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Interactive comment on "Improvements to Predictions of the Ionospheric Annual Anomaly by the International Reference Ionosphere Model" *by* Steven Brown et al.

Steven Brown et al.

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The authors would first like to extend their gratitude to the reviewer. We appreciate the reviewer's insight, time and diligence in reviewing this manuscript. What follows is a response to the referee's comments. We agreed with a majority of the issues/concerns raised by the reviewer and have replied with additional comments, edits and clarification. Thank you.

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[referee] 1) The 'prediction' is a mathematical operation where future values of a

discrete-time signal are estimated as a function of previous samples. Here, the study is retrospective and deterministic in the sense that a preset algorithm with defined coefficient set is run with different index values. Thus, this operation cannot be considered as 'prediction'. Therefore, the title and the wording in the text should be modified.

[response] We agree with the reviewer's logic, but want to point out that the use of "prediction", as is utilized in this manuscript, is an established practice throughout the ionospheric modeling community. A web search yields more than 40 journal articles that present retrospective comparisons between observations and IRI and use the term "prediction" in the title and throughout the manuscript.

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[referee] 2) The definition of AI and the explanation given under the equation 1 are highly problematic. The mean M is defined to be the sum of two numbers which is wrong. The equation should be corrected to reflect the proper implementation

[response] The equation presented in consistent with the AI expression presented in Rishbeth and Muller-Woodarg (2006). However the reviewer's point signals a need to clarify a few points in the text. To add clarification in its presentation, we make the following adjustments to the text:

In the introduction
(page 3, line 17), We replace
"The asymmetry index (AI), as introduce by Rishbeth and Muller-Wodarg (2006), commonly used to describe the magnitude of the annual anomaly is defined as: "
(page 3, line 19) Equation 1 is modified: removed "A/M"
(page 3, line 2) remove (A) and remove (M)
(page 3 line 20)

We include a explicit expressions for NmF2$_{NSJan}$ and NmF2$_{NSJuly}$

(page 3, line 21) We also include the following text: "NmF2$_N Sistheaverageofapair NmF2values frommagneticallyconjugatelocations.Thesubsc

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[referee] 3) The implementation of 'AI' is not clear. The explanation mentions that 'The AI is computed by using an average of the NmF2 from both Northern and Southern hemisphere which have similar geomagnetic latitudes ...' Yet, equation 1 does not indicate any averaging over the stations in both hemispheres. Further in the text, AI is applied to station pairs during daylight hours and for the months of January and July for a set of years. This operation is not reflected in equation 1. The definition of AI should be given properly to reflect the full intent and computation. In its present state, it cannot be accepted.

[response] As noted in our reply to the Reviewer's point (2) we have included an explicit expression for NmF2$_{NS}$.
We include the following text in the introduction (page 3, line 25):
"The AI has been used to describe the annual anomaly for numerous geophysical conditions and local times. The observational input to AI varies from NmF2 derived from using a pair of ionosonde observations at approximate geomagnetic conjugate latitudes or using NmF2 observed from satellites averaged over lines of constant geomagnetic latitude. Equation (1) is adjusted to fit each case. We reserve the discussion of the implementation of AI for this work or the methodology section"

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[referee] 4) The explanation for the interpretation of the value of AI and the example given are also wrong.

[response] As noted in our reply to the Reviewer's point (2) we have now rewritten this

part and changed the explanation. The interpretation and explanation on page 3 lines 22-25 are consistent with literature.

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[referee] 5) The information on the background literature is not given properly. Figure 1 which is taken from another paper, may have copyright issues. It is not clear how the AI index is applied to station pairs and what those legends on the subplots mean. The authors clearly mention that the application in the Rishbeth and Muller-Wodarg (2006) paper did not provide any satisfactory explanation to their results and it has 'reliability' issues, yet they adopted their line of computation of AI index between the station pairs! This is a contradiction in itself.

[response]
We appreciate the author's note on copywrite and will remove the figure, and instead will focus on the conclusions drawn by Rishbeth and Muller-Wood (2006).

We believe the author is referencing page 5, line 4 and onward: The 'Reliability' issues pertain to IRI's specification of the annual anomaly and not the quality or validity of the analysis carried out by Rishbeth and Muller-Woodarg (2006).

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[referee] 6) In the official site of IRI, irimodel.org, IG index is mentioned to be an ionospheric index not a 'solar cycle input'. The authors should clearly define what they mean by solar cycle input.

[response] We will emphasize this in the introduction by including the following text (page, 2 line 10),
"Currently, these models use the 12-month running mean of the official IG index, IG12 (this ionospheric index is also known as the "global sunspot number") (Liu et al., 1983),

in place of the solar sun spot number, as solar cycle input."

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[referee] 7) Apparently, the IRI model utilizes a set of coefficients and index values in the computation of NmF2 and foF2 for a user defined date, hour and location. The model uses IG12 from IGRZ.dat file. Since the model aims to produce hourly monthly medians, 12 month running median of IG is automatically input from the data files. If the user wishes to update input it separately at the time of run. How did the authors prepare the index set for IG and IGNS? Since they are not available in a format that can be input automatically in the online version of IRI-2016, did the authors run the model offline in the Fortran version?

[response] We used indices input files with a format identical to IG-RZ.dat with the offline IRI, but using the IGNS values in place of the IG12 values.

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[referee] 8) According to the information given in the introduction section, IGNS is developed using 50 ionosonde station so it is an ionospheric index more than a solar cycle input. In Figure 2, there is a map of the world with black dots indicating the ionosonde stations used in the study (and ionosonde is misspelt!). Then, there is Table 2 which lists a set of stations that are used in the study. Most of the stations indicated on the map are not listed in the Table and some stations such as Eglin, Florida and Huancayo, Peru are not on the map! The pairing of the stations are also flawed. The stations are paired according to not only north-south hemispheres but also east-west hemispheres! The geomagnetic coordinates are not taken into account and station in Virginia, USA is paired with another station in Tasmania. If the pairing is necessary, at least magnetic conjugates and local daylight hours should be considered. For example, the stations in Japan can be matched with those in Australia and New Zealand.

The stations in Europe can be matched with those in South Africa. If the authors have some other mechanism in mind, they have to explain this in a better way. Otherwise, this kind of station pairing does not make sense at all. Taking the 'mean' of latitude of two stations in two different hemispheres do not make any sense either mathematically or physically.

[response]

The number of stations used for the IGNS index is not stated in this manuscript.

This information has been added to the 2nd paragraph of the INTRODUCTION.

" The IGNS index is developed with 13 stations, IG12 currently uses 4 stations. Please refer to Brown et al., (2017) for a full description of the index computation."

Misspelling was corrected

The stations marked on Figure 2 are the stations used for the solstice analysis. The stations listed in Table 2 are the stations used for the asymmetry analysis. Stations used for the AI analysis need to have data that overlap time periods and are at similar geomagnetic latitudes over both hemispheres. These criteria limit the number of station pairs that can be used I this study thus ,there are less stations listed in table 2 than indicated in Figure 2.

The stations are paired by approximate geomagnetic latitude as determined by the IGRF model. Our stations pairings overlap with several of the pairings used by Rishbeth and Muller-Wodarg (2006) as well as Mikhailov and Perrone (2013). No stations of the same hemisphere were paired. We indicate this in table 2 by also including the geographic coordinates of the corresponding station pairs.

Boulder, Eglin and Millstone Hill were our only North American stations. Perhaps, 'Norfolk" was mistaken for Norfolk, Virginia, USA"? In our table, "Norfolk" refers to Norfolk Island is east of Australia and currently reports to GIRO. We included geographic coordinates in Table 2 for further confirmation. For added clarification we will change

“Norfolk” to “Norfolk Isl” in table 2

We included the following text to line 5 of page 7 of the manuscript to clarify the inclusion of the averaged geomagnetic coordinates: (page 7, line 5) “The station pairings are listed in Table 2. This table list each station pairing by name as well as their abbreviated label, geographic latitude, geographic longitude and geomagnetic latitude. The stations are listed in order of their mean absolute geomagnetic latitudes. The geomagnetic latitudes are specified by the International Geomagnetic Reference Field (IGRF) at a height of 300 km.”

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[referee] 9) The application of AI to a station pair, for daylight hours, for the months of January and July and for a set of years and ‘averaging’ should be clearly given in a mathematical equation with proper notation.

[response] The equation for the AI index is presented in the introduction is described as using monthly medians input from January and July. In our methodology, we described that for this work, we will use the median of observational data which fell between 10LT and 14LT describe the January and July monthly median values.

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[referee] 10) The authors should know by now that the units are never written in a mathematical equation. The unit of NmF2 is not 1/metercube but el/metercube. The unit of frequency is indicated by Hz not hz. The units are never written in italics. There should always be one blank space between the number and the unit. The asterisk is not a proper mathematical notation for multiplication.

[response] The units have been deleted from Equation (2) and the asterisk was replaced with the multiplication dot.

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[referee] 11) Equation 3 does not represent the parameters of the application. For one ionosonde station that computes foF2 every 15 minutes, how can there be one value for whole month of January or July?

[response] We take a median of all observational data which fell between 10LT and 14LT for the month of January as well as July. This is described at the end of paragraph 2 of the methodology.

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12) Figure3 is also very unclear. The horizontal line for 80 is missing. The main problem is that the plot is prepared for the 12 month running mean of IGNS not IGNS itself. Which input data file did the authors use in this study? The years chosen for various levels of solar activity are given in Table 3. According to these information, the study covers the years from 1970 to 2014, yet in the rest of the paper, the results are provided for 1970 to 1990 (such as Figure 4) or the years are not mentioned at all. For a list of 8 years for low activity years, there is only one value in the tables. What happened to the data? The criterion for less than 10 percent is not clear.

We will amend with a figure that includes the 80 line.
We used the 12-month running mean of the IGNS to define solar activity levels instead of a solar index such as F10.7 or sunspot number. The reasons for this are given in the penultimate paragraph of the methodology section.
The study covers observational data which span from 1970 to 2014. Figure 4, is a direct comparison with work presented by Rishbeth and Muller-Wodarg (2006) which describes the AI variation from 1970 to 1990. We will add the following text to the first paragraph of section 3.1.1

(page 12 line 1): “Data are presented for the Wallops–Hobart (green), Wakkanai–Port Stanley (blue), and Kodaikanal–Huancayo (red) station pairs for the years 1970-1990, a subset of our full data record. This subset is presented in order to recreate Figures 3 and 4 from Risbeth and Muller-Wodarg (2006) and perform a direct comparison with their work.

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[referee] 13) In Tables 4, 5 and 6, there are two stations and one ‘Iono’ value. How is this possible? How did the authors compute the values? The caption of the titles mention that the values are AI, yet the column titles indicate that they are IRI(IG) or Iono. The ‘average’ and ‘average*’ operations are not clear. Why did the authors include station pairs with no data into the tables?

[response] Ionosonde observations are not always available, and it is important to communicate this as well to support the integrity and validity of our results.

We will include the following text in the methodology section, page 8 line 13:

(page 8, line 13) The SfoF2 and the AI are computed for various levels of solar activity. Both parameters will be computed for every year of data available the stations listed in Figure 2 and Table 2. We then group these computed values by solar activity level and average. This presents the average AI and solstitial variation for a given station at various solar cycle levels. We use the index IGNS as a solar proxy.

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[referee] 14) In Table 6, the conclusions drawn are wrong. For 7 station pairs that have data, IG input matched 4 of these, whereas IGNS matched only 2. So IG is a better input for high solar activity years.

[response] Our conclusions are based on the overall average AI predicted by IRI, which

indicate IGNS is the better index. We will clarify this, with an additional error statistic.

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[referee] 15) Figure 4 does not include years from 1990 to 2014. It is not clear why all the stations are not given? What is the meaning of diamonds? Some lines have them and some does not. If they are the years of computation, this information does not match Table 3. The subplots are too crowded.

[response] We address the first part of this comment in 12).
In a subsequent submission will include a legend which indicates the dotted lines correspond with ionosonde observations.

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[referee] 16) The information on the computation of AI on page 12 is not clear at all. All mathematical computations should be clearly indicated with proper notation and equation numbers.

[response] We will all add a regressive equation to correspond with our explanation for figure 12.

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[referee] 17) I have reservations for the ‘missing data replacement’ as done in the manuscript.

[response] We agree with the reviewer’s reservations. Unfortunately, the choice to combine dataset was driven by a need to present a full picture, balanced by an availability of data.

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[referee] 18) Table 7 does not make sense at all. The correlation coefficients are computed for which data sets? What is NPTS mean? Is the correlation biased or unbiased? For what years and for which solar activity level?

[response] Table 7 computes an unbiased correlation between all of the AI from observations and from IRI for the entire data record using each station pair.

We will add this detail to the text on page 13 line 22. “We compute the correlation coefficient between all AI values from observations and the AI values from the IRI predictions for each station pair. We use the entire data record, instead of just 1970-1990 as presented in figure 4. These results are presented in table 7. “NPTS” indicates the number of data points used for the correlation coefficient. “

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[referee] 19) Figure 5 is also another mystery. Even the labels are misspelt. What does the vertical bars or lines represent? And so on...

[response] We have corrected the misspelling in table 5.
We also add the following text to 3.2 for added clarity:
(Page 14 line 14): “We draw vertical lines through data points which correspond to the same station to aid in the visual inspection of the chart”.

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[referee] 20) Table 8 is wrong.

[response] This comment is difficult to respond to directly unless there is a reference to contrary results from other literature. Our numbers are consistent with the observational data as well as similar analysis presented by Torr and Torr (1977) and Zhao et

al., (2008).

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[referee] 21) Since the equations for computation of AI, averaging of AI and SfoF2 are totally unclear and may possibly contain significant physical and mathematical errors, none of the comments in the discussion or the drawn conclusions are reliable.

[response]

Our definition and implementation of AI is consistent with previous studies of the annual anomaly using the AI index (this is addressed in points 3-5, 20). Regarding mathematical errors, We will add the following text for added clarity:

(Page 9, line 9) “The range of the observed AI values presented in these tables are consistent with previous literature (please reference 1). “

(Page 15, line 6) These trends and numerical values of the observed SfoF2 are consistent similar analysis presented by Torr and Torr (1977).

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[referee] 22) The paper is full of notational, grammatical and mathematical errors. The authors should start using at least a spell-checker and technical reviewer to edit the paper. There are syntax errors and singular-plural errors. There are many incidences of two verbs are used in the same sentence.

[response] Our document has been fully re-edited.

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[referee] 23) The authors should stop ‘suspecting’. ‘Suspect’ is not part of scientific

terminology.

[response] “We have removed ‘suspect’ from the body of the manuscript.

[referee] 24) There is no references for IGRF model and some of the data sources are not acknowledged.

[response] We will include the corresponding IGRF citation in the methodology (and append the reference list). We have also included an acknowledge to GIRO NDGC in our acknowledgements.

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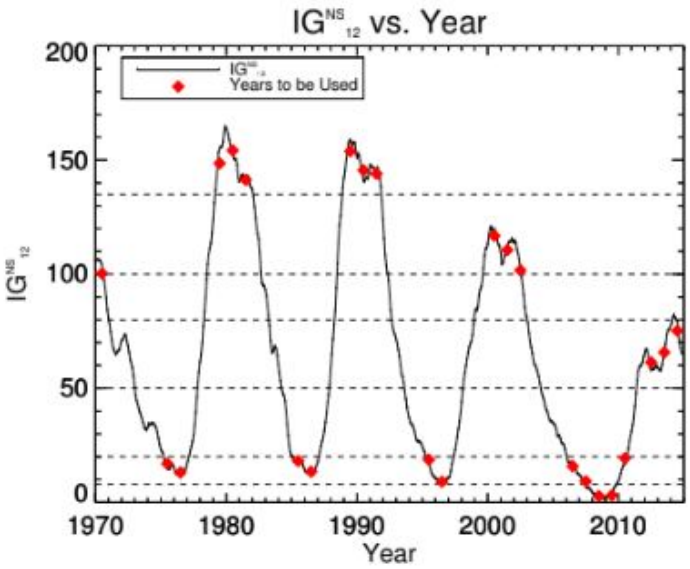

Figure 4.2: The 12-month running mean of IG^{NS}, $IG^{NS}{}_{12}$, as a function of time. The horizontal dotted lines indicate regions for which the solstices differences are calculated: deep low ($IG^{NS}{}_{12} < 8$), low ($8 < IG^{NS}{}_{12} < 20$), low moderate ($50 < IG^{NS}{}_{12} < 80$), high moderate ($100 < IG^{NS}{}_{12} < 135$) and high ($135 < IG^{NS}{}_{12}$). Only years in which $IG^{NS}{}_{12}$ changes by less than 10% are considered (red diamonds).

Fig. 1. revised figure 4.2