On ionospheric pre-storm phenomena

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Abstract

A study of the ionospheric pre-storm phenomena is presented using global ionosonde and geophysical data obtained during November 20-21, 2003. The results show that pre-storm phenomena don't originate from local time effect. Also a probable role by the magnetospheric electric fields as the main drivers of pre-storm phenomena could not be confirmed by the analysis of *hmF2* from the ionosonde stations. Furthermore, investigation of solar flare effects on the pre-storm phenomena didn't reveal them as the main drivers. The present results appear to suggest that pre-storm ionospheric phenomena exist but remain an unresolved problem.

1. Introduction

According to [1] the appearance of positive storm before the beginning of a geomagnetic disturbance in the mid-latitudes and the occurrence of strong negative phase at the equator, termed pre-storm phenomena, are two of the acute ionospheric problems. Recently, [2] showed these ionospheric phenomena are probable caused by the southward turning and intensification of B_z within a few hours interval. However, [3] have argued in a recent study that there are no convincing arguments that pre-storm phenomena at middle and sub-auroral latitudes bear a relation to magnetic and suggested that the *NmF2* pre-storm enhancements were due to the previous geomagnetic storm, moderate auroral activity or they represented the class of positive quiet time events and as such there is no such effect as the pre-storm *NmF2* enhancement as a phenomenon inalienably related to the geomagnetic storms. Using the results of [4, 5], we hereby present a probable explanation of the pre-storm phenomena.

2. Data and method of analysis

The Ionospheric data used in this study consists of hourly values of *foF2* obtained from SPIDR's network of ionosonde stations located in the East Asian sector: Hainan (HAI) Manzhouli (MAN),Chongqing (CHO),Guangzhou (GUA); the Australian sector: Darwin (DAR), Learmonth (LEA), Mundaring (MUN), the European/African sector: Juliusruh/Rugen (JUL), Rome (ROM), Athens (ATH), Grahamstown (GRA) and the American sector: Milestone Hill (MIL), Wallops Island (WAL), Puerto Rico (PUE), Goosebay(GOO), Jicamarca (JIC). The F2 region response to geomagnetic storms is described in terms of *D*(*foF2*) , that is the normalized deviations of the critical frequency *foF2* from the reference

$$D(f_oF2) = \frac{f_oF2 - (f_oF2)_{ave}}{(f_oF2)_{ave}} x100\% \qquad (1)$$

Following [6,7], positive and negative storms are here taken to occur when the absolute maximum value of *D*(*foF2*) exceeds 20%. The *D*(*foF2*) data for the present study are derived from respective hourly values of *foF2* on November 20-21, 2003 while the reference for each hour is the average value of *foF2* for that hour calculated from the four quiet days November 26-29, 2003. An important criterion used in choosing the reference period is that days must be devoid of not only of any significant geomagnetic activity but also there must be an absence of any considerable solar activity. [4] and references therein and [5] have shown that the reference period is devoid of any significant solar activity and that with values of *Dst* >-25, the reference days are strongly characterized by the absence of any significant ring current activity all [8].

3. Results and Discussion

Figures (1), (2) and (3) show that the pre-storm ionospheric phenomena occurred at Hainan at 0700 UT, and Learmonth, Mundaring and Goosebay at ~0800 UT on November 20 with respective moderate to intense

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enhancement in peak electron density and a strong depletion of *foF2* between 0100 and 0600 UT at Jicamarca on the same day. These pre-storm phenomena represent a 20% occurrence in available data. Observe that the pre-storm

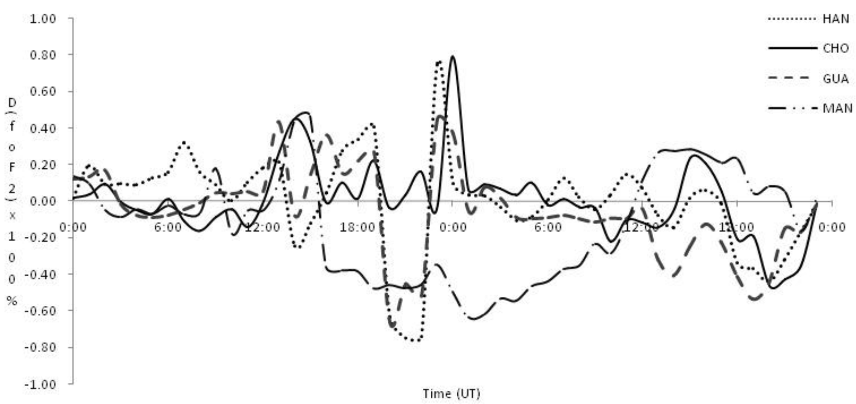

Figure 1: Variations in *D* (*foF2*) for East Asian sector for November 20-21, 2003.

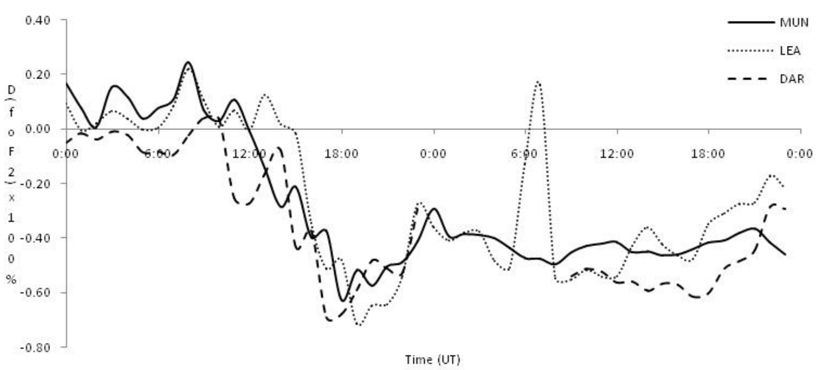

Figure 2: Variations in *D* (*foF2*) for Australian sector for November 20-21, 2003.

enhancement does not present any longitudinal dependence. The lack of longitudinal dependence of the pre-storm phenomena could suggest that their origin does not originate from local time effect whose explanation is based on the assumptions that positive storms are caused by meridional winds and negative storms by changes in the neutral gas composition [9]. However, the fact that the enhancements occurred in simultaneity at two widely separated longitudinal zones may suggest a role by the magnetospheric electric field imposed on the high latitude ionosphere penetrating almost instantaneously to middle and low latitudes on both dayside and the nightside [10] and references therein, as well as a role by the disturbance dynamo electric field. Its noteworthy that prompt penetration electric fields and disturbance dynamo electric fields have opposite polarity local time dependences. The role of magnetospheric electric field appears plausible given the analysis of the geomagnetic phenomenon which shows the arrival of the shock at 0900 UT [4], and according to [11,12], if there is a preexisting southward *Bz* upstream of the shock, the high-speed stream shock compression will intensify this component; [4] has shown the intensification of southward B_z during 0100- 0800 UT. It is probable that during this interval the normal shielding effect of the region 2 current sheet broke down and electric fields generated by the magnetosphere-ionosphere coupling processes penetrated to ionospheric middle and low latitudes. [2] had explained pre-storm phenomena during intense storms of March 13-15, 1989 and April 1-2, 1973on the basis of the intensification of southward B_z.

Under the above mentioned scheme, a prompt penetrating electric field would cause dayside enhancement at Hainan, Learmonth and Mundaring and on the other hand a disturbance dynamo electric field would cause nightside enhancement at Goosebay. But [5] has ruled out disturbance dynamo electric field as the probable cause of nightside enhancement at Goosebay. Now the pre-storm phenomena as observed do not display a systematic latitudinal dependence; they are strong at both low latitude and higher middle latitude, and this aspect of the phenomena led

[7] to suggest that an explanation by means of the magnetospheric electric field rather unlikely. But the existence of

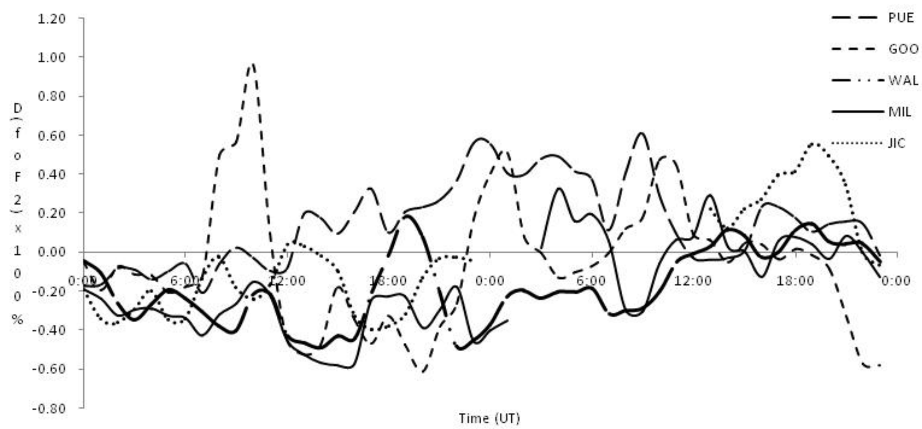

Figure 3: Variations in *D* (*foF2*) for American sector for November 20-21, 2003.

pre-storm phenomena at Hainan, Learmonth, Mundaring and Goosebay proposes the breaking down of region 2 current sheet and prompt penetration to middle latitudes of electric fields generated by magnetosphere-ionosphere coupling processes prior to the early phase of the present magnetic storm. According to [5], the 6% increase in *hmF2* observed at Learmonth cannot totally account for enhancement in *foF2* at that station; *hmF2* data were not available at Hainan, and Mundaring. Also the *hmF2* plot for Goosebay shows that the positive storm at 0800 UT at this station cannot be accounted for by the uplifting of the F2-region. The plot [5] shows that the ionospheric plasma at this station was moved downward by 8% at this time. On the account of the *hmF2* variations the present results appear to suggest that both prompt penetrating electric fields and disturbance dynamo electric fields are not the main drivers of pre-storm phenomena [5].

It is known [13, 14, 15] that the effects of solar flares on Earth's ionosphere results in the appearance of sudden ionospheric disturbances (SID) which are observed in the dayside. In this regards, a consideration of the flare activity is attempted to explain the pre-storm ionospheric phenomena during November 20, 2003. [4] has pointed out the occurrence of M1.4, and M9.6 flares respectively at 0212 and 0747 UT on November 20. Now during the respective 7 and 2 hours between these flares and the arrival of the shock, the *Dst* index largely maintained values of *Dst* >-25 [5]. These conditions provide the opportunity to analyze the direct effect of the flares on changes in the ionosphere without the ambiguity of any geomagnetic effects. The times of occurrence of the flares, according to the characteristics of solar X-ray flares during November 18-21, 2003 [4], on November 20 coincided with day time in both the East Asian and Australian sectors which appear to suggest that the flares could be responsible for the enhancements at mid latitude stations of Hainan, Learmonth and Mundaring. This proposal derives from the fact that intensification of the X-ray emission results in an increase in the electron density in the ionospheric D, E and F region [13, 14, 15, 16].

However, the postulation that flare activity was likely responsible for the pre-storm enhancements of *foF2* observed in the East Asian and Australian sector becomes minimal on the following facts: the pre-storm enhancements of *foF2* occurred in near simultaneity with the nighttime intense positive storm in the American station of Goosebay (nighttime events cannot be caused by flares [7] , the European/African zone didn't record any pre-storm ionospheric phenomena and there is the occurrence of depletion of *foF2* at the low latitude station of Jicamarca . Furthermore, the pre-storm enhancement at Learmonth and Mundaring that occurred at 0800 UT cannot be accounted by solar flares because the increase in electron density would probably have, according to [16] and references therein, decayed out. This leaves the enhancement at Hainan to probable be as a result of solar flares. It is therefore more plausible then to argue that solar flares are not the main drivers for the enhancements [6]. According to [7, 10], solar flares can occasionally strengthen the pre-storm enhancements of F2-region peak electron density, but are not responsible for their occurrence, at least not as a dominant or very important source of such events.

The present result taken together with earlier results do appear to suggest that pre-storm ionospheric phenomena could be the result of some underlying heliophysical and geophysical mechanisms that are working together to produce the observed storm effects, and their relative importance differs from case to case [5]; as such the real nature of the phenomena's characteristics and controlling mechanism still presents an unresolved problem in ionospheric physics. However, it is important to note that the very existence of pre-storm ionospheric phenomena appear to strongly indicate that preceding the arrival of a shock at the magnetosphere are some coupling mechanism between interplanetary features and the thermosphere-ionosphere system by which the solar wind continual modifies the dynamics, electrodynamics and chemistry of the Earth's ionosphere on a global level. [2] asserted that the non explanation of pre-storm phenomena is because in the studies of ionospheric storms it is assumed that the beginning of the disturbance is defined by storm sudden commencement or main phase onset (MPO) which as a scheme restricted the geoeffectiveness of the solar wind to post onset time thereby foreclosing the explanation of any aspect of the morphology of ionospheric storms whose origin precede the onset reference time.

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