Can biospheric models reproduce spatiotemporal variability of CO_2 fluxes as observed through atmospheric measurements?

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Our capability to project future climate and the carbon-climate interaction largely depends on the accuracy of biospheric carbon cycle simulated by terrestrial biospheric models (TBMs). Understanding the performance of the current TBMs to reproduce the net ecosystem CO_2 exchange (NEE) is an essential first step toward developing a robust TBM, and hence is a key question to the carbon cycle research community.

Geostatistical inverse modeling (GIM) estimates CO_2 fluxes with varying level of complexity of covariate matrix. When incorporated with model selection, GIM can determine covariate variables significantly explaining the spatiotemporal variability of CO_2 fluxes. In this paper, to directly evaluate the spatiotemporal variability of TBM simulated NEE, we develop the GIM-TBM method by applying simulated NEE fluxes as covariates. The TBM simulations discussed are CASA GFEDv2, ORCHIDEE, SiB3 and VEGAS from NACP. If a TBM is selected by GIM-TBM, it suggests this TBM reproduces the spatiotemporal variability consistent with that seen by the atmospheric measurement. We run an additional GIM case (GIM-ENV) using environmental variables as covariates to further interpret the model performance on a process level.

Out of 4 TBMs, SiB3 and ORCHIDEE are most frequently selected to significantly explain the variability in fluxes. By assessing BIC associated with each TBM, the overall performance is ranked as: SiB3>ORCHIDEE>CASA-GFEDv2>VEGAS2. 2/3 out of all 84 biome/month are not selected with any TBM, suggesting two possibilities, 1) current atmospheric data is not sufficient to constrain environmental processes; 2) TBMs cannot reproduce the right environmental processes and hence do not reproduce the correct spatiotemporal variability. The GIM-ENV case, however, show more frequent selections than the GIM-TBM case, suggesting that in some biome/month, environmental processes are well constrained by atmospheric measurements, yet are not correctly simulated in TBMs. The inconsistent selection of simple environmental drivers and TBMs are specifically obvious during the transition months. For example, over Eastern Temperate forest, TBMs are not selected over March, April, October and November while environmental variables are selected throughout the year. Further investigation indicates that TBMs cannot represent well either the transition between the processes associated with water availability and radiations during these months, or the sign of the association of fluxes with water availability and temperature. Our study suggests that these 4 TBM simulations have problems in simulating the transition associated with phenology, the environmental processes associated with water and temperature. Focusing on model representation of environmental processes can be a promising new direction to assess, inter-compare and improve TBMs.