Observations of Ionospheric irregularities across the African sector during 2014, at the peak of solar cycle 24

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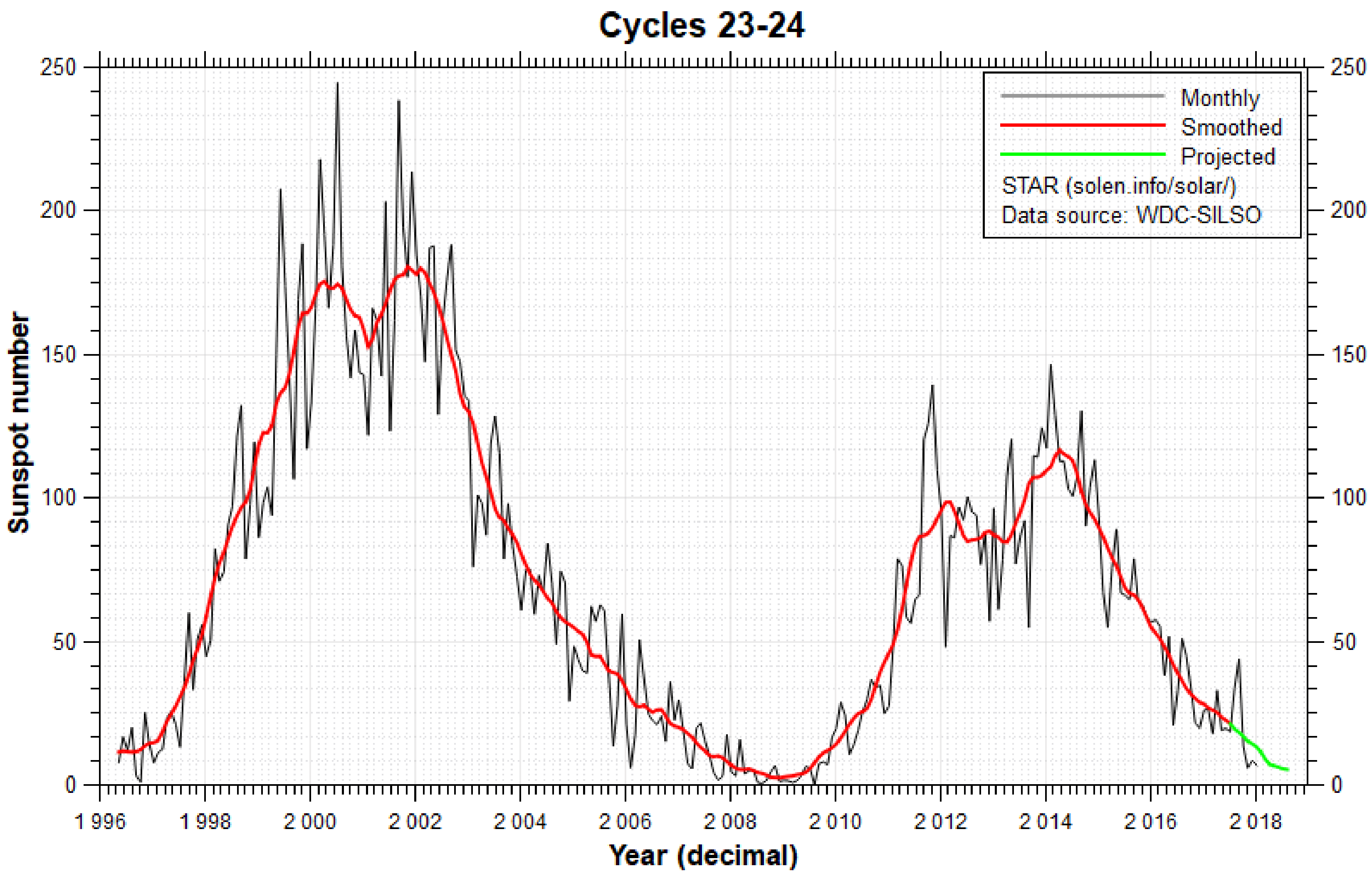
Abstract

- Irregularities in electron density of the ionosphere cause scintillation of trans-ionospheric signals.
- Scintillation can affect the accuracy of navigation by means of the Global Navigational Satellite System (GNSS).
- Within the African sector, the focus on mid-latitude is mainly Southern Africa
- Low-latitude and high-latitude scintillation is common, but mid-latitude scintillation is rare.
- Mid-latitude ExB associated with a strong Eastward Electric Field, and Travelling Ionospheric Disturbances (TIDs) may be responsible for the generation of mid-latitude scintillation.
- Spread F observations in ionosonde data at mid-latitude locations are linked to medium scale TIDs.

Background

- Most ionospheric studies over Africa have used data from a small number of GNSS receiver stations.
- The use of data from widely separated receivers severely restrict the temporal and spatial coverage of the African low and mid-latitude region.
- The focus of the work reported here is to use all the available data from the GNSS receiver network across Africa to derive monthly spatial trends in the occurrence of ionospheric irregularities during the peak of solar cycle 24

Solar Cycles 23-24

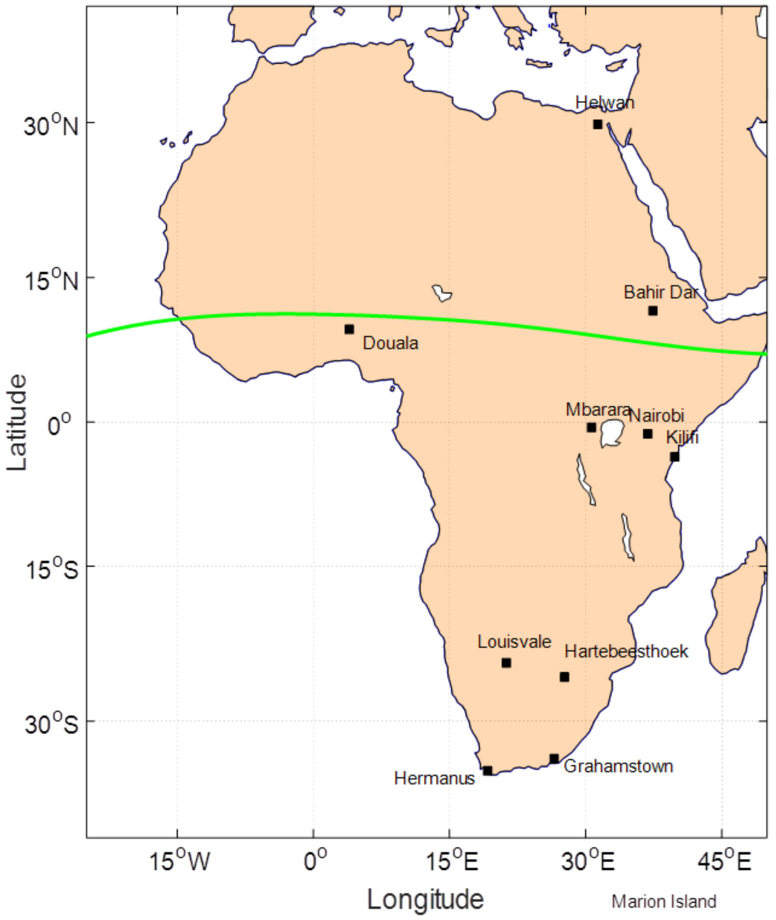


Solar cycle 24 reached its peak in 2014 with a mean annual sunspot number (SSN) of 113.

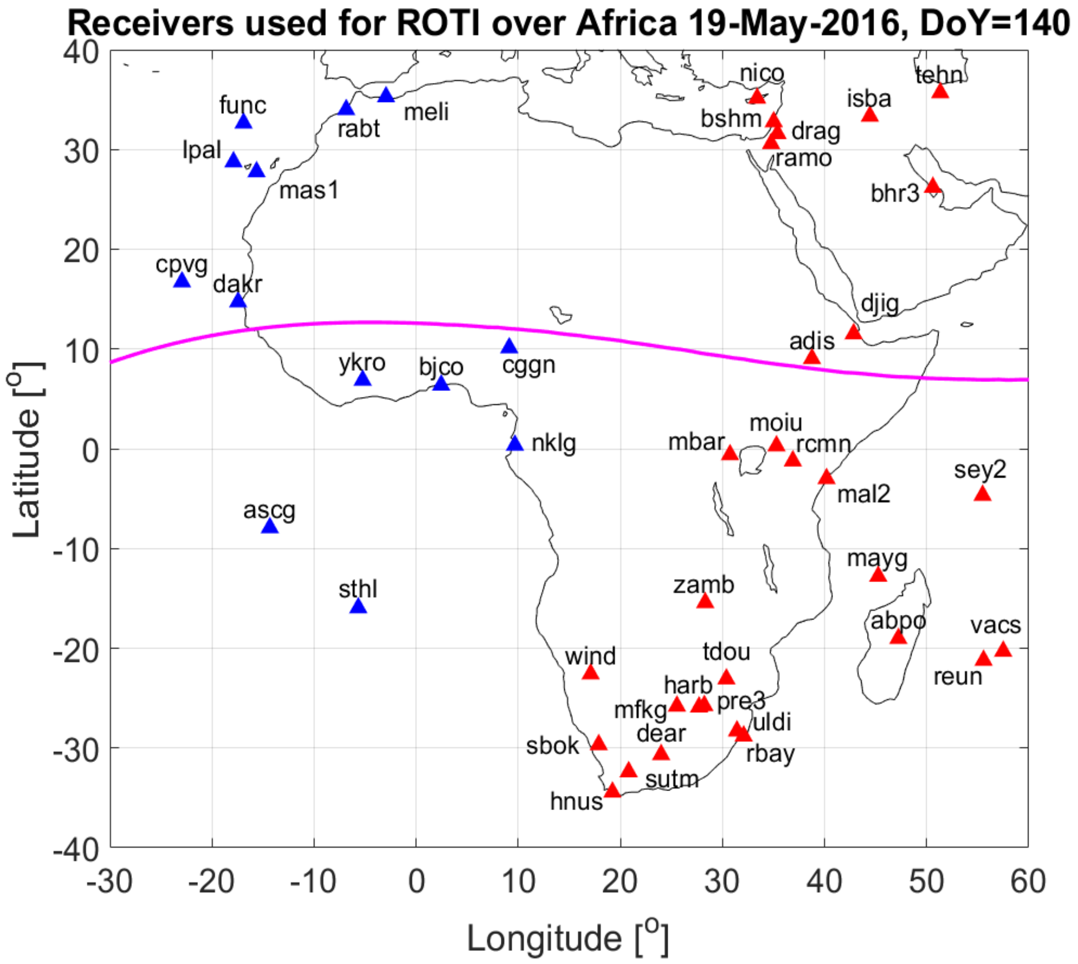
During this period there were significant space weather related irregularities in the mid-latitude ionosphere, which did not occur at any other time in the solar cycle.

Distribution of Scintillation receivers and GNSS receivers in Africa

Scintillation receivers



IGS GNSS receivers (UNAVCO)



There are only a small number of scintillation receivers in Africa. However, the GNSS network of receivers maintained by UNAVCO allows the estimation of scintillation over a wide spatial range through the ROTI index. The GNSS receivers marked in blue triangles are taken to represent Western Africa, while the data from the others marked in red are representative of Eastern Africa.

Rate of Change of TEC Index (ROTI)

- Rate of change of TEC

$$ROT = \frac{TEC_k^i - TEC_{k-1}^i}{t_k - t_{k-1}}$$

- Rate of Change of TEC Index (ROTI)

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

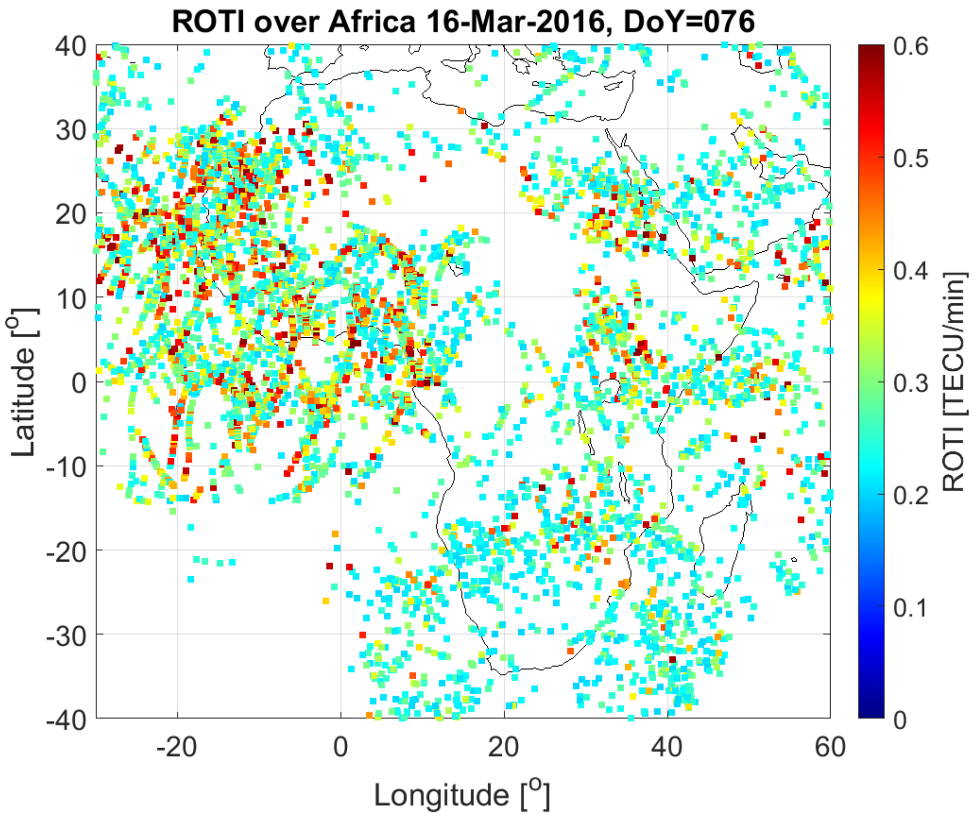
- Normalized ROTI>0.4 count

$$\%\ \text{ROTI-count} = \frac{\sum R > R_{\text{threshold}}}{\sum R} \times 100$$

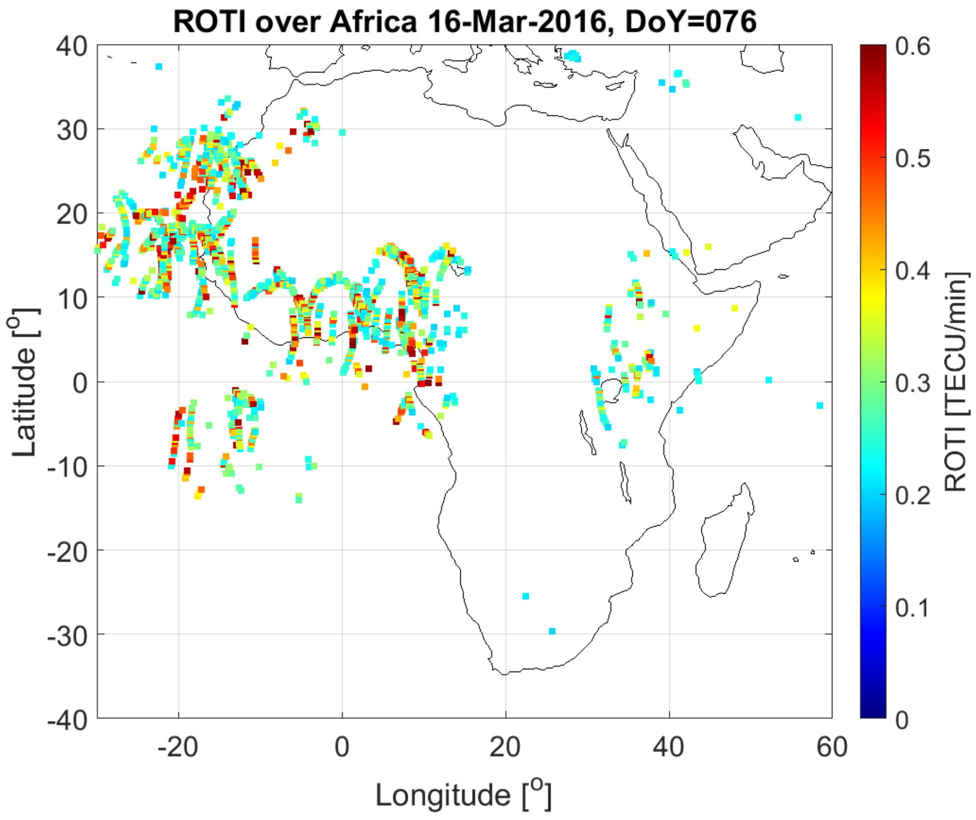
The threshold of ROTI > 0.4 was taken as representative of ROTI values which are most likely to be caused by significant ionospheric irregularities. The normalization is done to remove the possible bias of having a non-uniform distribution of receivers over Africa.

IPP coverage for ROTI>0.2 from 44 UNAVCO stations, 16 March 2016 (DoY 76)

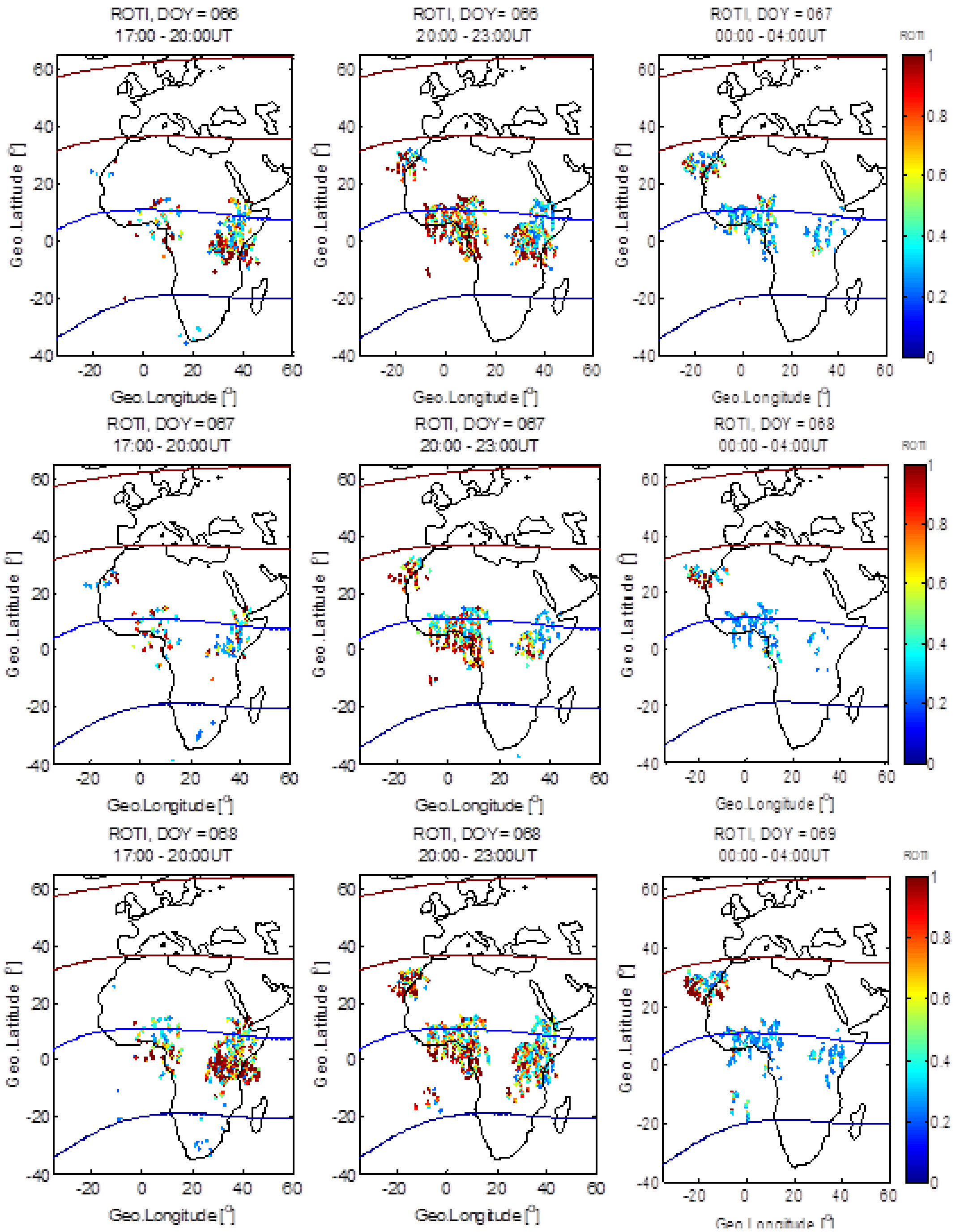
Elevation angle threshold 0°



Elevation angle threshold 20°



Left: The distribution of ionospheric pierce points (IPPs) for ROTI>0.2 for all GPS signal ray paths above the horizon (elevation angle threshold 0°) shows that the 44 UNAVCO GNSS stations provide substantial coverage over Africa.
Right: With an elevation angle threshold of 20° to remove multipath, the coverage still extends both sides of the geomagnetic equator, and covers both western and eastern Africa.



Spatial distribution of irregularities

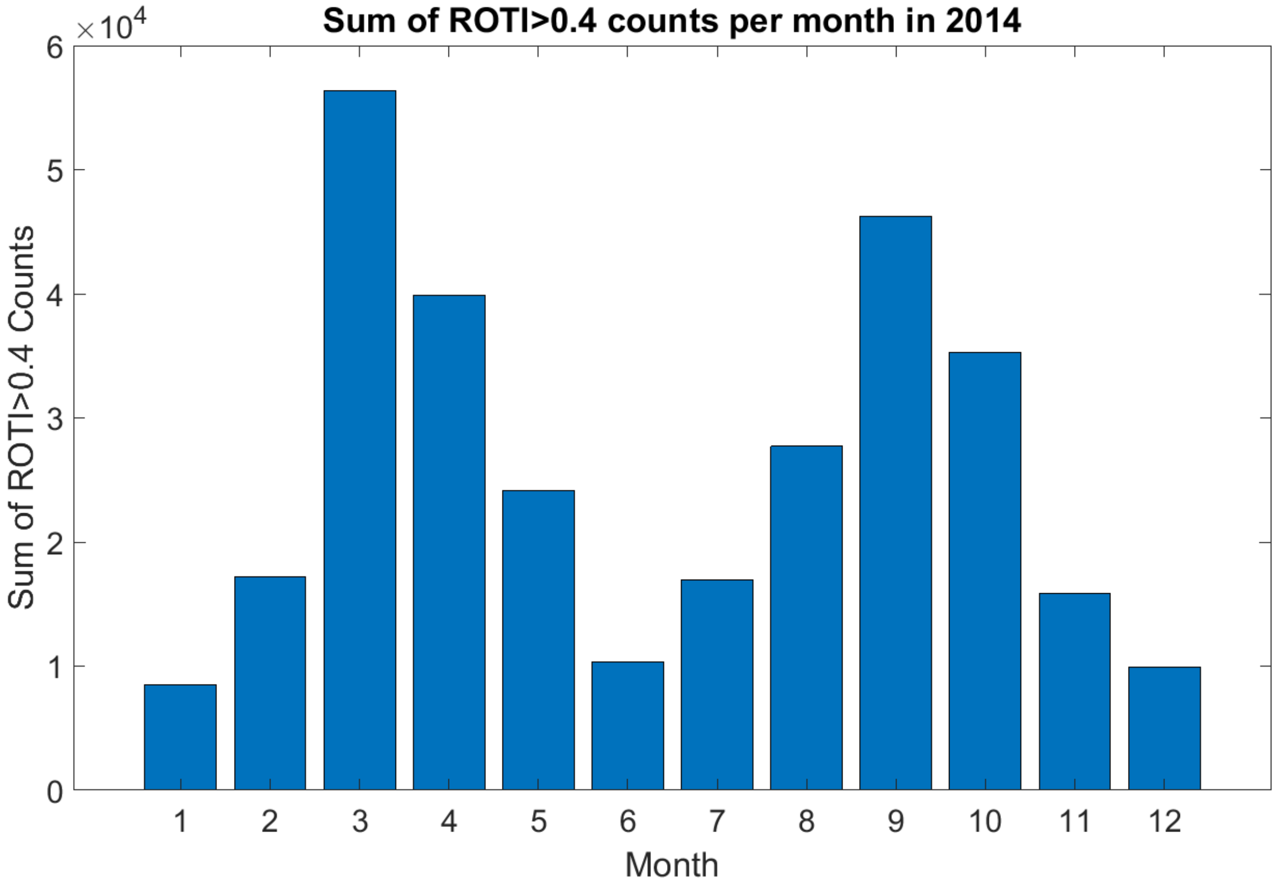
Occurrence of irregularities is strongly local time dependent as shown here for a number of consecutive days 7-10 March 2014 (DOY 66 to 69).

Panels on the left (17:00-20:00 UT) show the presence of irregularities mainly in East Africa, coinciding with post-sunset.

Panels in the middle (20:00-23:00 UT) show intense irregularities on both sides of Africa possibly due to the irregularities on the East occurring post mid-night while irregularities on the West, produced plasma bubbles, are yet to fully decay away.

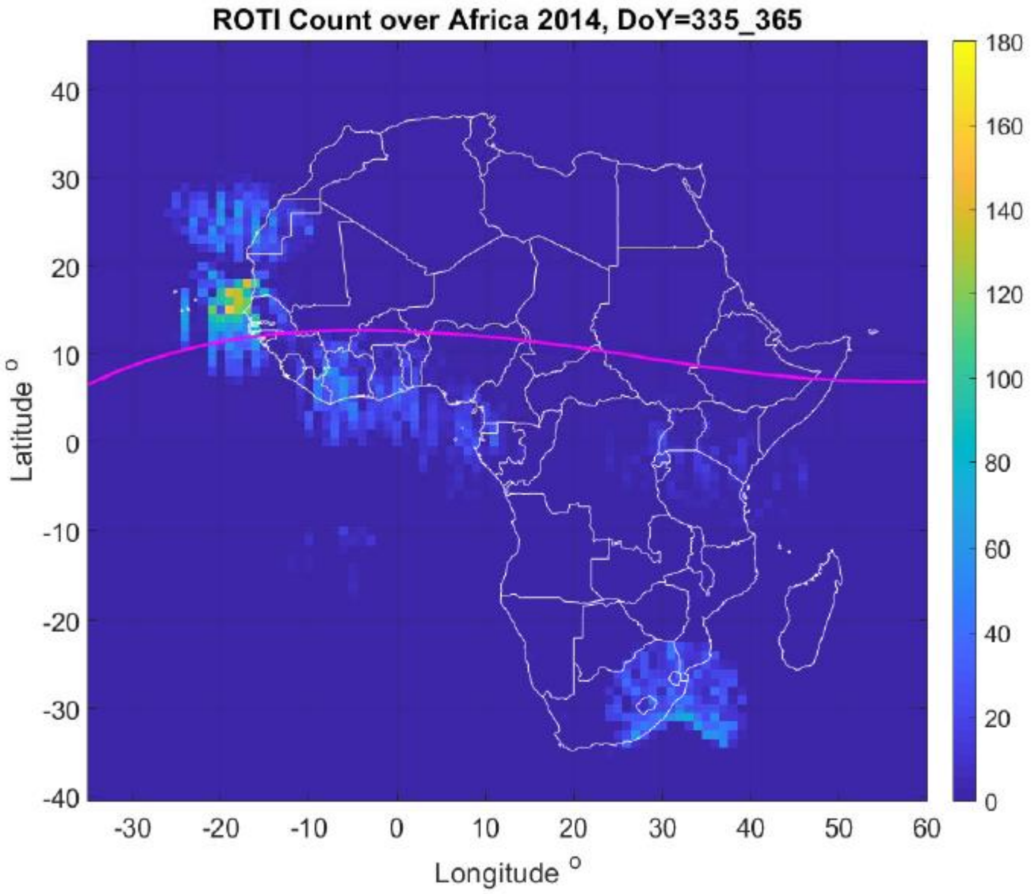
Panels on the right (00:00 to 04:00 UT) show a clear shift in the intensity of irregularity activity westward as we move to the near dawn hours on the Eastern side of the region.

Statistical Trends: Sum of ROTI counts 2014



The seasonal occurrence of irregularities show peaks in equinoxes and reduced values during solstices.

ROTI-count December 2014

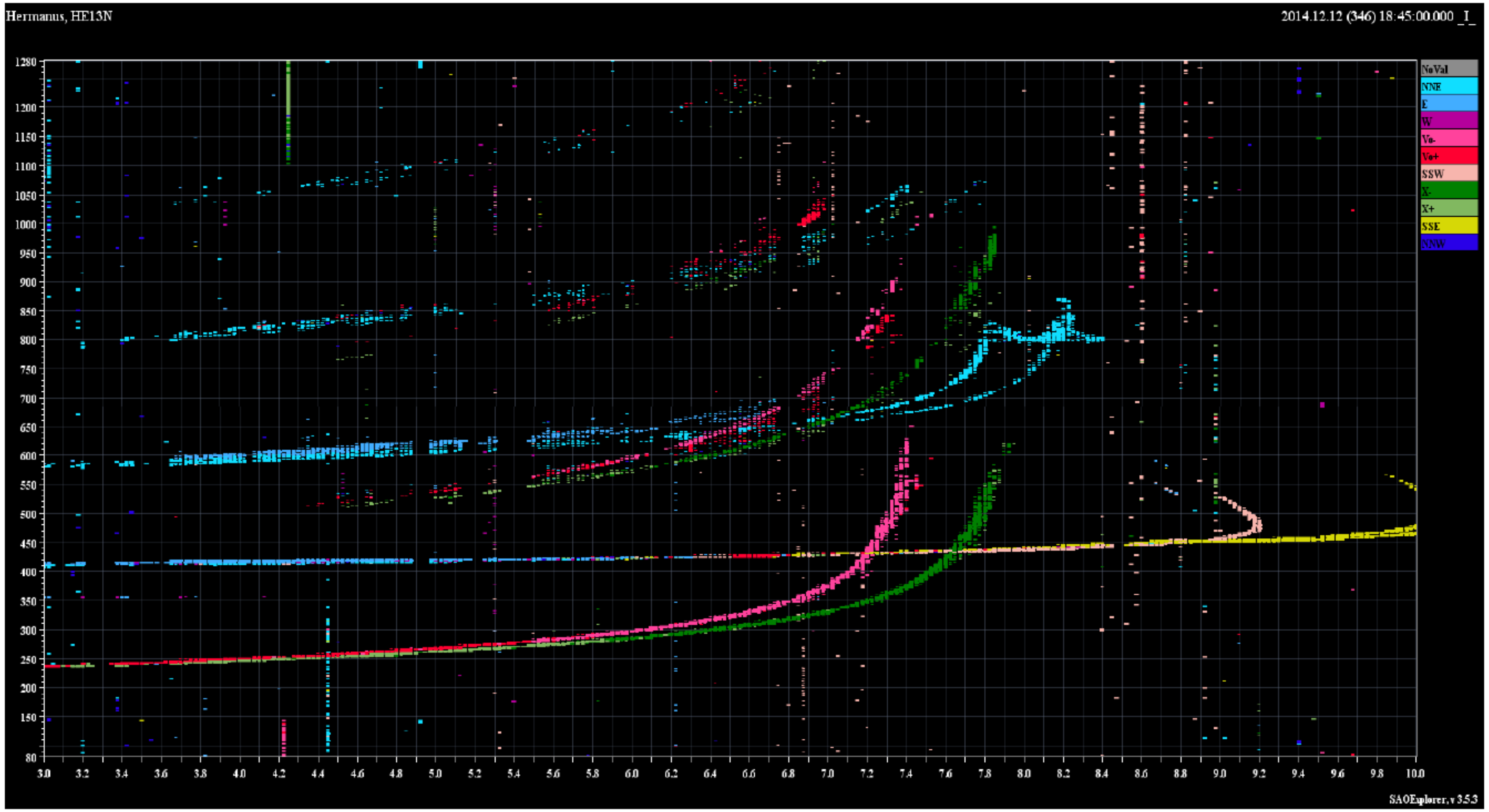


Spatial distribution of ionospheric irregularities based on monthly ROTI counts binned over 1x1 degree pixels for December 2014.

Note the occurrence of ROTI over Southern Africa, a mid-latitude region during the peak of the solar cycle.

Other observation seem to indicate that this data might have been due to unknown non-ionospheric sources.

Spread F in Hermanus Ionosonde data



Post-sunset ionogram recorded on 12 December 2014 in Hermanus at 18:45 UT (20:45 LT).
Note the occurrence of spread-F that coincides with the mid-latitude ROTI observations over the South African region.

Conclusions

- Ionospheric Irregularities as detected by ROTI are strongly local time dependent across the African region.
- A strong asymmetry is noticeable in both longitudinal and latitudinal occurrence of ionospheric irregularities.
- During the first 4 months of 2014 the strong irregularity events (ROTI>0.4) occurred predominantly on the western part of Africa.
- The occurrence of strong irregularities (ROTI>0.4) moved to the eastern part of Africa during the last 4 months of 2014.
- ROTI observations in western Africa indicated stronger irregularities near the ocean than in the central part of the continent.
- Further studies using appropriate ground and satellite-based data are required to understand the coupling between the lower atmosphere and the ionosphere over Africa, in order to explain the trends observed.