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# Diurnal Variation of the Surface Wind in the Coastal Boundary Layer

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**Abstract:** Diurnal variations of coastal surface wind speed are analyzed with five years of hourly wind data from Port Aransas, Texas. These data reveal the highest frequency of occurrence of the nighttime wind maximum near midnight, especially during those seasons when onshore flow prevails. Nighttime wind maxima with a southerly component occurred approximately three times more frequently than with a northerly component on the annual average. The neutral atmospheric stability prevails near the coast. Thus it allows downward transfer of momentum from the nocturnal low level jet under the onshore wind situation and strong wind shear between an elevated frontal and ground-based inversion for offshore wind, resulting in the nocturnal coastal surface wind maximum.

**要約** : 5년간의 시간별 풍속자료를 이용하여 연안 표층풍의 일변화가 분석되었다. 특히 내륙으로부는 바람(onshore flow)이 지배적인 계절에는 야간 최대풍의 최대출현빈도가 자정에 나타났다. 연평균 남풍계열을 갖는 야간 최대풍은 북풍계열 보다 약 3배이상의 출현을 보여준다. 중립의 대기 안정도가 연안에 지배적이므로 바람이 해양에서 내륙으로 불 경우는(onshore flow) 야간의 저층 jet로부터 운동량이, 내륙에서 해양으로 부는 경우(offshore flow) 상승된 전선역전층과 지표역전층에 의해 형성된 전단력(shear flow)이 연안경계층으로 전이되어 야간 연안 최대표층풍이 형성된다.

## INTRODUCTION

Diurnal variations of wind speeds along the Texas coast have received occasional study in recent years. The sea breeze regime was investigated in a three-year field program (Eddy, 1968; Hsu, 1969; Jehn, 1973; McPherson, 1968). During this field program a nocturnal coastal maximum wind was discovered by Yu and Wagner (1970). The nocturnal maximum was investigated further by Eigsti (1973). However, none of these studies has examined the climatology of the Texas coastal nocturnal wind maximum or the dynamic mechanisms for its production. In addition, these studies utilized a very limited data set. Friehe and Winant (1982) show the existance of a coastal low-level wind maximum along the California coast without the detailed information for the coastal wind field using vary short period observation data.

The important objective of the present research is to present wind statistics based on five years of hourly data obtained from a 30 m tower near the Texas coast at Port Aransas, Texas. These statistics include an analysis of the monthly and seasonal frequency of occurr-

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ence of the nighttime wind maximm.

## DATA

The set of data utilized in this study is characteristics of five years of surface wind data obtained by the University of Texas at a coastal location in Port Aransas, Texas. The importance of the Port Aransas data is that it comprises a long time series record of wind velocity precisely on the Texas coastline.

Port Aransas, Texas (28°N, 97°W) is located on the north end of Mustang Island, a narrow, flat barrier island oriented southwest to northeast at a 35 degree angle from north (Fig. 1). The wind recording instrument was located at the University of Texas Marine Science Institute in Port Aransas. This instrument was a Bendix Aerovane model 610/MMQIA anemometer, and was mounted on the top of a 30 meter tower, about 0.5 kilometer inland from the Gulf of Mexico coastline. This anemometer records wind velocity in X, Y component from, with wind speeds in statute miles per hour. In order to minimize lost data due to chart recorder failure, two Esterline-Angus strip-chart recorders were employed for each component. The fetch between the Gulf of Mexico and the tower consisted of a flat sand beach changing to low dunes generally less than 2 meters above mean sea level near the observation site.

Coastal winds for 5 years (from 20 June 1976

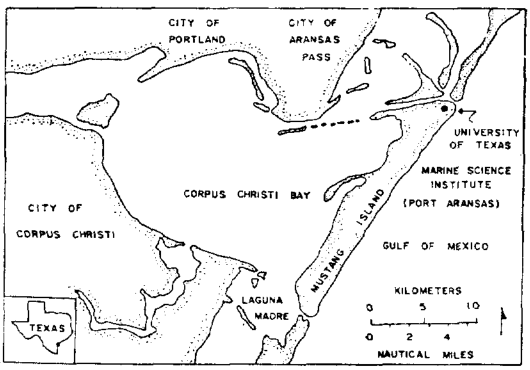


**Fig. 1.** Map of Corpus Christi-Port Aransas, Texas area

through 10 August 1980) were obtained from this anemometer. An acetate overlay with time marks was used to convert the analog data of the strip-charts into digital data which were then stored on magnetic tape. Data were reduced by reading a five-minute time average for each component every hour.

## ANALYSIS OF THE COASTAL WIND FIELDS

The existence of systematic diurnal wind speed maximum on the Texas coast is not at all well-established. Its previous note in the literature (e.g., Yu and Wagner, 1970) has been based upon relatively short anemometer records, and could be regarded as anecdotal. Therefore, one of the first concerns of this study was the statistical analysis of the long-term coastal wind data to establish the nature (and existence) of the phenomenon, and its general climatology, specifically magnitude, frequency of occurrence and seasonality.

The surface wind data taken at the Port Aransas site was evaluated for hourly average, daily average, and monthly average wind speed and hourly resultant, daily resultant, and monthly resultant wind direction. This basic data set was examined with special emphasis on the time of occurrence of the maximum surface wind speed. These data were examined in a variety of ways. Both hourly and day-night averages were examined, where daytime is defined as 0800 Central Standard Time (CST) through 1900 CST, and nighttime as 2000 CST through 0700 CST. Data were also stratified seasonally for summer (May through August), winter (November through February) and a transition season (September, October and March, April).

### a. Hourly distribution of maximum wind occurrences

Maximum wind was determined from the hourly average wind data by selecting the hig-

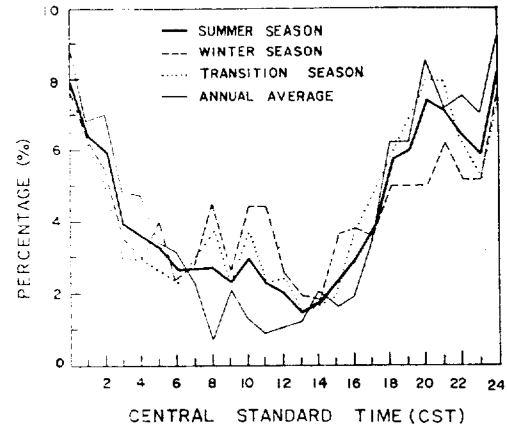


**Fig. 2.** Hourly occurrence of the coastal wind speed maximum based on 5 years of hourly data taken at Port Aransas

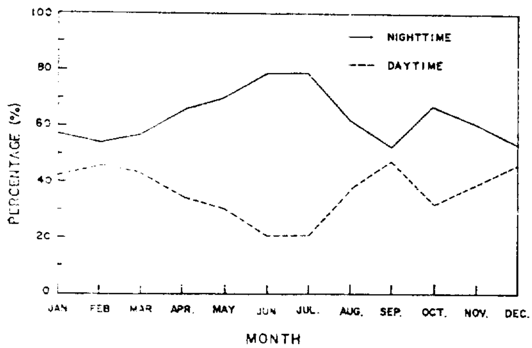


**Fig. 3.** Occurrence of coastal wind speed maximum for daytime and nighttime based on 5 years of hourly data taken at Port Aransas

hest wind speed during a calender day. If the same maximum wind occurred more than once during the day, each occurrence was counted. A total of 1942 maximum wind data points resulted from this analysis. The hourly occurrence of the coastal surface maximum wind speed for each season is shown in Fig. 2 and for each month of the three seasons in Fig. 3. The maximum frequency of occurrence of the coastal wind maximum during the summer season is at 0000 CST (0600 GMT) with a secondary maximum at 2000 CST (0200 GMT). The frequency of occurrence of maximum winds decreases rapidly with time after 0000 CST. A primary minimum and a secondary minimum occur at 0800 and 1100 CST, respectively.

The winter season shows a maximum at 0000 CST and a minimum at 1400 CST. During the transition season a similar tendency is shown. The primary maximum is observed at 2100 CST and a secondary maximum at 0000; the minimum is at 1300—1400 CST. The annual average occurrence of maximum wind speed shows a maximum frequency at night (0000 CST) and a minimum in the afternoon (1300 and 1400 CST).

**b. Day and nighttime occurrences of maximum winds**

Fig. 3 show monthly occurrence of the coastal surface wind speed maximum during the daytime and the nighttime. In general, the maximum wind speed occurs much less frequently during the daytime (0800~1900) than during the nighttime hours (2000~0700 CST). During the summer months the average nighttime occurrence of maximum wind speeds accounts for about 73% of the total occurrences for the season. This indicates that the daily wind maximum is observed about 2.6 times more frequently at night than during the daytime. In the winter season, the nighttime occurrence of the daily wind maximum is found 1.7 times more frequently than during the daytime. During the transition months the maximum wind is observed 1.5 times more frequently at night than in daytime.

Thus we conclude that the coastal surface wind speed maximum occurs predominantly at night, most frequently near midnight throughout the year. This result shows that the diurnal variation of coastal surface wind speed is contrary to that of inland surface wind speed which shows an afternoon speed maximum and an early morning minimum.

**c. Wind component stratification**

Large monthly and seasonal variations in the coastal surface maximum wind were shown above to occur in the data record at Port Aransas. We now examine the relation between these variations and the normal seasonal climatology of wind direction at Port Aransas. The large scale (synoptic) horizontal pressure field usually dictates southerly flow on the Texas coast during the summer months. During the wintertime this southerly flow is frequently inter rupted with the passage of a cold front giving northerly flow for a few days. Seasonal changes in the occurrence of southerly or northerly component maximum wind are dramatic and follow this same general pattern. Prevailing maximum winds for each season are indicated in Fig. 4 which show the ratio of the occurrence of southerly and northerly component winds to the total number of maximum winds for each month. A high percent frequency of occurrence of southerly component winds is shown in the summer season. In contrast, the majority of maximum winds during the winter months occurred with a northerly component.

The frequency of occurrence of the maximum wind (both day and night) with a southerly component in the summer months ranged from 85% in May to 97% in July. The summer sea son average occurrence of wind maximum with southerly flow is 91%. Thus, during the summer,

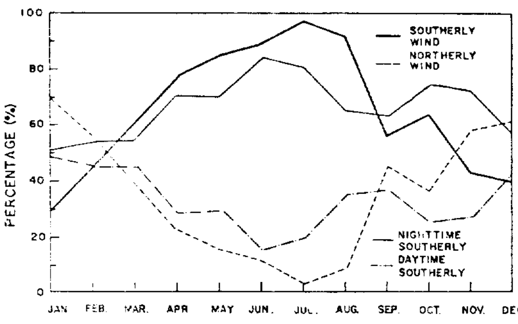


**Fig. 4.** Percent occurrence of maximum wind for southerly and northerly component, and southerly component maximum wind for daytime and nighttime based on 5 years of hourly data taken at Port Aransas, Texas.

most coastal surface maximum winds are southerly. Through the transition season the percent occurrence of southerly flow declines and varies from 55% in September to 77% in April with a transitional seasonal average of 64%. In contrast to the high percent occurrence of southerly component winds in summer, percent occurrence of southerly wind was found to range from 31 % in January to 45% in February with a winter season average of 39%. Thus in winter the northerly component dominates 61% of the time.

It is not unexpected that daily maximum wind speed should exhibit the same seasonal prevailing direction as the general wind climatology of the Texas coast. On the other hand, the nocturnal wind maximum might have a preferential direction and not necessarily follow the seasonal wind climatology; further, such a preferential direction, if it exists, could have implications for the driving mechanism of the phen omenon. We therefore examined the specific seasonal variation in direction of maximum winds catagorized by day or night occurrence.

The occurrence of nighttime and daytime-southerly component maximum winds is shown in Fig. 4. In the summertime, the daily wind maximum occurred at night with a southerly component three times more frequently than during the daytime. A high factor of 5.5 is reached during the month of June. The occurrence of southerly maximum winds in the winter months still favored night over day, though the difference was less than in the summer. A peak nighttime occurrence of southerly wind maxima of 72% occurred in November with a seasonal average occurrence of 66% for the the wintertime. During the transition season as well, the nighttime occurrence of southerly wind maxima exhibited a larger frequency of occurrence than the daytime. The nighttime maximum occurrence reached 75% in October. Average nighttime occurrence of southerly wind maximum was

**Table 1.** Occurrences of daytime and nighttime surface wind speed maxima during southerly and northerly winds at Port Aransas.

| Wind component | | Time (CST) Daytime 800~1900 | Nighttime 2000~0700 | Total |
|---|---|---|---|---|
| Southerly | Number | 405 | 900 | 1305 |
| | Ratio(%) | (20.9) | (46.3) | (67.2) |
| Northerly | Number | 305 | 332 | 637 |
| | Ratio(%) | (15.7) | (17.1) | (32.8) |
| Total | Number | 710 | 1232 | 1942 |
| | Ratio(%) | (36.6) | (63.4) | (100.0) |

about 66%, the sameas winter. Thus the nighttime southerly wind maximum occurs twice as frequently as the daytime during the transition season. A summary for southerly and northerly winds at the Port Aransas site is shown in Table 1. Among the total number of surface maximum winds (1942) the nighttime occurrence of southerly winds was detected approximately three times more frequently than the daytime occurrence, while for northerly winds daytime maxima were observed with about the same frequency as nighttime maxima.

## DISCUSSION

Air that has been over a uniform lower boundary surface of the sea for sufficient time comes into thermal and dynamic equilibrium with this surface. Air over a large body of water frequently develops a logarithmic (constant flux) wind profile and neutral (adiabatic) stability (Roll, 1965). As this air then crosses a coastline, there is a period of readjustment in both the motion and thermal structure of the air. This zone of adjustment called the internal boundary layer, is very shallow near the coastline, but incresases in depth as the overland distance increases (Echols and Wagner, 1972; Larsen, et al., 1982; Lu, 1973; Raynor, et al., 1979; Yu and Wagner, 1970).

During the daytime, with solar heating over the land, the air within the internal boundary layer becomes unstable. This leads to vertical convection and the associated vertical transfer of horizontal momentum. Because wind speeds usually increase with height, vertical momentum transfer downward will lead to an afternoon wind maximum near the earth's surface at inland stations. At night, due to the surface cooling the air overland becomes stable, and vertical convection is suppressed. The air motion near the ground is continually acted on by surface friction, and surface minimum wind speed is reached just before sunrise. This diurnal wind variation is observed near the earth's surface at most continental type stations.

At upper levels in the atmospheric boundary layer the wind regime is reversed. During the daytime, thermal convection transfers momentum downward, resulting in a daytime minimum wind speed. After sunset nighttime stability minimizes convection and momentum loss from this upper layer toward the lower layer when the Richardson number exceeds its critical value. Hence, maximum wind speeds at upper levels occur at night.

Over the water near the coastline the the diurnal wind variation may be quite different. We know there is a mechanism which increases the upper level wind at night over land. Frictional and thermal effects operate to give us the nighttime maximum wind speed, called nocturnal low lever jet. In summer the daily wind maximum predominantly occurred at night with a southerly component. For southerly jets, this air comes from over the Gulf of Mexico, hence we expect that wind speeds near an altitude of 1 kilometer over the Gulf coast also increase at night (Hsu, 1969). The nighttime stability, which minimizes vertical momentum transfer over land, is not present over the water (Fig. 5a). Thus nighttime wind speeds near the earth's surface over water will also increase. The coastal low level jet under the offshore wind

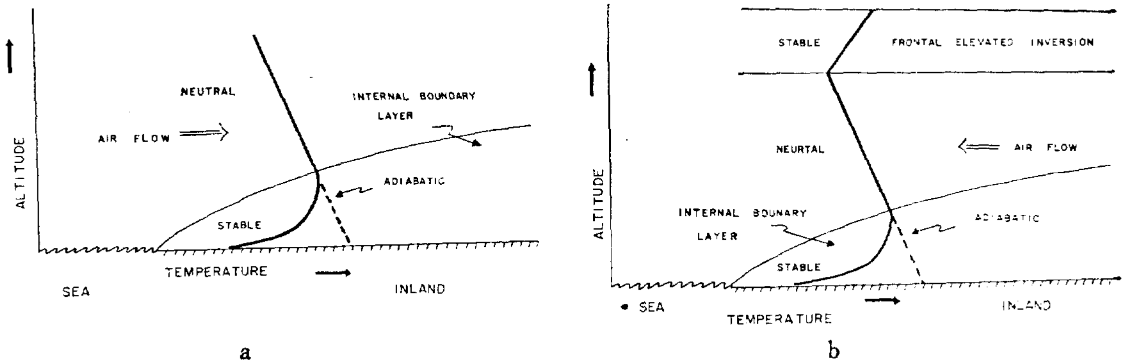


**Fig. 5. a.** Schematic profile of internal boundary layer and temperature near the coastal zone for onshore flow **b.** As in Fig. 5a except for offshore flow.

situation (i.e., from the northwest quardrant with the majority of the wintertime wind maxima in this study) results from the strong wind shear between an elevated and a ground-based inversion. With a frontal passage, cold air is confined below an elevated frontal inversion at all times, and at night, becomes decoupled from the ground by a ground-based inversion. This gives an elevated low level jet inland, but as the air approaches the Gulf Stream (passing over bays and estuaries) the surface-based inversion is destroyed allowing downward transfer of momentum and a coastal wind speed maximum (Fig. 5b). These are basically proposed mechanisms for the coastal wind speed maximum. It is a direct consequence of the existence of the low level jet and the difference in nighttime atmospheric stability between the land and water surface which produces an internal boundary layer.

Model predictions and observations of the thermal internal boundary layer suggest slopes which range from 1/15 (Lu, 1973) to 1/100 (Lettau, 1962; Yu and wagner, 1970). Thus when the wind is directly onshore, an anemometer on the 30 meter tower is just above the developing stable layer over the land. If the wind direction comes in at an angle to the coastline, the overland fetch increases, and the depth of the thermal internal boundary layer at the tower would increase. As the tower comes closer to being within the surface-based stable layer, the downward transfer of momentum would be decreased, leading to a decrease in the observed wind speed at the coastal site. It may also be that as the night progresses, the air near the tower becomes more stable. Thus momentum transfer might decrease after a certain time. This might explain why the coastal wind maximum on average occurs between midnight and 1:00 a.m. CST.

## CONCLUSIONS

From this study following conclusions may be drawn:

a. A surface wind speed maximum occurs on the Texas coast predominantly at night, especially near midnight (0000 CST), while a minimum occurs in the early afternoon (1300 to 1400 CST).

b. Average nighttime occurrence of the southerly wind maximum was 75% of the total occurrence of the southerly winds for the season in summer and 66% in both the transition season and winter. Nighttime wind maxima with a southerly component occurred about three times more frequently than with a northerly component on the annual average. Thus the nocturnal maximum is a phenomenon of southerly flow, best developed in the summer and transition season when the prevailing flow is southerly.

C. Vertical transfer of momentum depends strongly on the stability of the atmosphere. Since neutral stability prevails near the coast, under the onshore wind situation vertical momentum transfer from the nocturnal low level jet and for offshore wind strong wind shear between an elevated frontal and a ground-based inversion can take place toward the coastal surface. This appears to be the mechanism which results in the nocturnal coastal surface wind speed maximum.

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