Forecasting and nowcasting convective weather phenomena over southern peninsular India – Part II: Severe local storms

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A few case studies of severe thunderstorms especially hail storms, over Chennai and its neighbourhood within 250 km radius that occurred during 2002-2007 have been analysed in this paper. Pre-convective thermodynamic parameters have been computed using Chennai, Karaikal, Bangalore, Machilipatnam and Hyderabad RS/RW data; and empirical thresholds that are in vogue have been validated for the hail storms reported by print and electronic media. Hail stone size estimation has been attempted using build 9 algorithm of NEXRAD, USA and found to be working well for the tropical environment as well. The necessity of feedback from the public in timely reporting severe storms with precision and accuracy has been stressed for developing a database to fine tune the hail warning and hail stone size estimation algorithms.

Keywords: Severe local storms, Thunderstorm, Hail storm, Hail stone size, Mesoscale convective system, Convective available potential energy (CAPE)

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1 Introduction

Thunderstorms can be considered both as bane and boon to mankind in view of their devastating/catastrophic effects and providing fresh water besides functioning as a source for maintaining the energy budget. These thunderstorms associated with lightning, thunder, precipitation (rainfall, hail, sleet, snow, etc.), turbulence and icing are equivocally and commonly known as a cloud by name Cumulonimbus (Cb). These Cb cells individually have spatial dimensions of the order of a few kilometers in breadth (usually about 4 – 8 km) and a few tens of kilometer in length (normally about 10 – 20 km) and height exceeding 6 km and last for about 30 minutes to an hour or so. A squall line is defined as a line or narrow band of active thunderstorms. However, a chain of Cb clouds leaving almost no gap between them at times form as a line or curvilinear with length exceeding 100 km and length to breadth ratio of 10 : 1 or higher is generally known as line squall thunderstorms. The height of some of the Cb cells, either isolated or in a squall line, may exceed far more than 16 km in tropics.

Multiple definitions are available in the literature\textsuperscript{1-7} for sever local storms (SLS). A SLS is often defined as a thunderstorm family with any or all of the following components of weather elements or weather events:

- Tornadoes
- Thunderstorm cells occupying vast area
- Flash floods
- Hail stones of size atleast 19 mm
- Strong surface wind speed (gust exceeding 25.7 m s\textsuperscript{-1}) and squally winds. A squall is defined as sudden rise in wind speed and lasting for atleast one minute duration of sustained wind exceeding 22 kts.

However, the most commonly used definition of SLS in operational set up is that it a thunderstorm family producing heavy rainfall, hail stones, high wind speed, almost continuous lightning and thunder activities. In short, based on literature survey made, hail storms and line squall thunderstorms are considered as SLS in this paper.

2 Hail storm over Chennai and its neighbourhood

Chennai city has two class I meteorological observatories, one at Nungambakkam (13°04.092°N, 80°14.776°E) and the other at Meenambakkam Airport (12°59.61°N, 80°10.62°E) maintained by the India Meteorological Department (IMD). Climatologically, Chennai city had no hail storm during the past 100 years. However, interior places of Tamil Nadu and Andhra Pradesh states in southern peninsular India are reported to have some incidence of hail storms,
albeit very rare, but not supported by authentic climatological records. The causes for very low hail storm frequency over this peninsular India may perhaps be due to the facts that the hail leaving the freezing level (around 5000 m throughout the year) melts during its long travel before reaching the ground and/or there might have been incidence(s) of hail fall in some parts of the cities/villages but not in the vicinity of the meteorological observatories and hence, not reported for climatological records as the area of the hail fall (hail swath) is very much smaller than that of the rainfall.

3 Data

Doppler Weather Radar (DWR) data [radar reflectivity \( z \), radial velocity \( V \) and spectrum width \( W \)] and products for a few hail storm and squall line thunderstorm cases reported by print and electronic media during 2002-2007 have been collected from Chennai DWR station (13°05.031’N, 80°17.400’E) and analysed. Meteorological observations recorded by the two class I observatories maintained by India Meteorological Department (IMD) and one observatory each maintained by Indian Air Force at Tambaram and Indian Navy at Arakonam and surface rainfall recorded by ordinary rain gauges (ORG) and self recording rain gauges (SRRG) located within 100 km radius of Chennai DWR have been used in this study (Fig. 1). Upper air (RS/RW) sounding data of Chennai (13.00°N, 80.18°E), Machilipatnam (16.20°N, 81.15 °E), Karaikal (10.91°N, 79.83°E) and Bangalore (12.96°N, 77.58°E) have been used to assess the thermodynamic instability conditions of the atmosphere. Reports of hail storm events published/broadcast/telecast in the print and electronic media during 2002-2009 have been consulted.

4 Hail storms

A 10 cm wavelength DWR has been commissioned and put into operational cyclone detection and weather surveillance purposes by IMD with effect from 21.2.2002 at Chennai Port Trust building. Two incidences of hail storms: one on 29 May 2002 as reported by print and electronic media over Villivakkam (about 11 km from Radar and 5 km from Nungambakkam observatory); and another on 30 May 2002 by Naval Meteorological observatory at Arakkonam. These two cases were analysed in sequel with the analysis carried out in the literature using DWR data and interesting results including vertical integrated liquid (VIL), hail stone size estimation, convergence and divergence signatures, reflectivity thresholds, etc. have been published by Suresh & Bhatnagar. Since then, constant watch on reflectivity values conforming to hail signatures have been maintained and corroborated with electronic and print media reports, if any. A few of the hail storm cases that were reported in print and electronic media during 2003-2007 are presented in this paper.

4.1 Hail storm over suburbs of Chennai in Tiruvallur and Kanchipuram Districts on 23 May 2003

Print and electronic media reported hail storm with small hail stones over Thirunindravur (30 km west of DWR) in Tiruvallur district and at few places in Kanchipuram district (70 to 90 km in the southwest quadrant of DWR) on the afternoon of 23 May 2003. Energy (Stuve) diagram of 0000 hrs UTC of Chennai RS/RW has been shown as Fig. 2 and the thermodynamic parameters have been tabulated in Table 1. All the thermodynamic conditions, but for CINE, were conducive convective cloud developments. Sea breeze penetration could be identified from DWR products right from 0813 hrs UTC and the speed of propagation of the front was observed to be 10 - 15 km h\(^{-1}\). At 0943 hrs UTC, the sea breeze front was almost parallel to the coast at a lateral distance of 20 km. Low clouds were probed from 0813 hrs UTC and Cumuli form clouds were seen from 0913 hrs UTC. At 0943 hrs UTC, Cb

![Fig. 1 — Locations indicating meteorological observatories and rain gauge stations in and around Chennai within 100 km radius [range circles are 20 km apart; Nungambakkam (marked as NNG at 6 km west of Radar which is marked as MDS), Meenambakkam (marked as MO at 17 km SW of Radar) are the Class I Meteorological observatories of IMD and Tambaram (marked as TBM at 26 km SW of Radar and maintained by Indian Air Force), Arakonam (marked as ARK at 67 km west of Radar and maintained by Indian Navy) are the other meteorological observatories within 100 km radius from the Radar]
clouds were seen over Thirunindravur area with vertical extent of about 9 to 10 km (with echo top of 10 dBZ) and having the core reflectivity of 54-55 dBZ around 2 - 3 km above ground level (agl). Figure 3 shows Cb development during 0943 – 1013 hrs UTC. Between 1013 and 1043 hrs UTC, the Cb clouds had passed over the Thirunindravur area during which period the core reflectivity continued be around 55 dBZ at 2 - 3 km agl. Though media had reported hail stones during this said period, personal enquiry by the author with local public and school authorities revealed that bigger size rain drops were noticed by them but not hail stones. However, the rate at which the rain was pouring albeit for a very brief period of about 2 - 3 minutes only appeared as if hail stones were falling down. Surface rainfall intensity at a height of 1 km agl computed using \( z = 267 R^{1.345} \) (Ref. 8) confirmed that the rain rate was more than 90 mm h\(^{-1}\) at 0943 hrs UTC over the places of interest. This supports the necessity of feedback mechanism and volunteers to observe and report hail storm similar to what has been advocated for the storm data project by National Weather Service of USA (Refs (9-11)). Precipitation accumulation from 0800 to 1300 hrs UTC of 23 May 2003 over the area of interest was between 1 and 7.6 mm, which could not be verified for want of rain gauge data in that area (Fig. 4). Abbreviated three letters in Fig. 4 indicate the locations of rain gauges. It can be seen that precipitation eluded most of the rain gauges which had recorded practically no or very meager amount of rainfall while nearby places recorded fairly good amount of rainfall certifying the rainfall variability in meso \( \gamma \) scale.

However, the television channels in their local news telecasted about the occurrence of hail storm on 23 May afternoon over some areas in Kanchipuram district about 100 km south of Thirunindravur. Inland penetration of sea breeze front and development of cumulus congestus clouds little ahead of sea breeze front were noticed from 1013 hrs UTC and Cb clouds with reflectivity of more than 50 dBZ upto 6 km height and cloud top reaching 12 km agl were seen at many locations during 1043 - 1143 hrs UTC. At 1143 hrs UTC, core reflectivity of 58 dBZ was concentrated at height range 4 - 6 km agl and 45 dBZ echo top upto 10 km between Vandavasi (VVS) and Maduranthakam (MDK). The signatures, viz. core reflectivity well above 3 km and 45 dBZ echo top

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**Table 1 — Thermodynamic stability indices based on RS/RW data of Chennai**

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<td>Total Total Index (TTI) ([ \geq 42 ])</td>
<td>55.6</td>
<td>49.0</td>
<td>57.6</td>
<td>42.6</td>
<td>46.6</td>
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<tr>
<td>K index (KI) ([ \geq 27 ])</td>
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<td>45.4</td>
<td>26.5</td>
<td>34.3</td>
<td>42.6</td>
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<td>-3.3</td>
<td>-7.0</td>
<td>2.7</td>
<td>-1.1</td>
<td>-6.4</td>
</tr>
<tr>
<td>Deep convective index (DCI) ([ \geq 27 ])</td>
<td>47.2</td>
<td>44.5</td>
<td>46.4</td>
<td>25.7</td>
<td>37.1</td>
<td>40.0</td>
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<td>CAPE, J kg(^{-1}) ([ &gt; 900 ])</td>
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<td>3823</td>
<td>1277</td>
<td>234</td>
<td>3687</td>
<td>4185</td>
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<tr>
<td>CINE, J kg(^{-1}) ([ &gt; -100 ])</td>
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<td>-89</td>
<td>-445</td>
<td>-214</td>
<td>-1.0</td>
<td>-92</td>
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<tr>
<td>Precipitable water content (PWC), mm ([ \geq 45 ])</td>
<td>58.0</td>
<td>64.5</td>
<td>50.5</td>
<td>27.7</td>
<td>49.5</td>
<td>34.6</td>
</tr>
</tbody>
</table>

Note: Values exceeding thresholds and conducive for convective storm development in bold face

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Fig. 2 — Stuve energy diagram of Chennai at 0000 hrs UTC on 23.5.2003 [wind veering can be seen in this plot (Source: Wyoming University)]
well above the freezing level (4865 m at 0000 hrs UTC on 23 May 2003), are considered to be indicative of hail stones with more than 90% chance (probability 0.90) [Refs (10-13)]. At 1213 hrs UTC, the core reflectivity was much higher than 61 dBZ and concentrated between 3.2 to 6.5 km with 45 dBZ echo top beyond 11 km and cloud top above 16 km over a hamlet Acharapakkam (TV channels reported hail stone of size about 1 to 2 cm in this locality) about 12 – 14 km south-southwest of MDK. The

The hail stone size estimation algorithm as outlined by Witt et al.\textsuperscript{10} is briefly summarised here. Severe hail is considered as hail of size more than 19 mm. The severe hail index (SHI) is defined as:

\[
SHI = 0.1 \int_{H_o}^{H_T} W_T(H) E dH
\]

where, \(H_o\), is the environmental melting level; and \(H_T\), the height of the top of the storm cell. The temperature based weighting function \(W_T(H)\) is defined by:

\[
W_T(H) = \frac{(H - H_o)}{(H_{m20} - H_o)}
\]

where, \(H_{m20}\) is the height of –20°C environmental temperature. When the height \(H \leq H_o\), \(W_T(H) = 0\). When \(H \geq H_{m20}\), \(W_T(H) = 1\). The hail kinetic energy flux \(E\) is a function of reflectivity in dBZ which can be computed using Waldvogel et al.\textsuperscript{14}:

\[
E = 5 \times 10^6 \times 10^{0.084Z} W(Z)
\]

and weighting factor, \(W(Z)\), is given by \(W(Z) = (Z - Z_L)/(Z_U - Z_L)\) where, \(Z_L = 40\) dBZ; and \(Z_U = 50\) dBZ, are the lower and upper bounds of
reflectivity thresholds. The maximum expected hail size (MEHS) in mm is determined by

\[ MEHS = 2.54 \sqrt{SHI} \]

The probability of severe hail (POSH), in percentage, is given by:

\[ POSH = 29 \ln \left( \frac{SHI}{(57.5 H_0 - 121)} \right) + 50. \]

The hail stone size has been estimated using DWR data from 1113 to 1213 hrs UTC. It has been found that MEHS was varying between 13 and 45 mm over different locations. The maximum hail stone size was observed at 1213 hrs UTC. POSH was varying between 0.43 and 0.589. Vertically integrated liquid water (VIL) has been computed using Greene & Clark\textsuperscript{15} and Douglas\textsuperscript{16}. Figure 6 depicts VIL at 1213 hrs UTC using both the methods. Both the methods indicated VIL exceeding 56 kg m\(^{-2}\), when integrated upto 16 km height, over the areas in which hail was reported. The VIL density was 3.5 g m\(^{-3}\) confirming to the hail stone threshold outlined in the literature\textsuperscript{12,17}. The hail detection, hail stone size estimation and related algorithms used elsewhere by and large appear to work in this tropical weather conditions as well but for the fact that the reliable information regarding hail observation and size confirmation are needed to validate the size estimation algorithm.

4.2 Isolated hail storms in Tamil Nadu and Andhra Pradesh on 28 April 2005

During 28 – 30 April 2005, a number of hail storm reports have been reported from various parts of Tamil Nadu and Andhra Pradesh. The oppressive heat due to insulation was received over Tamil Nadu and Andhra Pradesh when the Sun was propagating from the equator to the tropic of cancer during this period. Pre-convective environment prevailed for the pre-monsoon thunderstorm activities over the southern peninsular India. Print and television media reported hail storm activities on 28 April 2005 over Salem district in Tamil Nadu and over a number of districts in Rayalaseema region of Andhra Pradesh. For the purpose of analysis, a few cases that have been documented well in print and electronic media (television, internet, published reports) are presented in this paper.

4.2.1 Hail storm in Salem district

Atmospheric conditions were conducive for convective cloud development around Chennai based on 0000 hrs UTC RS/RW ascent of 28 April 2005,
freezing level was at 5.298 km at 0000 hrs UTC and 4.928 km at 1200 hrs UTC on 28 April 2005. Upper winds were strengthening with height gradually up to 300 hPa and very steep increase was noticed aloft 250 hPa. Vertical wind shear as high as \(1.24 \times 10^{-3}\) s\(^{-1}\) was observed between 12.9 and 13.5 km revealing the presence of strong upper level divergence. All the thermodynamic parameters were favourable for strong convection (Table 1). Figure 7 depicts the Stuve’s energy diagram of 0000 hrs UTC Chennai RS/RW upper air data. Development of convective clouds have been probed by DWR from 0738 hrs UTC and at 0838 hrs UTC, Cb clouds were seen about 120 km west-northwest of Chennai (30 km north of Gadanki - GDK), 160 - 175 km west of Chennai and also about 220 km southwest of Chennai (60 km northeast of Salem – SLM). Between 0908 and 1038 hrs UTC, the Cb clouds in Salem district intensified very strong with the core reflectivity of 59.5 dBZ from 4.3 to 10 km agl indicating the presence of hail stones during 1008 - 1038 hrs UTC. Figure 8 shows panoramic view of maximum radar reflectivity plots at 1008 and 1038 hrs UTC. During this period, Cb cells almost continuously aligned like a squall line in north-south orientation at a distance of 170 km west of Radar. The MEHS was 70 mm with POSH 0.70. Field survey/enquiry revealed that hail stone of size up to 10 cm in length and a few cm in breadth with irregular shape was observed by local public in small hamlets like Malayalapatti and in Attur taluk which confirmed the MEHS through algorithm.

4.2.2 Hail storm at Arakonam and neighbourhood

Naval observatory at Arakonam recorded thunderstorm/rain from 1030 to 1600 hrs UTC and hail during 1122-1130 hrs UTC on 28 April 2005 in their routine meteorological observation records. Surface wind was recorded as northerly 20 kts during the hail storm epoch. Thunderstorm cells at a stretch of 100 km aligned in east-west direction and

Fig. 6 — Vertically integrated liquid (VIL) from surface to 16 km agl using Greene and Clark (left) and Douglas (right) methods

Fig. 7 — Stuve’s energy diagram of Chennai 0000 hrs UTC on 28 April 2005 RS/RW ascent data (Source: Wyoming University) [veering, strengthening of wind with height and upper level (12.9 – 13.5 km) strong wind shear (divergence signature) may be noted]
30-35 km north of Arakonam was observed at 0938 hrs UTC. These cells intensified and merged to form like a miniature mesoscale convective system between 1008 and 1038 hrs UTC close to Arakonam. Between 1108 and 1138 hrs UTC, this mesoscale convective system passed over Arakonam station. Thunder was continuously recorded from 1044 to 1104 hrs UTC, followed by thunderstorm with rain from 1108 to 1200 hrs UTC with hail during 1122-1130 hrs UTC in the aviation current weather register of this Naval Met stations catering to naval air base. However, there is no mention about the size of the hail stone in the aviation current weather log book. The MEHS was estimated to be around 13.6 mm and POSH 0.26. Higher rain drop sizes falling like hail pellets have been confirmed by Naval Met Office during subsequent enquiry. The rainfall between 0900 and 1200 hrs UTC was just 8.0 mm and from 0900 to 1500 hrs UTC was 12.8 mm.

From 1138 hrs UTC, the hail storm was found moving towards southwest of Radar and it was located around 75 km; around 85 - 100 km at 1208 hrs UTC; and around 120 km at 1338 hrs UTC (Fig. 9). The MEHS was estimated to be around 71 mm with POSH 0.7. At 1308 hrs UTC, the storm has intensified further and the cloud top with 20 dBZ reached 18 km agl. At 1338 hrs UTC, isolated hail storm was probed at 140 – 180 km northwest of Radar and a squall line, resembling a part of a circle and stretching more than 300 km in length, extended from 180 km northwest to 100 km southwest of Radar. At this point, a cloud mass of approximately 300 km$^2$ area started detaching from the squall line and behaved as a right moving storm and

4.2.3 Hail storm over Cuddappah (Kadapa) district

In view of range – height limitations in association with earth’s curvature effect, the development of convective clouds at a distance of 200 km (225/250/275 km) from the Radar can be probed by Chennai DWR only when the cloud extends to a height above 3.05 km (3.76/4.55/5.41 km) with the lowest elevation of 0.2°. At 0838 hrs UTC on 28 April, clouds at 85 km north-northeast of Cuddappah (CDP) were probed at a height of about 5 km and these clouds started moving towards Chennai DWR. At 1108 hrs UTC, severe Cb clouds were seen at 200 km north-northwest of Radar with core reflectivity exceeding 58 dBZ from 3 to 8 km, 45 dBZ echo top upto 12 km [confirming probability of hail as 0.9 (Ref. 13)] and 20 dBZ top upto 15.8 km. At 1238 hrs UTC, the storm was located 85 km east of CDP and 190 km north-northwest of Radar with core reflectivity exceeding 58 dBZ upto 8 km height and 20 dBZ echo top was seen upto 17.4 km. MEHS was estimated to be 71 mm with POSH 0.7. At 1308 hrs UTC, the storm has intensified further and the cloud top with 20 dBZ reached 18 km agl. At 1338 hrs UTC, isolated hail storm was probed at 140 – 180 km northwest of Radar and a squall line, resembling a part of a circle and stretching more than 300 km in length, extended from 180 km northwest to 100 km southwest of Radar. At this point, a cloud mass of approximately 300 km$^2$ area started detaching from the squall line and behaved as a right moving storm and
started moving right of the line, southwards. At 1408 hrs UTC, the squall line looked like a bow echo having heavy rain bearing clouds with continuous light to moderate rain bearing clouds (reflectivity exceeding 20 dBZ $\approx 1$ mm h$^{-1}$ to 42 dBZ $\approx 21$ mm h$^{-1}$) and the right moving storm was located at 120 km southwest of radar. Figure 10 shows panoramic view of maximum radar reflectivity products from 1308 to 1438 hrs UTC on 28 April 2005. The right moving storm had intense core reflectivity exceeding 58 dBZ upto 7 km till 1508 hrs UTC. MEHS was worked out to be 39 mm with POSH 0.55. The bow line echo dissipated at 1608 hrs UTC.

On 28 April 2005, hail storm was observed over many places in Tamil Nadu and Andhra Pradesh as confirmed by print and electronic media besides meteorological observatory at Arakonam. Hence, the applicability of thermodynamic parameters and stability indices was looked into in more detail. The thermodynamic parameters of 0000 hrs UTC RS/RW data of Karaikal and Bangalore (to study their impact for hail storm over Salem district and neighbourhood) and Machilpatnam and Hyderabad for Cuddappah district hail storm have been tabulated in Table 1. Of these stations, though Bangalore (921 m elevation) and Hyderabad (545 m elevation) may not be representative of hail storm areas in view of their high station elevations, they were still considered just because the hail storm was moving within 250 km radius from these stations. It is seen that all RS/RW soundings except the Bangalore RS/RW are suggestive of development of convective activities in their neighbourhood of 250 km radius. As such, the thresholds identified for Chennai and neighbourhood can be tried at other RS/RW stations as well and if found suitable can be operationally used.

4.3 Hail storm over Cuddappah district during April 2004

Severe convective clouds with hail caused damages to human lives and properties during 15-30 April 2004 in 20 districts of Andhra Pradesh state. As per the print media reports, as many as 12 people lost their lives in thunder bolts and lightning, damages to crops and horticulture amounting to Rs 5.16 crores out of which Rs 1.58 crore were allocated to districts affected hail storms. Peasants informed the press that the prevailing chill weather in the early morning and afternoon convective (hail) storms totally spoiled the flowering in mango trees and damages to other cash crops. In view of earth curvature effect, only 250 km weather surveillance has been analysed using DWR Chennai data. The hail storm on 24 April 2004 is presented here as a case study. Table 2 lists the

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Fig. 9 — Panoramic view at 1138, 1238 and 1338 hrs UTC of the hail storm that had passed through Arakonam on 28 April 2005
thermodynamic parameters computed using 0000 and 1200 hrs UTC RS/RW data of Chennai, Machilipatnam and Hyderabad. Chennai RS/RW data representative to cover upto Cuddappah was not favourable for the development of convective clouds. The extremely high value of CAPE and the barest minimum value of CINE suggest that in case an external trigger mechanism is available for lifting the

Table 2 — Thermodynamic stability indices based on RS/RW data of Chennai

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<td>Precipitable water content (PWC), mm [≥ 45]</td>
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<td>26.9</td>
<td>57.8</td>
<td>34.6</td>
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Note:
(i) Values exceeding thresholds and conducive for convective storm development in bold face
(ii) Dew point values of Hyderabad RS/RW data at 1200 hrs UTC erroneous and not available beyond 602 hPa at 0000 hrs UTC
(iii) There was no RS/RW sounding for 1200 hrs UTC from Chennai and 0000 hrs UTC from Machilipatnam
air parcel, the convective clouds may grow to great heights. The 1200 hrs UTC Machilipatnam sounding parameters are favourable for intense convective clouds. Despite the fact that dew point values were unavailable beyond 602 hPa at 0000 hrs UTC and erroneous at 1200 hrs UTC, the 0000 hrs UTC data was favourable for convective clouds but the 1200 hrs UTC data was not so favourable.

Cb cloud started appearing within 300 km north-northwest of Chennai DWR at 1038 hrs UTC. The Cb clouds had strong reflectivity exceeding 58 dBZ upto 6 - 7 km and moving towards Cuddappah and its neighbourhood. The 45 dBZ echo top was confined to 6 – 10 km during 1038 – 1338 hrs UTC which can be regarded as the probability of 0.1 to 0.9 (Ref. 13). During 1208 – 1338 hrs UTC, the intense core reflectivity was seen upto 8 km and the 20 dBZ echo top was seen upto 17.6 km height agl. MEHS was estimated to 40 mm with POSH 0.55. Figure 11 shows the propagation of hail storm over Cuddappah district between 1208 and 1338 hrs UTC.

Though there is no readily available information about the size of hail stones over the areas affected by the hail storm, based on the damages caused to properties and lives, it is hoped that hail stones of size between 20 and 60 mm could have been very probable.

4.4 Hail storm over Chennai on 27 September 2007

A few localities in Chennai metropolitan city (viz. Royapuram, Triplicane, Anna Nagar, Thiruvanmiyur, Enjambakkam, etc. located within 4-18 km radius from the Radar) experienced hail shower on the afternoon of 27 September 2007 between 0830 and 1130 hrs UTC. The size of the hail stones as per print and electronic media could be as low as 2 – 3 mm, which can be visualised from Fig. 12. All thermodynamic parameters, based on 0000 hrs UTC RS/RW data, were suggestive of convective cloud development. Isolated Cb cells with high reflectivity (50 - 58 dBZ) in the lower troposphere were probed in a range of 150 km from...
the Radar and a few cells were very close to the Radar. Since the maximum height with 21° elevation was hardly confined to 6 km only and the freezing level was at 4.758 km at 0000 hrs UTC and 4.766 km at 1200 hrs UTC, the size estimation can hardly be made for a vertical distance of just 1.2 km above the freezing level which may not reveal the true size of the hail stone.

5 Discussion on hail storm observations, reporting and estimation

In view of very localized passage of hail swath in comparison to the rain swath, one needs to collect immediate information about the hail storm and there must be volunteers having sufficient knowledge on measurement, preserving the hail stone for further analysis, etc. as has been demonstrated through storm data project envisaged by National Weather Service (NWS), USA for developing hail detection and size estimation algorithm (build 9 of NEXRAD) [Refs (7,10,11)]. NWS has trained and engaged volunteers in every 1000 habitation hamlets. Though the build 9 hail algorithm of NWS works well for Indian weather conditions as well\(^9\), fine tuning on POSH and probability based on 45 dBZ echo top\(^{13}\) relies on reliable and quality data input from the public since the hail stones are not expected to fall always over the meteorological observatories. A few more hail storm cases in and around Chennai upto 250 km radius have been reported in print and electronic media during 2002 – 2009 and similar analysis have been carried out. In all, the thermodynamic parameters generally give an idea about the convective storm development but the precise locations over which the storm may form or move are not known to the forecasters. Fine resolution NWP models are yet to be demonstrated for Indian weather situations to forecast the development of thunderstorm cell with precision and accuracy. The forecast based on thermodynamic parameters using R5/RW ascent data and NWP model outputs can be concatenated with DWR observations to nowcast the possible development and movement of thunderstorms and severe local storms. The DWR based radial velocity and spectrum width information will be useful for understanding the dynamics of the storm and movement of the storm which has been highlighted in the earlier paper (Part I published in this issue).

In addition to above mentioned hail storm cases, a number of thunderstorm cases have also been studied in-depth within 250 km radius of Chennai DWR. The forecasts issued in the operational set up using thresholds\(^{18}\) have been verified on a day-to-day basis using DWR observations and found to work satisfactorily well. As the human observations (both synoptic or aviation current weather observations) may have the distance restrictions due to eye sight limitations, remote sensing technique alone, especially radar probing in view of super fine resolutions, can help the forecaster for the forecast verifications. During the pre-convective environment in hot weather conditions that usually prevail during March – September over southern peninsular India, orographical lift is provided by eastern Ghat mountain chains from Rayalaseema to interior Tamil Nadu. The hail storm over Salem area is aided by Nagari hills located about 80 km west of Chennai and its continuation of high lands from the Seshachalam hills northwest of Chennai, Javadi Hills, Melagiri range

Fig. 12 — Hail stones collected at different locations in Chennai on 27 September 2007 [hail stone size can be guessed from the architecture of hands and fingers]
and Sheveroy/Yercaud hills in the west to southwest of Chennai. The severe local storms over these hilly regions go unnoticed in view of lack of observatories. The local public when contacted informed that hail storm over these region are quite common during pre-monsoon season (specifically April – May) and during September. Hence, in order to establish hail climatology, it is all the more necessary to engage volunteers and create awareness on the necessity of this vital climatic information. Though at the Chennai meteorological observatory, climatological hail storm frequency has been shown as nil upto the year 1990, there had been hail storms over Chennai and its neighbourhood during 2002 (Ref. 9) and during 2007 as discussed in this paper. The cases discussed in this paper are mostly based on the reports from print and electronic media, which the authors are in a position to corroborate with the DWR observations. DWR data serves as a vital tool to detect the possible hail storms over areas wherein no meteorological observatory is located and/or inaccessible due to terrain conditions lest this vital severe weather information goes unnoticed.

6 Summary and Conclusions

Though there are inaccuracies and lack of precision in the observed hail storm reports especially in regard to the time of occurrence and the exact size of the hail stones, the information reported through the print media serves as data base since the event reported upon had been verified by the radar probing and proven hail detection algorithms. Although satellite data may serve as another source to verify these severe storms, in view of its relatively lower temporal and spatial resolutions and lack of proven satellite data based algorithms especially for the Indian weather conditions, it is considered that in the absence of radar probing, it may be very difficult to confirm the hail storm events unless they occur over the well established meteorological observatories. As such, installation of more and more scanning weather radars preferably with Doppler capabilities to cover the entire lengths and breadths of the country is the need of the hour. It is hoped that the above objective will soon be met with the IMD’s modernization plan to install more DWRs in the country in the next five years or so.

In the United States of America, storm data had been generated and published on a monthly basis by the National Climatic Data Center (NCDC) for the purpose of validating the storm detection algorithms. The data consists of reports collected by National Weather Service (NWS) besides inputs from the general public, volunteers, non-governmental agencies/emergency management groups and print and electronic media. Even with the involvement of so many agencies in building up a storm data for validating and fine-tuning the NEXRAD algorithms, it has been observed by Witt et al. and Lenning et al. that these data are either inadequate or lack timeliness or precision especially in information pertaining to hail size/time of occurrence of hail storm. Nevertheless, such a database is needed not only for the algorithm development but also for validation purposes in our country. More scientific awareness has to be created and volunteers involved to report about the severe weather information so that suitable algorithms can be developed by the meteorological community which in turn will be useful to the public as part of early warning and to help the disaster mitigation agencies and insurance agencies to settle the claims.

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