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Using diurnal phase lags of turbulent heat fluxes to benchmark land surface models: revisiting the PLUMBER analysis

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Land surface models (LSM) jointly solve the water and energy balance at the surface and thereby link various critical processes to resolve land-atmosphere exchange of heat and mass. A recent benchmarking project (PLUMBER, Best et al., 2015) revealed that state of the art LSMs are outcompeted by out of sample empirical models highlighting that LSMs can be improved without further input data. In order to better understand which process parameterizations can be improved, we focus on the diurnal cycle of surface heat fluxes and aim to isolate typical signatures of land-atmosphere interactions from observations and test how state of the art models reproduces these. Therefore, we decompose the diurnal variation of surface heat fluxes into their direct response and a phase shift to incoming solar radiation. We employ the PLUMBER dataset consisting of 20 FLUXNET sites across continents with 13 different LSMs.

Observations under cloud-free conditions show a strong direct response of the turbulent heat fluxes to solar radiation with small but significant phase lags. Sites with short vegetation reveal an increase of the phase lag of the latent heat flux with wetness, whereas forest sites with closed canopies show rather stable positive phase lags. The phase lag of the sensible heat flux tends to negative values, i.e. preceding the diurnal course of solar radiation under ample moisture supply. We then benchmark the LSMs with the observed distributions of the phase lags for each site stratified by wetness conditions. Analysis of the phase lags of both, the sensible and latent heat flux clearly discriminates the performance of land-surface models. The best models match the observed distributions in about 42% of the cases, the poorest models capture only 9%.

All LSM use vapor pressure deficit as driving gradient which generally shows large phase lags (1-2h) when evaluated at air temperature. A constant surface conductance which is used for example in the Penman-Monteith FAO reference evapotranspiration approach leads to positive phase lags of latent heat fluxes while observations show smaller phase lags. Most LSM differ in their formulations of surface conductance and thus influence the simulated phase lags. It further appears that LSMs vary strongly in the diurnal magnitude of the simulated soil heat flux and its phase lag, which translates into phase lags of the simulated turbulent heat fluxes.

We conclude that current state of the art LSMs have major difficulties to reproduce observed signatures of the diurnal cycle. This indicates that parameterizations of land-atmosphere interactions in particular the exchange of heat above and below the surface need to be improved.

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