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Evaluation of probe-induced flow distortion of Campbell CSAT3 sonic anemometers by numerical simulation

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The Campbell CSAT3 sonic anemometer is one of the most trusted instruments for micrometeorological turbulence measurement. Although the uncertainty in the measurement due to probe-induced flow distortion has been previously quantified by field experiments and wind tunnel studies, there is no consensus on the magnitude of the error. Different studies suggest errors between 3% to 14% in the measurement of the vertical velocity fluctuations. In a field intercomparison, it is only possible to compare one instrument with another, and defining an absolute reference or etalon is not possible. In a wind tunnel, the quasi-laminar flow does not reflect the turbulence intensity that is typically observed in the atmospheric surface layer. Therefore, wind tunnel studies tend to overestimate the effect of distortion. Here, we study the probe-induced flow distortion of a CSAT3 in a numerical wind tunnel with fluctuating inflow using large eddy simulation. We prescribe horizontal and vertical velocity fluctuations at the inflow at frequencies that typically dominate the turbulence spectra of the surface layer. We find that the numerical wind tunnel with simplified fluctuating inflow quantifies the distortion effects better than the experimental method. The relative error in the standard deviation of the virtual measurement is found to be between 3% to 7% and 1% to 3% for vertical and horizontal velocity components, respectively. We further deduce that these errors are independent of the frequency of fluctuations at the inflow of the simulation. The analytical corrections proposed by Kaimal et al. (Proc Dyn Flow Conf, 551–565, 1978) and Horst et al. (Boundary-Layer Meteorol, 155, 371–395, 2015) reduce the error by up to three percentage points. However, we observe that to further reduce the error an azimuth-dependent correction needs to be formulated. This alternative numerical wind tunnel approach can be employed to characterize other models of sonic anemometers and it also serves as a preliminary study for a more detailed but expensive simulation with a high intensity turbulent inflow.