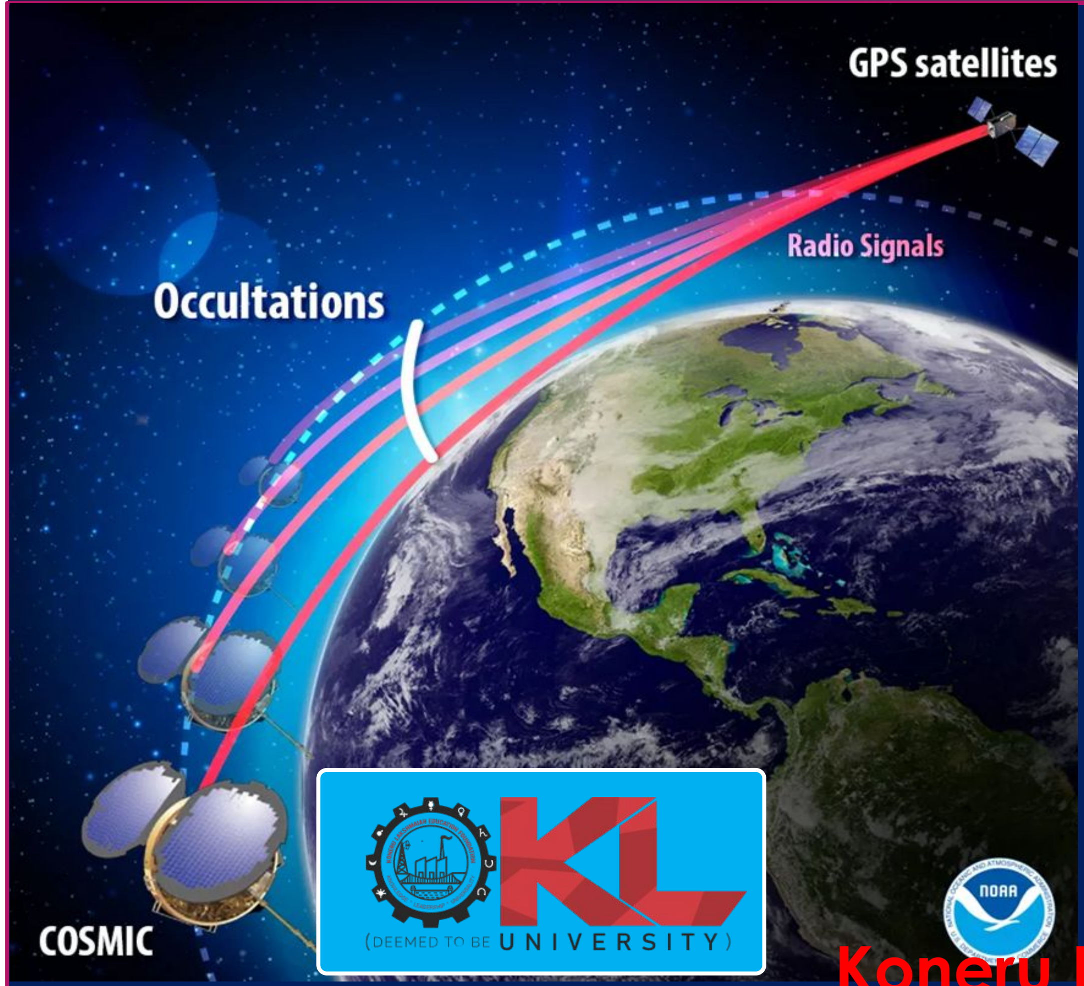
2025 Community Space Weather Modeling & Data Assimilation Workshop
UCAR Foothills Lab campus in Boulder, Colorado



Global Validation of Ionospheric Bottomside Profile Parameters (B0 & B1) from FORMOSAT-7/COSMIC-2 Radio Occultation Profiles with Digisonde and IRI-2020 Model

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Session 2 -11 am

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Outline of the presentation

- Introduction of the Ionosphere
- Electron Density Profile
- Motivation and Challenges
- Importance of Bottomside ionosphere
- Data methodology
- Results
- Conclusion

Introduction – Ionosphere

The ionosphere plays a major role in satellite communication because of high-frequency radio signals passing through the region.

It is a part of Earth's upper atmosphere having a lot of ions and electrons. This ionization mainly depends on the sun and its activity.

The ionosphere reflects and refracts the radio waves, enabling long-distance communication

Variation in the ionosphere will affect the satellite signal, including GPS

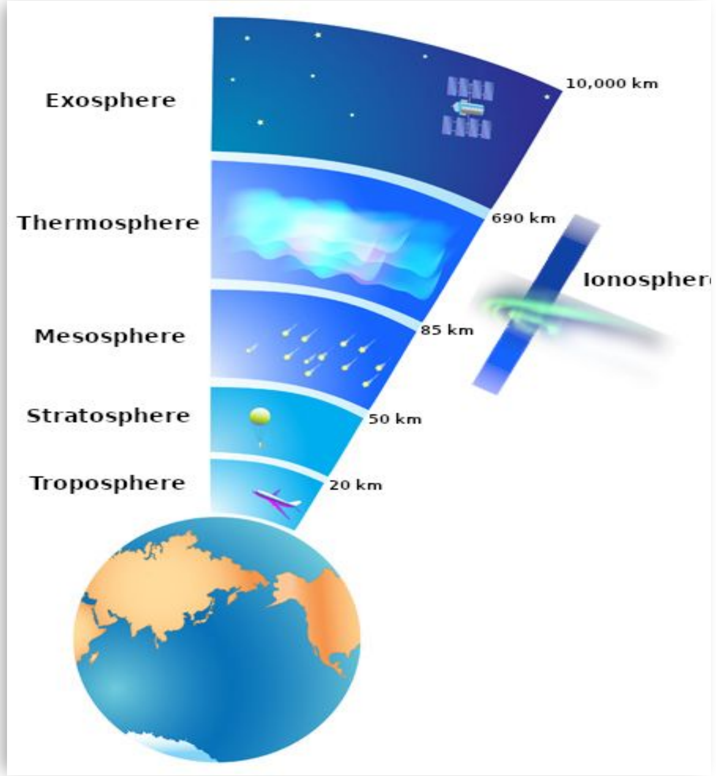
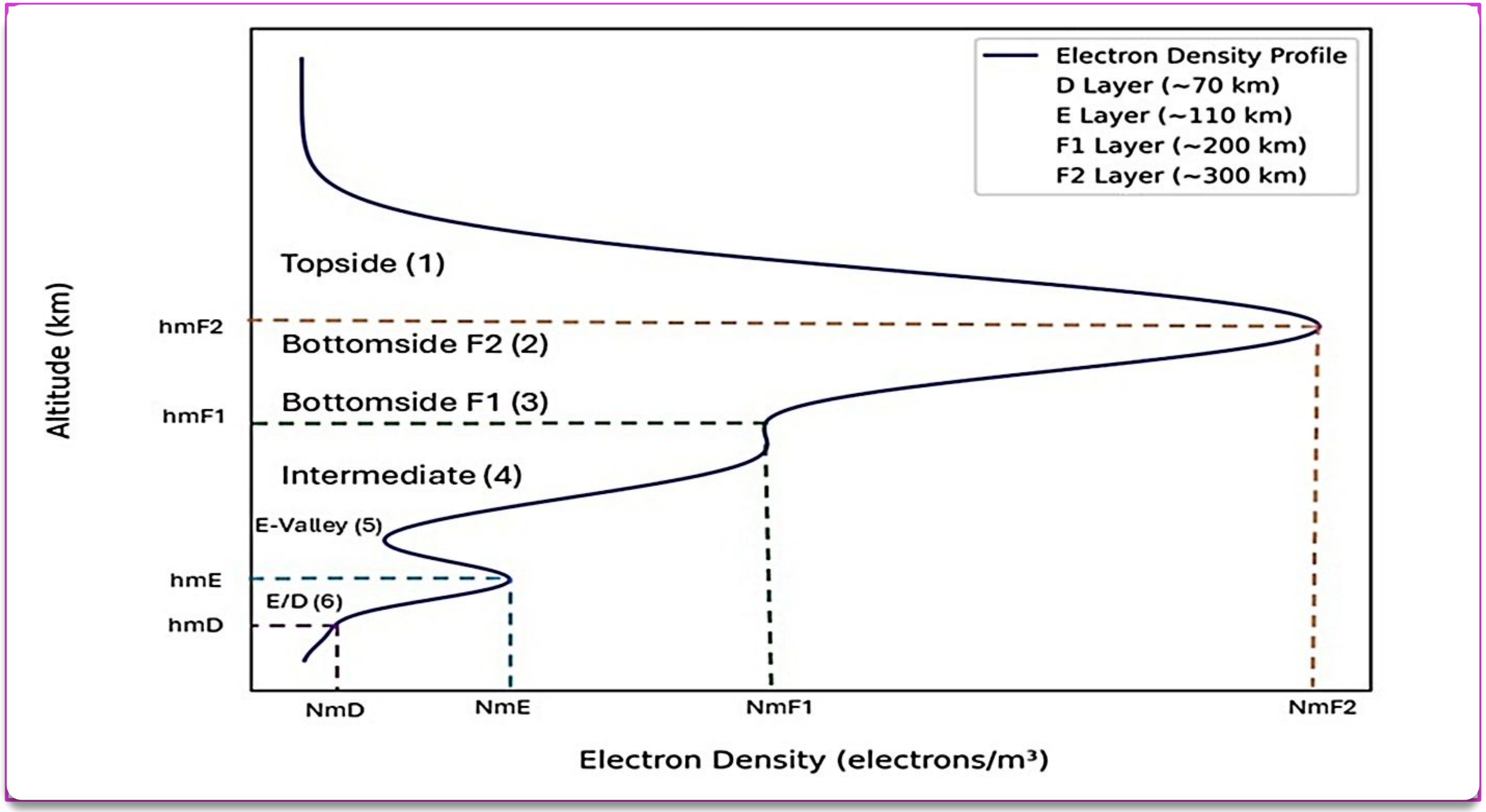


Fig.1 Layers of Earth's Atmosphere

Electron Density Profile and Its Key Parameters

- Peak Electron Density NmF2
- Altitude of peak electron density hmF2
- Bottomside parameters B0 and B1
- Scale height Ht
- Critical Frequency foF2
- Total Electron Content (TEC)



Motivation and Challenges

- Many regions, particularly **low-latitude equatorial** regions, lack sufficient observational data to validate or improve models. This leads to biases in Bottomside profile estimation due to reliance on limited datasets.
- Ground-based Digisondes provide accurate data but have sparse global coverage.
- The bottomside ionosphere, defined by B0 (thickness) and B1 (shape), determines how electron density increases from the E-layer to the F2 peak. Accurate representation of these parameters is essential for reliable estimation of TEC and for improving ionospheric models such as IRI.

Importance of Bottomside Ionospheric Profile Parameters

- Bottomside Thickness parameter (B0) and Bottomside Shape Parameter (B1) are essential for modeling the bottomside ionosphere's structure, which is critical for studying ionospheric dynamics and variations.
- These parameters are integral components of the International Reference Ionosphere (IRI) model
- Both B0 and B1 exhibit **variations with solar activity, season, latitude, and local time**, making them essential for understanding ionospheric responses to these factors.

Objective

- To find B0 and B1 for various locations by using the combination of Digisonde and COSMIC 2 data over a period of 3 years, 2020-2022.
- Analyzing the diurnal, seasonal, and longitudinal variations of ionospheric behavior over low latitude regions.
- Observed results are compared with the recent edition of IRI model, i.e., IRI-2020.

Digisonde stations around the world

Fig.3 Global Digisonde Stations - (https://giro.uml.edu/common/img/giro-map.gif)

COSMIC Satellite Data Sources

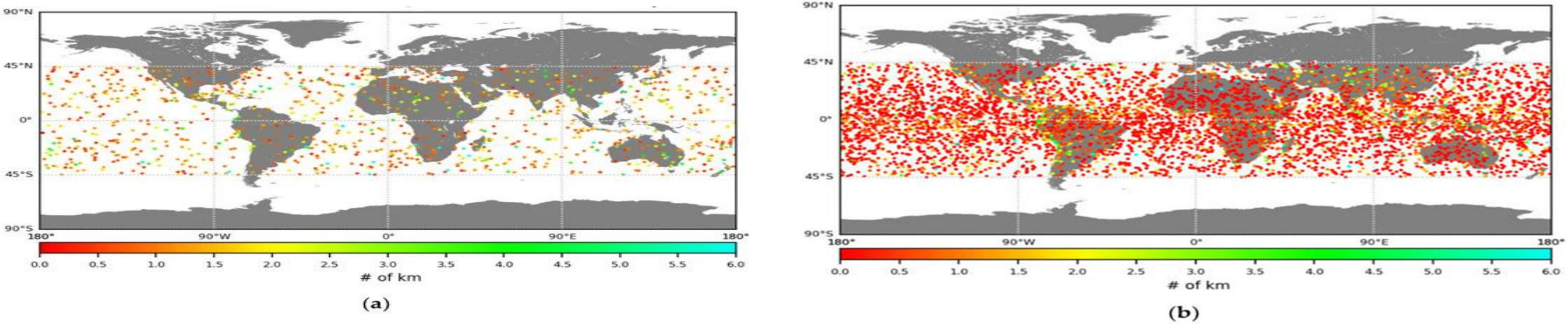
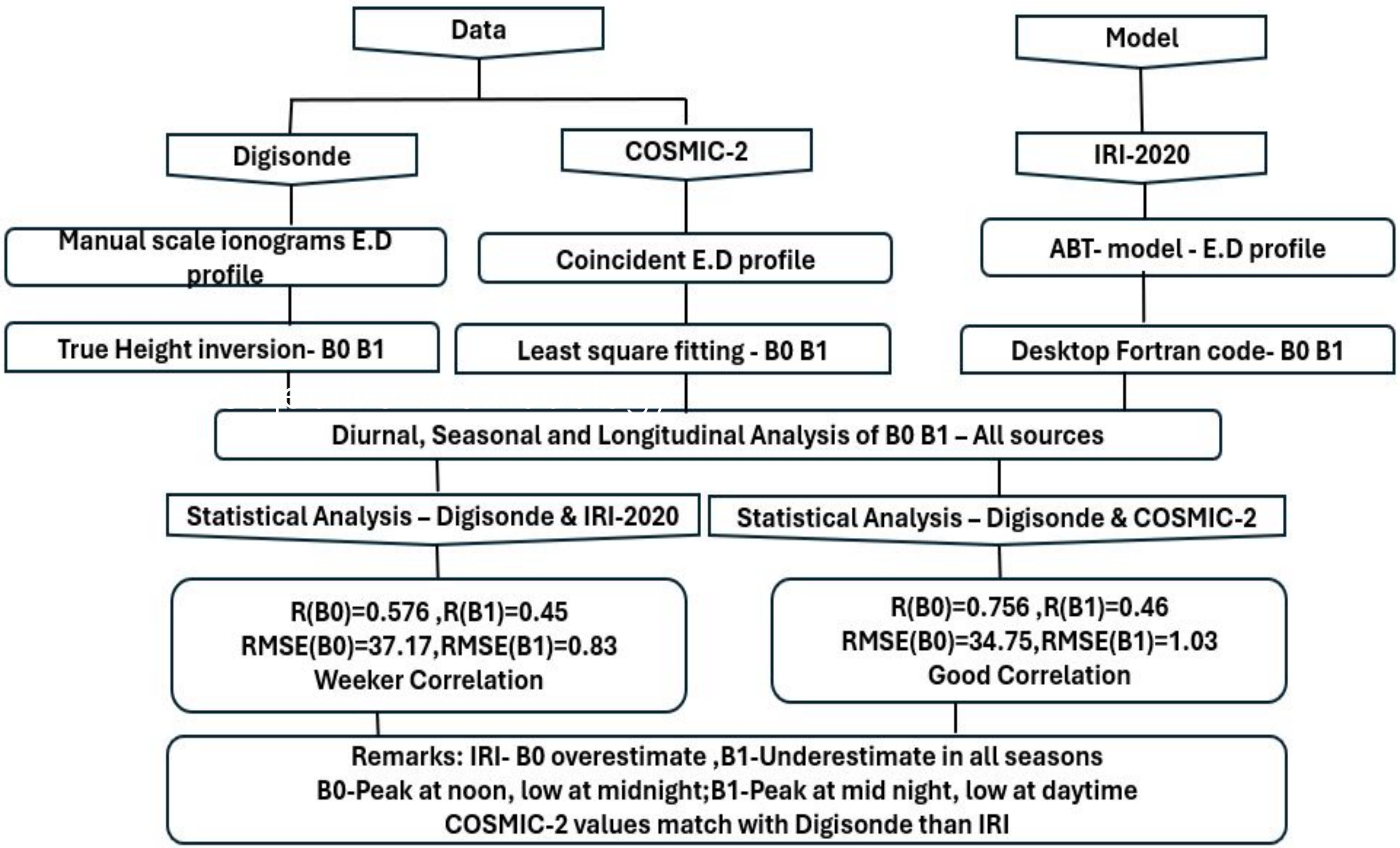


Fig.4 The radio occultation points within ±45 latitudes (a) for FORMOSAT-3 (b) for FORMOSAT-7 on 5 February 2020. [Chen et al., 2021]

Data Methodology



Global plot- Digisonde and COSMIC-2

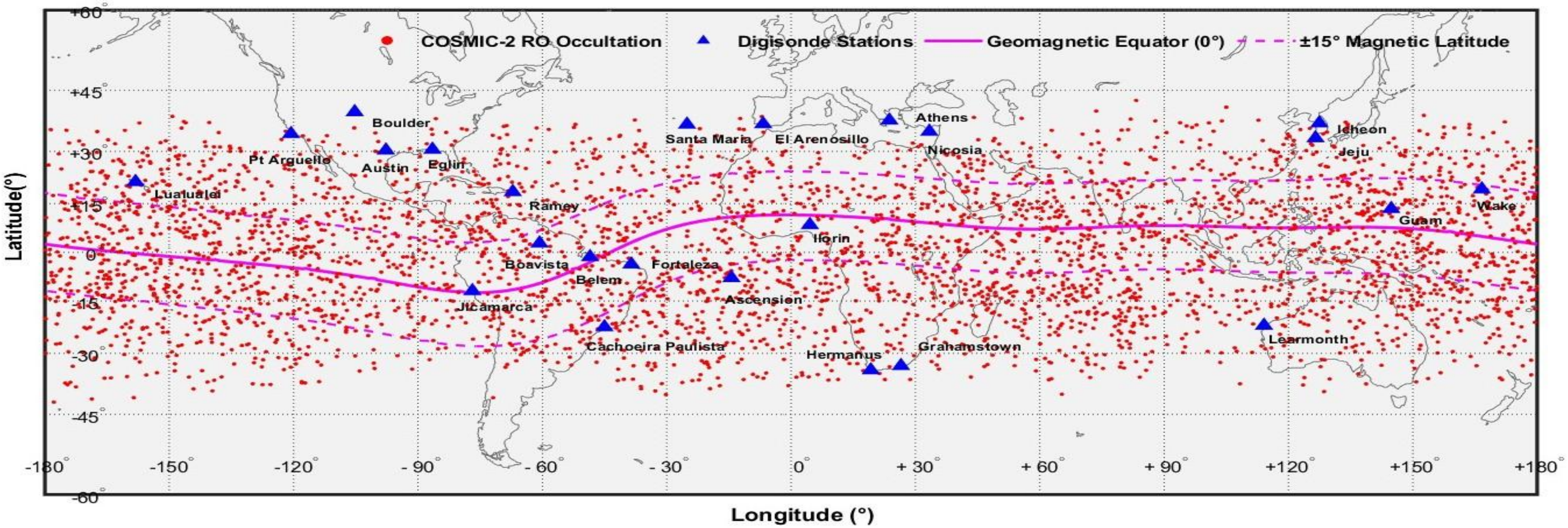


Fig.5 Global Distribution of COSMIC-2 RO occultation points during 24 hours period on 31st December 2020 (red dots) and Digisonde stations (blue triangles) around the globe considered in this study.

Table 1: Digisonde stations along with the number of coincident-colocated COSMIC-2 RO observations

S.No	Station Name	Country	Geographical Latitude (degree)	Geographical Longitude (degree)	Geomagnetic Latitude (degree)	Number of profiles
American Sector						
1	Fortaleza	Brazil	-3.73	-38.52	-6.41	421
2	Belem	Brazil	-1.45	-48.49	6.92	25
3	Cachoeira	Brazil	-22.67	-45.01	-14.17	832
4	Jicamarca	Peru	-11.95	-76.87	0.09	123
5	Ramey	Puerto Rico (USA)	18.5	-67.13	27.59	404
6	Pt. Arguello	USA	34.58	-120.62	40.31	66
7	Austin	USA	30.27	-97.74	32.64	390
8	Eglin	USA	30.48	-86.51	39.44	558
9	Boulder	USA	40.01	-105.27	-110.71	14
Asia-Pacific Sector						
10	Guam	USA (Pacific)	13.44	144.79	16.13	627
11	Wake	USA (Pacific)	19.28	166.65	14.19	573
12	Lualualei	USA (Hawaii)	21.43	-158.14	21.63	712
13	Jeju	South Korea	33.5	126.52	33.98	90
14	Icheon	South Korea	37.28	127.44	39.21	24
15	Learmonth	Australia	-22.22	114.09	-32.25	147
Europe-African Sector						
16	Boavista	Cape Verde	2.82	-60.67	5.62	261
17	Santa Maria	Portugal	36.97	-25.12	-20.63	391
18	Ilorin	Nigeria	8.51	4.55	-4.91	573
19	Ascension Island	UK (Atlantic)	-7.96	-14.37	18.28	518
20	Nicosia	Cyprus	35.18	33.36	29.23	570
21	El Arenosillo	Spain	37.09	-6.73	30.82	412
22	Athens	Greece	37.98	23.73	31.98	208
23	Hermanus	South Africa	-34.42	19.24	30.99	456
24	Grahamstown	South Africa	-33.31	26.52	-41.38	570
					Total profiles	**8965**

Representation of Bottomside Electron Density Profile

The analytical function to describe the bottomside electron density profile in IRI is as follows:

$$Ne(h) = NmF2 \cdot \frac{\exp(-Z^{B1})}{\cos h(Z)},$$

$$Z = \frac{hmF2 - h}{B0}$$

Global Diurnal Variation of B0 and B1

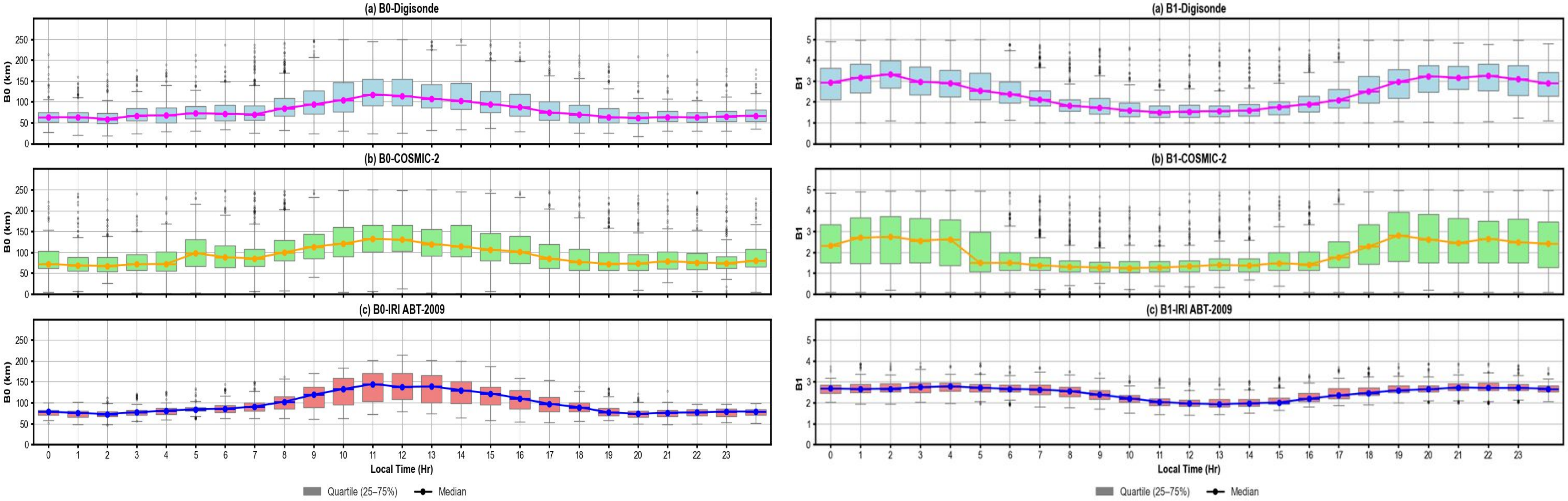


Fig.6 (Global Diurnal variation of the ionospheric B0 and B1 parameter from (a) Digisonde, (b) COSMIC-2, (c) IRI ABT-2009. Quartile (25-75%) boxplots illustrate the spread of B1 values at each local time, with lines indicating median trends across datasets.

Statistical Analysis

$$RMSE = \sqrt{\frac{1}{n}\Sigma(X - Y)^2} \quad (2)$$

$$Relative\ Difference(\%) = \frac{Y-X}{Y} * 100 \quad (3)$$

$$R = \frac{\sum(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum(X_i-\bar{X})^2} . \sqrt{\sum(Y_i-\bar{Y})^2}} \quad (4)$$

Here, X represents B0 or B1 derived from COSMIC-2 and ABT 2009 IRI sub-model, Y represents B0 or B1 extracted from Digisonde profiles, and n represents the number of samples.

Statistical Analysis of B0 and B1

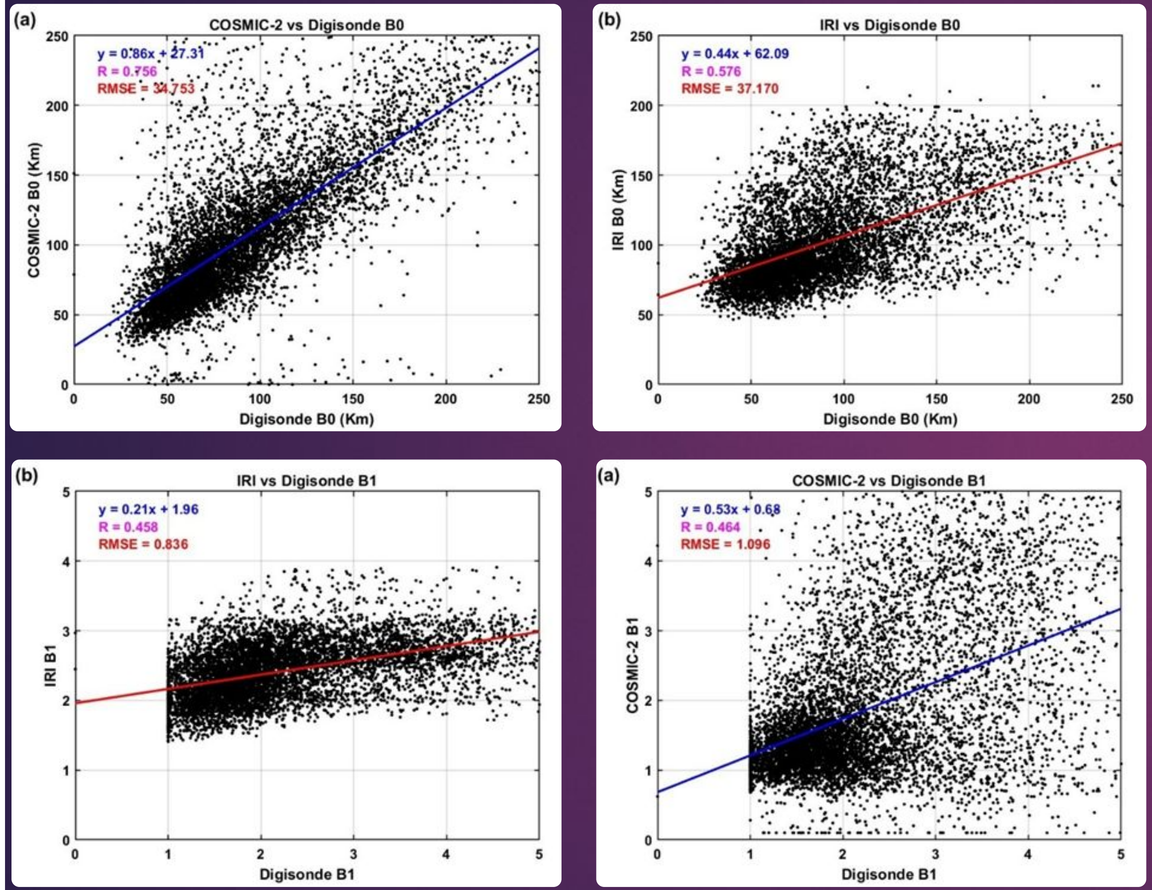


Fig.7 Scatter plots of fitting (a) Digisonde (Black dots) vs COSMIC-2 (Blue fitting line), (b) Digisonde (Black dots) vs IRI (Red fitting line)

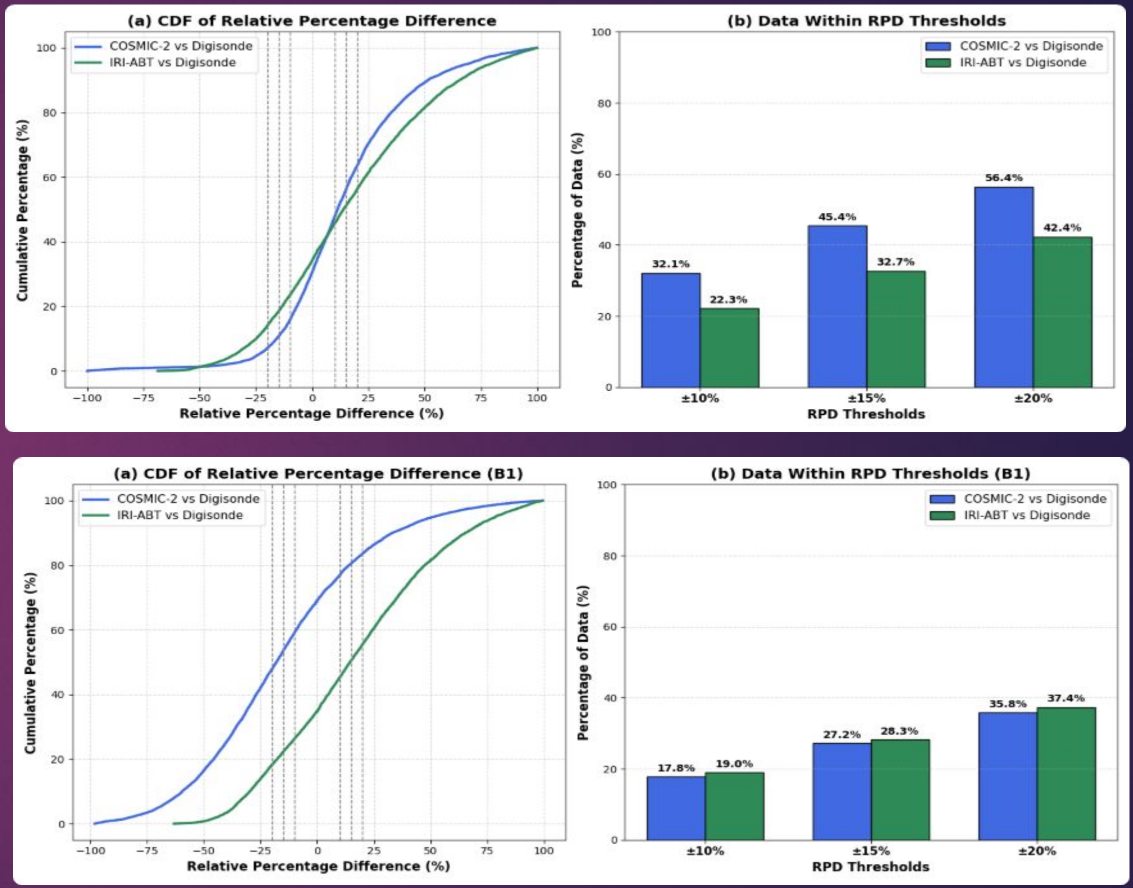


Fig. 8 Comparative statistical analysis of the Relative Percentage Difference between B from COSMIC-2(blue) and IRI-ABT-2009 (green) with Digisonde. (a) Cumulative Distribution Function vs RPD plot (b) Percentage of Data within RPD Threshold

Seasonal Analysis of B0 & B1

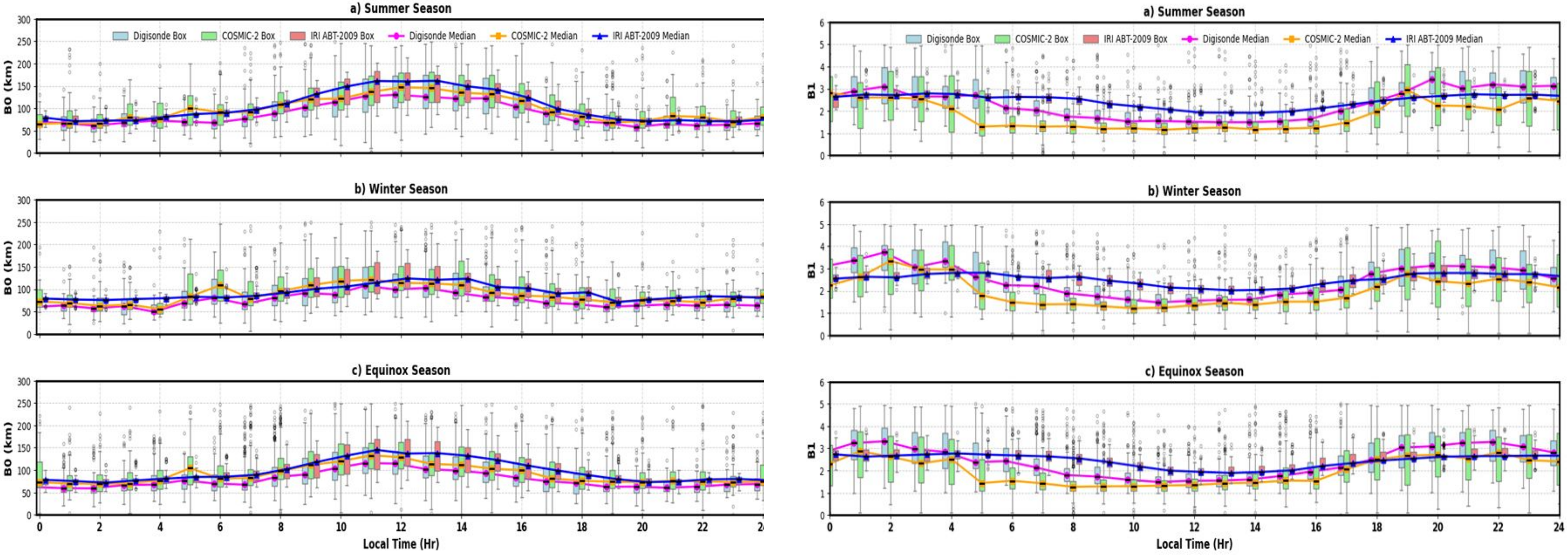


Fig. 9 Diurnal seasonal variation of the ionospheric B1 parameter during (a) Summer, (b) Winter, (c) Equinox using Digisonde, COSMIC-2, and IRI-2020 (ABT-2009). Quartile Boxplots show the spread of B values at each local time, and lines indicate median trends across datasets.

Longitudinal Analysis of B0 & B1

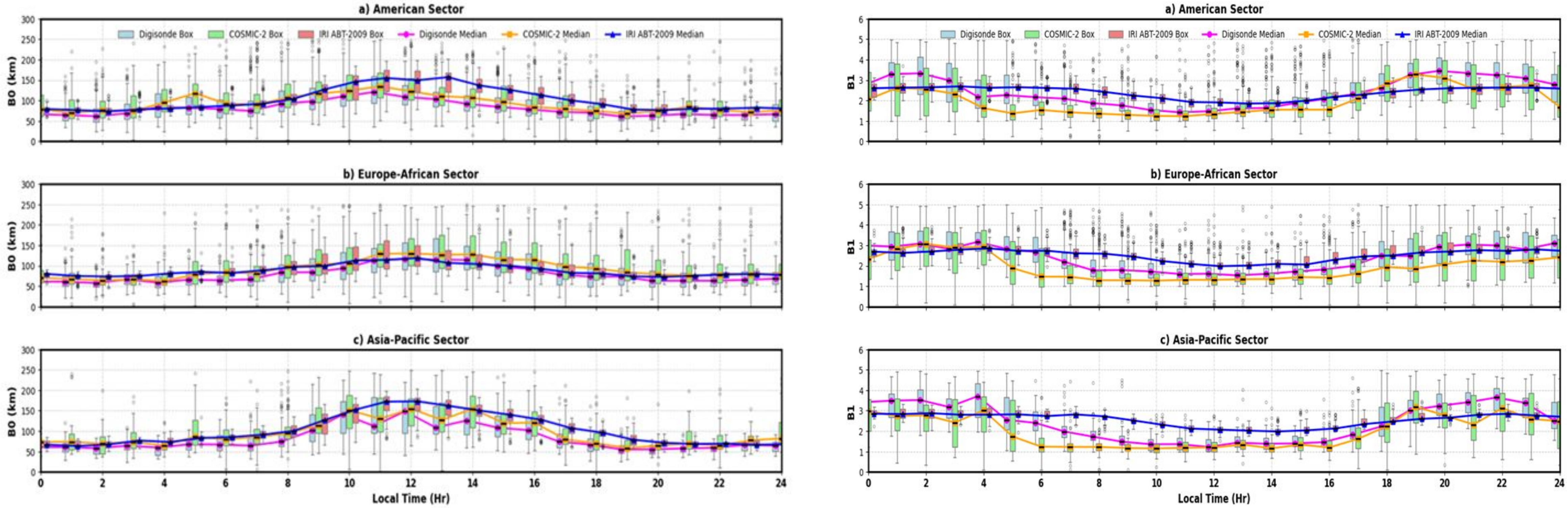


Fig. 10 Diurnal variation of the ionospheric B1 parameter over (a) American, (b) Europe-African, and (c) Asia-Pacific sectors using Digisonde, COSMIC-2, and IRI-2020 (ABT-2009) data. Quartile box plots show the spread of B0 values at each local time, and lines indicate median trends across datasets.

Conclusion and Future work

- ✔ We validate the accuracy of B0 and B1 from FORMOSAT-7/COSMIC-2 RO data with coincident globally distributed 24 Digisonde data across both equatorial and low to mid-latitude regions from 2020 to 2022.

- ✔ The validation of these parameters is a challenging and time-consuming process, often requiring expert advice and statistical analysis to handle large datasets.

- ✔ This study carefully removed the errors typically associated with manually checking and editing the data to ensure a more accurate and precise estimation of B0 and B1.

Key Findings

- ✔ The COSMIC-2 RO-derived bottomside ionospheric profile parameters have shown consistency with the Digisonde measurement rather than the IRI model.
- ✔ However, the biases observed across seasons and longitudes reinforce the importance of integrating satellite and ground-based data to improve empirical ionospheric models and regional predictions.

Acknowledgment

- The authors sincerely acknowledge the COSMIC data center for making FORMOSAT-7/COSMIC-2 data publicly available via https://www.cosmic.ucar.edu/what-we-do/cosmic-2/data/.
- The authors are grateful to the Global Ionosphere Radio Observatory (GIRO; https://giro.uml.edu/index.html) and the host institutions for their efforts in operating the Digisonde stations and providing access to the ionosonde data.
- The authors also appreciate the University of Massachusetts Lowell for providing the SAO-Explorer software (https://ulcar.uml.edu/SAO-X/) for the analysis of the Digisonde electron density profiles.

THANK YOU

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