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Abstract

A CO2-warming atmospheric scenario, whereby increased concentrations of 'greenhouse' gases result in warmer temperatures that either melt near-polar ice or cause thermal expansion of ocean waters, thus leading to increased sea-levels and exacerbated coastal erosion, assumes fundamental but unproven cause-and-effect relationships. General circulation models have reinforced claims of an accelerated warming and indirectly given support to the complete scenario, but ignore the point that global climate and not just air temperatures have changed over the past century. Indeed, it is difficult to prove that air temperatures have warmed naturally outside of urban centres over this period. To attribute recent temperature increases to anthropogenic factors and to extrapolate these trends to the future also ignores the historic variability of climate. What is more, an eustatic rise in sea-level cannot be discerned from the background noise of tectonically or climatically induced changes. Even if sea-level was rising, coastal erosion may be accounted for better by a suite of inter-related climatic factors including changes in rainfall regimes, hemispheric circulation and storminess.

Keywords

CO2 warming, sea level, beach erosion, critique

Disciplines

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CO_2-WARMING, RISING SEA-LEVEL AND RETREATING COASTS: REVIEW AND CRITIQUE

EDWARD BRYANT*

SUMMARY: A CO_2-warming atmospheric scenario, whereby increased concentrations of 'greenhouse' gases result in higher temperatures that either melt near-polar ice or cause thermal expansion of ocean waters, thus leading to increased sea-levels and exacerbated coastal erosion, assumes fundamental but unproven cause-and-effect relationships. General circulation models have reinforced claims of an accelerated warming and indirectly given support to the complete scenario, but ignore the point that global climate and not just air temperatures have changed over the past century. Indeed, it is difficult to prove that air temperatures have warmed naturally outside of urban centres over this period. To attribute recent temperature increases to anthropogenic factors and to extrapolate these trends to the future also ignores the historic variability of climate. What is more, an eustatic rise in sea-level cannot be discerned from the background noise of tectonically or climatically induced changes. Even if sea-level was rising, coastal erosion may be accounted for better by a suite of inter-related climatic factors including changes in rainfall regimes, hemispheric circulation and storminess.

A CO_2-warming atmospheric scenario, known as the 'greenhouse effect', postulates that climate is warming because of an increase in the amount of CO_2 in the Earth's atmosphere due to the accelerated combustion of fossil fuels over recent decades. It postulates also that this warming is already melting polar ice and causing worldwide (eustatic) sea-level to rise, and that if present trends continue over the next 30 to 50 years, a global warming of surface air temperature of 1.5 to 4.5°C could occur, resulting in catastrophic melting of near-polar ice and a raising of sea-levels of between 20 and 140 cm (Hansen *et al.* 1981; Carbon Dioxide Assessment Committee 1983; Gribbin 1983). One of the consequences of an accelerated rise in sea-level would be increased coastal erosion on a massive scale. The scenario of a warming globe is today taken so seriously that research is earnestly being performed to ascertain its effects upon worldwide agricultural production especially in marginal areas in Australia and Canada (Carbon Dioxide Assessment Committee 1983; Pittock and Salinger 1981; Pittock 1983; Bruce and Hengeveld 1985). Nonetheless, the case for such a scenario is by no means as clear-cut as its proponents assume. The aim of this paper is to summarise various aspects of the scenario and to discuss some of the uncertainties surrounding supportive evidence. Specifically, we will be assessing a set of interrelated questions: whether or not climate is warming; whether CO_2 or other 'greenhouse' gases are responsible for this warming; whether sea-level is rising; and whether beaches are necessarily eroding because of a rise in sea-level.

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IS CLIMATE WARMING?

It is common knowledge that the Earth's climate underwent a significant change beginning in the 1880s. Air temperature has been emphasised as the main component of this change, but substantial shifts worldwide in rainfall regimes, pressure patterns and sea surface temperature have also occurred (Lamb 1972; Bryant 1985; Folland *et al.* 1986). Land-based surface-air temperatures (Figure 1) began to increase in the 1880s, initiating retreat of alpine glaciers in both hemispheres (Hansen *et al.* 1981; Jones *et al.* 1982, 1986; Gribbin 1986). This increase abated about 1948, whereupon the Earth's atmosphere cooled slightly. However, by the early 1970s temperatures had stopped declining and by the mid-1980s had reached their highest summertime value in 1,000 years. Gribbin (1986) argues that air temperature records in both hemispheres show a global warming of 0.5°C in two stages, the first from 1920 to 1940 and the second over the past few years. Yet, one could argue just as well using Figure 1 that the northern hemisphere underwent a two stage decrease in temperature in the 1880s and 1950s-1970s. Even if global temperatures did increase 0.5°C, the change in both hemispheres was not contemporaneous. The southern hemisphere record does not evidence a two stage increase, but shows instead a steady increase over time that substantiates a warming hypothesis better than the northern hemisphere data.

These records indicate five important features inherent in most geophysical time series. Firstly, while a trend may be statistically significant, if the signal-to-noise ratio is low the trend may simply be an aberration of the record. Short term fluctuations in the temperature records in Figure 1 range in

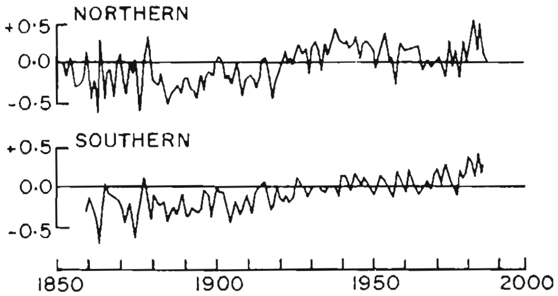

Figure 1: Land-based surface air temperature changes in °C for the northern and southern hemispheres 1850-1985 (based on Gribbin 1986).

amplitude between 0.1 and 1.0°C, being greatest for the northern hemisphere time series. A temperature record with a standard deviation of 0.5°C requires 45 years of data to determine a rise in temperature of 0.5°C with 95 per cent confidence. If the standard deviation doubles to 1.0°C then the length of record must be increased more than fourfold.

Secondly, the amplitude of these fluctuations may vary over time (non-stationarity). Fluctuations are appreciable in the northern hemisphere time series between 1850 and 1890 and again between 1975 and 1985. In reality these long term fluctuations may be indicative of a characteristic of temperature behaviour that is more important than any trend, namely that temperature vacillates notably over time. This vacillation applies to most aspects of climate, especially since 1948. Cold spells have become colder, storms more intense, rainfall events heavier and droughts more severe (Gribbin 1983). This variability has increased since 1970. In statistical terms, discerning warming trends on the order of 0.5°C per century from temperature time series containing non-stationarity is fraught with danger and predicting beyond the timespan of the data becomes virtually meaningless.

Thirdly, time series may not be continuous but show sudden changes or discontinuities over relatively short periods of time. These changes represent shifts in the mean of the record and may occur without a change in variance. Dury (1980) considers these changes to be random and describes them as step-functional. The jump in mean temperature around 1920 in the northern hemisphere is an example of this characteristic.

Fourthly, time series may evidence periodicity. This is especially so for the northern hemisphere temperature record which oscillates at an approximate wavelength of 40 years with an amplitude of 0.4-0.5°C. This characteristic imparts to the record substantial long term serial- or autocorrelation that presents statistical problems. In order to determine precisely the significance level of any trend line through the data, one must begin and end the time series at the same point in these oscillations. Otherwise, a significant rate of change can be calculated when in fact none exists. Autocorrelation also increases the number of data points required to obtain a statistically significant trend. Additionally, sampling lower frequency fluctuations over inappropriate timespans can generate trends that are not representative of the true behaviour of the time series, even if they are long term (Church 1980). Air temperature records over centuries, particularly in the northern hemisphere (Figure 2), manifest long term oscillations that are a natural part of their records. The cyclic structure of any such geophysical time series requires definition before one can interpret and predict from it.

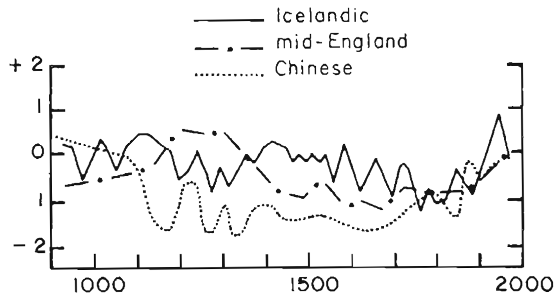

Figure 2: Temperature departures for the past 1000 years in Iceland, central England and China, referenced as closely as possible to departures from present values (based on Barry 1978).

Finally, geophysical time series may not be spatially contemporaneous. Figure 2 also elucidates this aspect. The peak of the Little Ice Age that reached Europe in the 1700s and 1800s appears to have shifted slowly across Asia from China beginning in the 1400s (Lamb 1972). This spatial variation is an inherent feature of other geophysical time series such as sea-level.

The quality of data used to construct Figure 1 also has to be questioned. While early temperature records are certainly subject to instrumental error and improper siting, the spatial representiveness of stations making up the record is biased. To construct Figure 1 accurately, stations characteristic of the temperature regime of large areas need to be incorporated into the data set. This immediately rules out stations in mountainous areas or close to large spatial gradients in temperature where slight changes in local climate can produce exaggerated shifts in 'average' temperature. Figure 1 is also biased by the inclusion of urban centres that, because of rapid population growth, have temperature records reflecting development of urban heat islands. This 'heat island effect' applies to urban centres in both hemispheres with populations as low as 100,000 people. Relative to small adjacent provincial centres, urban temperatures have increased 0.12°C per decade this century in the United States (Kukla *et al.* 1986), and 0.45°C per decade since the Second World War in Australia (Coughlan 1978).

These rates are respectively twice and ten times the global rate.

Even if the curves in Figure 1 are unbiased, they suffer from a more severe deficiency in that, being land-based, they exclude air temperature over the oceans which cover over 70 per cent of the globe and form by far the largest thermal store in the Earth-atmosphere system. Folland *et al.* (1984, 1986) compared land and ocean based records for the past century using over 40 million sea surface and marine night air temperatures collected by merchant ships (Figure 3). Their data cover 20 per cent of the ocean area before 1900, 60 per cent between the two world wars and over 80 per cent since 1970. Large areas of ocean around the Antarctic are, however, devoid of data at all times. Figure 3 indicates that ocean air temperatures have fluctuated from year to year (0.6°C) as much as land based air temperatures. The coldest and warmest periods are centred around 1905-1910 and 1935-1945 respectively. Fluctuations on time-scales as short as two years are similar in magnitude to and nearly coincident with climatic warmings and coolings for northern hemisphere land masses after 1900. Before 1900 ocean air temperatures deviate significantly from land temperatures. More importantly ocean air temperatures, while showing similar fluctuations to temperature over land, do not show any long term tendency for warming or cooling. Marine and land air temperature data also can be compared using cross-correlation. Table 1 shows that cross-correlation coefficients of 0.79 and 0.73 exist between land and ocean records in the southern and northern hemispheres respectively. While these cross-correlations appear strong, they still do not account for 40-50 per cent of the co-variance between land and ocean records.

Furthermore, the northern hemisphere oceans have responded quite differently from southern hemisphere ones as shown in Figure 4 (Folland *et al.* 1986). Temperature differences between hemispheres and successive years vary between 0.4 and 0.6°C. For the period 1920-1960 the southern oceans were up to 0.2°C cooler. Beginning in 1960 the southern oceans warmed while the northern oceans cooled. Only since 1980 has this trend changed with oceans in both hemispheres warming simultaneously. These types of changes can have a strong influence on temperature as well as rainfall over adjacent landmasses as ex-

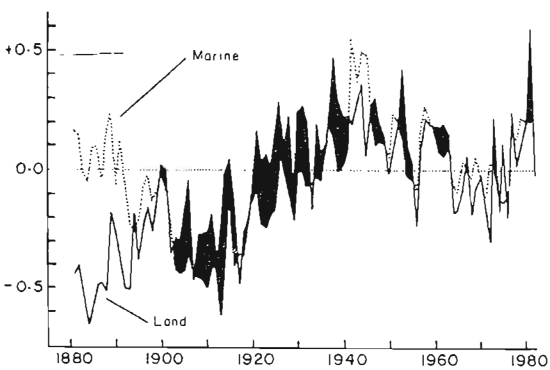

Figure 3: A comparison of marine and land surface air temperature departures in °C for the northern hemisphere from 1880-1980 (based on Folland *et al.* 1984). The zero line has been adjusted to match the zero line for northern hemisphere land-based departures plotted in Figure 1. Shaded areas represent times when land-based temperatures were warmer than marine ones.

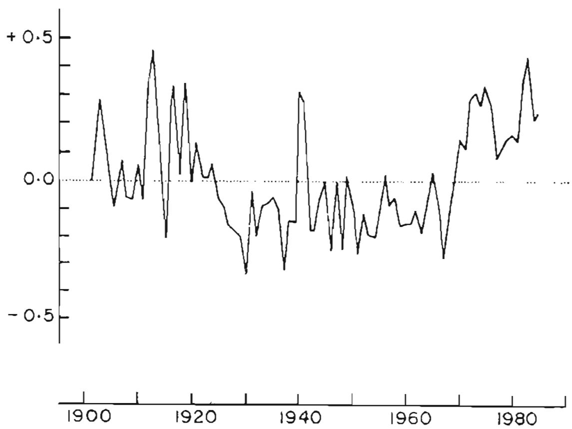

Figure 4: Sea surface temperatures in °C for all oceans in the northern hemisphere minus all those in the southern hemisphere 1900-1985 (based on Folland *et al.* 1986). The Indian Ocean is considered part of the southern hemisphere. Positive values indicate times when southern hemisphere oceans were warmer than northern hemisphere ones.

Table 1: CORRELATIONS BETWEEN LAND AND MARINE AIR TEMPERATURE RECORDS IN BOTH HEMISPHERES, 1904-1980

	Land		Ocean	
	S. hemisphere	N. hemisphere	S. hemisphere	N. hemisphere
Land				
S. hemisphere	—	0.64	0.79	0.69
N. hemisphere		—	0.55	0.73
Ocean				
S. hemisphere			—	0.73
N. hemisphere				—

Source: based on Jones *et al.* (1986).

emplified by the effects of spatial changes in sea surface temperature associated every three to seven years with El Nino-Southern Oscillation events in the South Pacific Ocean (Julian and Chervin 1978; Wyrtki 1982). The possibility that the long and short term fluctuations in temperature shown in Figure 1 merely reflect shifts in the temperature of nearby oceans cannot be ruled out. To date no one has attempted to weld the land and ocean air temperature time series together to produce a more accurate picture of global temperature behaviour over the past century.

Uncertainty 1: Global warming of air temperatures is not a confirmed or easily confirmable fact.

IF CLIMATE IS WARMING, IS INCREASED CO_2 RESPONSIBLE?

Much of the postulated recent warming is perceived to be due to the increase of man-made gases, mainly CO_2, from the burning of fossil fuels. The effect is known as the 'greenhouse effect' whereby certain gases are more transparent to incoming short wave radiation than they are to outgoing longwave radiation (for a more complete description see Bach *et al.* 1983; Liss and Crane 1983; or Davies 1985) and if an atmospheric 'greenhouse' gas increases in concentration, then surface air temperature must increase to compensate for the increased downward emitted longwave radiation. There is no doubt that the CO_2 content of the atmosphere has been rising as shown by the measurements at Mauna Loa in Hawaii between 1958 and 1986 (Figure 5). Over this period CO_2 increased from 311 to 348 parts per million (ppm) at a rate of 0.2 per cent per year. The record shows some indication of an accelerating increase that has been substantiated by other observations worldwide (Liss and Crane 1983). A global average as recently as 1950 is, however, conjectural. For a time the Mauna Loa record was the only one of its kind in the world, and only in the past decade has a worldwide network of CO_2 monitoring been established. Measurements in the upper atmosphere are still sparse. The records indicate that a seasonal variation of 6-7 ppm exists because of mainly northern hemisphere photosynthesis (Gribbin 1983); however this variation is not constant in time or space. Fluctuations increase towards higher latitudes (>9 ppm) and lower altitudes (Matthews *et al.* 1971). Because of this lack of accurate measurement and the indeterminant nature of the variance inherent in records, presently defined trends cannot be extrapolated reliably into the past.

Just how much CO_2 has been added to the atmosphere since the industrial revolution is uncertain. Concentrations between 250 and 290 ppm

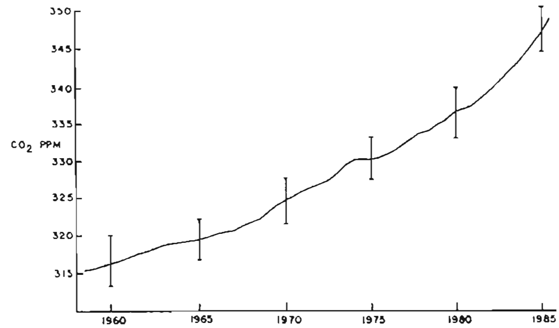

Figure 5: CO_2 concentrations in parts per million at Mauna Loa, Hawaii, 1958-1986. The bar lines at five year intervals plot the seasonal range in values.

have been proposed for the middle of the nineteenth century (Hansen *et al.* 1981; Gribbin 1983; Schneider 1983). This starting concentration is important because it not only determines how efficient oceans have been at absorbing CO_2 from the atmosphere, but also defines the sources of increased CO_2 over the past century. Estimates of the amount of fossil fuel burnt over the past 150 years have been used to deduce a 50 per cent depletion rate by oceans given a starting concentration of 290 ppm (Matthews *et al.* 1971). However the role of the oceans in moderating increases in carbon dioxide is poorly documented (Liss and Crane 1983). If concentrations started out lower, around 250 ppm, then the importance of the biosphere as a regulator of CO_2 has been underestimated. Wilson (1978) argues that there was a great spurt of CO_2 injected into the atmosphere between 1860 and 1890 because of vast forest clearing in temperate climates in North America, New Zealand, Australia, South Africa and eastern Europe preceding agricultural expansion in those areas. Stuiver (1978) argues from a comparison of C^{13} and C^{12} isotope ratios that as much CO_2 was produced by the destruction of forests between 1850 and 1950 as was produced by the burning of fossil fuels. Destruction of forests increases atmospheric carbon dioxide through decay of dead plant matter and a global reduction in photosynthesis. Present forest clearing mainly in the tropics may be contributing up to 30 per cent of the CO_2 presently being released into the atmosphere (Gribbin 1983). If the above estimates are correct then the role of the oceans and the biosphere in regulating the CO_2 flux have been underestimated, in the case of oceans by a factor of two.

The warming of the atmosphere can also be induced by the substantial increase in other 'greenhouse' gases, including both stable and unstable molecules such as carbon monoxide (CO), nitrogen oxides (N_2O, NO_x), methane (CH_4), ozone (O_3), ammonia (NH_3), sulphur dioxide (SO_2), and chlorfluorocarbons (CCl_2F_2, CCl_3F). Methane has increased because of the growth in the number of grazing animals since the Second World War, ni-

trogen oxides because of increased fertiliser use and urban pollution from motor vehicles and chlorofluorocarbons because of increased aerosol and coolant manufacture. Table 2 summarises the increased concentrations of some of these gases and the effect on modelled air temperature for a doubling in concentration (Hansen *et al.* 1981; Bach *et al.* 1983; Carbon Dioxide Assessment Committee 1983; Thompson and Cicerone 1986). Even accounting for the fact that concentrations are interdependent, the three gases N_2O, O_3 and CH_4 will produce a 'greenhouse effect' that is 50 to 100 per cent of the effect produced by CO_2 alone.

Table 2: INCREASES IN TRACE GAS CONCENTRATION AND EFFECT OF DOUBLING CONCENTRATIONS UPON MODELLED AIR TEMPERATURE

Gas	Rate of change per year (%)	Change in temperature if doubled (°C)
N_2O	0.2	0.6
O_3	0.07-0.15	0.5
CCl_3F, CCl_2F_2	0.3-10.0	0.03-0.05
CH_4	1.4-2.0	0.25-0.40
CO	?	0.03
NH_3	?	0.09-0.12
SO_2	?	0.02-0.03

Source: based on Hansen *et al.* (1981), Bach *et al.* (1983); Carbon Dioxide Assessment Committee (1983); Thompson and Cicerone (1986).

What is the future rate of CO_2 buildup in the atmosphere? Before the 'energy crisis' of 1974 world consumption of fossil fuel was increasing by 4 per cent per year (Gribbin 1983). Since then consumption has been rising at a rate of 2 to 2.5 per cent per year. If it is assumed that sinks in the carbon cycle will still absorb 50 per cent of the CO_2 produced by the burning of fossil fuel, then by the year 2087 the concentration of this gas in the atmosphere will double (Carbon Dioxide Assessment Committee 1983; Gribbin 1983; Jager 1983). Of course these rates could change if the pace of industrialisation in the Third World accelerates. Computer general circulation models have been used to model the resultant global temperature increase (Jager 1983; Liss and Crane 1983). These models divide the atmosphere into five to eleven layers and then, given an initial set of conditions, proceed to calculate temperature and moisture fluxes between layers until a steady state is reached. They have produced some startling and by now generally accepted results. If CO_2 doubles, surface air temperature will increase globally 0.7 to 10.0°C above present values, with the most reliable modelling producing values between 1.5 and 3.0°C (Hansen *et al.* 1981; Gribbin 1983).

These results have been queried, mainly by Idso (1980) who generated a temperature increase of less than 0.3°C for a doubling of CO_2 assuming that the Earth behaved as a blackbody. Idso's criticism of the accuracy of general circulation models has spawned the greatest ongoing controversy in the CO_2-warming atmosphere debate (Cess and Potter 1984). Existing general circulation models are far from perfect. Presently the models cannot take into account seasonal effects, have trouble modelling the complete globe and, because of the number of calculations involved, have poor spatial resolution (Liss and Crane 1983; Idso 1986). They fail to account adequately for the dampening effect of the ocean and sea-ice upon air temperature fluctuations, and to consider the negative feedback mechanisms produced by added cloud and moisture in the atmosphere under a warmer climate. Atmospheric dust changes, diurnal variations in solar radiation, ocean heat capacity and ocean circulation are also ignored (Davies 1985). General circulation models have not always fared well in modelling other global circulation phenomena such as the Southern Oscillation (Julian and Chervin 1978) and the possible effects of a nuclear war on global climate (Turco *et al.* 1983; Idso 1986). While the basic process of some El Nino-Southern Oscillation events can be successfully modelled, the detail of global teleconnections cannot be simulated. The models have failed to reproduce the minimal effect on global air circulation of natural events such as the Siberian fires of July-August 1915 (Seitz 1986) that generated smoke amounts (20-180 x 10^{12} g) similar in magnitude to those theorised for a large nuclear exchange.

Wigley and Jones (1981) state that statistically there is no basis for associating warming global air temperatures with the effects of increasing atmospheric CO_2. Statistical linear regression models (Schneider and Mass 1975; Hansen 1980; Gilliland 1982) have been used to unravel the relative roles of volcanic dust, variations in solar luminosity, sunspot cycles and CO_2 in determining the temperature fluctuations of the northern hemisphere over the past century. One of the significant facets of these models is the control volcanic dust and solar luminosity, rather than CO_2 increases, have had on temperature fluctuations. The former two variables account for most of the warming in the last century including the cooling which took place between 1960 and 1980 (Figure 6).

If temperature records are examined before the Industrial Revolution an additional question arises regarding a CO_2-warming atmosphere hypothesis. The summer temperatures of the temperate latitudes of the northern hemisphere this decade are matched only by those in the thirteenth and fourteenth centuries. What caused the warming in those centuries? It certainly cannot be attributed to increased CO_2, CH_4 or any other gas due to

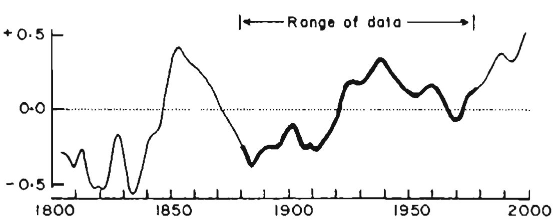

Figure 6: Modelled temperature departures in °C incorporating solar luminosity, 22 and 12.4 year cycles that may coincide with sunspot cycles, volcanic dust and CO_2 (based on Gilliland 1982). The thick line represents modelled temperatures over the timespan of the input data and compares well to actual departures plotted in Figure 1. The thinner line extrapolates results beyond the limits of the data.

man's activities even though more forests were cleared in Europe than at present. The role of 'greenhouse' gases in determining future air temperature increases must be set within the context of these past temperature fluctuations.

Uncertainty 2: Climatic warming due to anthropogenic increases in CO_2 or other 'greenhouse' gases is not a confirmed or easily confirmable fact.

IS SEA-LEVEL RISING?

Until very recently, the conventional wisdom held that sea-level was rising at the eustatic rate of 1.5 mm/yr. From an examination of sea-level records worldwide Emery (1980) proposed that sea-level was rising in the 1970s at an increased rate of 3 mm/yr. and fueled speculation that sea-levels could rise 50-100 cm eustatically in the next 100 years. The 1985 Villach Conference in Austria re-asserted this prediction by proposing a rise of 20 to 140 cm in the next century attributable mainly to the thermal expansion of oceans. A sea-level rise of this magnitude has destructive implications for the world's coastline. Beach erosion would be accelerated, lowlying areas would be permanently flooded or subject to more frequent inundation during storms, and the base line for watertables would be raised. This threat is illustrated in Figure 7 which shows that on the basis of present sea-level curves between 1930 and the mid 1970s four major cities, London, New York, Venice and Tokyo would be threatened by inundation. Given the predicted rates of sea-level rise, some of the world's major cities would require extensive engineering works to prevent flooding.

But is sea-level presently rising worldwide? A careful examination of Figure 7 indicates that sea-levels decreased noticeably in London and Venice after the mid 1960s. In fact the records in Figure 7 are not necessarily due to a eustatic rise in sea-level because local (isostatic) effects dominate some areas. For instance, London is in an area where the North Sea basin is tectonically sinking, Venice suffers from subsidence due to ground water extraction and Tokyo has had tectonic subsidence caused by earthquakes. The above question was evaluated using sea-level records compiled by the Permanent Service for Mean Sea Level, Bidston Observatory, UK for the years 1960 to 1979. Of 725 stations included in this data base, only 219 had adequate coverage (at least 15 years of measurement) to permit trends to be established using Pearson product moment regression. Over 50 and 75 per cent of the trends were statistically significant at the 95 and 90 per cent level of confidence respectively. Published results (Emery 1980; Aubrey and Emery 1983, 1986a, 1986b; Emery and Aubrey 1986) were used to extend coverage to those areas outside the data base. Areas with annual changes

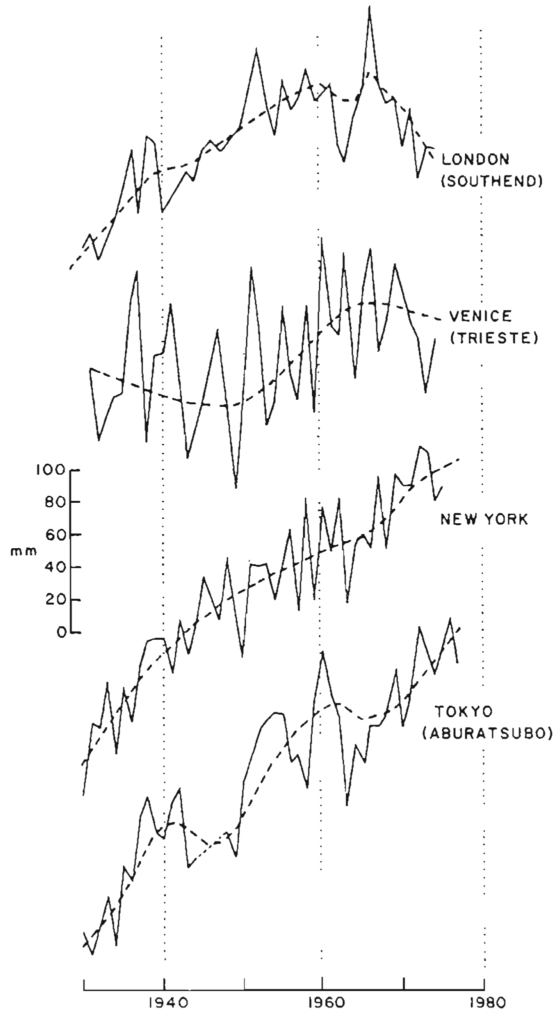

Figure 7: Annual changes in sea-level 1930 to mid 1970s at four diverse stations perceived as threatened by rising sea-level. (Data supplied by the Permanent Service for Mean Sea Level, Bidston Observatory, UK).

in sea-level >3 mm/yr have been differentiated from those with changes of 0-3 mm/yr. in Figure 8. Contrary to the general belief that sea-level is presently rising worldwide, sea-level has fallen along significant stretches of coastline mainly in western Europe, western North America and eastern Asia since 1960. Some of the areas of falling sea-level are outside zones affected by glacial deloading while others are in the zone of collapsing-forebulge submergence where sea-level should still be rising. Increasing sea-levels are restricted mainly to the Gulf of Mexico and the eastern coastlines of North America and Japan. Noteworthy is the fact that it is difficult to delineate large areas of consistent sea-level change because sea-level behaviour can change sign over distances of a few hundred kilometres or less. This is even apparent where rates of change are >±3 mm/yr as evidenced by the patterns of variation in northern Europe and eastern Asia.

Various studies have evaluated the causes of sea-level trends depicted in Figure 8. In the Yellow and East China Seas between China and Japan, sea-level motions simply reflect long term tectonic and isostatic behaviour that is documented in a series of extensive raised or submerged terraces along the coast (Emery and Aubrey 1986a). Land is rising by as much as 5 mm/yr. in areas of massifs and ancient foldbelts in the Korea-north China region, and subsiding by as much as 9 mm/yr in areas of Cenozoic basins and foldbelts in east China. Over periods of less than 25 years, fluctuations relate to the shifting behaviour of the Kuroshio Current that dominates oceanographic effects in eastern Asia, or to the large volume of freshwater runoff mainly from China (>1.2 x 10^{12} m^3/yr). Sea level trends around Japan can be ascribed purely to tectonic factors (Aubrey and Emery 1986a). Rates range from 24 mm/yr of submergence along the south east coast to 6.8 mm/yr of emergence along the north west coast. Shorter term fluctuations again correlate well with the behaviour of the Kuroshio current which temporally is linked to the Southern Oscillation. Along the east coast of North America, three independent coastal segments can be delineated for the period 1940-1980 with differing trends in sea-level behaviour that do not parallel depths in the shelf break or any other obvious topographic or structural feature (Aubrey and Emery 1983). Mean sea-level is increasing at a steady rate of 1.7 mm/yr

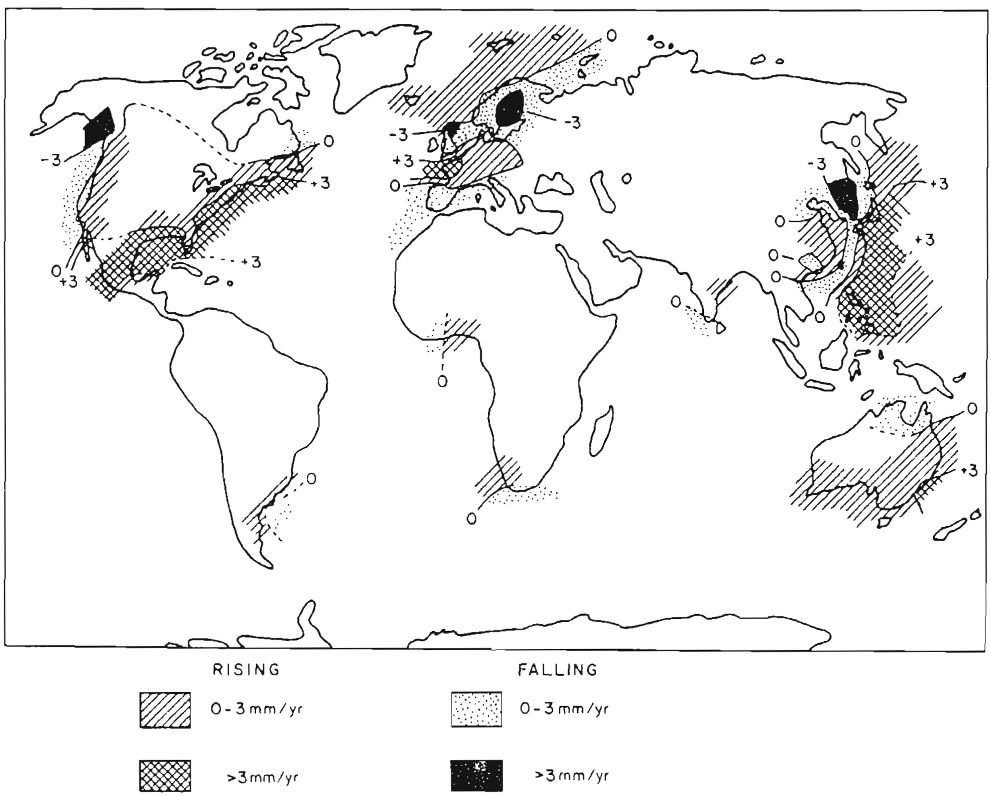

Figure 8: Average annual rates of change in worldwide sea-level mainly between 1960 and 1979. Data supplied by the Permanent Service for Mean Sea Level, Bidston Observatory, UK, and supplemented with additional information from sources Emery (1980), Aubrey and Emery (1983, 1986a, 1983b), Emery and Aubrey (1986). Unshaded sections of coastline do not have accurately defined and/or long term sea-level information.

that Brooks (1985) speculates is due to intensification of Gulf Stream impingement upon the shelf. In Australia sea-level is rising at the rate of 1.8 mm/yr in the south and falling at the rate of 0.5 mm/yr in the extreme tropical north (Aubrey and Emery 1986b). These patterns are ascribed to crustal cooling along rifted margins in the south and overriding of the Australian plate northwards. However Bryant *et al.* (1987) show that sea-level behaviour at Sydney correlates strongly to meteorological and oceanographic factors such as the Southern Oscillation, storminess, rainfall and sea surface temperature.

More importantly Figure 8 shows that there is too little information to state emphatically whether or not sea-levels are rising worldwide. More data are required from the centres of oceans and at regularly spaced intervals along coastlines to account for the speeding up or slowing down of ocean gyres that could affect sea-level in the short term. Sea-level also has great temporal and spatial variability (Bryant 1985). This variability can operate over timespans of days to years and can greatly complicate delineation of statistical trends. Seasonally mean sea-level fluctuates between 15 and 54 cm in such diverse locations as the Bay of Bengal, west coast of Mexico, north eastern Siberia and Australia. Over periods of days or months sea-level can fluctuate several tens of centimetres because of changes in atmospheric pressure, sea temperature, salinity, onshore wind stress components, current impingement on the coastline (as with the Kuroshio and Gulf Stream currents mentioned above) and mixing of surface and deep ocean waters. The changes in sea-level presented in Figure 8 evidence low latitude asymmetry in the Atlantic and Pacific Oceans with a western boundary rise and an eastern boundary decline. Such a pattern is consistent with either a change in intensity of westerly winds or a shift in the orographically controlled and oceanographically fixed pressure cells of the northern hemisphere. Sea-levels can also fluctuate over short distances because of shelf waves, storm surge or river discharge. Shelf waves, with a periodicity of one to seven days and amplitudes exceeding 50 cm have been found to travel anticlockwise around the southern Australian coastline (Provis and Radok 1979). River discharge can locally increase sea-levels as mentioned above in the case of the East China Sea. Between 7 and 21 per cent of the annual variance in sea-level along the eastern United States coast is due to this factor (Meade and Emery 1971). Even an increase in rainfall over the coastal sector of an ocean can cause a long term increase in sea-level measured at a tide gauge.

Of particular note is the persistent inter-annual fluctuations in sea-level associated with El Nino-Southern Oscillation events in the equatorial Pacific region (Wyrtki 1982). Generally tropical air movement in the Pacific is dominated by strong easterlies labelled the Walker circulation. Warm surface water is blown towards the western side of the Pacific where it piles up to heights of 20 cm or more. The Walker circulation oscillates (the Southern Oscillation) in strength every three to five years and has teleconnections with meteorological change worldwide. More importantly, the failure of the easterlies leading to an El Nino-Southern Oscillation event causes the water in the west Pacific to surge back eastwards across the Pacific in the space of two months. During the 1982/83 event, sea-levels fluctuated between 30 and 40 cm across the equatorial Pacific (Harrison and Cane 1984). Sea-level fluctuations are not restricted to the tropics. When the bulge reaches South America it then propagates north and south over several months with minimum dissipation because of shoreward trapping due to refraction over the shelf and landward directed Coriolis force (Enfield and Allen 1980). The 1982/83 El Nino-Southern Oscillation event raised sea-levels 35 cm above average along the Oregon coast (Komar 1986). What if El Nino-Southern Oscillation events occurred randomly with a greater frequency than the historical rate of three to five years? El Nino-Southern Oscillation events this decade have tended to recur every two years. Tide gauges in the west tropical Pacific would be perceived as falling, while those in the east tropical Pacific would record higher mean sea-levels, not generated by any eustatic change, but simply by this more frequent surging of water across the Pacific Ocean. Rises averaged over the short term could even exceed Emery's 3 mm/yr rate with a variance 1.5 to 2.0 orders of magnitude greater. Sea-level fluctuations at Sydney and probably other parts of the east Australian coastline are strongly linked to the Southern Oscillation and other climatic factors such as storms, rainfall and sea surface temperature (Bryant *et al.* 1987). For these locations, sea-level increases are no indication of an eustatic rise, but may simply reflect the regional consequences of climatic change in the south Pacific generated for example by more frequent El Nino-Southern Oscillation events.

Uncertainty 3: Rising worldwide sea-level is not a confirmed or easily confirmable, fact.

IS RISING SEA-LEVEL THE MAJOR CAUSE OF SANDY BEACH EROSION?

There is little argument that 90 per cent of the world's sandy beaches are eroding at average rates of 0.5-1.0 m per year (Bird 1985). This retreat operates according to the Bruun rule (Bruun 1983) which states that, on beaches where offshore profiles are in equilibrium and net longshore transport minimal, rising sea-level leads to

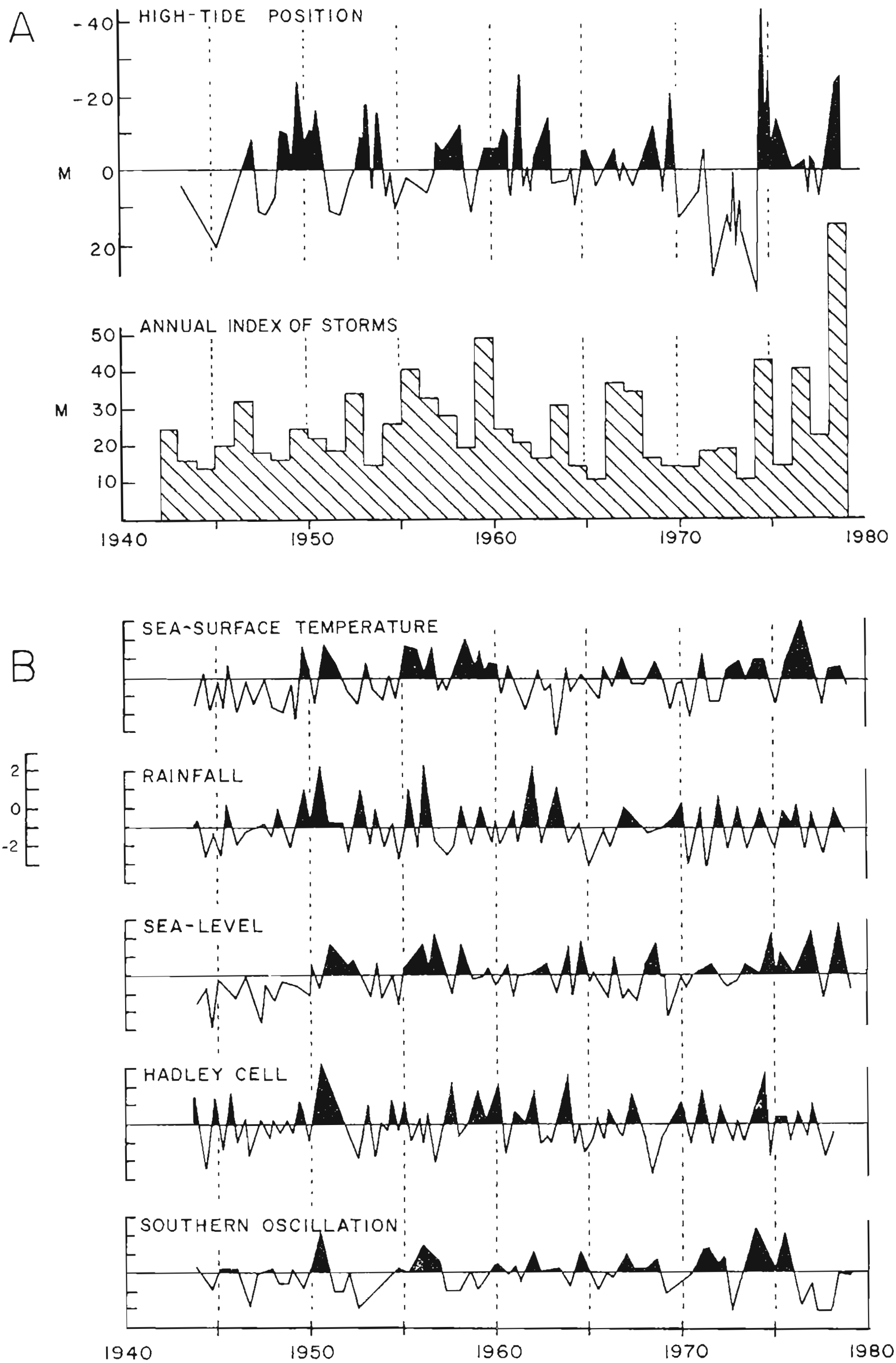

Figure 9: Plots of the 1943-1978 Stanwell Park data set used in the principal component analysis (based on Bryant 1983a, 1983b, 1985, 1987a, 1987b). Section A plots raw values, while Section B plots normalised data. Except for the high tide position time series, data have been summarised for illustrative purposes at half yearly or yearly intervals. This has tended to smooth extreme values in the records.

shoreline retreat. Retreat rates of 0.5 m of shoreline per 1 cm rise in sea-level have been substantiated by numerous studies at varying coastal locations (Bryant 1983b). A dichotomy exists however between measured rates of beach retreat and the present, postulated eustatic rise in sea-level. Shoreline retreat at the common worldwide rate of 0.5-1.0 m/yr would require sea-level rises three to seven times larger than the maximum rate of 3 mm/yr postulated by Emery (1980). Obviously, other factors besides sea-level rise must be involved in beach erosion.

Beaches retreat when sea-level rises because the base elevation of the watertable at the coastline is elevated. Water draining from the lower beach face decreases sediment shear resistance and enhances the possibility of sediment liquefaction. This process causes seaward erosion of sand and shoreline retreat and logically implies that any factor that affects the position of the beach watertable can control beach erosion. For instance, a sandy backshore absorbing rainfall acts as a time-delaying filter for subsequent discharge of this water to the sea through the lower foreshore. The process raises the watertable substantially for periods up to two months after heavy rainfalls. Under intense rainfall, sand elutriation is even possible. Not only may rainfall control beach retreat just as well as rising sea-level, but rainfall also does not suffer from the same global sparsity of data as sea-level does (Bryant 1985).

Rainfall as well as sea-level can fluctuate dramatically in the short term, mainly as a response to climatic forcing. It is unfortunate that these two parameters have been ignored at the expense of air temperature as indicators of climatic change this century. Since 1948 climate has tended to become more variable (Gribbin 1983). The concentration firstly upon a cooling of air temperature beginning in 1948 and then upon a reversal of this decline towards the end of the 1970s has been misdirected. All that has been substantiated is that air temperature, which is one facet of climate, has undergone increased variability since 1948. This variability has accelerated since 1970 and with it so has the variability of other climatic factors such as ocean temperature, pressure patterns, rainfall regimes and Southern Oscillation frequencies. All these changes have a direct influence on sea-level since sea-level is one of the most interdependent of meteorological and oceanographic variables. Researchers linking rising sea-levels to melting of ice-caps have missed the point as to the cause(s) of changing sea-level. Sea-level rises are induced as the result of natural climatic variability by increasing current impingement on the coast, direct rainfall, runoff, wind set-up within global air circulation, storm surge and sea surface temperature.

Logically, beach erosion may not be controlled by a single variable, sea-level, but by a myriad of other meteorological and climatic variables, some of which have significant prognostic value. This viewpoint has been emphasised for global beach erosion by Bird (1985) and is summarised here for one Australian beach, Stanwell Park on the New South Wales Central Coast. The Stanwell Park area has data between 1943 and 1978 on monthly rainfall, sea surface temperature, sea-level, storm waves and atmospheric circulation as measured by the latitude of the Hadley cell over the east coast and the state of the Southern Oscillation

Table 3: PRINCIPAL COMPONENT ANALYSIS OF THE STANWELL PARK DATA SET 1943-1978, WHICH INCLUDES AVERAGE HIGH-TIDE POSITION AND EIGHT OTHER METEOROLOGICAL AND OCEANOGRAPHIC VARIABLES. EIGENVALUES, PERCENTAGE VARIANCE OF THE DATA EXPLAINED AND CUMULATIVE PERCENTAGE VARIANCE ARE LISTED, TOGETHER WITH THEIR EIGENVECTORS FOR EACH VARIABLE. ONLY INFORMATION FOR EIGENVALUES ABOVE 1.0, THE NOISE LEVEL OF THE DATA SET, ARE PRESENTED. SIMILAR ABSOLUTE EIGENVECTORS ARE IN BOLD FACE.

	Eigenvalue			
	1	2	3	4
Value	2.92	1.83	1.36	1.13
% variance explained	24.34	15.21	11.30	9.45
Cumulative %	24.34	39.55	50.86	60.31
	Eigenvectors			
Variable				
High-tide position	**-0.336**	-0.060	0.071	-0.152
Hadley cell position	0.238	**-0.494**	0.091	-0.053
Sea-level	**0.366**	0.233	0.134	-0.116
Southern Oscillation index	0.176	-0.085	-0.139	**0.647**
Annual rainfall	0.262	-0.176	**-0.524**	0.171
3 monthly rainfall	**0.321**	**-0.348**	-0.031	0.163
Sea surface temperature	0.281	**-0.434**	0.252	**-0.397**
3 month storm waves	**0.427**	0.060	-0.035	-0.268
Annual storm waves	**0.349**	**0.448**	-0.038	-0.048

(Figure 9). A complete description of these variables can be found in Bryant (1987a, 1987b). As well, there exist 105 accurate measurements of average, high-tide beach position derived from oblique photographs randomly sampled over this period (Bryant 1983a).

This complete data set of nine meteorological and oceanographic terms plus average high-tide position was normalised, incorporated into a correlation matrix and analysed using principal component analysis (PCA). Ranked eigenvalues for the first four eigenvalues above the noise threshold of the Stanwell Park data set, together with their eigenvectors are presented in Table 3. Only the first eigenvalue, accounting for 24.3 per cent of the total data variance, favours high-tide position. Four casual or prognostic variables, sea-level, quarterly rainfall and storm wave heights accumulated quarterly and annually, are associated together with high-tide positions. All variables have been shown previously to be significantly related to beach position at Stanwell Park (Bryant 1983a, 1983b, 1985, 1987a, 1987b). A 0.1 m change in accumulative quarterly rainfall, a 0.01 m change in sea-level, and a 1 m change in quarterly and annual accumulated storm wave heights result in a 1.62 m (8.7% explanation of high-tide variance), 0.44 m (6.6%), 0.62 m (9.9%) and 0.47 m (16.6%) change in high-tide position respectively. Not only do these latter variables relate to beach change but the principal eigenvalue indicates that they also relate to each other.

Uncertainty 4: Rising sea-level may not be the prime factor causing worldwide beach erosion, but one of a suite of changing, interrelated meteorological and oceanographic variables that relate to both beach accretion and erosion.

CONCLUSIONS

The scenario of a CO_2-warming globe contains many uncertainties. The warming of the atmosphere is not an established fact, and even if it was there may be no need to invoke increased atmospheric CO_2 or other 'greenhouse' gases as the cause when such warmings have been a part of temperature time series historically. If temperatures are increasing, sea-levels may not be rising globally because of melting of near-polar ice or thermal expansion of oceans. Evidence now coming to light indicates that it is extremely difficult, if not impossible, to delineate an eustatic signature above tectonically or climatically induced ones. In this regard, sea-level rise may not be a hazard of the future except in local areas where isostatic factors are causing the land to sink (areas of subsidence) or the ocean to rise (for instance, areas affected by more frequent El Nino-Southern Oscillation events). The failure to substantiate an eustatic rise in sea-level casts severe doubt on the role sea-level has as a major cause of existing beach retreat. The beach erosion hazard may be evaluated better by examining recent changes in the world's rainfall regime or other oceanographic factors such storminess or wave regime characteristics. A common factor underpinning our uncertainties about a CO_2-warming atmospheric scenario is the fact that the Earth is not covered adequately with enough data points to evaluate the scenario conclusively. Even where geophysical time series are available, they are clouded by the inherent fluctuations of their variances. One fact is certain: global climatic variation is occurring. As a result rainfall, air and ocean temperatures, sea-level and beach erosion patterns worldwide are also changing.

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