Ionospheric variations during the solar eclipse event by space weather forecasting system

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Abstract

Using the physics-based thermosphere-ionosphere model (NCAR-TIEGCM) with an ensemble Kalman filter, this study reports the first data assimilative analysis of the ionosphere responses to the solar eclipse on 21 August 2017. The system, using a 2-minute assimilation cycle of data from ground-based GNSS observations, show dynamic variations of the equatorial ionization anomaly (EIA) due to the electrodynamic effects of the solar eclipse. Two major ionospheric responses are captured: (1) an early appearance of EIA at the westward boundary of moon shadow and (2) an enhanced EIA at lower latitudes and suppressed EIA at the higher latitudes. These eclipse-induced conjugate EIA variations are produced by an eastward electric field perturbation around magnetic equator and a westward electric field perturbation at the higher latitudes.

Key word: solar eclipse, space weather, ionosphere

1. Introduction

During the solar eclipse period, it is usually observed that the ionospheric electron density reductions and the F-region altitude increases. These eclipse-induced electron density changes can modify ionospheric electric conductivity and electric field distribution due to ionospheric electrodynamic processes.

The total solar eclipse event, 21 August 2017, occurred with a path of totality over the central USA, providing a good opportunity to investigate its effects on the photochemical and electrodynamic processes of the ionosphere. In this study, a three-dimensional global assimilative system is used to assimilate the ionospheric total electron content (TEC) observations from a dense network of Global Navigation Satellite System (GNSS) receivers over North America and further investigate ionospheric variation and its mechanisms during the 2017 August solar eclipse.

2. Results and discussions

Figure 1 shows the comparisons of GNSS TEC observations (a), the TIEGCM assimilation results on 20 August (one day before the eclipse) (b) and 21 August (eclipse day) (c), as well as the difference between the two-days assimilation results (d) around the North and South America regions at 1730 UT (top panels), 1800 UT (middle panels), and 1830 UT (bottom panels), respectively. The difference TEC (fig. 1d) shoes the clear TEC enhancements around equatorial ionization anomaly (EIA) regions, but with the TEC reductions around the obscuration region at each time frame. This eclipse-induced TEC depletion is around -4 TECU at 1830 UT, a roughly 40% decrease in respect to the background TEC (Fig. 1b). This result is similar to the previous eclipse observational and modeling papers (Tsai and Liu 1999; Le et al. 2008, 2009; Huba and Drob 2017). Furthermore, the related neutral temperature in the assimilation system was also decreased around the range of solar eclipse (figure not shown), which is consistent with the expectation of temperature reduction due to the solar eclipse.

The advantage of assimilation system is not only the modification of the ionosphere but also the other parameters in the model, such as the neutral density, neutral winds, and the neutral temperature, and let us can investigate its mechanisms behind the period of solar eclipse event. In order to investigate time variations as well as the latitudinal dependences of the ionospheric responses to the solar eclipse, Figure 2 shows the latitude-time variations of ionospheric TEC along the specific longitudinal plane (white line in Fig. 1) at 300 km altitude. It is clear show that the TEC reduction region occurred above the latitude of 36^{o}N as well as at the conjugate southern hemisphere around the occurrence time of 1830 UT, which is consistent with the conjugated responses reported by Huba and Drob (2017).

Figure 3 shows the relative latitude-time variations of eastward electric field perturbation along the specific longitudinal plane (same with Fig. 2) at 300 km altitude. Compared with the electron density variations shown in Fig. 2 and the electric field perturbations in Fig. 3, this implies that the ionospheric electron density morphology during the solar eclipse period is controlled by vertical plasma drift, upward (eastward electric field) at the low-latitude region and downward (westward electric field) at the mid-latitude region, respectively. Fig. 3 further shows that the eastward electric fields appeared around the morning hours and then reversed to the westward after the evening hours. This electric field variation may explain the early appearance of EIA in Fig. 2.

The possible mechanism of the modification of electric field perturbations in the ionospheric data assimilation system is showed in Fig. 4. First of all, the Moon's shadow decreases the ionizing radiation from the Sun during the solar eclipse, which causes a reduction in electron concentration. Conductivity becomes lower in the obscuration range of solar eclipse. Therefore, the change particles accumulate at the boundary of high and low conductivity. Due to the direction of electric fields at the low-latitude region, the positive (negative) charge particles accumulate at the southwestern (southeastern) boundary of the eclipse, which induces the eastward electric field at lower latitudes to further enhance the original background eastward electric fields. On the other hand, at higher latitudes, the background westward electric fields are also enhanced by the same mechanism. The aforementioned mechanism is confirmed by assimilation results in Fig. 3 showing the enhanced eastward (westward) electric field at the low-latitude (mid-latitude) region.

3. Conclusions

In this study, the ionospheric response during the total solar eclipse of 21 August 2017 was investigated using the coupled thermosphere-ionosphere data assimilation model for the first time. Compared with the electron density at the previous day of the solar eclipse day and the eclipse day, it shows the electron density decreased up to 4 TECU (~40% of the background TEC on the eclipse previous day) around the solar eclipse region at 1830 UT. The results further show that the upward plasma drift is one of the important factors to drive the feature of significant enhancements (reductions) in electron density at the equator-side (polar-side) of EIA crests. The morphology of low-latitude westward and mid-latitude westward electric fields might be caused by the eclipse-induced ionospheric conductivity changings. The assimilation analysis results show stronger eastward electric fields around the magnetic equator region at the beginning of the solar eclipse, providing upward plasma drift to uplift the ionospheric layer and lead the earlier forming of EIA crests.

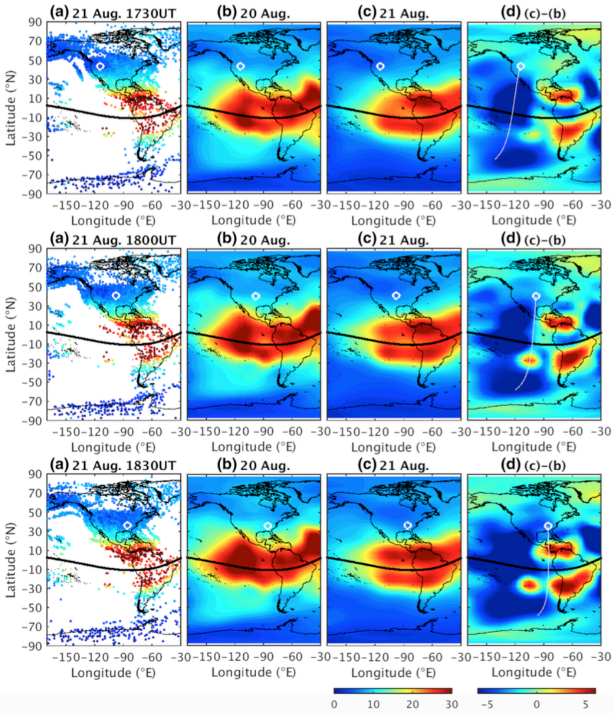

Figure 1. Comparisons of GNSS TEC observations (a), dataassimilation results on the eclipse previous day (b), and the eclipse day (c), and the TEC difference between these 2 days (d).

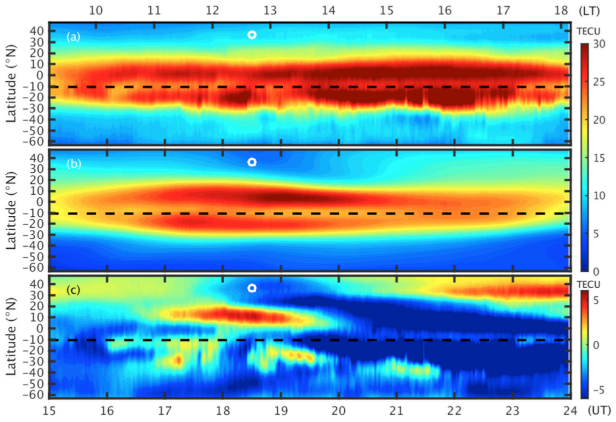

Figure 2. The latitude-time variations of TEC along the magnetic field line (shown by the while line in Fig. 1) on the eclipse previous day (a), and the eclipse day (b), and the difference (c) between the TEC of (a) and (b).

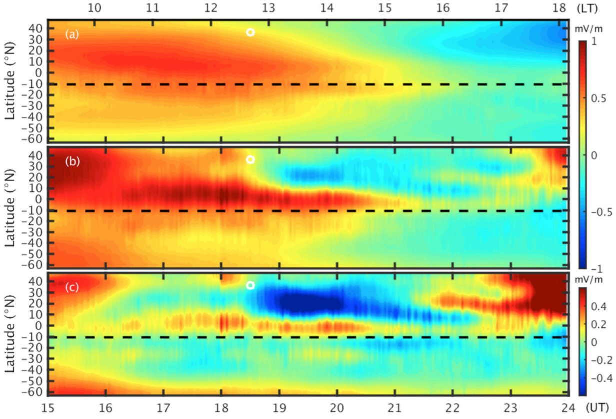

Figure 3. Same as Fig. 2 but for the eastward electric fields.

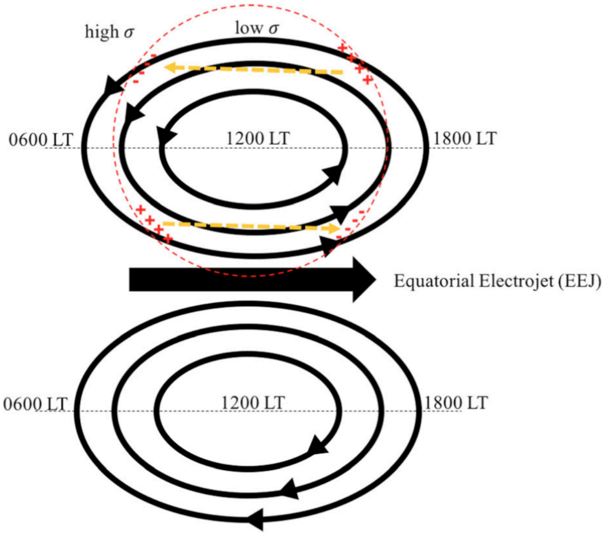

Figure 4. Illustration of eclipse-induced enhancement on the eastward and westward electric fields at the low- and mid-latitudes, respectively.