How to tell man-made and natural changes apart and forecast the future

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Introduction:

Few would deny that the global climate is changing. But it has never been completely stable so what is so special about the general warming that has been taking place over the last century or so? Well, the main thing is that, over that time mankind has caused billions of tons of carbon dioxide (and other gases) from burning fossil fuels, cutting down forests and so on to accumulate in the atmosphere and that is thought to have caused warming due to the greenhouse effect. This gets its name because carbon dioxide in the atmosphere lets in all the sun's rays and then emits everything except part of the infra-red end of the spectrum - like the glass in a greenhouse - and thereby warms the Earth. However, long before mankind did that, the world often warmed and cooled anyway so how can we tell for sure what is causing the present warming?

Here we explore the development of a new mathematical model that distinguishes between natural and man-made climate change and goes on to forecast future changes. The model was first published in 1984 when it forecast, among other things, that continuing "business-as-usual" would lead to the rapid global warming that we saw in the 1990s and the slight cooling in the present decade. It went on to forecast a rapid temperature increase of about 0.25°C in the next three or four years, followed by a fairly stable period until another rise of about 0.4°C around 2027 and accelerating – and possibly unstoppable - increase thereafter. It is hoped that, by emphasising the model's forecast now, the long temperature stasis expected after about 2012 will not induce complacency and weaken worldwide enthusiasm for controlling the greenhouse effect.

Development of a deterministic forecasting method – the boring bit:

While the Professor of Ocean Engineering at Newcastle University in the 1970s the writer, a civil engineer specialising in geotechnics, came upon a graph by Shackleton and Cita (1979) that showed the variation of the oxygen isotope ratio of benthic foraminifera from the Late Neogene at a site in the Atlantic in which he detected pseudo-cyclic fluctuations. The data covered a period of fairly steady deposition from about seven million to only a few thousand years ago and were said to correspond to global temperature changes over that period. The fluctuations appeared to be represented roughly by three superimposed sine waves, the period of the biggest being 4.8 million years, the next 2.4 million and the smallest 1.2 million years with the amplitude of the smaller components being slightly less than that of their greater neighbours.

The same pattern was subsequently found in other proxy climate data covering longer geological time scales. For instance, by superimposing the longest of the periodicities from the 7-million year variation and seeking greater, similarly related sine components, the same relationship was detected in the record of carbonate compensation depth in the South Atlantic reported by Le Pichon et al (1978) and in oxygen isotope ratios in planktonic foraminifera from the southern oceans by Sclater (1978), both extending over the most recent 50 million years. It was also found in the 600 million year record of solar radiation absorption at the Earth's surface deduced by Burnett (1982). Although even approximately continuous records for the really distant past are rarer than hen's teeth, a few, such as the global temperature variation described by Frakes (1979) and oxygen isotope ratios reported by Knauth and Epstein (1976), claim to represent temperature variation back to more than 3 billion years ago and were found to exhibit the same pattern.

Turning to shorter time scales and superimposing the shortest of the periodicities from the original 7-million year oxygen isotope stratigraphy, the 1,000,000 year record of February sea surface temperature in the tropical Atlantic interpreted from foraminifera populations by Imbrie and Kipp (1971) was also found to exhibit the same pattern. Applying the same method to the generalised global sea level trend over 130,000 years from Bloom (1971) extended the sine series further, as did applying it to the generalised temperature record for middle latitudes of the northern hemisphere from tree-line analysis over the last 25,000 years by La Marche (1974). Similarly for the most recent 6,000 years, the same pattern was also found in the variation of eucalyptus pollen abundance in south western Australia (Churchill, 1968) and in both the Californian upper tree-line (La Marche, 1973) and the proportion of deuterium in Californian bristlecone pine (Lamb, 1977) over the last 1,000 years. Several hundred other data sets over many time scales and from all over the world subsequently revealed the same pattern.

The model:

The inter-related sine components were then combined in such a way that all the cycles, from the longest to the shortest, were in step at one particular time (T_o) in the very distant past. As this was completed in 1980, To was selected in relation to the end of that year and found to be 17,344,398,261 years before that.

The resulting equation describing natural global temperature variation over any time scale is:

$$G(t) = \sum_{n=1}^{\infty} A(T)\, a^{n-1} \sin(b^{-n} \frac{\pi t}{T})$$

where G is the global temperature in °C, A and T are respectively the amplitude in °C and the period in years of the biggest sine component, a is the ratio of the amplitudes of successively smaller sine components (originally taken as 0.83 and subsequently amended to 0.9) and b is the ratio of their periods (i.e. 2), and t is time in years.

A man-made component of global temperature change, based on the conventional view that it increases by 3°C as the mass of atmospheric CO_2 doubles, was then added to reflect the anthropogenic impact of the industrial revolution and deforestation since it began to influence the climate in the mid nineteenth century. The combined natural and greenhouse model was first published by Denness (1984) and, allowing for a few subsequent minor amendments, its output has the verifiable 25-year track record shown in Figure 1.

The future:

After successfully forecasting the global warming near the end of the twentieth century, the model also identified the slight global cooling that set in during the last decade long before it began. It went on to forecast that continuing to emit greenhouse gases at the present rate would see a sharp increase of 0.25°C or so about 2012 followed by a period of approximate stasis until another sharp rise of about 0.4°C during 2027-29. The overall warming since it began in the mid-nineteenth century would pass 2.0°C in 2050 with an ever-accelerating rate thereafter as shown in Figure 1.

Faced with the possibility of that order of temperature increase, NASA's most prominent climate scientist has warned that global sea level could rise by up to five metres (Hansen, 2007) by 2100. To put that in perspective, at the end of the last ice age the overall world temperature rose by about six degrees in little more that 2000 years and global sea level rose some 100 metres or so. That is equivalent to about 50mm/year, i.e. 4.5m by 2100, which is consistent not only with Hansen's forecast but those by Denness (1985, 1986) based on the model described here.

The model can also identify the emission reduction rate of CO_2 (and other greenhouse gases) required to moderate future temperature. Figure 2 shows its global temperature forecast if the whole world were to pursue an 80% reduction in the emission of greenhouse gases by 2050, to which Britain has committed itself, and thereafter adhere to a "zero-carbon economy": the temperature increase since the beginning of the industrial revolution would just remain within the 2°C generally considered to be acceptable. That would require a reduction of about 4% per year from the current rate, which is currently growing apparently driven primarily by global industrialisation and population growth. In the absence of compensatory advances in energy efficiency technology, this would amount in effect to a simultaneous rate of economic contraction for the next four decades. On the negative side, those technological advances would also need to take account of emissions from cement production, agricultural NOx emissions, deforestation and so on, particularly in the developing world. On the positive side, the model's forecast does not take account of CO2 absorption by the oceans after 2050.

Conclusions:

A mathematical model has been developed combine both natural and man-made components of global temperature change over any time scale. Over the quarter of a century since its derivation it forecast the sharp rise in temperature that took place during the 1990s and the slight fall that has occurred in recent years. Among its forecasts for the future are that the world will experience a temperature rise of about 0.25°C around 2012 and that, if nothing were done to reduce the man-made greenhouse effect, this would be followed by a period of fairly constant temperature until another sharp rise of about 0.4°C during 2027-29 and an ever-increasing rate of warming thereafter.

The model also shows that to prevent the temperature exceeding an overall rise of 2°C since industrialisation took effect it will be necessary to cut the emission of global greenhouse gases by about 4% every year until 2050, which is

Figure 1: Natural and man-made global temperature - forecast and observed

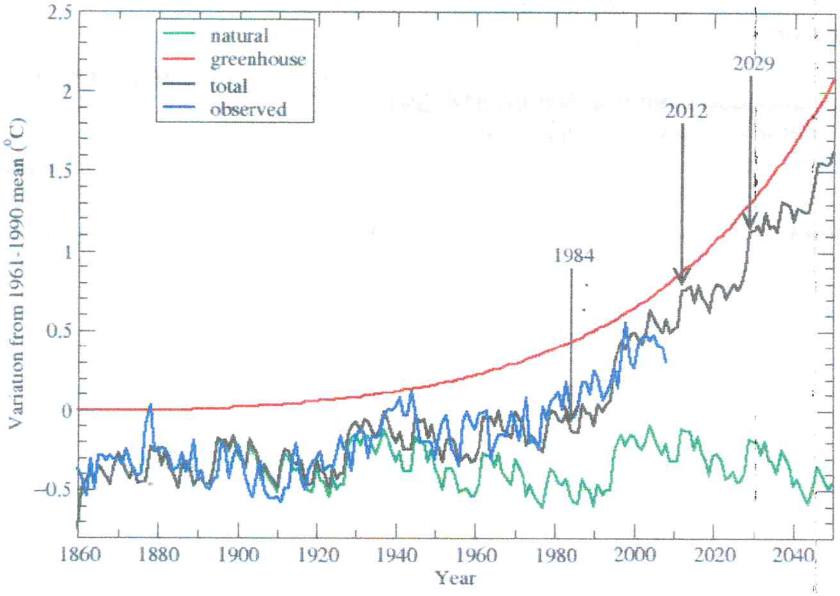
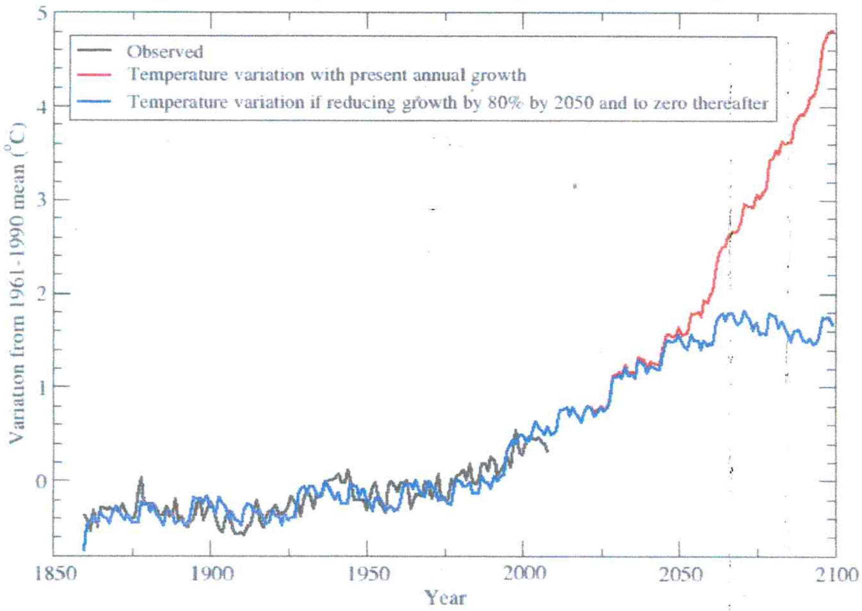


Figure 2: Global temperature with reduced growth of greenhouse gases



equivalent to Britain's commitment to reduce the emission of CO_2 80% by then, and pursue a "zero-carbon" econom[y] thereafter.

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