Bulgarian Journal of Physics **27** No 2 (2000) 35–42

SOLAR CYCLE INFLUENCE ON THE SEISMIC ACTIVITY

B. KIROV, K. GEORGIEVA

Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences

Bl.3 Acad.G.Bonchev str., 1113 Sofia, Bulgaria

Abstract

Based on data for the ancient earthquakes in the Mediterranean region, it is shown that the long-term variations of the seismic activity are related to the centennial solar cycle. In the 11-year solar cycle, a well expressed maximum in the number of strong (M≥7) earthquakes worldwide in the 20th century is found in the solar activity maximum, and a secondary one - on the descending branch of solar activity cycle coinciding with the period of the maximum of coronal holes - sources of high speed solar wind. In an attempt to identify the solar activity elements related to earthquake occurrence, the duirnal variations of the number of earthquakes are studied with respect to the days of arrival of high speed streams and fast interplanetary shocks.

1. Introduction

Recently a number of studies have been devoted to the role of solar activity in terrestrial seismicity [1-5]. Different elements of solar activity have been proposed to explain the mechanism of such an influence: solar proton fluxes [6], solar and lunar tides [7, 8], high speed solar wind [9]. However the problem remains controversial.

2. Long-term effects

To study the variations of earthquakes occurrence on time scales of the order of centuries, historical data about earthquakes have been used, compiled in the Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century [10]. The longest set of solar activity data is based on the estimations of Schove [11] from records about auroras and sunspot groups visible with naked eye It covers the period from 648 B.C. to present, however the set is continuous only since 296. Therefore, though data for earthquakes from 760-750 BC to 995 are available, only the ones between 296 and 995 are used in this study.

In Shove's data set, the years on minima and maxima of the 11-year solar activity cycles are given, and the approximate amplitudes of the maxima. In each such cycle, from minimum to minimum, we have summed the number of earthquakes and have compared them to the amplitude of the maximum between the two minima. The result, after a 3-point running mean smooth, is presented in Fig.1

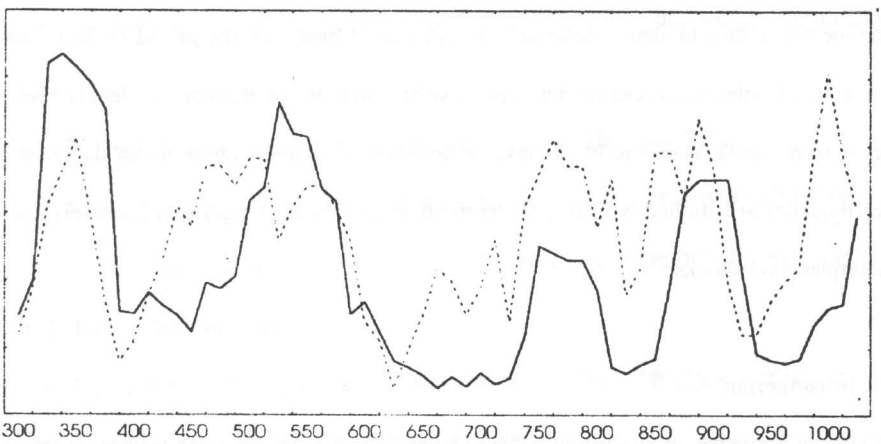

Fig.1. Number of earthquakes in the Mediterranean area summed over the 11-year solar cycles (solid line) and solar activity in the maxima of the solar cycles (broken line) in the period 296-1000; relative units. 3-point running means

The variations of solar activity explain 47% of the variations in the number of earthquakes, with $p<0.00015$. Taking into account that both data sets are based on fragmentary records and indirect estimations, this is a fairly good correlation over a period of seven centuries demonstrating that, at least in the Mediterranean region and in long time scales, seismic activity is indeed related in some way to solar activity.

3. The 11-year solar cycle

The statistics about numbers of earthquakes is most reliable since the beginning of the 20th century, so the global number of strong (with magnitude 7 or greater) earthquakes per year is studied, provided by the National Earthquake Information Center, World Data Center A for Seismology (http://neic.usgs.gov /neis/eqlists/7up.html).

The solar activity is presented by the yearly international sunspot number (http://ngdc.noaa.gov/stp/SOLAR/SSN/ssn.html).

Fig.2 shows the distribution of the number of earthquakes in the 11-year solar cycle calculated using the superposed epochs method [12] for the period 1900-1999. This period covers nine solar cycles during which 2002 earthquakes with M>7 have been registered. The solid line (left scale) denotes the average number of earthquakes in the year of the solar cycle maximum (year 0), one year before and after the maximum (-1 and +1, respectively), etc. The distribution of the average number of strong earthquakes closely follows the distribution of solar activity in the 11-year cycle (broken line, right scale) with a well expressed maximum in the solar activity maximum. A secondary maximum is observed four years after the solar activity maximum. This peak in seismic activity coincides with the maximum of solar coronal holes in the 11-year cycle, the coronal holes being the source of high speed solar wind leading to recurrent geomagnetic disturbances [13].

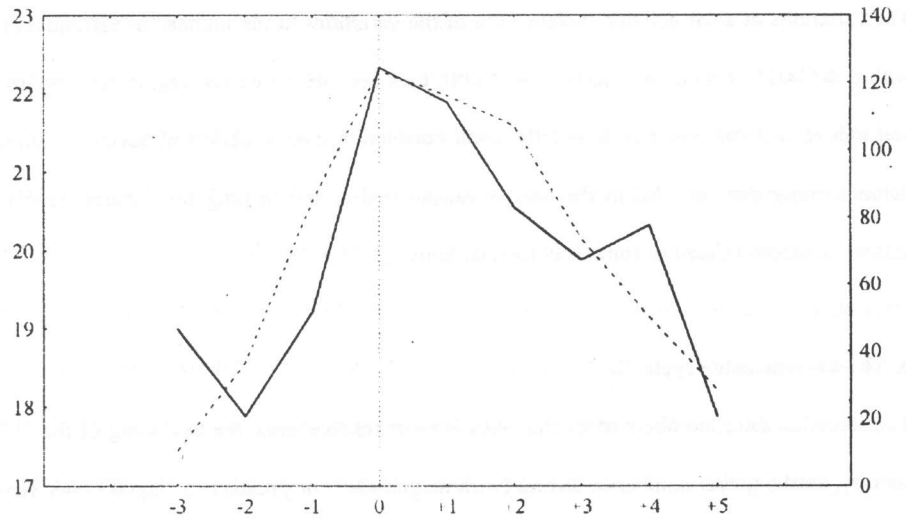

Fig.2. Average number of earthquakes (solid line, left scale) and solar activity (broken line, right scale) in the 11-year solar cycle for the period 1900-1999

4. High speed solar wind

Solar wind velocities have been measured since December 1973 by the Faraday cup experiment of the MIT Space Plasma Physics Group operating aboard IMP-8 satellite [14]. The high speed solar wind (HSS) is defined as a solar wind flow moving outward from the Sun with a high speed (bulk velocity Vb > 500 km/sec), accompanied by low density and high temperature protons, and extended for periods longer than a day. Using again the superposed epochs method, we take the dates of the arrival to the Earth of HSS as reference days to study the distribution of the number of earthquakes worldwide with magnitude 6 or greater, provided by the National Earthquake Information Center [15]. For the period 1973 - 1985 (605 earthquakes with $M \geq 6$ registered during 189 cases of HSS), a well expressed maximum in the number of earthquakes is observed one day before the arrival of the high speed solar wind - Fig.3. These results are in agreement with the ones of

Sytinskii [16] who studied the relation between strong earthquakes (with M ≥ 6 and M ≥ 6.5) with solar wind parameters and based on data for 1963-1972 showed that earthquakes most often occur one day before the dates with maximum speed of the solar wind. However, when studying the whole available period, December 1973 to June 2000 (408 HSS and 1383 earthquakes), a second maximum appears in the distribution of earthquakes on the third day after the arrival of the high speed solar wind - Fig.4. In the period 1986-2000, both maxima are present.

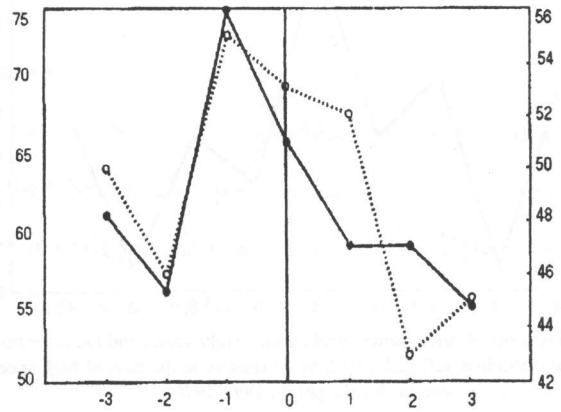

Fig.3. Number of earthquakes with M ≥ 6 relative to the days of arrival of high speed solar wind for the period 1973-1985

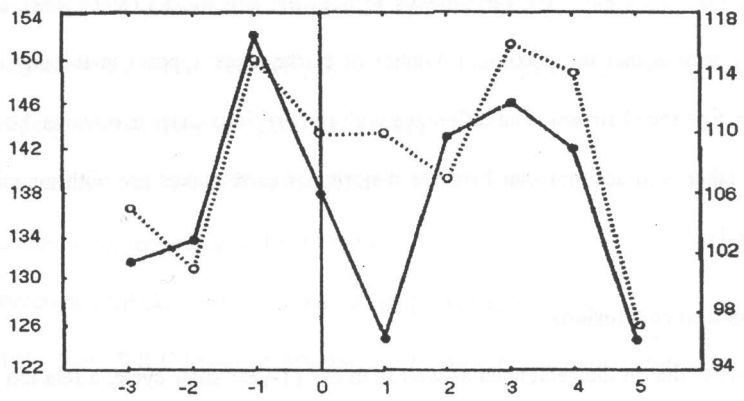

Fig.4. The same as Fig.3 for the period 1973-2000

The influence of the high speed streams on all earthquakes with magnitude 5 and greater, is studied for the period 1993-1996. The data for the earthquakes are from the composite catalog of the Council of the National Seismic System, prepared by the Northern California Earthquake Data Center, and the data for the high speed solar streams (32 days) - from the ISTP Solar Wind Catalog. The result of the superposed epochs method is presented in Fig.5.

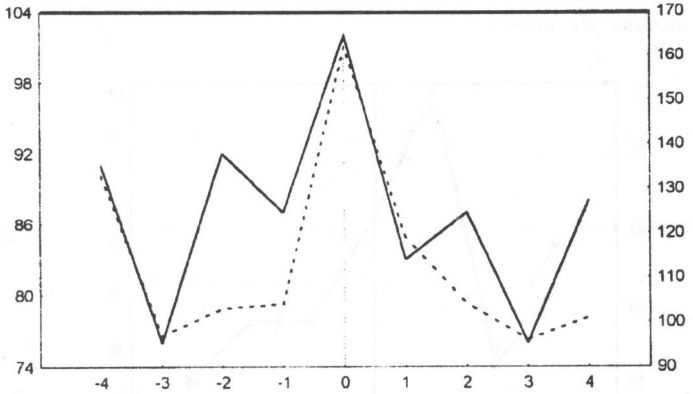

Fig.5. Total number of earthquakes (broken line, right scale) and the aftershocks substracted (solid line, left scale) with M ≥5 relative to the days of high speed streams for the period 1993-1996

The broken line (right scale) denotes all registered earthquakes with M ≥5 (1151 cases), and the solid line (left scale) - the earthquakes without the aftershocks (897 cases). In this figure clearly seen is that the maximum number of earthquakes appears in the day of the arrival of the high speed stream. The difference with the previous cases is obvious, however it should be taken into account that here the majority of earthquakes are with magnitudes between 5 and 6.

6. Discussion and conclusions

Our results show that in the centennial as well as in the 11-year solar cycle, a relation exists between solar activity and seismic activity, the increased solar activity being related to

increased number of earthquakes. The secondary maximum in the seismic activity on the descending branch of the 11-year solar cycle coinciding with the maximum of the coronal solar holes implies that high speed solar wind may be one of the solar agents triggering seismic activity. The investigations in the time scales of the order of days show that not only the strongest earthquakes but also the ones with magnitudes 5 or greater are affected by solar activity. However, the results strongly depend on the time period studied, on the magnitude and number of the earthquakes included which shows that the particular mechanism by which solar activity affects seismic activity is far from being disclised.

Acknowledgements

We thank the Instituto Nazionale di Geofisica - Rome for the Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century, and the providers of on-line data from the National Earthquake Information Center, Northern California Earthquake Data Center, National Geophysical Data Center and the MIT Space Plasma Physics Group.

References

1. J.F. Simpson, *Earth planet.Sci. Lett.* **3** (1968) 417.

2. A.Zatopek, Krivsky,L., *Bull.astr.Insts Csl.* **25** (1974) 257.

3. M.Anghel, *Revue roum.,Geol.Geophys.Geogr.,Ser. Geophys.* **23** (1979) 51.

4. M.Kopecky, *Studia geophys. geod.* **31** (1987) 43.

5. O.A.Khachay, *Vulk. Seismol.* **1** (1994) 45.

6. P.Velinov, *Bulg. geofiz. Spis.* **1** (1975) 51.

7. I.Jakubcova, M.Pick, *Annls Geophys.* **5 (B)** (1987) 135.

8. R.M.C.Lopes, S.R.C.Malin, A.Mazzarella, *Physics Earth planet. Interiors* (1990) **59** 127.

9. A.D.Sytinskii, *Dokl. Akad. Nauk SSSR* **249** (1979) 821.

10. Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century, 1995. Instituto Nazionale di Geofisica, Rome.

11. D.J.Schove, *J.Geophys.Res.*, **60** (1955) 127.

12. P.Ambroz, *Bull.Astron.Inst.Czeschoslov.*, 30 (1979) 114.

13. V.A.Kovalenko, *Solar wind* (Nauka, Moscow,1983)

14. http://www-istp.gsfc.nasa.gov/scripts/SWCatalog.html

15. http://quake.geo.berkeley.edu/cnss/

16. A.D.Sytinsky, *Geomag. Aeron.* **37 (2)** (1997) 138.