

## Paleoclimate modeling on various time scales

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Studies of the climate in the past are of importance beyond intellectual or academic curiosity. The climate system on which many aspects of our life critically depend is far more complicated and nonlinear than possibly described and understood from the first principles. Theoretical and observational studies of the current climate provide a basis of our understanding. Recent and potential future climate changes, on the other hand, require more comprehensive understanding of the system in larger phase space and on longer time scales than that can be achieved from modern meteorological data alone. Additional insight may be gained from paleoclimate, which the Earth actually experienced. Paleoclimate modeling provides measures: 1) to quantitatively test hypotheses for climate changes of the past; 2) to assist the interpretation of paleo-proxy records; and 3) to evaluate performance of models which are used for projections of the future climate change.

Three categories of models are generally used in paleoclimate modeling: conceptual or analytical models; reduced complexity models (EMIC: Earth system Model of Intermediate Complexity); and comprehensive models (GCM: general circulation model). In the first and second phases of Paleoclimate Modeling Intercomparison Project (PMIP), the performance of mainly GCMs, which are used for future projections, has been examined by model-data comparisons and model-model comparisons. It is not, however, only the 'performance' of models that has been focused, but also aimed to constrain the climate sensitivity, narrowly defined by the equilibrium surface temperature change when the atmospheric concentration of carbon dioxide is doubled. The strategy is to evaluate the simulated climate at the last glacial maximum (LGM) by proxy-based reconstructions and bridge this paleoclimatic information to the future through models.

The LGM is particularly useful for this purpose because forcing is reasonably well known, there is a strong forcing with the greenhouse gas forcing being close to the magnitude of concern for the near future, and a large number of proxy-based reconstructions are available. We will review three different types of approach: 1) to estimate climate sensitivity (parameter), broadly defined by the surface temperature change normalized by radiative forcing, based on proxy records; 2) to constrain the climate sensitivity by model-data comparison with emphasis on the PMIP activities; and 3) to produce probabilistic distribution of the climate sensitivity by perturbed physics ensemble experiments. We will also review how the climate sensitivity is determined by radiative feedback processes and studies on a relationship between the past and future climate sensitivity (parameter) through feedback processes.

As appeared in the paleoclimate chapter of the fourth IPCC assessment report, another important time window of the paleoclimate modeling in relation to the future climate is the late Holocene. Recently, the past millennium simulation of about 850 to 1850 A.D. is decided to be included in the third phase of the PMIP. Climate during this time period is influenced mainly by natural, external forcing and little 'contaminated' by a variety of anthropogenic radiative forcing agents. While the recent climate change may be placed in a long-term perspective based on proxy-based reconstructions alone, knowledge of and viability of models to simulate the response to natural forcing beyond the length of the instrumental records are essential for the detection and attribution of the recent climate change and for a better understanding of the climate system. In addition, there are a growing number of hydrological proxy records. There have been a number of simulations conducted by both EMICs and GCMs. One of the biggest challenges is that there is a considerable amount of uncertainty in solar and volcanic forcings. We will review the current status of these simulations and address future plans.