Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Long-term variations in solar activity and planetary configurations

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Abstract. We have analyzed the data on yearly mean international sunspot number ($R_{\rm Z}$) during the period 1610 – 2015 and orbital positions (ecliptic longitudes) of the giant planets in each 10-day interval during the period 1600 – 2099. We determined mean absolute difference ($\overline{\psi_D}$) of the orbital positions of the giant planets in each interval. We find that there exits a good correlation between cycle amplitude ($R_{\rm M}$, *i.e.* the maximum value of $R_{\rm Z}$) and the value of $\overline{\psi_D}$ at cycle maximum, suggesting that on longer time scales low/high solar activity associated with less/large spread in orbital positions of the giant planets (*i.e.* with a low/high value of $\overline{\psi_D}$).

Keywords. Sun: activity, Sun: magnetic fields, (Sun:) sunspots, solar system: general

1. Introduction

Planetary configurations may have an influence on solar activity. The exact physical connection of solar cycles with the planetary orbits is not clear yet (Javaraiah 2005; Stefani *et al.* 2016). The main concern is that the tidal forces of the planets are very weak and also the Sun's motion is believed to be free-fall in the solar system. However, the net torque on the Sun due to the gravitational forces of planets may not zero though it is small and it may cause some variation in the Sun's spin momentum. Therefore, there could be variations in solar differential rotation and hence in the strength of the solar dynamo. In this article we analyzed the data of yearly mean $R_{\rm Z}$ during the period 1610 – 2015 and the orbital positions of the giant planets in each 10-day interval during the period 1600 – 2099, and investigated the relationship between the long-term variations in solar activity and the alignment of the giant planets.

2. Data, method of analysis, and results

Here we have used the data on orbital positions (ecliptic longitudes in degrees) ψ_J, ψ_S, ψ_U, and ψ_N of the giant planets Jupiter (J), Saturn (S), Uranus (U), and Neptune (N) in each 10-day interval during the period 1600 – 2099. These data were provided by Ferenc Varadi (also see Javaraiah 2017). We determined the average value ($\overline{\psi_D}$) of the absolute differences $|\psi_J - \psi_S|$, $|\psi_J - \psi_U|$, $|\psi_J - \psi_N|$, $|\psi_S - \psi_U|$, $|\psi_S - \psi_N|$, and $|\psi_U - \psi_N|$ in each 10-day interval during the period 1600 – 2099. The yearly mean values of $R_{\rm Z}$ during the period 1610 – 2015 are taken from http://www.ngdc.noaa.gov/. We determined correlation between cycle amplitude ($R_{\rm M}$) and the value of $\overline{\psi_D}$ at cycle maximum.

Fig. 1 shows the ecliptic positions ψ_J, ψ_S, ψ_U, and ψ_N of the giant planets at the maximum epochs of solar cycles. As can be seen in this figure, the long-term trend from cycle 5 to cycle 19 indicates the existence of a 150 – 170 year cycle in the variation of Jupiter's orbital position. The minima of this cycle took place at the weak cycle 5 and the largest cycle 19. At these epochs there is a large difference in ψ_U of Uranus in such way

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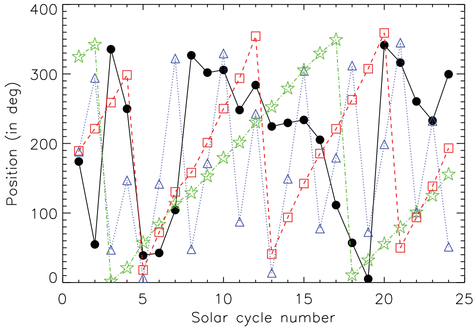

Figure 1. Plot of ecliptic positions (in deg.) ψ_J (closed circle-continuous curve), ψ_S (triangle–dotted curve), ψ_U (square-dashed curve), and ψ_N (star-dotted-dashed curve) of the giant planets at maximum epochs of solar cycles (*i.e.* at epochs of R_Z peaks) versus solar cycle numbers.

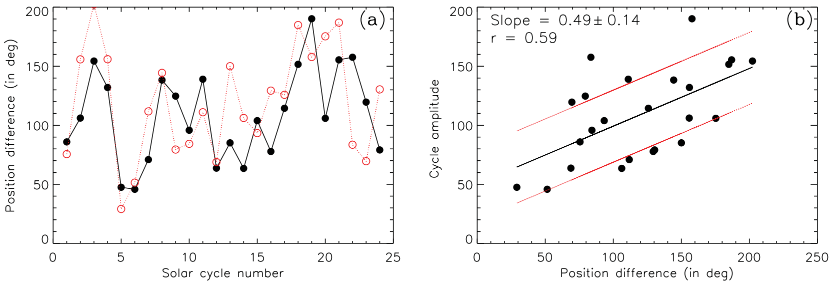

Figure 2. (a) Plot of the value of $\overline{\psi_D}$ at the maximum epoch of a solar cycle (open circle-dotted curve) and the value of $R_{\rm M}$ of the solar cycle (filled circle-continuous curve) versus the solar cycle number. (b) The scatter plot of $\overline{\psi_D}$ versus $R_{\rm M}$. The continuous line shows the corresponding best linear-fit and the dotted (red) lines are drawn at 1-root-mean-square (rms) deviation (30.52). The values of the corresponding slope and the correlation coefficient (r) are also given.

$\overline{\psi_D}$ of cycle 19 is much larger than that of cycle 5, indicating a long-term variation in solar activity depends on the relative positions of all the giant planets. Figs. 2(a) and 2(b) show the relationship between $\overline{\psi_D}$ at the maximum of a solar cycle and $R_{\rm M}$ of cycle. As can be seen in these figures there exists a reasonably good linear relationship between $R_{\rm M}$ and $\overline{\psi_D}$. The corresponding slope (0.49 ± 0.14) is reasonably significant (the slope is 3.5 times larger than the corresponding standard deviation) and the correlation ($r = 0.59$) is significant on 99% confidence level ($P < 0.01$ from Student's t-test). Cycles 19 and 22 (outliers) contribute a large part to the uncertainty. The results shown in Fig. 2(a) and 2(b) suggest that on longer time scales low/high activity associated with less/large spread in orbital positions of the giant planets (*i.e.* with a low/high value of $\overline{\psi_D}$).

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