The total solar irradiance, UV emission and magnetic flu during the last solar cycle minimum

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The last minimum of the solar activity separating the activity cycles 23 and 24 is often called “an unusual minimum”. A typical minimum lasts for about 486 spotless days (http://spaceweather.com), but since 2004 as many as 821 spotless days were observed. Such long and deep solar minimum gives a unique opportunity to analyze in detail variations of the total solar irradiance (TSI) and the spectral solar irradiance as a function of the magnetic flux and sunspot area. We can estimate the contribution of each complex of the solar activity to the TSI and UV, separately, taking into account a so-called TSI blocking effect, which usually makes it difficult to determine the relationship between the magnetic flux and the total solar irradiance. We can also compare these results with those for the time when the sunspots do not contribute to the TSI at all.

This period is interesting, in addition, due to overlapping of the activity complexes of the solar cycles 23 and 24.

Here, we use the data for TSI and UV (115-180 nm) obtained by the SORCE instruments (http://lasp.colorado.edu/sorce), the data for XUV (0.1-7 nm) and EUV (33.5 nm, Fe XVI line) obtained by theTIMED-SEE instrument ftp://laspftp.colorado.edu/pub/SEE_Data . The sunspot areas are taken from the web page (http://solarscience.msfc.nasa.gov/greenwch.shtml). The magnetic data are represented by synoptic maps of the Wilcox Solar Observatory (WSO, http://wso.stanford.edu).

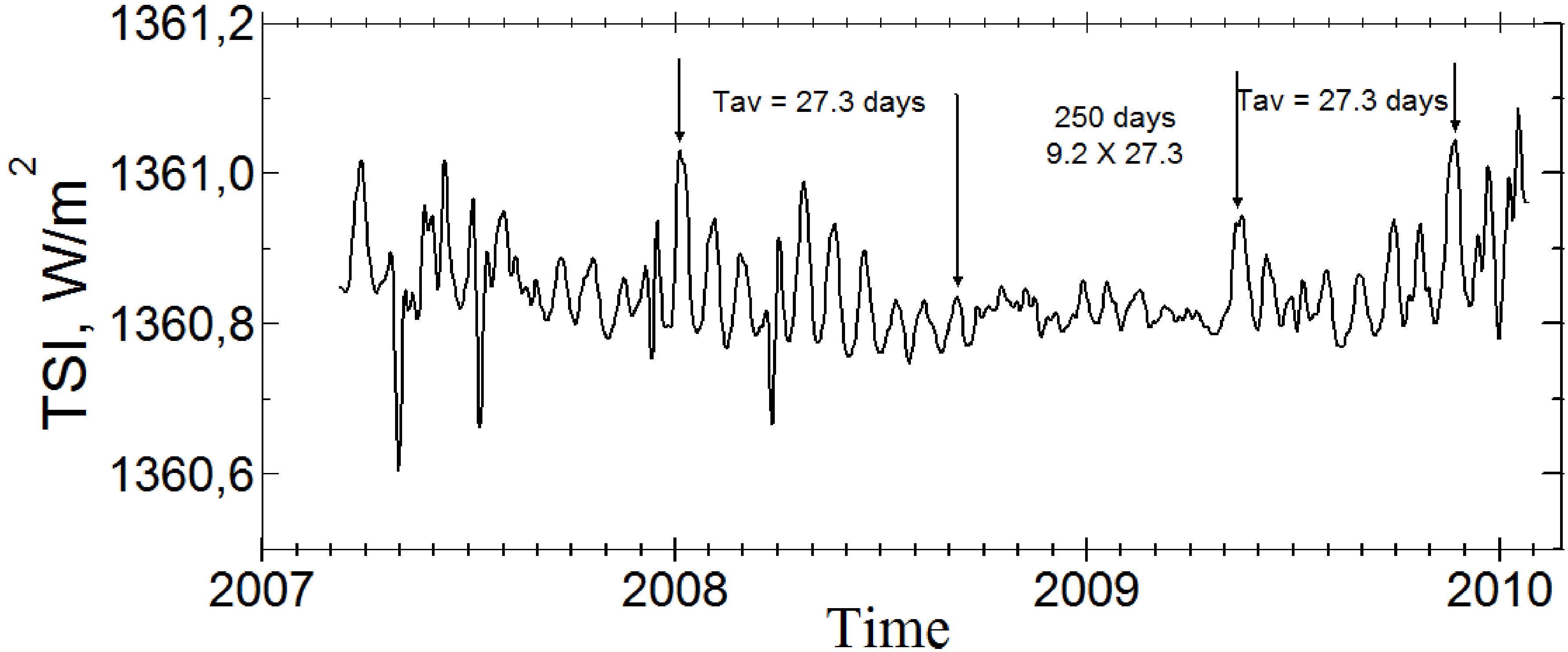


Figure 1. The daily values of the total irradiance (TSI) during the time 10 March 2007 - 23 January 2010.

One can see a strong longitudinal non-uniformity in the TSI value during 27 solar rotations. Here we analyze sources of such non-uniformity.

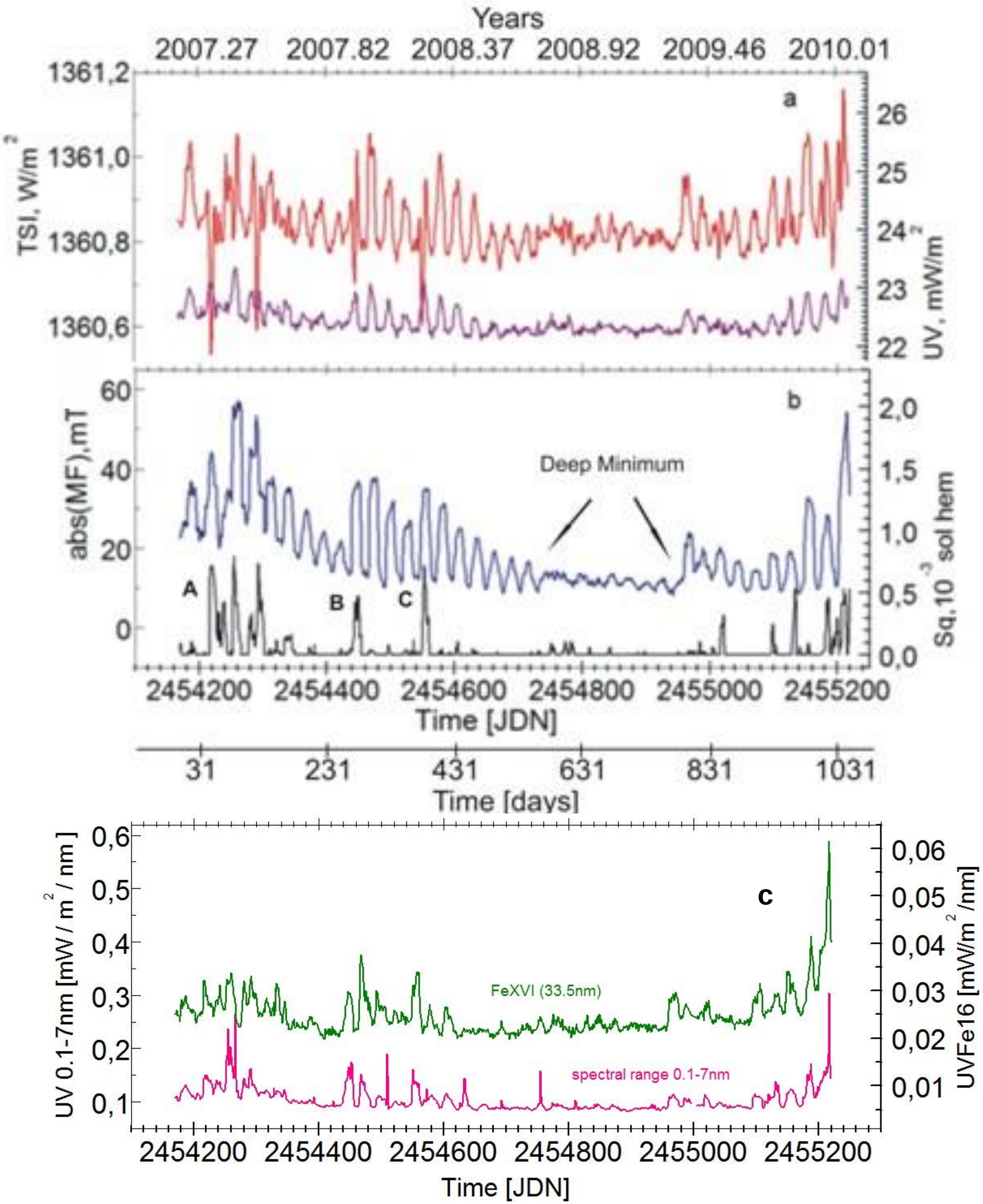
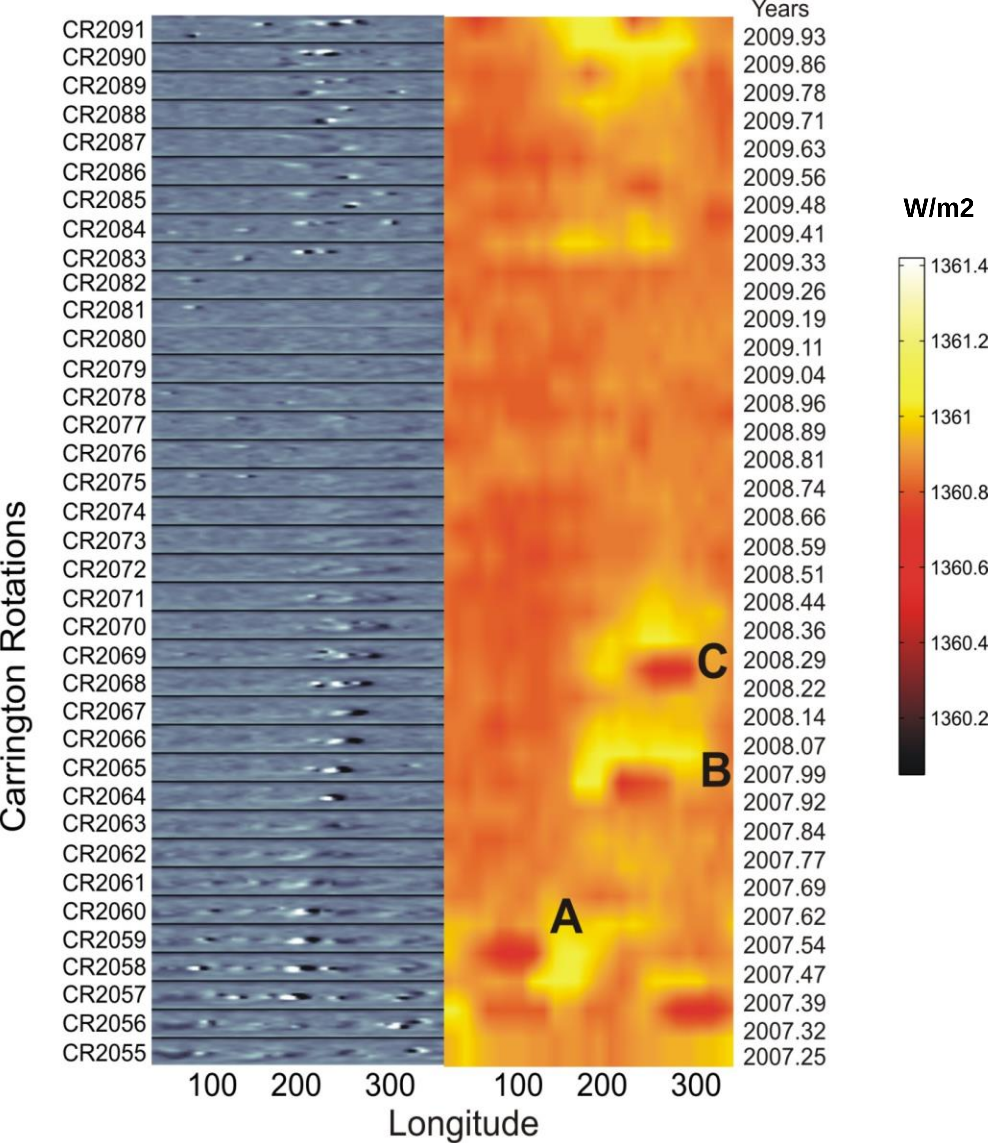


Figure 2. **The daily values of the total irradiance (TSI) during the time 10 March 2007 – 23 January 2010 (a, upper red line); the variations of the UV in the range of 115-180nm (a, bottom purple line); the WSO absolute values of the magnetic field strength of the line-of-sight component (magnetic flux, F mag) integrated over the latitude from -40o to 40o and from -90o to 90o over the longitude (b, upper blue line); the daily integrated sunspot area (b, bottom black line); the variations of the EUV in the line FeXVI-33.5nm (c, upper green line); the variations of the EUV in the range of 0.1-7nm (c, bottom pink line); A,B,C-activity complexes.**

The variables TSI and Fmag indicates their consistency, except for the times of strong TSI negative variations, which occurred due to the sunspot blocking effect. The increase in the daily integrated sunspot area corresponds to that in the integrated mid-latitude magnetic flux. There is a strong correlation between the Fmag and the intensity of the UV. The variations of the EUV and XUV irradiance from the transition region and corona mainly coincide in common with the variations of the Fmag and UV, but are becoming more pronounced, when sunspots appear on the solar surface.



Left: stacked WSO synoptic maps, 10 March, 2007 to 23 January, 2010, in gray scale from -250 to 250microTesla; Right: TSI as a function of the Carrington number and the Carrington longitude. Complexes of solar activity are marked with A, B, C. The time scale on the right indicates the beginnings of Carrington rotations.

During CR2055 - 2076 (March 2007 - November 2008) the strong magnetic activity exists in the longitudinal zone 200o- 280o and rotates with the velocity rate slightly exceeding that of the Carrington rotation. This magnetic structure, combined from ‘A’,’B’,’C’ activity complexes, contributes to the TSI due to the surrounding bright faculae. The solar complex ‘A’ corresponds to the multiple strong variations of the sunspot area, which occur during several Carrington rotations and are spread along the longitude. But only one of these fluctuations is related to the complexes of solar activity, exists inside the abovementioned longitudinal zone. The activity of B and C complexes is of special importance, as they belong to the overlapping cycles 23 and 24. During 2008—2009, the `old' magnetic flux (which belonged to the cycle 23) was concentrated in longitudinal zones, and the largest part of the `new' flux (which belonged to the cycle 24) with reversed magnetic polarity emerged in the same zones, within the longitude interval 180o - 270o.

After the deep minimum, sunspots of the cycle 24 tended to appear in the same longitudinal zone

A similar longitudinal pattern was observed at the beginning of the solar cycle 23 from June 1996 to June 1998 (Benevolenskaya, E. E.: 2002, Adv. Space Res., 29(12), 1941). During this time, the longitudinal distribution of the total solar irradiance, EUV irradiance from the transition region and corona, and solar magnetic flux integrated over solar disk increase in the same longitudinal zone (200o-300o).

The revealed tendencies make it possible to suppose that a long- lived local source of the emerging magnetic flux existed under solar photosphere. Our results also suggest that conditions for such a source to appear are stable relative to the process of cycle changing. According to the solar dynamo theory, the solar magnetic field during the minimum is expected to be a pure dipole. However, the existence of such a local long-lived subsurface source of magnetic field apparently indicates generation of a non-axisymmetrical component of the solar magnetic field due to dynamo process.

. **Cross wavelet transformation and coherence structure of TSI, UV, and F mag**

A cross wavelet power transformation reveals areas with high common power spectrum in the time – frequency space; the wavelet coherence transformation finds local phase-locked behavior in this space. The cross wavelet transformation (XWT) of two series X and Y can be defined as $W_n^{XY}(s) = W_n^X(s) W_n^{Y*}(s)$, where * denotes complex conjugation. The wavelet transformations of the series X and Y are $W_n^X(s)$ and $W_n^Y(s)$, where s is the scale, so that $\eta = s \cdot t$; η is the dimensionless time. The cross wavelet spectrum is complex and can be defined as the cross wavelet power spectrum $|W_n^{XY}(s)|$. Another useful parameter derived from the wavelet analysis is the wavelet transformation coherence (WTC) defined as the square of the cross spectrum (XWT) normalized to the individual power spectrum. Phase coherence is defined as $\tan^{-1}[Im[|W_n^{XY}(s)|]/Re[|W_n^{XY}(s)|]]$ [3].

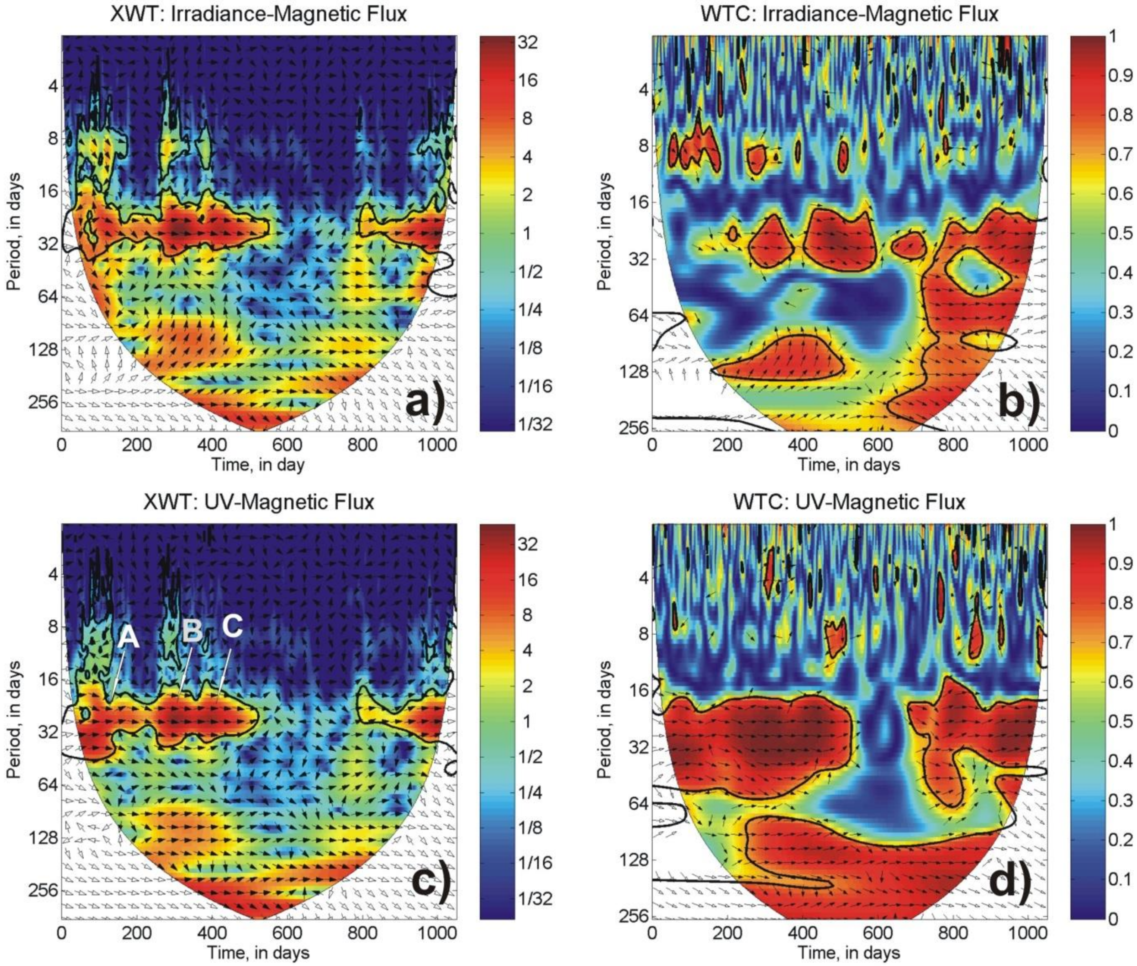


Figure 4. **a) Cross wavelet transformation of the irradiance and the magnetic flux;**
b) coherence of the irradiance and the magnetic flux;
c) cross wavelet transformation of the ultraviolet and the magnetic flux;
d) coherence of the ultraviolet and the magnetic flux.
Arrows indicate the phase relationship between the two data series in time-frequency space: 1) arrows pointing to the right show the in-phase behavior; 2) arrows pointing to the left indicate the anti-phase behavior; 3) arrows pointing downward show that the first data series is by 90 o ahead of the second series; 4) arrows pointing upward indicate that the second data series is by 90 o ahead of the first series. Complexes of solar activity contributing to the TSI and UV are marked by A, B, C in panel c.

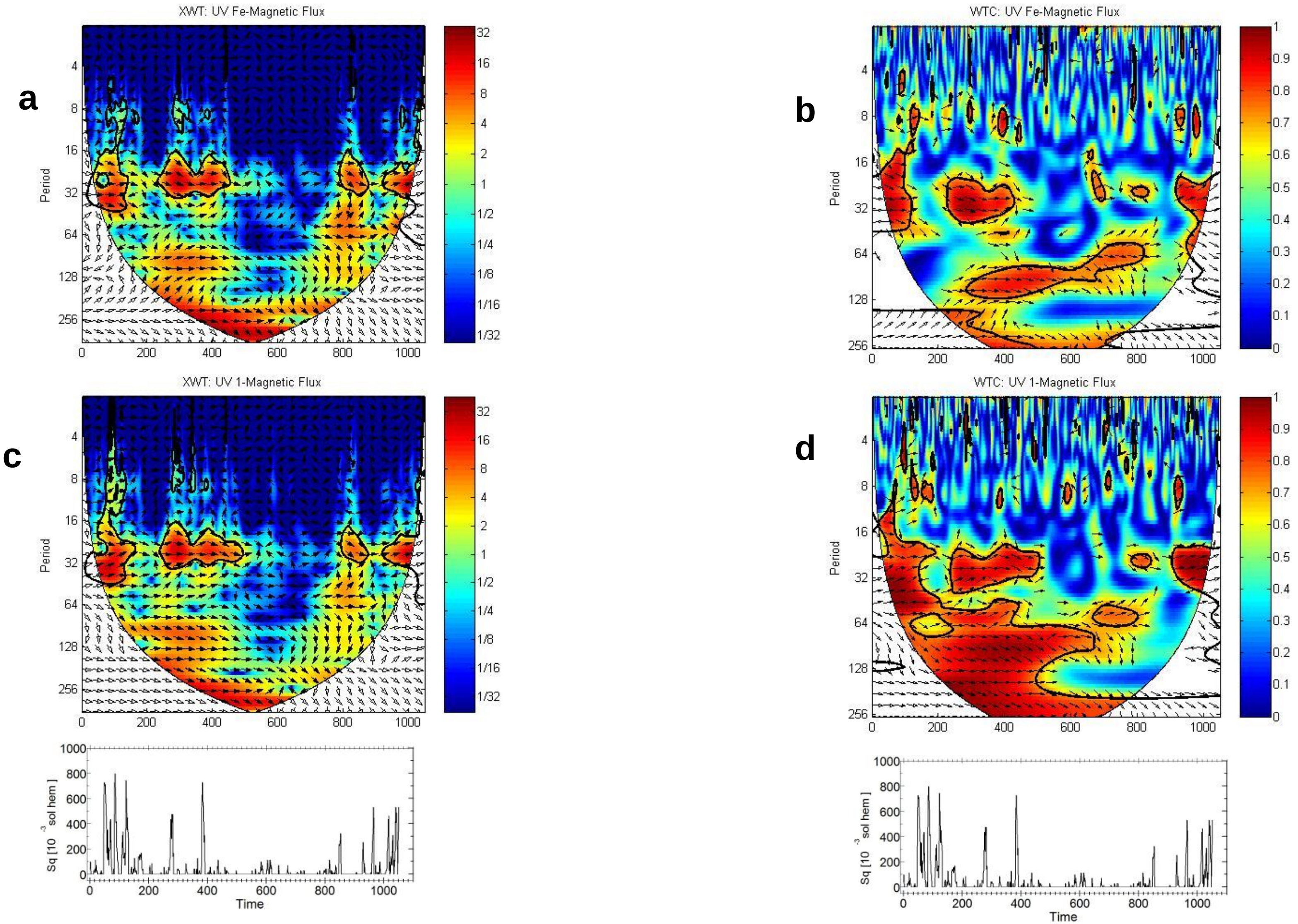


Figure 5. a) Cross wavelet transformation of the EUV FeXVI and the magnetic flux; b) coherence of the EUV FeXVI and the magnetic flux; c) cross wavelet transformation of the EUV in range 0.1-7nm and the magnetic flux; d) coherence of the EUV in range 0.1-7nm and the magnetic flux. Arrows indicate the phase relationship between the two data series in time-frequency space in the same way as in Figure 4.

The coherent structures between the mid-latitude magnetic flux and TSI / UV occurred in the case of the existence of the long-lived complexes of the solar activity. The coherent structures between the mid-latitude magnetic flux and EUV / XUV related to the appearence of sunspots in such complexes. Therefore, the non-uniform longitudinal distribution of the long-lived solar magnetic activity affects the solar irradiance.
Moreover, coherent structures between the TSI and the magnetic flux confirm the idea about the interrelation of the activity processes going on the Sun in total.

Conclusions

A pronounced longitudinal non-uniform emerging of faculae and sunspots, and, as a result, a non-axisymmetrical distribution of the total and spectral solar irradiance was observed during the long and deep minimum between cycles 23 and 24.

An evidence of generation of a non-axisymmetrical component of the solar magnetic field due to dynamo process?

The long-living complexes of sunspot activity make a significant contribution to the variation of the total solar irradiance and to the heating of the solar corona.

Acknowledgements

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THANK   YOU !