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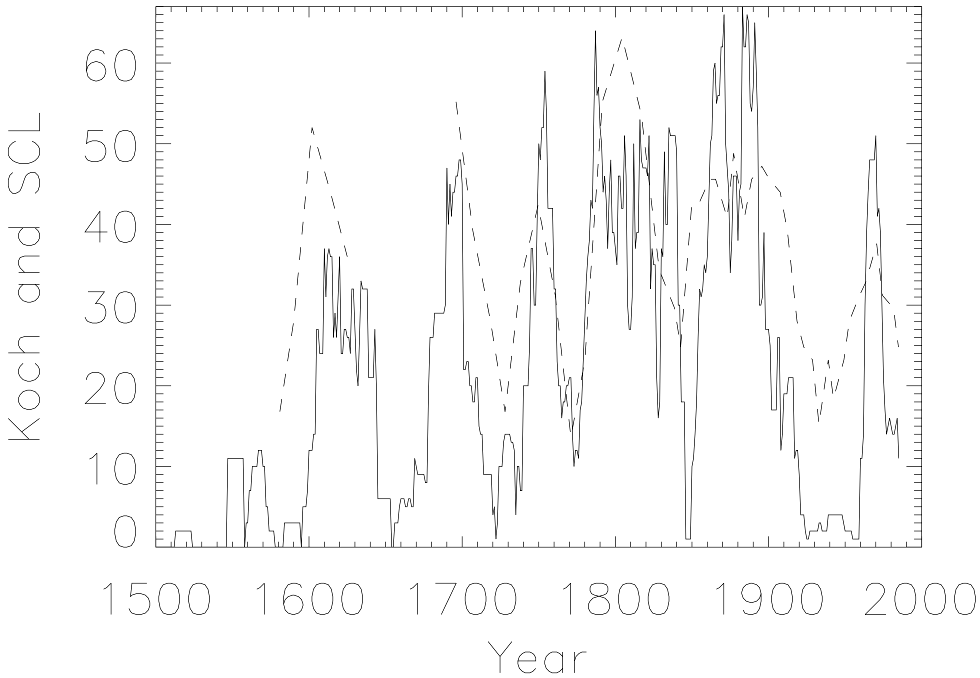
Multi-decadal variation of the East Greenland Sea-Ice Extent: AD 1500-2000

Knud Lassen and Peter Thejll



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Contents

Abstract

The extent of ice in the North Atlantic varies in time with time scales stretching to centennial, and the cause of these variations is discussed. We consider the Koch ice index which describes the amount of ice sighted from Iceland, in the period 1150 to 1983 AD. This measure of ice extent is a non-linear and curtailed measure of the amount of ice in the Greenland Sea, but gives an overall view of the amounts of ice there through more than 800 years. The length of the series allows insight into the natural variability of ice extent and this understanding can be used to evaluate modern-day variations. Thus we find that the recently reported retreat of the ice in the Greenland Sea may be related to the termination of the so-called Little Ice Age in the early twentieth century. We also look at the approximately 80 year variability of the Koch index and compare it to the similar periodicity found in the solar cycle length, which is a measure of solar activity. A close correlation (R=0.67) of high significance (0.5 % probability of a chance occurrence) is found between the two patterns, suggesting a link from solar activity to the Arctic Ocean climate.

Introduction

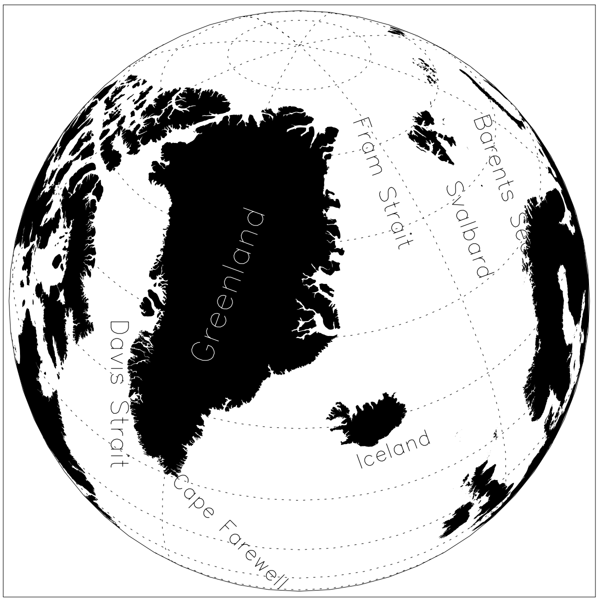

Figure 1.1: Map showing Greenland with surrounding waters

The East Greenland sea-ice has its origin in the Arctic sea. Very solid ice formed during several years is drifting along with the East Greenland current through the Fram Strait between Greenland and Svalbard (Figure 1), along the East Greenland coast to Cape Farewell and then to the north into Davis Strait along the West Greenland coast. (The ice is here called the ’Storis’). The 20th century global warming was accompanied by a rapid withdrawal of the limit of the Arctic sea-ice in the Nordic seas. Time series of seasonal values (April – August) of the ice extent in the Greenland Sea based exclusively on direct observations during more than a century were published by Lassen (1997, 1998) and in the Greenland as well as in the Barents Sea by Vinje (April only, Vinje 2001). The two published series (April – August and April) agree in demonstrating a decrease of more than 30% since the last decades of the nineteenth century. The average ice extent in April-August in the Greenland Sea below 80^oN has decreased from 0.7 Mkm^2 during the last decades of the nineteenth century to about 0.4 Mkm^2 at the end of the twentieth century. The decrease was rapid, like a change between two levels around 1920. Around 1970 the decrease was again obvious, though less abrupt.

The observed retreat of the ice has attracted public attention and given rise to speculations about the possibility of ice-free waters at the north pole in a not too distant future, with reference to the consequences of human activity on climate. However, considerable natural variations in the position of the ice edge have occurred more or less systematically since the last glaciation. Thus, Bond et al. (2001) have found a millennial periodic variation in the position of the ice border in the North Atlantic associated with a similar variation in atmospheric ^{14}C and ^{10}Be. Since both isotopes are regarded as signatures of the solar activity it was concluded that variations of the solar activity in this very low frequency domain influence the extent of the East Greenland sea ice. Also, long-term (multi-decadal) variations of Northern hemisphere land air temperature have been found (Friis-Christensen and Lassen, 1991) to be negatively correlated with the long-term variation of solar activity as represented by the smoothed solar cycle length (the so-called Gleissberg period, Gleissberg, 1944), and in a study of the variation of the air temperature since 1200 A.D. as deduced from the ratio of oxygen isotopes in an ice-core from Cape Century in Greenland Johnsen et al. (1970) found two dominant peaks that corresponded to 78 years (identified as the Gleissberg period) and 181 years, which they interpreted as originating from changing solar conditions. It is reasonable to believe that such natural oscillations of the arctic climate, including the extent of the sea-ice, have continued and still take place. Therefore, a complete understanding of the background for the ongoing retreat of the sea-ice and the role of human activity presupposes knowledge of the influence of natural climatic variations.

In the present study we analyse the available data series related to the East Greenland sea-ice to investigate the possibility of solar influence also in the form of the shorter (centennial) variation found in the land air temperature and suggested in the above-mentioned time series of the ice extent.

Data

Two longer series of direct observation of the position of the ice edge in the waters around Greenland are available for this purpose:

(1) Schmith and Hansen (2003) published a reconstruction of the ice export through the Fram Strait. Annual values of the ice export through the Fram Strait in the period 1830-1994 were modelled from historical observations of ’Storis’ in the southwest Greenland waters obtained from ships log-books and ice charts. The observations revealed the existence of a ’low frequency oscillation’ of the ice extent and consequently of the ice export with a period of 90-100 yrs which may explain at least part of the retreat of the ice after 1900 A.D.

(2) The East Greenland sea-ice has occasionally been observed close to the coast of Iceland. Reports of ice occurrence at Iceland dating back to the early colonisation were collected by several Icelandic authors and summarised by Koch (1945 and references therein) in the form of two time series, i.e. the annual number of weeks with ice observed from land and an index defined as the annual number of weeks weighted according to the maximal extension of the ice along the coast. The two series differ little from each other in shape. The index has been updated by Vedurstofa Íslands (Jónsson, see Frich, 1995, Wallevik and Sigurjónsson, 1998, and references therein).

The method used by Koch in 1945 to construct his ice index is in fact not known – the details given in Koch’s publication are not sufficient to understand how the index was constructed. However, Wallevik and Sigurjónsson have probably figured out what Koch did. By testing several algorithms on Koch’s original data they have reconstructed almost exactly the index, as published by Koch for the period 1880 to 1939. They have also extended the index using newer data and the likely Koch algorithm, so that the homogeneous index is now available from 1100 to 1990, using work detailed in Wallevik and Sigurjónsson (1998). See Figure 1.2.

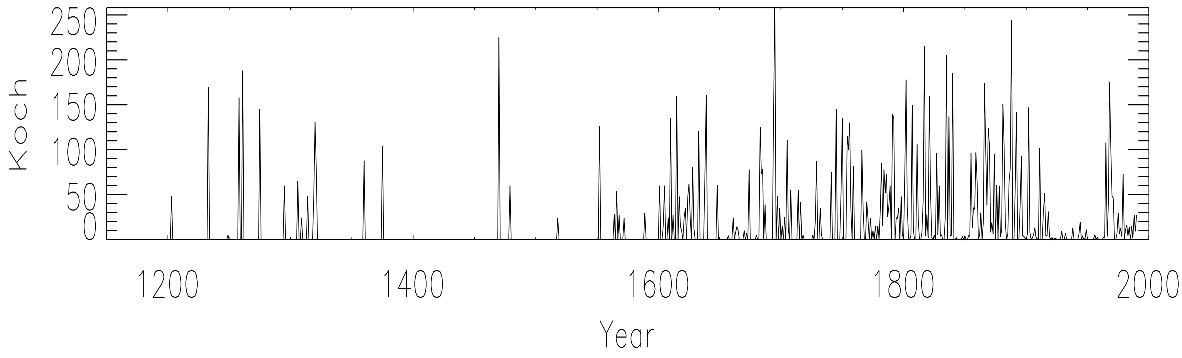

Figure 1.2: Annual values of Iceland ice index, from Koch (1945) and Wallewik and Sigurjónsson (1998)

In addition to the problem of the construction of the index comes the problem of data completeness. Ogilvie and others have in a number of publications presented new historic data sources which in principle enables an update of the database on which Koch's index was based and a corresponding correction of the index (Ogilvie, 1984; Ogilvie and Jónsdóttir, 2000). However, this was not done by Ogilvie, possibly because the likely Koch algorithm was not known at that time. Instead she introduced a different index for the sea-ice record for Iceland from the colonisation to 1780 A. D. (Ogilvie, 1984) based on a critical assessment of all available documentary sources. The reconstructed series has later been revised and extended to 1850 A. D. (Ogilvie and Jónsdóttir, 2000). Comparison of the original Koch index and the new index (Figure 1.3) shows that there are some differences, especially before 1780 that may not exclusively be due to the use of a different algorithm. Ogilvie points out this period as being affected by the revision of old as well as addition of new data. Apparently, the differences in the years before 1780 are in the amplitudes rather than in the wavy character of the curves.

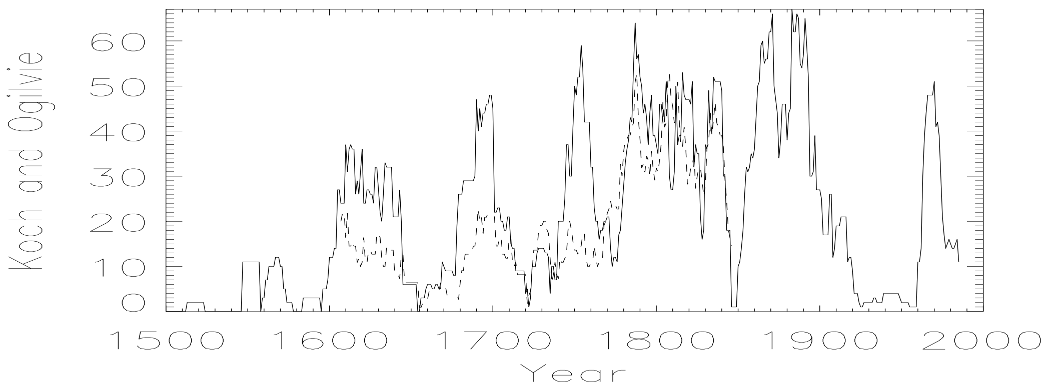

Figure 1.3: Comparison of time series of 11-yr running means of Iceland ice indices as defined by Koch (1945) (solid line) and Ogilvie (1984) (dashed line). Data from Koch (1945), Wallewik and Sigurjónsson (1998) and Ogilvie and Jónsdóttir, 2000). The Ogilvie data has been multiplied by a factor 10 to allow comparison.

For our investigations of the wavy character it will be important whether missing data can cause or alter periodicities in the data. Normally, missing data can cause trends to appear or disappear, but periodic variations are unlikely to occur due to data incompleteness.

Under the assumption that the data used for the Koch index is not likely to change much in future searches for new historic sources, we shall proceed to analyse the longer series, i. e. the Koch index as published by Koch, plus the extension given by Wallevik and Sigurjónsson (1998).

The year-to-year variation of the index since 1150 A. D. is shown in Figure 1.2. There are two periods of frequent occurrence of ice, separated by 2-3 centuries with nearly ice-free waters around Iceland. The first period with a maximum about 1300 A.D. is coincident with a period of severe climate in Europe (Willett, 1948). The second, about 1550-1900 A. D. with a maximum in the nineteenth century followed by an abrupt decrease in the first decades of the twentieth century, occurs at the same time as the so-called Little Ice Age (LIA). (Kreutz et al., 1997; Ogilvie and Jónsson, 2001). Data prior to 1500 A. D. are regarded as less reliable (Koch, 1945; Ogilvie, 1984). Therefore, we have limited our study to the interval 1500 – 2000.

Koch's index was discussed by Kelly et al. (1987). In their study covering the years 1953-1977 it was shown that sea-ice conditions on the Icelandic coast were associated with sea-ice concentration in the Greenland Sea, the correlation coefficient between monthly values for May - July being 0.6 - 0.7, significant at the 95% level. Although the Iceland ice index may thus give useful information on the variations of the ice extent, the information has limitations due to the fixed position of the observational area. Thus, a zero index only indicates that the ice did not reach Iceland; the ice-border may be situated at any position beyond a certain distance to the northwest of Iceland. Similarly, the index maxima do not indicate how far beyond Iceland the ice border has advanced.

As pointed out by Schmith and Hansen (2003) the most apparent feature in the Storis average summer extent and Fram export time series is a wave with maxima around 1880-1900 and 1970-1990 and minima 1840-1860 and 1940-1950. This is illustrated in Figure 4 in which the year-to-year variation of the ice export through the Fram Strait is shown together with the corresponding series of the Iceland ice index. The centennial variation of the ice index appears to be similar to the variation of the ice export for values of the latter above about 3000 km^3/yr. Apparently, ice export below this value does not penetrate to the waters around Iceland. The ice border was situated too far from Iceland to be observed from the shore. The Iceland ice index does not give details about the ice extent around the minimum years, but it may be regarded as a half wave indicator, giving information about the occurrence of years with severe ice caused by increased export from the polar sea through Fram Strait. An analysis of the Icelandic data series may therefore extend the knowledge about the centennial variation of the ice export to and the climate in the Greenland Sea to the last five centuries.

Centennial (Gleissberg) variation

Superposed upon the above-mentioned (dominating) variation with maxima 1200-1400 and 1500-1900 (Figure 1.2) there appears to be a rather regular shift between intervals with heavy and with light ice occurrence (Figure 1.3). The centennial variation shown in Figure 4 is part of this pattern. It has been suggested earlier (Friis-Christensen and Lassen, 1991) that intervals of reduced occurrence of ice at Iceland have been associated with low values of the solar cycle length (SCL), i.e. high solar activity (Granger,1957). This is illustrated and supported in Figure 5, in which smoothed annual values of the index are shown together with smoothed values of the solar cycle length. The quasi-periodic variation of the length of the solar cycle known as the Gleissberg variation (Gleissberg, 1944) appears to have its counterpart in the extent of the East Greenland drift

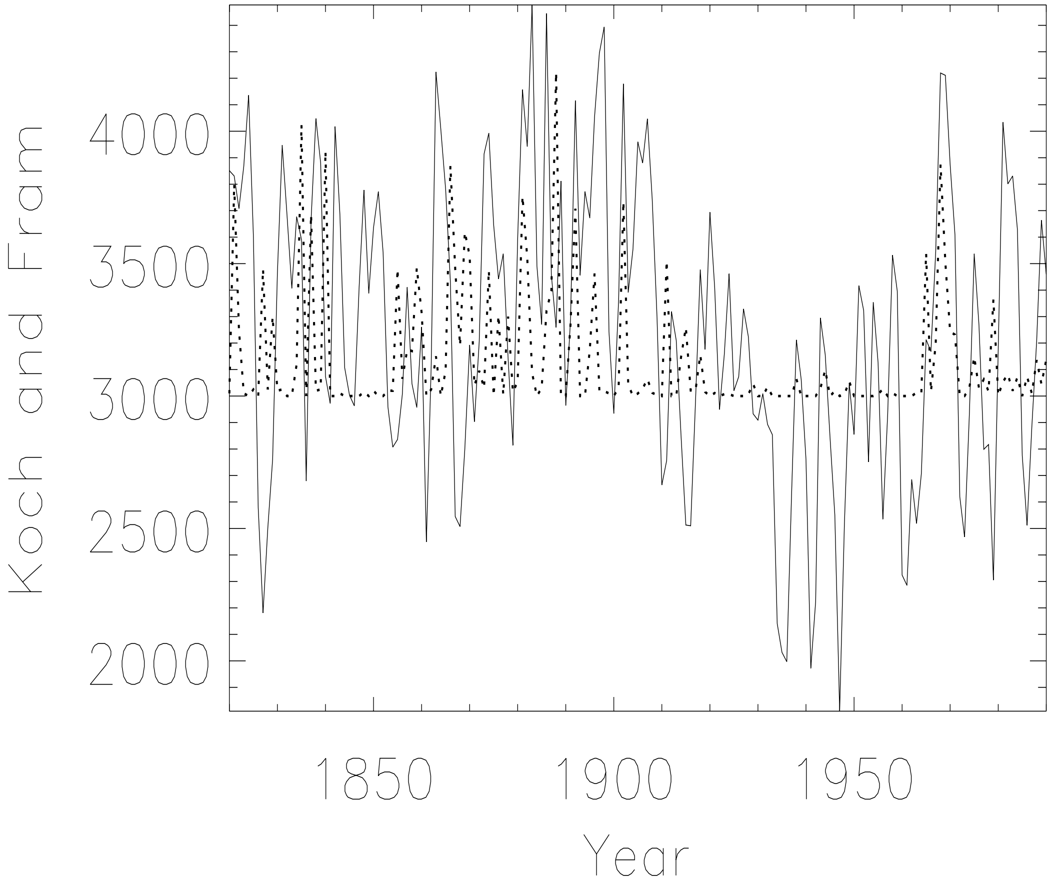

Figure 1.4: Comparison of time series of annual values of ice export through the Fram Strait (solid curve) in the period 1820-2000 (after Schmith and Hansen, 2003) in units of $km^3/year$, and the annual Koch index (dashed curve). The Koch index has been arbitrarily scaled and shifted vertically for comparison.

ice. A rapid increase in the solar activity in the first decades of the 20th century coincided with the ongoing retreat of the ice in connection with the termination of the Little Ice Age. It is our suggestion that this has contributed to the particularly rapid decrease in the extent of the ice.

Singular Spectrum analysis

We can investigate the relationship between solar activity and ice extent further, by applying Singular Spectrum Analysis (SSA) – a method suggested by Vautard et al. (1992) to be useful for decomposition of short and noisy time series.

The SSA method is first applied to the long Koch index (1100-1998) and then to the Koch index after 1550 AD. For the long index, using 120 lags, we find a first mode of variability (or Reconstructed Component – RC) that catches (explaining 10% of the Koch series variance) the slow variations in the Koch index – the 1300 AD episode and the larger LIA bulge of variability. Subsequent RCs represent higher frequencies. One noticeable set of RCs have captured the multi-decadal variation seen in the smoothed data in Figure 5. The RCs 6,7 and 8 together represent all of the variability in

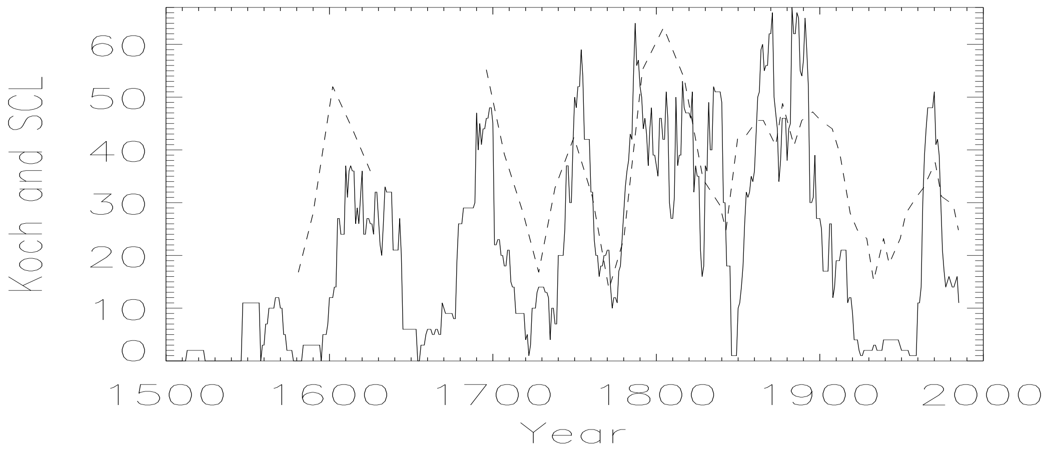

Figure 1.5: Comparison of time series of 11-yr running means of the Koch index (solid curve) and smoothed values of the solar cycle length (Lassen and Friis-Christensen, 1995, Thejll and Lassen, 2000, 2002) (dashed curve). The SCL values have been arbitrarily scaled and shifted vertically for comparison to the other curve.

this noticeable mode, which corresponds to about 5% of the series' variance. The remaining RCs are all related to higher frequencies. If we clip the years up to 1550 from the Koch series and reanalyse it with SSA, with 120 lags, we are able to find a set of RCs that represent this multi-decadal mode – this is an attractive exercise since there are many zero data points in the period before 1550 and it is necessary to know whether the phases of the oscillations extracted in the RCs 6,7 and 8 change if the data are treated in this way, i. e., if the results depend on arbitrary data handling steps. It turns out that the results do not depend on the presence of this early sequence of data.

We correlate the SCL index (annually sampled; sampling obtained with linear interpolation in the tables of Lassen and Friis-Christensen, 1995 and Thejll and Lassen, 2000, 2002) to the annually sampled multi-decadal mode from the Koch index series (RCs 6,7 and 8). We only use the years where the SCL(1,2,1) index is well defined – namely 1558-1625 and 1695-1980. We show these data in Figure 6. The correlation coefficient is 0.67, and to interpret this value in terms of significance we apply a non-parametric method based on Monte Carlo trials in which surrogate data with the same auto-correlative structure as one of the series are used. We find that the observed correlation coefficient only occurs, or is superseded, in random trials 0.5 % of the time, so that the significance level we may report is near 99.5%.

Conclusion

In view of the large significance observed we suggest that the correlation of 0.67, between multi-decadal modes in the Koch ice index and the solar cycle length, is indicative of a relationship not due to chance.

The multi-decadal modes still represent only a small fraction of the total variance in the ice series, which illustrates that while the kind of solar activity characterised by the variable length of the solar cycle may cause some of the variability seen in the ice series, the majority is caused by other factors.

Whereas the multi-decal mode may be a result of varying solar activity, the cause of the slowly varying mode is not directly seen from the data presented here. Obviously, it must be due to a natural

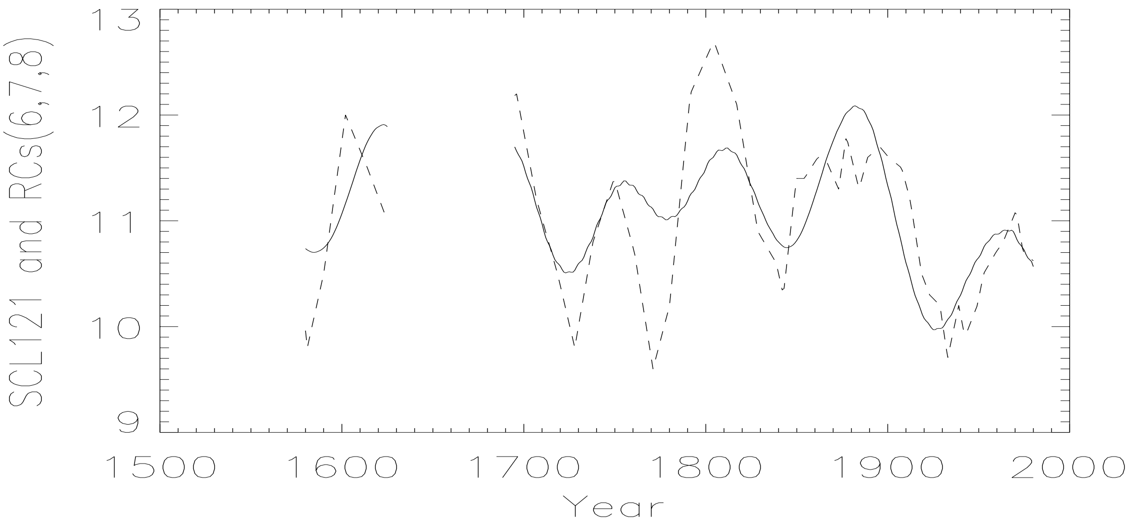

Figure 1.6: SCL121 and scaled values of the reconstructed components 6,7 and 8 from the Koch ice index data. The dashed line shows the SCL121 curve while the solid line shows the RC.

variation of the climate. A variation of similar shape may be recognised in the solar cycle length (Figure 5), but it has not been possible from the present data to deduce a correlation that is significant. Nevertheless, the similarity of the variation of the ice export through the Fram Strait and the smoothed variation of the solar cycle length shown in Figure 1.7 speaks in favour of the assumption that the solar cycle variation may include both natural modes. This conclusion is in accordance with the finding by Bond et al., 2001 (their Figure 2) that a persistent series of solar influenced millennial-scale variations, which include the Medieval Warm Period and the Little Ice Age, reflect a baseline of the centennial-scale cycles.

The ’low frequency oscillation’ that dominated the ice export through the Fram Strait as well as the extension of the sea-ice in the Greenland Sea and Davis Strait in the twentieth century may therefore be regarded as part of a pattern that has existed through at least four centuries. The pattern is a natural feature, related to varying solar activity. The considerations of the impact of natural sources of variability on arctic ice extent are of relevance for concerns that the current withdrawal of ice may entirely be due to human activity. Apparently, a considerable fraction of the current withdrawal could be a natural occurrence.

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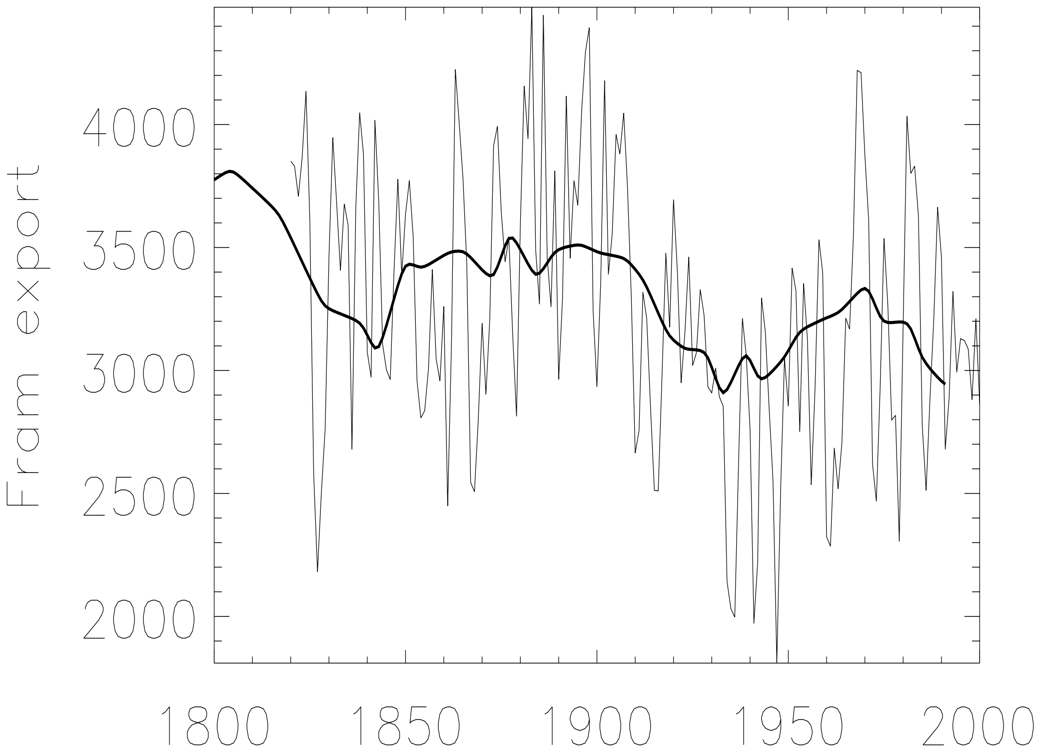

Figure 1.7: Variation of Ice export through the Fram Strait (in units of $km^3/year$) and smoothed values of solar cycle length (SCL121) (heavy curve).

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