



## Multiple steady states of Northern Hemisphere ice sheets and the timing of glacial cycles

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Wax and Wane of large Northern Hemisphere ice sheet occurred in the past few million years, characterized by a transition from a period of 40 thousand years cycle with small amplitude of ice sheet change to 100 thousand year cycle with a large amplitude, known as the Middle Pleistocene transition. Although the characteristics of the glacial cycle is well observed, the mechanism what determines the 100ka cycle and what controls the terminations are still under debate. Here we show that the pattern of the growth of the ice sheets during a glacial cycle follows the hysteresis (multiple steady states) structure of North American ice sheet versus insolation by modelling the three dimensional ice sheet. The 100 ka termination is punctuated by Northern American ice sheet responding basically to the precession cycle and summer insolation through its delayed bedrock depression and the large scale calving. Terminations occur when the summer insolation increases after a minimum eccentricity even under constant CO<sub>2</sub> level. Obliquity modifies the role of precession and becomes important for a glacial cycle especially when the eccentricity is small. The North American ice sheet is slightly more favorable for faster growth than Eurasian ice sheet when the ice sheet expands over Labrador and Hudson Bay, and suppresses the growth of Eurasian ice sheet through the atmospheric planetary wave feedback. As a result, the North American ice sheet can have affected the hemispheric climate and punctuated the ice sheet change in Eurasia and in Antarctica through CO<sub>2</sub> and sea level change. Furthur we show that a cooling due to, for example, the draw down of long term CO<sub>2</sub> level of 20ppm or so at most from 240ppm to 220ppm is enough for a switch from 40 ka cycle response to 100 ka cycle response of Northern Hemisphere ice sheet.