The Use of Land and Sea Based Wind Data in a Simple Circulation Model

FRANKLIN B. SCHWING AND JACKSON O. BLANTON
Skidaway Institute of Oceanography, Savannah, GA 31416

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ABSTRACT

The use of land based wind data in nearshore oceanographic work is common, but these winds do not accurately reflect coastal oceanic winds. Ocean winds are often underestimated by a factor of 2 and directional differences are also observed. Wind time series from land and sea regimes in the South Atlantic Bight (SAB) were applied to a reduced form of the momentum equation to estimate the alongshore current. Currents were closely approximated by ocean wind stress, but were consistently underestimated by land data. Further statistical analyses verified this discrepancy in speed and also indicated significant differences between ocean and speed-adjusted land winds. The bottom frictional coefficient required to balance alongshore momentum was unrealistically small when land based wind data were used as input.

1. Introduction

Oceanographers often use local wind records to determine the effects of wind stress on coastal currents. The lack of ocean-based wind stations generally makes it necessary to use data from land bases, often located many kilometers from the study site. Although land-based time series data are easier to obtain, there is evidence that they do not accurately reflect coastal oceanic wind regimes. Differences in surface roughness and thermal gradients can produce variations in wind stress on small spatial scales (SethuRaman and Raynor, 1980). San Diego Airport winds were comparable to ship winds only within 10 km of the coast (Dorman, 1982). On the New Jersey continental shelf, wind speeds at an offshore sea buoy were twice those at Atlantic City (Halliwell and Mooers, 1980). We found similar differences in magnitude, as well as periodic directional differences, after comparing land and ocean wind speeds in the South Atlantic Bight (SAB).

The discrepancy between land and sea wind regimes is significant. Wind velocity over a land or sea surface, even when free of topographic irregularities, is a complicated function of stress at the surface, height above the surface, and the thermal stability of the air (Kraus, 1972; SethuRaman and Raynor, 1980). Correctly adjusting wind velocity data over land to reflect stress on the nearby ocean accurately requires a knowledge of wind shear and thermal stability at both locations—a requirement that is seldom met in practice.

We have compared land- and sea-based wind regimes in the SAB by applying data from each into a simple model that calculates alongshore current from wind stress. Subtidal nearshore currents were estimated from wind stress values for land and ocean winds and these were compared to measured currents. This use of wind data is typical of applications which involve study of oceanographic processes. The land based sensor was at a height of 10 m, while the ocean based sensor was 30 m above the sea surface. Land winds were not adjusted, because precise corrections for ocean–land differences in vertical shear and stability are difficult to define, and oceanographers typically use unadjusted wind data in their work. In the course of this study, we make no attempt to model the nearshore current in any detail. Rather, we use a simple momentum-balance model to show the potential problems inherent when using land based winds in oceanographic work.

2. Data

The wind data were derived from hourly measurements collected 30 May–4 July 1977 at two sites in the coastal region of Georgia (Fig. 1). Land winds were taken from data collected by a National Weather Service Class 2 station at Travis Airfield (SAV), located 35 km inland. The anemometer was unobstructed in all directions for at least 1 km. Land winds were measured instantaneously each hour.

Ocean winds were measured at Savannah Navigational Light Tower (SNLT), 20 km offshore. The anemometer here was completely unobstructed. Current data (2 m from the bottom) were also collected at SNLT, where the mean depth is 16 m. Hourly values at SNLT were produced by averaging instantaneous values every 10 min. Land winds were measured instantaneously. All three series were adjusted to oceanographic sign convention and low-pass filtered with a ¼ power point at 40 h and resampled at 6 h intervals. The resulting series contain 144 values (Fig. 2).

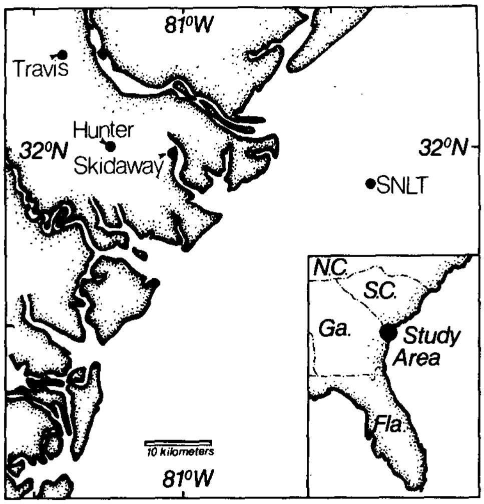

FIG. 1. Area map showing location of sampling sites. Land winds (SAV) obtained at Travis Airfield (Travis). Ocean winds (SNLT) and currents obtained at Savannah Navigational Light Tower (SNLT).

TABLE 1. Statistical summary of land and ocean wind and ocean current data derived from 40 h low-passed time series (30 May–4 July 1977; $n = 859$ hourly values). SE and NE refer to components offshore and alongshore, respectively. Spectral statistics represent averages for the bands less than 40 h (0.6 cpd); wind and current velocities are in units of m s^{-1} and cm s^{-1} respectively.

	Land wind	Ocean wind	Ocean current
Mean SE component	0.57 ± 1.46	0.01 ± 2.47	1.23 ± 2.49
Mean NE component	1.22 ± 1.76	3.17 ± 3.83	4.71 ± 4.94
Band average variance	2.63	13.28	20.73
	Cospectra	Phase (h)	Coherence squared
Wind (land–ocean)	5.54	0	0.88*
Land wind-current	5.47	6.5	0.73*
Ocean wind-current	11.78	7.5	0.84*

* Significant at 0.05 level.

3. Results

The means and standard deviations of all series were calculated from the hourly 40 h (0.6 cpd) low-passed data (Table 1). Vectors were rotated into alongshore (northeast) and cross-shore (southeast) components. In addition to an apparent directional difference of the mean vector, wind speed was greater at the ocean site. The variance in ocean winds was also higher, indicating a greater range in the overall wind field. In the current and wind series, variance was greater in the alongshore than in the cross-shore direction.

Total variance in each wind series is presented in spectra generated from 10 h (2.4 cpd) low-passed versions which preserve the sea breeze (Fig. 3). Two periods dominated the spectra: the sea-breeze peak at 1 day (1.0 cpd) and a low-frequency band at 3–5 days (0.2–0.33 cpd). Variance at SNLT was greater at all frequencies.

Total low-frequency variance in the band greater than 40 h verifies that winds over the ocean were significantly stronger than those over land (Table 1). Cross-spectral relations between winds and currents are also summarized in Table 1. Low-frequency winds were in phase and led the nearshore bottom current by ~7 h. Cross-correlations between land winds, ocean winds and currents were all coherent at the 0.05 level.

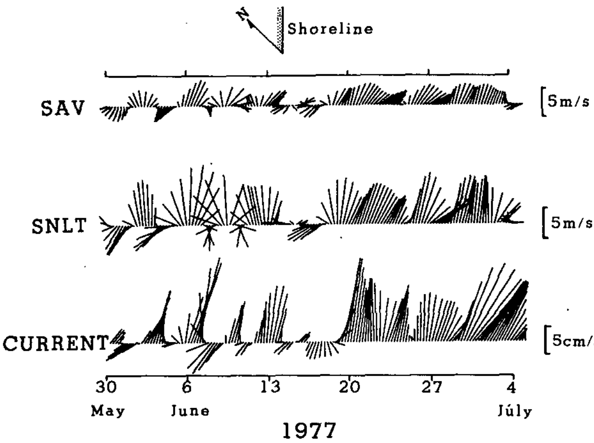

FIG. 2. Stick vector diagrams of 40 h (0.6 cpd) low-passed time series, 30 May–4 July 1977. SAV is land wind, SNLT is ocean wind. Currents obtained 2 m above bottom at SNLT; $\Delta t = 6$ h. All data are in oceanographic convention; i.e., wind vectors point downwind.

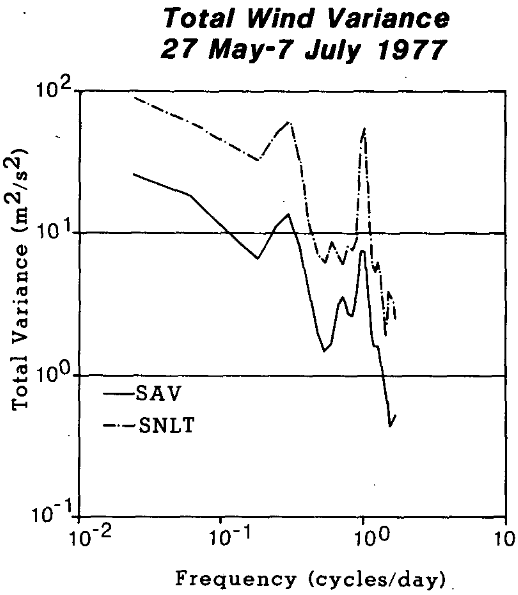

FIG. 3. Auto-spectra of 10 h (2.4 cpd) low-passed land (SAV) and ocean (SNLT) wind time series, 27 May–7 July 1977. Total energy in vectors is expressed in variance units.

4. Discussion

Past studies indicate that the low-frequency nearshore current off Georgia is primarily wind-driven (Blanton, 1981) and a simple momentum balance produces fairly accurate estimates of the alongshore current. The vertically integrated momentum balance is sufficient to demonstrate problems associated with the use of land-based winds. We emphasize that we are not attempting to model the near-shore current but are simply comparing local wind regimes using typical oceanographic analyses.

a. Momentum-balance model

The two series of wind records were used as input to the alongshore component of the vertically integrated momentum equation [Eq. (1)], i.e.,

$$C_D V_y |V_y| = \tau_y - \rho g h \partial\eta/\partial y, \qquad (1)$$

where C_D is the bottom stress coefficient, V_y and τ_y are alongshore components of current velocity and wind stress, respectively, ρ is density, g gravity, h total water depth, and $\partial\eta/\partial y$ the alongshore slope of sea level. The body force of sea level slope in shallow water is relatively small compared to the vertically integrated terms for surface and bottom stress. Blanton (1981) estimated alongshore slopes of $O(10^{-7})$. For water depths of 10 m, the last term of Eq. (1) is ~10% of the other two terms for a wind stress of 1 dyn cm^{-2} and bottom currents and C_D values typical of shallow water off the Georgia coast.

Thus, Eq. (1) was reduced to

$$\hat{V}_y = (|\tau_y|/C_D)^{1/2}, \qquad (2)$$

where the sign of $\hat{V}_y$ is that of τ_y. Because currents only 2 m off bottom were compared to $\hat{V}_y$ in Eq. (2), C_D was set to 1×10^{-2}, based on literature values for bottom stress in shallow water (Winant and Beardsley, 1979).

From Eq. (2), time series of estimated currents were produced from each wind record (Fig. 4). No attempt was made to rectify wind-current phase lags. Use of this extremely simple model shows that currents estimated from ocean wind-stress values closely approximate measured alongshore bottom currents at SNLT (Fig. 4a). Land winds, however, consistently underestimated the nearshore current (Fig. 4b). This is expected since the velocity of land winds is significantly less than ocean winds, hence producing significantly less stress. Surface roughness at the land site is 10–100 times greater than at the ocean site, causing a reduction in wind speeds (Kraus, 1972).

Obviously, winds measured on land yield different results from ocean winds. Wind stress over the ocean almost exclusively drives the nontidal nearshore current (Fig. 4a), as found in previous work in the SAB (Blanton, 1981; Schwing *et al.*, 1983). An interpretation of the land based results (Fig. 4b) may lead one to conclude that other forces act in conjunction with wind stress to produce the alongshore current. While this is partly true, other observations show that wind stress accounts for more of the current than is estimated by the land version of the model. It is expected that wind stress will overwhelm alongshore pressure gradients in shallow near shore waters (Csanady, 1973; Blanton, 1981).

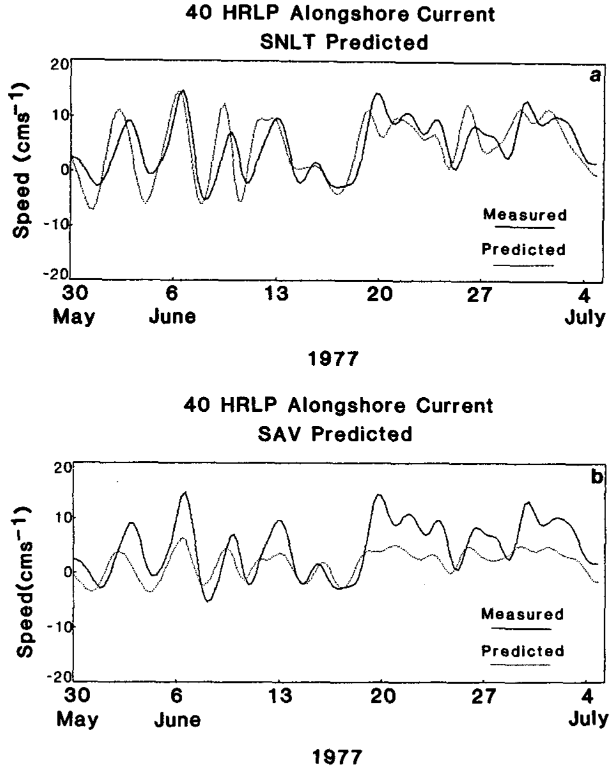

FIG. 4. Plot of alongshore currents estimated by model [Eq. (2)] from (a) ocean (SNLT) and (b) land (SAV) winds versus measured currents 2 m above bottom at SNLT, 30 May–4 July 1977. Uncorrected for phase lag.

b. Statistical models

The statistical relationship between each wind series and current data can be further examined using the simple linear regression of V_y on τ_y. The form of the equation is

$$V_y = \beta_0 + \beta_1 \tau_y. \qquad (3)$$

Writing Eq. (1) in this form, the intercept β_0 is equal to $-k\rho g h(\partial\eta/\partial y)$ and the slope β_1 is k, where $k = 1/(C_D \cdot V_{\mathrm{rms}})$, the inverse of the drag coefficient times the root-mean-squared tidal velocity. In the regression analysis, inputs are actual velocity and stress values. Using the same constants for ρ, g, h and C_D as in Eq. (1), a time-averaged V_{rms} and $\partial\eta/\partial y$ are obtained.

In addition to using land and ocean wind-stress data, a third series of wind stress was created by doubling land wind speeds to approximate those over the ocean.

TABLE 2. Summary of statistical tests applied to data for land-based winds, land-based winds whose speeds were adjusted by doubling, and ocean-based winds. See text for details.

	Land-based	Land-based (adjusted)	Ocean	Literature value
Simple linear regression:				
Correlation (r^2)	0.83*	0.83*	0.86*	
RMS current velocity (cm s^{-1})	2	10	13	13[1]
Sea level slope ($\times 10^{-7}$)	−0.3	−1.2	−1.1	−2.0[2]
Paired *T*-test:				
t	11.13*	5.17*	0.96	

* Significant at 0.05 level.

[1] Kundu *et al.*, 1981.

[2] Sturges, 1974.

Regression analyses (Table 2) show that r^2 is significant for all three wind series. Using τ_y as the only independent variable accounted for a significant amount of the variability in V_y. However, solutions for V_{rms} and $\partial\eta/\partial y$ were underestimated with land data. Kundu *et al.* (1981) calculated a V_{rms} of 13 cm s^{-1} 2 m from the bottom at SNLT. Regression estimates of V_{rms} were in close agreement for ocean and adjusted land series, but much lower for unadjusted land winds. Ocean and adjusted land values for $\partial\eta/\partial y$ were similar to the average Gulf Stream sea level slope of -2.0×10^{-7} (Sturges, 1974), while the slope determined from the land regression was an order of magnitude lower.

For a final statistical comparison of the wind data, paired *t*-tests were made between measured currents and currents estimated from the ocean and two land wind series (Table 2). Comparisons with unadjusted and adjusted land estimates were both significantly different at the 0.05 level, indicating that only currents estimated from ocean wind values were statistically similar to those measured.

5. Conclusions

The accuracy with which speed-adjusted land winds describe ocean winds can be questioned. Over several days, mean directional variability is probably not great (Blanton *et al.*, 1983), but accumulated small differences in speed and direction can cause large discrepancies in calculations of the overall momentum imparted to the water. This may be due to large differences in over-land convection and roughness lengths across the coastal boundary. Both act to decouple the land and ocean wind regimes at some frequencies.

To illustrate this point, accumulated wind impulse per unit area was plotted over time (Fig. 5). The accumulated impulse of land winds was much smaller than for ocean winds. Adjusted land impulse was also smaller, probably because of directional variability. A similar analysis of winter data (not shown) makes these differences particularly evident.

Direct comparisons of land- and ocean-based wind records in the SAB, along with simple oceanographic analyses of the wind-driven alongshore current, provide evidence that the two wind regimes are significantly different in magnitude and direction. Therefore, land-based data used in oceanographic models must be used with great caution. It may be possible to correct land data to resemble ocean winds, but directional variability makes the problem complex and corrections may not apply during some seasons (Weisberg and

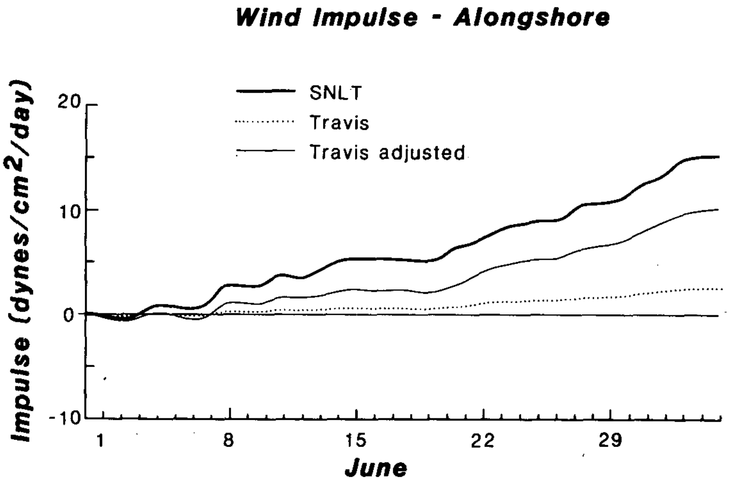

FIG. 5. Plot of accumulated wind impulse in alongshore direction from ocean (SNLT), land (Travis) and speed-adjusted land (Travis adjusted) winds, 30 May–4 July 1977. Land wind speeds were doubled before calculating Travis adjusted wind impulse series.

Pietrafesa, 1983). Statistical analyses show that currents estimated from unadjusted as well as speed-adjusted land winds were significantly different from measured currents. Thus, the speed of land winds must be corrected and directional adjustments are preferable, before such wind series can be used accurately to describe coastal ocean wind regimes.

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REFERENCES

Blanton, J. O., 1981: Ocean currents along a nearshore frontal zone on the continental shelf of the southeastern United States. *J. Phys. Oceanogr.*, **11**, 1627–1637.

——, F. B. Schwing, A. H. Weber, L. J. Pietrafesa and D. W. Hayes, 1983: Wind stress climatology. *Oceanography of the Southeastern United States.* Unpublished manuscript, 22 pp. + Tables, Figures.

Csanady, G. T., 1973: Wind-induced barotropic motions in long lakes. *J. Phys. Oceanogr.*, **3**, 429–438.

Dorman, C. E., 1982: Winds between San Diego and San Clemente Island. *J. Geophys. Res.*, **87**, 9636–9646.

Halliwell, G. R., Jr., and C. N. K. Mooers, 1980: Statistical analysis and hindcasts of atmospheric forcing fields in the Georges Bank–Gulf of Maine region. Appendix G of the 13th Quarterly Progress Report. EG&G Environmental Consultants, Waltham, MA.

Kraus, E. B., 1972: *Atmosphere-Ocean Interaction.* Clarendon Press, Oxford, 139–141.

Kundu, P. J., J. O. Blanton and M. M. Janopaul, 1981: Analysis of current observations on the Georgia shelf. *J. Phys. Oceanogr.*, **11**, 1139–1149.

Schwing, F. B., B. Kjerfve and J. E. Sneed, 1983: Nearshore coastal currents on the South Carolina continental shelf. *J. Geophys. Res.*, **88**, 4719–4729.

SethuRaman, S., and G. S. Raynor, 1980: Comparison of mean wind speeds and turbulence at a coastal site and an offshore location. *J. Appl. Meteor.*, **19**, 15–21.

Sturges, W., 1974: Sea level slope along continental boundaries. *J. Geophys. Res.*, **79**, 825–830.

Weisberg, R. H., and L. J. Pietrafesa, 1983: Kinematics and correlation of the surface wind field in the South Atlantic Bight. *J. Geophys. Res.*, **88**, 4593–4610.

Winant, C. D., and R. C. Beardsley, 1979: A comparison of some shallow wind-driven currents. *J. Phys. Oceanogr.*, **9**, 218–220.