IS CLIMATE CHANGE OCCURRING ALREADY?

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Introduction

Climate change and its possible link to human activities is a complex and emotive issue. The consequences of possible global warming are of great concern to each of us as inhabitants of our planet and to the energy industry, because of the adverse direct and indirect effects of inappropriate policies that might be implemented following the Rio Climate Convention (FCCC)[1)] to mitigate the accumulation of greenhouse gases in the atmosphere.

In an overview of the science of climate change (HSE/3, December 1994 (reference 1)) it was suggested that the scientific rationale for expecting climate change in response to continued man-made changes in atmospheric greenhouse gases cannot be dismissed. However, it was not possible at that time to assert that climate change is already occurring. Moreover, the Intergovernmental Panel on Climate Change (IPCC) itself had suggested that possibly 10 more years of observation and analysis would be required before such a "climate signal" might be unequivocally detected (reference 2).

Since the December 1994 report a number of claims have been made that the climate signal is now being detected. For example, on 1st April 1995 the Economist carried an article entitled "Reading the patterns, the evidence that greenhouse gases are changing the climate is getting stronger", while the New York Times (23rd May 1995) carried an article under the heading "More extremes found in weather pointing to greenhouse gas effect". Perhaps of greater significance, the latest IPCC Second Assessment report (reference 3) states:

"the best evidence to-date suggests that global mean temperature changes over the last century are unlikely to be entirely due to natural causes and that a pattern of climate response to human activities is identifiable in observed climate records".

The purpose of this paper is to examine the evidence that supports the claims that the climate signal is being detected.

The nature of the problem

The search for a climate signal is broken down into two questions:

1. Is global climate changing? - in other words, the "detection" issue.
2. If so, what is the cause of change? - the "attribution" issue.

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1) Framework Convention on Climate Change

Given the vast amounts of directly measured climate data available going back a century and more, the detection issue would appear to be the more easily resolved of the two. However, even detection is not straight forward. The historical record (figure 1) of global mean surface temperature is clear. Over the last century average temperature has risen by about 0.5 °C but the same record also shows large apparently random annual changes in mean temperature, as well as other trends including periods of decreasing temperature. The 0.5 °C change is well within the range of temperature variations detected even over recent geological time scales, such as the Little Ice Age in the middle of the millennium.

The detection problem arises because any climate change "signal" due to human influences, (such as changes in the emissions of greenhouse gases) is super-imposed on the background noise of natural climate variability. Natural climate variability has both internal and external components. The internal component is due solely to interactions within the coupled atmosphere-ocean-ice-land-biosphere system. The external component is primarily caused by natural changes in the Sun's output or in the volcanic aerosol loading of the atmosphere. Detection is thus by nature a statistical problem in which one attempts to determine whether the signal is significantly large relative to the noise.

For attribution, the established scientific method for investigating cause and effect is to carry out a series of experiments in which the response of a system to different perturbations (possible causes) is studied systematically. This technique cannot be used to study the real climate system. We have only one earth, and can only observe one evolution of our climate system. Our experimentation with the real earth's climate is not being done in any systematic way - we are varying a number of causes simultaneously (e.g. by changing land surface properties, concentrations of atmospheric greenhouse gases, and man-made sulphate aerosols, etc.), rather than changing an individual cause, observing a climate response, and then varying the next cause.

Experimentation is therefore limited to numerical models. The attribution of a detected climate change to a particular cause can be established only by testing competing hypotheses. Unique attribution of a detected climate change requires the explicit specification of the climate change signals of all possible competing causes, and statistical determination that none of these causes (either individually or in combination) could satisfactorily explain the observed changes. This is clearly a very difficult, if not impossible, task. Attribution could therefore never be certain even in a statistical sense. We can state only that the available observations are consistent or inconsistent with a postulated hypothesis at a given significance level, accompanied by the caveat that other explanations for the detected climate change signal cannot be ruled out, unless a rigorous attempt has been made to do so.

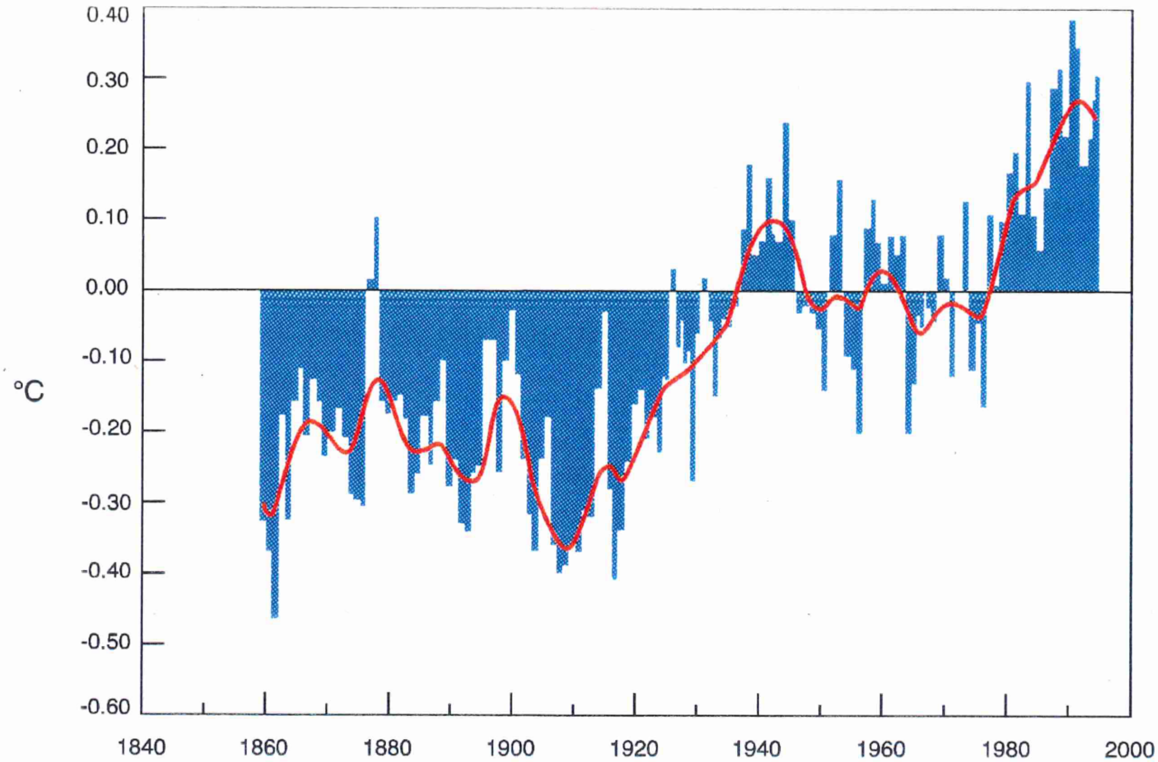
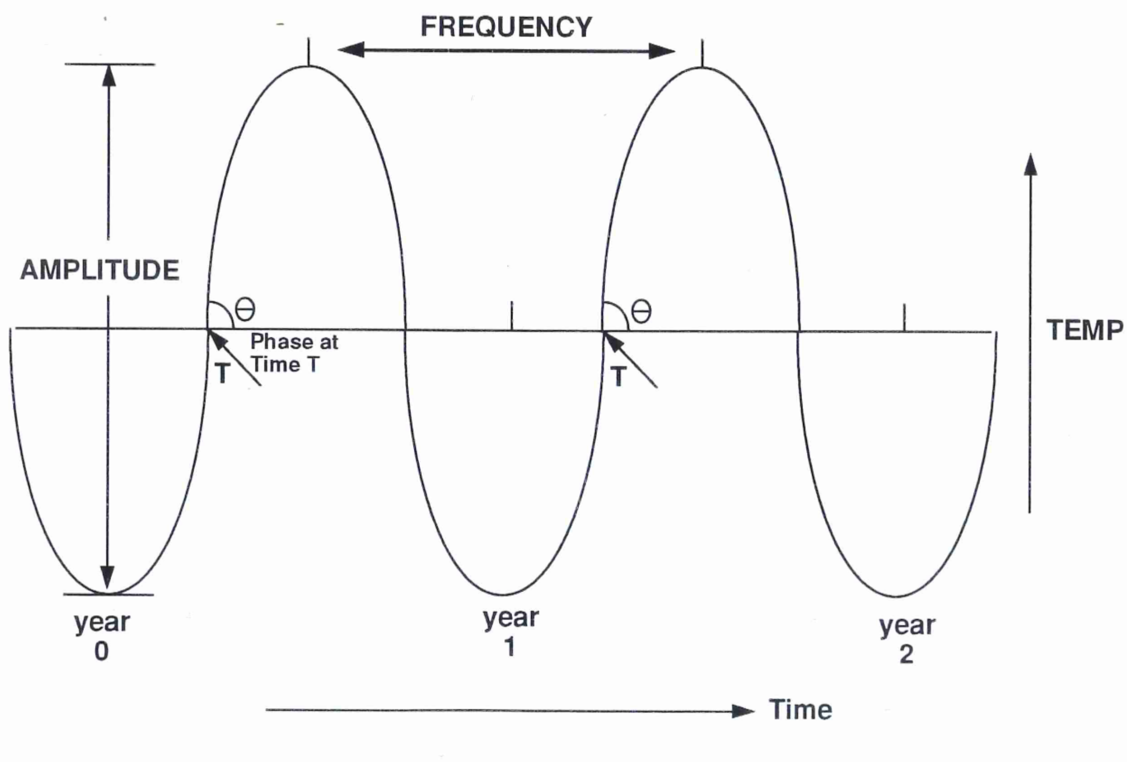


Figure 1 Combined land air and sea surface temperatures relative to 1951-80 averages

Figure 2



Schematic Analysis of the wave form of a seasonal series of temperature measurements made at a single location. The frequency of the wave is one year and the amplitude is the difference between the maximum (summer) and minimum (winter) temperatures. The timing of the seasons (phase) is defined by the angel θ at a given time, T, during the year.

In summary, statements regarding the detection and attribution of man's effect on climate are inherently probabilistic in nature. They do not have simple yes or no answers. The probability of success for detection of such an effect on climate will be given in ranges rather than as discrete values. Attribution is feasible only in the sense of demonstrating that the observed change is consistent or inconsistent with the climate responses to a given set of external forcing mechanisms.

The timing of the seasons - a novel approach

Possibly the most interesting recent publication on climate change is that by David Thomson from AT & T Bell Laboratories (reference 4). The interest stems from the surprising nature of his findings and his novel approach to study of the climate signal issue. Thomson is not a meteorologist but a notable figure in signal processing research. Recognising the difficulty of constructing the history of global average temperature from a meagre set of sampling locations, Thomson instead considered in detail particular sites with exceptionally long historical records. But he did not examine average temperature. Rather he carefully tracked the annual cycle, i.e. the timing (phase) of the seasons, using measurements from central England between 1651 and 1991 and a number of other locations in the Northern and Southern hemispheres.

Thomson treats the rotation of the earth around the sun (giving rise to seasonal changes in temperature) as a wave form that can be analysed in the same way as a radio wave. Radio waves carry information through changes in amplitude (Amplitude Modulation, AM) or frequency (Frequency Modulation, FM) of a carrier wave. Similarly the earth's rotational wave form (the carrier) evident as the seasonal variation in temperature, can be analysed for any temperature signals by complex statistical demodulation techniques. This is shown schematically in figure 2. The timing of the seasons is defined by the angle θ_T at a given point in time T during the year.

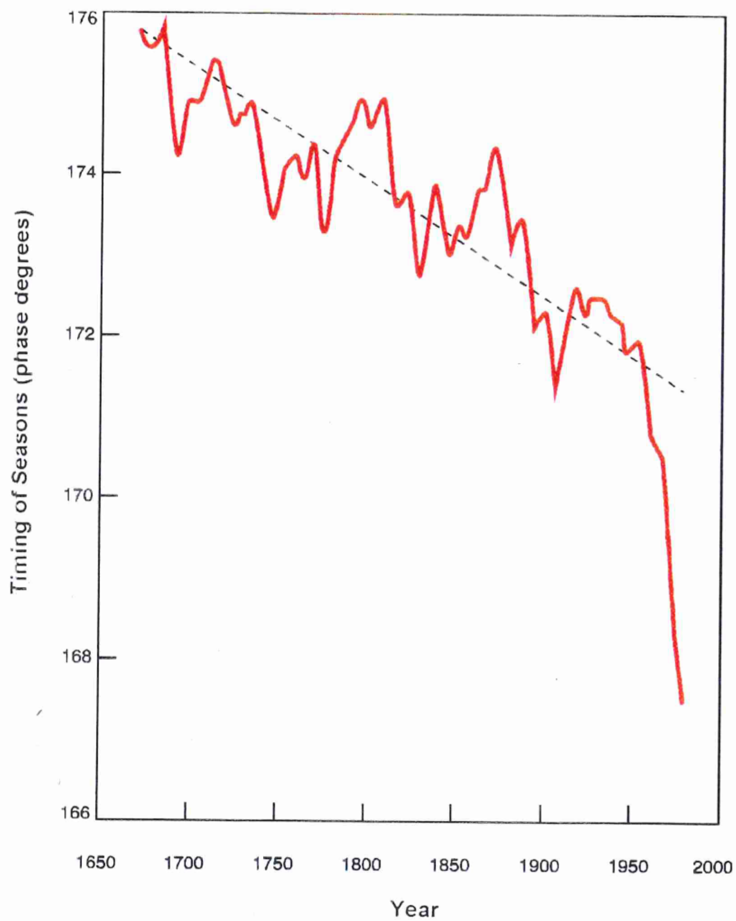
Our Gregorian calendar was designed to stay synchronised with the tropical year, i.e. the interval between the equinoxes. However, earth has a slightly eccentric orbit around the sun such that it is 0.0167 times closer at perihelion (January 3rd) and further away at aphelion (June 22nd). The time from perihelion to perihelion (the anomalistic year) is slightly longer than the tropical year by about one day per century. Thomson's analysis of the Central England series (figure 3) shows that the timing of the seasons has been changing by approximately one day per century, that is, in line with the anomalistic year. However, since the 1940s, a pronounced change in the timing of the seasons has appeared.

Figure 3

Change in timing of seasons (phase) for the Central England temperature record.

The slope (dotted line) shows that between 1650 and 1950, the timing of the seasons has been showing a steady shift of approx. 2 degrees in 300 years (i.e. 2/3 of a day per century)

Since 1950, the rate of change of this shift has significantly increased suggesting some systematic change.



Thomson uses his data to argue against solar variation as a cause of recent warming. He claims that only CO_2 changes are "significantly coherent with the observed recent large changes in phase [i.e. timing of the seasons] and average temperature".

In claiming a connection with CO_2 increases, Thomson glosses over important issues related to changes presumed to result from an enhanced greenhouse effect:

1. Simple physical reasoning (confirmed by models) shows that temperature changes driven by increases in greenhouse gasses do not occur instantly. While Thomson correlates change in temperature and CO_2 concentrations at the same time, effects should be related to lagged cumulative changes in greenhouse gases. It is unclear what effect this might have on his conclusions.

2. Temperature changes are expected to be related to the total effect of increases in all greenhouse gases and aerosols. Aerosol effects can result in large regional differences. Thomson's claims are based on correlations related only to CO_2 changes. Again the implications of these model-dependent aspects will have to be examined to see what effect they might have on his conclusions.

3. Thomson's conclusions are not based on statistical comparisons of predictions and data, but simply on empirical correlation between this trend and that trend. In many cases they have little or no quantitative or physical justification. They are in no sense a test of climate models.

The verdict of the climatologists is best expressed in the conclusions of the draft IPCC Second Assessment Report (reference 3):

"The occurrence of this phase shift at a time when atmospheric greenhouse gas concentrations and anthropogenic aerosol loadings were increasing rapidly is interesting information, but it does not prove that a causal relationship exists".

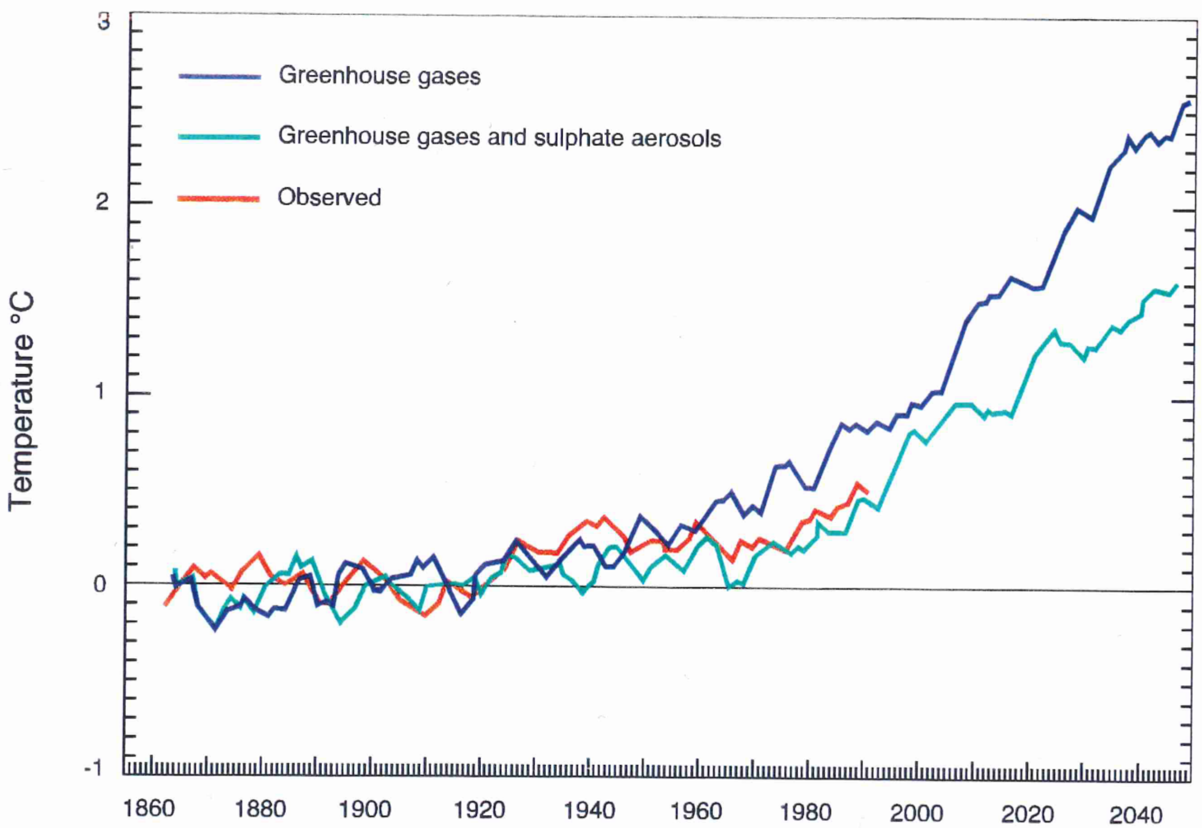


Figure 4 Predicted (1860-2050) and Observed (1860-Present Day) Surface Air Temperature changes (°C)

This paper makes an important contribution to the analysis of global trends with time. Findings about trends appear to be interesting and, perhaps, important. However, conclusions about the cause of change are premature and incomplete. The implications of the paper for confirmation or detection of climate change from an enhanced greenhouse effect are completely unclear at this time.

Climate modelling and aerosols

The second important recent publication on the detection/attribution issue has come from the UK Hadley Centre for Climate Prediction and Research (reference 5).

One of the major criticisms of climate models and of those who claim that the climate signal is detectable is that, while warming of 0.5°C is detectable over the last century, this is only about half the warming that is predicted by complex climate models. Since pre-industrial times, the CO_2 equivalent concentration of greenhouse gases in the atmosphere has risen by about 40%. This is no small amount, and it is an amount that should be big enough to produce an effect on global temperature.

The possible influence of sulphate and other aerosols on the global energy balance has been known for some time. In the 1994 Interim Report of the IPCC (reference 6), aerosols were estimated to have a direct cooling effect of some 1 W/m2 with an indirect component of similar magnitude (both of these estimates having large ranges of uncertainty). This compares with a direct warming effect of the trace greenhouse gases of 2.5 W/m2. In other words aerosols are known to be capable of offsetting the warming potential of greenhouse gases.

The Hadley Centre runs one of the largest and most comprehensive general circulation models (GCM) in the world. It include representations of the atmosphere, oceans, ice and vegetation. The report describes experiments in which the historic temperature record is modelled from 1860 to 2040 with and without estimates of the effect of sulphate aerosols. The results (figure 4), requiring 3 months computation time on one of the worlds fastest super-computers, show that the slow rise in global temperature since the middle of the last century can be replicated in broad terms. If greenhouse gases alone were influencing climate we would expect global temperatures to have risen some 0.6 to 1.3°C over the last century. By taking into account the sulphate aerosols, the model simulates a rise in temperature close to the observed 0.5°C. Moreover, the implied climate sensitivity (the global mean temperature response to a doubling of CO_2 equivalent greenhouse gas concentrations) at about 3°C is in the middle of the range of previous estimates of 1.5 to 4.5°C.

There is no doubt that this is an important step in the evolutionary process of identifying and predicting possible climate change. But at this stage there are a number of important caveats which do not preclude the possibility that this is just another arbitrary "tuning knob" used to force a model to more closely mimic the historic temperature record. This criticism has been justifiably levelled at the physically unrealistic adjustments to the flow of heat and water vapour between the ocean and atmosphere - the so-called flux correction factors used in this and other GCMs.

Caveats concerning the modelling of aerosols include the following:

1. Aerosols are of two main types: sulphate aerosols from both fossil fuel burning and natural sources (volcanoes, biota) and other aerosols e.g. soot from biomass burning. The experiment only covers sulphate aerosols.

2. Aerosols have direct and indirect effects. The indirect effects include acting as nuclei which promote cloud formation, which in itself may strongly effect the global radiative balance either negatively or positively. As far as the paper indicates, only the direct effects were considered.

3. Aerosols have life times of only days as opposed to hundreds of years for CO_2. There are no reliable historic data on the amounts and distribution of aerosols, even of those sulphate aerosols from fossil fuel burning. While the report is unclear on this point it is likely that sulphate aerosol quantities and distribution patterns are based on assumptions rather than data.

Insurance industry joins the battle

In recent months parts of the insurance industry have espoused the view that the climate signal has arrived and is evident from the mounting compensation claims from severe storms and floods. "Munich Re Feels Global Warming Impact on Growth" ran a headline in the Financial Times on the 9th November 1994. According to the article, Mr Wolff Otto Bauer, a director, is convinced the global trend to more frequent and damaging catastrophes would continue in the long term. "The signs that we are experiencing such a change in climate are increasing". Action groups have been keen to capitalise on this, most notably through a joint publication of Greenpeace and the insurance industry distributed at the first Conference of the Parties in Berlin.

Despite this, the factual evidence for this claimed increase in extreme weather events is remarkably absent. A recent paper (reference 7) deals with an analysis of the very comprehensive data available for the last hundred years at the US National Climate Data Centre. This study looks at a broad range of climate indicators for the USA including temperature, precipitation and drought, cloud cover and tropical storms. These have been used to develop a climate extreme index (CEI), the annual average of 5 indicators that measure unusual levels of temperature, precipitation events (or non-events), drought or moisture surplus. To the lay observer, there is nothing in the CEI data (figure 5) to suggest that the present level of the index is unusually high. Indeed the data series seems merely to emphasis the high level of background noise in the measure. To quote the authors of the paper:

"the CEI supports the notion that the climate of the US has become more extreme in recent decades, yet the magnitude and persistence of the changes are not now large enough to conclude that the climate has systematically changed to a more extreme state".

This ambiguous conclusion seems likely to satisfy both believers and disbelievers in equal measure.

Looking at the more detailed measures reported in the paper, reliable records of the number and intensity of tropical hurricanes that reach the US go back to at least 1900. The data show that both the frequency and the intensity of hurricanes has been relatively low over the past decades as compared to the middle of the century (figure 6).

Data for severe droughts and floods (moisture surplus) are shown in figure 7. The droughts of the 1930s and 1950s stand out as remarkable events, the drought of 1934 dwarfing by comparison the more recent drought of 1988. The authors suggest that the data shows that since 1970, a greater proportion of the country has been excessively wet, with the summer time catastrophic flooding of the Mississippi river in 1993 as a notable event. However, on balance it is difficult for most readers to see any trends in the data.

For the global view of extreme weather events, the draft Second Assessment Report of IPCC (reference 3) identifies a number of increases or decreases of such events in various regions but makes a surprisingly unambiguous statement:
"there is no evidence that, world-wide, climate variability or extreme events have increased over the 20th century".
This is qualified in the report by the lack of adequate data and the dearth of analysis.

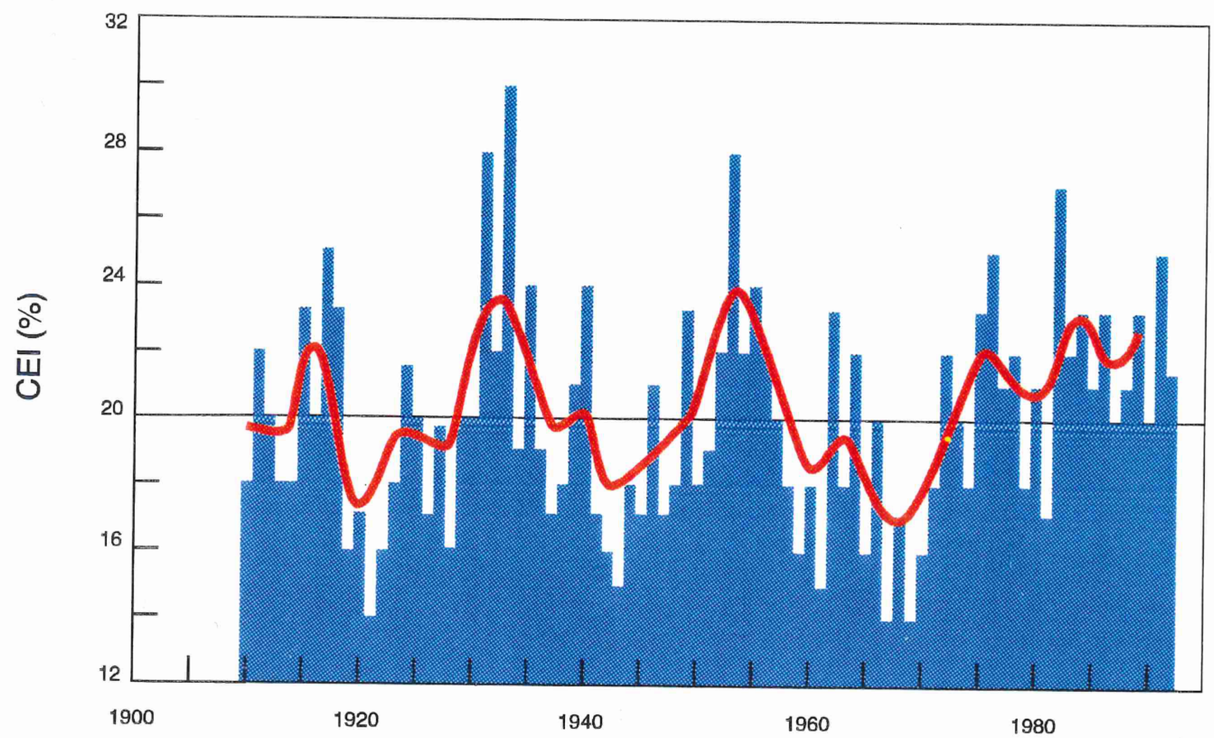


Figure 5 An annual U.S. Climate Extremes Index (CEI)

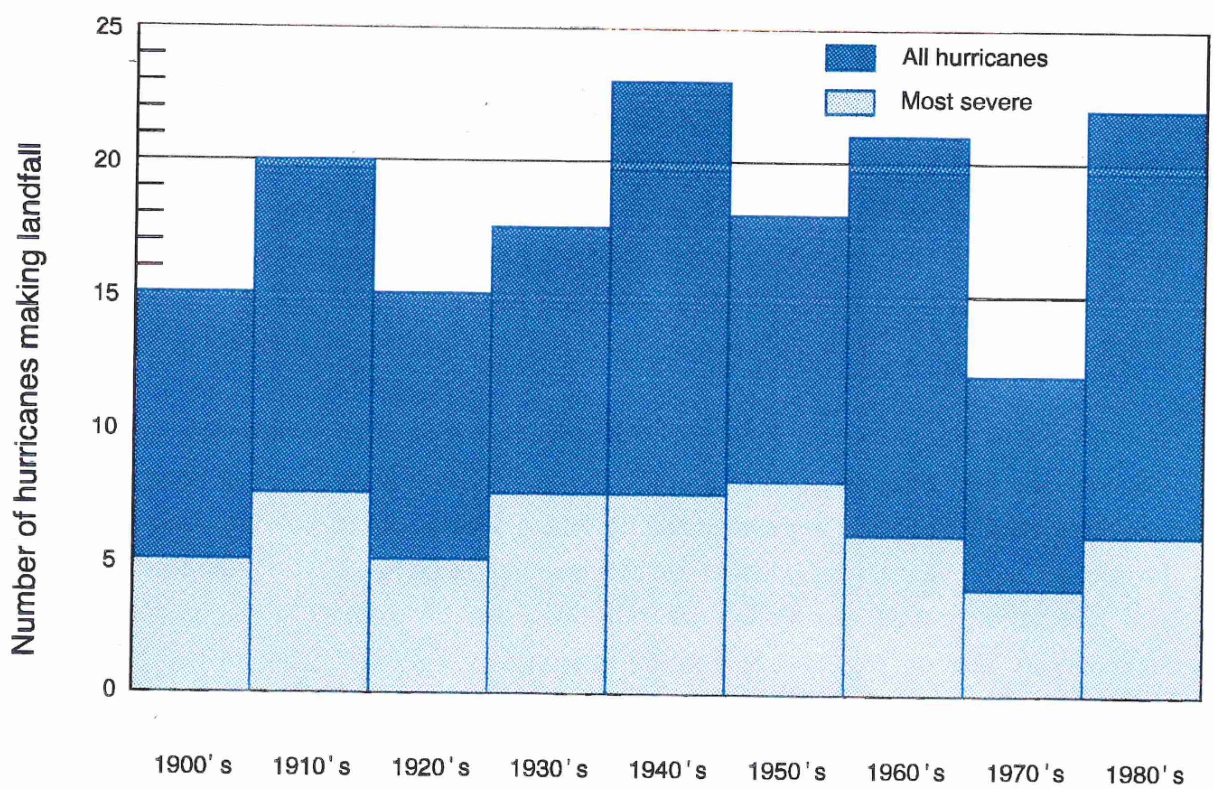


Figure 6 Number of all hurricanes (top bar) and the most severe hurricanes (lower bar) making landfall in the conterminous U.S.

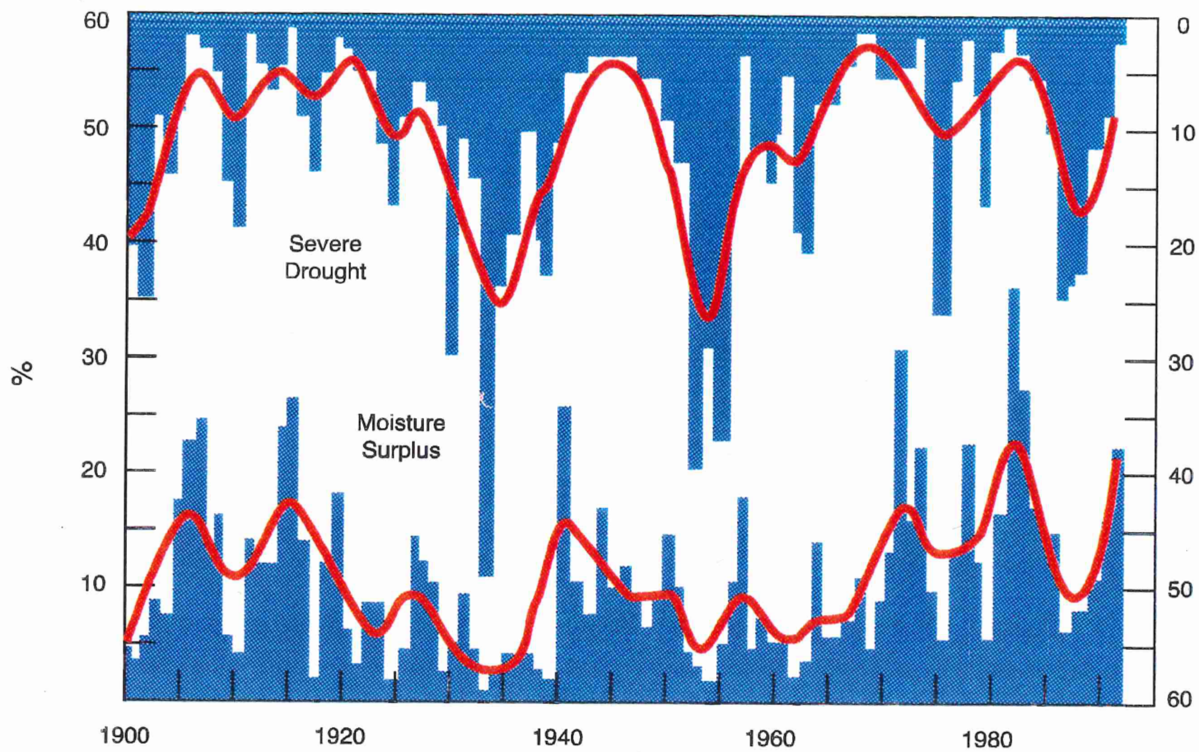


Figure 7 Percent area of the conterminous U.S. in severe moisture surplus (bottom curve, left scale) and in severe drought (top curve, right scale)

Melting of Antarctic Ice

One of the most consistent features of the predictions made by GCMs of the global climate system is that any enhanced greenhouse effect would be most evident at high latitudes, and least evident at the equator. Indeed, the historic temperature record already shows that the temperature in the Antarctic region has risen by 2.5°C in the last 50 years. There is much interest therefore in observing long term changes at the poles.

Recent, as yet unpublished, work from Ola Johannesen and colleagues at the Nansen Environmental and Remote Sensing Centre in Bergen, Norway, suggest that the polar ice caps are melting (reference 8). This is based on microwave measurements from satellites. Even without data for 1995 when an unusual number of icebergs, including one the size of the English county of Oxfordshire, broke off from the Larsen Ice Shelf in Antarctica, it is estimated that Antarctic sea ice is declining at the rate of 1.4% per decade. At the other pole, the rate of melting of sea ice is believed to have accelerated from 2.5% to 4.3% per decade.

However, the researchers themselves caution that while such changes may be statistically significant, the observations have not been made over a period long enough to determine whether it is due to natural variation or to an enhanced greenhouse effect.

So has the climate signal been detected?

As already discussed, a yes/no answer to the question cannot be given. Detection of a human induced change in the earth's climate will be an evolutionary and not a revolutionary process. It is likely that a slow accumulation of evidence, rather than a "smoking gun", will indicate man-made emissions as the cause of some part of observed climate change. While there is already a limited body of support for the existence of an anthropogenic climate signal, it is likely (if model predictions are correct) that this signal will gradually emerge more and more convincingly with time. It is probable that it will emerge first at the global scale and only later at regional scales, and that it will be clearer in some variables than in others. Convincing attribution, however, is likely to come from the analysis of full spatial patterns of change - again as an evolutionary process.

The gradual emergence of a man-made climate change signal from the background noise of natural variability, guarantees that any initial pronouncement that a change in the climate has been detected and attributed to a specific cause will be controversial. Nevertheless, if the current rate of increase of man-made emissions is maintained and if the sensitivity of the climate system is within the range predicted by current climate theory, it should become increasingly easier to eliminate natural variability and other "suspects" as a cause for most of the observed changes.

Finally we come to the most difficult question of all:

"when will the detection and unambiguous attribution of human induced climate change occur?".

In the light of the very large signal and noise uncertainties discussed here, it is not surprising that the best answer to the question is: "we do not know". Some would and have claimed on the basis of the present results, that the detection of a significant climate change has already occurred. Few if any would be willing to argue that unambiguous attribution of this change to man-made effects has already occurred, or is likely to happen in the next several years.

The Hague, 23 October 1995

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