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Earth System Dynamics Discussions

Interactive comment on "ESD Ideas: Why are glacial inceptions slower than terminations?" *by* Christine Ramadhin et al.

Anonymous Referee #1

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Overall:

This paper proposes two possible feedbacks due to Arctic sea ice that could influence Northern Hemispheric glacial-interglacial variations, in particular the sawtooth asymmetry long noted in 100,000 year cycles. Sea-ice feedbacks could well play a role in aspects of glacial-interglacial cycles, whether as primary feedbacks or as secondary influences among others. However, in my view the description of the mechanisms here is confusing, and I have several concerns that question their viability relating to the asymmetry. Given the main concerns (#1 to 4 described below), I think that the mechanisms in the paper are not organized in a physically coherent way, and the proposed sequence is not sufficiently developed and plausible for an ESD Ideas paper.

Specific points:

1. The text and Fig. 1 are confusing regarding the sequence of processes, mechanisms, and stages, and how they relate to the "inception" and "termination" periods of the title. The text should define the intervals (in years before present, ka) the intervals of "inception" (and also termination, presumably ∼20 to 10 ka), and the text and red arrows in the insets should specify more precisely to what parts of the long-term record the proposed mechanisms and stages apply. The time periods for each stage in the panels in Fig. 1 should be specified explicitly, either by giving ka values or with time bars in the insets relating to the long-term record.

In particular the time period referred to as "inception" is unclear. "Inception" is often taken to mean the first rapid buildup of ice following the last interglacial, around ∼120 to 110 ka. Given that, the long-term record in Fig. 1. insets does not have a pronounced difference in the slope (rate of growth), compared to the rate of retreat during the last termination ∼20 to 10 ka. By eye at least, they both look equally steep. In that case the whole premise of the paper is on shaky ground. But perhaps "inception" here refers to the later more gradual buildup over a longer part of the cycle, averaged over several orbital variations, even as long as ∼100 to 20 ka, which does give rise to the long-noted sawtooth asymmetry. This may be the case, as suggested by the phrase "changeover to a glacial period takes tens of thousands of years" (line 23).

Other sources of confusion are: (i) none of the arrows in Fig. 1, or the intervals referred to in the text, lie in the interval roughly ∼20 to 10 ka usually referred to as "termination", i.e., the last deglacial retreat since LGM, and (ii) it does not seem to matter whether the red arrows in the insets fall in a zenith or nadir of faster orbital/millennial fluctuations of the long-term record.

The long-term record in the insets of Fig. 1 is presumably from Fig. 1b of Bintanja et al. (2008), which is a model-dependent reconstruction. It would be better to use a purely data-based record, with ice-core, deep-sea-core d18O, or sea-level proxies.

2. Several aspects of the mechanisms discussed in the middle paragraphs (lines

38-89) are confusing and/or questionable. The first of the two feedbacks, "sea ice-precipitation", is reasonable and has been involved in previous studies, i.e., greater Arctic sea ice cover reduces evaporation and hence high-latitude precipitation, reducing the surface budget of Northern Hemispheric ice sheets. The second feedback, "sea ice-insulation", involves the sea-ice "lid" insulating the Arctic Ocean thermally from the atmosphere, but it is not clear in what sense this is a feedback, positive or negative, and how it influences ice-sheet growth or retreat. (It must have an effect on the latter, given the premise of the paper). Various processes are mentioned in lines 66-89 including buildup of geothermal heat flux, but how they are negative feedbacks on terrestrial ice sheet volume variations is absent or unclear.

3. Arctic sea ice, up to a few meters thick, is a "fast" component of the climate system, coming into quasi-equilibrium with the regional atmospheric and oceanic climate within a few decades, i.e, it has only decadal-scale inertia, and its mass turns over every few years to $\sim$decade. As such it can influence climate sensitivity to external changes (like water-vapor feedback for instance), or influence tipping points between multiple stable states. But it is not itself a long-term component of the climate system with inertial time scales of hundreds to many thousands of years (such as ice-sheet size, deep-ocean temperatures, bedrock deformation state, CO_2 level). This important distinction seems to be blurred in places, and sea ice is implied to have inertia of thousands of years, e.g., lines 85-86 ("since not all first-stage ice was lost") seem to require that the same sea-ice mass persists between the stages discussed here (Stage A to D, or perhaps C to D), tens of thousands of years apart. This contributes to the confusion regarding the sequence of mechanisms and processes in the middle paragraphs.

4. In places, the text neglects associated processes that are likely to dominate the process under discussion. For instance, in line 51, less summer melting of sea ice could well dominate over less precipitation, favoring and not hindering sea-ice growth. (A related point: the dominant control of Northern Hemispheric ice-sheet variations on orbital time scales is generally considered to be not snowfall, but ice melt in southern

ablation zones, i.e., summer atmospheric temperatures, not precipitation rates, as recognized by Milankovitch and many subsequent studies by choosing summer-season insolation at $\sim$60 or 70 N as the orbital metric). Sea ice-precipitation feedback may still function, but why it is not dominated by changes in summer air temperatures and ablation-zone melt should be justified if possible.

Another example is in lines 69-70 discussing the buildup of geothermal heat flux. The effect of this on Arctic ocean temperatures would likely be minor compared to changes in ocean circulation exchange between the deep Arctic and the North Atlantic.

5. Tziperman and Gildor (2003) referenced here and their related papers involve many of the same mechanisms as here: sea-ice switches, deep ocean temperatures, and the sea ice-precipitation feedback on ice sheets. How are the feedbacks and the sequences here different from theirs?

6. The scenarios here do not consider the possibility of very thick $\sim$1 km ice-shelf cover over the entire Arctic Ocean during some past glacial maxima, proposed by Jakobbson et al. (2016) referenced here. These thick ice shelves would have been supplied primarily by ice-sheet flow and would introduce very different physics and processes than here. This could at least be mentioned, as the Jakobbson study is used as a reference.

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