What will happen during a new Maunder Minimum?

According to the latest IPCC report, AR5, the influence of the sun on our climate since pre-industrial times, in terms of radiative forcing, is very small compared to the effect of greenhouse gases:

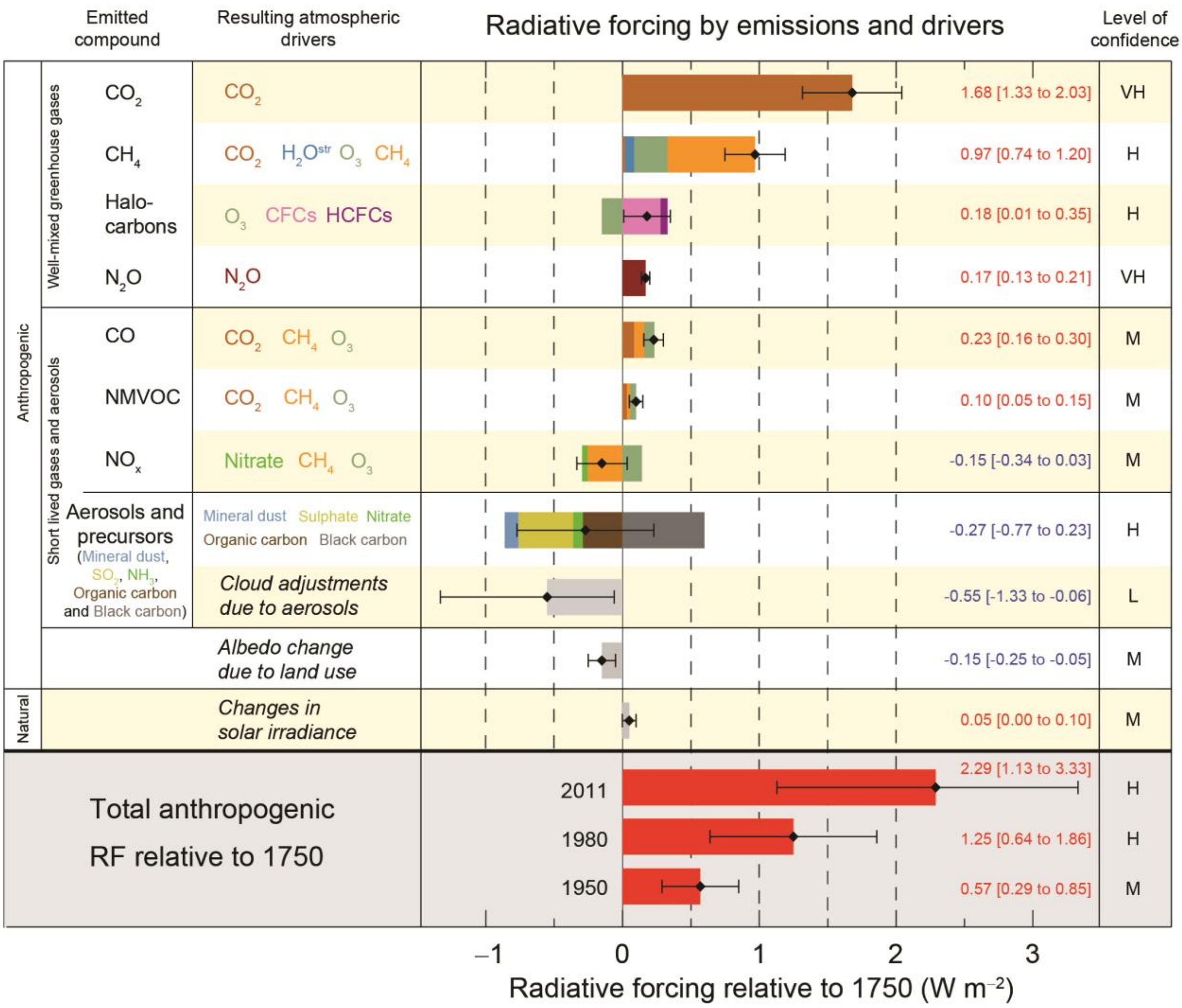

Figure 1: Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Replicated from figure SPM.5 in AR5.

The estimated increase in radiative forcing due to the sun since 1750 is only 0.05 W/m^2 compared to a total increase that is mainly caused by greenhouse gases of 2.29 W/m^2. This almost negligible influence is even smaller than the estimation in the fourth assessment report which was 0.12 W/m^2 on a total of 1.66 W/m^2. The reduction since AR4 has partly to do with the decreased solar activity in the current solar cycle 24.

Such a small solar influence might seem counterintuitive. The Little Ice Age, the period roughly from 1350 to 1850, in which especially winters on the Northern Hemisphere were severe, coincided with several solar minima (Wolf, Spörer, Maunder and Dalton Minimum, see figure 2).

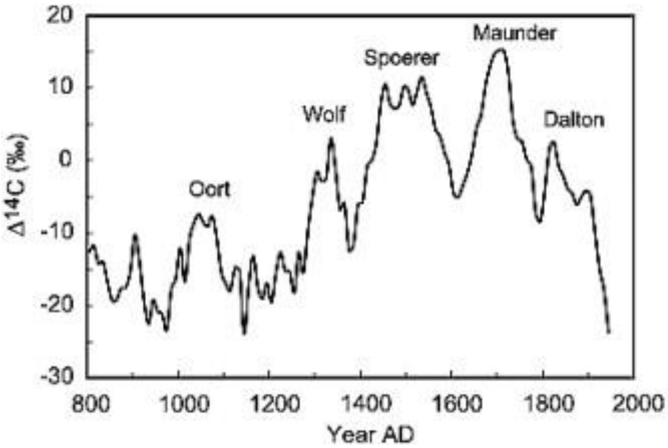

Figure 2, replicated from Feynman (2007)[i]. The radiocarbon proxy for the level of solar variability (Stuiver and Braziunas, 1988)[ii]. Higher Δ14C corresponds to lower solar activity. The Δ14C, which can be interpreted as roughly inversely proportional to the decadal running average of solar activity, changes on time scales of centuries. Several distinct periods when the solar activity was low (Δ14C high) have been given the names shown on the figure. Note the repeated periods of low solar activity between 1300 AD and 1750 AD, i.e. during the Wolf, Spoerer, and Maunder Minimums. The Maunder Minimum corresponds to the period 1645–1715 when there were almost no sunspots (Eddy, 1976)[iii].

Figure 2 also suggests that during the so-called Medieval Warm Period (the IPCC in AR5 uses the term Medieval Climate Anomaly) solar activity was relatively high. How cold it was globally in the Little Ice Age and how warm it was in the Medieval Warm Period is itself a matter of debate.

AR5 has this to say about it:

> New paleoclimate reconstruction efforts since AR4 (Figure 5.7; Table 5.4; Appendix 5.A.1) have provided further insights into the characteristics of the Medieval Climate Anomaly (MCA; Table 5.1) and the Little Ice Age (LIA; Table 5.1). The timing and spatial structure of the MCA and LIA are complex (see Box 6.4 in AR4 and Diaz et al., 2011; and Section 5.5), with different reconstructions exhibiting warm and cold conditions at different times for different regions and seasons. The median of the NH temperature reconstructions (Figure 5.7) indicates mostly warm conditions from about 950 to about 1250 and colder conditions from about 1450 to about 1850; these time intervals are chosen here to represent the MCA and the LIA, respectively.

Below we show figure 5.7a from AR5 which presents many different temperature reconstructions for the Northern Hemisphere. These reconstructions are based on many different proxies (tree rings, corals, ice cores, ocean/lake sediments etc.). Proxy data are scarce in the Southern Hemisphere and therefore most reconstructions focus on the Northern Hemisphere. Some reconstructions show quite a large temperature difference between the Medieval Warm Period and the Little Ice Age of almost two degrees Celsius. Other reconstructions are much flatter.

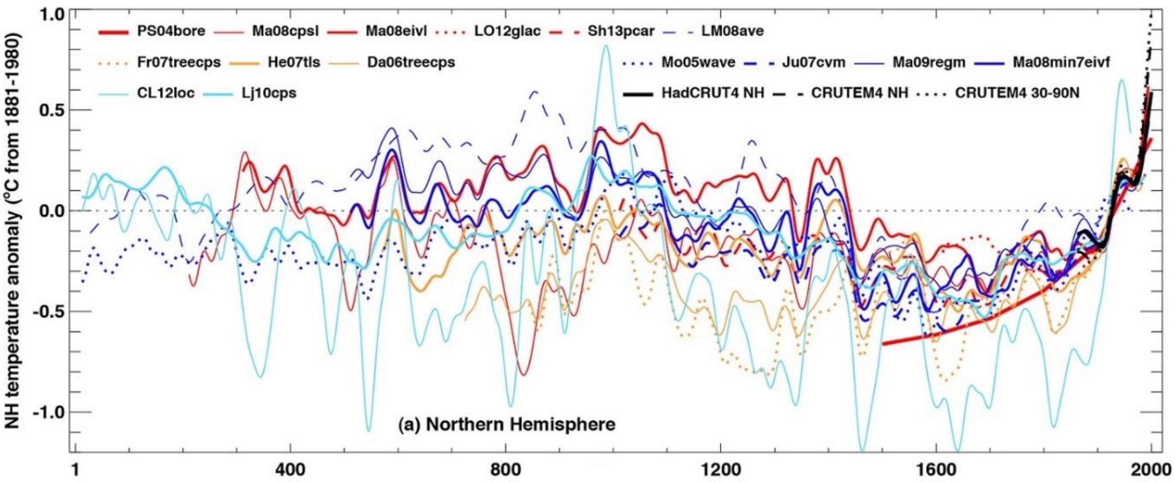

Figure 3: Reconstructed (a) Northern Hemisphere annual temperatures during the last 2000 years. Replication of figure 5.7a from AR5. Individual reconstructions (see Appendix 5.A.1 in AR5 for further information about each one) are shown as indicated in the legends, grouped by colour according to their spatial representation (red: land-only all latitudes; orange: land-only extra-tropical latitudes; light blue: land and sea extra-tropical latitudes; dark blue: land and sea all latitudes) and instrumental temperatures shown in black (Hadley Centre/ Climatic Research Unit (CRU) gridded surface temperature-4 data set (HadCRUT4) land and sea, and CRU Gridded Dataset of Global Historical Near-Surface Air TEMperature Anomalies Over Land version 4 (CRUTEM4) land-only; Morice et al., 2012). All series represent anomalies (°C) from the 1881–1980 mean (horizontal dashed line) and have been smoothed with a filter that reduces variations on time scales less than about 50 years.

Total Solar Irradiance

Direct temperature measurements are available since 1850 or so. However, direct measurements of the sun by satellite started only in 1978. There is still considerable debate about the exact absolute values of the Total Solar Irradiance (TSI) in this period. The difficulty is that one has to merge data from different satellites together. The most recent SORCE/TIM measurements are probably our best shot and the background level of TSI therefore seems to be around 1361 W/m^2 .

There are three groups (PMOD, ACRIM and RMIB) in the world who prepared a composite from all the TSI data. AR5 presented their results together with the more recent TIM measurements:

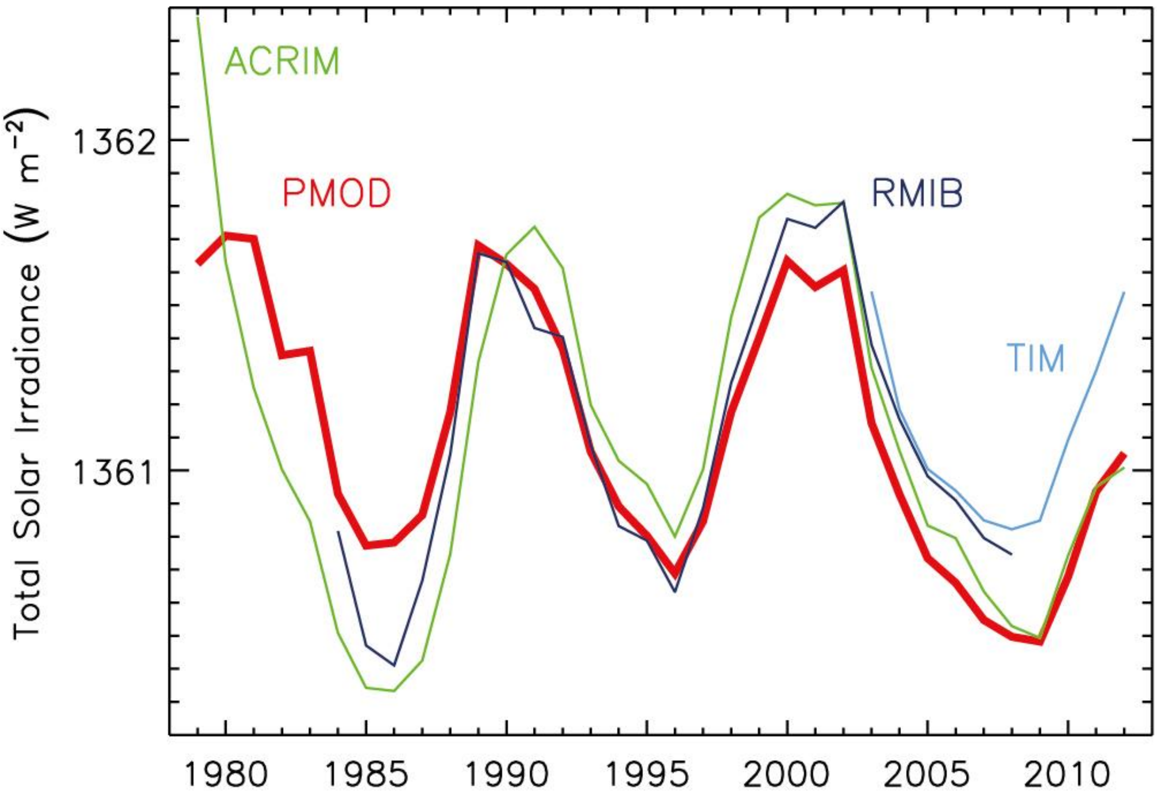

Figure 4: direct TSI measurements by satellite since 1978. Replication of AR5 figure 8.10.

The sun goes through cycles of approximately 11 years in which the activity goes up and down. The differences in TSI between the maxima and minima are very small however, on the order of 0.1%. Two of the datasets (PMOD and ACRIM) suggest that the most recent solar minimum in 2008 (the start of solar cycle 24) was somewhat lower than the TSI during the two preceding minima. In Box 10.2 of AR5 the IPCC concludes that "it is very likely that there has been a small decrease in solar forcing of –0.04 [–0.08 to 0.00] W/m^2 over a period with direct satellite measurements of solar output from 1986 to 2008" and therefore that "there is high confidence that changes in total solar irradiance have not contributed to global warming during that period".

TSI Reconstructions

Before 1978 there are no direct measurements and scientists have to rely on proxies for solar activity. Ultimately reconstructions of the TSI hundreds of years back in time always have to rely on either the sunspot record or on cosmogenic isotopes like Beryllium-10 and Carbon-14.[iv] Chapter 5 of the AR5 report presents the following figure with TSI reconstructions for the last millennium:

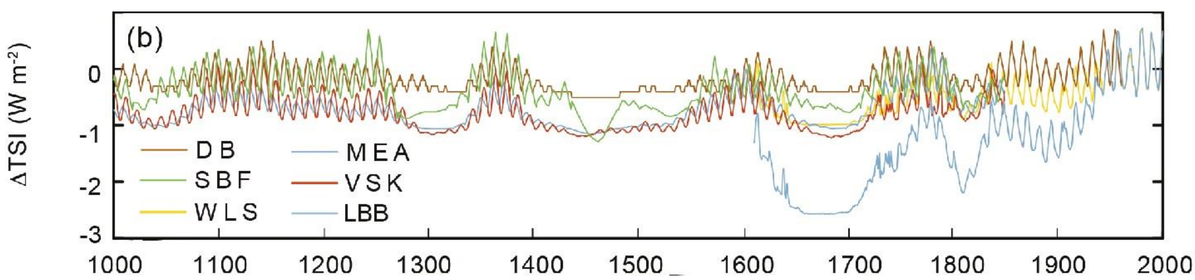

Figure 5: changes in TSI during the last millennium. Replication of figure 5.1b in AR5. The blue reconstruction is one published by Lean et al. 1995.[v] Since the 90-ies reconstructions of the TSI have become considerably flatter suggesting that the influence of the sun through time is relatively small. See AR5 for all the references.

Hoyt and Schatten (1994)[vi], based on the so-called group sunspot number, estimated the increase in TSI since the Maunder Minimum to be around 4 W/m² which translates into an increase in radiative forcing of around 0.7 W/m²,[vii] much larger than the increase in AR5. Lean et al 1995 (the blue curve in figure 5 above) also suggests a difference in TSI of several W/m² since 1700. However more recent TSI reconstructions found a much smaller difference in TSI between the Maunder Minimum and the present (see figure 5).

Shapiro (2011)[viii] using a new approach found a much larger difference in TSI between the Maunder Minimum and present, of about 6 W/m². They assume that the minimum state of the quiet sun (say during a Maunder Minimum) corresponds to the observed quietest area on the present sun.

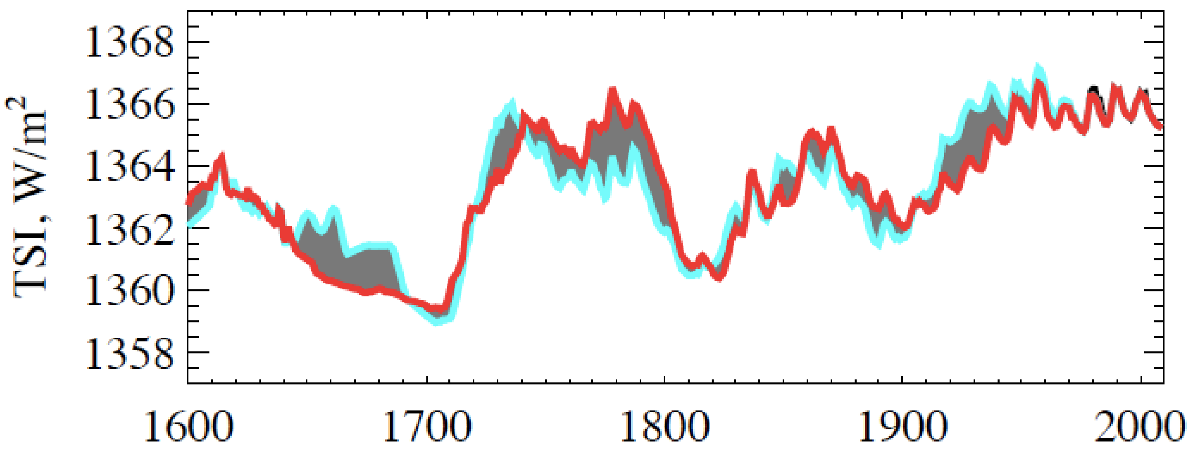

Figure 6, replicated from Shapiro (2011). The red reconstruction is based on ^{10}Be isotopes from an ice core drilled on the South Pole, the cyan curve is based on Greenland ^{10}Be measurements.

AR5 did not show the above reconstruction of Shapiro, but it discussed the paper shortly in chapter 5, saying:

> The larger range of past TSI variability in Shapiro et al. (2011) is not supported by studies of magnetic field indicators that suggest smaller changes over the 19th and 20th centuries (Svalgaard and Cliver, 2010[ix]; Lockwood and Owens, 2011[x]).

Schrijver (2011)[xi], not shown in the above figure either, concluded that the very low solar activity in 2008-2009, when the sun went into a long 'sleep' could be representative for earlier minima like the Maunder Minimum. They hypothesize therefore that the TSI during the Maunder Minimum was similar to the TSI in 2008-2009.

If indeed TSI during the Maunder Minimum was similar to levels today this raises lots of new interesting questions. If TSI can't explain the Little Ice Age, what else can? Some scientists think volcanism played a role. Or maybe the Little Ice Age was not a global phenomenon and therefore globally it wasn't that much colder so there is little need for other climate influences?

Sunspots
Sunspots are probably the most well-known proxy for the sun. Sunspots - darks spots on the sun caused by intense magnetic activity - are counted since 1610 (see figure 3 below). Although the dark sunspots are cooler areas at the surface of the sun, the surrounding margins of sunspots are brighter than the average. Overall, more sunspots increase the Sun's solar brightness. Sunspots were rarely observed during the Maunder Minimum in the second part of the 17th century (approximately from 1645 to 1715) for reasons which are not yet fully understood.

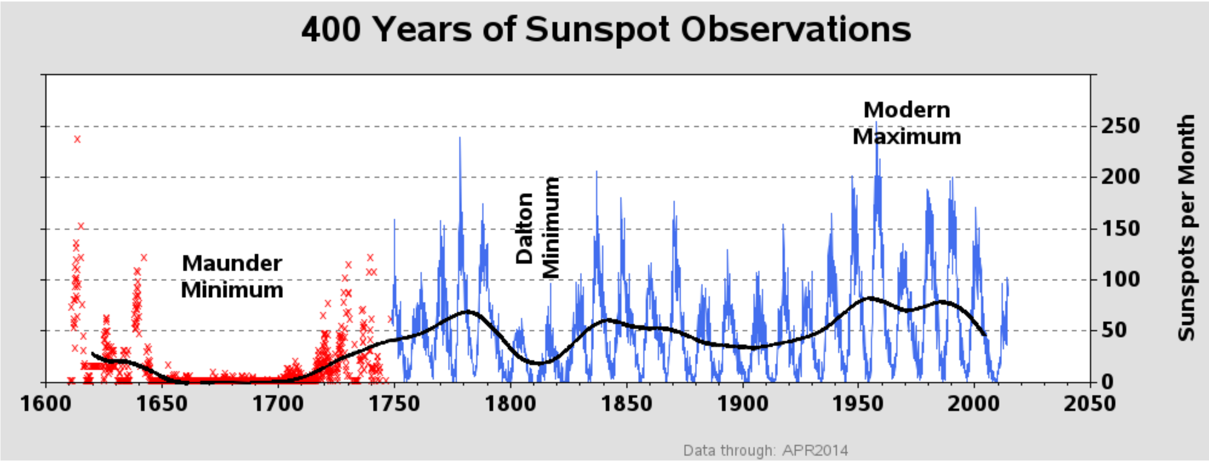

Figure 7: 400 years of direct sunspot observations. Source: Wikimedia Commons/Global Warming Art.

Sunspot numbers rise and fall on an irregular cycle of 11 years. The 11-year solar cycles are numbered sequentially, starting with the observations made in the 1750s. We are currently at or near the maximum of solar cycle 24.

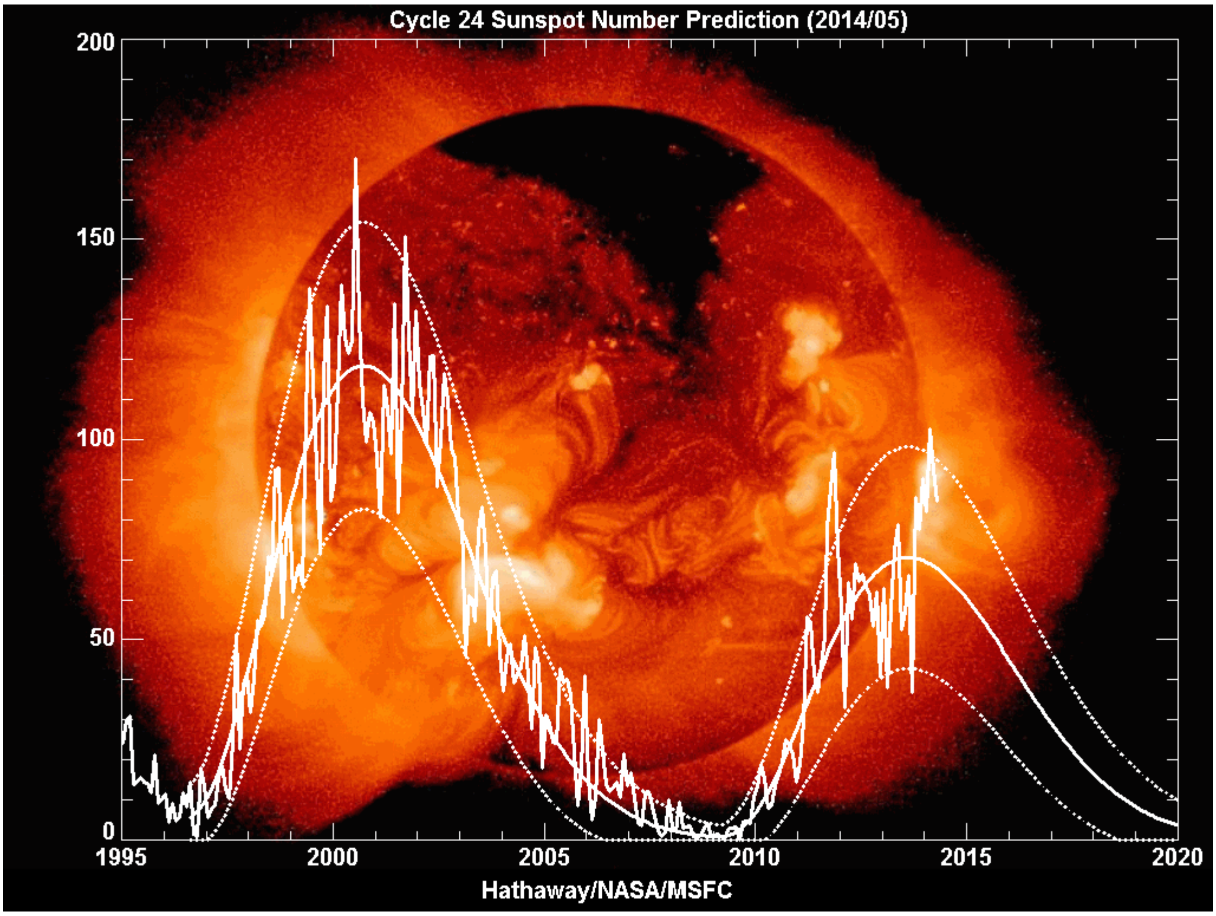

Figure 8: Sunspot numbers during solar cycles 23 and 24, updated in May 2014. Source: David Hathaway, Nasa. http://solarscience.msfc.nasa.gov/predict.shtml

Several papers in the last decade have claimed that solar activity in the second part of the 20th century was higher than any time in the past 10.000 years.[xii][xiii] Some solar physicists call the recent period of high solar activity the Grand Solar Maximum or the Modern Maximum. This would suggest that at least part of the warming since pre-industrial times could be attributed to increased solar activity.

However in recent years the concept of the Grand Solar Maximum has come under increasing scrutiny. Two methods for counting sunspots have been developed, the group sunspot number and the Wolf sunspot number. On top of that there are inhomogeneities in the series. A team of solar scientists led by Leif Svalgaard, organised a series of workshops, to correct the sunspot record.[xiv] Their corrected figure (the yellow line in figure 5 below) suggests there was no Grand Solar Maximum in the second part of the 20th century. However, before 1700 direct sunspot observations are not very reliable so it remains to be seen how many sunspots there were during the Maunder Minimum.

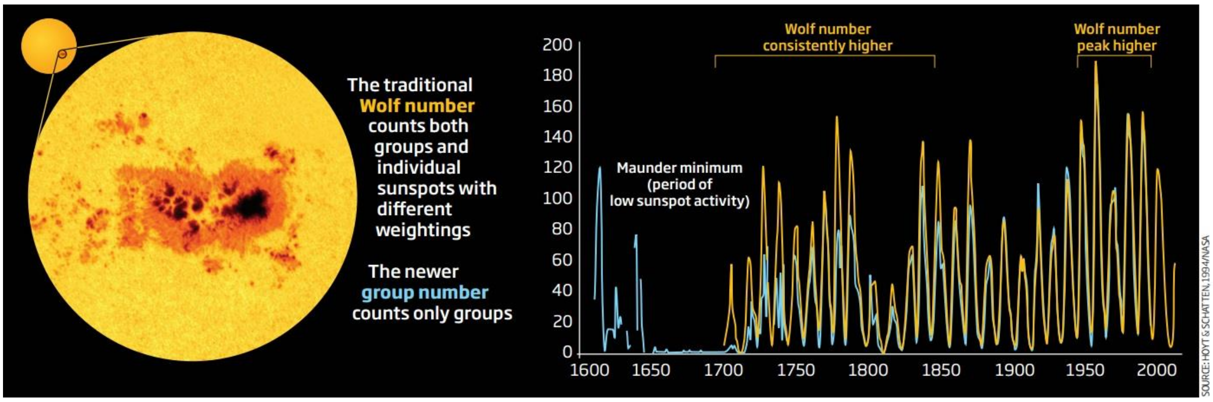

Figure 9: The group sunspot numbers (in blue) suggest a steady increase in solar activity since the Maunder Minimum. The corrected Wolf sunspot numbers however show periods of high solar activity in the 18th and 19th century that are similar to what is called the Modern Maximum. Source: Brian Owens, Spot of bother: have we been getting solar activity wrong?, New Scientist, 13 September 2013

To conclude, both temperature and TSI reconstructions of the past millennium are still pretty uncertain. In very general terms one could say that the amplitude of temperature reconstructions has become larger in recent studies while the amplitude of solar reconstructions has become smaller. This does not plea for a large solar contribution on the climate. Still the sun is a very popular alternative for CO_2 amongst climate sceptics. In this Climate Dialogue we want to explore why some climate scientists are still in favour of a large solar influence on the climate, even in the 20th century.

Amplification mechanisms

Studies that conclude a possible large solar effect on the climate, are often based on the suggestion there are large correlations between solar proxies and climate in the past[xvxvi], which implies that some amplification mechanism must be in play to explain how relatively small changes in the solar output can have relatively large effects on the climate. Shaviv (2008)[xvii] found that in the last 50 years the oceans have stored 5-7 times more solar energy during a solar cycle than the radiative forcing implies.

Several mechanisms for solar amplification have been proposed. The most famous one is the cosmic rays hypothesis which assumes that variations in cosmic rays which are related to solar activity cause changes in cloud cover. A second mechanism focuses on changes in UV radiation during a solar cycle which are much larger than the very minor change (0.1%) in TSI. The changes in UV influence the temperature of the stratosphere and these changes might influence the temperature of the troposphere. However most models indicate that on a global scale the influence is quite small.

Other studies focus on a role for the oceans. Van Loon and Meehl[xviii] published several papers in which they show a solar influence in the Pacific Ocean. Soon (2009[xix], 2013[xx]) suggested that solar influences can explain a large part of the temperature variations in the Arctic.

A new Maunder Minimum?
Many solar physicists expect the sun to move into a new minimum, comparable with the Dalton or even the Maunder Minimum. The current solar cycle 24 is the smallest sunspot cycle in 100 years and the third in a trend of diminishing sunspot cycles. Solar physicists expect cycle 25 to be even smaller than Cycle 24. There is, however a notion that the solar dynamo invoking solar activity is unpredictable. Methods are merely based on comparing the shape of a solar cycle with those in the past.

The current consensus among climate scientists seems to be that even when the sun enters a new Maunder Minimum this will not have a large effect on the global temperature, which will be dominated by the increase in greenhouse forcing because of its much larger magnitude.[xxi][xxii] Feulner (2010) found that a new Maunder Minimum would lead to a cooling of 0.3°C in the year 2100 at most – relative to an expected anthropogenic warming of around 4°C. Recently Schürer (2014)[xxiii] even took the large solar effect of the Shapiro (2011) paper into account and concluded that even that has only a small effect.

As IPCC puts it in AR5[xxiv]:

> Nevertheless, even if there is such decrease in the solar activity, there is a high confidence that the TSI RF variations will be much smaller in magnitude than the projected increased forcing due to GHG.

The next 20 to 30 years will be very interesting and probably a lot will become clear about the role of the sun by then.

Questions for this Climate Dialogue:

1) What is according to you the “best” solar reconstruction since 1600 (or even 1000) in terms of Total Solar Irradiance?

2) Was there a Grand Solar Maximum in the 20th century?

3) What is your preferred temperature reconstruction for the same period? How much colder was the Little Ice Age than the current warm period?

4) What is the evidence for a correlation between global temperature and solar activity?

5) How much of the warming since pre-industrial would you attribute to the sun?

6) Is the Total Solar Irradiance (TSI) of the sun all that matters for the Earth’s climate? If not, what amplification processes are important and what is the evidence these play a role?

7) what is the sun likely going to do in the next few decades and what influence will it have on the climate? Is there consensus on the predictability of solar variability?

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[iv] Cosmic rays produce ^{10}Be and ^{14}C high in the atmosphere by collisions with other molecules. When solar activity is high, less cosmic rays enter our atmosphere so less ^{10}Be and ^{14}C is produced. There is therefore an inverse relationship between these radioactive isotopes and solar activity.
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[xiv] An overview of recent issues can be found in this 2012 talk of Svalgaard: http://www.leif.org/research/TIEMS-Oslo-2012-Svalgaard.pdf. The SSN workshops page is: http://ssnworkshop.wikia.com/wiki/Home.
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[xxiv] AR5 section 8.4.1.