Reply

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It is encouraging that our generic formula relating the Bowen ratio B to the sea–air temperature difference under unstable conditions (Hsu 1998, 1999),

$$B = a(T_{\text{sea}} - T_{\text{air}})^b, \quad (1)$$

has received further independent verification by Sadhuram et al. (2001).

It is also interesting to note that their results from the Bay of Bengal at 20°N, 89°E are very similar to ours obtained from buoy 42040 in the Gulf of Mexico (Hsu 1998), which is also not very far from land. In this regard, caution must be exercised to extend these results from coastal seas to open ocean conditions. The reason is that over the coastal seas, if the wind blows from land to sea, an internal boundary layer (IBL, so named because this layer exists within the general atmospheric or planetary boundary layer) will develop (Hsu 1988). For example, when cold air is advected over the warmer water, the IBL height, h, is given by (Hsu 1988, p. 125)

$$h = \left[\frac{2C_D(\theta_{\text{warm}} - \theta_{\text{cold}})X}{\gamma(1 - 2F)}\right]^{1/2}, \quad (2)$$

where C_D is the drag coefficient inside the IBL, θ_{warm} and θ_{cold} are the potential temperatures over the warmer sea and colder water (or colder land) respectively, γ is the lapse rate above the IBL or upwind condition, F is an entrainment coefficient that ranges from 0 to 0.22, and X is the distance, or fetch, downwind from the temperature change, whether it is an oceanic front or a coastline. At sufficient distance X over the warmer seas away from the temperature change, cumulus clouds may form. The cloud base is equivalent to the height of the lifting condensation level (LCL) [Hsu 1998, Eq. (16)]. Hence, when the dewpoint depression is 5°C, the LCL $= 125 \times 5 = 625$ m $= h$ [the numerical value of 125 is based on Eq. (16) in Hsu 1998]. If one employs $C_D = 1.5 \times 10^{-3}$, $\theta_{\text{warm}} - \theta_{\text{cold}} = 10$°C, $\gamma = 1$°C/100 m, and $F = 0.2$, X can be estimated from Eq. (2). In this example, $X = 78$ km. In other words, the measurement station needs to be at least 78 km away from the coastline in order for the measurement to be representative of open ocean conditions. Note that, as long as the measurement station is inside the IBL, influences by upwind conditions (in this case, cold air advection) cannot be avoided.

While our generic formula for the Bowen ratio under unstable conditions provided in Eq. (1) has been further substantiated, its counterpart formula under stable conditions (i.e., $T_{\text{sea}} < T_{\text{air}}$) needs to be quantified. In this case, the structure of the stable IBL related to warm air advection over cooler seas must be taken into account. Some progress on this topic has been provided in Hsu (1988, pp. 208–211) and in Garratt (1992).

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