# Wind stress on nearshore and lagoonal waters of a tropical island[1]

*Abstract*—Wind profiles were measured over a windward lagoon and a quasi-leeward area in Barbados, West Indies, under the prevailing trade winds. Relationships between shear and wind velocities for these environments were determined. Under average wind conditions the shear stress on these coastal waters is about 72% of that of an oceanic region.

The wind stress $\tau$ $(=\rho U_*^2$, where $\rho$ is the air density and $U_*$ is the shear or friction velocity) is of considerable importance because it plays an essential part in all processes of momentum transfer across the air–sea boundary (Roll 1965). The relationship between $U_*$ and $U_z$ (the mean horizontal wind velocity at height $z$) or $C_z$ $[=(U_*/U_z)^2]$, the corresponding drag or resistance coefficient, has been investigated for more than 30 years (*see* Roll 1965; Wu 1969; Kraus 1972). Most experiments, however, have been designed to avoid coastal effects.

It has been recognized for some time that certain differences in $\tau$ values exist between oceanic and nearshore regions (Roll 1965; Hsu 1972). One obvious reason for these changes is that as deep water waves approach coastal regions they tend to reflect, diffract, or refract, depending on local conditions. Therefore, the airflow must readjust itself constantly not only between $U_*$ and $U_z$ but also among aerodynamic roughness, wave height, and phase velocity in the manner suggested by Hsu (1974). This report documents the $U_*$ values measured in the nearshore environments of a lagoon behind a linear fringing reef and the coastal water of a tropical island under the effect of trade winds and compares these with the results of similar investigations in an oceanic region.

[1] This study was supported by Office of Naval Research contract N00014-69-A-0211-0003, project NR 388 002. The Government of Barbados, and particularly G. Rudder of the Caribbean Meteorological Institute, cooperated on the project. N. Rector, R. Fredericks, and B. Montgomery helped perform the experiment.

This study is an integral part of an investigation undertaken by the Coastal Studies Institute, Louisiana State University, of the dynamical processes operating near the coast of a tropical island under the effect of prevailing trades. The field program was carried out in July–August 1973 on the island of Barbados.

Instruments used for this study included two identical portable Thornthwaite wind profile register systems (C. W. Thornthwaite Assoc. model 106) with six-unit, three-cup, fast-response anemometers mounted about 75, 95, 135, 215, 295, and 375 cm above the mean water surface of the lagoon near Bath Beach (referred to hereafter as lagoon site) and 140, 160, 200, 280, 360, and 440 cm above the mean water surface of the coastal water, which is about 230 m offshore from the beach near Hastings (hereafter referred to as the coastal water) (Fig. 1). The mean water depths were 1.8 and 8.0 m, respectively. The instrument setups were similar to those reported in Hsu (1972: fig. 2). The wind profile instrumentation, data reduction, and analytic procedures have been described elsewhere (Hsu 1971).

Several additional parameters were measured in the study areas for reference purposes: air–water temperature differences, tidal fluctuation, and wind speed and direction at 5 m above the ground level for the lagoon site and 10 m for the leeward site.

During the experimental period 1,034 samples of 15-min average wind profiles having statistically significant logarithmic wind distribution with height over the coastal water, and some 311 samples of 30-min average profiles over the lagoon site, were collected. These profiles were determined by the fact that, when plotted on semilogarithmic paper, they gave straight lines with a correlation coefficient $\geq 0.98$ (*see* Hsu 1971, 1972). Figure 2 shows the relationship between $U_*$ and $U_{10m}$ for the coastal water. The vertical bars in the figure represent the standard deviations.

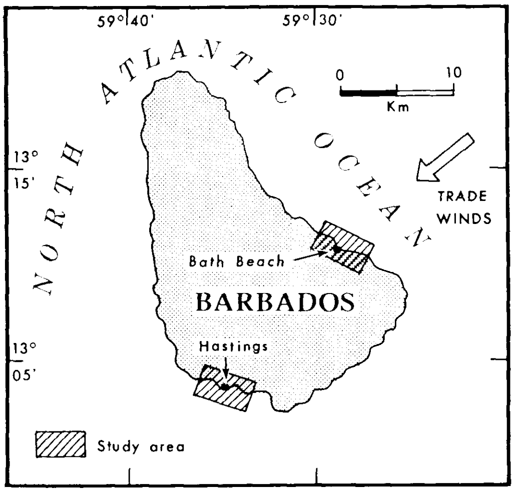


Fig. 1. Location map for the study areas.

Similarly, Fig. 3 shows the result for the lagoon site, except that here $z$ is chosen arbitrarily to equal 1 m instead of the conventional 10 m so that it may be compared with similar nearshore studies. In fact, the drag coefficient at 1 m over the lagoon is $0.9 \times 10^{-3}$ [calculated by $(U_*/U_{1m})^2$], which is in general agreement with similar measurements under shallow-water, fetch-limited, and near-neutral atmospheric stability conditions at a coastal inlet (Smith 1967;

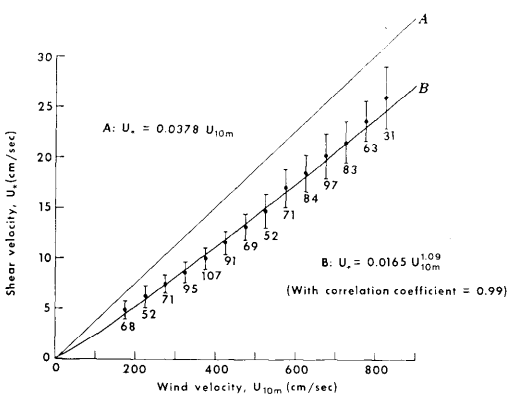


Fig. 2. Curve A is based on open ocean BOMEX data from Pond et al. (1971) with the stability and height corrections applied according to Hsu (in press) on the windward ocean east of Barbados. Curve B represents the measurements made on quasi-leeward coastal water near Hastings, Barbados.

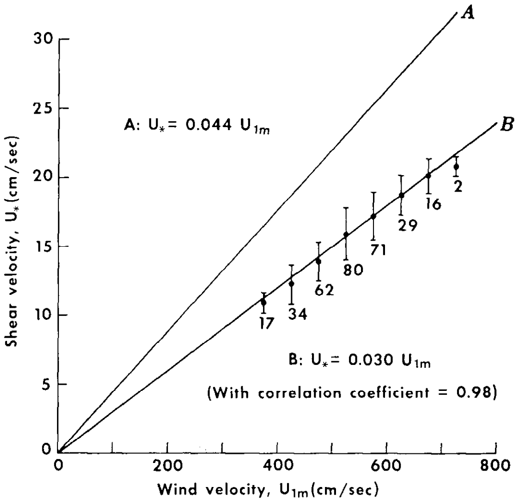


Fig. 3. Curve A is based on open ocean BOMEX data from Pond et al. (1971) with stability and height corrections applied according to Hsu (in press) on the windward ocean east of Barbados. Curve B is the measurements made in the lagoon near Bath Beach, Barbados.

Miyake et al. 1970). It is easy to transpose the results to 10-m height by using the logarithmic wind profile equation, $U_z = U_*/k \ln Z/Z_0$, where the symbols have their conventional meanings (e.g. Roll 1965).

For comparison purposes the open ocean condition east of Barbados (Pond et al. 1971) is also shown in Figs. 2 and 3. Note that the BOMEX data have been corrected from the wind profile under slightly unstable atmospheric stability conditions to the adiabatic logarithmic wind profile selected from the nearshore measurements (Hsu in press). The wind speed range of Pond et al. (1971) was from about 3 to 7 m $sec^{-1}$ and the standard deviation of the drag coefficient was $0.26 \times 10^{-3}$. These two data sets (i.e. the BOMEX data obtained by eddy correlation and my data obtained by the profile technique) may be reliably compared (Miyake et al. 1970).

Figures 2 and 3 indicate the following values for $U_*$, which may be compared with measurements at $Z = 10$ m:

For open ocean, $U_* = 0.0378\, U_{10m}$;
for lagoon environment, $U_* = 0.026\, U_{10m}$;
for coastal water, $U_* = 0.0165\, U_{10m}^{1.09}$.

Therefore I conclude that under average trade wind conditions (5–6 m $sec^{-1}$) the wind stress over the sea, averaged between the two nearshore study areas, is about 72% of the oceanic value. The reason for this reduction may be that the lagoon water is smoother, has smaller roughness length and hence smaller drag coefficients than the coastal water; the same relationship exists between coastal measurements and deep water observations. In fact, $U_*$ values, as inferred from the wind profile measurements, are in agreement with those read from the wind-stress nomogram provided by Hsu (1974) using wave measurements made by J. N. Suhayda (personal communication) in the general study area close to the wind profile stations.

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*References*

Hsu, S. A. 1971. Measurement of shear stress and roughness length on a beach. J. Geophys. Res. **76**: 2880–2885.

———. 1972. Wind stress on a coastal water surface, p. 2531–2541. *In* Proc. Coastal Eng. Conf., 13th, Vancouver, B.C., v. 3. Am. Soc. Civil Eng.

———. 1974. A dynamic roughness equation and its application to wind stress determination at the air-sea interface. J. Phys. Oceanogr. **4**: 116–120.

———. In press. On the log-linear wind profile and the relationship between shear stress and stability characteristics over the sea. Boundary-Layer Meteorol.

Kraus, E. B. 1972. Atmospheric-ocean interaction. Oxford.

Miyake, M., and others. 1970. Comparison of turbulent fluxes over water determined by profile and eddy correlation techniques. Quart. J. R. Meteorol. Soc. **96**: 132–137.

Pond, S., G. T. Phelps, J. E. Paquin, G. McBean, and R. W. Stewart. 1971. Measurements of turbulent fluxes of momentum, moisture and sensible heat over the ocean. J. Atmos. Sci. **28**: 901–917.

Roll, H. U. 1965. Physics of the marine atmosphere. Academic.

Smith, S. D. 1967. Thrust anemometer measurements of wind-velocity spectra and of Reynolds stress over a coastal inlet. J. Mar. Res. **25**: 239–262.

Wu, J. 1969. Wind stress and surface roughness at air-sea interface. J. Geophys. Res. **74**: 444–455.

*Submitted: 11 April 1974*
*Accepted: 22 July 1974*

# Nutrient transports through Lancaster Sound in relation to the Arctic Ocean's reactive silicate budget and the outflow of Bering Strait waters[1]

*Abstract*—Data from the Lancaster Sound region help balance the Arctic Ocean's reactive silicate budget, but a net removal is still indicated. The reactive phosphorus and reactive silicate concentrations in Lancaster Sound suggest an enrichment with Bering Strait waters.

Codispoti and Lowman (1973) in developing a reactive silicate (dissolved silicon) budget for the Arctic Ocean noted the lack of reactive silicate data from the Lancaster Sound region (Fig. 1), the site of the largest outflow (about half) through the Canadian Archipelago (Palfrey and Day 1968; Muench 1970). Data from this area were desirable because in the budget the total input exceeded the total outflow and a number of considerations indicated that Lancaster Sound might be an important exit for waters rich in reactive silicate entering the Arctic via Bering Strait.

To obtain such data five stations intercepting the Lancaster Sound outflow, and any outflow through Fury and Hecla Strait (probably minor), were occupied in August 1973 (Fig. 1). We will show the implications of these data for the reactive silicate

[1] Contribution No. 783 from the Department of Oceanography, University of Washington. This research was sponsored by Office of Naval Research contract N-00014-67-A-0103-0014.