Solar electromagnetic radiation changes during the transition epoch between Zurich cycles No 23 and 24

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Abstract. The dynamics of solar electromagnetic flux during the downward phase of sunspot cycle No 23 (SC23) and the upward phase of cycle No 24 (SC24) is analyzed. The instrumental data series of TIM (Total Irradiance Monitor) and SOLSTICE (The Solar Stellar Irradiance Comparison Experiment) instruments on the board of SORCE satellite during the period March-May, 2003 – February, 2011, are used. The study contain analysis of variations of TSI (Total Solar Irradiance), mid UV-range (180-310 nm) flux and the "faculae" MgII-index. A comparison with the sunspot and flare activity is made. The obtained results in the aspect of the long term variations of solar activity, as well as to the ozone and climate changes are discussed. In particular, evidences that the start of SC 24 may be the begining of a new supercenturial Dalton-type minimum, are pointed out.

Key words: Sun, solar electromagnetic radiation, solar cycle

Изменения на слънчевата електромагнитна радиация в преходната епоха между слънчевите цикли № 23 и 24

Борис Комитов

Анализирана е динамиката на слънчевата електромагнитна радиация по време на низходящата фаза на слънчевия петно-образувателен цикъл № 23 (SC23) и възходящата фаза на цикъл № 24 (SC24). За целта се използват редиците инструментални данни от приборите TIM (Total Irradiance Monitor) и SOLSTICE (The Solar Stellar Irradiance Comparison Experiment) на борда на спътника SORCE през периода март-май 2003 – февруари 2011 година. Изследването съдържа анализ на вариациите на индекса TSI (Total Solar Irradiance), потока в областта на средния УВ-диапазон (180-310 нм) и "факелния" MgII-индекс. Направено е сравнение между петнообразувателната и факелната активност. Получените резултати се дискутират от гледна точка на дългосрочните промени в нивото на слънчевата активност, озона и климатичните промени. В частност, изявени са свидетелства, че започващият цикъл № 24 може би е начало на нов свръхвекови слънчев минимум, от Далтонов тип.

1 Introduction

The problem about the variations of the solar electromagnetic flux in the UV, visible and infrared ranges is of high importance to the dynamics of processes in stratosphere and troposphere of the Earth, as well as to the conditions of other planets in the Solar system. The variations of mid and near UV-range (180-390 nm) are strongly related to the total ozone changes in the Earth atmosphere and in essential aspect to the climate, while the TSI (Total Solar Irradiance) is considered as an important parameter of the overall "Sun-climate" relationship.

The first systematic and enough precise TSI measurements has been started in November, 1978, as a part of the "Nimbus-7" satellite scientific program. These observations has been accompanied with solar MgII (λ=288nm) line intensity measurements for determination of the photospheric faculae activity, as well as by photometric filter observations in the solar mid and near UV spectral ranges. The observations, the corresponding results and their analysis has been described in details in many papers (Lean et al., 1997; Frolich & Lean 1998; Pap et al., 2002 etc.). Recently these observations has been continued by instruments on other satellites.

On the basis of all obtained data and their analysis it has been established an existence of quasi 11-yr oscillation in TSI, which is approximately in coincidence with the Schwabe-Wolf's cycle of overall sunspot activity. Its mean amplitude during the solar cycles No 21-23 (SC 21-23) is in the range of 0.1% related to the mean TSI value. No significant changes in this amplitude has been found from cycle to cycle.

An important question there concerns the stability of TSI 11-yr cycle amplitude in larger time scales. Is it constant and no any long-term changes, related to centurial or supercenturial solar activity variations exists, or there is a significant large time scale TSI dynamics too?

According to some authors there are significant long term TSI variations. It has been found by Krivova et al. (2007) that TSI has been increased by $\approx 1.3\ W.m^{-2}$ during the last 300 years, since the end of Maunder minimum (1700-1715 AD). This value is about 4 times larger than the mean absolute 11-yr TSI oscillation $\approx 0.3\ W.m^{-2}$ during the last ≈ 30 years of precise satellite observations. On other hand there are also some authors which consider the supercenturial TSI change effects as negligible.

The problem is important not only for the better explaining of the climate changes in the past, but also for the more realistic expectations about the last ones in the nearest future. Now there are many evidences that the present epoch (the beginning of 21st century) is characterized by transition from supercenturial solar maximum (solar cycles No 17-23) to a new supercenturial minimum, which could be an analogue in amplitude of the Dalton minimum (1795-1830) (Komitov & Bonev, 2001; Schatten & Tobiska, 2003; etc.). Indeed, the deep solar minimum in 2007-2009 AD marks the start of this new epoch in solar activity dynamics. In this aspect it is interesting to search are there some new tendencies in the behavior of TSI in the recent and the other solar electromagnetic radiation indexes lately and how it could affect the Earth environment parameters.

2 Data and methods

For the aim of the study the data series from two instruments on the board of SORCE satellite are used. The instruments are TIM (Total Irradiance Monitor) for TSI and SOLSTICE (Solar-Stellar Irradiance Comparison Experiment) for the middle UV-range (180-310 nm) correspondingly. These data are updated every day with a delay of 7 days and could be downloaded from the SORCE web site (*http://lasp.colorado.edu/sorce/*).

There are two types of TIM (TSI) data sets with different time steps – 24 and 6 hours. They are started since February 25. 2003. In the present study the mean daily (24 hour) data series are used.

The SOLSTICE data are presented as mean diurnal UV-spectra by resolution of 1 nm in the range of 180-310 nm. In this study these data has been used as integral mean daily solar flux in the whole range. In addition the UV-flux changes in four subranges (200-230, 230-260, 260-290 and 290-310 nm)were studied. The starting date of SOLSTICE data series is May 14, 2003. The real spectral resolution of SOLSTICE data is 0.1 nm, which is enough to derive the $MgII(288nm)$-index. It is also published in SORCE web site, as few values (usually 5-6) per day, i.e. without strong regularity. These data are used directly on this stage, i.e. without any calculation of the mean daily values.

The variations of TSI has been compared with other solar indicies – the mean diurnal values of International sunspot number Ri and the daily number of solar x-ray M and X classes flares, which are published by the National Geophysical Data Center. The changes between TSI and Ri has been studied by linear cross-correlation analysis for 81-day moving epochs with time shifting step of 7 days.

The TSI data used in this analysis are for the period February 25, 2003 – February 28, 2011, while all based on SOLSTICE measurements data are related to the interval May 14, 2003 – February 28, 2011.

3 Results and analysis

On Fig.1a the mean daily TSI values since February 25, 2003, up to February 28, 2011, are plotted. The highest levels occur during the first few months, at the beginning of SORCE mission, i.e. during 2003 AD (the first 300 days of observations). A general decreasing tendency corresponds to the downward phase of solar cycle No 23 up to 1700th day (the second half of 2008 AD). After that the increasing proceeds very slowly and at the beginning of 2011 the mean TSI level corresponds to the same one in 2005, being significantly lower than in 2003 AD. It have to be noted that the maximum of the TSI levels are not in 2003, but in 2000-2001 AD, when the SC 23 maximum has occured. Consequently, the increasing of TSI during the upward phase of SC 24 is going too slow in comparison with the SC 23 and the possible TSI magnitude of SC 24 should be expected to be the lowest for the whole period of observations since 1978.

There are many local extremums of TSI during the downward phase of SC 23. It could easily be established by comparison with Fig.1b that all well expressed minimums ("gaps") during this period are coinciding with local maximums of the sunspot index Ri. The deepest one is about 245-250 days after the start of observations, i.e. the end of October, 2003. This is coinciding with the period of the most powerful flare events during the sunspot cycle No 23 – the so called "Halloween storms". As it is well known, 10 very strong flares of x-ray class X occured between October 20 and November 4, 2003. Two of them are classified as "mega-flares" (class X17 on October 28 and class X28+ -on November 4). The very large areas of sunspot groups No 10486 and 10488 during this time is obviously the cause for such deep decrease of TSI. Obviously the faculae luminosity has been not enough to compensate the negative sunspot effect during this time.

It has been found by using of χ^2-test that the "preferable" days for X-class flare activity during the investigated period are these ones, when significant negative fluctuations of TSI ("gaps") occured.

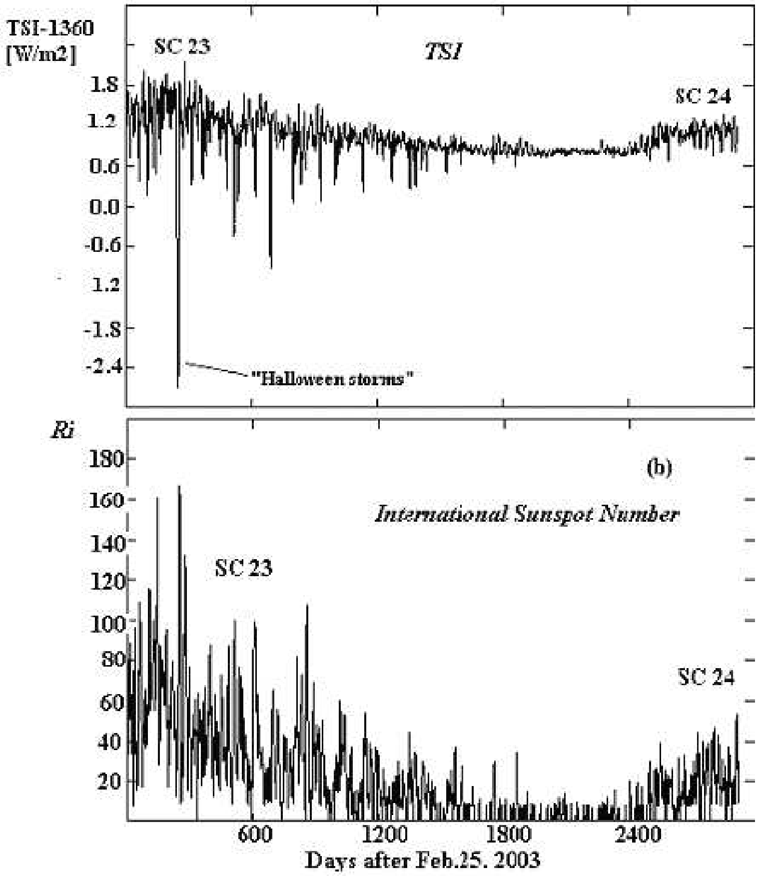

Fig. 1. a) The TSI daily data (February 25, 2003 - February 28, 2011); b) The International sunspot number (Ri) for the same period.

As a reference the mean TSI value of $TSI_{(m)}$=1360.02 $W.m^{-2}$ for the whole period February 25, 2003 – February 28, 2011, has been used. The corresponding mean standard deviation of TSI is σ=0.32 $W.m^{-2}$. Two alternative cases are used – days without such events and days with one or more X-class flares. They are compared with the corresponding daily TSI levels. The last ones has been separated in 6 groups: TSI<$TSI_{(m)}$-2σ; $TSI_{(m)}$-2σ $\leq$

$TSI \leq TSI_{(m)}$ -σ; ..... $TSI > TSI_{(m)}$ +2σ. The calculated χ^2=192, while the "critical" level for 99% probability is only 16.8.

However, it is necessary to note that this result is produced mainly by two relatively short periods – the "Halloween storms" period in the end of October 2003 and the date January 20, 2005. They contain 16 from the all 55 X-class flare events during the investigated period. The corresponding TSI deviations to $TSI_{(m)}$ has been <-2.5σ, i.e. strongly negative.

On the other hand there are also cases of strong flare events in days of positive TSI fluctuations. Such is the case of "mega-flare" on November 4, 2003. However, for this case it is necessary to note that the active region 10486 has been on western limb during the moment of the flare. Thus the Earth oriented side of Sun has been much less spotted as during the previous two weeks. The sunspot number index Ri has decreased from 165 on October 28 to 52 on November 4.

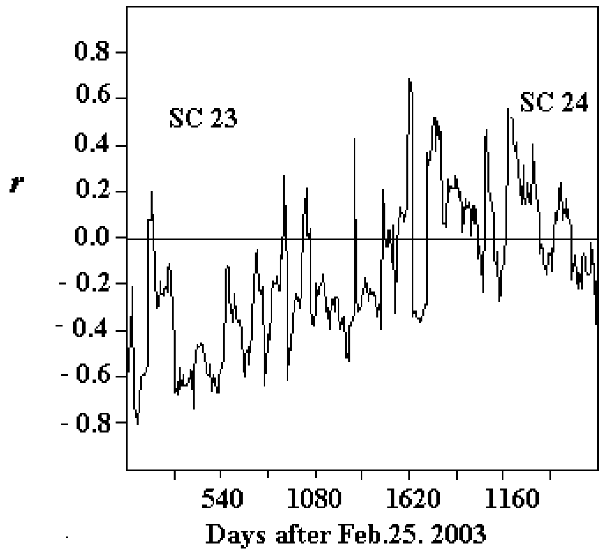

Fig. 2. The coefficient of linear correlation r between Ri and TSI, calculated for 81-days moving time intervals.

The general coefficient of correlation r between the TSI and Ri is + 0.19 for the whole series. It is small, but statistically significant. It has been found that this relationship is strongly variable by power and sign during the separate parts of the series. The last one is easily detected if the values of r for scanned "windows" by length of 81 days are calculated. As it is shown on Fig.2,we have predominantly r<0 during the downward phase of SC 23 as well as during the upward phase of SC 24 since the middle of 2010. It is predominantly positive during the sunspot minimum between 2007 and 2009 AD.

The last fact could be explained with a relatively stronger faculae activity simultaneously with the sunspot activity during this period. The sunspots during the solar minimum epoch have been usually small, very often single and very rare at all. However both the sunspot and faculae activity remain generally at very low levels. This is why TSI forms a continuous "flat" minimum with typical value of $\sim 1361\ W.m^{-2}$ between 2007 and 2009 AD without any significant fluctuations (Fig.1a). The generation of more stable and large sunspot groups with complicated structure in the second half of 2010 and the beginning of 2011 AD leads to restoring of the statistically significant anticorrelation between Ri and TSI. This is also possible if the increasing of faculae activity during the upward phase of SC 24 is too slow.

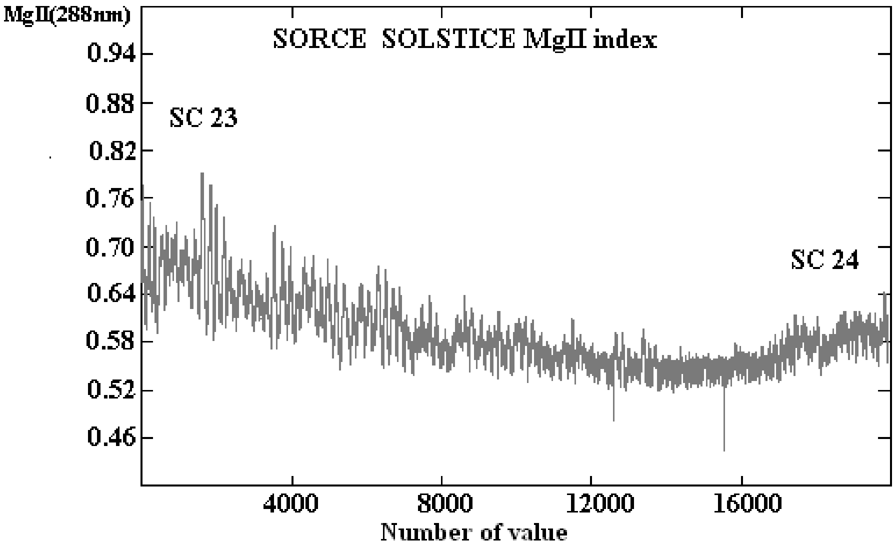

Fig. 3. The $MgII(288nm)$ index during the period February 25, 2003 – February, 28, 2011.

The last one is visible by the dynamics of $MgII$-index of faculae activity, which is shown on Fig.3. It is defined as ratio between the intensity in the center of solar MgII line and its adjacent spectral background (de Toma et al., 1997). The increasing of $MgII$-index (i.e. the faculae activity) during the first 2.5 years after the start of SC 24 is too slow, Thus the relative low levels of TSI during the upward phase of the present sunspot cycle are resulting effect of very low faculae activity plus generation of not so many, but relatively large and stable sunspot groups.

The variations of mid UV-flux (180-310 nm) are shown on Fig.4. On the upper panel the total flux in the range is presented, while below are the fluxes for four separated subranges (200-230, 230-260, 260-290 and 290-310 nm). The mid UV range is interesting especially due to the fact, that it almost coincides with the so called "Hartley's continuum" of the ozone absorbtion and photodissotiation. That is why their changes could be important for the balance of the stratospheric ozone. On other hand the radiation from the subrange 290-310 nm penetrates the troposphere and can even reach the Earth surface.

As it is shown, the total solar mid UV-flux has going down during the decreasing phase of SC 23. It reaches a minimum simultaneously with the sunspot one in 2007-2009. The most interesting fact there is that the integral mid UV flux *don't reach again* the value of the beginning of solar cycle No 24. The mean total decreasing of this part of solar radiation is about 0.8 % from 2003 to the beginning of 2011. If taken into account that the near-maximal phase of SC 23 was not in 2003, but in 2000-2001 AD it may concluded that the total decreasing of mid UV flux from solar maximum to solar minimum in 2007-2009 and after that to 2011 AD is about 1%. This result is in very good agreement with the earlier ones, obtained by Lean et al. (1997) about the changes of mid UV flux during the solar cycles No 21 and 22 (SC 21 and SC 22). The new moment there is the lack of increasing after the start of the new SC 24!

However, as it is shown in Fig.4 the picture is very different for the separated UV subranges. The downward SC 23 and upward SC 24 phases are clearly seen in 200-230 and 230-260 nm subranges. This is the same one for the subrange 180-200 nm subrange, which is not presented on Fig.4. The flux in the 260-290 nm subrange reproduces almost the same variability as the whole mid UV range, i.e. well expressed decreasing SC 23 phase and lack of increasing after the start of SC 24. The subrange 290-310 nm flux remain almost constant during the whole studied period (the lowest panel of Fig.4). However there are some weak tendencies too, it could be seen that there is a very flat slightly expressed maximum during the sunspot minimum in 2007-2009 AD. This could be explained by the almost total absence of sunspots during this period. The sunspot effect is very slightly visible during the downward SC 23 and upward SC 24 phases.

4 Discussion

The data and analysis presented in Section 3 lead to the conclusion that significant changes in the dynamics of solar electromagnetic flux are observed during the last few years, since 2007 AD, makeing the upward phase of the cycle SC 24 similar to the previous solar cycles (SC 21-23). The dominating tendencies are obviously downward for all important proxies in this case - TSI, the faculae $MgII$-index, as well as the International sunspot number Ri. All they increase much slowly after the sunspot minimum un 2008 AD. Especially the slow increasing of the $MgII$-index indicate for deficite of faculae activity during the first 30 months of SC 24. This could be also interpreted as a relative cooling of Sun photosphere in comparison with the increasing phases of the previous cycles SC 22 and 23. On the other hand the sunspots of cycle No 24 are obviously larger by size and more stable since the middle of 2010. This yields an additional stop-effect over the fast increase of TSI.

The downward tendency is very clearly shown in the solar middle UV-flux (180-310 nm). The absence of increasing related to the new sunspot cycle No 24, in addition for the above mentioned for TSI and $MgII$-index, point out

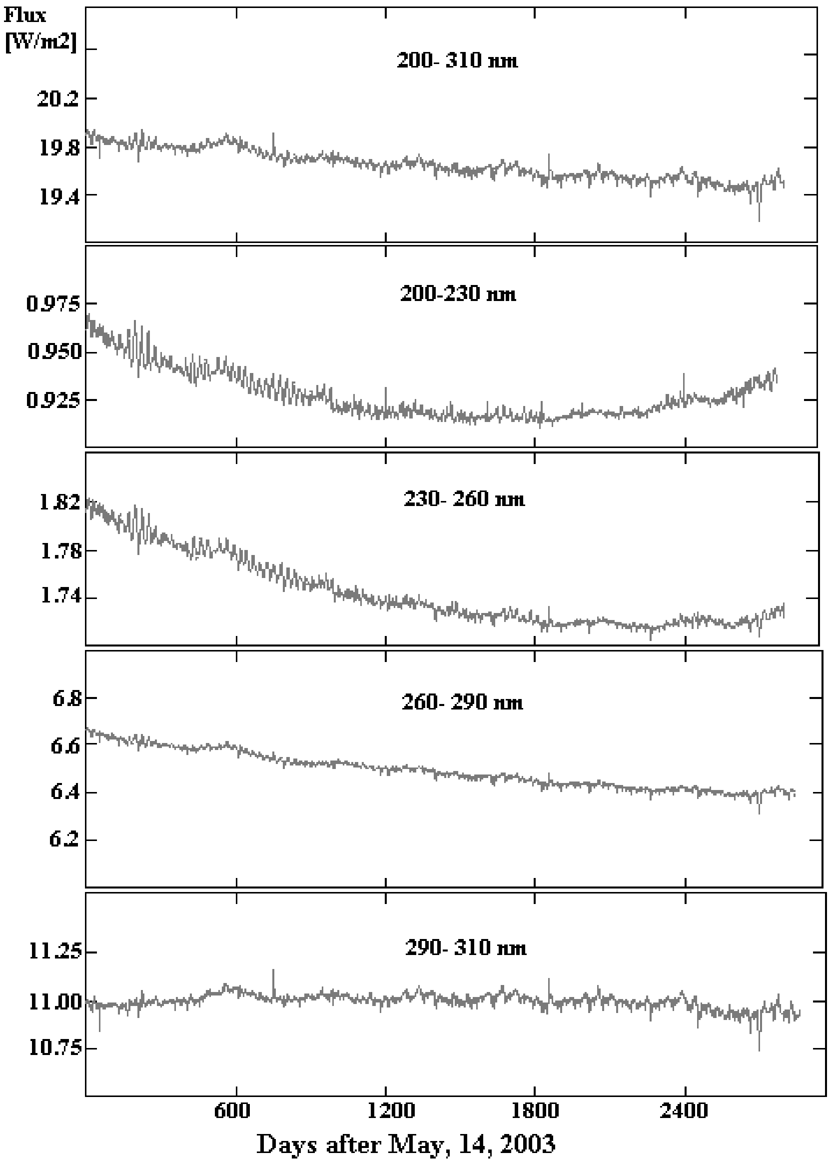

Fig. 4. The solar middle UV-flux during the period February 25, 2003 – February, 28, 2011.

that there is some new factor, which has been absent in the previous three decades. On our opinion it is in support of the idea that the start of SC 24 is a begining of a new supercenturial Dalton-type minimum. Thus we should consider the present results as an evidence that essential downward tendencies in solar electromagnetic radiation during the supercenturial solar minimums (called "grand mimima" by some authors, see Kitchatinov & Olemskoy, 2010) like these of Oort, Wolf, Spoerer, Maunder and Dalton really has been occurred. How such TSI decrease could be a cause for climate cooling tendencies during these epochs or there are also other mechanisms of solar influence over the climate is another, open yet question.

The absence of mid UV- flux increasing during the last years could help for a restoring of the planetary ozone content. It is needed to check for such possibility the satellite ozone data from the last decade.

The good correspondence between the strong negative TSI fluctuations ("TSI gaps") and strong solar flares (or respectively large sunspot groups) is an important, by our opinion, phenomena. Indeed, the general tendency for the TSI index during the periods of extreme flare activity is strongly downward. If there are some exclusions, most probably, they are related to flares on the solar limb when the corresponding regions of the photosphere are not good visible from the Earth. We have also to note that the very short and sharp increases of TSI during the same flares (Kretszmchmar et.al., 2010) don't affect essentially this negative relationship. These periods of strong TSI-gaps are usually of duration of 1-2 weeks. How such periods could lead to some detectable effects over the conditions in the troposphere is also an interesting problem. The relationship between the TSI "gaps" and strong flare activity periods could open an other interesting possibility too, namely to study for such possible "TSI-gaps" in the past on the base of historical messages for auroral activity or giant sunspot groups.

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