National Aeronautics and Space Administration

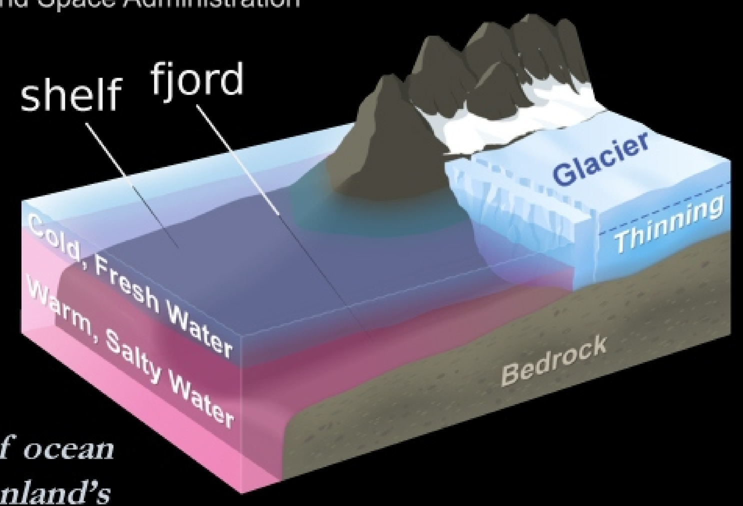

Fig 1. Schematic of ocean properties on Greenland's shelf and fjords

NASA's ***Oceans Melting Greenland*** Mission

Bathymetry Mapping for Sea Level Rise Science

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OCEANS MELTING GREENLAND (OMG) is a 5-year *Earth Venture Suborbital* mission initiated in 2015 to address the question:

To what extent are the oceans melting Greenland's glaciers from below?

During OMG, three elements of the physical environment around the Greenland Ice Sheet will be measured:

- *Bathymetry*
- *Ocean temperature and salinity*
- *Glacier surface elevation*

using six technologies:

- *Multibeam Echosounding (MBES)*
- *Singlebeam Echosounding (SBES)*
- *Airborne Gravimetry (AirGrav)*
- *Airborne eXpendable Conductivity-Temperature-Depth (AXCTD) profilers*
- *Ship-deployed Conductivity-Temperature-Depth (CTD) profilers*
- *Airborne Synthetic Aperture Radar Altimeter (AirGrav)*

Bathymetry campaigns from ship-based MBES and SBES and Airborne Gravimetry are conducted once while the campaigns to measure ocean temperature and salinity using AXCTDs and CTDs and the glacier surface elevation using the airborne radar will be repeated every year for five years.

Here, we describe the echosounding and airborne gravimetry bathymetry campaigns and show some results from the MBES campaigns in Umanak Fjord in Central West Greenland.

MOTIVATION

The recent acceleration of global mean sea level rise has been driven, in part, by melting of the Greenland Ice Sheet (~0.75 mm yr^{-1} of the total 3.2 mm yr^{-1}). Starting in the mid-1990s, a warming North Atlantic Ocean was followed by an increase of Greenland ice mass loss along its southeast and northwest margins (see Fig. 2) – sectors where the ice sheet is primarily drained by glaciers that terminate in the ocean.

The scientific community suspects that **warming Atlantic Waters** increased glacier melting but lacks direct oceanographic evidence.

Greenland's continental shelf is shallow (< 150 m) but occasionally crossed by deep (> 500m) submarine canyons (or troughs) carved out by more expansive ice sheets during earlier glacial periods. It is **only within these canyons** that **warm Atlantic Waters** can cross the shallow shelf and penetrate into glacial fjords. Because ***contiguous deep canyons and fjords are required*** *for the deep Atlantic Waters* to reach the glaciers, knowledge of shelf and fjord bathymetry is ***essential for predicting which glaciers are vulnerable to future ocean warming.***

At present, very few bathymetry data exist around Greenland and the properties and variability of Atlantic Water on the shelf and near the ice sheet are unknown.

During OMG, we will collect critical new bathymetry and oceanographic data that will enable us to the predict the circulation and variability of warm Atlantic Waters across Greenland's shelf and fjords to the ocean-glacier interface.

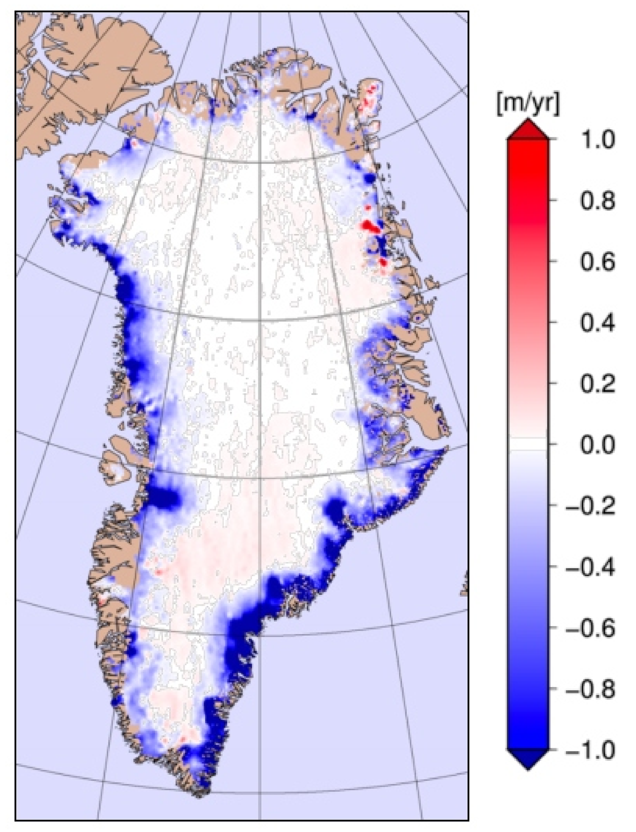


Fig 2. Greenland Ice Sheet surface elevation change in equivalent meters of ice (Sorensen et al., 2011. doi:10.5194/tc-5-173-2011)

BATHYMETRY MEASUREMENTS

ECHOSOUNDERS

high resolution + precision ship-based M/SBES surveys are focused in glacial fjords and shelf regions with submarine canyons

AIRBORNE GRAVIMETRY

lower resolution + precision AirGrav is used for the shelf and fjords that are inaccessible to ships.

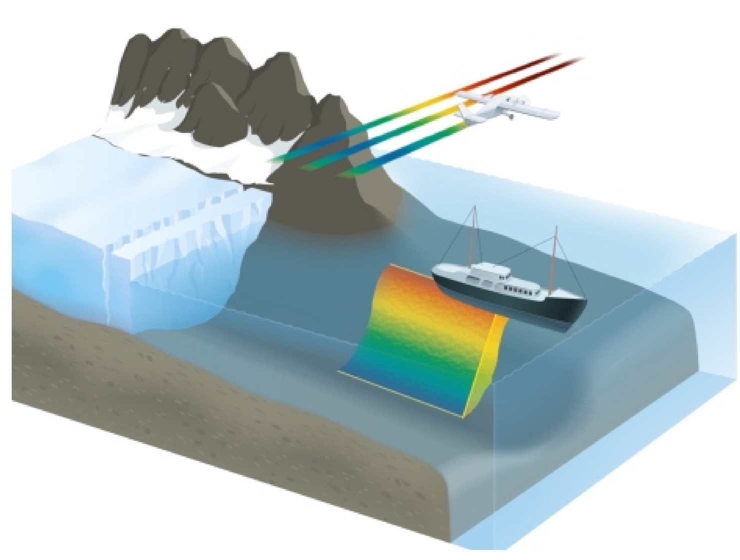
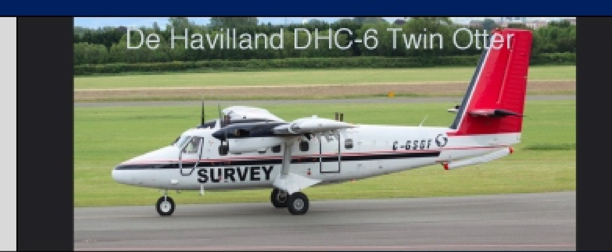
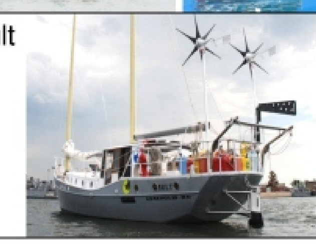


Fig 3. Cartoon of the OMG ship-based MBES and Airborne Gravimetry campaigns.

Campaign	Vehicle(s)	Instruments and Software
Airborne gravimetry bathymetry (AirGrav)	De Havilland DHC-6 Twin Otter 	Sander AIRGrav Airborne Gravimeter Sander SGDAS Navigation/Data Acquisition NovAtel GNSS Receiver GPS King KRA-10 Digital Radar Altimeter Riegl LD90-31K-HiP Laser 1200m Altimeter
Multibeam echosounder (MBES)	M/V Cape Race, R/V Adolf Jensen 	Reson—Teledyne Seabat 8160 50 KHz MBES Applanix POS-MV 320 Motion Ref. System NAVCOM SF-3050 GPS Ocean Science Underway CTD QINSy Vn 8.1 Data Acquisition System
Singlebeam echosounder (SBES)	R/V Ault 	Odom CV/200 single-beam sonar RBR CTD

GEOGRAPHICAL SCOPE

NW and SE Greenland have numerous marine-terminating glaciers in long and narrow fjords. The seafloor of the vast majority of these fjords and shelf has not been accurately mapped. In many fjords, icebergs and other icy debris near the glacier impede ship-movement. Submarine canyons on the shelf are long, narrow (2-5 km wide), and sinuous. To identify submarine canyons on the shelf we rely on airborne gravimetry because it allows large areas to be quickly mapped. In the NW and SE sectors, echosounder and airborne gravimetry surveys are complementary. Mapping in the NE is limited to AirGrav because of sea ice.

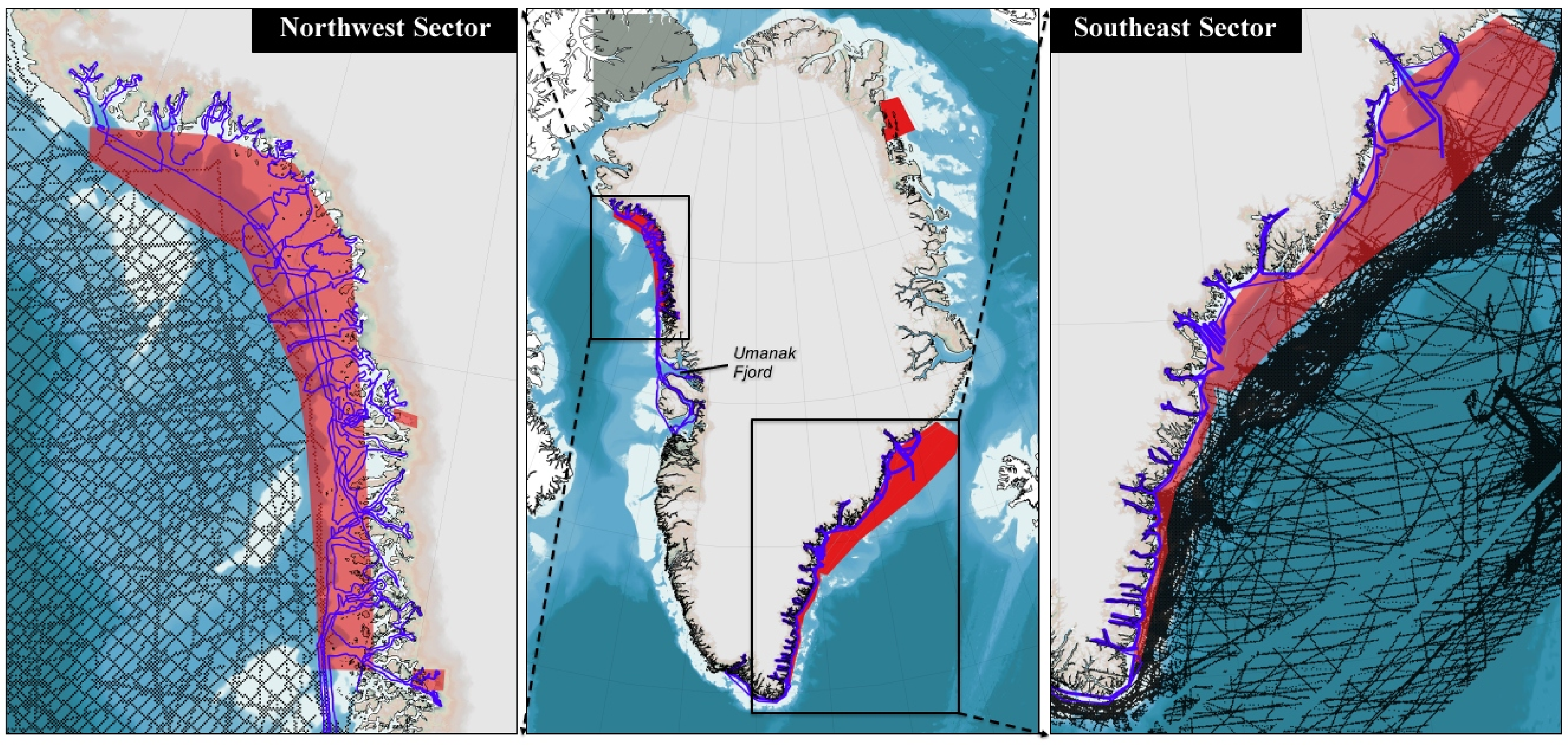


Fig 4. Geographical scope of OMG bathymetry campaign around Greenland (center). Airborne Gravimetry (AirGrav) shown in red polygons, Ship-based Multibeam Echosounder (MBES) shown as blue lines. Existing bathymetry source data in IBCAO v3 shown as black points in northwest and southeast sectors. (left and right). Note the absence of existing bathymetry data on the shelf and in glacial fjords. Location of Umanak Fjord is noted for Figs. 5 and 6.

KNOWLEDGE IMPACT

To Illustrate the impact of OMG bathymetry data collection, we examine W. Greenland's Umanak Fjord (see Fig. 4). New MBES data reveals much deeper fjords (> 500 m) compared with older data provided by IBCAO v3 (Fig. 5). Knowledge of which glaciers are in direct contact warm, deep Atlantic Water (T> 2.5 C) is essential information for predicting which glaciers will contribute to sea level rise with warming subsurface waters (Fig. 6).

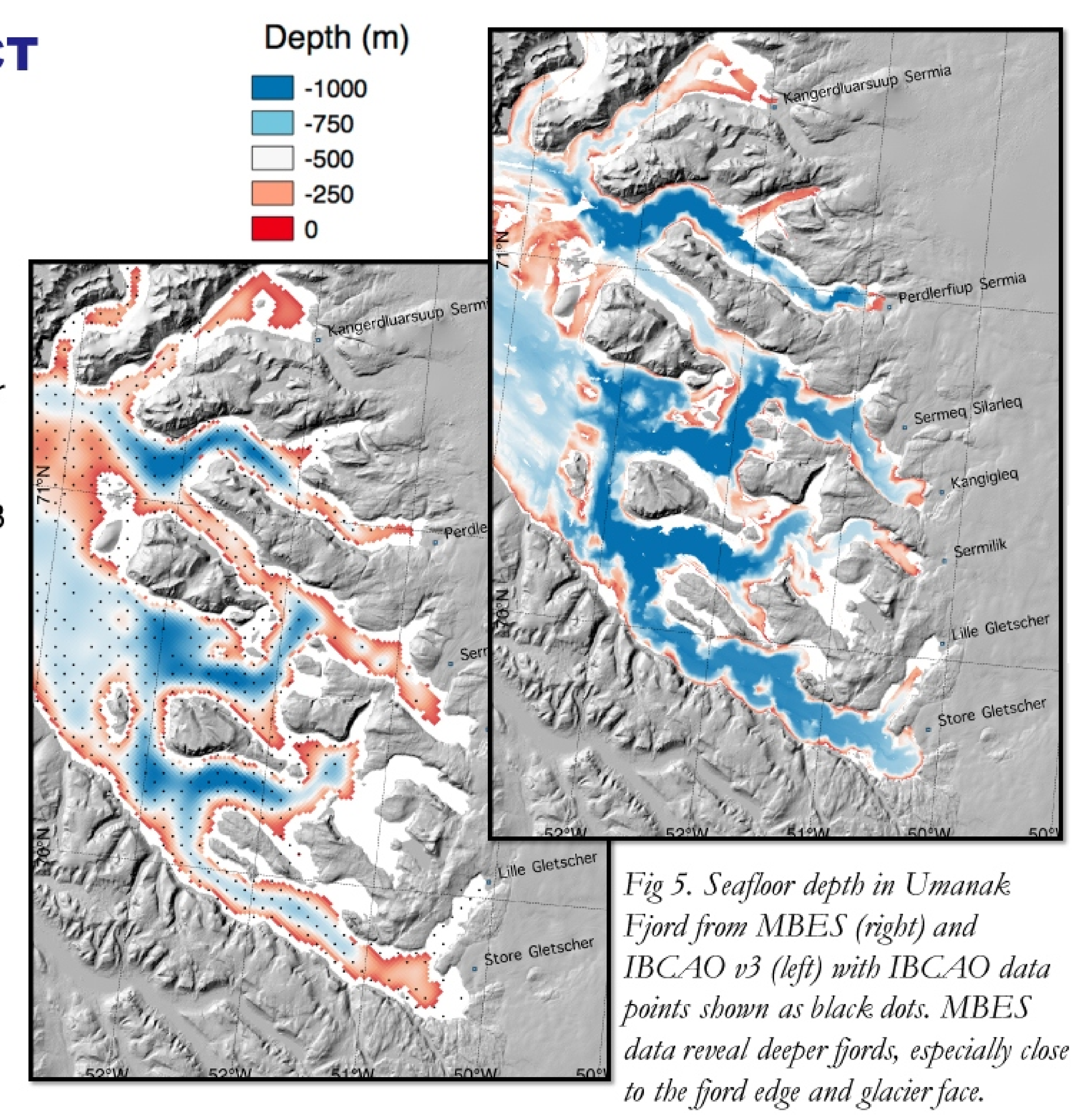


Fig 5. Seafloor depth in Umanak Fjord from MBES (right) and IBCAO v3 (left) with IBCAO data points shown as black dots. MBES data reveal deeper fjords, especially close to the fjord edge and glacier face.

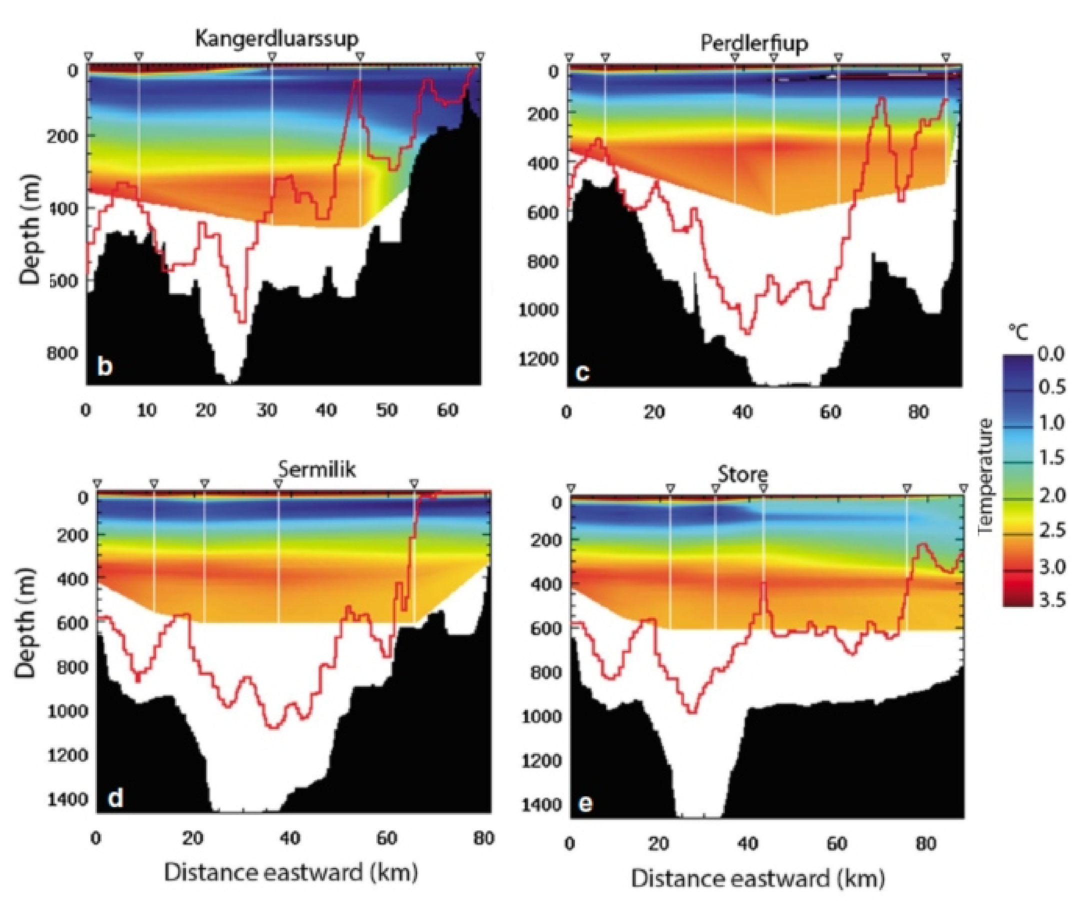


Fig 6. Temperatures and seafloor depths as a function of along-fjord distance from west to glacier faces to the east for four glaciers in Umanak Fjord (glacier locations identified in Fig 5.). Old seafloor depths from IBCAOv3 shown in red line, new MBES-measured seafloor as black. Atlantic Water temperature maxima between 300-450 m. Some glaciers are grounded in deep warmer waters (Sermilik and Store) while others are grounded in shallower cold waters (Kangerdluarssup and Perdlerfiup).

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