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# Rapid Changes in Coastal Sea Level

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**ABSTRACT**

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The changes in coastal sea-level position are the combined functions of the changes in ocean level and inland level. The rates and amplitudes of the parameters involved are estimated and combined into a comparative graph. The main division is between more continual and longer-term processes and the instantaneous variables like seismotectonics and tsunamis.

**ADDITIONAL INDEX WORDS:** *Sea-level changes, rates of change, eustasy, tectonics, isostasy, seismotectonics, tsunamis.*

## INTRODUCTION

The ocean and continent cover of the Earth's surface is 71% to 29%, respectively. The point where the ocean surface and the continent surface cross each other is known as the shoreline (or coast, in general). This point is not fixed in time and space but continually changes. The changes are caused by four main factors: (1) vertical changes in the ocean level (eustasy, dynamics); (2) vertical changes in the land level (tectonics, compaction); (3) re-shaping of the coastal morphology (erosion/deposition); and (4) changes in sea/land interaction (tidal range, wind direction, *etc.*). These factors include long-term (a century or more) components, short-term (annual to decadal) components, and even instantaneous components.

The present paper will primarily deal with those changes that can be called "rapid", i.e., those that occur in time periods of a century or less. The changes in coastal morphology—though very important for all kinds of coastal stability analyses—will not be discussed; they primarily represent coastal and engineering problems for which there are separate experts.

I have previously discussed the variables determining the present sea level as well as those responsible for the changes with time (MÖRNER, e.g., 1983, 1986, 1987a, 1987b). There are, of course, numerous other papers on this topic (*e.g.,* FAIRBRIDGE, 1961; PIRAZZOLI, 1991). This paper builds on the author's previous conclusions. The rates and amplitudes involved are of special significance in this context and the author's previous estimates are therefore reproduced in Figure 1. In this paper, I will re-investigate this question and add the "instantaneous" factors.

## CHANGES IN LAND LEVEL

Tectonically, there does not exist any "stable" point or area (e.g., NEWMAN and MUNSART, 1968; MÖRNER, 1983). There are rapidly uplifting coasts such as those bordering active subduction zones and those representing former glaciated areas. Rates of sea-level change of 10's of mm per year are not uncommon. The long-term uplift of young mountain chains often amounts to around 1 mm/yr (1 km/Ma). Major basin subsidence rates are in the order of 1 mm/yr or even more. The coast of the Netherlands is sinking at a rate of about 0.4 mm/yr. Land subsidence due to sedimentary compaction and withdrawal of water (or hydrocarbon) is a very serious problem in many low-elevation regions (such as, for example, Venice, Bangkok, Louisiana).

Seismotectonics may generate instantaneous changes in the land level. ATWATER (1987), for example, found evidence of six rapid subsidence events in the last 7000 years along the coast of Washington State, USA. Sometimes, it is possible to establish certain time/magnitude recurrence relations (e.g., WELLMAN, 1967; NAGATA *et al.,* 1979). These relations may change with time, however, and even suddenly change sign (which was the case in western Crete as established by PIRAZZOLI, 1986).

Submarine seismotectonics, volcanism and major earth slides may set up tsunamis that have disastrous effects on coastal habitation. In this case, it is important to note the difference between horizontal (strike-slip) and vertical faulting. The 7.0 magnitude earthquake at the Azores in 1980 was a strike-slip event and did not cause a tsunami. If it had been a vertical fault event, it would have set up a major tsunami wave that would have had terrible effects on the bordering coastal cities (especially Lisbon) of Europe and Northwest Africa.

## CHANGES IN OCEAN LEVEL

The changes in ocean level (eustasy) are due to (1) glacial eustasy, *i.e.,* changes in the oceanic water volume; (2) tectono-eustasy, *i.e.,* changes in the basin volume and the hypsographic land/sea relations; (3) geoidal eustasy, *i.e.,* deformations of the equipotential surface due to mass redistribution

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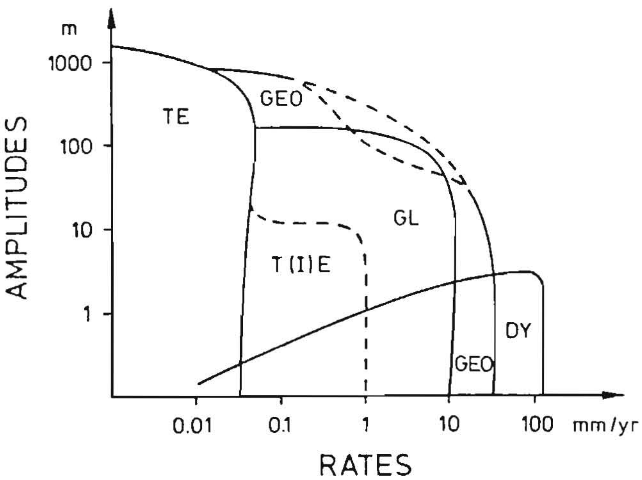


Figure 1. The relations among amplitudes and rates of the main eustatic variables (from MÖRNER, 1987a); (TE) = tectono-eustasy, T(I)E = global isostatic tectono-eustasy, GL = glacial eustasy, GEO = geoidal eustasy, and DY = dynamic sea-surface changes.

and/or rotational changes; and (4) dynamic sea-surface changes (MÖRNER, 1986).

With the discovery of geoidal deformations (MÖRNER, 1976), it became obvious that the available observational data base recording ocean level changes differ over the globe and can never be expressed in globally valid eustatic curves (MÖRNER, 1976, 1987b; NEWMAN *et al.,* 1980; PIRAZZOLI, 1991) as previously believed (e.g., FAIRBRIDGE, 1961; BLOOM, 1983). A similar conclusion was also reached by the theoretical models of global loading adjustments (*e.g.,* CLARK *et al.,* 1978; CLARK, 1980; PELTIER, 1982).

For the sake of continuity or discontinuity of forcing functions, it is important to realize that the Earth came into a new mode in Mid-Holocene time when the glacial eustatic rise (and corresponding rotational deceleration) finished, and the sea level changes became dominated by the redistribution of water masses due to the interchange of angular momentum between the solid Earth and the main circulation system of the oceans (MÖRNER, 1988, 1995).

With respect to Late Holocene sea-level changes in the order of decades to a century, there are small to insignificant effects from glacial eustasy, tectono-eustasy and geoidal eustasy due to mass distribution. Similarly, the steric effects on the water column seem only to be in the order of decimeters, at the most (NAKIBOGLU and LAMBECK, 1991; MÖRNER, 1994). The major effects are instead: the dynamic redistribution of water masses via the ocean current system, the deformation of the rotational ellipsoid, and various local dynamic factors. If mean global sea level has changed in the last 150 years, it can only be in the order of a 1 mm rise per year (MÖRNER, 1992, 1995).

Satellite altimetry (e.g., the Topex/Poseidon and ERS-1 missions) opens a more or less direct insight into the dynamics of the oceans as expressed by their annual to intra-annual changes in dynamic sea level (*e.g.,* LAMBECK, 1995).

Changes in coastal current forces, in coastal run-off, in prevailing wind directions and in meteorological pressure are all effective variables on the local ocean level position. The relation to changes in coastal morphology are essential for their effects. The tidal amplitude is subjected to time variations which may alter the coastal dynamics quite significantly. LAMB (*e.g.,* 1984) recorded considerable changes in storminess along the European coasts over the last millennium.

The combination of low pressure, strong storms, high waves and high tidal level often leads to extensive coastal damage. This was, for example, the case at the 1953 flooding event along the North Sea coasts. The coast of Bangladesh suffers frequent flooding events. Some areas (like the Gulf of Mexico region) are affected by hurricanes with well-known destructive effects on the coastal environment.

It may be interesting to note that all the drilling platforms in the North Sea originally were placed well above the highest storm level, but that most of them today are located well below this level due to unexpected local subsidence beneath the supporting "legs" of the rigs.

Tsunamis, during which waves may rise to immense size, represent the worst case of instantaneous changes in ocean level. Very destructive examples are known from historical time (e.g., from East Asia) and several research projects are now working on the recording of paleo-tsunamis. Tsunamis are generally induced by earthquakes. Sometimes, however, they may be caused by huge submarine slides (*e.g.,* DAWSON *et al.,* 1988).

## RATES OF COASTAL CHANGES

In Figure 2, I have combined different examples of rate estimates ranging from millions of years to seconds for the changes both in ocean level (A) and in land level (B). The main division is between more or less continual processes (right side) and the instantaneous point events (left side).

The vertical changes in sea level at a certain coastal point is the function of the combined interaction of all the variables controlling the ocean level and land level. The reactions in the coastal morphology to the vertical changes of the shore further determine the horizontal displacement of the actual shoreline. The local and regional dynamic sea surface can change significantly over time periods as short as days to decades. Ocean currents have a dynamic topography of up to 5 m (MÖRNER, *e.g.* 1987a, 1994). The low harmonic deviation from the geoid in dynamic surface is on the order of 2 m. River run-off changes are effective in altering the out-flow gradients. This is especially effective in inland seas like the Baltic and the Mediterranean where the surface gradients are dependent on the out-flow rates. The "instantaneous" factors covering seconds and minutes represent very destructive point events.

## CONCLUSIONS

In the Late Holocene, the continual sea-level oscillations are in the order of a mm per year. The short-term, high-amplitude "instantaneous" changes refer to seismotectonic deformations of the coast, tsunami-waves breaking over the coast and point storms such as hurricanes. This is a high-

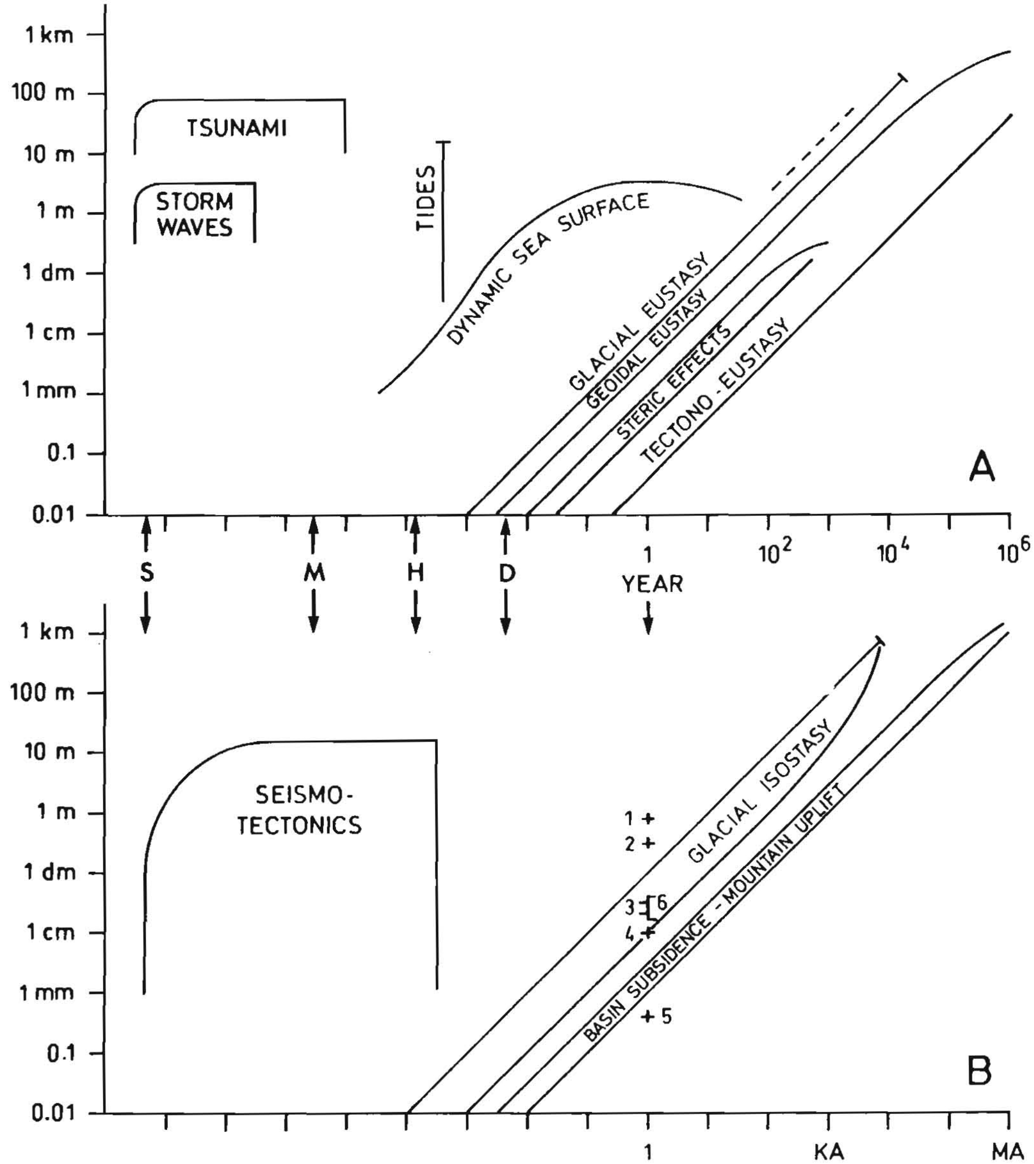


Figure 2. The relations among time and amplitude—*i.e.,* rates—of different variables controlling the ocean level (A) and the land level (B), respectively. The lines give maximum values. Scales are logarithmic; D = 1 day, H = 1 hour, M = 1 minute, S = 1 second. The numbers in B refer to: (1) crustal uplift at Pozzuoli in Italy due to magma chamber migration, (2) maximum rate of glacial isostatic uplift in the center of uplift in Sweden, (3) normal rates of sea floor spreading, (4) present day maximum rates of uplift in Sweden and in Caucasus, (5) the Late Holocene rate of subsidence in the Netherlands, and (6) the present rate of subsidence in Bangkok.

priority question in all Global Change scenarios and calls for a close co-operation between specialists on sea-level changes, coastal dynamics, neotectonics, paleoseismicity and seismicity.

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