Process attribution of observation-model error via time-series segmentation analysis

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Process-based carbon cycle models have been vital for understanding complex land-atmosphere feedbacks and for isolating mechanisms driving source-sink dynamics across space and time. Benchmarking these models to observational datasets has improved their usefulness and optimization of model parameters has continued to reduce uncertainty and improve confidence in predictions. However, past benchmarking and optimization efforts, while useful, have overlooked the nuance of the error structure in observation-model and model-model evaluations. For example, the phase and amplitude of seasonality of atmospheric CO_2 is often evaluated from a monthly-mean harmonic function. This makes sense if our aim is to generalize and identify major features of observation-model mismatch, yet this type of generalization reduces the error structure to single metrics and therefore overlooks subtleties that can be used to identify important mechanisms driving inter- and intra-annual variation in atmospheric CO_2. The wave-function segmentation method matches (rise and fall) segments between two curves and decomposes the error structure into a joint time-series of errors in phase and magnitude. We apply the segmentation method to a comparison between GOSAT-derived observations of column-averaged CO_2 (XCO2) (2009-2015), and carbon fluxes from the biosphere (7 processed-based carbon cycle models), fossil fuel, and ocean, which underwent forward-transport model simulation for purposes of reproducing atmospheric mixing and co-locating the simulated XCO2 to GOSAT observations; regional time-series of XCO2 (observed and modeled) first underwent standard wave-decomposition to separate the long-term and seasonal cycle and to retain short-term harmonic variability. We then demonstrate how, for each segment of the XCO2 curve, the time-series of errors in phase and magnitude can be attributed to issues in their practical representation in models. We also demonstrate how the time-series of errors can be used to inform model development by evaluating the effect of alternate models of phenology and land use change on the error structure with an objective to better mirror inter- and intra-annual variability in the observed time-series. Our approach for analysis improves observation-model and model-model evaluations by decomposing the error structure into a joint time-series of errors in phase and magnitude whilst preserving the natural asymmetries in the intra- and inter-annual variation of carbon fluxes.