17th International Conference on Environmental Science and Technology
Athens, Greece, 1 to 4 September 2021

Influence of Common Solar and Climate Cycles on Groundwater Level Variations

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Abstract. The groundwater is one of the most important natural resources. It provides drinking water and water for businesses. The level of groundwater varies in time. It has significantly seasonal oscillations and long-term variations, induced by rainfalls and climatic droughts. The seasonal, interannual and decadal cycles of groundwater level are studied by reconstructed time series for several groundwater stations in England for the period 1891-2015 provided by the British Geological Survey. The monthly groundwater level time series are created by the program AquiMod by real measurements of groundwater level data, precipitation, temperature and estimation of potential evapotranspiration, soil drainage, unsaturated-zone flow and groundwater flow. The common cycles of Total Solar Irradiance (TSI), precipitation and Palmer Drought Severity Index (PDSI) are determined by means of the Method of Partial Fourier Approximation. The solar and climate cycles are compared with the groundwater oscillations in narrow frequency bands with periodicities between 1 and 125 years. The variations of seasonal amplitudes are analyzed together with solar and climate Indices. The possibility of forecast of groundwater variations on the base of common solar, climate and groundwater cycles is discussed.
Keywords: groundwater level, precipitation, PDSI, solar cycles

1. Introduction

The global warming produces significant climate change in last decades, in particular expressed by many floods and landslides on territory of European Union. The reason of these events is the increase of global water circulation, due to warmer oceans and enhanced evaporation, followed by heavy rains and critical values of groundwater and river discharges. The groundwater is one of the most important natural resources. It provides drinking water and water for businesses. The level of groundwater varies in time. It has significantly seasonal oscillations and long-term variations, induced by rainfalls and climatic droughts. Usually, large regions of the land have significant lack of direct groundwater measurements. It is possible to estimate and analyzed groundwater variations by existing a large amount of climatic indices, whose time series are created from real observations or precise climatic and geophysical models. The most important climatic indices are precipitation and PDSI, whose data set covers global land. The solar activity cycles and their harmonics drive all climate processes on the Earth surface, so we expect a significant influence on groundwater variations.

2. Data and Methods

Time series of groundwater variations from historic reconstructions of monthly groundwater levels for UK boreholes Hucklow and Chilgrove (1891-2015) in NERC Environmental Information Data Centre (Bloomfield et al., 2018) are used (Figs 1, 2).

Figure 1. Location of Hucklow and Chilgrove boreholes.

The precipitation time series (Fig. 2, b) are extracted from the Climatic Research Unit gridded Time Series (CRU TS) dataset 4.04 (Harris et al., 2020) at the Centre for Environmental Data Analysis (CEDA). The global PDSI data (Dai et al., 2017; Dai, 2021) 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 1850 to 2018 (Fig. 2, c). The positive values of PDSI denote wet conditions, and negative values – dry conditions. The daily reconstruction of TSI since 1850 is a composite of SATIRE-T reconstruction from (Krivova et al., 2010) for 1850 to 22 August 1974; and SATIRE-S reconstruction from (Yeo et al., 2014a, 2014b) for 23 August 1974 onwards (Fig. 2, d, yellow color). The monthly values are calculated by the robust Danish Method (Fig.2, d, red color).

The time series spectra are calculated by the Fast Fourier Transform (FFT). The time series of oscillations with a given frequency are calculated by the Method of Partial Fourier Approximation (PFA), whose details are described in (Chapanov et al., 2015).

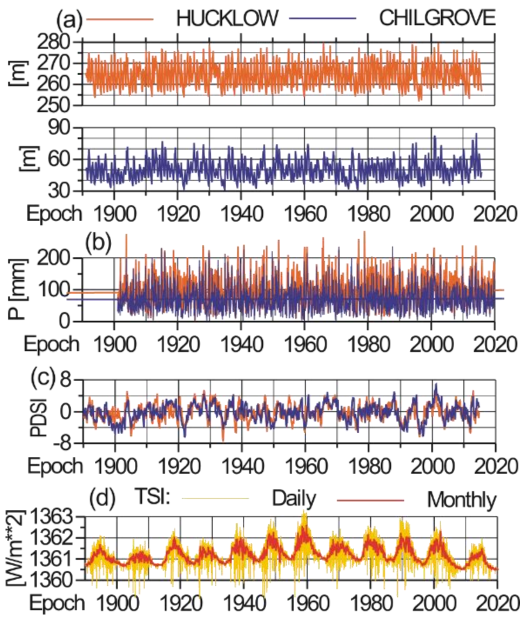

Figure 2. Time series of groundwater variations (a), Precipitation P (b), PDSI (c), and TSI (d).

3. Time series spectra

The FFT spectra of TSI and groundwater, precipitation, PDSI at Chilgrove and Hucklow boreholes are shown in Fig. 3.

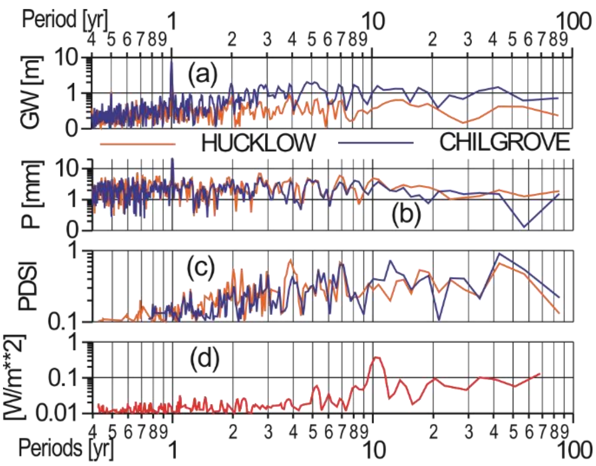

Figure 3. Time series spectra of groundwater variations (a), Precipitation P (b), PDSI (c), and TSI (d).

The time series of precipitation and PDSI over Chilgrove and Hucklow boreholes are partly correlated and their spectra have some common coherent oscillations, while the groundwater spectra are rather different. The Chilgrove aquifer is chalk, while the Hucklow aquifer is carboniferous limestone, so, this is possible reason for significant differences in groundwater variations.

4. Climate influence on groundwater variations

The influence of PDSI and precipitation variations on the groundwater level at Chilgrove borehole is shown in Fig. 4, and at Hucklow borehole - in Fig. 5. The long-term variations are calculated by 61 harmonics of PFA of PDSI and GW data, whose periods are between 2 and 123.7 years (time interval 1891.1-2014.8). The long-term oscillations of precipitation are determined by 58 harmonics of PFA with periods between 2 and 114.7 years (time interval 1901.0-2015.7). The annual cycles are composed by 25 PFA harmonics with periods between 0.95 and 1.18 year. The annual variations of groundwater at Chilgrove borehole have good agreement with the corresponding cycles of precipitation (Fig. 4, c), while these variations at Hucklow borehole are partly covered by precipitation cycles (Fig. 5, c).

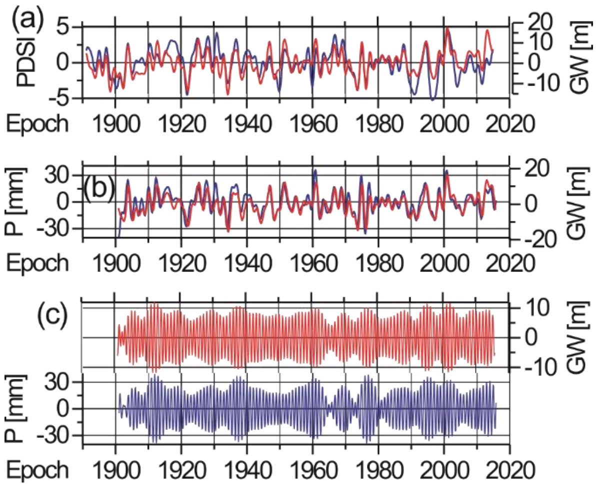

Figure 4. Groundwater variations at Chilgrove borehole (red line), due to long term cycles of PDSI - (a), Precipitation P - (b), and annual cycles of P - (c).

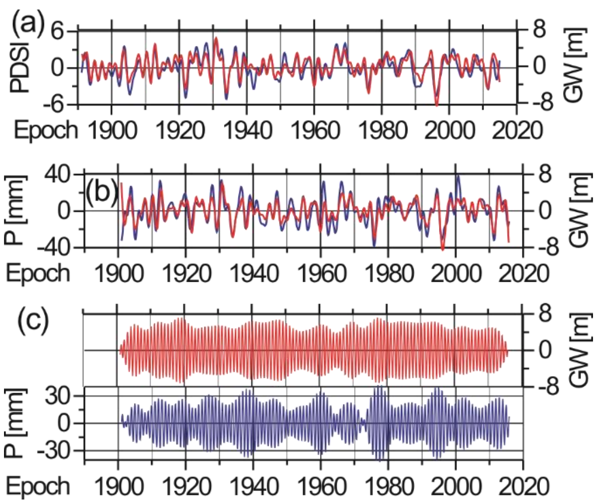

Figure 5. Groundwater variations at Hucklow borehole (red line), due to long term cycles of PDSI - (a), Precipitation P - (b), and annual cycles of P - (c).

The long-term variations of groundwater at Chilgrove borehole have better agreement with the precipitation cycles (Fig. 4, b) than the PDSI cycles, while at Hucklow borehole the PDSI curve almost exactly cover the groundwater curve (Fig. 5, a). The possible reason of this is different aquifer and different sensitive to the dry and wet conditions at the surface.

5. Solar influence on groundwater variations

The solar influence on groundwater variations at Chilgrove and Hucklow boreholes is revealed in 3 narrow frequency bands, whose periods are 13.8-15.6; 24.9-31.2; and 41.5-62.3 years (Figs. 6, 7). The TSI and groundwater variations have relatively good agreement. Better results are expected in models of solar-groundwater influences, based on variations of sunspot numbers, North-South solar asymmetry, galactic cosmic rays and geomagnetic field.

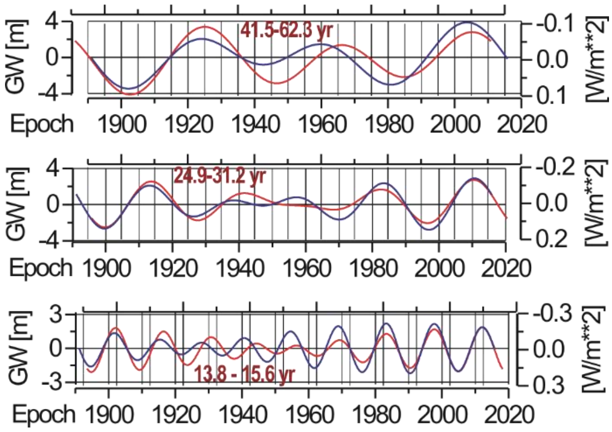

Figure 6. TSI influence (red line) on groundwater variations at Chilgrove borehole (blue line).

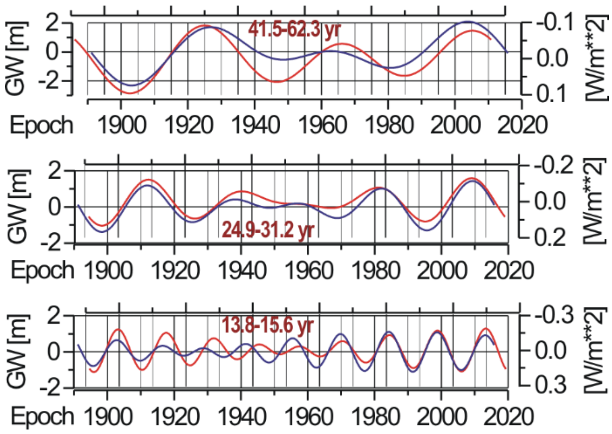

Figure 7. TSI influence (red line) on groundwater variations at Hucklow borehole (blue line).

6. Conclusions

The time series of groundwater level at 54 UK boreholes, created by the program AquiMod give good opportunity to study groundwater variations. The comparison of groundwater variations at Chilgrove and Hucklow boreholes with climate indices of wet and dry conditions shows that the groundwater cycles may strongly correlate with precipitation or PDSI in dependence of borehole location and aquifer composition. It is possible to create adequate long-term forecast of groundwater variations by the use of models of solar cycles and solar harmonics influence on precipitation, temperature, drought indices and other climatic parameters.

Acknowledgments

The study is supported by the National Science Fund of Bulgaria, Contract KP-06-N34/1 /30-09-2020 "Natural and anthropogenic factors of climate change – analyzes of global and local periodical components and long-term forecasts" and by the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01-322/18.12.2019).

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