CHAPTER 1

Climatology of Hailstorm

Almost everyone at one time or another has seen hailstones. They are large particles of ice which fall out of some thunderstorms. By convention, hail has a diameter of at least 5 mm. on the ground. For aviation purposes, the WMO's technical recommendations define the code GR (from the French word: grêle) for significant hail with diameters of 5 mm or greater, notably to distinguish from other forms of solid precipitation including snow pellets, ice crystals and pellets, snow grains and snow, all related to processes such as freezing of rain or successive melting rather than severe convection (WMO, 2008). In many parts of the world they appear rarely, but in some areas they occur with discouraging regularity. Prominent amongst the unlucky places are the north India and Himalayan region, equatorial Africa, Nigeria, Kenya, eastern and northwestern plains of United states and Canada, southern Europe e.g. north Italy, Southern Germany, France, Spanish plateau, region east of Adratic sea, the Caucasus region, southern Brazile, Northern Argentina and southeastern Australia. In these areas Hailstorms not only occur frequently but also with a violence that beats the crop into ground, strips fruits off trees and causes widespread damage to buildings. Hailstorms are great aviation hazards and in several cases have killed humans on ground.

Hail is the solid precipitation in the form of hard pellets of ice or lumps of ice which fall from cumulonimbus clouds. The pellets are spherical, conical or irregular in shape and often have a structure of concentric layers of alternatively clear and opaque ice. They are variable in size, usually a few millimeters in diameter but sometimes very much bigger. However, among the early documented hailstone accounts of giants, the official U.S record is held by one that fell in Potter, Nebraska, in 1928. It measured 17 inches in circumference and 5.4 inches in diameter and weighed one and half pound. Now there are several recorded evidences of much larger hails. During the storm that produced this giant, hailstones fell with such speed impact that many of them were buried in the ground.

1.1 Geographical Distribution of Hailstorm

Broadly latitudinal zones of hailfalls extend over the globe from equator to about 65^0 lat N and 60^0 lat S; albeit south of 55^0 S very few hailstorm are reported. The farthest polward storm in both the hemespheres is reported at Igarka, Russia, near 67.3^0 N; 90^0 E on afternoon of 28 July 2002 (Cecil and Blankenship, 2012). The wide zone of hailstorm occurrence in both the hemespheres is further modified by continents over which suitable instability is generated in moist warm airmasses containing not too large number of condensation nuclei. Chepovskaya (1966) has summed up the results of many investigations into the occurrence of hail in various regions of the globe. Over Kericho, a hill station in Kenya (east Africa) which is located within 50km from the equator has hailstorms frequency of about once in 3 days almost throughout the year (Sansom - 1971). At stations situated near large water bodies, the frequency of days with hail is approximately half (1/2) to two-third (2/3) to that at stations situated some distance from coast or within 500 km from the coast over oceans. The lesser hail activity near the large water basins and over seas and oceans is attributed to two factors. First one is comparatively meager convective activity due to lower temperature of underlying surface (Lemons 1942), Mason (1957), Pastukh and Sokhrina (1957). Second factor is the presence of considerable number of condensation nuclei (CCN) over the oceanic and coastal regions due to the bursting of sea water bubbles and their release into atmosphere (Sulakvelidze-1967). These condensation nuclie below the 0^0 C isotherm level cause shedding out of most of the water content as rain droplets below the freezing level by condensation and coalescence processes. Brook et al (2003) and Cecil and Blankenship (2012) produced climatology of large hails based on reanalysis of data and passive microwave images respectively. Their results are discussed in separate section in 1.2 for severe hailstorms.

Other than India hail fall is significantly observed over eastern and northwestern plains of USA, Mexico, Canada, western mountains of south American continent, southern Brazile and north Argentina southern Europe, north Italy,southern Germany, France, Spanish plateau, Caucasus region, regions east of Adriatic sea, northern planes of China and central Tibet(Zhang et al, 2008) central, western and south central Africa, Kenya, Negeria, Medagaskar, Armenia, Georgia, Azerbadzhan, Moldavia, Turkmenistan, Ukraine, North Krasnodar (Kabardino), Balkanian SSR, North Osselian SSR, Krasnodar and Stavnopol. Transcaucasia, North Caucasus and also south Kazakhstan, southeastern Australia are places with high frequency of hailfall. Large number of hailfall are reported from the northern region of Indian subcontinent, particularly northeastern India, Bangladesh, northwest India, north Pakistan and north Afghanistan. Annual frequency in this region is highest in the western Himalayan and Tibet region and next highest in the eastern Himalaya region and the mountainous tracts of North-West Frontier Province of Pakistan. It decreases rapidly towards adjoining plains. The coastal tracts of the peninsula are regions where hailstorms are comparatively less.

Surface-based climatology of hailstorms are, however, limited by inconsistencies in observational networks and reporting practices. These generally vary from country to country and also vary with population density within individual countries. Several previous studies have examined climatology from individual countries or groups of countries. Frisby and Sansom (1967), Williams (1973), and Barnes (2001) provide reviews of hailstorm climatology from many countries, but the disparities in reporting between those countries are obvious.

For practical reasons, hail frequency is often quantified in terms of hail days per year for a certain region instead of counting the number of all individual storms. In this definition, a hail day is considered a day when hail occurred anywhere within the reference area. In contrast to hailstorm counts, the specified number of hail days will not increase linearly with the extent of the reference area, as long as the latter is smaller or similar to the extent of hailstreak (refer sec. 1.6 for definition). This makes comparisons of hail day counts for regions of different sizes a difficult task. Due to the variable sizes and shapes of the reference areas considered in the literature, the count of hail days per year at a small reference area like a hailpad seems to be the most convenient measure.

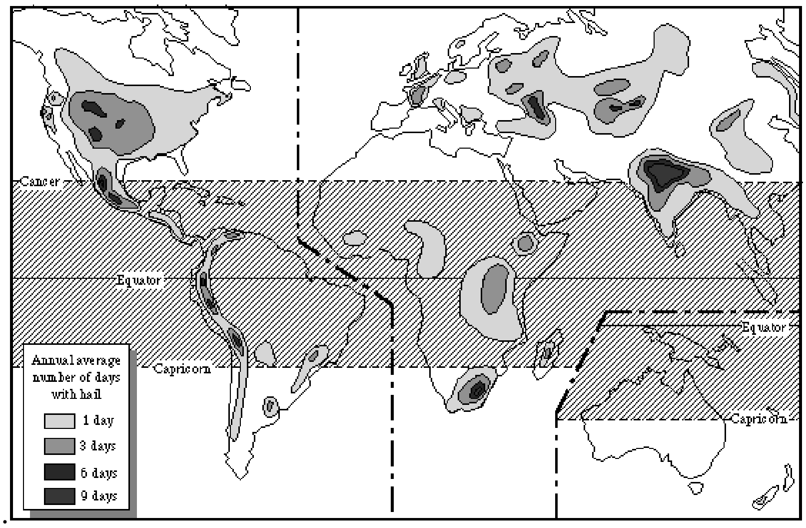


Fig. 1.1 Global map of annual hail days, from Williams (1973), based largely on Frisby and Sansom (1967) based on surface observations.
(Colour plates Pg. No. 351)

Fig. 1.1, by Williams (1973) shows a composite global map based on surface hail data largely by Frisby and Sansom (1967). It highlights mountainous areas that are more prone to graupel or small hail and showers of the large hail. Data collected, was from surface weather stations or hail pads and could be dominated by cases with hailstones ~1 cm in diameter or smaller.

Due to inconsistancies in surface observational network Hand and Cappelluti (2011) prepared global hail climatology based on the 1 Jan 2004 to 31 Dec 2008 data by Convection Diagnostic Procedure (CDP) of U.K. Met Office. Refer Fig. 1.2.

Seasonal hail day densities were calculated by dividing the number of hail days by the total number of possible daily diagnoses. Although CDP has limitation of not being able to dignose large hailstones (≥ 19 mm) it generally exhibits good result on comparing with ground observations.It rightly indicates high hail days over southeast Africa and over Andies during summers and pre summers of southern hemisphere. Absence of hail over India during southwest monsoon months Fig 1.2(c) and during this period high hail days over mid latitudes over Asia and Europe and south west Canada are compatible with the ground observations..

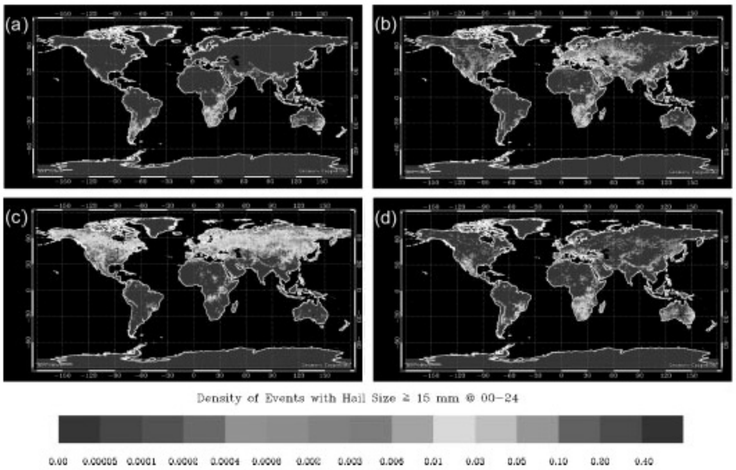


Fig. 1.2 CDP global distribution of seasonwise hail day density for hail size ≥ 15 mm (00 to 24UTC) in 1° × 1° squares. Fig. (a) December/January/February, (b) March/April/May, (c) June/July/August and (d) September/October/November. (Colour Plates Pg. No. 352)

1.2 Global Climatology of Severe Hailstorm

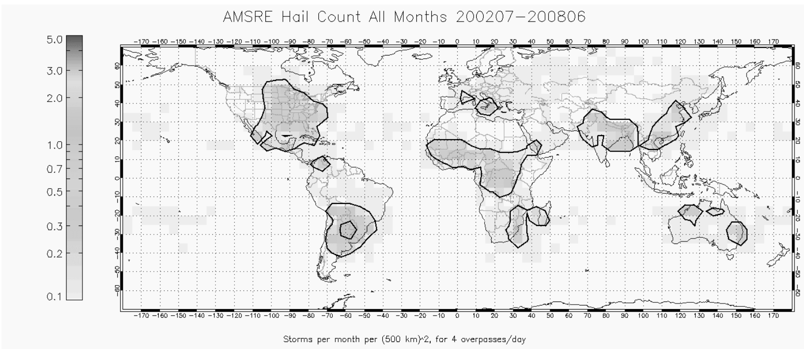
Brook et al (2003) used reanalysis dataset that cover the globe with special grid spacing of 200 km and temporal spacing of six hour from National Centre of Atmospheric Research (NCAR) and Unites States National Centre of Environment Protection (NCEP) for the period of three years (1997 to 1999). The thermodynamic criteria developed by them in eastern United States for large hail (≥ 5 cm in diameter), wind gust (at least 120 kmh^{-1}) or Tornado of at least F2 damage(refer Appendix-B) was applied to globe to estimate the frequency of favourable condition for severe thunderstorm. Albiet the study provided a glimps of global climatology of severe hailstorms but merely three year's data could not be considered enough for the purpose.

Satellite-borne passive microwave radiometers record brightness temperature (refer Appendix-B) depressions due to the scattering of upwelling radiation by large ice hydrometeors (graupel, hail). Cecil and Blankenship (2012) prepared global climatology (Fig.1.3) of storms producing large hail (1-in. diameter, or ~2.5 cm) on eight years data (2003 to 2010) from satellite measurements using Advanced Microwave

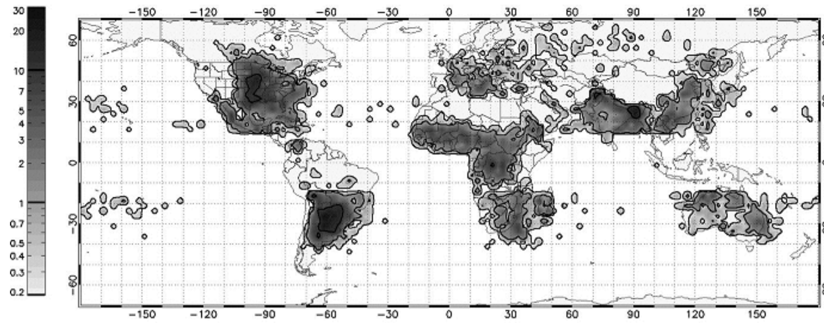
Scanning Radiometer for Earth Observing System (AMSR-E) instrument aboard the Aqua mission, by 36-GHz Polarized Corrected Brightness Temperature (PCT). Their method was compared with ground observations in United States and then it was extended to cover globe with assuming similar conditions.

Although this method provided a giant step towards unique, consistent comparison between regions that cannot be consistently compared using ground-based records because of varying data collection standards but regional variability in the thermodynamic profiles of regions out of U.S. may not be same with those in U.S. Hence a hailstone might be more likely to melt before reaching the surface in tropical Africa or India than in the United States. Also prediction of hailstorm over oceans by satellite borne observation is matter of severe scrutiny. The wavelength of 36 GHz is 8 mm. Half wavelength particle size (e.g. 4 mm) resonates best in this. Hence instead of a very large hailstones an ensemble of many 4 mm hails are likely to present even colder brightness temperatures (BT) which is likely to be mistaken as large hails over oceans. Hence satellite interpretation of hailstorm over ocean or over land where primarily oceanic air mass prevails in any particular season may give incorrect information with respect to occurrence of hailstorms.

Over India thunderstorms do occure but hailstorms are very few during Southwest monsoon season (July to September). This is mainly because oceanic air mass extends over the Indian subcontinent during the southwest monsoon months from July to September. As the southwest monsoon gradually advances from south east to northwest region of south Asia hail observations also incessantly shift westward. Hailstorm activity again increases over Indian region after the withdrawal of southwest monsoon i.e. post monsoon season over India.



(a)



(b)

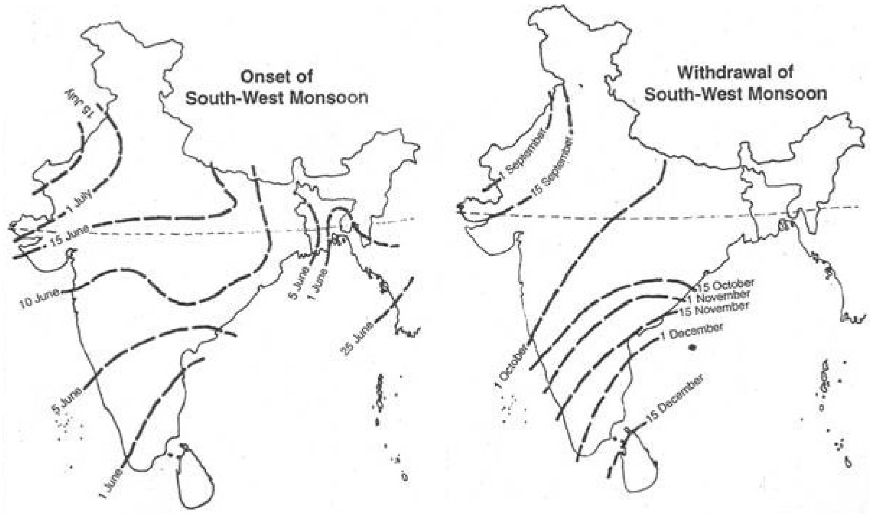
Fig. 1.3 Global climatology of storms producing large hail (1-in. diameter, or ~2.5 cm) on eight years data (2003 to 2010) from satellite measurements using Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) 36 GHz PCT; 500 km^2 per 4 satellite over passes in a day. Scale on left shows (a) storm per month (b) storm per year per.

In Fig. 1.3 severe (hail 1-in. diameter, or ~2.5 cm) hailstorms are indicated most often in a broad region of northern Argentina and southern Paraguay and a smaller region in Bangladesh and eastern India. Numerous hailstorms are also estimated in the central and south-eastern United States, northern Pakistan and north-western India, central and western Africa, and south-eastern Africa (and adjacent waters). Fewer hailstorms are estimated for other regions over land and scattered across subtropical oceans. Very few are estimated in the deep tropics other than in Africa.

The vast majority of potential hailstorms over the oceans are located within a few hundred kilometers of continents. A few are scattered across the open oceans, mostly between ±15° and 35° latitude in the Pacific and North Atlantic. Others are found over regions extending several hundred kilometers east from continents in the ±15°–40° latitude belts (offshore from the United States, Brazil, Uruguay, Argentina, South Africa, Mozambique, Australia, and China). Extension of Hailstorm off shore over the oceans is yet to be regionally validated by ground observation.

1.2.1 Seasonality in Severe Hailstorms

As per Cecil and Blankenship (2012) most continental regions show seasonality with hailstorms peaking in late spring or summer. The southwest monsoon alters the hailstorm climatology around the Indian subcontinent. About 75% of the hailstorms on the eastern side (around Bangladesh) occur from April through June, generally before monsoon onset.



(a) Onset Dates (b) Withdrawal dates

Fig. 1.4 Normal onset and withdrawal dates of southwest monsoon over Indian subcontinent.

Hailstorm activity shifts towards northwestward over northern India as the monsoon gradually advances over Indian region and engulfs entire continent by 15 August. Refer Fig. 1.4(a) for the normal dates of the onset over India. An arc along the foothills in northern Pakistan becomes particularly active from mid-June through mid-August. Details are discussed in sec. 1.4.

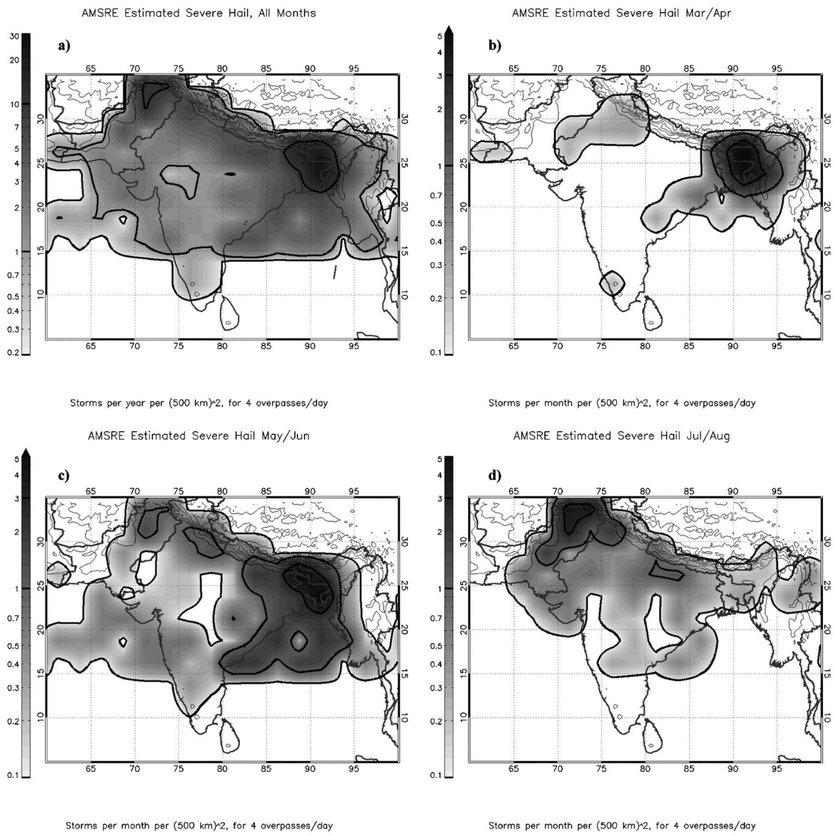


Fig. 1.5 AMSR-E hail climatology near India for (a) annual, (b) March–April, (c) May–June, and (d) July–August. Light contours are elevation, contoured at 1-km intervals.

The South Asian monsoon plays an important role in the distribution of hailstorms from Pakistan to east India. This region has two centers of peak activity (Fig. 1.5a), with the greatest concentrations in Bangladesh and northern Pakistan. During March and April, hailstorm locations are tightly concentrated over Bangladesh and east India (Fig. 1.5b). In May and June (Fig. 1.5c), this region expands to include the northern Bay of Bengal and more of eastern India, including the coasts of Orissa and Andhra Pradesh. Hailstorms begin to occur near the foothills of the Himalayas in northern India and northern Pakistan in late June. By July and August (Fig. 1.5d), northern Pakistan has a large number of hailstorms. This is in conformity with the expected view that hail forms over the region where oceanic salt rich aerosols containing airmass is diluted of its sea salt aerosols by the continental airmass. As during August entire Indian region is having oceanic airmass hail activity is sporadic only. Occasional hailstorms are spread across southeastern Pakistan and the northern half of India. Romatschke et al. (2010) showed a similar shift of deep convective cores from east in the premonsoon season to west during the monsoon.

In most individual years, hailstorm occurrence in and near Bangladesh, begins very near 1 April. The season peaks around 20 May, but it varies by a few weeks from year to year. Storm counts dramatically decrease after about 20 June, presumably with the onset of the monsoon (refer fig. 1.4 for onset dates over India). About 75% of the retrieved hailstorms in and near Bangladesh occur between 1 April and 20 June. Most years have a few hailstorms derived from AMSR-E data in September, but they are rare during July and August. Chowdhury and Banerjee (1983) show a sharp peak in April but with very few hailstorms after May. Frisby and Sansom (1967) list about 90% of the hail days in this region in 1951–60 as occurring during March–May, with a few more in June, and a few more in August–October. With the shift of storm locations from east to west, the region near the foothills in northern India has more storms during June and July. Some years have a concentrated period of 1-3 weeks with several storms. For the entire dataset, about one-third of hailstorms in the region occur between 20 June and 9 July. Almost half occur between 20 June and 29 July. Brightness temperature of ensamble of small hails may give spurious proxy for large solid hails hence is likely to introduce errors in the identification of hailstorm in place of thunderstorm.

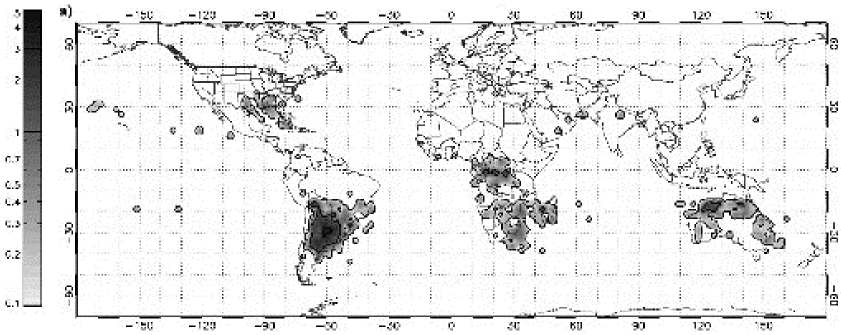
In the global, annual hailstorm climatology (Fig. 1.3b), an area in northern Pakistan (30°–35°N, 70°–75°E) has a higher concentration of storms than any place other than Bangladesh, the central United States, and southeastern South America.

Storm locations show a preference for the foothills, in arcs of foothills from norththwest to north to norththeast. A large number of hailstorms are restricted to a short period, usually from late June to mid-August (plus or minus a couple weeks from year to year). Only 1 out of 79 storms in the AMSR-E database for this region occurred earlier than 9 June. About 75% occurred between 20 June and 18 August. Houze et al. (2007) and Romatschke et al. (2010) describe the meteorological conditions as favoring deep, intense convection in this region: moist southwesterly flow from the Arabian Sea warms while crossing the desert and builds instability under a cap of warm, dry continental air advected from the

Afghan plateau. It is lifted by the terrain, and the concave indentation of the mountain barrier may add low-level convergence.

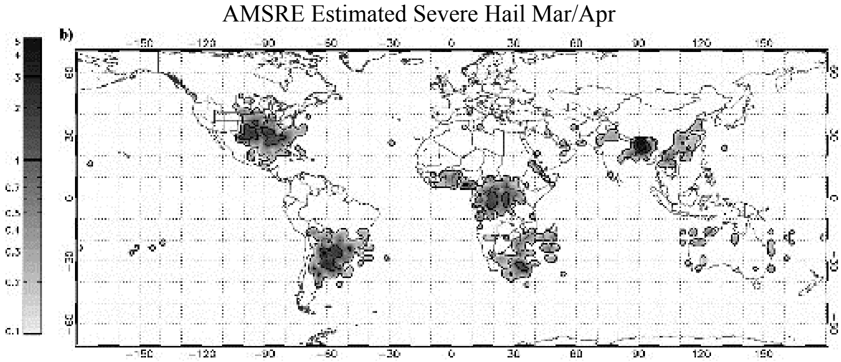
Figure 1.6 shows the global distribution of satellite-inferred severe hailstorms on a 2.5° grid in bimonthly intervals.

AMSRE Estimated Severe Hail Jan/Feb



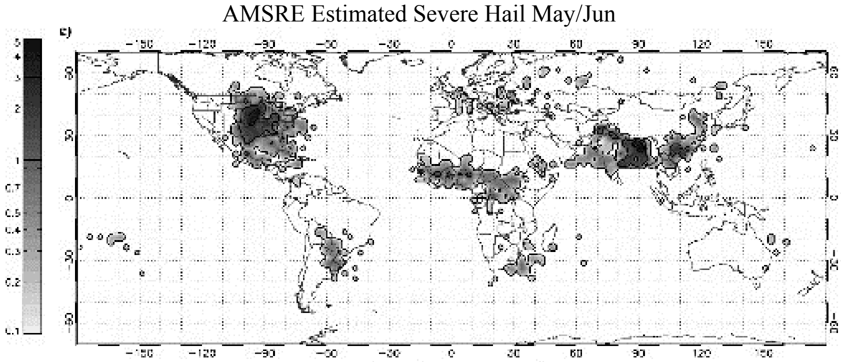
Storms per month per (500 km)–2, for a overposses/day

AMSRE Estimated Severe Hail Mar/Apr



Storms per month per (500 km) = 2, for 4 overposses/day

AMSRE Estimated Severe Hail May/Jun



Storms per month per (500 km)-2, for 4 overposses/day

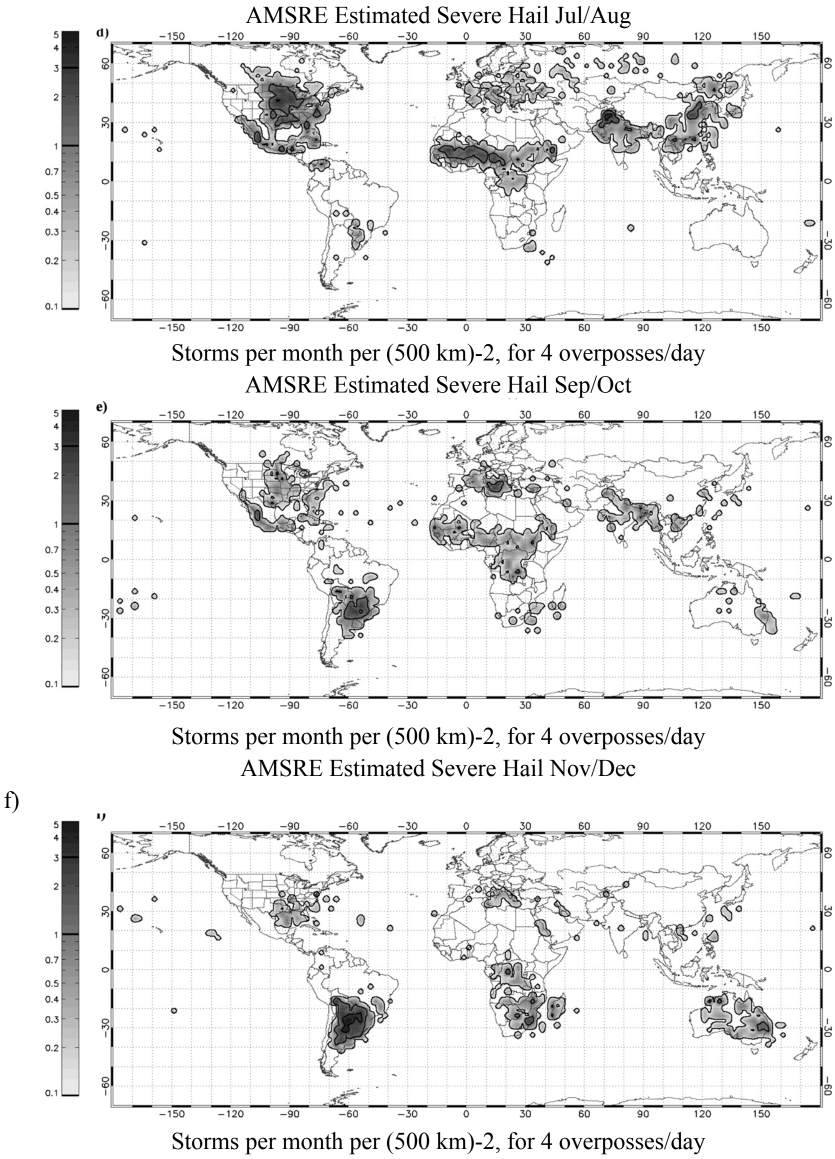


Fig. 1.6 Bimonthly AMSR-E hail climatology for (a) January–February, (b) March–April, (c) May–June, (d) July–August, (e) September–October, and (f) November–December.

The satellite-inferred hailstorms are most common in late spring and summer in particular locations. Tropical Africa has evidence of some hailstorms throughout the year, with the location of the maximum moving north and south following the noontime sun. This leads to seasonal peaks in Northern Hemisphere summer in West Africa and the Sahel Fig. 1.6d), and peaks near the equinoxes in equatorial Africa (Figs. 1.6 b, e). The seasonal peak for southeastern Africa is less pronounced (Figs. 1.6a, b, f), with storms over the offshore waters during much of the year. European activity generally peaks in summer (Fig. 1.6d), but storm counts are greater in autumn for the Mediterranean (Fig. 1.6e). This probably has to do with the Mediterranean Sea remaining warm while cooler air advances from Europe.

Over Australian region hailstorms inferred by AMSR-E are almost entirely during late spring and summer (Figs. 1.6 f, a). The few occurring in early spring tend to be near the east coast (roughly from Brisbane to Sydney), consistent with the result of Schuster et al. (2005), that the hail season extends from October to February in New South Wales and peaks in November–December. The AMSR-E-derived storms in summer cover a broader area, with a peak in the northwest. In East Asia. AMSR-E estimates that springtime hailstorms are concentrated from Thailand to Beijing, with peak activity between Hanoi and Hong Kong (Figs. 1.6b, c). Frisby and Sansom (1967) list several stations in Thailand with hail reports, primarily in March and April. They describe hail observations as rare in Vietnam and Hong Kong. In summer, the AMSR-E-derived storms extend through all of eastern and northeastern China, and into far southeastern Russia. Peak concentration is in the lower Yellow River basin (Fig. 1.6d). Very few storms meet hail criteria in this region after August. Xie et al. (2010) show a strong summer peak in large hail occurrence for northern parts of China, with a spring peak in southwestern China (Guizhou Province). Their data included hail sizes for only four regions in China, with only 6% of hail observations reaching the 2-cm diameter threshold they used to define "severe" hail. The percentage was about twice as large in Guizhou Province as in the northern regions, making it difficult to infer a climatology of large hail from the more general climatology of hail observations in China (Zhang et al. 2008).

North of 40°N across Europe and Asia, the hailstorms are almost entirely during the summer months (Figs. 1.6c,d), except for the aforementioned autumn storms near the Mediterranean. The summer peak in hailstorm frequency at high latitudes is expected and consistent with ground-based studies (e.g., Webb et al. 2001 for Britain; Tuovinen et al. 2009 for Finland). Not much seasonality is seen from the few storms scattered across open ocean regions, well removed from land. There may be a slight preference for autumn (South Pacific in Figs. 1.6b,c; North

Pacific in Fig. 1.6f) and winter (North Pacific in Fig. 1.6a). When vigorous extratropical troughs penetrate the subtropics and tropics in these seasons, they occasionally provide a favorable combination of dynamic support and thermodynamic instability over the relatively warm waters.

Southeastern South America has a broader region of frequent hailstorms, centered on northeastern Argentina and southern Paraguay. The peak in the concentration from AMSR-E is in the Chaco state of northern Argentina. Matsudo and Salio (2010) place the hail maximum farther southwest, based on reports at conventional surface weather stations in Argentina from 2000 to 2005. In early spring, the common storm locations according to AMSR-E center on southeastern Paraguay and extend into adjoining parts of southern Brazil and northeastern Argentina. Late spring and early summer have the most hailstorms, and the most active region extends from Bolivia and southern Brazil southward across Paraguay, Uruguay, and northern Argentina to about Santa Rosa in the state of La Pampa. No particular location has as high a concentration of storms as premonsoon Bangladesh, but the South American active region covers a much broader area. Further into summer, the center of activity shifts a bit southwestward and fewer storms are found in Brazil. Storm counts decrease in autumn and winter, with locations shifting toward the eastern side of the La Plata basin (Uruguay to eastern Paraguay) by midwinter (Fig. 1.6d).

In North America, winter (Fig. 1.6a) and early spring hailstorms are most common over the Gulf of Mexico and Gulf Coast states. By late spring, the hailstorm region extends into southern Canada and covers most of the United States east of the Rocky Mountains and south or west of New England. The highest concentrations in our AMSR-E sample are from Oklahoma to Iowa. A broad maximum centered on Iowa covers the midwestern United States by summer. Storm counts decrease in autumn (Fig. 1.6e) and are mostly limited to the southeastern United States for late autumn and winter (Figs. 1.6f,a).

1.2.2 Diurnal Variation Severe Hailstorms

Fig. 1.7 shows diurnal variation in severe hailstorm for five geographical regions e.g United States, southeast South America, central Africa, Pakistan, and Bangladesh. All five regions have minima between sunrise and 1200 LST and have maxima between 1500 and 2100 LST. Regionwise details of diurnal variability in India is described in separate chapters devoted for the Indian regions in this book. The southeastern South American (broadly defined in this subsection as 18°–38°S, 72°–52°W) grouping actually has a broad peak between 1500 and 2400 LST, with a little more than half its storms during those 9 h. The other regions have a rapid decrease in storm counts after 9:00 p.m. A disproportionate share of the southeastern South American storms are horizontally extensive, mature MCSs, lasting well into the night.

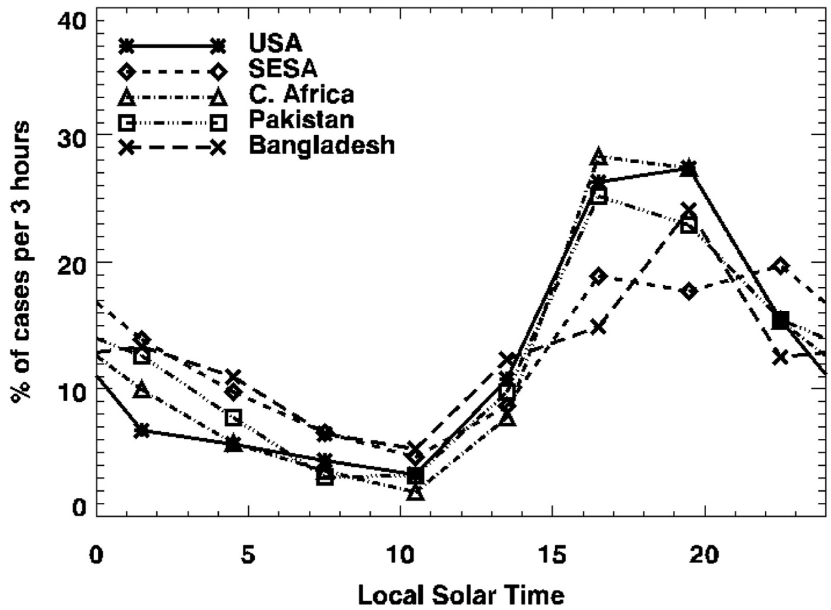


Fig. 1.7 Percentage of TMI-estimated hail cases in 3-h increments of LST for south central/southeastern United States, southeast South America, central Africa, Pakistan, and Bangladesh.

Ground-based hail reports from Chowdhury and Banerjee (1983) show a sharper afternoon peak for Bangladesh, between 1400 and 1800 LST. The diurnal cycle of Bangladesh's severe thunderstorms from Yamane et al. (2010) is more consistent with a peak occurrence between 2000 and 2100 and several still occurring after 2400 LST.

The diurnal curves for the United States (30°–38°N, 108°–80°W), central and West Africa (10°S–18°N, 20°W–40°E), and Pakistan (22°–38°N, 64°–76°E) are very similar to each other, with more than

50% of storms occurring between 1500 and 2100 LST and less than 10% between 0600 and 1200 LST. Pakistan has a smaller fraction during late afternoon than the United States and central and West Africa, and more between midnight and sunrise.

To put the AMSR-E observations into a diurnal context, (Cecil and Blankenship, 2012) also gridded and mapped the percentage of Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) derived hailstorms occurring between 0000 and 0300 and between 1200 and 1500 LST (not shown). As per them analysis, along with Fig.1.7, suggests that AMSR-E likely overestimates the number of hailstorms in the Bangladesh, Pakistan, and southeastern South American regions compared to the United States and central and West Africa. AMSR-E's diurnal sampling may underestimate the number of severe hailstorms in the central United States by ~20%–50%. That being said, a global (tropics and subtropics) climatology derived from TMI instead of AMSR-E also suggests Bangladesh and southeastern South America have more hailstorms per year than the other regions (equatorward of 38°).

1.3 Regional Climatology of Hailstorms

For regional hail climatology a few regions on globe are selected which represent diverse climate and geography. Hail climatology of Indian regions are covered in detail in other chapers of this book.

1.3.1 Canada

Average number of hail days per year, based on the 1951-1980 climate normals (Environment Canada, 1987) are shown in Fig. 1.8. The highest hail frequencies occur in interior British Columbia and Alberta. In British Columbia, the largest hail frequencies occur just northwest and northeast of Williams Lake, most likely as a result of a combination of daytime heating of the interior valley combined with upslope flow along the mountains adjacent to the valley.

In Alberta, the largest frequencies occur just east of the Rockies. A series of maxima and minima appear well correlated with topography, with the minima along the river valleys and the maxima over higher terrain.

Fig. 1.8 Average number of hail days per year, based on the 1951 – 1980 climate normals (Environment Canada, 1987). The contours were hand drawn, based primarily upon about 350 weather stations. Some secondary climate station data was included in a subjective way, but not documented (Etkin, D and Brun, 2001).

1.3.2 United States

Average annual number of hail days based on data from 1901 to 1994 are shown in fig 1.9. Major high hail frequency areas are in the Rocky Mountains and the northwest Pacific Coast, and the lowest frequencies are in the nation's southwest and southeast regions.The key aspect of the nation's hail pattern is the considerable spatial variability across the nation and in most states. The national frequency varies from less than one hail day per year along most of the East Coast and parts of the desert southwest, to more than five hail days annually in the mountains of Colorado and Wyoming and along the Pacific North west coast.

Fig.1.9 Average annual number of hail days based on data from 1901 to 1994 (from thunderstorms across the nation: An atlas of storms, hail and their damages in 20th century Copyright 2001 Stanley A, Changnon).

Several relatively high incidence areas are in and along the Rocky Mountains due to orographic effects. The Deep South and Gulf Coast have many thunderstorms but there is very little hail at the surface there because the descending hailstones melt in the high air temperatures below the cloud base and become rain drops. The highest frequencies are in areas extending from eastern Colorado into the Midwest, and in scattered locations in the northern Rockies and in the Pacific Northwest. In summer (June- August) the national pattern shows that the highest hail averages are in the Rockies, extending from Montana south into New Mexico. Orographically-induced hailstorms often develop along the front range of the Rocky Mountains.Due to the shape of the mountains, some areas are favored for storm development, and these result in paths of hailstorms that stretch eastward into the Dakotas, Nebraska, and Kansas. Summer hail is most frequent in June, decreasing in July, and becoming the least frequent in August. Hail in summer is very infrequent (0.1, or once in 10 years) in the Deep South and along the West Coast. The fall average hail-day pattern shows a few small moderate high hail days along the front range of the Rockies. The largest hail values exist along the Pacific Coast in Washington and Oregon, and in areas downwind of the Great Lakes. Pacific storms in the fall and winter frequently create small hailstones, leading to a 10 hail day annual average along the Washington coast.

1.3.3 South America

Hailstorms are generally observed over Southeastern South America mostly centered over northeastern Argentina and southern Paraguay. Argentina is, relatively highest risk zone of hailfall in south America.Therefore, a detailed climatology of hailstorm over Argentina is being discussed hereunder.

Based on data during the 1960–2008 regions lying between 30° and 40°S as well as those dominated by mountains present the highest hail frequencies in Argentina. Refer Fig. 1.10. The eastern and coastal areas of the country experience hail events mainly during springtime but they may start in late winter and continue through the beginning of summer. Events in western and central Argentina also predominate in spring but the maximum frequencies are observed during summer months.

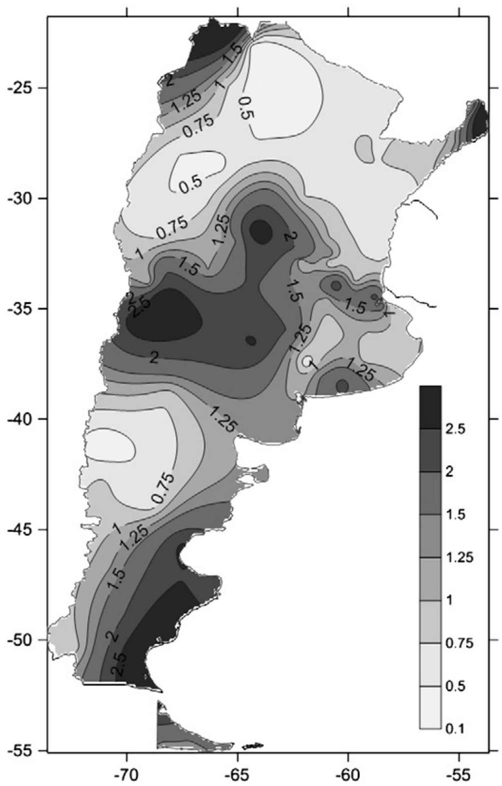


Fig.1.10 Mean annual hail events.

Trends in the annual number of hail events calculated for each region indicate that events in northwestern and northeastern Argentina have been increasing as well as in southern Patagonia. On the other hand, in central Argentina, southern Buenos Aires–La Pampa, northern Buenos Aires–Litoral and northern Patagonia trends are negative and statistically significant in the first two regions, basically by the decrease of events during spring and summer.

1.3.4 Africa

Mean annual hail frequency over Africa is shown in Fig. 1.11. In general hailstorms are observed from 10^0 N to farsouth over the African continent but high frequency (> 5 per year) are observed over central Ethopia, Kenya, Rawandi, Burundi, Tanzania in west central Africa and and over eastern south Africa and Lesotho region in the mainland. Central Medagasear Island also records (> 5 per year) hail frequency. All these high frequency zone fall over high topographic region of eastern and south eastern Africa. Over Kericho, a hill station in Kenya (east Africa) which is located within 50km from the equator has hailstorms frequency of about once in 3 days almost throughout the year (Sansom 1971).

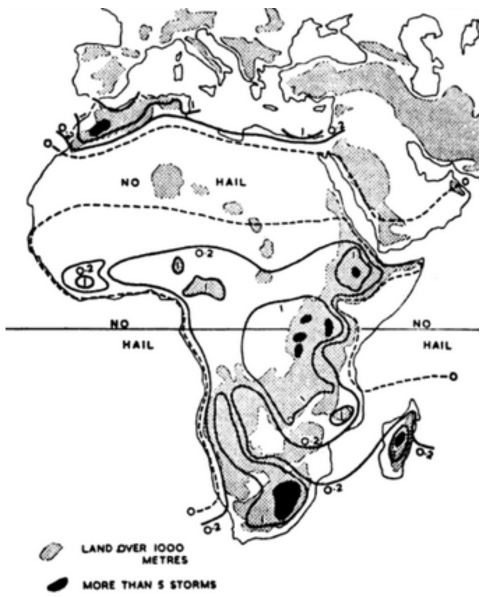


Fig. 1.11 Mean annual hail frequency over africa (sansom 1966).

(Narayan R. Gokhale. Hailstorms and Hailstone Growth, SUNY Press, 01-Jan-1975 - Hail - 465 pages)

More recently Le Roux and Oliver (1996) compiled hailday frequency based on 113 recording stations in South Africa, Lesotho and Swaziland as shown in Fig. 1.12.

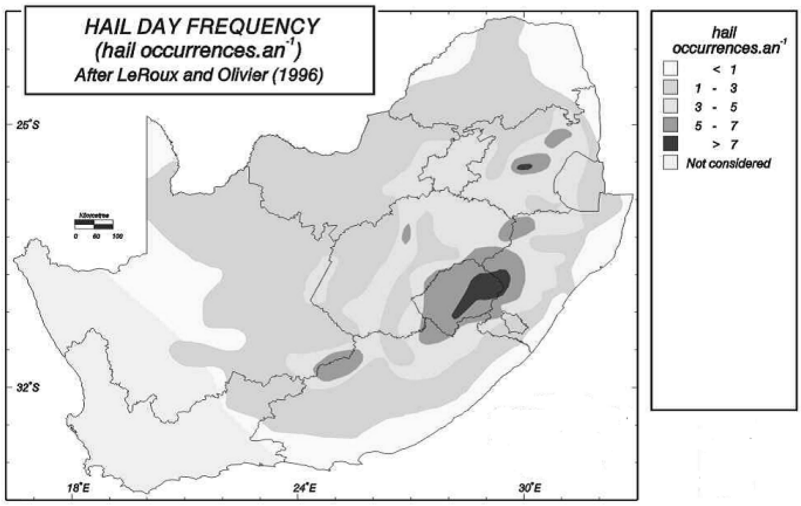


Fig. 1.12 Hail days per annum based on South African Weather Weather Bureau, 1986 from 113 recording stations in South Africa, Lesotho and Swaziland.(Le Roux and Oliver, 1996)

It indicates that at higher latitudes (> 32°S), HDF (Hail Days Frequency) increases with altitude. Between 26° and 32°S, HDF appears to increase rapidly up to altitudes of 600 m and then again between 1000-1500 m. In the subtropical regions at latitudes below 26 °S, the increase in HDF is again more or less linear with altitude, but it decreases above 1700 m.

1.3.5 Europe

In the central Eurpe (Germany, Switzerland, and Austria, it can be assumed that hail frequency decreases from west to east and from south to north. Western Europe is mainly influenced by the proximity to the Atlantic Ocean, which leads to higher static stability due to the damped diurnal and seasonal temperature amplitude. Thus, hail frequency varies substantially in Western Europe (Punge et al., 2014). Refer Fig. 1.13. France is frequently affected by severe hailstorms, hail occurs rarely in Benelux (Belgium, the Netherlands, and Luxembourg) and the British Isles.

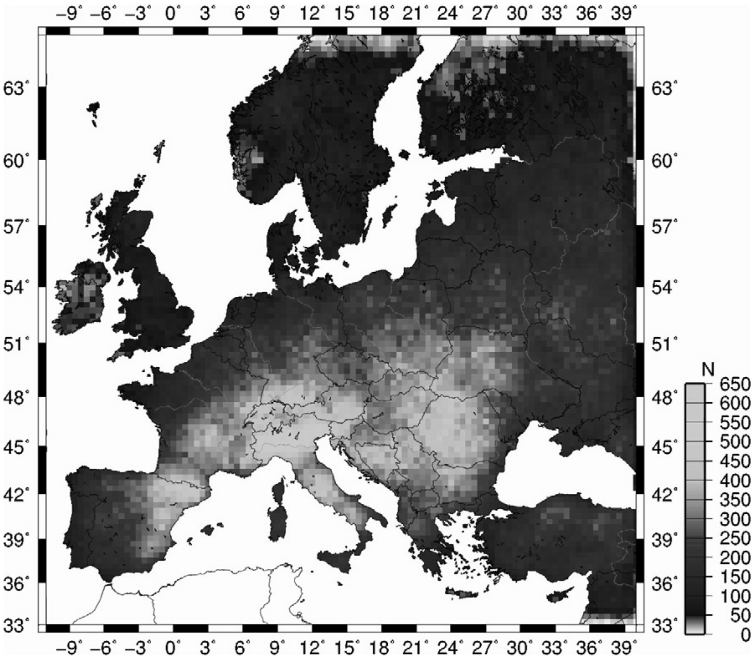


Fig. 1.13 Hail event frequency as estimated by Punge et al. (2014). (Colour plates Pg. No. 351)

In contrast, these latter regions are characterized by a high density of low pressure systems and associated fronts, and hence convective storms generating graupel or small hail occur quite frequently and throughout the year. The climate of Southern Europe including Italy and the Iberian Peninsular is dominated by the high insolation and proximity to the Mediterranean, where warm and moist air masses are advected from S to W directions. A few regions, such as northern Italy, feature some of the highest hail frequency in Europe (e.g., Punge et al., 2014). In Southeastern Europe, including the countries of Romania, Moldova, Bulgaria, Greece, Turkey, Cyprus, and those of the Balkan Peninsular, the general climate is strongly influenced by the Mediterranean and – for the eastern part – by the Black Sea. Hail occurs frequently at several hot spots, for example in the NWof Romania. However, only limited scientific literature is available, mainly based on hail observations at meteorological stations, which may also include ice pellets or graupel. In Northern Europe, hail is less common compared to most other parts of Europe, mainly due to the prevailing colder climate. In addition, the proximity to the seas, especially to the cool North Atlantic, inhibits strong convective activity. This applies especially for large hail. By contrast, ice pellets or graupel occur quite frequently and throughout the whole year, dominating in several cases the statistics, similar to the situation of the British Isles. Hail is a major peril in Russia, affecting around 5000 km^2 of agricultural area each year (Abshaev and Malkarova, 2006). The Northern Caucasus is sometimes considered the region with the highest hail hazard in Eastern Europe (e.g., Abshaev et al., 2003). Malkarova (2011) found natural crop loss ratios of 2.5% in Crimea and 4.4% in the region of Odessa (Ukraine), but more than 6% for the provinces in the N Caucasus. According to Abshaev et al. (2009), the loss ratio in agriculture exceeds 8% over several parts of the Caucasus foothills, and 2% everywhere over the foothills. These ratios are in the range of those found for other highly exposed countries such as N Italy or NE Spain. A map of hail frequency in Russia based on station data from1958 to 2008 (Abshaev et al., 2009) shows more than two hail days per year and station over the N Caucasus but also in Western Russia and the Voronezh Oblast, and several regions in the Asian part. The pattern matches relatively well with those estimated by Williams (1973). Most of the European part of Russia south of 62° N experiences around 1-2 hail days per year. Out of 40–50 hail days per year in the Southern Federal District of Russia (418,500 km^2), 5–6 lead to widespread ‘emergency’ damage (Abshaev and Malkarova, 2002; Abshaev et al., 2006). Point hail day frequencies in S Russia and the N Caucasus reach from 0.5 for the dry steppe, to 0.5–1 for the plain, 1 at the Black Sea coast, and finally 1–2 in the Central N foothills of the Caucasus (Abshaev et al., 2012). The 8 stations in the NW Caucasus flat-to-hilly district of Krasnodar had hail frequencies of about 1.1 on average (Malkarova, 2011).

1.3.6 China

Based on 1961 to 2005 data (Fig. 1.14) hail occurs most frequently in the high mountainous areas and northern plains. As a result, hail frequency is generally higher in northern China than in southern China. The hail frequency is highest over the central Tibetan Plateau. Hail seasons start in late spring and end in early autumn in northern and western China; they start mainly in spring in southern and southwestern China. On the diurnal time scale, hail events occur mainly between 1500 and 2000 local time in most of China except in Guizhou and Hubei Provinces (central western China), where hail events often occur during nighttime.

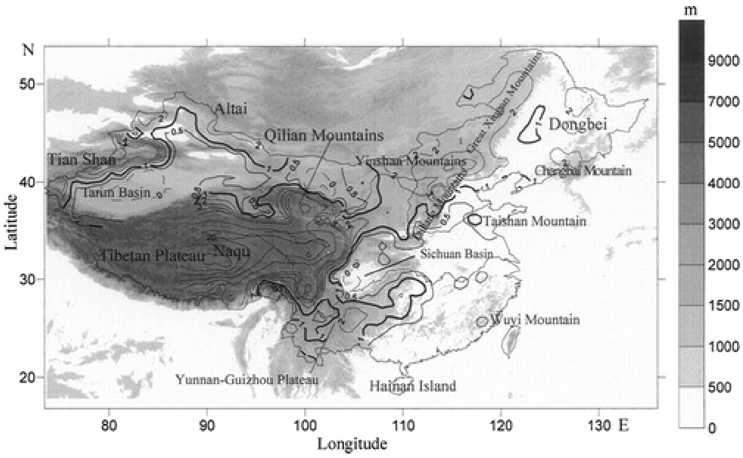


Fig. 1.14 The geographical distribution of mean annual hail frequency in China during 1961–2005. The contour interval is 0 (dashed line), 0.5, 1 (thick line), 2, 3. . . . Terrain is shaded, with scale bar on the right (m).

1.3.7 Australia

Total number of hail days based on grid at 0.5° for period 1998 to 2012 are shown in Fig. 1.15.

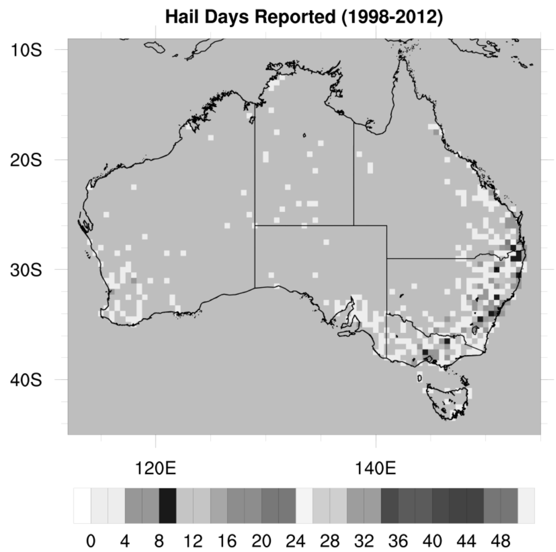


Fig. 1.15 Total number of reported hail days per grid cell (1998-2012). Australia Bureau of Meteorology: Severe Storms Archive. [http://www.bom.gov.au/Australia/stormarchive/] (Colour Plates Pg. No. 353)

The vast majority of reports occur along the southeast coast, where most of the population resides e.g south eastern South Australia, Victoria, South eastern Newsouth wales and adjoining southeastern Queens land. Major cities can be identified by local maxima in hail days. The grid cells containing Sydney and Brisbane both report about 3 days per year on average. South western region of Western Australia and Northern Territory also experiences sporadic hailstorms.

1.4 Hailstorms over India

In the Indian Meteorological Memoirs, Vol VI, Part 6, Sir John Eliot discussed the hailstorms which occurred in India during the period 1883-97. The data used in the above discussion consisted of reports of hailstorms communicated to Meteorological office by Collectors of districts, particularly during the period 1893-97, when special efforts were made by Sir John Eliot to collect a large amount of information. Most of these reports were fairly detailed as they were intended primarily for purpose of revenue assessment. They contained information of great value and interest regarding the intensity, extent and damaging effect on crops of the several hailstorms. The discussion of these data is the first attempt to study the occurrence of hailstorms over India. Based on Eliot's data Ramdas et al (1938) compiled the annual and monthly hailstorm frequency. Using the data based on 10 years report from 1957-1966, Philips and Daniel (1976) again presented monthly and annual charts showing the average number of hailstorms over India. As per their figures which exclude Pakistan, Bangladesh, Srilanka and Burma, the annual frequency of hailstorms is highest in the Assam valley, followed by Uttaranchal, Jharkhand and Vidarbha in the eastern parts of Maharashtra.

In the extreme North-East of the Assam Valley (Fig. 1.16(a)) Dibrugarh has an average of about 15 occasions. Other regions where high incidences of hailstorms are reported are the states of Tripura, the Uttaranchal and Jharkhand with about 6 occasions each. Since for each station considered the number of years of data were not same, Philips and Daniel (1976) converted their results into frequency of days with hailstorms during 100 years. Taking the year as a whole we find that the annual frequency is up to ten per year over the western Himalayan region, and up to five per year over the Eastern Himalayan region and the mountains tracts of the North-West Frontier Province; this decreases rapidly to once in two years over the adjoining plains. Over Gangetic West Bengal a hailstorm is usual once a year. The area consisting of the

Madhya Pradesh and the adjoining districts of Jharkhand, Bihar and the Utter Pradesh forms another centre of frequency of the order of once a year.

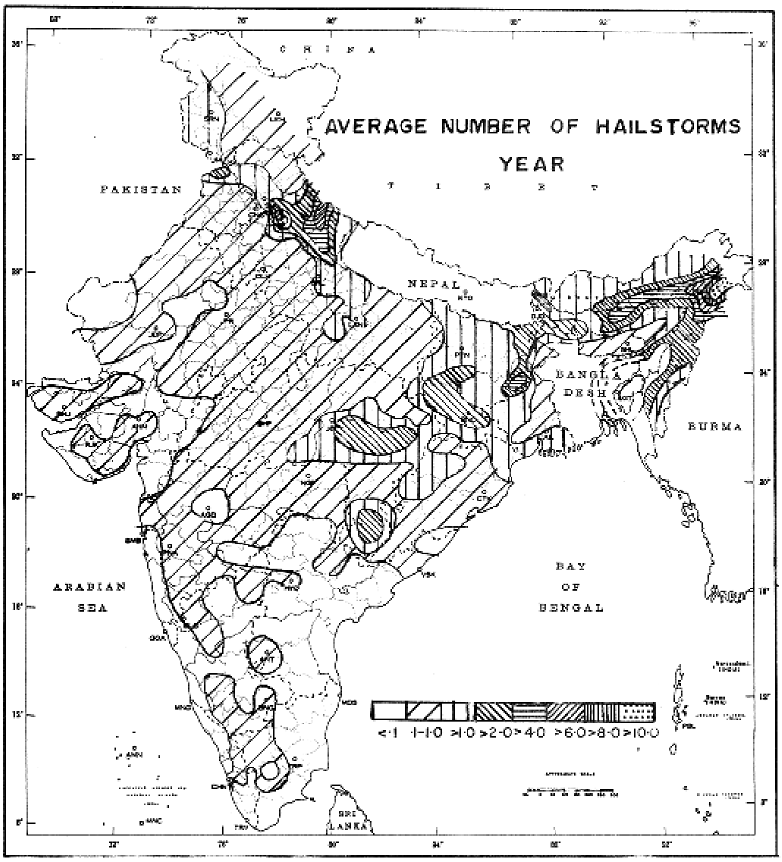


Fig. 1.16(a) Philips and Daniel (1976).

Philips and Daniel (1976) had made quite a detailed presentation of climatology of hailstorm. Due to lucidity of their presentation many recent authors (De et al, 2005; Ramesh, 2009) still refer to their climatological report. More recent statistics with respect to hailstorms based on 30 years data collected during 1961-1990 by the National Data Centre of India Meteorological Department was analysed by the author. Annual frequency of hailstorm based on these data is presented in figure 1.16(b). Frequency lines have been drawn at the interval of 0.1. But over northwestern and northeastern regions, due to strong gradient, isolines at the intervals of 0.2 or 0.4 or higher have also been drawn to avoid congestion.

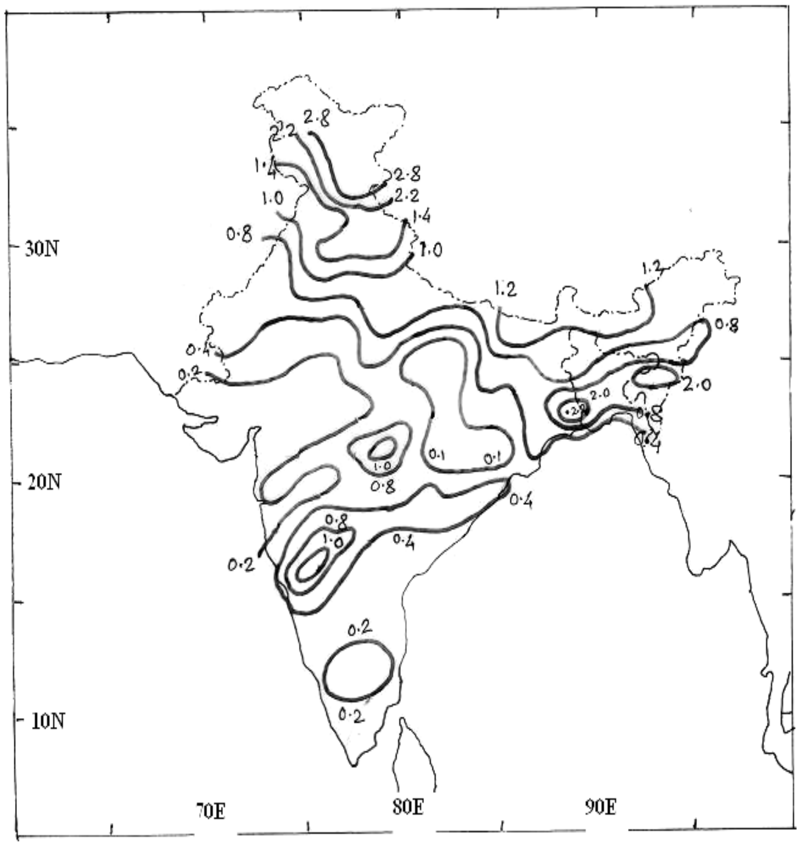


Fig. 1.16(b) Annual frequency of occurrence of hailstorm based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Comparison of Figs. 1.16(a) and 1.16(b) shows more or less the same pattern except for the North-East India. In figure 1.16(a) High Frequency Hailstorm Zone (HFHZ) in North-East is broadly confined to the north eastern Assam and adjoining Arunanchal Pradesh region whereas in Fig. 1.16(b) the region of high frequency is shown over south Assam and adjoining Mezoram region. A similar southward shift of HFHZ could be noticed over West Bengal where in Fig. 1.16(a) it is located on the foothills of Himalaya and in Fig. 1.16(b) it is shifted to the Gangetic West Bengal.

1.5 Seasonal Variation of Hailstorm in India

Over India, Philip and Daniel (1976) followed by Mishra and Prasad (1980) reported that north of 30°N during the month of December, January and February on 25% to 40% occasions thunderstorms may be associated with hailstorms. Frequency of hailstorm days in a month per thunderstorms days in a month (i.e. N = number of days of hailstorms/ Number of days of thunderstorms) are shown in Figs.1.17(a), (b), below.

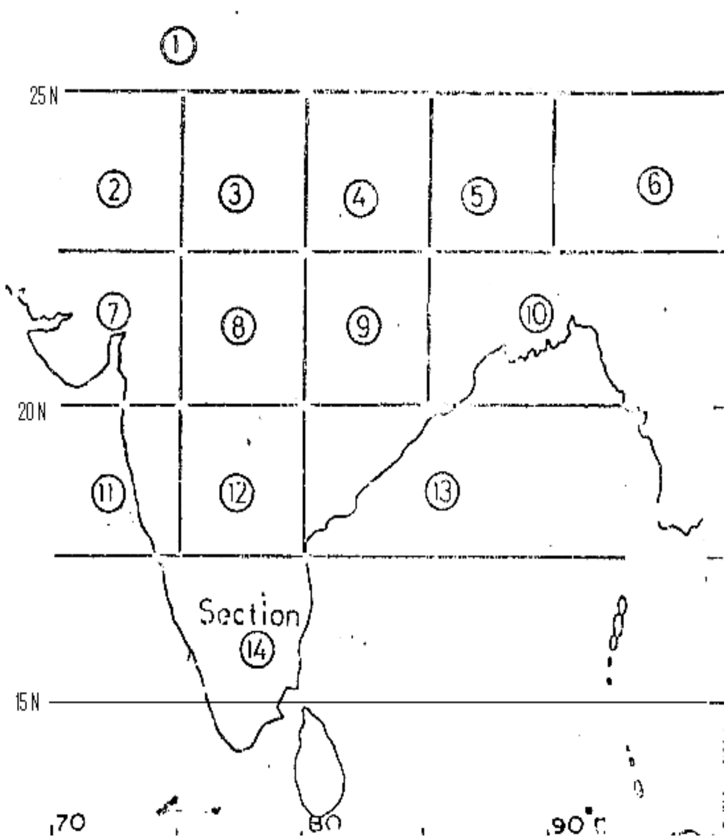


Fig. 1.17(a) Regions are marked by numbers.

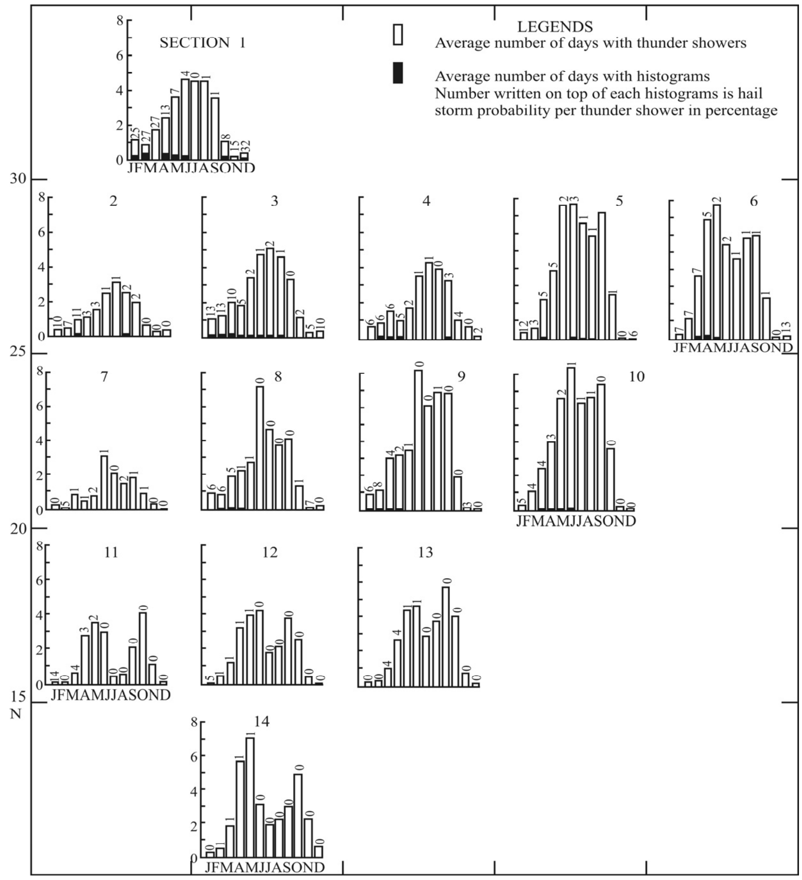


Fig.1.17(b) Histograms for each region by Mishra and Prasad (1980) showing frequency of hailstorm days in a month per thunderstorms days in a month (i.e., N= number of days of hailstorms/ Number of days of thunderstorms).

Remarkable coincidence is indicated by the seasonal and regional frequency of hailstorms with the presence of Jet stream above the thunderstorms. It may be inferred that Jet stream works as a ventilator for the latent heat of fusion to get out of the thunderstorm so as to prevent melting back of the ice-crystals already formed.

In this chapter previous monthly climatology compiled by Ramdas et al (1938) based on data collected during 1883-1897(15 years), for India, Pakistan, Bangladesh and Burma and by Philips and Daniel (1976), based on data collected during 1957-66 (10 years) have been presented on the same maps and the climatology based on the latest data collected during 1961-90 (30 years) has been put on separate maps for comparision.

Figs. 1.18(a) to 1.19(a) are maps showing the frequency of days with hailstorms based on Ramdas et al (1938), as the **isolines of frequency of days of hailstorms in 100 years** for each month of the year and also data compiled by Philips and Daniel (1976), as the hatched region for **average number of hailstorms each month** of the year. Details regarding the frequency intervals, at which Ramdas et al (1938) isolines have been drawn, are indicated in the maps. Month-wise climatology based on the recent data during 1961-1990 by the National Data Centre of India Meteorological Department and analysed by the author are presented in figures 1.18(a) to 1.19(b).

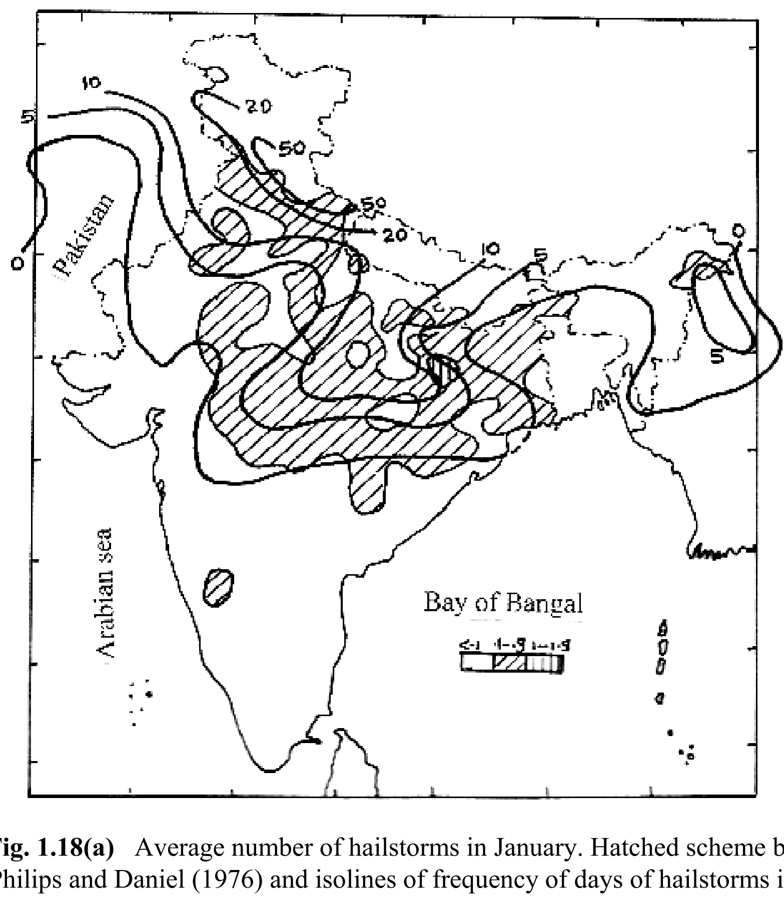


Fig. 1.18(a) Average number of hailstorms in January. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

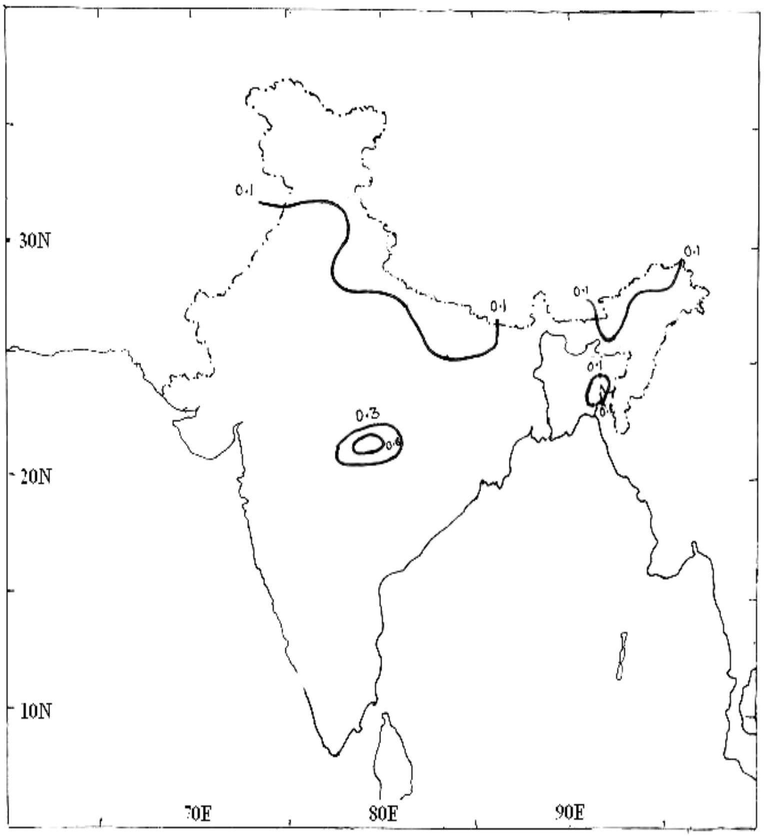


Fig. 1.18(b) Frequency of occurrence of hailstorm in January based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Comparison of Figs. 1.18(a) and 1.18(b) also reveal gradual decrease in the hailstorm frequency in general. Also hailstorm region have shifted closure to the foothills and northern Gangetic plains. Central Madhya Pradesh emerges as the HFHZ during January month.

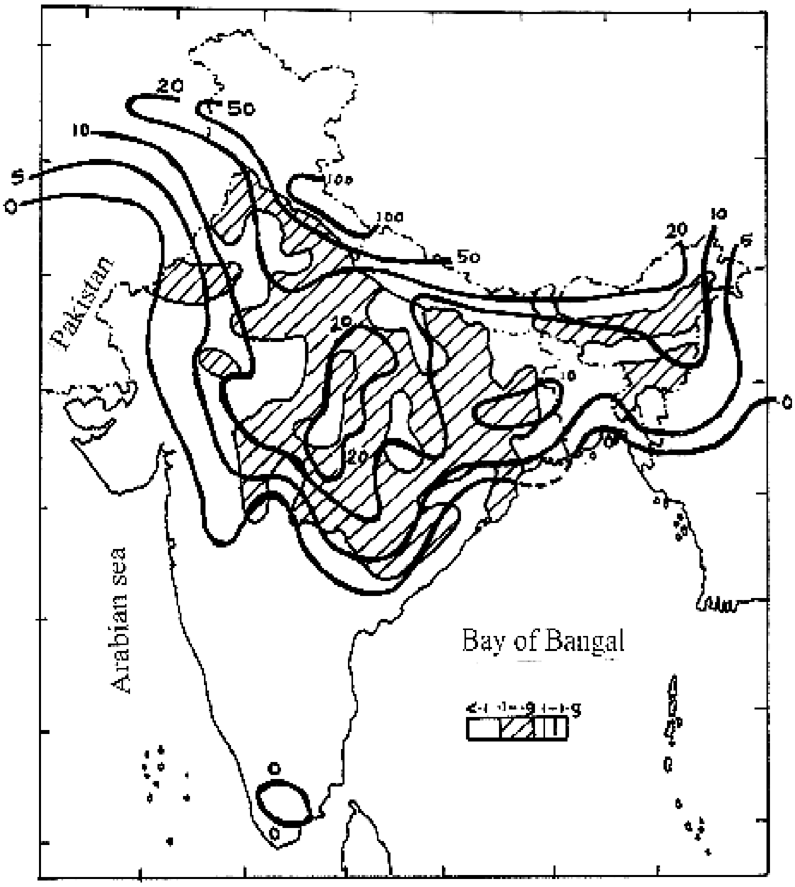


Fig. 1.19(a) Average number of hailstorms in February. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

Comparison of Figs. 1.19(a) and 1.19(b) also reveal that relatively high frequency of hail over foothills of Himanchal Pradesh, Punjab and Haryana region persists. But region of hailstorms over the central India has drastically shrunk. South-West shift of HFHZ over northeast India from north Assam and Arunanchal Pradesh to south Assam and adjoining Tripura region may also be noticed.

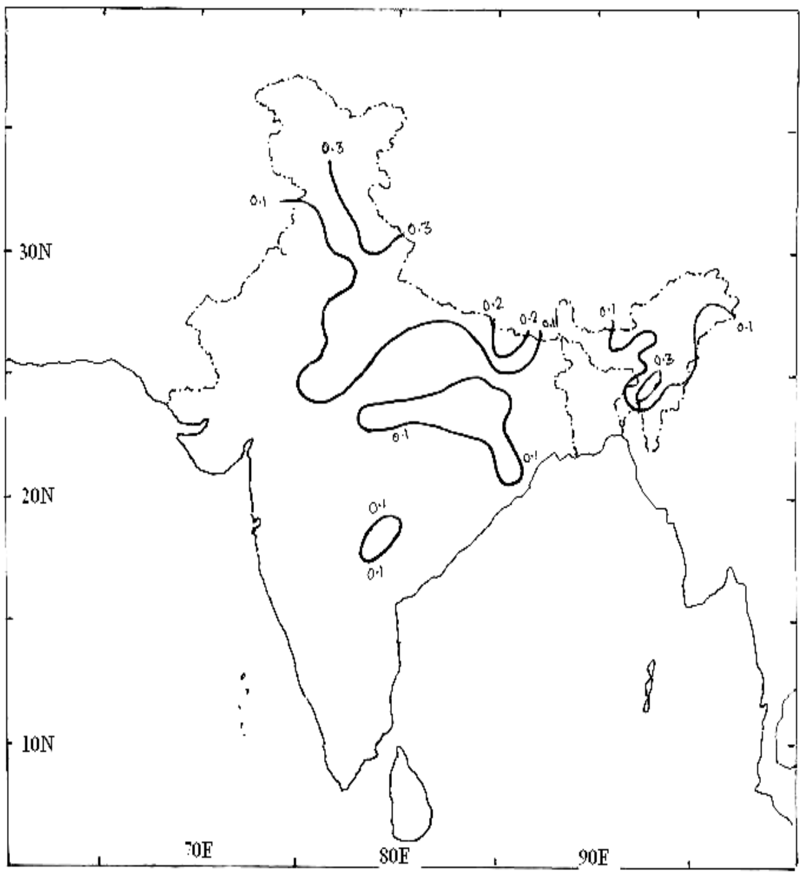


Fig. 1.19(b) Frequency of occurrence of hailstorm in February based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

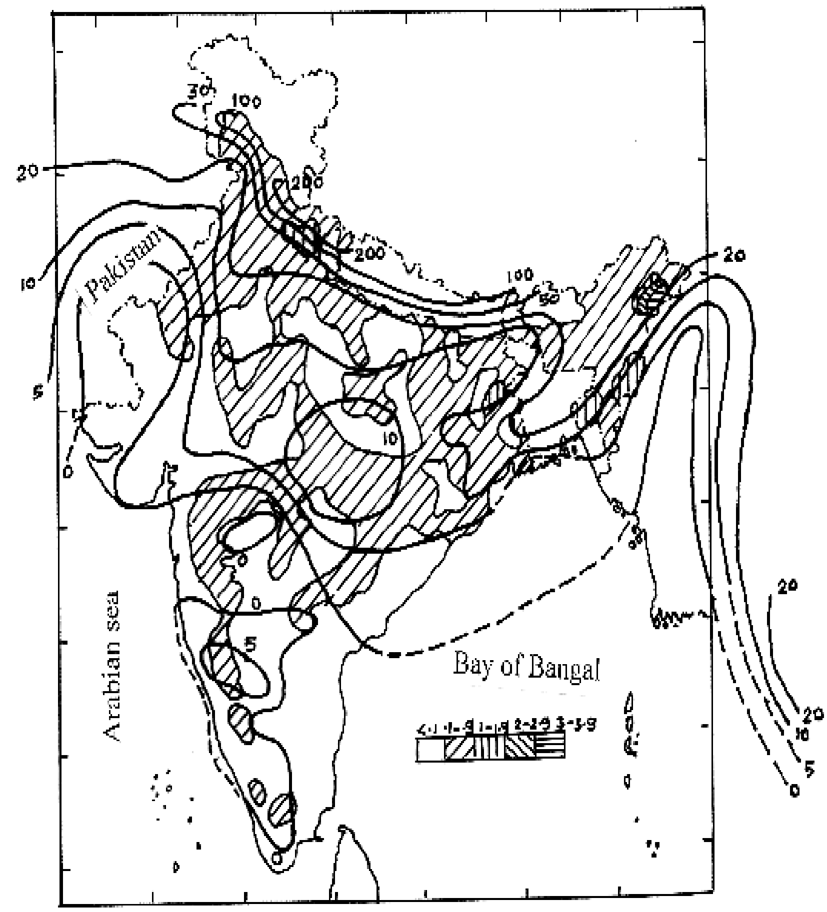


Fig. 1.20(a) Average number of hailstorms in March. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

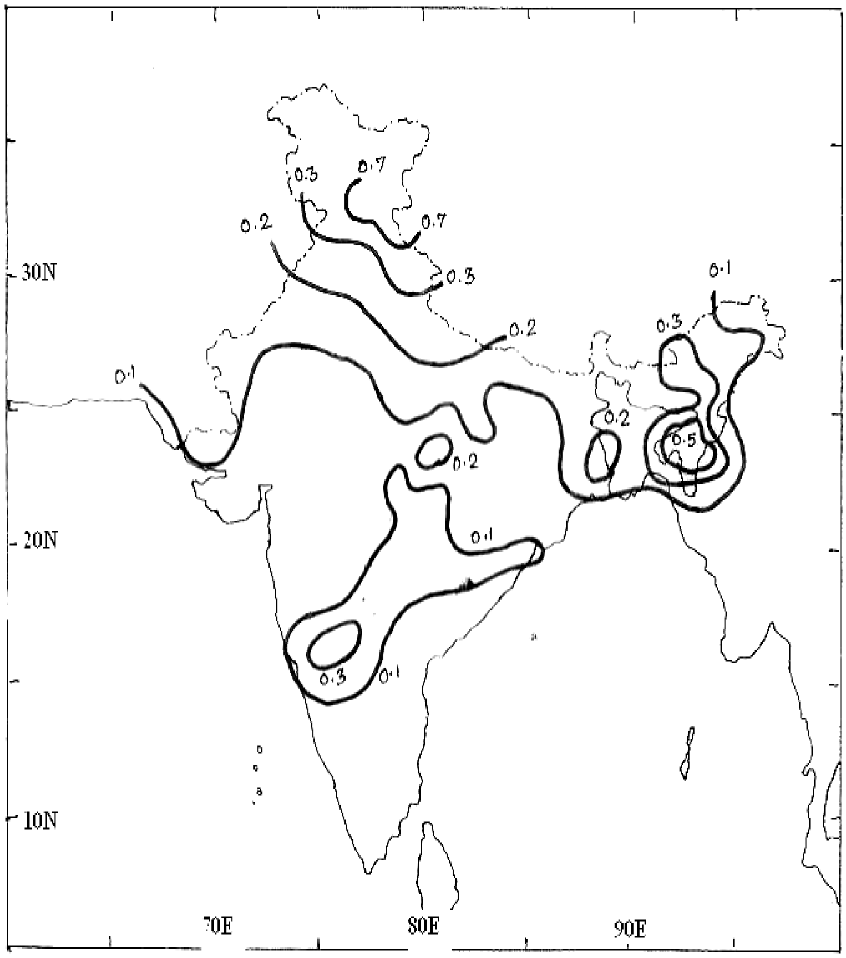


Fig. 1.20(b) Frequency of occurrence of hailstorm in March based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Comparison of figures 1.20(a) and 1.20(b) show marked decrease in the hailstorms over the central Himalayas. High frequency of hailstorms over northeast India can be marked over the southern Assam, Mizoram and adjoining Burmese region.

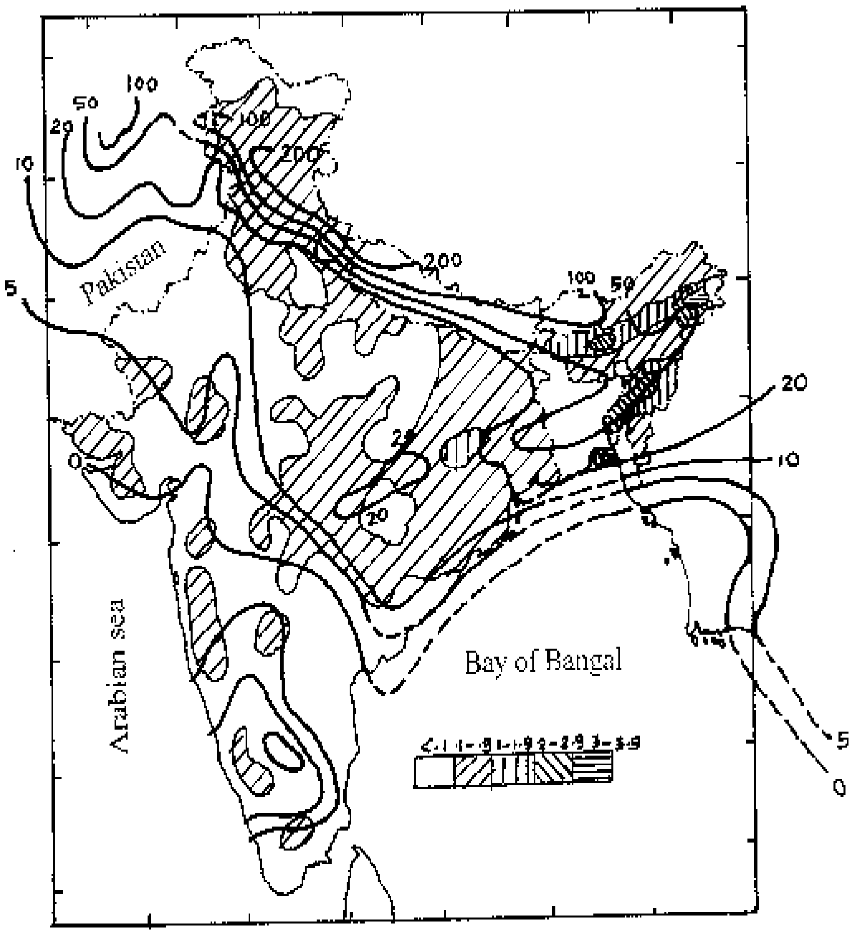


Fig. 1.21(a) Average number of hailstorms in April. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

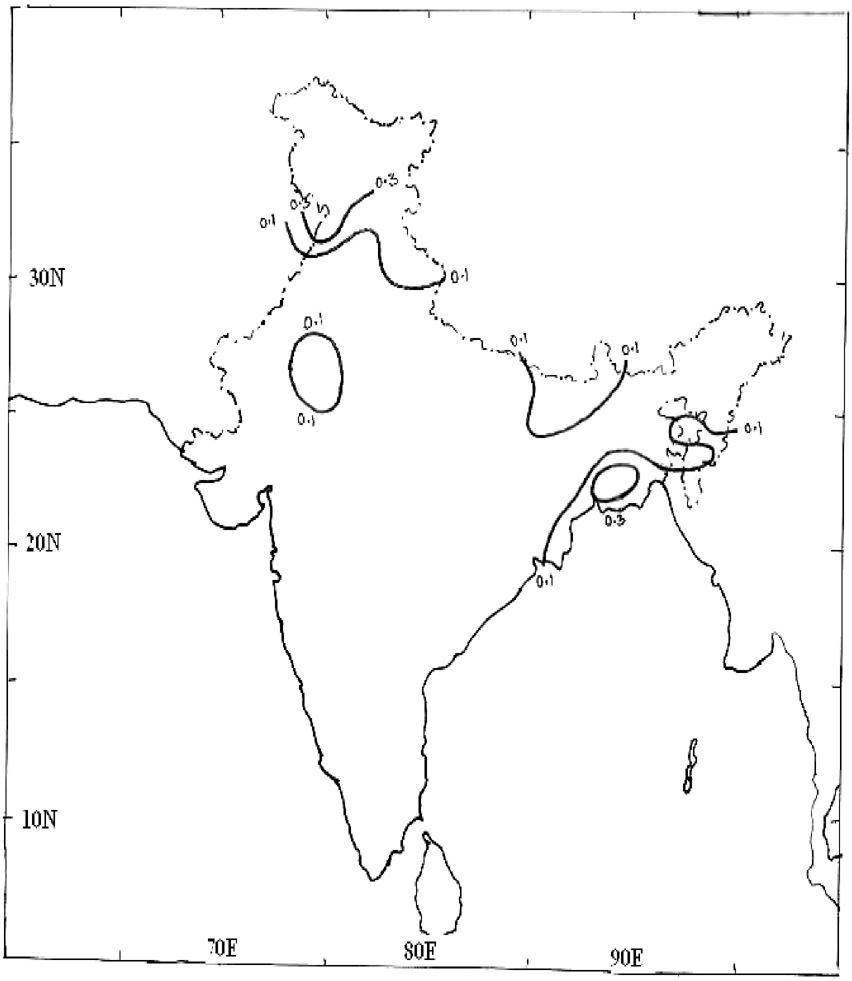


Fig. 1.21(b) Frequency of occurrence of hailstorm in April based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

It may be noted that occurrence of hailstorms over peninsula has totally disappeared in Fig. 1.21(b) as compared to the previous Fig.1.21(a).

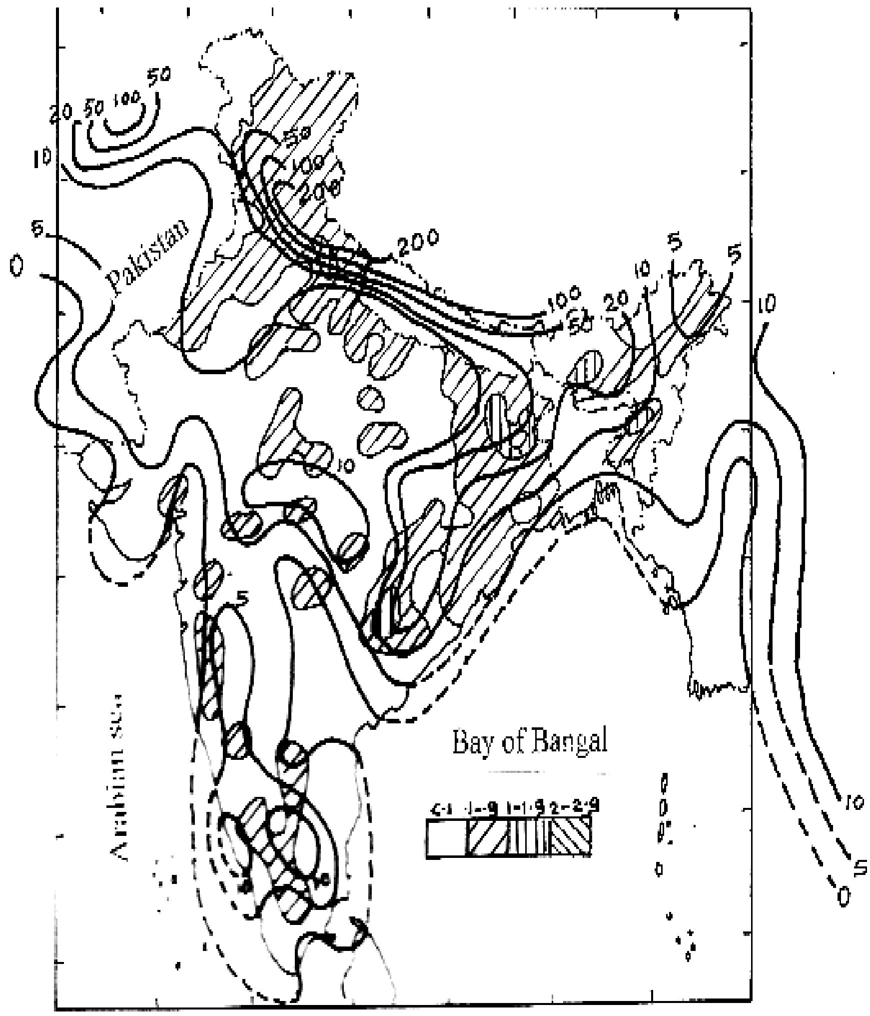


Fig. 1.22(a) Average number of hailstorms in May. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

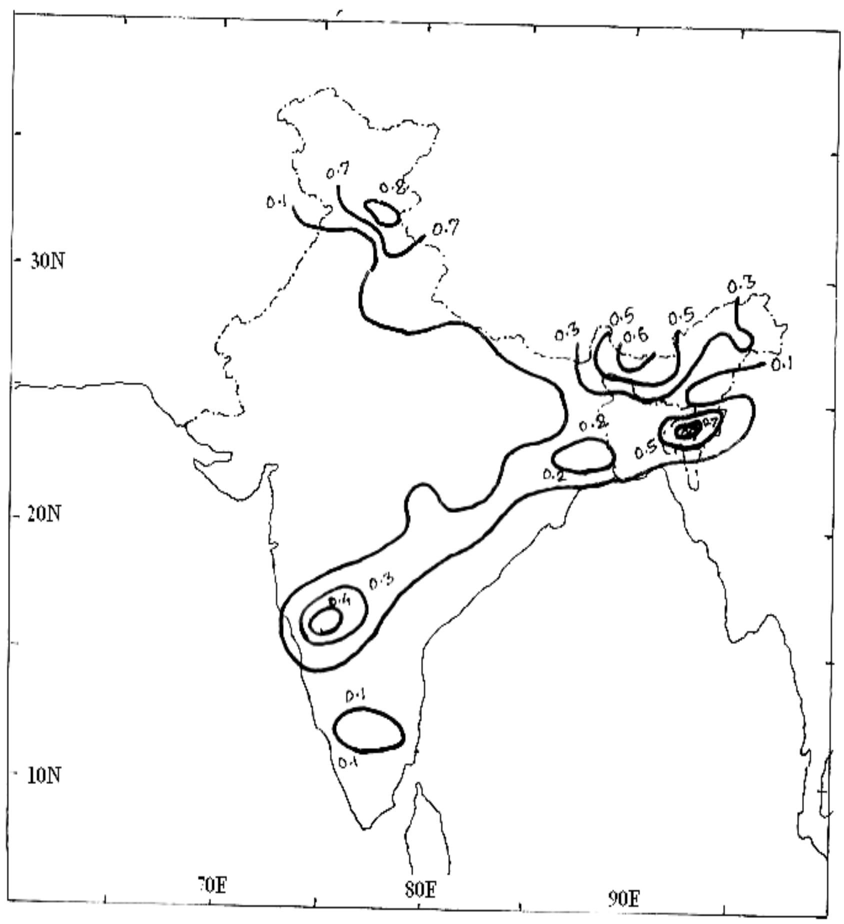


Fig. 1.22(b) Frequency of occurrence of hailstorm in May based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Southward shift of HFHZ over northeast towards south Assam and Mizoram can be noted.

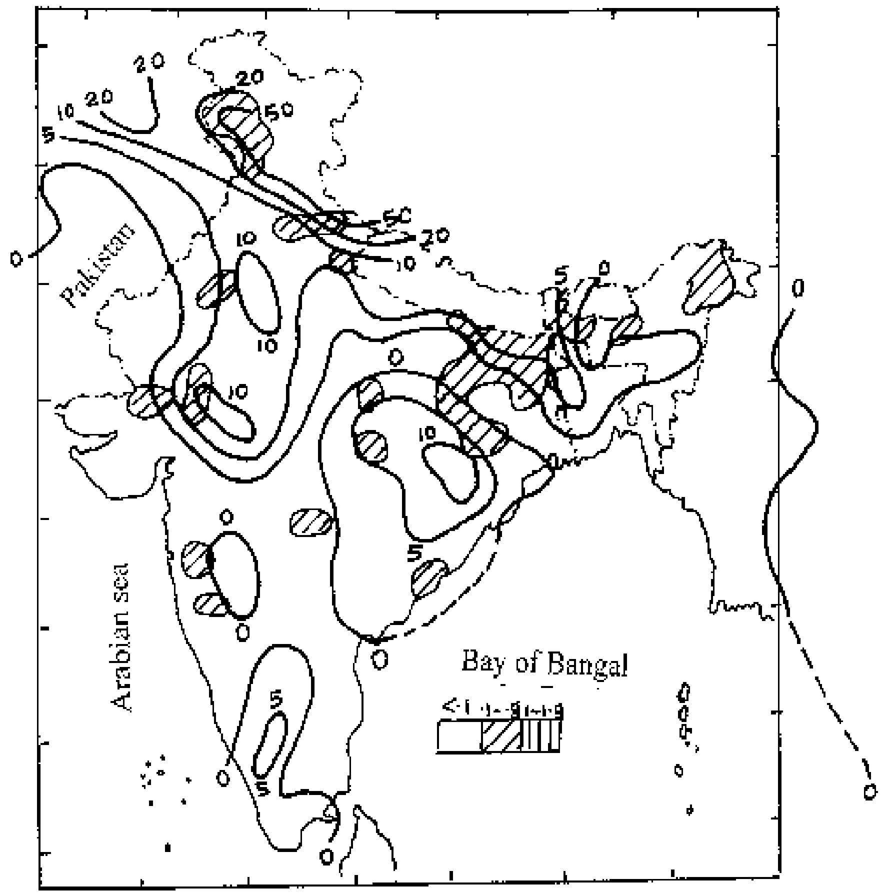


Fig. 1.23(a) Average number of hailstorms in June. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

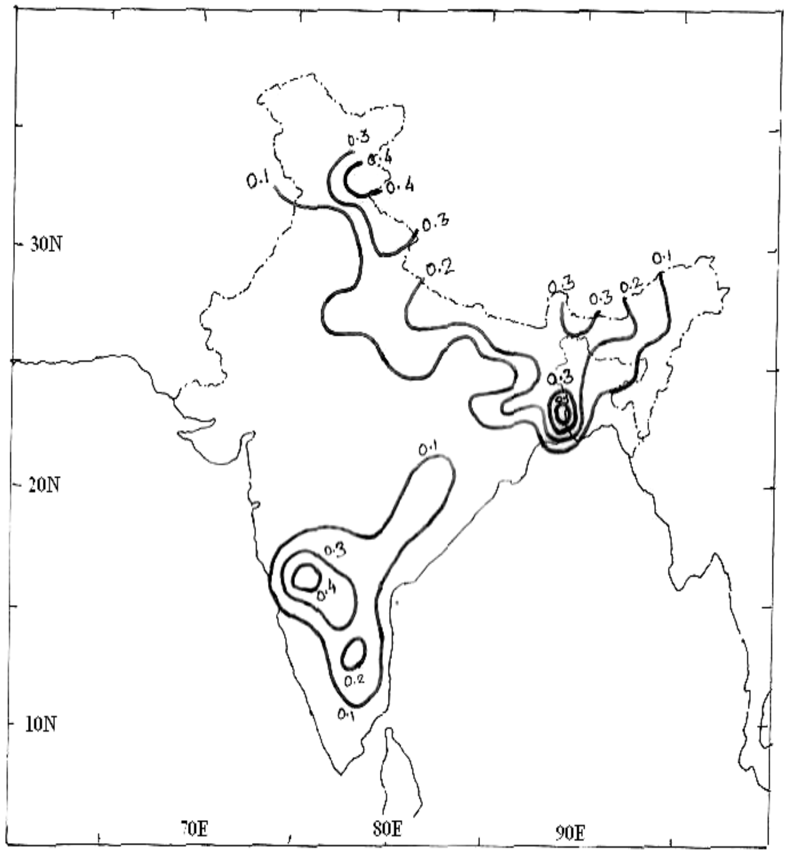


Fig. 1.23(b) Frequency of occurrence of hailstorm in June based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

HFHZ may be noticed over the Gangetic West Bengal region in Fig. 1.23(b) in contrast to Fig 1.23(a).

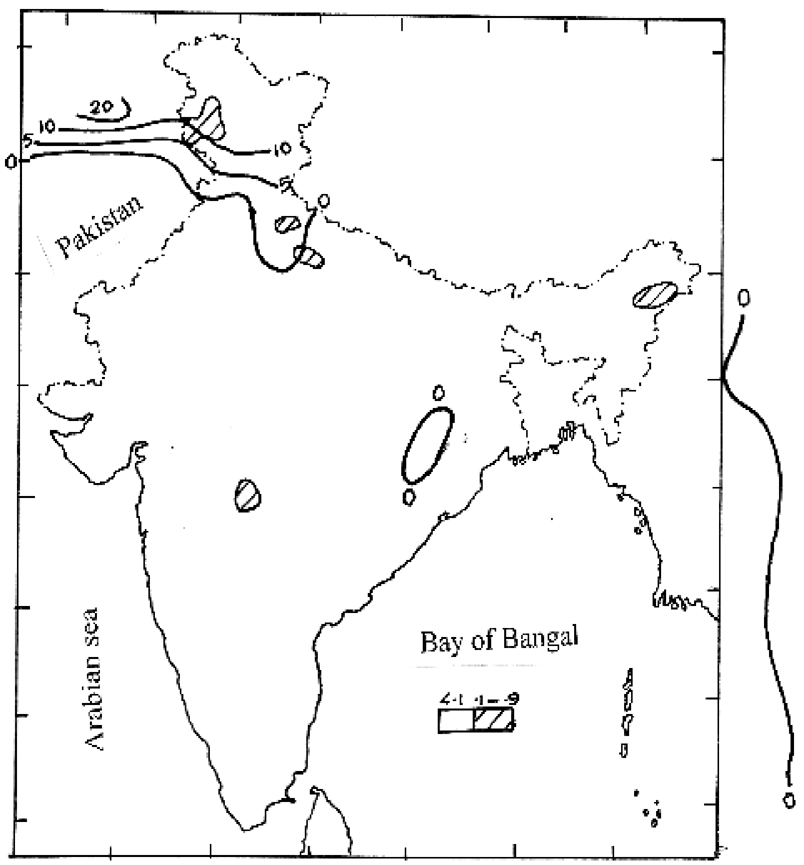


Fig. 1.24(a) Average number of hailstorms in July. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

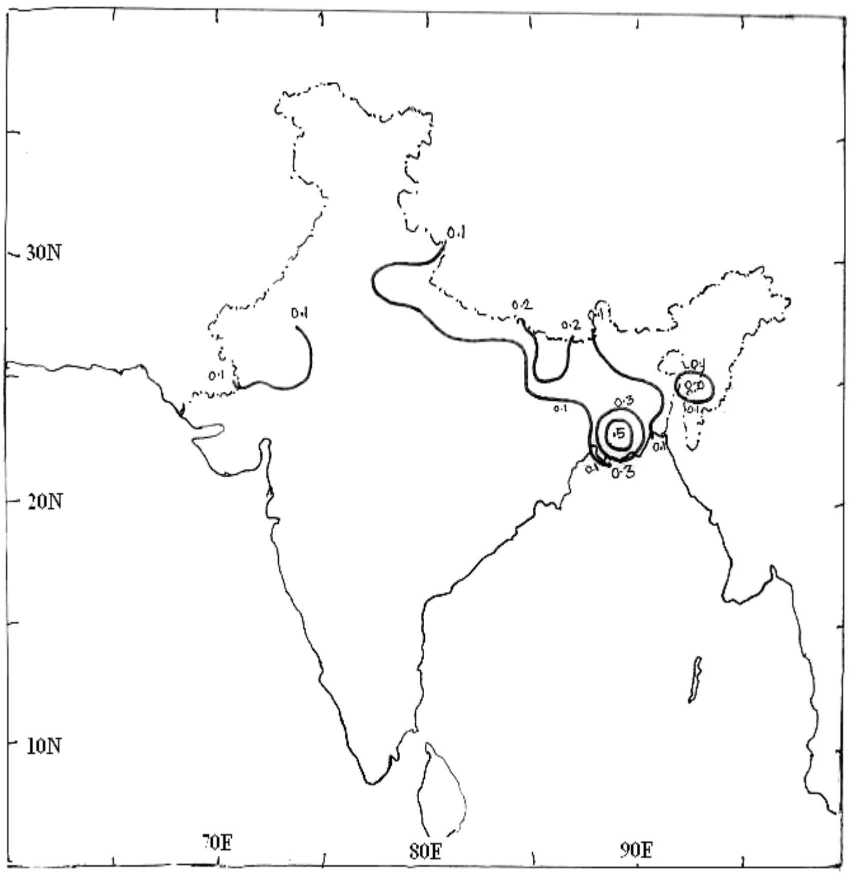


Fig. 1.24(b) Frequency of occurrence of hailstorm in July based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Generally July is the month of relatively low hailstorm activity. However, marked shift of high frequency hailstorm activity from western Himalayas Fig. 1.24(a) to the Indo-Gangetic plains in Fig. 1.24(b) and emergence of HFHZ over Gangetic West Bengal may be noted.

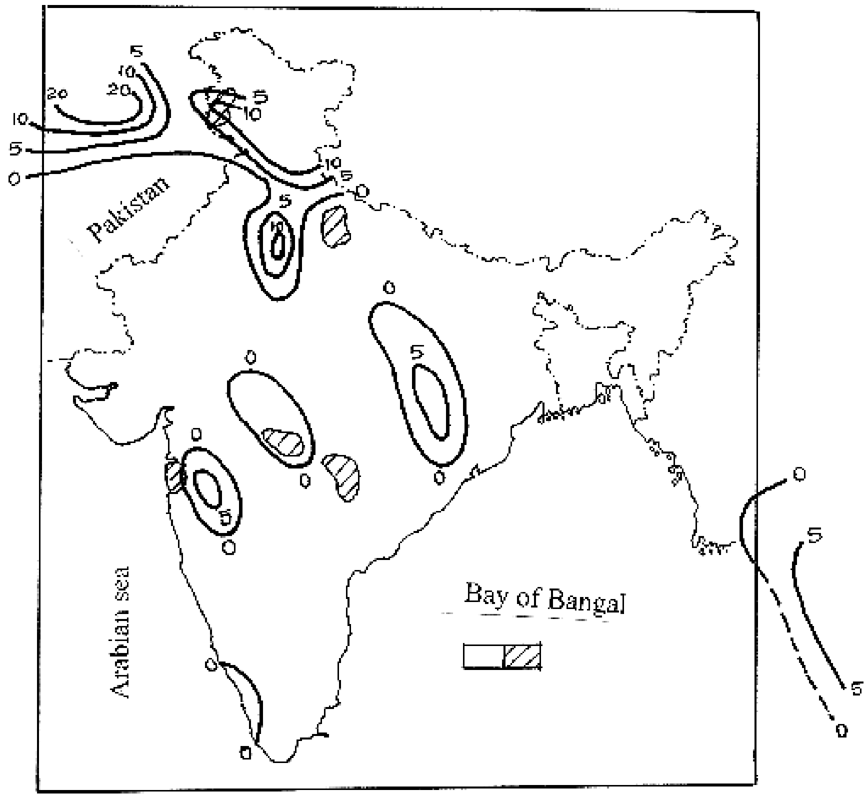


Fig. 1.25(a) Average number of hailstorms in August. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

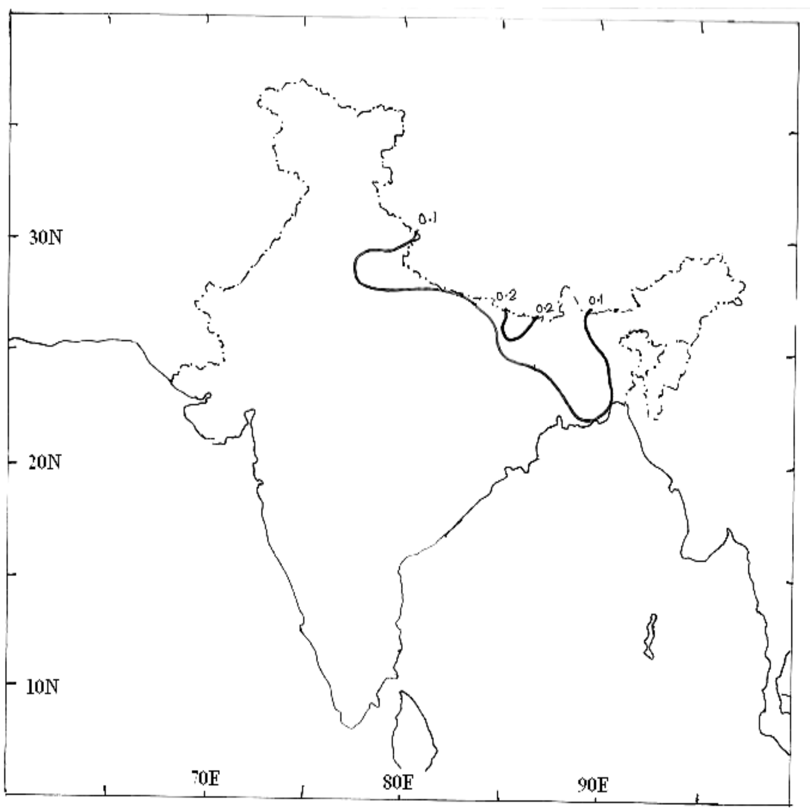


Fig. 1.25(b) Frequency of occurrence of hailstorm in August based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

During August month hailstorm activity has greatly reduced over the central and peninsular India. Over North Indian region high frequency zone shows marked eastward shift from western Himalayas and Kashmir region to Bihar and West Bengal region.

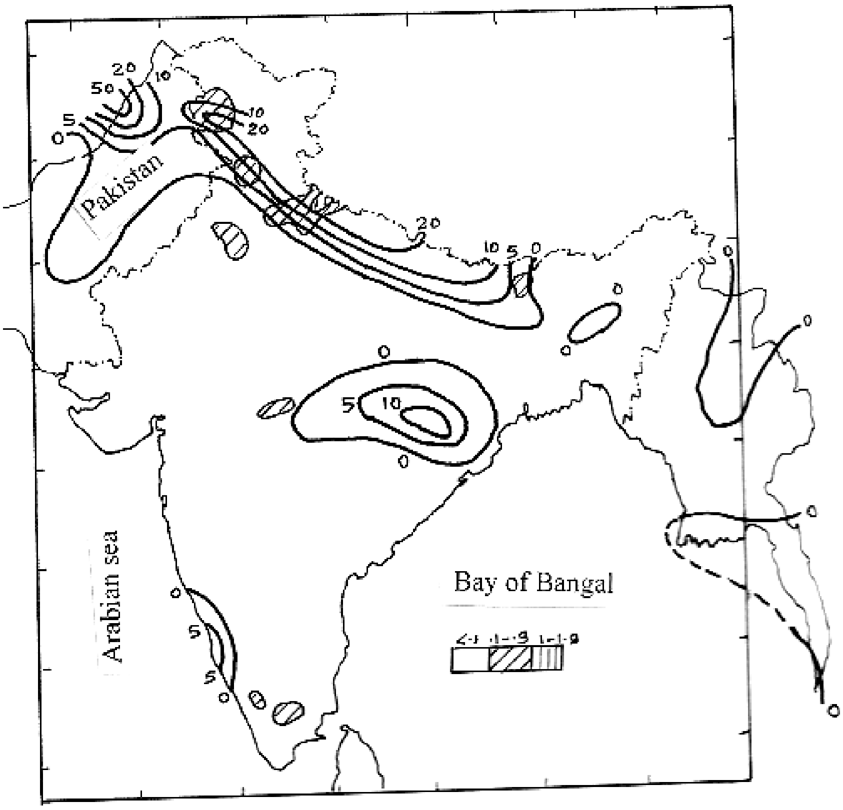


Fig. 1.26(a) Average number of hailstorms in September. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

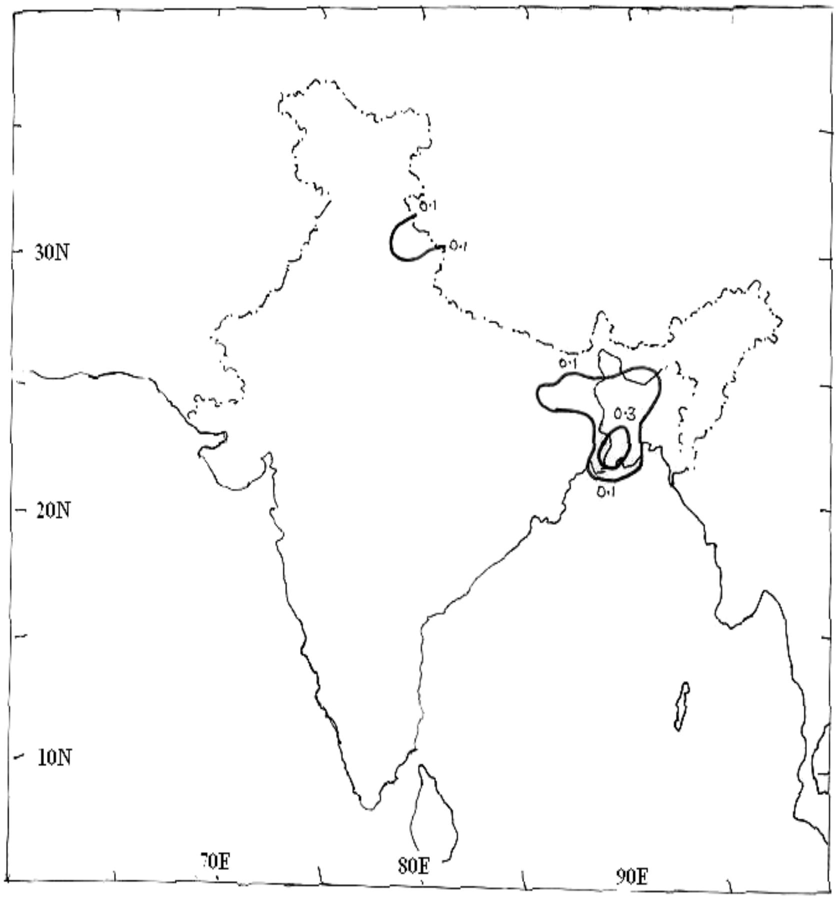


Fig. 1.26(b) Frequency of occurrence of hailstorm in September based on the data from 1961-1990 by the National Data Centre of India Meteorological Department

A comparision of Figs. 1.26(a) and (b) readily reveals significant shrinking of hailstorm activity over North-West India and northeastward shift of HFHZ from Orissa and adjoining Madhya Pradesh region to Gangetic West Bengal.

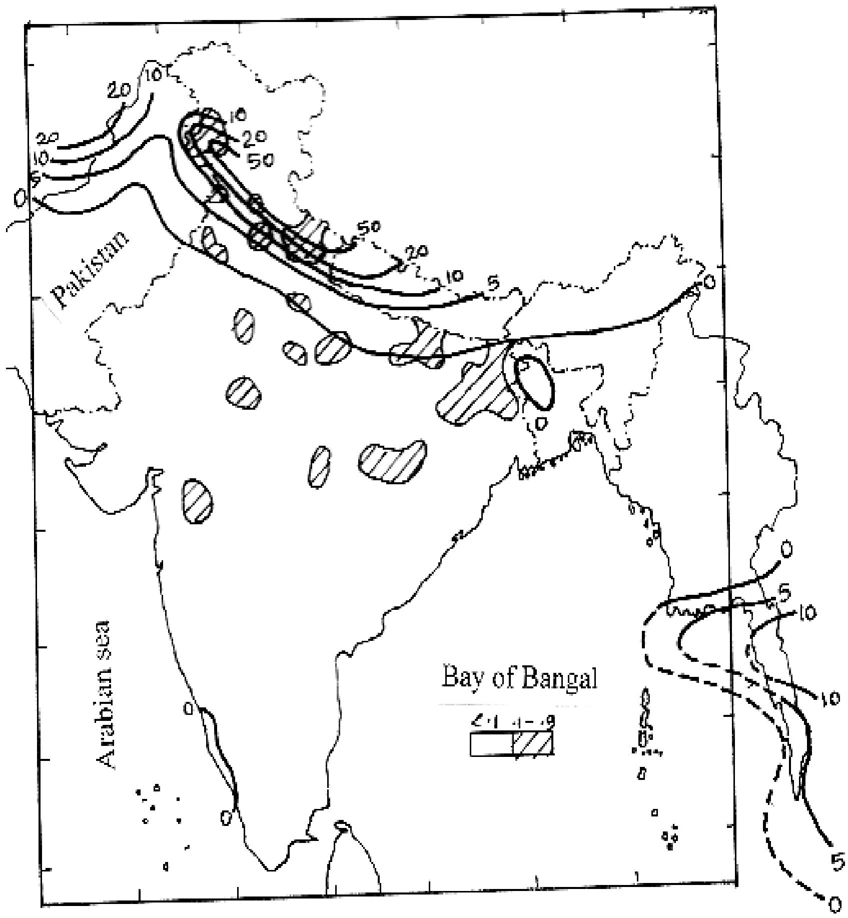


Fig. 1.27(a*)* Average number of hailstorms in October. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

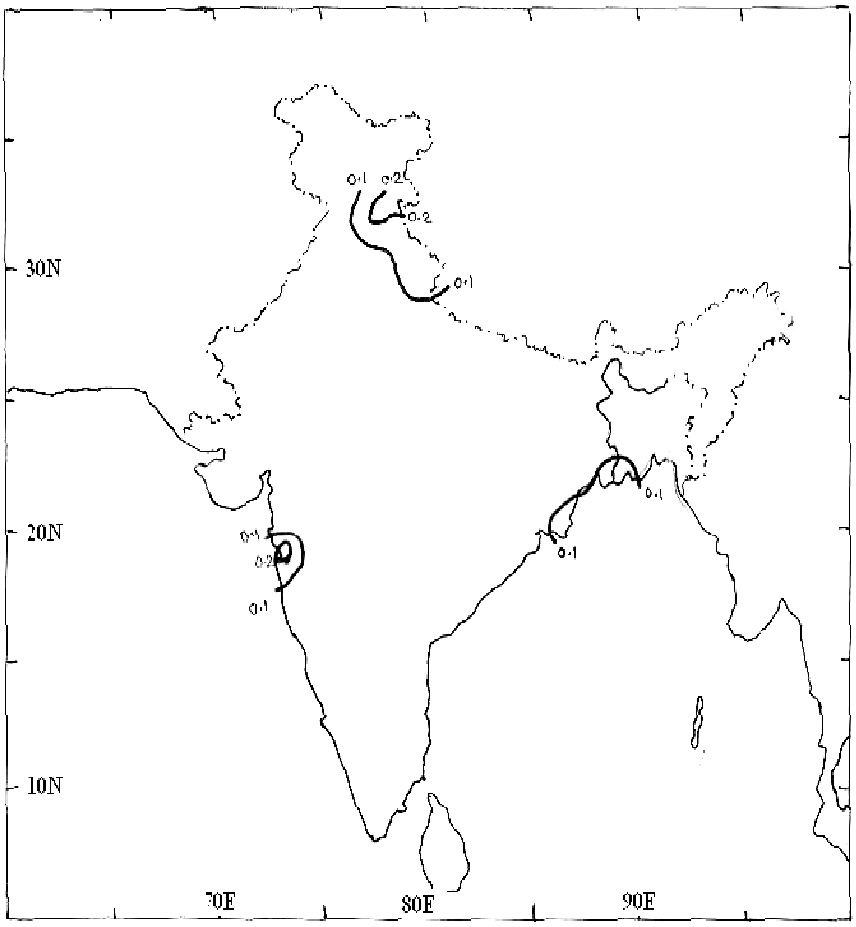


Fig. 1.27(b) Frequency of occurrence of hailstorm in October based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

A significant shrink in the hailstorm region over the foothills of Punjab, Haryana and Himanchal Pradesh may be noted during October.

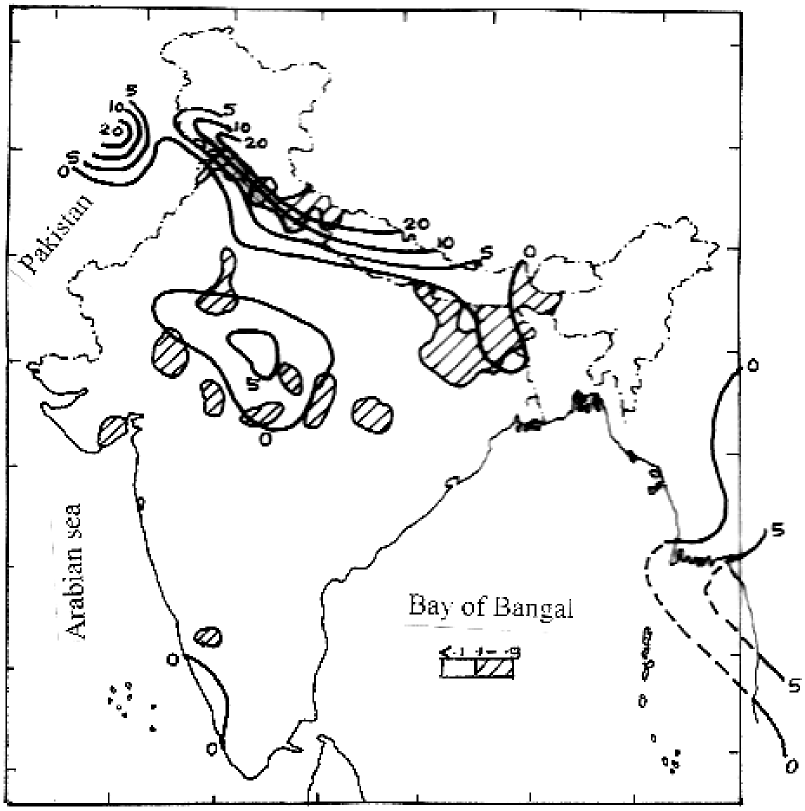


Fig. 1.28(a) Average number of hailstorms in November. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

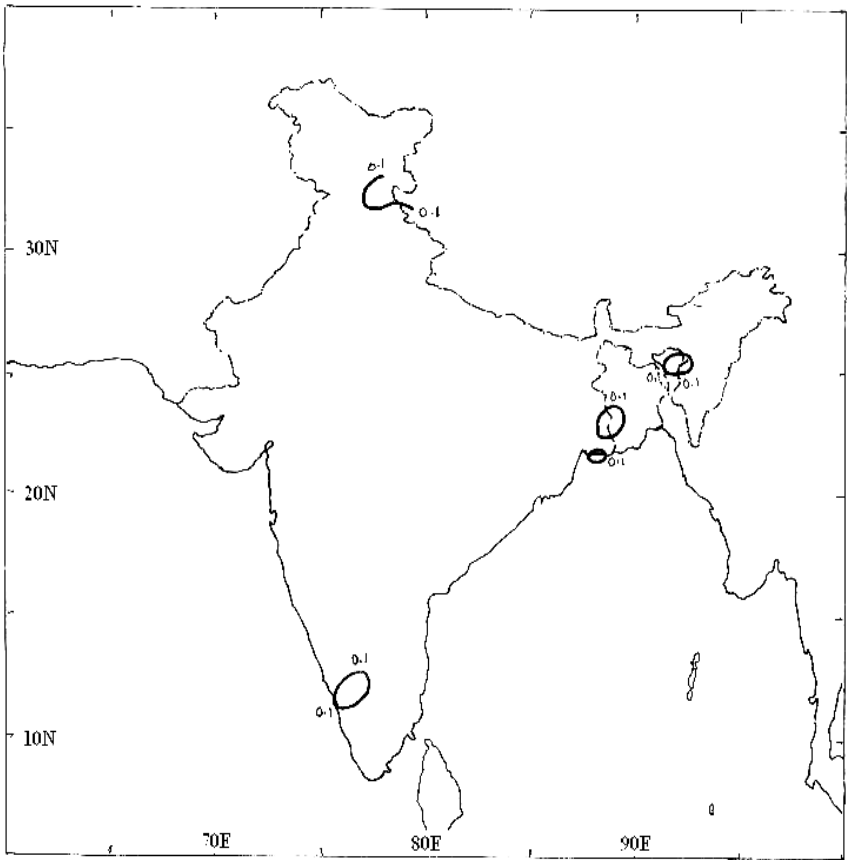


Fig. 1.28(b) Frequency of occurrence of hailstorm in November based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Complete disappearance of HFHZ from central India in figure 1.13(b) as compared to previous data (Figure 1.28(a)) can be noted during November month.

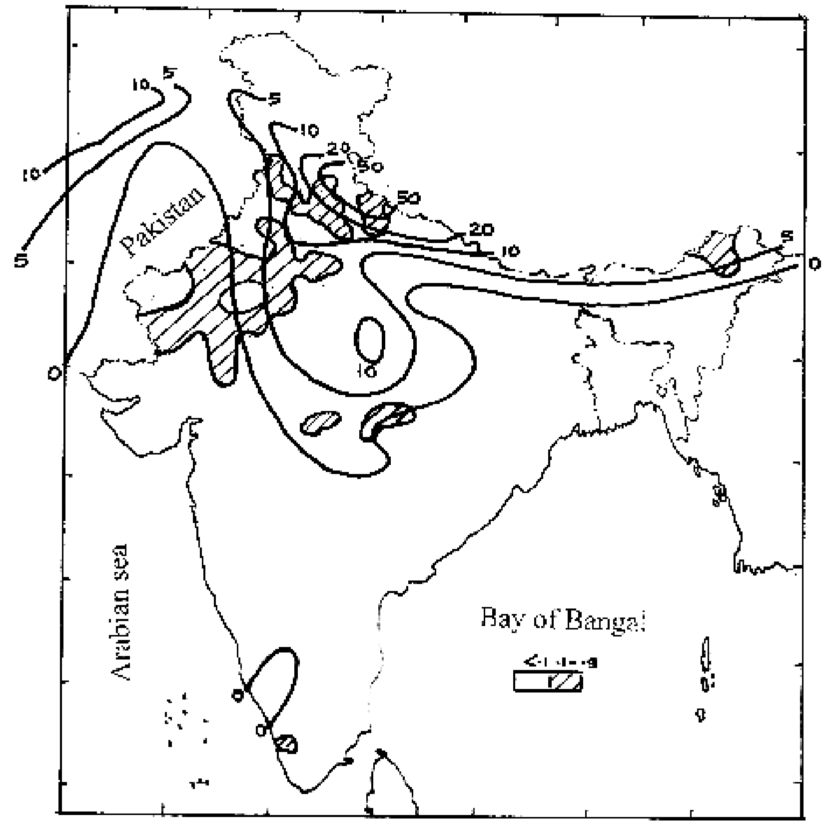


Fig. 1.29(a) Average number of hailstorms in December. Hatched scheme by Philips and Daniel (1976) and isolines of frequency of days of hailstorms in 100 years by Ramdas et al (1938).

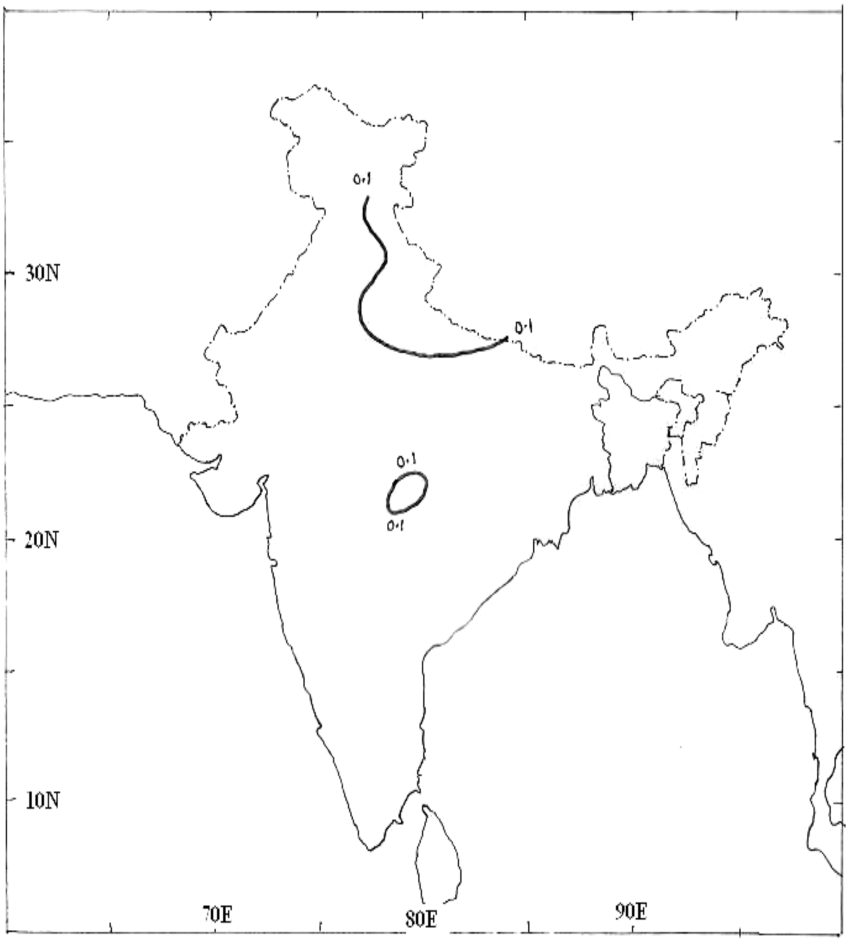


Fig. 1.29(b) Frequency of occurrence of hailstorm in December based on the data from 1961-1990 by the National Data Centre of India Meteorological Department.

Marked northward shrink of hailstorm zone from west central India towards northwest Uttar Pradesh and Uttaranchal may be noted during December.

Figures 1.30 and 1.31 by Philips and Daniel (1976) show for the various parts of the country the month and season normally having most hailstorms. It may be noted in figure 1.30 that in general from February to May most of the regions of central and north India experience most-hailstorm. Over peninsular India in general, most hailstorm occurring months are not quite specific and they are isolated regionwise and sporadic monthwise. As the latest statistics based on the 1961-90 data is not available for the months or seasons of most hailstorm days, based on the monthwise observations made in this section (figures 1.3 to 1.14) , reduction in monthwise and seasonwise activity may be inferred by the readers, while interpreting the figures 1.30 and 1.31 by Philips and Daniel (1976).

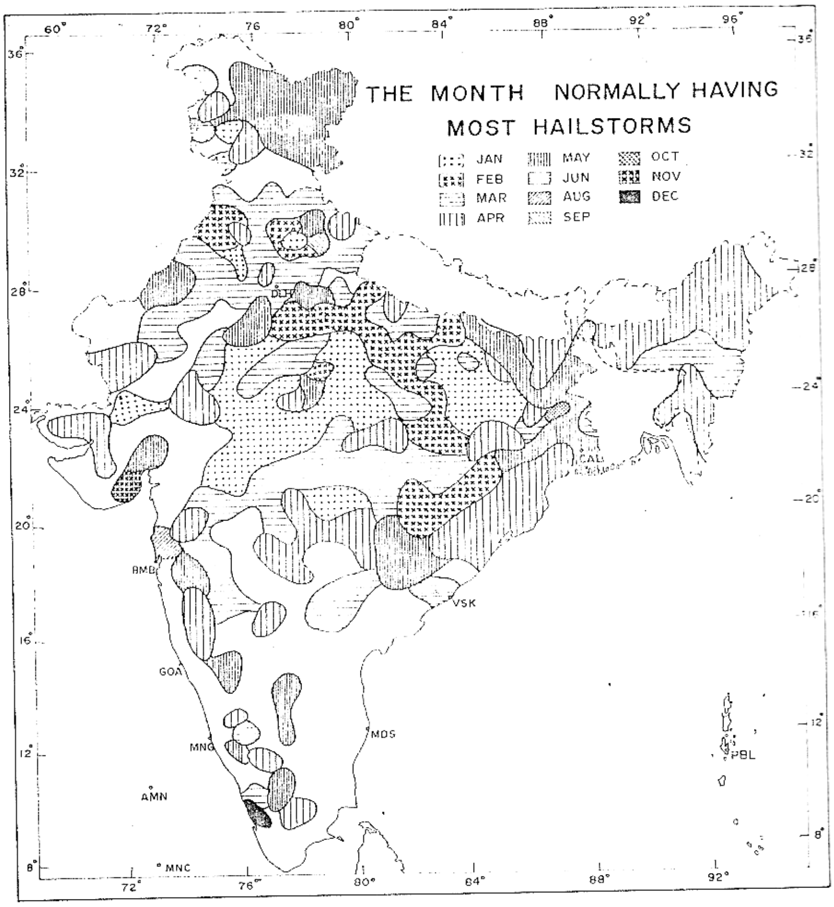


Fig. 1.30

Fig. 1.31 shows that season-wise, west central and North-West India, excluding Jammu and Kashmir region, experience most hailstorms. Over Jammu and Kashmir region, Assam and east central India April to May is the most hailstorm season, in general.

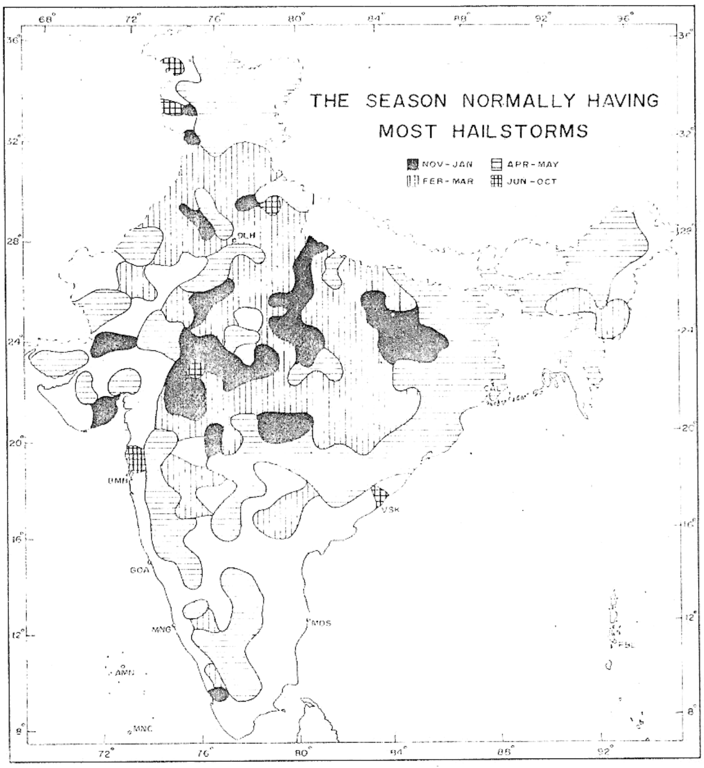


Fig. 1.31

1.6 Hail Path, Hail Streak and Hailswath

Damage of hailstones may be better understood by knowing the characteristics of the path made by the fallen hails on the earth surface. It has been investigated by many people. Prohaska (1900) gave data of hail paths in Austria (1888 – 1900), Gigeishvili (1960) in eastern Georgia (1938 – 1948), Chepovskaya (1966) in North Caucasus and Kozminski (1963 – 4) in Poland, Lemons (1942) and Schaefer (1948) in U.S.A. Gigineishvili (1960) noted that in number of cases the direction of the hail motion may change by 90^0. By studying different hail paths, he named the places where two of them intersect as "Hail – Nodes". It has been observed that when a cloud grows during a frontal process and acquires a mean velocity of about 15 –20 km/hr, then the mean length of hail path is observed to be around 15 –22 km.

Hailpath was the term used to define the road formed by hailstones fallen from the hailstorms. During mid 20^{th} centuries observations revealed that areas with nearly continuous damage were the result of several individual streaks of hail occurring within the same general area during 1-12 hour period (Chagnon and Stout, 1966). This led to the concept of hailstreak. A "Hailstreak" is defined as areas of hail continuous in space with temporal coherence (Chagnon et al., 1967). The average hailstreak represents a fast-moving, short lived, and relatively small phenomenon. 80% of the hailstreaks in U.S.A. had area less than 40 Km^2 and median affected area was $20.5km^2$. Extremes may range from 2.3 – 2040 Km^2. In central Europe the area affected by hailstreaks is usually less than 500 $km^{2.}$ (Punge and Kunz, 2016). Prefered location of occurrence of hailstreak is along the major axis of horizontal cloud base projected on the surface and during the mature stage of the convective cloud. Normally a convective cloud produces one hailstreak but 20% of them could produce four or more (Chagnon, 1970). Series of hailstreaks, often partially overlapping with each other, are termed as "Hailswath". Hence hailswath is defined as an enveloped area of hail comprising two or more hailstreaks separated by no more than 20 minutes during 12 hours or less. A hail producing system is a convective precipitation system that contains one or more hailstorms during its period of precipitation production. A hail producing system in an area of 4000 Km^2 may normally produce five hailstreaks with average separation distance of 24 km.

The results of the variou investigations with respect to the dimensions of hailswaths are given in Table. 1.1.

Table 1.1 Dimension of Hailswaths according to the data of different authors

		Length (Km)		Width(Km)	
Authors	**Location**	**Max**	**Mean**	**Max**	**Mean**
Prohaska*	Austria	Several hundred	10 – 20	10 – 20	8 – 9
Schaefer*	Grand Island	48	-----	8	----
Gigineishvili*	Eastern Georgia	90 – 100	20 – 30	10	5 – 7
Lemons*	U.S.A.	-----	----	----	1 –6
Chagnon**	Illinois, U.S.A.	240	-	48	-
Chepovskaya*	Northern Caucasus	400	15 – 20	8 – 10	1 –6
	Mean	----	15 –20	----	4 -

*Sulakvelidge(1969) ** Chagnon (1970)

The edges of the hailstreaks are usually parallel, but the width varies in the direction of motion. Some times it becomes wider as the hail fall intensity rises. The most intense hail fall is observed in the central part of the hailstreak, while within hailstreak small hail free regions may be encountered. The majority of hailstreak have a length of about 4-7 km. The width of severe hail damage caused by hailstreak, though may vary from a few meters to several kms but in majority of cases it is to 1.5 km. Length of most of the hailswaths are 15-20 km and width ~ 4 km.

According to the few available studies, the mean hailstreak length is around 50 km with an exponential decrease of the number with length. In very rare cases, hailstreaks may persist over several hundreds of kilometre. Puskeiler (2013) who reconstructed hailstreaks between 2005 and 2011 from 3D radar data and appropriate post-processing. Accordingly, most of the 2632 identified hailstreaks had a length of 20 km or less, whereas only 13 events reached a length of 300 km or more.

The mean including standard deviation and median were 48.0, ± 46.7 km and 40.0 km, respectively. Specifically for the region of León(Spain), Fraile et al. (1992) found an average hailstreak area of 44 km^2. For Moldova in Eastern Europe, Potapov et al. (2007) estimated typical hailstreak length of 20-25 km with a typicalwidth of 0.2–4 km.

In view of large literature on the dimension of hailstreak, over different regions of the world a typical Hailstreak may be said to have the width of 1-2.5 km and lenghth of about 10 km (Chagnon, 1970) is shown in Fig. 1.32.

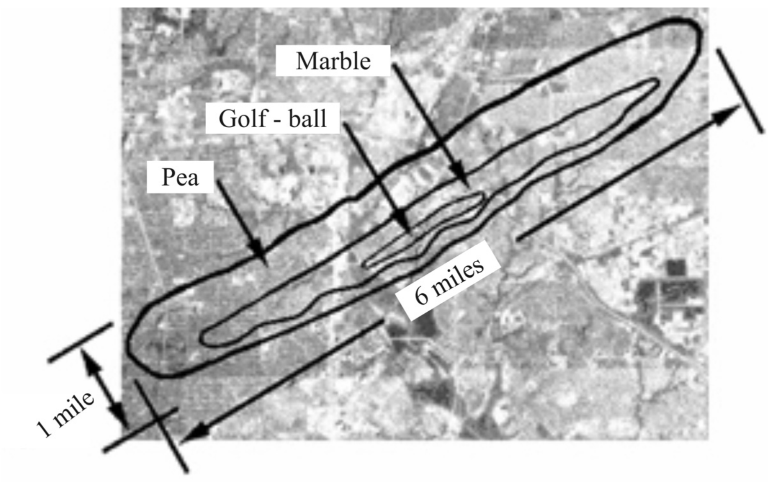


Fig. 1.32 A typical Hailstreak. (1 mile = 1.609 km). For nomenclature refer table 2.2.

1.7 Duration of Hail Fall

Usually the time during which hail inflicts damage at fixed place is taken as the duration of Hail fall. Duration of hail fall varies from a few seconds to sometimes even more then 60 minutes. Mean duration of hail fall however is normally 6 –7 minutes. Maximum duration has reached to even 90 minutes in France (Jeneve – 1961). Average point duration of hail in U.S.A is reported to be 3 minutes (Chagnon, 1970). Hail fall is in short spells followed by a short interval before the next spell. A documented report for the hail fall duration over Bamrauli (Allahabad) in Uttar Pradesh, India is mentioned below.

"On 07th Feb. 1961 hailstone of the size of 0.5 to 1 cm diameter lasted for two minutes. After a brief interval the subsequent spell was less dense and was comprised of larger size hailstone of diameter of 1 to 2.5 cm. This spell also lasted for two minutes. Again after a brief interval very large size (4 to 5 cm diameter) again fell, though, they were fewer and further apart (1 to 2.5 cm). This spell lasted for ½ minute. Last spell comprised of quite large hailstone a few among them were weighing even 35 gm".

Duration of hail fall lasted as much as 1 hour in one of the hailstorm over between Bhind in Madhya Pradesh, India on 30th Oct. 1961. But on an average hail fall duration lasts only 05 to 20 minutes over India. Duration of hail in other parts of the world is reported in Table. 1.2

Table 1.2 Duration (minutes) of Hail Fall According to Different Authors

Author	Location	Minimum	Maximum	Mean
Prohaska*	Austria	0.6	50	8 – 10
Gigineishvili*	Eastern Georgia	5 – 10	----	----
Bechwith*	Mountain regions USA	0.6	45	5
Defur*	Belgium	5	20	----
Teverskoi*	Rostov Region	5	20	10
Pastikh Sokhrina*	European path of the CIS	2	20 – 30	15
Chepovskaya*	Northern Caucasus	3	30	5 – 10
Jeneve*	France	1	90	5 – 10
Weickmann*	USA	----	85	5 – 10
Chagnon**	USA	-	-	3
Mean				6 – 7

* Sulakvelidge (1969) ** Chagnon (1970)

1.8 Duration of Hail Damage

When the cloud moves, for the time that hail falls, along the whole hailswath, from its beginning to its end, is known as the 'Duration of Hail Damage'. Duration of hail damage is identical to Duration of Hail Fall if the cloud is stationary. Duration of hail damage on the average does not exceed 80 minutes. But a maximum of 360 minutes was also observed over northern Caucasus on 10 January 1966.

Insurance sector, however, frequently use a term 'Damaging Event'. Damaging event is defined as extent of all settled claims in the reference area over a time span of 72 hours. But the time span may depend on business sector and regional practices.

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