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A synoptic climatology of convective weather in the Netherlands

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Abstract

Six kinds of convective weather phenomena, i.e. thunderstorm, tornado, hail, heavy shower, wind gust and lightning strike, have been examined to compile a synoptic climatology of convective weather in the Netherlands by:

1. determining a climatology of convective weather, and
2. establishing a relationship between convective weather and circulation pattern.

Extreme values of the different convective weather parameters have been established. For example, both the maximal daily rainfall (208 mm) and the maximal hourly rainfall (72 mm in 45 minutes) were caused by convective weather. Severe convective weather may inflict considerable damage and cause casualties. Information gathered on the loss of property and life are presented in this report.
For example: over the last 20 years 32 people were killed and 151 people were injured by four tornadoes. Lightning strike inflicted heavy damage; the average reported losses per year over the period 1961 through 1965 amounted to: 5 people being killed, 8 people being wounded and more than Mfl 1,5 loss in money and property. Moreover lightning initiated almost one hundred fires per year.

We found the following yearly occurrence of severe convective weather phenomena:

1. 2.64 tornadoes, 2.2 tornadic days on average per year.
2. Heavy rain (≥ 80 mm/day): 1.75 days per year.
3. Wind gust (≥ 20 m/s): 11 days per year.
4. Heavy showers (≥ 10 mm/h): 8.2 days; (≥ 25 mm/h): 1.8 days per year.
5. Hail size ≥ no.3 (marble size): 15.5 days; ≥ no.4 (wal - nut): 3.8 days per year.
6. Lightning strikes: 653 per year on 54.5 days per year on average.

Temporal (yearly, monthly and hourly) and spatial variation of convective weather were also investiga-ted.

The relationship between circulation pattern and convective weather indicates that most convective weather occurred in only three main circulation patterns and five sub patterns:

1. Upper air trough (T, no.1), including two sub patterns of South-West flow (Tsw, no.1a) and Nort-West flow (Tnw, no.1b). Most patterns were Tsw, and occurred in 31 days out of 50 days with strong convective weather. Very strong convective weather often occurred in this pattern, e.g. three strong tornadoes, three days with heavy rain (≥ 80 mm/day and ≥ 6 stations) and three days with big hail stones. All nine tornadoes of this investigation were found in this pattern. It means that this pattern is favorable for tornadic occurrence. Almost all high temperature days with convective weather were also found within this pattern; 14 days with maximum temperature ≥ 30 °C and 8 days with maximum temperature ≥ 28 °C.

2. Cold vortex (CV, no.2), including two sub patterns of the

central part (no.2a) and the north part of the cold vortex (no.2b). There were 11 out of 50 days with pattern 2a. More hail days were found in this pattern.

3. Shear line (Sl, no.3). This is the least common pattern: it only occurred 4 out of 50 days. More days with heavy rain were found in this pattern.

I. Introduction

Convective weather phenomena, such as tornado, hail, heavy shower, wind gust, thunderstorm and lightning strike often cause great damage to human life and property. That is why so much attention is paid to this kind of weather. Meteorologists in the Netherlands made many studies of convective weather. There are about one hundred papers and books dealing with tornadoes alone. Nell made the first analysis of a tornado in 1900. Since then almost all stronger tornadoes have been analysed. It is especially worth mentioning that KNMI has published 81 volumes of records and data on thunderstorm, hail, lightning, tornado etc. from 1879 through 1965. These books not only contain very useful data but also many papers dealing with case studies and statistics of damage caused by convective weather. From these data and papers the importance of convective weather in the Netherlands may be analysed.
In this paper we use these data because they gave us an opportunity to include more stations. The data from these synoptic stations were combined with the data from volunteer weather reporters, containing much information on convective weather in detail.
Unfortunately these data have not been published since 1965.
To complete our data records we added fifteen years of data from a Dutch magazine (Weerspiegel).
Ir H.R.A. Wessels kindly provided the data on tornadoes. The data of heavy rainfall were provided by the Climatological Division of KNMI. The Appendix to this Report reviews data sources, periods and the number of stations used.
In order to avoid or minimize damage caused by severe convective weather, good forecasts are essential. Forecasting convective weather requires much systematic research work. In particular a synoptic climatology of convective weather in the Netherlands should be established and a forecasting method should be developed.
In this paper a survey of a synoptic climatology of convective weather in the Netherlands is presented. It includes thunderstorm, tornado, hail, heavy shower, heavy rain, wind gust and lightning strike with their yearly, monthly and daily variation, spatial distribution, intensity variation and the relationship between convective weather and circulation pattern.

II. Extreme values and loss

The damage caused by convective weather phenomena is largely determined by their intensity (in particular its extremes) and their frequency. So both frequency and extreme intensity are important quantities.
From the records we established the following extremes, frequencies and damage:

1. Heavy rain and heavy showers

a. The maximal daily rainfall was 208.0 mm on August 3, 1948 in Voorthuizen.
b. The maximal hourly rainfall was 72 mm in 45 minutes on August 23, 1965 in Goudswaard and on September 6, 1958 in Deventer.
c. The largest scale of heavy rainfall took place between July 3 (08h)-July 4 (08h) 1952.
There were 5 stations reporting 100 mm or more, 14 stations ≥ 80 mm, 89 stations ≥ 50 mm, in total 328 stations.
During this period also big hail fell on a large scale.
These extreme values of rainfall were all caused by heavy showers with thunderstorm.

2. Hail

a. The largest size was 6.3 - 7.5 cm diameter (like a tennisball) on July 11, 1959 in Groningen.
Another one measured 6.8 cm diameter, found on September 6, 1958 in Bennekom.
b. The largest spatial scales are:
- 40 km x 80 km on July 11, 1959,
- on 81 stations on October 16, 1958
- a third of the Netherlands on May 28, 1961.
c. The longest hail period of 14 days took place from april 17 - 30, 1965.

3. Tornado

a. The most serious damage and casualties were inflicted on August 10, 1925 in Borculo: 4 people killed, 200 pe ople wounded, 2000 people homeless and two steeples destroyed.
b. An aircraft encountered a tornado on october 6, 1981 nearby Moerdijk, about 25 km south-south-east of Rotterdam: 17 people were killed, when the aircraft crashed.
c. Over the last 50 years the heaviest damage was on August 23, 1950.
d. Over the last 20 years (1971-1990) the number of killed and injured people increased:
- 7 people killed and 90 injured on August 11, 1972
- 17 people killed on October 6, 1981
- 6 people killed on May 12, 1983
- 2 people killed, 61 injured on July 17, 1983
In total 32 people were killed and 151 people injured.

4. Lightning strike

According to the statistics from 1961 to 1965 the yearly average loss of life or property is as follows:

a. 5 people killed and 8 wounded
b. a financial loss of more than 1,5 million guilders
c. almost 100 fires

III. Temporal and spatial variation

1. Classification

In this chapter six kinds of convective weather phenomena are considered: thunderstorm, tornado, hail, heavy shower, wind gust and lightning strike.

2. Temporal and spatial variation

2.1 Thunderstorm
Fig. 1a and 2a show the yearly variation. The average number of reported thunderstorms per year (1936 - 1965) was 3899; the maximum was 6919 in 1957 and the minimum was 1874 in 1945. The average number of days with thunderstorm was 108 per year, the maximum was 134 in 1960, the minimum was 69 days in 1940. From Fig. 1a it is obvious that the information from before 1966 (KNMI, 1896 - 1965) is incompatible with the information since 1976 and probably reflects the difference in number of stations used.
The monthly variation is very obvious from fig. 3a and 4a; the days with thunderstorm mostly occurred during summer, June till August. During this season there were on average 47 days with thunderstorm, 43% of the average yearly number, but in winter, December till February, only 9 days, 9% of the yearly number. From April till September there were 81 days with thunderstorm, 75% of the yearly number. The October till March season counted only 27 days on average, 25% of the yearly total. From fig. 5a it is clear that the daily variation was different from that of other convective weather phenomena, with a maximum at 20 GMT. From 14 to 23 GMT there was much more thunderstorm activity than during the rest of the day.

2.2 Tornado
a. Temporal variation
The average number per year (1945 - 1969) was 2.6 tornadoes, the maximum was 6 in 1946, 1950, 1964. The minimum was 0: no tornadoes were observed in 1945, 1951 and 1958. Fig. 1b shows the yearly variation. These thornadoes all caused damage. Fig. 2b shows the number of tornadic days per year. The average number of tornadic days was 2.2 per year. The maximum was 5 days in 1964, the minimum was 0 in 1945, 1951, 1958.
During the last 20 years, the number of the tornadic days is nearly the same, but the number of killed and injured people has increased. For example in 25 years (1945 - 1969) there were only 7 people killed (in 1967), although very strong tornadoes occurred in 1950 and 1967. According to the classification of Fujita these tornadoes belong to F3 causing heavy damage. But in recent 20 years (1971 - 1990) 4 tornadoes killed 32 people and 151 people were wounded. These events tell us that all tornadoes can cause damage, not only the stronger ones.
Fig. 3b and 4b show the yearly variation of the tornado number. The maximum was in August. About 0.7 tornado occurred on average in this month. From June to September there were on average 2.1 tornadoes (79% of the whole year). There were 1.8 tornadic days in the same months (78% of the whole year). From fig. 6a (date of tornadic days) we find that tornado occurrences are concentrated between the first of June and the twentieth of September.

There were on average 43 tornadoes, 78% of the yearly number, in this period of 112 days.
Fig. 5b gives the daily variation of tornadic number, with a maximum around 15 GMT. Most tornadoes were observed in the period 8 - 21 GMT, during daylight. Almost no tornadoes were observed between 22 and 7 GMT.

b. Spatial distribution
Fig. 6b indicates the locations where tornadoes occurred in the period 1945 - 1969. Concentrated regions are Friesland and Zuid-Holland.
For some tornadoes (≥ F3) also their paths are shown, these strong tornadoes mostly occurred inland.
When we compare the distribution of tornadoes in the period 1945-1969 with that of 1882 - 1925 (Everdingen, E. van, 1925), we find that in this earlier period tornadoes frequently haunted Zeeland and Friesland and remarkably spared the N.E. part of Groningen and Dutch Flanders.

2.3 Hail
a. Temporal variation
The average number of hail reports per year (1936 - 1965) was 875 (fig. 1c and 2c), the maximum was 1419 in 1952, the minimum was 396 in 1963. The yearly average number of days with hail was 114, the maximum was 153 (in 1952), the minimum was 78 days (in 1963).
The yearly variation of hail occurrence differs from that of thunderstorm (see fig. 3a, 3c and 4a, 4c). In winter and spring hail occurred more frequently than in summer. This is caused by the fact that temperature in winter and spring is more favourable for developing soft hail. Generally speaking, soft hail without thunder is not caused by convective weather however.
In order to distinguish non-convective hail from convective hail, we looked at hail accompanied by thunderstorm.
Fig. 7 shows the yearly variation of hail accompanied by thunderstorm. The average yearly number of days with hail accompanied by thunderstorm was 63, 55% of all hail days. Hail with thunder was concentrated in the warmer seasons. The monthly maximum was 9 days in July, the minimum was 2 days in February.
In summer (June-August) hail with thunder occurred on 24 days on average, which is 37% of the yearly total. From May to September, there were 37 days, 59% of the yearly total, in the other seven months only 26 days, 41% of the whole year.
Fig. 5c shows the daily variation of hail occurrence, the maximum was at 15 GMT, most hail occured between 11 - 19 GMT.

A number of synoptic stations show no hail reports at all in summer. For example in De Bilt or De Kooy, no hail was reported between June and August (1951 - 1980). This is caused by the fact that hail often is a very local phenomenon. Therefore, in order to study the spatial and temporal distribution of hail, we must combine the data from volunteer weather reporters with the data from synoptic stations. Actually most heavy damage caused by hail occurred in summer in the Netherlands.

b. Classification of the size of hail
In the weather reports, hailstone diameter is classified in five classes, as shown in Table 1.

Table 1. the size of hailstones.

Class	Example	Diameter (mm)
1	Pea	1 - 5
2	Bean	6 - 10
3	Marble	11 - 20
4	Walnut	21 - 40
5	Egg Small	41 - 50
	Big	51 - 60

Fig. 8 shows the distribution of the five hailstone size classes for hail accompanied by thunderstorm.
Fig. 9a and 9b show the yearly variation of hail of classes ≥3 and ≥4. On average there were 15.5 days with hail of size ≥3. The maximum was 3.1 days in July. From May to August, there were 9.4 days, 61% of the yearly total.

There were 3.8 days with size ≥4. The maximum was 1.1 days in July. From May to August there were 2.7 days, 71% of the year's total. From November to February only 0.1 day on average had hail.

c. Spatial extension of hail
Fig. 10a to 10d show the yearly variation of the number of stations reporting hail accompanied by thunderstorm. There were 51.2 days on average with ≥ 2 stations reporting hail, 31.2 days with ≥ 5 stations on average, 18.5 days with > 10 stati-ons, 8.7 days with ≥ 20 stations.

2.4 Heavy rain and heavy showers
a. Heavy rain
There were 120 cases in 124 years with a rainfall amount of ≥ 80 mm/day (1866 - 1989). Almost all cases were caused by convective weather, i.e. heavy showers with thunder-storms.
Since 40 years more than 300 stations do measure daily rainfall in the Netherlands, many more than in the 40 years before. So for analysis we selected the data from the last 40 years. Fig. 1d shows the number of reports of rainfall ≥ 80 mm/day for each year. The average number was 1.75, but there was considerable variation from year to year. The lar-gest amount fell on July 3 (08h) - 4 (08h) 1952, 14 stations reporting an amount of rain ≥ 80 mm during that day. It caused great loss of life and property: 1 person, 104 cows and horses were killed; 5 houses, 34 farms and 20 sheds were destroyed.
The minimum number of reports per year with ≥80 mm/day was 0. A period of several years without rain-fall of ≥ 80 mm/day is possible.
From the yearly variation (fig. 3d) we can see that most heavy rain occurs in summer. The maximum was 53 reports in July, 44% of the yearly total. There were 84 reports between July and August, 70% of the yearly total. There were 110 reports from June till September, 92% of the year-ly total. In the other eight months only very little heavy rain occurred.

b. Heavy showers
We divide heavy showers into three classes:

1. 10 - 24.9 mm of rainfall in one hour
2. 25 - 49.9 mm of rainfall in one hour
3. 50 mm rainfall or more in one hour

Fig. 2d shows the occurrence of these classes for each year (from 1956 - 1965 at 30 stations in the Netherlands). The average is 8.2 days per year with the distribution over the different classes shown in fig. 12.

Fig. 4d shows the yearly distribution of heavy showers. The maximum was 3.1 days in July, 6.8 days of heavy shower occurred from June to August, 83% of the yearly total.
Fig. 5d shows the daily variation.

2.5 Gales and gusts
a. Gales
Fig. 1e shows the reported number of gales in summer over 25 years. The standard is the average windscale ≥ 8 Beaufort. Although gales cannot be classified as convective weather, there is certainly a relationship between the occurrence of gales and convective weather.

b. Gusts
Gusts, defined here as a sudden violent rush of wind with a maximum windspeed equal to or more than a certain predefined windspeed, may be caused by showers, squall lines or tornadoes, sometimes accompanying thunderstorms. This kind of strong convective weather often causes damage.
Data were available only on gusts accompanying thunderstorms, so Figs.2e-5e refer to this type of gusts only. Two windspeed criteria were used. The first criterium, referred to in Figs. 2e-3e, is a maximum windspeed equal to or more than 20 m/sec.
Fig. 2e shows the reported number of such gust cases over 10 years. The average number per year was 10.8 days (1956 - 1965, 20 - 30 stations in the Netherlands). The maximum was 18 days in 1959, the minimum was 4 days in 1965. From month to month (Fig. 3e) the maximum was 2.3 days in July, followed by 2.0 days in August. The cases from July till August form 40% of the year's total. Fig. 3e shows the yearly variation of gusts.
Fig. 4e shows the gust days with thunderstorm (1976 - 1990), the criterion is different from fig. 2e and fig. 3e. It is defined by the SYNOP ww-code 17: the windspeed suddenly increases by 8m/sec and at the same time reaches 11 m/sec. or more. Fig. 4e shows that this occurs most frequently in June and May, least frequently in December and November.
Fig. 5e shows the daily variation of the gust reports.
Gusts were concentrated between 13 and 20 GMT.

2.6 Lightning strike
Lightning strike is defined as lightning striking the ground and causing damage. Every year this kind of lightning kills 5 people, injures 8 people and causes a loss of 1.5 million guilders in the Netherlands. Figs. 1f and 2f show the num-

ber of reports through the years. The average yearly number was 653, the maximum was 1327 in 1957, the minimum was 136 in 1945. The average number of days on which lightning strike was reported was 54.5 days per year, the maximum was 73 days in 1950, the minimum was 25 days in 1941. Fig. 3f and 4f show the yearly variation. The highest number was 210 in July, the maximum number of days was 10.4, also in July. Lightning strike days concentrated in the summer season. The total was 28.7 days, 53% of the year total. There were 45.7 days in the period from May to Septem-ber, 84% of one year, only 16% in the other seven months. Fig. 5f shows the daily variation of lightning strike number, the maximum was 110 at 15 GMT. Most lightning strikes are observed in the afternoon. There were 690 lightning strikes, 59% of the whole year, in the period from 12 to 20 GMT. The minimum was 21 at 1 GMT.

3. Relation between several kinds of convective weat-her phenomena

Most convective weather phenomena occur in nearly the same conditions. As a result different phenomena often coincide.

3.1 Heavy shower and hail

Out of a total of 82 days with heavy showers (≥ 10 mm/h), 70% was accompanied by hail. Out of 18 days of very heavy showers (≥ 25 mm/h), 78% was accompanied by hail.

3.2 Tornadoes and others

From the 54 tornadoes during 1946 - 1965, 49 tornadoes (91%) were accompanied by thunderstorm, 45 tornadoes (83%) were accompanied by hail, 11 tornadoes (11/27 = 41%) by heavy shower. Actually this last number is probably higher than 41%, because there is no report if the rainfall is less than 10 mm/h.

IV. The relationship between circulation pattern and convective weather

We have selected 50 cases of strong convective weather including tornadoes, hail and big showers and we looked at the corresponding circulation pattern and weather systems. Most convective weather occurred only in certain circulation patterns and weather systems. There were three main circulation patterns and five subpatterns; figs. 13 to 15 show these circulation patterns.

Bijvoet and Schmidt 1958) compiled a climatology of the Netherlands according to a classification of the circulation types in Europe (Gross Wetter Lagen: GWL). We tried to classify cases of strong convective weather according to these circulation types but found that this system does not reflect very well the occurrence of convective weather in the Netherlands. A new, simple and clear, classification of circulation types is proposed instead, suitable to classify cases of convective weather. It consists of three main circulation patterns and five sub-patterns, as shown in figs. 13-15. They are defined as follows:

1.Upper air trough (T)
This type shows an upper air trough accompanied by cold air above England. Two subpatterns may be distinguished:
1a Tsw
The Netherlands is ahead the upper air trough, South West flow above the Netherlands; (figs. 13a, b)
1b Tnw
Upper air trough is situated above England or the Atlantic Ocean, North West flow above the Netherlands. (figs. 13c, d)

2.Cold Vortex (Cv)
This type shows a cold vortex moving very slowly, or even stationary, above the Netherlands. At the surface sometimes cold fronts exist, sometimes not, but convective weather occurs often continously in this situation.
Again two sub-patterns may be distiguished:
2a (Cvs)
the Netherlands is located in the central or south part of the cold vortex; (figs. 14a, b)
2b (Cvn)
the Netherlands is located in the North part of the cold vortex. On the surface weather map a warm front moves to the West, bringing heavy showers or rain to the Netherlands (figs. 14c, d).

3.Shear line (Sl)
Over the Netherlands there is a shear line of wind direction in the upper air. Because of the convergence, heavy rain or hail often occurs in this circulation pattern. (figs. 15a, b)

The relationship between circulation pattern and convective weather will be investigated in a second report (Dong, 1993). Here we summarize some first results:

1. Most patterns, related to convective weather, were Tsw (31 days, 62%), the Cv patterns came second on 11 days (22%), and Sl came last on 4 days (8%).

2. Tornadoes often occurred in Tsw patterns.

3. The highest temperatures are found in Tsw pattern, with 14 days with maximum temperature ≥ 30 °C and 8 days with maximum temperature ≥ 28 °C.

4. Very strong convective weather phenomena often took place in Tsw patterns. There were three strong tornadoes, three cases of heavy rainfall (≥ 80 mm/day, ≥ 6 stations) and three big hail cases, all in this pattern. In these nine days, there were six days with maximum temperature ≥ 30 °C, two days with maximum temperature between 28 °C and 30 °C, one day with maximum temperature between 26 °C and 28 °C.

5. More hail days occurred in cold vortex (Cv) and also in Tnw pattern. The longest hail days were caused by cold vortex.

6. More heavy rain days occurred in shear line pattern.

Table 2 circulation pattern and convective weather

Pattern	no.1 Upper air trough		no. 2 Cold vortex		no.3 Shear line	
Sub Pattern	no. 1a Sw. flow	no. 1b Nw flow	no. 2a Centr.part	no. 2b North part		total
Occurred tornado	9 29%					9
Occurred hail	14 45%	2 100%	8 73%	1 50%	1 25%	26
Occurred heavy rain	8 26%		3 27%	1 50%	3 75%	15
Total	31 62%	2 4%	11 22%	2 4%	4 8%	50 100%

V.Conclusions

1. A general synoptic climatology of convective weather in the Netherlands is presented. In this paper, in order to obtain meaningful results, we combined the data from synoptic stations with volunteer weather reports. For example, in summer, we cannot find any hail reports from synoptic stations, but we found 23.5 hail days in summer (June - August) from volunteer reports. The same applies for tornadoes. This is caused by the local characteristic of convective weather phenomena.

2. There are several kinds of convective weather in the Netherlands, that can cause damage:

- Tornadoes: the average number of cases was 2.64 per year, the average number of tornadic days was 2.2 per year;
- Heavy rain: (≥ 80 mm/day) 1.75 days per year.
- Gust (≥ 20m/s) 11 days per year.
- Heavy showers: ≥ 10 mm/h) 8.2 days; ≥ 25 mm/h 1.8 days per year.
- Hail size: ≥ no. 3 (marble 1.6 - 2 cm) 15.5 days; size ≥ no.4 (walnut 2.6 - 3.1 cm) 3.8 days in each year.
- Lightning strike: 653 reports on 54.5 days per year.

3. The results in this paper are useful for understanding convective weather in the Netherlands. For instance from the relationship between the circulation pattern and convective weather we can primarily judge whether the weather will be convective or not.

4. In order to avoid or decrease loss, we must pay much attention to strong convective weather.

The Tornado and Storm Research Organisation (TORRO) of the U.K. held the first conference on tornadoes on 29 June 1985 and issued a Statement. This has value for the Netherlands because this country has a comparable climate.

The Statement reads as follows:

"This conference therefore closes with a statement from TORRO intended for national and European agencies concerned with weather and public safety:
It is formally urged that responsible authorities should

1. recognise that tornadoes are a significant weather hazard to which Britain and other European countries are subjected,

2. assess tornado risk probabilities for all European countries (as for the states of the U.S.A.),

3. re-examine building safety standards in the light of tornadic winds especially with regard to major structures such as nuclear power stations, factories manufacturing toxic chemicals, oil refineries, suspension bridges, and many other key structures, and

4. include tornado forecasting as part of national meteo-

rological services, and issue tornado warnings on occasions of possible severe tornadoes (as is done in the U.S.A.)."

In the Netherlands, a considerable amount of work has been carried out. For example, nuclear power facilities are designed to withstand tornadic damage. L.C. Heijboer et al (1987), developed an hourly now-casting and very short-range forecasting system for wind and pressure, R.A.A.M. Ivens presented a statistical method forecasting the maximum wind velocity in squalls and so on.

But still much more work needs to be done, for instance to improve the detection of hail or tornadoes and to better forecast convective weather such as hail, heavy shower, tornado, lightning strike and so on.

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References

. Bijvoet, H.C., en Schmidt, F.H., 1958, Het weer in Nederland in afhankelijkheid van circulatietypen. KNMI De Bilt, Wetenschappelijk rapport, W.R. 58 - 4.

. Delver, A., 1951, De windhozen van 23 Augustus 1950 (Veluwe). Hemel en Dampkring, 49, pp. 121 - 129, 148 - 157.

. Everdingen, E. van, 1925, The cyclone-like whirlwinds of August 10, 1925. Proc. Kon. Akad. v. Wetenschappen, Section of Sciences, 28, pp. 871 - 889

. Feteris, P.J., 1962, On the relations between the characteristics of thunderstorms and various meteorological parameters. Research Report. 's-Gravenhage

. Feteris, P.J., 1965, Statistical studies on thunderstorm situa-tions in the Netherlands. Journal of Applied Meteorology, 4, pp. 178 - 185.

. Forbes, G.S., 1985, Tornadic vortex along the cold front of a baroclinic mesocyclone in the Netherlands, not accompanied by thunderstorms. AMS, prepr. 14 th conf. on severe local storms, Indianapolis Ind., Oct. 29 - Nov. 1, pp. 212 - 215. Boston. Mass.

. Heijboer, L.C. et al., 1989,Description and performance of an hourly nowcasting and very short-range forecasting system. Q.J.R. Meteorol. Soc., 115, pp. 93 - 125.

. Ivens, R.A.A.M., 1987, Forecasting the maximum wind velocity in squalls. Proc. symp. Mesoscale Analysis & Forecasting, Vancouver, Canada, 17 - 19 August 1987, ESA SP - 282 , pp. 685 - 686 Paris

. KNMI, 1879-1881, Onweders in Nederland, waargenomen in ... Publ. 54 I, II.

. KNMI, 1882 - 1887, Waarnemingen van onweders in Nederland. Publ. 57 III - VIII

. KNMI, 1888 - 1895, Onweders in Nederland naar vrijwillige waarnemingen. Publ.69, IX - XVI.

. KNMI, 1896 - 1965, Onweders, optische verschijnselen, enz. in Nederland. Publ.81, XVII - LXXXI.

. Meaden, G.T., and Elsom, D.M. (eds), 1985, Proceedings of the First Conference on Tornadoes, Waterspouts, Wind-devils, and severe storm phenomena. Journal of Meteorology. 10, pp. 177 - 248.

. Pelleboer, J., 1983, Weerboek, Extreme weersituaties van de laatste twee eeuwen in Nederland. Uitgeverij Publiboek/Baart Deurne/Hilversum.

. Roach, W.T. and Findlater, J. 1983, An aircraft encounter with a tornado. The Meteorological Magazine 112, pp. 29 - 49.

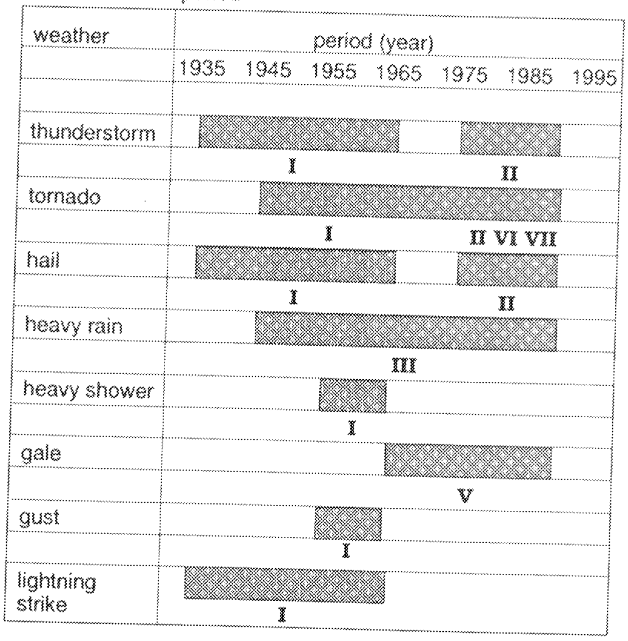
. Speheger, Douglas A, and others, 1990, A climatology of severe thunderstorm events in Indiana, AMS, Prepr. 16th Conference on severe local storms, Kananaskis Park, Alta., Canada, Oct. 22 - 26, 1990. pp. 18 - 23. Boston. Mass.

. Weerspiegel: maandblad voor weer geïnteresseerden, uitgegeven door de Werkgroep Weer-amateurs. 1976 - 1991.

. Wessels, H.R.A., 1968, De zware windhozen van 25 juni 1967 (Chaam, Tricht). Hemel en dampkring, 66, pp. 155 - 178.

Appendix

Data source and period



I. KNMI, 1896 - 1965, Onweders, optische verschijnselen, enz. in Nederland. Publ. '81
These data came from 321 stations (average number 1936 - 1965), distributed over the years as follows:

Year	1936	1937	1938	1939	1940	1941
	1942	1943	1944	1945	1946	1947
	1948	1949	1950			
Number of stations	238	249	270	292	230	224
	240	232	272	221	290	264
	286	309	348			

Year	1951	1952	1953	1954	1955	1956
	1957	1958	1959	1960	1961	1962
	1963	1964	1965			
Number of stations	320	305	323	390	361	410
	414	397	381	409	386	394
	392	402	381			

II. Weerspiegel, onweer, hagel, windstoten, tornado. 1976 - 1990.
These data came from 60 - 80 stations.

III.KNMI, KD, Neerslag Datum Locatie.
These data came from 300 stations (1950 - 1989).

IV.Wessels, Tornado Data (1945 - 1969).

V. KNMI publicatie nr. 176 Stormen kalender 1990.
These data came from 23 stations.

VI.Jan Pelleboer weerboek, 1983.

VII Newspapers in the Netherlands (1970 - 1990)

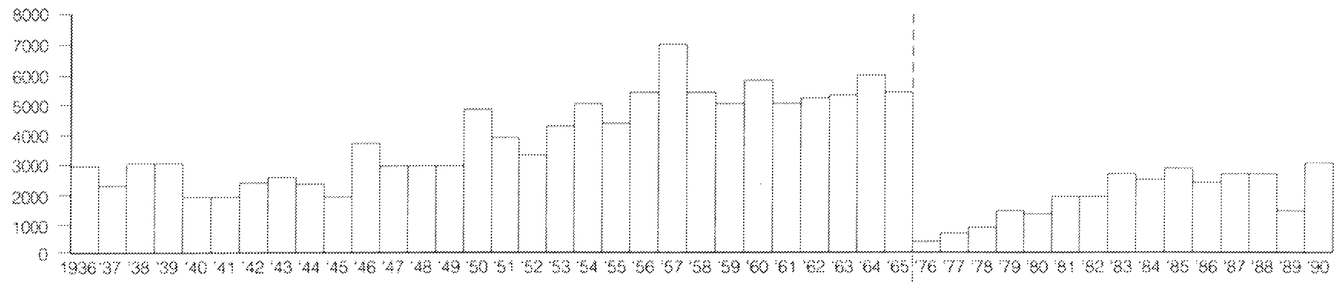


Fig. 1a Thunderstorm: number of reports per year

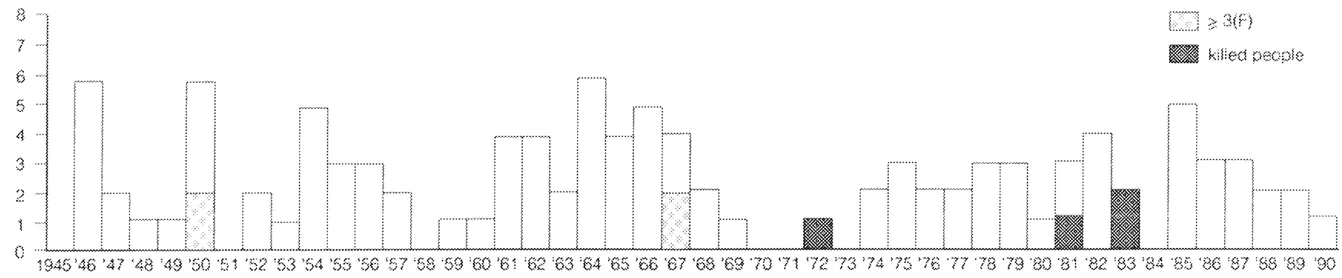


Fig. 1b Tornadoes: number of reports per year

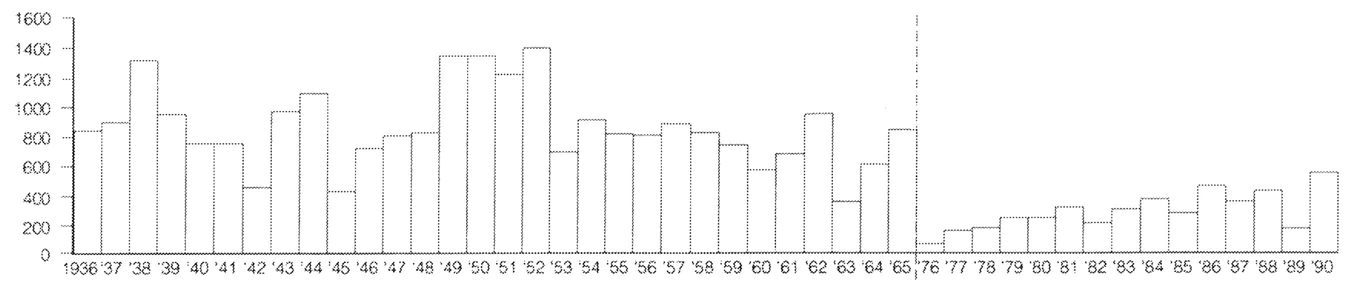


Fig. 1c Hail: number of reports per year

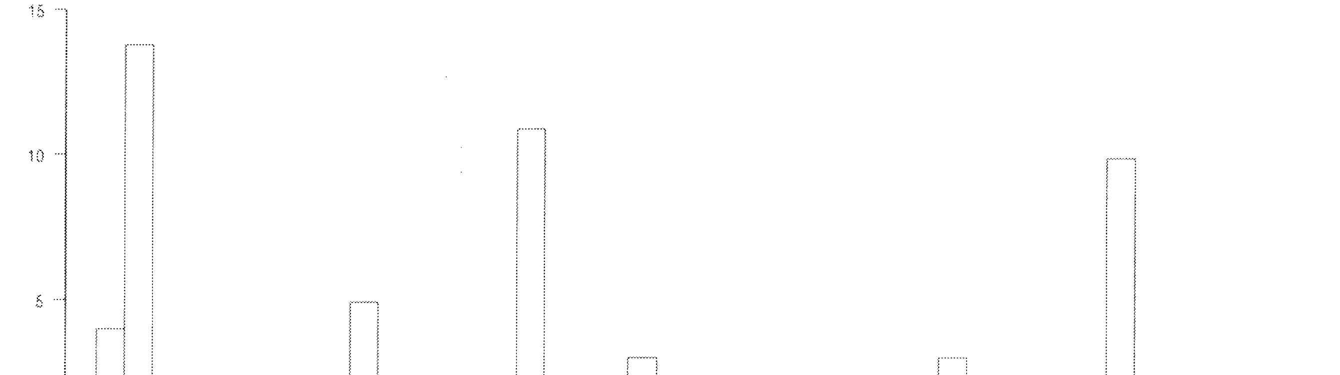


Fig. 1d Heavy rain (≥ 80 mm/day) number of reports per year.

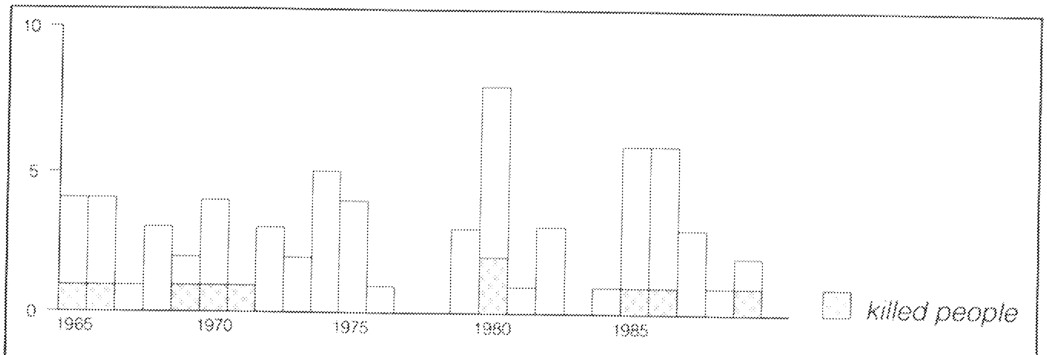


Fig. 1e Gale (≥ 8 Bft): nummer of reports per year (summer only)

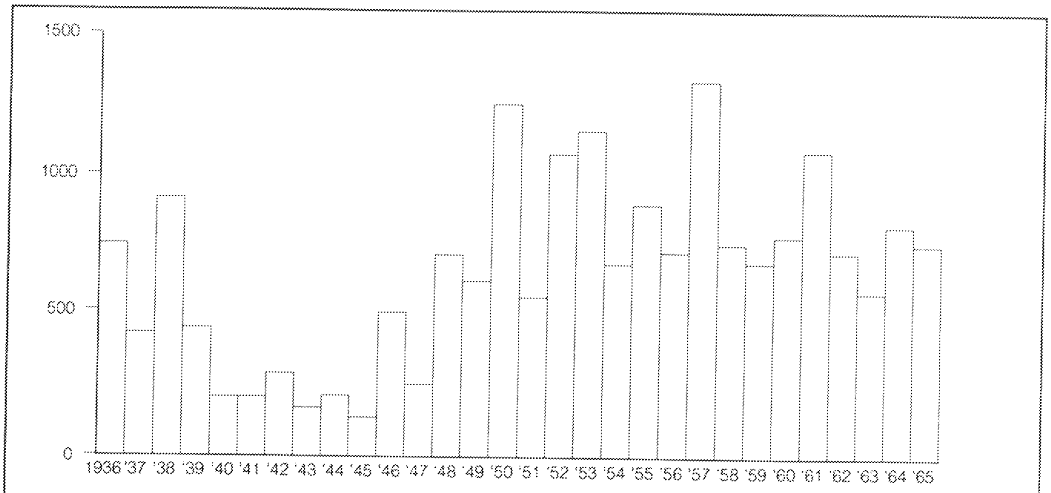


Fig. 1f Lightning strikes: number of reports per year

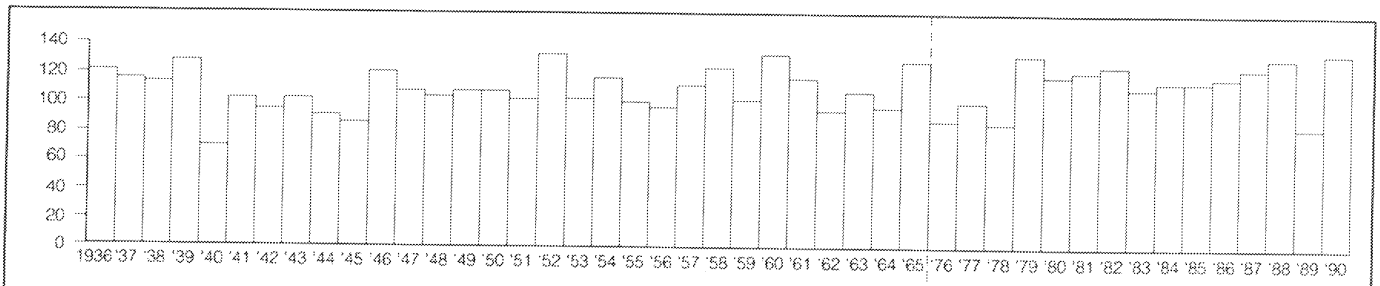


Fig. 2a Thunderstorm days per year

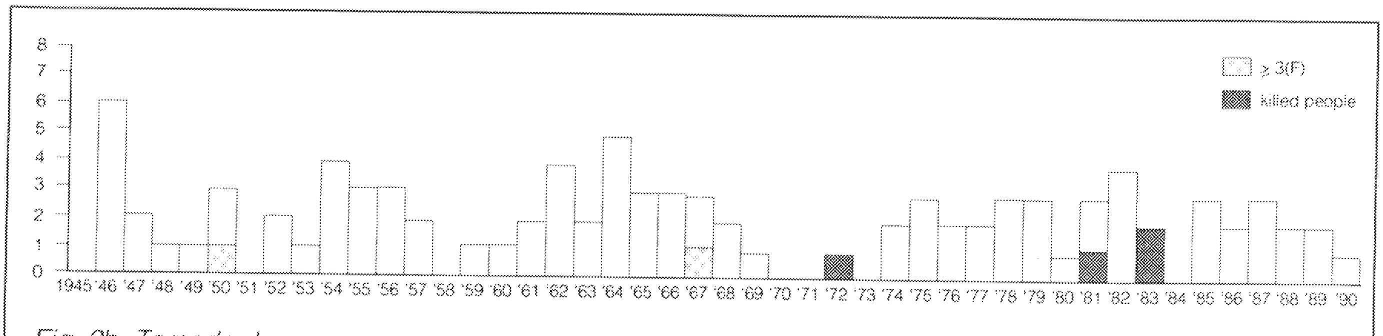


Fig. 2b Tornado days per year

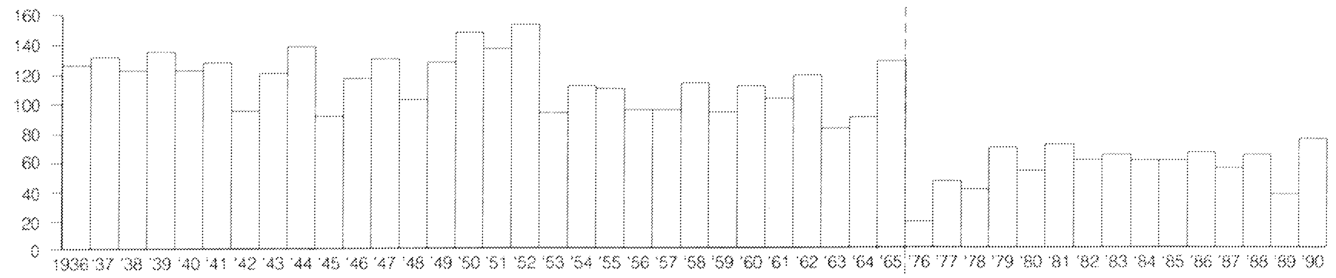


Fig. 2c Hail days per year

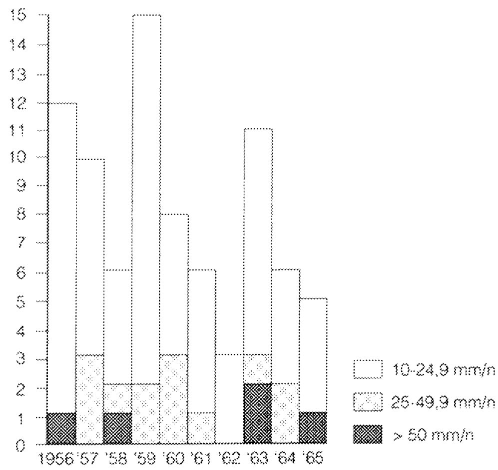


Fig. 2d Heavy shower days per year

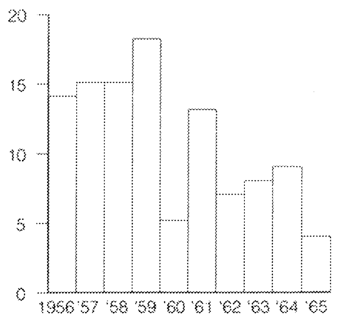


Fig. 2e Gust (⩾20 m/sec) with thunderstorm number of days per year

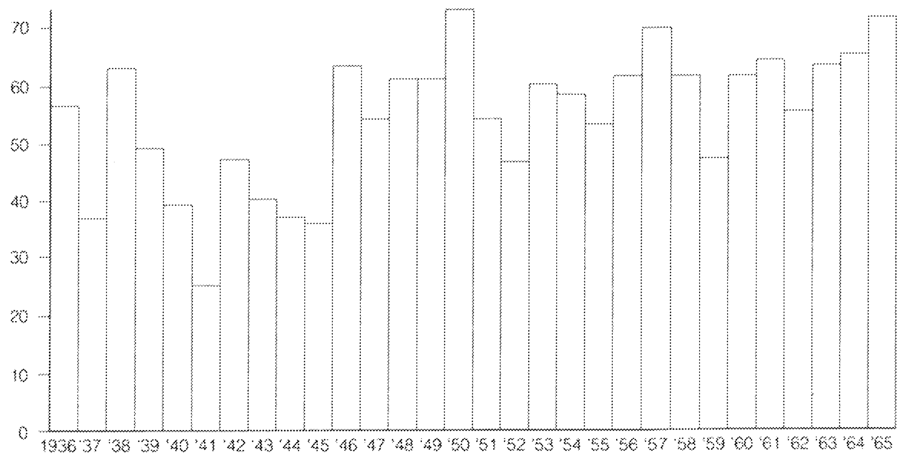


Fig. 2f Lightning strike days (ϟ) per year

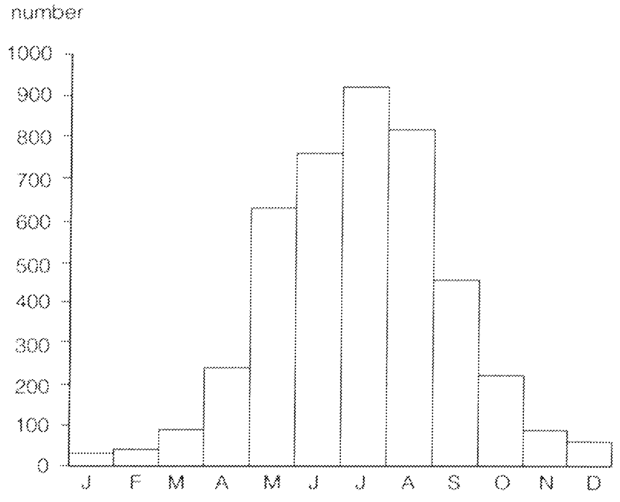


Fig. 3a Yearly variation of thunderstorm number

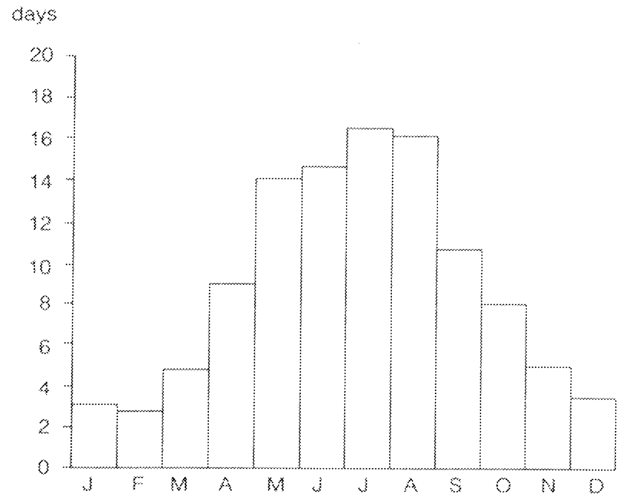


Fig. 4a Yearly variation of thunderstorm days

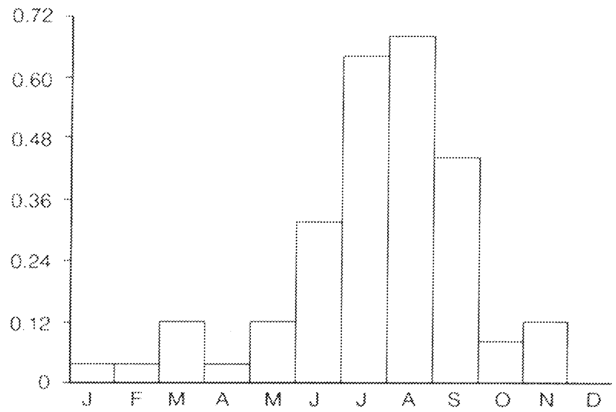


Fig. 3b Tornado number per month

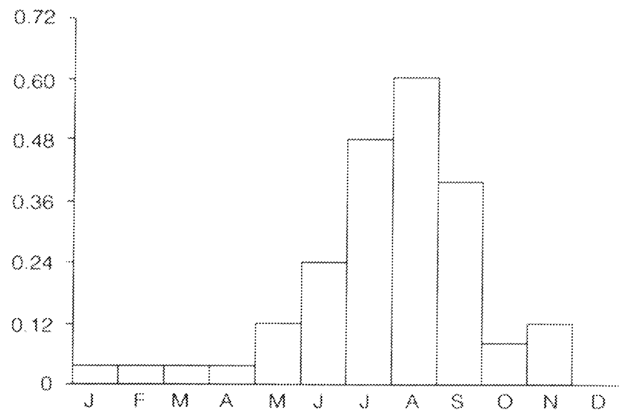


Fig. 4b Tornado days per month

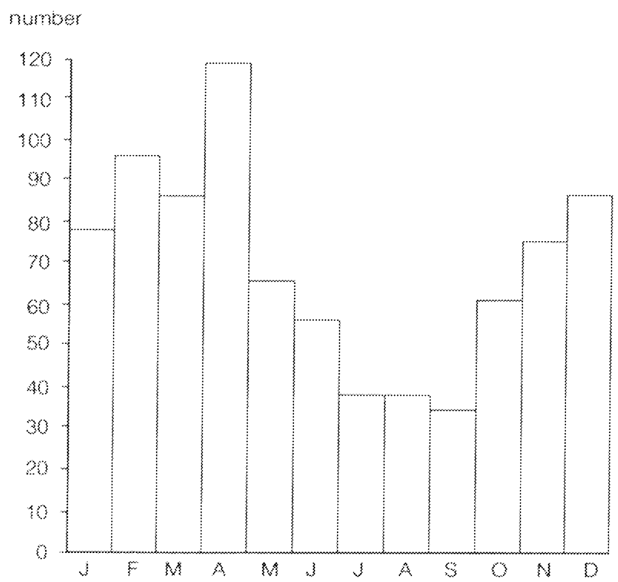


Fig. 3c Hail number per month

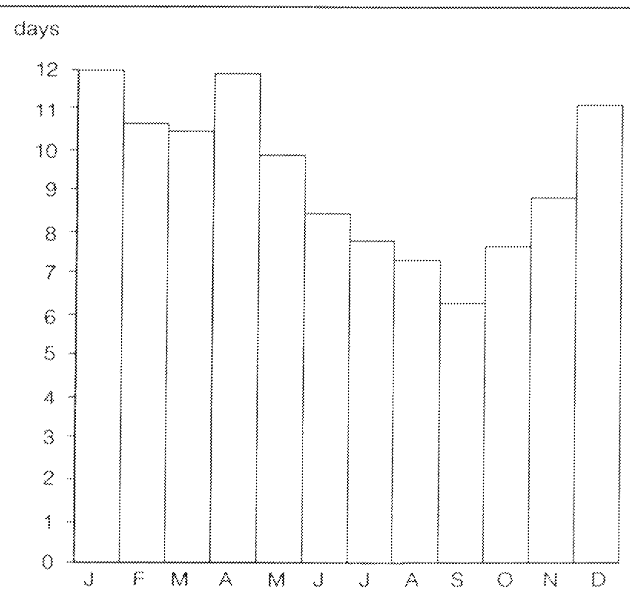


Fig. 4c Hail days per month

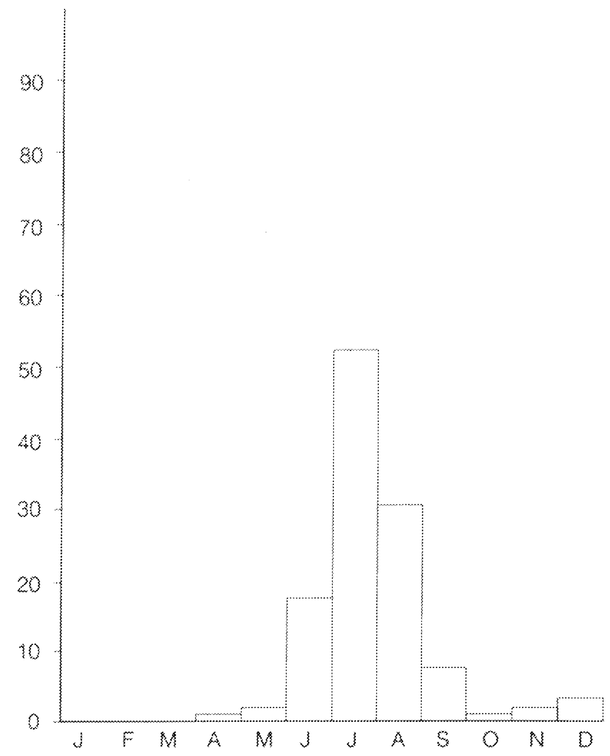


Fig. 3d Number of heavy rain ≥ 80 mm/day by month

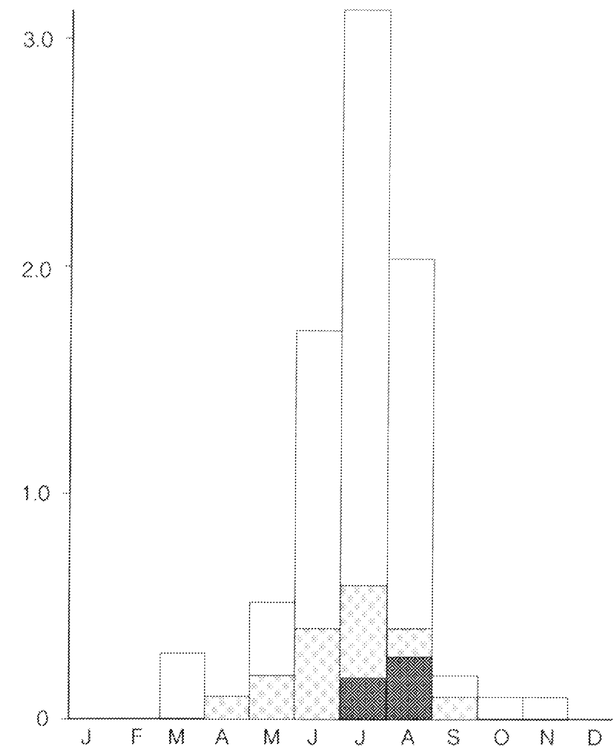


Fig. 4d Heavy shower days

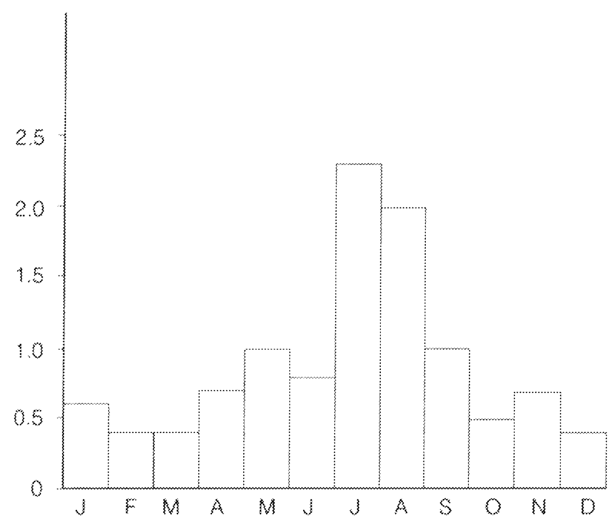


Fig. 3e Gust (≥ 20 m/sec) with thunderstorm: number of days per month (1956-1965)

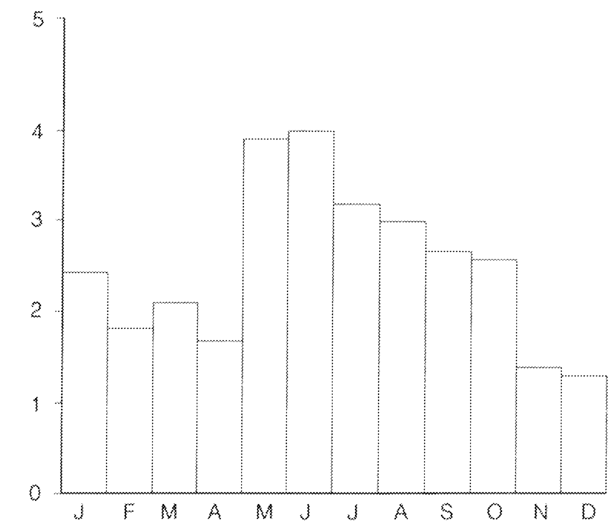


Fig. 4e Gust (ww=17) with thunderstorm number of days per month (1976-1990)

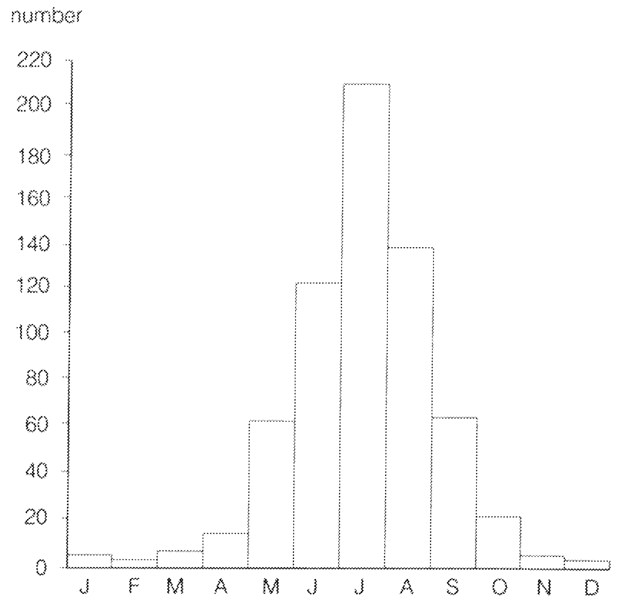


Fig. 3f Lightning strike number per month

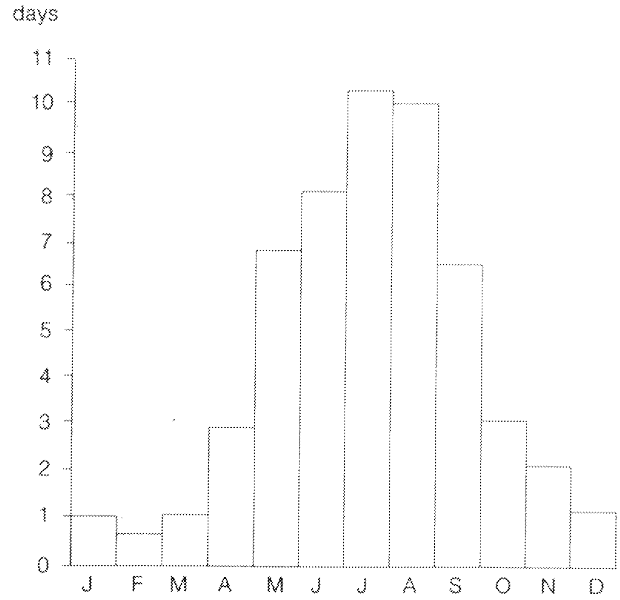


Fig. 4f Lightning strike days per month

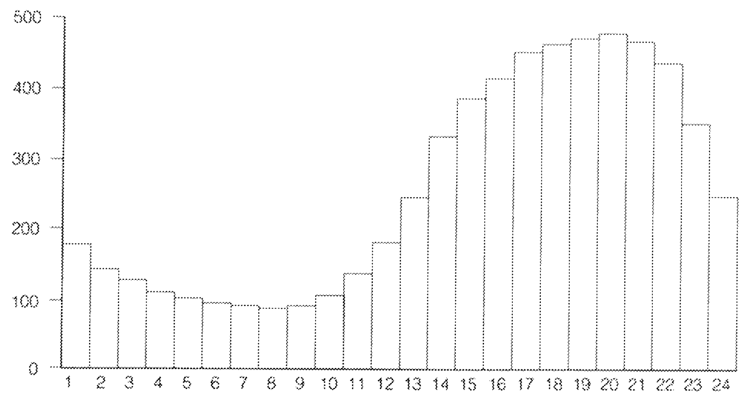


Fig. 5a Thunderstorm number by hour

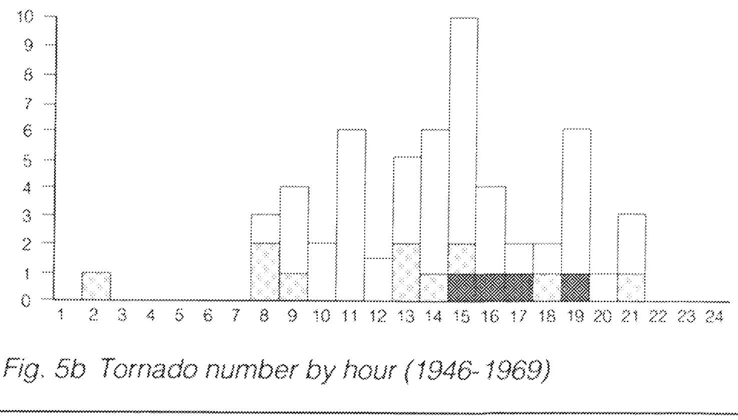


Fig. 5b Tornado number by hour (1946-1969)

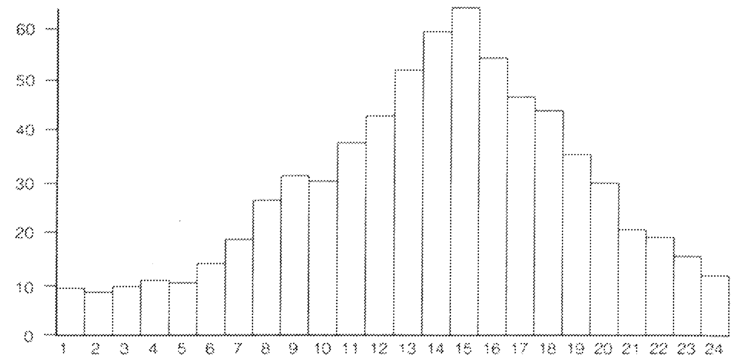


Fig. 5c Hail number by hour

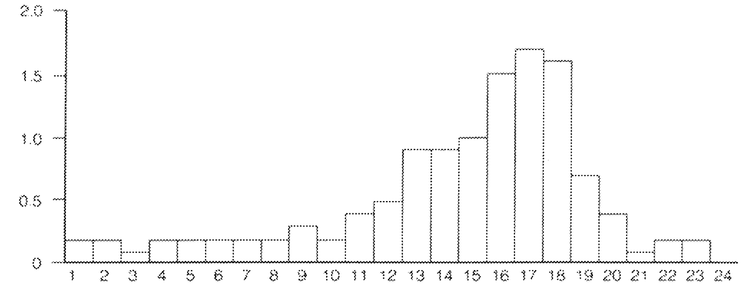


Fig. 5d Number of heavy shower by hour

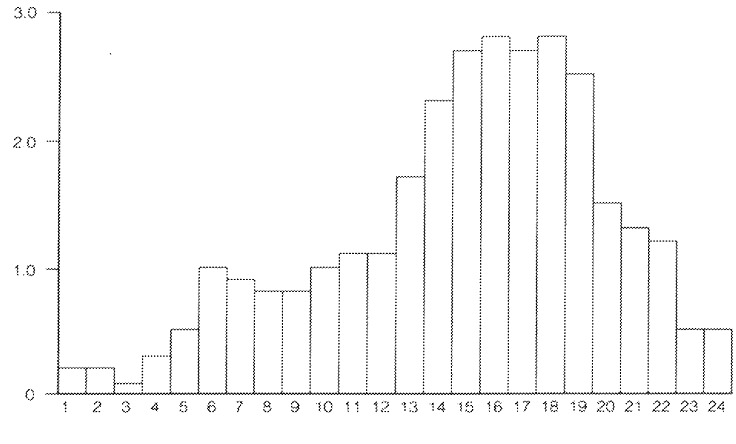


Fig. 5e Gusts with thunderstorm by hour

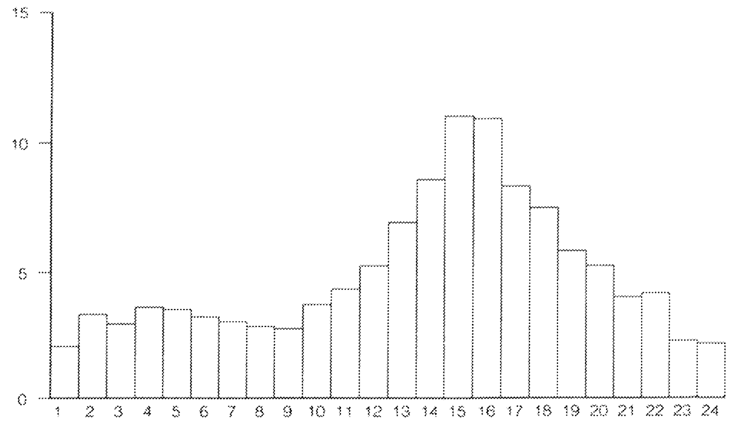


Fig. 5f Lightning strike number by hour (ϟ)

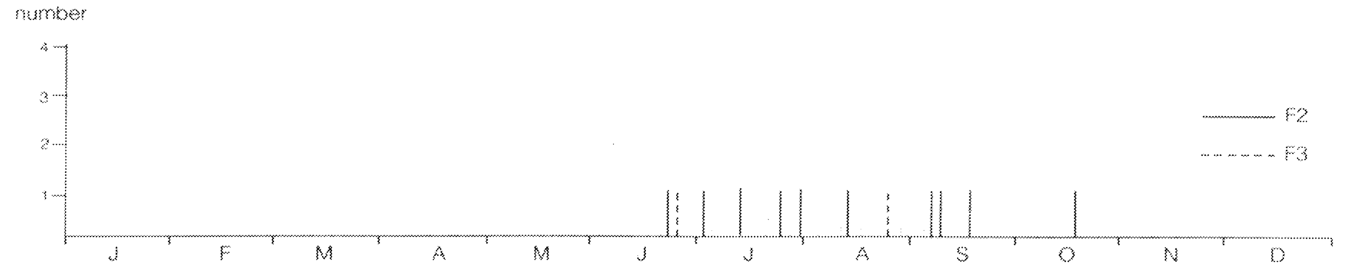


Fig. 6a The date of tornadoes (1945-1969)

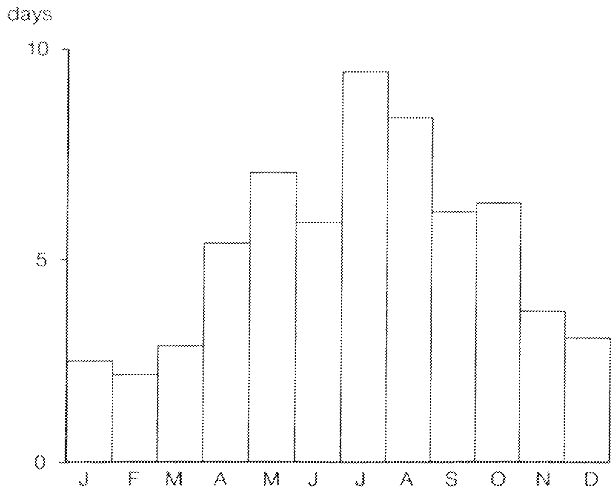


Fig. 7 Days of thunderstorm with hail by month

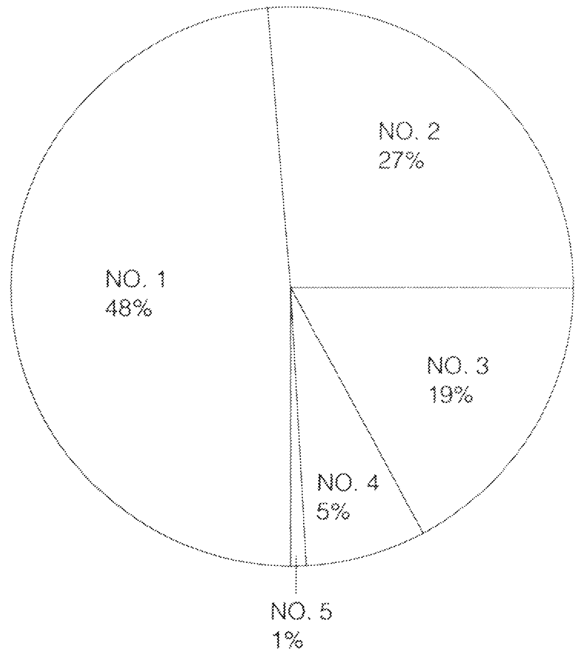


Fig. 8 Distribution of hail diameter classes

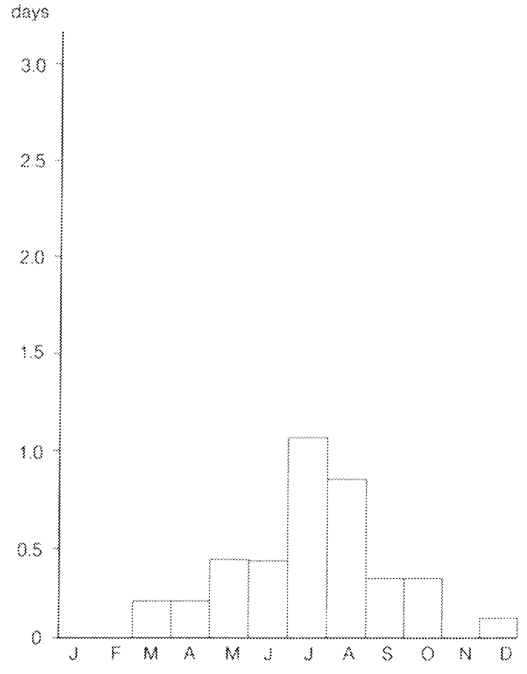


Fig. 9a Hail days of the size ≥ no. 4 (walnut 2.1-4.0 cm)

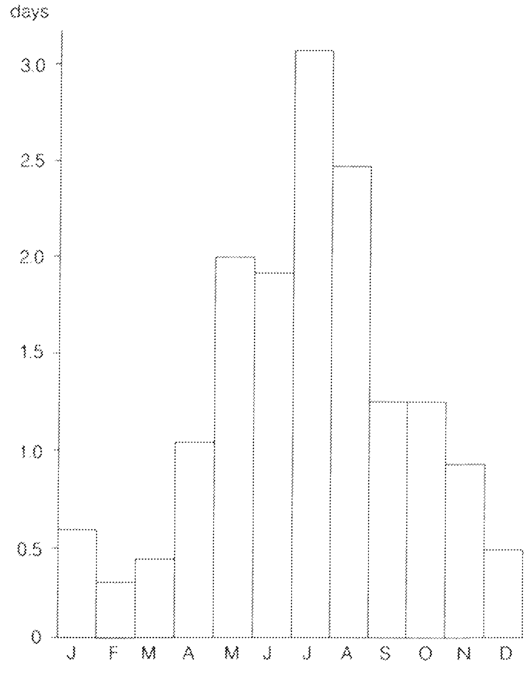


Fig. 9b Hail days of the size ≥ no. 3 (marble 1.1-2.0cm)

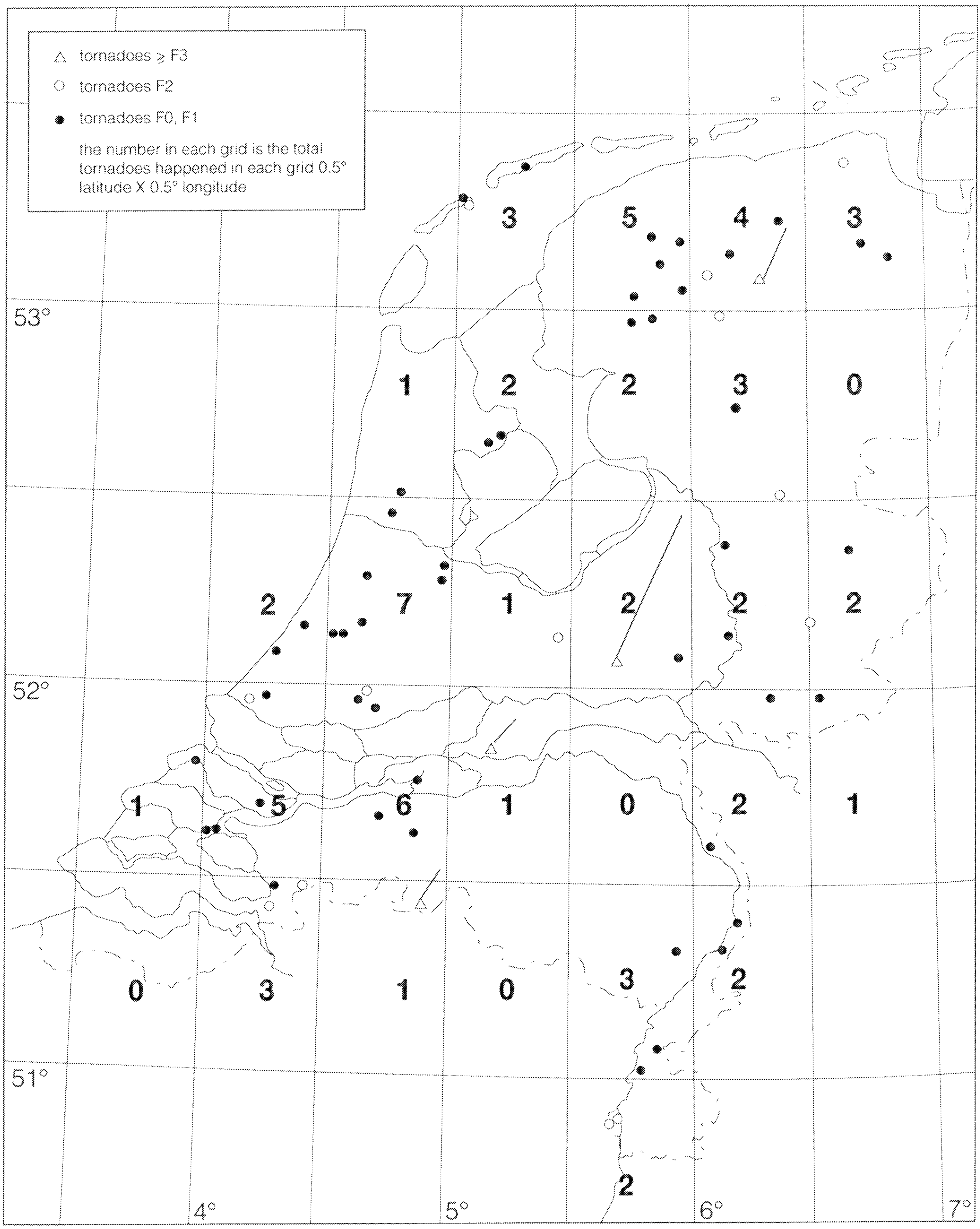


Fig. 6b Distribution of tornadoes in The Netherlands (1945-1969)

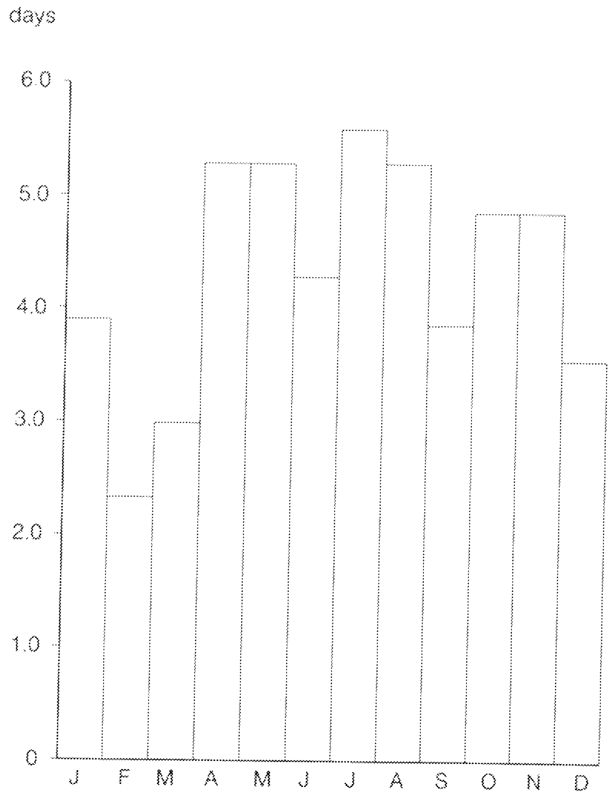


Fig. 10a Hail scale ≥ 2 stations with thunderstorm

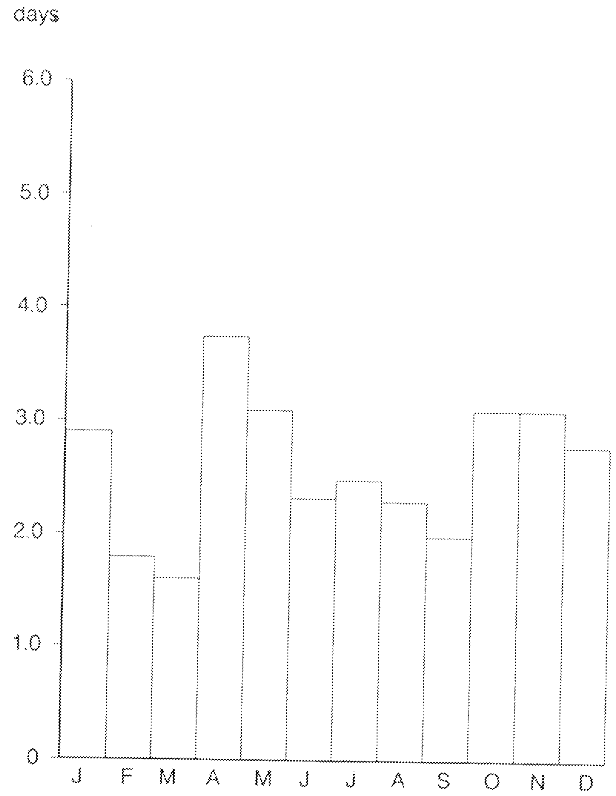


Fig. 10b Hail scale ≥ 5 stations with thunderstorm

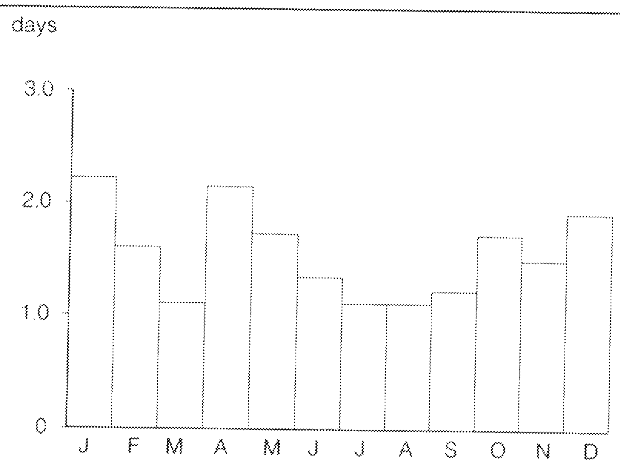


Fig. 10c Hail scale ≥ 10 stations with thunderstorm

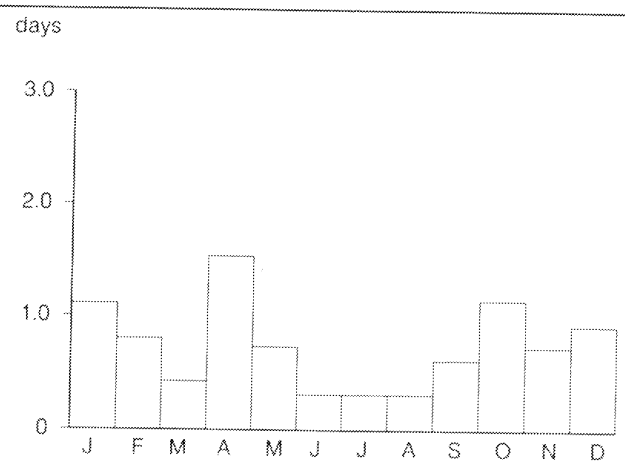


Fig. 10d Hail scale ≥ 20 stations with thunderstorm

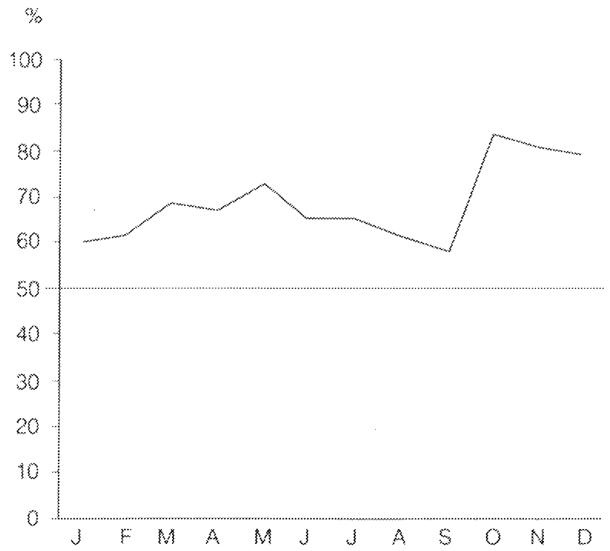


Fig. 11 Percentage of the persistent hail days (≥ 2 days)

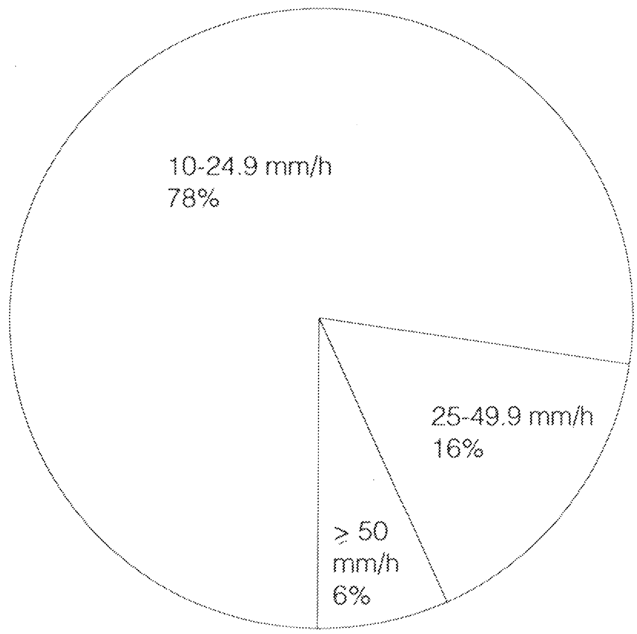


Fig. 12 Percentage of heavy showers

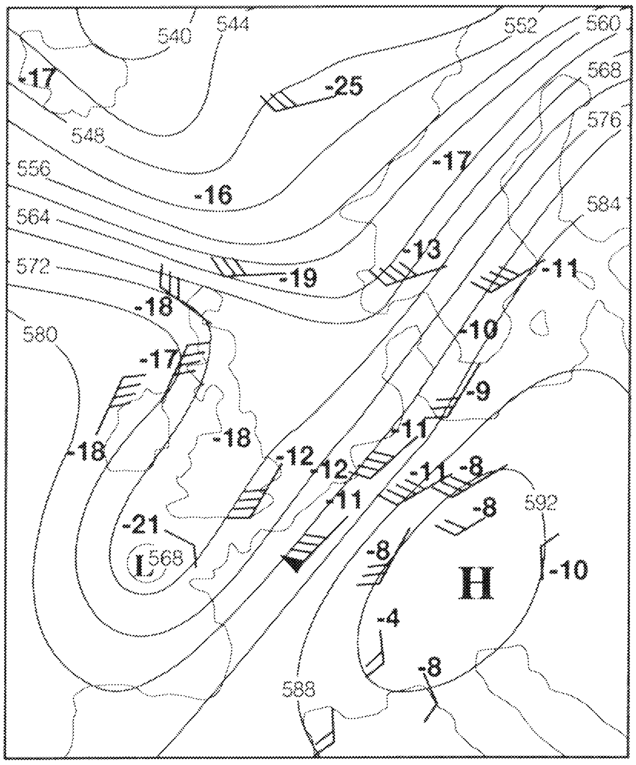


Fig. 13a Upper air through South West flow pattern (Tsw)

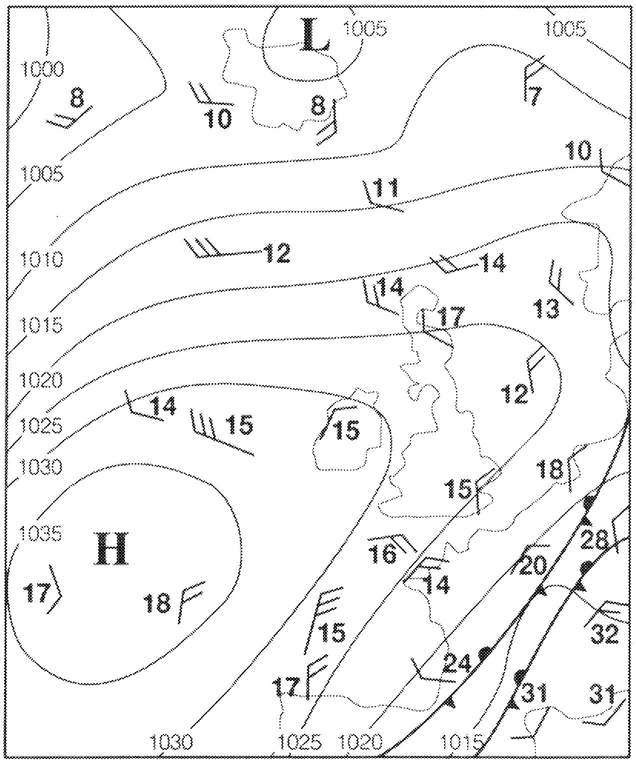


Fig. 13b Same as figure 13a surface weather chart

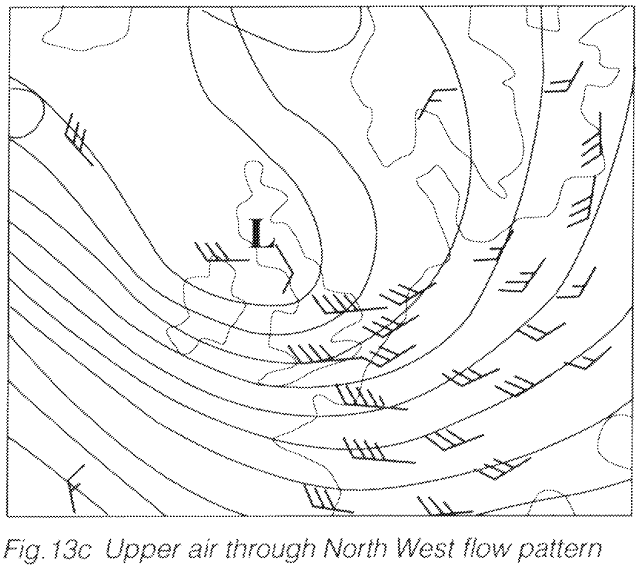


Fig.13c Upper air through North West flow pattern (Tnw)

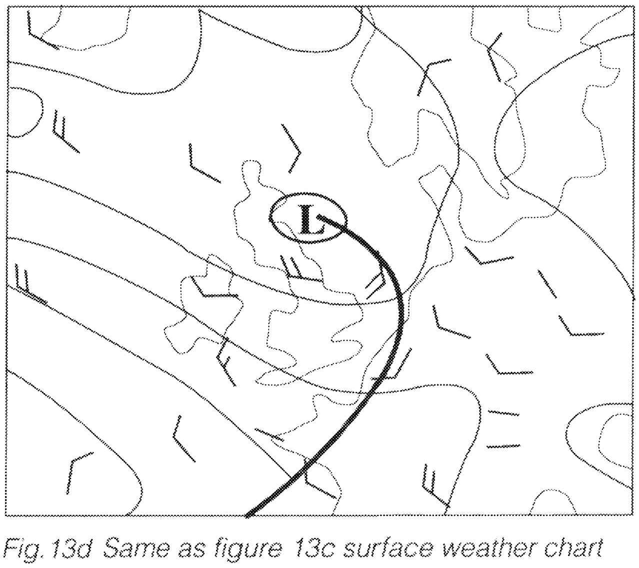


Fig.13d Same as figure 13c surface weather chart

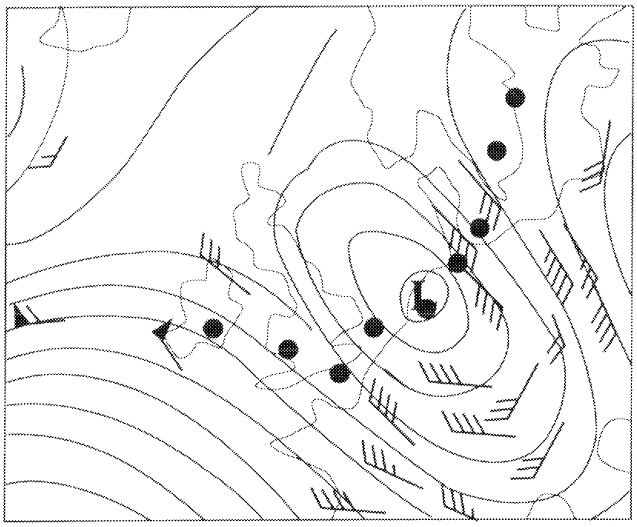


Fig. 14a Cold vortex central part (Cvs)

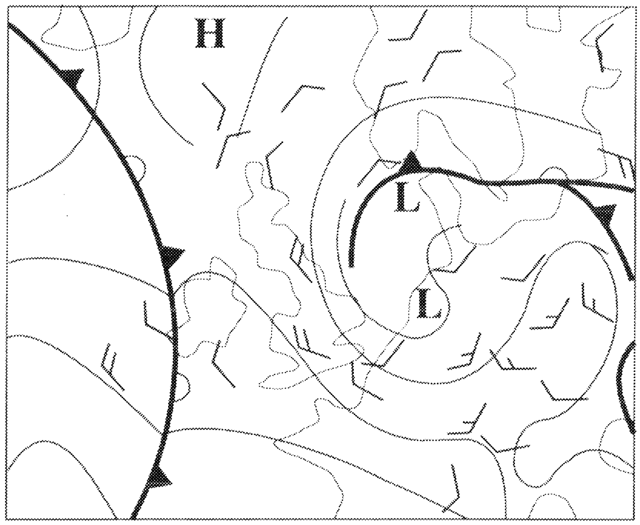


Fig. 14b Same as figure 14a surface weather chart

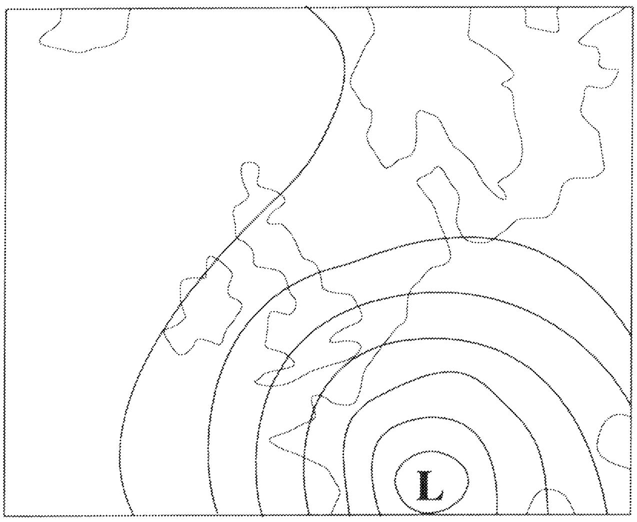


Fig. 14c In the North of cold vortex (Cvu)

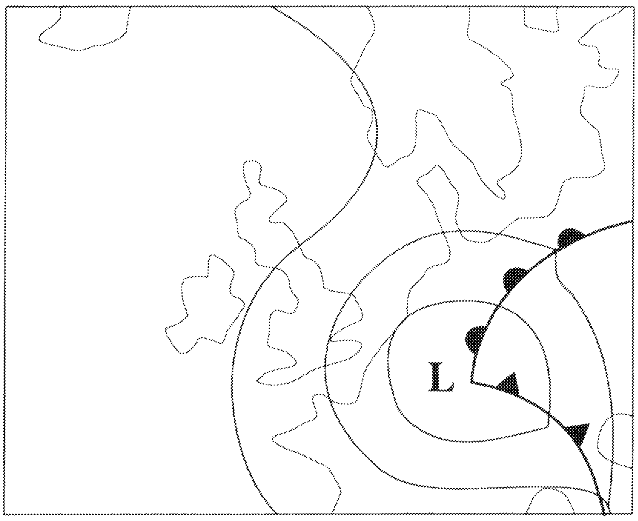


Fig. 14d Same as figure 14c surface weather chart

Fig. 15a Shear line pattern (Sl)

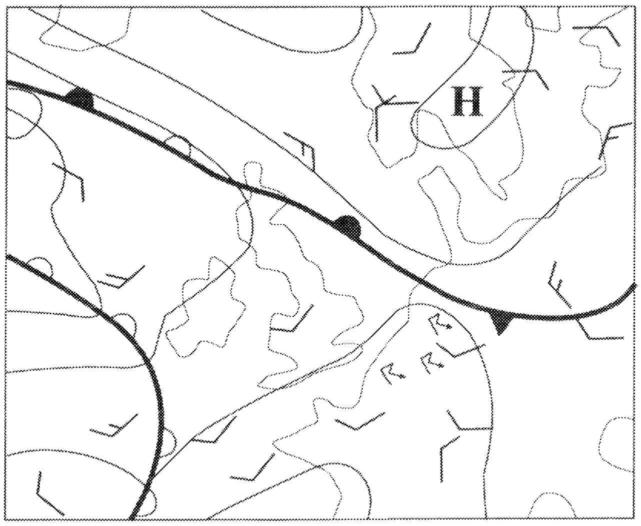


Fig. 15b Same as figure 15a surface weather chart