



Adaptation of Image Processing technique in identification of earthquake induced anomalous feature from TEC: A new Approach

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Abstract

The basic aim of the paper is to adopt image processing approach for extraction of pre-seismic features from global Total Electron Content (TEC) data with an aim of identification of impending earthquake (EQ). For this purpose an algorithm is developed using 'Color Histogram based Search and Retrieve Technology' in matlab environment where pixel information of the global TEC images are extracted. The conversion of these pixel information into coded form and translation of these cipher symbol into TEC magnitude are discussed in details in the paper. The final result is the comparison of anomalous symbolic pattern with reference to EQ time Equatorial Anomaly and those received in regular environment to identify an impending EQ. The technique is tested in two events and the reliability is assessed through real observation.

Key words: TEC, Earthquake, Image Processing, Color Histogram based Search and Retrieve Technology, Equatorial Anomaly

1. Introduction

Image processing technique is relatively well known approach for extraction of information from different shades of images [Jenson 2003; Gonzalez et al., 2007; Chitradevi and Srimathi 2014]. With the increasing demand of transmission of volume of information and data retrieval, the Image Processing Technique (IPT) merits significant importance with the application in fields like Atmospheric Remote Sensing, Medical Imaging, Forensic Studies, Material Science, Military, pattern recognition. The different approaches adopted in image processing modes of data retrieval aims at achieving enhancement and segmentation of images along with feature extraction and their classification [Jain 1989; Gonzalez et al., 2007; Choras 2007]. The retrieval of information from satellite image during natural calamities are proved to be very effective in providing percussive warning, however, this tool is yet to be utilised in extraction of relevant features from parameters like Total Electron Content (TEC), temperature, pressure and relevant atmospheric variabilities. In this aspect we may refer to the work of Devi et al., 2012 where they have

adopted DTW technique utilised as pattern recognition of TEC features for identifying an impending EQ. Reports of such percussive studies are now available from workers around the globe [Zaslavski et al., 1998; Devi et al., 2001, 2004; Liu et al., 2001, 2002] where EM technique is very fruitfully utilised in identification of an impending EQ by examining anomalous features TEC, critical frequency of F-layer and related parameter. In this aspect it is therefore felt that Image Processing can be utilised as a potential tool and this is the attempt of the paper.

2. Analysis and Approach

The main data source for this work is global TEC (<https://www.sws.bom.gov.au/Satellite>), TEC data collected from GPS receiver installed at Guwahati (26°10'N, 91°45'E) are used as supporting inputs when necessary. The main feature of the study will be Equatorial Anomaly, an effect that causes diurnal peak density not at the equator but around $\pm 15^{\circ}$ geomagnetic latitude through $E \times B$ force where E is the electric field generated by plasma drift and B is the Earth's magnetic field vector at the equator. The position of Guwahati (geomagnetic latitude 15.2° N, dip angle 37° N, magnetic latitude 20.64° N) being at the anomaly crest zone, the diurnal TEC profile carries signature of this phenomenon. A representative of this feature present in TEC over Guwahati is shown in figure 1(a) where density reaches maxima at post noon hours instead of showing its peak at noon. This peak is the result of Appleton Anomaly effect [Walker and Chen 1989; Horvath and Essex 2003; Anderson et al., 2006; Andreeva et al., 2000]. Figure 1(b) presents a normal condition where density maxima occur at local noon hours.

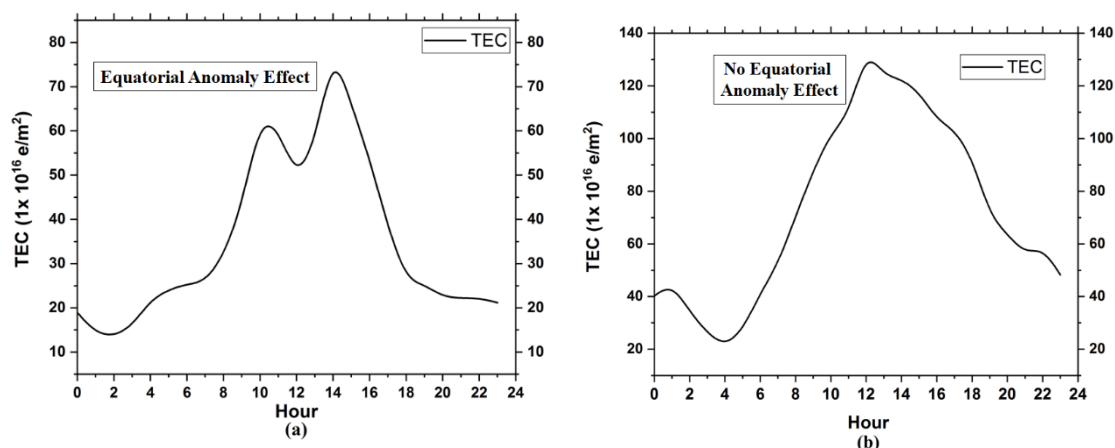


Figure1: Representative Diurnal profile of TEC over Guwahati displaying (a) Anomaly effect, (b) Normal feature.

Such effect is also clearly observed in global TEC contour plot presented in figure 2 where a high density zones are observed at around 15° - 20° geographic latitude (covering off-equatorial station both in northern and southern latitudes), 70° - 110° longitude at 9 UT or around noon local time. This phenomenon is identified as normal equatorial anomaly. The paper examines possible development of EQ time equatorial anomaly for the case considered here. For this purpose the image processing technique is adopted in Matlab environment as discussed in the next section.

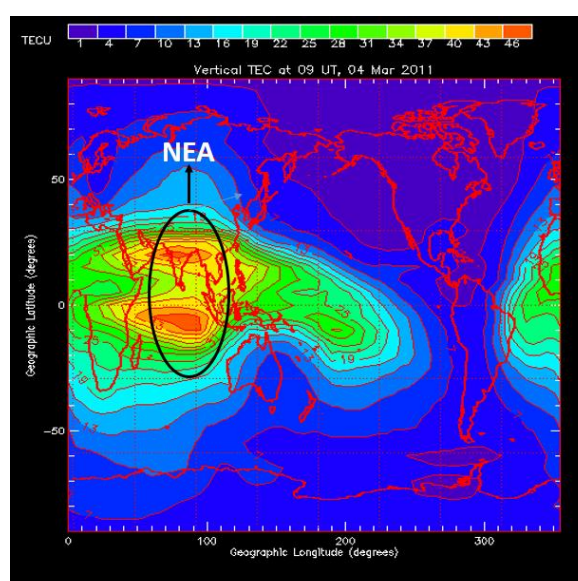


Figure 2: Global TEC map showing Development of Normal Equatorial Anomaly (NEA) around 80° E longitude at 9 UT (noon hours).

2.1 Technique adopted

Global TEC data are available as a color image as shown in figure 2. The color intensity of the image varies with magnitude of the TEC. Thus the pixel intensity of such images is directly proportional to the ionospheric density profile and hence through pixel intensity character TEC profile can be reconstructed which is the basic aim of this work. For this purpose image feature extraction technique is used where the pixel information of the global TEC images are converted in the form of histogram [Choras 2007; Gonzalez et al., 2009; Shih and Frank 2010; Saber and Tekalp 1998; Khotanzad and Hong 1990]. Color histogram describes the distribution of colours within a defined region of image. The RGB (red, green,

blue), one of the commonly used color model, is specified in terms of 3-D coordinate system and a subspace within it where each color is represented by a single point in 3 channel mode (as shown in Figure 4). Statistically, color histogram denotes the joint probability of the intensities of these three color channels. Let $\{F(x, y); x = 1, 2, \dots, X; y = 1, 2, \dots, Y\}$ be a two-dimensional image pixel array. For color images $F(x, y)$ denotes the color value at pixel (x, y) i.e., $F(x, y) = \{F_R(x, y), F_G(x, y), F_B(x, y)\}$. For black and white images, $F(x, y)$ denotes the grayscale intensity value of pixel (x, y) . Thus for a three-channel image, we will have three such histograms.

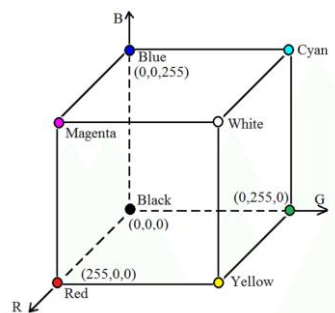


Figure 4: RGB color space.

The analysis started with selection of study zone within 70^0 - 130^0 Longitude and $\pm 20^0$ N latitude considering high seismic activity embedded in this area. For this purpose two EQ events with $M > 6$ are considered. This area of study is then segmented from the entire global TEC map (as shown in the figure 5.a) by using image threshold method. For the two EQ events considered here, 5 quiet days around the EQ date are identified first and RGB pixel information of the quiet days over the segmented zone is extracted in histogram form (as shown in Figure 5.b) and created a reference vector (I_{REF}). One can note that during the quiet day (Figure 5.a) at 12UT covering post sunset to night hours there is no development of equatorial anomaly at the study area and the pixel patterns from histogram indicate presence of mainly Green and Blue component with minimum Red intensity. This situation we consider as No/Normal Equatorial Anomaly (NEA) depending on the temporal status of the study zone. Next RGB pixel information of TEC around ± 7 days for the two EQ events considered here are extracted by histogram method which forms the input matrix (I_{INPUT}) for the selected case. The resultant RGB information (I_R) for every hour of a day is then calculated by comparing I_{REF} values with the I_{INPUT} matrix, i.e.

$$I_R = I_{INPUT} - I_{REF}$$

Once the I_R value is obtained, its pixel information is translated into six code messages where each code has its own identity. With $I_R = 0$, the corresponding TEC comes to around 40 TECU which is marked as code 3, i.e., condition of NEA. The code messages 4 and 5 indicate development of anomalous growth of TEC in relation to NEA. The most significant code here is message 6 that indicates highest TEC values that may increase by two folds from NEA values and this is associated with full development of an EQ time Equatorial Anomaly (EEA). Based on these code messages the identification of an impending EQ for the defined cases is presented.

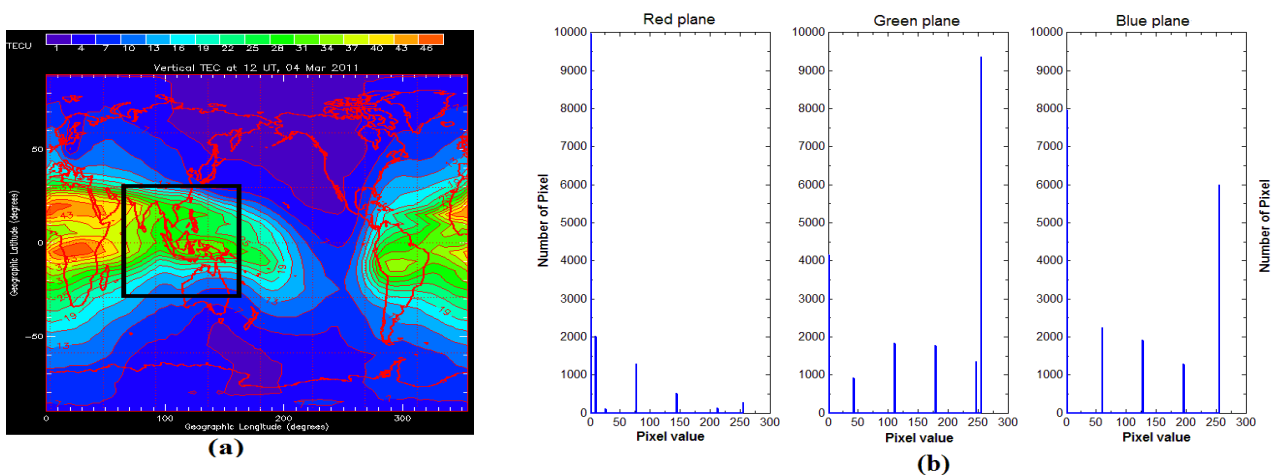


Figure 5: TEC global map for 4th March 2011 an example of NO- EQ day. (a) Study zone is shown by a square box in the global TEC image, (b) Pixel distributions of the study zone for Red, Green and Blue plane are shown in terms of histogram.

3. Results

3.1 Case 1: Indonesia Earthquake (IEQ) of 11th April 2012

The first case considered here is Indonesia earthquake (IEQ) of $M = 6.9$ that occurred on 12th April 2012, at 92.42° E, 0.76° N, a low latitude location. For this purpose, I_{REF} is evaluated through extraction of pixel information from global no EQ time TEC contour plot covering 70° - 160° E longitudinal and $\pm 30^{\circ}$ N latitudinal zone (the area as marked in Figure 5). The I_{INPUT} matrix is next evaluated for each day from 5th April to 15th April through pixel information of TEC contour map and the results for a few representative days are displayed in Figure 6.

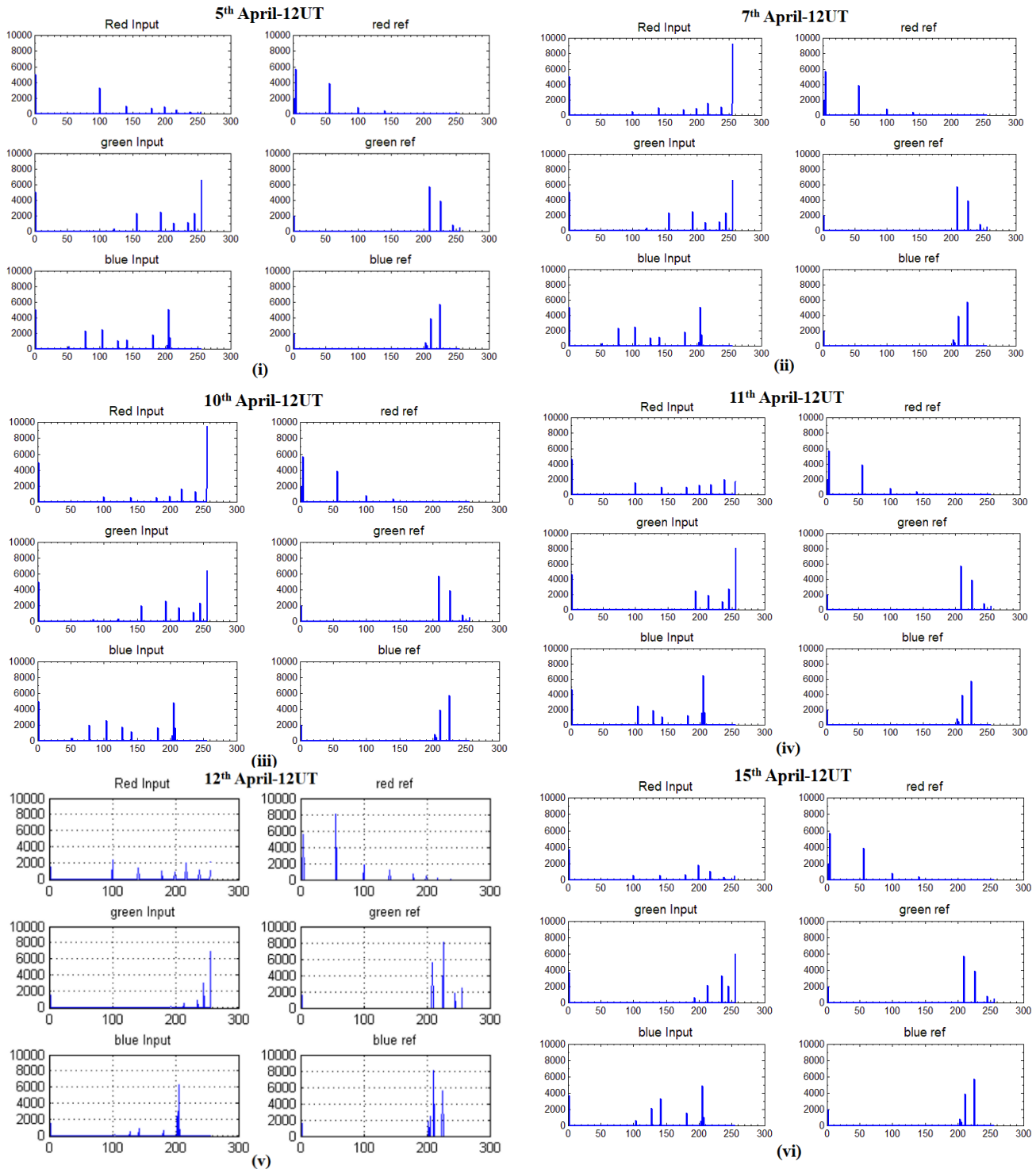
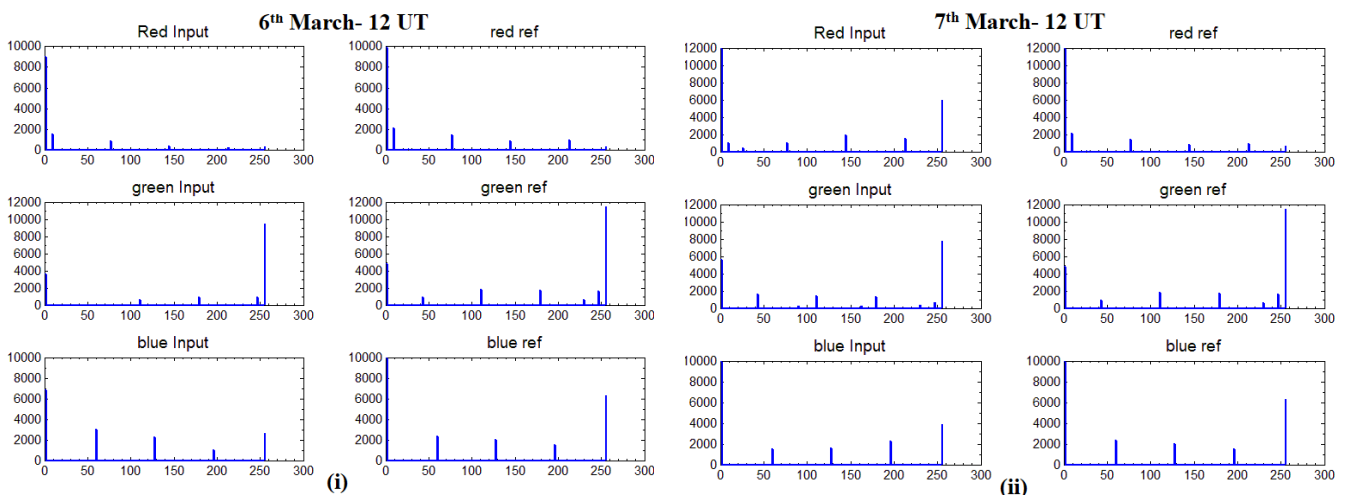


Figure 6: The pixel content based histogram analysis of global TEC images shows (i) low intensity of red plane representing NEA status 6 days prior to IEQ. Panel (ii) and (iii) display high pixel intensity of red plane at 12 UT, at the night sector in $90^{\circ}\text{E} - 110^{\circ}\text{E}$ on 7 and 10 April indicating high accumulation of density. Panel (iv), (v) and (vi) shows gradual decrease in the pixel intensity of red plane and recover to normal day condition from the EQ day.

Figure 6(i) shows very low pixel content in the red plane with high intensity in green and blue components on April 5th at 12 UT (night hours) indicating no development of equatorial anomaly, i.e., NEA status prevails. But on 7th April the pixel distribution of red plane at 256 range bin number shows significant enhancement indicating development of an EEA (code 6). The presence of EEA continued up to 10th April that offers a prelude of an impending EQ within 90⁰-110⁰E longitude and -15⁰ to -20⁰ latitude. The red pixel content started decreasing from 11 April. Considering our earlier definition of pointing the EQ day [Devi et al.,2013], we marked 11th April to be the probable day of occurrence of EQ event which is the correct prediction as IEQ did develop on this day. The EEA almost disappeared on 15th April with code message 3. The predicted and actual day of occurrence of the EQ indicate that IPT can be used as a tool for identifying anomalous situation in ionospheric electron content. However the approach still needs further refinement for identifying the epicentre position.

3.2 Case 2: Japan EQ of 9 and 11 March 2011

The major Japan EQs (JEQ), (M = 7.3 & M = 9.1) occurred at 135⁰-145⁰E and 35⁰-40⁰N respectively on March 9 and 11, 2011 and as in IEQ in this case too, the pixel information of TEC contour at 12 UT (night time) are extracted in the form of histogram (Figure 7).



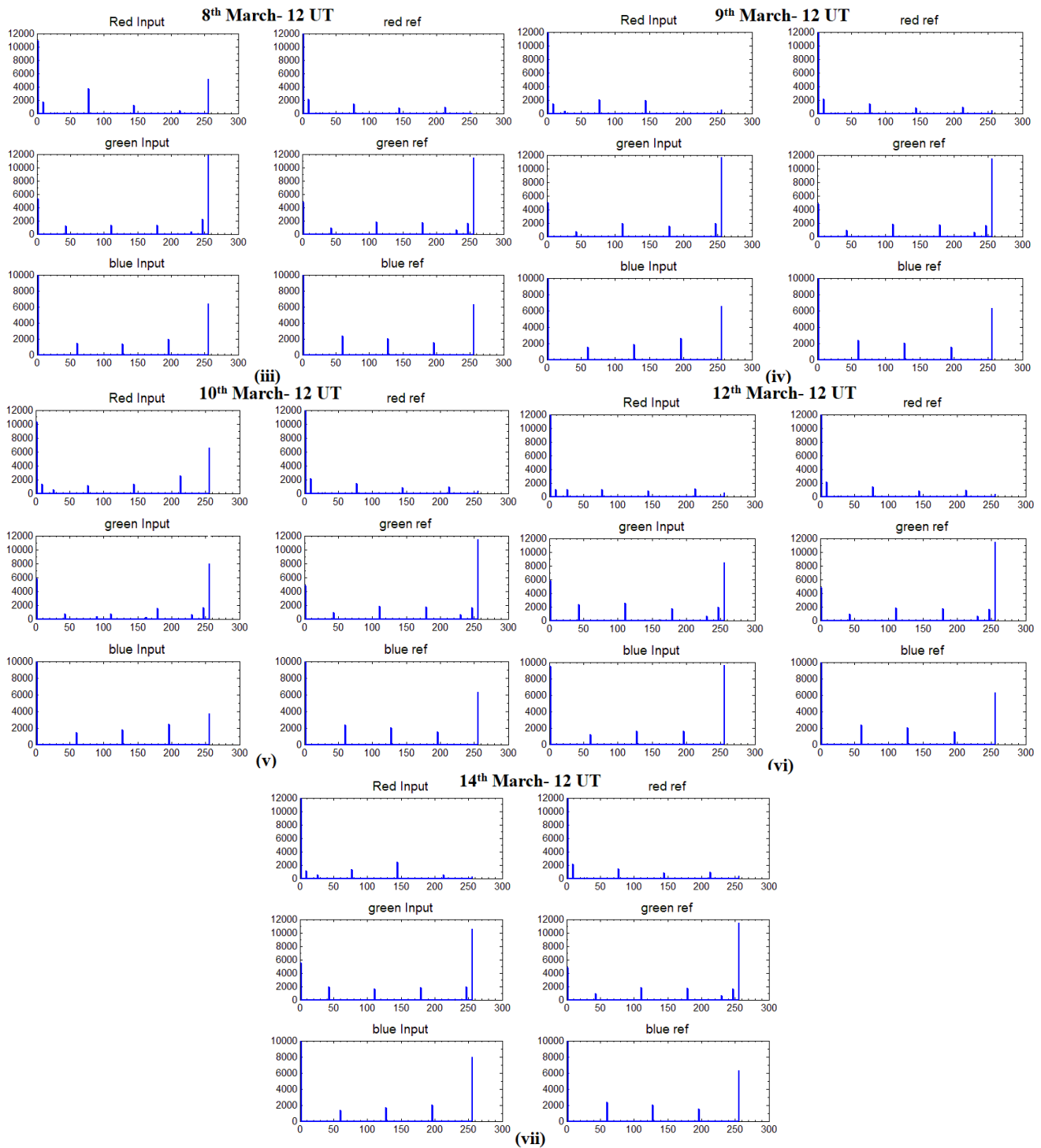


Figure 7: Shows pixel content based histogram analysis from March 6-15 covering prior to post JEQdays at 12 UT (local night hours). Here Panels (i): Low intensity of red color four days prior to EQ; (ii): Increase of red color intensity two day before EQ indicating development of EEA; (iii),(iv): Decrease of red color intensity; (v): Red color intensity value again increases on 10th March just one day before massive JEQ of 11 March; (vi),(vii) then red color intensity decays to normal condition.



The coded message displayed in Figure 7 clearly indicates a NEA condition three days prior to March 9 EQ but development of EEA with presence of code 6 is clearly seen on 7th March. With 5000 pixel intensity on March 8, code message 6 start decaying and totally disappear on next day. Our earlier definition of prelude to an EQ thus suggest the possible occurrence of an EQ on 8th of March. Significantly the message 6 with full intensity appeared again on March 10 and start decreasing from March 11 (not shown) and completely disappeared on March 12. Thus as per our earlier definition of prelude to an EQ the observation suggest the possible occurrence of an EQ on 8th and the other at 11th March, 2011. The normal condition reappeared from March 14 onwards with code 3. The prediction through image processing technique seems to be reliable with actual EQ occurrence dates with a delay of maximum one day. Therefore, EEA is a good feature for extraction of EQ information from TEC profiles.

4. Discussion and conclusions:

The pixel analysis of global TEC contour indicates growth of EEA three to four days prior to an impending EQ around the longitude of epicentre followed by its decay and return to the normal condition after the event. Such development of EEA prior to an EQ is also reported by many workers [Depueva and Ruzhin 1995; Depueva and Rotanova 2001; Devi et al., 2001, 2004, 2008, 2010, 2013, 2018; Shvets 2002; Sorokin et al., 2011; Hayakawa 2004; Depueva et al., 2007; Park 1971; Balan and Bailey 1995] through TEC profile shape, enhancement /decay of equatorial anomaly observed from ground based and satellite remote sensing technique. Thus, image processing approach adopted in this paper in identifying an impending EQ at the longitude sector of the epicentre seems to be an effective tool though one cannot locate the latitudinal coordinate of the epicentre through this technique. Such latitudinal position of the epicentre have been identified by monitoring relevant other parameter like azimuthal status of different satellites coming into field of view of trans receiving line [Devi et al., 2011; Devi and Barbara 2012]. But to adopt image processing approaches in extraction of information from azimuthal position of the satellite needs special tool for conversion of the same to coded segmentation. This is the future projection of the work. But the limitation is that one needs to have ground based GPS observation near to the epicentre location at different viewing angles, a challenging task at present. The most suitable candidate for such study is nano satellites observation with multivariable sensors (probe to measure density, electric field or temperature) in the same longitudinal zone covering equator to low, mid latitude station.

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