Scientific Research Publishing

Journal of Applied Mathematics and Physics, 2022, 10, 3562-3571
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

Comparative Study of foF2 during Quiet Geomagnetic Activity with URSI and CCIR Predictions during the Phase Minimum of Solar Cycle 22

Moustapha Konaté[1,2*], Abidina Diabaté[1,3], Kadidia Nonlo Drabo[1,4], Emmanuel Nanéma[1,4], Frédéric Ouattara[1]

[1]Laboratoire de Recherche en Energétique et Météorologie de l'Espace (LAREME), Université Norbert ZONGO, Koudougou, Burkina Faso
[2]Centre Universitaire de Gaoua, Université Nazi BONI, Bobo-Dioulasso, Burkina Faso
[3]Centre Universitaire de Banfora, Université Nazi BONI, Bobo-Dioulasso, Burkina Faso
[4]Centre National de la Recherche Scientifique et Technologique (CNRST), Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), Ouagadougou, Burkina Faso
Email: *konat_moustapha@yahoo.fr

How to cite this paper: Konaté, M., Diabaté, A., Drabo, K.N., Nanéma, E. and Ouattara, F. (2022) Comparative Study of foF2 during Quiet Geomagnetic Activity with URSI and CCIR Predictions during the Phase Minimum of Solar Cycle 22. *Journal of Applied Mathematics and Physics*, **10**, 3562-3571.
https://doi.org/10.4236/jamp.2022.1012236

Received: November 9, 2022
Accepted: December 6, 2022
Published: December 9, 2022

Abstract

This paper investigates the performance of the latest International Reference Ionosphere model to predict the critical frequency at low latitudes in the African region. The variability of the critical frequency of the F2 layer of the ionosphere (foF2) is studied for the different seasons of the phase minimum of solar cycle 22 during quiet geomagnetic activity at the Ouagadougou station. The data used are those provided by the ionosonde and the predictions of the two subprograms: International Radio Consultative Committee (CCIR) and International Radio-Scientific Union (URSI) of the 2016 version of the International Reference Ionosphere model. This study shows that, in general, URSI and CCIR of the IRI-2016 model are able to reproduce fairly well the variability of the critical frequency of the F2 layer of the ionosphere at low latitudes during the phase minimum at the Ouagadougou station. However, the model shows an almost homogeneous overestimation of the foF2 during the four seasons studied. The good response is observed between 0700 TL and 1900 TL for the available data. The agreement between the subroutine responses and the observed results is between reasonable and poor. The best match state response is obtained in winter with the CCIR subroutine. These results show that there is a need to improve both CCIR and URSI subroutines of the IRI-2016 model in low latitudes in the African region.

Keywords

foF2, IRI, Ionosonde, Quiet Time Periods, Solar Cycle Phase Minimum

1. Introduction

Studies of the signature of solar events on the ionosphere have shown that this layer of the Earth's upper atmosphere responds as a function of sunspot cycle activity, season and time of day [1] [2] [3] [4]. To predict the responses of ionospheric parameters, models have been developed [5] [6] [7] and the results of the studies have shown the need to improve the response of some models [8] [9] [10]. The response of the IRI (International Reference Ionosphere) model has been analyzed at low latitudes, not only to study the temporal variability of the main ionospheric parameters [11], but also to compare the prediction of different versions of the model evolution to the data observed in the different stations of the equatorial region of the African sector and this for different solar phases and cycles [12]. The objective of this work is to analyze during the minimum phase of solar cycle 22, the response of the two subroutines URSI and CCIR of the latest version of the IRI model, through the temporal variations of foF2 during the quiet geomagnetic activity. We compare the predictions of the URSI and CCIR subroutines with ionosonde data from the Ouagadougou station (latitude 12.4˚N and longitude 358.5˚E). This paper is a continuation of the work of the authors [13], who showed the need to improve the response of the IRI-2012 model by studying the variability of foF2 in quiet periods, and allows us to see if this version has corrected the problems observed in previous versions and to assess the response of the two main subroutines of IRI-2016 in periods of quiet geomagnetic activity at low latitudes.

2. Materials and Methods

2.1. Data Used

We use data from the ionosonde of the Ouagadougou station (latitude 12.4˚N and longitude 358.5˚E) which operated from 1966-1998 and was provided by Brest Telecom of Bretagne. We consider the characteristic year of the phase minimum of the solar cycle 22 determined by the sunspot number $Rz_{mean} < 20$ [14]. The ionospheric parameter studied is the critical frequency of the F2 layer in the equinox (March and September) and solstice (June and December) months. We use the quiet days of the month characteristic of the season. The monthly foF2 value is the arithmetic mean of the foF2 values of the five quietest days of the month. It is important to note a lack of data observed at certain times (**Table 1**).

2.2. Conditions of Use of IRI

The IRI model is a standard reference model which is used to design experimental measurements, to estimate the ionospheric environment and its effects,

Table 1. Observed values of foF2 during the four seasons of the phase minimum.

Hours (h)	0	2	4	6	8	10	12	14	16	18	20	22	24
foF2 (MHz) March	-	7	3.22	2.54	7.1	7.98	7.72	8.14	9.4	8.98	8.1	6.7	-
foF2 (MHz) June	3.5	2.75	1.93	4.55	7.04	7.68	7.36	7.22	7.84	8.3	7.12	4.46	4.25
foF2 (MHz) September	4.43	3.77	1.725	3.7	7	6.83	6.7	7.23	8.5	8.35	7.87	7	-
foF2 (MHz) December	6.17	4.98	2.93	2.4	7.08	7.78	7.56	8.18	7.96	7.74	6.2	7.1	-

to validate the hypotheses of the various theories… [15]. There are several versions of the IRI model and its latest version is 2016. The predicted hourly values of foF2 for calm days are obtained by running the two subroutines URSI and CCIR of IRI-2016 for the Ouagadougou station.

In this work, the model is executable through the site: https://ccmc.gsfc.nasa.gov/modelweb/models/iri2016_vitmo.php, under URSI and CCIR under the following conditions:

- Years: 1985.
- Month (to be defined: March, June, September, December).
- Day (to be defined: calm day), Hour = 1.5.
- Time_type = Local or Universal (because for Ouagadougou UT = LT).
- Coordinate_type = Geographic (Latitude = 12.5, Longitude = 358.5, Height = 350.)
- Prof.parameters: Start = 0. Stop = 24. Step = 1.

It generates the averages of the main ionospheric parameters as a function of time, date, at an altitude varying between 50 and 2000 km.

2.3. Methods

In this study, we use the calm days determined by the index Aa ≤ 20 nT [16] [17]. The season is characterized by its characteristic month namely: March for spring, June for summer, September for autumn and December for winter [18]. The phases of the solar cycle are determined by the annual average Zürich sunspot number (Rz). For the minimum phase average $Rz_{mean} < 20$, the ascending and descending phase $20 < Rz_{mean} < 100$ and the maximum phase average $Rz_{mean} > 100$ [19]. The study of the variation of ionospheric mean values [20] is performed using the arithmetic mean of the five calmest days to describe the whole season at the Ouagadougou station determined by the geographical coordinates: latitude 12.5˚N and longitude 358.5˚E. The IRI model is run to determine the hourly mean values of foF2 considering the solar cycle 22.

Our working method focuses on qualitative analysis based on purely visual observation of the results of the IRI-2016 model temporal profiles and the ionprobe data. We will use the quantitative analysis which will consist of determining the average modulus of relative deviation (Δ) and the percentage of deviation between the results of the two subprograms of the IRI-2016 model and the ionosonde data respectively by Equations (1) and (2).

$$\Delta = \frac{1}{N}\sum_i^n \frac{\left| foF2_i^{iono} - foF2_i^{IRI} \right|}{foF2_i^{iono}} \quad (1)$$

$$\sigma_{rel} = \frac{foF2_i^{iono} - foF2_i^{IRI}}{foF2_i^{IRI}} 100 \quad (2)$$

With $foF2_i^{iono}$ and $foF2_i^{IRI}$ as the values provided by the ionosonde and modeled by IRI-2016, respectively, and N the number of terms. For (Δ) ≤ 0.06 then the agreement between model and experiment goes from reasonable to good in the opposite case the agreement goes from reasonable to bad [10]. For $\sigma_{rel} < 0$, the model overestimates the observed values, and the model underestimates the observed values when, $\sigma_{rel} > 0$ [21].

3. Results and Discussion

Running the IRI model under the above conditions allows us to determine the hourly averages of the critical frequency (predicted data) of the five calmest days of each season. The observed data are provided by the ionosonde of the Ouagadougou station. All data are then exported to an Excel file for the determination of the daily mean value foF2 which represents the whole season and the plotting of the graphs. Finally, we determine the average relative deviation modulus and the percentage deviation between the results of the two subroutines of the IRI-2016 model and the ionosonde data.

Figure 1 shows the comparative temporal evaluation of the arithmetic mean foF2 of the five quietest days during spring (**Figure 1(a)**), summer (**Figure 1(b)**), autumn (**Figure 1(c)**), and winter (**Figure 1(d)**) for the minimum phase of solar cycle 22 at the Ouagadougou station. The continuous curves in blue represent the average variations of foF2 given by the ionosonde, the curves in red dashes show the evolution of the average variations of foF2 given by the URSI subprogram and those in green dashes concern the CCIR. The error bars on the temporal profiles of the observed data are standard deviations that allow us to appreciate the response of the IRI model.

Figure 2 represents the comparative temporal assessment of the percentage deviation of the URSI and CCIR subprograms of IRI-2016 from the arithmetic mean of the foF2 of the five quietest days in spring (**Figure 2(a)**), summer (**Figure 2(b)**), autumn (**Figure 2(c)**) and winter (**Figure 2(d)**) for the phase minimum of solar cycle 22 at the Ouagadougou station.

Figure 1(a) shows a plateau-like profile for URSI and a double peak with an inflection located at 1200 LT for CCIR and the observed data. The afternoon peak of the measurement data has higher amplitude than the morning peak. The URSI curve has a night peak at 2300 LT which is not observed on the CCIR curve.

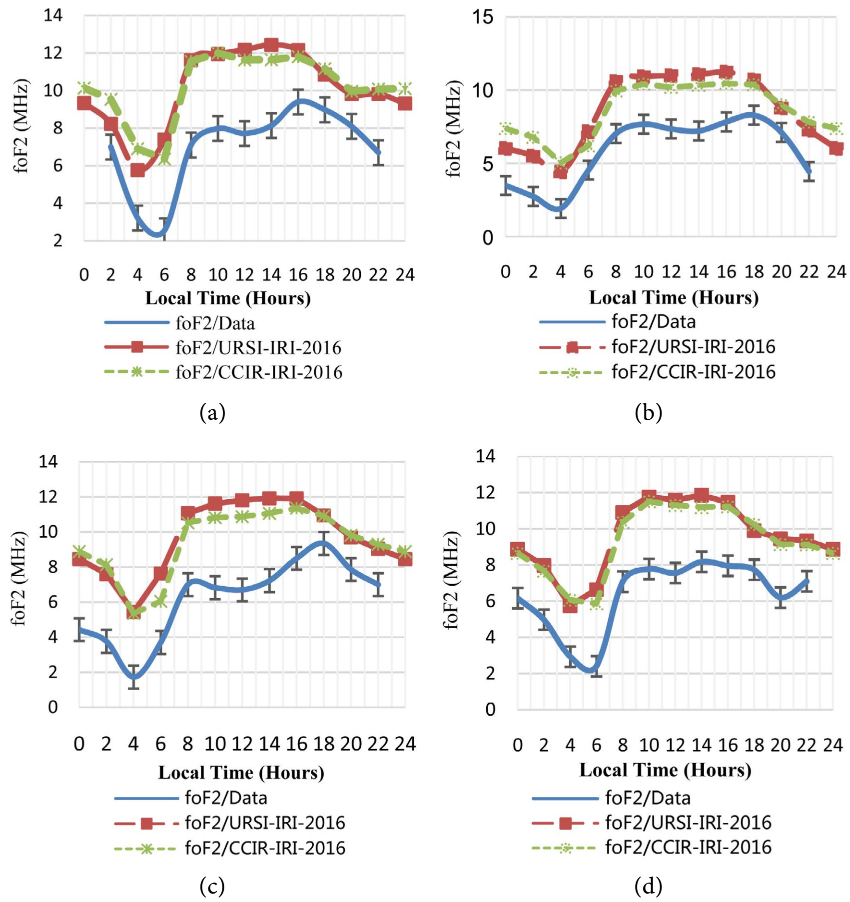

Figure 1. Comparative temporal evaluation of average foF2 of quiet periods during the phase minimum of solar cycle 22 at the Ouagadougou station. (a) Comparative time evaluation of foF2 in spring; (b) Comparative temporal evaluation of foF2 in summer; (c) Comparative temporal evaluation of foF2 from fall; (d) Comparative temporal evaluation of foF2 from winter.

The curve of the measurement data is lower than that of URSI and CCIR during the whole day. The maximum and minimum value of the critical frequency of the measurement data in spring are observed respectively at 1600 LT (9.4 MHz) and at 0600 LT (2.54 MHz). Between 0000 LT - 0500 LT and from 1700 LT - 2400 LT, the CCIR curve is higher than the URSI curve. The minimum value of foF2 is observed at 0400 TL (5.76 MHz) for URSI and at 0600 TL (6.36 MHz) for CCIR. The curve of URSI shows its maximum value at 1400 LT (12.43 MHz) and that of CCIR at 1000 LT (11.99 MHz).

Figure 2(a) shows an overestimation ($\sigma_{rel} < 0$) of foF2 by URSI and CCIR. The maximum overestimation value is obtained at 0600 TL ($\sigma_{rel} = -65.62\%$) for URSI and at 0500 LT ($\sigma_{rel} = -63.65\%$) for CCIR. The best overestimation ($\sigma_{rel} < -20\%$) is observed at 0200 LT and between 1700 TL - 2000 TL for URSI and between 1700 TL - 2000 TL for CCIR. Calculation of the average modulus of the relative deviation yields 0.58 for URSI and CCIR. This result is greater than 0.06 so the agreement between the model responses and the observed results ranges from reasonable to poor.

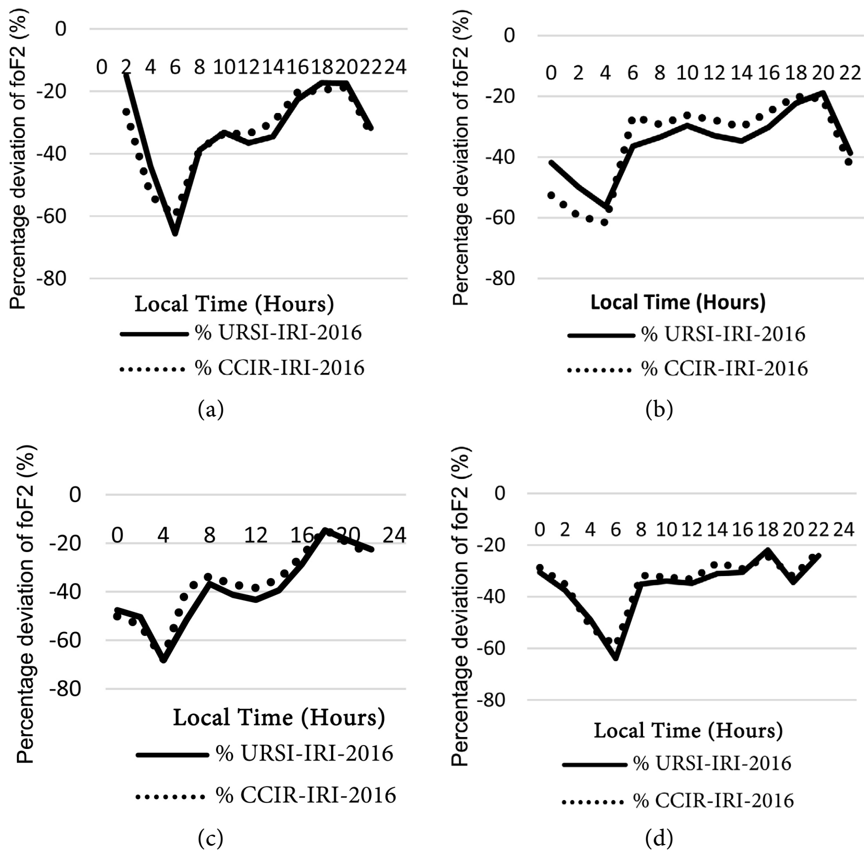

Figure 2. Comparative temporal evaluation of the percentage deviation of the URSI and CCIR subprograms of IRI-2016 from calm days during the phase minimum of solar cycle 22 at the Ouagadougou station. (a) Comparative temporal assessment of the percentage of deviation of URSI and CCIR during spring; (b) Comparative temporal assessment of the percentage deviation of URSI and CCIR over the summer; (c) Comparative temporal assessment of the percentage deviation of URSI and CCIR during the fall; (d) Comparative temporal evaluation of the percentage deviation of URSI and CCIR over the winter.

Figure 1(b) shows that in summer, a plateau-like profile is observed for URSI and a double peak with a trough at 1200 LT for CCIR and the observed data. The afternoon peak in the measurement data has a higher amplitude than the morning peak, which is still lower than that observed in spring. Unlike spring, the summer URSI profile does not show a nighttime peak. The curve of the measurement data is lower than that of the predicted data all day. The maximum and minimum value of the critical frequency the summer measurement data are observed at 1800 LT (8.3 MHz) and 0400 LT (1.93 MHz) respectively. Between 0000 LT - 0500 LT and from 1900 LT - 2400 LT, the URSI curve is lower than that of CCIR. The minimum value of foF2 is observed at 0400 LT (4.42 MHz) for URSI and 0400 LT (5.03 MHz) for CCIR. The URSI curve has its maximum value at 1500 LT - 1600 LT (11.23 MHz) and that of CCIR at 1600 LT (10.46 MHz). The profiles of the observed data, URSI and CCIR in summer are lower than those observed in spring respectively.

Figure 2(b) also shows an overestimation ($\sigma_{rel} < 0$) of foF2 by URSI and

CCIR. The maximum value of overestimation is obtained at 0500 LT (−63.33%) for URSI and at 0300 LT (−67.08%) for CCIR. The best overestimation is observed at 1900 LT ($\sigma_{rel} = -17.71\%$) for URSI and ($\sigma_{rel} = -18.47\%$) for CCIR. The average modulus of the relative deviation gives 0.61 and 0.66 for URSI and CCIR, respectively. These results are greater than 0.06 thus, the agreement between the sub-program responses and the observed results ranges from reasonable to poor. The best match state response is obtained in summer with the URSI subprogram.

Figure 1(c) is devoted to the profiles of measurement data and predicted data in autumn. The same type of profile as in spring is observed, namely a plateau for URSI and a double peak with a less marked inflection for CCIR compared to the measurement data. The nighttime peak in spring is not observed in the URSI profile. As in the previous two seasons, both curves of the predicted data are higher than that of the measurement data for the whole day. For this season, the maximum and minimum values of the critical frequency of the measurement data are observed respectively at 1800 LT (9.35 MHz) and 0400 LT (1.72 MHz). Between 0400 LT - 1800 LT, the URSI curve is higher than that of CCIR. The minimum value of foF2 is observed at 0400 LT (5.35 MHz) for URSI and CCIR. The curve of CCIR presents its maximum value at 1600 LT (11.36 MHz) and that of CCIR at 1400 LT (11.92 MHz).

Figure 2(c) shows identical overestimation in spring and summer namely ($\sigma_{rel} < 0$). The maximum overestimation value is obtained at 0400 LT ($\sigma_{rel} = -68.29\%$ for URSI and $\sigma_{rel} = -67.77\%$ for CCIR). The best overestimation is observed between 1800 LT - 2100 LT ($\sigma_{rel} < -20\%$) for URSI and CCIR. The average modulus of the relative deviation gives 0.72 and 0.65 for URSI and CCIR, respectively. The agreement between the subprogram responses and the observed results ranges from reasonable to poor. The best fit state response is obtained in the fall with the CCIR subprogram.

Figure 1(d) shows a double peak centered at 1200 LT for the three profiles studied. The amplitude of the afternoon peak in the measurement data is smaller than that observed for the other three seasons. The three curves show a night peak around 2200 LT in winter, which is more pronounced for the measurement data. As for the last three seasons, the curve of the measurement data is lower than that of URSI and CCIR during all the day. The maximum and minimum value of the critical frequency of the measurement data in spring are observed respectively at 1400 LT (8.18 MHz) and at 0600 LT (2.4 MHz). Between 0500 LT - 1700 LT, the CCIR curve is slightly lower than the URSI curve. The minimum value of foF2 is observed at 0400 LT (6.07 MHz) for URSI and at 0600 LT (5.86 MHz) for CCIR. The curve of URSI presents its maximum value at 1400 LT (11.86 MHz) and that of CCIR at 1000 LT (11.51 MHz).

Figure 2(d) shows an overestimation at the other three seasons. The maximum overestimation value is obtained at 0600 TL ($\sigma_{rel} = -63.90\%$ for URSI and $\sigma_{rel} = -59.10\%$ for CCIR). The best overestimation is observed between

1800 LT - 1900 LT and between 2100 LT - 2400 LT ($\sigma_{rel} < -30\%$). The average modulus of the relative deviation gives 0.56 and 0.52 for URSI and CCIR, respectively. The agreement between the subprogram responses and the observed results ranges from reasonable to poor. The best fit state response is obtained in winter with the CCIR subprogram.

Analysis of **Figure 1** shows that: 1) the URSI and CCIR predicted profiles have the same variability as the ionosonde data for each of the four seasons of the phase minimum; 2) the temporal profiles of the predicted values are higher than those of the predicted data throughout the day for all four seasons; 3) the good response is obtained between 0700 TL and 2400 TL for all seasons; 4) the URSI curve is higher than the CCIR curve between 0500 TL and 1700 TL for all four seasons; and 5) the error bar analysis indicates a better response in winter.

The analysis in **Figure 2** shows an almost homogeneous overestimation of foF2 by URSI and CCIR for all seasons of the minimum. The best overestimation is obtained between 1600 TL - 2400 TL ($\sigma_{rel} < -30\%$), and the worst between 0200 TL - 0600 TL ($\sigma_{rel} > -40\%$) for all seasons. The calculation of the average modulus of the relative deviation gives for URSI and CCIR respectively: 0.58 and 0.59 in March, 0.61 and 0.66 in June, 0.72 and 0.65 in September and 0.56 and 0.52 in December. The results obtained show that they are greater than 0.06. The agreement between the model responses and the observed results is between reasonable and poor for the whole cycle phase studied. The best response of the concordance state is obtained in winter with the CCIR subroutine (0.52) and the bad one in September with URSI (0.72).

These results are in agreement with the authors [22] who showed during quiet geomagnetic activity, that CCIR outperforms URSI after sunset in the equatorial ionization anomaly (EIA) region over China.

4. Conclusion

In this paper, we make a comparative study of the temporal variation of foF2 with the response of the URSI and CCIR subroutines of the IRI-2016 model for the different seasons of the solar cycle 22 phase minimum at the Ouagadougou station. This study shows that, in general, the two subroutines of the IRI-2016 model are able to reproduce the variability of the critical frequency of the F2 layer of the ionosphere quite well and that there is no great difference in performance between URSI and CCIR at low latitudes during the studied phase. In all cases, the model exhibits a near-homogeneous overestimation of foF2 during all four seasons. The best response is observed between 1700 LT and 2400 LT for the available data. The match between the subroutine responses and the observed results is between reasonable and poor for all seasons of the phase minimum. The best matching state response is obtained in winter with the CCIR subroutine and the worst in September with URSI. These results show that there is a need to improve the CCIR and URSI subroutines of the IRI model in the low latitudes of the African region.

Acknowledgements

The authors thank the managers of the International Reference Ionosphere model and Brest Telecom of Bretagne for making the data available and express their deep appreciation to the journal for their financial support.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

References

[1] Simon, P.A. and Legrand, J.P. (1989) Solar Cycle and Geomagnetic Activity: A Review for Geophysicists. Part II. The Solar Sources of Geomagnetic Activity and Their Links with Sunspot Cycle Activity. *Annales Geophysicae*, **7**, 579-594. https://ui.adsabs.harvard.edu/abs/1989AnGeo...7..579S

[2] Gorney, D.J. (1990) Solar Cycle Effects on the Near-Earth Space Environment. *Review of Geophysics*, **28**, 315-336. https://doi.org/10.1029/RG028i003p00315

[3] Ouattara, F. and Amory, C. (2009) Mazaudier: Solar-Geomagnetic Activity and Aa Indices toward a Standard. *Journal of Atmospheric and Solar-Terrestrial Physics*, **71**, 1736-1748. https://doi.org/10.1016/j.jastp.2008.05.001

[4] Ouattara, F., Amory-Mazaudier, C., Menvielle, M., Simon, P. and Legrand, J.-P. (2009) On the Long Term Change in the Geomagnetic Activity during the 20th Century. *Annales Geophysicae*, **27**, 2045-2051. https://doi.org/10.5194/angeo-27-2045-2009

[5] Dickinson, R.E., Ridley, E.C. and Roble, R.G. (1981) A Three-Dimensional General Circulation Model of the Thermosphere. *Journal of Geophysical Research*, **86**, 1499-1512. https://doi.org/10.1029/JA086iA03p01499

[6] Dickinson, R.E., Ridley, E.C. and Roble, R.G. (1984) Thermospheric General Circulation with Coupled Dynamics and Composition. *Journal of the Atmospheric Sciences*, **41**, 205-219. https://doi.org/10.1175/1520-0469(1984)041<0205:TGCWCD>2.0.CO;2

[7] Bilitza, D. (2001) International Reference Ionosphere 2000. *Radio Science*, **36**, 261-275. https://doi.org/10.1029/2000RS002432

[8] Bilitza, D., Altadill, D., Zang, Y., Mertens, C., Truhlik, V. and Richards, P. (2014) The International Reference Ionosphere 2012—A Model of International Collaboration. *Journal of Space Weather and Space Climate*, **4**, A07. https://doi.org/10.1051/swsc/2014004

[9] Abdu, M.A., Batista, I.S. and De Souza, J.R. (1996) An Overview of IRI-Observational Data Comparison in American (Brazilian) Sector Low Latitude Ionosphere. *Advances in Space Research*, **18**, 13-22. https://doi.org/10.1016/0273-1177(95)00893-4

[10] Bertoni, F., Sahai, Y., Lima, W.L.C., Fagundes, P.R., Pillat, V.G., Becker-Guedes, F. and Abalde, J.R. (2014) IRI-2001 Model Predictions Compared with Ionospheric Data Observed at Brazilian Low Latitude Stations. *Annales Geophysicae*, **24**, 2191-2200. https://doi.org/10.5194/angeo-24-2191-2006

[11] Gédéon, S., Roger, N., Moustapha, K. and Emmanuel, N. (2022) Seasonal Variability of foF and Nocturnal Winter Anomaly in E-Layer during Solar Cycles 21 and 22 at the Ouagadougou Station. *Physical Science International Journal*, **26**, 1-10. https://doi.org/10.9734/psij/2022/v26i230307

[12] Ouattara, F. and Rolland, F. (2011) Variability of CODG TEC and IRI 2001 Total Electron Content (TEC) during IHY Campaign Period (21 March to 16 April 2008) at Niamey under Different Geomagnetic Activity Conditions. *Scientific Research and Essays*, **6**, 3609-3622. https://doi.org/10.5897/SRE10.1050

[13] Ouattara, F. and Nanéma, E. (2014) Quiet Time foF2 Variation at Ouagadougou Station and Comparison with TIEGCM and IRI-2012 Predictions for 1985 and 1990. *Physical Science International Journal*, **4**, 892-902. https://doi.org/10.9734/PSIJ/2014/9748

[14] Nanéma, E., Konaté, M., Zoundi, C., Kotia, A.O., Zerbo, J.L. and Ouattara, F. (2021) Evaluating the Rate of Total Electron Content (TEC) Production in Ionosphere F2-Layer to Highlight Winter Anomaly by Running Thermosphere-Ionosphere-Electrodynamics General Circulation Model. *African Journal of Environmental Science and Technology*, **15**, 379-383. https://doi.org/10.5897/AJEST2021.3051

[15] Bilitza, D., Rawer, K., Bossy, L. and Gulyaeva, T. (1993) International Reference Ionosphere—Past, Present, Future: I. Electron Density. *Advances in Space Research*, **13**, 3-13. https://doi.org/10.1016/0273-1177(93)90240-C

[16] Nanéma, E., Konaté, M. and Ouattara, F. (2019) Peak of Electron Density in F2-Layer Parameters Variability at Quiet Days on Solar Minimum. *Journal of Modern Physics*, **10**, 302-309. https://doi.org/10.4236/jmp.2019.103021

[17] Konaté, M., Nanéma, E. and Ouattara, F. (2019) Variabilité du pic de la densité des électrons dans l'ionosphère au maximum de phase du cycle solaire. *Science et technique*, *Sciences naturelles et appliquées*, **38**, 93-100.

[18] Nanéma, E., Konaté, M., Gnabahou, A.D. and Ouattara, F. (2018) Effects of Height of F2-Layer on Critical Frequency by Use of Data at Ouagadougou Station. *Applied Physics Research*, **10**, 57-60. https://doi.org/10.5539/apr.v10n5p57

[19] Nanema, E., Zerbo, J.L., Konate, M. and Ouattara, F. (2018) Height of F2-Layer Peak Parameter Effects on Critical Frequency by IRI. *Journal of Scientific and Engineering Research*, **5**, 62-68.

[20] Rishbeth, H. and Mendillo, M. (2001) Patterns of F2 Layer Variability. *Journal of Atmospheric and Solar Terrestrial Physics*, **63**, 1661-1680. https://doi.org/10.1016/S1364-6826(01)00036-0

[21] Ouattara, F. (2009) Contribution à l'étude des relations entre les deux composantes du champ magnétique solaire et l'ionosphère équatoriale. Docteur d'État ès Sciences, Université Cheikh Anta DIOP de Dakar, Sénégal, Faculté des Sciences et Techniques, Département de physique, Dakar.

[22] Liu, Z.D., Fang, H.X., Weng, L.B., Wang, S.C., Niu, J. and Meng, X. (2019) A Comparison of Ionosonde Measured foF2 and IRI-2016 Predictions over China. *Advances in Space Research*, **63**, 1926-1936. https://doi.org/10.1016/j.asr.2019.01.017