Geophysical Research Abstracts
Vol. 17, EGU2015-5575, 2015
EGU General Assembly 2015

Methodology Aspects of Quantifying Stochastic Climate Variability with Dynamic Models

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The paleoclimatic records show that climate has changed dramatically through time. For the past few millions of years it has been oscillating between ice ages, with large parts of the continents covered with ice, and warm interglacial periods like the present one. It is commonly assumed that these glacial cycles are related to changes in insolation due to periodic changes in Earth's orbit around Sun (Milankovitch theory). However, this relationship is far from understood. The insolation changes are so small that enhancing feedbacks must be at play. It might even be that the external perturbation only plays a minor role in comparison to internal stochastic variations or internal oscillations. This claim is based on several shortcomings in the Milankovitch theory: Prior to one million years ago, the duration of the glacial cycles was indeed 41,000 years, in line with the obliquity cycle of Earth's orbit. This duration changed at the so-called Mid-Pleistocene transition to approximately 100,000 years. Moreover, according to Milankovitch's theory the interglacial of 400,000 years ago should not have happened. Thus, while prior to one million years ago the pacing of these glacial cycles may be tied to changes in Earth's orbit, we do not understand the current magnitude and phasing of the glacial cycles.

In principle it is possible that the glacial/interglacial cycles are not due to variations in Earth's orbit, but due to stochastic forcing or internal modes of variability. We present a new method and preliminary results for a unified framework using a fully coupled Earth System Model (ESM), in which the leading three ice age hypotheses will be investigated together. Was the waxing and waning of ice sheets due to an internal mode of variability, due to variations in Earth's orbit, or simply due to a low-order auto-regressive process (i.e. noise integrated by system with memory)? The central idea is to use the Generalized Linear Models (GLM), which can handle both continuous and discrete weather/ climate variables and stochastic processes. GLM permits the inclusion of annual cycles as well as conditions the model on large-scale atmospheric or oceanic circulation. Such modeling framework will be built from large sets of ESM model integrations and paleoclimatic records and will represent synthetic climate time series of any length. It will be further used to force an ice sheet model and to create a synthetic time series of ice volume.