Propagation conditions of 10 MHz signals along the paths between Rostov and Moscow

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Abstract. To determine the conditions for the propagation of HF signals through the ionosphere along various paths, there are several possibilities: (1) ionograms of vertical sounding, (2) ionograms of oblique sounding between transmission and receiver points, (3) receiving signals from transmitters of exact time at fixed frequencies (here ~10 MHz), (4) using ionospheric models. This paper presents the results of a comprehensive study that implements all these possibilities. They refer to the propagation of HF signals on reciprocal paths between Rostov and Moscow during the period of the lowest solar activity of cycle 24 (April-May 2020). It is shown that the maximum usable frequency (MUF) of propagation through the F2 layer of the ionosphere in the overwhelming majority of cases did not exceed 10 MHz both in the experiment and according to model calculations. The signals were propagated through the Es layer. If earlier it was shown that such a joint experiment allows revealing the presence of traveling ionospheric disturbances, the results of this work emphasize the role of the Es layer.

1. Introduction
Despite the development of various tools of satellite communication, terrestrial HF communication continues to play an important role. It is still the main option of communication in the Arctic (e.g., [1]), Antarctica (e.g., [2]), the African continent (e.g., [3]) and many other regions. The European Community is already openly setting the task of creating a backup information transmission system, alternative to the Internet. Within the framework of the European Union, a system has been developed that can replace the Internet - SWING (Short Wave Critical Infrastructure Network based on a new Generation high survival radio communication system) [4]. It includes a wide network of HF devices. Ionospheric models should play an important role in ensuring the operation of such networks up to the autonomous mode of their use. There are several possibilities to determine the conditions for the propagation of HF signals through the ionosphere: (1) ionograms of vertical sounding (VS), (2) ionograms of oblique sounding between points of transmission and receiving (OS), (3) receiving signals from transmitters of exact time at fixed frequencies (here ~ 10 MHz), (4) using ionospheric models. VS ionograms are historically the first and most widespread means of studying the ionosphere. One of the most difficult problems of this study and the use of its results for practical purposes is the presence of traveling ionospheric disturbances (TID) due to the unpredictability and high variability of its characteristics and propagation conditions. So far, scientific community is not talking about the development of the TID model. A way out of the impasse was found with the help of synchronization of ionosondes located at different distances. An example of such a system exists in Europe [5]. A similar approach has been implemented by us and will...
be used in this work. Figure 1 shows an example of combined vertical and oblique sounding ionograms obtained at the Rostov and Moscow ionosphere stations on 14.00 UT 20 April 2020.

Figure 1. Joint VS and OS ionograms from Rostov and Moscow stations.

In the HF band, radio transmitters of precise time signals continue to operate, emitting at highly stable fixed carrier frequencies. The signals from these transmitters can be used to obtain information about the current state of the ionosphere and the conditions of radio wave propagation on separate fixed radio paths using the oblique sounding method. Moreover, obtaining information can be provided by simple receiving and recording equipment that measures the levels of incoming signals, and by performing spectral analysis of signals [6]. Such equipment was created in the Rostov point (47°13’ N, 39°38’ E) and placed in the Research Institute of Physics of the Southern Federal University to receive signals from the RWM radio station (Moscow, 55°48’ N, 38°18’ E) [7]. Potentially, the equipment can operate simultaneously at three frequencies 4996 kHz, 9996 kHz, 14996 kHz. An example of recording the signal level is shown in figure 2 for a frequency of ~ 10 MHz.

Figure 2. An example of recording the signal level.

The combined use of the ionosonde data and the indicated equipment allows one to carry out comprehensive studies of the passage of HF signals along the Moscow-Rostov path (the length of the path is $D = 953.2$ km) [8].

In this work, the main parameters used are the critical frequencies $f_{oF2}$, $f_{oEs}$ of the F2 and Es layers, measured by ionosondes at the Rostov and Moscow points, and the maximum usable frequencies (MUF), measured on the Rostov-Moscow and Moscow-Rostov paths. Since the path is short, a simple and reliable Smith’s method was used to calculate the MUF, which allows determining the MUF by means of characteristics in the middle of the path: $MUF(D) = MD*f_{oF2}(D/2)$ [9]. These characteristics are the propagation coefficient $MD$ and the critical frequency $f_{oF2}$.
The aim of this work is to compare the experimental and model values of the characteristics associated with the propagation of HF signals under conditions of extremely low solar activity. The next section describes the experimental data and models, and section 3 gives the results.

2. Experimental data and models
The experimental data used were obtained: (1) critical frequencies foF2 for Rostov and Moscow stations according to the DIDBase website data (http://ulcar.uml.edu/DIDBase), (2) critical frequencies foEs and MUF frequencies according to the data of the corresponding ionosondes. The IRI-2016 [10] is used as a model, which is constantly being modified. An additional advantage of this model is the determination of the propagation factor of M3000F2 for a path length of 3000 km, which allows obtaining MUF3000F2. The propagation coefficient MD for the path with length D = 953.2 km is obtained by recalculating the traditional coefficient M3000F2 in accordance with [9]. For the foF2 value, two options are used: (1) the half-sum of the values of two ionosondes, (2) calculation for the IRI-2016 model at the point in the middle of the path (foF2(D/2)). Calculations according to the IRI-2016 model were carried out online on the website (http://omniweb.gsfc.nasa.gov/vitmo/iri2016_vitmo.html) using the default parameters.

3. Results
The first step is to assess the accuracy of the IRI model. Since the model is median, the accuracy of determining foF2 is estimated by comparison with experimental medians. Estimates are given in Table 1 as root-square-mean error RSME and normalized RSME for both stations and two months of 2020. Additionally, estimates for 2009 are given, which were made from the previous version of IRI-2012. One can see that the accuracy of the model has increased. This means that the modeling difficulties that the authors of the models faced for the first time in the previous period of extremely low solar activity (2006-2009) in cycle 23 (e.g. [11]) have been overcome.

|      | April | May |
|------|-------|-----|
|      | Rostov | Moscow | Rostov | Moscow |
| RSME | MHz    | MHz   | MHz    | MHz    |
| %    | %      | %     | %      | %      |
| 2020 | 0.35   | 0.28  | 0.28   | 0.28   |
| 2009 | 0.57   | 0.38  | 0.38   | 0.38   |

Figure 3 compares the foF2 medians for two months, their half-sum used to calculate the MUF, and the frequency of the IRI-2016 model calculated at the point in the middle of the path (51.25 ° N, 38.28 ° E) for April and May 2020.

![Figure 3](image-url)
It can be seen that the frequency of the IRI model is very close to the foF2(D/2) frequency, which is used to calculate the MUF frequencies, which are compared in figure 4 with experimental values for both Rostov-Moscow and Moscow-Rostov paths.

![Figure 4](image)

**Figure 4.** Behavior of the maximum usable frequencies on short paths in conditions of extremely low solar activity.

The RSME between paths is 0.37 MHz, the NRSME is 5.4% for April 2020 and 0.39 MHz and 9.09% for May 2020, respectively. The calculated MUFs in most cases lie between the experimental values, i.e. provide smaller RSME and NRSME.

Thus, it can be seen that in April, according to experimental data and calculations, signals with a frequency of ~10 MHz cannot pass along the paths, however, signals from the RWM station are constantly observed. In May, signals with a frequency of ~10 MHz can pass, but this applies only to the Rostov-Moscow path, but not the Moscow-Rostov path.

It was natural to assume that signals can propagate with reflection from the sporadic Es layer. And although, as the results of a more than 30-year study of this layer appearance probability according to the data of the rather close Rome station show, in these months the probability is high, regardless of the level of solar activity [12], it is necessary to have proof of the presence of this layer during the measurement period. Such proof is given in figure 5, which shows the frequencies of the Es layer measured at both stations.

![Figure 5](image)

**Figure 5.** Observation of the Es layer frequencies at two stations in the period April-May 2020.

As one can see, the layer is present in most cases simultaneously in the area of both stations. Thus, it can be assumed that the main propagation mechanism of 10 MHz signals in this case is reflection from the Es layer. At the same time, the observation of VS ionograms indicates that the Es layer was semitransparent.

4. **Conclusion**

The results of the joint experiment show: (1) the propagation of 10 MHz signals could pass with reflection from the Es layer, (2) the reception of the RWM transmitter signals allows monitoring the communication channel, (3) the IRI-2016 model has sufficient accuracy to set the conditions for the
propagation of HF-signal, (4) the experimental and model results can be used for forecasting propagation conditions with a shift in the 11-year solar cycle length, since it is assumed that the 25th cycle will be very close at 24, and the 26th cycle, possibly, will be weaker than 25 [13].

In conclusion, it should be noted that great attention was paid to these issues at the URSI GASS Assembly held on Rome, Italy, 28 August-4 September 2021, dedicated to the 100th anniversary of this organization. I. Galkin’s report “Predictive Properties of Real-Time Assimilative IRI” (authors I.A. Galkin, A. Vesnin, B.W. Reinisch, D. Bilitza) presents proposals for enhancing the technical capabilities of ionosondes to register TID, for using short paths. D. Bilitza’s report “International Reference Ionosphere-Update 2020” (authors D. Bilitza, D. Altadill, V. Truhlik, M. Friedrich, V. Shubin) presents a modification of the model IRI-2020 indicating the need to develop a model of the Es layer and its inclusion in the IRI. It should be noted that the absence of the Es layer model in the IRI model is constantly indicated as a shortcoming of the IRI. The question of including the parameters of this layer in the model was considered in [14]. The experience of the paper [15], which implemented two approaches in modeling the Es parameters: (1) based on the Ovezgeldyev model [16-17], 2) using the NGDC/STP database (NGDC/STP, 1994) [18] with filling in the gaps in accordance with the paper [19] showed that, for example, in a high-latitude zone, the first approach gives the best results, but these models are not enough.

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References
[1] Warrington E M, Stocker A J, Siddle D R et al. 2016 Radio Sci. 51 1048
[2] Chartier A T, Vierinen J and Jee G 2020 Atmos. Meas. Tech. 13 3023
[3] Aziz A Z and Hadi K A 2013 Iraqi Journal of Science 54(2) 475
[4] Zolesi B, Bianchi C, Meloni A, Baskaradas J A et al. 2016 Radio Sci 51 421
[5] Verhulst T, Altadill D, Mielich J et al. 2017 Adv. Space Res. 60 1644
[6] Ivanov I I, Kuleshov G I and Skazik A I 2017 Radiation and Scattering of Electromagnetic Waves RSEMW (Divnomorskoe Russia) (IEEE)
[7] Transmitter RWM Moscow 55°48’ N, 38°18’ E
[8] Denisenko P F, Kuleshov G I and Koledin N A 2012 Electromagnetic waves and electronic systems 17(6) 28
[9] Kotovich G V, Kim A G, Mikhailov S Y et al. 2006 Geomagnetism and Aeronomy 46 547
[10] Bilitza D, Altadill D, Truhlik et al. 2017 Space Weather 15 418
[11] Zakharenkova I E, Kramkowski A, Bilitza D et al. 2011 Adv. Space Res. 51 620
[12] Pietrella M and Bianchi 2009 Adv. Space Res. 44 72
[13] Javariah J 2017 Solar Physics 292 1
[14] Bradley P A 2003 Adv. Space Res 31(3) 577
[15] Anishin M M, Maltseva O A and Mozhaeva N S 2014 Technics of a radio communication 3(23) 11
[16] Ovezgeldyev O G and Mikhailova G V 1985 News of Turkmen AS, phys-techn series 6 23
[17] Ovezgeldyev O G and Mikhailova G V 1976 News of Turkmen AS, phys-techn series 3 65; 1976 6 48; 1977 3 48; 1981 5 40
[18] 1994 NGDC/STP, Ionosph Digital Database on CD-ROM ngdc.noaa.gov – Boulder Colorado
[19] Maksjutin S V and Sherstjukov O N 2003 Investigated In Russia 97 URL: http://zhurnal.ape.relarn.ru/articles/2003/009.pdf