The 24^{th} solar cycle: Prelyminary analysis and generalizations

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Abstract. A preliminary comparison of the present solar cycle No24 (SC24) and the previous cycles in relation to large number of "space weather" parameters (sunspot activity, radioindex $F_{10.7}$, X-ray flares, solar radiobursts, eruptive protuberances, Sun's polar magnetic fields, geomagnetic AA-index, galactic cosmic rays (GCR) fluxes etc.) is the main subject of this study. The lengths of the used there solar and geophysical data series are depending on the beginning of regular observations. For sunspot activity index R_i it is since 1749, for geomagnetic AA-index -since 1868 AD, while for some of parameters like eruptive protuberances or radiosweeps only data for the last two solar cycles SC23 and SC24 are used. All used data series ends on October, 31, 2017. As is shown in this "express" preliminary analysis SC24 is the weakest solar sunspot cycle at least since sunspot cycle No12 (1879-1889 AD) or (possible) even since SC6 (1810-1823). The "geomagnetic" SC24 is the weakest for the whole AA-index data series, i.e. since 1868 AD. This conclusion is valid for almost all studied parameters- flares, $F_{10.7}$, radiobursts etc. It was found that SC24 is positioned on long-term downward trend, which has been started for the most of the solar activity events earlier to the maximum of sunspot cycle No 22 (SC22), namely after 1991 AD. A prediction that the next solar cycle 25 (SC25) will be with almost the same amplitude or slightly stronger than SC24 is given. A possibility for "underdeveloped" SC26 is also discussed. Arguments that the present relatively weak SC24 is connected to the supercenturial and supermillenial solar activity oscillations (200-210 yr "Suess cycle" and 2200-2400 yr "Hallstadtzeit cycle") and for beginning of "Dalton-type" solar grand minimum are given.

Key words: sunspot cycle, 24th solar cycle, Schove series, Hallstadtzeit

1. Introduction

The solar activity is one of the most important Earth environmental parameters. It plays an important role for our planet's magnetosphere and atmosphere processes (geomagnetism, ionosphere, radio waves propagation, natural radiation background, small gaseous components dynamics, climate, hydrology etc.). It's influence traces in tectonic processes (seismic and volcanic activity), different geodynamical parameters such as LOD-index (length of day), biosphere processes etc. The solar active processes due to geomagnetism and solar energetic particles (SEP) take effects over technical infrastructure functioning. It's caused by the fact that during the last two centuries this infrastructure is all more based on technical applying of electrical, magnetic and electromagnetic phenomena. That's why the studies of solar activity and solar-terrestrial relationships behavior in time as well as the physical mechanisms of their generation are among the most important subjects of solar and solar-terrestrial physics. The study of present time depend tendencies of solar activity behavior as well as the possibility of its long-time prediction (at least two or three decades forward) is of high importance and is the subject of present paper. One of questions which will addressed is: Are there any indications in the light of present 24th solar cycle for grand solar minima beginning? (Note: grand solar minima - an epoch containing from two to few weak 11yr solar cycles, such as Maunder (1642-1715 AD) or Dalton (1794/98 -1830 AD) minima.)

The existence of stable quasi-cyclic oscillations in solar activity behavior is a big challenge for the authors of physical models. The "solar dynamo" theory in all its modifications can satisfactorily to explain the 11 and 22-year cycles. However there isn't convincing explanation within the framework of this theory concerning the existence of cycles by sub-century, quasi-century and super-century lengths. Obviously the last ones exists and they are easy detectable in the indirect solar activity data ("cosmogenic" isotopes,tree-rings width data, historical messages etc.(Schove, 1955),(Schove,1986), (Stuiver and Quay,1980), (Damon and Sonett ,1991), (Perystikh and Damon, 1998), (Komitov and Kaftan, 2003), (Komitov and Kaftan,2004),(Komitov and Kaftan,2013),(Bonev et al.,2004), (Dergachev, 2004), (Rasspopov et al.,2008)). Some of them argued that the 200-210 yr cycle are stable solar and climate features even in geological time scale (Rasspopov et al., 2008). The Sun's entering in a new grand minima during the 21st century (as it will pointed later) is an evidence, that the "solar dynamo" theory needs of serious developing in this course. An explanation that solar grand minima are stochastic phenomena is not convincing.

The sources of information for the grand solar minima in the past are summarized on table 1. It is clearly shown from him that the new super-century minima (if it take that the Sun is already fell into him)is the first one, for which the information on observations in whole electromagnetic range, solar and galactic cosmic rays, magnetic fields and plasma, plus by using of large number of ground based instruments as well as from interplanetary space probes and Earth satellites will be based .

The aim of this preliminary analysis of the already ending present solar cycle 24 (SC24) is to answer many questions: 1. What are the most remarkable solar phenomena during the present 24th Zurich solar cycle (SC24)? How their power and number are related to other similar phenomena in previous 11yr solar cycles? 2. What are the most interesting events , related to geomagnetic and aurora activity as well as other solar-terrestrial relationships manifestations during SC24? 3. What shows the time series behavior of International sunspot number Ri (the new version from 2015 AD), radio index $F_{10.7}$, Sun total quasi dipole magnetic field, galactic cosmic rays (GCR)flux and geomagnetic AA-index during the previous 11yr cycles and what shows comparison with the present SC24? 4. What shows the time series behavior of active solar events (X-ray and optical flares, eruptive protuberances, radiobursts and radiosweeps) during the last few 11yr solar cycles (SC20-SC24)? 5. Are there evidences, based on the obtained results from the analysis that a new deep solar activity minimum in 21st century is coming soon? 6. Is it possible any preliminary forecast about solar cycles No 25 and 26 (SC25 and SC26) to be made? How are the 11yr solar cycles in the end of 20th and the beginning of 21st centuries to the large scale solar activity variations related?

There is also another interesting question in this course, namely: What new about "Sun-climate" connection in light of the new results can be said? However, the answer will be discussed in additional separate paper.

Table 1. Historical and instrumental data for the grand solar minima in different epochs

before 2500 BC	"cosmogenic" isotopes (14C, 10Be etc.) in natural layer and ring structures, lunar regolith vertical column probes
2500 BC - 1610 AD	"cosmogenic" isotopes, ancient and medieval manuscript sources for aurora, giant sunspots, bright comets etc., extremely climatic events
Maunder (1642-1720 AD) and Dalton (1793/98-1830 AD) minima	"cosmogenic" isotopes, ancient and medieval manuscript sources for aurora, giant sunspots),visual telescopic observations
Gleissberg-Gnevishev minimum (1898-1923 AD)	telescopic observations (visual, photographic and spectroscopic), geomagnetic and aurora observations, continental ice nitrates
modern epoch	groundbased telescopic observations (CCD images, photometry and spectroscopy), satellite CCD images, photometry and spectroscopy in whole spectral range, solar wind, IMF, aurora, geomagnetic and GCR observations etc.

2. The observations, data and software

Let's summarize the used type of solar and solar-terrestrial data as well as of their sources. They are as follow:

A. Daily and monthly sunspot indexes data - from Goddard Space Flight Center (*https://omniweb.gsfc.nasa.gov/form/dx1.html*) and Royal Observatory of Belgium (*http://sidc.oma.be/silso/home*); for solar active regions (1874-1976 AD) - Marshal Space F light Center, division for solar physics (Huntsville, Alabama, USA)

B. Tabulated $F_{10.7}$, solar wind and interplanetary magnetic field (IMF) parameters - from Goddard Space Flight Center (https://omniweb.gsfc.nasa.gov/form/dx1.html) solar wind and IMF graphs - from ACE and DSCOVR ;

C. Solar X-ray and optical flares, radiobursts, radiosweeps, eruptive protuberances - from National Geophysical Data Center (ftp://ftp.ngdc.noaa.gov/STP/) and Space Weather Prediction Center of NOAA (Boulder, Colorado, USA) (http://swpc.noaa.gov)- the quasi-real time bulletins

D. Sun disk X-Ray images - from GOES satellite imagers - from Space Weather Prediction Center of NOAA

E. Sun disk EUV images and coronograph images - from SDO and SOHO satellites and STEREO-A and STEREO-B interplanetary space probes

F. Sun radio images at frequencies 5.7GHz and 17GHz - from Solar-Terrestrial Physics Institute (Irkutsk, Russia) and Nobeyama Radio Observatory (Japan)

G. Galactic cosmic rays (GCR) fluxes (tabulated data and graphs)in different time scales- from IZMIRAN (Troitsk, Russia) and Solar-Terrestrial Physics Institute (Irkutsk, Russia)

H. Monthly geomagnetic AA-index (1868 - 2017 AD)-from from National Geophysical Data Center of NOAA (ftp://ftp.ngdc.noaa.gov/STP/) and British Geological Survey (http://www.geomag.bgs.ac.uk/data_service/data/magnetic_indices/aaindex.html) I. Sudden Ionosphere Disturbances (SID-events)- from Solar and Solar - Terrestrial Monitoring Center project and People Astronomical Observatory (Stara Zagora, Bulgaria) (www.heliotaraxy.com)

J. Aurora photos - from www.solarham.net (Space Weather and Amateur Radio Website)

Since the end of 2011 AD in the Astronomical Observatory 'Yuri Gagarin' in Stara Zagora (Bulgaria) a SID-Monitor wich has been present from Stanford Center for Solar Physics on fixed frequency of f=24 kHz is working (fig. 1). It is used for measuring extinction/reflection processes over the lower ionosphere (D and E layers). It includes also these ones, which are caused by solar flares or strong solar proton events in daytime over the ionosphere D-layer. However regular qualitative observations in continuous 24-hour regime are provided since April 2012 AD. These observations. An newer model of Stanford SID-monitor has been placed at 50 km northern from the first one in Balkan Mountain Range (Stara Planina) (fig1,c,d) By the last one simultaneous observations in 6 different frequencies in frequency range 17-26 kHz can be provided. Some of the graphics, which present SID-events, are used in this paper for illustration of solar active phenomena over the Earth ionosphere. For primary data processing and visualization a Stanford Solar Center software, applied to both SID instruments is used.

In Stara Zagora there are also two other FM radio-detectors which are worked at fixed frequencies f=29.9MHz and 71MHz correspondingly. They are used for registration of solar radio -bursts. The primary data processing software for these observations is SkyPipe II, which has been developed in Goddard Space Flight Center (Greenbelt, Maryland, USA) for the aims of JOVE project (radiosky.com/skypipeishere.html). Some of graphics, obtained the use of these observations are shown in this paper.

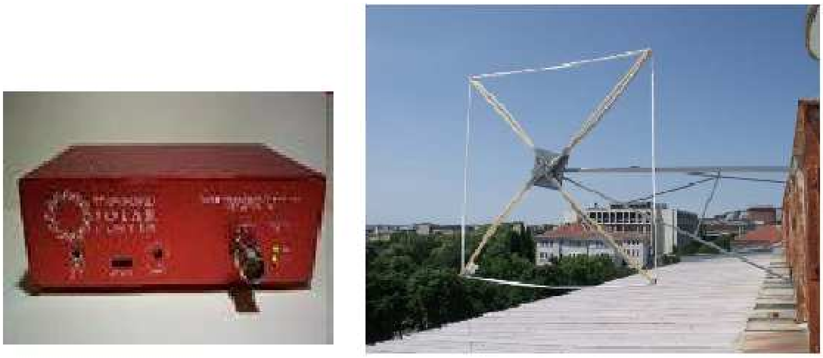

Fig. 1. SID-monitor in Astronomical Observatory 'Yuri Gagarin'-Stara Zagora; right: SID-monitor antenna

3. SC24: The most featured solar and geophysical events

First we will make an overview of the most featured solar and solar-terrestrial events which have occured during the 24th solar cycle(SC24) in chronological order.

January 04, 2008: The first SC24 region; The first 'trace' of starting new solar cycle has been detected by space probe STEREO-B extremely UV Imager on Jan.04.2008. It was a bright region on approximately 30 degree northern heliographic latitude (fig.02). Except the high latitude magnetic polarity of this region is reverse to the active regions magnetic polarity in northern Sun hemisphere during the old SC23. Later the observed spot of this region was labeled as AR10980. However the SC23 activity was still ongoing. It was gradually decreased during the first half of 2008, while from the new SC24 active regions nearly were missing. Using different methods and parameters it has been found that the beginning of SC24 was in January 2009.

The solar sunspot activity in nearly all 2009 was extremely low. The 'classical' International sunspot number (i.e. connected to Wolf's number) reached for first time in SC24 a value of 10 in December 2009. During 2010 the solar activity begin increase very slowly and the first X-ray solar flares by the moderate class M occured. The first strong planetary geomagnetic storm ($K_p = 7$) has been detected at April 05 2010.

February 15, 2011: "The St. Valentine flare"(X2.2): A serious solar activity increasing started in February 2011. It almost coincided with the So-

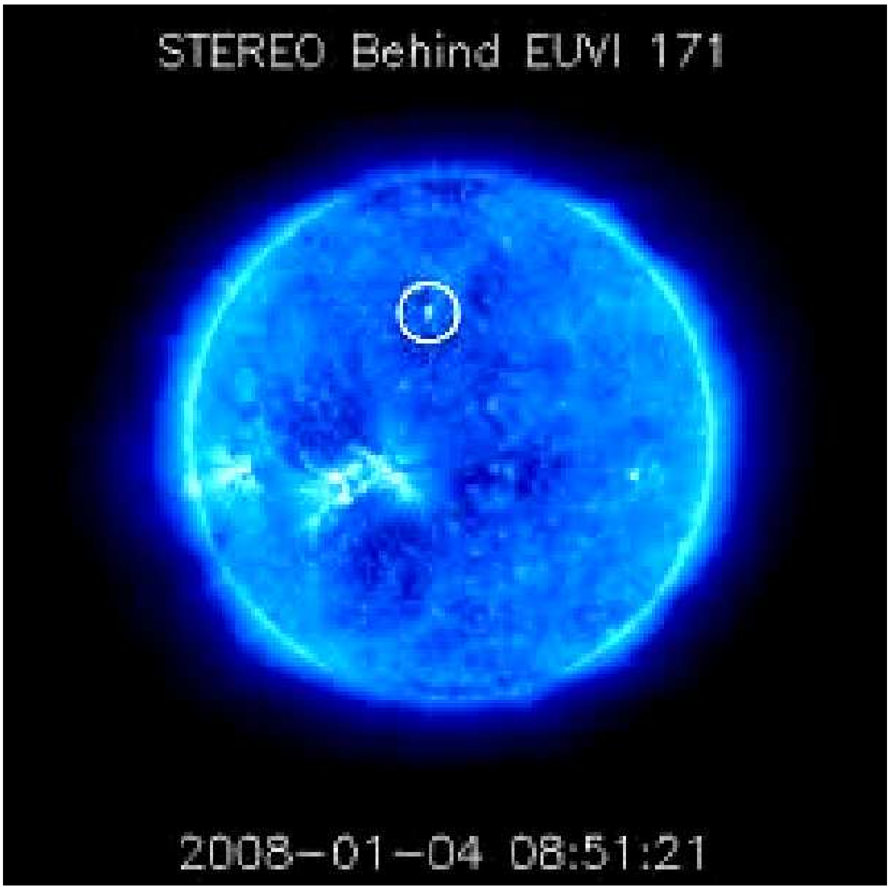

Fig. 2. AR10980- the first active region of 24th solar cycle (SC24)(stereo.gsfc.nasa.gov/browse/2008/01/04/ behind/euvi/171/512/)

lar Dynamics Observatory (SDO) satellite lunch anniversary (Feb.11.2010) (fig.03). One of the most interesting instruments on board of the satellite is Atmospheric Imaging Assembly (AIA)(fig.04). Using this camera the Sun is observed images in extreme and middle UV-range ($100 < \lambda < 175nm$) in 10 wavelengths on every 15 minutes.

On February 15 2011 the first big solar X-flare with magnitude X2.2 from the active region AR11158 occurred. It was labeled as 'Saint Valentine flare' (fig.05). The coronal mass ejection (CME) reached Earth on February 18 causing a weak planetary geomagnetic storm (maximal Kp=5). Our regular radio observations by FM radio detector at f=29.9MHz has also started on February 15, but few hours after the X2.2 flare. Two signal increases has been detected during the next 12 hours, most probably related to CME events, primary triggered by two C4.8 flares.

August 09, 2011: X6.9-flare; A large solar activity increasing began

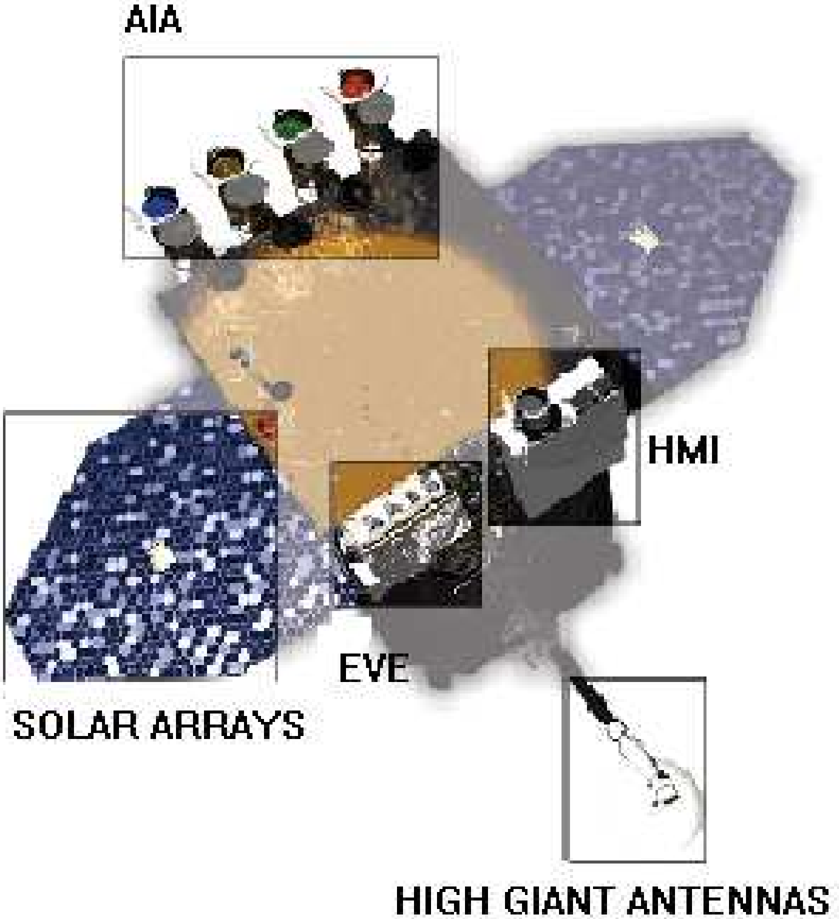

Fig. 3. The Solar Dynamics Observatory (SDO) satellite (sdo.gsfc.nasa.gov/mission)

in the first decade of August 2011. There where a series of three M-class flares. They could be characterized as 'moderate-strong' due to fact that their magnitudes are in the range M5.0-M9.9, i.e. the upper part of class M. A primary source of these flares was the active region AR11261 (or short sign as 1261). These flares due to corresponding CME's have caused a strong planetary geomagnetic storm (maximal $K_p = 8$), which was accompanied by strong aurora activity both on North and South Earth hemispheres. In many regions on high geomagnetic latitudes a very beautiful auroras was observed, including even the south American state Alabama.

Fig. 4. Atmospheric Imaging Assembly (AIA) (sdo.gsfc.nasa.govmissioninstruments.php).

The main event of this active episode in SC24 was a big X6.9 solar flare at 08h05min UT on August 09 2011. The source of this flare was the active region AR11263 (1263)(fig.06). It was the strongest solar flare during the SC24 until September, 06, 2017. The region 1263 during the X6.9 flare was very close to the north-western solar disk edge and because of this one it was geoeffectively weak - the trajectory of the ejected coronal mass cloud (CME) was oriented far west from Earth direction. A strong radioburst in MHz- and GHz ranges has been detected. Short radio communication black-outs occured in different regions of the world, as well as a weak radiation storm (S1).

April 2012 - October 2013: "Gnevishev's gap": During the spring of 2012 after one X5.3 flare (March 07 2011) a downward tendency of solar activity has begun- the so called "Gnevishev's gap". This is a common phase for every Schwabe-Wolf's 11yr sunspot cycle of duration of 12-20 months. It separates both main maximums of the sunspot cycle.Two short active episodes has been observed in July 2012 and in May 2013, where few X-class flares has been detected, but they did not affect essentially the generally quiet conditions during this period. In our opinion the "Gnevishev gap" phase for SC24 ended in October 2013.

October 2013: The main solar maximum episode has started; During the time interval 23-29 October five big flares of class X as well as few others of class M has been detected. This episode of solar activity is also interesting for us because of the first two SID-events registrations, which are related to X-class solar flares (fig.07). The second (higher than first one) maximum of SC24 occurred during the winter and the spring of 2014. On February, 24,

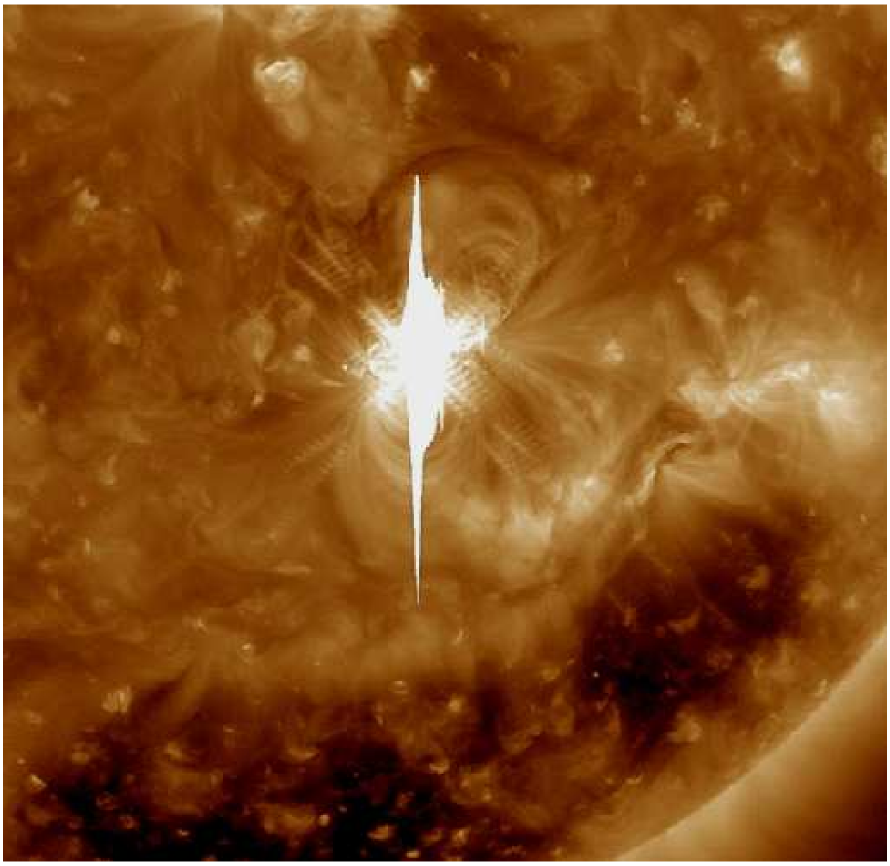

Fig. 5. 'Saint Valentine flare' on February 15, 2011 (sdo.gsfc.nasa.gov/data/)

2014 the active region AR11990 generated a strong flare with magnitude of X4.9. Up to now (December, 15, 2017) it is by power the fifth solar flare in SC24. It generated a weak radiation storm (S1), coronal mass ejection (CME) and moderate planetary geomagnetic storm (maximal $K_p = 6$).

The giant AR12192 sunspot group; The largest for the whole SC24 sunspot group AR12192 (2192) has been appeared on the solar disk during the time interval October, 17-29,2014. Its maximal area exceeded 2800 million parts of visible solar disk. The corresponding TSI index (Total Solar Irradiance) reduction was in order of $\approx 0.04\%$ (fig.08). This estimation is based on TIM instrument measurements on the board of SORCE satellite. The active region 2192 was a source of serious eruptive activity (many moderate M and strong X-class flares), but the number and the magnitudes of the observed corresponding CME's were too small.

The whole period of the main sunspot maximum of SC24 (2013-2015)

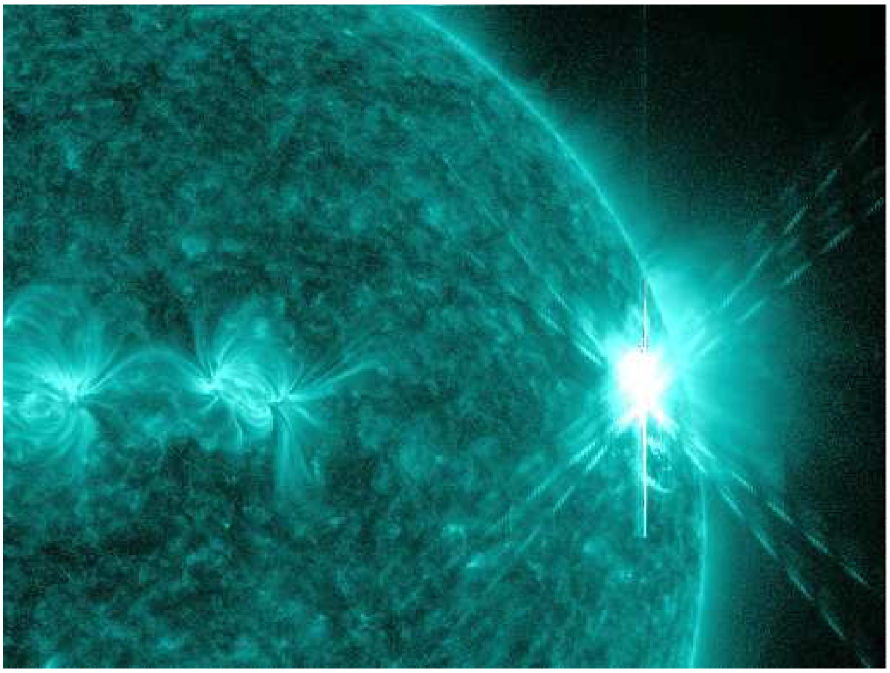

Fig. 6. The strong solar X6.9-flare on August 09, 2011 (sdo.gsfc.nasa.gov/data/)

is very rich of auroral events. Beautiful aurora over the Arctic Belt between Alaska on the west to Russian North on the east has been observed (fig.09).

March 17-19, 2015: The "St.Patric storm"; With no doubt the most spectacular event in the field of geomagnetic activity during the SC24 is "Saint Patrick storm" (March, 17-19, 2015). There was a combined effect of high solar wind velocity , caused by solar coronal hole (the so called "CHHSS-effect")and coronal mass ejection (CME). The last one has been caused by a "sub-moderate" C9-flare from the active region AR12297 (2297) (fig.10). As a result a very strong and continuous planetary geomagnetic storm (maximal $K_p = 8$) occured (fig.11). It has been accompanied by very strong auroral activity in both Earth hemispheres. Aurora has been observed even in regions too far from the polar aurora zones (polar ovals), for example Moscow and New Zealand.

During the second half of 2015 the solar flares power and frequency as well as the new sunspot groups appearance began to decrease more rapid. No strong solar X-class flares occured between April 2015 and September 2017 while M-class flares were very rare events during the same time.

September 2017: "Tempestuous" space weather. X9.3 mega-flare; Suddenly in the beginning of September 2017 the solar activity rised rapidly for short time (7-8 days) to highest levels since the end of 2006. The magnetic structure of sunspot group AR12673 (2673) start very quickly to develop and reached magnetic class "beta-gamma". Few M-class flares has been

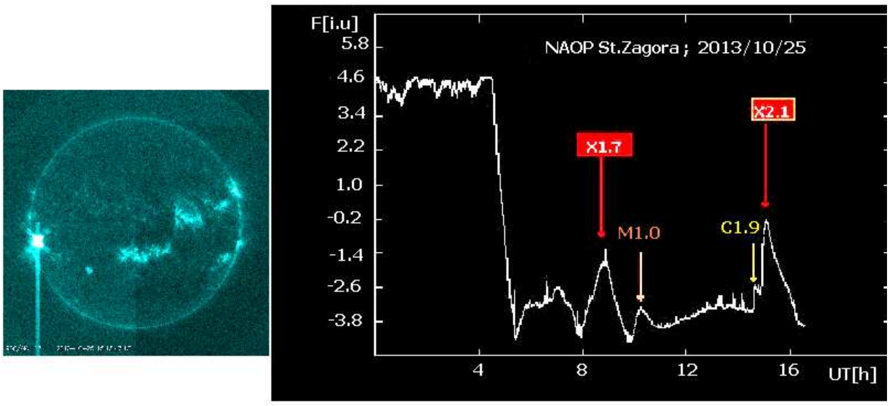

Fig. 7. Left: X2.1-flare on October 25,2013; Right: SID-event, caused by the flare (sdo.gsfc.nasa.gov/data/); Right: SID-event, caused by the flare

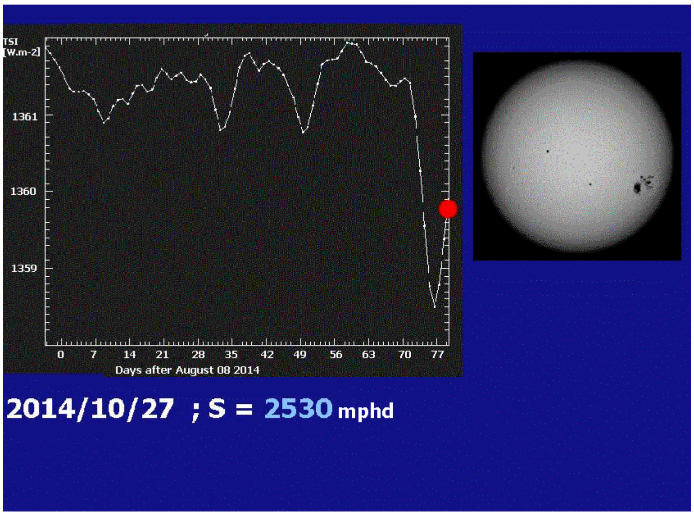

Fig. 8. The giant sunspot group AR12192 in October 27,2014 (right)(sdo.gsfc.nasa.gov/data/) and TSI reduction between October 17-29 (left)(lasp.colorado.edu/data/sorce/total_solar_irradiance_plots/images)

generated by this active region in September 04th. One of them was "moderate strong" by magnitude of M5.5. It was accompanied by a coronal mass

Fig. 9. Aurora Borealis over Alberta province (Canada); March 01, 2015 (solarham.net)

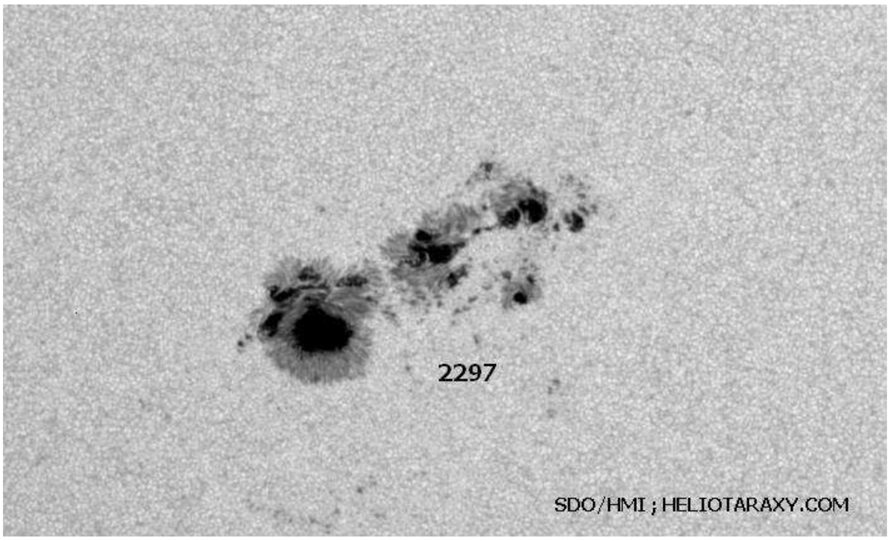

Fig. 10. Solar active region AR12297 in white light (sdo.gsfc.nasa.gov/data/)

ejection (CME) plus proton (SEP) eruption. The last one caused a radiation storm, which was supported by the followed solar proton events more than

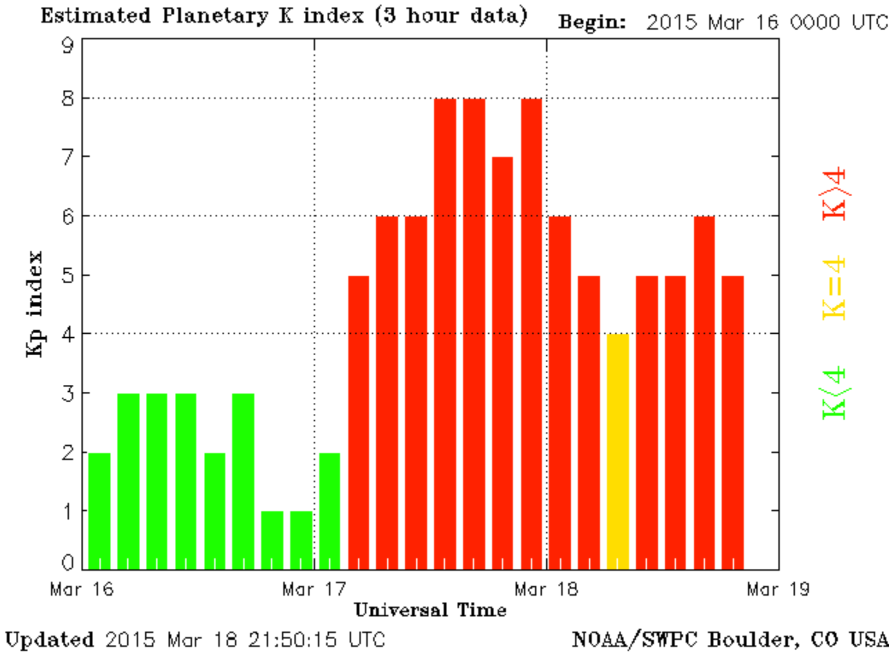

Fig. 11. The "Saint Patrick storm" (March 17-18, 2015)(services.swpc.noaa.gov)

a week. Two days later the main events have started, i.e. on September the 6th. First, at 09h10min UT, after pause of two years, the Sun "erupted" by X2.2 flare in region AR12673. The most powerful (X9.3) for the last 11 years (since Dec.05.2006) flare occured in the same region three hours later (in 12h05min UT)(fig.12).

This strong X-ray flare has been accompanied by proton (SEP) eruption. It supported the radiation storm beginning on September the 4th , which reach S2 level (i.e. moderate storm) (fig.13). The ejected during the X9.3 flare coronal mass (CME) cloud by very high initial velocity (1970 km/s) was characterized (fig.14). In the evening of September 07th this solar plasma cloud has reached the Earth and in the next hours a very strong geomagnetic storm (maximal $K_p = 8$) began. Aurora activity in the same time has been detected over Mexico (The probable connection between the solar - geomagnetic events and the strong earthquake by Richter magnitude M=8 in the same territory in the same time is not a subject of this study).

The next strong solar flare by magnitude of X8.2 was occured on September 10th, while active region 2673 was in position on the west side of solar limb (fig.15). It was accompanied by a bright coronal mass ejection (CME) and proton (SEP) eruption. Solar protons with energies of $E > 100$ MeV penetrate in the Earth lower atmosphere and the progressing radiation

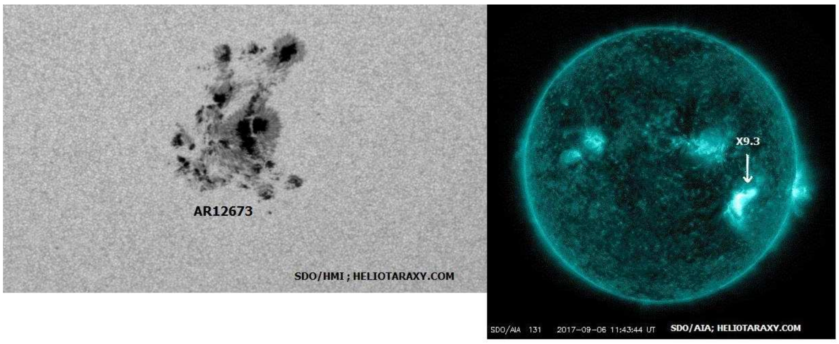

Fig. 12. Left: Solar active region AR12673 in white light; right: The X9.3 flare from region AR12673 (September 06, 2017)(sdo.gsfc.nasa.gov/data

storm reached S3 level (strong storm). The last one corresponds to a little risque for military as well as for civil aviation (both for avionics and people on the boards of aircrafts). The ejected from the Sun plasma CME cloud reached the Earth in the night on September 12th to 13th and caused a 6 hours long moderate planetary geomagnetic storm (maximal Kp=6).

How strong the solar flares in September 2017 have affected the atmosphere and surface of Mars? The active events, which are running on the Sun and in the interplanetary space in the beginning of September 2017 strongly affect the processes in atmosphere and the surface of Mars. The absence of significant planetary magnetic field as well as the very diluted atmosphere allow strong influence on the planet. The magnetosphere and relatively dense atmosphere on Earth are a very serious barrier for the penetration of high energetic particles to the surface The last one is possible if their kinetic energies exceeds 300-400 MeV. However in the case of Mars the lower energy threshold for reaching the Martian surface is only 1MeV. That's why the solar flares effects are much stronger and direct on Mars than our planet. Two cases of the influence of a strong solar flare from September 11th in Martian atmosphere and over the surface radiation conditions is shown on fig.16 and fig.17. The above mentioned flare is not observed from Earth.

In fig.16 (upper panel) the solar SEP flux, measured on orbit of the space probe MAVEN (Martian Atmosphere and Volatile Evolution) for the interval September 12-15 is shown. The radiation dose data, obtained by RAD instrument on board of Curiosity lander for Martian surface in the same period are shown on the bottom panel. An increasing in range of 2.5 times at September 11th in comparison to the previous date is clearly seen. It is related to the SEP flux increasing.

The vertical UV-emission Martian atmosphere profile for September 12th is shown in fig.17. It has been caused by solar coronal mass ejection (CME) a reaching Mars , most probably caused by the solar X8.2 flare from September 10th. As is visible it is about 25 times more powerful as the similar event from 8 of March 2015.

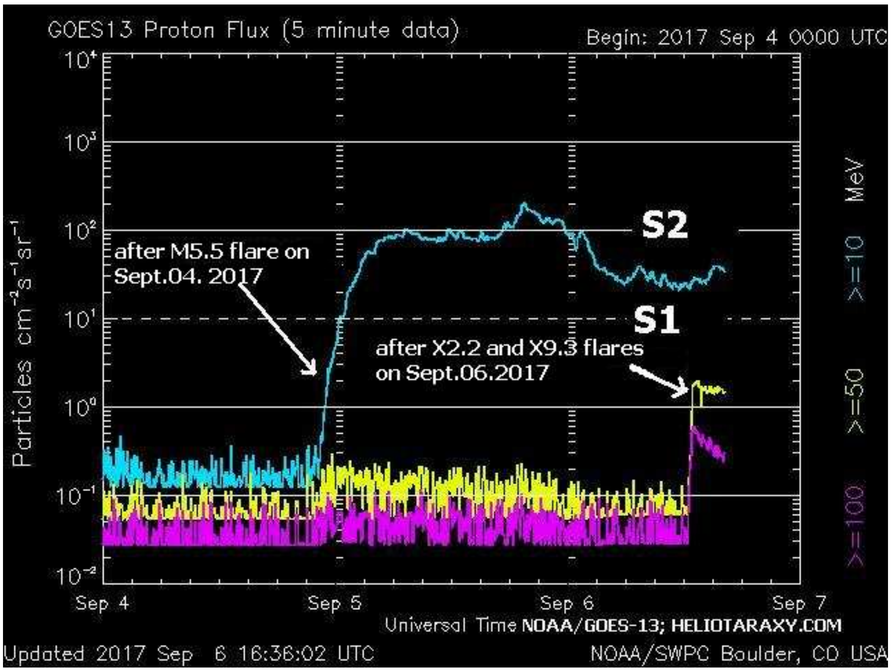

Fig. 13. Moderate radiation storm (S2 level) accompanied the X9.3 flare (September 06, 2017)(services.swpc.noaa.gov)

4.The 24th solar cycle and long-term solar and geophysical activity variations

4.1. Sunspot activity

The International sunspot number R_i - a modern version of "classical" Wolf's number is common not only for sunspots, but also for overall solar activity index.

Since July 01,2015 as an etalon for this index the observations of Specola observatory in Switzerland are used (Clette and Lefevre, 2015) . Their values are in average 1.5 times higher than the classical Wolf's number values. The new R_i index mean monthly values for interval January 1749 - October 2017 (SC0-SC24) are presented in fig.18. If take into account that SC24 started in January 2009 it suggests that the most part of the last one is already over. It is clearly seen from fig.18 that certainly the sunspot SC24 is weakest at least for the last 100 years and namely since SC14 or from Gleisberg-Gnewishev's secular minimum (1898-1923). However, de facto the 14th solar cycle (SC14) is slightly stronger than SC24 in the non-smoothed near maximal mean monthly values. The comparison with 11-year cycles in 19th century shows good similaties of the present cycle with SC12 (1879-1889) as well as SC6(1810-1823 AD), which is in the middle part of supercenturial Dalton minimum (1794/98 - 1833 AD).

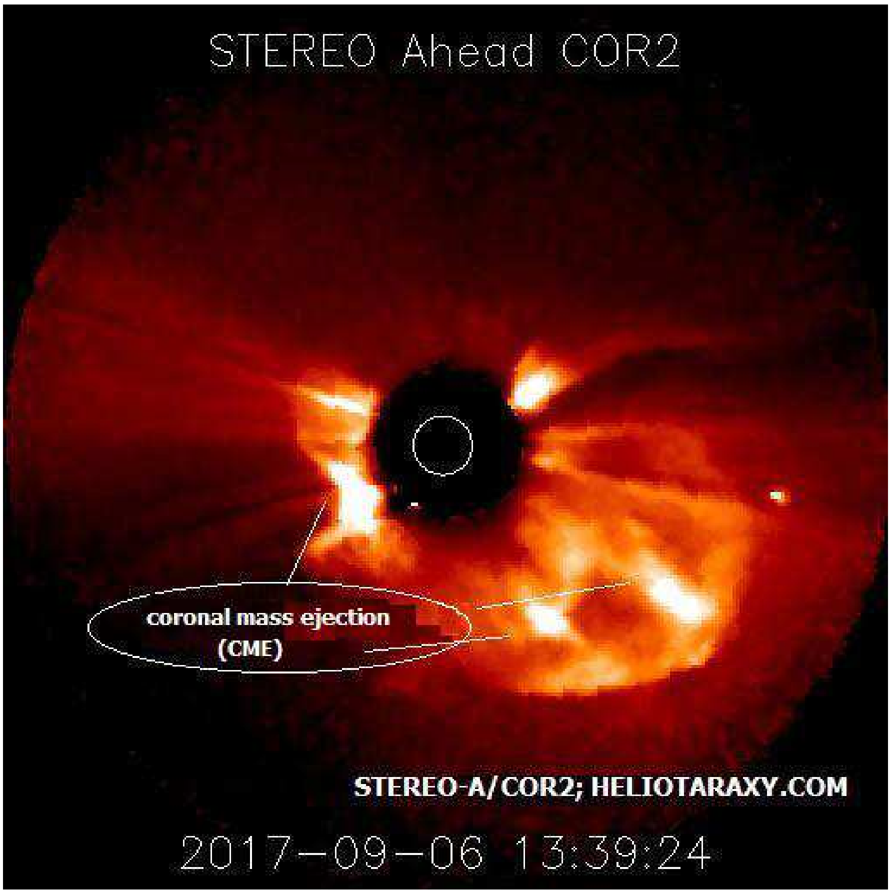

Fig. 14. Coronal mass ejection (CME) during the X9.3 flare - an image by COR2 coronograph on board of STEREO-A spacecraft (September 06, 2017)(stereo.gsfc.nasa.gov/browse/2017/09/06/ahead/cor2/512/thumbnal)

Consequently, by its amplitude SC24 is very similar to the sunspot cycles in the beginning of 20th or in the beginning of 19th centuries. In any case there is an indication, that SC24 is a part of an relatively low sunspot activity epoch, which contains at least two, but most probably more than two sunspot cycles. The start of a long term downward sunspot activity tendency as it is shown in fig.18 corresponds to the declining phase of SC22, i.e. between 1991/92 and 1995 AD.

4.2. Radioindex $F_{10.7}$

As it is well known, the radio index $F_{10.7}$ is well correlated with the solar X-ray and UV radiation as well as with the solar eruptive activity. The mean monthly $F_{10.7}$ values since January 1950 until October 2017 are shown in

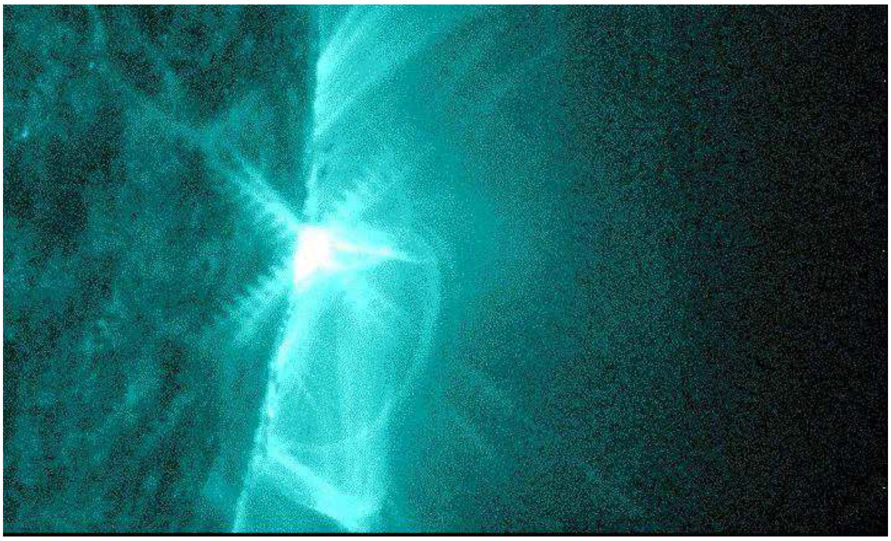

Fig. 15. X8.2-flare on the solar limb (September 10, 2017)(sdo.gsfc.nasa.gov/data/)

fig.19. The first 3 years of $F_{10.7}$ measurements (Feb.1947-Dec.1949) were excluded because of the significant data lack. Thus the studied data series includes a significant part of SC18 downward phase, whole solar cycles SC19-SC23 and the larger part (80% - 85%) from SC24. It is shown in fig.20 that SC24 is the weakest from all last six 11 year solar cycles. As in the case of sunspot activity a downward F10.7 trend after 1992-1995 AD is clearly traced.

4.3. Solar Wind

In fig.20 the smoothed 27-days solar wind flow pressure data SWp near to the Earth are shown (Svalgaard, 2017). Except weak expressed 11yr cycles a clear downward tendency after the very strong maximum of SWp related to SC22 in 1991 AD is clear shown. The present solar cycle SC24 is the weakest between the last fifth ones (SC20-SC24), i.e. during the whole epoch of instrumental solar wind observations.

4.4. Galactic cosmic rays (GCR)

The galactic cosmic rays flux (GCR), which reaches Earth atmosphere strongly depends on solar wind flux changes. This causes the so called "Forbush effect" - the observed anti-correlation between sunspot activity and GCR - flux. Extremely strong manifestations of this phenomena are labeled as "Forbush- decreases". They occur as obscured effects (from 3% to more than 20%) of GCR flux caused by massive coronal mass ejections (CME), which accompanying the strong solar flares. The last one is very clear shown

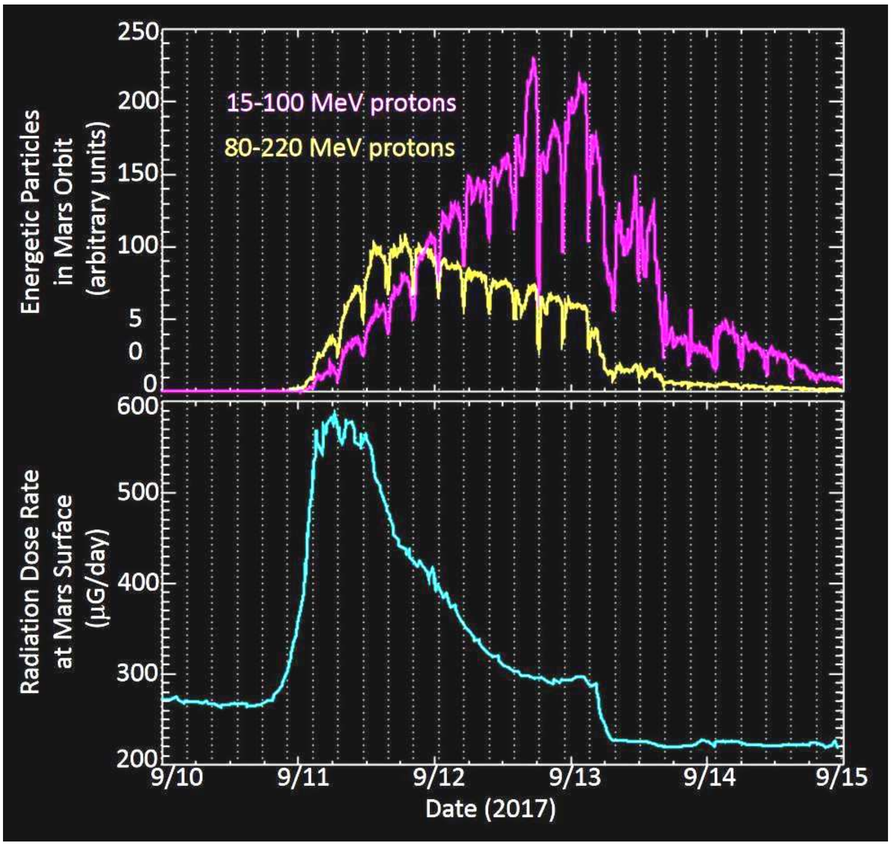

Fig. 16. Top: SEP-flux, measured by the MAVEN orbital module; bottom: the Martian surface radiation doze, measured by RAD-instrument on board of "Curiosity" lander (September 09-16, 2017)(nasa.gov/mission_pages/maven)

in fig.22 where the data of IZMIRAN neutron monitor in Troitsk (Russia) are presented. The deep minimum appeared in 1991 AD is related to the high flare activity and a large number of "Forbush decrease" events during the same year. The start of GCR-flux upward trend in the first half of 1990st is in a very good agreement with our above mentioned conclusions about the start of long term downward solar activity tendency almost immediately after SC22 maximum.

4.5. Geomagnetic *AA*-index

The geomagnetic SC24 is the weakest one since 1868 AD, i.e. since the systematic 3-hour, diurnal and monthly *AA*-index data series existed. A super centurial *AA*-index maximum near to the end of 20th century is clear shown in fig.22. The last one reached near to the maximum of SC22 and

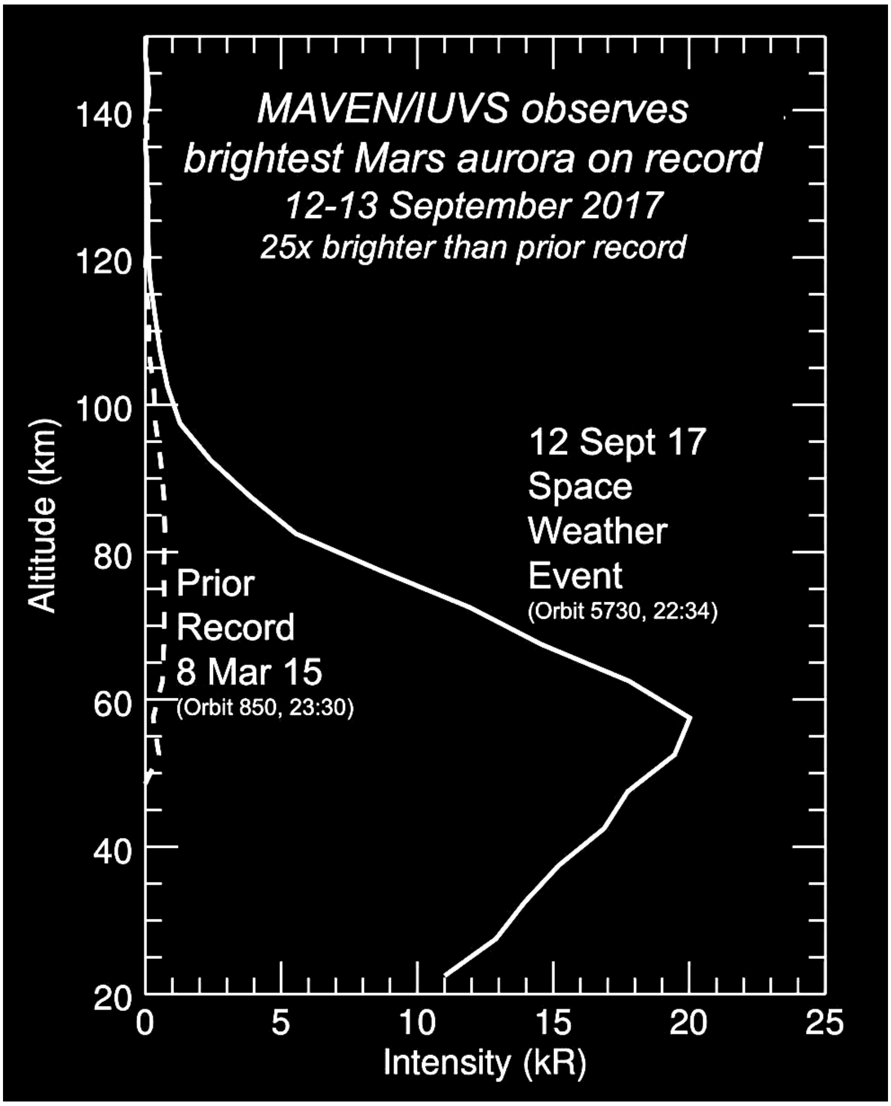

Fig. 17. The vertical UV-emission Martian atmosphere profile on March 08,2015 and September 12, 2017 (nasa.gov/mission_pages/maven)

after that a downward tendency began. Solar cycles 23rd and 24th (SC23 and SC24) are positioned over this downward tendency.

The "sunspot activity - geomagnetism" relationship is the first proved one between all solar -terrestrial connections,but it is far not so strong and stable in time. As it is shown in fig.23 the coincidence of both minima of quasi 11yr sunspot and geomagnetic cycles is the most certain moment

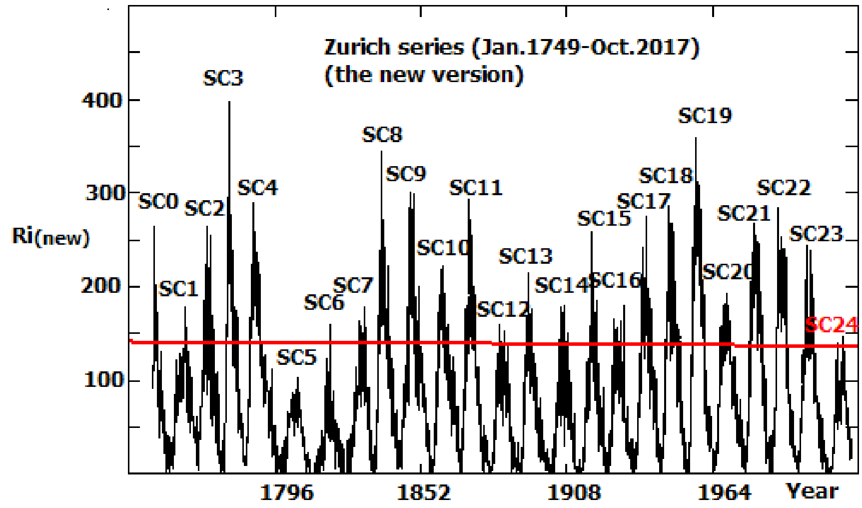

Fig. 18. The Zurich sunspot series (new version; 1749-2017)(Clette and Lefevre, 2015)

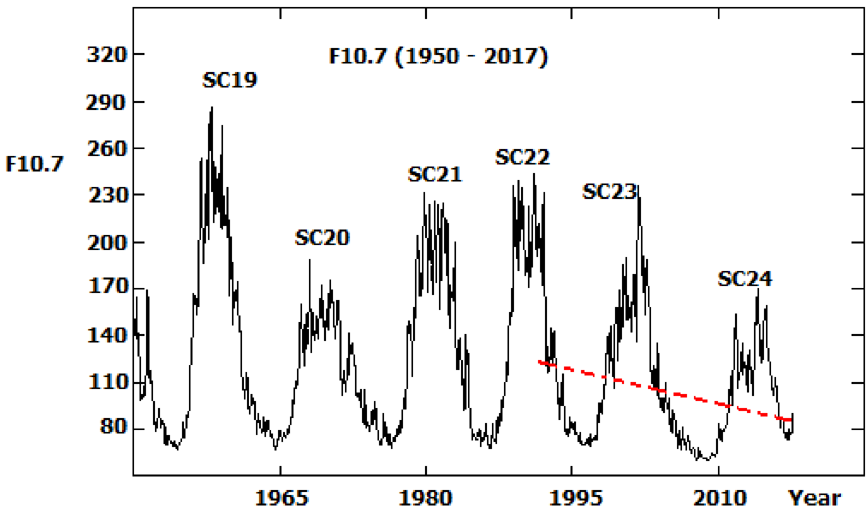

Fig. 19. Solar radioindex F10.7 (1950-2017)

in this relationship. On the other hand, usually there could be significant difference between 11 year maxima of sunspots and geomagnetic activity. In general the geomagnetic activity peak delayed relative to sunspot one in 1 to 3 years.

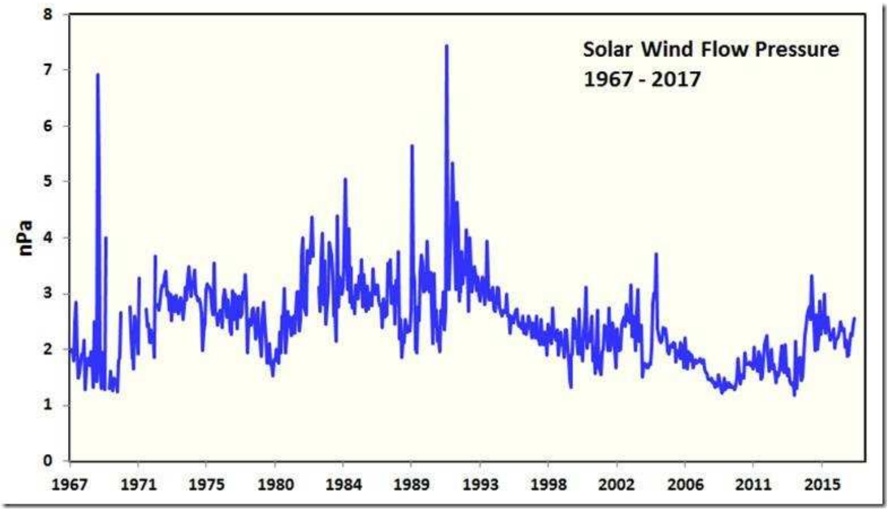

Fig. 20. Solar wind flow pressure (1967-2017 AD) (Svalgaard, 2017)

Fig. 21. The galactic cosmic rays flux, measured by the Moscow neutron monitor (IZMIRAN institute, Troitsk, Russia)(1958-2017 AD)

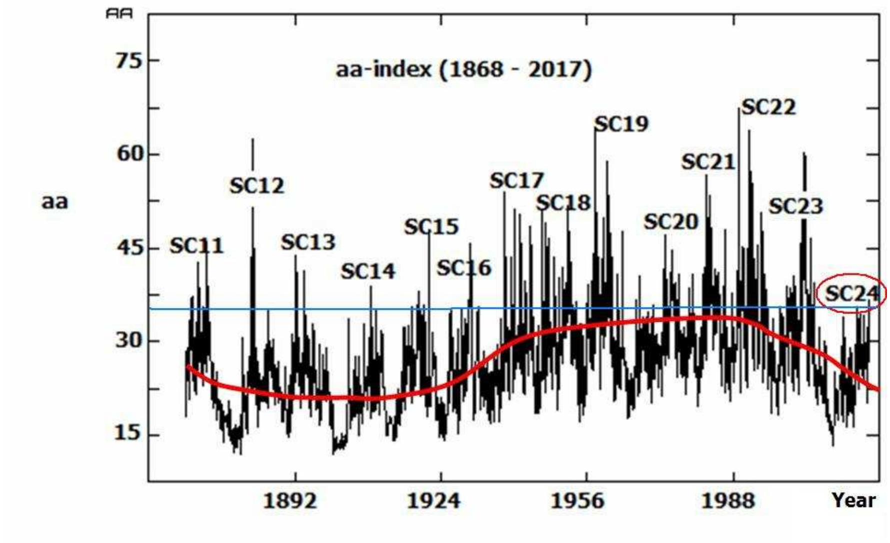

Fig. 22. The geomagnetic AA-index (1868-2017 AD)

As it is shown in table 2 the coefficient of linear correlation r between the mean monthly sunspot number R_i and the geomagnetic AA-index is very variable between one 11yr cycle to the other. The correlation coefficient r was highest at the beginning of AA-time series, namely for SC11.

It remains statistically reliable until the end of Gnevishev-Gleissberg minimum, i.e. including SC15 (1913-1923 AD). It is non-reliable for the next three solar cycles (SC16, SC17 and SC18). The relationship $R_i - AA$ increases rapidly for solar cycle 19th (SC19), but completely disappears for the next even-odd pair 11yr cycles (SC20 and SC21). The relationship strongly increases during SC22 and remain relative strong (r=+0.386; $|r/sr|$=5.27, where $sr = 1 - r^2/sqr(N)$, where N is the length of data series) for SC23. For the present solar cycle r falls again, but remains reliable.

It is easy to explain this non-stability of $R_i - AA$ relationship. The sunspots itself can not cause geomagnetic phenomena. The solar flares and accompaning coronal mass ejections (CME) are the primary sources for many of the geomagnetic disturbances and storms. The sunspots are visible in white light parts of active regions. But there are many additional conditions that are important, namely: First, solar flares sources are not all sunspot groups; second, not all flares, even if they be powerful, are certainly connected to the coronal mass ejections; third, the coronal mass ejection could reach Earth if the corresponding solar active region is in geoeffective position. The last one signs in very raw approximation that during the flare

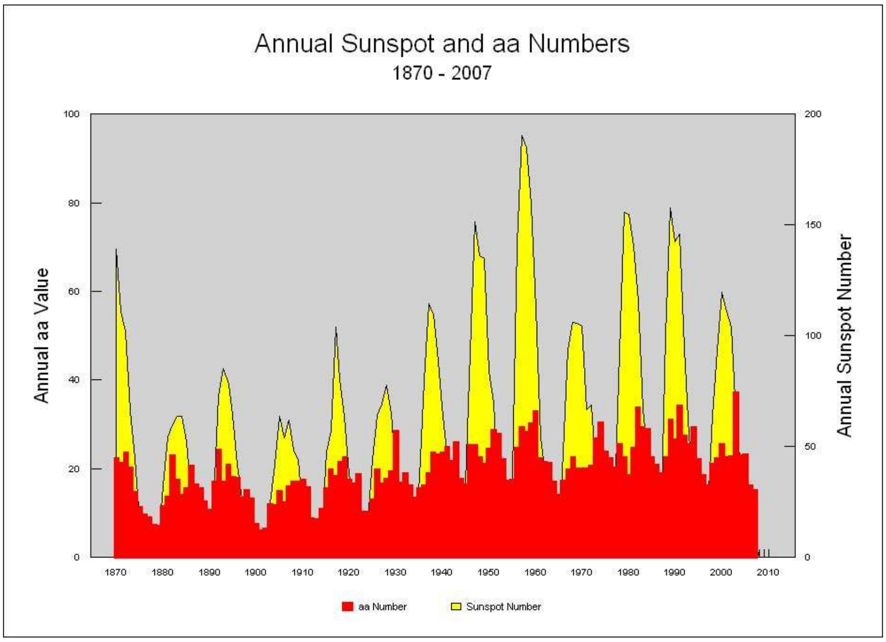

Fig. 23. Annual values of the International sunspot number (old version, yellow filled) and geomagnetic AA-index (red filled)(1870-2008 AD)

active region should be seen in the central parts of solar disk, as observed from Earth. On the other hand it should be taken into account, that a significant part of geomagnetic events are caused by other solar factors - coronal holes, eruptive protuberances, sector boundaries of interplanetary magnetic field etc. Some of these factors reach their maxima in other phases of 11 year solar cycle, which are different from the sunspot maximum. For example, the solar coronal holes are best expressed in downward phases of sunspot cycles - usually 3-4 years after the sunspot maximum. All circumstances mentioned above "wash away" the "sunspots - geomagnetism" relationship.

4.6. Solar X-ray flares

The SC24 power to previous solar cycles in relation to the most important eruptive events, such as X-ray and optical flares, radiobursts and eruptive protuberances has also been compared. For this aim the quasi-real time (between 5 and 30 min) bulletins, published by NOAA Space Weather Prediction Center in Boulder has been used (http://www.swpc.noaa.gov/products/solar-and-geophysical-event-reports). The publication of these bulletins has started in 1996 AD, i.e. approximately at the beginning of SC23.

That is why our analysis includes only both last cycles, i.e. SC23 and SC24. Based on the published bulletins data time series for 8 types eruptive

Table 2. Coefficients of linear correlation "r" between monthly values of Ri (new version) and AA-index for solar cycles No11 to No24

Solar cycle (SC)	r	$\|r/sr\|$
11	0.745	19.16
12	0.349	4.49
13	0.622	12.21
14	0.469	7.19
15	0.433	5.84
16	0.150	1.70
17	0.134	1.53
18	0.103	1.14
19	0.498	7.38
20	-0.013	0.15
21	0.026	0.28
22	0.404	5.57
23	0.386	5.27
24	0.190	2.03

solar events have been organized (X-ray flares, optical flares, radiobursts for $f > 200$ MHz, "ten-flares",i.e. radiobursts at f=2695 MHz, radiosweeps, eruptive protuberances on solar disk and on limb and "loop" prominences). For X-ray flares these data series have been extended in the past with data from GOES satellites since August 1976 AD (published in National Geophysical Data Center) as well as with modeled ("synthetic") data for the epoch January 1968- August 1976 (Komitov et.al.,2015). The radiobursts data series from Sagamore Hill (USA) are even longer in the past - since 1965 AD.

Firstly, an analysis of X-ray solar flares will be made. For best discovery of more details they are separated in relation to their power classes . In fig.24 the monthly sums of C-class flares (N_C) are shown. The monthly number of C-class flares decreases since the beginning of 1980th , i.e. after SC21 maximum. The 24th solar cycle is positioned over this downward tendency and it is the weakest one in comparison with the last four 11-year cycles, for which observational satellite data exist, i.e. SC21-SC24. However if SC20 is also included (the monthly numbers for which in "synthetic" series of Komitov et al.(2015)are given), it turns out that SC24 is the weakest one from the last five 11-year cycles in relation to the C-lass flares. There is a similar situation for the middle X-ray class M monthly number (N_M)as well as for the strong X-class flares (N_X) (see fig.25 and fig.26, respectively). However the downward tendencies for M and X class have started not since SC21, but since the descending phase of SC22. The total monthly flare number (N_{C+M+X}) (i.e.C+M+X classes)time series is very similar to the "pure" C-class series because of dominant relative part of C fares in comparison to both other more powerful classes M and X (fig.27).

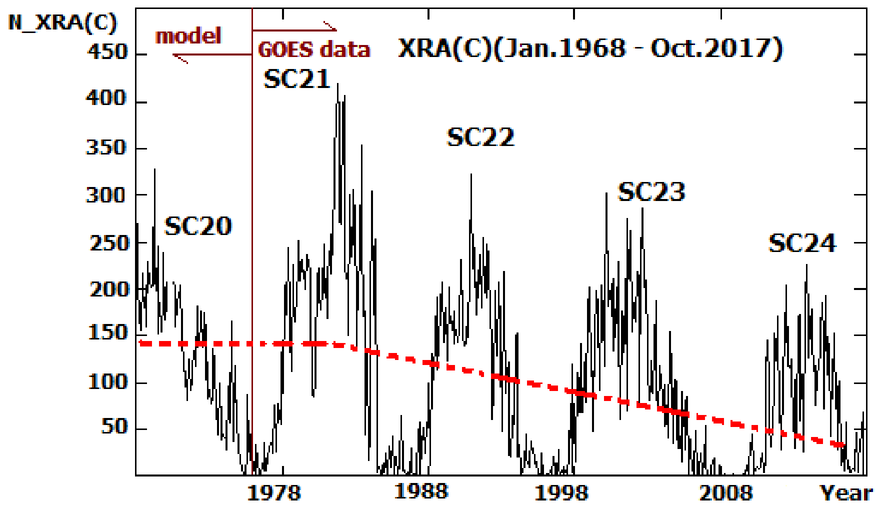

Fig. 24. The monthly numbers of C-class X-ray flares (1968-2017 AD)

In fig.28 the 132 months (11 years) smoothed ratios N_M/N_{C+M+X} and N_X/N_{C+M+X} are shown. Clear downward trends are visible for both quantities , which started since downward phase of SC20 in the beginning or in the middle of 1970th and continuing in 21st century, including SC24. It is better shown for X-class flares (the bottom panel).

In table 3 the distribution of very strong solar flares (so called "mega-flares") is shown. The lowest power index for them is X9.0. The solar activity is defined as "very high" if at least one "mega-flare" or at least 5 flares by power of M5.0 or higher have occured in the range of 24 hours. There are totally 27 "mega-flares" since the beginning of GOES satellites regular solar X-ray flux observations in 1976. From all of them only one (from September 6th , 2017) belong to SC24 and its power index (X9.3) is very close to the lower power limit for "mega-flare". It indicates roghly that in relation to the eruptive activity SC24 is the weakest one compared to the previous three solar cycles (SC21-SC23).

In table 4 the coefficients of linear correlation r between monthly numbers for every C,M and X classes plus the total monthly sums of all flares (N_C ,N_M, N_X and N_{C+M+X})and geomagnetic AA-index for every 11yr solar cycle since 1976 AD are shown. The relationships between solar flares numbers and geomagnetic activity are essentially stronger than these between sunspots and geomagnetism. Unlike table 3 all correlation coefficient values in table 4 are statistically significant by probability 95% or higher,

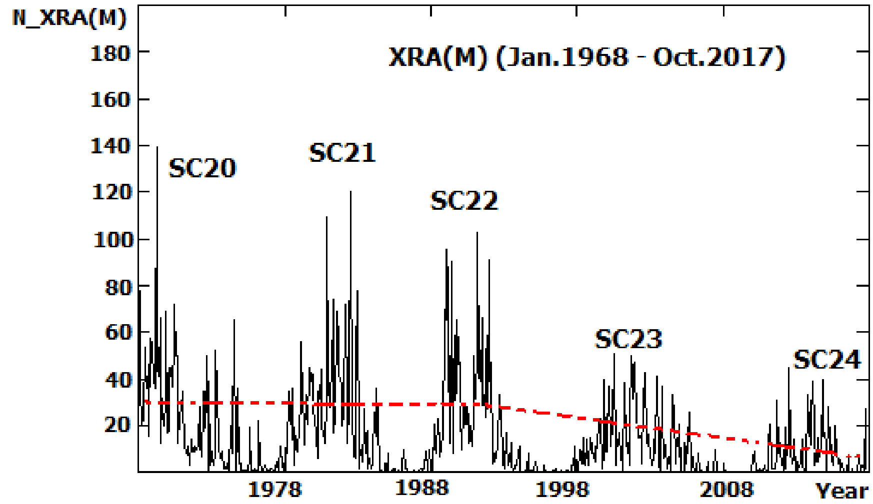

Fig. 25. The monthly numbers of M-class X-ray flares (1968-2017 AD)

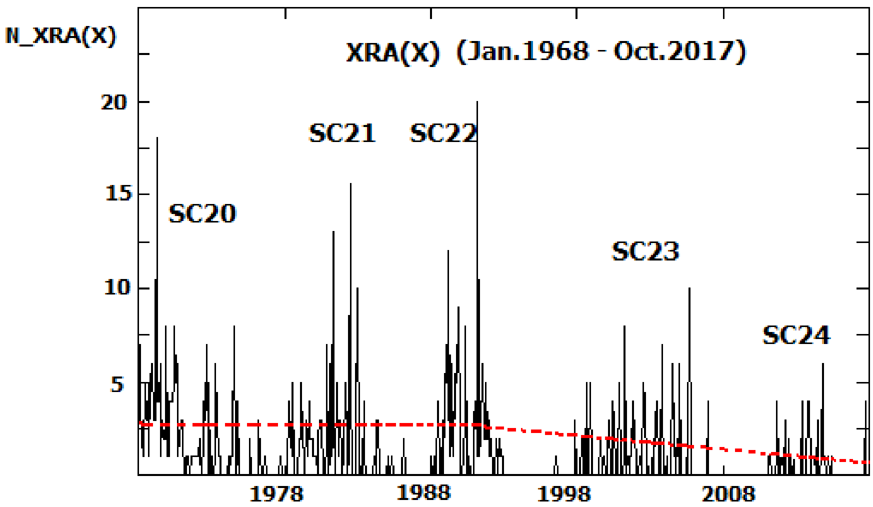

Fig. 26. The monthly numbers of X-class X-ray flares (1968-2017 AD)

i.e. $|r/sr| > 1.96$ This is due to the circumstance that real primary solar sources of geomagnetic activity are not the sunspot groups, but the flares which occur in that regions. As is shown in table 4 the strongest relationships between flare numbers and AA-index are during the solar cycles

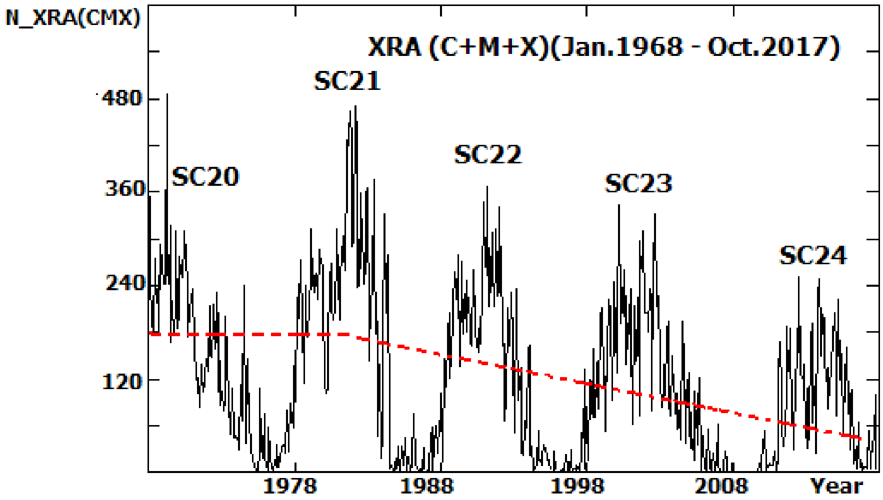

Fig. 27. The monthly numbers of C+M+X-class X-ray flares (1968-2017 AD)

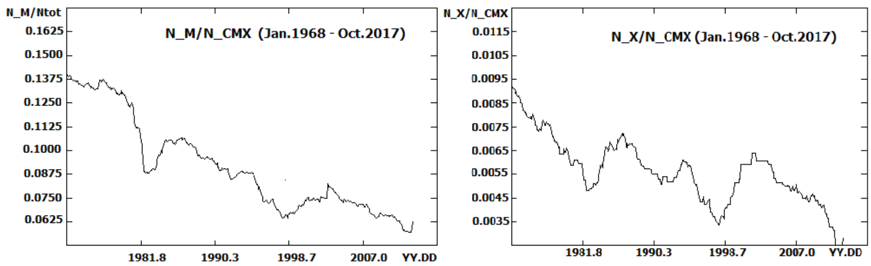

Fig. 28. The relative parts of M-class (left) and X-class (right) flares to the total number of C+M+X class flares (smoothed 132 months values; 1968-2017 AD)(Komitov et al., 2015)

22nd and 23rd (SC22 and SC23) and the weakest one is during the present SC24. SC20 isn't included there because the data used for them are not from observations, but from a statistical model.

Table 4 The coefficients of linear correlations between monthly numbers of X-ray flares from power classes C, M, X and geomagnetic AA-index during the epoch of GOES satellites observations (since 1976 AD)

4.7. Solar optical flares

The used there monthly number solar optical flares series contain data only for both last 11yr solar cycles SC23 and SC24. As is shown in fig.29 the

Table 3. Number of "mega-flares" (X9.0+) during the epoch of GOES satellites observations (since 1976 AD)

Solar cycle (SC)	X20+	X10-X19.9	X9.0-X10
21	0	6	2
22	1	7	3
23	2	3	2
44	0	0	1

Table 4. The coefficients of linear correlations between monthly numbers of X-ray flares from power classes C, M, X and geomagnetic AA-index during the epoch of GOES satellites observations (since 1976 AD)

Flare	SC21		SC22		SC23		SC224	
Class	r	$\|r/sr\|$	r	$\|r/sr\|$	r	$\|r/sr\|$	r	$\|r/sr\|$
C	0.300	3.57	0.347	4.30	0.433	6.55	0.245	2.68
M	0.276	3.25	0.453	6.22	0.474	7.50	0.332	3.84
X	0.284	3.36	0.437	5.90	0.527	8.98	0.194	2.07
C+M+X	0.314	3.79	0.395	5.11	0.457	7.10	0.265	2.93

number of optical flare events in SC24 is essentially lower than in SC23. The starting date is January 01,1997 and the month numbers after that are labeled on X-axis. The connection of these data with the old ones, which started since 1976 AD is planned.

4.8. Solar radiobursts and radiosweeps

Systematized and continuous information about solar radiobursts in MHz and low GHz ranges in National Geophysical Data Center for some stations (for example Sagamore Hill, Massachusetts, USA) have started since the middle of 1960s. For other ones, like Learmonth (Australia), the start of continuous quiring data is in 1970s. For the last 20 years, since 1997 AD, the exclusive bulletins in quasi-real time of Space Weather Prediction Center (SWPC) are used. The monthly numbers of radiobursts at f=410MHz, observed in Learmonth during the last four 11-year solar cycles (SC21-SC24) are shown in fig.30. There is a very strong downward tendency, which is traced for the whole time series. Thus SC24 is the weakest one for the whole epoch of these observations. However, the downward tendency is valid not only for the above mentioned station and frequency, but for all other radiobursts series, which has been studied.

As an additional example the monthly numbers of radiobursts at f=2695MHz (so called "ten-flares") from Sagamore Hill station are shown in fig.32. Ten-flares are taken as risk - indicators for wide range of technical infrastructure, which works in the low GHz-range (digital TV, internet,

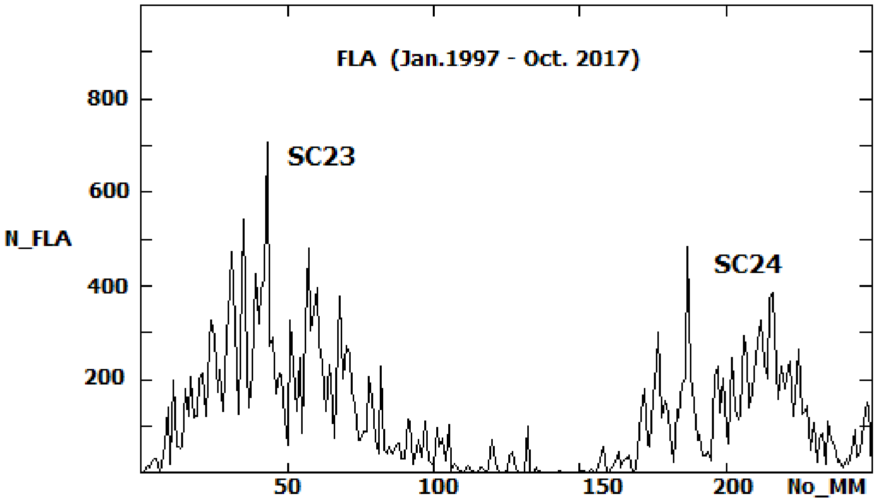

Fig. 29. Monthly numbers of optical flares during the solar cycles No23 and 24 (SC23 and SC24; initial date is January 01,1997)

mobile phone communications etc.). A very strong downward tendency of "ten-flares" is shown in fig.31. It is traced even in the declining phase of SC20 in 1970th . As for X-ray solar flares the Sun is much more quiet in radio range relative to the middle and the end of 20th century. It is very important conclusion, because it shows that the risks for radio-technical instruments working in MHz and GHz - ranges has been essentially decreased in last two decades. However, there is also a lucky circumstance - the most of the corresponding technical infrastructure is relative new and it has been built namely during the last 30 years. The question - what will occur when the long term tendency of the solar radiobursts changes from downward to upward is open. On the other side strong sporadic radiobursts and corresponding risk situations even in the weak solar cycles are possible too.

The 24th solar cycle is slightly poorer of radiosweeps as the previous SC23 (fig.32). Radiosweeps are radiobursts with variable frequency. They accompany the coronal mass ejections (CME) during the solar flares (type II radiobursts) or the solar proton events (type IV).

4.9. Eruptive protuberances

In fig.33 the monthly numbers of eruptive protuberances on solar disk and in fig.34 the eruptive protuberances on solar limb are shown. These are phenomena the only type of investigated solar events for which SC24 is anger than the previous SC23. However the number of loop prominences on limb during the solar cycle No 23 is higher than solar cycle No24 (fig.35), i.e. for these events SC24 is weaker than SC23.

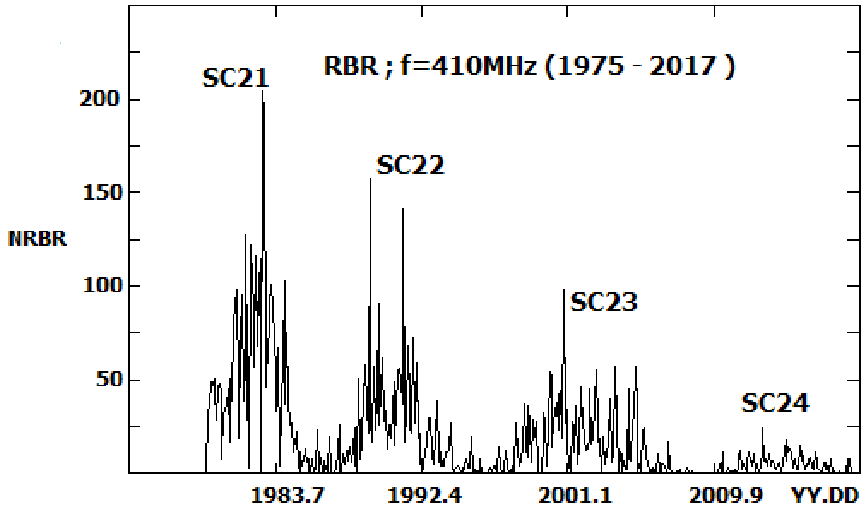

Fig. 30. Monthly numbers of radiobursts at $f=$ 410MHz during the solar cycles from No 21 to 24 (SC21-SC24; Learmonth, Australia)

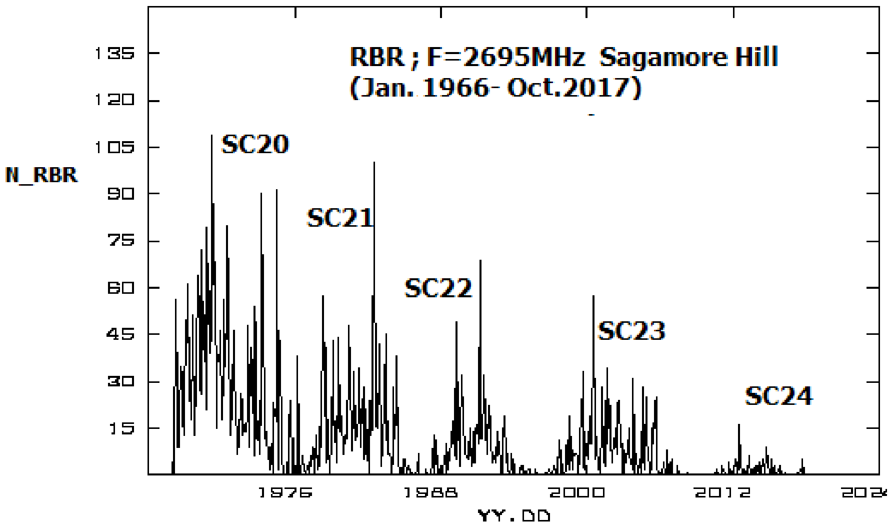

Fig. 31. Monthly numbers of radiobursts at $f=$ 2695MHz (ten-flares) during the solar cycles from No 20 to 24 (SC20-SC24; Sagamore Hill, USA)

4.10. Polar magnetic fields. The next three solar cycles SC25, SC26 and SC27

An important indicator of 11 year solar cycles power are the Sun near polar magnetic poles intensities during the sunspot minima epoch. According to

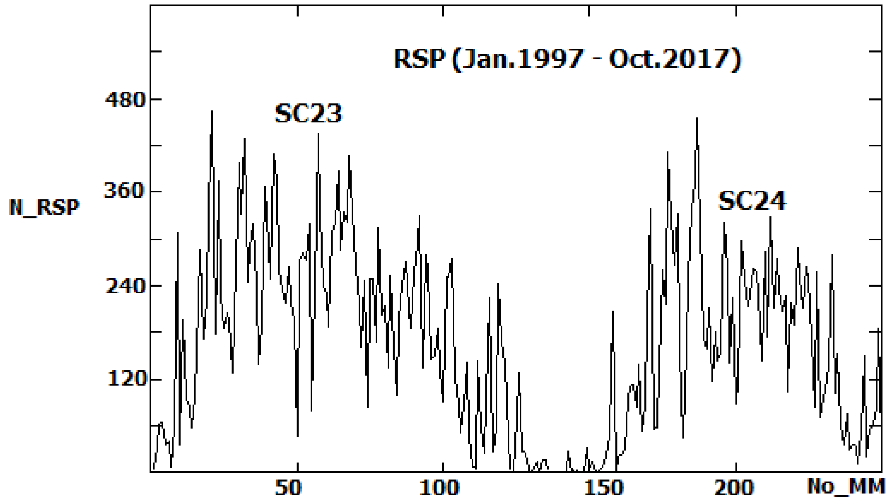

Fig. 32. Monthly numbers of radiosweeps during the solar cycles No23 and 24 (SC23 and SC24; initial date is January 01,1997)

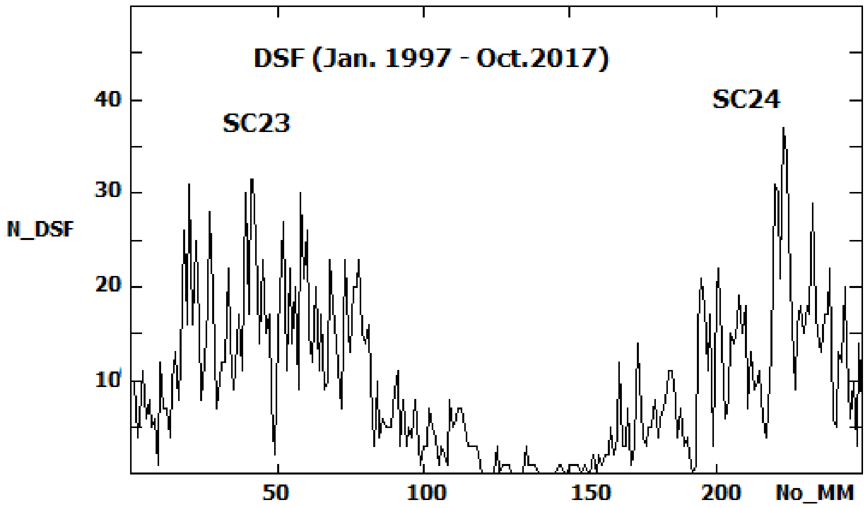

Fig. 33. Monthly numbers of eruptive protuberances on solar disk during the solar cycles No23 and 24 (SC23 and SC24; starting date is January 01,1997)

the "solar dynamo" theory the most powerful polar magnetic fields during the 11-year sunspot minimum corresponds to the most powerful coming

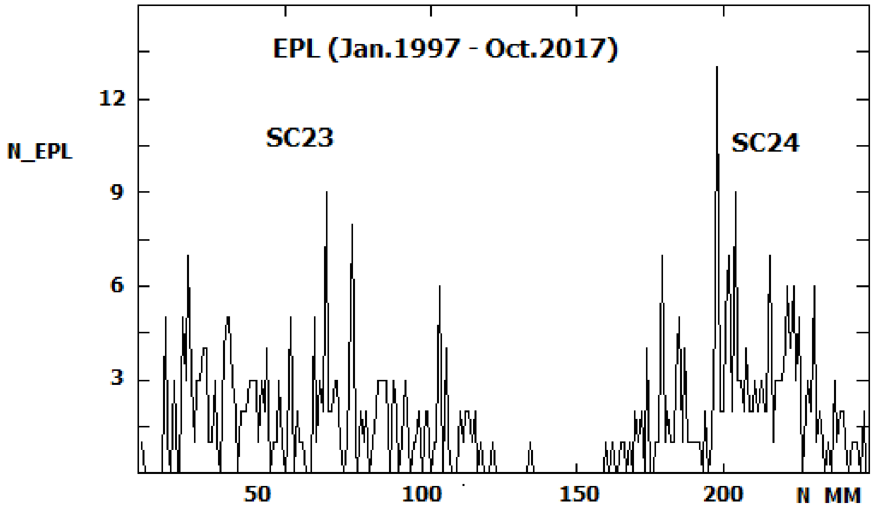

Fig. 34. Monthly numbers of eruptive protuberances on solar limb during the solar cycles No23 and 24 (SC23 and SC24; starting date is January 01,1997)

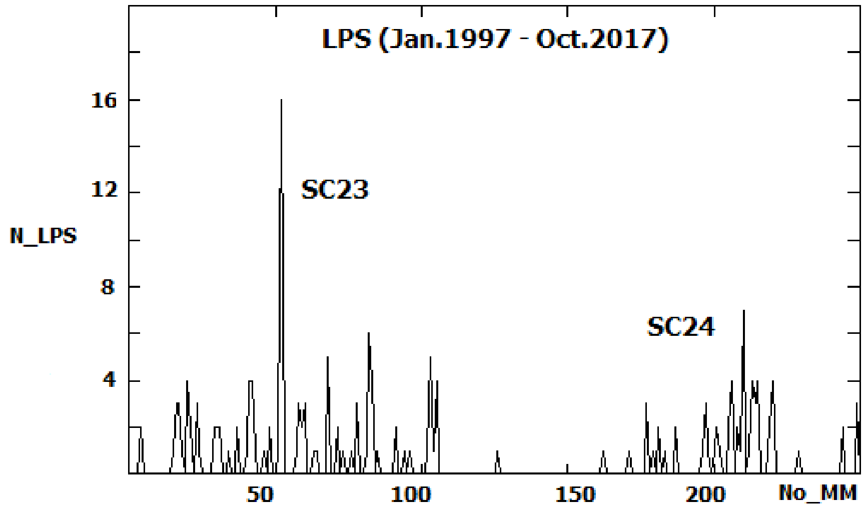

Fig. 35. Monthly numbers of loop prominences on limb during the solar cycles No23 and 24 (SC23 and SC24; starting date is January 01,1997)

11 year sunspot maximums. It is shown in fig.36 that the Sun near polar magnetic fields intensities are already close to their maximum, but it is

relatively low. Consequently it needs to expect weak sunspot cycle No 25 (SC25) or at least the last one could be slightly higher than SC24.

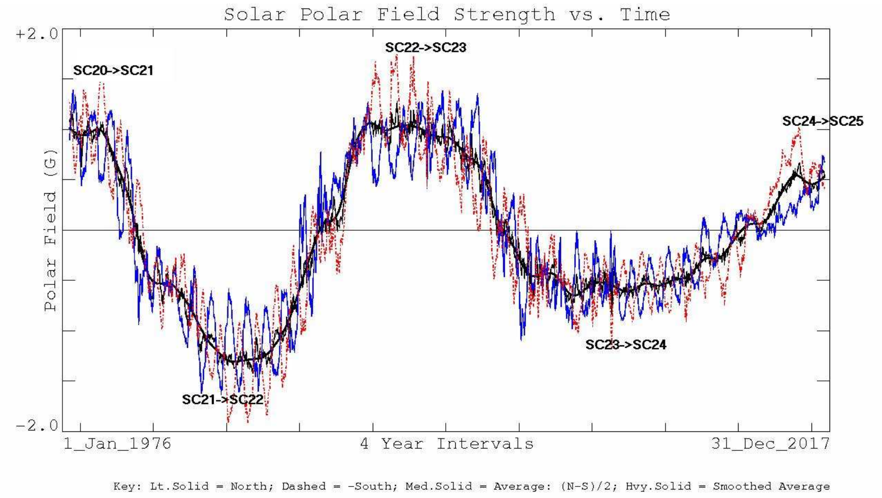

Fig. 36. Sun polar magnetic fields strengths (thin solid - north; red dashed -south; thick bold -mean)(Svalgaard, 2017)

An additional independent forecast for basic parameters of the next three sunspot cycles (SC25-SC27) has been provided. The old version of International Sunspot Number (Ri_{old})), which corresponds to the original Wolf's number has been used as sunspot index for the almost whole Zurich sunspot series (1749-2014 AD)(Komitov,2015). (The corresponding results were presented in regional workshop in February 2015 [Komitov,2015). The T-R periodogramm procedure for discovery of cycles and building of kinematic model of time series was used (Komitov 1997). The last one is presented in fig.37. It is shown that SC24 as well as the next five 11-year over a long-term low solar activity tendency such as minimum of Dalton or Gleissberg-Gnevishev are placed. It is shown also that SC24 and SC25 are very similar in power in this model, but slightly stronger is the solar cycle 24 (SC24). Thus for the pair "even-odd" sunspot cycles No 24 and 25 a weak violation of amplitude "Gnevishev-Ohl's rule" could occur according to the extrapolation of our model. On the other hand it is shown in fig.37 that the amplitude of SC26 is almost equal to SC24, but the following solar minimum before next SC27 is very shallow. Thus it is expected that SC27 will start significantly earlier than SC26 ending. As a result the both cycles will look almost as a general 20-22 year wave.

The look of such shallow sunspot minimum is demonstrated in fig.38. Most probably there will have a simultaneously existence in near-equatorial latitude zone of regions with the magnetic polarities of the older outgoing solar cycle No26 (SC26) plus regions with magnetic polarities (reversed to

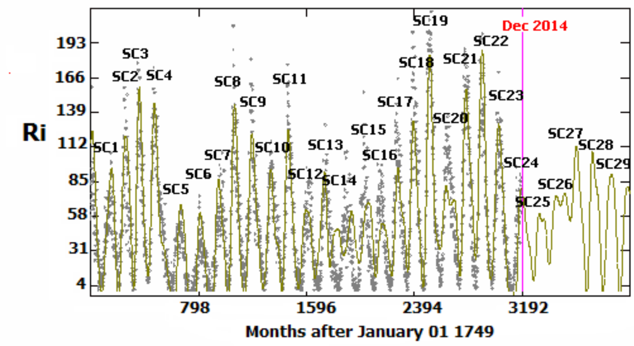

Fig. 37. Kinematic model of Zurich sunspot series (old version; 1749-2014) on the base of T-R periodogramm analysis and its extrapolation up to SC30 maximum (2080 AD)(Komitov,2015)

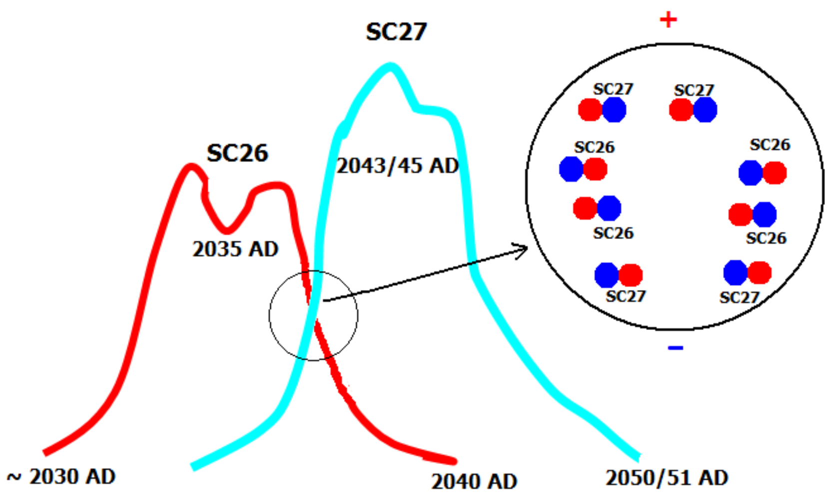

Fig. 38. An example for possible picture of SC26 and SC27 active regions superposition during the sunspot minimum between the both cycles

SC26-regions) of the new 27th solar cycle on higher latitudes. The simultaneous presence of active regions from two adjacent sunspot cycles during the epochs of their minima is not a precedent. However, in this case it can expect that the above mentioned phenomena will be essentially stronger expressed than as usual.

It is interesting to point out that in some other long term solar activity predictions SC26 is considered as a very peculiar epoch. According to one of these forecasts, which is based on "solar dynamo" theory, the SC26 amplitude will very close to zero. Thus between 2035-2040 AD on the Sun will be a situation very similar to Maunder minimum at the end of 17th century. In our opinion extreme situation shouldn't occur and some arguments for this one are given below.

5. Discussion

5.1. The 200-210 and 2200-2400 yr solar cycles

The long-term solar activity analysis, based both on instrumental and historical data ("cosmogenic isotopes" ^{10}Be and ^{14}C, ancient and medieval manuscript messages for aurora, giant susnspots, bright comets etc.) shows, that grand solar activity minima during the 21st century should be of "Dalton-type" (Komitov and Bonev 2000,2001), (Komitov and Kaftan, 2003,2004,2013), (Bonev et al., 2004). It is related to 200-210 yr solar cycle, very often labeled as "Suess-cycle" (Suess, 1980) or "De Vries oscillation" (de Vries, 1958), but before the others solar cycle with quasi-200 yr duration has been established by Anderson (1954), Schove (1955) and Bonov (1957). The last one has been discovered in almost all historical solar activity and climate data series (Schove, 1955,1983), (Stuiver and Quay, 1980 (Damon and Sonett,1991), (Dergachev and Chisyakov, 1993),(Fyodorov et al., 1995), (Rasspopov et al., 2008).

However, there is an amplitude modulation of deVries/Suess-cycle by the quasi-bimillenial solar 2200-2400 yr cycle (Hallstadtzeit)(fig.39). During both higher phases ("plateau" and main maximal phase) the amplitude of 200-210 yr cycle is lowest, while during the minima (Maunder-type epochs) it is higher (fig.40)(Damon and Sonett, 1991), (Komitov and Kaftan, 2013). In modern epoch (2000 AD) the 2200-2400 yr solar cycle ended its initial active phase since the end of Maunder minimum (1640-1720 AD) and the continuous relative still phase "plateau" has started. As it is shown in fig.40 it corresponds to essentially decreasing of 200-210 yr cycle amplitude and minimum of the last one in approxymately 2060 AD.

That is why the new supercenturial solar minimum will not be so deep as Spoerer and Maunder minima in 15th and 17th centuries correspondingly. By its depth it will be similar rather to Dalton minimum or the supercenturial solar minimum during the first calendar millennium. (Komitov and Bonev, 2001).

According to all studies for long-scale solar activity variations, based on historical data and concerning the solar 2200-2400yr (Hallstadtzeit) cycle, its last minimum corresponds either to Maunder minimum (1640-1720) or the epoch between 1400 -1700/1720 AD. The last one includes both deepest 200-210 yr solar cycle minima on the last 2000 years - these of Spoerer

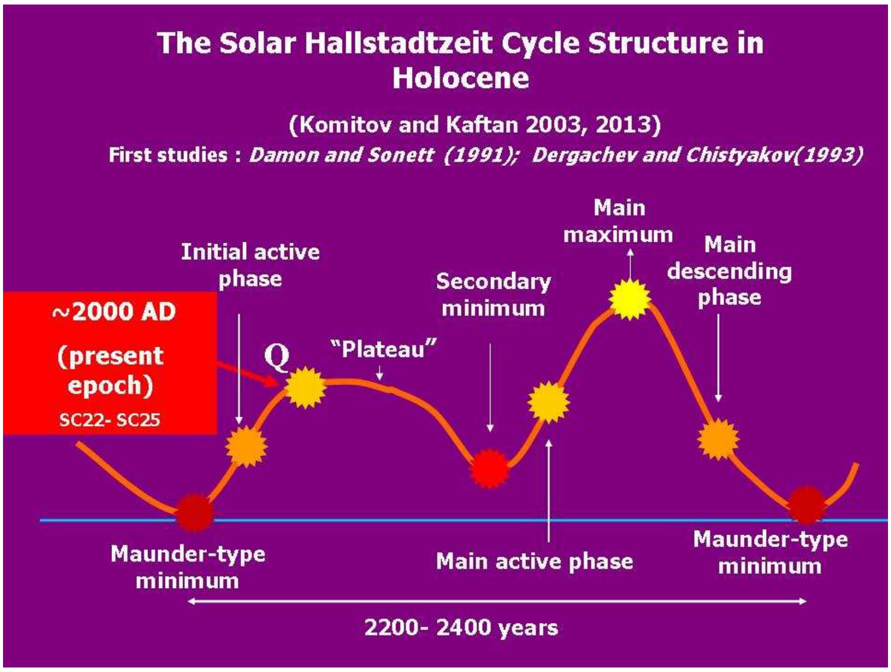

Fig. 39. The solar 2200-2400yr cycle structure (Komitov and Kaftan, 2003,2013)

(1420-1550 AD) and Maunder and "Renaissance maximum" (an interval of relatively high solar activity between 1550 and 1640 AD, i.e. between minima of Spoerer and Maunder (Komitov and Kaftan, 2003)).

The rapid increase after 1700 AD relates to the initial active phase of the present Hallstadtzeit. In our opinion and as follows by the presented plots and their analysis,its end corresponds to solar cycle 22 (SC22) maximum (1989-1991 AD) and a short transition epoch to "plateau" phase by duration of few decades is already started. On the other hand it is very possible that the transition point "Q" is damaged in some degree due to the efects from the new 200-210 solar cycle minimum and connected to them new grand solar minimum in 21st century. The last one hints that really the "Q"-event could occur during the next few decades since 1990-1991 AD until 2050 AD. However it is very difficult to determine exactly the "mean mathematical Q - moment" from our present viewpoint.

Consequently, during the last 300 years, should detect a statistically certain upward trend in all instrumental data series (the old version of connected with classical Wolf number R_i series, the new version of R_i(labeled also as SN (Clette and Lefevre , 2015), the Hoyt-Shatten GSN (Group sunspot number) series (Hoyt and Shatten, 1998) etc.).

This upward trend is best shown in Group Sunspot Number (GSN) mean annual data series for the interval 1700-1995 AD. The corresponding coefficient of linear correlation is r=+0.44 and the corresponding $|r/sr|$ is

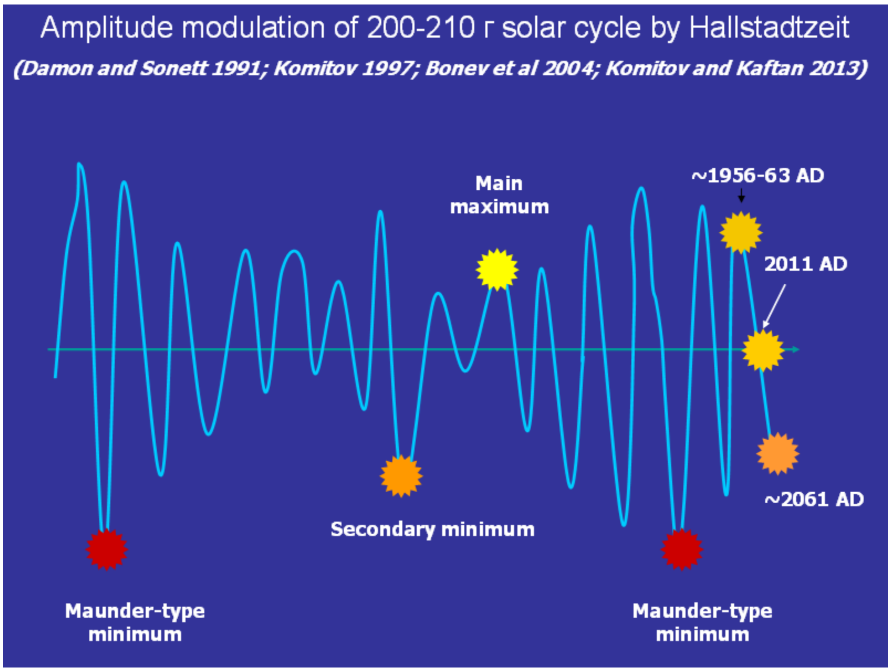

Fig. 40. The 200-210 yr solar cycle amplitude modulation by Hallstadtzeit

9.42. This series contains N=296 values. The mean monthly data series is impossible to use due to the serious lack of such data especially for the first half of 18th century. If this series is limited from 1749 to 1995 AD, than the calculated values of r and $|r/sr|$ are +0.33 and 5.92 respectively.

Contrary of the some statements that no long-term trend in the new version of $R_i(SN)$ series exists the statistical analysis shows rather the opposite. There is a weak detectable upward trend in new version annual sunspot R_i series for epoch 1700-2016 AD. The corresponding coefficient of linear correlation for N=317 is r=+0.138 and $|r/sr|$=2.52. The statistical significance of this trend is almost 99%, because the critical value of $|r/sr|$=2.56 for 99% or 1.96 for 95%.

Additional test shows that if the last 25 years are excluded from data series and the last one is limited between 1700 AD and 1991 AD (SC22 maximum) and N is 292, r increases to +0.180 and $|r/sr|$ is 3.17. The trend expression improvement is caused by removing SC22 decline phase plus SC23 and SC24, which are placed in the initial phase of the new grand sunspot minimum and plus (very probably) on the transition stage between initial active phase and "plateau" of the present solar 2200-2400 yr solar cycle (see fig.39)

5.2. The grand solar minima and sunspot cycle lenght

The 11yr (Schwabe-Wolf's) solar cycle lenght is one of the precursors of the beginning of a grand solar minimum. As is well known the mean length of the main sunspot Schwabe-Wolf's cycle is 11.04 years for the whole Zurich series since 1749 AD, but the individual lengths of separated cycles varies between 9 and 14 years. As it is shown in Schove series (Komitov, 2007) as well as in the instrumental Zurich series, the Schwabe-Wolf's cycles during the grand solar minima are featured by essentially longer than 11.04 year durations.

SC4 (1784-1798 AD) is an extremely long Schwabe-Wolf's cycle, which duration is approximately 13.6 years. It marks the end of a relatively high solar activity epoch after 1720 AD and the beginning of the grand Dalton minimum (1798 -1833 AD). Unfortunately the last decade of 18th century is lacking of telescopic observations of the Sun. During that time there was only one active observer of sunspots - the Danish astronomer Horrebow (Hoyt and Shatten, 1998). Almost all known instrumental observations in that period were provided by this observer. That is why some authors doubt about "official" accepted picture for SC4 declining phase. There is also a hypothesis for the "lost cycle" (Usoskin et al., 2001). According the last one SC4 has ended in 1793 AD and its was followed by a very weak and short sunspot cycle by duration of 7 years. This hypothesis was very popular 15 years ago, but finally after many discussions it was not accepted. Thus SC4 remains the longest Schwane-Wolf's cycle in whole Zurich series (1749-2017 AD).

The next three sunspot cycles (SC5-SC7), which are included in Dalton minimum are also longer (12.3 and 12.6 years respectively).

What is the situation with last sunspot cycle lengths?

The length of the sunspot cycle No22 (SC22) between September 1986 and August 1996 is 9.9 years, while the length of the next SC23 between August 1996 and December 2008/January 2009 is 12.3-12.4 years. The latter values are in a good agreement with the forecasts for long SC23, based kinematic models (Kaftan, 2006)(Kaftan and Krainev, 2007).

5.3. The amplitude "Gnevishev-Ohl's rule" violations and grand solar activity minima

In course of its study over the continuous part of historical Schove's series (1955, 1983) between 296 AD and 1996 AD Komitov (1997) found using discriminant analysis, that 11yr strong solar cycles, corresponding to the even cycles in Zurich series usually are followed by 11yr (odd numbered) cycles with lower amplitude. Thus for these pairs "even - odd" cycles the so called amplitude "Gnevishev-Ohl rule" (G-O)(Gnevishev and Ohl, 1948) (Kopecky, 1950)is violated for the strong even numbered 11yr solar cycles. The critical value of the mean yearly Wolf's number $R_{i(max)} = 125$ (old version) was found for even cycles. If $R_{i(max)}$ for even cycle is higher than above mentioned value the next odd one is lower than even one in almost 90% of the cases. Since 1749 AD the amplitude G-O rule has been violated only two times until 1986. On the base of a very high near-maximal yearly (old version) value $R_{i(max)} = 157$ a prediction for lower SC23 has been made (Komitov, 1997). The real near-maximal SC23 value (old version) is $R_{i(max)} = 121$ in 2000 AD and fully confirms this prediction.

Recently (Komitov and Bonev, 2000, 2001) on the base of Schove's series found again that a violation of G-O rule is a good indicator for incoming grand solar minimum. On this base an epoch of weak 11yr solar cycles in 21st century was predicted. Consequently, from this point of view the SC24 sunspot magnitude$R_{i(max)} = 82$ (essentially weaker than SC23) shouldn't be considered as a surprise.

The kinematic model extrapolations of Komitov and Kaftan (2003,2004) based on time series analysis of Schove's series and Greenland (Dye-3) ^{10}Be series predict a relatively long "Dalton-type" minimum during the most part of 21st century. Its deepest phase has to occur between 2060 - 2070 AD on the base of Schove series model extrapolation or around 2040-2045 if ^{10}Be series model is used. There are also a large number of predictions of authors, which based on different data and methods,which attain similar conclusions (Fyodorov et al., 1995), (Badalyan et al., 2000),(Abdussamatov,2004), (Solanki et al., 2004), (Ogurtsov, 2005), (Clilverd et al., 2006). On the other hand the most of present preliminary predictions indicate a low SC25 and low or a very low SC26 (Javaraiah, 2017), which is also in agreement with the previously mentioned.

In this corse it is interesting to note that according to the most of the forecasts for SC24, which were made before the beginning of this solar cycle, it should be stronger as the previous SC23 (see Pesnell (2007) and cites therein).

The start of a long downward solar activity tendency after SC22 maximum has been proposed by Duhau (2003). This phenomenon could be caused by long-term realignment of Sun's convective zone parameters (for example changes of its upper boundary depth, thickness or both). Indeed, such events occur every time in the initial phases of the grand solar minima epochs.

The solar cycle 24 (SC24) to this moment (December 2017) is not finished, but there are many indications that it is already in its pre-minima phase. The beginning of the next SC25 is expected in the end of 2019 AD or dn the first half of 2020 AD. Significant solar or solar-geophysical active events in the next two years seems less probable. Thus there is a very small chance for significant changes in described picture of solar cycle 24.

6. Conclusions

The here presented results and analysis about the ongoing solar cycle No24 lead to the following basic conclusions:

1. The solar cycle 24 (SC24) is the weakest one at least since SC12 or even (too possible) since SC6, i.e. for the last more than 100 years relative to the sunspot activity. It is also the weakest one since the beginning of AA-index data series, i.e. since 1868 AD or about for the last 150 years in relation to geomagnetic activity. The conclusion about the weakest SC24 is also valid for the whole series of almost all observed solar phenomena and parameters.

2. SC24 is positioned over long term downward solar activity trend, which starts during the descending phase of SC22 for the most important of studied solar activity and solar-terrestrial events (R_i, AA, $F_{10.7}$, GCR-flux, M and X-classes solar X-ray flares). However, it should also be pointed that for some events like radiobursts and overall X-ray flare activity well expressed downward trends are detected since the beginning of SC20 or SC21 (the middles of 1960s and 1970s, respectively).

3. The downward solar activity tendency, started generally after SC22 maximum in 1990-1991 AD is connected to the beginning of a new grand solar minimum epoch of "Dalton-type". It is related to the next 200-210 yr solar cycle minimum. It is important to taken into account the 2200-2400yr cycle transition from initial active to quiet ("plateau") phase in the present epoch as well as the connected with the last one amplitude fading of 200-210 yr cycle. By this follows that the new solar grand minimum in 21st century is expected to be relatively shallow and new very deep ("Maunder-type") grand solar minimum will not occur in foreseeable future.

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