Future Hazard Risks Case Study

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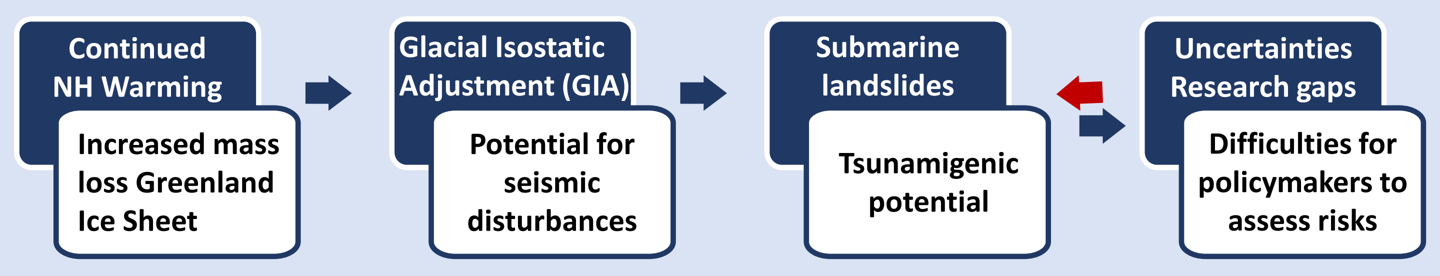
Greenland ice sheet mass loss: Potential consequences for mid-latitudes with a focus on the possibility of a tsunami occurrence in Scotland



Continued NH Warming

Increased mass loss Greenland Ice Sheet

Glacial Isostatic Adjustment (GIA)

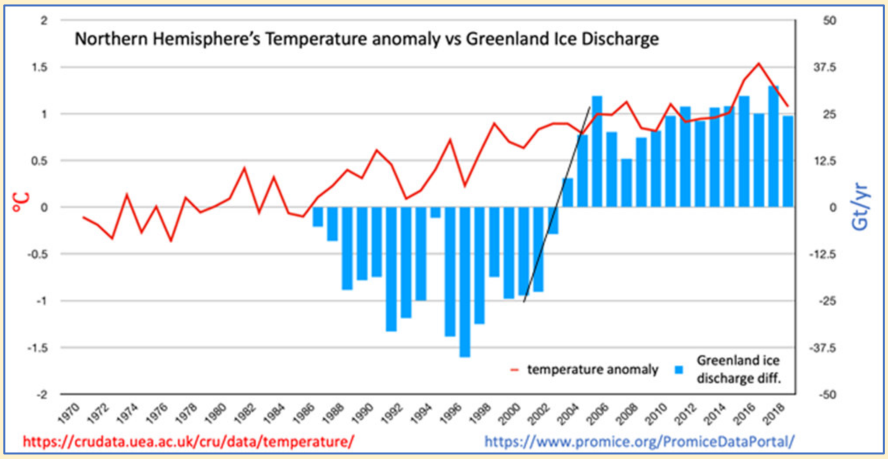
Potential for seismic disturbances

Submarine landslides

Tsunamigenic potential

Uncertainties Research gaps

Difficulties for policymakers to assess risks



https://crudata.uea.ac.uk/cru/data/temperature/ https://www.promice.org/PromiceDataPortal/

Figure 1: Relationship of Northern Hemisphere warming and ice discharge

Warming in the Northern Hemisphere (NH) attributes to the increase in ice discharge (fig. 1) of Greenland's ice sheet and glaciers although rising air temperatures are not the sole contributor.

Ocean temperatures can influence discharge rates additionally[1].

Since 1972 Greenland has lost a total of its ice sheet, amounting to 4,976 ± 400 Gt, equivalent to 13.7 ± 1.1 mm of sea level rise[2]. Major mass loss was observed in northwest (NW), southeast (SE) and central west (CW) Greenland (fig. 2).

This contribution to sea level rise (SLR) may affect the baseline for storm surges and tsunamis, making their consequences for coastal regions more extreme.

The scale of projected mass loss will depend on future emissions, commonly referred to as *Representative Concentration Pathways* (RCPs). RCP is a greenhouse gas (GHG) concentration trajectory which takes into account different GHG emission scenarios as well as mitigation potential (RCP 8.5 assuming the highest GHG emissions)[3].

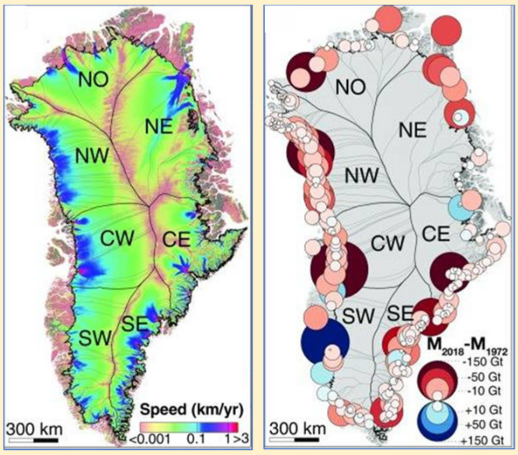


Figure 2:
Left: Glacier catchment/basins with ice speed
Right: Cumulative loss 2018 – 1972
Taken from: Mouginot et al. 2019.

By the year 3000 the Greenland Ice Sheet will have lost under different emission scenarios..

8 to 25% (RCP 2.6), or
26 to 57% (RCP 4.5), or
72 to 100% (RCP 8.5)

… contributing to the increase in global mean sea level[4]:

0.59 to 1.88 m (RCP 2.6), or
1.86 to 4.17 m (RCP 4.5), or
5.23 to 7.28 m (RCP 8.5)

Glacial Isostatic Adjustment (GIA), the rebounding of the earth's crust during and after deglaciation, has significant impacts, even readable in human timescales, on various processes including SLR and shoreline migration whereby the dynamics and effects vary depending on distance and the stage of the process[5] (fig. 3).

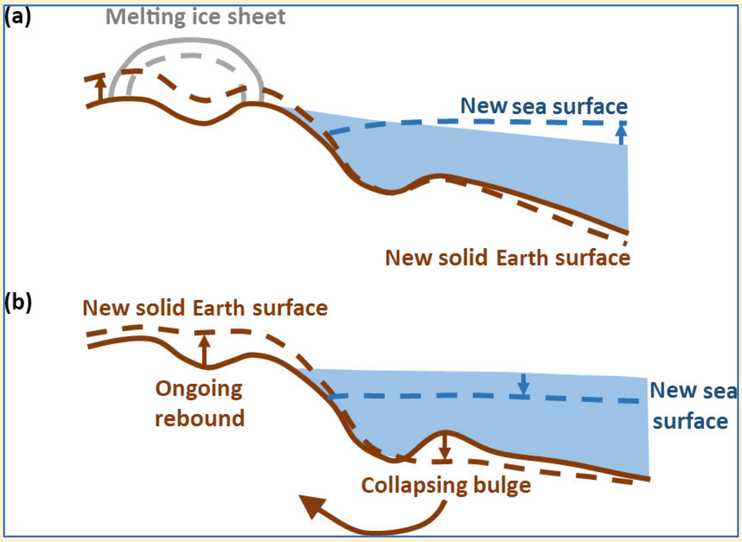


Figure 3: Dynamics of rebounding.
Taken from Whitehouse, 2018.

GIA's contribution to estimates of Greenland's ice sheet mass balance derived from *Gravity Recovery and Climate Experiment* (GRACE) tends to be less significant due to accelerated warming[6] but GIA and land hydrology combined still represent approx. 10 ± 5 cu km/yr of the total change in water volume[7].

The regionally different GIA rates are studied using the Greenland Global Positioning System (GPS) Network (GNET) stations[8] (fig. 4).

In southeast Greenland, GIA rates as high as 12 mm/yr have been recorded[8].

Such rapid deglaciation could result in earthquakes of considerable magnitude. A recent study found that deglaciation in Greenland could have produced a massive earthquake around 10600 years ago causing a tsunami affecting the British Isles and Canadian coasts with runup heights of ~5 resp. 6 m[9].

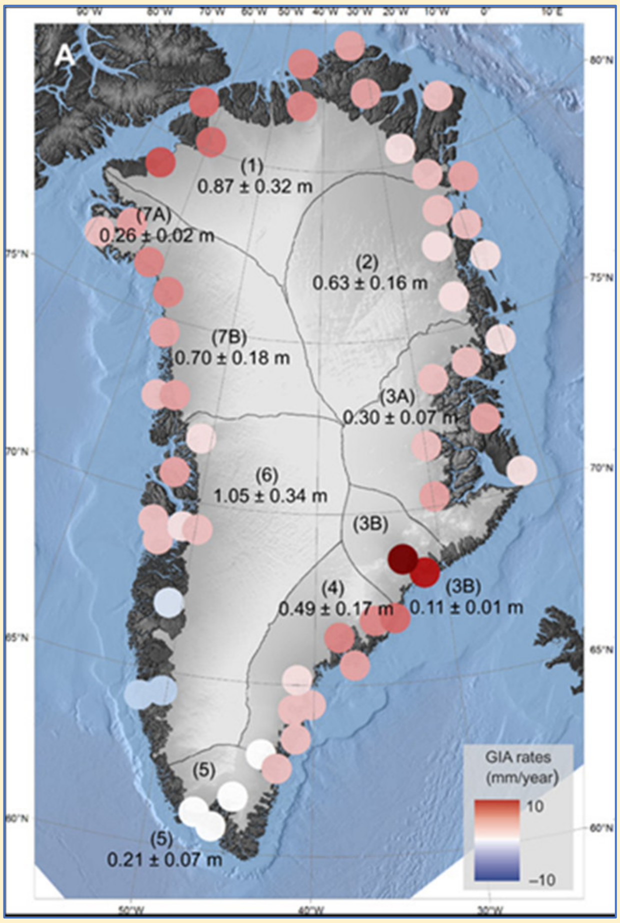


Figure 4: GIA rates at GNET stations.
Taken from Khan et al., 2016.

GIA uplift contributes to shoreline exposure, thereby promotes coastal erosion and together with particle-containing meltwater increases sediment loading regionally[10] (fig. 5) and elsewhere through bottom and surface currents and circulation[11]. These accumulations can be susceptible to collapse through seismicity or gravitational forces[12].


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Figure 5: Sediment plume, Greenland.
https://www.colorado.edu/today/sites/default/files/styles/hero/public/article-image/forweb.jpg?itok=EqG_xWSf

Seismic disturbances are common triggers of submarine landslides[13]. Several large slope failures are known to have occurred in the North-East Atlantic region in the past[14], some of which suspected and others - like the Storegga events - known to have resulted in a tsunami affecting coastal settlements in Scotland including Orkney and Shetland, Norway and the Faeroe islands (fig 6,) where deposits have been found[15]. Due to many additional factors, amongst others i.e. sediment accumulations and characteristics, amount of displaced material, velocity and the fact that submarine mass failures can occur on slopes with very low gradients[16], submarine landslides are extremely difficult to predict[17] and not every slide generates a large tsunami[18]. However, a climate control of these events appears evident[19], and the previously illustrated potential for increased seismic activity through Greenland's ice cap mass loss – combined with potentially compromised slope stability through gas hydrate dissociation[16] – becomes relevant in the light of the present rapid Arctic climate change.

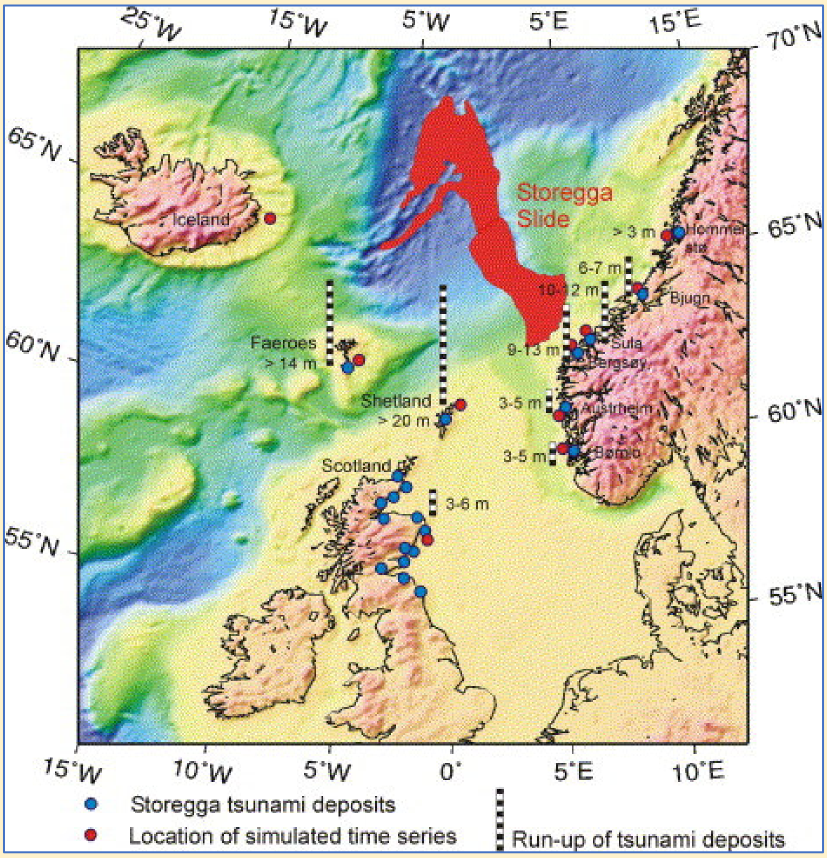

Figure 6: Location and characteristics of the Storegga slide, at around 8,200 years BP. Taken from: Bondevik et al. 2005

Nearly half of Scotland's total population lives in coastal regions including isolated and remote islands[20], which harbour also multiple economic assets and vital infrastructure[21]. Some regions are already vulnerable to coastal flooding due to low-lying characteristics and built environment located at the shoreline (fig. 7, 8, 9). A tsunami could result in significant economic and human life losses[22], with remoteness and impeded access exacerbating emergency response and relief efforts.


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Figure 7: Sanday (Orkney Isles). CC BY-SA.
https://www.geograph.org.uk/photo/231965

Figures 8 & 9: Whitehall & Lower Whitehall, Stronsay (Orkney Isles), during storm Vivian 27th Feb 1990. Images courtesy of Ian Cooper.

Uncertainties
Research gaps

Difficulties for policymakers to assess risks

Many stakeholders, from local to national government, from businesses to utility providers and populations in vulnerable regions, depend on science from a wide range of disciplines to inform policymaking and decisions and provide guidance and information (fig. 10).

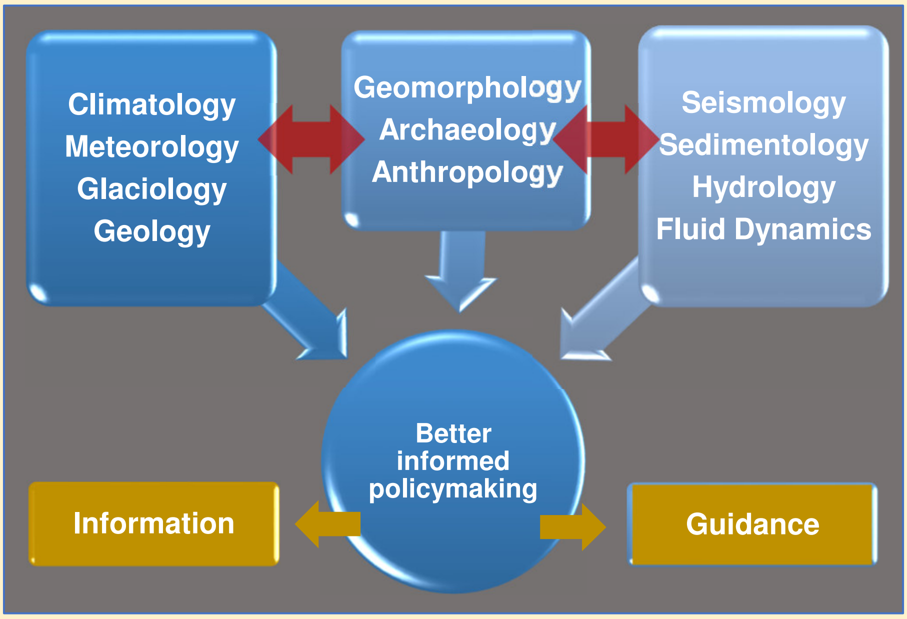

Figure 10: Multi-disciplinary collaboration informing policies.

The complexity of tsunamigenic submarine landslides, their occurrence in the region in distant history and their unpredictability make them - similarly to earthquakes - *Black Swan Events*[23]. The high costs associated with most protective measures may explain why this potential hazard so far has not received much attention and is only listed under 'risks in foreign countries' in the UK's *National Risk Register of Civil Emergencies*[24]. Also, the role of geology[25] and in a hazard context rarely considered disciplines[26,27] could have been underestimated when trying to determine frequency or magnitude of previous events.

Two DEFRA-commissioned studies (2005; 2006[28,29]) still guide UK tsunami hazard assessments[30]. These stated for earthquakes as potential tsunami triggers: 'As these were related to post glacial isostatic rebound, they are not likely to occur again until after the next glaciation.' The recent steep increase in ice discharge and potential consequences[9] (fig. 11) however underline the importance of robust climate projections to assess a possibly altered situation.

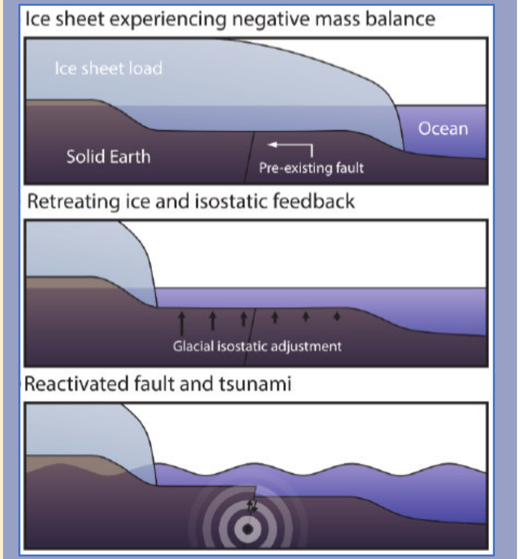

Figure 11: Illustration of mass loss induced seismicity triggering a tsunami. Taken from: Steffen et al. 2019.

The way forward:

More cross-disciplinary research is urgently needed to assess this potential future hazard. Continued accelerated warming in the Northern Hemisphere may alter the likelihood of events so far considered to be very low. Whilst the associated uncertainties do not justify major investments in protection at this point, policymakers can already integrate existing information in their local decision-making i.e. within frameworks of extreme flooding or when planning developments in potentially vulnerable locations.

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