Bayesian Evaluation of Earth System Models Using Soil Respiration Data

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Introduction

- 2016 was Earth's hottest year in the modern temperature record and the third consecutive record-breaking year.[1] As the planet continues to warm, temperature-induced changes in respiration rates of soil microbes could reduce the amount of carbon sequestered in the soil organic carbon (SOC) pool and accelerate global temperature increases.
- To predict the future size of the SOC pool, we use differential equation Earth system models (ESMs), which describe interactions between the biosphere and atmosphere. However, ESMs must be validated for consistency with observed data before they can be chosen for predictive use.
- In this study, we evaluate two ESMs called the conventional (CON) and AWB models using Bayesian inference. We present an approach to model comparison that identifies models already consistent with empirical data for further refinement.

ODE Models

Both models include equations representing SOC, dissolved organic carbon (DOC), and microbial biomass (MIC) pool sizes. The AWB model differentiates itself from CON with explicit representation of extracellular enzymes (ENZ) for added complexity.[2]

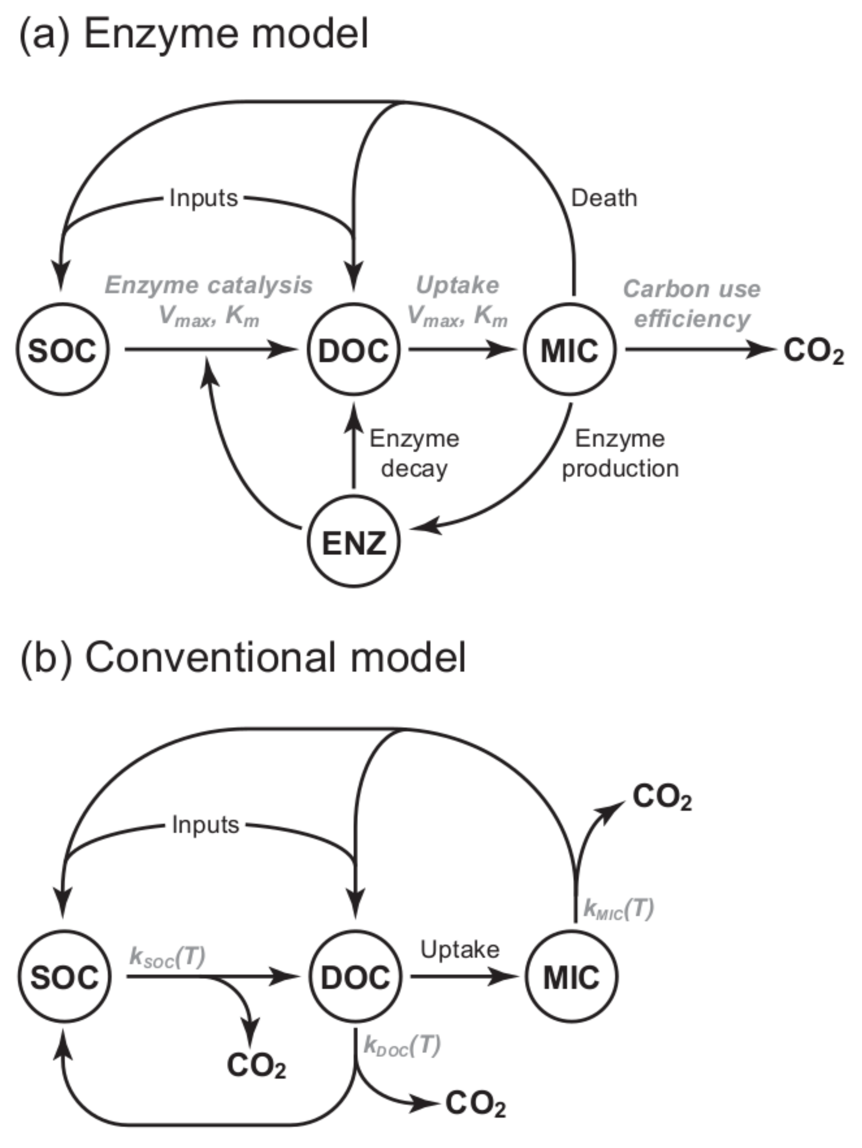

Figure 1: (a) AWB diagram (b) CON diagram

Data

Longitudinal data of CO_2 response ratios was aggregated from a meta-analysis of 25 field experiments studying the effect of warming on soil respiration.[3] The ratios consist of annually evolved CO_2 flux divided by the equilibrium flux of the ESM. We will refer to the data vector as $CO_2(t)$.

Statistical Model

To compare CON and AWB, we observe the ability of their posterior predictions $\hat{CO}_2(t)$ to fit $CO_2(t)$. We coded the ESMs in Stan to use its Hamiltonian Markov chain algorithm. We fixed initial pool sizes to maintain biological realism.

Priors: Informative, biologically realistic, and normally distributed priors based on previous experiments were assigned to model parameters.

Sampling Distribution: We superimposed a normal error model about the latent ODE state,

$$\mathrm{CO}_2(t) \sim \mathrm{N}(\hat{\mathrm{CO}}_2(t), \sigma),$$

where $\hat{CO}_2(t)$ are ESM-generated ratios and σ is noise representing model misprediction and measurement error.

Posterior Distribution: The posterior distribution of parameters θ in each ESM is given by

$$p(\theta|\mathrm{CO}_2(t), \mathrm{C}_0) \propto p(\mathrm{CO}_2(t)|\theta, \mathrm{C}_0)p(\theta)$$

where C_0 is the initial pool sizes vector and $p(\theta)$ are the priors.

Results

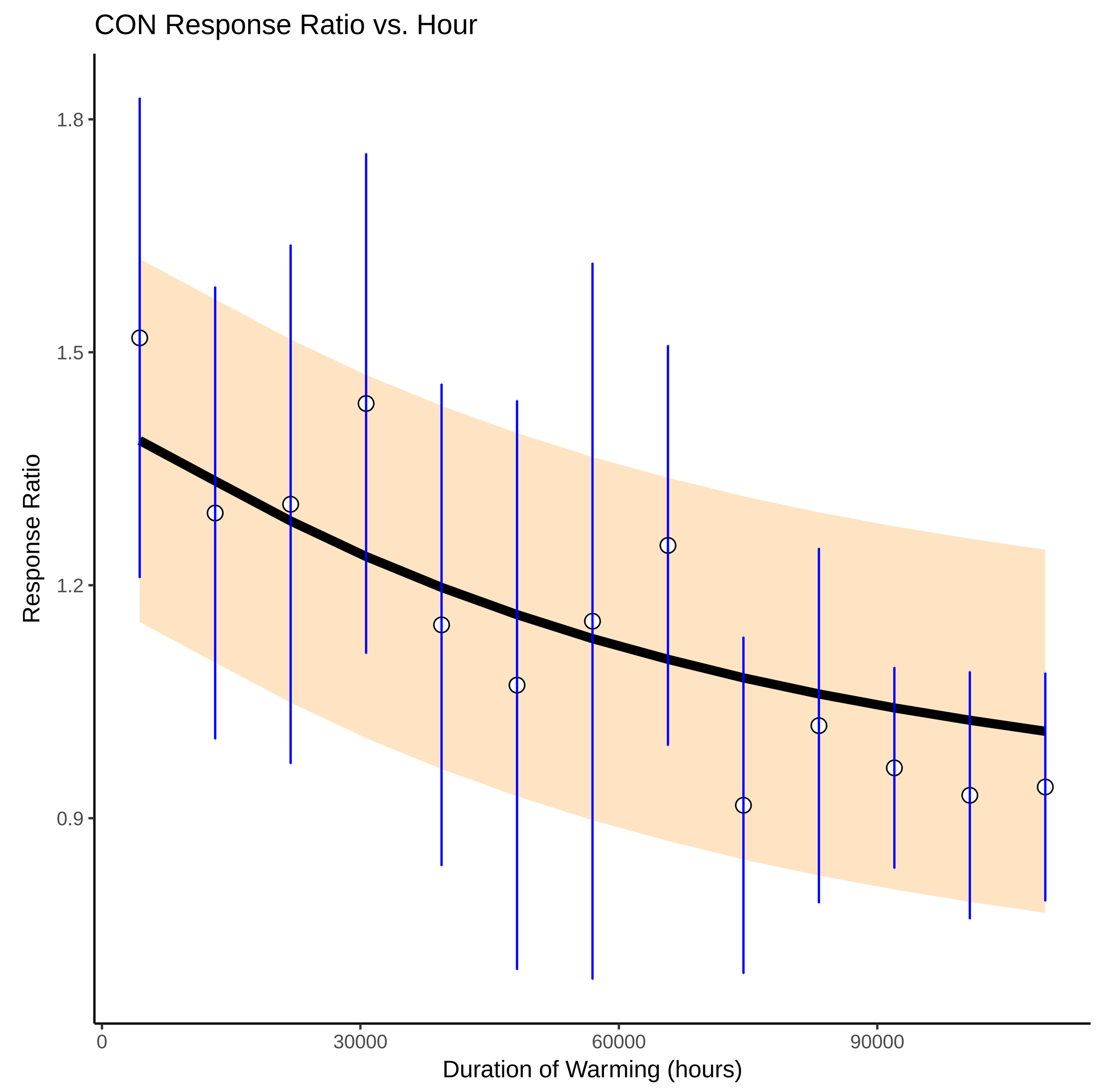

Figure 2: CON posterior median fit (black line) with predictive 95% (orange shading).

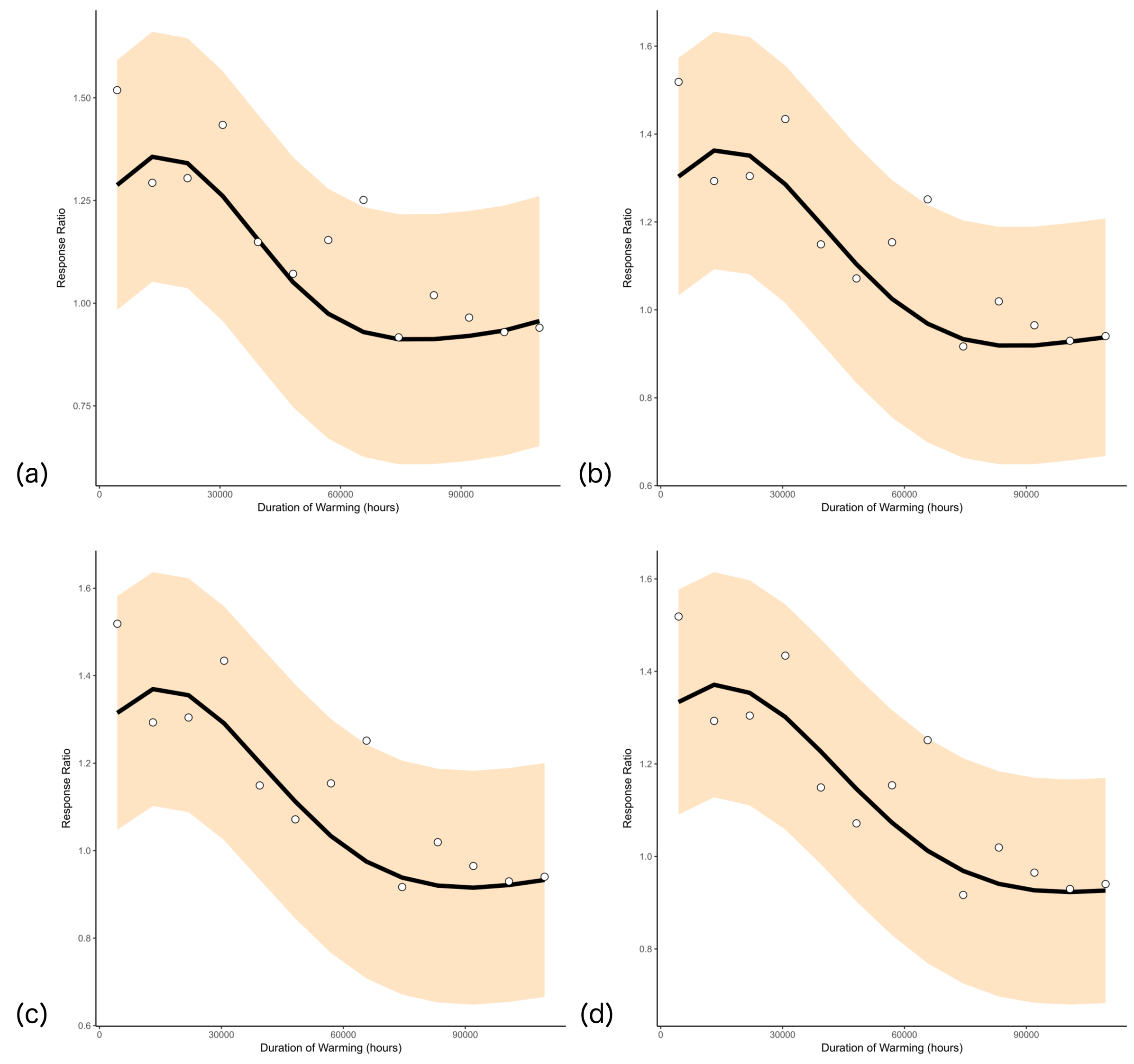

Figure 3: AWB posterior median fits. $DOC_0 = 2$, $MIC_0 = 0.18$, $ENZ_0 = 0.012$. (a) $SOC_0 = 100$ (b) $SOC_0 = 125$ (c) $SOC_0 = 150$ (d) $SOC_0 = 200$.

Conclusions and Forthcoming Research

- With appropriate pool sizes, AWB outperforms CON and could be a better candidate for predictive use. AWB's $\hat{CO}_2(t)$ curve displays quicker changes in slope magnitude and sign compared to that of CON.
- We are quantifying posterior model fits for AWB, CON, and other ESMs with Bayesian goodness of fit metrics such as posterior predictive p-values.

References

[1] NASA.
https://www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-globally.

[2] S. D. Allison, M. D. Wallenstein, and M. A. Bradford.
"soil-carbon response to warming dependent on microbial physiology".
Nature Geoscience, 3(52):336–340, April 2010.

[3] A. L. Romero-Olivares, S. D. Allison, and K. K. Treseder.
"soil microbes and their response to experimental warming over time: A meta-analysis of field studies".
Soil Biology and Biochemistry, 107:32–40, April 2017.

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