Differential Holocene Sea Level Changes Over the Globe

Evidence for Glacial Eustasy, Geoidal Eustasy, and Crustal Movements

Nils-Axel Mörner
Geological Institute
Stockholm University
S-10691
Stockholm, Sweden

ABSTRACT

The old theory of eustasy implied that the eustatic ocean level was displaced up and down simultaneously and equally over the globe. Due to the geoid deformation, however, two eustatic levels are never quite parallel. The present paper deals with the complexity of variables and the Holocene global observational records.

Key Words: Estuary, Geoid Deformation, Isotasy, Sea Level Change, Tectonics.

COMPLEXITY OF SEA LEVEL ANALYSES

The changes in level in a coastal area is a result of the complex interaction between changes in the level of the sea's surface and of the land's surface, both of which are controlled and affected by several different processes. What we observe is only the net effect of these variables; i.e., the relative sea level changes. This complex interaction of different variables is illustrated in Table 1. The novel factor is the geoid deformation with time (in the oceans as well as under the continents), which is shown to reach significant rates (10mm/yr seems commonly to have occurred) and gradients (several meters per km seems common). Sublithospheric processes affecting the geoid level are likely to be linked to stress changes that may affect the seismicity (and other geophysical variables).

The Land Level Changes (LL)

Rises (+) of the land level mean regressions of the relative sea level, while falls (—) mean transgressions.

Tectonics (T)

Tectonic movements include both vertical

TABLE 1
Changes in Level

Tectono-Eustasy Glacial Eustasy Geoidal Eustasy Dynamic Sea Surface	SEA	LAND	Tectonics Isostasy Geoid Deformation Compaction

Observed Relative Changes in Level

and horizontal crustal movements, and range in time from long-term changes to short-term changes and "instantaneous" movements in relation to seismic events.

Isostasy (I)

Glacial isostasy and sedimento-isostasy are well-known processes. There are many other forms of isostasy; for example, due to denudation, lake level changes and sea level changes (hydro-isostasy).

A quite different type of isostasy is that which we may term "super isostasy" or "spherical isostasy" and denotes the possible global response of the Earth to changes in the surface load (e.g., a glaciation), via a linear mantle viscosity profile. Some people think this is a fundamental factor (e.g., Clark, Peltier). Other find it to be non-real or insignificant (e.g., Mörner).

In connection with the downwarping or uplift of a region, it should be remembered that it is the rigidity or flexurality of the lithosphere which determines the lateral extension and character of these movements. Available data suggest that the lithosphere is more rigid than generally assumed.

Geoid Deformation (Ge)

As in the oceans, the continental geoid (our reference level) must deform with time. The Earth tides are, in fact, short geoid deformation cycles. Continental geoid deformation with time implies deformation of the reference level. Present deformations in the order of 50 mcgal/yr have been measured with instruments. Deformations in the order of 0.002 mgal/yr are indicated by the geological records.

Compaction (C)

Compaction may contribute to some analyses of the changes in sea and/or land level. This applies for Holocene short-term records as well as long-term sediment infill.

The Sea Level Changes (SL)

Rises (+) of the sea level mean transgression of the relative sea level, while falls (−) mean regressions.

Tectono-Eustasy (E^T)

Tectono-eustasy implies changes of the ocean's basin-volume (i.e., deformations of the hypsographic curve), causing the sea level to rise or fall. The processes that are capable of deforming the ocean's basin-volume to any significant degree are all slow processes.

Glacial Eustasy (E^{Gl})

Glacial eustasy implies changes of the ocean's water volume by changes in the global glacial volume. It must be remembered that all present day glaciers outside Antarctica and Greenland have been estimated to correspond only to 0.5-m sea level rise. In Mid Holocene time, these glaciers were even smaller.

Geoidal Eustasy (E^{Ge})

Geoidal eustasy has been used to denote deformations of the geoid relief; i.e., water level distribution changes. Changes in the Earth rate of rotation lead to geoid deformations of large wave-lengths. Gravitational changes caused by mass redistribution and density changes lead to deformations of the heavily irregular geoid surface. These deformations represent a novel factor. It seems clear now that these changes can occur more rapidly and amass greater amplitudes than originally suggested.

It should be noted that a 1-mgal gravitational change would deform the sea level by 3.3 m and the crustal level by 1.7 m giving a net change of about 5 m.

Dynamic Sea Surface (DS)

The actual mean sea level may differ from the ideal geoid level because of various dynamic factors (ocean currents, temperature, salinity, air pressure, prevailing wind, etc.). This surface is termed the dynamic sea surface. It, of course, deforms with the changes of the factors controlling it. The main low-harmonics structure over the globe is a difference of up to 2 m with respect to the geoid. The local small wavelength differences may, however, occasionally amount to several meters. So, for example, does the Gulf Stream raise the dynamic sea surface some 4 to 5 m over the geoid surface.

Relative Sea Level Changes (RSL)

The relative sea level changes are the result of the complex interaction of all these variables. We can write an equation as follows:

$$RSL = \Delta SL\,(E^{T} + E^{Gl} + E^{Ge} + DS) - \Delta LL\,(T + I + Ge + C)$$

HOLOCENE RECORDS

For deeper analyses of the sea level changes over the globe, we need well established local relative sea level curves and an evaluation/subtraction of the local changes of the land level, so that a local or regional eustatic curve can be established. At present, we only have two such regional eustatic curves, viz., that from Northwestern Europe and that from Brazil (Fig. 1). For the comparison of short-term oscillations (transgressions and regressions), relative sea level curves are fully conclusive (Fig. 1).

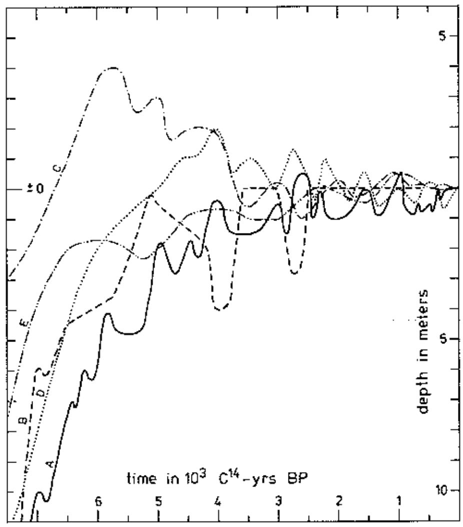

FIG. 1.

In Fig. 1, we compare the regional eustatic curves of Northwestern Europe (*A*) and Brazil (*B*) and the relative sea level curves of Viet Nam (*C*), New Zealand (*D*) and Japan (*E*). The sea level changes in the five curves differ in level, age, amplitude and frequency, giving clear evidence of non-synchronous global changes in sea level.

Prior to about 6000 BP, there is a general rise in all curves. This may, therefore, represent a glacial eustatic rise with local differentiations due to geoidal eustatic changes (and, maybe, some local crustal movements). The rise from 7000 to 5800 BP amounts to about 6 m in *A*, 2.1 m in *B*, 5.4 m in *C*, 6.5 m in D and 2.3 m in E, the difference of which reflects the effects of non-glacial eustatic factors.

All five curves exhibit oscillations. The amplitudes, the rates and the out-of-phase and often directly opposite sign of these fluctuations give evidence of short-term deformations of the geoid relief (the ocean water distribution) and clearly rule out all explanations in terms of glacial eustacy (during the last 6000 yrs) and "spherical isostasy".

It should be noted, for example, (1) that the large regression at around 4000 BP in Brazil (B) is directly counter balanced by transgressions in Europe (A) and New Zealand (D), (2) that the large regression at around 2700 BP in Brazil (B), Viet Nam (C) and South Carolina is counter balanced by distinct transgressions in Europe (A) and New Zealand (D), and (3) that the transgression in all curves except B at around 1000 BP is counter balanced by a large regression in West Africa.

CONCLUSIONS

The sea level changes recorded are the end products of a complex interaction of different variables. The Holocene records give evidence of a general glacial eustatic rise, differential crustal movements and geoidal eustatic changes that play the dominant role during the last 6000 years or so. Geoidal eustasy is an important factor.