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PRESENT EL NIÑO-ENSO EVENTS AND PAST SUPER-ENSO EVENTS EFFECTS OF CHANGES IN THE EARTH'S RATE OF ROTATION

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Because of the Earth's rate of rotation with a differential rotation of the various layers and sub-layers of the terrestrial system (the atmosphere, hydrosphere, "solid" Earth, liquid outer core, solid inner core), the oceanic water-masses are lagging behind the rotation of the "solid" Earth (measured in milliseconds, ms, of the length of the day, LOD) giving rise to the strong equatorial currents from east to west in all the three major ocean basins.

At times, the east-to-west transport of hot surface water is reversed so that the transport, instead, goes from west to east causing hot water to accumulate along the American coasts (where sea level rises some 30 cm, or so) and counter-acting the Humbolt Current and the coastal upwelling so that the entire bio-chemical environment changes off South America. These events are known as the El Niño events and the total atmospheric-oceanographic changes as ENSO events.

There must, of course, be a feed-back coupling between the rotation of the "solid" Earth and the lagging-behind of the oceanic water masses, the hydrosphere. During ice ages with sea level some 100–120 m lower, the rotation of the Earth must have been some 1500–2000 ms faster (compensated by a corresponding decrease in the Earth–Moon distance). At such occasions, the equatorial currents must have been increased with a stronger and more voluminous transport of water from the east to the west. This explains why much more hot surface water is found on the western side of the Pacific during the 18 Ka glaciation maximum. At these occasions, there could hardly have been any ENSO events, and we therefore predict that the ice ages should be characterized by a general lack of El Niño–ENSO events, whilst these events are common or characteristic for interglacial conditions. The slower rotation (= longer LOD), the stronger and more long-lasting ENSO events one would expect (at least in theory).

Present day ENSO events

The El Niño/ENSO events in the Pacific imply the interchange of angular momentum between the "solid" Earth and the hydrosphere (Mörner, 1987a, 1989a) with corresponding changes in sea level, sea surface temperature and ocean//atmosphere interchange of gases (including CO_2). This is illustrated in Fig. 1. In 1982 hot water accumulated in the west and started to drift eastwards at the same time as the "solid" Earth lost 0.4 ms in LOD. The

Fig. 1. The 1982/83 El Niño event (from Mörner, 1989a); LOD variations, equatorial hot water masses in the western Pacific, and trans-Pacific displacement of the hot surface water from west to east with corresponding sea level changes.

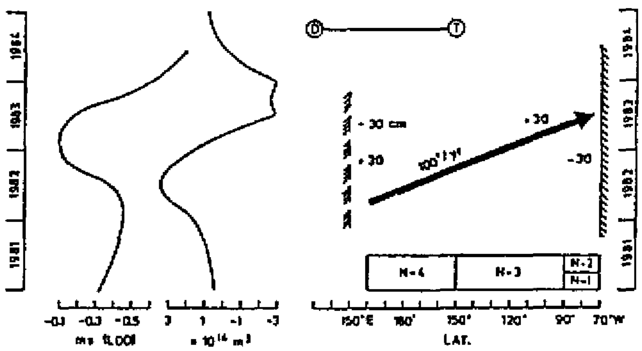

Fig. 2. The Northwest European eustatic curve (A) primarily based of the detailed archaeological-historical data from the Stockholm region, compared with the East African sea level indices (B), the "super-El Niño" high sea level record of Peru (C), the glacial readvance in Antarctica (D), the long-term CO_2 record (E), and the Chinese dust-fall record (F) as closely discussed elsewhere (Mörner, 1991b, 1992a).

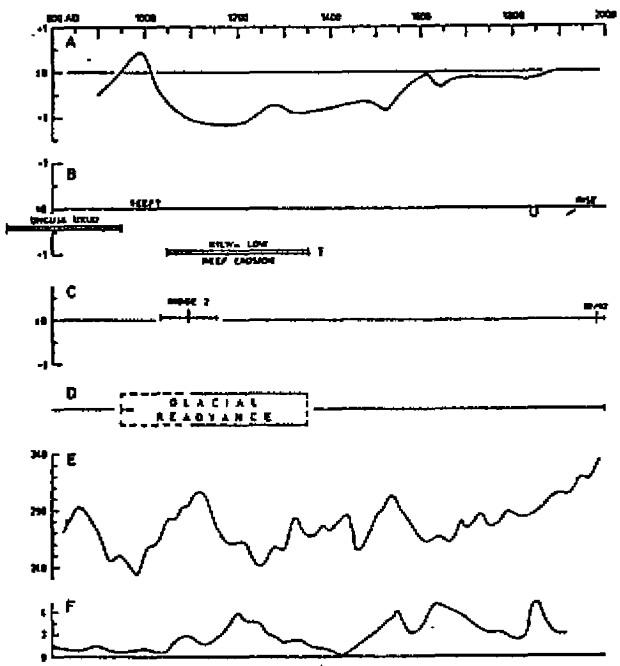

Table 1. Arbitrary classification of ENSO-type events.

Events recorded	Duration	Period of occurrence
El Niño - ENSO	1-3 years	this century also previously (Holocene)
Super-ENSO	up to 100-150 years	throughout the Holocene (some 16 events, or so)
Mega-ENSO	up to 1000 years	13.5 to 9.5 Ka high-amplitude changes
Absense/presence	10^4-10^5 years	long-term changes Milankovitch cycles

hot water was displaced eastwards – against the normal lagging-behind direction – at a rate of about 100°/yr. The moment the water hit the American coasts in mid 1983, angular momentum was transferred back to the "solid" Earth: from the hydrosphere, of course. This instrumentally firmly measured event can be taken as a model experiment for older and larger events of the same kind; i.e. Holocene "super-ENSO" events (Mörner, 1984a, b, 1988a, b, 1992a).

In January-83, there was an about 1 ms loss of angular momentum that was compensated by a corresponding increase in the jet streams (Mörner, 1989b, Figs. 1-2). Cross-continent winds characterize El Niño events in Southern Brazil (Suguio & Martin, 1992).

Super-ENSO events

The possible occurrence of "Super-El Niño" or "Super-ENSO" events was first proposed in 1984 and 1985 (Mörner, 1984a, 1985) and has later been discussed in details i separate papers (Mörner, 1988a, b, 1992a).

Modern eustatic sea level analyses indicate that the global distribution of the oceanic water masses (and hence sea level) changes both with the gravitational deformations of the geoid surface and/or with circulation changes due to variations in the Earth's rate of rotation. Major climatic changes and shifts in the order of decades and centuries are found to be regionally induced; not globally induced as previously generally assumed. Their duration is about 50–150 years and the amplitude may vary from a few parts of a centigrade up to several centigrades (Mörner, 1984b). This indicates that we are dealing with energy redistribution over the globe. The only agent capable of doing this and sustaining the signals for such periods of time, is the hydrosphere (i.e. the oceanic circulation system). Furthermore, these changes form frequency-changing cyclic patterns calling for a non-constant terrestrial feed-back mechanism. The interchange of angular momentum between the "solid" Earth and the hydrosphere was proposed (Mörner, 1984a) and later demonstrated (Mörner, e.g. 1988a). This mechanism has been shown to operate and explain recorded climatic–eustatic changes when it concerns (1) the major Late Glacial changes 13–10 Ka BP (Mörner, 1992b, 1992c), (2) the Holocene short-term changes, 16 events of which are recorded in the North Atlantic region (Mörner, 1984a, 1988a, b, 1992a), (3) the instrumental records of the last 300 years (Mörner, 1988a, b), and (4) the ENSO–El Niño events (Mörner, 1989a). Recorded pre-industrial CO_2 fluctuations are taken to represent major variations in the coastal upwelling in connection with past Super-ENSO events (Mörner, 1988a, b).

In early Medieval time, multiple data are available indicating a major Super-ENSO event (Mörner, 1991b, 1992a). Sea level fell by about 1 m between about 950 and 1050 AD in the Kattegatt–Baltic region. A similar regression is now recorded in East Africa. The glacial ice cap on Livingstone Island of the South Shetland Islands experienced a significant readvance at about the same time. Some of the Peruvian beach ridges seem to belong to the same period of time. The atmospheric CO_2 content increased (by about 30 ppm in 150 years). All these changes seem to represent different expressions of one and the same Super-ENSO event (Fig. 2) at about 1100-1200 AD.

In conclusion, all this means that the recorded changes in climate and sea level on the decadal to century time scale can be fully understood in terms of variations within given budget frames of energy, mass and momentum (Mörner, 1987b, 1988a). It is the redistribution of heat (recorded by paleoclimate) and mass (recorded by sea level) due to the interchange of angular momentum between the "solid" Earth and the hydrosphere that primarily drives these terrestrial variables. The pulzation of the Gulf Stream and the Kurosiwo Current have strong influence on climate and feed-back transfer of angular momentum because they bring hot water masses from equatorial to high latitudes. The pulzation of the currents generating coastal upwelling – like the Humbolt Current off South America – controll the marine biological productivity which also affects the ocean/atmosphere "ventilation" and the atmosperic CO_2 content.

Mega-"ENSO" events?

Within the time period 13.5 to 9.5 Ka, there occurred a series of high-amplitude changes in climate, paleoenvironment and ocean level distribution (Mörner, 1992b). These high-amplitude changes occurred within the period of superposition of two exponential curves in the eustatic rise in sea level. This intermediate period seems to represent the Earth's geodynamic response to the general deceleration due to the sea level rise. The deceleration caused water-masses to move polewards. At a critical point, the symmetry axes of the Earth's core and mantle were displaced with respect to each other along a meridional path recorded in a trans-polar shift of the axis of the geomagnetic dipole field (Mörner, 1991a). At about the same time, the Earth came into a new mode with large-scale interchanges of angular momentum between the "solid" Earth and the hydrosphere. These speeding-ups and speeding-downs of the hydrosphere caused increases and decreases in the ocean current system. The Gulf Stream affecting climate and sea level in Europe, the Labrador Current controlling climate and ice marginal changes in the Hudson Strait region. The Humbolt Current controlling climate and precipitation in South America, the coastal upwelling and the marine productivity and by that affecting the atmospheric CO_2 content. These ocean current changes are the main controlling factor of the high-amplitude changes within the intermediate period from about 13.5 to 9.5 Ka (Mörner, 1992b).

These events are different to the Super-ENSO events in the facts that they are both longer in frequency and stronger in amplitude. Also, the geophysical background seem somewhat different. These high-amplitude changes – which might deserve the name "Mega-ENSO" events – seem to be the function of a postglacial deceleration (due to increased radius because of the sea level rise) that had to occur in two steps (two superposed exponential curves of the sea level rise) with high-amplitude transfer of angular momentum during the intermediate period (13.5 to 9.5 Ka). Hence they represent the interaction between absolute deceleration (compensated by the Earth–Moon distance) and the interchange of angular momentum between the "solid" Earth and the hydrosphere (recorded by the ocean circulation and the water distribution).

Conclusions

The following conclusions are drawn (cf. Mörner, e.g. 1988a, 1992a, 1992b)

(1) The present-day El Niño-ENSO events are causally connection to a feed-back interchange of angular momentum between the "solid" Earth and the hydrosphere. At the 1982/83 event, this transfer amounted to about 0.4 ms. The speed of the reversed mass flow from west to east was about 100° Long per year. The sea level rise along the west coasts of the Americas, as a mountain torque effect, was in the order of 30 cm. The angular momentum interchange with the atmosphere is primarily an about 1 ms signal in January-83, giving rise to a significant increase in the jet streams. The El Niño effects on the coastal upwelling and hence biological production causes corresponding rises in the atmosperic CO_2 content. Paleo-El Niño/ENSO events have, of course, occurred back in time. Our paleo-records are, however, likely to be dominated by the more significant "super ENSO" events.

(2) During the Holocene, there seems to be a number of Super-ENSO events. Their duration range from between some decades up to a century or a little more. In the North Atlantic, about 16 such events seem to have occurred during the Holocene. Somewhat weaker events, though still of decadal frequence, are recorded by instrumental data for the last 300 years (LOD variations in general, plus temperature and sea level records in NW Europe). In early Medieval time, there was a strong event as indicated by data from Europe, East Africa, Antarctica and Peru (Mörner, 1991b, 1992a).

(3) Within the period of about 13,5 to 9.5 Ka, there occurred a series of high-amplitude changes – including the Younger Dryas event – that seem to follow processes very similar to the Super-ENSO events; i.e. they primarily represent the redistribution of energy (seen in paleoclimate) and water masses (seen in sea level) via major ocean current changes (in an angular momentum feed-back interchange betheen the "solid" Earth and the hydrosphere). This means climatic-eustatic changes of compensational nature over the globe, rather than of general rises and falls (as usually thought). These changes are provis-

ionally termed "Mega-ENSO" events.

(4) Because of the very much increased rate of rotation during ice ages and major glaciations with glacial eustatic sea level lowering and corresponding shortenings of the equatorial radius (which has to be compensated by a speeding up of the total Earth's system and a corresponding shortening in the Earth–Moon distance), the east-to-west transport of hot surface water had to be strongly increased (which is documented on paleontological grounds) leaving little or no room for ENSO-type reversals of this flow. Ice ages and glacial maxima are therefore likely to be characterized by the absence of El Niño-ENSO events, and probably also of Super-ENSO events.

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