Seasonal Variations of the Amplitude of the VLF Radio Signals and the Intensity of the Atmospheric Electric Field in Cryolithozone Conditions

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Abstract. It is performed an analysis of seasonal variations of the parameters of the underlying surface under cryolithozone conditions far from industrial interference at the SHICRA SB RAS radiophysical polygon near Yakutsk. Seasonal variations of the parameters of atmospheric electricity and the very low frequency (VLF) radio waves propagation from 2009 to 2018 are presented. It is obtained that for summer season the atmospheric electric field near the earth’s surface has a recession due to summer defrosting of the upper layer of permafrost and underlying surface conductivity changes and an increasing of radon output permeability. There is a slight decreasing of amplitude of VLF radio navigation signals received in Yakutsk in summer period. There is an asymmetry in seasonal daytime variations of the VLF signal amplitude. The VLF amplitude during autumn equinox more closely to summer solstice. The asymmetry determined by the season electron density profiles of the ionospheric D region.

1. Introduction

The fundamental problem in atmospheric electrical research is the measurement of variations in the electric field strength of the Earth. It is proportional to the ionospheric potential [1]. The geoelectric potential averaged over the past 50 years by the indications of many observatories remained relatively constant about 240 kV, except for a temporary increase of 40% after a period of intense nuclear tests in the atmosphere in 1960s. At the same time the seasonal changes in the electric field of the Earth is about 15% of the average value in the northern hemisphere with a maximum at the end in summer and a minimum in winter [1].

In seasonal variations of the atmospheric electric field intensity Ez for mountain stations at Cheget peak and Terskol peak the summer season is characterized by higher values than for the winter season, and the range of field strength variations for the summer season is wider. Seasonal variations in the highlands resembles the Carnegie curve obtained for observations in seas [2].

Observations on Kamchatka for zones with a winter snow cover and its absence in summer show that the maximum of the seasonal variation of electric field Ez falls in winter. The atmosphere electric field decreases during the summer period. It is associated with an increase in the radon flow to the...
atmosphere due to increase of a permeability of the upper soil layer [3]. The data on average annual X-ray background variations in the atmospheric surface layer at Apatity and Barentsburg stations presented in [4]. The flux increases in spring-summer reaching a maximum in July-August, and falling in winter reaching a minimum in March (Apatity) and in April-May (Barentsburg). The variation has a pronounced asymmetrical character: a rather wide flat maximum during the warm season, a decline during autumn-winter and a sharp increase in spring period. In this case, the recession begins earlier in Barentsburg, and the rise later. There is a somewhat sloping plateau during the warm period of the year, a decline in autumn and winter and a sharp rise in spring. It is assumed that the nature of this variation is the same as in the atmospheric surface electric field.

An anomalous behavior of the radio field strength of low frequency range (LF: 30-300 Hz) in winter was established in last century [5, 6]. According to the ideas of radio wave propagation at that time, the electromagnetic field strength in winter should be less than the summer one [7]. Experimental observations showed the opposite behavior of the radio field. The behavior of the field strength is explained by the influence of forest vegetation [8]. The forest cover conductivity measuring for the Novosibirsk LF range transmitter at distances up to 2000 km showed that the presence of a water-glycerin solution in winter increases the electrical wood resistance. The electrical resistance leads to variations of the electromagnetic fields intensity for the ranges: Short, Medium and Long waves [9]. The total field is defined as the sum of the primary field, which would be in the absence of trees, and the re-radiation field of the trees themselves. There is a complex interaction of various natural processes, leading ultimately to the anomalous behavior of the electromagnetic field intensity of the Very low frequency range (VLF: 3 – 30 kHz) in summer period [10].

2. Experimental data and analysis

The atmospheric electric field strength near the earth’s surface (surface electric field) has been regularly and continuously measured with 1-second resolution at the radiophysical polygon of the Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy of Siberian Branch of the Russian Academy of Sciences (SHICRA SB RAS) (61°55’ N, 129°21’ E) at 25 km far from Yakutsk [11]. The electrostatic field monitor EFM-100 used to measure variations of electric field strength under fair-weather, thunderstorm, foggy, and snowstorm conditions. The EFM-100 senses an electric field through the repeated exposure and shielding of a series of sensitive electrodes. The main EFM-100 hardware specifications are as follows: electric field range from -20 to +20 kV/m, response time of 0.1 s, and digital output resolution of 0.01 kV/m [12]. Figure 1 shows the seasonal variations of the strength of the atmospheric electric field. The variations presented as 5-day moving average.

![Figure 1. Seasonal variations of the strength of the atmospheric electric field registered in Yakutsk.](image-url)
There is a failure in the expected seasonal variations of the strength of the atmospheric electric field in Yakutia in summer. The summer falling of the strength of the atmospheric electric field begins in mid-April, and the transition to winter conditions occurs in early October. A wider range of the field strength variations is observed in summer from mid-June to mid-August. During 2009 - 2018 the seasonal course of electric field strength has a maximum in spring and autumn, and a minimum in winter. Seasonal electric field strength variations in a “good” weather for 2009 - 2013 repeated from year to year [13].

During 2009-2017 we registered the VLF signal amplitude of Novosibirsk transmitter (55°45′ N, 82°27′ E) at 14.9 kHz in Yakutsk (62° N, 129°42′ E). The transmitter sequentially emits pulses at frequencies of 11.9, 12.6 and 14.9 kHz. A cycle of the pulsed radiation is 3.6 seconds. A duration of each pulse is 0.4 seconds with a pause between other signals at 0.2 seconds. The signal received at the vertical whip antenna (effective height is 2 m) after pre-amplification passed to the input 14-bit analog-to-digital converter (ADC) USB3000. The timing and highly stable ADC sampling required for the VLF phase registration and run data collection in accordance with the transmitter mode, organized with a GPS clock (Trimble Thunderbolt E). The accuracy pulse per second (PPS) is UTC ± 50 ns. The accuracy of the harmonic signal (10 MHz) is 1.16×10⁻¹² after one-day operation (three sigma). External sampling for the ADC is 2.5 MHz. The sampling is a division of synchronized GPS clock harmonic signal (10 MHz). The digitized signal passed to a PC with a registration program developed by SHICRA SB RAS. The program carries out the selection of the amplitude and phase of three radio frequencies (11.9, 12.6 and 14.9 kHz) and saving data to disk. The selection organized by Fast Fourier Transform (FFT). The process greatly accelerated by the pre-formed array of trigonometric function values. The sampling interval is 2.688 ms, which provides the necessary frequency resolution [14].

Novosibirsk – Yakutsk propagation path is 2640 km. Figure 2 shows diurnal amplitude variations of Novosibirsk transmitter signal (14.9 kHz) registered in Yakutsk during 2009-2011. The variations are the result of a median averaging for each month for March, June, September and December 2009-2011.

![Figure 2. Diurnal variations of VLF signal amplitude (14.9 kHz) of Novosibirsk transmitter registered in Yakutsk during 2009-2011.](image)

The duration of daytime and nighttime radio propagation conditions changes from winter to summer. Diurnal variations of the amplitude of Novosibirsk transmitter signal (14.9 kHz) for December are 6.4 times: from 0.026 (01:24 UT) to 0.166 (21:48 UT) relative units (rel. units). Diurnal variations of the amplitude in March are 4.4 times: from 0.036 (23:24 UT) to 0.157 (13:36 UT) rel. units. Diurnal variations of the amplitude for June are 1.8 times: from 0.117 (19:08 UT) to 0.208 (04:54 UT) rel. units and for September are 2.3 times: from 0.091 (22:06 UT) to 0.207 (20:00 UT) rel.
units. The diurnal variations minima of the signal amplitude are explained by the radio waves interference changing Earth-ionosphere waveguide during sunrise or sunset. An analysis of diurnal variations of the field strength of Novosibirsk transmitter signal (14.9 kHz) showed that the daytime conditions of radio signal propagation on Novosibirsk-Yakutsk radio path correspond to a time interval of 3-7 UT. The nighttime radio propagation conditions for the path correspond to an interval of 16:30-17:30 UT [15]. Figure 3 shows the seasonal daytime variations of VLF signals amplitude of Novosibirsk transmitter received in Yakutsk during 2009–2017. The variations presented as 15-day moving average. The expanded seasonal variations for 2010 are shown in Figure 4.

![Seasonal daytime variations of the VLF signal amplitude of Novosibirsk transmitter received in Yakutsk during 2009-2017.](image1)

**Figure 3.** Seasonal daytime variations of the VLF signal amplitude of Novosibirsk transmitter received in Yakutsk during 2009-2017.

![Seasonal variations of the VLF signal amplitude of Novosibirsk transmitter (14.9 kHz) registered in Yakutsk in 2010.](image2)

**Figure 4.** Seasonal variations of the VLF signal amplitude of Novosibirsk transmitter (14.9 kHz) registered in Yakutsk in 2010.

Variations of VLF signal amplitude characterize the attenuation coefficient changes during radio wave propagation. Seasonal daytime variations are most pronounced which is associated with an increase in the ionization efficiency of the ionospheric D region from December to June. The solar zenith angle above the radio propagation path decreases, resulting the electron density gradient of the lower ionosphere increase. Such changes of the lower ionosphere properties lead to a decrease of VLF
radio waves attenuation. An asymmetry is observed in seasonal daytime variations of the VLF signal amplitude. The VLF amplitude during autumn equinox (September) more closely coincide with summer solstice and the amplitudes registered during spring equinox are closer to winter solstice [16]. The VLF amplitude differences for spring and autumn periods relative to the equinoxes are determined by the seasonal asymmetry of the electron density profiles of the ionospheric D region [17].

The lowest soil temperature is observed in December. The temperature is \(-6 \pm 1 \, ^{\circ}C\) for a depth of \(1.5 \, m\) with a relatively high humidity of \(21.5\%\) and \(-8 \pm 1.5 \, ^{\circ}C\) at a low humidity of \(8.7\%\). A freezing at this depth occurs in November. The soil temperature varies from \(0 \, ^{\circ}C\) to \(-6 \, ^{\circ}C\). A defrost occurs in May and the soil temperature changes from \(-1.5 \, ^{\circ}C\) to \(+1 \, ^{\circ}C\). The soil temperature at these depths reaches \(+4 \, ^{\circ}C\) in summer. A permafrost under Yakutsk has a thickness of 200-250 m and its temperature ranges from \(-2 \, ^{\circ}C\) to \(-8 \, ^{\circ}C\). The defrost depths surround Yakutsk are 2.2–3 m (for sandy soils), 1.4–1.8 m (for loams) and 1 m (for forest areas around the city). At the polygon where the registration was carried out the soil defrost depth is 1 m [18].

Resistivity measurements were carried out for electrodes distance by 1.5 and 3 meters. According to our measurements, the main changes in the soil resistivity occur when the air temperature changes from \(-5 \, ^{\circ}C\) to \(-25 \, ^{\circ}C\) (electrodes distance is 1.5 m). The changes in the resistivity of the soil occur for temperatures below \(-20 \, ^{\circ}C\) (electrodes distance is 3 m). In winter the resistivity remains almost constant. The temperature at \(-20 \, ^{\circ}C\) near Yakutsk is set around October 25 – November 3. It should be noted that in addition to freezing the soil from the surface, there is a depth soil freezing due to the permafrost layer [19]. The specific resistance of the soil begins decrease in May when the air temperature is about \(+7 \, ^{\circ}C\). Seasonal changes in the soil resistivity in a layer of 0.5 m (electrodes distance is 1 m) varied from 130 Ohm∙m to 470 Ohm∙m (3.6 times increase), the soil resistivity varied from 40 Ohm∙m to 200 Ohm∙m (almost 5 times increase) for the soil layer up to 1.5 m (electrodes distance is 3 m). The changes correspond to other work data [20].

We used brass nails for the resistivity measurements of growing trees. We measured the resistivity of a pine and larch with a diameter of 220 mm. The nails with a diameter of 6.3 mm and a length of 100 mm were clogged at 70 mm. The distance between the contact sections was 1 m, and the contact section consisted of 4 nails. Below a temperature of \(-5 \, ^{\circ}C\) (around October 10) the resistivity remains almost constant. The same happens for a larch. The increase of the trees resistivity with a decrease in the ambient air temperature is explained by the fact that for a cold weather, the moisture of the trees partially goes into the soil and partially turns into a gel inside the tree. Thus trees protect from frost themselves. The trees conductivity changes due to the water concentration inside them. The resistance of trees sharply increases with the onset of frost, when in a very short period trees are almost completely dehydrated. A tree has a very high specific resistance without moisture inside a trunk and branches. The specific resistivity of trees is much less (13.3 kOhm∙m) for spring the air temperature is \(-5 \, ^{\circ}C\) (about April 20 for Yakutsk), than for autumn at the same temperature (145 kOhm∙m). Consequently, the resistance decrease begins earlier for a lower temperature. Seasonal changes of a pine specific resistivity ranged from 4.7 kOhm∙m to 1100 kOhm∙m. The air temperature varied from \(+19 \, ^{\circ}C\) to \(-25 \, ^{\circ}C\). The specific resistance of a larch varied also from 4.7 kOhm∙m, but to 766.7 kOhm∙m. The air temperature during the period has values from \(+7 \, ^{\circ}C\) (May) to \(-25 \, ^{\circ}C\) (November).

3. Conclusion
The atmosphere electric field decrease in summer is associated with an increase of the radon flow to the atmosphere due to an increase in the permeability of the upper soil layer, the dissolution of snow covers and defrosting of the upper layer of frozen soil.

According to conductivity measurements of the forest cover and recording signals of Novosibirsk transmitter in Yakutsk it is concluded that the presence of a water glycerine solution in winter increases the electrical resistance of the wood. The forest resistance decreasing leads to a slight decrease of the electromagnetic fields intensity in forest cover state in summer on the Far East territory.
There is an asymmetry in seasonal daytime variations of the VLF signal amplitude. The average values of the VLF amplitude during autumn equinox (September) more closely coincide with summer solstice and the amplitudes registered during spring equinox are closer to winter solstice. The differences are determined by the seasonal asymmetry of the electron density profiles of the ionospheric D region.

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