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Numerical coefficients for generation of foF2 in the Indian zone : low solar activity

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Abstract : An empirical model for simulation of the peak density of the ionospheric F layer over the Indian zone is presented. foF2 data measured at Delhi, Ahmedabad, Hyderabad and Tiruchirapalli during the low solar activity year 1965 ($F_{10.7}$~75) are harmonically analyzed to obtain diurnal and seasonal coefficients. A set of 49 coefficients comprising the mean, first, second and third harmonic coefficients derived separately for each location is found to be sufficient to recreate monthly mean foF2 under low solar activity conditions. The proposed model requires only the precalculated set of coefficients as input and enables one to use the calculated foF2 as single station input of IRI or other similar models

Keywords : foF2, harmonic analysis

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1. Introduction

The characteristic frequency foF2 is the most important factor for HF radio communication as it determines the maximum usable frequency. Diurnal and seasonal variations of foF2 at low latitudes are influenced by the equatorial anomaly resulting in large departures from variations predicted by a Chapman model. Long term predictions for long distance HF communication require development of models of foF2 and M (3000) F2 factors based on long series of observations for varying levels of solar activity at each location and then predicting the expected ionospheric characteristics from observed/estimated solar activity levels. There have been worldwide efforts in this direction [1–5], though improvements in techniques of ionospheric predictions have not been as fast as expected [6]. As empirical model for regional mapping of foF2 in Indian sector during all levels of solar activity and season, has been proposed in an earlier communication [7].

We present here an empirical model of foF2 levels for the Indian zone stations *i.e.*, Delhi, Ahmedabad, Hyderabad and Tiruchirapalli. The model covers low lovel of solar activity.

2. Data base

The foF2 data used in this analysis cover the region Delhi (28.63°N, 77.2°E; mag lat 18.3°N), Ahmedabad (21.5°N, 69.4°E; mag lat 13.6°N), Hyderabad (17.35°N, 78.46°E; mag lat 11.1°N) and Tiruchirapalli (10.8°N, 78.7°E; mag lat 2.4°N) for the period January-December, 1965. The mean monthly $F_{10.7}$ cm solar flux varied from 71.9 to 79.6 units. Estimation of missing data points has been made from the existing data through interpolation which then formed the data base. foF2 is related to peak electron density NmF2 through relation

$$NmF2 = 1.24\ (foF2)^2\ el/m^3, \tag{1}$$

where foF2 is in MHz.

3. Development of the model

The diurnal and seasonai variations of most of the ionospheric parameters being cyclic in nature, it is possible to describe them with the help of empirical solutions which in turn will help in recreating the data in a given set of conditions. The method of analysis and development of the model is similar to the one described in an earlier communication [8].

The daily foF2 data for the entire period were subjected to a harmonic analysis consisting of a mean, first, second and third harmonic components and represented by a series of the form

$$\begin{aligned} N(t) &= N_0 + N_{24}\cos(2\pi t/24 + \phi_{24}) + N_{12}\cos(2\pi t/12 + \phi_{12}) \\ &\quad + N_8\cos(2\pi t/8 + \phi_8), \cdots \end{aligned} \tag{2}$$

where N_0, N_{24}, N_{12}, N_8 are the amplitudes of the mean, first, second and third harmonic components, and ϕ_{24}, ϕ_{12}, ϕ_8 are the phases of the first, second and third harmonic components respectively, and t is the hour of the day. Seven coefficients were thus obtained for each month of the period of observation. A second analysis was performed on each of the seven coefficients. The series function which will carry the annual dependence for each of the coefficients can be expressed as

$$\begin{aligned} N_0 &= A_{00} + A_{12}\cos(2\pi M/12 + \phi_{12}) + A_{06}\cos(2\pi M/6 + \phi_{06}) \\ &\quad + A_{04}\cos(2\pi M/4 + \phi_{04}), \cdots . \end{aligned} \tag{3}$$

and so on, where A_{00}, A_{12}, A_{06} and A_{04} represent amplitudes of the mean and first three harmonics of the annual components and ϕ_{12}, ϕ_{06}, ϕ_{04} the corresponding phases respectively and M represents months. Detailed method of development of this model has been reported in an earlier communication [8].

4. Reconstruction of foF2 and effectiveness of the model

The months of the year starting January were assigned values of M from 1 to 12. Then the 49 coefficients from Tables (1–4) were used in eq. (2) to calculate N_0, N_{24}, N_{12}, N_8, ϕ_{24}, ϕ_{12} and ϕ_8 necessary for the representation of the diurnal behaviour with the help of eq. (1).

Table 1. Annual coefficients of foF2 for Delhi.

	A_{00}	A_{12}	A_{06}	A_{04}	ϕ_{12}	ϕ_{06}	ϕ_{04}
N_0	5.48	0.871	0.593	0.143	3.11	2 02	–0.620
N_{24}	2 92	0.166	0.918	0.236	–2.98	2 33	–0.142
N_{12}	0.458	0.172	0.250	0.0833	–0.692	2.09	0.927
N_8	0 433	0.202	0 159	0.0527	0.945	2.57	–2.82
ϕ_{24}	2 44	0.286	0 0167	0.0167	–0.0504	2.09	–0 0025
ϕ_{12}	4.44	1.25	0.267	0.248	–0.462	2.09	–0.343
ϕ_8	4 62	0.650	0.578	0.893	–2.67	–0 552	–0.245

Table 2. Annual coefficients of foF2 for Ahmedabad.

	A_{00}	A_{12}	A_{06}	A_{04}	ϕ_{12}	ϕ_{06}	ϕ_{04}
N_0	6.10	0.290	0.549	0.184	3.01	2.65	0.0907
N_{24}	3.96	0.106	1.01	0.311	–2.21	2.63	0.271
N_{12}	0.592	0 0775	0.252	0.0898	1.65	2 21	1.19
N_8	0.558	0.257	0.217	0.0373	1.00	2.66	–1 11
ϕ_{24}	2.24	0.135	0.101	0.0373	0.462	1.49	1.11
ϕ_{12}	4.28	1.08	0.275	0.224	–0.438	1 66	–0.464
ϕ_8	4.71	0.251	0.309	0.250	1.71	1.09	–2.50

Table 3. Annual coefficients of foF2 for Hyderabad.

	A_{00}	A_{12}	A_{06}	A_{04}	ϕ_{12}	ϕ_{06}	ϕ_{04}
N_0	5.83	0.162	0.415	0.0667	1.11	1.92	1.57
N_{24}	2.26	0.153	0.301	0.232	2.50	0.200	–0.528
N_{12}	0.775	0.0998	0.233	0.164	–1.80	2.76	–1 15
N_8	0.692	0.138	0 0833	0.130	2.74	2.09	2.27
ϕ_{24}	2.12	0 108	0.136	0.0833	–2.91	–0.834	3.14
ϕ_{12}	1.38	0.879	0.109	0.0167	2.78	1.18	1.57
ϕ_8	5.03	0.221	0.448	0.118	0.634	1.93	–1.43

Table 4. Annual coefficients of foF2 for Tiruchirapalli.

	A_{00}	A_{12}	A_{06}	A_{04}	ϕ_{12}	ϕ_{06}	ϕ_{04}
N_0	5.85	0.816	1.18	1.08	3.03	2.78	2.86
N_{24}	1.98	0.173	0.530	0.378	-3.01	3.00	-2.42
N_{12}	0.708	0.197	0.196	0.121	-1.21	2.92	-0.0185
N_8	0.742	0.198	0.0726	0.142	-2.96	0.639	-2.78
ϕ_{24}	2.07	0.0884	0.192	0.190	1.73	0.0752	-0.0184
ϕ_{12}	1.56	0.867	0.444	0.367	2.71	0.751	-1.53
ϕ_8	0.524	0.242	0.304	0.154	-110	2.70	0.219

The monthly mean foF2 at every hour was then calculated for each month for the low solar activity period. The results plotted along with the observed data (Figures 1–4) for different

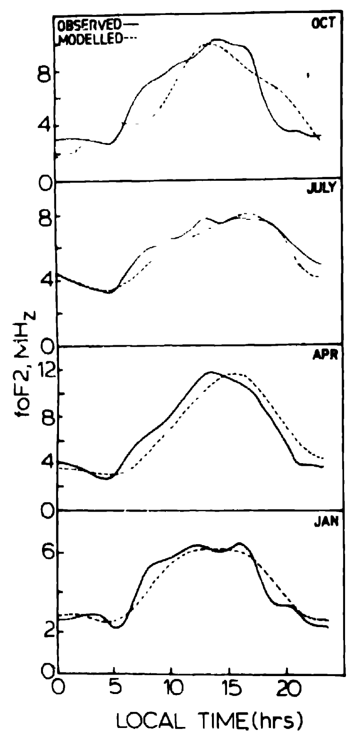

Figure 1. Diurnal variation of the modelled and observed foF2 for four months representative of the four seasons for Delhi station.

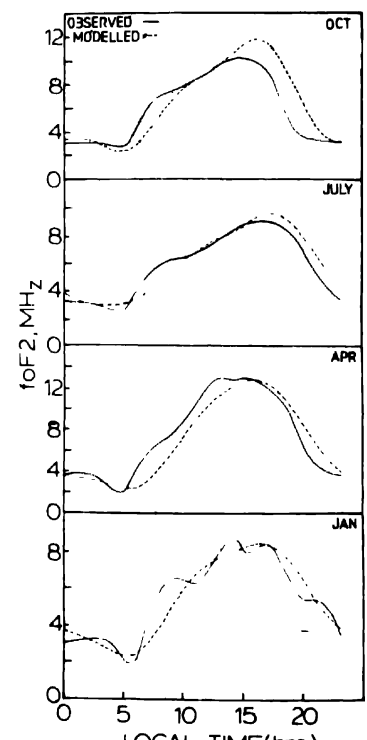

Figure 2. As in Figure 1 for Ahmedabad.

months, show very good agreement between computed and observed data for Delhi, Hyderabad and Tiruchirapalli. The maximum deviation between the two sets remains within 10% for these stations. However, the computed values for Tiruchirapalli in winter did not match so well with the observed data, the deviation at some hours being more than

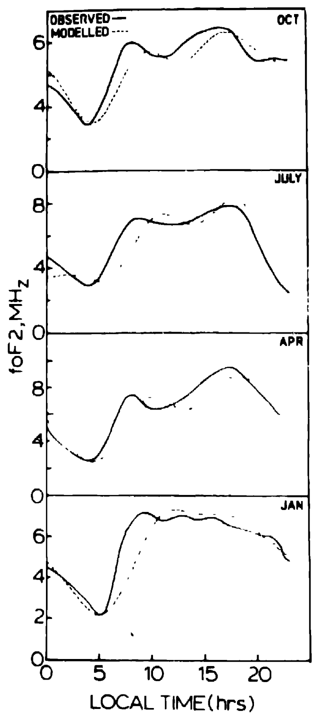

Figure 3. As in Figure 1 for Hyderabad.

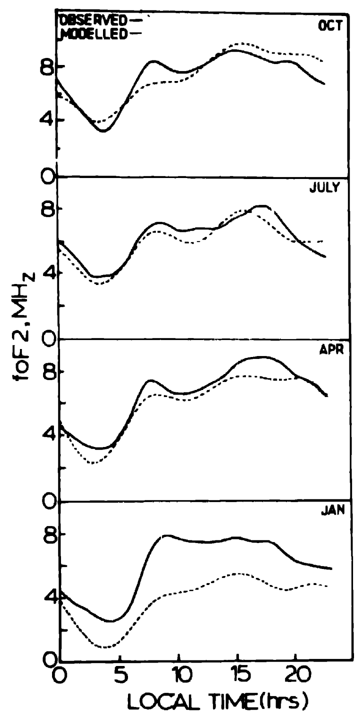

Figure 4. As in Figure 1 for Tiruchirapalli.

20%. The reason for this deviation might be the lack of sufficient data in winter at Tiruchirapalli.

5. Discussion

Following the work of Jones and Gallet [9], empirical models of ionospheric parameters have become an integral part of ionospheric propagation and prediction exercises. In addition to its use in HF radio communication, foF2 is used for correction of ionospheric refraction errors in radio astronomical observations [10]. In 1966, CCIR adopted a set of numerical coefficients that could be used to obtain the monthly median foF2 at any given space-time configuration on the globe. These coefficients were later updated [11,12] with a view to achieve more realistic representation of temporal and spatial variation of foF2 worldwide. Efforts are still continuing in this direction. Uncertainties in the maps of foF2 resulting mainly from inadequate representation of different regions of the globe and due to large variability to the F2 region electron density lead to errors in any ionospheric prediction scheme that uses these maps. At low latitudes, the scenario further worsens as a result of the existence of equatorial ionization anomaly which depending on local time and season, strongly influences the latitudinal structure. The International Reference Ionosphere (IRI) sponsored by URSI was first published in 1978 [13] and its latest updated version is IRI-90. Its standard option relies on the CCIR maps. Though the IRI is fairly comprehensive and broadbased, the low latitude component, particularly over India, is not adequately represented inspite of voluminous ionospheric data available from ionosonde stations in the Indian zone. In this context, the present model partly fills the void and can be used as an additional input to IRI for subsequent use in radio propagation prediction and ionospheric error correction schemes.

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