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## A Bayesian framework for emergent constraints: case studies of climate sensitivity with PMIP

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In this study we introduce a Bayesian framework, which is flexible and explicit about the prior assumptions, for using model ensembles and observations together to constrain future climate change. The emergent constraint approach has seen broad application in recent years, including studies constraining the equilibrium climate sensitivity (ECS) using the Last Glacial Maximum (LGM) and the mid-Pliocene Warm Period (mPWP). Most of these studies were based on Ordinary Least Squares (OLS) fits between a variable of the climate state, such as tropical temperature, and climate sensitivity. Using our Bayesian method, and considering the LGM and mPWP separately, we obtain values of ECS of 2.7 K (1.1 - 4.8, 5 - 95 percentiles) using the PMIP2, PMIP3 and PMIP4 data sets for the LGM, and 2.4 K (0.4 - 5.0) with the PlioMIP1 and PlioMIP2 data sets for the mPWP. Restricting the ensembles to include only the most recent version of each model, we obtain 2.7 K (1.1 - 4.3) using the LGM and 2.4 K (0.4 - 5.1) using the mPWP. An advantage of the Bayesian framework is that it is possible to combine the two periods assuming they are independent, whereby we obtain a slightly tighter constraint of 2.6 K (1.1 - 3.9). We have explored the sensitivity to our assumptions in the method, including considering structural uncertainty, and in the choice of models, and this leads to 95% probability of climate sensitivity mostly below 5 and never exceeding 6 K. The approach is compared with other approaches based on OLS, a Kalman filter method and an alternative Bayesian method. An interesting implication of this work is that OLS-based emergent constraints on ECS generate tighter uncertainty estimates, in particular at the lower end, suggesting a higher bound by construction in case of weaker correlation. Although some fundamental challenges related to the use of emergent constraints remain, this paper provides a step towards a better foundation of their potential use in future probabilistic estimation of climate sensitivity.