TEXAS SEA BREEZE: FACT OR FICTION?

AN INVESTIGATION OF TEXAS CLIMATE RECORDS FOR A SEA-LAND BREEZE SIGNATURE

A Senior Thesis

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1997-98 University Undergraduate Research Fellow

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Abstract

Texas Sea Breeze: Fact or Fiction?
An Investigation of Texas Climate Records for a Sea-Land Breeze Signature

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An analysis of the climatic averages from a number of locations in Texas is performed to ascertain whether they contain a sea-land breeze signature. Theory and previous research dictates that if any such signature exists, it should be confined to the region near the coast. The manner in which temperature, humidity, and wind should behave if influenced by the sea-land breeze on the climatic scale is first established. As a whole the coastal stations show varying amounts of evidence of a signature compared to the inland set of stations where it is presumed there is no sea-land breeze influence. Temperature and humidity data offers no conclusive evidence, but a clear indication the sea-land breeze is indeed present in the climate record comes from certain manifestations of the wind data. It is concluded there apparently is some kind of sea-land breeze signature in the climate records of the coastal set of stations. However, that signature is greatly concealed meaning the sea-land breeze is a minor factor in Texas climate compared to the large-scale synoptic weather pattern.

1. Introduction

a. Sea-land breeze circulation

At coastal locations a local wind pattern often exists independent of any other influence on surface winds that blows from sea to land during the day and from land to sea at night. This pattern is the surface portion of the sea-land breeze circulation system.

This thermally direct circulation is driven by a difference between the temperatures of the air over adjacent land and water. The lower atmosphere is almost completely warmed from below, so in general the warmer the surface is, the warmer the air above it will be. However, water has a significantly higher conductive capacity than land, meaning it requires more energy to be gained or released to warm or cool the same as land does. Thus, on a relatively clear and calm day solar heating will warm land and the air just above it more rapidly than nearby water and the air just above it. This uneven heating leads to a pattern of pressure gradients from land to sea. At the surface an inland flow results, while at a higher level a flow in the opposite direction is induced. Rising air over the land and subsidence over the water completes the loop as shown in Figure 1. The inland flow at the surface is what is recognized as the sea breeze.

At night the pattern is reversed. Since the air above the water does not cool as quickly as the air over land, the air over the water then is relatively warmer. The pressure gradients run in the opposite directions, so the surface flow is from land to sea. This is the land breeze. The land breeze is, as a general rule, weaker and less developed than the sea breeze because the temperature gradients which drive the circulation are not as strong at night as during the day.

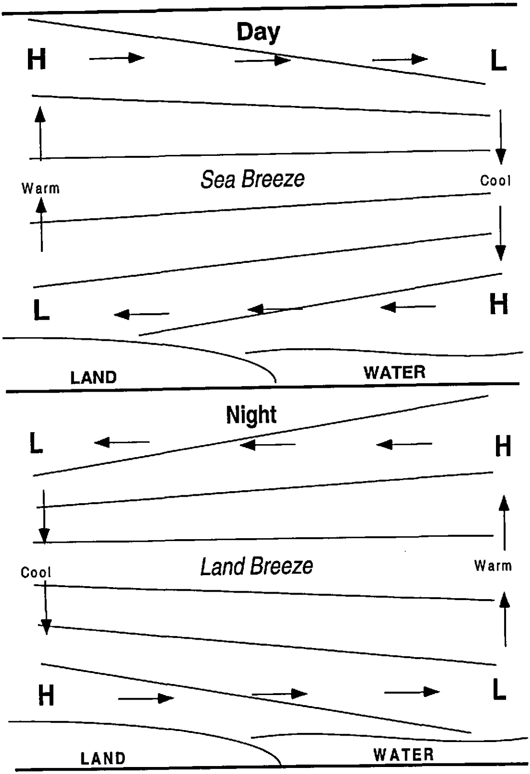


Figure 1 - Sea and land breeze circulations. Where the air is relatively warmer (over land during the day, over water at night), density is greater, thus thicknesses, the distances between pressure levels, are greater. When pressure surfaces slope air tends to travel down them from high to low. Departures from hydrostatic equilibrium cause the vertical motion that closes the circulation.

b. Purpose

The onset of sea and land breezes within the overall weather is often recognized by distinct and abrupt changes in wind speed and direction. Furthermore, these observations show the sea breeze usually decreases the temperature and increases the humidity by advecting inland cooler, more moist air from offshore. If the sea-land breeze was for the most part a daily phenomenon, these changes in the weather variables should be apparent in the climatic record. However, if it occurred without sufficient magnitude, frequency, or regularity it would have a negligible, unnoticeable effect in the long term.

The purpose of this study was to examine the climatic records from various Texas stations to determine whether there was a sea breeze signature, systematic diurnal variations in temperature, humidity, and wind indicative of sea-land breeze influence. Clearly, the focus of the study had to be near the coast where the temperature gradients that drive the circulation occur. But, if a sea-land breeze signature did exist it would be apparent to some distance inland. Finding the extent of that range was another goal.

Ultimately, an estimate was to be attained of the relative importance on the climatic time scale of the sea-land breeze circulation in comparison to the larger, more extensive synoptic pressure pattern. If no signature was found, the sea-land breeze would be presumed to be unimportant. If a signature was found, depending on its strength and clarity, the sea-land breeze would be considered a significant contributing factor in the Texas climate.

An immediate problem though is the fact that the sea-land breeze cannot simply be lifted from the climate record because it is embedded in the overall weather pattern when it does occur. Investigation of the climate record does not allow for selection of only days when the sea-land breeze would be most likely to form or at its strongest if it did form as is often done in other studies. That background weather could possibly conceal the sea-land breeze if it does occur or leave a mark indicative of the sea-land breeze when it really did not occur. It was necessary to set up a list of responses the climate record would have if the sea-land breeze had a noticeable role in the overall weather. The more completely those expectations were satisfied, the more likely it could be concluded a sea-land breeze signature did exist in the climate record. The background wind pattern often prevalent over much of Texas blows inland from the Gulf of Mexico. This pattern behaves similarly to the sea breeze, and it was recognized that it alone could often affect the weather in such a way that it could be mistaken for the sea-land breeze. Just because the wind blows from a direction from the water in over the land does not mean that wind is the sea breeze. Similarly, an offshore wind is not necessarily the land breeze.

In many places around the world sea breezes are important factors in local weather. Simpson (1994) describes several effects of sea breezes including afternoon cooling in very hot regions like the Near East, inducing precipitation over peninsulas such as Florida, and exacerbating pollution problems in urban areas such as southern California. As its structure is now fairly well understood, lately a great deal of the research involving sea breezes has focused on their effects on pollution.

The results from this study may prove beneficial in any number of ways. First, it should increase and refine understanding of the climate of Texas, a positive scientific result in its own right. Mesoscale modeling would be improved with a better understanding of the importance of the sea-land breeze in the overall scheme of the weather. This may be especially useful near Houston where pollution is a very significant problem. Further research may be performed to explain more quantitatively the results we reached for Texas, and the same sort of analysis could be performed for other areas near large bodies of water where sea-land breezes are known or suspected to exist.

c. Data and its sources

The data used was acquired for the eleven locations in Texas listed in Table 1. A map of the stations is shown in Figure 2. It would have been preferable to examine more stations to increase the spacial resolution in the study and have data from very near the coast, but hourly data proved somewhat limited.

City	Call Name	Latitude	Longitude	Elevation (ft)
Austin	A U S	30 18' N	97 42' W	587
Brownsville	B R O	25 54' N	97 26' W	19
Corpus Christi	C R P	27 46' N	97 30' W	44
Dallas-Fort Worth	D F W	32 54' N	97 02' W	551
Del Rio	D R T	29 22' N	100 55' W	1030
Houston	I A H	29 58' N	95 21' W	96
Port Arthur	B P T	29 57' N	94 01' W	16
San Angelo	S J T	31 22' N	100 30' W	1903
San Antonio	S A T	29 32' N	98 28' W	794
Victoria	V C T	28 51' N	96 55' W	104
Waco	A C T	31 37' N	97 13' W	500

City	Location	ISMCS Data	LCD Data
Austin	Municipal Airport	1948-1995	1980-1997
Brownsville	International Airport	1948-1995	1980-1997
Corpus Christi	International Airport	1948-1995	1980-1997
Dallas-Fort Worth	Regional Airport	1948-1995	1980-1997
Del Rio	International Airport	1951-1979	
Houston	International Airport	1969-1995	1980-1997
Port Arthur	Jefferson County Airport	1948-1995	1980-1997
San Angelo	Mathis Field	1948-1995	1980-1997
San Antonio	International Airport	1948-1995	1980-1997
Victoria	Regional Airport		1980-1997
Waco	Madison Cooper Airport	1948-1995	1980-1997

Table 1 – Region of Study.

Figure 2 - Map of Texas showing stations whose climate data was used for this study.

The data was taken from June, July, and August of the years listed. Missing dates indicate that the appropriate data from those locations were not available. The sources of the data were the International Station Meteorological Climate Summaries (ISMCS) and Local Climatological Data (LCDs) both compiled by NOAA. The ISMCS provided only frequency of wind direction and speed (knots) for 16 compass directions at three-hour intervals. The monthly LCDs provided air temperature (°F), dew point temperature (°F), wind speed (mph), and resultant wind speed (mph) and direction also at three-hour intervals. Temperatures and wind speed were averaged algebraically. Resultant wind speed and direction were acquired by averaging the vector sum of the individual winds. The data compiled for this study are in appendix A (LCDs) and appendix B (ISMCS).

2. Theory

It was first necessary to determine how the sea-land breeze behaved in isolation, without other forcing from the large-scale weather pattern. Then, the effects of the regular onshore synoptic flow over Texas on the sea-land breeze had to be determined. Once it was established what a sea-land breeze signature in the climate record of Texas ought to look like, then the record could be analyzed to see whether such a signature existed.

a. Frequency of occurrence

The formation and subsequent intensity of the sea-land breeze depend on location and time of year since the circulation requires significant warming to occur during the day over land. In the tropics conditions are favorable for the sea-land breeze through much of the year, and it occurs virtually every day during the summer (Ramdas, 1931). At higher latitudes it becomes less frequent. Mediterranean climates experience the sea breeze about one-third of the time during spring and autumn but 80-90% of the time during summer. Around the Baltic Sea, even during summer, it should only be observed no more than one-fifth of the time (Kaiser, 1907). Texas is most similar in climate to the Mediterranean, so it should favor sea breeze formation regularly during summer but not very often the rest of the year. Thus, the focus of this research was on the summer months of June, July, and August.

Clear, calm weather offers the best conditions for sea breeze development. At the Black Sea Defant (1951) quoted a strong relationship between cloudiness and sea breeze probability. With 50% cloudiness or less, sea breeze probability was 90%. But for increased cloudiness, the probability drops, as low as about 25% for overcast conditions. As skies are often clear or partly cloudy during the summer across Texas, cloudiness should not act as a major hindrance to sea-land breeze development on the climatic time scale.

b. Inland penetration

The sea-land breeze originates at the coast since the focus of its dynamics is there. It was necessary to know how far inland the sea breeze would reach into Texas, especially since none of the stations in the study are truly at the coast. It was possible the sea breeze would have a clear signature at the coast, but it would never be seen because all of the data was taken too far inland where the sea breeze did not reach.

The inland penetration of the sea breeze seems to be related to the magnitude of the temperature difference that drives it. There is a great variability in the values of inland penetration recorded throughout the world as shown in Table 2. In mid-latitude temperate regions the average is about 15-50 km (Defant, 1951; Atkinson, 1981). Defant claimed 50-65 km to be typical for tropical locations with occasional values more than twice that. Others (Wexler, 1946) have claimed values up to and over 300 km at some locations.

Hsu (1970) through observation and modeling put the inland extent in Texas at 50-65 km. However, Bose (1967) claimed that under ideal conditions the sea breeze may reach as much as 300 km inland, though 80 km was a more characteristic value. Case studies examining the sea breeze under ideal conditions may indeed show vast inland reach not representative of what would happen over the long term. As this project examined the climate record, the sea breeze had to occur regularly at a given location if evidence of it were to be found. So, based on this previous research, though it may on very rare occasions penetrate much farther inland, 50-80 km was taken to be a good estimate of the normal inland reach of the sea breeze over Texas.

Location	Inland Penetration (km)	Source
United Kingdom	10 to 15	Wexler (1946)
Flemish coast	15	qtd. in Defant (1951)
New England	16 to 32	qtd. in Defant (1951)
Baltic Sea	20 to 30	qtd. in Defant (1951)
Holland	30 to 40	qtd. in Defant (1951)
Massachusetts	40	Wexler (1946)
Albania	40	qtd. in Defant (1951)
Sweden	40 to 50	qtd. in Defant (1951)
Jutland	up to 50	qtd. in Defant (1951)
northern Java coast	over 50	qtd. in Defant (1951)
British Isles	55	Findlater (1963)
Texas	50 to 65	Hsu (1970)
Oregon	over 60	Johnson and O'Brien (1973)
Natal, South Africa	65	Preston-Whyte (1969)
California	100	Wexler (1946)
Poona, India	110	Ramanathan (1931)
Ismailia, Egypt	110	Pedgley (1958)
Harrogate, UK	113 to 129	Fergusson (1971)
UK	160	Smith (1974)
Australia	250 to 330	Clarke (1955)

Table 2 - Sea breeze penetration at selected locations

c. Time effects

Another factor that could make evidence of the sea-land breeze more difficult to find is the daily variation in the times it occurs. If the time at which the sea breeze begins varies greatly from day to day, its signature will be less coherent and harder to find in the climate record. Atkinson (1981) summarized major variations in the onset times of the sea breezes at various locations. Defant (1951) gave the following scheme of average times for the phases of the phenomenon, though he noted that they would change with place and time of year. The sea breeze starts between 1000 and 1100, reaches its peak intensity between 1300 and 1400, then subsides until about 2000 with the land breeze beginning soon after.

Certainly the cycle will not occur at precisely the same time every day. Yet in Texas temperature variation through the day is generally consistent through the summer, so it should follow a fairly regular pattern and not be so spread out a signature is blurred beyond recognition. Additionally, the data used here is at three-hour intervals, and the sea breeze often occurs over an extended period of the day. With the data only available at three-hour intervals it was thus not expected this factor would strongly obscure any signature. These temporal effects could instead mean any evidence found might not be completely indicative of the full strength of the sea-land breeze in Texas.

Hsu (1970) studied the diurnal variation in the sea-land breeze when the synoptic forcing was very weak over the upper Texas coast, roughly between Galveston and Port Arthur. He reached the following conclusions about the sea-land breeze there when it was nearly in isolation. Between 0900 and 1200 hours the temperature was the same over the land and the water, so the land breeze has ceased, and the sea breeze is about to begin. By noon the sea breeze is in effect though only extending about 20 km inland. Also, at about noon the difference between the air temperatures over the land and water is at its maximum. Thus, the sea breeze is fully developed and near its maximum by about 1500. The sea breeze remains in effect but gradually decreases in intensity through 2100. By midnight the sea breeze temperature and pressure differences are gone, and soon afterwards the land breeze begins. The land breeze maximizes around 0600 then decreases in strength until the cycle starts over during mid-morning. This model was comparable to other theory, and it served as a good basis for this analysis.

d. Synoptic wind influence

The background synoptic wind as described here is the gradient wind due to the large-scale horizontal pressure gradient. It generally blows from the south to southeast across Texas during the summer. Because of the orientation of the Texas coast, the sea breeze blows from about that same direction, and the land breeze blows in the opposite direction (refer to Figure 2). Unless this synoptic wind is very weak it will tend to cover up the sea-land breeze circulation in the overall flow so that the sea-land breeze is not necessarily obvious. This factor, as described later, was first analyzed by Haurwitz (1947). The synoptic flow may thus mask the sea-land breeze in Texas, but if they are of adequate strength when they occur, the sea breeze may have a noticeable additive effect and the land breeze a subtractive effect on wind speed.

Another important factor in our study introduced by an onshore synoptic wind was its tendency to weaken the development of the sea-land breeze circulation. Onshore winds diffuse the temperature gradient and thus the pressure gradient between the water and the land as shown by Estoque (1962). He also found an offshore background wind strengthened the circulation by intensifying the temperature gradient. Since structural studies are most easily performed on the strongest breezes, more investigation has been done on the effects of offshore rather than onshore or coast-parallel synoptic winds. Estoque's early study included only a constant background wind from the four directions parallel to and perpendicular to the coast. However, Arritt (1993) studied a wide range of winds from over 30 mph onshore to 30 mph offshore. In his model onshore synoptic flow of more than ten miles per hour suppressed the circulation. Zhong and Takle (1993) supported these conclusions with actual data from an area of Florida with an irregular coastline and complex coastal heating. They also found onshore flow caused the sea breeze to begin earlier in the day, previously noted by Frizzola and Fisher (1963), and the land breeze to begin later. But, strong onshore flow could keep the land breeze from even forming.

Bechtold et al. (1991) found that when offshore wind speed equaled the sea breeze front propagation speed the intensity of the circulation, as measured by the vertical velocities, was at its maximum. In that case though when the area of the strong temperature gradient is very narrow, the circulation would not extend inland to any great range. Onshore wind that still permits the sea breeze should weaken the circulation but also spread the temperature gradient over a wider range inland extending its penetration. Thus, for this study it was expected a sea breeze signature would be more difficult to find because of the negative effects of onshore background winds making it less intense. But, those winds could help allow the sea breeze, though weaker, to reach farther inland more frequently than it would reach otherwise.

e. Rotation of the wind

Many texts describe the sea breeze circulation simply as linear, as though its surface wind always blows perpendicularly to the coast, inland during the day and offshore at night. Early observations in mid-latitudes showed this was not the case, however. Time hodographs (explained in appendix C), which are charts of the movement with time of the end of the wind vector that begins at the origin, from observations produced two-dimensional results often like ellipses. Generally, observations showed the wind vector of the sea-land breeze veered (turned to the right) through the course of a day. The resulting curve on the hodograph thus had a clockwise orientation.

Haurwitz (1947) first showed how friction caused the sea breeze to reach its maximum intensity soon after the time of maximum temperature difference rather than when that difference became zero as previous theory had suggested. He then formulated a dynamic theory that accounted for the air in the sea-land breeze circulation not being in balanced motion. Because there was then an acceleration term in its equations of motion, the wind had to change with time by turning. This rotation was accounted for by the Coriolis force, which is due to the rotation of the earth. Because of their relatively short life span mesoscale winds like the sea-land breeze are not typically affected by the Coriolis force. The sea-land breeze circulation must then be largely closed for that to occur, otherwise the air would not be affected by the Coriolis force long enough to be deflected as it is. Haurwitz's theoretical results produced elliptical hodographs with a clockwise sense of rotation in good agreement with observations (Figure 3). He further noted the ellipses became more eccentric when the frictional force was increased.

Another factor studied by Haurwitz was the effect of different background winds on the sea-land breeze hodograph. Adding a background wind of approximately ten miles per hour did not alter the ellipse itself, but it did displace it so that the origin was no longer within the curve. This meant the wind vector itself did not turn through a full 360 degree rotation but only some much smaller angle. Still, the hodograph clearly showed the same sea-land breeze circulation pattern as the ellipse was exactly the same, except in its location, as when there was no background wind. He illustrated that certain synoptic winds concurrent with sea and land breezes could conceal them in the sense that there

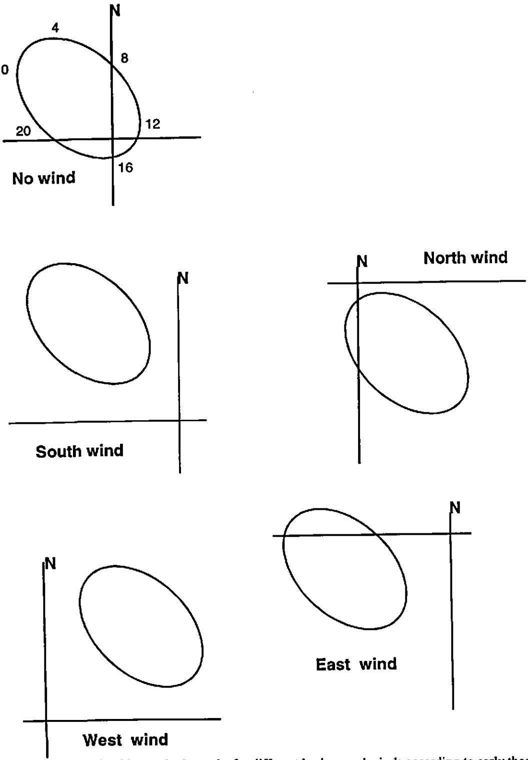


Figure 3 - Sea land breeze hodographs for different background winds according to early theory. In all cases land is west (left) of the north-south line and water is to the east (right). Numbers indicate time in hours after the time of maximum temperature difference between land and water and are in the same respective places on each hodograph. For south and east winds a true offshore land breeze never appears, and for a west wind a true onshore sea breeze never appears. (After Haurwitz, 1947.)

would not actually be an onshore or offshore wind when they would normally occur, as shown in Figure 3.

Schmidt (1947) also recognized the effect of the Coriolis force veering the wind in mid-latitudes. He calculated the sea breeze if in isolation would begin blowing to the left down the coast (looking inland) and end blowing in the opposite direction down the coast to the right. It would be normal to the coast fairly early so that it was about 33 degrees past the normal line at its maximum intensity.

Though theory suggests the sea breeze must veer in the Northern Hemisphere, observations at some locations have shown counterclockwise ellipses in their sea-land breeze hodographs. As Simpson (1996) summarizes this may be explained by local topographical influences, most notably mountains or coastline irregularities. Mountains were of no concern for this study, but there are coastal inlets to the southeast of both Victoria and Houston. Any earlier "local" sea breeze due to the bay would blow to the left of the later larger-scale "continental" sea breeze. So, as the day progressed the wind would veer resulting in clockwise rotation as first the local sea breeze formed then the continental breeze formed to its right.

f. Expectations for Texas

Assuming the sea breeze penetrates inland 50-80 km at the Texas coast and that during the summer months it occurs on upward of 75% of the days, its signature should be apparent in the long-term climatic records of coastal Texas stations. Brownsville, Corpus Christi, and Port Arthur are all less than 50 km from the Gulf of Mexico. Victoria and Houston are both closer to 80 km from the Gulf, but still within the expected range of the sea breeze. It was assumed then that if a sea breeze signature exists it would be found at these five stations which were thus referred to as coastal. For comparison the corresponding records of stations much farther inland were also analyzed. Though it may possibly occur on very rare occasions, the sea breeze was not expected to leave a mark in the climate records at Del Rio, San Antonio, Austin, San Angelo, Waco, and Dallas-Fort Worth, which were referred to as inland stations.

If all the stations across the state experience roughly the same average synoptic weather pattern through the summer months and similar non-sea breeze events such as frontal passages and mesoscale storms which cause deviation from that pattern, any major systematic differences between the two regimes should be attributable to the sea-land breeze.

g. Climate averages

It was first necessary to determine to what extent the summertime climatic averages could be considered representative of the individual days which comprised them. Experience indicates summer weather in Texas is fairly consistent. However, evidence, particularly in the winds, which may seem like indications of the sea-land breeze may possibly be explained otherwise if there exist systematic deviations to the regular synoptic weather pattern.

A rough analysis of surface weather maps was performed to establish the regularity of the large-scale pressure, and thus wind, pattern over Texas during June, July, and August. The analysis looked for times when there were significant differences from the average on the actual maps such as an either atypically strong or weak pressure gradient or a different orientation to the isobars compared to the average. The maps were at three-hour intervals and were from the years 1995-1997. They were compared to the monthly climatic averages from 1931-1960. Results and the average pressure map for June are shown in appendix D.

The average pressure patterns for each month were quite consistent. All featured a low pressure center over Arizona and a high pressure center over the Atlantic Ocean off the coast of the southeastern United States. Isobars over the interior of Texas ran generally north-south. Moving toward the Gulf of Mexico the isobars, particularly over the upper coast, turned so as to cross the coast nearly perpendicularly. That pattern produces the summertime winds that are overwhelmingly from the south and southeast over the area of Texas examined.

Overall, the pressure pattern was usually close to the climatic averages and differed significantly from them about one quarter of the time. The primary source of deviations was the occasional passage of cold fronts through the state that disrupted the climatically averaged low and high pressure patterns and caused the winds to vary from normal. Other less common causes of deviations included nearby tropical disturbances and surface troughs. Departures from the average isobaric pattern showed no diurnal tendencies and were spread about evenly across all hours of the day. As shown in appendix D the sums of the three months over the three years showed the months to be very similar to each other. When the years were compared to each other, 1996 more regularly agreed with the average, and 1995 differed more often from the average, though the differences were not extreme. Overall, it was concluded there was not a great deal of spatial or temporal variability to surface pressure patterns across Texas, so the averages were reasonably representative of the weather on a daily basis. Any sea-land breeze signature then should not be swamped and made impossible to confirm by other systematic deviations.

h. Expected behavior of variables

Sea breezes may cause significant changes to temperature and humidity, effects not really found with land breezes. Both will affect winds, but again due to its greater intensity, the sea breeze should be more influential.

1) Air temperature

An inland-propagating sea breeze transports onshore cooler and more humid air. Just as water warms and cools more slowly than land, moist air warms and cools more slowly than dry air. Thus, areas influenced by the sea breeze from late morning through afternoon should not warm up during the day as much as areas not affected by the sea breeze. A regular sea breeze may then be shown by more gradual and less total daily warming of air temperatures at coastal stations.

However, this should not be a major factor along the Texas coast. Because it blows from close to the same direction the general synoptic flow usually does, the sea breeze will not typically transport significantly different and cooler air into the regions it passes. The synoptic wind already blows air from out over the water inland. When the background wind is different from normal the sea breeze may then have a strong cooling effect, but generally its influence in this regard should not be great.

2) Humidity

Higher absolute humidity would be an expected effect of the sea breeze since it brings moisture inland. But generally during the afternoon hours when the sea breeze is strongest, the increased atmospheric turbulence caused by solar warming distributes the available moisture through a greater depth in the atmosphere decreasing the absolute humidity at the surface. Then at night when the air is calmer the moisture remains closer to the surface resulting in higher values of absolute humidity than during the daylight hours. Evidence of the sea breeze may be in the amount of moisture in the air at a station decreasing very little or even increasing during the middle of the day. The actual amount of moisture in the air is the absolute humidity, and this is measured by dew point temperature. Unlike wet-bulb temperature and relative humidity, dew point temperature measures humidity independently of the air temperature.

Again, as with air temperature, this may be only a minor factor in Texas because of the synoptic winds generally blowing from the same direction as the sea breeze. However, the land breeze normally would be blowing from inland and transporting drier air than the background flow usually does toward stations that experience it. So in Texas at night areas under land breeze influence would likely see a lesser increase or possibly a decrease in absolute humidity.

3) Winds

The synoptic pressure pattern in the absence of the sea-land breeze should produce a wind pattern largely consistent in blowing from the south to southeast. However, wind speeds vary as their horizontal momentum is transported vertically. This transport is influenced by convective heating during the day such that wind speeds are generally lower at night than during the day. Friction caused by the earth's surface produces a drag force that acts against the wind as it blows. This drag occurs in the planetary boundary layer that extends from the surface up to on average about one kilometer, decreasing from its maximum at the surface to negligible values above the boundary layer. Thus, wind speeds generally increase from the surface to the top of the boundary layer. During the day solar heating occurs causing thermals and convection cells to form at and move upward from the surface. This thermal turbulence results in vertical mixing of air which accelerates surface winds by linking them to the faster winds at higher levels. With greater heating the turbulence is greater causing the winds to tend to be more gusty. At night the heating and turbulence are less, so surface winds are less affected by higher level winds and are thus slower.

Given the background onshore wind typically over Texas during the summer, adding sea-land breeze forcing at coastal stations should increase the amount of variation in wind speed during the course of the day as Haurwitz (1947) described. Because the orientation of the Texas coast causes the sea breeze to blow roughly from the same direction and the synoptic winds, this combination should result in high wind speeds during the afternoon. But during the nighttime hours when land breeze forcing is in effect wind speeds should be low because that forcing is working in opposition to the synoptic flow, and the two should cancel each other out to some extent. Some such diurnal variation would be expected even without the sea-land breeze, but that additional forcing mechanism should further exaggerate the effect.

Directional variation may be shown in the winds, but with a regular onshore background wind the resulting total wind should mostly be from near the direction of that wind. If at times the synoptic forcing was weak compared to the sea-land breeze, the land breeze forcing would be able to manifest itself as an offshore wind. This effect would be shown in the ISMCS data by the wind being from an offshore direction more often during the early morning hours than the rest of the day.

Constancy, as described by Rosenburg (1974), is a unitless value that describes the variability in wind direction over a period of time. It is the ratio of the resultant wind speed, the vector sum average of all winds, to the algebraic average of those wind speeds without accounting for direction. Constancy is large when there is little variation in wind direction and small when there is much variation. If the wind were to blow from one direction all the time, the constancy would be 100%. If the wind blew equally from opposite directions, the vector sum would be zero, and so the constancy would be zero. Across much of Texas during the summer the synoptic wind is not highly irregular but predominantly from the south to southeast with occasional major deviations usually associated with storms and frontal passages. This implies constancy values in Texas should be rather high.

A strong sea-land breeze circulation at the Texas coast should increase the variability of the constancy ratio through the course of the average day in the climate record. During the afternoon when the synoptic forcing and sea breeze forcing are both in the same direction the wind should seldom vary from that direction resulting in high constancy values. The land breeze forcing is opposite the regular synoptic flow, so when it maximizes in the late night/early morning hours the wind may be much more variable.

Some of the time the land breeze forcing may be strong enough to overcome the synoptic flow and cause the wind to be from an offshore blowing direction. Other times the synoptic flow may remain dominant and maintain winds blowing inland. This variability would result in lower constancy values.

Another indication of the sea-land breeze would be shown if hodographs of resultant wind were in the form of ellipses with clockwise rotation.

3. Analysis of data

With a clear sense of exactly what kind of behavior by the temperature, humidity, and wind would indicate sea-land breeze influence on the climatic scale, the Texas records were then analyzed to find out whether a sea-land breeze signature exists. The data showed little variation among the summer months. Thus, their values for June, July, and August were averaged to get one value for each of the variables at the given times from midnight (0000 hours) through the day by three-hour increments to avoid redundancy.

a. Air temperature

The temperature changes over three hours periods from mid-morning to late afternoon were examined. As would be expected from daily solar warming, temperatures increased at all stations from 0900 to 1200 (Table 3). The coastal stations warmed noticeably less than the inland stations. The temperature also increased at all stations between 1200 and 1500 (Table 4) though the magnitude of the increase was much less than the previous three hours. Again the increases at the coastal stations were clearly less than those at the inland stations. From 1500 to 1800 temperatures fell at all stations (Table 5). However, for this period the coastal and inland stations did not fall into two clearly distinct regimes as they did before.

Table 3 - Air Temperature (°F): 0900-1200 increase (Coastal stations italicized)

BPT	*BRO*	*VCT*	*IAH*	*CRP*	DFW	AUS	SAT	ACT	SJT
3.8	4.7	5.3	5.5	5.5	7.2	7.3	7.4	7.8	8.4

Table 4 - Air Temperature (°F): 1200-1500 increase

BRO	*CRP*	*BPT*	*IAH*	*VCT*	ACT	DFW	AUS	SAT	SJT
0.1	0.3	0.3	1.2	1.4	2.9	3.0	3.2	3.7	4.0

Table 5 - Air Temperature (°F): 1500-1800 decrease

BRO	*CRP*	AUS	*VCT*	*BPT*	ACT	*IAH*	DFW	SAT	SJT
4.3	4.0	3.8	3.5	3.2	3.1	3.0	2.2	1.7	1.6

The increases from morning to mid-afternoon follow what would be expected if the coastal stations were under the influence of the sea breeze and the inland stations were not, though the afternoon decreases do not behave as expected. But the temperature changes almost certainly can be explained nearly completely without even considering the sea breeze. As shown by the 0900 dew point temperatures (Table 6), the air near the coast generally contains more moisture at the time the sea breeze begins. Since, again because of the high heat capacity of water, more humid air warms and cools more slowly than dry air, the coastal stations should experience less temperature variation than the inland stations even without sea breeze influence. The calculated variance of the temperature at the stations was almost as a rule smaller as the average dew point temperature for all hours increased (Table 7 & 8). It does not show the sea-land breeze is not in effect, but the temperature data also does not offer conclusive evidence of the sea-land breeze since it is not necessary to account for the temperature changes.

Table 6 - Dew point temperature (°F): 0900

BPT	*BRO*	*CRP*	*VCT*	*IAH*	AUS	SAT	ACT	DFW	SJT
75.4	74.5	74.2	74.2	73.6	71.4	70.8	70.6	69.4	66.4

Table 7 - Air Temperature (°F): Variance

BPT	*BRO*	*CRP*	*VCT*	*IAH*	AUS	SAT	DFW	ACT	SJT
25.6	28.1	30.5	31.7	33.5	37.2	38.5	39.4	47.4	53.1

Table 8 - Dew Point Temperature (°F): Average

BPT	*BRO*	*CRP*	*VCT*	*IAH*	AUS	SAT	ACT	DFW	SJT
74.2	73.9	73.5	73.0	72.0	69.6	69.0	68.9	67.7	63.3

b. Humidity

Dew point temperatures behaved very similarly to what would be expected with a sea breeze circulation in effect at the coast. The coastal and inland stations fell into two distinct groups for the 1200-1800 dew point change (Table 9). Except for Houston, which decreased very slightly, the coastal stations experienced a dew point rise. The inland stations all had a dew point decrease between these hours. At the opposite time of the day from 0000 to 0600, the coastal stations showed a decrease in dew point temperature while the inland stations showed an increase (Table 10).

Table 9 - Dew point temperature (°F) change: 1200-1800

BRO	*VCT*	*CRP*	*BPT*	*IAH*	DFW	ACT	AUS	SAT	SJT
0.7	0.5	0.2	0.1	-0.1	-1.9	-1.9	-2.0	-2.7	-3.5

Table 10 - Dew point temperature (°F) change: 0000-0600

CRP	*BPT*	*HOU*	*BRO*	*VCT*	ACT	DFW	AUS	SAT	SJT
-1.1	-0.9	-0.8	-0.8	-0.8	0.4	0.5	0.6	0.8	1.5

Once again though this evidence is not clearly indicative of a sea-land breeze signature. Though the sea-land breeze may play a role, the advection of moisture by the synoptic wind alone could account for these factors.

c. Winds

1. Variance and range

As previously discussed, wind speeds at most locations will tend to be higher during the day and lower at night, but in Texas this would be variation would be exaggerated by the sea-land breeze. The statistical variance of the wind speed across all hours showed some evidence of a sea breeze signature, though the coastal and inland regimes were not widely separated. Wind speed variance and the range of speeds (Table 11) were larger for the coastal stations and smaller for the inland stations as was theorized if the sea-land breeze occurred. To some extent, the wind speeds at the coastal stations were lower than the inland stations near the expected time of maximum land breeze forcing and faster near the expected time of maximum sea breeze forcing (Table 12).

Table 11 - Wind speed variance (top) and range in mph (bottom)

BRO	*CRP*	*VCT*	*IAH*	*BPT*	AUS	SJT	SAT	DFW	ACT
14.5	13.7	7.8	5.3	4.9	3.0	2.8	2.0	1.8	1.4
10.1	10.6	8.2	6.0	5.7	4.8	4.0	4.3	3.7	3.7

Table 12 - Wind speed in mph at 0600 (top) and 1500 (bottom)

BRO	*CRP*	*VCT*	*IAH*	*BPT*	AUS	SJT	SAT	DFW	ACT
5.4	6.0	5.1	3.9	4.5	4.9	7.4	6.2	7.7	7.9
15.5	16.2	12.3	9.6	10.2	9.7	11.4	9.9	11.2	11.4

2. Constancy

The statistical variance of constancy was mostly higher for the coastal stations than the inland stations, but this was not a rule (Table 13). The extremes fell into place with what would be expected due to sea-land breeze forcing, but the values in between did not clearly do so.

Table 13 - Constancy: Variance

IAH	BPT	VCT	CRP	AUS	SAT	BRO	DFW	ACT	SJT
326.9	303.8	289.6	110.6	96.7	88.4	40.8	26.1	23.1	21.6

3. Frequency of direction

The ISMCS data described much the same thing as the constancy ratio did but with more specificity to direction. Some of that data is summarized in Table 14. For each station an imaginary line was set parallel to the nearest portion of the coast. Winds crossing that line from the direction of the Gulf of Mexico were considered to be blowing inland, and winds blowing across from the interior of the land were considered to be blowing offshore. As would be expected with sea-land breeze forcing, the wind at the coastal stations blew in an onshore direction with much greater frequency during the afternoon and blew in an offshore direction much more frequently during the early morning. Del Rio, DFW, and San Angelo showed very little of this variation across the day as expected since no sea-land breeze was assumed at those locations. San Antonio and Austin showed more variability between morning and afternoon in the inland and offshore blowing winds and were seemingly closer in character to the coastal stations than the other inland stations. However, the amount of morning winds from an offshore direction at those stations is likely increased because of topographically induced downslope winds blowing down from the west and northwest rather than any sea-land breeze forcing.

Station		6 %	6 Speed	15 %	15 Speed
Austin	*Inland*	67.6	5.2	88.0	9.1
	Offshore	17.7	5.6	11.6	9.3
	Calm	14.8		0.8	
Brownsville	*Inland*	71.8	5.8	93.8	14.4
	Offshore	14.7	4.4	6.5	10.8
	Calm	13.8		0.2	
Corpus Christi	*Inland*	68.9	6.0	97.2	14.2
	Offshore	17.2	5.7	3.7	9.4
	Calm	14.3		0.2	
Del Rio	*Inland*	93.0	8.0	95.2	10.6
	Offshore	5.9	5.1	5.4	7.8
	Calm	1.5		0.5	
DFW	*Inland*	75.9	7.4	82.7	10.3
	Offshore	15.5	6.5	16.6	8.8
	Calm	8.4		1.0	
Houston	*Inland*	35.2	5.1	76.4	8.8
	Offshore	36.6	4.4	23.0	6.8
	Calm	28.2		1.3	
Port Arthur	*Inland*	36.2	5.6	79.1	9.8
	Offshore	49.3	5.0	20.2	7.9
	Calm	14.4		0.8	
San Angelo	*Inland*	72.9	7.8	82.7	10.6
	Offshore	12.8	6.4	15.8	9.1
	Calm	14.4		1.6	
San Antonio	*Inland*	62.5	6.3	90.1	9.3
	Offshore	29.6	4.7	9.8	8.5
	Calm	7.7		0.7	
Waco	*Inland*	76.5	8.3	83.2	10.7
	Offshore	15.4	6.0	15.5	9.6
	Calm	8.0		1.4	

Table 14 – Frequency and speeds of wind coming from directions considered inland and offshore as well as calm for 6am and 3pm. The coastal stations showed more offshore winds during the early morning when land breeze forcing should be strong and more inland winds during the afternoon when sea breeze forcing should be strong.

4. Resultant winds and hodographs

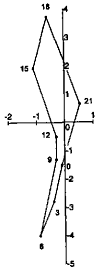
Hodographs of resultant wind alone showed almost no evidence of sea-land breeze influence (see appendix D). The inland stations were all quite similar to each other. The coastal stations as a group showed more variation, yet they were not greatly different from the inland stations. Most notably, all of the hodographs showed predominantly counterclockwise rotation. Only a small amount of clockwise orientation was shown at the times of expected maximum sea or land breeze forcing at some of the coastal stations. As described previously, the sea-land breeze alone would produce a hodograph whose curve had clockwise rotation. If the hodographs were roughly elliptical and had a clockwise orientation, that still would not necessarily prove the presence of the sea-land breeze because the synoptic flow could possibly produce that same result. However, the almost complete lack of clockwise rotation clearly illustrated that the sea-land breeze circulation is not a dominant forcing mechanism at work over even the coastal region of Texas. On the climate scale it must have a much less significant role in the overall weather than the synoptic pressure pattern which apparently contributes the great majority of what is shown on the hodographs.

5. Isolation of the sea-land breeze

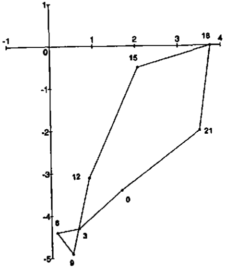
It was then decided to attempt to "remove" the synoptic flow from the wind data of the coastal stations to see whether a sea-land breeze signature remained. If it was assumed the total resultant winds of the coastal stations consisted of only the synoptic flow and the sea-land breeze, then subtracting the synoptic flow would leave only the sea-land breeze. To do this a good estimate of the background synoptic wind had to be developed. It had been assumed that the sea-land breeze had no effect on the inland stations. Plus, their hodographs were very consistent. Therefore, an average of the resultant wind at the inland stations was calculated and assumed to be the synoptic wind over the entire state. Such an approximation will clearly produce at least small systematic errors when applied to as large an area as the majority of Texas. But, neglecting any other mesoscale variations besides the sea-land breeze by assuming they are consistent across the state leaves only variation in the large-scale. The climatic pressure averages showed in Texas to the west a tighter pressure gradient, which implies faster winds and to the east a weaker pressure gradient, implying slower winds. Thus, the calculated average produced from those inland stations, which were clustered toward the center of Texas, should be quite representative of the synoptic flow in the middle of the state but somewhat too slow to the west and too fast to the east. This calculated synoptic wind was then subtracted from the resultant wind data of each coastal station, and hodographs were made from those differences, which were theorized to be the sea-land breeze.

These difference hodographs (examples are shown in Figure 4, and the complete set is in appendix C) provided the clear evidence of the sea-land breeze. Clockwise rotation was the general rule with only a small deviation for Port Arthur and about half of the Brownsville hodograph. The points on each curve farthest from each other should be the times of maximum sea breeze forcing and maximum land breeze forcing. A line drawn connecting these times would typically be turned away from perpendicular to the coast. This is in accordance with the theory that the breezes maximize after the time they were normal to the coast. The Victoria hodograph had the origin within it implying the difference wind went through a full rotation through the course of the day. Being nearer the middle of the coast than any of the other coastal stations it was expected to have an actual synoptic flow very close to the calculated average so that almost nothing but the sea-land breeze would be left after subtraction like the no wind example in Figure 3. If however the synoptic flow is slightly less at Victoria than the calculated average, that would account for the land breeze and sea breeze appearing to be roughly equal in magnitude, an unlikely prospect. The Brownsville and Corpus Christi hodographs were displaced to the left somewhat away from the origin. The actual synoptic winds at those more western, lower coast stations should be faster than the calculated average so that they are not completely removed by subtracting it from the total wind. Thus, a net southeast flow should still remain besides the sea-land breeze at those stations. Thus, according to the work of Haurwitz, the hodographs should be displaced about as they are. Similarly, along the upper coast too much is subtracted from the total winds at those stations leaving a net offshore flow. Again, the hodographs for Houston and Port Arthur are displaced away from the origin about as would be expected.

Victoria-average inland difference



Port Arthur-average inland difference



Corpus Christi-average inland difference

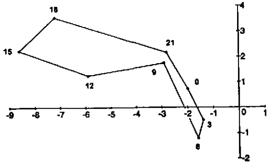


Figure 4 - Hodographs of differences of wind at three coastal stations and average wind synoptic wind calculated from the inland stations. Ideally, these would represent the sea-land breeze alone at each of the coastal stations. Though that is not strictly the case, they do agree very well with theoretical sea-land breeze hodographs.

4. Conclusions and Discussion

Ultimately a signature of the sea-land breeze was found in the climate records of the coastal stations in Texas. As expected though the background synoptic flow made the signature very difficult to locate. Temperature and humidity data showed tendencies that would be expected if the coastal region was under sea-land breeze influence, but those tendencies could be explained without mention of anything but the large-scale weather pattern. True and clear evidence of the sea-land breeze came only from the wind data. The diurnal variation of the wind speed was greater at the coastal stations. This agreed with what would be predicted with the combination of the two forcing mechanisms of a generally onshore synoptic flow and the sea-land breeze. Another obvious sign of the sea-land breeze came when a synoptic flow calculated from the average of the winds of the inland stations was subtracted from the winds of each of the coastal stations. In theory, this would leave the only the sea-land breeze of each coastal station. The results indeed were almost exactly what would be expected if those residual winds were primarily the sea-land breezes at the stations.

Though a signature was found, the lengths required to find it confirmed that the sea-land breeze is not at the same level of significance in the Texas climate as the synoptic weather pattern. It is a factor in the overall weather to the extent that it can be shown in the climate record but only as an addition embedded in the general weather pattern. It may dominate on certain individual days, but on the climatic scale it plays only a small part. The limited amount of data only permitted the conclusion that the sea-land breeze was apparent at the coastal stations and not the inland stations. There was no way to establish the exact inland penetration of the signature.

Additional research along these lines in Texas could attempt to find evidence in spring and autumn records. Critical points may be found when on average during the year the sea-land breeze signature arises within and disappears from the climate record. This scheme could be used in any coastal region where the sea-land breeze occurs to estimate its importance compared to the large-scale weather pattern there.

This study presented a method by which the influence of the sea-land breeze on climate can be analyzed. More sophisticated studies could pick up where this one left. Research projects that attempt to model mesoclimates of coastal regions, perhaps focusing on pollution, could incorporate and expand upon the basic ideas used here. With better knowledge of the relative importance and the effects of the sea-land breeze in climate a more complete understanding of local climates may be achieved.

5. Acknowledgments

Special thanks are due to Dr. Dennis Driscoll for providing the idea, motivation, and guidance needed for this research. Appreciation is expressed to Brian Belcher in the Office of the State Climatologist for his help in supplying the necessary climate data. Recognition is also given to the numerous other people who gave assistance and impetus throughout this study.

6. Appendices

Appendix A - Local Climatological Data

Local Climatological Data summaries are published monthly. For the stations analyzed they provided averages at three-hour intervals of air temperature, dew point temperature, wind speed, and resultant wind. Wind speed is merely the scalar average of all of the wind speeds without respect to direction, but resultant wind is the vector average, which has direction and speed. Overall, the differences among the months were not considered to be significant, so the monthly averages were combined into one average for the entire summer period. This was also done with the ISMCS data.

ustin		June	July	August	All
ir	0	76.4	79.2	79.2	78.3
emperature	3	74.4	76.5	76.6	75.8
	6	73.1	75.2	75.3	74.5
	9	79.7	82.6	82.7	81.7
	12	86.1	90.3	90.6	89.0
	15	89.1	93.4	94.1	92.2
	18	87.2	91.4	86.6	88.4
	21	80.2	83.6	83.3	82.4
Dew point	0	70.2	70.6	69.9	70.2
temperature	3	70.2	71.4	70.9	70.8
	6	69.8	71.6	71.1	70.8
	9	70.8	71.8	71.7	71.4
	12	69.9	69.3	68.8	69.3
	15	69.3	67.1	66.4	67.6
	18	69.0	66.8	66.2	67.3
	21	69.9	68.9	68.4	69.1
Wind speed	0	6.9	6.5	6.0	6.5
	3	6.1	5.7	5.0	5.6
	6	5.6	5.1	4.1	4.9
	9	8.6	9.0	8.0	8.5
	12	9.6	9.4	8.6	9.2
	15	10.2	9.6	9.2	9.7
	18	9.7	9.6	9.1	9.5
	21	7.4	7.1	7.1	7.2
Resultant	0	153	163	163	160
Wind	3	166	176	176	173
direction	6	155	177	166	168
	9	173	186	188	183
	12	163	171	169	168
	15	146	155	145	149
	18	136	145	132	138
	21	132	144	135	137
Resultant	0	4.0	5.5	4.3	4.6
Wind speed	3	3.2	4.6	3.2	3.6
	6	2.1	3.4	2.0	2.4
	9	4.7	6.8	4.8	5.4
	12	5.6	6.8	5.0	5.8
	15	6.1	7.0	5.5	6.2
	18	6.7	7.8	6.2	6.9
	21	5.3	6.0	5.1	5.5
Constancy	0	58.0%	83.8%	71.0%	70.5%
	3	52.9%	79.5%	64.3%	65.2%
	6	37.3%	66.2%	48.0%	49.6%
	9	54.4%	75.4%	59.9%	63.1%
	12	58.1%	71.8%	58.5%	62.8%
	15	59.9%	72.8%	59.6%	63.9%
	18	69.0%	81.1%	68.0%	72.5%
	21	71.5%	84.3%	71.8%	75.5%

Brownsville		June	July	August	All
Air	0	78.6	79.3	79.3	79.1
temperature	3	77.3	77.8	77.9	77.7
	6	76.4	77.3	76.6	76.8
	9	85.3	86.7	85.9	86.0
	12	89.5	91.3	91.3	90.7
	15	89.8	91.4	91.3	90.8
	18	85.8	86.6	86.9	86.5
	21	80.1	81.1	81.4	80.9
Dew point	0	74.4	75.2	75.0	74.9
temperature	3	74.2	74.7	74.7	74.5
	6	73.7	74.3	74.2	74.1
	9	74.2	74.2	75.0	74.5
	12	73.1	72.3	72.4	72.6
	15	73.2	72.2	72.5	72.6
	18	73.4	73.2	73.3	73.3
	21	74.4	74.7	75.0	74.7
Wind speed	0	7.8	7.7	6.6	7.4
	3	6.6	6.1	5.1	5.9
	6	5.8	5.7	4.6	5.4
	9	12.7	12.9	10.8	12.1
	12	14.0	15.0	12.9	14.0
	15	15.2	16.4	15.0	15.5
	18	14.4	15.4	14.3	14.7
	21	9.3	9.5	8.4	9.1
Resultant	0	145	152	147	148
Wind	3	151	157	155	154
direction	6	142	149	142	145
	9	156	162	160	159
	12	148	153	148	150
	15	135	141	134	137
	18	129	137	128	132
	21	132	138	129	133
Resultant	0	7.0	7.2	5.6	6.6
Wind speed	3	5.4	5.3	3.8	4.9
	6	4.1	4.6	2.6	3.8
	9	10.3	11.4	8.1	9.9
	12	11.2	13.0	9.7	11.3
	15	12.9	14.8	12.5	13.4
	18	12.8	14.4	12.6	13.2
	21	8.4	9.0	7.5	8.3
Constancy	0	89.6%	93.2%	85.0%	89.4%
	3	81.7%	87.8%	75.4%	82.0%
	6	70.5%	80.6%	56.8%	70.1%
	9	80.9%	88.1%	75.2%	81.7%
	12	80.3%	86.8%	75.4%	81.1%
	15	84.9%	90.4%	83.1%	86.1%
	18	88.7%	93.6%	88.1%	90.0%
	21	89.5%	94.2%	88.8%	90.8%

›rpus Christi		June	July	August	All
r	0	77.3	78.6	79.2	78.4
nperature	3	75.8	76.7	77.3	76.6
	6	74.8	75.6	76.1	75.5
	9	83.2	85.5	85.2	84.6
	12	88.1	91.0	91.0	90.1
	15	88.4	91.3	91.6	90.4
	18	85.1	87.1	87.0	86.4
	21	79.1	80.8	81.3	80.4
›w point	0	74.0	74.8	74.4	74.4
mperature	3	73.2	74.1	73.9	73.8
	6	72.9	73.5	73.3	73.3
	9	74.1	74.0	74.4	74.2
	12	73.1	72.3	72.2	72.5
	15	73.1	72.2	72.1	72.4
	18	72.9	72.5	72.7	72.7
	21	74.2	74.7	74.3	74.4
ʼind speed	0	8.6	8.8	8.8	8.7
	3	7.2	6.9	6.7	7.0
	6	6.5	5.8	5.9	6.0
	9	11.9	12.5	11.4	11.9
	12	13.2	13.7	13.0	13.3
	15	15.2	16.6	16.7	16.2
	18	15.5	17.1	17.2	16.6
	21	10.6	11.4	11.5	11.2
:esultant	0	143	149	148	147
ʼind	3	151	159	157	156
irection	6	138	147	137	141
	9	155	166	163	162
	12	138	141	130	137
	15	126	128	121	125
	18	129	131	125	128
	21	134	138	134	136
₹esultant	0	7.3	7.8	7.6	7.5
Vind speed	3	5.1	5.7	4.5	5.1
	6	3.6	4.7	2.5	3.6
	9	8.4	10.3	7.2	8.6
	12	10.2	11.4	9.8	10.4
	15	12.8	15.3	14.7	14.2
	18	13.7	15.9	15.9	15.2
	21	9.4	10.6	10.5	10.2
Constancy	0	84.2%	89.1%	85.8%	86.3%
	3	70.3%	82.9%	66.7%	73.2%
	6	55.7%	81.6%	43.1%	59.7%
	9	71.1%	82.2%	62.7%	72.0%
	12	76.8%	83.4%	74.8%	78.2%
	15	84.3%	92.3%	87.8%	88.0%
	18	88.8%	93.2%	92.9%	91.6%
	21	88.7%	93.0%	91.5%	91.0%

DFW		June	July	August	All
Air	0	76.5	80.6	80.3	79.2
temperature	3	73.6	77.6	77.4	76.2
	6	71.9	75.4	75.1	74.2
	9	79.8	83.7	82.9	82.1
	12	86.2	90.8	90.7	89.3
	15	89.2	94.1	93.6	92.3
	18	86.7	92.2	91.3	90.1
	21	80.1	84.8	83.8	82.9
Dew point	0	67.8	68.4	67.1	67.8
temperature	3	67.7	68.7	67.7	68.0
	6	67.8	69.1	68.1	68.3
	9	68.7	70.1	69.4	69.4
	12	68.1	68.6	67.7	68.1
	15	67.2	66.8	65.7	66.5
	18	67.1	66.4	65.2	66.2
	21	67.4	67.6	66.4	67.1
Wind speed	0	8.9	9.3	8.0	8.7
	3	8.5	9.2	7.7	8.5
	6	8.2	8.1	6.9	7.7
	9	10.9	11.1	9.6	10.5
	12	11.7	11.2	9.5	10.8
	15	11.9	11.7	9.9	11.2
	18	11.7	11.9	10.5	11.4
	21	9.1	9.5	8.3	8.9
Resultant	0	168	168	159	165
Wind	3	178	181	177	179
direction	6	174	181	173	177
	9	185	197	192	192
	12	179	189	180	183
	15	165	170	158	165
	18	156	160	147	155
	21	151	151	143	148
Resultant	0	5.7	7.5	5.6	6.2
Wind speed	3	4.9	7.0	5.0	5.7
	6	4.2	6.0	4.0	4.7
	9	6.7	7.9	6.2	6.9
	12	6.5	7.2	5.2	6.3
	15	6.8	7.5	5.5	6.6
	18	7.3	8.3	6.6	7.4
	21	6.2	7.4	5.9	6.5
Constancy	0	64.3%	80.7%	69.6%	71.6%
	3	58.0%	76.5%	65.3%	66.9%
	6	50.7%	73.4%	57.9%	60.7%
	9	61.2%	71.5%	64.7%	65.6%
	12	55.3%	64.2%	54.8%	58.1%
	15	56.8%	63.9%	56.2%	59.0%
	18	62.3%	69.8%	63.1%	64.9%
	21	68.4%	77.7%	72.0%	72.7%

ɔuston		June	July	August	All
ir	0	76.4	78.6	77.9	77.6
mperature	3	74.2	76.2	75.6	75.3
	6	73.5	75.1	74.5	74.4
	9	82.2	84.3	83.9	83.5
	12	87.2	89.9	89.8	89.0
	15	88.1	91.2	91.1	90.2
	18	85.9	87.9	87.7	87.2
	21	79.4	81.8	81.4	80.9
ew point	0	71.8	73.3	73.1	72.8
ımperature	3	71.1	72.9	72.6	72.2
	6	70.9	72.8	72.3	72.0
	9	72.3	74.2	74.2	73.6
	12	70.9	71.8	71.4	71.4
	15	70.4	70.9	70.2	70.5
	18	70.7	71.9	71.3	71.3
	21	71.5	72.9	72.8	72.4
/ind speed	0	5.7	5.3	4.5	5.2
	3	4.8	3.7	3.2	3.9
	6	4.6	3.7	3.3	3.9
	9	8.9	8.5	7.8	8.4
	12	9.5	8.1	8.1	8.6
	15	10.2	9.3	9.2	9.6
	18	10.3	10.1	9.4	9.9
	21	7.6	7.5	7.0	7.4
tesultant	0	152	166	165	160
Vind	3	155	183	169	167
lirection	6	109	136	33	90
	9	171	208	207	193
	12	159	179	152	164
	15	140	150	134	141
	18	136	142	134	138
	21	144	150	145	147
Resultant	0	3.0	3.1	2.0	2.6
Wind speed	3	1.6	1.3	0.1	1.0
	6	1.3	0.4	0.8	0.6
	9	3.5	3.8	1.4	2.7
	12	3.9	3.3	2.5	3.1
	15	5.4	5.1	4.8	5.1
	18	6.7	7.2	6.3	6.7
	21	5.0	5.5	4.6	5.0
Constancy	0	51.5%	58.0%	43.6%	51.2%
	3	34.2%	34.0%	3.7%	25.1%
	6	27.6%	9.7%	24.2%	16.3%
	9	39.0%	44.7%	17.7%	32.6%
	12	40.8%	40.2%	30.3%	36.6%
	15	53.2%	54.6%	52.4%	53.1%
	18	64.9%	71.7%	67.2%	67.8%
	21	66.2%	73.4%	66.1%	68.6%

Port Arthur		June	July	August	All
Air	0	75.8	77.2	76.8	76.6
temperature	3	74.9	76.3	75.9	75.7
	6	74.7	75.9	75.1	75.2
	9	82.7	84.7	84.1	83.9
	12	86.4	88.3	88.5	87.7
	15	86.6	89.1	88.4	88.0
	18	83.6	85.7	85.0	84.8
	21	77.7	79.0	78.3	78.3
Dew point	0	73.4	75.1	74.6	74.3
temperature	3	72.7	74.6	74.1	73.8
	6	72.5	74.3	73.5	73.4
	9	73.9	76.4	75.8	75.4
	12	72.9	74.8	74.2	74.0
	15	73.1	74.7	73.9	73.9
	18	72.9	74.9	74.5	74.1
	21	73.4	75.2	74.7	74.4
Wind speed	0	6.0	4.9	4.4	5.1
	3	5.6	4.2	4.3	4.7
	6	5.5	3.8	4.2	4.5
	9	9.5	8.3	8.1	8.6
	12	10.7	8.7	8.5	9.3
	15	11.1	9.9	9.5	10.2
	18	10.3	9.5	8.5	9.4
	21	6.8	5.7	5.4	6.0
Resultant	0	162	178	165	168
Wind	3	162	199	9	174
direction	6	125	348	15	48
	9	174	232	321	204
	12	166	196	152	174
	15	166	179	164	170
	18	169	176	168	171
	21	162	171	163	166
Resultant	0	3.1	2.4	1.3	2.3
Wind speed	3	2.0	1.2	0.3	0.9
	6	1.3	0.4	1.7	0.6
	9	3.4	2.6	0.5	1.7
	12	5.1	3.4	1.7	3.2
	15	6.5	5.8	4.5	5.5
	18	6.5	6.5	4.8	5.9
	21	4.1	3.3	2.2	3.2
Constancy	0	52.4%	50.2%	28.8%	44.7%
	3	35.6%	28.2%	7.6%	19.3%
	6	23.9%	10.8%	39.7%	14.1%
	9	36.1%	31.3%	6.5%	19.4%
	12	47.8%	38.7%	20.1%	35.0%
	15	58.0%	58.2%	46.9%	54.3%
	18	63.0%	68.2%	56.6%	62.7%
	21	60.1%	58.3%	39.8%	53.3%

an Angelo		June	July	August	All
ir	0	74.1	77.3	76.5	76.0
mperature	3	71.3	74.2	73.8	73.1
	6	69.3	71.9	71.4	70.9
	9	77.3	80.6	79.4	79.1
	12	84.9	89.1	88.5	87.5
	15	89.3	92.7	92.4	91.5
	18	87.9	91.7	90.1	89.9
	21	79.2	82.8	81.1	81.0
ew point	0	64.0	62.6	62.9	63.1
mperature	3	64.2	63.9	63.8	64.0
	6	64.3	64.8	64.8	64.6
	9	66.1	66.4	66.7	66.4
	12	65.1	63.4	64.0	64.2
	15	63.2	60.6	60.9	61.6
	18	62.3	59.6	60.4	60.7
	21	63.1	61.0	61.8	62.0
/ind speed	0	8.8	7.9	7.1	7.9
	3	8.8	8.2	7.3	8.1
	6	7.9	7.5	6.8	7.4
	9	11.9	11.4	10.1	11.1
	12	12.2	11.5	10.6	11.4
	15	12.0	11.7	10.6	11.4
	18	11.8	11.5	10.7	11.3
	21	9.2	8.7	7.8	8.6
tesultant	0	151	157	154	154
Vind	3	158	168	166	164
lirection	6	161	172	171	168
	9	170	178	177	175
	12	168	169	163	167
	15	151	154	142	150
	18	139	142	131	138
	21	136	142	133	137
Resultant	0	5.7	6.2	4.9	5.6
Wind speed	3	5.7	6.7	5.3	5.9
	6	4.3	5.7	4.3	4.8
	9	8.2	9.1	7.1	8.1
	12	7.6	8.0	6.4	7.3
	15	7.1	7.7	5.6	6.8
	18	7.7	8.0	7.0	7.5
	21	6.3	6.7	5.6	6.2
Constancy	0	64.7%	78.8%	69.3%	70.8%
	3	65.2%	82.3%	72.8%	73.1%
	6	55.2%	76.5%	64.0%	64.9%
	9	69.0%	80.3%	69.9%	73.0%
	12	62.2%	70.0%	60.5%	64.3%
	15	58.8%	66.4%	52.8%	59.4%
	18	65.4%	69.8%	65.2%	66.6%
	21	67.9%	76.4%	71.5%	71.8%

San Antonio		June	July	August	All
Air	0	76.6	79.3	79.4	78.5
temperature	3	74.6	76.7	76.8	76.1
	6	73.5	75.7	75.4	74.9
	9	79.7	81.7	82.0	81.1
	12	86.3	89.2	90.0	88.5
	15	89.8	93.2	93.7	92.2
	18	88.2	91.6	91.6	90.5
	21	81.4	84.3	84.2	83.3
Dew point	0	69.8	70.2	70.0	70.0
temperature	3	70.0	71.3	71.1	70.8
	6	69.8	71.6	71.1	70.8
	9	70.0	71.1	71.3	70.8
	12	68.8	68.6	68.2	68.6
	15	67.6	66.1	65.8	66.5
	18	67.0	65.6	65.2	65.9
	21	68.8	68.3	68.0	68.4
Wind speed	0	8.0	8.5	7.4	8.0
	3	7.0	7.2	6.0	6.7
	6	6.7	6.3	5.5	6.2
	9	8.8	8.6	7.9	8.4
	12	9.2	8.9	8.5	8.9
	15	10.1	10.0	9.5	9.9
	18	10.4	10.7	10.3	10.5
	21	9.5	10.2	9.5	9.7
Resultant	0	138	149	146	145
Wind	3	148	160	158	156
direction	6	149	166	159	159
	9	160	175	172	169
	12	147	159	152	153
	15	138	144	139	140
	18	129	135	127	131
	21	128	135	133	132
Resultant	0	5.8	7.3	5.8	6.3
Wind speed	3	4.2	5.8	3.7	4.5
	6	3.3	4.3	2.4	3.3
	9	5.2	6.4	4.5	5.4
	12	5.7	6.7	5.4	5.9
	15	6.6	7.5	6.6	6.9
	18	7.9	8.9	8.2	8.3
	21	7.8	9.1	7.9	8.2
Constancy	0	71.8%	86.3%	77.7%	78.5%
	3	60.1%	80.4%	61.8%	67.5%
	6	48.8%	68.0%	44.0%	53.5%
	9	59.8%	74.7%	57.2%	63.7%
	12	62.5%	75.2%	64.0%	67.0%
	15	65.4%	75.4%	69.4%	70.0%
	18	75.7%	83.3%	79.5%	79.4%
	21	81.8%	89.8%	83.0%	84.9%

ictoria		June	July	August	All
ir	0	76.6	78.3	78.2	77.7
ımperature	3	75.3	77.0	76.8	76.4
	6	74.2	75.9	75.6	75.2
	9	82.6	84.8	84.1	83.9
	12	87.4	90.3	89.7	89.2
	15	88.6	91.8	91.4	90.6
	18	85.3	88.1	87.8	87.1
	21	78.6	80.7	80.6	80.0
lew point	0	73.1	74.4	74.4	74.0
əmperature	3	72.7	74.4	74.3	73.8
	6	72.1	73.8	73.6	73.2
	9	73.3	74.4	74.8	74.2
	12	71.7	71.1	71.8	71.5
	15	71.7	70.5	71.0	71.0
	18	72.1	71.7	72.2	72.0
	21	73.2	74.2	74.2	73.9
Vind speed	0	7.2	6.7	6.2	6.7
	3	6.5	5.5	5.3	5.8
	6	5.8	4.8	4.7	5.1
	9	10.4	9.8	9.0	9.7
	12	10.9	10.2	9.6	10.3
	15	12.6	12.6	11.7	12.3
	18	13.1	13.6	13.2	13.3
	21	8.5	8.5	8.2	8.4
Resultant	0	146	158	148	151
Vind	3	143	169	151	155
direction	6	105	114	57	91
	9	167	191	176	179
	12	160	173	160	165
	15	152	156	149	153
	18	147	155	152	151
	21	142	150	148	147
Resultant	0	4.7	5.2	4.0	4.6
Wind speed	3	3.1	3.2	1.9	2.7
	6	2.0	1.3	1.8	1.5
	9	5.7	6.3	3.5	5.1
	12	6.8	6.7	4.7	6.0
	15	9.1	9.6	8.0	8.9
	18	10.2	11.7	10.9	10.9
	21	6.5	7.5	6.6	6.9
Constancy	0	65.8%	77.8%	65.0%	69.3%
	3	47.4%	57.9%	35.2%	46.1%
	6	34.1%	27.7%	37.9%	30.3%
	9	54.9%	63.7%	39.1%	52.1%
	12	62.2%	65.3%	48.7%	58.7%
	15	72.2%	75.9%	68.1%	72.1%
	18	77.9%	86.0%	82.8%	82.1%
	21	77.1%	88.2%	80.3%	81.8%

Waco		June	July	August	All
Air	0	75.7	80.1	79.6	78.5
temperature	3	73.2	76.9	76.6	75.6
	6	72.3	75.1	74.4	73.9
	9	80.4	84.4	83.5	82.8
	12	87.5	92.4	91.9	90.6
	15	90.2	95.2	95.0	93.5
	18	87.5	92.1	91.7	90.4
	21	79.4	83.9	83.3	82.3
Dew point	0	69.2	69.8	68.9	69.3
temperature	3	68.9	70.2	69.4	69.5
	6	68.8	70.5	69.6	69.7
	9	70.2	70.9	70.7	70.6
	12	69.4	68.9	68.4	68.9
	15	68.7	67.3	66.2	67.4
	18	68.1	67.1	65.9	67.0
	21	69.1	68.7	68.0	68.6
Wind speed	0	9.4	10.4	9.6	9.8
	3	8.7	9.4	8.6	8.9
	6	8.0	8.1	7.5	7.9
	9	10.1	10.4	9.9	10.1
	12	11.0	11.0	10.3	10.7
	15	11.7	11.8	10.8	11.4
	18	11.5	11.9	11.5	11.6
	21	9.0	10.2	8.9	9.4
Resultant	0	168	171	166	169
Wind	3	178	184	184	182
direction	6	175	181	179	179
	9	176	193	193	188
	12	170	174	170	172
	15	159	166	158	161
	18	148	153	139	147
	21	146	148	141	146
Resultant	0	6.7	8.8	7.2	7.5
Wind speed	3	5.7	8.0	6.5	6.7
	6	4.6	6.4	4.9	5.3
	9	6.1	7.8	6.2	6.6
	12	6.8	8.4	6.9	7.4
	15	7.1	8.4	6.6	7.3
	18	7.5	8.8	7.2	7.8
	21	6.4	8.3	6.6	7.1
Constancy	0	70.7%	84.7%	74.7%	76.9%
	3	65.4%	84.6%	76.0%	75.5%
	6	57.2%	78.5%	64.7%	66.8%
	9	60.2%	75.1%	62.3%	65.4%
	12	62.1%	76.9%	67.0%	68.7%
	15	60.8%	70.9%	61.1%	64.3%
	18	65.4%	74.3%	62.2%	67.1%
	21	71.5%	81.5%	74.3%	75.9%

Appendix B - International Station Meteorological Climate Summaries

ISMCS data provides at three-hour intervals the frequency with which the wind blows from each of the 16 compass directions and the speed from each direction. For each station those wind directions were divided into inland blowing and offshore blowing regimes that would exist if the station was moved to the coast along the normal line from the coast that intersects the station. It varied somewhat among the stations, but generally offshore winds were from the north and west, and inland winds were from the south and east.

Austin	All	0		3		6		9		12		15		18		21		All	
	N	1.6	6.4	1.5	5.8	2.6	5.6	1.8	7.6	2.2	8.1	1.7	8.6	1.1	9.2	1.5	7.3	1.7	7.2
	NNE	2.5	7.2	2.5	6.1	3.6	6.6	2.3	8.6	2.6	9.3	2.4	10.6	1.9	10.5	1.6	7.6	2.4	8.2
	NE	2.7	6.1	2.9	6.1	3.6	5.4	3.3	8.5	3.4	9.1	4.0	10.2	3.6	9.8	3.4	7.5	3.4	7.9
	ENE	2.1	5.5	1.7	4.9	2.2	4.9	2.5	6.8	3.3	8.0	4.3	9.0	3.2	9.5	3.0	6.5	2.8	7.3
	E	2.1	4.8	1.8	3.8	2.3	3.8	2.6	5.5	4.0	6.8	4.9	7.5	5.7	8.4	5.5	5.8	3.6	6.3
	ESE	3.1	5.0	2.2	4.4	3.3	4.4	2.9	6.0	4.5	6.6	7.2	8.2	9.6	8.8	8.5	6.1	5.2	6.8
	SE	7.5	5.6	5.3	4.8	7.1	4.5	4.5	6.5	8.4	7.5	14.2	8.7	21.1	8.9	21.1	6.6	11.2	7.2
	SSE	22.7	7.0	12.5	5.8	11.9	5.1	8.9	7.7	14.8	8.8	21.6	9.6	27.5	9.5	30.5	8.4	18.8	8.1
	S	36.6	7.5	31.5	6.3	24.9	5.6	23.6	9.2	28.5	9.5	24.0	9.6	19.9	9.0	16.5	7.7	25.7	8.0
	SSW	8.0	6.6	14.9	6.3	11.5	5.6	22.1	9.2	16.7	9.6	9.1	9.1	3.2	8.8	2.4	6.0	11.0	8.0
	SW	1.8	5.4	5.5	5.6	4.3	5.2	12.4	8.4	5.7	8.9	2.6	8.8	0.8	6.6	0.6	5.5	4.2	7.3
	WSW	0.7	4.4	1.4	4.8	1.1	4.5	3.8	6.4	1.5	6.4	1.0	6.3	0.3	7.2	0.3	5.0	1.2	5.8
	W	0.8	4.0	1.2	3.9	1.7	4.0	2.5	4.9	0.9	5.2	0.8	6.6	0.5	5.7	0.7	4.3	1.1	4.7
	WNW	0.6	7.3	1.3	6.3	1.5	5.2	1.7	6.7	0.7	6.9	0.5	8.1	0.4	6.8	0.5	5.9	0.9	6.2
	NW	0.8	5.4	1.6	5.5	2.3	5.9	1.4	7.1	0.7	9.1	0.5	9.2	0.3	8.6	0.6	7.0	1.1	6.6
	NNW	0.6	6.6	1.2	5.5	1.3	6.2	1.0	7.1	0.7	8.4	0.7	9.7	0.4	10.6	0.4	7.8	0.8	7.2
	Calm	5.9	0.0	10.8	0.0	14.8	0.0	2.4	0.0	1.3	0.0	0.8	0.0	0.7	0.0	3.0	0.0	5.0	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		83.9	6.9	75.4	5.9	67.6	5.2	79.7	8.4	86.0	8.8	88.0	9.1	91.0	9.0	88.1	7.3	82.5	7.7
Offshore		10.2	6.2	13.7	5.5	17.7	5.6	17.8	7.1	12.7	8.2	11.6	9.3	8.7	9.4	9.0	7.0	12.7	7.1
Calm		5.9		10.8		14.8		2.4		1.3		0.8		0.7		3.0		5.0	

Brownsville	All	0		3		6		9		12		15		18		21		All	
	N	0.4	3.0	1.3	3.8	3.0	3.8	2.5	5.8	1.1	7.7	0.6	8.4	0.3	5.3	0.4	4.4	1.2	5.2
	NNE	0.5	4.5	0.5	5.4	1.6	4.2	1.6	7.3	2.0	8.7	1.1	9.9	0.5	8.5	0.6	5.5	1.0	7.0
	NE	1.0	4.8	0.8	5.0	2.4	4.5	2.1	6.8	3.1	10.4	3.5	12.7	2.2	12.0	1.5	6.5	2.1	8.7
	ENE	2.0	5.0	1.5	4.9	2.8	4.3	1.8	6.9	3.6	9.7	4.1	11.7	4.3	11.0	4.1	5.6	3.0	8.0
	E	3.6	4.7	2.6	4.1	4.1	4.3	3.0	7.5	5.5	10.2	8.1	12.3	8.3	11.6	7.3	6.0	5.4	8.6
	ESE	10.4	5.6	5.7	4.9	9.7	4.9	5.4	9.0	8.0	11.2	14.3	13.5	21.6	13.2	22.0	7.7	12.1	9.5
	SE	33.6	7.5	22.6	6.0	23.3	5.8	17.0	11.2	24.5	13.3	35.2	14.9	40.8	14.7	44.2	9.4	30.1	10.7
	SSE	32.0	8.3	32.6	7.2	23.1	6.6	32.6	12.5	31.4	14.2	26.8	15.5	19.8	15.2	17.1	10.0	27.0	11.1
	S	7.4	6.7	12.7	6.3	7.3	6.3	23.1	11.6	14.4	13.1	4.8	13.8	1.1	10.2	1.6	6.3	9.1	9.9
	SSW	0.7	6.0	1.2	5.2	0.8	6.7	4.7	9.5	2.7	10.5	0.3	13.6	0.0	0.0	0.2	4.8	1.3	8.9
	SW	0.3	4.4	0.6	5.9	0.7	4.8	1.1	6.8	0.7	8.9	0.1	7.6	0.1	4.2	0.1	5.7	0.5	6.5
	WSW	0.3	5.6	0.7	4.8	0.4	4.3	0.5	6.6	0.5	7.4	0.2	7.6	0.1	4.7	0.1	5.0	0.3	5.9
	W	0.3	3.3	0.4	5.4	0.5	3.7	0.5	4.6	0.5	6.0	0.2	5.1	0.1	2.7	0.1	2.6	0.3	4.7
	WNW	0.3	4.8	0.9	4.3	0.7	4.6	0.6	6.2	0.5	6.9	0.2	8.8	0.1	5.1	0.0	2.1	0.4	5.4
	NW	0.7	5.2	2.0	4.9	2.4	5.3	1.4	6.6	0.6	9.2	0.2	11.1	0.2	2.6	0.2	3.6	1.0	5.9
	NNW	0.5	5.2	1.9	4.4	3.7	4.5	1.5	7.7	0.8	8.4	0.4	6.2	0.1	2.4	0.2	5.3	1.1	5.6
	Calm	6.8	0.0	12.8	0.0	13.8	0.0	1.1	0.0	0.4	0.0	0.2	0.0	0.1	0.0	1.3	0.0	4.6	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		89.8	7.3	79.5	6.3	71.8	5.8	88.6	11.3	90.9	13.0	93.8	14.4	97.0	13.9	96.7	8.6	88.5	10.3
Offshore		4.1	4.7	8.5	4.6	14.7	4.4	10.6	6.6	9.2	8.8	6.5	10.8	3.5	9.8	3.1	5.6	7.5	6.6
Calm		6.8		12.8		13.8		1.1		0.4		0.2		0.1		1.3		4.6	

Corpus Christi	All	0		3		6		9		12		15		18		21		All	
	N	0.6	5.5	2.0	5.8	4.2	5.8	2.7	6.9	1.4	6.5	0.8	7.4	0.5	9.4	0.4	5.3	1.6	6.3
	NNE	0.8	7.3	1.0	7.0	3.0	6.9	4.2	8.4	2.4	9.1	0.6	12.1	0.5	8.2	0.6	7.7	1.6	8.2
	NE	0.7	6.5	1.0	7.9	1.8	7.2	3.6	9.2	3.3	9.4	1.3	10.8	0.8	11.8	0.8	9.2	1.7	9.0
	ENE	0.8	7.4	0.7	7.2	1.6	5.9	2.3	8.2	4.9	10.2	3.1	11.9	1.5	12.1	1.1	8.1	2.0	9.6
	E	2.1	6.2	2.4	5.2	3.9	4.6	3.0	7.9	11.0	10.9	14.5	12.6	8.9	11.7	4.3	8.1	6.2	10.1
	ESE	8.8	6.6	5.1	5.4	8.6	5.0	4.7	8.6	12.1	11.3	24.2	13.5	23.7	13.4	16.0	8.6	12.9	10.6
	SE	30.9	7.5	16.7	6.2	17.1	5.7	11.4	10.7	23.0	13.0	35.6	14.8	46.3	14.8	45.7	9.8	28.3	11.1
	SSE	35.8	8.7	28.6	7.6	21.4	7.0	26.6	12.5	28.2	13.8	17.9	15.8	16.5	15.8	27.4	10.7	25.3	11.1
	S	12.6	7.5	19.7	6.8	12.3	6.3	23.5	11.6	8.5	11.2	1.4	12.8	0.9	11.7	2.5	8.1	10.1	8.9
	SSW	1.7	6.5	4.9	5.8	2.6	6.1	8.9	10.1	2.0	10.2	0.4	10.8	0.1	11.7	0.4	6.2	2.6	8.3
	SW	0.6	6.1	1.8	5.2	1.4	4.7	2.6	7.4	0.8	9.2	0.2	9.6	0.1	3.9	0.1	1.8	1.0	6.5
	WSW	0.4	4.8	1.2	4.9	0.9	4.7	1.4	6.8	0.5	6.5	0.1	4.3	0.0	2.9	0.1	4.5	0.6	5.7
	W	0.2	4.1	1.4	4.0	0.9	3.6	1.4	4.9	0.6	5.3	0.2	5.2	0.1	4.8	0.1	2.8	0.6	4.4
	WNW	0.4	3.8	1.3	5.0	1.8	4.4	1.0	6.3	0.3	7.7	0.3	8.2	0.1	5.1	0.2	4.6	0.7	5.2
	NW	0.4	6.2	1.2	5.4	2.2	5.0	0.9	7.5	0.6	8.4	0.2	7.4	0.2	7.6	0.2	3.9	0.7	6.1
	NNW	0.4	6.1	1.1	5.7	2.5	6.0	1.2	7.3	0.5	9.2	0.4	10.1	0.2	8.5	0.1	5.0	0.8	6.8
	Calm	3.4	0.0	10.4	0.0	14.3	0.0	1.5	0.0	0.4	0.0	0.2	0.0	0.1	0.0	0.6	0.0	3.9	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		93.3	7.8	79.9	6.7	68.9	6.0	82.9	11.1	90.5	12.4	97.2	14.2	97.9	14.3	97.6	9.7	88.4	10.5
Offshore		3.9	5.8	10.2	5.6	17.2	5.7	16.4	7.6	9.7	8.4	3.7	9.4	2.5	9.1	2.5	6.9	8.2	7.0
Calm		3.4		10.4		14.3		1.5		0.4		0.2		0.1		0.6		3.9	

Del Rio	All	0		3		6		9		12		15		18		21		All	
	N	1.0	4.3	0.7	5.3	0.7	4.3	0.8	5.8	1.0	6.1	1.0	6.6	1.0	8.9	0.6	7.8	0.9	6.1
	NNE	0.6	7.8	0.4	6.1	0.8	6.7	0.4	7.4	0.6	6.1	0.6	10.5	0.6	10.8	0.7	7.4	0.6	7.8
	NE	1.8	6.9	1.7	6.0	2.8	6.0	0.7	10.8	1.0	6.7	1.5	8.7	1.1	12.8	2.0	9.4	1.6	7.7
	ENE	2.9	6.9	4.6	6.0	7.9	6.0	1.5	7.8	1.1	8.7	2.0	7.6	2.1	10.1	4.4	7.4	3.3	7.1
	E	12.7	8.0	16.4	7.0	31.0	7.4	8.2	8.3	5.6	7.8	6.4	8.6	7.9	9.7	17.1	7.9	13.1	7.8
	ESE	43.5	10.2	44.7	8.9	40.1	8.5	29.0	9.8	20.8	10.0	20.9	10.3	21.5	11.0	36.8	8.9	31.8	9.5
	SE	30.4	10.4	26.2	9.3	12.8	9.3	44.2	10.0	40.2	10.9	37.2	11.3	39.0	11.1	28.7	8.2	32.5	10.3
	SSE	3.6	9.1	1.9	7.7	1.0	6.5	12.0	8.5	21.2	10.2	22.4	11.2	20.5	10.4	4.5	6.8	11.1	10.0
	S	0.5	4.6	0.4	5.8	0.1	1.7	1.2	6.0	5.1	7.9	5.3	8.7	3.2	7.9	0.9	5.4	2.1	7.7
	SSW	0.2	3.7	0.0	0.0	0.1	3.7	0.1	5.0	0.7	7.3	0.6	7.0	0.7	7.3	0.3	4.4	0.3	6.8
	SW	0.2	3.2	0.2	4.7	0.0	2.0	0.2	5.0	0.1	1.3	0.3	4.4	0.5	5.7	0.4	5.7	0.3	4.9
	WSW	0.2	4.3	0.1	6.4	0.1	2.6	0.1	2.0	0.2	3.8	0.1	1.3	0.2	2.2	0.2	3.9	0.1	6.1
	W	0.1	2.0	0.3	4.4	0.2	2.7	0.2	3.2	0.5	5.4	0.2	4.5	0.3	4.1	0.6	5.9	0.3	5.0
	WNW	0.4	5.6	0.3	8.8	0.3	3.4	0.3	4.8	0.4	4.8	0.5	10.8	0.4	6.4	0.5	8.7	0.4	7.2
	NW	0.3	6.1	0.4	5.0	0.6	3.3	0.4	6.7	1.1	7.8	0.9	7.2	0.7	8.7	0.8	7.2	0.7	7.0
	NNW	0.2	10.0	0.3	3.8	0.4	3.2	0.4	4.8	0.5	9.7	0.6	6.2	0.5	13.0	0.5	6.0	0.4	8.1
	Calm	1.5	0.0	1.7	0.0	1.5	0.0	0.9	0.0	0.6	0.0	0.5	0.0	0.4	0.0	1.8	0.0	1.1	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		94.1	9.8	94.5	8.5	93.0	8.0	96.4	9.5	94.9	10.1	95.2	10.6	95.4	10.6	93.2	8.3	94.6	9.4
Offshore		4.7	6.2	4.1	5.7	5.9	5.1	3.3	6.7	5.3	6.7	5.4	7.8	4.8	9.5	5.9	7.8	5.0	7.1
Calm		1.5		1.7		1.5		0.9		0.6		0.5		0.4		1.8		1.1	

DFW	All	0		3		6		9		12		15		18		21		All	
	N	2.9	7.0	3.6	6.6	4.2	6.2	2.3	6.9	3.5	8.1	3.5	8.3	3.0	9.6	2.3	6.4	3.2	7.3
	NNE	2.9	7.0	3.1	7.3	3.4	6.3	2.9	8.4	2.9	9.2	3.1	9.9	3.4	9.3	2.8	7.5	3.1	8.1
	NE	2.3	7.0	2.1	6.3	2.6	6.5	2.3	9.1	3.2	8.4	3.5	8.8	3.0	9.3	2.7	7.3	2.7	7.9
	ENE	2.1	6.5	2.2	6.4	2.5	6.7	3.1	7.2	3.1	8.5	4.5	8.9	4.2	9.4	3.4	7.3	3.1	7.9
	E	3.4	6.0	3.0	5.6	3.8	5.7	3.5	6.4	4.3	7.5	5.4	8.3	6.1	8.4	5.4	6.7	4.4	7.0
	ESE	7.8	7.1	4.5	6.3	4.9	5.8	4.4	7.6	5.1	8.5	7.7	9.3	11.1	9.2	11.7	7.8	7.1	7.9
	SE	12.0	7.2	6.5	6.3	6.6	6.0	4.7	8.0	6.5	8.6	9.2	9.4	13.5	10.0	20.9	7.9	10.0	8.0
	SSE	18.3	8.3	10.5	7.2	9.9	7.1	6.1	8.4	10.4	9.4	15.1	10.4	18.9	10.9	25.5	8.7	14.3	9.0
	S	29.9	9.3	29.3	8.9	28.3	8.2	18.9	10.5	21.3	11.1	23.0	11.6	23.2	11.3	15.9	9.1	23.7	10.0
	SSW	9.3	7.9	19.3	8.4	16.8	7.9	26.5	10.9	20.1	10.8	13.6	10.8	7.4	10.2	2.8	8.4	14.5	9.7
	SW	1.3	8.3	3.2	7.1	3.1	7.4	13.0	9.3	8.9	9.5	4.1	9.6	1.7	8.0	0.8	8.4	4.5	9.0
	WSW	0.9	6.0	1.5	6.3	1.0	6.0	4.7	7.9	3.6	7.4	1.7	7.8	0.8	6.4	0.7	6.3	1.9	7.3
	W	0.6	5.4	0.9	5.3	0.9	6.4	2.1	6.9	1.8	6.6	1.0	6.6	0.7	6.7	0.4	4.3	1.0	6.3
	WNW	0.3	8.3	0.5	7.9	0.4	6.9	1.2	7.3	1.1	8.3	1.0	8.7	0.5	10.1	0.3	8.3	0.7	8.0
	NW	0.6	9.9	0.8	6.7	0.7	7.3	0.8	9.2	1.1	8.5	1.2	8.8	0.7	10.2	0.5	8.2	0.8	8.5
	NNW	1.2	7.1	1.9	7.4	2.3	7.3	1.2	9.8	1.8	10.4	1.7	10.8	1.2	6.0	1.0	8.1	1.5	8.8
	Calm	4.8	0.0	7.2	0.0	8.4	0.0	2.5	0.0	1.6	0.0	1.0	0.0	1.3	0.0	3.7	0.0	3.8	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		83.9	8.2	78.5	7.9	75.9	7.4	80.2	9.7	79.7	9.9	82.7	10.3	86.0	10.3	86.5	8.3	81.7	9.0
Offshore		11.6	7.0	14.3	6.7	15.5	6.5	17.5	8.0	19.1	8.3	16.6	8.8	13.4	8.9	10.6	7.1	14.8	7.8
Calm		4.8		7.2		8.4		2.5		1.6		1.0		1.3		3.7		3.8	

Houston	All	0		3		6		9		12		15		18		21		All	
	N	2.8	4.1	4.0	4.1	5.7	4.1	3.3	5.4	3.4	5.6	3.1	6.6	2.7	5.4	2.5	4.4	3.4	4.9
	NNE	2.8	4.7	4.0	4.5	7.3	4.2	4.0	6.1	3.2	6.9	3.0	7.0	3.3	6.5	2.8	5.3	3.8	5.5
	NE	4.5	5.2	6.6	4.6	10.8	4.5	4.8	6.9	3.8	7.6	3.8	7.9	3.6	7.6	3.4	5.8	5.1	5.8
	ENE	5.8	4.7	5.2	5.0	8.5	4.6	7.4	7.0	5.5	8.3	5.7	7.5	4.5	7.5	5.0	5.4	6.0	6.1
	E	4.8	5.7	3.3	4.2	3.7	4.8	6.9	6.5	7.0	7.4	7.1	8.2	5.6	7.5	6.0	6.0	5.6	6.6
	ESE	3.6	6.0	2.1	6.0	2.4	5.4	5.4	6.8	8.3	8.0	13.5	9.4	16.1	8.9	10.5	6.5	7.7	7.9
	SE	8.2	6.3	3.7	6.2	3.2	6.0	5.2	7.4	9.5	8.5	15.7	9.5	24.7	9.1	17.3	6.9	10.9	8.1
	SSE	9.5	5.9	4.9	6.2	5.0	5.6	5.9	8.4	8.7	8.1	11.4	9.3	12.6	9.7	16.5	7.1	9.3	7.8
	S	14.6	5.5	8.2	5.7	5.1	5.2	10.6	8.1	11.4	8.4	11.2	8.6	12.6	9.2	19.6	6.9	11.7	7.3
	SSW	11.5	5.4	6.5	5.1	4.0	4.9	10.3	8.2	9.2	7.7	7.2	7.9	4.2	8.6	5.4	7.2	7.3	6.9
	SW	6.2	5.1	5.7	5.1	3.3	5.3	9.8	8.1	8.8	7.6	4.6	7.9	2.7	6.8	3.4	5.8	5.3	6.8
	WSW	2.2	4.4	3.3	4.5	3.0	5.1	9.0	7.8	7.7	6.9	4.8	6.5	1.9	6.4	0.8	5.8	4.1	6.5
	W	1.8	4.1	3.2	3.8	3.2	4.1	6.2	6.5	4.6	6.1	2.6	5.3	1.5	4.6	0.6	3.5	3.0	5.3
	WNW	2.0	4.4	2.7	4.2	2.1	4.3	4.4	6.9	3.3	6.3	1.9	7.0	1.2	6.8	1.1	4.5	2.3	5.7
	NW	1.4	4.2	3.3	4.0	2.2	4.8	3.0	6.2	2.0	7.7	2.0	6.7	0.8	7.1	0.9	5.0	2.0	5.6
	NNW	1.9	4.0	1.9	4.2	2.3	5.2	2.3	6.5	2.5	7.1	1.9	6.9	1.3	6.3	1.3	4.3	1.9	5.6
	Calm	15.6	0.0	30.6	0.0	28.2	0.0	2.3	0.0	1.4	0.0	1.3	0.0	1.3	0.0	5.1	0.0	10.7	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		64.2	5.6	39.6	5.4	35.2	5.1	61.5	7.7	68.5	8.0	76.4	8.8	83.0	8.9	83.6	6.7	63.7	7.3
Offshore		19.5	4.5	29.1	4.3	36.6	4.4	36.9	6.7	30.6	6.7	23.0	6.8	16.3	6.4	13.4	5.0	25.6	5.6
Calm		15.6		30.6		28.2		2.3		1.4		1.3		1.3		5.1		10.7	

Port Arthur	All	0		3		6		9		12		15		18		21		All	
	N	3.5	4.8	6.0	4.8	8.7	4.7	4.2	6.3	3.1	6.3	2.4	6.8	2.6	6.9	2.7	5.2	4.2	5.5
	NNE	3.7	5.7	5.9	5.5	10.1	5.3	4.7	7.4	3.5	7.5	2.5	9.2	2.5	8.4	3.5	6.5	4.5	6.4
	NE	4.6	6.0	6.4	5.8	10.2	5.5	7.0	7.9	4.8	8.3	3.1	8.7	3.3	8.1	3.3	6.5	5.3	6.8
	ENE	4.2	6.9	4.4	5.8	6.1	5.7	7.0	7.7	4.7	8.4	3.3	7.7	2.3	8.7	3.4	6.6	4.4	7.0
	E	4.6	5.4	3.1	5.3	3.3	5.3	6.7	7.6	7.0	8.1	4.8	8.2	3.4	8.0	4.7	6.0	4.7	6.9
	ESE	3.5	6.3	1.7	6.7	2.0	6.7	4.0	7.7	6.9	8.4	6.9	9.2	5.4	8.2	5.2	5.9	4.5	7.6
	SE	4.4	6.6	3.0	6.5	2.7	6.6	3.3	8.6	7.1	9.0	10.8	9.6	8.9	8.5	6.9	6.5	5.9	8.1
	SSE	11.2	6.4	7.3	6.5	5.6	6.0	4.7	9.7	7.0	9.3	10.3	9.9	10.3	8.9	12.7	6.1	8.7	7.7
	S	17.2	5.7	12.9	5.5	8.3	5.5	10.2	9.0	13.1	9.9	19.2	10.3	29.1	9.2	23.3	5.6	16.7	7.8
	SSW	10.1	5.3	7.4	5.2	4.3	5.3	8.9	9.0	9.8	10.0	15.7	10.6	19.8	9.3	13.9	5.5	11.2	8.1
	SW	8.3	5.1	7.1	5.0	4.0	5.0	8.8	8.3	8.8	9.1	8.1	9.3	5.2	8.6	7.7	5.4	7.3	7.1
	WSW	4.3	4.8	5.0	4.6	3.3	4.7	7.8	7.7	6.8	7.7	4.2	7.3	1.7	6.8	2.7	4.9	4.5	6.3
	W	2.7	4.1	4.3	4.5	4.0	4.4	7.5	7.3	6.4	7.0	2.9	7.0	1.2	5.0	1.8	4.2	3.9	5.9
	WNW	2.0	4.1	3.1	4.6	4.4	4.6	6.1	7.4	4.4	7.1	2.1	7.6	1.0	7.2	1.2	5.3	3.0	6.1
	NW	1.5	5.4	3.0	5.3	4.1	5.1	5.1	7.4	3.2	7.3	1.5	8.7	1.2	7.1	1.2	5.1	2.6	6.4
	NNW	1.7	5.2	3.2	4.7	4.7	4.6	2.8	7.0	3.4	7.0	1.5	8.4	1.1	8.7	1.2	5.8	2.3	6.0
	Calm	12.3	0.0	16.1	0.0	14.4	0.0	1.3	0.0	0.9	0.0	0.8	0.0	1.0	0.0	4.8	0.0	6.5	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		63.5	5.8	46.9	5.6	36.2	5.6	53.6	8.5	64.3	9.2	79.1	9.8	84.3	8.9	77.7	5.8	63.2	7.6
Offshore		24.1	5.1	36.9	5.0	49.3	5.0	45.1	7.4	35.7	7.3	20.2	7.9	14.6	7.4	17.6	5.6	30.3	6.2
Calm		12.3		16.1		14.4		1.3		0.9		0.8		1.0		4.8		6.5	

San Angelo	All	0		3		6		9		12		15		18		21		All	
	N	0.9	6.4	1.1	6.3	1.6	6.9	1.4	7.8	2.3	6.7	2.4	8.5	1.5	9.1	0.8	8.0	1.5	7.6
	NNE	1.6	8.0	1.6	6.7	1.9	6.7	1.9	9.1	2.9	9.0	2.9	10.4	2.1	10.7	1.6	9.1	2.1	9.0
	NE	3.5	7.8	4.1	6.7	3.6	7.3	3.2	9.1	4.6	9.2	5.6	9.6	4.5	10.4	3.3	8.9	4.0	8.8
	ENE	3.7	6.4	2.9	6.7	4.1	6.1	3.3	8.1	4.7	8.7	6.1	10.0	6.9	9.4	4.6	8.0	4.5	8.3
	E	3.2	6.8	2.7	5.7	3.2	5.1	2.8	7.4	3.8	7.6	5.9	8.9	8.0	9.4	6.0	7.2	4.5	7.6
	ESE	4.0	6.6	2.3	6.1	2.7	5.7	2.0	7.1	3.5	8.4	6.8	9.5	9.3	10.3	9.8	7.4	5.1	8.3
	SE	13.0	7.2	6.2	7.3	4.4	6.6	3.6	8.0	7.6	8.9	11.6	9.9	16.6	10.7	21.5	7.8	10.6	8.6
	SSE	24.7	8.3	19.2	9.1	12.8	8.2	13.7	10.5	15.5	10.8	17.3	10.9	19.2	11.2	23.7	8.5	18.2	9.6
	S	25.2	8.4	28.6	9.4	25.8	8.8	31.0	11.4	29.0	11.5	23.0	11.5	20.6	11.2	18.3	8.3	25.2	10.1
	SSW	8.8	7.5	11.4	8.0	14.5	8.0	19.0	11.2	13.1	11.3	9.3	11.0	6.1	10.8	4.9	8.4	10.9	9.7
	SW	2.4	7.1	3.4	6.5	5.4	6.9	7.9	10.2	4.4	10.5	2.8	10.3	1.5	10.2	1.2	8.2	3.6	8.9
	WSW	0.7	6.7	2.4	5.9	2.6	5.6	2.9	7.4	2.1	8.3	1.3	8.9	0.6	8.5	0.5	7.0	1.6	7.1
	W	0.8	5.9	1.0	4.6	1.3	4.7	1.6	5.5	1.6	6.1	0.9	6.5	0.7	7.1	0.4	6.1	1.1	5.7
	WNW	0.4	6.4	0.7	6.6	1.0	5.2	1.1	6.1	0.7	7.6	0.6	8.0	0.5	7.9	0.3	9.8	0.6	6.8
	NW	0.6	7.7	1.0	6.9	0.4	6.5	0.6	6.9	1.0	7.7	0.8	7.7	0.3	10.7	0.4	6.4	0.6	7.5
	NNW	0.4	8.5	0.4	6.4	0.5	7.5	0.6	9.8	1.3	7.2	1.3	8.2	0.6	11.3	0.5	11.5	0.7	8.3
	Calm	6.1	0.0	11.0	0.0	14.4	0.0	3.6	0.0	2.0	0.0	1.6	0.0	1.1	0.0	2.6	0.0	5.3	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		85.0	7.8	76.8	8.5	72.9	7.8	83.4	10.6	81.6	10.6	82.7	10.6	88.3	10.6	90.1	8.0	82.6	9.3
Offshore		9.0	7.4	12.3	6.3	12.8	6.4	13.3	7.8	16.5	8.1	15.8	9.1	10.6	9.9	7.7	8.6	12.3	8.0
Calm		6.1		11.0		14.4		3.6		2.0		1.6		1.1		2.6		5.3	

San Antonio	All	0		3		6		9		12		15		18		21		All	
	N	3.3	4.4	4.0	4.2	6.5	4.3	2.2	7.0	1.3	8.1	1.4	8.5	1.4	7.9	2.3	6.1	2.8	5.5
	NNE	2.4	5.7	3.6	5.0	4.9	4.8	2.3	8.2	1.9	9.0	2.0	9.6	1.8	8.8	2.1	6.5	2.6	6.6
	NE	3.1	5.7	3.3	5.5	4.3	5.2	4.3	7.9	3.3	8.4	3.4	9.3	3.0	10.4	3.1	6.7	3.5	7.3
	ENE	2.3	5.5	2.3	5.2	2.1	5.1	3.1	7.4	4.2	8.4	4.0	9.2	3.5	9.4	3.4	7.0	3.1	7.5
	E	4.2	5.6	3.4	4.1	3.6	4.3	3.3	6.5	5.0	7.6	7.5	8.3	8.6	9.2	6.6	6.5	5.3	7.0
	ESE	6.5	6.4	4.3	5.2	4.7	5.4	3.7	6.8	7.2	7.8	10.4	9.1	14.8	10.5	13.8	8.0	8.2	8.1
	SE	25.2	7.7	12.7	6.3	9.0	6.0	8.5	7.9	15.0	8.4	21.8	9.5	33.1	10.8	38.5	10.5	20.5	9.1
	SSE	31.5	8.3	24.5	7.2	17.7	6.9	18.4	9.1	22.5	9.3	24.2	9.9	22.5	10.3	22.3	10.7	23.0	8.9
	S	13.2	7.3	20.5	6.8	17.4	6.8	23.2	8.8	21.2	8.7	15.6	8.9	7.7	8.3	4.2	7.5	15.4	8.0
	SSW	1.5	6.3	4.1	6.2	5.3	6.5	13.4	8.2	8.9	8.2	4.8	8.7	1.2	8.4	0.6	6.0	5.0	7.7
	SW	0.7	5.6	2.5	5.1	2.7	5.5	8.9	7.1	5.1	7.2	1.8	7.6	0.7	7.1	0.2	6.8	2.8	6.7
	WSW	0.4	4.8	0.9	4.5	1.1	4.4	2.9	6.4	1.8	6.2	0.7	6.2	0.3	8.3	0.3	7.3	1.0	5.8
	W	0.3	4.1	0.7	3.5	1.0	3.7	1.9	5.1	0.8	4.7	0.6	4.5	0.3	4.5	0.2	3.2	0.7	4.4
	WNW	0.2	6.0	0.8	4.5	1.2	3.8	1.0	6.2	0.5	6.0	0.3	7.0	0.2	10.4	0.2	3.8	0.5	5.3
	NW	1.5	5.7	3.7	5.0	4.9	5.1	0.7	7.1	0.6	6.6	0.7	7.5	0.5	8.4	0.8	6.3	1.7	5.6
	NNW	1.7	5.1	3.3	4.6	5.7	4.6	0.9	7.4	0.6	9.3	0.6	8.6	0.7	10.5	0.5	7.2	1.7	5.6
	Calm	2.5	0.0	5.9	0.0	7.7	0.0	1.6	0.0	0.6	0.0	0.7	0.0	0.3	0.0	1.5	0.0	2.6	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		85.1	7.5	74.3	6.5	62.5	6.3	82.5	8.3	89.0	8.5	90.1	9.3	92.1	10.1	89.6	9.6	83.1	8.4
Offshore		12.8	5.2	20.1	4.8	29.6	4.7	16.2	7.1	10.8	7.7	9.8	8.5	8.1	9.2	9.4	6.4	14.6	6.1
Calm		2.5		5.9		7.7		1.6		0.6		0.7		0.3		1.5		2.6	

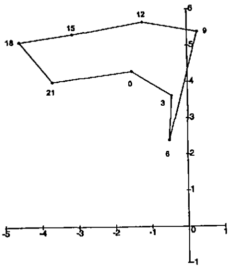
Waco	All	0		3		6		9		12		15		18		21		All	
	N	2.6	6.1	3.1	5.6	4.0	5.9	3.3	7.7	3.4	8.4	3.5	9.0	3.3	9.2	2.2	6.4	3.2	7.4
	NNE	1.5	6.4	1.8	6.2	1.9	6.6	2.7	8.3	2.5	9.3	3.3	9.7	2.6	10.2	1.7	7.0	2.3	8.4
	NE	1.7	6.8	1.6	6.1	1.6	6.4	2.4	8.4	3.4	8.6	4.1	10.2	4.5	10.2	3.1	7.7	2.8	8.7
	ENE	2.5	5.8	1.4	5.8	1.7	5.9	2.1	6.6	2.7	8.0	3.1	8.0	4.0	8.9	3.1	7.0	2.6	7.3
	E	3.7	5.7	1.7	4.6	2.6	5.1	2.5	6.1	2.8	6.8	4.4	8.1	6.3	8.5	6.2	6.3	3.8	6.8
	ESE	4.6	6.9	2.7	6.0	2.8	5.8	2.6	7.4	3.2	7.5	4.6	9.0	7.8	9.3	10.2	7.4	4.8	7.7
	SE	10.1	8.4	5.3	7.4	6.2	6.9	4.2	7.5	7.8	8.2	10.7	9.5	16.1	10.7	21.0	9.3	10.2	9.0
	SSE	24.1	10.9	14.4	9.6	14.1	9.0	10.4	9.4	18.4	10.5	23.3	11.5	26.5	11.9	30.2	10.8	20.2	10.7
	S	33.3	11.2	37.9	10.2	33.6	9.1	30.4	11.2	35.8	11.4	30.1	11.7	21.9	11.7	14.5	9.9	29.7	10.8
	SSW	6.2	8.1	14.9	8.6	12.9	7.9	19.2	10.8	9.6	10.5	5.6	10.0	2.7	9.9	1.8	7.6	9.1	9.4
	SW	1.5	6.9	2.9	6.9	2.5	6.4	8.1	8.9	1.9	9.1	1.5	9.1	0.5	10.4	1.0	6.6	2.6	8.1
	WSW	0.6	6.6	1.0	5.3	0.9	4.7	3.0	7.2	0.8	7.3	0.5	8.2	0.4	7.2	0.4	8.2	0.9	6.8
	W	0.7	4.5	1.2	4.0	1.0	4.3	1.7	5.5	0.9	5.4	0.6	6.8	0.3	6.3	0.5	5.0	0.9	5.3
	WNW	0.5	5.6	0.8	5.3	1.2	5.3	1.1	7.7	1.0	7.1	0.7	9.7	0.3	9.2	0.5	10.3	0.8	7.1
	NW	0.6	6.8	1.2	7.7	2.0	6.1	1.4	8.0	1.1	10.4	0.9	10.5	0.7	10.9	0.5	10.6	1.1	8.3
	NNW	1.7	7.8	2.2	6.2	2.9	7.0	1.7	8.1	1.6	10.3	1.8	10.1	1.2	12.0	1.3	9.1	1.8	8.5
	Calm	4.1	0.0	5.8	0.0	8.0	0.0	3.2	0.0	1.9	0.0	1.4	0.0	1.0	0.0	2.6	0.0	3.5	0.0
		%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed	%	Speed
Inland		86.0	9.9	81.2	9.2	76.5	8.3	79.5	10.0	82.3	10.3	83.2	10.7	85.8	10.9	87.9	9.3	82.8	9.8
Offshore		9.9	6.5	12.6	5.9	15.4	6.0	17.3	7.7	14.7	8.6	15.5	9.6	13.4	9.9	10.2	7.6	13.7	7.8
Calm		4.1		5.8		8.0		3.2		1.9		1.4		1.0		2.6		3.5	

Appendix C - Hodographs

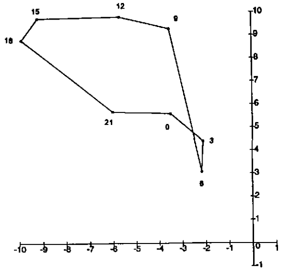
The hodographs in this study all plotted the change in time of the wind at the surface. Hodographs are also often used to plot the wind at changing heights for a fixed time. The curve represents the path of the end (the arrowhead) of the wind vector as it changes with time. A vector drawn beginning at the origin and ending at some point, which represents a time, on the curve gives the direction and magnitude of the wind at that time. Thus, if the origin lies within the closed curve of the time hodograph the wind rotates through all directions during the course of the day. If the origin is not within the curve the wind goes through only the range of the angle in the directional plane that the curve covers.

Included here are the hodographs of average resultant wind for all ten stations with LCDs, the hodograph of the calculated average inland station resultant wind, and the five differences of each coastal stations minus that inland average. Hours of the day, beginning with 0 hours (midnight local time) and by three-hour intervals, are shown. Numbers along the axes indicate miles per hour in those directions, positive being in the north and east directions and negative south and west. But, wind is described by the direction from which it comes, so a point on the curve in the upper left quadrant denotes a southeasterly wind, a point in the lower right quadrant denotes a northwesterly wind, and so on.

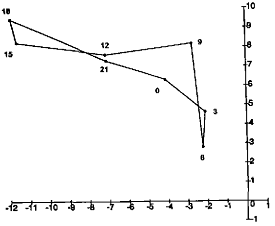
Austin resultant wind



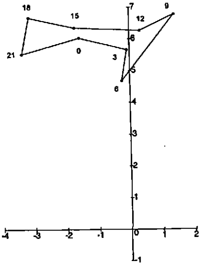
Brownsville resultant wind



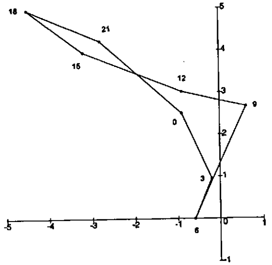
Corpus Christi resultant wind



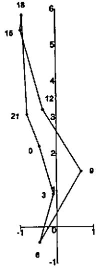
DFW resultant wind



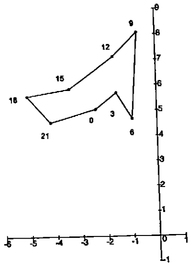
Houston resultant wind



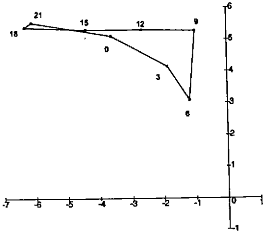
Port Arthur resultant wind



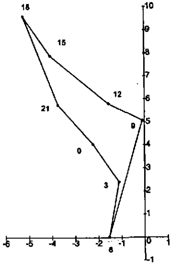
San Angelo resultant wind



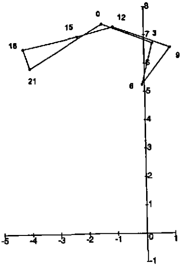
San Antonio resultant wind



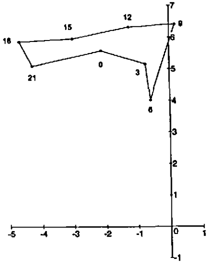
Victoria resultant wind



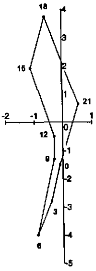
Waco resultant wind



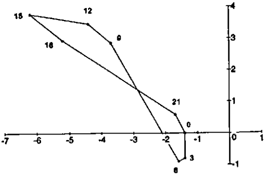
Average inland station resultant wind



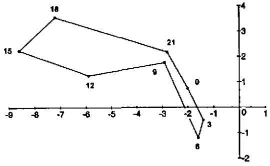
Victoria-average inland difference



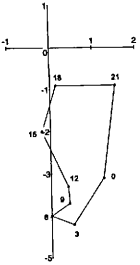
Brownsville-average inland difference



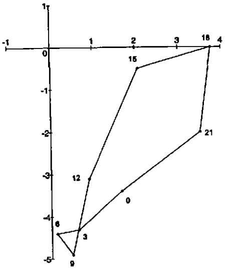
Corpus Christi-average inland difference



Houston-average inland difference

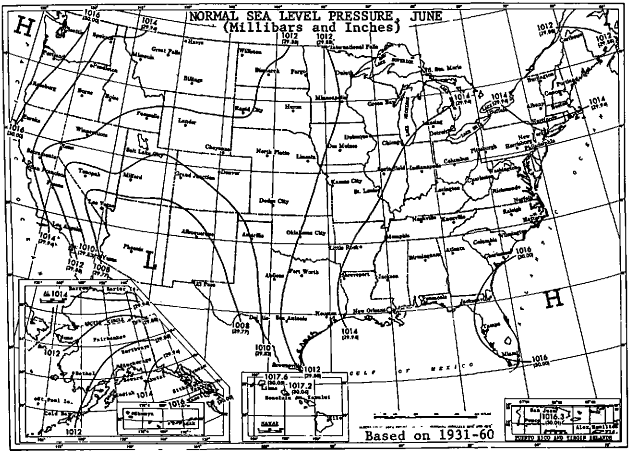


Port Arthur-average inland difference



Appendix D - Surface map analysis

If a sea-land breeze signature was to be apparent in the climate record there had to not be a preponderance of other variations to the overall weather pattern. Surface maps spanning three summers were compared to average pressure patterns, like the one for June below, to judge the regularity in the weather. The results, compiled on the following page, showed the weather during summer across Texas to be fairly consistent. Thus, a sea-land breeze signature should be neither concealed nor erroneously identified because of other regular aberrations to the over weather pattern.



	1995 June	1995 July	1995 August	1996 June	1996 July	1996 August	1997 June	1997 July	1997 August
Good	63	51	19	63	46	23	61	55	56
OK	50	52	88	104	110	72	62	91	48
Mid 1	29	33	46	27	42	52	21	10	37
Weak	40	32	10	4	7	12	11	12	15
Mid 2	27	49	51	7	17	15	27	14	22
Off	31	31	26	20	10	43	36	23	20

	June	%	July	%	August	%	All	%
Good	187	27	152	22	98	15	437	22
OK	216	32	253	37	208	32	677	33
Mid 1	77	11	85	12	135	21	297	15
Weak	55	8	51	7	37	6	143	7
Mid 2	61	9	80	12	88	13	229	11
Off	87	13	64	9	89	14	240	12

	1995	%	1996	%	1997	%	All	%
Good	133	18	132	20	172	28	437	22
OK	190	26	286	42	201	32	677	33
Mid 1	108	15	121	18	68	11	297	15
Weak	82	11	23	3	38	6	143	7
Mid 2	127	17	39	6	63	10	229	11
Off	88	12	73	11	79	13	240	12

Table 15 - Results of surface map analysis.

Good: Isobars on surface map aligned almost perfectly with average throughout state

OK: Isobars correspond reasonably well with average though signs of slight deviations apparent

Mid 1: Isobars clearly deviate from average but still hold same basic pattern; typically pressure gradient much stronger or weaker than average or isobars tilted some small angle (perhaps 20 degrees) away from alignment with average

Weak: Very slack synoptic pressure gradient; typically associated with high pressure behind a cold front where calm conditions favor sea breeze development but cooler temperatures hinder its formation

Mid 2: Isobars show clear, strong differences with average; typically associated with strong troughs or storm outbreaks or isobars tilted some large angle (perhaps 60 degrees) away from average

Off: No resemblance whatsoever to average; typically associated with presence of cold front across the state

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