SOLAR ROTATION, EARTH ROTATION AND SOLAR WIND

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, E-mail: bkirov@space.bas.bg, kgeorg@bas.bg
2 - Indian Institute of Astrophysics, Koramangala, Bangalore-560034, E-mail: 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. We demonstrate that the oscillations of both the Earth's rotation and the atmospheric circulation exhibit a 22-year periodicity. Differences between positive and negative polarity solar cycles are also found in the solar rotation rates, 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.

1. INTRODUCTION

It has long been known that the Earth's rotation rate is not constant, but varies on different time-scales – from centuries to days. The seasonal nontidal variations in the Earth's rotation rate, or the length of the day (LOD), are believed to be fully 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 Northern hemisphere is on average warmer than the Southern one, so the temperature difference in July is bigger than in January, and the Earth rotates faster. In April and in November, when the temperature in the two hemispheres is almost equal, the rotation rate is minimum. In Fig. 1. the monthly averaged daily values of LOD from the International Earth Rotation Service's (web site http://hpiers.obspm.fr) are presented.

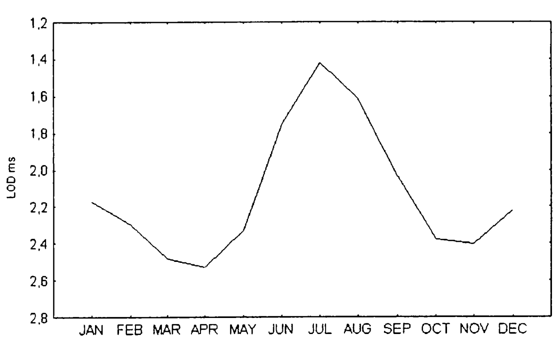

Fig. 1. Annual variations of LOD in ms for the period 1962-2000.

A connection is also supposed between the interannual to decadal LOD variations and changes in atmospheric circulation [2-4]. We have found that the correlation between the decadal variations in LOD and atmospheric circulation changes in the beginning of the 20th century, when the correlation between solar activity and surface air temperature in the 11-year solar cycle also changes [5]. The sign of the correlation between solar activity and temperature is found to be determined by the prevailing North-South solar activity asymmetry [6], while the long-term changes in Earth rotation rate are closely correlated to the North-South asymmetry of solar equatorial rotation [5], both quantities showing pronounced periodicities at 45-50 years. The same periodicity was found earlier in the solar inertial motion - i.e. the motion of the Sun around the center of mass of the Solar system [7]. In [8] it is demonstrated that, taking into account the movement of Sun around the center of mass of the solar system and the tilt of the solar spin axis, North-South solar asymmetries and solar differential rotation can be driven by or modulated by planetary-induced spin-orbit momentum coupling.

2. EARTH ROTATION AND ATMOSPHERIC CIRCULATION

In figure 2 the seasonal cycle of the Earth rotation is presented for NPSC and PPSC defined as years of solar activity minimum +/- 2 years [9]. The curves are derived by the superposed epochs method from monthly averaged values of daily LOD in the period 1962-2000.

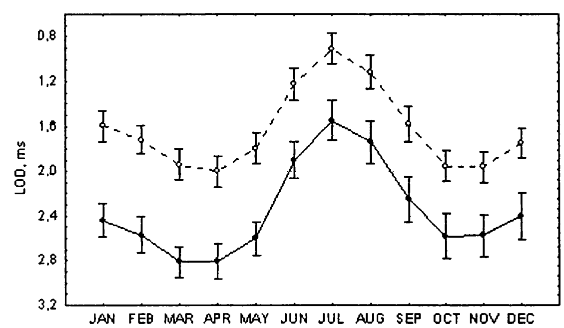

Figure 2: The same as figure 1 for PPSC (solid line) and NPSC (broken line), together with the error bars.

The Earth's rotation is systematically faster in NPSC. In the course of the year, the greatest differences between PPSC and NPSC are in spring and in autumn - in NPSC the Earth rotation rate is almost equal in spring and autumn

Proc. ISCS 2003 Symposium, 'Solar Variability as an Input to the Earth's Environment', Tatranská Lomnica, Slovakia, 23-28 June 2003 (ESA SP-535, September 2003)

equinoxes, while in PPSC the Earth rotates faster in autumn than in spring. Equinox periods, as already mentioned, are the periods in which the temperature differences between the two hemispheres are smallest and the influence of the atmosphere on the Earth rotation is smallest, so if some other factor influences the Earth's rotation rate, its effects 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 (compare with Fig. 1). Therefore, if some external factor changes this picture in the NPSC, it either accelerates the Earth rotation in spring or decelerates it in autumn. Equinoxes are also the periods in which the Earth is most exposed to the influence of the solar wind [10].

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.

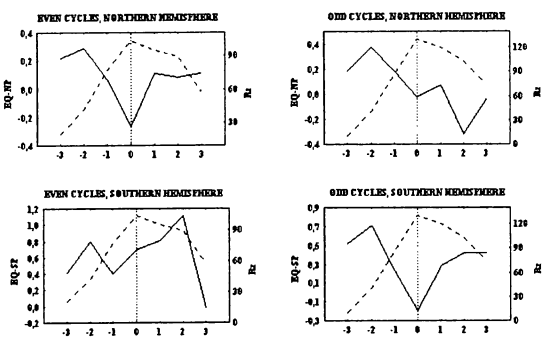

Fig.3. equator-pole temperature contrast (solid line) in the Northern hemisphere - EQ-NP (top panel) and in the Southern hemisphere - EQ-SP (bottom panel) and the sunspot numbers Rz (dashed line) for even (left side) and odd (right side) 11-year solar cycles.

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. 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 [11] 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.

3. SOLAR ROTATION

On the basis of observations on sunspots and hydrogen filaments during 1950-1990 and 1965-1993, respectively, it has been found that there are some differences in even and odd solar cycles in the North-South asymmetry of solar differential rotation [12]. From data on sunspot groups compiled from Greenwich Photo-heliographic Results for the period 1879-1976 [13], it is seen that 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 [14].

We use the Greenwich data to compare the solar rotation in positive and negative polarity solar cycles (PPSC and NPSC, respectively. The results are presented in Fig. 4.

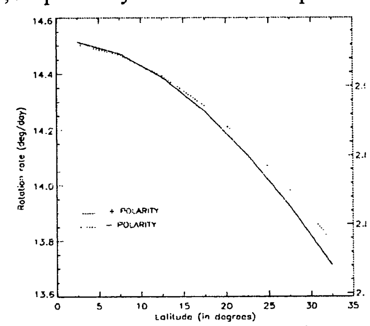

Fig. 4a. Solar differential rotation (average over the two solar hemispheres) in positive (solid line) and negative (broken line) polarity cycles.

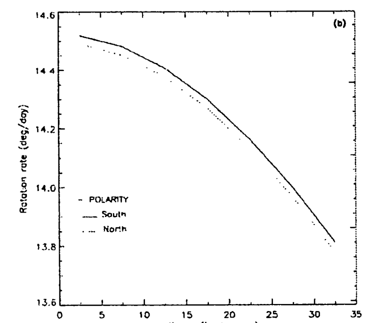

Fig. 4b. Solar differential rotation in the Southern (solid line) and Northern (broken line) solar hemispheres in negative polarity cycles.

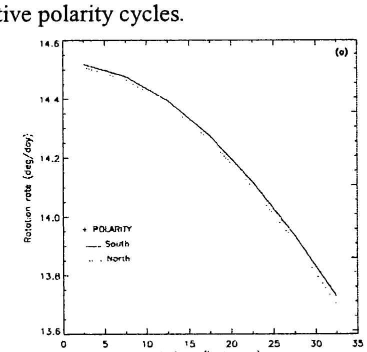

Fig. 4c. Solar differential rotation in the Southern (solid line) and Northern (broken line) solar hemispheres in positive polarity cycles.

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).

4. 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.

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 5 the annual cycle of IMF B_x component is presented in PPSC and NPSC.

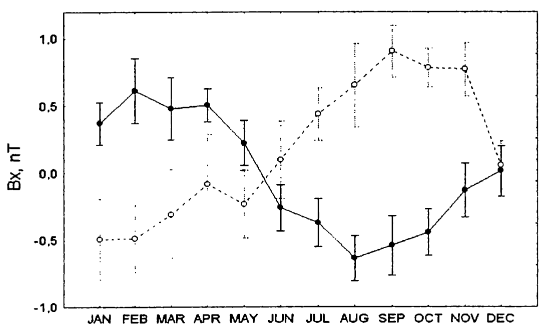

Fig. 5. Annual cycle of the IMF B_x component in PPSC (solid line) and NPSC (broken line).

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.

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

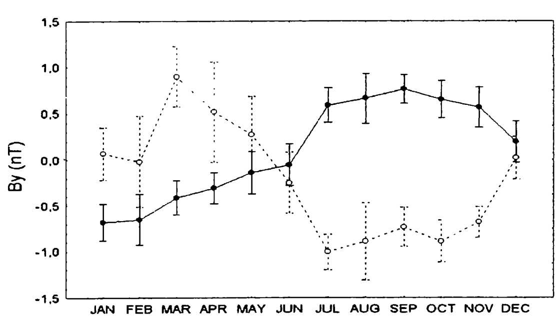

Fig. 6: Annual cycle of the IMF B_y component in PPSC (solid line) and NPSC (broken line).

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

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

Its behavior in PPSC and NPSC is demonstrated in Fig. 7.

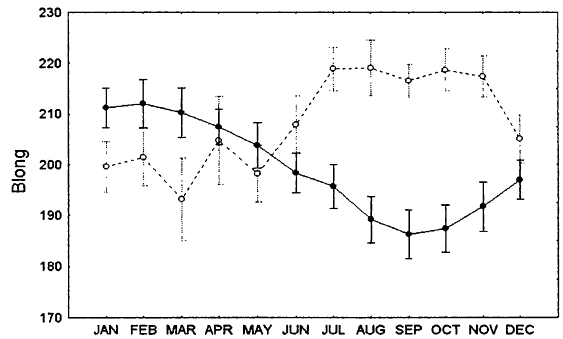

Fig. 7. Annual cycle of the IMF winding angle B_{long} in PPSC (solid line) and NPSC (broken line).

The basic geometry of the heliospheric magnetic field is described by the Archimedian spiral model of Parker [15]. In-situ measurements confirmed this general picture, and some differences were found between the calculated parameters and the measured ones. The winding angle B_{long} has been found to be always overwound by several degrees beyond the theoretical value, with a 10^{o} variation between solar minimum and solar maximum which has been shown to be in part a direct result of the solar cycle variations of solar wind speed, thus suggesting an 11-year variation [16]. However, taking into account that both B_x and B_y demonstrate a clear 22-year periodicity, we could suppose a 22-year periodicity also in the deviation of the theoretical values of B_{long} from the actually measured ones. In Fig. 8 the yearly averages of the difference between the obsereved and the calculated IMF azimuthal component, d B_y, (5-year running means) and between the obsereved and the calculated IMF winding angle d B_{long} (5-year running means).

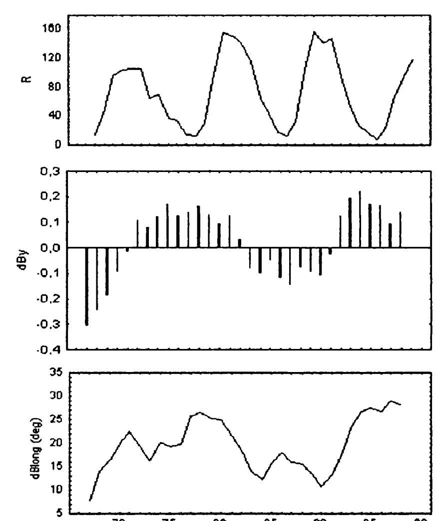

Fig.8. Yearly averages of sunspot numbers(upper panel) and the differences between the calculated and measured B_y (middle panel) and B_{long} (lower panel).

SUMMARY

The relation between the fluctuations in the rotation of the Earth and the Sun suggests that they may have a common origin. Their decadal periodicities coincide with the periodicity of the motion of the Sun about the center of masses of the Solar system [7]. The dynamics of the solar system may influence directly both the Sun and the Earth, or the influence on the Earth may be induced by the Sun, mediated by the solar wind. The 22-year periodicity found in the Earth rotation variations and atmospheric circulation, coinciding with the 22-year solar magnetic cycle, implies that more probable is the second possibility. A 22-year period is also found in the annual variation of geomagnetic activity [17]. A possible mechanism for the excitation of both LOD fluctuations [18] and the main driving force for the geomagnetic field variations [19] 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 [20]. 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.

REFERENCES

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

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

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

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

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

6. Georgieva, K. and Kirov, B., Secular cycle of the North-South solar asymmetry, *Bulgarian J. of Physics*, Vol.27 (2), 28-34, 2000.

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

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

9. 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.*, Vol. 28, 95-98, 2001.

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

11. Apostolov, E.M., Letfus, V., Dependence of the geomagnetic field North-South asymmetry on the interplanetary magnetic field polarity. C. R . Acad. Bulg. Sci. 45 (2), 39-41. 1992.

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

13. Howard, R., Gilman, P.I. and Gilman, P. A., Rotation of the sun measured from Mount Wilson white-light images. *Astrophys. J.,* Part 1, Vol. 283, 373-384, 1984.

14. 11. Javaraiah, J., 22-year Periodicity in the Solar Differential Rotation, *J. Astrophys. Astron*. Vol. 21, 167-172, 2000.

15. Parker, E. N., Dynamics of the interplanetary gas and magnetic fields. *Astrophysical J.*, November, 1958.

16. Smith. C.W. and Bieber, J.W., Solar cycle variations of the interplanetary magnetic field spiral. *Astrophysical.J.,* Vol. 370, 435-441, 1991.

17. 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.

18. Hide, R., The topographic torque on a bounding surface of a rotating gravitating fluid and the excitation by core motions of decadal fluctuations in the Earth's rotation, *Geophys. Res. Lett.* 22 (8), 961-964, 1995.

19. Le Mouel, J.-L., Courtillot, V., On the outer layers of the core and geomagnetic secular variation. *J. Geophys. Res.* 87, 4103-4108, 1982.

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