

***Interactive comment on* “Chemical sensor resolution requirements for near-surface measurements of turbulent fluxes” by M. D. Rowe et al.**

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We thank the anonymous referee for reviewing our manuscript. In general, the referee points out that our manuscript is biased toward water-atmosphere rather than land-atmosphere flux applications and toward gases rather than particles. This is true, and it stems from our experience. We agree that the treatment could be made more general, and therefore reach a wider audience, if it were expanded to include land-atmosphere flux applications, particles as well as gases, and additional methods such as virtual disjunct eddy covariance. We plan to make the language more general in the revised manuscript where appropriate. With regards to specific areas brought up

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by the referee, we prefer to expand the manuscript in some areas but not others, as described in response to specific referee comments below.

Referee's comments are repeated in italics.

(1) *Title: I am wondering whether the use of "chemical sensors" in the title and elsewhere in the paper is not too restrictive because it would for example exclude particle counters used for particle flux measurements. Why not say just "Sensor resolution requirements ..." or "Scalar sensor resolution requirements ..."?*

We aimed to have the style of the title consistent with that of Businger and Delaney (1990) (BD90). We agree that the approach could apply to fine particles as well as gases, with limitations that we discuss subsequently in these comments. After consideration, we felt that it would be better to modify the approach that we present to apply to particles over a broad size range in a separate manuscript; therefore, we prefer to keep the word "chemical" in the title to differentiate this manuscript from a follow-up manuscript to focus on particle flux measurement.

(2) *The authors appear somewhat biased towards water-atmosphere flux applications (while I am biased towards land-based studies ...). In order to provide some more balance I suggest to assure that in particular references reflect both fields - this will make the paper more appealing to a wider community. For example on p. 24410 I. 22 I would suggest citing for land-atmosphere eddy covariance CO2 flux measurements Baldocchi et al. (1988), Baldocchi (2003) and Aubinet et al. (2001).*

In the introduction we cite several references to provide relevant examples of micrometeorological flux measurement methods and applications. The referee suggests that we include some examples of land-based eddy covariance (EC) flux measurements for a more balanced presentation. The EC examples we cited were both for air-sea fluxes, while relaxed eddy accumulation (REA) and gradient examples that we cited included air-sea and land-based applications. We will cite examples of land-based EC methods, in the revised manuscript.

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We have considered whether the manuscript can be expanded to include land-based flux measurements and particle flux measurements. Section 4.2 (the ‘chemical parameter’, CP_c) and Fig. 3 are specific to air-water gas exchange; however, the remainder of the analysis is applicable to land-based gas exchange measurements as long as z is replaced with $z-d$, where d is the canopy height in the case of air-canopy exchange, as stated in the manuscript (P. 24411 L. 23-25). Wesely (1989) demonstrated a modeling approach to parameterize surface resistances that can be customized for atmosphere-water and atmosphere-land exchange in terms of resistances specific to surface types found on land and water. It is possible to formulate a simple version of CP_c equivalent to Eq 29b for the case of air-canopy or air-soil gas exchange using a dimensionless partition coefficient between air and the exchanging medium substituted for solubility in Eq. 27 if 1) partitioning is reversible, and 2) partitioning occurs in the linear portion of the sorption isotherm after the approach of Wesely (1989). A formulation of Eqs. 27-29 according to the resistance model for transfer velocity, and, for atmosphere-(land type) exchange, including a dimensionless partition coefficient substituted for solubility and circumstances under which its application is valid will be incorporated into the revised manuscript. It should be noted that the CP_c concept is not needed to estimate the required sensor resolution; if the anticipated magnitude of air-land gas exchange flux can be estimated, for example from literature values or a multimedia model, then Eqs. 4 and 26 can be used to estimate the required sensor resolution.

Regarding particles, very fine particles behave like gases, so the manuscript should apply as written if the measurements are made within a constant-flux surface layer. However, as particle size increases inertial and gravitational effects become more important, so modifications to the approach would be needed. For example, we used empirical relationships derived in the text and shown in Fig. 1 to estimate the scalar standard deviation as a function of stability. The scalar standard deviation is reduced as particle size increases to such an extent that inertial effects diminish the ability of particles to follow turbulent variations in velocity (e.g., Feng, 2008). In addition, micrometeorological methods measure only the turbulent component of the particle flux;

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the gravitational fall velocity must be estimated independently and multiplied by the particle concentration, then added to the turbulent flux to obtain the total particle deposition flux (e.g., Fairall and Larsen, 1984). We believe that it would be informative to modify the approach we have presented for application to particles; however, we began writing a section to be added to this manuscript that became quite substantial, and so we prefer to publish this work as a separate manuscript.

(3) *I find the use of two-letter symbols such as AP and CP in equations awkward - maybe the authors can do with a single letter or a (greek) symbol instead.*

We adopted the symbol AP from BD90, and then extended it to the “chemical parameter” CP_c . We prefer to maintain this nomenclature to be consistent the symbols and style of BD90. While there is some possibility for confusion, we limit the use of two letter symbols to these two cases, and include a list of symbols.

(4) *The authors cover the eddy covariance, conditional sampling and modified BREB methods. For many compounds virtual disjunct EC is the preferred method and I wonder whether the authors can say something about this method too.*

Virtual disjunct EC (dEC) is indeed a method that is of current interest (e.g., Turnipseed et al., 2009; Rinne et al., 2008). In dEC, a fast (≈ 0.1 s) air sample is collected at a longer interval (≈ 1 to $30+$ s) so that a relatively slow sensor may be used to measure the scalar concentration. The statistical sampling error variance of the flux measurement is greater for dEC than for conventional EC (EC) because fewer samples are collected over the averaging period (Lenschow et al., 1994). In addition, the contribution of the scalar sensor “white noise” is relatively greater for dEC than for EC. In EC, the noise contribution is reduced because the sampling interval is much less than the covariance integral time scale (Eq. 13 of the manuscript); several scalar measurements are averaged in the time it takes a typically-sized eddy to pass the sensor, providing some reduction in sensor noise by averaging. As the sampling interval is increased, fewer scalar measurements are available for averaging. We will develop a modified version

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of AP'_{cov} in the revised manuscript that can be applied to EC or to dEC.

(5) The authors make use of several equations that rely on empirical data - depending on which parameterisation is chosen results will be different. It would be very instructive to indicate the magnitude of systematic uncertainty due to these choices.

To estimate the effect of atmospheric stability on required sensor resolution, we needed to use several empirical expressions: Eq. 23b-24a, to estimate the covariance integral time scale, τ_1 ; Eq. 23a,24b-c, to estimate the scalar standard deviation, σ_{c1} ; Eq. 20a-c to estimate the vertical velocity standard deviation, σ_w ; and in Eq. 26b, the stability function for the dimensionless vertical gradient of a scalar, $\Psi(\frac{z}{L})$. Blomquist et al. (2010) compared relative error computed from the expression given as Eq. 30 in our manuscript to relative standard deviation of dimethylsulfide fluxes measured during the Southern Ocean GASEX project. Eq. 30 requires estimates of τ_1 , σ_{c1} , and σ_w . Fig. 9 of Blomquist et al. (2010) shows that Eq. 30 is biased by about 0 to -30% over the range of wind speed for that data set. Based on Fig. 1 and discussion in the manuscript, uncertainty in σ_{c1} from Eq. 23a, 24b-c is about 10% (unstable) and 30% (stable). Uncertainty in τ_1 from Eq. 23b and 24a is about 100% (unstable) and 50% (stable), based on one co-author's own data (CWF) and Lee et al. (2004). Uncertainty in $\Psi(\frac{z}{L})$ is about 10%, for example see discussion in the paper by Fairall et al. (2003).

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