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CLIMATOLOGY OF STORM DATA EVENTS FOR THE NWS MOUNT HOLLY FORECAST AREA

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ABSTRACT

Storm-related and other significant weather events in the National Weather Service Mount Holly forecast area, mainly during the period from 1993 to early 2014, have been examined to determine temporal and spatial patterns of their occurrence. Cool-season events include winter storms, heavy snow and ice storms, as well as less severe events such as "winter weather" and dense fog. Related phenomena that occur entirely or mainly during the cool season, such as high winds, extreme cold and coastal flooding, are also covered. Warm-season events include severe thunderstorms (damaging winds and large hail), tornadoes, flash floods, lightning damage, excessive heat and drought. Numerous graphs are presented to show the frequency of events by year, month, time of day and areas (counties) affected. These results should provide a better understanding of the likelihood and distribution of significant weather events in the region served by the Mount Holly National Weather Service Forecast Office.

1. Introduction

Forecasters at the National Weather Service (NWS) Forecast Office in Mount Holly, NJ (WFO PHI) are responsible for issuing watches, warnings, and advisories for many types of potentially hazardous weather phenomena that can occur within their geographic area of responsibility. The decision to issue a warning or related product is usually based on several factors, including recent observations, numerical or statistical guidance, and the forecaster's own professional experience. Of course, this experience is gained over a number of years and can vary considerably from one forecaster to another. This study is motivated in part by the belief that a good knowledge of the climatology of one's forecast area can at least partially compensate for the lack of experience, e.g., for a forecaster new to the area.

Climatological records in the NWS tend to focus on normals and extremes in temperatures and precipitation amounts. However, standardized records of many other weather phenomena have been maintained since the mid-1990s by the National Centers for Environmental Data (NCEI). Although climatological normals are typically based on a 30-year period of record, this study's somewhat shorter period (generally 21 years) should be sufficient to derive some useful information about the temporal and spatial distribution of significant weather events within the WFO PHI forecast area. At WFO PHI, Storm Data records have been produced primarily by one dedicated individual since 1994, and the quality of these records is believed to be consistently high.

The WFO PHI forecast area covers 34 counties in New Jersey, eastern Pennsylvania, Delaware, and northeast Maryland, as shown in Fig. 1. Elevation ranges from sea level along the New Jersey and Delaware coasts and the shores of Delaware and Chesapeake Bays to around 2000 feet MSL in the Pocono Mountains of Carbon and Monroe Counties in Pennsylvania. Approximately the southeastern half of the area is a rather flat coastal plain, while the northwestern half consists of rolling piedmont hills rising up to the mountains in the far northwest. These two regions are separated by the Fall Line which runs from northeast New Jersey southwestward across northwest Philadelphia and into the northeast corner of Maryland (see Fig. 1).

It should be noted that the WFO PHI forecast area took its present form in 1995 as part of the NWS modernization and restructuring program during the 1990s. Prior to 1995 the forecast area included the eastern half of Pennsylvania and the southern half of New Jersey, but did not include northern New Jersey or any part of Delaware or Maryland. However, all records used for this study correspond to the current forecast area.

The next section of this document (Data and Methodology) will describe the data sources, quality control and analysis methods used in this study. The following section (Results) will describe overall results from the study, followed by results for specific Storm Data phenomena; first those that occur primarily in the cool season and then those mainly associated with warm weather. The final section will summarize conclusions from the study.

2. Data and Methodology

2.1 Data Sources

The National Centers for Environmental Information (NCEI; formerly the National Climatic Data Center, NCDC) of the National Oceanic and Atmospheric Administration (NOAA) maintain a Storm Events Database of significant weather events in the United States. The database includes records of 48 types of events as defined by NWS directive (National Weather Service 2007) from 1996 to the present. In addition, records of severe thunderstorm winds and large hail extend back to 1955, and tornado records go back to 1950. Event data and descriptions are submitted monthly by local NWS field offices for their area of responsibility, to be included in the NWS *Storm Data* publication as well as the Storm Events database. This database is available online at http://www.ncdc.noaa.gov/stormevents/.

All available storm events within the WFO PHI forecast area from January 1950 through March 2014 were downloaded from the above NCDC web site. To supplement the data beyond convective severe weather, additional reports from local hard-copy Storm Data records for 1993-95 were added to form a 21-year database of multiple event types, containing well over 33,000 records. Cool season events generally begin in late 1993 and continue through March 2014, while most warm season events include the calendar years 1993 through 2013.

Although records of severe convective events extend back to the 1950's, only records from 1984 onward were used for damaging winds and hail. This provided an even 30-year period of record for those events. Also, a significant increase in those reports within the study area was noted in the mid- to late-1980s, after the NWS began a local storm warning verification program in 1979 (Pearson and David 1979). This increase in the 1980s was also noted in other parts of the U.S. by Hales (1987). For tornadoes, although the quality of some early reports is suspect, the full record back to 1950 was used owing to the combined rarity and significance of those events.

2.2 Quality Control

Since the early to mid-1990s there have been numerous changes to the way Storm Data events are reported. Also, different software has been used over time for data entry and formatting. One of the main issues with the data record is the changes in allowable event types over the years; the current list of 48 events types was established only in 2007 (National Weather Service 2005). For example, prior to 2003 there are numerous entries for "Snow", "Wintry Mix" and "Freezing Rain", but from 2003 onwards these were all listed as "Winter Weather". For this study, different types of winter weather prior to 2003 were similarly combined. As another example, no coastal flood events were reported from December 2002 through October 2005; instead they were reported as "Astronomical High Tide". Many other previously allowed event types have been eliminated, such as "Unseasonably Warm", "Below Normal Precipitation", "First Snow", etc.; none of these were included in the current study.

Of the 48 types of storm events, the following 12 types which occur exclusively or predominantly during the cool season (roughly November through March) were chosen for more detailed analysis: winter storm, heavy snow, ice storm, blizzard, winter weather, extreme cold, wind chill, high wind, strong wind, coastal flood, astronomical low tide (blowout tide) and dense fog. Certain cool-season events such as freezing fog, lake-effect snow and sleet were excluded because they are very rare or non-existent in the WFO PHI forecast area. Eleven predominantly warm-season types were also chosen: thunderstorm wind, large hail, lightning, tornadoes, funnel cloud, flash flood, flood, heavy rain, drought, wildfire and excessive heat. Hurricanes, waterspouts, rip currents and other marine and tropical phenomena were excluded due to the very limited number of reports available. Table 1 shows the events selected, their predominant season, period of record for each event type, and total number of events.

A few reports from the database were identified as duplicates; certain others lacked a time stamp. After screening for incomplete record periods and missing data elements, and removing event types deemed to be of lesser significance or too infrequent for valid results, about 28,600 records were retained for further analysis.

2.3 Data Analysis

Storm Data events are designated as either zone based or county based (see Table 1). Zone-based events are mainly the more widespread cool-season events such as winter storms, coastal flooding, etc., while county-based events are localized, mainly warm-season events such as damaging thunderstorm winds, flash floods, etc. On any given day, the maximum number of zone-based verifications, i.e., events, is limited by the number of zones (actually counties in this study; see below), but there is no such limit for county-based events since there can be multiple events in one or more counties.

In the WFO PHI forecast area, forecast zones boundaries mostly correspond to counties, except for certain counties that are split into two separate zones. The five NJ and DE Atlantic Coastal counties are each divided into an inland section and a relatively narrow strip along the immediate coastal area. These five coastal zones have been in place for the entire period of this study. Four other inland counties (Burlington in NJ and Chester, Montgomery and Bucks in PA) are split into two zones, but these splits occurred during the study period. For the best overall consistency in this study, all Storm Data events, whether zone-based or county-based, are located by county rather than zone. This may result in the loss of some information in the immediate coastal areas.

Records for each event type were stratified by year, month, hour (mainly for shorter-duration local events) and location by county. From these results, the number and percentage of event-days per month was computed, as well as the frequency distribution of event days according to the number of events per day. Analysis of the data was done using several locally-written BASIC computer programs and standard spreadsheet software. The latter was also used to create tables and graphs for each weather event type. Maps of event distributions by county were created using the web-based GPS Visualizer program [http://www.gpsvisualizer.com].

3. Results

3.1 General Results

The most numerous event types in the WFO PHI area (Fig. 2) were excessive heat, followed by damaging thunderstorm winds, winter weather (below warning criteria), and strong non-convective winds. Most events types showed considerable year-to-year variability (see individual descriptions below), while combined events (Fig. 3) showed less variability but perhaps a gradual rising trend.

The graph of all events by month (Fig. 4a) shows a bi-modal distribution with peaks in mid-summer and mid-winter. July had the most events, mainly excessive heat, while October had the least. Figures 4b and 4c show the monthly distributions of combined cool and warm season events, respectively. The most frequent cool-season events are winter weather (below winter storm criteria) and strong winds (below high wind criteria). The most frequent warm-season events are excessive heat and damaging thunderstorm winds.

Convectively driven events such as hail and flash floods showed a strong seasonal and diurnal signal, while most cool-season events showed strong seasonal but much weaker diurnal signals. Winter weather/storm events increased from south to north as expected, while convectively driven events were more evenly distributed across the study area.

Figure 5 shows the distribution of all events by county across the WFO PHI area. There does not seem to be any naturally based pattern to the distribution, although there are such patterns for many specific event types, as will be shown below. This distribution may be explained partly by county area and population, which may affect county-based event types but not zone-based events. Note the higher number of events for counties around Philadelphia, and the lower number for the sparsely populated Maryland Eastern Shore. Burlington County, NJ, has the greatest number of events (1213) and it is also the location of WFO PHI, which suggests that proximity to the weather office might also be a factor.

3.2 Cool Season Events

3.2.1 Winter Storms

For purposes of Storm Data, the term "winter storm" refers to an event where there are hazards from multiple precipitation types, including snow, sleet and freezing rain (National Weather Service 2007). If precipitation is all snow, then a heavy snow event may be recorded; if all freezing rain, an ice storm. The combined total amount must exceed predefined warning thresholds, which may vary from one part of the forecast area to another. There is a degree of subjectivity in determining whether mixed precipitation exceeds the criteria, especially if significant sleet is involved, since there is no formal warning criterion for sleet and no local criterion is used at WFO PHI.

A total of 1342 winter storm events occurred during the study period. Figures 6a through 6e show the distribution of events by year, month, event size and area. The number of events per season varies from less than 10 in 2001-02 and 2011-12 to over 100 in 1993-94, 2000-01 and 2002-03 (Fig. 6a). They can occur any time from late October through early April, but are most frequent during February (Fig. 6b). However, Fig. 6c shows the chance of a winter storm event somewhere in the forecast area is about the same (just under 8 percent) in both January and February. Comparing Figs. 6b and 6c shows that February has 491/47 = 10.5 events (counties affected) per storm day on average, while January has 346/50 = 6.9 events per day, so February winter storm days tend to be somewhat more widespread. Overall, the distribution of winter storm "size", or number of counties affected, ranges from one county to the maximum of 34 counties in the WFO PHI forecast area (Fig. 6d). However, most storm days affect four counties or less. The frequency of winter storm events decreases sharply from north to south across the area (Fig. 6e), as would be expected from both latitude and elevation.

3.2.2 Heavy Snow

As mentioned above, a heavy snow event is a winter storm in which the hazard is due to snow only, with snow exceeding specific thresholds. For the WFO PHI forecast area, the thresholds vary depending on location: either 4 or 6 inches in 12 hours, or either 6 or 8 inches in 24 hours. The lower values apply to areas mainly south of Philadelphia with higher values to the north.

A total of 823 heavy snow events occurred during the study period, indicating that pure snow events occur at about three-fifths the rate of mixed precipitation events. Figures 7a to 7e show the distribution of heavy snow events by year, month, etc. The annual variation (Fig. 7a) is again quite large. Heavy snow events can occur from October through April (Fig. 7b), but are most common in February. February also retains a slight edge in the number of heavy snow days per month (Fig. 7c). Most heavy snow days have five or less events (Fig. 7d); however, "big" days with more than 20 events account for more than half of all heavy snow events. The geographic distribution (Fig. 7e) shows that heavy snow frequency varies by about a factor of three from north to south across the WFO PHI forecast area.

3.2.3 Ice Storms

Ice storms involve ice accretion on trees and power lines as the primary hazard. To qualify as an ice storm the accretion must exceed a locally-defined threshold. For the WFO PHI forecast area during the study period, this threshold was generally ¼ inch of ice. However, starting with the winter of 2008-09 the threshold was raised to ½ inch for the seven northernmost counties.

There were a total of 147 ice storm events during the study period; they are somewhat rare compared to heavy snow or mixed precipitation type events. Of this total, about half occurred during the winter of 1993-94 (Fig. 8a). Several years had no events. The ice storm "season" is confined to November through March (Fig. 8b), with January having the most events by a considerable margin. January also has the most ice storm days. (These results are likely somewhat skewed by the one dominant winter noted above.) Ice storm days tend to cover smaller regions within the forecast area (Fig. 8d); with one exception, they all affected less than 10 counties. Geographic distribution is shown in Fig. 8e, indicating the vast majority of ice storm events occur north and west of Philadelphia. This could be due to the increased likelihood of milder oceanic air moving inland across the coastal plain.

3.2.4 Blizzards

A blizzard is a type of winter event defined in terms of wind speed and visibility. Specifically, a blizzard event requires "…(1) sustained winds or frequent gusts 30 kts (35 mph) or greater, and (2) falling and/or blowing snow reducing visibility frequently to less than 1/4 mile…", which last for at least three hours (National Weather Service 2007). Blizzards are quite rare in the WFO PHI forecast area: during the study period there were only five blizzard days, affecting a total of 56 counties. All the blizzards occurred during the period December through March. Because of the rarity, detailed plots of blizzard distributions are not likely meaningful and are not shown.

However, blizzard events are included in the combined winter storm section below.

3.2.5 Combined Winter-Storm Verifying Events

Figures 9a through 9e show the distributions of all 2368 "winter storm" type events combined, including heavy snow, ice storms and blizzards. Results for this combination are presented primarily for comparison with the combined "winter weather" events in the following section. There is a great deal of inter-annual variability in overall winter "storminess", but no clear trend towards increasing or decreasing. Except for ice storms in the 1993-94 season, these combined totals are dominated by winter storm events (mixed precipitation-type) and heavy snow events. February is the overall stormiest month (Fig. 9b) although, again, January has somewhat more days with at least one winter-storm type event. For both months, about 1 in 7.5 days has at least one event (Fig. 9c).

The distributions by event size (Fig. 9d) and by county (Fig. 9e) are consistent with results already shown; i.e., most days with winter-storm type events only have a few, and there is about a four-fold increase from south to north in the frequency of events. The number of events for Burlington County, NJ (81) seems slightly high compared to surrounding counties, but this could be partly explained by the relatively large area of the county, or perhaps the location of the WFO PHI forecast office in that county.

3.2.6 Combined Winter Weather Events

There is a secondary class of winter precipitation events which fall in the category of "winter weather". These are events not severe enough to verify a winter storm warning, but still able to pose a significant hazard, and would verify a winter weather advisory in the zones/counties where they occur. Prior to 2003 these events were classified as "snow", "freezing rain" or a "wintry mix", but subsequently they have been merged into the single "winter weather" category.

In the WFO PHI forecast area, the local criteria for a winter weather advisory vary somewhat from north to south. Generally, locations north of Philadelphia require at least three inches of snow in 12 hours, while locations south require at least two inches. A trace or more of freezing rain verifies an advisory anywhere.

During the period of study there were a total of 3866 winter weather events, or about two-thirds again as many as the combined winter storm events. The distributions of winter weather events are shown in Fig. 10a through Fig. 10e. There seems to be somewhat less inter-annual variability with winter weather versus winter storms (Fig. 10a). Aside from the variability, there also appears to be an overall increase in the number of events per year, whereas no such trend was noted for winter storms. The reason for this is not clear; one possible explanation is increasing societal sensitivity to smaller or less severe winter events.

Figure 10b shows the monthly distribution of winter weather events. January has the most events followed by February and December, in contrast with winter storm events which are most favored in February. The same pattern holds as well for winter weather days with at least one event (Fig. 10c), but such days occur at about the rate of 1 in 5 for both January and February. Figure 10d shows a pattern similar to Fig. 9d for winter storms, but is slightly less skewed toward the low end. In both cases the chance of a day with 14 or less events is about the same (50 percent) as the chance of a day with 15 or more. Finally, the areal distribution of winter weather events (Fig. 10e) is similar to winter storms, with a three- to four-fold increase from Delmarva northward to the Pennsylvania Pocono Mountains.

3.2.7 Extreme Cold

Extreme cold events are characterized by a wind chill temperature at or below certain locally defined threshold values which depend on the climatology of a particular region. For the WFO PHI forecast area, the wind chill threshold is -25°F. An extreme cold event verifies a wind chill warning for that time and area.

Distributions of extreme cold events are depicted in Figs. 11a through 11e. These events are somewhat rare, averaging slightly less than 20 per winter season. Many years had no events at all (Fig. 11a). January is by far the dominant month, containing over two-thirds (69 percent) of all events (Fig. 11b) and 14 of 20 total extreme cold days (Fig. 11c) during the period of study. When extreme cold occurs it often affects all 34 counties (Fig. 11d). Events are rather evenly distributed across the forecast area (Fig. 11e) with inland areas slightly favored.

3.2.8 Wind Chill

Less extreme cold events are designated as "wind chill" events. These correspond to wind chill advisories rather than warnings, and the WFO PHI advisory threshold varies from -15°F in the north to -10°F central and south. Wind chill events have been recorded only since 2006 or less than half the period of study, with 236 occurrences compared to over 400 extreme cold events. Therefore, for the most part, detailed wind chill results are not included here. However, it can be noted that the monthly distribution is similar to extreme cold, while the geographic distribution shows more of a south to north gradient. Also, there was only one wind chill day affecting the entire forecast area; most days affected only a few counties.

3.2.9 High Wind

High wind events are defined as "Sustained non-convective winds of 40 mph or greater lasting for 1 hour or longer or winds (sustained or gusts) of 58 mph for any duration…" (National Weather Service 2007). In practice for the WFO PHI area it is almost always the wind gusts that meet or exceed criteria. Expectation of these conditions would warrant issuance of a High Wind Warning. Current Storm Data rules state that high wind events should not include convective storms or tropical cyclones; however some past hurricanes have generated high wind entries (National Weather Service 2007).

Figures 12a through 12e show the distribution of high wind events for the WFO PHI area. There is considerable variability from year to year (Fig. 12a) with the 1995-96 winter season standing out for its large number of events. Being non-convective, these high winds are primarily a cool season phenomenon (Fig. 12b), occurring mostly from November through March, but also as early as September or as late as June. However, most of the September events are due to hurricanes Floyd (1999) and Isabel (2003). The number of high wind days (Fig. 12c) shows an approximately even distribution from November through March. Most high wind days have relatively few events (Fig. 12d); 115 of the 142 days have 6 events or fewer. The geographic distribution (Fig. 12e) shows high wind events most common over coastal section of New Jersey and Delaware, and generally decreasing farther inland. There is no apparent increase over the higher terrain of Carbon and Monroe counties in Pennsylvania (18 and 15 events, respectively) as one might expect. Certain areas of the Maryland Eastern Shore seem to suffer from a lack of reports.

3.2.10 Strong Wind

Strong wind events are similar to high winds but less severe. The criteria are sustained winds of 25 to 39 mph or wind gust of 46 to 57 mph. When these conditions are expected, a wind advisory would normally be issued for the affected area.

A total of 3375 strong wind events occurred during the study period, or about 4.5 times the number of high wind events. This ratio would be somewhat higher except that almost no strong wind events were recorded for the years 1993-1996. Figures 13a through 13e show the distribution of strong wind events; overall they are similar to high wind events. Figure 13a shows somewhat less year to year variation than Fig. 12a. The cool season dominance remains (Fig. 13b) although these events have occurred in all months. The distribution of strong wind days is somewhat smoother, perhaps due simply to the larger sample size. The proportion of days with several strong wind events, e.g., more than six, is significantly greater than for high winds (compare Fig. 13d with Fig. 12d). The geographic distribution again favors the Atlantic Coast as well as the western shore of Delaware Bay.

3.2.11 Coastal Floods

Coastal flooding occurs when waters along the ocean shore, bay shore or other tidal areas rise above normal levels due to meteorological effects (primarily wind) and flood adjacent coastal land areas. In Storm Data coastal flooding is classified as minor, moderate or severe. Within the WFO PHI area, coastal or tidal flooding can occur along the Atlantic coast, the shores of Delaware and Chesapeake Bays, and along the tidal portion of the Delaware River as far upstream as Trenton, NJ. This means that

22 of 34 counties in the study area are vulnerable to, and have experienced, coastal flooding under suitable conditions.

Figures 14a to 14e show the distributions of 769 coastal flood events during the period of study. The year-to-year variation (Fig. 14a) ranges from no events in the 1994-95 season to 111 events in 2006-07 (July to June). These events are generally more frequent during the cooler and transitional months (Fig. 14b), as they are often associated with East Coast extra-tropical cyclones, or "nor'easters". The high value for October and the low value for February are likely just random variations due to limited sample size. (October does include numerous reports from post-tropical storm Sandy.) Fig. 14c shows a similar pattern for coastal flood days, except that March is just slightly behind October. This results from March having more coastal flood days with events affecting just one to three counties. Overall, about half of all coastal-flood days have three events or less (Fig. 14d). The geographic distribution in Fig. 14e shows coastal flooding most frequent along the New Jersey Atlantic shore (except northernmost Monmouth County), followed by Delaware Bay and the lower (tidal) Delaware River. Tidal flooding is much less frequent along the upper eastern shore of Chesapeake Bay.

3.2.12 Blowout Tides

Abnormally low or "blowout" tides occur when strong, sustained northwest winds blow water out of the lower Delaware River, Delaware Bay and the back bays along the New Jersey and Delaware coast. This often occurs on the "back side" of a strong nor'easter. The resulting low water levels are a hazard to marine navigation, especially small boats in normally shallow water. The same 22 counties that experience tidal flooding have also experienced blowout tides, except for Mercer County, NJ, with no blowout tide reports during the study period.

Figures 15a to 15e show the distributions for 236 blowout tide events. These events were not recorded in Storm Data before 2007 (Fig. 15a) but have occurred every year since. During that same period (2007-2014) there were 220 coastal flood events, suggesting the two types occur with about equal frequency. The monthly frequency rises steadily through the winter months (Fig. 15b) but falls sharply in the spring; thus blowouts are much more confined to the cool season than coastal floods. Blowout tide days show a very similar pattern (Fig. 15c) with February having the most days by a wide margin. Details of these distributions should not be taken too literally owing to the rather small sample size. Blowout days do seem to affect more counties at once; compare Fig. 15d with 14d. The geographic distribution of blowout tides is also quite different from coastal flooding, with blowouts most common along the lower Delaware River and Delaware Bay rather than the Atlantic Coast (Fig. 15e).

3.2.13 Dense Fog

Fog is considered to be "dense" when it reduces visibility to one-quarter mile or less. For Storm Data records there is the additional requirement that it must significantly impact transportation or commerce (National Weather Service 2007). Therefore the results presented here should not be interpreted as a general fog climatology, since they may be skewed towards times and areas of increased traffic or other commercial activity.

The distribution of dense fog events is shown in Figs. 16a to 16f. The inter-annual distribution (Fig. 16a) is quite variable, ranging from zero events in some years to a maximum of 128 events from July 1999 to June 2000. Figure 16b shows the distribution of events by month, with 514 out of the 592 total (87 percent) occurring during the months of November through February. The monthly distribution of dense fog days, with at least one event (Fig. 16c), is similar but shifted to slightly earlier in the cool season. Half of all dense fog days affected eight counties or less (Fig. 16d) but there were several days with events in all 34 counties. Fig. 16e shows the distribution of starting hours for all events, which may typically continue for several hours. Dense fog in the WFO PHI area is mostly a nocturnal phenomenon, especially considering the longer nighttime period during the cool season. Finally, dense fog events are well distributed throughout this study area (Fig. 16f), with perhaps some preference for the Wilmington-Philadelphia-Trenton urban corridor.

3.3 Warm Season Events

3.3.1 Thunderstorm Winds

Measured wind gusts of 50 kts or greater associated with thunderstorms are considered severe and are routinely entered into Storm Data. However, in most cases the actual wind speed is not known and the severe wind report is based on damage to trees and power lines or other serious property damage. These reports may include downbursts and gustnadoes as well. Thunderstorm winds are distinguished from high winds (section 3.2.9) by their association with deep convection and (usually) lightning.

Figures 17a through 17f show the distribution of thunderstorm wind events within the WFO PHI study area. As noted earlier, records of these events actually extend back to 1955, but only those from 1984 onward were used in this study. The year-to-year graph (Fig. 17a) shows considerable variability but with a definite trend towards more reports. Some of this increase is likely due to non-meteorological factors such as increasing population, better communications, more aggressive verification, etc. The monthly distribution (Fig. 17b) shows a preference for early- to mid-summer (June, July) with a decrease into August and especially into September. On average, about one in every five days (~20 percent) of June and July has at least one severe wind report (Fig. 17c). However convective wind events can occur in all months of the year. These events can also occur any time of day or night (Fig. 17d), but are most frequent from late afternoon through early evening. Over half (464 of 842) of thunderstorm wind days had three or less reports (Fig. 17e), but about one in five was a "big" day with 10 or more reports. The geographic distribution in Fig. 17f does not show a clear pattern, although larger counties by area tend to have more events. About half of the county-to-county variability can be explained by county size alone.

3.3.2 Large Hail

Large hail events with hail diameter of 0.75 inch or greater are routinely entered into Storm Data, although hail of smaller diameter is also allowed under some circumstances. For this study, only hail greater than 0.75 inch diameter was considered. For most of the study period, 0.75 inch was the lower limit for "severe" hail, i.e., verifying a severe thunderstorm warning. In January 2010 the threshold for damaging hail was raised to 1 inch (http://www.nws.noaa.gov/oneinchhail/); however, hail reports of 0.75 inch or greater continued to be entered in Storm Data.

As with thunderstorm winds, the hail records extend back to 1955, but only those from 1984 on were included here. During this time there were 1180 hail events with hail diameter greater than 0.75 inch, or about one-quarter the number of wind reports during the same period. Removing hail with diameters less than one inch reduces this number by about half to 546 (546/1180 = 0.463).

The distribution of hail events is shown in Figs. 18a through 18f. The number of events has shown an overall increase over the study period (Fig. 18a) but especially since 2005. The reason for this is not clear except for possible factors mentioned above in regard to thunderstorm winds. Large hail frequency seems to peak in June (Fig. 18b), somewhat earlier than winds, and almost vanishes during the winter months. However, the number of *days* with large hail actually peaks in July (Fig. 18c). The diurnal distribution of hail (Fig. 18d) is quite similar to thunderstorm winds, with a strong peak in the late afternoon/early evening. Most hail days have only one or two events (Fig. 18e) and there are fewer "big" days (compared to wind events) especially for one-inch or larger hail size. The geographic distribution of large hail (1.00 inch or greater) again appears somewhat random (Fig. 18f), although there are clearly fewer reports from Delmarva and southernmost New Jersey.

3.3.3 Lightning

Thousands of cloud-to-ground lightning strikes occur over the United States on many days during the warmer months of the year. However, only those resulting in deaths, injuries or damage are included in Storm Data reports. So as with dense fog, the results here should not be taken as a general lightning climatology. Figures 19a through 19f show the distribution of these events over the WFO PHI study area.

There has been an overall increase in the number of annual lightning events since 1993 (Fig. 19a). However the two biggest years were 2000 and 2001, and since then the annual number has generally been steady in or near the 40 to 60 event range. Lightning events by month (Fig. 19b) show a steady increase from March through August, followed by a precipitous drop in September and October with rapid loss of solar heating. July and August are essentially tied for most lightning event days (Fig. 19c) with an average of about one event every six days. Lightning is closely tied to the convective heating cycle (Fig. 19d), showing a broad diurnal maximum from mid through late afternoon. The great majority of days with lightning events had three or less events (Fig. 19e), but a handful of days had 10 or more. The geographic distribution (Fig. 19f) shows no clear pattern, but the fact that the three counties with the most events are all on the Atlantic coast may indicate increased vulnerability to lightning in that area.

3.3.4 Tornadoes

A tornado is "A violently rotating column of air, extending to or from a cumuliform cloud, or underneath a cumuliform cloud, to the ground…" (NWSI 10-1605). "Landspouts" and cold-air funnels are also classified as tornadoes in Storm Data if they reach the ground. However, waterspouts, funnel clouds and dust devils are considered as separate event types. So-called "gustnadoes" are considered to be thunderstorm wind events. Only actual tornadoes are considered in this study owing to the rarity of the other event types mentioned above.

In the Storm Event database the tornado record extends back to 1950, a few years before the start of the thunderstorm wind and hail record. A few of the tornadoes from the 1950s and 1960s have suspiciously long tracks (e.g., the width of New Jersey) unlike anything in more recent years. However, it was decided to use the entire record since tornadoes are relatively rare but significant events.

Figures 20a through 20g show the distribution of tornado events in the WFO PHI study area. The number of tornadoes per year seems to increase through the early- to mid-1990s and then decrease thereafter (Fig. 20a). There is no obvious physical cause for such a trend however, so it is likely just a random fluctuation. Tornado frequency is greatest in July by a wide margin (Fig. 20b), although tornadoes have been reported in every month except December. Interestingly, the month of November has had more tornadoes than October (20 vs. 19 events, including 11 on November 16, 1989), and also more tornado days (14 vs. 10). November also showed an increase in thunderstorm wind events (Fig. 17b) suggesting a possible weak secondary maximum of severe weather in November. As with other convectively driven weather, tornadoes are most frequent from mid-afternoon through early evening (Fig. 20d) although they have occurred at all hours. The great majority of tornadoes (265/349 = 75.9 percent) fall into the "weak" EF0 and EF1 categories (Fig. 20e), while the remainder are mostly EF2s. EF3 tornadoes are very rare, and no EF4 or EF5 tornado has yet been reported in the WFO PHI area. The geographic distribution (Fig. 20f) appears to show an axis of higher frequency from southeast Pennsylvania southward through Delaware. However, this axis essentially disappears after county size is accounted for (Fig. 20g). Finally, out of 231 tornado days total, three-quarters of them produced only one tornado, and 95 percent produced three or less (graph not shown).

3.3.5 Funnel Clouds

Funnel clouds often occur under conditions that may also produce tornadoes. However by definition a funnel cloud does not reach the ground and cannot cause direct death or injury on the ground. Available funnel cloud records for Storm Data go back only to the early 1990s, but the total number of reports from 1993 through 2013 is similar to that for tornadoes (104 vs 115, respectively). The monthly, hourly, etc., distributions of funnel cloud reports are fairly similar to those for tornadoes. Because of their relative insignificance, rarity and short record length (compared to tornadoes), the distribution graphs for funnel clouds are omitted here.

3.3.6 Flash Flood

A flash flood is a type of flooding characterized by rapid rise in water level such that it poses a particular threat to life as well as property. For Storm Data, a flash flood is generally one that occurs within six hours of the causative event (heavy rain, dam failure, etc.). However, the distinction between flooding and flash flooding is not always clear, so the preparer of Storm Data must sometimes rely on professional judgement to distinguish one from the other.

The distribution of flash floods in the WFO PHI area is shown in Figs. 21a through 21f. There is some suggestion of an upward trend (Fig. 21a), especially considering that the "biggest" year (1996) was unusual with over half of events occurring during the cool season (October through March). Due to changes in criteria, some of those cool season events might now be considered floods rather than flash floods. Most flash floods occur during the warm season when convective rain is dominant (Fig. 21b), especially August followed by July, June and September. These four months account for 901 of the 1157 total events, or about 78 percent. Flash flood days are far more likely in June, July and August than other months (Fig. 21c). Flash floods can occur any time day or night, but are most frequent from mid-afternoon through early evening (Fig. 21d). This diurnal pattern is similar to other convectively driven events, but the afternoon/evening maximum is not quite as pronounced. Most days with flash flooding have only one or two events, with a few exceptions (Fig. 21e). Flash flooding is most frequent over southeast Pennsylvania and adjacent northern Delaware (Fig. 21f), while mostly flat terrain along with sandy soil limits the frequency of flash flooding over the Delmarva peninsula and southern New Jersey. It should be noted that certain small streams are particularly prone to flash flooding, e.g., the Christina River at Coochs' Bridge in northern New Castle County, Delaware, which partly accounts for the high frequency there.

3.3.7 Flood

In the most general sense, a flood is any inundation by water of a normally dry area;

but for Storm Data it must also pose a threat to life and property. Floods, including river floods, involve a slower rise in water level compared to *flash* floods, and the time delay is generally more than six hours after the causative event.

It is interesting to compare the distribution of flash floods with those for floods; the latter are shown in Figs. 22a through 22f. Over the period of study there were roughly equal numbers of events (1239 flood vs. 1157 flash flood). The distribution by year (Fig. 22a) again suggests an increase with time. Floods events are more or less evenly distributed throughout the year (Fig. 22b; compare Fig. 21b). Although classified as such in this study (Table 1), it could be argued that these slower-acting floods are not really warm-season events since they are most frequent in March and December. The distribution of flood days by month (Fig. 22c; compare Fig. 21c) also shows a fairly random pattern. The start times for flood events seem to be rather evenly spread around the diurnal cycle (Fig. 22d; compare Fig. 21d). The distribution of flood days by number of flood events is also quite similar to that for flash floods (Fig. 22e; compare Fig. 21e). Finally the geographic distribution of floods (Fig. 22f) is similar to flash floods, except there is a secondary maximum over northern New Jersey in Morris and Somerset Counties. This is due primarily to frequent flooding of the Raritan, Passaic, Millstone and other rivers that flow through this area.

3.3.8 Heavy Rain

A heavy rain event is defined as one not associated with a flash flood or flood, but causing some kind of damage or other economic impact (National Weather Service 2007). In the WFO PHI Storm Data records, heavy rain events seem to be connected mainly with urban or poor draining flooding, and thus are of lesser significance than floods or flash floods. The total number of heavy rain events (1221) is similar to that for floods, and the event distributions are also similar and are not shown here. An exception is the geographic distribution (Fig. 22g) which shows a relatively greater proportion of events over the coastal plain of southern NJ and the Delmarva region. It is generally more difficult for heavy rain to produce a flood in that area given the flat terrain and sandy soil.

3.3.9 Drought

Drought is defined as an extended period of deficient precipitation resulting in crop damage or other adverse impacts on people or livestock. The current version of *Storm Data* instructions (National Weather Service 2007) states that drought events should be included for areas classified as D2 or higher in the United States Drought Monitor (http://droughtmonitor.unl.edu/); however in prior years drought conditions have been determined by local criteria. Droughts typically persist for long periods of time, i.e., months, so for any specific zone or county there will be only one drought entry per month, as long as the drought continues. Thus the concept of a “drought day” does not apply; one should think of “drought months" instead when viewing the following figures.

Figures 23a through 23e show the distribution of drought events in the WFO PHI area. While many years had no drought conditions (Fig. 23a), the years 1999 and 2002 stand out as being especially dry. In particular, 2002 had drought conditions over almost the entire area during each month except December. Drought is most common or widespread during the late summer into early fall (Fig. 23b) and least likely during the spring. Almost half of all September months (9 of 21) during the study period have experienced some drought (Fig. 23c). Droughts tend to affect the same areas for several months at a time; the area can range from a few counties to the entire WFO PHI area (Fig. 23d), as in 2002. The geographic distribution (Fig. 23e) shows a great deal of homogeneity by state, likely because state governments often make the official drought declarations for their domains.

3.3.10 Wildfire

For purposes of Storm Data, a wildfire is considered to be a fire outside of urban areas that burns out of control for a period of time, and results in one or more fatalities or injuries, or causes damage to property. Generally speaking, smaller wildfires are not included in Storm Data, but the decision to include or not depends somewhat on the judgement of the person preparing the Storm Data entries.

Figures 24a through 24e show the distributions of wildfire events over the WFO PHI area. There is considerable variation from year to year (Fig. 24a), ranging from 32 events in 2012 to none in 2003 and some preceding years. Of course, "none" means no events were judged worthy of inclusion. There is a strong preference for the month of April (Fig. 24b) when stronger winds combine with stronger daytime heating to produce lower relative humidity, drier fuels and more favorable conditions for rapid wildfire spread. The months of March and April together account for over half of all significant wildfires (124 of 208 events). Those two months also include about half of the total 148 wildfire days (Fig. 24c). Figure 24d shows the distribution of starting times for wildfires, i.e., the time when the fire became out of control. (In many cases this is likely when the fire was first reported.) There is a decided preference for wildfires during the daytime hours, especially around mid-day. Geographically, wildfires occur most often in the "pinelands" of southern NJ (Fig. 24e), with a secondary maximum around the Pocono Mountains in northeast PA and adjacent northwest NJ. Wildfires tend to be fairly isolated events and the vast majority of wildfire days (115 of 148) involve only one county (graph not shown).

3.3.11 Excessive Heat

Excessive heat is defined as a condition where high temperature and humidity combine to pose a serious threat to human health. This combined effect is measured as a Heat Index. These conditions should normally be anticipated by an excessive heat watch and/or warning. A less extreme condition, designated simply as "Heat" would be anticipated by a heat advisory.

The WFO PHI area is unique in that special procedures for assessing heat risk in the Philadelphia metropolitan area were developed in the mid-1990s by Dr. Lawrence Kalkstein (Kalkstein et al. 1996) at the University of Delaware. These procedures have been modified over the years since but are still used for Philadelphia and nine surrounding counties. Otherwise, a heat index threshold of 110°F is used for upper Delmarva and southernmost New Jersey, while 105°F is used for areas farther north in New Jersey and Pennsylvania. Before 1996 the term "Heat Wave" was used instead of or along with "Excessive Heat". The specific definition of Heat Wave is not known for certain, but is probably related to the traditional criterion of three or more consecutive days with maximum temperature reaching or exceeding 90°F (American Meteorological Society 2016).

Excessive heat is the most frequent type of hazardous weather, i.e., Storm Data "worthy" event in the WFO PHI area (Fig. 1). This is partly because heat events tend to cover a large area and often last several days. For example, if excessive heat occurs in ten counties for three days, that would count as 30 excessive heat events.

The breakdown of excessive heat events in the WFO PHI area is shown in Figs. 25a to 25e. The number of events varies widely from year to year (Fig. 25a), from none in 2004 to almost a thousand in 2002, by far the greatest number. (Note 2002 was also the biggest drought year.) The monthly distribution (Fig. 25b) shows 98 percent of events occur in the months of June, July and August, with almost twice as many in the hottest month (July) as in the second hottest (August). This pattern holds for excessive heat days (Fig. 25c) with about 1 out of every 5 days in July experiencing excessive heat somewhere in the WFO PHI area. Excessive heat days may affect anywhere from one county to all 34 counties (Fig. 25d), but most days affect over half, and many have affected all 34. Excessive heat is most frequent in the urban heat island of Philadelphia (Fig. 25e) and least frequent in the higher elevations of the Pocono Mountains in northeast Pennsylvania.

4. Summary and Conclusions

This Technical Memorandum has described development of a climatology based on Storm Data events within the forecast area of the National Weather Service Forecast Office at Mount Holly, NJ. A total of 23 weather event types were examined, including 12 predominantly cool-season events and 11 predominantly warm-season events. The study area included 34 counties covering all or part of four states: New Jersey, Pennsylvania, Delaware and Maryland. The study period for most event types extended from January 1993 through March of 2014, or about 21 years. Exceptions were tornadoes, thunderstorm winds and large hail, for which a longer data record was available.

Perhaps the most surprising result from this study was the number of excessive heat or heat-wave events (just over 6000), which were by a wide margin the most frequently occurring Storm Data event. These heat events along with thunderstorm winds produced an overall event maximum in July, while winter weather and strong (non-convective) wind events produced a secondary maximum in January. Although most types of events showed a seasonal preference, a few such as areal/river flooding were more or less evenly distributed throughout the year.

Most cool season events did not show any diurnal preference, although high winds did seem to favor the daylight hours to some degree while fog was more frequent at night. On the other hand, and not unexpectedly, convectively driven events such as severe weather and flash flooding showed a strong diurnal signal with maximum frequency from mid- to late-afternoon into early evening. These convective events also showed some subtle differences in their warm-season distribution, with hail most frequent in June and flash flooding most frequent in August.

The distribution of winter storm and winter weather events across the study area showed an expected gradient from south to north, while extreme cold events were more evenly distributed and high and strong wind events showed a preference for coastal areas. Convectively driven events such as thunderstorm winds, hail and flash flooding were more randomly or evenly distributed, especially after accounting for county area.

The results of this study should provide useful background and familiarization for current and future forecasters in the WFO PHI forecast area. As part of the data analysis, many types of event-days have been identified and cataloged; these can be the basis for further climate studies, e.g., weather patterns associated with severe weather days of various magnitudes (number of events), or a comparison of the relative societal impacts of different kinds of events. The climatological frequency of events can serve as a basis for measuring forecast skill (improvement over climatology) for those events. Finally it is hoped that this study can serve as a model for local studies at other forecast offices that may wish to take advantage of the growing length of record in the Storm Event Database. Such studies could help identify similarities among and differences between neighboring forecast offices.

Acknowledgements

This work would not have been possible without the dedicated efforts of the WFO PHI staff over the years to collect and record information about significant weather events in our forecast area. Special credit goes to lead forecaster (now retired) Tony Gigi who served from 1994 to 2015 as Storm Data focal point. During that time he compiled an unusually thorough record of these events which will serve as a valuable source of information for many years to come. Also, Brent MacAloney of the NWS Performance and Evaluation Branch provided helpful information about the history of Storm Data methodology and criteria.

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TABLE AND FIGURES

Table 1. Storm Data event types included in this study.

Event Type	Predominant Season	County or Zone-based	Period of Records	Total # of Reports
Winter Storm	Cool	Zone	Oct 1993 to Mar 2014	1342
Heavy Snow	Cool	Zone	Oct 1993 to Mar 2014	823
Ice Storm	Cool	Zone	Oct 1993 to Mar 2014	147
Blizzard	Cool	Zone	Mar 1993* to Mar 2014	56
Winter Weather**	Cool	Zone	Oct 1994 to Mar 2014	3866
Extreme Cold	Cool	Zone	Oct 1993 to Mar 2014	405
Wind Chill	Cool	Zone	Jan 2005 to Mar 2014	236
High Wind	Cool	Zone	Oct 1993 to Mar 2014	754
Strong Wind	Cool	Zone	Oct 1993 to Mar 2014	3375
Coastal Flood	Cool	Zone	Aug 1993 to Mar 2014	769
Blowout Tide	Cool	Zone	Jan 2004 to Mar 2014	236
Dense Fog	Cool	Zone	Jan 1994 to Mar 2014	592
T-storm Wind	Warm	County	Jan 1984 to Dec 2013	4787
Large Hail***	Warm	County	Jan 1984 to Dec 2013	1180
Lightning	Warm	County	Apr 1993 to Dec 2013	972
Tornado	Warm	County	Jan 1950 to Dec 2013	349
Funnel Cloud	Warm	County	Apr 1993 to Dec 2013	104
Flash Flood	Warm	County	Apr 1993 to Dec 2013	1157
Flood	Warm	County	Apr 1993 to Dec 2013	1239
Heavy Rain	Warm	County	Jan 1996 to Dec 2013	1221
Drought	Warm	Zone	Sep 1993 to Dec 2013	1033
Wildfire	Warm	Zone	Jan 1994 to Dec 2013	208
Excessive Heat	Warm	Zone	Apr 1993 to Dec 2013	6008

* The March 1993 blizzard is included to enhance a sparse record.
** Winter weather includes snow, freezing rain and "wintry mix" before 2003.
*** Hail diameter ¾ inch or greater.

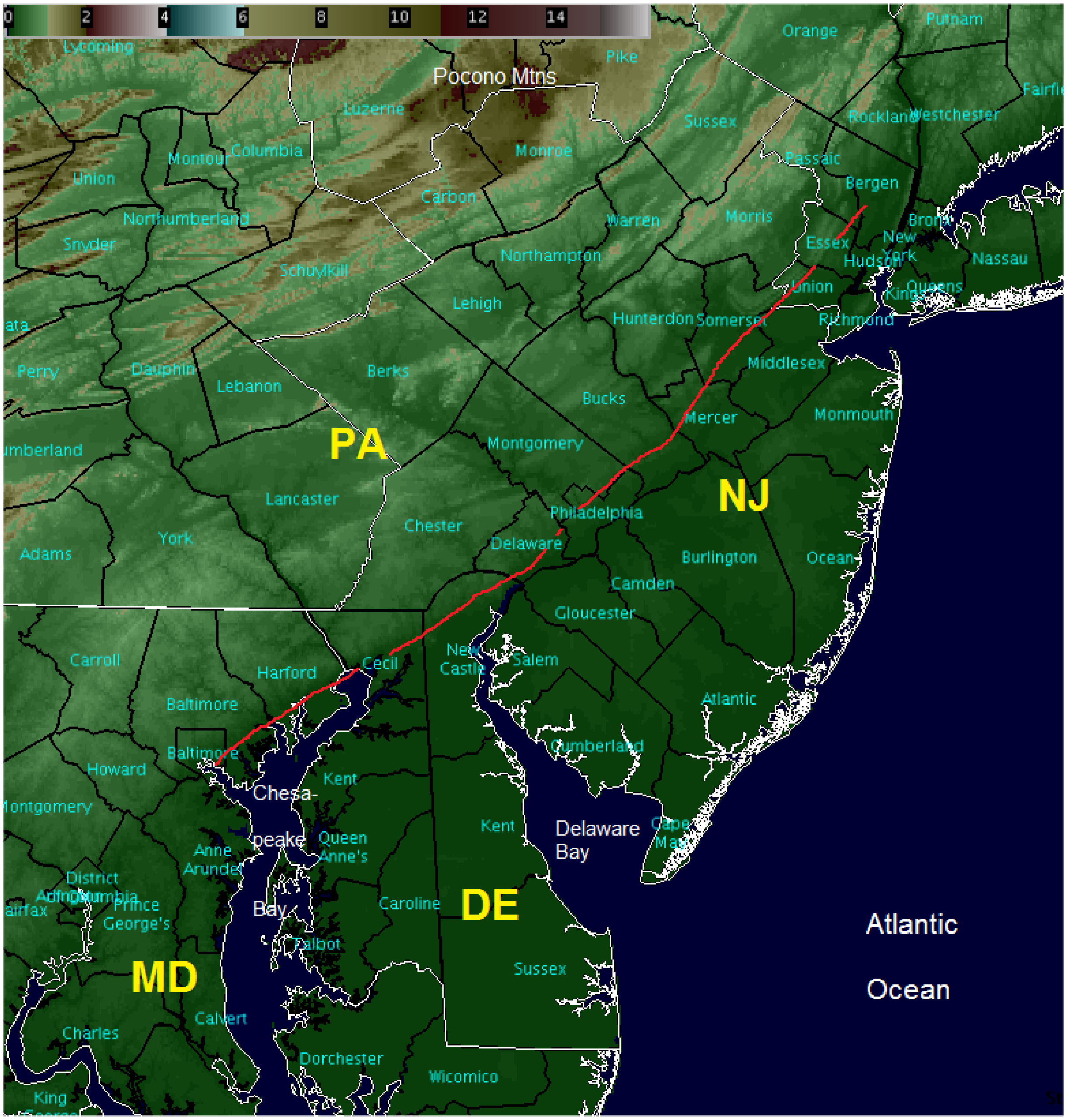

Figure 1. Political and geographic features in or near the WFO PHI forecast area. State abbreviations are yellow, county names are light blue, county boundaries are black and forecast area boundaries are thin white. A portion of the fall line (see text) is in red. The elevation scale at the top is in thousands of feet.

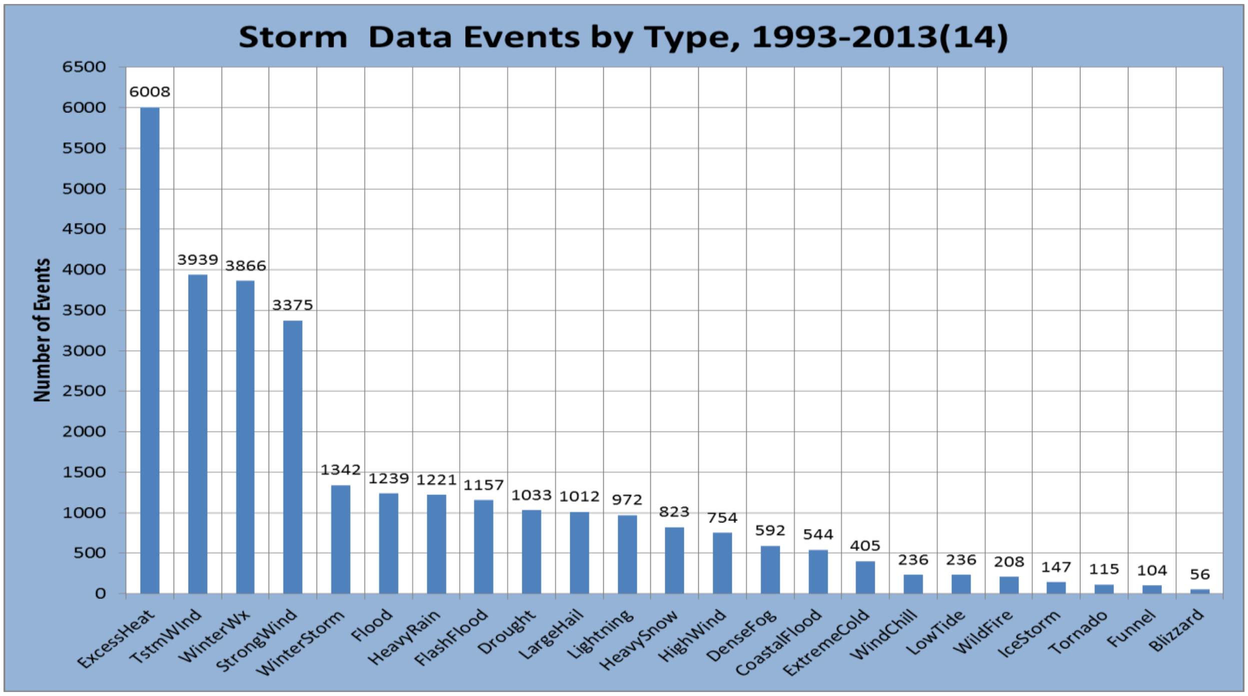

Figure 2. Distribution by event type of selected Storm Data events within the WFO PHI forecast area from 1993-2013(14). Note, thunderstorm winds, hail and tornadoes before 1993 are excluded here.

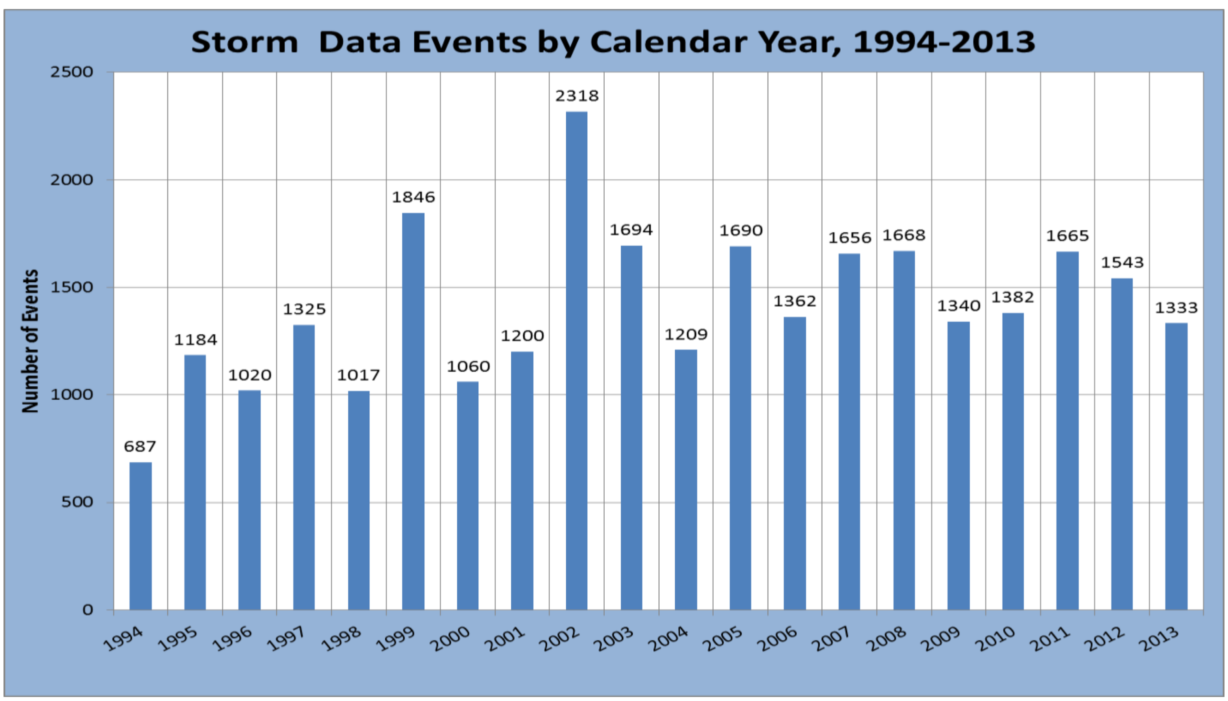

Figure 3. Storm Data events by year within the WFO PHI forecast area.

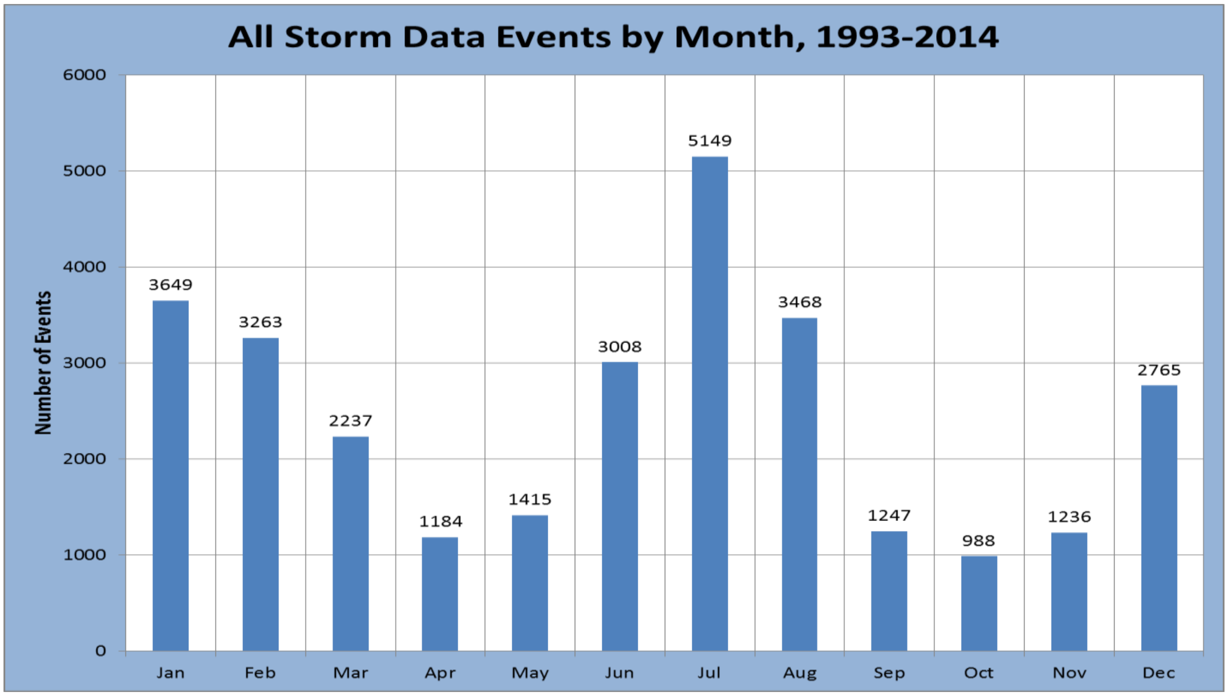

Figure 4a. All Storm Data events by month for the WFO PHI forecast area.

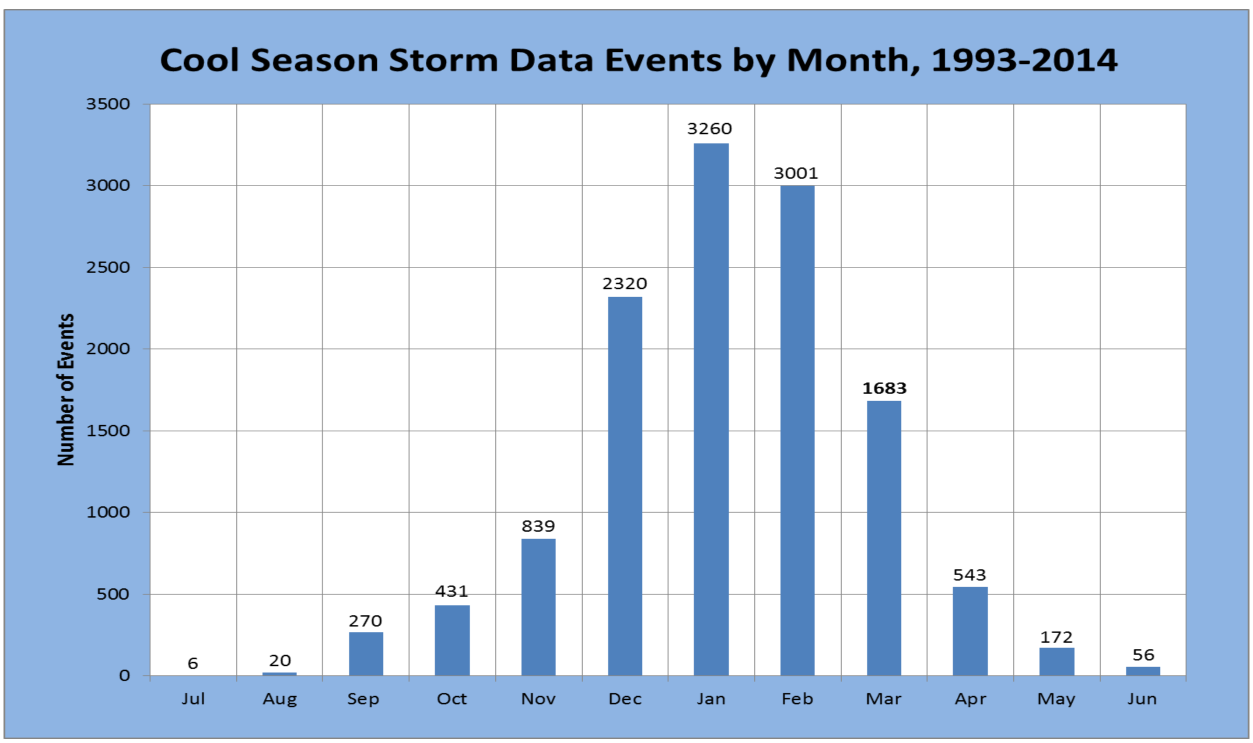

Figure 4b. Predominantly cool-season Storm Data events by month and event type. All monthly graphs for cool-season events are centered on December and January.

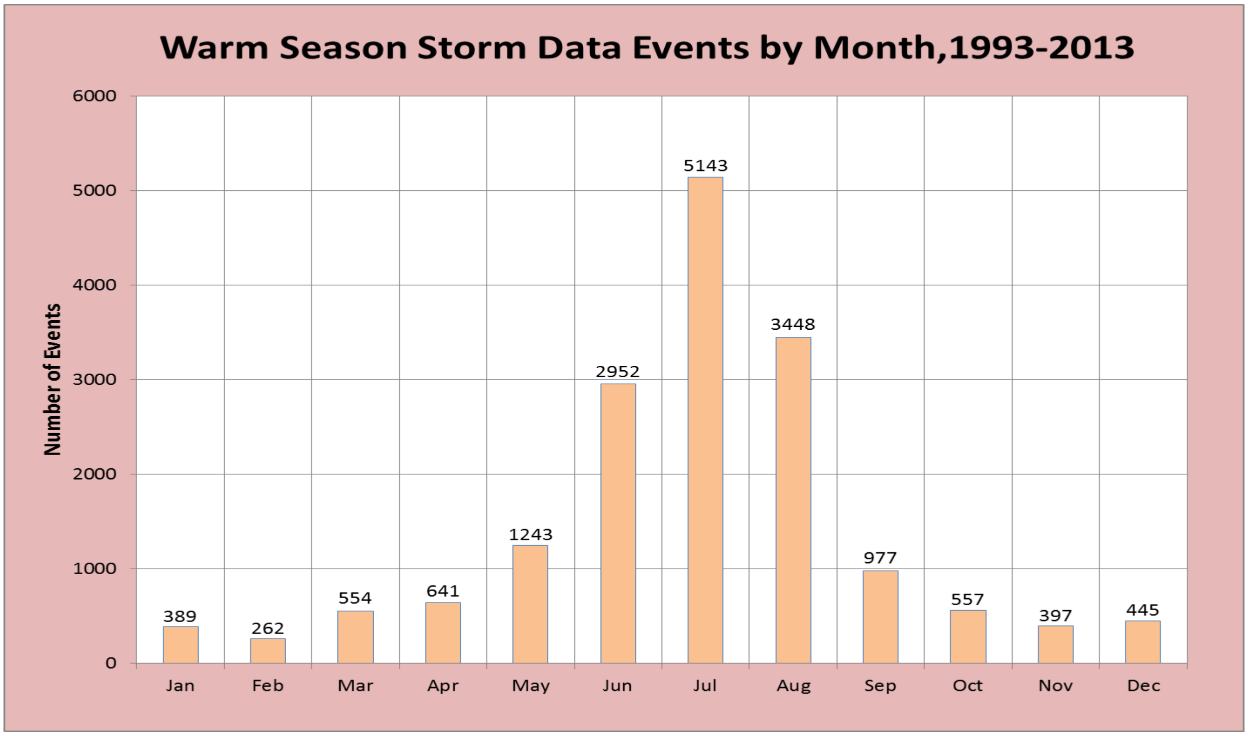

Figure 4c. As in Fig. 4b but for predominantly warm-season events. All monthly graphs for warm-season events are centered on June and July.

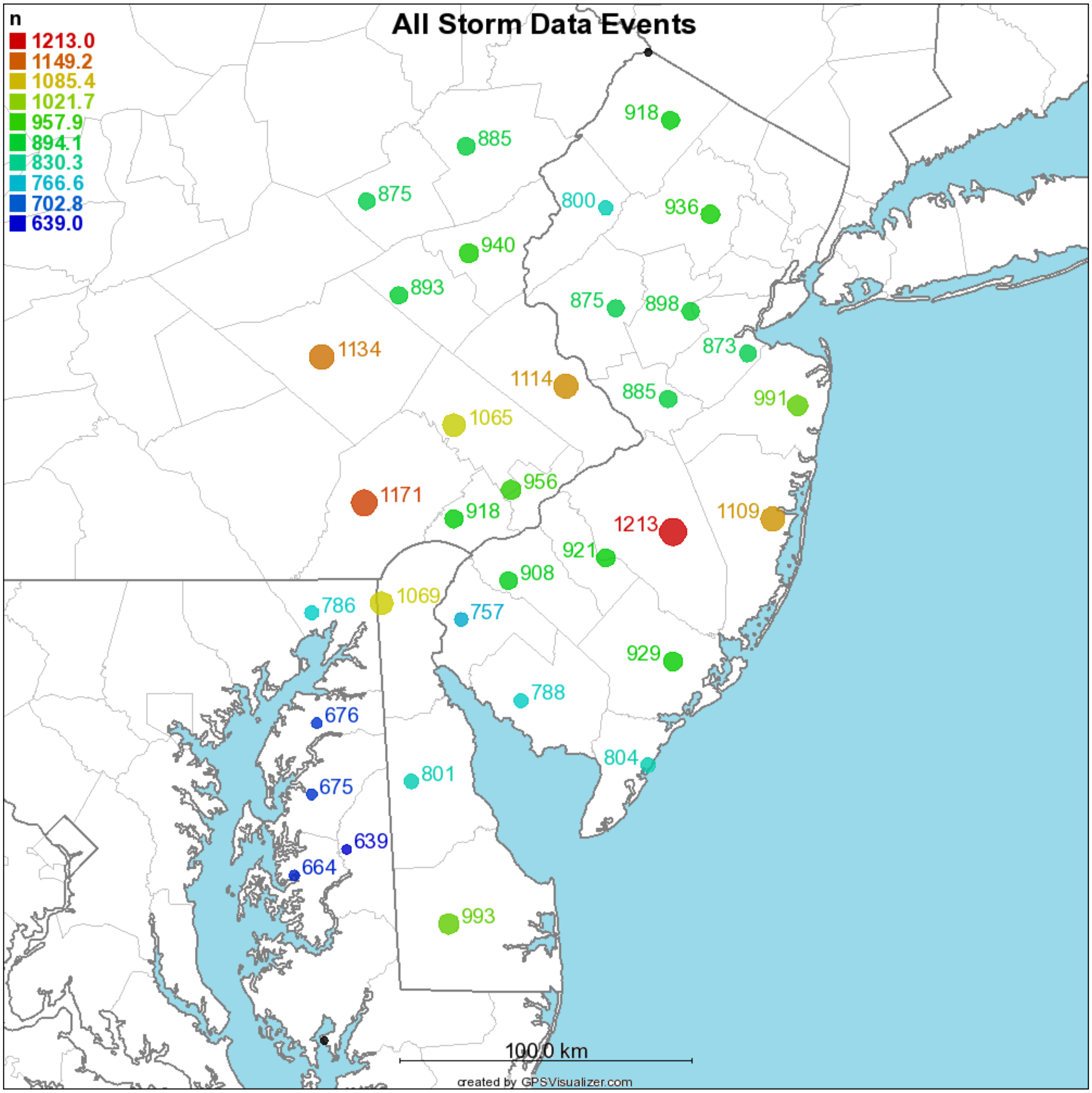

Figure 5. Distribution of combined Storm Data events over 34 counties in the WFO PHI forecast area. Size and color of each circle corresponds to the number of events in the county. This and following maps were created with GPS Visualizer web program (http://www.gpsvisualizer.com).

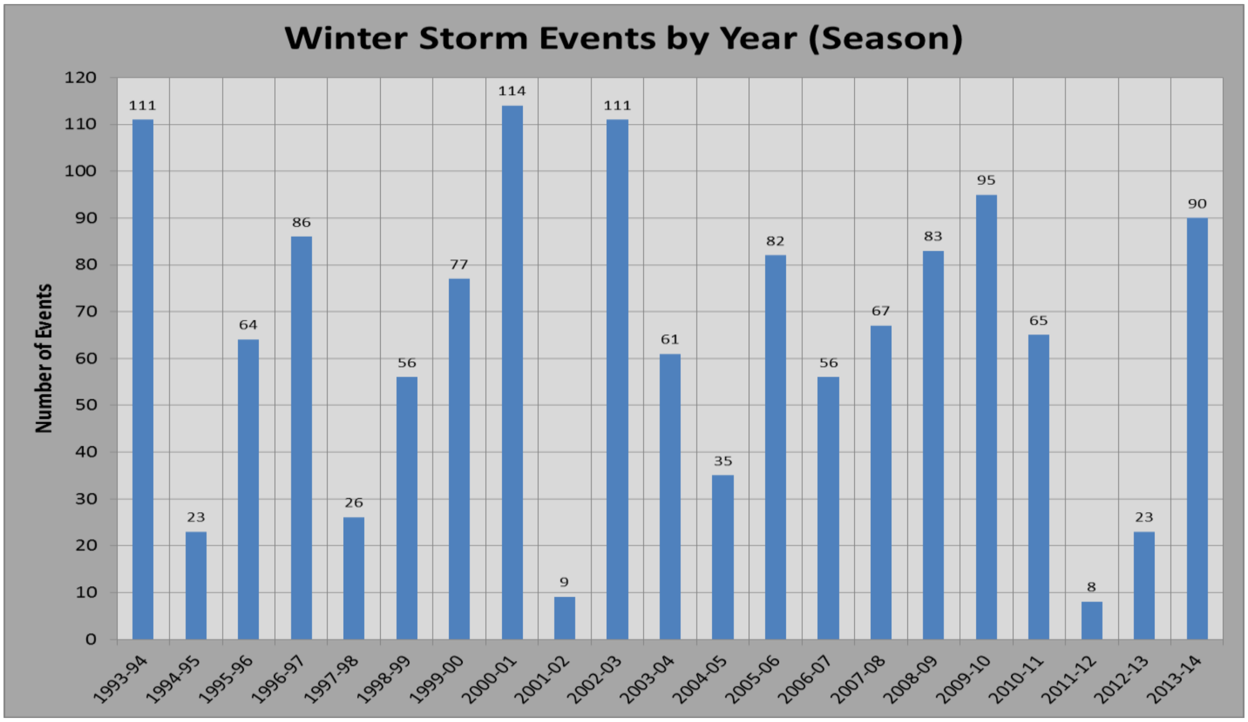

Figure 6a. Distribution of 1342 total winter storm events over 21 cool seasons in the WFO PHI forecast area.

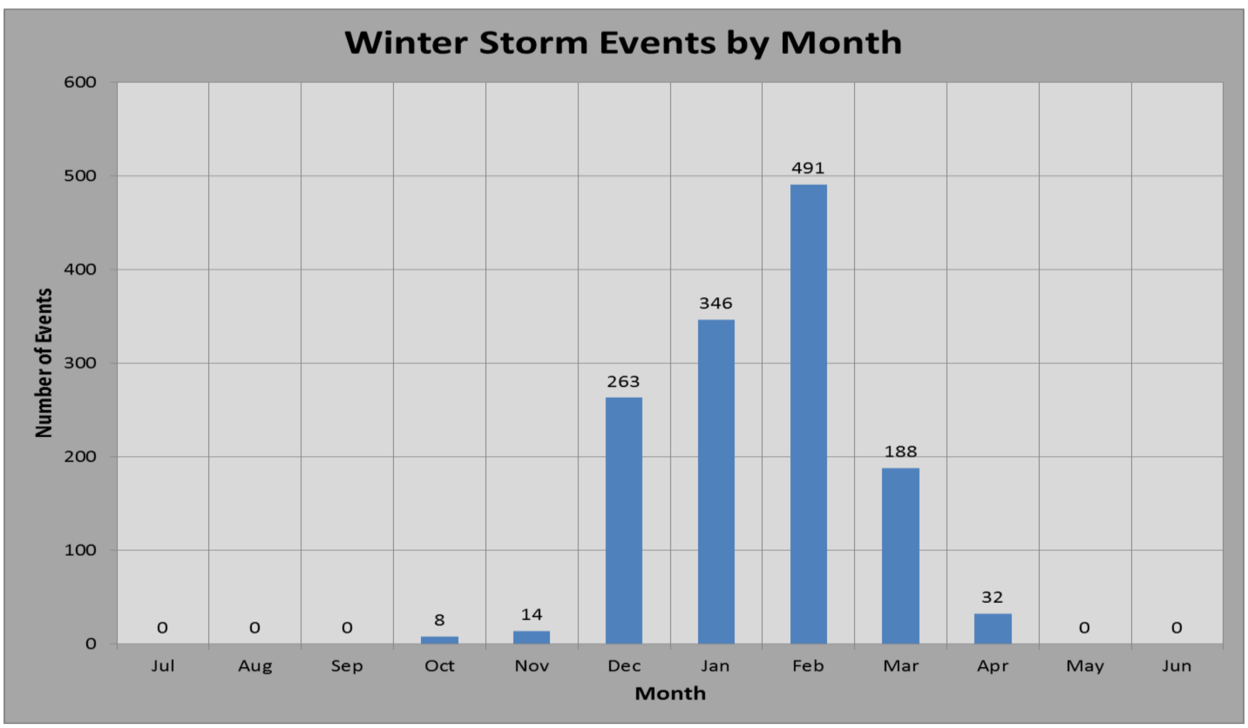

Figure 6b. Distribution of winter storm events by month in the WFO PHI forecast area.

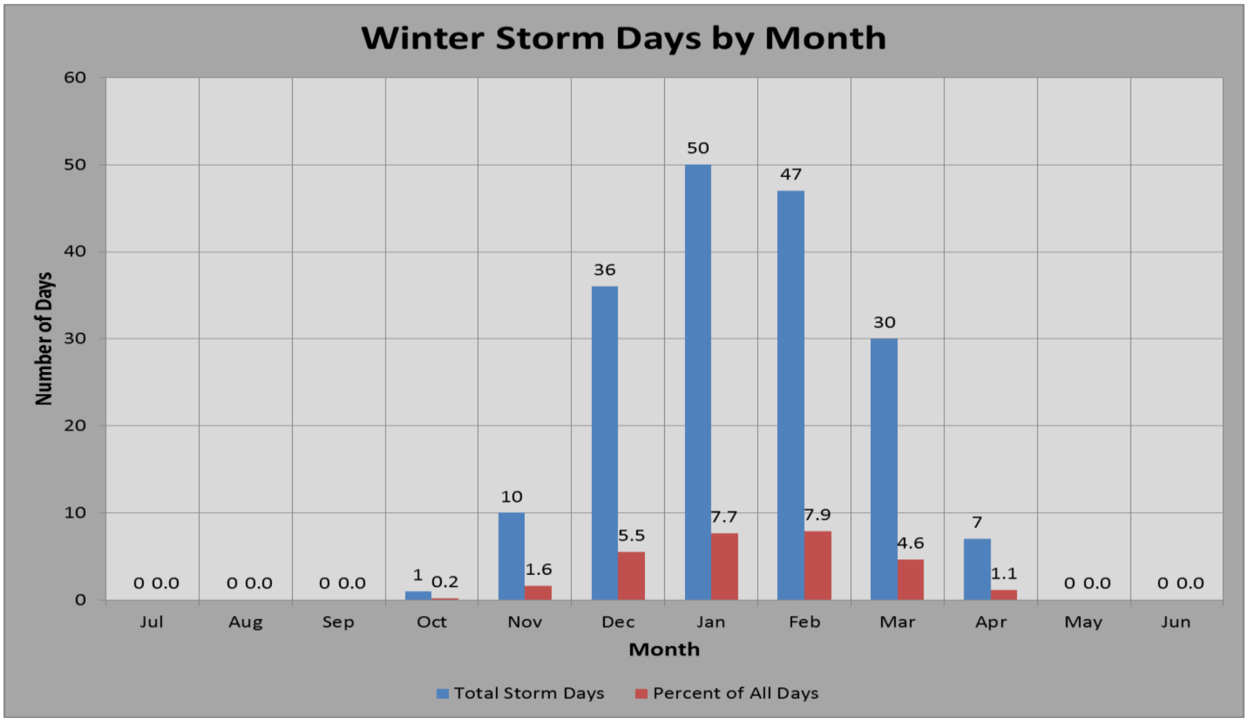

Figure 6c. Number and percentage of days per month with at least one winter storm event in the WFO PHI forecast area. Total is 181 days.

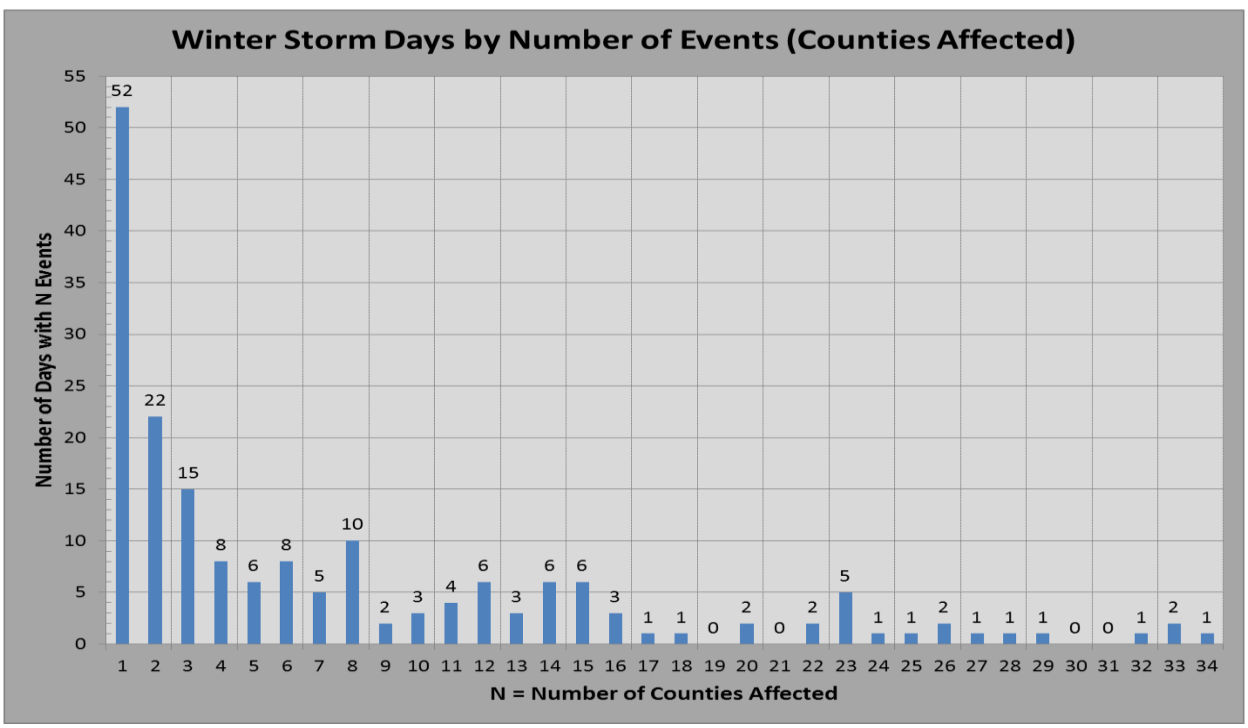

Figure 6d. Distribution of winter storm days by the number of events per day.

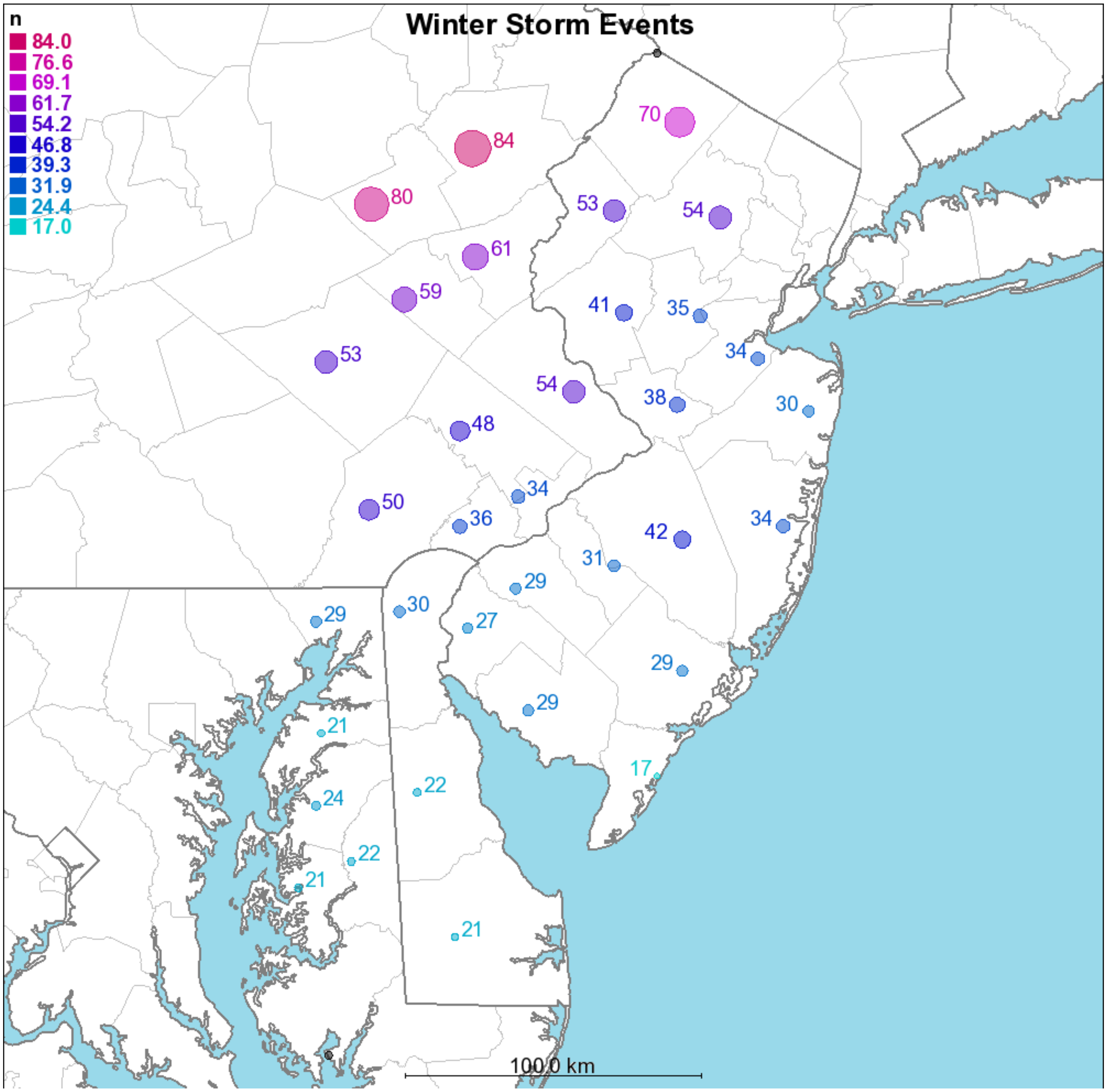

Figure 6e. Distribution of winter storm events by county in the WFO PHI forecast area.

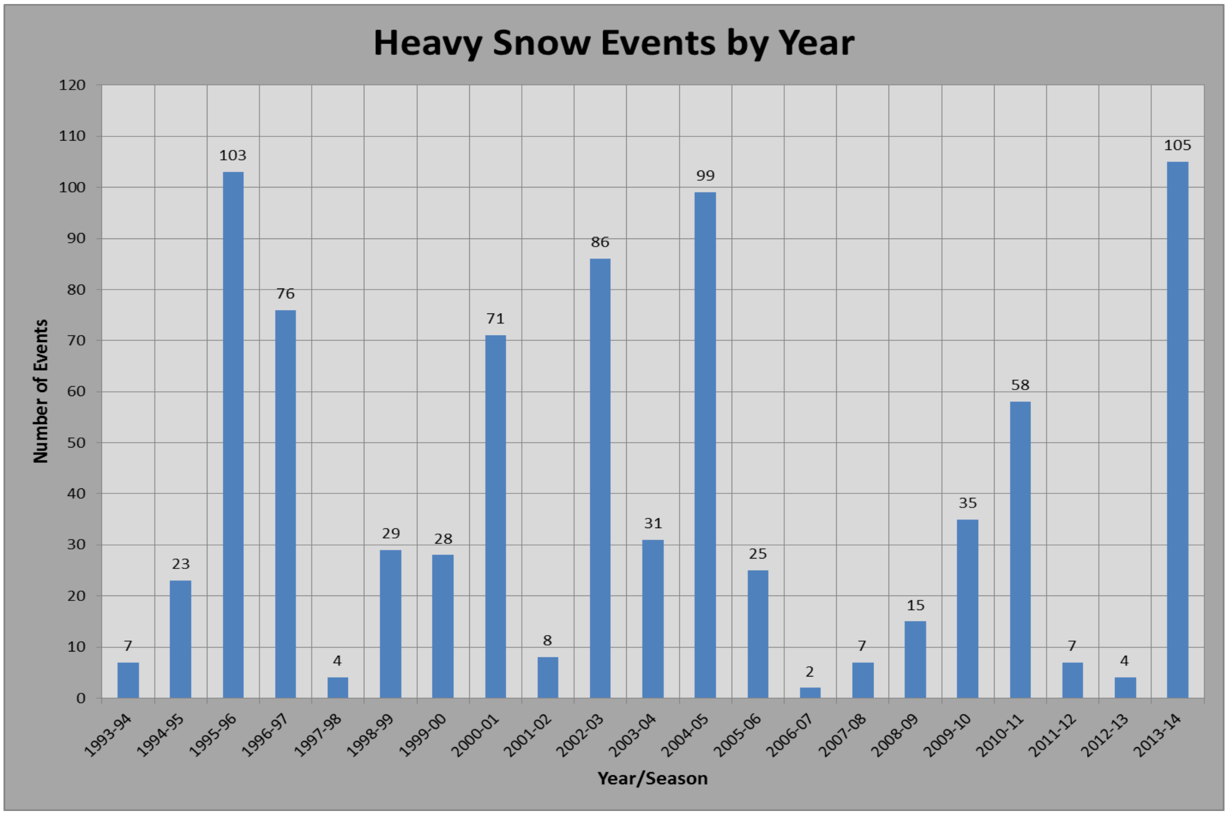

Figure 7a. As in Fig. 6a, except for 823 total Heavy Snow events.

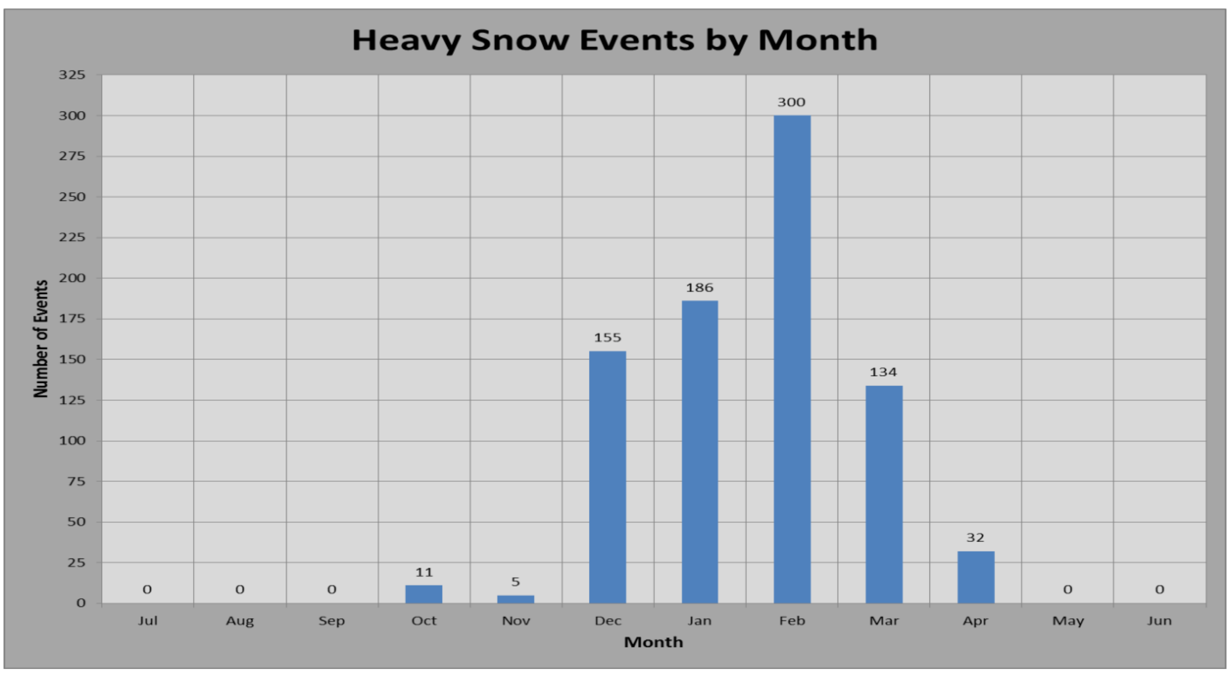

Figure 7b. As in Fig. 6b, except for Heavy Snow events.

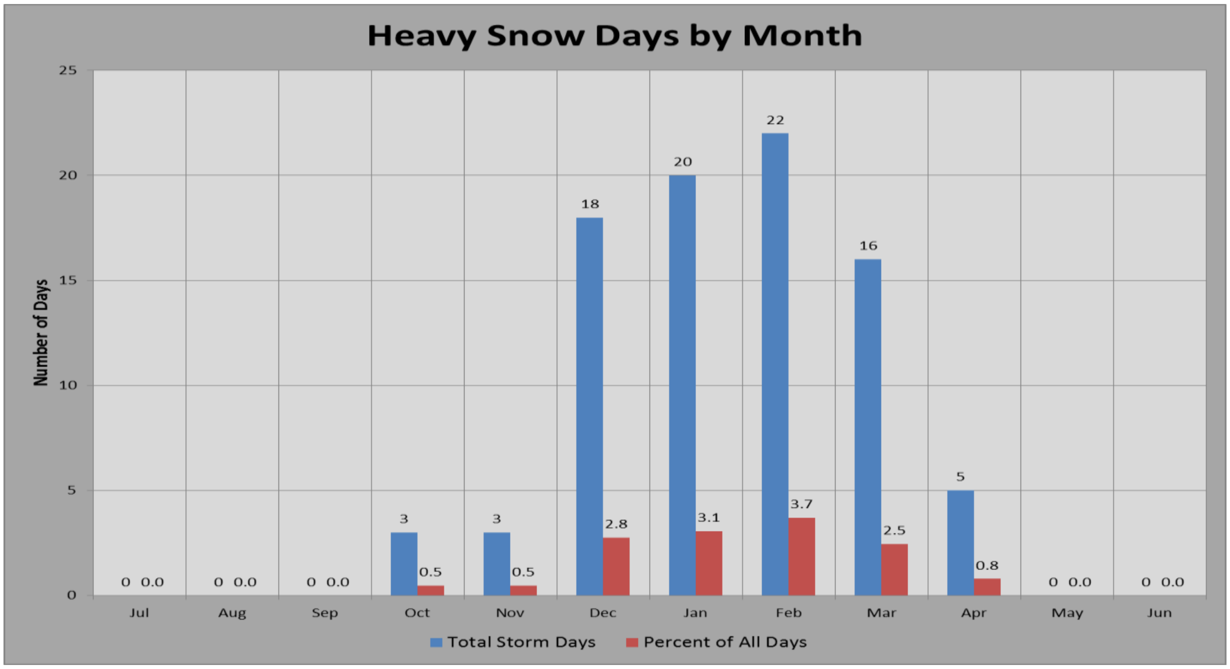

Figure 7c. As in [Fig. 6c](), except for 87 total days with Heavy Snow events.

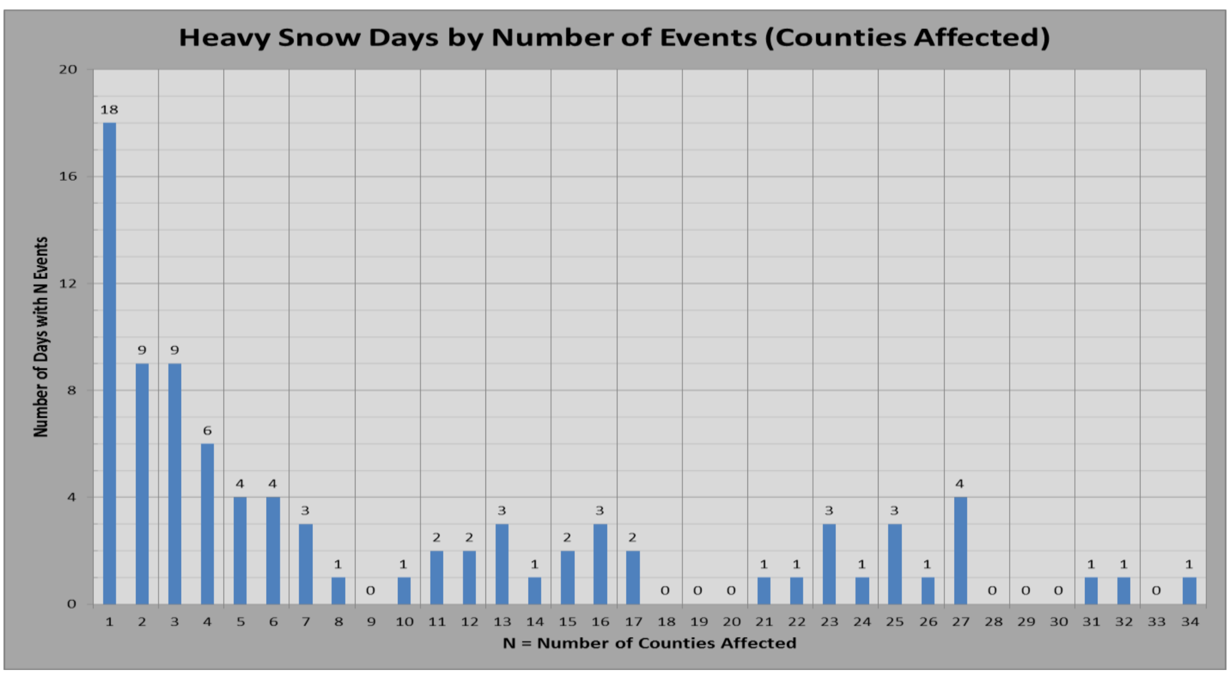

Figure 7d. As in [Fig. 6d](), except for Heavy Snow days.

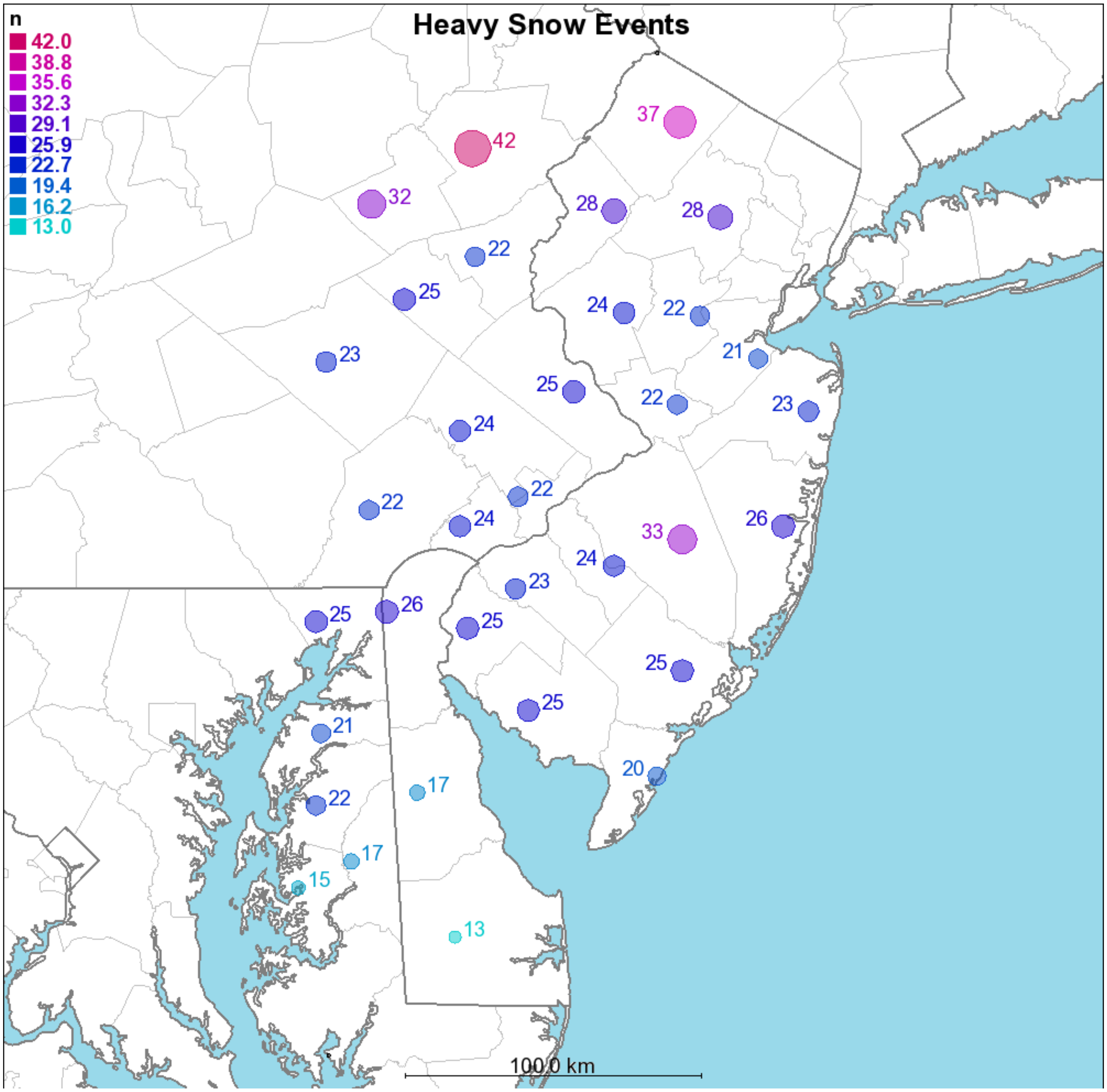

Figure 7e. As in Fig. 6e, except for Heavy Snow Events.

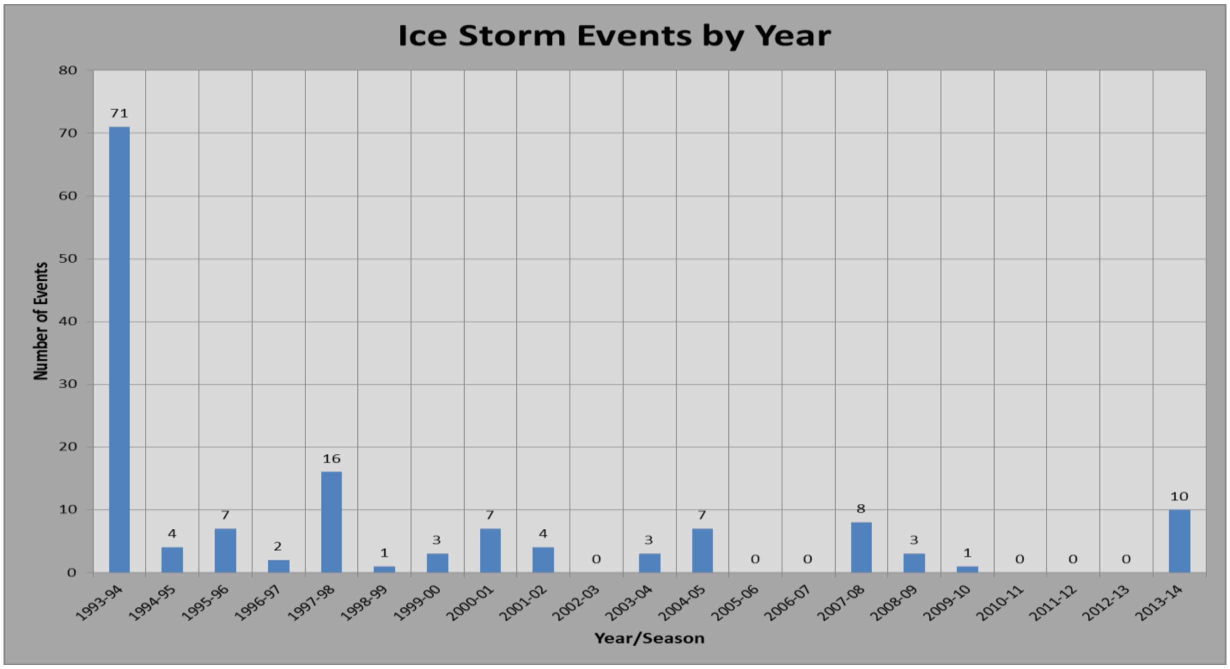

Figure 8a. As in Fig. 6a, except for 147 total Ice Storm events.

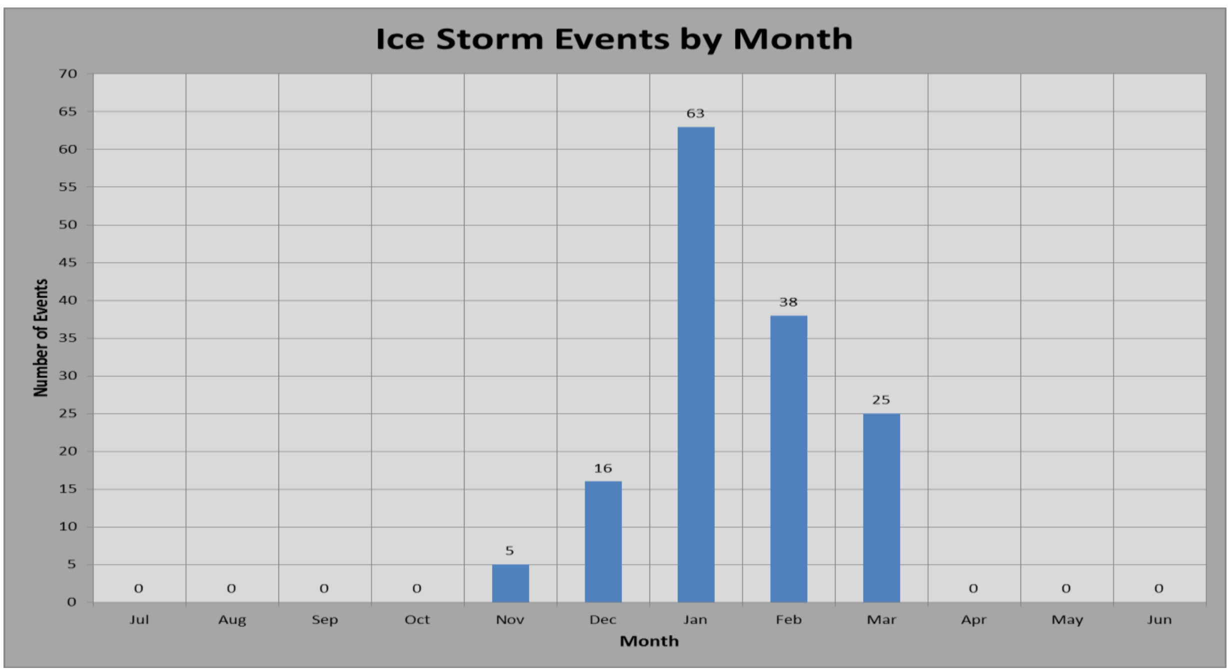

Figure 8b. As in Fig. 6b, except for Ice Storm events.

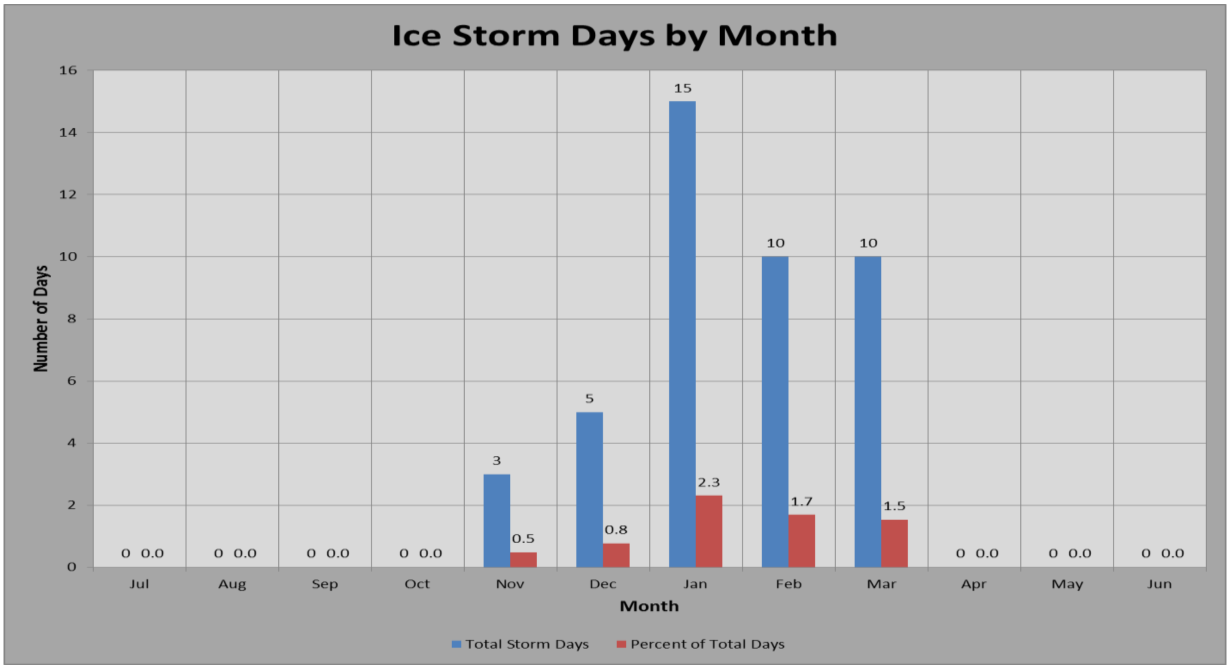

Figure 8c. As in Fig. 6c, except for 43 total days with Ice Storm events.

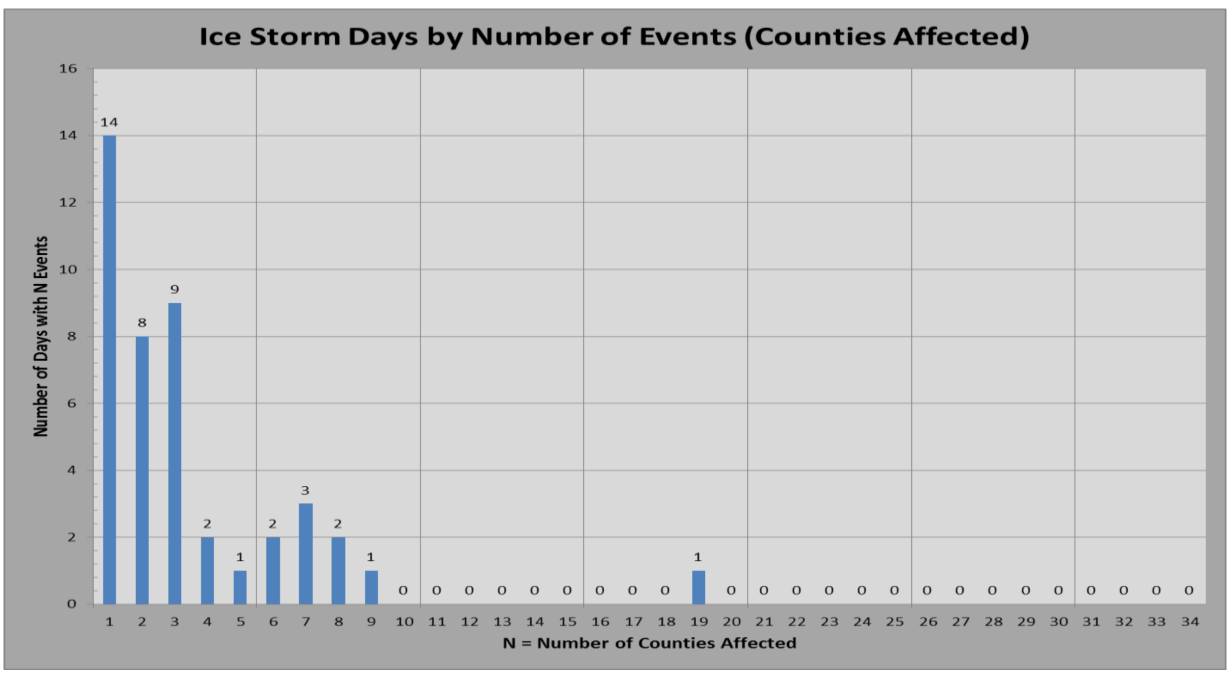

Figure 8d. As in Fig. 6d, except for Ice Storm days.

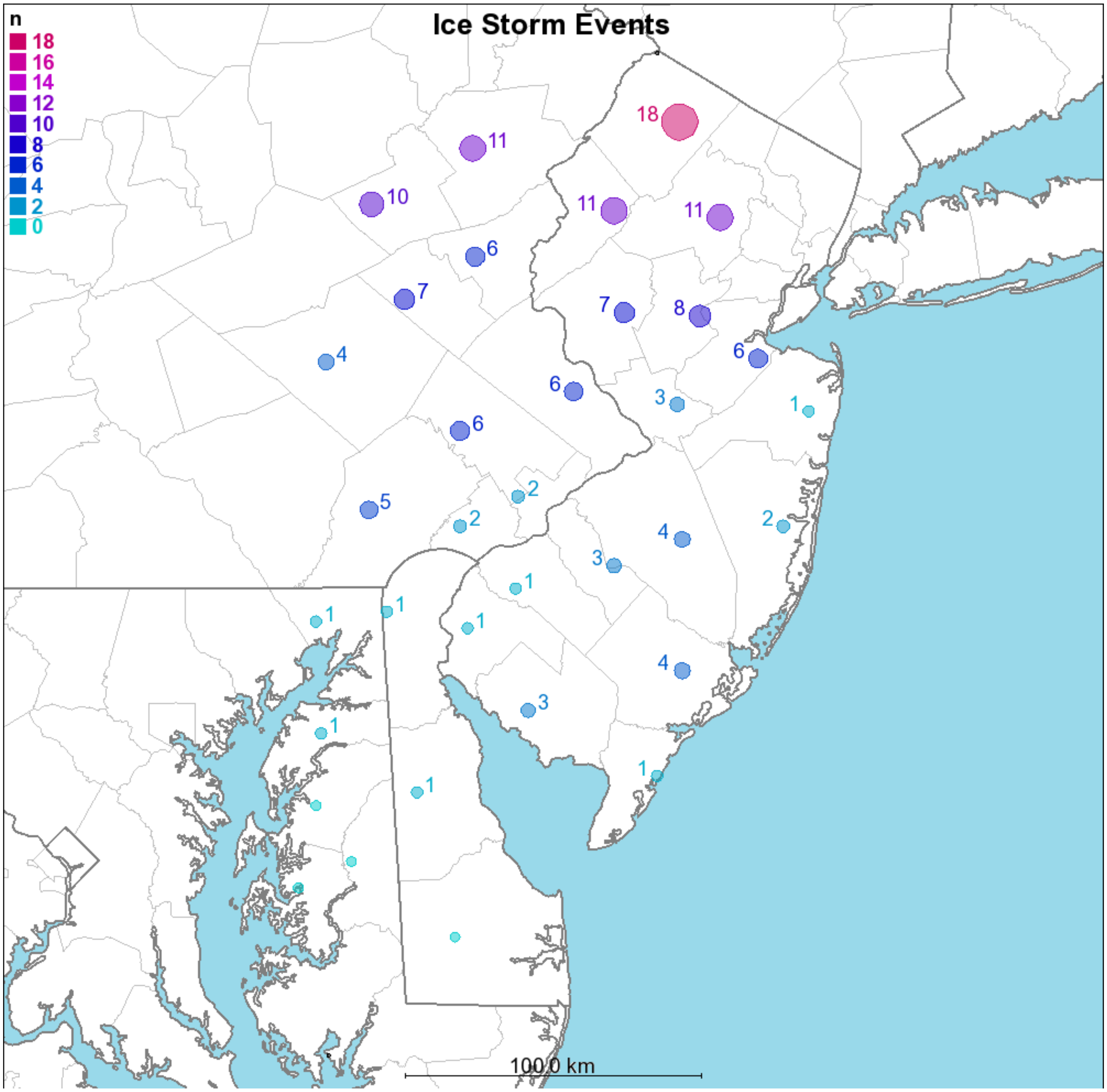

Figure 8e. As in Fig. 6e, except for Ice Storm events.

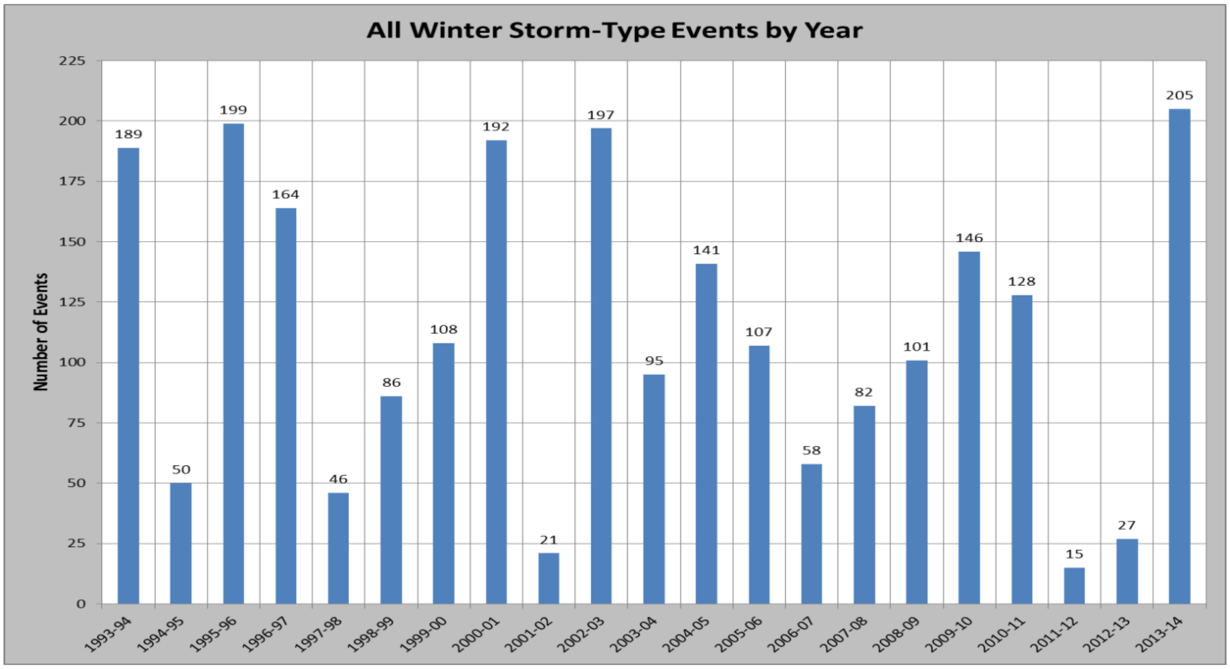

Figure 9a. As in Fig. 6a, except for all 2368 winter storm verifying events, including heavy snow, ice storm and blizzard events.

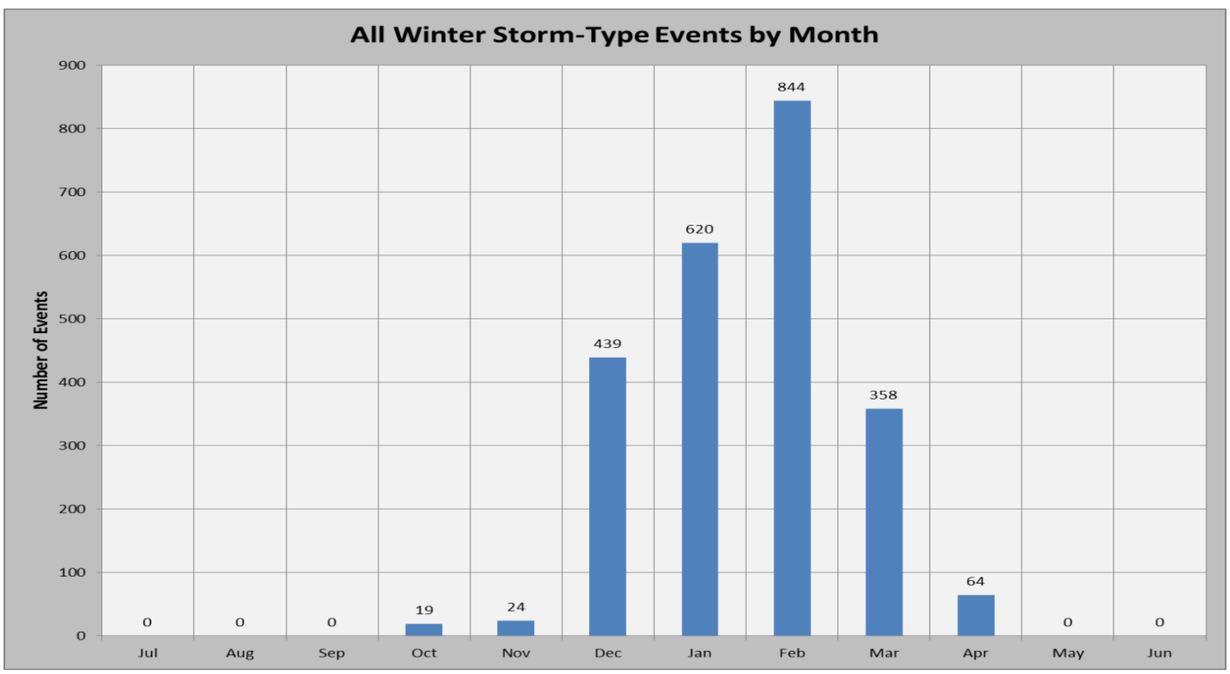

Figure 9b. As in Fig. 6b, except for all winter storm verifying events.

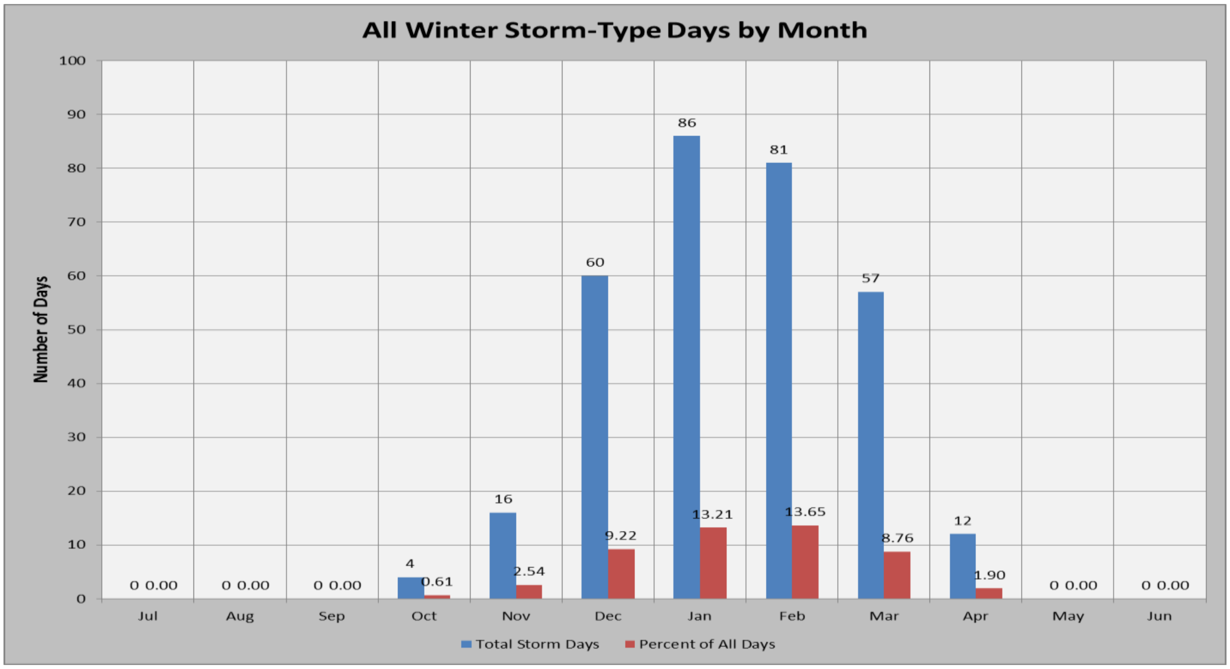

Figure 9c. As in Fig. 6c, except for all 316 total days with winter storm verifying events.

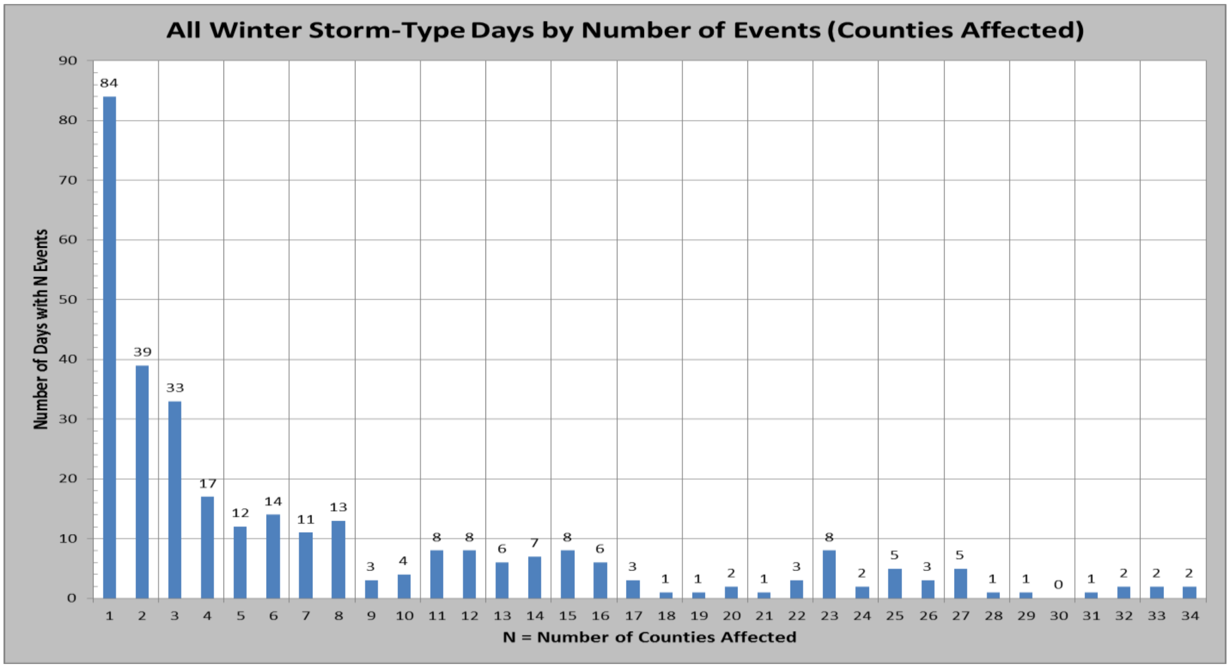

Figure 9d. As in Fig. 6d, except for all winter storm verifying days.

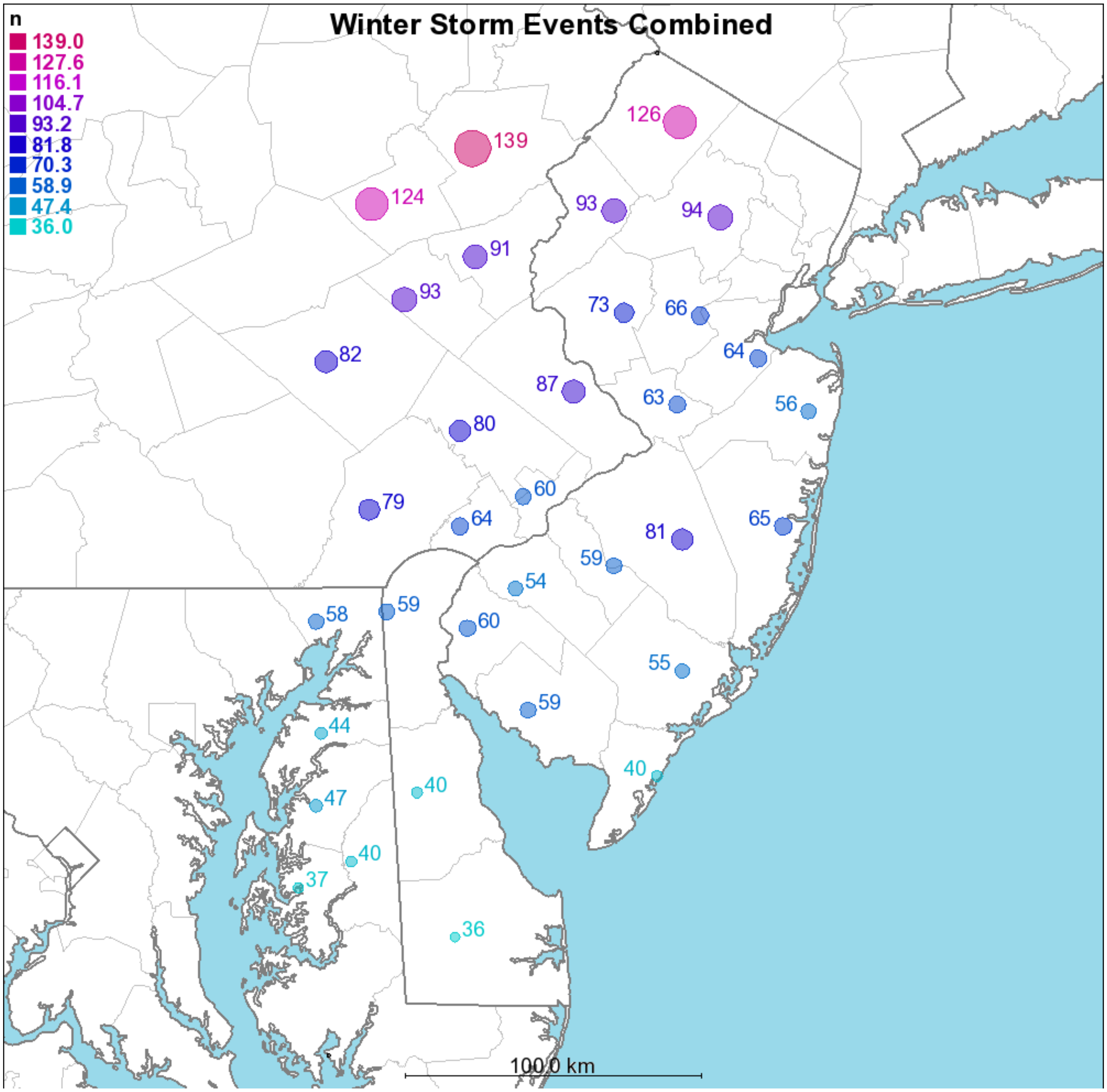

Figure 9e. As in Fig. 6e, except for all winter storm verifying events.

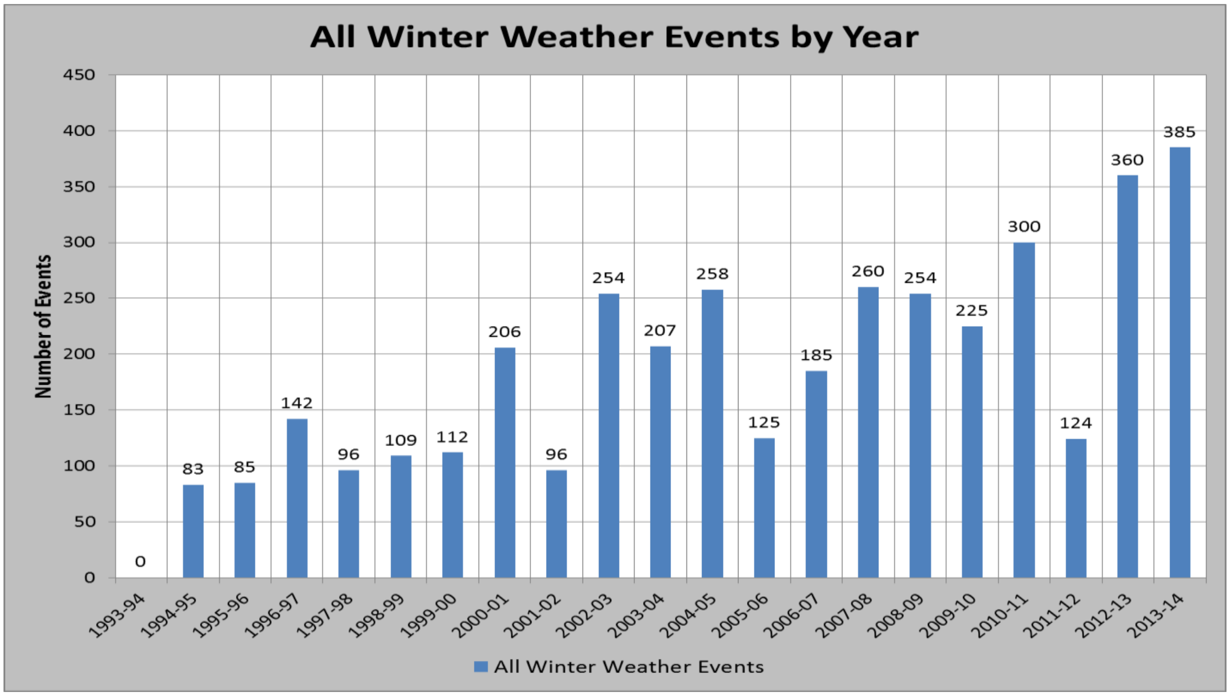

Figure 10a. As in Fig. 6a, except for 3866 total winter weather (sub-warning) events.

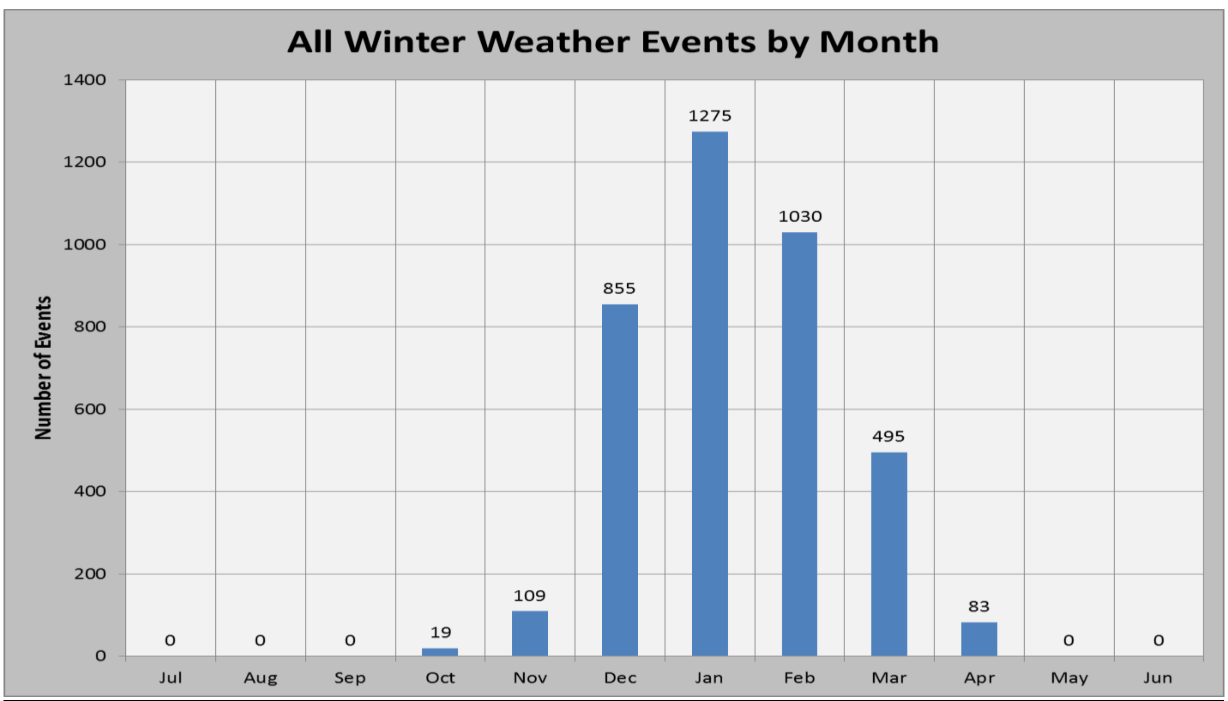

Figure 10b. As in Fig. 6b, except for winter weather events.

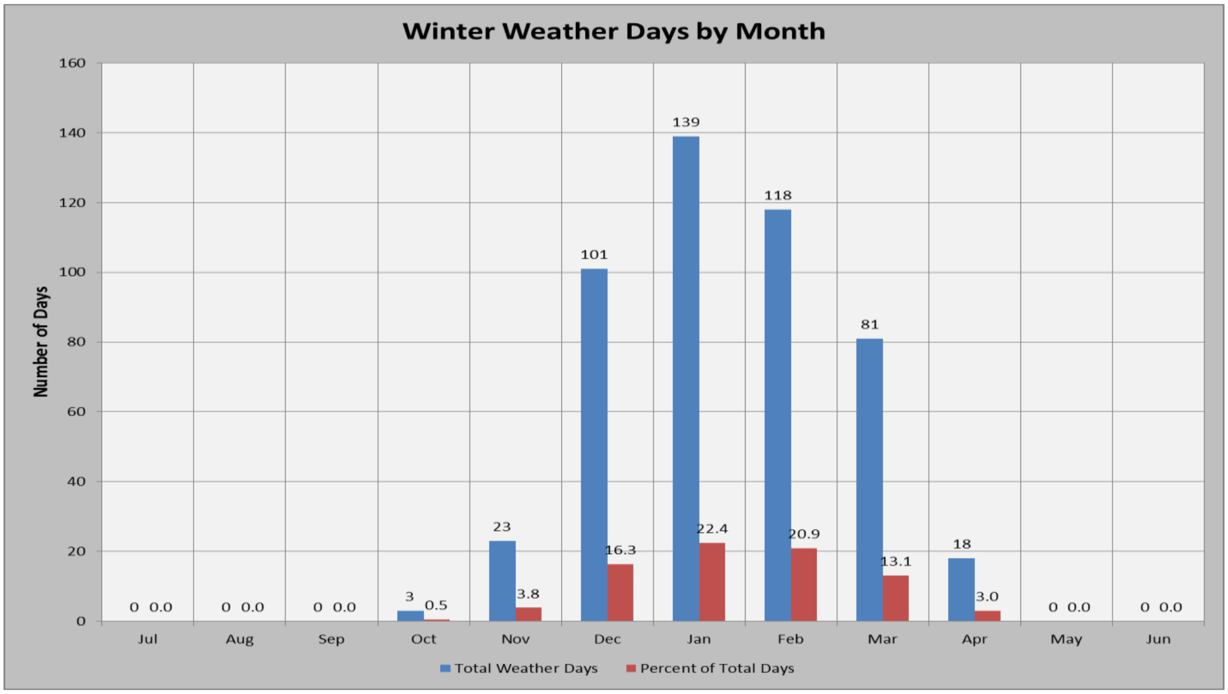

Figure 10c. As in Fig. 6c, except for 483 total days with winter weather events.

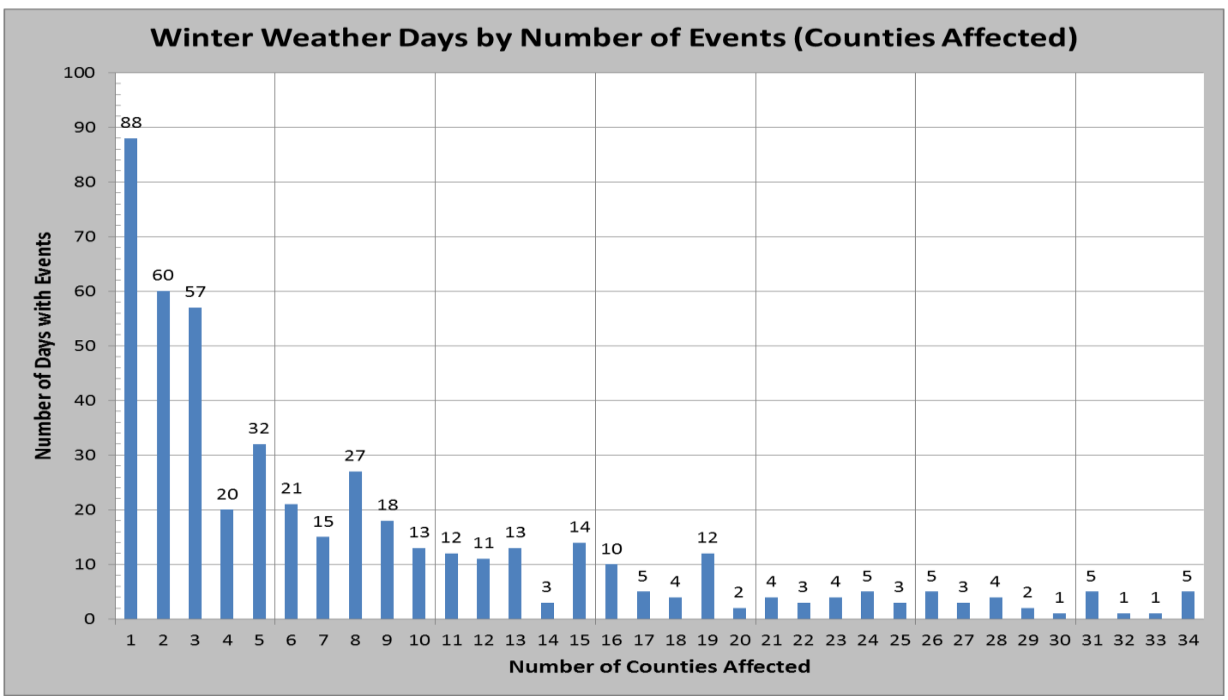

Figure 10d. As in Fig. 6d, except for winter weather event days.

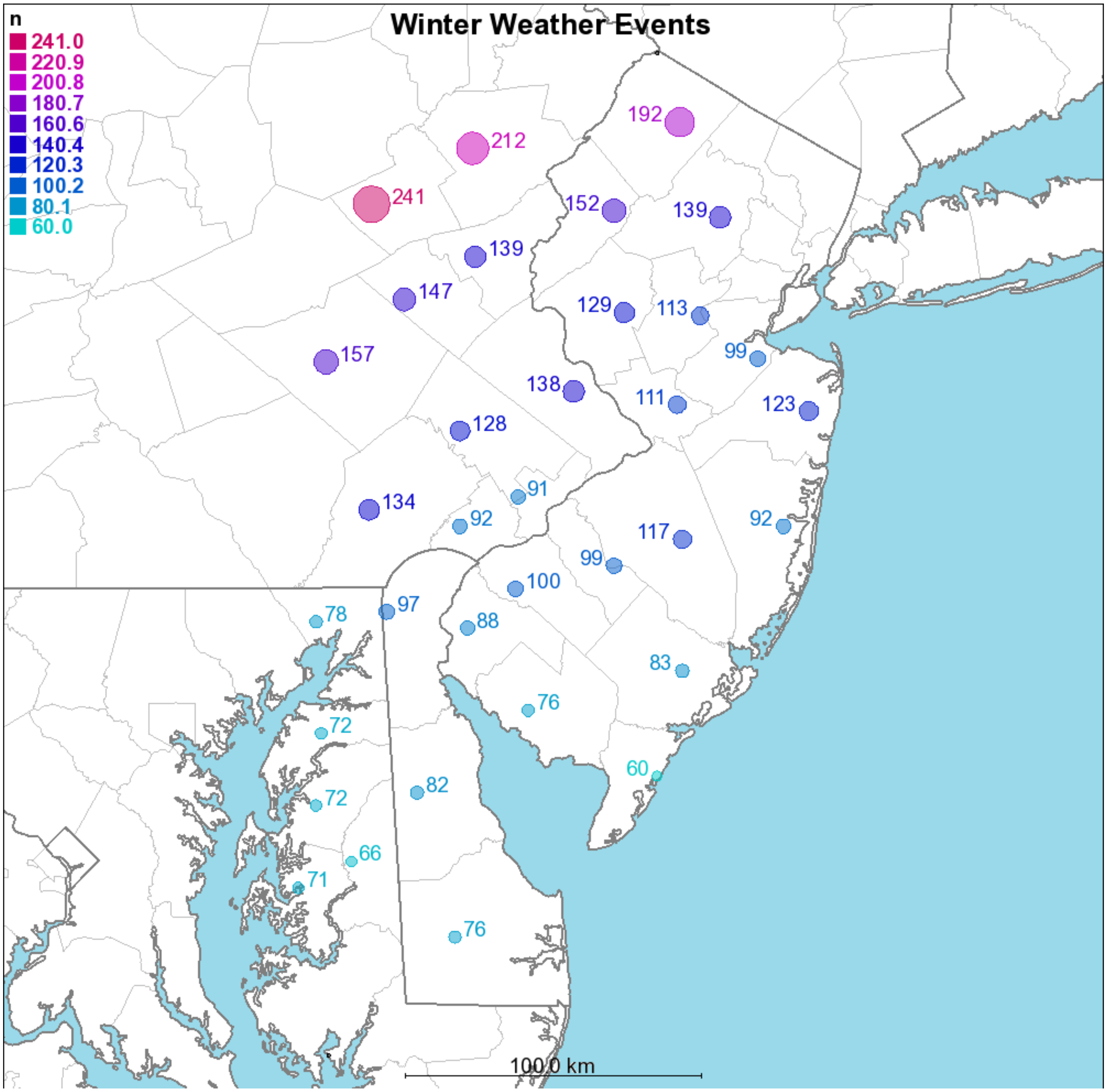

Figure 10e. As in Fig. 6e, except for winter weather events.

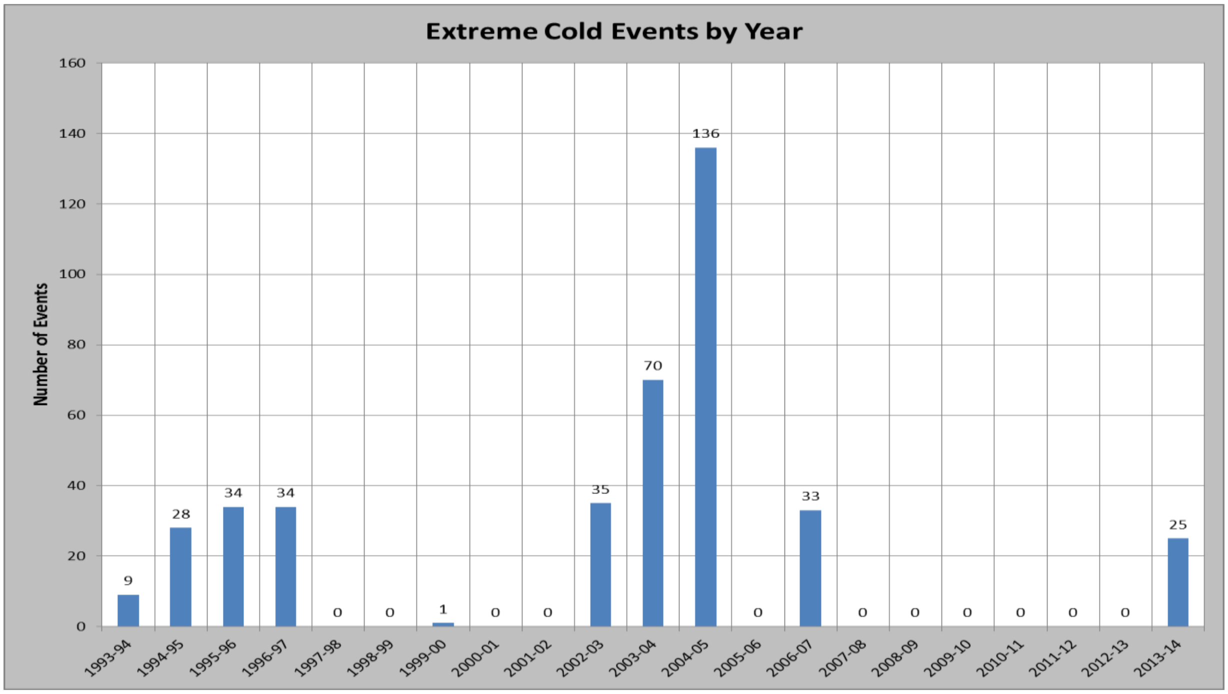

Figure 11a. As in Fig. 6a, except for 405 extreme cold events.

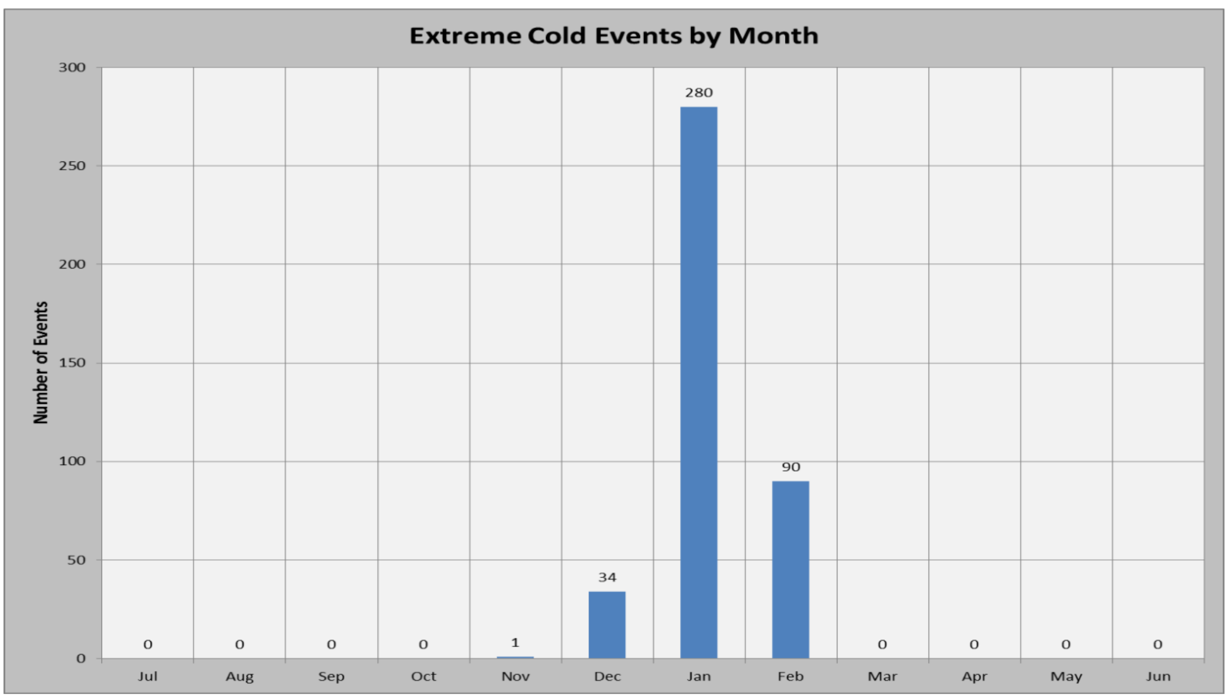

Figure 11b. As in Fig. 6b, except for extreme cold events.

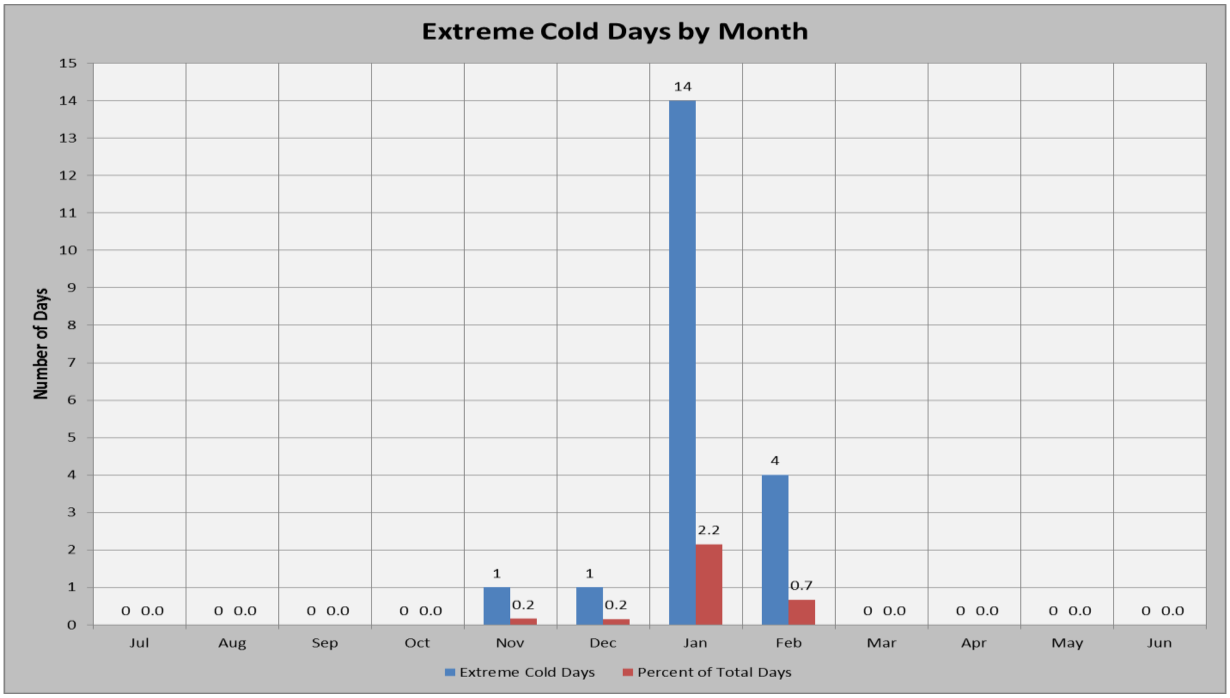

Figure 11c. As in Fig. 6c, except for 20 total days with extreme cold events.

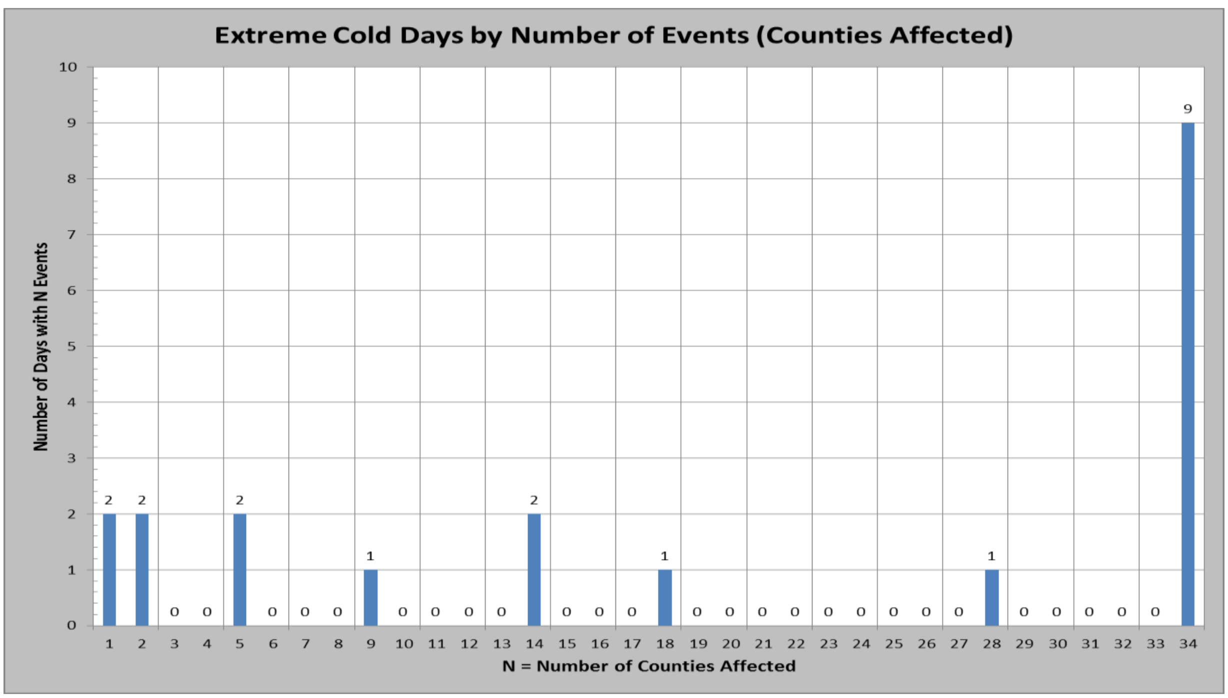

Figure 11d. As in Fig. 6d, except for extreme cold days.

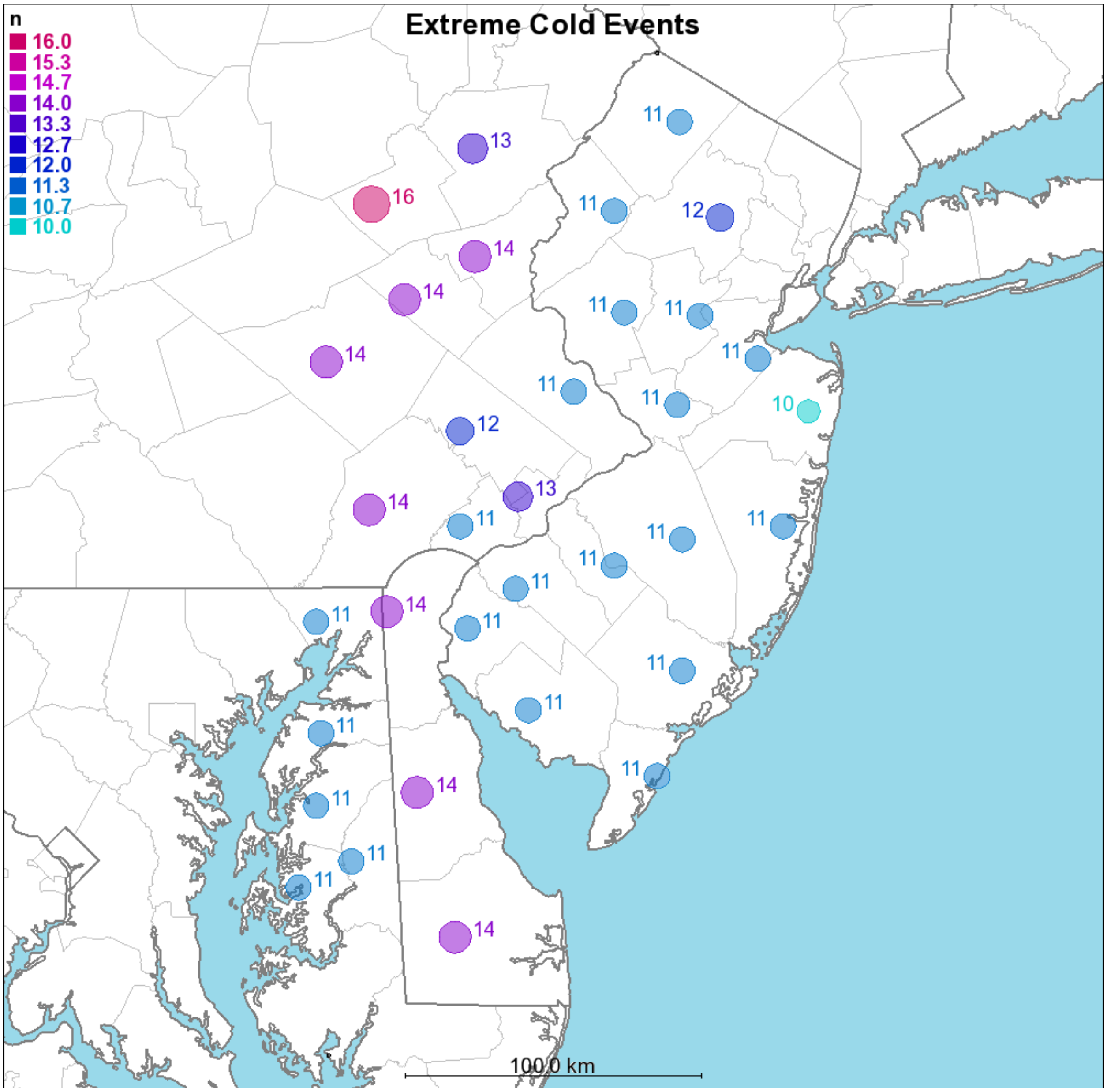

Figure 11e. As in Fig. 6e, except for extreme cold events.

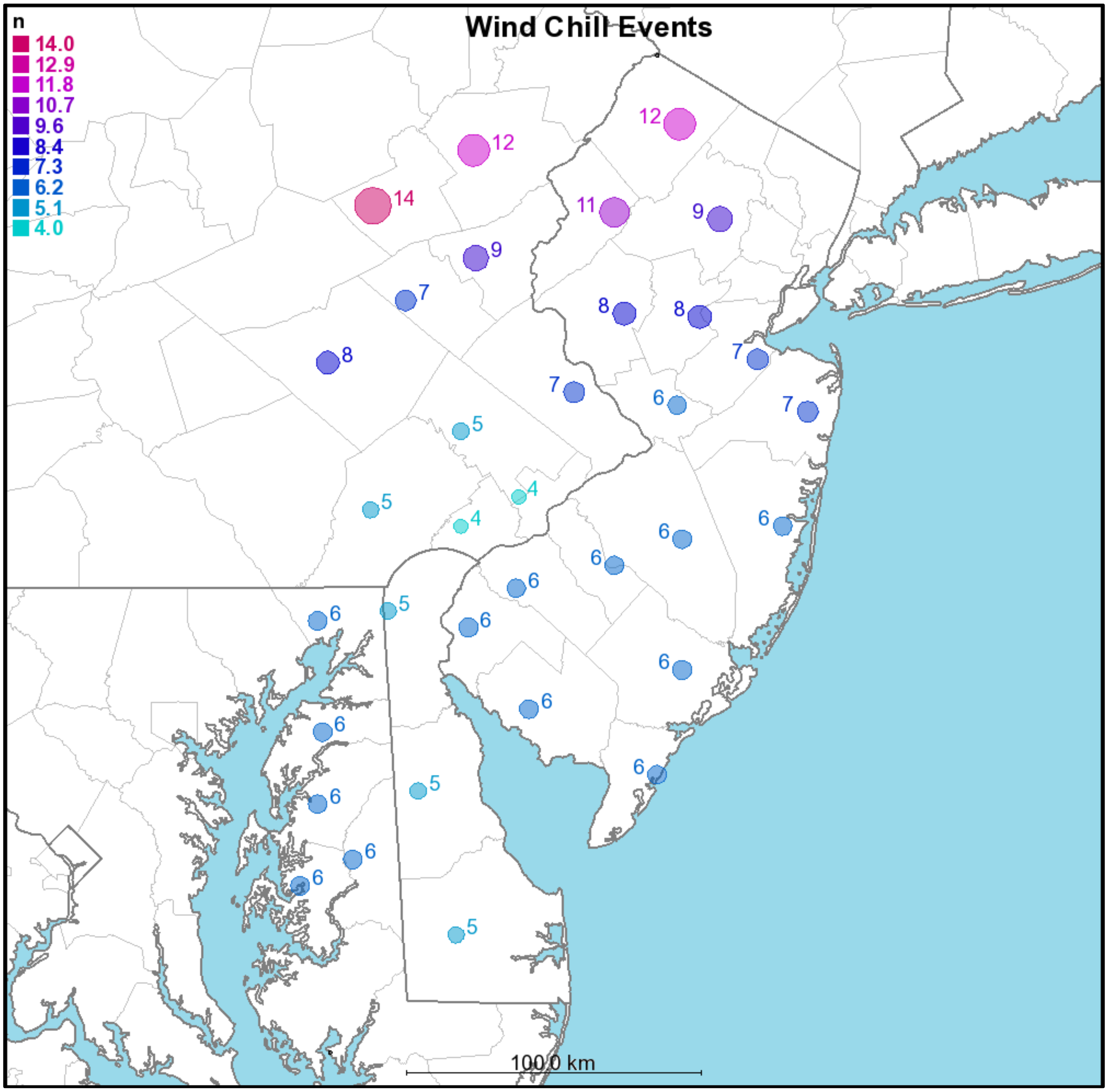

Figure 11f. As in Fig. 6e, except for wind chill events.

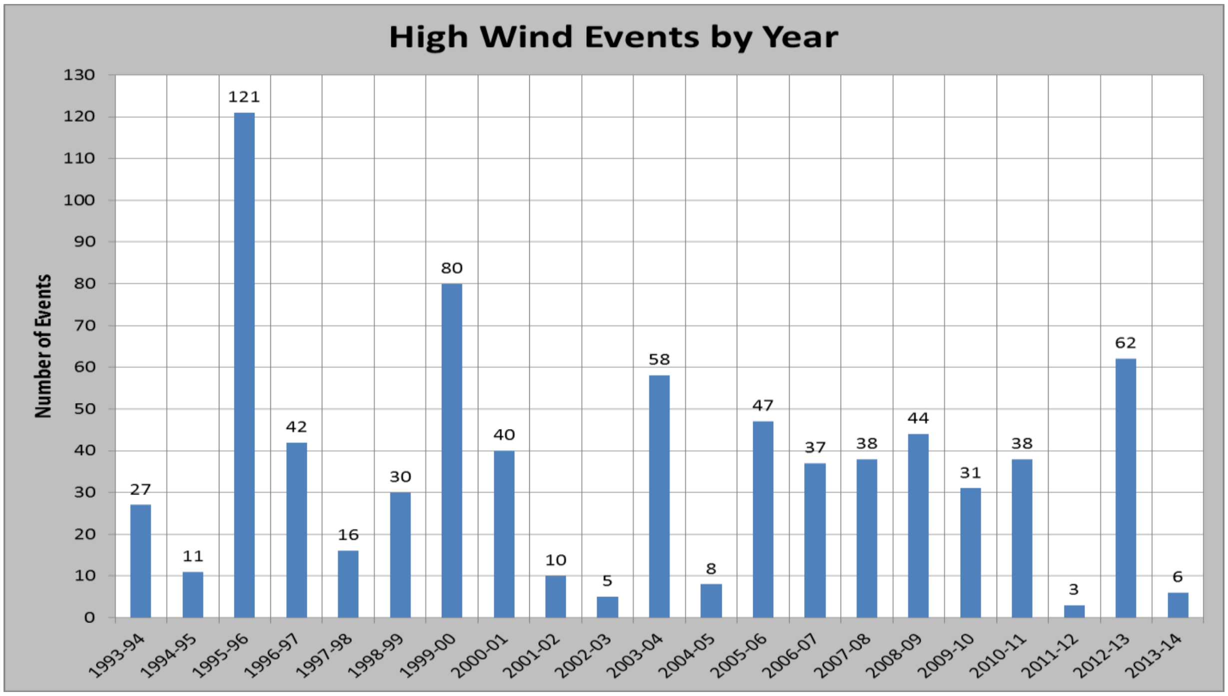

Figure 12a. As in Fig. 6a, except for 754 total high wind events.

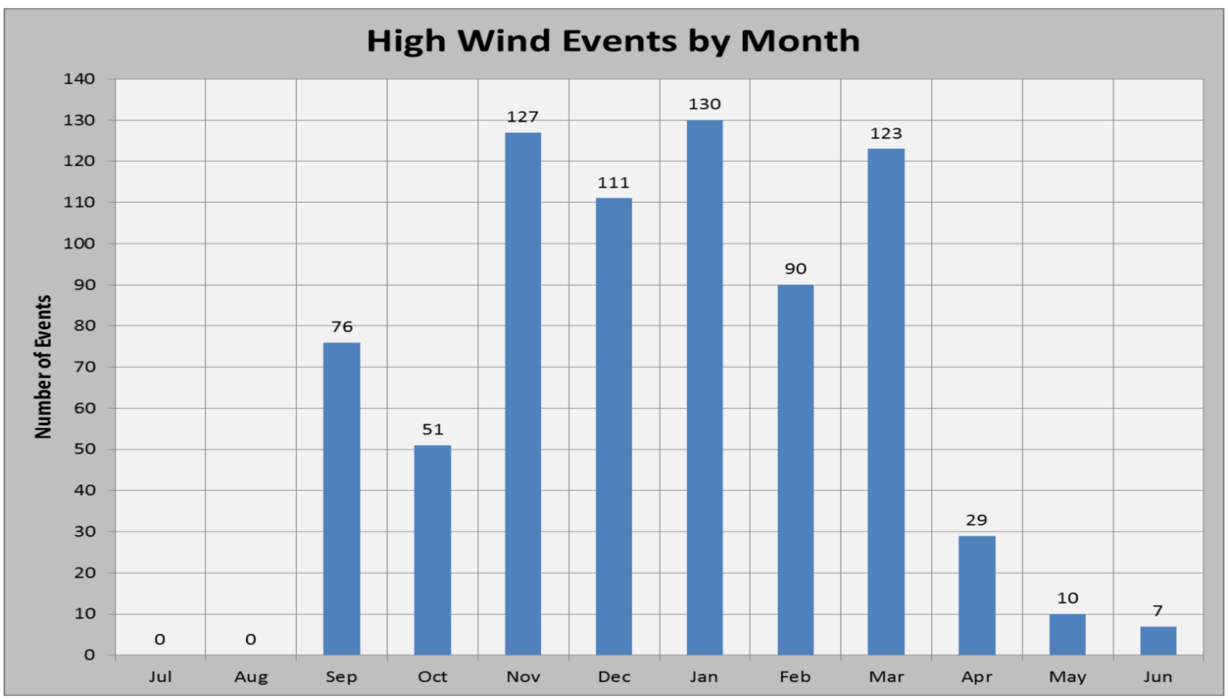

Figure 12b. As in Fig. 6b, except for high wind events.

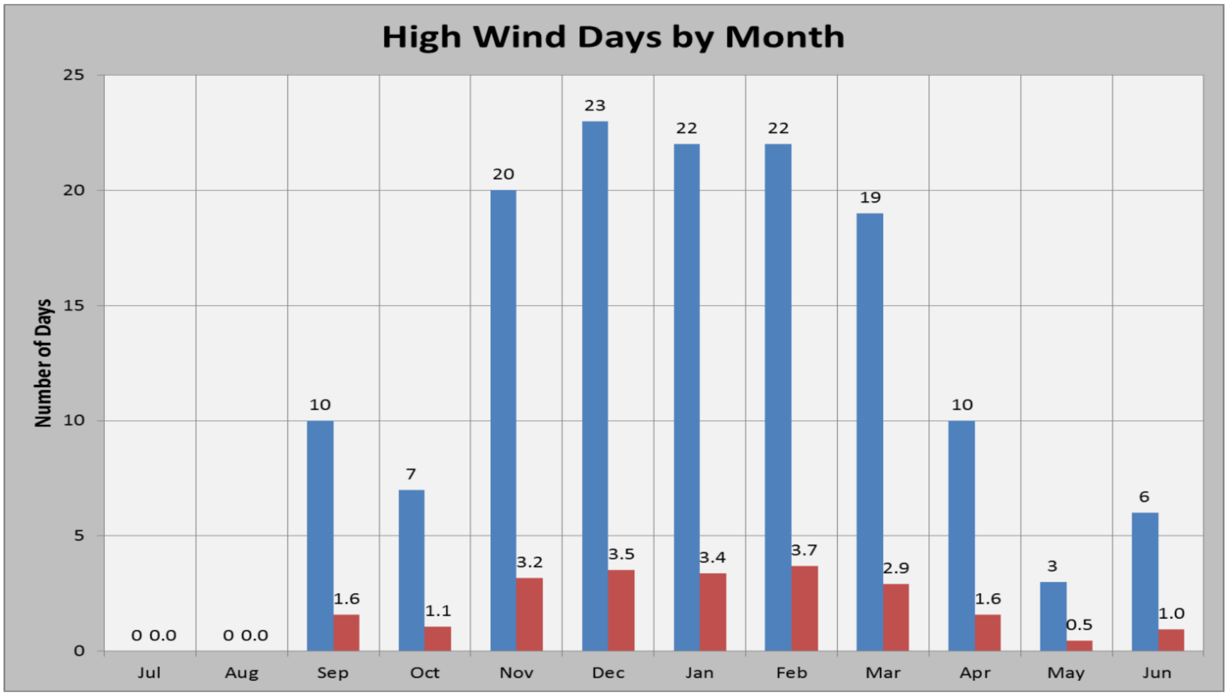

Figure 12c. As in [Fig. 6c](#), except for 142 total days with high wind events.

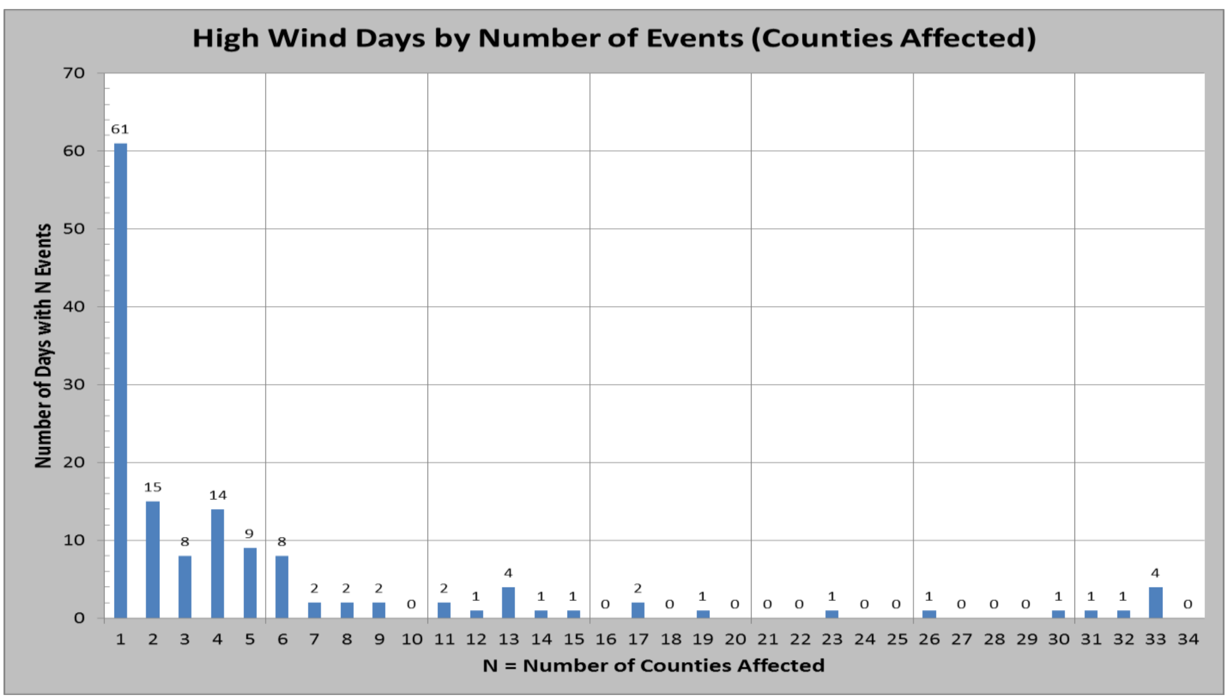

Figure 12d. As in [Fig. 6d](#), except for high wind days.

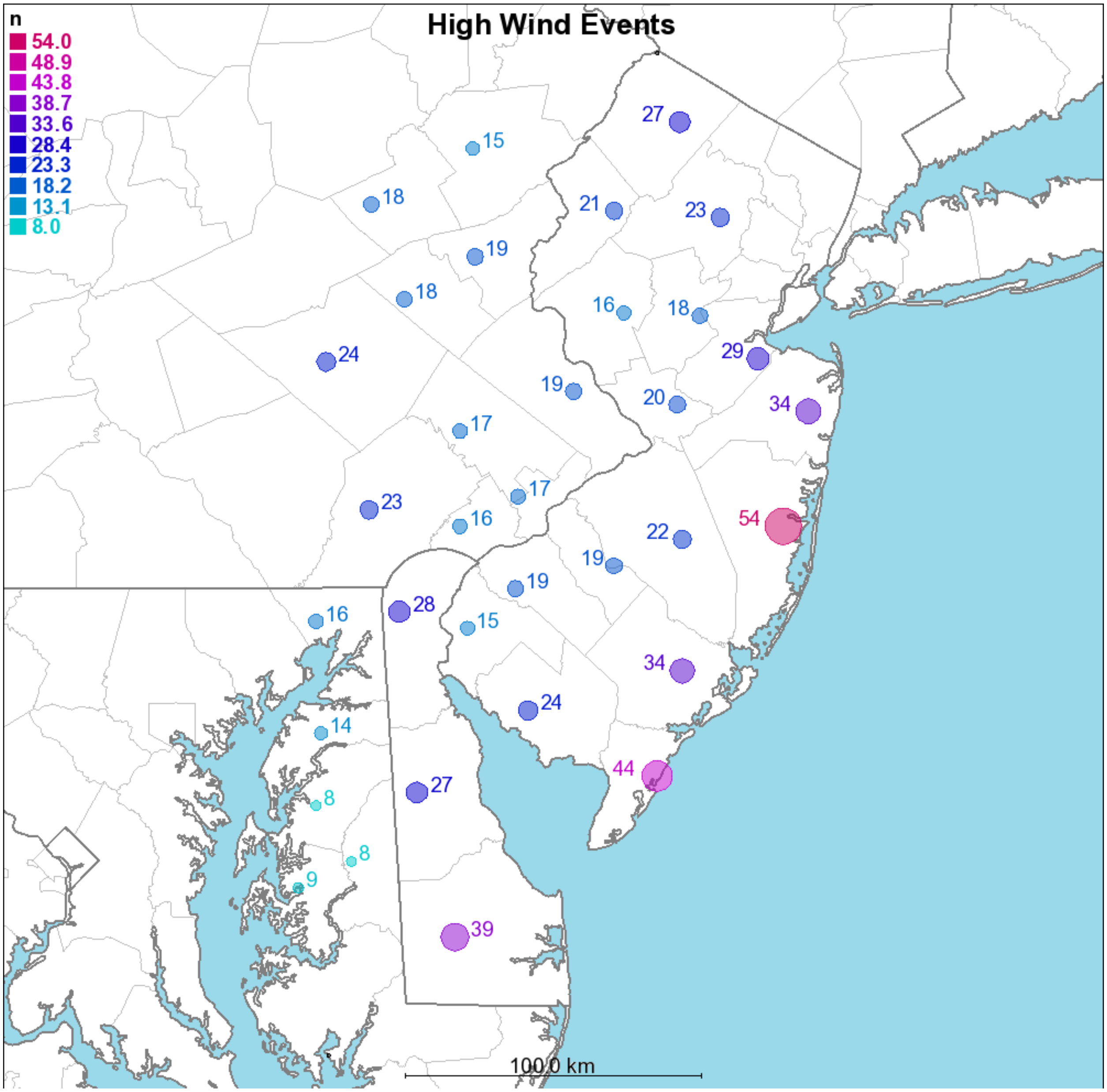

Figure 12e. As in Fig. 6e, except for high wind events.

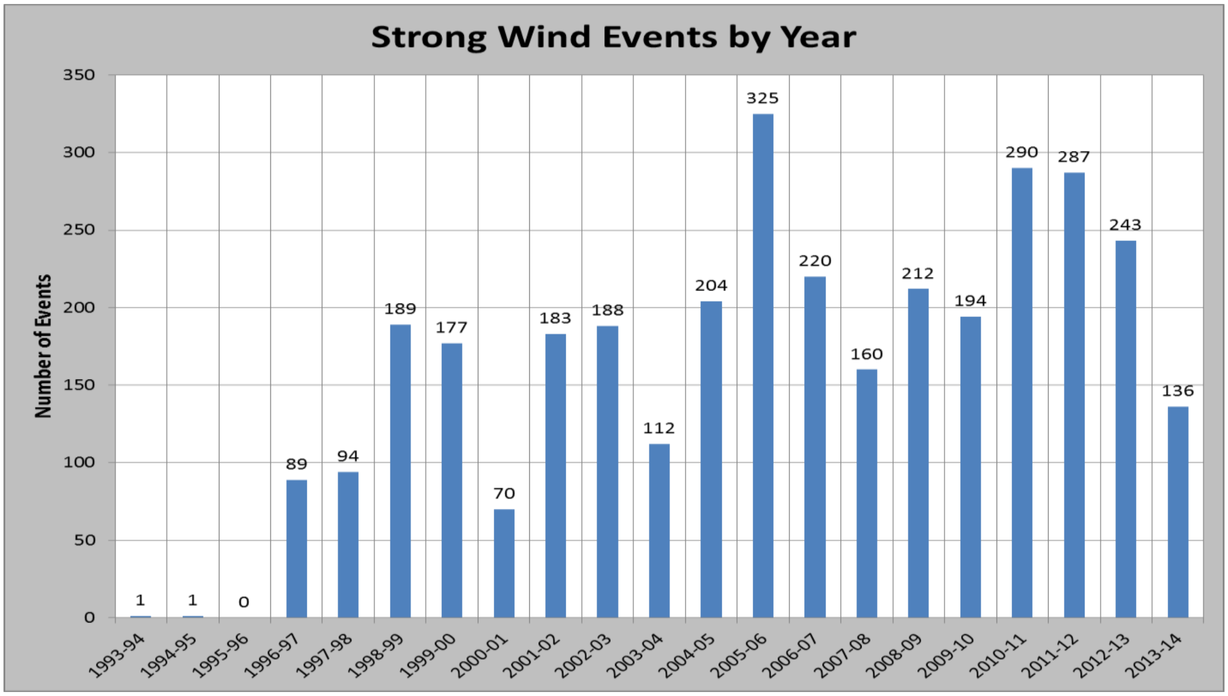

Figure 13a. As in Fig. 6a, except for 3375 total strong wind events.

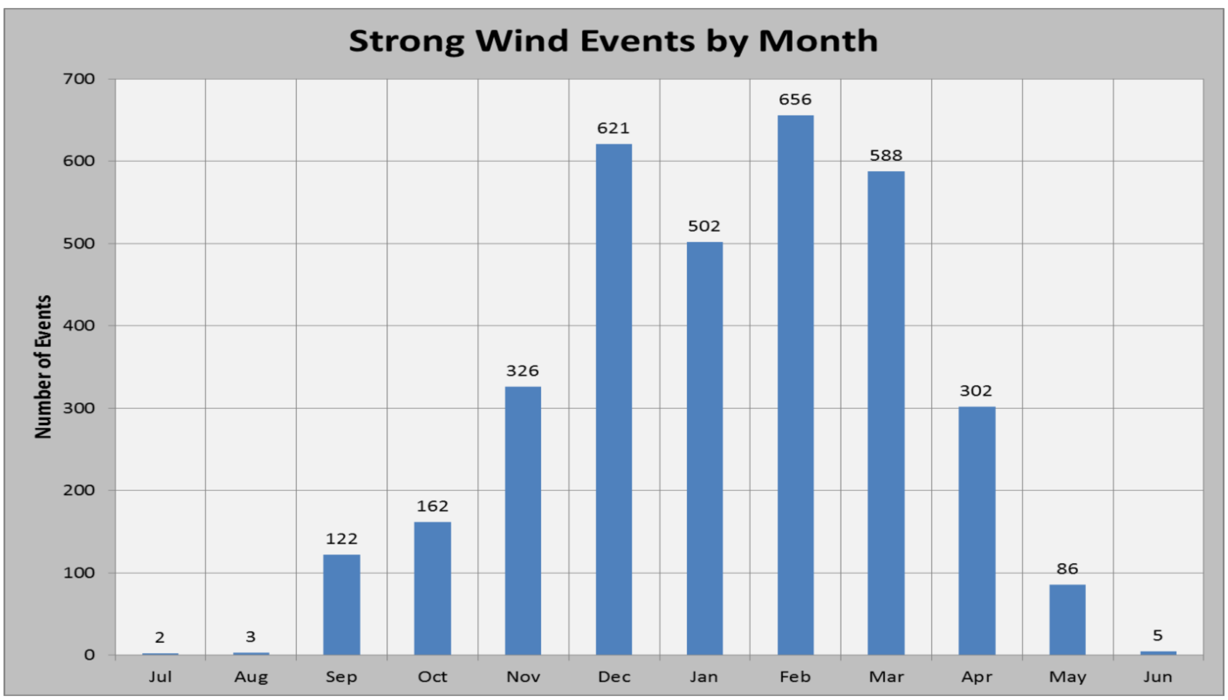

Figure 13b. As in Fig. 6b, except for strong wind events.

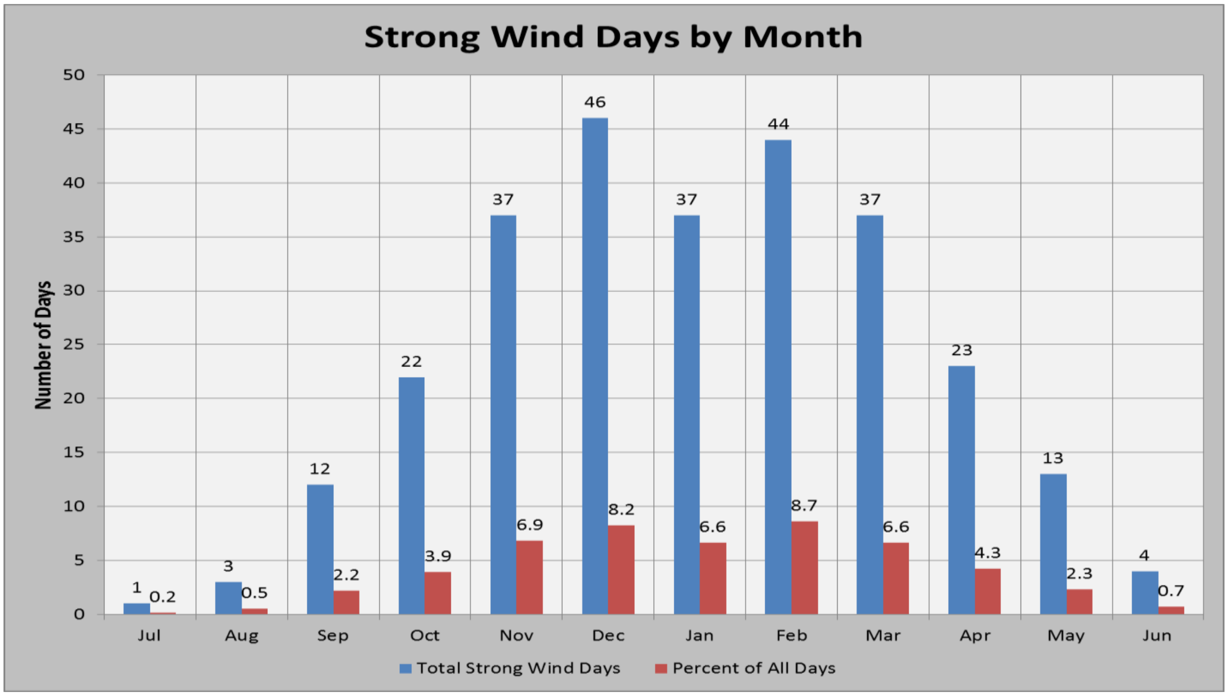

Figure 13c. As in Fig. 6c, except for 279 total days with strong wind events. (percentages based on 18 seasons)

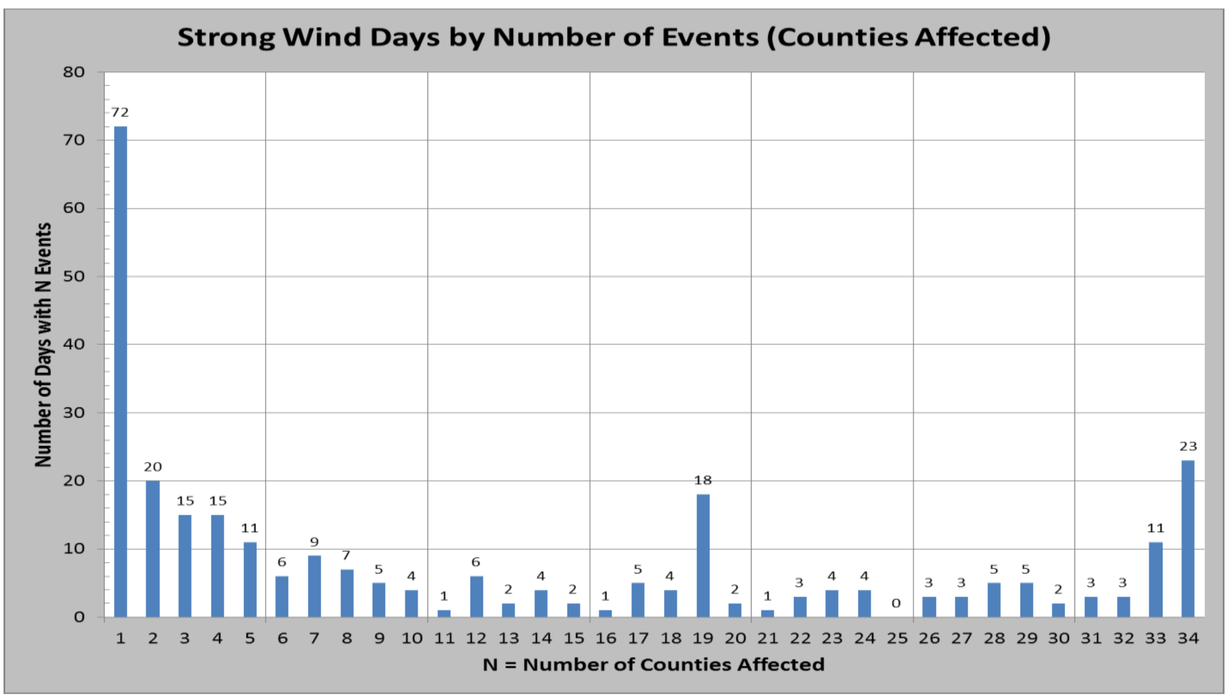

Figure 13d. As in Fig. 6d, except for strong wind days.

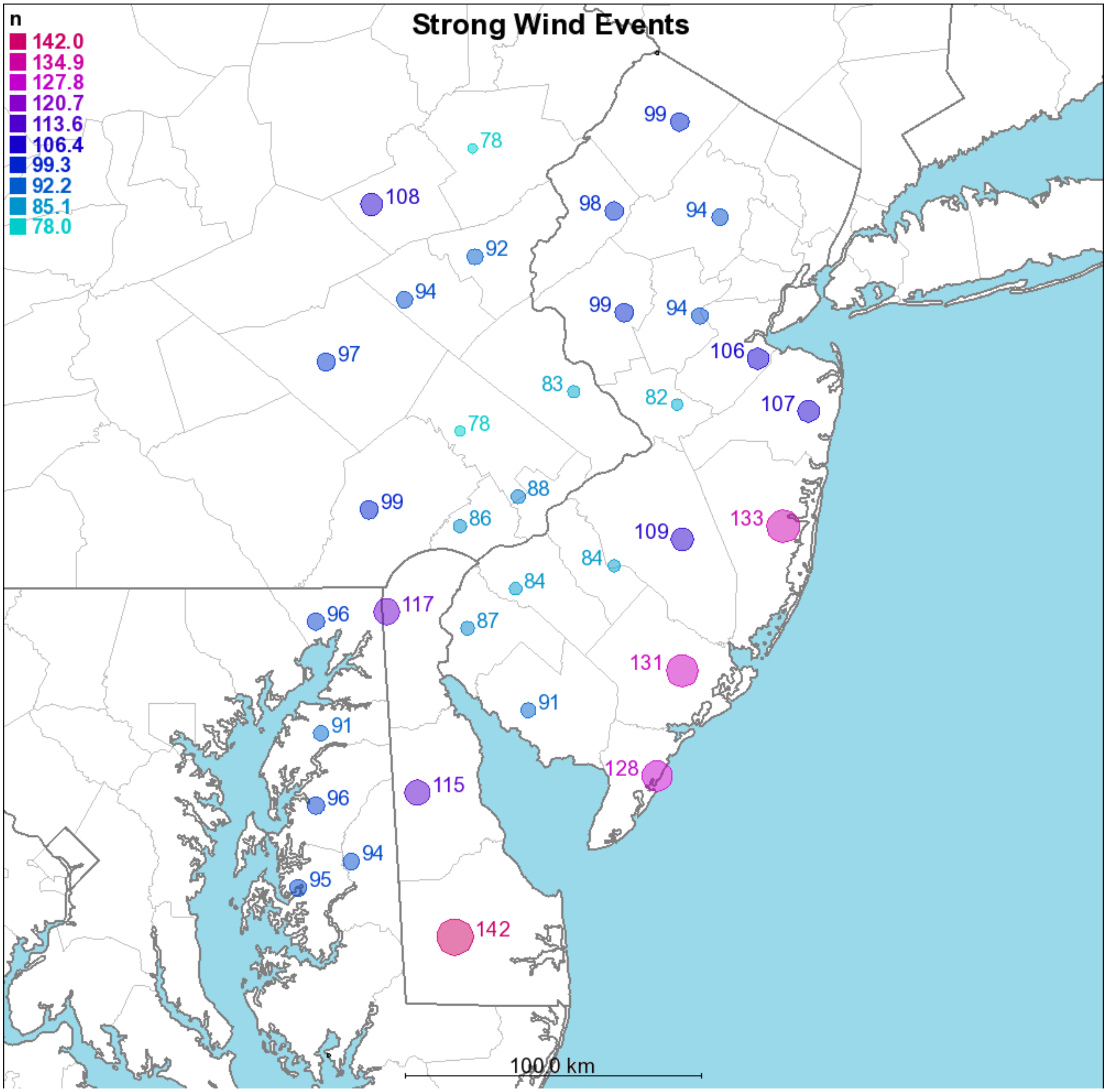

Figure 13e. As in Fig. 6e, except for strong wind events.

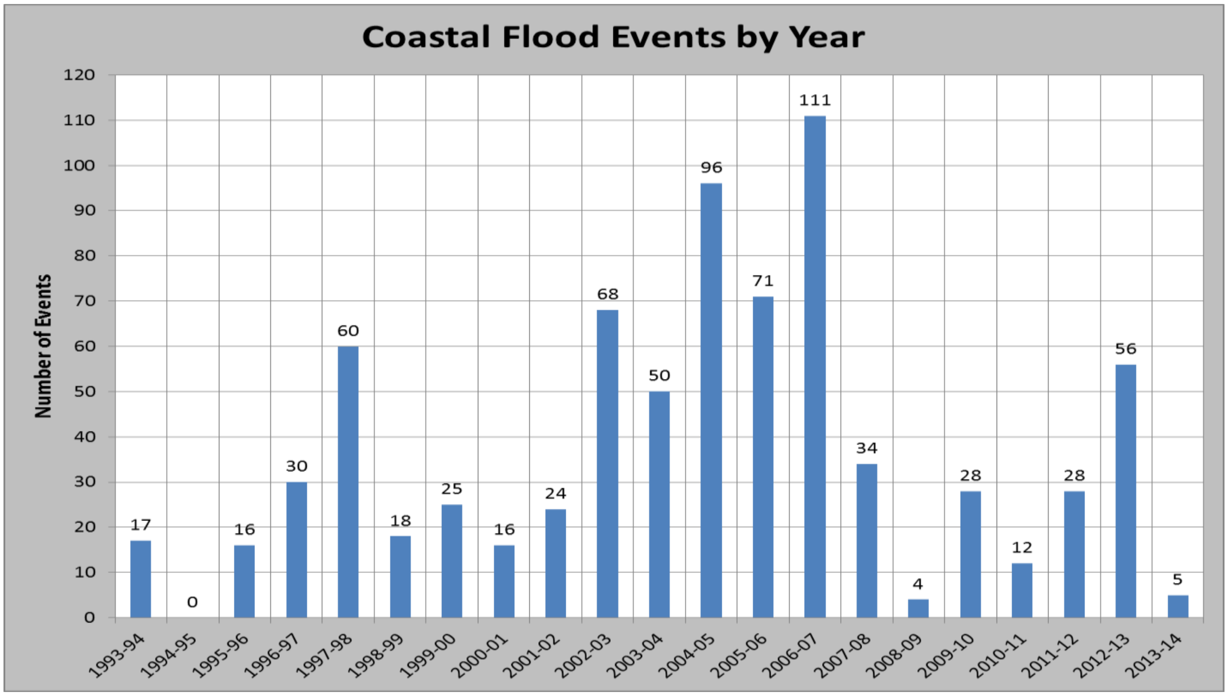

Figure 14a. As in Fig. 6a, except for 769 total coastal flood events.

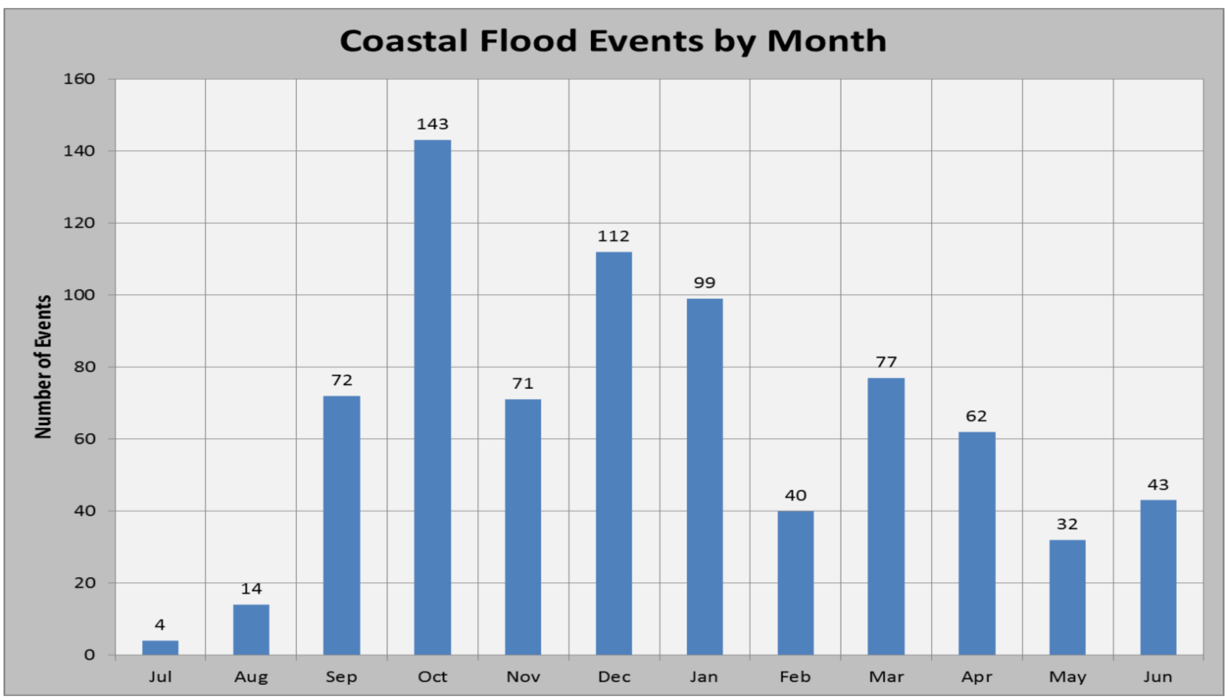

Figure 14b. As in Fig. 6b, except for coastal flood events.

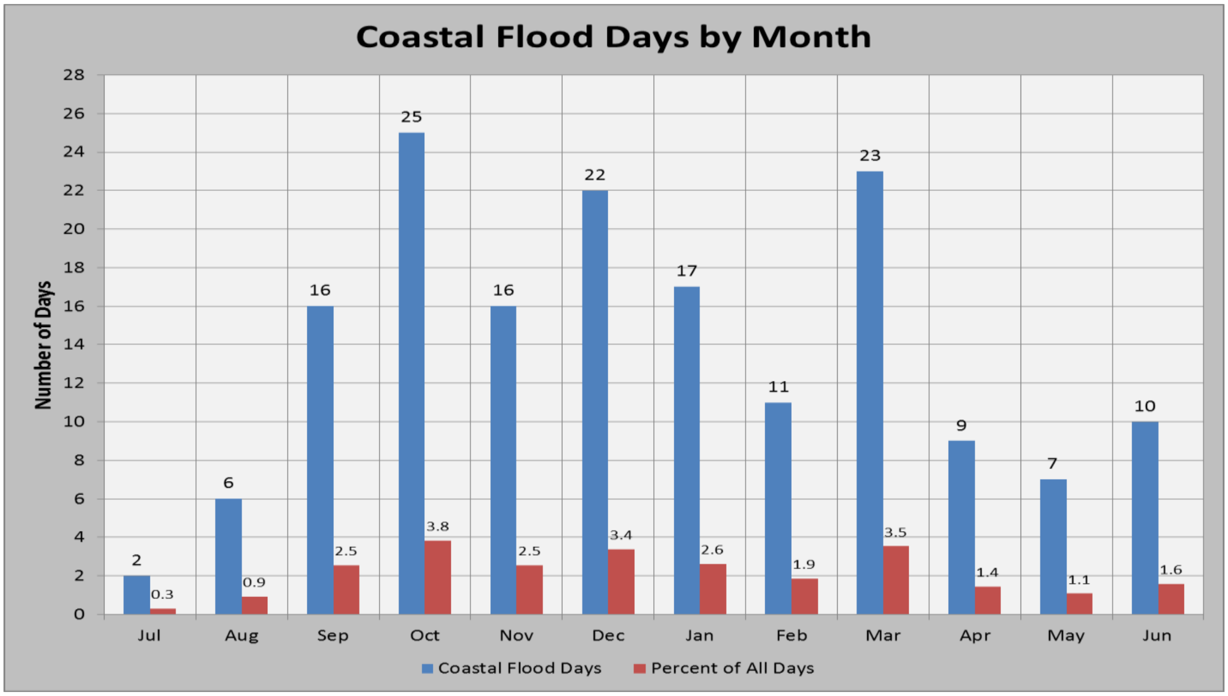

Figure 14c. As in Fig. 6c, except for 164 total days with coastal flood events.

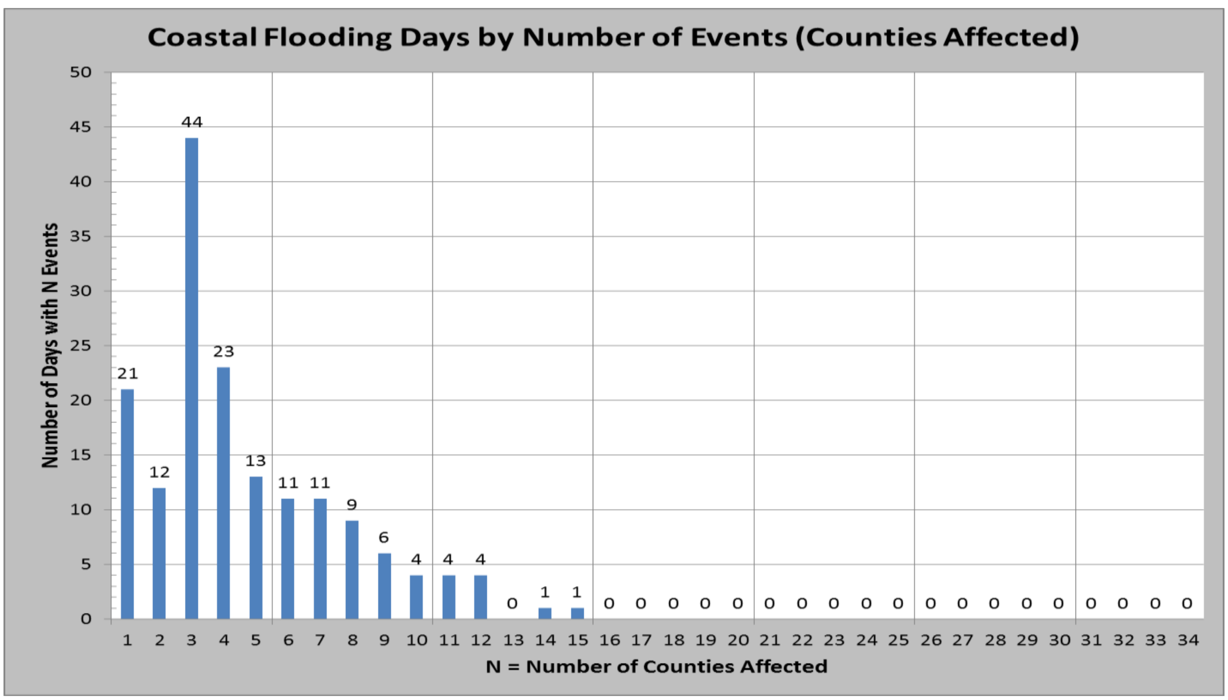

Figure 14d. As in Fig. 6d, except for coastal flood days.

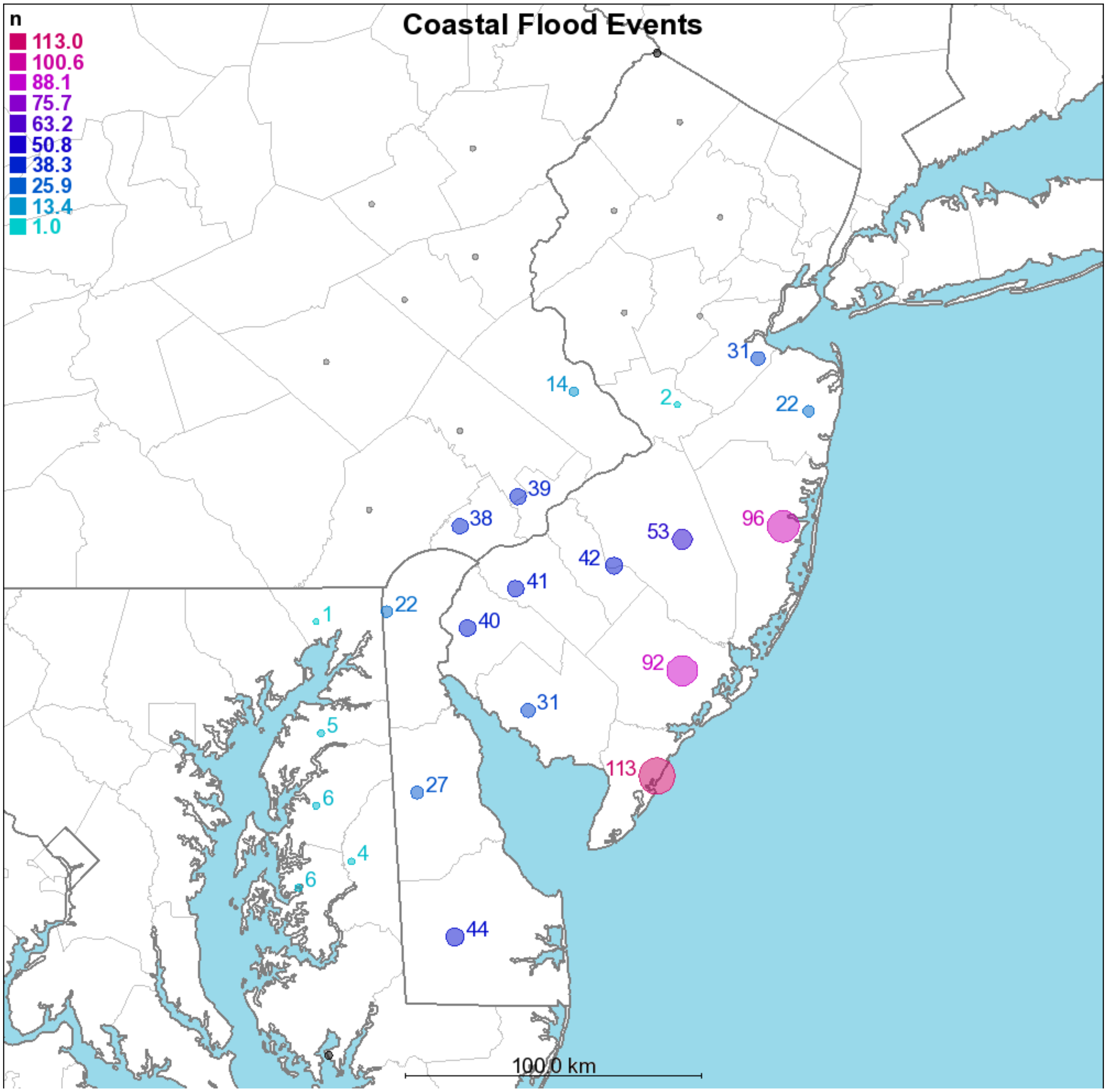

Figure 14e. As in Fig. 6e, except for coastal flood events.

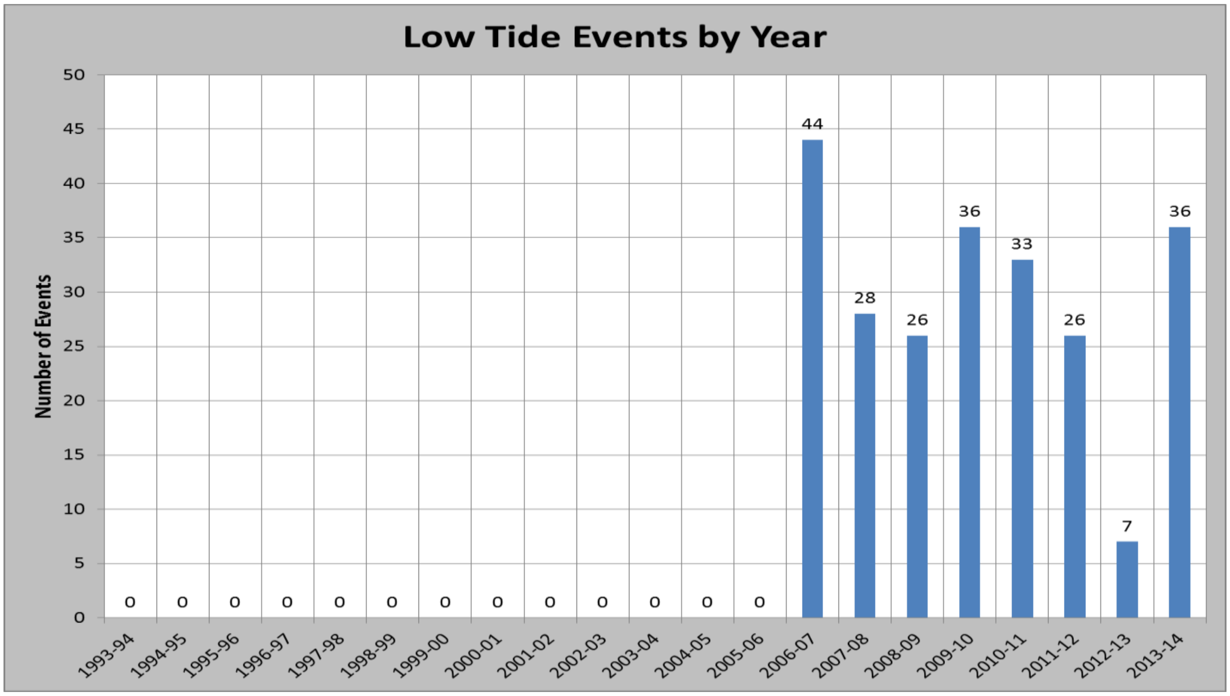

Figure 15a. As in Fig. 6a, except for 236 total blowout tide events.

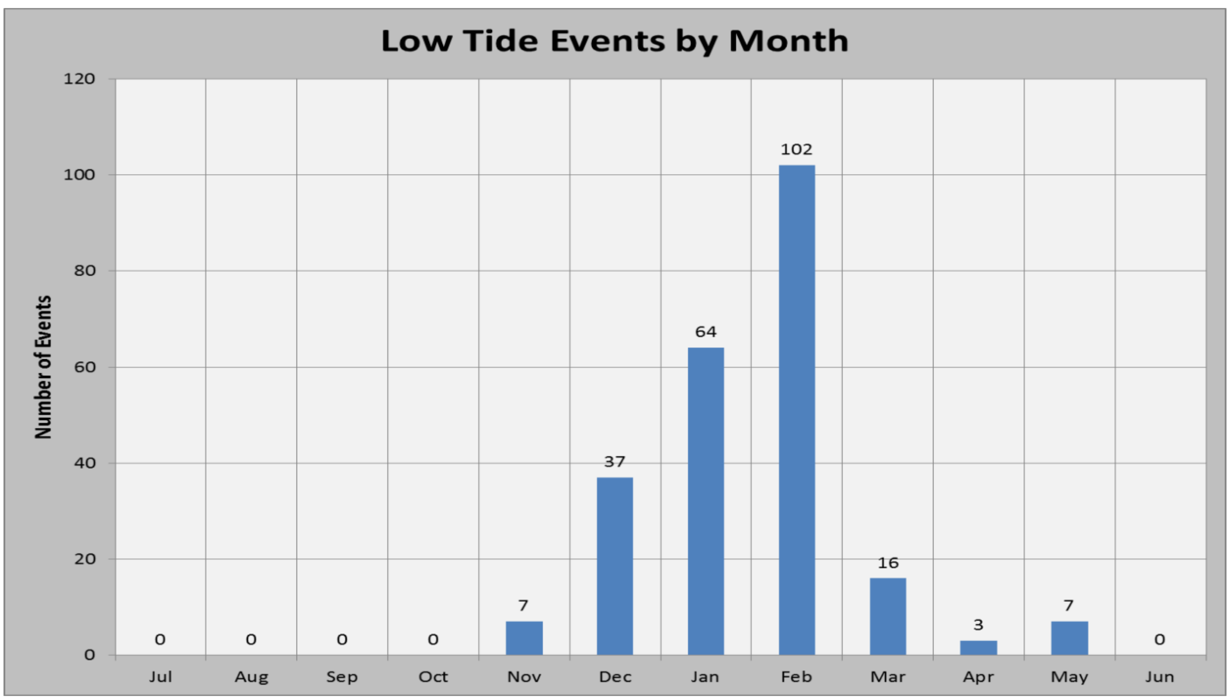

Figure 15b. As in Fig. 6b, except for blowout tide events.

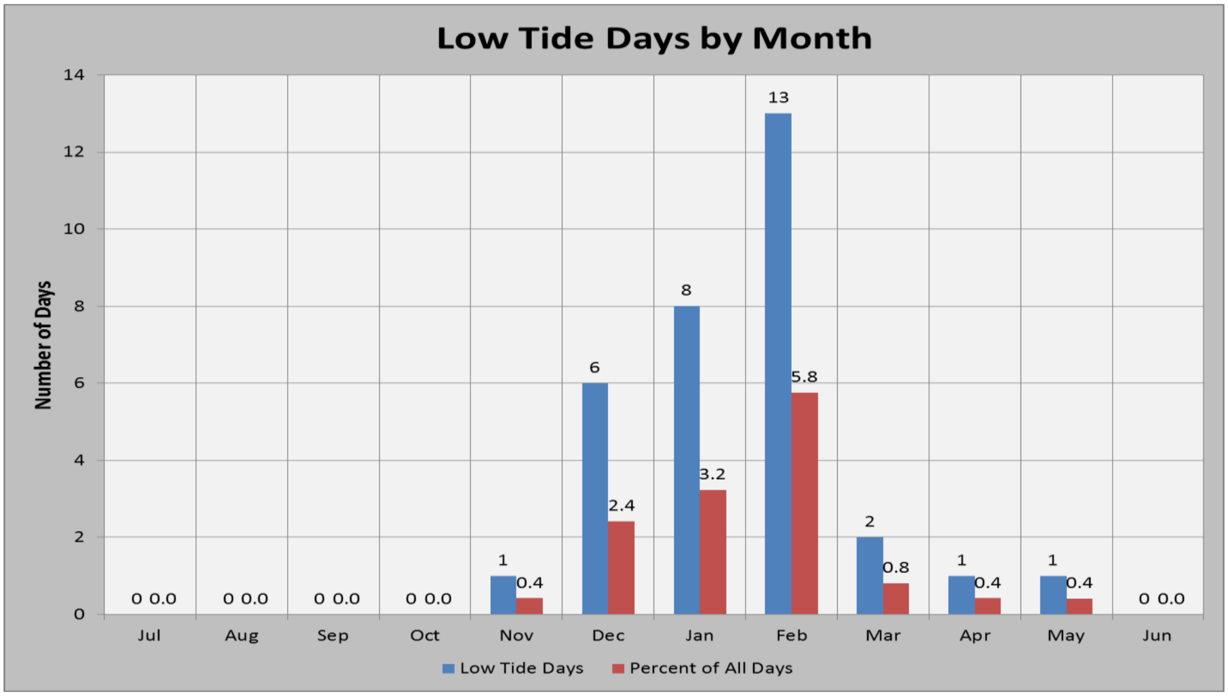

Figure 15c. As in [Fig. 6c](#), except for 32 total days with blowout tide events. (percentages based on only 8 seasons)

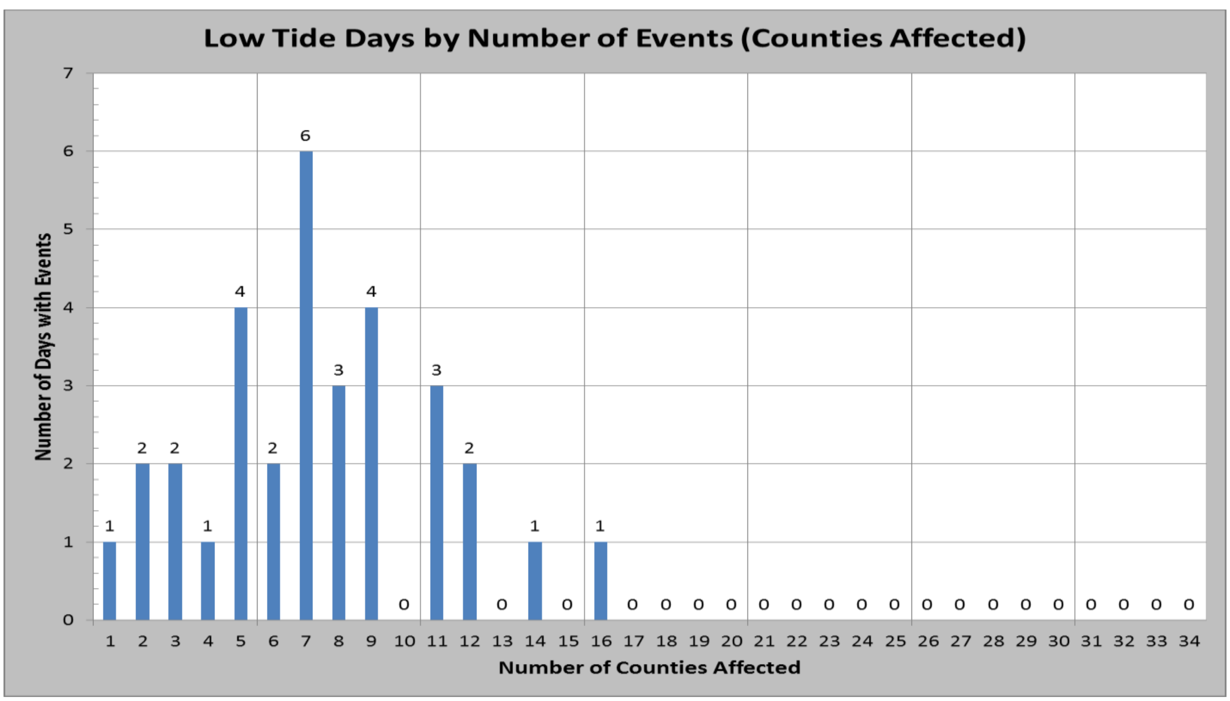

Figure 15d. As in [Fig. 6d](#), except for blowout tide days.

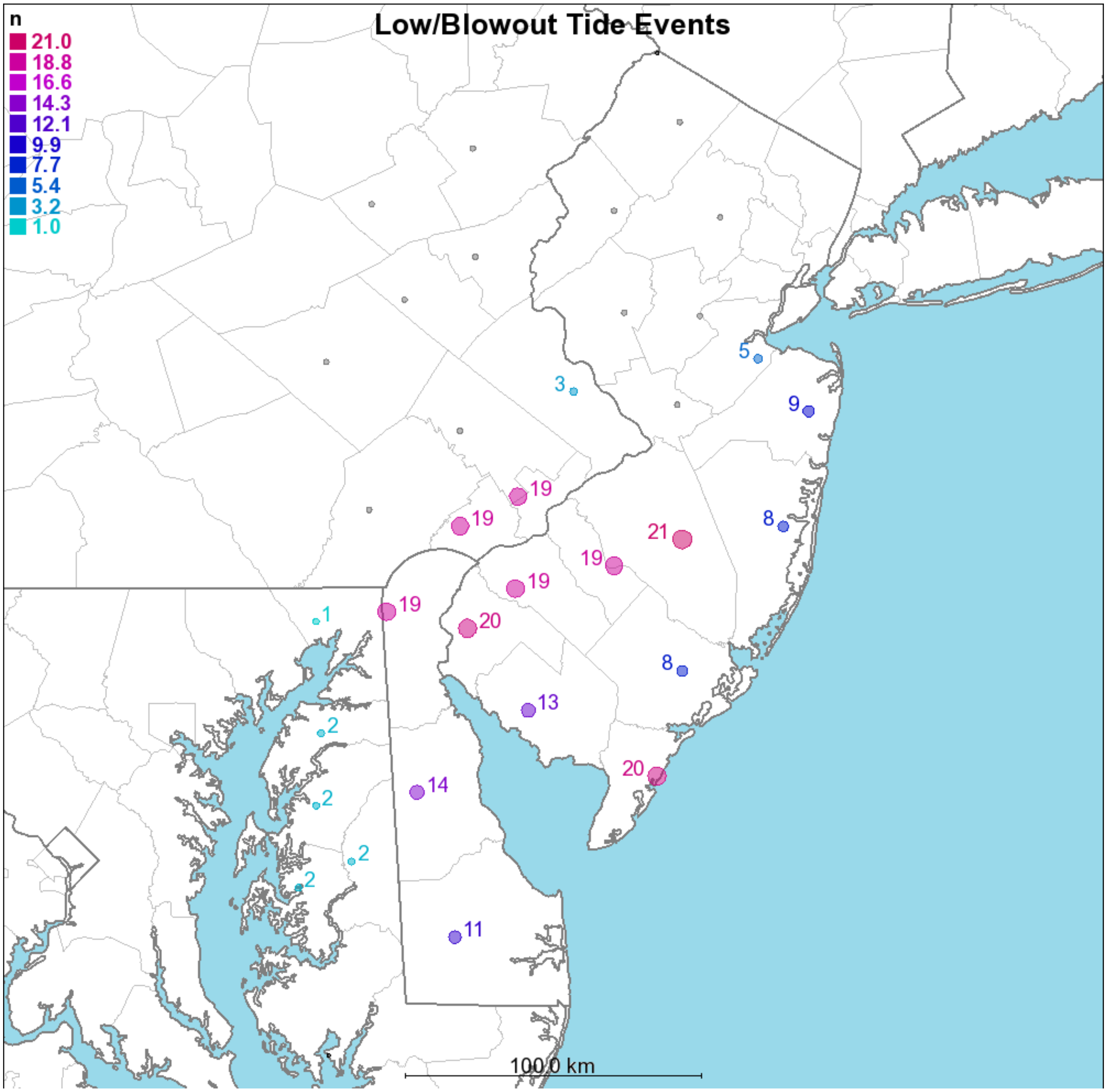

Figure 15e. As in Fig. 6e, except for blowout tide events.

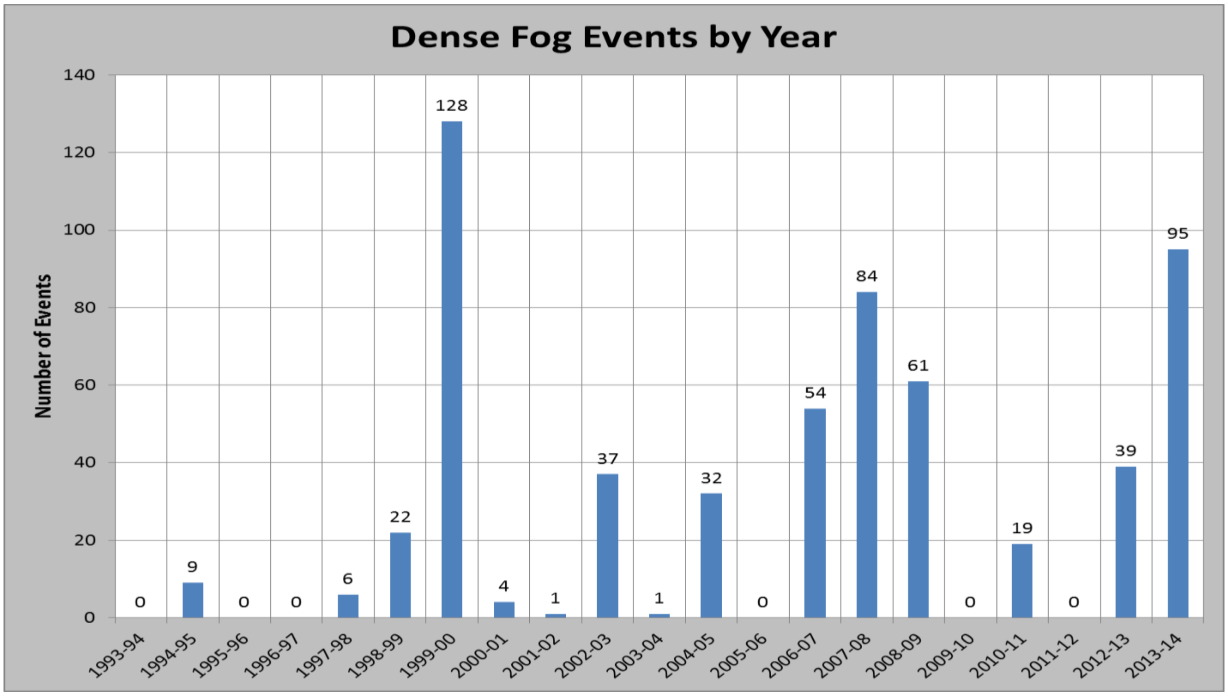

Figure 16a. As in Fig. 6a, except for 592 total dense fog events.

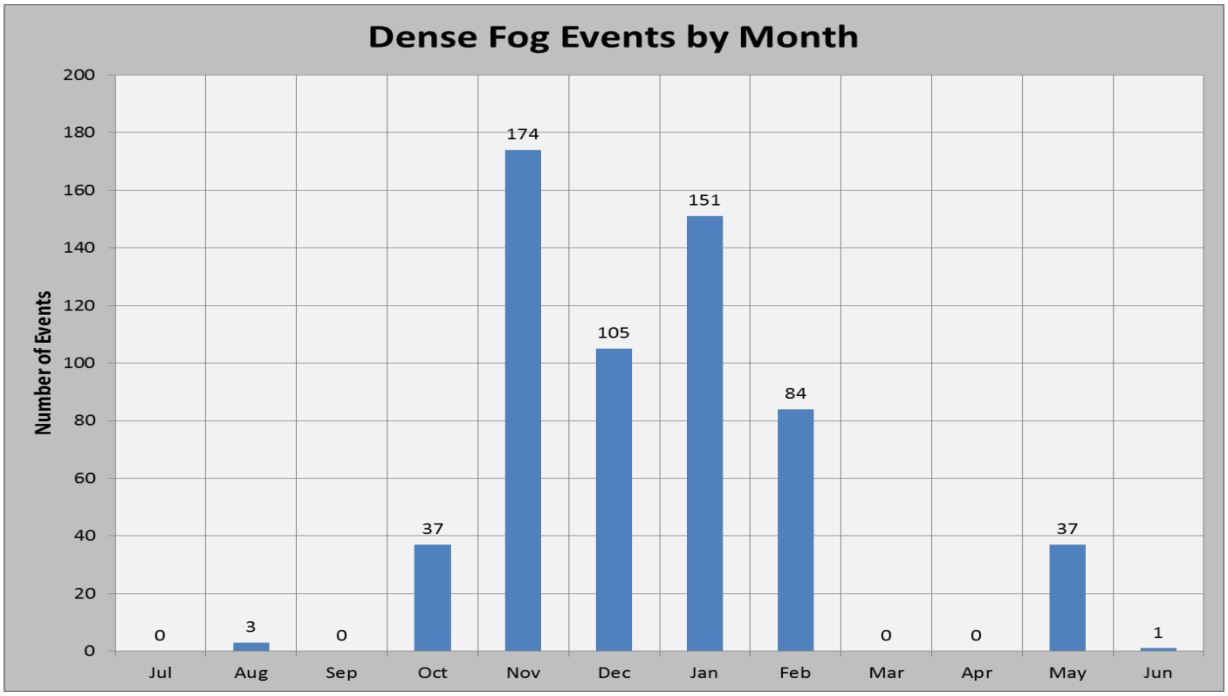

Figure 16b. As in Fig. 6b, except for dense fog events.

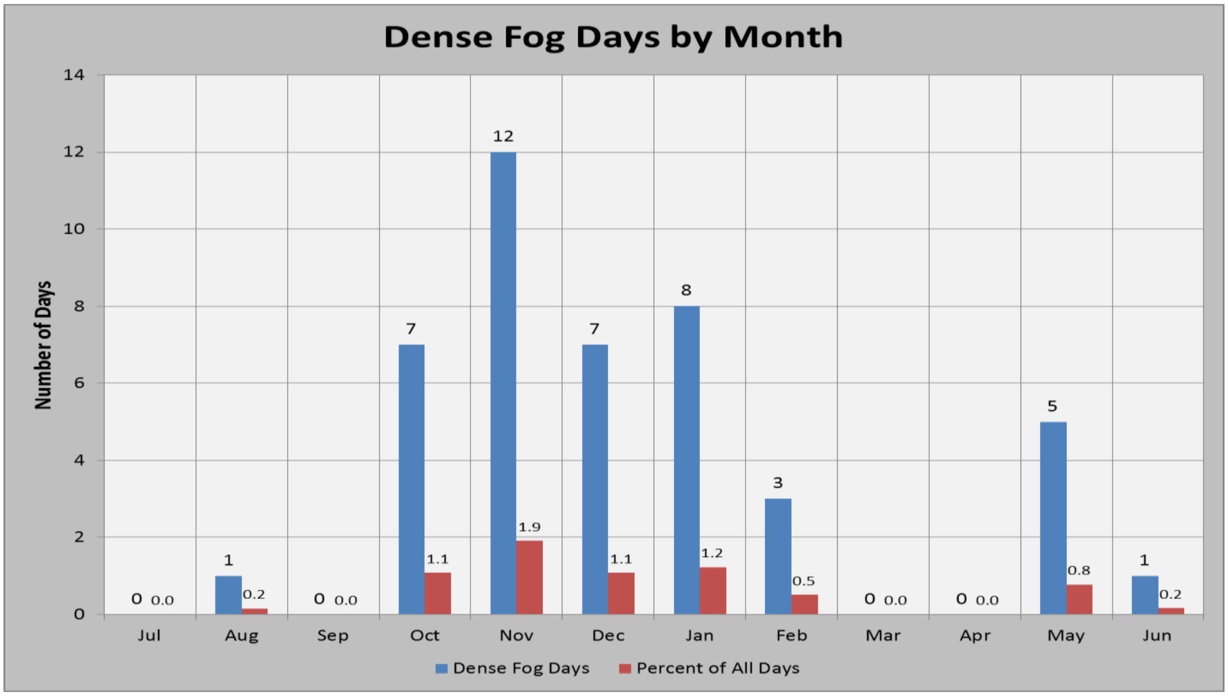

Figure 16c. As in Fig. 6c, except for 44 total days with dense fog events.

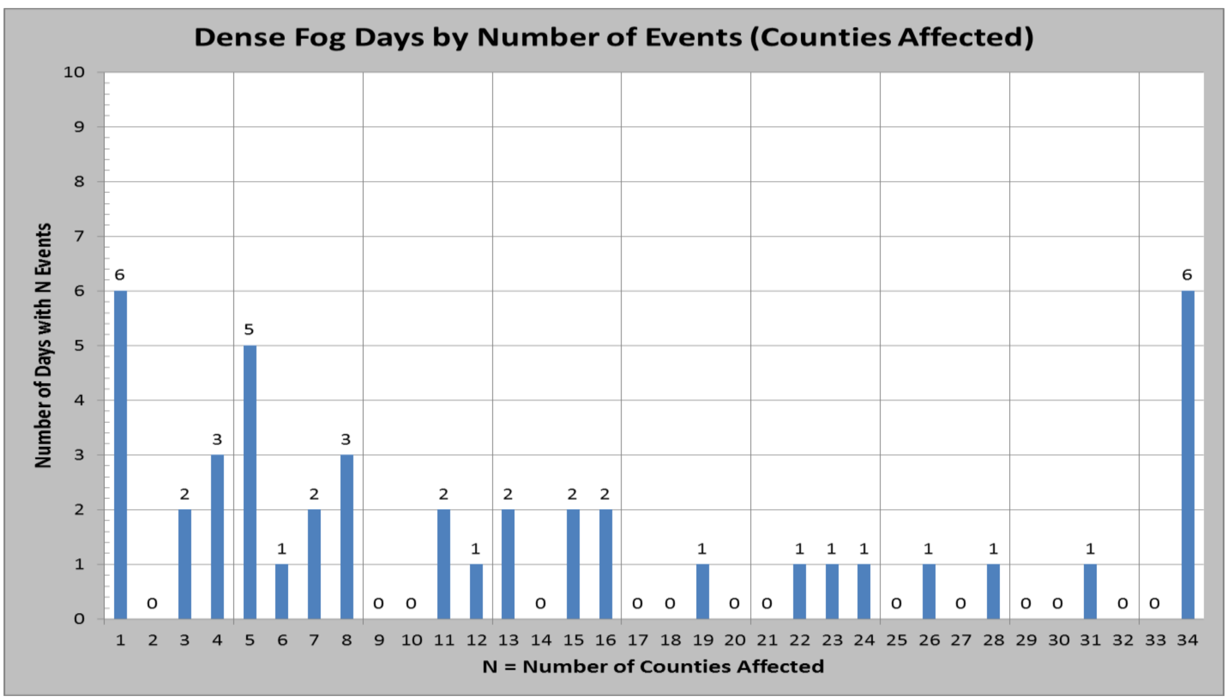

Figure 16d. As in Fig. 6d, except for dense fog days.

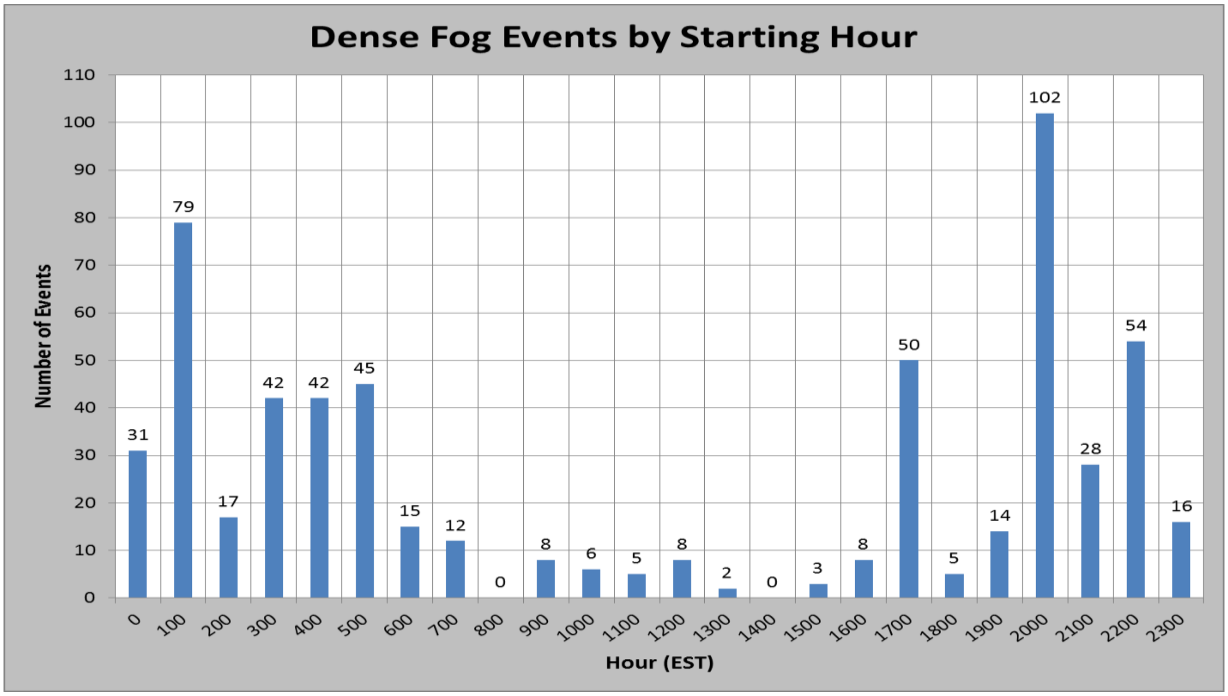

Figure 16e. Distribution of dense fog events by the starting hour.

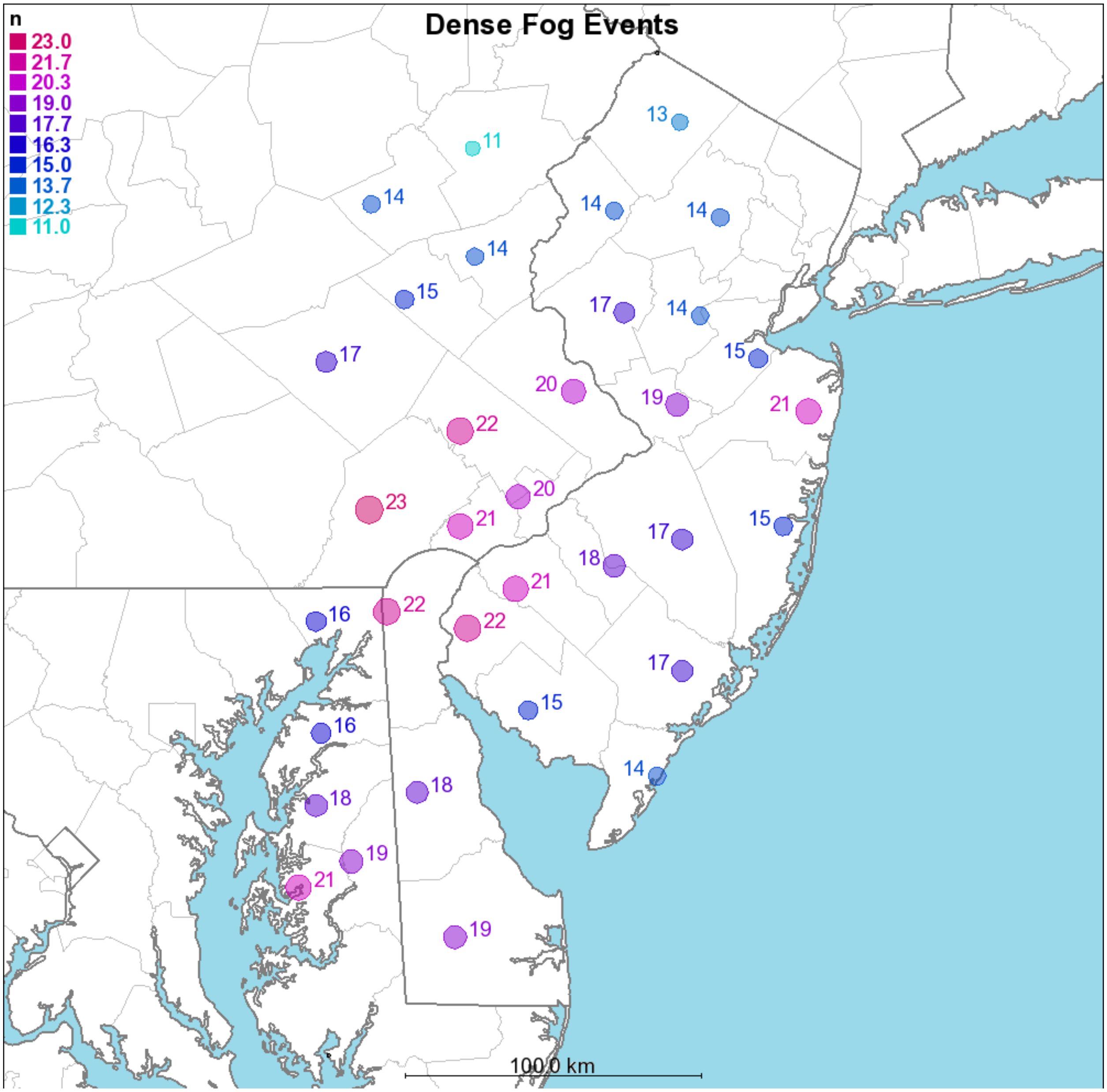

Figure 16f. As in Fig. 6e, except for dense fog events.

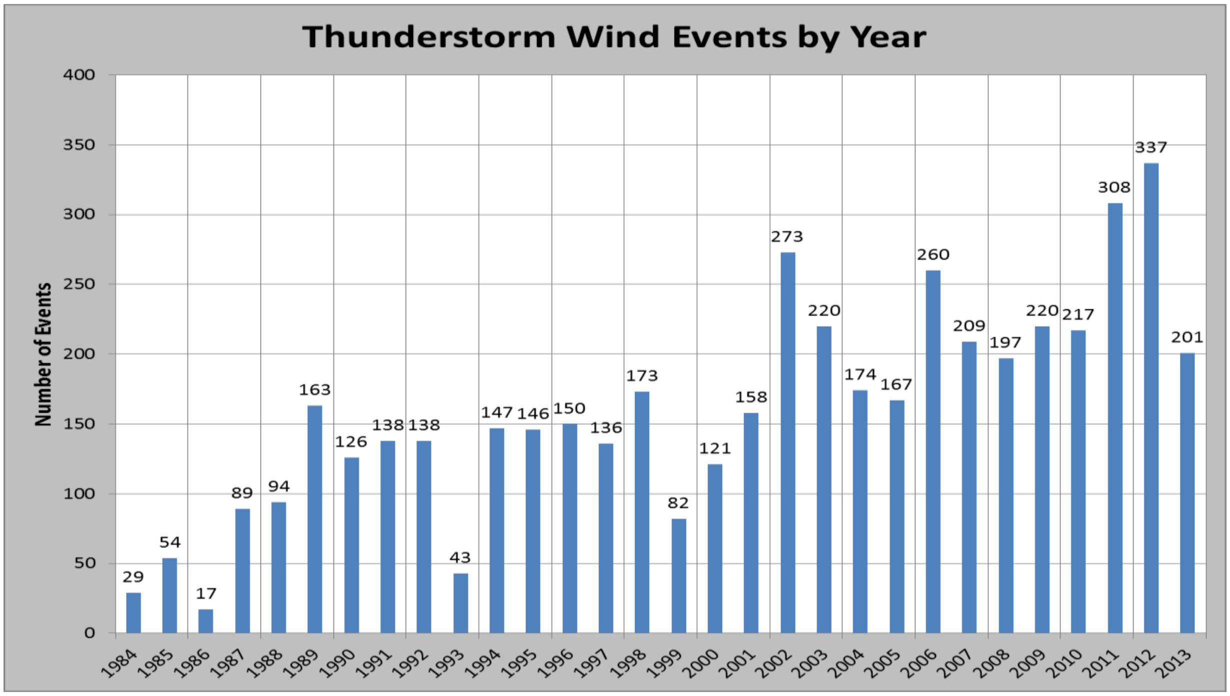

Figure 17a. Distribution by year of 4787 total severe thunderstorm wind events in the WFO PHI forecast area.

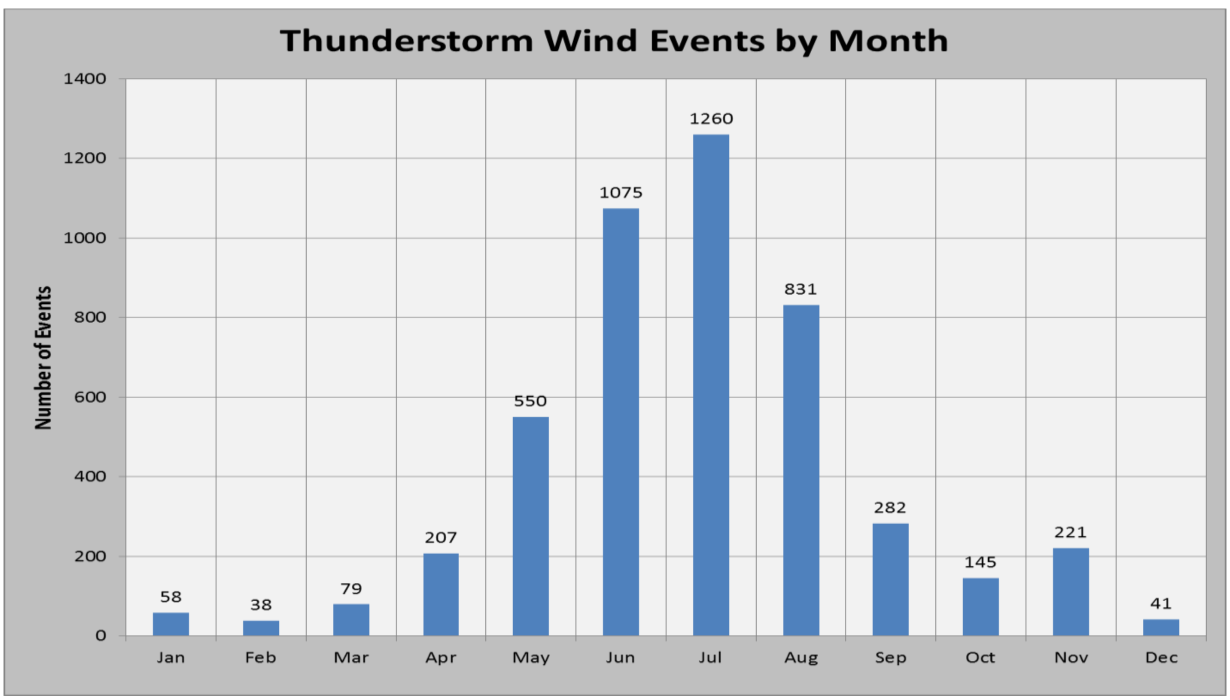

Figure 17b. Distribution of severe thunderstorm wind events by month in the WFO PHI forecast area.

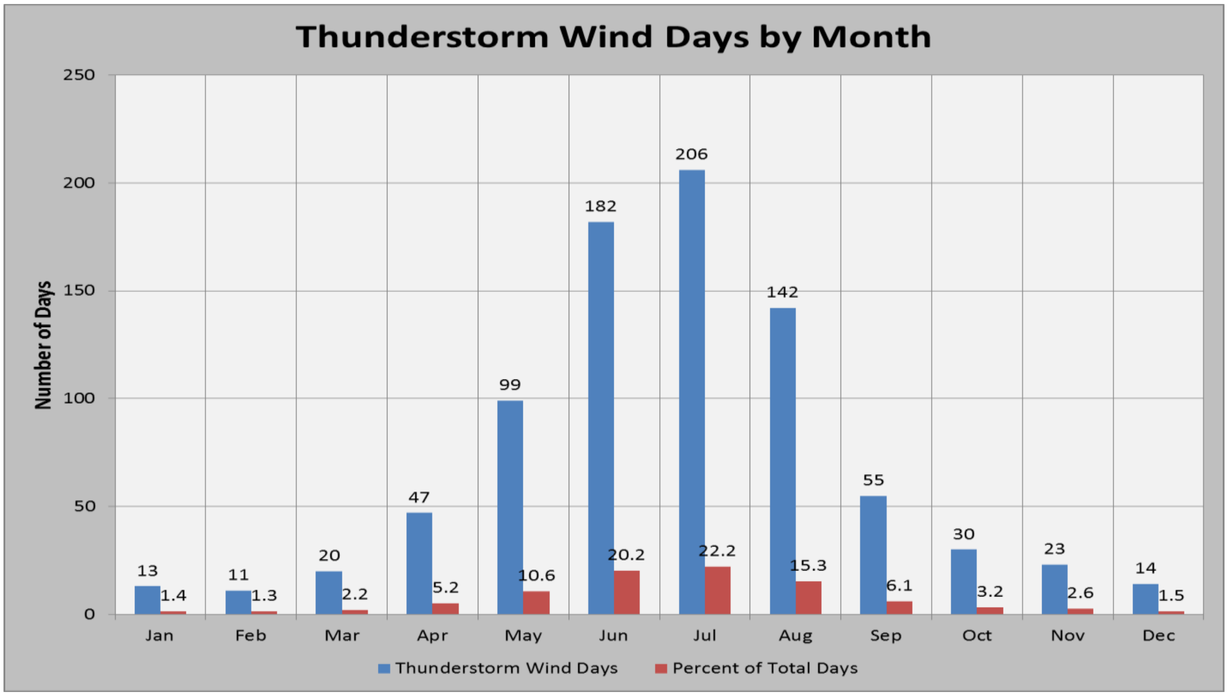

Figure 17c. Number and percentage of days per month with at least one severe thunderstorm wind event in the WFO PHI forecast area. Total number of days is 842.

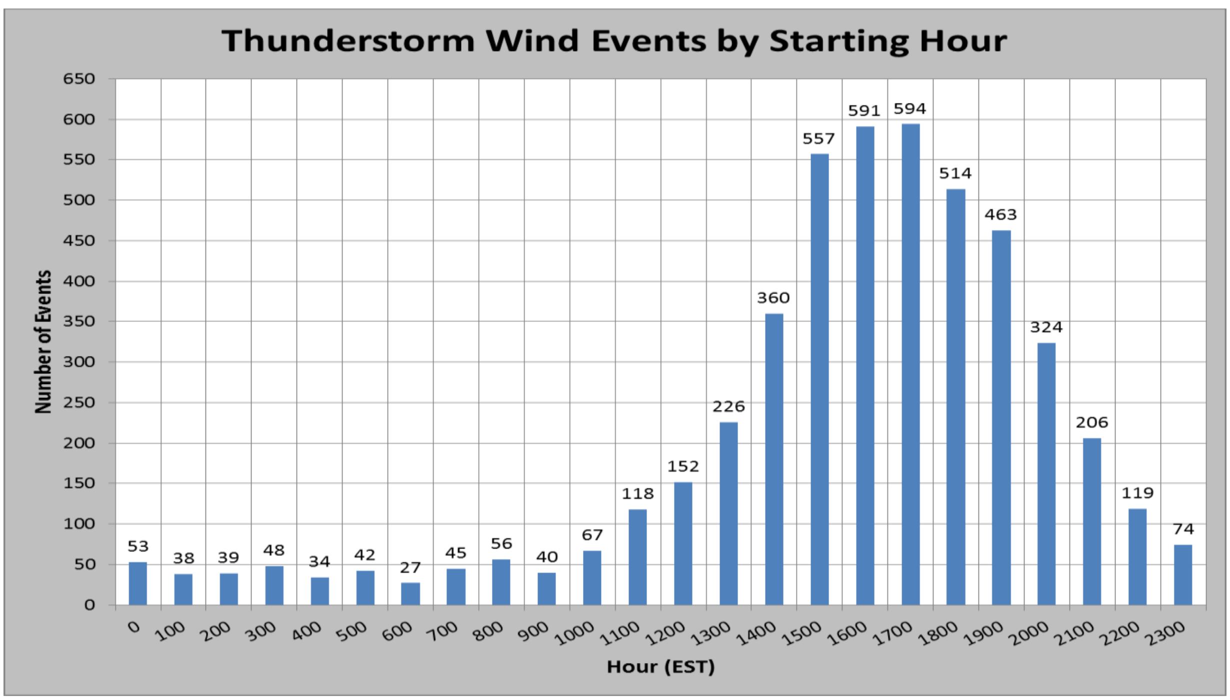

Figure 17d. Distribution of all severe thunderstorm wind events in the WFO PHI forecast area by hour of occurrence.

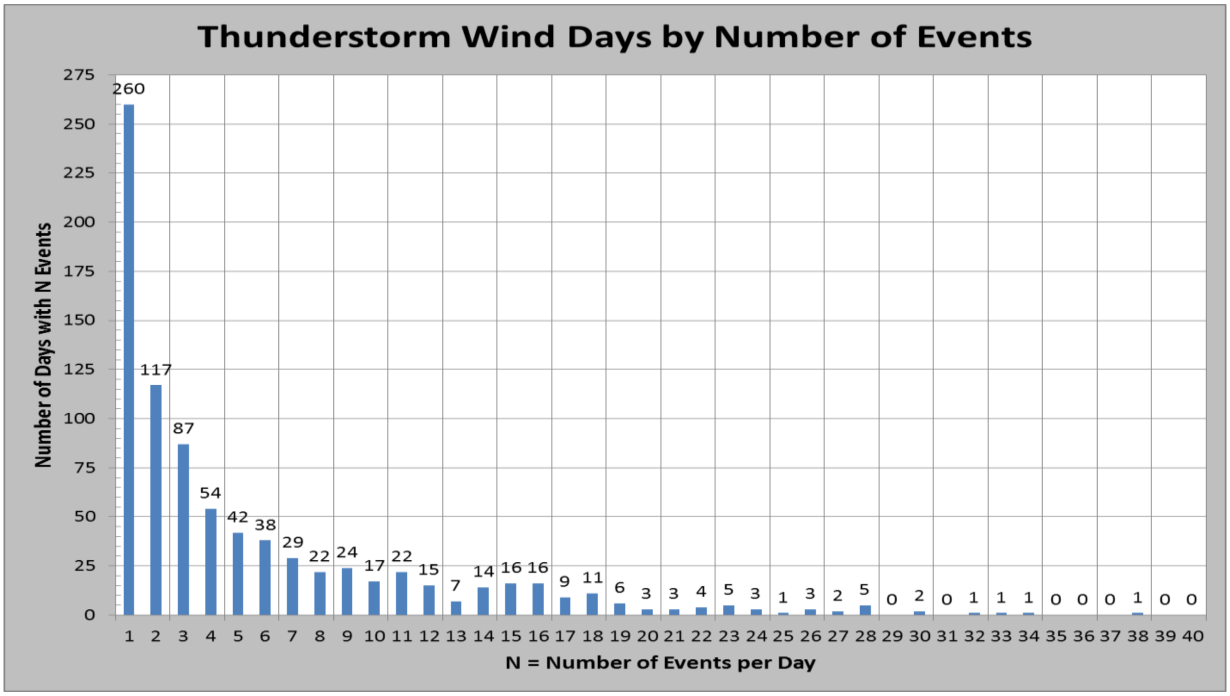

Figure 17e. Distribution of severe thunderstorm wind event days by the number of events. (One day with 51 reports is not shown here.)

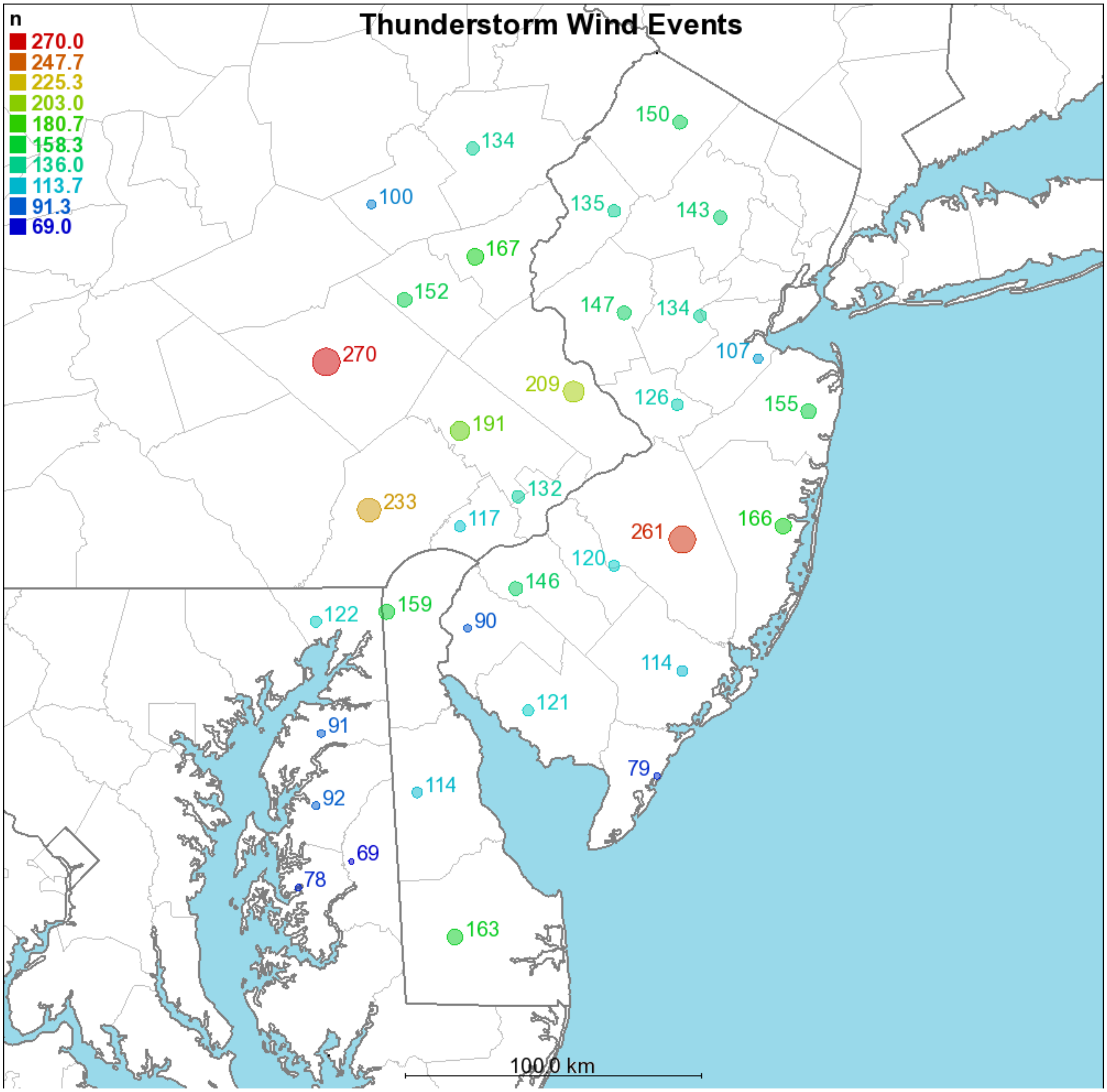

Figure 17f. Distribution of severe thunderstorm wind events by county in the WFO PHI forecast area.

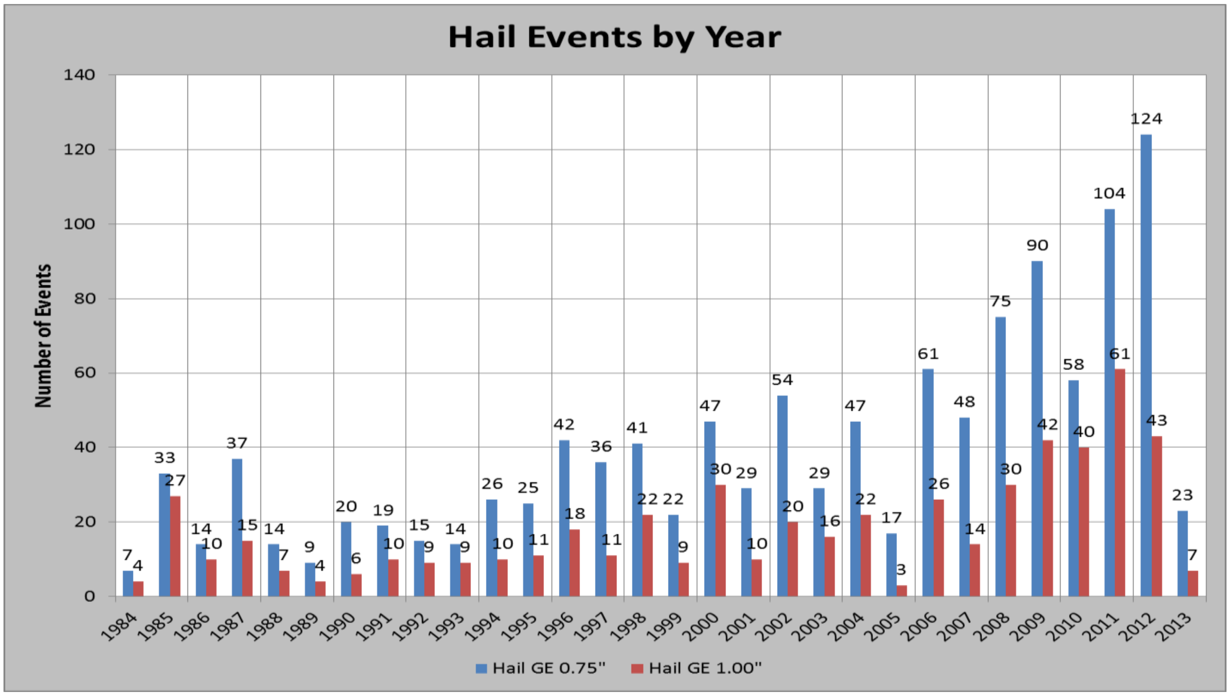

Figure 18a. As in Fig. 17a, except for 1180 (546) large hail events, with hail size greater than or equal to 0.75 inch (1.00 inch).

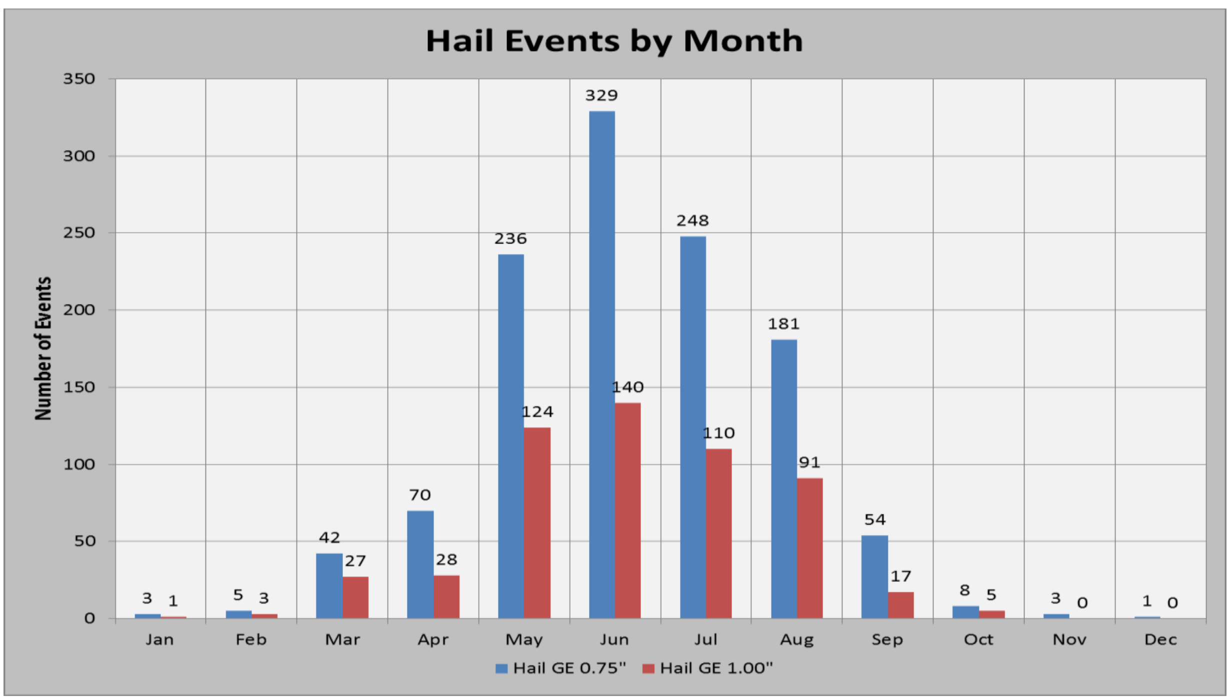

Figure 18b. As in Fig. 17b, except for large hail events.

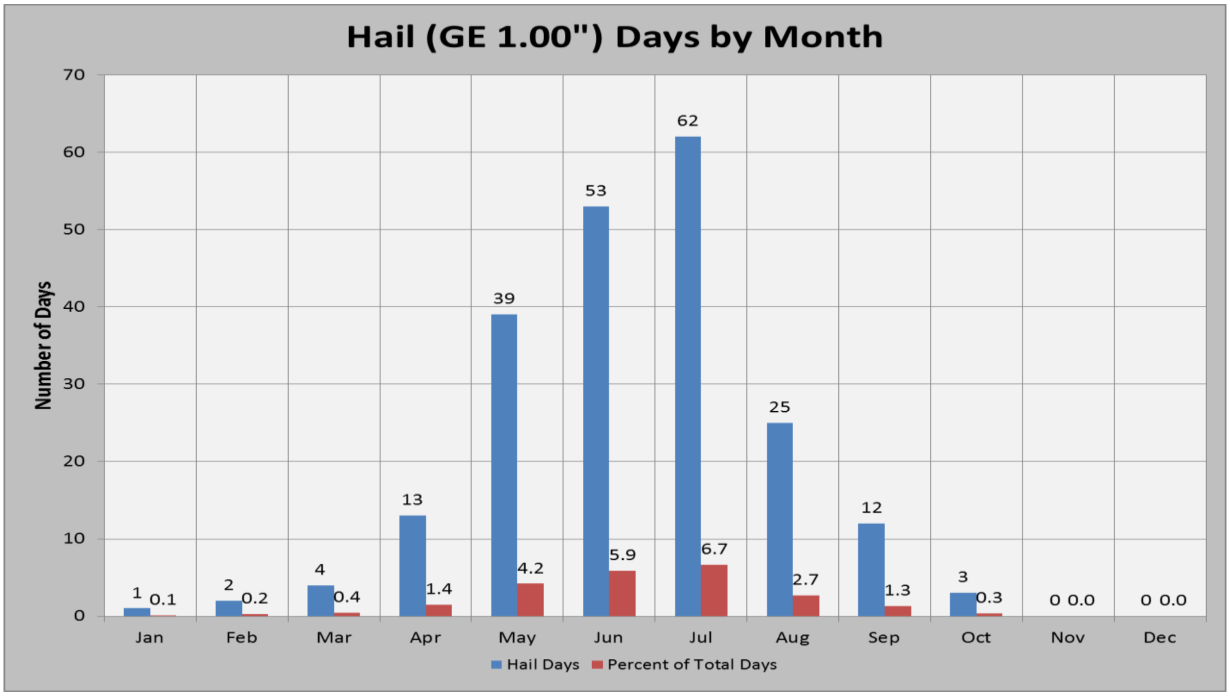

Figure 18c. As in [Fig. 17c](#), except for 214 total days with large hail events (greater than or equal to 1 inch only).

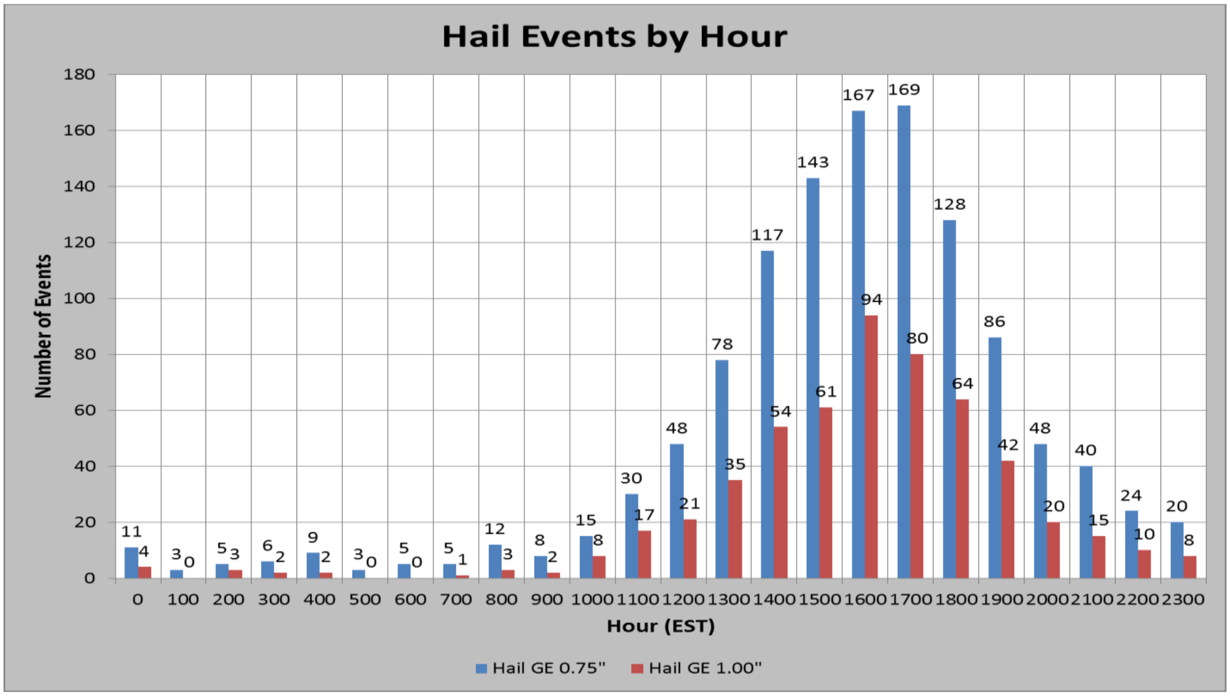

Figure 18d. As in [Fig. 17d](#), except for large hail events (greater than or equal to 1 inch only).

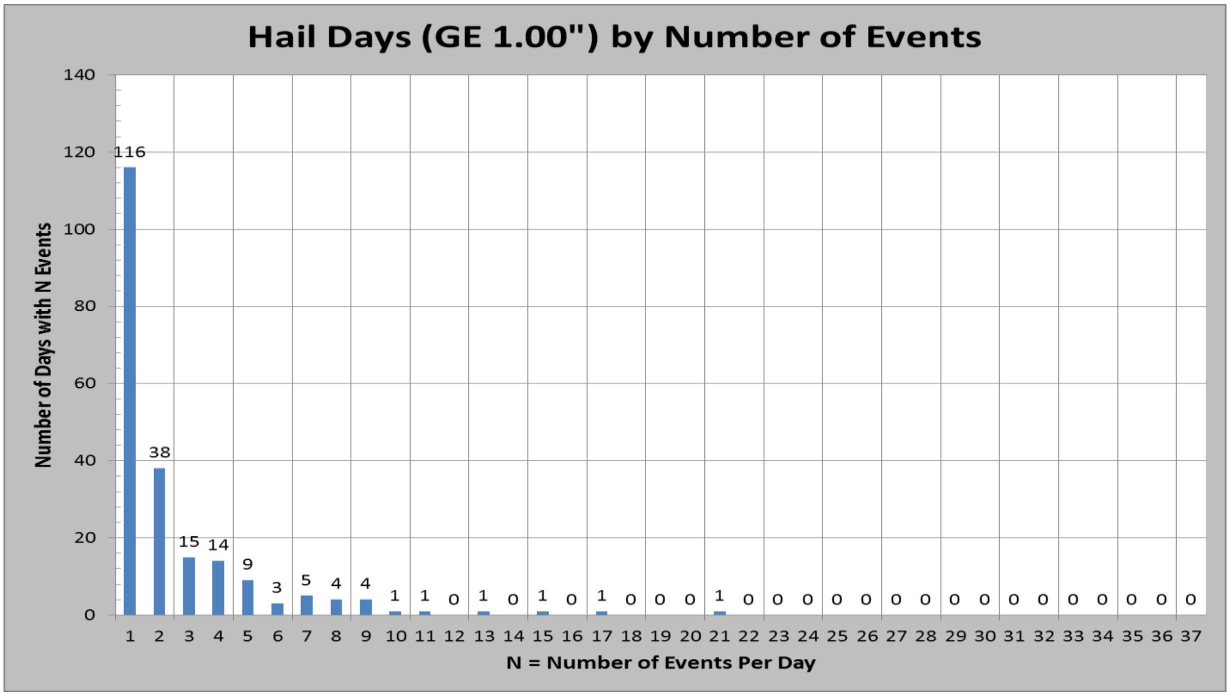

Figure 18e. As in Fig. 17e, except for large hail days (greater than or equal to 1 inch only).
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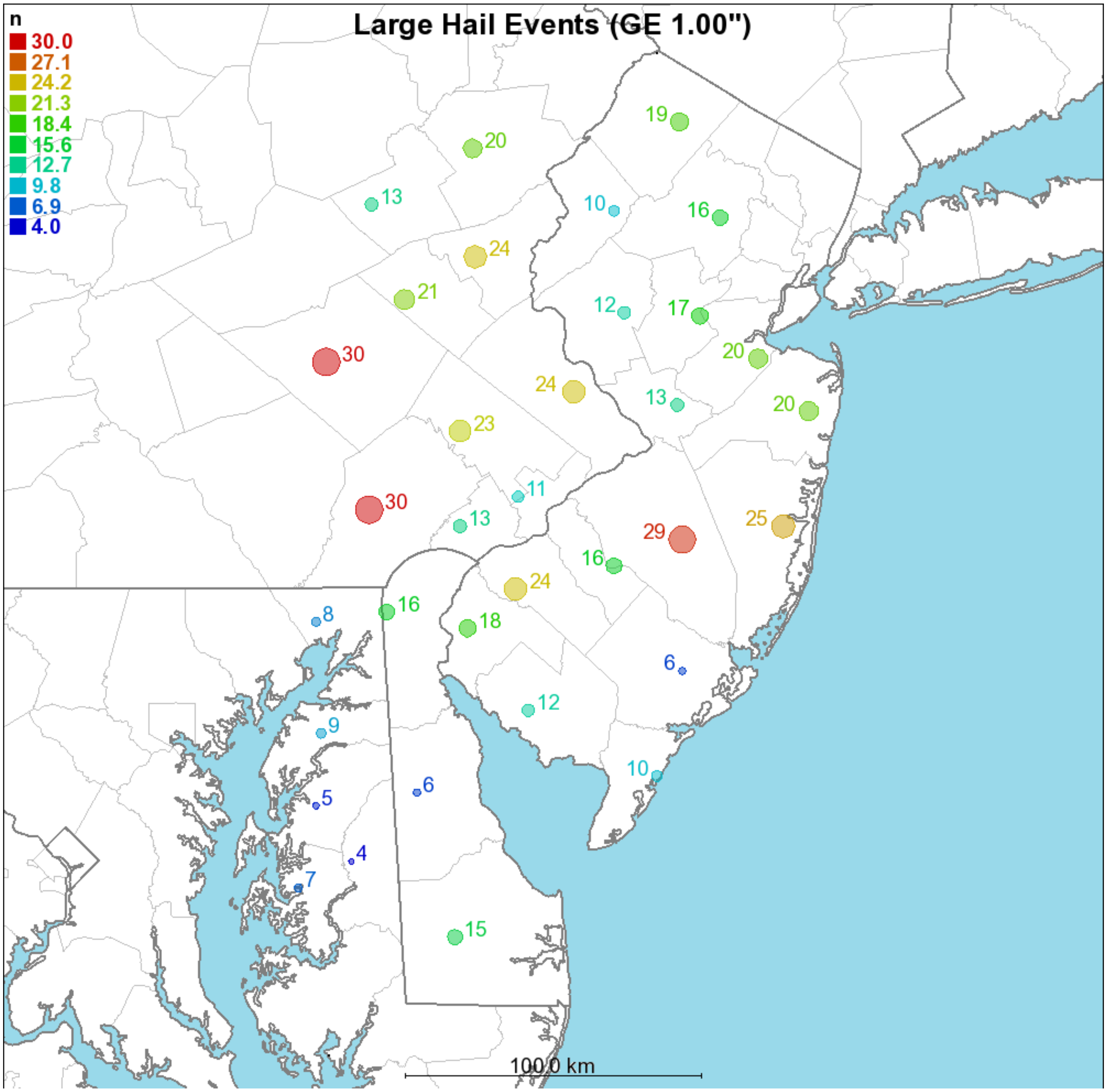

Figure 18f. As in Fig. 17f, except for large hail events (greater than or equal to 1 inch).

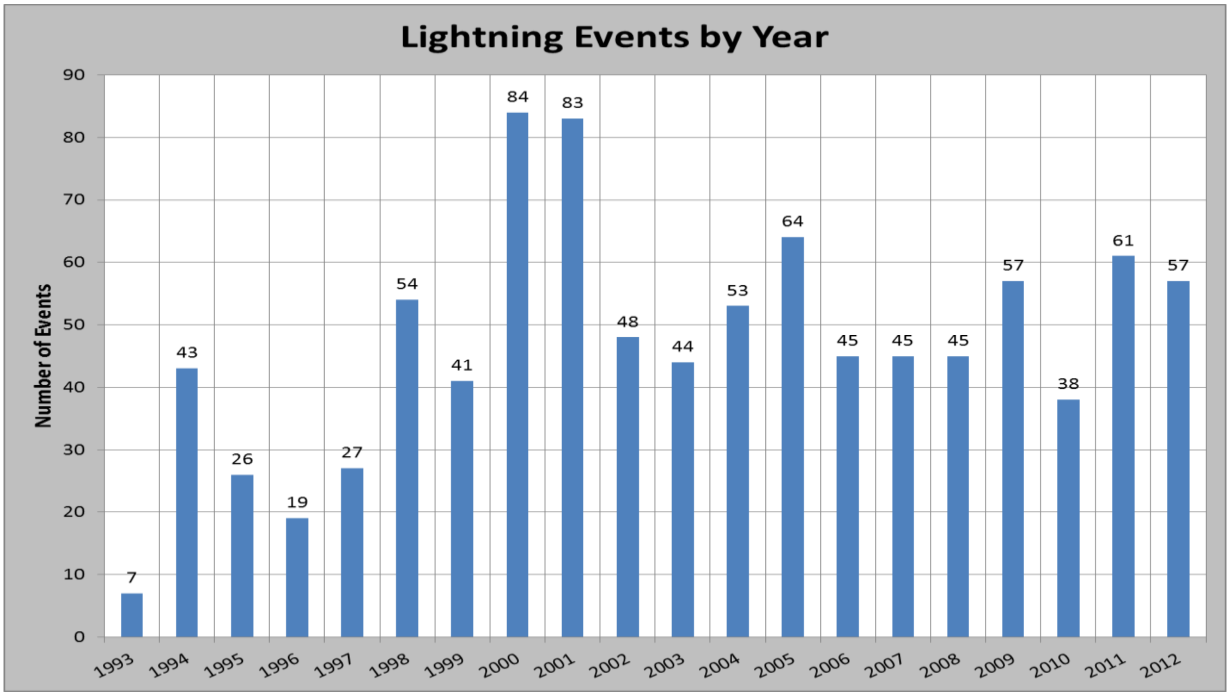

Figure 19a. As in Fig. 17a, except for 972 total lightning events.

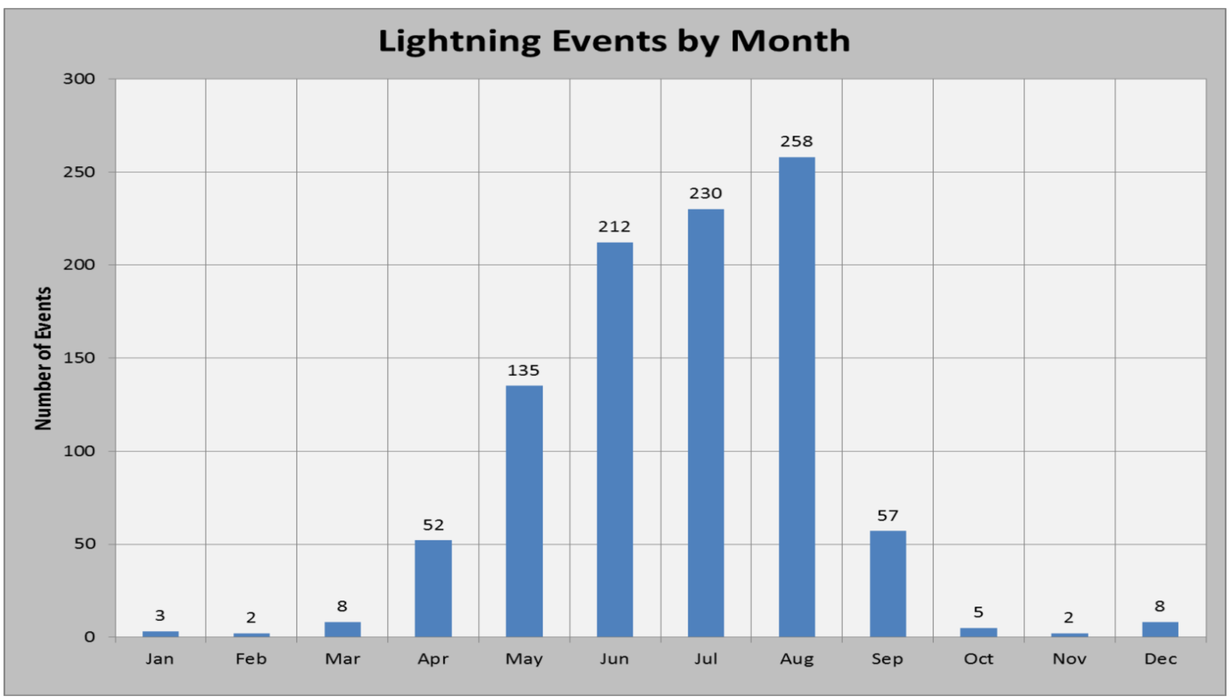

Figure 19b. As in Fig. 17b, except for lightning events.

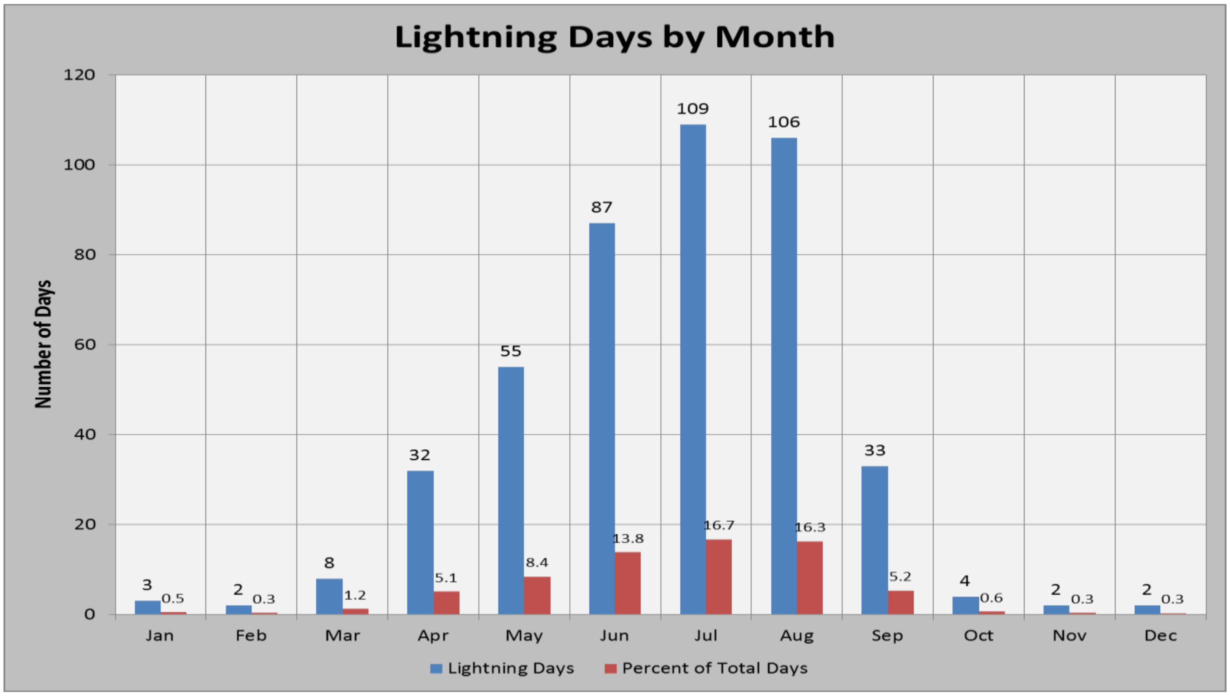

Figure 19c. As in Fig. 17c, except for 443 total days with lightning events.

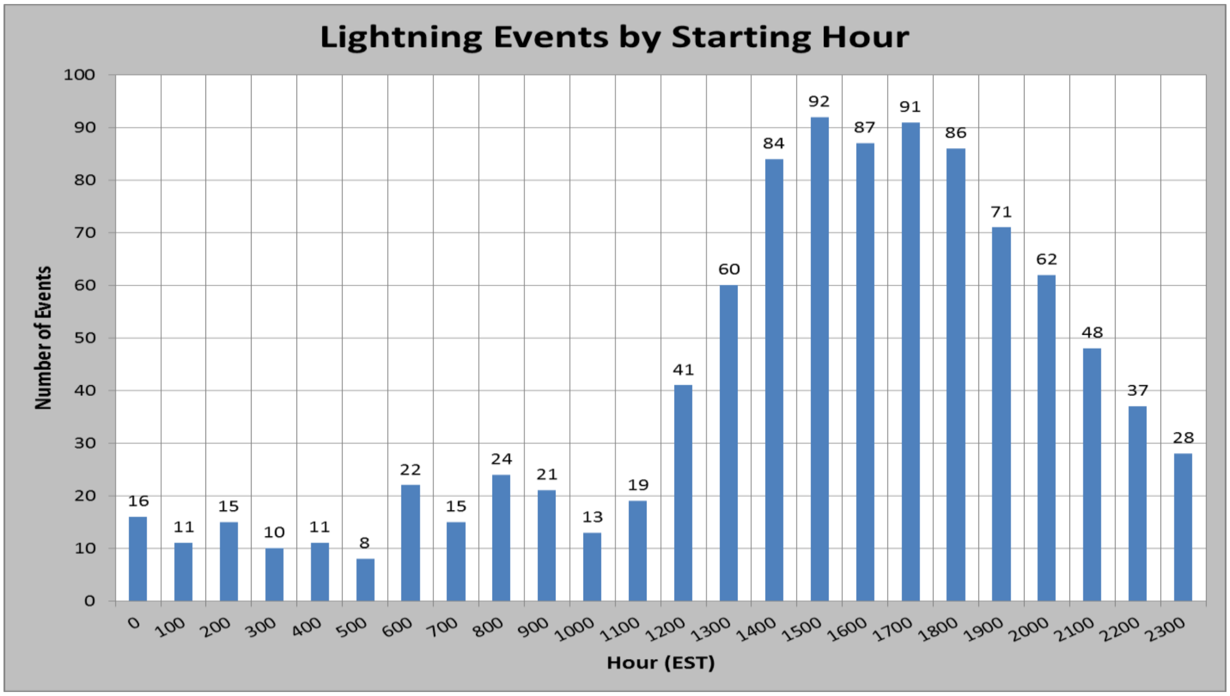

Figure 19d. As in Fig. 17d, except for lightning events.

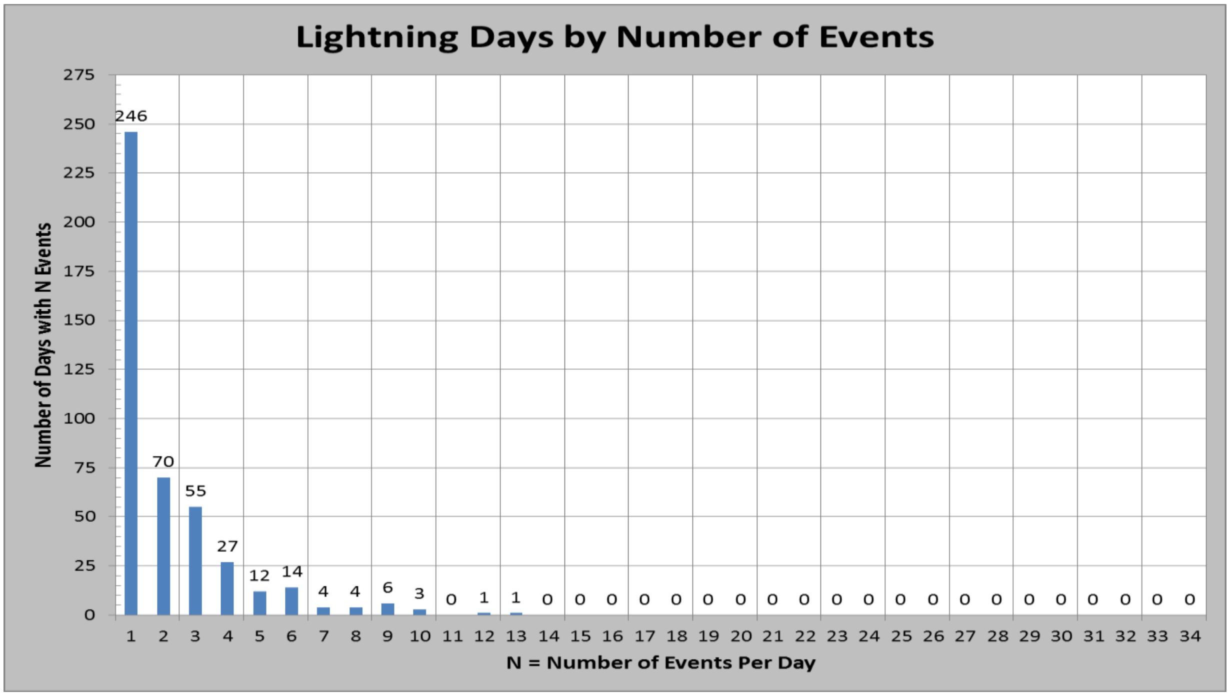

Figure 19e. As in Fig. 17e, except for lightning days.

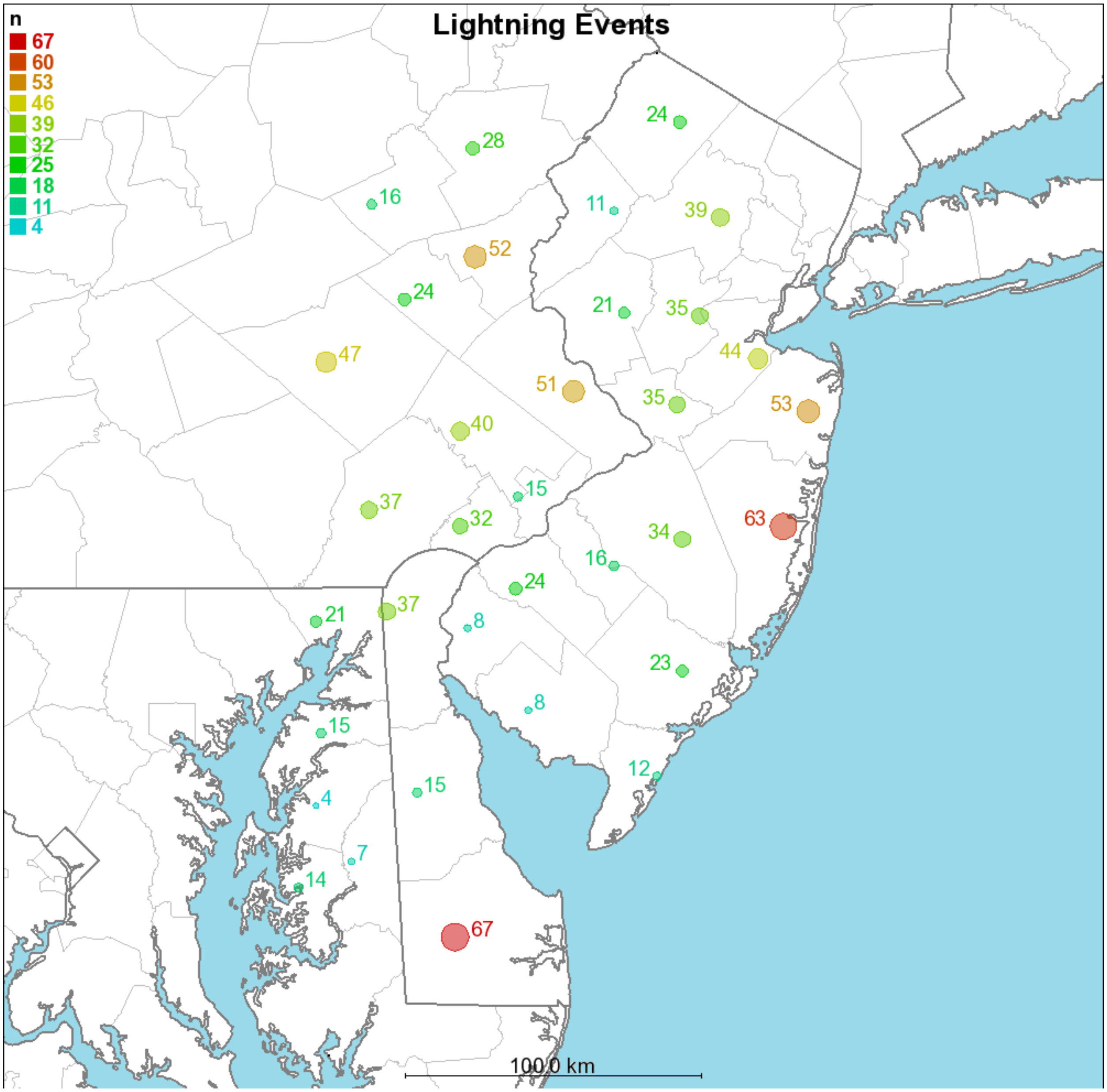

Figure 19f. As in Fig. 17f, except for lightning events.

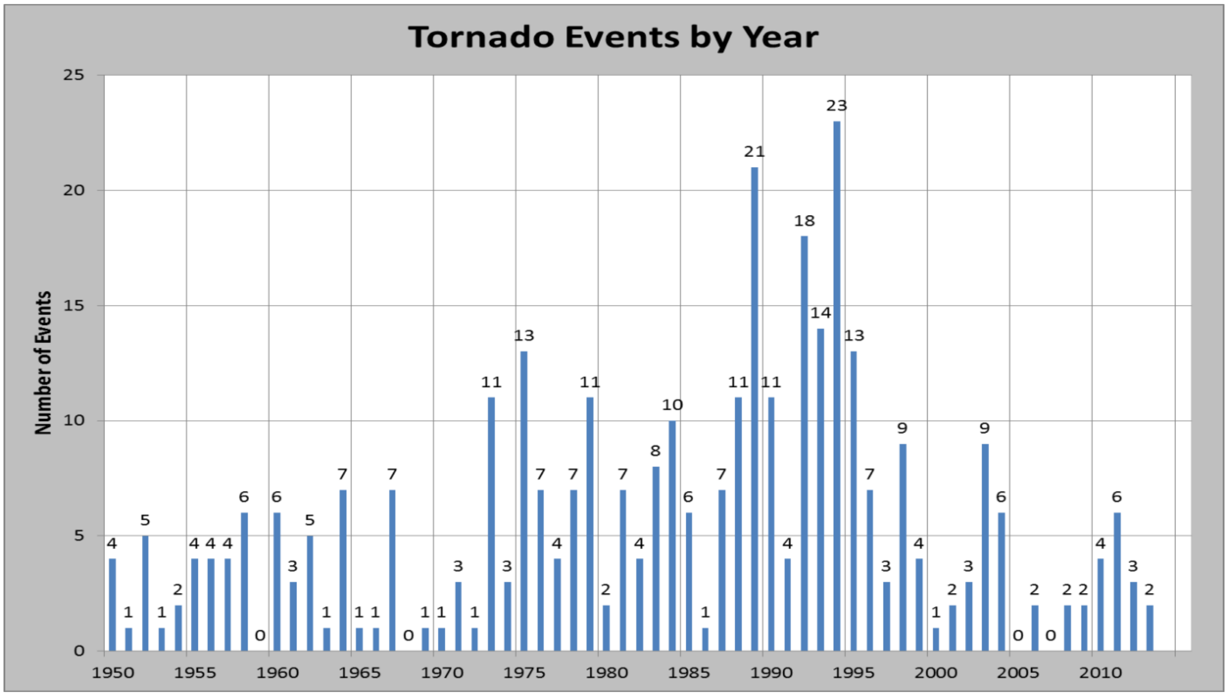

Figure 20a. As in Fig. 17a, except for 349 total tornado events.

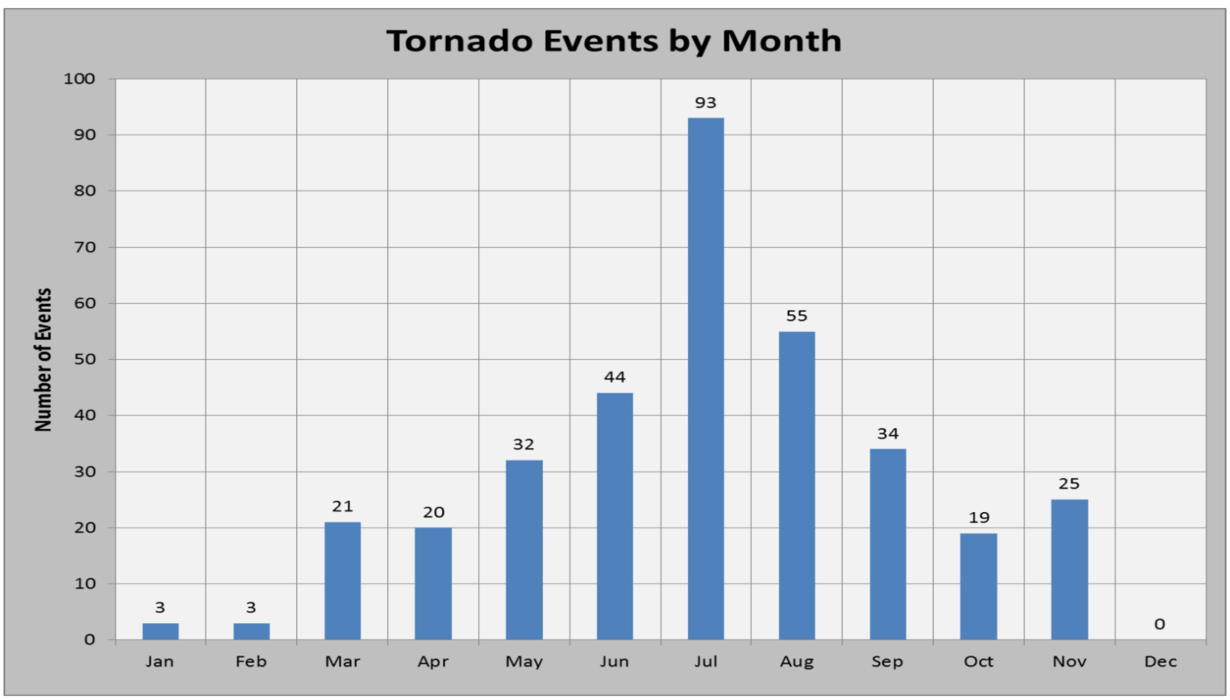

Figure 20b. As in Fig. 17b, except for tornado events.

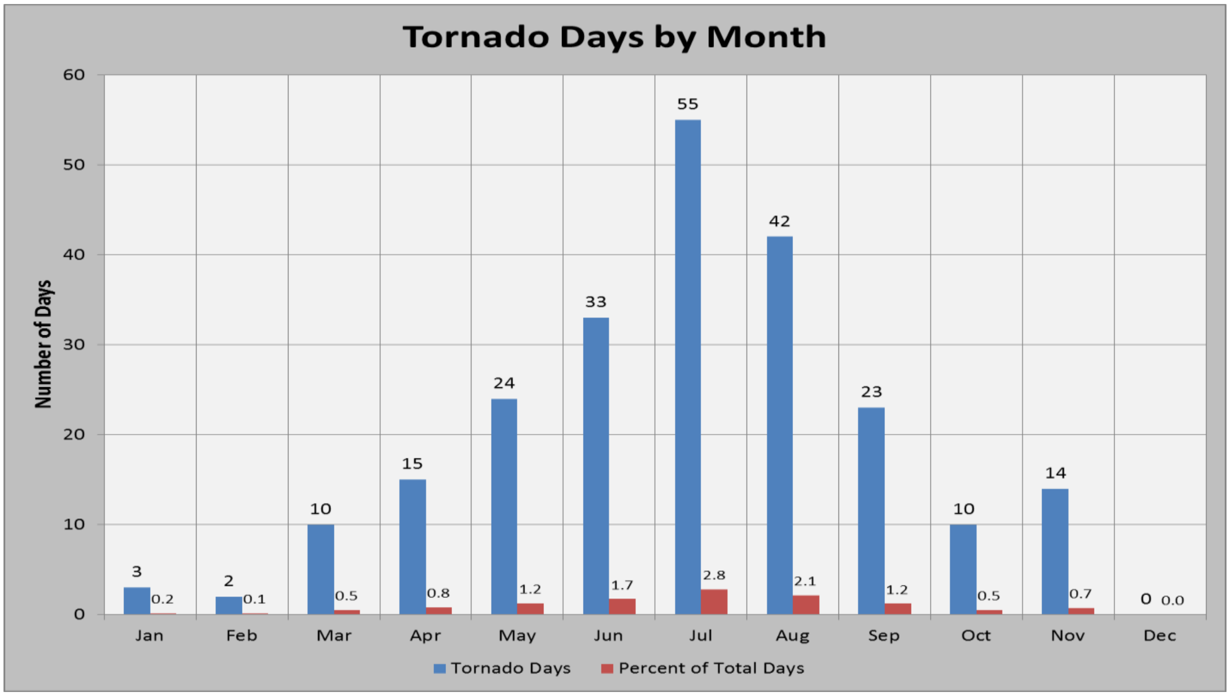

Figure 20c. As in Fig. 17c, except for 231 total days with tornado events.

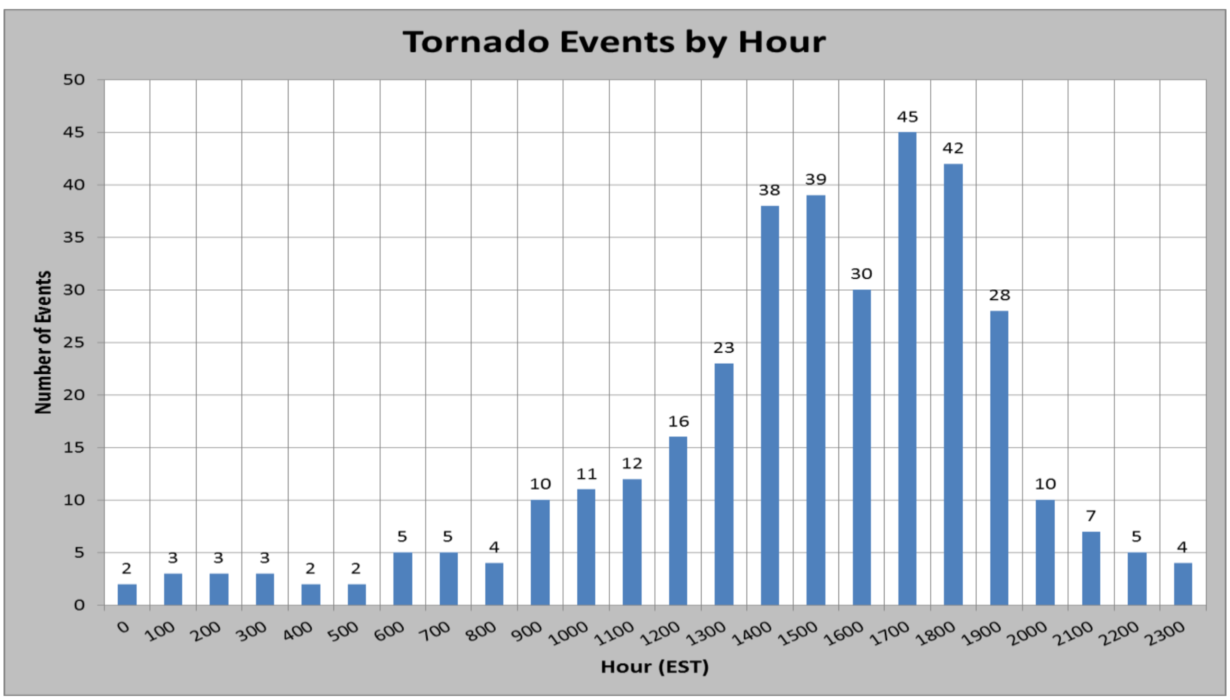

Figure 20d. As in Fig. 17d, except for tornado events.

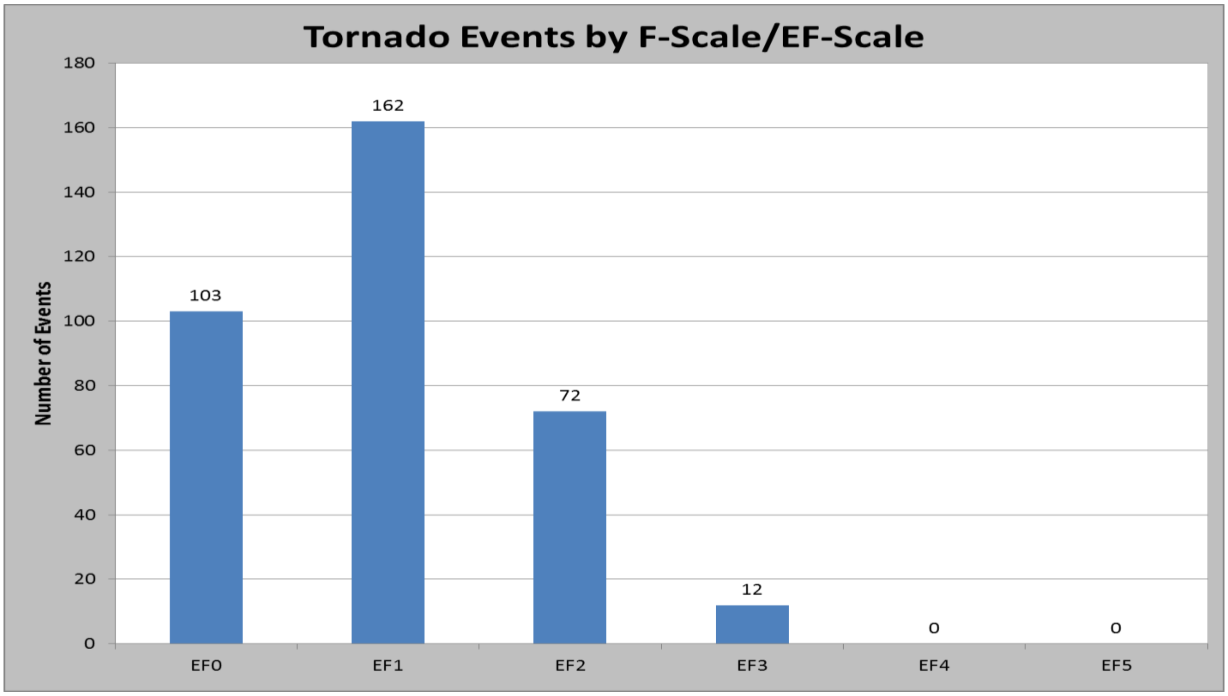

Figure 20e. Distribution by EF-scale of tornado events in the WFO PHI forecast area (F-scale before 2008).

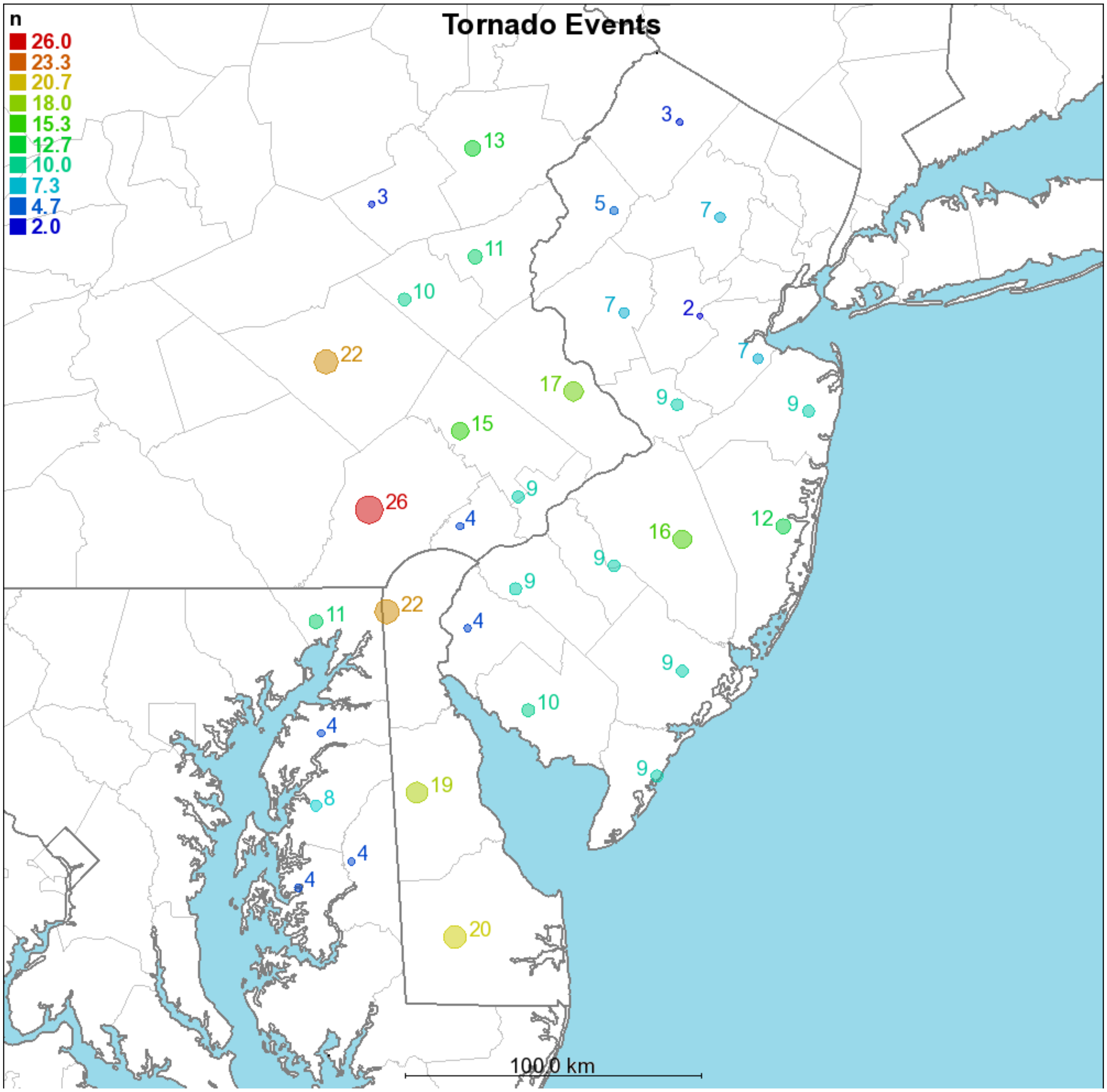

Figure 20f. As in Fig. 17f, except for tornado events.

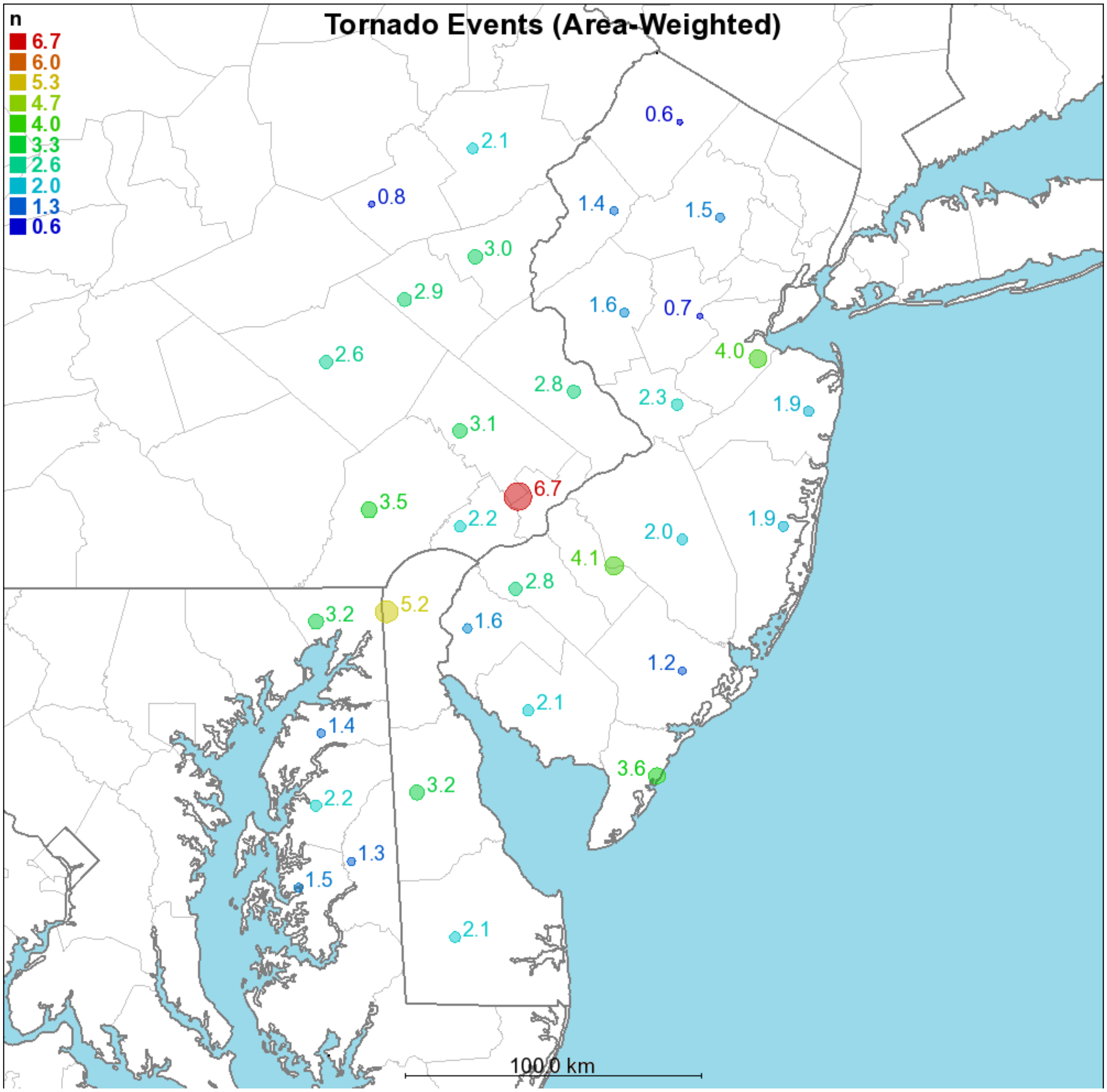

Figure 20g. As in Fig. 17f, except weighted for county-area size.

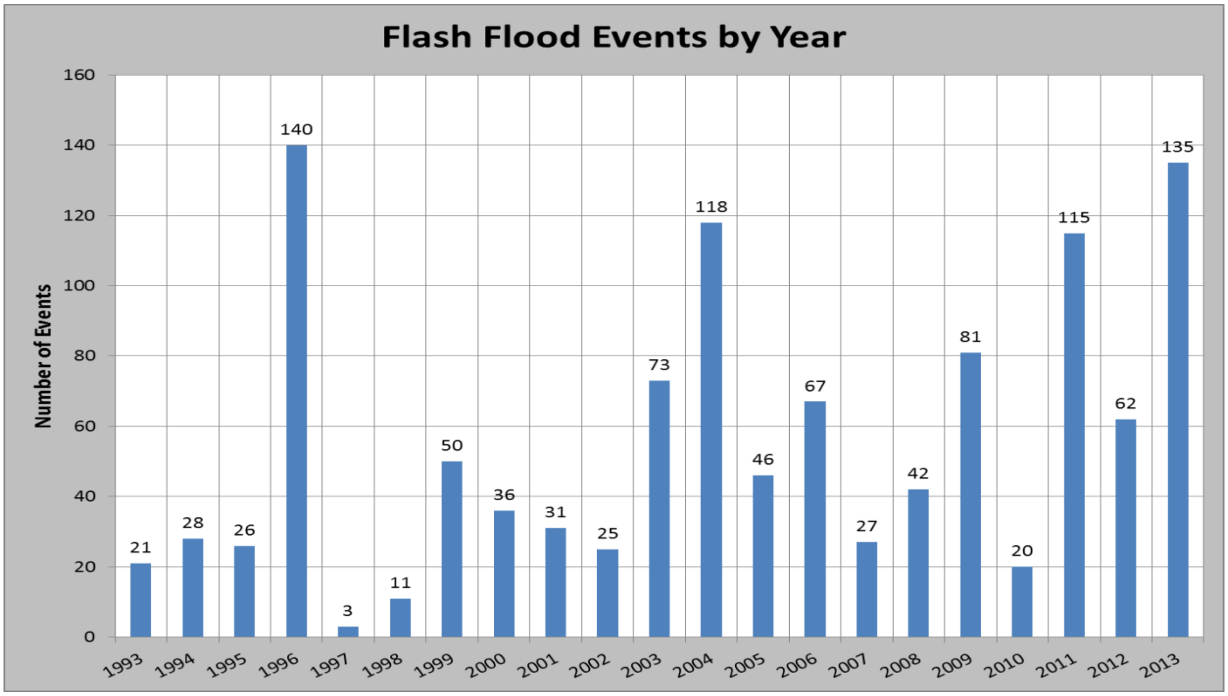

Figure 21a. As in Fig. 17a, except for 1157 total flash flood events.

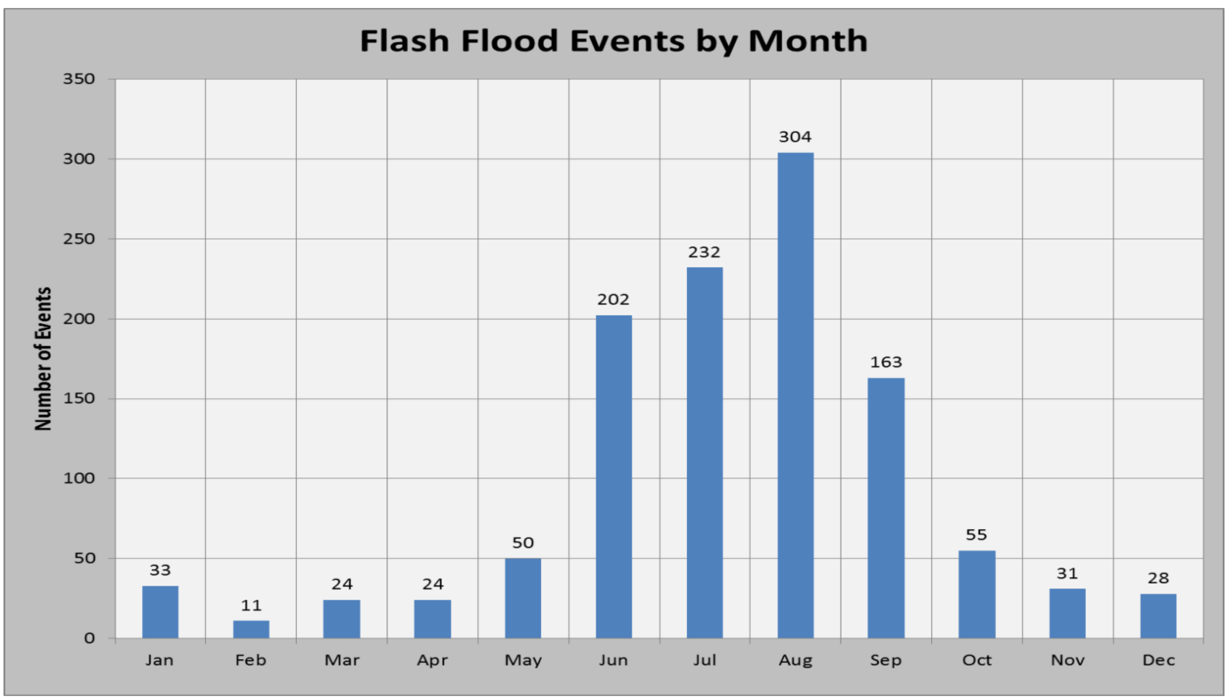

Figure 21b. As in Fig. 17b, except for flash flood events.

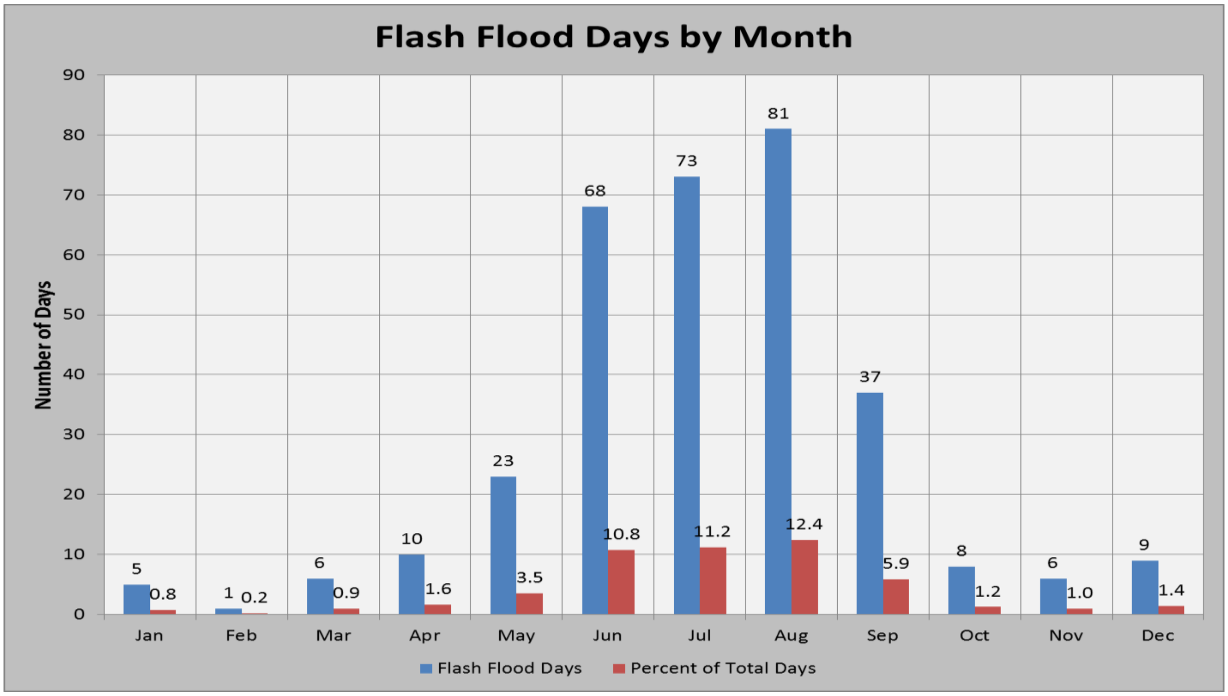

Figure 21c. As in Fig. 17c, except for 327 total days with flash flood events.

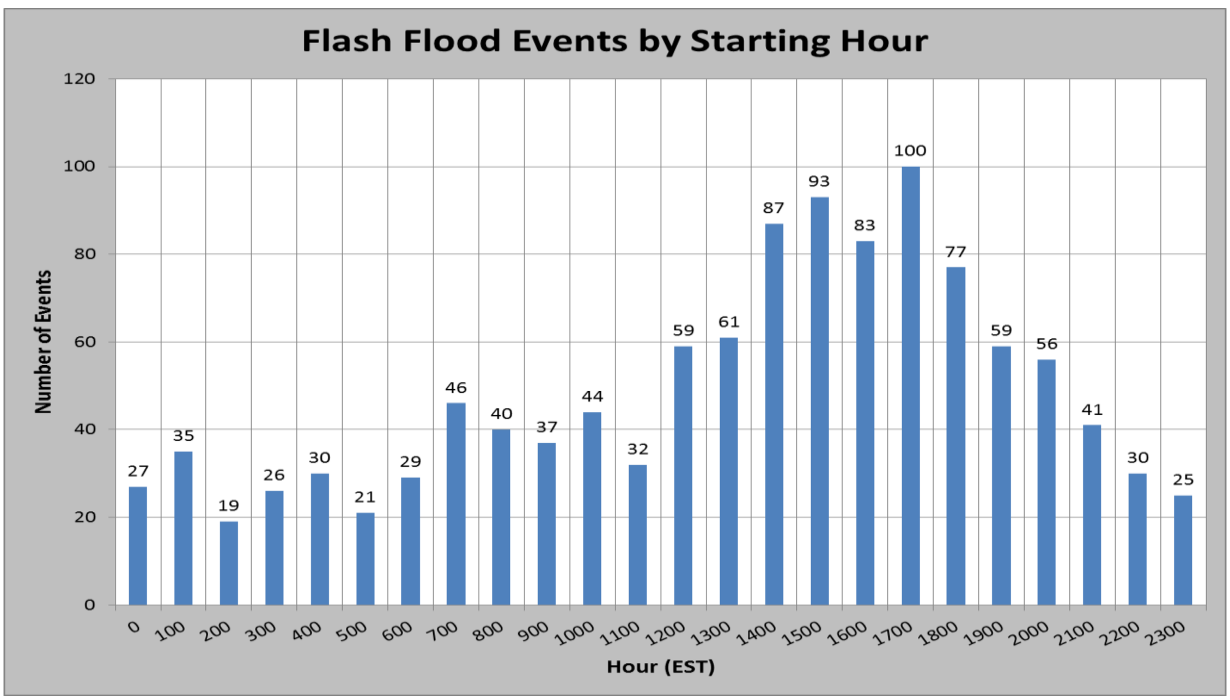

Figure 21d. As in Fig. 17d, except for flash flood events.

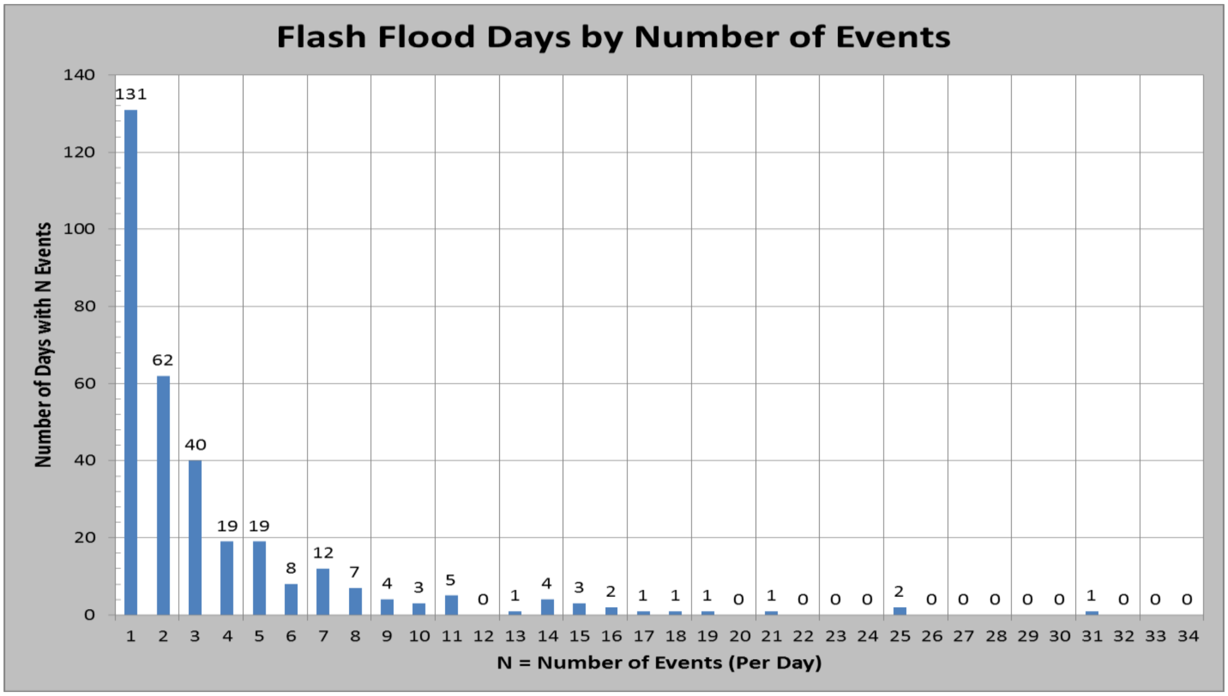

Figure 21e. As in Fig. 17e, except for flash flood days.

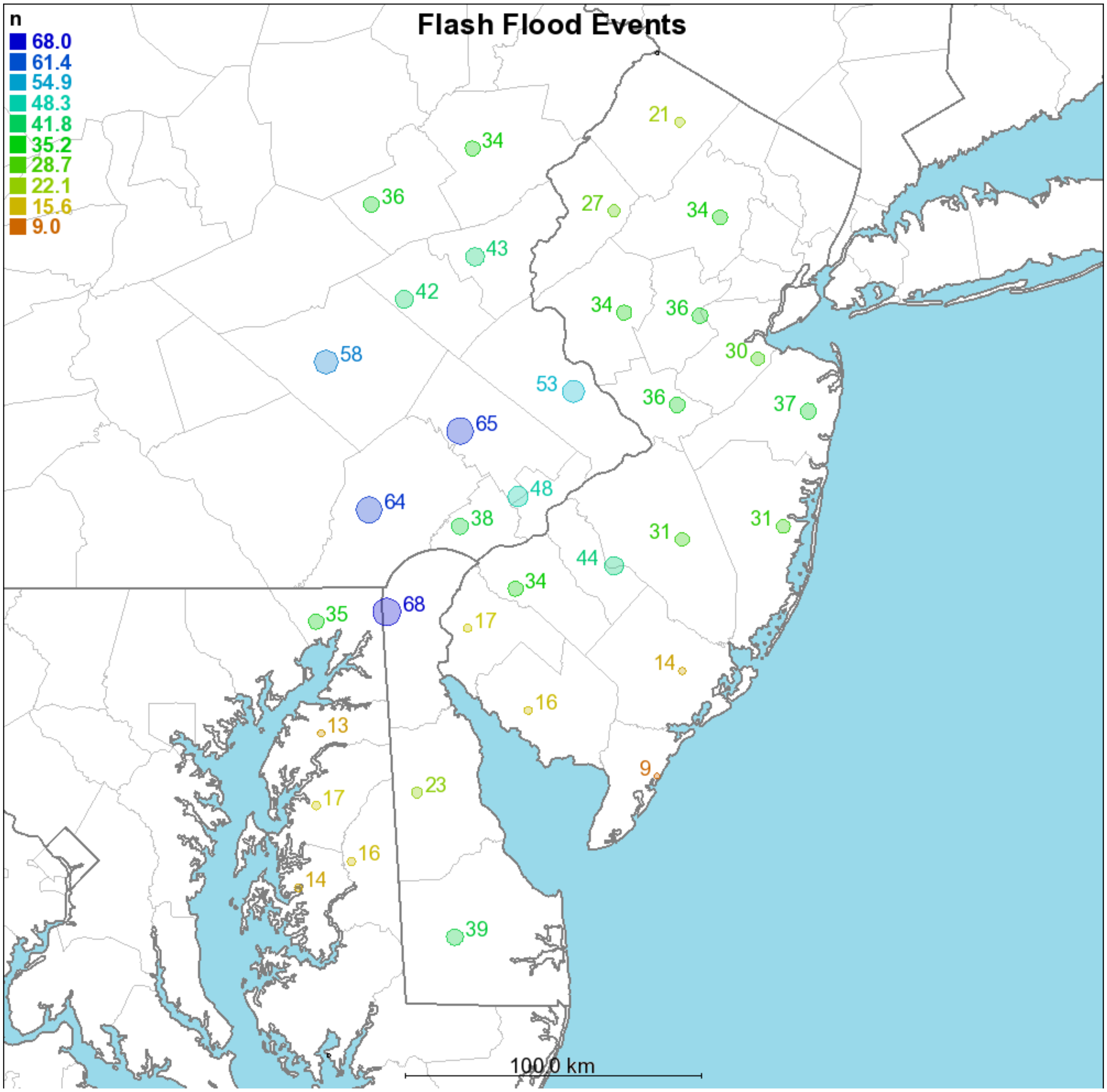

Figure 21f. As in Fig. 17f, except for flash flood events.

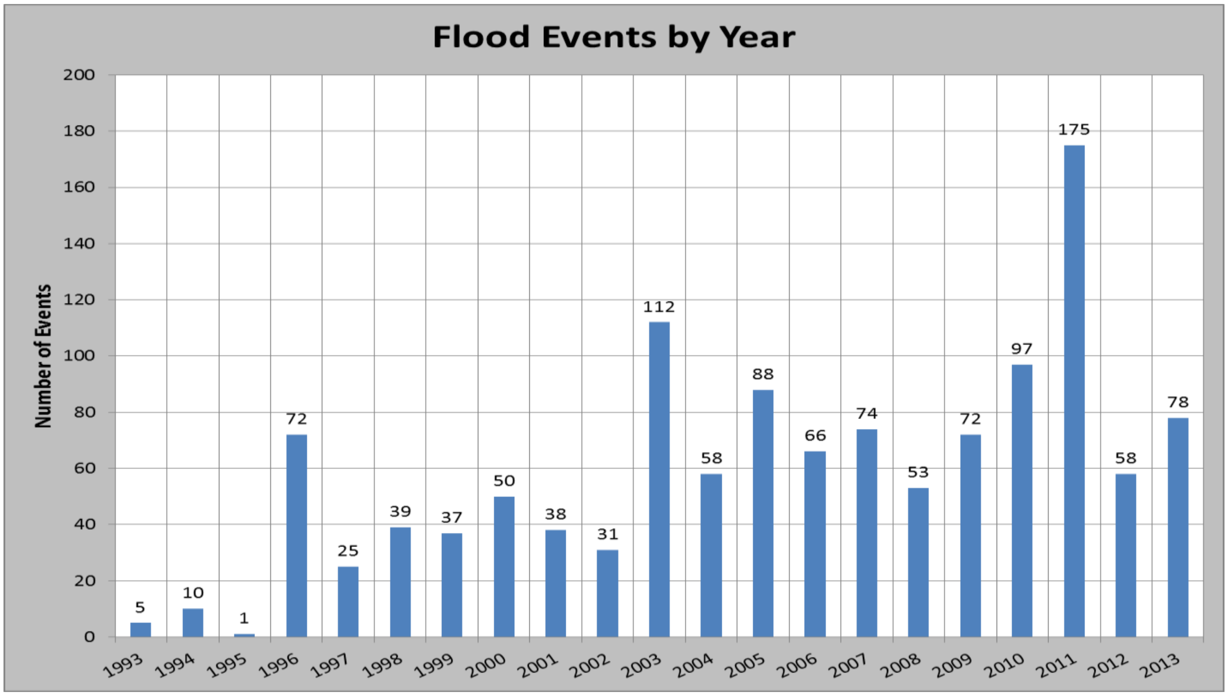

Figure 22a. As in Fig. 17a, except for 1239 total flood events.

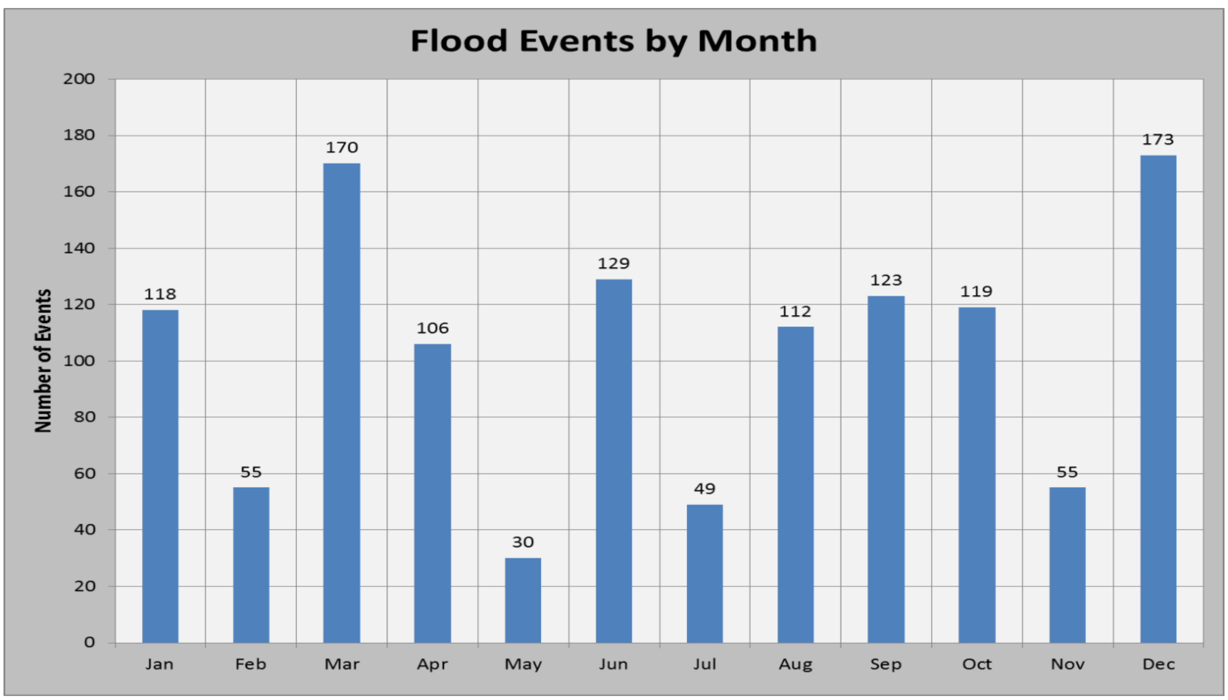

Figure 22b. As in Fig. 17b, except for flood events.

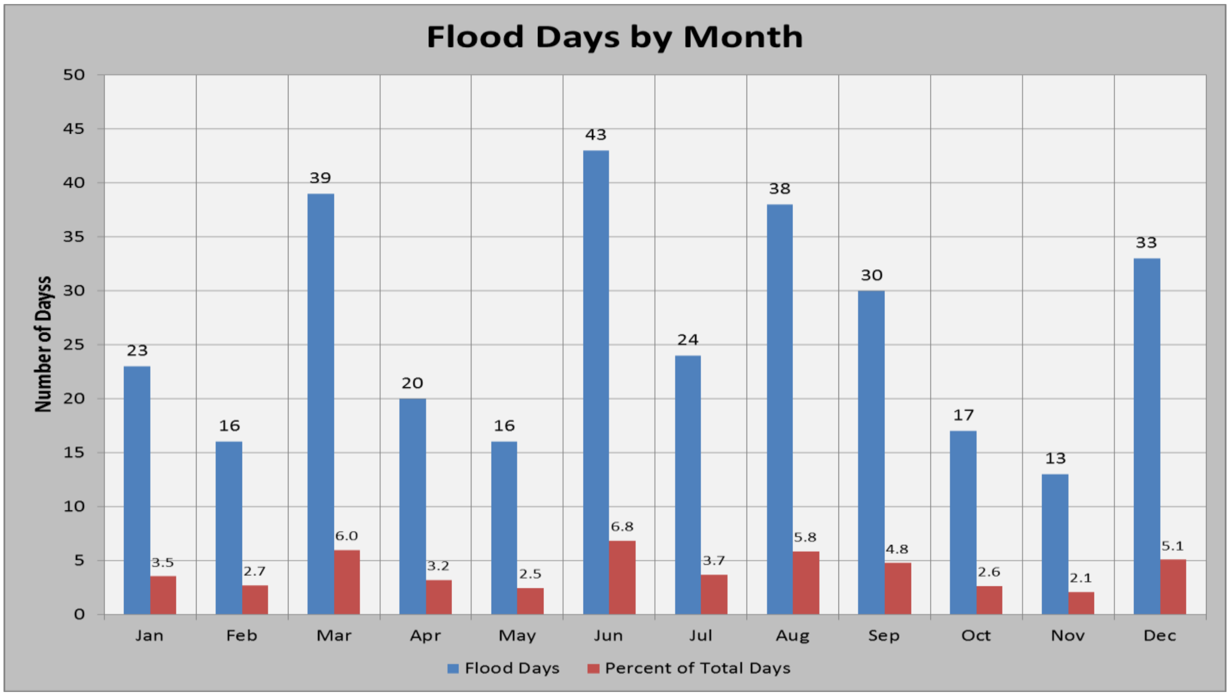

Figure 22c. As in Fig. 17c, except for 312 total days with flood events.

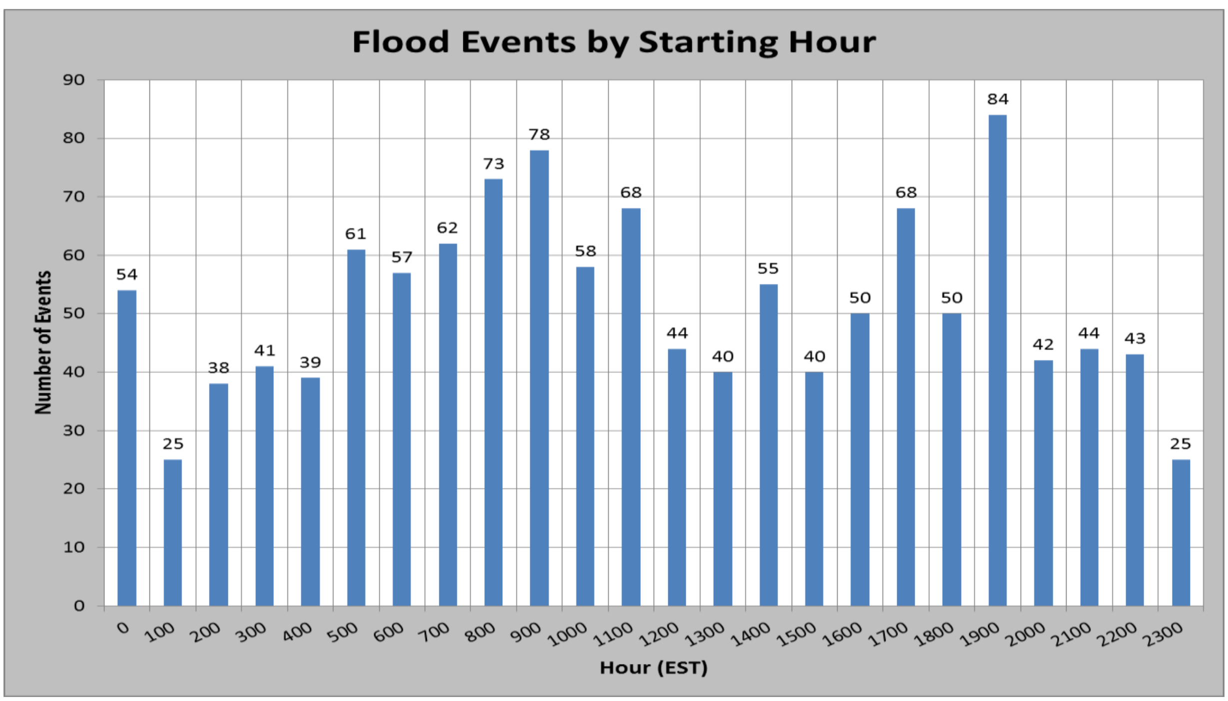

Figure 22d. As in Fig. 17d, except for flood event starting hour.

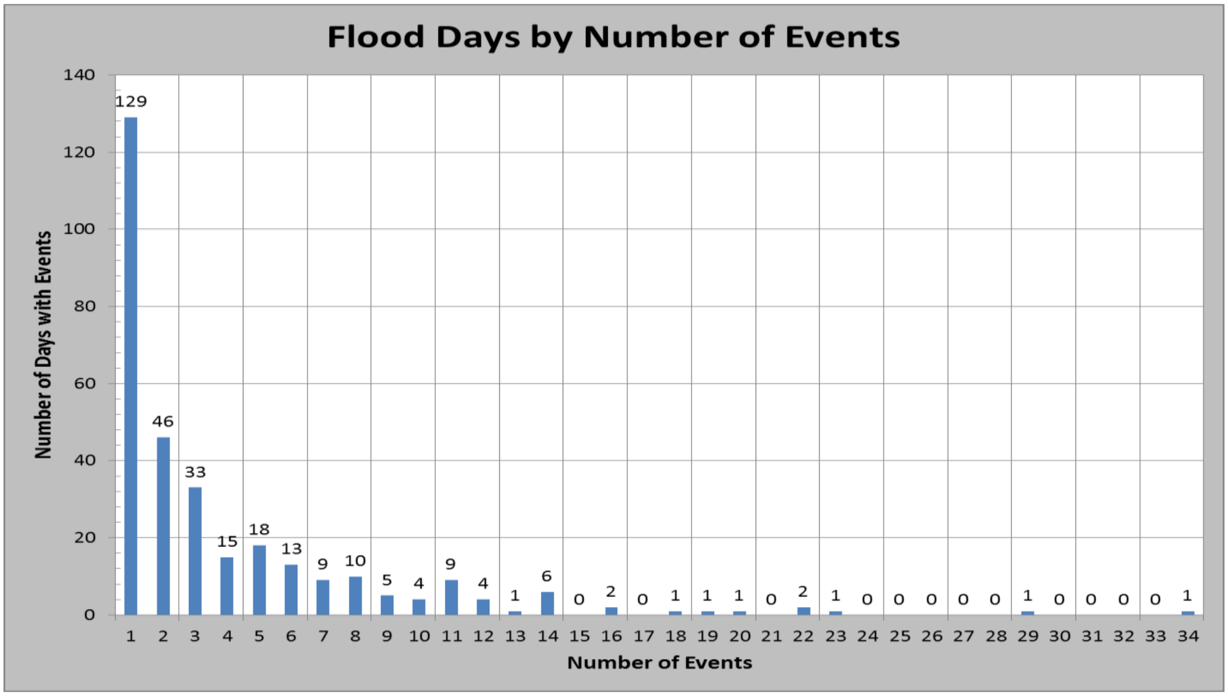

Figure 22e. As in Fig. 17e, except for flood days.

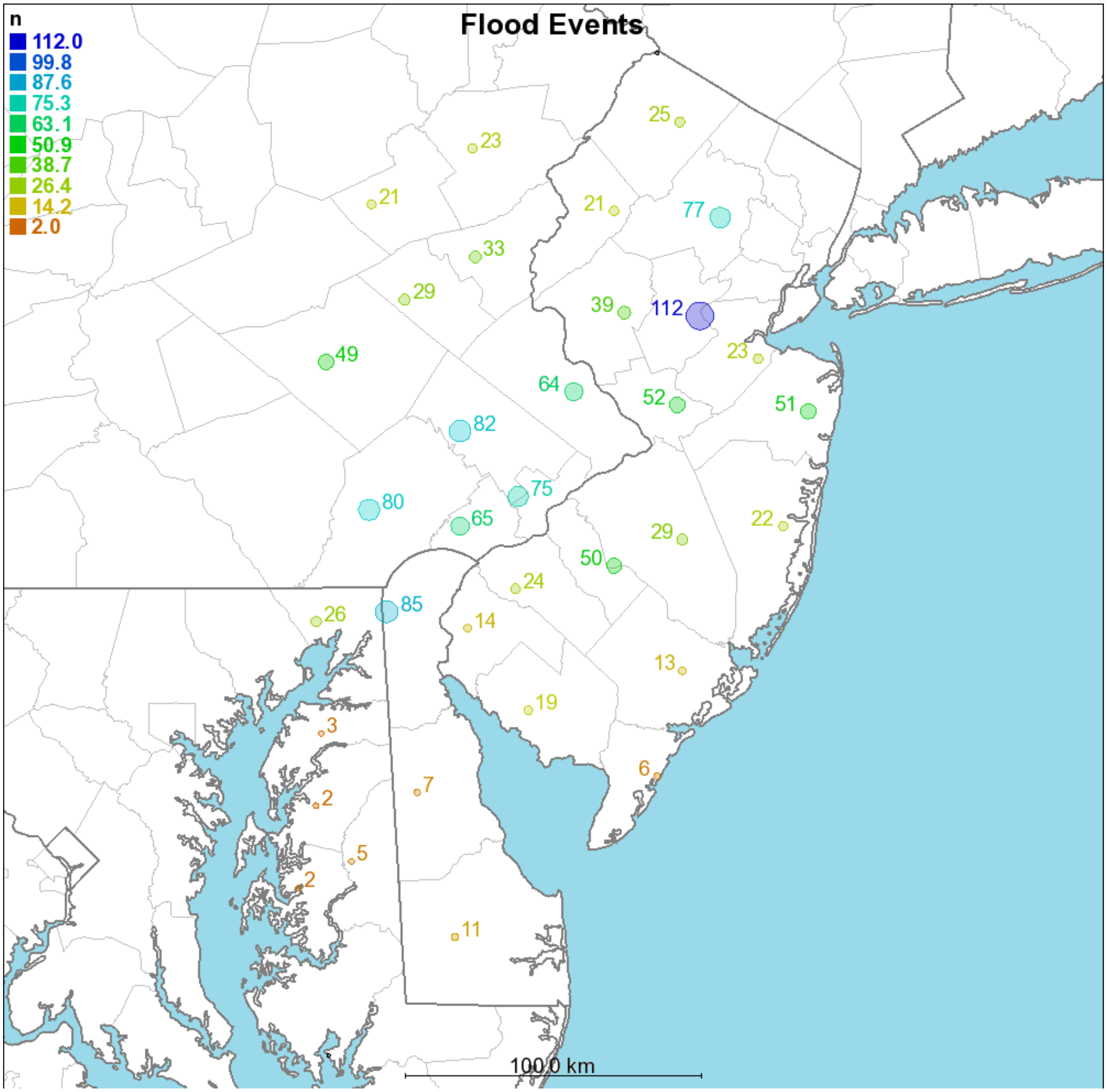

Figure 22f. As in Fig. 17f, except for flood events.

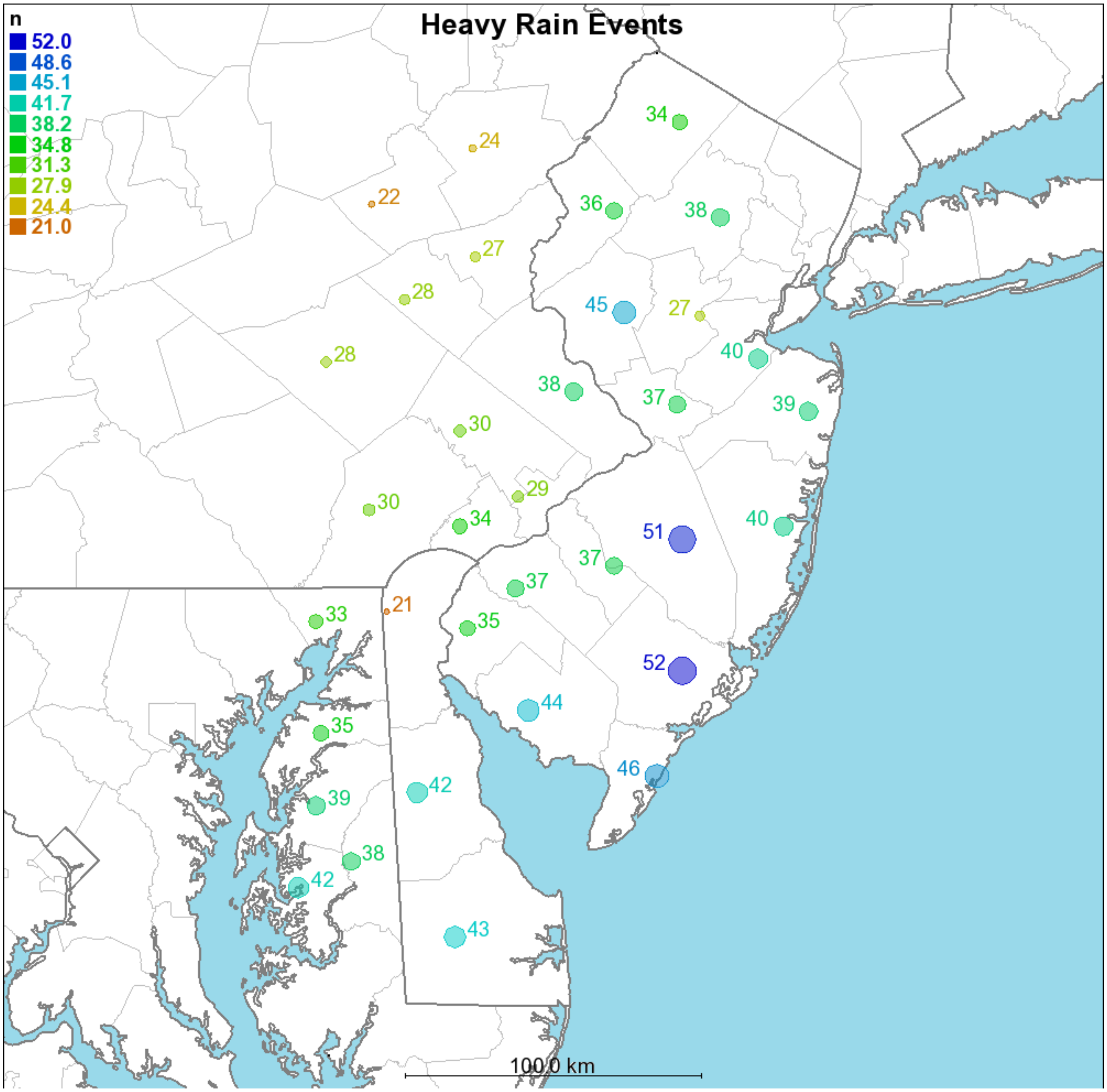

Figure 22g. As in Fig. 17f, except for heavy rain events.

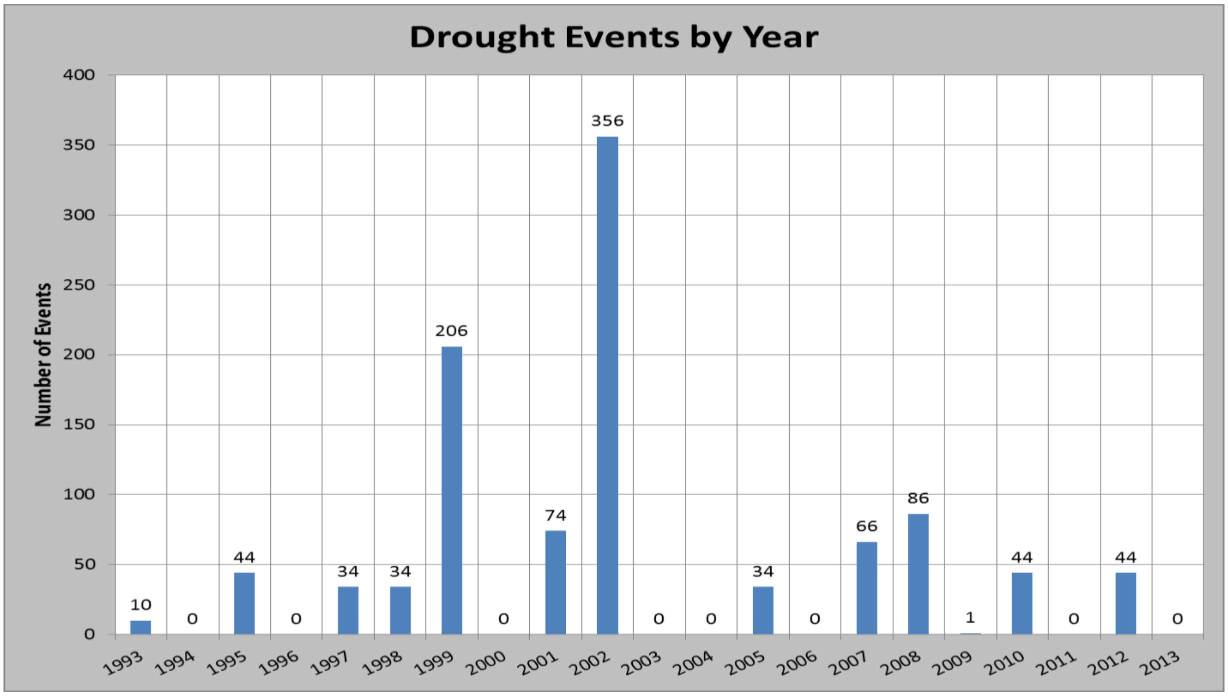

Figure 23a. As in Fig. 17a, except for 1033 total drought events.

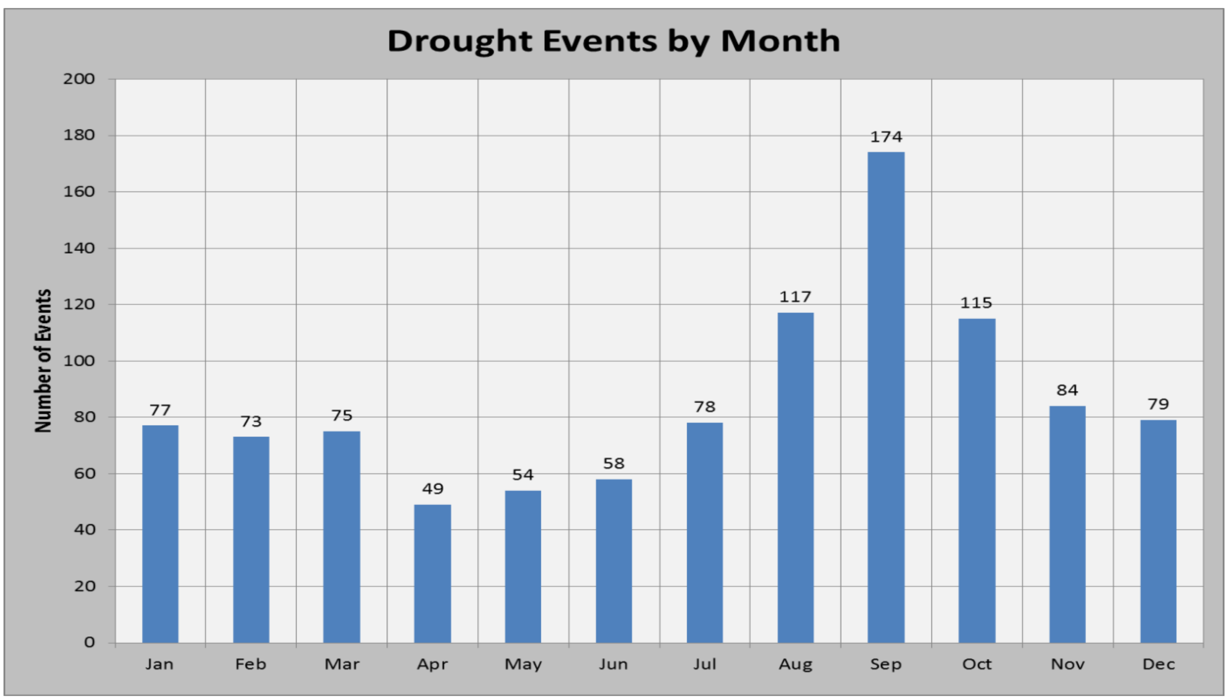

Figure 23b. As in Fig. 17b, except for drought events.

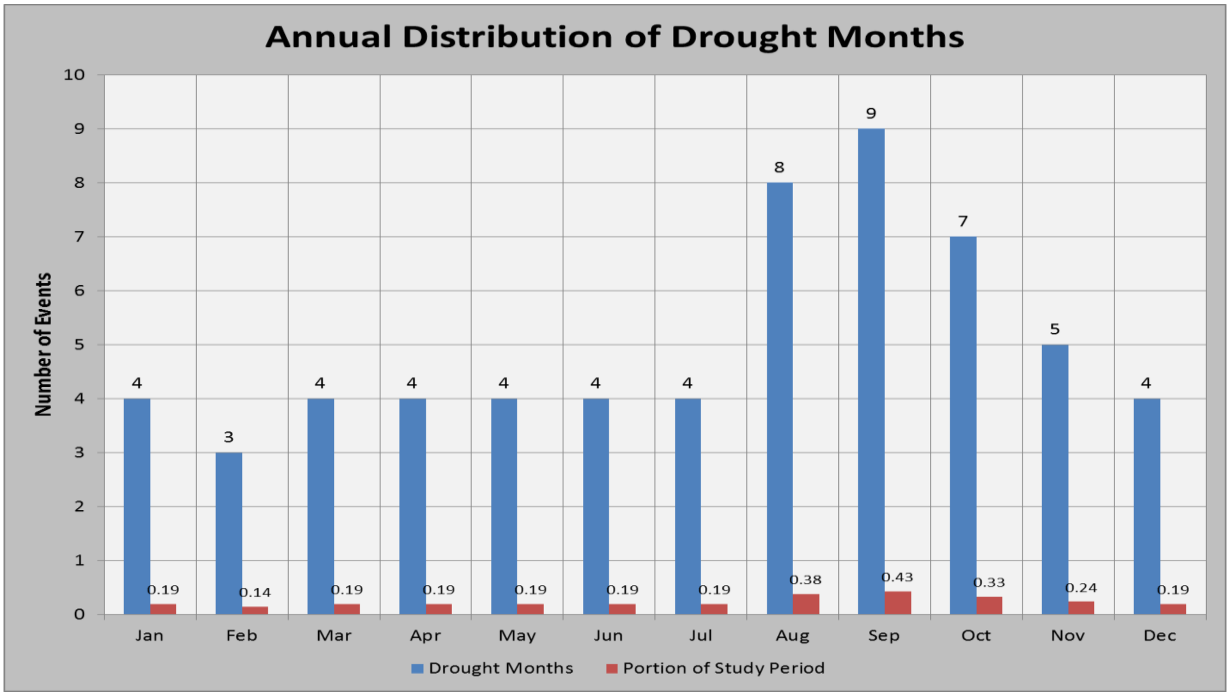

Figure 23c. Frequency of drought conditions (in one county or more) by month. "Portion" is based on 21 total years in the study period, e.g., 21 possible January's.

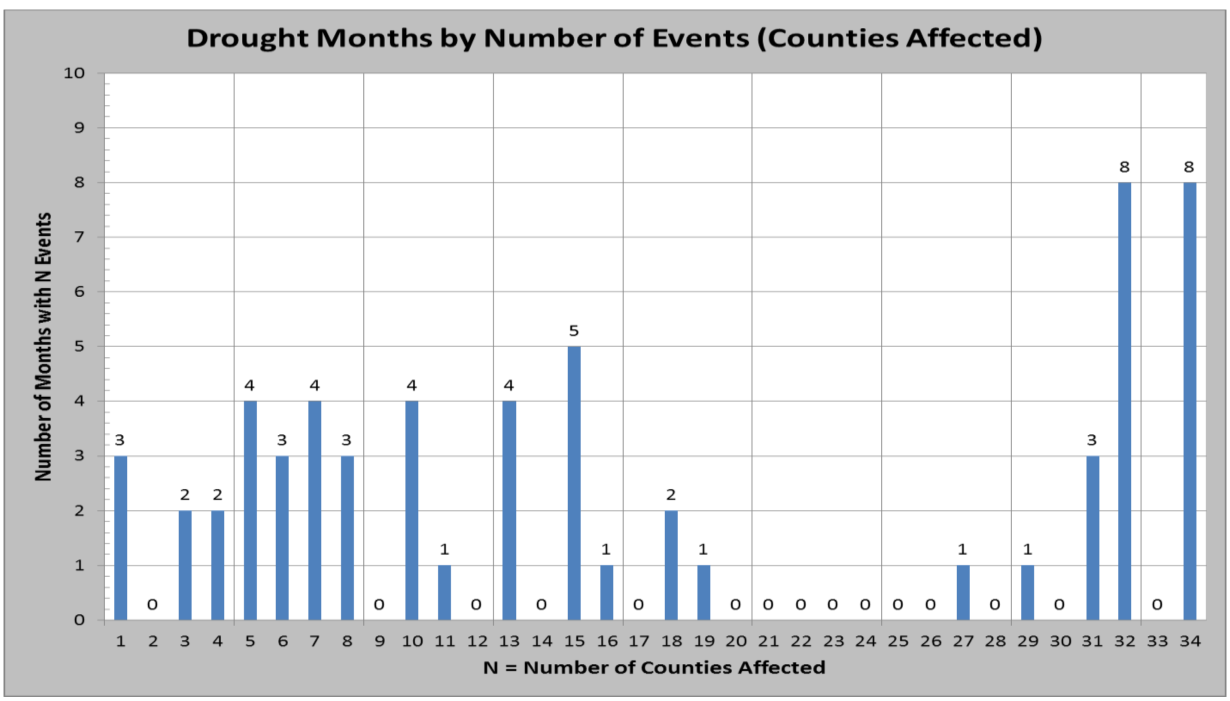

Figure 23d. As in Fig. 17e, except for drought months (not days).

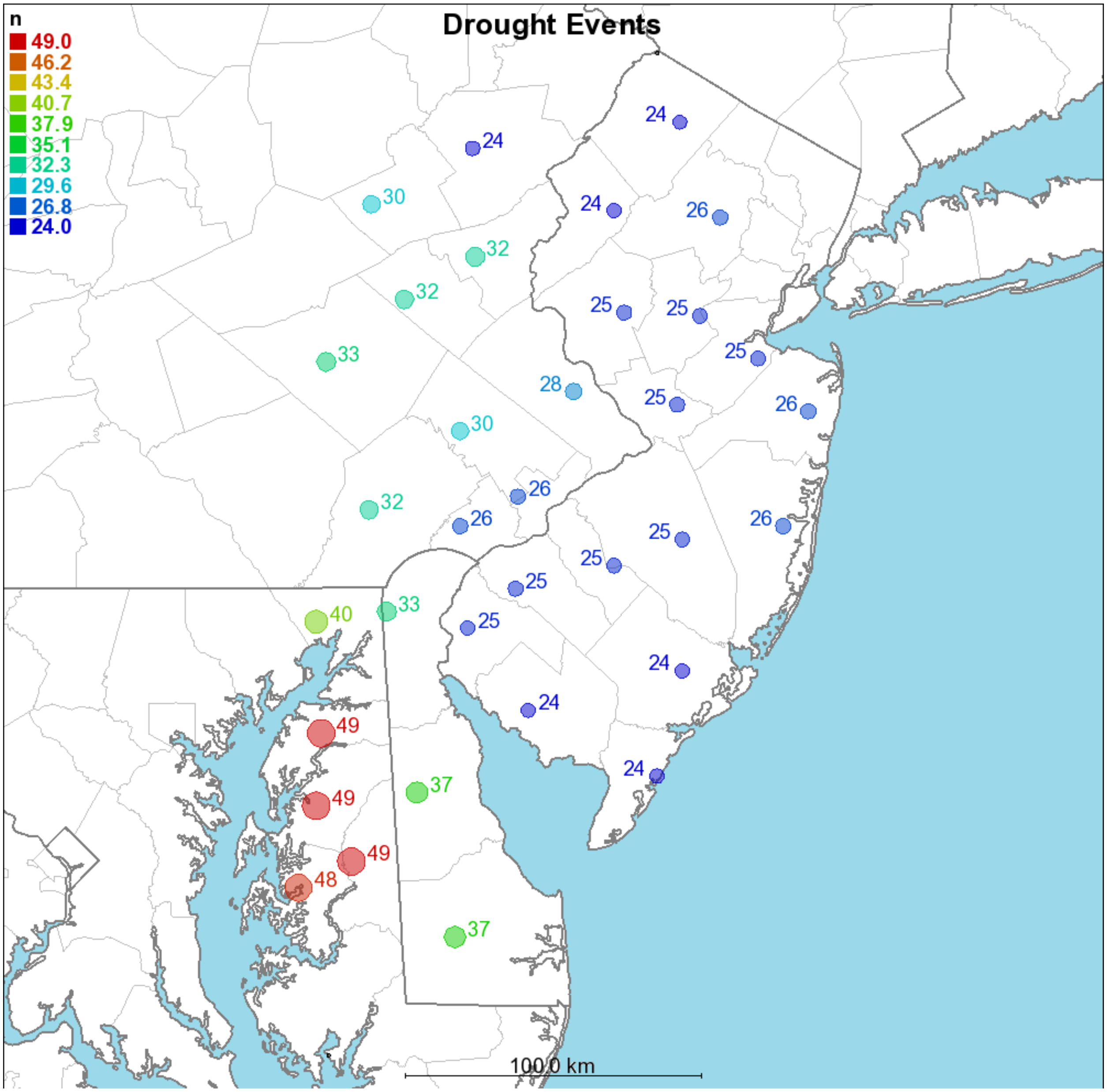

Figure 23e. As in Fig. 17f, except for drought events (months).

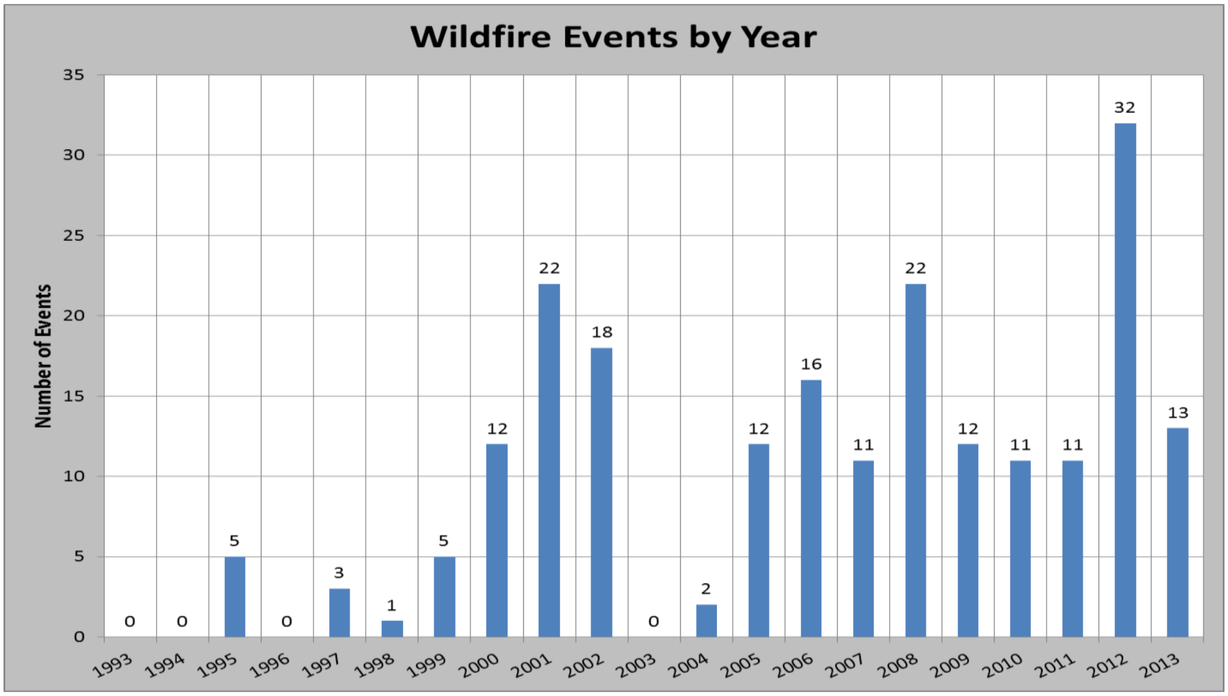

Figure 24a. As in Fig. 17a, except for 208 total wildfire events.

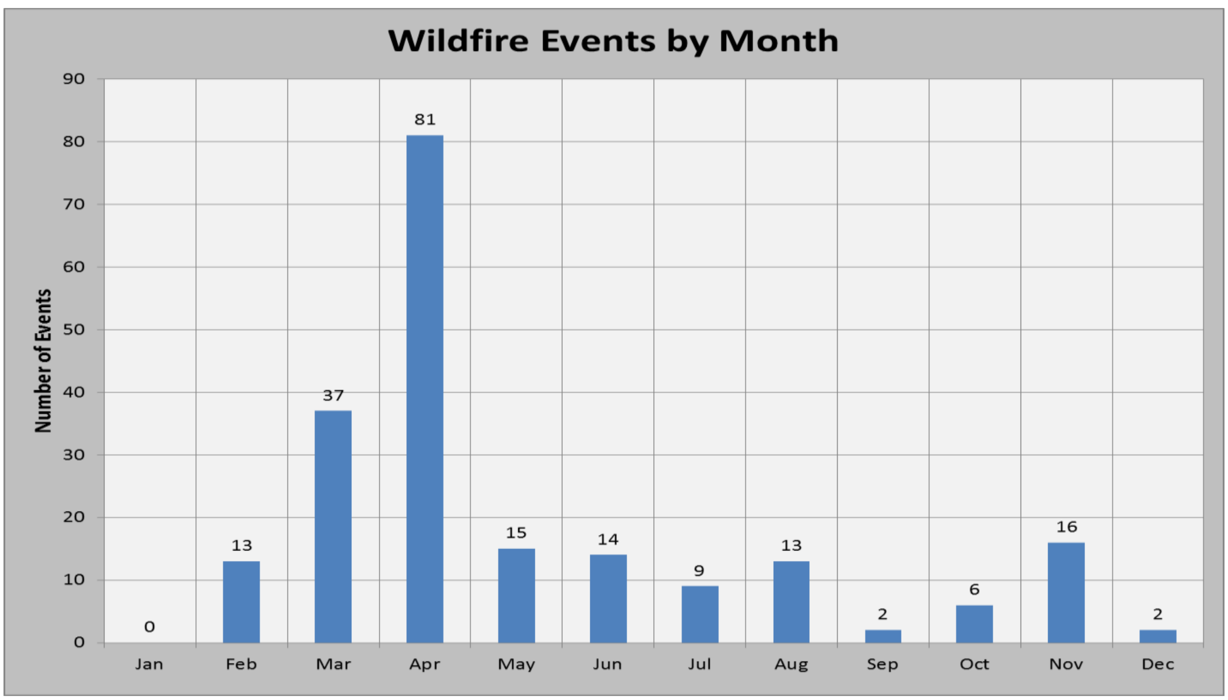

Figure 24b. As in Fig. 17b, except for wildfire events.

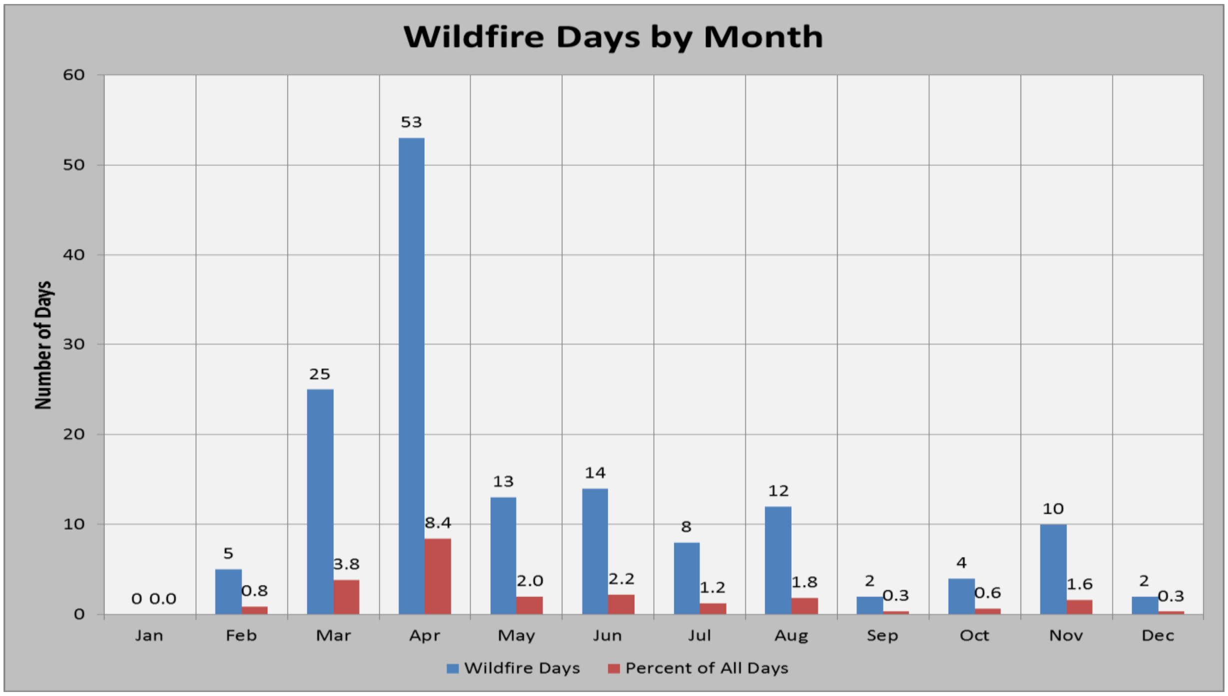

Figure 24c. As in Fig. 17c, except for 148 total days with wildfire events.

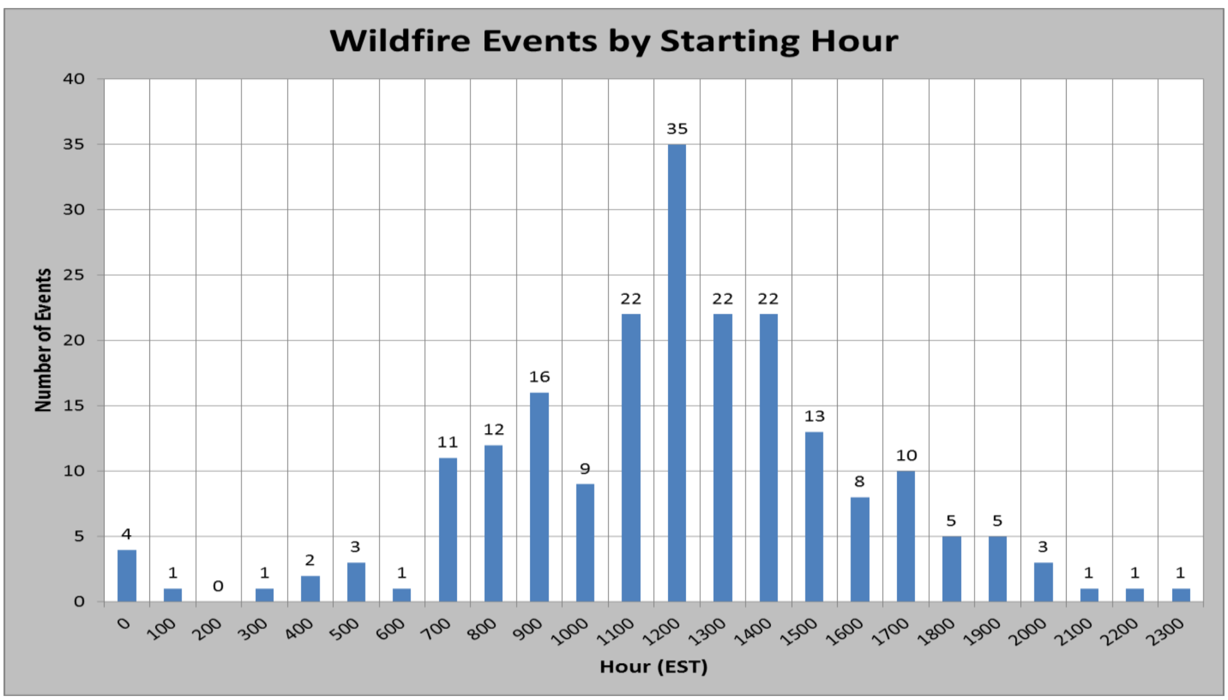

Figure 24d. As in Fig. 17d, except for wildfire events.

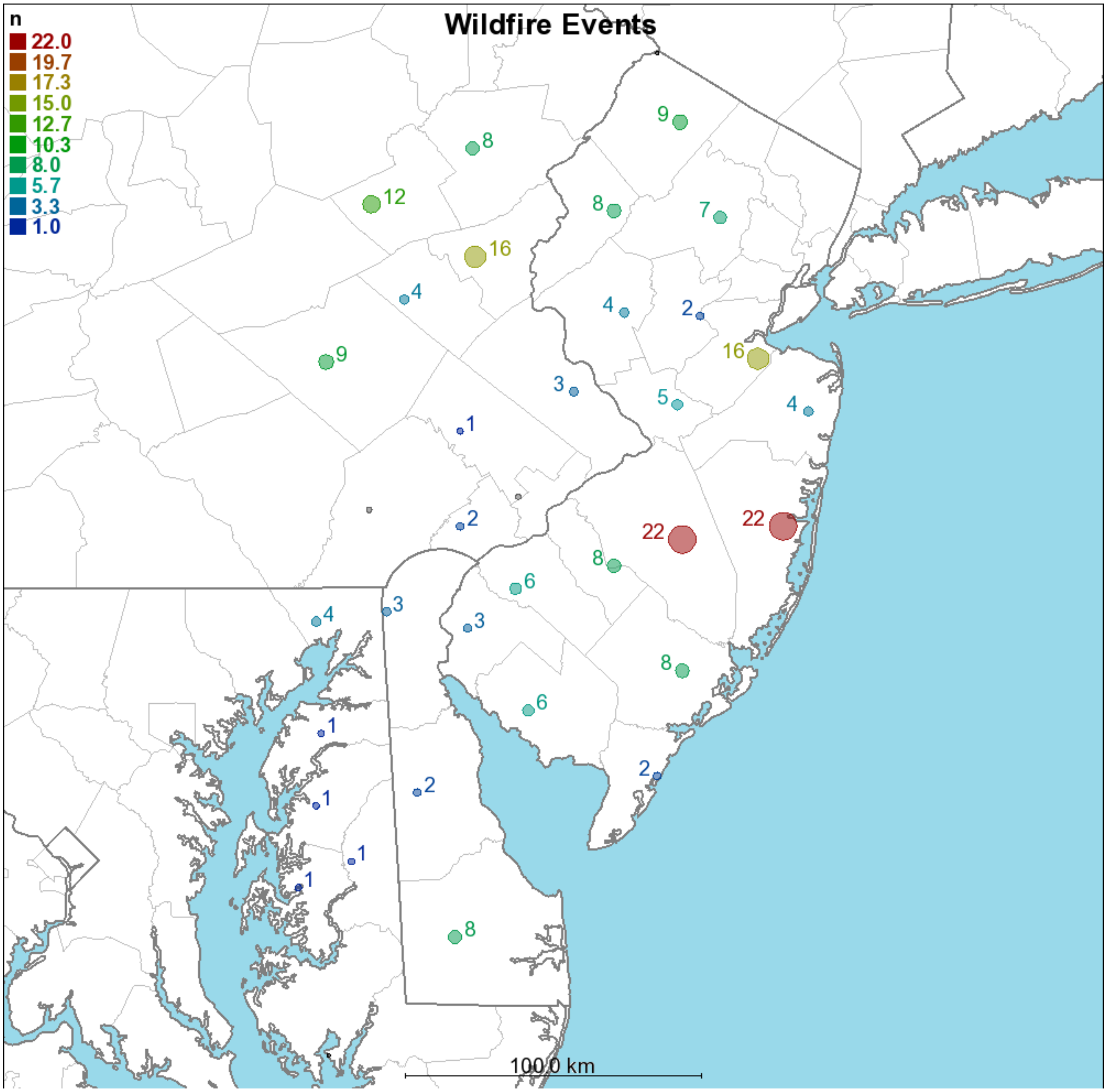

Figure 24e. As in Fig. 17f, except for wild fire events.

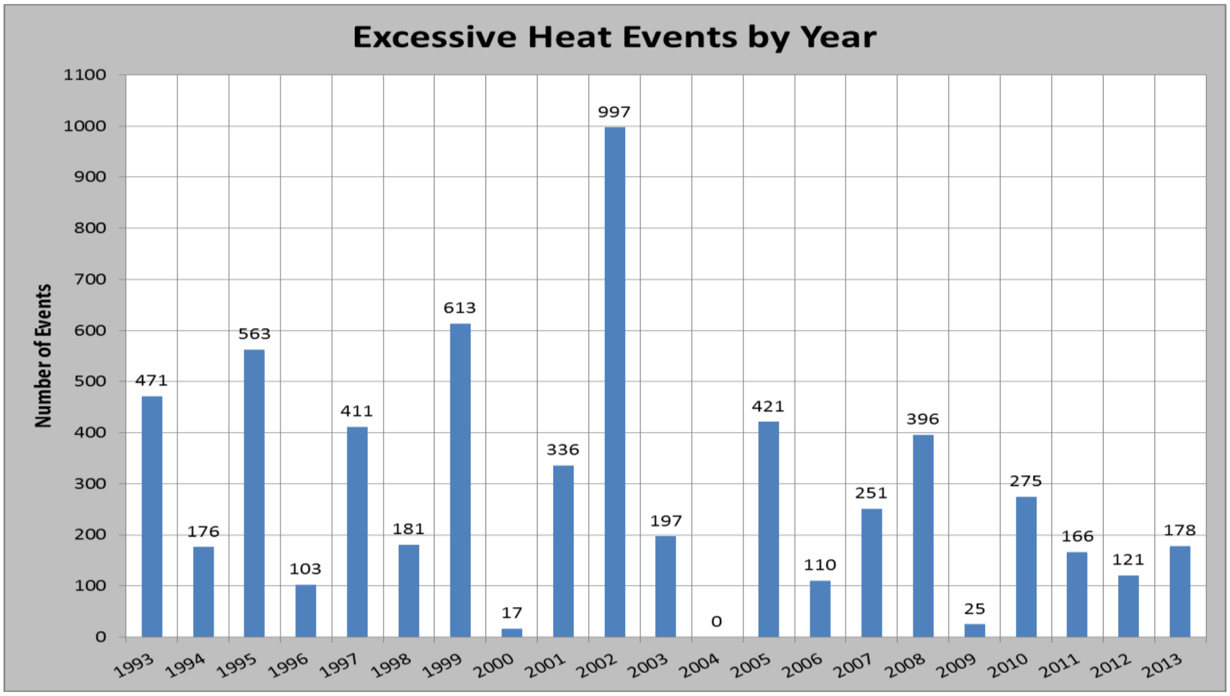

Figure 25a. As in Fig. 17a, except for 6008 total excessive heat events.

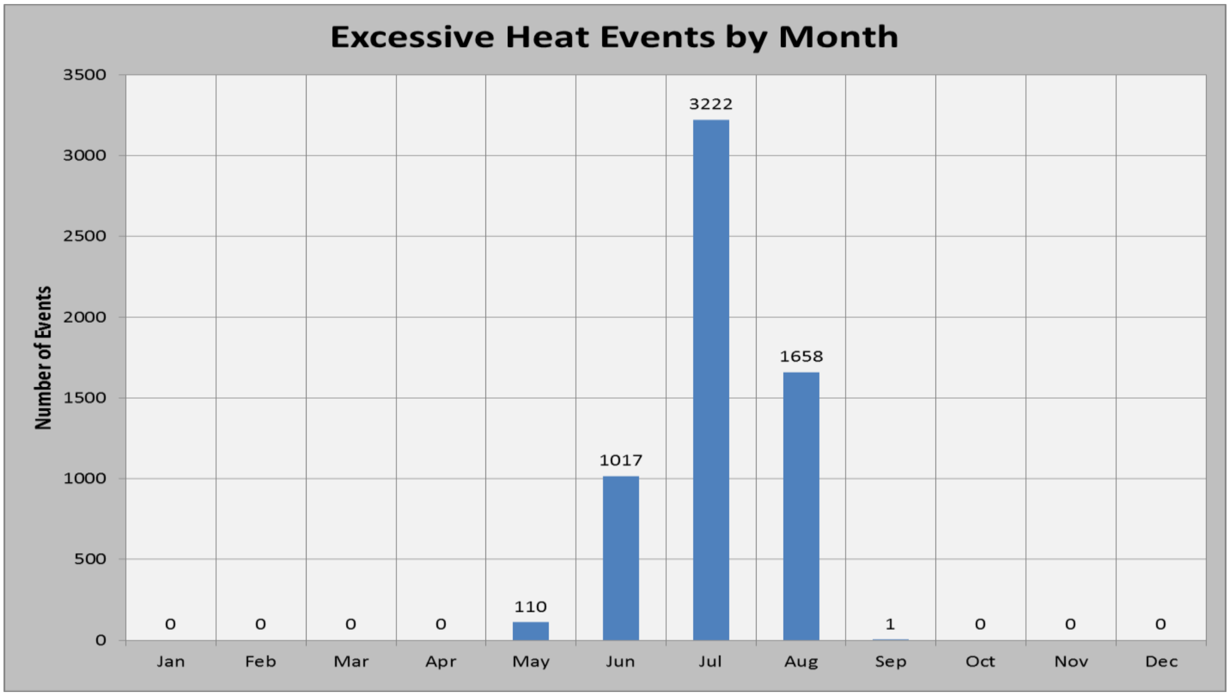

Figure 25b. As in Fig. 17b, except for excessive heat events.

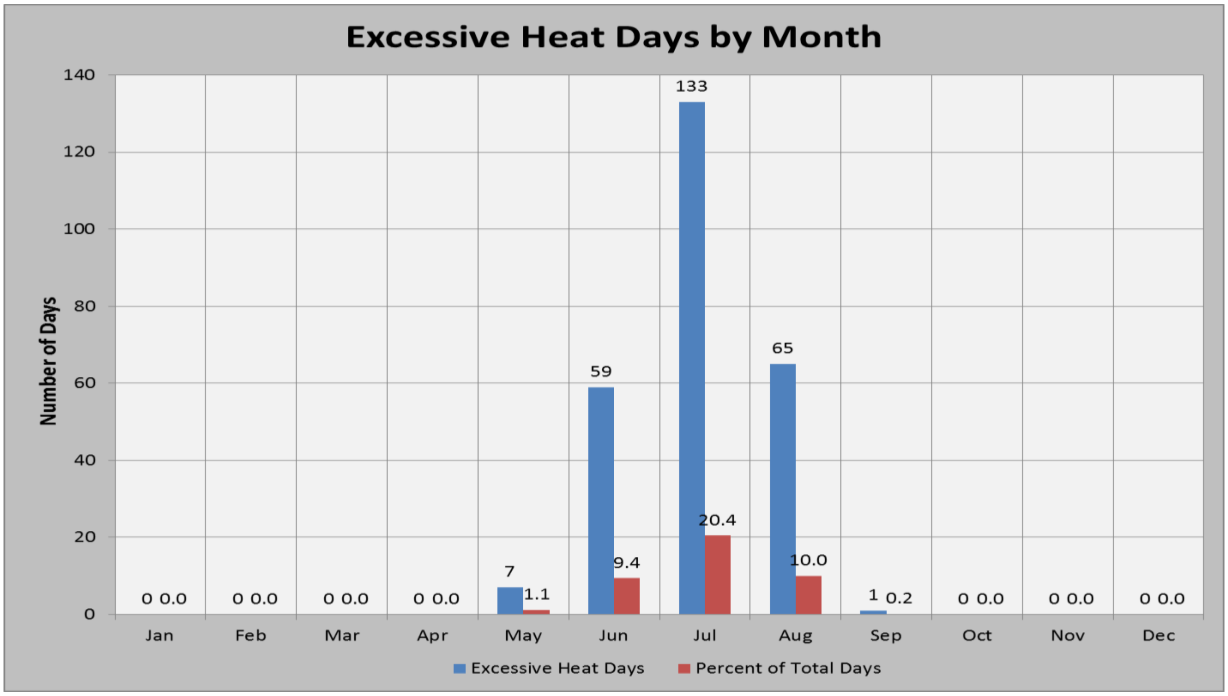

Figure 25c. As in Fig. 17c, except for 265 total days with excessive heat events.

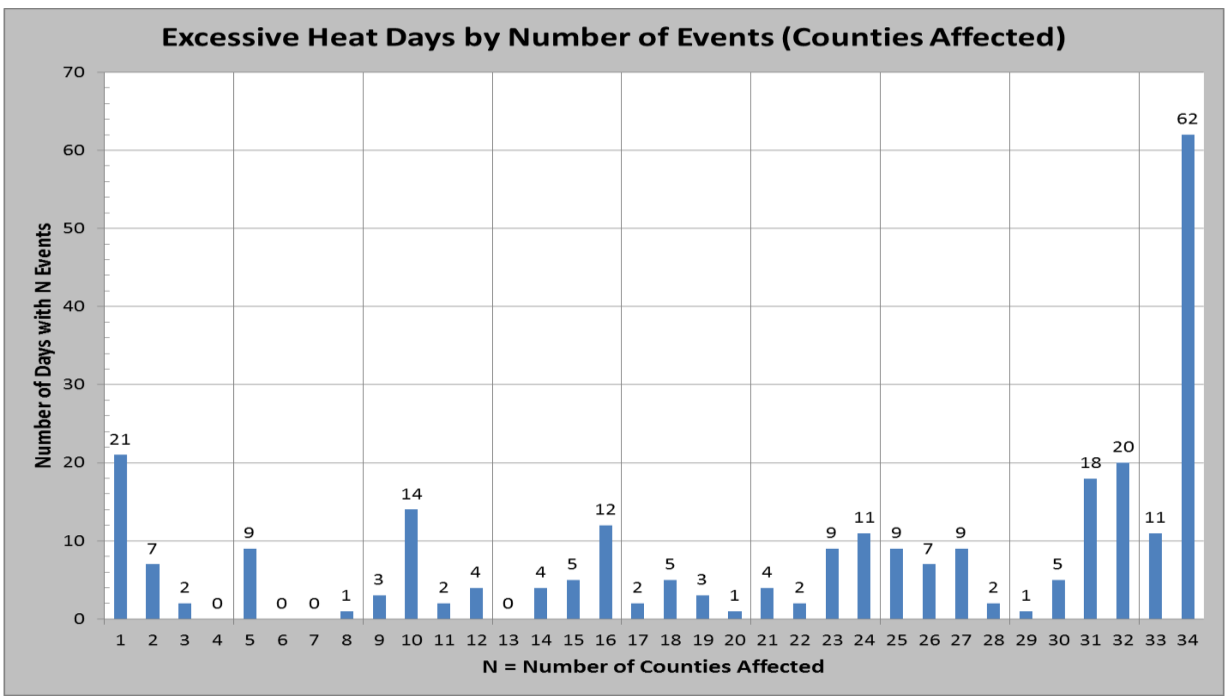

Figure 25d. As in Fig. 6d, except for excessive heat days.

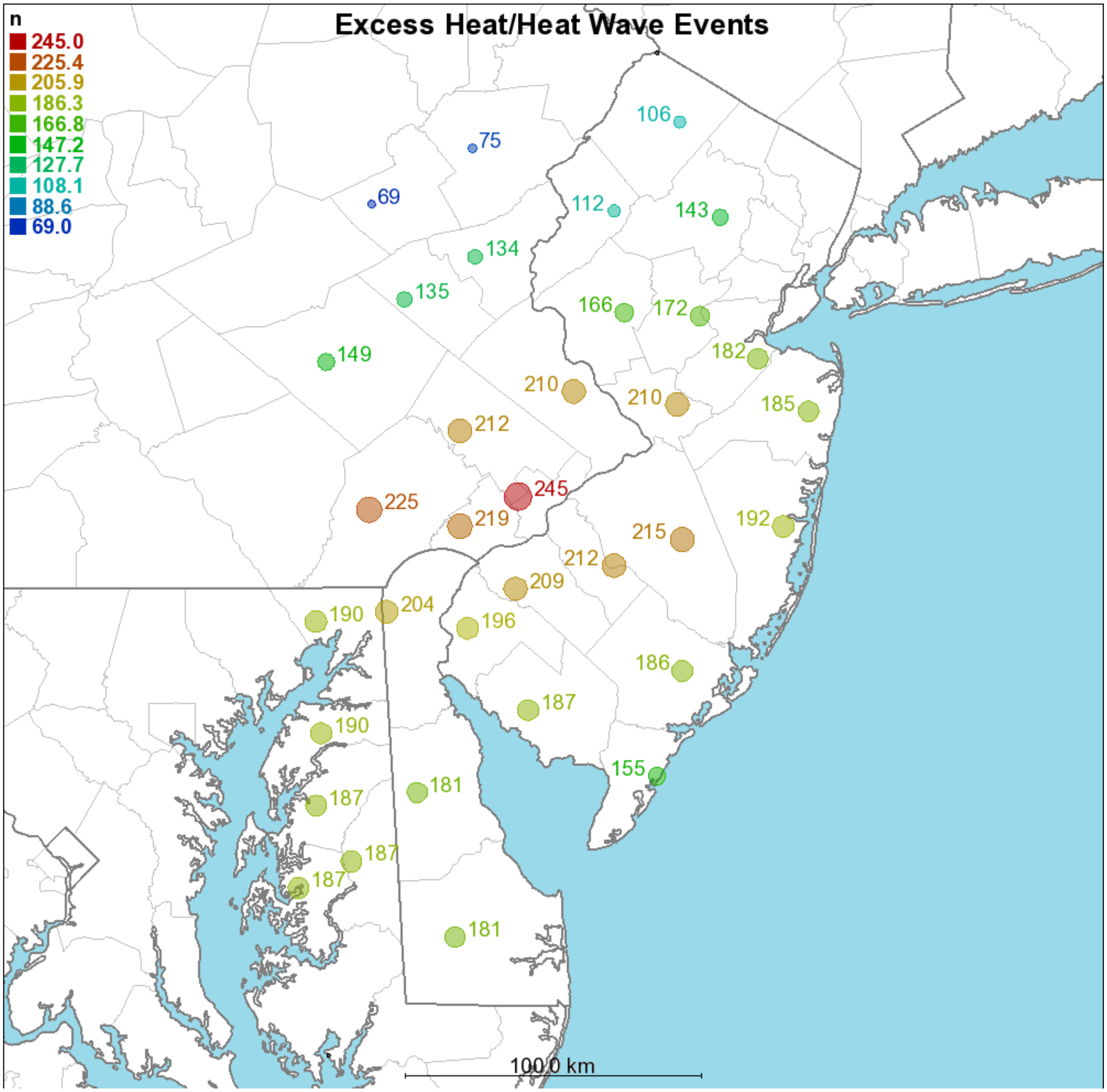

Figure 25e. As in Fig. 17f, except for excessive heat events.