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Ionospheric effects of the solar flare of 15 February 2011

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The solar X2 flare of 15 February 2011 occurred at ~ 0200 hrs UT, which was night time in Americas and Europe and no instantaneous solar flare increases of ionospheric foF2 were observed. But further in the East, the day-lit regions of Australasia, there were substantial solar flare effects during and few hours after the occurrence of the flare. Thus, this solar flare was very effective for ionospheric foF2 increases.

Keywords: Solar flare, Ionospheric disturbance, Ionospheric foF2 increase, Cosmic ray decrease, Forbush decrease

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1 Introduction

Sunspots are caused by very strong magnetic fields on the solar surface. Due to the differential rotation of the Sun at different latitudes, the sunspot magnetic fields are twisted. When the tangled fields reach a breaking point, like a rubber band that snaps when wound too tight, huge bursts of energy are released as the field lines reconnect (http://hesperia.gsfc.nasa.gov/sftheory/flare.htm). These bursts are termed as solar flares. A super flare was observed first by Carrington[1].

Solar flares have three distinct effects[2,3]. One direct effect is the emission of electromagnetic radiations, viz. (i) visible, which are studied through optical telescopes; (ii) ultraviolet (UV) and extreme ultraviolet (EUV), which increase the number density in the terrestrial ionospheric F region; and (iii) X-rays, which affect the ionospheric E and D regions. Indirect effects are: (a) associated emission of solar energetic particles (SEP), which cause ground level enhancements (GLE), observed as large increases in cosmic ray intensities before cosmic ray Forbush decreases[4] and (b) coronal mass ejections (CME), discovered by Tousey[5]. While propagating out in space, the CMEs get modified and their modified form is termed as ICME (interplanetary CME). If an ICME blob encounters the Earth, magnetic storms occur if the blob has a substantial negative Bz component of magnetic field. This occurs because of the reconnection of Bz with terrestrial magnetic field and formation of a neutral point in the magnetospheric tail, allowing solar wind to enter in the magnetosphere (Dungey mechanism[6]). The indirect effects occurring several tens of hours after the solar flare (in the present case about 70 hours) are not considered here.

Solar flares are classified as A, B, C, M or X according to the peak flux (in watts per square meter, W m^{-2}) of 100 to 800 picometer X-rays near Earth, as measured on the GOES spacecraft. Each class has a peak flux ten times greater than the preceding one, with X class flares having a peak flux of order 10^{-4} W m^{-2}. Within a class, there is a linear scale from 1 to 9, so an X2 flare is twice as powerful as an X1 flare, and is four times more powerful than an M5 flare.

On 15 February 2011 at 01:44 hrs UT, a very large X2 solar flare occurred, the first of sunspot cycle 24 (September 2009 onwards), one of the largest in recorded history. It peaked at 01:56 hrs UT and disappeared at 02:06 hrs UT (total duration 22 minutes). Popular reports appeared in the website Valentine Day Solar Flare (http://journeytothestars.wordpress.com/2011/02/25/valentines-day-solar-flare/). The direct radiation effects were reported in press as substantial with telecommunications disturbed in China.

In the present paper, the evolution of ionospheric foF2 at various longitudes around the globe during 0000-1200 hrs UT on 15 February 2011 has been illustrated.

2 Data plots

When solar UV and EUV radiations from a flare impinge on the terrestrial atmosphere, ionospheric F region number density NmF2 increases. The ionospheric foF2 is proportional to the square root of NmF2. Hence, a study of foF2 changes is enough to estimate the NmF2 changes. The average daily variation of foF2 at low and middle latitudes is: an increase from early morning to about noon, persistence for several hours, and then a decline after evening hours. From the SPIDR website (http://spidr.ngdc.noaa.gov/spidr/), 15-minute data of foF2 were downloaded for twelve locations at different low and middle latitudes at different longitudes. Since the data did not change much from one 15-minute interval to the next, only a few points at roughly 30-minute intervals have been considered. Table 1 gives the details of the locations.

Figure 1 shows the plots of ionospheric foF2 during 0000 – 1200 hrs UT on 15 Feb 2011. The top plot in the left column is for Boulder (BOU). The vertical line indicates the 0200 hrs UT when the solar flare occurred. In each plot, the full lines are for 15 Feb 2011. To compare with a quiet day, the crosses show the values for the preceding day, i.e. 14 Feb 2011. As can be seen for Boulder, the crosses almost match with the full lines, indicating that there was no extra solar flare effect at Boulder, where the flare occurred at 1900 hrs LT (late evening, almost night). The succeeding plots are for Ascension Island (flare LT 01), Dourbes (flare LT 02), Athens (flare LT 03), Grahams Town (flare LT 04) and Ashkhabad (flare LT 06). For all these, the crosses and full lines almost match indicating no flare effects. The reason is that for these locations, the local times are all in the night or early morning hours when Sun was not yet shining on these locations and the foF2 has not yet developed. At Athens, there is some indication that the crosses are below the full line at the flare time 0200 hrs UT. But the LT was 0300 hrs LT and no solar effects could be expected. It should be remembered that there are hour-to-hour and day-to-day changes even on quiet days and two successive days may have slightly different foF2 values at the same LT. Thus, differences of about 0.5 MHz may not be fully storm time changes and also include data inaccuracies.

Table 1—Details of the locations for which foF2 data were used

Symbol	Station	Latitude	Longitude	Time of flare (0200 hrs UT), hrs LT
BOU	Boulder	40°N	106°W	1900
ASC	Ascension Is	8°S	14°W	0100
DOU	Dourbes	50°N	05°E	0200
ATH	Athens	39°N	22°E	0300
GRA	Grahams Town	38°S	27°E	0400
ASH	Ashkhabad	38°N	58°E	0600
BEI	Beijing	40°N	116°E	1000
DAR	Darwin	12°S	131°E	1100
KOK	Kokubunji	36°N	140°E	1100
CAN	Canberra	35°S	149°E	1200
BRI	Brisbane	28°S	153°E	1200
NOR	Norfolk Is	29°S	168°E	1300

The right hand column plots of Fig. 1 are for more eastern, Australasian longitudes. The top plot is for Beijing. The LT of the flare was at 1000 hrs LT when the Sun was already shining. Near the vertical line, there are very small differences in the full lines and crosses, but four hours later, near 0600 hrs UT, there were considerable differences, with foF2 increase of about 1 MHz (marked shaded black). Whether this was solar flare effect is a moot question; but it does look like a delayed effect. In the next plot for Darwin (flare LT 11), the same pattern is seen, namely large foF2 increase (about 2 MHz) but four hours after the flare. In the third plot for Kokubunji (flare LT 11), there is a clear foF2 increase at the flare hour (vertical line) but there is also a small increase four hours later. In the fourth plot for Canberra, there are two peaks (marked shaded black), one at the flare time and another almost equally prominent five hours later. Further plots are for Brisbane and Norfolk. The peaks near the flare hour are now very prominent, but there are subsidiary peaks five hours later. For Darwin, Canberra, Brisbane and Norfolk, the foF2 seems to go below average at 1200 hrs UT (hatched marking). The four hour delay is probably due to local dynamic effects of foF2 evolution.

The foF2 increase at Norfolk is spectacular, about 2 MHz, which with a base level of 8 MHz gives a 25% increase. The Nmf2 increase will be almost 50% indicating a very large solar flare effect. The longitudes further east are in the Pacific Ocean and no data were available to see whether these enormous increases persisted though after about 200°E (flare LT 15), it would be local afternoon and flare effect magnitudes would be lesser.

3 Results and Discussion

Since the solar flare of 15 Feb 2011 occurred at ~0200 hrs UT, most of the locations in Americas and Europe were still in the night hours and no

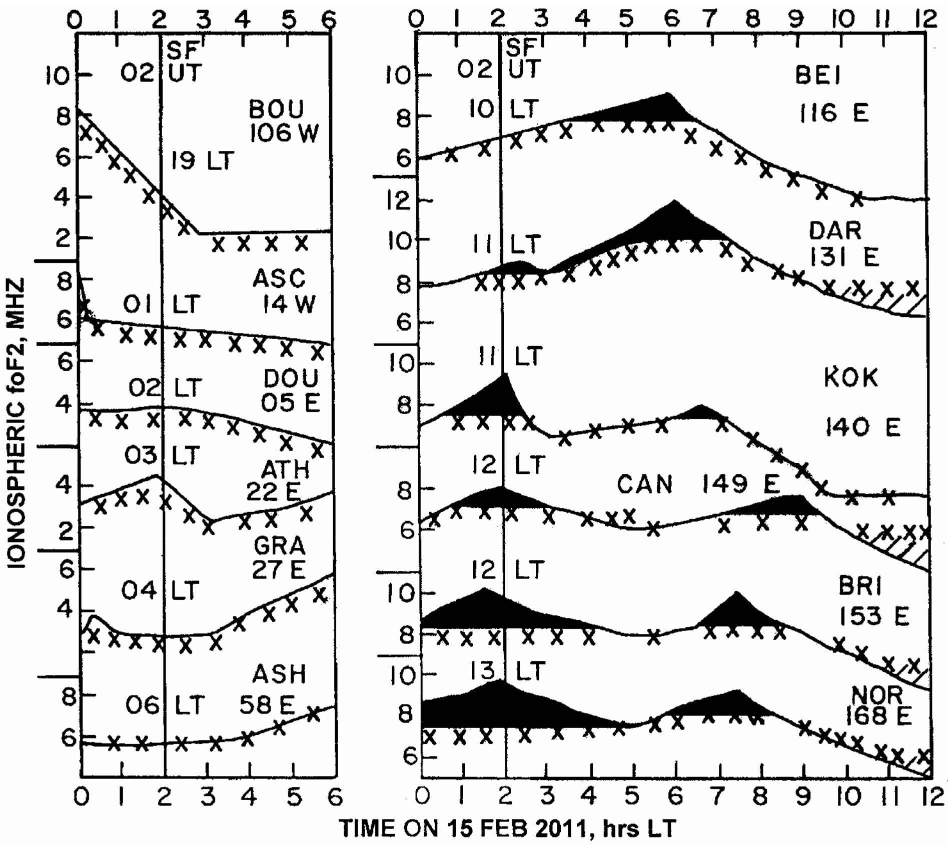

Fig. 1—Plots of the 15-minute values of ionospheric foF2 during 0000-1200 hrs UT on 15 Feb 2011 for twelve selected locations at low and middle latitudes at different longitudes [vertical lines mark the flare hour 0200 hrs UT; numbers near the vertical line for each station indicate local time (LT) of the flare occurrence at that location; full lines are for 15 Feb 2011 and crosses are for the preceding day 14 Feb 2011; black shadings indicate foF2 increases above the quiet day level on 14 Feb 2011; hatched marking at 1200 hrs UT for some locations indicate decreases below average level]

instantaneous solar flare increases of ionospheric foF2 were observed. But further east, in the day-lit regions of Australasia, there were substantial solar flare effects during and a few hours after the occurrence of the solar flare, which caused considerable telecommunication disturbances as mentioned in the press reports for China. Thus, this solar flare was very effective for ionospheric foF2 increases.

The present example is for a very large solar flare, first in the present sunspot cycle 24 (2009 onwards). In the past, some very large solar flares have shown similar large ionospheric effects, for example during the Halloween events of 28-29 October 2003 (ref. 2).

It may be noted that solar flares have also an indirect effect on ionosphere, namely ionospheric storms associated with geomagnetic storms that are due to the arrival of an ICME at the orbit of the Earth, several tens of hours after the solar flare (in the present case almost 70 hours) and hence far beyond the data time range shown in Fig. 1. Such an ionospheric storm is not considered here only the instantaneous effect of the solar flare and the few hours after that have been considered.

It should be remembered that ionospheric foF2 can have variations every day, not necessarily related to solar flares or geomagnetic storms, such as internal travelling waves, waves from the lower atmosphere, etc. These may be different at different latitudes and longitudes and may result in different storm time magnitudes for similar longitudes but different latitudes (or hemispheres), as in the case of Kokubunji and Darwin.

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References

1 Carrington R C, Description of a singular appearance seen in the Sun on September 1, 1859, *Mon Not R Astron Soc (UK)*, 20 (1859) 13.

2 Tsurutani B T, Judge D L, Guarnieri F L, Gangopadhyay P, Jones A R, Nuttall J, Zambon G A, Didkovsky L, Mannucci A J, Iijima B, Meier R R, Immel T J, Woods T N, Prasad S, Floyd L, Huba J, Solomon S C, Straus P & Viereck R, The October 28, 2003 extreme EUV solar flare and resultant extreme ionospheric effects: Comparison to other Halloween events and the Bastille day event, *Geophys Res Lett (USA)*, 32 (2005) L03S09, doi: 10.1029/2004GL021475.

3 Tsurutani B T, Verkhoglyadova O P, Mannucci A J, Lakhina G S, Li G & Zank G P, A brief review of "solar flare effects" on the ionosphere, *Radio Sci (USA)*, 44 (2009) RS0A17, doi: 10.1029/2008RS004029.

4 Shea M A & Smart D F, A summary of major proton events, *Sol Phys (Netherlands)*, 127 (1990) 297.

5 Tousey R, The solar corona, In *COSPAR Space Research XIII*, edited by M J Rycroft & S K Runcorn (Akademie-Verlag, Berlin), 1973, 713.

6 Dungey J W, Interplanetary magnetic field and the auroral zones, *Phys Rev Lett (USA)*, 6 (1961) 47.