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Estimation of offshore humidity fluxes from sonic and mean temperature profile data

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A new simple method is employed to estimate the virtual potential temperature flux in marine conditions in the absence of any reliable hygrometry measurements. The estimate is made from a combination of sonic and cup anemometer measurements. Since the measurement of temperature by a sonic is humidity dependent, it overestimates the heat flux by a magnitude of $0.51\Theta\overline{w'q'}$, where Θ is the potential temperature in Kelvin and $\overline{w'q'}$ is the humidity flux. However, the quantity of interest for many applications is the virtual potential temperature flux $\overline{w'\theta'_v}$, which itself overestimates the heat flux by a magnitude of $0.61\Theta\overline{w'q'}$. The virtual potential temperature flux is thus estimated by

$$\overline{w'\theta'_v} = \overline{w'\theta'}_s + 0.1\Theta\overline{w'q'}, \tag{1}$$

where $\overline{w'\theta'}_s$ is the measured sonic anemometer heat flux. To properly estimate $\overline{w'q'}$, fast response hygrometers are required, but in their absence, mean measurements can be used. While we have access to standard hygrometers, there are reasons to question the validity of results from these. Therefore, we propose that $\overline{w'\theta'_v}$ be estimated by equating the stability parameter z/L, where z is the height and L the Obukhov length (which contains $\overline{w'\theta'_v}$ and hence eq. (1)) with the bulk Richardson number and solving for $\overline{w'q'}$, giving

$$\overline{w'q'} = -10\left(\frac{u_*^3 R_b}{kzg} + \frac{\overline{w'\theta'}_s}{\Theta_v}\right). \tag{2}$$

Upon substituting eq. (2) into (1), and comparing terms on the right hand side of eq. (1), it is found that the contribution of the moisture term is an order of magnitude greater than that of the sonic measurement. This result is broadly consistent with previously published measurements, for example by Sempreviva and Gryning (1996) and Edson et al. (2004), of humidity fluxes using fast-response hygrometers in marine environments.

We conclude that moisture effects are the chief determinant of instability in the marine surface layer. Consequently, the not unusual neglect of humidity effects in analytical and modelling efforts will result in a poor estimation of such quantities as the Obukhov length, dimensionless temperature gradient, turbulent kinetic energy, etc, in unstable marine conditions. We will show unstable potential temperature and humidity fluxes from eq. (1) and (2) and discuss them in terms of atmospheric stability. The findings presented here may have considerable impact on the formulation of turbulence parameterization in mesoscale models for offshore applications.