RELATIONS BETWEEN THE EQUATORIAL VERTICAL DRIFTS, ELECTROJET, GPS-TEC AND SCINTILLATION DURING THE 2008-09 SOLAR MINIMUM

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ABSTRACT

Over an extensive period of time, tremendous amount of scientific effort has been committed to the forecasting of equatorial ionospheric scintillations. This study delineates the interrelationship between the equatorial vertical ExB drift, 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 indications of the occurrence of ionospheric irregularities. Data from ground based observations such as magnetometers, ionosondes, GPS receivers and Incoherent Scatter Radars in the low latitudes of the American longitude sector were examined during the 2008-09 solar minimum. The difference between horizontal components (H) of the geomagnetic field (at and off by 6-9 degrees to dip equator) from a pair of magnetometers is a measure of EEJ strengths and this can be used to estimate vertical drifts. Ionosondes and radars data are expected to give a much more accurate measure of the vertical drifts. The electric field controlling EEJ and ExB drifts might determine whether we have favorable condition for the development of postsunset equatorial plasma bubble (EPB) and scintillations or not. The data show a strong relationship between the electric field and GPS-derived TEC. This presentation will also discuss the relationship between daytime equatorial vertical ExB drift and postsunset ionospheric scintillation.

1. INTRODUCTION

On account of its peculiar properties, low latitude ionosphere has become one of the widely studied research podia in the past few decades. Even though forecasting the ionospheric irregularities phenomena is a challenging portfolio in the scientific community, many researchers contributed significantly till the date. The explosion of interest in the issue of low latitude ionosphere irregularities has been boosted excessively. This is because the behavior of equatorial ionosphere differed impressively from the behavior of the ionosphere in other region. The special magnetic field geometry at the geomagnetic equator of the earth leads to various geomagnetic as well as ionospheric phenomena, many of which are unique**.** The transport of charged particle along geomagnetic line of force in the equatorial region is associated with a two-humped latitudinal distribution of electron density, with minimum at the magnetic equator. Another distinguishing feature of the equatorial ionosphere is the relative abundance of ionosphere electron density irregularities. The equatorial anomaly in the top side ionosphere and its correlation with E region current system near the magnetic equator of the earth have been studied by many researchers [*Cohen, et al., 1967; Fejer, et al., 1980; Kelley, 2009*]. The electrons and ions in plasma are always in thermal motion and cause fluctuations in the number density. These fluctuation caused by plasma instabilities in the E region ionosphere is called sporadic E and that in F region is spread F. Those plasma irregularities in the ionosphere are usually field-aligned and a function of space and time [*Onwumechili, 1997*]. Predicting ionospheric irregularities is identified as the topmost priority in the national space weather program implementation plan. Therefore understanding and forecasting the occurrence and impact of ionospheric irregularities is a critical public need.

In presence of solar radiation, the electron density in the E region ionosphere starts to rise and the H field shows a steady enhancement until around noon, after which it starts decreasing. Such behavior of magnetic field is due to eastward electric field during daytime that causes intense current system to exist in the low latitudes. An intense electric current flowing eastward in the ionospheric E-layer in a narrow belt latitudes ($\pm 2^0$) centered at the dip equator is called equatorial electrojet (EEJ), that term is coined by Chapman [1951]. Owing to this electric field and horizontal magnetic field at the equator, ExB drifts are produced and the electrons (plasma) are lifted to higher altitudes. The lifting of plasmas take place to certain height then diffuse along magnetic field lines to the F region of higher latitudes ($\sim 20^0$) thereby causes the post sunset scintillations in the low latitude belt [*Deshpande, et al., 1977; Banola, et al., 2001*]. The plasma diffused down around 20^0 latitudes from either sides of magnetic equator creating two plasma crests, is called Equatorial Ionization Anomaly (EIA). The equatorial daytime vertical plasma drift in the equatorial F-region of the ionosphere is the key transport mechanism for determining the electron density profiles near dip latitude as a function of altitude, latitude, and local time. The equatorial daytime vertical drift observation is random, but is very important element for ionospheric theoretical models. The strength of the daytime equatorial electrojet could be measured using a pair of magnetometers, one situated on the magnetic equator and the other displaced by 6 to 9 degrees away. The difference of noontime enhancement of H component observed from two magnetometers placed on and off-equator by $\sim 6^0$ to 9^0 is related to the equatorial electrojet strengths and also quantitatively with vertical ExB drift in the F region ionosphere [*Rastogi, et al., 1990; Anderson, et al., 2002, 2004*]. In absence of EEJ, the performance of magnetometer is not reliable on vertical drift measurement. The profile of true height variation with the time obtained from ionogram at particular sounding frequency can also give an estimate of the vertical drifts [*Bertoni, et al., 2006*].The discrepancy seen in the magnetometer drift measurement can be overcome by Digisonde and ISR (Incoherent Scatter radar) and JULIA (Jicamarca Unattended Long-term Ionosphere Atmosphere) measurement at Jicamarca.

The equatorial ionosphere starts to restructure after sunset causing plasma instabilities called equatorial spread-F (ESF).Consequently one can expect the occurrence of low latitude scintillation and TEC depletion associated with change in equatorial electrojet strengths and vertical drifts. The TEC is an indicator of ionospheric variability and defined as the total number of electrons integrated along the path from receiver (GPS) to satellite. It is measured in the units of TECU (1 TEC Unit = 10^{16} electrons/m²). The ESF that occurs at the bottom side of the F-region ionosphere thereby adversely affect the amplitude and phase of the radio waves of various frequency bands. An unusual fluctuation of phase/ amplitude of radio-frequency signal when it passes through an ionospheric region of random irregularities in electron density that acts as variable refractive index in the medium is called ionospheric scintillation. These scintillation phenomena initially/mainly occur in the geomagnetic equatorial region even though observed at all latitudes with minor scale intensity. The signal distortion caused by scintillation can degrade the performance of navigation system and generate errors in received messages. The high priority has given to study the ionospheric scintillation because of its significant impact on satellite radio communication. Quantitatively, scintillation intensity is measured as scintillation index (S_4) and defined as normalized variance of the signal power [*Valladares et al., 2004; Wernik et al., 2004*]. The physical parameters and processes concerning the generation, dynamics and decay of scintillations are known to vary widely. Present study focused only on particular characteristic of scintillation and irregularities. Incorporating such evidences, our study guides to develop a technique for the prediction of the interconnectedness of disturbances on GPS-derived TEC and then scintillation after sunset on the basis of Electrojet strength seen as a noontime enhanced H component and then by daytime equatorial vertical ExB plasma drift in the F region ionosphere.

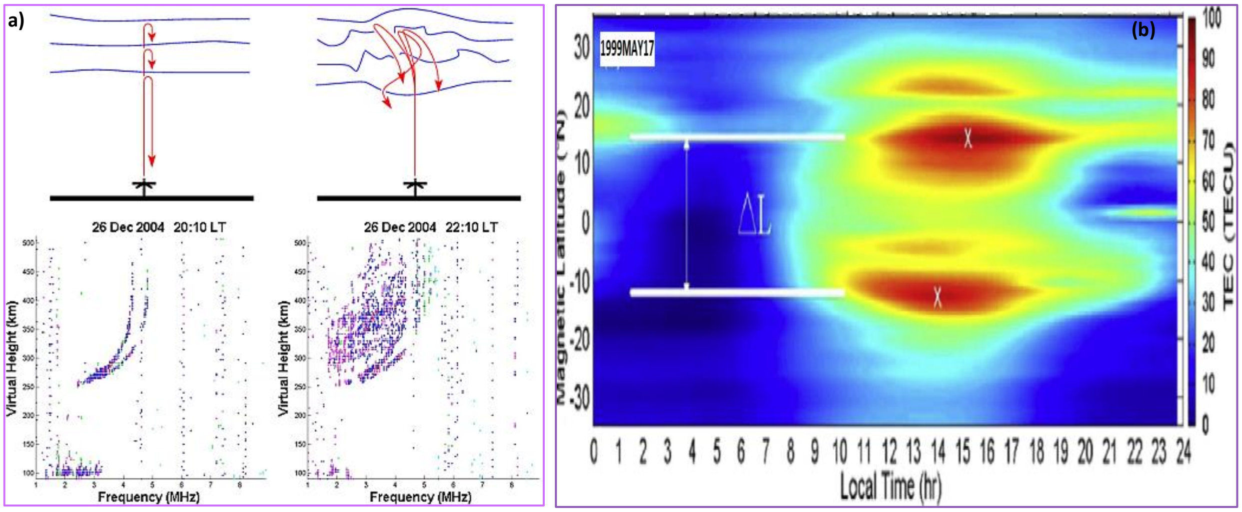

Fig. 1: a) Radio signal in normal and disturbed ionosphere, b) EIA crests. Source: Chen, et al. [2008].

2. DATA SELECTION AND ANALYSIS

The data from the permanent array of geophysical instruments deployed in the low latitude region of South America have been giving great impact in the study of equatorial ionospheric phenomena. It has already been revealed that the equatorial vertical ExB drift velocity is a strategic parameter for the prediction and analysis of the structures and dynamics of the ionosphere. For the analysis and implement our code we have use data from recent solar minimum of the year 2008-09. Measurements from ground based receiver chains of GPS (Global Positioning System), magnetometers, Ionosondes and radars of the low latitudes in the Peruvian sector of South America were examined.

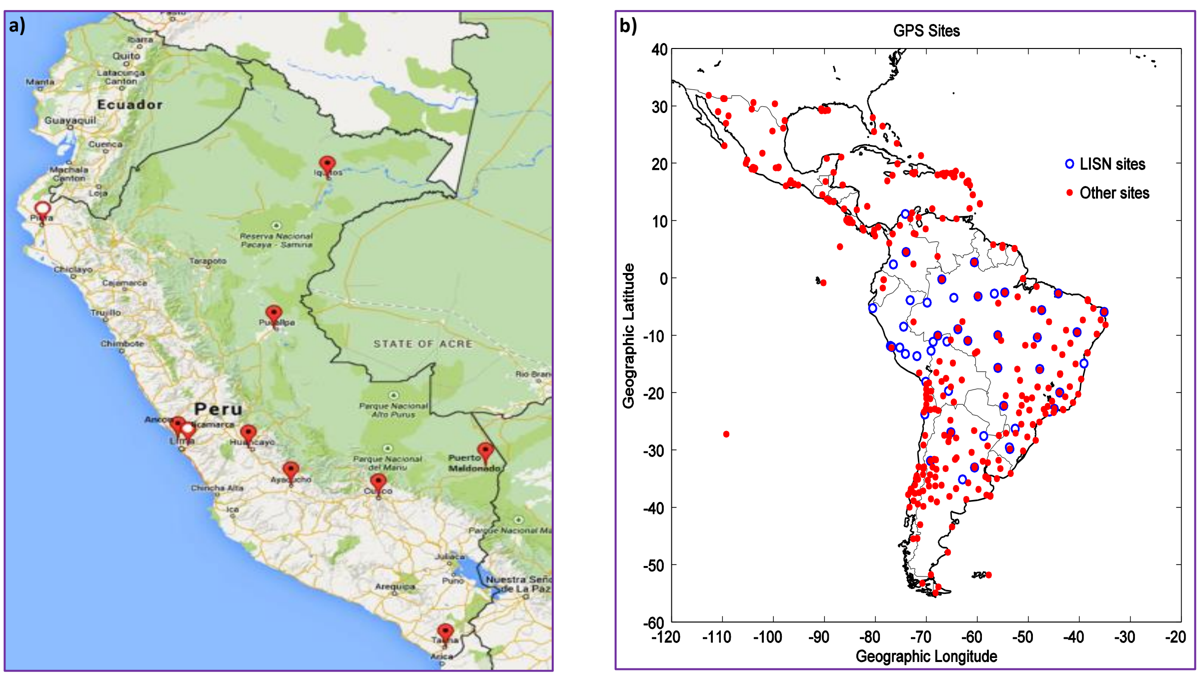

Fig. 2: a) Analyzed GPS stations for S_4 index, landmarks with white spot in the map represent Magnetometer and ionosonde stations as well, b) GPS sites in Central and South America.

For the current analysis, magnetometer data from Jicamarca (geog.11.9^{0}S, 283.1^{0}E, 0.8^{0}N dip latitude) and Piura (geog. 5.2^{0}S, 279.4^{0}E, 6.8^{0}N dip latitude) are used to get strength of EEJ and to infer ExB vertical drift. The H component observations from these two magnetometers are subtracted to eliminate Dst ring current and S_q dynamo contribution and, to get only electrojet contribution on H [*Rastogi, et al., 1990*]. The magnetometer inferred vertical drift is accurate if there is presence of ionospheric current in the E layer of the ionosphere. To get whole day span of vertical drifts by overcoming magnetometers' discrepancy, Jicamarca Digisondes, ISR, JULIA data are used to estimate the vertical drift. The TEC derived from GPS receivers spread in the South America is used to detected the strength, location and occurrence of the equatorial anomaly which is escorting by vertical plasma drifts. This study mainly emphasized on the occurrence of ionospheric disturbances phenomena observed via GPS-TEC, S_4 index and associated EEJ as accompanied by daytime equatorial vertical ExB drift form Magnetometer/Digisonde/ISR/JULIA observation during the recent solar minimum years.

Data analysis is mainly executed for low solar activity condition (2008 and 2009) and artificial neural network approach has been employed in estimating daytime equatorial vertical ExB drifts. The daily average of solar radio flux related F10.7 index was less than 80 during this period of extremely low solar activity period and offers an opportunity to study the quiet time drifts at lower solar activity levels than that of previously observed. Artificial multilayer feed-forward neural networks have powerful function-approximation capabilities for pattern recognition, control and signal processing [*Haykin, 2005*]. Here, artificial neural network technique has been considered in order to establish the relationship between ExB drift velocities and the most relevant six inputs to the network. The six inputs are year, DOY (day of the year), F10.7, a_p index, LT (local time) and dH (difference of H measured at Jicamarca and Piura), which are influencing parameters for the vertical drifts. For the supervised training phase, 264 days of data between January-2008 and December-2009 were used for desired output drift measured from Jicamarca Incoherent scatter Radar (ISR). The weights in multilayer neural network are obtained with many epochs for six inputs in order to calculate the nonlinear relationship with ExB drift velocities. Having established the quantitative relationship between Electrojet strengths and ExB vertical drifts, our next intension is to investigate the dependence of the TEC and the nighttime scintillation. The TEC behavior and scintillation were examined using dual frequency measurement from LISN (Low Latitude Ionospheric Sensor Network) GPS spread on the low latitude in the Peruvian sector of South America. The TEC data were plotted over continental map of South America for the corresponding day of EEJ and vertical drifts measured to see their interconnectedness.

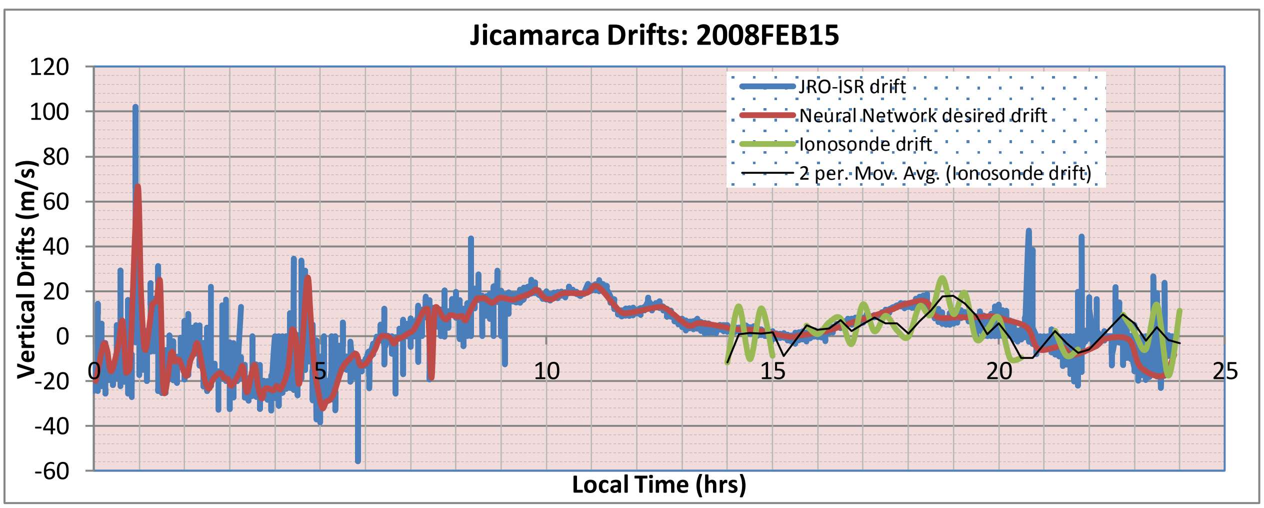

Fig. 3: Equatorial vertical drifts measured using Jicamarca Ionosonde and Incoherent Scatter Radar (ISR).

3. RESULTS AND DISCUSSION

The data plots presented here are chosen from the pool of analysis that has been done for the year 2008 and 2009. The following investigation compares two cases, quiet and non-quiet day phenomena, with various ionospheric parameters and indices. On a quiet day, planetary K_p index value is less than 3 and that for a non-quiet day is equal to 4.

Case-I: Strong EEJ/ Higher Vertical ExB Drift during Quiet Day (Oct-16, 2008)

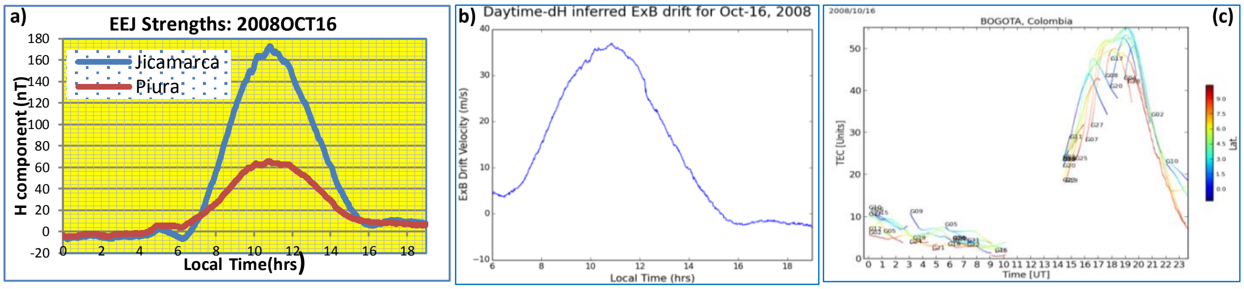

Fig. 4: Quiet day: a) EEJ, b) Magnetometer inferred vertical ExB drift using neural network, c) TEC variations.

The plots above in fig.4 (a) shows the variation of horizontal component of earth's magnetic field in the two stations, Jicamarca (geog.11.9^{0}S, 283.1^{0}E, 0.8^{0}N dip latitude) and Piura (geog. 5.2^{0}S, 279.4^{0}E, 6.8^{0}N dip latitude) in Peruvian sector observed from magnetometer. It is clearly seen that there was an enhancement of H during noon time. Now, it is well understood that dH (difference of H from these two stations) gives the strength of EEJ contribution only. The effect of the Dst ring current and S_q dynamo contribution will be excluded while taking their difference. The variation of vertical ExB drift inferred from magnetometer observation as shown in fig.4 (b) is evaluated using artificial neural network technique. The neural network is trained with the desired output drifts (red curve in fig.3) for each day which are measured using Jicamarca incoherent scatter radar as shown in fig.3 above. We attempt to cover 24 hours vertical drifts variations using ionosondes and magnetometers. ISR drift measurement data cannot be available for all day since this experiment is very expensive to run. It seems that there is higher value of total electron content (fig.4c) in the evening time of the higher vertical drifts day.

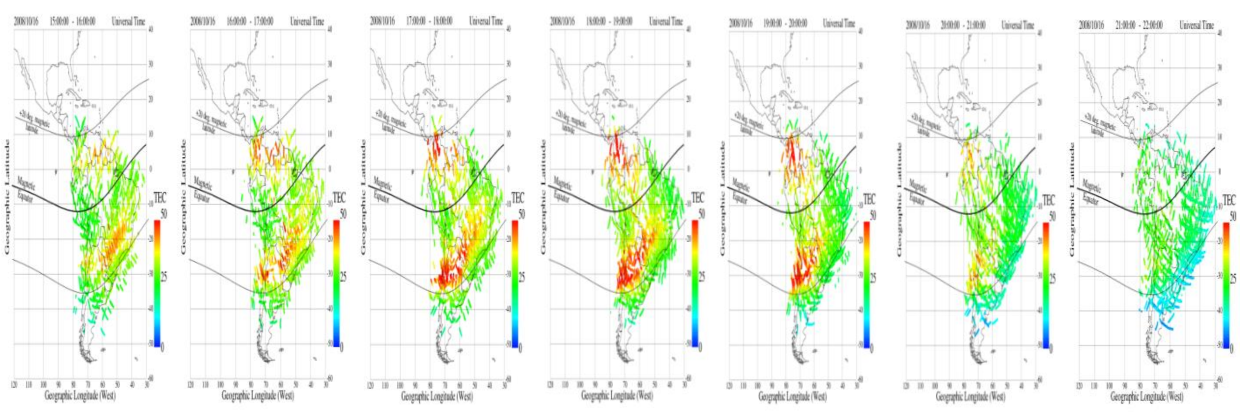

Fig. 5: Quiet day: Continental TEC distributions over South America between 15 to 22 UT.

The ionospheric total electron content (TEC) values are plotted over geographic map of South America in the fig.5. The equatorial ionization anomalies (EIAs) are seen distinct, well separated and intense in nature for higher vertical drift condition on quiet day.

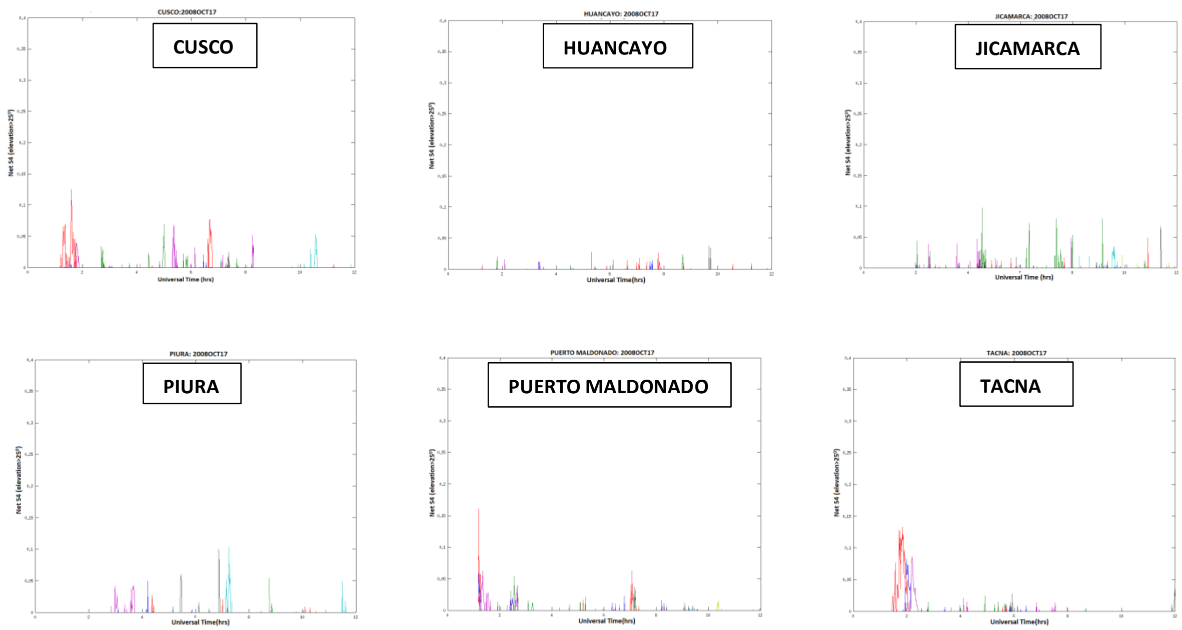

Fig. 6: Quiet day: Net scintillation (S_4) at night after masking background and elevation in Peruvian sector.

The scenario of scintillation index (S_4) on the night time of Oct-16, 2008 from 6 different stations in Peruvian sector, these are landmarked in fig.2 (a), are plotted for 12 hours period starting at 19:00LT (0 to 12:00 UT, Oct-17, 2008) as shown in fig.6. The net values of scintillation (S_4) are obtained after masking the effect of the low elevations and background value. The background masked line is modeled on the basis of elevation and set to zero in those plots.

Case-II: Weak EEJ/ Lower Vertical ExB Drift during Non-Quiet Day (Nov-08, 2008)

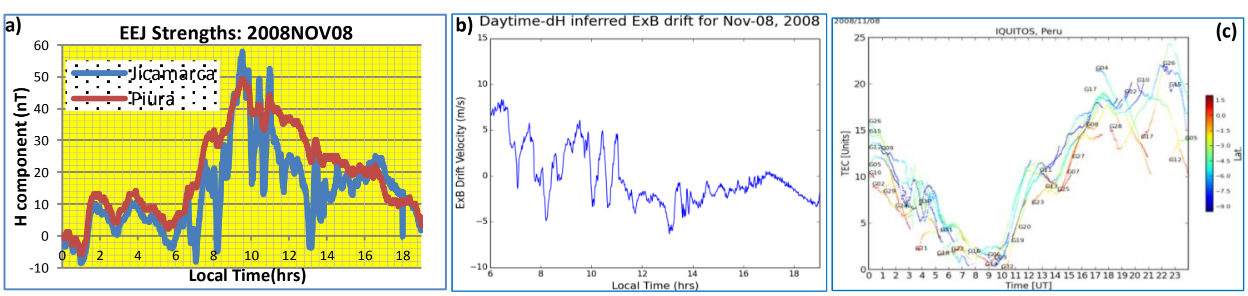

Fig. 7: Non-Quiet day: a) EEJ, b) Magnetometer inferred vertical ExB drift using neural network, c) TEC variations.

Similarly, the EEJ strength, magnetometer inferred vertical drift and TEC variations for the non-quiet day are shown in fig.-7. The EEJ strength seems weak and then vertical drift. The ionospheric TEC value on that evening is also smaller than that on higher vertical drift day. Fig.8 shows the geographic map of continental TEC over South America for the corresponding night of the non-quiet day. The EIA crests in lower vertical drift day could not be formed properly as that of higher drift case.

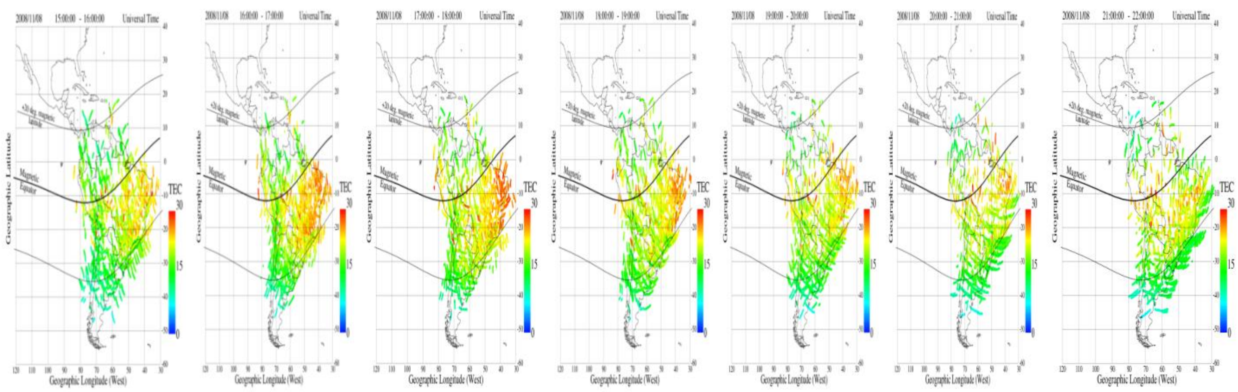

Fig. 8: Non-Quiet day: Continental TEC distributions over South America between 15 to 22 UT.

Twelve hours period plots of net S_4 starting at 19:00LT (0 to 12:00 UT, Nov-09, 2008) are shown below in fig.9 for non-quiet day. The variation of net S_4 index values on non-quiet day shoots to bigger value than that on the quiet day during same interval of time while comparing it from same six stations located in the Peruvian sector of South America.

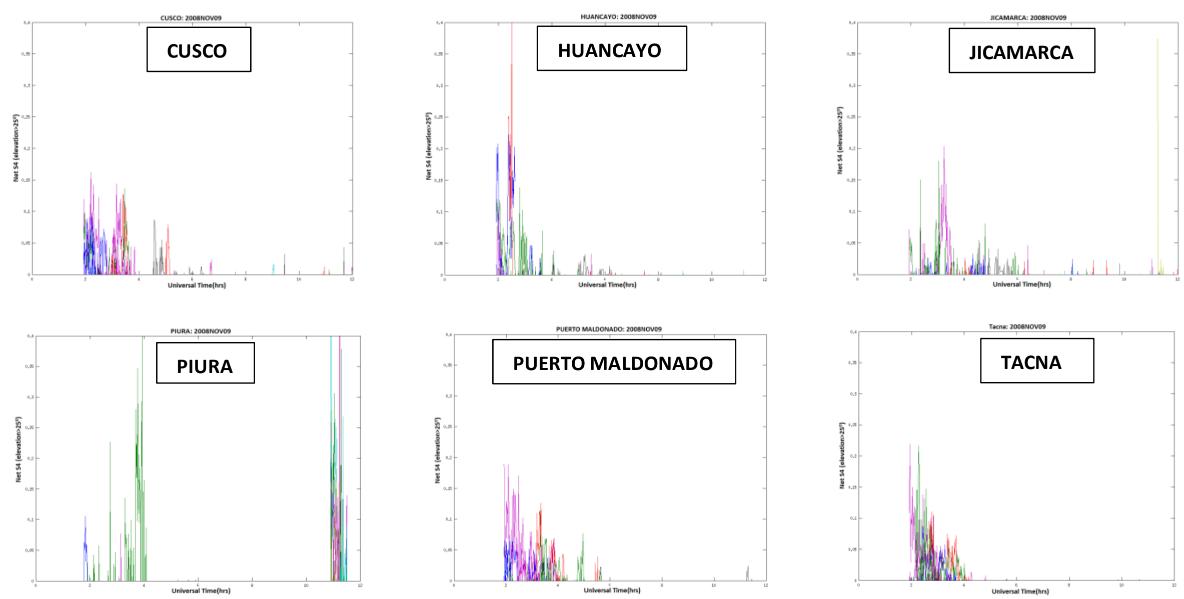

Fig. 9: Non-Quiet day: a) Net scintillation (S_4) at night after masking background and elevation in Peruvian sector.

Since, the daytime eastward current in E region ionosphere regulates the strength of EEJ as well as vertical drift. Comparing TEC on geographic map of South America in fig.5 and 8, it can be said that higher vertical drift causes the electron density anomalies to move farther from magnetic equator region and vice versa. But, for the scintillation, one should be interpreted on the basis of the starting time of magnetic disturbance. The strong Electrojet current in the E region ionosphere, associated equatorial vertical ExB plasma drift in the F region ionosphere and the accompanying noontime enhancement of H component, might be interconnected to electron densities irregularities and corresponding plasma bubbles that show an indication of the TEC disturbances after sunset in the F region ionosphere.

SUMMARY AND CONCLUSIONS

A comparative study of vertical ExB drift, electrojet current strength, TEC, and S_4 scintillation index from magnetometers, Jicamarca ISR/JULIA radar, digisonde, and GPS receivers at low latitude stations has been conducted to investigate potential predictive signatures for the occurrence of disturbances in the equatorial ionosphere. We found that days with higher value of daytime vertical ExB drift are associated with higher TEC values, but there is no apparent correlation with the S_4 scintillation index observed later during the nighttime. This research study suggests that there might be some association between magnetometer-derived daytime vertical ExB velocities (which are proportional to EEJ strength) and GPS-derived TEC. However, there is little correlation between these two quantities and the corresponding S_4 scintillation index observed after sunset.

A large dataset on EEJ strength, ExB drift velocity, and TEC (based on magnetometers, ionosonde, GPS, and radar measurements) are needed to establish precise relationships between them under various background conditions. 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.

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