Apocalypse now: considerations of past and future climate using generalised energy balance models

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One of the lessons one learns from the EPICA Antarctic Ice Sheet ice core, which describes climatic history over the last 800,000 years, is that atmospheric CO_2 has fairly faithfully followed proxy (δD) temperatures over the entire period. In turn, this tells us that carbon variation in the atmosphere is a major cause of palaeoclimatic ice ages. In order to understand this, we need to include a description of the carbon cycle. This includes the production of CO_2 by volcanoes, its loss from the atmosphere by acid rain and consequent weathering and run off to the ocean, and the buffering of carbon in the ocean between the reservoirs of bicarbonate, carbonate and dissolved CO_2.

The simplest possible model for the interaction of these components is a compartment (o.d.e.) model for the concentrations of HCO_3^-, CO_3^{2-}, CO_2, as well as calcium ion Ca^{2+}, calcium carbonate $CaCO_3$ and acidity H^+ ($pH = -\log_{10}[H^+]$) in the ocean, together with a conservation law for atmospheric CO_2. To this set we add the simplest (o.d.e.) energy balance model describing the dependence of temperature on cloud and ice albedo, and on CO_2 and cloud greenhouse effect, as well as an ice sheet growth model which allows for nucleation and the ice sheet elevation effect, thus providing for bistability in the growth of the Pleistocene ice sheets.

The simplest asymptotic reduction of this generalised energy balance model is to two equations for ice sheet volume I and $CaCO_3$ concentration N, and in certain circumstance the model exhibits self-sustained oscillations, which represent a candidate for the 100,000 year periodic ice ages of the last half a million years.

In passing, we note the implication of the model for anthropogenic warming: century scale equilibration to an atmosphere where the ice sheets melt, as they are apparently doing, with consequent sea level rise of a metre or more per century.

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