The annual wobble excitation due to the seasonal atmospheric loading on continents

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Abstract

Northern Eurasian continent has been regarded as the main source of seasonal atmospheric pressure loading, producing the annual wobble of the Earth polar motion. Prior to the 1980's, when reliable data of global atmospheric pressure were not accessible, this dominance had remained an hypothesis. Nowadays, however, European Centre for Medium-Range Weather Forecasts and National Center for Environmental Prediction produce reliable datasets, that allow to clearly quantify this unique feature. Both Earth's polar motion and global atmospheric state being known with unprecedented accuracy, we hereby scrutinize to which extent Siberia and Manchuria dominate the annual polar motion.

Annual Wobble Excitation

Annual wobble is one of the two main components of Earth's wobbling motion. While Chandler wobble excitation mechanism has been controversial for a long time, it is evident that annual wobble is driven by geophysical phenomena having periodic seasonal variations. And it has been presumed since early times that Siberia does a noticeable role in the annual wobble excitation, i.e., periodic loading/unloading of air mass over the wide Siberian land may result in major contribution on the Earth's annual wobble.

Approaches

Information of worldwide weather are gathered and assimilated in European Centre for Medium-Range Weather Forecasts (ECMWF) and National Centers for Environmental Prediction (NCEP) for the purpose of weather forecasting as well as to provide datasets necessary for scientific investigations. The 6-hr period global data coverage by ECMWF on wind velocity and barometric pressure can be used to infer the atmospheric excitation of Earth rotation. From monthly average values of differential surface atmospheric pressure in the year of 2016, on the northern part of Eurasian continent, i.e., Siberia and Manchuria, high atmospheric pressure exists from October to March, while low atmospheric pressure prevails from May to August.

For closer comparison between winter and summer seasons January and July average pressure as well as the deviatoric pressure from the local year average are illustrated together in Figure 1. Although this seasonal loading/unloading cycle has been thought as the main input to annual wobble since the beginning of last century (Munk and MacDonald 1960), reliable estimations have been deferred until the advent of accurate source of information, such as ECMWF dataset or comparable sort.

In this study, we compare (1) the observed geodetic excitation inferred from the recent polar motion data and (2) the calculated atmospheric excitation due to seasonal atmospheric loading/unloading on Northern Eurasia as well as four other continents, namely, North America, South America, Australia, and Africa. We used IERS EOP C04 and ECMWF atmospheric pressure datasets each.

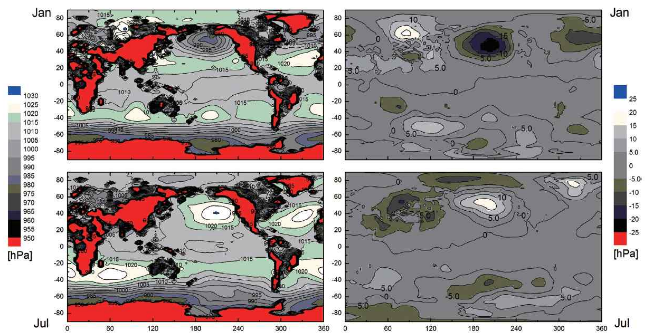

Figure 1. January and July average barometric pressure distributions on the globe in 2016 (ECMWF) and their differential values after deduction of the year average pressure. Sea level reduction not applied.

Excitation Functions

A Simple Relation between polar motion and excitation function in the frequency domain has been defined (Na 2013). From a dataset of polar motion, one can derive its excitation function by Fourier transform. Usually the excitation function derived from polar motion time series through this procedure is called 'geodetic excitation'. With known perturbation due to certain geophysical processes on the Earth's surface or its interior, polar motion excitation function can be expressed as below (Gross 2009).

$$\chi_i = \frac{1.608 h_i}{(C-A)\omega_0} + \frac{1.100 \Delta I_{i3}}{C-A} \quad (i=1,2)$$

where C and A are the two principal moments of inertia of the Earth along z-axis and x-axis, and h_i and ΔI_{i3} are the imposed perturbing angular momentum and the perturbation in the Earth's inertia tensor.

In case of considering barometric pressure loading/unloading only, the polar motion excitation function can be expressed as follows (Eubanks 1993, Gross 2009).

$$\chi_1 = -\frac{1.100 a^4}{(C-A)g}\int_0^{2\pi}\int_0^{\pi} \Delta P(\theta,\lambda)\cos\theta\sin^2\theta\cos\lambda \, d\theta d\lambda$$
$$\chi_2 = -\frac{1.100 a^4}{(C-A)g}\int_0^{2\pi}\int_0^{\pi} \Delta P(\theta,\lambda)\cos\theta\sin^2\theta\sin\lambda \, d\theta d\lambda$$

where ΔP is the excessive barometric pressure, and a and g are the radius and surface gravity of the Earth.

To extract seasonal variation (1-year period sinusoidal oscillation) from given time series of polar motion, we used least square fitting (Chung and Na 2016). Similarly, least square error fittings have been done on the observed or calculated excitation functions as follows.

$$\chi_1(t) = \chi_1(t_0) + L_1(t-t_0) + \sum_{k=1}^{2} C_k \cos[\Omega_k(t-t_0)+\phi_k^1]$$
$$\chi_2(t) = \chi_2(t_0) + L_2(t-t_0) + \sum_{k=1}^{2} D_k \sin[\Omega_k(t-t_0)+\phi_k^2]$$

Results

We used IERS EOP C04 and ECMWF atmospheric pressure datasets each. As the results, we have five-year (2010-2015) geodetic excitation function for χ_1 and χ_2. Each function consists of five components which are geodetic excitation, atmospheric excitation (wind and pressure), atmospheric excitation (wind only), atmospheric excitation (pressure only), and atmospheric excitation (pressure of Siberia and Manchuria) as shown in Figure 2.

We repeated the computation for atmospheric pressure excitation on other continents, North America, South America, Australia, and Africa. The amplitudes of the geodetic excitation and calculated excitation due to atmospheric pressure on the five continents are illustrated together in Figure 3. It has been found that the atmospheric pressure loading/unloading annual cycle on Siberia and Manchuria gave rise to 15.61 mas in χ_2, which is 54% of total excitation observed, while the same area gave rise to much smaller χ_1 excitation. The atmospheric loading/unloading on Australia gave rise to rather large excitation both on χ_1 and χ_2.

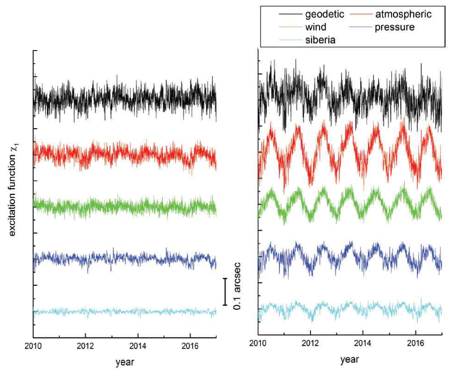

Figure 2. Comparison of polar motion excitation function χ_1 (right) and χ_2 (left).

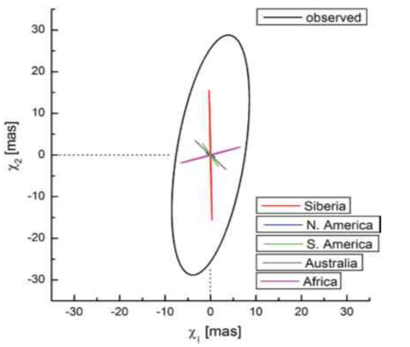

Figure 3. Comparison of geodetic excitation and five annual excitation fits on the atmospheric pressure loading/unloading on the 5 continents – Eurasia, N. America, S. America, Australia, and Africa.

Conclusions

From the comparison of observed geodetic excitation inferred from IERS C04 polar motion dataset and calculated excitation function via integration of ECMWF pressure data, we hereby confirm that the atmospheric seasonal loading cycle in the area of Siberia and Manchuria with their neighbors in the Northern Eurasian continent, plays the major role in the annual wobble of the Earth's spin rotation axis in the Earth's reference system.

References

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