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AN ANALYSIS OF SYNOPTIC SCALE FLOOD EVENTS IN THE EASTERN UNITED STATES DURING 1980-1989

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1. INTRODUCTION

The eastern United States, in part due to its orography and proximity to large moisture sources, is prone to a wide variety of flood events, ranging from small scale flash flooding to major river flooding. Flash floods are typically a result of the interaction of synoptic scale and mesoscale weather systems, often interacting with topographic, or other factors (e.g., saturated soil and snowmelt) that focus rainfall/runoff in a small area, usually a portion of a river basin or sub-basin and over a short time period, generally less than 6-12 hours. Widespread flood events can cover several river basins, with the event lasting more than 12 hours. In this latter case, the mechanism for producing the heavy rain is usually synoptic scale in nature. The focus of this paper is on these larger scale events.

Maddox et al. (1979) compiled a list of flood producing synoptic and meso-alpha scale systems. For the eastern United States, these include: 1) synoptic events; 2) frontal events (east-west oriented fronts); and, 3) mesohigh events. Frontal and mesohigh events are typically sub-synoptic scale in nature, and are frequently associated with more localized flash flood events. While this paper will concentrate on cases typical of Maddox's synoptic events, his event composites were not used. In addition, this study includes tropical systems, and the tropical systems that interact with synoptic scale weather systems.

This paper examines the large scale features that produced significant flood events in the National Weather Service (NWS) Eastern Region (ER) (Figure 1) during the 1980's. These large scale features are classified by type and frequency tables are provided. In addition, seasonal and monthly variations are detailed. The data are also sorted by state, with examples presented to illustrate each type of event.

2. BACKGROUND

Several reports have examined case studies of synoptic scale flood events in the Eastern United States. U.S. Weather Bureau (1941) described a synoptic overview of the March 1936 flood (among others). This flood was caused by an extratropical (migratory) cyclone associated with a large, 500 mb negatively tilted trough. The presence of abundant moisture and convective storms were key factors in the synoptic scale system's ability to produce copious amounts of rainfall.

Budd (1988) analyzed a case of record flooding in Maine. The synoptic situation associated with the flooding displayed many similarities of a north-south frontal system (similar to the Maddox et al. (1979) synoptic events). Glass and Grumm (1990) described another case of a north-south frontal system in their analysis of the mesoscale and synoptic scale aspects of the 5-6 May 1989 Mid-Atlantic flood. These papers, as well as Maddox et al. (1979), point out the importance of the availability of abundant moisture, and the role of deep convection in the flood-producing rains.

Several accounts of major floods associated with tropical systems have been documented. One of the most destructive hurricanes in United States history was Agnes in August of 1972. Interestingly, damage from this storm was due almost entirely to the torrential rains that approached 15 inches. Bailey et al. (1975) provide a detailed review of the ravaging floods due to Agnes, and its interaction with an extratropical system, as it tracked through the NWS ER. Record and near record floods affected 12 states (10 in the ER), causing $3.1 billion (in 1972 dollars) in damages and claiming 117 lives. The abundant tropical moisture combined with the system's slow movement (remaining nearly stationary for a period of 24 hours) to produce the substantial rainfall.

The slow movement of Agnes is a common feature of many other synoptic scale flood producing storms. The presence of a front, or a cyclonic circulation center, is required to focus the abundant moisture (and associated deep convection) over the same area long enough to create flood producing rains. On a large scale, this is best accomplished by cut off, or negatively tilted 500 mb lows/troughs associated with slow moving migratory cyclones, slow moving north-south oriented fronts, or sub-tropical or quasi-stationary lows.

Theories about antecedent conditions for floods have changed little over the years. A good description of how such factors as snow melt, ice jams, frozen ground, saturated ground, and vegetative cover affect runoff and flood potential can be found in Brooks and Thiessen (1937). This paper gives an excellent account of many of the great floods from the late 1800's through the flood of January 1937, and the effects of antecedent conditions.

More recent studies of flood events in the NWS ER also address the roles played by antecedent conditions. Budd (1988) discussed the effects of excessive runoff from a dense snowpack in combination with the heavy rainfall. Smith and Reed (1990) detailed some of the effects of snowmelt, ice jams, and heavy rainfall associated with the flood of 1936. Harley (1990) described a flood event in western Ohio associated with a prolonged period of excessive rainfall. In particular, a record wet spring at Dayton, OH, set the stage for major flooding after another bout of heavy rainfall, which alone probably would not have caused the kind of flooding that was observed.

3. METHODOLOGY AND DATA

Data were collected for the years 1980 through 1989 to determine the number of flood events in the NWS ER associated with synoptic scale weather features. In particular, synoptic scale heavy rain events were assessed by using the Daily Weather Maps series (U.S. Department of

Commerce 1980-1989a). For an event to be included in this analysis, precipitation over a 24-hour period (ending at 1200 UTC) had to exceed 1 inch, for two or more of the first order stations depicted on the Daily Weather Map precipitation analysis, with at least one report in the NWS ER. This step served to screen out mesoscale events that are typically evident only through analysis of finer networks of precipitation reporting stations. There were a few occasions when a Daily Weather Map reporting (first order) station was within a mesoscale event. However, the criterion of requiring two stations reporting rainfall of an inch or more helped ensure that only synoptic scale events were considered. As a result, most events in this study affected an area that included two or more states.

Of course, the large distance between the reporting stations, and situations when the window of a precipitation event stretched across two 24-hour rainfall reporting periods, posed problems for this approach. A synoptic scale heavy rain event could occur in a data void area, with reporting stations showing less than an inch. However, if the synoptic scale pattern suggested the potential for a heavy rain event, or if two successive Daily Weather Maps added up to an inch or more rainfall, then the event was considered for further examination. Surface and 500 mb charts from the Daily Weather Maps were then studied to determine the type of synoptic scale system responsible for the heavy rain event. Details of storm tracks, locations, orientations, and movement of surface features, and the type and movement of the 500 mb features were noted.

Five types of events were found to impact the NWS ER. The first type was extratropical (migratory) cyclones (Type E). These events were associated with a negatively tilted 500 mb trough (or migratory 500 mb closed low center), within a moderate to strong meridional flow. An example of a Type E system is shown in Figure 2a-c. Flooding was reported in Maine, New Hampshire, Connecticut, New Jersey, Virginia, and North and South Carolina with this system. Heavy rain in Type E systems typically occurs on the cold side of the low (or point of occlusion).

The second type of event was comprised of quasi-stationary fronts (Type Q) that were oriented generally north to south. These fronts were typically associated with a neutrally or slightly positively tilted 500 mb trough within a moderate to strong meridional flow. An example of a Type Q event is shown in Figure 3. Flooding was reported in Pennsylvania, New York, Massachusetts, Connecticut, Maine, New Hampshire, and Vermont. For Type Q events such as this system, the heavy rain was usually observed on the warm side of the front, although there were a few cases where the heavy rain occurred on the cold side of the front. In these cases, weak, stable waves traversed the front from south to north.

Other types were tropical systems (Type T), and tropical systems merging with an extratropical system (either a mid-latitude cyclone or an old frontal system--Type TS). Figures 4 and 5 show a Type TS system that originated as Tropical Storm Juan. After moving onshore along the Gulf Coast, Juan subsequently combined with a north-south oriented front and an associated 500 mb migratory cyclone. This event resulted in record flooding in Virginia and West Virginia, with flooding also occurring in North Carolina, Washington, D.C., Maryland, New York, Pennsylvania, and Ohio.

Finally, a miscellaneous classification (Type M) was used for quasi-stationary, or sub-tropical low pressure systems associated with a 500 mb low height center (usually weak) that showed little movement. Figure 6 illustrates a type M event where flooding was reported in Maine and New Jersey.

The next step involved an examination of **Storm Data** (U.S. Department of Commerce 1980-1989b) for flood events. First, the duration of the heavy rainfall event was noted. If the event was less than 12 hours duration then it was not considered as a synoptic scale (long duration) event, and was removed from the database. Next, the event descriptions were examined to determine the type and extent of flooding that occurred. Based upon the Crysler et al. (1980) flood classification scheme (see Table 1), only major flood events (Types B, C, and D) were included in the database. Type A events were discounted since only insignificant, or very minor flooding occurred. In addition, coastal flood events due to high tides, heavy surf, or storm surge were removed, as were flood events due to ice jams and/or snowmelt associated with melting, if little or no precipitation was observed. Finally the mention of any antecedent conditions was noted. These included (but were not limited to): 1) previous rainfall (saturated ground); 2) snow melt; and 3) ice jams.

4. RESULTS

As shown in **Figures** 7 and 8, the results of this study indicate that during the 1980's, of the 76 major synoptic scale flood events that occurred: 35 events were caused by a migratory extratropical cyclone (Type E); 24 events by a north-south quasi-stationary front (Type Q), with 21 occurring on the warm side, and 3 on the cold side of the front; 6 events were associated with tropical systems (Type T); 5 were caused by tropical storms interacting with an extratropical system (Type TS); and 6 were the result of a quasi-stationary, or sub-tropical low (Type M).

The breakdown by season (Figures 7 and 9) indicates that Spring (March-May) was the period of highest synoptic scale flood frequency with 33 of 76 events (43%). During the Spring, certain antecedent conditions, such as snow/ice melt, are prevalent, probably enhancing the frequency of major flood events. April recorded the most events for any month (Figure 10). Summer had the second highest frequency of events, 18 (24%), followed by Autumn with 15 events (20%), and Winter with 10 (13%). December and January, in particular, displayed a minimum in flood event frequency.

All 11 tropical system related events (Types T and TS) occurred during Summer or Autumn (Figure 7), resulting in the secondary frequency peak in August and September (Figure 10). Migratory cyclones, and north-south fronts (Types E and Q), both had the highest frequency in the Spring, although both types occurred throughout the year. Quasi-stationary lows (Type M) also showed a maximum frequency in the Spring, with no events recorded during the Winter.

Based on the **Storm Data** descriptions, 20 of the events were preceded by a rainfall event that created a saturated ground environment; 11 events involved snow melt; and 6 events occurred with ice jams. There were 31 total events with noted antecedent conditions (snow melt and ice jams usually occurred simultaneously). However, the information in **Storm Data** is not always complete (Maddox et al. 1979), particularly in regard to the antecedent conditions.

The number of flood events by state are listed in Table 2. Every state in the NWS ER experienced significant synoptic scale flooding during the 1980s. As expected, the larger states, especially those with substantial topographic variability (e.g., New York, Pennsylvania, and Virginia) showed a higher frequency of flooding, while smaller size states (e.g., Delaware, Rhode Island, and Vermont) were less likely to report significant large scale flooding.

The relatively low frequency of large scale flood events for West Virginia, a mountainous, and average sized state in the NWS ER, probably is associated with the nature of flood events that occur in the state. Apparently, localized flash flood events are much more common in West Virginia than significant synoptic scale flooding. Also, the majority of the state is on the west side of the Appalachians, which may reduce the influx of Atlantic moisture during major east coast synoptic scale events. This limiting factor for synoptic scale flooding appears to be reinforced by the fact that Ohio also only reported six significant large scale flood events during the 1980s. A breakdown of flood event types by state (Table 3) shows that only half of the six events in West Virginia were associated with migratory cyclones or north-south fronts. These type of events were frequently involved with flooding in most other states.

Another interesting result is that the number of events for Vermont is about half the number for New Hampshire (Table 2). These states are about the same size and have similar terrain. The difference in flood event frequency for these two states may also be explained by the "shadow" effect caused by the north-south oriented Appalachians and the proximity of New Hampshire to Atlantic moisture.

Most states followed the same seasonal frequency pattern as the NWS ER overall (e.g., a maximum frequency of flood events in the Spring and a minimum in the Winter). Two exceptions were North Carolina and South Carolina. This can be explained by the higher frequency of tropical systems that impact these southern coastal states during the Summer and Fall. Also, antecedent conditions (such as snow melt and ice jams) may not be as great a factor in Spring flooding compared to more northern states.

Finally, it should be noted that several drought periods were experienced in the NWS ER during the 1980's. It is beyond the scope of this study to determine to what extent this factor influenced the synoptic scale flood frequencies.

5. SUMMARY

Five basic synoptic scale patterns were identified that produced significant flooding over a large area in the eastern United States during the period 1980-1989. All of these systems tended to be slow-moving, and were associated with abundant available moisture.

The Spring season experienced the most flooding, with antecedent conditions, such as snow melt and ice jams, playing an important role. Tropical systems were the main consideration during late Summer and early Autumn. Eleven of 25 events (44%) during the hurricane season (June through November) were directly attributed to a tropical system (or the remnants of a tropical system interacting with an old frontal boundary or being drawn into a synoptic scale cyclonic circulation).

Of course, other large scale features not described here can contribute to significant flooding, although these are typically flash flood events of short duration, and occur over a small area. East-west oriented fronts (and meso-highs) are important synoptic, and sub-synoptic scale features that should also be considered by the operational meteorologist when evaluating excessive rain/flood potential. Synoptic scale features that produce excessive rain should be recognized, then mesoscale analyses should be used to locate more precisely the area(s) prone to heavy rain and flooding.

References

Bailey, J. F., J. L. Pattersson, and J. L. H. Paulhus, 1975: Hurricane Agnes Rainfall and Floods, June-July 1972. U. S. Geological Survey Professional Paper 924, 87 pp.

Brooks, C. F., and A. H. Thiessen, 1937: The Meteorology of Great Floods in the Eastern United States. The Geographical Review, **27**, 2, 269-290.

Budd, B. W., 1988: The 1987 April Fools Flood in Maine: A Hydro-Meteorological Account. Nat. Wea. Dig., **13**, 4, 6-15.

Crysler, K. A., L. R. Hoxit, and R. A. Maddox, 1980: A Climatology of the Flash Flood Hazard in a Four State Region of Appalachia. Preprints, Second Conference on Flash Floods. Amer. Meteor. Soc., Atlanta, Ga., 62-69.

Glass, F. H., and R. H. Grumm, 1990: The Meso and Synoptic Scale Aspects of the 5-6 May 1989 Mid-Atlantic Flash Flood and Severe Weather Outbreak. Preprints, Sixteenth Conference on Severe Local Storms. Amer. Meteor. Soc., Kananaskis Park, Alberta, Canada, 643-647.

Harley, S. B., 1990: Flooding in Western Ohio on May 26, 1989. Eastern Region Tech Attachment No. 90-5E, NOAA/NWS, Bohemia, NY, 16 pp.

Maddox, R. A., C. F. Chappell, and L. R. Hoxit, 1979: Synoptic and Meso-alpha Scale Aspects of Flash Flood Events. Bull. Amer. Meteor. Soc., **60**, 2, 115-123.

Smith, D. T., and D. B. Reed, 1990: A Centennial Survey of American Floods: Fifteen Significant Events in the United States, 1890-1990. NOAA Technical Memorandum NWS SR-133, NOAA/NWS, Fort Worth, TX, 91 pp.

U. S. Department of Commerce, 1980-1989a: Daily Weather Maps - Weekly Series. Dec. 31, 1979 - Jan. 6, 1980 through Dec. 25 - 31, 1989. [Available from NOAA/NWS Climate Analysis Center, Washington, D. C. 20233.]

U. S. Department of Commerce, 1980-1989b: Storm Data. Vol. 22 - 31. [Available from NOAA/NWS National Climatic Data Center, Asheville, NC 28801-2696.]

U. S. Weather Bureau, 1941: Maximum Possible Precipitation Over the Ohio River Basin Above Pittsburgh, Pa. Hydrometeorological Report No. 2., U. S. Waterways Experiment Station, Vicksburg, MS, 122 pp.

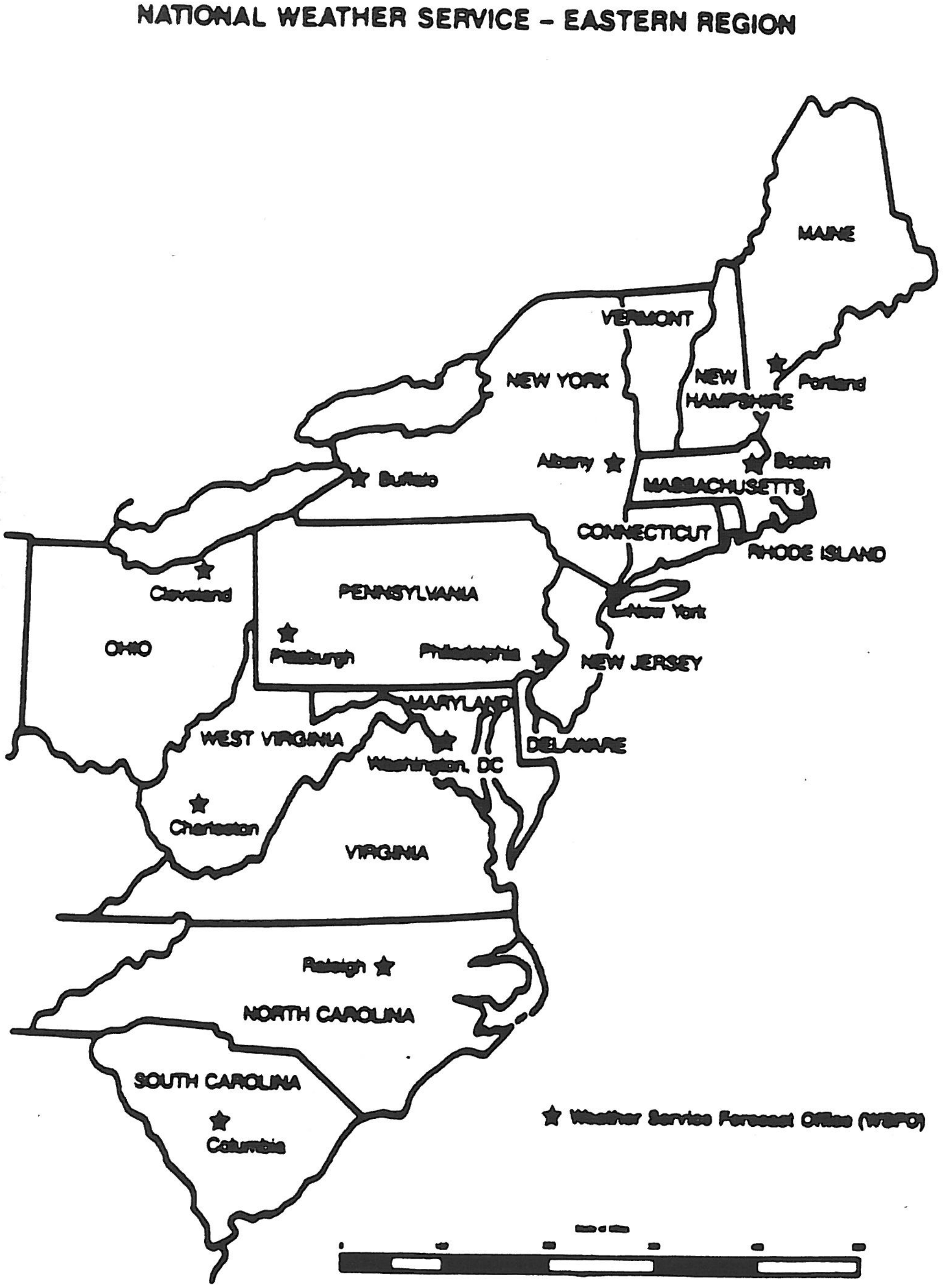

Figure 1. Map of the National Weather Service Eastern Region.

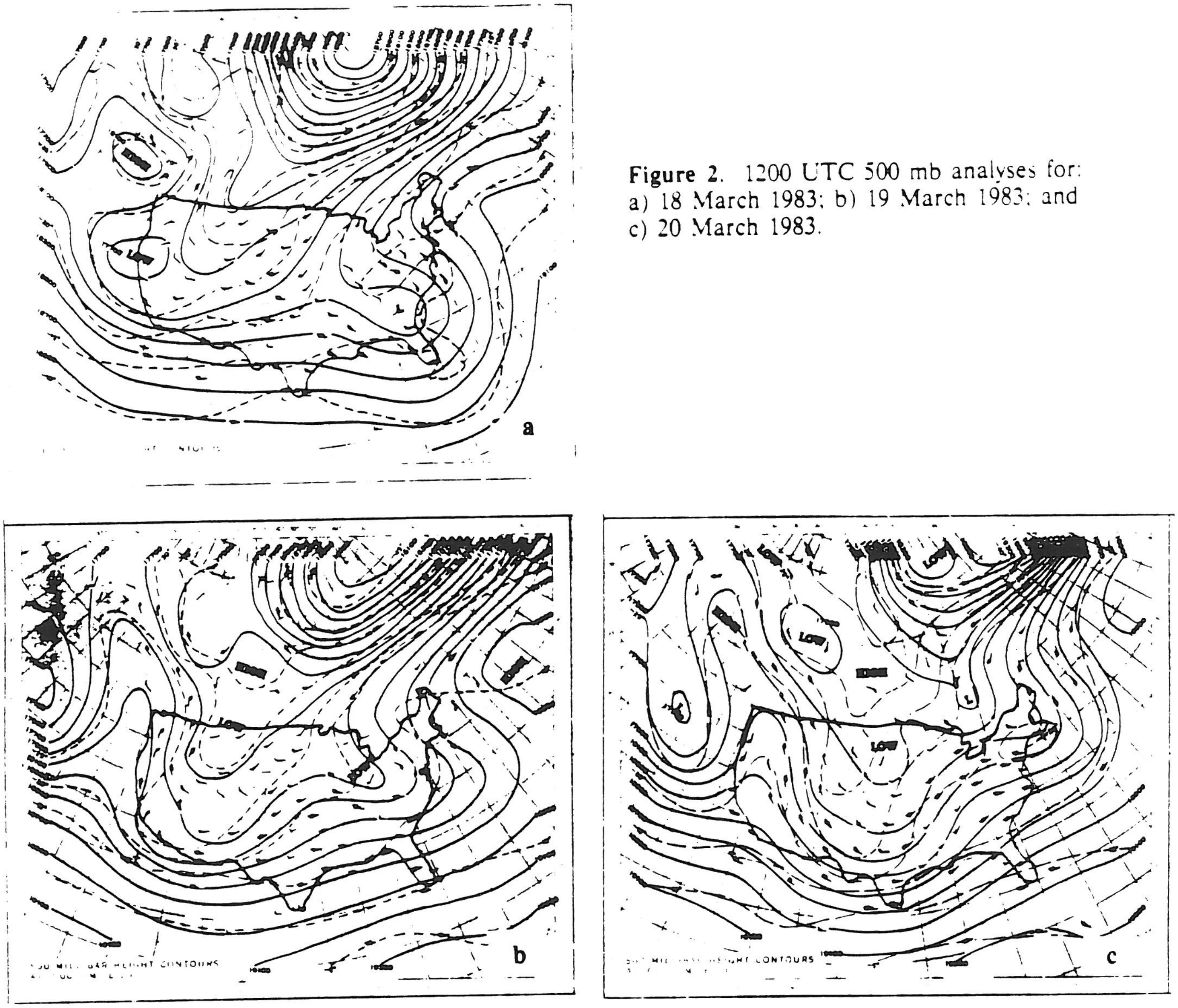

Figure 2. 1200 UTC 500 mb analyses for: a) 18 March 1983; b) 19 March 1983; and c) 20 March 1983.

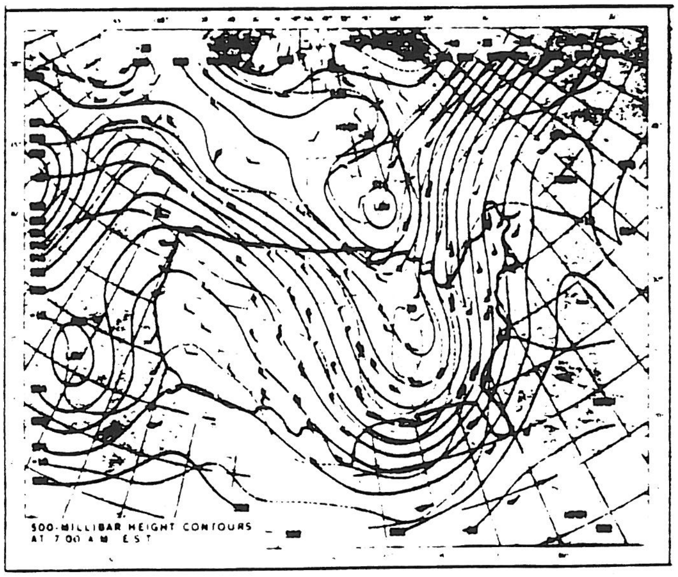

Figure 3. 1200 UTC 500 mb analysis for 31 March 1987.

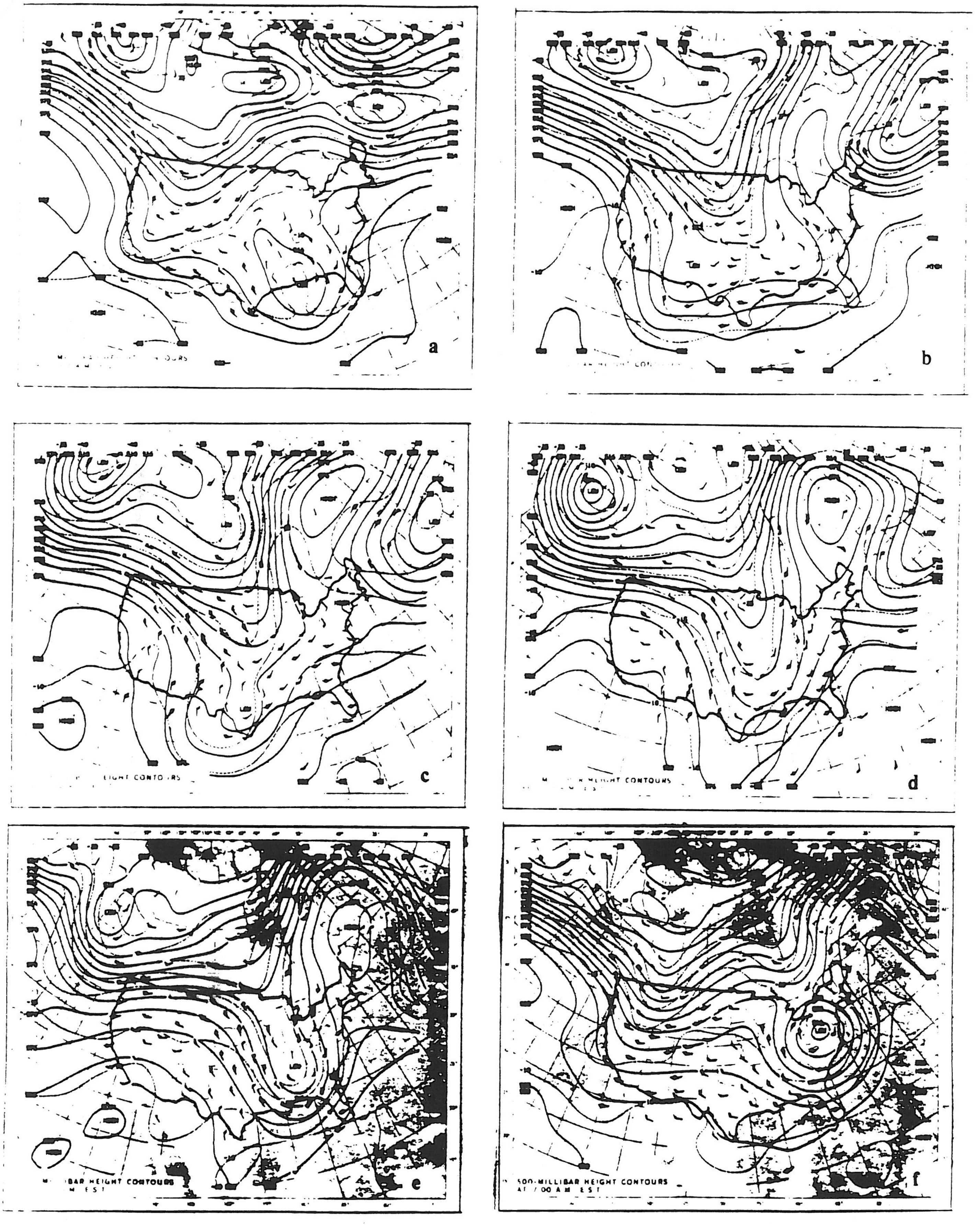

Figure 4. 1200 UTC 500 mb analysis for: a) 31 October 1985; b) 1 November 1985; c) 2 November 1985; d) 3 November 1985; e) 4 November 1985; f) 5 November 1985.

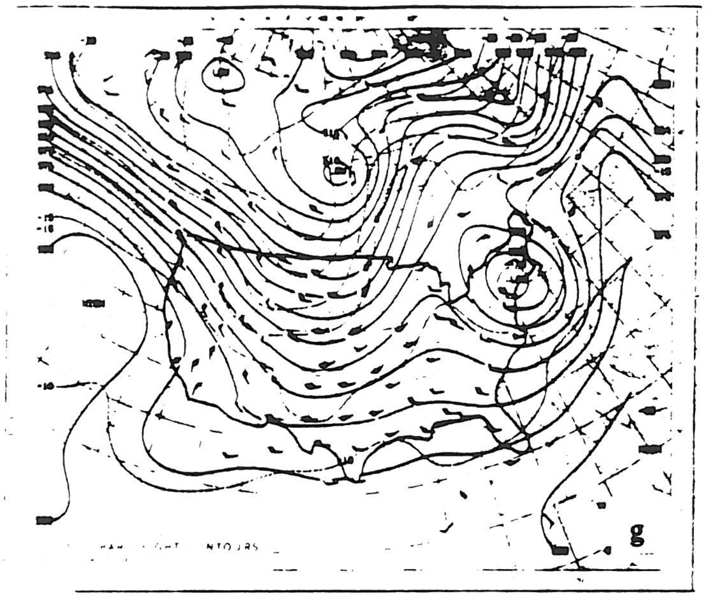

Figure 4 (continued). 1200 UTC 500 mb analysis for: g) 6 November 1985.

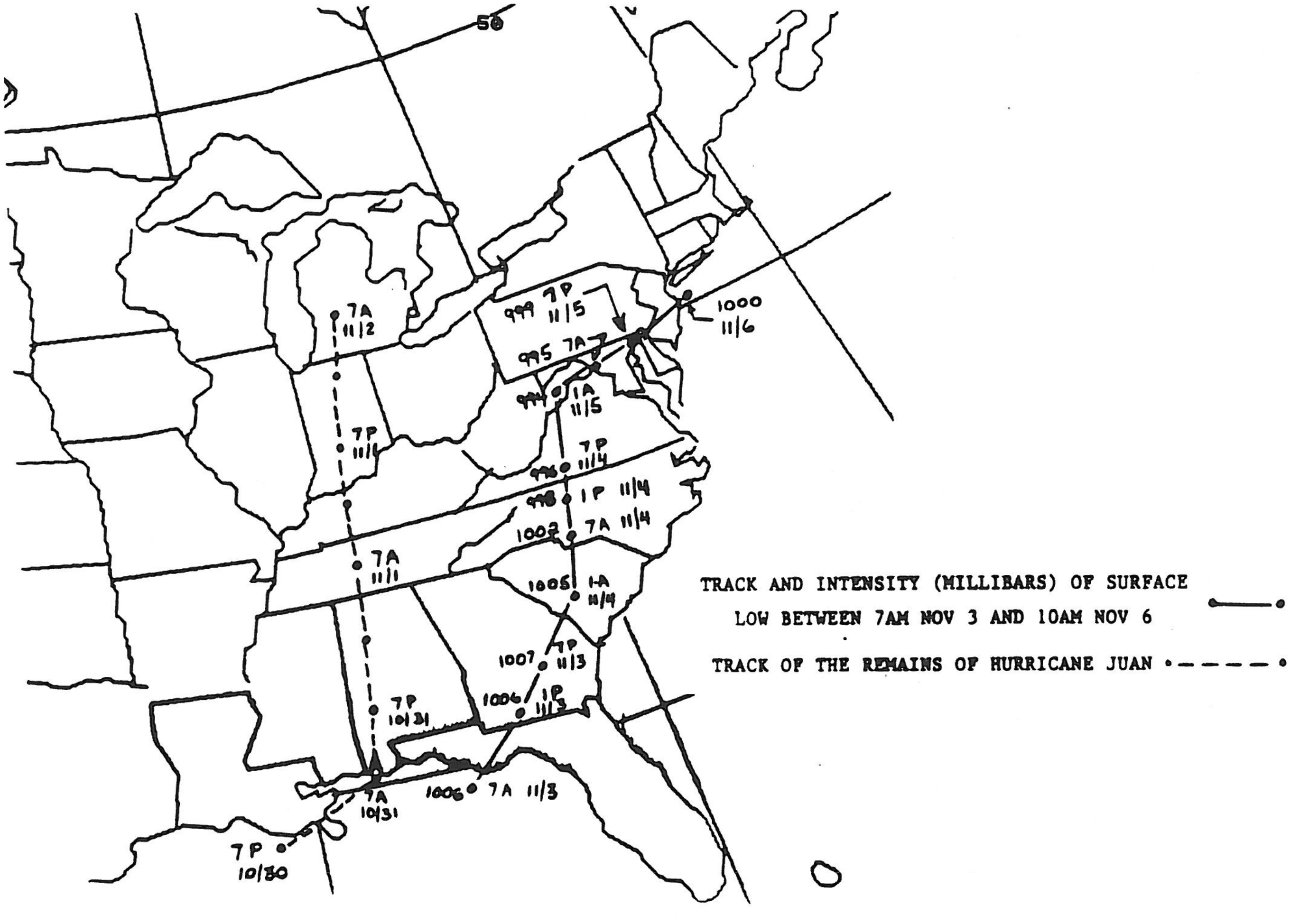

Figure 5. Track of Tropical Storm Juan (dashed), and extratropical surface low (solid) from 30 October 1985 to 6 November 1985.

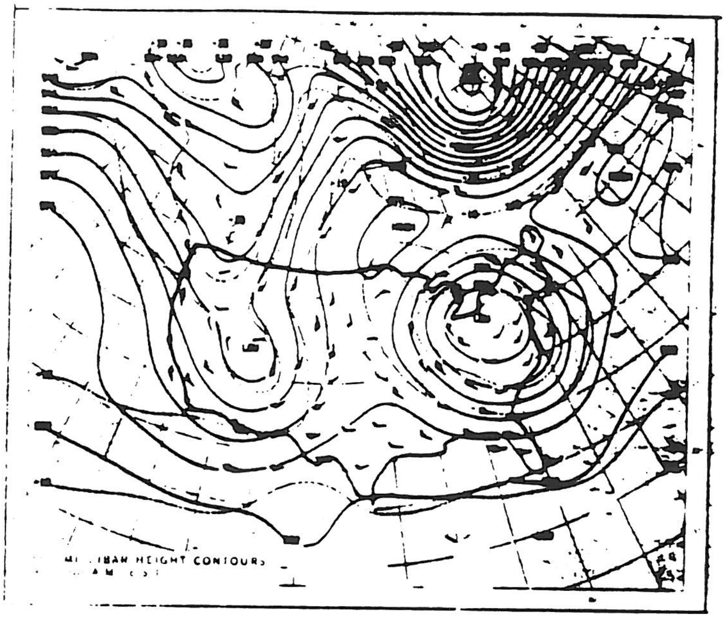

Figure 6. 1200 UTC 500 mb analysis for 12 May 1989.

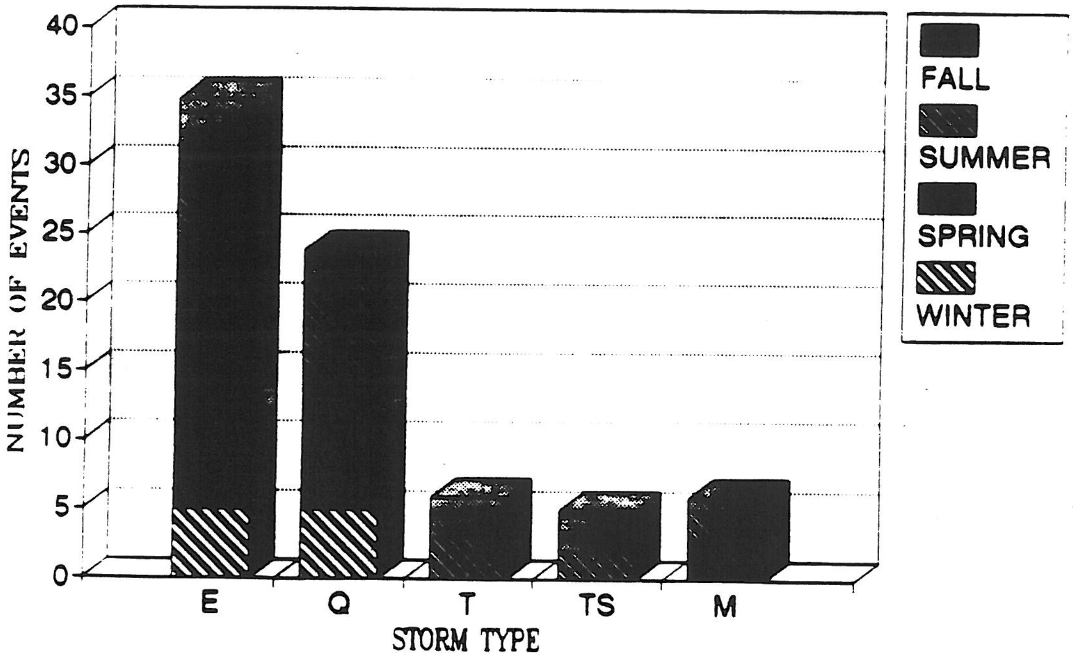

Figure 7. Number of flood events in the NWS ER during 1980-89 by type and season. Each event is classified by synoptic type and may include several states.

	URBAN	RURAL
A Minor	Urban flooding; street flooding; minor flooding; basement flooding.	Minor flooding; very heavy rains noted but no damage reported. (This class may not be very significant in rural areas).
B Light Damage	Small stream flooding; low lying areas flooded; light damage to homes, businesses, and buildings.	Lowland flooding; swollen creeks; mud slide/rock slides; light erosion/crop damage; roadway flooding; basement flooding.
C Heavy Damage	Evacuations; heavy damage to property; numerous roads washed out.	Serious erosion; considerable crop damage, fields flooded; houses, buildings damaged; livestock lost; bridges and roadways washed out; evacuations.
D Extreme	Extreme damage - approaching millions in monetary losses; buildings destroyed; hundreds evacuated; numerous deaths/ injuries.	Thousands of acres washed away; homes destroyed; widespread devastation.

Table 1. Classification of flood events by degree of flooding (from Crysler et al. 1980).

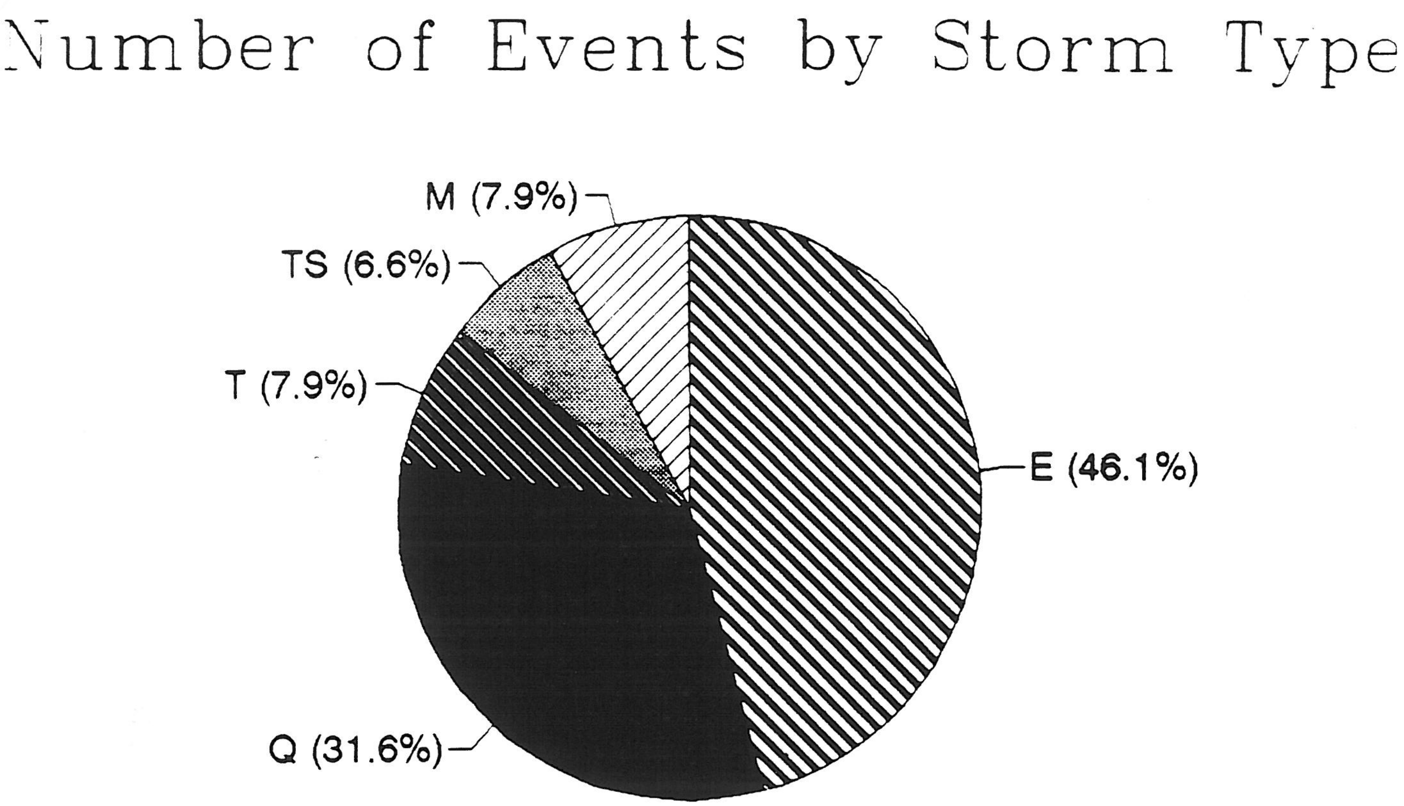

Figure 8. Percent of flood events by synoptic type.

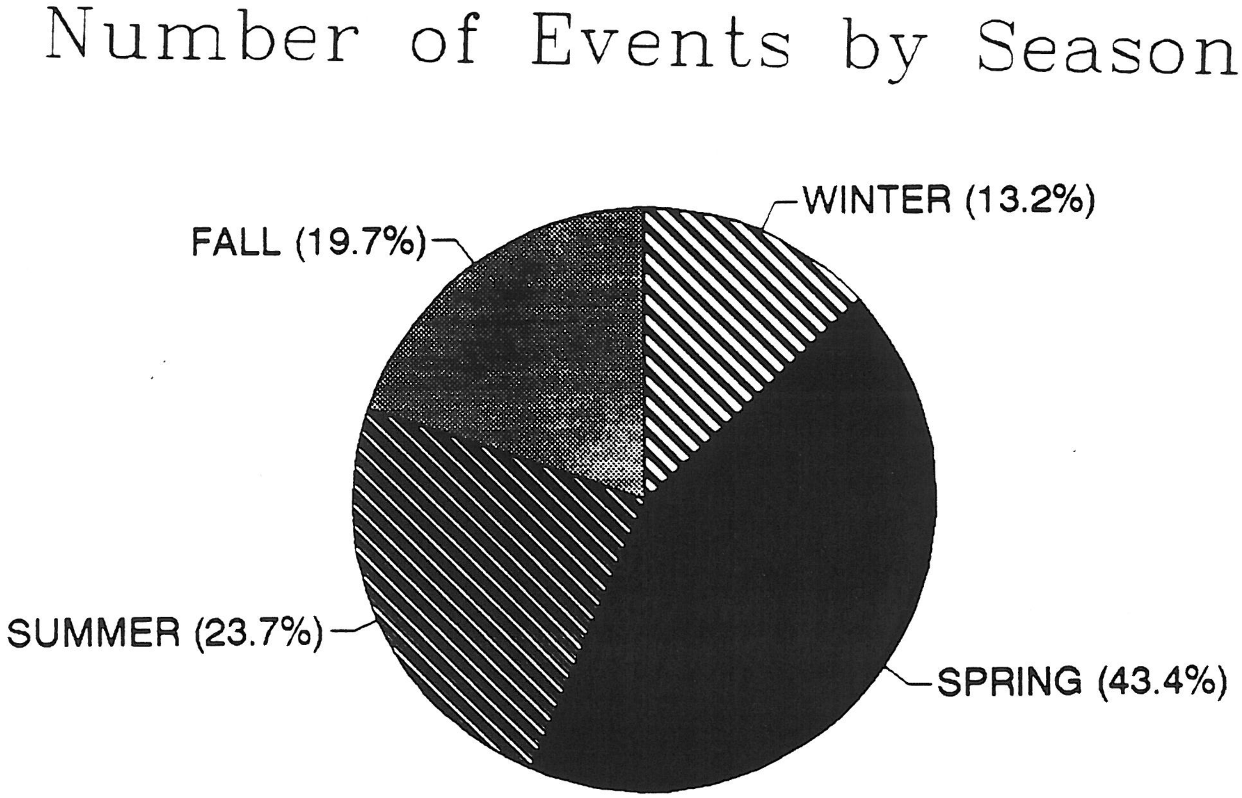

Figure 9. Percent of flood events by season.

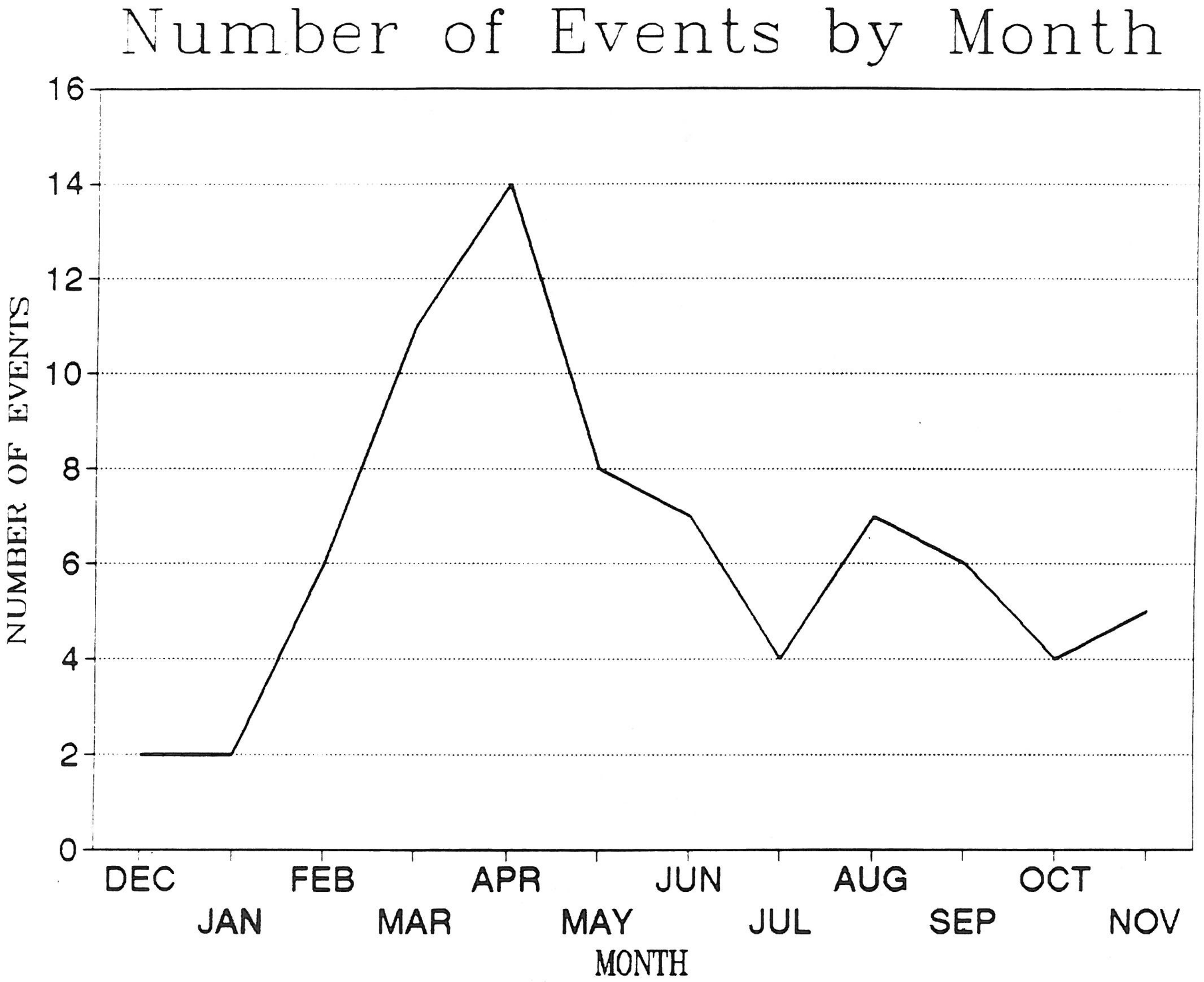

Figure 10. Number of flood events by month.

		Number of Events			
State	Winter	Spring	Summer	Fall	Total
Connecticut	0	10	4	2	16
Delaware	1	1	1	1	4
Maine	1	9	1	1	12
Maryland	4	6	5	3	18
Massachusetts	1	5	4	3	13
New Hampshire	3	7	1	2	13
New Jersey	1	6	2	4	13
New York	4	13	5	6	28
North Carolina	0	5	7	6	18
Ohio	0	2	1	3	6
Pennsylvania	5	8	6	5	24
Rhode Island	1	4	2	0	7
South Carolina	2	5	5	6	18
Vermont	0	4	1	1	6
Virginia	1	8	5	7	21
West Virginia	0	4	1	1	6
Washington DC	2	1	1	1	5

Table 2. Number of flood events for every state in the NWS ER for the period 1980-1989. The total exceeds the 76 synoptic flood events since more than one state could have been impacted by any given flood event.

		Number of Events			
State	Type E	Type Q	Type T	Type TS	Type M
Connecticut	9	6	0	1	0
Delaware	2	0	1	1	0
Maine	6	5	0	0	1
Maryland	5	8	2	2	1
Massachusetts	7	5	0	1	0
New Hampshire	8	4	0	1	0
New Jersey	6	4	1	1	1
New York	13	10	2	2	1
North Carolina	4	5	7	1	1
Ohio	2	2	1	1	0
Pennsylvania	8	11	1	3	1
Rhode Island	5	2	0	0	0
South Carolina	6	3	6	1	2
Vermont	3	3	0	0	0
Virginia	8	6	4	2	1
West Virginia	2	1	0	1	2
Washington DC	1	3	0	1	0

Table 3. Same as Table 1 except for different types of flood events for each state.