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SIMULATION OF POLAR MOTION WITH A DYNAMIC EARTH SYSTEM MODEL OVER A PERIOD OF 200 YEARS (1860-2060)

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ABSTRACT. On time scales between months and decades the Earth's polar motion is mainly influenced by redistributions and motions of atmospheric and hydrospheric masses. Here we report the results of a long-term simulation of polar motion with the dynamic Earth system model DyMEG which is forced by the consistently coupled atmosphere-hydrosphere model ECOCTH. Simulations are performed for five ensemble members of ECOCTH and cover a period of 200 years between 1860 and 2060. Since rotational deformations of the Earth are regarded in DyMEG, forced variations of Earth rotation due to atmospheric and hydrologic angular momenta influence the free polar motion (Chandler oscillation) of DyMEG. The 200-year forcing allows for long-term studies of the excitation mechanism of the Chandler oscillation as well as for the prediction and statistical evaluation of polar motion variations until 2060. Statistical comparisons of modelled and observed polar motion time series over 200 years verify a realistic weather variability of ECOCTH.

1. DYNAMIC EARTH SYSTEM MODEL

Geometric and gravimetric space geodetic techniques, such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS) and the gravity field missions CHAMP and GRACE observe the Earth system since many years and map it into time series of geodetic parameters related to geometry, gravity field and orientation of our planet. Temporal variations of these parameters reflect a broad spectrum of exogenous and endogenous forces which are the hurriers of continuous geophysical processes within and between individual Earth system components. In order to interpret the geodetic time series in terms of underlying geophysical processes, the connection between the parameters and individual geophysical processes has to be ascertained.

Geodetic parameters are integral quantities, what implies that specific features in the time series cannot be related to particular causative processes and contributions of individual system components without knowledge from additional observations or from independent theoretical models.

In the following we discuss forward-modelled time series of geodetic parameters which are based on simulations with the dynamic Earth system model DyMEG (Dynamic Model for Earth Rotation and Gravity). DyMEG integrates rotation, gravity field and geometry of the Earth and is consistent with respect to applied model parameters, the reference system and geophysical forcing. The set-up of DyMEG has been described and extensively discussed in various publications and shall not be repeated here (see, e.g., Seitz 2004, Seitz and Schmidt 2005). Its set-up is depicted in Figure 1.

DyMEG is forced by the fully coupled and self-consistent model of the subsystems atmosphere, ocean and continental hydrosphere ECOCTH which covers a period of 200 years between 1860 and 2060. ECOCTH has been developed in interdisciplinary co-operation between groups at the University of Hamburg, the University of Bonn, and the Deutsches GeoForschungsZentrum GFZ (Potsdam). Its set-up is described in detail by Jungclaus et al. (2006) and in other articles in this volume.

Modelled variations of the distribution and motions of mass elements from five ensemble runs of ECOCTH are introduced as forcing into DyMEG. Variations of Earth rotation and gravity field are computed simultaneously with solid Earth deformations due to loading effects. In this article we concentrate on the discussion of numerical model results for polar motion, i.e. the variations of the position of the Earth rotation axis with respect to an Earth-fixed coordinate system.

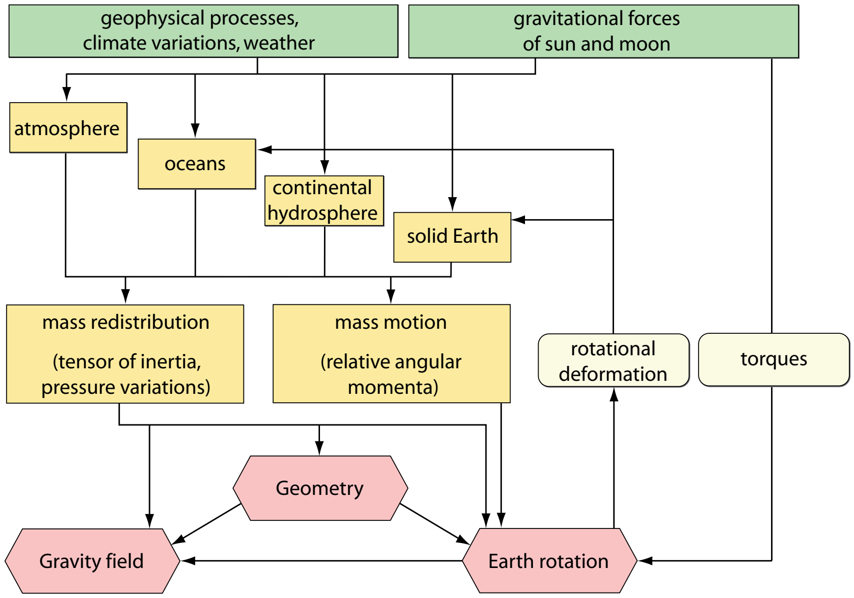

Figure 1: Set-up of the Earth system model DyMEG.

2. RESULTS FOR POLAR MOTION

On time scales from months to decades polar motion is mainly influenced by the variability of angular momentum within and between the atmosphere and the hydrosphere. Model time series of variations of the Earth's tensor of inertia and relative angular momenta due to the motion of atmospheric and hydrospheric mass elements with respect to an Earth-fixed reference frame are introduced into DyMEG and numerically balanced with the Earth rotation vector according to the Liouville differential equation (see Seitz 2004 for details). The resulting time series of polar motion is displayed in Figure 2 for each of the five runs (x-components). For comparison the time series C01 of astrometrical and geodetic observations of polar motion as released by the International Earth Rotation and Reference Systems Service (IERS) is displayed, too.

There are significant differences between the runs that reflect the internal variability of the five ensemble members of ECOCTH. In all cases a clear beat between the two prominent signals, the annual and the Chandler oscillation, is obvious. Signal analysis by means of wavelet filtering (Seitz and Schmidt 2005) reveals, that the annual components of all runs are characterised by rather stable amplitudes over the entire time span of 200 years. However the mean annual amplitudes of all runs amount to 0.16 as (arc seconds), which is almost twice as much as observed (0.09 as). This implies that the annual cycle is overestimated by ECOCTH. While the annual oscillations of the five results are very similar, there are large discrepancies between the modelled Chandler oscillations (Figure 3).

While the annual component of polar motion is a forced phenomenon due to the annual variability of atmosphere and hydrosphere, the Chandler oscillation is a free rotational mode of the Earth which is caused by misalignment of figure axis and rotation axis. However since the Earth's body is deformable this misalignment would diminish, until both axes would coincide after few decades if no counteracting mechanism would perpetuate the Chandler oscillation. The deformations of the Earth's body which occur as a consequence of polar motion (so-called rotational deformations) are a back-coupling mechanism of polar motion on mass redistributions within the solid Earth as a consequence of centrifugal potential variations.

In DyMEG the Chandler oscillation is modelled as a damped oscillation on the basis of rotational deformations and complex Love-Numbers. This way forced variations of Earth rotation due to atmospheric and hydrologic excitations influence the Chandler oscillation of DyMEG. Obviously all runs of ECOCTH allow for the excitation of the Chandler oscillation, even though the shapes of the resulting curves are very different. But concerning the general signal characteristics (distribution of nodes and maxima) the runs are similar and agree well with the observations. Since the Chandler frequency is a resonance frequency of the Earth, energy is required in a spectral band close to the Chandler frequency in order to excite the oscillation. But since there are no periodic or quasi-periodic signals present in the Chandler frequency band of the spectra of the atmospheric and hydrospheric forcing, the question arises where the necessary excitation energy emerges.

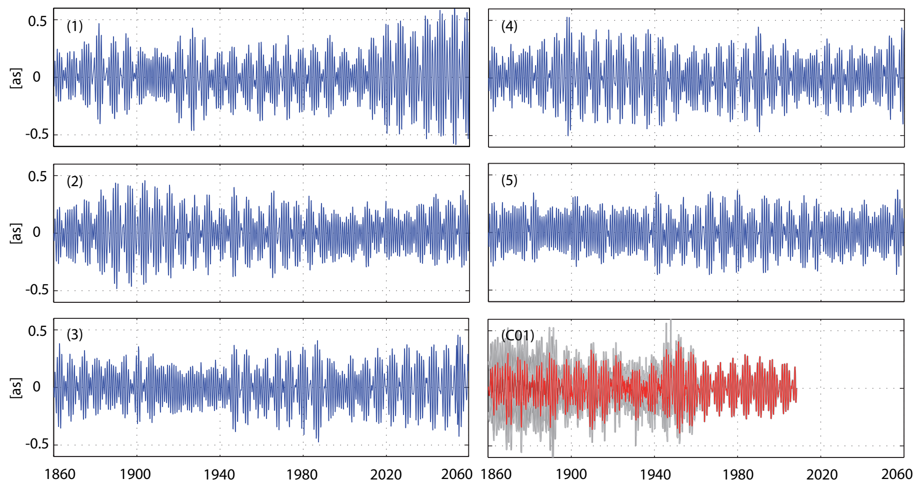

Figure 2: Model results from DyMEG for polar motion (x-components) over 200 years for the five scenario runs (1-5) in comparison with the geodetic observations of the C01-series of the IERS (red). The 3σ-error margin of the observations is diplayed in gray.

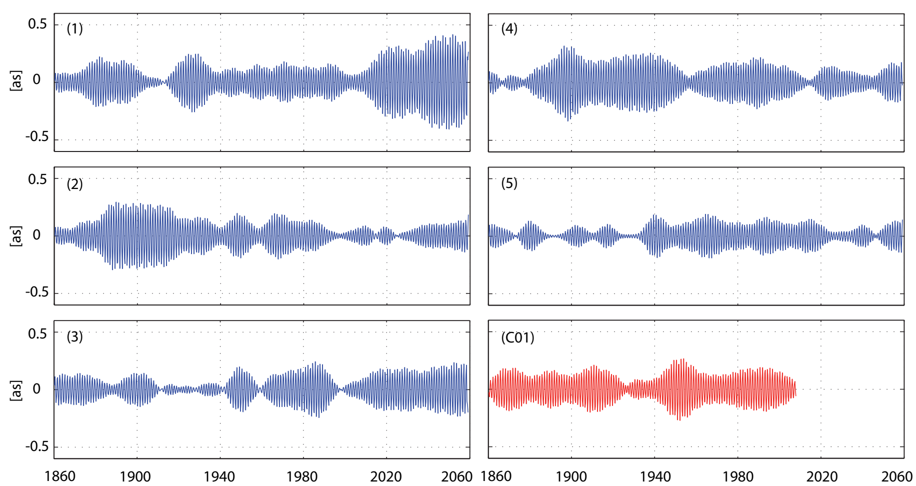

Figure 3: Chandler oscillation (x-components) of the model results and the C01-series determined by wavelet filtering.

3. WHITE NOISE EXPERIMENT

It is assumed that the Chandler oscillation of DyMEG is excited by atmospheric and hydrospheric background noise which is caused by stochastic weather phenomena. Furthermore it is assumed that the noise level (i.e. the amount of excitation energy) is high enough to induce the observed Chandler amplitude variations. Due to the stochastic trait of the simulated weather variations of ECOCTH the five runs lead to results that are quite different at particular points in time, but similar with respect to their general characteristics. In order to corroborate the assumption that the Chandler oscillation can be excited by the stochastic background signal, an experiment is conduced in which the ECOCTH excitations are replaced by white noise. This procedure is similar to runs performed by Seitz et al. (2005), however in the following the experiment is extended to a period of 1000 years between 1900 and 2900.

The model values of the off-diagonal tensor elements $\Delta\mathbf{I}_{xz}$ and $\Delta\mathbf{I}_{yz}$ as well as the equatorial components of the relative angular momentum vector are substituted by synthetic time series of equally distributed random numbers (white noise) from the interval $[-1, +1]$ multiplied by a constant factor l in order to vary the noise level. It has been shown by Seitz et al. (2005) that for a factor of $l = 1 \cdot 10^{29}$ the noise level of the random number time series is just as high as the noise level of the background signal of the atmospheric and hydrospheric tensor variations. Figure 4 displays the result for the model Chandler oscillation (x-component) when DyMEG is forced with respective random excitations. The first 100 years of the time series are compared with the observed Chandler oscillation.

Again model result and observation show the same characteristics, and the alternation of the Chandler amplitude (increasing and dying down) keeps on going for the entire simulation period of one millennium. The maximum amplitude which can be attained is limited by the noise level. Since the noise level of the applied random excitations is just as high as the noise level of the ECOCTH forcing, we conclude that the stochastic atmospheric fluctuations due to weather variations are indeed the prominent hurriers of the Earth's free polar motion.

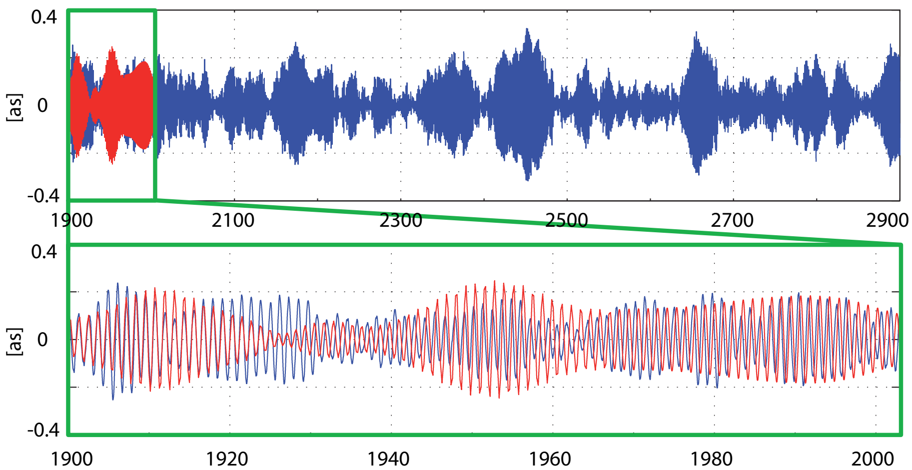

Figure 4: Model result from DyMEG for polar motion (x-components) over 1000 years with white noise forcing instead of atmospheric and hydrospheric excitations (top panel) and comparison with the geodetic observations of the C01-series of the IERS (red) during the last century (lower panel).

4. RÉSUMÉ

From the numerical model results of DyMEG for polar motion quality and potential of the atmosphere-hydrosphere model ECOCTH can be assessed. While the annual cycle turns out to be overestimated in ECOCTH, the physically consistent and fully coupled model has been shown to be a valuable tool for long-term studies of the Chandler oscillation since the five equiprobable ensemble members feature a statistically realistic weather variability over 200 years.

5. REFERENCES

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