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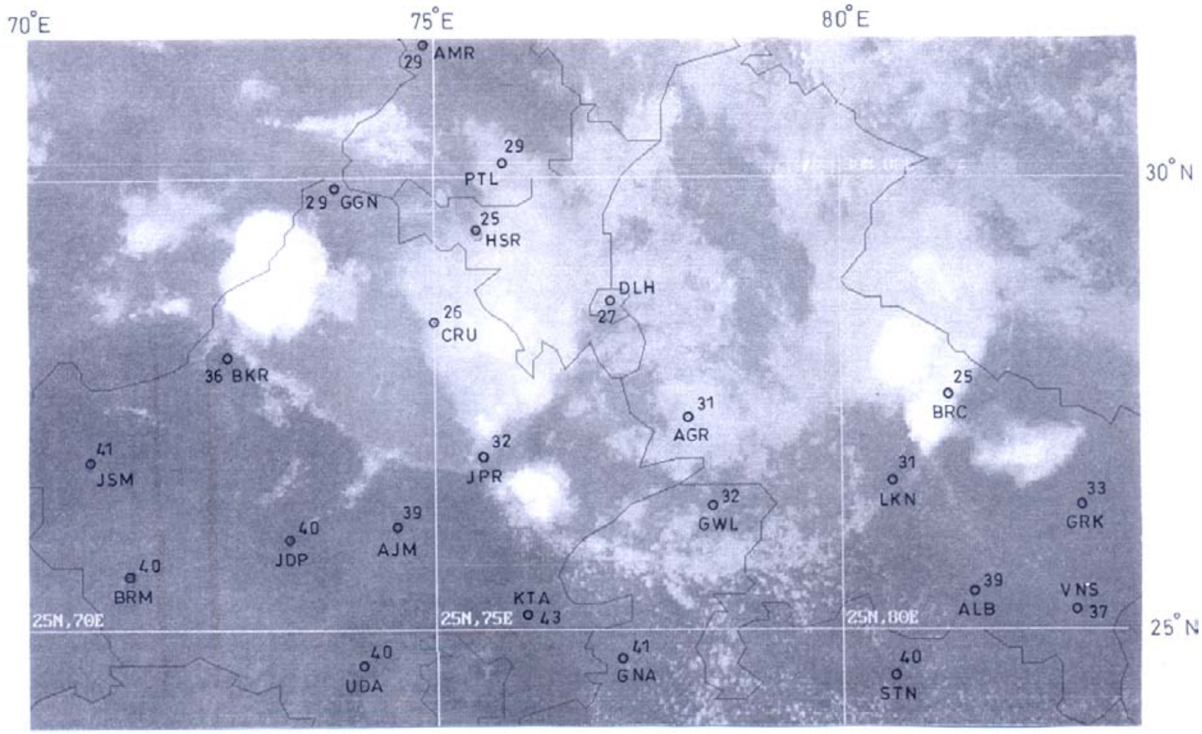
ARC LINE CLOUD IN SATELLITE IMAGERIES OVER NORTH INDIA – A CASE STUDY

1. An arc shaped line of convective cloud is often observed on satellite imageries in association with boundary layer outflow from thunderstorms mainly during hot weather season (Pre-monsoon season in India). Three semi-circular arc line shape cloud imageries were seen over North India in NOAA satellite images on 27 May 2004. Temperature anomalies of the order of 8-12° C were noticed between inner and outer arc line areas both on the surface charts and the satellite images (IR). The study reveals the formation of semi circular/arc line shape of cumulus cloud images due to the sudden surge of cold air spreading uniformly from the thunderstorm downdraft on three different locations and severe thunderstorm developed over areas of intersection of the arc lines.

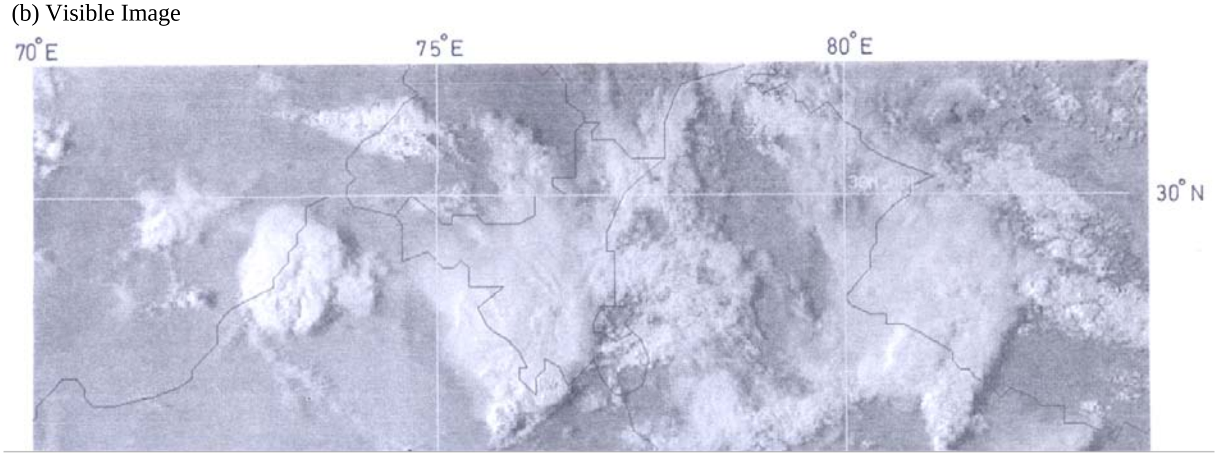
The satellite picture contains cloud patterns, which are not perceptible either on the chart or in the reports of the individual reporting stations. Convective cloud over continental areas is characterized by groups of irregularly shaped elements of different sizes and depths, which often organized into lines or bands, or sometimes-cellular pattern (Bader, *et al*. 1995). The meso-scale high-pressure system (mesohigh) and development of an intense thunderstorm area around has been explained by Fujita (1963).

Characteristics and significance of the arc line of thunderstorm and severe weather systems have been explained by Purdom (1973, 1973a, 1974 & 1979) and Scorer (1990). AVHRR (Advanced Very High Resolution

(a) IR Image



(b) Visible Image



Figs. 1(a&b). NOAA-12 [(a) IR and (b) VIS] satellite imageries of 1059 UTC, 27 May 2004. Surface temperature recorded at 1200 UTC superimposed on IR image

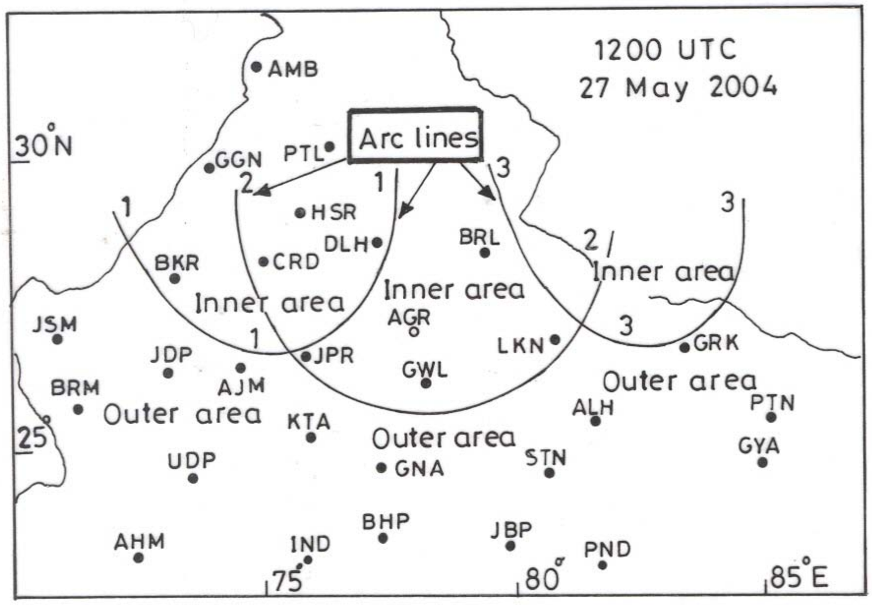


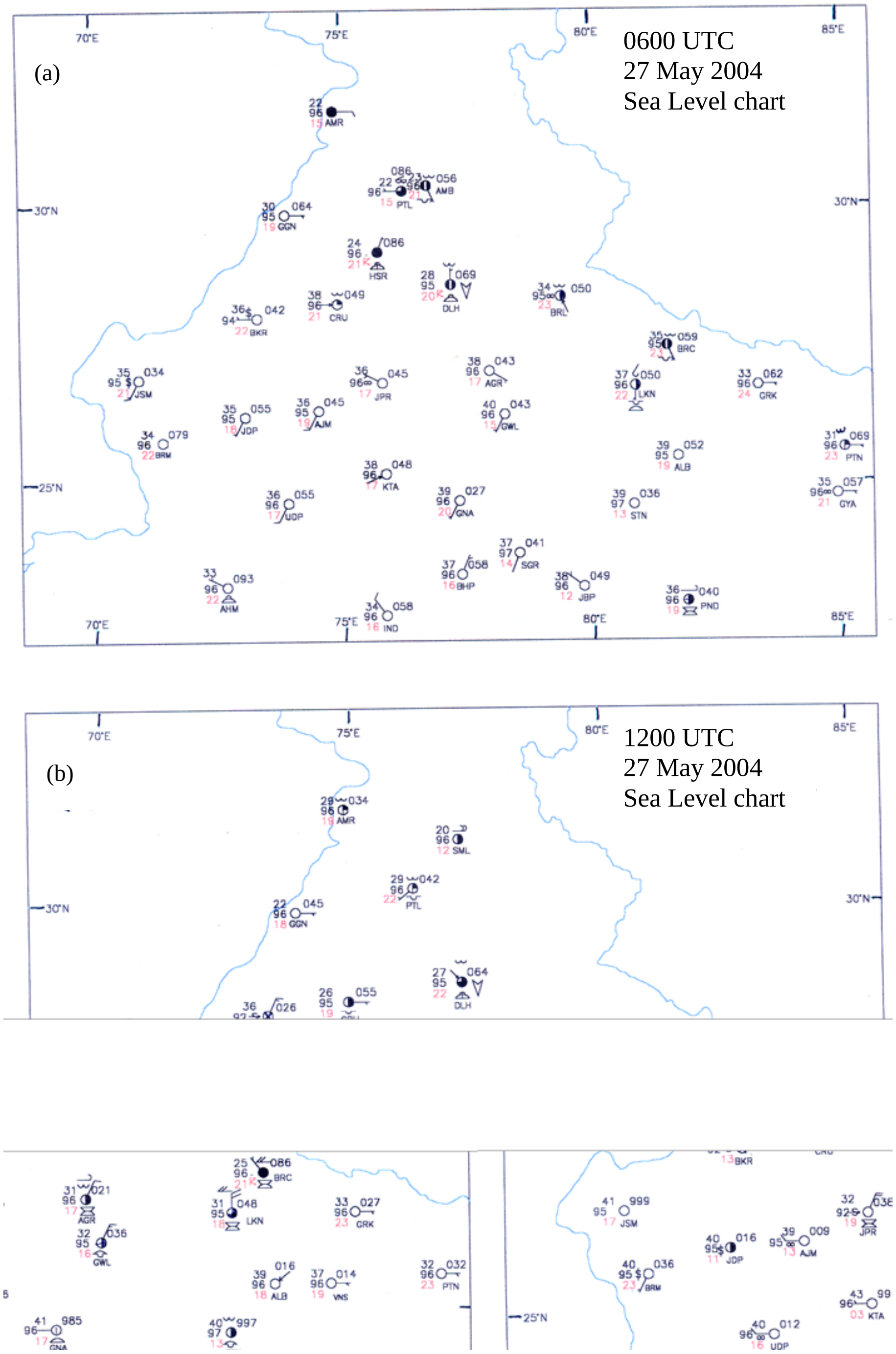
Fig. 2. Approximate positions of arc lines seen in satellite images

Radiometer) on board NOAA satellite with a resolution of 1.1 km in both VIS and IR images gives a unique view of convective activity. The meso-scale seen in NOAA-12 satellite cloud imageries on 27 May 2004 over northern parts of India is shown in Figs. 1(a&b) which cover inland over rectangular area bounded points by 23° N / 70° E; 32° N / 70° N; 32° N / 85° E and 23° N / 85° E shown in Fig. 2.

2. *Formation of arc lines over north India* – A cyclonic circulation extending upto 2.1 km a.s.l. over central Pakistan adjoining west Rajasthan seen in the morning upper air chart of 27 May 2004 has moved over west Rajasthan and adjoining central Pakistan in the evening. Also a Western Disturbance (WD) as an upper air system extending upto 3.6 km a.s.l. noted over north Pakistan and adjoining Jammu & Kashmir in the morning persisted by the evening when it extended upto 4.5 km a.s.l. Under the influence of WD, the initial thunder cloud (Cb) developed just west of Hissar (HSR) in the morning. The cold downdraft from this Cb cloud moved towards Delhi in a southeast direction and met the dry hot air which cause instability in the lower atmosphere that helped the formation of a small arc line as cumulus clusters. Many stations including Ambala (AMB) and Hissar (HSR) reported less than 25° C as dry bulb (DB) temperature at 0600 UTC on 27 May 2004. This arc line further expanded southeastwards later beyond Delhi. After 0600 UTC isolated convective types of cloud developed near Delhi. The sudden downdraft from the thunder cloud in north of Delhi strengthen the advection of cold air further towards south and the area of arc line also became larger around 1100 UTC. The appearance of cumulus cloud clusters like an arc in VIS and IR cloud image of AVHRR [Figs. 1(a&b)] is clear and the approximate positions of such arc lines are shown in Fig. 2.

Also some amount of cold air from NW parts of India and neighbourhood rushed into southerly direction which caused the formation of another arc line (arc line-1 in Fig. 2) in west Rajasthan intersecting the main (initial) arc line near Jaipur. After 0700 UTC, an isolated cumulus cloud intensified into cumulonimbus (Cb) over western Nepal. The cold downdraft from this Cb cloud moved mainly southwards. The 0900 UTC surface observation of Bahraich (BRC) confirms the advection of cold air towards south from western Nepal and this cold air met at the boundary line of hot air in the south causes the formation of third arc line. However this arc line is very small compared to other two arc lines and intersects with the initial arc line (arc line-2 in Fig. 2) between Lucknow (LKN) and BRC (Bahraich).

3. *Arc lines in satellite images* – IR and VIS cloud images of AVHRR received by HRPT station, Chennai at 1059 UTC on 27 May 2004 can be seen in Figs. 1(a&b). The VIS image shows three different arc lines cloud, one from the border area of west Rajasthan making a semi-circle ends at New Delhi and the other arc line starts from the western Nepal Himalayas passing



Figs. 3(a&b). Sea level chart (a) 0600 UTC and (b) 1200 UTC on 27 May 2004

through central Uttar Pradesh, northern part of Madhya Pradesh, meets the first arc line near Jaipur and then extend towards east Rajasthan area border with Haryana state. The third arc line is small compared to other two arc lines and appeared late in the afternoon. This arc originates from western Nepal Himalayas, passing through central part of Uttar Pradesh and then extended to eastern Nepal through east Uttar Pradesh. Intense convective type of clouds were observed near northwest Indo-Pakistan border of Rajasthan, the area between the intersection of two arc lines (northeast parts of Rajasthan, Haryana, a portion of west Uttar Pradesh and Delhi) and western

Nepal and convective Cu lines could be seen over the arc lines in satellite picture. Fig. 1(a) shows the 1200 UTC surface air temperature of some important stations over North India is superimposed in HRPT (IR) picture. The temperature anomaly of about 8 – 12° C between inside the curved areas and outer areas of arc lines noticed in IR image. The middle arc line was bigger in size and observed for longer period. The arc line-3 appeared later and disappeared early before 1300 UTC. The arc line-1 dissipated about 1500 UTC and the primary arc line-2 existed till 1700 UTC and dissipated later.

4. *Sea level chart* – Figs. 3(a&b) shows the sea level chart of 0600 and 1200 UTC of 27 May 2004. At 0600 UTC, most of the stations reported clear sky in north India. Hissar (HSR) was experiencing thunderstorm, which cooled down the surface air temperature to 24° C. New Delhi also reported thunder but without any precipitation which brought down the temperature to 28° C only. Most stations in North India reported more than 35° C and dry weather prevailed. Most of the stations in Rajasthan state and Guna (GNA) reported "dust rising". Squall was reported at Palam and Safdarjung airports, New Delhi (DLH).

At 0600 UTC New Delhi (DLH) reported a squall from north where the cold air as downdraft advected beyond Delhi and hence the stations in Punjab and northern part of Haryana reported the dry bulb (D.B.) temperatures less than 25° C while Delhi reported 28° C. All other stations in north and northwest India reported the DB temperatures of more than 30° C. However, at 1200 UTC surface observations show the DB temperatures in north and east Rajasthan, Haryana, Delhi, west and northeast Uttar Pradesh (UP), west Bihar and extreme northern parts of Madhya Pradesh are within 33° C and rising trend in surface temperature is noticed from north to south as well as southeast directions. This advection of cold air in the level just above the surface is reflected in IR image of NOAA-12 [Fig. 1(a)]. The VIS and IR imageries show the formation of arc lines along the narrow areas where the meeting the cold air from north and hot air in the southern side that causes the development of small and medium cumulus cloud clusters. The sudden advection of cold air from north of Delhi confirms 0600 UTC synoptic observation and the surface temperature cooled by 8° C from 36° C to 28° C seen in Fig. 3. Due to another squall at 0740 UTC the D.B. temperature of Delhi has further dipped to 21° C.

Within the arc line-2, the advected cold air was just south of Delhi at 0600 UTC and the area of cold air has further expanded towards south of 23° N. While at 1200 UTC cold air has further moved beyond Gwalior (GWL) and so Gwalior reported 32° C at 1200 UTC while it reported 40° C at 0600 UTC and can be matched with NOAA satellite picture [Fig. 1(a)]. The 1200 UTC surface observation data shown in Fig. 4 can be related with HRPT pictures (VIS and IR) shown in Figs. 1(a&b).

At 1200 UTC, New Delhi experienced thundershower and the surface air was cooled to 27° C. Agra (AGR) and Lucknow (LKN) reported 31° C while Gwalior (GWL) reported 32° C. The cold air mass from New Delhi moved outwards mainly southerly direction, which caused the formation of primary Cu arc line-2 appeared in AVHRR picture. The strong cool downdraft from Cb cloud near Hissar spread out in SW direction, interacted with dry air in the south formed a semi circle Cu arc line CD. These two arc lines intersect at the point E near Jaipur (JPR). The area between AED reported intense to very intense convective cloud. The downdraft of cold air from convective cloud north of Bahraich (BRC) spread in the southeasterly direction that caused the appearance of third arc line. The arc lines 2 & 3 intersect between LKN and BRC stations. Both Palam and Safdarjung airports, New Delhi reported squall in the forenoon on 27 May 2004. A light wind was followed by squall that reached its maximum of 31 knots from NW direction at Palam and 29 knots at Safdarjung airport.

5. *Weather conditions at major airports on 27 May 2004* – The arc shaped cloud line played a key role in the tornadic activity in Texas, U.S.A (Purdom, 1976). In India, formation of tornado is rare in North India but the activity of *'Andhi'* (dust storm) with severe thunderstorm is not uncommon during hot weather season. During arc line formation and sustaining period on 27 May 2004, the weather condition at three major airports in North India were considered and hourly/half-hourly METAR/SPECI were studied and analyzed. Fig. 4 shows the diurnal variation of pressure (QNH), surface air temperature, wind speed and visibility of three airports.

(a) *Delhi (Palam) Airport* – The surface visibility was poor between 2000 M and 3500 M since 0000 UTC on 27 May 2004 till 0530 UTC mainly due to wide spread dust/smoke in suspension in the lower level. An isolated Cb (cumulonimbus cloud) was reported since 0430 UTC. At 0541 UTC, a sudden squall followed by rain dashed the area from northerly direction at the speed of 20 knots. This sudden cold downdraft from the thundercloud brought down the surface air temperature by 8° C from 36° C to 28° C between 0530 and 0540 UTC and later cooled to 22° C at 0750 UTC (Fig. 4) and the sky became overcast. Before precipitation, the gust front rose as blowing dust/sand storm and rushed towards southerly direction. The precipitation continued till 0830 UTC. Convective type of clouds continued till the end on the day. The thunderstorm acts as a mesoscale high-pressure

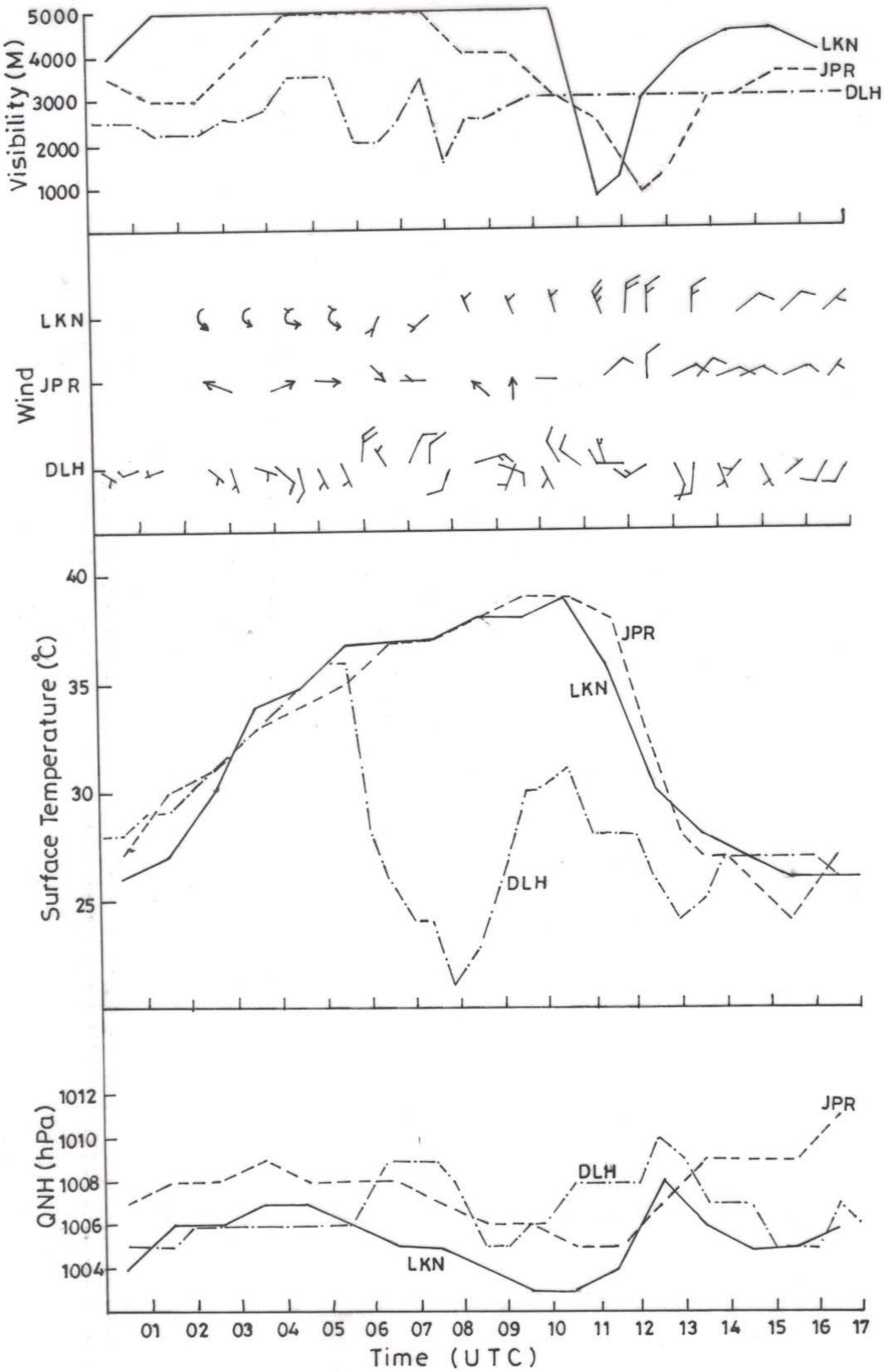


Fig. 4. Diurnal variation of pressure (QNH), surface air temperature, wind and visibility at New Delhi (Palam), Lucknow and Jaipur airports on 27th May 2004

system (meso-high) and there was a sudden rise of pressure by 3 hPa between 0541 and 0621 UTC could be seen in the Fig. 4.

(b) *Jaipur Airport* – The sky was clear till 0630 UTC and the visibility was between 3000 M and 5000 M mainly due to dust haze. Convective type of clouds formed after 1000 UTC and the wind was northeasterly 10 knots. At 1150 UTC, a cold downdraft from a thunderstorm shot up the surface wind became stronger to 20 knots from northwesterly direction, which raised dust storm and brought down the visibility very poor to 400 M from 3000 M. The dust storm continued till 1500 UTC. The sudden cold downdraft cooled the surface air temperature by 7° C from 38° C to 31° C between 1130 and 1215 UTC and the pressure shot up by 2 hPa within 20 minutes between 1130 and 1150 UTC could be seen in Fig. 4. A rise of 2 hPa between 1000 and 1100 UTC, in contrast to the diurnal pressure minima during the said period, can be attributed to the meso-high.

(c) *Lucknow Airport* – The visibility at the airport was about 5 km mainly due to haze since early morning. Light wind prevailed till 1100 UTC. Convective clouds (Cu, Cb) developed later and the surface wind became stronger about 25 knots in northwesterly direction. At 1121 UTC, the wind became gusty and shot up to 35 knots maximum due to sudden gust of cold wind, which raised blowing dust storm. The dust storm reduced the visibility to 800 M for an hour. The cool air brought down the ambient temperature by 9° C from 39° C to 30° C. The pressure also shot up by 4 hPa between 1121 and 1221 UTC due to thunderstorm activity could be seen in Fig. 4.

6. The arc lines seen in summer season regularly are more clear in HRPT pictures than in geostationary images because of better resolution. Appearance of three arc lines covering larger north India rarely observed. The arc lines existed over many hours from morning to late evening on 27 May 2004 over north India. Severe thunderstorm developed over areas of intersection of the arc lines and the fall of dry bulb temperature about 5° C – 10° C in the afternoon/evening hours are noticed.

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