S E S 2 0 1 3
Ninth Scientific Conference with International Participation
SPACE, ECOLOGY, SAFETY
20 – 22 November 2013, Sofia, Bulgaria

SOLAR EXCITATION OF DECADAL CLIMATE, MEAN SEA LEVEL AND EARTH ROTATION CYCLES

Yavor Chapanov

National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences
e-mail: yavor.chapanov@gmail.com

Keywords: *decadal oscillations, solar activity, climate, mean sea level, ice thickness, Earth rotation*

Abstract: *The global hydrologic cycles are widely affected by climatic variations, which are mostly driven by solar-terrestrial influences. The decadal climatic signals are associated with the solar activity cycles with periods of 11, 22, 45 and more years. The solar effects on climate and environment are synchronous oscillations of the water content, mean sea level and polar ice thickness and volume, due to global water redistribution between ocean and continental polar ice. The polar ice thickness increases and the mean sea level decreases during the solar maxima, followed by the decrease of the mean Earth radius and the principle momentum of inertia relative to the rotational axes. Any change of the principle momentum of inertia leads to significant variations of the Earth rotation, due to the conservation of the Earth angular momentum. The synchronous decadal cycles of solar and climate indices, mean sea level and Universal Time UT1 are analysed.*

Introduction

The long-term variations of many Earth systems are mainly caused by the displacements of matter in different parts of the planet whose excitation mechanism is 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. The climate response to the solar activity consists of cycles whose periods are decadal, centennial, millennial and their harmonics. The climate variations are mostly due to the total solar irradiance variations. The TSI variations significantly affect water evaporation and global water cycles. The global water redistribution between the oceans and continental polar ice leads to periodical changes of the principal moment of inertia C, followed by earth rotation variations, according to the low of the angular momentum conservation. The solar excitation affects cycles of climate, mean sea level, river flow, ice thickness and Earth rotation. All of these cycles are highly correlated and it is possible to predict or reconstructed some of them by the models, based on the existing observational data. Linear regression models between the long term variations of the mean sea level, the Universal Time or solar indices are created, also a model of global water redistribution between the ocean and continental polar ice during the decadal solar cycles.

Time series data

The observational data consist of UT1 variations for the period 1623.5-2005.5 (Fig.1 a), the Wolf's numbers W_n combined by annual values for the period 1700-1748 and monthly values since 1748 (Fig.2, a), The numbers of solar spots over the South S_s and North S_n hemisphere, the detrended mean sea level at Stockholm for the period 1800-2002 (Fig.4, a), the Greenland ice thickness accumulation data from the Agassiz Ice Cap (Fig.5), the Palmer Drought Severity Index PDSI for South-East Europe (Fig.7) and streamflows of river Rio Grande near Del Norte in New Mexico (Fig.6, a).

The long-periodical part of UT1 variations (Fig.1, b), determined by parabolic trend remove, are used to extract the decadal cycles of the Earth rotation. The solar magnetic cycles are represented by the extended time series of 22-year Wolf's numbers (Fig.2, b), determined by sign alternation of the even 11-year Schwabe cycles. The index S_a of equatorial solar asymmetry (Fig.3, b) is determined from the numbers of solar spots over the South S_s and North S_n hemisphere by the formula

(1) $S_a=(S_n-S_s)/(S_n+S_s)$.

The long-term S_a variations (Fig.3, a) are determined by Vondrák -Whitaker (Vondrák , 1969, 1977) filtration. The long-term variations of the mean sea level at Stockholm are determined by 5-year averaging (Fig.4, b). The long-term streamflows variations of river Rio Grande (Fig.6, b) are determined by Vondrák –Whitaker filtration.

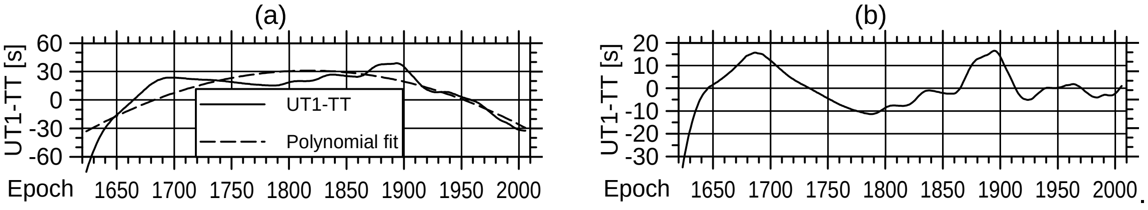

Figure 1. UT1 data for the period 1623.5-2005.5 (a) and periodical part of UT1 variations (b)

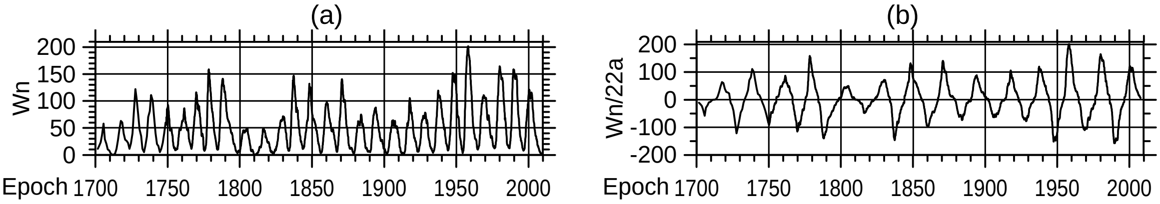

Figure 2. Wolf’s numbers W_n represented by annual (1700-1748) and monthly values (a). Extended time series of 22-year cycles of the wolf numbers $W_{n/22a}$ (b)

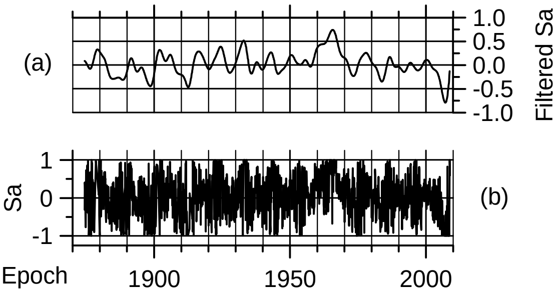

Figure 3. Index S_a of equatorial solar asymmetry (b) and long-term S_a variations (a)

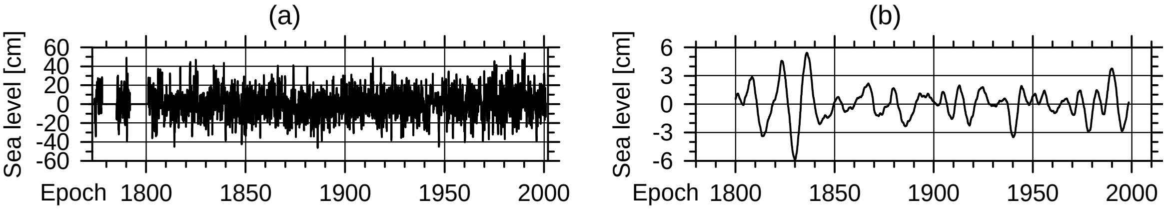

Figure 4. Sea level data from Stockholm mareograph station, after the linear trend remove (a). Long-term variations of the mean sea level at Stockholm for the period 1800-2002, 5-year averaging (b)

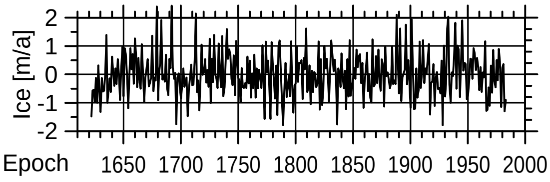

Figure 5. Greenland annual ice thickness accumulation data from the Agassiz Ice Cap

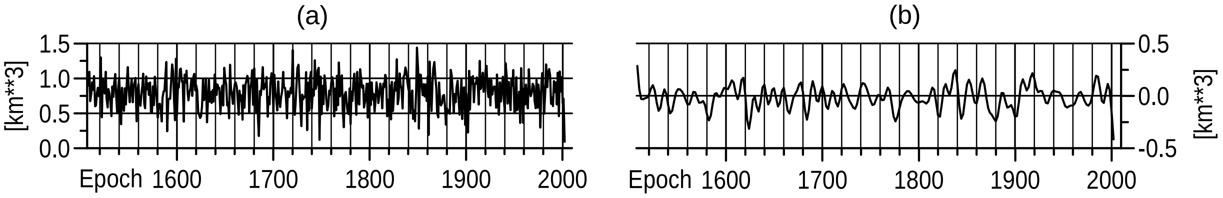

Figure 6. Annual streamflow of river Rio Grande near Del Norte in New Mexico (a) and it long-term variations (b)

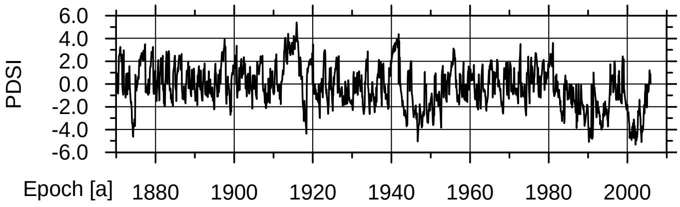

Figure 7. Variations of the PDSI for South-East Europe

The Palmer Drought Severity Index (PDSI) is involved by Palmer (1965) 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 (Dai et al., 1998; 2004) consist of the monthly surface air temperature (Jones and Moberg 2003) and precipitation (Dai et al., 1998; Chen et al., 2002) over global land areas from 1870 to 2006. These data is represented as PDSI values in global grids 2°.5×2°.5. The time series of the PDSI variations are determined by the mean values from all grid data from the selected area. The PDSI variations over the South-East Europe are determined for area between longitude 10°-30° E and latitude 32°.5-50° N (Fig.7). The mean values are computed by means of the robust Danish method (Kubik, 1982; Juhl, 1984; Kegel, 1987). This method allows to detect and isolate outliers and to obtain accurate and reliable solution for the mean values.

Decadal solar cycles and Earth rotation

The decadal cycles of Earth rotation for the period 1623.5-2005.5 are extracted by means of Fourier approximation of the UT1-TT variations with use of 100 harmonics, which includes oscillations with periods above 3.8a and estimation accuracy of the amplitudes about 11ms. The harmonic coefficients are estimated by means of the Least Squares Method. Parts of the peaks of UT1 amplitude spectrum are connected with the cycles of some natural phenomena: 45-year solar equatorial asymmetry, 22-year solar magnetic cycle, 18.6-year tides due to motion of lunar node, 11-year sunspot variations and many signals coming from the liquid core of the Earth. The periodical oscillations of UT1 are separated into different bands (Figs.8-10). The oscillations with periods below 15 years consist of significant noise before 1700, so the decadal UT1 cycles are determined from data after 1700.

The mean value of the sunspot cycles after 1750 is rather close to 11.2a, so the 34-th harmonics of the Fourier approximation of UT1 data is used as initial Earth rotation response to the solar activity (Fig.8). The 11.2-year UT1 oscillations are delayed by 3 years with respect to the Wolf's numbers variations (Fig.8).

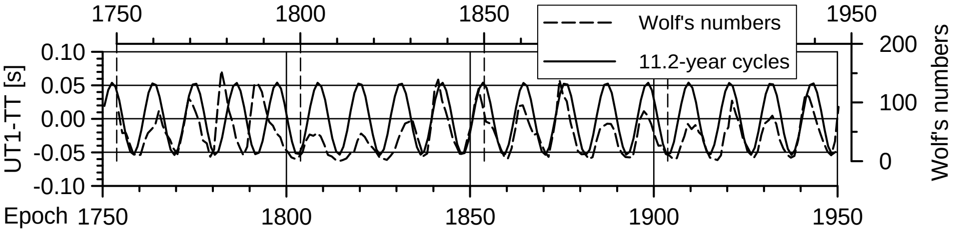

Figure 8. Comparison of 11-year UT1 cycles and Wolf's numbers W_n

The 11-year UT1 cycles are positively correlated with the Wolf's numbers, so the time angle (or Earth angular velocity) increases during the solar maxima and decreases during the solar minima. The 22-year and 45-year solar and UT1 cycles are positively correlated, too. The 45-year solar cycles are determined by 3 harmonics of partial Fourier approximation of the long-term variations of equatorial solar asymmetry with periods from band 34a-51a.

The 22-year UT1 cycles are composed by Fourier harmonics with periods between 21a and 24a and they are significantly correlated with the extended time series of 22-year solar cycles (Fig.9). The 45-year UT1 cycles are determined by Fourier harmonics with periods from band 33a-45a. They have excellent agreement with the 45-year oscillations of equatorial solar asymmetry, whose periods are from the same band (Fig.10). The time delay between 22-year solar cycles and Earth rotation response is 3 years and between 45-year cycles – 8 years.

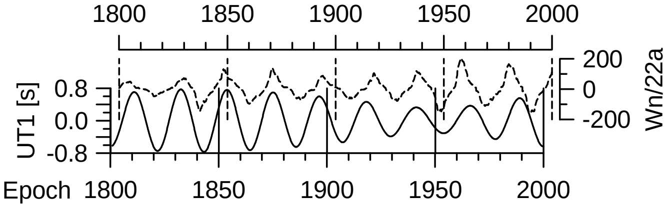

Figure 9. Comparison of 22-year UT1 cycles and Wolf's numbers $W_{n/22a}$..

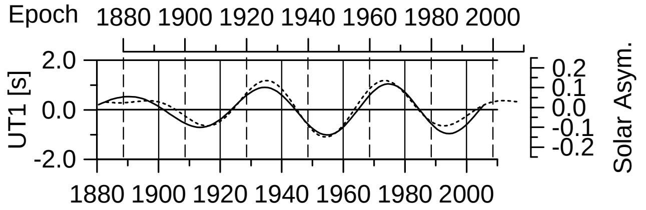

Figure 10. Comparison of 45-year UT1 oscillations (bold line) and solar asymmetry index (dashed line)

Decadal solar cycles and mean sea level

The global oscillations of the mean sea level with periods 11a, 22a and 45a are due to the Total Solar Irradiance (TSI) changes during the solar cycles. The TSI is arising during the solar maxima by up to 0.5W/m^2 and this leads to additional water evaporation. The evaporated water is redistributed over the ocean, continents and continental polar ice. The arising of the continental polar ice during the solar maxima and TSI increase is the primary reason of the observed MSL oscillations with the solar frequencies.

The 11-year MSL cycles are negatively correlated with the Wolf's numbers (Fig. 11), so the time MSL increases during the solar minima and decreases during the solar maxima. The 22-year and 45-year solar and MSL cycles are negatively correlated (Figs. 12, 13), so the correlation coefficients between the MSL and UT1 decadal oscillations are negative.

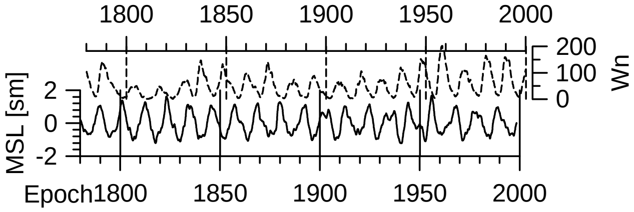

Figure 11. Comparison of 11-year MSL cycles at Stockholm and Wolf's numbers W_n

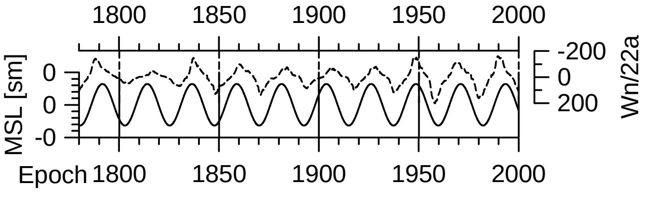

Figure 12. Comparison of 22-year MSL cycles at Stockholm (bold line) and extended Wolf's numbers $W_{n/22a}$ (dashed line)

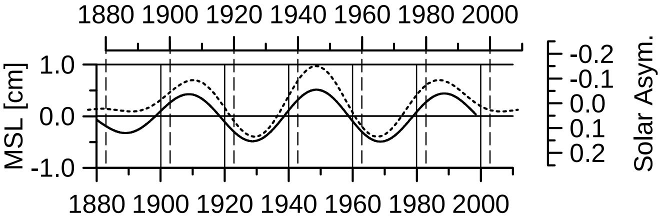

Figure 13. Comparison of 45-year oscillations of MSL (bold line) and the solar asymmetry index (dashed line)

Decadal solar cycles and polar ice accumulation

The 11-year and 22-year Ice accumulation rates at Greenland are highly correlated with the solar indices with positive coefficients (Figs. 14, 15). Thus, these cycles of polar ice thickness are positively correlated with the decadal UT1 cycles, as it is visible in Fig.16, where the 45-year cycles of UT1 and ice thickness rate are compared.

The variations of the rate of the polar ice accumulation with periods 11a, 22a and 45a are due to the total solar irradiance changes during the solar cycles and corresponding additional water evaporation. When the evaporated water is redistributed over the continental polar ice it leads to arising of the continental polar ice during the solar maxima, so the TSI variations are the reasons of the observed polar ice thickness oscillations with the decadal solar frequencies.

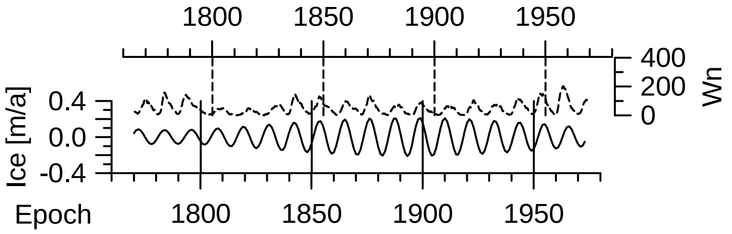

Figure 14. Comparison of 11-year Ice accumulation cycles and Wolf's numbers W_n.

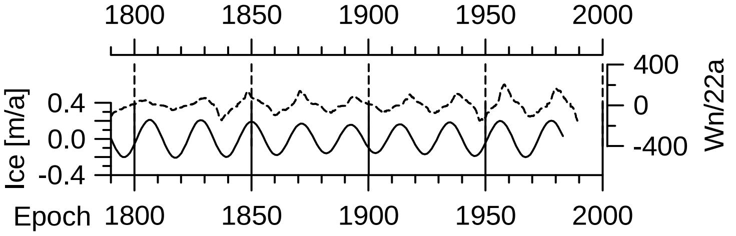

Figure 15. Comparison of 22-year ice accumulation cycles and extended Wolf's numbers $W_{n/22a}$.

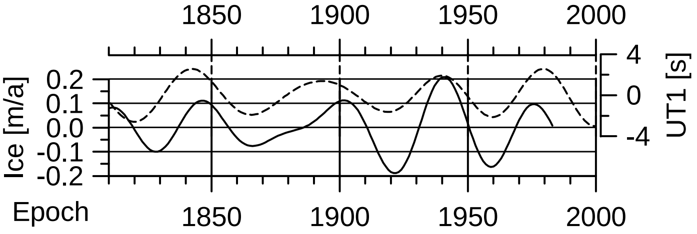

Figure 16. Comparison between 45-year cycles of UT1 and ice thickness rate

Decadal solar influences on climate and hydrological variations

The TSI variations affect ground water lost during the solar cycles. This is revealing by the 11-year oscillations of PDSI index (Fig.17), where the PDSI is negatively correlated with the Wolf's numbers, while the 22-year and 45-year solar indices and PDSI are positively correlated (Figs. 18, 19). The Palmer classification of drought conditions is in terms of minus numbers: between 0.49 and -0.49 - near normal conditions; -0.5 to -0.99 - incipient dry spell; -1.0 to -1.99 - mild drought; -2.0 to -2.99 - moderate drought; -3.0 to -3.99 - severe drought; and -4.0 or less - extreme drought. The positive values are similar about the wet conditions. Thus, the maxima of decadal solar cycles cause water lost from the ocean, similar to the dry condition over the continents during the maxima of 11-year solar cycle. The wet conditions over the continents occur during the maxima of 22-year and 45-year solar cycles, due to additional amount of rainfall.

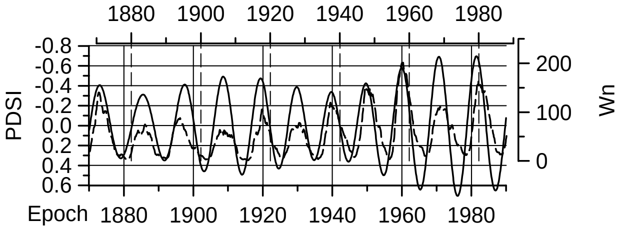

Figure 17. Comparison of 11-year oscillations of the PDSI over South-East Europe (bold line) and monthly mean variations of the Wolf's numbers (dashed line)

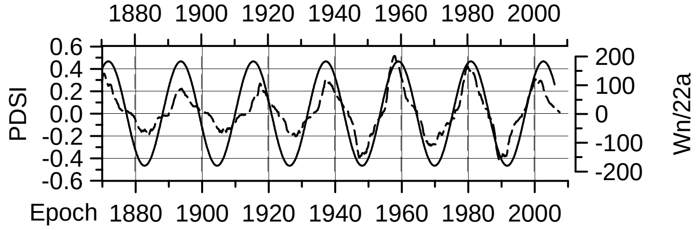

Figure 18. Comparison of 22-year oscillations of the PDSI over South-East Europe (bold line) and the extended time series of the 22-year Wolf's numbers oscillations (dashed line)

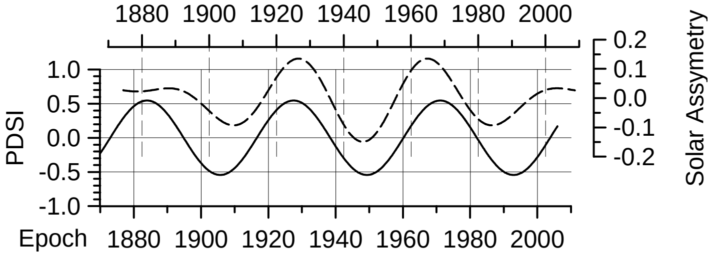

Figure 19. Comparison of 45-year oscillations of the PDSI over South-East Europe (bold line) and the solar asymmetry index (dashed line)

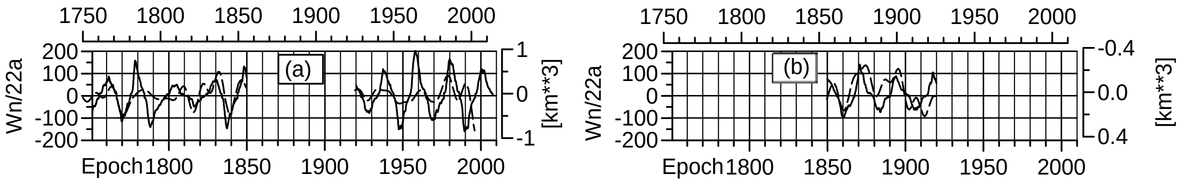

Figure 20. Comparison between 22-year sunspot cycles $W_{n/22a}$ (bold line) and Rio Grande streamflow (dashed line). Positive correlation (a) and negative correlation (phase reverse) - (b)

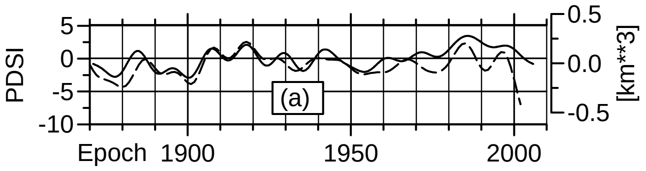

Figure 21. Comparison between PDSI (bold line) and river Rio Grande streamflow (dashed line)

The 22-year cycles of the solar activity have strong influence on climate variations. The extended index of 22-year Wolf's number variations is highly correlated with the long-term oscillations of Rio Grande streamflow (Fig.20). This correlation is positive for the periods 1750-1850 and 1920-2000 (Fig. 20, a) and negative for the time interval 1850-1920 (Fig.20, b), so this points out to sudden reverse of the phases in 1850 and 1920. The long term variations of river streamflow are highly correlated with the PDSI variations over New Mexico (Fig.21).

A model of solar excitation of decadal Earth cycles

The following model explains the observed common decadal cycles of solar activity, climate, mean sea level, continental polar ice thickness accumulation and Earth rotation.

Let consider a homogeneous sphere with radius R=6371km, density 5.519g/cm^3 (Neff and Zitewitz, 1995), inertial moment C, angular velocity ω and constant mass M. From the conservation of angular momentum, any change of inertial moment ΔC is connected with a corresponding change of angular velocity $\Delta\omega$ by the expression

(2) $$\Delta C\omega + C\Delta\omega = 0$$

The variation ΔC depends on variation of radius ΔR by the formula

(3) $$C + \Delta C = \frac{2}{5}M\left(R^2 + 2R\Delta R + \Delta R^2\right),$$

and from (2) and (3), after neglecting the second order term ΔR^2, we obtain

(4) $$2\Delta R\omega + R\Delta\omega = 0\,.$$

The formula (4) expresses the relationship between the variations of the radius and angular velocity of an ideal flexible homogeneous sphere without external moments, hence the necessary change of radius ΔR, which corresponds to observed variation of time angle ΔUT for time interval P is

(5) $$\Delta R = -\frac{1}{2}R\frac{\Delta UT}{P}.$$

In case of periodical variation of time angle ΔUT with observed amplitude A_{UT} and period P, the necessary amplitude A_R of the periodical oscillations of the radius with opposite phase is

(6) $$A_R = \frac{1}{2}R\frac{A_{UT}}{P},$$

and the amplitude A_{UT} of the Universal Time UT1 oscillations depends on the amplitude A_R of the Earth radius oscillations by the expression

(7) $$A_{UT} = 2P\frac{A_R}{R}.$$

The Earth area with intensive water lost, due to the additional water evaporation during the solar cycles, depends on the level of water change. In the case of significant MSL variations (similar to those during the glacial cycles), only the ocean provides necessary water amount. The case of small MSL variations (similar to the recent MSL changes) includes water evaporation from all Earth surface, more intensive from the free water surfaces and less intensive from the ground. Let consider the second case of small MSL variations with equal water level lost from the ocean and ground. The mean density of sea water at the ocean surface is 1.025g/cm^3, or 5.38 times less than the mean Earth density, while the fresh ground water is 5.52 times less. Then the mean density of the redistributed total water before the evaporation is 5.4 less than the mean Earth density.

The necessary change of the Earth axial moment of inertia during a sunspot cycle is provided by mean sea level oscillations with 5.42 times higher mean amplitude A_{MSL} than A_R or

$$\begin{aligned} A_{MSL} &= \frac{1}{2}kR\frac{A_{UT}}{P} = kA_R, \\ A_{UT} &= 2P\frac{A_{MSL}}{kR}, \\ k &\approx 5.4, \end{aligned} \tag{8}$$

where the coefficient k is transfer coefficient between the homogeneous elastic sphere and the real Earth. The value of the coefficient k plays a key role for proper determination of A_{MSL}. It is possible to determine the proper value of k by means of all data of temporal changes of the continental water storage.

Let consider 11-year solar cycle. In this case A_{UT} is 65ms; P = 11a = 3.47×10^8s, and we obtain from (6) A_R = 0.6mm and from (8) - A_{MSL}=3.24mm. The change of inertial moment of continental polar ice, due to the variations during a single sunspot cycle is approximately 3% of ΔC, which need to increase A_{MSL} by 1.5% to the value of 3.3mm. The necessary energy to evaporate a 6.6mm (doubled amplitude A_{MSL}) thin layer of sea water with surface of 1m^2, salinity 3.5% and mean temperature 16°C is 6.6/×0.989kg×2440kJ/kg=15.9MJ, collected for time interval of 1/2×11a (one half for daylight time only), or 1.73×10^8s. The corresponding deviation of the total solar irradiance is 0.1W/m^2 only, which is 10 times less than the total solar irradiance variations due to the solar activity. The observed 11-year amplitude of MSL oscillations is higher than the necessary value, arising from Earth rotation observations.

Conclusions

The decadal variations of the PDSI over South-East Europe are highly-correlated with the 11-, 22- and 45-year cycles of the solar activity. The amplitudes of the PDSI responses to the solar cycles are between 0.4-0.7 and the cumulative effect of the solar activity on the PDSI variations is less than ±2 and this effect have not enough power to present full explanation of the observed severe dry and wet events over the South-East Europe for the period 1870-2006.

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

The main source of excitation of the 11-, 22- and 45-year variations of Earth rotation are climatic variations due to the solar activity and connected with them oscillations of the mean sea level and continental polar ice. The solar activity cycles affect climate by variations of the total solar irradiance with maximal amplitudes between 0.2–0.5W/m^2. These variations provide additional amount of energy (~10^{17}MJ for the whole Earth and 130–260MJ per square meter on the equator) during these cycles. This energy is capable to evaporate 50–100 liters of water from 1 square meter equatorial ocean surface and 20–40 liters of water from 1 square meter ocean surface from the north latitudes.The changes of MSL, due to total solar irradiance variations and additional evaporation, followed by global water redistribution and ice thickness variations over the polar caps, lead to corresponding oscillations of the axial Earth moment of inertia, and according to the low of angular momentum conservation – to changes of Earth rotation velocity.

The proposed model of global water redistribution determine the relationships between the observed periodical oscillations at the solar activity frequencies of the Earth rotation, mean sea level and ice thickness accumulation rate over the polar continental ice sheets. It is possible to reconstruct the periodical behavior of the global hydrological cycles by means of available astronomical data, or to reconstruct Earth rotation data by means of available mean sea level changes.

The local and global hydrological cycles are more sensitive to the total solar irradiance variations due to solar activity than the surface temperature and atmosphere parameters changes, because the additional water evaporation during solar maxima produces significant cooling effect. It is important to study the influence of solar cycles on all hydrological events, including soil water content, ice thickness variations and the thickness of the warmed surface ocean water during the solar maxima.

References:

1. Chen, M., P. Xie, J.E. Janowiak, and P.A. Arkin, 2002: Global land precipitation: a 50-yr monthly analysis based on gauge observations. J. Hydrometeorol., 3, 249-266.
2. Dai, A., I. Fung, and A. D. Del Genio, 1997: Surface observed global land precipitation variations during 1900-1988. J. Climate, 10, 2943-2962.
3. Dai, A., K. E. Trenberth, and T. Karl, 1998: Global variations in droughts and wet spells: 1900-1995. Geophys. Res. Lett., 25, 3367-3370.
4. Dai, A., K. E. Trenberth, and T. Qian, 2004: 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.
5. Jones, P.D., and A. Moberg, 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. J. Climate, 16, 206-223.
6. Juhl, J., 1984: The “Danish Method” of weight reduction for gross error detection, XV ISP Congress proc., Comm. III, Rio de Janeiro.
7. Kegel, J., 1987: Zur Lokalizierung grober Datenfehler mit Hilfe robuster Ausgleichungsfervahren, Vermessungstechnik, 35, №10, Berlin.
8. Kubik, K., 1982: An error theory for the Danish method, ISP Symposium, Comm. III, Helsinki.
9. Neff, R. F. & P. W. Zitewitz, 1995: Physics, Principles and Problems. New York: Glencoe, 159 pp.
10. Palmer, W. C, 1965: Meteorological Drought. Res. Paper No.45, U.S. Weather Bureau, Washington, 58 pp.
11. Stephenson, F. R., Morrison, L. V., 1984, Long-Term Changes in the Rotation of the Earth: 700 BC to AD 1980, Philosophical Transactions of the Royal Society of London, Ser. A, pp. 47--70.
12. Vondrák, J.: 1969, Bull. Astron. Inst. Czechosl., 20, 349−355.
13. Vondrák, J.: 1977, Bull. Astron. Inst. Czechosl., 28, 84−89.