Purpose of Research:

Caroline and I set out to interactively map archival iceberg data from the International Ice Patrol and elsewhere in an interactive and user-friendly manner. We used this visualization to write a paper on the relationship between North Atlantic iceberg counts and climatic change over the previous century. Our work is intended to end in a published article.

Methods:

133 years of data was accessed and collated using Python and Excel. Some R was used for data analysis. Visualization of icebergs was made in Javascript, using the d3.js module.

Results, Conclusions, and Recommendations:

We found several trends. Iceberg abundance in the Grand Banks area appears to track North Atlantic SST. Increased solar activity and the positive phase of the North Atlantic Oscillation may be necessary but not sufficient conditions for a particularly severe iceberg season. As a result of these trends, icebergs do not appear to reach as far south as they once had. Furthermore, we found that icebergs were likely much larger from 1880-1930 than they were in any time period since. We conclude that iceberg dynamics in the North Atlantic track global climate change, and are likely to change in the coming years under a new, warmer climate regime.
Climate change and long-term trends in distribution of icebergs in the Northwest Atlantic (1880-2013): A data-rescue analysis.

Abstract

This study uses a recently expanded record of iceberg sightings in the NW Atlantic Ocean in the vicinity of the Grand Banks from 1880 to present to attempt to determine whether there is a correlation between the number and distribution of icebergs and oceanographic and climatological evidence of climate change. This new record uses iceberg sightings reported to the United States Hydrographic Office by mariners (1900-1926), sightings published in various maritime newspapers (1880-), shipboard sightings collected by the U.S. Coast Guard via the International Ice Patrol (IIP) from 1912 – 2013, supplemented by aerial surveillance, radar after WWII and most recently satellite imagery. Using this new dataset, the record of icebergs passing latitude 48°N and 44° N are compared. The record associated with 44°N has a stronger correlation with local sea-surface temperatures (SSTs) than the IIP’s previous dataset. The expanded dataset also suggests that icebergs may have been consistently larger from 1880-1930 than during any other period in the record. The expanded dataset shows no correlation between sunspots and iceberg abundance, and a very weak correlation between the North Atlantic Oscillation and iceberg abundance. This analysis suggests that increasing SST associated with warming-driven climate change may be driving changes in calving and drift of icebergs from the Greenland ice sheet.

Introduction

For as long as mariners have sailed the North Atlantic, there have been strategic and commercial interests in creating a record of iceberg sizes and locations. The potential of such a record to both predict the severity of current and future iceberg seasons and serve as a proxy for climatic change has led to interest from industry and climatologists alike. Previous analyses have used a simplified record provided by the International Ice Patrol (IIP) to draw correlations between icebergs and Greenland glacier calving\(^1\), sea ice extent\(^2,3\), solar activity, and the North Atlantic Oscillation (NAO)\(^4\). There is disagreement as to the relative causative power of each of these correlations\(^1,3\), and the limitations of the sighting record contribute to uncertainty. This study seeks to shed light on
these correlations by using an expanded and fully manipulable iceberg record created from the IIP’s records, archived bulletins of the United States Hydrographic Office, and a record of notices published in shipping newspapers collected from 1880-2013.

The availability of this larger, more detailed iceberg record leads to several paths of inquiry. First, is the IIP’s existing iceberg record, based on number of icebergs below the latitude 48° N, a good indicator of year-onto-year iceberg abundance/severity, or are there other geographic proxies with different annual distributions that may complicate that iceberg severity profile? Second, do any of these alternative proxies provide new insight into the environmental determinants of iceberg abundance? Third, are there non-geographic aspects of the iceberg record, e.g. iceberg size, that give new insight into the environmental determinants of iceberg sightings? A greater question that weaves these three together is whether this new database as a whole constitutes a sound scientific record, or if its multiple data collection methods call into question its utility for understanding the effect of climate change on the speed and consequences of ice melt in the NW Atlantic. This addressed at length in the “Data and Methods” section.

Background

The best existing long-term ice record lists the seasonal and annual abundance of icebergs south of 48N (approximately Newfoundland) from 1900 to the present day. Don Murphy, former oceanographer for the IIP and author of the dataset, used this and other data on iceberg season length and areal extent to create a seasonal Iceberg Severity Index. Severity in this context is loosely defined as those seasons most likely to infringe upon North American shipping lanes. Murphy concluded that the least severe recorded seasons were associated with mild winters, warmer Newfoundland sea surface temperature (SST), onshore winds, and weak offshore currents as protective factors for the iceberg-wary mariner.

Since its inception, the 48N dataset has frequently been used as a proxy for overall iceberg abundance in any given year. Skinner et al. recently did an analysis of the 48N dataset with respect to the most frequently claimed correlations: sunspot activity, sea ice extent, and the NAO. They were unable to find any correlation between sunspot activity or the NAO with the existing 48N data series using LOESS smoothing, cross-
Correlation, or linear autocorrelation techniques, and found a limited correlation with sea ice extent.

Sea ice extent in the Labrador Sea is thought to be a determinant of an iceberg’s progress toward the North Atlantic shipping lanes. Sea ice acts as a buffer for icebergs, preventing melting by keeping SST low and preventing grounding by extending far from the shallow coast (Figure 1). It follows that years with heavy sea ice are likely to result in more-southerly icebergs. Marko et al. established a correlation between 48N and the sea ice extent in the Labrador Sea and the Davis Strait, but also suggested a recent weakening of the Davis Strait relationship.  

Map 1. Likely iceberg migration pathways between Newfoundland and Greenland. Attribute to Skinner et. al [8].

In contrast to the sea ice hypothesis, Bigg et al. used a non-linear regression model based on the 48N data to link North Atlantic iceberg
abundance primarily to the calving rate of the Greenland ice sheet, and furthermore suggested a regime shift in the glacial origin of icebergs.¹ According to their analysis, icebergs originated more often in south Greenland before mid-century, and more often in west Greenland in later centuries. Icebergs originating in the south circumvent a northern journey through the Labrador Sea, and therefore would have follow a shorter and safer journey to 48N (Map 1). However, direct observations of this trajectory have yet to be found (Brian Hill, personal comm.).

Little analysis has been done on iceberg size, given the sporadic nature of the archival record. John Newell did a case-by-case analysis of ice islands from 1900 to 1993 based on the IIP records, and concluded that early century icebergs may have been larger than the icebergs commonly seen from the 1980s to 1990s.⁹

**Iceberg Data**

The IIP has kept extensive data on iceberg sightings in the North Atlantic east of Newfoundland for the past 113 years, recording over 200,000 data points with longitude, latitude and qualitative identifiers of size and shape. Technical limitations in transcribing scanned data from the first half of the century, paired with frequent methodological changes in the latter half of the century, have previously made the IIP’s dataset unworkable in whole and questionable in part. Recent archival efforts by Brian Hill, formerly of the National Resource Council of Canada (NRC), have made possible not only the unification of the IIP dataset, but also its pairing with a wealth of earlier, but more scattered sighting sources in the form of weekly reports from the now-defunct Bulletin of the US Hydrographic Office and periodic articles in maritime newspapers such as Lloyd’s List and the New York Maritime Register.¹⁰,¹¹ This paper combines Hill’s archival work with the IIP’s existing electronic records to create a unified iceberg record covering the 1880-2013.
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Figure 1: Two examples of sources that extend the IIP’s electronic records. Above is the New York Maritime Register, which often records iceberg sightings. Below is a scanned copy of the IIP’s iceberg record from 1926.

Data for the years 1960-2013 were retrieved from the International Ice Patrol’s sightings archived at the National Snow and Ice Data Center (NSIDC). All other data were accessed from Hill’s dataset hosted on ACADIS, covering 1880-1959. The ACADIS data includes transcriptions of all of the IIP’s records since 1912, and segues seamlessly into the NSIDC dataset. Non-IIP sources compose all of the data from 1880-1912, and...
supplement IIP data at a decreasing rate until 1947. Together, this dataset represents over 300,000 iceberg sightings over 133 years, with up to 8,000 sightings in any given year.

Data were collated with differences in recording methods in mind. Some aspects of sightings, like iceberg shape, were excluded because of the subjective nature of the observations and the impossibility of reconciling differences in shape definition. Size was recorded for many sightings, although those data are analyzed cautiously. While the IIP vouches that the overall standards for “small” and “large” icebergs have remained similar throughout the previous century, there are to this day a significant number of bergs for which size was not recorded.\textsuperscript{12} The size distinction “medium” did not exist until 1960, although its addition did not significantly change the overall ratio of “large” to “small” sightings, and so likely did not borrow from one category or the other.

The unified dataset analyzed here consists of sightings, with a “sighting” being defined as a visual identification and a spatial record of one to several icebergs. Multiple entries are recorded if icebergs of different sizes, e.g. a growler and a large iceberg, are reported in the same area. This dataset also indicates “resights” – repeat sightings of the same iceberg after having moved – tabulating over 70,000 resights in addition to 200,000+ unique sightings. The true number of unique sightings is likely lower, given the susceptibility to error in differentiating one iceberg from another with different observers on different vessels using different sighting methods. The ACADIS and the NSIDC datasets have iceberg sightings that may be resights but cannot be confirmed in retrospect; this problem occurs across each decade, and can be considered a persistent bias in the dataset. The 48N dataset provided by the IIP has undergone additional quality control to remove some of these erroneous sightings, and so has consistently fewer sightings than the 48N dataset derived in this paper.

Insights into iceberg distribution are invariably complicated by varying sighting methods. Over the past century, the IIP has modified its surveying area, changed its sighting method from ship to plane to airborne radar to satellite imagery, and continuously integrated iceberg sightings from passing mariners, the so-called “thousand eyes of the Ice Patrol”. The Hydrographic Bulletin and newspaper reports have no established sighting
area, and so their sightings are often concentrated on shipping lanes. All of these different sources and methods result in persistent, idiosyncratic bias. Given these biases, geographic trends are restricted to those southernmost regions that are recorded in all datasets because of their proximity to the most-frequented shipping lanes.

Methods

Correlations between iceberg sightings and SST, NAO, and sunspot activity are obtained from using Pearson’s correlation coefficient. When possible, correlations are fit with a logistic growth curve. Sea surface temperature data were accessed from the Kaplan SST V2 dataset provided by the NOAA/OAR/ESRL PSD at http://www.esrl.noaa.gov/psd/. NAO data were accessed from Jim Hurrell’s dataset via the National Center for Atmospheric Research. This NAO index is based on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland. Sunspot data were accessed from the WDC-SILSO via the Royal Observatory of Belgium, Brussels.

Results

The 48th Parallel as a Measurement Standard

The number of icebergs below 48N is a somewhat arbitrary measure of north Atlantic iceberg abundance, originally chosen as a boundary line beyond which icebergs become a menace to transatlantic mariners. The IIP’s 48N dataset has several advantages: it is heavily quality-controlled, its sighting database is sufficiently large for analysis, and it sighting area is covered in every year of IIP surveillance. However, because it was in effect randomly chosen, one can choose other latitudinal boundary lines and find entirely different distribution of icebergs in the past century (Fig 2-4).
The 48N standard (Fig 2) shows a bias towards higher iceberg counts later in the century, with graphical analysis alone suggesting that iceberg abundance has slightly increased from 1880 to 2013. Readjusting the standard to 44N decreases the relative abundance of icebergs at midcentury, giving the timeline a dipped appearance. Readjusting the standard to 42N places heavy emphasis on those decades before 1930; icebergs in later decades rarely pass below 42N at all (Fig 4).

In general, the 48N standard becomes continuously less correlated as one compares to increasingly southerly standards (Fig 5). There is no correlation with those icebergs below 40N, and less than a 0.5 correlation with those icebergs below 44N. The 40N standard is a fairly small dataset (~245 sightings), and its zero correlation may be a result of the highly variable nature of the iceberg record (Fig 4). The 44N standard, however, remains a large dataset (~15,153 sightings) and its difference is unlikely to be explained by random variation alone.
The following statistical analyses are performed using the 48N and the 44N standard, as it is distinct from the normally-used 48N standard but still of sufficient size to suppress natural variability.

**Atlantic SST Anomaly**

Icebergs persist in the Arctic and North Atlantic up until they melt, usually in the relatively warm Gulf Stream and North Atlantic Current. Barring other factors, those years with higher SST should have fewer southerly icebergs, given their increased rate of melting. This analysis correlates North Atlantic SST anomalies with icebergs below 48N and 44N. North Atlantic SST did not track global SST from roughly 1930-2000, and is likely to have a more direct effect on iceberg abundance.\(^\text{14}\)

North Atlantic SST anomalies are calculated as differences from the 1970 mean SST from 0N to 70N in the Atlantic Ocean. Data were originally presented in monthly format, so annual estimates are derived from averaging the averages of each month. Winter SST is defined as the period of December-March previous to the recorded year. The 48N dataset has little to no correlation with North Atlantic SST in the same year \((r^2 = .02)\),
the previous year ($r^2 = 0$), or the previous winter ($r^2 = 0$). The 44N dataset features stronger correlations with annual SST ($r^2 = .17$), previous year SST ($r^2 = .18$), and winter SST ($r^2 = .19$). The top 25 years with the most sightings all occurred with cold winter SST anomalies, and only 27% of years with greater than 25 sightings (13/48) occurred during a warm winter anomaly. The 42N shows similar results to the 44N standard.

Regardless, the high variability of the dataset does not lend it to correlation analysis with Pearson’s coefficient. Qualitative graphical analysis shows a pattern whereby cold winters lead to highly active iceberg seasons from 1880-1930 and from 1990-1994 (Fig 7). Correlation between winter SST anomaly and iceberg abundance seems to increase after 1970 ($r^2 = .24$) compared to 1880-1970 ($r^2 = .17$).
Figure 7. This is a time series of the annual abundance of icebergs below 44N, overlaid with the previous winter’s SST anomaly. Blue areas represent negative anomalies, while orange areas represent positive anomalies. Greater heights in either direction represent stronger anomalies.

North Atlantic Oscillation

The following NAO index represents the state of a reoccurring climactic phenomena in the North Atlantic, whereby atmospheric pressure gradients change to such an extent as to affect wind patterns, humidity, storm severity, and other weather patterns. The NAO fluctuates on a roughly decadal scale, and can vary in positive or negative intensity from year to year. With regard to the North Atlantic and the Grand Banks, a positive NAO index is said to correspond to increased sea ice extent, increased offshore winds, and increased icebergs in the vicinity of the Grand Banks (Murphy, Hicks, personal comm). Offshore winds particularly are instrumental in generating icebergs, as they help dislodge icebergs from warmer, senescent coastal waters.

This analysis uses the DJFM NAO dataset provided by Jim Hurrell, which averages the NAO index from December to March. The 48N dataset had no correlation with the DJFM NAO ($r^2 = .03$), while the 44N dataset also had a very weak correlation with the NAO ($r^2 = .09$). 12 out of the top 14 sighting years occurred during a positive NAO (Fig 8). Similarly, the 42N data had no correlation with the NAO, but had the top 10 years in iceberg abundance all occur during a positive-phase NAO. Qualitative analysis of
the NAO time series gives little insight as to its possible connection with iceberg abundance.

Figure 8. Each dot represents one year of data. The x-value is equivalent to how many icebergs were recorded south of 44N in that year, while the y-value is equivalent to the indexed NAO of the same year. The DJFM NAO index records the average pressure difference between Reykjavik, Iceland and Lisbon, Portugal.

**Sunspots**

Recently, the relationship between sunspots and North Atlantic icebergs was tested using the IIP’s 48N dataset. Sunspots had already been implicated in the extent of the Newfoundland ice sheet (Hill 1990), and it was supposed that sunspots as a proxy for solar activity may also have a controlling influence on iceberg abundance. The following analyses uses an annual average of sunspots to test this theory.

Data were correlated with an annual average number of sunspots observed during that year. The 48N data has no correlation with the sunspot time series in the current year ($r^2 = 0$) or the previous year ($r^2 = 0$). The 44N data showed no correlation with the current year ($r^2 = .03$) or the previous year ($r^2 = 0$). Overall, sunspots are uncorrelated with the iceberg record (Fig 9). However, 8 out of the top 10 most severe iceberg seasons coincided with below-average sunspot years.
Iceberg Size

Iceberg size can reflect several factors. Icebergs become smaller as they melt, sometimes breaking into several pieces, and so iceberg size may be primarily controlled by SST, air temperature, or solar activity. Currents may also affect iceberg size – icebergs with a more circuitous journey from the Arctic to the Atlantic may have had more time to melt. North Atlantic iceberg size may also be controlled by the size-at-calving from the Greenland ice sheet, with larger calving size being hypothetically correlated with greater iceberg size near the Grand Banks. The following analysis correlates observed iceberg size with SST, and notes a general decline in large icebergs since the 1930s.

Icebergs considered “large,” “very large,” or “ice islands” were sighted in far greater proportion in the period before 1930 (30% of all sightings, 48N) than they were in any time afterwards (7% of all sightings, 48N). They were also greater in absolute number: 69% of all “large” iceberg sightings occurred before 1930 (9,479/13,788, 48N). This trend is evident in the both the 48N and the 44N datasets (Fig 10).
The annual number of “large,” “very large,” and “ice islands” under 48N held a correlation with annual SST ($r^2 = .22$) and previous winter SST ($r^2 = .21$, Fig 11). These correlations weakened under the more restrictive 44N standard ($r^2 = .14$ for both annual and winter). No correlation was found with the NAO or sunspots, regardless of sighting standard used.

Figure 11. Each dot represents one year of data. The x-value is equivalent to how many “large” icebergs were recorded south of 48N in that year, while the y-value is equivalent to previous winter SST anomaly in the North Atlantic.
Discussion

Icebergs, bound as they are to their parent glaciers before calving off into the sea, are integrators of a great many environmental variables, including. It has thus been perplexing as to why the IIP’s existing record correlates so poorly with environmental indicators like SST and the NAO. Accordingly, this paper set out to answer three questions:

- First, is the existing standard for measuring iceberg abundance in the North Atlantic a valid proxy for iceberg abundance?
- Second, given a newly expanded iceberg record, is there a long-term trend in the abundance and distribution of icebergs that correlates with our existing knowledge of climate change in the North Atlantic?
- Third, do qualitative records of iceberg size give valuable insight into the existing records of location and abundance?

In response to the first question, the existing measurement standard of “all icebergs below 48N” may not capture the full sensitivity of the iceberg system to environmental change. North Atlantic SST, the phase of the NAO, and sunspots all have very weak or no correlation with the 48N standard. This suggests that iceberg abundance in certain areas of the North Atlantic — e.g. the Grand Banks — may be relatively impervious to climate change or climate forcing. It may also be that an unconsidered variable controls the abundance of icebergs below 48N, such as sea ice extent or glacier calving. Further analysis with an extended sea ice dataset may help to explain long-term trends in icebergs below 48N.

This paper uses a new proxy of “all icebergs below 44N.” In contrast to the 48N proxy, 44N gives information on those bergs that travel unusually far southward and infringe upon transatlantic shipping lanes. This proxy showed a weak, but present correlation with North Atlantic SST, and no correlation with phases of the NAO or annual sunspot activity. However, particularly severe iceberg seasons seem often to be in low-solar activity, positive NAO phase years. It may well be that NAO and sunspots are necessary but not sufficient conditions for a particularly severe iceberg season. Additional statistical analysis, or investigation of years on a case-by-case basis, may illuminate the relationships between icebergs, solar activity, and the NAO.
The correlation between 44N and North Atlantic SST is most interesting, as it provides insight into how future iceberg seasons may operate in an increasingly warm planet. Barring massive changes in carbon output, SST is likely to continue to rise in the Arctic and North Atlantic. If warmer temperatures lead to fewer icebergs, transatlantic mariners can look forward to an increasingly iceberg-free journey in the next century. Furthermore, industries looking to either extract resources from the Grand Banks or chart a shipping lane through the Northwest Passage may encounter fewer obstacles in a global warming future.

One must bear in mind that the iceberg record is highly variable, and there are many years that have high iceberg counts despite high SST temperature. Furthermore, the iceberg regime is likely to be non-linear, and thus could switch into a new dynamic once SST reach a critical point. Both Marko et al and Bigg et al have suggested a regime shift in iceberg dynamics sometime in the last century\textsuperscript{1,3}. Bigg et al. suggest that icebergs may have once taken a shorter, safer journey to the IIP’s sighting area from more southerly glaciers, and that a shift to more northerly glaciers occurred sometime in the mid-1900s. This could explain the sudden drop-off in iceberg size around the 1930s, or the drop-off in iceberg abundance itself. Marko et al. suggested the established linkage between iceberg and sea ice extent may have become weaker in the 1990s, especially with regards to the Davis Strait sea ice extent. This could be reflected in the corresponding increased correlation between SST and 44N iceberg abundance seen in the 1980s and 1990s in this extended dataset. This paper also does not address the effect of the Gulf Stream / North Atlantic currents, which have a powerful influence on iceberg distribution apart from SST or weather patterns.

What size data is available shows that icebergs were often larger before 1930, or at least considered by their observers to be larger. It is also evident that the proportion of large icebergs in a year is also correlated with North Atlantic SST and the NAO. Unfortunately, multiple biases work in a tug-of-war to either inflate or deflate size estimates. On the one hand, modern sighting methods cover a wider area and often are more accurate than sighting methods in the first half of the century. Early decades may be biased towards large iceberg sightings, as they would be spotted much easier. On the other hand, earlier observers could see icebergs from the
decks of their ships, rather than through the screen of an aerial radar sweep, and thus may have been better positioned to record accurate size measurements. Thus, while it appears that large icebergs are more likely in colder SST, this correlation is more suspect due to the difficulty of quantifying iceberg size.

There is practically limitless environmental data sealed away in paper records from naval, merchant, scientific, and civilian sources. Efforts at transcribing this data may yet give insight into previously unknowable systems. Specific to the Northwest Atlantic, whalers’ and sealers’ logbooks contain an enormous amount of environmental data, yet remain untranscribed. Future efforts of understanding either the ecology or the physical dynamics might turn to these logbooks for additional data points, as Brian Hill and others have done with icebergs in the Grand Banks.

Conclusion

- The expanded iceberg record (1880-2013) developed by Brian Hill and the IIP, which is composed of IIP observations from ships, aircraft, radar, satellites and buoys; the bulletin of the United States Hydrographic Office; and maritime newspapers is likely a reliable data source given strong correlations with North Atlantic SST.
- “All icebergs below 48N,” the current proxy for iceberg season severity, may not capture the full extent of climate-iceberg couplings in the Grand Banks.
- There is good evidence that the average number of icebergs sighted below 44N has declined and will continue to decline. In the past decade, the average number of sightings below 44N was ~5% of the average from 1880-1930. Increasing Atlantic SST, driven by the greenhouse effect, may perpetuate this trend.
- North Atlantic annual SST, previous winter SST, and NAO all have weak correlations with the 44N iceberg record. Low winter SST is the best indicator available for severe iceberg seasons. Sunspots shows no correlation with the iceberg record.
- Large icebergs comprised a greater proportion of the sighting record before 1930, and may have also been more abundant in absolute number. 70% of all large iceberg observations in this dataset occurred before 1930.
Supplemental Material

A visualization of the entire iceberg data record can be seen at http://andrew-beers.github.io/International-Ice-Patrol-Mapper/.

Acknowledgements

I would like to thank Brian Hill, for providing me with the archival iceberg data; Donald Murphy and Michael Hicks for the their valuable insight into the IIP, the staff of the NSIDC, and Caroline Karp for first pointing me towards the IIP’s records.

References


http://navcen.uscg.gov/?pageName=iipWhyWasThe1999IcebergSeasonSoMild


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