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SOLAR ACTIVITY, EARTH ROTATION AND ATMOSPHERIC CIRCULATION

Boian Kirov

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mail: bkirov@space.bas.bg

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Abstract: *Earth rotation rate varies on different time-scales – from centuries to days. The seasonal nontidal variations in the Earth rotation rate, or the length of the day (LOD), are believed to be fully explained by large-scale atmospheric motions caused by the temperature differences between the summer and the winter hemispheres. A connection is also supposed between the decadal LOD variations and changes in atmospheric circulation. We demonstrate that the Earth rotation is different in positive and negative solar polarity cycles, therefore even on these time-scales the Earth-atmosphere system is not closed. The correlation between the decadal variations in LOD and atmospheric circulation changed in the beginning of the XX century, so there is no direct relation between the Earth rotation and large-scale atmospheric circulation on decadal time-scales, rather they are both modulated by solar activity. We look for an explanation for the solar activity influences on the Earth rotation and on the atmospheric circulation*

ВРЪЗКА МЕЖДУ СЛЪНЧЕВАТА АКТИВНОСТ, СКОРОСТТА НА ВЪРТЕНЕ НА ЗЕМЯТА И АТМОСФЕРНАТА ЦИРКУЛАЦИЯ

Боян Киров

Институт за космически изследвания и технологии – Българска академия на науките
e-mail: bkirov@space.bas.bg

Ключови думи: *Слънчева активност, продължителност на деня, атмосферна циркулация*

Резюме: *Скоростта на въртене на Земята се мени в различни времеви мащаби – от векове до дни. Приема се, че сезонните не-приливни вариации в скоростта на въртене, или дължината на деня (Length Of the Day, LOD), напълно се обясняват с едромащабни атмосферни движения, предизвикани от температурните разлики между лятното и зимно полукълбо. Предполага се, че съществува и връзка между десетилетните вариации на LOD и измененията в атмосферната циркулация. Ние показваме, че скоростта на въртене на Земята е различна в цикли с положителна и отрицателна магнитна полярност на Слънцето, следователно дори в тези времеви мащаби системата Земя-атмосфера не е затворена. Търси се обяснение за влиянието на слънчевата активност върху въртенето на Земята и атмосферната циркулация.*

Introduction

Seasonal nontidal variations in the Earth's rotation rate, or the length of the day (LOD), are explained by the action of the atmospheric “interhemispheric heat machine”, fed by the temperature differences between the summer and the winter hemispheres [1]. In July and in January, when the temperature difference between the two hemispheres is greatest, the Earth rotates fastest. The temperature difference in July is bigger than in January because the Northern hemisphere is on average warmer than the Southern one, so the Earth rotates faster in June than in January. In April and in November, when the temperature in the two hemispheres is almost equal, the rotation rate is minimum – Fig. 1.

Attempts have been also made to explain the interannual to decadal LOD changes by long-term changes in atmospheric circulation. Loginov [2] demonstrated a satisfactory agreement between the changes in the number of days with zonal types of circulation and in the angular velocity of the

Earth's rotation. According to other authors, on the contrary, changes in atmospheric circulation are caused by changes in the Earth's rotation rate. Monin [3] commented that a change in the Earth's rotation rate could lead to a change in the extend of the trade winds and Rossby waves, and to changes in the equator/pole temperature contrast, hence the zonality of atmospheric circulation. According to [4], changes in the rotation rate cause a deformation in the sea surface resulting in a slope toward the pole or toward the equator. If the slope is toward the pole, the ocean currents like Gulfstream and Kuroshio strengthen and more warm water is transported to the pole, the equator/pole temperature contrast decreases, and so does the zonal circulation.

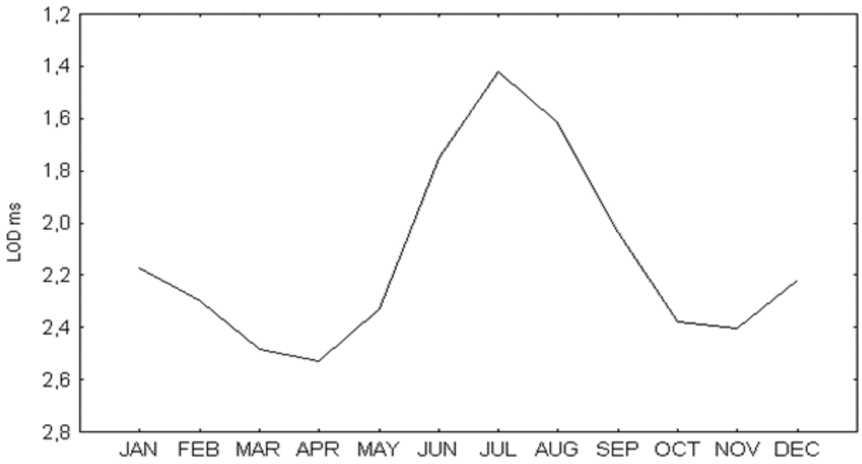

Fig. 1. Annual variations of LOD in ms for the period 1962-2000

Whatever the cause-effect consequence, all studies proving the relation between the Earth's rotation rate and atmospheric circulation are confined to the Northern hemisphere and cover only the 20th century, because of data limitations. In the present paper we use proxy data to extend this study to the middle of the 19th century and to include the Southern hemisphere as well.

Data

The intensity of zonal circulation is determined by the temperature contrast between the equator and the pole. So, as an indirect measure of the strength of the zonal circulation we use the temperature difference between the equatorial and polar regions in both hemispheres. The longest data-set providing zonaly averaged mean annual temperatures is the one of the Goddard Institute for Space Science [5], from which the annual mean temperature anomalies with respect to the base period 1951–1980 averaged over the zones 64–90N and 64–90S were taken as the Northern and Southern polar temperatures, respectively (NP and SP), and over the zone 24N–24S – as the equatorial temperatures (EQ). The 64–90N and 24N–24S temperature anomalies are evaluated since 1866, and the 64–90S one – since 1903. Therefore, our EQ–NP temperature differences were calculated for the period 1866–2000, and EQ–SP – for the period 1903–2000. To validate them, they have been compared to the ones calculated from another long-term data-set, of the St.Peterburg State Hydrological Institute [6] giving the Northern hemisphere zonal means from 1880 to 1987 and the Southern hemisphere ones – from 1957 to 1987. The EQ–NP temperature differences derived from the two data-sets agree within 97.7% with $p < 0.01$, and the EQ–SP ones – within 88.9% with $p < 0.001$.

The Earth's rotation rate was estimated by the LOD measurements provided by the International Earth Rotation Service through their web-site http://hpiers.obspm.fr. LOD is defined as the difference between the astronomically determined duration of the day and 86,400 SI s (24 h*60 min*60 s). The mean annual values of LOD are available since 1623. The accuracy of determination of LOD varies throughout this period, after 1840 the error being less than 0.6 ms [7] and small enough to relate to the atmosphere [8]. The decadal oscillations obvious in time-series derived from different types of observations agree fairly well to be concluded that they are a real feature of LOD [9].

Earth rotation

In Fig. 2 the seasonal cycle of the Earth rotation is presented for negative polarity solar cycles (NPSC) and positive polarity solar cycles (PPSC) defined as years of solar activity minimum +/- 2 years [10]. The curves are derived by the superposed epochs method from monthly averaged values of daily LOD**.**

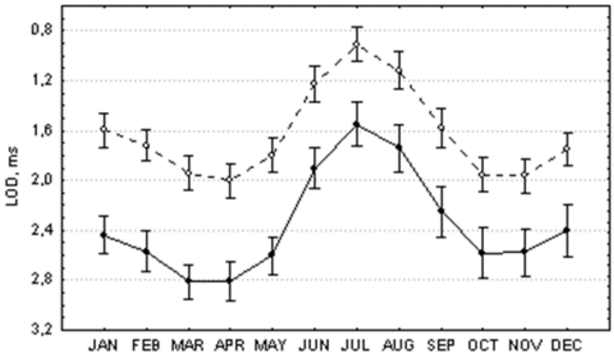

Fig. 2. Same as figure 1 for PPSC (solid line) and NPSC (broken line), together with the error bars

As on decadal time-scales, the Earth rotates faster in periods with bigger North-South asymmetry of solar rotation (NPSC). Besides, as can be noted in Fig. 2, the greatest differences in the seasonal variations of the Earth rotation between PPSC and NPSC are in spring and in autumn - in NPSC the Earth rotation rate is almost equal in spring and autumn equinoxes, while in PPSC the Earth rotates faster in autumn than in spring. Equinox periods, as already mentioned, are the periods in which the influence of the atmosphere on the Earth rotation is smallest, so the effects of other forces can be best seen then. From the theory of the interhemispheric heat machine it follows that in autumn Earth should rotate faster than in spring as the temperature differences between the two hemispheres are greater. Therefore, if some external forces change this picture in the NPSC, they either accelerate the Earth rotation in spring or decelerate it in autumn. Equinoxes are also the periods in which the Earth is most exposed to the influence of the solar wind [11], so we could suppose the solar wind is this external factor, and study its annual variations in PPSC and NPSC.

Atmospheric circulation

The 22-year magnetic solar cycles is evident also in atmospheric circulation. In Fig. 3 the mean zonal circulation expressed by the temperature contrast between the equatorial and polar regions is presented for the Northern and Southern hemispheres in odd and even solar cycles. In even cycles, there is a pronounced minimum in the zonality of the circulation in the Northern hemisphere in solar activity maximum, and a maximum in the Southern hemisphere 2 years after the solar activity maximum.

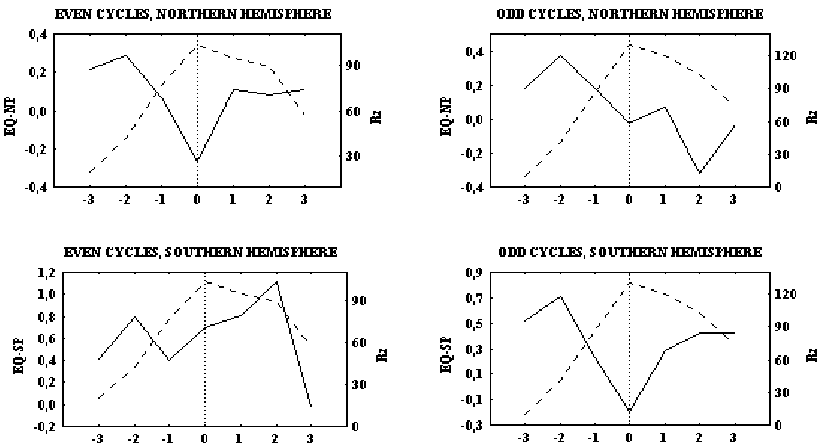

Fig. 3. equator-pole temperature contrast (solid line) in the Northern hemisphere - EQ-NP (top panel) and in the Southern hemisphere - EQ-SP (bottom panel) and the sunspot numbers Rz (dashed line) for even (left side) and odd (right side) 11-year solar cycles

The picture in odd cycles is quite opposite: a deep minimum in zonal circulation is observed in the Southern hemisphere in years of solar activity maximum, and a minimum in the Northern hemisphere 2 years after the solar activity maximum. Due to the small number of data samples (5 even and 5 odd 11-year cycles for the Southern hemisphere, Zurich numbers from 14 to 23, and 6 even and 7 odd cycles for the Northern hemisphere, Zurich numbers from 11 to 23), the statistical significance of this result is not very high, however the differences in the behavior are obvious. This result bears some similarity to the one in [12] where the dependence of geomagnetic field North-South asymmetry on the polarity of the interplanetary magnetic field is studied and is found it is different in even and odd solar cycles.

Solar wind

Solar wind parameters have been measured by a series of spacecraft since the beginning of the space era, mid 1960's, and are compiled in OMNI data base of the National Space Science Data Center http://nssdc.gsfc.nasa.gov/omniweb/. Here we use their monthly averaged daily values.

Bx and By components of the interplanetary magnetic field, as well as the magnetic field winding angle Blong show pronounced periodicities at about 22 years. In figure 4 the annual cycle of IMF Bx component is presented in PPSC and NPSC.

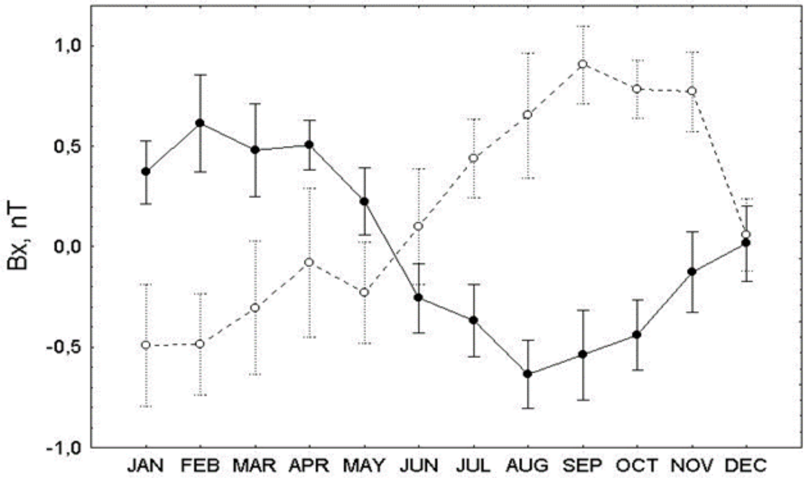

Fig. 4. Annual cycle of the IMF B_x component in PPSC (solid line) and NPSC (broken line)

In spring the Earth is at highest Southern heliolatitudes, and in PPSC, in the Southern solar hemisphere the magnetic field is toward the Sun, so IMF Bx component near the Earth is positive. In autumn, when the Earth is at highest Northern heliolatitudes, the field is away from the Sun and Bx is negative.The behavior of By component is opposite to the one of Bx.

Summary

The 22-year periodicity is found in the Earth rotation variations and atmospheric circulation, coinciding with the 22-year solar magnetic cycle. A 22-year period is also found in the annual variation of geomagnetic activity [10]. A possible mechanism for the excitation of both LOD fluctuations [13] and the main driving force for the geomagnetic field variations [14] are considered to be processes in the core and the mantle. A dominant 22-year periodicity is found in the electromagnetic core-mantle coupling torques [15]. The 22-year periodicity in solar wind parameters supports the idea that the solar wind mediates the influence of the solar rotation on the Earth rotation

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