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# Variability of TEC in the Equatorial Region (Uganda)

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# TEC DEPLETIONS IN EAST AFRICA (UGANDA & KENYA)

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**Workshop on Science Applications of GNSS in Developing Countries**

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# Introduction:

- The dynamics of the equatorial ionosphere are dominated by plasma interchange instabilities after sunset, which generate large-scale depletions (or bubbles).
- This phenomenon is called the equatorial spread F (ESF); so called primarily because of the way they affect ionograms, on which the F layer trace becomes very wide (“spread”).
- The presence of the plasma irregularities within these depletions disrupts communications and navigation systems by scattering radio wave signals that pass through them.
- This phenomenon is known as ionospheric scintillations, and refers to the rapid fluctuations of the phase and amplitude of the RF signal, as it passes through these irregularities.

# TEC Depletions:

- A TEC depletion consists of a sudden reduction of TEC followed by a recovery to a level near the TEC value preceding the depletion.
- It occurs when one or more plasma bubbles drift across the line-of-sight between the GPS receiver and the satellite.
- TEC depletions are a manifestation of the equatorial plasma depletions (also called bubbles).

# What is a plasma bubble?

- It is a plasma density depletion region which appears in the equatorial ionosphere.
- It is generated in the bottom side of the F layer of the ionosphere through plasma instability, after sunset.
- It is accompanied by electron density irregularities.
- Plasma disturbances cause loss-of-lock of the GPS radio wave at the ground-based stations.

# Research Area:

- This presentation shows TEC values and GPS scintillations measured by two SCINDA GPS receivers in an effort to assess the longitudinal extension of the plasma bubbles.
- Data for same days with TEC depletions have been compared for the two stations.
- The GPS receivers were located at Makerere University, Uganda (Lat: $0^{o}$ 18′ 27″ N; Lon: $32^{o}$ 28′ 32.1″ E) and at the University of Nairobi, Kenya (Lat: $1^{o}$ 16′ 60″ N; Lon: $36^{o}$ 49′ 0″ E), both in East Africa.
- Data used is for a period of two years: 2010 and 2011.

Mak (Lat: 0° 18′ 27″ N; Lon: 32° 28′ 32.1″ E)
UoN(Lat: 1° 16′ 60″ S; Lon: 36° 49′ 0″ E)

## Experimental Details:

- GPS SCINDA receivers have been used at both stations.
- The GPS SCINDA is a real-time GPS data acquisition and ionospheric analysis system, and computes ionospheric parameters $S_4$ and TEC using the full temporal resolution of the receiver.
- The TEC is computed from the combined L1 (1,575 MHz) and L2 (1,228 MHz) pseudo ranges and carrier phase.
- The equipment is suited for studying several parameters simultaneously, but this study will focus on the $S_4$ index and TEC measurements.

# S4 Index:

- This is a statistical measure of the intensity of amplitude scintillations given by $S_4$.
- It is the fractional fluctuation of the signal due to ionospheric modulation, given by:

$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$

where *I* is the intensity of the signal.

# Total Electron Content (TEC):

## (*1 TEC unit = $10^{16}$ electrons/$m^2$*)

- TEC is defined as the number of electrons in a column of 1 $m^2$ cross-section, from the height of the GPS satellite (~20,200 km) to the receiver on the ground.
- Estimation of the absolute TEC involves two steps:
  - Relative TEC:

    $TEC_R = TEC_\varphi + < TEC_R - TEC_\varphi >;$
  - (calibration) gives the absolute TEC:

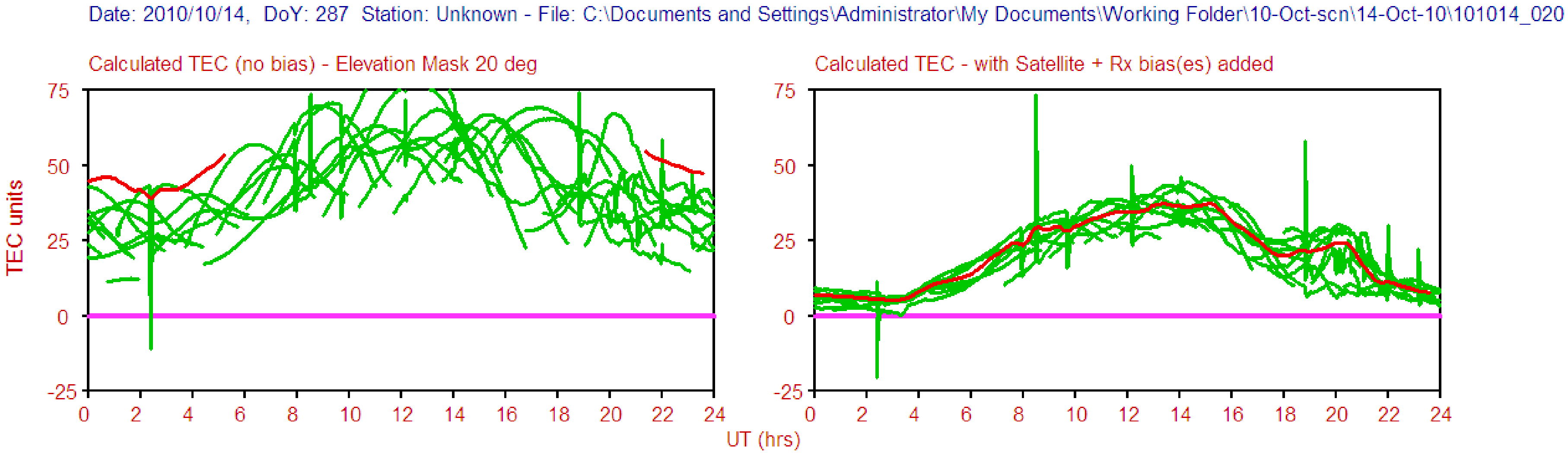
    $TEC = TEC_R - (b_R + b_S),$
- where $b_R$ and $b_S$ are the receiver bias and satellite bias, resp.
- When the TEC varies, the phase and group velocities of signals from the satellites are affected.

# Analysis of Results:

- The analysis has been carried out using the Gopi GPS-TEC analysis application software, version 1.45 (Gopi, 2010).
- The program gives plots of vertical TEC on the screen and writes ASCII output files which are used for further analysis of the data.
- ASCII files are:
  - TEC output file with satellite and receiver biases (*.CMN)
  - Mean TEC output files (*.std).

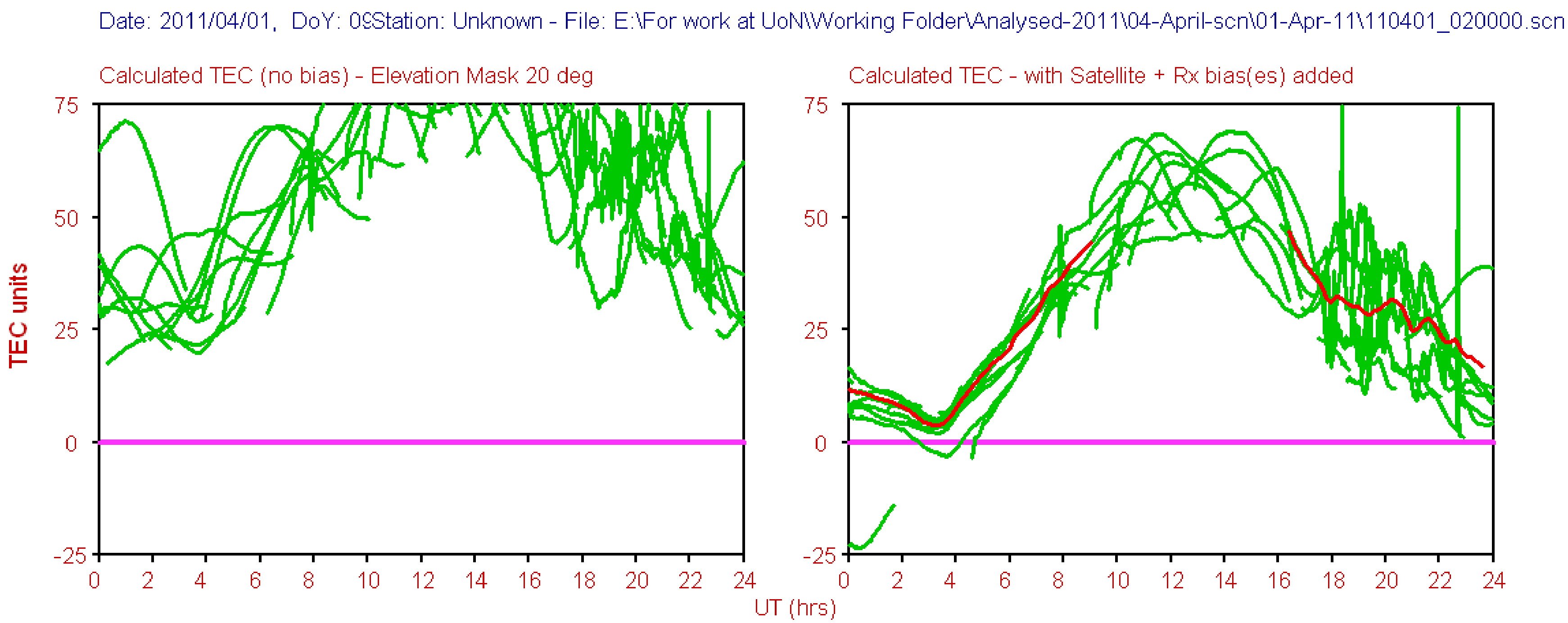
# Diurnal Variability of TEC:

*On a normal day at Mak (14th October 2010)*



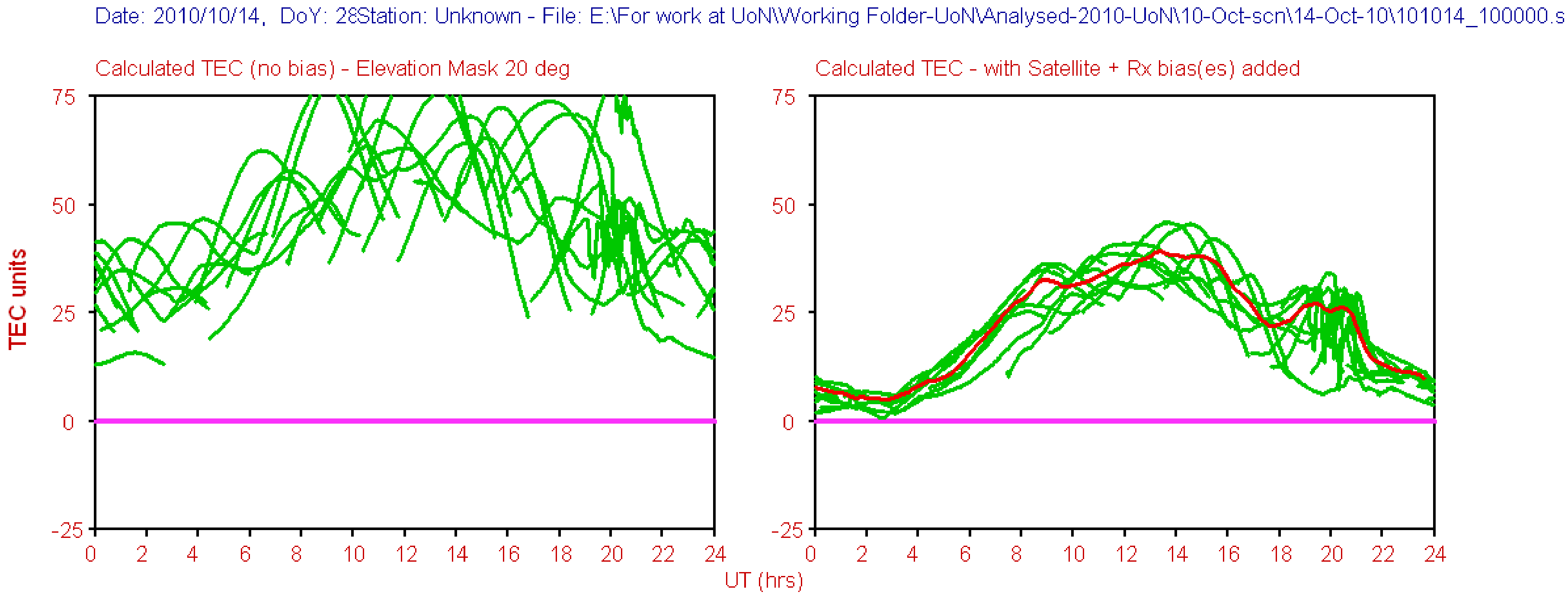
# Diurnal Variability of TEC:

*Active day at Mak (1st April 2011)*



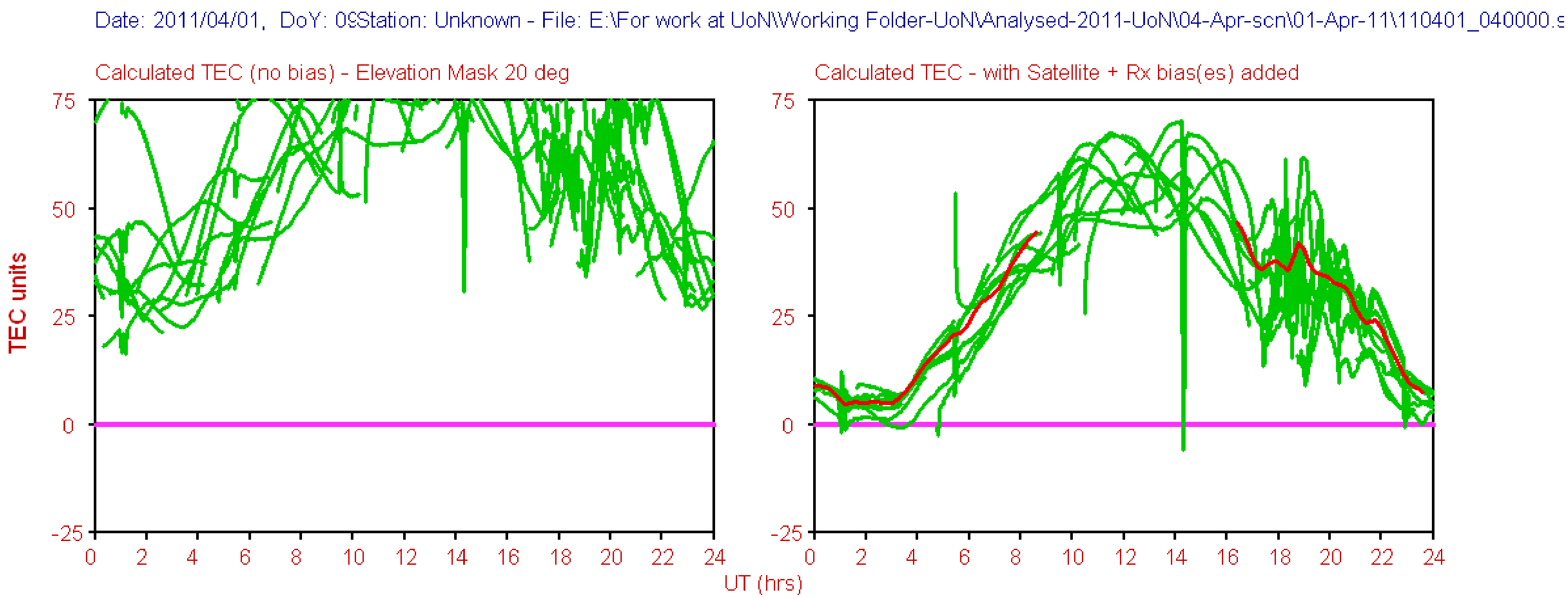
# Diurnal Variability of TEC:

*On a normal day at UoN (14th October 2010)*



# Diurnal Variability of TEC:

*Active day at UoN (1st April 2011)*



# TEC Depletions:

# April 1, 2011 – PRN 26 (*refer to diag.*)

- The 1st panel shows that the satellite was in view for both stations at almost the same time.
- The 2nd panel shows a series of depletions at Mak that started at 17:50 UT and ended at 20:10 UT, while those at UoN started just a little earlier at 17:45 UT and ended at 20:00 UT.
- This time difference is very small and it actually does not reflect the longitudinal separation between the stations of about 500 km.
- This may be explained if we allow the bubbles to tilt westward at altitudes above the F-region peak (Valladares).
- The westward tilt will make the part of the TEC depletions that extends to higher latitudes to appear at slightly later times.

# April 4th 2011 (*comparing different PRNs*)

- PRN 26 is viewed both at Mak and UoN at the zenith.
- A much deeper depletion is sighted at UoN and starts 15 min earlier than that at Mak.
- However, the one at Mak is followed by many small depletions, causing scintillations that go on up to 20:08, while those at UoN end at 19:30.
- PRN 4 (Mak) and PRN 5 (UoN) view the same depletion, but due to the smaller look angle, it is seen with an apparently wider width.

# Artificial signal fluctuations: (*October 8, 2010 – PRN 3*)

- Multipath can also produce artificial signal fluctuations that may show elevated $S_4$ values.
- However, these multipath enhanced $S_4$ indices occur when the satellite elevation is low, say around 20° or below.
- At16:30 UT at Mak $S_4$ of magnitude 0.4;
- At16:00 UT at UoN $S_4$ of magnitude 0.35.
- TEC depletions are shown at both stations between 18:30 and 20:00 UT.

# Depletions at Mak, but not at UoN: *(September 10, 2011)*

- PRN 3 is overhead at both stations.
- At Mak, TEC registers a depletion of depth 11.5 TECU at 19:00 UT, which triggers a scintillation index > 0.4.
- However, the TEC at UoN does not register any sort of depletion, neither does it show any scintillations.
- On the same day, PRN 6 is overhead at both stations.
- At Mak, a disturbance in TEC appears, registering two small TEC depletions and $S_4$ index ~ 0.6.
- Just as in Fig. 5, the UoN site does not register any TEC depletion or any significant scintillation during that period.

# Different shape of depletions:
*(September 22, 2011)*

- Satellite PRN 3 is overhead at both stations but the TEC depletions have very different patterns.
- Mak depletions show spikes, which do not translate into significant $S_4$ indices.
- However, both sites show high levels of scintillation between 17:30 and 20:00 UT, though those at Mak go on for an extra 20 minutes.

CME hit Earth's magnetic field on March 8th 2012, around 1100 UT. The impact was weaker than expected. [Aurora seen in Russia.]

# ANOTHER CME IS HEADING FOR EARTH: 9th March 2012

Sunspot AR1429 has unleashed another strong solar flare, an M6-class eruption on March 9th at 0358 UT. The blast hurled a CME almost directly toward Earth. It will arrive on March 11th at 0649 UT (+/- 7 hr) adding to the geomagnetic unrest already underway. A forecast shows that the cloud will also hit the Mars Science Lab spacecraft and Mars itself on March 12th and 13th, respectively.

# Aurora seen in Iceland on 9th March 2012.

# TEC Depletions on March 8$^{th}$ and 9$^{th}$ 2012:

- Strong solar flares that hurled large CMEs towards Earth, were expected to affect the space weather.
- PRN 15 & PRN 27 on 8$^{th}$ showed some scintillations, but since they were at low elevation angles, results could not be trusted.
- On 9$^{th}$, there was no disturbance as indicated by PRN 26.

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# Thank you for listening!