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First observations of oblique ionospheric sounding chirp signal in Mexico

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ABSTRACT

The results of the first experiment of oblique ionospheric sounding (OIS) chirp signal reception in Mexico are reported. Maximal and Lowest Observed Frequencies variations were studied under the quiet Space Weather conditions. The diurnal ionospheric variations by OIS signal confirm the results based on GNSS data in the Mexican region. The best HF radio propagation conditions along the considered path are during morning and daytime hours. The multi-hop propagation is frequent. The interlayer propagation modes are present at nighttime.

Introduction

Ionospheric sounding is one of the main methods to study the ionosphere. Oblique ionospheric sounding (OIS) provides information about radio propagation conditions along the radio path and about the state of the ionosphere near the mid-point of this path. Currently, the only available source of the ionosphere information in Mexico has been GNSS data that allowed us to calculate and analyze the Total Electron Content (TEC) variations [1]. An urgent need of ionosonde measurements in the Mexican region was emphasized in [2]. In 2018, National Space Weather Laboratory of Mexico (LANCE) began its OIS experiments to fill this gap. The results of the first OIS measurements performed in Mexico are reported in this work.

Experiment description

For the experiment, the receiver station of chirp OIS signal was temporally located in the Institute of Geophysics in Morelia, Mexico (19.64 N, 101.22 W). It operated in the range of 2–30 MHz with the frequency sweep rate of 100 kHz/s and frequency turning step ≤ 1 Hz. The signal was received from Virginia, U.S. (37.56 N, 77.02 W). The path length is about 3077 km (Fig. 1a). The mid-point of the path lies southward of New Orleans, in the Mexican Golf, which is a zone of special interest because many air routes from Europe to Mexico City pass there. The Maximum and the Lowest Observed Frequencies (MOF and LOF) were detected from the ionograms which were taken at 10th and 22nd minute of each hour. The measurements were performed during October 28–29, 2018 under quiet Space Weather conditions (solar minimum, Dst = $5 \div 23$ nT, no flares).

Results and conclusions

The most intense signal was received in the afternoon hours near 15 LT. The highest MOF value (20 MHz) was observed during several day hours, the lowest MOF value (4 MHz) – at midnight and at 20:10 LT. In general, LOF followed the same tendency as MOF. The frequency range Δ = MOF − LOF was the narrowest at midnight, 6:10 LT and 20:10 LT. The widest Δ was between 14:22 and 15:10 LT. Fig. 1b shows the diurnal variation of MOF and LOF. The drastic growth of parameters was observed at 7:10 LT, which is the moment of sunrise at the path's

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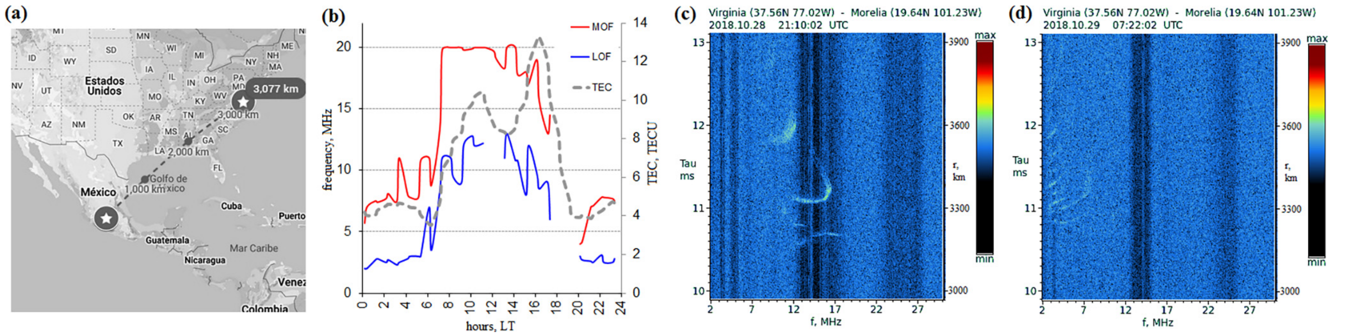

Fig. 1. Map of stations locations (a). Diurnal MOF, LOF and TEC variations in the region (b). Examples of the obtained IOS ionograms taken under the daytime (c) and nighttime (d) conditions.

mid-point zone. The intensity of the signal at ionograms was very low between 18 and 20 LT (the gap in Fig. 1b). After that, the range of the observed frequencies was the narrowest. Sunset at midpoint occurred at 18:16 LT. Therefore, the propagation conditions are affected by the solar terminator passage. The nighttime enhancement as a second diurnal density maximum, which is present with high probability in the region, was confirmed by MOF data. The growth/decrease of TEC and MOF occurred at the same time intervals (Fig. 1b). The highest daytime and nighttime MOF values preceded the highest daytime and nighttime TEC values.

One-hop reflections were observed at all hours of the day. This could be expected because this is a short radio path (< 4000 km). Two and even three hop reflections were detected frequently during daytime. Fig. 1c is an example at 15:10 LT: three reflections from the F2-layer (MOF = 16 MHz at $\tau = 11.1$ ms; MOF = 12 MHz at $\tau = 11.8$ ms and the weak reflection with MOF = 9 MHz at $\tau = 12.8$ ms) and two disperse reflections from the Es-layer. Multi-hop propagation dominated at night hours: three main propagation mode hops (detected at daytime) and up to six additional hops which in our view correspond to the interlayer propagation modes. Fig. 1d illustrates the nighttime results at 00:22 LT. The phenomenon of the interlayer propagation modes at night is rather unusual and new and serves as the focus for further study. The obtained patterns were confirmed by the OIS experiments performed on other quiet days at the nearby sites.

One of the ionospheric research aspects is the modeling of the ionospheric parameters. The most popular model is the International Reference Ionosphere, which, in particular, provides foF2 and M3000F2 parameters calculation. OIS data allows us to estimate the accuracy of the model for the region. The length of the Virginia-Morelia path is close to D = 3000 km. Therefore, the modeled value of the Maximal Useful Frequency (MUF(D)F2) can be determined by foF2 and M3000F2 values at the mid-point of the path (29.14°N, 90.18°W). For instance, the modeled values for the ionogram in Fig. 1c are: foF2 = 6.797 MHz, M3000F2 = 3.462 MHz and MUF = 23.53 MHz. It is seen that the model overestimates the values.

To sum up, the results of the first OIS in Mexico are as follows. (1) The overall diurnal MOF variation follows the pattern of the diurnal TEC variation. The shift between the highest MOF and TEC values was revealed. The presence of nighttime enhancements of the electron density was confirmed with MOF. (2) The best HF radio propagation conditions along the path in terms of the widest Δ were observed in the morning and daytime hours. (3) The multi-hop propagation is frequent at the path. The interlayer propagation modes were detected at nighttime and will be the subject for the future study.

LANCE plans to organize and perform the continuous OIS measurements from different chirp signal transmitters for the development of the ionosphere studies in Mexico. LANCE acknowledges partial support from CONACyT LN 293598, CONACyT PN 2015-173, CONACyT-AEM Grant 2017-01-292684, and DGAPA-PAPIIT Grant IN106916. D.V. Blagoveshchensky acknowledges grant № 18-05-00343 from Russian Foundation for Basic Research. O.A. Maltseva acknowledges grant under the state task N3.9696.2017/8.

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