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A dynamical systems approach to the Pleistocene climate

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In 1990, K. Maasch and B. Saltzman introduced a three-dimensional dynamical system to explain central features of the glacial cycles observed in the climate record of the Pleistocene Epoch. The model incorporates interactions between the Earth's oceans, atmosphere, and cryosphere, emphasizing the role of atmospheric carbon dioxide. We show that, in most parameter regimes, the long-term system dynamics occur on certain intrinsic two-dimensional invariant manifolds in the three-dimensional state space. These invariant manifolds are slow manifolds when the characteristic time scales for the total global ice mass and the volume of the North Atlantic Deep Water are well separated, and they are center manifolds when these characteristic time scales are comparable. In both cases, the reduced dynamics on these manifolds can be examined with unfolding techniques for multi-parameter bifurcation problems. The resulting bifurcation curves organize the parameter regions in which the model exhibits limit cycles of different types. In addition, knowledge of the reduced systems and their bifurcations is useful for understanding the effects of slowly varying parameters, which cause passage through Hopf bifurcations, and of orbital (Milankovitch) forcing. Both are central to the mechanism proposed by Maasch and Saltzman for the mid-Pleistocene transition.