The Interconnectedness of Ionospheric Phenomena in the Low Latitudes: A Forecasting Sequence for Space Weather

Sovit Khadka[1, 2], Cesar Valladares[3] and, Patricia Doherty[2]

[1]Physics Department, [2]Institute for Scientific Research, Boston College, MA, USA

[3]William B. Hanson Center for Space Sciences, University of Texas at Dallas, TX, USA

Correspondence: khadkas@bc.edu

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Abstract: At equatorial and low latitudes, most of the post sunset ionospheric plasma behaviors depend on the plasma drifts or electric fields and their drivers, e. g. neutral winds. This process is an indication of the possible connection between pre- and post-sunset ionospheric electrodynamics. Mutual relationship studies provide a possible route to predict the occurrence of plasma density fluctuation and scintillation in the ionosphere during the late afternoon and night respectively based on daytime measurement of the equatorial ionosphere. Present study aims to develop a technique to predict the interconnection of disturbances of afternoon GPS-derived TEC and scintillation after sunset on the basis of noontime electrojet strengths. Through statistical and case study analyses, the drivers of ionospheric scintillation and disturbance events are investigated in light of different databases observed in the American low-latitude sector. In addition, the role played by various input parameters of the equatorial and low-latitude ionosphere and their electrodynamic processes in the development of irregularities and influences of solar activity on space weather variations will also be discussed. These investigations can provide significant advances to improve the predictability of low-latitude space weather events and mitigate their effects on space-based technologies.

BACKGROUND

- Space weather: A broad field covering the conditions of the sun, solar wind, magnetosphere, ionosphere, and thermosphere that can impact the performance and reliability of space-borne and ground-based technological and infrastructure systems and can also endanger human life or health.
- A recent study shows that the equatorial region is more susceptible to space weather than previously thought (poleward of ~60°). The equatorial electrojet (EEJ) is the primary cause of this newly recognized threat, due to its ability to amplify magnetic perturbations from interplanetary shock arrivals by severalfold [*Carter et al., 2015*].

Fig.: 1

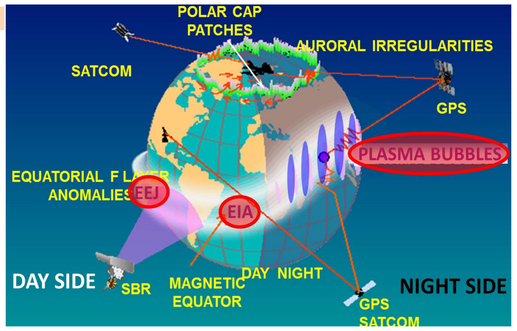


Figure-1: Sketch illustration showing various ionospheric phenomena in the different parts of the Earth. Particularly EEJ, EIA and plasma bubbles regions in the low latitudes are analyzed area for this study.

- Interestingly, the geomagnetic field strength depends not only on the geodynamo of inner core magma of the bulk Earth, but also an ionospheric current due to the E region dynamo at the upper atmosphere. The equatorial electrojet (EEJ) is a narrow, laterally limited (±3° latitudes) band of intense current flowing at the ionospheric E region over the dip equator, and produces strong geomagnetic field variations during the daytime.
- The elements controlling the ionospheric weather in the low latitude can be represented by: electric field (e.g.: EEJ), currents, plasma drifts, instabilities, and plasma structuring. The sunset electrodynamics in the ionosphere is responsible for the generation of the plasma bubble that can cause scintillation or even disruptions of satellite and navigation system [*Abdu ,2016*].

Fig.: 2(a)

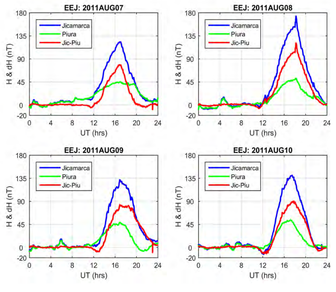


Fig.: 2(b)

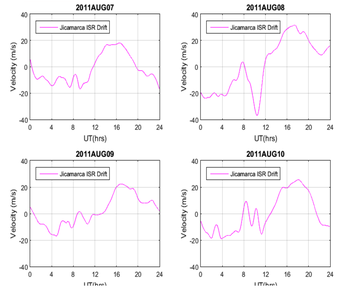


Figure-2:

a) Plots showing normalized earth's H component observed from two magnetometer stations, one located at Jicamarca, an EEJ region (blue) and another at Piura, an off-EEJ region (green). The difference in dH (red) from two magnetometer stations refers noontime enhancement of equatorial electrojet which is the proxy of the eastward electric field along the geomagnetic equator in the western longitude sector of South America.

b) Plots showing real time measurement of average vertical plasma drift profiles in the ionospheric altitude range 250-400 km from Jicamarca incoherent scatter radar (ISR) at geomagnetic equator.

- This poster presents the interrelationship between the equatorial electrojet (EEJ) strength, Global Positioning System (GPS)-derived total electron content (TEC), and postsunset scintillation from ground observations with the aim of finding reliable precursors of the occurrence of ionospheric irregularities. Mutual relationship studies provide a possible route to predict the occurrence of TEC fluctuation and scintillation in the ionosphere during the late afternoon and night respectively based on daytime measurement of the equatorial ionosphere.

DATA ANALYSIS

Fig.:3(a)

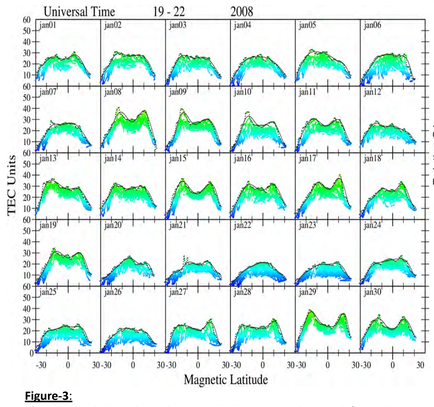


Fig.: 3(b)

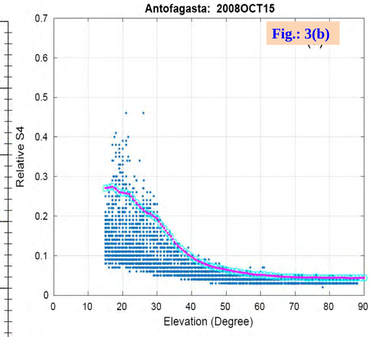


Fig.: 3(c)

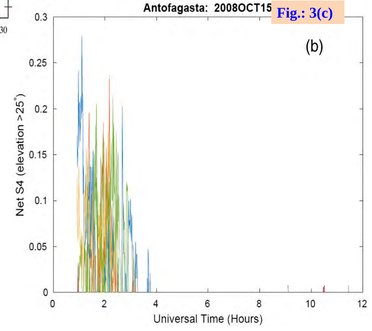


Figure-3:

a) Vertical TEC data during 19UT - 22UT obtained from GPS networks and their profiles within ±30° magnetic latitude in January 2008. Dotted and continuous black curve represent maximum values of TEC data and fitted data points, respectively.

b) Relative S_4 index observed at Antofagasta GPS station and threshold line (pink) against elevation. The pink line over S_4 data is a model threshold curve which is a border curve between background (below pink curve) and net S_4 index (above pink curve) data.

c) Net S_4 index against universal time after subtracting the background and low elevation contribution.

RESULTS

Fig.: 4(a)

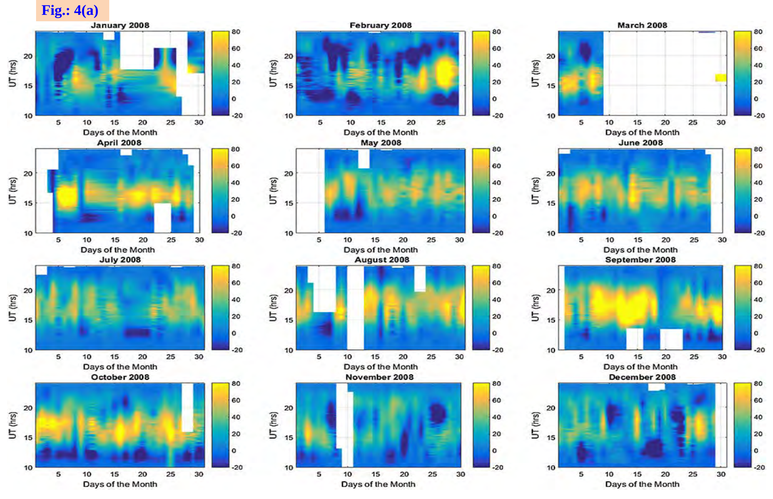


Figure-4 (a): Day-to-day variability of the EEJ during 10–24 UT of the day observed using magnetometers located at Jicamarca and Piura stations during solar minimum 2008. For each of the monthly plots, EEJs are clearly seen enhanced and centered about local noon (17 UT) time. The local noontime EEJ is more intense during/around equinox months than that in solstice months [*Khadka et al., 2016*].

Fig.: 4(b)

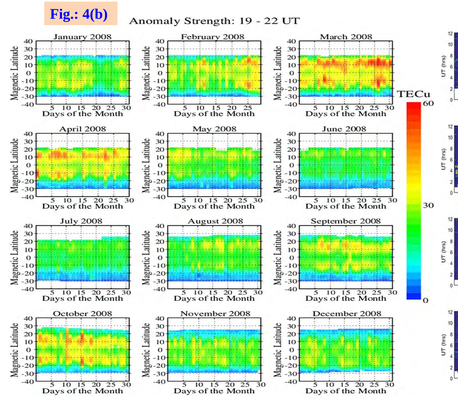


Fig.: 4(c)

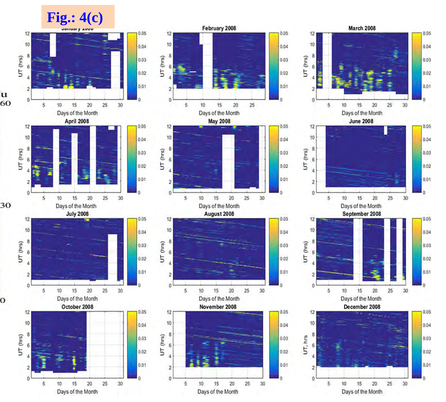


Figure-4:

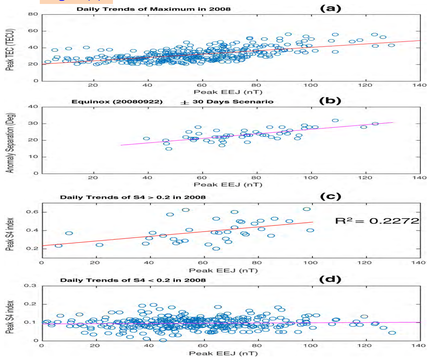
b) Latitudinal distributions of day-to-day variability of TEC profiles within ±30° from magnetic equator in the Peruvian sector follow exactly the same variation pattern as that seen in electrojet variations in Fig. 4a. The location, strengths, and the span of the anomaly crests show a large degree of variability. These observations show that local late afternoon TEC variations are very dependent on the corresponding EEJ variations near local noontime. This relationship study supports the idea of forecasting TEC fluctuations a few hours earlier than their occurrence by knowing the EEJ at low latitudes [*Khadka et al., 2016*].

c) Day-to-day variability of scintillation S_4 index during 00–12 UT obtained from GPS receivers spread on magnetic equator to either sides of anomaly region during solar minimum 2008.

d) Correlation analysis of the daily trends of the peak value of equatorial electrojet data in the year 2008 with (a) maximum TEC during 19–22 UT, (b) the separation of the anomaly crests on equinox (22 September) ±30 days, (c) S_4 index greater than 0.2, and (d) S_4 less than 0.2 observed during 00–12 UT.

Overall, We found that days with higher value of the equatorial electrojet and hence higher daytime vertical $E \times B$ drifts are associated with higher TEC values and a greater separation of the equatorial anomaly crests. But there is no apparent correlation with the S_4 scintillation index observed later during the nighttime.

Fig.: 4(d)



CONCLUSIONS

- **Day-to-day characteristics of EEJ are a useful tool to probe equatorial and low-latitude ionospheric electrodynamics associated with plasma density variabilities a few hours in advance.**
- **A clear picture of the linear dependence of peak values of afternoon TEC and anomaly separation is seen on noontime EEJ strengths in the low latitude ionosphere. The day-to-day variability and the characteristic features of the EIA crests exhibit a strong correlation with the EEJ variabilities.**
- **Minor correlation of peak value of EEJ with net S4 index greater than 0.2 likely exists, but there is no correlation at all below 0.2 for the solar minimum year 2008. Noontime EEJ strengths is not a good predictor for the nighttime scintillation during solar minimum period in the low latitude ionosphere.**
- **As in the polar region, the equatorial region is also highly susceptible to ionospheric scintillations during strong solar activity periods. Extending this analysis to solar maximum with larger database of nighttime S4 index will certainly be worthwhile project in accessing correlations with peak values of daytime EEJ.**
- **Collection of long-term statistics relating magnetometer-derived drifts and radar-measured drifts can contribute significantly to a more economical way to characterize the occurrence of ionospheric irregularities. The development of such model and statistical relations can help in real-time ionospheric monitoring and improvement in GPS navigation capabilities by assessing space weather impacts.**

REFERENCES

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3. *Khadka, S. M., C. Valladares, R. Pradipta, E. Pacheco, and P. Condor (2016), On the mutual relationship of the equatorial electrojet, TEC and scintillation in the Peruvian sector, Radio Sci., 51, 742–751, doi:10.1002/2016RS005966.*