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Ice-driven CO_2 feedback on ice volume

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Abstract. The origin of the major ice-sheet variations during the last 2.7 million years is a long-standing mystery. Neither the dominant 41 000-year cycles in $\delta^{18}O$/ice-volume during the late Pliocene and early Pleistocene nor the late-Pleistocene oscillations near 100 000 years is a linear ("Milankovitch") response to summer insolation forcing. Both responses must result from non-linear behavior within the climate system. Greenhouse gases (primarily CO_2) are a plausible source of the required non-linearity, but confusion has persisted over whether the gases force ice volume or are a positive feedback. During the last several hundred thousand years, CO_2 and ice volume (marine $\delta^{18}O$) have varied in phase at the 41 000-year obliquity cycle and nearly in phase within the ~100 000-year band. This timing rules out greenhouse-gas forcing of a very slow ice response and instead favors ice control of a fast CO_2 response.
In the schematic model proposed here, ice sheets responded linearly to insolation forcing at the precession and obliquity cycles prior to 0.9 million years ago, but CO_2 feedback amplified the ice response at the 41 000-year period by a factor of approximately two. After 0.9 million years ago, with slow polar cooling, ablation weakened. CO_2 feedback continued to amplify ice-sheet growth every 41 000 years, but weaker ablation permitted some ice to survive insolation maxima of low intensity. Step-wise growth of these longer-lived ice sheets continued until peaks in northern summer insolation produced abrupt deglaciations every ~85 000 to ~115 000 years. Most of the deglacial ice melting resulted from the same CO_2/temperature feedback that had built the ice sheets. Several processes have the northern geographic origin, as well as the requisite orbital tempo and phasing, to be candidate mechanisms for ice-sheet control of CO_2 and their own feedback.

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