

CHAPTER 145

WIND STRESS ON A COASTAL WATER SURFACE

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ABSTRACT

Simultaneous measurements of horizontal wind velocity above the water surface, air and water temperature difference, and water level were made during the summer of 1971 at an exposed field site off the northwest coast of Florida. Three identical vertical arrays of six-cup anemometers were used; they were located in the surf zone, in the area between the inner and the outer bars, and on the outer slope of the outer bar. The distances of these three stations from the mean shoreline were approximately 30, 130, and 230 m. Mean water depths were 1.5, 4.3, and 5.0 m.

Analysis of the profile data under adiabatic and onshore wind conditions indicates that better than 90 percent of the valid wind profile measurements are logarithmic. It was found from the nearly fifteen hundred 15-minute logarithmic wind profiles that the shear velocity U_* was not a linear function of wind speed, as is usually assumed in coastal applications, but had a functional relationship with velocity at 10 m or U_{10m} (from 0.5 to 8.5 m/sec), such that $U_* = 0.37 U_{10m}^{2/3}$.

Comparison with similar investigations in deeper water and oceanic regions was also made.

INTRODUCTION

In the lowest turbulent layer of the atmosphere over water under adiabatic conditions, logarithmic wind-velocity distribution with height has been observed over the sea (see, e.g., Roll, 1965, and Ruggles, 1970) and in laboratory channels (Wu, 1968, and Lai and Shemdin, 1971). The logarithmic law states that

$$\overline{U}_z = \frac{U_*}{\kappa} \ln \frac{z}{z_0} \quad (1)$$

where \overline{U}_z is the mean horizontal wind velocity at a certain height z ,



Fig. 1. Five identical cup anemometer arrays, located in the berm scarp, swash zone, surf zone, area between the inner and the outer bars, and on the outer slope of the outer bar on the coast of the Gulf of Mexico near Fort Walton Beach, Florida (see text for station identification). Three resistance-wire wave gages are shown on the left (cf. Fig. 2).



Fig. 2. One of the three identical cup anemometer arrays located on a fixed offshore mast in the area between the outer and the inner bars on the coast of the Gulf of Mexico near Fort Walton Beach, Florida. Two resistance-wire wave gages are shown in the background.

U_* is the shear (or friction) velocity $[= (\tau/\rho)^{1/2}]$, where τ is the vertical transport of horizontal momentum and ρ is the air density], κ is the von Kármán constant (≈ 0.4), and Z_0 is the aerodynamic roughness parameter or the dynamic roughness obtained under the boundary condition that $\overline{U_z} = 0$ at $Z = Z_0$, where Z_0 depends upon the boundary roughness as well as the characteristics of the boundary layer.

The wind stress $\tau (= \rho U_*^2)$ is of considerable importance because it plays an essential part in all processes of momentum transfer across the air-sea boundary, including generation of ocean surface waves and drift currents by wind action, wind set-up, and storm tides (Roll, 1965). The relationship between U_* and U_z or $C_z [= (U_*/U_z)^2]$, the drag or resistance coefficient at a certain height z over the water surface, has been investigated for more than 30 years (see information compiled and summarized by Roll, 1965; Wu, 1969; and Kraus, 1972). However, there are no systematic and simultaneous measurements in the nearshore areas, ranging from swash zone, surf zone, area between the inner and the outer bars, and the outer slope of the outer bar. Therefore, in order to study the nearshore waves, currents, and other meteorologically related coastal engineering processes, drag coefficients obtained from deeper water or oceanic regions generally are assumed. The purposes of this paper are to provide wind-profile and stress measurements in these nearshore regions and to compare with similar investigations in deeper water and oceanic regions.

FIELD EXPERIMENT

This study is an integral part of an investigation undertaken by several related disciplines of the Coastal Studies Institute, Louisiana State University, of the dynamical processes operating near an open coast as a function of the sea-air-land interaction system (SALIS Project). The field program was carried out in June-July 1971 on Santa Rosa Island (Eglin AFB), Florida, where the mean tidal fluctuation was about 30 cm.

Instruments used for this study included three identical portable Thornthwaite Wind Profile Register Systems (C. W. Thornthwaite Associates, Model 106) with six-unit, three-cup, fast-response anemometers mounted at 145, 165, 205, 285, 365, and 445 cm above the mean water surface (Fig. 1). These three anemometer arrays were located in the surf zone, in the area between the inner and the outer bars, and on the outer slope of the outer bar. The distances of these three stations from the mean shoreline were approximately 30, 130, and 230 m. Their mean water depths were 1.5, 4.3, and 5.0 m. Some of the instruments are shown in Figure 2. The wind profile instrumentation and the data-reduction and analysis procedures have been described elsewhere (Hsu, 1971).

In addition, several other parameters were measured in the study area for reference purposes. They were air and water temperature differences at a distance of approximately 2.8 m (Weathermeasure Corporation, Model T-601), tidal fluctuation (a capacitance water level gage developed by N. H. Rector and R. G. Fredericks, of the Coastal Studies Institute),

and wind speed and direction at 10 m above the ground level (Science Associates, Inc., Model 162). Temperature and humidity gradients were also measured at 1.7, 3.6, and 5.5 m above a grass-free berm surface by three identical recording hygrometry systems (Taylor Instrument Company, Series 76J, having readings within ± 1 percent of any given chart range). The sensors were mounted on a 10-m meteorological tower. Furthermore, four resistance-wire wave gages were also installed in the study area (Fig. 2).

RESULTS

From June 15 through July 2, 1971, approximately fifteen hundred 15-minute wind profiles having statistically significant logarithmic wind distribution with height were obtained. When plotted on semi-logarithmic paper, straight lines with a correlation coefficient ≥ 0.98 were obtained. Some examples are shown in Figures 3 through 5. It should be noted that in this analysis only those onshore winds under adiabatic conditions were used (Roll, 1965, and Hsu, 1969). Note also that, for brevity, only those profiles which do not overlap are plotted in these figures. Figure 6 shows the wind stress under adiabatic onshore wind conditions as a function of wind velocity at 10 m above the mean sea surface for water depth ≤ 5 m. The vertical bars in this figure represent the variations of the mean U_* values obtained at three offshore stations, namely, in the surf zone, in the area between the inner and the outer bars, and on the outer slope of the outer bar.

It can be seen immediately that the difference of the mean U_* values at a given wind speed for these three stations is relatively small. It was also found from the present data that the shear velocity was not a linear function of wind speed, as is usually assumed in coastal applications, but has a functional relationship with wind velocity (from 0.5 to 8.5 m/sec), such that

$$U_* = 0.37 U_{10m}^{2/3} \quad (2)$$

or

$$\tau = \rho U_*^2 = 1.64 \times 10^{-4} U_{10m}^{4/3} \quad (3)$$

in which U_{10m} is the wind speed in centimeters per second at the conventional reference level of 10 m above the mean sea surface. In Figure 6, comparison with similar investigations in deeper water (≈ 20 m) (Ruggles, 1970) and oceanic regions (Wu, 1969) is presented. The reason for the systematic discrepancy is not known because the three curves delineated in Figure 6 were not measured at the same period and in the same general region. It is suggested that such simultaneous measurements be executed in order to further our understanding of the interaction of the air-sea interface.

- | | |
|---------------------------------|---------------------------------|
| ① 0315-0330 hr., June 19, 1971 | ⑥ 1230-1245 hr. } June 16, 1971 |
| ② 0900-0915 hr. } | ⑦ 1700-1715 hr. } |
| ③ 0730-0745 hr. } June 17, 1971 | ⑧ 1645-1700 hr. } |
| ④ 0430-0445 hr. } | ⑨ 1615-1630 hr. } June 15, 1971 |
| ⑤ 1815-1845 hr. June 16, 1971 | ⑩ 1530-1545 hr. } |

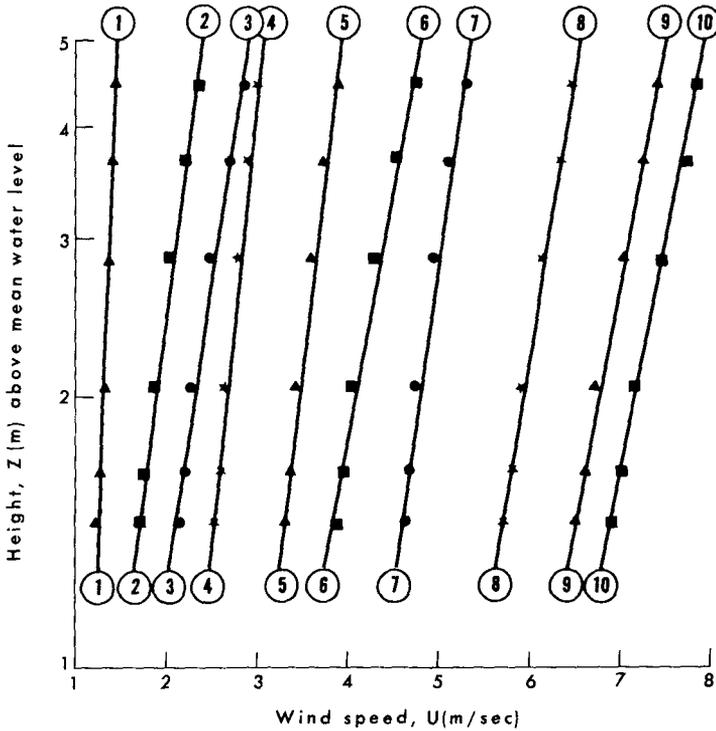


Fig. 3. Some examples of the 15-minute measurements of mean wind speed as a function of height (on a logarithmic scale) in the surf zone. Symbols represent measuring points.

- | | |
|--|--------------------------------|
| ① 0735-0750 hr., June 25, 1971 | ⑥ 2235-2250 hr., June 23, 1971 |
| ② 1230-1245 hr., June 20, 1971 | ⑦ 1415-1430 hr., June 20, 1971 |
| ③ 1050-1105 hr., June 23, 1971 | ⑧ 1600-1615 hr., June 19, 1971 |
| ④ 2035-2050 hr. }
⑤ 1835-1850 hr. } June 24, 1971 | ⑨ 2115-2130 hr., June 20, 1971 |
| | ⑩ 1230-1245 hr., June 22, 1971 |

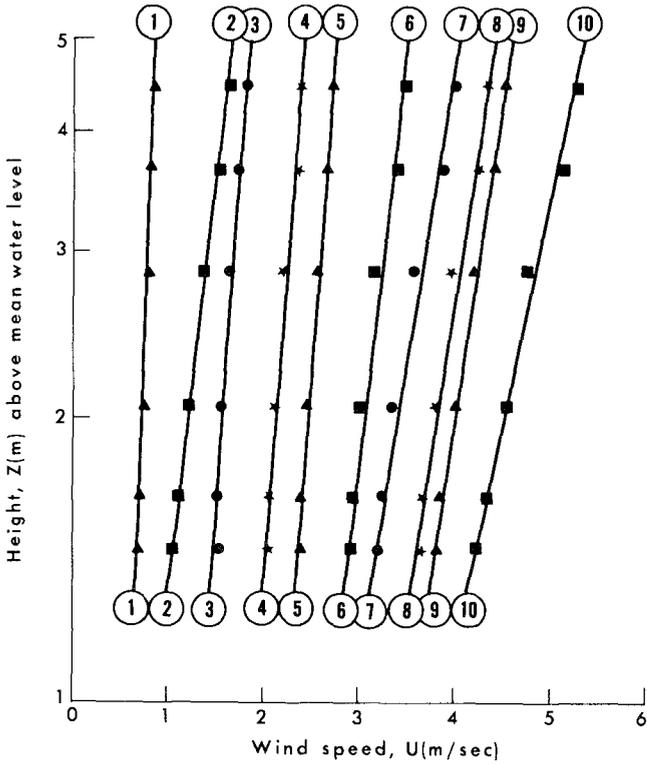


Fig. 4. Some examples of the 15-minute measurements of mean wind speed as a function of height (on a logarithmic scale) in the area between the inner and the outer bars.

- | | |
|--|--|
| ① 0910-0925 hr., June 30, 1971 | ⑥ 1440-1455 hr., July 1, 1971 |
| ② 0940-0955 hr. }
③ 1025-1040 hr. }
④ 1140-1155 hr. }
⑤ 1340-1355 hr. } | ⑦ 1325-1340 hr., June 29, 1971 |
| June 25, 1971 | ⑧ 1855-1910 hr. }
⑨ 1910-1925 hr. } |
| | June 30, 1971 |
| | ⑩ 1255- 1310 hr., June 29, 1971 |

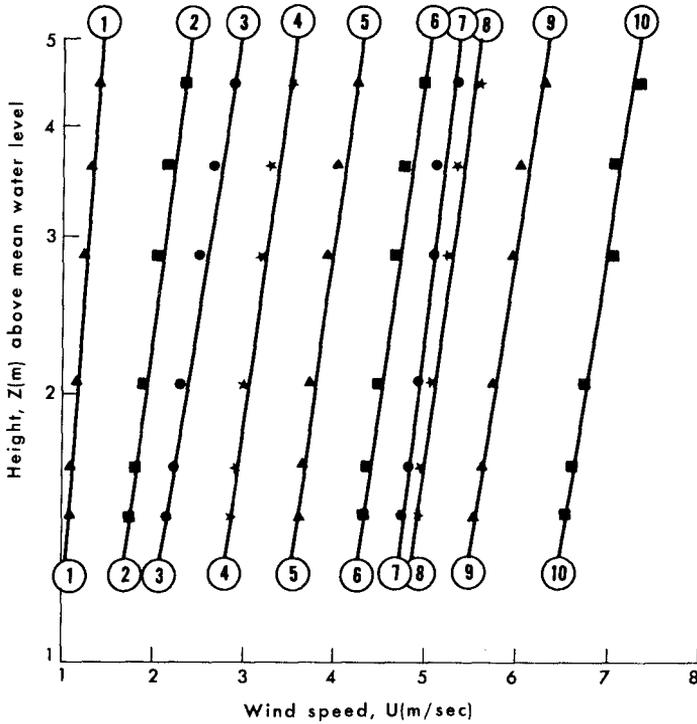


Fig. 5. Some examples of the 15-minute measurements of mean wind speed as a function of height (on a logarithmic scale) in the area on the outer slope of the outer bar.

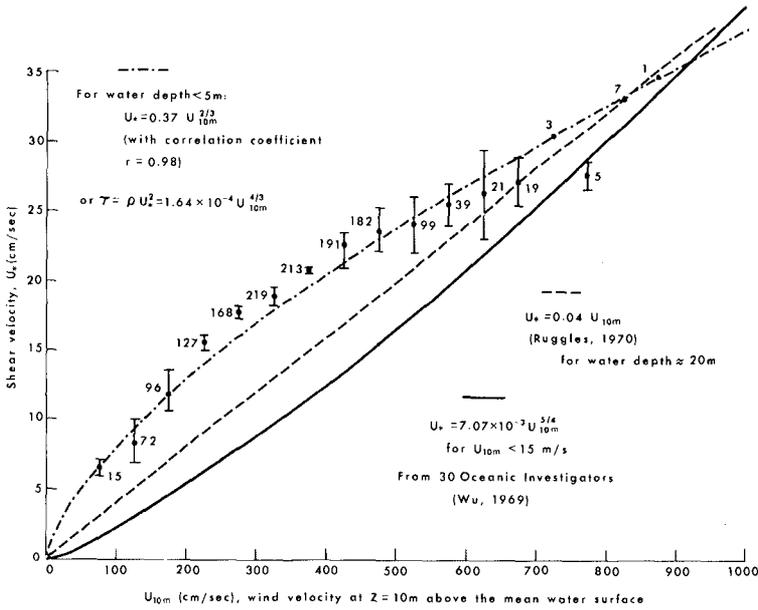


Fig. 6. Shear stress under adiabatic onshore wind conditions as a function of wind velocity at 10 m above the mean sea surface for water depth ≤ 5 m. The vertical bars represent the variations of the mean U_s values obtained at three offshore stations. Comparison with similar investigations under adiabatic conditions in deeper water and oceanic regions is also made.

CONCLUDING REMARKS

On the basis of nearly fifteen hundred 15-minute wind-profile measurements over a coastal water surface, it has been demonstrated that the atmospheric shear velocity and the wind speed are inter-related; these functional relationships are given in Figure 6. Since the logarithmic wind law can be valid only under the adiabatic condition (but not very close to the air-sea interface), the results presented in this study may not be applicable to synoptic and sub-synoptic systems which have different atmospheric stability [e.g., sea breezes, when the synoptic effect is minimal in the Gulf of Mexico coastal regions (Hsu, 1970 a and b), some weather systems in the Atlantic Ocean (DeLeonibus, 1971), and air flows over the Beaufort Sea in the Arctic region, where, in addition, the possible effect of a humidity gradient on stability exists (Banke and Smith, 1971)].

Also, caution should be used in applying the present study to other phenomena, such as wave-induced perturbations and their importance in transferring momentum to waves; in this regard, DeLeonibus' (1971) field study and Lai and Shemdin's (1971) laboratory investigations may be consulted.

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