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Hard to measure, hard to model: Using information theory to understand turbulent heat fluxes

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Measurements and models constitute the core modes of understanding environmental processes, where a major paradigm of doing science involves confronting hypotheses (represented by models) with data from measurements. Of course, both models and measurements involve uncertainties which can make reasoning about the validity of our hypotheses difficult. This difficulty is exemplified in the study of turbulent heat fluxes where measurements made by eddy-covariance towers often have energy balance gaps and simple regression models often outperform the most sophisticated physically-based models. Our study addresses these issues by identifying the conditions in which either or both models and measurements break down as well as identify potential reasons for these breakdowns.

We use the Structure for Unifying Multiple Modeling Alternatives (SUMMA) to develop an ensemble of models representing multiple hypotheses about how turbulent heat fluxes are generated and compare them against measurements from FluxNet towers at a number of hydro-climatically diverse sites. We evaluate the models against the measurements using both traditional error measures as well as with a general framework based on information theory and conditional probabilities. Extending this base analysis, we compute conditional mutual information of the modeled and observed relationships between turbulent heat fluxes and other meteorological variables (such as shortwave radiation, air temperature, and humidity). This allows us to go further than traditional error measures to explore how well the modeled relationships match the observed, providing a proxy for process correctness. We perform this analysis for a variety of conditions. We first analyze how much information the meteorological variables provide to the observed heat fluxes to estimate the robustness of the measurements. We then compare this with the amount of information that the meteorological variables provide to the simulations to determine whether there are significant deviations between the shared information from the simulations to the observations. This analysis is used to provide recommendations for post processing observations as well as identifying possible process deficiencies in our models.