Diurnal and seasonal amplitude and phase variations of the radio signals of RSDN-20 transmitters and the intensity of radio noise (11.9 kHz) registered in Yakutsk during 2009-2017

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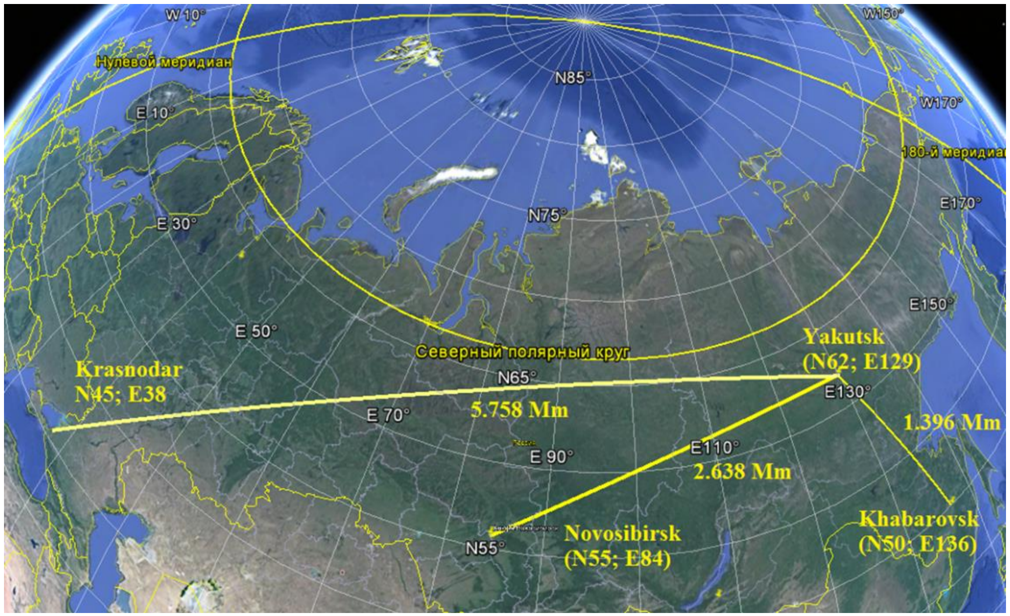
- The variations of parameters of radio station signals are registered in the very low frequency range (VLF: 3-30 kHz) for sounding the lower ionosphere.
- The VLF radio waves sensitivity to various geophysical phenomena depends on the location of the transmitter and receiver, the signal propagation direction, the propagation path length and the signal frequency [*A.B. Orlov, G.V. Azarnin, 1980*].

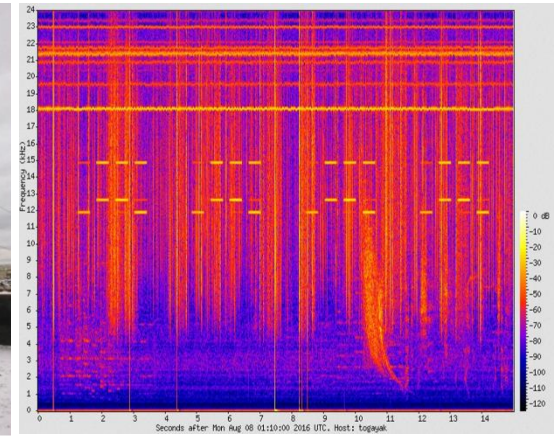
- The flux of ionizing radiation changes in the solar activity cycle.

$$qL\alpha = 2.91*10^{11} *(1+0.2*(F10.7 - 65)/100), \qquad (1)$$

qLα - Lyman-alpha (121.6 nm) solar flux intensity in photons*cm^{-2}*s^{-1};
F10.7 - radiation flux at a wavelength of 10.7 cm [10^{-22} W*m^{-2}*Hz^{-1}]
[*M.I. Panasyuk, et al., 2007*].

VLF signals from 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 (effective band is 334.8 Hz) [R.R. Karimov et al, 2012, V.I. Kozlov et al, 2017].





The signal received at the vertical whip antenna (effective height is 2 m) after pre-amplification passed to analog-to-digital converter (ADC). Timing and highly stable ADC sampling required for the registration phase and run data collection in accordance to the navaid system, organized by GPS clock.

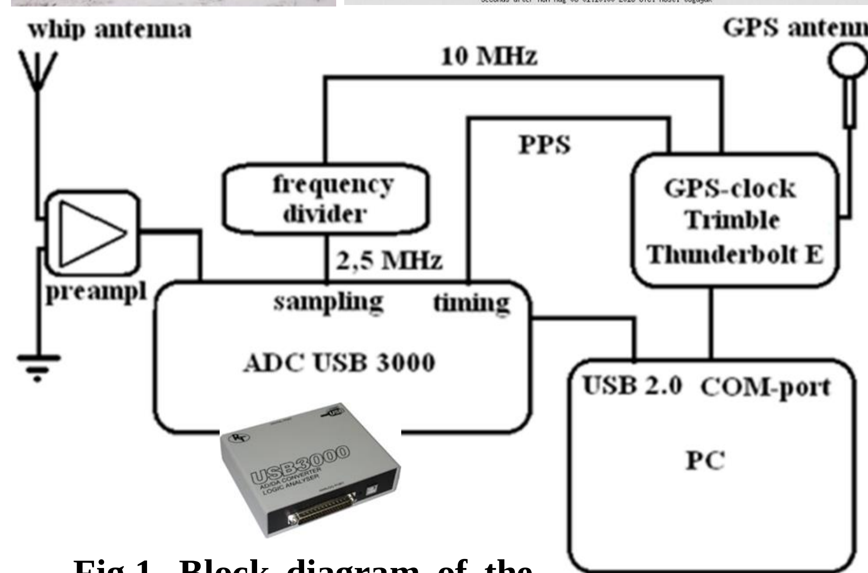


Fig.1. Block diagram of the VLF receiver in Yakutsk.

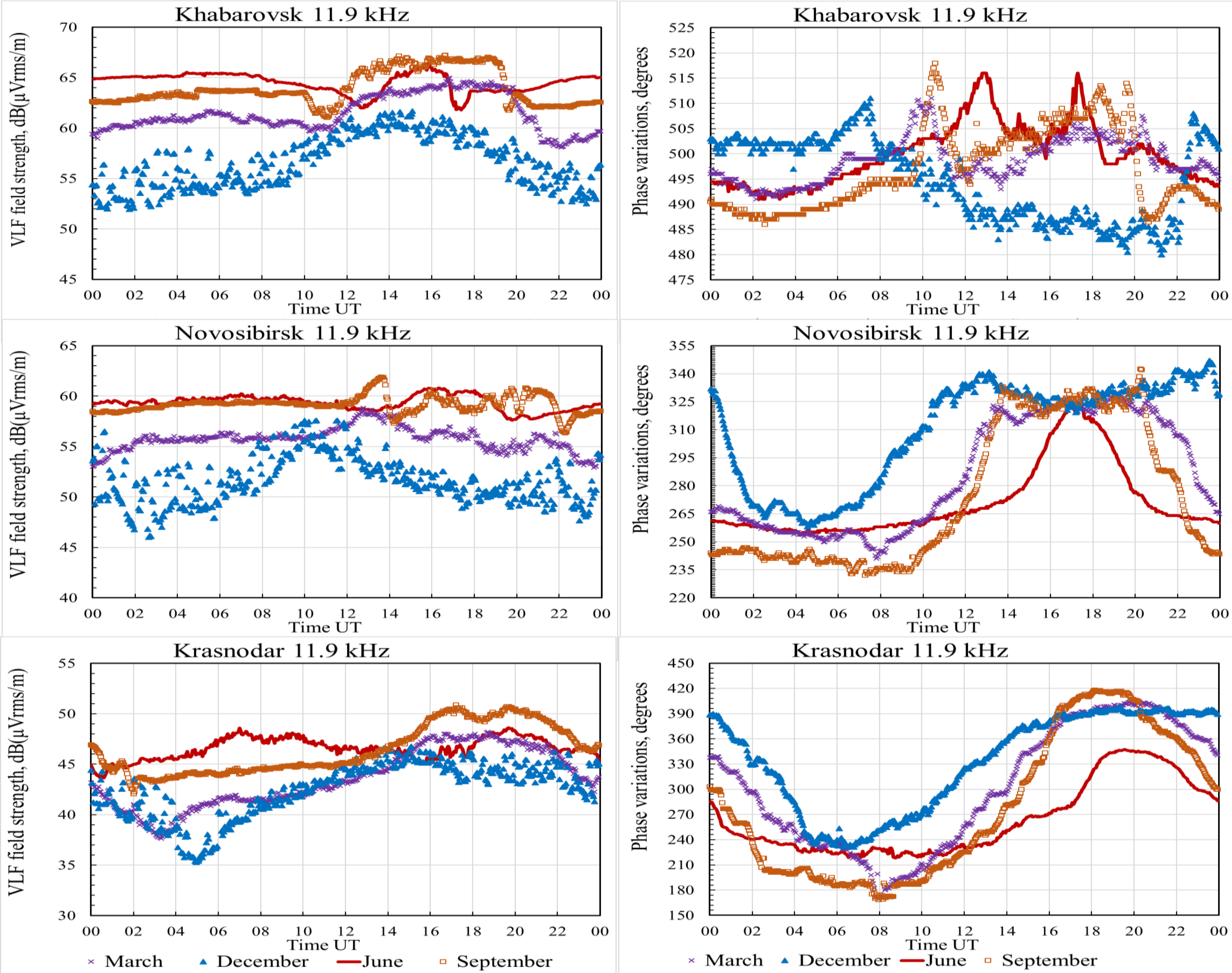


Fig. 2. Diurnal and seasonal amplitude and phase variations of the radio signals (RSDN-20 navaid system, 11.9 kHz) registered in Yakutsk in 2015

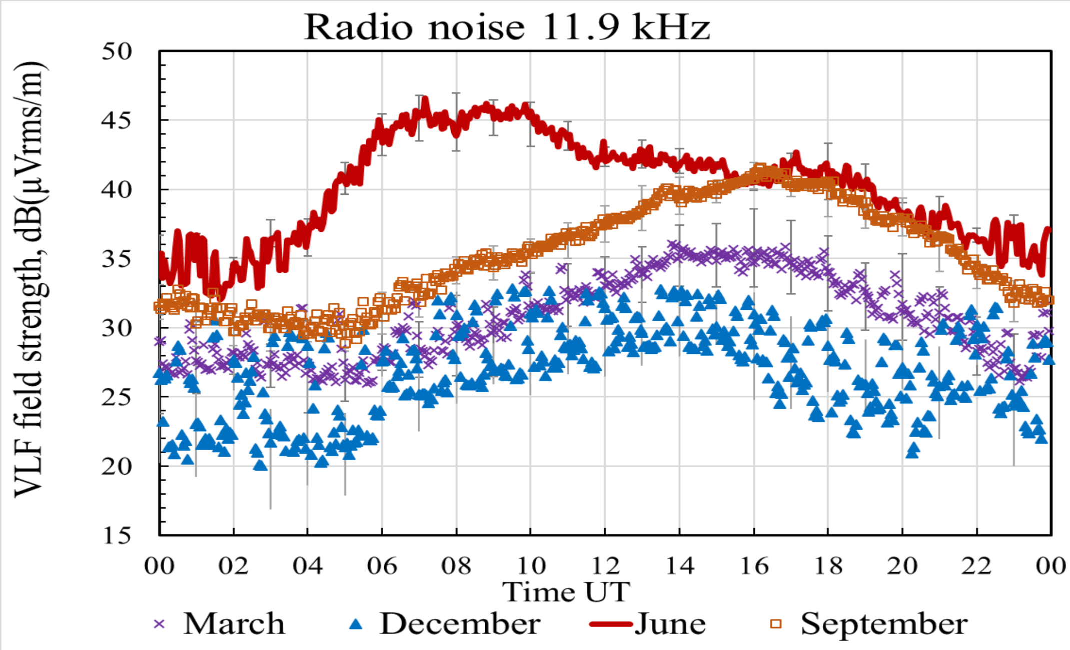


Fig. 3. VLF field strength of radio noise (11.9 kHz) detected in Yakutsk in 2015. Effective band is 334.8 Hz.

The smallest signal-to-noise ratio for the Krasnodar transmitter which is farther from Yakutsk is 2.5 dB (summer period of 6-9 UT). The period 6-9 UT is the maximum of local thunderstorm activity.

Table 1. Diurnal and seasonal amplitude (root mean square) and phase variations of the VLF signals and radio noise (11.9 kHz) registered in Yakutsk in 2015

VLF emission source	**Season**	**VLF field strength, dB(μVrms/m)**		**VLF phase variations, degrees**	
		Daytime	**Nighttime**	**Daytime**	**Nighttime**
Khabarovsk	**March**	**61** (2-6 UT)	**64** (15-16 UT)	**493** (2-6 UT)	**501** (15-16 UT)
	June	**65** (2-6 UT)	**66** (15-16 UT)	**493** (2-6 UT)	**502** (15-16 UT)
	September	**63** (2-6 UT)	**66** (15-16 UT)	**488** (2-6 UT)	**504** (15-16 UT)
	December	**54** (2-6 UT)	**60** (15-16 UT)	**502** (2-6 UT)	**488** (15-16 UT)
Novosibirsk	**March**	**56** (3-7 UT)	**57** (16:30-17:30 UT)	**254** (3-7 UT)	**324** (16:30-17:30 UT)
	June	**60** (3-7 UT)	**60** (16:30-17:30 UT)	**256** (3-7 UT)	**322** (16:30-17:30 UT)
	September	**59** (3-7 UT)	**59** (16:30-17:30 UT)	**239** (3-7 UT)	**328** (16:30-17:30 UT)
	December	**50** (3-7 UT)	**51** (16:30-17:30 UT)	**264** (3-7 UT)	**322** (16:30-17:30 UT)
Krasnodar	**March**	**42** (5-7 UT)	**48** (18-19 UT)	**235** (5-7 UT)	**393** (18-19 UT)
	June	**47** (5-7 UT)	**47** (18-19 UT)	**226** (5-7 UT)	**335** (18-19 UT)
	September	**44** (5-7 UT)	**50** (18-19 UT)	**187** (5-7 UT)	**415** (18-19 UT)
	December	**38** (5-7 UT)	**44** (18-19 UT)	**238** (5-7 UT)	**394** (18-19 UT)
radio noise	**March**	**28** (3-7 UT)	**35** (16:30-17:30 UT)	-	-
	June	**40** (3-7 UT)	**42** (16:30-17:30 UT)	-	-
	September	**30** (3-7 UT)	**41** (16:30-17:30 UT)	-	-
	December	**25** (3-7 UT)	**27** (16:30-17:30 UT)	-	-

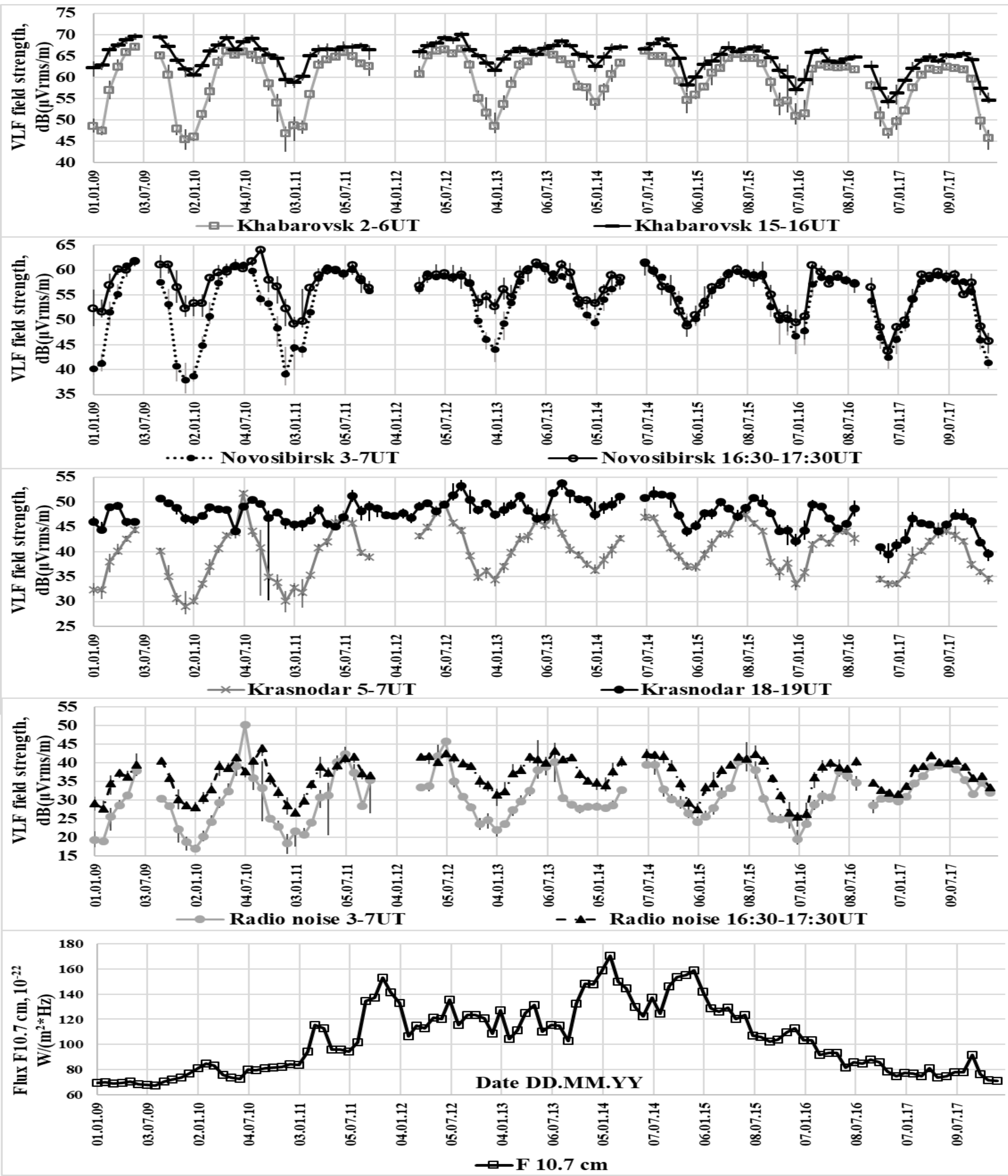


Fig. 4. Seasonal variations of the VLF field strength (11.904 kHz), for daytime and nighttime propagation v.s. F10.7 index.

- Khabarovsk radio signal strength increases by 9 ± 1 dB and 4 ± 1.5 dB for daytime and nighttime conditions respectively with increasing solar activity (2014) in winter.
- Novosibirsk radio signal strength increases by 11 ± 1.5 dB and 6 ± 1.3 dB for daytime and nighttime respectively with increasing solar activity (2014) in winter. For summer: 2 ± 0.6 dB from min to max solar activity.
- Krasnodar radio signal strength increases by 6 ± 1.2 dB and 8 ± 1.8 dB for daytime and nighttime respectively with increasing solar activity in winter. For summer: 3 ± 0.7 dB (day), 3 ± 0.6 dB (night) from min to max solar activity.
- Radio noise rms field strength increases by 11 ± 1.2 dB and 6 ± 1.5 dB for daytime and nighttime respectively with increasing solar activity in winter.

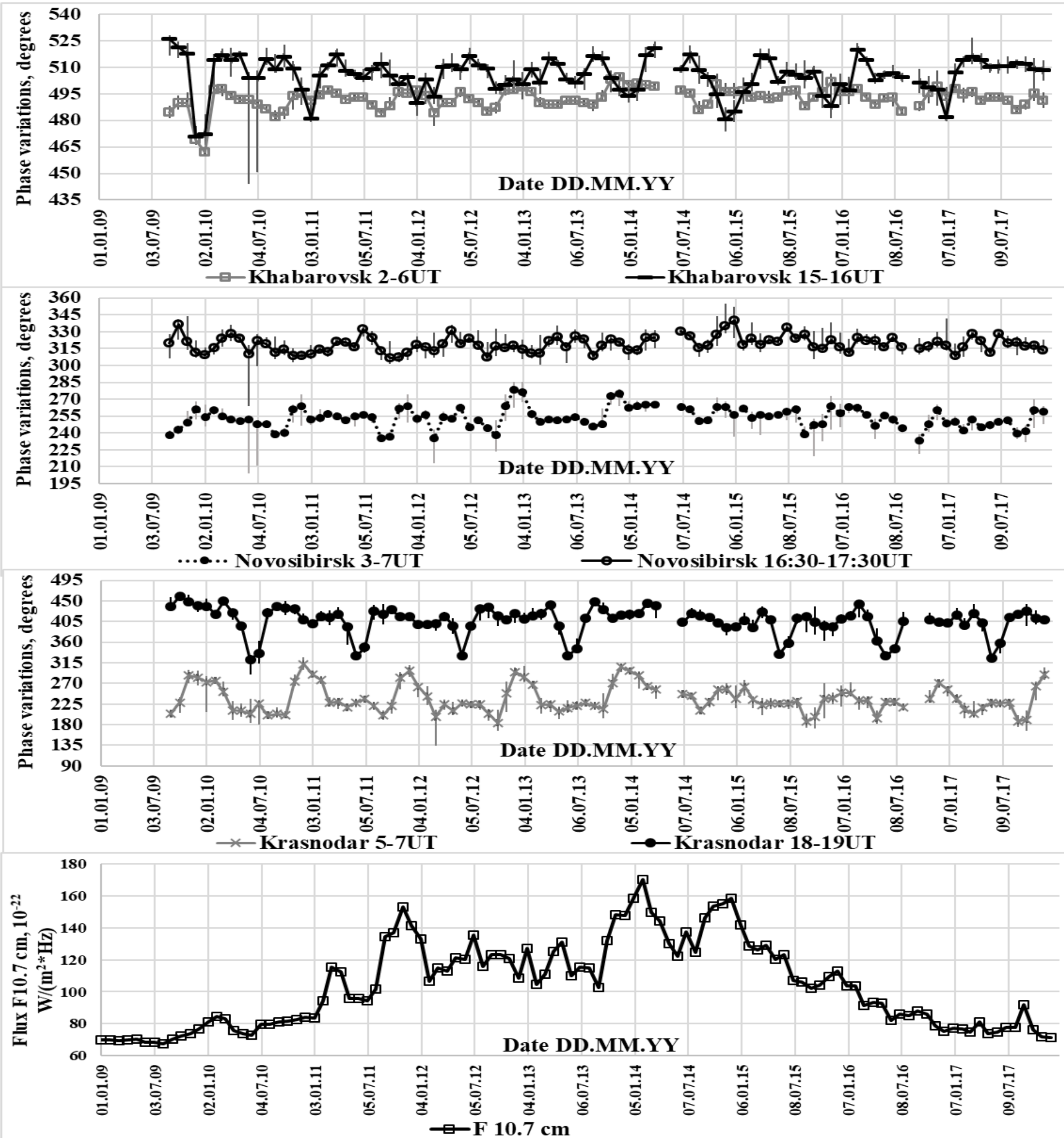


Fig. 5. Seasonal phase variations of the VLF signal (11.904 kHz), for daytime and nighttime propagation v.s. F10.7 index.

Against the background of seasonal variations, interannual variations in the phase of the VLF radio signals are not distinguished.

CONCLUSIONS

- The amplitude of the VLF signal is less during the day than in night.
- The maximum amplitude for the signal is recorded in summer during the Solar zenith is in the middle of the radio path.
- The seasonal daytime amplitude variations are most pronounced. It is associated with a decreasing of the solar zenith angle over radio paths from December to June, and with an increasing of the altitude gradient of electron concentration in the lower ionosphere.
- There is an asymmetry of the seasonal daytime VLF amplitude variations. The amplitude during the autumn equinox is closer to the summer solstice and the amplitude of the spring equinox - to the winter solstice. This is consistent with the seasonal asymmetry of the altitude profiles of the electron concentration of the lower ionosphere [***Ya.L. Al'pert, 1972***].
- An increase of the received signal phase delay from day to night is noted. It is typical for nighttime increasing the effective height of the Earth - ionosphere waveguide. An exception is the nighttime phase delay decrease for the Khabarovsk-Yakutsk propagation path (the result of higher-order modes interference).
- The behavior of the interannual variations of the field strength of the VLF radio noise and the radio station signals for the nine-year interval are similar to the behavior of solar activity (F10.7 index) both for summer and for winter. The VLF signal level registered in winter, relative to the summer, is more sensitive to the period of increase, maximum and decline of the 24th solar cycle.
- Against the background of seasonal variations the interannual variations in the phase of the VLF radio signals are not distinguished for the period of increase, maximum and decline of the 24th solar cycle activity.

The study was supported by the Ministry of Education and Science of the Russian Federation and by Siberian Branch of the Russian Academy of Sciences (Project II.16.2.1, registration number AAAA-A17-117021450059-3). The study was partially supported by RFBR, research project No. 18-45-140028 r-a.

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Thanks for your attention !