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A SEVERE WEATHER, HURRICANE, AND FLOOD CLIMATOLOGY FOR THE AUSTIN/SAN ANTONIO WFO COUNTY WARNING AREA

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1. INTRODUCTION

As part of the NWS Modernization and Associated Restructuring (MAR), several NWS offices in South Texas will be combined into a new office at New Braunfels. The new office is designated the Austin/San Antonio WFO (Warning and Forecast Office). Its responsibilities will eventually incorporate some or all of the responsibilities of the present offices at Del Rio (WSO), Austin (WSO), Victoria (WSO), Hondo (WSMO), and San Antonio (WSFO). The resulting Austin/San Antonio WFO County Warning Area (CWA) will comprise 33 counties. The CWA will be under surveillance of three WSR-88D Doppler radars: the Department of Commerce/NWS radar in New Braunfels, and Department of Defense (DoD) radars at Brackettville and Granger (Fig. 1).

This study was undertaken to compile a detailed climatology of severe weather, hurricane, and flood events for the Austin/San Antonio (hereafter referred to as AUS/SAT) CWA for the benefit primarily of forecasters and others who may be unfamiliar with the new area of responsibility. Event data were provided by the National Severe Storms Forecast Center (NSSFC). The data base used was NSSFC's Severe Plot (SVRPLOT) software (Hart 1993).

The western and central counties of the CWA have low population densities, since much of the area comprises large ranches. With only a few populated towns along major highways, severe weather reports from these areas are sparse.

2. TERRAIN AND CLIMATE OF THE AUSTIN/SAN ANTONIO AREA

The AUS/SAT CWA geography includes parts of the Coastal Plains, the Balcones Escarpment, the Hill Country, and the Edwards Plateau (Fig. 2a). This region ranges in elevation above sea level from just above 100 ft in the Coastal Plains to almost 2500 ft in the Edwards Plateau. A large portion of the AUS/SAT CWA is known as the Hill Country. This area lies just north and west of the Balcones Escarpment, a curving landform that separates the Coastal Plains from the Edwards Plateau. As a transitional zone from the Coastal Plains to the Edwards Plateau, the Hill Country ranges in elevation from 900 ft to slightly over 2000 ft (Estelle 1979).

A major part of the AUS/SAT CWA is popularly characterized as having a nearly ideal climate. This is significant because it contributes to several large, albeit localized, population centers and numerous visitors to areas that are prone to heavy rains and flash floods. The climate in the area consists of three types: subtropical humid in the counties that lie in the Coastal Plains; subtropical subhumid in the counties that lie in the region of the Hill Country, Balcones Escarpment, and the Edwards Plateau; and subtropical steppe in the counties that border the Rio Grande River (Fig. 2b). These climate types are characterized by the following:

(1) Subtropical Humid is noted for warm summers.

(2) Subtropical Subhumid is characterized by hot summers and dry winters.

(3) Subtropical Steppe is a semi-arid to arid region.

In general terms, the climate types are a result of the CWA being located (1) downwind from mountain ranges to the west, (2) between the Gulf of Mexico and the southern Great Plains, (3) west of the center of the Bermuda High, (4) in low latitudes, and (5) in an area of significant terrain gradients (Larkin 1983).

3. SEVERE THUNDERSTORM CLIMATOLOGY

The combination of upward-sloping terrain and moist tropical air, along with other meteorological conditions, produces thunderstorms that can develop into severe thunderstorms. The NWS defines a severe thunderstorm as having one or more of the following: a tornado, hail greater than or equal to ¾ inch in diameter, wind gusts greater than or equal to 50 kt, or convective wind damage. Hales (1988) defined a significant weather event as having one or more of the following: a tornado of strength F2 or greater, wind gusts 65 kt or greater, hail 2 inches in diameter or greater, at least one fatality, three injuries, or damage in excess of $50,000 in non-agricultural losses.

It should be pointed out that fatalities, injuries, and damage associated with thunderstorms are important sociological factors which may result in a storm being classified as severe or significant; but those factors are not necessarily relevant in a meteorological sense. Schaefer and Galway (1982) give a good example of this point:

> Killer tornadoes are serendipitous. Fatalities occur because someone is unlucky enough to be where a tornado causes damage, not because of any significant meteorological factor.

Figure 3, using data from NSSFC logs, shows a yearly distribution of all the severe weather reports in the AUS/SAT CWA for the period 1950-1993. Over this period, there was a gradual, but somewhat unsteady, increase in severe weather reports. The year 1980 saw an unusually high number of reports, and the annual average for the dozen or so years following appears to be roughly twice that for the years prior to 1980. This discontinuity might be attributed to increased reporting of marginal severe weather events, which is related to the NWS's process for verifying severe thunderstorm and tornado warnings. Also, there has been an increased emphasis on gathering ground truth during and after severe weather events for aid in the development of new technologies such as Doppler radar (Hales 1993).

The way in which severe weather reports are collected by the NWS may produce a bias in the event data base favoring the less severe storms (Hales 1993). Other factors influence the data base as well; population density, distance from the warning office (which relates to collection of reports, not necessarily issuance of warnings), and various other post-storm event gathering activities (Hales 1985, 1988, 1993). Population density has been shown to be particularly important. For example, in a densely populated area there is a good chance that all severe weather events, both marginal and significant, will be reported. However, in sparsely populated areas only the most significant severe weather events may be reported (Hales 1988). After an event, the collection of post-storm reports can be related to the level of effort offices are able to put into it. Field surveys or extensive phone calls are often not possible, and assessing the accuracy of reports—especially in marginal situations—always involves some subjectivity.

All of these factors should be taken into account when using the event data base to draw conclusions about an area's severe weather climatology. On the other hand, Hales (1993) suggests that to reach more accurate conclusions about events which are of greatest sociological interest, only significant severe weather reports should be analyzed.

3.1. Tornadoes

Drawing conclusions from the tornado data base can be as difficult as with the other severe weather events. Data are plagued with similar problems due to population biases, changes in population densities, increased emphasis on storm spotting and chasing, and non-uniform event gathering procedures (Ostby 1993). Grazulis (1993) documents inconsistencies, missing events, and erroneously recorded events in the NSSFC tornado data base, even since 1950. F-scale (Ahrens 1991) estimates of tornado intensity (more properly, damage) are biased in similar fashion and are quite subjective (Doswell and Burgess 1988, Grazulis 1993).

Figure 4 shows the 446 SVRPLOT tornado track segments* in the AUS/SAT CWA for the period 1950-1993. Several counties in the western region and a few counties in the central region of the CWA show very few or no tornadoes reported. There may be meteorological factors involved, but this is most likely due to sparse population in the area. Tornado segments that do show up in the western counties are primarily along major roads and highways or in populated areas. Eastern sections of the CWA show more uniformly distributed reports of tornadoes, which can be attributed to more cities and metropolitan areas such as San Antonio and Austin.

Figure 5 shows the yearly distribution of all tornadoes based on data in Fig. 4. The number of tornadoes in the AUS/SAT CWA varies considerably from year to year, but a few years stand out in particular because of tornadoes associated with tropical cyclones. Tropical cyclone tornadoes were reported in seven years out of the 44-year period, with a maximum number of 32 reports in 1967 (Beulah). Secondary maxima occurred in 1980 (Allen) with 19 reports and 1988 (Gilbert) with 15 reports. The average number of tornadoes per year was about 10 during

*Tornadoes in SVRPLOT are actually tornado *segments*. A new path segment begins when a tornado crosses a county line (Hart 1993). This method of recording tornadoes at the NSSFC is an artifact of the warning verification process, since warnings are issued for counties. If the same tornado touches down in one county, moves completely across a second, and lifts in a third, then it is recorded as three tornado segments. This should be kept in mind during subsequent discussions of the number of tornadoes in this paper. The number is somewhat exaggerated, since there are more segments than tornadoes.

the study period. Hales (1993) suggests that after the mid-1970s the fluctuation was more a function of the shifting weather patterns than the reporting system. For example, the noticeable decrease in tornadoes in the 1980s corresponds with a decrease in the number of severe thunderstorms (Fig. 3).

The monthly distribution of tornadoes (Fig. 6) indicates two active seasons—one in the spring, with the maximum occurring in May; and another in late summer and early fall, with the maximum occurring in September. The second season corresponds with the tropical cyclone season. Figure 7 shows the number of tropical cyclone tornadoes that were reported during the months of June through September. There is a maximum of reports in September. When these tropical cyclone tornadoes are subtracted from all the tornado reports (Fig. 8), the result clearly shows a spring peak.

The hourly distribution (Fig. 9) indicates that the prime hours for tornadoes to form are during the late afternoon to early evening (1500-1900 CST). The number of tornadoes reported during those hours was about 40 percent of the total number reported. Tornadoes associated with tropical cyclones may occur at any hour, depending on storm landfall (Figure 10). The maximum number of reports occur near the time of landfall.

Table 1 shows the Fujita Scale (F-scale) which relates damage to estimated wind speeds associated with tornadoes. Figures 11-13 depict the distribution or tornadoes by F-scale, fatalities, and injuries. Doswell and Burgess (1988) note that:

> ...tornadoes occurring in open country do not damage anything by which an F-scale estimate can be made. Any cursory examination of F-ratings shows a clear bias; tornadoes that strike a populated area are much more likely to have a high F-rating than those that remain over open country.

In the area and time period studied, there were 279 reported injuries and 15 fatalities attributed to tornadoes (Fig. 11). Strong tornadoes (F2-F3) accounted for 66 percent of the total injuries and had the highest number of injuries in both tropical and non-tropical tornadoes. Of the 15 fatalities, strong tornadoes were responsible for 47 percent, and violent tornadoes were responsible for 47 percent.

Of all the tornadoes associated with tropical cyclones (Fig. 12), 51 percent were weak and 21 percent were strong. Of all non-tropical cyclone tornadoes (Fig. 13), 68 percent were classified as weak (F0-F1), 28 percent were strong (F2-F3), and 0.8 percent were violent (F4-F5). In 44 years, there have only been three reported F4 events in the AUS/SAT CWA, and no reported F5 events. It is well known that most tornadoes are weak. The apparent relative incidence of weak tornadoes may be increasing due to such things as an increased interest in storm chasing and the advent of the video camera, which have led to some weak tornadoes being detected that previously would have been missed (Ostby 1993). (This might lead to a conclusion that concentrating on the significant tornadoes may result in climatological statistics that are at least more accurate, if not more useful.)

3.2. Convective Wind Events (Greater than 50 kt)

Figure 14 shows the location of 769 damaging wind reports in the AUS/SAT CWA for the period 1955-1993. It is interesting to note that events in the western counties of the CWA tended to align with major highways where population is also concentrated. A yearly distribution of wind events and wind damage days is shown in Fig. 15. The number of reports was more or less steady (averaging about 9 per year) between 1955 and 1978, but then increased noticeably after 1978 to about 37 per year. 406 wind damage days occurred during the study period. The average number of wind damage days was about 10 days per year for the 39-year period; however, the average is about 17 days per year during the last 15 years. This change may reflect some population trends, but likely is related more to increased emphasis by the NWS on verifying strong wind events. The unusually high number of events in 1980 and 1982 (nearly twice the average of surrounding years) has not yet been studied.

The monthly distribution of damaging wind events is shown in Fig. 16. Late spring (May) is clearly a time of highest frequency of damaging winds, which corresponds with a similar peak in non-tropical cyclone tornadoes (Fig. 8) and presumably severe thunderstorms. Figure 17 shows that damaging winds occur most often during the afternoon and early evening, as might be expected.

3.3 Hail Events (Greater than ¾ Inch)

Figure 18 shows the location of 1273 large hail reports during the study period. The yearly and monthly distribution of hail events and hail days (Figs. 19 and 20) are almost identical to those for damaging winds (Figs. 15 and 16). The average number of reports of large hail for the 39-year period is about 33 reports per year; however, the 15-year average from 1979-1993 is about 58 reports per year. The total number of hail days for the study period is 440 days. The average number of hail days for the 39-year period is about 11 days per year; the more recent 15-year average is about 16 days per year. This seems more representative and reflects greater efforts toward identifying and reporting events in recent years. The number of reports for the years 1980, 1992, and 1993 was considerably higher than the average, for reasons not yet investigated.

Figure 20 shows that large hail events peak in May (averaging 475), but show a much more precipitous drop afterward than do damaging wind events. Kessler (1986) points out that:

> ...regions of greatest thunderstorm frequency (Florida and the Gulf states) are also the regions of lowest hailstorm frequency. In any one place, years of high thunderstorm frequency are also years of high hail frequency. On the other hand, the ratio of hail to thunderstorm occurrences reaches a minimum at the time of the maximum occurrence of both hail and thunderstorms during the warmest months.

One possible explanation for this is that lower freezing and wet bulb zero levels in the spring are a determining factor for hail. In the warmest months when these levels are higher, much of the hail melts before reaching the ground.

The diurnal variation in hail reports, as shown by Fig. 21, displays a maximum during the evening hours from 1500-2100 CST. This diurnal variation is very similar to that of the wind and tornado reports. All the reports tend to show a marked increase between the hours of 1400-1500 CST and begin to decrease between 2000-2200 CST.

Figure 22 shows that almost one-half (48 percent) of the hail reported was 1¾ to 2¾ inches in diameter. The next two highest occurrences in hail size were ¾ to 1¾ in (545 reports) and 2¾ in and larger hail (108 reports).

4. FLOODS AND FLASH FLOODS

Although heavy rain and flooding are not included among criteria for defining severe thunderstorms, Doswell (1982) noted that "Convective flash flooding is certainly as potentially dangerous as any aspect of thunderstorms." Flash floods are one of the leading causes of fatalities associated with weather phenomena (lightning is the other). One reason for this leading cause of fatalities is that more people are using recreational areas that are prone to flash flooding (Doswell 1985), and those individuals may not appreciate the danger posed by heavy rains.

Flash flooding may result from a combination of several circumstances; but with the exception of the sudden release of water by the breakup of an ice jam or a dam failure, all are related to convective precipitation. Isolated thunderstorms cause many floods, especially if slow-moving, or train-echo storms are involved. Some flash floods are associated with thunderstorms in land-falling tropical storms. Occasionally synoptic scale events (or mesoscale convective systems) may have embedded thunderstorms which result in excessive rainfall (Doswell 1985).

Within the AUS/SAT CWA, the Hill Country is historically prone to heavy rains and flash floods. In fact, verification statistics have shown that most flash floods occur in the southern U.S., and most of those are in Texas. Most of the Texas floods occur in the AUS/SAT CWA! Ideal conditions, including moist tropical air and upslope flow in the low levels, can contribute to convective rains of over 10 inches in 24 hours. In 1932, near Kerrville, the State Fish Hatchery received 35 inches of rain in a 36-hour period. In 1936, 1959, and 1978 devastating floods again hit the Hill Country. Over the years the Texas Hill Country has been recognized as an area prone to flash flooding. It is also of concern because of the large number of people who camp and visit in the Hill Country each year, creating the potential for large losses of life (Estelle 1979).

Figure 23 shows the yearly distribution of flash floods/floods in the AUS/SAT CWA. Data for this figure was taken from *Storm Data 1973-1992*. In the Hill Country, most reported floods are listed as flash floods; in the Coastal Plains they are listed as floods. In most urban areas, flash floods and floods are generally less of a threat than flooding of low-lying streets and roadways. During the 20-year period there were 831 reported flash floods/floods, 143 fatalities, and 375 injuries. This illustrates that at least in the area studied, flash floods/floods are the number one killer of people. The same events also contribute to the largest number of injuries. The average number of flash floods/floods each year for the 20-year period was about 42.

A good example of a flash flood/flood event which claimed the lives of many people was in 1978. On July 31, 1978, remnants of Tropical Storm Amelia moved inland over the South Texas coast. Abundant moisture from the storm resulted in record rainfall amounts over portions of the Hill Country:

> While heavy rains were expected as it moved across Texas, no one ever foresaw the extraordinary efficiency with which the atmosphere would dump water...over the Hill Country northwest of San Antonio.... (Estelle, 1979).

Between August 1 and 3, locations in the Hill Country received over 30 inches of rain (Fig. 24). The heavy rains produced extensive flash flooding and river flooding which took the lives of 27 people in four counties within the CWA of AUS/SAT (Fig. 25). Property damage from these floods was estimated to be in the tens of millions of dollars (Estelle 1979).

A memorable recent example occurred in 1987 on the Guadalupe River near Comfort in Kendall County. This flash flood claimed the lives of ten summer camp children who died when the bus in which they were riding stalled while trying to cross the flooded Guadalupe River and was swept away.

5. TROPICAL STORMS AND HURRICANES

While the majority of the AUS/SAT CWA is not directly affected by hurricane winds and storm surge, hurricanes and their associated widespread heavy rains can produce flooding problems, as well as tornadoes. Counties closer to the coast may experience almost the full force of a land-falling tropical storm or hurricane.

In this section, we examine the number of tropical cyclones which have affected the Texas coast during the period 1871-1993, based on the work of Neumann, et al. (1993). The entire Texas coast was used for this study, since any tropical cyclone that makes landfall along the Texas coast has the potential to affect the AUS/SAT CWA. Figure 26 shows the distribution of tropical storms by month. Maximum occurrence is in August and September with 28 and 27 storms, respectively. The tropical cyclone season for the Texas coast appears to be confined primarily to June through September. Of the 94 tropical cyclones that affected the coast, 51 were hurricanes and 34 were tropical storms. The other nine are listed as unknown, since classification of tropical cyclones into the categories "tropical storm" and "hurricane" was not done before 1886.

Figures 27-30 show yearly distributions of tropical cyclones for 1871-1993, broken down by roughly 30-year periods. The average number of tropical cyclones per year for the 123-year period was 1.32. The odds that a tropical cyclone will strike given areas along the Texas coast in any one year are given in Fig. 31, and range from a high of a 17 percent chance along the central coastal area closest in proximity to the AUS/SAT CWA, to a low of a 9 percent chance along the upper coast.

6. SUMMARY

The climatology of severe thunderstorms, flooding rains and tropical cyclones which affect the AUS/SAT CWA and surrounding areas shows distinct active years, prominent seasons, and definite diurnal variations. The intent of this study was to provide a brief overview of these variations to forecasters.

Flood-producing rains are certainly common, and they may occur in any season. The tornado climatology of the area is strongly affected by landfalling tropical cyclones in August and September. The gradual increase in severe weather reports over the last 43 years is most likely due to a growing population, changes in reporting techniques, and emphasis on warning verification by the National Weather Service.

One might also wonder why there are many more reports of large hail than damaging wind or tornadoes. Wind damage, wind gusts, and tornadoes (as opposed to straight-line winds) are not easily measured, especially by the general public. However, hail is a more tangible and relatively easily quantifiable size during a storm or shortly after it has passed.

In the AUS/SAT CWA, most severe thunderstorms form in the late spring (April-May) when warm humid air advects across the region from the Gulf of Mexico, providing sufficient moisture and instability to support severe thunderstorms. The AUS/SAT CWA may contain favorable triggering mechanisms such as differential surface heating, orographic effects, and lifting along a frontal zone or mesoscale boundary. Thunderstorms typically form along the dryline in western portions of the CWA early in the afternoon and move to the southeast, dissipating after dark. During this time of year, the polar jet core extends far enough south to interact with the subtropical jet, aiding in the formation of severe thunderstorms. Often, during other times of the year there is insufficient moisture, daytime heating, or instability. During the summer, a ridge generally predominates over the area; and an elevated, warm mixed layer effectively caps the tropical summer airmass, usually preventing severe convection.

Most severe thunderstorms form in the late afternoon or early evening hours between 1500-2100 CST, which shows the importance of daytime heating. Djuric (1992) has noted:

> Thunderstorms exhibit a prominent diurnal variation. Late afternoon and evening hours are favorite times for thunderstorms in most places. This variation points to the importance of daytime heating. Convection is most stimulated at the time of warmest surface, but develops later even more when the latent heat becomes the primary source of energy.

Statistically, flash floods and flooding are the most deadly of all weather phenomena in the AUS/SAT CWA. Flash floods/floods tend to occur during the summer months when the atmosphere over South Texas is moisture laden. This is also the time of the greatest tropical cyclone occurrence. Floods are possible year-round, however.

By studying the severe weather, flash flood/flood, and tropical cyclone climatology for the AUS/SAT CWA forecasters can become better acquainted with forecast problems associated with their area of responsibility. This can lead to improved forecasts and warnings. Verification and report gathering techniques should be looked at closely to ensure as much as possible that the data base of severe weather events is not biased by non-meteorological factors. It is hoped that this study will assist in all of these areas.

7. ACKNOWLEDGEMENTS

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TABLE 1

Fujita Scale (F-Scale) for Damaging Wind

SCALE	CATEGORY	WINDSPEED (MPH)	WINDSPEED (KNOTS)	EXPECTED DAMAGE
F0	Weak	40-72	35-62	Light: tree branches broken, sign boards damaged
F1	Weak	73-112	63-97	Moderate: trees snapped, windows broken
F2	Strong	113-157	98-136	Considerable: large trees uprooted, weak structures destroyed
F3	Strong	158-206	137-179	Severe: trees leveled, cars overturned, walls removed from buildings
F4	Violent	207-260	180-226	Devastating: frame houses destroyed
F5	Violent	261-318	227-276	Incredible: structures the size of autos moved over 100m, steel-reinforced structures highly damaged

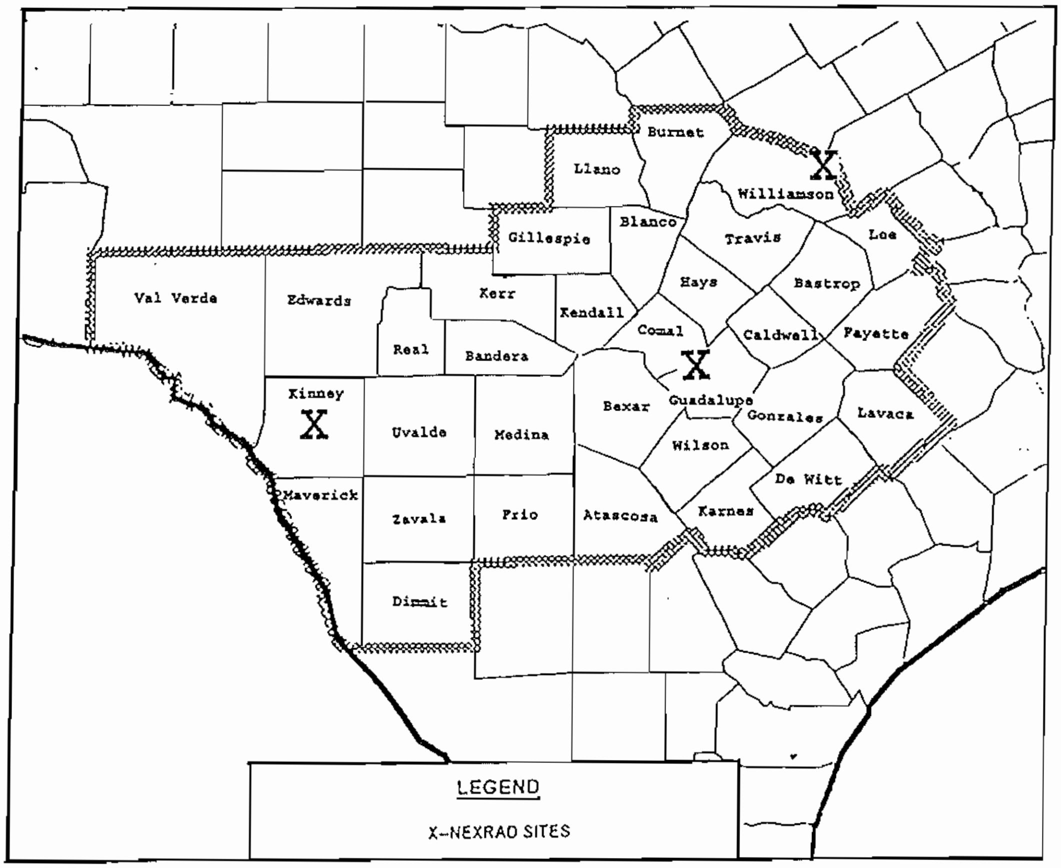
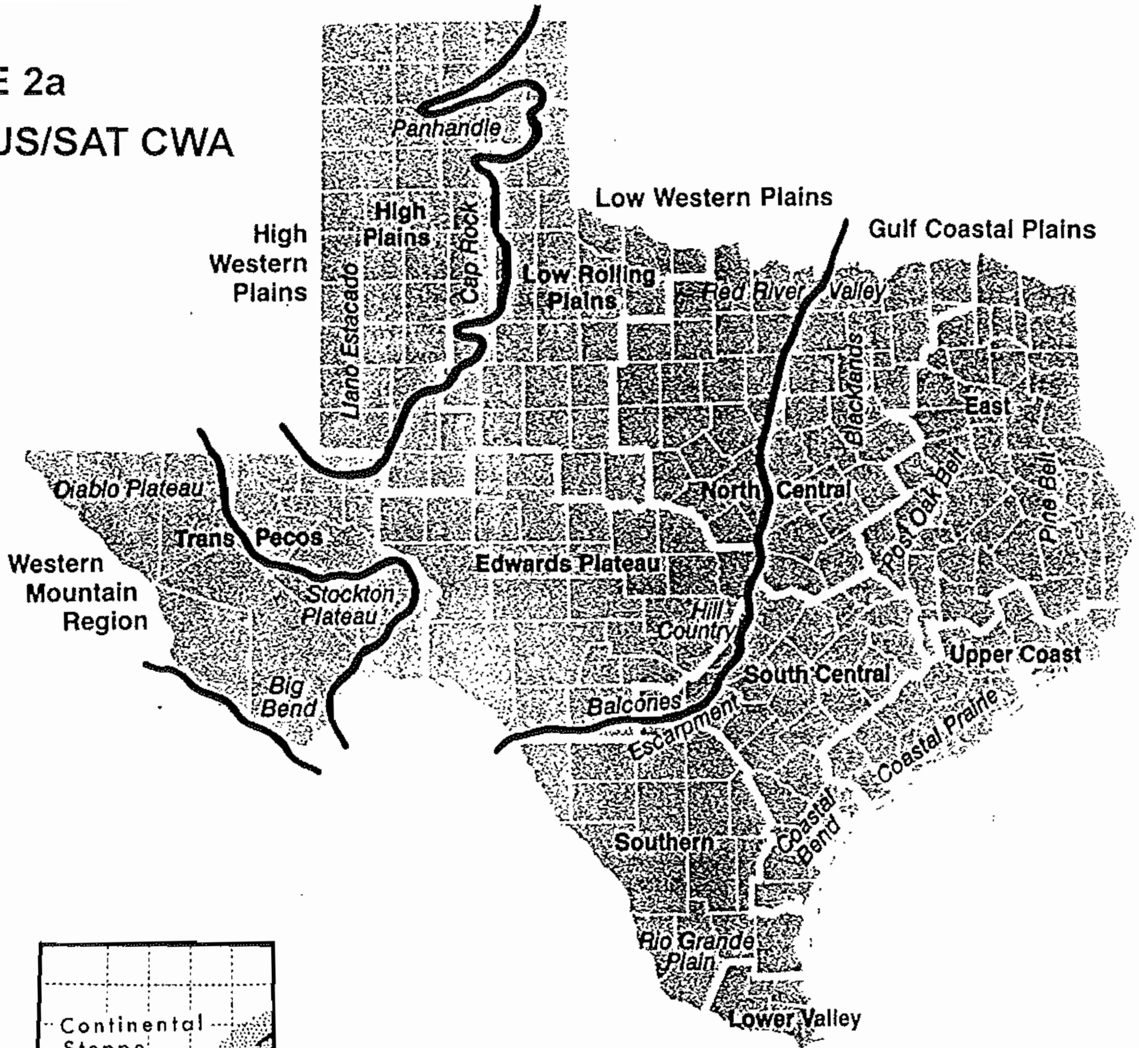


FIGURE 1
Austin/San Antonio WFO County Warning Area

FIGURE 2a
Terrain of the AUS/SAT CWA



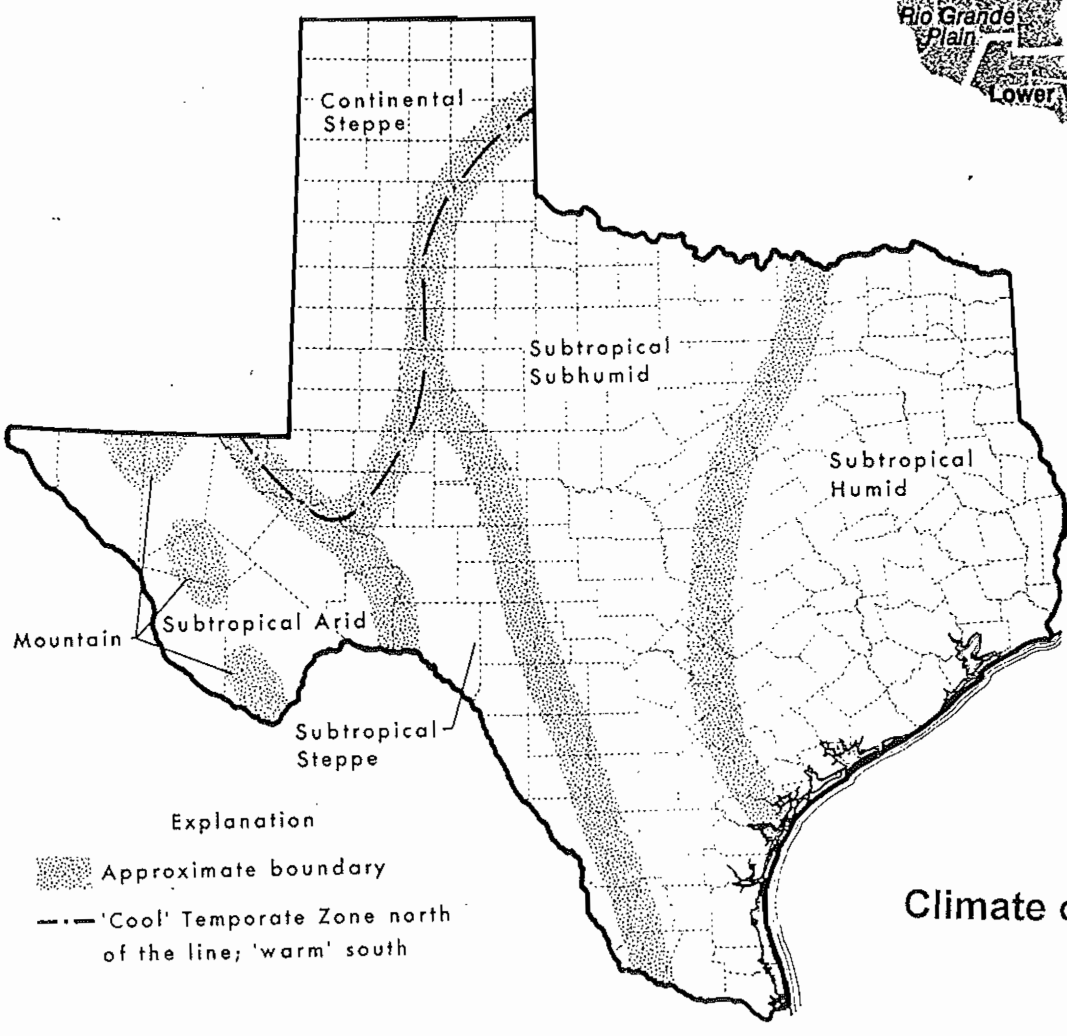


FIGURE 2b
Climate of the AUS/SAT CWA

FIGURE 3

Yearly Distribution of all Severe Weather Events In The AUS/SAT CWA

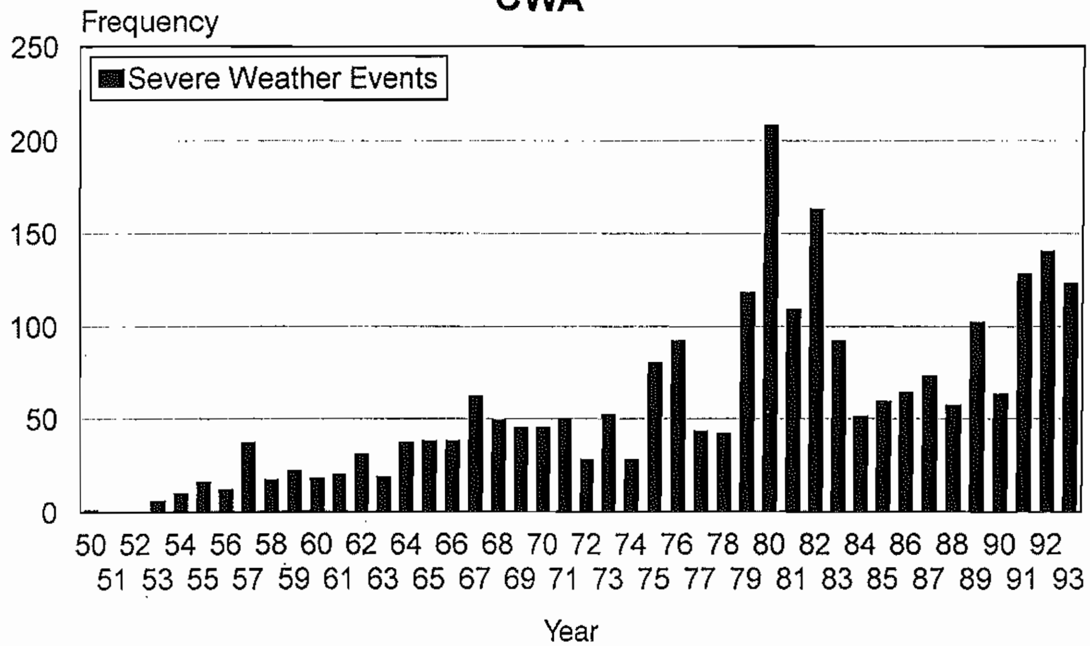
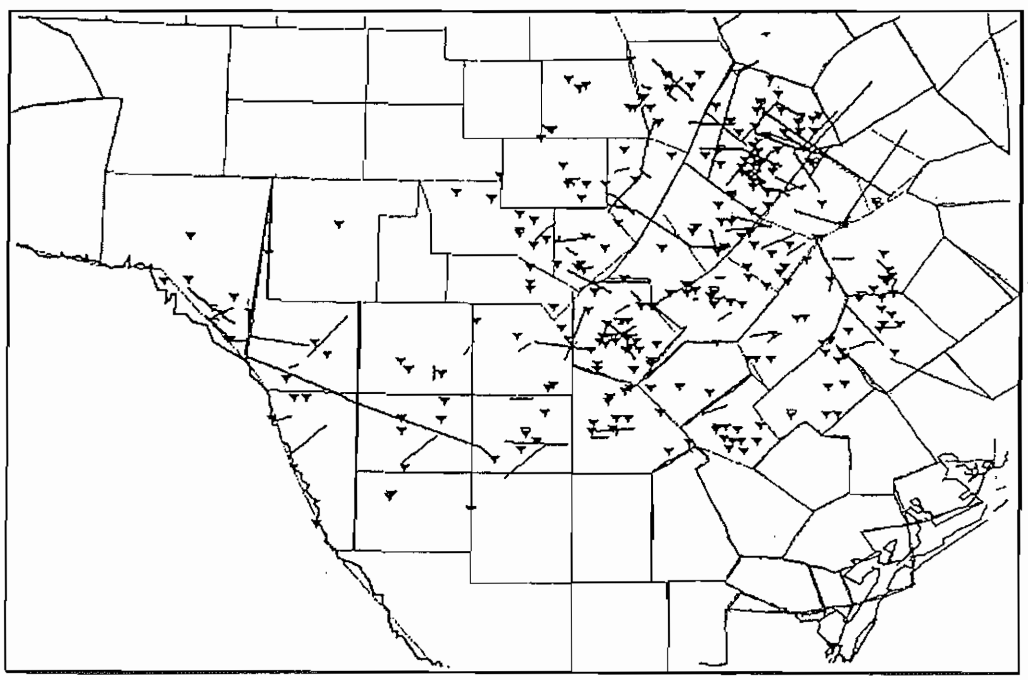


FIGURE 4

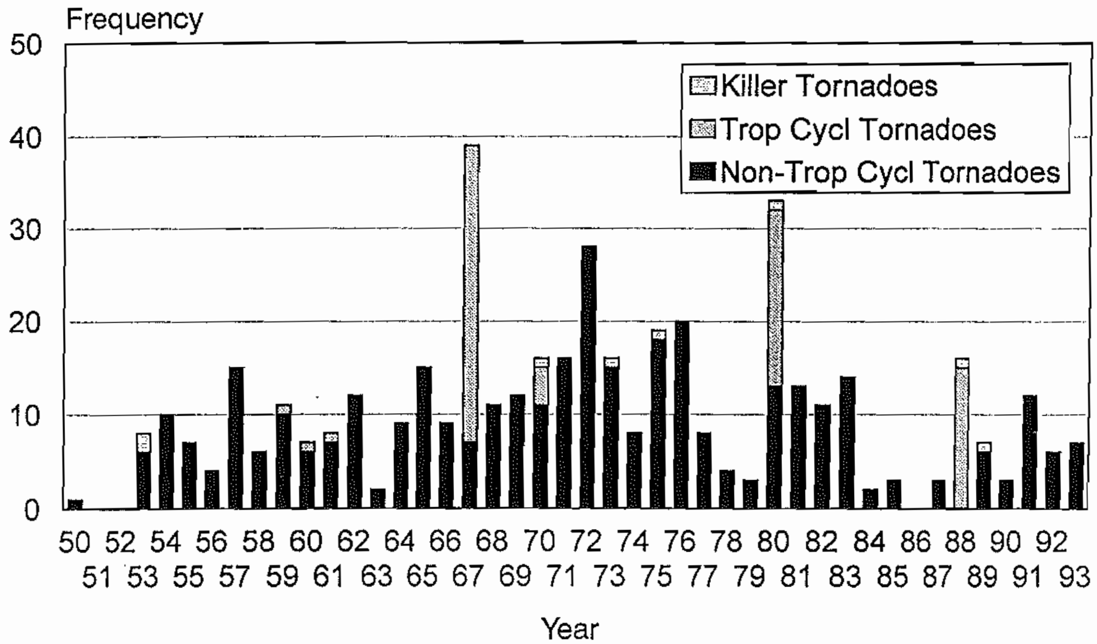
446 *Tornadoes In The AUS/SAT CWA For The Period 1950-1993



Inverted Triangles Identify Tornado Touchdowns. Plotted Paths Identify Tornado Tracks *A new path segment begins when a tornado crosses a county line (Hart, 1993)

FIGURE 5

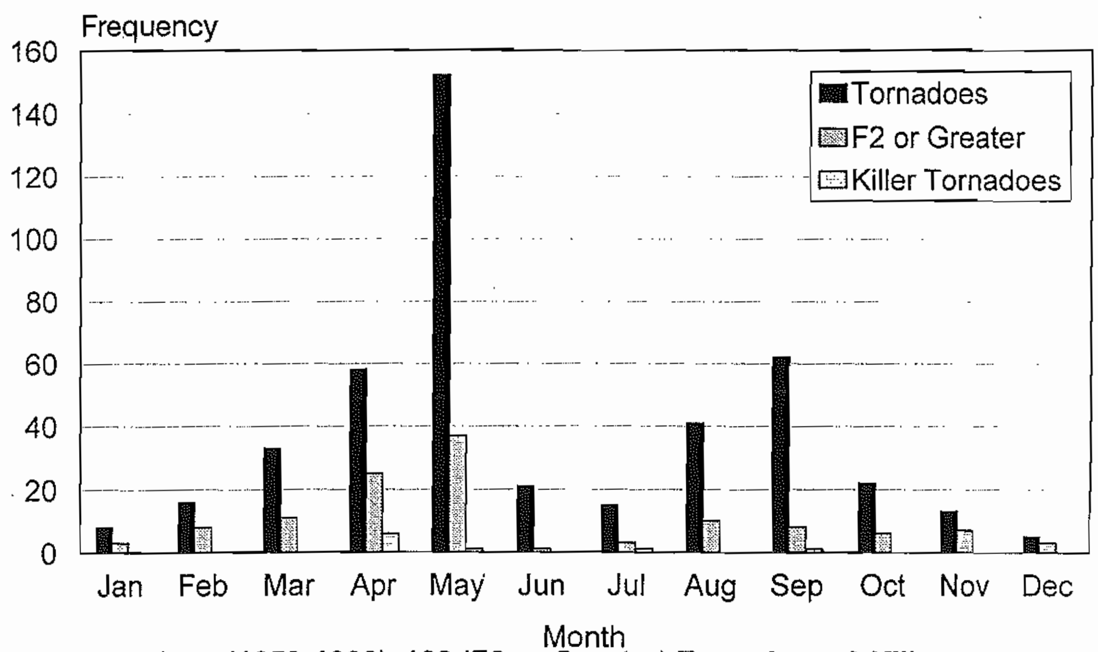
Yearly Distribution of Tornadoes In The AUS/SAT CWA



446 Tornadoes, 73 Tropical Cyclone, 373 Non-Tropical Cyclone, 8 Killer Tornadoes (1950-1993)

FIGURE 6

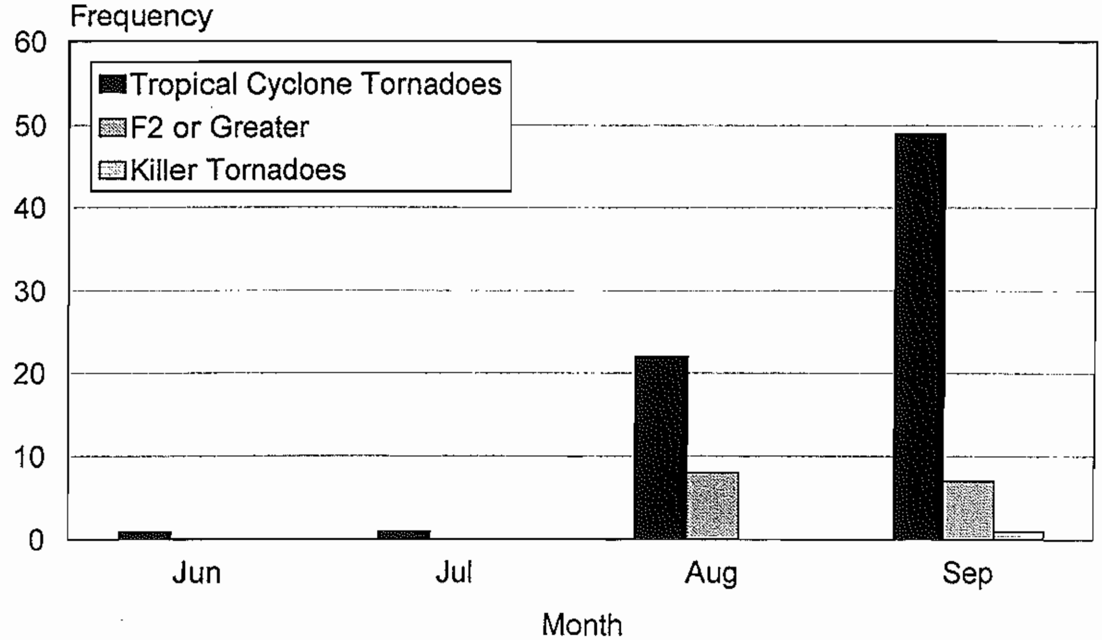
Monthly Distribution of Tornadoes In The AUS/SAT CWA



446 Tornadoes (1950-1993) 122 (F2 or Greater) Tornadoes 9 Killer Tornadoes

FIGURE 7

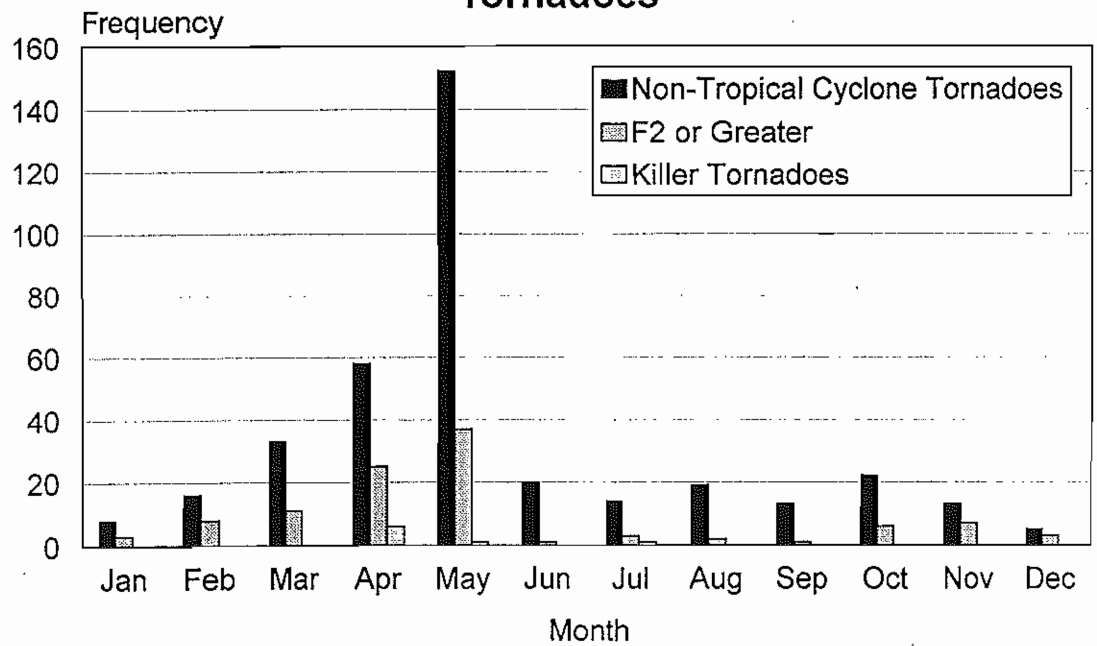
Monthly Distribution of Tropical Cyclone Tornadoes In The AUS/SAT CWA



73 Tropical Cyclone Tornadoes (1950-1993) 15 (F2 or Greater) Tornadoes 1 Killer Tornado

FIGURE 8

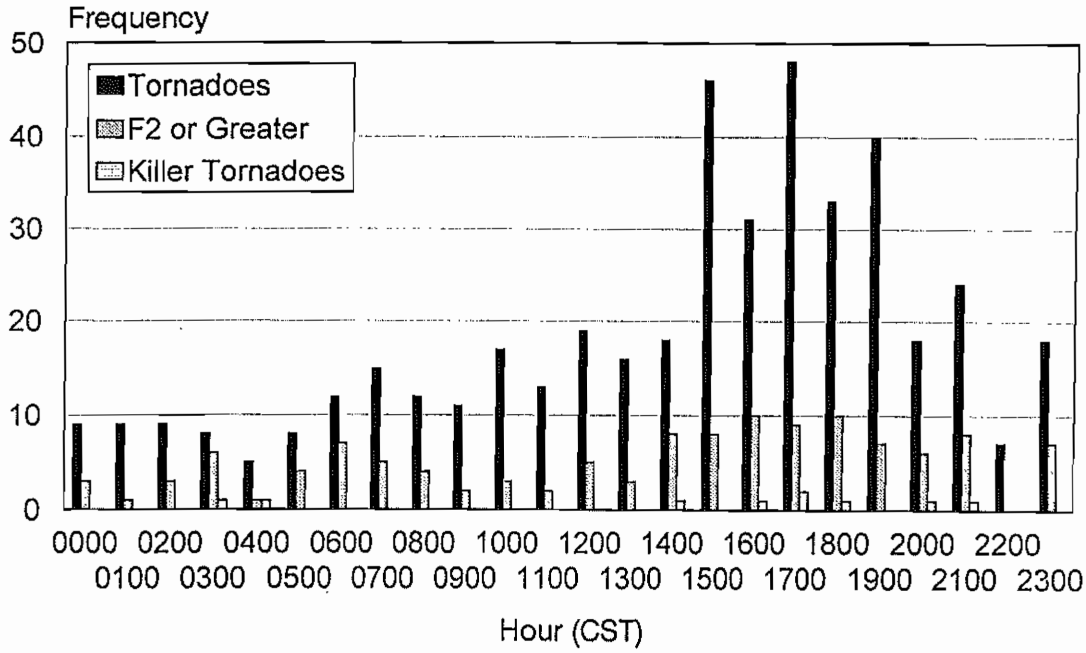
Monthly Distribution of Tornadoes Minus the Tropical Cyclone Tornadoes



373 Non-Tropical Cyclone Tornadoes (1950-1993) 107 (F2 or Greater) Tornadoes 8 Killer Tornadoes

FIGURE 9

Hourly Distribution of Tornadoes In The AUS/SAT CWA



446 Tornadoes (1950-1993) 122 (F2 or Greater) Tornadoes 9 Killer Tornadoes

FIGURE 10

Hourly Distribution of Tornadoes Spawned by Hurricanes Beulah, Allen, and Gilbert

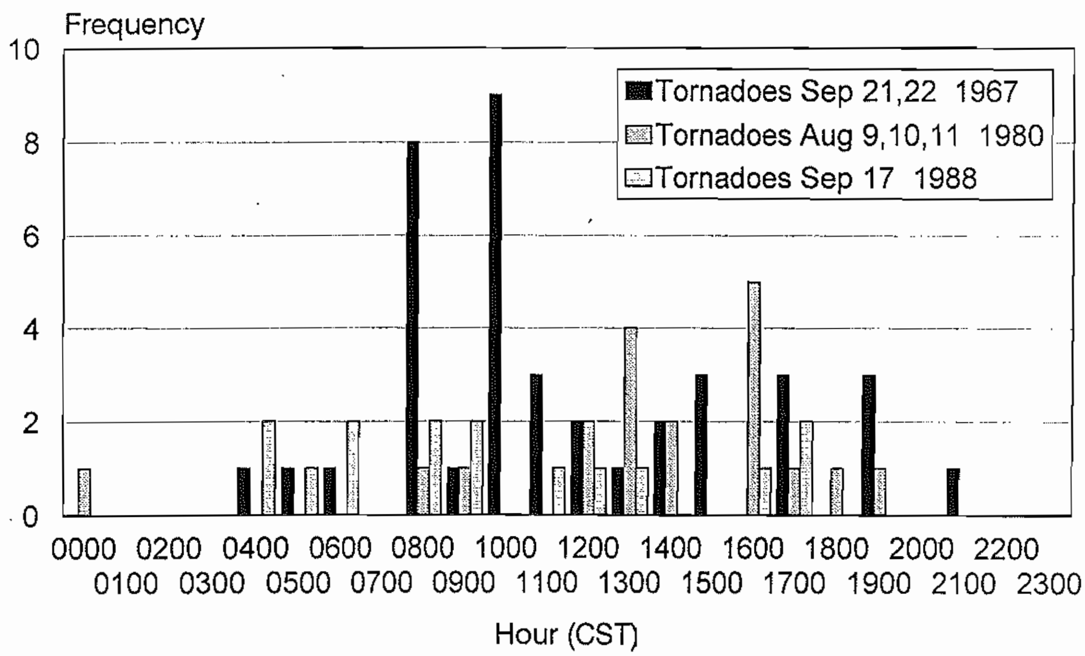
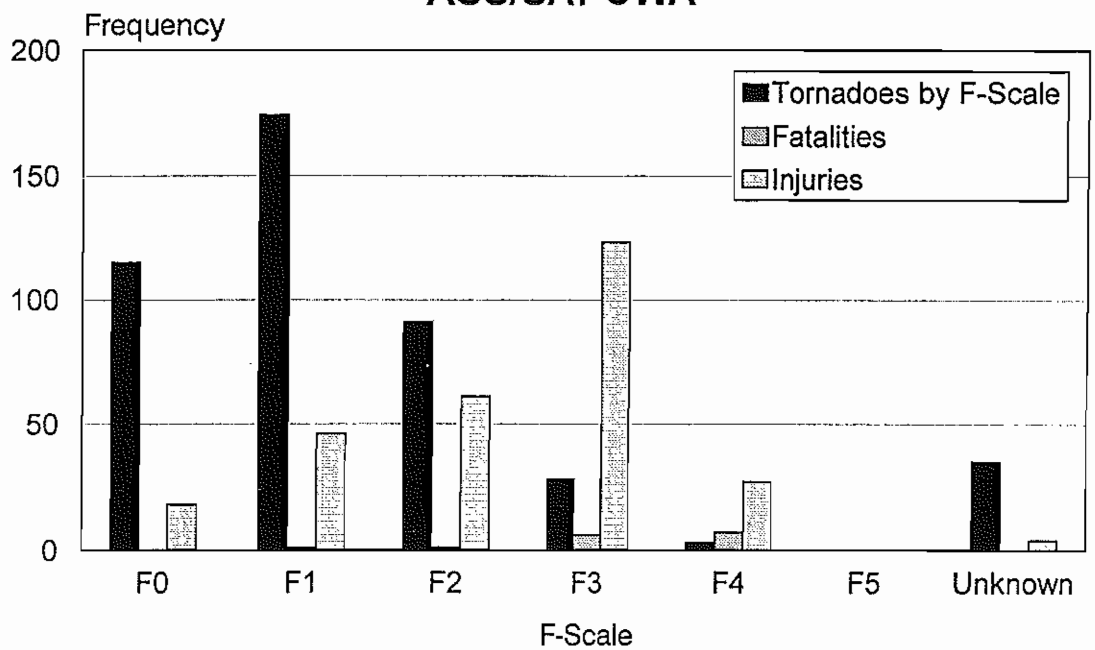


FIGURE 11

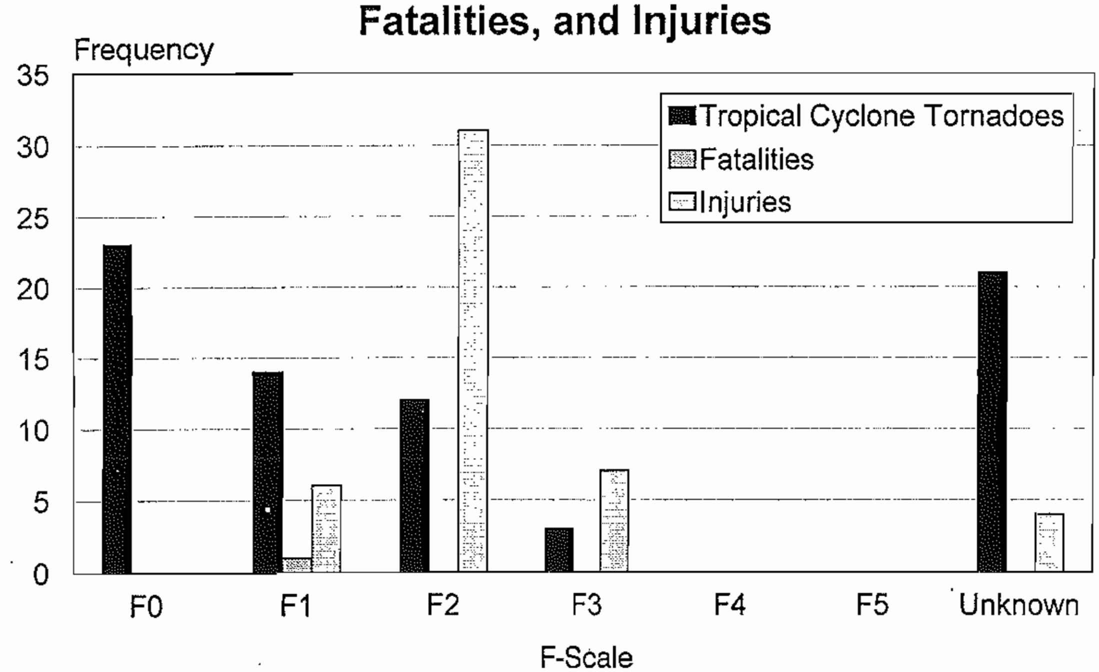
Distribution of Tornadoes by F-Scale, Fatalities, Injuries In The AUS/SAT CWA



446 Tornadoes, 15 Fatalities, 279 Injuries (1950-1993)

FIGURE 12

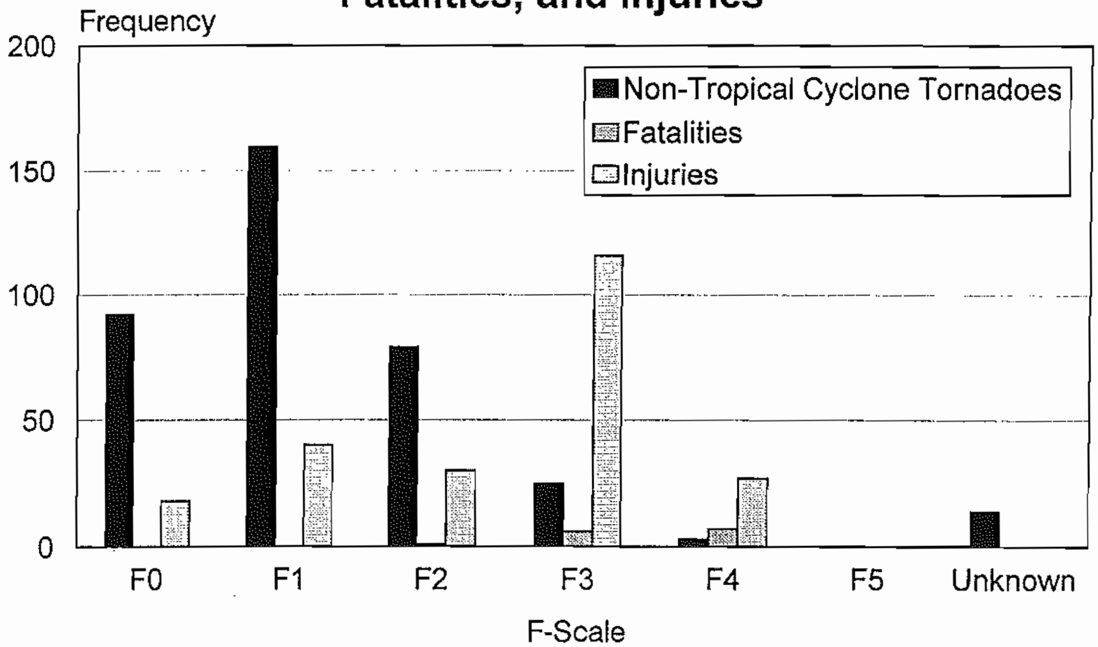
Distribution of Tropical Cyclone Tornadoes by F-Scale, Fatalities, and Injuries



73 Tropical Cyclone Tornadoes, 1 Fatality, 48 Injuries (1950-1993)

FIGURE 13

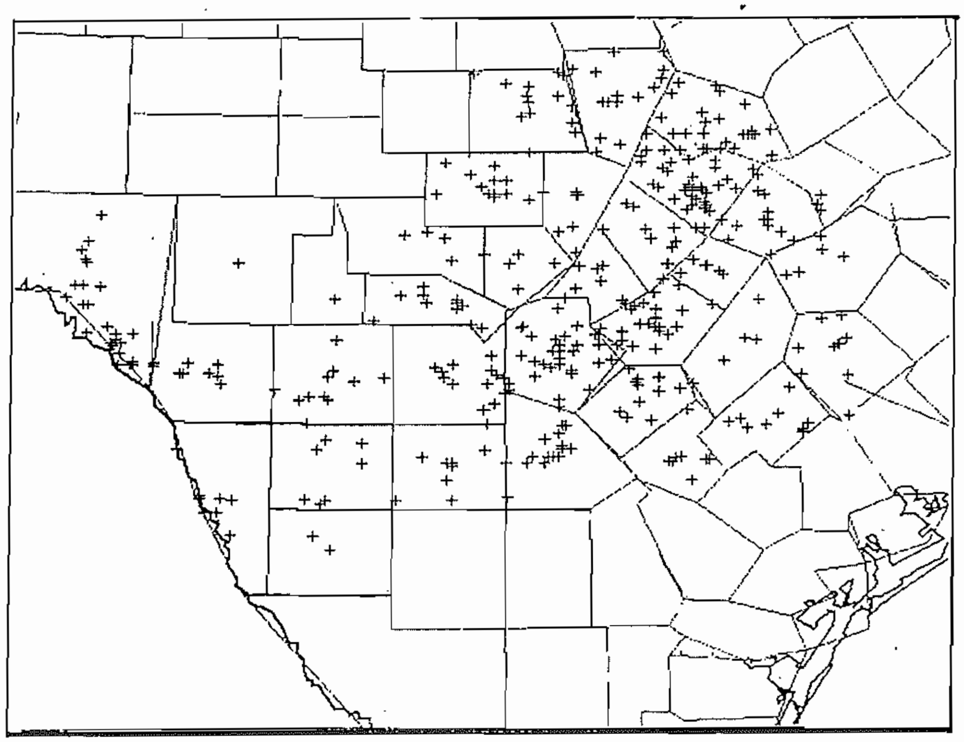
Distribution of Non-Tropical Cyclone Tornadoes by F-Scale, Fatalities, and Injuries



373 Non-Tropical Cyclone Tornadoes, 14 Fatalities, 231 Injuries (1950-1993)

FIGURE 14

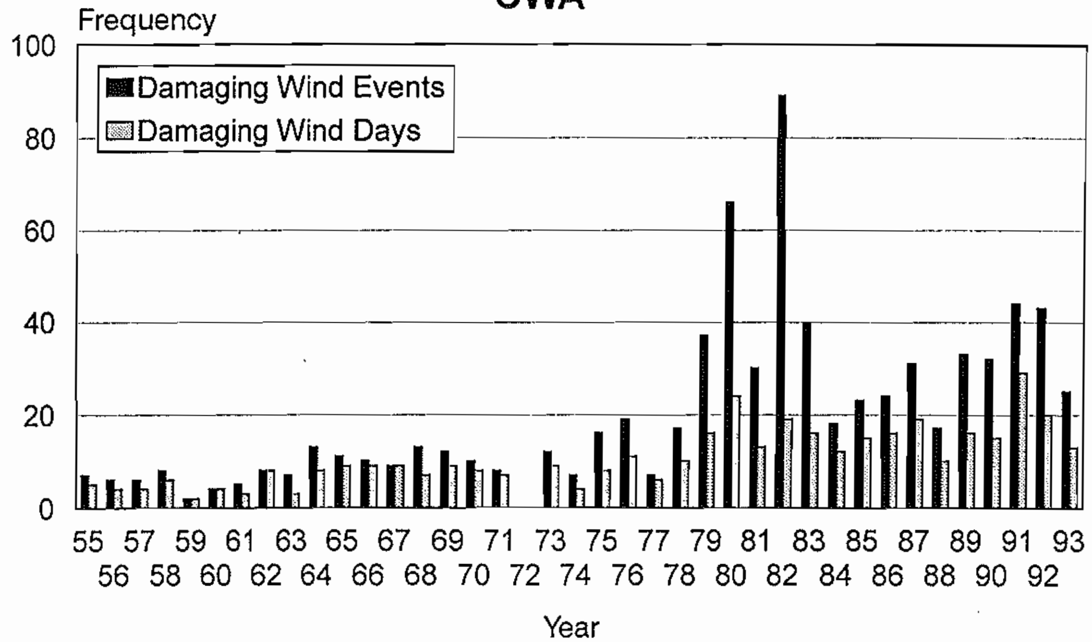
769 Damaging Wind Reports In The AUS/SAT CWA For 1955-1993



Severe Thunderstorm Wind Gusts 50 kts. or Greater/Convective Wind Damage

FIGURE 15

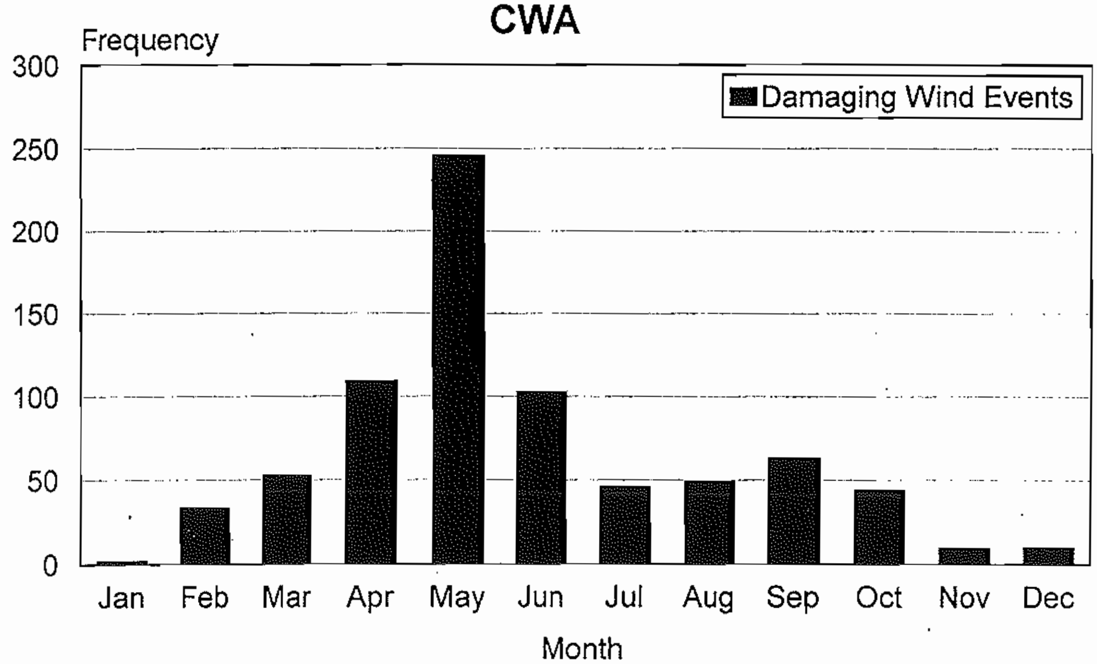
Yearly Distribution of Damaging Wind Events In The AUS/SAT CWA



769 Damaging Wind Events (1955-1993) 406 Damaging Wind Days (1955-1993) **Hail/Wind Missing 1972

FIGURE 16

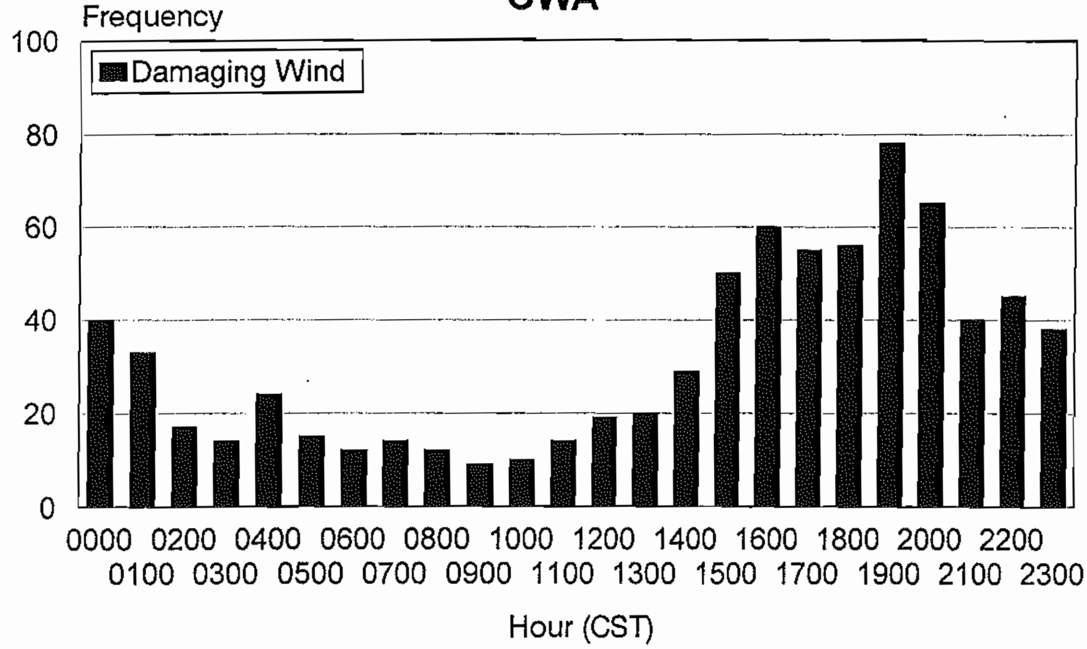
Monthly Distribution of Damaging Wind Events In The AUS/SAT CWA



769 Damaging Wind Events (1955-1993) **Hail/Wind Missing 1972

FIGURE 17

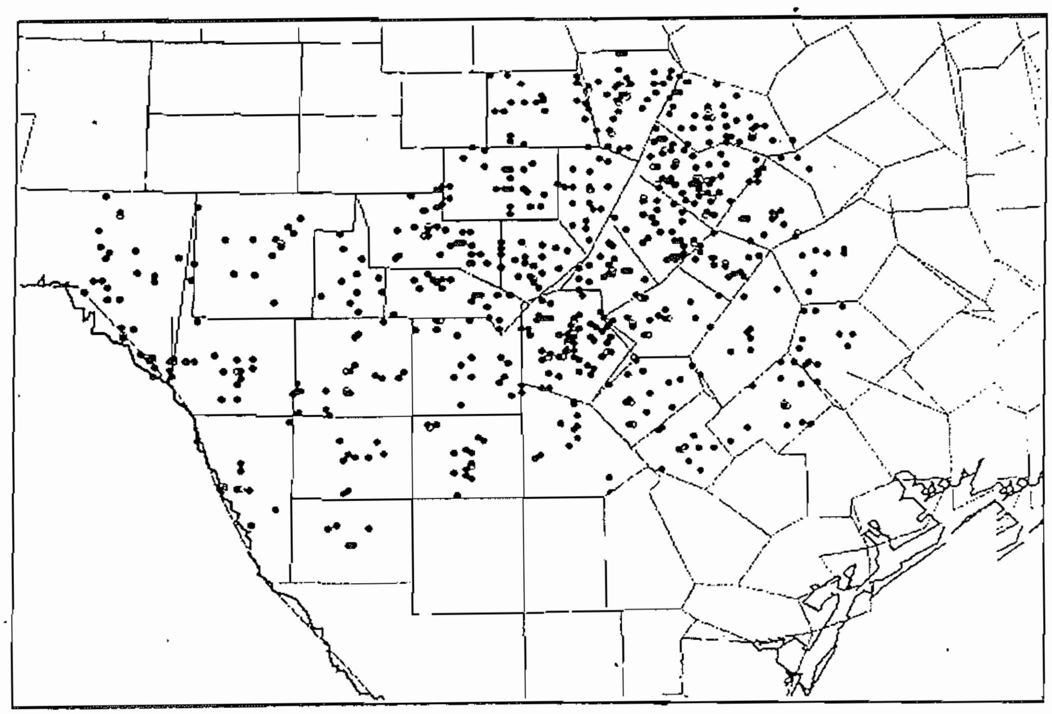
Hourly Distribution of Damaging Wind Events In The AUS/SAT CWA



769 Damaging Wind Events (1955-1993) **Hail/Wind Missing 1972

FIGURE 18

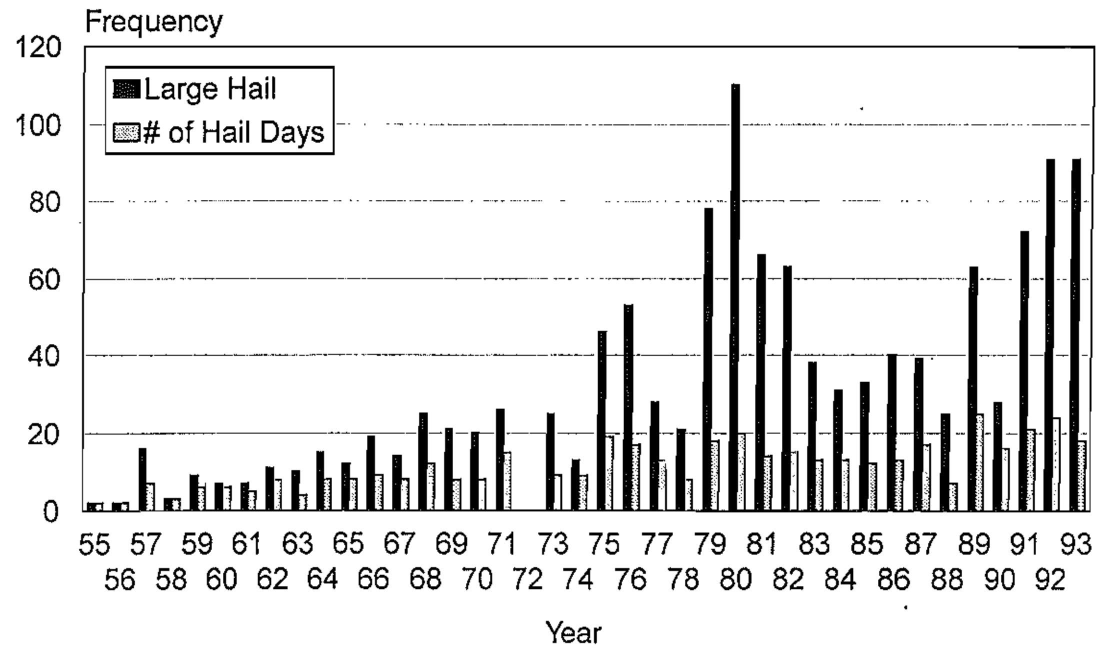
1273 Severe Hail Reports In The AUS/SAT CWA For 1955-1993



Severe Thunderstorm Hail 3/4 in. or Greater

FIGURE 19

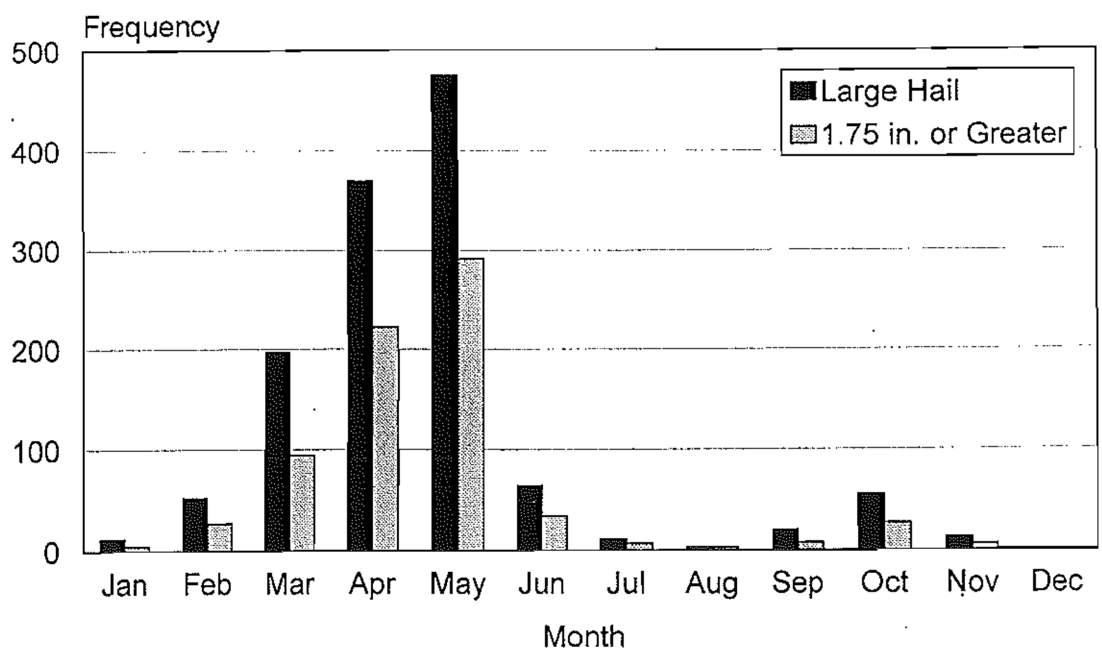
Yearly Distribution of Severe Hail Events In The AUS/SAT CWA



1273 Severe Hail Events (1955-1993) 440 Hail Days (1955-1993) **Hail/Wind Missing 1972

FIGURE 20

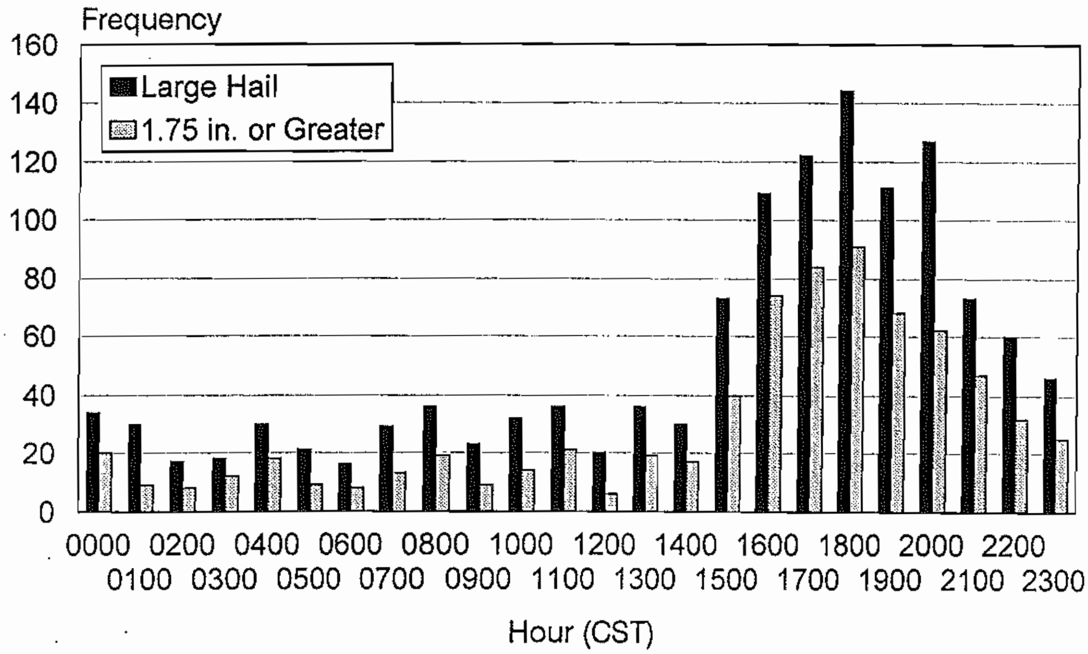
Monthly Distribution of Severe Hail Events In The AUS/SAT CWA



1273 Severe Hail Events (1955-1993) 725 (1.75 in. or Greater) Hail Events **Hail/Wind Missing 1972

FIGURE 21

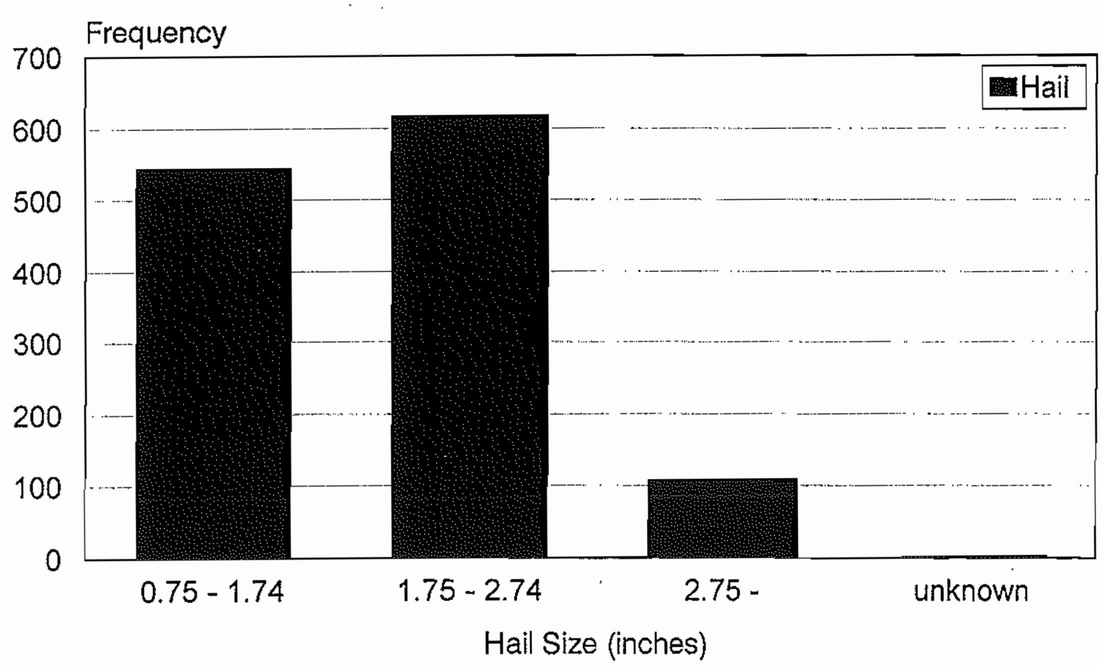
Hourly Distribution of Severe Hail Events In The AUS/SAT CWA



1273 Severe Hail Events (1955-1993) 725 (1.75 in. or Greater) Hail Events
****Wind/Hail Missing 1972**

FIGURE 22

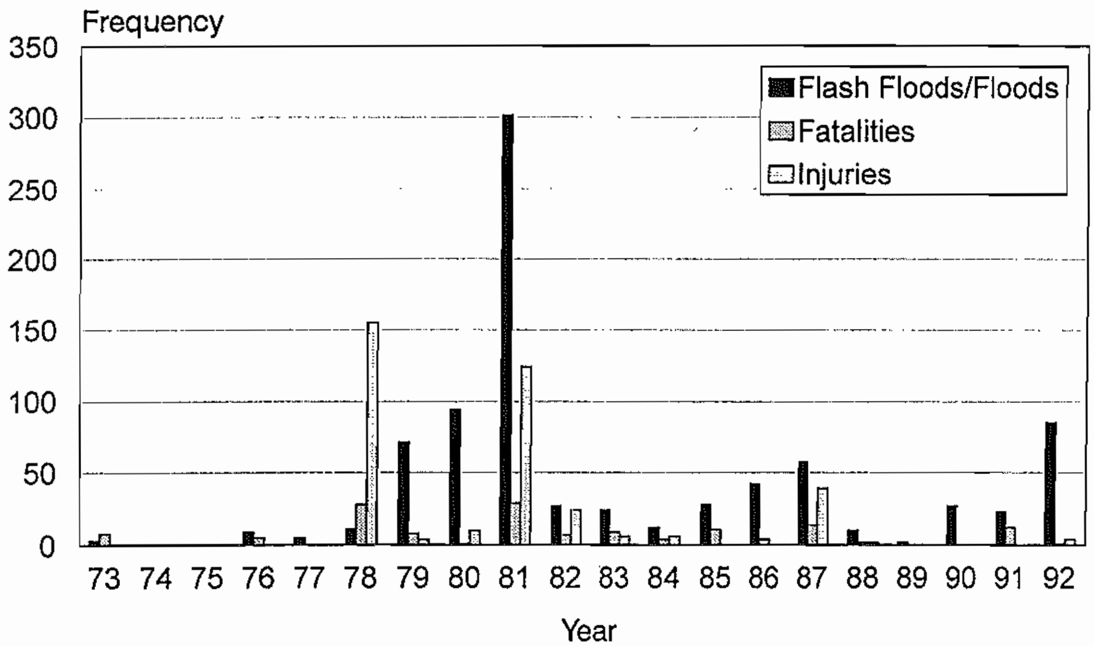
Distribution of Hail Size in the AUS/SAT CWA



1273 Severe Hail Events (1955-1993) **Hail/Wind Missing 1972

FIGURE 23

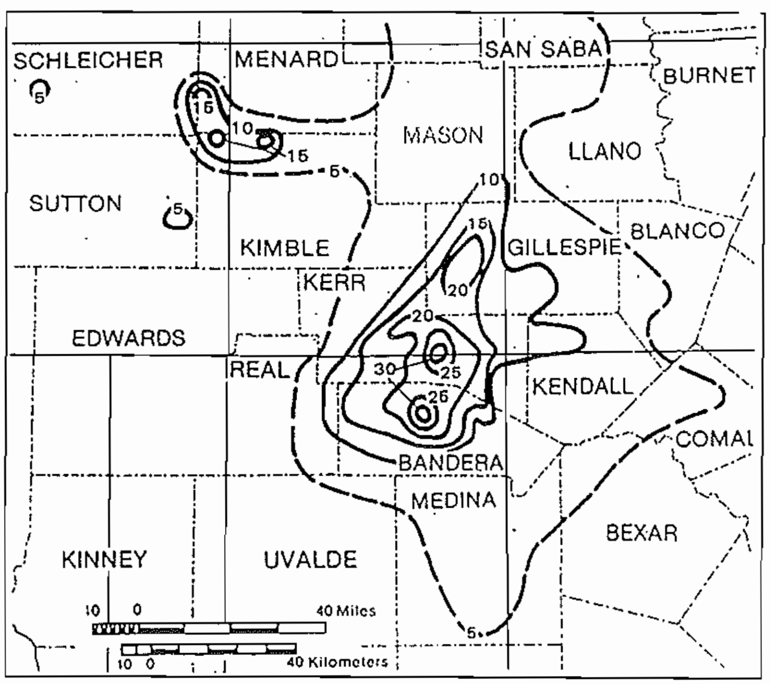
Yearly Distribution of Flash Floods/Floods, Fatalities, and Injuries



831 Flash Floods/Floods (1973-1992), 143 Fatalities, 375 Injuries **Flash Flood Statistics are From Storm Data from 1973-1992

FIGURE 24

Isohyetal Map (In Inches)



From (Estelle, 1979)

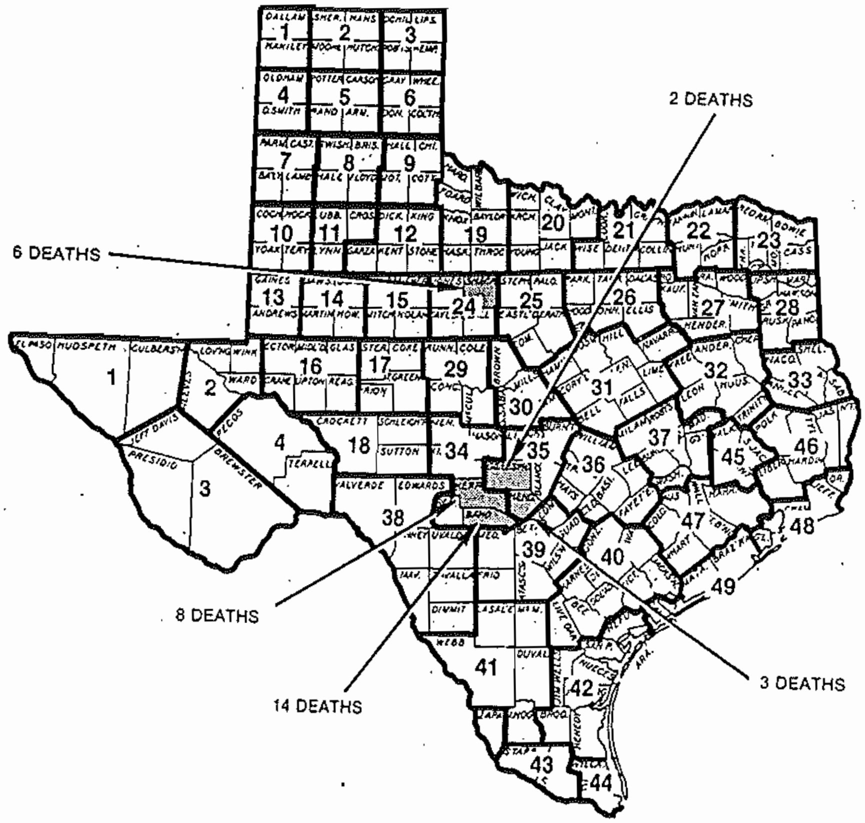
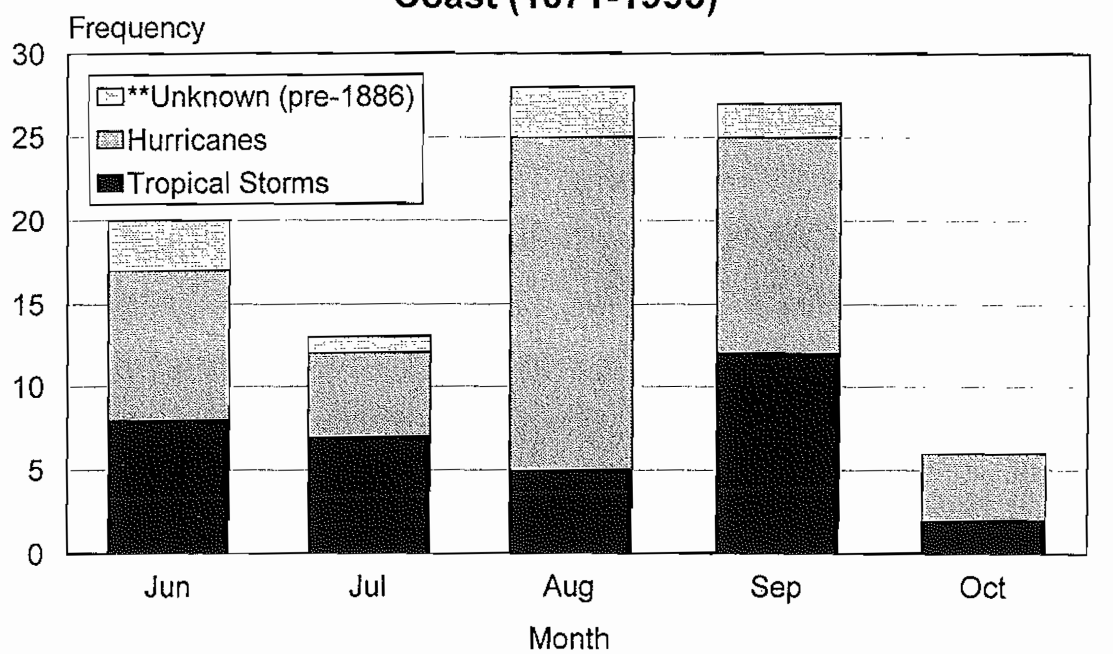


FIGURE 25

Distribution of Deaths fro[illegible]e 1978 Hill Country Flood

FIGURE 26

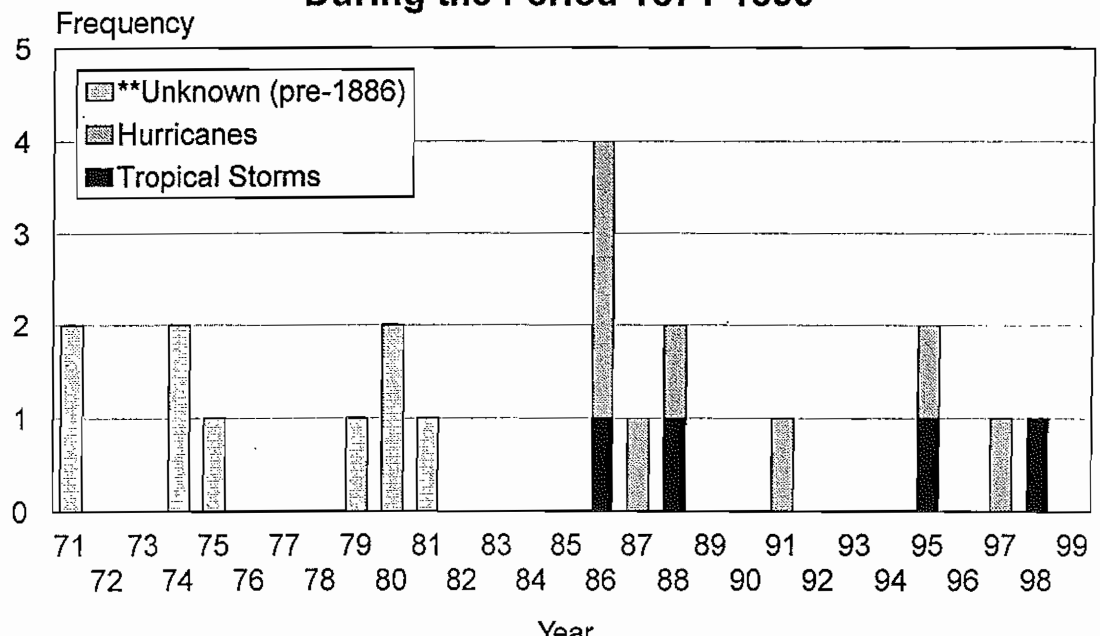
Monthly Distribution of Tropical Cyclones Affecting the Texas Coast (1871-1993)



94 Tropical Cyclones(1871-1993) 34 Tropical Storms, 51 Hurricanes, and 9 **Unknown (Not Classified as Tropical Storms or Hurricanes Before 1886)

FIGURE 27

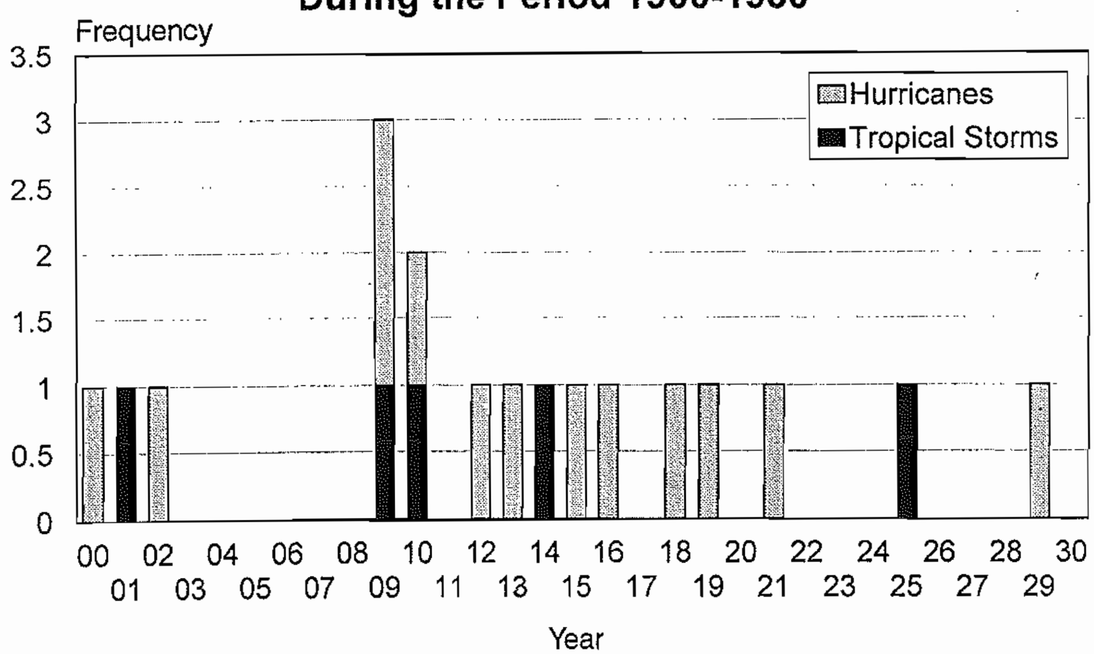
Yearly Distribution of Tropical Cyclones Affecting the Texas Coast During the Period 1871-1899



21 Tropical Cyclones (1871-1899) **Unknown (Not Classified as Tropical Storms and Hurricanes Before 1886)

FIGURE 28

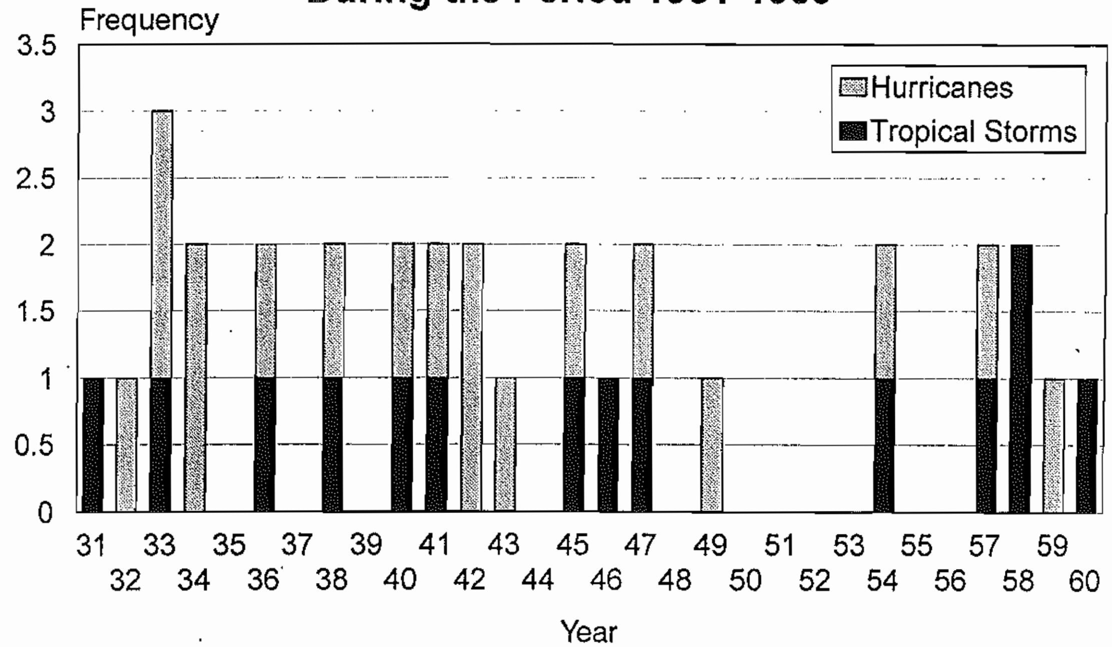
Yearly Distribution of Tropical Cyclones Affecting the Texas Coast During the Period 1900-1930



18 Tropical Cyclones (1900-1931)

FIGURE 29

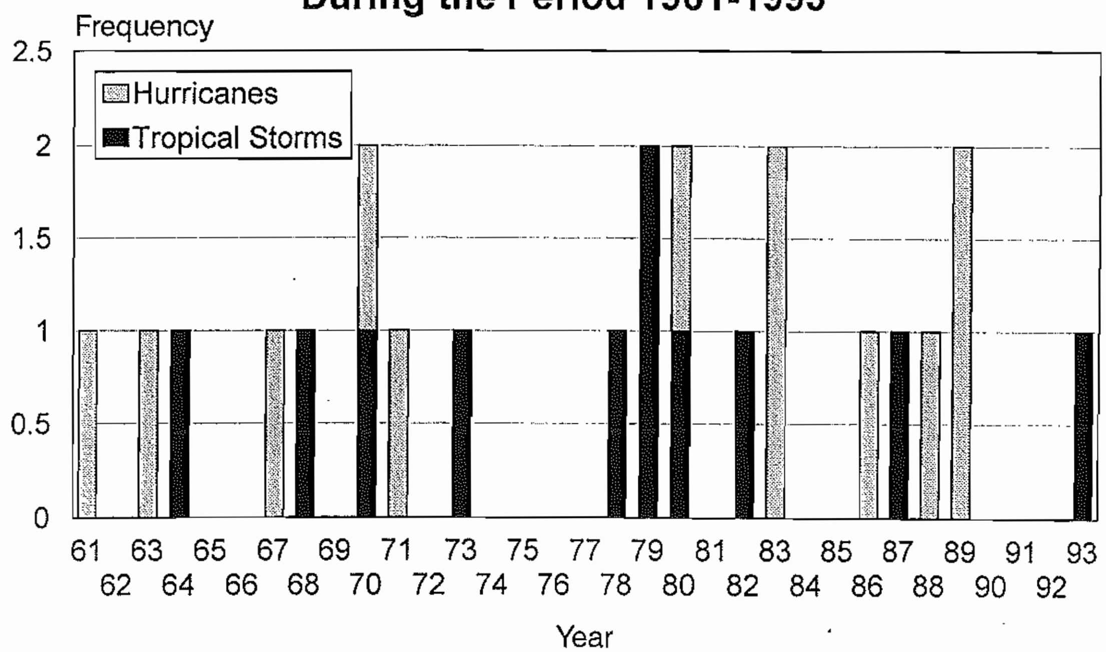
Yearly Distribution of Tropical Cyclones Affecting the Texas Coast During the Period 1931-1960



32 Tropical Cyclones (1931-1960)

FIGURE 30

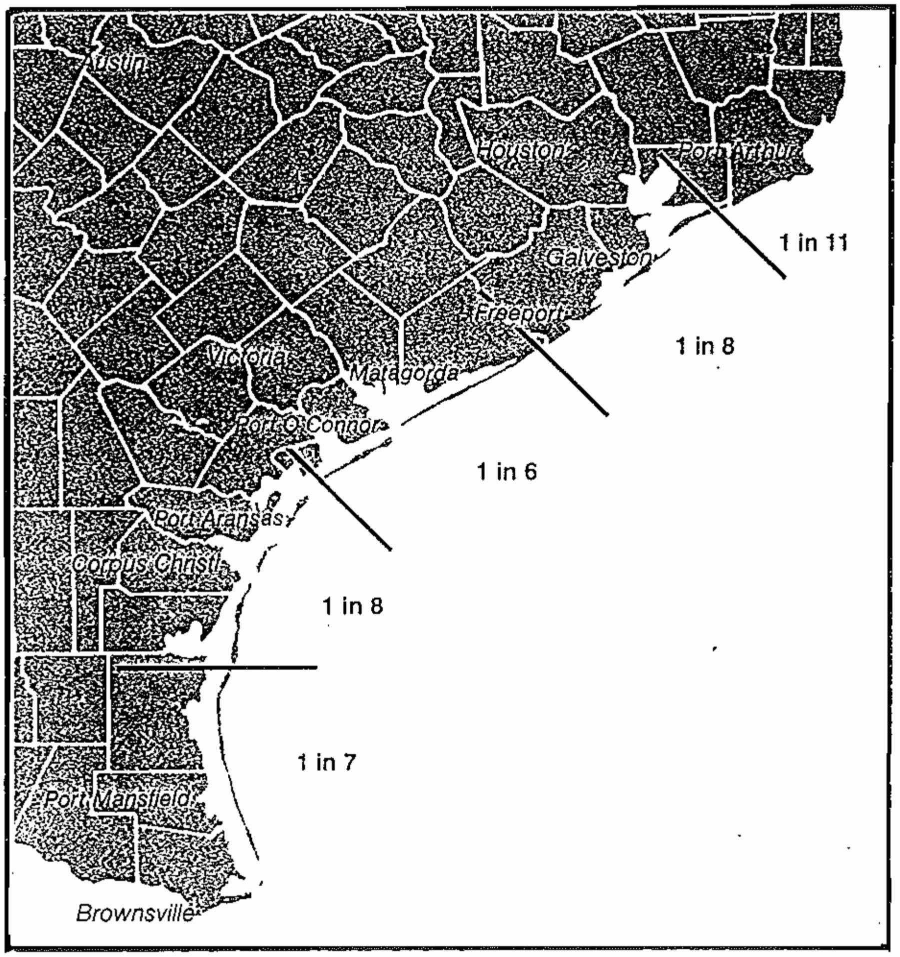
Yearly Distribution of Tropical Cyclones Affecting the Texas Coast During the Period 1961-1993



23 Tropical Cyclones (1961-1993)

FIGURE 31

Probability That a Tropical Cyclone Will Make Landfall In Any One Year



Computed From a 112 Year Period From (Bomar, 1983)