The 40-kyr glacial cycles in the Early Pleistocene (~1.6-1.2Ma): Roles of precession, eccentricity, and obliquity

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The long-term climate change in the Quaternary Period is characterized by the glacial cycles. In the Late Pleistocene, the glacial cycles are characterized by the 100-kyr cycles with asymmetric shape and large amplitude (e.g. Lisiecki and Raymo, 2005). In the Early Pleistocene, on the other hand, the dominant periodicity of the glacial cycles is 40-kyr and the pattern of the ice-sheet evolution is characterized by relatively weak asymmetric shape and small amplitude compared with the late Pleistocene (e.g. Lisiecki and Raymo, 2005). According to the classical Milankovitch theory (Milankovitch, 1941), the 20-kyr variation of precession plays an important role in driving the glacial cycles. The 20-kyr variation of precession has a central role in setting the timing of each deglaciation (e.g. Raymo, 1997; Abe-Ouchi et al., 2013), while combined effect of obliquity and precession is important as a pacemaker of glacial cycles in the Late Pleistocene (e.g. Huybers, 2011). In the Early Pleistocene, however, only weak variance in the $d^{18}O$ proxy record has been observed at the dominant periodicity of precession (Raymo et al., 2006), partly due to the lack of the resolution for precession (Lisiecki, 2010a; Huybers, 2011). For this reason, the role of precession in the Early Pleistocene is still unclear.

In our presentation last year, we simulated the 40-kyr cycles in the Early Pleistocene (~1.6-1.2 Ma) and explained the formation mechanism using a three-dimensional ice sheet model IcIES with climate parameterization based on MIROC (IcIES-MIROC; Abe-Ouchi et al., 2013). In this presentation, we compare the typical 40-kyr cycle with the typical 100-kyr cycle and focus on the role of the 20-kyr variation of precession in the Early Pleistocene. We show that precession is important in (1) determining the timing of the threshold for deglaciations, (2) making the deglaciation usually faster than the glaciation, (3) sometimes forming thin but extensive ice-sheet at the glacial maximum, which waxes and wanes in one precession cycle, and (4) shaping the time-series of the ice-volume, such as 'pulse-like', 'U-shaped', and 'saw-toothed' patterns in the early Pleistocene, which is consistent with the proxy record (e.g. Lisiecki and Raymo, 2005; Hodell and Channell, 2016).

We further infer that the relatively high 100-kyr power of eccentricity in our experiment period (Lisiecki, 2010a) helped form the 40-kyr glacial cycles. This allows the 40-kyr variation of obliquity to assist the deglaciation even when eccentricity is small, and this makes the 40-kyr cycles in the experiment period (~1.6-1.2 Ma) clear.

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