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The Arctic is melting - so what?

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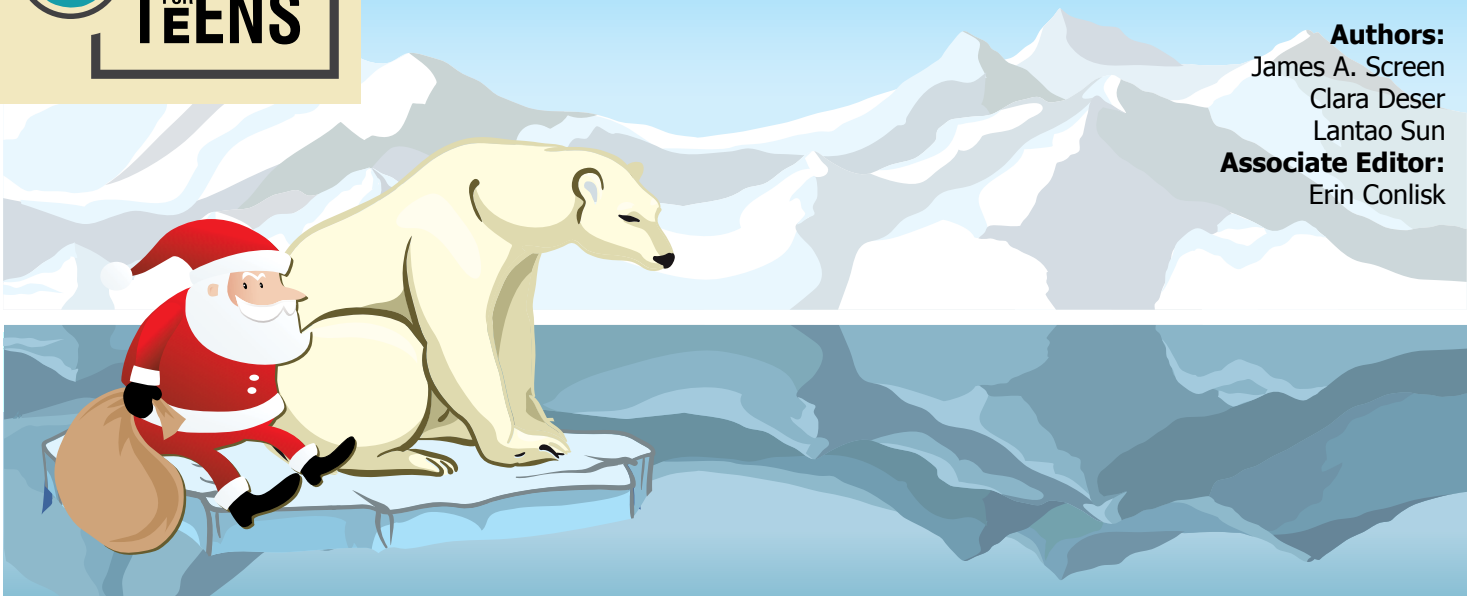

Abstract

The Arctic sea ice over the North Pole is melting - faster than humans have ever witnessed - as a result of climate change. How does this affect the weather elsewhere, though? Does it? We wanted to know if people outside the Polar Circle would experience more extreme weather as a result of the melting.

We entered predications for sea ice loss as input into a climate model. The goal was to estimate the number of warm, cold, wet, and dry days as a result of the melted ice. According to the model, in more northern locations, like Siberia, Scandinavia and northern North America, people would experience fewer cold days and more warm days. In addition, Eastern U.S., Central Europe, Siberia, and all of Asia can expect fewer dry days while the Mediterranean, Siberia and northern North America will face more wet days. Lots of changes in store, right? And not just in the Arctic!

Introduction

If Santa does live at the North Pole, he lives on a big ice "cube" (really a vast sheet that is typically only a few meters thick) floating over the Arctic Ocean. This could become problematic by 2100 when much of this sea ice is expected to melt out every summer (Figure 1). (Sea ice over the Arctic is not to be confused with Antarctica – the snow-covered continent at the South Pole.) Historically, Arctic sea ice would be at a maximum in March, when cold temperatures cause the surface of the ocean to freeze (Figure 1, left figure) and about 60% of the sea ice would then melt by September (Figure 1, third from left). With global warming, more sea ice is melting in the summer than can form in the winter, potentially creating an ice-free Arctic Ocean (Figure 1, right

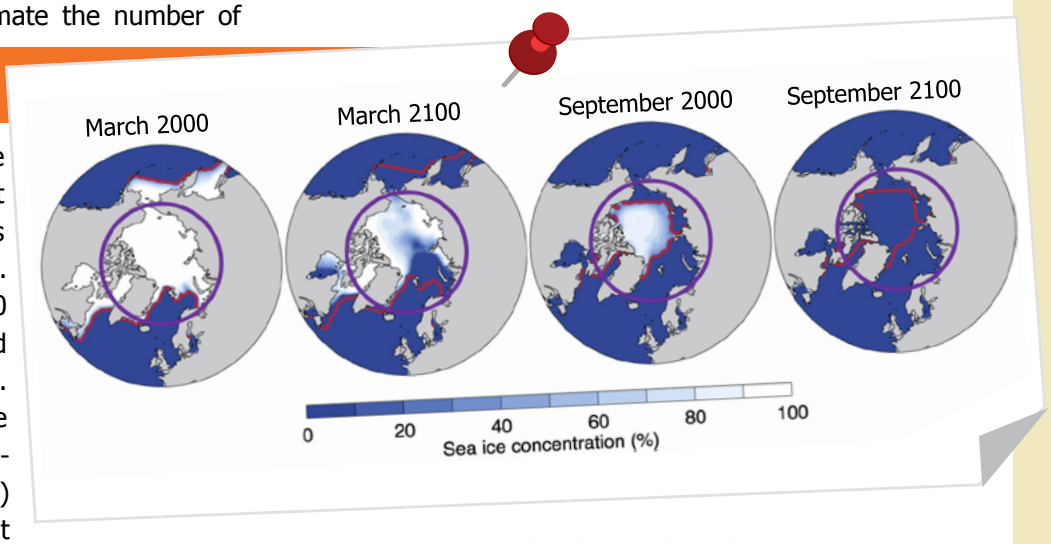

Figure 1. *Sea ice in March and September in the year 2000 versus 2100 from the Hadley model. The purple circle is the "Arctic" region. The red outlines are the extent of sea ice under current conditions in March 2000 and September 2000. These outlines are preserved in the second and fourth figures from the left to show how sea ice is declining in 2100.*

column). At which point, Santa, elves, and reindeer would need to relocate!

But Santa's troubles are the tip of the iceberg (which is not made of sea ice but formed when glaciers on land reach the ocean and chunks fall into the sea). Loss of Arctic sea ice can feedback on continued climate change through the albedo effect (see Glossary) and disrupt Arctic wildlife. Polar bears are the most common example of wildlife dependent on sea ice. Polar bears stand on the sea ice when they hunt; without this platform they can't catch their prey. But creatures, such as polar bears, at the "top" of the food web aren't the only ones that depend on sea ice for food. Sea-ice phytoplankton are blooming at different times, disrupting prey availability for crustaceans that are eaten by larger fish, such as cod (Post et al. 2013).

In this paper, we want to explore how sea ice loss can affect extreme weather throughout the Northern Hemisphere (any part of the world north of the Equator). Extreme weather, which we define as weather (or atmospheric conditions over short time frames; climate describes weather over longer time frames) that has been historically uncommon, has important impacts on humans and nature. For example, for humans, extreme cold requires greater energy use, often through the use of fossil fuels, to heat our homes and clear our roads (Figure 2). For wildlife, behavioral changes (such as finding more food, better shelter, or a warmer location to move to) to accommodate extreme cold may not be sufficient and animal species may die off. Very high rainfall can lead to flooding that impacts human structures and wildlife.

Figure 2. *A winter service vehicle abandoned and stuck on the roadside in Chicago during a winter storm. Extreme cold weather can paralyze entire cities and economies.*

Methods

We used models (representations, often a simplifications, of a structure or system) to predict how the climate might change in the coming decades to centuries. Climate models are incredibly complex. For example, climate models must describe how water that evaporates in one region is transferred through the atmosphere to another region, potentially hundreds of miles away, and falls to the ground as precipitation. The exact location of evaporation and precipitation depend on the land surface (are there mountains? what vegetation is on the landscape? etc.).

We used two well-established climate models – (i) the UK's Hadley Centre model (GAM2) and (ii) the US's National Center for Atmospheric Research (CAM4) model. These models have been used previously (as part of the fifth Intergovernmental Panel on Climate Change, or IPCC, report) to predict how much sea ice we expect in 2100. We do not describe the climate models in detail in this paper because it would take thousands of pages. If you want to learn more about it, check out Rubenstein 2010.

We then used these sea ice predictions as model input. We held everything in the model constant except how much sea ice is in the Arctic. Our model functions like our experimental system in which we compare two treatments: the current sea ice extent versus the reduced sea ice coverage predicted for 2100.

We expected that by changing the model's input (describing the amount of sea ice in the Arctic), the model would predict weather changes in other parts of the world, particularly in locations north of the Equator. We were interested in the following four measures of extreme weather:

1. **Warm days:** Percent (%) of days when the maximum temperature is greater than the 90th percentile of historic weather,
2. **Cold days:** Percent (%) of days when the maximum temperature is less than the 10th percentile of historic weather,
3. **Wet days:** Number of day per years when daily precipitation is greater than 1 cm, and
4. **Dry days:** Number of day per years when there is no precipitation.

To define warm and cold days, we looked at the historic weather for a particular location and ordered all observed temperature values for a particular day of year. The 10th percentile reflects the temperature value where 10% of all the temperature values fall below that value. Because only a few observations are colder than the 10th percentile, we define it to be a "cold" day. Similarly, the 90th percentile reflects the temperature value where 90% of all the temperature values fall below that value. A day that was historically hotter than most days (i.e. at the 90th percentile) is thus defined as a "warm" day.

Results

The amount of sea ice in the Arctic will have different impacts on extreme weather depending on the location in the northern hemisphere. In more northern locations, like Siberia, Scandinavia, and northern North America, decreases in sea ice will lead to significantly more warm days and fewer cold days (Figure 3).

The impact of sea ice loss on precipitation will occur at both southern and northern locations. Overall, the model predicts an increase in precipitation. In the Eastern US, central Europe, Siberia, and all of Asia the number of dry days are expected to decrease. In Central Asia, the Mediterranean, Siberia, and northern North America the number of wet days will increase (Figure 3).

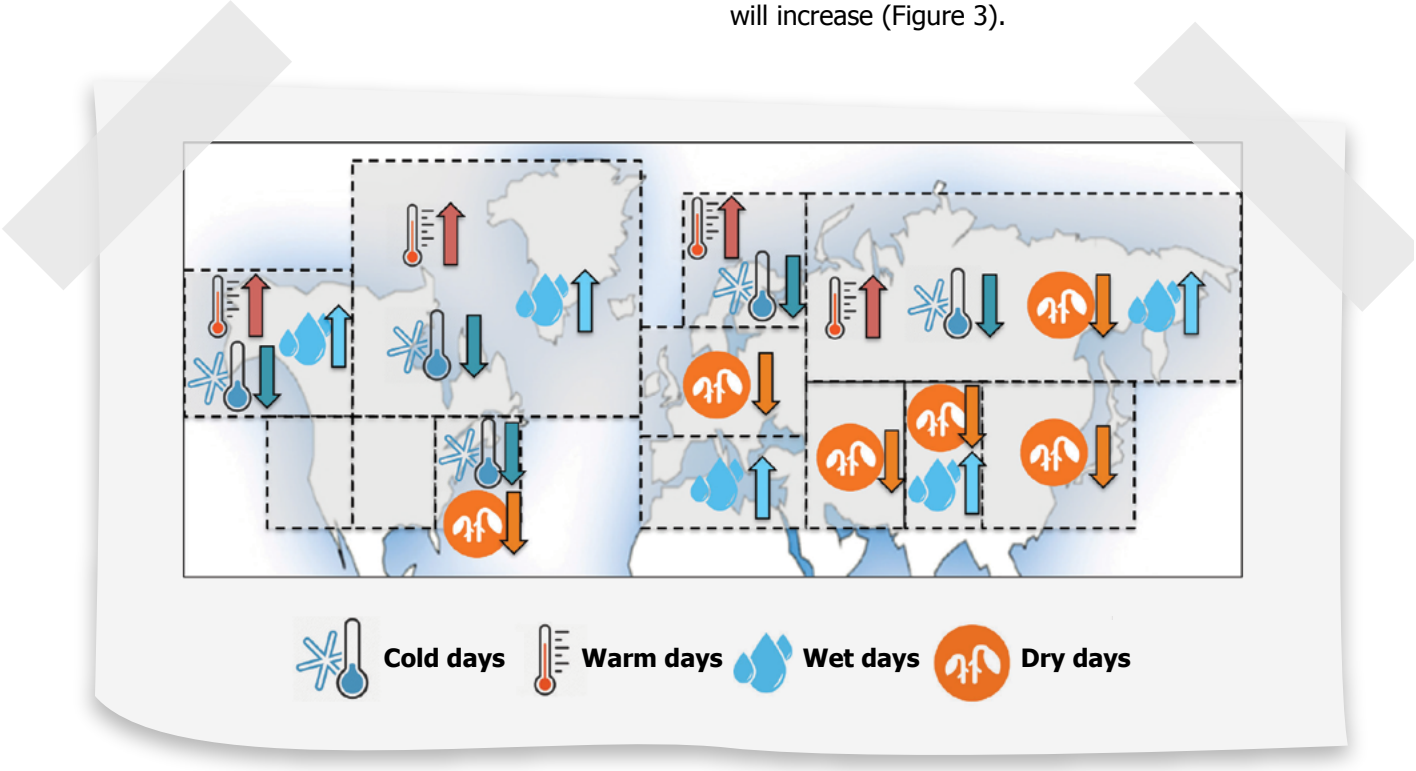

Figure 3. *Changes in local weather predicted by the model as a result from Arctic sea ice loss.*

Discussion

According to the climate model, loss of sea ice will lead to local warming in the Arctic which then will move to nearby locations in northern North America, Scandinavia, and Siberia. This will cause more warm days and fewer cold days.

Further, we can expect a lower variance in the temperature (in other words, the temperature had more similar values from day to day).

Conclusion

There are three important things that can be done with the information in this paper. First, work to reduce greenhouse gas emissions that cause climate change and associated melting of sea ice – for the sake of the polar bears and Santa! In particular, try to avoid using fossil fuels for transportation, use less energy at home and try to consume less "stuff". Almost any item you buy likely required fossil fuels to create and also to transport to the store.

Second, climate change is a global phenomenon: sea ice loss in one part of the world can affect the weather where you live. Similarly, the choices you make will affect the magnitude of this problem across the entire planet.

Third, understand how scientists create and predict future climate. A lot of people (especially those as old as Santa!) have trouble understanding what models do and how to interpret uncertainty. The best scientists agree that the changes we are observing now are evidence that climate change is real and already profoundly impacting our planet. However, uncertainties about specific climate change phenomenon (e.g. was this particular hurricane caused by climate change) are used to justify political inaction. While you don't have to be an expert to interpret scientific information, you do have to practice. Flexing your critical thinking "muscles" will keep them "strong".

Discussion Questions

1. Does melting sea ice in the Arctic increase sea level directly? Why or why not?! How would melting over Antarctica be different?
2. Describe (or draw) the albedo feedback discussed in the paper. (Hint: How does melting sea ice speed up warming in the Arctic?)
3. According to the climate model experiments, what types of weather extremes (cold, warm, wet, dry) are expected to change in number where you live? Think of one way that this change would be a good thing and one way it would be a bad thing.

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TEACHER'S GUIDE

Grade level: High school
Key terms: models, climate change, extreme weather, sea ice loss, statistics, Arctic

Glossary of Key Terms

Albedo effect – Derived from the Latin word for "whiteness", the albedo effect is the amount of incoming solar radiation that is reflected by a surface.

Arctic – An area surrounding the North Pole that includes the Arctic Ocean, most of Greenland, parts of northern Russia, Alaska, Norway, Sweden and Finland, and most of the islands north of the Canadian mainland. Not to be confused with the Antarctic which is area surrounding the continent of Antarctica at the South Pole.

Atmosphere – The envelope of gases surrounding Earth.

Climate – Weather conditions prevailing over a specific regions over a long period.

Equator – An imaginary line (at 0o latitude) around the Earth that is equidistant from the North and South Poles, dividing the world into the Northern and Southern Hemispheres.

Evaporation – The changing of a liquid to a gas, often under the influence of heat (such as boiling of water).

Feedback – The modification of a process by its own results. For example, sea ice loss can "feedback" on climate in two important ways: (1) through the "albedo" effect, and (ii) by lifting the "lid" on the heat stored in the Arctic Ocean. The albedo effect refers to the reflection of incoming solar radiation by light-colored (white) surfaces. If you have ever gone skiing on a sunny day, you know that the snow reflects visible light. It also reflects infrared (heat) radiation. If there is less sea ice, then there is less solar reflection, which leads to more heat being absorbed by the dark ocean water and continued sea ice loss. Sea ice can also cool the Arctic air temperatures by insulating the heat within the Arctic Ocean. The Arctic Ocean never drops more than a couple degrees below 0^{o} C (or 32^{o} F) (the dissolved salt in the water lowers the freezing point of ocean water). If the ocean were exposed to air, it would warm Arctic air which is often below -20^{o}C (-4^{o} F) in winter.

Glacier – A persistent body of ice on land, formed by the accumulation of snow (and thus it is freshwater ice). About two-thirds of the freshwater on Earth is in glaciers. If all glaciers were to melt, this would increase sea level because this ice is not currently in the ocean.

Iceberg – a large (greater than 5 m across) floating mass of freshwater ice that has broken from a glacier or ice shelf and is floating freely in open water. The saying "tip of the iceberg" comes from the fact that most of the ice – over 90% - in an iceberg is below the surface of the water.

IPCC – The International Panel on Climate Change is a scientific body set up by the members of the United Nations to explore the potential speed of climate change and its impacts.

Model – A representation of a thing or system. A paper airplane is a very simple model of a Boeing 747. The simpler the model, the fewer the details that it incorporates.

Percentile – Given a set of numbers, the value below which a given percentage of observations fall. For example, if we had the following set of numbers {4, 7, 3, 9, 3} the 60th percentile would be 4, because 3/5 x 100% = 60% of the set are equal to or less than 4.

Glossary of Key Terms

Precipitation – Rain, snow, sleet or hail.

Sea ice – Frozen seawater. Sea ice covers about 7% of the Ocean surface at any given time. If all sea ice were to melt now, it would have little impact on sea level rise because the ice formed from sea water originally. However, it would impact sea level through climate "feedbacks" (decreased Arctic albedo and Ocean heat insulation).
By the way, there really are about 200 terms for ice and they are important for scientists (compare the implications of sea ice versus glaciers melting). The Editor's favorite is "frazil", the soft or amorphous ice formed by the accumulation of ice crystals in water that is too turbulent to freeze solid. Imagine the ice formed in the ocean under wave action! (See the following website for a description: **http://www.arctic.noaa.gov/essay_wadhams.html).**

Statistically significant – A result that is likely not due to chance, but rather due to a real process. Typically scientists define a result as "significant" if it would happen by chance less than 5% of the time. The p-value is the scientists best estimate of how likely the result would be due to chance. Statistical significance is an important way for scientists to deal with uncertainty. A new study in psychology finds that p-values are doing their job: the lower the p-value the more likely the study is to be repeatable: **http://fivethirtyeight.com/datalab/psychology-is-starting-to-deal-with-its-replication-problem/**

Validation – to check the accuracy of something. For example, to validate a climate model, scientists run the model to "predict" the weather patterns over the past 20 years. Then they compare the output with the actual measurements and observations we have collected for that time.

Variance – The variance of a set of numbers is a measure of how different the numbers in the set are from one another. For example, the two sets of numbers {6, 2, 3, 1} and {2, 4, 3, 3} have the same average, or mean, of 3, but the first set has greater variance. The variance is calculated as:

$$\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})$$

where n is the number of x observations in the set, i is an index for each of the observations, Σ means take the sum over the n observations in the set, and we assume that the mean, $\bar{x}$, is known ahead of time. (If the mean is not known ahead of time, then the 1/n before the summation becomes 1/(n-1). If this doesn't make sense see Bessel's correction in Wikipedia: **https://en.wikipedia.org/wiki/Bessel%27s_correction** If it still doesn't make sense, rest assured that this is college-level statistics.) For example, the variance of the first set is [(6-3)2 + (2-3)2 +(3-3)2 +(1-3)2]/4 = 3.5. Prove to yourself that the variance of the second set is 0.5.

Weather – The short-term conditions (temperature, dryness, windiness, etc.) of the atmosphere at a place and time.