

GLOBAL CLIMATE CHANGE; A GEOLOGICAL PERSPECTIVE.

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Climate is changing globally! The world is about 0.6°C warmer than 100 years ago and, in the UK, seven of the warmest years ever recorded have been in the present decade. The 1990's have, so far, been about 0.5°C warmer than the 1961-1990 average and the five warmest years in the 340-year Central England Temperature Series have occurred since 1988.

Coupled with these temperature changes there is evidence of major change in the world's atmosphere. The levels of ozone in the atmosphere, particularly over Antarctica, are known to be decreasing. Concentrations of atmospheric carbon dioxide are known to be rising and this rise can be traced back to the industrial revolution; it is reportedly anthropogenic and not (apparently) part of a natural cycle.

The debates over the cause of these changes, and their impact, will continue well into the future. While many find it difficult to come to terms with the idea of climate change, geologists have a wealth of experience to bring to the discussions. Ten thousand years ago the last ice age maximum was coming to an end, with temperatures changing and sea level rising rapidly as a direct result of the melting icefields. Since that time there have been less severe, but nonetheless significant reversals of the warming trend. Historians have vividly described the effects of the "little ice age" when the River Thames regularly froze in winter over an extended period of years.

Geologists appreciate these global changes and have documented the climatic changes that have shaped the planet over periods of hundreds of millions of years. Using radiometric and palaeomagnetic time-scales we now have an appreciation of the natural rates of change that have left a record in the geological succession.

The current climatological data suggest a modern rate of change that is beyond our geological experience and, as a direct consequence of this, there have been established a number of key bodies; e.g., the **UK Climate Impacts Programme** and the **Inter-Governmental Panel on Climate Change**. Models of climate change, and the associated rise in global sea levels, are now available and it is the responsibility of the science community to present these in a way in which the general public can appreciate both the problem and the likely consequences. This must, however, be done in a measured way and we all have a responsibility in this regard. A classic example of this being hi-jacked by the media was the cliff-fall at Beachy Head in 1999. The chalk cliffs of Sussex have developed, by such falls over recent millennia and to attribute the last such event to "global warming" is to totally miss the point. Coastal stability may well be an issue for future investigation. Many major landslides (e.g., the Lyme Regis area) have a history back into the Pleistocene and will, almost certainly, be affected by changes in sea level and increased winter rainfall. Quick soundbites are, however, not the appropriate way by which to communicate the problems that may confront many coastal areas.

Geologically speaking, we are in an inter-glacial period in Earth History. The evidence suggests that extensive glacial conditions will return to N.W. Europe in the not too (geologically) distant future. The dilemma for humanity is which gets us first — ice-house or greenhouse?

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INTRODUCTION

The climate of the early Earth was probably very warm (Figure 1). This was the direct result of the build-up of gravitational energy, loss of kinetic energy and the heat liberated by short-lived radio-isotopes as the planet was forming 4,600 million years ago. Despite the calculated increase in solar luminosity during geological time, the surface temperature of the Earth has, in general, reduced since the Archean, apart from occasional warm intervals, especially in the Cretaceous. The main controls on the global climate through the Phanerozoic appear to be :-

- the bio-regulatory effect of photosynthetic marine/terrestrial algae and plants;
- the movements of the crustal plates and the rate (s) of sea floor spreading;
- the increasing solar luminosity(?); and
- the variations in the proportion of "greenhouse" gases in the atmosphere.

Throughout this time the Earth has migrated between "greenhouse" and "icehouse" conditions, when large terrestrial and marine ice sheets expanded over significant areas of the globe. Between these major glacial expansions (shown in Figure 1) there may have been intervals with little (see Keller & Stinnesbeck, 1996; Miller *et al.*, 1999) or no polar ice.

GLOBAL CLIMATE CHANGE

Throughout geological time the climate has been changing and it should come as no surprise that these natural processes are ongoing. The latest figures suggest that the average temperature of the planet is about 0.6°C warmer than one hundred years ago (Hulme & Jenkins, 1998). The warmest year since records began in the UK (the 340-year Central England Temperature Series) was 1999, with 1997, 1995 and 1990 also recording some of the highest values on record. The 1990's have been about 0.5°C warmer than the 1961-1990 average and 1999 is the warmest year since about 1204 (using tree-ring data as a proxy for temperature).

Over the next 100 years the rate of global warming (Hulme & Jenkins, 1998) is predicted to rise between 0.16°C per decade to 0.35°C per decade. In the same time period global sea level is predicted to rise from between 2.4 cm per decade to 10.0 cm per decade (see Table 1). These rates of change are quite dramatic and most geologists regard them as extra-ordinary. There have been times, however, when comparable rates of change have been recorded (e.g., the Younger Dryas period) although, for much of the geological record, such accurate measurements would be impossible.

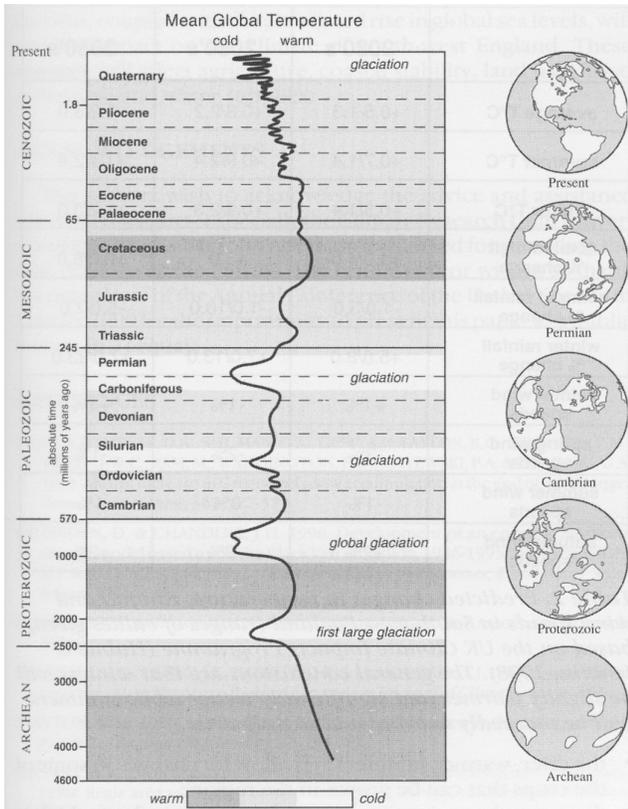


Figure 1. Generalised temperature history of the Earth (adapted from Merritts et al., 1998).

THE CENOZOIC CLIMATIC DECLINE

After the mid-Cretaceous temperature maximum (Figure 1) global temperatures fell, although the details of the changes are relatively little known. In the mid-Late Turonian there was a dramatic drop in global sea level (Hancock & Kauffman, 1979; Hart, 1990 and references therein) the cause of which is not fully understood. Few authors have suggested that an Antarctic ice cap was present in the Cenomanian or Turonian (see Price, 1999, for a recent review) although it has been suggested (Keller & Stinnesbeck, 1996; Miller *et al.*, 1999) that ice may have been present in the Maastrichtian. As indicated in Figure 2 there was little change between the latest Cretaceous and the earliest Cenozoic (aside from the short-term perturbations at the K/T boundary— however caused). The Cenozoic temperature maximum was in the Early Eocene and is marked, in the UK, by the presence of *Nummulites* spp. (a large, benthonic, foraminiferid) in the Hampshire Basin (Murray *et al.*, 1989); the northernmost occurrence of this normally Tethyan genus. With the progressive build-up of glaciers on the Antarctic landmass, global temperatures declined through the remainder of the Palaeogene, with an associated drop in global sea levels. With the major ice advance in the Antarctic during the mid-Miocene the pattern of cooling accelerated and about 3.5 million years ago the Arctic Ocean began to be closed over by an ice sheet. During the Pleistocene the major advances of this ice sheet covered substantial parts of Northern Europe, Asia and North America. Since the last glacial maximum temperatures have improved rapidly (in geological terms), despite a major reversal in the Younger Dryas, attained modern levels about 11,600 years ago (Alley *et al.*, 1993). Fluctuations in oxygen isotope ratios in ice cores provide a major source of information on which such interpretations are based.

Over the last 3,500 years dendrochronology not only provides a valuable time-scale but the relative size of the growth rings of trees such as the Bristlecone Pines of the Western USA provide a good proxy of temperature (Figure 3). From a maximum temperature in 1204

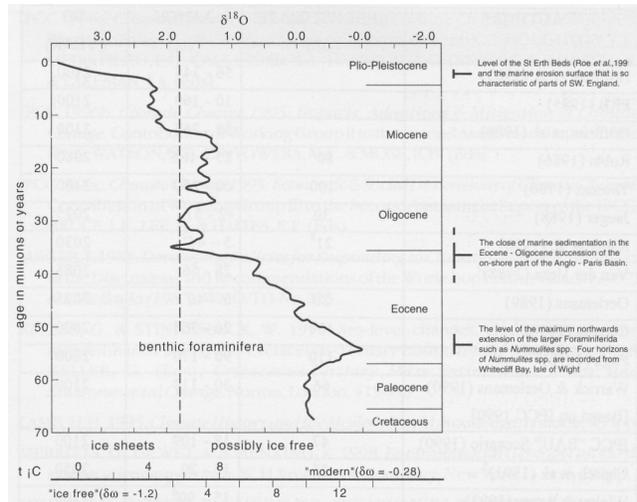


Figure 2. Cooling of the Earth after the latest Cretaceous as recorded by oxygen isotopes in benthonic marine Foraminifera (adapted from Miller *et al.*, 1987).

temperatures have fallen and, by the time the Central England Temperature Series began in 1659, temperatures were at a low level. Even at the beginning of the 19th Century the Little Ice Age was still having an effect, with warming only taking place after about 1820.

THE 19TH AND 20TH CENTURY WARMING

Since the industrial revolution in N.W.Europe there has been an increasing discharge of pollutants into the atmosphere. The years between 1750 and 1830 are generally regarded as the crucial years of the industrial revolution in the UK and elsewhere in Europe (Burke, 1974). With the near-exponential rise in the human population and the increasing use of fossil fuels, the emissions are carbon dioxide, chlorofluorocarbons, methane and nitrous oxide (Merritts *et al.*, 1998). Unfortunately, for scientists trying to understand the present rise in temperature, this increasing anthropogenic impact on the atmosphere began at about the time of the Little Ice Age.

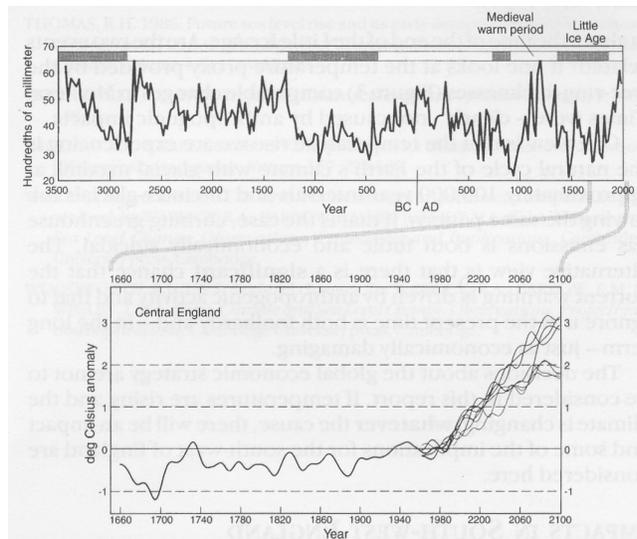


Figure 3. Predicted temperature curve for the last 3500 years based on the proxy data from growth-ring thicknesses in the Bristlecone Pine trees in the western USA (based on Lamb, 1995, using data supplied by Professor V.C.La Marche). The lower graph shows the post-Little Ice Age data of the Central England Temperature Series to which have been added some of the present temperature predictions of the Climate Research Unit (Hulme & Jenkins, 1998).

AUTHORS	BEST ESTIMATE (cm)	RANGE (cm)	TO (YEAR)
Hoffman et al. (1983)		56 — 345	2100
PRB (1985)		10 — 160	2100
Hoffman et al. (1986)		58 — 367	2100
Robin (1986)	80 ¹	25 — 165 ¹	2080
Thomas (1986)	100	60 — 230	2100
Jaeger (1988)	30	-2 — 51	2025
Raper et al. (1990)	21 ²	5 — 44 ²	2030
Van der Veen (1988) ³		28 — 66	2085
Oerlemans (1989)	20	0 — 40	2025
Clayton (1990)	164	26 — 365	2030
Pugh (1990) ⁴	110	90 — 170	2100
Warrick & Oerlemans (1990) [Based on IPCC 1990]	66	30 — 110	2100
IPCC "BAU" Scenario (1990)	47	18 — 109	2100
Church et al. (1991) ⁵	35	15 — 70	2050
Wigley & Raper (1992) [Based on IPCC 1992]		15 — 90 ⁶ (22 — 115) ⁷	2100 2100
Wigley & Raper (1993)	46 ⁸	3 — 124 ⁹	2100
Woodworth (1993)	61		2087
Titus & Narayanan (1995) ¹⁰	34	5 — 77 ¹¹	2100
IPCC (1996) ¹²	49	20 — 86	2100

Table 2. Estimations of change in global sea-level (after Hart, A.B., 1997).

¹ Estimated from global sea level and temperature change from 1880-1980 and global warming of 3.5+/-2.0°C for 1980-2080.

² Internally consistent synthesis of components.

³ For a global warming of 2-4°C

⁴ Surface air temperatures are assumed to increase linearly until 2050, to an average value of 3° higher than at present, and then to remain constant.

⁵ Assumes rapid warming of 3°C by 2050 for best guess scenarios.

⁶ Best guess with a temperature change of 1.7-3.8°C.

⁷ Base case forcing with a temperature change of 2.1-5.0°C.

⁸ For IPCC (1992) Policy Scenario B, best estimate model parameters.

⁹ For IPCC (1992) forcing scenarios A & C with high and low model parameters, respectively.

¹⁰ Incorporates subjective probability distributions for model parameter values based on expert opinion.

¹¹ Represents 90% confidence level.

¹² For the IPCC IS92a forcing scenario, using a climate sensitivity of 2.5°C for the mid projection and 1.5°& 4.5° for the low and high projections respectively. (See also Raper *et al.* 1996)

Table 1. Estimations of change in global sea level (after Hart, A.B., 1997).

Are the two events related? If one looks at the temperature proxy provided by the tree-ring thicknesses (Figure 3) comparable changes in Medieval Times were - clearly - not caused by anthropogenic impacts.

One view is that the temperature rise we are experiencing is the natural cycle of the Earth's climate with glacial maxima at approximately 100,000 year intervals and the inter-glacials following the same pattern. If that is the case, curbing greenhouse gas emissions is both futile and economically suicidal. The alternative view is that there is a **significant** chance that the current warming is driven by anthropogenic activity and that to ignore it at the present time is both foolhardy and - in the long term - just as economically damaging.

The decisions about the global economic strategy are not to be considered in this report. If temperatures are rising and the climate is changing, **whatever** the cause, there will be an impact and some of the implications for the south-west of England are considered here.

IMPACTS IN SOUTH-WEST ENGLAND

South-west England is predicted to suffer changing climatic conditions over the next century and models are now available as part of the UK Climate Impacts Programme. As indicated in Table 2 the West Country may experience:-

- winters that are slightly warmer and significantly wetter;
- summers that are markedly warmer and slightly drier. There are a number of consequences that follow from these predictions.

	2020's	2050's	2080's
average T°C	+0.5/1.3	+0.8/2.2	+1.2/3.0
summer T°C	+0.7/1.4	+0.9/2.4	+1.4/2.9
winter T°C	+0.5/1.4	+0.9/2.3	+1.2/3.0
total rainfall % change	+1.0/4.0	+3.0	+2.0/6.0
summer rainfall % change	-1.0/3.0	-1.0/10.0	-5.0/7.0
winter rainfall % change	+5.0/8.0	+7.0/13.0	+7.0/23.0
winter wind speeds	+1%	-1%	+1%
spring wind speeds	-3%	-2%	-1%
summer wind speeds	-1%	0%	+1%
autumn wind speeds	+2%	+2%	+2%

Table 2. Predicted changes in temperature, rainfall and wind speeds in South-west England (ranges of values given) based on the UK Climate Impacts Programme (Hulme & Jenkins, 1998). The general conclusions are that winters will be slightly warmer and significantly wetter while summers will be markedly warmer and slightly drier.

- the drier, warmer summers may allow for changes in some of the crops that can be grown in the region;
- there may be an impact on water supply, much of which is reservoir-based;
- there may be a significant risk of flooding during the winter months and flood protection works and/or drainage schemes should be considered a priority (e.g., problems in Devon during December 1999 and the significant flooding of the Somerset Levels);
- instability of hedge banks and soil run-off in the sunken lanes that are so typical of this region; and
- increased instability of pre-existing landslides that are already known to be triggered by excessive rainfall levels (Brunsdon & Chandler, 1996).

The increased sea levels (see Table 1) would almost certainly affect the landslide stability on the Devon/Dorset coastline as the toes of the slips become attacked by the sea. That removal of material, coupled with more rainfall-induced activity, could significantly change the disposition of slides on Black Ven, Stonebarrow Hill, etc., and make occupancy of Higher Sea Lane in Charmouth (Conway, 1976; Denness *et al.*, 1975) a problem.

The increase in winter rainfall is primarily due to the increased temperature of sea water in the North Atlantic Ocean and the generation of more active depressions. There is, below each depression, a significant "bulge" of sea water caused by the low pressure. This bulge, coupled with strong winds and high tides (or both) can cause significant coastal erosion or flooding. As illustrated by Hart (2000) it was a situation such as that outlined above that caused the disastrous flooding of East Anglia in 1953 and which, directly, led to the building of higher marine defences and the Thames Barrier. During December 1999 strong winds, an high tide and a depression-induced bulge threatened the Sussex coastline with flooding and severe damage. This was only averted by a last minute change in wind direction.

CONCLUSIONS

While the majority of environmental scientists believe that the present rise in global temperatures is anthropogenic in origin, there are those that would claim that it is the direct result of the Earth's natural evolution. Whatever the cause, the outcome is the same. The Earth is experiencing a rapid rise in global temperature and this, coupled with

the associated rise in global sea levels, will directly impact on the climate of south-west England. These changes will affect agriculture, coastal stability, land use, flood protection and water supplies.

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