EARTH ROTATION PARAMETERS OBTAINED FROM A DYNAMICALLY COUPLED ATMOSPHERE-HYDROSPHERE MODEL

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ABSTRACT. A state-of-the-art climate model has been modified in order to obtain an Earth system model with consistent mass, energy and momentum fluxes. Five climate future scenarios from 1860 till 2059 are performed. Till the year 1999 the model is forced by observed greenhouse gas emissions and pre-calculated sulfate aerosols. For future climate predictions the model is forced by the IPCC A1B scenario. The influence of all parts of the Earth near-surface system, namely the atmosphere, the oceans and the continental hydrology, on the Earth's rotation can be consistently analyzed on daily to decadal timescales. We present first model results, i.e. Long periodic length of day variations induced by climate events and short-term length of day variations induced by lunisolar tides.

1. INTRODUCTION

Variations of the Earth's rotation are determined by mass redistributions within the Earth's system. As parts of the Earth's system atmosphere and hydrosphere (ocean and continental hydrology) contribute largely to these variations. It is of considerable interest to estimate the contribution of these subsystems. Studying each of these subsystems separately leads to inconsistencies in energy, mass and angular momentum transfer between the subsystems and thus in conservation of these quantities. However, for analyses of Earth rotation it is substantial to allow for mass and angular momentum conservation. Thus, coupling the subsytems of atmosphere, continental hydrology and ocean is necessary to allow for an improved simulation of variations of the Earth's rotation induced by atmospheric and hydrospheric mass redistributions.

We used a state-of-the-art dynamically coupled atmosphere-hydrosphere model suited for climate predictions to determine Earth rotation parameters. Several modifications of the climate model, described in Chapter 2, were necessary for a sufficient conservation of mass and angular momentum. In Chapter 3 we present first results from this Earth system model approach.

2. MODEL

The model chosen in the present study is the climate model of the Max Planck Institute for Meteorology in Hamburg. The atmospheric component of the model (ECHAM5; Roeckner et al., 2003) has a spatial resolution of T63 (corresponding to a grid box size of 1.875°x1.875°) with 31 vertical layers. The oceanic component (MPI-OM; Marsland et al., 2003] is a z-coordinate ocean general circulation model with integrated sea-ice model and it utilizes horizontally a bipolar orthogonal grid where the positions of the North and South pole can freely be chosen. Thus, the singularity at the geographical North pole can be avoided by replacing the grid North pole on land. In this configuration the North pole is centered on Greenland (30°W, 80°N) and the South pole on Antarctica (30°W, 80°S). The horizontal resolution of the grid ranges from three to one degree, between 12 km near Greenland and 180 km in the tropical Pacific. Vertically the grid has 40 layers, where 20 layers are distributed over the upper 700 m. The ECHAM5 is coupled via the OASIS interface (Terray et al., 1998) without any flux correction to the

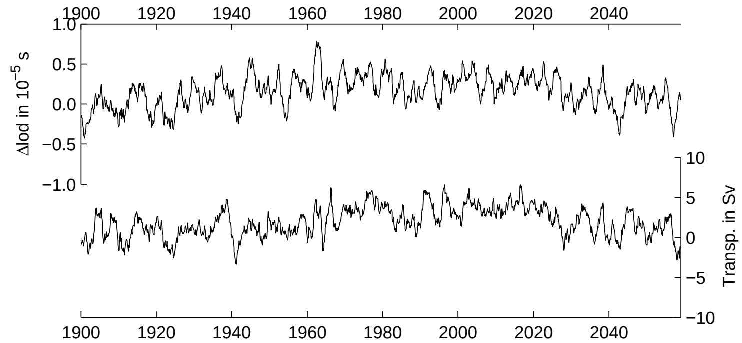

Figure 1: Time series from 1900 till 2059: (top) The variation of LOD (detrended, 12-month running mean) caused by variations of the oceanic motion term. (bottom) Time series of the variation in transport of the Antarctic circumpolar current (detrended, 12-month running mean) in the Drake Passage. The correlation of the two time series amounts to 0.68.

MPI-OM. Further, the climate model consists of a land hydrology model, embedded in ECHAM5. This climate model version was used for the 4th IPCC assessment report simulations.
Several modifications are done in order to improve the conservation of mass, energy and momentum within the climate model. Firstly, in the standard version of the model the coupling interface between ocean surface and atmosphere neglects the atmospheric pressure on top of the ocean. We implemented the 'dynamic pressure' to the coupling variables of the OASIS interface. The 'dynamic pressure' is defined as the atmospheric pressure on the ocean surface and thus the ocean gets explicitly forced by atmospheric pressure. Secondly, the steric sea level correction is implemented in order to allow for mass conservation. This correction is necessary since the ocean model is a z-coordinate model and thus the model is volume conserving rather than mass conserving. In order to allow for mass conservation a correction term was implemented according to Greatbatch (1994). And thirdly, the ocean tides are implemented in the ocean model. The ocean tides are essential when considering Earth rotation parameters, but are still missing in all state-of-the-art climate models. We extended the MPI-OM by the implementation of the complete lunisolar tidal forcing of second degree. This real time forcing describes the tidal potential of second degree in terms of ephemerides (Thomas et al., 2001). Thus, all tidal harmonics of second degree are forced in the model explicitly. Further, routines are included into the model to compute online the Earth rotation parameters of atmosphere, ocean and continental hydrology. The time resolution of atmosphere and ocean model are 720 s and 2160 s, respectively. The time-step of the ocean model is reduced compared to the standard MPI-OM version (3600 s) for the reliable representation of semi-diurnal and diurnal ocean tides. Five 200 year experimental runs are performed, with simulation periods from 1860 to 2059. Till the year 1999 the model is forced by observed greenhouse gas emissions and pre-calculated sulfate aerosols. For future climate predictions the model is forced by the A1B scenario. For the initial conditions we are using the 500 year IPCC pre-industrial control experiment, where the model was run with fixed pre-industrial GHG conditions. The state of the Earth system is taken in one hundred year intervals from the control experiment, and each of these five states are used to initialize the five experimental runs.

3. INTER-DAILY AND INTER-ANNUAL VARIATIONS IN LOD

In this section we present variations of the Earth rotation parameters as obtained by five climate model experiments. We are focusing on the length of day (LOD) variations, which are caused through pressure torque induced by zonal pressure gradients on the solid Earth, through changes in the moment of inertia of the coupled system (matter term) and through changes in the angular momentum stored in the ocean and atmosphere (motion term). The motion term is defined by the angular momentum stored in the ocean and atmosphere:

$$L_1 = R \int_V \rho u(\phi, \lambda) \cos \phi dV$$

there u are the zonal velocities of fluid elements with density ρ, R is the distance to the earth's center and ϕ and λ are geographical coordinates. Solely the zonal ocean currents and atmospheric winds cause

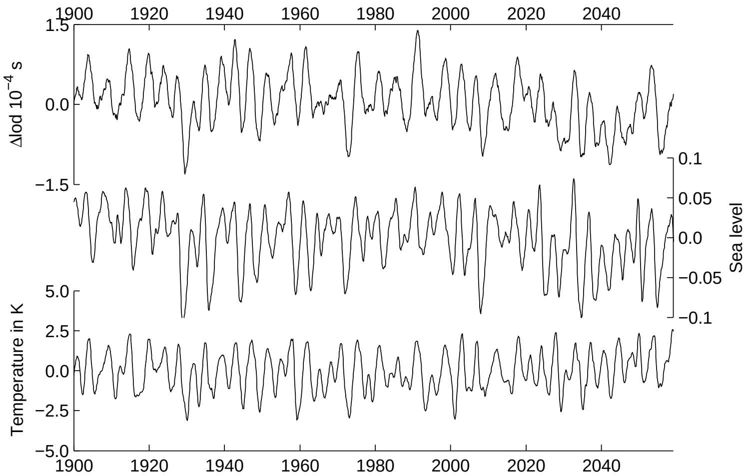

Figure 2: Time series from 1900 till 2059: (top) The variation of LOD (detrended, 12-month running mean) caused by variations of the oceanic matter term. (middle) The variations in sea level (detrended, 12-month running mean) averaged over the equatorial Pacific region extending from 9°S-9°N and 150°W-270°W. (bottom) Time series of the sea surface temperature anomalies in the Niño3.4 region. The correlation beween the temperature (sea level) anomalies and the LOD variations amounts to 0.7 (0.6).

changes in LOD. The LOD is written as

$$\Delta LOD = 86164s\frac{L_1 - L_{1(t=0)}}{L_1^E + L_1},$$

where L_1^E is the angular momentum of the solid earth. The matter term depends on the moment of inertia I_{33} relative to the Earth's axis of rotation, defined through

$$I_{33} = R^2 \int_V \rho(\phi, \lambda) \cos^2 \phi dV.$$

The variations of the matter term (or the moment of inertia) induced by the ocean, the atmosphere and the continental hydrology is determined through the meridional and vertical redistribution of mass. The induced change in LOD is written as

$$\Delta LOD = 86164s\frac{I_{33} - I_{33(t=0)}}{I_{33}^E + I_{33}}.$$

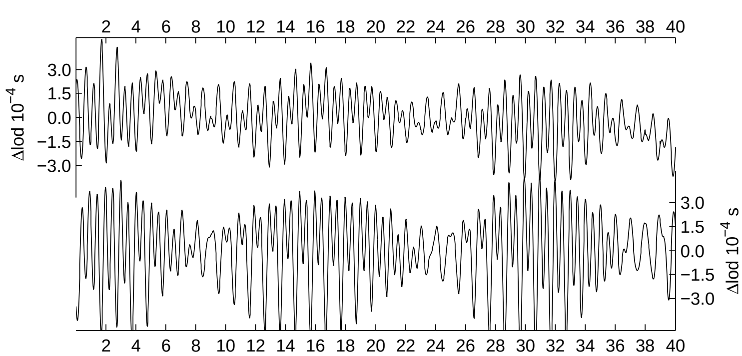

Figure 3: Time series of 40 days in 1900 : The LOD time series caused variations of the oceanic matter term (top) and motion term (bottom).

LOD variations induced by the oceanic motion term are determined by variations of oceanic zonal currents. The major zonal ocean current is the Antarctic Circumpolar Current (ACC) and indeed inter-annual variations in the motion term are mainly controlled by changes in the magnitude of the ACC (Brosche & Sündermann, 1985). In Fig. 1 the variation of the ACC, in the Drake Passage, and the LOD variation induced by the motion term are shown. The magnitude of the ACC shows an inter-annual variability with an amplitude of around $5Sv$ and induces LOD variations of up to $10^{-5}s$. The correlation between these two time- series amounts to 0.7, indicating that the ACC determines to a large extent the LOD variations induced by the oceanic motion term.

The inter-annual variations of LOD induced by the oceanic matter term are shown in Fig. 2 (top). Further, the temperature anomaly in the Niño 3.4 Region is shown Fig. 2 (bottom). This region is in the western equatorial Pacific, bounded by 120°W-170°W and 5°S- 5°N. El Niño events are accompanied by warming the central and eastern tropical Pacific Ocean, thus are indicated by positive temperature anomalies in Niño 3.4 Region. The El Niño episodes are often followed by La Niña events, indicated through negative temperature anomalies in the tropical Pacific Ocean. Obviously the temperature anomaly of the Niño3.4 region correlates well with the ocean induced LOD variation (correlation 0.7). El Niño events lead to positve LOD changes with values up to $1.5 \cdot 10^{-4}s$ and La Niña events lead to negative LOD changes, vice versa.

The variation in the motion term can either result from redistribution of density in the ocean water column or through changes in sea level. The averaged sea level change in the equatorial Pacific region, extending from 9°S to 9°N and 150°W to 270°W, is shown in Fig. 2 (middle). It is well correlated with the LOD and thus with the Niño 3.4 temperature anomalies, as well (correlation 0.6). It seems that the sea level variation, and not the density redistribution, is mainly responsible for inter-annual LOD variations. To clarify the role of the sea level variation, the contribution of the sea level variation to the total moment of inertia is determined in the following. As in Fig. 2 shown, the averaged amplitude in sea level is around 5 cm. The size of the region (9°S-9°N, 150°W-270°W) amounts to $2.6 \cdot 10^{13}m^2$. This corresponds to a water mass of around $1.4 \cdot 10^{15}kg$, which in turn is equivalent to a variation of the moment of inertia of about $5.6 \cdot 1028kg \cdot m^2$. This variation of moment of inertia results in a LOD variation of around $0.7 \cdot 10^{-4}s$, comparable with the LOD variations shown in Fig. 2. This clearly suggests that the inter-annual LOD variations induced by the oceanic matter term are due to the sea level anomaly in the tropical Pacific interconnected with the ENSO variability.

In Fig.3 sub- to inter-daily LOD variations induced by the matter and motion term are shown. Lunisolar ocean tides are the dominant in exciting these harmonic oscillations. The semi-diurnal and diurnal oscillations and their longer period modulations can clearly be identified. The amplitude of these oscillations in LOD are up to $3.5 \cdot 10^{-4}s$ and similar in size for motion and matter term.

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