Geophysical Research Abstracts
Vol. 20, EGU2018-19476, 2018
EGU General Assembly 2018

Forcing of late Pleistocene ice volume by spatially variable summer energy

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Changes in Earth's orbit have been dubbed a pacemaker of Quaternary glacial-interglacial climate variability. However, the significance of latitudinally varying insolation as a dynamical forcing of late Pleistocene climate changes remains unclear. Here we use a model-free state-space reconstruction method to quantify the strength of the dynamical influence of locally varying summer energy on global ice volume, with orbitally independent age assignments. Our empirical approach suggests that integrated summer insolation at specific latitudes was a significant driver of ice volume during the past 800,000 years. Summer energy impact on ice volume is detected in a continuous latitudinal band at \textasciitilde50-90${\circ}$N, consistent with the role of summer melting of Northern Hemisphere ice sheets predicted by Milankovitch theory. Insolation forcing at southern mid-latitudes strongly covaries with the canonical Milankovitch forcing, and coincides with the subtropical front and the mid-latitude westerlies, the modulation of which has been implicated in Quaternary climate changes. In contrast, the dynamics of summer energy forcing in the Northern Hemisphere south of the extent of ice sheets is different, possibly capturing ice volume sensitivity to latitudinal insolation gradients. Our results show that the importance of external forcing on late Pleistocene ice ages cannot be fully accounted for by a unique insolation forcing time series. The global ice volume response to spatially variable summer energy encompasses a range of physical processes that operate at different times of the year, including forcing signals with a wide spectrum of obliquity-to-precession frequency ratios.