DISTRIBUTION OF AIR MASS THUNDERSTORMS IN NEW ENGLAND

by

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Submitted to the Department of Meteorology on June 20, 1966 in partial fulfillment of the requirements for the Degree of Master of Science.

ABSTRACT

The SCR-615-B radar data was used to locate air mass thunderstorms and hailstorms in New England. A total of 64 out of 71 air mass and 148 non-air mass thunderstorm days between March and October of the years 1958 through 1965 had suitable radar data. A majority, 108, of the non-air mass thunderstorm days were accompanied with cold fronts or quasi stationary fronts.

Various synoptic parameters that indicated stability and moisture on the air mass days were recorded. It was found that 61 out of 64 days with air mass thunderstorms had sea breezes and 40 out of 64 days had confluence at 500 meters.

The area covered by the radar was divided into a grid of ten-by-ten mile squares, and the frequency of occurrences, formation and dissipation of thunderstorms and hailstorms in each square were recorded. Detailed maps are presented showing the distributions for days grouped according to the 500-mb flow. Areas of maximum frequency of occurrence were about a band about 30 miles wide extending from just east of Concord, N.H. to central Massachusetts and northern Rhode Island, the eastern sides of major river valleys and near certain mountains. Regions of minimum frequency of occurrence were east of the 500-ft MSL contour in Maine and the south coast of New England and its adjacent coastal waters from New Haven, Connecticut to Cuttyhunk Island, Massachusetts.

Maps are presented showing the tracks of thunderstorms. They were nearly all parallel to the 500-mb flow and most of the tracks had lengths less than 15 miles. Tracks that were longer than 30 miles were made by relatively large cells with one dimension greater than five miles.

Thesis Supervisor: Dr. Pauline M. Austin
Title: Research Associate

ACKNOWLEDGEMENTS

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I wish to thank Mr. Edward C. Nelson, of the Synoptic Meteorology Department for typing this manuscript.

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1. INTRODUCTION

Almost all reliable observers are aware of preferred areas for thunderstorms, but there has rarely been any quantitative and objective assessments of the actual frequencies of occurrence within these areas.

The author decided to study only air mass thunderstorms as some previous studies have been of squall lines and thunderstorms associated with cold fronts in New England. Air mass thunderstorms usually have a smaller areal coverage than other types and are simpler to analyze. Moreover, theoretical considerations and European studies indicate that there would be more likelihood for preferred areas of occurrence, as well as for formation and dissipation because they would be less influenced by the larger scale circulation.

This type of study is best done by radar analysis, as a radar can locate all thunderstorms and follow their life cycle. Data accumulated by the Weather Radar Research project at the Massachusetts Institute of Technology was used for this project.

There are many benefits to be derived from this type of research and it could be expanded into a climatological study. If there are preferred areas of thunderstorm activity, weather forecasts could be improved and be more specific regarding areas of possible occurrence. This would be important in the summer when the majority of inland New England precipitation is of the showery type. Climatological statistics could then be suitably modified and this information would be useful to agriculturists and insurance companies.

It might also assist water conservationists in planning distribution of water and building of dams to relieve water shortages and mitigate pollution problems.

The question of whether or not thunderstorms will occur in some general area depends on atmospheric conditions rather than topography. The ideal conditions for occurrence of air mass thunderstorms are instability, convergence at low levels, orographic uplift, low level heating and sufficient moisture, while large hail requires in addition, strong wind shears and a freezing level near or above the cloud base.

There is little doubt that orography and elevations do have an effect on precise locations of thunderstorms. A number of studies of this effect have been made in Europe and the mid western United States.

The author noted, during the years 1953 through 1957 and 1961 through 1964, that in the densely spaced (approximately 15 miles apart) network in the United Kingdom, meteorological stations in positions with upslope flow reported more thunderstorms and heavy showers than those with no upslope flow.

Ludlam (1962) studied the 18 June 1957 thunderstorms in the South of England and found that hill and sea breeze circulations were pronounced over peninsulas. There were definite preferred areas for thunderstorm occurrences to the lee of the highest hills and ridges of high ground.

In Germany, Trautmann (1960) studied the hailstorms in Bayern during the period 1952 through 1956. The regions most highly affected include the Ober Bayern of the Alps where the elevation is over 2000 feet, the hilly Mittel Franken near Nürnberg where the elevation is over 2000 feet and the upper course of the river Fränk Saale near Schweinfurt.

Ortmeyer (1952) in a study of the 1924 through 1941 data found streaks of hail damage parallel to the Erz Mountains, showing the effect of topography.

Schleusener (1961) found that hail genesis regions in northeastern Colorado during 1960 and 1961 were in the areas of topographical uplift, when the cloud bases originated below 5000 feet MSL.

Zinkiewicz (1955) studied 2,257 hail cases during the period 1946 through 1950 in Poland and found the greatest frequency of hail on the high plains.

Frisby (1962 and 1963) found that 72% of the Upper Great Plain "straight line" hailstorms of 1951 through 1960 originated over higher ground. When all types of hailstorms were included however, the number of storms over equal areas of hill and valley were about identical. A study of 1961 hailstorms showed no clear indication that elevation played any part in hailstorm origins.

Stout and others (1959) stated that in the High Plains of the United States, there is a definite increase of hail crop damage losses with increasing elevation. However, they found that in Illinois, where there is not much difference of elevation, that there is a marked regional variation. Stout (1962) suggested that it could be explained by microphysical features, such as surface slopes, terrain roughness and land use.

There is some evidence that land use affects the frequency of thunderstorms. Certainly the ground temperature would have some effect on convective activity and depends on the exposure to sunlight, the type of soil, moisture and other factors.

Trautmann (1960) found that arable lands in Bayern were more severely damaged than forests and meadows.

Zinkiewicz (1955) stated that in the high elevations of Poland, the forests may decrease the convective activity and reduce the hail frequency

In this study, detailed maps have been constructed showing the frequency of occurrence of air mass thunderstorms and hailstorms in New England, as indicated by quantitative radar observations. The number of storm formations and dissipations have also been mapped. The results were then compared with the various terrain features.

2. PREVIOUS STUDIES OF THE DISTRIBUTION OF THUNDERSTORMS IN NEW ENGLAND

A. General topographical features.

Since terrain does have an effect on thunderstorm activity, a detailed study was made of the terrain within a radius of 120 statute miles of M.I.T. Figure 1, "General terrain map of New England", shows the predominant White Mountains of central New Hampshire, the Green Mountains of Vermont, the Berkshire Hills of Western Massachusetts and scattered mountains in southwestern New Hampshire and central Massachusetts east of the Connecticut River. Figure 2, "Elevations in hundreds of feet", shows smoothed contours at more frequent height intervals.

B. Climatological Studies of thunderstorms and hailstorms.

The typical thunderstorm and hail frequency charts are based on reports from widely scattered weather stations that provide only point frequencies and may not be representative, even locally.

The typical U.S. Weather Bureau first order station now has a large "background" noise so that distant thunder (thunderstorm reported as observed) cannot be discerned as readily as desirable. Thunder is seldom heard farther than 15 miles, with 25 miles the approximate upper limit and 10 miles being a fairly typical range of audibility.

In addition to regular station reports, some severe weather incidents are reported by private individuals. Recently there has been an improved reporting system as well as an interest by the general public in reporting severe weather. As more areas become heavily populated, more severe weather reports can be expected. The U.S. Weather Bureau makes cost estimates of damage and uses a newspaper clipping service for their "Local Storm" data publication.

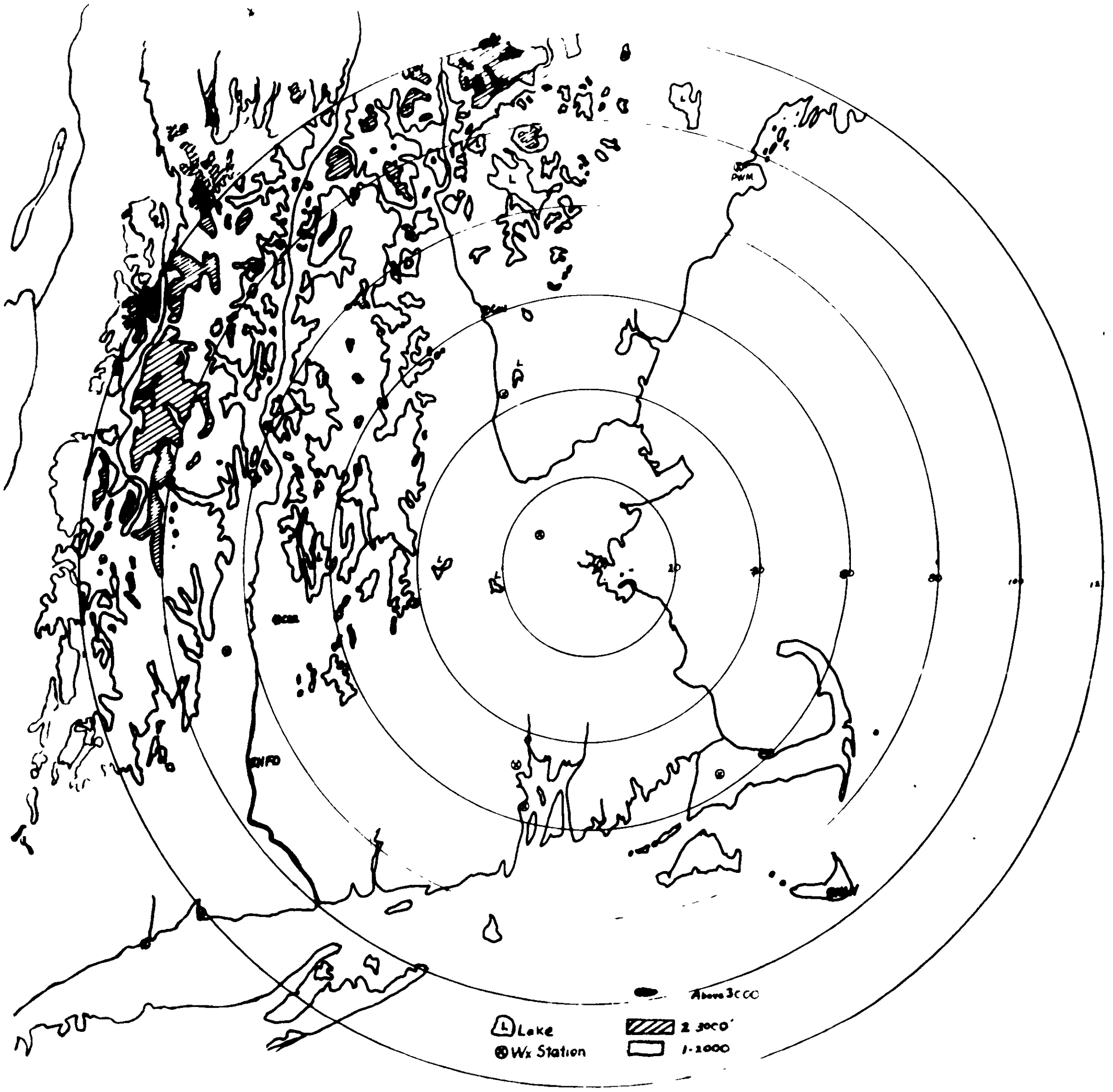
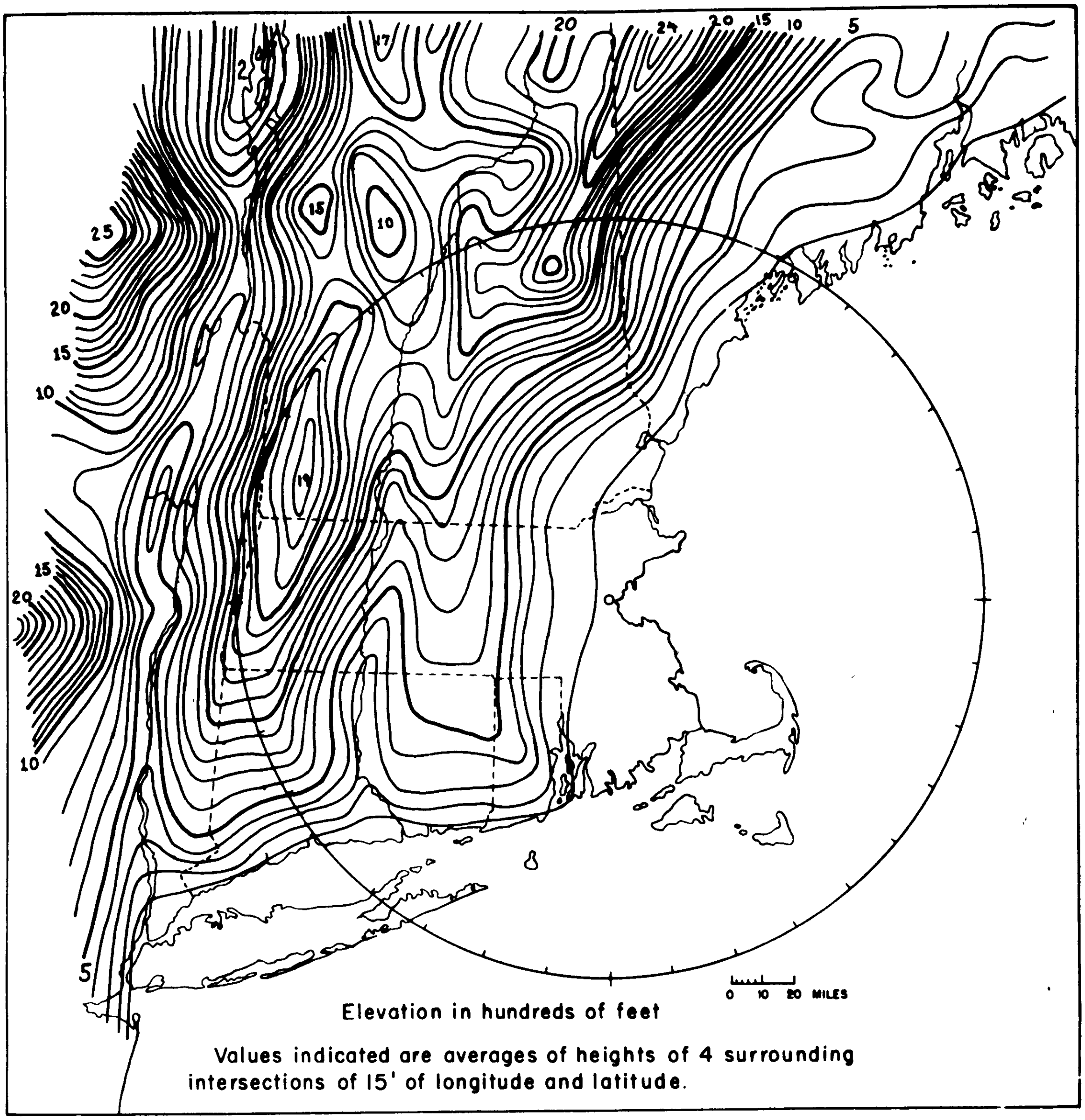


Fig. 1. General terrain map of New England. Range marks in statute miles.



Elevation in hundreds of feet

Values indicated are averages of heights of 4 surrounding intersections of 15' of longitude and latitude.

Fig. 2. Smoothed topographical map of New England, Elevations in hundreds of feet. (After Tweedy,1965).

The Crop-Hail Insurance Actuarial Association gathers reports of crop damage by hail and bases hail crop insurance rates on these data. The data indicate that one hailstorm may be more damaging than several others, depending on wind force, crop maturity, size and number of hailstones, nature of exposed property and many other factors. Detailed, more reliable hail climatological studies have been made in the Mid West and Illinois, based mainly on crop damage reports.

Another important consideration in determining the actual distribution of hail is the ratio of "area" to "point" frequency of hail occurrence where area frequency is based on an increased network density. Although present statistics are based on point frequencies, it appears that area frequency would be more accurate. Alfred Angot of the French Meteorological Service estimated that an ideal reporting network for obtaining realistic area frequencies of hail should be one station for each four square miles.

Several studies have been made of the hail to thunderstorm ratio and they all indicate that the ratio decreases with increasing network density. Table 1, "Area to point hail frequencies", shows the effects of an increased network density.

Table 1. Area to point hail frequencies.

Investigation:	Region:	Area Covered (sq. mi.)	Number of stations:	Ratio of area to point frequency:
Shands (1944)	Iowa	56,000	150	15:1
Beckworth (1957)	Denver, Col.	72	40	4:1
Atlas (1965)	Caucasus,	446		8:1
	USSR	1,000		13:1
		1,340		16:1

Figure 3, "Average annual number of thunderstorm days", is based on U.S. Weather Bureau and selected cooperative stations with at least 20 years

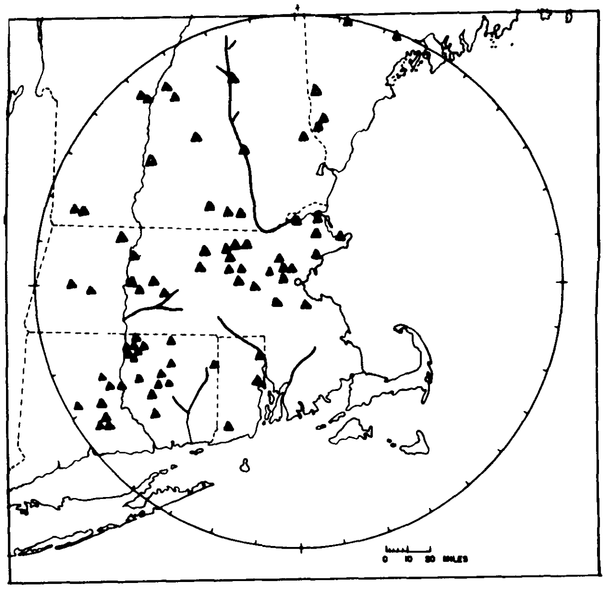


Fig. 4. Hail reports in New England based on the years 1953 through 1962.

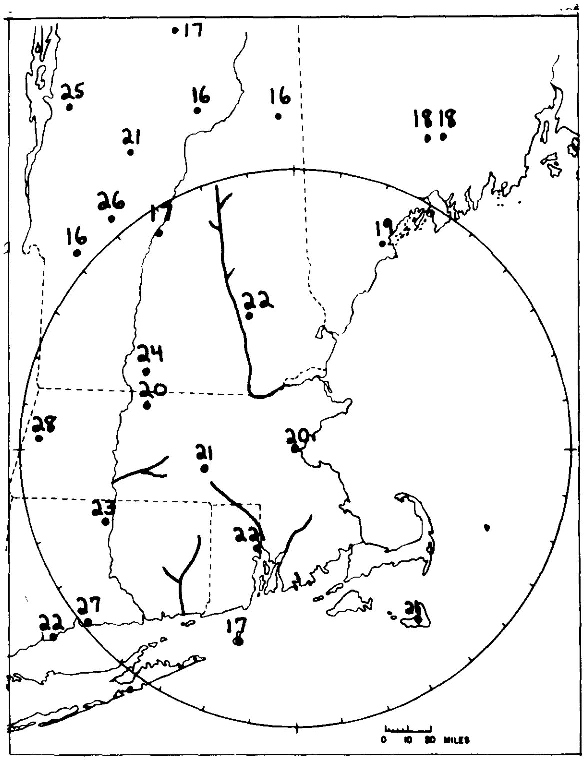


Fig. 3. Average annual number of thunderstorm days, based on more than 20 years of record.

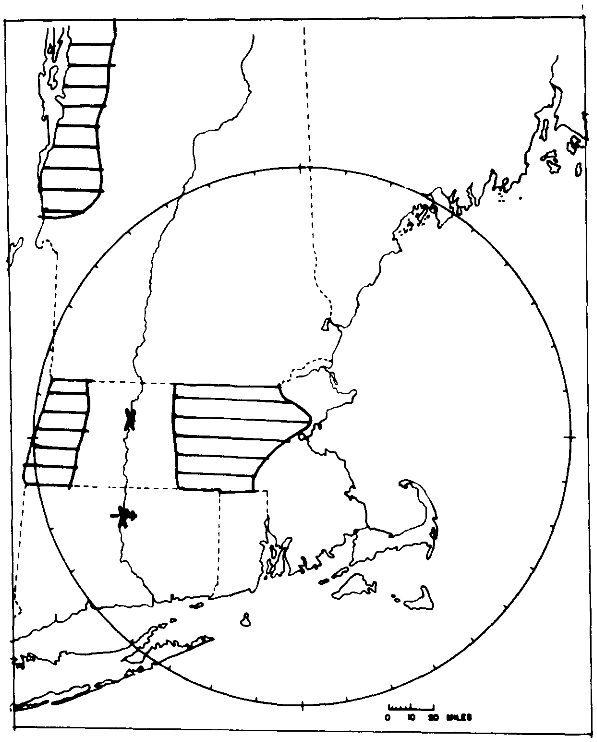


Fig. 5. Areas with highest hail crop insurance rates. Legend: X tobacco; ≡ general crops.

of data[1]. It shows only a small variation of thunderstorm days in New England, although there is a minimum in northern New England and a maximum of 28 days in the Housatonic River Valley at Pittsfield, Massachusetts.

The seasonal distribution of thunderstorms shows a maximum of less than 15 days in the summer, four to seven days in the spring, less than three days in the fall and less than one thunderstorm in the winter.

Table 2, "Diurnal variation of thunderstorm frequency", was obtained from Hydrometeorological Report No. 5, Thunderstorm Rainfall, U.S. Weather Bureau. The stations in extreme southern New England are grouped together to show the affect of different regions. The table shows a pronounced maximum of thunderstorm activity during daylight hours in the summer, particularly between the hours of 1200 and 1800 EST. In extreme southern New England and its coastal waters, just as many thunderstorms occur during nocturnal as in daylight hours during the spring and possibly fall.

The hail to thunderstorm ratio for New England, based on the years 1904 to 1943 is 3 to 5%, with the maximum near and west of the Connecticut River in southwestern Massachusetts and northwestern Connecticut.

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1. Provided by Mr. Lautzenheyer, U.S. Weather Bureau Climatologist, Boston, Massachusetts.

Table 2. Diurnal variation of thunderstorm frequency. (1906-1925)inclusive).
After Hydrometeorological Report No. 5, USWB 1945.

Months:	Location:	Number of cases:	Percentage of time during hours: 00-06	06-12	12-18	18-00
December-February	Nantucket, Mass.	21	35	35	0	25
	Block Island, R.I.	12	5	45	5	45
	New Haven, Conn.	-	15	15	30	35
	Providence, R.I.	7	25	25	0	45
March-May	Nantucket, Mass.	104	30	20	25	20
	Block Island, R.I.	101	25	20	25	30
	New Haven, Conn.	119	20	10	30	30
	Providence, R.I.	100	20	10	20	40
June-August	Nantucket, Mass.	211	20	15	30	25
	Block Island, R.I.	210	20	20	30	26
	New Haven, Conn.	360	15	5	50	30
	Providence, R.I.	286	5	10	50	26
September-November	Nantucket, Mass.	77	15	18	26	30
	Block Island, R.I.	61	25	10	30	26
	New Haven, Conn.	80	5	10	35	30
	Providence R.I.	58	20	15	20	35
December-February	Hartford, Conn.	3	7	20	15	55
	Albany, N.Y.	7	40	10	28	15
	Concord, N.H.	4	0	0	25	75
	Portland, Me.	4	25	25	50	0
	Boston, Mass.	8	25	25	10	40

Table 2 (continued)

(1)	(2)	(3)	(4)			
			00-06	06-12	12-18	18-00
March- May	Hartford, Conn.	133	20	15	30	30
	Albany, N.Y.	134	10	5	40	30
	Concord, N.H.	71	10	15	50	25
	Portland, Me.	41	10	7	45	35
	Boston, Mass.	80	15	12	30	35
June- August	Hartford, Conn.	439	10	5	50	25
	Albany, N.Y.	449	5	10	55	25
	Concord, N.H.	314	10	8	55	25
	Portland, Me.	231	10	8	55	20
	Boston, Mass.	254	5	5	55	25
September- November	Hartford, Conn.					
	Albany, N.Y.	91	15	10	35	35
	Concord, N.H.	54	10	10	50	30
	Portland, Me.	52	15	5	27	50
	Boston, Mass.	57	30	10	35	26

Table 3, "Total number of hail days", shows a maximum of hailstorms in the interior regions of New England during the summer. Extreme southern New England and its coastal waters have maxima during the spring and fall months.

First order U. S. Weather Bureau station data in New England indicate only one to two hailstorm days per year. The author has seldom seen hail, and it was less than one quarter" in diameter in the vicinity of Vineyard Sound and Buzzards Bay, Massachusetts. Hail occurred there only in cold, unstable air.

Table 3 Total number of hail days (After Hydrometeorological Report No. 5, USWB, 1945).

Station:	No. of Years:	Jan:	Feb:	Mar:	Apr:	May:	Jun:	Jul:	Aug:	Sep:	Oct:	Nov:	Dec:
Nantucket, Mass.	40	0	0	4	5	3	1	0	0	1	1	4	2
Block Island, R.I.	40	0	1	5	5	2	2	1	3	2	1	4	1
Naragansett Pier, R.I.	14	5	6	6	7	0	1	1	0	1	0	1	6
Providence, R.I.	39	0	0	2	3	6	5	9	3	3	0	0	0
New Haven, Conn.	40	1	1	3	4	10	4	5	3	1	2	1	0
New York, N.Y.	40	1	1	3	4	17	11	11	7	2	4	2	1
Boston, Mass.	40	0	0	1	3	5	5	8	3	1	0	2	0
Portland, Me.	40	0	0	2	4	4	3	6	6	2	6	0	0
Hartford, Conn.	39	0	0	2	5	11	12	15	7	1	1	2	1
Albany, N.Y.	40	1	0	3	4	14	9	11	5	3	1	1	0
Burlington, Vt.	37	0	0	1	1	5	4	7	3	4	1	0	0
Northfield, Vt.	35	1	0	1	1	6	11	6	5	2	3	0	0

Galway (1963) plotted 123 hail reports (see Fig. 4), in New England for the period 1953 through 1962. He found a cluster of reports in north central Connecticut approximately the tobacco growing belt, a crop which is quite susceptible to damage by hail. Several reports of large hail were in east central Vermont, an area which was void of tornado reports. Severe weather reports clustered in the vicinity of the heavier populated areas (interior river valleys) and with the exception of northeastern Massachusetts, away from the coastline.

Insurance companies do not write a large amount of crop-hail insurance in New England and consequently, the statistics would not provide an indication of the distribution of hailstorms.

Differences in rates have been made from statistics with a liberal sprinkling of seasonal judgement.

Figure 5, "Areas with highest hail-crop insurance rates", shows the areas where tobacco is grown near Hartford, Connecticut and north of Springfield, Massachusetts. The highest rates in Connecticut are on the east side of the Connecticut River, indicated by "plus" signs while the rates are lower as close as five miles to the west.

The highest rates for general crops in Massachusetts are for Berkshire, Worcester and Middlesex Counties while in Vermont, Addison and Rutland Counties have the highest rates.

C. Shorter period investigations.

As previously mentioned, most studies of thunderstorms in New England have been concerned with squall lines or cold fronts. In a study based on synoptic data for four years, Penn (1955) found that 40% of New England squall lines formed east of 75°W (Massena, New York to Philadelphia, Pennsylvania) and 63% to the east of 80°W (Toronto, Ontario to Pittsburgh, Pennsylvania).

Swisher (1959) studied radar data of five squall lines in New England and found the regions of development to be the Pocono Mountains in eastern Pennsylvania and the Catskill Mountains of New York. Next came the Berkshire Hills of western Massachusetts and the largest increase of development was in the Connecticut River Valley. The squall lines decreased in intensity near the coast of Maine and in the extreme southern coastal areas of New England, where the bands dissipate. These results are in agreement with those of Boucher (1958). Stem (1964) studied M.I.T. radar data during four days of air mass thunderstorms, near Boston, Massachusetts and found that these thunderstorms did not seem to form in a strictly random manner. There were preferred areas of formation, based on a combination of the low level convergence field (sea breeze effect) and local topography. He also observed that the air mass thunderstorms began to lose intensity on approaching the coast.

Some experienced forecasters, through personal communications, have provided the following observations regarding air mass thunderstorms.

Mr. Larry H. Shaw, Chief Forecaster at Westover Air Force Base, Chicopee Falls, Massachusetts said that air mass thunderstorms observed with the AN/CPS-9 radar, appear to have a preferred area for formation near Quabbin Reservoir, Massachusetts, perhaps on the west shore. This result agrees with observations made by Mr. Thomas Pisinski with the WSR-1 radar at Worcester, Massachusetts during the summers of 1960 through 1963. Mr. Shaw noted another preferred area for formation in the northern Berkshire Hills and a few times that air mass thunderstorms formed about 15 miles southeast of Westover Air Force Base, Massachusetts. Many of the thunderstorms moving into western and central Massachusetts formed in the Adirondack or Catskill Mountains of New York and moved eastward. They often dissipated before reaching the Connecticut River Valley, or shortly thereafter.

Mr. Robert L. Carlson, MIC at Green Airport, Hillsgrove, Rhode Island, stated that in that region air mass thunderstorms occur primarily over northern, Rhode Island and their frequency is greater during the evening hours.

Voyles and Zavos (1953) made a study of 1248 radar echoes of precipitation cells in New England moving from the southwest and which dissipated over water areas. The dissipations were 55% greater than would be expected under a uniform distribution, particularly in the summer and autumn when the temperature contrasts between water and land diminish. Six hundred fifty one cells which moved in any direction formed near the Connecticut River Valley north of Northampton, Massachusetts. Eighteen and seven tenth's per cent of all cells formed in this area, whereas uniform distribution would account for 3.6%. The frequency is 415% greater than would be expected if the distribution were uniform.

3. EFFECT OF TERRAIN ON AIRFLOW

A. Orographic and thermal effect.

There is a dynamical or orographic effect as the wind is forced to blow up a slope. This will start upcurrents and initiate the development of storms. A valley wind would enhance convective activity by carrying more moist air from low levels upward towards nearby hills or mountains and the level of condensation would be lowered.

The thermal effect of terrain occurs when the slopes of hills or mountains are more perpendicular to the sun's rays than the valley floors, thus receiving more radiation per unit area. The slopes then are warmer than any horizontal surface and there is effectively a "high level" heat source. Streamlines would rise over the heat source and there is an effective higher ridge.

B. Lee wave effect.

It was not until the 1940's that any serious study was made of mountain waves. Observational evidence was obtained in Europe by Förchtgott, Manley, Kuetter, and others and later theoretical studies were developed that finally agreed with observations. The theory was mainly due to the works of Scorer (1949, 1953, 1954, 1955) and Corby and Wallington (1956), in which a parameter ℓ^2 was related to the lapse rate and wind speed in the vertical. They found that lee waves were more likely to occur with an increase of wind with height and/or an increase of stability.

Bérenger and Gerbier studied the effect of the size and shape of topography on lee waves in the French Alpes in 1956, 1957 and 1958.

Davis and Booker (1962) studied the lee waves in the Alleghany Mountains of central Pennsylvania and related them to local formation and dissipation of unstable cloud systems. They found that lee waves were more likely to occur simultaneously with thunderstorms and theorized that outrush of cold low level air from a thunderstorm would enhance lee waves.

Cumulus growth would be discouraged in the descending part of the wave and growth might be enhanced in the rising portion, so that in some cases, the cloud would attain a sufficient buoyancy to survive the following descent. Thus waves could either encourage or discourage cumulus growth, depending upon timing of the growth with respect to the wave and the phasing of the waves with the terrain.

Figure 6, "Major terrain features near the watersheds of the ponds at Lakeville, Mass", shows minor ridges to the west and southwest of Copicut Hill, about every five nautical miles. This hill has a theoretically ideal condition for thermals with a southwestward facing slope and a pronounced valley to the southwest. A southwest wind would then start thermals because of the orographic effect and the resulting clouds would not shield the slope from the sun.

One one occasion the author observed lee waves continuously forming cumulus congestus clouds about five miles east of the 354 foot Copicut Hill. They then moved eastward with the wind flow.

On 8 June 1965 from about 1330 to 1630 EST, the author observed a cumulonimbus calvus cloud forming continuously to the lee of Copicut Hill. Individual cells were obscured by surrounding clouds and the radar data unfortunately were not available at this time. The author attempted to show that these air mass

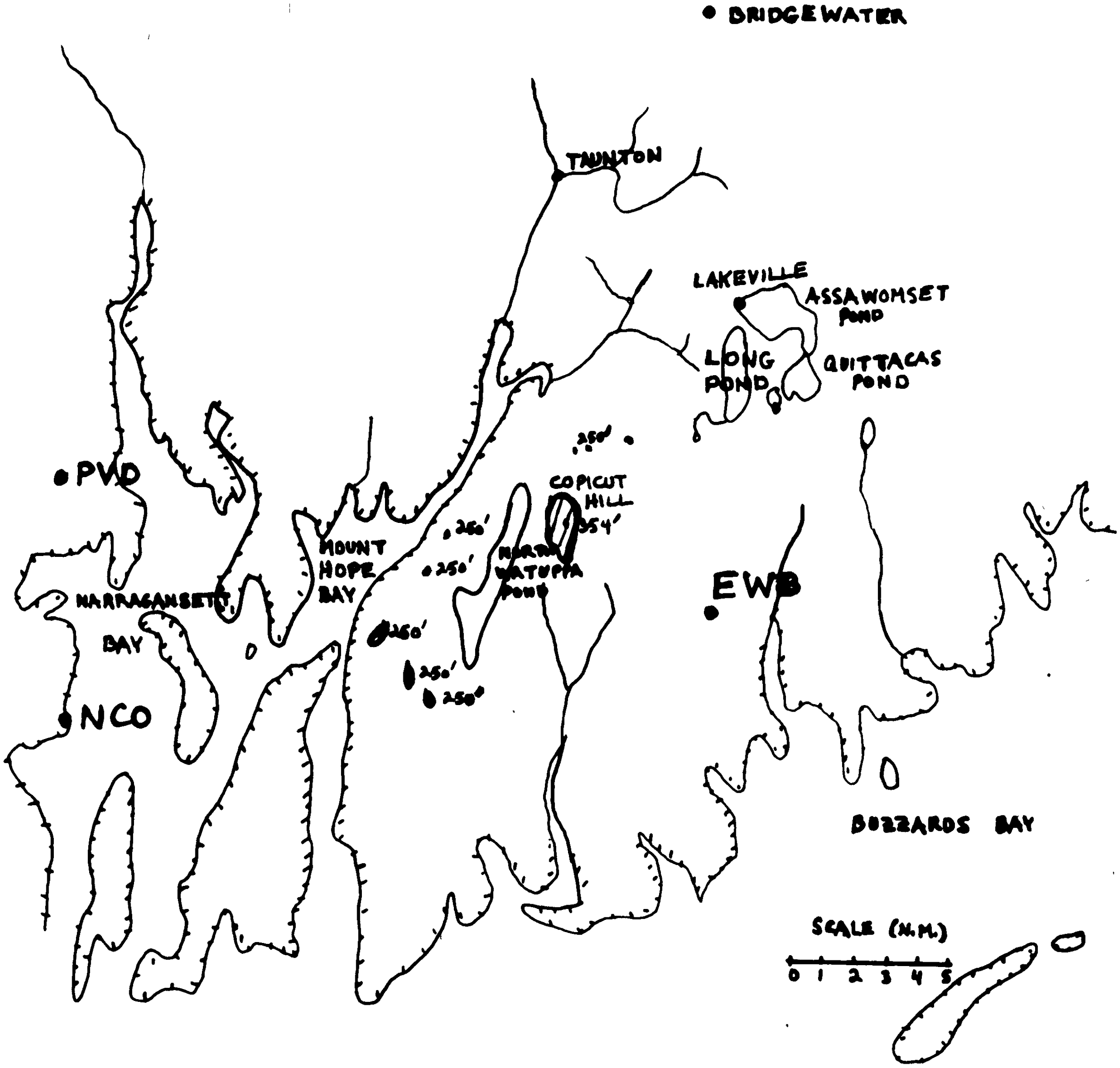

Fig. 6. Major terrain features near the watersheds of the ponds at Lakeville, Massachusetts.

thunderstorms were enhanced at the areas of maximum uplift by lee waves, but there was insufficient surface and radar data.

Mr. Miles Standish, State Conservation Officer confirmed that air mass thunderstorms occur with an exceptionally high degree of frequency to the east of Copicut Hill, according to his observations of the past 15 years.

4. DATA AND METHOD OF ANALYSIS

A. Use of radar to locate thunderstorms.

The quantity measured by a radar when observing precipitation is the radar reflectivity per unit volume η. When the scattering particles are spherical and small, compared with the radar wavelength, and are composed entirely of ice or water, η is proportional to the reflectivity factor $Z \equiv \Sigma D_i^6$, Di being the diameter of the individual scattering particles and the sum being taken over a unit volume. This is in the Rayleigh scattering region and $\eta = \frac{\pi^5 |K|^2 Z}{\lambda^4}$, (1) where $|K|^2 = 0.93$ for water particles and 0.197 for ice particles.

The limits of the Rayleigh region are not precise, but depend on the degree of accuracy required. Actually it can usually be applied satisfactorily to particles considerably larger than $\frac{\lambda}{10}$, but not as large as $\frac{\lambda}{3}$.

When Z is obtained by applying equation (1) to measured reflectivities rather than from observed drop diameters, it is called equivalent Z and denoted by Ze. When the conditions for Rayleigh scattering are fulfilled, Z and Ze are the same within the limits of experimental error. For hailstones, the Rayleigh approximation is good within 2 db for diameters up to 3 cm when $\lambda = 10$ cm (Austin, 1962), but the suitability of using the relation for water particles depends upon the distribution of water and ice in the hailstones.

A criteria is now being sought for recognizing thunderstorms, using Ze Donaldson (1961, 1965), Wilk (1961), Arnold (1961) and Hitschfeld and Douglas have made studies of the associated hail occurring with a given Ze, using 3 cm radar. These measurements are meaningful only if they are made at 20,000 feet or higher, because of severe attenuation by water in the lower portions of the storms.

Geotis (1963) found with the 10.7 cm radar that when log Ze was greater than 5.5 near the ground, there was almost always hail in New England. The units for Ze are mm^6/m^3, but it is more convenient to use log units.

Ward (1965) used a 10 cm radar in Oklahoma and found that hail occurs occasionally with log Ze as low as 4.0, but the hail was usually not larger than about 1/4 inch in diameter. Ninety per cent of the reported hailstorms had cores with log Ze $>$ 4.0, most of the storms with log Ze slightly less than 5.0 contained some significant hail, but the majority of hailstorms had log Ze about 6.0. Log Ze was not often greater than 6.0, even in severe storms. These results agree with those of Geotis (1963) in Massachusetts.

In this study, a storm was considered to be a thunderstorm when log Ze $\geq$ 4.5, which was equivalent to 25 mm/hr of precipitation. A hailstorm was assumed when log Ze $\geq$ 5.5, equivalent to 100 mm/hr, as observed by Geotis (1963). These log Ze criteria are somewhat arbitrary but appear to be reasonable since they are based on the observations just described.

B. Radar data used in this study.

To determine when thunderstorms were observed by the M.I.T. SCR-615-B radar, every PPI observation between March and October of the years 1958 through 1965 was examined to find storms with log Ze $\geq$ 4.5. Intensity levels appear five db apart, a factor of three in reflectivity or two in equivalent rainfall rate.

The SCR-615-B radar has a wavelength of 10.7 cm and a beam width of three degrees between half power points, which is 5 miles across at a range of 95 miles. The elevation was usually set at one degree to get most of the power above the horizon. The range was usually set at 120 statute miles and occasionally at 60 statute miles.

The PPI radar data are averaged, range normalized signal intensity contours, which can be interpreted as lines of equal Z values or of equal rainfall rate.

Every calibration and check were plotted to maintain the accuracy of Ze. Austin and Geotis (1960) have shown that when short period fluctuations are averaged electronically, and when the radar is carefully and frequently calibrated, that measurements of radar reflectivity are accurate to about 2 db.

The M.I.T. radar is normally operated during the working hours 0800L to 1700L, Monday through Friday and after 1700L if the precipitation continues or is pretty clearly predicted. Nocturnal thunderstorms and weekend thunderstorms are often missed. Great emphasis was placed on squall line and frontal thunderstorms and some scattered air mass thunderstorms have been missed. The lack of nocturnal thunderstorm data can be a significant loss in and near the coastal areas of southern New England in the spring and fall months. The author made a pilot study of every nocturnal thunderstorm from April 1958 to April 1960 that was observed by 1st order U.S. Weather Bureau and military weather stations in southeastern New England. It revealed 37 thunderstorm days, and of these 28 were air mass thunderstorms, the remaining seven being associated with cold fronts. At least four of the days with air mass thunderstorms had troughs or closed lows near the 250 mb level, but not discernable at lower heights.

C. Selection of air mass thunderstorms.

Thunderstorms are assumed to be of air mass origin when surface fronts are at least 200 miles away. Penn (1955) in a study covering four years of New England squall lines found that the distance between the cold front and squall line averaged 125 miles in the northern portion and 190 miles in the southern portion. A typical example of a day with air mass thunderstorms is a cold front in extreme western New York with scattered thunderstorms in New England. If the cold front approached eastern New York, the thunderstorms in southeastern Vermont would not be considered as air mass type.

D. Method of analysis.

The PPI films were viewed through a modified TDC Mainliner number 200 projector and a Holmes number 3852 projector. Tracings were then made of "levels" that correspond to $\log Ze \geq 4.5$ and $\log Ze \geq 5.5$. There would be an error in these tracings if in the process of photography, the scope was distorted or if there is a human tracing error when the image is projected.

Normally, a photograph was made of one level during each revolution of the antenna. This resulted in an average of about four minutes between successive photographs of the level corresponding to $\log Ze \geq 4.5$ or those for $\log Ze \geq 5.5$.

Since the air mass thunderstorms did not have an erratic behavior, it was easy to interpolate their areal coverage and time durations, even with time breaks. Tracing sheets had to be renewed about every 60 minutes of PPI data to simplify any analysis.

The area swept within the radar range was divided into a grid of 100 square mile areas. Each area had coordinates N, S for the north-south axis and W, E for the west-east axis, using M.I.T. for the origin. The frequencies of occurrence, formation and dissipation of thunderstorms for each of these areas were recorded as well as cell characteristics such as size and orientation. If a cell extended more than three miles into an area from an adjacent area, it was considered as existing in both areas.

In order to find the effects of topography, a topographical barrier chart for southern New England was drawn. Then the pertinent 500-mb charts were examined for evidence of troughs and the general flow pattern. Since most of the topographical barriers in southern New England are oriented north northeast to south southwest, the 500-mb flow was grouped into the southwest, northwest, north and southeast sectors as well as a closed low or pronounced trough category. Then the formations, dissipations and durations of cells in each area were recorded for all these 500-mb flow patterns. Cell tracks were also drawn for each 500-mb flow pattern in order to determine their lengths and direction of movement.

All available National Meteorological Center synoptic and facsimile charts were scanned to record general features and any parameters that indicate stability and moisture.

5. RESULTS

A. Number of days when thunderstorm echoes were observed.

As mentioned previously, the data consisted of radar records for the months March through October of the years 1958 through 1965.

All storms with log Ze$\geq$4.5 were considered to be thunderstorms and all with log Ze$\geq$5.5 were called hailstorms. There were 212 days when thunderstorms occurred. Synoptic analysis indicated that on 148 days the thunderstorms were not of the air mass type but were associated with the following large scale weather features. Cold fronts (70) and quasi stationary fronts (38) accompanied the majority of non-air mass thunderstorms. Warm fronts (21), occluded fronts (7), warm sectors (3), hurricanes or tropical storms (3) and cyclones (3) were responsible for the remaining cases. Appendices A and B give brief summaries of these synoptic features.

B. Characteristics of air mass thunderstorm days.

Days when air mass thunderstorms occurred were classified as to the 500-mb pattern. The direction of wind flow or the presence of closed lows and/or deep troughs with wind direction shear were recorded. Since the major topographical barriers in New England are oriented in a north northeast to south southwest direction, the flow direction was classified as southwest, northwest, north, southeast and south southwest, as shown in Appendix B.

Out of 64 days with cells log Ze$\geq$4.5, the flow was southwest to west (clockwise) at 500 mb on 41 days, west northwest to north on 11 days, a closed low or deep trough on eight days, south southwest flow on two days, southeast to south southeast flow on one day and north flow on one day.

On 38 out of 64 days, some cells had log Ze$\geq$5.5. The 500-mb flow was southwest to west (clockwise) on 29 days, west northwest to north on six days and there was a closed 500-mb low or deep trough on three days.

The low level flow was examined by recording the 500 meter winds for Albany, N.Y., J.F. Kennedy International Airport, N.Y., Nantucket, Massachusetts and Portland, Maine. On 40 out of the 64 days when storms with log Ze$\geq$ 4.5 were observed, there was confluence of the 500 m. wind flow at either one or both of the southern radiosonde stations with respect to the northern ones.

The surface winds for the coastal or near coastal stations of Providence, R.I., Logan International Airport, Boston, Massachusetts and Portland, Maine were examined, and showed that 61 out of the 64 days had sea breezes. The Providence, R.I. surface winds would back and increase in speed, indicating a gradient induced sea breeze convergence line. This is similar to the circulations over the Brest peninsula of France and the peninsula of southern England.

Appendix C, "List of days and their characteristics when the SCR-615-B radar recorded air mass cells with log Ze$\geq$4.5", gives a very brief description of the synoptic situation, data obtained from the U.S. Weather Bureau Local Climatological Data, Synoptic and Daily Weather Maps, National Meteorological Center facsimile charts and PPI radar data.

The Showalter index is used to indicate the stability and is computed by lifting a parcel of air dry adiabatically from the 850 mb level until it reaches saturation, assuming a constant mixing ratio. The saturated parcel is then lifted wet adiabatically to the 500-mb level and the difference there with the actual 500-mb environment in °C is the index. It is best to use the Showalter index from the nearest radiosonde station in New England, rather than to interpolate. The Showalter index and other parameters were obtained from available National Meteorological Center facsimile charts since 1962. The Showalter index was $\leq +5^{\circ}$C on all 35 days examined when log Ze$\geq$ 4.5 for the air mass cells.

The vertical velocity, w in cm/sec at 600 mb was $\geq$ 0 cm/sec on 20 out of 22 days examined when air mass cells with log Ze$\geq$ 4.5 were recorded.

The precipitable water is obtained by condensing out all the moisture in a vertical column from the surface to 500 mb, where most of the available moisture is. The precipitable water was greater than one half inch on all 39 days examined and 10 days had less than one inch.

The average relative humidity between 1000 mb and 500 mb was available on 15 days and exceeded 50% on all of them.

C. Characteristics of air mass cells.

A "cell" is defined for this study as the area enclosed by a contour "level" corresponding to log Ze = 4.5. This is then considered a thunderstorm.

A total of 3878 individual cells were traced. The average daily number of cells was 28 and that of hailstorms was five. The maximum number of cells occurred on 10 July 1961 when there were 205 and 33 of these were hailstorms.

Cells vary in shape and size during their lifetimes, so the "average" cell size for each day was determined by inspection. This "average" cell size for each day is recorded in Appendix D and varied from 1 by 1 to 12 by 6 miles For all days, the average was 5 by 3½ miles.

The largest cell measured 26 by 8 miles on 10 July 1961 and 20 by 10 mile cells occurred on 14 June 1963, 6 July 1964, 12 and 31 July 1962, 29 July 1963, 10 August 1960 and 31 August 1959. The number of days with cells having one dimension greater than 10 miles was compiled for each 10x10 mile area. The number of cells per area ranged from 0 to 4 and minima for large cell occurrences were in Maine and the coastal and sea areas off southern New England

Most cells were nearly circular but a few were very elongated, such as the 20 by 5 mile cells on 19 July 1960 and 23 June 1965. The average orientation of the cell's major axis for each area is shown in Fig. 7. Most of the cells had a north to south or north northeast to south southwest orientation of their axis. Beyond the 90 mile range, the axis became oriented perpendicular to the radar beam which is very evident to the north of M I.T. in central New Hampshire. This indicates the beam filling effect, assuming that the cell's main axis actually remains oriented in a north northeast to south southwest direction. Most of the cells had an axis orientation within 40° from the average. These greater than 40° had a northwest to southeast orientation or east to west orientation.

The quantitative analysis of cell duration was not made, but it was noted that small cells (2 by 2 miles) usually did not last more than about 12 minutes. The cell heights recorded on the RHI of the AN/CPS-9 radar were available for 46 days. The average height of the cell tops was 34,000 feet and on three days they reached 50,000 feet. Stem (1964) analyzed RHI data of air mass cells and found that their life cycle was similar to one found by Byers and Braham.

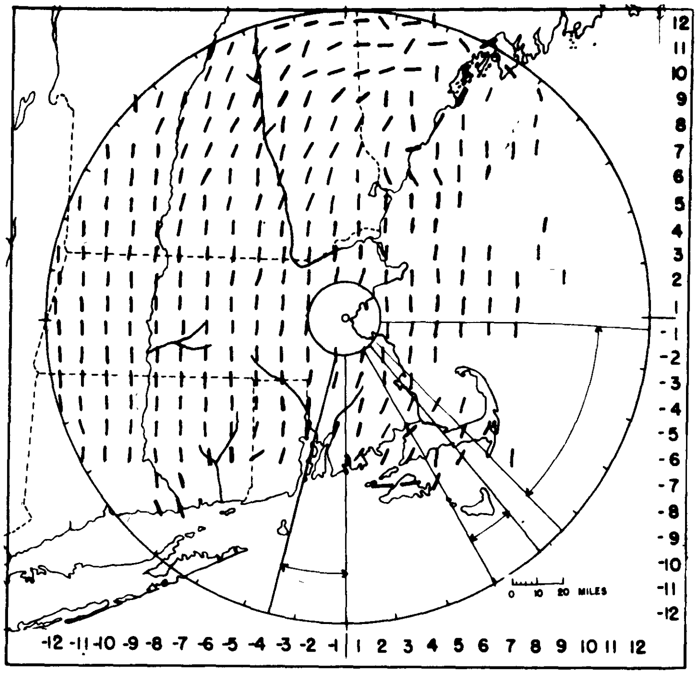

Fig. 7. Average orientations of air mass cells with log $Z_e \geq 4.5$ in each 10x10 mile square.

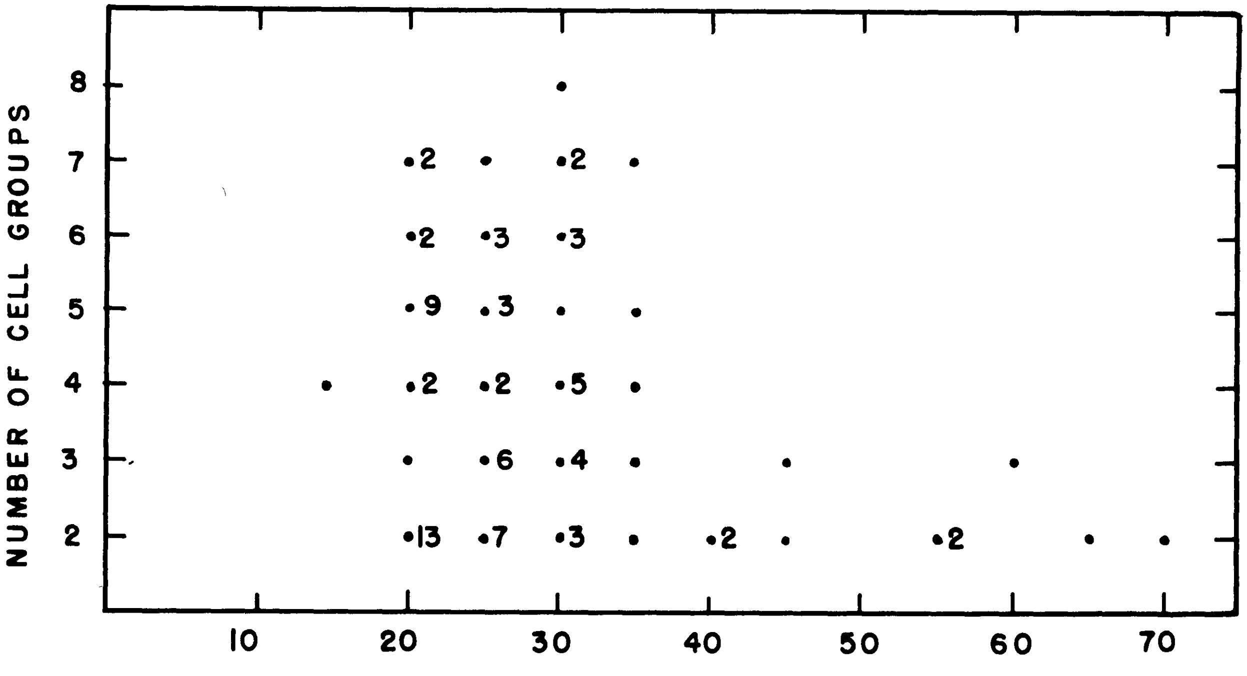

FIG. 8 DISTANCE BETWEEN LARGE CELL GROUPS (miles)

It was noted on many days that cell groups consisting of small cells (2x2 miles) appeared to be equally spaced. Groups of larger cells (one axis $\geq$ 5 miles) tended to be lined up rather than scattered about in a random fashion The average distance between cell groups on 39 days was 30 miles. This agrees with Cochran (1961). The distance distributions are shown in Fig. 8. Any number to the right of the plotted data represents the number of occurrences.

There was a tendency for twice the individual day's average cell group distance when one or more cell groups were more distant from one another.

For example, on 19 July 1960, two cell groups were 55 miles apart while the remaining 13 were 25-35 miles apart; on 10 July 1961, two were 45 miles apart and 20 were 20 to 30 miles aparts; on 31 July 1962 two were 40 miles apart and five were 20 miles apart and on 25 July 1963, two cell groups were 70 miles apart while seven were 35 miles apart.

D. Cell motions.

The tracks of air mass cells were generally short ($<$15 miles), and usually corresponded to small cells with a short duration. Table 4 shows this distribution of cell track lengths. The four days that did not have any noticeable tracks had 500 mb lows or deep troughs. The longest cell track was probably at least over 100 miles, partly in the radar shadow area on 9 June 1965. Other dates of long tracks were 23 June 1965, 14 August 1963, 12 September 1963, 31 May 1962, 12 July 1962. There were 17 days with cell track lengths $\geq$ 30 miles and 12 of these had cells with log Ze $\geq$ 5.5. All but one of the 17 days had cells with one dimension equal or greater than five miles.

Table 5 shows the distribution of 500 mb wind speed when long cell tracks occurred. There were no wind speeds less than 20 kts.

Figure 9 shows the distribution of distances between cell tracks. Days with large distances had few tracks. When they were widely scattered, there was a tendency for distances to be in multiples of the average, 22 miles. On 31 July 1959, cell tracks were 25 and 45 miles apart.

Table 4. Length of cell tracks on 60 days.

Length of cell track (mi)	Number of cell tracks	Length of cell tracks (mi)	Number of cell tracks
1-5	698	56-60	4
6-10	549	61-65	5
11-15	150	66-70	2
16-20	124	71-75	1
21-25	44	76-80	3
26-30	36	81-85	0
31-35	24	86-90	1
36-40	14	91-95	0
41-45	8	96-100	0
46-50	10	101-105	1
51-55	5		

Total number of tracks: 1679

Total number of tracks $\leq$ 15 mi : 1397

Table 5. Number of days with cell tracks greater than 30 miles and their 500 mb wind speeds.

500 mb wind (kts)	Number of days
20	3
25	2
30	1
35	6
40	3
45	1
50	1

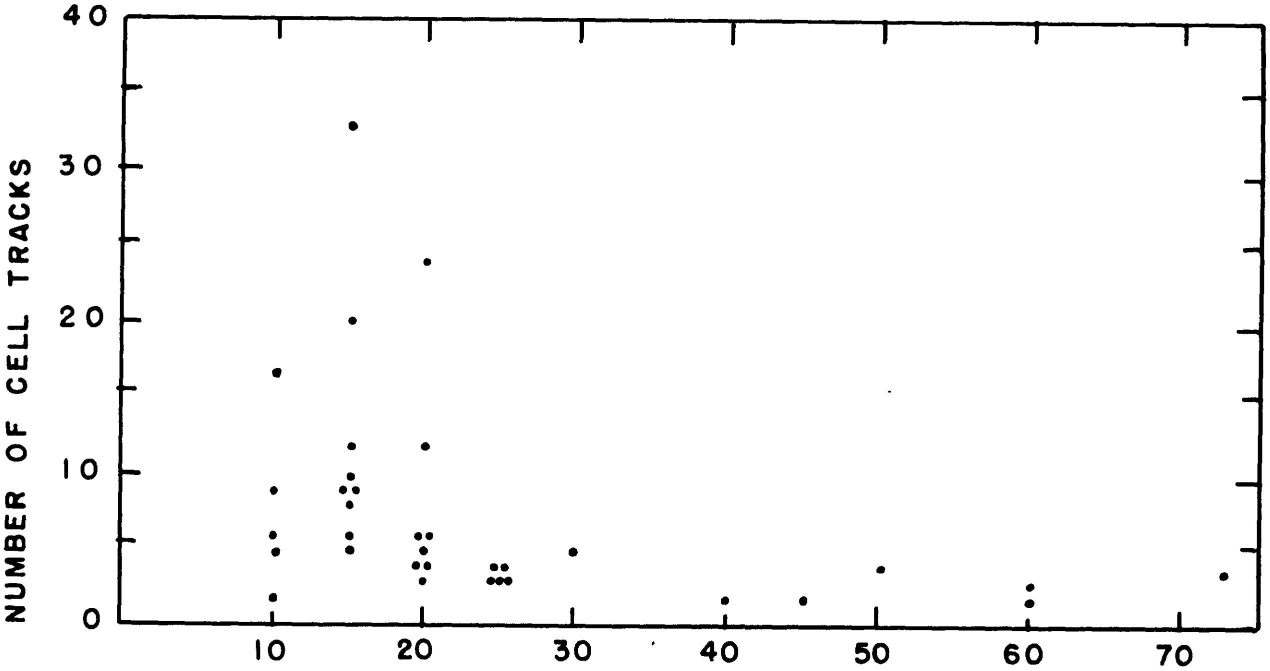

FIG. 9 DISTANCE BETWEEN CELL TRACKS (*miles*)

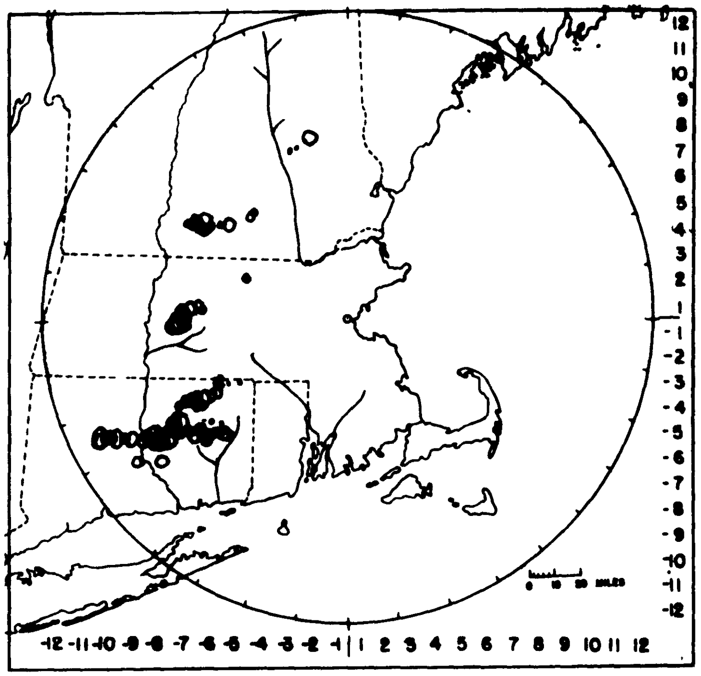

Fig. 10. Tracks of air mass cells with log $Z_e \geq 4.5$ which moved in different directions on 24 June 1959.

There is normally very little wind direction shear between 850 mb and 500 mb during days with air mass cells, except near a closed low or deep trough at 500 mb. This explains why the 500 mb flow was observed to be nearly parallel to the direction of cell motion, as shown in later figures of cell tracks.

Table 6 shows the distribution of wind direction shears (850 mb to 500 mb) on 24 days when air mass cells were near radiosonde stations. There was usually a backing of winds with height and most wind shears were less than 20°.

Table 6. Wind direction shears (850 mb to 500 mb) when air mass cells occurred. Positive is backing and negative is veering with height. Total number of days was 24.

Wind shear (deg)	Number of radiosonde reports
+40°	1
+30°	2
+20°	2
+10°	7
0°	9
-10°	5
-20°	0
-30°	2
-40°	1

On 18 July 1962 and 31 May 1962, the large intense cells moved at about 35° to the right of smaller cells, the latter moving parallel to the 500-mb flow. This movement is quite common with severe thunderstorms; Newton (1959).

On three days cells moved from the southwest to the northeast in southern New England, whereas those in central New England moved from west to east. The dates were 12 July 1962, 11 August 1961 and 31 July 1959 and the phenomena could be explained by a small backing of the upper level winds in southern New England.

On the afternoon of 24 July 1959, very unusual motion was observed. Cells with log Ze ≥ 4.5, measuring about six by five miles in horizontal dimension, moved eastward with the 500-mb flow in southern Connecticut, while smaller cells (four by three miles) about 15 miles to the north moved northeastward. Figure 10 shows tracings of the cell positions at about four minute intervals. The cells moved to the east in areas 5S, 10-5W and 6S, 9-8W Other cells moved northeastward in areas 5S8W, 5S7W, 4S7W, 4S6W and 3S5W

The cells that moved eastward were in the Connecticut River Valley and just south of the 500 foot contoured plateau in southern Connecticut while those that moved northeastward started near Medhomasic Mt (800 feet) and were confined to the hilly plateau of eastern Connecticut.

Table 7 shows west southwest flow at station 74486, J.F. Kennedy International Airport, N.Y., which is similar to the Albany, N.Y. and Nantucket, Mass. winds.

Fortunately some RHI observations were made with the AN/CPS-9 radar and they showed small turrets with tops to 40,000 feet and 45,000 feet of both cell groups that moved in different directions.

If field experiments near area 5S8W revealed complex lee waves with intersecting maxima nodes extending in a southwest to northeast direction over the plateau, the different cell movements could be explained.

E. Detailed topography of area.

A topographical chart of southern New England showing the orientation of the axis of pronounced ridges and mountains is in Fig. 11. It was constructed by indicating where slopes are greater than 250 feet per mile in semi-flat plain areas where the mean elevation is less than 500 feet MSL, the mean 500 feet MSL contour and the most prominent hills and mountains with steep slopes where the mean elevation is greater than 500 feet MSL. Some major features, other than those previously mentioned, are the steep escarpments along the east side of the Connecticut River Valley in Connecticut and Massachusetts, the plateau with elevation greater than 500 feet MSL in eastern Connecticut and western Rhode Island and minor hills such as the 350 feet Copicut Hill immediately east of Fall River, Massachusetts in area 5S1E. Table 8 lists a few areas with their topographical features that are referred to.

Table 7. Upper air winds on 24 July 1959 when cells moved in different directions near Middletown, Connecticut.

Station 74486 JFK

Wind directions are in degrees and wind speeds in m/sec

July 1959	Surface	150 m	300 m	500 m	1000 m	1500 m	2000 m
24/1200Z	240 03	242 08	246 11	258 13	261 12	248 12	240 13
24/1800Z	240 06	241 07	242 09	243 10	250 11	251 12	248 10
	2500 m	3000 m	4000 m	5000 m	6000 m	7000 m	8000 m
24/1200Z	239 13	242 14	255 17	260 19	269 17	261 19	250 12
24/1800Z	258 16	257 16	258 16	266 21	256 18	252 17	250 18
	9000 m	1000 m	11000 m	12000 m	13000 m	14000 m	15000 m
24/1200Z	249 13	273 12	281 08	269 09	278 16	322 13	315 06
24/1800Z	249 15	250 13	251 15	251 16	253 17	264 15	290 05
	16000 m	17000 m	18000 m				
24/1200Z	304 05	026 02	029 03				
24/1800Z	021 02	100 02	130 04				

Some rivers are also shown, which are the long Connecticut River from Long Island Sound northward through Connecticut and Massachusetts and forming the boundary between New Hampshire and Vermont. The Ware and Quaboag Rivers

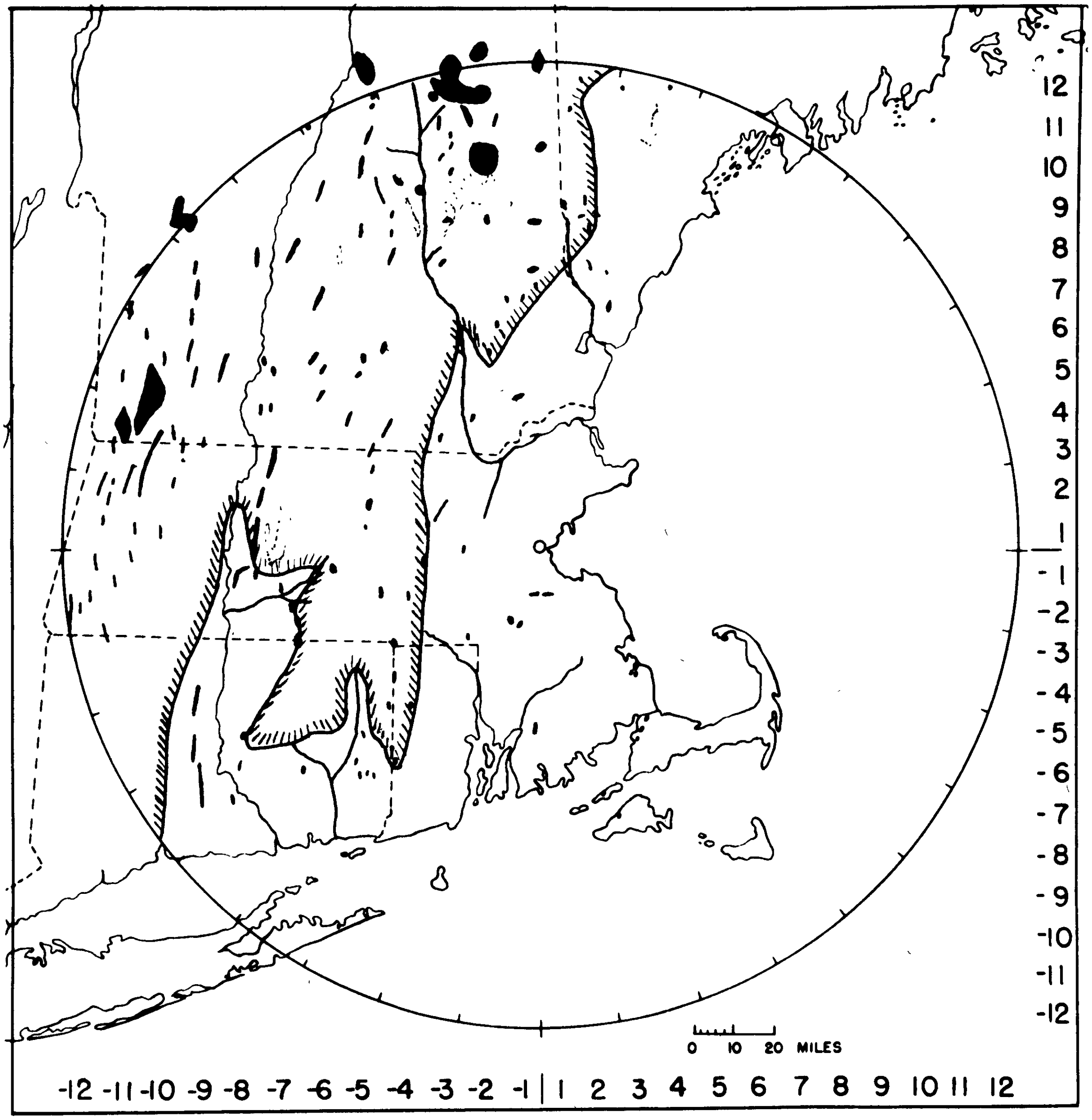

Fig. 11. Map showing topographical barrier, 500 ft contour and major rivers and lakes (dotted areas).

Table 8. Topographic features of 10x10 mile areas. Coordinates are centered at M.I.T.

Area:		Topographical features:
12N	1W	Valley, surrounded by mountains.
12N	1E	Valley, one mountain
11N	4W	Mountains in west
11N	3W	Mt. Tecumseh (4,000 feet), Sandwich Mt. (3,993 feet and Trypyramid (4,140 feet).
11N	2W	Sandwich Mt. (3,993 feet), Mt. Israel (2,636 feet), Squam Mts.
11N	1W	Plateau
11N	1E	Valley
11N	2E	One half of area < 500 feet MSL.
11N	3E	Sebago Lake
10N	6W	Moose Mt (2,300 feet)
10N	2W	Ossipee Mts. (2,973 feet)
10N	1E	One mountain (2,975 feet)
10N	2N	One half of areas < 500 feet MSL
10N	3E	Area < 500 feet MSL
10N	6E	Casco Bay
9N	5W	Mt. Cardigan (3,121 feet) to east.
9N	3W	Pemigawasett River Valley area
9N	2W	Lake Winnipesaukee
9N	1E	One mountain (1,745 feet)
9N	3E	Area < 500 feet MSL
9N	4E	Area < 500 feet MSL
8N	5W	Sunapee Lake
8N	4W	Mt. Kearsage (2,937 feet) and Ragged Mt. (2,225 feet).
8N	3W	Pemigawasett River Valley
8N	1E	Moose Mt. (1,756 feet) and Parker Mt. (1,451 feet) to west.
8N	4E	Saco Bay area
7N	3W	Merrimac River Valley
7N	2W	East of Merrimac River Valley
7N	1W	Catamount Mt. (1,334 feet) and Blue Hills Range (1,220 feet).
7N	1E	One half of area < 500 feet MSL.
7N	3E	Crescent Surf and coast
7N	4E	Crescent Surf area
6N	4W	Mt. Wallingford (1,197 feet) to south
6N	3W	West of Merrimac River Valley
6N	2W	Merrimac River Valley
6N	1W	One half of area < 500 feet MSL, Fort Mt. (1,410 feet)
6N	2E	Piscataqua River Valley, Great Bay area
6N	3E	York harbor area
6N	4E	Gulf of Maine area
5N	8W	Connecticut River Valley, Mt. Pisgah (3,605 feet) to west.

Table 8 (continued)

Area:		Topographical features:
5N	5W	Lemster Mt. (2,743 feet), Lovewell Mt. (2,473 feet)
5N	4W	Mt. Wallingford (1,197 feet) in north
5N	3W	Merrimac River Valley to east
5N	2W	Merrimac River Valley
5N	1W	Area less than 500 feet MSL
5N	2E	Hampton harbor and coast area
5N	3E	Little Harbor area
4N	10W	3,000 foot mountains near Bennington, Vermont.
4N	9W	West of Connecticut River Valley
4N	7W	Mt. Surrey (1,500 feet), Pisgah Mt. (1,510 feet)
4N	5W	Monadnock Mt. (3,165 feet)
4N	4W	Pack Monadnock Mt. (2,130 feet)
4N	1E	Merrimac River Valley
4N	2E	Plum Island area
3N	6W	Plateau
3N	5W	New Ipswich Mt. (1,848 feet)
3N	4W	Pack Monadnock Mt. (2,310 feet) in northwest
3N	2W	Merrimac River Valley
3N	1W	Merrimac River Valley
3N	4E	Massachusetts Bay off Rockport, Massachusetts
2N	7W	Craig Mt. (1,500 feet), ridge in west
2N	6W	Valley in plateau
2N	5W	Valley in plateau
2N	3W	Three quarters of area less than 500 feet MSL
2N	2W	Plain
2N	1W	Plain
2N	1E	Plain
2N	2E	Gloucester harbor area
2N	5E	Massachusetts Bay east of Gloucester, Massachusetts.
1N	7W	Mt. Lincoln (1,238 feet) and Brushy Mt. (1,260 feet) in west. Quabbin reservoir.
1N	6W	Valley in plateau
1N	5W	Plateau, Mt. Wachusett (2,006 feet), one hill
1N	4W	Plateau
1N	3W	Three quarters of area $<$ 500 feet MSL, Wachusett reservoir, ridge.
1N	2W	Plain
1N	4E	Massachusetts Bay, off Boston harbor
1S	8W	Holyoke Range, Mt. Tom (1,200 feet) and Mt. Holyoke (878 feet) in the Connecticut River Valley.
1S	7W	Ware River Valley
1S	6W	Ware River Valley, Ragged Hill (1,227 feet)
1S	5W	Plateau, hill (1,667 feet)
1S	4W	Plateau
1S	3W	Three quarters of area $<$ 500 feet, hill (755 feet).

Table 8 (continued)

Area:		Topographical features:
1S	2W	Plain, Nobscott hill (500 feet) in north
2S	11W	Plateau, Bradford Mt. (1,927 feet)
2S	7W	Connecticut River Valley, Minnechoag Mt. (931 feet) in east
2S	6W	Plateau, Moon Mt., Rattlesnake Mt. (1,000 feet)
2S	5W	Plateau
2S	4W	Plateau, one hill (1,411 feet)
2S	3W	Three quarters of area less than 500 feet MSL.
2S	2W	Plain
2S	1E	Plain, Blue Hills to northwest
3S	8W	Connecticut River Valley
3S	7W	Connecticut River Valley, plateau in east
3S	6W	Plateau, Bald Hill
3S	5W	Plateau, Quinebaug River Valley
3S	4W	Plateau, Jerimoth Hill (804 feet).
3S	2W	Plain, Seekonk River Valley
3S	1E	Plain
4S	9W	Connecticut River Valley, Rattlesnake Mt. (750 and 685 feet)
4S	8W	Connecticut River Valley, plateau in east
4S	7W	Plateau, Connecticut River Valley to west
4S	6W	Plateau
4S	5W	Quinebaug River Valley
4S	4W	Plateau, Cucumber Hill (685 feet)
4S	3W	Plain, plateau to west
4S	2W	Plain
5S	8W	Connecticut River Valley, Medhomasic Mt. (800 feet)
5S	7W	Three quarters of area is a plateau
5S	6W	One half of area is Shetucket River Valley
5S	4W	Plateau, 2 hills (629 feet and 555 feet)
5S	3W	Plain
5S	2W	Upper Narragansett Bay
5S	1E	Plain, Copicut Hill (354 feet) in west
6S	9W	Connecticut River Valley, Beseck Mt, Higby Mt.
6S	8W	Connecticut River Valley, Bear Hill
6S	7W	Connecticut River Valley
6S	5W	Valley and hills
6S	4W	Valley and hills
7S	4E	Nantucket Sound, east of Martha Vineyard Island.

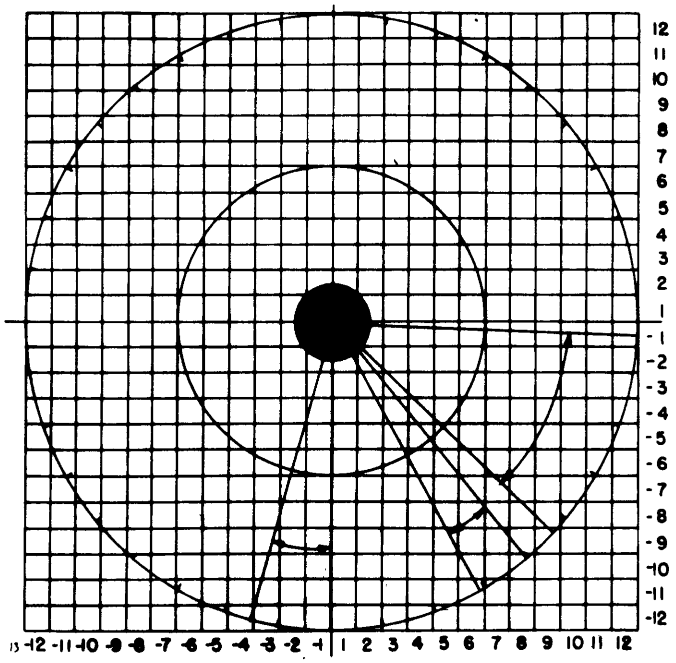

Fig. 12. Radar shadow areas observed with the SCR-615-B radar at MIT.

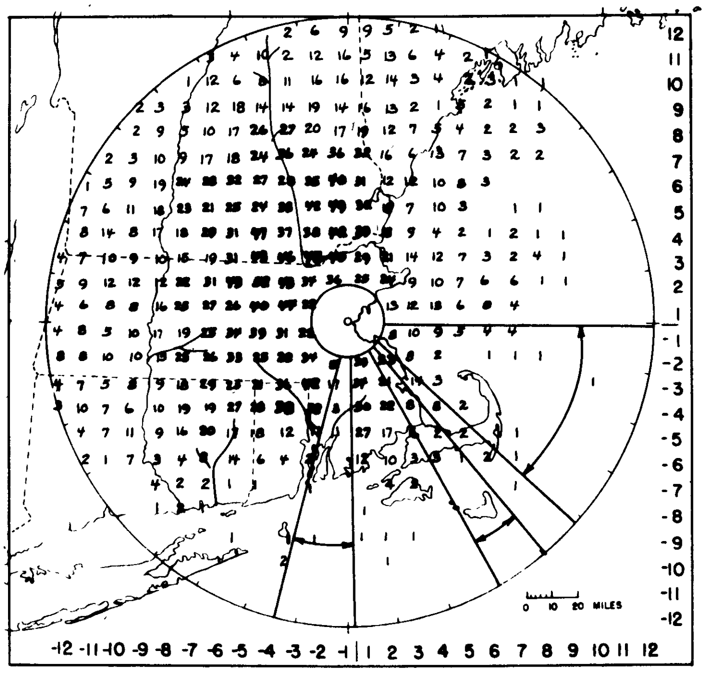

Fig. 13. Number of cells with log $Z_e \geq 4.5$ which occurred in each 10x10 mile square. Total number of cells on 64 days was 3878.

join the Connecticut River in western Massachusetts. In eastern Connecticut, the Shetucket and Quinebaug Rivers join to form the Thames River leading to the Long Island Sound. At least two rivers lead into Narragansett Bay, Rhode Island; the Blackstone and Seekonk rivers and the Taunton River of Massachusetts leads into Mount Hope Bay, Rhode Island, as shown in Fig. 6. The Merrimac River of central New Hampshire and northeastern Massachusetts is fed by the Pemigawasett, Mad and Baker Rivers of northern New Hampshire.

F. Geographical distributions for all air mass thunderstorms.

The distribution of durations, formations, dissipations and tracks of air mass cells whose log Ze $\geq$ 4.5 will be presented for the various 500-mb flow patterns.

Before presenting the results, some PPI radar data problems should be mentioned. There were radar shadow areas caused by surrounding buildings which are shown in Fig. 12. They were mainly in the east to southeast and south southwest sectors. This was unfortunate, as it is in the area of sea breeze convergence lines, small hills on a general plain and a probable area of maximum nocturnal thunderstorms.

A thunderstorm at a great distance from the radar would fill less radar beam, both horizontally and vertically, particularly if it were a relatively small cell and thus might appear weaker. Surface weather observations from Portland, Maine, 90 miles away, Providence, Rhode Island and Worcester, Massachusetts both 50 miles, Concord, New Hampshire 60 miles and New Haven, Connecticut, 120 miles away were scanned when the SCR-615-B radar was operating. This would determine if any thunderstorms were missed because of this beam filling problem or improper calibration or if the radar indicated a too high value of log Ze.

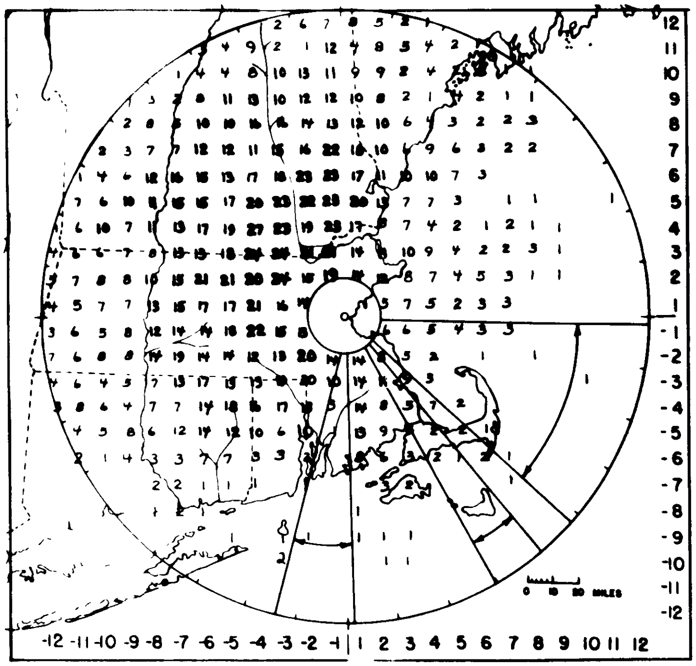

Fig. 14. Number of days when air mass cells with log $Z_e \geq 4.5$ occurred in each 10x10 mile square. Total number of days when log $Z_e \geq 4.5$ was 64.

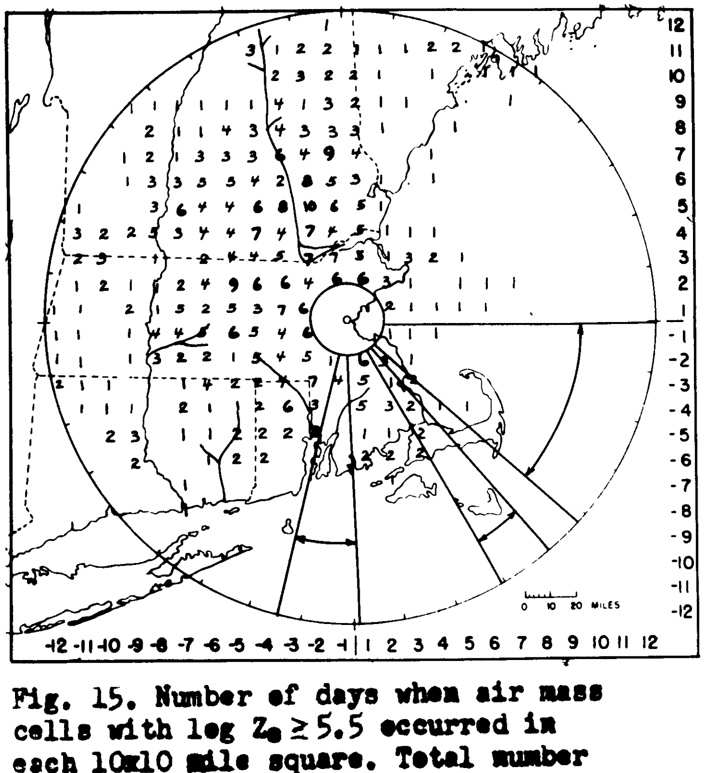

Fig. 15. Number of days when air mass cells with log $Z_e \geq 5.5$ occurred in each 10x10 mile square. Total number of days with Log $Z_e \geq 5.5$ was 38.

Table 9 compares the surface with radar observations and shows that the SCR-615-B radar can observe scattered, "medium sized" thunderstorms to 120 miles, but it does suggest a range effect.

Table 9. Comparison of surface and radar observations of thunderstorms
Number of thunderstorm days observed by:

Surface Station		SCR-615-B Radar
Providence, Rhode Island	12	13
Worcester, Massachusetts	10	11
Concord, New Hampshire	21	20
Portland, Maine	10	7
New Haven, Connecticut	2	1

Figure 13 shows that the total number of cells in each 10x10 mile area. In every direction the number of cells observed decreases with range beyond about 60 miles. This is an instrumental effect resulting from the broad beam of the radar. Intense cores in the thunderstorms are often small and fail to fill the beam, so that at large ranges, the storms appear less intense than at close ranges.

Areas of maximum frequency defined by more than 35 cells extend from just east of Concord, New Hampshire, (7N 1W) southwest along a plateau and plain to central Massachusetts, then southeastward to northern Rhode Island, including the inland plains to the east.

The eastern side of the Connecticut River Valley has more cells than the western side. This is particularly noticeable in Massachusetts and northern Connecticut where there are some steep escarpments and mountains on the extreme eastern side of the valley. There is a rapid increase of cells inland from the coastal waters of northeastern Massachusetts and southern New Hampshire This must be related to the sea breeze which moves inland. Davis, Schultz and Ward in 1888 indicated that the maximum penetration of the sea breeze inland in this region was 22 to 25 miles. The Pemigawasett River Valley of New Hampshire (9N3W) and just to the east of it, the Lake Winnipesaukee area of New Hampshire (9N2W) and the mountainous areas of 8N4W and 4N10W which contain Mt. Kearsage, New Hampshire and 3,000 foot mountains near Bennington, Vermont, respectively, shown weak maxima. Square 7N3W in the Merrimac River Valley of New Hampshire has a maximum frequency of cell occurrence (36).

There is a minimum number of cells east of the 500 foot MSL contour in Maine, especially areas 9N4E and 9N3E, and all the sea areas, particularly off southern New England.

Figure 14 shows the number of individual days when cells occurred in each square and resembles Fig. 13, the number of cells. An area of maximum frequency of thunderstorm days defined by more than 20 days extends from area 7N1W along a plateau and plain to central Massachusetts. The east sides of the Connecticut and Pemigawasett River Valleys have more thunderstorm days than the west sides. Areas 8N4W and 4N10W again have maxima and areas 4N4W containing the Pack Monadnock Mt., 7N1W with Catamount Mt. and Blue Hills Range, 2S7W in the eastern Connecticut River Valley, 3S6W just east of this valley and 4S5W, the Quinebaug River Valley, show definite maxima. There is a definite decrease of thunderstorm days near the southern New England coastline and the adjacent sea areas. A similar decrease is seen in Maine eastward from the 500 foot contour and in the Gulf of Maine.

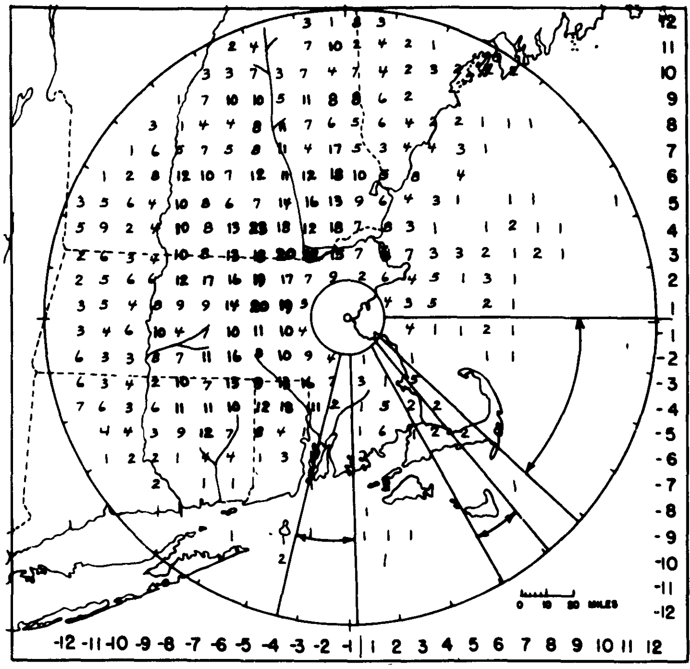

Fig. 16. Number of cell formations when log Z_e increases to 4.5 in each 10x10 mile square.

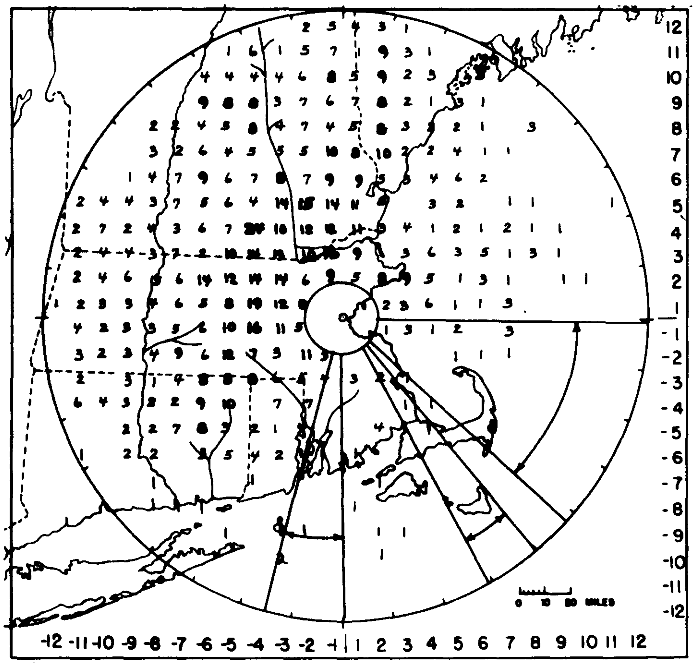

Fig. 17. Number of cell dissipations when log Z_e decreases to below 4.5 in each 10x10 mile square.

Figure 15 shows the number of hailstorm days and in general resembles Fig. 14, the number of thunderstorm days. Squares of maximum frequency are 2N5W and 5N2W, 6N2W, 7N1W in and east of the Merrimac River Valley of New Hampshire and 4S3W. The sea and coastal areas are practically devoid of hailstorms except possibly in the radar shadow area of southeastern Massachusetts.

Figure 16 shows the formations of all cells and resembles Fig. 13, the number of all cells. The area of most frequent cell formation extends from just east of Concord, New Hampshire, 7N1W, southwestward along a plateau and plain to central Massachusetts and then southeastward to northern Rhode Island. The Merrimac River Valley, except for the Pemigawasett River Valley of New Hampshire 3W, 9 to 12N has a maximum number of cell formations and the east side of the Connecticut River Valley has more formations and also more dissipations than the west side.

There is an area of fewer than average cell formations east of the 500 foot MSL contour in Maine, which is the border between 2E and 3E. All the sea areas show practically no cell formations.

The number of cell formations and dissipations sometimes varied rapidly from one 10 by 10 mile square to another. It was therefore decided to designate a single square as a "significant" maximum or minimum when it is 100% larger or 50% smaller respectively than the average of the surrounding eight squares.

"Significant" squares of maximum cell formation were 12N1E, 7N1W, 4N10W and 1S8W, which is in the eastern Connecticut River Valley with three small mountains.

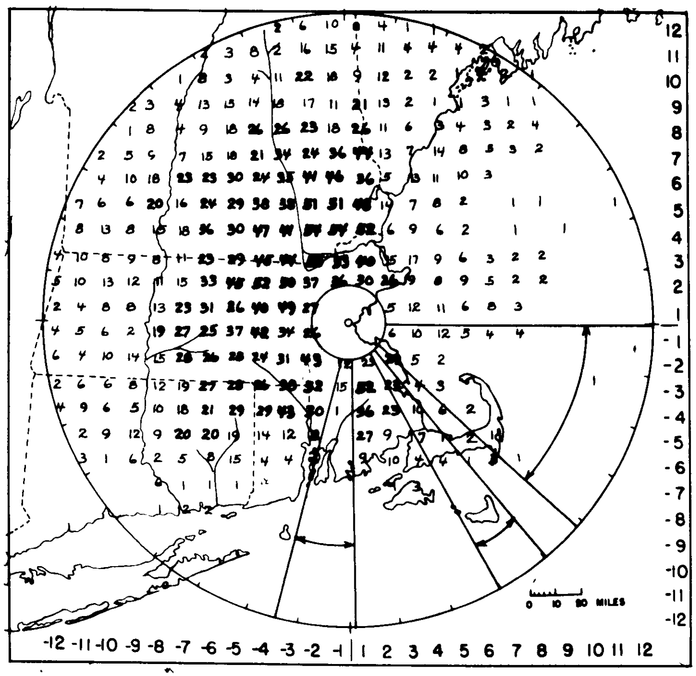

Fig. 18. Total time in tens of minutes when cells with log $Z_e \geq 4.5$ were in each 10x10 mile square.

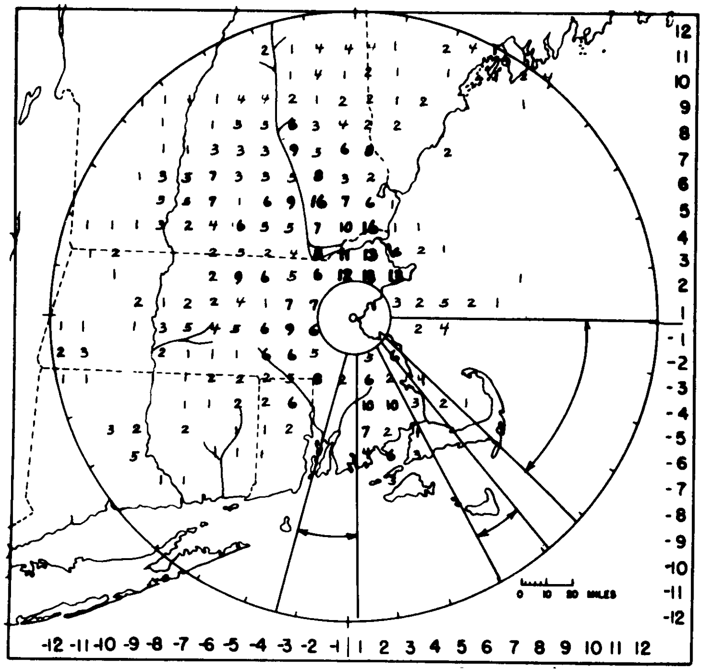

Fig. 19. Total time in tens of minutes when cells with log $Z_e \geq 5.5$ were in each 10x10 mile square.

"Significant" squares of minimum cell formation were 12N1W, 11N3W, 11N1E, 9N3W, 7N2W, 6N4E, 2N1E, 1N2W, 1S2W, 5S3W and 6S4W. These areas have terrain features varying from plains to mountains.

Figure 17 shows the dissipation of all cells. There is a maximum number of cell dissipations along the 500-ft MSL contour in Maine, 2E from 7N to 11N. This area then widens near 7N1E to east central Massachusetts and northern Rhode Island. There is also a weak, narrow maximum about 25 miles to the east of the Maine, New Hampshire and northeastern Massachusetts coast line. "Significant" squares of maximum cell dissipation are 4N4W, 2N6W, 1N4E and 2S2W which have topographical features varying from ocean to mountain.

Areas of minimum dissipation are over the sea areas except for the narrow strip off the east coast that was just mentioned. This minimum is explained by a lack of cells over the sea.

"Significant" squares of minimum cell dissipation are 11N3W, 11N1E, 9N3W, 5N4W, 5N3E, 4N9W, 3N6W, 2N2W, 2S3W, 3S8W and 5S3W which again have varied terrain features.

Cell formation minima and dissipation minima are in squares 11N3W, 11N1E and 9N3W.

There were more cells than those forming and dissipating within a 90 mile radius of M.I.T., which is explained by advection of cells. A few areas beyond 90 miles had more combined cell formations and dissipations than the total number of cells because some cells would form and dissipate in the same square.

Figure 18 shows the number of tens of minutes of cells in each area and resembles Fig. 14, the number of thunderstorm days. The areas of maximum times

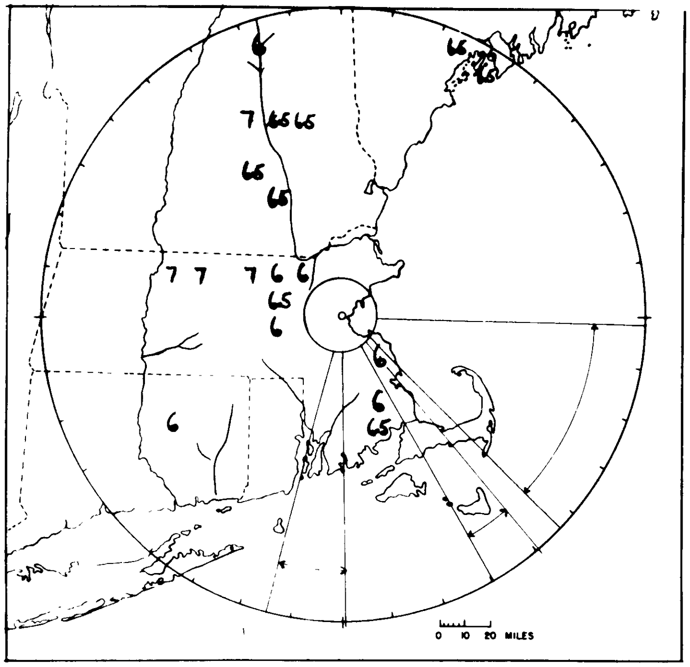

Fig. 20. Locations and intensities of cells with log $Z_e \geq 6.0$.

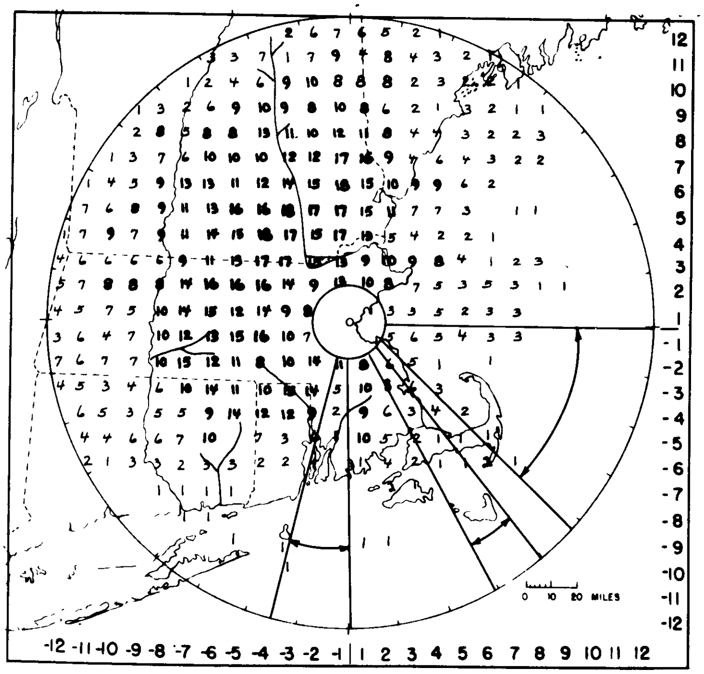

Fig. 21. Number of days when air mass cells with log $Ze \geq 4.5$ occurred. 500-mb flow: SW to W. Total number of days: 47.

defined by more than 400 minutes extend from area 7N1E southwestward to east central Massachusetts and then southeastward to southeastern Massachusetts and northern Rhode Island. The east sides of the Merrimac River Valley of New Hampshire and the Connecticut River Valley have maximum times. There is a secondary maximum area along the Maine coast, particularly square 7N4E off Crescent Surf. "Significant" squares of maximum time are 11N2W, 10N6W, 7N4E, 2S7W, 5S7W and 6S5W.

Areas of minimum time are just east of the 500-ft MSL contour in Maine and the south coast and coastal waters from New Haven, Connecticut, 8S9W to Cuttyhunk Island, 7S1W, near Martha's Vineyard, Massachusetts. "Significant" squares of minimum times are 11N3W, 10N3E, 9N4E, 9N3E, 8N4E, 7N3E, 6N2E, 4N9W and 6S8W.

Figure 19, the number of tens of minutes of hailstorms shows a maximum time in the plains surrounding Boston, Massachusetts and in the area between radar shadows to the southeast. "Significant" squares of maximum time are 11N2W, 11N1W, 7N1E, 5N2W and 2N5W.

Minimum times occur in the Gulf of Maine and the south coast and adjacent sea areas from New Haven, Connecticut, 8S9W, to Cuttyhunk Island, Massachusetts, 7S1E. "Significant" minimum times are in squares 5N5W, 3N4W, 1N4W, 2S6W and 2S5W.

Figure 20 shows the locations and intensities of cells with $\log Ze \geq 6.0$ They were mainly in the northwest and southeast sectors.

G. Distribution for days with southwest flow.

Figure 21 shows the number of days with thunderstorms when the 500-mb flow is southwest to west. It resembles Fig. 14, the total number of thunderstorm days, as 47 out of 64 days had this flow.

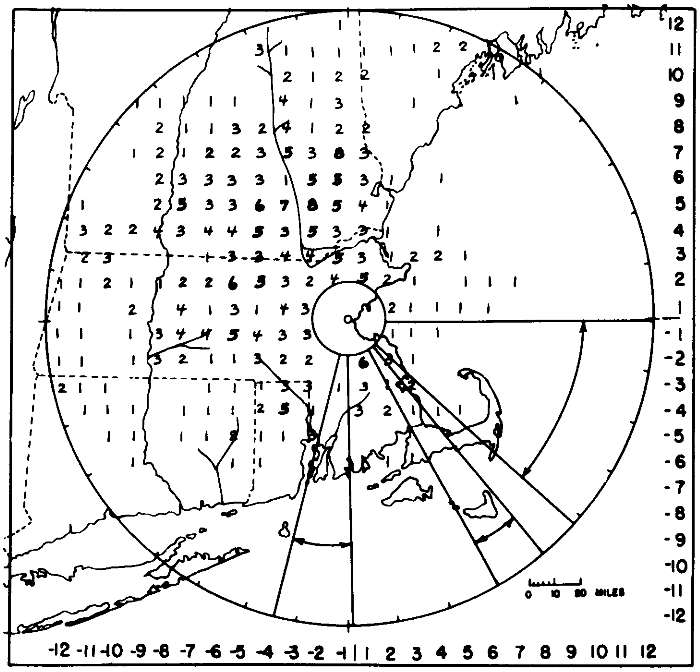

Fig. 22. Number of days when air mass cells with log $Z_e \geq 5.5$ occurred. 500-mb flow: SW to W. Total number of days: 29.

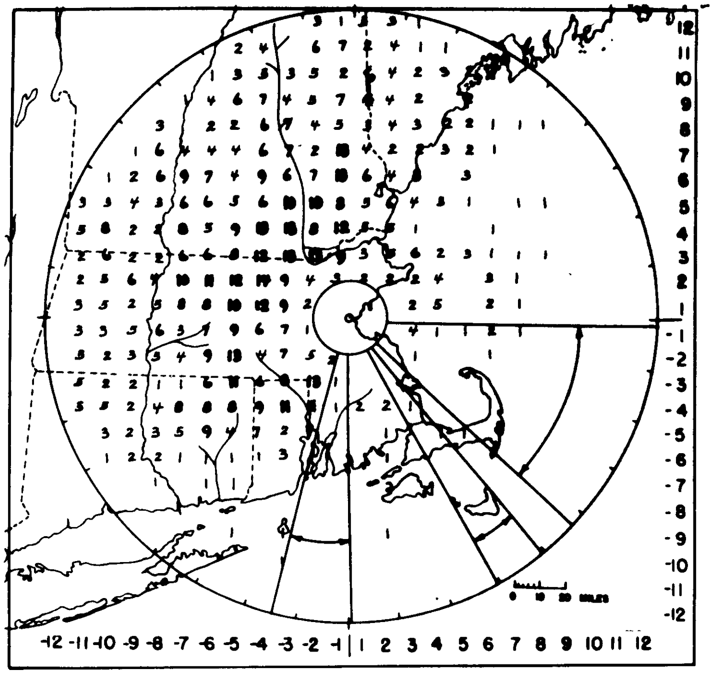

Fig. 23. Number of cell formations when log Z_e increases to 4.5 and 500 mb flow is southwest to west.

Relatively high frequency occurs in the following general areas:

2E, 7-12N: all figures are at least twice as large as those in the adjacent column 3E, 7-12N, where the latter is less than 500-ft MSL.

7N1E to 2N6W: 16 or more days were recorded in a number of squares throughout this mainly plateau area.

8W, 4S to 1N and 6N to 9N: all figures are at least 1½ times as great as those in the adjacent column, 9W. Areas 8W, 4S to 1N are on the east side of the Connecticut River Valley and areas 8W, 6N to 9N are to the lee of the ridges.

Squares 2S7W in the eastern Connecticut River Valley, 4S5W in the Quinebaug River Valley and 1S5W and 1S4W to the lee of the Ware River Valley have maximum numbers of days. The Pemigawasett River Valley of New Hampshire 3W, 8N to 11N seemed to have little effect.

Minimum number of days occurred to the east of the 500-ft MSL contour in Maine and the south coast and adjacent sea areas from New Haven, Connecticut, 8S9W to Cuttyhunk Island, Massachusetts, 7S1E. Square 11N3W had a "significant" minimum.

Figure 22 shows the number of hailstorm days when the 500-mb flow was southwest to west.

Maximum frequency occurs in the following general areas:

3W, 7N to 9N in the lower Pemigawasett River Valley of New Hampshire.

7N1W to 2N5W: four or more days were recorded in a number of squares in the Merrimac River Valley and plateau.

5N7W and 4N8W in the Connecticut River Valley just north of Keene, New Hampshire

1S, 7W to 4W in the Connecticut and Ware River Valleys and to the lee.

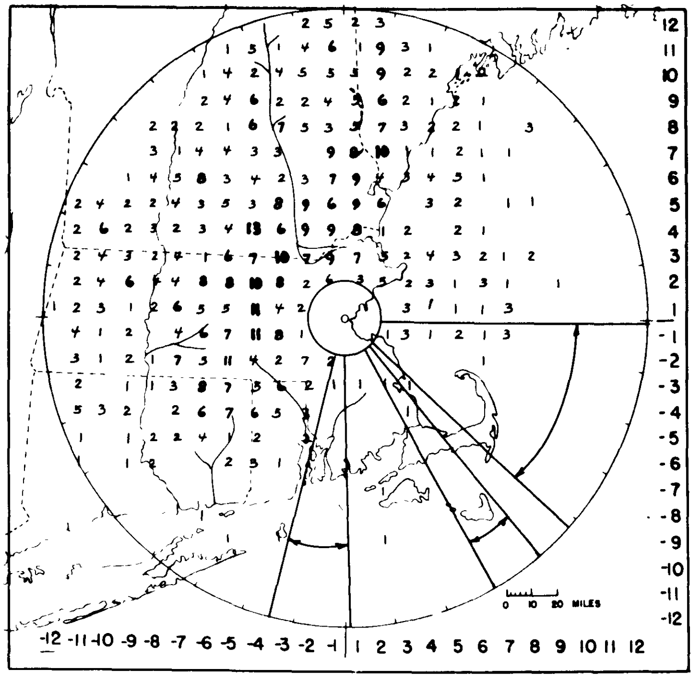

Fig. 24. Number of cell dissipations when log Z_e decreases to below 4.5 and 500 mb flow is southwest to west.

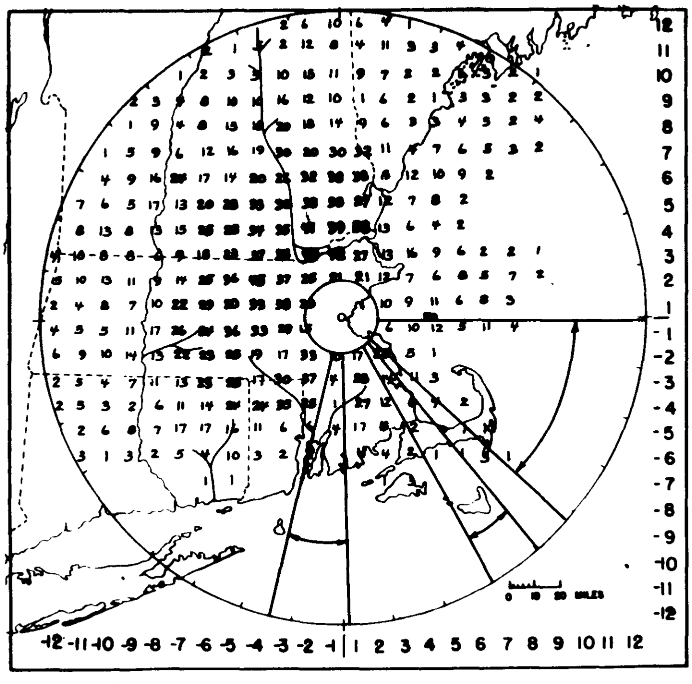

Fig. 25. Total time in tens of minutes when cells with log $Z_e \geq 4.5$ were in each 10x10 mile square. 500-mb flow:SW to W.

"Significant" maximum number of days are in squares 9N3W the Pemigawasett River Valley, 7N1W east of the Merrimac River Valley, 2S5W, 1N7W the Quabbin reservoir area, 2S1E and 4S3W just east of a plateau.

Minimum numbers of days occur in the same general areas as those of Fig. 21, the number of thunderstorm days, except for some hailstorms over the coastal waters of eastern Massachusetts. "Significant" areas of minimum number of days were 6N3W, 1N6W and 1N4W.

Figure 23 shows the number of cell formations when the 500-mb flow is southwest to west.

Maximum frequency occurs in the following general areas:

2E, 9N to 12N has twice as many formations as column 3E, the latter being less than 500-ft MSL.

7N1W to 1N5W: 10 or more formations occurred in many of the squares of a plateau and the Merrimac River Valley.

7W from 1N to 6N has 1½ times as many cell formations than column 8W, 1N to 6N, the former being on the east side of the Connecticut River Valley.

7W from 5S to 3S has 1½ times as many cell formations than column 8W, 5S to 3S, the former being on the east side of the Connecticut River Valley.

3S5W and 2S5W have a maximum number of cell formations.

The lower Pemigawasett River Valley has a weak maximum. "Significant" maximum formations occur in areas 7N1W, 6N3E York Harbor, 4N10W, 3S2W a plain with the Seekonk River and 5S2W the upper Narragansett Bay.

Areas of minimum formations are the same as areas of minimum number of thunderstorm days, Fig. 21 and include the upper Pemigawasett River Valley of New Hampshire. "Significant" areas of minima formations are 11N1E, 10N1W just

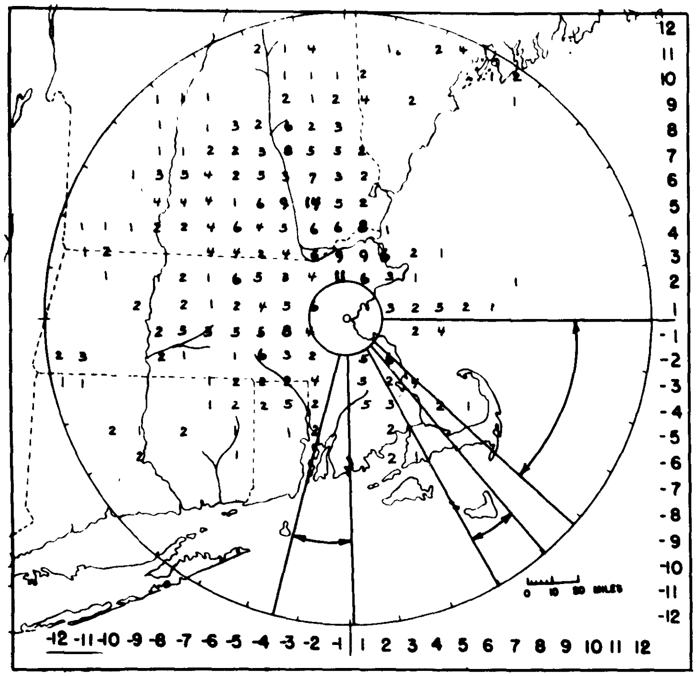

Fig. 26. Total time in tens of minutes when cells with log $Z_e \geq 5.5$ were in each 10x10 mile square. 500-mb flow:SW to W.

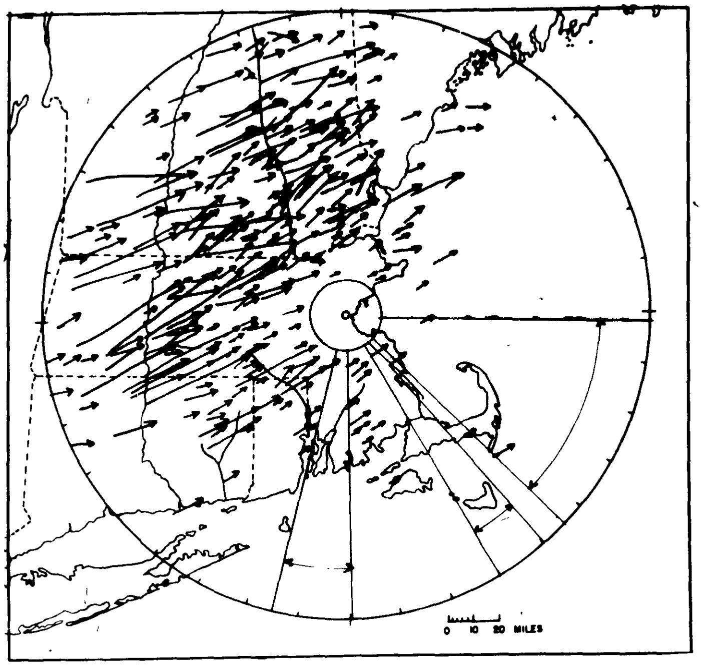

Fig. 27. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is southwest. Total number of days:10.

east of the Ossipee Mountains, 8N5W, 7N2W, 3N1E, 1N9W, 1S7W part of the entrance to the Ware River Valley, 3S8W and 5S3W.

Figure 24 shows areas of cell dissipations when the 500-mb flow was southwest to west.

Maximum frequency occurs in the following areas:

2E, 7N to 11N have maxima as compared to 3E, 7N to 11N. The latter are below 500-ft MSL.

1E, 6N and 4N have maxima compared to 2E, 6N and 4 N. The latter are close to the coast.

7W, 3S to 1N have at least 3 times as many dissipations as 8W, 3S to 1N. The former are on the east side of the Connecticut River Valley.

3N3W to 2S5W form a line of at least 10 cell dissipations in each square

4W, 8N to 9N and 8N3W have maximum cell dissipations. They are in the lee of ridges.

"Significant" areas of maximum number of cell dissipations are 11N4W, 11N2E, 10N2E, 8N4W, 7N1W, 4N10W, 4N4W, 2S7W, 2S2W and 5S6W.

Cell dissipation minima occur near and just west of the Connecticut River "Significant" areas of minimum dissipation are 11N3W, 11N1E, 9N3W, the Pemigewasset River Valley, 9N2W Lake Winnipesaukee, 7N7W, 7N2W, 5N3E, 4N2E, 3N6W, 2N2W, 1S8W, 2S3W, 3S2W and 4S8W. Areas 11N1E and 7N2W have a minimum number of both formations and dissipations.

In general, areas have both dissipation maxima and formation maxima.

Figure 25 shows the number of tens of minutes that cells occurred in each area when the 500-mb flow was southwest to west. It resembles Fig. 21, the number of thunderstorm days.

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Maximum frequency occurs in the following areas:

2E, 7N to 12N has at least twice as much time as column 3E, 7N to 12N. The latter is below 500-ft MSL.

7N1E to 1S5W form an area about 30 miles wide where at least 30 tens of minutes were recorded in each square; most of the area is in plain and plateau. Areas 4N2W, 3N2W and 3N1W in the Merrimac River Valley and 2N4W in the lee of Mt. Wachusett have over 40 tens of minutes.

2S2W to 4S3W form a narrow line of squares with over 30 tens of minutes and is in a plain.

7W, 2S to 2N, 5S to 4S have at least 1½ times as many minutes as column 8W, 2S to 2N and 5S to 4S. Column 7W is here on the east side of the Connecticut River Valley.

6N7W in the Connecticut River Valley and 4N 10W with high mountains, have maximum numbers of minutes.

A "significant" maximum time is in area 6S5W, east of the Quinebaug River Valley of Connecticut.

Areas of minimum time are east of the 500-ft contour in Maine, the sea areas and particularly the south coast and adjacent sea areas from New Haven, Connecticut (8S9W) to Cuttyhunk Island, Massachusetts (7S1E).

"Significant" minimum times are in areas 11N3W, 11N1E, 10N3E, 5S3W and 6S8W.

Figure 26 shows the number of tens of minutes of hailstorms when the 500-mb flow was southwest to west.

Maximum frequency occurs in the following areas:

8N3W to 3N1E forms a region about 20 miles wide where there are more than five tens of minutes recorded in each square. This area includes most of the Merrimac River Valley and the lower Pemigawasett River Valley.

7N, 3W to 1W; 5N, 4W to 1W and 3N, 2W to 2E form narrow rows of maximum times The middle row starts on a plateau to the lee of hills.

2N1W to 2S4W forms a narrow area of maximum time and is chiefly in plains.

2N, 5 W to 4W have over five tens of minutes and are in a plateau area.

2S2E and 4S3W possibly form the ends of an area of maximum time whose central part is in the radar shadow.

"Significant" areas of maximum time are 2N5W, 1S7W, 1S3W, 2S11W, 2S4W, 3S2W and 6S9W which are mainly valleys or close to the 500-ft MSL contour.

Minimum time areas are east of the 500-ft MSL contour in Maine and the south coast and adjacent sea areas from New Haven, Connecticut (8S9W) to Cuttyhunk Island, Massachusetts (7S1E).

"Significant" minimum times are in areas 5N5W, 1N4W and 2S6W.

Figures 27 through 31 show cell tracks for various flow patterns from the southwesterly sector. There are fewer tracks in the radar shadow area of southeastern Massachusetts and tracks end in Maine when the 500-mb flow is southwest, compared with westerly flow. With west flow, the cell tracks increase over the coastal waters of eastern Massachusetts, New Hampshire and Maine Any tracks that appear to move in odd directions can be explained by backing of winds, trough passage, or by large intense cells moving to the right of the 500-mb flow Figure 32 shows cell tracks when log Ze was slightly less than 4.5 and the 500-mb flow was southwest or west southwest. It was prepared to obtain more data in southeastern New England where sea breeze convergence lines are common and to show that heavy rainshowers occur in the same areas as thunderstorms.

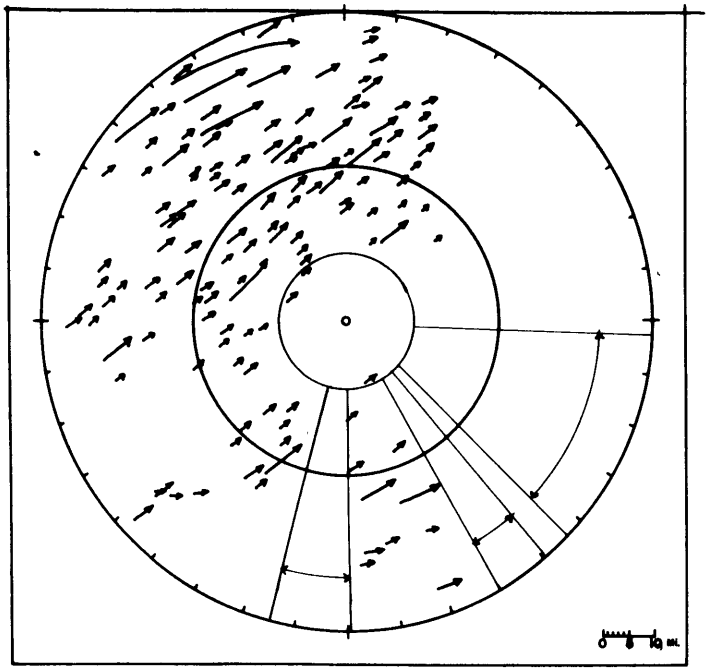

Fig. 28. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is southwest. Total number of days: 6. Range: 60 miles.

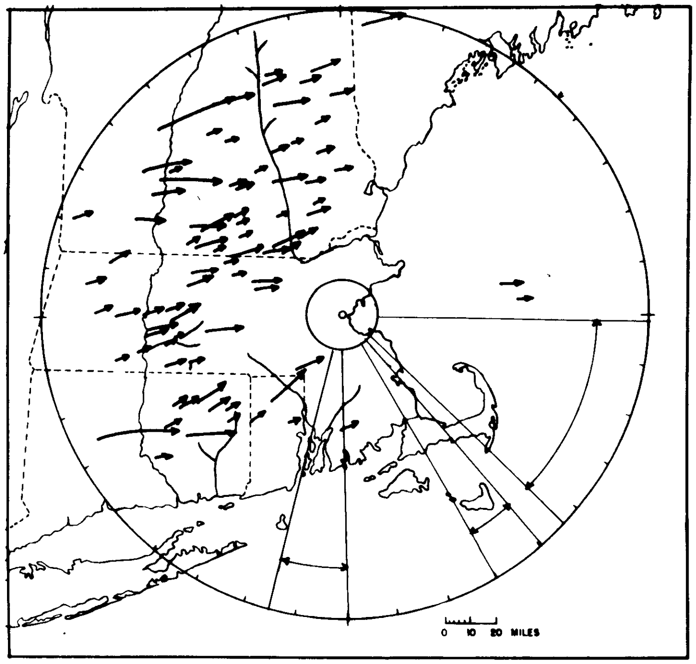

Fig. 29. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is west southwest. Total number of days was six.

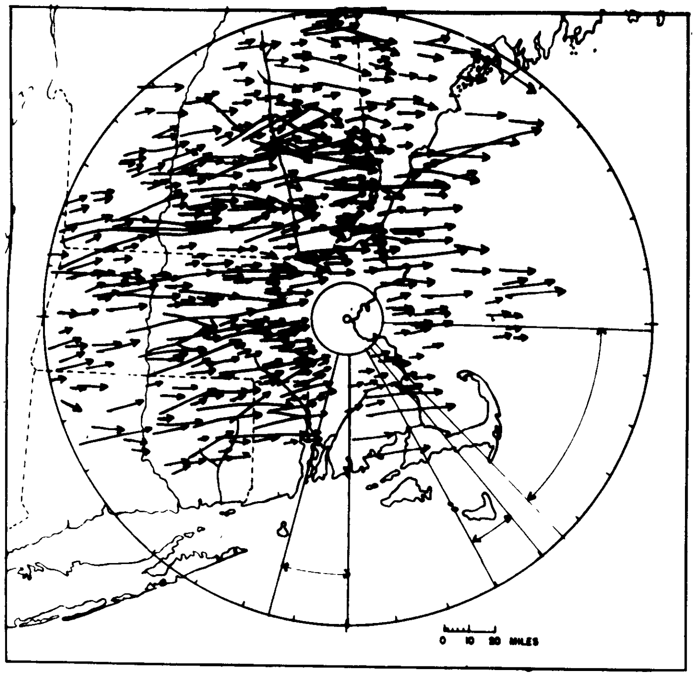

Fig. 30. Cell tracks when log $Z_e \geq 4.5$ and 500mb flow is west. Total number of days was 22.

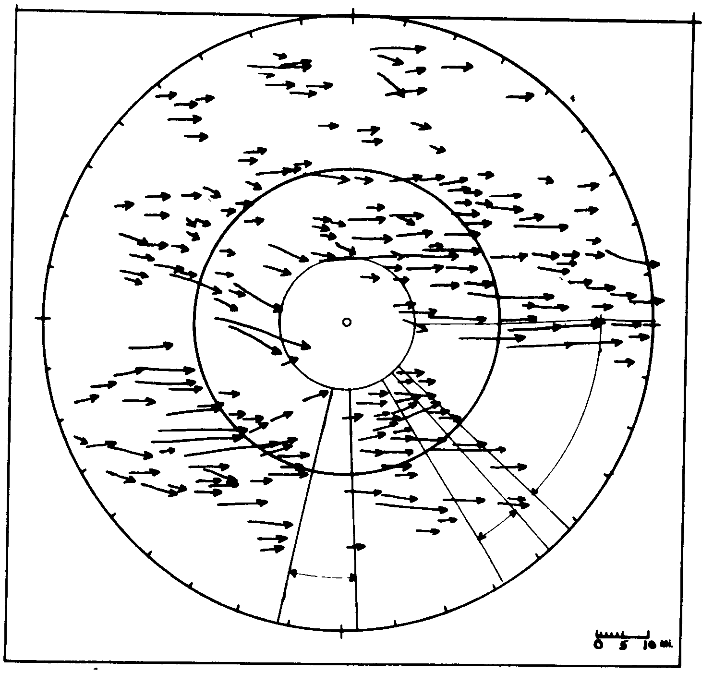

Fig. 31. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is west. Total number of days: 8. Radar Range: 60 miles.

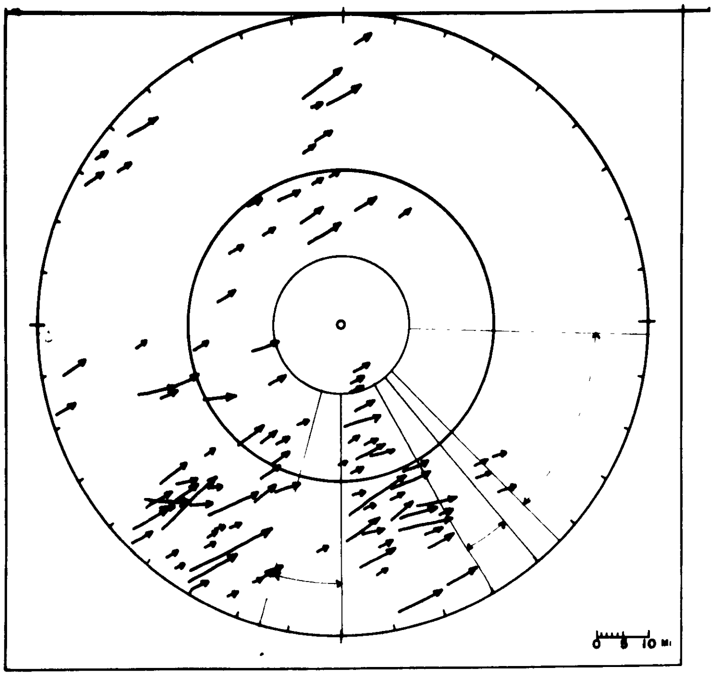

Fig. 32. Selected cell tracks when log Z_e is slightly less than 4.5. 500-mb flow: SW to WSW. Total number of days: 4. Radar range: 60 miles.

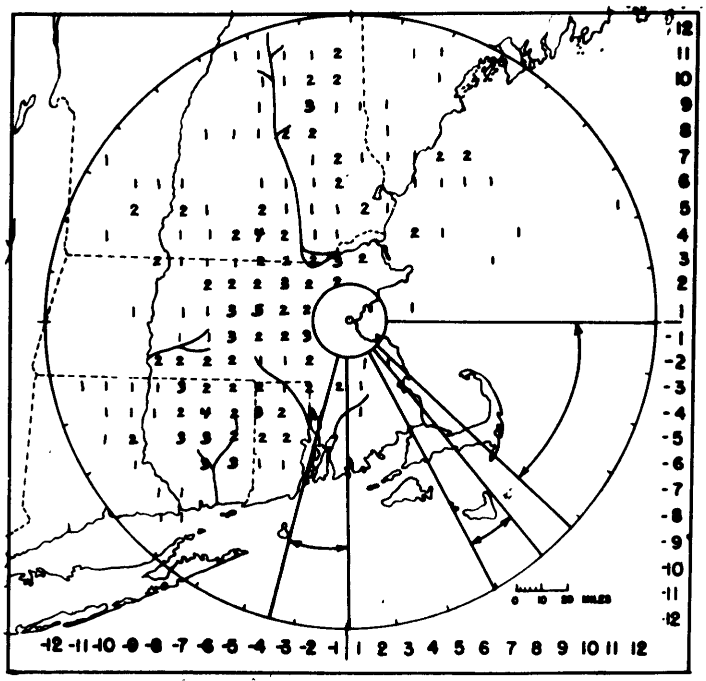

Fig. 33. Number of days when air mass cells with log $Z_e \geq 4.5$ occurred. 500-mb flow: NW. Total number of days: 11.

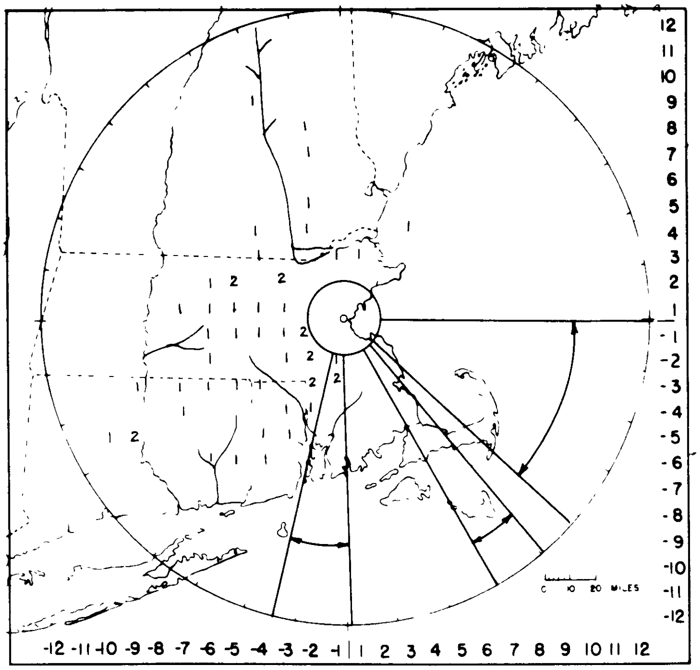

Fig. 34. Number of days when air mass cells with log $Z_e \geq 5.5$ occurred. 500-mb flow:NW. Total number of days:6.

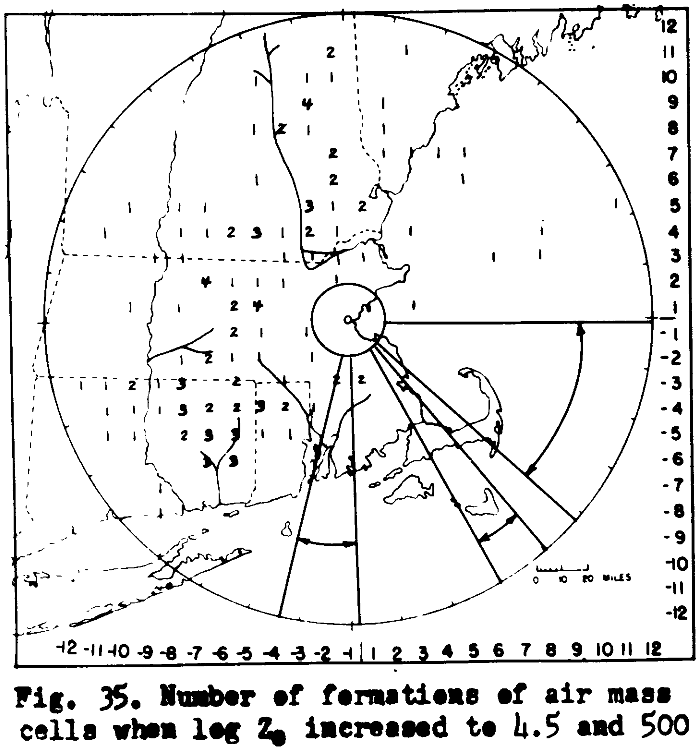

Fig. 35. Number of formations of air mass cells when log Z_e increased to 4.5 and 500 mb flow is northwest.

H. Distributions for days with northwest flow

Figure 33 shows the number of thunderstorm days when the 500-mb flow is west northwest to north. There were a total of 11 thunderstorm days.

Areas of maximum frequency ($\geq$ 3 days) follows:

9N2W, Lake Winnipesaukee area
4N4W, Pack Monadnock Mt. and plateau
3N1W, Plain with Merrimac River Valley
1S5W to 2N3W form a narrow axis of maximum frequency, and is chiefly on a plateau. Square 1N4W to the lee of Mt. Wachusett has five thunderstorm days.
3S7W to 6S5W form a region of maximum frequency and are chiefly on a plateau or to its lee in the Quinebaug River Valley.
4S4W, to the lee of the Quinebaug River Valley.

Areas of minimum thunderstorm days are along the south coast and adjacent sea areas from New Haven, Connecticut (8S9W) to Cape Cod, Massachusetts (5S3E)

Figure 34 shows the number of days with hailstorms when the 500-mb flow is west northwest to north. There were only six days, so no definite conclusions regarding distribution could be made. Squares 1S2W to 3S1W form a narrow area of two hailstorm days and are in a plain.

Figure 35 shows the distribution of cell formations. Areas of maximum formation ($\geq$ 3 cells) follow:

9N2W, Lake Winnipesaukee
5N2W, Merrimac River Valley
4N4W, Pack Monadnock Mt. on a plateau
2N6W, Valley in a plateau
1N4W, plateau
3S7W, eastern Connecticut River Valley

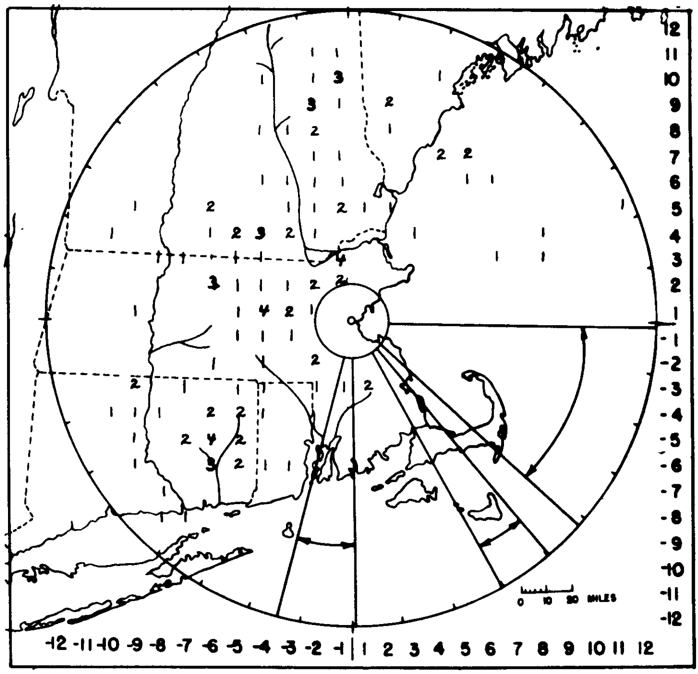

Fig. 36. Number of dissipations of air mass cells when log Z_e decreased below 4.5 and 500 mb flow is northwest.

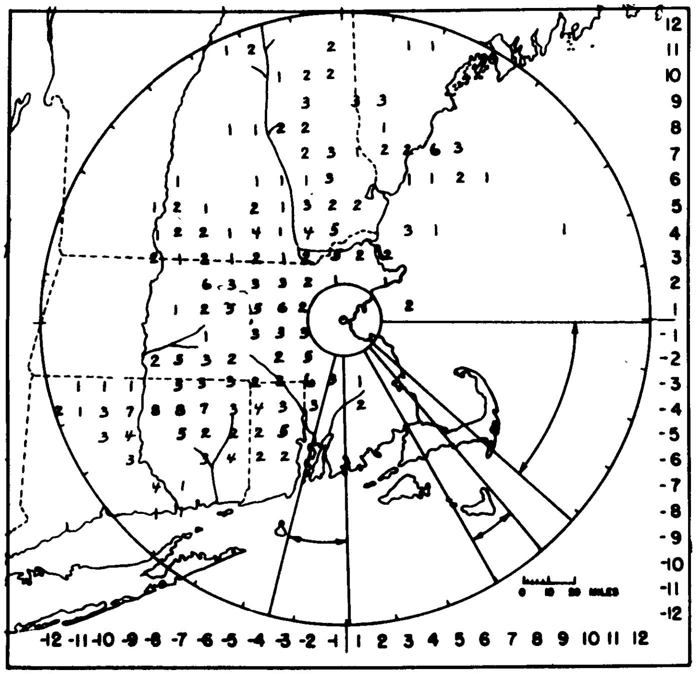

Fig. 37. Total time in tens of minutes when air mass cells with log $Z_e \geq 4.5$ were in each 10x10 mile area. 500-mb flow: NW.

4S4W, to the lee of the Quinebaug River Valley

3S7W to 6S5W, form a narrow area of maximum frequency mainly in a plateau and to its lee in the Quinebaug River Valley.

Areas of minimum formation are 3S6W and 3S4W and all the south coast areas.

Figure 36 shows the distributions of cell dissipations when the 500-mb flow is west northwest to north. In general, the same areas have both formation maximum and dissipation maximum, including areas 2N6W and 1N4W.

Areas of maximum dissipation ($\geq$ 3 cells) follow:

10N1W to the lee of the Ossipee Mts.

9N2W Lake Winnipesaukee

4N4W Pack Monadnock Mt. on a plateau

3N1W in the Merrimac River Valley has four cell dissipations

2N6W Valley in a plateau

1N4W, a plateau has four cell dissipations

5S6W to the lee of a plateau in the Shetucket River Valley

6S6W in the Shetucket River Valley

Figure 37 shows the number of tens of minutes of thunderstorms when the 500-mb flow was west northwest to north. There is a slight indication that the east side of the lower Pemigawasett and Merrimac River Valleys of New Hampshire have maximum times.

Areas of maximum times ($\geq$ 50 minutes) follow:

7N4E Crescent Surf, Maine, area

1W, 3N to 4N in a plain of the Merrimac River Valley

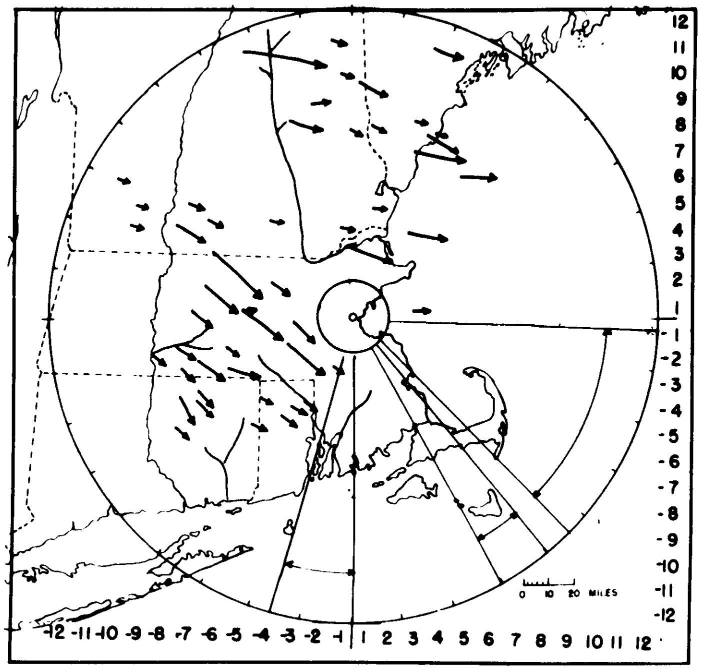

Fig. 38. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is west northwest. Total number of days was six.

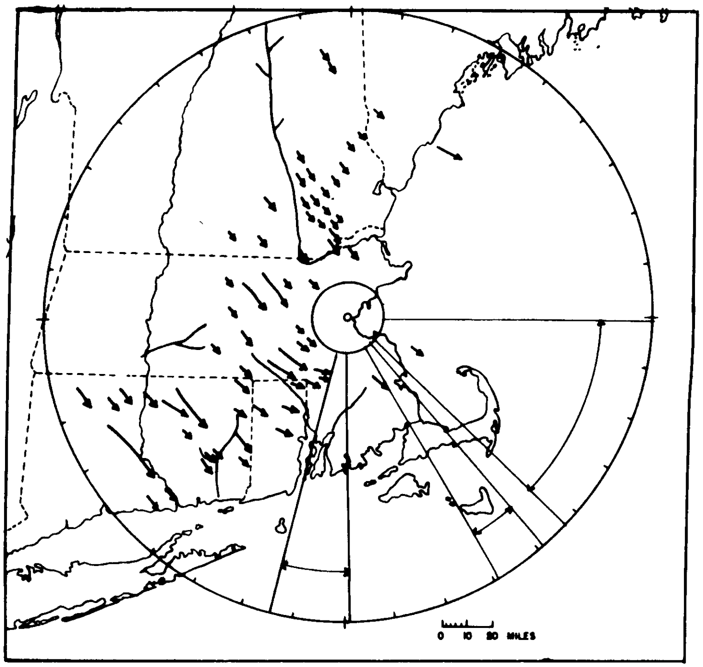

Fig. 39. Cell tracks when log $Z_e \geq 4.5$ and 500 mb flow is northwest. Total number of days: 5.

2N6W to 1N3W form a narrow area of maximum frequency in a plateau area
2W, 3S to 2S in a plain to the lee of a plateau
5S3W to the lee of a plateau
7W, 5S to 2S mainly in the eastern part of the Connecticut River Valley
4S, 9W to 6W mainly in the eastern part of the Connecticut River Valley

Areas of minimum cell time are the south coast of New England. "Significant" areas of minimum time are squares 9N1W, 8N1W, 8N1E, 4N3W, 3N5W, 1S5W, 2S4W, 5S8W, 6S7W and 6S8W.

The number of minutes of hailstorms when the 500-mb flow is northwest is too small to make any conclusion about distribution. There are areas of maximum time in the Merrimac River Valley, the Connecticut River Valley in southern Connecticut and the plains surrounding Boston, Massachusetts, which may possibly be significant.

Figures 38 and 39 show pronounced cell tracks starting in the Connecticut River Valley, the Merrimac River Valley and others just skirting the south of Boston, Massachusetts.

I. Distributions for days with closed lows or deep troughs at 500 mb.

Figure 40 shows the number of thunderstorm days in each area when there was a closed low or deep trough at 500 mb. There was a total of eight thunderstorm days.

There is evidence of a weak maximum number of days in the lower Pemigawasett River Valley of New Hampshire and the Connecticut River Valley of Massachusetts.

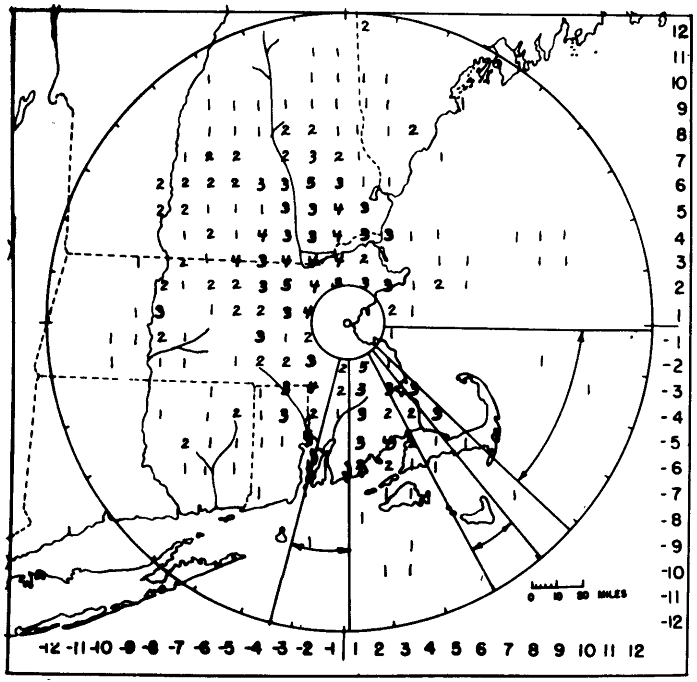

Fig. 40. Number of days when air mass cells with log $Z_e \geq 4.5$ occurred with closed low or deep trough at 500 mb. Total number of days: 8.

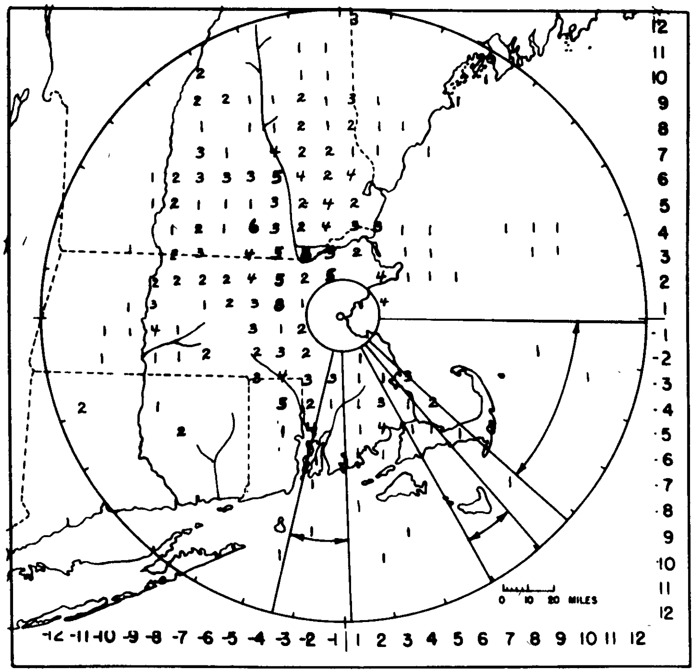

Fig. 41. Number of formations of air mass cells when log Z_e increased to 4.5, with closed low or deep trough at 500 mb.

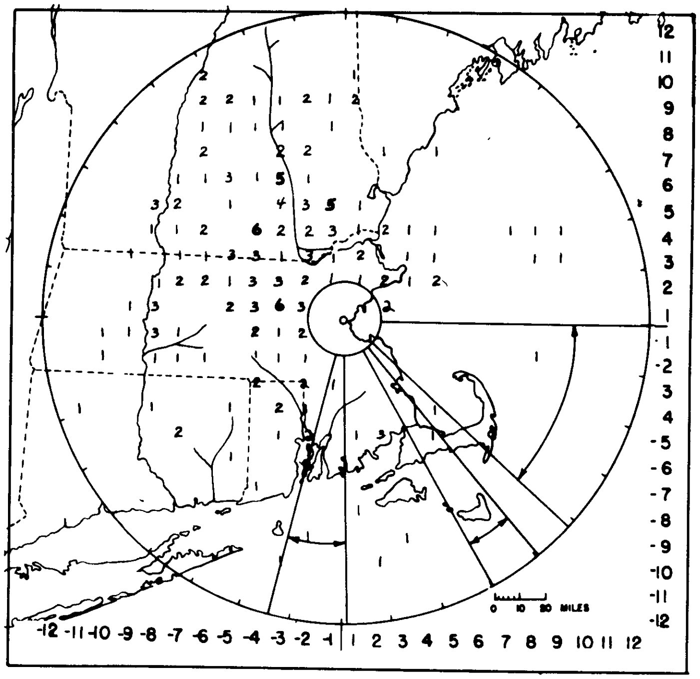

Fig. 42. Number of dissipations of air mass cells when log Z_e decreased to below 4.5, with closed low or deep trough at 500mb.

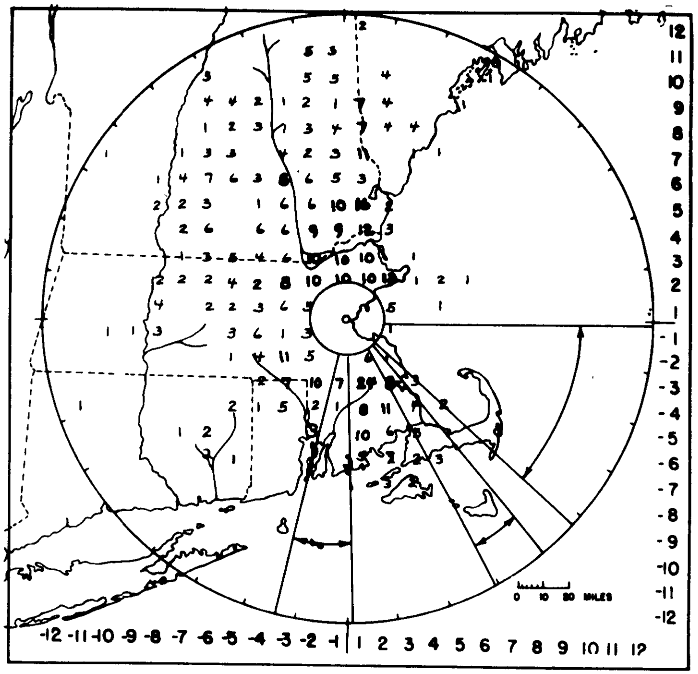

Fig. 43. Total time in tens of minutes when air mass cells with log $Z_e \geq 4.5$ were in each square, when there was a closed low or deep trough at 500 mb.

Areas of maximum frequency ($\geq$ 4 days) follow:
6N2W to 4N1W, to 1N2W form a narrow region of maximum frequency in and east of the Merrimac River Valley which broadens in Massachusetts.
6N2W and 2N3W have five days and the entire area is in a plain.
4N4W and 3N5W each have four days and are areas with a plateau and mountains.
2S1W to 5S2E may form a region of maximum frequency with the radar shadow covering the central portion.
3S2W and 5S2W have four days and are in a plain.

There is a minimum number of thunderstorm days east of the 500-ft MSL contour in Maine, to the north of Saco Bay, Maine (8N3E) and the south coast and sea areas from New Haven, Connecticut (8S9W) to Block Island, Rhode Island (9S3W).

There were only three hailstorm days, not enough to make any conclusions regarding distribution. There were no hailstorms over the Gulf of Maine or the coast and sea areas from New Haven, Connecticut (8S9W) to Cuttyhunk Island, Massachusetts (7S1E).

Figure 41 shows the distribution of cell formations. There are indications of a maximum number of cell formations in the Connecticut River Valley of Massachusetts.

Areas of maximum frequency of cell formation ($\geq$ 4 cells) follow:
7N3W to 6N2W in the Merrimac River Valley.
6N1E to 4N1W form a narrow area and are in an inland plain.
4N4W to 1N3W and 3N, 5W to 1W are the diagonals of a rectangle containing maximum cell formations. This is an area of plains and plateaus with mountains.

2E, 1N to 2N in a coastal and water area.

3S3W to 5S2W, to the east of a plateau.

2E, 5S to 4S form an area between radar shadows that has a maximum cell formation.

"Significant" areas of maximum cell formation are 12N1E, 4N4W, 3N2W, 1N3W and 4S3W.

Figure 42 shows areas of cell dissipations. In general, individual areas can have both maximum number of dissipations and formations, including areas 4N4W and 1N3W.

"Significant" areas with maximum number of dissipations are 6N3W, 5N1W, 4N4W and 1N3W.

Figure 43 shows the number of tens of minutes when cells occurred. There is a general maximum time with cells in the plains north and south of Boston, Massachusetts.

The Connecticut River Valley in Massachusetts has a weak maximum as well as near Lebanon, New Hampshire, areas 6W, 9N to 10N.

Areas of maximum time frequency follow:

2W, 10N to 11N and 1W, 10N to 11N in and near the Ossipee Mountains.

2E, 9N to 10N has no time period to the east where the elevation is below 500 feet MSL.

1E, 3N to 8N and 2E, 1N to 2N have many more minutes than the area to the east which is near and over the sea.

3W, 4S to 2S and 1N to 2N have at least twice as many minutes than any individual areas to the west.

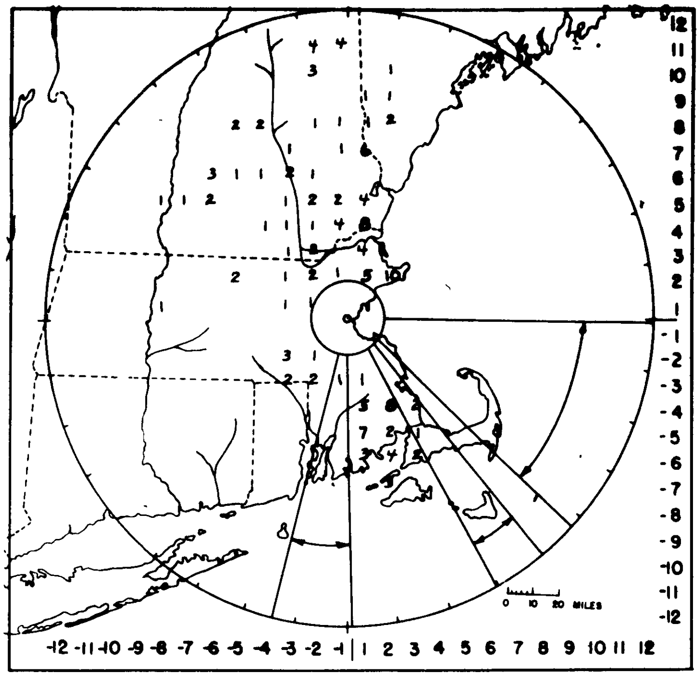

Fig. 44. Total time in tens of minutes when air mass cells with log $Z_e \geq 5.5$ were in each square, when there was a closed low or deep trough at 500 mb.

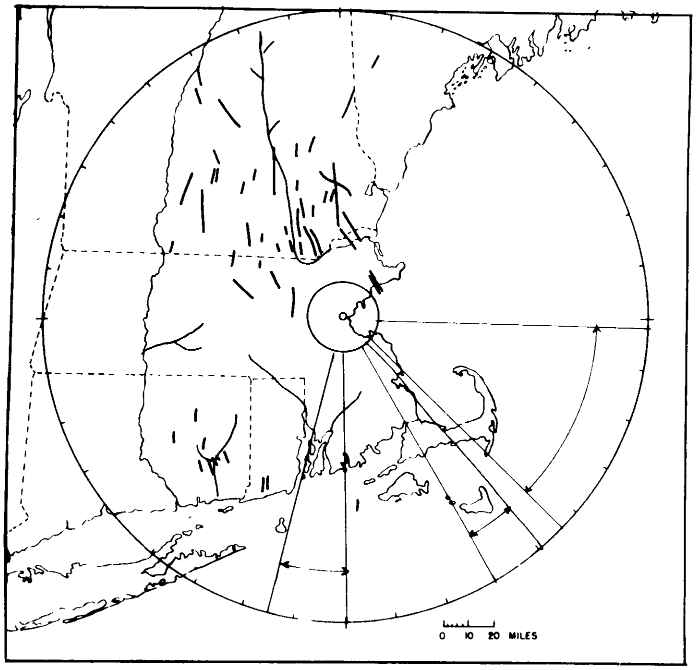

Fig. 45. Axis orientations of air mass cells when log $Z_e \geq 4.5$, and when there was a closed low or deep trough at 500 mb.

"Significant" areas of maximum time frequency are 8N1E, 7N1E, 6N6W, 6N3W, 4N6W, 2N2E, 1S4W, 2S3W and 3S1E.

Minimum time frequency occurs generally east of the 500-ft MSL contour in Maine, to the north of Saco Bay (8N4E), the Gulf of Maine and the south coast and adjacent sea areas from New Haven, Connecticut (8S9W) to Block Island, Rhode Island (9S3W).

Figure 44 shows the number of tens of minutes when hailstorms occurred. There is a maximum time frequency of cells in the plains north and south of Boston, Massachusetts and in the southern White Mountains of New Hampshire.

Areas of maximum time frequency follow:
11N, 2W, 1W and 10N2W which contain mountains
2E, 8N to 10N have no areas to the east with hailstorms
5N1E to 2N2E form a narrow area of maximum time frequency near the coast.
4S1E to 6S2E form an area between radar shadows where there is a maximum time frequency.

"Significant" areas of maximum time frequency are 11N2W, 11N1W, 7N1E, 6N6W, 6N3W, 4N1E, 2N1E, 2N2E, 2S3W, 3S3W, 4S2E and 5S1E.

Areas of minimum time frequency are east of the 500-ft MSL contour in Maine, the Gulf of Maine and the south coast and adjacent sea areas from New Haven, Connecticut (8S9W) to Cuttyhunk Island, Massachusetts (7S1E).

Figure 45 shows the axis of orientation of cells. The majority have a north-south oriented axis. There were no cell tracks near the 500-mb low or deep trough because advecting winds were light.

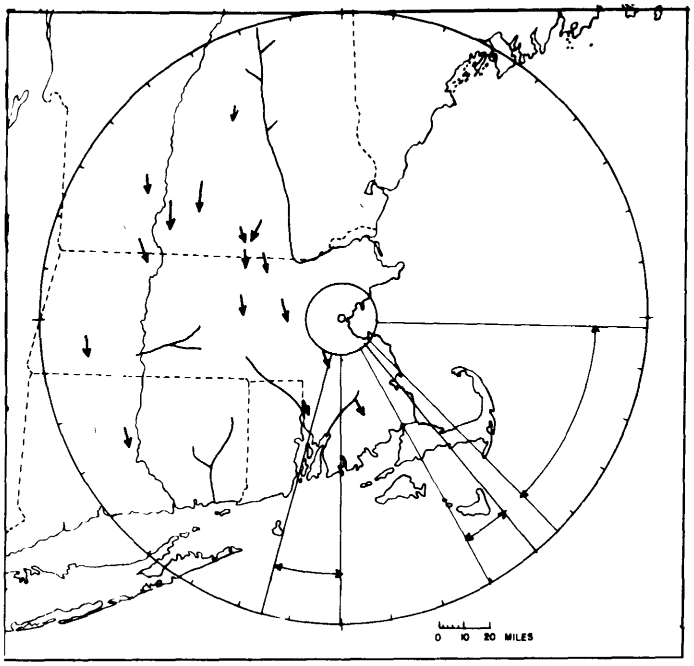

Fig. 46. Tracks of cells with log $Z_e \geq 4.5$ for one day when 500 mb flow was north.

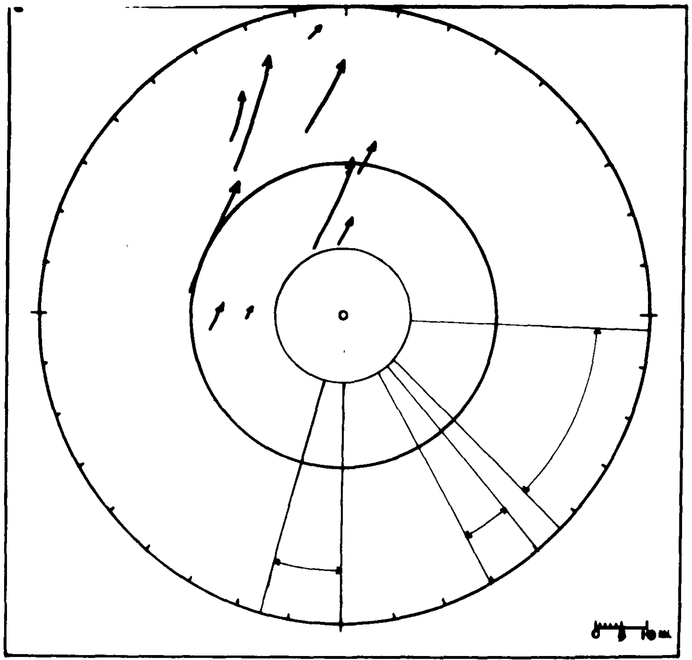

Fig. 47. Tracks of cells with log $Z_e \geq 4.5$ for two days when 500 mb flow was south southwest.

J. Distributions for other directions of flow.

Figure 46 shows the short cell tracks that occurred on 25 July 1963 when the 500-mb flow was north. The locations are in the plains around Boston, Massachusetts, parts of the Connecticut River Valley and plateau areas.

Figure 47 shows the cell tracks that occurred on two days when the 500-mb flow was south southwest. The cell tracks are in the plain area of Boston's northwest sector and very close to the 500 foot MSL contour.

Figure 48 shows cell tracks when the 500-mb flow was south southeast. The date was 28 August 1962 and as Hurricane Alma approached, the cells near its periphery were excluded. The cell tracks were short and generally began in the plateau area near the 500 foot MSL contour of Massachusetts and New Hampshire and just west of the lower Pemigawasett River Valley of New Hampshire

K. Discussion of results.

In a climatological study such as this, it would be ideal to have as much data as possible. If there are many samples available, a representative distribution should result in most areas. Then physical reasoning may explain some of the results.

There were 41 out of 64 thunderstorm days that were accompanied by southwest to west flow at 500 mb for which radar data was available. This number of samples would be fairly representative of the distribution in most areas.

It has been shown that the SCR-615-B radar has a beam filling effect, so that some small, low cells beyond 60 miles may have been missed. There were also distinct radar shadow areas in the southeasterly and south southwestern

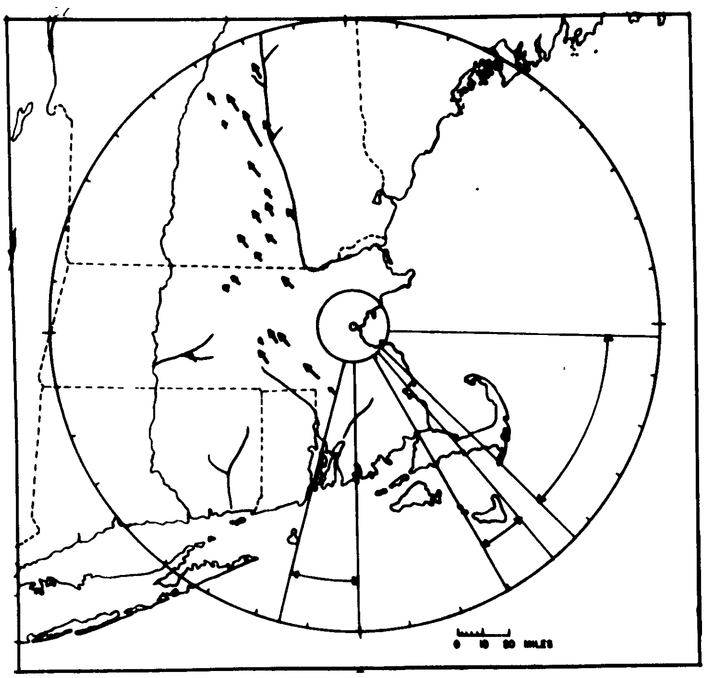

Fig. 48. Tracks of cells with log $Z_e \geq$ 4.5 for one day when 500 mb flow was south southeast.

sectors. There may have been other small areas because of hills and buildings near M.I.T. Squares 11N3W and 11N1E had consistent minima of thunderstorm activity.

When radar tracks were plotted, it was found that southeastern Massachusetts and Maine had fewer thunderstorms when the 500-mb flow was southwest, rather than westerly. This suggests that sea breezes restricted the thunderstorms to inland areas. With northwesterly flow, cell tracks usually ended in southeastern Massachusetts, suggesting that slight downslopes flow to the east of a plateau was sufficient to dissipate thunderstorms.

It is interesting to see what effect lakes have on air mass thunderstorms. Quabbin reservoir, Massachusetts, (1N7W) had a "significant" maximum number of hail days when the 500-mb flow was southwest to west. Thunderstorms would occur there readily, without the presence of any 500-mb trough.

Sebago Lake, Maine, (11N3E) did not seem to have any significant effect, but it was 110 miles away from the radar set.

Lake Winnipesaukee, New Hampshire, (9N2W) was 90 miles away and showed a "signigicant" maximum number of cell formations when the 500-mb flow was west northwest to north and a "significant" minimum of cell dissipations when the 500-mb flow was southwest to west.

The evaporation from inland lakes is apparently more important for occurrences of air mass thunderstorms than the "damping" effect of cooler water surfaces. Even square 5S2W, the upper Narragansett Bay of Rhode Island has a maximum number of cell formations when the 500-mb flow is southwest to west.

All the sea and coastal areas have a minimum number of thunderstorms. When the 500-mb flow has a larger component from land areas, there are more thunderstorms over the sea. There was a maximum area of cell dissipation about 25 miles off the east coast of New England.

Apparently the lack of turbulence over water and the relatively cool surface temperatures inhibits thunderstorms, Voyles and Zavos (1953).

There is a rapid decrease of thunderstorms as they approach the coast and sea from inland areas. This is apparently because sea breeze fronts can move inland as much as 20 miles.

The terrain of inland New England becomes more complex because of hills, valleys and mountains.

It was very apparent that the 500-ft contour line in Maine seemed to be an excellent separation of thunderstorm frequency, with a minimum to the east. This forested, sparsely inhabited area with occasional sea breezes is contrasted by the rugged, high terrain to the west where thunderstorms are more frequent. Square 7N1W which contains the Catamount Mt. (1,334 ft) and the Blue Hills Range (1,220 ft) had a definite "significant" maximum of thunderstorm and hailstorm activity.

Squares 4N10W containing the Bald Mt. (2,700 ft), Prospect Mt (2,537 ft), the Dome (2,754 ft) and the Elbow and 4N4W containing Pack Monadnock Mt. (2,310 ft) had maximum thunderstorm days, formations and dissipations of cells.

The uplift caused by these mountains apparently causes this maximum of thunderstorm activity.

Square 2N5W had significant maximum number of hailstorm days and time with hailstorms, when the 500-mb flow was southwest to west. Square 2N6W had a maximum number of cell dissipations and formations when the 500-mb flow was west northwest to north. They both are valleys in a plateau.

It is interesting to see the effect of the major river valleys of New England. There is a definite maximum frequency of thunderstorm activity on the eastern sides of the Connecticut River Valley and the Merrimac River Valley of New Hampshire. With the normal westerly flow, there would be upslope flow on the eastern sides of these valleys, especially where there are steep escarpments on the east side of the Connecticut River Valley. The surface temperatures should be higher on this east side during the afternoon because the ground would be more perpendicular to the sun's rays and as a result of the downslope motion which occurred on the west side of the valley.

The Ware River Valley (1S7W) which joins the Connecticut River Valley, had a "significant" maximum time of hailstorms when the 500-mb flow was southwest to west. Square 2S7W had a "significant" maximum of thunderstorm activity when the 500-mb flow was southwest to west. It is in the eastern Connecticut River Valley with the Minnechoag Mt. (931 ft). Square 3S7W in the eastern Connecticut River Valley had a "significant" maximum of cell formation when the 500-mb flow was west northwest to north.

Square 5N2W in the Merrimac River Valley of New Hampshire had "significant" maximum times and days of hailstorms for all combined flows and also cell formations when the 500-mb flow was west northwest to north.

Square 4S5W in the Quinebaug River Valley of Connecticut had a "significant" maximum number of days for all combined flows and square 6S5W had a "significant" maximum time of thunderstorms when the 500-mb flow was southwest to west.

The Plains of northeastern Rhode Island have a 500 ft plateau immediately to the west and presumably have higher surface temperatures because of slight downslope flow when westerly winds occur. They are also near the average line of sea breeze convergence during the warm months.

Square 4S3W has a "significant" maximum number of times and hailstorm days when the 500-mb flow is southwest to west and has a "significant" maximum number of cell formations when there is a closed low or deep trough at 500-mb.

Square 3S2W has a "significant" maximum number of cell formations when the 500-mb flow is southwest to west and a "significant" maximum time of thunderstorms when the 500-mb flow is west northwest to north.

It was noted that cell formations tended to reoccur on the same day and in the same area on days with sea breeze convergence lines in southern New England. The dates were 8 June 1965 and 9 June 1965 and cells reformed in areas 1S5W, to the lee of the Ware River of Massachusetts, 4S5W in the Quinebaug River Valley of Connecticut and 4S7W on a plateau east of the Connecticut River Valley.

Some "significant" areas of maximum hailstorm activity have been mentioned. The sea breeze convergence zone can explain the maximum number of hailstorm days in extreme southeastern New England. The eastern side of the Connecticut River Valley of Massachusetts, the Merrimac River and Pemigawasett River Valleys of New Hampshire have more hailstorm days than on the western sides.

Appendix C shows that there were 28 out of 64 days when a 500-mb trough of any intensity was present. Less than 40% of thunderstorm days in the Connecticut River Valley, western Massachusetts, most of southern Vermont, central New Hampshire, the Portland, Maine area and east of Portsmouth, New Hampshire had 500-mb troughs present.

Squares 1S6W, the Ware River Valley and 1N7W, the Quabbin reservoir strikingly showed thunderstorm days with no 500-mb troughs serving as "triggering" mechanisms.

Hailstorm days usually had 500-mb troughs present, except possibly in areas 1S4W and 1S5W.

6. CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

The SCR-615-B radar data, corroborated by other radar and surface observations, show that there are preferred areas for air mass thunderstorms in New England. They can partly be explained by local topographical features. These areas can be very important as occurrence of air mass thunderstorms during the daytime accounted for an absolute minimum of 30% of all thunderstorm days for the period 1958 through 1965.

In general, most of the air mass thunderstorms were accompanied by 500-mb flow from a westerly sector and there was a maximum occurrence in a band about 30 miles wide extending from just east of Concord, New Hampshire to central Massachusetts and then to northern Rhode Island. There was a minimum frequency of occurrence in Maine where the elevation was below 500-ft MSL, in the sea areas off eastern New England and in extreme southern New England and its adjacent sea areas. The seaward sides of sea breeze fronts generally outlined areas of minimum frequency of occurrence.

The eastern sides of the Connecticut River Valley and the Merrimac River Valley of New Hampshire consistently had more thunderstorms than the western sides. The east side would normally have higher surface temperatures and more upslope flow. The Quinebaug River Valley of Connecticut also had a maximum number of thunderstorm days.

Hailstorms mainly occurred on the eastern sides of the Connecticut River Valley of Massachusetts, the Merrimac and Pemigawasett River Valleys of New Hampshire and in southeastern New England near the sea breeze convergence lines.

The scale of resolution, 10 by 10 mile squares, was too crude to permit detailed observation of the effects of individual mountains. Definite maxima in frequency of occurrence or formation were observed, however, in the vicinity of several of the most outstanding peaks such as squares 4N10W with four rugged mountains nearly 3000 ft high and 4N4W containing Pack Monadnock Mt. (2,310 ft). Area 7N1W, which is on a plateau containing four mountains, is a very significant area for maxima days, time and formations of air mass thunderstorms. Apparently the close proximity of the Merrimac River Valley and sea breeze fronts in this hilly terrain explain these maxima.

Cell formations have maximum frequency in the eastern part of the Connecticut River Valley where there are steep escarpments along the western edge of a plateau, the Merrimac and lower Pemigawasett River Valleys.

Evidence of the effect of inland lakes is not conclusive, but does suggest that they encourage thunderstorm activity. Apparently the availability of moisture by evaporation is more important that any cooling effect at the lake's surface.

Cell dissipations have a maximum about 25 miles off the eastern New England coast north of Boston, Massachusetts, which agrees with surface observations at Truro, Cape Cod, Massachusetts, and immediately to the west of the 500-ft contour in Maine.

It is suggested that radar observations be made of nocturnal thunderstorms to determine whether they occur in the same areas of southern New England and to improve statistics of thunderstorm frequencies.

A new 10.7 cm radar with better resolution and without the shadow area in the southeast has been installed at M.I.T.

Sea breeze convergence fronts and accompanying thunderstorms or heavy showers can now be studied in the southeastern sector. It would be interesting to determine how far these thunderstorms travel before dissipating over Cape Cod Bay and Massachusetts Bay.

With better resolution, it might be possible to determine whether or not there is a significant lee wave effect. The only evidence now available are visual observations near Copicut Hill, Massachusetts. The new radar can observe this area and other possible sites.

The life cycles of these storms could be determined by RHI scans of the vertical cell structures.

If any future climatological and synoptic studies of thunderstorms are made, they should be separated into air mass and non-air mass thunderstorms. Then it could be easily determined how important air mass thunderstorms are during drought years. Upper air charts at and above the 300-mb level should be analyzed for possible "triggering mechanisms".

This study could be enlarged to include thunderstorm distributions associated with fronts and squall lines. Some of the latter studies indicate similar distributions to those of air mass thunderstorms. It is the author's opinion, based on surface observations near Vineyard Sound and Buzzards Bay, Massachusetts, that thunderstorms accompanied by cold fronts would occur more uniformly.

Finally, all results should be coordinated with hydrological and cloud seeding projects to enable better planning for water conservation and depollution.

APPENDIX A

List of days when the SCR-615-B recorded cells with $\log Ze \geq 4.5$, which were not of the air mass type.

Year:	Date:	Synoptic Situation:
1965	4 May	Cold front, nocturnal
	10 May	Cold front in northern New England extending east-west.
	13 May	Cold front.
	17 May	Cold, warm fronts;complex. Early morning, afternoon thunderstorms.
	27 May	Warm front;squall line in eastern New York.
	2 Jun	Quasi stationary front
	24 Jun	Cold front
	29 Jun	Cold front in central New England
	17 Jul	Cold front extending east-west
	18 Jul	Quasi stationary front in northern New England; warm front in Long Island
	2 Aug	Cold front in central New York; warm front in New Jersey.
	10 Aug	Cold front
	13 Aug	Cold front extending east-west
	17 Aug	Quasi stationary front in central New England
	19 Aug	Cold front. Early nocturnal thunderstorms
	28 Aug	Cold front
	16 Sep	Warm front. Early morning thunderstorms
	24 Sep	Cold front
	10 Oct	Closed 500mb low. Early morning, afternoon thunderstorms. No radar data.
	15 Oct	Warm front. Trough with southwest flow at 500mb. No radar data.
1964	26 Mar	Warm front
	15 Apr	Occluded front
	9 May	Warm front
	13 May	Warm front
	19 May	Warm front
	8 Jun	Cold front
	10 Jun	Cold front
	20 Jun	Cold front, squall line
	21 Jun	Quasi stationary front
	24 Jun	Cold front
	30 Jun	Warm front, becoming air mass
	1 Jul	Cold front extending east-west
	2 Jul	Quasi stationary front
	21 Jul	Warm front
	22 Jul	Quasi stationary front in northern New England
	23 Jul	Quasi stationary front in southern New England
	29 Jul	Cold front

APPENDIX A (continued)

Year:	Date:	Synoptic Situation:
1964	5 Aug	Cold front
	12 Aug	Cold front, squall line
	18 Aug	Cold front
	26 Aug	Cold front
	31 Aug	Quasi stationary front
	11 Sep	Cold front
	14 Sep	Hurricane
1963	13 Mar	Cold front; complex
	14 May	Occluded front
	18 May	Cyclone and warm front to the southwest.
	3 Jun	Tropical storm to the southwest
	6 Jun	Cold front in extreme northern New England
	9 Jun	Cold front
	28 Jun	Quasi stationary front
	2 Jul	Warm sector; squall line in western New York
	8 Jul	Occluded front
	17 Jul	Stationary front
	18 Jul	Warm sector
	19 Jul	Cold front extending east-west
	8 Aug	Within 12 hours of cold frontolysis
	23 Aug	Quasi stationary front
	3 Oct	Cold front
1962	24 May	Front
	1 Jun	Cold front
	19 Jun	Cold; warm front
	26 Jun	Quasi stationary front
	9 Jul	Cold front
	13 Jul	Cold front
	21 Jul	Cold front
	23 Jul	Quasi stationary front; cyclone in western New York
	26 Jul	Cold front
	1 Aug	Occluded frontolysis
	7 Aug	Cold front
	8 Aug	Cold front
	14 Aug	Cold front
	17 Aug	Cold front
	20 Aug	Cold front
	29 Aug	Cyclone southeast of Cape Cod
1961	24 Apr	Warm front
	26 Apr	Occluded front; complex
	16 May	Cold front
	26 May	Cold front

APPENDIX A (continued)

Year:	Date:	Synoptic Situation:
1961	29 May	Cold front
	6 Jun	Cold front extending east northeast to west southwest.
	9 Jun	Quasi stationary front. No radar data. Southwest flow at 500mb.
	10 Jun	Stationary front. Trough with west flow at 500mb.
	12 Jun	Warm front moving southward
	14 Jun	Cold front
	24 Jun	Cold front
	30 Jun	Cold front. Investigated by Baily (1962).
	2 Jul	Warm sector
	3 Jul	Cold front
	14 Jul	Quasi stationary front in southern New York
	17 Jul	Quasi stationary front
	20 Jul	Quasi stationary front
	31 Jul	Stationary front
	21 Aug	Warm front, cyclone to southwest
	15 Sep	Cold front
	21 Sep	Hurricane Esther
	25 Sep	Tropical cyclone to the southwest
	3 Oct	Quasi stationary front
1960	31 Mar	Cold front
	12 May	Quasi stationary front in southeastern New England
	13 May	Quasi stationary front off east coast
	16 May	Cold front off Cape Cod
	31 May	Occluded front
	3 Jun	Cold front in central New York
	4 Jun	Cold; quasi stationary front
	15 Jun	Warm front; complex
	17 Jun	Cold front in central New York
	24 Jun	Warm front
	30 Jun	Cold front
	1 Jul	Cold front in New Jersey
	3 Jul	Warm front
	14 Jul	Quasi stationary front
	27 Jul	Warm front; complex
	30 Jul	Tropical cyclone
	3 Aug	Cold front becoming quasi stationary
	8 Aug	Warm; cold front
	23 Aug	Cold front
	12 Sep	Hurricane
	19 Sep	Quasi stationary front in southern New England
	20 Sep	Quasi stationary front in southern New England

APPENDIX A (continued)

Year:	Date:	Synoptic Situation:
1960	28 Sep	Quasi stationary front off southeastern New England.
	30 Sep	Quasi stationary front southeast of Boston
	20 Oct	Cold front; cyclone
	24 Oct	Occluded front
	16 Nov	Front. Investigated by Mason (1965).
1959	2 Apr	Warm front in New Jersey; occluded front in central New York.
	6 Apr	Cold front
	26 Apr	Cold front
	22 May	Cold front in northwestern New England
	10 Jul	Cold front
	13 Jul	Quasi stationary front extending northeast-southwest
	14 Jul	Quasi stationary front extending northeast-southwest
	15 Jul	Quasi stationary front off southeastern New England coast
	21 Jul	Cyclone, fronts
	18 Aug	Cold front
	30 Aug	Quasi stationary front in southern New England
	1 Sep	Quasi stationary front in eastern New York
	3 Sep	Cold front
	15 Sep	Quasi stationary front in southern New England
	24 Sep	Cold front in central New England extending east northeast-west southwest
	1 Oct	Cyclone, cold front
	6 Oct	Quasi stationary front in southern New England
	7 Oct	Quasi stationary front in southern New England
	9 Oct	Quasi stationary front in southern New England; complex
	24 Oct	Warm front; complex
1958	4 Aug	Cold front
	7 Aug	Cold front
	13 Aug	Cold; warm front
	14 Aug	Quasi stationary front

APPENDIX B

Number of days in each year, from March through November, when the SCR-615-B recorded cells with log Ze ≥ 4.5.

	1958	1959	1960	1961	1962	1963
Air mass (total usuable)	0	8	10	10	13	9
log Ze ≥ 5.5	0	2	3	8	5	8
Synoptic situation:						
Cold front	3	7	10	9	12	6
Quasi stationary front	1	9	7	8	2	3
Warm front	0	2	5	3	0	1
Occluded front	0	0	2	1	1	2
Warm sector	0	0	0	1	0	2
Hurricane or tropical storm	0	0	2	2	0	1
Cyclone	0	2	0	0	1	0
Total non-air mass	4	20	26	24	16	15
500mb flow (clockwise)						
Southwest to west	-	6	5	6	7	6
West northwest to North	-	1	2	3	3	1
Closed low or pronounced trough	-	0	3	0	2	1
South southwest	-	1	0	1	0	0
Southeast to south-southeast	-	0	0	0	1	0
North	-	0	0	0	0	1
Total air mass	0	8	10	10	13	9

APPENDIX B (continued)

Number of days in each year, from March through November, when the SCR-615-B recorded cells with $\log Z_e \geq 5.5$

	1964	1965	1958 to 1965	
Air mass (total usuable)	5	9	65	
$\log Z_e \geq 5.5$	5	7	38	
Synoptic situation:				
Cold front	11	12	70	
Quasi stationary front	5	3	38	
Warm front	6	4	21	
Occluded front	1	0	7	
Warm sector	0	0	3	
Hurricane or tropical storm	1	0	6	
Cyclone	0	0	3	
Total air mass	24	19	148	
500mb flow (clockwise)				$\log Z_e \geq 5.5$
Southwest to west	3	8	41	28
West northwest to north	1	0	11	6
Closed low or pronounced trough	1	1	3	3
South southwest	0	0	2	0
Southeast to south southeast	0	0	1	0
North	0	0	1	0
Total air mass	5	9	61	38

APPENDIX C

List of days and their characteristics when the SCR-615-B radar recorded air mass cells with log Ze ≥ 4.5.

Date:		Hour Start:	 End:	500mb flow Deg:	 Kts:	500 meter flow at: Deg: ALB IDL	m/sec PWN ACK	Stations reporting sea breeze: BOS; PWN; PVD	
1965	7 Jun	1425	1646	270	25	190/18	300/02		PWN
						270/06	240/22		PVD
	8 Jun	1217	1656	260	30	230/07	260/10		PWN
						240/21	240/27		PVD
	9 Jun	1510	2130	270	35	290/04	250/04	BOS	PWN
						250/16	240/26		PVD
	18 Jun	1125	1515	Trough		310/04	330/05	BOS	PWN
				360	05	350/11	010/03		PVD
	23 Jun	1503	2110	240	35	230/13	220/24		PVD
						240/26	230/34		
	30 Jun	1208	2011	270	40	030/17	280/03	BOS	PWN
						320/08	170/06		PVD
	14 Jul	1522	2216	250	35	310/20	290/04		
						230/25	240/36		PVD
	9 Aug	1040	1709	230	35	MSG	210/22		
						200/25	220/32		PVD
	18 AUG	1310	1920	240	30	MSG	230/11		
						180/08	210/19		PVD
1964	3 Jul	1016	2136	260	40	220/12	208/18	BOS	PWN
						249/20	MSG		PVD
	6 Jul	0930	1934	Trough		338/14	077/02		PWN
						340/12	MSG		PVD
	7 Jul	1134	1517	290	25	311/14	311/14	BOS	
						234/10	240/12		PVD
	8 Jul	1200	1212	270	20	175/18	195/10	BOS	PWN
		1235	1333			208/14	254/16		PVD
		1357	1439						
	9 Jul	1415	1420	250	20	125/04	223/12	PWN	
		1703	2158			095/10	MSG		PVD
1963	14 Jun	1241	1703	300	20	112/16	171/16	BOS	PWN
						184/18	273/16		
	17 Jun	1402	1517	280	25	216/08	181/16	BOS	PWN
		1540	1705			218/10	240/12		
	14 Jul	1357	1648	220	40	173/30	211/14	BOS	PWN
						184/34	207/24		PVD
	25 Jul	1531	1810	340	10	230/04	240/14	BOS	PWN
						218/04	258/16		PVD

APPENDIX C (continued)

					500 meter flow Deg: m/sec at:		Stations reporting sea breeze:	
					ALB	PWN	BOS;	PWN;
	Hour		500mb flow		IDL	ACK		PVD
Date:	Start:	End:	Deg:	Kts:				
1963 28 Jul	1454	1700	Trough		184/10	203/16	BOS	
					219/16	227/12		PVD
29 Jul	1258	1634	220	20	205/20	209/22		PWN
					212/22	230/30		PVD
7 Aug	1240	1438	260	20	213/16	287/20	BOS	PWN
	1502	1855			262/20	224/24		PVD
14 Aug	0858	1131	280	40	300/30	316/28		PWN
					318/38	303/32		PVD
12 Sep	1027	1716	240	45	286/36	217/40		PWN
					226/28	211/52		PVD
1962 31 May	1353	2110	250	35	278/08	265/06		PWN
					245/20	252/36		PVD
6 Jun	1636	1808	300	45	030/14	024/14	BOS	PWN
					158/04	020/28		PVD
11 Jun	1113	1620	260	40	313/12	295/24		
					244/24	239/40		PVD
15 Jun	1540	1628	Trough		316/06	045/20	BOS	PWN
					351/04	250/12		PVD
24 Jun	1335	1557	240	30	303/12	202/34	BOS	PWN
					214/18	220/34		PVD
12 Jul	1400	1816	260	25	224/10	291/18	BOS	
					276/44	278/22		PVD
16 Jul	1235	1422	Trough		136/14	042/06	BOS	
	1438	1530			099/18	050/10		PVD
18 Jul	1217	1637	290	20	232/06	255/18	BOS	
					182/08	241/16		PVD
19 Jul	1424	1515	300	20	316/20	305/12	BOS	
					253/10	250/16		PVD
31 Jul	1011	1502	260	30	198/14	202/20	BOS	
					205/12	MSG		PVD
6 Aug	1250	1724	240	20	183/32	208/24		PWN
					197/24	213/18		
21 Aug	1131	1338	270	50	296/22	258/10	BOS	
					270/22	270/22		PWN
28 Aug	1427	1535	190	10	035/14	170/10	BOS	
	1602	1652			047/24	097/26		PWN
	1704	1704						
1961 22 May	1136	1600	330	15	065/08	310/16	BOS	PWN
					317/20	252/14		PVD
13 Jun	1434	2025	250	30	200/18	261/28		PWN
					232/22	248/40		PVD

APPENDIX C (continued)

Date:	Hour Start:	End:	500mb flow Deg:	Kts:	500 meter flow Deg: m/sec at: ALB IDL	PWN ACK	Stations reporting sea breeze: BOS;	PWN; PVD
1961 21 Jun	1316	1458	220	35	183/26	194/36		
					187/42	169/24		
6 Jul	1227	1600	260	25	276/06	191/16	BOS	PWN
					097/08	202/06		PVD
10 Jul	1237	1654	270	25	295/24	250/10	BOS	PWN
	1740	2130			278/10	262/18		PVD
11 Jul	1235	1400	290	35	255/18	262/24		
					244/26	244/34		PVD
13 Jul	1200	1437	290	20	177/12	050/16		PWN
					204/10	237/18		PVD
29 Jul	1225	1307	270	20	182/18	227/22	BOS	PWN
	1444	1452			135/22	194/02		PVD
	1509	1630						
11 Aug	1314	1715	270	30	220/12	263/20		
					282/16	244/34		PVD
23 Aug	0701	0710	240	25	127/12	025/04	BOS	PWN
					186/06	120/06		
1960 18 May	0729	1419	Trough		046/10	112/14	BOS	PWN
					280/08	165/08		PVD
24 May	0648	1020	280	20	108/04	089/18	BOS	PWN
	1044	1950			251/16	181/32		PVD
1 Jun	1605	1630	Trough		294/18	076/10	BOS	PWN
			280	20	302/14	229/10		PVD
11 Jun	1343	1655	Trough		191/12	231/18		PVD
			280	10	190/02	156/08		
19 Jul	0834	0922	240	35	308/28	226/10		PWN
	1450	1614			239/18	246/20		PVD
	2036	2316						
20 Jul	0928	1025	270	40	307/24	319/20		
	1338	1518			322/16	220/10		
5 Aug	0631	0742	250	30	175/22	185/08	BOS	PWN
					152/10	093/10		PVD
10 Aug	0736	0818	250	35	323/02	078/06	BOS	PWN
	1014	1024			260/08	186/14		PVD
	1051	1113						
11 Aug	0824	0849	250	30	062/12	054/08	BOS	PWN
					037/12	018/14		PVD
25 Oct	0752	0803	320	45	355/44	MSG		
	0934	0934			297/32	255/38		
1959 6 Jul	1223	1807	220	50	229/14	185/20	BOS	PWN
					258/14	MSG		PVD

APPENDIX C (continued)

Date:		Hour Start:	Hour End:	500mb flow Deg:	500mb flow Kts:	500 meter flow Deg: m/sec at: ALB IDL	500 meter flow Deg: m/sec at: PWN ACK		Stations reporting sea breeze: BOS; PWN; PVD
1959	22 Jul	1314	1537	270	20	188/10	268/14		PWN
						192/08	255/26		PVD
	24 Jul	1335	1658	240	40	236/16	239/24		PWN
		1852	2011			268/22	242/28		PVD
	30 Jul	1625	1625	260	05	177/22	205/14		PWN
						157/08	175/10		PVD
	31 Jul	2042	2140	230	15	215/08	201/32		PWN
						233/20	217/10		PVD
	5 Aug	0800	0804	250	10	164/24	130/02	BOS	PWN
		0837	1015			078/26	148/06		PVD
		1032	1044						
		1130	1243						
	27 Aug	1448	1706	300	15	270/02	019/14	BOS	PWN
						268/12	244/12		PVD
	31 Aug	0745	1643	240	20	180/18	217/18		PWN
						189/22	236/12		PVD

(1) Date:

(2) Showalter index (°C)
ALB PWN ALB PWN
IDL ACK IDL ACK

(3) Freezing level (thousands of feet)

(4) Relative Humidity (Surface to 500mb) (%)

(5) Precipitable water (Surface to 500mb) (inches)

(6) Vertical velocity at 600mb (cm/sec)

	(1)	(2)				(3)	(4)	(5)	(6)
		07/1200Z		08/0000Z					
1965	7 Jun	+3	+5	+2	+4	13.5	~50	~1	
		+2	+8	+3	+7				
		08/1200Z		09/0000Z					
	8 Jun	+2	+2	+3	+3	13.5	~50	~1	
		+4	+4	-1	+5				
				10/0000Z					
	9 Jun	MSG		+3	+1	12.0	75	~1	
				+4	+3				
		18/1200Z							
	18 Jun	+5	+4			8.0	40-50	0.5	
		+4	MSG						

APPENDIX C (continued)

	(1)	(2)				(3)	(4)	(5)	(6)
		23/1200Z		24/0000Z					
1965	23 Jun	+3	+9	+4	-2	13.5	~50	~1	
		+5	+5	-1	+4				
		30/1200Z		01/0000Z					
	30 Jun	+7	+8	+2	+3	10.0	~50	~1	
		+3	+6	+2	+4				
		14/1200Z		15/0000Z					
	14 Jul	+5	+11	0	+1	14.0	~50	~1	
		+6	+ 5	+4	0				
		09/1200Z		10/0000Z					
	09 Aug	+2	+4	0	0	14.0	~50	~1	
		+1	+7	-2	2				
		18/1200Z		19/0000Z					
	18 Aug	-1	+3	+1	+2	14.0	~60	~1	
		+4	+5	+2	+5				
		10/1200Z		11/0000Z					
	10 Oct	MSG	MSG	MSG	MSG	7.0	70	0.7	
		+3	MSG	+4	MSG				
		03/1200Z		04/0000Z					
1964	3 Jul	-1	+1	-2	-1	12.0	~60	1.5	
		-1	+1	-3	MSG				
		06/1200Z		07/0000Z					
	6 Jul	+1	-1	+3	+6	9.0	~50	1	0
		+5	0	+4	+6				
		07/1200Z		08/0000Z					
	7 Jul	+4	+3	+4	+2	10.0	50	0.75	MSG
		+4	+4	+6	+6				
		08/1200Z		09/0000Z					
	8 Jul	+3	+3	+3	+5	9.5	~50	1	+0.5
		+2	+6	+7	+6				
		09/1200Z		10/0000Z					
	9 Jul	+4	+4	+4	+4	10.5	~70	>1	0
		+3	+9	+3	+4				
		28/1200Z		29/0000Z					
1963	28 May	+18	+15	+5	+13	12.0	UNK	0.75	MSG
		+16	+16	+3	+13				
		14/1200Z		15/0000Z					
	14 Jun	+6	+5	+2	+7	9.0	UNK	~0.6	~0
		+9	+5	+3	+6				
		17/1200Z							
	17 Jun	+4	+2			8.5	UNK	0.6	MSG
		+8	+4						
		14/1200Z		15/0000Z					
	14 Jul	+7	+6	+6	+2	10.5		~1	+0.5
		+2	+4	+7	+10				

APPENDIX C (continued)

(1)		(2)				(3)	(4)	(5)	(6)
		25/1200Z		26/0000Z					
1963	25 Jul	+1	-2	-1	-2	13.0		~1	~-0.0
		+4	+4	+4	0				
		28/1200Z		29/0000Z		14.0		~1	~0.0
	28 Jul	+3	+4	0	0				
		+2	+6	+1	+3				
		29/1200Z							
	29 Jul	-1	+2			13.5		~1.5	~0.0
		0	+3						
		07/1200Z		08/0000Z					
	7 Aug	+2	+3	+2	+3	11.5		~1	~0.0
		+4	+4	0	+10				
		14/1200Z		15/0000Z					
	14 Aug	+2	0	+7	+12	9.5		1	~0.0
		+4	+5	+9	+10				
		13/0000Z							
	12 Sep	+3	+2			12.0	~60	1.4	~1
		+1	+4						
		31/1200Z		01/0000Z					
1962	31 May	0	+3	+1	+4	12.0		~1	~0.0
		+6	+13	+2	+2				
		06/1200Z		07/0000Z					
	6 Jun	+5	+2	+5	+7	10.5		0.75	~0.0
		+6	+5	+5	+11				
		11/1200Z		12/0000Z					
	11 Jun	0	+1	+5	+2	13.0		~1	~0.0
		+1	+5	+1	+1				
		15/1200Z		16/0000Z					
	15 Jun	+3	+3	-1	+11	11.0		~0.6	0.0
		+9	+7	+4	+2				
		24/1200Z		25/0000Z					
	24 Jun	+1	+2	+1	-1	12.0		~1	~0.5
		+1	0	+3	+4				
		12/1200Z		13/0000Z					
	12 Jul	+2	+1	-1	0	11.0		1	~0.0
		+4	+3	+0	+1				
		16/1200Z		17/0000Z					
	16 Jul	+9	+4	+16	+9	10.0		0.8	~0.0
		+8	+5	+10	+10				
		18/1200Z		19/0000Z					
	18 Jul	+5	+5	0	+3	10.5		~1	~0.0
		+5	+2	+2	+3				
		19/1200Z		20/0000Z					
	19 Jul	+4	+3	+6	+5	11.5		0.8	~-0.0
		+6	+4	+6	+7				

APPENDIX C (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
1962	31 Jul	01/0000Z +4 +3 +2 +4	12.0		1	~0.0
	6 Aug	06/1200Z 07/0000Z +3 0 +1 +1 +3 +4 +2 +7	14.0		1	+0.25
	21 Aug	21/1200Z 22/0000Z +3 +4 +4 +2 0 +2 +5 +4	12.5		1	+0.25
	28 Aug	28/1200Z 29/0000Z +3 +5 +2 +4 +5 +5 +5 +2	12.0		~1.25	+1
	05 Sep	05/1200Z 06/0000Z +7 +14 +3 +10 +4 MSG +1 +12	12.5		~1	~0.5

Date:		Synoptic situation:
1965	7 Jun	A quasi stationary front was in northern New England, with west flow at 500mb
	8 Jun	A warm front was in southern Canada, with a sea breeze in southern New England. There was a west flow at 500mb.
	9 Jun	Surface trough and a sea breeze were in southern New England, with west flow at 500mb.
	18 Jun	A weak surface trough was in northern New England, and a trough at 500mb was in eastern New England.
	23 Jun	A warm front was in northern New England, with a weak surface trough in the Hudson River Valley. There was southwest flow at 500mb.
	30 Jun	A surface trough was in southern New England, with a trough and west flow at 500mb.
	14 Jul	A surface trough was in eastern New England with west flow at 500mb.
	9 Aug	A quasi stationary front was in northern New England, with southwest flow at 500mb.

APPENDIX C (continued)

Date:		Synoptic situation:
1965	18 Aug	A quasi stationary front was in northern New England, with west flow at 500mb.
	10 Oct	A surface cyclone was east of Boston and a trough at 500mb had a southwest flow.
1964	3 Jul	A warm front was in extreme northern New England with a surface trough south of Albany. There was a west flow with maximum winds near 43°N at 500mb.
	6 Jul	A surface cyclone was east of Boston. There was a closed 500mb low in northern New Hampshire, with a trough in eastern New England.
	7 Jul	A weak surface cyclone was near Portland, Maine. There was a trough at 500mb near 60°W, with west northwest flow.
	8 Jul	A surface cyclone was in the Gaspee peninsula, and also in northern Virginia. There was a closed 500mb low in Gaspee, with a trough in northern New England extending to the Great Lakes. The 500mb flow was west.
	9 Jul	A surface cyclone was off the New Jersey coast and near Montreal. There was a trough at 500mb in extreme northern New England extending to the Great Lakes, with west southwest flow in New England.
1963	28 May	A surface anticyclone was southeast of Cape Cod, with west southwest flow at 500mb.
	14 Jun	A weak surface cyclone was near Montreal and West Virginia with a surface trough between them. There was a closed 500mb low near Prince Edward Island with west northwest flow.
	17 Jun	A cold front was in extreme northern New England, with a surface trough in eastern New England. The 500mb flow was west.

APPENDIX C (continued)

Date:		Synoptic situation:
1963	14 Jul	A weak surface cyclone was in southern New Jersey, with a warm front extending eastward. There was a trough at 500mb with strong southwest flow.
	25 Jul	A quasi stationary front extended from Nova Scotia to New Brunswick. There was a trough at 500mb extending southwestward from just southeast of Nantucket, with north flow in New England.
	28 Jul	A surface trough was along the east coast of New England with a trough at 500mb in central New England.
	29 Jul	A surface trough was in central New England and the 500mb flow was southwest.
	7 Aug	A surface trough was in central New England with west southwest flow at 500mb.
	14 Aug	A surface trough was along the east coast of New England. There was a weak 500mb trough in central New England with west flow and a jet stream along the south coast of New England.
	12 Oct	A surface cyclone was moving through the St. Lawrence Valley with a cold front moving into New York from the Great Lakes. There was a strong southwest flow at 500mb.
1962	31 May	A quasi stationary front was in central Maine, with a squall line in southern New England. The 500mb flow was west.
	6 Jun	A surface cyclon was east of Boston. There was a closed low at 500mb in southeastern New Brunswick with a trough extending to Nantucket and the east coast. The 500mb flow was northwest with a jet stream extending from Syracuse to Nantucket.
	11 Jun	A surface cyclone was near Prince Edward Island with a cold front moving into central New England by sunset. The 500mb flow was west.
	15 Jun	A surface trough was in eastern New England. There was a closed 500mb low over Long Island with a trough in central New England.

APPENDIX C (continued)

Date:		Synoptic situation:
1962	24 Jun	A surface cyclone was moving into the St. Lawrence Valley near Montreal. There was southwest flow at 500mb, with a jet stream extending from Albany, New York, to Caribou, Maine.
	12 Jul	A surface cyclone was near Montreal with an approaching cold front in eastern New York and a squall line in eastern New England. There was southwest flow at 500mb with a jet stream off the southern New England coast.
	16 Jul	A surface cyclone was in central North Carolina. A pronounced 500mb trough extended east to west through central New England, with a jet stream in southern New England.
	18 Jul	Cold frontogenesis was in western New England during the afternoon. There was a trough with west flow at 500mb and a jet stream was off the southern New England coast.
	19 Jul	A weak surface cyclone was in the Bay of Fundy with a surface trough along the east coast of New England. A trough at 500mb was off the east coast with northwest flow.
	31 Jul	An occluded front was approaching central New York. There was a trough at 500mb with west flow and a jet stream was in southern New England with diffluence in northern New England.
	6 Aug	Stationary frontolysis was in western New England with southwest flow at 500mb.
	21 Aug	A quasi stationary front was off the southern New England coast. A trough at 500mb had west northwest flow and a jet stream was in central New England.
	28 Aug	Hurricane Alma was moving northward along the Delaware Coast. A closed 500mb low was in central New York and with the hurricane. There was south southeast flow in eastern New England.
	5 Sep	A cold front was in western New England and a surface cyclone was off the Delaware Coast. There was west southwest flow at 500mb.

APPENDIX C (continued)

Date:		Synoptic situation:
1961	22 May	A surface cyclone was east of Cape Cod, with a trough in eastern New England. A trough at 500mb was near 68°W and in Vermont, with northwest flow.
	13 Jun	A weak surface cyclone was in Nova Scotia, with a cold front extending westward through north central Maine. There was west flow at 500mb with weak confluence.
	21 Jun	There was cold frontolysis in western New England. The 500mb flow was south southwest with a jet stream from New York, N.Y., to Caribou, Maine.
	6 Jul	A surface trough was in central New England and a trough at 500mb had west flow.
	10 Jul	A weak surface trough was in central New England with a trough and west flow at 500mb.
	11 Jul	There was westerly flow at the surface and west northwest flow at 500mb.
	13 Jul	A weak surface cyclone was in northern New York, with a surface trough extending to Boston, Mass. There was west northwest flow at 500mb with confluence in eastern New York.
	29 Jul	A weak surface cyclone was in eastern Maryland, with a surface trough extending northwest to New York. There was a trough at 500mb with a west flow.
	11 Aug	A weak surface cyclone was near northern New York. There was west flow at 500mb with diffluence in New England.
	23 Sep	A quasi stationary front extended from central Ohio to Tennessee and the 500mb flow was southwest.
1960	18 May	A surface cyclone was moving southeastward off the Delaware Coast with a surface trough in New England. There was a trough at 500mb in eastern New England.

APPENDIX C (continued)

Date:		Synoptic situation:
1960	24 May	A weak surface cyclone was in northern New York, with a surface trough in southern New England. There was a closed 500mb low in southern Vermont with an elongated east to west oriented trough.
	1 Jun	A surface cyclone was near Montreal with a surface trough extending into southeastern New England. There was a closed 500mb low in northern New Hampshire with a trough in eastern New England.
	11 Jul	A surface cyclone was off the Delaware Coast. A closed 500mb low was near Nantucket with a trough extending southwestward.
	19 Jul	A surface cyclone was east of Boston with a quasi stationary front south of New England. A cold front was approaching central New England by the late evening. There was a weak 500mb trough in eastern New York with southwest flow.
	20 Jul	A surface cyclone was in the Gaspee peninsula with a cold front southeast of Nantucket. There was a closed 500mb low in the Gulf of Maine with a trough in eastern New England and west flow. The jet stream extended from Albany, N.Y., to Boston, Mass.
	5 Aug	A weak surface cyclone was in southern New York with a quasi stationary front off the Delaware Coast. The 500mb flow was strong from the west southwest.
	10 Aug	A surface cyclone was in New York, with a warm front off the Delaware Coast. There was west southwest flow at 500mb with confluence in northern New England.
	11 Aug	A surface cyclone was east of Nantucket. There was a weak 500mb trough in eastern New England with west flow and confluence in southern New England.
	25 Oct	A surface cyclone was off the southeastern Maine coast. There was a closed 500mb low in the Gulf of Maine with northwest flow and a jet stream extending from Vermont to Nantucket, Mass.

APPENDIX C (continued)

Date:		Synoptic situation:
1959	6 Jul	A surface trough was in the Hudson River Valley. The 500mb flow was southwest, with a jet stream extending from Pennsylvania to eastern New York.
	22 Jul	There was light southwest flow at the surface and west flow at 500mb.
	24 Jul	A squall line was in the southern Hudson River Valley and the 500mb flow was west southwest.
	30 Jul	There was light southerly surface flow and southwest flow at 500mb.
	31 Jul	A surface cyclone was near Montreal with a cold front in western New York. The 500mb flow was west southwest.
	5 Aug	A surface cyclone was in eastern Pennsylvania with a warm front extending southwestward off the New Jersey coast. There was a closed 500mb low in northeastern New York with a trough in western New England and west southwest flow.
	27 Aug	A quasi stationary front was near 69°W in the Gulf of Maine with west northwest flow at 500mb.
	31 Aug	A quasi stationary front extended from the Gulf of Maine to Portland, Maine and northeastern New Hampshire, with southwest flow at 500mb.

APPENDIX D

Characteristics of radar echoes from air mass thunderstorms.

(1) Date:

(2) Number of cells with log Ze ≥ 4.5 ≥ 5.5

(3) Horizontal cell size (mi) log Ze≥ 4.5 "Average" Maximum

(4) Cell heights (thousands of feet)

(5) Number of cell groups

(6) Average distance between groups (mi)

(1)		(2)		(3)		(4)	(5)	(6)
1965	7 Jun	11	3	6x3	12x5	30 to 40	3	25
	8 Jun	18	3	3x2	10x7	UNK	0	-
	9 Jun	46	17	8x4	12x6	25 to 50	6	20
	18 Jun	14	0	1x1	3x3	UNK	0	-
	23 Jun	16	7	11x4	20x5	30 to 50	4	20
	30 Jun	29	1	3x2	10x4	30	0	-
	14 Jul	17	4	9x4	12x4	40	4	20
	9 Aug	18	0	3x2	8x4	25 to 40	0	-
	18 Aug	17	0	3x2	5x5	18 to 22	0	-
1964	3 Jul	28	9	8x5	15x5	35 to 49	4	21
	6 Jul	147	79	8x4	20x10	25 to 30	5	28
	7 Jul	11	1	3x3	10x6	27	1	-
	8 Jul	15	5	4x3	10x5	20 to 25	4	30
	9 Jul	8	0	2x2	4x3	30 to 31	0	-
1963	14 Jun	22	10	10x5	20x10	20 to 35	4	26
	17 Jun	12	2	5x4	12x6	15 to 25	2	25
	14 Jul	31	0	4x3	10x5	30 to 35	8	24
	25 Jul	16	10	6x4	8x7	35 to 40	8	35
	28 Jul	36	10	8x6	12x8	28 to 40	6	30
	29 Jul	10	2	10x6	20x10	37 to 43	2	26
	7 Aug	32	10	6x4	10x5	UNK	4	30
	14 Aug	13	1	8x6	12x6	10 to 30	2	35
	12 Sep	20	2	5x5	14x5	20 to 35	3	30
1962	31 May	26	21	10x6	13x8	25 to 40	7	25
	6 Jun	5	1	2x2	8x5	20	1	-
	11 Jun	9	0	2x2	5x5	20 to 30	0	-
	15 Jun	10	0	2x2	3x3	UNK	0	-
	24 Jun	12	0	2x2	2x2	25	0	-
	12 Jul	35	0	8x6	20x10	35 to 40	7	27
	16 Jul	12	0	2x2	3x3	UNK	0	-

APPENDIX D (continued)

(1)		(2)		(3)		(4)	(5)	(6)
1962	18 Jul	12	4	8x8	12x8	20 to 29	3	23
	19 Jul	1	0	3x2	6x3	UNK	0	-
	31 Jul	23	8	10x8	20x10	20 to 35	7	30
	6 Aug	15	7	6x4	10x6	UNK	2	25
	21 Aug	3	0	4x4	5x5	UNK	0	-
	28 Aug	23	0	3x3	7x5	25	4	20
1961	22 May	56	11	6x5	10x5	25	7	21
	13 Jun	9	4	10x5	10x5	17 to 30	4	47
	21 Jun	9	1	2x2	5x3	20	0	-
	6 Jul	27	2	4x4	7x7	15 to 30	2	30
	10 Jul	205	33	10x6	26x8	13 to 30	21	25
	11 Jul	5	2	3x3	7x7	30	3	60
	13 Jul	3	0	2x2	2x2	25	0	-
	29 Jul	54	18	2x2	8x6	UNK	5	25
	11 Aug	23	3	2x2	5x5	17 to 39	2	23
	23 Aug	2	0	1x1	1x1	19	0	-
1960	18 May	29	0	2x2	3x3	20	0	-
	24 May	80	4	2x2	3x3	22	0	-
	1 Jun	5	0	4x3	5x4	UNK	2	40
	11 Jun	53	0	2x2	4x4	10 to 32	3	45
	19 Jun	46	2	5x5	20x5	30 to 35	15	35
	20 Jul	16	0	4x3	7x3	UNK	0	-
	5 Aug	8	0	2x2	2x2	UNK	0	-
	10 Aug	20	0	5x3	20x8	22 to 25	2	55
	11 Aug	7	1	2x2	10x8	UNK	0	-
	25 Oct	3	0	5x4	5x4	UNK	0	-
1959	6 Jul	26	0	4x3	7x5	40	1	-
	22 Jul	19	8	8x5	15x7	UNK	6	30
	24 Jul	23	0	5x4	10x9	20 to 38	5	35
	30 Jul	3	0	1x1	2x2	30	0	-
	31 Jul	21	0	3x3	10x10	UNK	2	20
	5 Aug	25	0	2x2	10x5	UNK	0	-
	27 Aug	54	0	10x8	10x10	30 to 40	2	25
	31 Aug	195	15	12x6	23x8	35 to 42	16	23

APPENDIX D (continued)

Date:		Number of tracks		Track lengths Average (mi)		Remarks
		<15mi	>15mi	<15mi	>15mi	
1965	7 Jun	5	3	9	20	
	8 Jun	9	8	10	26	
	9 Jun	24	19	9	37	Two distinct tracks were along a sea breeze convergence line. Cells with log Ze≥4.5 end by 2130 EST
	18 Jun	2	0	11	-	No cells with log Ze≥5.5
	23 Jun	24	10	10	42	A band extending in a north northeast to south southwest orientation moved eastward. Cells with log Ze≥4.5 end by 2110 EST.
	30 Jun	25	3	7	22	Cells with log Ze≥5.5, moved east southeastward. A band of weak intensity has a east northeast to west southwest orientation. Cells with log Ze≥4.5 end by 2011 EST.
	14 Jul	13	4	8	49	Nocturnal thunderstorms.
	9 Aug	12	9	10	24	A band of weak intensity to the northwest of Boston, Mass., extended in a northeast to southwest orientation. No cells with log Ze≥5.5
	18 Aug	14	4	8	18	Nocturnal thunderstorms, No cells with log Ze≥5.5
	10 Oct	-	-	-	-	No radar data available. Line of thunderstorms formed in the early afternoon from NAS Quonset Point, R.I. to NAS South Weymouth, Mass.
1964	3 Jul	27	20	9	26	Nocturnal Thunderstorms.
	6 Jul	6	11	10	22	Cells with log Ze≥5.5 had a diameter of 20 miles in the area about 40 miles south southeast of Boston, Mass. Cells with log Ze≥4.5 dissipated by 1934 EST.

APPENDIX D (continued)

Date:		Number of Tracks		Track lengths Average (mi)		Remarks
		<15mi	>15mi	<15mi	>15mi	
1964	7 Jul	7	2	9	23	
	8 Jul	9	1	9	18	
	9 Jul	3	0	6	-	A band with weak intensity is near Boston, Mass.
1963	28 May	-	-	-	-	AN/CPS-9 data. Investigated by Nason (1965)
	14 Jun	16	5	9	23	
	17 Jun	8	1	9	18	Cells with log Ze≳4.5 are north of the 500mb maximum wind belt.
	14 Jul	26	3	8	20	No cells with log Ze≳5.5. Investigated by Stem (1964)
	25 Jul	12	0	8	-	Investigated by Stem (1964)
	28 Jul	0	0	-	-	Investigated by Stem (1964)
	29 Jul	6	5	9	29	Investigated by Stem (1964)
	7 Aug	25	6	9	21	Cells with log Ze≳4.5 dissipated by 1855 EST. Investigated by Stem (1964).
	14 Aug	9	12	10	38	Cells with log Ze≳4.5 are north of the jet stream.
	12 Sep	17	9	10	31	Cells in Vermont near a cold front are excluded.
1962	31 May	12	33	10	32	Cells with log Ze≳5.5 are moving east southeastward. Nocturnal thunderstorms. Investigated by Nason (1965).
	6 Jun	3	1	10	20	Cells with log Ze≳4.5 are northeast of the jet stream.
	11 Jun	11	0	8	-	No cells with log Ze≳5.5.
	15 Jun	0	0	-	-	No cells with log Ze≳5.5.
	24 Jun	10	0	4	-	No cells with log Ze≳5.5. Cells with log Ze≳4.5 are southeast of the jet stream.
	12 Jul	31	14	8	27	No cells with log Ze≳5.5. Cells with log Ze≳4.5 are north of the jet stream.
	16 Jul	0	0	-	-	No cells with log Ze≳5.5.
	18 Jul	5	7	7	21	Cells with log Ze≳4.5 are north of the jet stream. Larger cells are moving from the northwest.
	19 Jul	1	0	12	-	No cells with log Ze≳5.5.

APPENDIX D (continued)

Date:		Number of tracks		Track lengths Average (mi)		Remarks
		<15mi	>15mi	<15mi	>15mi	
1962	31 Jul	17	9	10	33	Cells with $\log Ze \geq 4.5$ are north of the jet stream. A band with weak intensity is in New Hampshire.
	6 Aug	16	2	7	23	
	21 Aug	2	1	6	35	No cells with $\log Ze \geq 5.5$.
	28 Aug	23	1	6	18	No cells with $\log Ze \geq 5.5$. Cells with $\log Ze \geq 4.5$ near the hurricane are excluded.
	5 Sep	-	-	-	-	AN/CPS-9 Data.
1961	22 May	54	0	6	-	
	13 Jun	7	3	9	20	Nocturnal thunderstorms.
	21 Jun	7	4	6	21	
	6 Jul	24	1	6	18	
	10 Jul	288	6	7	19	Band developed after 1740 EST. Cells with $\log Ze \geq 4.5$ dissipated by 2130 EST. Numerous cells and short tracks.
	11 Jul	3	2	8	17	
	13 Jul	3	0	5	-	No cells with $\log Ze \geq 5.5$
	29 Jul	26	0	6	-	
	11 Aug	21	4	6	24	Cells with $\log Ze \geq 4.5$ move from the southwest to the south of Boston.
	23 Aug	2	0	3	-	No cells with $\log Ze \geq 5.5$
1960	18 May	0	0	-	-	No cells with $\log Ze \geq 5.5$
	24 May	85	0	3	-	Numerous cells. Cells with $\log Ze \geq 4.5$ end by 1950 EST.
	1 Jun	5	0	4	-	No cells with $\log Ze \geq 5.5$
	11 Jul	53	0	3	-	No cells with $\log Ze \geq 5.5$
	19 Jul	37	17	5	22	Nocturnal thunderstorms. Bands to the west southwest of Boston are associated with cold frontolysis.
	20 Jul	12	1	5	25	No cells with $\log Ze \geq 5.5$. Cells with $\log Ze \geq 4.5$ are north of the jet stream.
	5 Aug	8	0	2	-	No cells with $\log Ze \geq 5.5$
	10 Aug	10	4	9	22	No cells with $\log Ze \geq 5.5$

APPENDIX D (continued)

Date:		Number of tracks		Track lengths Average (mi)		Remarks
		<15mi	>15mi	<15mi	>15mi	
1960	11 Aug	7	0	5	-	Cells with log $Ze \geq 4.5$ end by 0849 EST.
	25 Oct	3	0	5	-	No cells with log $Ze \geq 4.5$. Cells with log $Ze \geq 4.5$ are northeast of the jet stream.
1959	6 Jul	26	0	3	-	No cells with log $Ze \geq 5.5$. Cells with log $Ze \geq 4.5$ are southeast of the jet stream.
	22 Jul	14	4	9	18	
	24 Jul	17	5	5	21	No cells with log $Ze \geq 5.5$. Two tracks in the Connecticut River Valley area are oriented southwest to northeast. Cells with log $Ze \geq 4.5$ end by 2011 EST.
	30 Jul	2	0	5	-	Sea breeze front to 5000 feet. No cells with log $Ze \geq 5.5$.
	31 Jul	15	5	7	18	No cells with log $Ze \geq 5.5$. Two tracks of nocturnal thunderstorms are oriented southwest to northeast.
	5 Aug	25	0	3	-	No cells with log $Ze \geq 5.5$.
	27 Aug	51	6	5	25	No cells with log $Ze \geq 5.5$.
	31 Aug	183	20	6	20	

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