How to initiate and maintain a Greenland ice sheet during the late Pliocene warm period?

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The first major pulse of ice-rafted debris on Greenland continental margin is observed at 3.3 Ma, correlated with oxygen isotope signal, suggesting the first expansion in Greenland ice volume, with later increase occurring from 3 Ma (Kleiven et al., 2002). The extent of the Greenland Ice Sheet (GrIS) during the late Pliocene (3.3 to 3 Ma) remains largely unconstrained, but was fixed to 50% of its present-day volume for simulations of the late Pliocene climate (Dowsett et al., 1999; Hill et al., 2007). Reconstructed pCO_2 for this period vary during the time interval and among reconstructions. Seki et al. (2010) suggest values between 330 to 400 ppm, and Bartoli et al. (2011) propose minimal CO_2 estimates of 245 ppm.

Through a series of simulations with the IPSL-CM5A-LR coupled model used to force the GRISLI ice sheet model, we investigate the possibility of initiating and maintaining an ice sheet on Greenland during the late Pliocene warm period. First, starting from ice-free conditions on Greenland, we force the GCM with CO_2 levels of 405, 360 and 280 ppm and different orbital configurations (namely, a cold orbit leading to the minimum insolation at 65°N at summer solstice occurring between 3.8 and 3 Ma, and the preindustrial orbit). We find that even with a minimum insolation, CO_2 level has to be lowered to 280 ppm in order to build an ice sheet on the southeast mountainous regions of Greenland, with a volume of ~1 m sea-level equivalent. This ice sheet is then used as a boundary condition in the GCM which is forced with 360 and 405 ppm and preindustrial orbit or a warm orbit leading to a maximum of insolation at summer solstice. Results show that, unless combining a maximum insolation and 405 ppm of CO_2, which leads to a reduced and thin ice sheet less than 500 meters high, the ice sheet barely melts, because of strong ice-albedo feedbacks. Recoupling experiments using the GrIS simulated with low insolation and 360 or 280 ppm of CO_2 are currently carried out in order to investigate the strength of the ice-albedo feedback in a cold climate, which could lead to a larger glaciation. Nevertheless, GCM outputs show higher summer temperatures downwind of the GrIS when compared to the ice free experiments, possibly preventing its further growth because of a föhn effect, as in Langen et al. (2012).