SOME NOTES ON SEA-LEVEL CHANGE AROUND THE AUSTRALIAN COASTLINE

(with especial reference to southern Australia)

Professor R.M. Carter
James Cook University, Townsville

June 7, 2008

IMPORTANT NOTE ON TERMINOLOGY

A proper understanding of the risk associated with sea-level change can only be attained by adherence to accurate terminology. In particular, it is vital to recognize the distinction between changes in ***eustatic sea-level***, which correspond to changes in a notional world-wide average, and changes in ***local relative sea-level*** (LRSL), which correspond to changes in actual sea-levels at real and particular coastal locations.

In general, statements made by the IPCC, CSIRO and government planning and management authorities, which use the unqualified and ambiguous term "sea level", are referring to eustatic sea level. On its own - without taking into account the factors of local tectonics, isostatic adjustment and sediment supply - a knowledge of eustatic sea-level behaviour does not enable the likely determination of specific future shoreline positions, and is therefore of little value for coastal management and environmental protection purposes.

> *"Sea level rise is one of the most feared impacts of any future global warming, but public discussion of the problem is beset by poor data and extremely misleading analysis."*
>
> *"Most discussion, including that of the IPCC, is formulated in terms of global average* [eustatic] *sea level. Even assuming that this statistic can be estimated accurately, it has little practical policy value. Local relative sea-level (LRSL) change is all that counts for purposes of coastal planning, and this is highly variable worldwide, depending upon the differing rates at which particular coasts are undergoing tectonic uplift or subsidence. There is no meaningful global average for LRSL.*"
>
> (Singer et al., NIPCC, 2008, p. 51).

LIST OF ACRONYMS AND ABBREVIATIONS

AHD Australian height datum
CSIRO Commonwealth Scientific & Industrial Research Org.
DSE (Victorian) Dept. Of Sustainability & Environment
ENSO El Nino-Southern Oscillation
GAB Great Australian Bight
IPCC (UN) Intergovernmental Panel on Climate Change
ka thousands of years ago
ky thousands of years
LIH last interglacial highstand
LRSL local relative sea-level
Ma millions of years ago
My millions of years
MIS marine (oxygen) isotope stage
NAO North Atlantic Oscillation
PDO Pacific Decadal Oscillation
RDA (East Beach) residential development area
SAM Southern Annular Mode

REGIONAL SETTING OF THE SOUTHERN AUSTRALIAN CONTINENTAL MARGIN

The southern Australian continental margin, lies on a passive rift-drift margin that developed ~160 Ma in the Jurasssic. The margin has been tectonically stable through recent geological time, apart from minor flexuring or faulting associated with Neogene intraplate volcanism, and isostatic responses to shifting sediment or ocean loading - especially responses associated with major sea-level fluctuation during the Quaternary.

Regionally, the offshore southern Australian margin today is subject to very slow, post-rift, thermal subsidence, though in the vicinity of the shoreline this regional effect is added to or counteracted by other effects, especially hydroisostasy - which causes minor rotational tilting across the inner shelf-coastal region, with a hinge point between uplift (onshore) and depression (offshore) located near the shoreline (e.g. Chappell et al., 1983). For example, Harvey et al. (1999) have shown that at Port Pirie isostatic uplift at a rate of 0.33 mm/yr has caused sea-level to fall 2.2 m since 6.7 ka; after correcting tide gauge data for this effect, these authors estimate that the current rate of LRSL rise in the vicinity is 0.31 mm/yr.

Interpretation

Though it would be possible for modern dune blowouts to be located at heights of 6 m AHD and greater, marine terracing and soil capping just landward of the shoreline, as represented in places around the southern Australian shoreline, is unlikely to have been produced at such a height by Holocene or recent shore processes. Many studies from around Australia have shown that early Holocene sea-levels occur only up a maximum of about 2 m above modern sea-level (e.g. Baker et al., 2005). Belperio et al. (2002), comparing early-middle Holocene coastal data from around the Australian coast, concluded that the maximum uplift likely in South Australia from hydroisostasy is about 3 m - a figure which agrees with earlier geophysical models (Lambeck & Nakada, 1990).

It is therefore likely that where Quaternary terrace sands and sand dunes occur higher than this they represent LIH deposits, i.e. are about 120,000-130,000 years old (cf. Appendix 1).

It is well established that the last interglacial (Marine Isotope Stage 5; MIS 5) was slightly warmer than the Holocene (MIS 1), as manifested by a higher eustatic sea-level than today's and therefore an inferred lesser global ice volume. This accepted, controversy exists over the exact ages and heights of the different phases of the MIS 5 highstand (e.g., Plaziat et al., 2008). Despite such uncertainties, reliable evidence worldwide suggests a eustatic height for the different pulses of MIS 5 between 2.5 and 8.5 m above modern sea-level (Stirling et al., 1995; Vezina & Jones, 1999; Hearty & Neumann, 2001), and a widely adopted reference level for MIS 5e has been +6 m (e.g., Veeh, 1966; Chappell, 1974, Bloom et al., 1974).

For Australia, Murray-Wallace and Belperio (1991, p. 455) proposed a lower MIS 5e reference level of +2-3 m, based on their interpretation of LIH sediments around the Eyre Peninsula, Spencer Gulf and Gulf St Vincent. Palaeosol horizons along the western Victorian coast occur at ~+6-7 m AHD, matching well with global estimates for MIS 5e. Therefore, an alternative to Murray-Wallace & Belperio's interpretation is that western Victorian coastal terrace deposits may give the best Australian "reference" level for MIS 5e, and that the South Australian 5e shoreline features either reflect subsidence there (cf. Belperio, 1993) or were formed at a slightly younger, and lower sea-level, part of MIS 5 (MIS 5a or 5c).

RECENT AND LIKELY FUTURE SEA-LEVEL CHANGE

Appendix 1 contains a selective review and summary of recent independent published research on sea-level change. It highlights the need mentioned at the beginning of this evidence to clearly distinguish between eustatic and LRSL.

IPCC estimates of sea-level change are eustatic, and based upon socio-economic scenario modelling (Fig. 1). The known inadequacies of the scenarios that IPCC has adopted (Castles & Henderson, 2007) mitigates against the accuracy of their sea-level predictions, which have anyway decreased successively with every Assessment Report until their low end now overlaps with the more reliable empirical estimates (Fig. 2).

The management of coastal development, and rational environmental planning, must necessarily be considered in the context of changing LRSLs, not theoretical models of global eustasy, and it is to this matter that we now turn.

Tide gauge records of Local Relative Sea-level

It is widely and wrongly assumed by the public and politicians that "sea-level" is rising all around the Australian coast. The reality is that LRSL change occurs at greatly different rates and directions for different coastal locations. Around continental Australia, sea-level change ranges from a maximum rate of fall of -2.5 mm/yr at Stony Point, Victoria to a maximum rate of rise of +2.7 mm/yr at Weipa, Cape York (Australian Bureau of Meteorology, 2006; cf. Fig. 9).

Four feasible approaches can be used to estimate the past, and therefore likely future, change in LRSL at any point around the Australian coastline. These approaches are illustrated by considering the case for Port Fairy, western Victoria. All data cited are based on tide gauge records of the national inventory provided by the Australian Bureau of Meteorology (2006). None of these records show any significant recent acceleration of sea-level rise, as is predicted by global warming theory. Parenthetically, it should be noted too that some tide gauge records are known to be affected by local uplift or subsidence (e.g. Adelaide, where sinking of 2.8 mm/yr is estimated by Belperio, 1993), which makes their derived sea-level rates unsuitable for use away from their site of measurement without correction; other sites (e.g. Portland) have an inadequate length of record.

The four chosen approaches are:

1. *Consider the nearest "far field" tide gauge to Port Fairy*, which is Geelong. The record is 33 years long and records a rise at an average rate of 0.47 mm/yr (Fig. 4). This yields an estimated sea-level rise by 2100 of 4.4 cm.

A tide gauge record is also available for Port Fairy itself for the years 1966-1976 (Fig. 5). Though too short to delineate an accurate long-term trend, no obvious change in sea-level is apparent over the ten years of record - suggesting that the true Port Fairy rate of rise may perhaps be even less than that recorded at Geelong.

2. *Consider the average of the best "far field" tide gauge records from across the Great Australian Bight*, which are Albany, Esperance, Thevenard, Victor Harbour, Geelong and

Hobart. Each station has between 33 and 40 years of record, and their average rate of sea-level change up until 2006 was a rise of 0.58 mm/yr (Fig. 4). This yields an estimated sea-level rise by 2100 of 5.5 cm.

3. *Consider the average of the best tide gauge records on the GAB margin that have been corrected for local tectonic and anthropogenic effects*, which are Thevenard, Port Pirie, Outer Harbour Adelaide, Inner Harbour Adelaide, Port Lincoln, Victor Harbour and Port MacDonnell (Harvey et al., 2002).

The corrected LRSL rates of rise at these sites are 0.08, 0.14, 0.21, 0.59, 0.75, 0.67 and 0.76 mm/yr, respectively, which yields an average rate of rise of 0.46 mm/yr. This number is indistinguishable from the rate of rise estimated already for Port Fairy (based on Geelong; 1, above), and implies a sea-level rise by 2100 of 4.3 cm.

4. *Consider the average change in the two best long-record tide gauges from "southern" Australia*, which are Fremantle (since 1897) and Fort Denison (Sydney Harbour; since 1914). The long-term average from these two sites is a rise of 1.2 mm/yr (Fig. 4). This yields an estimated rise by 2100 of 11.3 cm.

As a fifth alternative, it might be suggested that a national average LRSL figure should be used for planning, based upon records from all stations of the Australian tide gauge network. This average is a rise of 0.7 mm/yr (Australian Bureau of Meteorology, 2006), which falls within the range of numbers already considered and translates to a sea-level rise by 2100 of 6.6 cm. Of course, the number is a statistical construct only; to use it for environmental planning for a specific project would be to accept the quaint premise that the average of all the wrong numbers is the right number.

The most thorough study available of corrected southern Australian tide gauge data is that of Harvey et al. (2002). After fully discussing all the factors involved, these authors (p. 10) conclude that the two most reliable estimates of LRSL rise in southern Australia are Thevenard (0.08 mm/yr) and Port Pirie (0.14 mm/yr). Averaging these two figures, the best estimate of "far field" LRSL rise available for the GAB margin is 0.11 mm/yr, which implies a total rise by 2100 of only 1 cm.

Subsequent to Harvey et al.'s review, in 1992 the Australian Baseline Sea-level Monitoring Project (Australian Bureau of Meteorology, 2007) started collecting GPS height measurements at a number of baseline tide gauge stations, in order to be able to correct the records for substrate sinking or rising trends. The 5 or 6 measurement points available at each station over the 12 years 1992-2004 are not yet enough to define statistically significant trends, but this data will come to assume importance as a longer record accrues.

Previous estimates of sea-level rise at East Beach

Marine flooding setback: application of the Brunn Rule

The Brunn Rule (Brunn, 1988) was developed as a method for predicting the marine flooding that would result from a rising sea-level as it affected a flat, sandy coastal plain. Brunn assumed that in these circumstances the shelf-beach profile would keep a constant shape and position relative to a rising sea-level, as the shoreline migrated landward. Depending upon the slope of the substrate, application of the Brunn Rule often results in predicted shoreline transgressions at rates of 50-100 times the rate of sea-level rise. From this has arisen the common planning practice, codified by some Australian state governments, of calculating likely flooding setback contours set at, say, 100 times the amount of predicted sea level rise.

Applying this reasoning to the possible sea-level rises of 5, 10 and 20 cms at Port Fairy by 2100 (derived above), indicates flooding setback lines located 5, 10 and 20 m inland in a horizontal direction from the present 0 m AHD contour.

Such Brunn Rule calculations are, however, inapplicable to the East Beach, Port Fairy

First, because the coast is cliffed whereas the Brunn Rule has only been tested for flat coastal areas. Second, because the cliff is developed in LIH sediments which include consolidated palaeosol horizons; such sediments are less easily eroded than the free-running modern sand envisaged in the Brunn model. Riedel & Byrne (2006) estimated storm erosion recession of the shoreline cliff of less than 3 m over 50 years, and commented that a precautionary 5 m setback would be conservative even allowing for sea-level rise.

Most earlier writers have recommended somewhat longer erosion setback distances, but their estimates were based on unrealistically high sea-level rises of 6 mm/yr, i.e. about 12 times the current rate. Patterson & Tilbury (1996) estimated a 10-13 m setback for a sea-level rise of 260 mm over 50 years. Riedel & Byrne (2006) calculated 8 m of "dune recession" from a 50 year sea-level rise of 300 mm, then added an ad hoc 5 m in recognition of the prior higher Patterson & Tilbury estimate, then almost doubled the resulting 13 m estimate to arrive at a development set-back of 20 m. Patterson (2006a, p. 2), commenting on this, and on the high uncertainty attendant on future sea-level, observed that "*the recommended provision of 13 m* [of setback] *for sea level rise appears reasonable and conservative for the 50 year planning period and 300 mm sea level rise adopted*". If we correct the sea level estimate to its likely 24 rather than 300 mm of rise, then Riedel & Byrne's analysis would indicate a setback value, in itself again conservative, of just 1 m.

The only higher estimates of coastal recession at the East Beach RDA are those of Rosengren (2005), who predicted 23 m and 39 m of recession for respective sea-level rises of 300 mm and 500 mm over 50 years. The numerical model on which these results are based has not been made available, but is said to be designed for low profile shorelines and does not "*fully evaluate the buffering role of the elevated terrace as a defence against shoreline recession"*. Even were the model applicable to East Beach, which seems unlikely, the inflated sea-level rise assumed has obviously resulted in exaggerated estimates of recession. Recalculating the figures *pro rata* for a 50 year rise of 24 mm results in reduced recession estimates of 1.8 m and 3.1 m respectively.

Brunn calculations for East Beach based on a realistic rate of sea-level rise of 0.47 mm/yr indicate only a small flooding setback of about 1 m. Adopting a conservative setback of 5 m would be strongly precautionary. In actuality, and provided the longshore sand supply for the modern beach-berm sand reservoir remains at adequate levels, little coastal retreat will occur at all except minor mass wasting of the beach scarp.

5. CONCLUSION

Unvalidated computer forecasts of changing global eustatic sea-level – such as those of the IPCC - are, on their own, of little relevance to coastal planning for specific shoreline locations. What is relevant is determining the appropriate value for Local Relative Sea Level (LRSL) rise.

Appendix 1

MEASURING SEA-LEVEL CHANGE

Geological background rates of change

Changes in sea-level over long periods of time (millions of years) are inferred from geological evidence. By their nature, such records are of local relative change, and they require correction if they are to be translated into eustatic estimates (e.g., Kominz et al., 1998).

For about the last 3 million years, however, a high-quality proxy for eustatic sea-level is represented by the oceanic oxygen isotope record (e.g., Liesecki & Raymo, 2006; Fig. 6a). This curve is based upon the measured ratio of two isotopes, ^{16}O and ^{18}O, that are fractionated in sea-water, and hence vary in the shells of fossil animals that lived in that water in accordance with fluctuations of planetary ice volume through time. High resolution (millenial) oxygen isotope curves from all ocean basins and latitudes contain a common signal pattern that has become a standard for subdividing Quaternary time into climatic Marine Isotope Stages (MIS), numbered backwards through time. Thus the ~125 ka last interglacial sands that underlie the Port Fairy development site were deposited during MIS 5, the last glaciation at 20 ka coincided with MIS 2, and the Holocene is in large part synonymous with MIS 1 (Fig. 6b).

Over the post-glacial, ice-melting part of this climatic cycle, sea-level rose at rates as high as >20 mm/yr (Liu et al., 2004) until 8 ka, and Belperio (1995) suggested rates of LRSL of 9 mm/yr and 24 mm/yr occurred in the early Holocene of South Australia, after which a more gentle rate of rise has continued up to the present day (Fig. 7).

Historic rates of change

Over shorter, historic time scales, sea-level can be measured directly, either (since about 1700; Fig. 8) using tide gauge readings, or (since 1992; Fig. 9) using precise altimetry from satellite-mounted radars. Both these methods measure changing sea-level heights through time at particular locations, and therefore provide many differing records of LRSL change at different places (Fig. 10). Corrections are then applied for site-specific tectonic or oceanographic-meteorologic distortions of the underlying eustatic signal, at least in principle, to derive a truly global (eustatic) signal.

The longer term tide-gauge data, after correction for subsidence, document a 20th century sea-level rise of +1-2 mm/yr (Fig. 8), whereas the more modern satellite altimetry indicates a rate of rise between 1992 and 2007 of +3.2 mm/yr. Based on these records, IPCC (2001) estimates an average rate of eustatic rise of 1.6 mm/yr between 1900 and 2000. However, the derivation of such rates of change is achieved by simple least-squares linear trend analysis. Such calculations are highly sensitive to the start and end points selected for the data set being considered, and they also ignore short-term and multi-decadal changes in sea-level known to be associated with meteorological and oceanographic oscillations.

Decadal and multi-decadal sea-level change

Sea-level changes on a decadal or multi-decadal scale are driven by changes in the heat energy or dynamics of the ocean system. They include the effects of spinning up or slowing down major current gyres and the effects of established climatic oscillations such as ENSO (El Nino-Southern Oscillation), the PDO (Pacific Decadal Oscillation) and the SAM (Southern Annular Mode). Sea-level change forced by such mechanisms is generally of low magnitude (centimetres to a metre or two only), but can operate at rates as high as 5-10 mm/yr. Another important cause of shorter term changes in sea-level is that produced by heating or cooling of the ocean, termed the *steric effect*. After a phase of warming, expansion and steric sea-level rise during the late 20th century, ocean cooling has led to steric sea-level fall since 2002 (Fig. 11).

Correction of trend analyses for short-term change and rhythmicity is a particular problem for the satellite altimeter sea-level records, which currently indicate a eustatic rise of 3.4 mm/yr for the period 1992-2007. However, these measurements can not yet be viewed as securely accurate. First, because of their limited accuracy (nominally about +/- 100 mm, which can be improved to about +/- 20 mm by averaging 10-day-separated repeat measurements at particular locations); second because of corrections that are needed for orbital drift and the stitching of records from different satellites, and third because of the short length of record of only about 15 years, whereas a minimum 40-50 year length of record is required to delineate a meaningful long-term trend.

Kolker & Hameed (2007) have shown that short term, non-tidal, local sea-level variability is much greater than the magnitude of long term trends. The cause of this variability is partly unknown, but it is thought to include the effects of storms, winds, floods, wind-driven Rossby waves, shifts in major ocean currents, volcanic heating and meteorological phenomena such as ENSO and the PDO. That much sea-level variability is driven by meteorological and oceanographic processes that redistribute water, heat and ocean response to atmospheric pressure, which is a main conclusion of this paper, is however scarcely surprising.

The unresolved conflict between the different rates of eustatic rise derived from satellite and tide gauge measurements is the subject of much discussion and active research. But the primary interest of this research is anyway for climate change study - because they enable the relationships between global ice volume and sea-level to be explored and modelled. Knowledge of such eustatic sea-level estimates, and their extrapolation into the future, has little direct relevance to coastal management at specific sites.

Recent acceleration in rate of sea-level change

Because much sea-level change is periodic on a decadal scale, linear regression though eustatic data is an unreliable technique with which to establish long-term sea-level trends for use in environmental management. It is obvious, therefore, that the accurate portrayal of any long-term ocean-heating (steric) sea-level rise, putatively due to human influence, is only possible after short-term periodic sea-level behaviour has been identified and the records adjusted to account for it.

The question therefore is not “is sea-level rising”, for the geological and tide gauge record indicates that it is and, other things being equal, will continue to do so. Rather, to provide evidence for increased rates of rise due to human influence necessitates that the question be "is sea-level rise accelerating?". The answer is no.

For example, the IPCC (2001) wrote "*no significant acceleration in the rate of sea level rise during the 20th century has been detected*". In 2007 they said that "*global average sea level rose at an average rate of 1.8 [1.3-2.3] mm per year over 1961 to 2003. The rate was faster over 1993-2003: about 3.1 [2.4-3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear*".

Amongst recent writers, Church & White (2006) are the only authors who claim to have established that sea-level rise accelerated during the late 20th century. Their study is based on the same tide gauge dataset used by other authors (who have drawn different conclusions), and also conflicts with earlier analyses of the same dataset by the same authors (e.g. Church et al., 2004; IPCC, 2007). In any case, it remains possible that the enhanced rate, similar to that indicated by the TOPEX-Poseidon dataset, is caused by oceanographic rather than human steric effects.

Many other recent studies have confirmed a lack of observed acceleration in 20th century sea-level records, including all those listed below. At the same time, most of these studies consistently report averages for eustatic sea-level rise that are less than the IPCC's 2007 estimate of 1.8 mm/yr. For instance:

- Unnikrishnan & Shankar (2007), analysing tide gauge data from the Indian Ocean, reported that the average rise across the five stations that they judged to be most reliable was ***1.29 mm/yr***;

- Berge-Hguyen et al. (2008), using a combination of data for temperature change in the upper 700 m of the ocean, estimated a 1955-2003 rise in sea-level of ***1.48 mm/yr;***

- Kolker & Hameed (2007), in a study of 5 selected Atlantic Ocean tide gauges since 1900, determined that the North North Atlantic Oscillation (NAO) accounted for a "major fraction of the variability" and was "a meteorological driver of sea level trends", and documented a 20th century rate of rise of between ***0.49*** and ***0.93 mm/yr*** (average ***0.71 mm/yr***);

- Woppelmann et al. (2007), in one of the first studies to use GPS observations to correct for crustal vertical motion at tide gauge stations, estimated a global rise of ***1.31 mm/yr*** for the short period 1999-2005;

- Holgate (2007), using nine highest quality long tide gauge records from non-tectonic locations around the world, estimated a 20th century rise of ***1.74 mm/yr***; and far from the rate of rise accelerating, the first half of the record (1904-1953) has a higher rate of rise of 2.03 mm/yr compared with the 1954-2003 rate of 1.45 mm/yr, Holgate noting that "*a greater rate of rise in the early part of the record is consistent with previous analyses of tide gauge records which suggested a general deceleration in sea level rise during the 20th century*";

- Larsen & Clark (2006), studying longer term sea-level change in eastern USA over the last few thousand years, and using radiocarbon-dates on basal, transgressive peat horizons, show LRSL rise rates for four localities that lie between ***1.3*** and ***2.0 mm/yr*** and comment that "*there is no discernible divergence in the rate of sea-level rise over the past two centuries to suggest a connection with the documented increase in atmospheric CO_2 concentration*";

- Jevrejeva et al. (2006) used spectral analysis to remove the multi-decadal (2-30 year) meteorological/oceanographical signature from worldwide tide gauge data for 12 ocean regions, reporting, similar to Holgate (2007), a rate of rise for 1920-1945 of 2.5 mm/yr, effectively the same as the ***2.4 mm/yr*** that they estimate for 1993-2000;

- Cazenave & Nerem (2004), using TOPEX-Poseidon altimeter data, identified a rate of rise of ***2.8 mm/yr***, at the same time acknowledging that part of the trend may reflect decadal-scale variability; they identified "*non-uniform geographical distribution of sea level change, with some regions exhibiting trends about 10 times the global mean*", which led them to question "*whether the rate of 20th-century sea level rise, based on poorly distributed historical tide gauges, is really representative of the true global mean*".

- Church et al. (2004) applied empirical orthogonal functions to TOPEX-Poseidon altimeter data, and estimated a rate of global average sea-level rise between 1950-2000 of ***1.8 mm/yr***, stating that "*decadal variability in sea level is observed, but to date there is no detectable secular increase in the rate of sea level rise over the period*";

- White et al. (2005) conducted another analysis of tide gauge data over 1950-2000, and also concluded there had been "*no significant increase in the rate of sea level rise during this 51-year period*";

- Lombard et al. (2005) worked with global ocean temperature data to estimate the rate of steric sea-level change in the last 50 years, finding large fluctuations in the rate of change with time in accord with oscillations like ENSO, PDO and NAO, ***including sea-level fall of up to 1.5 mm/yr during the 1970s and 1980s***; they noted that the high recent sea-level trends measured with TOPEX-Poseidon data are largely non-permanent and associated with natural thermal expansion, and concluded that "*we simply cannot extrapolate sea-level into the past or the future using satellite altimetry alone*";

- Carton et al. (2005) used re-analysis data for global temperature, salinity and sea-level for 1968-2001, determining that salinity effects on sea-level are small and that steric effects "*are enough to explain much of the observed rate of increase in the rate of sea level rise in the last decade of the 20th century without need to invoke acceleration of melting of continental ice*";

- Hannah (2004), using the longest tide gauge sea-level record from New Zealand reports an average rate over the last 100 years of ***1.6 mm/yr***, and concluded that “there continues to be no evidence of any acceleration in relative sea levels over the record period.

Evidence for recent planetary and ocean cooling, i.e. steric sea-level fall

It is now acknowledged that the mild late 20th century episode of global warming terminated in 1998. This warming phase has been followed, first, by stasis, and then, since 2002, by cooling (Keenlyside et al., 2008; d’Aleo, 2008a).

The cause of the change from warming to cooling is not fully understood. However, many experienced meteorologists and solar physicists believe that the change may have been driven by the behaviour of the sun, which is currently in a quiescent state between solar cycles 23 and 24. The average length of a solar cycle is 11.1 years, and it is observationally established that cycles longer than this average are followed by later cyles of lesser intensity, and, commensurately, a cooling climate. Solar cycle 23 has now extended almost 2 years past the average duration, which points to continued and possibly even severe near future cooling (e.g., Clilverd et al., 2006; Archibald, 2007; Schatten & Pesnell, 2007; d’Aleo, 2008b).

Perhaps not surprisingly, therefore, since 2003 ocean temperatures have also been cooling (Willis et al., 2007; 2008) (Fig. 11). Indeed, Harrison & Carson (2007), studying ocean temperature change between 1950 and 2000, suggested that ocean cooling may have been cooling since the late 1970. It is the case, however, that the databases around which these and other similar papers are constructed are far from satisfactory. In a study published only last month, Carson & Harrison (2008) showed that previously inferred warmings of the oceans were largely an artefact of the data interpolation schemes used, which were biased towards the 30% of the ocean that warmed and ignored regions that cooled. This immediately casts doubt, for instance, on the claims by IPCC (2007) that extra heat has accumulated in the oceans since 1960.

Scientific validity of sea-level scares

That sea-level changes is a commonplace. That those changes can have an adverse impact on humanity has been known to nationalities like the Dutch for centuries, and appropriate adaptive responses have of course been made. There is therefore no question that it is duty of governments to plan for likely future sea-level changes, as they do for other major natural hazards that affect their nations such as earthquakes or volcanic eruptions.

That current and future sea-level change is linked in any measurable way to the influences of mankind on the planetary climate is a much more disputed topic. Indeed, much of the public discussion on this issue is more akin to science fiction than to sensible science (cf. Hansen, 2007).

Based on geological studies, it appears that slow sea-level rise has been taking place monotonically over about the last 8 ky, with slow multi-decadal variability embedded in the trend. It is established too by many studies that over the last 150 years eustatic sea-level has risen at an average rate of 1-2 mm/yr, which represents the slow continuation of a melting of the ice sheets that began about 17 ka. 1 mm of this can be accounted for by the combined effects of continuing ice melt (~0.3 mm/yr) and steric ocean expansion (~0.7 mm/yr), and the residuum, if correctly estimated, may relate to dynamic oceanographic and meteorological factors.

There is, therefore, no scientific basis for the oft-repeated suggestion that “global warming” will melt so much ice that sea levels will imminently rise by Mr Al Gore’s imagined 20 ft. The IPCC has now reduced its estimate of the maximum sea-level rise to the year 2100 by one-third, from 0.88 m (~3ft) to 0.59 m (< 2ft), and nearly all of this projected increase arises from thermosteric expansion of the oceans, which are currently cooling.

Morner (2004), who is recognized as a foremost sea-level expert, has commented that there is no basis even for the UN’s best estimate of a 0.43 m (17 in) rise in sea level to 2100. Rather, his own best estimate, which corresponds with NIPCC (2008), is that there will be about the same rise in this century as in the last, i.e. about 20 cm.

The coastal topography and modern sedimentary systems around Australia have been primarily moulded by sea-level change at the glacial-interglacial level. These are the changes that have preconditioned the coastal geomorphology and the position and nature of the modern shoreline. Assessing the coastal hazard of future sea-level change at any particular locality requires an understanding not only of the long-term geologic setting of the shoreline, but also of the shorter term geologic and oceanographic factors that influence LRSL.

Nearly all of the papers that I have cited in this analysis have been normally peer-reviewed, with the exception of the IPCC reports. Taken together, both the older and the more recent independent scientific literature demonstrates that there is no scientific basis for alarmist propositions about rapidly rising eustatic sea-level having damaging effects around the Australian coastline. Added to which, local relative sea-level rise, which is what is most relevant to coastal developments, has historically occurred at low rates of 1-2 mm/ yr in Australia, and show no signs of acceleration today.

REFERENCES

Australian Bureau of Meteorology, 2006. Australian Mean Sea Level Survey. National Tidal Centre, Bureau of Meteorology. *ftp.bom.gov.au/anon/home/ntc/paul/monthlies/AustMeanSeaLevelSurvey2006.pdf*

Australian Bureau of Meteorology, 2007. Australian Baseline Sea Level Monitoring Project, Annual Sea Level Data Summary Report, June 2006-July 2007 Report. *http://www.bom.gov.au/ntc/IDO60202/IDO60202.2007.pdf.*

Baker, R.G.V., Haworth, R.J. & Flood, P.G., 2005. An oscillating Holocene sea-level? Revisiting Rottnest Island, Western Australia, and the Fairbridge eustatic hypothesis. *Journal of Coastal Research 42, 3-14.*

Belperio, A.P., 1993. Land subsidence and sea level rise in the Port Adelaide estuary: implications for monitoring the greenhouse effect. *Australian Journal of Earth Sciences 40, 359-368.*

Belperio, A.P. 1995 Quaternary, in: Drexel, J.F. & Preiss, W.V. (eds.), “The Geology of South Australia. Vol. 2. The Phanerozoic”. *South Australia Geological Survey Bulletin 54, 219-281.*

Belperio, A.P., Harvey, N. & Bourman, R.P., 2002. Spatial and temporal variability in the Holocene sea-level record of the South Australian coastline. *Sedimentary Geology 150, 153-169.*

Bloom, A.L., Broecker, W.S., Chappell, J., Matthews, R.K. & Mesolella, K.J., 1974. Quaternary sea level fluctuations on a tectonic coast: new 230Th/234U dates from the Huon Peninsula, New Guinea, *Quaternary*

Research 4, 185-205.

Brunn, P., 1988. The Brunn Rule of erosion by sea level rise. *Journal of Coastal Research 4, 627-648.*

Cabanes, C., Cazenave, A. & Le Provost, C., 2001. Sea Level Rise During Past 40 Years Determined from Satellite and in Situ Observations. *Science 26 October 2001 294: 840-842 [DOI: 10.1126/science.1063556] (in Reports).*

Castles, I. & Henderson, D., 2003. The IPCC emission scenarios: an economic-statistical critique. *Energy & Environment 14, 159-185.*

Chappell, J., Chivas, A., Wallensky, E., Polach, H.A. & Aharon, P.,1983. Holocene paleo-environmental changes, central to north Great Barrier Reef inner zone. *Bureau of Mineral Resources Journal of Australian Geology and Geophysics 8, 223-236.*

Emanuel, K, R. Sundararajan & J. Williams, 2008. Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *Bulletin of the American Meteorological Society, 89, 347-367.*

Harvey, N., E. Barnett, R.P. Bourman & Belperio, A.P., 1999. Holocene sea-level change at Port Pirie, South Australia: A contribution to global sea-level rise estimates from tide gauges. *Journal of Coastal Research* 15(3), 607-615.

Harvey, N. Belperio, A., Bourman, R. & Mitchell, W., 2002. Geologic, isostatic and anthropogenic signals affecting sea level records at tide gauge sites in southern Australia. *Global & Planetary Change 32, 1-11.*

Hearty, P.J., 2003. Stratigraphy and timing of eolianite deposition on Rottnest Island, Western Australia. *Quaternary Research 60, 211–222.*
Hearty, P.J. & Neumann, A.C., 2001. Rapid sea level and climate change at the close ofthe Last Interglaciation (MIS 5e): evidence from the Bahama Islands. *Quaternary Science Reviews 20, 1881–1895.*

Intergovernmental Panel on Climate Change (IPCC), 2001. *Climate Change 2001. 3rd Assessment Report of the IPCC.*

IPCC, 2007a. *Climate Change 2007: The Physical Science Basis. Summary for Policy Makers. 4th Assessment Report of the IPCC.*

IPCC, 2007b. *Climate Change Impacts, Adaptation and Vulnerability. 4th Assessment Report of the IPCC.*

Lambeck, K. & Nakada, M., 1990. Late Pleistocene and Holocene sea-level change along the Australian coast. *Palaeogeography, Palaeoclimatology, Palaeoecology 89, 143-176.*

Lisiecki, L. E. & M. E. Raymo, 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic del-18O records. *Paleoceanography 20: PA1003. DOI:10.1029/2004PA001071.*

Murray Wallace, C.V. & Belperio, A.P., 1991. The last interglacial shoreline in Australia - a review. *Quaternary Science Reviews 10, 441-461.*

NIPCC, 2008. Nature – Not Human Activity – Rules the Climate. *http://www.sepp.org/publications/NIPCC_final.pdf.* Also available as an e-book at http://www.nzcpr.com/ebookNIPCC.htm.

Orth, K., 1988. Geology of the Warrnamboo, 1:50 000 map. *Geological Survey of Victoria, Report 86, 83 pp. & map.*

Patterson, D., 2006a (August). Port Fairy East Beach. Review of Shoreline Stability Study by Coastal Engineering Solutions. *BMT WBM Pty. Ltd. for Moyne Shire, 5 pp.*

Patterson, D., 2006b (Nov.). East Beach Port Fairy. Comparative Review of Coastal Process Studies. *BMT WBM Pty. Ltd. for Department of Sustainability & Environment, 30 pp.*

Patterson, D., 2007 (August). Port Fairy East Beach. Coastal Erosion Engineering & Feasibility Study. *BMT WBM Pty. Ltd. for Department of Sustainability & Environment, 76 pp.*

Patterson, D. & Tilbury, R., 1996 (June). Draft Coastal Study of East Beach, Port Fairy. *WBM Oceanics for the Moyne Shire.*

Plaziat J.-C., Reyss J.-L., Choukri A. & Cazala C., 2008. Diagenetic rejuvenation of raised coral reefs and precision of dating. The contribution of the Red Sea reefs to the question of reliability of the Uranium-series datings of middle to late Pleistocene key reef-terraces of the world. *Notebooks on Geology, Brest, Article 2008/04 (CG2008_A04).*

Proudman Oceanographic Laboratory, 2008. Permament Service for Mean Sea Level, Tide gauge sea level records from Aus and NZ. *http://www.pol.ac.uk/psmsl/psmsl_individual_stations.html.*

Rahmstorf, S., 2007. A semi-empirical approach to projecting future sea-level rise. *Science 315, 368-370.*

Riedel, P. & Byrne. G. 2007 (Oct.) Port Fairy Shoreline Stability Study, Supplementary Report No. 2. *Coastal Engineering Solutions for Marcson Pty. Ltd., 5 pp.*
Rosengren, N., 2005 (July). Griffiths Street, Port Fairy - Geomorphology & Coastal Processes in
Siddall, M., Rohling, E., Almogi-Labin, A., Hemleben, C., Meischner, D., Schmelzer, I. & Smeed, D.A., 2003. Sea-level fluctuations during the last glacial cycle. *Nature, 423, (6942), 853-858. (doi:10.1038/nature01690).*

Singer, S.F., 1997. Hot Talk, Cold Science: Global Warming's Unfinished Debate. *Independent Institute (revised edition, 1999).*

Veeh, H.H., 1966. Th/U-38 and U/U28s ages of Pleistocene high sea level stand. *Journal of Geophysical Research 71, 3379-3386.*

Vezina, J. & Jones, B., 1999. Sea-Level Highstands Over the Last 500,000 Years: Evidence from the Ironshore Formation on Grand Cayman, British West Indies. *Journal of Sedimentary Research Volume 69 (1999).*

Archibald, D. 2007. The past and future of climate. *Rehabilitating Carbon Dioxide, Lavoisier Group meeting, Melbourne on 29-30 June, 2007. <http://www.nzclimatescience.org/images/PDFs/archibald2007.pdf>.*

Australian Bureau of Meteorology 2006 Australian Mean Sea Level Survey. National Tidal Centre, Bureau of Meteorology. *ftp.bom.gov.au/anon/home/ntc/paul/monthlies/AustMeanSeaLevelSurvey2006.pdf*

Australian Bureau of Meteorology 2007 Australian Baseline Sea Level Monitoring Project, Annual Sea Level Data Summary Report, June 2006-July 2007 Report. *ftp.bom.gov.au/*

Belperio, A.P. 1995 Quaternary, in: Drexel, J.F. & Preiss, W.V. (eds.), "The Geology of South Australia. Vol. 2. The Phanerozoic@, South Australia Geological Survey Bulletin 54, 219-281.

Belperio, A.P., Harvey, N. & Bourman, R.P. 2002 Spatial and temporal variability in the Holocene sea-level record of the South Australian coastline. Sedimentary Geology 150, 153-169.

Berge-Nguyen, M., Cazenave, A., Lombard, A., Llovela, W., Viarrea, J. & Cretaux J.F. 2008 Reconstruction of past decades sea level using thermosteric sea level, tide gauge, satellite altimetry and ocean reanalysis data. Global and Planetary Change 62, 1-13 (doi:10.1016/j.gloplacha.2007.11.007)

Carton, J.A., Giese, B.S. and Grodsky, S.A. 2005. Sea level rise and the warming of the oceans in the Simple Ocean Data Assimilation (SODA) ocean reanalysis. Journal of Geophysical Research 110: 10.1029/2004JC002817.

Carson, M. and Harrison, D.E., 2008. Is the Upper Ocean Warming? Comparisons of 50-Year Trends from Different Analyses. Journal of Climate, 21(10): 2259-2268.

Cazenave, A. and Nerem, R.S. 2004. Present-day sea level change: observations and causes. Reviews of Geophysics 42: 10.1029/2003RG000139.

Church, J.A., White, N.J., Coleman, R., Lambeck, K. and Mitrovica, J.X. 2004. Estimates of the regional distribution of sea level rise over the 1950-2000 period. Journal of Climate 17: 2609-2625.

Church, J. A., White, N. J., 2006. A 20th century acceleration in global sea-level rise, Geophysical Research Letters 33, L01602, doi:10.1029/2005GL024826.

Clilverd, M.A., Clarke, E., Ulrich, T., Rishbeth, H. & Jarvis, M.J., 2006. Predicting Solar Cycle 24 and beyond. Space *Weather 4, S09005, doi:10.1029/2005SW000207, 2006.* <*http://www.pdfdownload.org/pdf2html/pdf2html.php?url=http%3A%2F%2Fusers.telenet.be%2Fj.janssens%2FSC24Clilverd.pdf&images=yes*>

D'Aleo, J., 2008a**.** Even Flawed Data Can't Hide the Cooling. <*http://icecap.us/index.php/go/joes-blog*/P15>, Monday, May 19, 2008.

D'Aleo, J., 2008b. Ultralong Solar Cycle 23 and possible consequences. <*http://www.intellicast.com/Community/Content.aspx?ref=rss&a=130*>.

Fairbanks, R.G. 1989. A 17,000 year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Paleoceanography 342: 637-642.

Hannah, J. 1990 Analysis of mean sea level data from New Zealand for the period 18-99-1988. Journal of Geophysical Research 95, 12,399-12,405.

Hansen, J. 2007 Scientific reticence and sea level rise. Scientific Research Letters 2, 1-16.

Harrison, D.E., and M. Carson. 2007. Is the World Ocean Warming? Upper-Ocean Temperature Trends: 1950–2000. Journal of Physical Oceanography, 37, 174-187.

Holgate, S.J. 2007. On the decadal rates of sea-level change during the twentieth century. Geophys Res Lett 34, L01602, DOI: 10.1029/2006GL028492,2007.

Intergovernmental Panel on Climate Change (IPCC) 2001 Climate Change 2001. 3rd Assessment Report of the IPCC.

IPCC 2007a Climate Change 2007: The Physical Science Basis. Summary for Policy Makers. 4th Assessment Report of the IPCC.

IPCC 2007b. Climate Change Impacts, Adaptation and Vulnerability. 4th Assessment Report of the IPCC.

Jevrejeva, S., Grinsted, A., Moore, J.C., Holgate, S . 2006. Nonlinear trends and multiyear cycles in sea level records. Journal of Geophysical Research 111, C09012, doi:10.1029/2005JC003229, 2006.

Keenlyside, N.S., Latif, M., Jungclaus, J., Kornblueh, L. & Roeckner, E., 2008. Advancing decadal-scale climate prediction in the North Atlantic sector. *Nature 453, 84-88, doi:10.1038/nature06921.*

Kolker, A. S., and S. Hameed. 2007. Meteorologically driven trends in sea level rise. Geophysical Research Letters, 34, L23616, doi:10.1029/2007GL031814.

Kominz, M.A., Miller, K.G. & Browning, J.V. 1998 Long-term and short-term global Cenozoic sea-level estimates. Geology 26, 311-314.

Larsen, C.E. and I. Clark. 2006. A search for scale in sea-level studies. Journal of Coastal Research, 22(4), 788–800.

Lisiecki, L. E. & M. E. Raymo 2005 A Pliocene-Pleistocene stack of 57 globally distributed benthic ?18O records. Paleoceanography 20: PA1003. DOI:10.1029/2004PA001071

Liu, J.P., Milliman, J.D., Gao, S. and Cheng, P., 2004. Holocene development of the Yellow River's subaqueous delta, North Yellow Sea. Marine Geology, 209(1-4): 45-67. Doi:10.1016/j.margeo.2004.06.009

Lombard, A., Cazenave, A., Le Traon, P.-Y. and Ishii, M. 2005. Contribution of thermal expansion to present-day sea-level change revisited. Global and Planetary Change 47: 1-16.

Lyman, J.M., et al. 2006. Recent cooling of the upper ocean. Geophys. Res. Lett. 33: L18604. DOI:10.1029/2006GL027033.

Mörner, N.A. 2004. Estimating future sea level changes from past records. Global and Planetary Change 40 (1-2): 49-54.

NIPCC 2008 "Nature – Not Human Activity – Rules the Climate". http://www.sepp.org/publications/NIPCC_final.pdf. Also available as an e-book at http://www.nzcpr.com/ebookNIPCC.htm.

PSMSL 2008 Tide gauge sea level records from Aus and NZ. http://www.pol.ac.uk/psmsl/psmsl_individual_stations.html.

Qiu, B. & Chen, S. 2006 Decadal variability in the large-scale sea surface height field of the South Pacific Ocean: observations & causes. Journal of Physical Oceanography 36, 1751- 1762.

Schatten, K. & Pesnell, W.D. 2007. Solar cycle 24 and the solar dynamo. *NASA Goddard Space Flight Center, <http://www.pdfdownload.org/pdf2html/pdf2html.php?url=http%3A%2F%2Fntrs.nasa.gov%2Farchive%2Fnasa%2Fcasi.ntrs.nasa.gov%2F20070032658_2007033016.pdf&images=yes>*

Unnikrishnan, A.S., and D. Shankar. 2007. Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates? Global and Planetary Change, 57, 301–307.

White, N.J., Church, J.A. and Gregory, J.M. 2005. Coastal and global averaged sea level rise for 1950 to 2000. Geophysical Research Letters 32: 10.1029/2004GL021391.

Willis, J.K., et al. 2007. Correction to "Recent cooling of the upper ocean." Geophysical Research Letters 34: 16. DOI 10.1029/2007GL030323.

Willis, J. K., Chambers, D.P. & Nerem, R.S., 2008. Assessing the globally averaged sea level budget on seasonal to interannual timescales, *Journal of Geophysical Research* 113, C06015, doi:10.1029/2007JC004517.

Woppelmann, G., Martin Migues, B., Bouin, M.-N. & Altamimi, Z. 2007 Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges world-wide. Global & Planetary Change 57, 396-406.

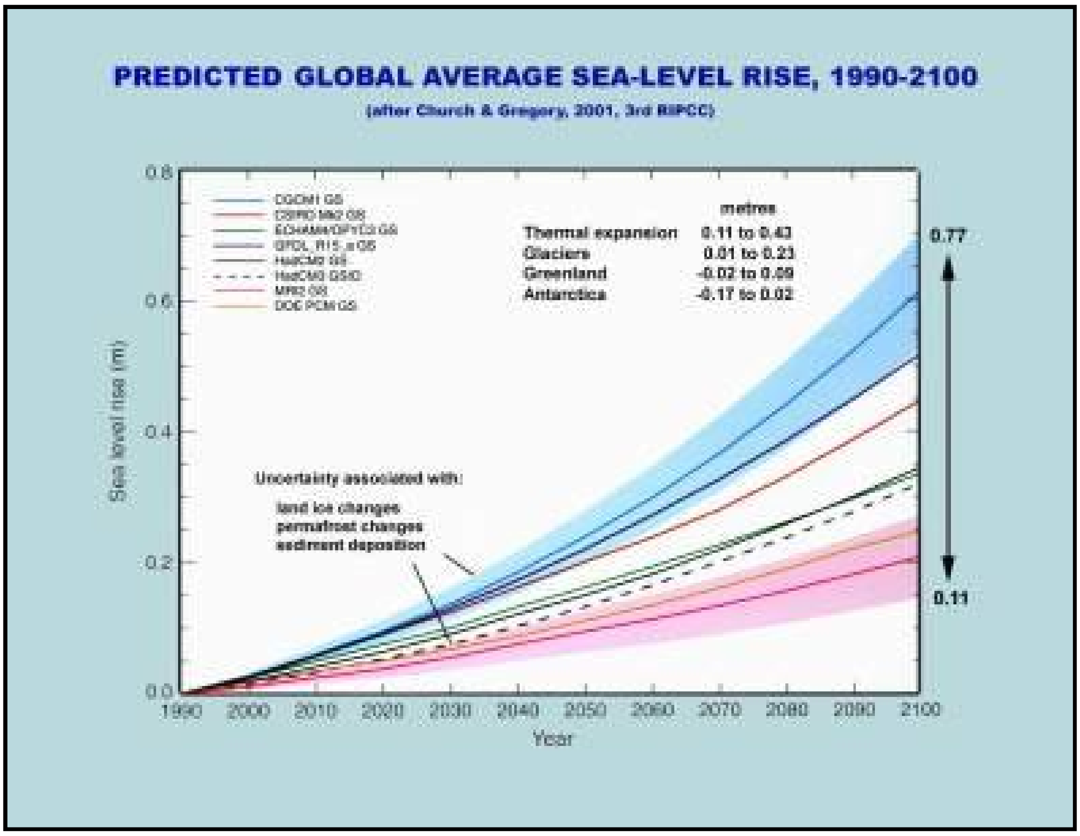
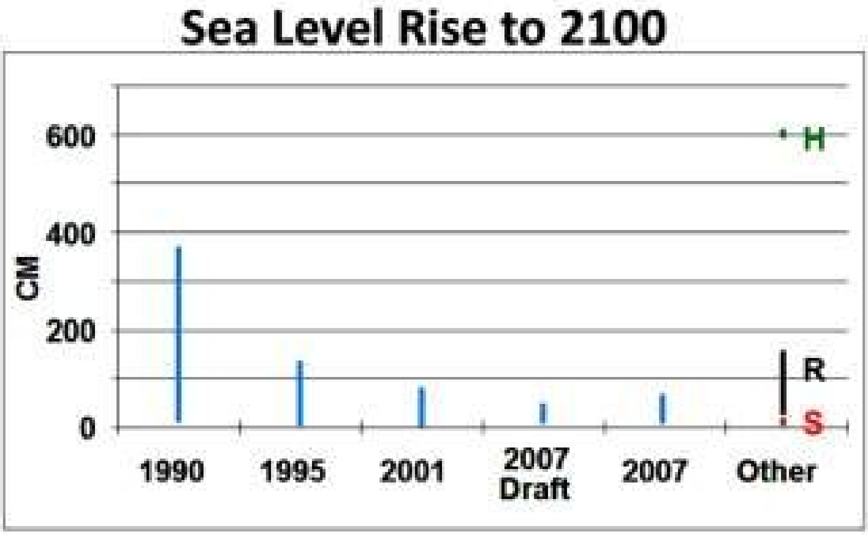


Fig. 1. Predicted eustatic sea-level rise by 2100, based on GCM scenario modelling (IPCC, 2001).



	IPCC 1990	IPCC 1995	IPCC 2001	2007 Draft	IPCC 2007	Hansen (H)	Rahmst. (R)	Singer (S)
Max	367	124	77	43	59	600	140	20
Min	10	3	11	14	18	600	50	18

Fig. 2. Estimates of sea-level rise to 2100 from IPCC reports of 1990, 1995, 2001, and 2007 (after NIPCC, 2008). Note the strong reduction in estimated maximum rise. Also shown are the published sea level rise values of Hansen (H) (2006), Rahmstorf (R) (2007) and Singer (S) (1997). Both H and R are well outside of the maximum IPCC values. The ongoing rate of rise in recent centuries has been 18 cm per century.

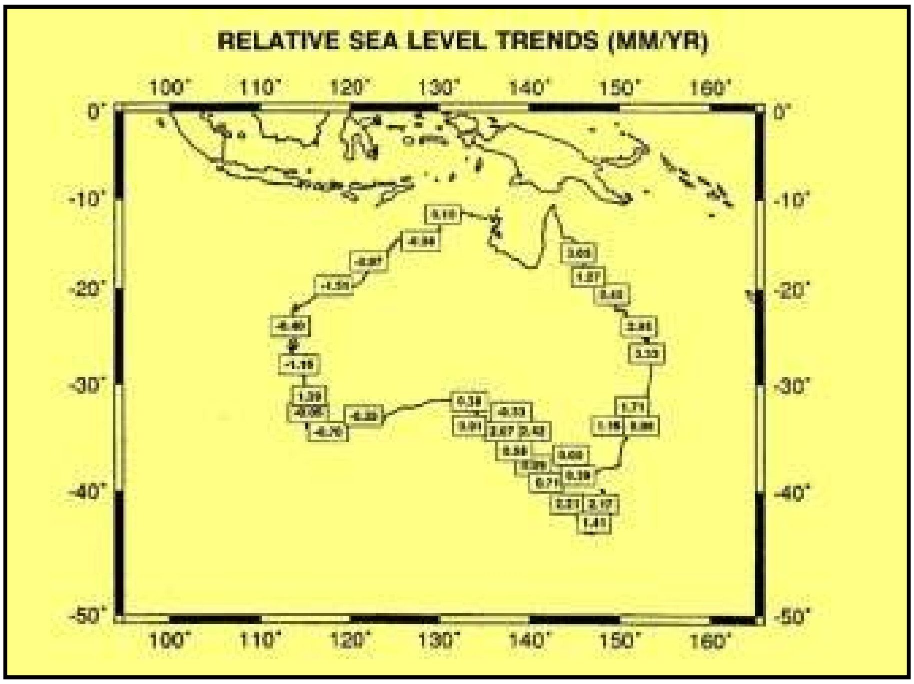


Fig. 3. The variable pattern of rates of local relative sea-level change around Australia in mm/yr, based on tide gauge records longer than 25 years (Australian Bureau of Meteorology, 2000).

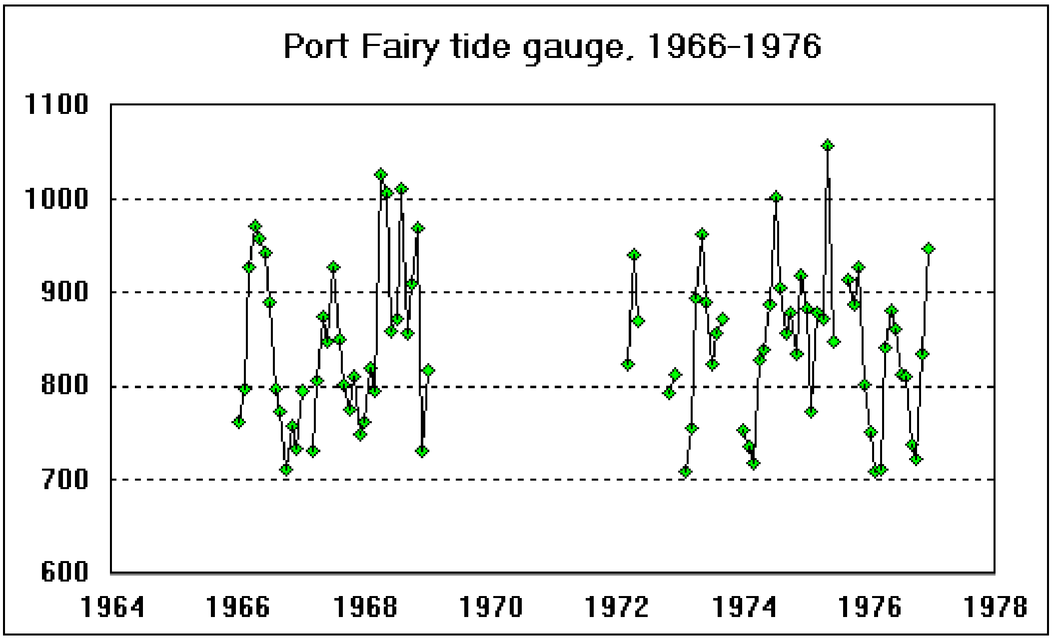


Fig. 5. 1966-76 tide gauge record for Port Fairy (data after Proudman Oceanographic Laboratory, 2008). Though only a short-term record, no significant change in LRSL is recorded.

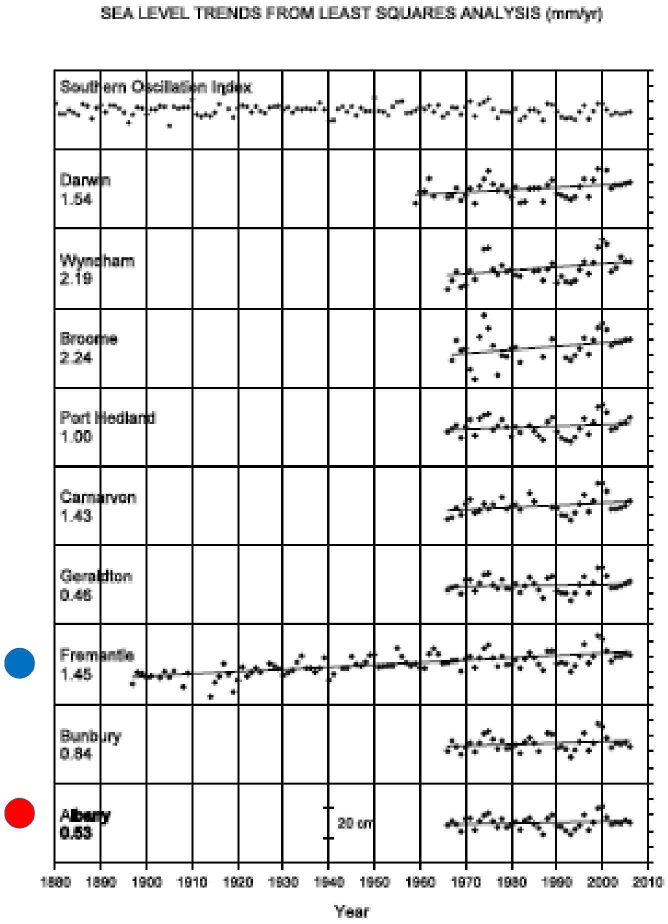


Figure 1a. Relative sea level trend estimates for tide gauges around Australia that have at least 25 years of hourly data on the NTC archive. The plotted points represent the observed annual mean sea levels. The annual Southern Oscillation Index is also plotted for comparison.

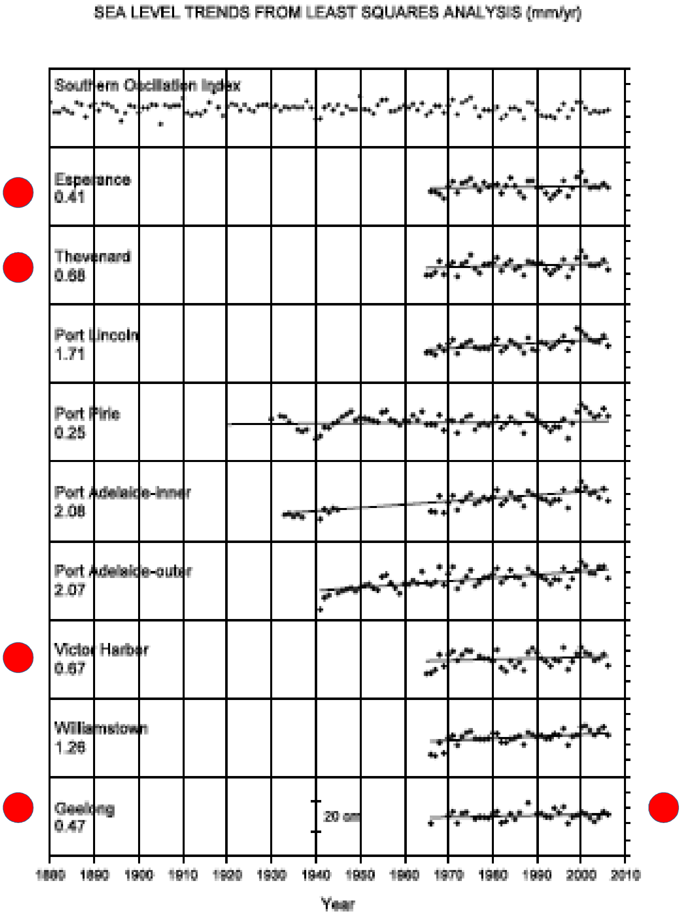


Figure 1b. Relative sea level trend estimates for tide gauges around Australia that have at least 25 years of hourly data on the NTC archive. The plotted points represent the observed annual mean sea levels. The annual Southern Oscillation Index is also plotted for comparison.

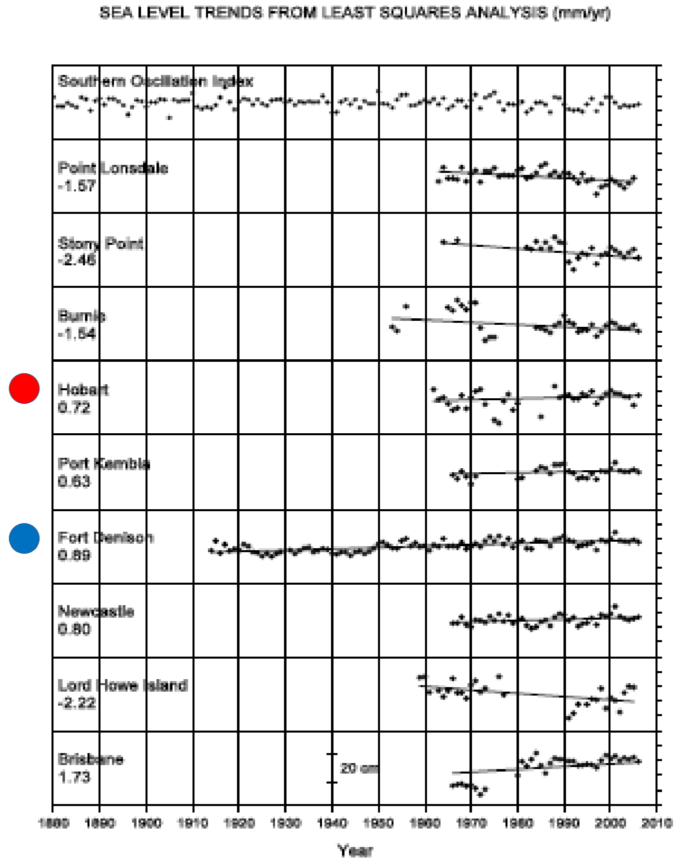


Figure 1c. Relative sea level trend estimates for tide gauges around Australia that have at least 25 years of hourly data on the NTC archive. The plotted points represent the observed annual mean sea levels. The annual Southern Oscillation Index is also plotted for comparison.

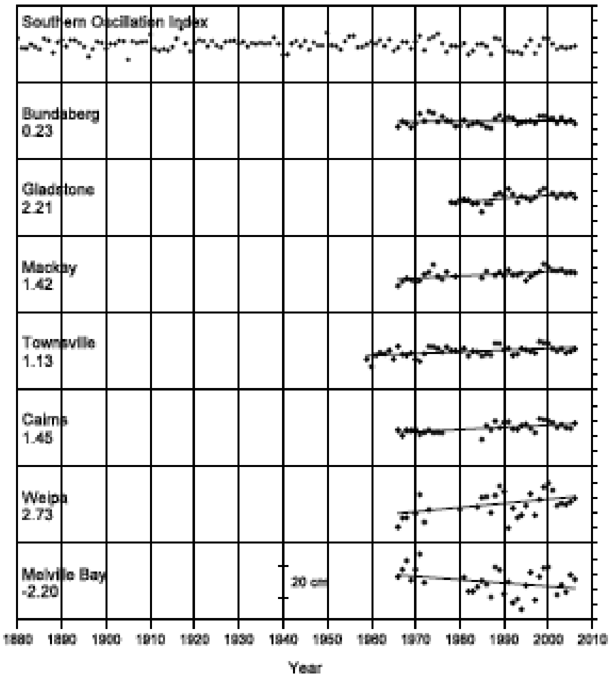
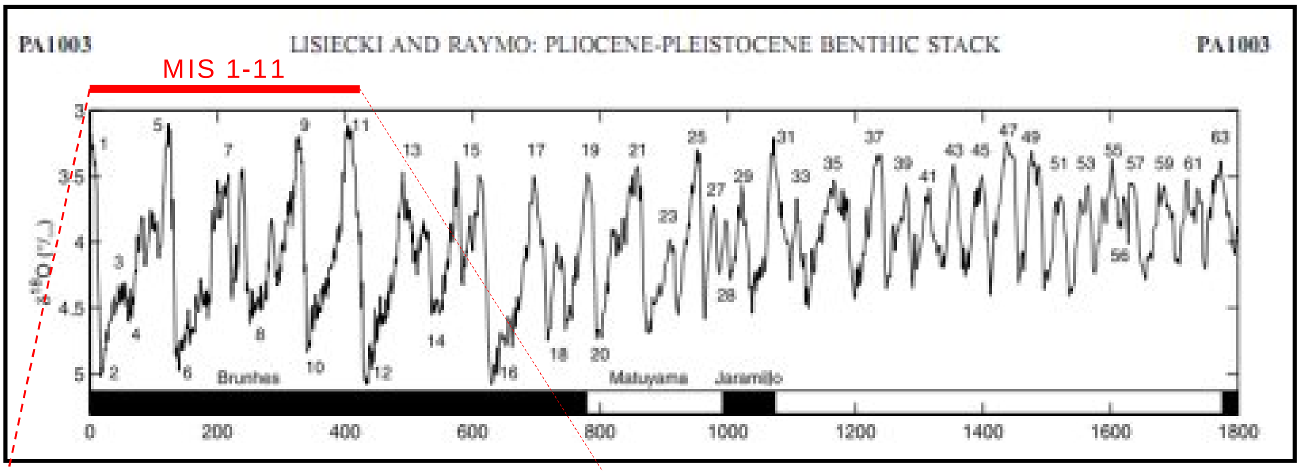
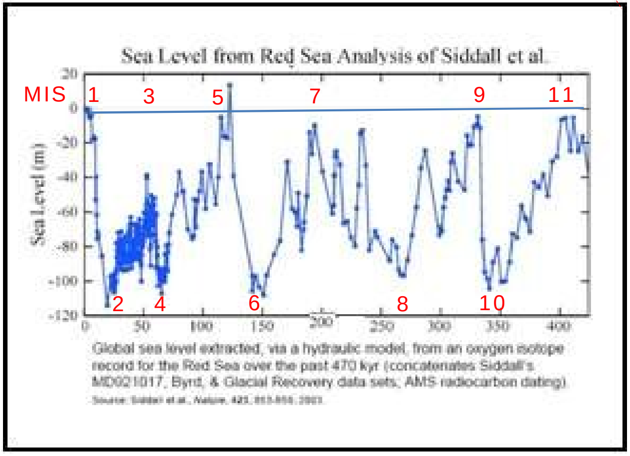


Figure 1d. Relative sea level trend estimates for tide gauges around Australia that have at least 25 years of hourly data on the NTC archive. The plotted points represent the observed annual mean sea levels. The annual Southern Oscillation Index is also plotted for comparison.

Fig. 4. (Red spots) tide gauge records for Geelong, Albany, Esperance, Thevenard, Victor Harbour; (Blue spots) records for Fremantle and Fort Denison (Sydney). After Australian Bureau of Meteorology; 2007).





Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating).

Source: Siddall et al., Nature, 423, 853-856, 2003

Fig. 6a (above). Averaged oxygen isotope curve for the last 1.8 My, with numbered isotope stages (MIS) (after Lisiecki & Raymo, 2005). This curve serves as proxy for climatic change, sea-level change and marine temperature change.

Fig. 6b (left). Eustatic sea-level reconstruction for MIS 1-11, based on data from the Red Sea (after Siddell et al., 2003). Note that the MIS 5 peak exceeds that for the Holocene by several metres.

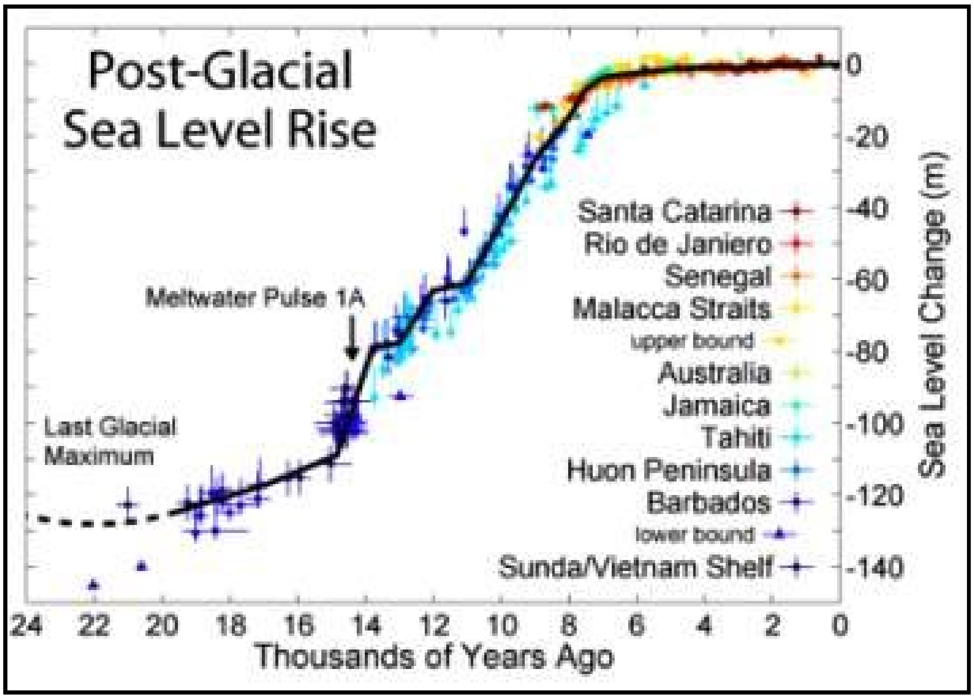
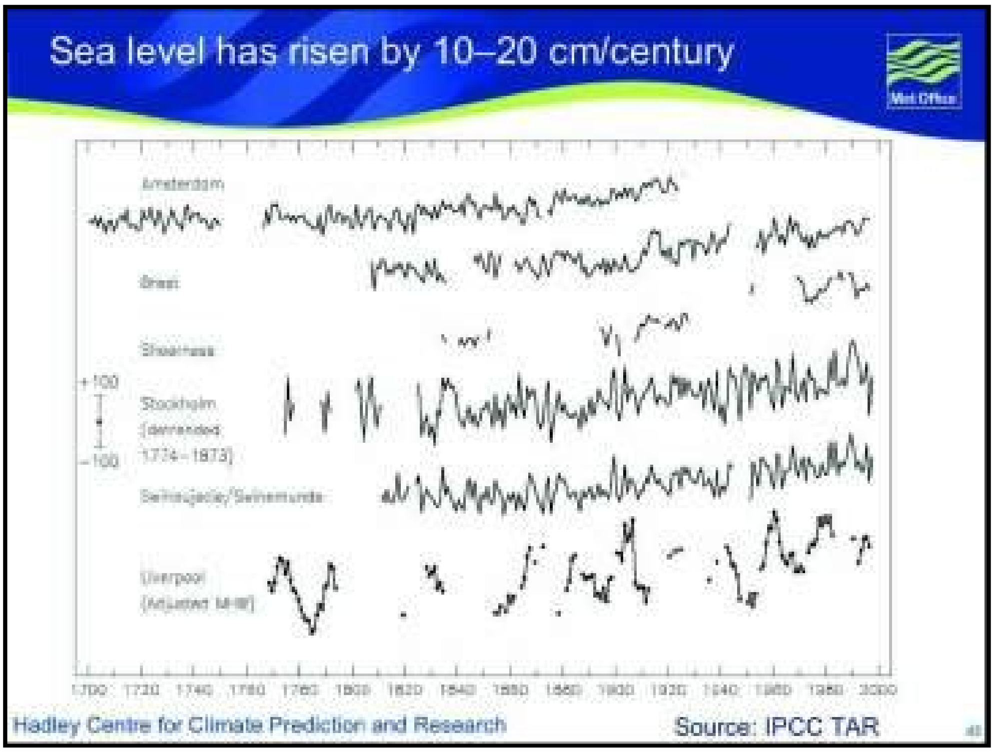


Fig. 7 Sea-level curve since the last glaciation at 20 ka (MIS 1-2), based largely on dated corals (after Fairbanks, 1989 and other authors). The total rise since 18 ka is about 125 m. Note the rapid rate of rise as the ice-sheets melted, levelling of to a slow incremental rise during the Holocene, which has continued through historic times.



Sea level has risen by 10–20 cm/century

Hadley Centre for Climate Prediction and Research

Source: IPCC TAR

Fig. 8. Selected long-term tide gauge records, corrected for local tectonic effects (after IPCC, 2001). The average rate of increase in estimated eustatic sea-level during the 20th century is about 1.6 mm/yr, with no acceleration.

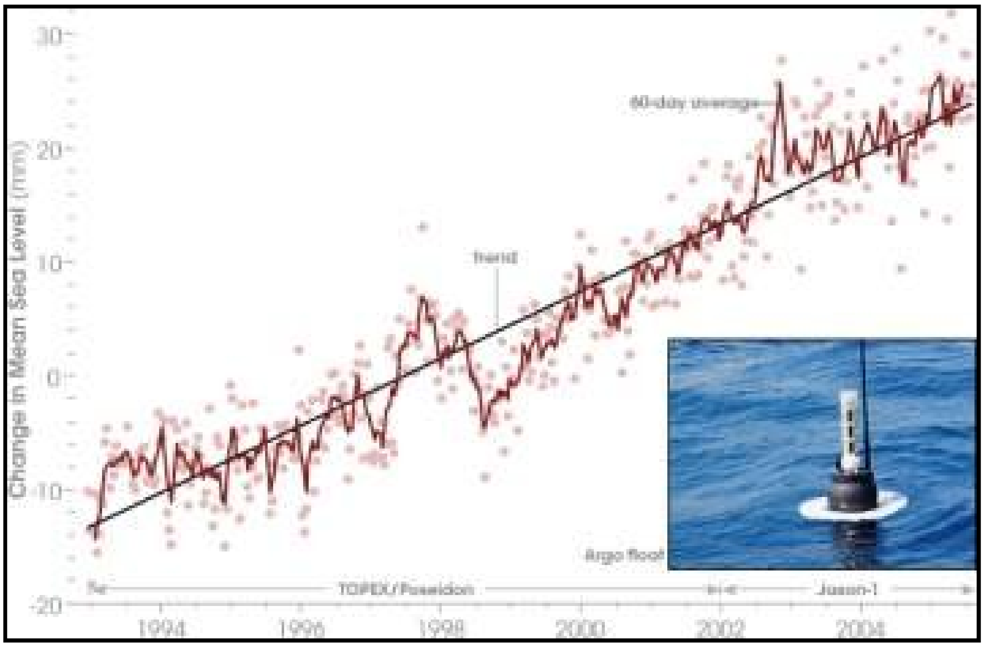
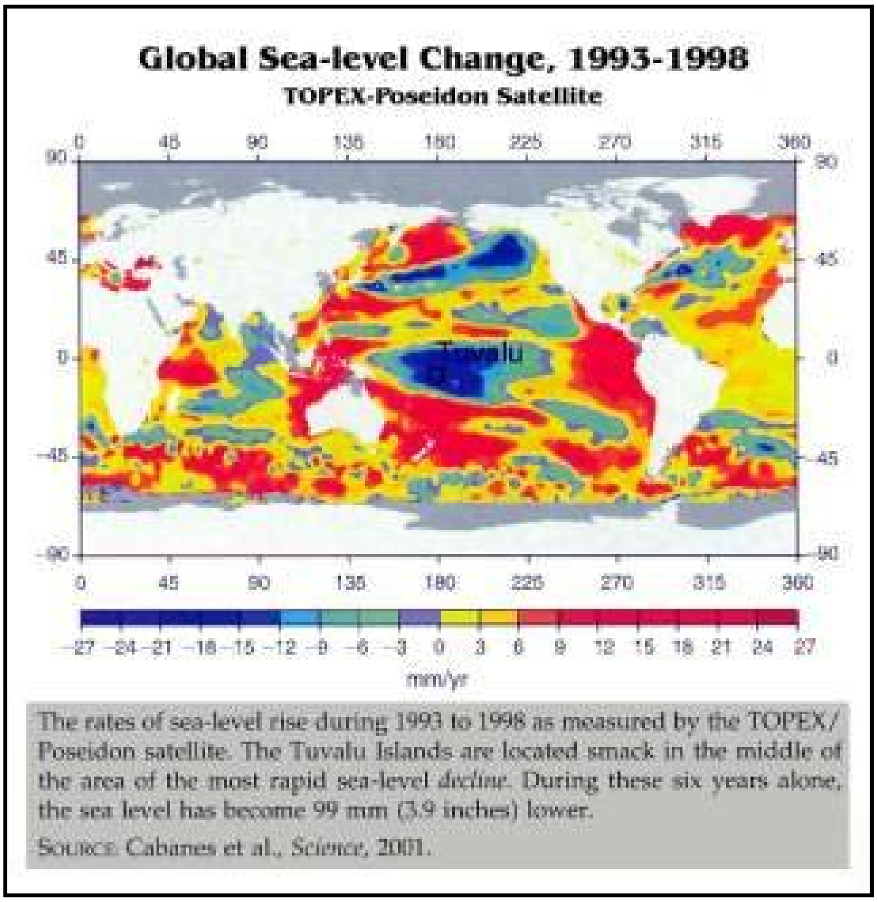


Fig. 9 Global eustatic sea-level curve determined by TOPEX-POSEIDON satellite altimetry for 1992-2007. The fitted trend line, at c. +3.2 mm/yr, obscures short term rate fluctuations, and in particular a lessening of the rate of rise since 2003 (after http://www.indybay.org/newsitems/2007/03/16/18377388.php)



The rates of sea-level rise during 1993 to 1998 as measured by the TOPEX/Poseidon satellite. The Tuvalu Islands are located smack in the middle of the area of the most rapid sea-level *decline*. During these six years alone, the sea level has become 99 mm (3.9 inches) lower.

SOURCE: Cabanes et al., *Science*, 2001.

Fig. 10. Globally variable pattern of rates of sea-level change between 1993 and 1998 in mm/yr, as measured by satellite altimetry (after Cabanes et al., 2001).

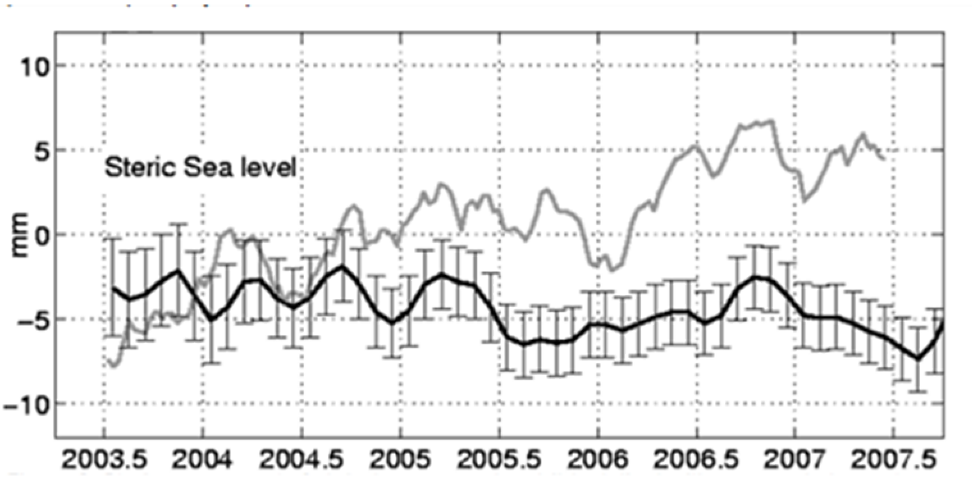


Fig. 11. (i) Black curve with error bars: Global steric sea-level curve for 2003-2007; (ii) grey curve: total global sea-level curve minus ocean-mass variability (from Willis et al., 2008). The steric sea-level curve is calculated from ARGO float measurements, and is a surrogate measure of ocean heat variation; note that it shows a cooling trend since 2003.