SEA LEVEL CHANGES AND PALEOCLIMATE IN VIEW OF OCEAN CIRCULATION CHANGES

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Résumé

Les modifications globales dans circulation océanographique ont un impact sur la redistribution de la masse océanique et de la chaleur stockée dans le globe. Ces modifications ont eu une répercussion, au plan régional, sur le climat et niveau de la mer au moins depuis l'Holocène Moyen et Supérieur.

Abstract

The ocean circulation changes play a central role in the redistribution of water masses and stored heat energy over the globe, hence controlling and affecting regional sea level and climate that seems to have been dominant, at least, for the Mid to Late Holocene time.

Mots clés : Modifications de la circulation océanique, variations estatiques depuis 20 Ka, variations holocènes et séculaires (phénomènes El Niño), variations futures.

Key-words : Ocean circulation changes. Main Post 20 KA eustatic rise, Changes during the Holocene, records of the last centuries (El Niño events), future changes.

OCEAN CIRCULATION CHANGES

The Earth rotates faster than the hydrosphere causing the ocean to experience a general lagging-behind which primarily is manifested in the major east-west equatorial current systems in the three main oceans. During general, glacial eustatic, sea level falls, the Earth speads up, whilst it slows down during sea level rises. During periods of generally stable sea level radius of the Earth (which seems to have been the case for the last 5000-6000 years, or so), the "solid"

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Earth experiences changes in the rate of rotation (measured in length of the day; LOD). These changes need to be compensated – to keep the total angular momentum constant – by a countermotion by some other part of the Earth's system; in this case the core, the hydrosphere or the atmosphere. The interchange of angular momentum between the "solid" Earth and the hydrosphere has been found (Mörner, 1988) to play a very significant role for the redistribution of water masses (seen in regional sea level changes) and heat (seen in regional climatic changes) via the ocean current system (Fig. 1). There is a feed-back coupling between the redistribution of water masses and the interchange of angular momentum between the "solid" Earth and the hydrosphere (Mörner, 1984a).

Fig. 1 gives a schematic box representation of the Atlantic side of the globe and its main ocean circulation system. When Earth speeds up, water is piled up on the western side (where sea level hence is rising, whilst it is falling on the eastern side) increasing the Gulf Stream so that sea level is rising and climate gets warmer in the Northwest European region, too. When Earth slows down, the trend is reversed; rising sea level outside Africa, falling sea level outside northern Brazil, and falling sea level and cooler climate in Northwest Europe. Because the South Equatorial Current splits up in one branch that feed the Northern Hemisphere and one branch that feeds the Southern Hemisphere, unbalances in the distribution of water to the two branches may give rise to opposed heat budgets in the two hemispheres. When more hot equatorial water is distributed to the northern branch, climate gets warmer in the Northern Hemisphere whilst it gets colder in the Southern Hemisphere. When more hot water is dicharged to the Southern Hemisphere, the trend is reversed; warming in the south and cooling in the north. There are multiple examples of this inter-regional and inter-hemispheral differences in sea level and climate (Mörner, 1984a, 1984b).

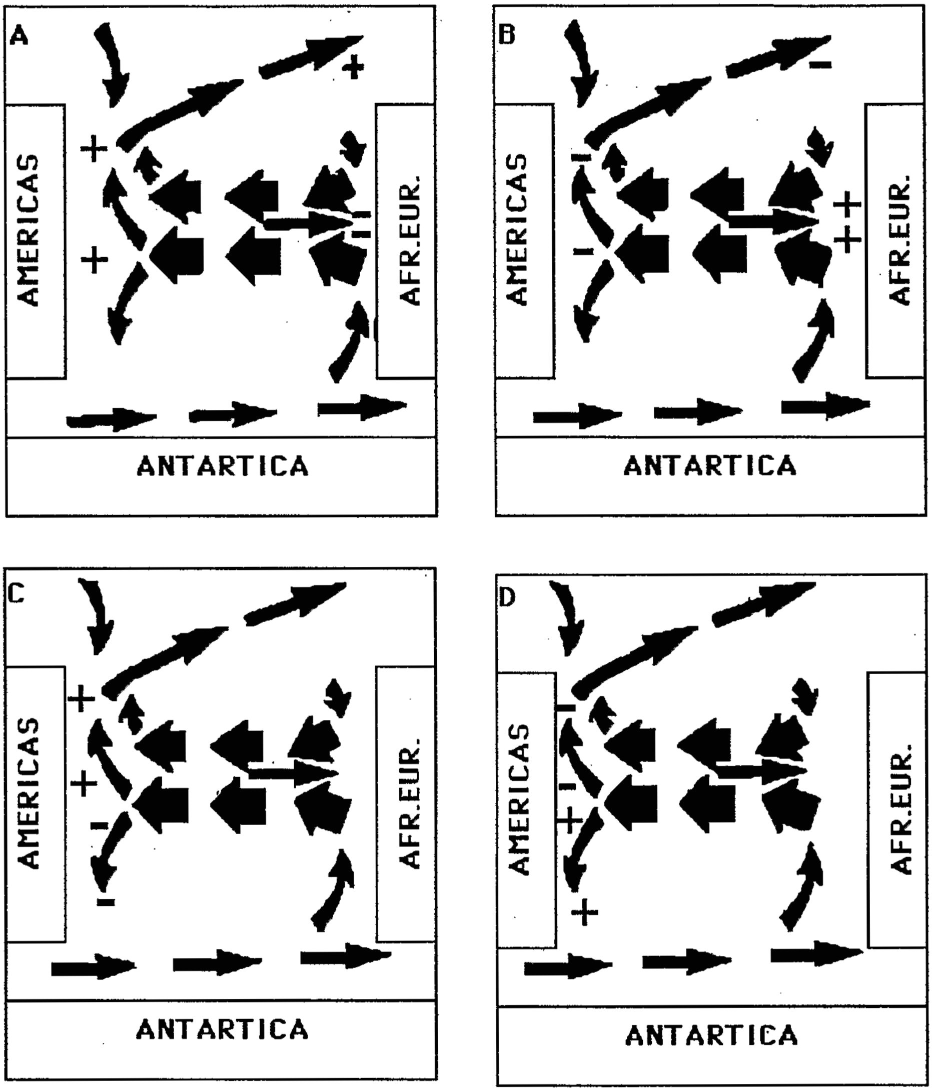

Fig. 1. Main Atlantic ocean circulation and its response to differential rotation. (A) Earth accelerates with the hydrosphere lagging behind causing sea level to rise on the western side and intensifying the Gulf Stream so that sea level and heat increase in Northwestern Europe. (B) Earth decelerates with the hydrosphere gaining against it so that water is piled up on the eastern side (with regression on the western side and in Europe). (C) Water and heat are lost from the Southern (cooling) to the Northern (warming) Hemisphere. (D) Water and heat are lost from the Northern (cooling) to the Southern (warming) Hemisphere.

THE MAIN POST 20 KA EUSTATIC RISE

The major paleoclimatic and glacial eustatic changes exhibit a close linkage with the Milankovitch variables: whether the causal connection goes via direct insolation variations (e.g. Berger, 1988) or via internal processes (Mörner, e.g. 1978, 1984a, 1991a) is another question, however. The last glaciation maximum was reached at about 20 Ka both in North America and in NW Europe. The deglaciation seems generally to have set in at about 18 Ka: the South American ice cap was gone by about 14 Ka, the Fennoscandian by about 9 Ka and the Canadian by about 7 Ka. The general eustatic sea level rise can be approximated by two superposed exponential curves with a transitional area in the time range of 13-10 Ka (this was first demonstrated by Mörner & Rickard, 1974, and has recently been confirmed by the Barbados record of Fairbanks, 1989) as illustrated in Fig. 2.

At around 13,200 BP, there was a sudden transpolar shift of the geomagnetic pole (from Arctic Siberia to Arctic Canada) followed at around 13,000 BP by a rapid increase in the Gulf Stream transport of hot Atlantic water to high latitudes in the northeastern Atlantic indicating a major change in the Earth's rate of rotation (Mörner, 1984a, 1991b). It is probably most significant that the classical late glacial climatic fluctuations in Scandinavia occurred within the time range of 13-10 Ka, i.e. within the transitional period of the two exponential eustatic curves (Fig. 2) with heavy fluctuations in the eustatic rates (primarily out of phase and opposed between the two curves).

The rise in sea level after the 20 Ka glaciation maximum must have caused a deceleration of the Earth's angular velocity in the order of 1500–2000 ms. The significantly higher rate of rotation at around 20 Ka explains why the hot equatorial surface water was concentrated on the western side of the Pacific so that the El Niño events probably could not occur.

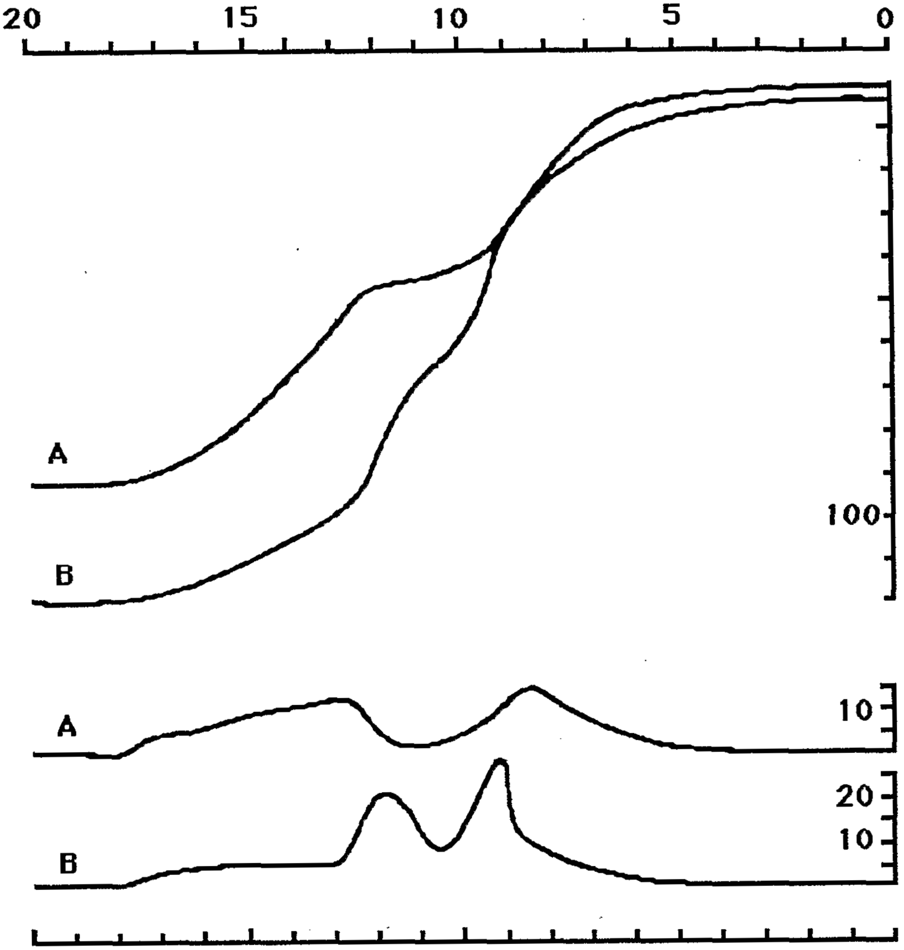

Fig. 2. Eustatic sea level curves (above) for northwestern Europe (A) and for Barbados (B), and corresponding rate curves (below) in mm/yr. Both curves show the superposition of two exponential rises with a transitional period at about 13,000–10,000 BP, during which period the rate curves exhibit heavy fluctuations that primarily are out of phase and opposed.

THE HIGH-AMPLITUDE CHANGES 13–10 KA

This theory of redistribution of energy and mass via the ocean current system due to a feed-back interchange of angular momentum seems also to apply to the high-amplitude changes between 13,000 and 10,000 BP as illustrated in Fig. 2.

The classical Scandinavian paleoclimatic record gives a sudden warming at about 13,000 BP, a sudden cooling at the onset of the Younger Dryas Stadial at about 11,000 BP, and a drastic warming at the end of the Younger Dryas Stadial at about 10,300-10,000 BP. This scheme has been widely used (even in global context), though it should be limited to NW Europe (Mörner, 1984b). The corresponding sea level changes are a rising, a falling and a rising trend, respectively. From West Africa, Tastet (1989) has presented a sea level record which gives exactly opposite trends, however. This seems to indicate that we are primarily dealing with ocean circulation changes (due to the interchange of angular momentum between the "solid" Earth and the hydrosphere), causing the redistribution of mass (sea level) and heat (climate) in line with the theory of Mörner (1984a, b, 1991b). The cold Labrador Current has a counter balancing relation to the warm Gulf Stream. In further support of the ocean circulation model for the high-amplitude changes 13–10 Ka, it therefore seems highly significant that Miller & Kaufman (1990) reported glacial fluctuations in the Hudson Strait region that are directly opposite to those recorded in Fennoscandia. All this is illustrated in Fig. 3.

The sea level record from the northeastern Brazilian-Guayana coast should be directly opposite to the West African record. This illustrates the key position of sea level studies within the Guayana-Brazilian region (Mörner, 1990).

THE LOW-AMPLITUDE CHANGES DURING THE HOLOCENE

In northwestern Europe, 16 low-amplitude eustatic oscillations have been recorded during the Holocene (Mörner, e.g. 1980), which correlate with continental air temperature fluctuations as recorded by a detailed oxygen isotope record (Mörner, e.g. 1980, 1984a) besides different paleoclimatic proxy data.

The same cycles are also recorded in Atlantic deep-sea cores, providing evidence of corresponding Gulf Stream pulsations (Mörner, 1984a). Taken together, this indicates that the sea level oscillations (mass) and temperature fluctuations (energy) in Northwest Europe primarily are the function of changes in the Gulf Stream activity, the changes of which are driven by the interchange of angular momentum between the "solid" Earth and the hydrosphere in a feed-back mechanism (Mörner, 1984a, b, 1988).

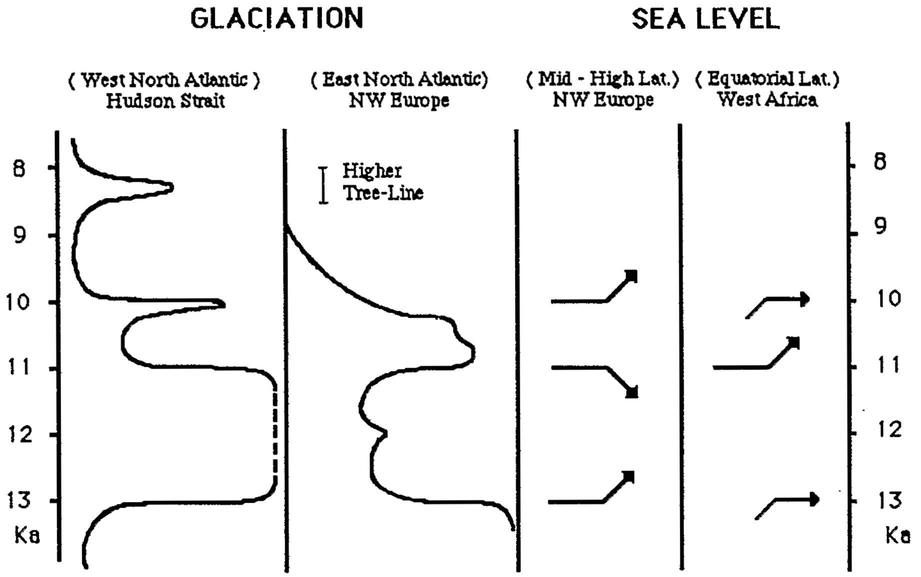

Fig. 3. High-amplitude climatic-eustatic changes 13,000 and 10,000 BP. The classical Northwest European glaciation changes are directly opposed to those recorded in the Hudson Strait region. The sea level records from NW Europe are directly opposite to those recorded off West Africa, indicating the displacement of ocean water masses between the two sides of the Atlantic (when water masses hit the American coasts, the Gulf Stream is intensified, and vice versa). The Gulf Stream is counter-balanced by the cold Labrador Current (hence explaining the climatic-glaciologic counter-balance between the east and west sides of the North Atlantic. All this indicate the redistribution of heat and water masses due to a fead-back interchange of angular momentum between the "solid" Earth and the hydrosphere, which was especially strong during the transitional stage between the two exponential phases of the eustatic rise (Fig. 1) after the last glaciation maximum.

Such ocean circulation changes must, of course, also have affected the east-west distribution of water in the equatorial regions of the Atlantic and the Pacific. Some of the Northwest European sea level oscillations are directly opposite to the Brazilian record (e.g. Mörner, 1981, 1983). It is of utmost importance, however, to undertake detailed comparisons between the West African records (e.g. Faure, 1980) and the northeast Brazilian–Guyana records (e.g. Prost, 1990; Wong, 1991). We are here dealing not only with sea level and paleoclimate but fundamental aspects on Earth's geophysics.

Mörner (1984a, cf. 1988) introduced the term "super-El Niño" or "super-ENSO" for these events. The dates given by Ortlieb et al. (1989) for extra strong "paleo-El Niño" events in the Peruvian coastal plain fit well with the eustatic ows in Northwestern Europe, lending support to Mörner's theory (1984a, b, 1988) on ocean circulation changes due to differential rotation. Consequently, these events must have differential global significance. Recent data from equatorial East Africa on the interaction between coastal habitation and sea level changes indicate that the east–west redistribution of water masses via the equatorial currents in the Indian Ocean has played a significant role for the sea level changes during the last 2000 years in the East African region (and, in general, agrees well with the recorded beat of the Gulf Stream in the North Atlantic, hence indicating a main controlling factor in ocean circulation changes due to the interchange of angular momentum).

THE INSTRUMENTAL RECORDS OF THE LAST CENTURIES

During the last centuries, we have instrumental records not only of sea level changes (since 1682) and temperature (since 1756) but also of the changes in the length of the day (LOD, since 1620), i.e. the Earth's spin velocity. Mörner (e.g. 1988) showed that there is a very close linkage between the rotational changes and the changes within the Northwest European region in sea level, ocean temperature, land temperature and various climatic proxy data, indicating that the climatic-eustatic impulses from the Gulf Stream to Northwest Europe play a controlling factor for regional climate and eustasy, and that the Gulf Stream variability is a function of the interchange of angular momentum between the "solid" Earth (LOD) and the hydrosphere (in this case the east–west equatorial current balance and the corresponding response of the Gulf Stream).

THE EL NIÑO-ENSO EVENTS

Even the ENSO events represent the interchange of angular momentum between the "solid" Earth and the hydrosphere; the 1982/83 event being quantifiable at 0.4 ms transfer of angular momentum from the "solid" Earth to the hydrosphere and then – when the water masses hit the American west cost – back again (Mörner, e.g. 1989). Consequently, these events have a differential global significance. "El Niño-like" events have, for example, also been reported from the Brazilian coasts (Martin et al., 1989).

THE PRESENT AND NEAR FUTURE SEA LEVEL TREND

In response to the global increase in CO2, it is often cited that we will face, not only a rise in temperature, but also a rise in sea level. Whilst the inferred temperature rise seems quite real, the inferred sea level rise is very dubious. No general present trend in sea level can be given, rather a very complicated picture varying significantly over the globe (e.g. Pirazzoli, 1986). A global warming will not automatically lead to a sea level rise. Only if the Antarctic ice cap starts to melt, there are reasons to expect a global sea level rise. In the Mid-Holocene time, when the temperature was about 1°C warmer and sea level had reached its present position, the Antarctic ice cap experienced a readvance in many areas (a similar Antarctic readvance is recorded during the Medieval warm optimum in Northwest Europe). During the Last Interglacial, however, when temperature was some 2°C warmer, sea level seems to have been significantly higher (probably due to the melting of the West Antarctic shelf ice). At present, eustastic sea level seems to change in the order of 1 mm/yr (during maximum deglaciation, it was 10–20 times higher; Fig. 2) except for local points with the combination of several factors. In a century, this would give a change of not more than 1 dm which is rather insignificant. Hence, we should reduce the fear of future "flooding".

It has sometimes been claimed that the thermal expansion of the water column may rais sea level significantly in the near future as a function of a global atmospheric warming. The sea surface temperature may well rise but the corresponding thermal expantion would only amount to a few cm or dm, at the most. A warming of the deep-water need a considerable time factor, and the effects would not become significant until at the end of the next millennium. Besides, there seems, in general, to have been a cooling trend of the deep-water during the last 2000-1000 years. In conclusion, neither ther-mal water expansion seems to be able to generate any significant sea level rise in the near future as a function of present day atmospheric warming.

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