At what Speed is Greenland's Ice Sheet Melting?

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Greenland - Overview

Greenland is an island and autonomous Danish territory located between the North Atlantic and Arctic Ocean. Most of the land is covered by a massive ice sheet. In fact, this ice sheet is one of the only two existing on this Earth. The other ice sheet covers Antarctica. The Greenland Ice Sheet (GrIS) covers approximately 81 percent of Greenland. This ice sheet is 2,480 kilometers long, up to 750 kilometers wide, and has an average thickness of 2.3 kilometers.[1] It contains about 8 percent of Earth's fresh water. Greenland has a coastline that is more than 27,000 miles (44,000 kilometers) long. This is mostly due to the multitude of fjords along the coast, a number of which contain glaciers. Some of these glaciers are marine terminating, while others are land terminating. Most of the population lives along the ice-free coast, concentrated in the southwest. Additionally, Greenland's continental shelf is characterized by many underwater canyons, a remnant from the last ice age. Greenland's Ice Sheet is melting at an increased rate due to the effects of climate change and warming oceans. Scientists are now trying to answer the question about how fast it is melting, but Greenland's complex topography and a lack of data on what it looks like underneath the ice makes that a difficult question to answer.

Melting of the Greenland Ice Sheet

Overall, studies in recent years have shown that Greenland is losing ice. Throughout the year, the GrIS is in constant motion. Inland it is flowing downhill due to its own weight. However, near the coast, the ice moves faster enabled by outlets such as ice streams, glaciers and ice shelves.[2] For an ice sheet to remain stable, it needs to regain the mass lost to the ocean. This occurs mostly during the winter months. Warming temperatures have contributed to increased melt and glacier movement on Greenland's coastal area. In 2016, the extent of the GrIS melt was above average, ranking tenth highest in the 38-year satellite history.[3] Although some high latitude inland areas may be experiencing periods of increased snowfall, this does not offset ice loss in coastal areas. Additionally, melt seasons over the last few years have increasingly led to dark ice exposure. Dark ice is older and located under younger and brighter snow. Exposure of black ice decreases the albedo effect, the reflectivity of Earth's surface. "Areas of dark ice, or low albedo, are common along the western coast [of Greenland], but albedo values during the past summer (2016) were exceptionally low. This summer also experienced new areas of dark ice in isolated patches along the southeastern coast."[4] Larger areas of dark ice ultimately act like a positive feedback, reflecting less incoming sunlight, therefore absorbing more heat and accelerating ice melt.

Scientists have shown that Greenland's Ice Sheet is melting. The question, therefore, has shifted to: "How fast is the GrIS melting"? However, in addition to climate change, there are other, less obvious factors contributing to GrIS melt. One is concerned with the tectonic history of Greenland. A study by Shafqat A. Kahn et al. published in *Science Advances* in 2016 found that annual ice losses could be more extensive than previously thought. The study takes into consideration glacial isostatic adjustment (GIA), which has been occurring since the Last Glacial Maximum (over 20,000 years ago).[5] This means that, as the ice sheet melts, the Greenland landmass gradually rises. The study found that "new deglaciation history and GIA uplift estimates suggest that studies that use the Gravity Recovery and Climate Experiment satellite mission to infer present-day changes in the GrIS may have erroneously corrected for GIA and underestimated the mass loss by about 20 gigatons/year."[6] Simplified, imagine 500 Gt loss due to ice melt, but a gain of 400 Gt due to uplift. Satellites will detect a change of -100 Gt. However, previously calculated uplift rates may assume gains of 300 Gt due to uplift. Therefore, the model will calculate only 400 Gt of ice loss due to melt. This mistake was made because some areas have been shown to display a greater uplift than previously thought, particularly in southeast Greenland. The upper mantle at this location displays lower viscosity and is thought to be warmer. This is a result from Greenland's past from 40 million years ago, when it passed over a hot spot which is now associated with Iceland's volcanoes. "A warmer upper mantle in southeast Greenland (and presumably along the past hot spot track) may also have a large influence on ice sheet or glacier flow dynamics, because a greater geothermal heat flux at the base of an ice mass will affect its internal thermal regime and the presence of basal melt water."[7] The study suggests that rheology of Greenland's mantle has not been fully taken into account in previous studies. Tectonic history could be an indicator for why some regions of Greenland are melting faster than others.

Another factor deals with the presence of underwater canyons. A boundary current system circulates water from the North Atlantic subpolar gyre, Baffin Bay, the Arctic Ocean and the Greenland Sea around Greenland. Near the Arctic, the warmest water is found deep in the ocean, due to the thermocline. Warm, salty water arrives from the south, the subtropics, while cold, fresher water arrives from the north, the Arctic. These waters do not mix. The warm water usually cools through lateral mixing and exchange with colder Arctic waters. However, if canyons are deep enough, they can transport warmer water towards the coast and even underneath marine terminating glaciers. Marine canyons in Greenland are deeper than 500m. At some locations these canyons align with glacial fjords, allowing warm water to reach the ocean-glacier interface.[8] However, to understand how each glacier reacts to such changes depends on factors such as bedrock geometry and composition, subglacial water transport and ice rheology.[9] A mission by NASA is aiming to collect data surrounding ocean circulation and marine terminating glaciers.

NASA's OMG Mission

NASA has a field mission named Oceans Melting Greenland (OMG), which aims to improve understanding of how the oceans and the atmosphere are contributing to melting of the Greenland Ice Sheet. The mission specifically asks the question: "To what extent are the oceans melting Greenland's ice from below?"[10] OMG will run five years (2015-2020) and costs $30 million. Warm subsurface waters are present below 200-250 meters in Greenland's fjords. This ocean water may interact with the glacier, or not, depending on the bathymetry of the fjord. Predicting Greenland's Ice Sheet melt and projections of sea level rise rely on computer models. However, these models are based on bed topography that is incomplete. "Accurate bed topography in the vicinity of calving fronts is critical for numerical models, as the shapes of the glacier bed and of the nearby bathymetry control both the ocean circulation in the fjord and the stability and response of the ice sheet to climate warming."[11] The data will be published and should be used to complement earlier and ongoing observations. Previously, glacier ocean interaction was studied and evaluated individually. OMG is collecting data concerning this relationship for the entire island. Satellite data in and of itself will not be sufficient. OMG uses ocean sensors which are dropped from an airplane and which will measure temperature and salinity of coastal water up to a depth of 3,000 feet (1,000 meters). GLISTIN-A (a radar instrument) maps the ice height over a 10-kilometer swath. A sonar on a ship measures the topography of the seafloor, while another airplane will measure gravity over the ocean.[12] OMG aims to make a map that shows Greenland's coast and continental shelf and monitor, through yearly measurements, all of Greenland's coastal glaciers.

In a study conducted by Morlighem and Willis, published in *Oceanography* (2016), the researchers demonstrate how NASA's OMG data is already improving topography mapping of Greenland glaciers.

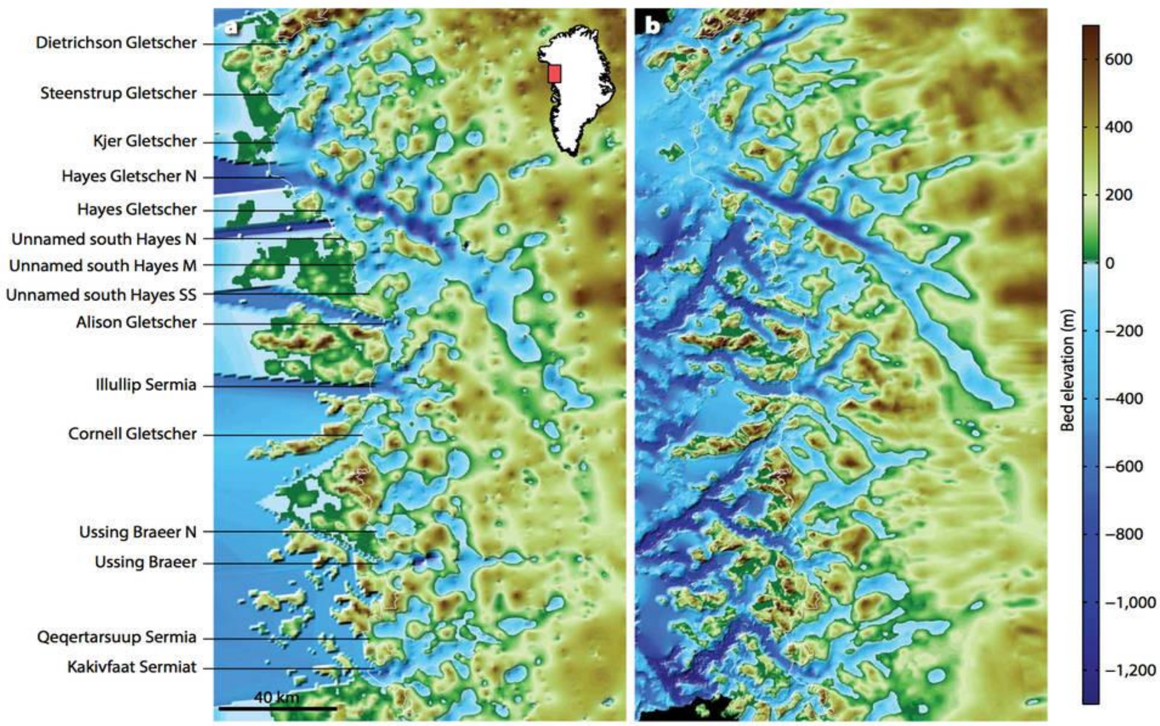

Figure 1: Bed elevation and bathymetry of Northwest Greenland from Bamber et al. (2013) (a) and from mass conservation combined with OMG data (Morlighem et al., 2016)

As Figure 1 shows, some fjords cross further inland and are deeper than previously expected.[13] Findings such as this can have various effects on research. In some areas warmer, salty ocean water reach further inland than previously thought, which can lead to faster-than-projected glacier melt.. Glaciers previously identified as land terminating turn out to be marine terminating. Figure 2 shows data provided by a study by Bamber et al., which identifies the Savissuaq Gletscher as land terminating, while Morlighem et al. data clearly show that it is indeed marine terminating.[14] These are only the first round of interpretations of a first data set provided by OMG. To evaluate the full significance of data more research is necessary, especially after the mission's completion in 2020.

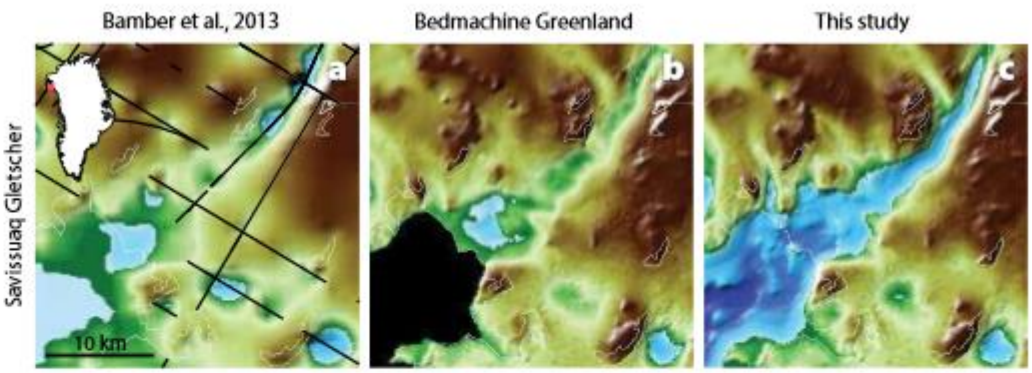

Figure 2: Bed elevation under Savissuaq Gletscher. Data: Bamber et al. (2013) in (a), Morlighem et al. (2014) using mass conservation in (b), and including bathymetry data in (c). Areas below sea level are blue. (Morlighem et al., 2016)

Conclusion

NASA is a federal agency and therefore financed through the annual federal budget passed by the US Congress. The Trump administration is actively looking to reduce spending on climate change mitigation or climate change related research. Trump's budget proposal demands cuts to NASA and NOAA Earth Science programs. NOAA would receive a cut of $250 million, eliminating coastal and ocean research grants, as well as funding for weather satellites.[15] NASA would see a significant cut of $102 million to its Earth-monitoring programs.[16] While NASA's budget would only decrease by 0.8 percent, it demands a reallocation of resources. The administration demands focus on space exploration. However, as has become clear, we need NASA, as well as NOAA, data to analyze how warming oceans will affect GrIS melt and sea level rise. With every new research, new findings emerge painting a gloomy picture for the Greenland Ice Sheet and the Arctic. Furthermore, funding for scientists is needed to interpret data. However, we may have to rely on international scientists and, for example, the European Space Agency's Observing the Earth Program to collect data. There are still too many unanswered questions concerning Planet Earth and the effect the human race has on it.

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Notes

1. Kendall Haven, "Greenland's Ice Island Alarm," *Earth Observatory NASA*, published August 28, 2007, accessed March 23, 2017, https://earthobservatory.nasa.gov/Features/Greenland/greenland_sidebar.php

2. "Quick Facts on Ice Sheets," *National Snow & Ice Data Center*, accessed March 27, 2017, https://nsidc.org/cryosphere/quickfacts/icesheets.html

3. "Greenland Ice Sheet Today | Surface Melt Data Presented by NSIDC," *National Snow & Ice Data Center*, published October 26, 2016, accessed March 22, 2017, http://nsidc.org/greenland-today/.

4. Ibid.

5. Shfaqat A. Khan, et al, "Geodetic Measurements Reveal Similarities between Post-Last Glacial Maximum and Present-Day Mass Loss from the Greenland Ice Sheet," *Science Advances* (Sep 2016): 1.

6. Ibid.

7. Ibid, 6.

8. I. Fenty et al, "Oceans Melting Greenland: Early Results from NASA's Ocean-Ice Mission in Greenland," *Oceanography 29(4) (2016):* 74.

9. Ibid, 76.

10. "Earth Expeditions," *NASA*, accessed March 21, 2017, https://www.nasa.gov/content/earth-expeditions-omg.

11. M. Morlighem et al, "Improving Bed Topography Mapping of Greenland Glaciers using NASA's Oceans Melting Greenland (OMG) data," *Oceanography* 29(4) (2016): 62-71.

12. Tony Greicius, "Q&A with OMG Scientist Josh Willis," *NASA*, published March 21, 2016, accessed March 29, 2017. https://www.nasa.gov/feature/jpl/qa-with-omg-scientist-josh-willis

13. M. Morlighem et al, "Improving Bed Topography Mapping of Greenland Glaciers using NASA's Oceans Melting Greenland (OMG) data," *Oceanography* 29(4) (2016): 70.

14. M. Morlighem et al, "Improving Bed Topography Mapping of Greenland Glaciers using NASA's Oceans Melting Greenland (OMG) data," *Oceanography* 29(4) (2016): 67.

15. Sarah Zhang, "All the Ways Trump's Budget Cuts Science Funding," *The Atlantic*, published March 16, 2017, accessed March 29, 2017, https://www.theatlantic.com/science/archive/2017/03/trumps-science-health-budget/519768/.

16. "NASA 2018 Budget Blueprint," *NASA*, released March 16, 2017, accessed March 29, 2017. https://www.nasa.gov/sites/default/files/atoms/files/2018_blueprint_nasa.pdf.

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