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PRESENT EL NIÑO-ENSO EVENTS AND PAST SUPER-ENSO EVENTS

*Nils-Axel Mörner**

Abstract

Present ENSO events and past Super-ENSO events represent the redistribution of energy and mass within the terrestrial system due to the interchange of angular momentum between the "solid" Earth and the hydrosphere. The presen El Niño-ENSO events exhibit clear correlations with interannual decelerations in the Earth's rate of rotation; the length-of-day (LOD) increases. Though it is generally claimed that these rotational changes are caused by the interchange of angular momentum with the atmosphere, it is here shown that much, maybe most, of the LOD variations are, in fact, due to the interchange of angular momentum between the "solid" Earth and the hydrosphere in a feed-back coupling system. This mechanism also operates on the decadal-to-century time scale giving rise to Super-ENSO events. A number of such events are identified during the Holocene. A major event took place in Medieval time. High-amplitude changes in the period 13.5-9.5 Ka may represent some sort of Mega-ENSO events. During the Ice Ages with much higher total rate of rotation, ENSO-El Niño events are likely to be absent. In the short-term records of the past, inprints from Super-ENSO events are likely to be much more frequent than real interannual ENSO events simply because these records are too short and usually too small.

Key words: *El Niño, Super-ENSO, Mega-ENSO, Earth rotation rate, LOD, Paleogeophysics.*

ACTUALES EVENTOS EL NIÑO-ENSO Y ANTIGUOS EVENTOS SUPER-ENSO

Resumen

Los actuales eventos ENSO y los antiguos eventos Super-ENSO representan la redistribución de energía y masa en el sistema terrestre, debido al intercambio de momento angular entre la Tierra "sólida" y la hidrósfera. Los actuales eventos El Niño-ENSO muestran una clara correlación con deceleraciones interanuales de la velocidad de rotación de la Tierra. la duración del día (LOD) aumenta. Aunque generalmente se sostiene que estos cambios rotacionales son causados por intercambio de momento angular con la atmósfera, aquí mostramos que gran parte, tal vez la mayor parte, de las varaciones del LOD son en realidad causadas por el intercambio de momento angular entre la Tierra "sólida" y la hidrósfera en un sistema acoplado de regeneración. Este mecanismo también actúa en escalas de tiempo decadal a secular dando lugar a eventos Super-ENSO. Varios de estos eventos se han identificado en el Holoceno. Un evento mayor ocurrió en la era medieval. En el período de 13.5 a 9.5 Ka, los cambios de gran altitud pueden representar eventos de Mega-ENSO. Durante las edades glaciales, con una velocidad de rotación mucho mayor, se piensa que los eventos ENSO-El Niño deberion estar ausentes. En los registros del pasado, de corto término, las imprentas de eventos Super-ENSO deben ser mucho más frecuentes que aquellas de verdaderos ENSO interanuales, simplemente porque estos últimos son demasiado breves y usualmente demasiado leves.

Palabras claves: *El Niño, Super-ENSO, Mega-ENSO, velocidad de rotación terrestre, LOD, paleogeofísica.*

* Papeogeophysics & Geodynamics, Stockholm University, S-10691 Stockholm, Sweden

LES ÉVÉNEMENTS ENSO ACTUELS ET LES ANCIENS ÉVÉNEMENTS SUPER-ENSO

Résumé

Les événements ENSO actuels et les anciens événements Super-ENSO représentent la redistribution d'énergie et de masse dans le système terrestre, due à l'échange de momentum angulaire entre la Terre "solide" et l'hydrosphère. Les événements El Niño-ENSO actuels montrent une corrélation claire avec des décélérations interannuelles de la vitesse de rotation de la Terre : la durée du jour (LOD) augmente. Bien qu'il soit généralement considéré que ces changements de rotation sont causés par l'échange de momentum angulaire avec l'atmosphère, nous démontrons ici qu'une grande partie, peut-être la majeure partie, des variations du LOD sont causées en réalité par l'échange du momentum angulaire entre la terre "solide" et l'hydrosphère dans un système couplé de régénération. Ce mécanisme agit aussi sur des échelles de temps qui vont de la décennie au siècle, provoquant des événements Super-ENSO. Plusieurs de ces événements ont été identifiés au cours de l'Holocène. Un événement de plus grande envergure a eu lieu à l'ère médiévale. Au cours de la période qui va de 13.5 a 9.5 Ka, les changements importants peuvent représenter des événements Mega-ENSO. Au cours des âges glaciaires, avec une vitesse de rotation plus grande, il est probable que les événements ENSO-El Niño furent absents. Dans les enregistrements du passé, de courte durée, les empreintes d'événements Super-ENSO doivent être beaucoup plus fréquents que ceux de véritables ENSO interannuels, simplement parce que ces derniers sont trop brefs et généralement trop légers.

Mots clés : *El Niño, Super-ENSO, Mega-ENSO, vitesse de rotation de la Terre, LOD, paléo-géophysique.*

1. BACKGROUND

The Earth's rotation is, in fact, a multi-body system with a differential rotation of the various layers and sub-layers; 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 the thermocline sinks) counter-acting the Humboldt (Peruvian) Current and the coastal upwelling so that the entire biochemical 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 (Mörner, 1992a).

The slower rotation (= longer LOD), the stronger and more long-lasting ENSO events one would expect (at least in theory).

2. PRESENT DAY ENSO EVENTS

The El Niño/ENSO events in the Pacific imply the interchange of angular momentum not only between the atmosphere and the rest of the Earth but also between the "solid" Earth and the hydrosphere (Mörner, 1989) with corresponding changes in sea level, sea surface temperature and ocean/ /atmosphere interchange of gases (including CO_2; Newell & Hsiung, 1984). This is illustrated in Fig. 1. In 1982 hot water accumulated in the west and started to drift east-wards at the same time as the "solid" Earth lost 0.4 ms in LOD. The 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; 1984b; 1989; 1992a; 1992b).

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, 1990, Figs. 1-2). Cross-continent winds characterize El Niño events in Southern Brazil (Suguio & Martin, 1992).

Fig. 2 gives the LOD variations, the Modified Southern Oscillation Index (MSOI) and the ENSO events from 1964 to 1989 (Dickey, 1992). The LOD/MSOI/ENSO correlations are obvious. In Fig. 3, the LOD and MSOI values of the mid-points of the ENSO and non-ENSO event periods in Fig. 2 have been plotted against each others. There is a clear division into an ENSO population of high ms and mbar values, and a non-ENSO population of low ms and mbar values.

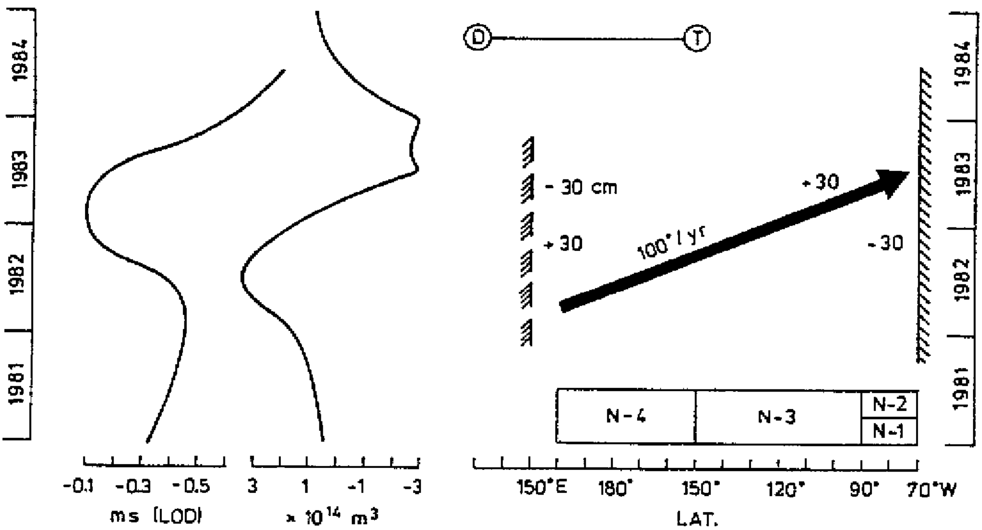

Fig. 1 - The 1982/83 El Niño event (from Mörner, 1989); LOD variations, equatorial hot water masses in the western Pacific, and trans-Pacific displacement of the hot surface water from west to east with correspon-ding sea level changes.

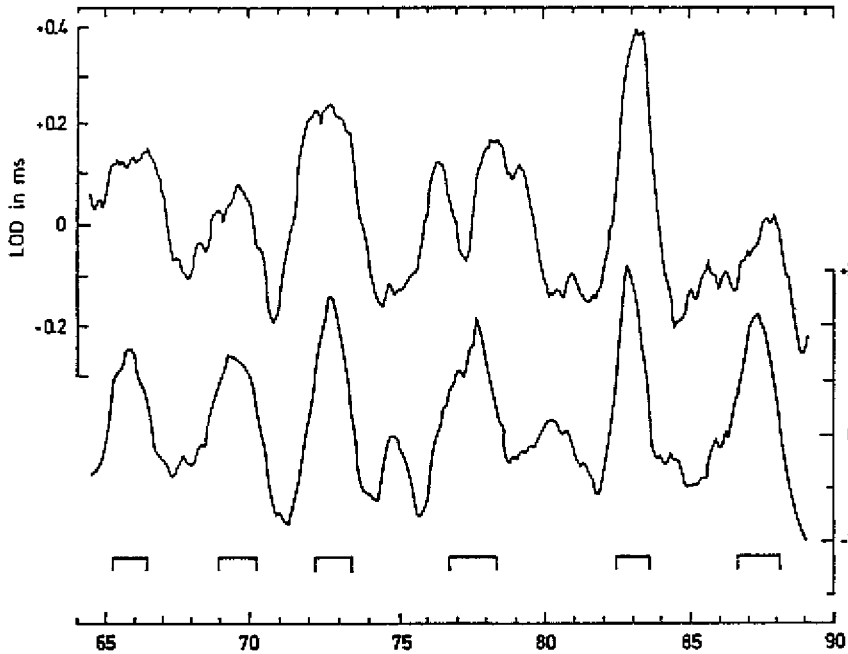

Fig. 2 - ENSO events (bars) and changes in MSOI (Modified Southern Oscillation Index; lower curve)) and LOD (upper curve) during the period 1964-1989 (Dickey et al., 1992a; Dickey, 1992b). The ENSO/MSOI/LOD correlations are obvious. As indicated by the Fig. 1 relations, a substantial (maybe dominant) part of the LOD variations must be due to the interchange of angular momentum between the hydrosphere and the "solid' Earth.

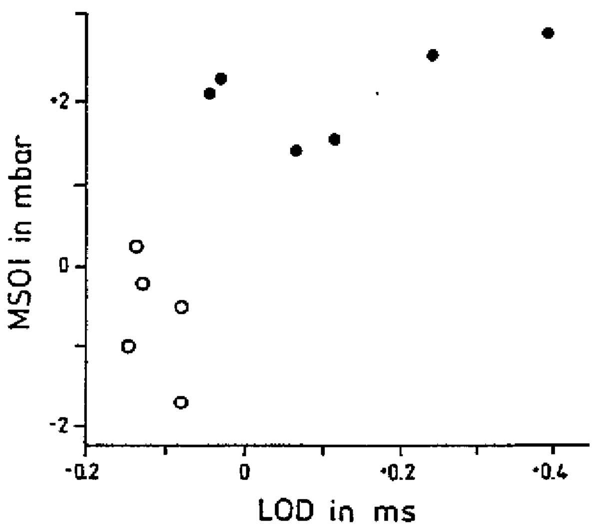

Fig. 3 - The LOD values (in milliseconds) and MSOI values (in millibars) of the mid-points of the ENSO (filled circles) and non-ENSO (open circles) periods in Fig. 2. An ENSO high-values population is clearly distinguished from a non-ENSO low-values population.

Many authors have delt with the LOD/ENSO correlations (*e.g.* Chao, 1984; 1988; Eubanks *et al.*, 1986; Dickey, 1992). They all consider that the interchange of angular momentum primarily takes place between the atmosphere and the rest of the Earth. Fig. 1 demonstrates that the hydrosphere plays a significant role (Mörner, 1988; 1989). Furthermore, the LOD changes generally starts before the MSOI changes (Fig. 2) indicating that these atmospheric changes do not initiate and lead the LOD variations. This is concordant with the author's opinion that the initial and dominant interchange of angular momentum is between the hydrosphere and the "solid" Earth. The LOD peaks of the ENSO events also persist far longer than the MSOI peaks in Fig. 2.

The effect of the hydrosphere on the angular momentum budget has recently also been documented by the close correlation between sub-daily LOD variations and the ocean tidal changes (Lichten *et al.*, 1992; Dickey, 1992).

3. 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 in separate papers (Mörner *e.g.* 1988; 1989; 1992a; 1992b). Similar results have been obtained by Martin *et al.* (*e.g.* 1992) studying paleoclimatic records from South America.

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.* 1989). 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, 1992c); (2) the Holocene short-term changes, 16 events of which are recorded in the North Atlantic region (Mörner, 1984a; 1988; 1992b); (3) the instrumental records of the last 300 years (Mörner, 1988); and (4) the ENSO–El Niño events (Mörner, 1989). Recorded pre-industrial CO_2 fluctuations are taken to represent major variations in the coastal upwelling in connection with past Super-ENSO events (Mörner, 1988) in analogy with present ENSO event relations of smaller amplitudes (Newell & Hsiung, 1984).

In early Medieval time, multiple data are available indicating a major Super-ENSO event (Mörner, 1992a, 1992b). 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 western parts of South America experienced a significant warming. 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 at around 1100–1200 AD (Fig. 4). Strong Supra-non-ENSO events precede (at around 950–1000 AD) and follow (at around 1200-1300 AD) the early Medieval Supra-ENSO event suggesting the changes between two dominant geodynamic modes (Mörner, 1992b).

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, 1988). 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 Humboldt Current off South America– controll the marine biological productivity which also affects the ocean/atmosphere "ventilation" and the atmosperic CO_2 content.

4. 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, 1992c). 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, 1991). 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 slowing-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, and the Humboldt 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, 1992c).

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 (Mörner, 1992a) – 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

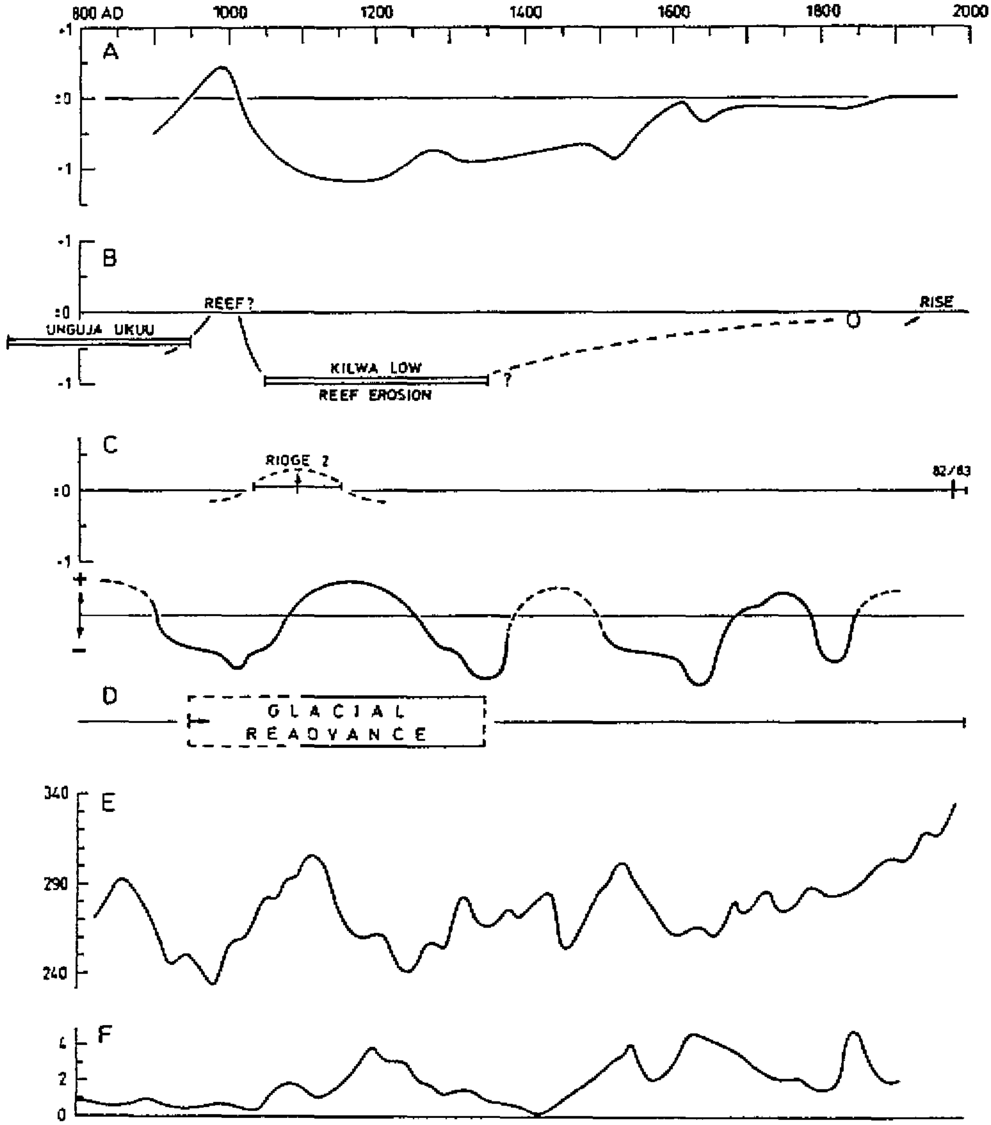

Fig. 4 - Records of the last 1200 years (Mörner, 1992a; 1992b): (A) the Northwest European eustatic curve, primarily based of the detailed archaeological-historical data from the Stockholm region, (B) the East African sea level indics, (C, above) the "super-El Niño" high sea level record of Peru (Ortlieb *et al.*, 1992) and (C, below) the general cold/warm changes in the Andean region (primarily from Villalba, 1991), (D) the glacial readvance in Antarctica, (E) the long-term CO_2 record (*in* Bojkov, 1983), and (F) the Chinese dust-fall record (Liu *et al.*, 1989). A major Super-ENSO event at about 1100–1200 AD is preceded an followed by its opposite major non-ENSO events (Mörner, 1992b).

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).

5. CONCLUSIONS

The following conclusions are drawn (*cf.* Mörner, *e g.* 1989; 1992a; 1992b)

(1) The present-day El Niño-ENSO events are causally connected to a feed-back interchange of angular momentum between the "solid" Earth and the hydrosphere. At the 1981/82 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-82, 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 (Newell & Hsiung, 1984). 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 weeker 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, Antartica and South America (Mörner, 1992a; 1992b).

(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 provisionally termed "Mega-ENSO" events (Mörner, 1992a).

(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.

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	104-105 years	long-term changes Milankovitch cycles

Table 1. Arbitrary classification of ENSO-type events Mörner, 1992a).

(5) All this implies that the interchange of angular momentum between the "solid" Earth (LOD) and the hydrosphere (the atmosphere, too) plays a very important role in the redistribution of heat (controlling regional climate changes) and water masses (controlling regional eustatic sea level changes).

(6) Records of former ENSO events are likely rather to represent major Super-ENSO events of decadal-to-century duration than real interannual ENSO events (which generally are too short to be recorded). We therefore believe that the 8-10 beach ridges recorded in northern Peru (Ortileb *et al.*, 1992) rather represents Super-ENSO events (*cf*. Fig. 4) than real intrerannual ENSO events (Ortlieb & Macharé, 1992).

(7) The geodynamic changes associated with the ENSO-type events (normal, super, mega) include multifacetted responses and fead-back couplings within the Earth's given frames of energy, mass and momentum. In this way, they represent the Earth's own beating system or "heart". It is a truely and deeply interdisciplinary subject.

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