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Solar Influence on Ozone Variations over ENSO Regions

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Abstract.

The most important source of ENSO (El-Nino Southern Oscillation) excitation is the influence of harmonics of solar activity cycles. The solar activity is reveling mainly by the Total Solar Irradiance (TSI) variations, solar wind and variations of solar magnetic field. While the TSI variations affect directly earth surface temperature, the solar wind and magnetic field modulate changes of the heliosphere, geomagnetic field and cosmic ray variations. The cosmic ray variations drive ozone production in low stratosphere near the tropopause, and next a chain process affects surface temperature. These effects are proved in polar and ENSO regions. In previous studies, a strong correlation has been found between ozone and El Nino variations; and between the variations of indices of N-S solar asymmetry and Nino 3.4. So, the possible transmitter between solar signals and ENSO event is low stratospheric ozone, whose variations are affected by solar activity. The solar influence on ozone variations over ENSO regions is investigated by means of time series of solar activity indices and ozone variations at 70 HPa over Nino 3.4 regions around equatorial part of Pacific Ocean. The common harmonics of solar and ozone cycles are determined by means of recently developed Method of Partial Fourier Approximation, where the trigonometric coefficients are estimated by the Method of Least Squares. The results of common frequency bands with interannual, decadal and centennial periodicity of solar and ozone data may improve models of solar influence on Pacific temperature anomalies and recent climate change.

Keywords: N-S solar asymmetry; ozone; ENSO**.**

Introduction

The solar activity affects all geosystems, including climate and weather. The TSI cycles are the main source of climate indices variations. Recently a new mechanism of climate modulation, based on cosmic rays variations has been proposed (Kilifarska et al., 2005, 2008; Kilifarska 2011; Velinov et al., 2005). This mechanism is based on chain processes near tropopause at 70 hPa geopotential height, approximately 17 km above sea level. The several steps of ozone production, due to cosmic rays are followed by temperature variations, vertical winds and water content change. The last step of this chain affects 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 CR, whose total energy is relatively small, cause climatic effects with much more energy. The solar activity cycles modulate CR directly by the heliosphere and indirectly by the geomagnetic field changes, whose effect is visible mainly at high latitudes.

The solar activity affects terrestrial systems by means of direct radiation over Earth surface, 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 heliosphere. The cosmic rays near Earth are modulated by Earth magnetic field variations, too. The variations of solar magnetic field are presented by the Index of North-South Solar Asymmetry (N-S SA). A strong correlation between variations of N-S solar asymmetry and ENSO has been discovered in (Chapanov, 2021, 2022). The changes of

ENSO phase due to near-tropopause ozone has been discover in (Kilifarska and Velichkova, 2021). According to these results, the possible transmitter between the variations of N-S solar asymmetry and ENSO event is low stratospheric ozone.

Data and Methods

The solar data are presented by the Total Solar Irradiance (TSI) and North-South solar asymmetry variations. The daily reconstruction of TSI data since 1850 is a composite of SATIRE-T reconstruction from (Krivova et al., 2014) for 1850 to 22 August 1974; and SATIRE-S reconstruction from (Yeo et al., 2014) for 23 August 1974 onwards (Fig.1). The 0.1-year values of TSI are calculated by means of robust Danish method (Juhl, 1984; Kegel, 1987; Kubik, 1982). This method allows to detect and isolate outliers and to obtain accurate and reliable solution for the mean values.

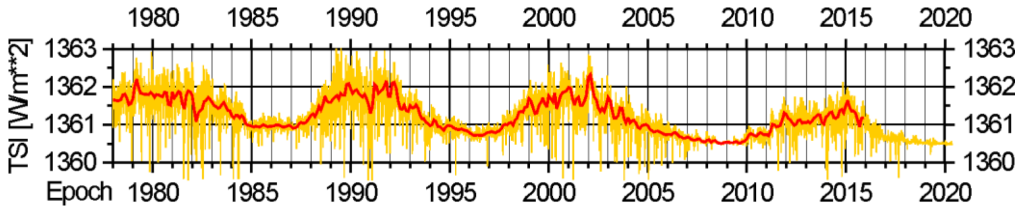

Figure 1. Time series of 0.1-year (in orange color) and daily values (in yellow color) of TSI.

The North-South solar asymmetry (Fig. 2) is determined from the relation $(S_n\text{-}S_s)/(S_n+S_s)$, where the S_n and S_s are monthly sunspot area on the Northern and Southern solar hemispheres, respectively (in units of millionths of a hemisphere). The data since 1874 are observed by the Royal Greenwich Observatory and merged after 1976 with the US Air Force (USAF) and the US National Oceanic and Atmospheric Administration (NOAA) data by D. Hathaway (https://solarscience.msfc.nasa.gov/greenwch.shtml).

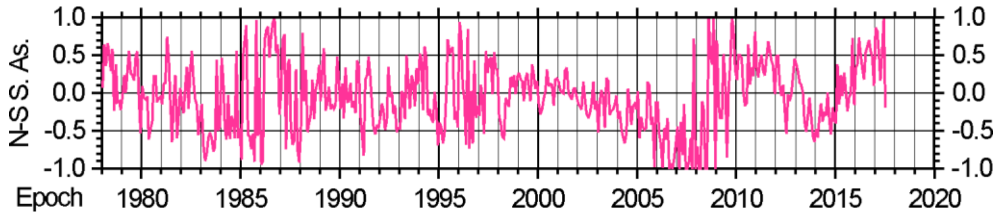

Figure 2. Time series of North-South solar asymmetry.

The ozone and air temperature data are taken from Copernicus servers (Hersbach, 2019) over the region between 5° South - 5° North and 120° - 170° East of ENSO Index Nino 3.4. The time series of ozone and air temperature at 70 hPa over ENSO region are compared in Fig.3. It is remarkable their strong correlation and in phase annual oscillations, which is in full accordance with the Kilifarska's model of ozone influence on climate variations.

The comparison between stratospheric ozone variations and surface temperature at 1000 hPa is shown in Fig.4. It is visible that the maxima of ozone cycles correspond to minima of temperature oscillations. This result corresponds to the Kilifarska's model of ozone influence on climate variations, too.

To prove that the possible transmitter between the variations of N-S solar asymmetry and ENSO event is low stratospheric ozone, the solar and ozone oscillations in narrow frequency bands will be compared. The solar and atmospheric cycles will be retrieved by means of the Method of Partial Fourier Approximation (PFA), whose details are described in (Chapanov et al., 2017).

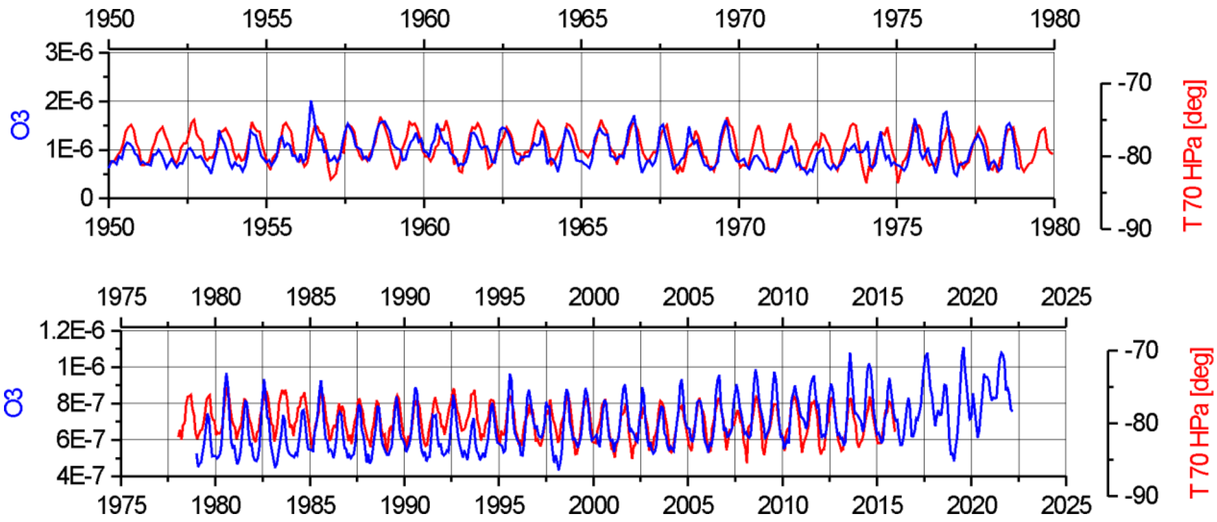

Figure 3. Time series ozone (O3, blue color) and air temperature (red color) at 70 hPa over ENSO region for periods 1950-1979 (upper graph) and 1979-2016.

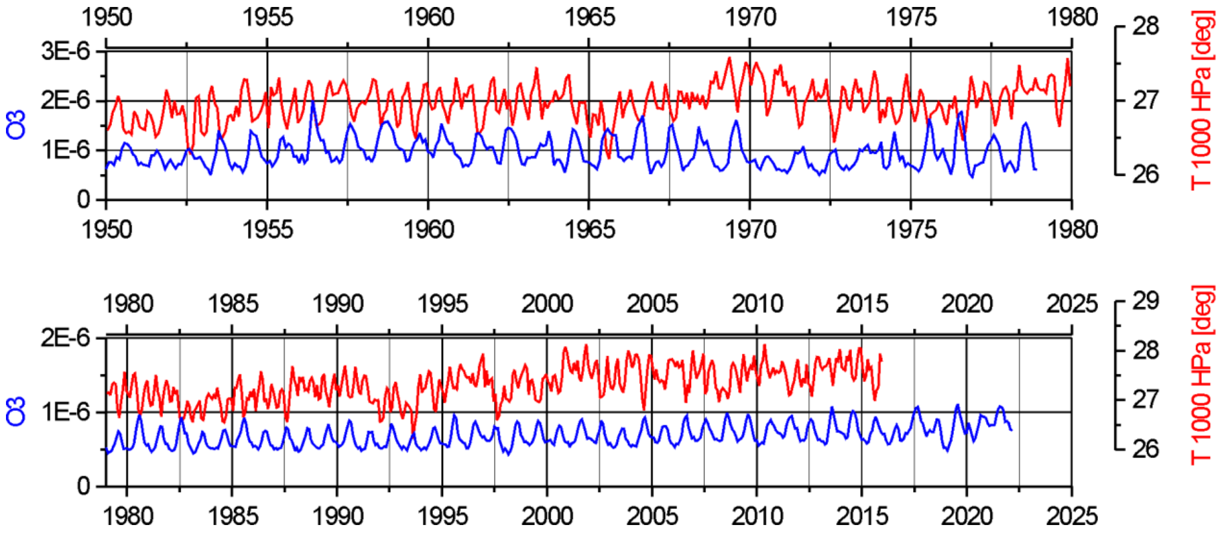

Figure 4. Time series comparison of ozone at 70 hPa and air temperature at 1000 hPa for periods 1950-1979 (upper graph) and 1979-2016.

Results

- ***Time series spectra***

The time series spectra of solar indices and stratospheric ozone (Fig.5) are calculated by Fast Fourier Transform (FFT). The spectrum of N-S solar asymmetry has better coherence with ozone spectrum, then the TSI – ozone spectra, especially for the ENSO frequencies, whose periods are between 2 and 8 years. Other decadal oscillations of N-S solar asymmetry may modulate the amplitude of ENSO variations.

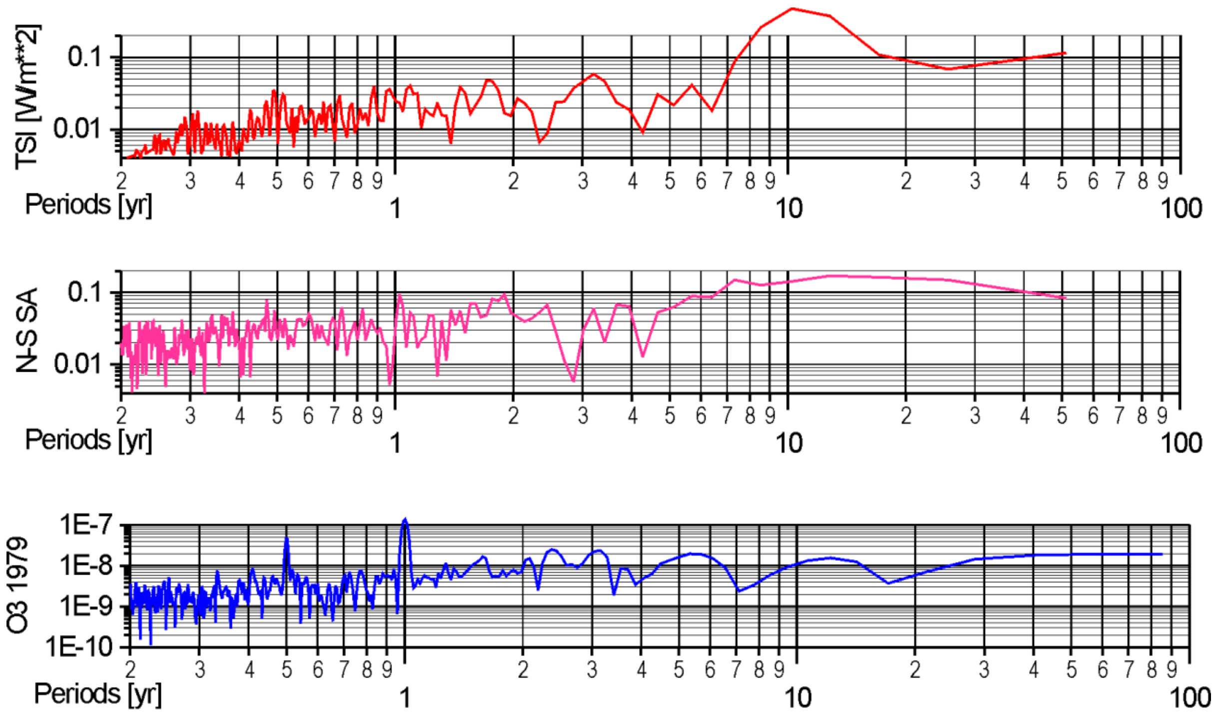

Figure 5. Time series spectra of solar indices and stratospheric ozone variations.

- ***Solar influence on ozone variation at 70 hPa geopotential height***

Common solar and ozone cycles are divided into narrow frequency bands by superposition of neighbor harmonics of their Partial Fourier Approximations. The accuracy of PFA trigonometric coefficients is better than 0.03 for N-S solar asymmetry and better than 3×10^{-9} for ozone data. The influence of N-S solar asymmetry on long-term oscillation of stratospheric ozone is visible in Fig.6, where relatively good agreement exists between solar and ozone cycles in antiphase with periodicity 21.5-43.0 years.

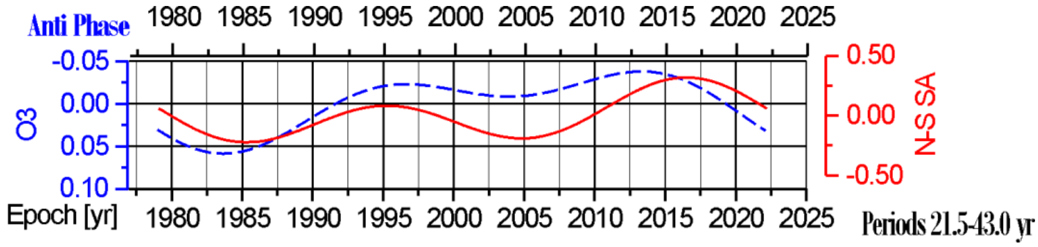

Figure 6. Time series spectra of solar indices and stratospheric ozone variations.

The decadal and short-term influence of N-S solar asymmetry on stratospheric ozone is shown in Figs. 7-9, where common solar-ozone cycles are divided into 9 narrow frequency bands, whose periods are: 2.2-2.4; 2.7-2.9; 3.3-3.6; 3.9-4.3; 4.3-4.8; 4.8-5.4; 6.2-7.2; 7.2-8.6; 10.8-14.4 years. A half of these common bands represent in phase solar and ozone cycles, while the other half represent antiphase cycles. Possible reason of this behavior is different connection of outer and inner radiative belts with the oscillations of solar wind and solar magnetic field. Most of these periods correspond to the essential ENSO frequencies and part of their amplitude modulation.

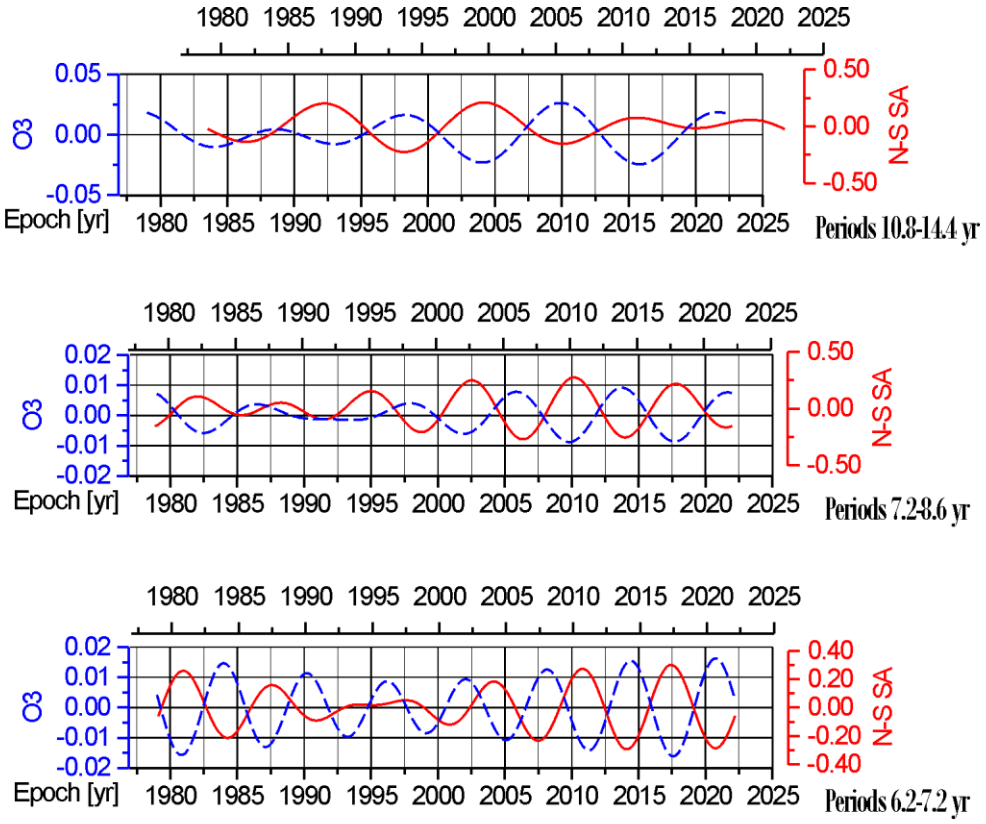

Figure 7. Common solar and ozone cycles with decadal and sub-decadal periods.

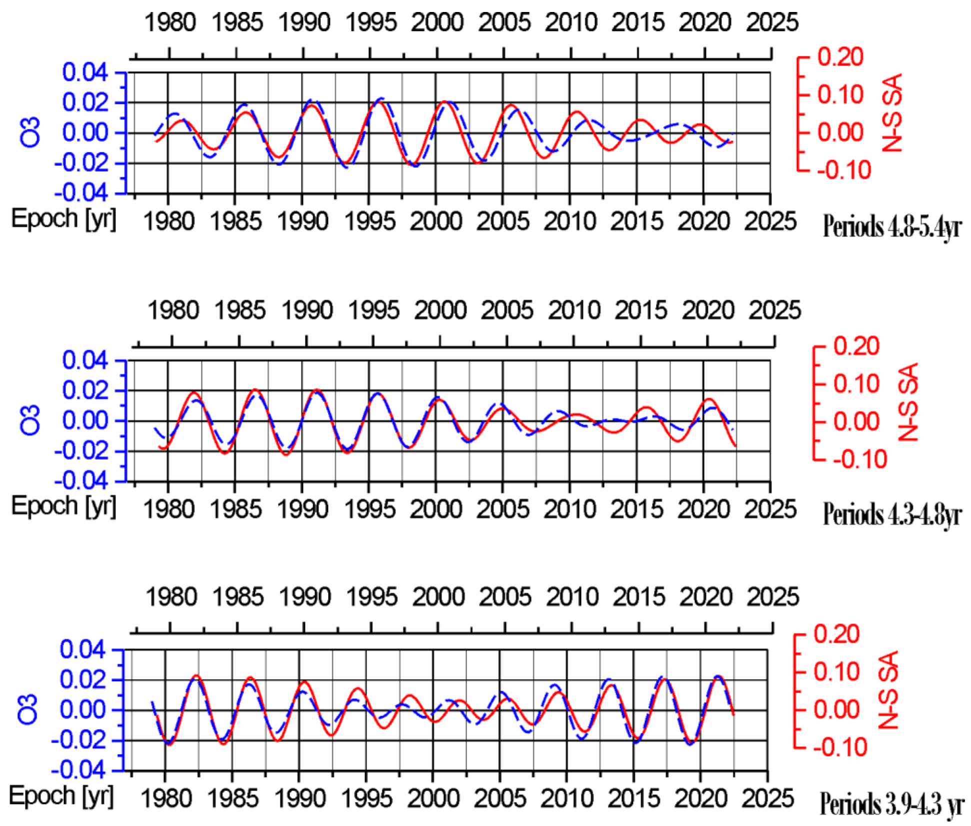

Figure 8. Common solar and ozone cycles with sub-decadal periods between 3.9 and 5.4 years.

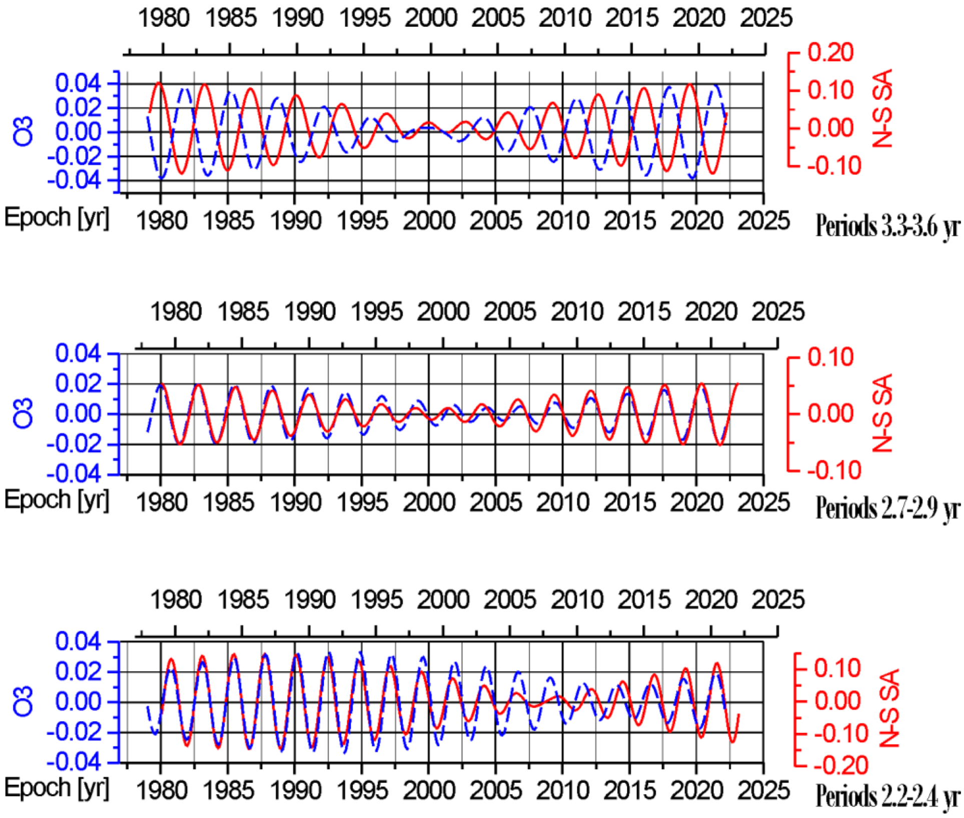

Figure 9. Common solar and ozone cycles with sub-decadal periods between 2.2 and 3.6 years.

Conclusions

The time series of ozone variations at 70 hPa, approximately 17 kilometers above sea level, have been analyzed together with time series of air temperature at 70 hPa and 1000 hPa. The data is calculated over the regions of Enso Index Nino 3.4. The ozone and air temperature have common in phase annual oscillations at 70 hPa height, while some annual oscillations of the surface air temperature at 1000 hPa have antiphase cycles with the annual ozone cycles. These facts confirm Kilifarska's model of stratospheric ozone influence on climate, where the maxima of ozone variations correspond to minima of surface temperature.

The solar magnetic influence on stratospheric ozone variations, over the region of Nino 3.4, is determined in 10 narrow frequency bands, whose periods are in the range of ENSO oscillations between 2 and 8 years, and decadal cycles with periodicity 10.8-14.4 and 21.5-43.0, whose role in ENSO variations is decadal modulation of ENSO amplitude. The last results also confirm the Kilifarska's model of energetic particles influence on ozone and climate variations.

The obtained results may improve our knowledge about important processes in low stratosphere and near tropopause, connected with the climate change.

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