Correction of Land-Based Wind Data for Offshore Applications: A Further Evaluation

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ABSTRACT

A formula that linearly relates the difference in wind speed between onshore and offshore regions, as tested successfully in the Great Lakes region, has been revised and extended to other parts of the world. This formula is further substantiated theoretically by using an approximation of the equations of motion. Contribution of air–sea temperature difference to wind speed and direction, as well as the meteorological conditions under which this formula may be applied, are also evaluated.

1. Introduction

Recent papers by Schwing and Blanton (1984) and Liu et al. (1984) discuss the correction of land-based wind data for offshore applications. This topic is of major concern to nearly all physical oceanographers and marine meteorologists working in the coastal zone.

Since it has long been known that a difference exists between onshore and offshore wind speeds (e.g., Hsu, 1981), it is not the purpose of this note to further discuss these differences. Rather, we provide substantial evidence to further support and extend to other parts of the world a formula that was tested successfully in physical oceanographic studies in the Great Lakes region.

2. Evaluation of formulas

The equations of motion have been used to derive the following formula (see Hsu, 1981, Eq. 7):

$$\frac{U_{\text{sea}}}{U_{\text{land}}} = \left[\frac{H_{\text{sea}} \cdot C_{D\,\text{land}}}{H_{\text{land}} \cdot C_{D\,\text{sea}}}\right]^{1/2} \tag{1}$$

where U, H, and C_D are the wind speed, height of the planetary boundary layer (PBL), and drag coefficient, respectively. Subscripts "sea" and "land" represent offshore and onshore conditions, respectively. Equation (1) should be applicable whether the wind blows from land to sea or vice versa, assuming that the geostrophic wind above the PBL across the coastal zone does not change appreciably.

For a given climatological regime, values of parameters on the right-hand side of Eq. (1) are known. For example, using data from Holzworth (1972) and SethuRaman and Raynor (1980) for the New York-Massachusetts region (see Hsu, 1981) and Eq. (1), $U_{\text{sea}}/U_{\text{land}} = 1.7$, where $H_{\text{sea}} = 620$ m, $H_{\text{land}} = 1014$ m, $C_{D\,\text{land}} = 0.0083$, and $C_{D\,\text{sea}} = 0.0017$ (at 8 m above the land and sea surfaces). Therefore, from Eq. (1) and this example, U_{sea} is linearly related to U_{land}. From a statistical point of view, we then have

$$U_{\text{sea}} = A + BU_{\text{land}} \tag{2}$$

where values of A and B are to be determined empirically.

Note that since a low-level jet may prevail over a coastal region near the surface, particularly in the offshore region (e.g., see Hsu, 1979a), U_{sea} may not be equal to zero when U_{land} is zero. In other words, when onshore conditions are calm, it is not necessary that winds offshore also be calm. This is because strong pressure gradient and baroclinic effect exist across the coastal zone, so that during the day there might be a sea breeze and at night stronger winds such as a land breeze or low-level jet might prevail offshore (Hsu, 1970, 1979a). Thus parameter A in Eq. (2) is also a necessary meteorological requirement.

Most recently, Liu et al. (1984) refined equations originally developed by Schwab (1978) based on graphs given by Resio and Vincent (1977) for the Great Lakes region when the wind was blowing from land to water:

$$\frac{U_{\text{sea}}}{U_{\text{land}}} = \left(1.2 + \frac{1.85}{U_{\text{land}}}\right)\phi(\Delta T) \tag{3}$$

$$\phi(\Delta T) = 1 - \frac{\Delta T}{|\Delta T|}\left(\frac{|\Delta T|}{1920}\right)^{1/3} \tag{4}$$

$$\Delta\theta = (12.5 - 1.5\Delta T) - (0.38 - 0.03\Delta T)U_{\text{sea}} \tag{5}$$

where ΔT is the air–water temperature difference (°C) and $\Delta\theta$ is the clockwise angle between over-land and over-lake winds (degrees).

Equations (3), (4) and (5) have been successfully applied to modeling storm surge and current fluctuations in the Great Lakes (Schwab, 1978, 1983).

Equations (4) and (5) are related to the correction of the ratio of $U_{\text{sea}}/U_{\text{land}}$ by air–sea temperature differ-

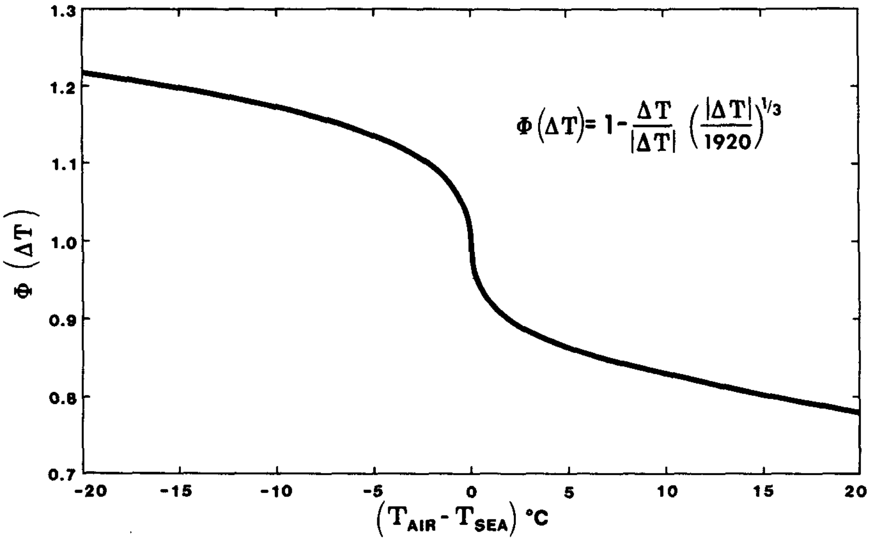

FIG. 1. An evaluation of Eq. (4) (see text for explanation).

ence and the difference in wind direction between land and sea, respectively. If the corrections predicted by Eqs. (4) and (5) can be shown to be smaller than the reported differences resulting from instrumental noise and recorder errors, one may neglect these differences. This was done, and is demonstrated as follows.

Equations (4) and (5) are plotted in Figs. 1 and 2, respectively. It can be seen that for $|\Delta T| \leq 5$°C, the correction to $U_{\text{sea}}/U_{\text{land}}$ is less than 15%, and the value of $\Delta\theta$ is less than 18°. Also, the contribution of U_{sea} to $\Delta\theta$ is small. Note that even when T_{sea} is 20°C warmer than the air, $\Delta\theta \approx 38°$.

On the other hand, it has been shown by Haltiner and Martin (1957, p. 235) that the difference in values of the surface cross-isobar angle between onshore and offshore airflow can be 20°. Furthermore, according to Mazzarella (1985, p. 291), the field accuracy for wind direction for a common wind vane is approximately

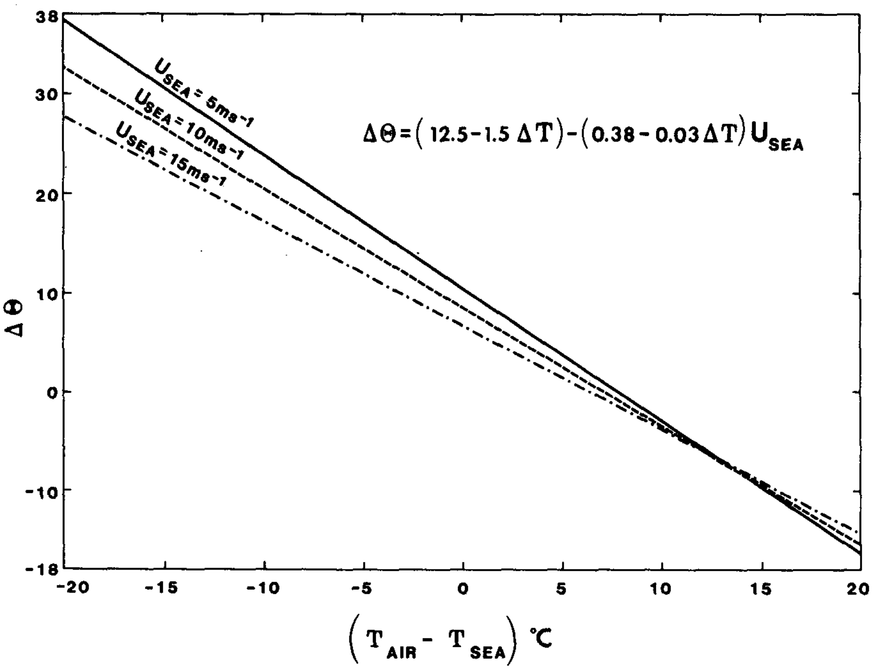

FIG. 2. An evaluation of Eq. (5) (see text for explanation).

8°, and gust direction, 15°. The recorded resolution for the wind vane is 10°. Therefore, the composite contribution by frictional effects, instrument error, and recorder inaccuracy may reach 45° in wind direction. In other words, for the same geostrophic wind across the coastal zone, the difference in wind direction between onshore and offshore near the surface may be as large as 45°. For this reason, and because most of the time $|\Delta T|$ is much less than 20°C, corrections of $\Delta\theta$ by U_{sea} and ΔT are not very important operationally, as shown in Fig. 2.

From the above evaluation a criterion may be set: If the difference in direction between onshore near-surface winds and offshore near-surface winds is within 45°, Eq. (1) may be employed, whether the wind blows from land to sea or vice versa. From a meteorological point of view, then, this criterion should be applicable under weather systems such as land and sea breezes (e.g., Hsu, 1970), hurricanes near landfall (Powell, 1982), and other larger (or synoptic scale) phenomena such as cyclones (lows), monsoons, and anticyclones (highs), but not during the passage of atmospheric fronts and squall lines across the coastal zone. This criterion also implies that climatological wind data onshore (say, monthly averages) would be used for offshore estimates, since the transient weather systems, e.g., squall lines, frontal passages, and local thunderstorms, usually do not last more than a day or two. If we assume that ΔT is small in Eq. (3) (Fig. 1), say less than ±5°C, as normally is the case, and since the aggregate wind estimation error cannot be less than 10% at airports, where most official weather service stations are located (see, Wieringa, 1980), we have (by setting $\phi(\Delta T) \approx 1$)

$$\frac{U_{\text{sea}}}{U_{\text{land}}} = 1.2 + \frac{1.85}{U_{\text{land}}}$$

or

$$U_{\text{sea}} = 1.85 + 1.2U_{\text{land}}. \qquad (6)$$

This further supports the general form of Eq. (2). On the other hand, one may state that the semiempirical formula shown in Eq. (6) is supported by our theoretical considerations, shown in Eq. (1).

Based on many pairs of datasets, from environments ranging from the tropics to the Gulf of Alaska, Eq. (2) is verified as shown in the following section.

3. Experimental results

Many pairs of onshore and offshore measurements under land and sea breezes, monsoon, and synoptic-scale weather systems have become available recently (Hsu, 1981). In addition to those listed in Hsu, one more pair, obtained under hurricane landfall conditions, is included in Table 1. Ratios of $U_{\text{sea}}/U_{\text{land}}$ were analyzed as a function of U_{land}. Note that in Hsu (1981) wind speeds were below 18 m s^{-1}. The data set provided in Powell (1982) included hurricane-force wind measurements obtained during Hurricane Frederic, which struck the Alabama coast in 1979. Although there are differences in measuring distances between onshore and offshore stations as well as lateral distance from the eye of the hurricane, the data are grouped here, as shown in Table 1, for operational use. Note that the datasets in Table 1 satisfy the criterion discussed in the previous section. Statistical evaluation such as mean and standard deviations for pairs of observations in these various regions are also included in Table 1.

Pairs of U_{sea} obtained from column (10) in Table 1 and U_{land}, from column (1), were linearly regressed as guided by Eq. (2). The result is plotted in Fig. 3, and the linear regression equation is

$$U_{\text{sea}} = 1.62 + 1.17U_{\text{land}} \qquad (7)$$

with a very high value of coefficient of determination, $r^2 = 0.99$.

For comparison, Eq. (6) is also plotted in Fig. 3. It is shown that the difference between Eqs. (6) and (7) is not significant; for example, at the highest wind speed observed, i.e., $U_{\text{land}} = 35$ m s^{-1}, the difference between the values of U_{sea} is less than 1.5 m s^{-1}. Since Eq. (7) did not take air–sea temperature differences into consideration, these differences are surprisingly negligible. Equation (7) is thus recommended for operational use. If $|\Delta T|$ is large, say, 5°C, Eqs. (3) and (4) (or Fig. 1)

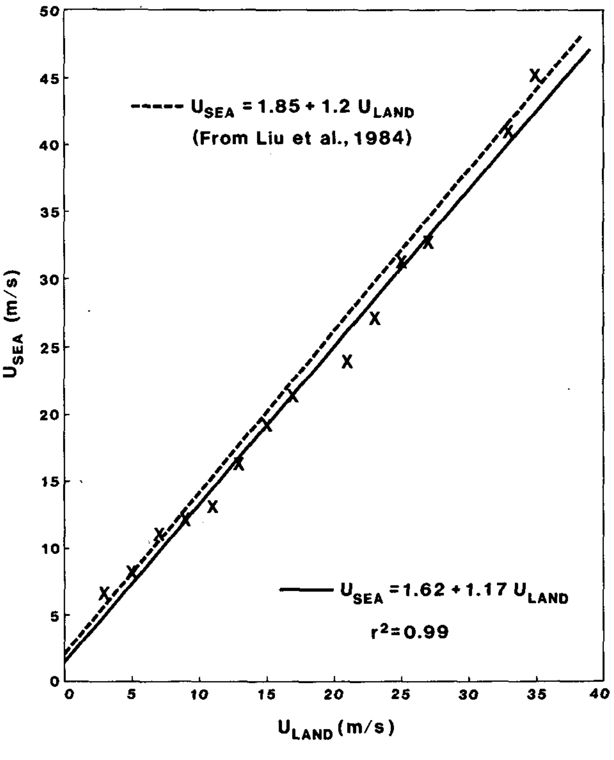

FIG. 3. Variation of U_{sea} as a function of U_{land}.

TABLE 1. Summary of the ratio of U_{sea}/U_{land} as a function of U_{land} (in m s^{-1}) as measured at coastal stations and offshore buoys, ships, and research platforms.

U_{land} class (m s^{-1}) Interval (1)	Midpoint (2)	NOAA buoys vs coastal sta.[a] (3)	BNL buoys vs onshore tower[d] (4)	NCSC platform vs Apalachicola[e] (5)	Ship vs Mogadishu[f] (6)	Ship vs Gardo[g] (7)	Hurricane Frederic, 1979[h] (8)	Average by region[i] (9)	U_{sea} (m s^{-1}) (10)[k]
2.0–3.9	3.0	1.51 ± 0.42[b] (5)[c]	2.30	1.99 ± 0.70 (102)	2.64 ± 0.94 (5)	2.52 ± 1.52 (7)		2.19 ± 0.45 (8)[j]	6.6
4.0–5.9	5.0	1.34 ± 0.32 (39)	2.02	1.42 ± 0.54 (35)	1.72 ± 0.71 (25)	1.72 ± 1.20 (7)		1.64 ± 0.27 (8)	8.2
6.0–7.9	7.0	1.36 ± 0.08 (4)	1.59	1.33 ± 0.43 (8)	1.50 ± 0.62 (39)	2.19 ± 1.26 (14)		1.59 ± 0.35 (8)	11.1
8.0–9.9	9.0		1.35	1.19 (1)	1.38 ± 0.47 (13)	1.52 ± 0.72 (5)		1.35 ± 0.13 (4)	12.2
10.0–11.9	11.0		1.23	1.09 (1)	1.13 (1)	1.31 ± 0.32 (15)		1.19 ± 0.10 (4)	13.1
12.0–13.9	13.0		1.20			1.29 ± 0.21 (7)		1.25 ± 0.06 (2)	16.3
14.0–15.9	15.0		1.20			1.35 ± 0.25 (2)		1.28 ± 0.06 (2)	19.2
16.0–17.9	17.0		1.20				1.32 ± 0.02 (3)	1.26 ± 0.08 (2)	21.4
18.0–19.9	19.0								
20.0–21.9	21.0						1.14 (1)	1.14 (1)	23.9
22.0–23.9	23.0						1.18 (1)	1.18 (1)	27.1
24.0–25.9	25.0						1.25 (1)	1.25 (1)	31.3
26.0–27.9	27.0						1.21 ± 0.02 (2)	1.21 (1)	32.7
28.0–29.9	29.0								
30.0–31.9	31.0								
32.0–33.9	33.0						1.24 (1)	1.24 (1)	40.9
34.0–35.9	35.0						1.29 (1)	1.29 (1)	45.2

[a] From four geographic regions ranging from tropical to arctic (see Fig. 1 in Hsu, 1981).

[b] Mean ± standard deviation.

[c] Total number of observational pairs (onshore and offshore).

[d] Averaged data pairs between beach tower at Long Island, New York, and offshore Brookhaven National Laboratory buoy (from SethuRaman and Raynor, 1980).

[e] U.S. Naval Coastal Systems Center platform offshore from Panama City, Florida, and NOAA Apalachicola station (see Hsu, 1979a).

[f] Merchant ship observations vs Mogadishu, Somalia (under conditions of general summer monsoon, but away from the Somali jet). For this experiment, see Fein and Kuettner (1980) and Hsu (1981).

[g] Merchant ship observations vs. Gardo, Somalia (under conditions of Somali low-level jetstream).

[h] Based on Powell (1982).

[i] Mean ± standard deviation averaged from five columns between (3) and (8).

[j] Total areas studied. Note four areas already included in Fig. 1 in Hsu (1981).

[k] Obtained by multiplying column (9) by column (2).

may be employed. Equation (7) should also be useful for climatological applications.

However, as stated in Hsu (1981), for the more accurate forecasting required by marine meteorologists at the National Weather Service, Eq. (1) should be used. The value for H_{sea} may be estimated from H_{land} (Hsu, 1979b), which is routinely available from radiosonde measurements. To obtain the value of $C_{D\ \text{land}}$, one may use 10×10^{-3}, as obtained by Garratt (1977). For values of $C_{D\ \text{sea}}$, other studies may be consulted, e.g., Large and Pond (1981).

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