Is a warming of the Antarctic continental shelf reversible?

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The Antarctic ice sheet mass loss and thus global sea-level rise is closely related to enhanced ice stream discharge to its fringing ice shelves. The transfer of mass into the ocean occurs via iceberg calving and ice shelf basal melting (Jacobs et al., 1992). For decades the balance of both terms was assumed to be in favor of the former (Jacobs et al., 1996), but recent results, based on remote sensing, revealed the latter to be the larger term (Rignot et al., 2013). Basal melting is either fueled by heat transported from the open ocean across the continental shelf to deep grounding lines or by high-saline waters formed in coastal polynyas. A recent model study indicates that future atmospheric conditions in the southern Weddell Sea may switch the shelf circulation, formerly dominated by cold saline waters, to one influenced by warm waters of open ocean origin (Hellmer et al., 2012) with consequences for the basal mass flux and ice shelf/ice sheet dynamics (Thoma et al., 2015). Here, we investigate the possibility of the southern Weddell Sea to return from a 'warm state' to present conditions with cold saline shelf water and the slope current following the continental shelf break. We continue the simulations showing a warming of the Filchner-Ronne Ice Shelf cavity, applying 20th-century atmospheric and basal mass flux forcing at different future points in time.

Altered atmospheric conditions were applied at different stages of the 'warm state' by changing at two points in time (2100 and 2200) to the 20th-century atmospheric forcing of the period 1880-1979. The results show that, regardless when during the 'warm phase' (2075-2200) the starting point is chosen, the basal mass loss (BML) drops towards a new 'quasi' equilibrium at 800 Gt/yr (Fig. 1a). In parallel, the sea-ice volume in the southern Weddell Sea, starting to decrease during the 21st-century, recovers within 10 years to continue with the same interannual variability, but at a slightly lower mean level, as during the 20th-century (Fig. 1b). The glacial melt input is still too large and/or the salinification due to sea ice formation too small to re-establish dense saline water on the continental shelf. I.e, once the system reaches the 'warm state', a positive meltwater feedback stabilizes the shelf circulation such that warm waters of open ocean origin continuously flush the ice shelf cavity.

A reduction to 20th-century basal mass fluxes, however, can stop warm water from penetrating onto the continental shelf and into the sub-ice cavity. I.e., an oceanic tipping point exists in the southern Weddell Sea close to the Antarctic Ice Sheet, which has long-term consequences for the ice sheet stability. We admit that the existence of this tipping point strongly depends on the atmospheric conditions projected for the region (Timmermann & Hellmer, 2013). The process seems to be irreversible as long as deep basal areas provide sufficient glacial melt to freshen the continental shelf waters. The decay of the ice shelf and a significant elevation change in the ice streams' catchment basins seem to be the ultimate consequence of a redirection of the slope current in the southern Weddell Sea.

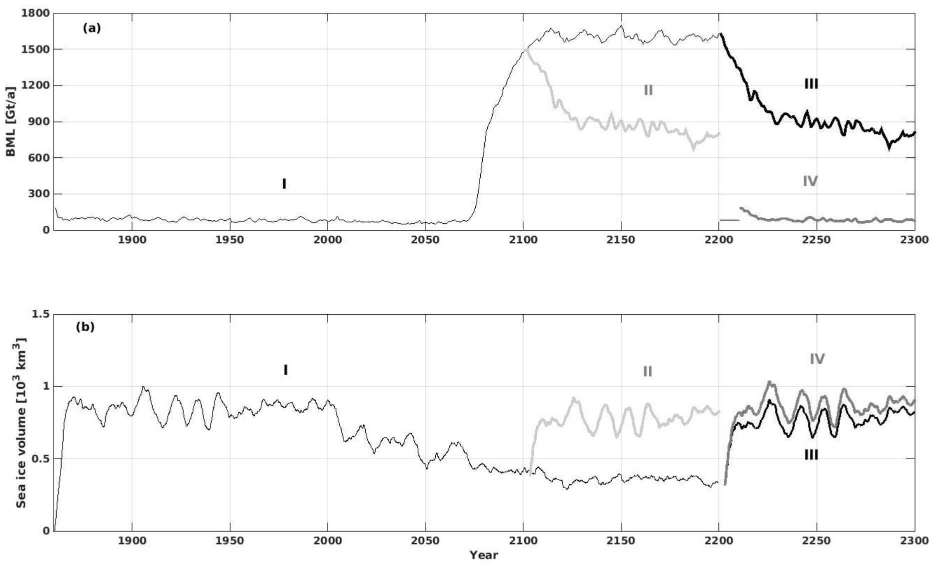

Figure 1. Spliced time series from year 1860 to 2300 for (a) Fichner-Ronne Ice Shelf basal mass loss (BML) and (b) sea ice volume on the southern Weddell Sea continental shelf (5-year running mean). Atmospheric forcing was extracted from HadCM3 20th-century (1860-1999) and SRES-A1B (2000-2199) output (I - thin black line), extended with HadCM3 forcing of the period 1880-1979, starting at years 2100 (II - light grey line) and 2200 (III - thick black line) of the 'warm phase'. In addition, climatological mean basal freshwater flux was applied for ten years only together with 100 years of atmospheric forcing of the period 1880-1979, starting in year 2200 (IV - grey line).

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