MITx Video | 12.340xForcing03v02

Let's now turn our attention to the effect of variations in the sun itself. The sun is not entirely constant. We've known that since we started to observe the sun carefully, after the invention of the telescope. So here is a record-- about 400 years long-- of sunspot observations.

Sunspots are, of course, the dark spots that appear on the surface of the sun that are associated with solar flares and magnetic disturbances. This record goes back from the present, more or less, to 1609 or so, about the time the telescope was invented.

What you can see in the sunspot record starting in about 1750 or so-- quite clearly-- is a very nice periodic oscillation in the number of sunspots. There's a prominent solar cycle of a period of about 11 years. So we have 11 years of variation from relatively low to relatively high sunspot activity.

This, by the way, is associated with the 11-year variations of geomagnetic storms, including such phenomena as the aurora. On top of the 11-year variations, one can see other variations in the magnitude of the solar forcing. This black line is sort of a smooth rendition that takes out the 11-year cycle.

One can see, for example, that there are a relatively small number of sunspots very early in the 19th century, here. But there was this very interesting period from the beginning of the 17th century to later in the 18th century, where there were hardly any sunspots at all. And this corresponded to almost no observations of the aurora from places like Scandinavia.

This particular long stretch of very little sunspot activity is called the Maunder Minimum. And this minimum in solar activity is also thought to coincide with climate anomalies that were observed, particularly in northern Europe, during this time.

Now, sunspots and geomagnetic activity are one thing. But what we're mostly concerned about for climate is the actual electromagnetic radiation, so-called solar irradiance. This is a record that's been compiled from modern satellite observations showing total solar irradiance. We've really only been able to estimate it accurately since we had earth-orbiting satellites, going back to the 1970s or so.

The green and red curves are more-or-less instantaneous observations of solar irradiance. And the black curve shows a smooth rendition of that. And one can see that going along with the 11-year cycle in sunspot activity, there's a nice 11-year cycle in total solar irradiance, so there's a correspondence between solar output and solar magnetic phenomena on this 11-year period.

Now, the total solar irradiance is given here on the left. And you'll notice that the scale is in watts per meter squared. This is incident radiation at the top of the atmosphere. Now remember, to get the actual radiative forcing, we have to take this solar irradiance, divide by 4 and multiply by 1 minus the planetary albedo. By the time we do that, we see that we have variations due to the 11-year cycle on the order of a few tenths of a watt per meter squared.

What's the connection quantitatively between the magnetic variations of the sun as indicated by sunspots, solar flares, and so forth, and total solar irradiance? Well, that's indicated by this graph, again made during the era of satellite observations, extending here from the mid '70s.

The yellow curve on this graph is the daily irradiance. And the red curve is its annual average. So let's focus on that red curve. The sunspot observations are given by blue.

So you see there's quite a nice correlation between sunspots and solar irradiance on this time scale. Now, remember that we showed a few slides ago that sunspot counts vary-- not just on an 11-year time scale, but on longer time scales. Because the satellite record is so short, we don't have any guarantee that the relationship we see on 11 years also holds for these longer time scales.

But there are other proxies for solar activity. A very interesting one is an isotope of carbon-- C-14. C-14 is generated when cosmic rays bombard the high atmosphere and cause beta decay of nitrogen into C-14. The C-14 then shows up, and is incorporated in vegetation, such as wood. So that by looking at the concentration of C-14 in trees and counting tree rings, we get some idea of the variations of C-14 over a long time.

Now, what causes variations in the cosmic ray flux entering the top the atmosphere? To some extent, this is caused by variations in solar magnetic activity. The solar wind, which is the flux of very high energy particles from the sun-- which also carry with them magnetic fields-- tend to sweep out cosmic rays.

And so variations in solar magnetic activity can cause variations in cosmic ray flux into the top of the atmosphere, which are ultimately recorded in things like tree rings. Unfortunately, there are other things that can cause carbon isotopes to vary in vegetation, including local changes in biogeochemical cycles, and so forth. So this is not a perfect proxy.

But here we have, from about 800 AD to the present, a measure of C-14 in tree rings, which is thought to have been caused principally by changes in solar activity. There are very interesting minima that occur along here, including most recently the Maunder Minimum, which we just talked about, in the late 17th to mid 18th century. And we see that we're sort of at a maximum of solar activity right about now.

So we have various different ways of trying to reconstruct solar activity going back. There is also, as seen in this graph, a correlation between C-14 and other measures of solar magnetic activity. So this is the same graph we showed before, with sunspot numbers. But the gray curve that you see here is the delta C-14. So you can see some correlation between that and sunspot counts.

This is an attempt to put it all together and reconstruct the solar irradiance going back several hundred years. This is based both on sunspot observations-- the modern observed relationship between sunspots and solar irradiance-- and the C-14 isotopes. And these are reconstructions by various groups. So one can see some measure of uncertainty by comparing them.

The 11-year cycle is very prominent in some of these measures. One sees that we had a fairly high level of solar activity in the 19th and 20th centuries-- although it's been declining a little bit more recently-- and quite a low level of activity, for example, around 1800. Now again, when we divide by four and subtract out the planetary albedo, we're talking about variations in total solar irradiance of a few tenths of a watt per meter squared.

What is the relationship between solar variability deduced this way and climate? So this graph shows three quantities-- the global mean temperature with a smooth rendition in red going back to about 1850, more or less to the present. We have the sunspot number, and a smooth rendition of this in yellow. And we have the carbon dioxide content from ice cores and some direct measurements in blue.

So one can see going back to the record that before the really prolonged uptick in carbon dioxide emissions in the 20th century, solar variations may have had something to do with observed variations in the Earth's temperature.

So there are many things, of course, that can affect the surface temperature of the Earth. This simply shows two of those forcings and what they might have done to temperature.

To finish up this section, let's try to think more carefully about what the magnitudes of these forcings actually mean. So here's a few facts, just from a very simple energy balance. If we change the solar constant by about 1.6%, that's equivalent to four watts per meter squared of radiative forcing. That would produce-- in the absence of feedbacks-- about a one degree Centigrade change in surface temperature.

Doubling the carbon dioxide content of the atmosphere is also equivalent to about four watts per meter squared of net radiative forcing, and therefore also would produce about one degree Centigrade change in surface temperature in the absence of feedbacks.