Solar Variability and Global Climatic Change

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The extent of human impact on climate remains a highly complex scientific matter. The United Nation's Intergovernmental Panel on Climate Change (IPCC) made clear in its recent report the uncertainties in understanding climatic change, including natural factors.[1] One uncertainty is the impact of solar variability on the climate.

There are two separate but related issues to be considered: (1) the inability of the computer simulations of the climate to succeed at validation; (2) the known incompleteness of the computer simulations, which must be addressed by seeking other natural causes of climatic variability.

Computer simulations of the earth's climate try to calculate the warming due to the greenhouse gases caused by human activity. The latest "best estimate" by the IPCC calls for a globally averaged temperature increase of about 2.5°C, given assumed rates of accumulation of greenhouse gases (IPCC I 1996: 289).

Testing the projections

How can the computer forecasts of the climate 100 years into the future be verified? The rules of science give clear guidance on how to test this or any hypothesis. Richard Feynman, physicist at the California Institute of Technology and Nobel Laureate, takes the view of Poincaré[2] when he writes: "*The test of all knowledge is experiment*. Experiment is the *sole judge* of scientific 'truth'" (Feynman, Leighton, and Sands 1963: 1-1). The increase in all greenhouse gases from human activities over the past 100 years, added together, are equivalent to a 50 percent increase in carbon dioxide alone—that is, halfway to the benchmark that the IPCC considers, an effective doubling of carbon dioxide alone. The accuracy of the climatic forecasts based upon computer projections may be tested, therefore, by examining the climate's response to the increase that has already taken place.

In considering the projections against the measured temperature response, the IPCC and scientists affiliated with the IPCC agree that the computer simulations are insufficient for the tasks of explaining the current climate and projecting reliably future climatic change:

> [The model results] cannot be considered as compelling evidence of a clear cause-and-effect link between anthropogenic forcing and changes in the earth surface temperature. (IPCC I 1996: 411)

> [T]he GCM considered cannot be used for any physical experiment devoted to studying real climate change, such as greenhouse warming, paleoclimate reconstructions, or El Niño prediction. (Polyak and North 1997: 1921)

> [I]t [is] clear that using the GCM for investigation of the real climate variability ... has no scientific justification. (Polyak and North 1997: 6799)

> [W]ithout knowing the dynamical heat fluxes, it is clear that one cannot even calculate the mean temperature of the earth. (Lindzen 1997: 8335)

Temperature records from the Arctic

One demanding test of the validity of the computer simulations of the climate of the earth is based on temperature records from the Arctic. According to the computer forecasts, the polar areas are very sensitive to global warming. The forecasts say that the polar regions should have warmed enough during the last 50 to 100 years to begin melting polar ice. In addition to the predominant positive feedback assumed for water vapour (see below, p. 80), there is a positive feedback, specific to the melting of the polar ice, that amplifies any warming. Ice reflects sunlight and helps keep the polar regions cold. As the temperature rises and the ice melts, the bare ground or sea underneath absorbs more of the sun's energy and magnifies the warming.

According to the computer simulations, a rapid and significant temperature increase is projected to have already occurred in the last 50 years in the latitude band 60°N to 90°N[3] because of the recent increases in greenhouse gases caused by human activity and the models' expectations of amplified Arctic warming. But the temperature measurements show that there has been no net warming over the last several decades, especially in the winter, which is the season projected by the computer simulations to have the fastest increase in temperature. Specifically, the observational evidence shows that "greenhouse-induced warming is not detectable in the Arctic troposphere for the 1958–1986 period" (Kahl *et al.* 1993: 825). An independent study found that, in agreement with the previous results, the Arctic surface air had not warmed between 1950 and 1990 (Kahl *et al.* 1996: 1297).

Another indication that the Arctic region is warming would be that the winter weather system, the polar vortex, is shrinking. However, "the January circumpolar vortex has expanded over the last two decades ... contrary to general circulation model forecasts that predict a decrease in the meridional temperature gradient of the Northern Hemisphere as trace-gas concentrations increase" (Davis and Benkovic 1994: 415).

Further, the United Kingdom's monthly compilations of surface-air temperatures (Jones *et al.* 1986: 161), which contain the temperature record widely used by those studying climate and by the IPCC, were analyzed by I. Polyak and G. North, who found that there has been no significant warming trend at high northern latitudes since 1946, and that the earlier portion of the record is too unreliable for determining a trend (1997: 1921).

Finally, the satellite data from Microwave Sounding Units (MSU) for the period from 1979 to 1996 and the balloon radiosonde data for the period from 1958 to 1995 show no net warming in the high (60° to 90°) northern latitudes (J. Christy, personal communication, 1997). The computer simulations of climatic change make specific projections for temperature increases in the lower troposphere due to increases in greenhouse gases. Note that temperatures in the lower troposphere would be least affected by systematic errors such as the "urban heat-island effect" in surface temperatures near cities experiencing significant population growth and development. Combined with the high precision of the satellite data from MSU, the tropospheric temperatures are an excellent test of the climatic projections and they show that, on average, the temperature has not risen in the north polar region.

When tested against the Arctic temperature record, therefore, the computer forecasts are seen to exaggerate the projected warming by a large amount.

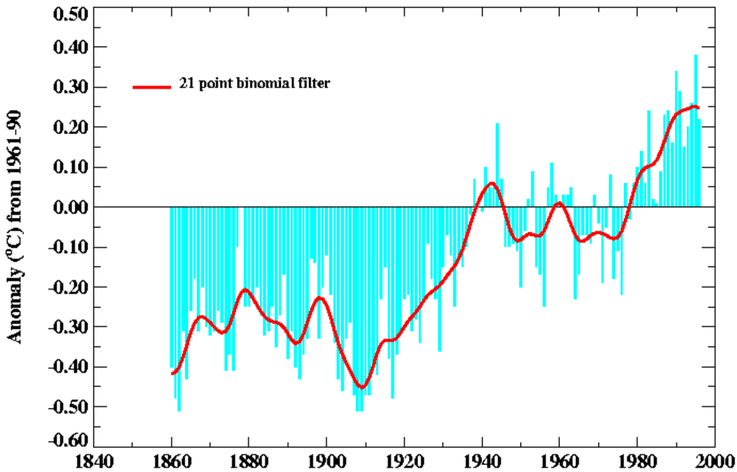
Exaggerated warming

The computer projections are exaggerating the greenhouse warming by a large factor, partly because they are subject to major errors due to the assumption that water vapour is a strong, positive feedback. But the effect of water vapour is not understood.[4] Without the assumed gain from the water-vapor feedback, there would be little amplification of the warming caused by the increases in the minor greenhouse gases (Lindzen 1994: 353). What, then, is the maximum amount of warming due to increased greenhouse gases that can be expected to occur, if the exaggerated forecasts are reduced to the limits allowed by the actual temperature measurements? The answer is that the corrected warming in the next century, at present rates of increase in the greenhouse gases, will be less than a few tenths of a degree Celsius.

Solar cycle of magnetism

Sunlight supplies most of the energy that drives the dynamics of the terrestrial climate. Speculation on the role of changes in the sun and their influence on changes in the earth's climate has been ongoing for centuries. The great astronomer Sir William Herschel, who discovered the planet Uranus, speculated, "I am now much inclined to believe that openings with great shallows, ridges, nodules and corrugations, instead of small indentations, may lead us to expect a copious emission of heat, and therefore mild seasons. And that on the contrary, pores, small indenta-

Figure 1 Smoothed surface-temperature record, 1860–1996 (updated from IPCC I 1996: 26, fig. 8). The base period is 1961–1990. Source: downloaded from UK Meteorological Office at www.meto.govt.uk/sec5/CR_div/Tempertr/Index.html. Note the sharp temperature rise between 1910 and 1940.



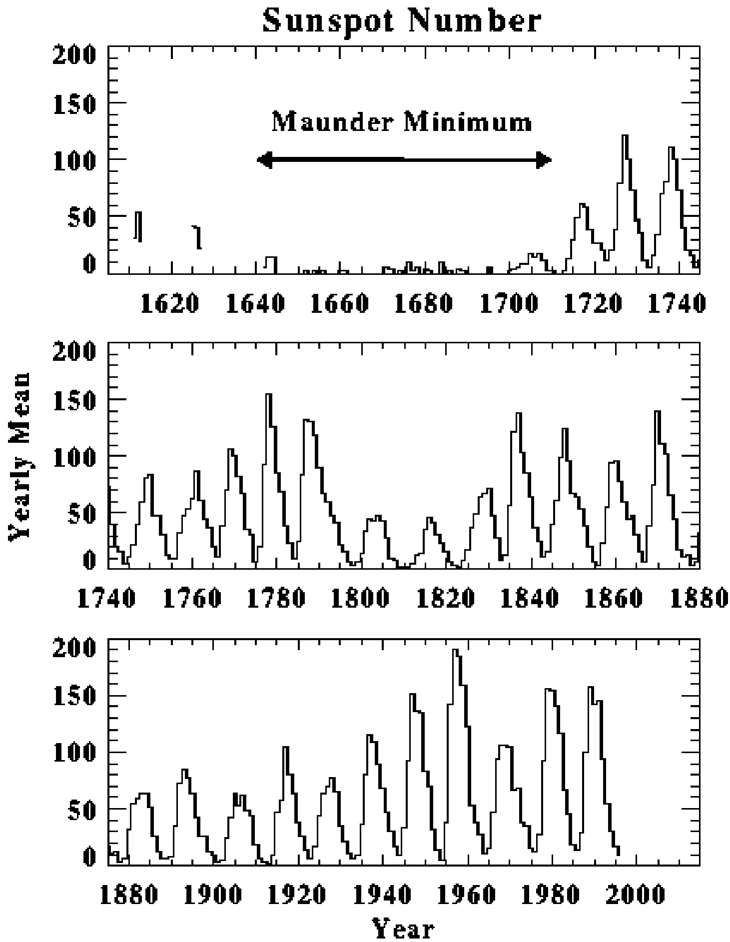
tions, the absence of ridges and nodules, and of large openings and shallows, will denote a spare emission of heat, and may induce us to expect severe seasons" (Herschel 1801: 265).

Empirical evidence on solar variability and climatic change

An important feature of the surface temperature record of the last 100 years (figure 1) is that the temperature rose sharply by about 0.4°C between 1910 and 1940. Most of the increases in greenhouse gases, however, occurred after 1940 and, therefore, cannot be the cause of the 0.4°C warming that occurred earlier in the twentieth century. Most of the warming early in this century, then, must have been due to natural causes of climatic change, and these natural causes must be understood in order to make an accurate assessment of the effect upon climate of any human activities that may have been added to the natural changes.[5]

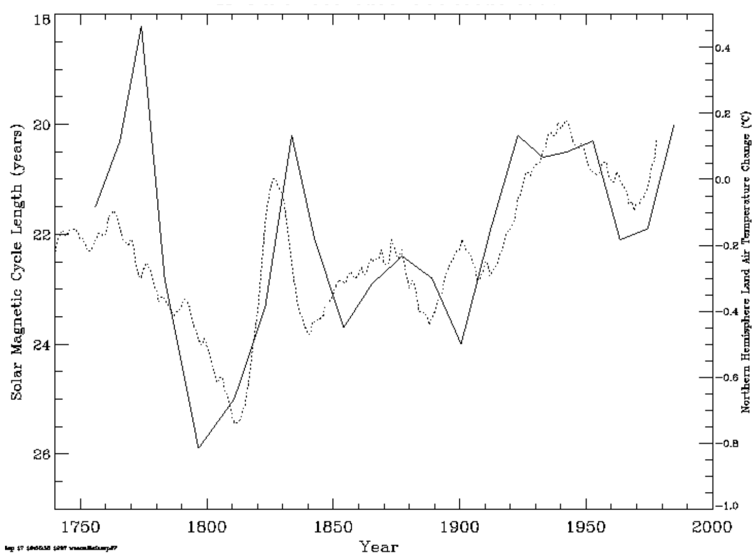
One possible natural cause of climatic change is variation in the brightness of the sun. The surface magnetism on the sun shows a pronounced cycle of variation roughly 11 years in length (figure 2).

Figure 2 Annual numbers of sunspots from 1610 to 1996. From J.A. Eddy, *Science* 192 (1976): 1189 and updates from NOAA-National Geophysical Data Center Solar-Geophysical Data Reprints. The number of sunspots indicates the strength of, and coverage by, surface magnetic fields on the sun.



According to recent findings based on measurements from NASA satellites, the sun also brightens and fades in total irradiance, or radiative energy output, in step with its 11-year cycle of changes in magnetism. This observed association of changes in irradiance

Figure 3 The 22-year solar magnetic cycle (*solid line*) and changes in land temperatures in the northern hemisphere (*dashed line*) (Grovesman and Landsberg 1979: 767; Jones *et al.* 1986: 161). From Baliunas and Soon 1995: 896.

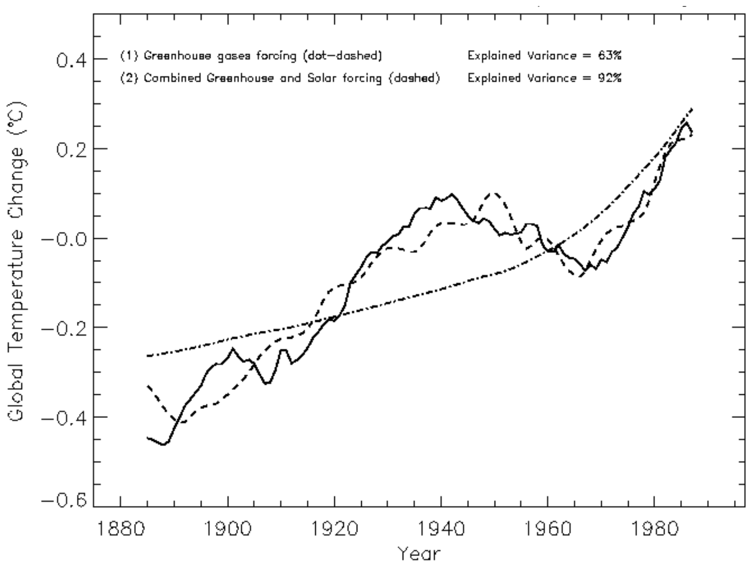


with magnetic change over nearly two decades is the basis for estimating changes in the sun's energy output in coordination with recorded changes in magnetism over many decades.

Such changes in irradiance could, if large enough, drive significant climatic change and the climatic record, indeed, does indicate a solar influence of this kind. Figure 3 shows records of the sun's magnetism and of land temperatures of the northern hemisphere over the last 240 years.[6] The two parameters are highly correlated, suggesting that changes in the sun's surface magnetism are linked to changes in the temperature. These changes in surface magnetism may reflect changes in total solar irradiance over periods of time—ranging from decades to centuries in length—for which measurements are lacking.

Assuming that the timing of such magnetic changes reflects changes in solar irradiance, computer simulations (figure 4) of the climate suggest that roughly 0.4 percent changes in solar irradiance over many decades would produce global temperature

Figure 4 Observed (solid line) and simulated (dot-dashed line, greenhouse gases alone; dashed line, solar irradiance change plus greenhouse gases) temperature anomalies. From Soon et al.1996: 891; the solar-forcing profile is from Hoyt and Schatten 1993: 18,895. The solution for solar forcing corresponds to a total solar irradiance change of at most 0.5%.



change of about 0.5°C (Soon, Posmentier and Baliunas 1996: 891). There is evidence of a solar change of just this magnitude in a recent report of an observed difference of total solar irradiance between two sunspot-cycle minima—1986 and 1996—that would amount to about 0.4 percent change in irradiance over a century (Willson 1997:1963).

There is additional evidence of the sun's effect upon the climate over several millennia. Every two centuries or so, the sun's magnetism drops to very low levels for several decades. One instance is the low level of the sun's magnetism during the seventeenth century (*ca*. 1640 to 1720, the "Maunder Minimum"). A fainter sun at that time could have contributed to a climatic period called the "Little Ice Age," when the average global temperature was about 1°C cooler than it is today.

Quantitative records of the sun's magnetism over millennia come from measurements of radiocarbon (^{14}C) in tree rings and beryllium (^{10}Be) in ice cores. Records of the abundances of those isotopes confirm the occurrence of the magnetic Maunder minima every few centuries, plus occasional, sustained magnetic maxima. During the magnetically low periods, the sun might dim compared to magnetically high intervals, when the sun should brighten. The brightness changes are estimated to be relatively small—several tenths of a percent during these large swings in magnetism—but such modest changes are enough according to some climatic simulations to explain the reconstructed global temperature changes of about 1°C.

The influence of the sun on the climate is also inferred from records covering about 5000 years and showing that 6 out of 7 observed cold spells approximately coincide with long-term lulls in solar magnetism, perhaps similar to the Maunder minimum (Wigley and Kelly 1990: 547). Records from Scandinavia over the last 10,000 years suggest that 17 out of 19 cold spells are coincident with major lows in the sun's magnetism (Karlén and Kuylenstierna 1996: 359).

Other possible mechanisms of the sun's effect on climatic change

Modeling efforts generally treat an increase in the input from the solar constant to the climatic system[7] to be radiatively equivalent to that from an increase in atmospheric concentration of the trace greenhouse gases produced by human activity. It is often pointed out that a change of, say, 0.4 percent in the total solar irradiance over a time frame of 100 years (Soon *et al.* 1996: 891) is about 1 Watt/m^2 at the surface of the earth. Since the known increase in greenhouse gas radiative forcing is over 2 Watts/m^2 in the last 100 years, it is supposed that the sun has been and will continue to be of lesser importance compared to the forcing from the increase in greenhouse gases. However, such a comparison misses a key point: it is not the arithmetic magnitude of the forcings *per se* but the *responses* of the climatic system to these forcings that must be considered. The conjecture that the two radiative inputs give similar responses in the climatic system is an unverified assumption.

Is change in total solar irradiance the sole or major driver of solar-influenced climatic change? The signature of solar variability appears in meteorological records in ways that suggest that change in total irradiance is not the only impact the sun has on the terrestrial climate. For example, there is a positive correlation between the north polar winter temperature (at the height of the 50 millibar geopotential) and phase of the solar cycle when the Quasi-Biennial Oscillation (QBO) winds are westerly (Labitzke 1987: 535).

Further, changes in solar irradiance in ultraviolet wavelengths may affect the chemistry in the stratosphere and troposphere Haigh 1996: 981) while changes in irradiance in the visible wavelengths may affect the lower atmosphere and sea surface (White, Lean, Cayan, and Dettinger 1997: 3255). The responses to those separate portions of the solar spectrum may combine to influence the dynamics of the large-scale (roughly 1000 km in wavelength) planetary waves and Hadley circulation.[8] Then, too, the sun's surface magnetism and the wind modulate the galactic cosmic rays impinging on the geomagnetic field, and so affect the electrical (Tinsley 1997: 341) and chemical (Chamberlain 1977: 737) properties of the upper atmosphere. This, in turn, may cause changes in cloud microphysics and cloud coverage (Svensmark and Friis-Christensen 1997: 1225).

The consequence of the existence of these significant *non-radiative* mechanisms of solar influence on climatic change is important: the assumption of equivalence in the radiative inputs of the sun and increases in greenhouse gases is not valid.

The sun's radiative energy is emitted at many wavelengths; the sun also emits energetic particles and both are variable in time and space. The distinct components of the earth's atmosphere and surface should respond differently to the diverse aspects of the sun's energy outflows. Modeling the climatic response to the sun's variability faces two major barriers: (1) the lack of a complete description of solar variability; and (2) the lack of knowledge of the response of climate to changes in solar output (or indeed, the response of the climatic system to most natural forcings).

Conclusions

The processes of "fingerprinting" various mechanisms of climatic change and projecting climatic change requires knowing *all* the relevant factors, both those that are natural[9] and those that are the result of human activity. And, these factors must be considered *simultaneously* in a model (Schneider 1994: 263, 341; Rind 1996: 563). Once such a model is verified, then only can each mechanism be identified. Since the mechanisms of climatic change are not fully known—as we have shown, the question how the sun affects the climate is unresolved—and the models have not been verified (Barnett *et al.* 1996: 255; Polyak and North 1997: 1921, 6799), fingerprinting is not yet possible. Understanding all the important causes of climatic change, both those that are natural and those that are the result of human activity, is key to projecting future climatic change and crafting an effective response to it.

Herschel made a very modern speculation on the influence of the sun's surface magnetism upon the climate of the earth: "A constant observation of the sun with this view, and a proper information respecting the general mildness or severity of the seasons, in all parts of the world, may bring this theory to perfection or refute it if it be not well founded" (1801). It remains to be seen what the mechanisms of solar change are and what the climatic response to them is; studying them is essential if we want to create the best climatic simulations possible.

Notes

1 "Our ability to quantify the human influence on global climate is limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors" (IPCC I 96: 5).

2 On the role of experiment: "Experiment is the sole source of truth. It alone can teach us something new; it alone can give us certainty." (Poincaré 1902, part IV, ch. 9).

3 See, for example, Figure 8.12 and accompanying text in IPCC I 1996. The smallest increase is for a model with sulfate aerosol cooling; however, the sulfate cooling effect is too large, according to more recent work of Hansen *et al.* (1997: 6831). They find that the net effect of sulfate aerosols on the global average surface temperature is nearly zero. In that case, with the cooling effect of aerosols removed from the models' projections, the relevant temperature projections for the high northern latitudes are in the upper end of the quoted range.

4 In calculating the response to climatic forcing it is important to note that the computer simulations rely on a positive feedback provided by water vapour in the upper troposphere to amplify the small warming directly resulting from the increase in carbon dioxide and other minor greenhouse gases. This amplification is the predominant source of temperature gain in the computer simulations. "This feedback operates in all the climate models used in global warming and

other studies" (IPCC I 1996: 200, 4.2.1). However, note: "[I]ntuitive arguments for [the feedback] to apply to water vapour in the upper troposphere are weak; observational analyses and process studies are needed to establish its existence and strength there" (200, 4.2.1). Also: "Feedback from the redistribution of water vapour remains a substantial uncertainty in climate models" (201, 4.2.1). The assumption that the feedback from water vapour is positive has been challenged by theory (Sun and Lindzen 1993: 1643) and by observations (Spencer and Braswell 1997: 1097).

5 The overall warming trend (whose time scale of variability is >40 years) in the temperature record is the only statistically significant component of variability. No other component can be distinguished at the 95 percent confidence level from red noise. Because the signal is spatially ubiquitous, it is consistent with a global change in external forcing (Allen and Smith 1994: 883).

6 (Baliunas and Soon 1995: 896) Note that the shorter, global surface temperature record also shows a significant correlation with the length of the 11-year cycle of solar magnetism (Lassen and Friis-Christensen 1995: 835). Due to the lack of globally-averaged temperature records, to study the presence of correlations over longer time scales, regional records such as land temperatures for the northern hemisphere must be considered.

7 A physically more correct prescription would be an increase of total irradiance.

8 Hadley Circulation is the general pattern of atmospheric motions that prevail in the tropics. The circulation pattern is that of warm, moist air rising from the surface to the tropopause (about 12 km) and cool, dry air subsiding down to the surface.

9 For clarity it should be noted that this meaning of natural forcing differs from that of the IPCC I 1996: "'[N]atural' variability arises from the internal process at work in the climate system and not from changes in external forcing" (Summary for Policymakers: 33). The IPCC's model-based definition of natural variability excludes time-dependent forcing caused by, e.g., intrinsic solar variability.

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