Detailed Answer to the comments

Firstly, we thank the referee for providing useful comments on our manuscript. Following the referee's comments, we will carefully go through the manuscript and revise it. Herewith, we provide the answers to the referee's comments:

Abstract:

« The current study finds that 18/31 type II radio events are precursors for space weather because they are associated with immediate space weather events such as radio blackouts and polar cap absorption events and exhibit band-splitting features or are followed by type III and IV bursts »

This sentence should be split in two. As it is written, it can be understood that type II radio events are precursors for space weather because they exhibit band-splitting features, which is not the case. Also are they followed by or associated with type IV bursts. (This sentence appears in a more or less similar way elsewhere in the paper).

Answer:

The statement is rephrased as follows, and everywhere in the manuscript is harmonized.

Based on the current analysis, it is found that 18 out of 31 type II bursts are associated with immediate space weather events in terms of radio blackouts and polar cap absorption events, making them strong indications of space weather disruption. Consistent with previous research, type II radio bursts, that often may occur in association with type III and type IV bursts, are probably the most relevant events to predict the space weather.

Comments on section 3

1. The authors use TEC information from different GNSS stations to study the implication of type II bursts on space weather effects. They consider two periods to analyze these effects. They should introduce in this section the effects on TEC which are expected as a response to a flare (e.g., linked to the radio black-out phenomena mentioned earlier) or to particles.

   Answer: Total electron content (TEC) is one of the significant ionospheric parameters to indicate the integrated electron density along the line of sight/path of the signal. Solar flare radiation, mainly from the extreme ultraviolet and X-ray wavelengths, interacts with ionospheric constituents, causing an immediate rise in total electron density in the ionosphere. It is known that ionospheric TEC varies day to day, season, latitude, and longitude, along with the solar and geomagnetic activity (Seemala et al 2023).

   The extent of ionospheric TEC augmentation appears to be determined by the kind of solar flares (Liu et al, 2006, J Geophys Res, 111; Kumar and Singh, 2012, IJR & Space Physics, 141). During the peak of an X-ray solar flare, ionospheric TEC abnormalities are frequently suppressed due to accelerated solar energetic particles (Oljira, 2023, AdSp Res, 3868). The rate at which TEC varies temporally is related to the effective flare radiation flux (Wan et al 2002, Sci. China Ser A, 142).

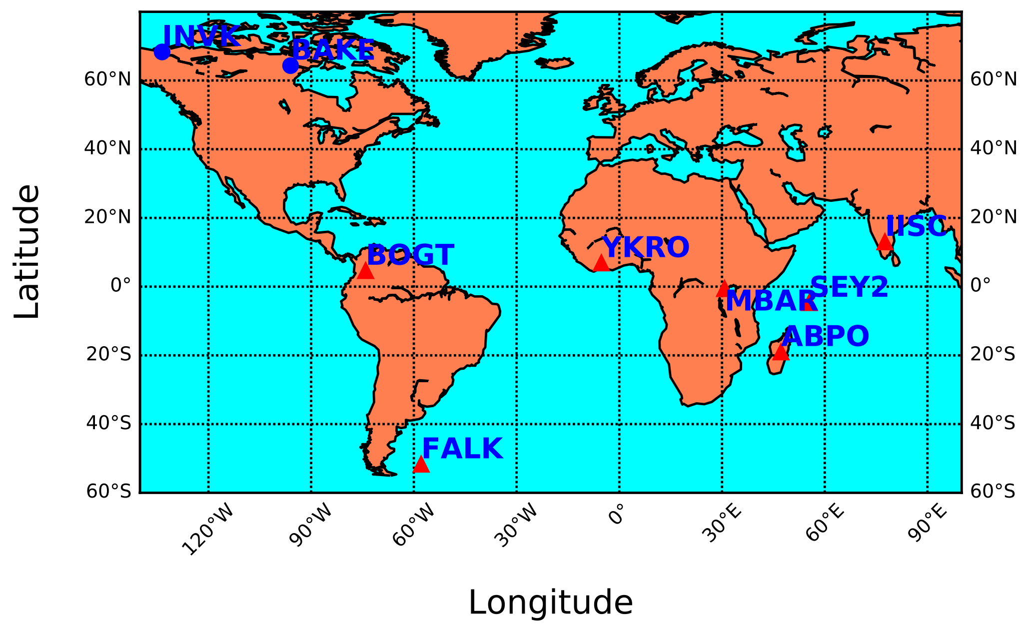
2. How are these effects varying with terrestrial longitude/latitude ?

   Answer: All terrestrial regions are exposed to such effects depending on the strength of radiation because weak particles are sent to polar regions (high latitude) where they give rise to aurorae phenomena.

3. The figures showing the TEC evolution should be better explained so that the reader clearly understands what is usual diurnal variation and what is due the effect of the flares .

Answer:

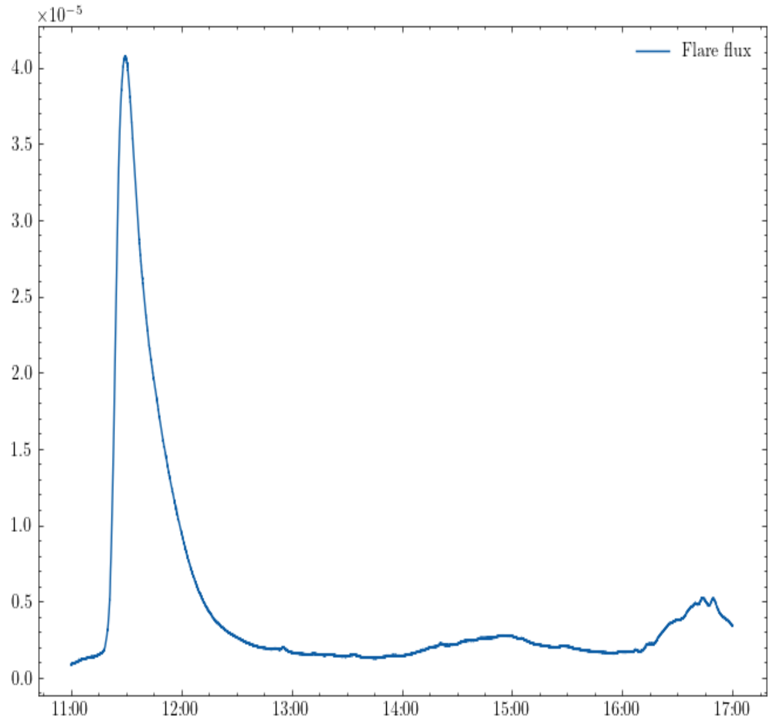
For the sake of clarifying the abnormalities in TEC in the revised manuscript, the Rate of TEC Index (ROTI) is now used to quantify the variability of TEC in line with observed solar events. In this regard, the 5 -minute averaged ROTI data over the stations listed in Figure below are plotted as a function of universal time (UT).

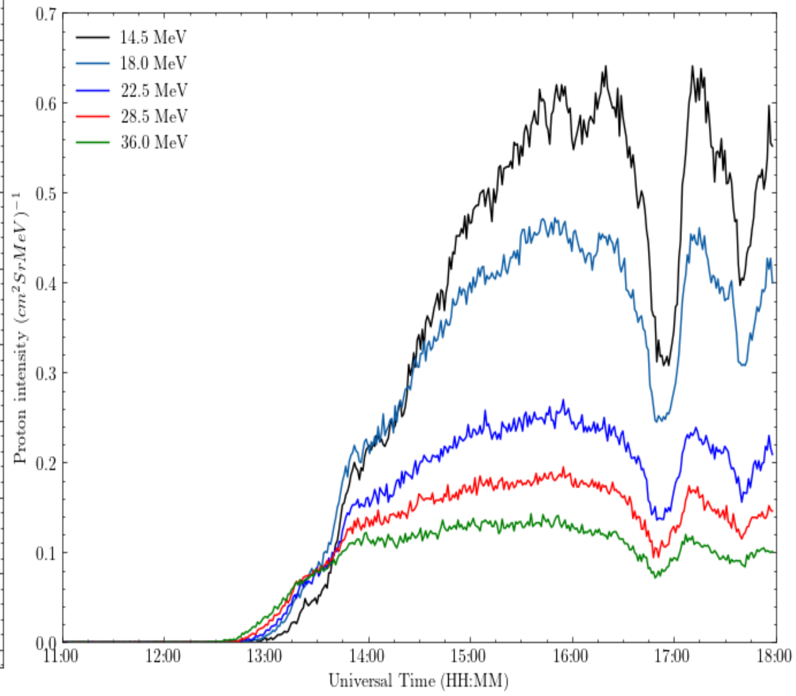


It is important to note that three events, among others, are associated with major solar energetic particles (> 10 MeV), and the illustrative examples given in the current documents are subjected to the analysis of their effects on the ionosphere.

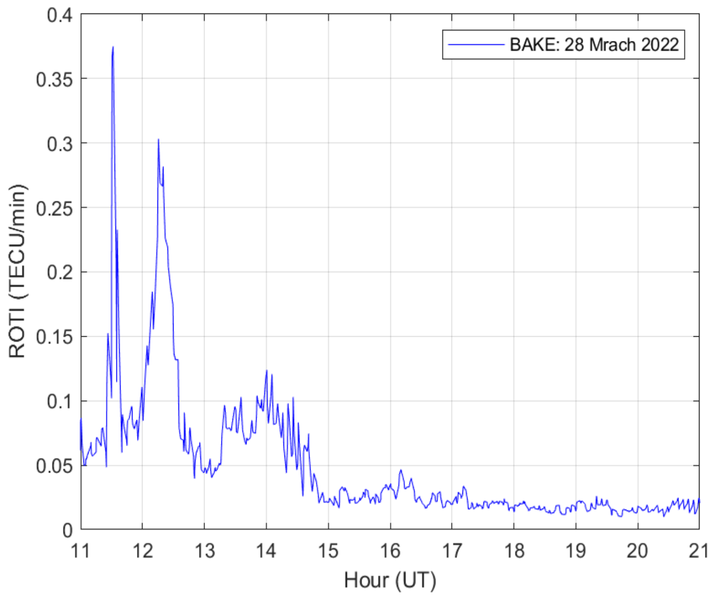
For example, on 28 March 2022, a type II burst observed by the CALLISTO spectrometer at the Arecibo Observatory during 11:23 UT - 11:28 UT, followed by a type IV radio burst during 11:26 UT - 11:36 UT are associated with an M-class flare that erupted at 10:58 UT and continued until 11:45 UT.

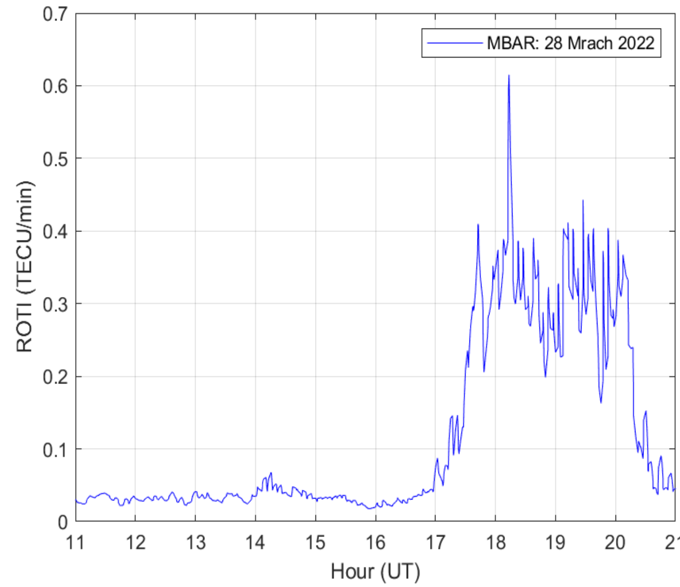
The following figures show the solar flare and major SEP associated with the above solar radio bursts. The left figure shows the solar flare while the right shows the SEP in 5 energy channels.





The following two figures show the ROTI variation in response to the solar flare and SEP. At high latitude at the BAKE (Canada) station, the ROTI reached 0.37 TECU/min at the peak of flare at 11:29 UT and decreased to 0.08 TECU near the end of solar flare. However, no TEC variation was detected in the equation or mid-latitude regions. Using one station in the equatorial region (MBAR, Uganda), there is prominent TEC enhancement (ROTI>0.2 TECU/min) in response to the SEP at to its peak time (17:52)





4. What are the time scales for the effects on TEC ?

   Answer: The effects are proportional to the time rate of change of flare radiations (Liu et al, 2006). Further note that ionospheric TEC varies day to day, season, latitude and longitude along with the solar and geomagnetic activity (Seemala et al 2023).

5. The authors also mention several times in this section CIR. These phenomena are not described earlier in the paper.

   Answer:

A statement explaining CIR is added to the revised manuscript as follows.

Corotating Interaction Region (CIR) is a compressed solar wind plasma that forms between slow solar wind and high speed solar wind streamers (HSS) that emanate from the coronal holes (Belcher and Davis, 1971; Siscoe, 1972; Krieger, Timothy, and Roelof, 1973). During the solar minimum, the corotating interaction regions (CIRs) are the principal source of energetic particles in the heliosphere (e.g., Richardson et al., 1993). CIRs develop when a rapid solar wind emerges from a coronal hole that reaches low latitudes and overtakes a parcel of slow solar wind generated by the Sun at earlier times. The solar rotation causes these plasmas of different speeds to become radially aligned and interact (e.g., Gosling and Pizzo, 1999).

6. I wonder what is the link with the type II/shock/CME.

Answer:

Coronal mass ejection is a huge bubble of plasma that is ejected from the lower corona and propagates through the heliosphere. If the speed of CME exceeds the local background Alfvén speed, it produces a plasma shock at the CME nose or at the flanks. Such shocks further produce the radio type II bursts via plasma emission mechanism. Note that shocks are observed at extreme ultraviolet, white lights and radio wavelengths (Maguire et al, 2020, Carley et al 2021). Coronal Mass Ejections trigger space weather hazards by compressing the Earth's magnetosphere upon their arrival at the Earth which results in channelizing the particles into the Earth atmosphere to produce Auroras. CMEs are also responsible for geomagnetic storms, power grid disruptions, and to accelerate solar energetic particle (SEP) events etc. Since type II bursts are signatures of the coronal shocks and reach Earth in 8 minutes, they serve as a proxy to predict space weather events.