Statistical Analysis of Saturation Effect in GIM TEC Response to Solar Activity

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Abstract

This study investigate the saturation effect in the ionospheric total electron content (TEC) in the global ionosphere maps, particularly in response to solar activity of F10.7 index and the 81-average F10.7 proxy. We found that saturation features in TEC appear more frequently at the low, especially equatorial ionization anomaly (EIA) during post-noon period. At nighttime, the saturation effect mainly occurs in the magnetic equatorial region and Weddell Sea Anomaly (WSA) region. This indicates that the ionosphere intrinsically has a certain limited capacity, while over the EIA and WSA region, the dense ambient electron density has very limited room and tend to become saturated. The saturated values of F10.7 during 1999~2020 is around 180 sfu.

Introduction and Motivation

- Scientists found that foF2 shows a linear relationship at low values of the sunspot numbers, but foF2 seems to show a saturation effect at high sunspot numbers (Lakshmi et al., 1988)
- Balan et al. (1993, 1994a, 1994b, 1996) found a nonlinear relationship between the solar EUV and F10.7 and consider the saturation of ionization to be caused by the saturated production of ionization due to the nonlinear increase of the solar EUV fluxes.
- Richards et al. (1994) used P = (F10.7A+F10.7)/2 as the proxy and show a linear relationship between the F10.7 proxy and EUV flux.
- Many physical model use the F10.7 proxy as a driving parameter. However, is there no saturation effect between the F10.7 proxy and plasma density?

Methodology

A two-segmented linear regression model with unknown change-point c is applied in this study.

$$y = \theta_1 + \theta_2\theta_3 - \theta_2 x, \qquad x \le \theta_3$$
$$y = \theta_1, \qquad x > \theta_3$$

Where θ_3 is the change point, θ_1 represents the expected y value when x is greater than θ_3, and $-\theta_2$ is the slope or changing rate of the first segmented linear regression model (Liu et al., 2003).

- To test the goodness-of-fit for the two-segmented linear regression model, a simple linear regression model is also fitted into the data. The residual sum of squares of segmented regression and simple linear regression are obtained as RSS(SL) and RSS(L), respectively.

$$F = \{(n-3)RSS(L)\}/\{(n-2)RSS(SL)\}$$

Use monthly average TEC values and apply a 12-month running mean to remove the seasonal variation.

Apply the two-segmented model to find the changed point

Use the F-index to determine whether a two-segmented regression or a linear regression is more suitable for the case.

Construct global maps using F index to identify which regions are more prone to the saturation effect and examine if a similar phenomenon occurs when using F10.7 proxy.

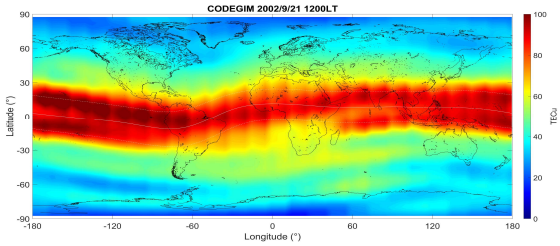


Figure 1: CODEGIM global LT map on 21st Sep. 2002, illustrating the distribution of TEC.

Example of Saturation Effect

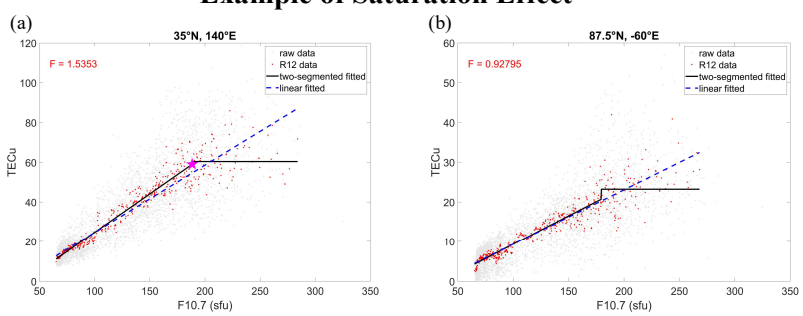
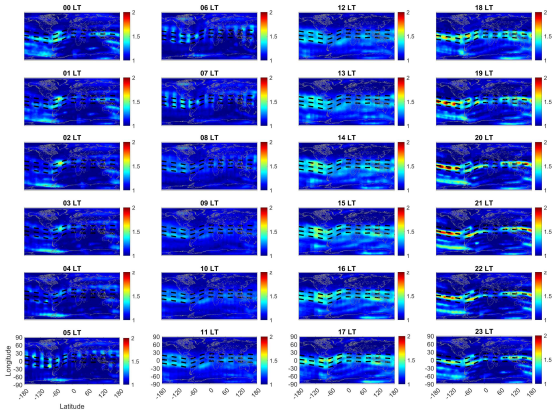


Figure 2: F10.7 versus TEC plots at 1400 LT. The grey dots indicate the original data, the red dots are 12-month running mean monthly average TEC, the black solid lines are two-segmented fitted lines, and the blue dashed lines are linear fitted lines. If the F index > 1, it indicates that the two-segmented regression is more appropriate.

Global Saturation Effect

F10.7 F index map



F10.7 proxy F index map

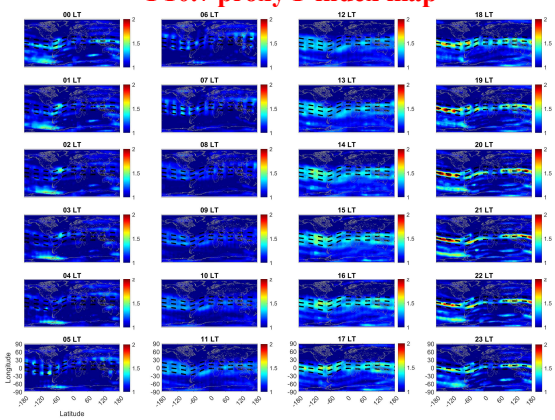


Figure 3: Global map of F index in (a) F10.7 versus TEC and (b) F10.7 proxy versus TEC during 1999~2020. The black lines indicate ±15° magnetic latitudes and magnetic equator.

Summary and Future Work

- Using the F10.7 proxy to examine its relationship with TEC also reveals a significant saturation effect.
- Saturation features in TEC appear more frequently at the low latitudes, especially equatorial ionization anomaly (EIA), than those at the middle or high latitudes during daytime.
- At nighttime, the saturation effect in TEC is mostly concentrated in the magnetic equatorial region. Interestingly, the saturation effect can also be observed in the WSA region.
- In the future, we plan to also consider EUV observation to investigate the saturation effect and to check if model simulations (such as TIEGCM) exhibit this phenomenon as well.