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The impact of astronomical forcing on the Late Devonian greenhouse climate

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The geological record of the Paleozoic often exhibits cyclical or rhythmical characteristics, in many cases the result of cyclical changes in paleoclimate. However, a thorough understanding of the climatic processes that were driving Paleozoic climate change remains a challenge, for example because of relatively poor time-control on much of the Paleozoic paleoclimate archives. A good comprehension of the Paleozoic climate is crucial in order to grasp how the Earth's climate system works under conditions completely different than the ones of today. We apply Late Devonian (375 Ma) preconditions to the Hadley Centre general circulation model (HadSM3). In this work, we constrain the climatic steering role of the astronomical parameters, by keeping all other potential forcing factors (e.g. paleogeography, pCO_2, vegetation distribution) fixed. Thirty-one different "snapshots" of Late Devonian climates were simulated, by running the model into steady-state with 31 different combinations of eccentricity, obliquity and precession. To assess the performance of the model, we confronted a simulated Late Devonian climate with a moderate astronomical forcing regime to lithic indicators of paleoclimate and oxygen-isotope paleothermometry. This model-data confrontation provides good comparison, indicating that the model succeeds in simulating reasonable climates for the Late Devonian. The different simulations demonstrate that the coldest and driest global climates occur under low obliquity and low eccentricity. Under low obliquity, northern hemispheric sea-ice can form and the Gondwanan winter snow cover reaches a maximal extent, triggering an albedo-feedback mechanism and thus global coolness. However, even those coolest global climates undergo too hot austral summers for continental ice to build up in the southern hemisphere. Tropical and monsoonal precipitation intensity demonstrates a strong direct dependence on precession-driven quantity of summer insolation. Temperature, on the other hand exhibits a quadratic response, with increasing temperatures under low quantities of summer insolation. The latter is explained by a combination of a latent heat and a cloud-albedo negative feedback mechanism. Obviously, the large uncertainties on the fixed forcing factors, such as paleogeography or pCO_2, make that the reported sensitivity of Late Devonian climate to astronomical forcing can only be used as a first estimate of its order of magnitude. Nevertheless, the present simulations of Late Devonian paleoclimates provide a useful guide to the interpretation of astronomical rhythms in the geological record.