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# Comparative studies of Traveling Ionospheric Disturbances (TID) at North, South and Equatorial African Continent

Oluwadare T. Seun[1,2], Chinh Nguyen Thai[1,2], Oladipo E. Abe[3], Cesar E. Valladares[4], Mahdi Alizadeh[2,5], Harald Schuh[1,2]

(1) German Research Centre for Geosciences (GFZ), Telegrafenberg, section 1.1 - Space Geodetic Techniques, Potsdam,Germany (2) Institut für Geodäsie und Geoinformationstechnik, Technische Universität Berlin(TU Berlin),Berlin, Germany, (3) Physics Department, Federal University Oye-Ekiti, Nigeria, (4) Hanson Center for Space Sciences, University of Texas at Dallas, USA, (5) Faculty of Geodesy and Geomatics Engineering, K.N. Toosi, University of Technology, Tehran, Iran

*Corresponding author: oluwa@gfz-potsdam.de

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## Background

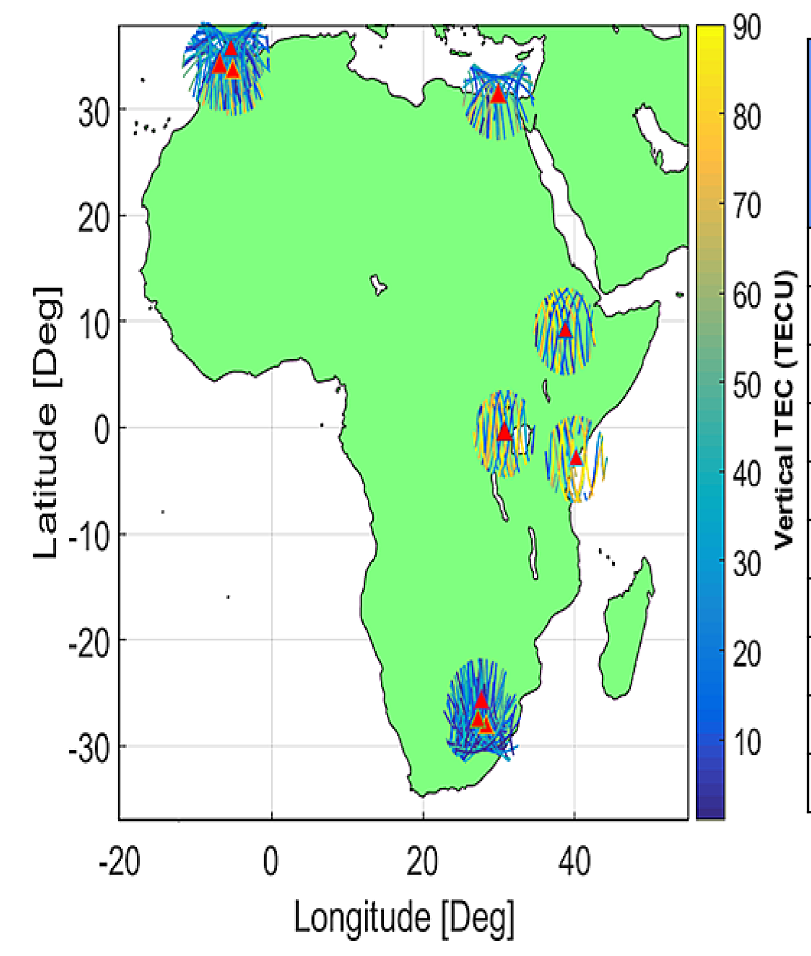
One of the frequent ionospheric irregularity phenomena at the F region which causes signal loss or degradation to both communication and navigation systems is the Traveling Ionospheric Disturbance (TID) (Nishioka., et al; 2009). Medium scale TIDs (MSTIDs) frequently appear as oscillating waves in electron density (i.e: wave-like structure) induced by the presence or passage of atmospheric gravity waves (AGW) propagating the neutral atmosphere (Yu. P. Fedorenko et al., 2010), and consequently causes fluctuations in Total Electron Content (TEC). Several previous studies have identified the sources to also be from either solar terminator or Perkins instability. Most MSTIDs propagate in any direction (C. E. Valladares., et al; 2012), but some studies have reported an equator-ward propagation direction (Jonah et al; 2016), while some reported that MSTID propagation direction is seasonal dependent. Although very few studies on MSTIDs characteristics in the mid-latitudes (African southern hemisphere) have been carried out, but the mid-latitudes at African northern hemisphere and low latitudes MSTIDs studies have not been carried out. Hence, this study simultaneously studies the MSTIDs in the low and mid ionosphere for the first time, using the TEC data obtained from the networked GPS receivers located at the three geographical sectors (southern hemisphere (SH), northern hemisphere (NH) and equatorial latitude (EL) zone) in African region. We considered selected days of geomagnetic conditions (kp < 4), during different solar activity years; i.e. 2008, 2014 and 2016.

## Objectives

The objectives of this study are to:

- Observe MSTID distribution in African region at different geographical sectors with GPS receiver arrays.
- Estimate MSTID percentage of occurrence rate (POR) and dominant periods.
- Estimate other MSTID characteristics by using statistical angle of arrival and Doppler method for GPS interferometry (SADM-GPS) developed by Afraimovich et al. (1998).

## Geographical study area



| Country/GPS stations | Station Coordinates Geog. (LAT, LON) |
|---|---|
| Morocco, TETN | 35.561, -5.363 |
| Morocco, RABT | 33.998, -6.854 |
| Morocco, IFR1 | 33.514, -5.126 |
| Egypt, ALX2 | 31.197, 29.911 |
| Ethiopia, ADIS | 9.035, 38.766 |
| Uganda, MBAR | -0.601, 30.738 |
| Kenya, MAL2 | -2.996, 40.194 |
| S.Africa, HARB | -25.887, 27.707 |
| S.Africa, KSTD | -27.664, 27.241 |
| S.Africa, BETH | -28.250, 28.334 |

**Fig. 1.** The IPP trajectory of all GPS satellites as observed at different GPS locations on day 28th March 2014 with an elevation mask ≥ 35°. Similar behavior of TEC over each geographical sector suggests similar mechanism(s) in operation within the same sector.

## Method of obtaining MSTIDs

In this study **MSTID**s are defined as TEC perturbations (dTEC) which satisfy the following criteria:
The dTEC has an amplitude **> 0.07** TECU (1TECU= $10^{16}$ electron/ $m^2$)
The dTEC horizontal wavelength is < 1000km
The dTEC period is less than 60 minutes (mins)

- Extract TEC from GPS observation and convert to vertical TEC (VTEC)
- Locate wave-like structure in VTEC data
- Deploy Singular Spectrum Analysis (SSA) for fitting a smooth curve into wave-like structure in TEC data. See SSA details and their applications are discussed in (Nina Golyandina and Anatoly Zhigljavsky, 2013).
- Find the difference between the original TEC and fitted TEC to obtain TEC perturbation (dTEC)
- Compute the standard deviation of dTEC of all epochs to determine appropriate MSTIDs threshold.
- Set a threshold point to determine MSTIDs event /MSTIDs occurrence
- Plot time versus dTEC values and determine MSTIDs number of events
- Compute MSTIDs POR. (We defined MSTIDs POR as the number of events detected (amplitude greater than 0.07 TECU/min) over the total number of considered observation points expressed as a percentage)
- Estimate MSTID dominant periods using wavelet analysis
- Compute MSTIDs characteristics (velocity and direction of propagation.) using SADM-GPS algorithm.

SADM-GPS algorithm uses the spatial and temporal derivatives of TEC measurements from three spaced GPS locations in an x-y plane and it comprises from eight (8) equations:

$$\alpha(t) = \tan^{-1} [ I'_y(t) / I'_y(t) ] \quad (1) \qquad U_x(t)= [ I'_t(t) / I'_x(t) ] \quad (2)$$

$$U_y(t)= [ I'_t(t) / I'_y(t) ] \quad (3) \qquad U(t) = [ |U_x(t).U_y(t)| / \sqrt{( U^2_x(t) + U^2_y(t))} ] \quad (4)$$

$$V_h(t) = U(t) + w_x(t)\sin(\alpha(t)) + w_y(t)\cos(\alpha(t)) \quad (5) \qquad I'_t(t) = G_t = [ (Y(t+dt) - Y(t)) / dt ] \quad (6)$$

$$I'_x(t) = G_x = [ Y_I(TECP_J - TECP_K) - Y_K(TECP_J - TECP_I) / (X_IY_K - X_KY_I) ] \quad (7)$$

$$I'_y(t) = G_y = [ Y_K(TECP_J - TECP_I) - Y_I(TECP_J - TECP_K) / (X_IY_K - X_KY_I) ] \quad (8)$$

**$I'_x$ (t), $I'_y$ (t), and $I'_t$ (t)** correspond to **$G_t$, $G_x$** and **$G_y$** respectively and they are spatial and time derivatives, **$u_x(t)$, $u_y(t)$** are the propagation velocities of the phase fronts along the x and y axes (assumed in east and north directions). **$w_x$** and **$w_y$** are the **x** and **y** projections of the sub-ionospheric intersection velocity, **$v_h$** is the horizontal velocity of the TID. **Y** is the TEC perturbation (**TECP**) at the reference station (**J**) and **dt** is the sampling period of the data, **$TECP_J$, $TECP_K$** and **$TECP_I$**, are the **TECP** at stations **J** and **K** and **I** respectively, where **J** is the reference station and **$X_I$, $Y_I$, $X_K$**, and **$Y_K$** are the coordinate distances of station **I** and **K** from the reference station **J** in a Cartesian system.

## Result

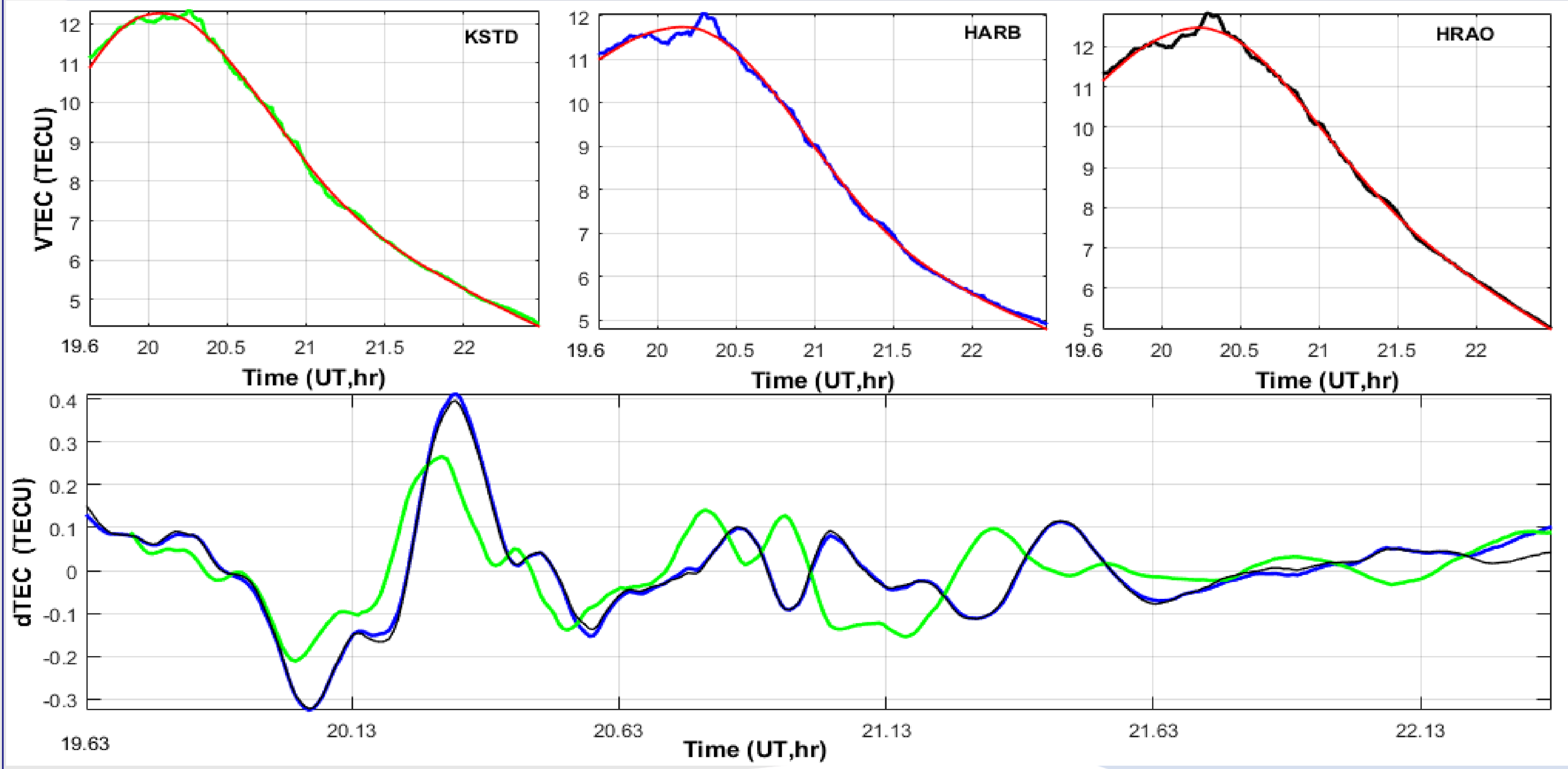


**Fig2:** The upper panel represents TEC values (irregular TEC structure) versus UT measured at stations KSTD, HARB and HRAO (array 1; SH) located in South Africa on 29th March 2016. The fitted red lines over the TEC series at the respective station were generated using SSA which gives the estimated background/unperturbed TEC values. The three stations exhibited same ionospheric irregularity pattern of TEC as seen from same GPS satellite (PRN=25). The second panel is the respective TEC perturbations which consequently shows the presence of sporadic TID exhibited at the three stations having passed the threshold of 0.07 TECU.

## Result (cont'd)

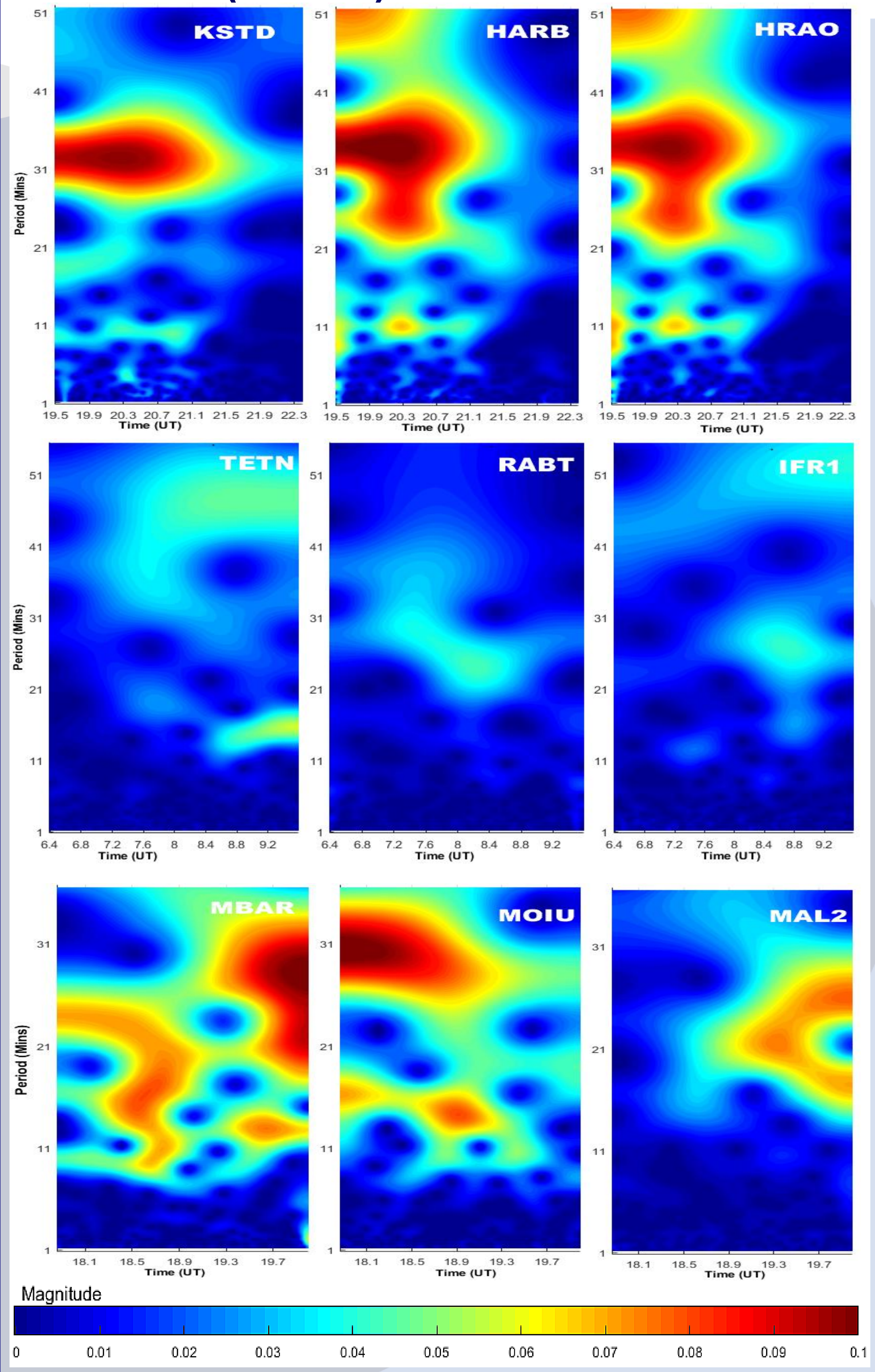


**Fig 3**. Power spectrum using wavelet analysis to show wave-like structures and to illustrate periods of the observed TID events, extracted from array 1 (figure 2), array 2 (TETN, RABT, IFR1; NH) and array 3 (MBAR, MOIU, MAL2; EIA) for 29th March 2016. Note that array 2 and array 3 figures are not shown. All the arrays show dominant period between 15 minutes and 49 minutes, which connotes a typical MSTIDs

**Table.1:** The average period of MSTID events for all the PRNs at different arrays for the selected days (18th Nov. 2008 , 28th March 2014 and 29th March 2016 ) during different solar activity years.

| ARRAYS \ YEARS | 2008 | 2014 | 2016 |
|---|---|---|---|
| Array 1, SH | ~ 39 mins | ~42 mins | ~40 mins |
| Array 2, NH | ~ 41 mins | ~44 mins | ~43 mins |
| Array 3, EIA | ~ 35 mins | ~34 mins | ~35 mins |

## Result (cont'd)

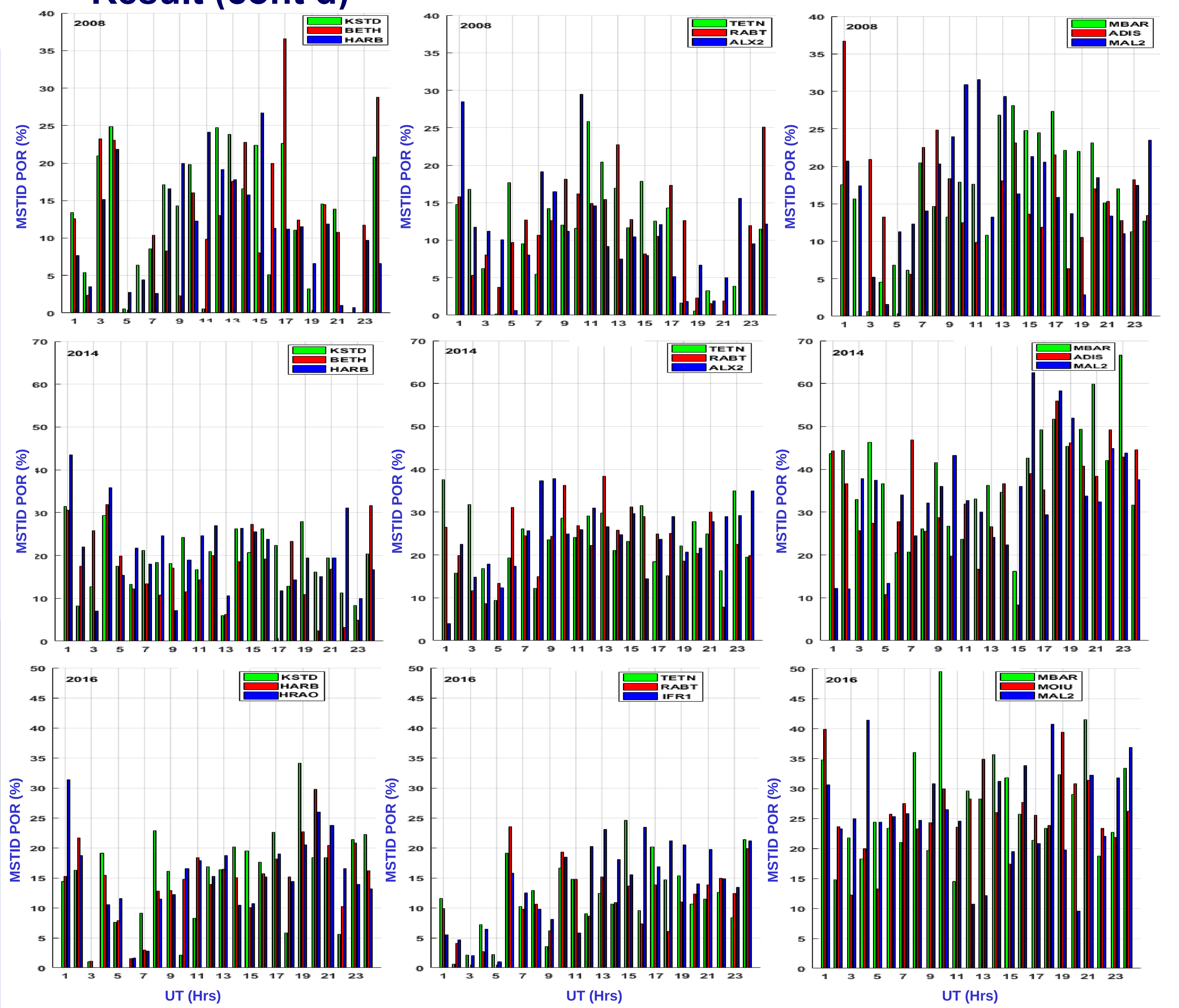


**Fig 4**: Grouped bar chart of array 1-3 indicating MSTIDs percentage of occurrence (POR) in hourly bin of all PRNs for 18th Nov. 2008 (top panel), 28th March 2014 (middle panel) and 29th March 2016 respectively (bottom panel).

## Conclusion

In this study and for the first time, we have investigated and compared MSTIDs occurrence at the North, South and Equatorial sector of African region by using TEC data obtained from GPS observations. MSTIDs POR and characteristics were determined and we conclude that :

- MSTIDs POR (fig.4) quantification reveals that MSTID events are concentrated at day time (0600-1800 UT) at all sector in 2008, but consistently increases only at NH during 2014 and 2016 and these has been attributed to the passage of AGW while at SH sector MSTIDs POR is dominant at night time which could be due to electrodynamics processes involving polarization electric field.
- MSTID occurrence periods (table.1) are found within 34 – 44mins and it increase or deceases with solar phase in 2014 having the highest MSTIDs occurrence period.
- MSTIDs occurrence period (table.1) is predominantly high in the mid latitude (NH and SH) but low in POR and vice versa for station at equatorial latitude. The high occurrence period at mid latitudes shows that MSTIDs are major source of mid latitude electron density irregularities.
- The MSTID horizontal propagation velocities estimated by SADM algorithm were found to be in the range of ~ 69 – 224 m/s, and its propagation direction is generally equator-ward, except at NH where TID the propagation direction is northward.

## Outlook

Using large data set covering African region to statistically determining the MSTID POR during day and night time, establish predominant electrodynamics mechanism responsible for MSTIDs occurrence and developing a two-dimensional TEC perturbation map, associated with MSTIDs.

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