from the radar by 1512 IST. The squall line further elongated and was about 30 to 40 km away from Safdarjung and Delhi airports at 1612 IST as may be seen from Fig. 6(c). At 1643 the echo was overhead Safdarjung and Delhi airports. The duststorm occurred at Delhi airport at 1617 IST. The radar echo at the time of the duststorm may be considered to be about 30 km. away from the duststorm.

4.3. *Andhi of* 11 *May* 1976

4.3.1. Fig. 7 shows the visibility and wind variations associated with this duststorm at Delhi airport. Visibility began falling at 2101 IST and in about two minutes reached the minimum visibility of 380 metres. Phases A, C and D are seen

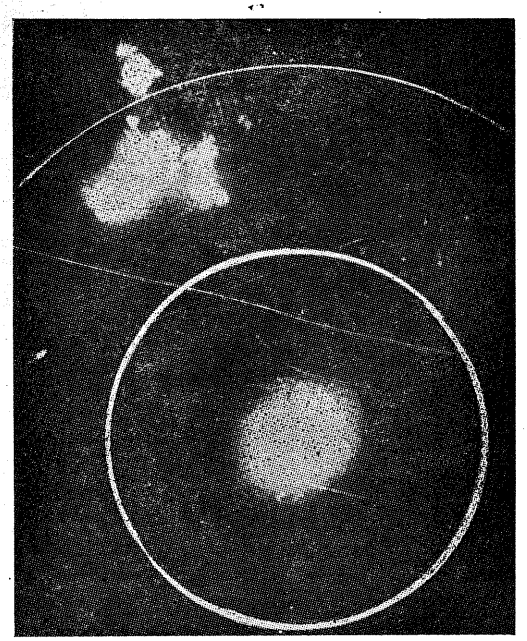

Fig. 6(*a*). PPI picture at 1411 IST, range 400 km, elevation 0.5° of 20 May 1976. Radius of inner range ring—100 km

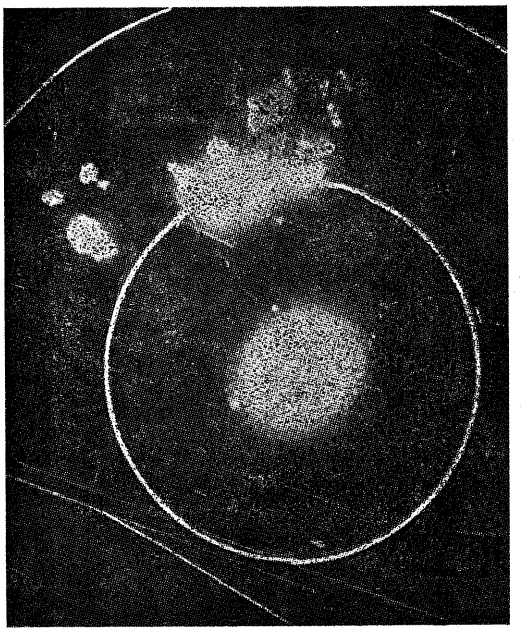

Fig. 6(*b*). PPI picture at 1512 IST, range 400 km, elevation 0.5° of 20 May 1976. Radius of inner range ring—100 km

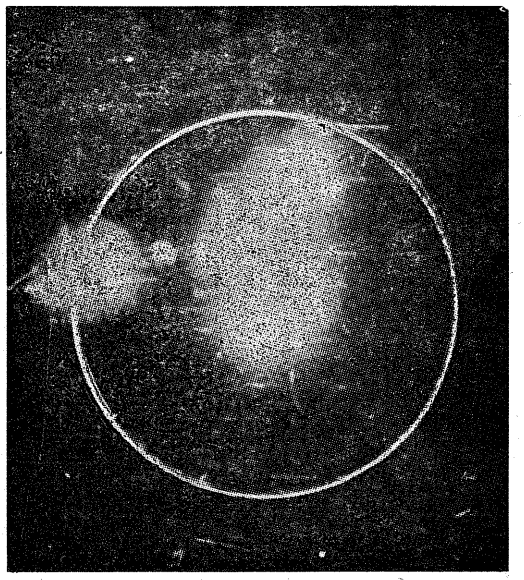

Fig. 6(*c*). PPI picture at 1612 IST, range 400 km, elevation 0·5° of 20 May 1976. Radius of range—100 km

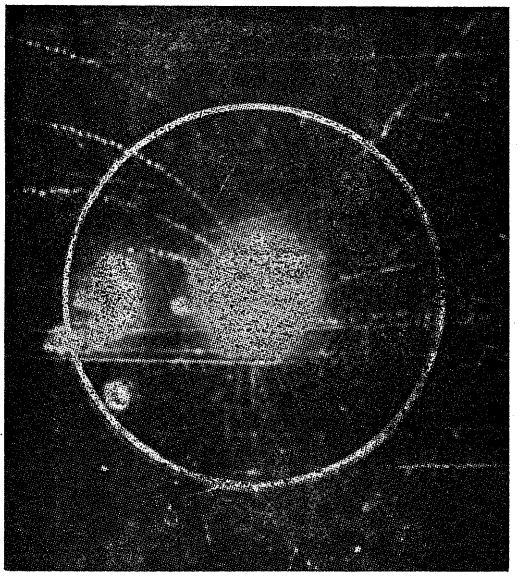

Fig. 6(*d*). PPI picture at 1643 IST, range 400 km, elevation 0·5° of 20 May 1976. Radius of range—100 km

in this duststorm also as in the case of the duststorm of 13 May 1973, but during phase B there is big fluctuation in the visibility. This moderate duststorm lasted 13 minutes. The associated wind variation is of the sharp squall type, with Dines' P. T. Anemograph recording a maximum wind speed of 77 km. p.h. and the electrical anemograph recording a speed of 91 km. p.h. The squall was from north-northwest direction.

4.3.2. There was no rainfall associated with this duststorm at Delhi airport but Safdarjung airport recorded 0.8 mm of rainfall during the period 2130 to 2145 IST. The duststorm had hit Safdarjung almost at the same time as Delhi airport.

4.4. *General characteristics of type* 1 *Andhi*

4.4.1. Examining the available 14 cases it is found that visibility falls rapidly (in 1 to 3

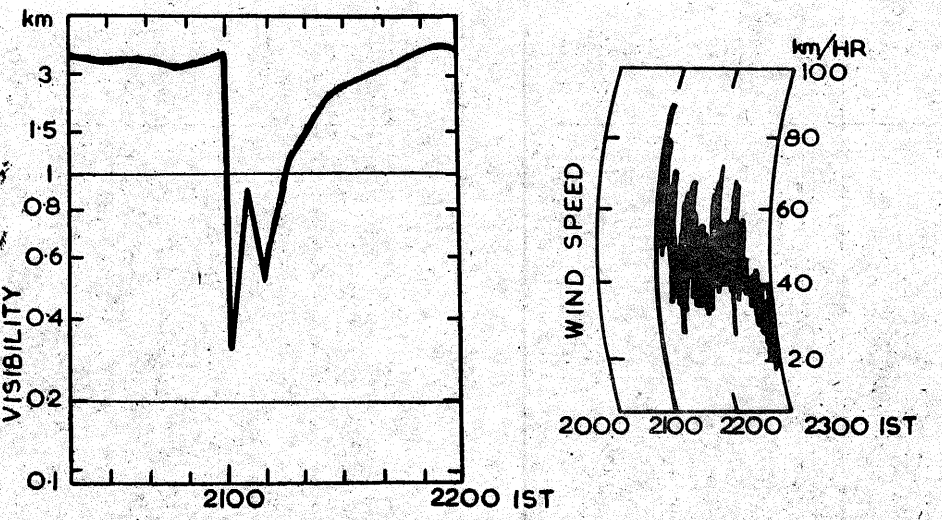

Fig. 7. Visibility and wind speed variations in type-1 Andhi of 11 May 1976

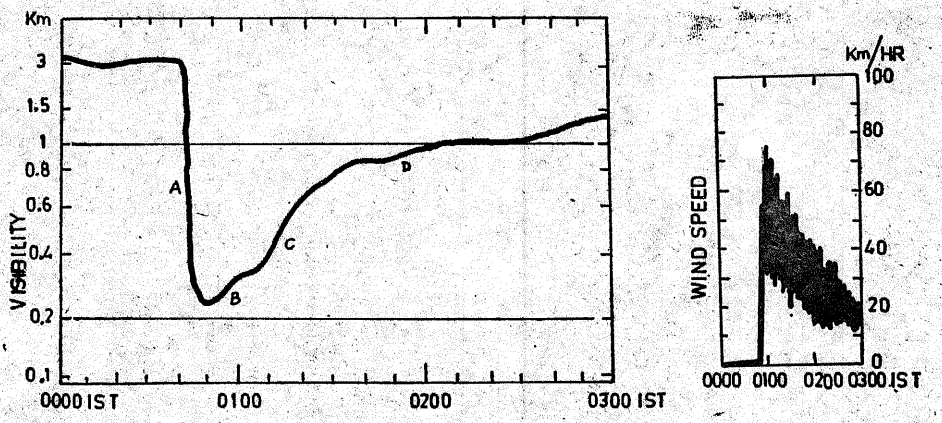

Fig. 8. Visibility and wind speed variations type-2 Andhi of 22 May 1976

minutes) from about 3 km, the general prevailing visibility during the duststorm season (April, May and June) to as low a value as 100 metres in association with the squall of an advancing thunderstorm cloud. The squall is such that the wind speed suddenly rises to the maximum value at the beginning itself and the wind speed thereafter gradually falls off during the next one to two hours. A few minutes after the initial fall of visibility to the lowest value the visibility begins to improve at first rapidly and thereafter more slowly. In the phase of rapid improvement of visibility surface wind associated with the convective cloud is still strong and gusting.

4.4.2. Some details regarding the 14 cases of type 1 duststorm are given in Table 2. In general it is seen that there is an inverse relation between squall speed and the minimum visibility reached. There is another inverse relationship between the minimum visibility and the duration of the duststorm (period during which visibility is less than 1,000 metres). Grouping the duststorms of type 1 according to their intensity, the averages of minimum visibility, squall speed and duration of the duststorms have been worked out for the 3 intensity classes and given in table 3.

5. Type-2 Andhi

5.1. This type is similar to type 1 except that the improvement in visibility is markedly slow. The associated wind speed variations (squall) is of the same type as in type 1 *Andhi*. Records for six *Andhis* of this type are available and these duststorms have occurred during the period 2107 to 1054 IST (night and morning hours). Two cases are described in the following paragraphs.

5.2. *Andhi of 22 May 1976*

5.2.1. Fig. 8 gives the records of visibility and surface wind speed variations (recorded by Dines' P.T. Anemograph) associated with this duststorm at Delhi airport. Visibility began falling rapidly at 0041 IST. The minimum visibility recorded

TABLE 2

Meteorological data in respect of the 14 cases of type 1 *Andhi*

(As recorded at Delhi airport)

S. No.	Date	Time of beginning of dust-storm IST	Duration of dust-storm minutes	Lowest visibility in the dust-storm metres	Maximum wind speed in the associated squall recorded by anemograph		Type of dust-storm	Temperature change due to the duststorm (in deg. C)		Humidity change due to the duststorm (in per cent)		Rainfall associated with the dust-storm (in mm)	Remarks
					Electrical	Dines P.T.		From	To	From	To		
1	2	3	4	5	6		7	8		9		10	11
1	7-6-72	1920	10	120	—	95	S	38.5	29.0	10	38	Nil	
2	13-5-73	1515	28	110	84	74	S	41.2	35.0	12	28	Nil	
3	14-5-73	1726	22	120	97	90	S	40.0	28.0	28	32	14.5	
4	27-5-74	1752	6	620	52	48	L	34.5	30.0	28	41	Nil	
5	22-6-74	2102	11	450	66	51	M	36.0	32.5	34	52	Nil	
6	5-5-75	1826	1	900	76	57	L	36.2	31.0	16	24	Nil	Safdarjung airport recorded trace rainfall from 1850 IST.
7	30-5-75	1504	12	540	74	61	L	42.0	39.3	16	18	Tr.	
8	7-6-75	1207	10	300	82	67	M	38.5	26.5	—	—	3.5	
9	24-4-76	1957	2	800	89	70	L	33.0	29.5	50	54	Nil	
10	11-5-76	2101	13	380	91	78	M	38.0	31.2	28	37	Tr.	
11	20-5-76	1617	14	280	80	73	M	38.0	25.0	31	70	0.3	
12	12-6-76	1653	9	340	70*	72	M	39.0	26.0	36	78	18.8	*record very faint
13	6-6-77	1838	4	320	120	100	M	38.0	23.7	35	76	8.0	
14	13-6-77	1952	3	820	75	68	L	35.0	29.5	33	48	Nil	Safdarjung airport recorded trace rainfall from 2030 IST.

L—Light M—Moderate S—Severe Tr.—Trace

TABLE 3

Mean parameters of light, moderate and severe dust-storms of type 1

Intensity of duststorm	Number of cases	Mean minimum visibility reached (in metres)	Mean wind speed in the associated squall (in kilometre per hour) recorded by anemograph		Maximum duration of the dust-storm (in minutes)
			Electrical	Dines P.T.	
Light	5	736	75	61	5
Moderate	6	345	85	73	10
Severe	3	117	91*	86	20

*Average of two cases only.

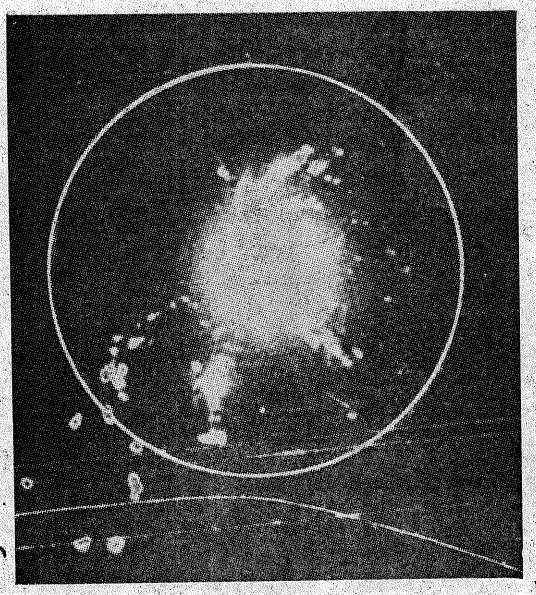

Fig. 9(*a*). PPI picture at 2311 IST, range 400 km, elevation 0.5° of 21 May 1976. Radius of range ring—100 km

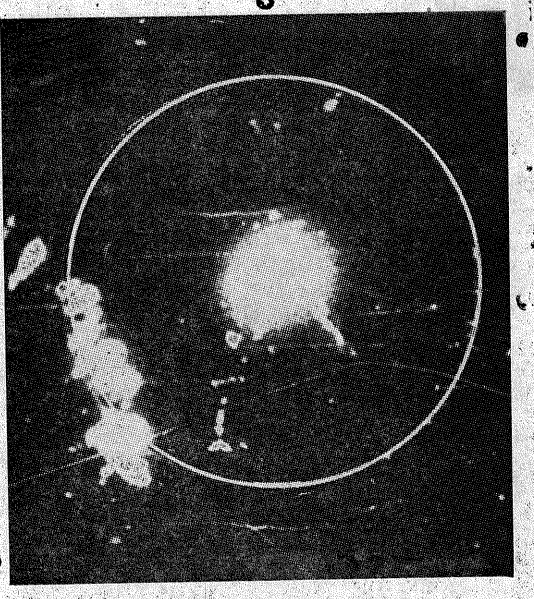

Fig. 9(*b*). PPI picture at 0011 IST, range 400 km, elevation 0.5° of 22 May 1976. Radius of range ring—100 km

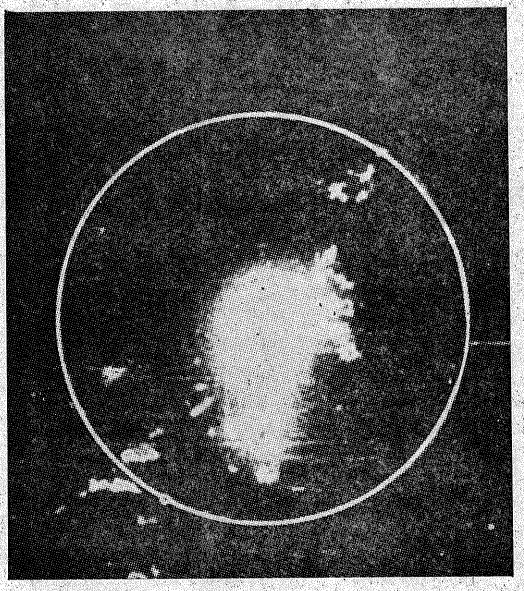

Fig. 9(*c*). PPI picture at 0111 IST, range 400 km, elevation 0.5° of 22 May 1976. Radius of range ring—100 km

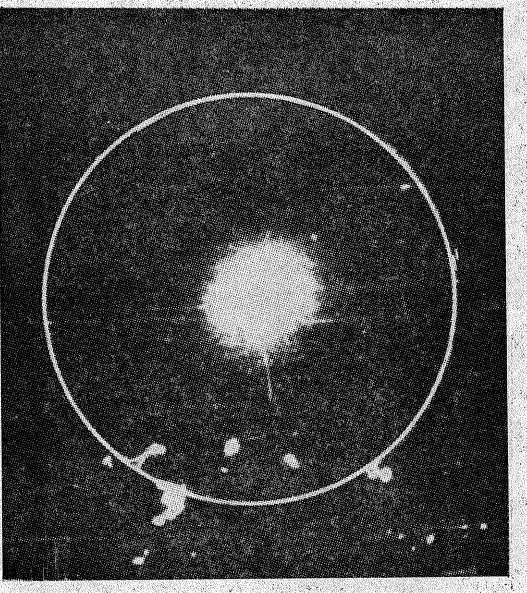

Fig. 9(*d*). PPI picture at 0211 IST, range 400 km, elevation 0.5° of 22 May 1976. Radius of range ring—100 km

was 230 metres. Visibility remained below 1000 metres (*i.e.*, duration of the duststorm) for 80 minutes and the improvement beyond 1000 metres was very slow. All the four phases A,B, C and D of the *Andhi* as seen in the type 1 case of 13 May 1973 are seen here also, but each phase is found to take more time than in type 1. The wind record in this type 2 case was exactly similar to that of the *Andhi* of 13 May 1973 ; the maximum squall speed is also the same in both the cases.

5.2.2. There was no precipitation associated with this *Andhi* both at Delhi and Safdarjung airports. During the dustorm temperature fell from 34°C to 31°C and humidity rose from 34 to 37 per cent.

5.2.3. Fig. 9 (a, b, c, d) gives PPI pictures taken in the Safdarjung radar kept in range of 400 km. At 2311 IST of 21 May 1976 scattered echoes are seen roughly in the form of a diffused line at a distance of about 160 km in the southwest to west sector. At 0011 IST of 22 May 1976

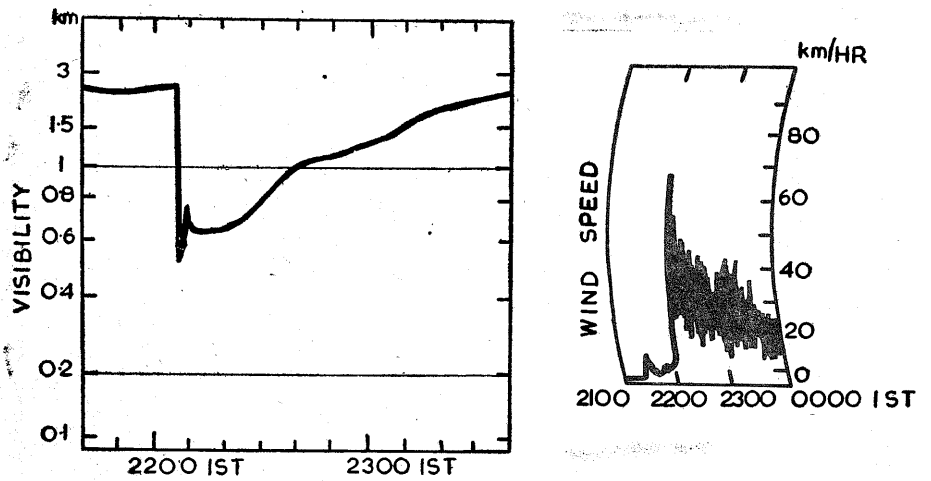

Fig. 10. Visibility & wind speed variations in type-2 Andhi of 1 June 1975

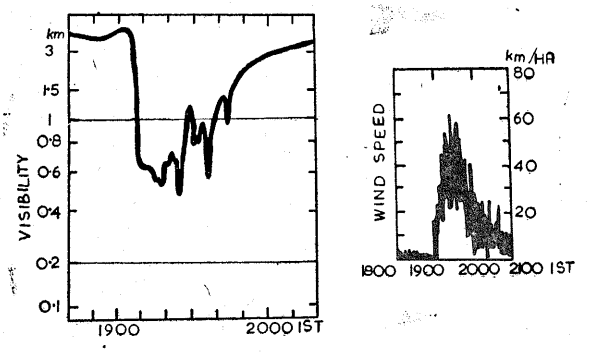

Fig. 11. Visibility and wind speed variations in type-3 Andhi of 20 April 1975

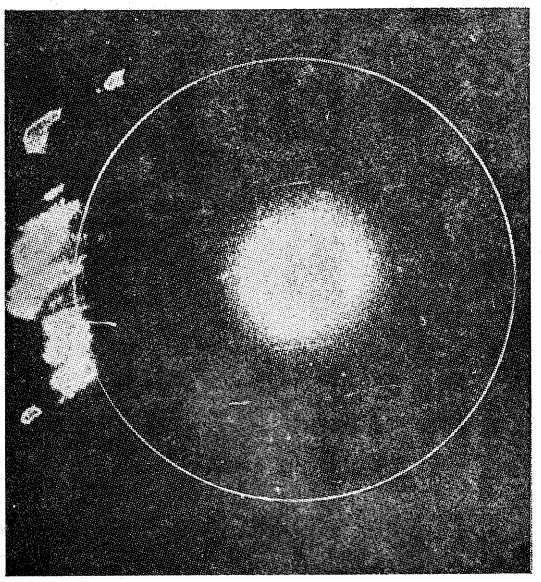

Fig. 12(*a*). PPI picture at 1712 IST, range 400 km, elevation 0·5° of 20 April 1975. Radius of range ring—100 km

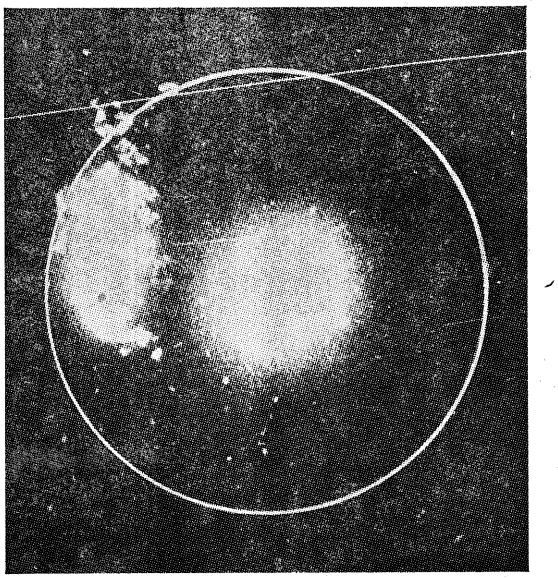

Fig. 12(*b*). PPI picture at 1810 IST, range 400 km, elevation 0·5° of 20 April 1975. Radius of range ring—100 km

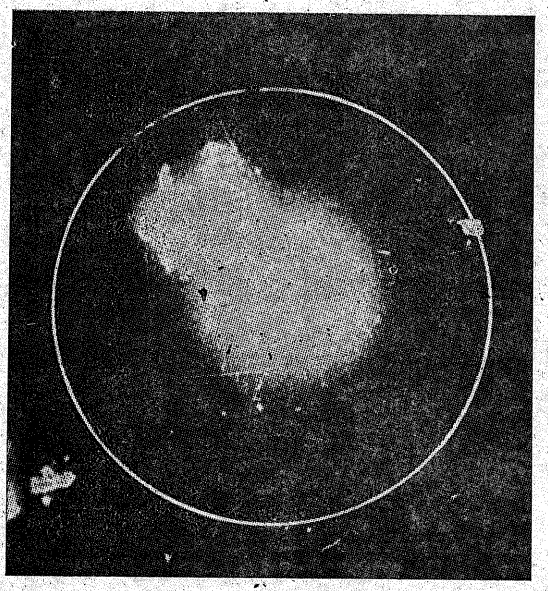

Fig. 12(*c*). PPI picture at 1911 IST, range 400 km, elevation 0·5° of 20 April 1975. Radius of range ring—100 km

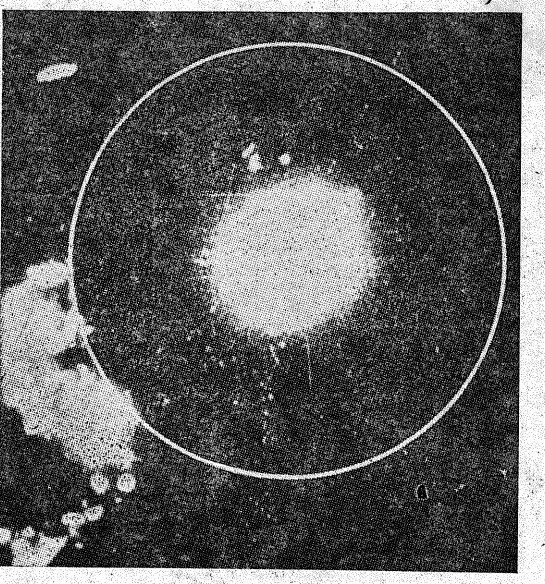

Fig. 12(*d*). PPI picture at 2013 IST, range 400 km, elevation 0·5° of 20 April 1975. Radius of rang ring—100 km

a well defined squall line had formed about 90 km away. The squall line moved eastwards and was almost overhead Delhi airport by 0111 IST. The duststorm occurred at Delhi airport at 0041 IST. It may therefore be inferred that the squall line was about 40 km away from Delhi airport when the duststorm hit Delhi airport. Fig. 9(d) shows that the echo has completely dissipated by then.

5.3. *Andhi of* 1 *June* 1975

5.3.1. Fig. 10 gives the records of visibility and wind variations (recorded by the electrical anemograph) associated with this duststorm which began at 2207 IST of 1 June 1975. This is also similar to a type 1 duststorm except that each of the phases B, C and D is slower than that of type 1; phase A is however similar to type 1 as it has occurred in about 2 minutes. The minimum visibility recorded in this duststorm was 520 metres. The duststorm lasted 33 minutes. The maximum squall speed as recorded by the electrical anemograph was 67 km. p.h.

5.3.2. There was no precipitation associated with this duststorm both at Delhi and Safdarjung airports. During the duststorm temperature dropped from 30.5°C to 28.5°C and humidity fell from 38 per cent to 36 per cent.

6. Type-3 Andhi

6.1. In this type of duststorm the surface wind variations associated with the downdraft of the thunderstorm cloud are not of the sharp squall type, although the strong wind associated with the squall lasts 1 to 2 hours. The wind variations are irregular. The wind maximum is reached 10 to 20 minutes (or even later than that) after the downdraft wind has set in at the station. Correspondingly the visibility variations are also irregular. A typical example of this type is described in the following paragraphs.

6.2. *Andhi of* 20 *April* 1975

6.2.1. Fig. 11 gives the records of visibility and surface wind (recorded by Dines' P.T. Anemograph) associated with this duststorm. Surface wind speed increase began at 1900 IST and the maximum wind speed of 62 km. p.h. (in Dines' P.T. Anemograph) was reached by 1925 IST. The corresponding visibility variations were irregular although a rather sudden fall of visibility began at 1905 IST. The peak showing the minimum visibility was at 1925 IST coinciding with the peak in wind speed.

6.2.2. There was no precipitation associated with this duststorm at Delhi airport ; Safdarjung airport recorded trace rainfall. During the duststorm temperature fell from 35.5°C to 32.2°C and humidity rose from 17 per cent to 22 per cent.

6.2.3. Fig. 12 (a, b, c, d) gives the PPI pictures taken in the Safdarjung radar kept in range 400 km. At 1712 IST a squall line is seen 100 km to the west (near the inner most range ring). The squall line is the one that caused the *Andhi* at Delhi airport. Another area with scattered cloud echoes is seen between 200 and 300 km away to the southwest. Fig. 12(b & c) show that the squall line moved northeastwards dissipating as it approached Delhi airport. At 1911 IST

Fig. 12(c) the *Cb* cloud echo is seen about 30 km to the north of Delhi airport. Fig. 12(b) gives the position at 1810 IST. The duststorm hit Delhi airport at 1905 IST very close to the picture time of Fig. 12(c). By 2013 IST Fig. 12(d) the squall line had completely dissipated and in the PPI scope the other cloud cluster which has become a squall line by then is seen at a distance of 100 km.

7. Conclusion

7.1. The study presented in this paper using available meteorological records has given some useful information regarding the downdrafts and the visibility variations in *Andhi* occurring at Delhi airport. From the nature of variations of visibility and surface wind it was found that 4 types of *Andhi* occur. A rough picture of the distance between the cumulonimbus or squall line and the ground level position of the gust-front or the dust-wall has also been obtained.

7.2. More studies are needed particularly on the structure of the *Andhi* dust-wall and its speed of movement, development and decay. The vertical structure of the *Andhi* atmosphere has also to be studied. These studies are needed to understand the mechanism of the formation of the *Andhi* dust-wall and its maintenance and propagation.

7.3. The study of air motions in and around the *Andhi* dust-wall is also important in relation to aircraft operations. Soon after an *Andhi* has hit a station visibility begins to improve and the initial improvement is fast. During this period of rapid improvement in visibility strong down-drafts can be expected which could pose problems for aircraft operations if these down-drafts are not properly understood and suitable procedures drawn to cope with them.

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