A comparative study on ionospheric parameter measured with ionosonde and predicted using IRI – 2007 model at Japanese longitudes during low solar activity years

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ABSTRACT
This paper presents a comparative study on the important parameter of the ionosphere critical frequency of F2 layer (foF2) retrieved using ground based ionosonde radars and predicted by International Reference Ionosphere (IRI-2007) model at three different locations including Okinawa (Geographic Lat. 26.4° N, Geographic Long. 128.1°E), Yamagawa (Geographic Lat. 31.2° N, Geographic Long. 130.37° E), and Kokubunji (Geographic Lat. 35.4° N, Geographic Long. 139.29° E), in the Japanese longitudes during low sunspot activity years 2007 and 2008. From the present study it is revealed that the highest values of foF2 are observed during equinox and lowest values are observed during summer and winter seasons over Okinawa, and Yamagawa, but at Kokubunji highest values of foF2 are observed during summer and lowest values are observed during winter. A comparative study between ionosonde retrieved and IRI-2007 model derived foF2 values reveals that the IRI predicted values exhibit better agreement during all four seasons.
Key words: Ionosphere, IRI-2007 model, Ionosonde, ExB drifts, dynamical, electro dynamical processes.

1. Introduction

The radio wave communication systems are often subjected to marked changes in their performance owing to the variations in the ionosphere. During past few decades, a wide range of models including empirical models have also been developed in an effort to describe the ionospheric behavior. International reference ionosphere (IRI) is a permanent scientific project of the committee on space research (COSPAR) and the international union of radio science (URSI) started in 1968. It is the international standard for the terrestrial ionosphere since 1999. The goal of the IRI model is to predict the variations of various ionospheric parameters based on reliably measured data obtained with ground- and space-based methods. The IRI [1] is one of the most comprehensive empirical models to describe the global topside ionospheric behavior and variation up to several hundreds of kilometers (~1500km), and this has been steadily improved with newer data and with better mathematical descriptions of global and temporal variation pattern since its inception [2]. Being a data based model, the accuracy of the IRI model in a specific region and time period depends on the availability of reliable data for specific region and time [2]. Further, the IRI model describes the general behavior of foF2 at lower ionosphere only, which implying that the IRI model should be updated to better characterize the general behavior of topside electron density profile [3].

The pulse sounding technique of Briet and Tuve [4] is the nemesis for the sounding of the ionosphere, which relies upon full wave reflection from ionospheric layers and it operates in the frequency range from ~1 to 30 MHz, known as ionosonde. Ionosonde is one type of radars, which transmits a signal vertically with frequency continuously sweeping from 1 to 20 MHz in 15 seconds. Calculating the time delay of reflected signal as a function of frequency, a plot is derived with virtual height (h’F) on y-axis and operating frequency on x-axis, known as an Ionogram. The net ionization in the upper atmosphere varies significantly from hour to hour and day to day owing to the operation of additional processes such as the wind, electro dynamical drifts and the global electric fields. These variations play very different roles in the prediction of
ionospheric parameters for applications in the trans-ionospheric communication systems. Although many studies have been carried on the variation of the ionospheric parameters over 60 years the exact causative mechanisms for the day to day variability in the equatorial ionosphere have not been completely understood. In view of the application purposes such as radio communications and satellite based navigation forecasting or now casting understanding of the parameters like the electron density and irregularities in the ionosphere have gained much importance. In recent times, the precise modeling of the ionospheric electron density and related parameters has become essential in assessing the range delays in satellite based communication and navigation system applications.

The present paper presents a study on the diurnal, day-to-day, seasonal and latitudinal variations of ionospheric F-region parameter (foF2) over three different locations in the Japanese sector during low sunspot years 2007 and 2008. Further, a comparative study between ionosonde retrieved and IRI modeled F-region parameter has been carried out and the corresponding results are presented.

2. Data and method of analysis

The hourly ionogram data from different stations in Japanese sector namely Okinawa (26.4° N, 128.1°E), Yamagawa (31.2°N, 130.37°E), and Kokubunji (35.4°N, 139.29° E) during the years 2007 and 2008 are considered in the present study. These ionograms are obtained from National Institute of Information and Communication Technology (NICT) website http://wdc.nict.go.jp/IONO/HP2009/ISDJ/index-E.html and the important ionospheric F-region parameter foF2 are retrieved from these ionograms manually. The IRI model derived foF2 are obtained from the website http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php. A comparative study between the experimental and model derived F-region parameter has been carried out on a seasonal basis by dividing each year into four seasons namely vernal equinox (March, April), and summer(May, June, July, August), autumn equinox(September, October) and winter (November, December, January, February) respectively.

3. Results and discussions
3.1 Variation of foF2 over Okinawa

The diurnal and seasonal variations of foF2 at Okinawa derived from Ionosonde for the years 2007 and 2008 are presented in Figure 1(a) and 1(b) respectively. During both vernal and autumn equinox seasons the foF2 values are higher than the foF2 values during summer and winter seasons. The monthly mean values of foF2 show higher values during daytime compared to those during nighttime hours in all four seasons. The foF2 values start to increase gradually from 0600 hrs LT onwards for all the four seasons and diurnal peak is observed around 1500-1700 hrs LT during summer and winter seasons 1300-1500 hrs LT during both equinoctial seasons. The average variations of foF2 during four different seasons are separately presented in Figure 1(a). The mean seasonal variation of foF2 shows higher values during daytime hours in both vernal and autumn equinox seasons when compared to summer and winter seasons. In summer as well as autumn equinox seasons, a spread is observed from 0800-1800hrs LT. A double peaking is observed in the diurnal variation of foF2 during summer months at 0800LT and 2000 hrs LT. Reasonably well.

Figures 2(a) and 2(b) represent the seasonal average plots of the diurnal variations of foF2 derived from IRI at Okinawa during 2007 and 2008 respectively. During both vernal and autumn equinox seasons the foF2 values are higher than the foF2 values during summer and winter seasons. The monthly mean values of foF2 show higher values during daytime compared to those values during nighttime hours in all four seasons. The foF2 values start to increase gradually from 0600 hrs LT for all four seasons and diurnal peak is found to be centered on 1400 hrs LT during all four seasons. The mean seasonal variation of foF2 shows higher values during daytime hours during both vernal and autumn equinox seasons when compared to summer and winter seasons. When ionosonde data is compared with IRI model data, not much variation is observed. During vernal equinox season, the maximum value of foF2 at 1400 hrs LT is 11 MHz, during autumn equinox season the maximum value is 9 MHz, respectively. During summer as well as in winter seasons the foF2 values are 8 MHz. Most of the cases indicate that the IRI model predicts the observed values reasonably well.
Fig. 1(a). Diurnal and seasonal variations of foF2 measured using ionosonde at Okinawa during 2007.

Fig. 1(b). Diurnal and seasonal variations of foF2 measured using ionosonde at Okinawa during 2008.

Fig. 2(a). Diurnal and seasonal variations of foF2 measured using IRI at Okinawa during 2007.

Fig. 2(b). Diurnal and seasonal variations of foF2 measured using IRI at Okinawa during 2008.

Figures 2(a) and 2(b) represent the seasonal average plots of the diurnal variations of foF2 derived from IRI at Okinawa during 2007 and 2008 respectively. During both vernal and autumn equinox seasons the foF2 values are higher than the foF2 values during summer and winter seasons. The monthly mean values of foF2 show higher
values during daytime compared to those values during nighttime hours in all four seasons. The foF2 values start to increase gradually from 0600 hrs LT for all four seasons and diurnal peak is found to be centered on 1400 hrs LT during all four seasons. The mean seasonal variation of foF2 shows higher values during daytime hours during both vernal and autumn equinox seasons when compared to summer and winter seasons. When ionosonde data is compared with IRI model data, not much variation is observed. During vernal equinox season, the maximum value of foF2 at 1400 hrs LT is 11 MHz, during autumn equinox season the maximum value is 9 MHz, respectively. During summer as well as in winter seasons the foF2 values are 8 MHz. Most of the cases indicate that the IRI model predicts the observed values reasonably well.

3.2 Variation of foF2 over Yamagawa

Figures 3(a) and 3(b) represent the seasonal average plots of the diurnal variations of foF2 derived from Yamagawa Ionosonde during 2007 and 2008 respectively. The average variation of foF2 ranges from a minimum of 2MHz to a maximum of 10MHz. The monthly mean values of foF2 show higher values during vernal equinox season during day time, low foF2 values of 6 MHz during winter season. The foF2 values increase gradually from around 0500 hrs LT onwards for both equinox and summer seasons. During winter the foF2 values start increasing from 0600 hrs LT onwards. During vernal equinox the maximum peak is observed at 1300 hrs LT (8MHz), during autumn equinox the maximum peak is at 1400 hrs LT (7 MHz), and during winter at 1400 hrs LT (6.5MHz). During summer the delayed maximum is attained around 1900 hrs LT (7MHz). The mean seasonal variation of foF2 shows higher values during daytime in both equinox seasons of about 8MHz when compared to summer and winter seasons. During winter low values of foF2 are observed of about 6MHz. During summer and autumn equinox seasons a spread is observed from 0800-1800hrs LT but in summer the spread extends up to 2000 hrs LT. During summer, two maximum peaks at 0800 hrs LT and 2000hrs LT are observed.

Figures 4(a) and 4(b) represent the seasonal average plots of the diurnal variations of foF2 derived from IRI data at Yamagawa during 2007 and 2008 respectively. From Figure 4(a), it is
observed that the $foF2$ values start to increase from 0500 hrs LT in all four seasons. During both equinox seasons, the winter seasons is 7 MHz at around

maximum values that attained are 9 MHz around 1400 hrs LT. The maximum value of $foF2$ attained during summer as well as in

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**Fig. 3(a).** Diurnal and seasonal variations of $foF2$ measured using ionosonde at Yamagawa during 2007.

**Fig. 3(b).** Diurnal and Seasonal variations of $foF2$ measured using Ionosonde at Yamagawa during 2008.

**Fig. 4(a).** Diurnal and seasonal variations of $foF2$ measured using IRI at Yama
gawa during 2007.

**Fig. 4(b).** Diurnal and seasonal variations of $foF2$ measured using IRI at Yamagawa during 2008.
1500 hrs LT in summer and 1300 hrs LT during winter season. The mean seasonal variation of foF2 shows higher values during daytime in both equinox seasons, which is around 9 MHz. During summer and winter months low values of about 7 MHz are observed. While comparing with IRI modeled data during both vernal and autumn equinox seasons as well as in winter season, the model data overestimates the experimental data. During summer the model is in good agreement with the ionosonde data. The foF2 values are ranging from a minimum of 2 MHz to a maximum of 9 MHz during both equinox seasons. The foF2 values vary from 2 MHz to 8 MHz during summer and in winter seasons.

3.3 Variation of foF2 over Kokubunji

Figures 5(a) and 5(b) represent the seasonal average plots of the diurnal variations of foF2 retrieved from ionosonde at Kokubunji during 2007 and 2008 respectively. The values of foF2 start to increase from 0500 hrs LT during both equinox seasons. During summer and winter seasons, the foF2 values increase from 0600 hrs LT onwards. The foF2 values vary from a minimum of 2 MHz to a maximum of 8 MHz during summer and winter seasons. During both equinox seasons, the foF2 values vary from 2 MHz to 9 MHz. The monthly mean values of foF2 show higher values (7 MHz) during both equinox seasons as well as in summer seasons. During winter, low values of foF2 are observed around 6 MHz. The maximum peak is observed at around 1200 hrs LT. The mean seasonal variation of foF2 show higher values during daytime hours during vernal equinox and summer seasons. During summer, a spread is observed from 0800 to 1800 hrs LT and autumn equinox season spread is observed from 0700 to 1700 hrs LT. Two maximum peaks at 0800 hrs LT and 2000 hrs LT are observed during summer.

Figures 6(a) and 6(b) represent the seasonal average plots of the diurnal variations of foF2 derived from IRI at Kokubunji during 2007 and 2008 respectively. The value of foF2 starts to increase from 0500 hrs LT during all the four seasons. The foF2 values vary from a minimum of 2 MHz to a maximum of 8 MHz during both vernal and autumn equinox seasons. During summer the foF2 value varies from 2 MHz to 6 MHz. During winter the foF2 value varies from 2 MHz to a maximum of 7 MHz. The monthly mean
values of foF2 show higher values (8MHz) during both equinox seasons. Low value of foF2 (6MHz) is observed during summer.

Fig. 5(a). Diurnal and seasonal variations of foF2 measured using ionosonde at Kokubunji during 2007.

Fig. 5(b). Diurnal and seasonal variations of foF2 measured using Ionosonde at Kokubunji during 2008.

Fig. 6(a). Diurnal and seasonal variations of foF2 measured using IRI at Kokubunji during 2007.

Fig. 6(b). Diurnal and seasonal variations of foF2 measured using IRI at Kokubunji during 2008.
The maximum peak is observed at around 1300 hrs LT. The mean seasonal variation of foF2 show higher values during daytime hours during both vernal and autumn equinox seasons, lower values of foF2 during winter season. The spread is observed during summer as well as in autumn equinox seasons from 0800 to 1800 hrs LT. While comparing with IRI modeled data during vernal equinox season the model underestimates the ionosonde data. During summer the model is in good agreement with experimental data. On contrary, during autumn equinox as well as in winter seasons the model overestimates the experimental data. In IRI model data also we observed the spread during summer and autumn equinox seasons.

4. Discussion and conclusion

Several important features have been observed in this study. The earlier comparative studies have shown that, in general, over the South African region IRI-2001 predictions of foF2 are more accurate. The CCIR and URSI IRI-2001 options generated similar results for foF2; however, on average, the CCIR option performed better than the URSI options for foF2.

Prasad et al. [10] studied the day-to-day, seasonal and diurnal variations and reported that the average variation of foF2 shows maximum during most of the daytime hours. Ratovsky et al. [15] studied the summer diurnal and winter nighttime behavior of foF2, the solar activity dependence of the diurnal foF2 minimum. Oinats [13] studied the comparison of the ionospheric characteristics measured at Irktusk in 2003 with IRI – 2001 model data and reported that the foF2 values show very good agreement during December where as in January the predicted system underestimates the observations. For monthly mean values IRI model overestimates the ionosonde measured values during March, April, May and September. In summer the predicted diurnal range of foF2 values is much less than the observations. The predicted morning foF2 peak is absent in the observed diurnal variations where as evening peak is in very good agreement with the data. Murtaza et al. [7] studied the comparison of ionosonde measured values with IRI model data over Pakistan and reported that the IRI represents overall good agreement with ionosonde values. Ratovsky et al. [15] studied the diurnal and seasonal variations of F2 layer characteristics over Irktusk during the decrease in solar activity in 2003-2006.
observations and compared with IRI-2001 model and reported that with decreasing solar activity the nighttime foF2 prediction systematically underestimates the observations which is in contrast to our result of overestimation in all the seasons at all three places. The reason of this disagreement is associated with different solar activity dependence of nighttime foF2 values. Since foF2 is directly related to the maximum electron density of the ionospheric plasma, it begins to reach a maximum value around 1200-1400 hours LT. During daytime, as the temperature increases, loss rate also increases and it might happen that loss rate overwhelms the production rate, thus resulting in gradual decrease in the values of foF2. In the evening since the primary source of ionization is no longer present, foF2 values attain the lowest values.

For the seasonal variations in foF2, the daytime values are greater in the equinoctial seasons than during summer while the lowest values are observed during winter season. Therefore, the maximum value of foF2 is observed during equinoctial seasons. The winter anomaly is not observed during low solar activity period. In case of foF2 the highest values of foF2 are observed during equinox and lowest values are observed during summer and winter seasons over Okinawa, and Yamagawa, but at Kokubunji highest values of foF2 are observed during summer and lowest values are observed during winter. From a comparative study between ionosonde measured foF2 values and IRI-2007 model derived values reveals that IRI predicted values exhibit better agreement with foF2.

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