Response of the Snowball Earth Climate to Orbital Forcing at High CO$_2$ Level

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It is commonly accepted that the Milankovitch cycles have modulated the glacial-interglacial cycles during the Quaternary Period. However, how the climate during the Neoproterozoic snowball Earth events, the most extreme glaciations that have occurred on Earth, was affected by the orbital forcings remains largely unclear. Especially, whether the snowball Earth deglaciation might occur more easily at some orbital configurations than others is an important question. Here a coupled atmosphere-land model (CAM3 and CLM3) is used to investigate the response of temperature and hydrological cycle during a snowball Earth to this forcing at an atmospheric CO$_2$ level of ~0.1 bar. To simplify the analysis, we have chosen to remove the continents. The results show that the climate is very different under different orbital configurations. The globally averaged annual surface temperature can differ by 2.4 °C while the difference in the monthly mean can reach 3.7 °C in the subtropical region. Surprisingly, we find that the Milankovitch theory does not only work in the extratropical region but also in the tropics; the snow thickness in the tropical region is inversely proportional to the summer insolation received in this region. After adding an explicit meltpond module, we find that the threshold CO$_2$ that is needed to trigger the deglaciation may be reduced from 0.12 bar (low eccentricity) to 0.07 bar (high eccentricity). Moreover, the summer insolation in the tropics is more important than that in the subtropical region for the formation of a perennial meltwater belt. Hence, we conclude that the orbital forcing is important to the snowball Earth climate at its late stage and would assist Earth to get out of this state when the eccentricity was high.