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A severe hailstorm over Guwahati airport and its vicinity on 2nd April 2006 : Synoptic and thermodynamic perspectives

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सार – गुवाहाटी हवाई अडडे और इसके आसपास के क्षेत्रों में जलवायविक दृष्टि से मानसून – पूर्व ऋतु में गर्ज भरे तूफान का आना एक सामान्य बात है। किन्तु लम्बे समय तक बड़े आकार के ओलों वाली प्रंचड़ ओला वृष्टि बहुत कम होती है। गुवाहाटी हवाई अडडे (26.1°उ, 91.6°पू) पर 2 अप्रैल 2006 को मध्य रात्रि के समय लगभग 25 मि. मी. के आकार के ओलों वाली ऐसी ओलावृष्टि हुई। इस शोध पत्र में ओलावृष्टि के साथ संबद्ध वायुमंडल की पूर्वापेक्षित सिनॉप्टिक और तापगतिकीय अवस्थाओं की जाँच करने का प्रयास किया गया है। गर्ज भरे तूफान की परिघटना की अनुकूल सिनॉप्टिक और अस्थिरता की अवस्था में 6.2 एम.एस.$^{-1}$ कि.मी.$^{-1}$ से अधिक की क्षैतिजीय पवनों की उर्ध्वाधर पवन अपरूपण सहित हिमतल और 500 हेक्टापास्कल स्तर के बीच गुवाहाटी में दक्षिणावर्त पवने ओलावृष्टि के बनने में अधिक अनुकूल पाई गई है। स्थिरता के बिन्दु अर्थात शॉवल्टर, के, टोटल – टोटल और प्रचण्ड मौसम आंशका (एस.डब्ल्यू.ई.ए.टी.) सूचकांक इस घटना की प्रागुक्तिता को दर्शाते है।

ABSTRACT. Climatologically thunderstorm activity is quite common features over Guwahati Airport and its vicinity during premonsoon season. But a severe hailstorm with large size of hailstones and long duration is a rare event. Such a hailstorm with hailstone size of about 25mm occurred over Guwahati Airport (26.1°N, 91.6°E) on 2nd April, 2006 during midnight. In this paper an attempt has been made to investigate prerequisite synoptic and thermodynamic conditions of the atmosphere associated with this hailstorm. Under favourable synoptic and instability condition of thunderstorm occurrence, veering of winds over Guwahati between freezing level and 500 hPa level with vertical wind shear of horizontal winds exceeding 6.2 ms^{-1}km^{-1} more appears to be conductive for the development of a hailstorm. Stability Indices *viz*., Showalter, K, Total-Total and Severe Weather Threat (SWEAT) index have shown predictability for this event.

Key words – Hailstorm, Guwahati, Synoptic, instability, Wind Shear.

1. Introduction

A common feature of weather during pre-monsoon season (March to May) over Northeast India is thunderstorms which are commonly known as Nor'wester. In Northeast India thunderstorm appears with severe intensity (Hoddinot, 1986) causing extensive damages to property and sometimes injury or loss of life. Hailstorms are one of the greatest weather hazards to aviation. Climatologically, frequency of thunder and hailstorm over Guwahati Airport (26.1° N, 91.6° E) during pre-monsoon months (March to May) are 36.1 and 1.1 respectively. On 2nd April, 2006 a severe hailstorm occurred with hail size about 25mm diameter lasting about 15 minutes over Guwahati Airport during midnight.

Over Indian region, especially over northeast region many attempts have been made in the past to explore the favourable condition for occurrence of thunderstorm activity by different authors *e.g*., Koteswaram and Srinivasan (1958), Sen and Basu (1961), Chaudhury (1961), Mukherjee (1983). A synoptic and radar study on severe hailstorm of 27th May 1959 near Sikar (Rajasthan) has been made by Mull and Kulshrestha (1962). They suggested that the border region of cyclonic and anti-cyclonic vortices might have provided a suitable place for the occurrence of hook-shaped protuberance. Suresh and Bhatnagar (2004) have analyzed unusual hailstorms around Chennai by using data from single Doppler weather radar. They observed vertical extent of the hailstorm which was well beyond 20 km with high

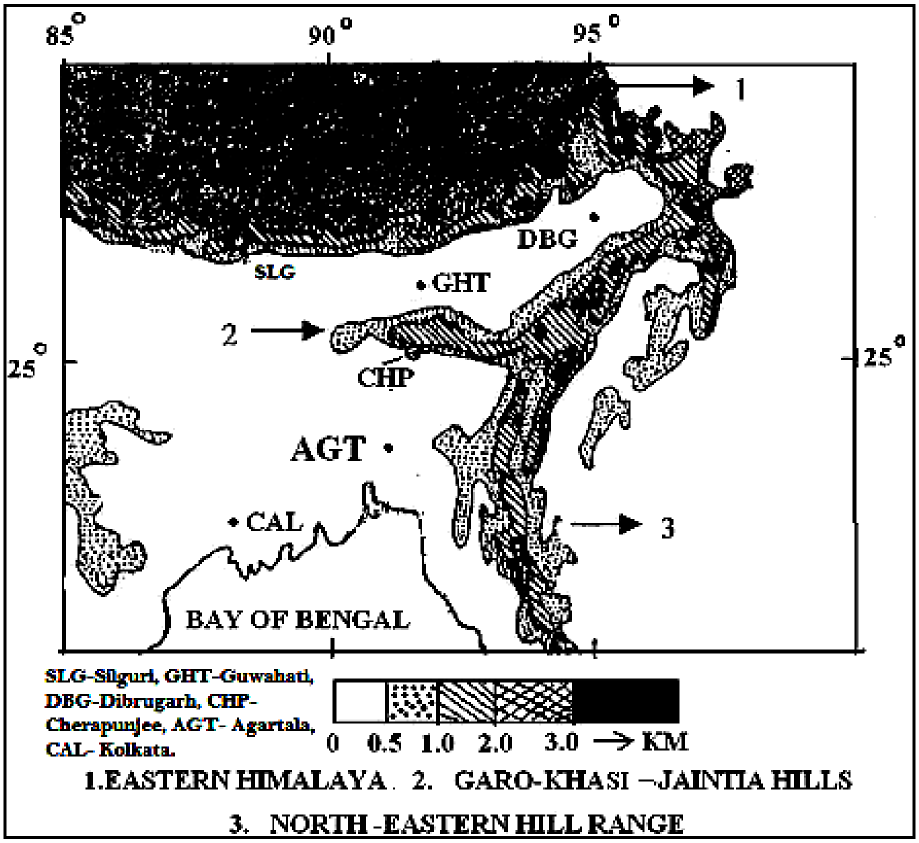

Fig. 1. Physiographic map of northeast India

reflectivity (above 45 dbZ) seen upto 18.5 km. Rao and Mukherjee (1958) used 24hrs vectorial wind changes at 1.5 km level to forecast hailstorm over northwest India. They concluded that conjecture of cyclonic and anticyclonic vortices, cyclonic vortex being embedded in a moist air stream are favourable for development of hail producing thunderstorm. A radar study has been done by Sharma (1965) on hailstorm over Guwahati. Mukherjee *et al*. (1962) have studied the structure of hailstones and prevailing meteorological situation on an unusual hailstorm event over Guwahati on 18th March, 1961. They concluded that sufficient amount of moisture; local orographic features and latent instability in the atmosphere seem to have given a rise to the hailstorms. Further they found that hailstorms were in association with strong vertical wind shear. Mukherjee (1964) has shown that the frequency of thunderstorm over Guwahati was highest in night time during premonsoon and also inferred that hills in this region play an important role in the development of thunderstorm. Recently Gajendra Kumar and Mohapatra (2006) studied the climatology of thunderstorm over Guwahati Airport.

Relatively a very few studies have been carried out in precise analysis of synoptic and thermodynamic structure of atmosphere associated with very severe convective storms over northeast region. An attempt has been made to identify the prerequisite synoptic and thermodynamic features of the atmosphere for occurrence of severe hailstorm over Guwahati on 2nd April, 2006.

2. Data and method of analysis

A severe hailstorm with hail size about 25mm diameter accompanied by heavy shower over Guwahati Airport during midnight 2328 hrs (IST) to 2342 hrs (IST) of 2nd April, 2006 was recorded by Guwahati Airport Meteorological Observatory of India Meteorological Department. As per press report it caused extensive damages to the Rabi crops of several villages neighbouring Guwahati City. Autographic charts of Guwahati Airport, Synoptic weather charts and Radiosonde data of Guwahati, Agartala, Siliguri and Dibrugarh have been analysed in this study. All data and information have been collected from Regional Meteorological Centre Guwahati.

Surface meteorological parameters like pressure, dry bulb temperature, relative humidity etc before and after occurrence of the hailstorm have been extracted from Autographic charts. Both surface and upper air charts during week *viz*., 28th March to 3rd April, 2006 have been critically analyzed. The vertical wind shear of horizontal winds has been computed.

As one of the most important factors causing thunderstorm events associated with squall, hail, heavy rain etc. is the thermodynamic instability of the atmosphere, various type of stability indices have been proposed by many researchers to measure quantatively the instability condition of the atmosphere for forecasting thunderstorm events. Mukhopadhyay *et al.* (2003) have studied 11 indices to identify suitable index and threshold value of the index for prediction of thundery and non-thundery days over three northeastern stations namely Guwahati, Agartala and Dibrugarh. They found that Humidity index is the best predictor for thunderstorm over this region. In the present case significance of some important indices *viz.*, Showalter stability index, K-index, Total-Total index, Humidity index, Severe Weather Threat (SWEAT) index and Boyden index have been tested.

Convective Available Potential Energy (CAPE) represents the amount of buoyant energy available to accelerate a parcel vertically. It has been shown to play an important role in mesoscale convection systems (Moncrieff and Miller, 1976). The same was tested by Bhat *et al*. (1996) in the tropical atmosphere. Convective Inhibition Energy (CINE) has been studied in relation to premonsoon convective activity over West Bengal by Chaudhury and Chattopadhyay (2001). The height at which the wet bulb temperature is 0° C often referred as 'Wet Bulb Zero (WBZ) height' which is a useful predictor for hail formation (Miller, 1972). In the present case study CAPE, CINE and WBZ height values of four upper air observatories of Northeast India *viz*., Guwahati, Siliguri, Agartala and Dibrugarh have been critically analyzed.

3. Result and discussions

3.1. *Physiographic features*

Guwahati is situated in the Brahmaputra Valley and at the foothills of Garo-Khasi-Jaintia hill range of average height about 1.5 km on the south bank of Brahmaputra River. The great Himalayan range lies to the north with high average height and many snow covered peaks. The valley has a gentle slope from east to west as the height of Dibrugarh (located at extreme east) is 112 meter and of Dhubri (located at extreme west) is 32 meters. A Physiographic map of northeast India with location of Guwahati has been shown in Fig. 1. Valley circulation and establishment of low level convergence together with moisture inflow are conductive for development of convective cell over this area.

3.2. *Autographic chart analysis*

Autographic charts *viz*., Self recording Rain gauge, Hair Hygrograph, Barograph and Thermograph recorded at Guwahati Airport during the occurrence of the hailstorm are shown in Figs. 2(a-d) respectively. The relative humidity, pressure and dry bulb temperature values for a few days (1st to 10th April, 2006) during 2100 - 0100 hrs (IST) (prior to and after the hailstorm occurrence) have also been examined.

Self Recording Raingauge Chart [Fig. 2(a)] indicates that rain started at about 2300 hrs (IST) of 2nd April and continued upto 0030 hrs (IST) of 3rd April, 2006 and total rainfall amount was 14 mm. The chart shows that about 10 mm rainfall was recorded within 15 minutes period [2330-2345 hrs (IST)] during the occurrence of hailstorm. Hair hygrograph [Fig. 2(b)] shows decrease in Relative Humidity (RH) about 2130 hrs (IST) from 80% to 66% at 2200 hrs well before commencement of hailstorm. Increasing tendency in RH is seen from 66% at 2245 hrs (IST) to about 90% at 2345 hrs (IST). However a sharp increase in RH is noticed from 2315 hrs (IST) from 70% to 80% just 15 minute before occurrence of hailstorm and continued its trend till end of this event. Asnani (1961) states that in case of severe hailstorm there is a possibility of dip in Barograph traces. In the present case Barograph [Fig. 2(c)] indicates a fall of 1 hPa just about 20 minutes before the commencement of the hailstorm. The Thermograph traces [Fig. 2(d)] indicates sharp decrease in surface temperature about 6.5° C starting from 2300 hrs (IST) to 2350 hrs (IST) and it falls about 4° C within a very short period as 15 minutes at the time of occurrence of hailstorm. While the assessment of diurnal variability showed only 1-2° C decrease of temperature during two hours period [2200 – 2400 hrs (IST)].

3.3. *Surface chart analysis*

In the surface chart of 1200 UTC of 2nd April, 2006 a feeble heat low was seen over Jharkhand centered near Ranchi (23.3° N / 85.3° E) and adjoining Gangetic West Bengal and Bihar. Relatively steep pressure gradient was present between Dibrugarh (Located at extreme Northeast Assam) and the centre of feeble low. While 6 hPa pressure difference was observed between Dibrugarh (27.5° N / 95.0° E) and Patna (25.6° N / 85.1° E) located at Bihar on 2nd April, only 1 to 2 hPa difference was observed on a

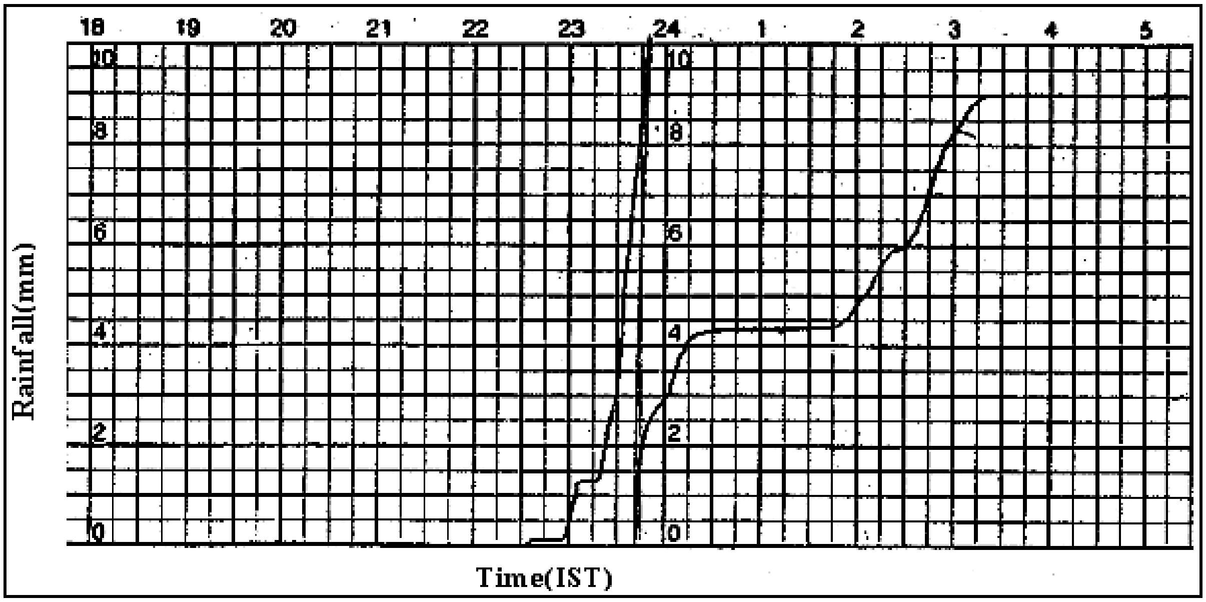

Fig. 2 (a). Autographic chart - Self Recording Raingauge recorded at Guwahati on 2nd April [1800 hrs (IST)] to 3rd April, 2006 [0500 hrs (IST)]

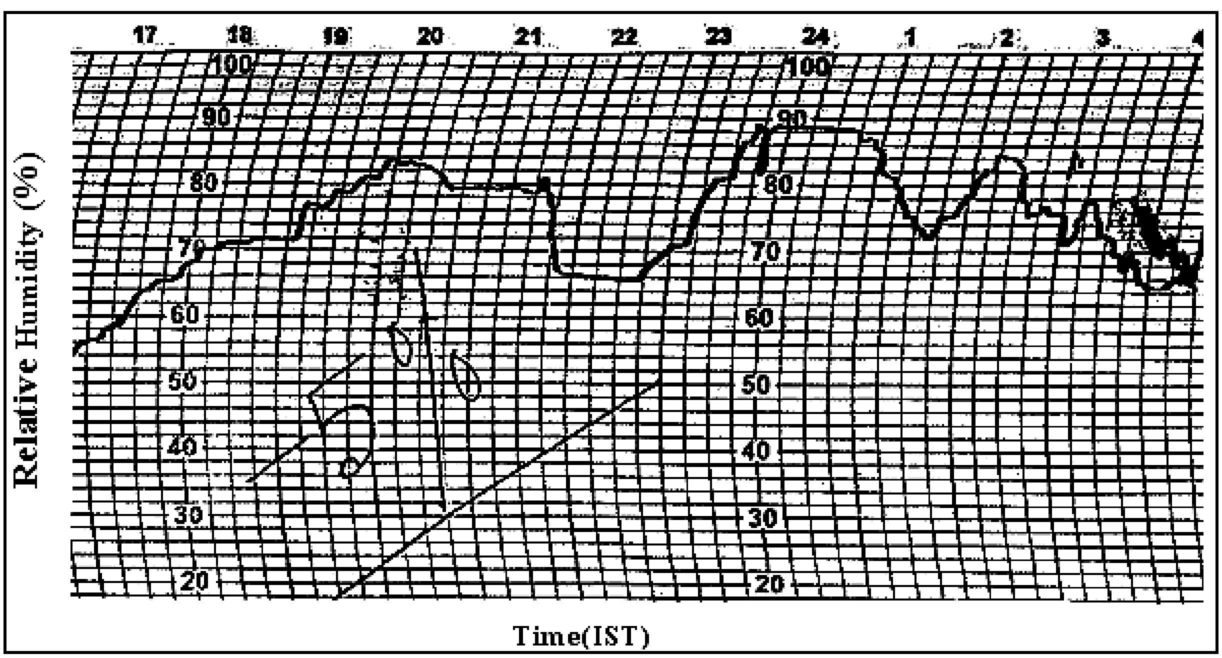

Fig. 2(b). Autographic chart – Hair hygrograph of Guwahati for 2nd April [1700 hrs (IST)] to 3rd April, 2006 [0400 hrs (IST)]

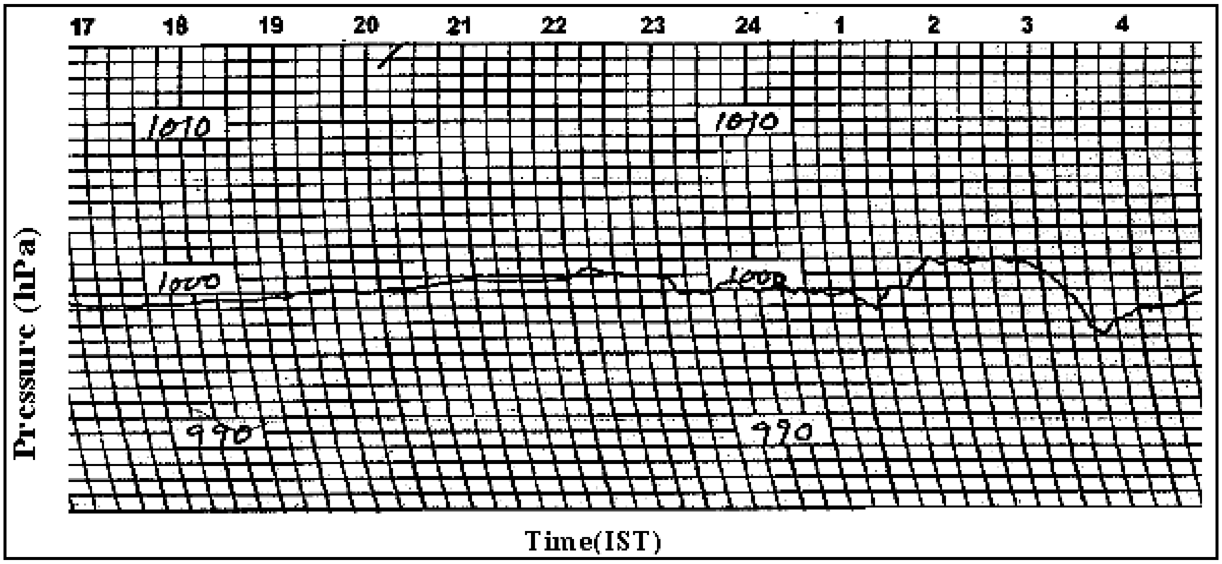

Fig. 2(c). Autographic chart – Barograph of Guwahati for 2nd April [1700 hrs (IST)] to 3rd April, 2006 [0400 hrs (IST)]

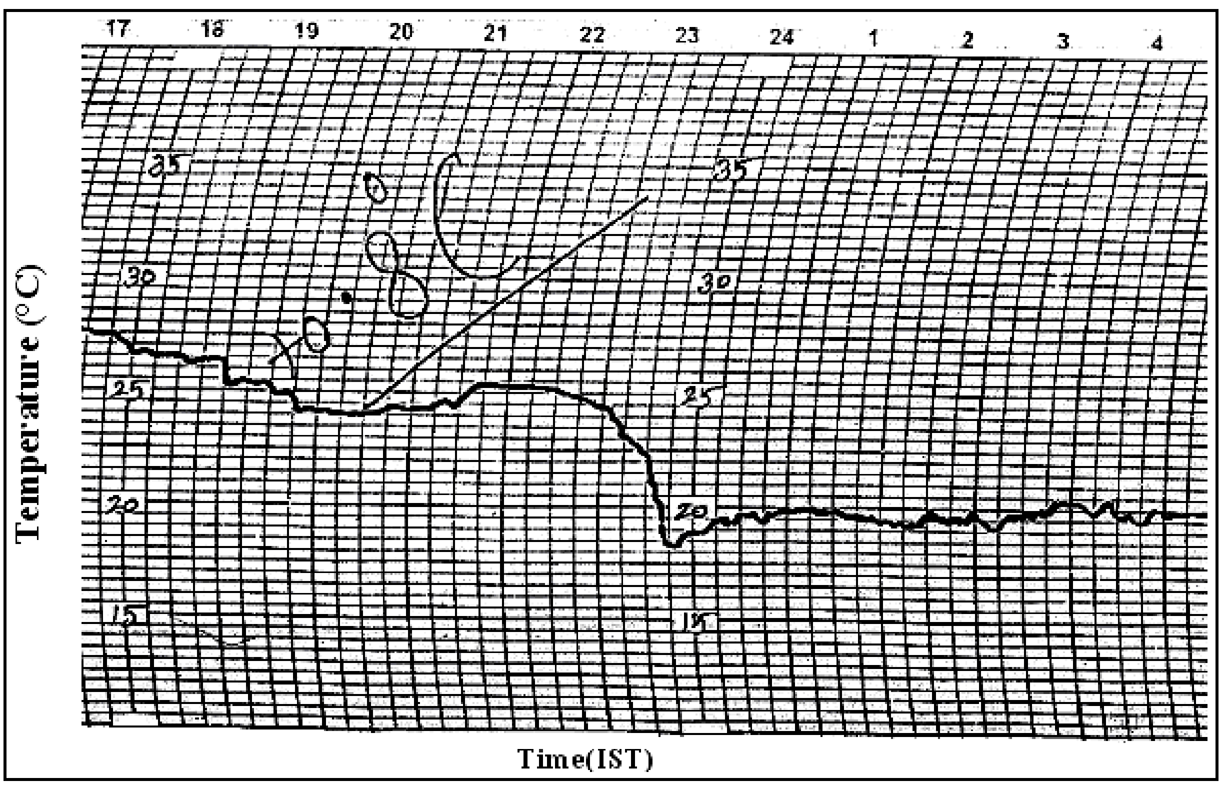

Fig. 2(d). Autographic chart – Thermograph of Guwahati for 2nd April [1700 hrs (IST)] to 3rd April, 2006 [0400 hrs (IST)]

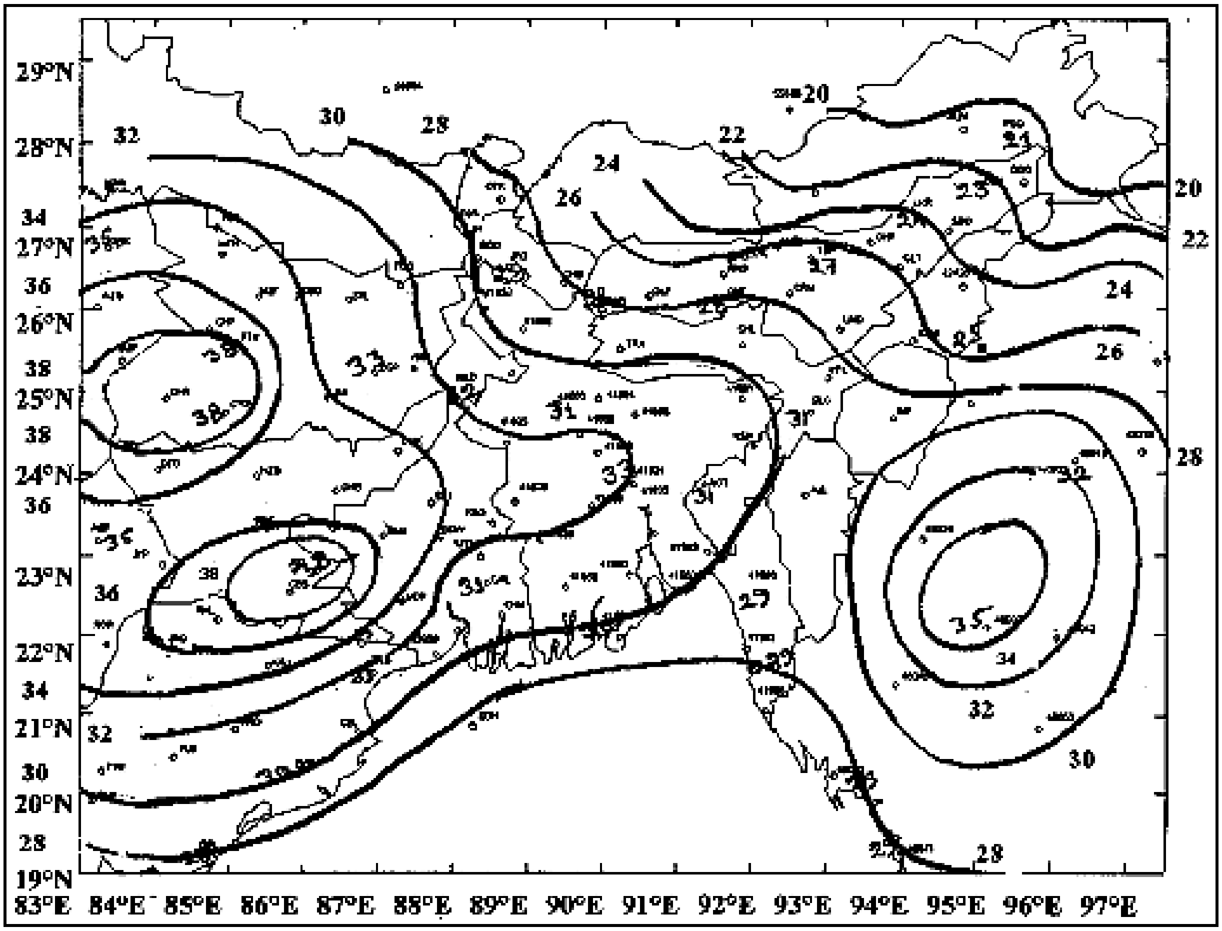

Fig. 3. Analysis of dry bulb temperature (isotherms at 2°C intervals) over region of interest on 2nd April, 2006 at 1200 UTC

few days earlier *viz.*, on 1st April it was 1.6 hPa, on 31st March 0.4 hPa.

Isotherm analysis of dry bulb temperature data at 1200 UTC of 2nd April, 2006 (Fig. 3) shows very high temperatures were recorded over Bihar, Jharkhand, Chattisgarh and north Orissa and low temperatures over extreme northeast region *viz.*, over East Arunachal Pradesh and adjoining Myanmar. Also temperatures over south of 25° N was relatively higher. A steep temperature gradient existed over Guwahati and its suburbs. Temperature difference between Guwahati and Pasighat (28.1° N / 95.4° E) was 7°C and temperature difference between Patna and Guwahati was 10° C. Also between Agartala and Guwahati, the temperature difference was 3° C.

Dew point temperature distribution of 1200 UTC of 2nd April, 2006 reveals north or northeastern side (Northeast Assam adjoining Arunachal Pradesh) of Guwahati was relatively dry (dew point temperature about 16° C) whereas moist air were present (dew point greater than 26° C) over Bangladesh (southwest of Guwahati). So a steep gradient of dew point temperatures was present near Guwahati and neighbourhood.

From the above discussion of dry bulb and dew point temperatures and isobar analysis it is clear that steep air temperature, pressure and dew point temperature gradients were evident at 1200 UTC (about 6 hrs in advance from the time of occurrence of hailstorm) over Guwahati and adjoining areas.

3.4. *Upper air chart analysis*

The lower troposphere flow pattern at 0000 UTC of 2nd April showed a cyclonic circulation extending upto 0.9 km above sea level (asl) over west Assam and adjoining

TABLE 1

Wind direction (ddd) and speed in knots (ff) at Agartala (23.9° N, 91.3° E) at various pressure levels upto 500 hPa from 28th March to 2nd April 2006

Date	Time (UTC)	Wind direction and speed at various pressure level							
		925 hPa		850 hPa		700 hPa		500 hPa	
		ddd	ff	ddd	ff	ddd	ff	ddd	ff
28 Mar 2006	0000	345	4	295	14	260	27	--	--
	1200	315	9	310	13	275	23	--	--
29 Mar 2006	0000	320	12	305	14	275	26	--	--
	1200	--	--	--	--	--	--	--	--
30 Mar 2006	0000	340	5	305	8	285	21	--	--
	1200	260	9	280	13	255	17	285	35
31 Mar 2006	0000	260	10	265	7	315	10	335	20
	1200	230	10	275	11	305	13	5	20
01 Apr 2006	0000	--	--	--	--	--	--	--	--
	1200	200	13	210	12	275	10	280	29
02 Apr 2006	0000	195	15	230	13	300	18	265	30
	1200	200	18	235	18	270	16	310	44

TABLE 2

Winds at freezing level (FL) and at 500 hPa level of Guwahati Airport and vertical wind shear of horizontal winds from 28th March to 3rd April, 2006

Date	Time (UTC)	500 hPa level height (meter)	FL (meter)	Wind at FL		Wind at 500 hPa level		Vertical wind shear (Absolute value in $ms^{-1}km^{-1}$)
				Direction	Speed (knots)	Direction	Speed (knots)	
28 Mar 2006	0000	5749	3981	265	36	256	39	1.9
	1200	5756	3943	268	35	261	49	4.2
29 Mar 2006	0000	5750	3617	249	31	258	40	2.6
	1200	5730	3740	242	25	252	37	3.4
30 Mar 2006	0000	5711	3377	286	40	237	25	*6.6*
	1200	5652	3039	262	26	293	23	2.6
31 Mar 2006	0000	5683	3169	293	16	358	17	3.6
	1200	5701	3804	358	10	324	33	6.9
01 Apr 2006	0000	5776	4385	236	25	260	24	3.8
	1200	5690	3465	266	18	271	35	4.0
02 Apr 2006	0000	-	-	-	-	-	-	-
	1200	5710	3620	252	21	272	44	6.2
03 Apr 2006	0000	5689	3458	264	35	267	46	2.6
	1200	5688	3579	282	26	277	45	4.7

Meghalaya and Bangladesh centered nearby in southwest of Guwahati. Another cyclonic circulation was seen over Bihar and neighbourhood extending upto 1.5 km asl. At 1200 UTC of 2nd April both cyclonic circulations moved slightly northeastwards and roughly centered over Guwahati and over Bihar and adjoining Sub Himalayan West Bengal respectively. Also synoptic charts revealed that vigorous moisture incursion from Bay of Bengal through south or southwesterly wind in association with a high pressure area over Bay of Bengal (South of 20° N) vertically extending upto 1.5 km asl. To visualize the intensity of moisture incursion over northeast India, lower/midtropospheric winds at Agartala (23.9° N / 91.3° E) have been considered (Table 1). Strong south

TABLE 3

Stability indices values on day of occurrence of the hailstorm and its comparison with mean of one week value, 24 hours change prior to/after the event

Stability indices >	SI	KI	HI	TTI	SWEAT	BI
Value on 2nd April	-4.3	31.9	27.4	58.2	456.3	99.2
Mean value of the week	2.6	19.2	41.7	46.3	184.2	96.2
Standard deviation	3.4	9.6	14.2	6.4	127.3	1.4
Anomaly from mean value	-6.9	12.7	-14.3	11.9	272.1	1.0
24 hrs change from the previous day	-5.2	2.4	10.8	9.2	197.9	-0.5
24 hrs change with the next day	-8.0	5.6	-8.4	14.8	188.7	3.0

southwesterly winds veering with height upto 500 hPa was observed on the day of occurrence of hailstorm which suggests warm moist air advection over the region. It has been observed that wind direction has changed from northwesterly to south southwesterly at lower levels (925 to 850 hPa level) two days prior to the day of occurrence of hailstorm. Though on 1st and 2nd April the wind direction was more or less same but wind speed was more on 2nd April. It may also be noted that thunderstorm activity over Assam and adjoining states was observed on 1st April itself. From the above discussion of upper air chart analysis it may be inferred that the severe thunderstorm associated with unusual hailstorm on 2nd April over Guwahati and adjoining areas occurred in an environment of the atmosphere where a lower level cyclonic convergence was present and strong moisture incursion was taking place.

3.5. *Wind Shear and Hodograph analysis*

Hailstorms are frequently associated with strong vertical wind shear (Das, 1962). The presence of strong wind shear may aid for the formation of convective cloud of large vertical extent with moisture convergence. So, vertical wind shear of horizontal winds between various levels over Guwahati has been examined for the period 28th March to 3rd April, 2006. It is found that vertical wind shear and also change in direction of winds between freezing level and 500 hPa play an important role in formation of the hailstorm. This result is shown in Table 2. The Vertical wind shear between freezing level and 500 hPa for April 2006 was 4 $ms^{-1}km^{-1}$. However at 1200 UTC of 2nd April the shear was high at 6.2 $ms^{-1}km^{-1}$. The hodograph of 2nd April at 1200 UTC over Guwahati reveals winds veering with height which is associated with warm air advection over the station. The warm air advection together with strong vertical wind shear indicates the chances for the formation of severe convective cell associated with hail.

3.6. *Stability indices*

Stability indices of Guwahati have been statistically analysed and results summarized in Table 3. Description of various Stability indices tested in this paper has been well documented in literature (Mukhopadhaya *et al*. 2003, Jacovides and Yonetani, 1990). From Table 3 it is found that Showlter stability index (SI) value was highly negative at – 4.3 on the day of occurrence of hailstorm with large deviation from mean value of SI during the event week as well as from previous and the next day of occurrence of the storm. Thus high degree of latent instability was observed about six hours before of occurrence (at 1200 UTC of 2nd April) of the hailstorm. The K-Index (KI) value was 31.9, which is higher than weekly mean value. Humidity index (HI), a measure of saturation at 850, 700 and 500 hPa levels, is the sum of dew point depression (T – Td) at these levels. From Table 3 it is seen that though HI was lower than the mean value of the week, it did not have predictive value as the HI on 2nd was higher than the previous day and no hail was reported on 1st. Value of Total-Total index (TTI) was much higher at 58.2 due to proximity of higher lapse rate between 850 and 500 hPa. In their study, Khole and Biswas (2007) worked out a threshold value of TTI 48.4 for 1200 UTC as an indicator in forecasting of thunderstorm-occurrence over Kolkata during pre-monsoon season. The value of SWEAT index in association with the hailstorm was significantly different from weekly mean and before and after the day of occurrence of the hailstorm. Boyden index (BI) indicates the changes in thermal and geopotential field at lower levels. From Table 3 it is found that BI has no significant predictability for this event. This corroborates an earlier study of thunderstorm over Chennai by Suresh and Bhatnagar (2005). Thus from above discussion, it is evident that SWEAT and Showalter index, TTI and KI have shown the best predictability for this particular event of severe thunderstorm associated with hail.

TABLE 4

CAPE, CINE, WBZ and FL values over Guwahati, Agartala, Siliguri and Dibrugarh at 1200 UTC on day of occurrence of hailstorm, before and after day of the event

Station	Date	CAPE(J/kg)	CINE(J/kg)	WBZ (meter)	FL (meter)
	01 Apr 2006	707.1	-107.5	3021	3465
Guwahati	02 Apr 2006	1601.1	-156.4	3014	3620
	03 Apr 2006	136.4	-262.4	3283	3579
	01 Apr 2006	839.1	-53.5	3106	3138
Siliguri	02 Apr 2006	5274.1	0.0	1968	2489
	03 Apr 2006	233.2	-115.4	3641	4129
	01 Apr 2006	4110.4	-44.5	2886	4326
Agartala	02 Apr 2006	4911.4	-6.2	2782	3496
	03 Apr 2006	1698.6	-302.0	3167	4041
	01 Apr 2006	1144.3	-103.0	2628	3312
Dibrugarh	02 Apr 2006	448.2	-234.2	3237	3560
	03 Apr 2006	0.0	-51.1	3766	4027

3.7. *Analysis of CAPE, CINE and WBZ height*

The values of CAPE, CINE and WBZ height at 1200 UTC observation of 2nd April, 2006 *i.e.*, day of occurrence of hailstorm and also the values of observations before and after 24 hrs (*i.e.*, 1200UTC of 1st and 3rd) for four Radiosonde observatory *viz.*, Guwahati, Siliguri, Agartala and Dibrugarh have been tabulated in Table 4. High value of CAPE was noticed on 2nd April in comparison to those observed on 1st and 3rd over Guwahati, Siliguri and Agartala. The value of CAPE on 2nd April over Dibrugarh was very less. CINE inhibits the convection over an area and very high absolute value of CINE is representative of stabilized atmospheric condition. But little or moderate value of CINE may be overcome by triggering force of convection and thereby severe convective outbursts may take place. From Table 4 it can be seen that little CINE at -156 Joule/kg was present at Guwahati however at Agartala and Siliguri CINE value were nearly zero on 2nd April 2006. Thus values of CAPE and CINE at Siliguri, Guwahati and Agartala may provide prior indication about impending severe thunderstorms event associated with hail over Northeast India. It may be mentioned here that high CAPE over Siliguri and Agartala had been conductive for a hailstorm over Guwahati though the CAPE over Guwahati was much less. This reconfirms the earlier findings to this effect by Suresh and Bhatnagar (2005) that tropical convection is triggered by large scale flow pattern and not necessary depend on local value of CAPE.

A WBZ height in the range of 2100 to 3300 meter has been found favourable for large hail reaching the ground (Miller, 1972) over U.S.A. The physical reasoning behind low probability of surface hail for WBZ heights lying outside the range as mentioned above may be due to the fact that for low WBZ height, there is a lack of available moisture and with a very high WBZ height, conditions favour melting of the hail before it reaches on the ground. However, in the present case WBZ height on 2nd April at 1200 UTC was 3014 meter which is not significantly different from previous and next day of the storm and also from values at other stations. Freezing level heights to compare with WBZ have also been mentioned in Table 4. But no significant differences were observed on 2nd April. Thus a detailed investigation taking the climatological data series of hailstorm may be carried out to examine the role of WBZ as a hail forecasting parameter for tropical region.

3.8. It is clear from foregoing discussion that synoptic to meso scale interactions combined with various physical processes contributed to the formation of a hailstorm over Guwahati. However for accurate prediction of hailstorms extensive study based on data from dense observational network equipped with modern equipments may be needed.

4. Conclusions

The following salient features are revealed during the study of the hailstorm over Guwahati Airport on 2nd April 2006.

(*i*) Sharp fall in surface relative humidity about 1½ to 2 hours prior to the occurrence of hailstorm and a sudden rise (22%) of RH during the hailstorm were observed at Guwahati Airport. A sudden drop of 4°C temperature during the occurrence of hailstorm was also noticed.

(*ii*) Under favourable synoptic and instability condition of thunderstorm occurrence, veering of winds over Guwahati between freezing level and 500 hPa level with vertical wind shear of horizontal winds exceeding 6.2 $ms^{-1}km^{-1}$ more appears to be conductive for the development of a hailstorm.

(*iii*) Showalter, K, Total-Total and SWEAT Index have predicted this event well.

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