Ionospheric foF2 anomalies during Halloween events: A preliminary Look

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Abstract

The global evolutions of foF2 anomalies were examined for the very intense geomagnetic storms, namely the Halloween events of October-November 2003 (Event X, Oct. 29-30, 2003, Dst -401 nT; Event Y, Nov. 20-21, 2003, Dst -472 nT). For Event X (Oct. 29-30, 2003, slight winter in NH and summer in SH), troughs (negative storms) were clearly seen for ~65°N at nighttime, but not at any other LTs. Troughs were strongly seen in high southern latitudes, as if this was a summer storm for SH. For northern midlatitudes as also for low latitudes, there were very strong positive effects on Oct. 29, followed by negative effects next day. For Event Y (Nov. 20-21, 2003, winter in NH and summer in SH), there were no troughs in NH high latitudes for morning and evening hours but there were troughs for night. For midlatitudes and low latitudes, some longitudes showed strong negative effects in the early morning as expected, but some longitudes showed strong positive effects at noon and in the evening hours. A disconcerting feature was the presence of strong positive effects in the 24 hours *before* the storm commencement.

1. Introduction

The Earth's ionosphere responds markedly to varying solar and magnetospheric energy inputs. The ionospheric electron density Ne at a given altitude and location depends on the solar EUV fluxes, the neutral composition, and dynamical effects of neutral winds and electric fields (details from the review Buonsanto, 1999, also in other reviews e. g., Abdu 1997; Fuller-Rowell et al., 1997; Prölss, 1997; Rees, 1996; Schunk and Sojka, 1996). The ionized and neutral species in the upper atmosphere are closely coupled, so it is not possible to attain a physical understanding of geomagnetic storm effects on ionospheric electron density without considering effects on the neutral thermosphere. Ionospheric storms result from large energy inputs to the upper atmosphere associated with geomagnetic storms. Strong magnetospheric convection electric fields map down along magnetic field lines to the high latitude ionosphere, and ions and electrons drift in the **E** x **B** direction. Strong localized electric fields often develop at subauroral latitudes and combine with increased conductivities resulting from energetic particle impact to give substantial electric currents and strong Joule heating of the atmospheric gases. The neutrals are heated and the neutral atmosphere expands, creating pressure gradients, which modify the global thermospheric circulation. The neutral expansion is rapid during geomagnetic storms and may cause upwelling, i.e., the motion of air through constant pressure surfaces, which results in departures from diffusive equilibrium and increases in the mean molecular mass, i.e., decreases in the ratio of atomic oxygen density [O] to molecular nitrogen [N2] and oxygen [O2] densities (Rishbeth et al., 1987). As mentioned in Buonsanto (1999), the expected storm-time patterns are as follows:

(a) High latitudes: Deep troughs of ionization at night at high and subauroral latitudes, often accompanied by enhancements in electron temperature, electric fields and ion outflow. During storms, extended troughs at progressively lower latitudes during the course of the night. Narrow troughs are associated with localized electric field enhancements, while extended troughs can span several degrees of latitude equatorward of the region of diffuse aurora, associated with flux tubes which "stagnate" and convect westward for extended periods through the nightside, allowing the plasma to steadily recombine.

(b) Dusk effect: After a geomagnetic storm SSC, large enhancements in the afternoon and evening hours, earlier at higher latitudes.

(c) Long duration positive storm effects: Caused by downwelling of neutral atomic oxygen and uplifting of the F layer due to winds. Both of these rely on large-scale changes in the thermospheric circulation caused by heating in the auroral zone.

(d) Negative phase: the ionospheric storm negative phase in NmF2 and TEC occurs in a composition disturbance zone which reaches lower latitudes in summer than in winter and has a preference for the night and morning sectors due to the local time variation of the neutral winds.

(e) Low latitude and equatorial zone: The **E** x **B** drifts are affected by prompt penetration of magnetospheric convection electric fields, as well as by longer-lived dynamo electric fields from the disturbance neutral winds and storm-related changes in ionospheric conductivity (Fejer, 1997). In addition to the drifts caused by electric fields, TADs and also longer duration disturbances in the global thermospheric circulation with resulting neutral composition changes have important effects on the low latitude region during storms.

(f) Even under geomagnetically quiet conditions, electron density is extremely variable in the equatorial zone between sunset and midnight due to the presence of irregularities with scale sizes ranging from less than 1 m to greater than 200 km. How geomagnetic storms affect the development of equatorial irregularities depends on longitude and varies from storm-to-storm.

Two very intense geomagnetic storms occurred recently in quick succession, namely Halloween events of Oct. 29-31, 2003, Dst -401 nT and Nov. 20, 2003, Dst -472 nT. The ionospheric foF2 anomalies were examined for these storms.

2. Data analysis

Fig. 1 (a) shows a plot of hourly Dst values during the 27-day interval Oct. 28-Nov. 23, 2003. The first storm (henceforth called Event X) started at ~06 UT on Oct. 29, reached a maximum depression of -363 nT at 00 UT of Oct. 30 (main phase of 18 hours), recouped but had a second maximum depression of -401 nT at 22 UT on Oct.30, and then recovered first rapidly and then slowly. Thus, this was a complex storm. (The triangles indicate solar flare occurrence. There were two strong solar flares, one on Oct. 28 and another on Oct. 29). The second storm (henceforth called Event Y) started at ~11 UT of Nov. 20, reached a maximum depression of -472 nT at 19 UT of Nov. 20 (main phase of 9 hours), and then recovered first rapidly, then slowly. There was a strong solar flare on Nov. 18. In between, there was a small storm on Nov. 4 (Dst -89 nT). There was a very, very intense solar flare on Nov. 4 (largest in known history so far), but it was a limb flare, did not have emissions (CMEs) directed towards the Earth and no disturbances were produced. The mild storm of Nov. 4 was caused by less strong solar flares which occurred on Nov. 2-3.

Fig. 1 (b) shows a plot of hourly foF2 (MHz) at the location Juliusruh/Rugen (54.6^{o}N, 13.4^{o}E) in European midlatitude, LT about 1 hour ahead of UT. There is a substantial daily variation, with a maximum of ~7-10 MHz at about noon and a minimum of ~1-2 MHz soon after midnight. The storm effects are superposed on this background daily variation. To isolate the storm effects, the background daily variation needs to be subtracted. In conventional methods, the background is estimated as a monthly mean. However, this may get polluted by storm days. In the present case, the interval Nov. 7-16 was geomagnetically quiet. Hence the average daily variation for these 10 (or less, as available) days was considered as an estimate of the background. Then, two methods were employed. In one method, the background was subtracted from the actual hourly values. The *deviations* foF2 minus foF2 (average) were considered as anomalies (in MHz) and will be called henceforth as *Anomalies*, plotted in Fig. 1 (c). Positive deviations are painted black and negative deviations are shown hatched. This location has negligible anomalies during Nov. 7-16, indicating that the background daily variation has been eliminated adequately. The storm effects are mostly positive, during Oct. 29-30 and Nov. 20-21, but also during Nov. 4, when there was a small storm (Dst -89 nT). In the second method, the *ratio* of hourly foF2 to foF2 (average) was calculated. Henceforth, these will be called *Ratios* and are shown in Fig. 1 (d). The fluctuations (anomalies and ratios) in Figs. 1 (c) and (d) are very similar, so any one of these can be used for the study. Small differences are mainly at low values of foF2. Thus, a foF2 value of say, 8 MHz increasing to 9 MHz would imply an anomaly of +1 MHz and a ratio of 1.125 (12.5% increase). However, a foF2 of say, 2 MHz increasing to 3 MHz would also imply an anomaly of +1 MHz, but an enormously large ratio 1.50 (50% increase).

Using data for about 80 locations at different longitudes and latitudes, and combining data for nearby latitudes in different longitude bands, the following conclusions were obtained.

3. Conclusions

(1) For Event X (Oct. 29-30, slight winter in NH and summer in SH), the troughs (negative storms) were clearly seen for ~65^{o}N at nighttime, but not at any other LTs. Troughs were strongly seen in high southern latitudes, as if this was a summer storm for SH. For northern midlatitudes as also for low latitudes, there were very strong positive effects on Oct. 29, followed by negative effects next day. The results for this storm are uncertain because firstly, it was a mixed, double storm (one on Oct. 29 at 05 UTand another 36 hours later on Oct. 30 at 17 UT) and secondly, data for some locations were missing for Oct. 29.

(2) For Event Y (Nov. 20-21, winter in NH and summer in SH), there were no troughs in NH high latitudes for morning and evening hours but there were troughs for night. For midlatitudes and low latitudes, some longitudes showed strong negative effects in the early morning as expected, but some longitudes showed strong positive effects at noon and in the evening hours. Thus, some results conformed with the model predictions, others did not.

(3) A disconcerting feature was the presence of strong positive effects in the 24 hours *before* the storm commencement.

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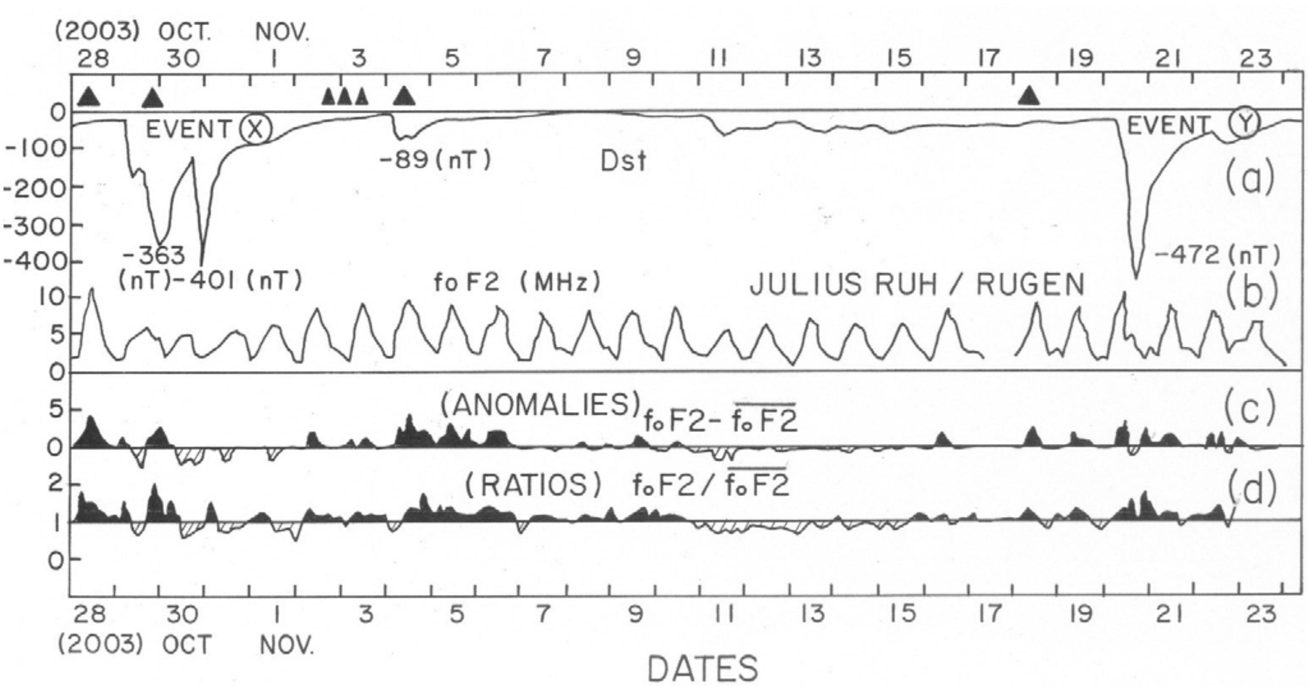

Fig. 1

Fig. 1: Plots for the 27-day interval Oct. 28-Nov. 23, 2003 of the hourly values of (a) geomagnetic Dst, (b) ionospheric foF2 at the midlatitude European location Juliusruh/Rugen (54.6^{o}N, 13.4^{o}E), (c) foF2 anomalies, (d) foF2 ratios. Positive deviations and ratios above 1.0 are painted black, negative deviations and ratios below 1.0 are shown hatched.