PREDICTION OF EQUATORIAL IONOSPHERIC BUBBLES IN THE POST-SUNSET HOURS

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INTRODUCTION

The irregularities in the electron density distribution of the ionosphere over the equatorial zone frequently disrupts space-based communication and navigational channels by causing severe amplitude and phase scintillations of signals. Prediction of scintillations has now become a very important part of the Space Weather program.

It has been suggested in recent years that there is a correspondence between the development of the electrojet during the daytime and the post-sunset enhancement of the eastward electric field although the physical mechanism connecting the two is not fully clear. The equatorial electrojet controls the development of the equatorial anomaly through the fountain effect. Under strong electrojet conditions, the anomaly is developed in the afternoon hours with a steep gradient of the F-region ionization or Total Electron Content (TEC) in the region between the crest and the trough. Thus a measurement of the latitudinal gradient of electron content would provide an indication of the post-sunset eastward electric field enhancement and could validate the above suggestion. A developed equatorial anomaly in the afternoon hours may then be taken as a precursor to scintillations on transionospheric links [*Raghavarao et al*, 1988]. In the early days of satellite beacon observations, Faraday Rotation measurements with transmissions from Low Earth Orbiting (LEO) satellites had been utilized to show that the TEC exhibits a pronounced latitudinal variation similar to that observed with the F-region maximum ionization (N_mF_2) [*Basu and DasGupta*, 1967]. In recent years however, such measurements have been rare because of non-availability of suitable satellite transmissions. The only available satellites of the NOAA series transmitting plane-polarized signals at 136/137MHz may however be used to study the above latitudinal features for TEC. The association between the occurrence of bubbles and the strength of the equatorial electrojet has also been studied. Generation of equatorial irregularities over the magnetic equator in the post-sunset hours is intimately related to the variation of height of the F-layer (h'F) around sunset. It is established that a sharp rise of F-region altitude due to the pre-reversal enhancement of the eastward electric field is often followed by the generation of intense irregularities through Rayleigh-Taylor mechanism [*DasGupta et al*., 1983]. The present paper reports one such study to examine the correspondence between the development of daytime Equatorial Anomaly and pre-reversal enhancement of the eastward electric field, and the equatorial bubbles in the equatorial region.

DATA

Transmission from a low earth orbiting (LEO) satellite is more suitable for studying the latitudinal variation of TEC. The Faraday Rotation of plane polarized VHF signal at 137MHz from the sun-synchronous LEO NOAA14 has been recorded at Calcutta (lat: 22.58^{0}N, long: 88.38^{0}E geographic; dip: 32^{0}N) during August through October 2000. Amplitude scintillations from geostationary satellites FLEETSATCOM (FSC, 244MHz, 73^{0}E) and INMARSAT (1.5GHz, 65^{0}E) and Medium Earth Orbiting (MEO) Global Positioning System (GPS, 1.6GHz) are also recorded at this location situated under the northern crest of the Equatorial Anomaly. The latitudinal gradient of electron content between 15^0-25^{0}N geographic is routinely scaled for the ascending node of NOAA14 in the afternoon hours (1620 hrs LT) to obtain a measure of the development of anomaly. This data is combined with scintillations recorded with the geostationary FSC and INMARSAT links during the equinoctial months August through October 2000.

The development of the Equatorial Anomaly is mainly controlled by the equatorial electrojet. The strength of the electrojet is measured by the differences between the hourly inequalities (ΔH) of the horizontal component (H) of the geomagnetic field at Tirunelveli (lat: 8.67^{0}N, long: 77.82^{0}E geographic; dip: 0.5^{0}N) (ΔH_T), situated close to the axis of the equatorial electrojet, and Alibag (lat: 19.00^{0}N long: 72.83^{0}E geographic; dip: 24.75^{0}N) (ΔH_A) located away from the magnetic equator The intensity of the post-sunset scintillations observed at Calcutta is indicated by the S_4 index at 1.5GHz.

In order to examine the correspondence between the daytime electron density gradient, post-sunset F-region height rise, and generation of ionospheric bubbles, ionosonde data from Kodaikanal (lat: 10.23^{0}N, long: 77.47^{0}E geographic; dip: 1.5^0N), a station situated close to the magnetic equator, has been utilized along with ground-based satellite beacon records of Calcutta. Due to the separation in the longitudes between Calcutta and Kodaikanal, no point-to-point correspondence should be expected, although the average behavior would be the same.

RESULTS

Fig. 1 and 2 show samples of latitudinal variation of TEC in the afternoon hours (1620 hrs LT) on two days. The quasi-transverse (QT) propagation condition occurs when the satellite passes over 28^0N and 29^0N latitude and the Faraday Rotation angle attains a minimum value around those latitudes. To avoid the uncertainties of Faraday Rotation in the QT region, the plots are restricted to latitudes sufficiently south of the QT point. It may be observed that the anomaly was remarkably developed on September 17, 2000. On this day, saturated scintillations at VHF (>20dB) and intense scintillations at L-band (21dB) were observed at Calcutta. On the contrary, no scintillations were observed on September 10, 2000, a day with a much less latitudinal gradient.

Fig. 3 shows a plot of latitudinal gradient of TEC measured on different days of the period August through October 2000. The filled-in circles correspond to days with equatorial type scintillations at VHF and L-band whereas the crosses are for days with no scintillations. The correspondence between a developed equatorial anomaly in the afternoon and occurrence of scintillations in the early evening hours is remarkable. A latitudinal gradient in excess of 8 TEC units per degree, indicated by the horizontal line, may be taken as a measure of the development of the daytime anomaly necessary for causing scintillation effects in the post-sunset hours.

The maximum values of S_4 at 1.5GHz observed from Calcutta are plotted against the diurnal maximum of (ΔH_T-ΔH_A), shown in fig.4 and integrated values of (ΔH_T-ΔH_A), integrated over the time interval 0800-1400EMT (75^0East Meridian Time) shown in fig.5. The difference (ΔH_T-ΔH_A), indicates the strength of equatorial electrojet in the Indian region. A significant association between the diurnal maximum values of (ΔH_T-ΔH_A) and the occurrence of scintillations is noted at 1% level by performing a chi-square test. From fig.4, it is observed that on most of the days when there has been a development of intense equatorial bubbles (S_{4max}> 0.6 at L-band), the maximum value of (ΔH_T-ΔH_A) exceeded 72nT. However, the reverse is not true. A significant association between the integrated values of (ΔH_T-ΔH_A) and the occurrence of scintillations is also noted at 1% level by performing a chi-square test. It is observed from fig.5, that on most of the days when there has been a development of intense equatorial bubbles (S_{4max}> 0.6 at L-band), the integrated value of (ΔH_T-ΔH_A) exceeded 380nT. However, the reverse is not true; there are days with strong electrojet but with no scintillations.

Fig.6 shows the correspondence between the post-sunset F-region height rise (value of dh'F/dt over the time interval from local sunset to 2000LT) over the magnetic equator obtained from the Kodaikanal ionosonde data and the maximum values of S_4 at 1.5GHz obtained from ground-based satellite beacon records of Calcutta. Intense L-band scintillations (S_{4max} > 0.6) occurred on 19 nights during the period of study i.e. August through October 2000. On 16 such cases, the upward drift of the F2 layer over Kodaikanal exceeded 30m/s. In order to quantify the relationship between the two events, a chi-square test was performed. It showed a strong association at 2.5% level. The latitudinal gradient of TEC is also closely associated at 1% level with the same parameter. Again the reverse is not true. A rapid height rise does not necessarily mean occurrence of scintillations.

DISCUSSIONS

It has been proposed that "bubbles" in the post-sunset hours are more probable on days when the daytime anomaly is more developed, although no interconnection between the two phenomena has yet been established. Intense scintillations in the equatorial zone of the ionosphere are caused by plasma bubbles, which develop during the post-sunset hours by Rayleigh-Taylor instability, subsequent to an enhancement of the upward ExB drift velocity. The coupling between the E and F layers in the vicinity of the solar terminator has been worked out by *Haerendel and Eccles* [1992] and *Eccles* [1998]. According to this model, a portion of the dayside equatorial electrojet diverts into the F-layer and causes the low-latitude plasma to rise in the early post-sunset hours.

The equatorial anomaly is not confined to the maximum ionization height h_mF_2, but extends up to several hundred kilometers in the topside of the ionosphere. In situ measurement of electron density with orbiting satellites in the height range of 400-600km have been used to study the development of equatorial anomaly. Measurement of latitudinal variation of electron content by recording Faraday Rotation of plane polarized signals transmitted by LEO satellites have also established that the TEC exhibits features similar to that of the anomaly observed with f_0F_2. The study clearly establishes that days with developed daytime anomaly in the afternoon, as indicated by the gradient of TEC, are definitely followed by the generation of intense equatorial bubbles resulting in scintillations during the local post-sunset to midnight hours. Hence, the measurement of latitudinal variation of TEC in the equatorial region by the Faraday Rotation technique during the afternoon hours with LEO satellites may be provide a very simple and inexpensive method for forecasting scintillations in the post-sunset hours.

Measurement of the electrojet strength from the magnetic data does not conclusively establish the correspondence of electrojet strength with the occurrence of bubbles, as it has shown that on many days no scintillations were observed even though $(\Delta H_T - \Delta H_A)$ attained large amplitudes. Similarly, h'F rise velocity also does not conclusively prove the association between F-region height rise and occurrence of bubbles.

ACKNOWLEDGEMENTS

Magnetic data have been obtained from the prompt geomagnetic data reports published by the Indian Institute of Geomagnetism (IIG). Professor J.H. Sastri was kind enough to provide the Kodaikanal ionosonde data. This work is supported in part by the University Grants Commission (UGC) through the Eastern Center for Researches in Astrophysics (ECRA) and the Center of Advanced Study (CAS). The author (AP) thanks Professor A. DasGupta and Ms. Sarbani Ray for help in analyzing the data and discussions. The author (AP) acknowledges the financial assistance of the Council of Scientific and Industrial Research (CSIR) in the form of a Senior Research Fellowship.

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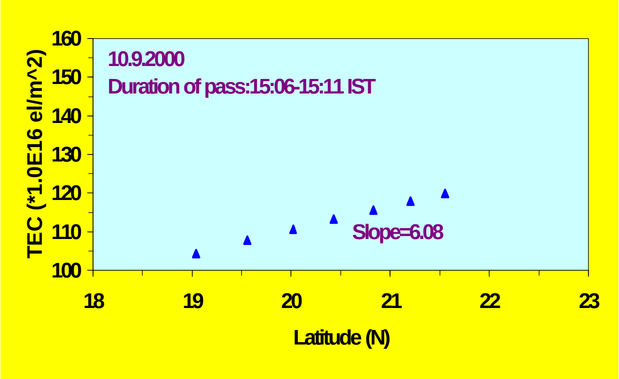

Fig.1 Latitudinal variation of TEC on a day with no scintillations.

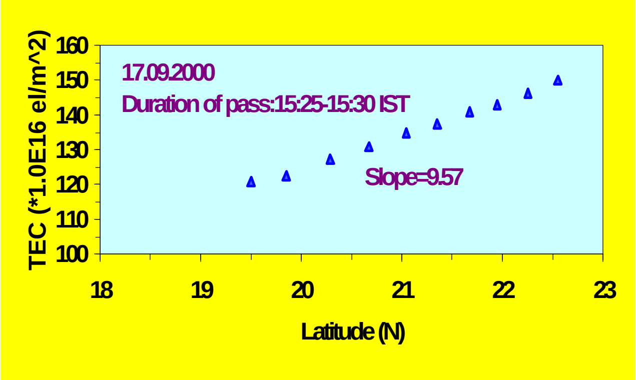

Fig.2 Latitudinal variation of TEC on a day with scintillations.

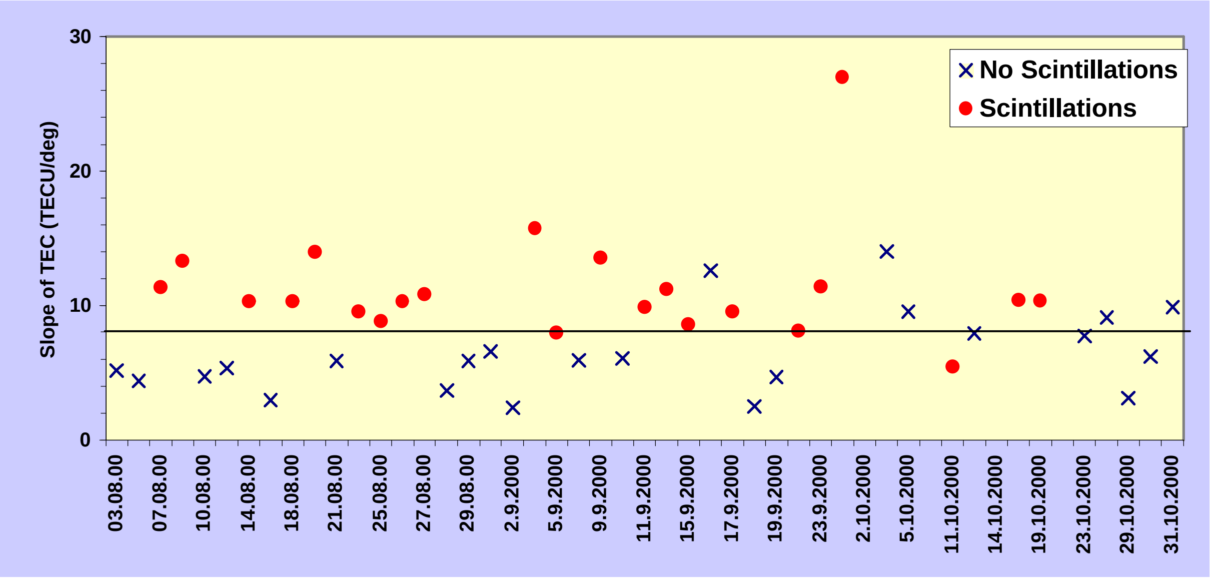

Fig.3 Latitudinal gradients of TEC on different days of August-October 2000. The red circles correspond to days with scintillations whereas the crosses are for days with no scintillations.

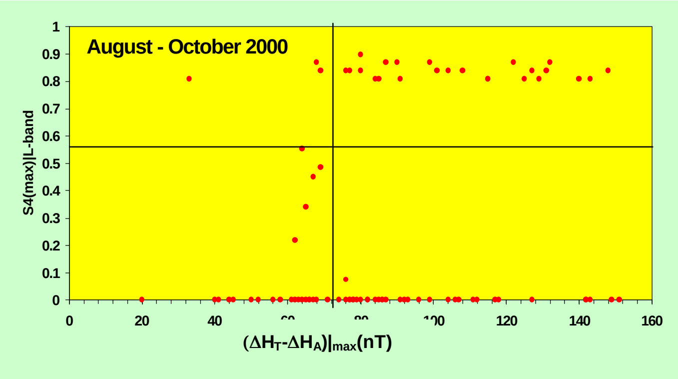

Fig.4 Maximum value of S_4 observed from Calcutta as a function of the diurnal maximum value of (ΔH_T-ΔH_A)

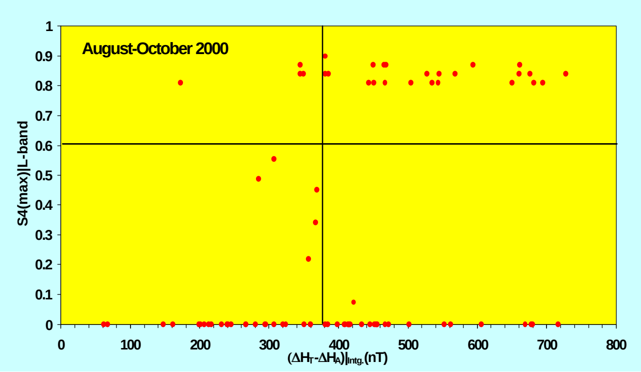

Fig.5 Maximum value of S_4 observed from Calcutta as a function of the integrated value of (ΔH_T-ΔH_A)

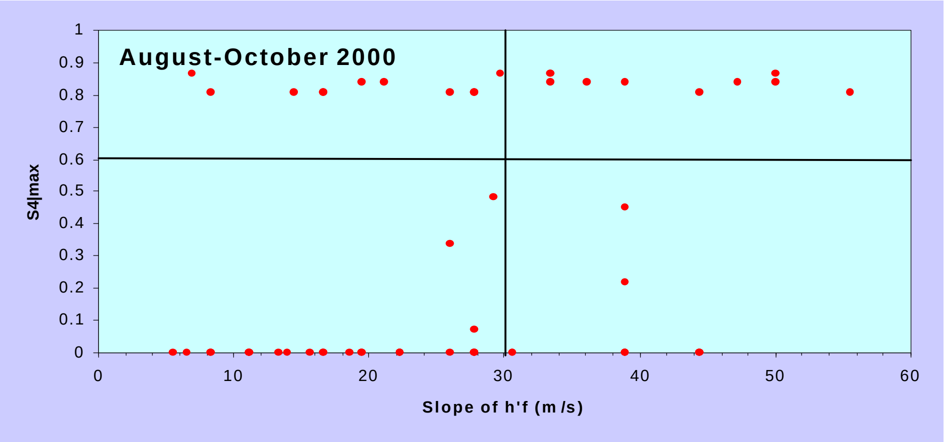

Fig.6 Maximum value of S_4 observed from Calcutta as a function of the h'F vertical rise velocity at Kodaikanal