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IRI TASK FORCE ACTIVITY AT ICTP: PROPOSED IMPROVEMENTS FOR THE IRI REGION BELOW THE F PEAK

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ABSTRACT

The Aeronomy and Radiopropagation Laboratory of the International Center for Theoretical Physics (ICTP) in Trieste, Italy has hosted special IRI Task Force Activities (TFAs) annually since 1994. This article reviews the format and results of the 1994, 1995, and 1996 TFAs. The prime focus of these TFAs has been the F1 region and the bottomside F2 region. Each meeting has tackled a specific subset of modeling problems using morning round-table discussions and afternoon computer sessions to solve the 'problem of the day'. Data, models and related software were provided by the participants on electronic media or were retrieved over the internet. As a result of this effort several improvements have been proposed for the IRI description of the region below the F2 peak: (1) A more accurate description of the probability of the existence of the F1 layer, (2) A more realistic description of the bottomside thickness parameters, (3) A set of new anchor points to define the intermediate region between the E valley top and the bottomside F2 region.

INTRODUCTION

The International Reference Ionosphere (IRI) is a joint project and Working Group of the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). The charter is to establish and improve a standard ionospheric model for use in satellite design and environment studies (COSPAR) and for radio propagation studies (URSI). During annual IRI Workshops shortcomings and improvements of the IRI model are discussed and new additions and enhancements are proposed. The meetings are also the time when special task groups report about their progress and new task groups are formed to tackle specific problems. In 1993 the annual IRI workshop was held at the International Center for Theoretical Physics (ICTP) in Trieste, Italy organized by ICTP's Aeronomy and Radiopropagation Laboratory. The very successful and productive meeting resulted in better descriptions of several IRI parameters and was a critical milestone on the route to the IRI-95 version of the model. The papers presented at the meeting can be found in Advances in Space Research, Volume 15, Number 2, 1995 (editors: K. Rawer, W.R. Piggott, and A.K. Paul).

An important outcome of the 1993 IRI Workshop was the initiation of a special IRI Task Force Activity (TFA) at ICTP focusing on the electron density profile in the region between the E and F peaks and starting with the 1997 TFA also on the topside profile. ICTP is the perfect partner in this undertaking since one of its goals is to provide a forum for the exchange of ideas, expertise and data between developing and developed countries. IRI depends strongly on such an exchange since it needs to provide a balanced global mapping of ionospheric parameters. Currently some of IRI's major shortcomings are in the equatorial and low latitude region, i.e. a zone where many of the developing countries are located. By improving IRI at low latitudes the TFAs also provide a service back to the developing countries in the form of more reliable ionospheric predictions for telecommunications and of more accurate ionospheric corrections for Earth observations from space (e.g. satellite altimetry).

WORKSHOP FORMAT AND PARTICIPANTS

To accomplish the set task the IRI team decided to test an approach different from the traditional meeting and workshop format. A small group of modellers and data providers, about half and half from developing and developed countries, met in front of computer terminals and blackboards to discuss and resolve a specific IRI modeling problem. The specific TFA modeling problem was divided into six well-defined well-focused science questions. These topics were than tackled (one a day) during the TFA week. During round-table discussions and presentations in the morning, a strategy was developed for testing and exploring particular modeling issues and assumptions. This was followed in the afternoon with 2-3 person teams in front of computer terminals with access to ICTP's computer and network connectivity.

Task Force Activities were held in July 1994, November 1995, August 1996 and June 1997. The core task team included J.O. Adeniyi (Nigeria), D. Bilitza (USA; IRI Chair), M.E. Mosert Gonzalez (Argentina), S.M. Radicella (ICTP, local organizer), B.W. Reinisch (USA; IRI Vice-Chair), M.-L. Zhang (China), S.-R. Zhang (China), B. Zolesi (Italy). In addition the following scientists participated in at least one TFA meeting: J. Boska (Czech Rep.), G. Franceschi (Italy), T. Gulyaeva (Russia), R. Leitinger (Austria), S. Pulinets (Russia), C. Luigi (Italy), K. Mahajan (India), M. Moorhead (UK), C. Scotto (Italy), P. Spalla (Italy), and J. Titheridge (New Zealand).

DATA AND SOFTWARE

The TFA topics were studied with data from the a number of ionosonde stations whose geographic coordinates and modified dip values are listed in Table 1.

TABLE 1. List of Ionosonde Stations that contributed data to the TFAs

	Latitude	Longitude	Modip
Lannion, France	**48.8**	**356.6**	**48.2**
Poitiers, France	**46.6**	**0.3**	**53.2**
Beograd, Yugoslavia	**44.8**	**20.5**	**52.0**
Wrumchi, China	**43.8**	**87.7**	**51.9**
Millstone Hill, USA	**42.6**	**288.5**	**56.0**
Roma, Italy	**41.9**	**12.5**	**49.3**
Wuchang, China	**30.6**	**114.3**	**39.5**
Chongqing, China	**29.5**	**106.4**	**38.2**
Ramey, Puerto Rico	**18.5**	**292.9**	**41.8**
Ouagadougou, Burkina Faso	**12.4**	**358.5**	**5.7**
Ibadan, Nigeria	**7.4**	**356.1**	**- 6.6**
Jicamarca, Peru	**-12.0**	**283.1**	**- 2.8**
Tucuman, Argentina	**-26.9**	**294.6**	**-21.2**
Buenos Aires, Argentina	**-34.6**	**301.5**	**-31.6**
San Juan, Argentina	**-31.5**	**290.4**	**-27.9**
Port Madryn, Argentina	**-42.7**	**294.7**	**-39.3**
Ushuaia, Argentina	**-54.8**	**291.7**	**-49.3**

In addition data were used from the EISCAT incoherent scatter radar facility in Tromsø, Norway (69.7N, 19.0E). Satellite Langmuir Probe and Retarding Potential Analyzer data from the Atmosphere Explorer C, D, and E satellites were obtained from the AE CD-ROM created by the World Data Center A for Rockets and Satellites in Greenbelt, Maryland. Another CD-ROM data set that was very helpful for the TFAs was the ionosonde data CD-ROM created by the World Data Center A for Solar-Terrestrial Physics in Boulder, Colorado.

An important topic during the TFAs was ionogram reduction software. B. Reinisch made available the ARTIST true height program developed at the University of Massachusetts in Lowell (UML) which is used in the Digisondes. J. Titheridge provided his POLAN true height program. As a result of the TFA both programs where enhanced and now also include the computation of the IRI bottomside parameters B0 and B1. B. Reinisch and his group also contributed the software for computing the Average Representative Profile (ARP) (Huang and Reinisch, 1996).

A theoretical model of the middle ionosphere developed by Zhang and Huang (1995) was used to study the dependence of F1 region electron densities on different physical parameters such as the ion transition height from O^+ to molecular ions and the height that marks the transition from the lower photochemistry-dominated region to higher up where dynamics are of paramount importance.

More information about the activity and summary reports can be found at the IRI Web-site: http://nssdc.gsfc.nasa.gov/space/model/ionos/iri.html. The presentations and discussions of the 1995 and 1996 TFAs were published in special ICTP Reports (Radicella, 1996, 1997). A similar publication is also planned for the 1997 TFA papers.

F1 LAYER

The well established Ducharme et al. (1973) model is used in IRI to represent the F1 critical frequency foF1. This model is based on a large amount of ionosonde data. In addition to giving monthly median foF1 values it also provides criteria for the occurrence of an F1 layer by specifying the cut-off limiting solar zenith angles beyond which it cannot occur; they are given as a function of the geomagnetic latitude φ, and the 12-month running mean of the sunspot number R_{12}. Data-model comparisons presented during the TFAs confirmed that (i) if an F1 layer is present its critical frequency is well predicted by the model, and (ii) the F1 occurrence criteria often underestimate the actual diurnal and seasonal time span for which an F1 layer is observed. IRI actually uses a slightly modified version of the model based on follow-on work and recommendations by one of the model authors (Eyfrig). These changes are: (1) specifying the median foF1 values as function of magnetic dip latitude rather than geomagnetic latitude, (2) limiting F1 layer occurrence to daytime and to non-winter months. Overall the data-model comparisons presented during the TFAs showed that the occurrence criteria are too restrictive and in many cases IRI did not predict an F1 layer even though it was clearly present in the data (see Figures 1, 2, 3).

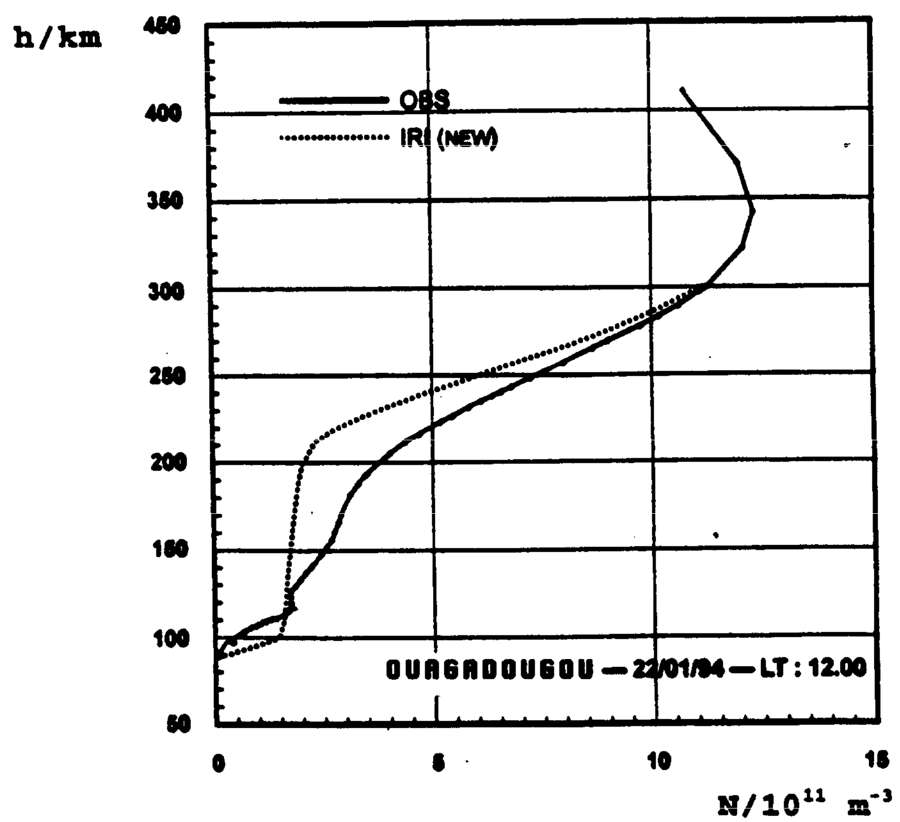

Fig. 1. Local Noon Profile Corresponding to an Ionogram with a well Defined F1 Cusp for Ougadougou, Burkina Faso during Winter and Low Solar Activity (IRI does not Predict an *foF1* in Winter); *IRI(NEW)* is using the Gulyaeva option for the F2 bottomside thickness *B0*.

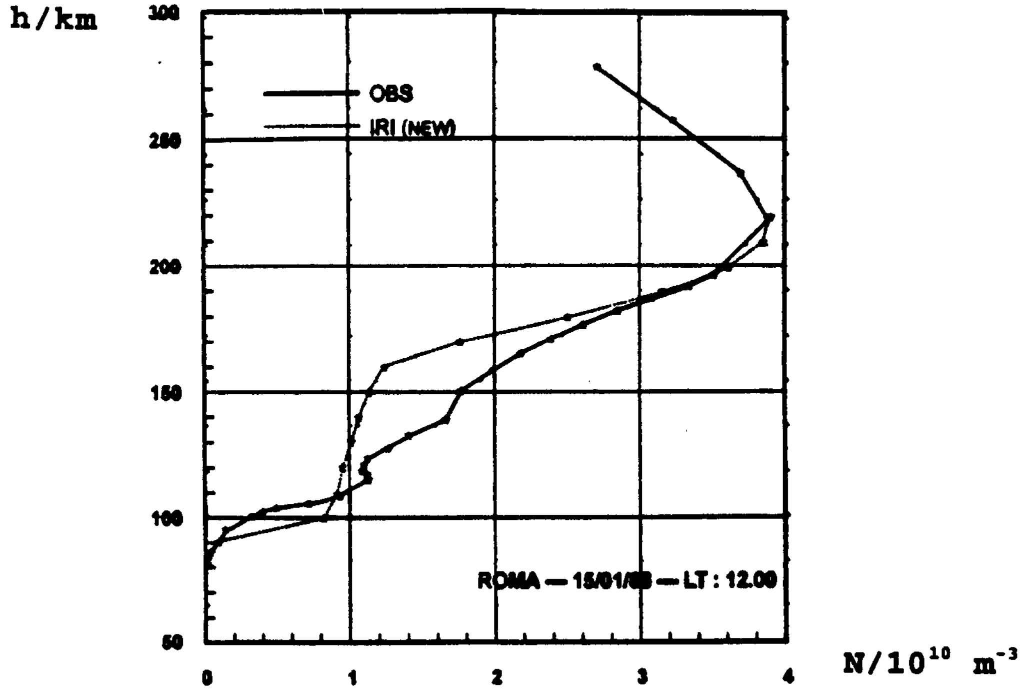

Fig. 2. Local Noon Profile Corresponding to an Ionogram with a well Defined F1 Cusp for Roma, Italy during Winter and Low Solar Activity (IRI does not Predict an *foF1* in Winter); *IRI(NEW)* is using the Gulyaeva option for the F2 bottomside thickness *B0*.

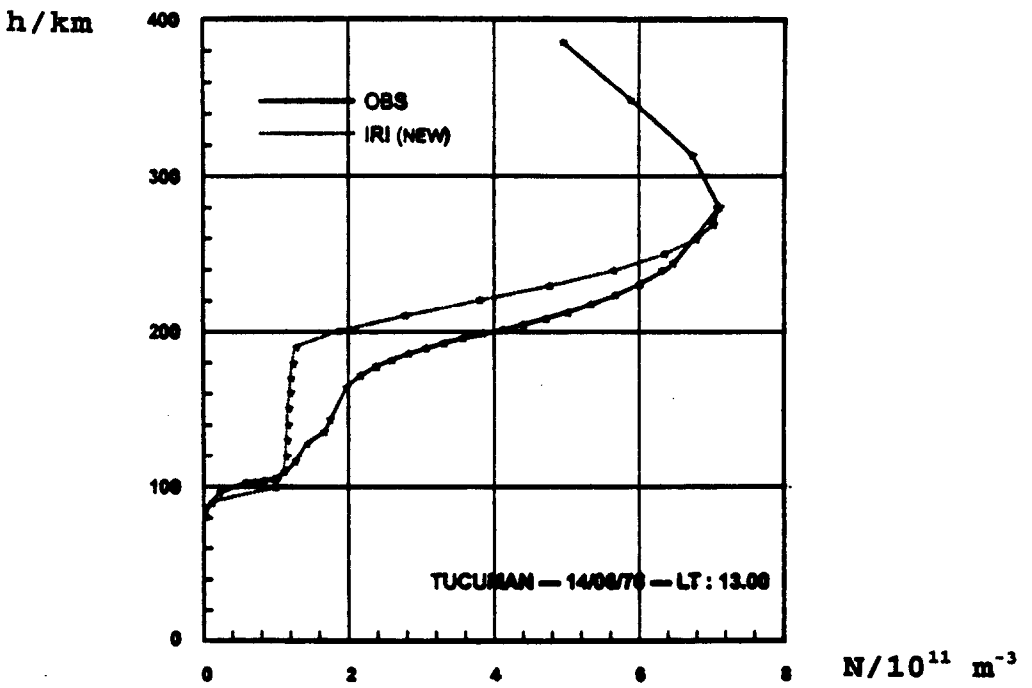

Fig. 3. Local Noon Profile Corresponding to an Ionogram with a well Defined F1 Cusp for Tucuman, Argentina during Winter and Low Solar Activity (IRI does not Predict an *foF1* in Winter); *IRI(NEW)* is using the Gulyaeva option for the F2 bottomside thickness *B0*.

To overcome the shortcomings in F1 occurrence predictions, Scotto et al. (1997) proposed the use of an F1 occurrence probability function instead of the simple on-off condition given by Ducharme's limiting solar zenith angles. The function is of the form

$$P(\chi,\varphi,R_{12}) = (0.5+0.5\cos\chi)^{\gamma} \tag{1}$$

where χ is the solar zenith angle, φ the geomagnetic latitude, and R_{12} the 12-month-running mean of the sunspot number. The model parameter γ and its dependence on φ and R_{12} was determined by fitting Eq. 1 to the large data base of worldwide hourly ionosonde observations from 1969 to 1990 that are available on the Ionospheric Digital Database CD-ROM of the World Data Center A for Solar-Terrestrial Physics in Boulder, Colorado.

$$\begin{aligned} \gamma &= a + b\varphi + c\varphi^2 \\ a &= 2.98 + 0.0854R_{12} \\ b &= 0.0107 - 0.0022R_{12} \\ c &= -0.000256 + 0.0000147R_{12} \end{aligned} \tag{2}$$

If L-condition cases are included than the value of γ is found to be approximately 2.36 independent of φ and R_{12}. By international convention ionosonde operators use the descriptive letter "L" in the monthly median tabulation of *foF1* when the ionogram indicates the presence of an F1 ledge even though a clear F1 cusp is not seen.

Inclusion of the new probability function (1) in IRI could provide two enhancements to IRI: (a) an additional parameter (the probability of the presence of an F1 layer) that is of importance for many radio propagation applications, and (b) the criteria P > 0.5 (meaning that a F1 layer is expected for more than half the days of the specific month during the specific hour of the day) could be used to replace the current, clearly insufficient criteria of the limiting solar zenith angles and seasons.

RECOMMENDATION FOR IRI: Inclusion of Eq. 1 in IRI thus giving IRI users the probability of the presence of an F1 layer as a new IRI output parameter; An option to either include or exclude L-condition cases; Replace the current F1 occurrence criteria with criteria based on Equation (1): P > 0.5.

BOTTOMSIDE THICKNESS PARAMETERS

The current IRI bottomside electron density model is based on the work of Ramakrishnan and Rawer (1972) who deduced the following representative formula from a study of composite ionograms from several middle latitude ionosonde stations:

$$N(h)/NmF2 = exp(-x^{B1})/cosh(x), \quad x=(hmF2-h)/B0 \tag{3}$$

Based on their data they established *B1*=3 as the best choice for the exponent and compiled a table of *B0* values for different seasons, local times and latitude ranges as shown in Table 2. As a second IRI option the

TABLE 2. IRI Table for Bottomside Thickness Parameter *B0*.

B0/km		Spring		Summer		Fall		Winter	
		LT = 12	LT = 0	LT = 12	LT = 0	LT = 12	LT = 0	LT = 12	LT= 0
Modip	R = 10	114	64	134	77	128	66	75	73
= 18	R = 100	113	115	150	116	138	123	94	132
Modip	R = 10	72	84	83	89	75	85	57	76
= 45	R = 100	102	100	120	110	107	103	76	86

parameter *B0* can be also deduced from Gulyaeva's (1987) model for the ratio between the half-density height *h0.5* and the F2 peak height *hmF2*; *h0.5* is the height where the bottomside profile has reached half the F2 peak density. Comparisons with data have shown that neither model option adequately describes the low latitude and equatorial F2 layer. This is not surprising since only magnetic mid-latitude data sources were used in developing these models. TFA comparisons alos confirmed this point and showed that of the two options the Gulyaeva (1987) model provides the better results at low latitudes because of its close coupling with *hmF2*.

With respect to the bottomside parameters we found two important results. Firstly, Reinisch and Huang (1998) showed that bottomside profiles can be much better represented by Formula (3) if one allows not only *B0* to vary with time and location but also *B1*. Actually *B1* is not always equal to 3 in IRI, since *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. A variable *B1* is clearly the better solution.

Secondly the TFAs produced a wealth of new data for *B0* and *B1* (see Table 3 and 4) that will be used to improve and extend Table 1 for *B0* and will be used to produce a similar table and model for *B1*. Preliminary tables established during the 1997 TFA will soon be finalized. For the first time these tables will include input from equatorial zone stations (Jicamarca/ Peru, Ouagadougou/Burkina Faso, Ibadan/Nigeria). First comparisons during the 1997 TFA have shown largest improvements in the representation of the low latitude bottomside profile.

TABLE 3. Mean Experimental *B0* and *B1* Parameters and the Corresponding IRI *B0* Values for the Standard Table Option (B0old) and for the Gulyaeva Option (B0new); n is the number of profiles used.

Month	B0exp	B1exp	B0old	B0new
TUCUMAN (n = 45)				
January	150	2	136	205
April	90	1.98	126	115
July	85	2.4	83	82
October	123	1.79	108	167
SAN JUAN (n = 47)				
January	138	1.36	140	166
April	100	1.79	126	119
July	82	1.89	87	77
October	127	1.6	108	153
Bs As (n = 24)				
January	116	1.72	116	170
April	87	1.72	107	95
July	75	2.47	74	71
October	106	1.9	99	152
ROMA (n = 25)				
January	80	2.61	64	70
April	111	2.08	94	109
July	146	1.87	141	162
October	109	2.43	104	108
USHUAIA (n = 20)				
January	110	2.29	116	138
April	63	2.34	104	74
July	78	2.3	61	65
October	81	2.15	92	106

TABLE 4. Mean *B0* Values for Winter (W) and Summer (S) during Low Solar Activity (LSA) and High Solar Activity (HSA).

STATION	B0 W LSA	B0 S LSA	B0 W HSA	B0 W HSA
Ushuaia	80	78	69	108
P. Madryn	-	125	-	-
Buenos Aires	80	104	97	155
San Juan	-	-	83	142
Tucuman	82	109	92	168
Ibadan	209	163	-	-
Jicamarca	210	200	-	-
Ouagoudogou	171	189	-	-
Ramey	120	160	-	-
Rome	65	-	102	146

RECOMMENDATION FOR IRI: Replace the old IRI *B0* table option with the new TFA *B0* table which now includes also equatorial data input; Allow *B1* to vary and use the new TFA *B1* tables for the description of *B1*.

NEW ANCHOR POINTS

The IRI model in its current version does not include separate anchor points in the region between the E-valley top and the F2 peak. The F1 point is not really an independent anchor point because the height of the F1 point, *hmF1*, is found as the point on the bottomside profile where the density reaches the value *NmF1* and is thus determined by the bottomside profile function. As a result one gets different *hmF1* values with the two different options for the bottomside parameter *B0*. Reinisch and Huang (1996) have studied F1 region characteristics deduced from Digisonde measurements and found *hmF1* values to be highly variable much more so than the *NmF1* values. They recommend therefore using the electron density at the fixed height of 170 km and/or 180 km as an independent anchor point. During the TFAs it was confirmed that the variability as a function of height reaches a minimum between 170 km and 180 km. Simulation with the theoretical model of Zhang and Huang (1995) also clearly indicated such a minimum. All said so far relates to daytime since ionosondes do not provide nighttime data for 170 km. During nighttime this region is within the deep nighttime valley between the E and F layers with steep altitudinal gradients and high variability.

As a first step towards a global representation of the electron density at 170 km, data have been collected from ionosonde as well as satellite insitu measurements. Figures 4 and 5 show the latitudinal dependence of the day and night values, respectively, of the density at 170 km (±5 km) as observed by the Atmosphere Explorer C (AE-C) Cylindrical Electrostatic (Langmuir) Probe (CEP). Modeling the nighttime values will be an especially challenging task in view of the large variability which reaches up to two orders of magnitude in Figure 5. A description in terms of solar zenith angle and dip latitude is now in preparation for next year's TFA.

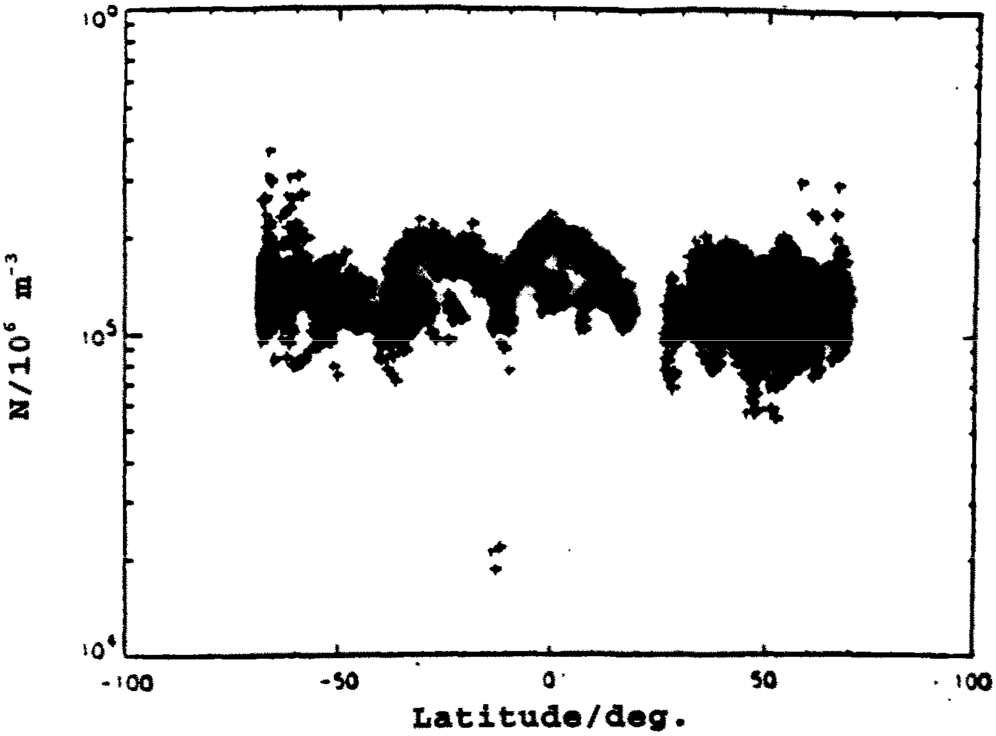

Fig. 4. Latitudinal Dependence of N170 during Daytime (χ < 70°) as Seen by the Atmosphere Explorer C Cylindrical Electrostatic Probe (CEP) Instrument.

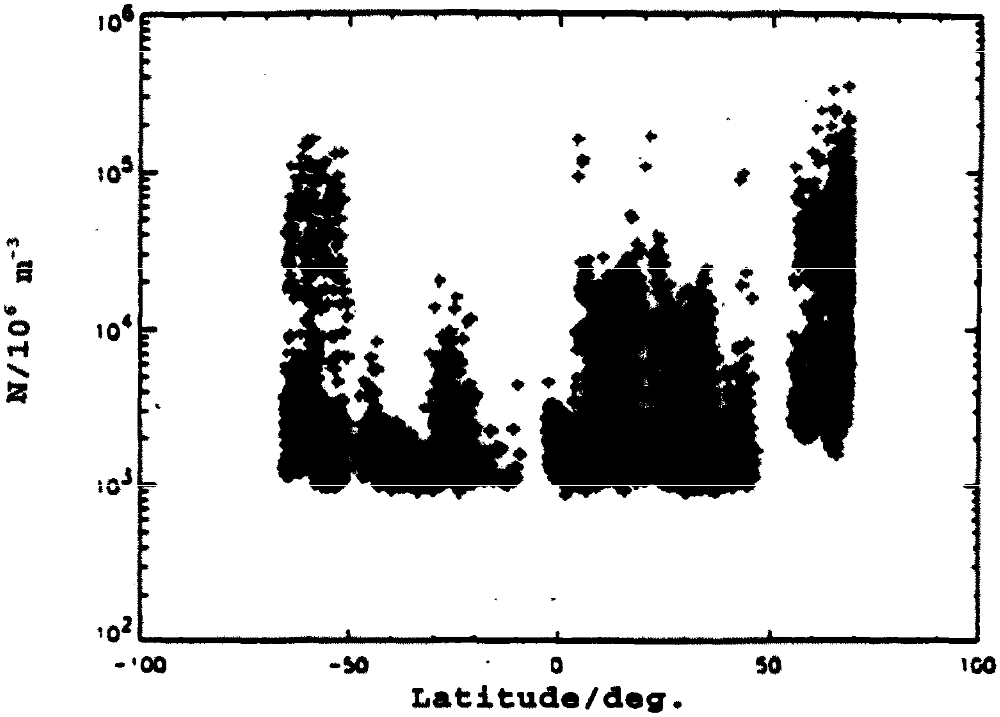

Fig. 5. Latitudinal Dependence of N170 during Nighttime (χ > 100°) as Seen by the Atmosphere Explorer C Cylindrical Electrostatic Probe (CEP) Instrument.

CONCLUSIONS

The IRI Task Force Activity meetings at ICTP have been very successful and resulted in several recommendations for improvements of the IRI model and of ionogram data reduction in general. Specifically the TFA team

- has established a new model for the occurrence probability of an F1 layer,
- has produced a more accurate table option for *B0* resulting in significant improvements in the low latitude zone,
- has produced a new table of values for *B1* which leads to a closer and more flexible representation of the bottomside profile,
- has introduced new anchor points in the intermediate region (between E-valley top and F1 region), and
- has developed first-order global models for these points.

The ICTP Task Force Activity was strongly endorsed by the IRI Working Group during its annual meetings and ICTP was encouraged to continue and possibly expand this type of activity. After each TFA there was a general sense of accomplishment shared by all the participants. The TFAs showed what can be accomplished by a small group of ionospheric scientists with access to computers and networks, focusing on a specific problem area of the IRI model.

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