A SEARCH OF THE 10-ROTATION QUASI-PERIODICITY IN ACTIVE LONGITUDES

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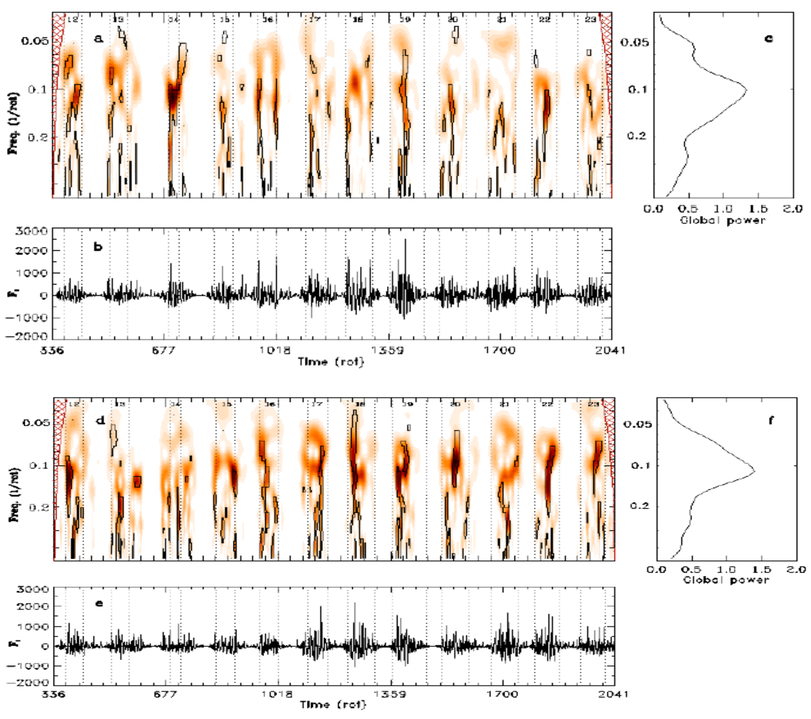

Figure 1. **a:** Wavelet power spectrum of F_i^n for cycles 12-23 mapping a time-frequency evolution of about 10-rotation periodicity. Top values of wavelet power are denoted by gradual darkening. Black contours denote significance levels of 95 % for detected peaks. A cone of influence is marked by the dashed region. **b:** Time series $\{F_i^n\}$ for cycles 12-23. **c:** Corresponding global wavelet power spectrum. The same, but for fluctuations from the southern hemisphere are given in (d)-(f).

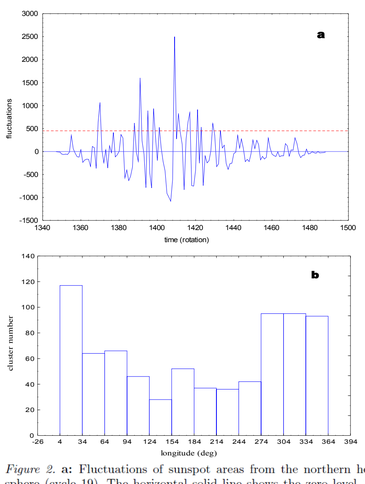

Figure 2. **a:** Fluctuations of sunspot areas from the northern hemisphere (cycle 19). The horizontal solid line shows the zero level. The dashed red line represents 1σ level ($F_i > 1\sigma$ indicates the strong fluctuations). **b:** The best histogram of sunspot group clusters from the northern hemispehere calculated for clusters existed during the strong sunspot area fluctuations from cycle 19.

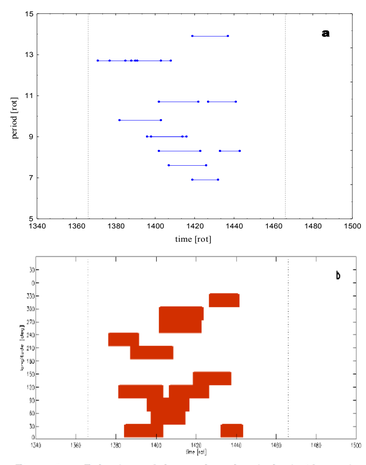

Figure 3. **a:** Behaviour of the northern hemispheric 10-rotation quasi-periodicity for cycle 19. Vertical dotted lines show the high- and the low-activity periods. **b:** Filled red areas demonstrate the presence of the northern hemispheric 10-rotation quasi-periodicity in 30º wide longitude bins during cycle 19. Vertical dotted lines show the high- and the low-activity periods.

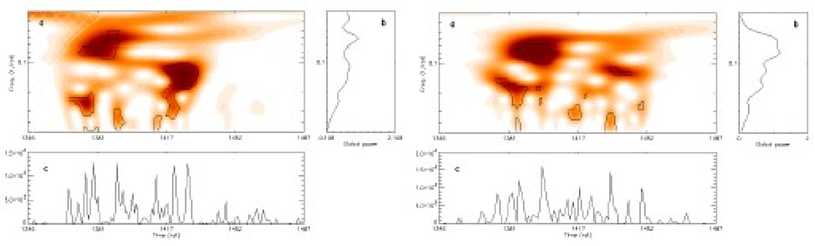

Figure 4. The same as in Fig. 1, but for the longitude bin $334^o - 4^o$.

Figure 5. The same as in Fig. 1, but for the longitude bin $4^o - 34^o$.

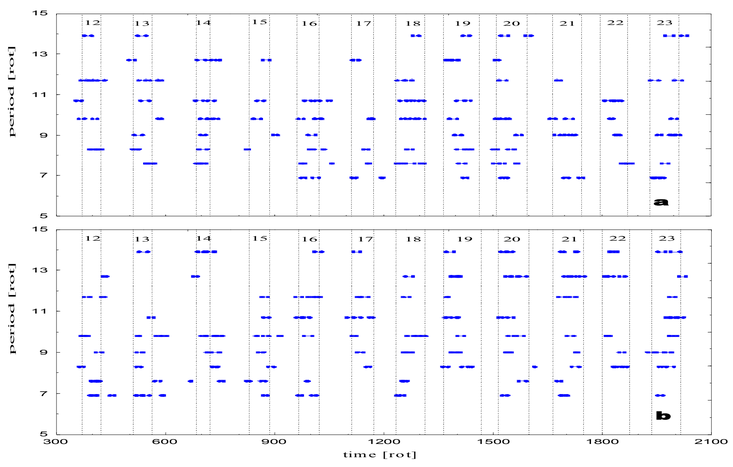

Figure 6. **a:** Behavior of the northern hemispheric 10-rotation quasi-periodicity for the cycles 12-23. Vertical dotted lines show he high- and the low-activity periods. The cycle numbers are given for all high-activity periods. **b:** Same as for **a**, but for the southern hemisphere.

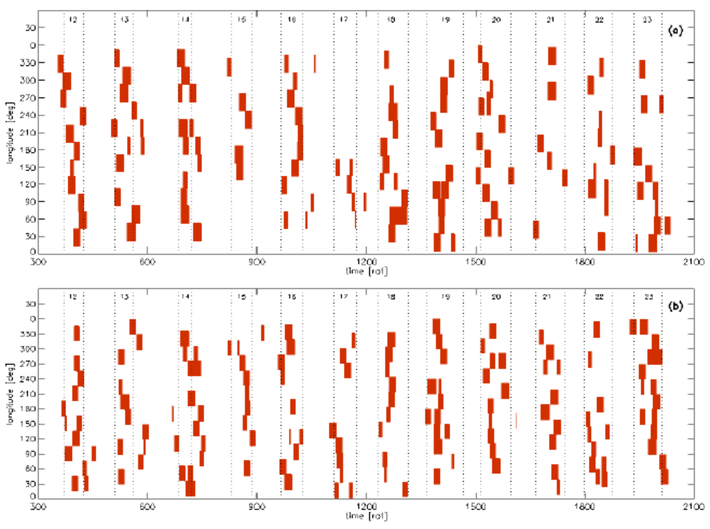

Figure 7. **a:** Filled red areas demonstrate the presence of the northern hemispheric 10-rotation quasi-periodicity in 30^o wide longitude bins during cycles 12-23. Vertical dotted lines show the high- and the low-activity periods. The cycle numbers are given for all high-activity periods. **b:** Same as for **a**, but for the southern hemisphere.

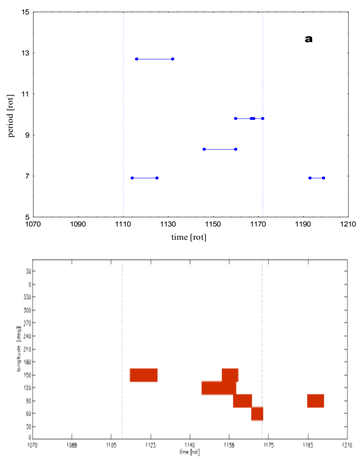

Figure 8. The same as in Fig. 4, but for the cycle 17 in the northern hemisphere.

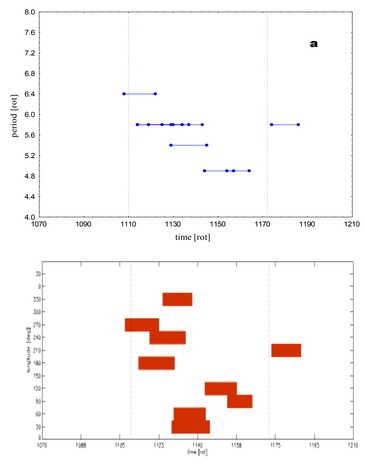

Figure 9. The same as in Fig. 9, but for the 5-rotation quasi-periodicity.

ABSTRACT:

The auto-correlation and the wavelet analyses of rotational sunspot area fluctuations over the epoch of 12 solar cycles (12-23) indicate the domination of the 10-rotation quasi-periodicity which exists from a few to 25 rotations during each high-activity period in each solar hemisphere. The sunspot group clusters (Getko, 2013) from 12 solar cycles are used to find active longitudes for each solar cycle and for each solar hemisphere separately. The divison of each solar hemisphere into 30^0 wide longitude bins and the wavelet calculations for the areas of sunspot clusters belonging to these 30^0 bins enable one to detect from 1 to 4 active longitudes at the same time in which the 10-rotation quasi-periodicity exists. These active longitudes are detected during the whole high-activity periods (from 47 rotations for cycle 14 in the northern hemisphere to 96 rotations for cycle 23 in the northern hemisphere).

DATA:

The daily sunspot groups positions and areas (in units of millionths of a hemisphere) for the northern hemisphere (D_l^n) and the southern hemisphere (D_l^s) for the years 1878-2008 (solar cycles 12-23) available at the National Geophysical Data Center (NGDC) (http://solarscience.msfc.nasa.gov/greenwch/) are considered. For the *i*-th Carrington rotation the mean sunspot area for the northern hemisphere (S_i^n) is given as :

$$S_i^n = \frac{1}{L}\sum_{l=1}^{L} D_l^n,$$

where L is the number of days for the *i*-th Carrington rotation. The fluctuation (F_i^n) of the mean sunspot area (S_i^n) from the consecutively smoothed mean sunspot area is defined by

$$F_i^n = S_i^n - \overline{S_i^n} \quad \text{for} \quad i = 1, \ldots, N,$$

where $\overline{S_i^n} = \frac{1}{13}\sum_{j=i-6}^{i+6} S_i^n$ is the 13-rotations running mean. The fluctuation F_i^n is strong when $F_i^n > 1\sigma$.
The high-activity periods for each solar cycle are defined by the monthly smoothed Wolf numbers: for each solar cycle all *i* for which the values of monthly smoothed Wolf numbers R_i are greater than 0.67* max(R_i) define these periods.
For each sunspot group its mean position and the sum of its areas during each Carrington rotation for each solar hemisphere separately are evaluated. To find the most active longitudes for each solar cycle in each solar hemisphere the clusters of sunspot groups and their positions evaluated by Getko (2013) are used.

ANALYSIS:

- To analyse 10-rotation quasi-periodicity during cycles 12-23 the Morlet normalized wavelets with the standard assumption $2\pi\omega=6$ are applied (Torrence & Compo 1998).

Figure 1 (a) presents the wavelets of fluctuations for the northern hemisphere during cycles 12-23. In this wavelet map the 10-rotation quasi-periodicity extends in time during the high-activity period and dominates the integrated spectrum (c). The fluctuations are shown in (b). The same, but for fluctuations from the southern hemisphere are given in (d)-(f).

- For each i-th rotation (such that $F_i^n > p$) the weighted positions of the area and the total area of each cluster created by large groups and all smaller groups which are close to one another are considered. Almost all clusters have a longitudinal extent up to 30^o (Getko, 2007). To obtain their longitude distribution the solar disk is divided into 30^o wide longitude bins. For each bin the number of clusters from one solar hemisphere is determined. To skip a phase shift problem thirty histograms such that their first bin started from 0^o to 29^o every 1^o are took into consideration. For each of them the sum of the squares of the deviations of the empirical frequencies from the uniform distribution values is calculated. For the best histogram this sum is to be greater than from any other histogram. Such a longitude division provides the 12 time series each of which contains the total areas of all the clusters and all other sunspot groups (which do not create clusters) occurring in the 30-degree bin. To find the mid-term periodicities for each longitude bin the wavelets are applied.

Figure 2 (a) demostrates the sunspot area fluctuations (F_i^n) for the most active solar cycle 19 in the northern hemisphere. The red horizontal line indicates the level p which evaluates the strong positive fluctuations. (b) shows the best histogram of sunspot group clusters which create the strong positive fluctuations.

Figure 3 (a) shows the behavior of the northern hemispheric 10-rotation quasi-periodicity for cycle 19. Vertical dotted lines show the high- and the low-activity periods. (b) Filled red areas demonstrate the presence of the northern hemispheric 10-rotation quasi-periodicity in 30^o wide longitude bins during cycle 19. Vertical dotted lines show the high- and the low-activity periods.

Figure 4 contains the wavelets of sunspot areas from the longitude bin 334^o - 4^o for cycle 19 in the northern hemisphere.

Figure 5 presents the wavelets of sunspot areas from the longitude bin 4^o - 34^o for cycle 19 in the northern hemisphere.

Figure 6 (a) shows the behavior of the northern hemispheric 10-rotation quasi-periodicity for cycles 12-23. Vertical dotted lines show the high- and the low-activity periods. The cycle numbers are given for all high-activity periods. (b) The same, but for the southern hemisphere.

Figure 7 (a) Filled red areas demonstrate the presence of the northern hemispheric 10-rotation quasi-periodicity in 30^o wide longitude bins during cycles 12-23. Vertical dotted lines show the high- and the low-activity periods. The cycle numbers are given for all high-activity periods. (b) The same, but for the southern hemisphere.

Figure 8 (a) shows the behavior of the northern hemispheric 10-rotation quasi-periodicity for cycle 17. Vertical dotted lines show the high- and the low-activity periods. (b) Filled red areas demonstrate the presence of the northern hemispheric 10-rotation quasi-periodicity in 30^o wide longitude bins during cycle 17. Vertical dotted lines show the high- and the low-activity periods.

Figure 9 (a) presents the behavior of the northern hemispheric 5-rotation quasi-periodicity for cycle 17. Vertical dotted lines show the high- and the low-activity periods. (b) Filled red areas demonstrate the presence of the northern hemispheric 5-rotation quasi-periodicity in 30^o wide longitude bins during cycle 17. Vertical dotted lines show the high- and the low-activity periods.

CONCLUSIONS

- The wavelets of the sunspot area fluctuations from each of solar hemisphere for cycles 12-23 show the statistically significant values at $\tau \in [7,13]$ rotations. These quasi-periodicities exist from a few to 25 rotations during each high-activity period in each solar hemisphere and dominate the integrated spectra.
- The division of each solar hemisphere into 30^o wide longitude bins and the wavelet calculations for the areas of sunspot clusters belonging to these 30^o bins enable one to detect from 1 to 4 active longitudes at the same time which show the 10-rotation quasi-periodicity. They always present during the high-activity periods (from 47 rotations for cycle 14 in the northern hemisphere to 96 rotations for cycle 23 in the northern hemisphere).
- It is difficult to find one or more active longitudes which exist during the whole high activity period.
- The 5-rotation quasi-periodicity is also detected, but it needs more investigations.

REFERENCES

Getko, R. 2007, Advances in Space Reasearch, 40, 981

Getko, R. 2013, J. Space Weather Space Clim., 3, A09