Arctic Happenings – Global Impacts of the Melting Greenland Ice Sheet and Melting Sea Ice

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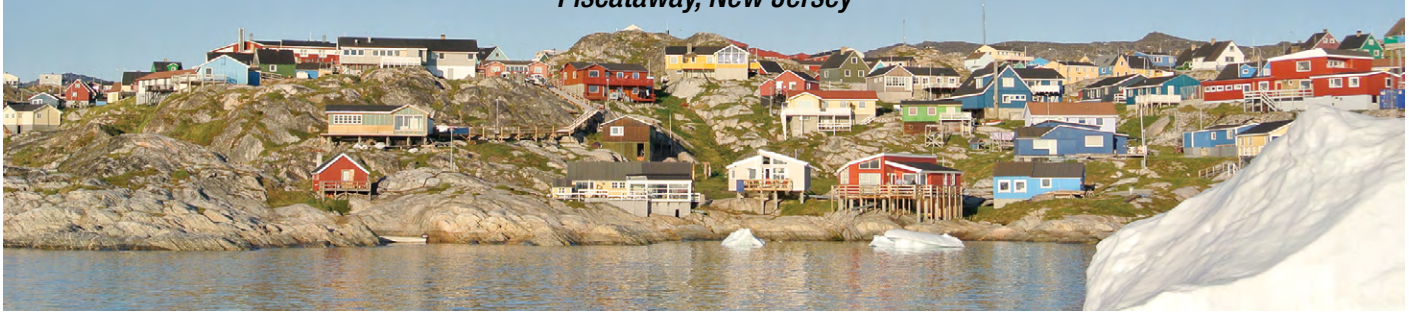

Abstract

In the Arctic region, global climate change is quickly transforming the environment. Melting of the Greenland ice sheet and loss of Arctic Ocean sea ice are two processes that have increased dramatically since the late 20th century. Here, we present a four-part educational module focused on these two processes designed for upper middle school, high school and undergraduate students. Through this investigative module students learn critical science skills as they collect, analyze and draw conclusions from data and engage with some of the most urgent environmental questions of our time. Finally, they are challenged to think about how these changes are affecting their lives and the lives of others around the globe. All the digital materials for this module are freely available online and include rich video and data resources plus step-by-step instructions.

Introduction

Global, near-surface, air temperatures have risen fast since the beginning of the 20th century, but the Arctic region stands out as one of the places with the most rapid increase. Here, air temperatures are now 3.5°C higher than in the early 1900s (Richter-Menge, Overland, & Mathis, 2016), and has together with other climate changes transformed the Arctic environment. Two of the most noteworthy changes are the rapid loss of the Greenland ice sheet mass and the shrinking Arctic Ocean sea ice cover. September sea ice extent is 40% less today (2007-2010) than it was 20-30 years ago (Stroeve et al., 2012), and Greenland ice sheet mass balance has catapulted from a net zero between 1960 and 1991 to a decrease of -16±2.8 Gt water equivalent per year in the 1991-2015 period (van den Broeke et al., 2016). Both these changes may influence the global climate system in a variety of ways. Loss of the white reflective sea ice cover (high albedo) reveals a dark ocean (low albedo) that readily absorbs more solar radiation and subsequently warms the lower atmosphere. Through this process, sea ice loss has been connected to more persistent and extreme weather in the mid-latitudes (Overland et al., 2016). Greenland ice sheet mass loss, in turn, may influence marine environments (Arrigo, Dijken, Castelao, Luo, & Rennermalm, 2017) and raise global sea levels (Clark, Church, Gregory, & Payne, 2015). Already, Greenland ice sheet mass loss has contributed 0.59±0.16 mm

(1992-2011) of the global mean sea level rise of 3.2±0.4 (1993-2012, derived from satellite altimetry) (Clark et al., 2015), which is about 18% of the total increase.

The net Greenland ice sheet mass loss is primarily the result of two processes, calving of icebergs where the ice sheet is in direct contact with the ocean, and surface mass balance. In the mid-20th century, snow adding to Greenland's surface mass balance was almost offset by surface melting running off to the ocean in the summer. However, this changed in the late 20th century when meltwater runoff surpassed snow accumulation and resulted in increasingly negative mass balance (van den Broeke et al., 2016). Thus, ice sheet meltwater runoff is a critical process to understanding Greenland ice sheet influence on global sea levels. Ice melting can be stimulated by above-freezing air temperatures (Hock, 2005) because they move in concert with the many of the actual forcings. Those forcings are a complex interaction of large-scale atmospheric circulation (Mcleod & Mote, 2016), meltwater refreezing (Machguth et al., 2016), ice sheet hydrology, and surface energy balance (Rennermalm et al., 2013) all influencing melting. For example, the darkening of the ice sheet surface, i.e. lowered albedo, which has been documented since the early 2000s (Stroeve, Box, Wang, Schaaf, & Barrett, 2013) has resulted in a greater uptake of solar radiation driving some of the increased contributions to global sea levels.

Building Awareness

These dramatic changes found in the Arctic should be alarming to people living everywhere on Earth. However, connecting people, including students, to a far-away location is sometimes difficult unless there is something meeting their interest at a location. For example, polar bears and penguins are the interest-grabbers for the polar regions; however, to sustain interest, a personal connection beyond polar bears and penguins is needed. In the case of students, this can be done by identifying climate phenomena that connects the lives of students to the Arctic, but also engages them in the climate mechanisms at work in the Arctic. For instance, students near a coastal location are interested in sea level rise; students living elsewhere are interested in climate system feedbacks related to surface warming and increased temperatures and stronger storms. Building off these connections, this multi-part module with four activities assists students with integrating numerous climate change factors, including those which will impact them during their lifetime. Each activity within this 5-E (engage, explore, explain, elaborate, evaluate) module effectively blends disciplinary core ideas, science and engineering practices, and crosscutting concepts to assist learners with making sense of phenomena affecting their lives as prescribed by *A Framework for K-12 Science Education* (National Research Council, 2012, p. 218). In addition, students develop their modeling, data analysis, and spatial skills as they create and analyze a model of the Greenland ice sheet using data from current research. Table 1 provides an overview of the activity sequence in this module and appropriate connections to the Next Generation Science Standards (NGSS, 2013). Visit the module website (ahrl.rutgers.edu/greenland-lessons) to download teaching material and video resources.

Activity 1: My Burning Feet!

To introduce students to the climate mechanisms at play in the Arctic, this "engage" activity about surface albedo connects student understanding of solar energy interactions with various surfaces in their location to solar energy interactions with the Greenland ice sheet. It opens with groups of students seeking to answer the question "Why do my feet burn more when walking barefoot on some surfaces and not others?" They create the protocol that employs easily obtainable infrared thermometers to collect the data; however, they need to be mindful of their data collection technique to ensure they collect quality data that can be compared across groups. Once the data has been collected and shared in the class, students seek patterns in the data, and ultimately define the term "albedo" and relate it their data. This activity ends

Table 1: Greenland Ice Sheet - From Warming Climate to Sea Level Rise Module Overview

Activity	Activity Question(s)	NGSS Components (Grades 6-8 & 9-12)	
1. My Burning Feet! (Engage)	Why do my feet burn more when walking barefoot on some surfaces and not others?	**SEP:**	Planning & Carrying Out Investigations
		DCI:	PS4.A & PS4.B
		CCC:	Patterns
2. From burning feet to the Greenland Ice Sheet: Examining model estimates of Greenland ice sheet mass loss, its drivers, and its impact on global sea levels (Explore & Explain)	What is causing the Greenland ice sheet to melt? How will this affect global sea level rise?	**SEP:**	Analyzing and Interpreting Data
		DCI:	ESS2.D
		CCC:	Cause & Effect
3. Should I Move Inland? What About Others Around the World - Should They Move to Higher Ground? (Elaborate)	How will sea level rise affect me, the people I know, and people around the world?	**SEP:**	Analyzing and Interpreting Data
		DCI:	ESS3.D
		CCC:	Cause & Effect
4. How Does Melting Arctic Ice (sea ice & ice sheets) Impact the Climate Where I live? (Evaluate)	Do both melting sea ice and melting ice sheet contribute to sea level rise? What are the connections to this melting on the weather and climate on the mid-latitudes or where I live? What evidence supports this claim?	**SEP:**	Engaging in Argument from Evidence
		DCI:	ESS2.A & ESS2.C
		CCC:	Cause & Effect & Stability & Change

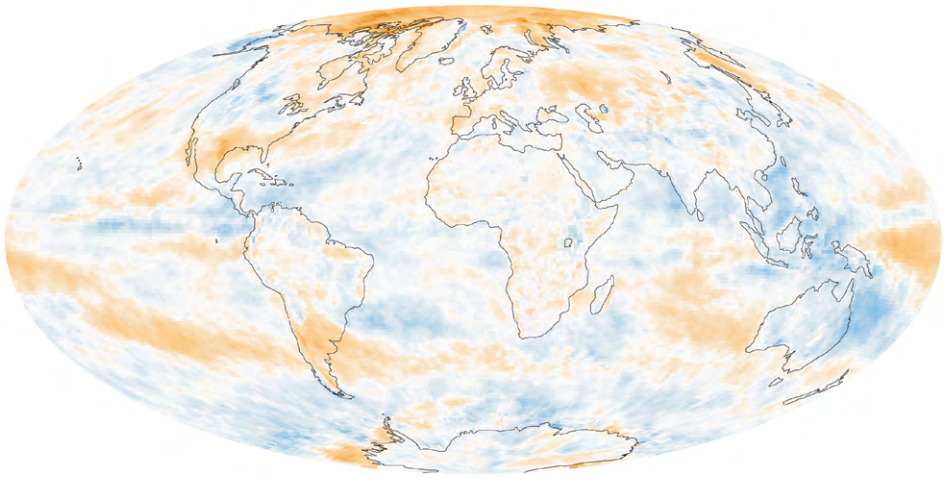

Figure 1. NASA Earth Observatory image by Robert Simmon based on data from CERES satellite. (earthobservatory.nasa.gov/IOTD/view.php?id=84499)

with an interpretation of global images of surface albedo such as those found on the NASA Earth Observatory web site (see Figure 1 and earthobservatory.nasa.gov/) and a discussion about how and why albedo varies around the globe.

Activity 2: From Burning Feet to the Greenland Ice Sheet: Examining model estimates of Greenland ice sheet mass loss, its drivers, and its impacts on global sea levels

Over the next few class periods students explore Greenland ice sheet datasets using the public domain software, ImageJ (imagej.nih.gov/ij/). With ImageJ, the user can model and analyze spatial data (see Figure 2). Here, the students create and interpret models of spatial data to explain the connections between changing surface albedo and the surface hydrology of Greenland ice sheet. The activity contains all the necessary background information for students and the teacher, including the data, the metadata, definitions, and additional software needs (word processing and spreadsheet software). The data is taken from Modele Atmospherique Regional (MAR), a widely used regional climate model that simulates

atmosphere-land mass and energy exchanges over Greenland (Fettweis, 2007; Fettweis et al., 2013). This activity uses MAR version 3.5.2 with boundary forcings from the global National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis model. In should be noted that although MAR compares well with similar models, no model perfectly captures the true conditions (Fettweis et al., 2016). In fact, a complete understanding of the actual surface mass balance components are challenging since ground and satellite observations are sparse and has mostly started in the latter part of the 20th century (Rennermalm et al., 2013). Regardless, comparisons with MAR 3.5.2 and existing observations give confidence in using MAR, but it should be noted that it overestimate albedo in the melting zone and has a slight cold bias, particularly in the summer months. (Fettweis et al., 2016).

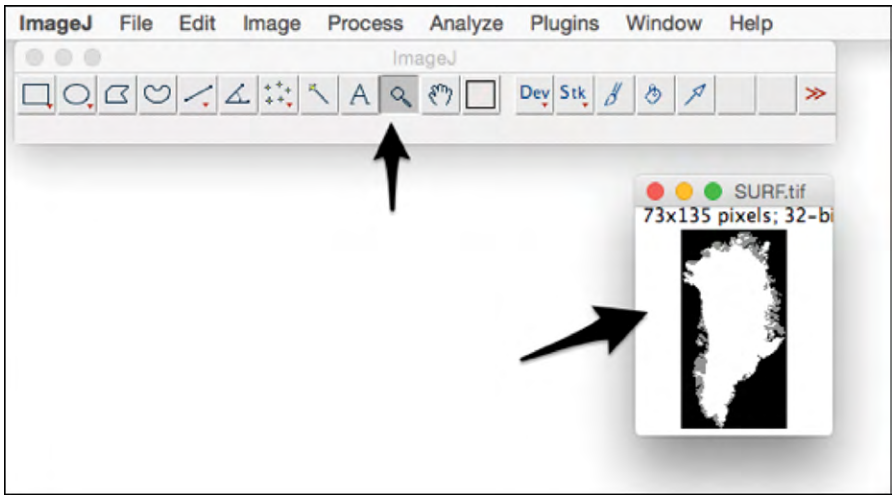

Figure 2. Screenshot of Image J software, and Greenland surface data.
(Figure provided by the authors).

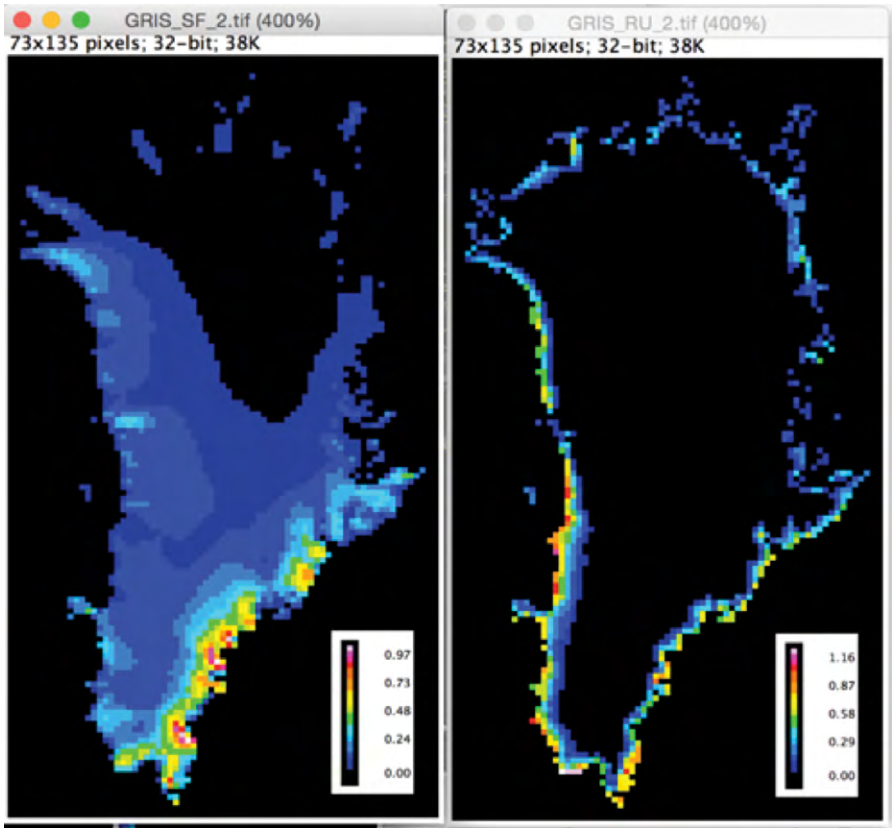

Figure 3. Screenshot of a comparison of snowfall (left) and runoff data (right). (Figure provided by the authors). The color bars show the average annual water equivalent (2005-2016) of snowfall or runoff in units of km3/year.

Step by step instructions and screenshots are included throughout the activity to assist students while they navigate the use of the software. The activity contains seven steps which begins with two steps that orient students to the software as they explore the types of surfaces and elevation on Greenland. Next, students import MAR data for albedo and above freezing temperatures and compare values across the ice sheet over time. They continue this effort by importing and assessing snowfall values over time (See Figure 3). Students then create transects, profiles, and animations to model changes in the data over time. Following this step, the data is imported into a spreadsheet program where students make scatterplots, add trendlines, and assess the resulting correlation coefficient. In the final step, they use the data from ImageJ to estimate sea level rise resulting from the melting of the ice sheet and compare it to the current projected values. They use the products of this activity to create an evidence-based argument for the melting ice and its resultant impact on global sea level rise. From the successful completion of this activity, students gain numerous scientific skills related to modeling, data analysis, and developing arguments from evidence.

Activity 3: Should I Move Inland? What About Others Around the World – Should They Move to Higher Ground?

Once students have made the connection between the melting Greenland ice sheet and global sea level rise, they elaborate on the impacts of sea level rise on coastal communities in the United States and around the world. After learning how to manipulate sea level rise mapping tools from the National Oceanic and Atmospheric Administration (NOAA), pairs of students use these tools to compare the impacts on the populations and infrastructure at various coastal locations around the United States. They create a report from the viewpoint of a federal government scientist and share their findings with the class. After all the presentations have been made, students discuss the variation in vulnerabilities found around the country. Identifying solutions for sea level rise is complicated since there are so many facets to the issue such as economic implications, social implications, and political implications. A class discussion organized around all the possible decision-making factors and possible solutions assists students with understanding how to address complicated issues. In the final component of this activity, students venture out of the boundaries of the United States to explore how sea level rise will impact our neighbors in different countries.

Activity 4: How Does Melting Arctic Ice (Sea Ice and Ice Sheets) Impact the Climate Where I live?

In this final activity of this module the focus shifts from the melting Greenland ice sheet to melting sea ice in the Arctic. Students apply what they learned from previous parts of this module to a new scenario as the teacher evaluates their understanding of the core ideas related to melting Arctic ice (sea ice and ice sheet). It opens with a demonstration designed to dispel the conception that melting sea ice will cause sea levels to rise. A clear glass is filled with ice and water and students are asked what will happen to the water level if the ice were to melt. After the ice melts, students recognize that the water level did not change, but are then challenged to identify the effects of melting Arctic sea ice. They brainstorm the cause-effect relationships between sea ice and our climate system while considering the associated climate feedbacks as sea ice dwindles, including the impacts on midlatitude weather and climate. Next, pairs of students seek datasets such as those suggested in the activity to support their claims. These datasets may include raw data, graphs, images, animations, and models. To close the module, students report their findings to their classmates during a discussion on the complexity of the climate system that includes the far-reaching effects of melting sea ice and melting ice sheets.

From the Arctic to Our Backyards

Additional resources are available online to support this module, including an annotated PowerPoint presentation, videos and selected weblinks. The four high-quality videos were created to help students connect to the Arctic region and the people who collected the data in this module. Each video is about 3 minutes long and contains stunning footage from Greenland and introduces four scientists who explain their background and research methods. By completing this module students learn that what happens in the Arctic does not stay in the Arctic, and that we are all vulnerable to the changes occurring there. With scientific understanding of our climate system they are better prepared to discuss measures to mitigate the effects of climate change as well as ways to adapt to the effects of climate change.

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