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Examining the use of the NeQuick bottomside and topside parameterizations at high latitudes

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Abstract

An examination of the high latitude performance of the bottomside and topside F-layer parameterizations of the NeQuick electron density model is presented using measurements from high latitude ionosonde and Incoherent Scatter Radar (ISR) facilities.

For the bottomside, we present a comparison between modeled and measured B2Bot thickness parameter. In this comparison, it is seen that the use of the NeQuick parameterization at high latitudes results in significantly underestimated bottomside thicknesses, regularly exceeding 50%. We show that these errors can be attributed to two main issues in the NeQuick parameterization:(1) through the relationship relating foF2 and M3000F2 to the maximum derivative of F2 electron density, which is used to derive the bottomside thickness, and (2) through a fundamental inability of a constant thickness parameter, semi-Epstein shape function to fit the curvature of the high latitude F-region electron density profile.

For the topside, a comparison is undertaken between the NeQuick topside thickness parameterization, using measured and CCIR-modeled ionospheric parameters, and that derived from fitting the NeQuick topside function to Incoherent Scatter Radar-measured topside electron density profiles. Through this comparison, we show that using CCIR-derived foF2 and M3000F2, used in both the NeQuick and IRI, results in significantly underestimated topside thickness during summer periods, overestimated thickness during winter periods, and an overall tendency to underestimate diurnal, seasonal, and solar cycle variability. These issues see no improvement through the use of measured foF2 and M(3000)F2 values. Such measured parameters result in a tendency for the parametrization to produce a declining trend in topside thickness with increasing solar activity, to produce damped seasonal variations, and to produce significantly overestimated topside thickness during winter periods.

Keywords: NeQuick; Topside; Bottomside; Ionosphere; High latitudes; Ionosonde; Incoherent scatter radar

1. Introduction

Originally proposed by Di Giovanni and Radicella (1990), the NeQuick electron density model, similarly to the International Reference Ionosphere (IRI), provides a global 3D representation of ionospheric electron density (Nava et al., 2008). The NeQuick G is now the accepted European Space Agency (ESA) standard for system assessment analysis and is included as the ionospheric correction model for single-frequency use of the European GALILEO satellite navigation system (Radicella, 2009). The latest version of the model (NeQuick 2) was presented in Nava et al. (2008) and features a series of semi-Epstein layers with single thickness parameters to represent electron density from the lower E-region to the upper topside at 20000 km. These layers are represented by the following parameterization

$$N(h) = \frac{4N_{max}}{(1+\exp(z))^2}\exp(z) \quad (1)$$

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$$z = \frac{h - hmax}{H} \quad (2)$$

where $N(h)$ is the electron density at height h, H is the layer thickness parameter, N_{max} is the peak electron density of the layer, and $hmax$ is the layer peak height.

The particular components of the NeQuick that are evaluated in the current study include the F2 bottomside thickness and topside thickness. While the bottomside thickness parameterization has not been altered since the model's inception in Di Giovanni and Radicella (1990), the topside has evolved over the years, beginning first as a constant scale height model before becoming the present-day parameterization of Coïsson et al. (2006), which features a varying scale height with asymptotic behavior at high altitudes. This newest version of the topside model was developed with a limited dataset of topside sounder data, little of which came from high latitude regions. While, like the IRI, the NeQuick model can be considered reasonably accurate at mid latitudes, its application at high latitudes remains untested. That said, it is expected that the NeQuick model suffers similar limitations to those of the IRI (Themens et al., 2014; Themens and Jayachandran, 2016) due to their common use of the same critical frequency (foF2) maps, their similar hmF2 parameterizations, their common use of the CCIR propagation factor (M(3000)F2) maps, and their shared use of the NeQuick topside parameterization.

Previous work has shown significant shortcomings in the use of the CCIR foF2 and M(3000)F2 maps at high latitudes. These works also pointed to potential issues in the NeQuick topside parameterization at these latitudes; however, no direct examinations of the source of these issues were undertaken. Themens et al. (2014), Bjoland et al. (2016), and Themens and Jayachandran (2016) suggest that the NeQuick topside parameterization is significantly underestimating the seasonal variability of the topside thickness, resulting in significant errors in the overall topside representation and in IRI-derived Total Electron Content (TEC).

The present study focuses on the NeQuick's representation of the F-layer, particularly the topside thickness parameter, as it is an integral part of both the NeQuick and IRI topside parameterizations. Through this work we attempt to identify the specific problem areas resulting in the errors presented in Themens et al. (2014), Bjoland et al. (2016), and Themens and Jayachandran (2016), where we offer recommendations to the NeQuick team for future model adjustments.

2. Bottomside thickness

Despite our focus on the topside thickness, the NeQuick topside parameterization is highly reliant on the calculated bottomside thickness. The NeQuick F2 bottomside thickness parameter is given by the following relationship

$$\ln\left(\left(\frac{dN}{dh}\right)_{max}\right) = -3.467 + 1.714\ln(foF2) + 2.02 \times \ln(M(3000)F2) \quad (3)$$

$$B2_{Bot} = \frac{0.365NmF2}{(dN/dh)_{max}} \quad (4)$$

where foF2 is the peak critical frequency of the F-layer, M(3000)F2 is the propagation factor, and B2Bot is the bottomside thickness parameter. The first of the above parameterizations is empirically derived based on the work of Mosert de Gonzales and Radicella (1990). The second relationship is analytically derived assuming that the semi-epstein function can properly represent the shape of the F-region bottomside.

To evaluate the use of these parameterizations at high latitudes, we make use of a Canadian Advanced Digital Ionosonde (CADI) operated by the Canadian High Arctic Ionospheric Network (CHAIN) at Resolute, Canada (74.75N, 265.00E) (Jayachandran et al., 2009). This ionosonde provides ionograms every minute. Data from this ionosonde has been manually scaled and inverted using the POLynomial ANalysis (POLAN) method of Titheridge (1988) at 30-min temporal resolution. From this ionosonde, we can:

(B1) calculate the expected B2Bot from measured foF2 and M(3000)F2 values (using Equations (3) and (4)),
(B2) do the same using CCIR-modeled foF2 and M(3000)F2 values,
(B3) analytically calculate the maximum derivative of the vertical electron density profile to ultimately derive B2Bot from the NeQuick parameterization function (using Eq. (4)), or
(B4) use a least squares fit of the semi-epstein layer function to the ionosonde-derived electron density to derive a measured B2Bot value.

Some examples of peak-relative bottomside electron density profiles derived from each of the above methods are provided in Fig. 1. Fig. 1a demonstrates somewhat of an ideal scenario, where the semi-Epstein function clearly fits the measured profile very well and only relatively small errors are seen in the profile generated using fitted $(dN/dh)_{max}$. The small disagreement in Fig. 1a highlights the strong sensitivity of the NeQuick parameterization to even slight departures from the idealized semi-Epstein shape, where seemingly innocuous differences in the electron density profile result in significant differences in the profile slope and thus result in significant errors in the densities generated through method B3. Fig. 1b demonstrates a situation where the semi-Epstein shape almost perfectly matches the measured shape in the near-peak portion of the profile, as demonstrated by the strong agreement between methods B3 and B4. It is important to note that despite this agreement, both profiles significantly diverge from the measured profile beyond the region of fitting

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