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The Cryosphere
Discussions

Interactive comment on "Warming of waters in an East Greenland fjord prior to glacier retreat: mechanisms and connection to large-scale atmospheric conditions" *by* P. Christoffersen et al.

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We are very pleased by the positive comments in this review.

The referee's main suggestions are to (1) make the paper more appealing to glaciologists, and (2) highlight the time scales over which glaciers respond to oceanic forcing.

We addressed (1) by expanding section 6 entitled 'Synthesis'. We added a new figure (Figure 11), which shows that the connection between synoptic atmospheric pressure variations and properties of coastal water is not only valid for the Kangerdlugsuaq region, but for the entire east coast south of 69°N. This new paragraph is:

"The wider effect of ΔP on coastal water temperature and glacier dynamics are shown in Figure 11. The figure shows changes in the frontal position of 30 marine-terminating glaciers fronts in East Greenland, as reported by Seale et al. (2011). The figure clearly shows that retreats were common in 2000-05 for glaciers south of 69°N (Fig. 11a), whereas glaciers further north remained largely unchanged (Fig. 11b). The retreat of the southern glaciers coincides with major warming of the entire water column at adjacent coastal sites (Fig. 11c). Furthermore, the connection between ΔP and water mass change, as discussed above, remains intact when assessed on a regional scale (Fig. 11c). The role of the geostrophic wind and the mechanisms of water mass exchange between the Irminger Sea and KTr thus apply to the shelf seas of East Greenland south of 69°N, causing impact on outlet glaciers along the entire southeast coast of Greenland. The setting of glaciers north of 69°N is considerably different in that temperature of coastal waters are largely below 0°C (Fig. 11d). The unchanged position of northern glaciers may thus be explained by cold properties of coastal shelf waters (Seale et al., 2011). The cold state of shelf waters north of Denmark Strait is associated with transport of cold polar waters and sea ice from the Arctic Ocean and a much more limited and distant supply of AW."

To address (2), we added a paragraph to section 4 entitled 'The abrupt retreat of KG in 2004-05'. This paragraph is:

"The delayed retreat of KG relative to peak heat flow into KTr is similar to the delayed retreat of glaciers farther south relative to peaks seen in sea-surface temperature data (Howat et al., 2008). Howat et al. (2008) suggest the delay is connected to initial slow retreat over topographic high points and subsequent fast retreat across over-deepened troughs with reverse bed slopes. Whereas Helheim Glacier retreated across an over-deepening (Nick et al., 2009), it is not certain that glaciers undergoing significant retreat are necessarily positioned over topographic over-deepenings. The observed delays may in general be connected to the period over which water masses travel from deep ocean, across the continental shelf and into fjords, as well as the sensitivity of individual glaciers to oceanographic change.

The aim of this paper is to explain why Greenland fjords contain subtropical waters and why the amount of subglacial water varies over time. Although we present hydrographic data acquired in Kangerdlugssuaq Fjord, these datasets are spaced 11 years apart. The assessment of temporal variability is modelling-based and synoptic in scale. Hence, we cannot easily identify the exact time scales over which glaciers should respond to oceanographic change. We therefore finish the above (new) paragraph with the following sentence:

"The latter is beyond the scope of this study, but includes the influence of glacier geometry and calving-related processes, such as ice-front melting (Rignot et al., 2010) and presence of proglacial ice melange and sikussak (Reeh et al., 2001, Joughin et al., 2008b; Amundson et al., 2010)."

Reeh et al. (2001) and Joughin et al. (2008b) was added to our list of references.

To integrate (1) and (2) in the conclusions, as suggested by the referee, we added the following short paragraph to our conclusions:

"Our findings show that the geostrophic wind should be regarded as a key factor in the oceanographic forcing of the Greenland Ice Sheet. The connection between the position of the IL and ΔP and its influence on coastal waters apply to the shelf seas south of 69°N, causing impact on outlet glaciers along the entire southeast coast of Greenland. The same mechanism explains the warming observed in coastal waters along the west coast (Holland et al., 2008), as coastal waters from East Greenland are transported to the west coast in coastal currents. Khan et al. (2010) report a shift in the centre of ice-sheet mass losses, from southeast to northwest Greenland after 2007, and these losses may comprise a delayed response of north-western tidewater glaciers to warm coastal waters originating from the east coast."

Khan et al. (2010) was added to our list of references.

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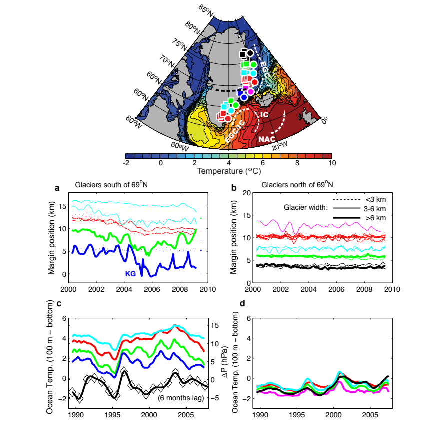

Figure 11. Map of Greenland and surrounding seas (top) with coloured squares showing locations of marine-terminating glaciers whose frontal positions are shown in (a) and (b). Coloured dots show adjacent locations where subsurface temperatures are examined in ocean reanalysis (c-d). The colour scale show sea surface temperature averaged for 2004. (a) Changes in the position of calving fronts for glaciers south of 69°N. The colours represent three glaciers in Mogens Fjord (red), Tingmjarmiut and A. P. Bernstoffs Gletscher (cyan); Helheim Glacier (green), and three glaciers in KFj including KG (blue). (b) Same as (a) but for glaciers north of 69°N. The glaciers are Borggraven (magenta); eight glaciers in Scoresbysund including Daugaard-Jensen (red); Hisingers and Nordenskjorlds Gletscher near Mestervig (cyan); four glaciers in and around Kejser Franz Joseph Fjord (green), and four glaciers near Danmarkshavn (black). Colours match locations shown on map (top). (c) Subsurface temperature from ocean reanalysis averaged from 100 m to bottom for sites near glaciers south of 69°N. Seasonal temperature variations are excluded by filtering the time-series of monthly means with a 12-month-moving average. Colours correspond to those in (a) and locations shown on map (top). Black diamonds and solid black line show winter atmospheric pressure difference across Denmark Strait (ΔP) as seen in station records from Tasiilaq and Stykkishólmur (see Fig. 1 for location). (d) Same as (c) but temperature is for sites near northern glaciers. Modified from Seale et al. (2011).

Fig. 1. See caption embedded in figure