The Relationship between Solar Activity and Soil Water Balance

D.Roša [1], I.Pilaš [2], J.Roša [3], B.Vršnak [4], D.Maričić [1], D.Hržina [1]

[1] Astronomical Observatory Zagreb, Zagreb, Croatia

E-mails: drosa@zvjezdarnica.hr, darije.maricic@zg.htnet.hr,

dhrzina@zvjezdarnica.hr

[2] Department of Ecology and Silviculture, Forest Research Institute,

Jastrebarsko, Croatia, E-mail: ivanp@sumins.hr

[3] Croatian Forests, Zagreb, Croatia, E-mail: jadranka.rosa@hrsume.hr

[4] Hvar Observatory, Faculty of Geodesy, Zagreb, Croatia, E-mail: bvrsnak@geodet.geof.hr

Accepted: 18 July 2009

Abstract: In this paper we present the relationship between the soil water deficit and the solar activity as a possible factor that influences the Earth's climate. Using the Fast Fourier Transform, a periodicity of 10.9 years was found in the data series of soil water deficit based on the Thornthwaite method of calculating evapotranspiration, which is similar to the periodicity of 10.5 years found in the series of Wolf's relative number of sunspots. According to these results we can implicitly confirm that anomalies in the soil water regime i.e. the occurrence of dry spells (1991-1993, 2000-2003), are closely related to an increase in solar activity.

Keywords: Sun, solar activity, dry spells

Introduction

The IPCC (Intergovernmental Panel of Climate Change) report predicts a further increase in the global mean temperature, as well as in climate variability and extreme events, which present an increased risk of more abrupt and non-linear changes in forest ecosystems. Increased frequency of heat stress, droughts and flooding events reduce yields and forest productivity beyond the impacts due to changes in mean variables alone, causing strong uncertainty in predicting future forest tree reactions. In the commonly established theories, the major cause of global warming is anthropogenic emissions of greenhouse gases that increase the global temperature on Earth. On the other hand, there is some evidence that the global temperature on Earth also correlates to the solar activity. The explanation of astronomic influence is often based on galactic cosmic ray modulation by an 11 years period of solar activity and also longer solar cycles [1-3].

Shortwave solar radiant energy is the basic energy source driving plant growth and hence all biological processes. The visible part of solar energy (light), referred to as photosynthetically active radiation is the main driver for plant photochemical processes so in

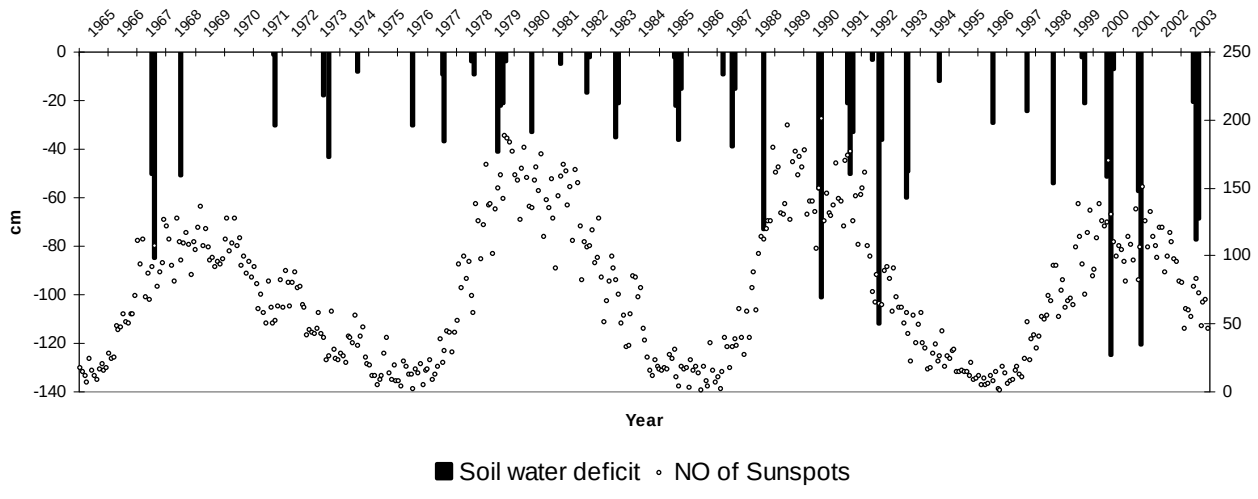

Fig.1. Relation of the sunspot number (dots) and the soil water deficit (columns).

temperate regions of the world there is clear synchrony between seasonal increase of solar radiation and hence the air temperature, with plant vegetation season [4]. On the other hand, the increased seasonal solar radiation is related to increase of vaporization from soils and vegetative surfaces [5]. For retaining regular yearly plant growth, the equilibrium should be established between the amount of solar energy required for photosynthetical activities and the amount of solar energy which will not exceed soil water limits needed for plant growth through vaporization processes in soils and plants (evapotranspiration).

According to the existing meteorological measurements in Croatia (www.meteo.hr), dry spells were very prominent in the last two decades especially from 1991-1993 and 2000-2003, characterized by extremely high temperatures and a very low precipitation. Another characteristic of dry spells is that they have effect on almost the whole country area. Apart from their negative effect on agriculture production, they negatively affect also the forested areas causing either unavailability of soil moisture for forest growth in mountainous forests or decline of shallow groundwater tables in the lowland or wetland forest sites. In this respect we note that the Croatian tree species most sensitive to soil water disturbance is the common oak (*Quercus robur L.*), being a dominant forest resource in Croatian forestry. It inhabits the lowlands, thus requiring a vast amount of water for its growth, i.e. its transpiration rate is somewhat larger than the total precipitation in the vegetation period. In past decades the decreasing trend of groundwater reserves in lowland forests is incredibly obvious and can be a result of global warming. During the last dry spell episodes in Croatia, a significant reduction in forest tree increment was evident, as well as the enhanced decline of common oak forests [6].

Having that in mind, the working hypothesis of this research is that dry spells are related to the 11-year variations in solar activity, and that an empirical relationship between the solar activity and the soil water availability could be used in the dry spell forecasting. With this aim, we analyzed cyclic behavior of sunspot activity (sunspots number) and the amount of soil water inferred from meteorological data.

Research Methods and Results

Historical records of soil moisture content measured in situ are often too short to be useful for comparison of their cyclical patterns with long-term series of solar activity. As a proxy for the unavailable soil moisture data, the values of soil water balance were used in this research to determine water shortages. A general water balance equation predicts the change in water storage as a result of precipitation, runoff, and evapotransportation. In hydrology, a water balance equation can be used to describe the flow of water in and out of a system. A system can be one or several hydrological domains, such as a column of soil or a drainage basin. In this research, we analyze the relationship between fluctuations in the water balance based on measurements from the meteorological station of Forestry Institute in Jastrebarsko and the solar activity as a global factor possibly causing the variability of the soil-water resources. A general water balance equation predicts the change in water storage as a result of precipitation, runoff and evapotranspiration.

For the calculations of the water balance the Thornthwaite method of calculating evapotranspiration was used [7]. According to this method, evapotranspiration (ETP) depends on the monthly-averaged temperature (t), yearly caloric index (I) evaluated as a sum of monthly indexes (i), and a correction factor (k) that depends of the geographic latitude ($ETP = 1.6\, k(10t/I)^a$). The parameter (a) is also derived from the caloric index (I). From the monthly evapotranspiration values and monthly precipitation, the soil water balance was calculated as the difference between the amount of water that gets to the soil by precipitation and the amount of water lost by evapotranspiration, taking into account the previous amount of water in soil. Using this method, the soil water reserve is calculated for soil depth of 1 *m* which is a commonly accepted productive soil limit used in agrometeorology. The value of soil water which exceeds the depth of 1 m during calculations is termed “soil water deficit”.

To establish the relationship between the soil water and the solar activity (Fig.1) we used the soil water deficit as a parameter which is hypothetically predominantly related to dry spells. The evapotranspiration formula of Thornthwaite is unlikely to provide accurate values for the water use of forests, but according to [2] it does provide a reasonable indication of evaporation regimes and the overall water balance. Thus, to analyze cyclic behaviour of the soil water data, it represents quite a good estimation. For indices of solar activity we used a series of the Wolf's relative sunspot number.

Fast Fourier Transform method (FFT) was used to analyze cyclic fluctuation [7]. The AutoSignal procedure (SeaSolve Software Inc.) was used, providing an advanced package for signal or data series processing and analysis. The FFT in this work was performed using the FFT Radix 2 algorithm as the conventional power of two procedures.

The significance of the largest spectral component with respect to the white and red noise was tested using the peak-based critical limit significance levels, being an option included in the AutoSignal procedure.

The assessment of relations between different data series, i.e., the sunspot number and the soil water was performed by quantitative comparisons of their periodogram ordinates or spectral densities. The outcome of the FFT analysis, i.e., the periodogram of the soil water deficit is presented in Fig. 2 and the periodograms of the solar activity in Fig. 3.

From the FFT periodograms it is evident that the soil water deficit shows a cyclic behaviour with strongest periodicity (significance level between 50 and 90%) at frequency of 0.091635 yr^{-1} (10.9 years). This periodicity is very similar to a highly significant periodicity (>99%) of the solar activity with estimated frequency of 0.094856 yr^{-1} (10.5 years).

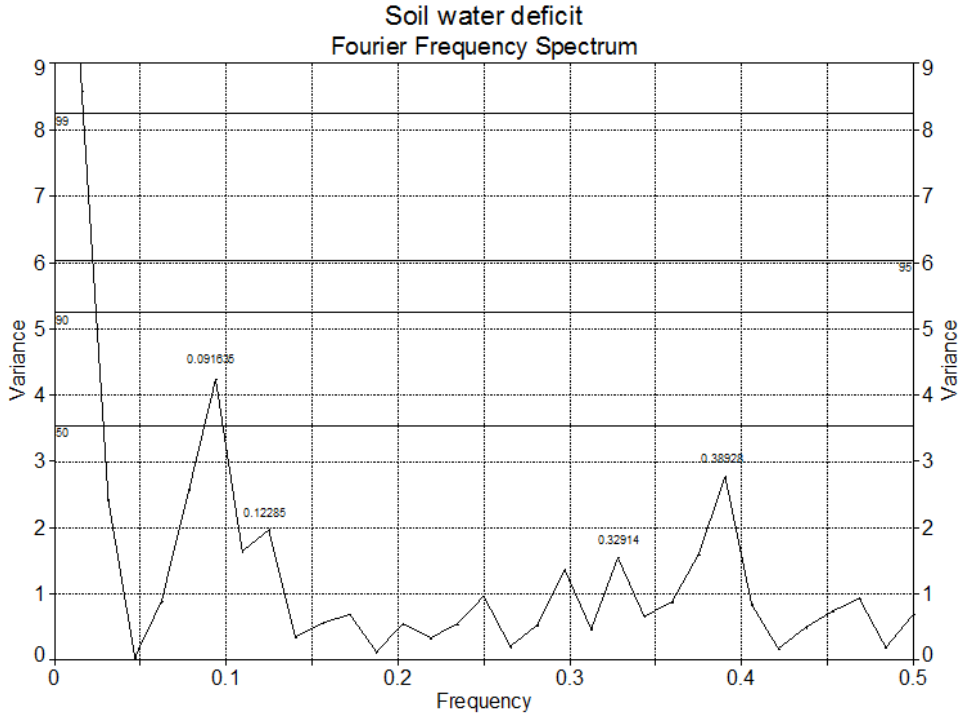

Fig.2. FFT periodogram of the soil water deficit with significance intervals

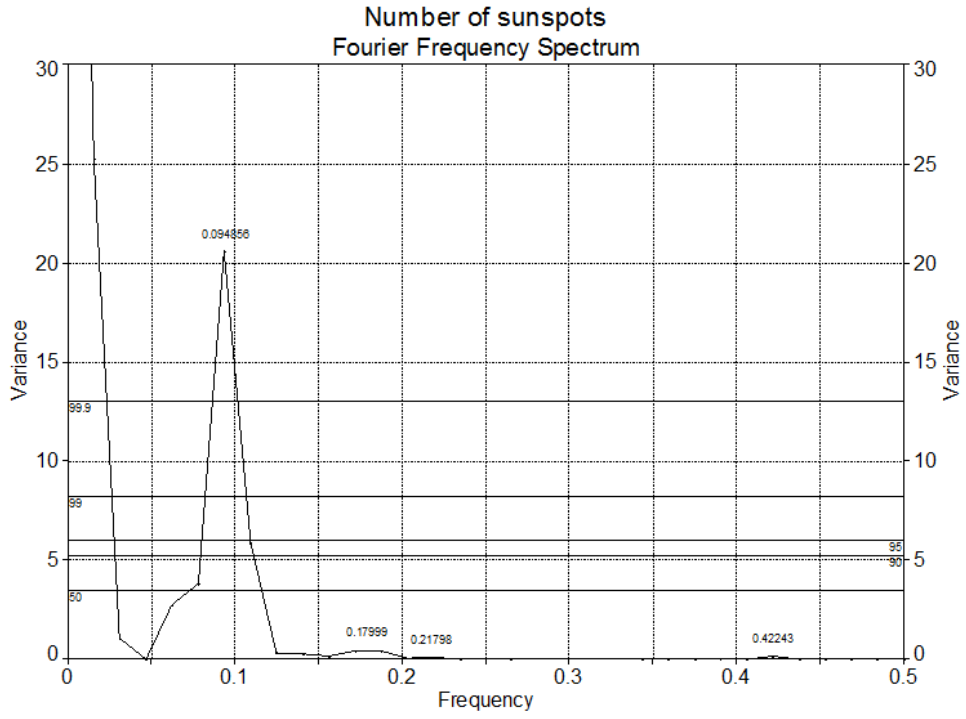

Fig.3. FFT periodogram of solar activity with significance intervals.

Discussion and Conclusion

The presented analysis confirms that dry spells, i.e., periods of soil water deficits are related to increases of the solar activity, with the periodicity between 10 and 11 years. This relationship is especially evident during the last two solar activity maxima (1990-1993, 2000-2003, and to a certain degree 1967-1968).

The periodicity of 10.9 years found in the soil water deficit is also significant because it cannot be found directly in the meteorological data from which the soil water balance was calculated. In temperature and precipitation data from same meteorological stations the periodicity of 10-11 years did not show up in the FFT analysis [8]: the temperature and precipitation show a periodicity with shorter cycles (2.5-2.7 years), which might be interpreted as harmonics of the 10.5 – 10.9 year periodicity. Taking into account that there is also a general long-term trend of the solar activity increase, our results indicate that the solar-activity significantly influences the atmospheric processes and global climate changes on Earth. With this preliminary study we aimed to emphasize this very actual problem but for the better understanding of the processes involved, a more detailed research is needed, considering also other influential factors and including a longer meteorological data series.

REFERENCES

[1] Marsh N., Svensmark H., Space Science Reviews, 2003, vol.107, p.317.
[2] Shaviv N. J., J. Geophys. Res., 2005, vol.110, p.A08105.
[3] Usoskin I.G., Schüssler M., Solanki S. K., Mursula K., J.Geophys. Res., 2005, vol.110, A9, p.10102.
[4] Landsberg J.J., Gower S.T., Applications of Physiological Ecology to Forest Management, Academic Press, 1997, 354.
[5] Chang M., Forest hydrology. An Introduction to Water and Forests, CRC Press, 2006, 474.
[6] Pilaš I., Lukić N., Vrbek B., Dubravac T. Roth. Ekologia (Bratislava), 2007, vol.26, n.2, pp.122-131.
[7] Kirkham M.B., Principles of Soil and Plant Water Relations, Elsevier Academic Press, Boston, 2005.
[8] Pernek M., Pilas I., Vrbek B., Benko M., Hrasovec B., Milkovic J., "Forecasting the impact of the Gypsy moth on lowland hardwood forests by analyzing the cyclical pattern of population and climate data series", Forest Ecology and Management, 2008, vol.255, pp.1740–1748.