The Empirical Canadian High Arctic Ionospheric Model (E-CHAIM): NmF2

Abstract

It is well known that the high latitude ionosphere poses significant challenges for empirical modelling through its highly dynamic nature, via coupling with the interplanetary magnetic field, and the scarcity and quality of data in these regions. The International Ionosphere (IRI) model suffers reduced accuracy in its representation of the high latitude ionosphere. These inaccuracies are believed to exist a much larger dataset of high latitude observations of ionospheric electron density. These new data sources allow for the opportunity to revise the IRI’s representation of the high latitude ionosphere.

1. Introduction

To represent the behaviour of NmF2 at high latitudes, we introduce the NmF2 portion of the Empirical Canadian High Arctic Ionospheric Model (E-CHAIM), from the Global Navigation Satellite Systems (GNSS) radio occultation (RO) measurements of the COSMIC, CHAMP, and GRACE radio occultation missions, and the construction of the Poker Flat, Resolute, and EISCAT Incoherent Scatter Radar systems. These new datasets afford an improvement over the IRI, and the scarcity and poor quality of data in these regions. In terms of RMS errors, the E-CHAIM model represents ionospheric electron density in the region of sparse ground instrument coverage, such as in the arctic regions and over the oceans.

2. E-CHAIM

The Empirical Canadian High Arctic Ionospheric Model (E-CHAIM) is intended as a replacement for the use of the International Ionosphere (IRI) model at high latitudes. To this end, the model represents ionospheric electron density in the region of high latitudes, including in its performance is also presented, where we see improvement over the IRI.

3. Data

E-CHAIM is a part of the Space Physics Interactive Data Resource (SPIDR), which has gathered ionogram data from 82 ionosondes. The Ionospheric Radio Observatory (GIRO) available at http://giro.uml.edu/ [9 has measurements come in the form of new ionosonde observations of ionospheric electron density. These new baseline data are supplemented by measurements from the Canadian High Arctic Ionospheric Network (CHAIN) available at http://chain.physics.unb.ca [8 and the Global Navigation Satellite Systems (GNSS) radio occultation missions, and the construction of the Poker Flat, Resolute, and EISCAT Incoherent Scatter Radar systems. These new datasets afford an improvement over the IRI, and the scarcity and poor quality of data in these regions. In terms of RMS errors, the E-CHAIM model represents ionospheric electron density in the region of sparse ground instrument coverage, such as in the arctic regions and over the oceans.
4. Quiet-Time Model Parameterization

Equation for the quiet-time NmF2 model parameterization:

\[ G = e^{\text{Dst} / 300} - e^{-30 \text{Ap} / 30} - e^{\text{AE} / 700} \]

where Dst’ is the integrated hourly Dst index from the Kyoto World Data Center (WDC) for Geomagnetism, ap’ is the integrated hourly Ap index from the National Geophysical Data Center (NGDC), and AE’ is the integrated hourly AE index gathered from the UKSSDC, and \( \chi \) is the solar zenith angle, \( \alpha, \beta, \gamma, \delta, \) and \( a_{ij} \) are fitting coefficients.

5. NmF2 Perturbation Model

Equation for the NmF2 perturbation model:

\[ \text{NmF2} = G + \sum_{l=0}^{L} \sum_{m=0}^{M} \left[ A_{lm} \cos \left( \frac{\text{DoY}}{365} \lambda \right) + B_{lm} \sin \left( \frac{\text{DoY}}{365} \lambda \right) \right] P_{lm}(\eta) + \eta = \cos \left( 90 - \varphi \right) \frac{\pi}{45} \]

\[ A_{lm} B_{lm} = (y_{lm} F_{1} + \delta_{lm} F_{2}) \cdot \sin^{2} \left( \frac{\theta \cdot \text{DoY}}{180} \right) + (C_{lm} F_{1} + D_{lm} F_{2}) \]

\[ C_{lm}, D_{lm} = \sum_{i=1}^{5} \left[ a_{i}\cos \left( \frac{2\pi i - 0.05}{365.25} \right) + \beta_{i}\sin \left( \frac{2\pi i - 0.05}{365.25} \right) \right] \]

\[ G = F10.7 \cdot (a_{1}\cos(\chi) + a_{2}\sin(\chi)) + \sqrt{F10.7} \cdot (a_{3}\cos(\chi) + a_{4}\sin(\chi)) + F10.7^{2} + a_{5}G^{2} \]

\[ F_{1} = F10.7^{0.81} \quad F_{2} = (F10.7^{0.81})^{1.19} \]

where \( \lambda \) is magnetic local time, \( \varphi \) is geomagnetic latitude,
\[
\log \left( \frac{N'F_2}{N_mF_2} \right) = \sum_{l=0}^{N} \sum_{m=0}^{\min(l,0)} \left[ A_{lm} \cos \left( \frac{\pi m}{180} \lambda \right) + B_{lm} \sin \left( \frac{\pi m}{180} \lambda \right) \right] P_{lm}(\eta)
\]

where \( \lambda \) is magnetic local time, \( \varphi \) is geomagnetic latitude, \( F_{10.7} \) is the 81-day smoothed F10.7 solar flux, and \( \theta \) is the magnetic dipole tilt angle. \( A, B, \gamma, \) and \( \delta \) are fitting coefficients. The maximum order and degree of the expansion was set to five and three, respectively, for this portion of the model. The reduced degree of the spherical cap expansion is a consequence of the reduction in the quality of ionosonde data during geomagnetic storm events, which tended to exaggerate noise in the storm output.

6. Validation

For the purpose of this summary paper, we shall solely examine the model validation at a single high latitude location, Resolute Canada (74.75N, 265.00E). The authors invite the reader to examine the full student paper for detailed validation results.

The validation of the quiet-time model primarily examines the model's capability to represent monthly median \( N_mF_2 \) and will include comparisons to the URSI \( f^iF_2 \) maps of the IRI model. To that end, we present the monthly median \( N_mF_2 \) from the Resolute validation site in Figure 2.

Figure 2. Ionosonde-measured (left column), E-CHAIM-modeled (middle column), and IRI-modeled (right column) \( N_mF_2 \) for the Resolute site. 

Figure 3. Monthly RMS errors in E-CHAIM (solid line) and IRI (dashed line) \( f^iF_2 \) at the Resolute site. 

Figure 4. (Top Row) Ionosonde-measured (black), E-CHAIM-modeled (blue), and IRI-modeled (red) \( N_mF_2 \) around the May 29th, 2010 geomagnetic storm at the Resolute site. (Middle Row) Differences between observations and the E-CHAIM (blue) and IRI (red) modeled observations for the corresponding stations. (Bottom Row) \( K_p \) index for the periods presented.
7. Conclusions

In all cases, to our surprise, the CHAIM model performed better than the IRI during a prolonged Kp = 5 storm beginning in May 2010, we see a significant improvement over the IRI’s performances during storm periods. This, however, implies that the IRI is likely to perform better during storm periods. This is, in fact, the IRI's negative phase response in observed NmF2 that is captured by both the CHAIM model and the EISCAT Svalbard radar measurements.

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9. References


