CORRESPONDENCE

Comments on "Comparison of Mean Wind Speeds and Turbulence at a Coastal Site and an Offshore Location"

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1. Introduction

SethuRaman and Raynor (1980, hereafter SR) present results of comparing mean wind speeds and turbulence measurements at a beach and an offshore buoy. Some of their results are unexpected and thus require a closer inspection.

2. Points of disagreement

At first, the striking feature in the SR's results is that the mean wind speed ratio U_O/U_B (indices O and B refer to ocean and beach, respectively) shown in their Fig. 7 is larger for onshore than for offshore winds when U_B is less than about 9 m s^{-1}. This is in contradiction with the generally observed phenomenon that winds accelerate over the sea (e.g., Kindle *et al.*, 1976), whereas the wind speed observed near the coastline represents well the wind speed at sea for onshore conditions as quoted by Raynor *et al.* (1975) for the same study area. Wood (1978) showed also that the transition is stronger for a rough-to-smooth case (offshore) than for a smooth-to-rough case (onshore).

Second, there are some internal discrepancies between their results for the longitudinal velocity standard deviation ratio $(\sigma_u)_O/(\sigma_u)_B$ and for the mean wind ratio U_O/U_B. Considering the simple neutral case (i.e., at strong wind speed) with the logarithmic profile, we can form the mean wind ratio

$$\frac{U_O}{U_B} = \frac{u_{*O}\ln(z/z_0)_O}{u_{*B}\ln(z/z_0)_B} = 2.2\,\frac{u_{*O}}{u_{*B}}\,, \tag{1}$$

with u_* the friction velocity and z_0 the roughness length and where we use SR's data i.e., $z = 8$ m, $z_{0O} = 5 \times 10^{-4}$ m and $z_{0B} = 0.1$ m. Taking further that $\sigma_u = cu_*$ (Lumley and Panofsky, 1964) where $c = 2.5$ is a constant, we get

$$\frac{U_O}{U_B} = 2.2\,\frac{(\sigma_u)_O}{(\sigma_u)_B}\,. \tag{2}$$

SR's data for $(\sigma_u)_O/(\sigma_u)_B$ in their Fig. 6 show that this ratio is around 1.2 for both onshore and offshore cases at high velocity. Substituting into (2) yields

$$\frac{U_O}{U_B} = 2.6 \tag{2'}$$

instead of the observed ratio of 1.2. SR explain this inconsistency by roll vortices in onshore situations and by a huge increase of z_{0O} in offshore situations. The former explanation seems unlikely in the mean, since roll vortices occur in slightly unstable conditions (LeMone, 1973) which occur rather seldom in SR's data according to their Fig. 2. Neither does the increase of z_{0O} up to 10^{-1} m, due to developing waves, seem likely at a distance of 5 km from the shore because the maximum predictable value of z_{0O} from both Charnock's formula and Garratt's (1977) review is $\sim 10^{-1}$ cm, i.e., 10^2 times smaller than the beach roughness. The value 1.2 seems logically more appropriate for the ratio U_O/U_B (wind somewhat accelerates over the smoother sea) than for the ratio of standard deviations (turbulent fluctuations are stronger over rough surfaces).

We can try to estimate numerically the standard deviation ratio from a simple model of a sea-land transition. Neglecting pressure effects, virtually limited to a narrow zone close to the transition, and the Coriolis effect, we have the following system of equations in the surface layer:

$$U\,\frac{\partial U}{\partial x} + W\,\frac{\partial U}{\partial z} = -\,\frac{\partial \overline{u'w'}}{\partial z} - \frac{\partial \overline{u'^2}}{\partial x}\,, \tag{3}$$

$$\frac{\partial U}{\partial x} + \frac{\partial W}{\partial z} = 0, \tag{4}$$

where the mean horizontal wind U is along the x axis, itself perpendicular to the shoreline. W is the mean vertical velocity which is non-zero only downstream of the transition and u' and w' are the longitudinal and vertical velocity fluctuations, respectively. In principle, a sea-land transition is not only a roughness discontinuity but is also a temperature and moisture transition. However, Rao

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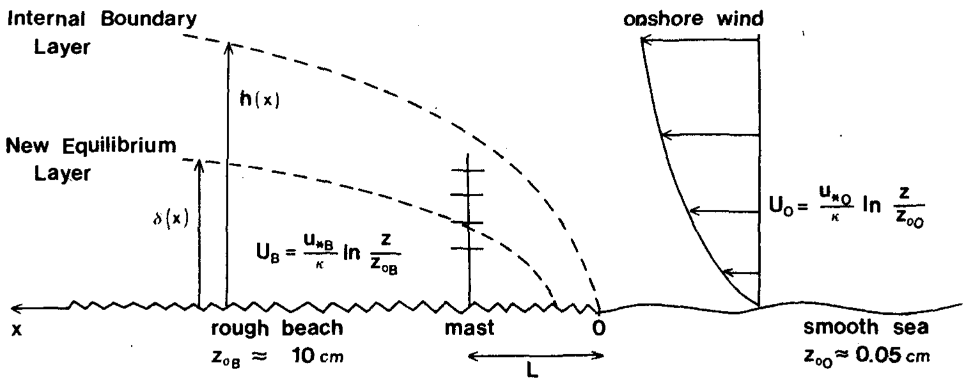

FIG. 1. Schematic representation of a smooth-to-rough transition for pure neutral conditions.

et al. (1974b) showed that the mechanical effects are the primary ones as long as the newly created internal boundary layer (IBL) has not engulfed the whole planetary boundary layer. Thus, we shall consider a simple roughness discontinuity with the geometry of the problem presented in Fig. 1.

We integrate horizontally these equations from a distance $-L$ upwind to a distance L downwind at the location of the mast for instance. We further assume the existence of an equilibrium constant flux layer upwind and downwind the transition, neglecting the short fetch (typically a few meters only) of readjustment to the new equilibrium where similarity theories are not valid. Thus, the first term of the right-hand side of (3) disappears and we have

$$\frac{1}{2}\int_{-L}^{L} \frac{\partial U^2}{\partial x} dx + \overline{W}\int_{0}^{L} \frac{\partial U}{\partial z} dx = -\int_{-L}^{L} \frac{\partial \sigma_u^2}{\partial x} dx, \quad (5)$$

where the effective mean vertical velocity $\bar{W}$ can be extracted from the continuity equation (4), i.e.,

$$\int_{-L}^{L} \frac{\partial U}{\partial x} dx = U_B - U_O = \int_{0}^{L} \frac{\partial W}{\partial z} dx \approx \frac{\overline{W}}{z} L$$

or

$$\overline{W} \approx \frac{U_B - U_O}{L} z. \quad (6)$$

Developing (5) and including (6) yields

$$\frac{1}{2}(U_B^2 - U_O^2) + \frac{(U_B - U_O)}{L} z\left[\frac{u_{*B}}{\varkappa z}\phi_{mB}\right]L = (\sigma_u^2)_O - (\sigma_u^2)_B,$$

in which $\varkappa$ is the von Kármán constant (0.4) and ϕ_m the dimensionless wind-shear function depending only on a stability parameter $\xi = z/L_*$ where L_* is the Monin-Obukhov length. Finally, we obtain the expression

$$\frac{(\sigma_u^2)_O}{(\sigma_u^2)_B} = 1 + \frac{(U_B - U_O)}{(\sigma_u^2)_B} \times \left[\frac{1}{2}(U_B + U_O) + \frac{u_{*B}}{\varkappa}\phi_{mB}\right]. \quad (7)$$

From (7), one notices immediately that since $U_B < U_O$, the right-hand side main term is negative and the standard deviation ratio is less than 1. This is a logical result since the beach is rougher. Considering a neutral case (i.e., $\phi_{mB} = 1$) and using the drag coefficient C_D definition $u_{*B} = C_{DB}^{1/2} U_B$ (with $C_{DB}^{1/2} = \varkappa[\ln(z/z_0)_B]^{-1} = 0.09$), Eq. (7) reduces to

$$\frac{(\sigma_u^2)_O}{(\sigma_u^2)_B} = 1 + \frac{(U_B - U_O)}{(\sigma_u^2)_B}(0.73 U_B + 0.5 U_O).$$

We can express $\sigma = (\sigma_u)_O/(\sigma_u)_B$ as a function of U_B only, if we take the relationship (2), leading to

$$\frac{U_B^2}{(\sigma_u^2)_B} = \frac{1 - \sigma^2}{2.44\sigma^2 + 0.5\sigma - 0.73}. \quad (8)$$

This means that $0.45 < \sigma < 1$ (otherwise $U_B^2 < 0$) and for the strong wind range the ratio σ is ~0.46. Substituting this value into (2) gives $U_O/U_B \approx 1.02$. Obviously, results from a simplified model like this can only be approximate. However, this is a more reasonable value than the one obtained in (2′).

We investigate also the implications of SR's results for the ratio I_O/I_B of the turbulence intensities $I = \sigma_u/U$. We can form the ratio

$$\frac{I_O}{I_B} = \frac{(\sigma_u/U)_O}{(\sigma_u/U)_B} = \frac{\ln(z/z_0)_B}{\ln(z/z_0)_O}\left(\frac{1 - 0.228\Psi_{mB}}{1 - 0.103\Psi_{mO}}\right), \quad (9)$$

where Ψ_m is the integrated form of the function ϕ_m (Paulson, 1970). Using the roughness parameter values given by SR, we get

$$\frac{I_O}{I_B} = 0.45\left(\frac{1 - 0.228\Psi_{mB}}{1 - 0.103\Psi_{mO}}\right). \quad (10)$$

For strong wind situations, i.e., in neutral conditions, $\Psi_{mB} = \Psi_{mO} = 0$ and the ratio I_O/I_B should tend toward 0.45. Searching now for the conditions required to give the high values of SR for the ratio I_O/I_B at weak onshore winds, we imagine four different possibilities of respective stability over the sea and over land. Moreover, in order to obtain a quantitative estimate, we assume that typical stability conditions over land are 20 times stronger (in terms of $|\xi|$) than over the sea. From SR's Fig. 2 the maximum value of $|\xi|$ over the sea is ~0.05 (with $\xi \approx 2$ Ri$_4$ in unstable cases and $\xi \approx 2$ Ri$_4(1 - 10$ Ri$_4)$ in stable ones). We can then compute the values of the bracketed term in (10) with expressions for Ψ_m given by Webb (1970) and Paulson (1970): this is shown in Table 1. According to Table 1, the only way to obtain large values of I_O/I_B like those of SR is for stable conditions over land accompanied with slight stability or instability over the sea. Taking into account that their observation period goes from May to October, one would expect a strong weight on convective situations over land. Thus, either nocturnal observations have been strongly favored or there are some discrepancies in the data.

TABLE 1. Values of the diabatic correction in Eq. (10) to the neutral ratio of turbulence intensities I_O/I_B for four different cases of the respective stability over the beach and over the ocean.

$\lvert\zeta_O\rvert$	$\lvert\zeta_B\rvert$	$\frac{\text{unstable}}{\text{unstable}}$	$\frac{\text{unstable}}{\text{stable}}$	$\frac{\text{stable}}{\text{unstable}}$	$\frac{\text{stable}}{\text{stable}}$	$\frac{B}{O}$
0.01	0.2	0.90	0.89	1.23	1.22	
0.03	0.6	0.82	0.80	1.70	1.66	
0.05	1.0	0.76	0.73	2.17	2.09	

3. Representativeness of the data

This leads us to search for an explanation of such discrepancies. One central feature of horizontal heterogeneities is the formation of an internal boundary layer (IBL) of height $h(x)$, in which the new surface conditions have been felt by the flow. Within this IBL, one must define a new equilibrium layer (NEL) of height $\delta(x)$ in which the profiles are in equilibrium. Thus, the layer between δ and h is a transition layer with a distorted profile where classical similarity theories cannot be applied (see Fig. 1).

First considering onshore conditions, SR quotes an observed value of $h \approx 10$ at the mast emplacement ($x = 50$ m) and a theoretical value of $h = 8.5$ m from Elliott's (1958) expression. One remembers that measurements were carried out at $z = 8$ m. SR found this satisfactory, just quoting that "measurements have been made within the IBL." However, it looks to us as though the turbulence field was measured close to a discontinuity interface, causing alternate sampling in the distorted part of the IBL and outside it (this latter alternative corresponding to oversea conditions). On the other hand, sample data are really characteristic of the new surface only within the NEL (Rao *et al.*, 1974a) where the readjustment is fulfilled to a certain level (90 or 95%). The growth of the NEL is much slower than the ⅘ power law of IBL growth. Computations of Rao *et al.* (1974a) and Shir (1972) indicate that $\delta/h \approx 1/5$ for a smooth-to-rough transition. Thus, the NEL height is ~2 m at the mast and SR's data for onshore wind situations are not representative of the beach wind field. This may explain the inconsistencies within their data.

For offshore wind situations, the buoy mast should always be well within the IBL, since Elliott's formula gives $h = 180$ m and then $\delta \approx 18$ m (for a rough-to-smooth case the ratio δ/h is 1/10). However, the beach site is preceded by Shinnecock Bay, so that another IBL forms over the narrow sandy tongue of Tiana Beach. According to the scale of their map, we evaluate it as ~600 m wide. Elliott's formula gives $h = 60$ m and then $\delta \approx 12$ m, what is rather satisfactory. However, if stable conditions are prevailing, a growth in $x^{0.7}$ (or $x^{0.6}$) is predictable from theory, thus shrinking the NEL to 5 (to 2 m), and one must be aware of such situations.

4. Concluding remarks

Thus, we feel that much caution should be taken in the interpretation of these data, especially with respect to the position of the IBL. Moreover, in SR's type of study, the data should be such that they can be classified according to the respective thermal stability over the beach and over the ocean; otherwise the results might not "reveal the effect of changes in surface roughness", but rather just reflect the relative weight of the different stability conditions in the data. One can wonder also about the representativeness of the study area, since the beach mast is surrounded by different bodies of water so that thermo-dynamical perturbations might be advected easily.

One final uncertainty is the dependence of the sea surface roughness on the wind wave fetch. For offshore winds perpendicular to the shoreline the fetch is 5 km, then only for weak winds (2–3 m s^{-1}) can we consider the waves as developed. On the other hand, winds from 280°, still considered as offshore winds according to SR's classification, would reach the buoy after a fetch of ~14 km, thus allowing a wider spectrum of wind velocity cases for well-developed waves.

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