Determining the Power-Law Wind-Profile Exponent under Near-Neutral Stability Conditions at Sea

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ABSTRACT

On the basis of 30 samples from near-simultaneous overwater measurements by pairs of anemometers located at different heights in the Gulf of Mexico and off the Chesapeake Bay, Virginia, the mean and standard deviation for the exponent of the power-law wind profile over the ocean under near-neutral atmospheric stability conditions were determined to be 0.11 ± 0.03. Because this mean value is obtained from both deep and shallow water environments, it is recommended for use at sea to adjust the wind speed measurements at different heights to the standard height of 10 m above the mean sea surface. An example to apply this P value to estimate the momentum flux or wind stress is provided.

1. Introduction

The vertical distribution of the wind or wind shear over the water surface is an important factor to consider since it is not only related to the momentum flux, which is the driving force in the generation of wind waves and wind-drift ocean currents, but also to the wind loads on ships and marine structures such as oil platforms.

In the atmospheric surface boundary layer extending to not more than 100 m above the surface (e.g., Sutton 1953, 14–15), the logarithmic wind profile has been used extensively (e.g., Panofsky and Dutton 1984). For practical applications at sea, however, in situ measurements of the aerodynamic roughness length are not always available, because it is related to both the wind speed and to the wave characteristics (Hsu 1988). Therefore, the simple power-law wind profile is often employed because it is quite accurate and useful for engineering applications (e.g., Panofsky and Dutton 1984).

The power-law wind profile states that

$$\frac{u_2}{u_1} = \left(\frac{z_2}{z_1}\right)^P, \tag{1}$$

where u_2 is the wind speed at height z_2, u_1 and z_1 are the wind speed and height already known, respectively, at a reference height, and the exponent P is a function of both the atmospheric stability in the layer over which P is determined to be valid and the underlying surface characteristics.

Davenport (1965) speculated that for the open sea, the exponent P is approximately 0.10. On the basis of a detailed tethersonding of the atmospheric boundary layer over the Mediterranean Sea under near-neutral stability conditions, Hsu (1988, 201–203) found that $P = 0.10$. The near-neutral condition over the water surface is defined as the $|Z/L| \leqslant 0.4$ (where L is the Monin–Obukhov stability length) (see Hsu 1992). The purpose of this research note is to further substantiate this value based on more datasets available recently.

2. Methods

In order to obtain the exponent P in Eq. (1), we take the logarithm on both sides of the equation so that

$$\ln\left(\frac{u_2}{u_1}\right) = P \ln\left(\frac{z_2}{z_1}\right)$$

or

$$P = \frac{\ln(u_2/u_1)}{\ln(z_2/z_1)}. \tag{2}$$

Since many marine operations such as frequent helicopter landings on offshore oil rigs require wind information at elevations much higher than the 5–10 m

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above the sea surface as normally measured by most National Data Buoy Center (NDBC) buoys, meteorological measurements at higher elevations are needed. The airflow distortion by the rig structure itself must be minimized, however (e.g., Katsaros et al. 1987). On the basis of both field measurements (e.g., Thornthwaite et al. 1965) and laboratory simulations (Wills 1984), the datasets selected for this study are considered to be representative within 5% between the measurements employed and those under undisturbed conditions. Note that because the flow distortion problem was considered in the very beginning for the instrument siting by NDBC, the anemometers on these offshore structures are located in the area where the structure effect is minimal. Since the aggregate wind estimation error cannot be less than 10% at airports on land, where most official weather service stations are located (see Wieringa 1980), the offshore wind measurements selected for this study are considered to be reasonable.

a. Open-ocean conditions

For open-ocean conditions, two platforms in the Gulf of Mexico along the continental shelf break with anemometers at different heights were available, as shown in Fig. 1. Note that at both sites dual wind measurements were needed to ensure data continuity (one was considered a backup). They were Coastal-Marine Automated Network (C-MAN) station Garden Banks block 236A and moored buoy station 42019. A description of the platforms and data retrieval methods is provided as follows (National Data Buoy Center 1990a, 1992):

1) GARDEN BANKS 236A (GBCL1)

GBCL1 is a high-pressure natural gas production platform installed and operated by Chevron Oil Company in the Gulf of Mexico (Fig. 2). The measurements were taken by an NDBC C-MAN system consisting of two anemometers and an air temperature sensor mounted on a gas boom approximately 57.5 m above mean sea level (MSL) and a barometer with the vent port on the boom at 49.7 m MSL (Fig. 3). The boom slightly obstructed the anemometers in a narrow zone between approximately 180° and 200°T. The water temperature sensor was mounted at approximately 1.5 m below MSL on the inboard side of a boat landing on the west side of the platform. Unfortunately, the C-MAN station at GBCL1 was removed in the summer of 1992.

2) MOORED BUOY STATION 42019

NDBC buoy station 42019 is a 3-m discus-shaped buoy made of aluminum (Fig. 4). The buoy design and characteristics are discussed in detail by Hamilton (1988). The buoy provides the same kind of measurements as GBCL1. The anemometers are located approximately 4.9 m above the nominal waterline. The barometers and thermometer are 3.5 m above the water, while sea temperature is measured through the hull at a depth of approximately 0.5 m. Meteorological measurements are taken during an 8-min sampling period at 1 Hz starting 18 min before each hour.

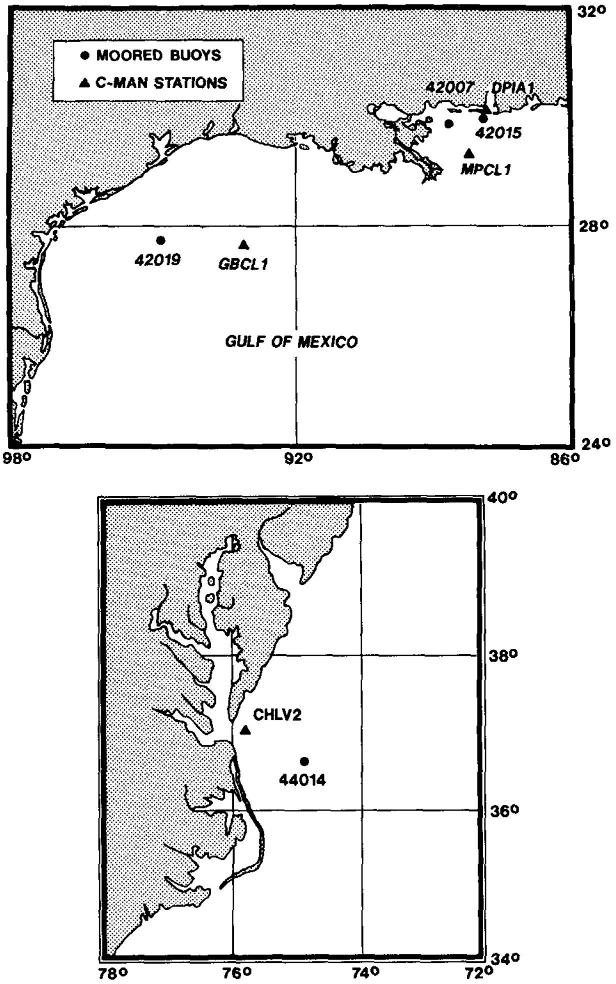

FIG. 1. Map showing the locations of moored buoys and C-MAN stations used in this study: (a) in the northern Gulf of Mexico; (b) on the mid-Atlantic coast near Chesapeake Bay, Virginia. Buoy station 42016 is not plotted, because of its close proximity to station 42015.

b. Coastal ocean conditions

Three pairs of dual-anemometer stations were incorporated into this study. Two station pairs are in the northern Gulf of Mexico. They are Main Pass 133C (MPCL1) and moored buoy station 42007, and Dauphin Island (DPIA1) and either moored buoy station 42015 or 42016. The third pair was the Chesapeake

FIG. 2. Chevron Oil Company's Garden Banks 236A gas production platform. The photo was taken prior to installation of the C-MAN measurement equipment, including a 6.1-m mast and anemometers near the end of the boom.

Light Station (CHLV2) and moored buoy 44014 located off the mid-Atlantic coast (Fig. 1 and Table 1).

1) MAIN PASS 133C (MPCL1)

The anemometers at MPCL1 were located 40.2 m above the water on a mast near the end of a flare boom that extended due south from the south corner of the platform. They were slightly obstructed to due south by the flare boom itself. The thermistor was at 40.2 m, water temperature was measured by a thermistor on the south platform leg at approximately 1-m depth.

2) MOORED BUOY STATION 42007

Moored buoy 42007 is a discus-shaped hull made of steel that is 12 m in diameter. The two anemometers and the air temperature sensor are 10 m above the water. Water temperature is measured through the hull at 1.1-m depth.

3) DAUPHIN ISLAND (DPIA1)

DPIA1 is collocated with a National Ocean Service (NOS) tide station just north of the eastern end of Dauphin Island, Alabama. The station is at the end of a pier that extends northeast approximately 75 m from shore. Wind sensors are 17.4 m above MSL; air temperature is measured at 16.8 m; sea temperature is measured at 1-m depth. Fort Gaines, a large structure, is located approximately 100 m southwest of the DPIA1 pier. While the anemometers are approximately 10 m above the Fort Gaines battlements, the size of the fort probably influences winds blowing from the southwest.

4) MOORED BUOY STATIONS 42015 AND 42016

The moored buoys at both 42015 and 42016 are 3-m discus buoys described earlier. Data from 42015

FIG. 3. A close-up view of the C-MAN anemometer system on the boom of station GBCL1. Note that the dual-anemometer system was installed on the station so that one of them could act as a backup.

was used in the study except for periods during which it failed or was retrieved. In these events, data from 42016 were used.

5) CHESAPEAKE LIGHT STATION (CHLV2)

CHLV2 is a steel framework tower operated by the U.S. Coast Guard. The anemometer is located 43.3 m above the water in an unobstructed position on the southeast corner of the structure. The air temperature is measured at 22.3 m above the water, while the water temperature thermistor is attached to a leg of the structure approximately 2.5 m below MSL.

6) MOORED BUOY STATION 44014

Moored buoy 44014 is a 3-m discus buoy similar to the systems described earlier, except that a wind fin was attached to the buoy's nominal stern in order to turn the buoy into the wind. This feature should have no effect on the data in this study.

c. Data sampling and retrieval

Data for all fixed platforms were obtained during a 2-min sampling period at 1 Hz. For GBCL1, MPCL1, and DPIA1, the sampling interval was from minute 23 to 25 of each hour; for CHLV2, the interval was from minute 58 to 60. All moored buoy data were sampled

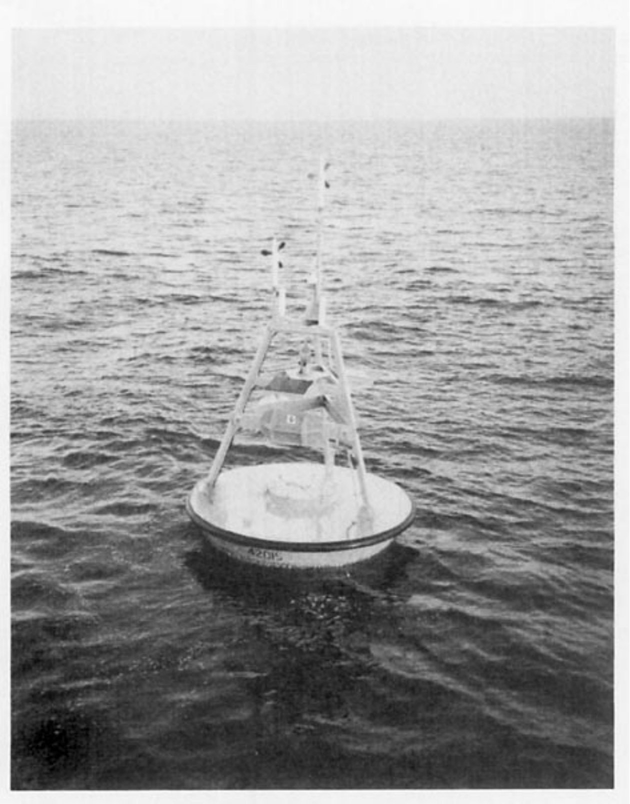

FIG. 4. Photograph of an NDBC 3-m discus buoy similar to the system deployed at station 42019. Note that the dual-anemometer system was installed on the station so that one could act as a backup.

at 1 Hz for 8 min from minute 42 to 50 of each hour. Wind directions represent a unit-vector average; wind speeds were scalar averaged on both fixed platforms and moored buoys. Although wind information is normally available at NDBC from the two anemometers at each station, data from only one instrument is archived and used in this study. There are two main purposes of the second anemometer: first, it is heavily relied upon to verify data quality from the "primary" anemometer in "real time"; second, it is a hot backup in the event the operational anemometer fails.

Following sampling, data underwent preliminary processing and transmission each hour via a National Oceanic and Atmospheric Administration Geostationary Operational Environmental Satellite to ground receiving facilities operated by NOAA's National Environmental Satellite Data and Information Service at Wallops Island, Virginia. From Wallops Island, data were transferred by landline to the National Weather Service Telecommunications Gateway, Silver Spring, Maryland, for further processing that included data quality checking, encoding, real-time distribution, and archiving.

3. Results and discussions

In order to ensure that the stability is near neutral based on the criterion provided in Hsu (1992), only monthly maximum wind speeds for these stations as published in the *Mariners Weather Log* are used in

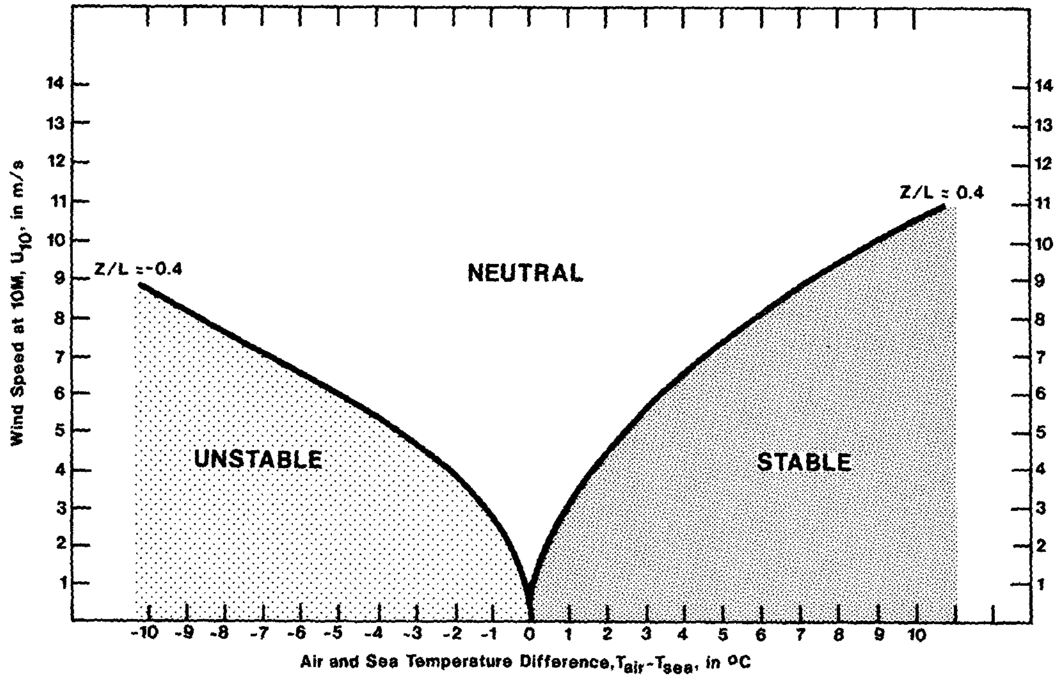

FIG. 5. The stability criteria used in this study [simplified from Hsu (1992)].

TABLE 1. Location, water depth, and anemometer heights (MSL) of stations used in this study.

Station identification	Station/hull type	Location	Water depth (m)	Anemometer height (m)
GBCL1	platform	27°46′N, 93°08′W	183.0	57.5
42019	3-m discus	27°54′N, 95°00′W	119.8	4.9
MPCL1	platform	29°24′N, 88°36′W	55.0	40.2
42007	12-m discus	30°05′N, 88°46′W	13.0	10.0
DPIA1	pier	30°15′N, 88°05′W	0.0	17.4
42015	3-m discus	30°09′N, 88°10′W	15.3	4.9
42016	3-m discus	30°10′N, 88°06′W	12.8	4.9
CHLV2	platform	36°54′N, 75°43′W	11.6	43.3
44014	3-m discus	36°35′N, 75°50′W	47.5	4.9

this analysis. By placing the difference in air and sea temperatures on the horizontal axis and the wind speed on the vertical axis in Fig. 5, the atmospheric stability was indeed found to be nearly neutral for all the cases listed in Tables 2–5. Furthermore, to avoid the local rig and platform effects, wind speeds at C-MAN stations must be higher than those at buoys. These values are available in the *Mariners Weather Log* (1990a–d, 1991a–d, 1992a–d). Data from buoy 42019 have been available since May 1990; therefore, relatively few near-simultaneous measurements were available from both stations. Nevertheless, Table 2 shows that from June 1990 through February 1992 we have eight sets of these measurements. The maximum speed values in each set were measured within 6 h of each other, a duration that was required for a minimum wind speed of 10 m s^{-1} (see Table 2) to reach from one station to the other since the distance between the two stations is approximately 200 km. A similar situation exists between C-MAN station CHLV2 and buoy station 44014.

In Table 2, the difference in wind direction between GBLC1 and 42019 was within 27° and the difference in sea level pressure was within approximately 3 mb in a distance of 200 km. Since the general pressure gradient at the surface is about 1 mb per 100 km for the synoptic weather system (e.g., McIlveen 1986, p. 175), the dataset compiled in Table 2 may be considered to be nearly homogeneous in space. Further inspection of daily surface weather maps (in the weekly series published by NOAA) showed that in all cases selected no frontal systems were located between these two stations.

Similar conditions existed between buoy 42007 and C-MAN station MPCL1 as shown in Table 3 in which the maximum difference in wind direction between these stations was 32°, and in sea level pressure 3.6 mb. Because the distance between buoys 42015 and 42016 and C-MAN station DPIA1 was much closer than the other pairs (see Fig. 1), the maximum difference in wind direction between them was 15°, and in sea level pressure 2.2 mb (see Table 4).

Because the location of the Chesapeake Light Station is closer to the shore than buoy 44014 (Fig. 1), the maximum difference in wind direction shown in Table 5 was 50° on 17 October 1991, and the sea level pressure 3.1 mb. The wind direction difference for the other six cases was within 20°, however. Note that the large

TABLE 2. Near-simultaneous measurements of atmospheric pressure (Pa), wind speed and direction (Wd), and air–sea temperature differences at C-MAN station GBCL1 and NDBC buoy station 42019 in the Gulf of Mexico (see Fig. 1). Values of the exponent *P* of the power-law wind profile are calculated from Eq. (2).

		C-MAN GBCL1					Buoy 42019				
Month	Day/hour (UTC)	$u_{57.5\,m}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{air} - T_{sea}$ (°C)	Day/hour (UTC)	$u_{4.9\,m}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{air} - T_{sea}$ (°C)	P
June 1990	02/0900	15.4	157	1015.6	0.1	02/0800	12.2	151	1013.3	−0.8	0.095
November 1990	29/1300	18.7	32	1029.8	−7.4	29/1400	15.1	23	1031.0	−8.8	0.087
December 1990	03/1600	18.8	2	1016.9	−4.9	03/1400	14.6	338	1015.2	−0.2	0.103
January 1991	15/0400	18.3	149	1010.6	−0.1	15/0100	14.5	135	1007.3	−3.3	0.095
March 1991	29/0900	17.8	328	1000.6	−1.5	29/0700	14.2	323	1001.8	1.3	0.092
June 1991	08/0100	16.4	98	1014.5	−1.5	08/0700	12.1	99	1014.0	−2.3	0.123
January 1992	15/0400	18.3	19	1020.9	−8.3	15/0100	14.5	26	1020.3	−10.2	0.095
February 1992	05/1400	23.1	314	1003.6	−7.3	05/1200	17.1	341	1005.8	−9.2	0.122
Mean		18.4					14.3				0.102
Standard deviation											0.014

TABLE 3. Same as Table 2 except C-MAN station MPCL1 and NDBC buoy station 42007 in the Gulf of Mexico (see Fig. 1). Values of the exponent P of the power-law wind profile are calculated from Eq. (2).

	C-MAN MPCL1					Buoy 42007					
Month	Day/hour (UTC)	$u_{40.2\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	Day/hour (UTC)	$u_{10\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	P
January 1989	21/0900	16.2	44	1022.5	M*	21/0500	13.6	12	1023.5	−5.6	0.126
February 1989	23/0000	16.9	330	1024.6	M	23/0300	14.6	332	1026.9	−9.7	0.105
October 1989	19/1500	17.6	323	1023.4	M	19/1300	14.3	327	M	M	0.149
May 1990	13/2100	16.2	127	1015.3	−1.0	13/1600	14.5	115	1017.7	−3.1	0.080
November 1990	10/0100	19.0	303	1010.4	−9.9	10/0100	16.1	306	1009.0	−7.9	0.119
December 1990	24/0400	15.5	335	1021.7	−11.2	24/0800	13.7	349	1024.3	M	0.089
February 1991	15/1100	18.6	314	1014.6	M	15/1400	15.6	324	1018.2	M	0.126
December 1991	20/0700	18.1	108	1031.5	−3.2	20/0500	15.1	104	M	−2.0	0.130
Mean		17.3					14.7				0.116
Standard deviation											0.023

* Missing data.

pressure difference on 26 October 1990 was due to an intense low pressure system located farther offshore from buoy 44014.

Again, inspection of the daily weather maps for all cases listed in Tables 2–5 showed that there were no fronts between the pairs of stations, indicating that our datasets for these pairs were nearly homogeneous in space.

On the basis of these datasets as shown in Tables 2–5, values of P are calculated from Eq. (2). It can be seen that the mean and standard deviation for all 30 samples is 0.106 ± 0.029, which further substantiates the recommendation made in Hsu (1988, Table 8.5, p. 202). It is therefore suggested that $P = 0.10$ is a good approximation for use at sea under near-neutral stability conditions.

As an example, the momentum flux or wind stress τ $(=\rho u_*^2)$ can be estimated by $u_* = u_{10}C_{10}^{1/2}$, where ρ $(\approx 1.2\ \mathrm{kg\ m^{-3}})$ is the air density, u_* is the shear velocity, and C_{10} and u_{10} are the drag coefficient and wind speed at 10 m above the sea surface, respectively. According to Hsu (1988, p. 200) $C_{10}^{1/2} = \kappa P$ where κ (= 0.4) is the von Kármán constant and P is the exponent of the power law. In our case since $P = 0.106$, $C_{10}^{1/2} = 0.0424$ and since the composite mean of u_{10} from these 30 samples as evaluated in Tables 2–5 is 15.2 m s^{-1}, $u_* = 0.64$ m s^{-1}, and $\tau = 0.49$ N m^{-2}. On the other hand, according to the WAMDI (Wave Model Development and Implementation) Group (1988), $C_{10}^{1/2} = [(0.8 + 0.065u_{10}) \times 10^{-3}]^{1/2} = 0.0423$; therefore, $u_* = 0.65$ and $\tau = 0.51$ N m^{-2}, which are in good agreement with our estimates.

4. Conclusions

On the basis of the datasets compiled in Tables 2–5, it is found that near-neutral stability conditions prevail at sea. The mean and standard deviations of P in Eq. (1) for all 30 samples were determined to be 0.11 ± 0.03. It is therefore concluded that $P = 0.11$ is a good approximation for use at sea.

TABLE 4. Same as Table 2 except C-MAN station DPIA1 and NDBC buoy station 42015 and 42016 in the Gulf of Mexico (see Fig. 1). Values of the exponent P of the power-law wind profile are calculated from Eq. (2).

	C-MAN DPIA1					Buoy 42015 or 42016*					
Month	Day/hour (UTC)	$u_{17.4\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	Day/hour (UTC)	$u_{4.9\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	P
March 1989	22/0100	15.7	347	1016.2	−6.8	22/0100*	14.1	358	1014.0	−5.8	0.085
May 1989	01/1200	13.8	12	1010.2	−4.0	01/1200*	11.9	4	1009.1	−3.1	0.117
September 1989	24/0600	14.3	13	1013.9	−4.7	24/0600	12.4	3	1013.3	−5.9	0.112
October 1989	19/2300	13.7	325	1024.7	−6.1	19/2300	11.6	328	1024.1	−11.9	0.131
March 1990	17/0200	14.5	352	1012.4	−5.1	17/0200	12.0	354	1012.4	−4.8	0.149
April 1990	07/1000	16.2	15	1020.3	−8.2	07/1000	14.7	10	1019.8	−7.7	0.077
August 1990	30/2200	17.1	360	1011.9	−8.1	30/2200	13.8	15	1011.7	−4.9	0.169
Mean		15.0					12.9				0.120
Standard deviation											0.033

TABLE 5. Same as Table 2 except C-MAN station CHLV2 and NDBC buoy station 44014 off east coast of United States (see Fig. 1). Values of the exponent P of the power-law wind profile are calculated from Eq. (2).

	C-MAN CHLV2					Buoy 44014					
Month	Day/hour (UTC)	$u_{43.3\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	Day/hour (UTC)	$u_{4.9\ \mathrm{m}}$ (m s^{-1})	Wd (°)	Pressure (Pa)	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	P
October 1990	26/1100	24.1	4	999.8	−7.7	26/1300	21.6	352	994.4	−5.9	0.050
February 1991	14/1500	16.5	223	998.0	5.2	14/1500	14.5	210	988.9	1.3	0.059
June 1991	23/2100	15.1	40	1014.5	−1.8	23/2100	13.4	31	1012.4	−0.9	0.055
October 1991	17/1300	23.2	332	1008.1	−8.6	17/1100	18.2	282	1005.0	−4.2	0.111
November 1991	09/2200	23.8	45	1017.7	−2.8	09/2300	17.4	25	M	−1.5	0.144
February 1992	29/1600	18.9	345	M	−2.0	29/1900	16.1	325	1010.2	−4.2	0.074
June 1992	22/0500	12.9	341	1014.8	−2.4	22/0600	9.9	338	1012.7	M	0.121
Mean		19.2					15.9				0.088
Standard deviation											0.037

Note that, according to Panofsky and Dutton (1984, p. 131),

$$P = \left[\ln\left(\frac{z}{z_0}\right)\right]^{-1}, \tag{3}$$

where $z = 10$ m and z_0 is the roughness length. For the smooth terrain on land ($z_0 = 1$ cm), therefore, $P = 0.14$ or $1/7$, a value commonly suggested in engineering texts for land-based use. For offshore applications, however, z_0 ranges from 10^{-4} to 10^{-3} m (see Panofsky and Dutton 1984, Table 6.2, p. 123). Therefore, P varies from 0.087 to 0.109. If we take the mean z_0 of 5×10^{-4} m and substitute it into Eq. (3), we have a typical offshore value of $P = 0.10$, which is nearly identical with the value as suggested in our study. The discussion explains that the typical value of P on land is 0.14, and offshore 0.10. This is mainly due to the larger value of roughness length z_0 on land than offshore.

It should also be noted that, according to Panofsky and Dutton (1984, p. 123), the value of z_0 for off-sea wind in coastal areas is around 10^{-3} m, which is on the top of their list for large expanses of water. Therefore values of P for the coastal regions such as provided in Tables 3 and 4 are larger than those farther offshore as shown in Table 2. Since z_0 is inversely proportional to the wave age at sea for the same wind speed (Maat et al. 1991) and since the Atlantic along the eastern seaboard (Table 5) experiences more swell (older waves) than the Gulf of Mexico, the value of P is also smaller. In order to demonstrate that the result is useful, Table 6 is provided. From this table and Fig. 5 it can be seen that from a marine climatic point of view the near-neutral stability prevails in the surface boundary layer at sea. Therefore, Eq. (1) with $P = 0.11$ should be applicable most of the time at sea.

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TABLE 6. Monthly mean wind speeds and air–sea temperature differences for NDBC buoys 42008 (1980–84), 42007 (1981–88), and CHLV2 (1984–88). For station locations, see Fig. 1.

	42008		42007		CHLV2	
Month	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	$u_{14.9\ \mathrm{m}}$ (m s^{-1})	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	$u_{10\ \mathrm{m}}$ (m s^{-1})	$T_{\mathrm{air}} - T_{\mathrm{sea}}$ (°C)	$u_{43.3\ \mathrm{m}}$ (m s^{-1})
January	−0.5	6.4	−2.8	5.5	−2.4	8.1
February	−0.7	6.8	−0.5	5.6	−0.6	8.0
March	−0.2	6.4	−0.6	5.7	1.1	8.4
April	0.2	6.6	−0.4	6.0	1.3	7.6
May	−0.5	6.6	−0.7	5.3	1.2	6.4
June	−0.8	6.0	−0.7	4.7	1.0	6.4
July	−1.0	5.6	−0.7	4.1	0.8	5.6
August	−1.3	5.3	−0.9	4.2	−0.2	5.8
September	−1.4	6.4	−1.3	5.1	−1.0	6.2
October	−0.8	6.5	−1.6	5.4	−1.8	7.1
November	0.6	6.3	−1.5	5.9	−2.0	7.7
December	0.1	7.0	−2.0	5.9	−2.6	7.5

* Data source: National Data Buoy Center 1990b.

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REFERENCES

Davenport, A. G., 1965: The relationship of wind structure to wind loading. National Physical Laboratory, Symposium No. 16. *Wind Effects on Building and Structures,* Her Majesty's Stationary Office, 54–102.

Hamilton, G., 1988: Small coastal data buoys. *Proc. Fourth Conf. on Meteor. and Oceanogr. of the Coastal Zone,* Anaheim, California, Amer. Meteor. Soc., 74–78.

Hsu, S. A., 1988: *Coastal Meteorology.* Academic Press, 260 pp.

——, 1992: An overwater stability criterion for the offshore and coastal dispersion model. *Bound.-Layer Meteor.,* **60,** 397–402.

Katsaros, K. B., S. D. Smith, and W. A. Oost, 1987: HEXOS—Humidity exchange over the sea, a program for research on water-vapor and droplet fluxes from sea to air at moderate to high wind speed. *Bull. Amer. Meteor. Soc.,* **68,** 466–476.

Maat, N., C. Krann, and W. A. Oost, 1991: The roughness of wind waves. *Bound.-Layer Meteor.,* **54,** 89–103.

Mariners Weather Log, 1990a: *NDBC Station Data Summary.* National Oceanographic Data Center, 88–91 (winter).

——, 1990b: *NDBC Station Data Summary.* National Oceanographic Data Center, 96–99 (spring).

——, 1990c: *NDBC Station Data Summary.* National Oceanographic Data Center, 90–93 (summer).

——, 1990d: *NDBC Station Data Summary.* National Oceanographic Data Center, 89–92 (fall).

——, 1991a: *NDBC Station Data Summary.* National Oceanographic Data Center, 80–83 (winter).

——, 1991b: *NDBC Station Data Summary.* National Oceanographic Data Center, 96–99 (spring).

——, 1991c: *NDBC Station Data Summary.* National Oceanographic Data Center, 76–79 (summer).

——, 1991d: *NDBC Station Data Summary.* National Oceanographic Data Center, 84–87 (fall).

——, 1992a: *NDBC Station Data Summary.* National Oceanographic Data Center, 81–83 (winter).

——, 1992b: *NDBC Station Data Summary.* Natioanl Oceanographic Data Center, 85–87 (spring).

——, 1992c: *NDBC Station Data Summary.* National Oceanographic Data Center, 81–83 (summer).

——, 1992d: *NDBC Station Data Summary.* National Oceanographic Data Center, 75–78 (fall).

McIlveen, J. F. R., 1986: *Basic Meteorology—A Physical Outline.* Van Nostrand Reinhold Co., 457 pp.

National Data Buoy Center, 1990a: *Coastal-Marine Automated Network (C-MAN) Users Guide.* NOAA, National Data Buoy Center, 51 pp.

——, 1990b: *Climatic Summaries for NDBC Buoys and Stations—Update 1.* NOAA, NDBC, 454 pp.

——, 1992: *Coastal-Marine Automated Network (C-MAN) Users Guide.* NOAA, National Data Buoy Center, 65 pp.

Panofsky, H. A., and J. A. Dutton, 1984: *Atmospheric Turbulence.* Wiley, 397 pp.

Sutton, O. G., 1953: *Micrometeorology.* McGraw-Hill, 333 pp.

WAMDI Group, 1988: The WAM Model—A third generation ocean wave prediction model. *J. Phys. Oceanogr.,* **18,** 1775–1810.

Thornthwaite, C. W., W. J. Superior, and R. T. Field, 1965: Disturbance of airflow around Argus Island tower near Bermuda. *J. Geophys. Res.,* **70,** 6047–6052.

Wieringa, J., 1980: Representativeness of wind observations at airports. *Bull. Amer. Meteor. Soc.,* **61,** 962–971.

Wills, J. A. B., 1984: HEXOS model tests on the Noordwijk Tower. Report R184, British Maritime Technology, 53 pp.