

Spatial and Temporal Variability of Precipitation Runs in the Southeast U.S. and Their Potential Impact on Agriculture

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Abstract. Consecutive days of precipitation (**precipitation runs**) in the Southeast U.S. are evaluated for spatial and temporal variations. A 55-year dataset of daily precipitation totals from selected stations across the study area was used to identify precipitation runs. The variations in consecutive days of precipitation are related to potential agricultural yields in the Southeast U.S.

Time series analysis reveal a North-South gradient of precipitation runs in the Southeast. The N-S gradient can be separated into three regions, each of which have their own independent pattern for precipitation runs annually and seasonally. Interannual to interdecadal signals are found at various stations, but they are not coherent within the three regions.

The results highlight the role of precipitation runs on agriculture impacts for three different regions in the Southeast U.S. An increase or decrease in precipitation runs may benefit or adversely impact agricultural yields. The author notes that the probability of how many precipitation runs that occur in a season is important for agricultural purposes. The mitigatable economic value of crop yields in the Southeast U.S. could be better predicted with improved precipitation run studies.

1. Introduction

Consecutive days of precipitation (**precipitation runs**) are analyzed over the Southeastern U.S. to identify decadal, inter-annual, and seasonal variations. Regional patterns are also identified. The main focus of this study is on identifying precipitation run variability; however, a secondary goal is to relate the variations to Southeast agricultural stakeholders. Variations in precipitation runs are critical to many agricultural sectors (i.e., too much rain in the harvest season or too little rainfall in the growing season, etc.).

Studies have linked global variations of temperature and precipitation to El Niño-Southern Oscillation (ENSO), (e.g., Douglas and Englehart, 1981; McBride and Nicholls, 1983; Ropelewski and Halpert, 1986, 1987, 1996; Sittel, 1994; Green, 1996). Studies linked to effects of ENSO variability on precipitation in the southeastern U.S. have found key results such as the southeast U.S. typically has wet El Niño and dry La Niña in the winter season. Increased winter precipitation during El Niño events in Florida was noted by Douglas and Englehart (1981), Sittel, (1994), and Ropelewski and Halpert, (1989).

Previous variability studies reveal a mitigatable value for yields of crops like corn, cotton, and soybeans which are grown in the southeastern U.S. and are affected by precipitation anomalies during ENSO (El Niño Southern Oscillation) events. Adams et. al. (1994) determined the mitigatable value of improved ENSO forecasts for the spring growing season is over \$100 M a year in the southeast United States. Similarly, for the entire U.S. market, this estimate increases to exceed \$200 M annually (Solav et al., 1998). Links to agriculture yields in the U.S. can be found from studies involving other countries. For example, total precipitation anomalies during an ENSO warm phase are associated with less than normal agriculture yields in some regions of Africa (Cane et. al., 1994).

Most of these previous studies linked to agriculture have used monthly means of totals for precipitation but recent studies suggest that variations in daily precipitation play a role in simulated crop yields (Mearns et al., 1996). Variability of total precipitation has received extensive study in the Southeast. Daily precipitation totals are used in this study.

Two at-risk crops that may be dependent on precipitation runs are corn and cotton. Not enough rain in the summer growing season can reduce corn yields while too much rainfall can put the cotton harvest in fall at risk. For example, an increase in 5-day run events during the fall harvest season could flood the fields damaging the cotton crop yields and a decrease in all runs during the summer growing season could reduce the corn crop yields.

The present analysis uses a 55-year dataset to study the variability in consecutive days of precipitation and how the variability is related to potential impacts on agriculture. Multiple plotting methods and analyses reveal three main variations that precipitation runs have on Southeastern U.S. climate. In addition, the precipitation runs can be separated into latitudinal zones and also show state-to-state variability patterns. Section 2 presents the data and methodology for calculating consecutive runs of precipitation along with techniques used to identify variations in precipitation run data. The results are presented in section 3, discussion is in section 4, and conclusions and ideas for future research are outlined in section 5.

2. Data and Methodology

The data for this project were obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina and contain a quality-controlled set of daily surface minimum and maximum temperature (degrees Fahrenheit) and precipitation totals (hundredths inches); (NCDC, 2001). The area of study is the extreme Southeastern United States and includes 3 states: Florida, Alabama, and Georgia. Out of the over 150 network stations for these 3 states, 33 observing stations were selected for the study (Fig. 1). These stations were selected because they have a nearly even spatial distribution throughout the Southeast and a time series of 50 or more years in length. Long records are needed to identify interannual to decadal variations in precipitation runs. To be used for this study, a station must have at least 90 % of precipitation data available. Only three stations out of the 33 selected stations fell below the set criteria: Gainesville, FL, Orlando, FL, and Huntsville, AL. These stations had approximately 15-20 % of the data missing but were still used for the study for spatial representation of the entire set. With the exception of the previously mentioned stations, the time series for the selected stations consists of daily values for the period 1948-2002.

Precipitation runs are defined as consecutive days with precipitation totals greater than or equal to 0.01 inches. Totals below this threshold (e.g., trace precipitation) are not included in runs. The number of consecutive days with measurable precipitation defined the length of the run and for convenience runs were dated with the last day of the run. For example, if in the first week of October 1948 there were seven days of precipitation of more than 0.01 inches at Tallahassee, FL, then this would be categorized as a seven day run ending on October 7, 1948.

Precipitation runs are analyzed temporally, spatially, and by using animations. Through these methods, state-to-state patterns, seasonal differences, inter-annual to decadal variations,

and any long-term movement of “dry” and “wet” precipitation runs were detected. Time series are created for calendar years and four seasons to identify variations on timescales important to agriculture (e.g., growing and harvest seasons). A calendar year is defined as starting in January and ending in December of the same year. Seasons were defined as follows: Spring starts in March and ends in May, Summer starts in June and ends in August, Fall starts in September and ends in November, and Winter starts in December and ends in February of the following year. Time series in the form of bar plots for calendar years and seasons were used to identify inter-annual, decadal, or inter-decadal signals, while animations showed movement of precipitation runs in time and space. Spatial plotting is used to find north to south gradients in precipitation runs.

The analysis of precipitation is especially difficult when compared to temperature because there are inhomogeneities in station records (Ropelewski and Halpert, 1986). Legler et al. (1998) and Sittel (1994) identified state-to-state variations in total precipitation and mean temperature and noted that precipitation anomalies have more spatial variation than temperature anomalies. The analysis of precipitation is especially difficult because there are inhomogeneities in station records and individual stations may be unrepresentative of the large scale due to local effects. One would expect station to station variability to also show in precipitation runs.

However, little research has been discovered that focuses on state-to-state variations in consecutive days of precipitation. Because of the spatial variability associated with precipitation, it makes it difficult to study such a variable over a wide area. Therefore, individual stations may be representative of large-scale features due to local effects at those stations.

To alleviate some of the local effects, anomalies were created for some analyses using:

$$\frac{x_r - \bar{X}_r}{\bar{X}_r}$$

where x_r is the number of counts of length r ($r = 2, 3, 4, \dots, n$) for a specified time period (season or year) and \bar{X}_r is the average counts for all 55 years (seasons) for a station. The anomaly ratio shows movement of “wet” and “dry” years when plotted as animations.

3. Results

Using conventional time series, geometric time series, and histograms, three key precipitation run results were found for the Southeast; (1) state-to-state variations in precipitation runs, (2) a notable trend of summer increases in runs in Florida/South Alabama/South Georgia, and (3) temporal preference to what length of run will occur in the Northern section of the study area.

A. Climatology

Overall annual distributions of consecutive precipitation runs in the Southeastern U.S. (Fig. 2) reveal differences based on the length of the run. In Florida, 2 day runs occurred less than 750 times throughout a 55-year period and there was an evenly distributed decrease as the number of days in a given run increased. In contrast, Georgia and Alabama collectively have more than 875 2-day runs throughout the 55-year period (Fig. 2). Alabama shows a similar overall distribution as Georgia. On average, 2-day run events occur 125 more times in Georgia and Alabama than Florida. The distributions for Georgia and Alabama are also more skewed toward lower runs, which is representative of their mid-latitude locations making them susceptible to frontal systems. Florida has the best chance for multi-day precipitation runs of 5 or more days, and has seventeen 10-day plus events when compared with Georgia and Alabama. Very few runs of greater than 6 days occurred over the period in Alabama and Georgia. These climatological differences are in part associated with a North-South gradient in precipitation run frequency.

B. North-South Gradient

The seasonal concentration of precipitation runs varies from North to South in the study area. The temporal distribution of runs (Fig. 3) can be grouped by latitude into three regions:

North Alabama/North Georgia (Region 1), North Florida/South Alabama/South Georgia (Region 2), and South Florida (Region 3): (Fig. 1). Region 3 shows a strong concentration of runs in the summer season as illustrated by the distribution for Bradenton, FL (Fig. 3a). The northernmost stations (e.g., Talladega; Fig. 3d) in Region 1 show no strong preference for runs in any season or concentration of runs annually. Runs in Region 1 are scattered throughout the year with more runs occurring some years than others and an almost equal chance of runs occurring in each month. In between these two latitudinal belts lies Region 2, a transition zone for the seasonality of runs. In the southern portion of this transition belt (e.g., Tallahassee, FL: Fig. 3b), there are summer seasonal concentrations of runs but there are also minor concentrations of runs in other seasons, which are not seen in the other two belts. In the northern part of this transition belt (e.g., Columbus, GA: Fig. 3c), there are the same summer concentrations, but are less defined farther north in the region.

This North-South seasonal gradient in precipitation runs can also be shown in the exceedence probability distributions for different length runs. In South Florida the probability of 2, 3, 4, and 5 or greater day runs is greater during the summer. For example, there is an 80 % probability that 2 or more 5 or greater day runs will occur at Bradenton, FL in the summer season (Fig. 4). Fall shows the second highest probability of precipitation runs in Region 3, with a 30 % chance that runs of 5 days or greater will occur 2 or more times. In Region 1 (represented by Talladega, AL; Fig. 7), the lack of variation by season is prominent for 3, 4, 5 and greater day events, with almost equal chance of having these runs anytime in the year. 2-day run events show some variation by season in Region 1, being slightly more common in the spring and least likely in the fall. Region 2, represented by Tallahassee, FL (Fig. 5) and Columbus, GA (Fig. 6) shows higher probability of 3, 4, and 5 or greater day runs in the summer versus other seasons. The

summer chance for 5-day precipitation runs decreases from south to north in Region 2. The probability of having three 5-day runs at Tallahassee, FL is 50 % and the chance of having the same amount of runs drops to 20 % at Columbus, GA. South Alabama and South Georgia create nearly 50 % more rainfall in the winter for north Region 2 when compared to the panhandle of Florida, south Region 2. The Florida Panhandle has a 50 % chance of having triple the amount of 2 and 3-day runs in the winter than South Alabama and South Georgia. Also in Region 2, the seasonality of 2 and 3-day events decreases and becomes more equal among the seasons in the northern sections towards Region 3. This is best shown in Fig. 7.

C. Long-term Variations in Precipitation Runs

Region 3 is best represented by Bradenton, FL where three patterns were analyzed. Starting in the mid 1970's to the late 1970's and then into the late 1990's, a low run pattern is represented (Fig. 8). This pattern is more predominant in 2-day runs but it can also be seen in the total bars of all runs. There are two maxima for the signal; in 1983 and 1997 respectively, where there are approximately 18 and 15, 2-day run events. In the later periods and up until 2002, 2-day runs are decreasing to around 5 events in 2002 and all other types of runs are increasing, like 6, 5-day run events in 2002. Like the other analyses, precipitation runs are concentrated in the summer season for Region 3 leading to strong intra-annual to decadal patterns (Fig. 9). Inter-annual variability is best represented for Bradenton and Region 3 by 4-day and 5-day runs in the summer with 3-4 year cycles of variability. An example of this is the period from 1953-1957 where there are two maxima; one in 1953 and the other in 1957 which have approximately 12 total run events. In the middle of this period, total run events are approximately 10 or less. It should also be noted that when 5-day runs decrease, 4-day runs increase in number and vice versa. This change is also most predominant in the summer season (Fig. 9).

Region 1 is represented by Birmingham, AL (Fig. 10 and Fig. 11). Region 1 has no extended periods of low numbers of total run events and also all seasons show no predominant patterns. It is noted that Birmingham, AL has three high run event years (counts); 1949, 1982, and 1997. In these years, more than 25, 2-day run events and 10, 3-day run events occurred approximately (Fig. 10). For Region 1, 3-day runs don't vary much over time and when they do, it is best seen in the winter season (Fig. 11). Approximately 10-15, 3-day run events occur per year for the 55-year period. The winter season variability for 3-day run events exhibits a decadal pattern (e.g., approximately 1 run event in the early 1950's and approximately 5-6 run events in the early 1960's).

The transition belt, Region 2, is represented by Eufaula, AL for variations (Fig. 12 and Fig. 13). The annual bar plot (Fig. 12) shows an inter-decadal pattern of "wet" and "dry" years for total runs. There is an anomalously wet period from the late 1950's to the mid 1960's with more than 30 total run events and there is an anomalously dry period from the late 1970's until the mid 1980's with less than 25 total run events and a minimum of 18 run events in 1977. Another anomalously wet period starts in the late 1980's and continues until the mid 1990's with more than 30 total run events and a maximum of 39 run events in 1992. From the late 1990's until 2002 it appears that Eufaula, AL is entering another anomalously dry period with 19 total run events in 1998. When broken up seasonally, no coherence of trends with other stations were seen in Region 2.

4. Discussion

The North-South gradient in precipitation runs can be associated with three different climate regimes. The precipitation run variability (not the gradient) may be related to different atmospheric flow patterns associated with ENSO, Pacific-North American (PNA) pattern, or the Pacific-Decadal Oscillation (PDO). Future predictions of these atmospheric flow patterns may lead to advance knowledge of future precipitation runs frequency. If precipitation run frequency can be better predicted, the predictions would be important for agricultural stakeholders, possibly leading to mitigation of detrimental impacts of increased or decreased runs.

The North-South gradient is most likely created because of three factors: proximity to the ocean, diabatic processes, and susceptibility to frontal systems. These three factors are characteristics of three different climate regimes in the southeast. Region 3 has two types of regimes: a summer wet regime and a winter dry regime (O'Brien et. al., 1999). During the summer, the subtropical high creates an easterly flow over Region 3 providing ample moist air for daily precipitation. The close proximity to the ocean also leads to frequent seabreeze fronts in Region 3 during the summer season, resulting in consecutive days with convective rains. As a result, Region 3 is prone to multi-day runs in the summer (Fig. 3a). The winter season in Region 3 is drier and is less susceptible to frontal systems particularly due to its southerly location with respect to Region 1 and Region 2. Region 1 is influenced by both daytime convection in the summer and precipitation from low pressure and frontal systems in the winter. Region 1 is remote from the ocean and is unaffected by sea/land breeze systems. Region 2 has a combination of the regimes from Region 3 and Region 1, making them a transition region in the southeastern U.S. The location of Region 2 makes it susceptible to not only summer-time precipitation induced by seabreeze and airmass convection but also precipitation runs from low pressure

systems and fronts that make it that far into the south. In the coastal areas of Region 2, sea breeze fronts may also induce summer-time precipitation.

The agricultural yields in each of the three regions in the Southeast may be impacted by precipitation runs. In all the regions in the southeast, too little or too much rain can decrease agricultural yields though the magnitude of the impact will depend on the type of crop. Tomato and green peppers grown in the southern Region 3 could be negatively affected by too many precipitation runs in the winter. From previous research, it was found that El Niño winters result in increased precipitation for the southeast leading to the possibility of more runs (Ropelewski and Halpert, 1989). If there are too many precipitation runs in winter in south Region 3, the tomatoes and green peppers may rot or become infected with disease. An example is the mid 1980's and mid 1990's when more than 3, 5-day events occurred at Bradenton, FL (Fig. 9). On the other hand, northern Region 3 could be negatively affected by too few precipitation runs. Impact crops include hay/grass production in the pastures where precipitation is needed to have positive yields. If there are not enough runs of precipitation in the spring and summer seasons, hay production may be limited.

Region 1 is possibly the least predictable of all the regions of when to plant, grow, and harvest any type of crop. Precipitation runs have little seasonal concentration (Fig. 11) probably making it difficult for growers to have a regular agricultural yield of a particular crop. From various sources and agricultural censuses, I found that Region 1 has grown hay, cotton, and wheat predominantly but I found no annual agricultural yields that are impacted by a particular season. Unlike Region 2, Region 1 is at risk year-round for planting, growing, and harvesting and there is less predictability.

The impact crops in Region 2 are predominantly peanuts (underground) and cotton (above ground) and they may be affected by too many runs in the harvest season which is late fall. If it is an anomalously wet fall season, crop yields of peanuts and cotton may be swamped out. An example is in the late 1950's to early 1960's when more than 8 total run events occurred per fall season in Eufaula, AL (Fig.13).

5. Conclusions

Using daily precipitation totals for 33 Southeast U.S. stations, categorized runs of precipitation were calculated and analyzed annually and seasonally. The results identified three regions in the Southeast U.S. which exhibit different climatologies and long-term variations of precipitation runs. The three regions were: North Alabama/North Georgia (Region 1), North Florida/South Alabama/South Georgia (Region 2), and South Florida (Region 3): (Fig. 1). Each of the regions had their own climate regimes with dominant seasons and long-term changes.

The impact of precipitation runs on Southeast agriculture is the most significant in Region 3, somewhat significant in Region 2, and not much significance in Region 1. Several at-risk crops were presented and discussed for positive and negative impacts from precipitation runs. The mitigatable economic value of improved precipitation run forecasting could be essential for crop yields in the Southeast U.S.

Finally, expanded analysis including more stations will greatly improve the robustness and clarity of the results found. Further analysis incorporating crop yields and other agricultural resources will aid in determining mitigatable values of this research. Also, a threshold of 0.25 inches of precipitation for a run may prove to be better than the current threshold of 0.01 inches. This will not only allow for more accurate studies on agriculture but also allow for studies of impacts on flooding for emergency management stakeholders as well. Long-term periods of below or above normal precipitation runs may be associated with large scale atmospheric patterns such as ENSO, PNA, or PDO and this could be found in future work. The results of these efforts will be reported elsewhere.

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Southeast US Station Map

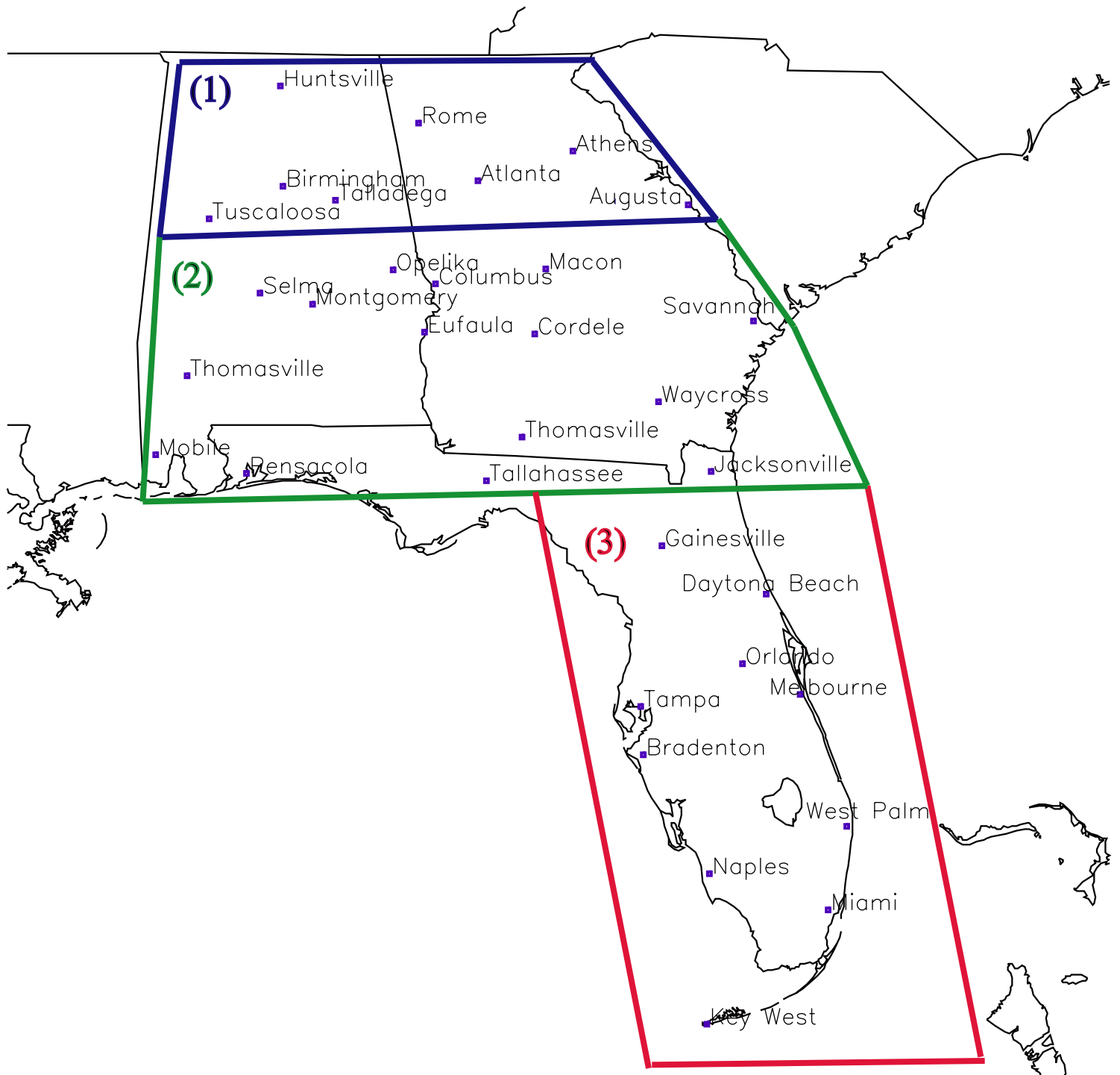


Figure 1. Stations Map

Locations of the 33 stations used in this study. Also three regions are highlighted. The three regions exhibit similar temporal variations in precipitation runs (see text).

Histogram of Precipitation Runs for Florida, Georgia, and Alabama

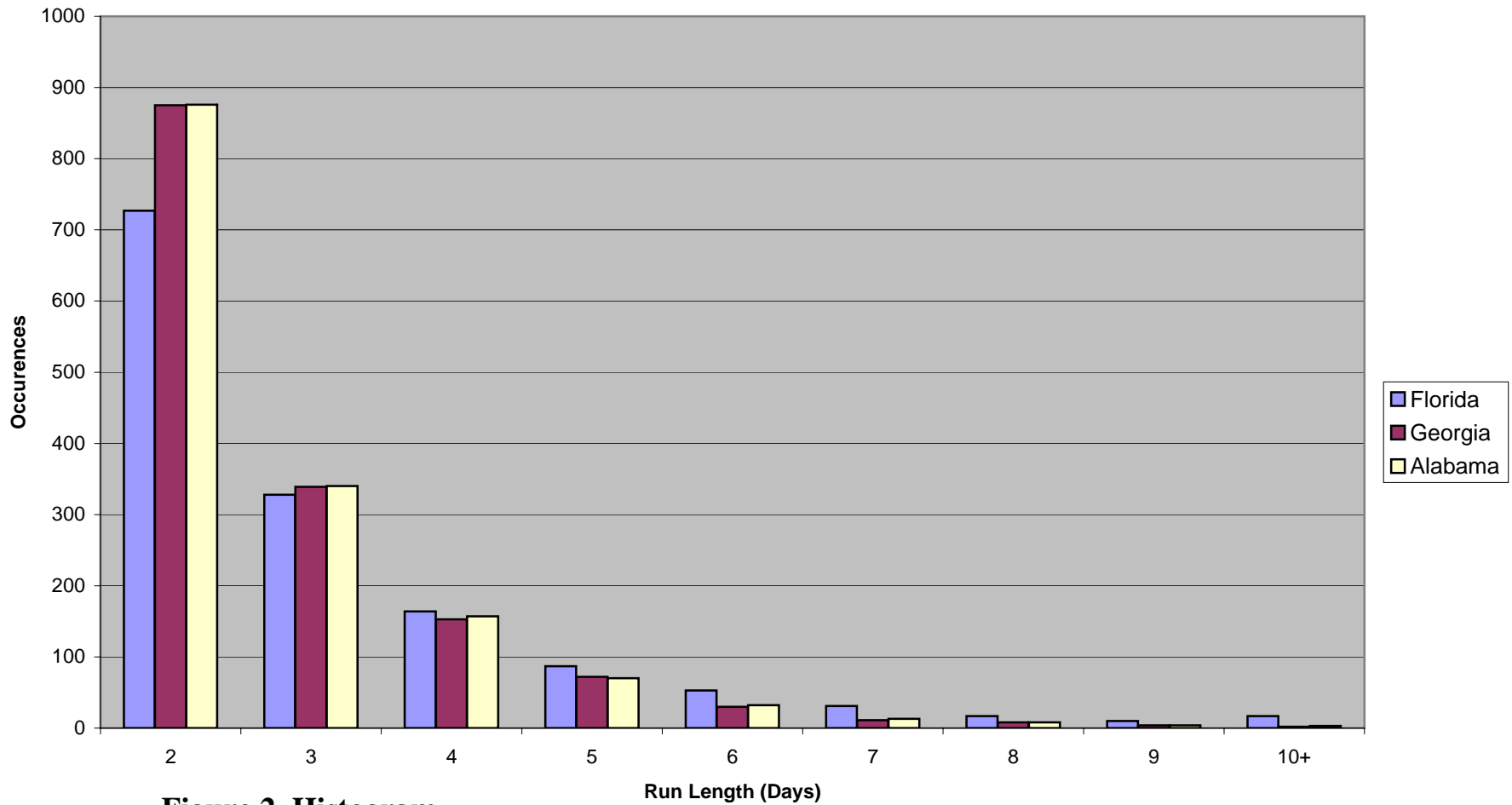


Figure 2. Histogram

Showing the underlying distribution of precipitation runs for Florida, Georgia, and Alabama. Runs are placed into 1-day run bins and are counted (1948-2002).

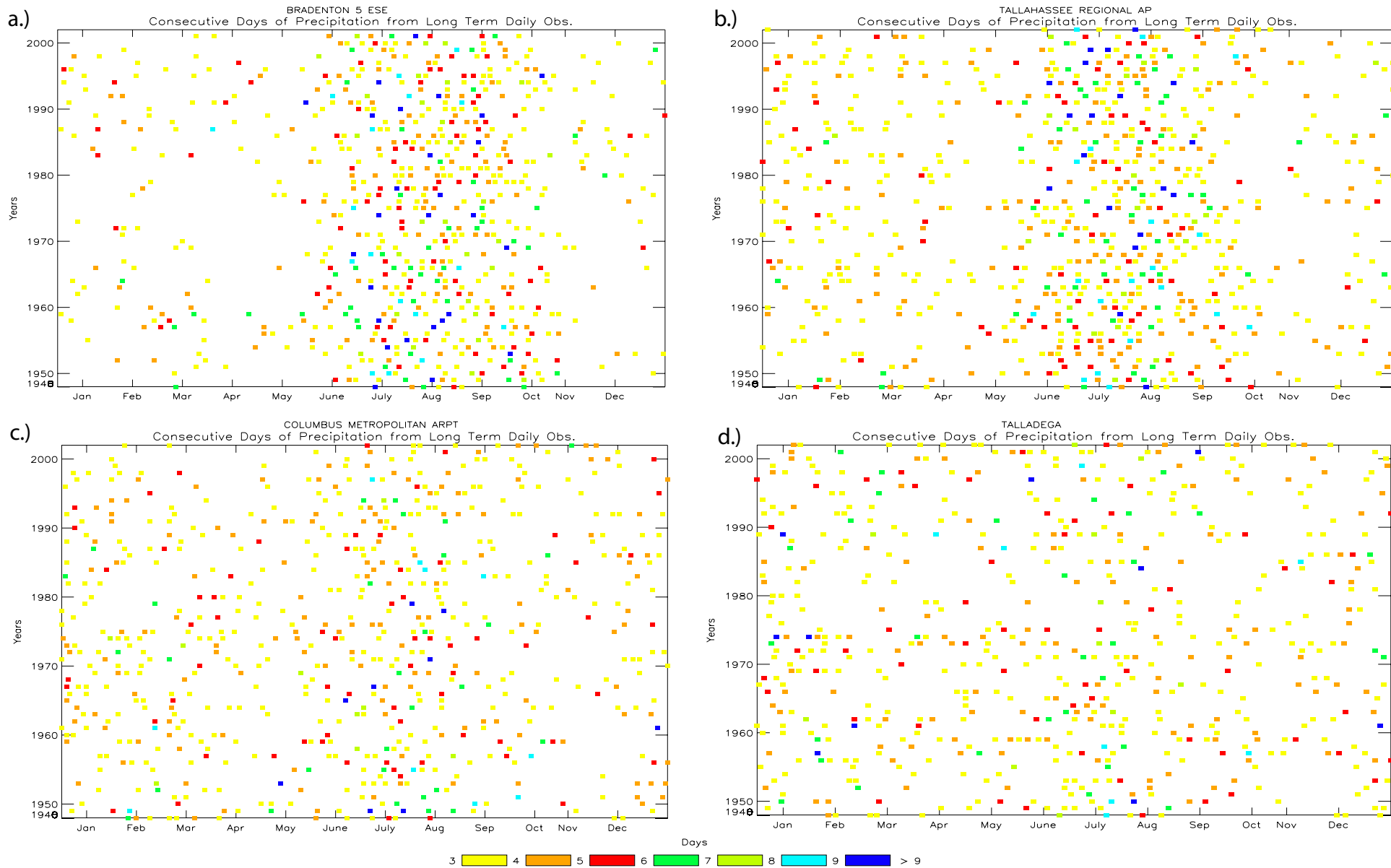


Figure 3. Temporal Distribution of Precipitation Runs

Colored boxes represents a run (see legend for length) ending on that day. The center of the month is marked on the x-axis. For clarity, only runs 3 days and greater are plotted.

Excedence Probability Distributions – BRADENTON 5 ESE

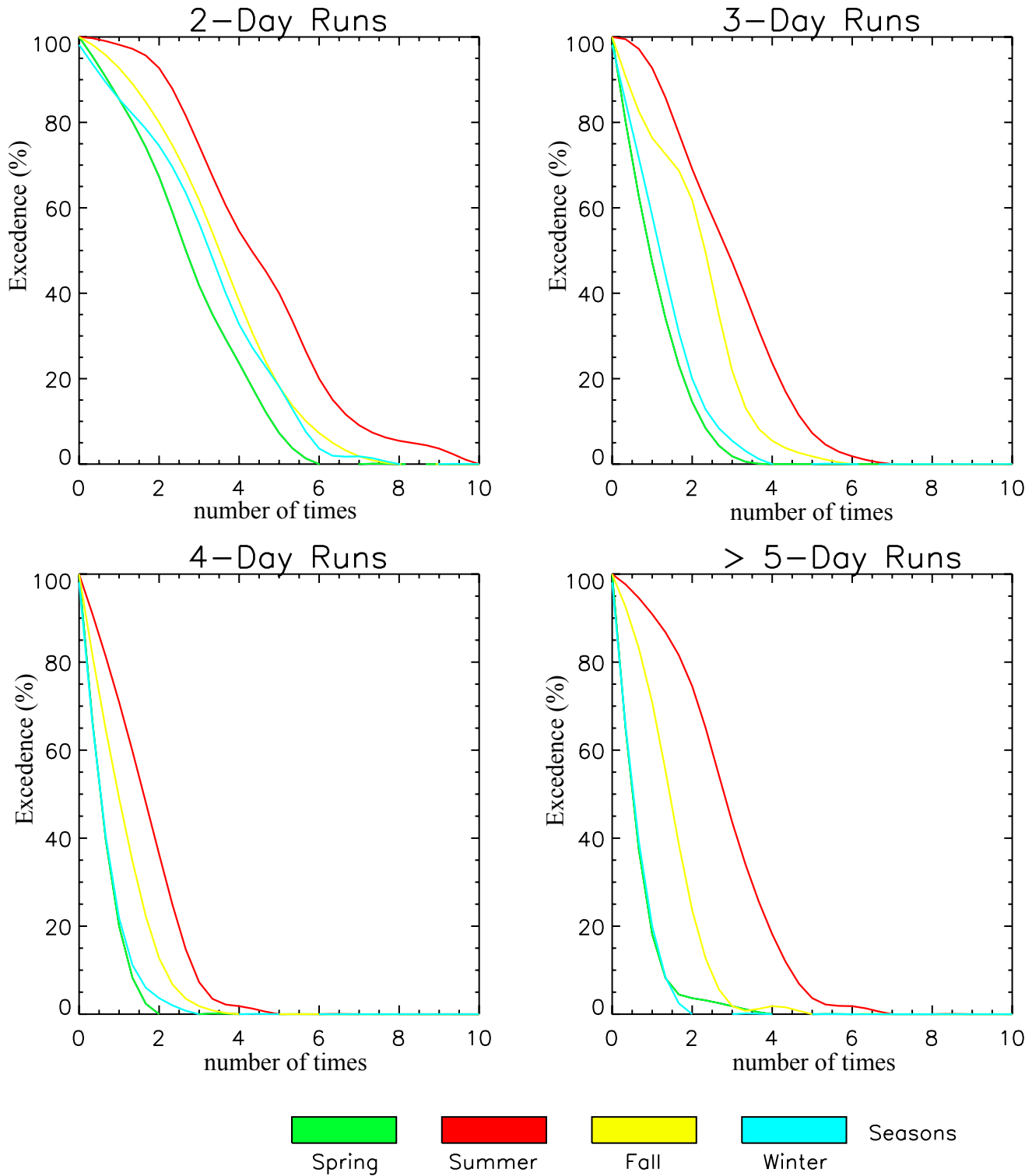


Figure 4. Seasonal Excedence Probability Distributions

This four-panel plot shows the probability of how many times a certain length run may occur at Bradenton, FL. Colored lines correspond to the different seasons and there are plots for 2, 3, 4, and 5 or greater day runs.

Excedence Probability Distributions – TALLAHASSEE REGIONAL AP

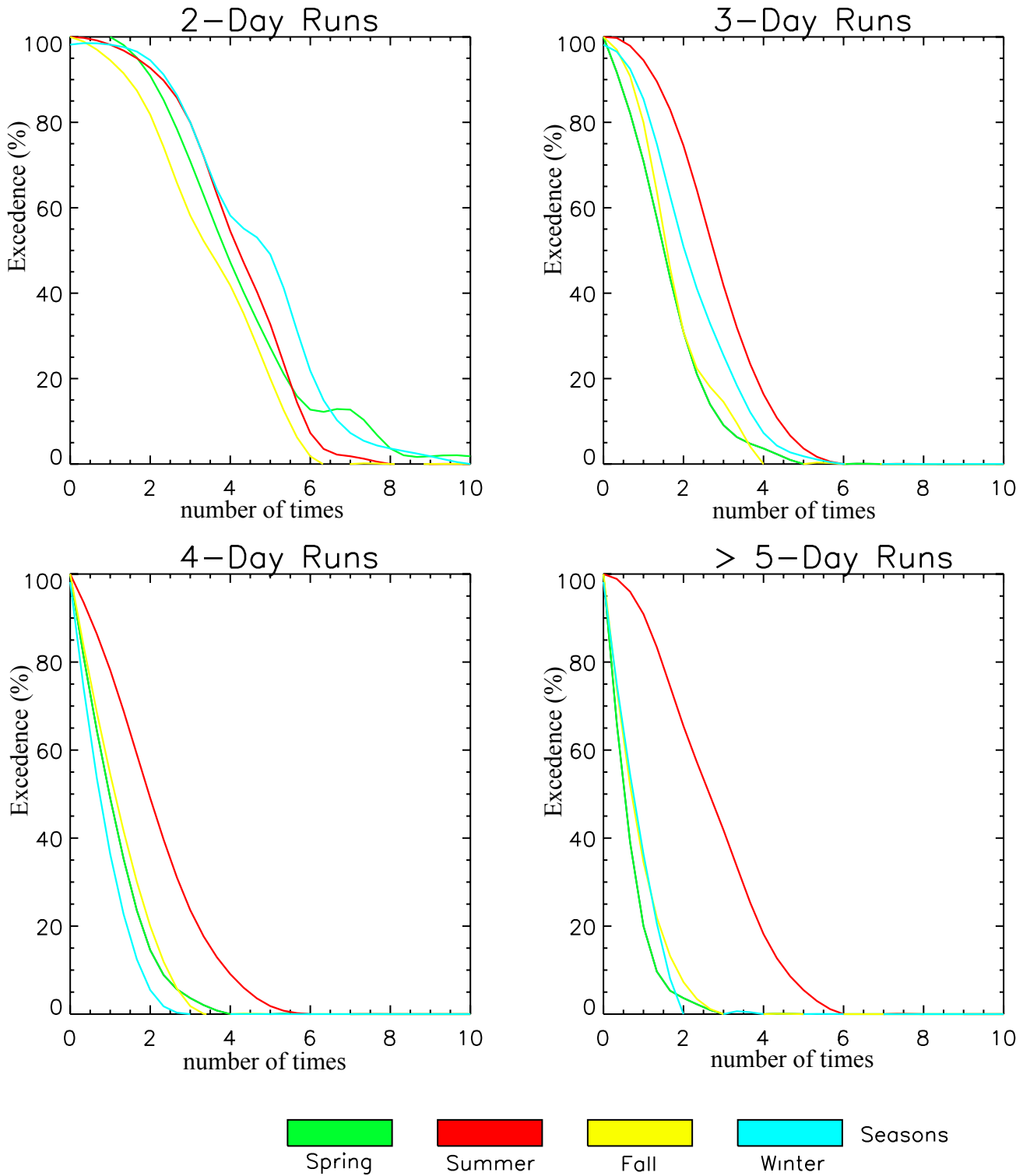


Figure 5. Seasonal Excedence Probability Distributions
Same four-panel plot as in Fig. 4 but this shows Tallahassee, FL.

Excedence Probability Distributions – COLUMBUS METROPOLITAN ARPT

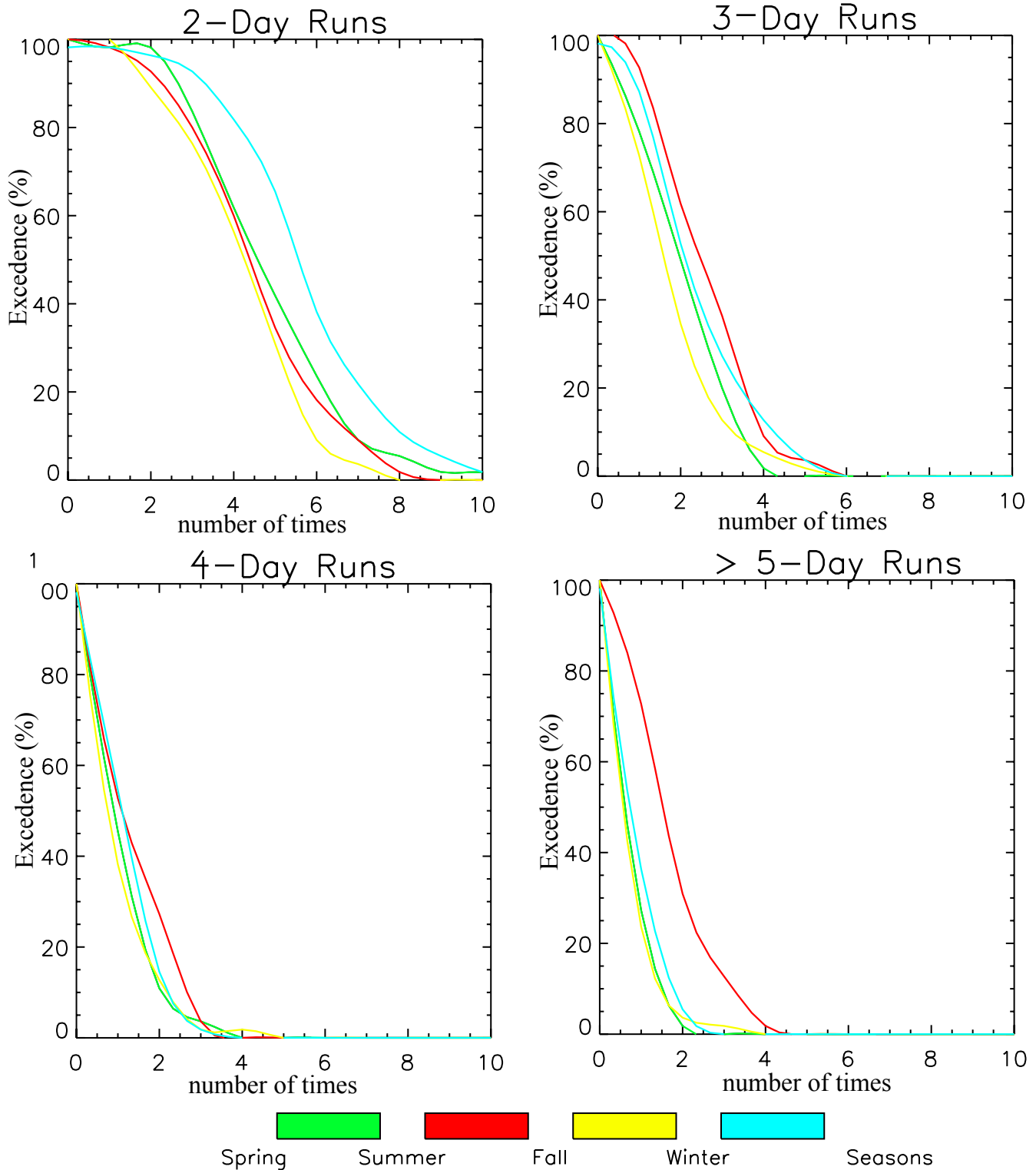


Figure 6. Seasonal Excedence Probability Distributions
Same four-panel plot as in Fig. 4 but this shows Columbus, GA.

Excedence Probability Distributions – TALLADEGA

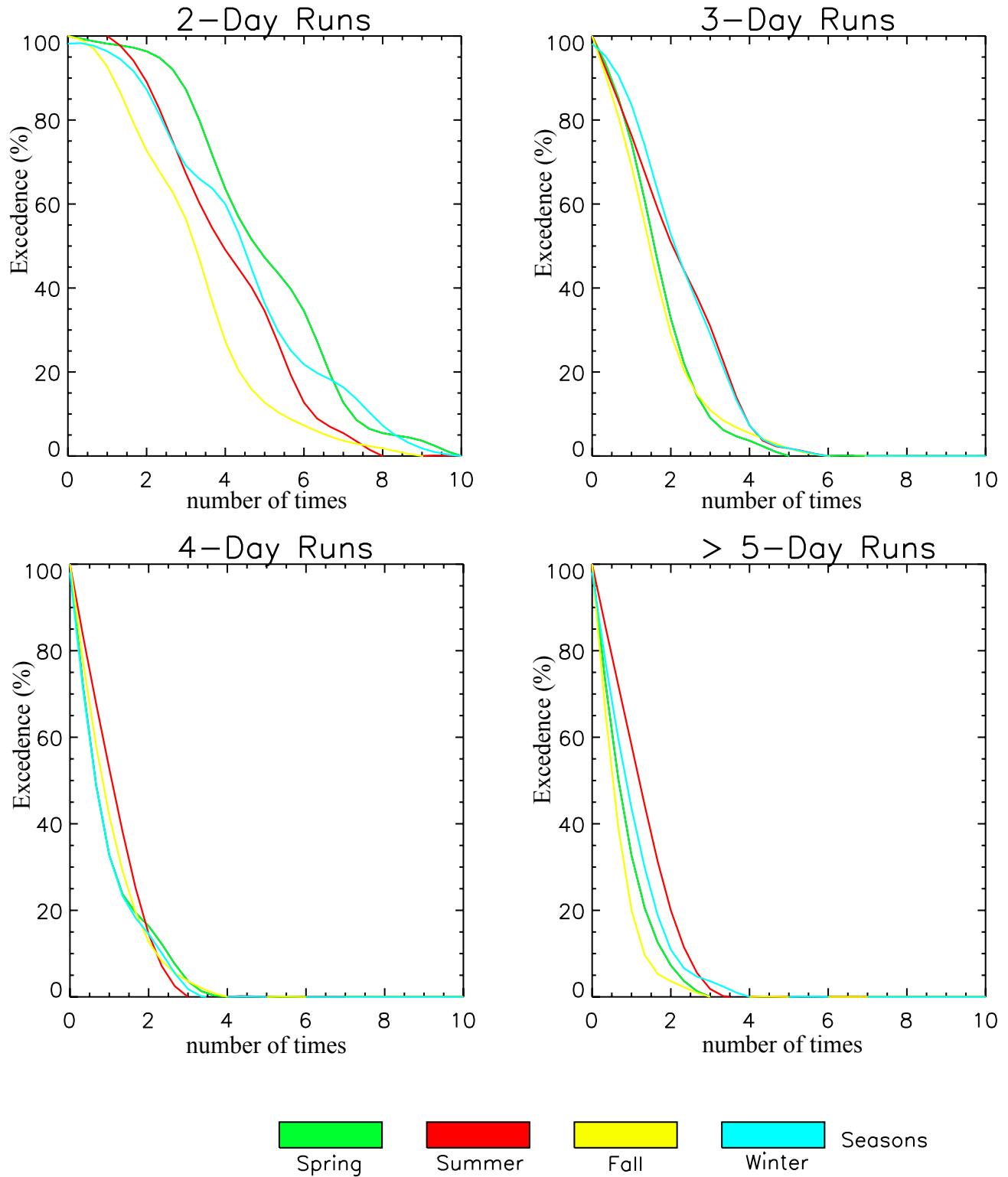


Figure 7. Seasonal Excedence Probability Distributions
Same four-panel plot as in Fig. 4 but this shows Talladega, AL.

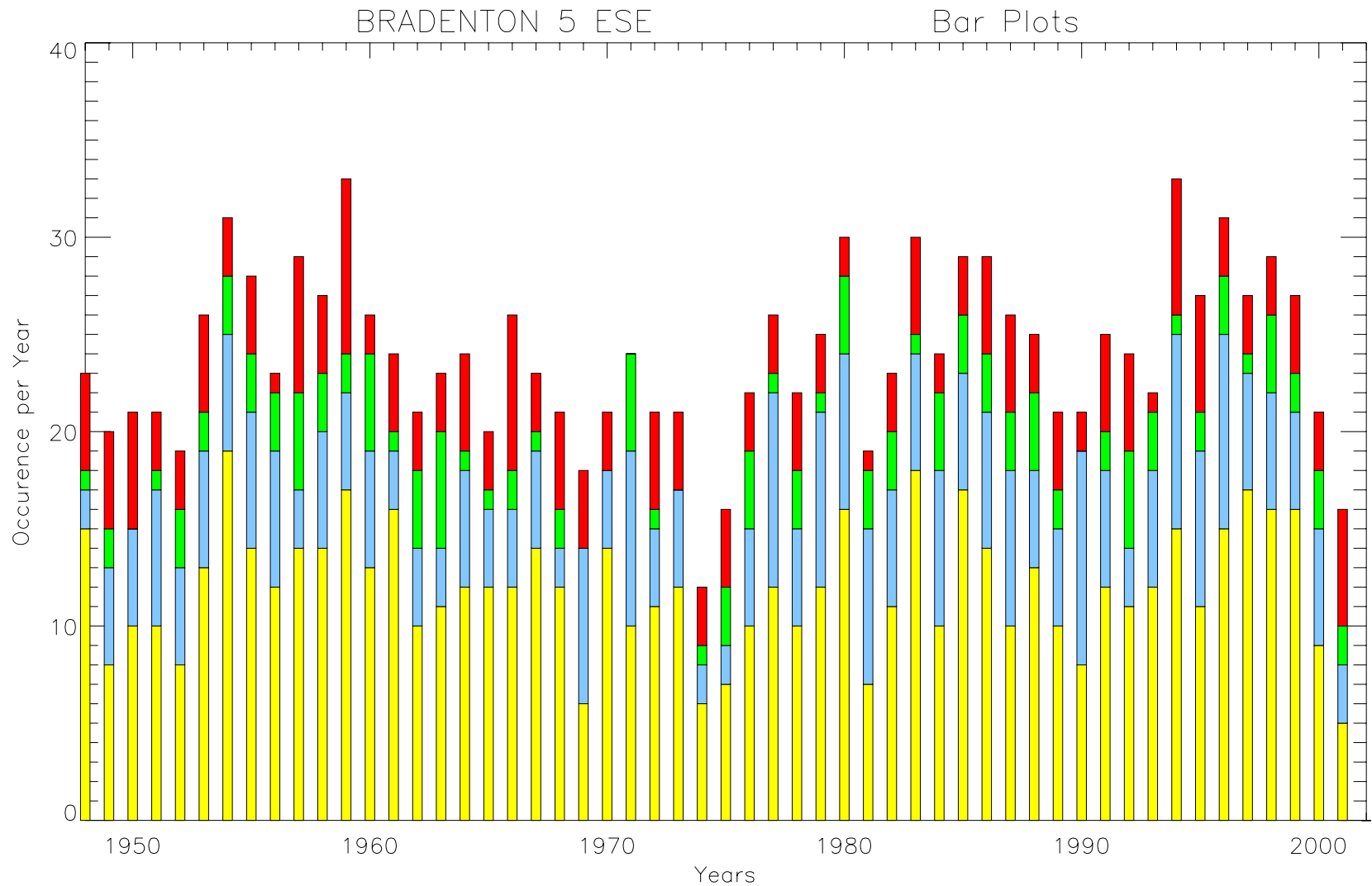
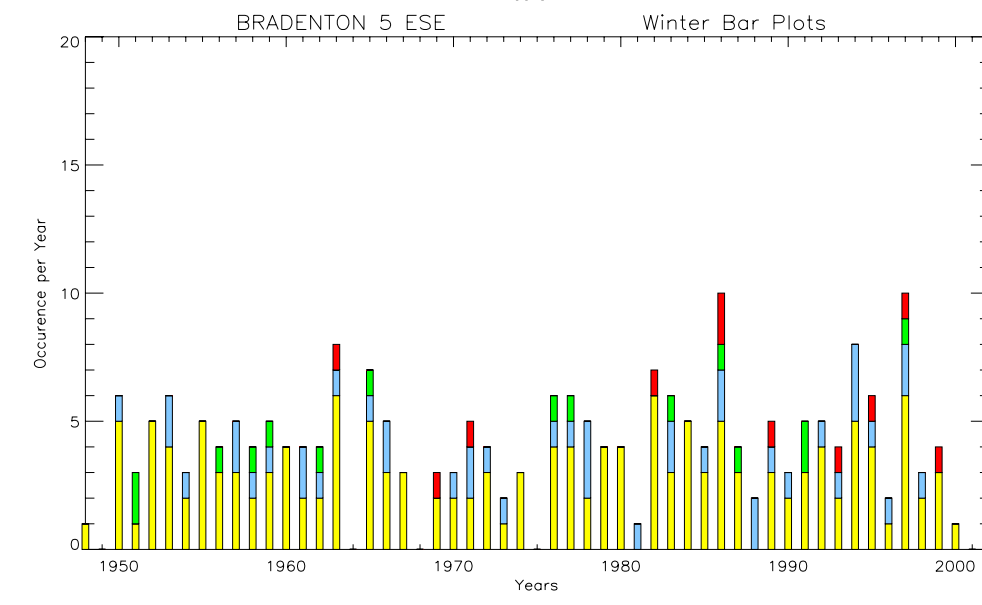
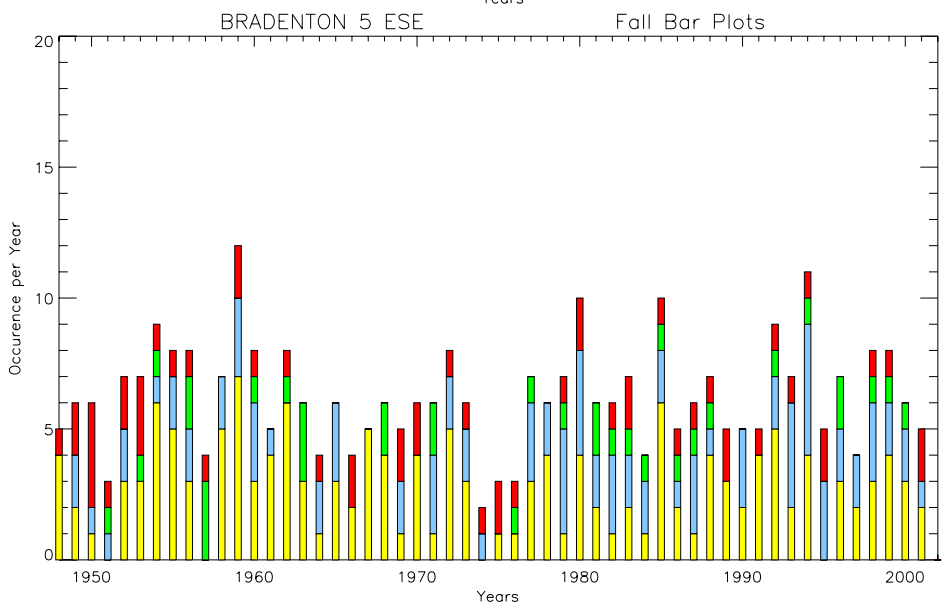
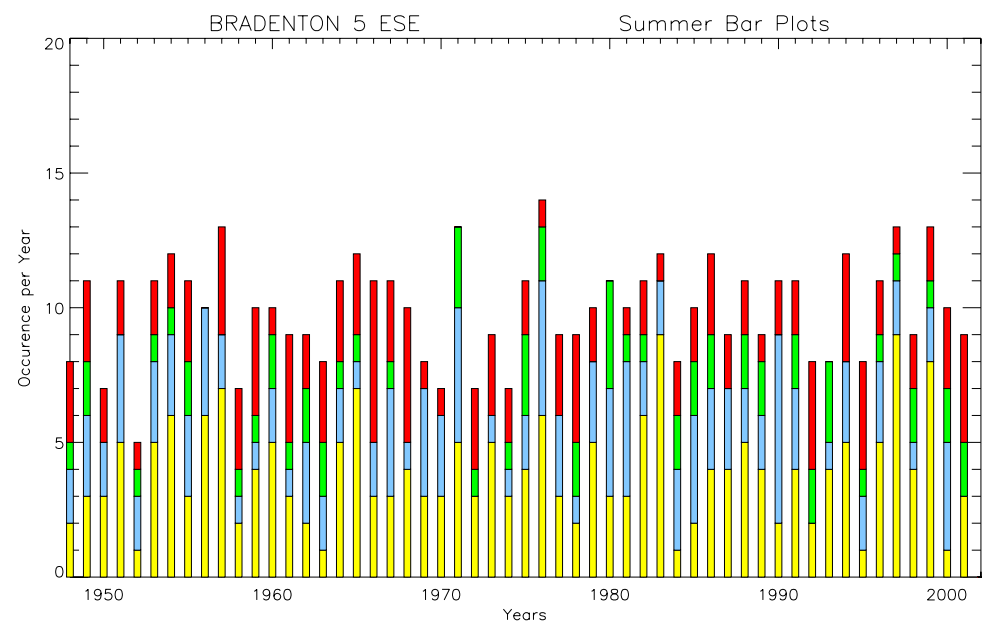
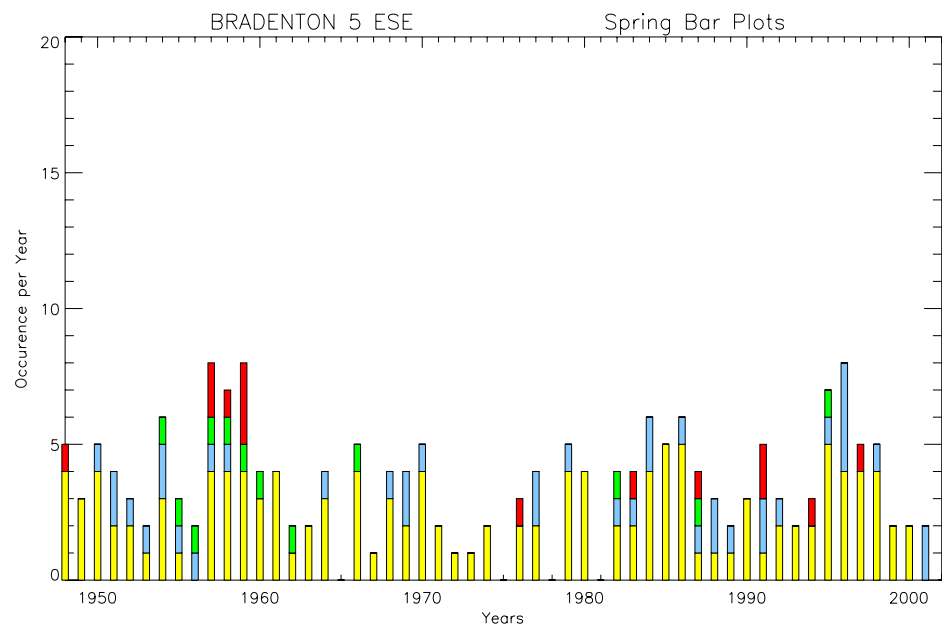


Figure 8. Annual Bar Plot

This plot shows the annual occurrences in each run category (see legend) at Bradenton, FL. Colored bars correspond to the type of run with years on the x-axis and number of times occurred on the y-axis.



2 Day Runs
 3 Day Runs
 4 Day Runs
 5 or more Day Runs

Figure 9. Seasonal Bar Plots

The same technique as used in Fig. 8 but this time broken into seasons. Each plot represents a season and colored bars correspond to a type of run. It should be noted that the winter season starts in December of the same year and ends in February of the following year. This figure shows Bradenton, FL.

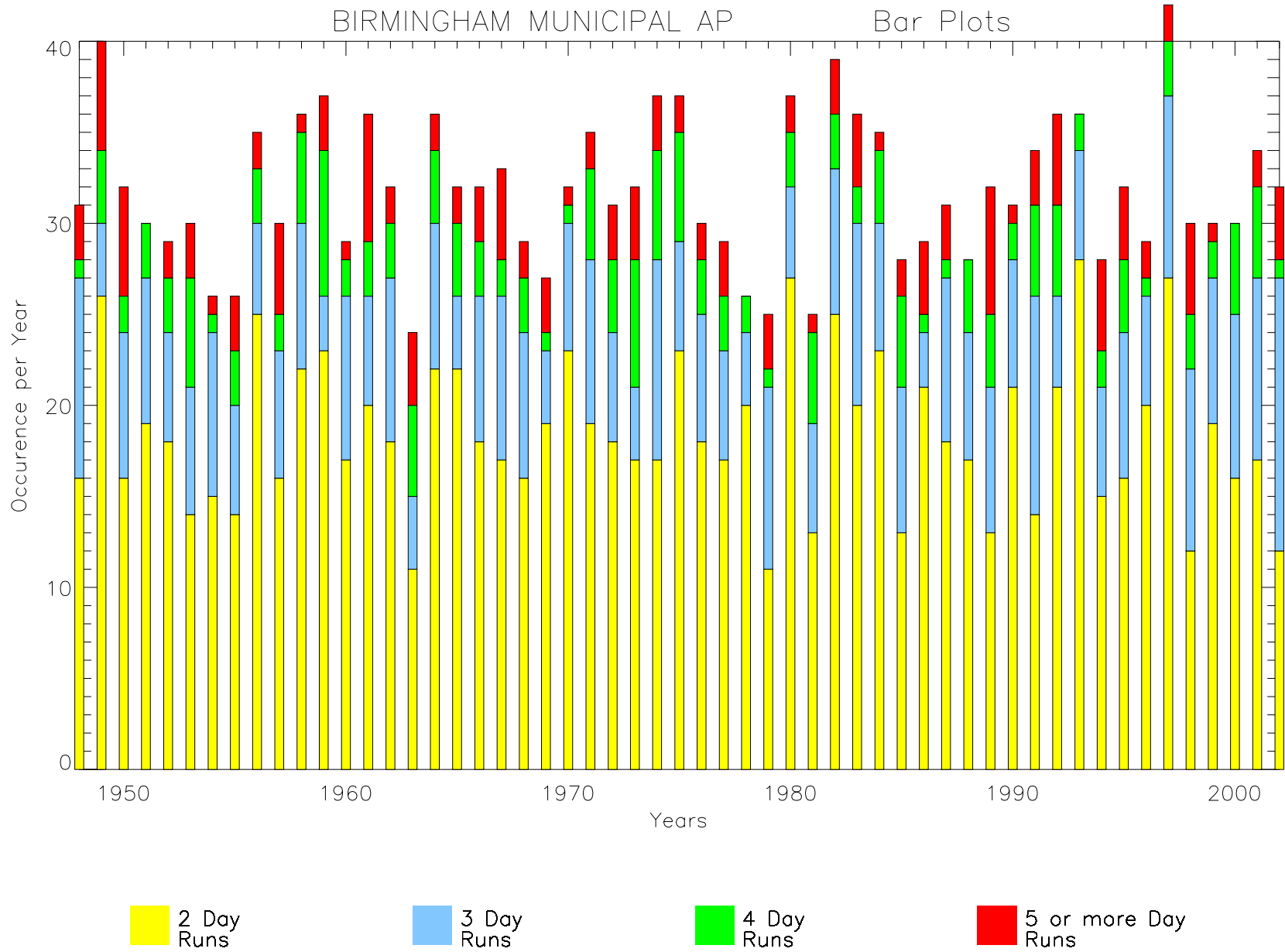


Figure 10. Annual Bar Plot

Same as in Fig. 8 but this shows Birmingham, AL.

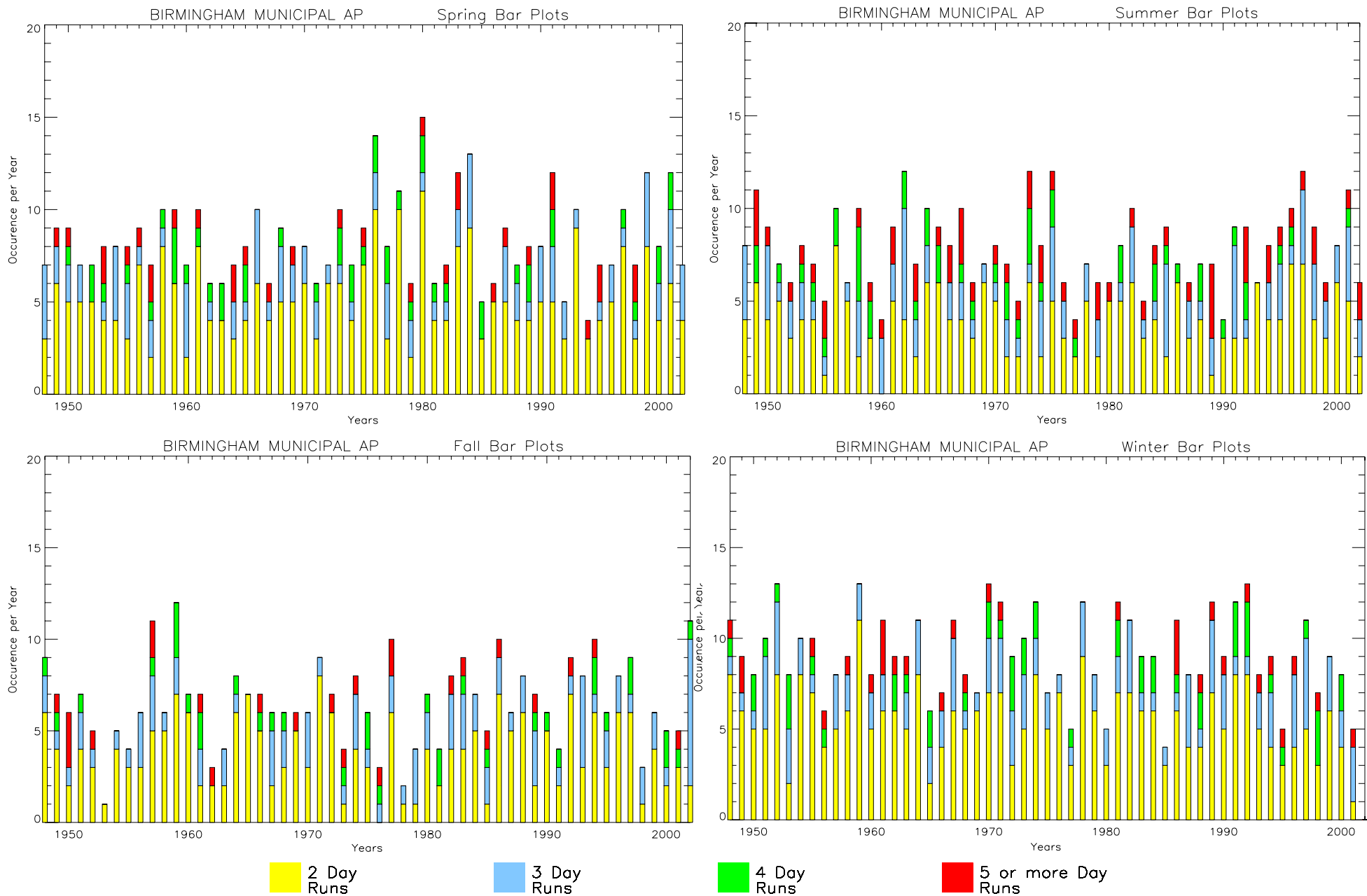


Figure 11. Seasonal Bar Plots

Same as in Fig. 9 but this shows Birmingham, AL.

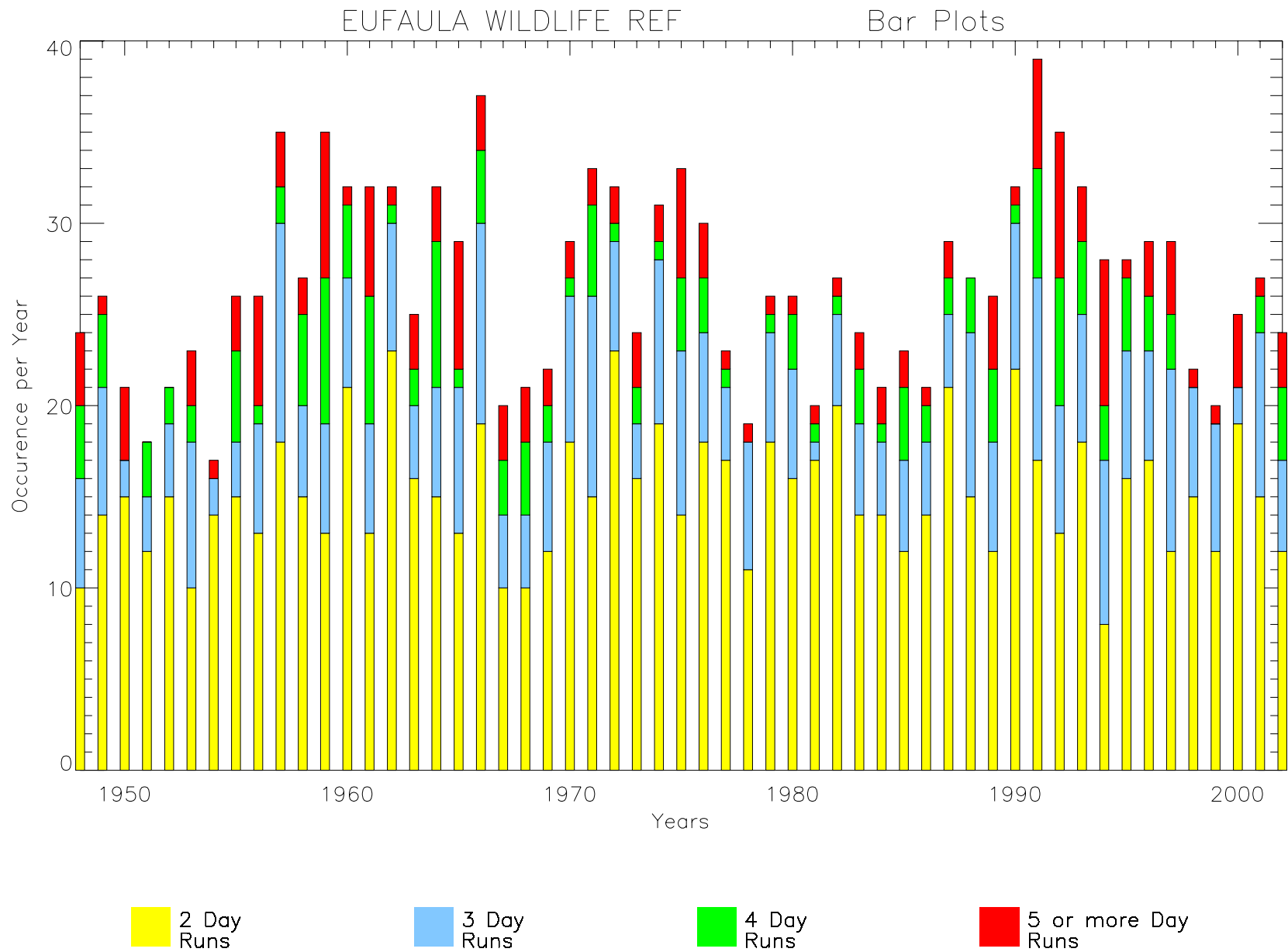
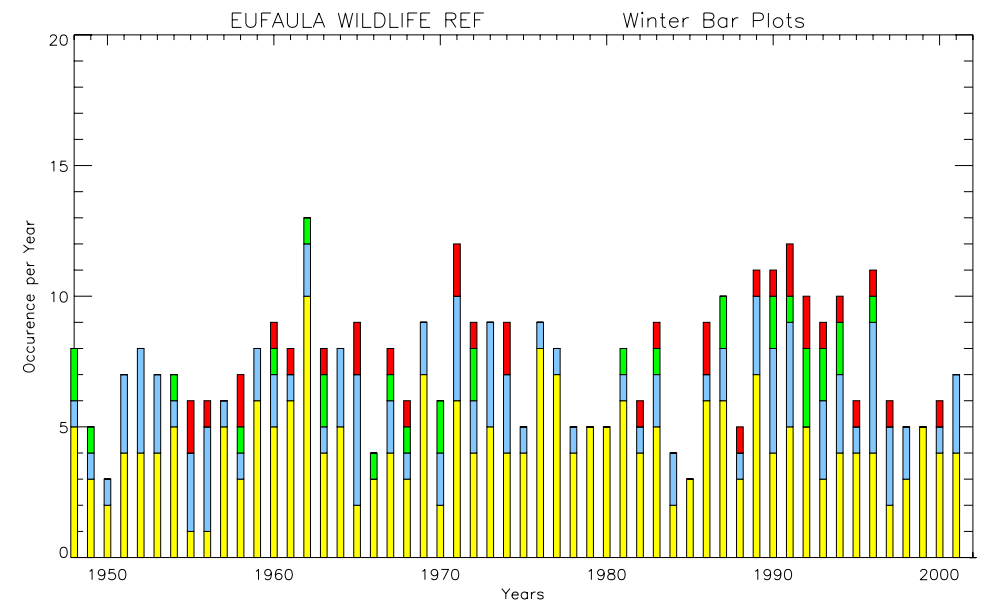
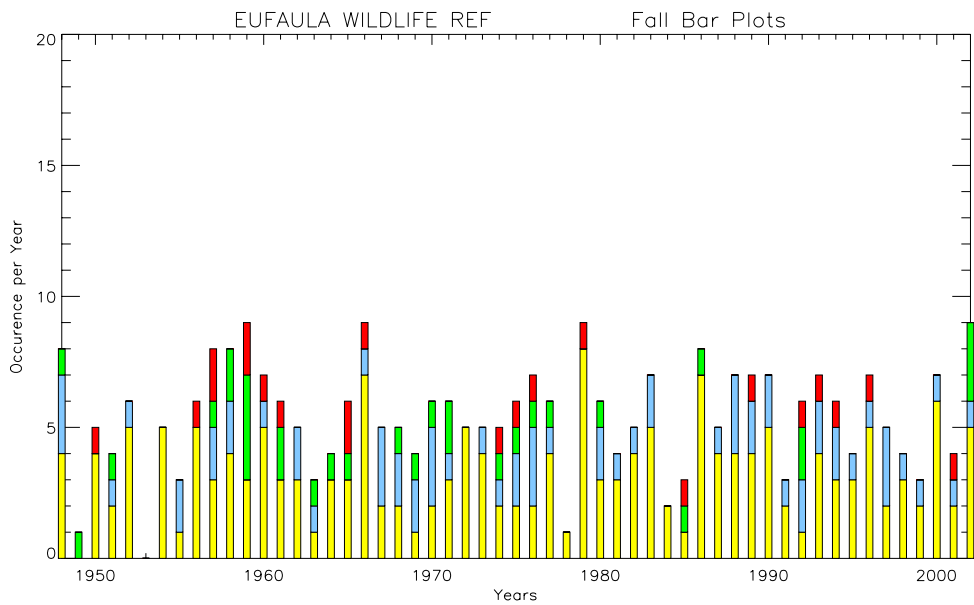
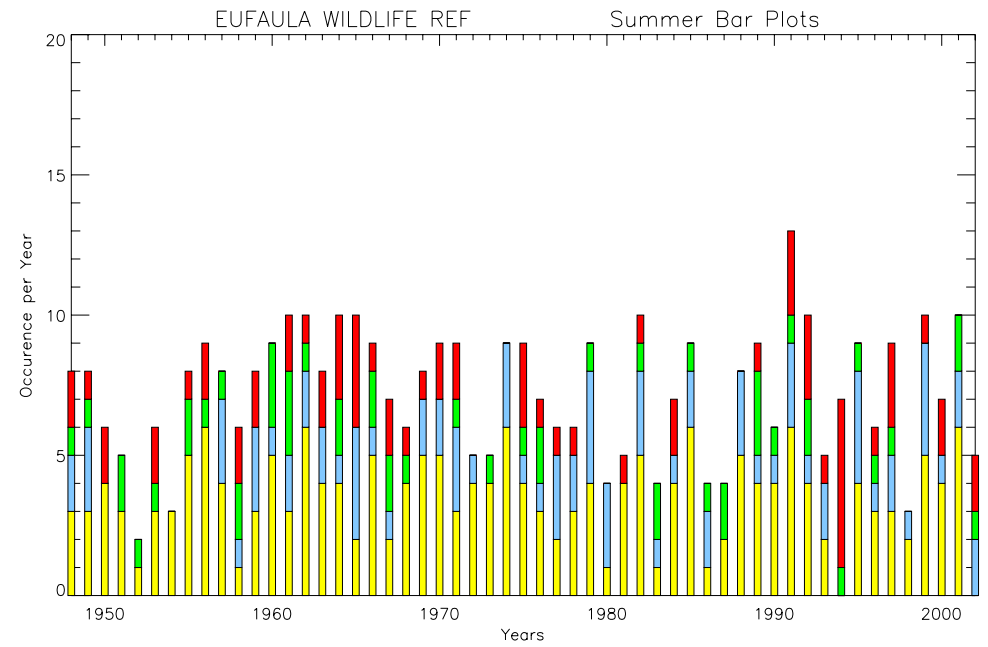
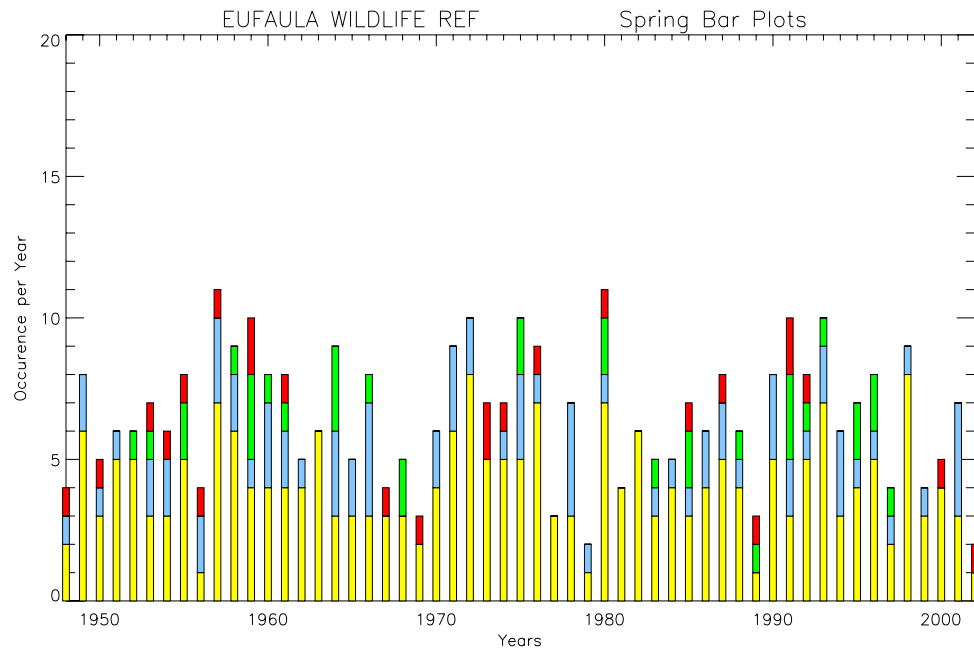


Figure 12. Annual Bar Plot
 Same as in Fig. 8 but this shows Eufaula, AL.



2 Day Runs
 3 Day Runs
 4 Day Runs
 5 or more Day Runs

Figure 13. Seasonal Bar Plots

Same as in Fig. 9 but this shows Eufaula, AL.