DOI: 10.31401/WS.2020.proc.20

Solar Influence on Seismic Energy

Chapanov Ya.[1], Ron C[2], Vondrák J.[2]

[1]Climate, Atmosphere and Water Research Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria
E-mail: chapanov@gmail.com
[2]Astronomical Institute, Czech Academy of Sciences, Boční II 1401, 141 00 Prague, Czech Republic

Abstract.

The solar activity affects all surface geosystems, including weather and climate indices, winds, rains, snow covers, mean sea level, river streamflows and other hydrological cycles. The Total Solar Irradiance (TSI) acts directly on Earth systems variations, while the solar wind affects the variations of geomagnetic field. The solar magnetic field and solar wind determine the properties of the heliosphere up to the heliopause. The variations of geomagnetic field and heliosphere have ability to modulate the charged particles of the cosmic rays. The recent models of ozone production by the cosmic rays in upper atmosphere and its influence on water content, which is the most powerful greenhouse gas, point out to significant effects on local and global temperature and climate processes. The variations of winds, air pressure, rains, snow covers, mean sea level and other hydrological cycles, produce small local and global crust and mantle deformations. These deformations may trigger earthquake and volcanic seismicity with synchronous periodicity of the cosmic ray and solar activity. The solar influence on seismicity is investigated by common cycles of cosmic rays, solar, and Earth data. The solar data consist of centennial time series of TSI and North-South solar asymmetry. The Earth data are represented by geomagnetic index AA since 1870 and time series of earthquakes since 1898. Relatively good agreement exists between long-term variations of seismicity, cosmic ray, solar and geomagnetic indices.

Introduction

The earthquakes and volcanic eruptions are the results of material circulation in the Earth that appear near the Earth's surface. Volcanoes and earthquakes have a lot in common. They both occur mostly near to the boundaries of tectonic plates. They have potential to cause significant damage. Volcanic eruptions are caused by the tectonic plates shifting and that can cause earthquakes. The seismic activities cause frequent natural disasters in many Earth regions. It is necessary to study not only earthquakes themselves but also all processes affecting them to predict seismic activity. The solar and geomagnetic activity affect significantly seismic variations. Some identical cycles of cosmic rays, solar and geomagnetic indices on the one hand, and earthquake energy on the other hand, are presented in this work.

The solar activity affects terrestrial systems by means of direct radiation over Earth surface, influences charged particles of the 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 solar system. The cosmic rays near Earth are modulated by Earth magnetic field variations, too. Recently, a new mechanism of climate variations, due to cosmic rays was proposed (Kilifarska and Haight, 2005; Kilifarska, 2008, 2011; Velinov et al., 2005). According to the new models, the cosmic rays produce an ionization of the atmosphere, changes of atmosphere conductivity, and lightning, and an increase of ozone concentration. 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 strongly 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 cosmic rays, whose total energy is relatively small, cause climatic effects with much more energy. The solar activity cycles modulate the cosmic rays directly by the heliosphere and indirectly by the geomagnetic field changes, whose effect is visible mainly at high latitudes.

We suppose that the solar and space effects on climate variations produce different local deformation of the earth crust and they trigger earthquakes with a certain periodicity, equivalent for the whole seismic events. These periodic variations of seismicity are possible to be determined as seismic energy oscillations, whose cycles are identical with the cycles of cosmic rays, solar and geomagnetic variations. Assuming that the time series of seismic energy variations consist of artificial and natural linear trends and jumps, induced periodic cycles and instrumental random noise, we may separate these components and investigate them.

Data

The data consist of centennial time series of total solar irradiance, North-South (N-S) solar asymmetry, cosmic rays, geomagnetic index AA, earthquake numbers and magnitudes. The earthquake magnitudes are transformed into periodic variations of energy magnitude.

The TSI and N-S solar asymmetry time series are presented in Fig.1. The last version of estimated solar irradiances for the last 400 years is based on the NRLTSI2 historical TSI reconstruction model by J. Lean (Coddington et al., 2015). The N-S solar asymmetry (N-S SA, Fig. 1) is determined from the relation $(S_n\text{-}S_s)/(S_n+S_s)$, where the S_n and S_s are areas of sunspots on the Northern and Southern solar hemispheres, respectively.

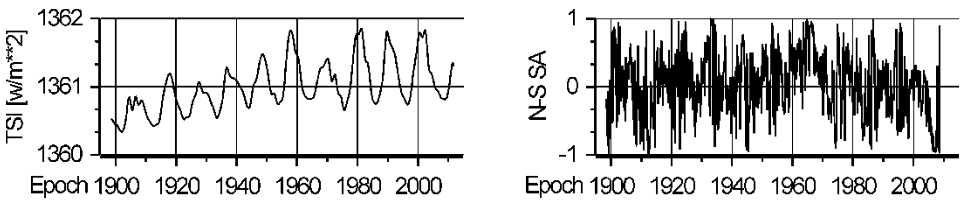

Fig.1. TSI and N-S solar asymmetry time series for the period 1898-.2012.

Usoskin calculates the intensity of galactic cosmic rays (CR) at the Earth's orbit since 1610 (Usoskin, 2002, 2005), see Fig. 2, left. The geomagnetic Index AA since 1868 is available at the International Service of Geomagnetic Indices. The mean variations of AA are determined by average in 27-day window (Fig. 2, right).

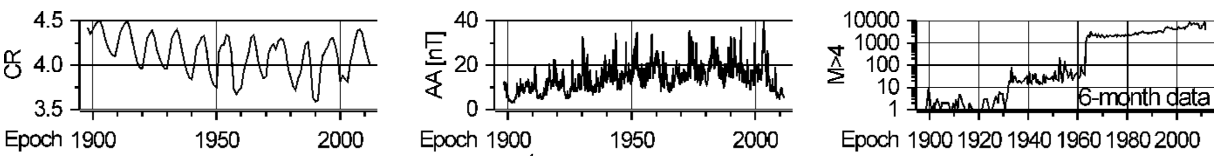

Fig. 2. Time series of Cosmic Rays CR (×10^4 counts/hour), geomagnetic Index AA and earthquakes number with magnitude M>4.

The number of registered earthquakes significantly vary in time (Fig.2, right panel). Initially, prior to 1930, limited number of short distance earthquakes have been registered, due to insufficient number of seismic stations with low level of sensitivity. The earthquake registration was improved significantly twice - in 1932-1962 and after 1963 by network modernization and involve of new station with higher sensitivity. The earthquake number slightly increase in all three time intervals, but it is difficult to separate effects of network improvement from natural reasons. So, the investigation of whole earthquake data since 1898.5 as a homogenous time series is not possible.

Methods

A new Method of time series determination of uniformly distributed seismic energy, with some homogeneity of oscillations at given frequency and amplitude variations, is proposed and applied here. This Method is based on excluding the piece-wise linear trends from the time series. The released energy E during the earthquake with magnitude M is generally

$$E = K10^{1.5M}, \tag{1}$$

where K is dimension coefficient in Joules. Then the magnitude M is

$$M = \frac{1}{1.5}\lg\frac{E}{K} \tag{2}$$

The global seismic energy release $E_{0.1}$ at 0.1-year time interval is a sum of energy from all seismic events in this interval

$$E_{0.1} = K\sum_{t\in 0.1yr} 10^{1.5M(t)} \quad . \tag{3}$$

Let introduce E_M – magnitude of the global seismic energy release at 0.1yr. Then we may determine E_M analogous to (2)

$$E_M = \frac{1}{1.5}\lg\frac{E_{0.1}}{K}, \tag{4}$$

or calculate E_M by the expression

$$E_M = \frac{1}{1.5}\lg\sum_{t\in 0.1yr} 10^{1.5M(t)} \quad . \tag{5}$$

The time series of calculated seismic energy magnitude are given in Fig. 4. The jumps and linear trends in time series of seismic energy are determined by the method of jump detection, described in (Chapanov et al., 2017). This method is highly sensitive to very small data jumps, because it transforms the initial data to a new series by numerical integration. Any data jump is detectable as linear break in integrated time series, where the linear trends of original data are expressed by parabola, while the constant data variations - by straight lines. The corresponding parts with detected trends and jumps of integrated and original data are marked with red and blue color in Fig. 4. There are 6 parts with linear trends and one constant part in original data, separated by jumps in 1918.5, 1930.0, 1934.0, 1957.0, 1963.0 and 1995.0 (Fig. 4). The detrended time series of energy magnitude are shown in Fig. 5. After the trend remove, the new time series contain periodic variations and random noise, whose value is relatively high in 1928-1958.

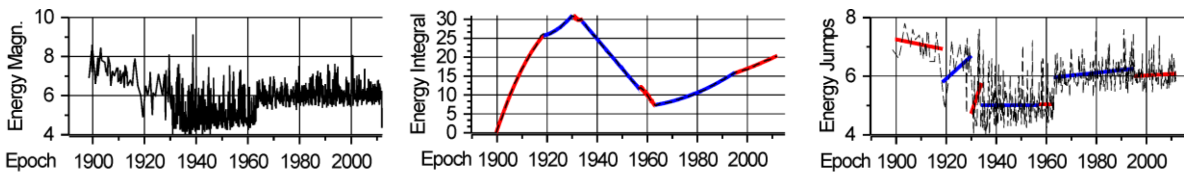

Fig. 4. Determination of linear trends in time series of energy magnitude by the method of jump detection.

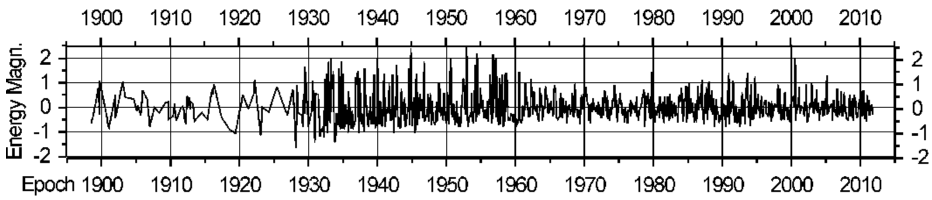

Fig. 5. Periodic variations and random noise in detrended time series of energy magnitude.

The time series of oscillations from a given frequency band are calculated as a superposition of two neighbor Fourier harmonics, whose coefficients are estimated by the Least Squares Method inside the Method of Partial Fourier Approximation (PFA). The details of the last method are described in (Chapanov et al., 2015).

Solar influence on earthquakes

All solar and space factors influence seismic activity indirectly. The prime effect of earthquakes is supposed the local crust deformations nearby the faults. The local crust deformations are due to the change of ocean and atmosphere load, precipitation and ground water content, tides, snow and ice shit thickness variations. The solar heat, represented by the TSI, and cosmic rays influence directly the climatic effects on crust deformation. The solar wind and solar magnetic field modulate and form solar plasma inside the whole heliosphere. The interconnection between the cosmic rays and heliosphere modulates the intensity of incoming particles of the cosmic rays. The geomagnetic field, affected by the variations of solar wind and N-S solar asymmetry, plays a role of last focussing lens of incoming charged cosmic rays.

Earthquake energy variations due to cosmic rays

The cosmic rays have common subdecadal cycles with earthquake energy variations with periods between 3.3-3.4yr; 4.7-4.9yr and 6.3-6.7yr. These cycles have similar phase and amplitude variations with small time delay as can be seen at Fig. 7. The 20-year shift between the minima of CR and E_M amplitudes in case of oscillations with 3- and 4-year periods means that these oscillations are disturbed by TSI variations, too. So, the best pattern of CR influences on earthquake energy are 6.3-6.7 cycles.

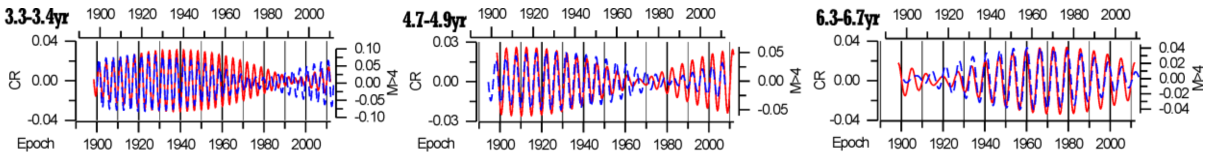

Fig. 7. Common oscillations of cosmic rays CR (solid red line) and earthquake energy (dashed blue line) with periods 3.3-3.4; 4.7-4.9 and 6.3-6.7 years.

Earthquake energy variations due to TSI cycles

The Fig. 8 shows common cycles of TSI and earthquake energy from different frequency bands. Almost exact match exists between TSI and earthquake energy cycles with periods 7.5-8.1, 12.6-14.2 and 16.2-18.9 years. The cycles with periods 6.6-7.1 and 8.7-9.4 years have very good agreement. The 14.2-16.2yr cycles are affected by phase reverse during 1930-1960. The subdecadal oscillations with periods 4.9-5.1 are affected by the CR variations, too.

Earthquake energy variations due to solar and terrestrial magnetic fields

The long term variations of earthquake energy are governed by the solar and terrestrial magnetic fields variations. In Fig. 9 and 10 these variations are represented by indices N-S SA and AA. Their variations cover all long periodical oscillations of earthquake energy between 28 and 113 years with a significant minimum in 1990-2000, and clear increase after that. The negative correlation coefficient between AA and E_M variations is a signature of CR influence, too.

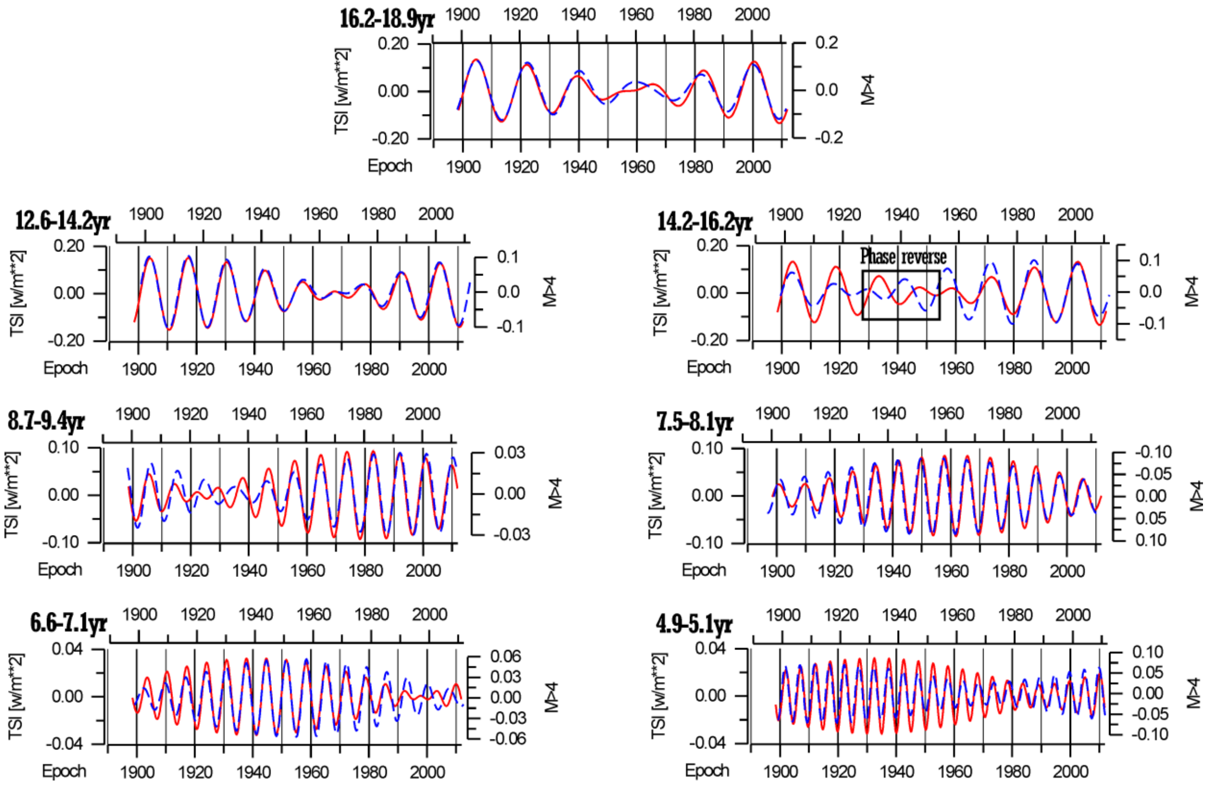

Fig. 8. Common cycles of TSI (solid red line) and earthquake energy (dashed blue line) with periods 4.9-5.1; 6.6-7.1; 7.5-8.1; 8.7-9.4; 12.6-14.2; 14.2-16.2 and 16.2-18.9 years. The curves with negative coefficient of correlation are drawn with reversed y-axis.

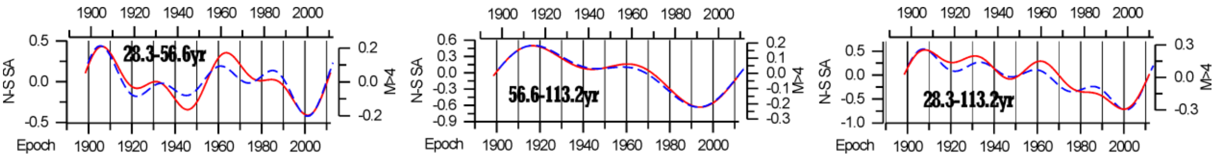

Fig. 9. Long term variations of earthquake energy (dashed blue line) due to N-S solar asymmetry (solid red line).

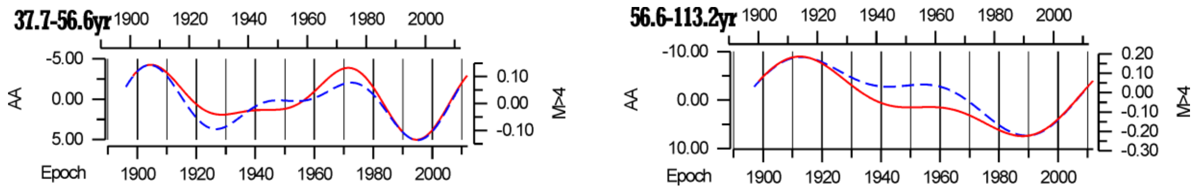

Fig.10. Long term variations of earthquake energy (dashed blue line) due to geomagnetic field oscillations (solid red line). The curves with negative coefficient of correlation are drawn with reversed y-axis.

Conclusions

The shapes of decadal and centennial solar cycles are rather different from sinusoidal form, and this is the reason to generate a lot of subdecadal and decadal harmonics. The solar activity affects all geosystems, including climate and weather. The TSI cycles are the main source of climate indices variations. The solar wind and solar magnetic field form heliosphere plasma, whose interaction with the galactic cosmic rays modulates their intensity. The solar wind modulates the shape of geomagnetic field, which plays a role of focusing lens of the falling cosmic rays. The cosmic rays produce a chain process near tropopause by ozone production, temperature variations, followed by vertical winds and water content change. The last step of this chain strongly affects surface temperature, because the atmospheric water is one of the most powerful greenhouse gas. The cosmic rays, whose total energy is relatively small, cause climatic effects with much more energy by this cascade process. The climate cycles, induced by direct and indirect effects of solar activity, produce local crustal deformations, that are supposed to trigger seismic activity. The TSI and N-S solar asymmetry have individual spectra in some frequency bands, so they affect differently climate and seismic variations.

The registered earthquakes since 1898.5 are not regular in time and it is difficult to analyze these centennial time series. Supposing that the periodical components of earthquake energy variations depend on intensity and frequency of external forces, we remove all significant linear trends from the time series of earthquake global energy release at 0.1-year steps. The transformed time series consist of random noise and periodical component, synchronized with the oscillations of external forces, and they have tidal, solar and space origin. The individual analyzes of solar and space influences on earthquake energy variations show that the TSI variations have major influence on seismic oscillations. The TSI harmonics with periods between 5 and 20 years affect seismic energy by identical cycles from several frequency bands. The long-term variations of seismic energy are affected by N-S solar asymmetry and geomagnetic field modulation with periodicities between 28 and 113 years. The cosmic ray harmonics affect seismic energy variations with periods below 7 years.

Acknowledgements:

This research was financially supported by the project RVO:67985815 provided by the Czech Academy of Sciences; and by the National Science Fund of Bulgaria, Contract KP-06-N34/1 "Natural and anthropogenic factors of climate change – analyzes of global and local periodical components and long-term forecasts".

References

Chapanov, Ya., Ron C. and Vondrák, J.: 2015, Millennial cycles of mean sea level excited by Earth´s orbital variations. Acta Geodyn. Geomater., 12, 3 (179), 259–266. DOI: 10.13168/AGG.2015.0028

*Chapanov, Ya.***,** *Ron, C. and Vondrák, J.: 2017, Accuracy and sensitivity of a method of impulse detection, evaluated by simulated time series. Acta Geodyn. Geomater., 14, 1 (185), 73-82, DOI:10.13168/AGG.2016.0029.*

Coddington, O., Lean, J.L., Pilewskie, P., Snow, M. and Lindholm, D.: 2015, A solar irradiance climate data record, Bull. American Meteorological Soc. doi: 10.1175/BAMS-D-14-00265.1

Hempel, L., and F. Thyssen. 1992. Deep radio echo soundings in the vicinity of GRIP and GISP2 drill sites, Greenland. Polarforschung 62:11-16.

Kilifarska, N.A. and Haight, J.D.: 2005, 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. DOI: 10.1016/j.jastp.2004.10.003

Kilifarska, N.A., Tassev, Y.K. and Tomova, D.Y.: 2008, Cosmic ray showers and their relation to the stratospheric sudden warmings. Sun and Geosphere, 3, 1, 10-17.

Kilifarska, N.A.: 2011, Long –term variations in the stratospheric winter time ozone variability – 22-year cycle. Comptes rendus de l'Académie bulgare des Sciences, 64, 6, 867-874.

Palais, J.M., Germani, M.S. and Zielinski, G.A.: 1992, Interhemispheric transport of volcanic ash from a 1259 A.D. volcanic eruption to the Greenland and Antarctic ice sheets. Geophysical Research Letters 19:801-804. doi:10.1029/92GL00240

Palais, J.M., Taylor, K.C., Mayewski, P.A. and Grootes, P.M.: 1991, Volcanic ash from the 1362 A.D. Oraefajokull eruption (Iceland) in the Greenland ice sheet. Geophysical Research Letters 18:1241-1244, DOI: 10.1029/91GL01557

Usoskin, I.G., Mursula, K., Solanki, S.K., Schüssler, M. and Kovaltsov, G.A.: 2002. A physical reconstruction of cosmic ray intensity since 1610. J. Geophys. Res., 107(A11), 1374. doi:10.1029/2002JA009343

Usoskin, I.G., Alanko-Huotari, K., Kovaltsov, G.A. and Mursula, K.: 2005, Heliospheric modulation of cosmic rays: Monthly reconstruction for 1951-2004. J. Geophys. Res., 110(A12), A12108. doi:10.1029/2005JA011250

Velinov, P.I.Y., Mateev L. and Kilifarska N.A.: 2005, 3-D model for cosmic ray planetary ionisation in the middle atmosphere. Ann. Geophys., 23, 9, 3043-3046. DOI: 10.5194/angeo-23-3043-2005

Wills, R. C. J., Armour, K., Battisti, D. S. and Hartmann, D. L.: 2019, Ocean–atmosphere dynamical coupling fundamental to the Atlantic multidecadal oscillation. J. Climate, 32, 1, 259-272. DOI:10.1175/JCLI-D-18-0269.1