This is the print version of the Skeptical Science article 'A grand solar minimum could trigger another ice age', which can be found at http://sks.to/solarminimum.

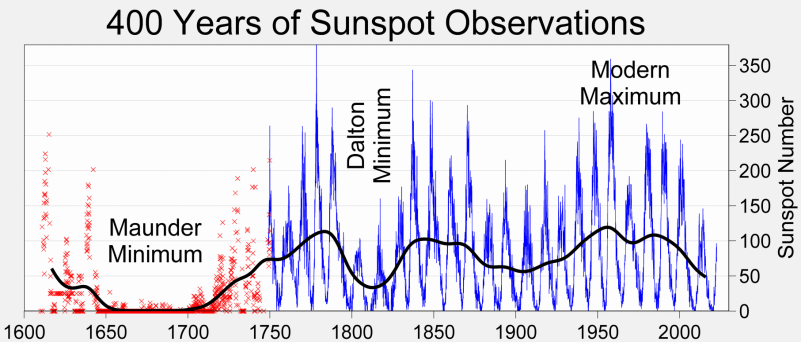
A grand solar minimum would barely make a dent in human-caused global warming

What The Science Says:
Peer-reviewed research, physics, and math all tell us that a grand solar minimum would have no more than a 0.3°C cooling effect, barely enough to put a dent in human-caused global warming.

Climate Myth: A grand solar minimum could trigger another ice age

> "The sun is acting bizarrely and scientists have no idea why. Solar activity is in gradual decline, a change from the norm which in the past triggered a 300-year-long mini ice age" (Dick Ahlstrom, The Irish Times)

The Maunder Minimum was a period of very low solar activity between 1645 and 1715, and the Dalton Minimum was a period of low (but not as low as the Maunder Minimum) solar activity between 1790 and 1830. Solar research suggests that we may have a similar period of low solar activity sometime this century.



400 years of sunspot observations data, via Wikipedia

Articles in the Danish newspaper Jyllands-Posten (translation available here) and in the Irish Times both ran headlines claiming that another grand solar minimum could potentially trigger an "ice age" or "mini ice age" this century. These articles actually refer to the Little Ice Age (LIA) – a period about 500 to 150 years ago when global surface temperatures were about 1°C colder than they are today.

Thus a grand solar minimum would have to cause about 1°C cooling, plus it would have to offset the continued human-caused global warming between 1 and 5°C by 2100, depending on how our greenhouse gas emissions change over the next century. Though in the Jyllands-Posten article, Henrik Svensmark (the main proponent of the galactic cosmic ray-climate hypothesis) was a bit more measured, suggesting,

> "I can imagine that it will become 0.2°C colder. I would be surprised if it became 1–2°C"

So these two articles are suggesting that a grand solar minimum could have a cooling effect of about 1 to 6°C, depending on how human greenhouse gas emissions change over the next century. Is it plausible that a grand solar minimum could make that happen?

The short answer is, 'No.'

Fortunately, Solar Output is Stable

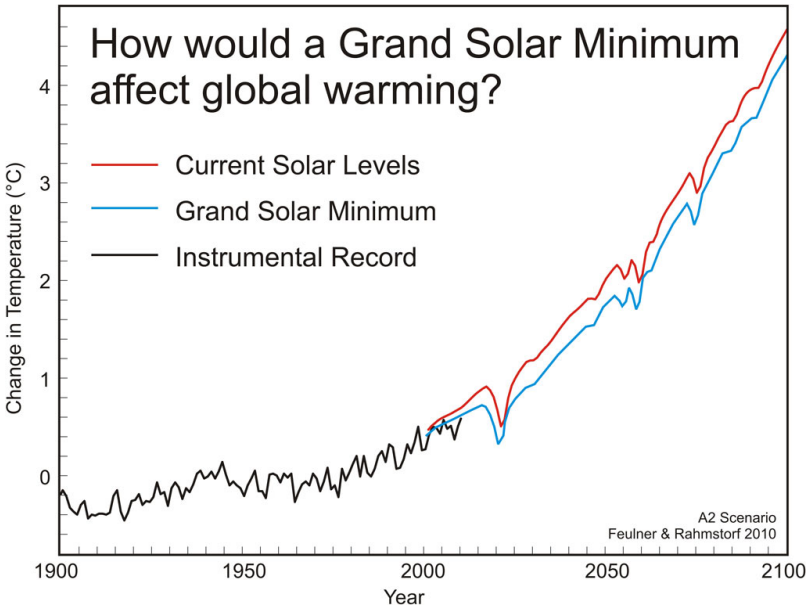
We're fortunate that the amount of solar radiation reaching the Earth's surface is very stable. Climate contrarians will often ask if we'd prefer if the planet were warming or cooling, suggesting that global warming is a good thing because at least the planet isn't getting colder. This is a false dichotomy - an ideal climate is a stable one. The relatively stable climate over the past 10,000 years has allowed establishment of human civilization, by making it possible to create large stationary agricultural farms because we could rely on stable weather patterns.

What difference would a grand solar minimum make in the amount of solar energy reaching us? Relative to current levels, the Dalton Minimum represents a 0.08% decrease, and the Maunder Minimum represents a 0.25% decline in solar radiation at the Earth's surface. That's how stable solar activity is. That's also why we're playing with fire by increasing the greenhouse effect so much and so quickly. We're threatening the stability of the climate that has been so favorable to our development.

Peer-Reviewed Research Says Global Warming will Continue

There have been several studies in recent years investigating what impact another grand solar minimum would have on global surface temperatures, since solar research suggests it's possible we could be due for another extended minimum. Generally these studies will run climate model simulations under a given greenhouse gas emissions scenario with stable solar activity, then run the same scenario with the sun going into a grand minimum, and look at the difference in resulting global surface temperature changes.

Feulner & Rahmstorf (2010) (PDF available here) estimated that another solar minimum equivalent to the Dalton and Maunder minima would cause 0.09°C and 0.26°C cooling, respectively.



The global mean temperature difference is shown for the time period 1900 to 2100 for the IPCC A2 emissions scenario (relative to zero for the average temperature during the years 1961 to 1990). The red line shows predicted temperature change for the current level of solar activity, the blue line shows predicted temperature change for solar activity at the much lower level of the Maunder Minimum, and the black line shows observed temperatures from the NASA GISS dataset through 2010. Adapted from Feulner & Rahmstorf (2010).

Jones et al. (2012) (PDF available here) arrived at a nearly identical result, with cooling from a Dalton and Maunder minimum equivalent at 0.09°C and 0.26°C, respectively. Similarly, a new paper by Anet et al. (2013) found that a grand solar minimum will cause no more than 0.3°C cooling over the 21st century.

Consistent with these previous studies, Meehl et al. (2013) (PDF available here) estimate a Maunder Minimum would cause about 0.26°C cooling, but as soon as solar activity began to rise again, that cooling would be offset by solar warming. This is a key point, because a grand solar minimum would not be a permanent change. These minima last for a few decades, but eventually solar activity rises once again. Thus any cooling caused by a solar minimum would only be temporary.

A Rough Estimate without Climate Models

The cooling effect of a grand solar minimum can also be estimated very easily without the aid of climate models. The change in the amount of total solar irradiance (TSI) reaching the Earth's surface is directly proportional to the temperature change it causes. Earth's surface reflects about 30% of incoming sunlight (multiply TSI by 0.7), and TSI must also be divided by 4 to account for the Earth's spherical geometry.

To convert the energy change to a temperature change, we then just need to multiply by the climate sensitivity parameter. This is where it gets tricky for climate contrarians, because if the global climate is insensitive to rising greenhouse gases (as contrarians argue is the case), it's also insensitive to natural influences like changes in solar radiation. If we assume the most likely climate sensitivity estimate is correct (3°C for the equivalent of a doubling of atmospheric CO2), the equilibrium climate sensitivity parameter is 0.8. But only about two-thirds of that temperature change will be realized over short timescales, due to the thermal inertia of the global climate. So we can estimate:

$\Delta T_{2100} = 0.7*0.25*0.8*0.67*\Delta TSI = 0.09*\Delta TSI$

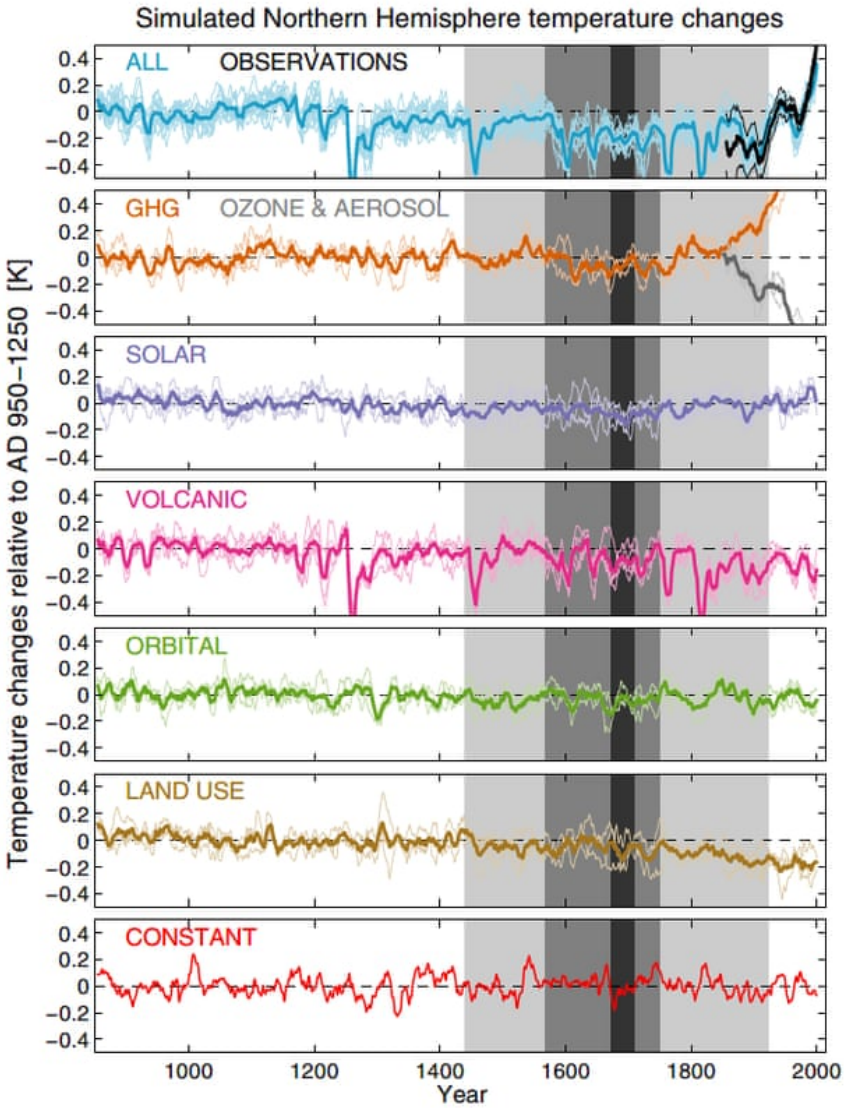
So for a 0.25% change in TSI to Maunder Minimum levels (that's 3.4 Watts per square meter), our crude estimate is that a 0.3°C cooling would result by 2100; right in line with the model estimates.

Human Influence on Climate Change is Bigger than the Sun's

The bottom line is that the sun and the amount of solar radiation reaching Earth are very stable. Even during the Maunder and Dalton grand solar minima, global cooling was relatively small - smaller than the amount of global warming caused by human greenhouse gas emissions over the past century.

A new grand solar minimum would not trigger another LIA; in fact, the maximum 0.3°C cooling would barely make a dent in the human-caused global warming over the next century, likely between 1 and 5°C, depending on how much we manage to reduce our fossil fuel consumption and greenhouse gas emissions. While this is equivalent to about a decade's worth of human-caused warming, it's also important to bear in mind that any solar cooling would only be temporary, until the end of the solar minimum.

The science is quite clear that the human influence on climate change has become much bigger than the sun's.



Simulated northern hemisphere temperature changes resulting from individual climate factors, as compared to the observed changes in the top panel. The bottom panel shows a simulation with no changes to climatological factors, to illustrate the level of natural variability in the climate. Illustration: Owens et al. (2017), Journal of Space Weather and Space Climate

A grand solar minimum probably isn't imminent

Although it would have a relatively small impact on the climate, it's still an interesting question to ask whether we're headed for another quiet solar period. Valentina Zharkova thinks so. Her team created a model that tries to predict solar activity, and suggests another solar minimum will occur from 2020 to 2055. However, other solar scientists have criticized the model as being too simple, created based on just 35 years of data, and failing to accurately reproduce past solar activity.

Ilya Usoskin, head of the Oulu Cosmic Ray Station and Vice-Director of the ReSoLVE Center of Excellence in Research, published a critique of Zharkova's solar model making those points. Most importantly, the model fails in reproducing past known solar activity because Zharkova's team treats the sun as a simple, predictable system like a pendulum. In reality, the sun has more random and unpredictable (in scientific terms, "stochastic") behavior:

> *For example, a perfect pendulum – if you saw a few cycles of the pendulum, you can predict its behavior. However, solar activity is known to be non-stationary process, which principally cannot be predicted (the prediction horizon for solar activity is known to be 10-15 years). Deterministic prediction cannot be made because of the*

essential stochastic component.

Just imagine a very turbulent flow of water in a river rapid, and you throw a small wooden stick into water and trace it. Then you do it second time and third time ... each time the stick will end up in very different positions after the same time period. Its movement is unpredictable because of the turbulent stochastic component. This is exactly the situation with solar activity.

Solar expert Mike Lockwood agrees that we don't yet have a proven predictive theory of solar behavior. He has published research examining the range of possible solar evolutions based on past periods when the Sun was in a similar state to today, but as he puts it, "that is the best that I think we can do at the present time!"

Solar physicist Paul Charbonneau at the University of Montreal also concurred with Usoskin. He told me that while scientists are working to simulate solar activity, including using simplified models like Zharkova's,

on the standards of contemporary dynamo models theirs is extremely simple —in fact borderlining simplistic ... To extrapolate such a model outside its calibration window, you need an extra, very strong hypothesis: that the physical systems underlying the magnetic field generation retain their coherence (Phase, amplitude, etc.). As my colleague Ilya Usoskin has already explained, this is very unlikely to be the case in the case of the solar activity cycle.

Also see this excellent video by Peter Sinclair of Climate Crocks debunking this myth.

[*see video at* ***this link.***]

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