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NEW *B0* AND *B1* MODELS FOR IRI

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ABSTRACT

The electron density profile in the F region bottomside is described in the International Reference Ionosphere (IRI) by two parameters: a thickness parameter *B0* and a shape parameter *B1*. The models used for *B0* and *B1* in IRI are based on ionosonde data from magnetic mid-latitude stations. Comparisons with ionosonde data from several stations close to the magnetic equator show large discrepancies between the model and the data. We propose new models for *B0* and *B1* based on data from several ionosondes including low and mid latitude stations. Close to the magnetic dip equator the new *B0* model provides an improvement over the current IRI model by a factor of up to 1.5.

INTRODUCTION

The region right below the F2 peak, i.e. the bottomside F region, is represented in IRI by the formula

$$N(h)/NmF2 = \exp\{-x^{B1}\}/\cosh\{x\}, \quad x = (hmF2 - h)/B0 \qquad (1)$$

It can easily be shown that *B0* is the height difference between hmF2 and the height h0.24 where the electron density profile has dropped down to 0.24*NmF2 (x=1). *B0* therefore provides a measure of the thickness of the bottomside profile. *B1* determines the shape of the profile between hmF2 and h0.24: the larger *B1*, the larger the densities in that region. In the current IRI *B1* is set equal to a constant value of 3. If merging between the F2 bottomside profile and the E-valley profile from below can not be accomplished then *B1* is increased in increments of 0.5 up to a value of 5.

Two options are provided for the parameter *B0* in IRI. The standard model is based on a table of values deduced from ionosonde measurements (Ramakrishnan and Rawer, 1972; Bilitza, 1990). The other option is based on Gulyaeva's (1987) model for the half-density height; this height is defined as the height where the bottomside density has dropped down to half the F2 peak density. Comparisons with data have shown that both options have considerable shortcomings at low latitudes (e.g., Reinisch and Huang, 1996; Adeniyi, 1997). This is not surprising since both models are based primarily on data from middle latitudes with a few additional data points from low and equatorial latitudes. In our present study we present data from several stations that have not yet been used in the IRI development and we deduce a new table of *B0* values that we propose for use in the next version of IRI.

DATA USED

Our study is based on the ionosonde data listed in Table 1. All *B0* and *B1* values were obtained by using the POLAN ionogram inversion program (Titheridge, 1985) modified to also determine the best fit *B0* and *B1* values for each true-height electron density profile (Titheridge, 1995). The Wuchang data and analysis was described in detail by Zhang and Huang (1998).

TABLE 1. Location and Time Period of Data Used in this Study

Station	*Lat.*	*Long.*	*Modip*	*Solar activity (Rz12)* *Time period*		*Winter/Spring/* *Summer/Fall*	*Noon* *Midn.*	*Number of points* *for averages*
Wuchang, China	30.6	114.3	39.5	10-17 7/95-6/96	146 12/90-9/91	Dec/Mar/ June/Sep	12 LT 0 LT	20
Ouagadougou, Burkina Faso	12.4	358.5	5.7	27-34 1994	142-146 1991	Jan/Apr/ Jul/Oct	10-14 22-2	15
Korhogo, Ivory Coast	9.3	354.6	-1.8	27-37 1/94-10/94	55-76 10/92-7/93	Jan/Apr/ Jul/Oct	10-14 22-2	15
Ibadan, Nigeria	7.4	356.1	-6.6	3-15 1964	93-129 1960	Jan/Apr/ Jul/Oct	12 LT	5-30
Tucuman, Argentina	-26.9	294.6	-21.2	13-15 1976	65-80 1971	Jul/Oct/ Jan/Apr	12 LT 0 LT	3-31 (Jan: 3-9 only).
Buenos Aires, Argentina	-34.6	301.5	-31.6	15-23 1975	142-148 1991	Jul/Oct/ Jan/Apr	12 LT 0 LT	10-30
San Juan, Argentina	-31.5	290.4	-27.9	65-80 1971	140-146 1981	Jul/Oct / Jan/Apr	10-14 22-2	10-30

B0 PARAMETER MODEL

The current IRI table-option for *B0* is based on *B0* values for a mid latitude (modified dip latitude = modip =45°) and a low latitude (modip=18°) location, for midday (LT=12) and midnight (LT=0), for low (Rz12 =10) and high (Rz12=100) solar activity and for all four seasons. The values currently used in IRI for these conditions are included in Table 2. For intermediate times and location an interpolation scheme is employed as follows. A linear interpolation is used in solar activity up to a sunspot number (Rz12) of 150. A constant value is assumed above that level. For the diurnal variation IRI assumes a smooth transition from a constant daytime value to a constant nighttime value; this diurnal pattern is modeled with Epstein step functions at sunset and sunrise. Epstein transition functions are used to represent the modip variation assuming linear variation of *B0* in each modip segment with smooth transitions at the modip boundaries. The modip segments are defined by the segment boundaries at +45°, +18°, -18° and +45°, whereby the hemispherical differences are assumed to be fully represented by the seasonal differences. For northern summer the four anchor points are therefore *B0*(18°,summer), *B0*(45°,summer), *B0*(18°,winter), *B0*(45°,winter). For modip latitudes beyond 45° a constant value is assumed, e.g. *B0*(modip>45°) = *B0*(modip=45°). The pre-1993 IRI also assumed a constant *B0* value in the equatorial region from modip=18° to modip=-18°. Because of the severe underestimation of *B0* values in the equatorial ionosphere in 1993 a pseudo *B0* anchor point was introduced at modip=0° (see Bilitza, 1998). For the same reasons a special IRI Task Force Activity was started in 1994 at the International Center of Theoretical Physics (ICTP) (Radicella et al., 1998) with the goal to assemble a representative data base of *B0* values from stations close to the magnetic equator and to recommend *B0* values for IRI for modip=0. Our paper describes the result of this effort.

For all our data sets we have computed averages for a noon and a midnight LT time period in each season. The exact time periods and number of points are indicated in the previous section. Assuming linear variation with the 12-month-running mean of sunspot number, Rz12, we then established the average *B0* values for Rz12 =10 and Rz12=100, based on the low and high solar activity data given for each location. The results are listed in Table 2 together with the values currently used in IRI. For the two stations closest to the

TABLE 2. Average *B0* values for different conditions.

	LT=12								LT=0							
	Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall	
Modip V | Rz12=	10	100	10	100	10	100	10	100	10	100	10	100	10	100	10	100
45 IRI	57	76	72	102	83	120	75	107	76	86	84	100	89	110	85	103
39 Wuchang	75	93	94	114	112	145	94	114	64	78	74	79	77	80	74	79
18 IRI	75	94	114	113	134	150	128	138	73	132	64	115	77	116	66	123
6 Ouagadougou	159	185	191	244	189	218	164	210	75	67	70	83	66	95	74	71
-2 Korhogo†	119	230	119	230	119	230	119	230	54	88	54	88	54	88	54	88
-7 Ibadan†	184	221	184	221	184	221	184	221								
-21 Tucuman	81	98	102	147	133	173	106	105	75	80	70	81	82	103	70	70
-28 San Juan	67	83	78	87	139	140	59	120	74	81	78	84	100	100	76	82
-32 Buenos Aires	65	79	79	112	113	152	85	84	109	117	105	110			110	92

† data averaged over all seasons

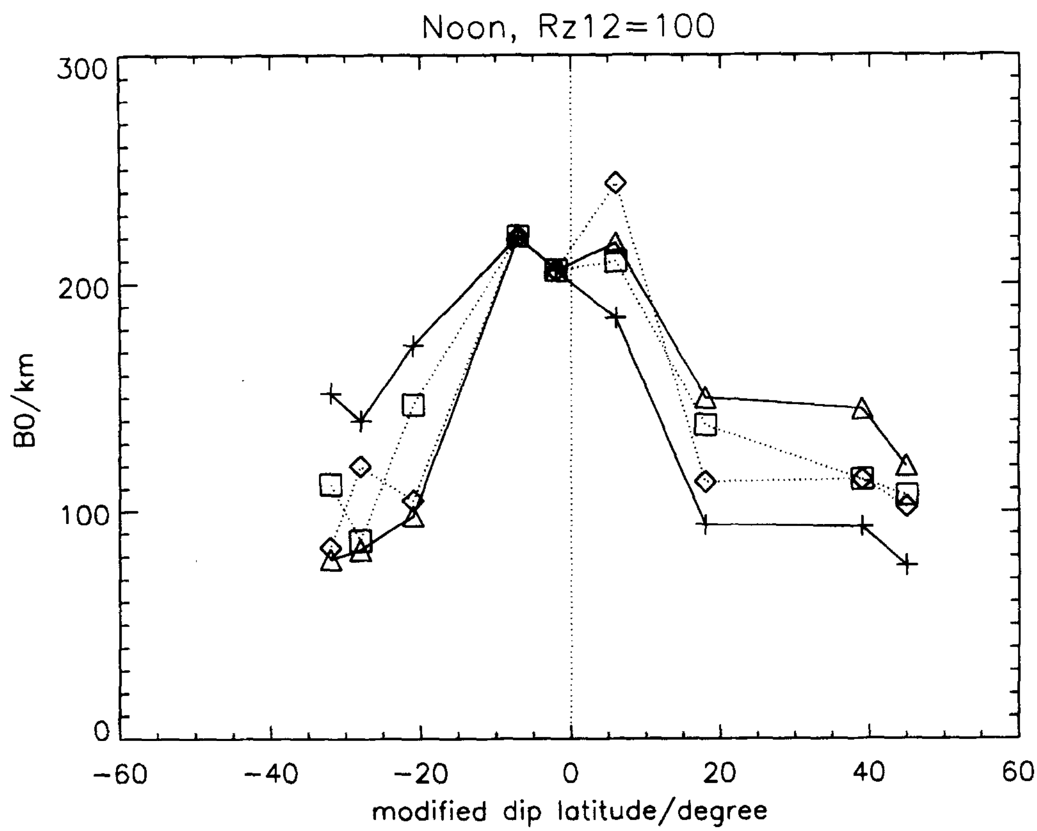

Fig. 1. Variation of the average *B0* values with modified dip latitude for local noon, high solar activity (12-months-running mean sunspot number RZ12=100) for January (plus signs), April (diamonds), July (triangles), and October (squares).

geographic equator (Korhogo and Ibadan) we had only a small amount of data and since the observed seasonal changes are small, we have not separated the data for these stations by season. In Figure 1 the B0 values for noon and high solar activity are plotted versus modified dip latitude for both hemispheres.

Analyzing these data we observe the following trends:
* The largest values of *B0* are found at equatorial latitudes.
* Noon values are generally larger than midnight values and the day-night difference is largest at the magnetic equator; the current IRI actually predicts quite often a larger *B0* value during nighttime, especially for modip=45° and Rz12=10.
* *B0* for high solar activity is in general larger than for low solar activity with a few exceptions during nighttime. The amplitude of the solar cycle variation is largest at the magnetic equator and small for mid-latitudes.
* *B0* values are highest in summer and lowest in winter (see Figure 1). Seasonal changes are most pronounced at middle latitudes.

In Figures 2a,b,c,d,e,f,g,h we have plotted the *B0* values from Table 2 versus modip for the different seasons and solar activities considered in the IRI table-option. Each plot shows midnight (diamonds) and noon (plus signs) values. Based on these plots we have deduced a new set of *B0* values for the table-option now also including a modip=0° case. These new values are listed in Table 3.

TABLE 3. New *B0* Table

		Winter		Spring		Summer		Fall	
Modip	**Rz12**	**LT=12**	**LT=0**	**LT=12**	**LT=0**	**LT=12**	**LT=0**	**LT=12**	**LT=0**
0	10	199	67	201	68	210	61	192	68
0	100	230	65	240	80	245	83	233	71
18	10	77	75	108	65	142	81	110	68
18	100	96	112	124	98	164	100	120	94
45	10	65	70	78	81	94	84	81	81
45	100	81	78	102	87	127	91	109	88

Figures 2 also include the current IRI table-option for *B0* (solid lines) and our newly proposed model (broken lines) based on Table 3. The current IRI model clearly underestimates the observed daytime *B0* close to the magnetic equator for all the cases considered here (all seasons, high and low solar activity). At nighttime the observations are below the IRI predictions for all seasons during high solar activity. Our new model corrects both of these serious shortcomings of the IRI model.

B1 PARAMETER MODEL

In the present IRI model the bottomside shape parameter *B1* is generally set to a constant value of 3 unless forced to higher values by continuity requirements. *B1* is used in the current IRI computer program to facilitate the merging between the bottomside and E-region profiles; if merging is not possible *B1* is changed from 3 to 3.5 to 4 and so on up to 5. This of course leads to discontinuities and has long been noted as one of the shortcomings of the current modeling approach. Reinisch and Huang (1998) showed that bottomside profiles can be much better represented by Formula (1) if one allows not only *B0* to vary with time and location but also *B1*. All our ionosonde true-height profiles were obtained from fitting procedures that allowed *B1* to vary.

The *B1* values in Figure 3 were obtained from bottomside profiles measured at Korhogo, Ouagadougou, and San Juan. The data exhibit a distinct day/night variation but little change with solar activity, modip and

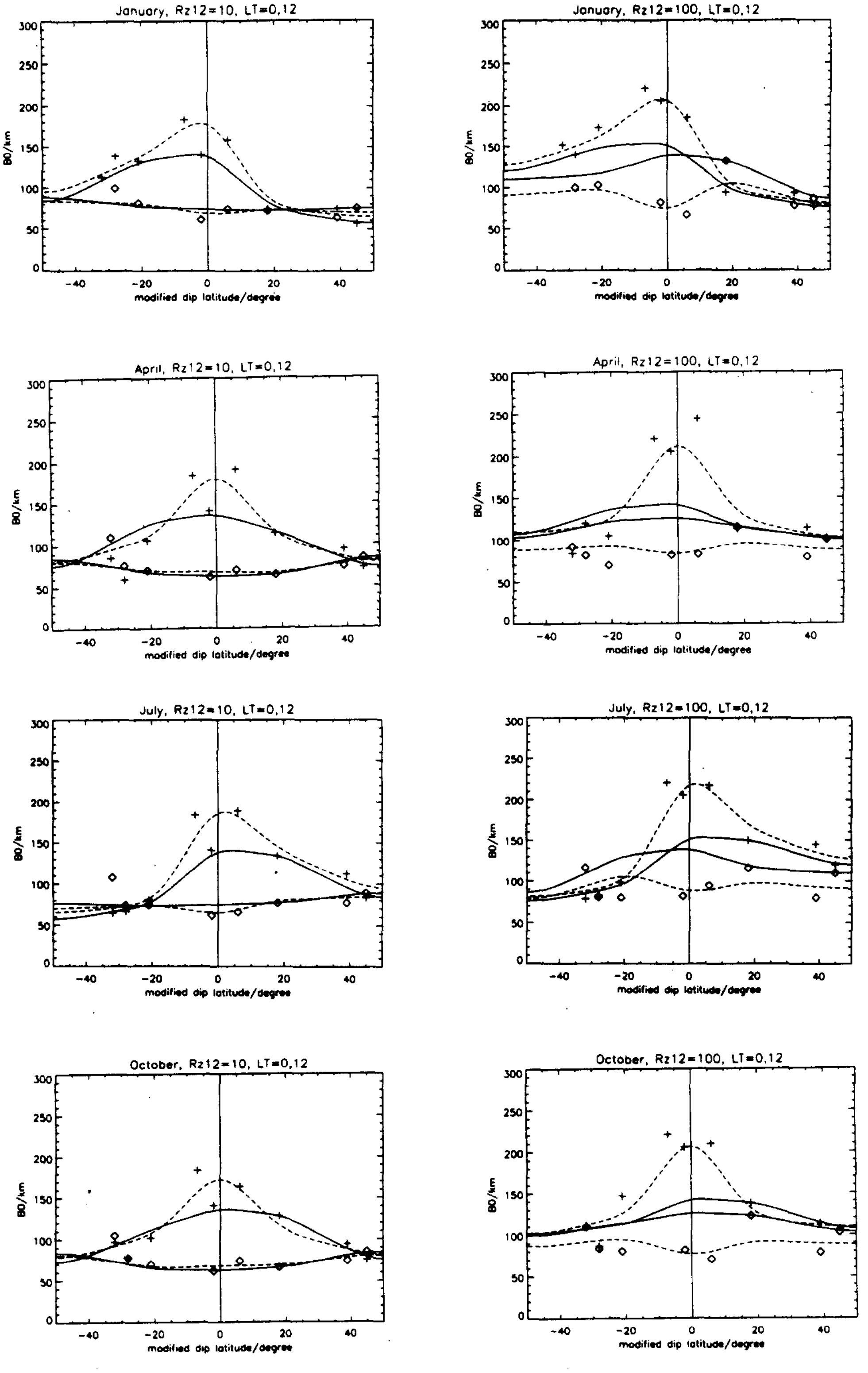

Fig. 2a,b,c,d,e,f,g,h. Average *B0* values versus modified dip latitude for local noon (plus signs) and midnight (diamonds) for different conditions (as indicated at the top of each panel). Also included are the current *B0* model (solid line) and the new *B0* model (broken line) proposed by this study. NOTE: The currently used IRI values are the values at modip=18 and 45.

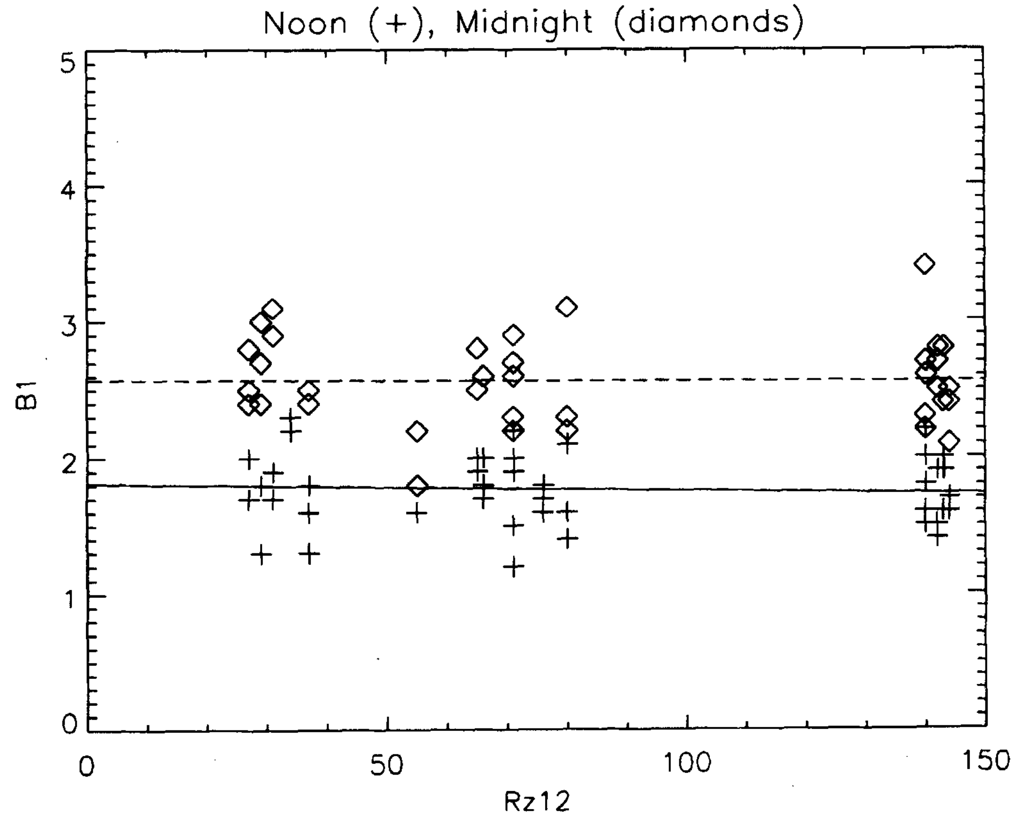

Fig. 3. Average *B1* values obtained at San Juan (Argentina), Ouagadougou (Burkina Faso), and Korhogo (Ivory Coast) versus 12-month-running mean sunspot number (Rz12) for all seasons, and for LT=11-13 (plus signs) and LT=23-1 (diamonds). Also shown is the least-square fitted linear representation of the day (solid line) and night (broken line) data.

season. Based on our set of data we recommend a constant value of 1.9 during daytime and 2.6 during nighttime. If we look at the stations individually we find a slight decrease of *B1* with increasing solar activity for stations close to the magnetic equator, but this variation is within the RMS spread of the data. A value of 3, as used in IRI, is clearly the upper limit for the data shown here. So rather than increasing *B1* from 3 upward, IRI should really decrease *B1* downward if *B1* needs to be changed in an attempt to facilitate merging between the E and F layers.

Reinisch and Huang (1998) studied the diurnal variation of B1 obtained from profiles measured at Jicamarca (Peru), Ramey (Puerto Rico), and Puerto Madryn (Argentina) during moderate solar activity. Their results agree with our study for daytime, but during nighttime the Jicamarca and Ramey B1 values reach as high as 5 and 6; the Puerto Madryn nighttime data are close to the average of 2.6 suggested by the present study.

CONCLUSIONS

We have presented a new table of *B0* values for IRI based on ionosonde measurements from Wuchang (China), Ouagadougou (Burkina Faso), Korhogo (Ivory Coast), Ibadan (Nigeria), Tucuman, Buenos Aires, and San Juan (all Argentina). With our new values IRI will provide a more realistic representation of the bottomside electron density profile in the equatorial ionosphere. The increase of the *B0* thickness parameter in this region by a factor of up to 1.5 will not only help to alleviate the underestimation of observed bottomside densities that have been found particularly during high solar activity (Adeniyi, 1997) but it will also lead to increased total electron content (the bottomside contributes about 1/4th to 1/3rd of the ionospheric content) and thus help to overcome another shortcoming of the IRI model; the underestimation of ionospheric content at equatorial latitudes was, for example, noted by Batista et al. (1994).

Concerning the shape parameter *B1* we find that the current IRI value of 3 is at the upper limit of the observations. Based on our data we recommend that IRI uses a value of 1.9 during daytime and of 2.6 during nighttime. The discrepancies at nighttime with the results of the study by Reinisch and Huang (1998), however, suggest that a more comprehensive global B1 database is required to establish a reliable representation for this bottomside parameter.

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