Read at the Annual Conference of the Ussher Society, January 2000

GLOBAL CLIMATE CHANGE; A GEOLOGICAL PERSPECTIVE.

M. B. HART & A B. HART

Hart, M.B. and Hart, A.B. 2000. Global Climate Change; a geological perspective.
Geoscience in south-west England, **10**, 14-17

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 green-house?

M.B.Hart, A.B.Hart, Department of Geological Sciences and Plymouth Environmental Research Centre,
University of Plymouth, Drake Circus, Plymouth PL4 8AA

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 "green-house" 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.

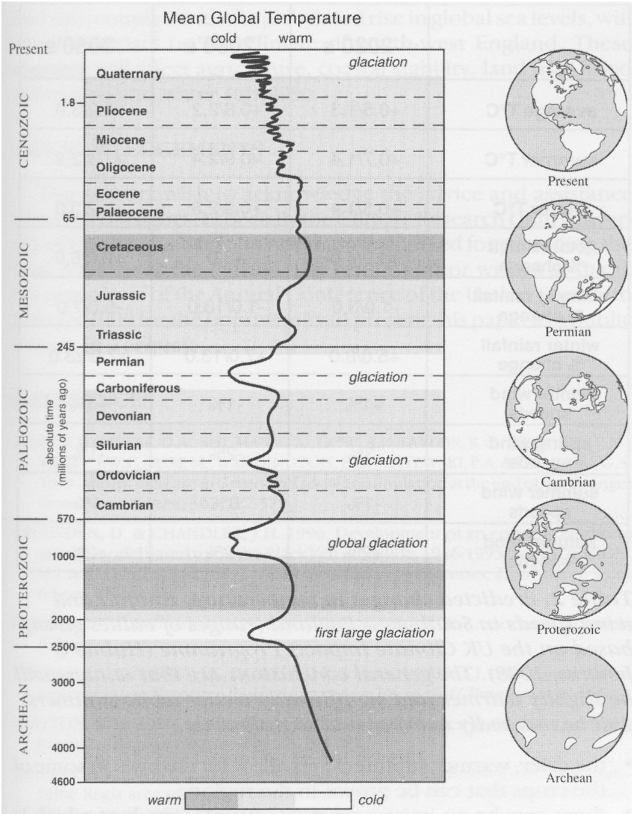

Figure 1. *Generalised temperature history of the Earth (adapted from Merritts* et al., *1998).*

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

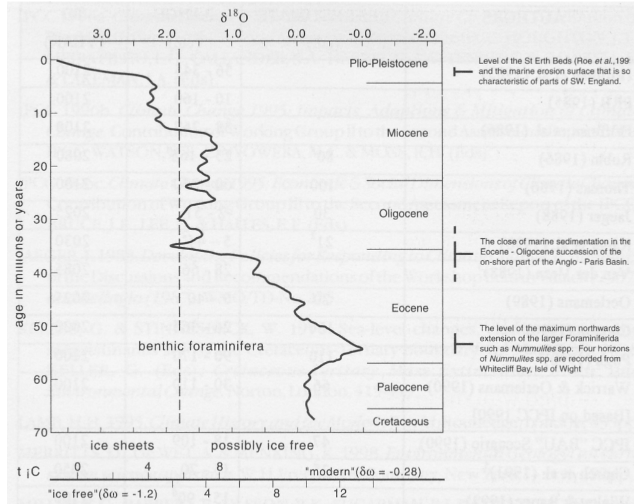

Figure 2. *Cooling of the Earth after the latest Cretaceous as recorded by oxygen isotopes in benthonic marine Foraminifera (adapted from Miller* et al., *1987).*

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.

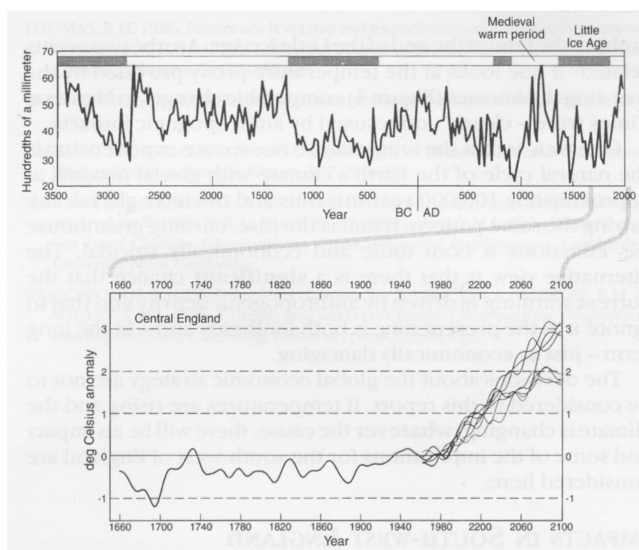

Figure 3. *Predicted temperature curve for the last 3500 years based on the proxy data from growth-ring thicknesses in the Bristlecone Pine trees in the western USA (based on Lamb, 1995, using data supplied by Professor V.C.La Marche). The lower graph shows the post-Little Ice Age data of the Central 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 &Narrayanan (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 (Brunsden & 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.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the advice and assistance given by colleagues, especially the Climate Research Unit, University of East Anglia. Mr John Abraham is thanked for providing the final versions of the figures. The senior author wishes to thank the organisers of the Annual Conference of the Ussher Society in January 2000 for the opportunity to present this paper as a public lecture in Torquay.

REFERENCES

ALLEY, R.B., MEESE, DA., SHUMAN, C.A, GOW, A.J., TAYLOR, KC., GROOTES, P.M., WHITE, J.W.C., RAM, M., WADDINGTON, E.D., MAYEWSKI, P.A & ZIELINSKI, G.A 1993. Abrupt increase in Greenland snow accumulation at the end of theYounger Dryas event. *Nature,* **362**, 527-529.

BRUNSDEN, D. & CHANDLER, J.H. 1996. Development of an episodic landform change model based upon the Black Ven mudslide, 1946-1995. In: ANDERSON, M.J. & BROOKES, S.M. *(Eds), Advances in Hillslope Processes,* **2**, 869-896, J. Wiley & Sons, Chichester.

BURKE, J. 1974. *An Illustrated History of England.* Book Club Associates, Norwich, 349pp.

CHURCH, JA, GODFREY, J.S., JACKETT, D.R. & McDOUGALL, T.J. 1991.A model of sea level rise caused by ocean thermal expansion. *Journal of Climate,* **4**, 438-456.

CLAYTON, K.M. 1990. Sea-level Rise and Coastal Defences in the UK. *Quarterly Journal of Engineering Geology,* **23**, 283-287.

CONWAY, B.W. 1976. Coastal terrain evaluation and slope stability of the Charmouth - Lyme Regis area of Dorset. *British Geological Survey, Geophysical Division, Engineering* Geology Report No. EG76/10

DENNESS, B., CONWAY, B.W., McCANN, D.M. &GRAINGER, P. 1975. Investigation of a coastallandslip at Charmouth, Dorset. *Quarterly Journal of Engineering Geology,* **8**, 119-140.

HANCOCK, J.M. & KAUFFMAN, E.G. 1979. The great transgressions of the late Cretaceous. *Journal of the Geological Society, London,* **136**, 175-186.

HART, A.B. 1997. A *risk assessment of the inland area around Charmoutb, West Dorset.* Unpublished M.Sc. Thesis, University ofPortsmouth.

HART, M.B. 1990. Cretaceous sealevel changes and global eustatic curves. *Proceedings of the Ussher Society,* **7**, 268-272.

HART, KB. 2000. Construction of theThames Barrier: an application of micropaleontology to the solution of an environmental problem. In: MARTIN, RE. (Ed.), *Environmental Micropaleontology*, Volume 15, *Topics in Geobiology*, Kluwer Academic/Plenum Publishers, NewYork, 429-459.

HEAPS, N. S. 1977. Development of storm surge models at Bidston. *Internal Report,* No. 51, Institute of Oceanography.

HOFFMAN, J.S., KEYES, D. & TITUS, J.G. 1983. *Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2000, and Research Needs.* United States Government Printing Office # 055-000-0236-3, Washington, D.C.

HOFFMAN, J. S., WELLS, J.B. &TITUS, J.G. 1986. Future global warming and sea Level rise. In: SIGBJARNASON, G. *(Ed.), Iceland Coastal and River Symposium,* National Energy Authority, Reykjavik, 245-266.

HULME, M. & JENKINS, G.J. 1998. *Climate Change Scenarios for the U.K: Scientific Report.* UKCIP Technical Report No.1, Climate Research Unit, Norwich, 80pp.

IPCC 1992. *Climate Change* 1992: *The Supplementary Report to the IPCC Scientific Assessment.* HOUGHTON, J.T., CALLANDER, BA & VARNEY, S.K (Eds), Cambridge University Press, Cambridge, 200pp.

IPCC 1996a. *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group 1 to the Second Assessment Report of the IPCC. HOUGHTON, J.T., MEIRAFILHO, L.G., CALLANDER, BA, HARRIS, N., KATTENBERG, A., MASKELL, & LAKEMAN, J.A. (Eds).

IPCC 1996b. Climate Change 1995: *Impacts, Adaptions & Mitigation of Climate Change.* Contribution of Working Group ll to the Second Assessment Report of the IPCC. WATSON, R.T., ZINYOWERA, M.C. &MOSS, R.H. (Eds).

IPCC 1996c. *Climate Change 1995: Economic & Social Dimensions of Climate Change.* Contribution of Working Group ill to the Second Assessment Report of the IPCC. BRUCE, J.P., LEE, H. & HAITES, E.F. (Eds).

JAEGER, J. 1988. *Developing Poficies for Responding to Climate Change*: a Summary of the Discussions and Recommendations of the Workshop held inVillach (1987) and Bellagio (1987). WMO/TD-No.225.

KELLER, G. & STINNESBECK, W. 1996. Sea-level changes, elastic deposits and megatsunamis across the Cretaceous-Tertiary boundary. In: MacLEOD, N., & KELLER, G. (Eds), *Cretaceous-Tertiary Mass Extinctions: Biotic and Environmental Change*. Norton, London, 415-449.

LAMB, H.H. 1995. *Climate History and the Modern World,* Routledge, London, 433pp.

MERRITTS, D., DE WET, A. & MENKING, K. 1998. *Environmental Geology: an earth system science approach.* W.H. Freeman & Company, New York, i-xxvi, 452pp.

MILLER, KG., BARRERA, E., OLSSON, R.K., SUGARMAN, P.J. & SAVIN, S.M. 1999. Does ice drive early Maastrichtian eustacy. *Geology,* **27**, 783-786.

MILLER, KG., FAIRBANKS, R.G. & MOUNTAIN, G. S. 1987. Tertiary oxygen isotope Synthesis, sea level history and continental margin erosion. *Paleoceanography,* **2**, 1-19.

MURRAY, J.W., CURRY, D., HAYNES, J.R. &KING, C. 1989. Palaeogene. In: MURRAY, J.W. & JENKINS, D.G. *(Eds), Stratigraphical lndex of Fossil Foraminifera,* (2nd Edition), Ellis Horwood Ltd., Chichester, 490-536.

OERLEMANS, J. 1989.A projection offuture sea level. *Climate Change,* 15, 151-174.

POLAR RESEARCH BOARD (PRB). 1985. *Glaciers, Ice Sheets and Sea Levek Effect of a* CO_2 *induced Climate Change*. Report of a Workshop held in Seattle, Washington, September 13-15, 1984, United States DOE/ER/60235-1.

PRICE, G.D. 1999. The evidence and implications during the Mesozoic. Earth during the Mesozoic. *Earth Science Reviews*, **48**, 183-210.

PUGH, D.T. 1990. Is there a sea level problem? *Proceedings of the Institute of Civil Engineers*, **88**, 347-366.

RAPER, S.C.B., WARRICK, RA & WIGLEY, T.M.L. 1990. Global sea level rise: past and future. In: MILLMAN, J.D. (Ed.), *Proceedings of the SCOPE Workshop in Rising Sea Level and Subsiding Coastal Areas, Bancock* 1988, John Wiley& Sons, Chichester.

ROBIN, G. de Q. 1986. Changing sea level. In: BOLIN, B., DOOS, B.R., JAEGER, J. & WARRICK (Eds), The Greenhouse Effect, Climatic Change and Ecosystems, John Wiley& Sones, Chichester, 323-359.

TITUS, J.G. & NARRAYANAN, V. 1995. *The Probability of Sea Level Rise.* U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Climate Change Division, EPA230-R-95-008, EPA, Washington, DC, 186pp.

THOMAS, R.H. 1986. Future sea level rise and its early detection by satellite remote sensing. In: TITUS, J.G. (Ed.), *Effects of a changing Stratospheric Ozone and Global* Climate, Volume 4, Sea Level Rise.

VAN DER VEEN, C. J. 1988. Projecting future sea level. *Surveys in Geophysics,* **9**, 389-418.

WIGLEY, T.M.L. & RAPER, S.C.B. 1992. Implications for climate and sea level of revised IPCC emissions scenarios. *Nature,* **357**, 293-300.

WIGLEY, T.M.L. &RAPER, S.C.B. 1993. Future changes in global mean temperature and sea level. In: WARRICK, RA, BARROW, E.M. & WIGLEY, T.M.L. (Eds), *Climate and Sea Level Change: Observations, Projections and Implications*, Cambridge University press, Cambridge

WOODWORTH, P.L. 1993. Sea level changes. In: WARRICK, R.A., BARROW, E.M. & WIGLEY, T.M.L. (Eds), *Climate and Sea Level Change: Observations, Projections and Implications*, Cambridge University press, Cambridge.