Journal of Atmospheric and Solar-Terrestrial Physics 67 (2005) 1779–1785

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

The periodic spatial–temporal characteristics variations of the total ozone content

R.A. Sych[a,b,*], G.K. Matafonov[b], A.Ju. Belinskaya[b], N.J. Ferreira[a]

[a]National Institute of Space Research, Sao Jose dos Campos, 12.227-010 Brazil
[b]Institute of Solar-Terrestrial Physics, 664033, PO Box 4026, Irkutsk, Russia

Available online 26 August 2005

Abstract

This paper deals with quasi-periodical processes related to variations in the total ozone content (TOC) and solar radio emission at 10.7 cm. For the detection of the hidden period in TOC variations, the wavelet transform was used to analyze the dynamic spectral analysis, the power spectra, and also the degree of correlations for selected harmonics. The harmonics obtained are related both to TOC variations and radio emission from the Sun, and they can be separated into four groups: (a) solar cyclic harmonics (periods of 5, 7, 11 and 22 years), (b) quasi-biennale modulation (about 2.5 years), (c) long periodical modulation with periods of 30, 60, 180 and 365 days, and (d) high-frequency modulation with a period of 6 days for ozone and 27 days for radio emissions. It is shown that the quasi-biennale harmonic represents a superposition of two close harmonics with periods of 1.8 and 2.7 years, the power maximum of which occurs in the minimum of solar activity. For the 6-day component, the expressed response is associated both with volcanic activities, having global character (e.g. eruption of the volcano Pinatubo), and solar flares with a noticeable proton component on July 13, 1982. It is also shown that there is a 180-day modulation of the climatic harmonic. Considering the zonal dependence of the integrated ozone power spectra, the latitude of 10°S was selected as the minimal power of the significance harmonics of the observed spectrum. The latitude asymmetry of the spectral component power change was also diagnosed.

Keywords: Quasi-periodical processes; Wavelet analysis; Total ozone content; Radio emission

1. Introduction

The problem of the possible influence of solar activity variations on atmospheric, climate and weather processes has attracted researchers' attention for years. It is known that the ozonosphere, as a part of the terrestrial atmosphere, plays a key role in many processes, determining global climate changes and connections with various atmospheric layers.

The first results concerning the influence of solar activity on changes of total ozone content (TOC) were considered by Paetzold studies (Paetzold, 1969; Paetzold et al., 1972). The analysis of vertical sounding using Paetzold–Kulke optical ozone probes for the 1958–1968 period has shown that there is a dependence between TOC changes and the phase of solar activity. Analysis of the reasons that would support this finding (including changes in the circulation winds, and also the photochemical reactions resulting in the ozone formation) could not explain the results observed. Therefore, a hypothesis concerning the change of an ultra-violet component of solar emission with a phase of solar activity was assumed and an 11-year modulation of

*Corresponding author. Institute of Solar-Terrestrial Physics, 664033, PO Box 4026, Irkutsk, Russia. Fax: +7 (3952) 425557.
E-mail address: sych@iszf.irk.ru (R.A. Sych).

1364-6826/$ - see front matter
doi:10.1016/j.jastp.2005.03.011

formation of ozone in the atmosphere was explained. Further observations obtained in the work of Angell and Korschover (1978) have confirmed increases in the ozone contents at heights above 16 km from the minimum to the maximum of a solar cycle. It was also shown that emission at 160–210 nm wavelength changes more than 60% depending on the intensity of calcium floccules (Prag and Morse, 1970). Once more, a component of solar emission is the factor in a relative number of solar spots. The analysis of stratosphere measurements carried out by London and Dutsch (1977) has shown a correlation between TOC and the number of solar spots. Comparison of emissions close to the 122 nm spectral line and TOC (Nimbus-4) for 10 days (Blackschear and Tolson, 1978) was also done. In all cases, the data on TOC variations and solar factors showed a good correlation.

Another hypothesis on the TOC variation was the assumption that there is a solar modulation of a nitric oxide source, created by galactic rays at high latitudes in the stratosphere (Ruderman and Chamberlain, 1975). The further calculation of the Forbush effect caused such modulation to show that this contribution is minimal (Crutzen, 1975).

A special role in the short-term change of the TOC is played by powerful X-ray flares. The first assumptions about the influence of high-energy particles (protons) during a solar flare were proposed by Zerefos and Crutzen (1975). A similar study was executed for a proton flare on July 13 1982 (Solomon et al., 1983).

It is important to mention that all previous studies searching for a correlation between solar activity and the TOC were carried out for signals containing total modulated components with different weight factors, which can describe relationships only in general. Therefore, it is very important to understand the contribution of each spectral component in integrated signals (e.g. TOC), radio emission and their relationships.

In this paper, we present a new wavelet-based strategy for obtaining spectral characteristics of frequency harmonics and their correlation between sets of the TOC and solar radio emission at 10.7 cm. Experimentally, we tested the reliability of a 6-day component response in association with volcanic activities on a global scale and the importance of solar flares (proton component) for change in the TOC. For fluctuations in the TOC, significant periods are obtained and a correlation was shown between them with similar periods in radio emission (10.7 cm) from the Sun.

2. Instrumentation

The dataset used in this study comprises observation of the TOC, measured by the total ozone mapping spectrometer (TOMS) on board the Nimbus-7 satellite during the 1979–1992 period. The data are daily averages on a spatial grid with a $1^\circ \times 1.25^\circ$ (latitude–longitude) cell. The TOC (in Dobson units) is defined as the absorption of diffused solar ultra-violet emission at different wavelengths (312 and 331 nm); the measurement error is ~2–4%. Innumerous comparisons of these data with ground measurement devices have already shown their reliability. NASA distributes TOC data on compact discs in various package versions. In the current study, the time series of the TOC with daily temporal resolution on a spatial grid with a 5° latitude and longitude resolution were investigated. Also, the solar activity impact on TOC changes was found using the Sun radio emission data at 10.7 cm, received by the solar radio monitoring from the Dominion Astrophysical Observatory (Canada). The accessible database includes two components, the measurements of the Sun radio flux during the day and its average value. Each radio flux can be presented in three aspects: "observable", "corrected" and the so-called "URSI Series D". The "observable" events are the direct response by the antenna system on the received radiation. It is modulated by two components: the level of solar activity and the change in Earth–Sun distance. The "corrected" ones are the flux where the annual change was corrected and the flux for the average distance between Sun-Earth is given. In the case of the "URSI Series D" data, to apply absolute binding of a radio flux to density flux on different frequencies (spectral characteristics), the scale factors were used. In our case we used the "observable" radio flux to study events connected with the terrestrial and space factors. The flux of radio emission at 10.7 cm is given in terms of solar flux unit (SFU, $1\,\mathrm{SFU} = 10^{-22}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$).

3. Experimental data

Fig. 1a shows the time dependence of the daily solar radio emission for the 01/01/1979–12/31/1992 period; the dataset length is 5112 days. In this figure, the global flux modulation is clearly seen as two 11-year solar cycles (21 and 22) with an increase in the power of high-frequency components in a growth phase and during the maximum activity of intensive short-term emissions. Similar behavior is typical for changes in solar activity and connected to a 27-day time period rotation of the solar surface. This feature is well traced in the example of the occurrence and disappearance of solar group spots generating radio emission at 10.7 cm.

To study the solar activity influence on the TOC, we used coincident time series of the latter variable and radio-emission data. The equatorial flux variation was analyzed from 0° to 360° of longitude every 5°, and for a fixed 120° longitude band from 60°N to 60°S. An example of TOC variation as a function of time for an