E3S Web of Conferences **20**, 01005 (2017) DOI: 10.1051/e3sconf/20172001005
Solar-Terrestrial Relations and Physics of Earthquake Precursors

Seasonal variations of mesopause temperature and the amplitude of the VLF signals of the Novosibirsk radio station during 2009-2016

Alexey Korsakov[1,*], *Vladimir* Kozlov[1,2], *Anastasia* Ammosova[1], *Petr* Ammosov[1], *Galina* Gavrilyeva[1], *Igor* Koltovskoi[1], and *Yegor* Pavlov[2]

[1]Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS, 677980 Lenin Ave, 31, Yakutsk, Republic of Sakha (Yakutia), Russian Federation
[2]Physical Technical Institute of the North-Eastern Federal University, 677000 Belinsky St., 58, Yakutsk, Republic of Sakha (Yakutia), Russian Federation

Abstract. Dynamics of seasonal variations of the amplitude of the VLF radio signal received in Yakutsk from the navigation station near Novosibirsk and the P-branches of the OH band (6-2) radiation intensity in the wavelength range 835 - 853 nm are considered. The radiation variations give information about mesopause region measured at the Maimaga station (130 km from Yakutsk). The observation from 2009 to 2016 covers period with minimum and maximum solar activity. The mesopause temperature and the VLF signal increase with increasing solar flux F10.7 in winter. The mesopause temperature seasonal variations and the VLF signal strength for the Novosibirsk-Yakutsk path are regularly inverted from year to year. By decade data averaging the VLF radio signal strength dependence on the temperature of the atmosphere at the OH excitation height can be expressed by a linear function. The coefficient of determination: R^2 = 0.59, the anticorrelation coefficient: r_{10} = - 0.77. The variations of the VLF radio noise and the radio station signal for the eight-year interval are similar to solar activity (F10.7 index). The signal level of the radio station and radio noise registered in the winter is more sensitive to variations of F10.7 index in 24th solar cycle activity.

1 Introduction

The variations of parameters of electromagnetic signals of radio navigation stations are registered in the very low frequency range (VLF: 3-30 kHz) for sounding the lower ionosphere. The radiation intensity is also recorded in the wavelength range from 835 to 853 nm, where the p-branches of the OH (6-2) emission band provide information of the mesopause region condition.

The excited hydroxyl molecule makes $2 \cdot 10^4$ collisions per second before the radiation which is enough to thermalization with the environment [1]. Thus the OH rotational temperature calculated from night sky spectra is equal to the neutral atmosphere

* Corresponding author: korsakovaa@ikfia.ysn.ru

temperature at the mesopause region altitudes. The region altitude, temperature and thickness along with the lower ionosphere conductivity vary on different space-time scales. Ionizing radiation for the lower ionosphere (D and E regions) is the most energetic part of the solar X-ray spectrum, the intense solar line of hydrogen Lyman-α (121.5 nm) and extreme ultraviolet radiation [2]. The mesopause region temperature is characterized by large seasonal variations reaching 30 K at latitudes ~ 40° N [3]. For latitudes 60° N the seasonal variations increase to ~ 60 K [4, 5]. The mesopause region altitude in winter is ~ 100 km. After the transition of the atmosphere general circulation to summer regime the mesopause region shifts lower up to an altitude of 86 km [6]. It was found that for the latitude region 40 - 60° N the summer temperature of the hydroxyl molecular band response on the solar activity variation was equal to 2.5 ± 1 K/100SFU and the winter temperature response estimated as 6.5 ± 2K/100SFU [7, 8]. SFU is the solar flux unit radio emission at a wavelength of 10.7 cm, equal to 10^{-22} W/(m^2·Hz). The amplitude of the annual component varies from 18.2 K for the years of minimum solar activity to 64.7 K for the years of the maximum and the amplitude of the semiannual component increases from 6.8 K to 26.6 K [9].

The VLF radio waves sensitivity to various geophysical phenomena depends on the geographical location of the transmitter and receiver, the signal propagation direction (relative to the Earth's magnetic field), the propagation path length and the signal frequency [10]. It is shown an anticorrelation relationship between the mesopause temperature and the intensity of narrow-band VLF radio signals reflected from the lower ionosphere at the middle and tropical latitudes [11]. The variability of the mesopause temperature and the VLF signals amplitude by ~ 72% is due to seasonal changes in solar radiation, and ~ 28% have other sources. There are quasi-semiannual mesopause temperature and nighttime ionosphere parameters variations in dynamics of the received VLF radio stations signals [12].

2. Registration methods

The OH(6-2) rotational temperature were obtained by the infrared digital spectrograph. The device is installed at the Maimaga optical station (63° N, 129.5° E) which located at 120 km north of the Yakutsk. The observations were carried out in cloudless nights, with the sun at least 9° below the horizon. The emission spectrum of the night sky is observed in the range from 836 nm to 853 nm, where the P-branch of OH(6-2) band emission is located. The model spectrum whose deviation from the actual one is less than the registration noise is considered to correspond most closely to the reality; and the rotational temperature determined based on this spectrum corresponds to the temperature at the mesopause height. During such sampling, rotational temperature values with systematic errors exceeding random ones are excluded from further processing. The estimates indicate that random errors in temperature measurements vary from 2 to 5 K depending on the signal-to-noise ratio [13].

VLF signals from the stations of the radio technical long-range navigation system (RSDN-20) are continuously recorded in Yakutsk from 2009 to the present. Transmitters are located near Krasnodar, Novosibirsk and Khabarovsk. In the intervals between radio pulses of navigation stations at the same frequencies (11.904, 12.649 and 14.881 kHz) radio noise is recorded. The method makes it possible to record amplitude and phase variations of the signal and radio noise in the 372 Hz band [14, 15].

The radio noise measuring in VLF range is taken into account that the natural radio noise consists of fluctuation and impulse components. The main contribution to pulsed radio noise is made by radio pulses of nearby lightning discharges (atmospherics). Fluctuation radio noise is a continuous random sequence superimposed on each other by pulses of distant lightning discharges, which have experienced large attenuation during propagation. According to the recommendations of the International Telecommunication Union, measurements of radio noise at frequencies below 30 MHz (http://www.itu.int/publ/R-REC/en) it should be carried out in a small frequency band or at several frequencies. We registered the radio noise level at three close frequencies of 11.904 kHz, 12.649 kHz and 14.881 kHz in 372 Hz band in radio stations off air time intervals. It is assumed that the intensity of a radio noise in a narrow frequency band can be characterized by the median value of the spectral component amplitude. The contribution of the impulse component decreases with the median averaging of the values at each stage. For the first stage, the median averaging is performed in selected interval (0.4 sec) during the reception of the corresponding radio station pulse in each packet of RSDN-20. The duration of the packet, and hence the frequency of each radio station pulse on each of the three frequencies is 3.6 seconds. At the second stage, a median averaging of radio station amplitude values is performed for each of the three frequencies in the interval of 3 minutes (50 packets of RSDN-20). Similarly, for radio noise, a median averaging is performed in the "empty" dispatch of the packet (on condition in the absence radio stations signals).

3. Experimental data

The ground base observations by infrared digital spectrograph are carried out in the territory of central Yakutia from the middle of August to the middle of May. The seasonal changes of temperature can be estimated as a sum of an annual, semiannual and terannual harmonics with amplitudes of 28.6 K, 10.6 K and 3 K respectively [9]. The rotational temperature OH(6-2) seasonal variations and the variations in the VLF signal field strength of the radio station Novosibirsk (14.881 kHz) for nighttime conditions of Novosibirsk-Yakutsk VLF propagation path (15 - 19 UT) for the period 2009 - 2016 are shown in Figure 1.

DOI: 10.1051/e3sconf/20172001005

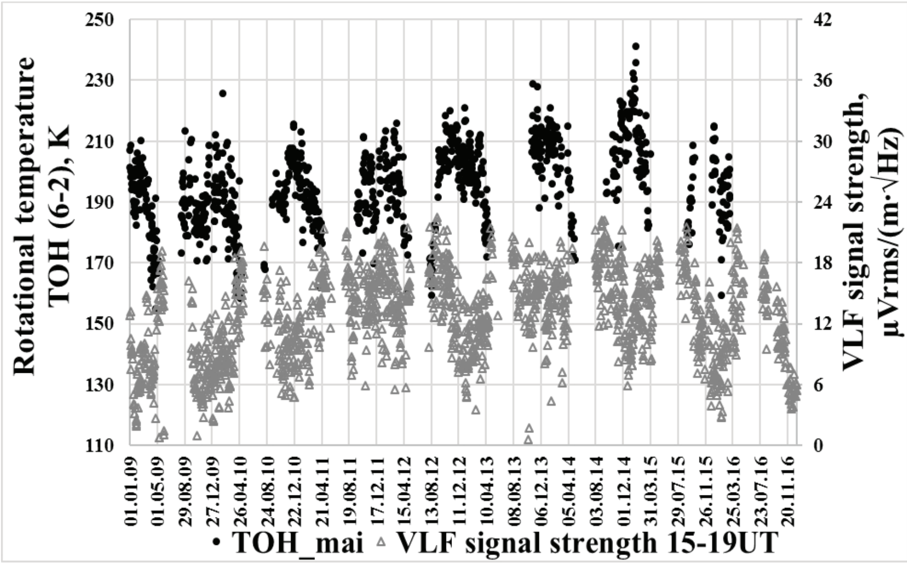

Fig. 1. Seasonal variations of rotational temperature OH (6-2) and field strengths of VLF signal Novosibirsk (14.881 kHz) for the period 15 - 19 UT 2009 - 2016.

For a convenience of comparison, the signal strength values outside the periods of the rotational temperature variation observation are excluded. The VLF field strength variations were distorted due to damage ground bus of the receiver from November 2011 to April 2012. Excluding this interval, the temperature seasonal variations of the mesopause region and the field strength received by the VLF signal for the Novosibirsk-Yakutsk path are regularly inverted from year to year, as in researches for similar VLF paths [11].

Based on the available data of the rotational temperature and electromagnetic field strength received the VLF signal of the radio station Novosibirsk for 7 years from 2009 to 2016 the median averaging seasonal night variations were prepared. For this case the cross-correlation coefficient is r = - 0.52. The data are shown in Figure 2. As can be seen from the figure, both the rotational temperature and the field strength of the VLF signal variations have significant fluctuations.

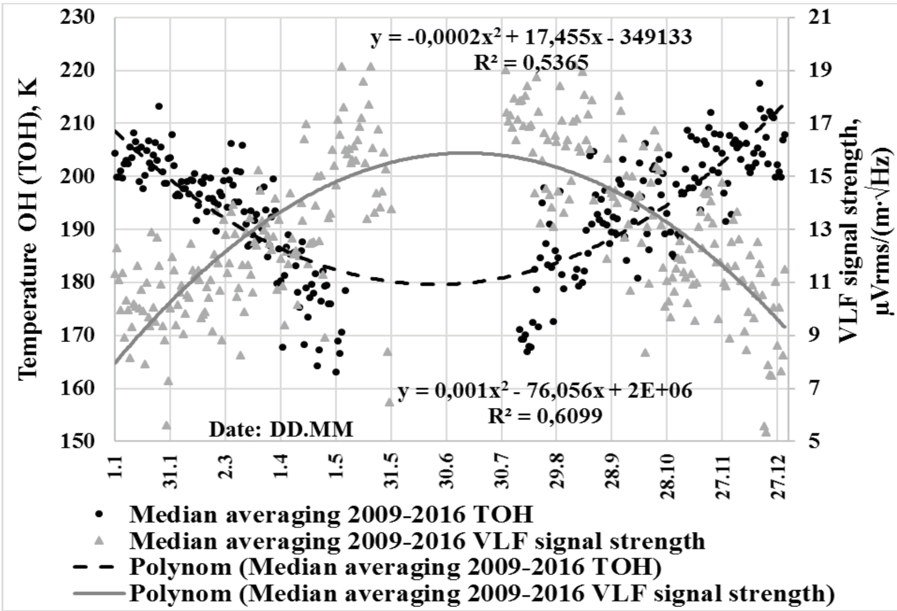

Fig. 2. Median averaging from 2009 to 2016 seasonal night time variations of the rotational temperature and Novosibirsk station VLF radio signal strength.

A decade (10 day) data averaging of the OH rotational temperature and the VLF signal strength was performed to reduce the fluctuations and to determine the relationship. The anticorrelation coefficient is r_{10} = - 0.77. The VLF signal strength dependence on the atmospheric temperature at the OH excitation height presented in Figure 3. The dependence can be expressed by a linear equation (1):

$$A_{Novosibirsk} = - 0.16 \cdot TOH + 44.42, \quad (1)$$

where the field strength of the VLF signal received in Yakutsk from the radio station Novosibirsk $A_{Novosibirsk}$ is measured in µVrms/(m √Hz), and the OH rotational temperature *TOH* is measured in degrees K. The coefficient of determination for the linear dependence is R^2 = 0.59, which corresponds to the anticorrelation coefficient r_{10} = - 0.77.

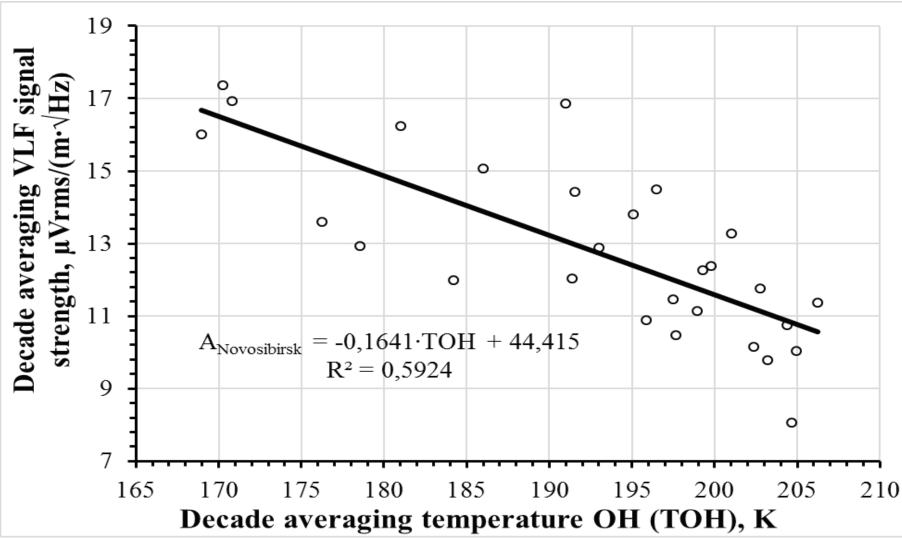

Fig. 3. VLF signal strength dependence on the atmospheric temperature at the OH excitation height.

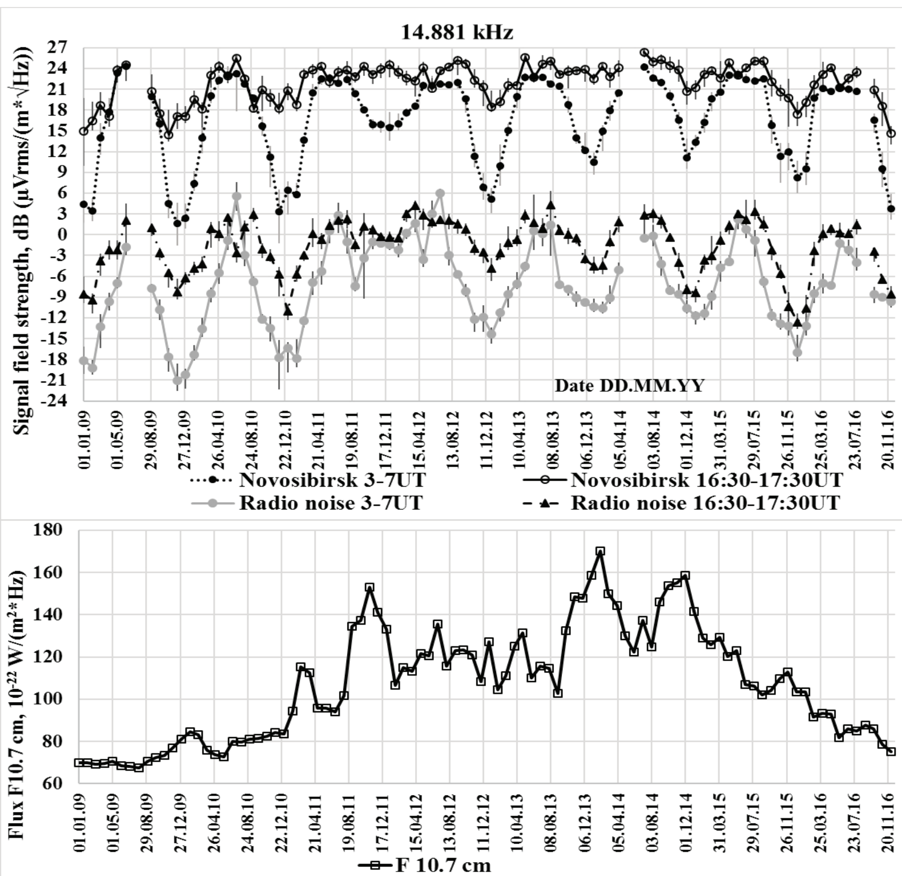

Fig. 4. Variations of the Novosibirsk radio station signal field strength and radio noise (14.881 kHz), the solar radio flux F 10.7 cm 2009-2016.

Seasonal variations of the signal field strength of the Novosibirsk radio station and radio noise (14.881 kHz), in daytime (3-7 UT) and nighttime (16:30-17:30 UT) Novosibirsk-Yakutsk propagation path conditions (2.64 Mm) and also data on solar activity - the solar radio flux at 10.7 cm wavelength (F10.7 index) (US Dept. Of Commerce, NOAA, Space Weather Prediction Center (SWPC). URL: http://www.swpc.noaa.gov/products/solar-cycle-progression) for the period 2009 to 2016 are shown in Figure 4. Monthly median averaging was performed. The quartiles of 25% and 75% are presented as fluctuations. The signal field strength seasonal variations are most pronounced in daytime. The variations associated with the increase D region ionization efficiency from December to June: the solar zenith angle decreases over the path, so the gradient of the ionosphere electron concentration increases and VLF attenuation decreases. The asymmetry is observed in the amplitude seasonal variations which manifested the fact that the average median values of these parameters during the autumn equinox (September) are closer to the summer solstice. The recorded parameters of VLF radio signals during the vernal equinox are closer to the parameters of the winter solstice. This asymmetry agrees with the seasonal asymmetry of the D region electron concentration profiles [16].

The strength of the radio signal field increases by 3 ± 1 dB and 4 ± 1.5 dB for registered in daytime (3 - 7 UT) and night time (16:30 - 17:30 UT) conditions respectively with increasing solar activity (2014) in summer period. Variations in the signal level (from the minimum to the maximum solar activity 2009-2014) were 9 ± 2 dB for both day and night propagation conditions in winter. In 2015 - 2016 years the signal level decrease to the values of 2009-2010. The behaviour of the signal strength interannual variation of Novosibirsk radio station on an eight-year interval both for summer and for winter periods is similar to the behaviour of solar activity variations (F10.7 index). The field strength variations of the radio noise (14.881 kHz) are 7 ± 2 dB and 3.3 ± 1.5 dB when registered in daytime (3 - 7 UT) and night time (16:30 - 17:30 UT) conditions respectively in summer. Variations in the radio noise level (from the minimum to the maximum of solar activity 2009-2014) amounted to 10.4 ± 2 dB in daytime and 6.5 ± 1.5 dB in night time conditions of registration in winter. There is a decrease radio noise level in the winter 2015 – 2016 approaching to the values 2009 – 2010.

4. Discussion

It should be noted that the signal level of the radio station and radio noise registered in winter, relative to the summer season, is more sensitive to F10.7 index variations from the minimum to the maximum of the 24th solar cycle activity. The seasonal variations of lower ionosphere parameters were considered earlier [17]. The effective recombination coefficient is lower in winter. The differences are due to seasonal variations in the mesosphere region meteorological parameters. Hence there is the high sensitivity of the received VLF signal parameters in winter season relative to summer, which is also noted for sudden ionospheric disturbance effects [18].

For the solar cycle activity maximum, the VLF signals level of radio stations noontime recorded (low and medium latitudes for the most part of the selected extended radio paths crossing the equator), approximately by 0.3 ± 0.1 dB/Mm more than in the solar minimum period [19]. The variations correspond to our analysis data. The greater attenuation in the solar cycle activity minimum can be partially due to a decrease in the Lyman-α flux, the main ionization source of the atmosphere at altitudes 65 – 80 km, while an intensity of cosmic particles flux increased. The cosmic particles flux causes an increase the lower altitude electron concentration, where the VLF radio attenuation is greater due to even greater concentration of neutral particles.

5. Conclusions

Seasonal variations in the mesopause region temperature and the field strength of VLF signal received for the Novosibirsk – Yakutsk propagation path are in anticorrelation relationship regularly from year to year.

The VLF radio signal strength dependence on the temperature of the atmosphere at the OH excitation height can be expressed by a linear function. The linear function slope is -0.16 and the constant term (line offset) is·44.42. The coefficient of determination for the linear dependence is R^2 = 0.59, which corresponds to the anticorrelation coefficient r_{10} = -0.77.

The behavior of the interannual variations of the field strength of the VLF radio noise and the Novosibirsk radio station signal for the eight-year interval are similar to the behavior of solar activity (F10.7 index) both for summer and for winter. The signal level of the radio station and radio noise registered in the winter season, relative to the summer season, is more sensitive to variations of F10.7 index from minimum to maximum of the 24th solar cycle activity.

The study was supported by RFBR, research projects No. 15-45-05005 r_vostok_a, 16-35-00121-mol_a, 16-35-00204-mol_a, 15-05-05320-a, 17-05-00855 A.
The study was supported by the program of complex scientific research in the Republic of Sakha (Yakutia) 2016-2020.

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