A Radar-Based Climatology of Thunderstorm Days across New York State

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ABSTRACT

Archived radar reports, derived from the National Weather Service radar network, were used to estimate the average annual frequencies of thunderstorm days across New York State for the period 1978–81. The archival records consist of manually-digitized radar (MDR) data, available on magnetic tapes and arranged as hourly, digitally-encoded radar reflectivity values within a high-resolution grid of reporting blocks, each 45 × 45 km. Analyses of these data made use of an experimentally-derived relationship between radar reflectivities and the presence and intensities of thunderstorms. The radar-based thunderstorm day climatology generally agreed to within 15% of conventional, surface-based thunderstorm day statistics reported for the same period by National Weather Service (NWS) offices located within range of two or more network radars in the State. Poorest agreement between annual totals was found at selected NWS offices in the Greater New York City Metropolitan Area and northward into the lower Hudson River Valley, in far western New York and over far northern New York. Where redundant, near-continuous network radar coverage was available, a northwest-to-southeast increase of thunderstorm days, approaching an annual maximum of 45 in downstate New York was revealed. This gradient in thunderstorm day activity is significantly different from that depicted on isokeraunic maps derived from conventional thunder observing protocol. Because the MDR data are archived on a high-resolution grid of reporting blocks, local thunderstorm maxima on a scale of tens of kilometers may be resolved. Analyses further revealed that 5–25% of all thunderstorm days contained sufficiently vigorous storms to be characterized as "intense". The greatest frequency of intense thunderstorm days, approaching 8 annually, was located in the highly-populated region of the State along the New York–New Jersey borders, northwest of the Greater New York City Metropolitan Area.

1. Introduction

For certain lightning-sensitive business interests, the geographic distribution of yearly thunderstorm frequencies and associated intensities is not sufficiently detailed to be of practical value for long-term planning purposes. Techniques for detecting and locating lightning discharges to ground have been developed within the past decade, but only recently have lightning detection networks been established to provide comprehensive, wide-area surveillance (e.g., Krider *et al.*, 1980; Lyons and Bent, 1983; Orville *et al.*, 1983). Over the past several decades it has become international convention to empirically relate lightning activity to the thunderstorm day, also known as the thunder day or thunderheard day (World Meteorological Organization, 1953). One limitation in using the thunderstorm day as an index of lightning activity is that flash characteristics, particularly flashing rate and flash density as a function of flash type, cannot be specified (Prentice, 1977). Furthermore, there are only 450 primary observation sites across the United States at which routine thunder reports are made, far less than the number needed to properly characterize mesoscale thunderstorm "nests."

Only the broad features of yearly thunderstorm day frequencies may be derived from inspection of isokeraunic maps developed from surface thunder reports (Court, 1974; Court and Griffiths, 1982). For instance, in New York the statewide keraunic pattern depicted in Fig. 1 is based upon a ten-year period of record (1953–62) from eight first-order National Weather Service offices—Albany, New York City, LaGuardia Airport, John F. Kennedy International Airport, Binghamton, Rochester and Syracuse. Because the audibility of thunder is generally limited to less than 25 km (Fleagle and Businger, 1963), each station provides a representation of local thunder frequency within an area not exceeding 2000 km^2 (Fig. 2). Additional thunder observations are provided by NWS-affiliated Flight Service Stations and military airfields, including Elmira, Glens Falls, Griffiss Air Force Base, Massena, Poughkeepsie, Suffolk County Air Force Base, Utica and Watertown (Changery, 1981). However, these sixteen Weather Service offices afford routine thunder coverage only over 15–20% of the State's area.

On the other hand, weather radar has provided a convenient means of wide-area, storm-related precipitation surveillance. The National Weather Service Radar Network consists of 56 WSR-57 (10-cm wavelength) radars, each operated to provide nearly continuous and partially overlapping coverage out to a distance of 230 km. An additional 68 local warning radars furnish supplementary observations to the na-

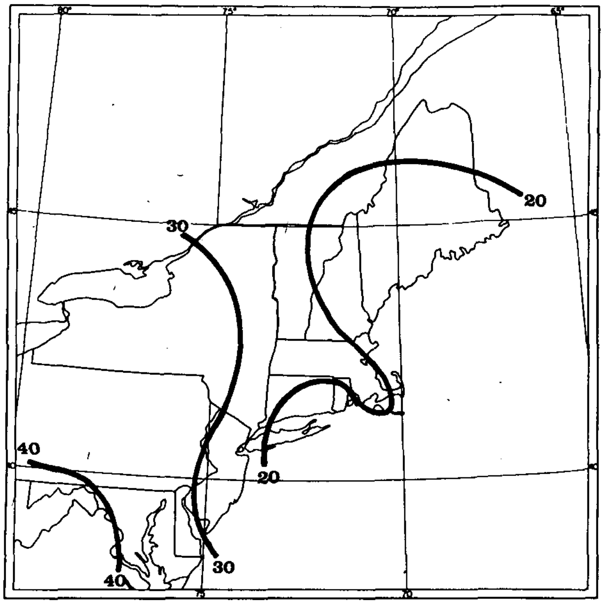

FIG. 1. The mean annual number of thunderstorm days in the northeastern United States (From Court, 1974).

tional network whenever threatening storm activity approaches or develops within a severe weather forecast area or whenever a primary network radar is unable to transmit observations into the network (U.S. Department of Commerce, 1981).

Correlational analyses of reflectivity patterns on WSR-57 radar systems to the presence and intensity of thunderstorms has been reported by several investigators (Henz, 1974; Reap and Foster, 1979; Holle *et al.*, 1983). Although there is no analytical relationship between radar echo brightness and the electrical properties of the precipitation cell producing the echo pattern, at least two field studies have provided a sufficiently large data base to statistically relate thunderstorm occurrence or nonoccurrence to reflectivity values. Reap and Foster (1979) conducted a two-year, nationwide validation program, comparing thunderstorm reports from 269 NWS offices to radar echo brightness levels across the MDR reporting grid. They concluded that 82% of the thunderstorms reported by ground-based observers corresponded to radar reflectivities equal to VIP3 or greater, equivalent to minimum brightness values of 41 dB(Z) (Table 1). Conversely, more than 80% of the nonthunderstorm events occurred at levels below VIP3. These results are consistent with those reported by Holle *et al.* (1983) using data accumulated during the 1978 Florida Area Cumulus Experiment (FACE).

The validity of defining thunderstorms on the basis of a particular reflectivity, or VIP level, has been called into question (Weiss *et al.*, 1980). We would point out that there may be individual thunderstorms whose radar reflectivities are below VIP3 and some nonthunderstorms whose radar echo brightness exceeds this reflectivity threshold. For certain research, this simple thunderstorm predictor may require substantial refinement. However, during the course of any given calendar day, or portion thereof, thunderstorms passing through, or developing within, a 45 × 45 km MDR reporting block are likely to produce a VIP3 signal on at least one network radar. It does not matter how long such a cell lasts or how much brighter than 41 dB(Z) the echo might be. We are satisfied that Reap and Fosters' thunderstorm criterion is of sufficient reliability to permit the establishment of a thunderstorm day climatology, particularly in those regions of the State where dual surveillance by network radars is available.

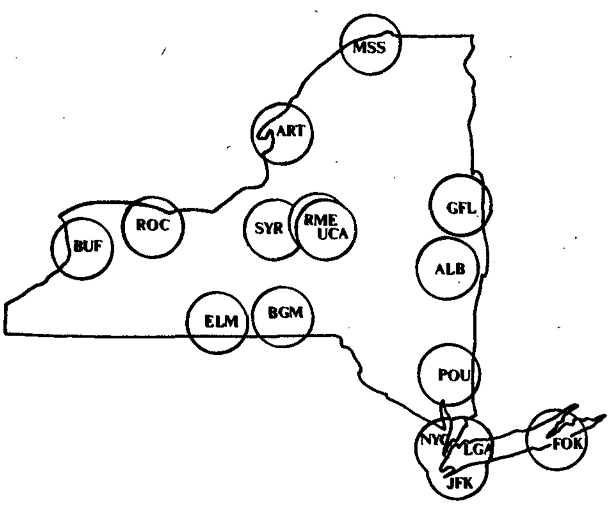

FIG. 2. Audible range of thunder at the sixteen primary National Weather Service-affiliated offices in New York, assuming optimal environmental conditions. Three-letter station codes follow conventional NWS reporting protocol. Radius of each circle is 25 km.

2. The New York State Radar Data Base and processing protocol

Coded MDR data for a high-resolution grid of 89 MDR reporting blocks across New York (Fig. 3) were

TABLE 1. *V*ideo *I*ntegrator and *P*rocessor (VIP) levels and associated categories of radar echo and precipitation intensities. The levels represent time-averaged values of echo reflectivities. dB(Z) = 10 logZ_e (mm^6 ms^{-3}) where Z_e is the equivalent radar reflectivity.

VIP level	Reflectivity [dB(Z)]	Echo intensity	Precipitation intensity	Equivalent convective rainfall rate (cm h^{-1})
0	None	None	None	0.0
1	<30	Weak	Light	0.0–0.5
2	30–41	Moderate	Moderate	0.5–2.8
3	41–46	Strong	Heavy	2.8–5.6
4	46–50	Very strong	Very heavy	5.6–11.4
5	50–57	Intense	Intense	11.4–18.0
6	>57	Extreme	Extreme	>7.1

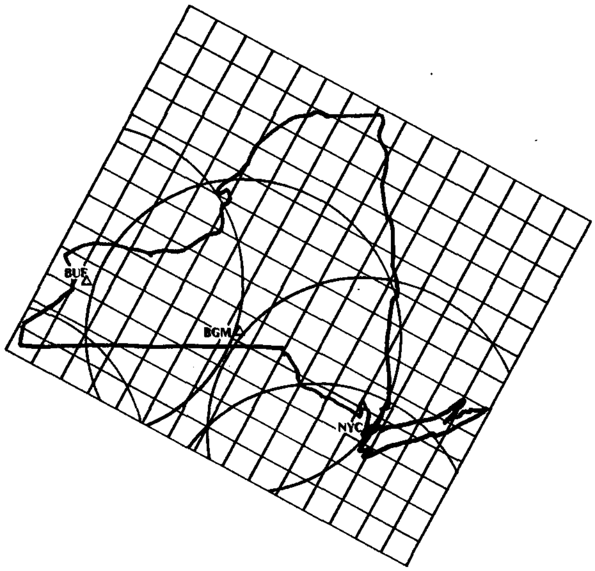

FIG. 3. Fine-mesh grid of radar reporting blocks (45 × 45 km) used in the 1978–81 thunderstorm day climatological analyses. Circles denote range of coverage out to 230 km furnished by the National Weather Service network of radars at Buffalo (BUF), Binghamton (BGM), New York City (NYC), Pittsburgh (PIT) and Atlantic City (ACY). Irregular coverage from local warning radar units in Albany and Burlington extends across far northern New York State.

obtained from the NWS-Techniques Development Laboratory. These data, available on magnetic tapes beginning 1 March 1978, are arranged as hourly values of the maximum VIP level code in each reporting block. In New York, primary coverage over 75–80% of the State's land area is provided by network radars in Buffalo, New York City, Binghamton, Pittsburgh, Pennsylvania and Atlantic City, New Jersey. Of this area, an estimated 40% is within range of coverage of network radar pairs (e.g., Buffalo–Pittsburgh, Buffalo–Binghamton, Binghamton–New York City, Binghamton–New York City, Binghamton–Atlantic City and New York City–Atlantic City). Additional surveillance in far northern and western New York is furnished on an irregular reporting schedule to the national network by local warning radars in Albany, Burlington, Vermont and Erie, Pennsylvania.

Radar data processing involved extracting all calendar days during each month, 1978–81, on which a maximum VIP level code of 3, 4, 5 or 6 had been registered in any one of the New York reporting blocks. These days were saved as thunderstorm days from which individual monthly totals were derived, assuming that a month consisted of at least 600 hourly observations. Average monthly thunderstorm day totals were then formed from the individual monthly totals. Annual average thunderstorm days were represented as the sum of the twelve monthly averages for the period 1978–81.

In addition to the monthly and annual thunderstorm day averages, mean monthly and annual occurrences of "intense" thunderstorm days were computed. In contrast to the meteorologists cognitive definition of severe thunderstorms (e.g., hail, strong or damaging winds, flash flooding, intense lightning and so forth), intense thunderstorms were simply assigned to those precipitation cells producing maximum VIP codes of 5 or 6, in accordance with Table 1. No other quantitative information on the severity of the storm cell in a given reporting block may be derived from this data set.

3. The 1978–81 radar data analyses and discussion

The average annual occurrence of thunderstorm days over the grid of 89 radar reporting blocks is presented as Fig. 4a. Thunderstorm days generally increase from approximately 10 annually along the far northeastern shores of Lake Ontario to slightly less than 45 per year along the New York–New Jersey state borders. Regional maxima are found along the southern shores of Lake Ontario (25–30), in far western New York (25–30), in the central tier along the New York–Pennsylvania border (25–30) and in far downstate New York (40–45). Statistics from far northern New York are incomplete due to lack of continuous network radar coverage. The 1978–81 radar-based, annual average thunderstorm day distribution reveals a prominent northwest-to-southeast gradient, thereby distinguishing itself from the long-term, average pattern developed from reports of surface observers (cf. Fig. 1). Comparisons between annual average thunderstorm days computed from the MDR data and from NWS surface observations for the 1978–81 period (Table 2) reveal two features of interest. First, at those Weather Service offices within range of the Buffalo and Binghamton radars (e.g., Rochester, Syracuse and Elmira), or the Binghamton and New York City radars (e.g., Albany and Poughkeepsie), annual averages agree to within 15%, the only exception being Poughkeepsie, where an unexplained discrepancy of 60% appears. Secondly, Weather Service offices in far downstate New York which receive simultaneous coverage from network radars in New York City and Atlantic City, or at offices served by only one network radar, show little agreement with MDR-derived thunderstorm day totals. For instance, in the Greater New York City Metropolitan Area, radar observations yield annual totals 65–165% in excess of those derived from conventional thunder reports. This major discrepancy is likely attributable to the difficulty of hearing thunder over the general level of background noise in midtown Manhattan and at LaGuardia and Kennedy Airports. Whether the intense local ground clutter pattern due to densely-packed high-rise structures in downtown New York City produces anomalously higher radar return signals during precipitation episodes cannot be determined at this time. In contrast, observers at NWS offices within the single radar coverage zone report an average of 5–55%

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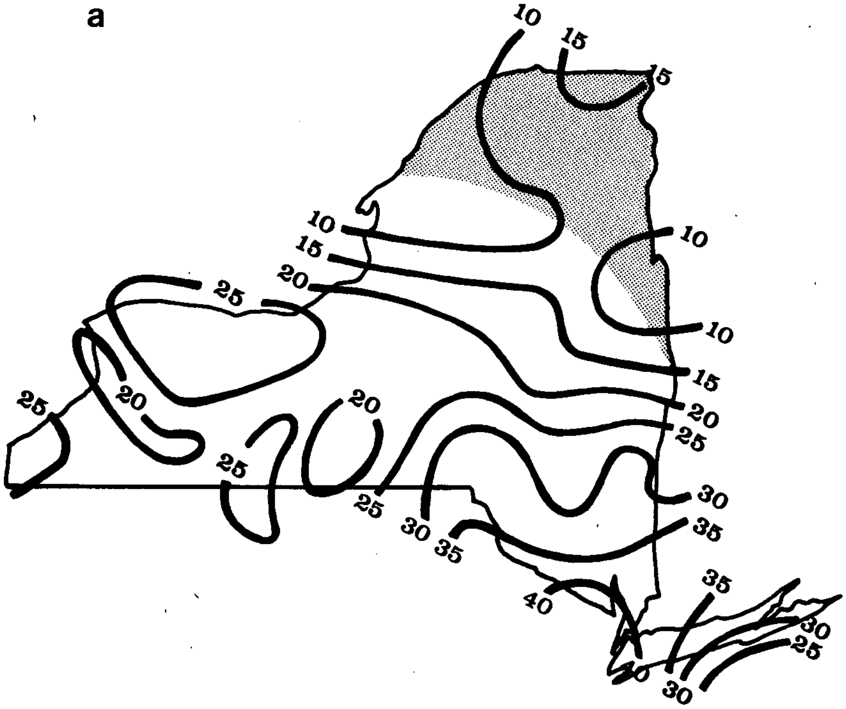
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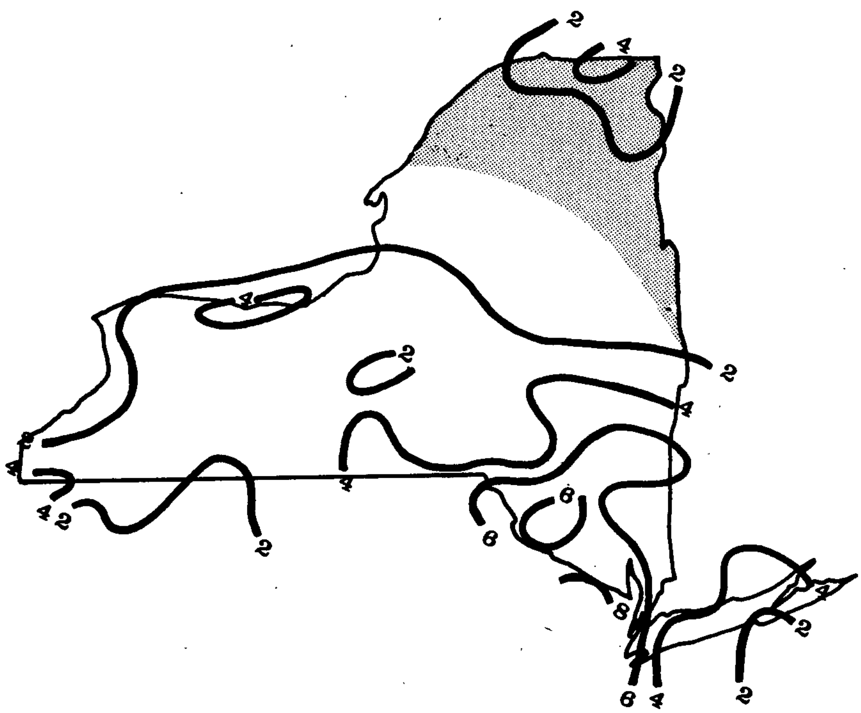
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TABLE 2. Yearly average frequency of thunderstorm days during 1978–81 at selected locations across New York State.

NWS office location	NWS identifier	Observational Official	Method radar	Percentage difference	Radar coverage
Rochester	ROC	28.5	29.1	+2.1	BUF–BGM
Syracuse	SYR	23.8	22.9	−3.8	BUF–BGM
Albany	ALB	19.8	20.3	+2.5	NYC–BGM
Binghamton	BGM	26.0	22.3	−14.2	BGM
Buffalo	BUF	28.5	18.3	−35.8	BUF
Central Park-NYC	NYC	15.5	41.1	+165.2	NYC–ACY
LaGuardia Airport	LGA	22.8	37.6	+64.9	NYC–ACY
J.F.K. Airport	JFK	22.8	39.5	+73.2	NYC–ACY
Utica	UCA	22.0	21.0	−4.5	UCA
Elmira	ELM	26.0	22.0	−15.4	BGM–BUF
Watertown	ART	18.5	9.0	−51.4	BGM
Glens Falls	GFL	21.8	10.0	−54.1	BGM
Poughkeepsie	POU	21.3	34.0	+59.6	NYC–BGM

Official thunderstorm day totals derived from observer reports of thunder at each National Weather Service office.

more thunderstorm days annually than are resolved by radar. At Buffalo, radar-based annual totals are thought to be lower than those compiled from observer reports due to such factors as the inclusion of public reports of thunder in the official airport statistics and to the occasional presence of shallow, but electrically-active, VIP1 or VIP2 level precipitation systems to the lee of Lake Erie. Watertown and Glens Falls, both located at the maximum effective range of the Binghamton radar unit (approximately 230-km), are sufficiently distant that significant numbers of isolated thunderstorms may be missed. This is due to incomplete radar beam filling, discussed in most radar fundamentals handbooks (cf. U.S. Department of Commerce, 1981).

The average distribution of intense thunderstorm days, as presented in Fig. 4b, follows the pattern of thunderstorm day maxima and minima across New York depicted in Fig. 4a. Approximately 5 to 25% of all thunderstorm days are associated with storms characterized as intense. Intense thunderstorm days are most prevalent in far western and southern counties of the State. The occurrence of 6–8 intense thunderstorm days annually derived from the MDR data across downstate New York, northwest of the Greater New York City Metropolitan Area, is considered significant in view of the fact that nearly 50% of the State's population is located here.

4. Conclusions

The thunderstorm day climatology presented here represents a unique application of digitally-encoded National Weather Service radar data as an alternative to traditional, surface-based observer reports of thunder. The nearly continuous coverage which National Weather Service network radars furnished across most of New York State and the ease of access to the magnetic data tapes archived by the NWS-Techniques Development Laboratory was the basis for exploring the reliability of these data for thunderstorm analyses. Reference was made to previous field experiments conducted by the Techniques Development Laboratory and others, which show that radar reflectivities of 41 dB(Z) or greater (VIP3–VIP6) are highly correlated with surface observations of thunder. Intense thunderstorms were arbitrarily assigned to all radar reports whose reflectivities exceeded 50 dB(Z) (VIP5–VIP6).

Hourly, digitized MDR radar observations were available for the State in a high-resolution grid of reporting blocks, each nearly 45 × 45 km. Comparisons of annual average thunderstorm day totals for the period 1978–81 based on the analyses of the radar and surface weather observation data sets indicated agreement to within 15% in upstate New York where overlapping radar coverage within the national network was available. In the Greater New York City Metro-

FIG. 4a. The mean annual number of thunderstorm days (VIP3–VIP6) in New York State, 1978–81, based on analyses of the NWS-Techniques Development Laboratory's manually-digitized radar (MDR) data. Regions of the State under irregular surveillance by the National Weather Service radar network are indicated with shading.

FIG. 4b. The mean annual number of "intense" thunderstorm days (VIP5–VIP6) in New York State, 1978–81. Regions of the State under irregular surveillance by the National Weather Service radar network are indicated with shading.

politan Area, where redundant network surveillance may be seriously compromised by local noise pollution, annual means derived from the MDR data were from 65 to 165% greater than those based upon conventional thunder reports. Otherwise, where only single radar coverage was available, thunderstorm day totals from the national network were typically 5–55% lower than were obtained from surface observations of thunder.

Annual average occurrences of between approximately 10 and 45 thunderstorm days were found in the MDR data base for the years 1978–81. This stands in contrast to the narrower range of approximately 20–30 thunderstorm days yearly derived from official, surface-based statistics compiled over a ten-year period at eight first-order National Weather Service offices in New York. Analyses of the network radar data further indicate that between 5 and 25% of all thunderstorm days can be characterized as intense on the basis of the maximum radar echo brightness values in excess of 50 dB(Z) which these storms produce. The 6–8 intense thunderstorm days observed along the New York–New Jersey borders is frequent enough to warrant the attention of lightning-sensitive business interests. For instance, with slightly more than one-half of the State's population and slightly less than one-half of New York Telephone wire centers located in this region, it would be economically imprudent not to consider various lightning damage mitigation strategies.

Several other clusters of thunderstorm day maxima, amounting to 25–30 days per year, were found in western and west-central counties of the State. Thunderstorm day minima appear to coincide with those areas just beyond range of the network radars at Buffalo, Binghamton and New York City. Generally less than 15 thunderstorm days per year are observed over far eastern and northern New York, sections of the State under irregular observation by local warning radars at Albany and Burlington, Vermont.

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