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Transient Variations of Total Electron Content (TEC) Over a Terrestrial Point within Magnetic Anomaly Region

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Author's contributions

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

This paper investigate the variability of Total Electron Content TEC over a terrestrial point within equatorial anomaly region using the NovAtel GSV 4000B GPS-SCINDA system at Akure (7.3°N, 5.2°E), Nigeria. This system is capable of tracking up to 14 GPS satellites simultaneously. Total Electron Content (TEC) over equatorial region using a real time data collected via a GPS-SCINDA facility were analyzed to study the ionospheric variations in terms of Total Electron Content (TEC) for the period of three years. Diurnal variations and Monthly mean variations of Total Electron Content within the equatorial anomaly region were examined. The diurnal variation of TEC showed pre-dawn minimum for a short period of time, followed by a steep early morning increase and then reached maximum value between 14:00 UT and 16:00 UT. The influence of solar activity on VTEC was investigated by taking the correlation coefficients between VTEC, F10.7cm radio flux index and sunspot numbers. The range of solar flux variation during the period of observation is very limited; there is high positive correlation (Correlation Coefficient 0.61) between daytime peak TEC and the solar F10.7 flux.

Keywords: Total electron content (TEC); solar activity; GPS.

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1. INTRODUCTION

The ionosphere contains sufficient electron in such a proportion that enable it to influence (both advantages and disadvantages) the propagation of electromagnetic waves [1]. The advantages are in radio communication and disadvantages are in all branches of tele-communication. It is to exploit the advantages and find remedies for the disadvantages that we started studying the ionosphere. The existence of the ionosphere is also a worrying problem for radio astronomers as it causes irregular changes in the amplitude and phase of the radio signals that pass through it, the so-called Ionospheric Scintillations [1].

The name ionosphere is given to that region of the atmosphere from about 50 to 1,000 km above the Earth where electron density is sufficiently high to effect the transmission of electromagnetic waves at radio frequency. It is the ionized component of the atmosphere comprising free electrons and positive ions, generally in equal numbers, in a medium that is electrically neutral [2]. Though the charged particles are only a minority amongst the neutral ones, they nevertheless exert a great influence on the electrical properties of the medium and it is their presence that brings about the possibility of radio communication over large distances by making use of one or more Ionospheric reflections. Before the term ionosphere gained worldwide acceptance, it was called the Kennelly-Heaviside layer, the upper conducting layer, ionized upper atmosphere [2].

The ionosphere plays a basic role in long-distance communication. Ionospheric effects are less apparent in the very high frequencies (30-300 MHz), but they persist at least through 432 MHz.

Significant research on ionospheric study has been done and several ionospheric models have been introduced for mid-latitude regions. Comparatively, few corresponding research has been done on the low latitude (equatorial) ionosphere. The ionosphere in Nigeria is unique because of her location near the equator, where a lot of phenomena such as the equatorial anomaly and fountain effect make it interesting for studies. There are however, significant differences in the structure and effect on radio propagation of the ionosphere at these latitudes including the equatorial electrojet and accompanying equatorial anomaly, greater absorption and the geomagnetic field orientation being nearly horizontal [3]. The results obtained from this study will be of interest to civilian users, particularly those attempting to achieve high levels of accuracy in equatorial regions.

The total electron content (TEC) provides an overall description of the ionization in the ionosphere, and it is also one of the most important ionospheric quantities for various practical applications. The TEC, defined as the number of free electrons in a column of $1m^2$ cross section extending from the ground to the top of the ionosphere, it is a parameter of great importance for systems which use trans-ionospheric radio waves [4]. When a radio wave traverses the ionosphere, several effects are produced in it. Most of these effects are proportional, at least to the first order, to the TEC. The highest TEC values in the world occur at the equatorial anomaly (EA) peaks located at approximately 15^o either side of the magnetic equator [5].

Accurate TEC values are for example required to correct ionospheric range error for single-frequency GPS users. Over the last decade, an extensive database of TEC measurements has become available from both ground- and space-based observations. The Global Positioning System (GPS) satellites continuously provide TEC data through the world-wide network of GPS ground receivers [6]. The 32 operational satellites transmit radio signals in the L-band on two coherent carrier frequencies (L1 = 1575 MHz L2 = 1228 MHz) allowing the estimation of TEC by different techniques [7]. All modern TEC measuring techniques rely on the observation of signal phase difference or on pulse travel time measurements based on geostationary and orbiting satellite signals. A standard way of measuring TEC is to use a ground-based receiver capable of processing signals from satellites in geostationary orbits and polar orbiting satellites [8].

TEC is significant in determining scintillation and group delay of a radio wave through a medium. Ionospheric TEC is characterized by observing carrier phase delays of received radio signals transmitted from satellites located above the ionosphere, often using Global Positioning System satellites. TEC is strongly affected by solar activity.

The estimation TEC using a dual frequency GPS receiver is made possible by the dispersive nature of the ionized medium between the GPS satellites and a GPS receiver on the ground. Since the ionosphere and plasmasphere are weakly ionized plasmas, both contribute to the TEC that is measured using a GPS receiver. With the increasing trans-ionospheric communication system used in the navigation of space-borne vehicle the measurement of the true value of the Total Electron Content of the ionosphere has become important for making appropriate range corrections as well as in accounting for errors introduced in the range delays owing to the effects of space weather related events such as geomagnetic storms and scintillations due to ionospheric irregularities [8].

The ionosphere, being a weakly ionized plasma, imparts a group delay (Δt) and carrier phase advance to an radio frequency (RF) signal that, to first order, are equal in magnitude, opposite in sign, and proportional to the total number of electrons encountered along the line of sight (LOS) as given by [9] is

$$\Delta t = 40.30\,\frac{TEC}{\left(cf^{2}\right)} \tag{1}$$

where f is the frequency of the signal in Hertz and c is the speed of light in m/s. By measuring the group delay or carrier phase advance imparted by the ionosphere on the two GPS carrier signals, L1 (f1 = 1575.42 MHz) and L2 (f2 = 1227.60 MHz), the TEC encountered along the signal propagation path may be inferred.

2. METHODOLOGY

The GPS-SCINDA software provides a real time display during operation to assist the researcher in identifying ionospheric activity and also to help the field technician maintain and troubleshoot the system. It provides a user friendly interface for toggling the mode of operation between Campaign Mode (where both raw and processed data are collected) and Normal Mode (where only processed data is collected). The mode of operation may also be modified remotely by editing configuration files, thereby enabling "virtual campaigns" to be conducted during which the full data rate of the equipment is utilized and large quantities of raw data are acquired. The flexibility to collect high rate raw data is helpful when conducting scientific experiments over short periods of time (days to months), while the normal mode of operation is better suited to long periods of unattended operation [10].

The GPS-SCINDA system consists of a GPS receiver, a GPS antenna, the GPS-SCINDA data collection software and a computer running the LINUX operating system with access to the Internet. The GPS antenna is mounted on a pole in clear view of the sky, with a minimum of obstructions nearby (in particular, metallic objects and power lines should be avoided). The antenna is connected to the receiver using the supplied antenna cable [10].

The GPS-SCINDA receiver tracks up to 14 GPS satellite signals simultaneously at the L1 frequency (1575.42 MHz) and the L2 frequency (1227.6 MHz). The GPS-SCINDA data acquisition system runs on a PC or laptop running LINUX and displays GPS tracking and ionospheric parameters with real-time updates. It measures phase and amplitude (at 50-Hz rate) and code/carrier divergence (at 1-Hz) for each satellite tracked on L1 and then Slant Total Electron Content (STEC) are computed from the combined L1 and L2 pseudorange and carrier phase measurements for all the visible Global Positioning Satellite (GPS) satellites (up to fourteen). The Signals were sampled at 50Hz and 1Hz and recorded every minute (60seconds interval).

The Slant Total Electron Content (STEC) is the measure of the total number of free electrons in a column of the unit cross section along the path of the electromagnetic wave between the satellite and the receiver. The total number of free electrons is proportional to the ionospheric differential delay between L1 (1575.42 MHz) and L2 (1227.60 MHz) signals.

$$STEC = \int_{receiver}^{satellite} N ds \tag{2}$$

where N is the electron density; 1 TEC Unit = 10^{16} electrons/m^2.

Since slant TEC is dependent on the ray path geometry through the ionosphere, it is desirable to calculate an equivalent vertical value of TEC which is independent of the elevation of the ray path. The Vertical TEC was obtained by taking the projection from the slant to vertical using the thin shell model assuming a height of 350 km, following the technique given by [9]:

$$VTEC = STECx \cos\left[\sin^{-1}\left(\frac{R_e \cos\theta}{R_e + h_{max}}\right)\right] \tag{3}$$

where R_e=6378 km, h_{max}=350 km, θ = elevation angle at the ground station.

3. RESULTS AND DISCUSSION

Fig. 1 illustrates the diurnal variations of Vertical Total Electron Content for January to December 2007 while Fig. 4 illustrates the monthly mean diurnal variations of Vertical Total Electron Content for January to December 2007. Figs. 2 and 3 illustrate the diurnal variations of Vertical Total Electron Content for January to December 2008 and 2009 respectively. Figs. 5 and 6 illustrate the monthly mean diurnal variations of Vertical Total Electron Content for January to December 2008 and 2009 respectively.

Generally the diurnal pattern of VTEC exhibited a steady increase from about sunrise to an afternoon maximum and then falls to attain a minimum just before sunrise. The diurnal variation in vertical total electron content (VTEC) at Akure, Nigeria show many characteristics typical of low latitude ionosphere such as a vertical total electron content (VTEC) minimum at pre-dawn and gradual increase with the time of the day attaining a maximum in the afternoon and a gradual decrease after sunset [11] and [12]. The daily peak occurred around 14:00UT. In low latitude regions, the highest daytime peak TEC values depend greatly on the strength of the equatorial ionization anomaly [11].

Figs. 1, 2 and 3 show the mass plots of vertical total electron content (VTEC) diurnal variations for 2007, 2008 and 2009, respectively. These curves show appreciable day-to-day variations of TEC, particularly, during the mid-day to pre-dawn hours which is a serious concern in forecasting and navigation [11] and [8]. It is observed from these Figures that there was considerable spread in the diurnal variations of VTEC derived from different satellite passes which was visible in all the months owing to the spatial and temporal variations in TEC because thee values were derived from different GPS satellite passes that were spread in different parts of the sky and at different times over Akure. It may also be observed from these Figures that the diurnal maxima of VTEC were highest during the month of March followed by the month of December. During the summer month of June the diurnal maxima are minimum. In the months of March of 2007, 2008 and 2009, the diurnal minimum occurred around 05:00UT to 06:00UT. The day maximum was relatively broad and was of longer duration as it could be observed in all the months of the period studied. The day-to-day variations of TEC [13,14,15] may be attributed to the changes in Solar activity and associated changes in the intensity of the coming radiations and the zenith angle at which they impinged on the Earth's atmosphere as well as the contributions by the various parameters like EUV flux, geomagnetic activity [16], Equatorial Electrojet (EEJ) strength and local atmospheric conditions in the thermosphere [17]. The plasma flow associated with the equatorial ionospheric anomaly (EIA) may also play a significant role in the day-to-day variations of the observed diurnal variations in TEC. The maximum value of total electron content (TEC_{max}) usually happened near mid-day, while the minimum value of total electron content ($TEC_{min)}$ occurred at night. TEC_{max} increases from 50 TECU to 80 TECU over the three years while TEC_{min} increases from 20 TECU to 30 TECU over the same period. The daytime VTEC values were obviously larger than the nighttime values and the occurrence time of the maximum/minimum varied with season. There is usually a deep pre-sunrise depression which becomes more prominent as TEC increases with the increasing solar activity [18].

Similarly, the monthly mean Diurnal Variations vertical total electron content (VTEC) for 2007, 2008 and 2009 are shown in Figs. 4, 5 and 6 respectively. TEC exhibited the usual diurnal variation of a minimum in the pre-sunrise hours (0500 UT) and a maximum between 1200 and 1400 UT.

The diurnal peak TEC showed semi-annual variation with a peak during the equinox period and a trough during the solstice period. There appeared to be a prominent secondary peak after sunset which was referred to as post-sunset secondary maximum (PSSM) throughout the period of the study. PSSM normally occurred in the evening before midnight and were more pronounced during equinoxes, during high solar activity, the mechanism which could be caused by the irregularity developed by Raleigh-Taylor instability due to the influence of gravitational, electric and magnetic fields [19]. PSSM is also due to the ExB drift from the equatorial anomaly Region [20].

The Sun emitted a wide spectrum of radiation along with high energy particles. Along with the sunspot number, the flux of the Sun's radio emission at a wavelength of 10.7 cm (2.8 GHz) was a useful indicator of solar activity relevant to ionospheric effects [11]. [17] reported the direct control of solar activity on the ionization level, with higher values during a high solar activity period and low value during a low solar activity period. Although the range of solar flux variation during the present period of observation was very limited, there was a high positive correlation (Correlation Coefficient = 0.61) between daytime peak TEC and the solar F10.7 flux. During the period of a low sunspot number, the TEC built up was quite slowly, resulting in a low value of day maximum [21] reported higher values of TEC with increasing solar activity.

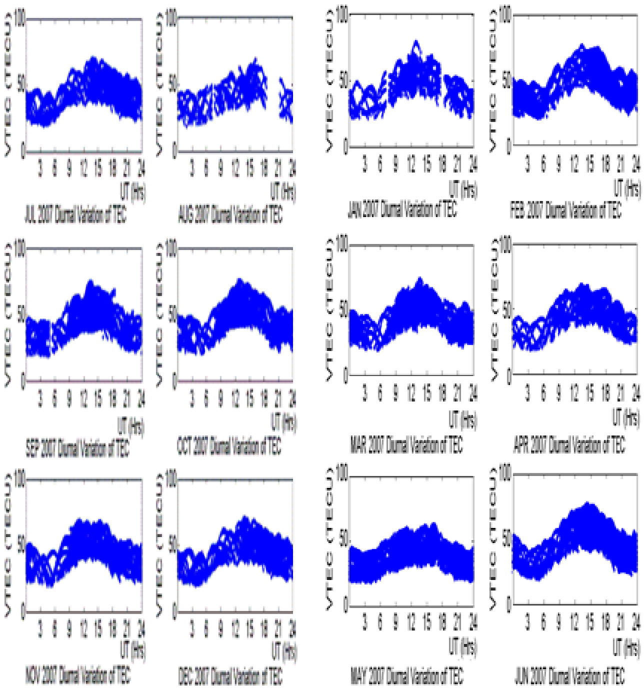

Fig. 1. Diurnal variations of vertical total electron content (VTEC) for year 2007

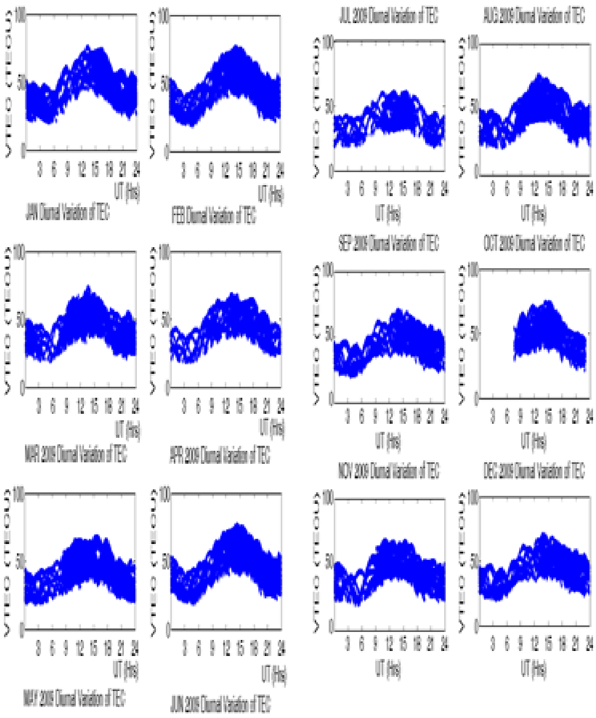

Fig. 2. Diurnal variations of vertical total electron content (VTEC) of year 2008

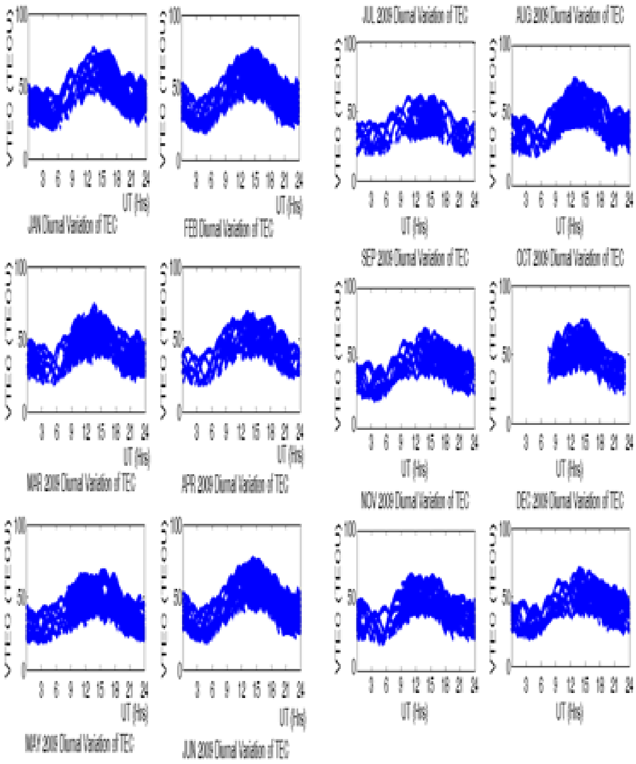

Fig. 3. Diurnal variation of vertical total electron content (VTEC) of year 2009

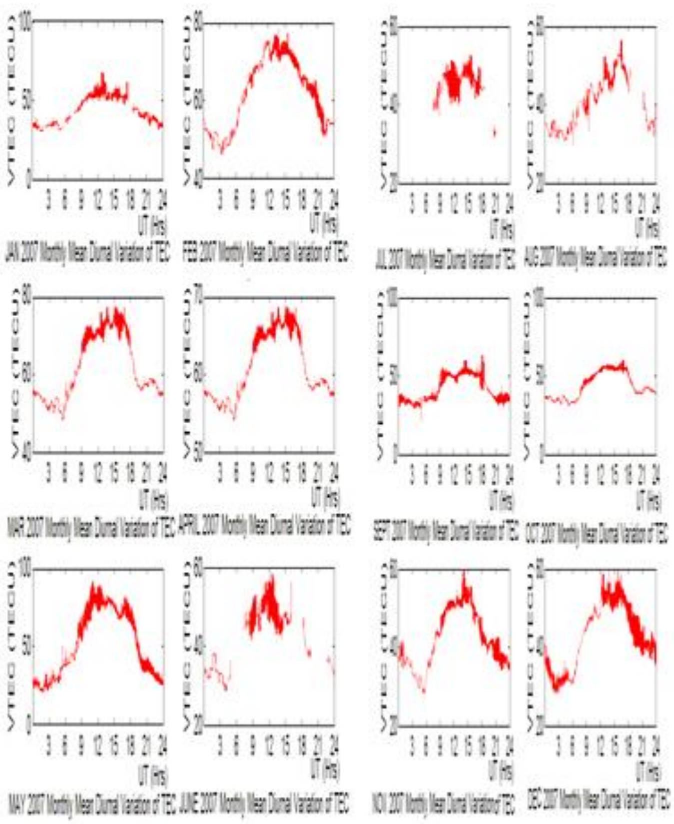

Fig. 4. Monthly mean diurnal variation of VTEC for year 2007

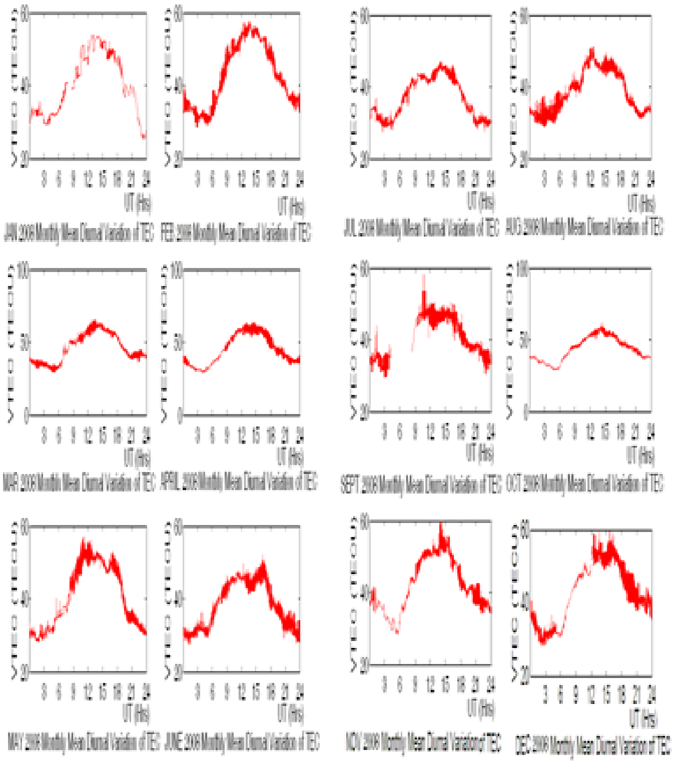

Fig. 5. Monthly mean diurnal variations of VTEC for year 2008

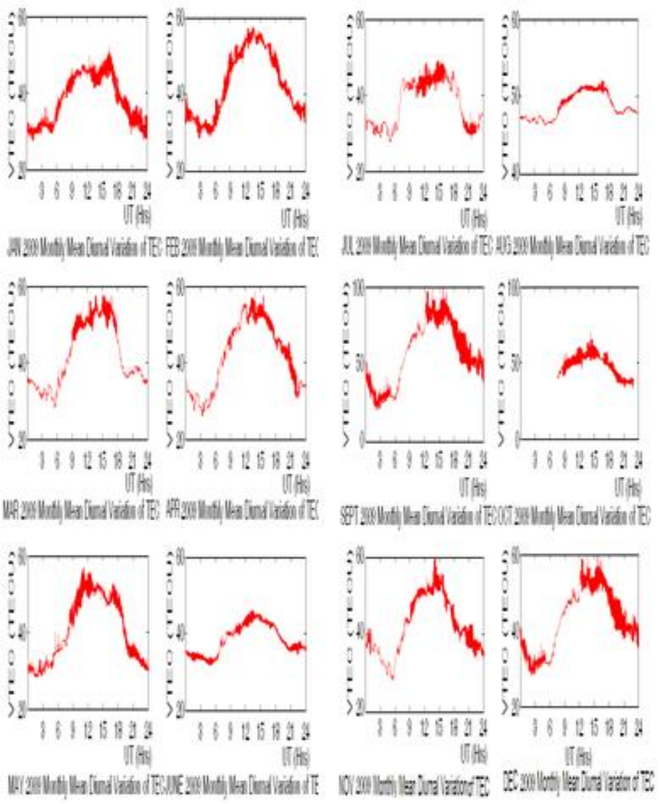

Fig. 6. Monthly mean Diurnal Variation of VTEC for year 2009

4. CONCLUSIONS

In this paper Transient variation of total electron content over a terrestrial point within magnetic anomaly region was studied. The analysis carried out suggests that the diurnal variation of vertical total electron content (VTEC) shows pre-dawn minimum for a short period of time, followed by a steep early morning increase and then reaches maximum value between 14:00 UT and 16:00 UT. TEC maximizes during Equinox months (March, April, September, October), and minimizes during the winter months (November, December, January, February), with intermediate values during summer months (May, June, July, August), showing a semiannual variation. The semiannual variation of TEC is asymmetry with maximum in Spring Equinox. The day time TEC values are obviously larger than the nighttime values. The occurrence time of the maximum/minimum ionosphere TEC values varies with season. A high positive correlation (r = 0.61) was obtained between daytime peak VTEC and Solar F10.7 flux for the period of study. SCINDA provides real-time monitoring of scintillation activity and ionospheric structure for a wide range of modeling and research activities

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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