

# Global Warming - Man or Nature

C.J. Butler

*Armagh Observatory, College Hill, Armagh BT61 9DG. N. Ireland*

## Abstract

Over the last decade the general public has become increasingly aware of the changes in climate that have occurred in the past and the problems that could arise in future. But, just how variable is the Earth's climate and how significant are the changes we have seen in recent times in the broader context? What are the causes of climate change and how much of the current change is due to natural causes and how much to the enhanced greenhouse effect we hear so much about? These are some of the questions we discuss in this paper.

## Introduction

The 'global warming' debate developed in the 1980s and 1990s as it was realised that tropospheric temperatures had risen since the late 19th century by roughly 1°C and were continuing to rise by a further 0.1°C per decade. Global warming, if it continues at its present rate, is expected to cause increasing desertification of some parts of the world, simultaneously with a melting of the polar ice-caps and a rise in sea levels. No country is likely to be immune from the effects of global warming, but those with extensive coastlines, such as Ireland, have particular reason for concern.

The causes of global warming are not well established. Most climatologists accept that increasing carbon dioxide levels in the atmosphere due to human activities, are an important contributory factor, however, this effect is superimposed on top of long term changes due to 'natural' causes, such as the well documented *Little Ice Age* which occurred from 1570 to 1730 AD. The relative importance of the natural and the human-induced global warming is controversial; some scientists believe that increasing carbon dioxide levels are entirely responsible, whereas others hold that natural causes due to changes in the Sun predominate.

Our first priority must be to look at whatever data we can find to assess how variable the climate was over past centuries and millenia in order to assess the background against which the modern trends can be compared. Secondly we must try to ascertain what physical processes have been at work to produce these changes in the past and how they will affect future climate.

*Paper presented to AGU conference  
29 Feb 2000 Dublin*

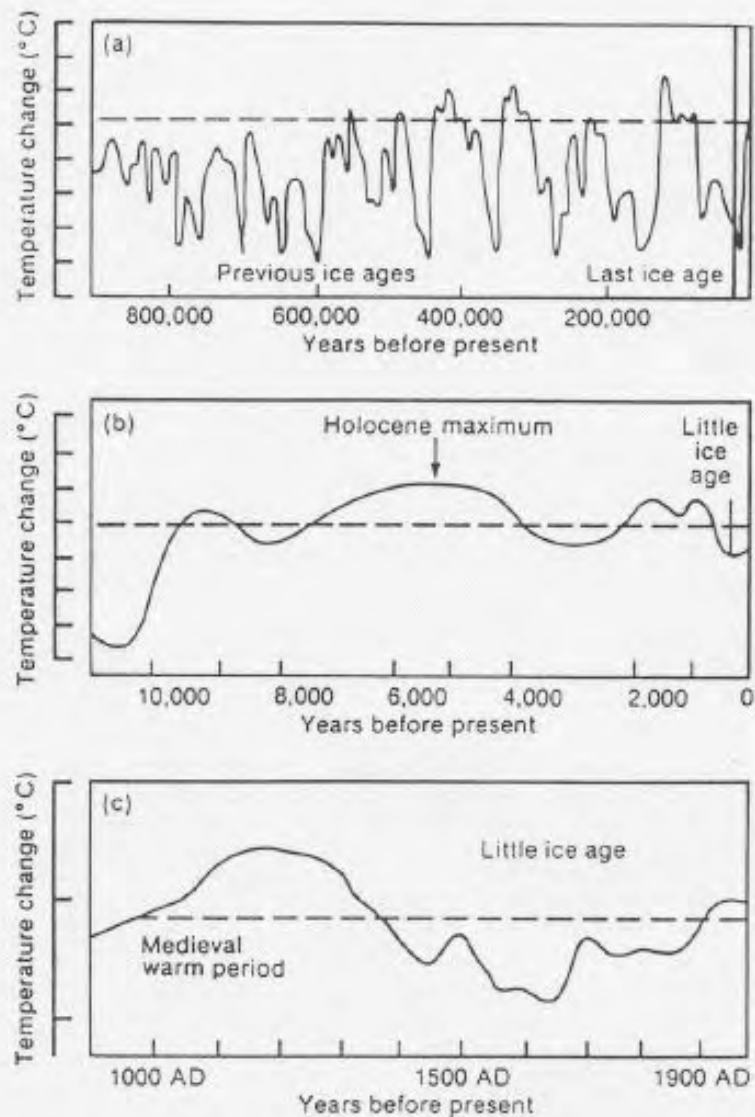
## Climate Change in the Past

Geological evidence indicates that the Earth has in the past suffered wide departures from its current relatively temperate state. For approximately 98% of the last 600 million years of Earth's history, the average global temperature far exceeded current levels, with a mean global temperature of  $\sim 22^{\circ}\text{C}$ . as compared to  $\sim 14^{\circ}\text{C}$ . at present. There is no real reason to suspect that we shall not eventually, on a time-scale of millions of years, return to this state. Indeed, the slowly increasing brightness of the Sun (by approximately 1% per 100 million years), brought about by the gradual enlargement of the hydrogen burning core of the Sun, will eventually ensure that temperatures go well beyond previous hot periods. But of somewhat more immediate interest to us are the dramatic periods of global cooling termed the *ice ages*, which last overall for a few million years and from which we are currently in a temporary respite. The ice age periods are broken up by interglacial periods lasting several tens of thousands of years, one of which we currently enjoy. During these brief interglacials, temperatures lie roughly halfway between the extremes of the very hot periods and the ice ages proper. In table 1 we give the general characteristics of these three principal climatic regimes, the hot, the cold and the interglacial. Though we know the Earth has moved between these three states in the past, it is evident that there may not be a strictly defined separation and that many intermediate stages may occur. However it is of interest to note how similar the timescale of the last great ice age is to that of the evolution of the human race in its present form, which is strongly suggestive that mankind is in some ways a product of the ice ages.

Table 1. Climatic Stages

Stage	Duration	Interval	Mean Temp. ( $^{\circ}\text{C}$ )
Hot	245my	250my	22
Ice Age	few my	250my	6
Interglacial	10-30ky	100ky	14

Our current understanding is that ice age conditions will return in the next few millenia. This is due to gradually changing parameters associated with the Earth's orbit around the Sun which are cyclic and lead to a predictable change in the average radiation received by the Earth at different seasons. Currently, we are well past the optimum conditions for the melting of ice in the northern hemisphere summer which are believed to be required for the ice-caps to retreat and an interglacial to develop. As time progresses and we move further from the optimum, if there is a sudden drop in temperature due to volcanic activity, ocean current changes, cometary or asteroid impact, or whatever, the ice formed in winter does not melt during the following summer and we enter a new ice age from which we cannot recover until the next optimum occurs some hundred thousand years later.



**Figure 1.** A schematic diagram illustrating global temperature variations over the past million years: (a) the last million years, (b) the last ten thousand years, (c) the last thousand years. (from *'Climate Change – The IPCC Scientific Assessment'* 1990)

Thus, on the timescale of millenia, we are poised to enter a new ice age and the question arises whether or not we should be grateful for a little, possibly temporary, global warming; from whatever cause? The alternative, I think most from these latitudes would agree, would be far less comfortable, if not totally disastrous for mankind in northern Europe. Recent evidence from oxygen isotope ratios taken from ice cores drilled from the Antarctic and Greenland ice caps indicates that the descent into an ice age can occur quite abruptly, on the timescale of a decade or so and within a human lifetime.

Leaving aside these very long term changes, even though they may occur quite suddenly, we are interested to know how climate has changed over recent millenia, since say, the arrival of man in Ireland around 7,000 BC. From knowledge of the species which flourished at that time, we can build up a picture of how the climate changed after the end of the last great ice age 10-15 thousand years ago. During the neolithic period (C 4000-2000BC) temperatures are believed to have been one or two degrees above their current levels. However, early in the first millennium BC, a sudden fall in temperature, along with increasing levels of rainfall, lead to a deterioration in climate followed by the formation of extensive bogs in NW Europe in general and Ireland in particular. Temperatures remained low during the first millennium BC but recovered somewhat during classical and Roman times. A further, perhaps more prolonged, warm period occurred in the late medieval period when vineyards prospered in central England. It is interesting to trace the migration of mankind under the influence of climate change during the centuries since Christ - the occupation of most of Europe by the Roman legions in the early centuries, their retreat in later centuries, the migration southwards of the Danes and Vikings during the ninth and tenth centuries and the Norman conquest of Britain and Ireland in the 11th and 12th centuries at a time when these islands again became attractive to the inhabitants of more southerly countries, (see Lamb, 1982).

From around 1300, the climate again took a distinct turn for the worse as Europe entered a cold period which lead into the *Little Ice Age* - a prolonged period of cool climate that reached its peak in the 17th and early 18th centuries. Indeed some climatologists would suggest that this cool period lasted well into the 19th century and that the current global warming is merely part of the recovery.

During the present century we have seen further warming but not in a strictly monotonic fashion. Temperatures rose quite steeply in the period 1900 to 1940, then levelled off and indeed fell for a decade or two after which the warming has resumed till the present day.

Thus, our conclusions, based on the empirical evidence available, much of it from proxy temperature indicators such as tree-ring widths, prevalence of species and isotope ratios, is that the Earth's climate is variable on all timescales from decades to millions of years and that this variability has, in the past, come about through natural causes not related to the activities of mankind.

### **Causes of the current Global Warming**

Many physical mechanisms have been proposed to account for the climate change that has occurred on Earth. As with so many complex systems, it sometimes helps to clarify the situation if one considers the system at its most basic level. To a first approximation, we can consider the Earth as an isolated body orbiting the Sun on which the incident radiation from the Sun is balanced by the outgoing radiation from the Earth. The inward directed radiation from the Sun can change due to inherent solar variability and from geometrical effects associated with the Earth's orbit around the Sun.

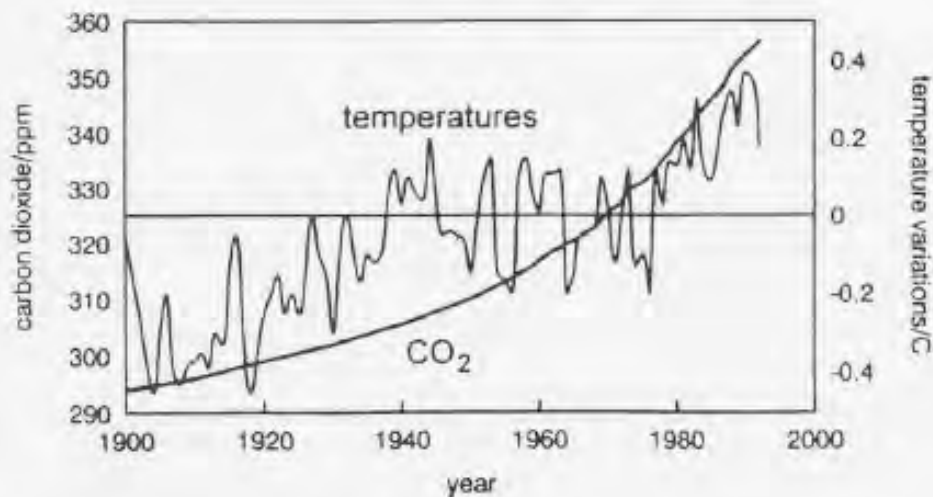
The outward directed radiation is partly solar radiation reflected by the clouds, the ice caps or the Earth's surface, whether it be land or sea, and partly infra-red radiation emitted from the Earth. As with the incident solar radiation, the outgoing radiation can also be reflected back to Earth by overlying clouds in the atmosphere. In addition, there are minor constituents in the atmosphere such as water vapour, carbon dioxide and methane, which are transparent to radiation in the visual and near infra-red but opaque to the far infra-red. These gases, which allow short wavelength solar radiation to penetrate to the Earth's surface but obstruct outgoing infra-red radiation, are known as *greenhouse gases*.

In addition to the gaseous component of the atmosphere, small particles of dust, whether of volcanic or meteoritic origin can increase the reflectivity (albedo) of the Earth and thereby alter the proportion of the incident solar radiation that is absorbed by the system. If any component of the energy entering or leaving the system changes, then some other component of the system must also change in order to restore the balance between ingoing and outgoing radiation.

When the current global warming trend was first recognised, climatologists were quick to point to the rising carbon dioxide levels from man's industrial activities as a possible cause via an enhanced greenhouse effect. This conclusion was reinforced by subsequent ice core measurements of carbon dioxide concentration during the last glacial maximum and previous interglacial which showed a roughly parallel rise in carbon dioxide and global temperature. Early computer models of the behaviour of the atmosphere however gave an excessive temperature rise as they did not take into account the cooling effect of sulphur compounds in the atmosphere; also a byproduct of industrial activity. Throughout the period during which the enhanced greenhouse effect has been considered the most likely candidate, the case of Venus with its 90% carbon dioxide atmosphere and huge greenhouse effect (523 deg C.) has served as a warning to what might happen on Earth if a runaway greenhouse effect were to become established here.

However there are problems with the enhanced greenhouse effect interpretation. Firstly, the ice core data during the last glacial maximum and previous interglacial suggest that previous rises in temperature slightly preceded the carbon dioxide increase indicating that the temperature rise may have caused the carbon dioxide enhancement, rather than vice-versa. It has been estimated that the amount of carbon dioxide dissolved in the oceans is 50 times as much as that in the atmosphere. As carbon dioxide solubility in water increases with decreasing temperature, a global warming from whatever cause, would drive carbon dioxide from the sea and increase its concentration in the atmosphere.

A further difficulty with the enhanced greenhouse effect mechanism for global warming is that the carbon dioxide and temperature trends in the 20th century (during which we have reliable instrumental temperature data) do not follow each other closely. It has been pointed out by Soon et al. (2000) that whereas half of the temperature rise from 1900-1990 occurred in the interval 1900-1940, only 20% of the carbon dioxide rise occurred at that time. In addition, we note the hump in the temperature that occurred from 1940-1950 and the slight fall in temperature in the 1960s and 70s which preceded the current upward trend. During this whole period the carbon dioxide concentration in the atmosphere increased monotonically. This fact alone is strong evidence that some other mechanism is involved.



**Figure 2.** Mean sea and surface temperature changes plotted together with the atmospheric carbon dioxide concentration (parts/million). (from Barrett, 1996)

Volcanic activity on Earth, which increases the amount of dust in the upper troposphere and sometimes the stratosphere, is known to affect the Earth's climate. The dramatic eruption of Mount Pinatubo in the Philippines in 1992 led to an increased albedo for the earth and a reduced transparency of the atmosphere giving rise to lower than normal temperatures in the troposphere for the following two years. Similar effects can be seen in tree-ring data throughout history - one of the most dramatic being the decade-long cool period betrayed by narrow tree-rings around 1150BC which coincided with the eruption of the volcano on Santorini and is believed to have wiped out the Minoan civilisation on Crete, (see Baillie and Munroe, 1988).

So far, we have discussed how atmospheric changes, whether caused by man or not, may affect the global climate through an enhanced greenhouse effect or albedo changes. The other possible cause of climate change is a modification of the solar energy received by Earth, either through the variability of the Sun itself or changes in the incident solar radiation due to changes in the Earth's orbit. Whilst the latter are reasonably predictable, depending as they do on the dynamics of the solar system, the intrinsic variability of the Sun is not well understood, in particular the variability of its magnetic field.

What evidence is there that solar variability affects climate? Overall, the energy radiated by the Sun has been observed to vary by ~0.1% over the past decade or so since precise satellite observations have been made. This is not sufficient to cause global temperature changes of the amplitude seen in this century.

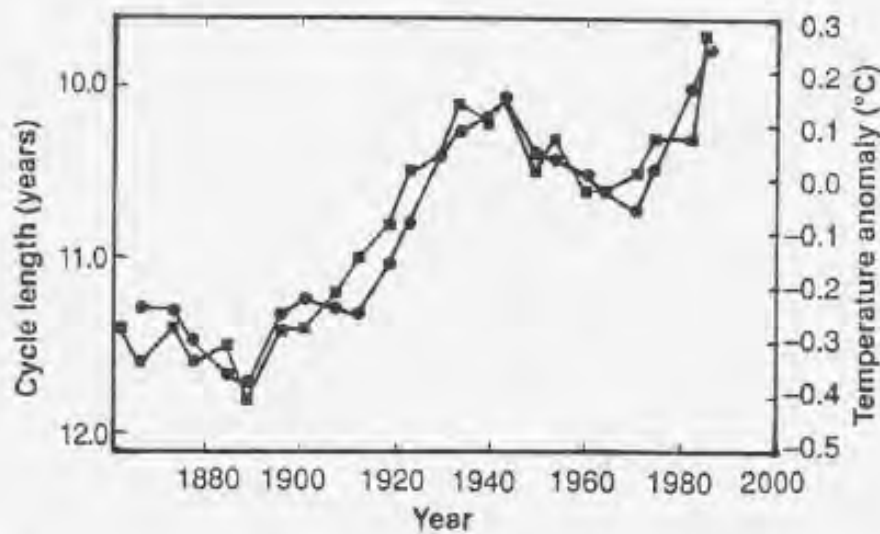
Apart from the long term increase in brightness of the Sun predicted by evolutionary theory and mentioned earlier, the most obvious aspect of solar variability is that associated with the Sun's magnetic field. The solar magnetic field has a roughly 22-year cycle in which the polarity of the field switches from one half of the cycle to the next. The two halves of the cycle form the well known *Schwabe* or 11-year solar cycle, most conspicuous in the sunspot number and which has been known for over 150 years. The

literature reports many attempts to link the sunspot cycle with climate change, one of the most obvious of which is the apparent coincidence of the *Maunder Minimum* (1650-1720), during which very few sunspots were observed, and the coolest part of the *Little Ice Age*. However, from carbon isotope analysis of tree rings, it is possible to derive information on the solar activity levels in earlier centuries when records of sunspots are few or nonexistent. This allows us to compare known climate changes with solar activity levels over a much longer period. A list of abnormal climate conditions and unusually high and low solar activity levels is given in Table 2. It is evident, from this table, that cool periods almost invariably accompany low solar activity and warm temperatures accompany high solar activity levels.

**Table 2.** Comparison of Temperature and Solar Activity Extremes, 1000 BC - 2000 AD

Temperature Extremes			Activity Extremes		
Name	Warm/Cold	Interval	Name	High/Low	Interval
Late Bronze Age	C	c850BC		L	850BC
Medieval Optimum	W	1100-1300	Medieval Max.	H	1100-1300
14thC Cold	C	1300-1490		L	c1350
				L	1470-1530
Little Ice Age	C	1570-1730	Maunder Min.	L	1650-1720
Early 19thC Cold	C	1800-1820	Dalton Min.	L	1795-1820
Modern Warm	W	1980-	Modern Max.	H	1980-

Other corroborating evidence comes from spectral analysis of time series of climate and activity related parameters. Such analyses often show up periodicities in both types of parameter of similar length. For instance the 11 and 22 year magnetic cycles of the Sun also appear in sea-surface and polar temperatures, as well as in rainfall in various parts of the world. The longer cycles of 80-90 years (the *Gleissberg Cycle*) and 180-220 years, associated with the modulation of the envelope of solar activity, are also found in tree ring widths of some long-lived North American species. However, the most dramatic confirmation of an influence of solar activity on global temperatures was the almost perfect correspondence between changes in the sunspot cycle length and average temperatures in the northern hemisphere shown by Friis-Christensen and Lassen (1991). This correspondence (see Figure 3) convinced many former sceptics of the validity of the solar activity - climate connection.



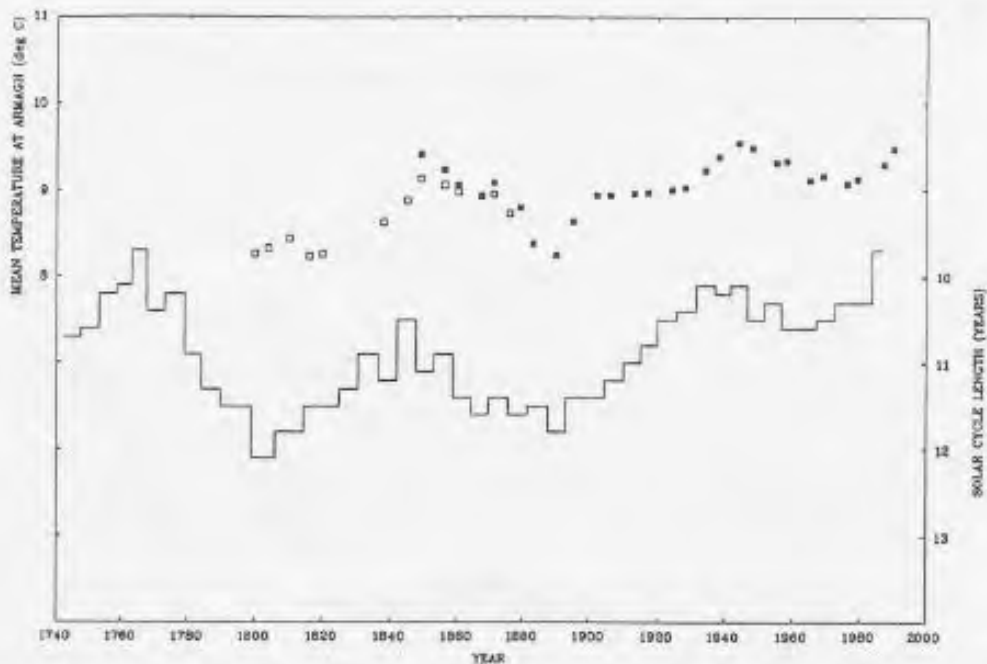
**Figure 3.** The northern hemisphere mean temperature anomaly (circles) and the length of the sunspot cycle (squares) since 1865. (after Friis-Christensen and Lassen, 1991)

The length of the solar cycle, which averages 11 years, has varied in the past from 9.5 to 13 years, with shorter cycles roughly corresponding with periods of higher activity and longer cycles of low activity. But why chose solar cycle length from all the available solar activity parameters? The answer appears to be because it fits! However unsatisfactory this may be, the closeness of the fit during the 20th century as compared to the poor fit of the carbon dioxide concentration, convinced many that solar activity must play some role in the current global warming. Further evidence for this conclusion was provided by the sea ice prevalence in arctic waters (see Friis-Christensen and Lassen, 1991). The long temperature series from Armagh Observatory (Butler and Johnston, 1996) dating from 1795 was also found to confirm the FC-L result and extended it to the late 18th century (see figure 4).

Though the evidence for a link between solar activity and climate is now statistically stronger than ever before, the actual physical mechanism remains unclear. The simplest mechanism would involve a direct temperature rise from increased solar irradiance, however the satellite observations show the Sun to be brighter by only ~0.1% during sunspot maximum than at sunspot minimum. This amplitude of variation does not appear to be sufficient to explain more than about 20% of the temperature change that has occurred since the end of the last century. Nevertheless, the change predicted does go in the correct sense, with high solar activity leading to a warmer climate. What surprised many workers in the field was that during periods of high solar activity when sunspots are common the Sun is actually brighter than during sunspot minimum. If only sunspots were important the reverse would have been true as sunspots are cooler than surrounding areas of the photosphere, however active regions on the Sun also contain areas of enhanced ultraviolet emission (plages) as well as a more pervasive bright network which together with the plages dominates the reduced emission from sunspots leading to a greater solar



brightness overall (see figure 5). These results became evident once sufficiently accurate measurements of the solar energy output could be made from above the Earth's atmosphere.



**Figure 4.** 11-year mean temperatures at Armagh Observatory (points in upper figure) and sunspot cycle length (histogram in lower figure) against time. Open squares are from twice daily temperature measurements and filled squares from the mean of maximum and minimum temperatures. Note the good correspondence of peaks and troughs between the sunspot cycle length and temperature.

As the amplitude of the change in solar luminosity does not appear to be sufficient to explain more than 20% of the global cooling since the last century, other solar-related possibilities must be considered. The variability of the Sun is highly wavelength dependent with almost all of the variation occurring in the ultraviolet and X-ray regions. The near infra-red, where most of the solar energy is emitted, remains practically constant. It is the high energy ultraviolet and X-ray radiation that has most affect on the upper atmosphere of the Earth, producing the ozone layer and raising the temperature of the stratosphere. But the Sun also produces copious particle emission, particularly from open magnetic structures such as coronal holes. These impact on the Earth's atmosphere and are strongly related to the Sun's magnetic state.



**Figure 5.** A view of the Sun in an ultraviolet emission line showing the bright network and plage regions surrounding a spot in the Sun's photosphere.

Another promising line of enquiry is the effect of the solar magnetic field on incoming cosmic radiation from the Galaxy. The interplanetary magnetic field, which is highly dependent on the solar field, deflects cosmic rays from the Earth during periods of high solar activity and allows them to pass through to Earth during low activity. Thus, a plot of the flux of cosmic rays with time is a mirror image of the sunspot number variation. Though the cosmic rays penetrate to ground level, their maximum ionisation in the atmosphere occurs between 10 and 20 km altitude. It is possible, and indeed there is some evidence to support the suggestion, (see Svensmark and Friis-Christensen, 1997), that the solar induced changes in cosmic rays directly affect the cloudiness over oceans and thereby alter the Earth's albedo and energy balance. Clouds both warm and cool the Earth, depending on their height and the time of day - on average, however, it is believed high clouds warm and low clouds cool the climate. Detailed studies of these effects are underway and we can expect some results in the near future.

Meanwhile, attempts have been made to fit the global temperature trends by various combinations of carbon dioxide induced enhanced greenhouse effect and solar activity effects. In all cases it appears that some solar activity effect must be included to give the

general shape of the temperature curve since the last century, as discussed earlier. It is even possible that all of the effect can be accounted for by solar activity, however most attempts find that a reasonable fraction of the variation that has occurred since the 19th century must be attributed to the greenhouse effect, particularly in the second half of the 20th century. However, these trend fits do not include a true physical interpretation of how the solar activity effect may work and usually include some arbitrary *stretching factor* which amplifies the known change in total solar brightness.

### Conclusions

In this review we have seen that the evidence of proxy temperature indicators from ice cores, tree rings, geological data etc, shows that the climate of the Earth is variable on all timescales from decades to millions of years from natural, but as yet not fully understood, causes. The changes that have occurred over the past century seem to be well within the limits of variability that has occurred in the past and indeed are very much smaller than the wider departures which have previously occurred on millennial timescales and which could quite reasonably be expected to return from purely natural causes. However, this does not rule out the possibility that some of the recent global warming is due to industrial pollution and that this may prove to be a serious concern in the future. Though we have made significant progress in the last decade we still need to devise a viable physical mechanism for the observed influence of solar activity on climate before we can ascertain just how much global warming remains to be explained by the greenhouse effect. However, even when we have that knowledge and are able to bring pollution effects under our control, it is unlikely that we shall be able to avoid substantial climate change in future of a purely natural origin.

**Acknowledgements:** Research at Armagh Observatory is grant-aided by the Department of Culture for Northern Ireland.

### References:

- Baillie, M.G.L. and Munro, M.A.R., 1988, *Nature* 332, 344.
- Barrett, J., 1996, *'The Global Warming Debate'*, Emsley, J. (ed), ESEF.
- Butler, C.J. and Johnston, D.E., 1996, *J. Atmos. Sol. Ter. Phys.* 59, 1225.
- Friis-Christensen, E. and Lassen, K. 1991, *Science* 254, 698.
- Lamb, H. 1982, *Climate History and the Modern World*, 2nd Ed., Routledge.
- Soon, W., Balliunas, S.L., Robinson, A.B., Robinson, Z.W. and Idso, S.B., 2000, *Climate Research* (in press)
- Svensmark, H. and Friis-Christensen, E., 1997, *J. Atmos. Sol. Ter. Phys.* 59, 1225.

