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The long sunspot cycle 23 predicts a significant temperature decrease in cycle 24

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ABSTRACT

Relations between the length of a sunspot cycle and the average temperature in the same and the next cycle are calculated for a number of meteorological stations in Norway and in the North Atlantic region. No significant trend is found between the length of a cycle and the average temperature in the same cycle, but a significant negative trend is found between the length of a cycle and the temperature in the next cycle. This provides a tool to predict an average temperature decrease of at least 1.0 °C from solar cycle 23 to solar cycle 24 for the stations and areas analyzed. We find for the Norwegian local stations investigated that 25–56% of the temperature increase the last 150 years may be attributed to the Sun. For 3 North Atlantic stations we get 63–72% solar contribution. This points to the Atlantic currents as reinforcing a solar signal.

1. Introduction

The question of a possible relation between solar activity and the Earth's climate has received considerable attention during the last 200 years. Periods with many sunspots and faculae correspond with periods with higher irradiance in the visual spectrum and even stronger response in the ultraviolet, which acts on the ozone level. It is also proposed that galactic cosmic rays can act as cloud condensation nuclei, which may link variations in the cloud coverage to solar activity, since more cosmic rays penetrate the Earth's magnetic field when the solar activity is low. A review of possible connections between the Sun and the Earth's climate is given by Gray and et al. (2010).

Based on strong correlation between the production rate of the cosmogenic nucleids ^{14}C and ^{10}Be and proxies for sea ice drift, Bond et al. (2001) concluded that extremely weak perturbations in the Sun's energy output on decadal to millennial timescales generate a strong climate response in the North Atlantic deep water (NADW). This affects the global thermohaline circulation and the global climate. The possible sun–ocean–climate connection may be detectable in temperature series from the North Atlantic region. Since the ocean with its large heat capacity can store and transport huge amounts of heat, a time lag between solar activity and air temperature increase is expected. An observed time lag gives us an opportunity for forecasting, which is the rationale for the present investigation.

Comparing sunspot numbers with the Northern Hemisphere land temperature anomaly, Friis-Christensen and Lassen (1991) noticed a similar behavior of temperature and sunspot numbers from 1861 to 1990, but it seemed that the sunspot number R appeared to lag the temperature anomaly. They found a much better correlation between the solar cycle length (SCL) and the temperature anomaly. In their study they used a smoothed mean value for the SCL with five solar cycles weighted 1-2-2-2-1. They correlated the temperature during the central sunspot cycle of the filter with this smoothed weighted mean value for SCL. The reason for choosing this type of filter was that it has traditionally been used to describe long time trends in solar activity. However, it is surprising that the temperature was not smoothed the same way. In a follow up paper Reichel et al. (2001) concluded that the right cause-and-effect ordering, in the sense of Granger causality, is present between the smoothed SCL and the cycle mean temperature anomaly for the Northern Hemisphere land air temperature in the 20th century at the 99% significance level. This suggests that there may exist a physical mechanism linking solar activity to climate variations.

The length of a solar cycle is determined as the time from the appearance of the first spot in a cycle at high solar latitude, to the disappearance of the last spot in the same cycle near the solar

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equator. However, before the last spot in a cycle disappears, the first spot in the next cycle appears at high latitude, and there is normally a two years overlap. The time of the minimum is defined as the central time of overlap between the two cycles (Waldmeier, 1939), and the length of a cycle can be measured between successive minima or maxima. A recent description of how the time of minimum is calculated is given by NGDC (2011): "When observations permit, a date selected as either a cycle minimum or maximum is based in part on an average of the times extremes are reached in the monthly mean sunspot number, in the smoothed monthly mean sunspot number, and in the monthly mean number of spot groups alone. Two more measures are used at time of sunspot minimum: the number of spotless days and the frequency of occurrence of old and new cycle spot groups."

It was for a long time thought that the appearance of a solar cycle was a random event, which means that each cycle length and amplitude were independent of the previous. However, Dicke (1978) showed that an internal chronometer has to exist inside the Sun, which after a number of short cycles, reset the cycle length so the average length of 11.2 years is kept. Richards et al. (2009) analyzed the length of cycles 1610–2000 using median trace analyses of the cycle lengths and power spectrum analyses of the O–C residuals of the dates of sunspot maxima and minima. They identified a period of 188 ± 38 years. They also found a correspondence between long cycles and minima of number of spots. Their study suggests that the length of sunspot cycles should increase gradually over the next ~ 75 years. accompanied by a gradual decrease in the number of sunspots.

An autocorrelation study by Solanki et al. (2002) showed that the length of a solar cycle is a good predictor for the maximum sunspot number in the next cycle, in the sense that short cycles predict high R_{max} and long cycles predict small R_{max}. They explain this with the solar dynamo having a memory of the previous cycle's length.

Assuming a relation between the sunspot number and global temperature, the secular periodic change of SCL may then correlate with the global temperature, and as long as we are on the ascending (or descending) branches of the 188 year period, we may predict a warmer (or cooler) climate.

It was also demonstrated (Friis-Christensen and Lassen, 1992; Hoyt and Schatten, 1993; Lassen and Friis-Christensen, 1995) that the correlation between SCL and climate probably has been in operation for centuries. A statistical study of 69 tree rings sets, covering more than 594 years, and SCL demonstrated that wider tree-rings (better growth conditions) were associated with shorter sunspot cycles (Zhou and Butler, 1998).

The relation between the smoothed SCL and temperature worked well as long as SCL decreased as shown in Fig. 1. But when the short cycle SC22 was finished Thejll and Lassen (2000)

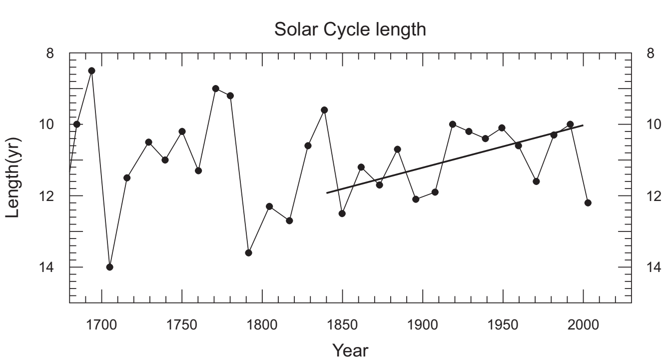

Fig. 1. Length of solar cycles (inverted) 1680–2009. The last point refers to SC23 which is 12.2 years long. The gradual decrease in solar cycle length 1850–2000 is indicated with a straight line.

reported a developing inconsistency. In order to explain the high temperatures at the turn of the millennium, the not yet finished SC23 had to be shorter than 8 years, which was very unlikely, since there had never been observed two such short cycles in a row (see Fig. 1). They concluded that the type of solar forcing described with this SCL model had ceased to dominate the temperature change. Since the final length of SC23 became 12.2 years, the discrepancy became even bigger.

A more rigorous analysis was done by Thejll (2009), this time with a filter 1-2-1 also used for temperature. In particular he investigated if the residuals from the relation between Northern Hemisphere (NH) land (t_{121}) and SCL_{121} were independent and identically distributed. He also investigated possible lags between SCL_{121} and t_{121}, and found that time lags of 6 or 12 years were necessary to obtain zero serial correlation in residuals in the dataset used by Friis-Christensen and Lassen (1991). For updated NH-land series from the HadCRU Centre, serial correlation in residuals could not be removed (Thejll, 2009).

In addition to the relation between solar cycle length and the amplitude of the next R_{max}, it is reasonable to expect a time lag for the locations investigated, since heat from the Sun, amplified by various mechanisms, is stored in the ocean mainly near the Equator, and transported into the North Atlantic by the Gulf Stream to the coasts of Northern Europe. An example of time lags along the Norwegian coast is an advective delay between the Faroe-Shetland Channel and the Barents Sea of about 2 years determined from sea temperature measurements (Yndestad et al., 2008).

Formation of NADW represents transfer of upper level water to large depths. The water is transported and spread throughout the Atlantic and exported to the Indian and Pacific oceans before updwelling in Antarctic waters. The return flow of warm water from the Pacific through the Indian ocean and the Caribbean to the North Atlantic, a distance of 40 000 km, takes from 13 to 130 years (Gordon, 1986). There appears to be solar "fingerprints" that can be detected in climate time series in other parts of the world with each series having a unique time lag between the solar signal and the hydro-climatic response. Perry (2007) reports that a solar signal composed of geomagnetic *aa*-index and total solar irradiance (TSI) is detected with various lags from 0 years (Indian Ocean) to 34 years (Mississippi river flow) and 70 years (Labrador Sea ice). Mehl et al. (2009) have shown that two mechanisms: the top-down stratospheric response of ozone to fluctuations of shortwave solar forcing and the bottom-up coupled ocean–atmospheric surface response, acting together, can amplify a solar cyclical pulse with a factor 4 or more. Since our stations are located near or in the North Atlantic, solar signals in climatic time series may arrive with delays of decades. If we can detect a solar signal and measure the delay for individual regions, we may have a method for future climate predictions.

Recognizing that averaged temperature series from different meteorological stations of variable quality and changing locations may contain errors, and partially unknown phenomena derived from the averaging procedure, Butler (1994) proposed instead to use long series of high quality single stations. This might improve the correlation between SCL and temperature.

He showed that this was the case when using temperature series obtained at the Armagh Observatory in Northern Ireland 1844–1990. Since the Armagh series correlated strongly with the NH temperature, he concluded that this indicates that solar activity, or something closely related to it, has had a dominant influence on the temperature of the lower atmosphere in the Northern Hemisphere over the past 149 years (Butler, 1994). This investigation was later expanded to the period 1795–1995 by Butler and Johnston (1994), who found a relation $t_{ARM} = 14.42 - 0.5 L_{SC}$, where L_{SC} is the smoothed length of the solar cycle determined by the 1-2-2-2-1 filter. They concluded