Characteristics of Hailstorms in Japan*

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Abstract

This paper is prepared for giving climatological information on hail occurrence in Japan. It is pointed out that there are two kinds of maxima in the distribution of the number of hail days in Japan. The maxima along the coast of the Sea of Japan are attributed to hailstorms mostly occurring in the cold season, (October—March). Whereas inland maxima are mostly due to hail in the warm season (April—September). Observational records of 4 selected weather-stations, 2 in one of the west coast maxima and 2 in one of the inland maxima, are examined in detail. It is found that cold season hail occurrence shows practically no diurnal variation, but warm season hailstorms occur mostly in the afternoon through the evening hours. Warm season hailstorms are almost always associated with thunderstorms, but there are many cases of hailstorms without thunderstorm in the cold season. Some other features of interest on hail in Japan are also described.

1. Introduction

In Japan the hail problem is considered as less serious one compared with other natural disasters such as floods, high winds, cool summers, etc. Nevertheless, when severe hailstorms occur they cause heavy damages to crops. For example, combined damages by recent three severe hailstorms in Kanto District (22 May, '63; 4 Sept. '65; 7 June '66) are estimated at about 7,000,000,000 yen (U. S. \$ 1=360 yen). There were several less severe hailstorms in May through July of 1967, the total damages by these are estimated at about 5,000,000,000 yen. The purpose of this paper is to present some climatological information about hail occurrence in Japan.

2. Data

Discussions of the sections 3 and 4 are based on the data given in the Monthly Climatological Data of Japan, published by JMA (Japan Meteorological Agency). In this publication is given the number of day with hail for about 140 regular weather stations and about 1300 cooperative stations of JMA. Unfortunately this monthly bulletin had been published for only 11 years and discontinued since December 1964. As no summary of hail observations is available even at individual stations,

the nation-wide statistics are made only this 11 year period, i. e., 1954-1964.

The date used in the sections 5 and 6 are taken from observational records of selected weather stations of JMA. As seen in the examples given in the section 5, they describe time change of weather phenomena in detail. At the present time to obtain such data one must visit each station to copy them. Therefore, in the present study the data of only 4 stations are used. The locations of these stations and other places appearing in the text are given in Fig. 1.

Fig. 1. A map of Japan giving geographical locations of areas and places which appear in the text.

3. Distribution of number of hail days

The distribution of the total number of days with hail during the 1954-1964 period is given in Fig. 2. We notice that there are two groups of areas where hail occurrence is relatively frequent.

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FIG. 2

Fig. 2. Distribution of the number of days with hail during 1954-1964.

FIG. 3

Fig. 3. Distribution of the number of days with hail in the cold season (October—March), of the 1954-1964 period.

FIG. 4

Fig. 4. Distribution of the number of days with hail in the warm season (April—September), of the 1954-1964 period.

One is along the coast of the Japan Sea, the other is the maxima in the northern Kantō, and other inland areas. It is also seen that hail occurrence is rare along the coast of the Pacific Ocean, especially to the west of Kantō District.

The result is somewhat surprising, for, to our knowledge, the coastal regions of the Japan Sea suffer little damage by hail. This is partly explained by the fact that most of fail days in this area occur in the cold season, as shown in Fig. 3. On the other hand, in northern Kantō where hail is one of the major factors causing disaster in agricultural productions, most hailstorms occur during the warm season as seen in Fig. 4. The difference in patterns of occurrence of fail between the warm season (April—September) and the cold season (October—March) is remarkable. In the cold

season, there is a belt of frequent hail along the west coast of Japan from Hokkaido through Kyushū. On the other hand, in the warm season, maxima appear inland, viz., mountain areas.

It has been known (e. g., Japan Meteorological Agency, 1957) that in the cold season a belt of relatively frequent thunderstorm occurrence appears along the coast of the Japan Sea. This feature seems related to the existence of a belt of relatively frequent hail in the same region during the cold season. It will be shown later, however, the hail-thunderstorm relationship during the cold season is not so close as that during the warm season. It is also discussed later that there are distinct differences in the characteristics of hailstorms between the warm and the cold season.

General appearances of the distributions of hail

frequency in Japan are similar to those in the United States (U. S. Weather Bureau, 1947, see also Flora, 1956); namely there are maxima along the west coast and the central parts (mountain areas and the eastern slope), and the occurrence is rare along the east coast. The similarity is of particular interest, for, Japan consists of a chain of island (forming a narrow land area) and the United States is a part of a broad continent.

4. Types of monthly distribution of hail occurrence

Next we consider variation of hail occurrence using relative frequency by months. Since the data over the 11-year period are not sufficient to examine at individual stations, total hail data over areas of certain sizes are studied. Most of these areas are based on administrative divisions, as climatological data are assembled for these. The boundaries used for the study are indicated in Fig. 5. The monthly relative frequency (=total number of hail days of each month/total number of hail days during the entire period) is obtained to each of such 57 areas. Some of the typical examples are also shown in Fig. 5. It appears that these frequency distributions may be reasonably classified into three types, each of which is again subdivided according to variations mainly attributed to the latitudinal influence. The characteristics of these types are summarized below, in the parentheses are the names of areas to which frequency distributions are given in Fig. 5.

Fig. 5. Classification according to the type of annual change of hail frequency. Typical examples for selected areas are also given.

- Type I : The early summer maximum is very pronounced, and hail occurs mostly in the warm season.
- Ia : Although the early summer maximum is very pronounced there is a distinct autumn maximum (Fukushima).

ma).

- Ib : Typical one maximum distribution, the autumn maximum is very weak (Gunma).
- Type II : Two distinct maxima in the annual change, and hail occurs mostly in the cold season.
- IIa : The autumn maximum is more pronounced than the spring maximum (Rumoi).
- IIb : The spring and the autumn maxima are almost equal (Kushiro and Yamagata).
- IIc : The spring maximum is more pronounced (Tottori and Toyama).
- IId : Maxima appear in the late autumn and in the early spring, the winter minimum is indistinct (Nagasaki and Izu).
- Type III : In this group seasonal variation of hail occurrence is not clear, all show three maxima in the annual change.
- IIIa : The spring maximum is the most pronounced (Nara).
- IIIb : Three maxima are almost equal (Kōchi).

As we can see from Fig. 2, the hail occurrence is rare in the areas where the type III distributions are observed. Therefore, irregularities in the seasonal change may be partly due to poor data. It is found that in some respects hail occurrence in Izu island are similar to those along the coast of the Japan Sea, though these island are in the Pacific Ocean south of Kantō. The similarity in the type of thunderstorm occurrence between Izu islands and the Japan Sea coast was also pointed out by Terada (1935).

5. Characteristics of hail in the west coast of the northern Honshu

Characteristics of hail in the west coast of northern Honshū are studied by examining daily observational records at Akita and Sakata for the period 1937-1966. Monthly frequency of hail occurrence at these stations are shown in Fig. 6. It is found that the frequency distributions for these stations over that 30 year period are similar to those of Akita (for Akita) and Yamagata (for Sakata, see Fig. 5) prefectures, in which these stations are located. The data for these stations may be considered as representing the typical cold season hail although hailstorms occur in the warm season less frequently.

The data used in the study described in this and the next sections are the records of detailed

Fig. 6. Number of hail days by months at Akita and Sakata for the period 1937-1966.

visual observations. In the records, for example, are given times when intensity of precipitation changes. Two of the examples of interest are given below, where symbols $\blacktriangle$, $\bullet$, $\triangle$, and ∇ are hail, rain shower, *arare* shower, and sleet shower, respectively. Here *arare* is a Japanese word for precipitation corresponding to soft hail, graupel or snow pellets. Superscripts indicate intensity of precipitation, viz., 0=weak; 1=moderate; 2=intense. Times are in local times, 1008 reads as 10 h 08 m.

Example I: A portion of the record at Akita on 5 December, 1956.

....., ∇^0 0845— ∇^0 0910... $\triangle^0$ 1008— ∇^0 1009— ∇^2
 $\blacktriangle^2$ 1201— ∇^0 1204— ∇^0 1210— ∇^0 1213— ∇^2 $\blacktriangle^2$
 1221— ∇^0 $\blacktriangle^0$ 1223— ∇^0 $\triangle^0$ 1224— ∇^1 $\blacktriangle^2$ 1230— ∇^1 $\triangle^0$
 1231—...

Example II: A Portion of the record at Sakata on 29 November, 1942.

....., ∇^1 $\blacktriangle^1$ 1312— ∇^0 1314— ∇^0 $\blacktriangle^0$ 1510— $\blacktriangle^1$ (8mm)
 1511— ∇^0 1513— ∇^1 1608— ∇^0 1610—...

As seen from these records we find precipitation of other kinds is observed on the day with hail. In the table 1 is given the summary for the occurrence of other type precipitation on hail days, where numbers in the parentheses indicate days when only rain was observed.

Table 1. Associated precipitation with hail

	Akita	Sakata
Number of days with hail	67	42
Rain was also observed	64(33)	42(11)
Snow was also observed	15	6
<i>Arare</i> was also observed	25	14
Sleet was also observed	6	13

From the table we see that almost always rain shower is observed on the day with hail. Three exceptional days, when no rain was observed, occurred when hail were reported on the day when only snow and *arare* were precipitations of other kinds.

The result indicates that hail does not occur on too cold days, for, normal winter precipitation in this area is snow and *arare**. This character is also evident from annual change as the midwinter minimum is evident (see Fig. 6). From the examples of observational records, though these are two of the most complicated cases, we find that hail and precipitation of other kinds occur simultaneously or in succession. This situation is particularly interesting when the latter is *arare* or sleet. For these and hail are solid precipitation of more or less in spherical sphere. This aspect is discussed in the last section.

In Fig. 7 are shown frequencies of hail occurrence at different hours at Akita and Sakata. Nevertheless there is a common tendency that hail is less frequent during midnight through early morning. Since conditions for visual observations is poor during these hours, we may consider that there is practically no diurnal variation of occurrence of hail at these stations.

From the observational records the relationship between occurrences of hail and thunderstorms (thunder, lightning or both) at Akita is examined.

Fig. 7. Number of hail occurrence by hours at Akita and Sakata for the period 1937-1966.

*) Normal number of days with snow in a year at Akita and Sakata are 99 and 89 days, respectively.

The result is given in the table 2. We find that in many cases hail was reported not accompanied by thunderstorms. At Akita, about half of the cases thunderstorm did not occur within 2 hours of hail observations.

Table 2. Relationship between the occurrences of thunderstorms and hail at Akita (1937-1966)

Number hail occurrences	137
Thunderstorms within 10 min.	46
Thunderstorms within 2 hours	64
Thunderstorms on the hail days	78

6. Characteristics of hail in the northern Kantō

The characteristics of hail in the warm season is studied by examining observational records at Maebashi (1917-1966) and Chūgūji (1944-1966), the weather stations in the northern Kantō. The monthly frequency of hail occurrences at these stations are given in Fig. 8. The frequency distributions at these stations are very similar to those for Gunma (for Maebashi, see Fig. 5) and Tochigi (for Chūgūji) prefectures, using the 11 year data.

Fig. 8 Number of hail days by months at Maebashi (1917-1966) and Chūgūji (1944-1966).

The observational records for these stations are examined in the similar manner as for those at Akita. However, the results are remarkably different from those given in the section above. As shown in the table 3, with a few exceptional cases only rain shower is the associated precipitation with hail.

In this table one day with **arare** at Maebashi occurred in March, one of the rare cold season hail at this station, but two days with snow at

Table 3. Associated precipitation with hail

	Maebashi	Chūgūji
Number of days with hail	33	44
Rain was also observed	33	44
Snow was also observed	0	2
Arare was also observed	1	0
Sleet was also observed	0	0

Chūgūji occurred in April. The reason why snow is observed at this late spring is the latter station is located a mountain are at 1336 m above sea-level. Some of the hail storms in the warm season at this station showed similarities with cold season hail.

The effect of diurnal variation is very clear for hailstorms in this region as seen from Fig. 9. With a few exceptions at Chūgūji, almost all hail observations were taken in the afternoon through the evening. The relationship between the occurrences of hail and thunderstorms is summarized in Table 4. It is clear that most of the hailstorms occur with thunderstorms. At Maebashi the exceptional cases when thunderstorm was not observed within two hours of hail occurred only in the case of cold season hailstorms. However, at Chūgūji such situations occurred even in the warm season.

Fig. 9. Number of hail occurrence by hours at Maebashi (1917-1966) and Chūgūji (1944-1966).

Table 4. Relationship between the occurrences of thunderstorms and hail at Maebashi and Chūgūji

	Maebashi	Chūgūji*
Number of hail occurrence	36	51
Thunderstorms within 10 min.	31	33
Thunderstorms within 2 hours	33	41
Thunderstorms on the hail days	33	46

7. General remarks

Since hail is one of the rare and localized phenomena, we naturally suspect reliability of

* The data of 2 hail days in May, 1967 are included.

climatological informations based upon data of only 11 years. In connection with this, it is pointed out (Stout et al, 1960) that the general appearance of hail frequency maps of the State of Illinois for each of the five decades are similar to that for a 50 year period for the state, nevertheless there are appreciable variations between individual decades. Since frequency distributions by month for the selected stations over 30 years or more are similar to those over the 11 years for the area in which these stations are located, we may consider that general statements in the sections 2 and 3 will not be significantly altered by using data over a longer period, say 50 years.

However, the discouraging result comes out in concluding that 11 year data is really satisfactory when the long term variations of the hail occurrences are considered. Two of the examples showing distinctly the existence of active and inactive periods of occurrences of hail are given in Fig. 10. The block diagram is the data for Saitama prefecture (after Kantō District Meteorological Office, 1966) just south of Maebashi, and a curve is the 5 year running mean of hail occurrence at Maebashi. It is quite disturbing that despite these places are adjacent (see Fig. 1), the patterns are quite different. The long term variations are also evident at Akita and Sakata, but again the tendencies for these stations are different. Before making any further comment, it is desirable to examine data for many more stations and localities.

Fig. 10 Number of days with hail in Saitama prefecture at 5 years intervals (blocks) and the running means of the number of days with hail at Maebashi (stippled).

The records of visual observations given in the section 5 are two of the most complicated records,

and most of the records examined indicate only one hail occurrence on each days with hail. Yet records at Akita and Sakata indicate that the conditions of wintertime hailstones and *arare* or sleet particles are critical. Also it seems there is no clear distinction between *arare* and hail so that it will be difficult to distinguish these precipitation. In order to find out whether or not *arare* and sleet is essentially different from hail (according to the Japanese definition), very careful studies are necessary. Such studies will be helpful in understanding the mechanism of formation of hailstones and other precipitation elements in the cold season. Furthermore, the studies may be useful to find if there are significant differences between hailstorms in the cold season and those in the warm season.

It has been pointed out (Flora, 1956) that hailstones of the Pacific Coast hail maximum is basically different from those of the Rockies and the Great Plains of the United States. The former is described as small and soft. Similar difference seems to exist between hailstones in the cold season and those in the warm season hailstorms in Japan. It is pointed out above that at Akita only half of the hailstorms are associated with thunderstorms. Similar result has been shown by the U. S. Weather Bureau (1947, see Flora, 1956) namely, hail/thunderstorm ratio is 100% or more along the west coast of the United States implying more days with hail in a year than those with thunderstorms. This ratio, however, computed simply by dividing the number of days with hail and that with thunderstorms not considering if thunderstorm is actually observed on the days with hail.

References

- FLORA, S. D., (1956) *Hailstorms of the United States*. Univ. Oklahoma Press. 201 pp
- Japan Meteorological Agency (1957) *Five years Summary of Thunderstorms* (in Japanese).
- STOUT, G. E., R. H. BLACKER, and K. E. WILK (1960) Hail studies in Illinois relating to cloud physics. *Physics of Precipitation*. Geophys. Mono. No. 5, 360-383.
- TERADA, K., (1935) On the geographical features of the thunderstorms in Japan (in Japanese) Jour. Met. Soc. Japan. Ser. II. **13**. 245-255.
- Tōkyō Meteorological District Office (1966): On the hailstorm of 7 June, 1966. Report of Unusual Weather. (in Japanese).
- U. S. Weather Bureau (1947): *Thunderstorm rainfall*. U. S. W. B. Hydromet. Report No. 5.

わが国における降ひようの特徴

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1954—1964の11年間の資料を用いて、全国の降ひよう頻度分布を調べた。この期間中に降ひようの多かったのは北海道北西部、東北地方日本海沿岸及び関東北部・西部山岳地帯の三地域で、一方関東以西の太平洋岸では全く降ひようを観測しなかつた地点が少なくなかつた。降ひよう頻度の分布は寒候期(10月～3月)と暖候期(4月～9月)とで明瞭な差がある。寒候期には日本海沿岸が多ひよう地帯となり、暖候期には内陸に多い。北日本の日本海側では降ひよう日数が多いにもかかわらず農作物のひよう害が少ない。これは降ひようが主として寒候期に発生する事、及びひようが小粒である事によると考えられる。

降ひよう頻度の年変化は大きく三つの型に分類される。内陸及び本州太平洋側では初夏に著しい極大がある一山型、北海道及び本州日本海側では春と秋に明瞭な極大がある二山型の変化をする。西日本の資料からは初春、夏、初冬に極大のある三山型の変化が得られた。し

かし、統計年数が短く、降ひよう回数の絶対値が小さいことから、この分布がどれ程信頼できるものかは不明である。

次に、日本海側多ひよう地帯にある秋田、酒田および関東北部多ひよう地帯にある前橋、中宮祠の観測資料を整理して、寒候期および暖候期の降ひようの特性を調べてみた。それによると寒候期の降ひようは殆んど日変化がなく、雷を伴わない場合が少なくない。一方暖候期の降ひようは主として午後に観測され、殆どが雷雨に伴って発生していることがわかつた。以上の事から寒候期と暖候期の降ひよう系の発生機構に差があるのではないかと考えられる。また、寒候期の降ひようの前後にしばしばあられおよび凍雨が観測されており、これ等との成因、性質の差についても更に詳しい研究が望まれる。

最後に降ひよう頻度の長期変動および我が国と米国における降ひようの特徴の類似点について簡単に述べた。

支 部 だ よ り

1. 信州支部第14回研究発表会ひらかる

42年10月3日、長野農試で開かれ、多数(100名以上)参集のもとに盛裡に終了した。

研究発表

1. 水稻の反収と気象との関係 樺沢(長野気象台)
2. 作況試験からみた本県稲作の特色
丸山(長野統調)
3. 収量構成からみた最近の長野県の稲作
坪井(長野統調)
4. 水稻の障害型冷害に関する研究
田島(長野農試)
5. 日本における水稻多収穫栽培からみた増収理論
飯田(長野農試)

シンポジウム

長野県における米の増収と気象要素

座長 古閑(長野統調)

2. 近畿支部大会ひらかる

42年11月12日、甲南小学校(神戸市)でひらかれ、多

数参集のもとに盛会裡に終了した。

研究発表

1. 植物体と大気との物質交換に関する研究(1) — 葉面上の境界層について
矢吹・石橋・宮川°(大阪府大)
2. 植物用人工光源に関する研究(1) 光質と光合成との関係 矢吹°・石橋・高・西内(大阪府大)
3. 空気中の CO₂ 濃度とレタスの生育・収量
織田°・矢吹・今津(大阪府大)
5. 運動量・熱量および水蒸気量輸送のスペクトル的考察 佐橋(京大理)
5. 地表面の熱収支と地面(水面)温度との関係
東(京都府大)
6. 群落光合成と光入射角の關係の理論的解析
黒岩(京大)
7. 水稻の風害対策(立毛結束2条刈刈取法)
西内°・上和田(大阪府大)
8. ワシントン大学に滞在して 佐橋(京大理)
9. 生物季節学の動向 松野(甲南大)