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Reply on RC1

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Author comment on "Temporal and altitudinal variability of the spread F observed by the VHF radar over Christmas Island" by Ricardo Yvan de La Cruz Cueva et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2021-70-AC1, 2022

We take this opportunity to thank the editor and reviewers of our paper for their kind collaboration in the improvement of this manuscript. We have taken into account all the concerns raised and we made the suggested modifications. We have implemented numerous improvements to the paper. Below we justify our replies to the suggestions made by the respected reviewers of this paper. So, in the following, we include our answers point-by-point.

ANSWERS TO REVIEWER 1:

1. The title is confusing, I guess that "Temporal and altitudinal variability of the Spread F observed by a VHF radar over Christmas Island" sounds better for the purpose of the manuscript.

Thank you for your observation, and we agree. So, the new title:"*Temporal and altitudinal variability of the Spread F observed by the VHF radar over Christmas Island".*

2. Several sentences of the manuscript are not written in the usual English language, producing some misunderstanding. So, I suggest a deep revision of the concepts. A strong example is that: the work investigates Spread F from VHF radar echoes. Sometimes, the authors say that they are investigating "Spread F echoes" that is correct, but sometimes, they refer simply as echoes and it can make confusion in the reader. I suggest using the same term in all sentences or define all the terms that could have the same meaning.

A revision of the English was done according to the referee's suggestion.

3. The definition of season presented in the lines 99-100 is not correct. It can produce different interpretations for the results. For instance, the Summer usually starts on 21 June and ends on 22 September. In my opinion, if the authors would like to emphasize the seasonal effects on the Spread F, they should use the correct definition for the season. Additionally, it can be

interesting for the discussion because they will be able to make comparisons with other observations (previous works) that use the correct definition of the seasons. Only after these corrections, we can examine the real effect of the season on the Plumes over Christmas Island. I have other observations to make on this topic that are presented in the manuscript, but I prefer to see whether the correct definition of the season will not address those points.

Thank you the reviewer for the observations. Dear reviewer, we believe that when you mention June 21 (summer) you refer to Midsummer's Day, which is based around the summer solstice, the longest day of the year., and the solstice fall in the middle of summer.

Is possible to find the same seasonal periods in papers like Koustov et al., 2019 (https://doi.org/10.1186/s40623-019-1092-9), Denardini et al., 2005 (10.1016/j.jastp.2005.04.008), and Niranjan et al., 2003.

We updated the text to:

"*The solstice is when the Sun reaches the most southerly or northerly point in the sky, while an equinox is when the Sun passes over Earth's equator. For example, June solstice, or June 21, is the longest day of the year in the northern hemisphere. So, to sort our measurements according to the four seasons Spring, Summer, Fall, and Winter we use 91 days of data centered on each day 21 of March, June, September, and December, respectively".*

4. The authors are suggesting that the occurrence of Spread F are inversely proportional to the solar cycles. They must explore this result more and try to explain how it can be explained physically.

The result that comes up with this study shows spread F occurring along the entire solar cycle, and showing a negative correlation with solar activity. Physically, there are two conditions for spread F occurrence, one is the seeding of the RT instability, and the other is the uplift of the F layer.

We clarify the text as:

"*During high solar cycle spread F occurs more often after sunset and rare/uncommon observations around midnight hours. These structures reach higher altitudes. The RT instability occurs at the magnetic equator after sunset when the eastward electric fields increase and structures reaching higher altitudes are due to vertical ExB drift at the equator, which is well acknowledged for high solar flux periods. However, during low solar cycle (years 2006 to 2009) spread F don't reach higher altitudes -as before, their appearance is very frequent around midnight hours, and last for many hours. The mechanism that governs its appearance is no longer the prereversal enhancement because it just happens around the sunset terminator. The generation mechanism for the post-midnight irregularities at a quiet time during solar minimum conditions is still not clear, or not completely understood. Some authors also found occurrence, in the solar minimum period, of plasma density irregularities mostly after midnight (Heelis et al., 2010, Li et al., 2011and Dao et al., 2011).*

Under quiet magnetical conditions, and solar minimum conditions there are some possible seeding mechanisms competing that increase the probability for spread F generation along

all night (pre-midnight and post-midnight), as well as uplifting the F layer. For example, gravity waves, launched from the active convection region in the troposphere, could propagate into the ionosphere (Takahashi et al., 2009, 2010) and contribute to the instability seeding. Another is the Medium-scale traveling ionospheric disturbances (MSTID) activity providing perturbations in the electric fields for the low latitude F region to be unstable at postmidnight hours, which can seed the RT instability at the magnetic equator (Otsuka et al., 2009, Yokoyama et al., 2011 and Narayanan et al., 2019). Another mechanism could be the uplift of the F layer around midnight (Nicolls et al., 2006) caused by decreasing westward electric field in conjunction with sufficient recombination and plasma flux. However, the causes of midnight F-layer increase are not yet clearly established".

5. Is Figure 4 really necessary in the Conclusion section? Why do not the author include it in the result and Result and Discussion section to explore better the results?

Thanks for the comment, we just re-wrote the text about Figure 4 as follows:

"*Our findings are summarized in Figure 4. On the top panel is presented UT (LT=UT+14) in the vertical axis for the time peak echoes occurrence along the solar cycle separated by seasonality. We can clearly observe the peak time echoes occurrences being closer to the time of PRE during high solar activity years (see 2003, 2004 and 2011, and 2012) and around midnight during solar minimum conditions (see years 2007 to 2009). December solstice season during high solar conditions is not following this trend, and further study must be necessary at this point.*

The bottom panel in Figure 4 shows altitude peak variation along the solar cycle, also separated by seasonality. The altitude parameter seems to follow a very good trend, being higher altitudes for solar maximum conditions and lower altitudes for solar minimum conditions. Again December solstice doesn't match very well with this trend. The altitude parameter is an important parameter since it is one key process in the generation mechanism for ionospheric irregularities. Peak altitude echoes of June solstice reaches higher altitude difference from solar maximum to solar minimum periods, when compared with March and September equinoxes which were closer to 300kms most of the solar cycle period".

6. Line 59: "large data" => "long term data".

Thak the referee #1 for this observation, so, we agreed and made the suggested correction.

7. What is "SRI" in line 71?

The acronym SRI stands for Standford Research Institute. The SRI/Geospace Division supported the VHF radar from 2002 to 2007, under the coordination of Dr. R. Tsunoda, with National Science Foundation's grants.

The text added:

"*Stanford Research Institute – SRI International.*"

8. Line 74: Please, explain what is the reason to use the North beam of the radar only.

We apologize for not being clear on this point, we added a text in section 2.1 VHF radar measurements:

"*The coherent radar detects fluctuations related to the plasma instabilities called field-aligned irregularities, then detection of such irregularities requires the antenna to be pointing perpendicular to the geomagnetic field line (Tsunoda et al., 2000; Tsunoda et al., 1979). Then the north beam antenna was chosen due to being pointed in the north direction to reach perpendicularly to the magnetic field line".*

9. Lines 85-89: I guess it can be removed to another section. It is not necessary in the Data analysis description

We thank the referee for this comment. We moved this paragraph to section 2.1 VHF radar measurements.

10. Lines 91-94: The authors must remind that the disburbed dynamo is another phenomenon that can produce unexpected behaviour in the dynamics of the F region at low latitudes in addition to the prompt penetration electric field..

Thank you, is good to mention.

We organize the text in the manuscript as follows:

"*It is well known that high geomagnetic activities directly cause drastic perturbations in the zonal electric field, in the equatorial and low latitude regions, affecting the growth and development of ionospheric irregularities. These perturbations can be categorized as prompt penetration (PP) and disturbance dynamo (DD) electric field (Abdu et al., 2018; Astafyeva et al., 2018; and Shreedevi & Choudhary, 2017). These perturbed electric fields occurring in the post-sunset period can enhance/weaken the regular eastward vertical plasma drift, then affecting the uplift of the F layer (Fejer et al., 1991), and as a consequence affecting the generation of irregularities (Aarons. 1991; Abdu, 2012).*

In sequence, to avoid the disturbed geomagnetic periods and their effects on irregularity generations, we classify ..."

11. Lines 112-116: This paragraph could be shifted to a place after the presentation of the results. It could help the author in the discussion.

Sure, we agree with your comment dear referee. So, we moved this paragraph to the beginning of section 3.2.

12. Line 131: "... provided by Digisondes." I could not see those profiles in the chart of Figure 3 and 4.

By curiosity, we were trying to compare the profile of the figure with the usual digissonde

density profiles from other stations like Sao Luis (Brazil). We removed this from the manuscript.

13. Lines 174-177: I do not agree with the author that it is clear in Figure 4.

We clarify the explanation as:

"*Our findings are summarized in Figure 4. On the top panel is presented UT (LT=UT+14) in the vertical axis for the time peak echoes occurrence along the solar cycle separated by seasonality. We can clearly observe the peak time echoes occurrences being closer to the time of PRE during high solar activity years (see 2003, 2004 and 2011 and 2012) and around midnight during solar minimum conditions (see years 2007 to 2009). December solstice season during high solar conditions is not following this trend, and further study must be necessary at this point".*

14. Lines 179-181: I guess these conclusions are not totally supported by the results. However, after the revision of the seasons, the authors can do a check.

We re-wrote the sentence by:

"*So, for the Christmas Island sector, we can conclude that spread F echoes occurs along with all solar flux conditions. The PRE is the main mechanism for spread F generation, consequently, occurrences arising closer to the sunset terminator, with higher structures and short duration for solar maximum conditions. Spread F occurrence over the December solstice season needs more study since it doesn't follow the peak time occurrence for solar maximum condition. For solar minimum conditions, the mechanisms necessary for spread F generations are not clear, being the seeding of the RT instability and the uplift of the F layer. Anyway, the spread F occurrences are happening along all night with high occurrence mainly around local midnight, with peak altitude echoes distribution remaining around 300kms, and with long time duration".*