MAUSAM, **68**, 1 (January 2017), 75-92

551.578.7 : 632.116.3

Occurrence of hail storms and strategies to minimize its effect on crops

N. CHATTOPADHYAY, S. SUNITHA DEVI, GRACY JOHN and V. R. CHOUDHARI

India Meteorological Department, Pune 411 005, India

(*Received 15 September 2015, Accepted 3 May 2016*)

e mail : nabansu.nc@gmail.com

सार – चरम मौसम की घटनाओं के बीच हाल के दिनों में मूसलधार बारिश की वजह से देश भर में महत्वपूर्ण फसल क्षति। के दौरान 2014 और 2015 बेमौसम बारिश और ओलावृष्टि में मार्च और अप्रैल में बड़े पैमाने पर देश के कई हिस्सों में रबी फसलों के साथ-साथ बागवानी फसलों को नुकसान पहुंचा। इस पत्र, एक विस्तृत मूसलधार बारिश की घटना की भारत की चार समरूप क्षेत्रों में पिछले 35 वर्षों के दौरान 1981 से 2015 के लिए विश्लेषण किया गया है में, ओलावृष्टि के साथ जुड़े जलवायवीय और अनुकूल संक्षिप्त पहलुओं पता लगाने के लिए इतना है कि चेतावनी और कृषि मौसम परामर्श के समय पर जारी करने वाले फसल क्षति / नुकसान को कम कर सकता है। अधिकतम ओलावृष्टि 14 मार्च को 24 फरवरी के दौरान 11 दिनों के उच्चतम घटना के साथ अध्ययन की अवधि के दौरान महाराष्ट्र (31 वर्ष) में हुई है करने के लिए मनाया गया 2014. इसके अलावा महाराष्ट्र घटना की अधिकतम संभावना के साथ देश में अन्य राज्यों की तुलना में ओलावृष्टि के लिए और अधिक होने का खतरा है (91-95%), जबकि घटना (6-10%) की संभावना को गुजरात, छत्तीसगढ़, तमिलनाडु, त्रिपुरा, मेघालय, सिक्किम और नगालैंड में कम से कम है। महत्वपूर्ण संक्षिप्त ओलावृष्टि की घटना के साथ जुड़े स्थितियों मग़रिबी हवा में संवहनी गतिविधि और प्रणालियों के कारण हवा अलगाव के उत्तर-दक्षिण लाइन होना पाया जाता है। इस अध्ययन में उत्पन्न जानकारी कृषि मौसम फील्ड इकाइयों (AMFUs) राज्य कृषि विश्वविद्यालयों और आईसीएआर के संस्थानों में स्थित के साथ सहयोग में भारत मौसम विज्ञान विभाग / पृथ्वी विज्ञान मंत्रालय द्वारा शुरू की परिचालन कृषि मौसम सेवाओं के माध्यम से फसल नुकसान को कम करने में बहुत उपयोगी हो पाया था और इस परियोजना के ग्रामीण कृषि मौसम सेवा (GKMS) के तहत आईआईटी।

ABSTRACT. Among the extreme weather events hailstorm in recent past caused significant crop damage across the country. In 2014 and 2015 unseasonal rains and hailstorms during March and April damaged *rabi* crops as well as horticultural crops extensively in many parts of the country. In this paper, a detailed analysis of occurrence of hailstorm in four homogenous regions of India during past 35 years from 1981 to 2015 has been made, to find out the climatological and favourable synoptic aspects associated with hailstorms so that timely issuing of warning and Agromet Advisories could minimize the crop damage/loss. Maximum hailstorms were observed to have occurred in Maharashtra (31 years) during the period of study with highest occurrence of 11 days during 24 February to 14 March, 2014. Also Maharashtra is more prone to hailstorms than other States in the country with maximum probability of occurrence (91-95%) while the probability of occurrence (6-10%) is least in Gujarat, Chhattisgarh, Tamil Nadu, Tripura, Meghalaya, Sikkim and Nagaland. The significant synoptic situations associated with occurrence of hailstorms are found to be the north-south line of wind discontinuity causing convective activity and systems in westerlies. The information generated in this study was found to be very useful in minimizing crop loss through operational agromet services launched by the India Meteorological Department/Ministry of Earth Sciences in collaboration with the Agromet Field Units (AMFUs) located at State Agricultural Universities and institutes of ICAR and IITs under the project Gramin Krishi Mausam Sewa (GKMS).

Key words – Hailstorm, Crop damage, Synoptic situations, Agromet Advisory.

1. Introduction

In the last decade, India has been repeatedly battered by different extreme events like heavy rainfall causing extensive flooding, droughts, unseasonal rainfall, hailstorm etc. The 2001-2010 decade witnessed the intensification of climate and weather extremes such as destructive flooding, severe droughts, heat waves, heavy rainfall and severe storms. The number of extreme events of very heavy rainfall has almost doubled in the country in the last 50 years (Goswami *et al.*, 2006). Among other extreme events unseasonal rains and hailstorms are mostly observed during pre-monsoon season from March to April in the country. In some years it also occurred early, during end of February and late during mid-May also. The unseasonal rains and hailstorms have destroyed crops in lakhs of acres of farmland in many states including Himachal Pradesh, Uttar Pradesh, Uttarakhand, Punjab,

Haryana, Madhya Pradesh, Gujarat, Rajasthan, Maharashtra and Andhra Pradesh causing huge losses to farmers. Hailstorm causes substantial damage to the standing crops as well as the horticultural crops within a very short time. Very recently (March, 2015), heavy rains accompanied by hailstorm damaged wheat, sugarcane and oilseed crops in thousands of hectares in Punjab and Haryana. Though occurrences of hailstorm are unavoidable, need is felt now for its prediction followed by recovery, rescue and remedial measures. There are methods available these days to detect hail-producing thunderstorms using weather satellites and weather radar imagery. Severe weather warnings are issued now for hail when the hail reach a damaging size, as it can cause serious damage to structures, crops and live stocks.

The statistics on hailstorm in India was first computed for the period 1883-1897 and published by Eliot (1898). Ramdas *et al.* (1938) analysed and published hail reports received from 141 observatories during the period 1898-1935. Gokhale (1975) and Ramanamurthy (1983) reproduced the time and space dimensions of hail occurrence for hundred year period as given by Ramdas *et al.* (1938). Philip and Daniel (1976) observed that in the eastern part of India hailstorms occur with average frequency of 10 hailstorms per year (slight, moderate and heavy) over extreme northeast Assam, six over Uttar Pradesh and portions of east Bihar and about two to three over east Madhya Pradesh and west and north Bihar. According to Seneviratne *et al.* (2012) the atmospheric conditions for hailstorm occurrence, typically estimated from reanalysis or from Radio Sonde data are associated with high uncertainty. Though De *et al.* (2005) made a systematic attempt to bring the information on these extreme events over the Indian region; assessment of changes in hail frequency is difficult. As occurrence of hailstorms has become more frequent in recent years and the associated crop damage increasing, there is an urgent need to forecast the occurrence of hailstorms in India using the present 'state of art' technology and also for issue of corresponding advisories to minimise the crop losses. Across India, many attempts have been made in the past, especially over northeast region to explore the favourable conditions for occurrence of thunderstorms/ hailstorms. Biswas *et al.* (2010) studied a severe hailstorm over Guwahati airport and its vicinity on 2nd April, 2006 and found that under favourable synoptic and instability conditions 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 $ms^{-1}km^{-1}$ appears to be conducive for the development of a hailstorm. Das *et al.* (2010) identified sea level trough from East Uttar Pradesh/Bihar to North-East India and low level cyclonic circulation over Bihar and neighbourhood as the significant synoptic situation associated with occurrence of hailstorms over Guwahati during pre-monsoon season.

Weather radar is a very useful tool to detect the presence of hail-producing thunderstorms. However, radar data has to be complemented by knowledge of current atmospheric conditions which can allow one to determine if the current atmosphere is conducive to further hail development. Suresh and Bhatnagar (2004) have analysed unusual hailstorms around Chennai by using data from single Doppler weather radar. They observed vertical extent of the hailstorm which was beyond 20 km with high reflectivity above 45 dbZ upto 18.5 km. A radar study has been done by Sharma (1965) on hailstorm over Guwahati and concluded that low over Nepal /North Bengal and its movement towards Guwahati was responsible for occurrence of hook shaped perturbance. Mukherjee *et al.* (1962) had studied the structure of hailstorm and prevailing meteorological situation on an unusual hailstorm event over Guwahati on 18th March, 1961 and opined that sufficient amount of moisture; local orographic features and latent instability in the atmosphere appear to have given rise to the hailstorm.

In the present paper, extensive study has been made regarding the occurrence of hailstorms in different parts of the country for a relatively long period and also its impacts on the crop damage. Studies have also been made on the synoptic features associated with the formation of such hailstorms including the forecasting tools available for its forecast, to identify the regions with high vulnerability and hail frequency in the different States in the country and also to issue of subsequent agromet advisories to protect the crops and minimize the losses.

2. Data and methodology

Data regarding occurrence of hailstorms for 34 years from 1981 to 2014 across different States have been collected from the publication "Disaster Weather Events", annually issued by National Climate Centre, India Meteorological Department (IMD) Pune. Hailstorm data for the year 2015 was collected from Agromet Field Units located at different State Agricultural Universities and centres of Indian Council of Agricultural Research (ICAR) in the country. Thus a total of 35 years data have been used in this study. Synoptic charts for the period 1981-2015 were obtained from Weather Section, IMD, Pune. Data on hailstorm and corresponding synoptic situations during the period 1981-2015 have been analysed to understand meteorological aspects of incidence of hailstorm. The number of days and distribution of hailstorm during last 35 years are presented in Figs. 1[(a-d)]. To identify the regions with high vulnerability to hail (frequency) in the different States in

North Region

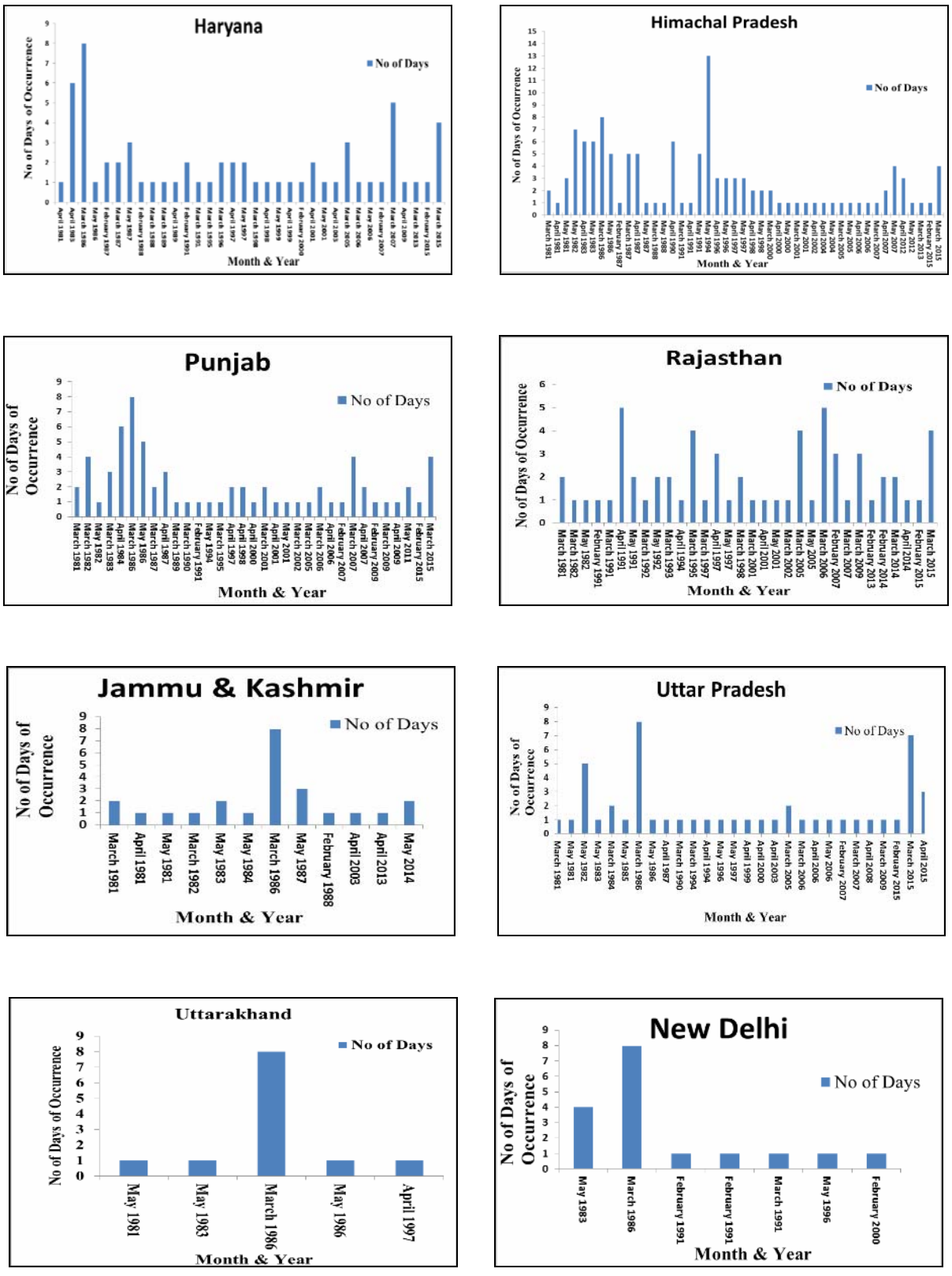


Fig. 1(a). Occurrence of hailstorms in North regions of the country during the period 1981-2015

Central & West Regions

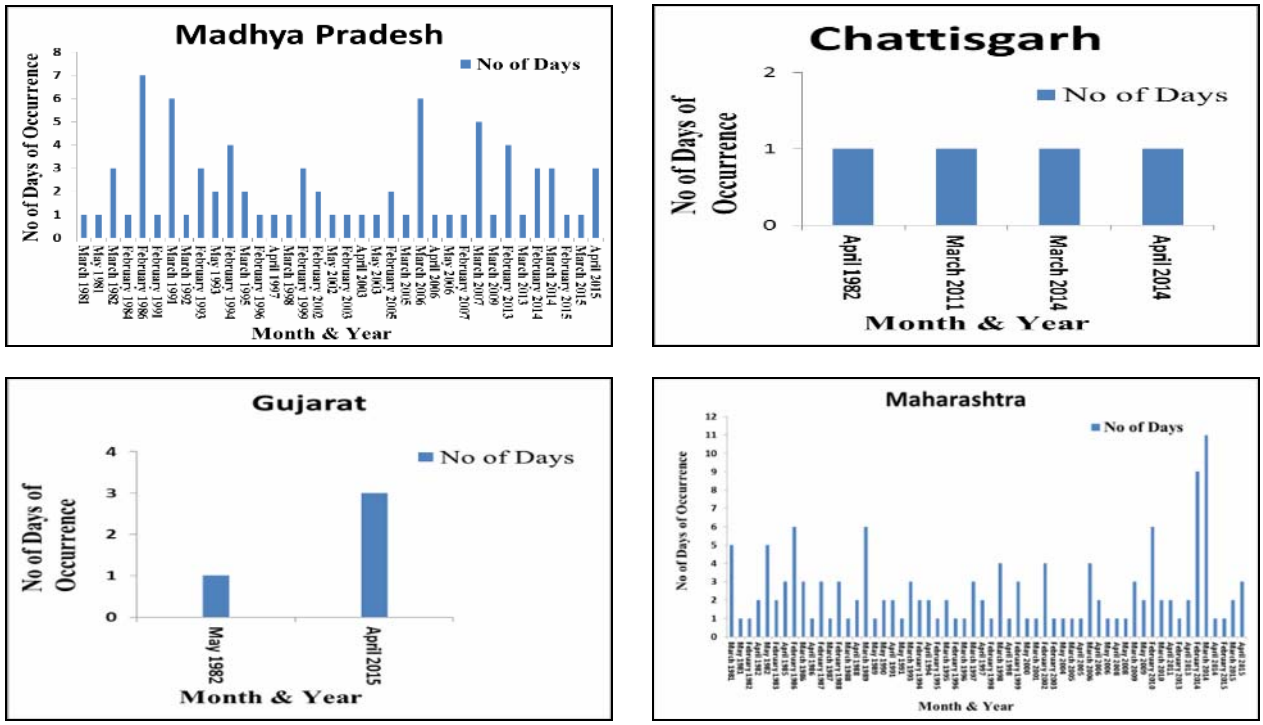


Fig. 1(b). Occurrence of hail storms in Central regions of the country during the period 1981-2015

the country, the probability of occurrence of hailstorms has been computed and presented in Fig. 2. Some images of crop damage in Maharashtra and Punjab during March 2015 are given in Fig. 3. Synoptic situations for some of the hailstorms during the year 2014 and 2015 are given in Figs. 4(a-d). The locations of All India Nowcast and IMD-DWR Network is given in Fig. 5.

Recent state of art technology of forecasting hailstorm, a case study of hailstorm events during 2014 and 2015, appropriate advisories given during pre and post hailstorm periods to minimize crop loss have also been discussed here. Doppler Weather Radar (DWR) images of hailstorm events in some parts of Maharashtra during 3rd to 5th March, 2014 are given in Figs. 6(a-d). Some of the types of protection of crops against hailstorms are given in Fig. 7. Table 1 shows crop damage in different states of the country due to recent hailstorm (28th February to March, 2015).

3. Results and discussions

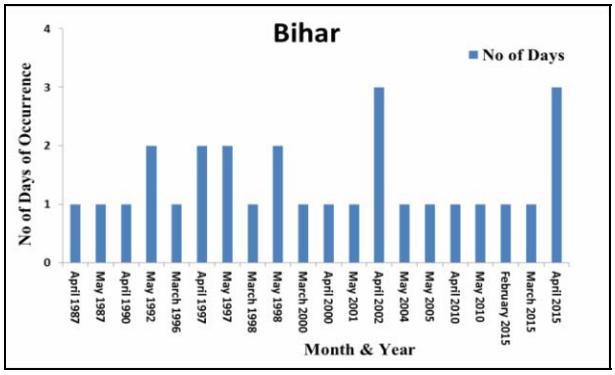
3.1. *Frequency and distribution of hailstorm*

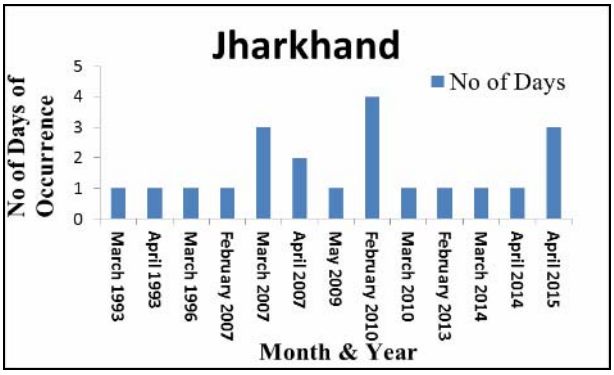
At the beginning an attempt was made to know the prone zones, time of occurrences of hailstorm and the frequency of occurrence, within and among four homogeneous regions (North, East and Northeastern, Central & West and South Region) of India. Figs. 1[(a-d)] shows the statistics of occurrence of hailstorm in different regions of the country.

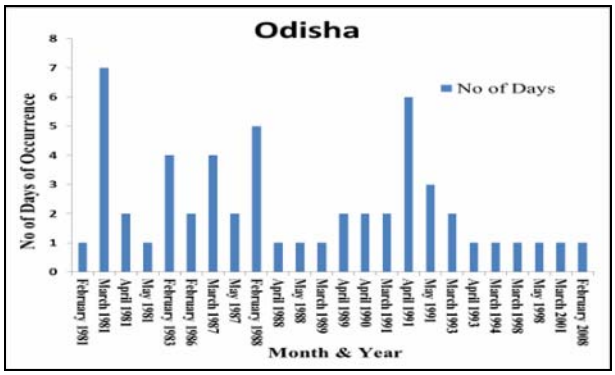
3.1.1. *Northern region*

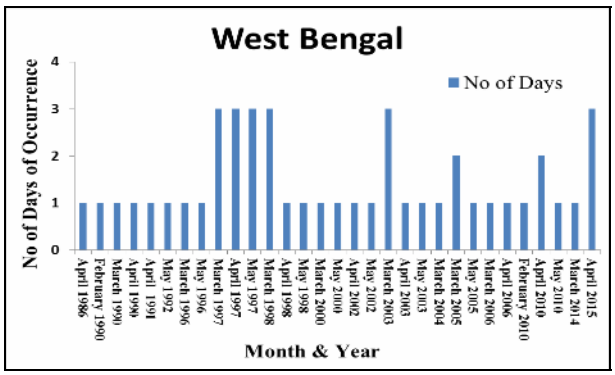
The number of days and frequency distribution of hailstorms presented in Fig. 1(a) shows that in Northern region during last 35 years, hailstorms occurred during 20 years in Himachal Pradesh with maximum occurrence of 13 days during May 1994, followed by 8 days in March 1986. Also one day events of hailstorm occurrence were more common in Himachal Pradesh with maximum occurrence during the month of May during the period of study. Hailstorms occurred during 22 years in Punjab, 20 years in Uttar Pradesh and Haryana and 10 years in Jammu & Kashmir with maximum hailstorms of 8 days during March 1986 while in Rajasthan hailstorms occurred in 22 years with a maximum of 5 days during April 1991. Hailstorm occurrence was least in Uttarakhand (4 years) followed by Delhi (5 years) with a maximum of 8 days during March 1986 during the period of study. It is also noticed that widespread hailstorm events affected North region during March 1986.

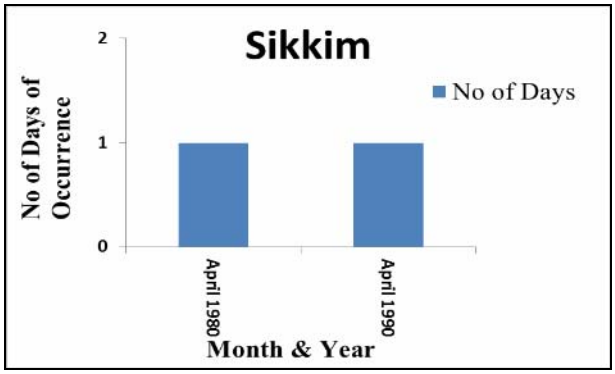
East and North East Regions

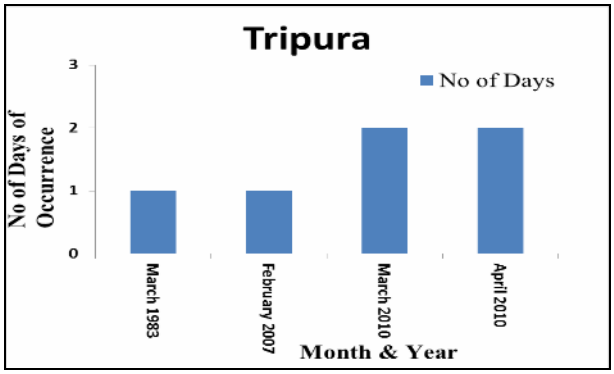


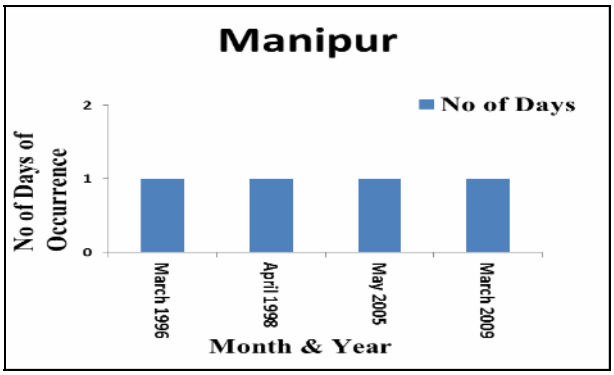


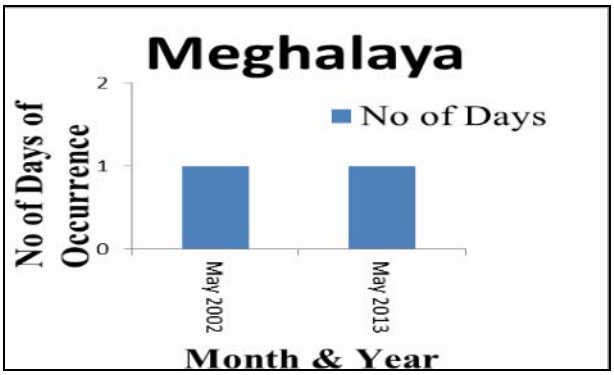












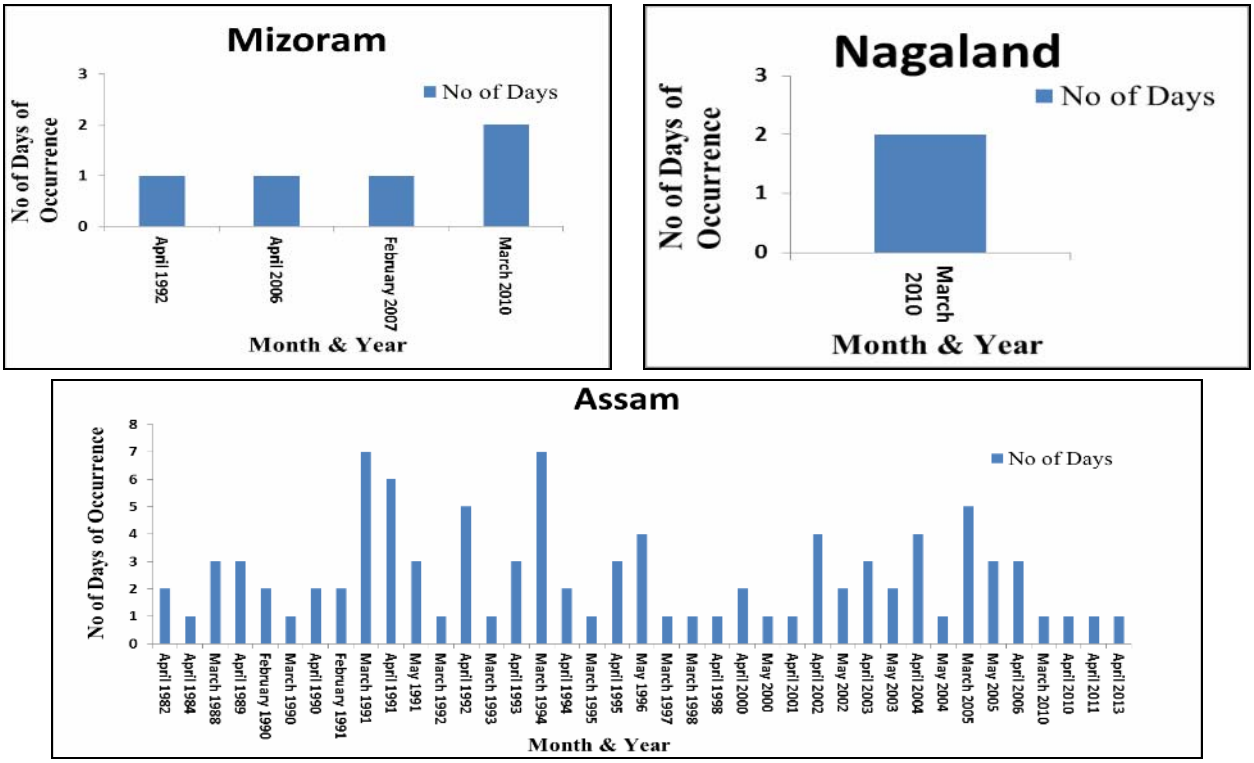


Fig. 1(c). Occurrence of hail storms in East and North East regions of the country during the period 1981-2015

South Region

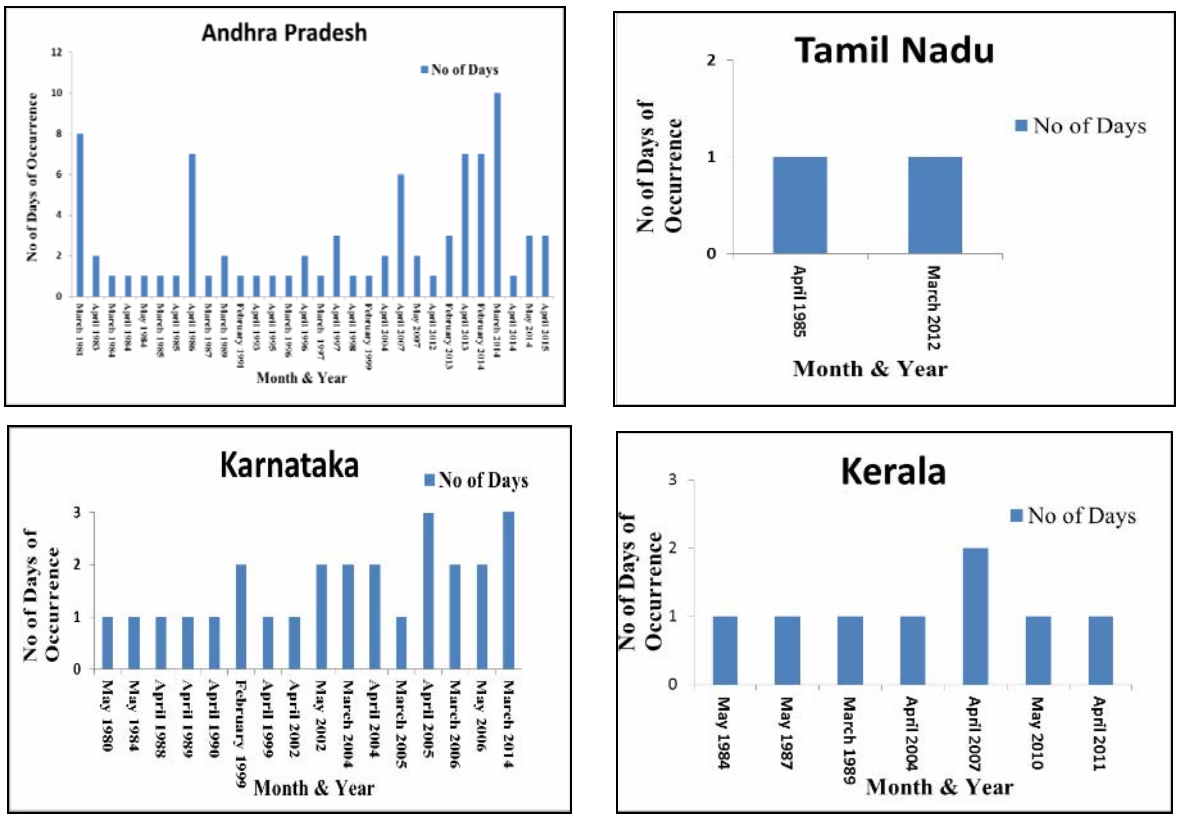


Fig. 1(d). Occurrence of hail storms in South regions of the country during the period 1981-2015

TABLE 1

Crop damage in different states of the country due to hailstorms/ rain on during 28th February to March 2015

State	Date	Standing crops	Stage	Crop damage
Haryana (All districts)	28 February to 1 March, 2015	Wheat	Earhead emergence-Anthesis	Lodging due to high winds and rain
		Mustard	Maturity/Harvesting	Lodging due to high winds and rain
		Vegetables (Peas)	Flowering/Fruiting	Lodging due to high winds and rain
Punjab		Wheat	Booting - Flowering	Lodging due to high wind and rain except in Western Zone and Western Plain Zone of Punjab
Uttar Pradesh		Wheat	Flowering	Lodging due to high wind and rain, 20-25% damage
		Arhar	Flowering	Lodging due to high wind and rain, 20-25% damage
		Gram	Flowering	Lodging due to high wind and rain, 20-25% damage
		Mustard	Harvesting	50% damage in 17 districts of East UP and other districts 25% damage
Bihar		Wheat	Dough Stage	Lodging due to high wind and rain in Northwest Alluvial Zone
		Pulses/Oilseeds	Maturity	Damaged due to water logging in South Bihar Alluvial Zone
Madhya Pradesh		Early Wheat , Gram, Mustard and Pulses	Maturity	5 to 10% damage due to heavy rain in East MP; waterlogging in wheat and barley fields. In mustard, delay in harvesting, crop lodging, scattering losses of 10-15%
Rajasthan		Mustard	Harvesting	Due to rainfall with high wind and hail, 5-10% damage is recorded in mustard crop in Bharatpur, Jodhpur and Udaipur district of Rajasthan. It resulted in delay in harvesting, crop lodging, and scattering losses
		Cumin	Harvesting	5-15% in Bikaner, Jodhpur` and Udaipur and 30-40% in Fatehpur
Himachal Pradesh		Apple and Vegetables	Vegetative	No damage in Apple Orchards; minor damage in vegetables due to heavy rain/snow
Maharashtra		Mango	Fruit setting	Fruit dropping (approx. 10%), occurrence of powdery mildew and anthracnoac, mango hopper in Konkan region
		Cashew	Maturity/Harvesting	40% harvesting completed, less fruit dropping in Konkan region
		Summer rice	Tillering	No impact in Konkan region
		Wheat	Dough/ Maturity	Logging, degradation in quality. Occurrence of tikka/rust in Madhya Maharashtra region
		Jowar/ Gram	Maturity/ Harvesting	Logging in jowar, degradation in quality in Madhya Maharashtra region
		Onion	Bulb growth/ Maturity	Due to water logging, chances of bulk rot. Occurrence of blight in Madhya Maharashtra region
		Grape	Fruit setting/ Maturity	Fruit cracking due to sudden drop in temperature. Occurrence of downy/powdery mildew in Madhya Maharashtra region
		Pomegranate	Pruning	Fungal disease, due to rain no dropping of leaves in Madhya Maharashtra region
		Wheat	Maturity	Logging in some pockets, degradation in quality in Marathawada region
		Jowar	Maturity/harvesting	Logging in some pockets, degradation in quality quality in Marathawada region
		Grapes	Fruiting/maturity	Occurrence of downy/powdery mildew in Marathawada region
		Wheat	Dough maturity	Due to high wind, logging, chances of sprouting in Vidarbha (West) region

TABLE 1 (*Contd.*)

State	Date	Standing crops	Stage	Crop damage
		Orange	Fruit development/maturity	Fruit dropping, occurrence of pest in Vidarbha (West) region
		Banana	Maturity	Due to high wind and weight of the bunch, logging in Vidarbha (West) region
Haryana (All districts)	13 March to 15 March, 2015	Wheat	Earhead emergence-Anthesis	Significant damage reported
		Mustard	Maturity/Harvesting	Significant damage reported
		Vegetables(Peas)	Flowering/Fruiting	Significant damage reported
Punjab		Wheat	Booting - Flowering	No significant damage is reported on 13th March
Uttar Pradesh (East UP)		Wheat	Flowering	Lodging due to high wind and rain , 5% damage
		Arhar	Flowering	Lodging due to high wind and rain, 10% damage
		Gram	Flowering	Lodging due to high wind and rain, 4% damage
		Potato	Harvesting	13% damage due to water logging
		Wheat	dough/maturity stage	In Ahmedabad and Bhavnagar districts, crop lodging occurred due to rain with strong winds
Ahmedabad and Bhavnagar districts of Gujarat		Cumin	Maturity	In Ahmedabad and Bhavnagar districts, rain has damaged the already harvested crop in the field & stacks in threshing yard. Rain has damaged the seed colour & quality and it may result in the dew formation for next few days which may create the spreading of diseases
		Cotton		In Ahmedabad and Bhavnagar districts, the quality of seed cotton will be deteriorating due to the rain and subsequent dew formation also during morning hours for next few days
		Castor, Wheat, Cotton, Orchards		In Ahmedabad and Bhavnagar districts, mechanical damage has also took place. Water stagnation condition is observed at some places in irrigated crop fields
Junagadh and Porbander districts of Gujarat		Wheat	Maturity (Harvesting)	• Difficulties in harvesting and threshing due to lodging of crop • Due to rain, disease/fungal development in spikes • Fodder quality deteriorated • Shattering of spikes
		Chickpea	Maturity (Harvesting)	• Moisture content increases in seed, due to this seed quality (germination, disease infection, storability etc.) is deteriorated
		Cumin and Coriander	Maturity (Harvesting)	• Disease incidence in grain (Powdery mildew) • Quality of seed in deteriorated
		Onion/Garlic	Maturity (Harvesting)	• Disease incidence in fruit • The storability is affected in harvested crop
		Summer sesame	Germination/early vegetative stage	• Incidence of sucking pests may increase • Seed emergence is affected
		Summer Groundnut	Early vegetative	• Incidence of sucking pest may increase
		Vegetables	Fruiting/Flowering	• Dropping of flowers and fruits • Disease and pest infestation may increase
		Mango	Fruiting/Flowering	• Flowers and fruits drop • Physical damage to branches • Disease /pest infestation
		Pomegranate	Fruiting/Flowering	• Flowers and fruits drop • Disease /pest infestation may increase

3.1.2. *Central & west region*

The number of days and distribution of hailstorm in Central region presented in Fig. 1(b) shows that, hailstorms occurred in 23 years out of 35 years in Madhya Pradesh with maximum of 7 hailstorm days during February 1986 and most of these hailstorms occurred during end of February to early March with 2 or more hailstorm days. In Chhattisgarh, hailstorm occurrence was less (3 years) with one day duration during April 1982, March 2011, March and April 2014.

From Fig. 1(b) it is seen that Maharashtra experienced frequent hail storms during February to April. During the study period (35 years), Maharashtra experienced maximum hailstorm occurrences of 31 years with 11 days during 24 February to 14 March, 2014 followed by a frequency of 6 days during February 1986, March 1989 and February 2010. Rao. VUM *et al*. (2014) in their study found highest frequency of hailstorm events over districts in the northern part of Vidarbha region of Maharashtra that are adjoining to the state of Madhya Pradesh. According to their study, the highest frequency of 40 events was noticed in Nagpur district followed by Akola and Amravati districts (25 to 30 events).

In Gujarat, occurrence of hailstorm was the least with two occurrences in May 1982 and April 2015 during the period of study.

3.1.3. *East and northeastern regions*

Occurrence of hail storms in East and Northeast regions presented in [Fig. 1(c)] shows that, in East region, hailstorms were observed in 13 years in Odisha and Bihar with maximum of 7 days in Odisha during March 1981 and 3 days in Bihar during April 2002. Jharkhand experienced mostly heavy hailstorms but the occurrence were less (8 years) during the period of study with a maximum of 4 hailstorm days during February 2010 while West Bengal experienced hailstorms in 16 years with maximum of 3 days during March, April and May in 1997, March 1998, March 2003 and April 2015 respectively. Hailstorm incidence was rare in Sikkim with 2 occurrences with 1 day hailstorm in April 1980 and April 1990 during the study period.

In Northeast region, maximum hailstorms occurred in Assam (23 years) with a maximum of 7 days during March 1991 and 1994, while Nagaland experienced minimum of 1 hailstorm (2 days) during March 2010 during the study period (1981-2015). Meghalaya experienced 2 hail storm incidences of 1day each during May 2002 and 2013. In Tripura, hail was observed in 3 years with 2 days hailstorm during March and April 2010. Manipur and Mizoram experienced 4 hail storms each with a maximum of 2 days during March 2010 in Mizoram and all one day occurrences in Manipur.

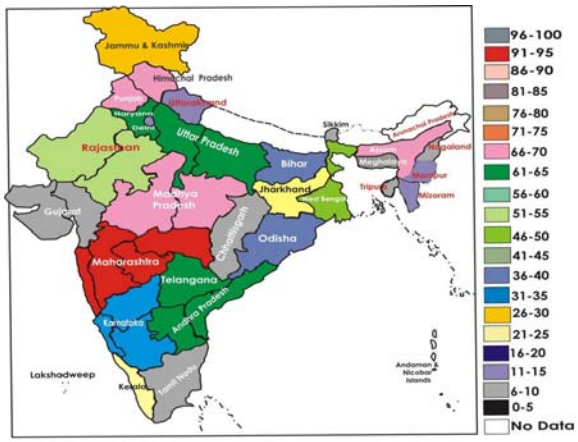


Fig. 2. Probability of occurrence of hailstorms in different states of India

3.1.4. *Southern region*

Fig. 1(d) shows that Andhra Pradesh experienced maximum hailstorms (20 years) with a maximum of 10 days during March 2014 followed by 16 years in Karnataka with a maximum of 3 days in April 2005 and March 2014. Kerala experienced hailstorms of average 1 day duration in 6 years and 2 days duration in one year (April 2007) while in Tamil Nadu hailstorm incidences were rare with 2 occurrences (1 day each) during April 1985 and March 2012.

3.2. *Probability of occurrence of hailstorms across the country*

The probability of occurrence of hailstorms presented in Fig. 2 shows that the State of Maharashtra is more prone to hailstorms than other States in the country with maximum probability of occurrence in the range of 91-95% followed by Himachal Pradesh, Punjab, Assam and Madhya Pradesh with probability of occurrence in the range of 66-70%. Andhra Pradesh, Telangana, Uttar Pradesh and Haryana followed closely with probability of occurrence in the range of 61-65%. In Rajasthan the probability of occurrence is in the range of 51-55% while in West Bengal the probability of occurrence is in the range of 46-50%. In Odisha and Bihar the probability of occurrence is in the range of 36-40%. In Karnataka the probability of occurrence is in the range of 31-35% while in Jammu & Kashmir the probability of occurrence is in the range of 26-30%. In Kerala and Jharkhand the probability of occurrence is 21-25%. In Delhi, Uttarakhand, Manipur and Mizoram the probability of occurrence is between 11-15% while the least probability of occurrence of hailstorm between 6-10% is seen in

Gujarat, Chhattisgarh, Tamil Nadu, Tripura, Meghalaya, Sikkim and Nagaland.

3.3. *Synoptic situations favourable for occurrence of hail storms in general*

Synoptic charts during the period 1981- 2015 have been analysed and the following synoptic situations are found to be favourable for occurrence of hailstorms over the broad regions of India, *viz*., north India, central & west India, east & northeast India and south India :

(a) *North region*

(*i*) Systems in westerlies and moisture incursion from the Arabian Sea.

(*ii*) Active western disturbances with the presence of a wind discontinuity and confluence of winds in the lower levels and the core of sub-tropical westerly jet stream over the region.

(*iii*) Continued passage of systems in westerlies, perturbations in easterlies causing convective activity.

(b) *Central & west region*

(*i*) Favourable interaction between a high amplitude trough in the tropical easterlies and a deep mid-latitude trough in the mid & upper tropospheric westerlies.

(*ii*) Trough in the mid and upper tropospheric westerlies and gradual westward progression and amplification of the troughs in the easterlies.

(*iii*) Perturbations in the westerly and easterly wind regimes.

(*iv*) A combined result of (*a*) passage of western disturbances, (*b*) a stronger than normal and southward located Sub-Tropical Westerly Jet stream & (*c*) presence of warm & moist easterlies in the lower troposphere.

(c) *East & northeastern region*

(*i*) Downstream convergence, orography and moisture incursion due to the low level southerly winds.

(*ii*) Depressions forming over east central Bay of Bengal and neighbourhood.

(d) *Southern region*

(*i*) A combined result of (*a*) passage of western disturbances, (*b*) a stronger than normal and southward located Sub-Tropical Westerly Jet Stream and (*c*) presence of warm & moist easterlies in the lower troposphere.

(*ii*) Upper level divergence provided by the sub-tropical westerly jet stream, in combination with the formation of a feeble north-south wind discontinuity providing convergence in the lower levels along with the temporary establishment of the oceanic highs.

The above listed synoptic features independently or in combination lead to intense convective activity which manifest in the form of damaging hailstorms.

3.4. *Crop damage due to hail storms during 1981-2014*

Major parts of Andhra Pradesh were affected by hailstorms during March 1981 and about 87819 hectares of cropped area was damaged. During March 1982 in Punjab and May 1982 in Himachal Pradesh there was extensive damage by hail to *rabi* crops. In Himachal Pradesh during April 1983 also orchards and cereals crops were extensively damaged and there was extensive damage to standing wheat crops in neighbouring Haryana and New Delhi where vegetables and *rabi* crops were also damaged in May 1983. During February and April 1984, crops and orchards were extensively damaged in Punjab. Wide spread hail storms affected North India and many parts of Central and Western India during February, March and May 1986 causing extensive damage to standing crops and horticultural crops.

Hail storms during February 1987 damaged 80% of wheat crop in Maharashtra while rice and vegetable crops were damaged in Odisha and Jammu & Kashmir during March and May 1987. In February 1988, wheat, green pea and mango (at flowering stage) were damaged in Maharashtra. Also in Maharashtra during March 1989, wheat, mango and orange crops were badly damaged. During March and April 1991, there was heavy loss to standing crops in Madhya Pradesh and Rajasthan. In Madhya Pradesh during February1993 there was extensive damage to standing *rabi* crops. Tea gardens were extensively damaged in Assam during March 1994 and mango and peach crops were damaged in Himachal Pradesh during May 1994.

Hail storms during March to May 1997 damaged standing *rabi* crops in Maharashtra, Andhra Pradesh, Himachal Pradesh and West Bengal. In Vidarbha region, during March 1998 wheat, jowar, gram, red gram, cotton, chilli, orange and banana orchids were damaged. In West Bengal during February 2005, potato, mustard and wheat crops were damaged. During March 2007, there was an extensive damage to rice crops in Madhya Pradesh and

Fig. 3. Hail and crop damage due to hailstorms in Maharashtra and Punjab

Jharkhand and also rice, mango, orange, banana and chilli crops were damaged in Andhra Pradesh during April 2007. Heavy damage was reported to *rabi* crops and vegetables in Jharkhand and orange, wheat and gram in Maharashtra during February 2010. Agriculture crops of 1,47,986 hectares and Horticulture crops of 1,45,000 hectares were damaged in Andhra Pradesh during February 2013.

During late February to March 2014, hailstorms have damaged various agri-horticultural crops on approximately 16 lakh ha area in Vidarbha, Marathwada and Western Maharashtra regions in Maharashtra. Standing crops like cotton, wheat, chickpea, sorghum and maize and horticultural crops like grapes, pomegranate, sweet lime and mango were affected. Among the hail affected districts in Maharashtra, Nagpur district with about 25% losses was the worst hit (Bal *et al*., 2014). Also crop damages were reported in Rajasthan, Haryana and Uttarakhand due to hailstorms during end of February to mid of March 2014.

3.5. *Crop damage due to hail storms in different regions in the country for the year 2015*

Unseasonal rains and hailstorms across much of the Central, Northern and Western parts of the country during the late part of February have wreaked havoc on farmlands and agricultural output. Normally, after February, western disturbances tend to reduce from 4 or 5 to 3 in March. But in the year 2015, not only were these disturbances more active, they extended up to April. This led to heavy showers from back to back Western disturbances from 1stto 5th March. The showers and hail, which came at a time when the *rabi* crops were to be harvested, hit about 10 million hectares of the 60 million hectares of sown area. The standing wheat, mustard and bengal gram crops were hit the hardest. Wheat crop in 21 per cent of the overall sown area has been completely damaged. Lakhs of farmers have been driven to despair by the unseasonal rains and hailstorms which extensively damaged *rabi* crops like wheat, pulses and oilseed in various States, bengal gram, cotton, jowar, summer onion, horticultural crops like papaya, sweet lime, grapes are battered and orchards which took years to grow were destroyed in Maharashtra, Punjab, Madhya Pradesh and Haryana. While 11.5 lakh hectares of crops were affected in 51 districts of MP, crops across 17.7 lakh hectares in Maharashtra's 28 districts were left damaged by untimely rains and hailstorms. Hail and some of the crop damages due to hailstorms in Maharashtra and Punjab are shown in Fig. 3.

In the month of February-March 2015, many States like, Punjab, Himachal Pradesh, Haryana, Maharashtra, Bihar, Uttar Pradesh, Uttarakhand, Madhya Pradesh, Rajasthan, Gujarat, Jammu & Kashmir, West Bengal, Telangana and Kerala were hit by hailstorms followed by untimely rainfall. As per inputs received from States, State wise crop area affected due to hailstorm and unseasonal rains in country on the basis of preliminary assessment are given below :

S. No.	*States*	*Total Area (lakh ha) (as on 16th April, 2015)*
1.	Gujarat	1.75
2.	Madhya Pradesh	5.70
3.	Maharashtra	9.89
4.	Rajasthan	16.89
5.	Haryana	22.24
6.	Punjab	2.94
7.	Uttar Pradesh	29.64
8.	Uttarakhand	0.39
9.	Himachal Pradesh	0.67
10.	Bihar	1.86
11.	J&K	1.33
12.	Telangana	0.01
13.	Kerala	0.01
14.	West Bengal	0.49
	Total Area	93.81

(*Source* : agricultural situation in India May, 2015)

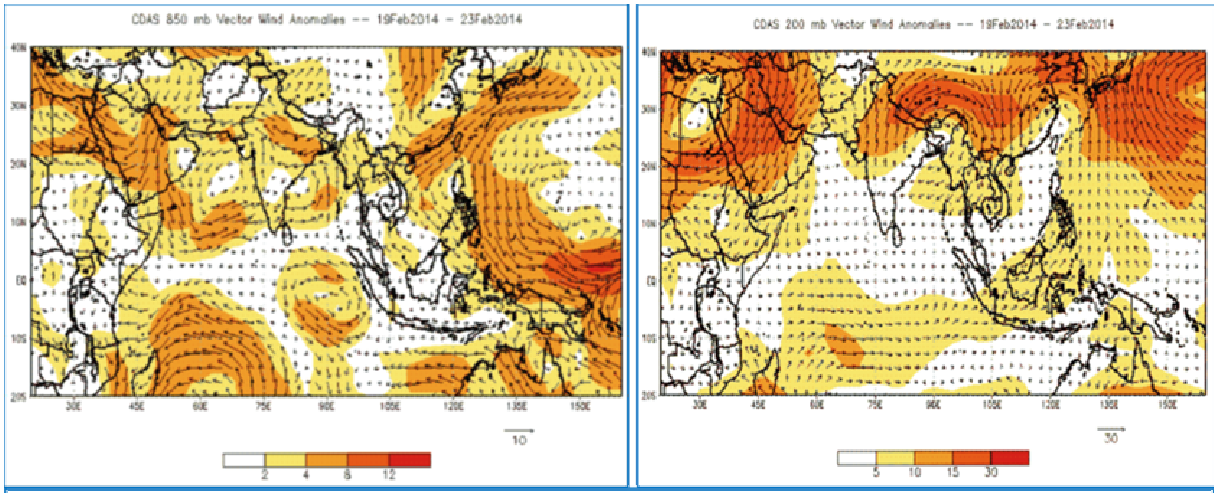


Fig. 4 (a). Synoptic situation for the week 19th February to 23rd February, 2014 (week ending 26th February, 2014)

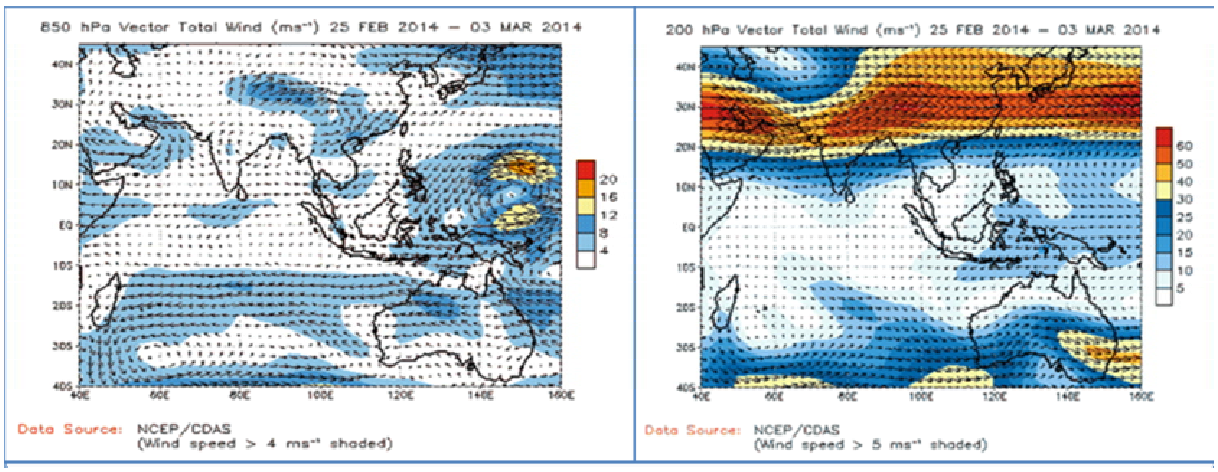


Fig. 4 (b). Synoptic situation for the week 23rd February to 3rd March, 2014 (week ending 5th March, 2014)

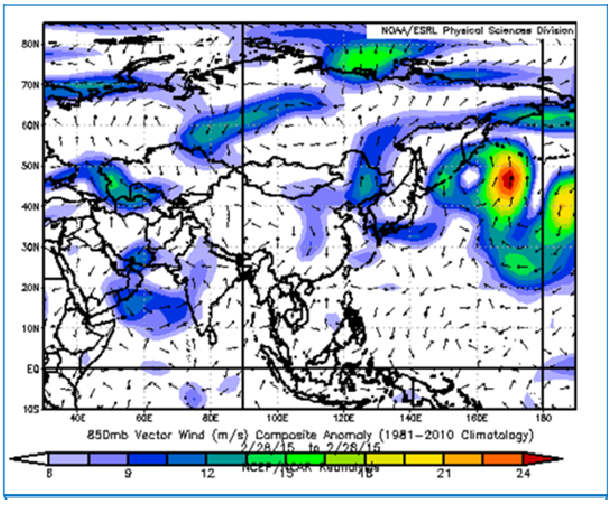


Fig. 4 (c). Synoptic situation of 28th February, 2015

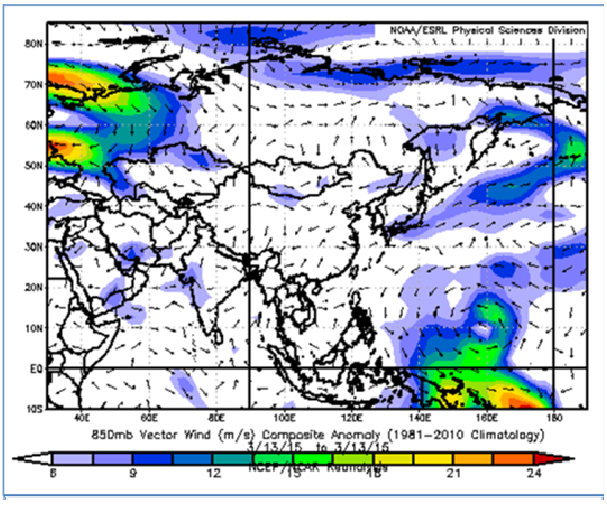


Fig. 4 (d). Synoptic situation of 13th March, 2015

Since there has been an increased hailstorm activity during 2014 and 2015, an in depth study of the hailstorm events during 2014 and 2015 have been made and the major synoptic situations associated are presented below:

3.6. (a) *Synoptic situation associated with hailstorms during 2014*

The major synoptic situation which caused hail storms during February-March 2014 had been an anomalous southward shifting of the core (zone of maximum wind) of the sub-tropical westerly jet stream in association with a high amplitude mid-latitude westerly trough and moisture abundance in the lower tropospheric levels in the presence of warm and moist tropical easterlies. The strong vertical wind shear and upper level divergence provided by the jet maximum created conducive conditions for the development of convective cells. Strong upper level wind caused the CAPE (Convective Available Potential Energy) to be maximised to its fullest potential. Also the strong upper level winds aided in tilting the updraft of the developing thunderstorms, thereby causing the updraft and downdraft to be separated from each other. This might have produced higher UVVs (Upward Vertical Velocity) in the updraft portion. This might explain the unprecedented damage occurred over parts of peninsular India, including Maharashtra, Karnataka and Andhra Pradesh owing to large sized hailstones. Wind confluence and moisture incursion from the Indian Seas caused scattered to widespread rainfall and isolated hailstorms over central and adjoining northern parts of peninsular India.

The meteorological situation as depicted above is quite unusual over central and adjoining northern parts of peninsular India during this part of the year. Hence, capturing the very first event in our day-to-day weather forecasts could not be accomplished. However, the spatial distribution and intensity of rainfall had been predicted well. Also the subsequent events had been warned sufficiently in advance (2 days is the maximum lead time that can be achieved at present, with available resources).

This part of the season is a transition period from winter to summer and climatologically the probability of Hailstorms/Thundersqualls is the minimum over the peninsular India. Usually the occurrence of Hailstorms during this period is mainly confined to the northwestern parts of the country, in association with the eastward movement of the weather systems in the mid-latitude westerlies. As already been stated, pin-pointing the location where the hailstorm is going to create havoc is a highly difficult task. At the most, warnings in the form of very short range forecasts are possible at district level and the same are being attempted currently by IMD.

In the meteorological accounts published in the recent past spanning a period of 20 years, there is no such record of a similar event which had been widespread and extended, as happened during 23rd February to 9th March, 2014 of severe hailstorms. Thus it may be categorized as an unusual meteorological occurrence. Figs. 4 (a&b) show the synoptic situation for the week ending 26th February and 5th March, 2014 respectively.

(b) *Synoptic situation associated with hailstorms during the year 2015*

In the year 2015, widespread hailstorm events occurred over Rajasthan, Gujarat, Maharashtra, Punjab, Haryana, Himachal Pradesh, Uttarakhand and Uttar Pradesh during 28th February to 3rd March and 13-16 March, 2015.

Some of the synoptic situations associated with the hailstorm events are as follows :

(*i*) Subsequent to the eastward movement of the Western Disturbance (WD) by 27th February, another WD as a deep/high amplitude trough in the mid-latitude westerlies has approached from the west, whose upper level divergence induced a fresh low pressure area over south Pakistan and adjoining Saurashtra & Kutch by 28th February, evening.

(*ii*) Consequently, warm and moist air from the tropical Oceans, confined to a very shallow depth (up to 925 hPa), reached upto Central India and northern plains from 28th February evening. This situation created a highly unstable environment (sporadic growth of CAPE) which could generate 'super-cell thunder storms' in which 'Hailstones' grow at a rapid rate.

(*iii*) Constructive interaction between a trough in the mid-latitude westerlies in the mid & upper tropospheric levels and a trough in the tropical easterlies in the lower tropospheric levels caused well distributed rainfall with isolated heavy falls and 'Hailstorms' over northwest, north, central and adjoining peninsular India during 13-16 March [Fig. 4(d)].

Figs. 4(c&d) show the synoptic situation of 28th February, 2015 and 13th March, 2015.

The widespread hailstorm events during 28th February to 3rd March, 2015, over major parts of the country, mainly affecting the Met-subdivisions, *viz*., Jammu, Rajasthan, Maharashtra, Ghat section of South Interior Karnataka, Telangana, Madhya Pradesh, Chhattisgarh, Uttar Pradesh & Bihar and thunder squall events over Kerala and Ghats of Tamil Nadu was

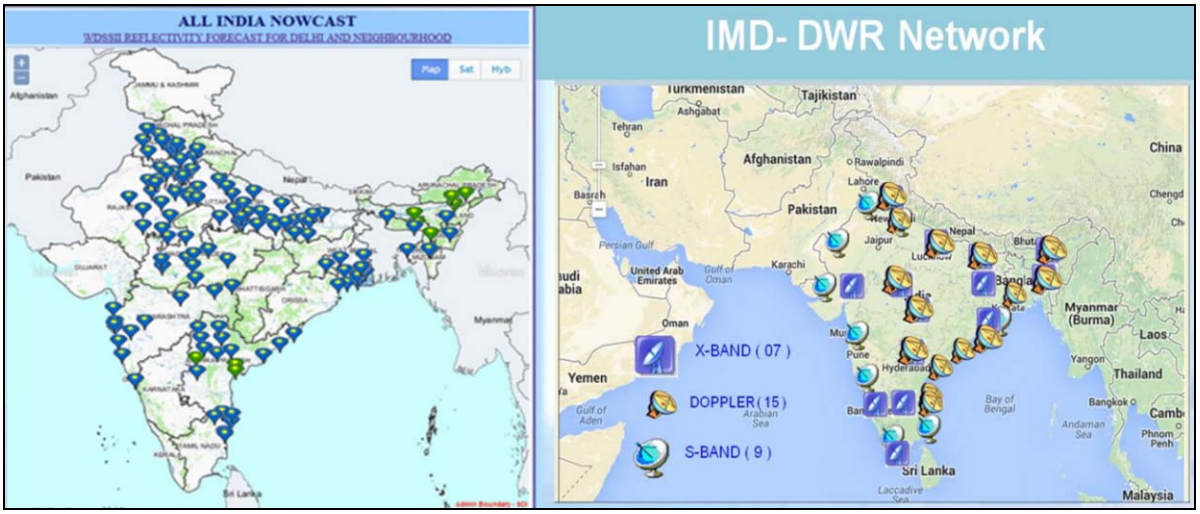


Fig. 5. All India nowcast and IMD-DWR network

forecasted and the spatial extent and severity was at its peak on 1st March, 2015 and it had been communicated to the relevant field forecasting offices in-order to take up the matter with respective State government authority well ahead of time for preparedness as well as to farmers for taking up pre-cautionary measures including spreading of 'Hail Net' etc. for orchard crops.

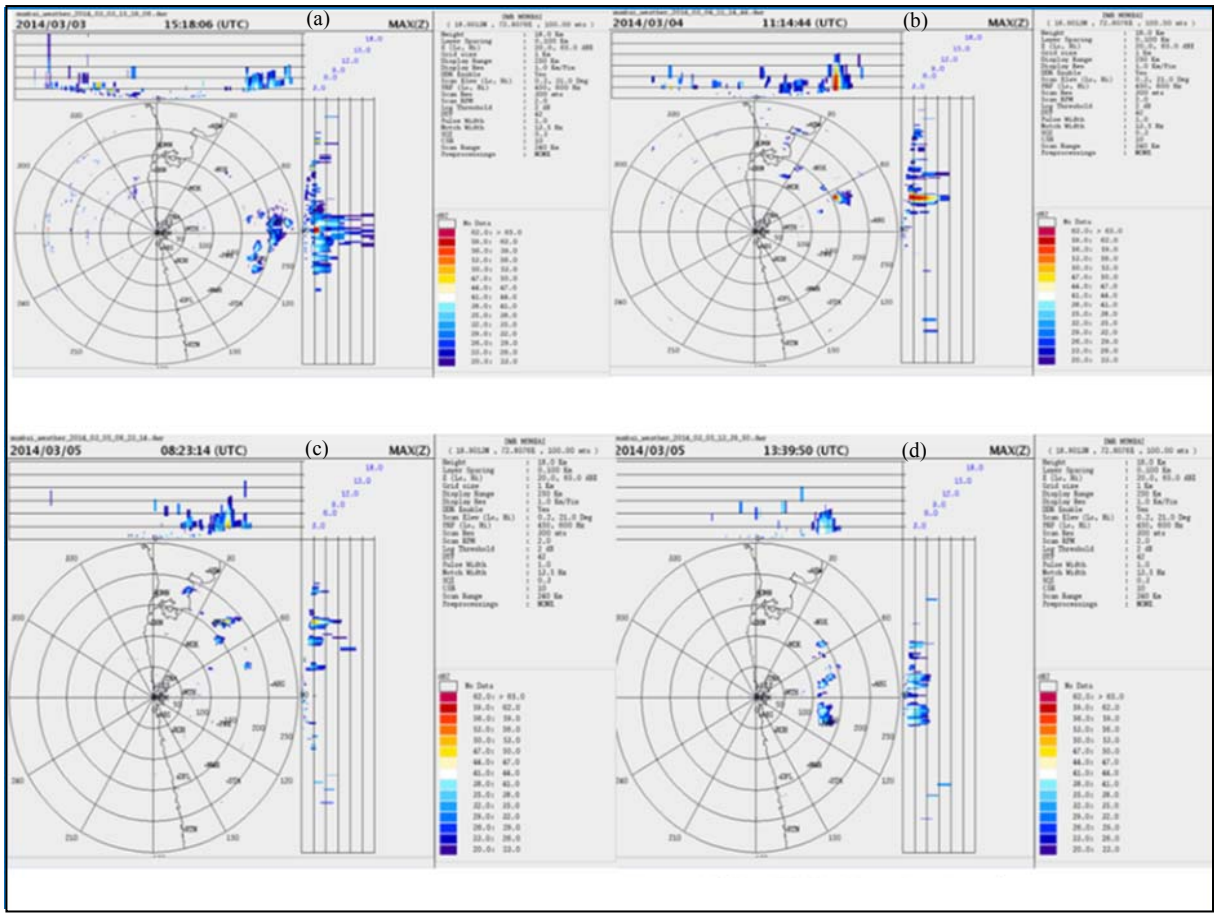
3.7. *Operational capability of hailstorm forecast*

In addition to the short range weather forecasting, nowcasting system is used in the country to forecast convective activities and associated hailstorms. Nowcasting comprises of a detailed description of the current weather along with forecasts obtained by extrapolation for a period of 0 to 6 hours ahead.

Nowcasting in India has benefited from major developments in observational meteorology and computer-based interactive data processing and display systems in IMD. In view of the recent improvement in monitoring and forecasting due to introduction of digital and image information at 10 minutes interval from a network of 15 Doppler Weather Radars, a dense automatic weather station (AWS) network, half hourly satellite observations from Kalpana and INSAT-3D satellites, better analysis tools in synergy system at forecaster's workstation, availability of mesoscale models and computational and communication capabilities, IMD has implemented nowcasting of thunderstorms, squalls and hailstorms. Considering the importance and reliability of DWR based information for nowcast of thunderstorm and associated weather, in the first phase, major stations/cities which come under the coverage of DWR are included for nowcasting of convective weather. A total of 148 stations within 200 km radius of various Doppler Weather Radars are selected and nowcast is uploaded every 3 hourly interval utilising Synoptic Data, Model outputs, Satellite products and finally various Radar outputs. These nowcasts are primarily made by forecasters at various Meteorological Centres and Regional Meteorological Centres of India Meteorological Department. The verification of Nowcasts for the year 2013 and 2014 indicate an average all India POD (Probability of detection) as between 0.6 and 0.8 and FAR (False Alarm Rate) less than 0.4. Fig. 5 shows the All India Nowcast and IMD-DWR Network.

The dissemination of Nowcast forecasts to the users is a challenge considering the short lead time and validity period of the generated information into the public domain to support decision making by users. Therefore automatic dissemination of warnings for disastrous weather events like severe thunderstorms, hail, squalls etc. to all mobile users of that particular area, for which warning is issued, through SMS alerts is being initiated. These Nowcasts are city-specific and uploaded on the server linked to IMD website at every three hourly interval. These Nowcast alerts are based on Doppler data and are issued few hours before the event and thus would be very useful to alert the farmer community about the occurrence of the adverse weather.

Based on the climatology, synoptic situation and Nowcasting, it is now possible to give hailstorm warning in advance. Through short range forecast, hailstorm warning can be issued before 72 hours of the hailstorm events and by Nowcasting it is able to pinpoint the



Figs. 6 (a-d). Doppler weather radar images of hailstorm events in some parts of Maharashtra during the period 3rd to 5th March, 2014

locations. Figs. 6(a-d) shows some images of Doppler weather radar of hailstorm events in some parts of Maharashtra. In order to extend the time period of Nowcasting beyond 6 hours, some Nowcasting systems use the combination of radar extrapolation techniques with satellite and Numerical Weather Prediction (NWP) model products to produce an extended short-period forecast.

Under this situation, the related agromet advisory within a very short period can be communicated to the farming community to protect their crop from hail injury and also the steps to be taken during the post hail period.

3.8. *Agrometeorological advisories to minimize crop damage before and after hail storm occurrence*

Along with hail storm forecast by IMD, the following Agromet Advisories can be issued and disseminated to the farmers by the Agrometeorological Field Units for the respective States.

Before the occurrence of hailstorms :

(*i*) Use hail net for orchard crops to protect from hail damage.

(*ii*) Use hail caps to save the nurseries and young plants.

(*iii*) Also undertake propping in sugarcane, provide mechanical support to banana, young fruit plants and vegetables to prevent the crops from lodging due to strong winds. Keep already harvested crops at safer places.

(*iv*) Arrange for adequate drainage to avoid water stagnation in standing crop fields.

Care and advisory for management of hail affected crops :

Hailstorms can vary in intensity, duration and when they occur during the growing season, hail can severely damage all types of plants. The hail damage to plants/

Fig. 7. Protection of crops against hailstorms

trees, varies in severity depending upon the type of tree and the force and size of hail that falls. This damage can include tattered leaves, broken or damaged shoots and wounds on scaffold branches, fruit damage and even fruit being knocked to the ground. Sensitive leaves of plants become shredded, pock marked or ripped by hail. Hail crop damage can severely affect the health of plant and decimate the harvest. In case of new plants which are sprouting and growing tender leaves and stems, hail can completely kill seedlings. Hail damage to trees shows up as split and broken stems/ branches. The tips and tops of trees become scarred and pitted by the hail. This can increase the chance of disease, rotting and insect's infestation. Fig. 7 shows some of the types of protection of crops against hailstorms.

The following Integrated Management Strategies may be adopted during post hail period :

(*i*) To clean up the debris and fallen fruits from orchards and trim off broken stems and leaves of plants to avoid further spread of pest and diseases.

(*ii*) If crop has not been fertilized, application of fertilizer to the impacted plants can help them to regrow and develop new foliage.

(*iii*) Injuries to trees that are minor will heal but benefit from an application of fungicide to prevent rot from entering before the wounds are able to seal.

(*iv*) Open wounds on the growing shoots, branches and scaffolds present entry points for bacterial and fungal pathogens and also insects.

(*v*) Plants damaged in the spring season benefit from a layer of mulch around the base of the plant to help it survive in summer.

(*vi*) Some plants are too heavily affected and fixing hail damage is not possible. These plants should be removed and replaced with new plants.

General recommendations for hail storm damaged horticultural crops are, to first evaluate the extent of the damage. According to the stage of the crop and extent of damage, determine if the crop can be salvaged. The devastation left in the wake of a hail storm can be partial or total. In regions where hail day frequency is higher, it is advisable to farmers to take hail insurance as a safety measure. Crop hail insurance gives acre-by-acre protection that can be as much as the actual cash value of the crop, thereby protecting the farmer's investment.

The widespread hailstorm events during 28th February to 3rd March, 2015 and 13th to 15th March, 2015 over major parts of the country was forecasted by IMD and the spatial extent and severity was communicated to the relevant field forecasting offices and with the improved forecasting abilities, IMD can improve hail forecasting further with more lead time thereby helping the concerned State government officials and farmers to be prepared to meet these eventualities.

4. Conclusions

The following conclusions are drawn on the basis of the results and analysis made in this study.

(*i*) Maximum hail storms occurred in Maharashtra (31 years) during the period with a peak occurrence of 11 days during 24th February to 14th March, 2014. Also Maharashtra is more prone to hailstorms than other States in the country with maximum probability of occurrence (91-95%) while the probability of occurrence (6-10%) is least in Gujarat, Chhattisgarh, Tamil Nadu, Tripura, Meghalaya, Sikkim and Nagaland.

(*ii*) In the North region Himachal Pradesh and Punjab experience maximum hailstorms compared to other States in the region. In Northeast region, Assam experiences frequent hailstorms during pre-monsoon season. In South region, Andhra Pradesh experiences frequent hailstorms.

(*iii*) Unseasonal rain and hailstorms during end of February and in March 2014 and 2015 caused extensive damage to standing as well as matured *rabi c*rops like mustard, wheat, barley, gram and orchard crops in Punjab, Haryana, Himachal Pradesh, Rajasthan, Andhra Pradesh and Maharashtra.

(*iv*) Alongwith short range forecast, Nowcast alerts based on Doppler data issued a few hours before the event would be very useful to alert the farmer community about the occurrence of hailstorms.

(*v*) The following Significant Synoptic Situation are found favourable for occurrence of hailstorms during 2014 and 2015 :

- Unstable conditions caused by the wind discontinuity in the lower tropospheric levels in association with moisture incursion from the tropical Seas causing convective activity.
- An active western disturbance, with presence of a wind discontinuity and confluence of winds in the lower levels.
- Strong vertical wind shear and upper level divergence provided by the jet maximum create conducive conditions for the development of convective cells.

The above listed synoptic features independently or in combination can lead to intense convective activity which can manifest in terms of damaging hailstorms on most of the days.

(*vi*) There is a need for adequate RADAR network in the country to forecast the occurrence of hailstorms over larger areas. Issuing timely warnings and Agromet advisories before and after hailstorm incidence will help the farmers to protect the crop and minimize the loss besides adopting integrated management strategies for early recovery of the crops/trees.

References

Anonymous, 2015, "Agricultural Situation in India", VOL. LXXII May, 2015.

Bal, S. K., Saha, S., Fand, B. B., Singh, N. P., Rane, J. and Minhas, P. S., 2014, "Hailstorms : Causes, Damage and Post-hail management in Agriculture", Technical Bulletin No. 5, National Institute of Abiotic Stress Management, Malegaon, Baramati, Pune, Maharashtra, p44.

Biswas, H. R., Chakrabarti, D., Kore, P. A. and Das, G. K., 2010, "A severe hailstorm over Guwahati airport and its vicinity on 2nd April, 2006 : Synoptic and thermodynamic perspectives", *Mausam*, **61**, 391-400.

Das, G. K., Samui, R. P., Kore, P. A., Siddique, L. A., Biswas, H. R. and Barman, B., 2010, "Climatological and Synoptic aspect of hailstorm over Guwahati airport during pre-monsoon season", *Mausam*, **61**, 3, 383-390.

De, U. S., Dube, R. K. and Prakasa Rao, G. S., 2005, "Extreme Weather events over India in last 100 years", *J. Ind. Geophys*, Union, **9**, 3, 173-187.

Eliot, J., 1898, "Hailstorm in India during the period 1893-1897 with a discussion on their distribution", *Memoirs*, IMD Vol. VI part IV, IMD, Pune.

Gokhale, N. R., 1975, "Hailstorms and hailstone growth", State University, New York Press, Albany, 465pp.

Goswami, B. N., Venugopal, V. D., Sengupta, D., Madhusudan, M. S. and Xavier, P. K., 2006, "Increasing trend of extreme rain events over India in a warming environment", *Science*, **314**, 1442-1445.

India Meteorological Department, 1981-2014, "Disaster Weather Events", National Climate Centre, India Meteorological Department (IMD), Pune.

Mukherjee, A. K., Ghosh, S. K. and Arunachalam, G., 1962, "Hailstorm at Guwahati on 18th March 1961", *Ind. J. Met. Geophys*, **13**, 213-216.

Philip N.M. and Daniel CEF., 1976: "Hailstorms in India", IMD Meteorological Monograph, Climatology No.10

Ramanamurthy, Bh. V., 1983, "Some cloud physical aspects of local severe storms", *Vayu Mandal*, **13**, 3-11.

Ramdas, L. A., Satakopan, V. and Rao, S. G., 1938, "Agricultural meteorology: frequency of days with hailstorms in India", *Indian J. Agri. Sci*., **8**, 787-805.

Rao, V. U. M., Bapuji Rao, B., Sikka, A. K., Subba Rao, A. V. M., Singh, Rajbir and Maheswari, M., 2014, "Hailstorm threat to Indian Agriculture: A historical perspective and future strategies", Technical Bulletin- 01/ 2014, AICRPAM, CRIDA, Hyderabad, p44.

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodness, C. M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., MecIness, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C. and Zhang, X., 2012, "Changes in climate extremes and their impacts on the natural physical environment. in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", [Field, C. B., V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor and P. M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel of Climate Change, 109-230.

Sharma, B. L., 1965, "Radar study of a hailstorm over Guwahati on 17 April 1962", *Indian J. Met. Geophys*, **16**, 459-466.

Suresh, R. and Bhatnagar, A. K., 2004, "Unusual hailstorms during May 2002 in Chennai and its suburbs - A study using data from single Doppler weather Radar", *Mausam*, **55**, 655-670.