

Interannual variations of the intensity of narrowband VLF radio noise and radio station signals registered in Yakutsk in 2009-2017

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Abstract. Major natural sources of VLF radio noise registered in Northern Asia in summer are local thunderstorm activity and in winter thunderstorms of Northern India and China. A VLF propagation function is obtained by simultaneous registration in 2009-2017 in Yakutsk (62 N, 129.7 E) of the intensity of radio noise and signals of an Alpha navaid system: Novosibirsk (55.75 N, 82.45 E) and Khabarovsk (50.07 N, 136.6 E) transmitters. At a solar activity maximum (2014-2015) there is a decrease in the VLF signal attenuation. Taking into account the VLF radio signal propagation, changes in the VLF noise source intensity are obtained. There is a trend towards increased thunderstorm sources intensity, especially in summer (local thunderstorm activity). The intensity increase from 2009 to 2017 is about 4 dB (daytime) and 1.6 dB (nighttime). According to the World Wide Lightning Localization Network, the total number of lightning discharges for Northern Asia (40-80 N, 60-180 E) increased in summer by 5 dB, and for Northern India (17-36 N, 68-94 E) and Southern China (10-33 N, 94-126 E) the total number of discharges increased in winter by 2.3 dB (2009-2017). The thunderstorm activity increase may be caused by global warming.

1. Introduction

Radio signals of a very low frequency range (VLF: 3-30 kHz) can propagate over long distances with a small attenuation of ~ 0.3 dB / 1000 km in the waveguide. The lower waveguide boundary is the water or terrestrial surface (Earth), and the upper boundary is the lower ionosphere (region D: height of 65-80 km for daytime, region E: 90-110 km for nighttime) [1]. This feature of propagation allows remote monitoring of thunderstorm activity, since lightning discharges are the main natural VLF radio emission source.

There are pulsed (atmospherics) and fluctuation (overlapping radio pulses) components of radio noise [2]. To investigate variations of distant lightning sources intensity by VLF radio noise receivers, it is necessary to take into account the propagation conditions that have diurnal, seasonal, and interannual characteristics. This ambiguity can be eliminated by simultaneously receiving VLF noise and reference radio signals from similar directions. As reference signals we use VLF signals of the radio navigation system "Alpha".



2. Experimental data and analysis

The amplitude and phase variations of signals of the Radio Technical Long-Range Navigation System RSDN-20 (Alfa) have been recorded in Yakutsk (62 N, 129.7 E) almost continuously since 2009. The stations emit radio pulses at frequencies of 11.9, 12.6, and 14.9 kHz. In the intervals between the radio pulses, at the same frequencies the intensity of the radio noise in the band of 372 Hz is recorded by "Alpha" [3].

The local thunderstorm activity is the main source of VLF radio noise in summer. Northern India and China thunderstorms are the main VLF noise source in winter. Diurnal and seasonal variations in the intensity of radio noise and signals from the radio stations Khabarovsk (50.07 N, 136.6 E) and Novosibirsk (55.75 N, 82.45 E) at 14.9 kHz are shown in Figure 1.

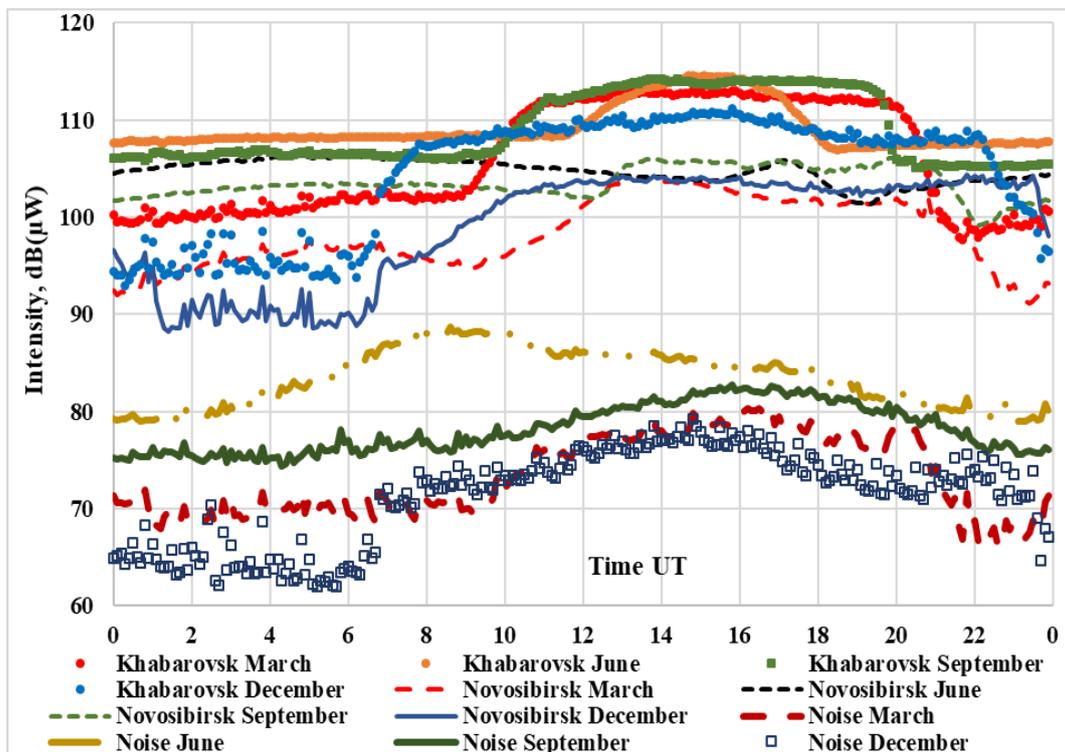


Figure 1. Diurnal and seasonal variations of the intensity of radio noise and signals from radio stations Khabarovsk, Novosibirsk at 14.9 kHz.

One can see in Figure 1 that a period of 16-17 UT corresponds to nighttime VLF attenuation decrease for all seasons at Earth-ionosphere waveguide propagation. The daytime interval of 3-7 UT corresponds to a minimum associated with a decreased thunderstorm activity in Asia and maximum signal attenuation [4]. Diurnal intensity variations of the radio noise have a maximum at 4-11 UT during the summer period which corresponds to the local thunderstorm activity.

It should be noted that the Novosibirsk – Yakutsk radio path can be considered as a part of the thunderstorm signal propagation path from Northern India to Yakutsk. Signals of the radio station Khabarovsk are received in Yakutsk from a nearby direction, which is also the radio noise of Southern China thunderstorms. The Novosibirsk – Yakutsk path length is 2640 km and the Khabarovsk – Yakutsk one is 1400 km. The daytime conditions for the VLF signal propagation paths also correspond to the interval of 3 - 7 UT, and the interval of 16-17 UT corresponds to the night propagation.

In this paper, the VLF propagation function in the Asian region is presented in the form of geometric mean values of Novosibirsk and Khabarovsk signal amplitudes. The amplitude variations of

the radio station signals and the intensity variations of radio noise at a frequency of 14.9 kHz in the band of 372 Hz during registration in Yakutsk in summer and winter periods of 2009-2017 are presented in Figure 2.

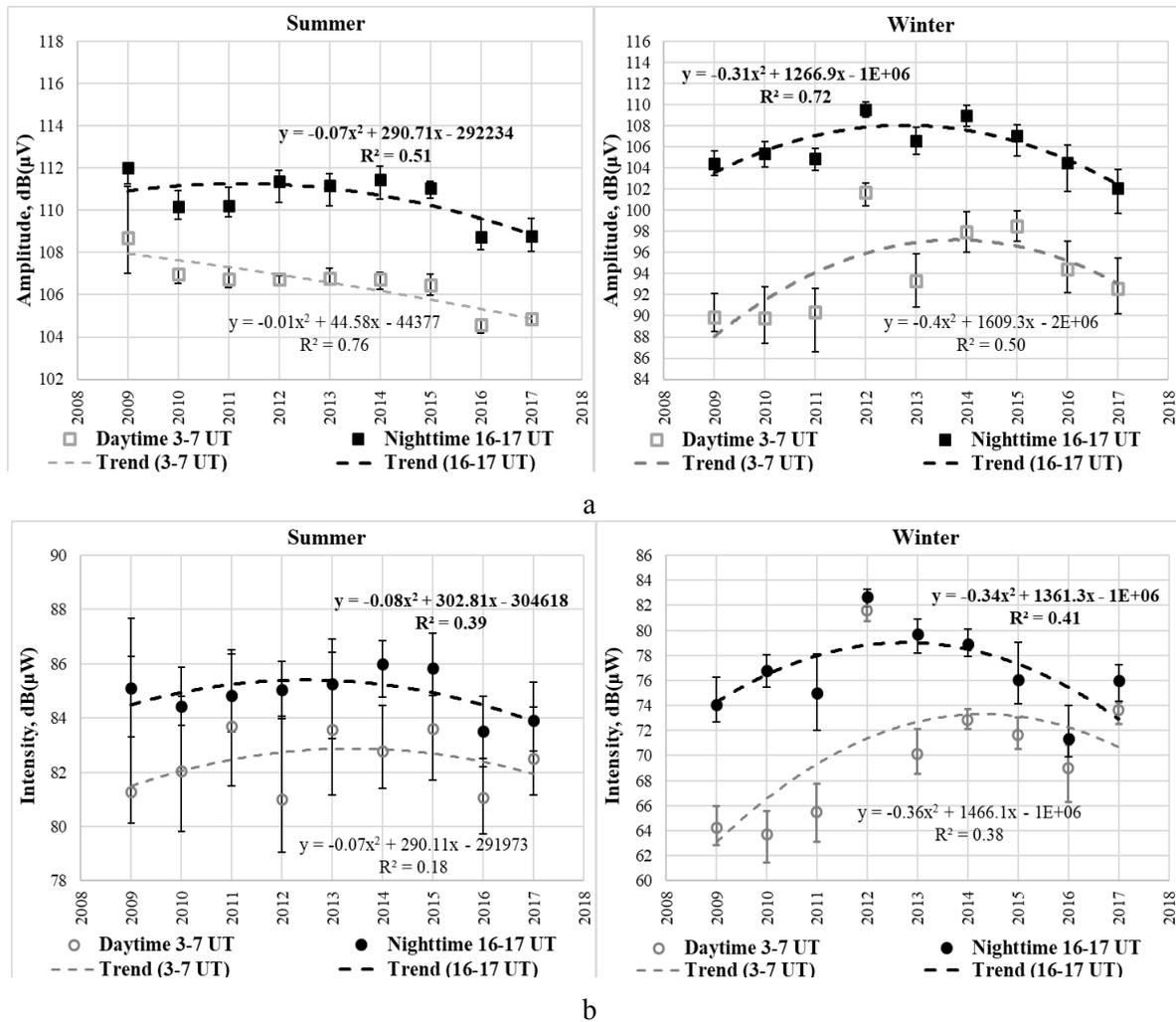


Figure 2. Amplitude variations of radio station signals (a) and intensity variations of radio noise (b) at the frequency of 14.9 kHz in the band of 372 Hz during registration in Yakutsk in summer and winter periods of 2009-2017.

The interannual amplitude variations of radio station signals correspond to changes in the 24th solar activity cycle. The maximum of solar activity (index F10.7) corresponds to 2014 - 2015, and there is also a peak in 2012 (US Dept. of Commerce, NOAA, Space Weather Prediction Center (SWPC). URL: <http://www.swpc.noaa.gov/products/solar-cycle-progression>). At the solar activity maximum the detected signal amplitude is greater than at the minimum one. During the summer period, the amplitude changes in Yakutsk were recorded at 1.3 ± 0.7 dB for the daytime propagation conditions (3 – 7 UT) and at 1.5 ± 0.7 dB for the nighttime conditions (16 – 17 UT). For winter there is an amplitude increase at 7 ± 2 dB (3 – 7 UT), 6 ± 1.5 dB (16 – 17 UT). With decreasing solar activity (2016 - 2017) there is a VLF attenuation increase. The obtained data are in accordance with [5], which indicates that for the solar activity maximum the level of radio station signals registered at noontime at the low and middle latitudes for extended radio paths crossing the equator is approximately 0.3 ± 0.1 dB / 1000 km greater than in the minimum.

At the solar activity maximum, the VLF radio noise intensity registered in Yakutsk is greater than at the minimum. During the summer period we recorded the noise intensity changes by 2.2 ± 1.6 dB for the daytime propagation conditions (3 – 7 UT) and by 1.2 ± 1 dB for the nighttime conditions (16 – 17 UT). During the winter period we recorded the intensity increase by 9.1 ± 1.6 dB (3 – 7 UT) and 6 ± 1.3 dB (16 – 17 UT). With decreasing solar activity (2016 – 2017) the VLF radio noise intensity decreases. The VLF noise intensity variations registered in Yakutsk from 2009 to 2017 are determined mainly by the propagation conditions in the Earth – ionosphere waveguide.

The variations in the intensity of the radio noise source are estimated by subtracting the intensities of the radio station signals from the intensity of the radio noise. It is assumed that VLF radio noise and signals from radio stations are received from similar directions. The variations of the radio noise intensity at 14.9 kHz (the band is 372 Hz) recorded in Yakutsk for summer and winter in 2009 – 2017 taking into account the VLF propagation function are presented in Figure 3.

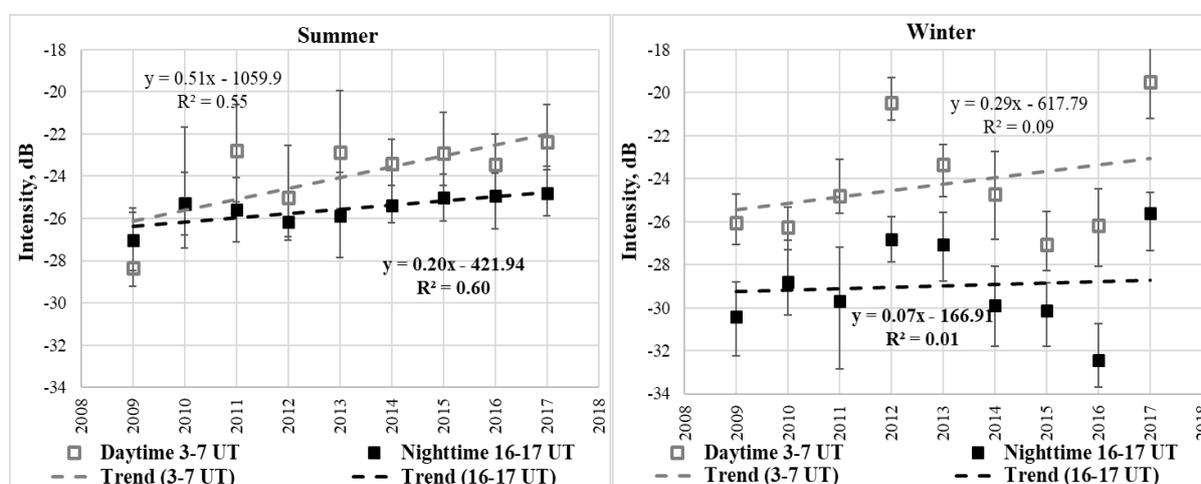


Figure 3. Variations of radio noise intensity at 14.9 kHz (the band is 372 Hz) recorded in Yakutsk for summer and winter of 2009 – 2017 taking into account the VLF propagation function.

It should be noted that there is a tendency to increase the intensity of thunderstorm radio noise sources from 2009 to 2017, especially in summer (local thunderstorm activity in Northern Asia). The increase in the intensity of VLF noise sources is 4 dB (3 – 7 UT) and 1.6 dB (16 – 17 UT) for 9 years in summer. There is a small trend to increasing the intensity of radio noise sources in winter.

The total number of lightning discharges in the territory of Northern Asia (40-80 N, 60-180 E) for three summer months and in the territory of two Southern Asia regions, Northern India (17-36 N, 68-94 E) and Southern China (10-33 N, 94-126 E), for three winter months (16-17 UT) is presented in Figure 4. The results are based on the World Wide Lightning Localization Network (WWLLN) [6]. One of the WWLLN network receiver station installed in Yakutsk in NEFU.

According to the WWLLN network data from 2009 to 2017, the total number of lightning discharges increased both in Northern Asia (40-80 N, 60-180 E) in the summer by 5 dB and in Southern Asia in winter by 2.3 dB.

There has been an increase in the thunderstorm activity in South-East China from 1990 to 2012 [7]. Based on the general circulation model (GCM), the Goddard Institute for Space Studies (GISS) estimates the global thunderstorms changes. The global thunderstorm changes are by 5 – 6 % for global warming and cooling for every 1 °C [8]. It is indicated that an increase in the global thunderstorm activity corresponds to the global climate warming. The magnitude of the simulated lightning discharge changes depends on the season, location, and time of the day.

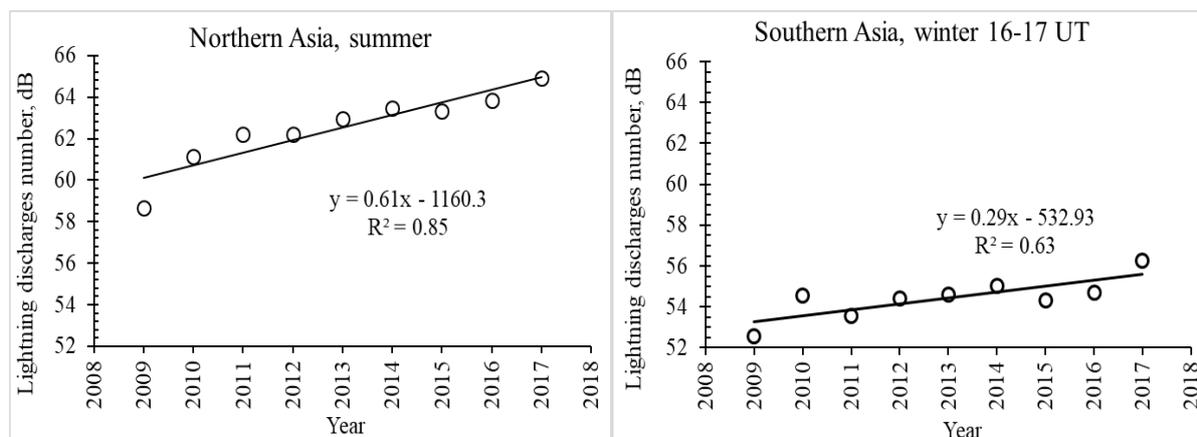


Figure 4. The total number of lightning discharges in the territory of Northern Asia (40-80 N, 60-180 E) for three summer months and in the territory of two Southern Asia regions: Northern India (17-36 N, 68-94 E) and Southern China (10-33 N, 94-126 E) for three winter months (16-17 UT).

3. Conclusions

Based on a simultaneous registration of variations in the intensity of VLF radio noise and signals at the Alfa navigation radio stations in Yakutsk in 2009 – 2017, it was found that the attenuation of the VLF signals decreases at a solar activity maximum (2014-2015). The VLF attenuation changes are 1.3 ± 0.7 dB (daytime propagation: 3 – 7 UT), 1.5 ± 0.7 dB (nighttime propagation: 16 – 17 UT) in summer and 7 ± 2 dB (daytime 3 – 7 UT), 6 ± 1.5 dB (nighttime 16 – 17 UT) in winter. The variations in the VLF radio noise intensity registered in Yakutsk from 2009 to 2017 are determined mainly by the conditions of wave propagation in the Earth – lower ionosphere waveguide.

Taking into account the peculiarities of the propagation of VLF radio signals, a trend in the radio noise source intensity was identified. The tendency towards increased intensity of the lightning sources according to the registration of VLF radio noise from 2009 to 2017 in summer (local thunderstorm activity in Northern Asia) is 4 dB for daytime (3 – 7 UT) and 1.6 dB for nighttime (16 – 17 UT).

According to the World Wide Lightning Localization Network data of 2009 to 2017, there is also an increase in the total number of lightning discharges in Northern Asia (40-80 N, 60-180 E) by 5 dB in summer and by 2.3 dB in Southern Asia (Northern India (17-36 N, 68-94 E) and Southern China (10-33 N, 94-126 E)) in winter.

The registered tendency towards increased thunderstorm activity may be caused by global warming.

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