Validation of Equatorial Ionization Anomaly with IRI-2012 and NeQuick-2 Models during a Sudden Stratospheric Warming

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ABSTRACT

This work presents the validation of EIA from the GPS observation during the 2009 sudden stratospheric warming event (SSW) with the IRI-2012 and NeQuick-2 models over the African sector using the measurements of slant total electron content (STEC) from seventeen (17) GPS receivers located across the African latitudes (~30°N - ~ 40°S, geographic latitude). Interestingly, the significant reductions across the hemispheres during the SSW peak phase from experimental observations could not be reproduced by any of the models. The NeQuick-2 model could not predict the EIA trough and as well over-estimated the middle latitude crests in all the phases compared to the GPS observations and IRI-2012 model (all options included).

Aim and Scope of Study

The equatorial ionization anomaly (EIA), an equatorial and low-latitude (ELL) phenomenon characterized by depletion of plasma around the geomagnetic equator (trough) and two TEC peaks (crests), one each on either side of low latitudes plays significant role in determining the morphology of ionospheric parameters over any ELL locations on daily, monthly and seasonally basis. Apart from the space weather effect from the Sun, a number of studies have shown that sudden stratospheric warming (SSW) modified and changes the pattern of EIA from total electron content (TEC) that were obtained from GPS observables (Goncharenko et al. 2010b). Also, Goncharenko et al. (2012) compared modified TEC observations due to SSW with the International Reference Ionosphere (IRI) model. Their results over the American sector showed large day-to-day variability in Global Positioning System (GPS) TEC, which is not present in the IRI model. These indicate that EIA characterization from TEC due to strong forcing from the lower atmosphere that coupled the ionosphere during SSW have been extensively investigated in the American and Asian sectors. However, the African sector has been poorly studied. Apart from this, the validation of EIA from TEC produced from two ionospheric empirical models; the IRI and NeQuick-2 during the SSW have not been investigated. Hence, in this study, we attempt to investigate the variability of EIA using GPS observations and compare with the IRI and NeQuick-2 models during a major SSW in 2009 over the African sector.

Methods

The polluted slant TEC (STEC) from the GPS observations are converted to the vertical TEC (VTEC) with the expression $V \quad = S \quad - \frac{[b_S+b_R+b_R \ ]}{S(E)}$ (1)

Where b_S, b_R, b_{RX} and S(E) is satellite differential delay, receiver differential delay, receiver inter-channel bias and the obliquity factor with zenith angle, Z, at the ionospheric pierce point (IPP). Mannuci et al. (1993) defined S(E) as $S(E) = \frac{1}{c \quad (z)} = \left\{1 - \left(\frac{R_E \, X \, c \quad (E)}{R_E+H_s}\right)^2\right\}^{-0.5}$ (2)

Where E is the elevation angle of the satellites in degree, R_E is the radius of the earth measured in kilometer (Km) and H_s is the height of the ionosphere from the surface of the Earth, which is approximately equal to 350 Km.

The TEC from IRI-2012 (all three options) and the NeQuick-2 model was accessed from http://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.html and www.t-ict4d.ictp.it/nequick2/nequick-2-web-model, respectively. Stratospheric data are retrieved from National Center for Environmental Prediction (NCEP). To investigate SSW that occured in January, 2009, daily observations of VTEC from GPS observations and their corresponding values from models were categorized into four phases: SSW pre-condition (day 1 to 16), SSW ascending phase (day 17 to 21), SSW peak phase (day 22 to 24) and SSW descending phase (day 25 to 31). For a phase, all the days were averaged and 17 GPS stations were plotted in two-dimension from the Northern hemisphere (Tetouan, TETN) to the Southern hemisphere (Sutherland, SUTH) through the equator (Nazret, NAZR).

Results

The remaining 13 stations codes apart from those aforementioned are shown on the right-hand side of the y-axis. The left-hand side of the y-axis shows the latitudinal distribution, the top and bottom x-axis shows the SSW phases and universal time (UT) in hours, respectively. The unfilled (white background) contours in the plots are results of interruptions in the data recordings, which are due to epileptic power supply. As a results of the strictness regarding this extended abstract, we are unable to show all our results. But, we will discuss some of them here and present them in full during the symposium. The EIA signatures from GPS observations are shown with Fig. 1. Fig. 2 shows the EIA signatures reproduced by the NeQuick-2 model. Our results showed that all the models conveniently reproduced the EIA signature similar to that of the GPS observations for the first time over the African sector. However, there are discrepancies in the magnitudes of TEC over the latitudes as shown with the colour bar closer to the contour plots, the development of EIA crests was faster for models compared to GPS observations, which indicate that the locations of EIA crests are not the same. Others are stronger EIA crest in the southern hemisphere of the GPS observations compared to its northern hemisphere that was revealed only by IRI-2001 option. An interesting result was found during the SSW peak phase of the GPS observation, where all the models could not reveal the two EIA crests at the northern hemisphere associated with significant reduction in the magnitudes of TEC across the hemispheres. The characteristics of the middle atmosphere during this phase shows that stratospheric mean air temperature reached a maximum value of 256 K while the stratospheric zonal mean wind is at zero and about reversing easterly. This signifies damping (Meyer, 1999) that modulated the tidal components in the middle atmosphere and simultaneously coupled the upper atmosphere as revealed by the GPS EIA. Another interesting results is the intrusion of plasma into the middle latitude via the southern hemisphere (middle latitude crest), which was revealed by all the models with respect to the GPS observations. In contrast to GPS observations and other models, NeQuick-2 model over-estimated the middle latitude crests in all the phases. The consequence is higher values at the middle latitude crests compared to its low latitude EIA crests. Also, the trough of the NeQuick-2 model were observed between ~ 3°S and ~ 7°S in all the phases of the SSW. This shows that the NeQuick-2 model failed to model the EIA trough compared to the IRI-2012 model that reproduced the trough of the GPS observations well at equatorial latitudes.

Conclusions

It is clearer from our results that the models were not able to capture exactly the morphology of GPS EIA before and during the SSW event of 2009. We therefore recommend that for future IRI and NeQuick-2 models, the effect of lower forcing from middle atmosphere due to SSW should be considered.

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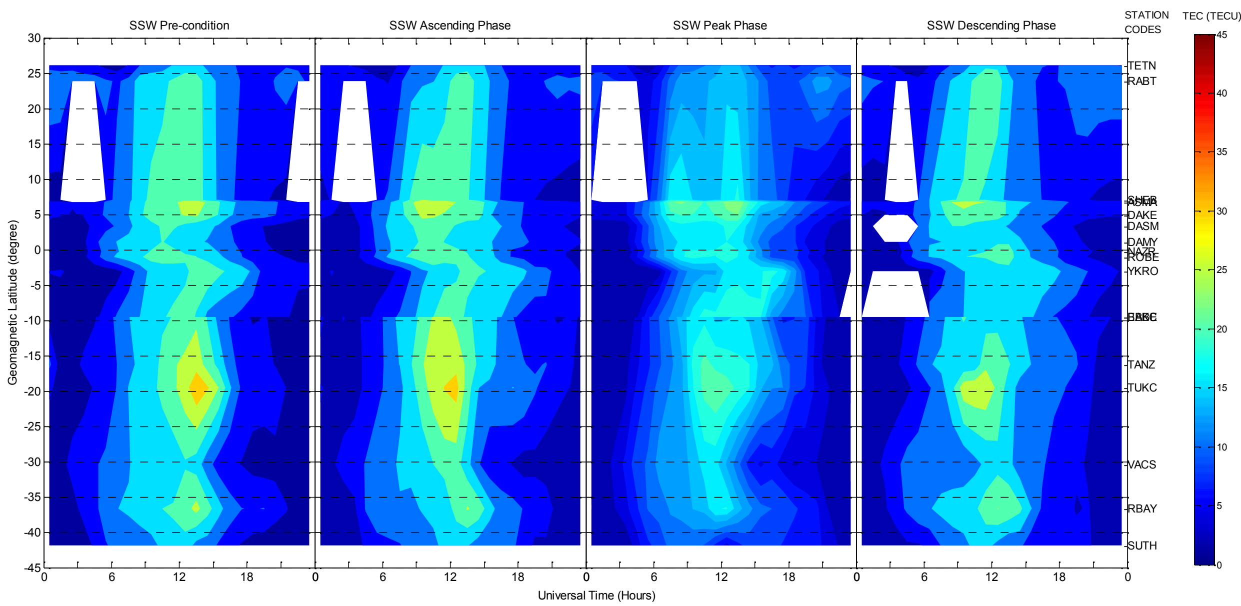

Fig. 1: EIA from GPS TEC on all hours across African latitudes during the SSW event of January 2009.

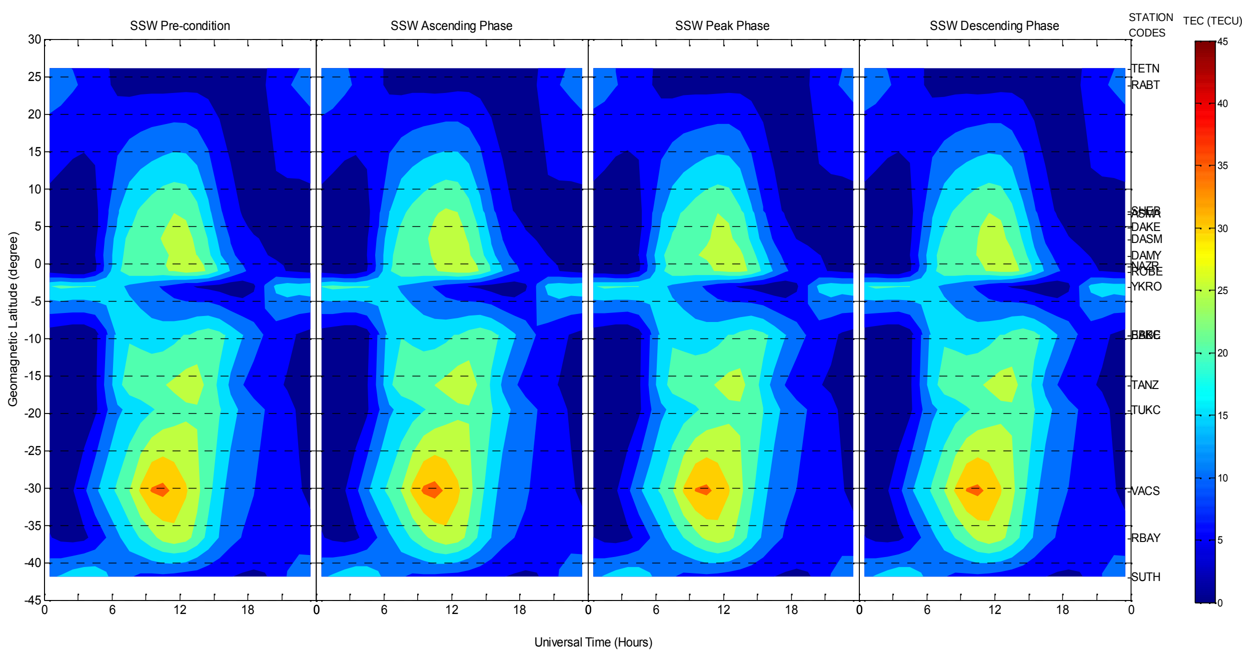

Fig. 2: EIA from NeQuick-2 model on all hours across African latitudes during the SSW event of January 2009.