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Sea-Level Changes and Earth's Rate of Rotation

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ABSTRACT

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The mean global sea-level changes today and in the near past (and by that also in the near future) have not been able to establish in a satisfactory way, either by mathematical treatments of tide-gauge data, by geophysical modelling or by geological considerations. We here propose a new means of studying global mean sea level; *viz.* changes in the Earth's rate of rotation (the variations in the length of the day). Any global change in sea level must be seen in the Earth's rate of rotation as this is a direct function of any change in its radius. The decadal changes in rotation swing around a sinusoidal, about century long, mean trend that might represent such a global sea level factor. This factor is consistent with a sea level rise in the order of 11 cm in 100 years (which is a fraction of often claimed values for the hypothetical greenhouse generated sea level rise today and in the near future). This can be taken as a measure of the maximum possible rise in global mean sea level during the last 150 years. It can, however, not be excluded that it represents the interchange of angular momentum with a more slowly moving oceanic intermediate or bottom water currents. If so, there would be no significant global rise in mean sea level during the last 150 years. The recording of LOD changes is a powerful tool for monitoring and predicting global sea level changes.

ADDITIONAL INDEX WORDS: *Sea-level change, Earth's rate of rotation, length of day, global sea level, world ocean level.*

INTRODUCTION

Sea level cannot change without a corresponding response in the Earth's rate of rotation and vice versa (*e.g.* DICKE, 1966). During the deglaciation phase with a general glacial eustatic rise in sea level, the Earth experienced a deceleration (totally amounting to up to 1,500–2,000 msec). When the glacial eustatic rise finished some 6,000–5,000 years ago, the sea level changes seem to have become dominated by the redistribution of the water masses over the globe due to gravitational and rotational forces (*e.g.* MÖRNER, 1988).

During the last 300 years, we have instrumental records of the changes in rotation and corresponding retardations/accelerations (*i.e.* pulzation) in the major current system leading to the redistribution of water masses (recorded by sea level) and stored energy (recorded by climatic parameters).

We are now able to split the rotational record into a mean long-term trend, a major century cyclic component, a decadal oscillation primarily coupled to surface water distribution, an irregular 2–3 year oscillation that represents the ENSO events, and intra-annual changes that are coupled to the atmospheric changes. Hence LOD-recording should be included as a powerful tool for the recording and prediction of sea level changes.

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EARTH'S ROTATION AND SEA LEVEL

From 18,000 BP up to about 5,000–6,000 BP, global sea level rose as a function of the melting glaciers (glacial eustasy) and the Earth had to compensate its increasing radius by a successive deceleration (in its turn compensated by an increase in the Earth–Moon distance). In Late Holocene time, when the deceleration due to sea level rise had finished, the Earth should only experience a long-term deceleration due to tidal friction. On theoretical grounds, this has been calculated at 2.4 msec per century (msec/cy). The observed LOD change between the Babylonian time and the Arabic time (Figure 1) is 2.4 msec/cy (STEPHENSON and MORRISON, 1984; STEPHENSON, 1991)

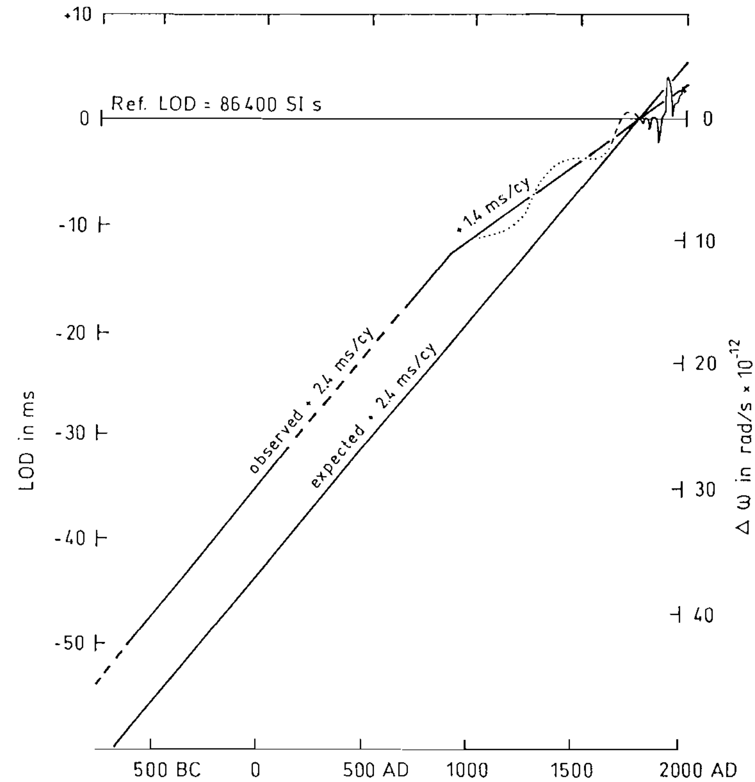

Figure 1. Changes in the Earth's rate of rotation expressed as changes in the length of the day (LOD) since Babylonian time (based on data from STEPHENSON and MORRISON, 1984; STEPHENSON, 1991). The expected long-term deceleration due to tidal friction of +2.4 msec/cy and the observed long-term changes; +2.4 msec/cy by combining the Babylonian and Arabic data, but only +1.4 msec/cy by combining the Arabic data with the present reference level. The last millennium trend might better be approximated by a sinusoidal wavy curve, however, as indicated by a dotted line. The last centuries' instrumental record show high-amplitude low-frequency changes (so-called decadal changes).

and is in full agreement with the expected deceleration due to tidal friction. After about 900–1000 AD, there was a drastic change, however, and the mean long-term deceleration only amounts to 1.4 msec/cy (Figure 1). This implies an extra acceleration on the order of 1.0 msec/cy to interact with the 2.4 msec/cy deceleration so that the total long-term deceleration became 1.4 msec/cy. Such an acceleration could be brought about by a sea level lowering of about 6.5–7.5 cm/cy. There are some records suggesting that there really was a period of general regression after about 1,000 BP (MÖRNER, 1991, 1992). The data points between about 1000 AD and 1600 AD are few and uncertain, and there are reasons to suspect that the real long-term changes in LOD after 1,000 BP followed a sinusoidal wave pattern (dotted line in Figure 1) instead of a straight line.

Figure 2 gives the changes during the last centuries based on instrumental records. The high-amplitude decadal changes represent the interchange of angular momentum between the "solid" Earth (*i.e.* the mantle + lithosphere) and the core (as previously usually claimed; *e.g.* ROCHESTER, 1984) or the hydrosphere (as recently demonstrated by MÖRNER, 1988, 1989). The beat of the Gulf Stream and the corresponding changes in regional climate and sea level in NW Europe exhibit a strong correlation with the LOD changes (MÖRNER, 1988: Figure 7).

A long-term mean sinusoidal trend (on the order of a century) can be fitted to the decadal changes (Figure 2). This curve may represent either (1) total changes in the Earth's rate of rotation due to global sea level changes increasing or decreasing the radius, or (2) the interchange of

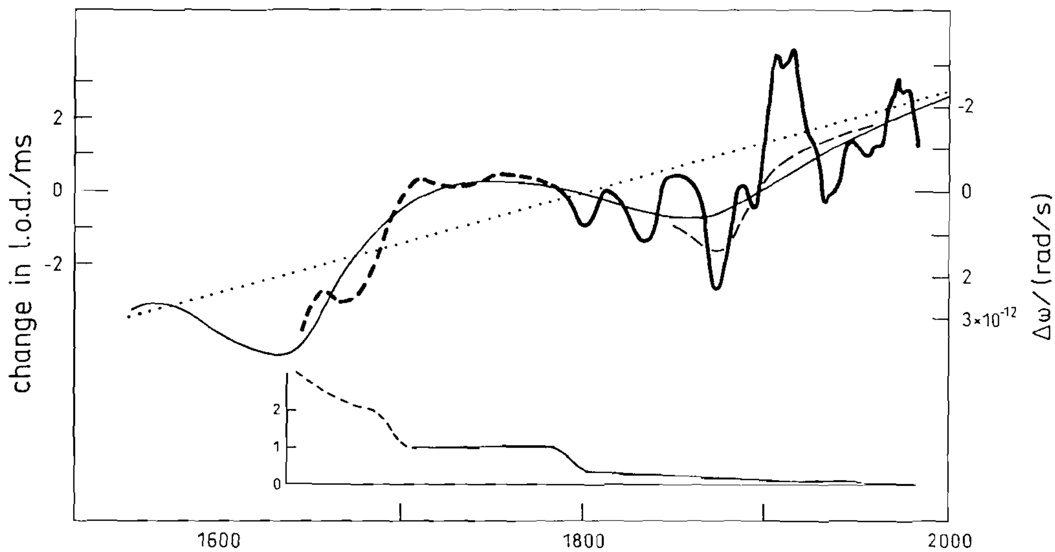

Figure 2. The Earth's rate of rotation expressed as changes in the length of the day (LOD) for the last four centuries (STEPHENSON and MORRISON, 1984; STEPHENSON, 1991). The dotted line gives the long-term deceleration. The thick line gives the decadal changes and the thin line a mean curve of these changes that might represent secular changes in rotation due to sea level changes of the Earth's radius (the thin dashed line gives a more extreme drawing of this curve). The basic graph gives the α-95 of the LOD changes (*op. cit.*).

angular momentum with a more slowly moving layer than the surface currents, which might be intermediate ocean currents or bottom water currents.

If this LOD curve is a function of global sea level, it would provide a perfect means of calculating the global mean trend of sea level changes from the otherwise fairly inconclusive complex of sea level curves. We can also turn the reasoning and say that any changes in global sea level, *i.e.* in the Earth's radius, must show up in one way or the other in the LOD record.

Figure 3 gives the long-term mean LOD changes with respect to the long-term general deceleration. In Figure 4 this curve has been recalculated to corresponding sea level changes. The Northwest European regional eustatic curve (MÖRNER, 1973) has been added for comparison (it is also given in Figure 3 recalculated to msec LOD changes). For the last 150 years there is a remarkably good correlation between the two curves with about 40 years' time lag. This can be taken to indicate that the global mean rise in sea level during the last 150 years was about 11 cm (15 cm with an extreme drawing of the mean LOD curve). At least, it can never have been more than that (which is very important with respect to much higher rates and amplitudes often claimed in association with possible greenhouse effects; *e.g.* PELTIER and TUSHINGHAN, 1989; TRUMPIN and WAHR, 1991).

It cannot be excluded, however, that the curve in Figure 3 may instead represent the interchange of momentum with a more slowly moving water body than the surface water currents like main intermediate water currents or bottom currents. If this would be the case, there can only have been insignificant changes in mean global sea level (a fact obscured by the absence of a good global data coverage).

CONCLUSIONS

Because available tide-gauge data, geodetic records and satellite data do not permit the definition of a mean global sea-level trend today and in the near past, and it has become extremely urgent to try to predict the sea level changes in a realistic way for the near future, we need to investigate all available means of calculating or establishing the recent mean sea-level changes.

We have explored the Earth's changes in its rate of rotation which probably is the natural and sensitive physical process in this respect. Any change in global sea level will alter the Earth's

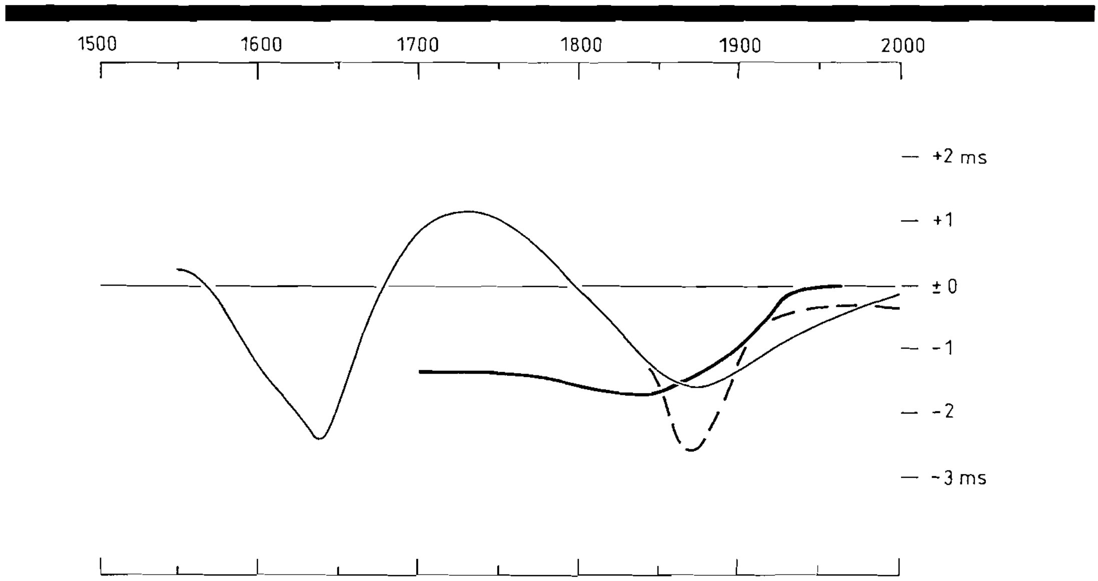

Figure 3. The smoothed mean curve of the "decadal" changes (with the long-term deceleration trend as zero) in msec LOD. The regional Northwest European eustatic curve (MÖRNER, 1973), recalculated into msec LOD, is added for comparison.

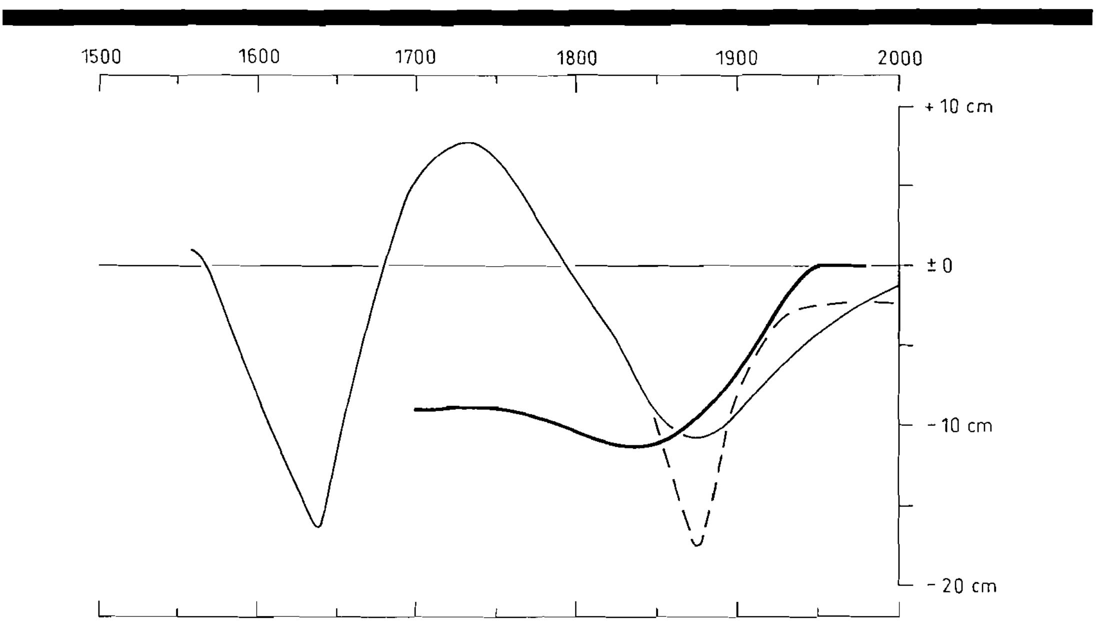

Figure 4. The smoothed mean curve of the "decadal" changes (with the long-term deceleration trend as zero) recalculated to cm sea level changes assuming that the rotation changes are due to the changes in radius due to sea level changes. The regional eustatic curve of Northwestern Europe (MÖRNER, 1973) is added for comparison. The two curves are closely similar for the last 150 years (with a 40 year time lag), but totally different prior to 1850.

radius and this will inevitably lead to a compensation in the Earth's rate of rotation (and the Earth-Moon distance).

The rotational data record a sinusoidal century-long deceleration since 1850 that may represent a global rise in mean sea level of about 11 cm (at the very most 15 cm). Sea level cannot have risen more. It can have risen less, however, or not at all (if the rotational change does not represent a radius change compensation within the Earth-Moon system but an interchange of angular momentum within the terrestrial system).

In conclusion, this novel analysis of Earth's LOD variations allows us to determine the mean global sea level change during the last 150 years at about 11 cm, at the most, according to one way of analysis (the one favoured) or hardly any change at all according to another way of analysis (less favoured but still quite reasonable).

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□ RÉSUMÉ □

Le niveau global de la mer change actuellement et, dans le proche passé (et en cela, dans le proche futur), n'a pu être établi de manière satisfaisante, soit par traitement mathématique, soir par données de marégraphes, soit par modélisation géophysique ou par considérations géologiques. On propose d'étudier le niveau global par rapport aux modifications de l'axe de rotation de la terre (variations de la longueur du jour). On peut déceler toute modification du niveau global de la mer dans la vitesse de rotation de la Terre, directement fonction de tout changement de son axe. Les modifications décennales oscillent sur une sinusoïde, longue environ d'un siècle et dont la tendance moyenne pourrait représenter un facteur du niveau global de la mer. Ce facteur est compatible avec une hausse du niveau de la mer de l'ordre de 11 cm pour 100 ans (ce qui est une fraction des valeurs que l'on proclame pour la hausse de niveau générée peut être par l'effet de serre). On peut le prendre comme une mesure du maximum possible de l'élévation moyenne du niveau global de la mer pour les 150 dernières années. On ne doit pourtant pas exclure le fait que cela représente un échange du moment angulaire avec un intermédiaire océanique se déplaçant plus lentement, ou des courants de fond. Si tel est le cas, il n'y aurait pas de hausse significative du niveau global de la mer dans les 150 dernières années. Les enregistrements des modifications de la longueur du jour est donc un moyen puissant pour suivre et prédire les changements globaux du niveau de la mer.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ RESUMEN □

Los cambios globales del nivel medio del mar, en el presente y en el pasado cercano (y también en un futuro próximo), no han podido ser establecidos de manera satisfactoria, ya sea, por el tratamiento matemático de los datos de los mareógrafos, o por modelos geofísicos o por consideraciones geológicas. Aquí de propone una nueva forma de estudio del nivel medio del mar global, frente a los cambios en el ritmo de rotación de la Tierra (variación en la longitud del día). Cualquier cambio global en el nivel del mar debe poder verse en el ritmo de la rotación terrestre como una función directa de una variación en su radio. Los cambios decenales de la rotación terrestre se mueven alrededor de una sinusoide, de aproximadamente una centuria de longitud, tendencia media que puede representarse por un factor global de nivel del mar. Este factor, es consistente con un ascenso del nivel del mar del orden de los 11 cm en 100 años (el cual es una fracción de los valores usualmente atribuídos, en la actualidad y en un futuro cercano, al ascenso del nivel del mar por un hipotético efecto invernadero). Esto puede ser tomado como una medida del máximo ascenso posible en el nivel medio global del mar durante los últimos 150 años. Sin embargo, no se debe excluir la posibilidad que represente el intercambio de la cantidad movimiento angular con las lentas corrientes oceánicas intermedias y de fondo. Si ha sido así, el ascenso del nivel medio del mar global durante los últimos 150 años, podría haber sido poco importante. Los cambios en los registros de LOD son una herramienta potente para muestrear y predecir los cambios globales del nivel del mar.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*

□ ZUSAMMENFASSUNG □

Die Ursachen für die gegenwärtigen, vergangenen (und damit auch zukünftigen) weltweiten Veränderungen des mittleren Meeresspiegelniveaus sind bisher noch nicht zufriedenstellend geklärt worden, weder durch mathematische Bearbeitung von Gezeitenmeßdaten noch durch geophysikalische Modellierung oder durch geologische Betrachtungen. Hier wird eine neue Möglichkeit vorgeschlagen, weltweite Meeresspiegelschwankungen zu studieren, nämlich aufgrund von Änderungen der Rotationsgeschwindigkeit der Erde (und damit der Tageslängen). Jeder weltweite Wandel des Meeresspiegels muß in bezug auf die Rotationsgeschwindigkeit der Erde gesehen werden, da er eine direkte Veränderung des Erdradius bewirkt. Die Ånderungen der Erdrotation pro Jahrzehnt beschreiben eine sinusförmige Kurve mit einem etwa hundertjährigen Trend. Das könnte ein globaler Faktor für Meeresspiegelschwankungen sein. Dieser Faktor entspricht einem Meeresspiegelanstieg in der Größenordnung von 11 cm in 100 Jahren (und damit einem Bruchteil der oft behaupteten Werte für einen durch den hypothetischen Treibhauseffekt bedingten Meeresspiegelanstieg in der Gegenwart und der nahen Zukunft). Das kann als Maß für den maximal möglichen Anstieg des weltweiten Meeresspiegelniveaus während der letzten 150 Jahre angesehen werden. Allerdings ist nicht ausgeschlossen, daß es den Austausch zwischen Winkelimpuls und langsamen innerozeanischen oder am Meeresgrund verlaufenden Strömungen darstellt. Wenn das der Fall ist, dann wäre kein signifikanter globaler Anstieg des Meeresspiegels in den letzten 150 Jahren erfolgt. Auf jeden Fall bieten Messungen der Veränderungen der Tageslängen eine gute Möglichkeit, um Meeresspiegelschwankungen zu überwachen und vorherzusagen.—*Helmut Brückner, Department of Geography, University of Marburg, Germany.*