In: Proceedings of the "Journées 2011 Systèmes de
référence spatio-temporels", H. Schuh, S. Böhm, T.
Nilsson and N. Capitaine (eds), Vienna University of
Technology, 2012.

SIMULATION, PREDICTION AND ANALYSIS OF EARTH ROTATION PARAMETERS WITH A DYNAMIC EARTH SYSTEM MODEL

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ABSTRACT. Dynamic processes in the Earth system involving mass transports in the subsystems atmosphere and ocean are known to be the prominent sources for changes of Earth rotation on subseasonal to interannual time scales. Since respective geodetic observations of polar motion and variations of length-of-day are integral quantities, numerical model approaches are required in order to assess individual contributions from underlying processes in different subsystems. This paper discusses simulations of polar motion from the dynamic Earth system model DyMEG. Results for two different model set-ups are presented: First, realistic forcing based on reanalysis data is applied. Second, DyMEG is forced by scenario runs over 200 years (1860-2060) based on a fully coupled atmosphere-hydrosphere model. Special attention is drawn to the long-term development of the modelled Chandler oscillation and its excitation mechanisms. It is shown that simulated and observed patterns of amplitude variations of the Chandler oscillation agree very well. Various experiments reveal that wind is its most important driving mechanism.

1. INTRODUCTION

The rotation of the Earth and its temporal variation are monitored by geodetic and astrometric observation systems since decades with very high accuracy. Observations of the orientation of the Earth axis and the angular velocity of the rotation are transformed into time series of Earth rotation parameters (ERP) polar motion and length-of-day respectively. Precise knowledge of temporal variations of the ERP is essential for various applications, such as the realisation of time systems, the highly precise computation of geodetic reference frames, the relation of Earth-fixed and space-fixed coordinate systems, and precise navigation on Earth and in space. In addition, ERP are interesting quantities for various disciplines of geosciences since dynamic processes in the Earth system are reflected in their temporal variations.

The analysis of ERP time series allows for conclusions with respect to processes and changes in the Earth system on various temporal scales. But since ERP are integral quantities of the Earth system whose variations are caused by a multitude of superposed effects, additional information from physical modelling is indispensable. In the following, results of the geophysical forward model DyMEG (Dynamic Model for Earth Rotation and Gravity) are presented which has been developed in order to simulate variations of rotation, gravity field and surface deformations of the Earth in a physically consistent way (Seitz 2004). The focus of this presentation is put on inter-annual variations of polar motion that are caused by processes in the coupled atmosphere-hydrosphere system.

This paper is a direct follow-up of the article of Seitz and Drewes (2009). Therefore the description of both the set-up of DyMEG and the atmospheric-hydrospheric forcing is kept very short intentionally in order to provide room for the discussion of numerical results of extended experiments.

2. SIMULATIONS OF POLAR MOTION

DyMEG is based on the Euler-Liouville Equation that describes the balance of angular momentum in an Earth-fixed coordinate system. External gravitational torques from Sun, Moon and planets are balanced with variations of angular momentum in the Earth system. Those are caused by mass transports (i.e. the redistribution and motion of mass elements) and changes of the Earth rotation vector. By solving the Euler-Liouville Equation for the latter, variations of ERP are determined.

In order to obtain meaningful results various forcings and parameters need to be introduced into

DyMEG. Beside ephemerides of external celestial bodies that are required for the computation of gravitational torques and tidal deformations of the Earth, information about mass transports in the (relevant components of the) Earth system must be available. Respective mass redistributions and motions are converted into temporal variations of the Earth's tensor of inertia and so-called relative angular momenta. Furthermore the model requires a number of geometrical, physical and rheological parameters of the Earth. Naturally the model result is highly dependent on the completeness of the considered effects as well as on the quality and consistency of applied forcing and model parameters.

2.1. Experiment 1: Realistic Forcing

In a first experiment numerical values for variations of the tensor of inertia and relative angular momenta are deduced from the atmospheric reanalyses of NCEP and the unconstrained version c20010701 of the global ocean circulation model ECCO. ECCO is forced by NCEP fields of wind stress, heat and freshwater fluxes. Consequently the combination of those two models allows for a consistent description of mass transport processes in the subsystems atmosphere and ocean. Water storage variations and related mass redistributions in the continental hydrology are derived from the global hydrological model LaD. Minor effects (e.g., earthquakes, volcanic eruptions, postglacial uplift, core/mantle interactions) are neglected. The results from DyMEG are displayed in Figure 1. The modelled curves for polar motion and the geodetic observations (series C04 of the International Earth Rotation and Reference Systems Service, IERS) agree very well. The correlation coefficients amount to 0.98 (x-component) and 0.99 (y-component), and the respective RMS differences are 29.5 and 23.3 mas. This result can be seen as a proof that DyMEG is suitable of producing a result for polar motion which highly corresponds to observations when the model is forced with realistic forcing based on reanalysis data.

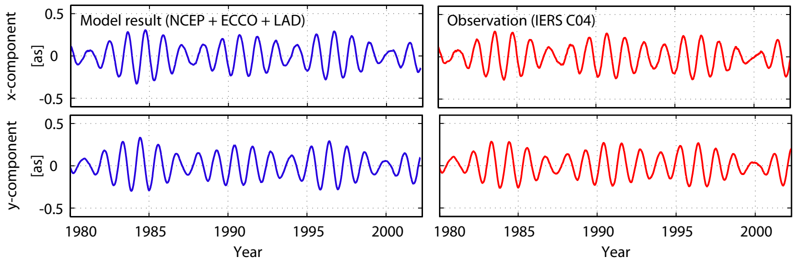

Figure 1: Model result for polar motion from DyMEG with realistic forcing (left) in comparison with geodetic observations (right)

2.2. Experiment 2: ERP predictions with scenario runs over 200 years

In a second experiment DyMEG is forced by the fully and self-consistently coupled atmosphere-hydrosphere model ECOCTH. ECOCTH is based on atmosphere-ocean model combination ECHAM5-T63/MPI-OM (Jungclaus et al., 2006) that has been extended by a land surface hydrology model. The model simulates fluxes of momentum, energy and mass between atmosphere, ocean and continental hydrosphere. Five equiprobable scenario runs were produced for a period of 200 years between 1860 and 2060. The runs differ solely with respect to the initial conditions for the atmospheric-hydrospheric state of 1860. ECOCTH simulations until 1999 were performed under observed climate forcing taking into account anthropogenic and natural influences. Climate prediction simulations for the 21st century were performed under the A1B scenario for future man-made climate forcing (see Sündermann and Hense, 2009, for details). Since the coupled model is absolutely free, only statistical conclusions can be drawn from the results, i.e. an analysis with respect to real time is not possible.

ECOCTH predictions of mass transports are introduced as forcing into DyMEG. A run with DyMEG is performed for each of the five ensemble members. The respective results for polar motion are displayed in Figure 2 of the article by Seitz and Drewes (2009) together with astrometric/geodetic observations from the C01 series of the IERS. Even though identical climate forcing is applied to all five ensemble members of ECOCTH the resulting curves for polar motion from DyMEG are very different. This implies that the excitation of polar motion depends largely on random processes in the atmosphere-hydrosphere system. A decomposition of the curves into the two largest signal components, the Chandler and the annual oscillation, is performed by means of wavelet filtering (Seitz and Schmidt, 2005). Figure 2 displays the results for two of the runs (runs 1 and 4) together with respective curves determined from observations.

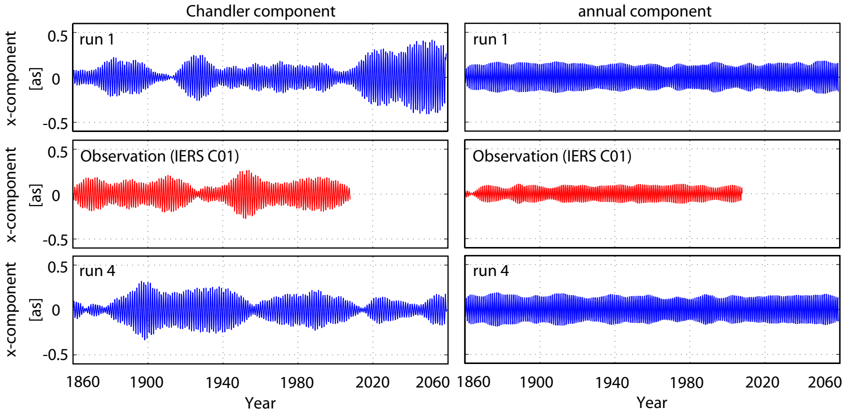

Figure 2: Chandler and annual oscillations of model results from DyMEG (ECOCTH forcing; runs 1 and 4) in comparison with respective signal components from geodetic observations (x-components).

As discussed by Seitz and Drewes (2009) the annual components are similar and feature rather stable amplitudes in all runs. However, the annual amplitudes are nearly twice as large as observed which indicates an overestimation of the annual variability by ECOCTH. The Chandler components differ significantly between the runs (cf. also Figure 3 of Seitz and Drewes, 2009). But the overall signal characteristic showing increasing and decreasing amplitudes corresponds well with the observations.

By taking a closer look at the time series of the Chandler oscillation pieces of the curves can be identified that look very similar in the model results and the observations (Figure 3). For the two displayed runs these pieces cover almost 100 years (run 1) and 90 years (run 4). Shifting the pieces by +26 and +54 years respectively leads to remarkable correlation coefficients of 0.74 and 0.92. As stated above the simulated dynamics of ECOCTH are not related to real time. Therefore a time shift between the curves is irrelevant for the analysis of the results.

The Chandler oscillation is a free rotational mode of the Earth. Due to the anelastic response of the Earth's mantle to polar motion its amplitude is damped and would diminish within a few decades if no counteracting mechanism would excite it. Broad consensus has been reached in the scientific community that the Chandler oscillation is excited by dynamical processes in atmosphere and hydrosphere. Forced polar motion caused by mass transports in these subsystems is coupled back to so-called rotational deformations. Those deformations involve mass redistributions in the solid Earth and in the oceans that are known to influence the Chandler amplitude. The results of DyMEG indicate that ECOCTH is very well suited for analysing the relevant dynamical processes. In this context the long time period of ECOCTH is of special interest since it allows for studying the mechanisms of excitation and damping of the Chandler oscillation over many decades.

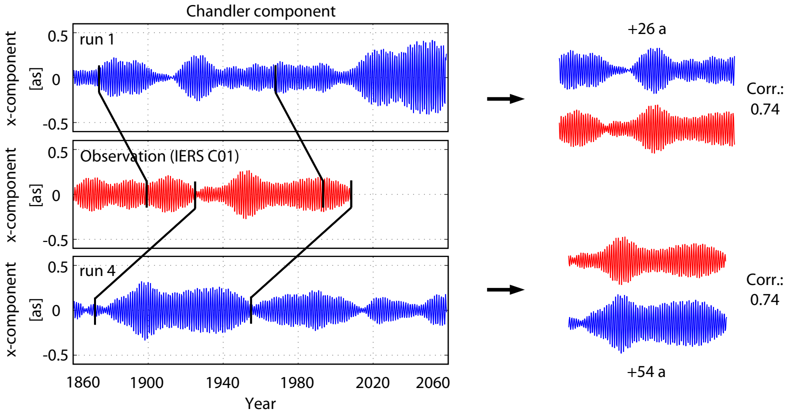

Figure 3: Analysis of the Chandler oscillations from DyMEG (runs 1 and 4) w.r.t. geodetic observations.

3. EXCITATION OF THE CHANDLER OSCILLATION

In order to identify the strongest contributors to the excitation of the Chandler oscillation additional experiments with DyMEG are performed. Exemplarily ECOCTH forcing of run 4 is applied. First, the joint effect of redistributions and motions of mass elements is studied separately for the two subsystems atmosphere and ocean. Respective variations of the tensor of inertia (mass effect) and relative angular momenta (motion effect) are deduced from the model components ECHAM5-T63 and MPI-OM. Mass transports in the continental hydrology are not considered here since their effect on the Chandler oscillation is very small (Seitz and Schmidt, 2005). The results of this experiment are displayed in Figure 4 (first column). For either case DyMEG produces an oscillation that shows increasing and decreasing amplitudes. Thus both subsystems atmosphere and ocean clearly contribute to the excitation of the Chandler oscillation. The atmospheric contribution is a bit stronger, and maxima and minima of both curves are not necessarily synchronous. In a second experiment mass and motion effects are separated (Fig 4; second column). Now atmosphere and ocean are introduced into DyMEG simultaneously, but either only mass redistributions (i.e. tensor variations) or only mass motions (i.e. relative angular momenta) are considered. The motion effect on the excitation of the Chandler oscillation turns out to be significantly stronger than the mass effect. In further experiments mass and motion effects are studied separately for atmosphere and ocean (Figure 4; third and fourth column). All model results are linear, i.e. the sum of the curves obtained for individual effects is equal to the curve obtained for the respective joint effect. In sum the experiments indicate that (1) the atmosphere is the strongest contributor, and that (2) in particular the atmospheric motion component (that is related to equatorial winds) is a very important excitation mechanism of the Chandler amplitude.

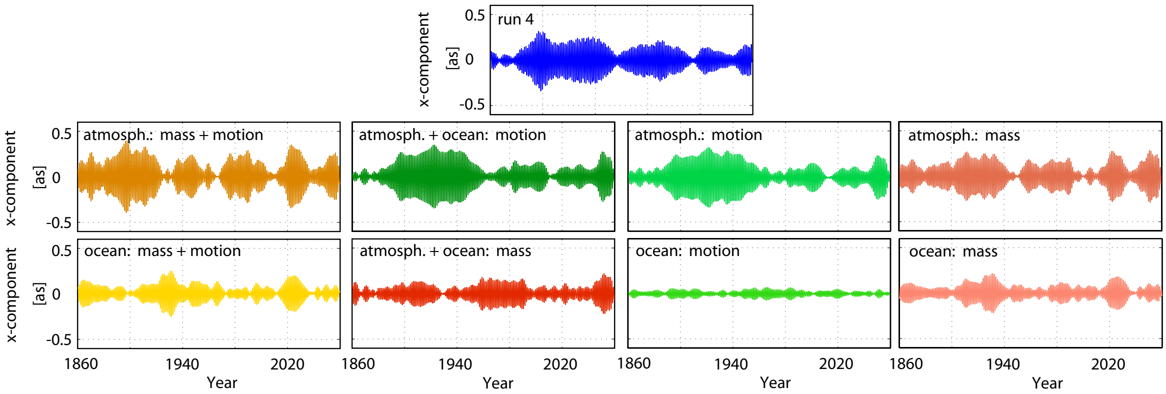

Figure 4: Top panel: Chandler oscillation from DyMEG for run 4 (full forcing, cf. Figure 2). Lower panels: Chandler oscillations from various experiments with partial forcing.

4. RÉSUMÉ

The Dynamic Model for Earth Rotation and Gravity (DyMEG) has been applied for simulations of polar motion. An experiment with realistic forcing demonstrated the model's ability for producing meaningful results for polar motion. The fully coupled atmosphere-hydrosphere model ECOCTH provides an ideal data basis for studies of the dynamical mechanisms of the excitation of polar motion and in particular of the Chandler oscillation over many decades. Future investigations will be directed towards the identification of specific dynamical states of the atmosphere-hydrosphere system and processes of mass transports that are responsible for the amplitude variations of the Chandler oscillation.

5. REFERENCES

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