Climatic Influences on the Annual Iceberg Flux off the Coast of Newfoundland

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Abstract: There is a suggestion that the annual iceberg flux off the shores of Newfoundland may be influenced by various natural climatic phenomena. Such phenomena include solar activity, the North Atlantic oscillation (NAO), and sea ice coverage. The purpose of this paper is to investigate the likelihood and nature of potential relationships between iceberg flux and these climatic phenomena. Several approaches are taken to analyze the data ranging from simple exploratory analysis to time series modeling. The analysis has revealed that there is generally no correlation between most of the data sets and that it is unlikely that any of the climatic phenomena investigated influences the iceberg flux off the coast of Newfoundland. The model of the sunspots data is much more complex than any of the other data sets which follow much simpler models with time. The NAO shows significant annual variation with no discernable long term trend or obvious correlation structure. Iceberg flux was shown to be correlated with sea ice coverage but this conclusion is based on a much shorter sea ice data set. However, this conclusion is supported by physical reasons and previous studies.

1. Introduction

Recent work by researchers at Memorial University has focused mostly on modelling iceberg deterioration patterns and investigating the potential relationships which may exist between iceberg flux and various other environmental driving forces in the context of climate change (Bruneau, 2008; Skinner, 2009). The purpose of this study is to investigate statistically whether there is any relationship between iceberg flux and three important natural climatic phenomena: solar activity, the North Atlantic oscillation (NAO), and the prevalence of sea ice. Reliable data of these phenomena are widely available online from several sources. The occurrence of icebergs in the North Atlantic Ocean can be characterized in many ways, but for the purpose of this study the iceberg flux across lower latitudes is of interest. Therefore a time series of annual Iceberg Flux below the 48th parallel is selected as the climatic descriptor for this variable. This data set is provided by the International Ice Patrol (IIP), a section of the U.S. Department of Homeland Security (International Ice Patrol - U.S. Coast Guard, 2008). The data series began in 1900 and was initially collected due to increased shipping activity on the Grand Banks and a rise in the number of iceberg related disasters. Today, the data are even more closely monitored due to the numerous oil and gas exploration and production activities in the vicinity.

It has been widely speculated that solar activity (beyond that which may be characterized as long-term mean solar output) influences oceanic, terrestrial and atmospheric phenomena. If so, then the duration, intensity and timing of natural cycles such as weather patterns, oceanic currents and all manner of responses in the biosphere would be influenced. Thus it is reasonable to contemplate a link between iceberg flux and irregular or periodic solar activity, either as a direct or indirect result.

To represent solar activity the international mean annual sunspot number which has been recorded from 1700 to the present is used in this paper. The data are acquired through the National Geophysical Data Centre of the National Ocean and Atmospheric Administration Satellite and Information Service (National Geophysics Data Center - NOAA Satellite and Information Service, 2008).

The NAO is a climatic phenomenon in the North Atlantic Ocean defined by fluctuations in the difference of sea level pressures between the Icelandic low and the Azores high (Bruneau, 2008). These oscillating fluctuations in pressure control the severity and direction of storms tracking across the North Atlantic; the area in which icebergs are first set adrift from glaciers in Greenland. Consequently one can envision a link between the two phenomena, if not directly then indirectly through storm and drift interactions. The NAO is the subject of numerous climatic investigations and as such there are several indices which measure its effect. For this study the Annual Station Based NAO Index is selected which measures the difference in normalized sea pressures between Ponta Delgada, Azores and Stykkisholmur/Reyjavik, Iceland. The index is provided by the National Centre for Atmospheric Research and provides a data set from 1865 to 2002 (National Centre for Atmospheric Research, 2009).

Sea ice in the North Atlantic has been linked to iceberg deterioration in a number of studies with evidence to suggest that sea ice coverage directly influence the lifespan of an iceberg (Marko, Fissel, Wadhams, Kelly, & Brown, 1994; Bruneau, 2008). It has been proposed that sea ice may in fact be the critical factor in assuring the survival of icebergs to lower latitudes. The sea ice acts to suppress ocean temperature and calms the sea surface thus sheltering icebergs from wave erosion. The majority of icebergs produced in the northern hemisphere originate on the West coast of Greenland in Baffin Bay. Apparently, the majority of these completely disintegrates in that region and do not survive to exit the Bay through the Davis Strait and into the Labrador Sea. Thus it has been speculated that the sea ice coverage within Baffin Bay has a considerable influence on the availability of icebergs in any given year. To test this statistically, a sea ice data series has been derived from the Baffin Bay Sea Ice Area Coverage data as provided by the National Snow and Ice Data Centre in Denver, Colorado (National Snow and Ice Data Centre, 2009). Unfortunately the data set is only available from 1979 to 2007, representing 29 years. This is a considerably shorter data record than the other phenomena under consideration, but valid nonetheless and presently the best data available for this study. Figure 1 displays the iceberg drifting patterns and NAO location, while Table 1 summarizes the data used in this study.

Table 1: Summary of Data Series

Data Type – Short Name	**Sample size**	**Years (Range)**	**Source**
Icebergs below the 48th Parallel – Iceberg Flux	109	1900-2008	International Ice Patrol of the U.S. Department of Homeland Security
Mean Annual Sunspot Number – Solar Activity	109	1900-2008	National Geophysical Data Centre of the National Ocean and Atmospheric Administration Satellite and Information Service
North Atlantic Oscillation – NAO	103	1900-2002	National Centre for Atmospheric Research
Baffin Bay Sea Ice Coverage – Sea Ice	29	1979-2007	National Snow and Ice Data Centre

To gain a better understanding of the nature of the time series, several approaches are taken to analyze the data. First basic exploratory data analysis is used to see if there are obvious patterns in the data. The goal is to gain an understanding of each individual data set and to investigate whether each process follows similar patterns with time. Following this initial inspection various statistical techniques will be performed to check whether there is any correlation among the data sets. The correlations at lag zero and the cross-correlations at various lags will be investigated. Finally, the serial correlation structure of each series will be investigated and compared using a variety of time series techniques. In particular, its autocorrelation and partial autocorrelation functions, and spectral density function will be investigated.

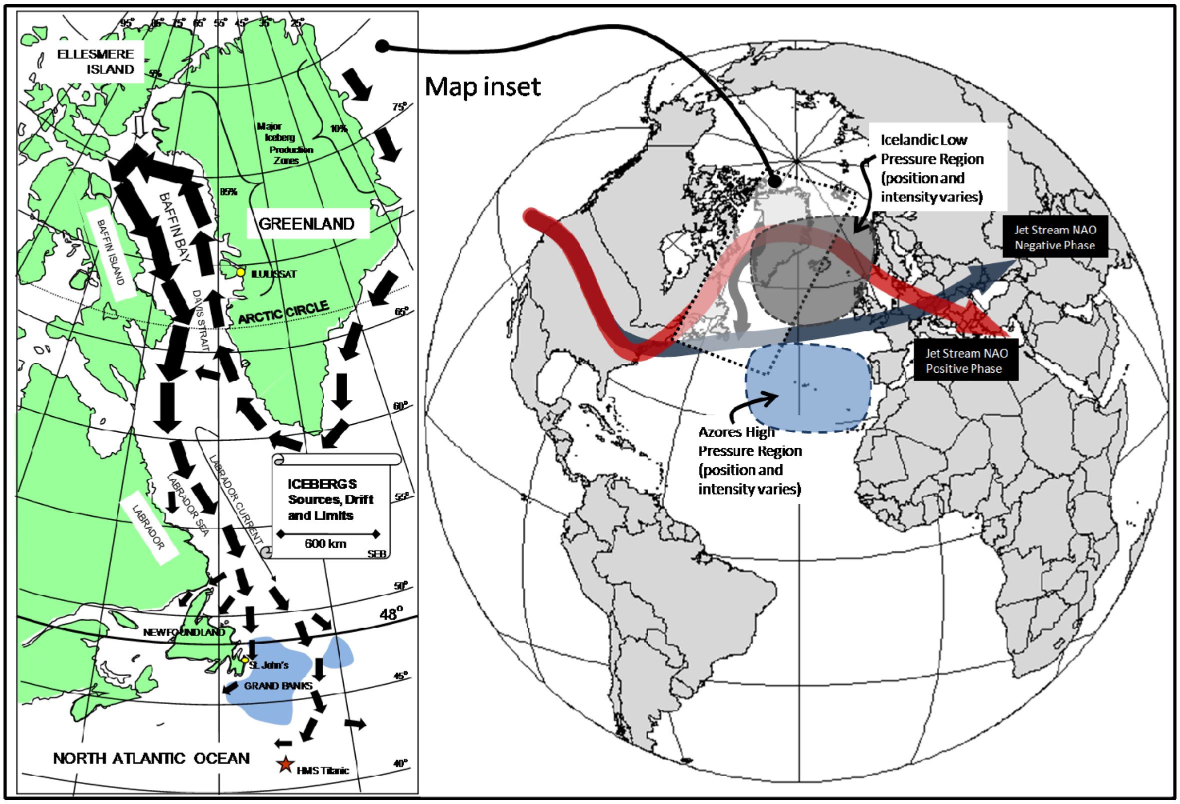

Figure 1: Iceberg Migration and the NAO

2. Exploratory Data Analysis

While a graphical analysis provides no statistical proof of correlation or serial dependence, it does provide an intuitive feeling for the possibility of a correlation. The graphical approach is first meant to reveal any apparent trends than can be seen within the data sets. For instance the data may follow a cyclic pattern with a constant frequency or amplitude, or it may be completely random and scattered. It is also valuable to graph multiple series on the same plot to visualize relationships between the various series. This may include observing near direct correlations as well as inversed or lagged relationships. To do this the data must be represented in its standardized form. If a graphical approach seems to suggest that causality between series may exist, further analysis can be performed to look into the relevance of these findings with proper statistical methods.

2.1 Time Series Plots

Figures 2a to 2d are four time series plots of the individual data sets. The data are plotted with lines connecting the observations to aid in deciphering trends. As well, a locally weighted scatter plot smoothing (LOWESS) line has been added to smooth the time series data to reveal any significant long term trends. The plots reveal that all four series have some form of cyclic pattern with time. Solar activity appears to have the most uniform and consistent pattern, following a recurring cycle of approximately 11 years. The NAO and iceberg flux also follows a similar cyclic pattern, but with much more variation and randomness. This is likely due to the numerous environmental effects that affect these series on a yearly basis. The Baffin sea ice data plot also shows somewhat of a cyclic pattern, but this is inconclusive due to limited data.

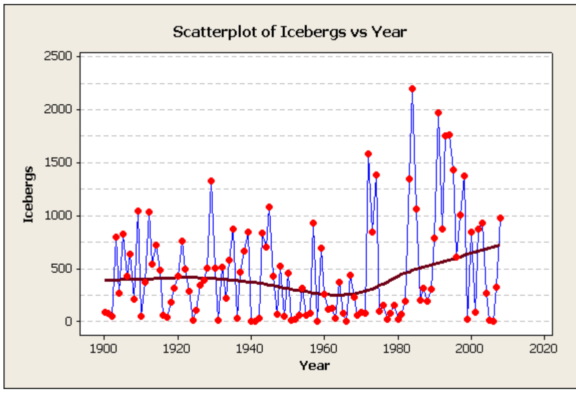

Figure 2a: Time series plot of iceberg data

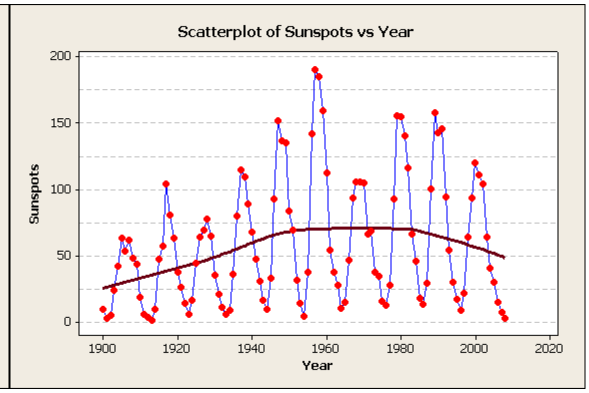

Figure 2b: Time series plot of sunspot data

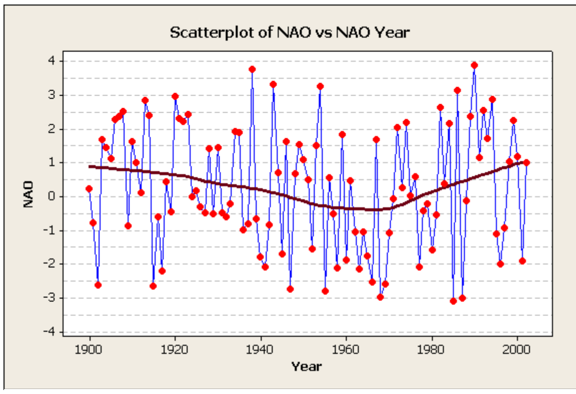

Figure 2c: Time series plot of NAO data

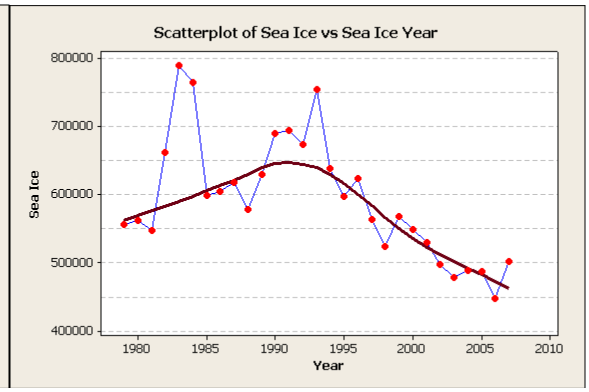

Figure 2d: Time series plot of sea ice data

The LOWESS line also reveals some interesting long term tendencies. The sunspot data appears to hit a high during the mid century and is now declining. This is a function of a long term dominant frequency with a period of about 80 years. The iceberg flux and NAO appear to have a long term trend present in which the mean seems to increase in the last 30 to 40 years. To further visualize potential relationships in the data sets overlay plots are used. Here the data are presented in their standardized form, as well as applying a five year moving average to smooth the data. Six cases were considered. This is useful for direct comparison between two series and it is also used to organize cases for the cross correlation analyses to follow.

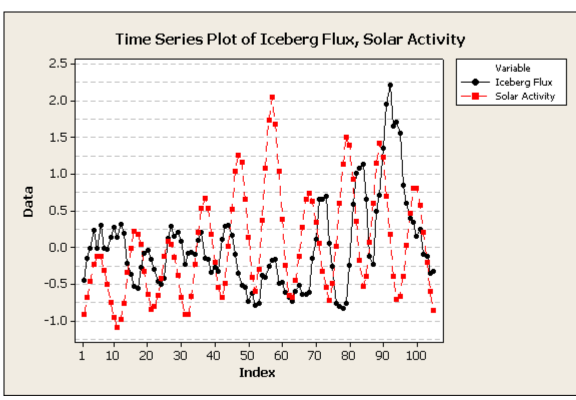

Figure 3a: Plot of iceberg flux and solar activity

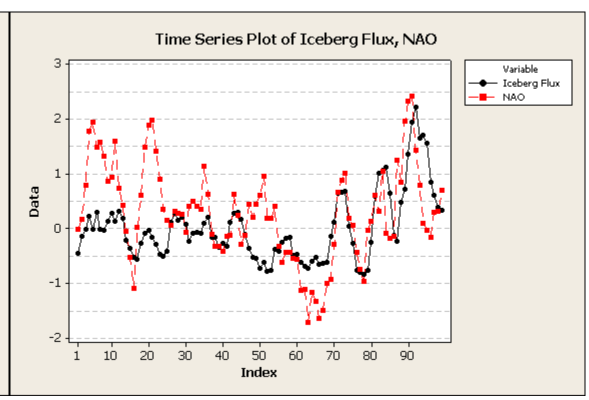

Figure 3b: Plot iceberg flux and NAO

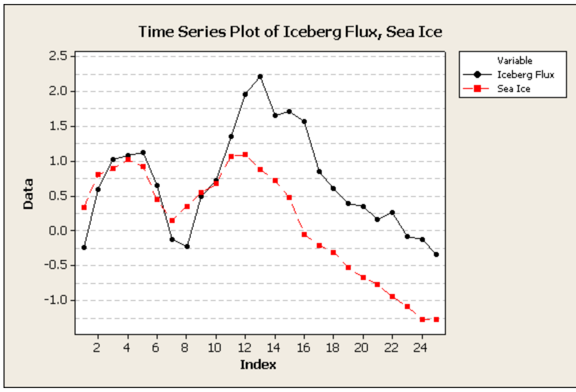

Figure 3c: Plot of iceberg flux and sea ice

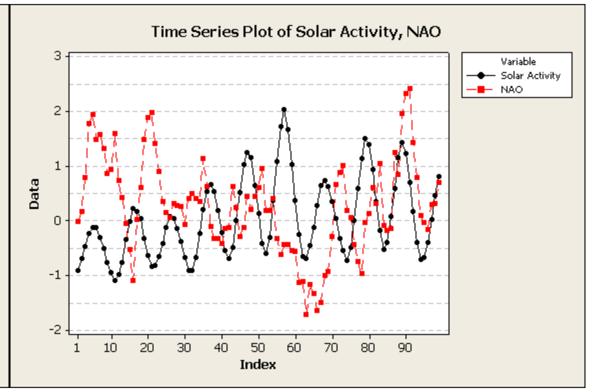

Figure 3d: Plot of solar activity and NAO

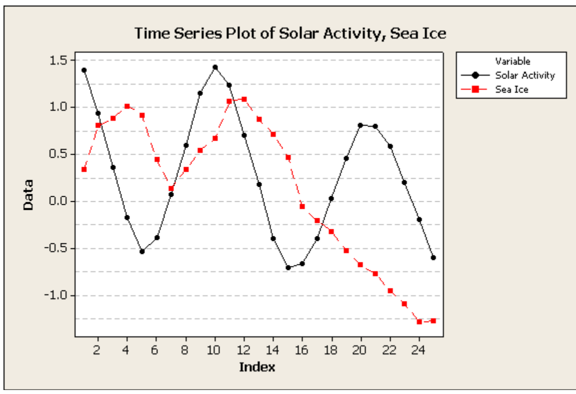

Figure 3e: Plot of solar activity and sea ece

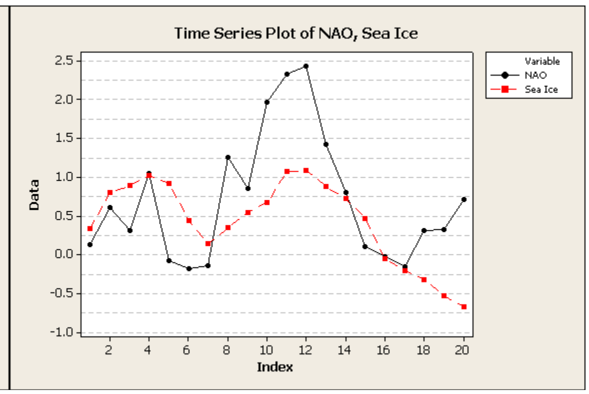

Figure 3f: Plot of NAO and sea ice

Figures 3a to 3f reveal some potentially intriguing relationships. Figure 3a shows that iceberg flux and solar activity appear to have a near equal period, as well as a possible lagged or inverse relationship. Essentially when solar activity is at a minimum the number of icebergs is at a maximum. This appears to be true in the early and late century, but the trend appears to diminish near mid century. This may be a result of it being the period with the highest solar activity and the least number of icebergs. Figure 3b shows that iceberg flux and NAO may be directly correlated with no lag effect. This is especially evident from 1970 onwards, but the data are much more sporadic prior to this date. Nevertheless the possibly of a correlation is worth further investigation. Figure 3c shows that Iceberg flux and sea ice may be directly related. Though their magnitudes are different, the cyclic behaviour of the two series seems to be near perfectly in phase. This is of great significance and deserves a more detailed investigation. But the lack of data limits the reliability of the conclusion. The remaining plots appear to show very little evidence of similarities in behaviour of the series. Despite this, all cases are further analyzed to determine the magnitude of any potential correlations.

3. Correlation Analysis

Correlation analysis involves measuring the strength and direction of relationships between variables. Graphically the relationships can be visualized using scatter-plots, while the measure of correlation is obtained via the Pearson correlation coefficient. This can be expanded to measure the correlation at lagged intervals via cross correlations. This is investigated in the following sections.

3.1 Lag Zero Correlation

Figures 4a to 4f are six scatter-plots illustrating the strength of direct relationships between each of the four data sets. They are generated with zero lag and indicate how changes in one variable impact the other. As with the time series plots a LOWESS line has been added to eliminate noise and aid in revealing trends. Sunspots appear to have no meaningful relationship with any of the other series. Likewise there appears to be no relevant relationship between the NAO and sea ice. The plot of icebergs versus sea ice does reveal a linearly dependant trend, indicating that as the amount of sea ice increases, so too does the number of icebergs. There is significant scatter in the data but a clear trend can be seen. A less apparent trend can also be seen between icebergs and the NAO. As the NAO becomes more positive, the number of icebergs tends to increase. This can be seen in the linearity and slope of the LOWESS line. Unfortunately there is significant scatter, with virtually no increase in the NAO during periods of very high iceberg frequency.

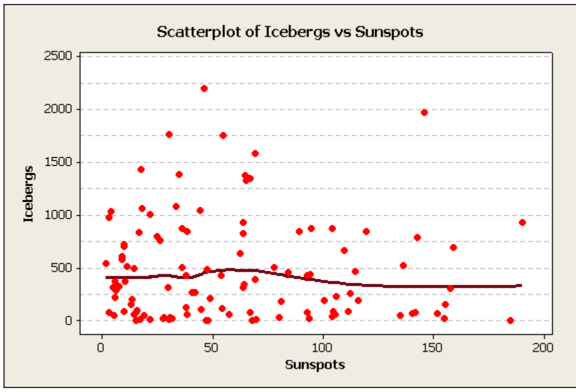

Figure 4a: Direct Cor. Icebergs vs. Sunspots

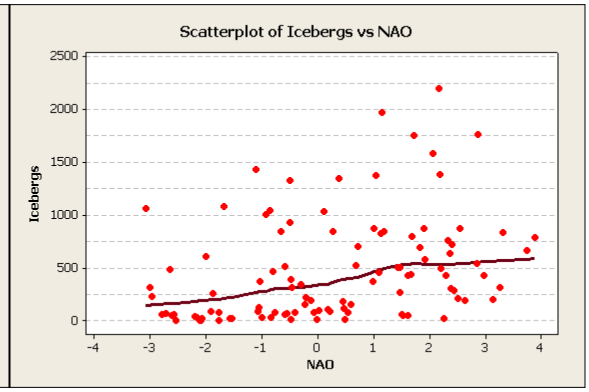

Figure 4b: Direct Cor. Icebergs vs. NAO

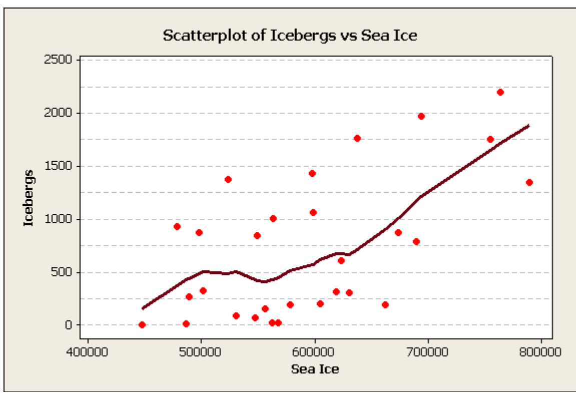

Figure 4c: Direct Cor. Icebergs vs. Sea Ice

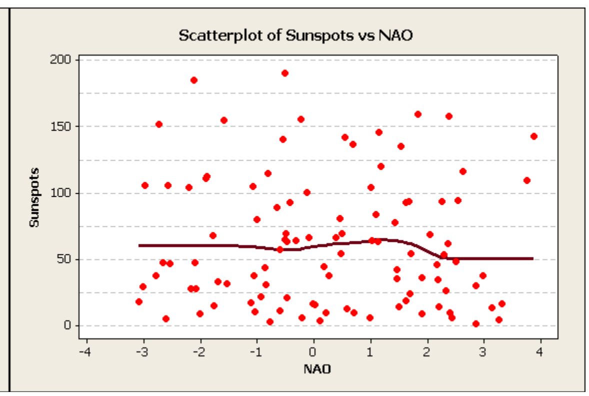

Figure 4d: Direct Cor. Sunspots vs. NAO

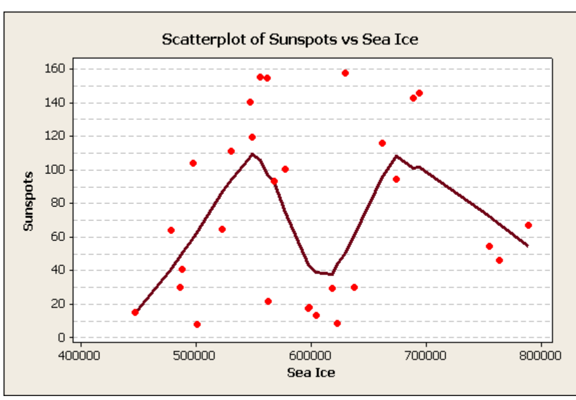

Figure 4e: Direct Cor. Sunspots vs. Sea Ice

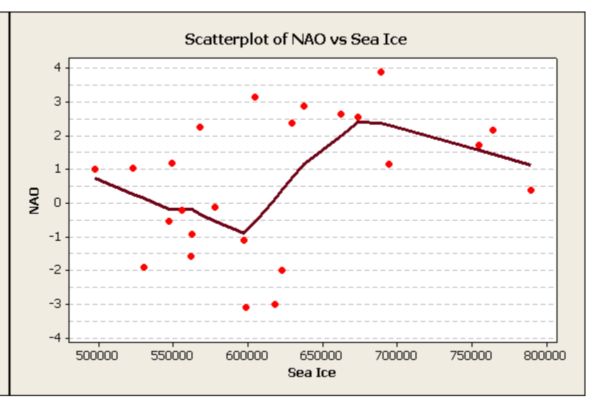

Figure 4f: Direct Cor. NAO vs. Sea Ice

3.2 Cross Correlation

Cross correlation can be defined as the measure of similarities between two series. The method works via a sliding dot product operation in which a series is tested at various lags to determine its correlation with respect to each other, and is therefore a function of the relative lag time between two series. If two series have perfect causality and are lagged, the cross correlation function will yield a value of 1 when applied at the correct lagging interval. The cross correlation function is extremely valuable in pattern recognition of lagged data series. Figures 5a to 5f show plots of the cross correlations for each of the six possible permutations of the four data sets. Please note the data has been analyzed in its standardized form.

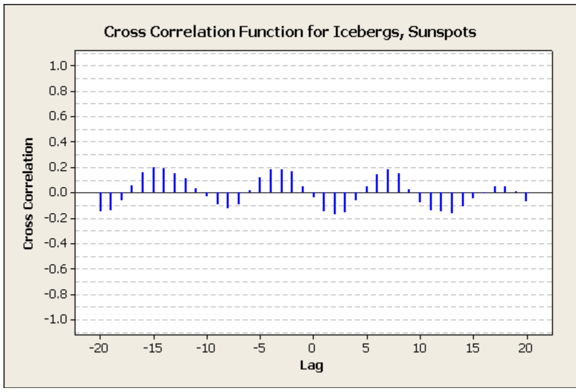

Figure 5a: Cross Cor. Icebergs vs. Sunspots

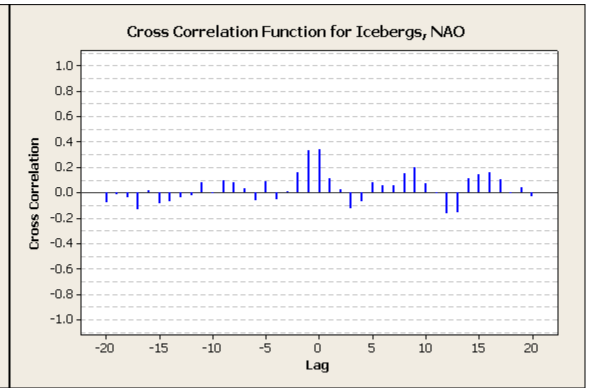

Figure 5b: Cross Cor. Icebergs vs. NAO

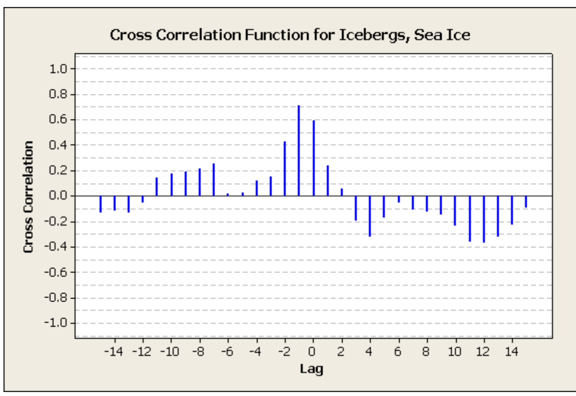

Figure 5c: Cross Cor. Icebergs vs. Sea Ice

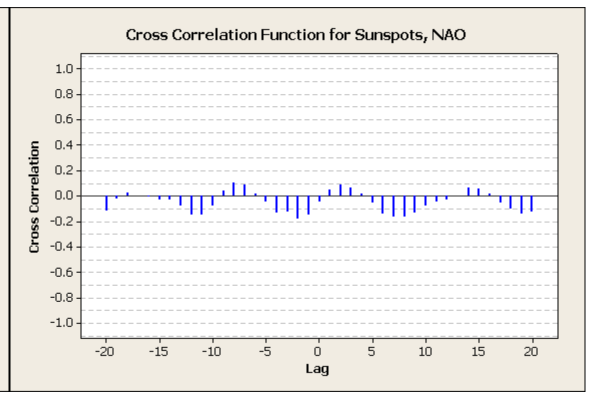

Figure 5d: Cross Cor. Sunspots vs. NAO

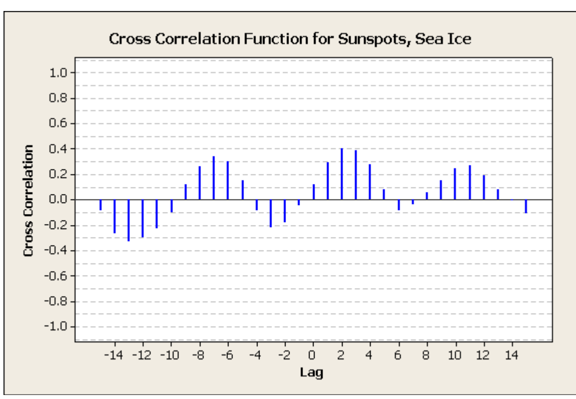

Figure 5e: Cross Cor. Sunspots vs. Sea Ice

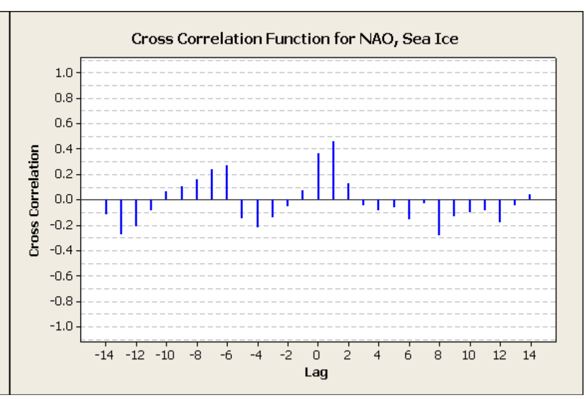

Figure 5f: Cross Cor. NAO vs. Sea Ice

As seen above, there is a wide range of values for each case comparison. Only case 3 between iceberg flux and Baffin sea ice can be considered to have a significant correlation of statistical relevance. The remainder of the cross correlation comparisons appears to have either moderate or low correlations.

4. Time Series Analysis

4.1 Autocorrelation and Partial Autocorrelation Functions

Figures 6a to 6f are the sample autocorrelation (ACF) and partial autocorrelation functions (PACF) for iceberg flux, solar activity, and NAO, respectively. The Baffin Sea ice ACF and PACF are very similar to that of the iceberg flux. If two phenomena are related one would expect that the individual series would follow similar model structures. Only iceberg flux and sea ice appear to have similar autocorrelation and partial autocorrelation functions. The ACF of the sunspots data is periodic and the PACF shows that not only are the first 3 lags statistically significant but also at lags 7, 8, and 9. For the NAO data, both ACF and PACF did not show statistical significance at any lag indicating a random series with no autocorrelation structure.

4.2 ARIMA Modeling

ARIMA models stands for autoregressive integrated moving average models. ARIMA models are typically expressed at ARIMA (p,d,q) where p is the autoregressive term, d is the number of non-seasonal differences, and q is the moving average term. Identification of the correct models is based on the structure of the ACF and PACF. Details about model identification are found in Box and Jenkins (1976).

The sunspot data has been analyzed over the years with numerous models being applied to the data. Yule (1927) applied an autoregressive model of order two or ARIMA (2,0,0) to the data and so did Box and Jenkins (1976); and others have suggested models up to order 9 (Hipel and McLeod, 1994). This analysis shows that with an ARIMA (3,0,0) model there is still significant autocorrelations left in the residuals meaning that the model is definitely more complex than an ARIMA(3,0,0). The other series follows much simpler structures. Iceberg flux and sea ice flux both show that the data can be represented an ARIMA(1,0,0) or AR1 model with an autocorrelation coefficient of 0.38 for iceberg flux and 0.80 for sea ice. For the NAO, it appears that the data are essentially white noise.

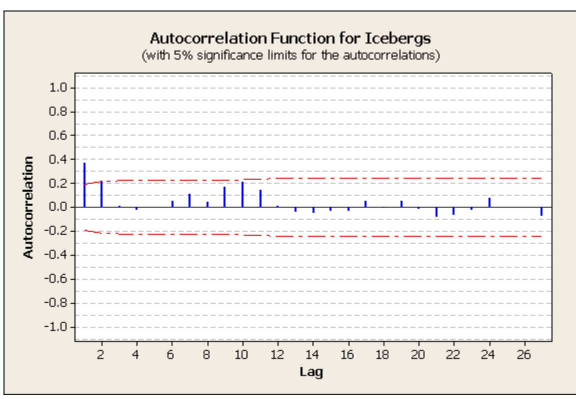

Figure 6a: ACF of Iceberg Flux

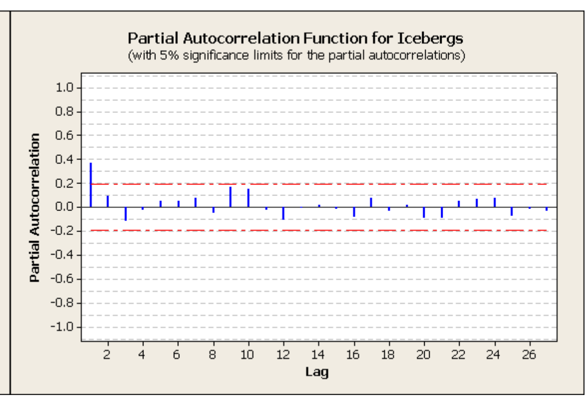

Figure 6b: PACF of Iceberg Flux

4.3 Spectral Density Function

The previous methods of time series analysis were performed in the time domain, applying various lags to the data sets and measuring the correlation. A spectral density analysis eliminates the temporal aspect of the data, transforming it into the frequency domain. A spectral analysis has been performed on the sunspot, iceberg, and NAO data sets. The sea ice data set is too small to generate meaningful results.

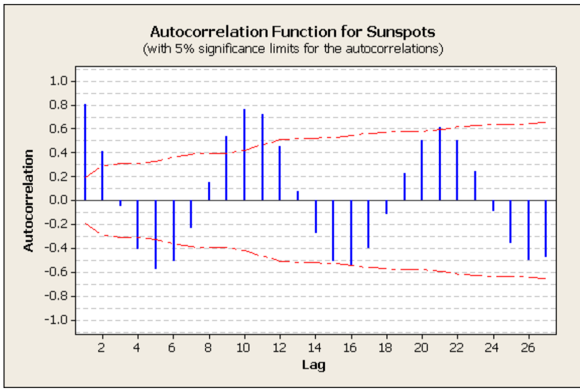

Figure 6c: ACF of Sunspots

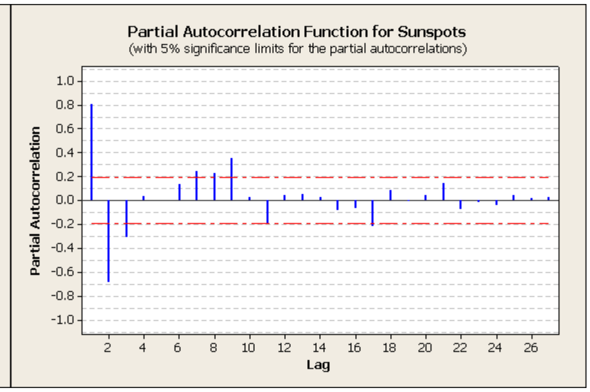

Figure 6d: PACF of Sunspots

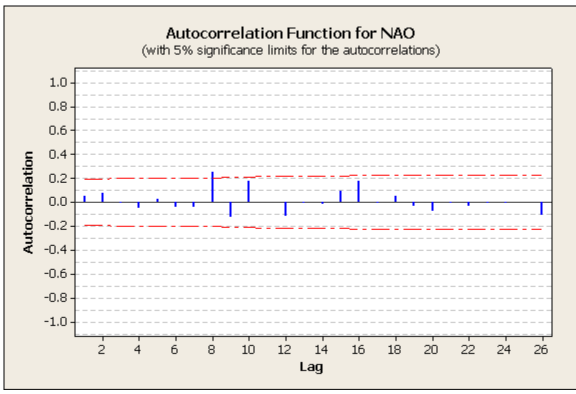

Figure 6e: ACF of NAO

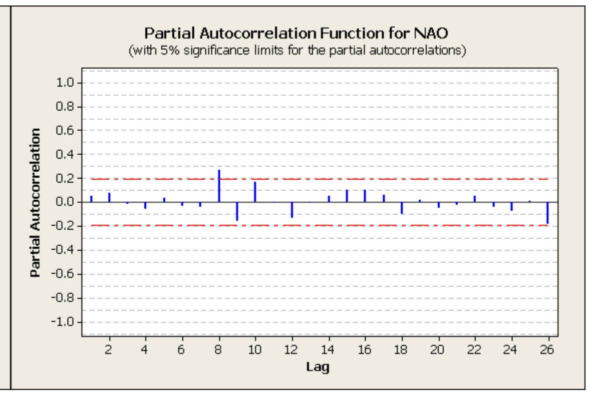

Figure 6f: PACF of NAO

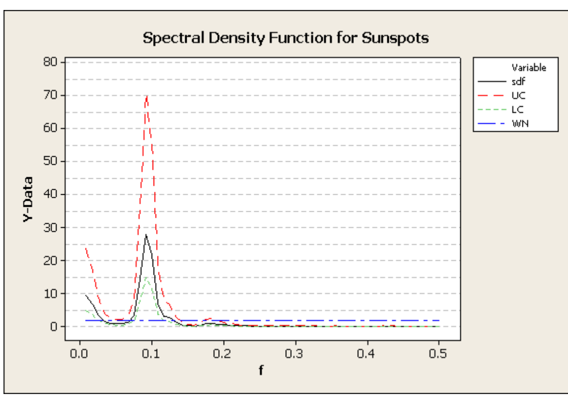

Figure 7a: Sunspot Spectral Density Function

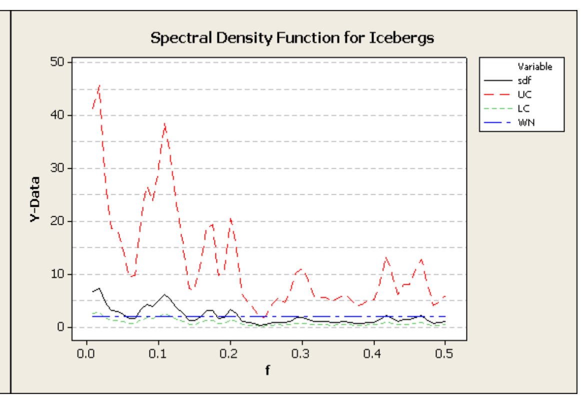

Figure 7b: Iceberg Spectral Density Function

Figures 7a through 7c show the spectral density function (SDF) for the respective data sets. The black line represents the value of the SDF, the red and green lines represent the upper and lower 95% confidence levels, and the blue line represents white noise. For significance, the value of the SDF must show an obvious peak on the plot with lower confidence level being above the white noise line. The sunspot plot reveals an obvious peak at a frequency of 0.0917. This represents a period of 10.9 years, confirming the well known 11 year sunspot cycle. For the iceberg flux SDF, only one peak is significant with a lower confidence value above that of the white noise. This occurs at a frequency of 0.108, translating to a period of 9.3 years, approximately 2 years shorter than that of the sunspot data. Even though there appears to be a cyclic pattern with a period of 9 years, the value of the SDF is small, representing only 21% of the energy exhibited by the sunspot cycle. The SDF of NAO shows the lower confidence level never rises above the level expected of white noise.

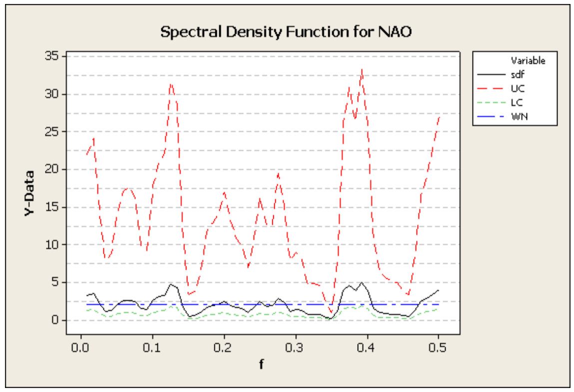

Figure 7c: NAO Spectral Density Function

5. Conclusions

While it is inevitable that the sun affects all natural cycles on earth, the analysis reveals that solar activity is unlikely linked to any of the other phenomena observed. The sunspot data series has been shown to be of a complex nature. This however is not the case for the other series which followed much simpler structure with time. The NAO also appears to have no correlation with any of the remaining data sets. The NAO data set is essentially white noise. There is some evidence to support a weak correlation with both iceberg flux and sea ice coverage, as shown in the moderate cross correlation values of 0.34 and 0.40 respectively. Only iceberg flux and sea ice coverage can be considered as correlated data sets and can be corroborated by numerous papers suggesting the existence of this link. As well, the relationship can be easily explained via an interaction process in which sea ice protects the icebergs from wave action, thereby extending its lifespan and allowing it to drift to lower latitudes. While most of the links in question have been nullified, this is not to say that no linkages occur between them. In all likelihood solar activity and atmospheric pressures significantly influence iceberg deterioration and drift patterns. But the earth has numerous complex systems in which numerous variables interact continuously to influence numerous other parameters, all of which may influence our variable of choice. Therefore one cannot imply that these factors are not related in a more complex, indirect manner.

6. References

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