22-YEAR PERIODICITY IN SOLAR ROTATION, SOLAR WIND PARAMETERS AND EARTH ROTATION

B. Kirov[1], K. Georgieva[1] , J. Javaraiah[2]

1 - Solar-Terrestrial Influences Laboratory at the Bulgarian Academy of Sciences, Bl.3 Acad.G.Bonchev str., 1113 Sofia
2 - Indian Institute of Astrophysics, Koramangala, Bangalore-560034
tel.: +359-2-9793432/ +91-80-5530672/ fax +359-2-700178/+91-80-5534043
e-mail: bkirov@space.bas.bg/ kgeorg@bas.bg/ jj@iiap.ernet.in

ABSTRACT

It is generally accepted that the annual variation in the Earth's rotation rate is fully determined by large-scale seasonal changes in atmospheric circulation, while the decadal changes in Earth's rotation have been shown to be closely correlated to the North-South asymmetry in solar differential rotation. In the present paper we demonstrate that the oscillations of both the Earth's and the solar rotation rates are different in cycles with negative end positive solar polarity. We find that differences between positive and negative polarity solar cycles exist also in solar wind velocity and interplanetary magnetic field parameters, and suggest that the solar wind mediates the transfer of angular momentum from the Sun to the Earth.

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 (Sidorenkov, 1978). 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 - figure 1.

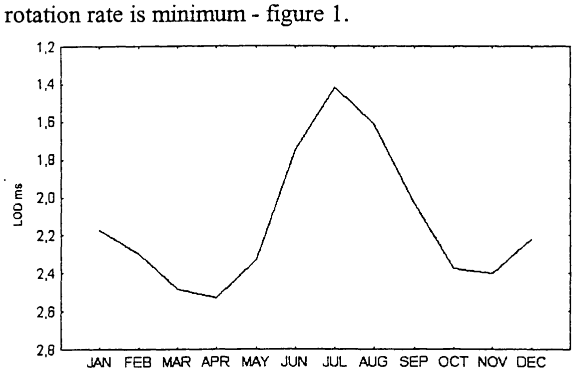


Figure 1: Annual variations of LOD in ms for the period 1962-2000.

The data for LOD is from International Earth Rotation Service's web site http://hpiers.obspm.fr, monthly averaged daily values of LOD for the period 1962-2000.

Attempts have been also made to explain the interannual to decadal LOD changes by long-term changes in atmospheric circulation. Loginov (1992) 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 (1969) 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 Maximov and Smirnov (1964), 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.

It has been recently shown (Georgieva, 2002) that, on decadal time scales, neither the changes in atmospheric circulation could be considered the reason for the changes in the Earth's rotation rate, nor vice versa, as the relation between the two changes in the beginning of the 20th century. This coincides with the period of a change in the sign of the correlation between solar activity and surface air temperature in the 11-year solar cycle which has been attributed to long-term changes in North-South solar activity asymmetry (Georgieva and Kirov., 2000). A close correlation was found between the long-term changes in Earth rotation rate and in the North-South asymmetry of solar equatorial rotation, both quantities showing pronounced periodicities at 45-50 years. The same periodicity was found earlier by Bucha et al. (1985) in the solar inertial motion (i.e. the motion of the Sun around the center of mass of the Solar system). Javaraiah (1996) suggested that the temporal variations of the solar differential rotation which agree with the known periodicities in the photospheric magnetic field, represent the "even-parity" torsional oscillations of the Sun, while the periodicities in the North-South asymmetry of solar

Proc. 10th. European Solar Physics Meeting, 'Solar Variability: From Core to Outer Frontiers', Prague, Czech Republic, 9-14 September 2002 (ESA SP-506, December 2002)

equatorial rotation, also found in sunspot activity, represent the "odd-parity" torsional solar oscillations, and showed that the amplitudes of the symmetric and antisymmetric torsional oscillations depend upon the contribution of the main planets to the symmetric and asymmetric parts of the angular momentum of the solar system. Juckett (2000), taking into account the movement of Sun around the center of mass of the solar system and the tilt of the solar spin axis, demonstrated that North-South solar asymmetries and solar differential rotation can be driven by or modulated by planetary-induced spin-orbit momentum coupling.

The close connection between the long-term fluctuations of Earth rotation rate and solar differential rotation may be due to the direct influence of the solar system dynamics on both the Earth and the Sun, or the variations in the Earth rotation rate may be induced by the solar wind transferring angular momentum and magnetic field from the Sun. To check the latter possibility, in the present paper we are comparing the fluctuations in solar rotation rate and in the Earth rotation rate to the variations of the parameters of the solar wind.

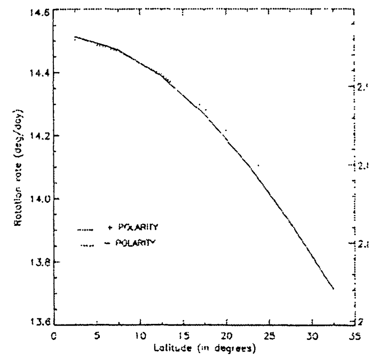
ANNUAL VARIATIONS IN POSITIVE AND NEGATIVE POLARITY SOLAR CYCLES

It has long been known that geomagnetic activity has an annual variation, with maximums in equinoctial periods and minimums around solstices (Russell and McPherron 1973). Bolton (1990) reported about an annual variation in solar wind speed and ion density, which was confirmed by Paularena et al. (1995). Zieger and Mursula (1998), comparing the annual variations in solar wind speed and geomagnetic activity since mid 1960's, found that the phase of the annual variation changes from one solar minimum to another, reflecting its relation to solar magnetic cycle, and explained this phase reversal by a North-South asymmetry in solar wind speed. In a following paper Mursula and Zieger (2001) studied the long-term evolution of the annual variation and showed that the solar wind asymmetry is opposite in the 19[th] and in the 20[th] centuries, implying a century-scale oscillation of solar North-South asymmetry. This finding confirms an earlier hypothesis about a secular cycle of North-South solar asymmetry derived from climatic data (Georgieva and Kirov, 2000).

SOLAR ROTATION

Gigolashvili (2001), on the basis of observations on sunspots and hydrogen filaments during 1950-1990 and 1965-1993, respectively, studied solar differential rotation separately for the northern and southern solar hemispheres, and found some dissimilar behaviour of the N-S asymmetry for even and odd solar cycles. Javaraiah (2001) studied the North-South asymmetry of solar differential rotation for the period 1879-1976 computed from data on sunspot groups compiled from Greenwich Photo-heliographic Results, and found that it is different in even and odd 11-year cycles: in odd numbered solar cycles the Sun's equatorial rotation is significantly larger and the rotation is more differential, and the North-South asymmetry in equatorial rotation is greater than in even numbered solar cycles.

To comply with the differences in the annual cycle of geomagnetic activity, we have compared the solar rotation in positive and negative polarity solar cycles (PPSC and NPSC, respectively) from the Greenwich data.



Fiure 2a: Solar differential rotation (average over the two solar hemispheres) in positive (solid line) and negative (broken line) polarity cycles.

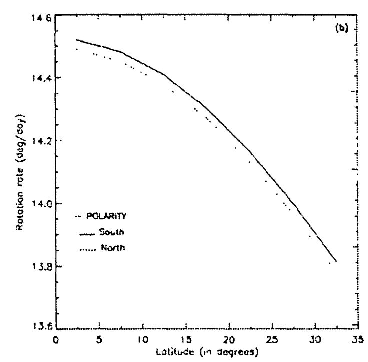


Figure 2b: Solar differential rotation in the Southern (solid line) and Northern (broken line) solar hemispheres in negative polarity cycles.

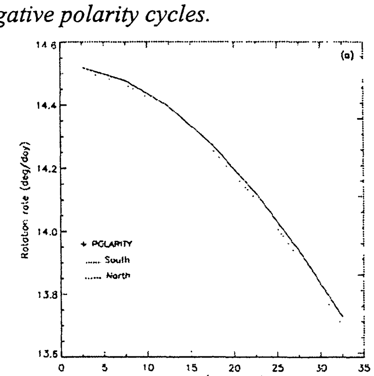


Figure 2c: Solar differential rotation in the Southern (solid line) and Northern (broken line) solar hemispheres in positive polarity cycles.

In PPSC solar equatorial rotation is faster (at a significance level of 2 sigma) and the latitudinal gradient of the rotation rate is greater (at 4 sigma) than in NPSC (figure 2a). The

North-South asymmetry in the equatorial rotation rate is 3 sigma in NPSC (figure 2b) while in PPSC it is not significant - only 1 sigma (figure 2c).

EARTH ROTATION

In figure 3 the seasonal cycle of the Earth rotation is presented for NPSC and PPSC defined as years of solar activity minimum +/- 2 years (Mursula and Zieger, 2001). The curves are derived by the superposed epochs method from monthly averaged values of daily LOD.

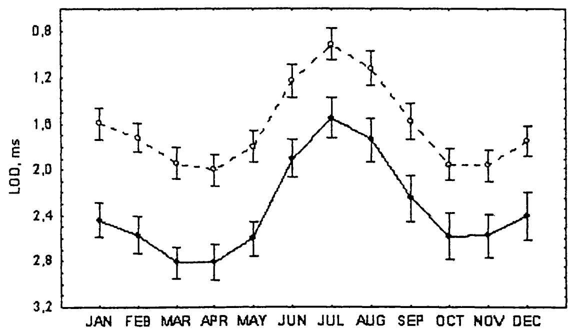


Figure 3: Same as figure 1 for PPSC (solid line) and NPSC (broken line), together with the error bars.

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 figure 3, 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 (Russell and McPherron, 1973), so we could suppose the solar wind is this external factor, and study its annual variations in PPSC and NPSC.

SOLAR WIND

Solar wind parameters have been measured by a series of spacecraft since the beginning of 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.

B_x and B_y components of the interplanetary magnetic field, as well as the magnetic field winding angle B_{long} show pronounced periodicities at about 22 years. In figure 4 the annual cycle of IMF B_x component is presented in PPSC and NPSC.

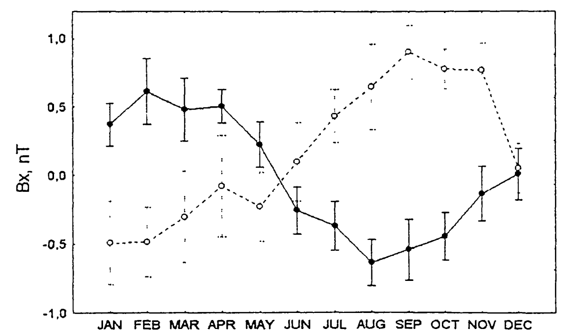


Figure 4: Annual cycle of the IMF B_x component in PPSC (solid line) and NPSC (broken line).

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 B_x component near the Earth is positive. In autumn, when the Earth is at highest Northern heliolatitudes, the field is away from the Sun and B_x is negative.

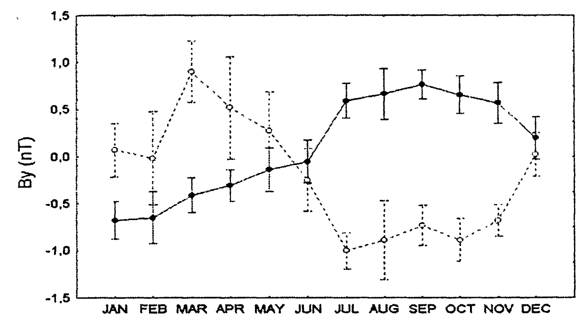


Figure 5: Annual cycle of the IMF B_y component in PPSC (solid line) and NPSC (broken line).

The behavior of B_y component is opposite to the one of B_x.

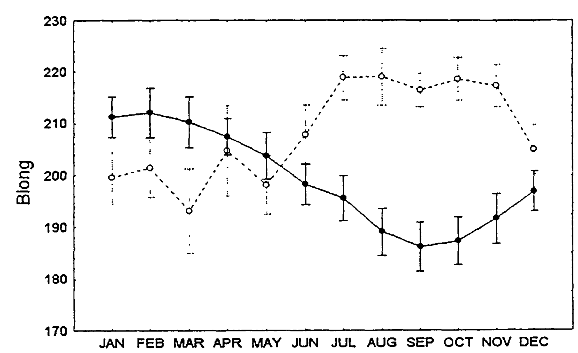


Figure 6: Annual cycle of the IMF winding angle B_{long} in PPSC (solid line) and NPSC (broken line).

The IMF winding angle is determined by the ratio between Bx and By components:

$$B_{long} = \arctan (B_x/B_y)$$

SUMMARY AND DISCUSSION

Laptukhov (1980) proposed a qualitative mechanism relating Earth's rotation rate to solar activity involving heating of the earth's mantle by an alternating electromagnetic field whose intensity increases with solar activity. Plakhoutnik (1983) established a frequency-dependent correlation between spatial-temporal changes in solar activity, geomagnetic fields, and rotation velocity vectors of the liquid and solid earth shells, and showed that the effect of solar fluxes on the geomagnetic fields varies with cyclic changes in solar magnetic fields and with reorientation of magnetospheric fields. Krymskij (1993) proposed a mechanism accounting for the effects of the solar wind and interplanetary magnetic field on the rotation rate of the earth based on the generation in the magnetotail plasma layer of Hall currents which, by closing through the high-latitude ionosphere, cause the rotation of the atmosphere continually transmitted to the earth. According to Gu (1998), the interaction between the solar wind and the magnetosphere of the Earth leads to additional magnetic pressure in the magnetic tail, which could be considered as a source of effecting the long term variation of the earth rotation.

Our results demonstrate a pronounced difference in solar rotation rate, solar wind parameters and Earth's rotation rate in PPSC and NPSC confirming the influence of solar dynamics on the Earth's dynamics through the solar wind. A further evidence that the influence is of an electromagnetic nature is provided by the spectra of the electromagnetic core-mantle coupling torques calculated by Greiner-Mai (1987) in which the main periodicities are at 22 and 47 years, while these periodicities are lacking in the spectra of the mechanical torques.

REFERENCES

Bolton, S.J. (1990): One year variations in the near earth solar wind ion density and bulk flow velocity, *J. Geophysical Res*earch, Vol. 17, pp. 37-40, 1990.

Buchha, V., Jakubcova, I. and Pick, M. (1985): Resonance frequencies in the Sun's motion. *Studia Geophys. Geod*. Vol. 85 No.2, pp. 107-111, 1985.

Georgieva, K., Tsanev, V. and Kirov, B. (2000): Solar asymmetry, QBO and climate, Proceedings of the SPARC 2000 Second Assembly of the SPARC/WCRP Project, SPARC Office, - www.aero.jussieu.fr/~sparc/SPARC2000_new/posterSess3/Session3_3/Georgieva/doklad.htm, 4-10 November, 2000.

Georgieva, K. (2002): Long-term changes in atmospheric circulation, Earth rotation rate and North-South solar asymmetry, *J. of Physics and Chemistry of the Earth*, Vol. 27, pp. 433-440, 2002.

Gigolashvili, M. (2001): About N-S Asymmetry of Differential Rotation of the Sun, *Astronomische Gesellschaft Abstract Series*, Vol. 18, abstract #P249, 2002.

Greiner-Mai, H. (1987): The influence of the electromagnetic core-mantle coupling torques on Earth's rotation, *Astron. Nachr*., Vol. 308, No. 3, pp. 217-226, 1987.

Gu, Zh. (1998): An interpretation of the non-tidal secular variation in the Earth rotation: the interaction between the solar wind and the Earth's magnetosphere, *Astrophyics and Space Sci*ence, Vol. 259 No. 4, pp. 427-432, 1998.

Javariah, J. (1996): Periodicities in the Sun's "torsional MHD oscillations" and planetary configurations *Bulletin Astronomical Soceity of India*, Vol. 4, pp.351-354, June, 1996.

Juckett, D.A. (2000): Solar activity cycles, North/South asymmetries, and differential rotation associated with solar spin-orbit variations, *Solar Phys*ics, Vol. 191, pp. 201-206, 2000.

Krymskij, P. F. (1993): A possible mechanism of the effect of the interplanetary medium on the diurnal rotation rate of the earth, *Geomagnetizm i Aeronomiya*, Vol. 33, No. 3, pp. 7-13, 1993. (In Russian)

Laptukhov, A. I. (1980): The mechanism of the influence of solar activity on the rotation of the earth, *Geomagnetizm i Aeronomiia*, Vol. 20, pp. 670-673, 1980. (In Russian)

Loginov V.F., (1992): Causes and consequences of climatic changes, Navuka I tehnika, Minsk, 1992 (In Russian)

Maximov, I.V. and Smirnov, I.P. (1964): Changes in the Earth's rotation rate and mean global sea-level. *Oceanology,* Vol. 4, No. 1, pp. 9-18, 1964.

Monin, A.S., Weather forecast as a task of physics, Nauka, Moscow, 1969. (In Russian).

Mursula, K., and B. Zieger, Long-term north-south asymmetry in solar wind speed inferred from geomagnetic activity: A new type of century-scale solar oscillation?, *Geophys. Res. Lett*., **28**, 95-98, 2001.

Paularena, K.I, Szabo, A, .and.Richardson, J.D. (1995): Coincident 1.3-year periodicities in the ap geomagnetic index and the solar wind, *Geophys. Res. Lett*., **22**, 3001-3004, 1995.

Plakhotniuk, V. N. (1983): Characteristics of the rhythm of solar, geomagnetic, and atmospheric phenomena and their relation to the earth rotation, *Magnitosfernye Issledovaniia*, Vol. 2, pp. 93-102, 1983. (In Russian)

Russell, C.T., and R.L.McPherron, Semiannual variation of geomagnetic activity, *J. Geophysical Research*, Vol. 78, pp. 92-108 , January, 1973.

Sidorenkov N.S. (1978): Nonuniformities in the Earth's rotation and processes in the atmosphere, *Trudy Gidrometcentra SSSR,* Vol. 205, 48-66, 1978. (In Russian)

Zieger, B., and Mursula, K. (1998): Annual variation in near-Earth solar wind speed: Evidence for persistent north-south asymmetry related to solar magnetic polarity, *Geophysical Research Lett*ers,Vol. 25, pp. 841-844, 1998; Correction of editorial errors in GRL, Vol. 25, 2653-2656, 1998.