Agricultural and Forest Meteorology 328 (2023) 109250

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Comment on "Physical mechanism of vertical gradient of pressure flux and its impact on turbulent flux estimation"

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ARTICLE INFO

Keywords
Pressure covariance
Enthalpy
Sensible heat
Coherent structures

Following recent precedent regarding the measurement of turbulent pressure (p) fluctuations, Wei et al. (2022) assess and interpret the vertical velocity (w) and p covariance term ($\overline{w'p'}$) as representing a "pressure flux" (m s^{-1} Pa). They furthermore relate its spatial gradient, with components such as $\frac{\partial \overline{w'p'}}{\partial z}$ that they name a "pressure flux divergence (FD)", to the effects of larger-scale eddies on turbulent transport. But to appreciate both the significance of $\overline{w'p'}$ and its spatial gradients, it is essential to recognize that it is an energy flux density (W m^{-2}) and an integral but minor part of the turbulent heat flux density (H).

Because the temperature (T) is not conserved through adiabatic p changes, a formulation of H in terms of T fluctuations alone is valid only for the isobaric case. More generally, theoretical definitions of H are expressed correctly in terms of a covariance with the potential temperature (θ) as $\overline{w'\theta'}$ (Stull, 1988; Steinfeld et al., 2007). But since θ cannot be measured directly, a re-examination of the 1st Law of Thermodynamics from which it derives is useful, in order to specify the effects of diabatic heating on atmospheric state variables and thereby to appreciate the meaning of $\overline{w'p'}$ and its spatial gradients.

The 1st Law for 1kg of air can be expressed as

$$dq = c_p\, dT - \alpha\, dp, \tag{1}$$

where dq is the increment of heat added, c_p the specific heat at constant p, and α the specific volume (Petty, 2008). This form of the 1st Law is the basis for Poisson's equation for adiabatic processes ($dq = 0$), and its primary advantage in meteorology is that it allows detecting the effects of heating using T and p sensors. The same is true in micrometeorology; when expressed using the common notation for turbulent fluctuations (using primes rather than differentials), multiplied by fluctuations in w, averaged, and finally scaled by the air density (ρ), this expression for detecting the effects of diabatic heating requires the inclusion of $\overline{w'p'}$ in the formal definition of H (Kowalski and Argüeso, 2011), as

$$\underset{(I)}{H} = \underset{(II)}{\rho\, c_p\, \overline{w'T'}} - \underset{(III)}{\overline{w'p'}} \tag{2}$$

The terms in (2) are flux densities of (I) heat, (II) enthalpy (in an isobaric context, this is a synonym for sensible heat; Petty, 2008), and (III) energy that differentiates heat and enthalpy when the pressure fluctuates. Dimensional analysis confirms that the product of w (m s^{-1}) and p (Pa) represents an energy flux density (kg s^{-3}), with units exactly equivalent to W m^{-2}.

Like previous authors, Wei et al. (2022) have determined that $\overline{w'p'}$ ($\sim$1 W m^{-2}) represents a tiny fraction of H ($\sim$100 W m^{-2}), justifying its frequent neglect in a thermodynamic context (but see Burns et al., 2021 who found it to reach 20 W m^{-2}). However, when characterizing divergent energy flux densities, they examine gradients in $\overline{w'p'}$ without considering those in the enthalpy flux density that overwhelmingly dominates H. Spatial differences in $\overline{w'p'}$ – typically $\sim$0.1 W m^{-2} over several meters distance, as presented in their Figure 5 – are much smaller than even the measurement uncertainties associated with the enthalpy flux, whose spatial differences are measured but not presented. This casts much doubt on the authors' conclusions regarding the association between divergences/convergences in energy flux densities and coherent structures in the boundary layer. Credible assessments of such associations must include terms such as $\rho\, c_p \frac{\partial \overline{w'T'}}{\partial z}$, which are likely to

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https://doi.org/10.1016/j.agrformet.2022.109250
Received 28 June 2022; Received in revised form 17 October 2022; Accepted 9 November 2022
Available online 18 November 2022

dominate divergences in H.

Declaration of Competing Interest

The authors declares the following financial interests/personal relationships which may be considered as potential competing interests: Andrew S. Kowalski reports funding that was provided by University of Granada. Andrew S. Kowalski reports a relationship with University of Granada that includes: employment and non-financial support.

Data availability

No data were used for the research described in the article.

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