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STUDY OF HF RADIO WAVES ABSORPTION EFFECTS DURING X-RAY SOLAR FLARES USING AMPLITUDE CHARACTERISTICS OF CHIRP SIGNALS

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Abstract. Using oblique incidence sounding data obtained over Salekhard-Norilsk and Amderma-Norilsk paths in 2016 we study response of amplitude characteristics to the several M-class X-ray solar flares. We use two approaches for the analysis of amplitudes. The first approach is based on the evaluation of maximum amplitude for each frequency of HF radio signal registered at the oblique incidence sounding ionogram. The second approach is based on the summation of HF signals amplitudes over the frequency range with the step 0.3 MHz with the goal of more accurate recording of information about the useful signal. We have carried out the comparison of results for both methods. For the studied X-ray flares we have calculated temporal variations of amplitude sums and maximum amplitudes for the frequency range of chirp signal registered at the several moments of the solar flares. Decrease of the value of maximum amplitude sums and maximum amplitudes has been determined for the moments near maximum intensity of the studied solar flares for the frequencies under 10 MHz. This effect is connected with the increase of HF radio signal absorption at the D-region of ionosphere while the ionization of D-region is increased during the X-ray solar flare event.

Introduction

Study of solar activity manifestations in the Earth's upper atmosphere is one of the most important goals of the space weather. As it is known there are two main channels of energy transfer from the Sun. The first channel is connected with propagation of electromagnetic eradiation with various wave lengths, the second one is associated with motion of charged particles of different velocities and energies. In this study we analyze the short-term influences to the Earth's ionosphere connected with the splashes of X-ray solar radiation with wavelengths from 1 to 8 angstrom. As a result of such influences the sudden ionospheric disturbances (SIDs) are observed. During SID the intensified X-ray flux enhances ionization of the ionospheric D-layer which increase the absorption of high frequency (HF) radio waves. This absorption depends on the frequency of HF radio waves [*Settimi et al., 201*4]. If the frequency is lower the absorption is higher. Therefore the most attenuation of HF signal during solar flare emission events is at the lower frequencies. For the frequency range from 2 to 30 MHz the strongest absorption is at frequencies under 10 MHz.

Our previous study has been devoted to the influence of X-ray solar flares (SFs) on the frequency characteristics of HF radio wave propagation [*Ivanova et al., 2013*]. It was shown that lowest observed frequencies (LOF) are increased sharply at the maximums of the four investigated M- class solar flares. But generally, for series of other events connected with solar flares the LOF are not obviously changed especially for the northern paths. Therefore we have begun analysis of chirp signal amplitude characteristics to find the most evident parameter connected with the absorption of the decameter radio waves in the D-region of ionosphere. For the two X-ray SFs of X-class on 06.09.2017 we have studied temporal dependencies of LOF and sum amplitudes through the whole ionograms [*Yasyukevich et al., 2018*]. But we did not recognize amplitude characteristics of chirp signals for separate ionogram in dependence of frequency. For the purposes of obtaining the additional riometric information from the vertical and oblique-insidence sounding ionograms the important task is to compare chirp sounding data with the results of equipment operated at the several HF fixed frequencies such as Ekaterinburg Coherent Radar [*Berngardt et al., 2018*]. The aim of this study is to choose the most suitable method for the analysis of the chirp signals attenuation during the geophysical events of short temporal duration namely X-ray solar flares.

Data

The transmitters in Salekhard (66.5°N, 66.7°E) and Amderma (69.6°N, 60.2°E) are in operation of Arctic and Antarctic Research Institute (St. Petersburg). The receiver in Norilsk (69.4°N, 88.4°E) is under control of Institute of Solar-Terrestrial Physics SB RAS. Intervals between soundings are 15 minutes. For our investigation we used data of Salekhard-Norilsk and Amderma-Norilsk paths because they are located in the field of view Ekaterinburg Coherent Radar of the CUTLASS SuperDARN class. In our future research we are going to compare OIS amplitude characteristics with the EKB Radar data.

It should be noted that oblique-incidence sounding (OIS) data are processed by primary filtration. The typical OIS ionogram is the matrix consisting of the three columns. The first column is frequency, the second one is group path

and the third one is amplitude. During the standard processing of OIS ionograms the first and the second columns from each ionogram are used to obtain distance-frequency characteristic (DFC). Information about amplitudes is used indirectly to build DFC. But for the purpose of the study of ionospheric D-region response to SF it is necessary to directly consider amplitudes as energetic characteristic of HF signal.

For our analysis we used two methods. The first approach is based on the selection of maximum amplitude for each frequency of the OIS ionogram. The second method is based on the summation of amplitudes with the 0.3 MHz step across the frequency range of the OIS ionogram for the accumulation information about useful chirp signal. Our amplitude analysis is qualitative because the antenna in Norilsk is not calibrated.

Geomagnetic conditions for the studied periods of X-ray flares were quiet. The periods of X-ray SFs, classes of the studied flares and summarized Kp-indexes are in Table 1 (*http://satdat.ngdc.noaa.gov/, http://wdc.kugi.kyoto-u.ac.jp/*). As we can see in Fig. 1 the X-ray SF on 18.04.2016 had sharp beginning and smooth recession. Two splashes of X-ray flux on 23.07.2016 registered from 5 UT till 5:33 UT we can consider as one event due to 15-minutes intervals between OIS soundings.

Table 1. Geomagnetic conditions and periods of studied X-ray flares.

Date	Class of X-ray solar flare	UT of the start of the X-ray flare	UT of X-ray flare maximum	UT of the end of the X-ray flare	∑Kp
18.04.2016	M6.7	0:14	0:29	0:39	9-
23.07.2016	M5.0	1:46	2:11	2:23	13
	M7.6	5:00	5:16	5:24	
	M5.5	5:27	5:31	5:33	

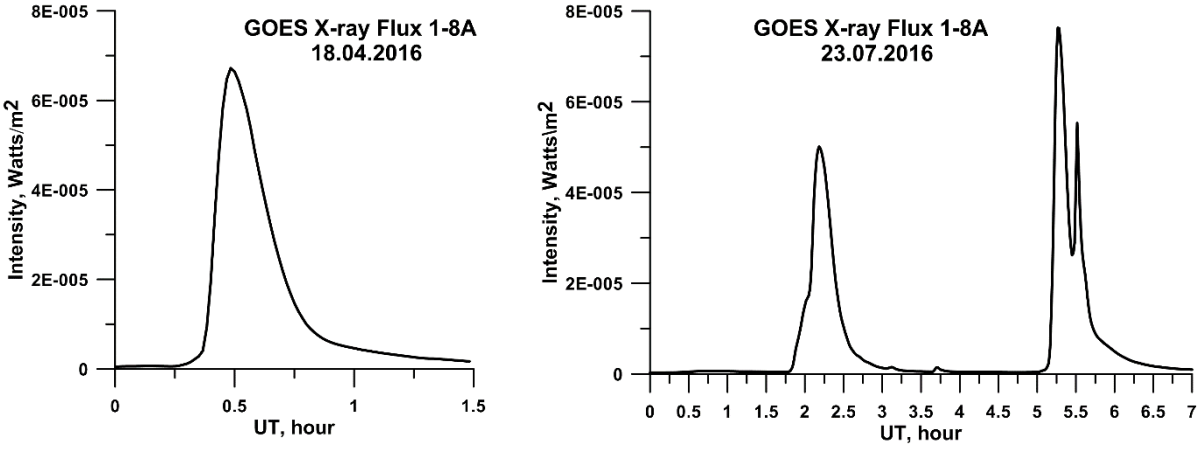

Figure 1. Variations of X-ray Solar Flux obtained at GOES satellites on 18.04.2016 and 23.07.2016.

Results

As we can see on 18.04.2016 over Salekhard-Norilsk (S-N) and Amderma-Norilsk (A-N) paths strong amplitude characteristics response to the M6.7 class SF was registered at 0:37UT and 0:34UT respectively (Fig. 2). The main response over S-N path is for the frequencies near 5 MHz on 18.04.2016 and near 7 MHz on 23.07.2016. Concerning A-N path the most sensitive frequencies on 18.04.2016 are from 5 to 10 MHz. There was no useful signal at ionograms obtained over A-N path on 23.07.2016 through the whole day therefore we did not analyze these data.

It should be noted that maximum amplitudes calculations for the separate working frequencies is very sensitive to electromagnetic noise. For example on 18.04.2016 at 0:07UT for S-N path and on 23.07.2016 at 5:07UT and 5:37UT for S-N path for the frequencies above 20-25 MHz powerful noise components were registered.

Full absorption of useful signal has been observed at 5:22UT and 5:37UT on 23.07.2016. The method of maximum amplitudes has not recognized this situation but the method of amplitudes summation has detected the absence of useful signal decently. From the other hand the noise constituents of HF signal are also sensitive to the increase of D-region absorption [*Berngardt et al., 2018*] and for the occurrence of S-N path on 23.07.2016 we can observe the decrease of the maximum amplitudes over frequency range from 5 to 10 MHz at 5:22UT and 5:37UT compared to 5:07UT. This maximum amplitudes decrease is connected with attenuation of HF signal during M7.6 and M5.5 X-ray solar flares on 23.07.2016.

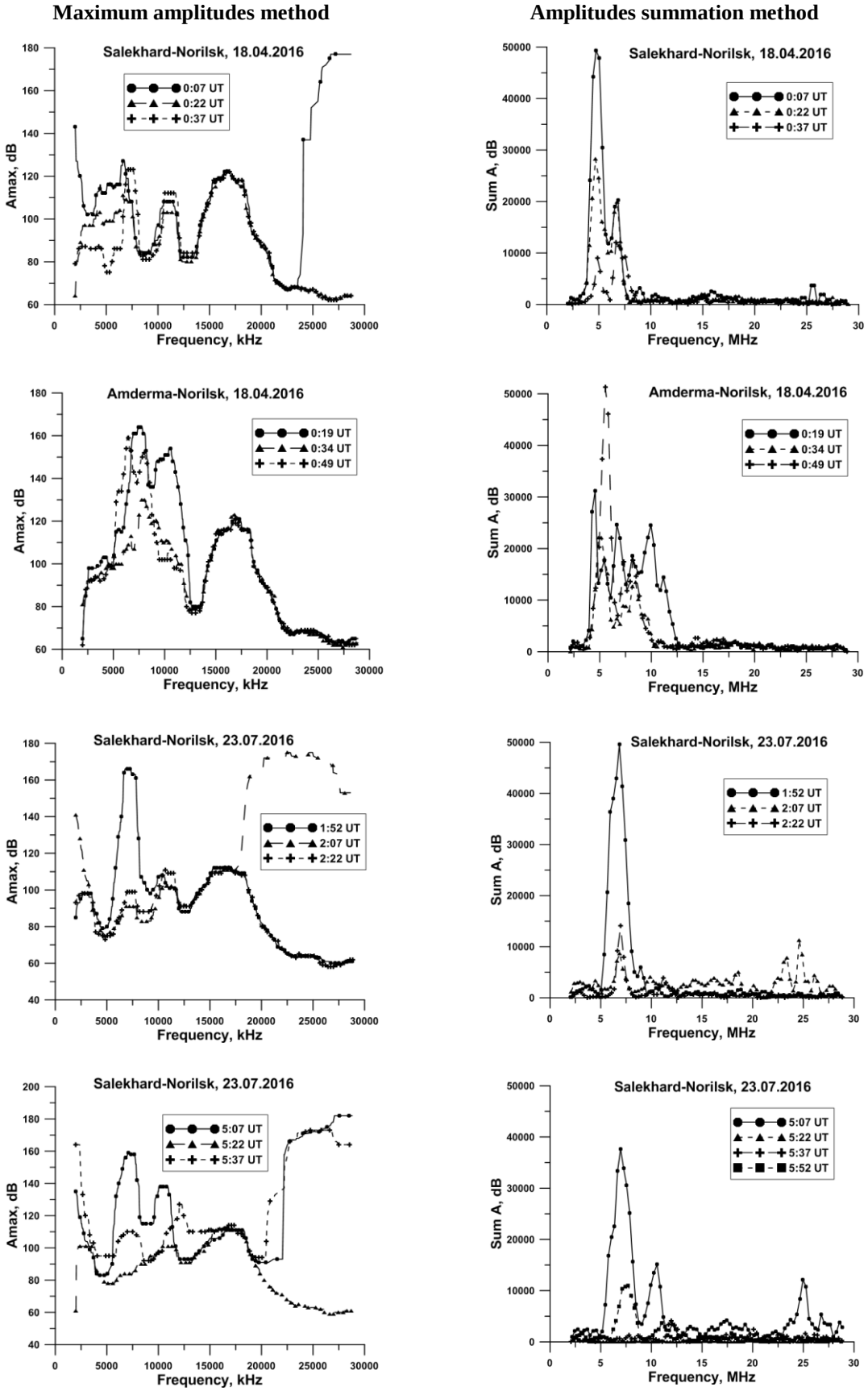

Figure 2. Calculations of amplitude characteristics using both studied methods for the several moments of enhanced X-ray intensity during SFs and before the SF events.

Conclusion

For the several X-ray flares of M-classes the response of amplitude characteristics of chirp signals has been analyzed by two different methods. Sharp decreases of the amplitudes sums and maximum amplitudes have been observed near maximums of X-ray flux splashes. The most precise result was shown by the method of amplitudes summation because it takes into consideration absence the useful signal at the OIS ionogram at the moments of the full absorption of the useful signal during M7.6- and M5.5-classes solar flares on 23.07.2016 over Salekhard-Norilsk path. The strongest attenuation of HF signals for the moments of the studied solar flares is observed at the frequencies under 10 MHz. Our future research efforts will be guided to cooperative studies using oblique-incidence and vertical sounding data over northern region of Russian Federation and Ekaterinburg Coherent Radar data.

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