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SOLAR INFLUENCE ON RIVER STREAMFLOW

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Abstract: *The solar activity cycles excite periodical and pseudo periodical variations of all Earth systems, including climate, water cycles, rainfalls, streamflow, groundwater etc. The water cycles have short term, seasonal, interannual and long term periodicities with different local revealing. The interannual and decadal water cycles are strongly driven by the solar activity due to periodical variations of the Total Solar Irradiance (TSI) and cosmic ray modulation by the solar wind, geomagnetic and the interplanetary magnetic field. The solar influence on river streamflow is investigated by means of time series of TSI, sunspot numbers (SSN), Cosmic Rays (CR), Palmer Drought Severity Index (PDSI) and reconstructed streamflow of Rio Grande (1508–2003) and Alamosa river in Colorado (1632–2002). The local variations of the PDSI are investigated close to the river basins. The correlation between solar and climatic indices and water data is analyzed.*

Introduction

The river streamflow analyses can be successfully used in water resource planning and management, depending on the needs of the wide range users. It is possible to use these applications in several general directions: as informal, qualitative guidance for water managers, stakeholders and decision makers and prediction about long-term drought variability; for quantitative assessments of long-term hydrologic variability and assessment the severity and duration of drought cycles; as direct inputs into hydrologic models of a water system, etc.

The irregular and long-term variations of the Earth physical systems are mainly caused by the influence of the Sun and solar activity cycles. The solar cycles can drive great number of geodynamical processes connected with the convections of the Earth fluids on the surface and inside the Earth. Many of climate and weather parameters are affected directly by the variations of the solar activity including water cycles, rainfalls, streamflows, groundwater etc. The interannual and decadal water cycles are strongly driven by the solar activity due to periodical variations of the total solar irradiance and energy transfer from the sun to the Earth by the solar wind and the interplanetary magnetic field. Recently a new mechanism of climate modulation, based on cosmic rays variations, has been proposed [1–4]. This mechanism is based on chain processes near tropopause by ozone production, temperature variations, followed by vertical winds and water content change. The last step of this chain affects surface temperature, because the atmospheric water is one of the most powerful greenhouse gas. This model provides an explanation for the cascade processes in which CR, whose total energy is relatively small, cause climatic effects with much more energy. The solar activity cycles modulate CR directly by the heliosphere and indirectly by the geomagnetic field changes. The solar influences on local variations of river streamflows are investigated by means of TSI, CR and PDSI time series and reconstructed streamflows of Rio Grande (1508–2003) and Alamosa river in Colorado (1632–2002).

Data and Methods

The observed river streamflow has relatively short history. Longer time series of observed data are available for some North American rivers – since 1890 (Rio Grande); 1935 (Alamosa), and etc. The determination of the solar influence on the hydrological cycles need longer water data series, available from the reconstructed streamflow. The reconstructed streamflow from tree-ring data is the best method of determination of past variations, proved by the relationship between tree-ring time series and observed streamflow over the modern period. The TreeFlow is a comprehensive web resource for tree-ring reconstructions of streamflow and climate, providing easy access to reconstruction data (http://treeflow.info). A forward stepwise regression procedure was used to calibrate the observed flow record with a pool of potential predictors consisting of tree ring chronologies from Colorado and northern New Mexico. The reconstructed streamflow time series cover almost 4 centuries for Alamosa river and 5 centuries for Rio Grande. The long-term streamflow variations are determined by Fourier approximation with truncation of terms shorter than 9a for Rio Grande basin (Fig. 1).

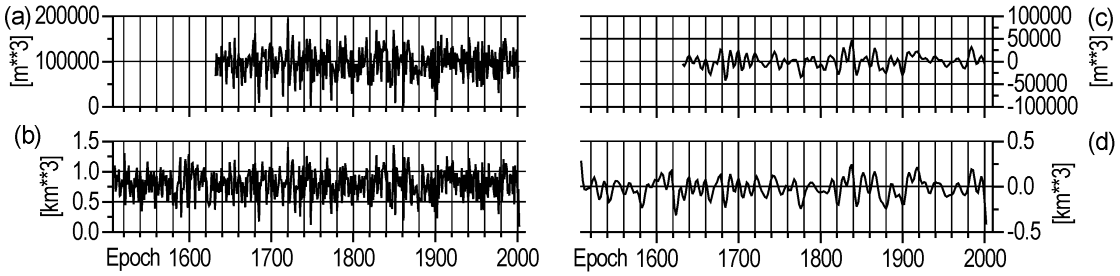

Fig. 1. Annual streamflows of rivers Alamosa in Colorado (a) and Rio Grande near Del Norte in New Mexico (b) and their long-term variations (c) and (d)

The Palmer Drought Severity Index (PDSI) is involved by Palmer [5] to represent the severity of dry and wet spells over the U.S. based on monthly temperature and precipitation data as well as the soil-water holding capacity at that location. The global PDSI data [6, 7] consist of the monthly surface air temperature [8] and precipitation [9, 10] over global land areas from 1870 to 2006. These data is represented as PDSI values in global grids 2°.5 × 2°.5. The PDSI variations are between –10 and +10, where the drought conditions are in terms of minus numbers and the wet conditions – in terms of positive numbers.

The time series of the PDSI variations are determined by the mean values from all grid data from the selected area. The mean values are computed by means of the robust Danish method (8, 9, 10). This method allows to detect and isolate outliers and to obtain accurate and reliable solution for the mean values. The PDSI values are calculated for the region of Rio Grande basin (Fig. 2). Their RMS errors are less than 0.1. The Rio Grande basin cover area between longitude 100°–112.5° W and latitude 30°–40° N with grid numbers up to 20. The long-term variations of PDSI time series are determined by Fourier approximation with truncation of terms shorter than 9a for Rio Grande basin (Fig. 3, b).

Fig. 2. Map of Rio Grande basin, area 100°–112.5° W and 30°–40° N

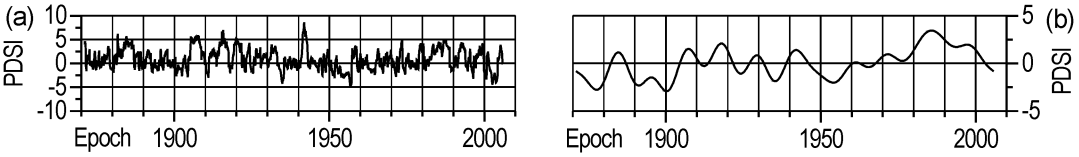

Fig. 3. Palmer Drought Severity Index (PDSI), calculated for Rio Grande and Alamos rivers basin (a), and their long-term variations (b)

The annual and daily values of SSN for the period 1700.0-now are provided by the Royal Observatory of Belgium. The 22-year solar magnetic cycles are represented by the extended 22-year SSN variations (SSN_22yr), determined by altering the even 11-year SSN cycles (Fig. 4). The time series of the TSI for the period 1610.5-2010.5 are reconstructed in [11]. The intensity of galactic CR at the Earth's orbit since 1610 has been calculated in [12–14] (Fig. 5)

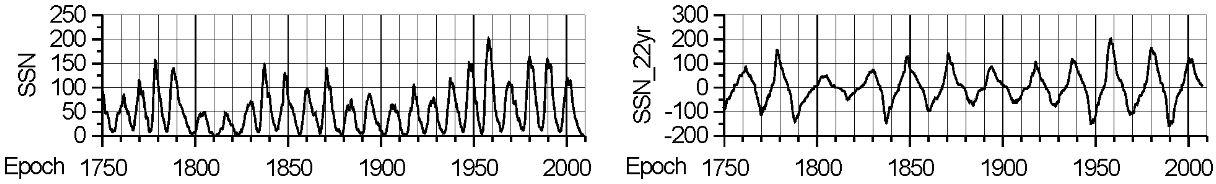

Fig. 4. Time series of SSN and extended 22-year SSN variations (SSN_22yr)

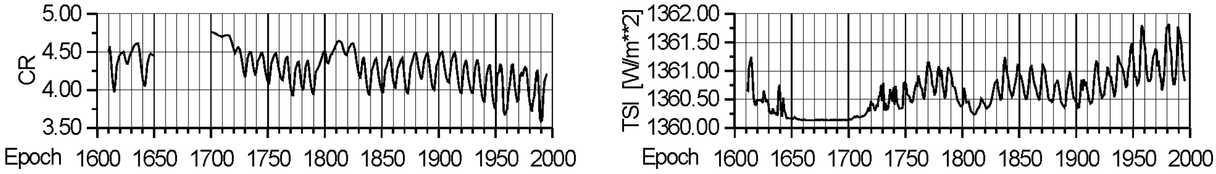

Fig. 5. Reconstructed time series of CR and TSI

The periodical variations are derived from the data by means of Partial Fourier Approximation based on the Least-Squares (LS) estimation of Fourier coefficients [15]. The Partial Fourier Approximation $F(t)$ of discrete data is given by

$$F(t) = f_0 + f_1(t-t_0) + \sum_{k=1}^{n} a_k \sin k \frac{2\pi}{P_0}(t-t_0) + b_k \cos k \frac{2\pi}{P_0}(t-t_0), \tag{1}$$

where P_0 is the period of the first harmonic, t_0 - the mean epochs of observations, f_0, f_1, a_k and b_k are unknown coefficients and n is the number of harmonics of the partial sum, which covers all oscillations with periods between P_0/n and P_0. The application of the LS estimation of Fourier coefficients needs at least $2n + 2$ observations, so the number of harmonics n is chosen significantly smaller than the number N of sampled data f_i. It should be kept in mind that the small number of harmonics n yields to LS estimation of the coefficient errors, too. This estimation is the first essential difference with the classical Fourier approximation. The second essential difference with the classical case is the arbitrary choice of the period of first harmonic P_0, instead of the observational time span, so the estimated frequencies may cover the desired set of real oscillations. This method allows a flexible and easy separation of harmonic oscillations into different frequency bands by the formula:

$$B(t) = \sum_{k=m_1}^{m_2} a_k \sin k \frac{2\pi}{P_0}(t-t_0) + b_k \cos k \frac{2\pi}{P_0}(t-t_0), \tag{2}$$

where the desired frequencies ω_k are limited by the bandwidth

$$\frac{2\pi m_1}{P_0} \le \omega_k \le \frac{2\pi m_2}{P_0}, \tag{3}$$

After estimating the Fourier coefficients, it is possible to identify a narrow frequency zone presenting significant amplitude, and defining a given cycle. Then this cycle can be reconstructed in time domain as the partial sum limited to the corresponding frequency bandwidth. Doing this for terrestrial and solar time series we shall identify their respective cycles, isolate and compare the common ones.

The estimation accuracy of amplitudes is better than 1 for SSN; 0.01W/m^2 for TSI; 0.02 km^3 for Rio Grande streamflow; and 2 x 10^3 m^3 for Alamosa streamflow.

Results

Rio Grande streamflow is compared with the 22-year solar magnetic cycles in Fig.6. The common cycles between CR, TSI and river streamflows are shown in Figs. 7 and 8 The PDSI and river streamflows variations are compared in Fig. 9.

Partial correlation between solar magnetic cycles and Rio Grande streamflow exists with positive correlation coefficient for time intervals 1750–1850 and 1920–2000 and negative coefficient – for time interval1850–1920 (Fig. 6).

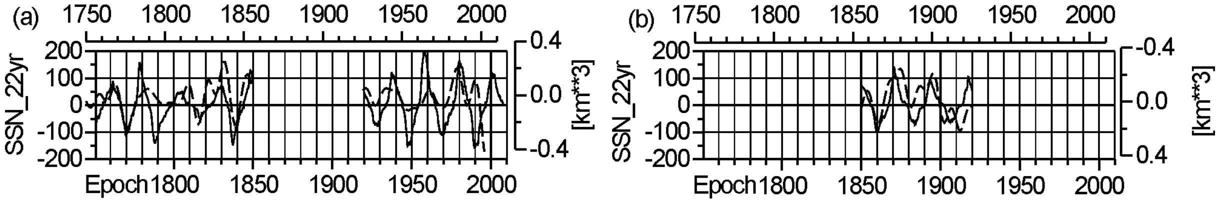

Fig. 6. Influence of solar magnetic cycles on Rio Grande streamflow, (a) – with positive correlation, (b) – with negative correlation coefficient

The TSI and CR have different long-term spectra, so they individually dominate in river streamflows variations in some frequency bands. The solar activity and modulated cosmic rays by solar wind and magnetic fields affect river streamflows in large number of decadal and centennial periodicities between 9 and 200 years. The variations of river streamflows have identically cycles with CR and TSI oscillations in most frequency bands in Figs. 7 and 8 with exception of 4 short-time phase reverses. The influence of CR and TSI on river streamflows variations is frequency dependent, so it is not possible to study their correlation by direct comparison of time series. The time lag is usually below 10yr with exception of centennial variations, where the time lag reaches 20–25 yr.

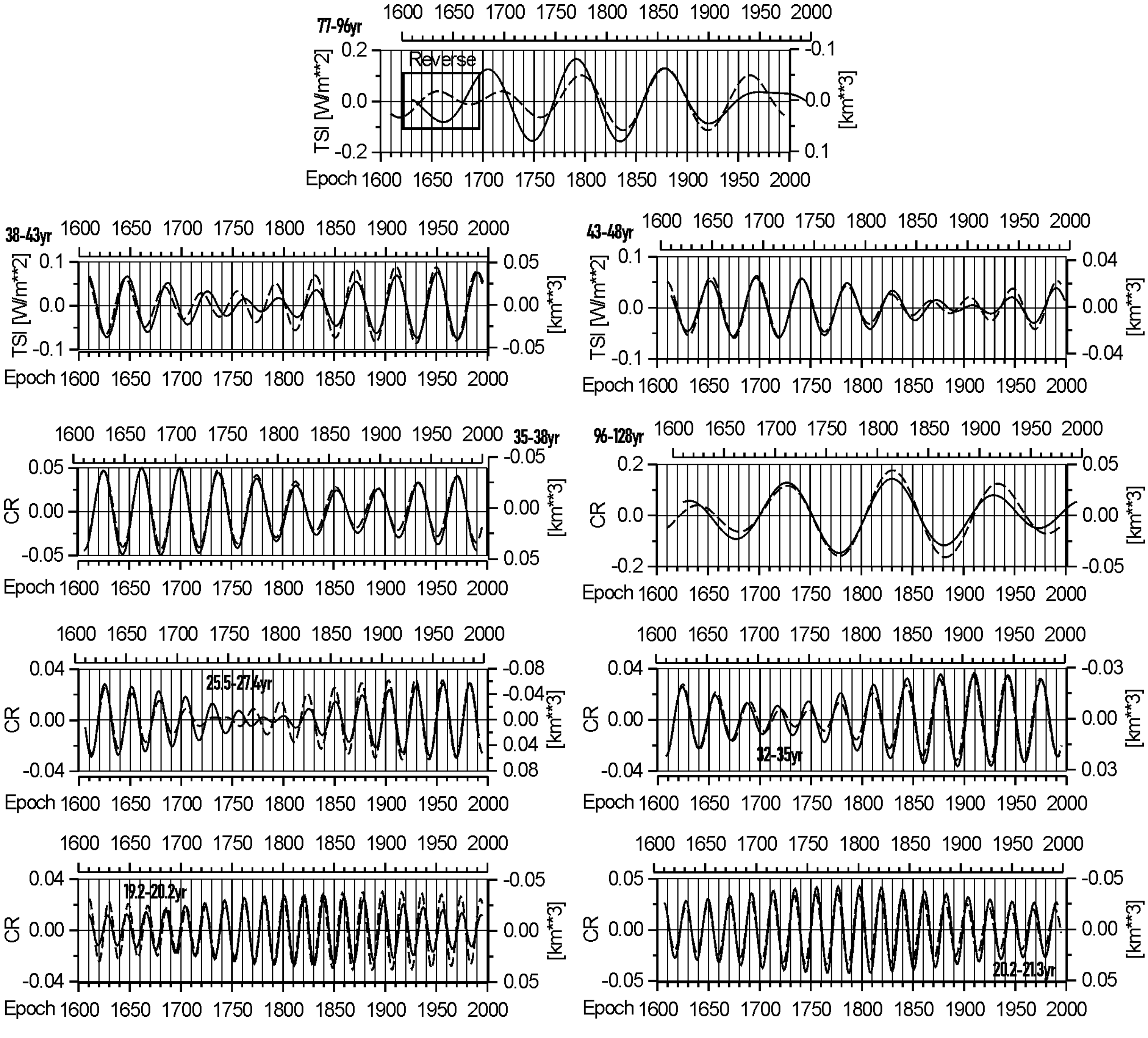

Fig. 7. CR and TSI (solid lines) influence on Rio Grande river streamflow variations (dashed line)

The solar activity affects terrestrial systems by means of direct radiation over Earth surface, solar wind, and the solar magnetic field. The solar wind directly affects Earth magnetic field, ionosphere and atmosphere. The variations of solar magnetic field modulate solar wind and cosmic rays in the frame of the heliosphere. The cosmic rays near Earth are modulated by Earth magnetic field variations, too. A significant part of cosmic rays consists of charged solar particles, whose interaction with the Earth atmosphere is preceded by focussing effect of geomagnetic field over polar regions, while the most energetic galactic cosmic rays affect all Earth regions. The cosmic ray intensity is controversial to the TSI variations. The TSI is strong during solar activity maximum, when the cosmic ray intensity has minimum and vice versa. So, during TSI maxima, the warming processes occur on Earth surface, and during TSI minima the thermal cycle amplitudes are amplified, due to cooling effects of cosmic rays.

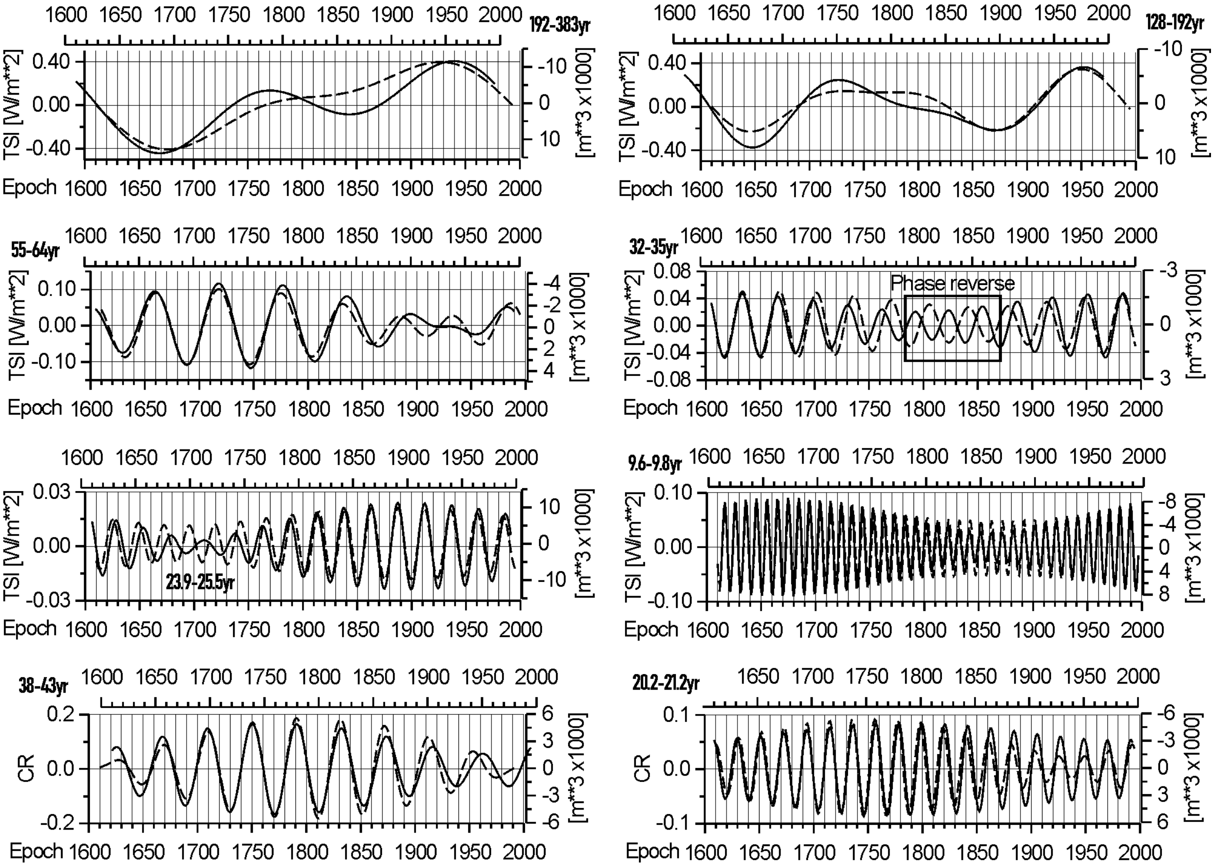

Fig. 8. TSI and CR (solid lines) influence on Alamosa river streamflow variations (dashed line)

The influence of solar activity on river streamflows is not direct. The TSI and CR variations affect initially various climatic parameters. The climatic changes over Rio Grande basin are presented by means of PDSI variations. The PDSI variations have good agreement with the Rio Grande and Alamosa river streamflows long-term oscillations (Fig. 9).

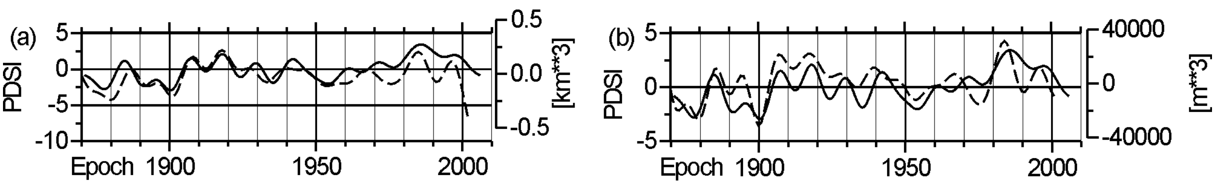

Fig. 9. PDSI (solid lines) influence on Rio Grande river (a)
and Alamosa river (b) streamflows (dashed lines) variations

Conclusions

The solar activity strongly affects the local variations of river streamflows especially of the rivers with large streamflows. The type of solar influences on river streamflows is direct by means of total solar irradiance variations and non-direct by means of solar wind and interplanetary magnetic field variations, followed by geomagnetic disturbances, cosmic particles, local variations of temperature, humidity, rainfalls, climate and weather and etc. The solar wind variations affect interplanetary and Earth magnetic fields, whose changes modulate the cosmic rays. The cosmic rays produce a ionization of the atmosphere, changes of atmosphere conductivity, lightning, and an increase of ozone concentration. The changes of atmospheric water vapor content and ozone plays significant role in climate variations.

Strong correlation exists between the river streamflow variations and 22-year solar cycles. Unfortunately, these dependences are broken by sudden phase reverses, leading to switch between the positive and negative correlation. The phase reverses are big problem in streamflow models of interannual and long-term periodical variations and their prediction.

The dominant factors of the long term variations of river streamflows are the local and regional climatic influences represented by the local PDSI variations, calculated for the area over the river basins. Significant correlation between the PDSI variations and 11-, 22- and 45-year solar cycles was determined in [16]. The local PDSI variations have strong positive correlation with the long-term river streamflow variations with small deviation for some frequencies and time intervals. The local PDSI index itself is not enough to create reliable models of streamflow variations. It is necessary to involve all available solar and space indices.

The common decadal and centennial solar-terrestrial cycles are determined by superposition of two oscillations with neighbor periods and their comparison. The CR and TSI harmonics have identical cycles with river streamflows in several frequency bands with periods between 9 and 192 years. Some common cycles have phase reverse for short-time intervals. The Rio Grande streamflow has positive correlation coefficients with TSI oscillations and negative correlation coefficients with CR oscillations, while the Alamosa river streamflow is vice versa. So, the Rio Grande streamflow is affected by the water transport from the ocean, and it has significant increase during TSI maxima and CR minima. The Alamosa river streamflow depends on local climatic variations and expose significant decrease during TSI maxima.

References:

1. Kilifarska, N. A. and J. D. Haight, The impact of solar variability on the middle atmosphere in present day and pre-industrial atmospheres. J. Atmos. Solar Terr. Phys., 67, 3, 241–249, 2005, DOI: 10.1016/ j.jastp.2004.10.003
2. Kilifarska, N. A., Y. K. Tassev, and D. Y. Tomova, Cosmic ray showers and their relation to the stratospheric sudden warmings. Sun and Geosphere, 3, 1, 10–17, 2008
3. Kilifarska, N.A., Long-term variations in the stratospheric winter time ozone variability – 22 year cycle. Comptes rendus de l'Académie bulgare des Sciences, 64, 6, 2011, 867–874.
4. Velinov, P. I. Y., L. Mateev and N. A. Kilifarska, 3-D model for cosmic ray planetary ionisation in the middle atmosphere. Ann. Geophys., 23, 9, 3043–3046, 2005, DOI: 10.5194/angeo-*23*-3043-2005
5. Palmer, W. C, Meteorological Drought. Res. Paper No.45, U.S. Weather Bureau, Washington, 58pp, 1965.
6. Dai, A., K. E. Trenberth, and T. Karl, Global variations in droughts and wet spells: 1900–1995. Geophys. Res. Lett., 25, 3367–3370, 1998.
7. Dai, A., K. E. Trenberth, and T. Qian, A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. J. Hydrometeorology, 5, 1117–1130, 2004.
8. Jones, P. D., and A. Moberg, Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. J. Climate, 16, 206–223, 2003.
9. Chen, M., P. Xie, J. E. Janowiak, and P. A. Arkin, Global land precipitation: a 50-yr monthly analysis based on gauge observations. J. Hydrometeorol., 3, 249–266, 2002.
10. Dai, A., I. Fung, and A. D. Del Genio, Surface observed global land precipitation variations during 1900-1988. J. Climate, 10, 2943–2962, 1997.
11. Kopp, G., Krivova, N., Lean, J., and Wu, C.J. The Impact of the Revised Sunspot Record on Solar Irradiance Reconstructions, Solar Physics, 2016. doi: 10.1007/s11207-016-0853-x.
12. Usoskin, I. G., K. Mursula, S. K. Solanki, M. Schuessler, and G. A. Kovaltsov, A physical reconstruction of cosmic ray intensity since 1610, J. Geophys. Res., 107(A11), 1374, 2002. doi:10.1029/2002JA009343.
13. Usoskin, I., K. Alanko-Huotari, G. Kovaltsov, K. Mursula, Heliospheric modulation of cosmic rays: Monthly reconstruction for 1951-2004. *J. Geophys. Res.*, 110, A12108, 2005. doi:10.1029/2005JA011250JGR.
14. Alanko-Huotari, K., I. G. Usoskin, K. Mursula, G. A. Kovaltsov, Global Heliospheric Parameters and Cosmic-Ray Modulation: An Empirical Relation for the Last Decades, *Solar Physics*, 238, 391–404, 2006. doi: 10.1007/s11207-006-0233-z.
15. Chapanov Y., C. Ron, J. Vondrk, Decadal cycles of Earth rotation, mean sea level and climate, excited by solar activity, Acta Geodyn.Geomater., 14, No. 2 (186), 241250, 2017. DOI:10.13168/AGG.2017.0007
16. Chapanov, Ya., D. Gambis, Drought cycles over South-East Europe for the period 1870–2005 and their connection with solar activity. Proc. BALWOIS, 2010, Ohrid, 2010.