Submarine glacial landforms in Southeast Greenland fjords reveal contrasting outlet-glacier behaviour since the Last Glacial Maximum

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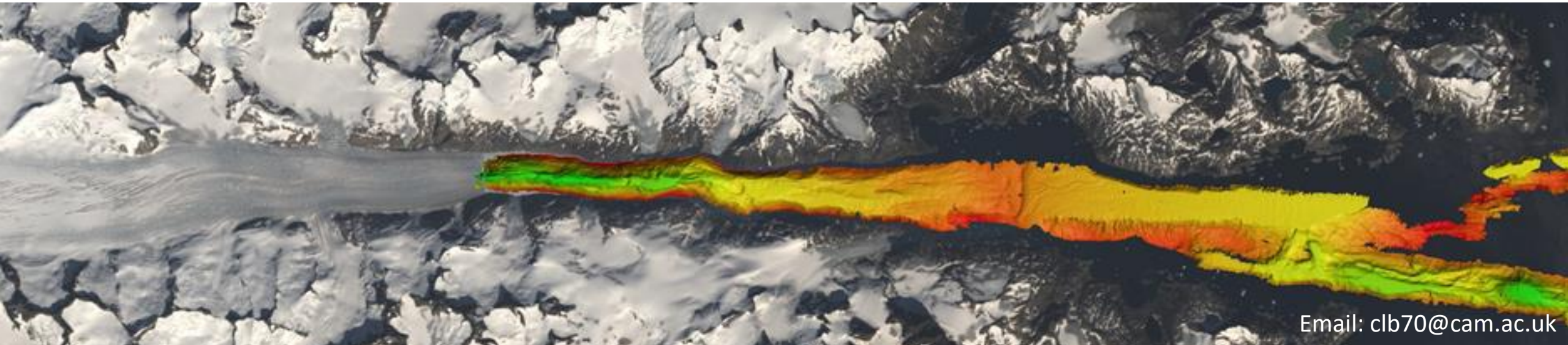

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1. We use bathymetric data to investigate the deglacial history of SE Greenland

- The SE Greenland margin (**Fig. 1**), which includes the Julianehåb Ice Cap (JIC), is suggested to have been sensitive to past climatic changes (Bjørk *et al*., 2012).

- Mountainous terrain and a lack of ice-free areas have hitherto largely prevented analysis of the deglacial and Holocene behaviour of SE Greenland's marine-terminating outlet glaciers.

- We use bathymetric data, from NASA's Oceans Melting Greenland (OMG) mission and from gravity inversion derived from Operation Icebridge gravity data (Millan *et al*., 2018), to map the distribution of submarine moraines (**Fig. 1**).

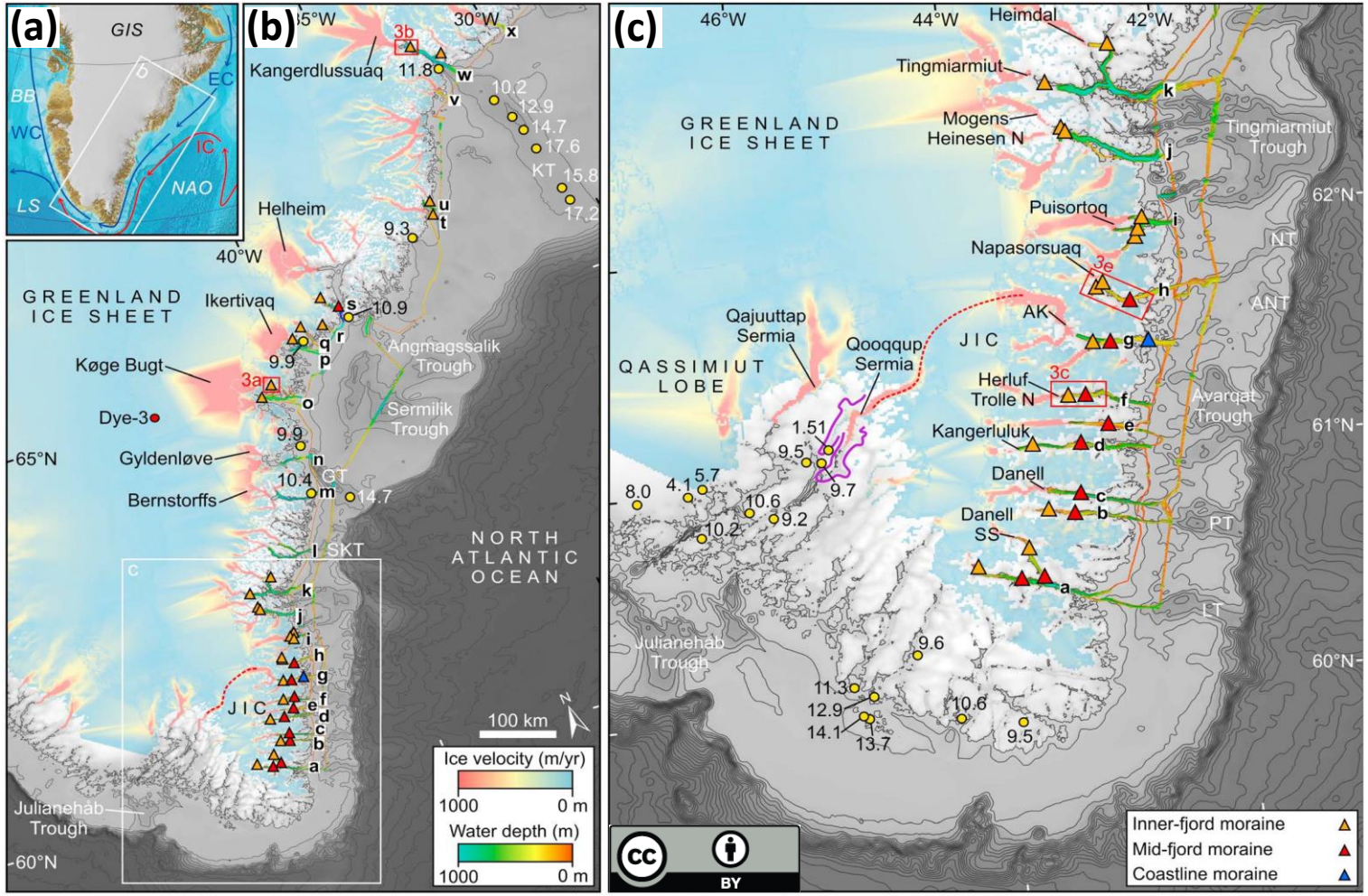
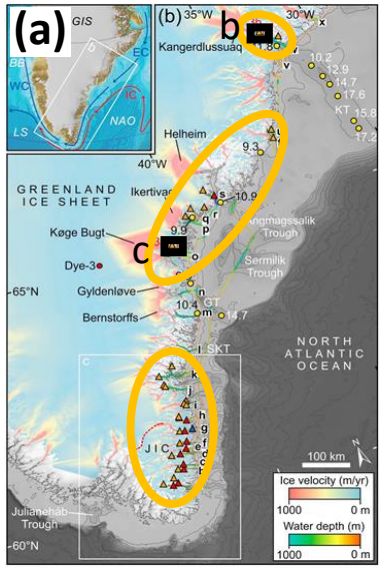
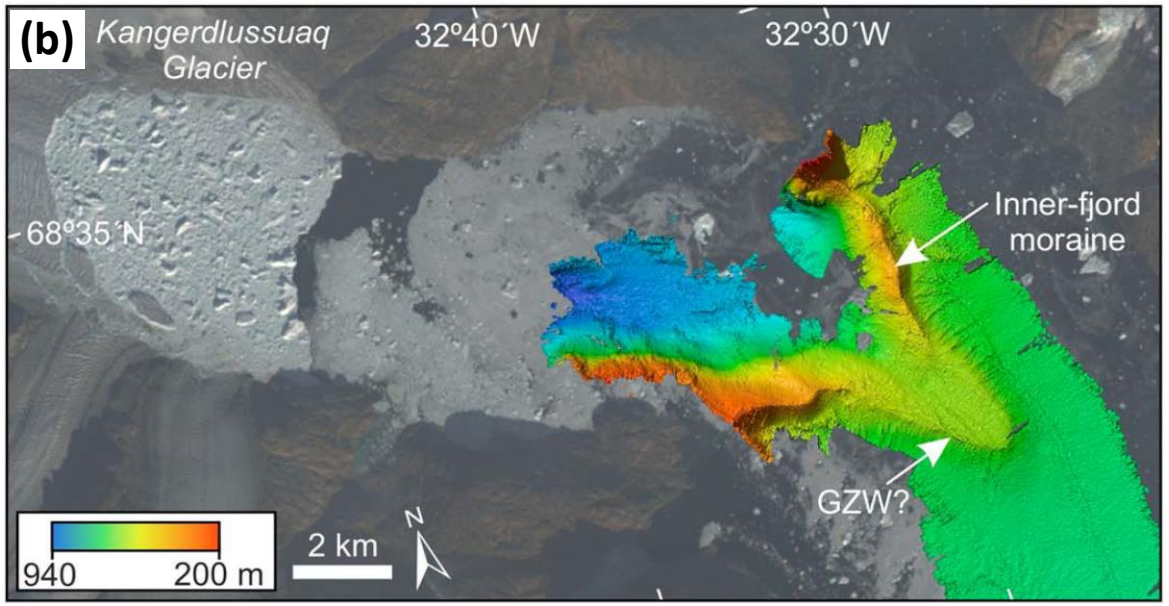


Fig. 1. (a) Map of SE Greenland and major ocean currents. **(b)** and **(c)** Maps of the SE Greenland margin and the Julianehåb Ice Cap (JIC), respectively, showing OMG bathymetric data and the distribution of submarine moraines. Background is IBCAO bathymetry (Jakobsson *et al*., 2012). Yellow circles are published ^{10}Be and ^{14}C deglacial ages (Bennike and Björck, 2002; Weidick *et al*., 2004; Roberts *et al*., 2008; Larsen *et al*., 2011; Dyke *et al*., 2014; Winsor *et al*., 2014). Adapted from Batchelor *et al*. (2019).

2. Inner-fjord moraines exist in many SE Greenland fjords

- Major moraine ridges exist in an inner-fjord (landward third of the fjord length) setting for 26 (~65%) of the surveyed fjords of SE Greenland, including beyond the JIC (**Fig. 2a**).
- The moraines are up to 2 km long and 150 m tall, and span the fjord width (**Fig. 2b and c**).
- The inner-fjord moraines are all located beyond the oldest ice-marginal position as mapped from aerial photographs (Bjørk et al., 2012).
- They are interpreted to have formed sometime during the Neoglacial (since ~4 ka), which includes the Little Ice Age (~1450–1850).





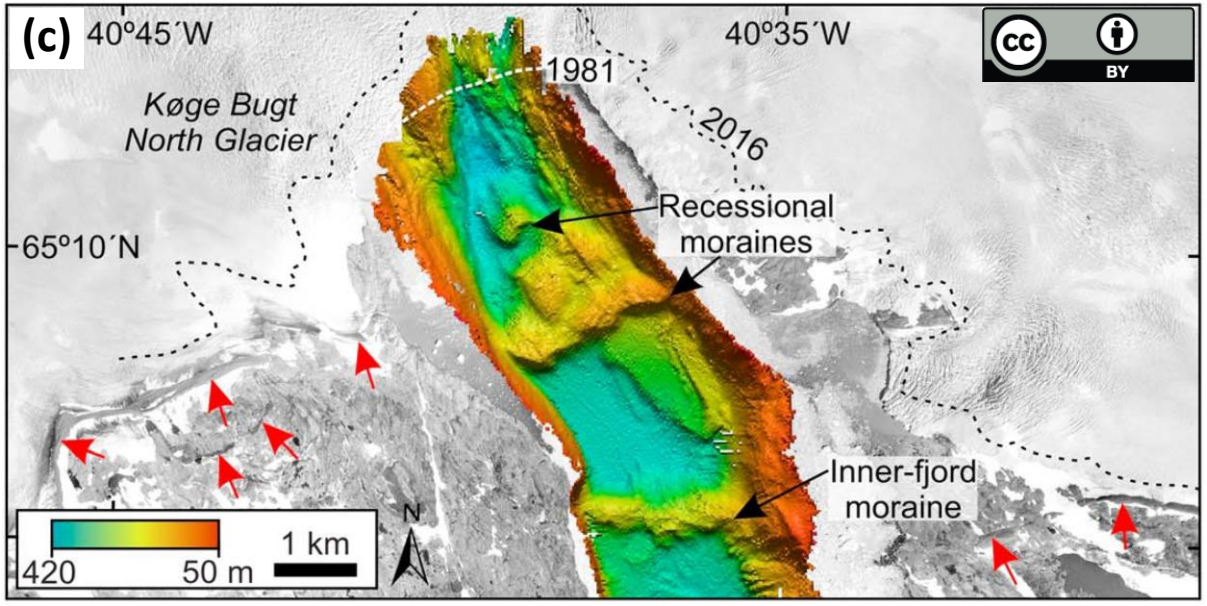


Fig. 2. (a) Map of SE Greenland showing the distribution of inner-fjord moraines (yellow). **(b)** Example of an inner-fjord moraine beyond Kangerdlussuaq Glacier. Background is Landsat 8 satellite imagery (2016). **(c)** Example of an inner-fjord moraine and recessional moraines beyond Køge Bugt North Glacier. Red arrows are prominent terrestrial moraines. Background is 1981 aerial photography from G150 AERODEM (Korsgaard *et al*., 2016). Adapted from Batchelor *et al*. (2019).

3. Mid-fjord moraines are identified beyond the Julianehåb Ice Cap

- Major moraine ridges exist in a mid-fjord setting (close to the fjord midpoint, beyond the inner-fjord moraines) in all of the nine fjords of the eastern Julianehåb Ice Cap, yet in only one of the fjords of the SE Greenland Ice Sheet (**Fig. 3a**).
- The moraines are up to 3 km long and 150 m tall, and span the fjord width (**Fig. 3b**).

- Given the distribution of published deglacial ages (Bennike & Björck, 2002; Knutz et al., 2011; Larsen et al., 2011), we suggest that the mid-fjord moraines were formed during <u>an ice-cap-wide still-stand or re-advance that occurred during the early Holocene.</u>

- *Could there have been a climatic control, e.g. the 8.2 ka event that has been recorded from Greenland ice cores (Alley et al., 1997)?*

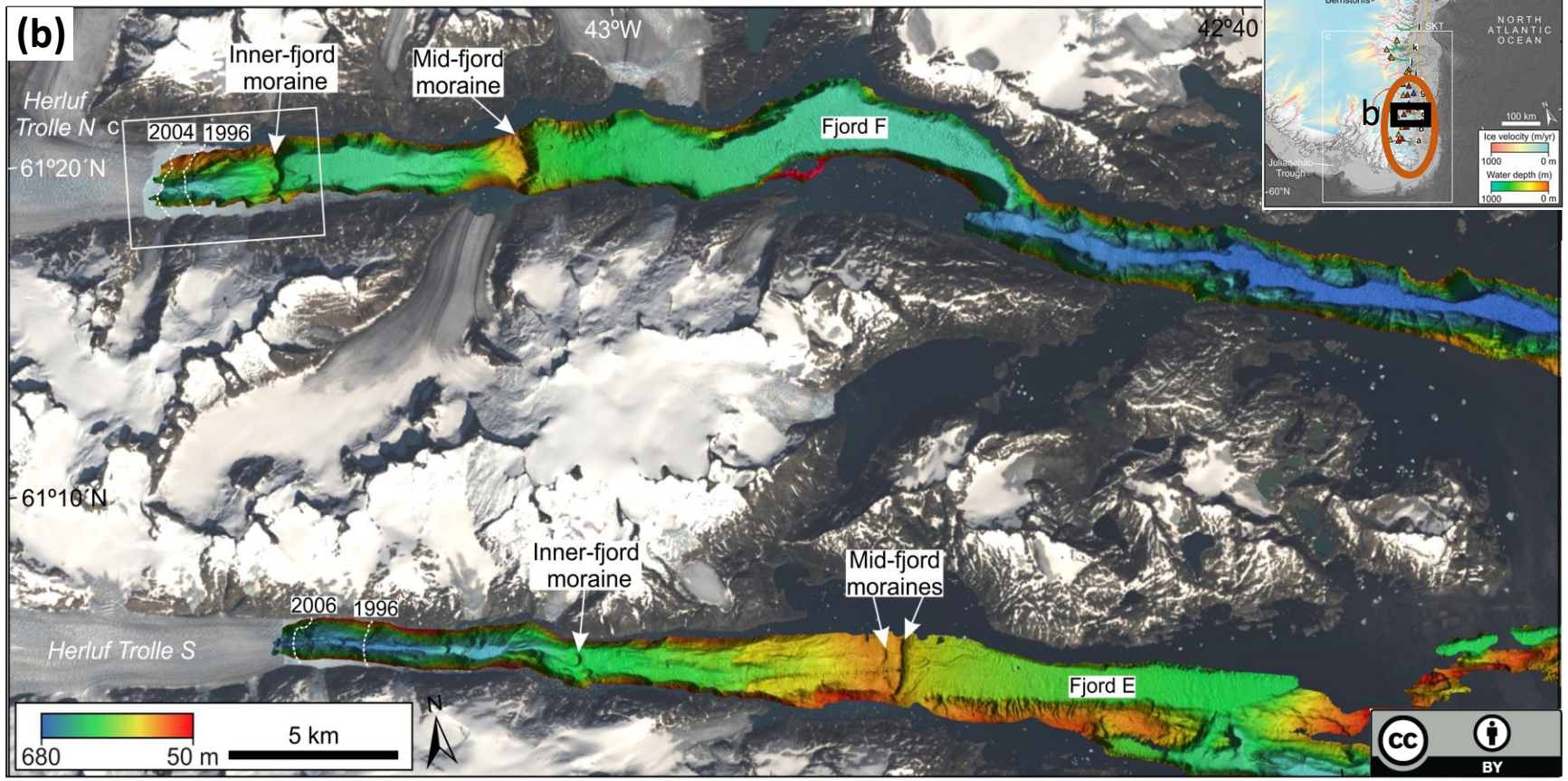


Fig. 3. (a) Map of SE Greenland showing the distribution of mid-fjord moraines. **(b)** Mid-fjord moraines beyond Herluf Trolle N & S glaciers. Background is Landsat 8 satellite imagery (2016). Adapted from Batchelor *et al*. (2019).

4. Fjord water depth is an important control on the speed and style of deglaciation

- The narrower and shallower fjords of the Julianehåb Ice Cap probably encouraged ice-margin stabilisation during the early Holocene through increasing basal and lateral drag, as well as by preventing the incursion of warm subsurface water of Atlantic origin (typically below 300 m depth) to the ice margin (**Fig. 4**).

- In contrast, the general absence of mid-fjord moraines from the fjords of the SE Greenland Ice Sheet is probably related to the greater depth of these fjords.

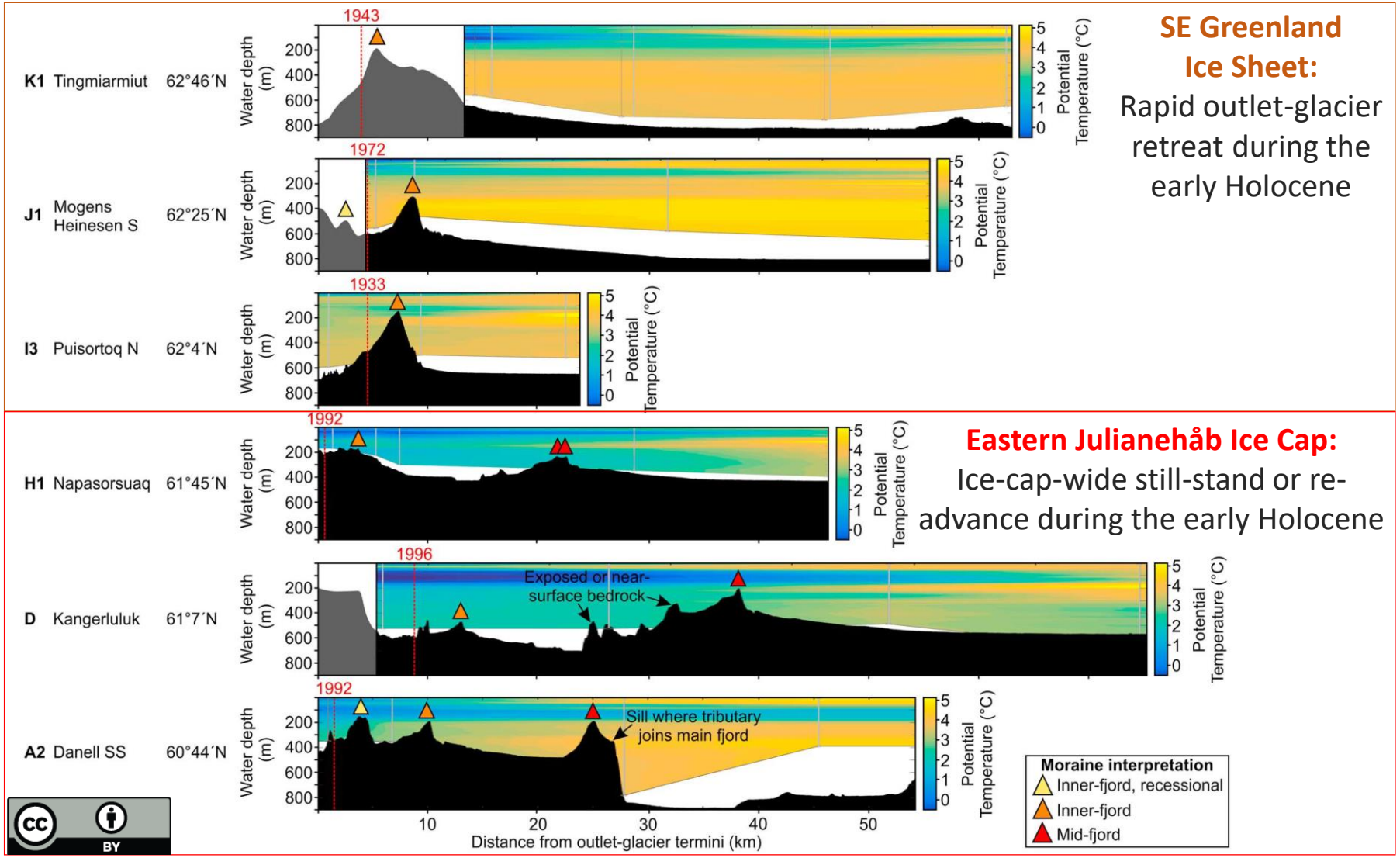


Fig. 4. Selected profiles along the fjords of SE Greenland, showing the locations of major moraines and the potential water temperature of the fjords. The black and grey areas show seafloor depth from OMG bathymetric data and free-air gravity anomaly data, respectively. Dashed red lines are former outlet-glacier positions. Adapted from Batchelor *et al*. (2019).

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Acknowledgements:

We thank NASA's Oceans Melting Greenland (OMG) project and the crew of the M/V Neptune for collecting the bathymetric and water temperature data in SE Greenland. The data are contained at https://doi.org/10.5067/OMGEVBTYSS, at http://omg.jpl.nasa.gov, and at https://faculty.sites.uci.edu/erignot/. During this work, CLB was in receipt of a Junior Research Fellowship at Newnham College, University of Cambridge, and a VISTA scholarship to the Norwegian University of Science and Technology (NTNU), Trondheim, Norway.