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Sensitivity of glacial states to orbits and ice sheet heights in CESM1.2

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Changes between icehouse and greenhouse states are known to be the result from non-linear climate responses. However, the magnitudes of these responses are not well constrained. Recent work shows that climate models, specifically the Community Earth System Model version 1 (CESM1), have improved substantially in their capacity to quantify the Last Glacial Maximum (LGM) state. Given that CESM1 can reproduce the LGM well, we consider the combined impacts of estimated ice sheet heights, Quaternary orbits, and greenhouse gas changes for a range of Quaternary climate states. To that end, we conducted two sets of experiments: first, a series of sensitivity experiments on the Preindustrial climate and second, experiments on Quaternary glacial states.

In the first set of the experiments, we show how CESM1 quantifies the impacts of ice height, orbit, and greenhouse gas changes by considering each component incrementally. Then we demonstrate that they combine through non-linear impacts. The analysis is based on seven sensitivity experiments: 1) Late Holocene orbit, 2) Representative Concentration Pathway 8.5 (RCP85) greenhouse gases, 3) LGM orbit, 4) LGM greenhouse gasses, and 5) Greenland icesheet height changes, 6) LGM orbit with Greenland icesheet height changes, and 7) LGM orbit with LGM greenhouse gases and Greenland icesheet height changes. We show that adding individually these component changes do not linearly combine to match the simulations with combined changes.

These non-linear effects guide the second set of experiments, because non-linear systems are predictable due to state dependent outcomes. We use of 4 glacial ice sheet height differences and 4 glacial maximum orbital states (LGM, and Marine Isotopic Stage 4,6, and 8), for a total of 16 sensitivity experiments. These orbits are known glacial maximal states, and the 4 ice sheet heights are within the range of estimated ice volumes. We analyze these simulations in two ways, 1) the explicit effect of changes in orbit while holding the ice sheet constant, and 2) the explicit effect of changes in ice sheet height, while holding the orbit constant.

Our results show that ice sheet heights dominate the changes in climate system, regardless of orbit. But, there are subtle regional effects that orbit has that are not explained by ice sheet height changes. For example, higher ice sheets induce a global temperature increase, but regionally within Europe, there are non-linear changes in warming or cooling that are unexplained by the ice

sheets. As the ice sheet height is lowered, the changes in Europe do not linearly change, and are dependent on the orbit configuration.

These results show that there are specific pathways for climate that occur due to the combination of icesheet height and orbit, and theoretically imply a constraint on the real climate state. In a linear system, these 16 states would represent the variability of the Quaternary, but as this is a non-linear system only 1 state is physical for a given orbit. As proxy data spatial and temporal resolution improves for the Quaternary, combined with these modeled climates, we expect substantial constraints on the available realistic climate states.