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Satellite Navigation Science and Technology for Africa

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The African Ionosphere

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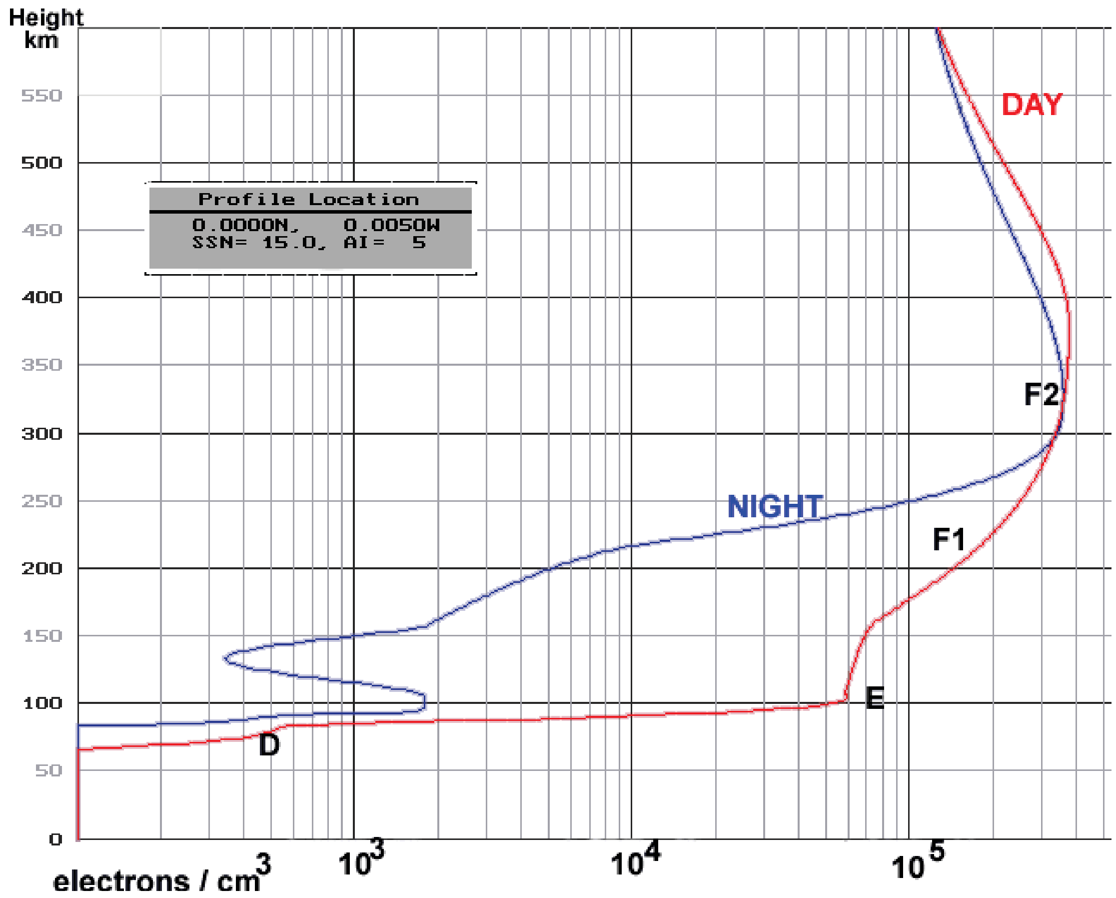
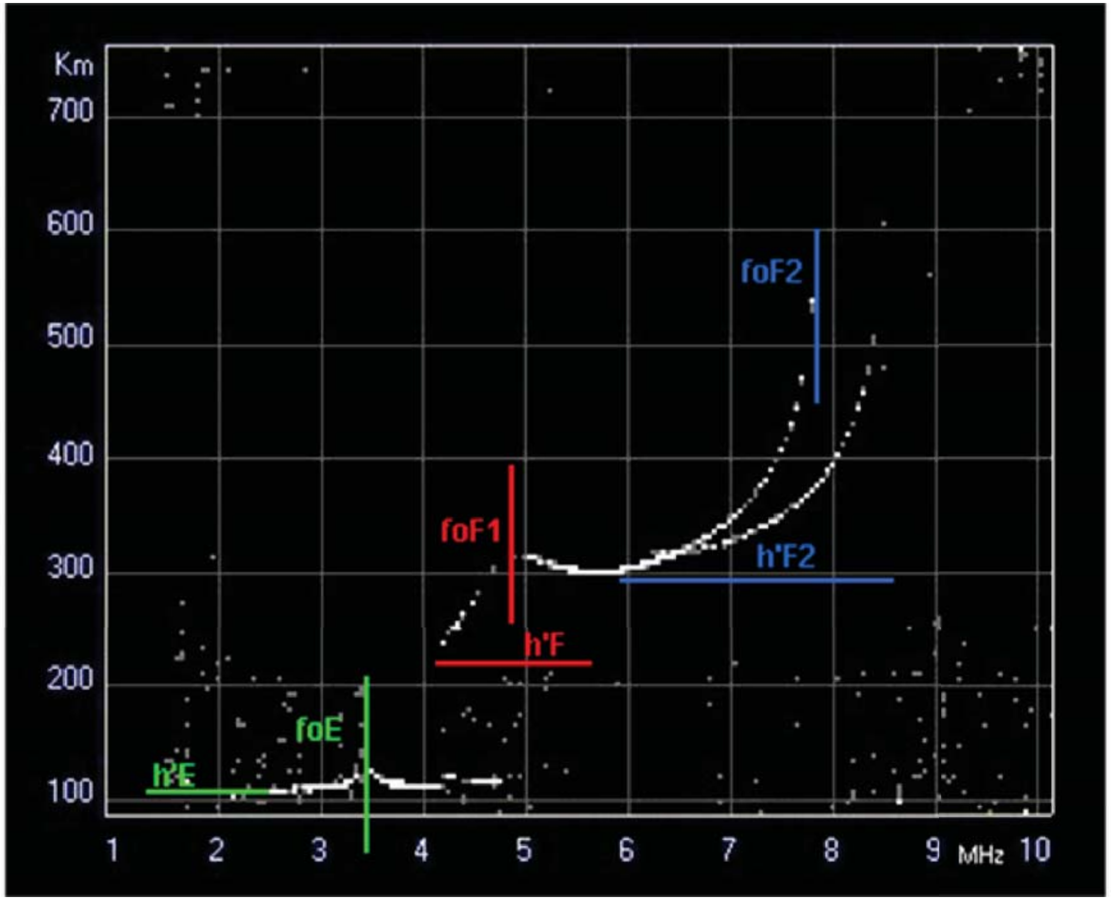
A “climate” description of the African Ionosphere

Defining an important parameter: foF2

Electron density profile in the ionosphere



The ionogram



foF2

The frequency at which a wave just penetrates the ionospheric F2 layer is known as the critical frequency of that layer. The critical frequency is related to the electron density by the simple relation:

$$N = 0.124 \times 10^{11} \left(f\right)^2$$

$$N \left[m^{-3}\right] \quad f \left[MHz\right]$$

How to define a “climate” description of the ionosphere

- Two basic parameters of the Ionosphere are the NmF2 and the hmF2.
- ITU-R (formerly CCIR) coefficients are used to compute foF2 and M(3000)F2 over the entire globe.
- They have been derived from monthly medians of foF2 and M(3000)F2 obtained by the worldwide network of ionosondes (about 150 stations) during the years 1954 to 1958
- This technique was first developed by Jones and Gallet using only a dependence on latitude and longitude, but soon a dependence on modip was introduced.
- These coefficients are given for low (R12=0) and high (R12=100) solar activity conditions. For other solar activities conditions simple interpolation is used.

Introducing “modip”

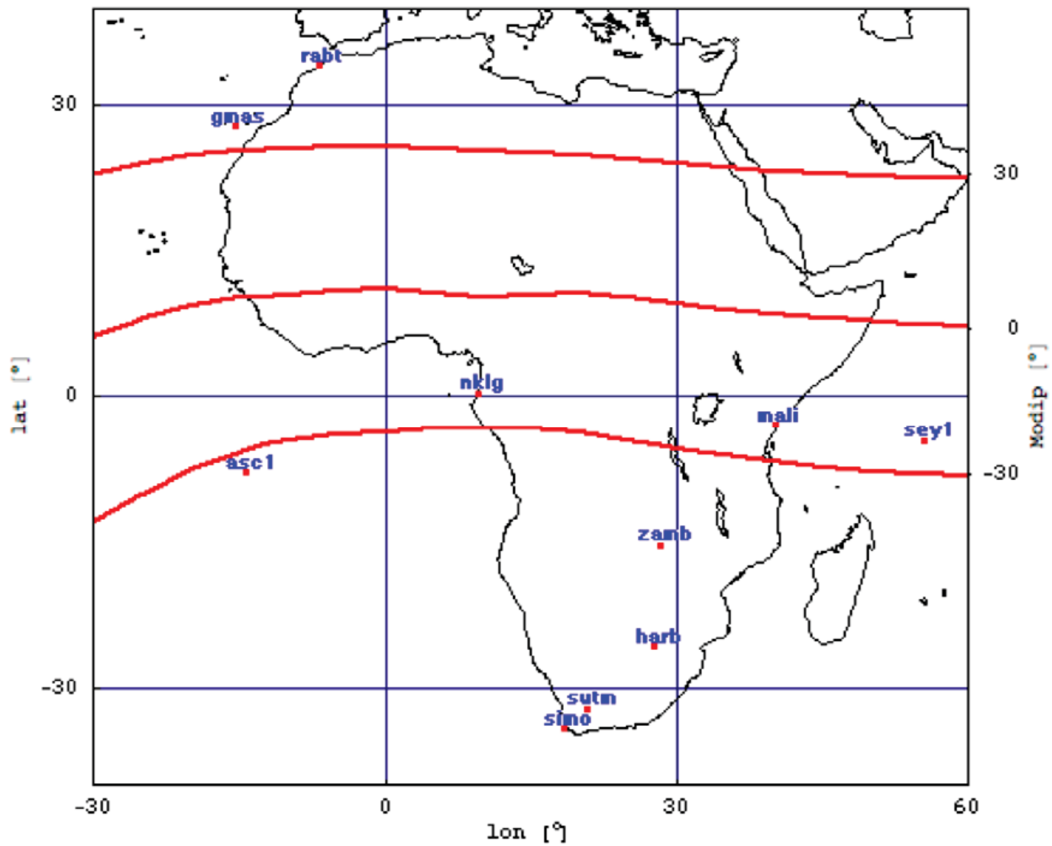
A geomagnetic coordinate introduced by Rawer [1963] to be applied in ionospheric studies particularly related to low latitudes:

$$\tan \mu = \frac{I}{\sqrt{\cos \varphi}}$$

Where I is magnetic inclination or dip at 300 km and φ is the latitude of the considered location.

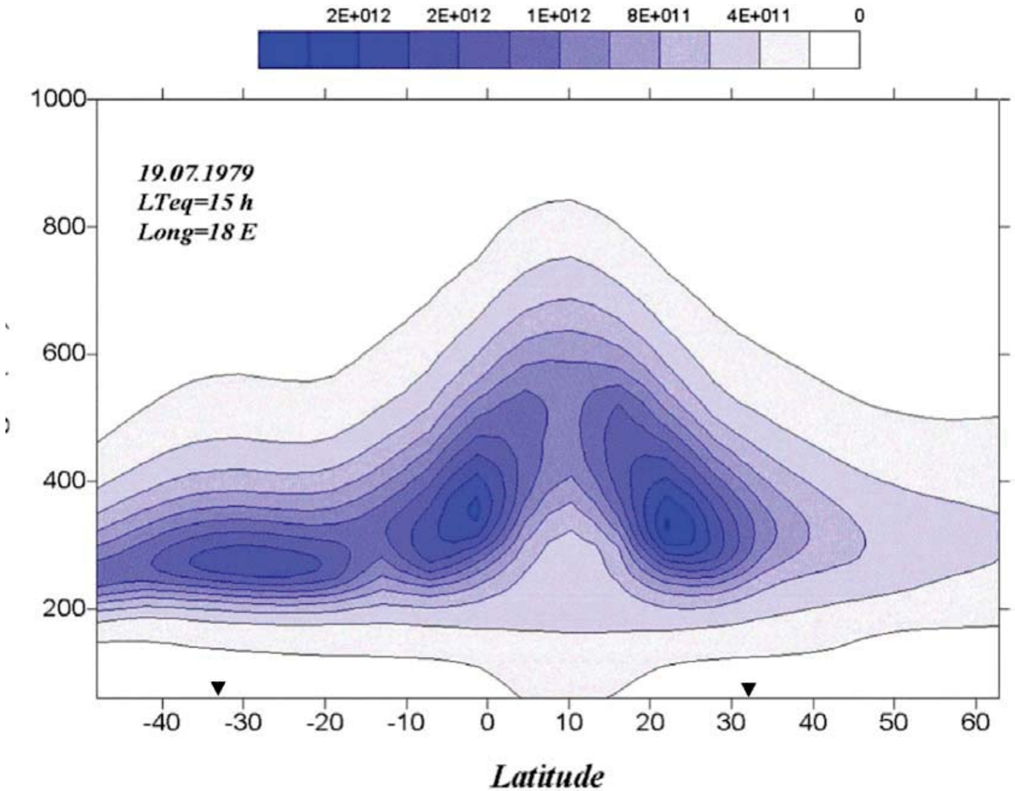
Modip is near magnetic dip at low latitudes and gets closer to geodetic latitudes at higher latitudes.

Modip over Africa



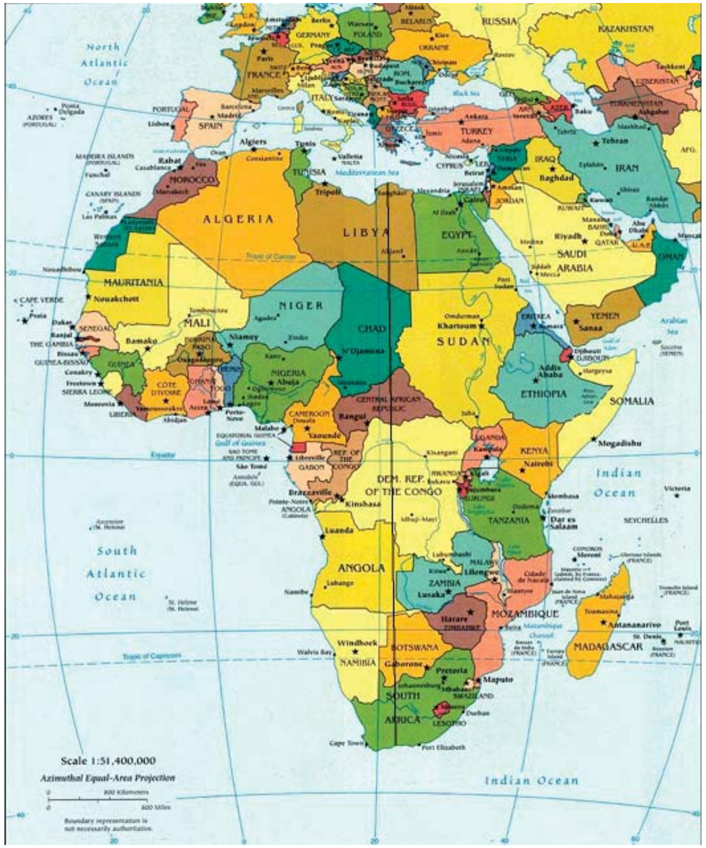
The process that dominates the African Ionosphere

The physical process that dominates the behavior of the Ionosphere over Africa is the Equatorial Anomaly.

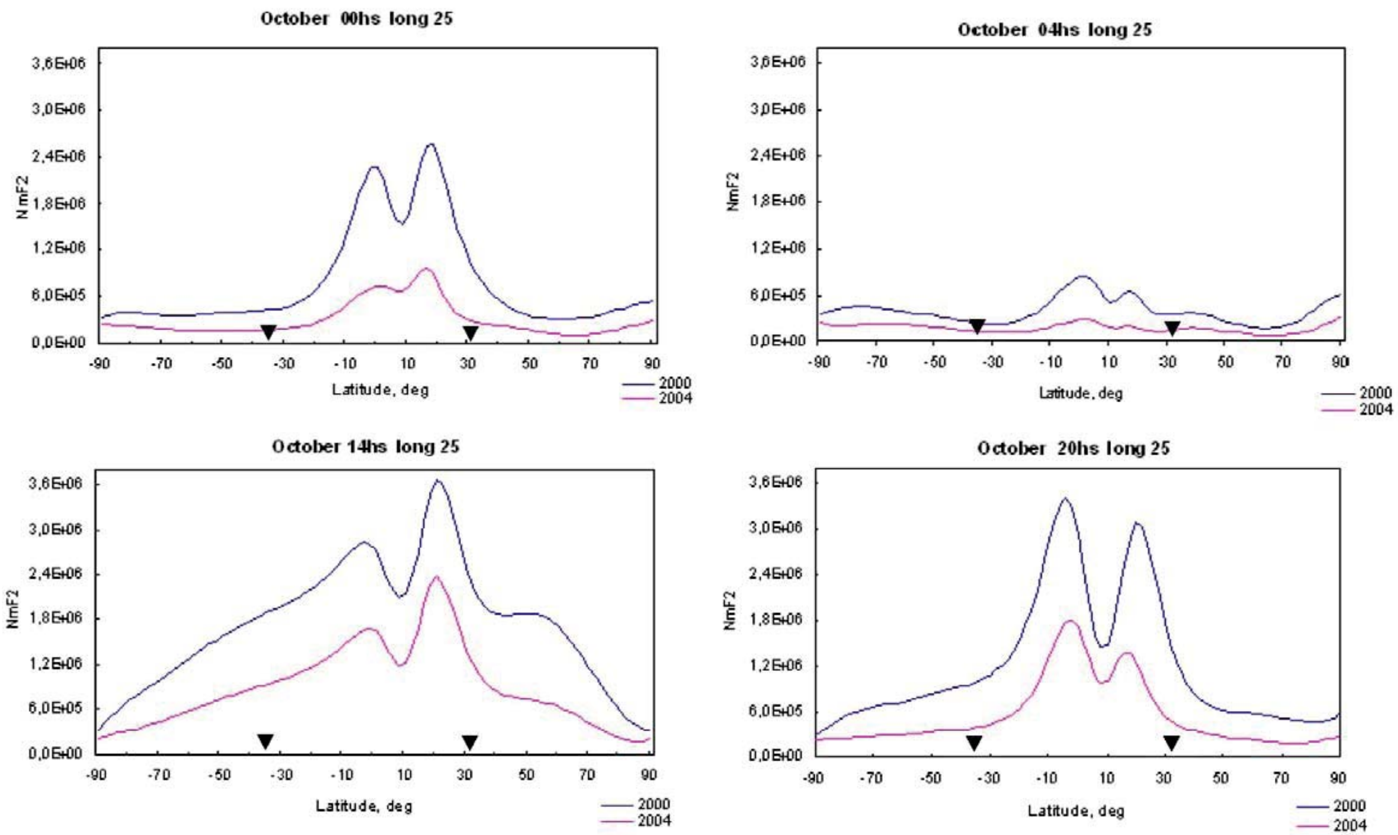


Meridional cross-section of the electron density profile at a given time. From Nava et al. (2001). Arrows indicate the limits of continental Africa.

A meridional cross section of continental Africa

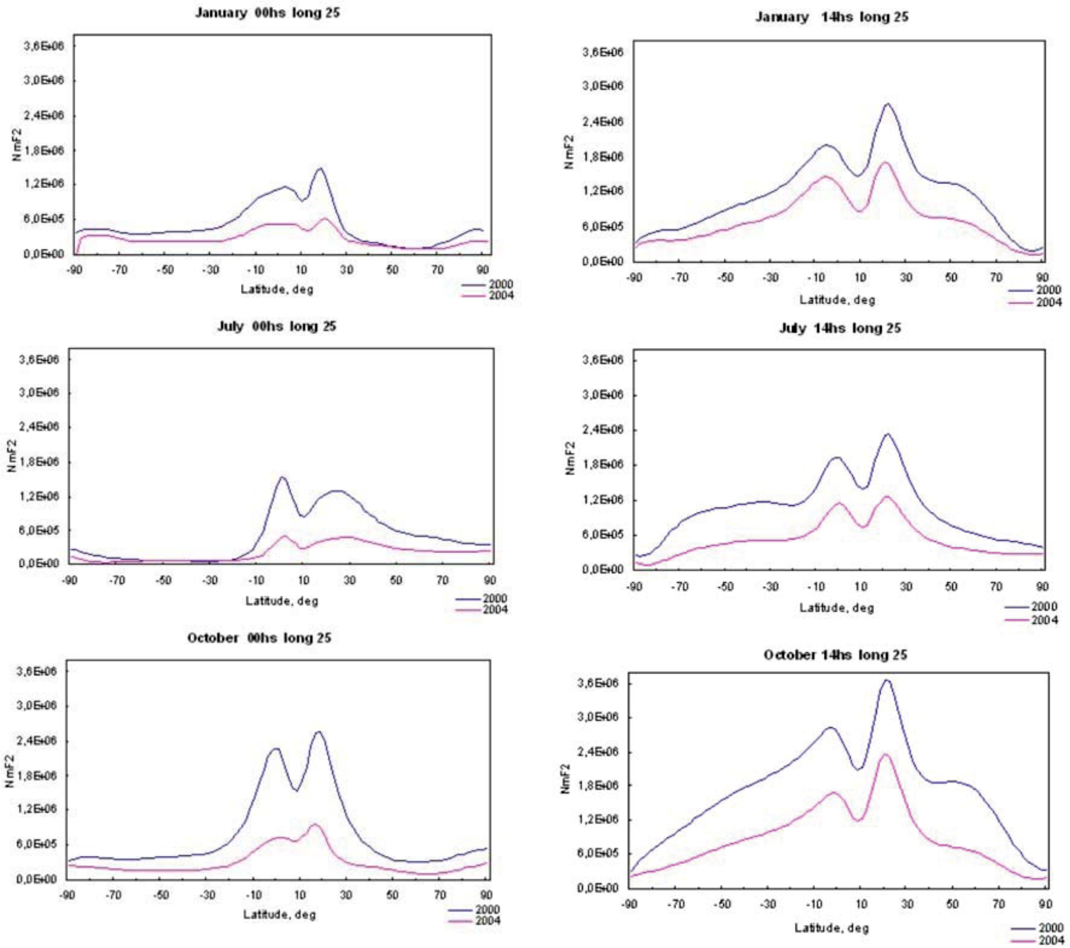


The dominant process as seen by the ionospheric "climate"



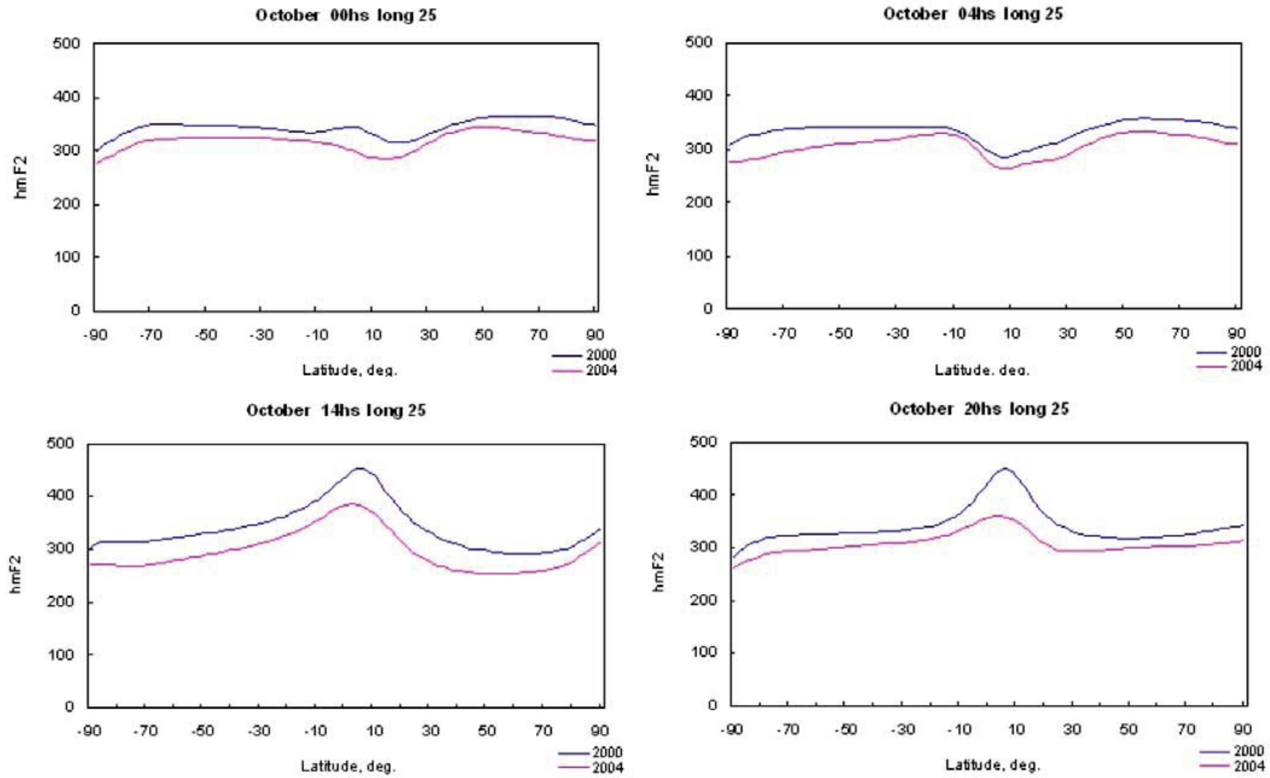
Meridional cross-sections (25º E) of NmF2 at four different hours (LT). October 2000 (blue) and 2004 (magenta). Arrows indicate the limits of continental Africa.

The dominant process as seen by the ionospheric "climate" (cont.)



Meridional cross-sections (25º E) of NmF2 at 00.00 and 14.00 (LT). January, July and October for years 2000 (blue) and 2004 (magenta)

The dominant process as seen by the ionospheric climate (cont.)



Meridional cross-sections (25º E) of hmF2 at four different hours (LT). October 2000 (blue) and 2004 (magenta)

Introducing TEC and its variability over Africa:

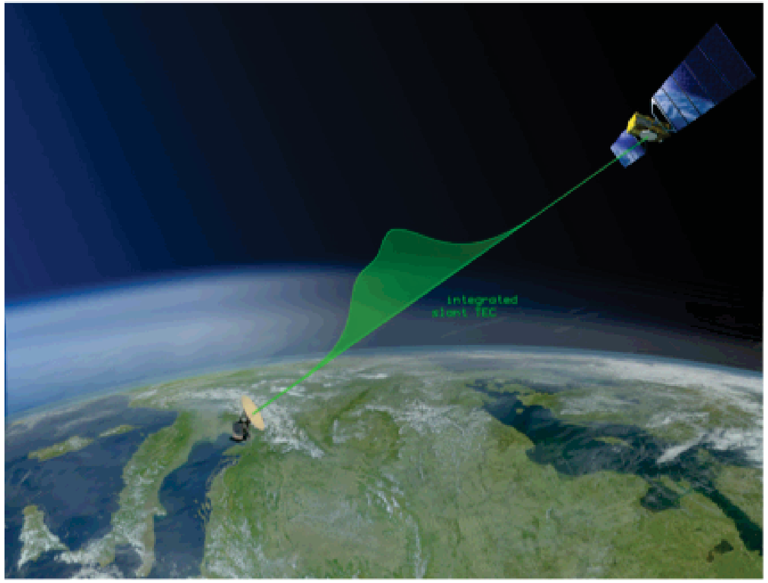
A measure of “ionospheric weather”

Another ionospheric parameter: TEC

The total electron content (TEC) is the number of electrons in a column of one metre-squared cross-section along a trans-ionospheric path.

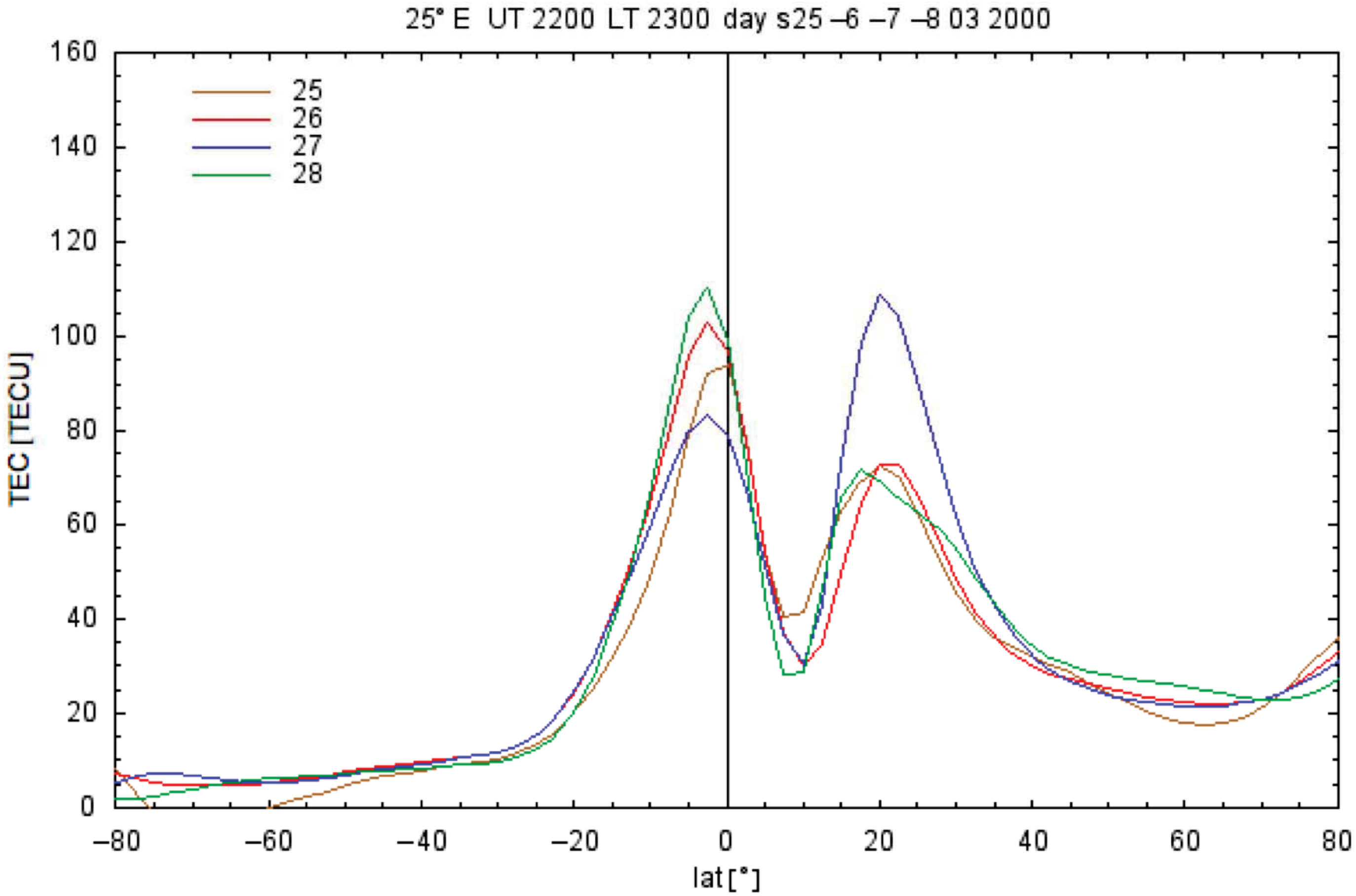
$$N_T = \int_S N\left(s\right) ds$$

$$1\,TEC = 10^{16}\,m^{-2}$$



Day to day variation of the equatorial anomaly development over Africa

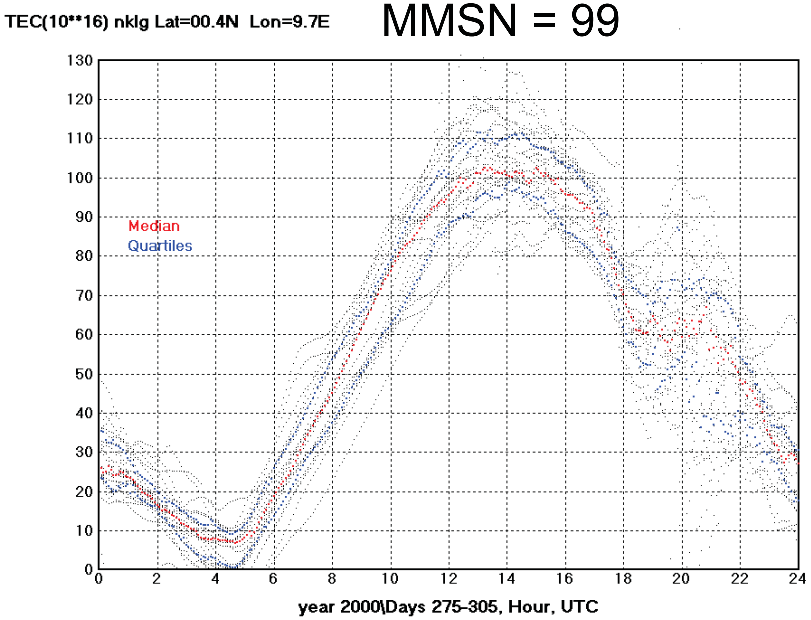
Vertical TEC over Africa and its variability



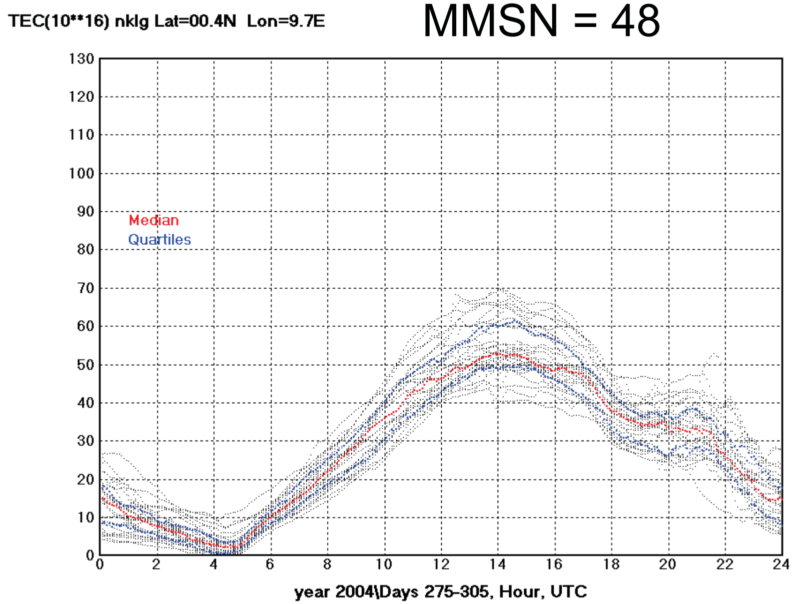
Four consecutive days meridional cross sections (25º E) of vertical TEC from global maps at 23.00 LT.

Vertical TEC over Africa and its variability (cont)

MMSN = 99



MMSN = 48



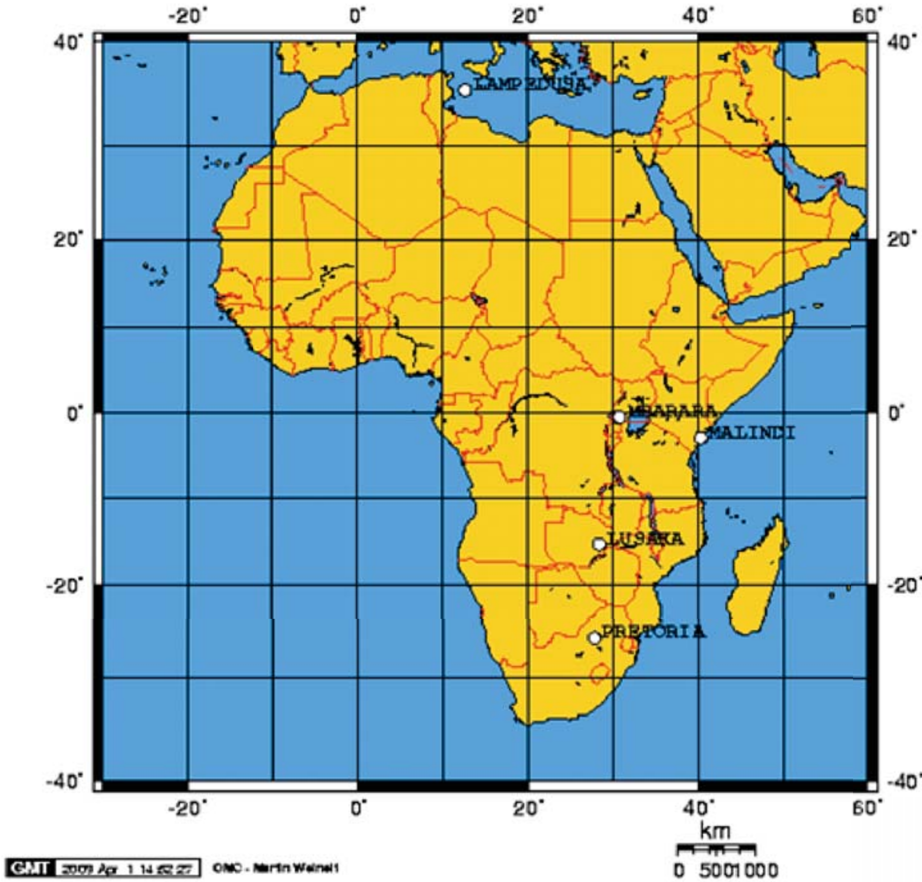
GPS derived vertical TEC at 5 min interval for Libreville (Lat. 0.4º N, Long. 9.7º E, modip – 24.6º), October 2000 and October 2004.

Daily values black points, median values red points and quartile values blue points.

Quiet and disturbed conditions

slant and vertical TEC variations over Africa

Slant and Vertical TEC over Africa and its variability

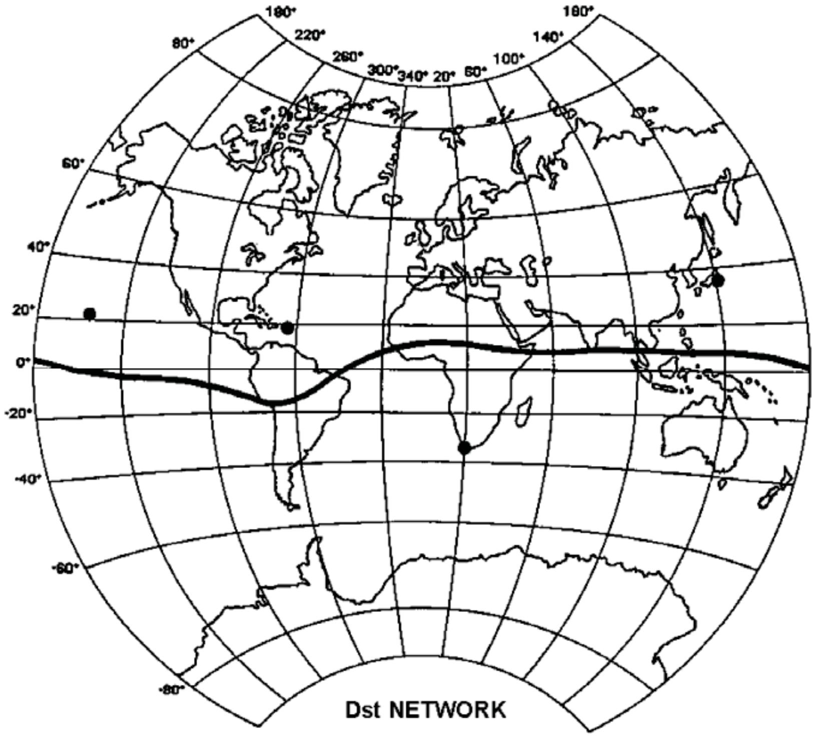


STATIONS USED

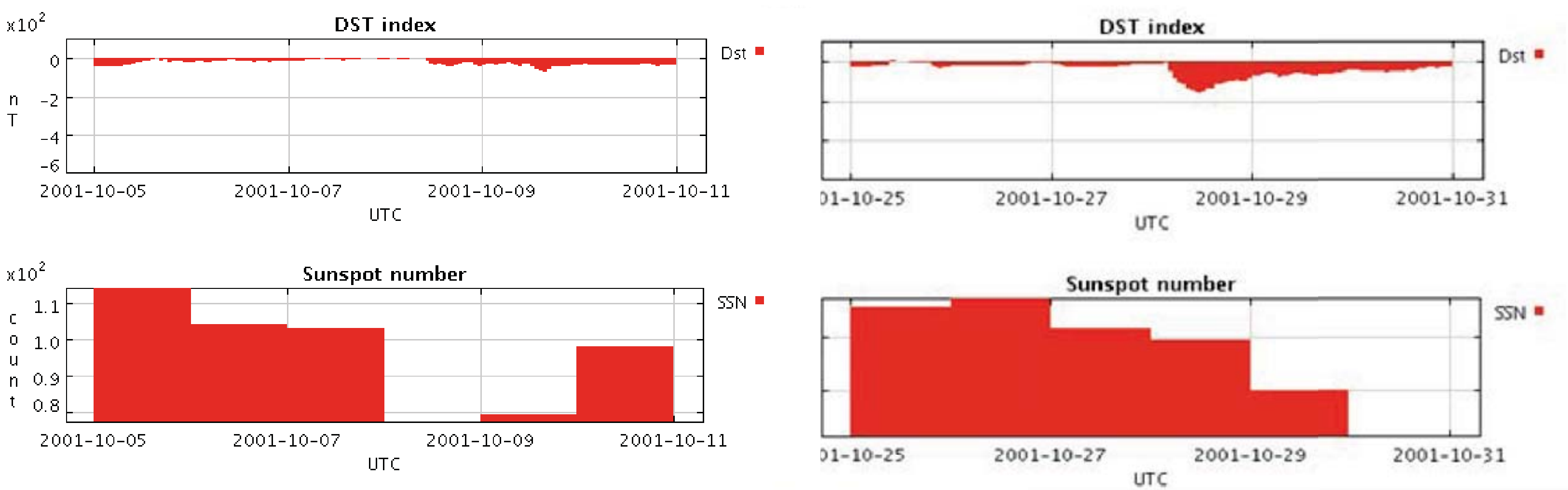
Introducing geomagnetic activity index DST

Dst Index

- The hourly Dst index is obtained from four magnetic observatories, Hermanus, Kakioka, Honolulu, and San Juan.
- These observatories were chosen on the basis the quality of observation and for the reason t their locations are sufficiently distant from the auroral and equatorial electrojets and that the are distributed in longitude as evenly as possib
- At such latitudes the H (northward) componen of the magnetic perturbation is dominated by intensity of the magnetospheric ring current.
- The Dst variation provides a quantitative meas of geomagnetic disturbance that can be correlated with other solar and geophysical parameters.
- This variation clearly indicates the occurrences of magnetic storms and their severity when they occur.



Dst Index and Sunspot number for the periods analyzed: HSA



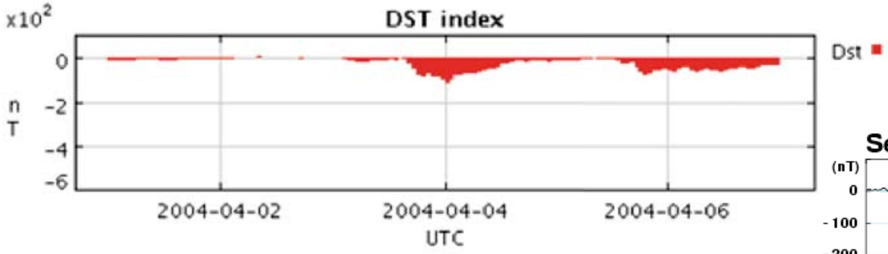
Low: Dst > -20 nT

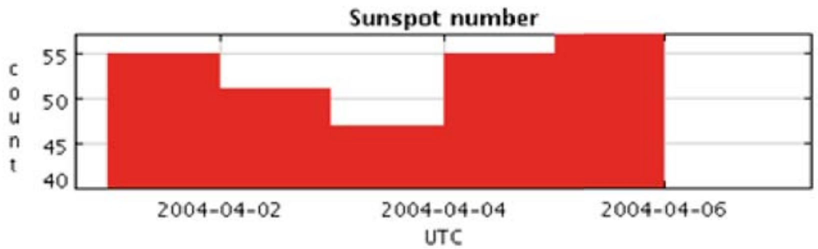
Medium: -20 nT > Dst > -50 nT

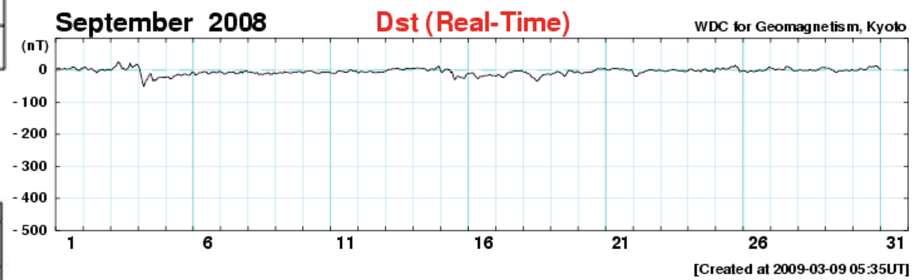
High: -50 nT > Dst > -100 nT

Extreme: Dst < -100 nT

Dst Index and Sunspot number for the periods analyzed (LSA and minimum SA)





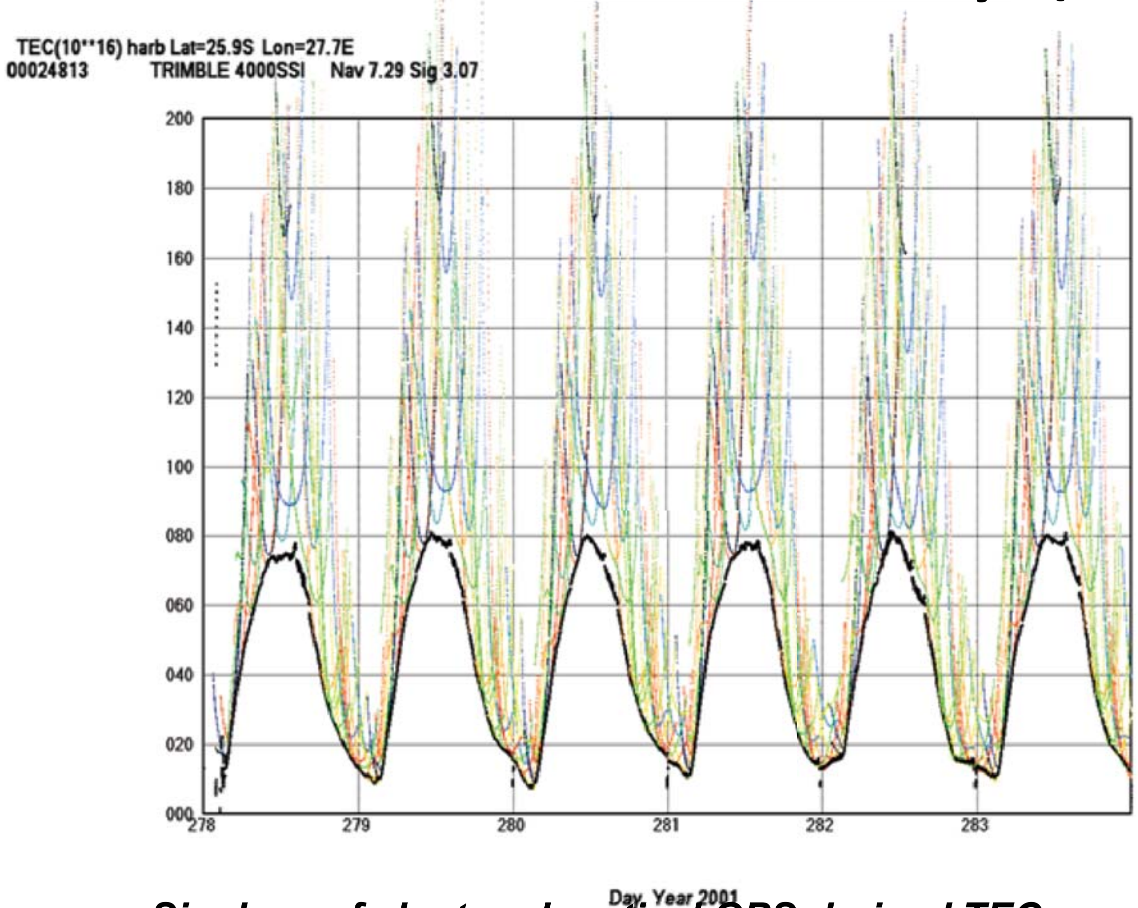


International Sunspot numbers 2008

2008	01	3.3
2008	02	2.1
2008	03	9.3
2008	04	2.9
2008	05	3.2
2008	06	3.4
2008	07	0.8
2008	08	0.5
2008	09	1.1
2008	10	2.9
2008	11	4.1
2008	12	0.8

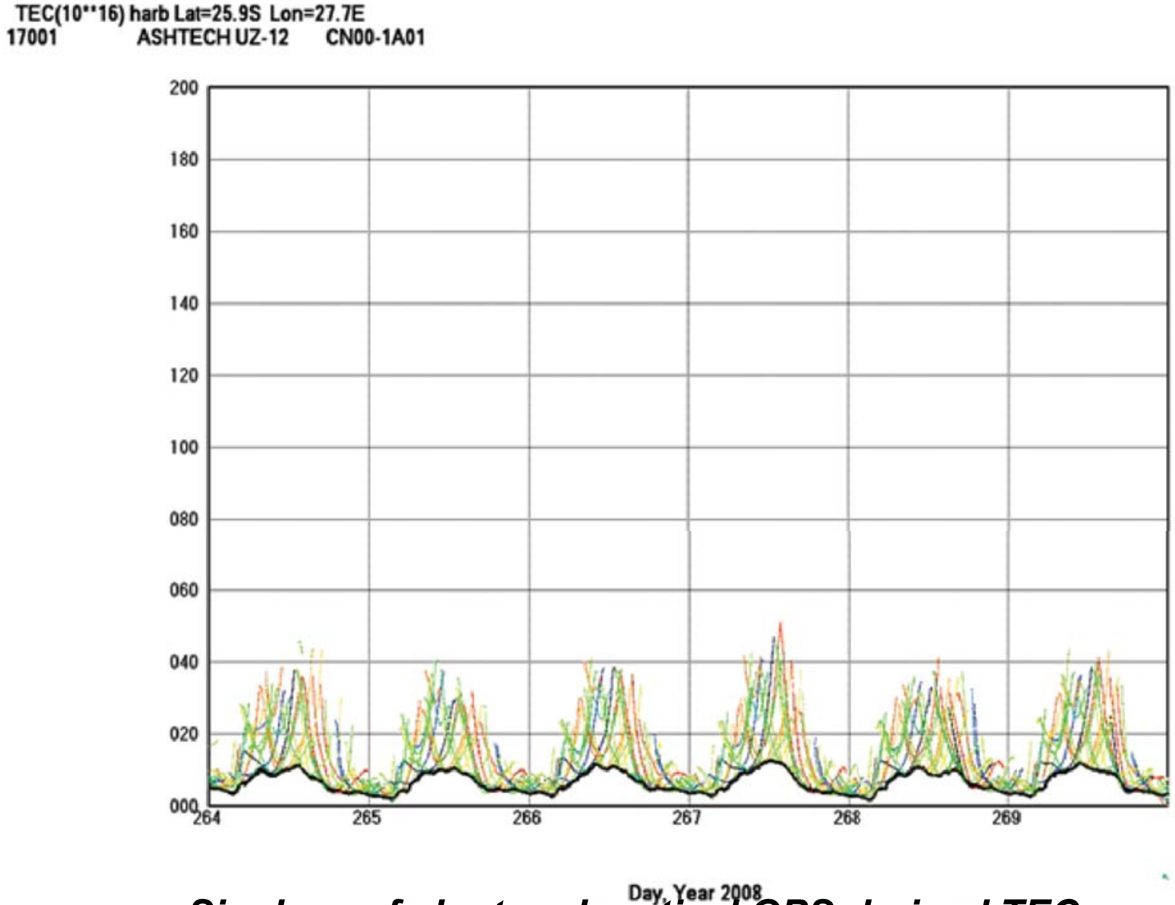
Middle latitudes conditions

Slant and Vertical TEC over Africa and its variability (cont)



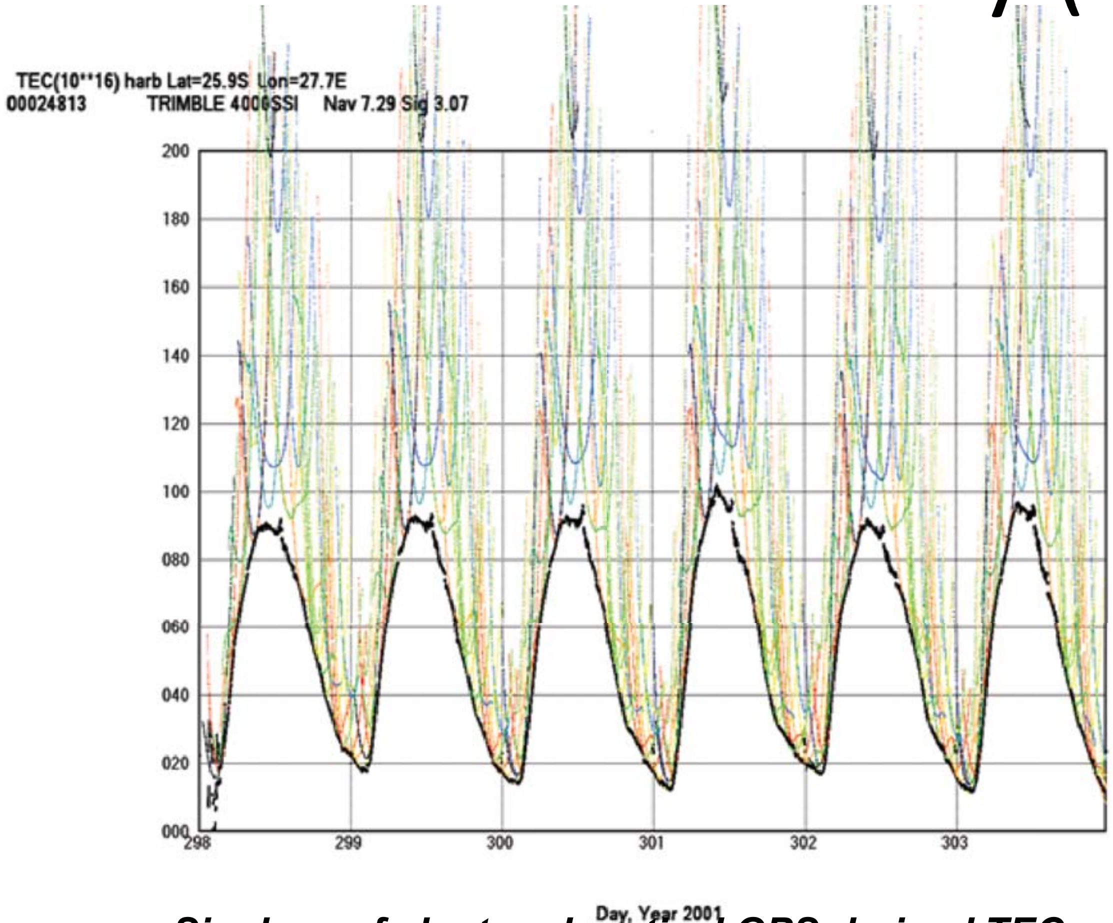
Six days of slant and vertical GPS derived TEC over Pretoria during quiet geomagnetic conditions and high solar activity (5-10 October 2001)

Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Pretoria during quiet geomagnetic conditions and low solar activity (20-25 September 2008)

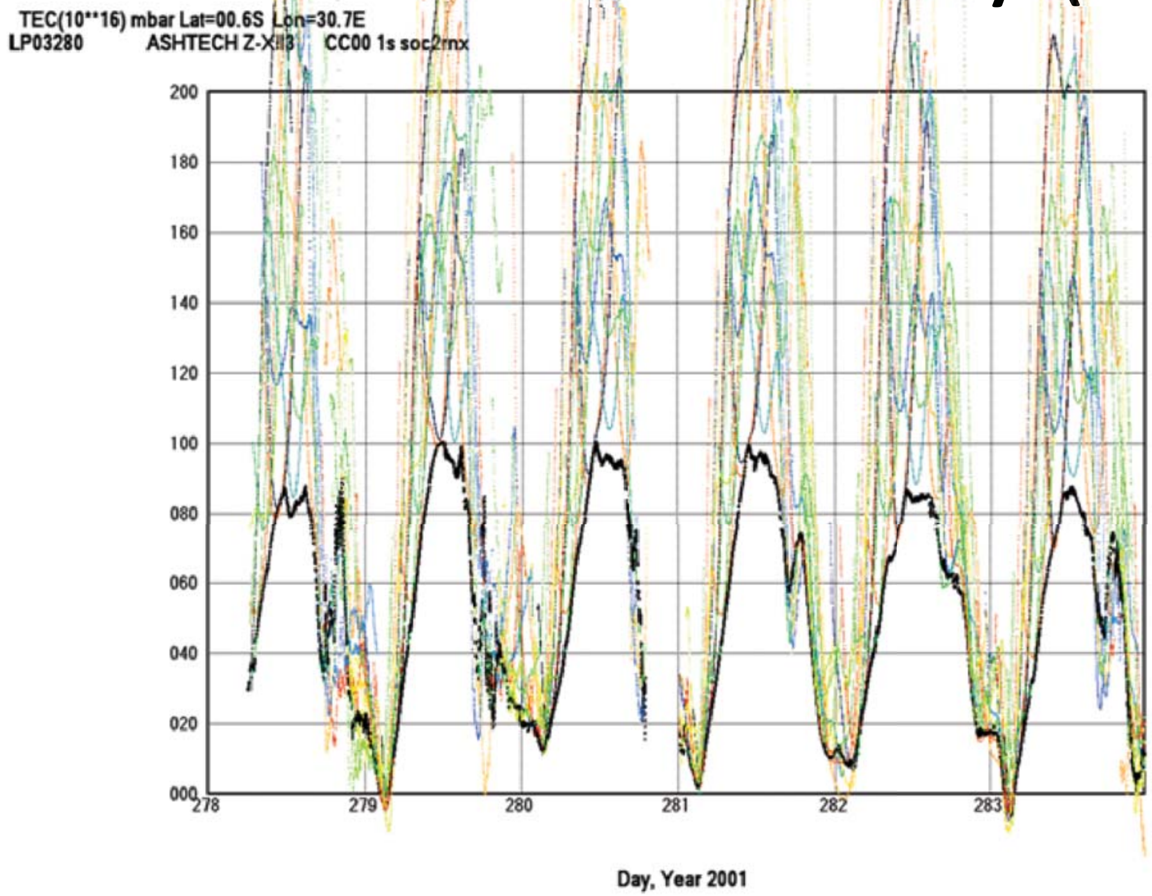
Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Pretoria including disturbed geomagnetic conditions and high solar activity (25-30 October 2001)

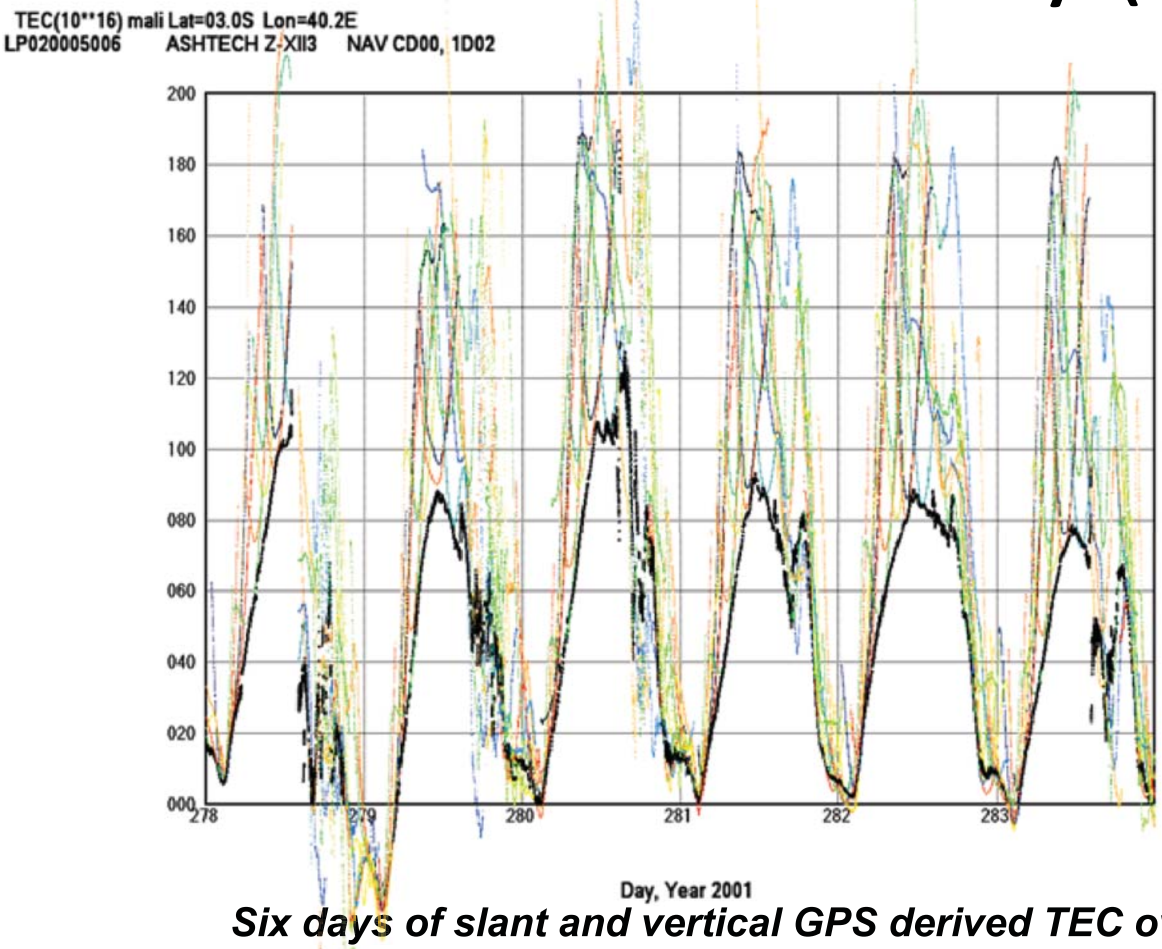
Conditions under the African southern crest of the equatorial anomaly

Slant and Vertical TEC over Africa and its variability (cont)



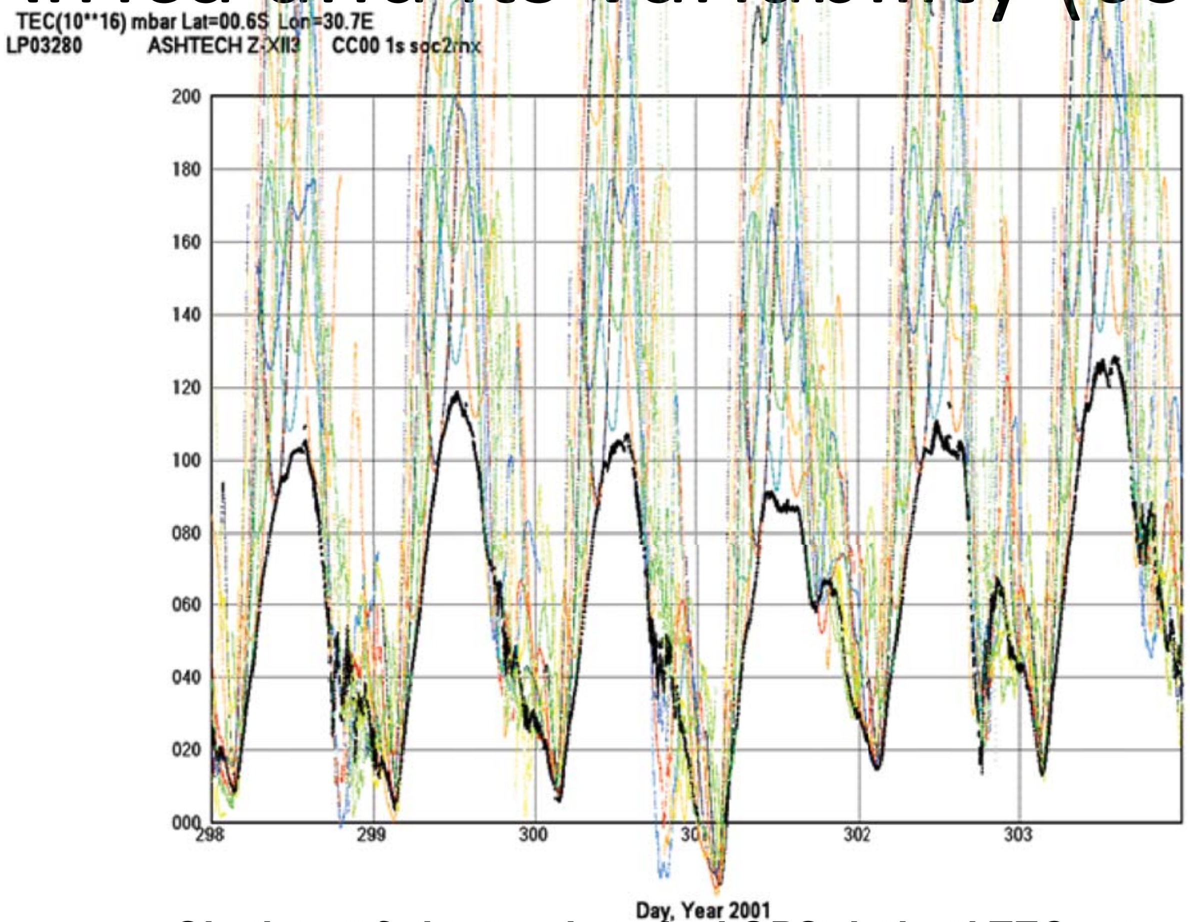
Six days of slant and vertical GPS derived TEC over Mbarara during quiet geomagnetic conditions and high solar activity (5-10 October 2001)

Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Malindi (modip – 24.9) during quiet geomagnetic conditions and high solar activity (5-10 October 2001)

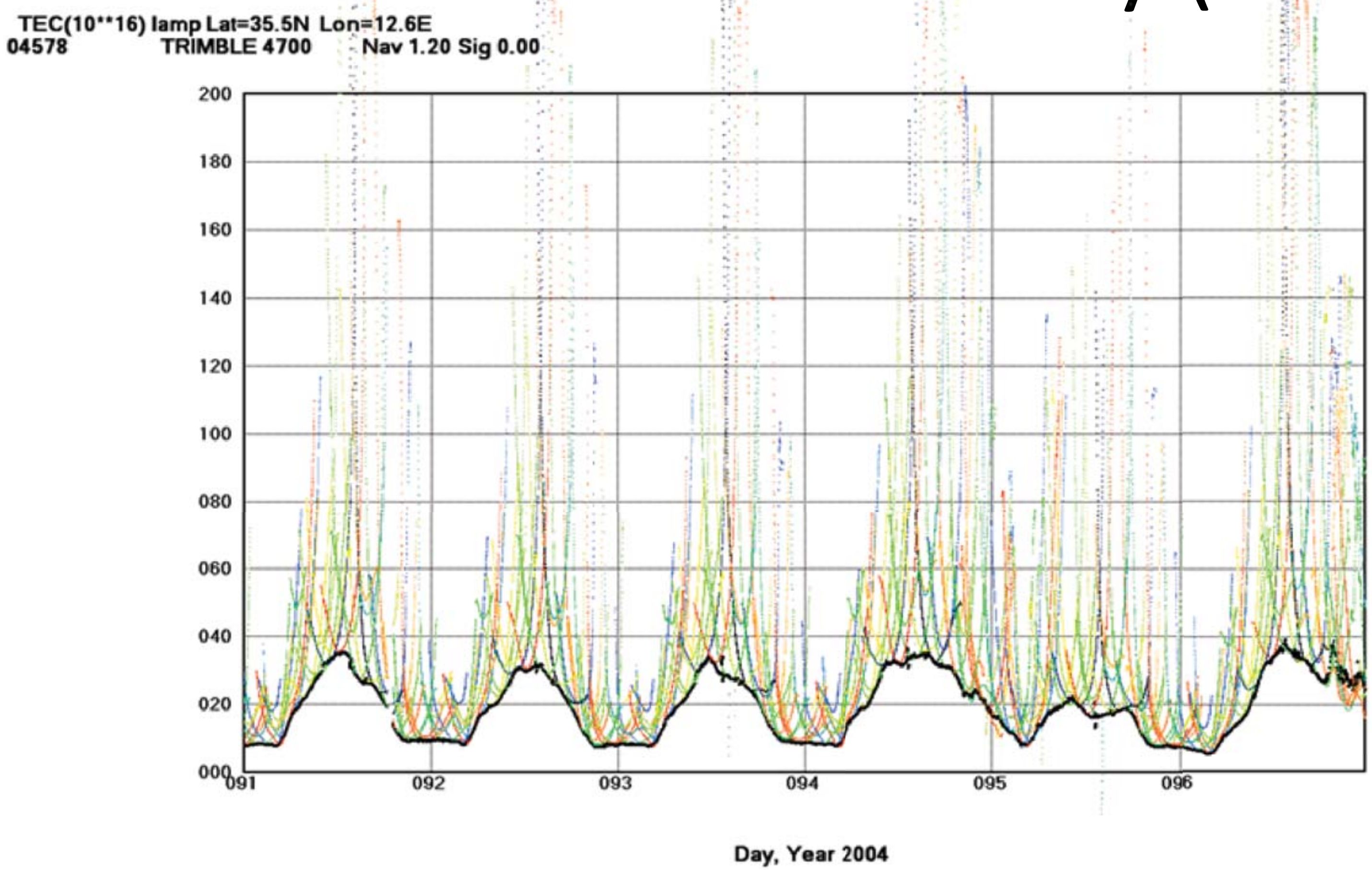
Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Mbarara including disturbed geomagnetic conditions and high solar activity (25-30 October 2001)

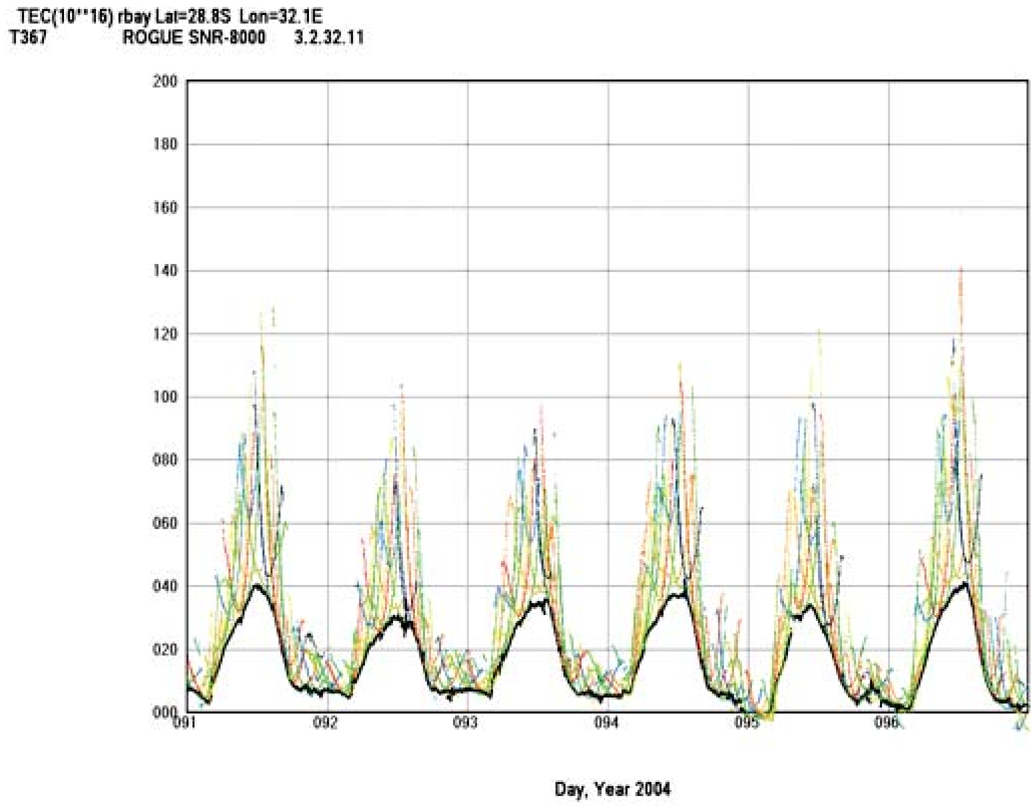
Geomagnetic disturbed conditions at middle-low latitudes north and south in the African sector

Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Lampedusa (modip 43.9) including disturbed geomagnetic conditions and low solar activity (31 March - 5 April 2004)

Slant and Vertical TEC over Africa and its variability (cont)



Six days of slant and vertical GPS derived TEC over Richardsbay (modip -48.9) including disturbed geomagnetic conditions and low solar activity (31 March- 5 April 2004)

Introducing slant TEC rate of change

TEC gradients and TEC rate of change

- TEC spatial and temporal gradients are features of the ionosphere that lead to errors in navigation and positioning augmented GNSS (SBAS) systems.
- In most of the conditions found at middle latitudes the effect of gradients is very small under ionospherically quiet conditions.
- Under disturbed conditions like those that occur during geomagnetic storms, gradients at middle latitudes can reach values that degrade the performance of the systems.
- At low latitudes both spatial and temporal gradients of TEC are larger and can complicate the operation of SBAS also under nominal conditions due to the dynamics of the development of the equatorial anomaly.
- Rapid TEC fluctuations associated with the irregularities that develop during the build up of the equatorial anomaly and produce scintillations of the transionospheric propagating signals can also impact on the use of GNSS operations at low latitudes.

TEC gradients and TEC rate of change (cont.)

- *When using GPS derived TEC data, the only quantitatively measurable parameter related to the presence of time and spatial (horizontal) gradients is the slant TEC rate of change.*
- *At present it does not appears possible to separate the contribution of geometry and gradients from the calculated slant TEC rate of change.*
- *The rate of change is measured in TECu/min.*

TEC gradients and their impact on GNSS operations

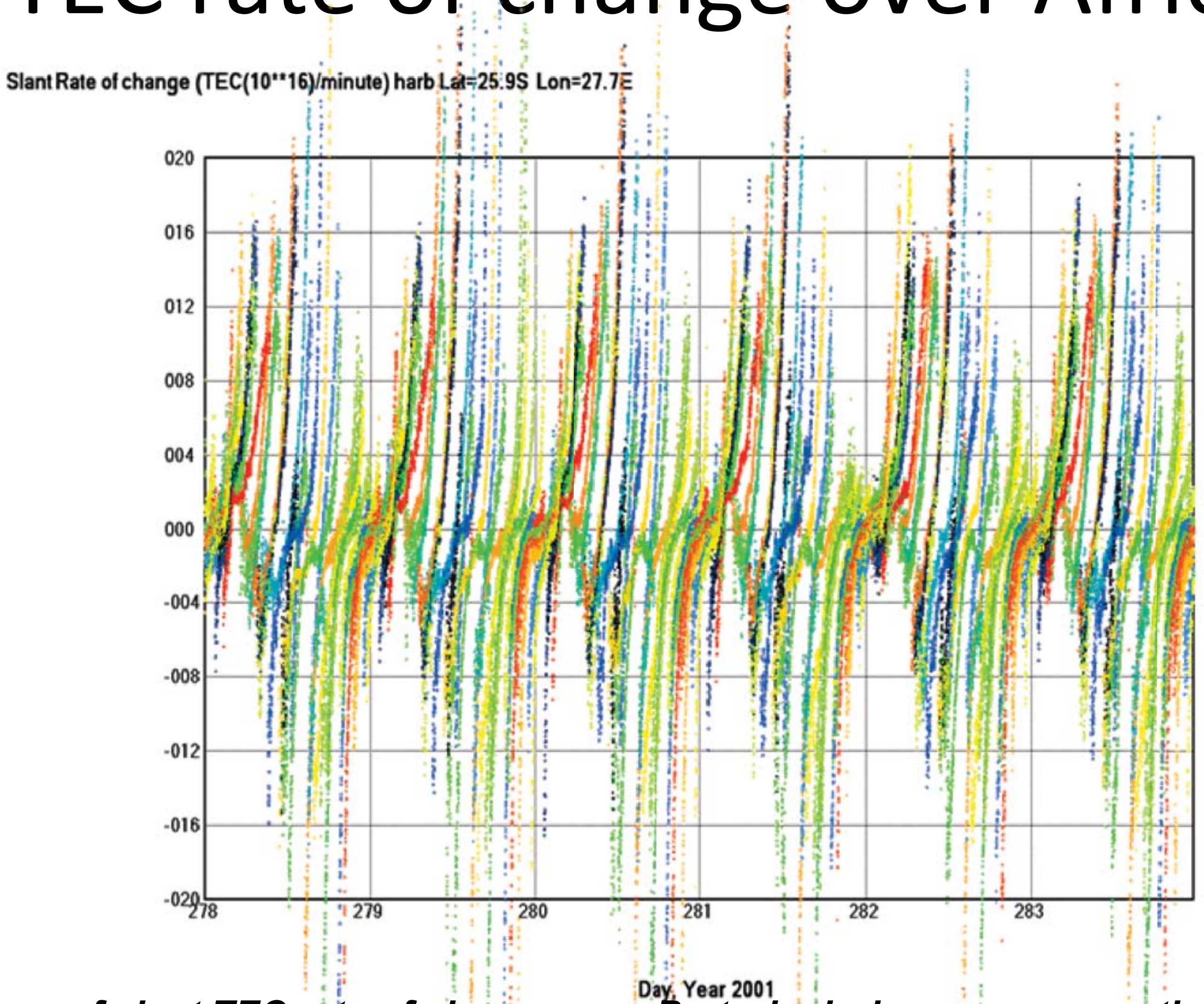
- Global Navigation Satellite Systems operations can be seriously affected in their range accuracy in regions or conditions where large gradients of TEC are found.
- Space Based Augmentation Systems (SBAS) broadcast equivalent Grid Ionospheric Vertical Delays (GIVD) to correct ionospheric delays. Ionospheric Grid Points (IGP) are given every 5ºx5º.
- From GIVDs, users interpolate to obtain the equivalent vertical delay at each IPP using interpolation algorithms that work appropriately at middle latitude during nominal quiet conditions where spatial gradients of TEC are small.
- When gradients are much larger it may be expected that the range delay correction method used by SBAS would not provide adequate ionospheric corrections.

TEC gradients and their impact on GNSS operations (cont.)

- In addition, SBAS operations are based on real-time broadcasts of ionospheric corrections that are updated periodically at given time intervals (5 min).
- Time-dependent changes in the ionosphere may degrade or even make obsolete the old broadcast correction before a new one is available to the user.
- Limits on temporal gradients or rate of change must be determined to protect users from potentially hazardous rates of change that may occur at the users' ray-path lines of sight.

TEC rate of change at a middle latitude location in Africa

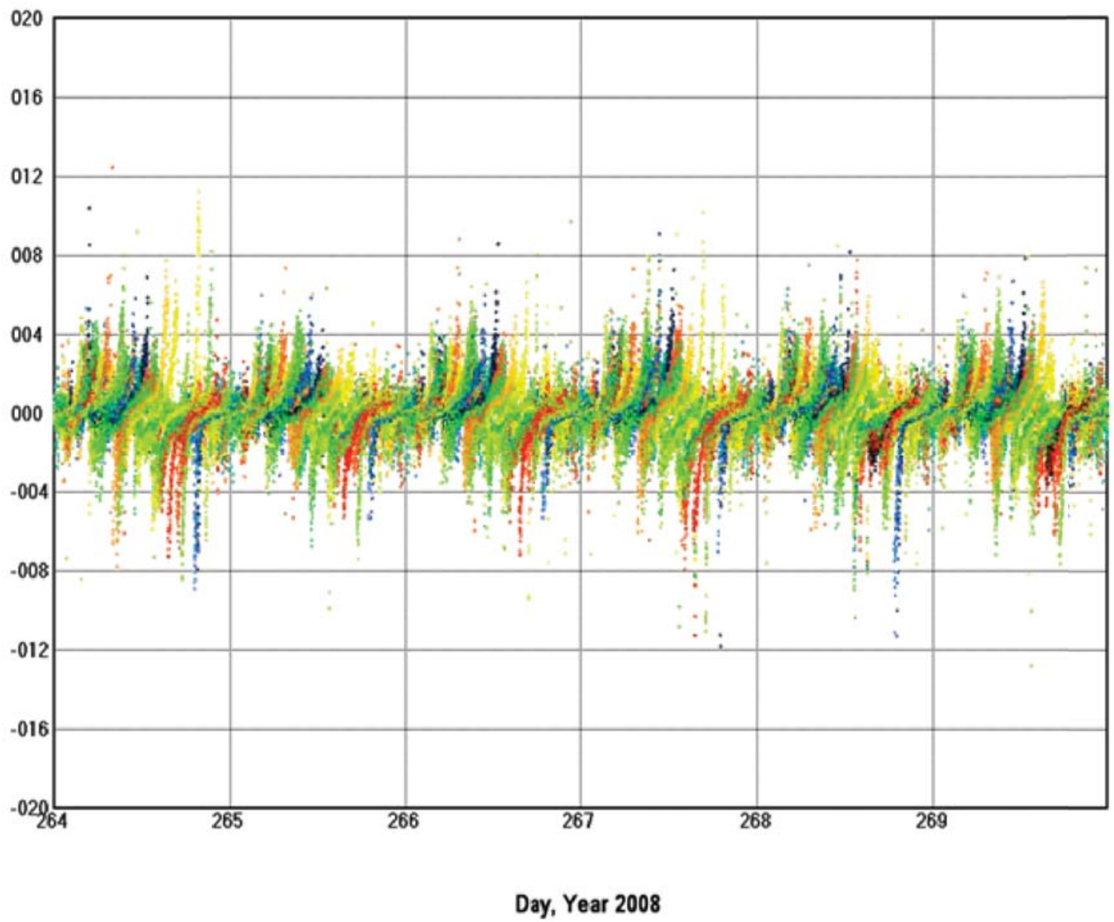
TEC rate of change over Africa



Six days of slant TEC rate of change over Pretoria during a geomagnetic quiet period in high solar activity (5-10 October 2001)

TEC rate of change over Africa (cont.)

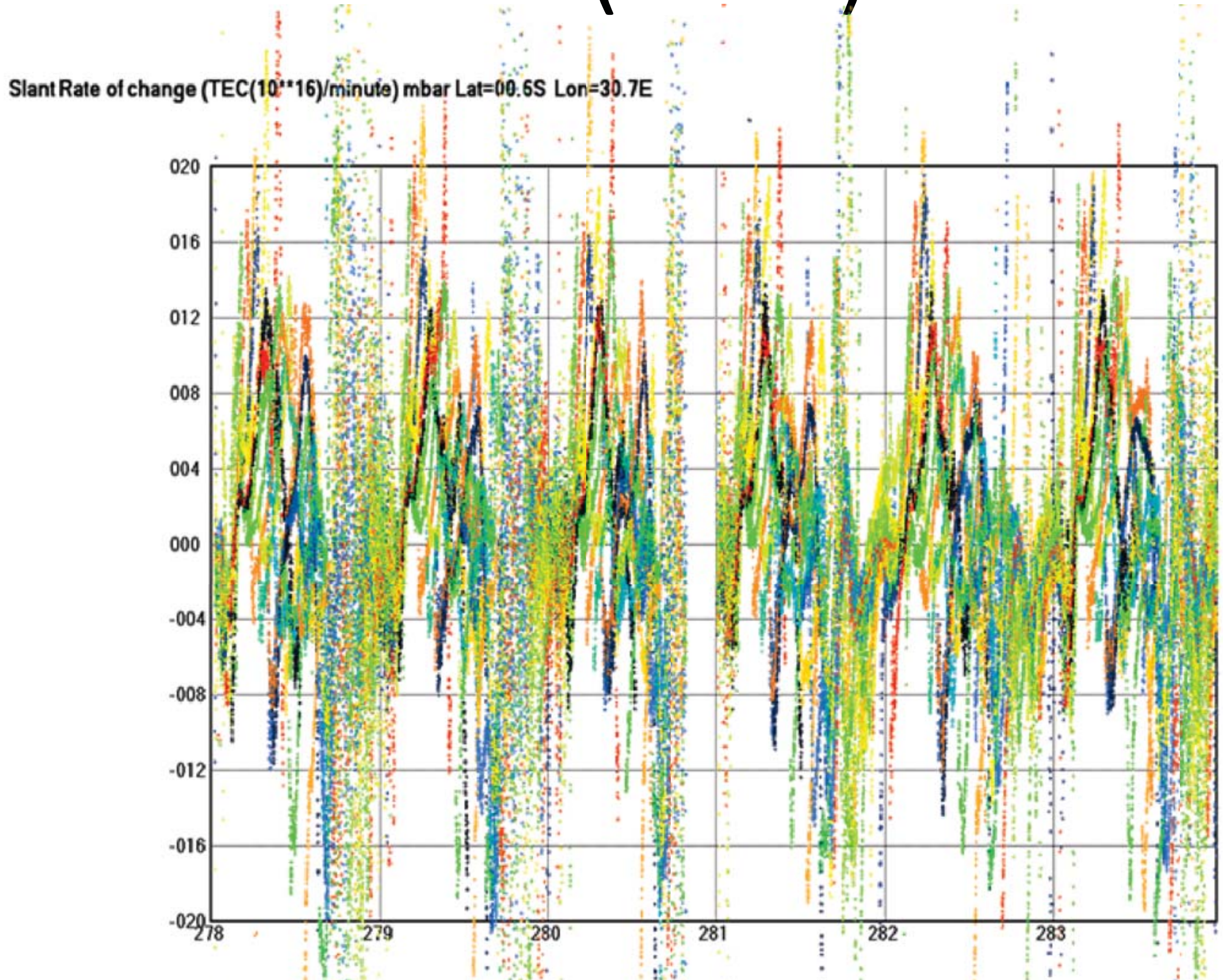
Slant Rate of change (TEC(10**16)/minute) harb Lat=25.9S Lon=27.7E



Six days of slant TEC rate of change over Pretoria during a geomagnetic quiet period in high solar activity (20-25 September 2008)

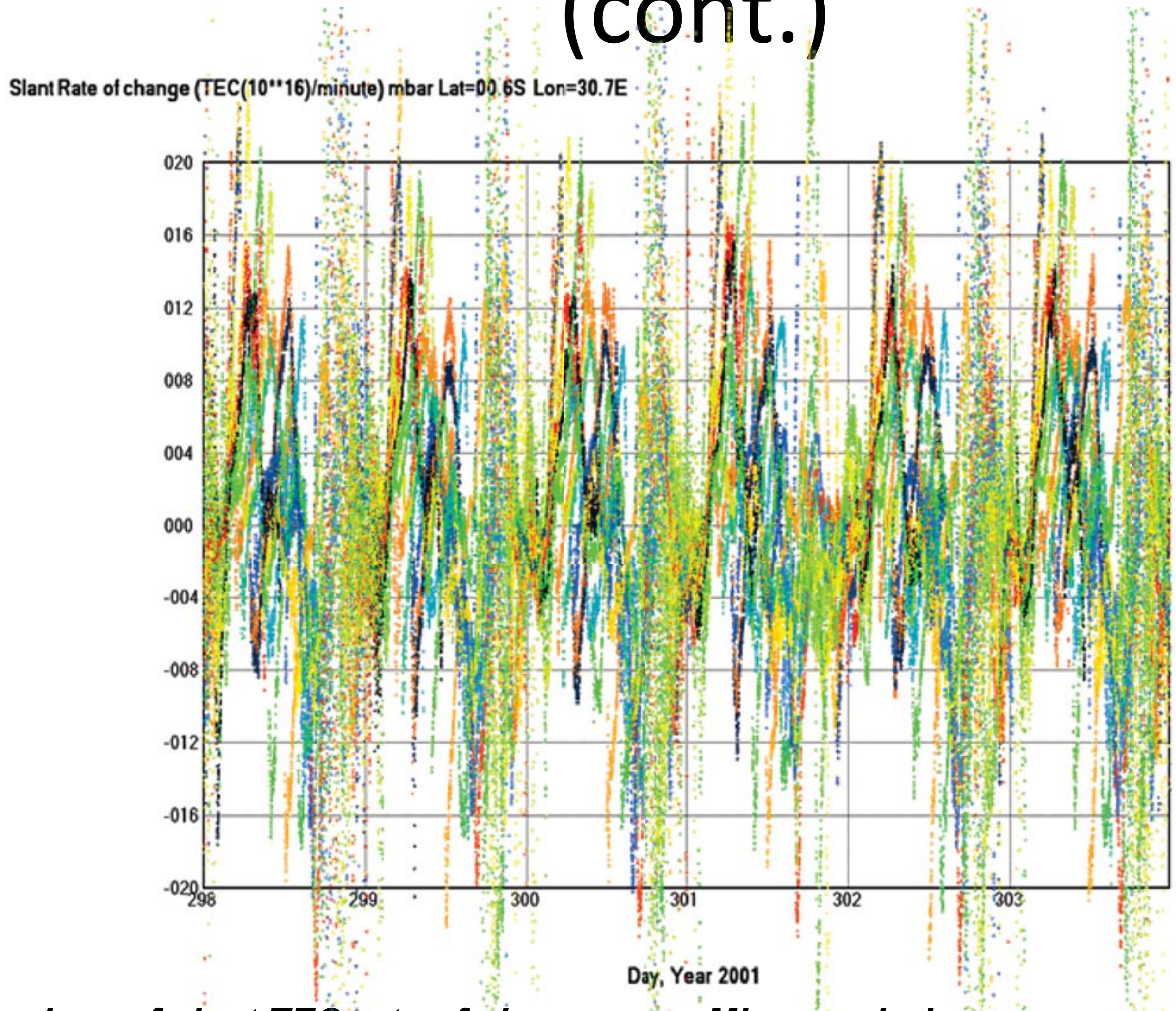
TEC rate of change at a location in Africa under the southern crest of the equatorial anomaly

TEC rate of change over Africa (cont.)



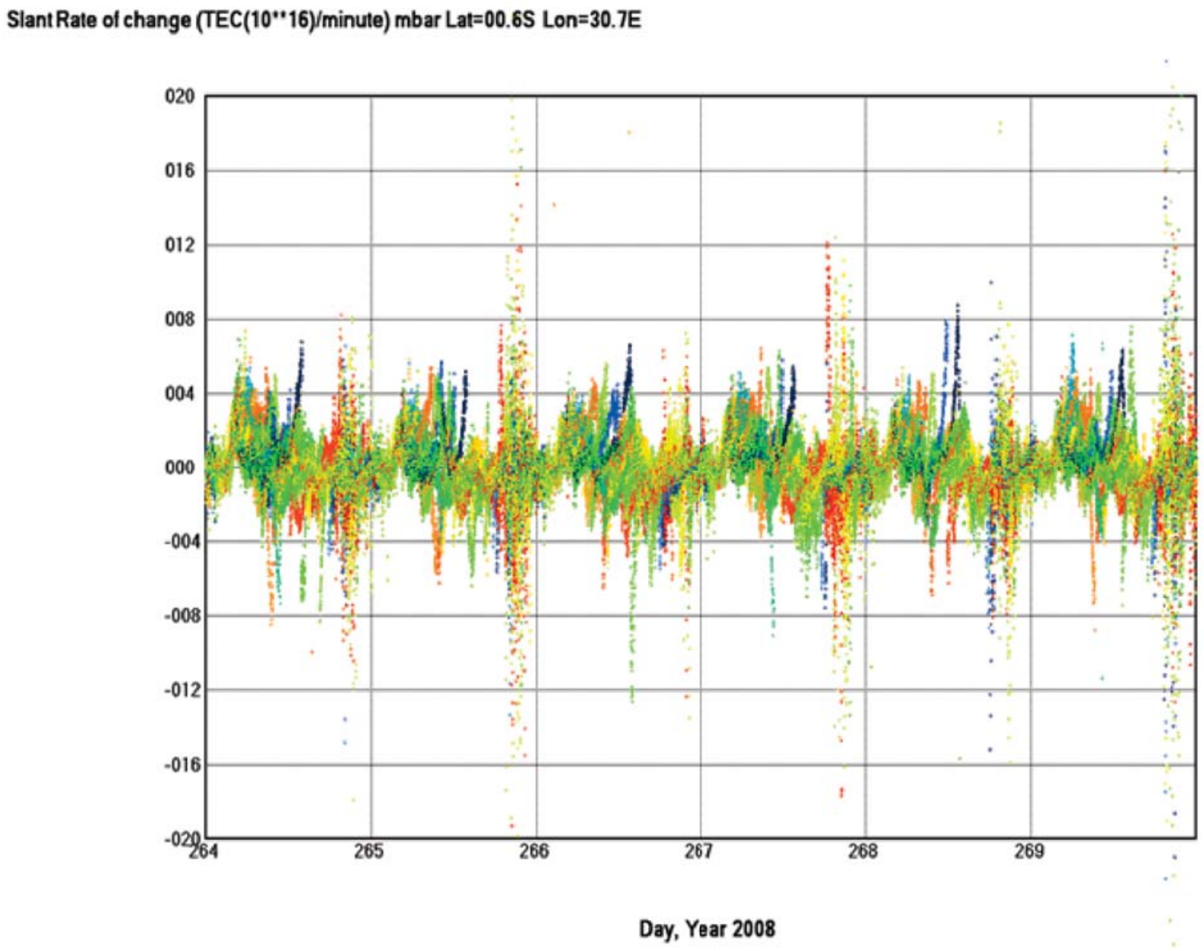
Six days of slant TEC rate of change over Mbarara during a geomagnetic quiet period in high solar activity (5-10 October 2001)

TEC rate of change over Africa (cont.)



Six days of slant TEC rate of change over Mbarara during a geomagnetic disturbed period in high solar activity (25-30 October 2001)

TEC rate of change over Africa (cont.)



Six days of slant TEC rate of change over Mbarara during a geomagnetic quiet period in minimum solar activity (20-25 September 2008)

Electron density depletions or “bubbles”

What they are

- ***Electron density depletions or "bubbles"***: regions of the ionosphere where

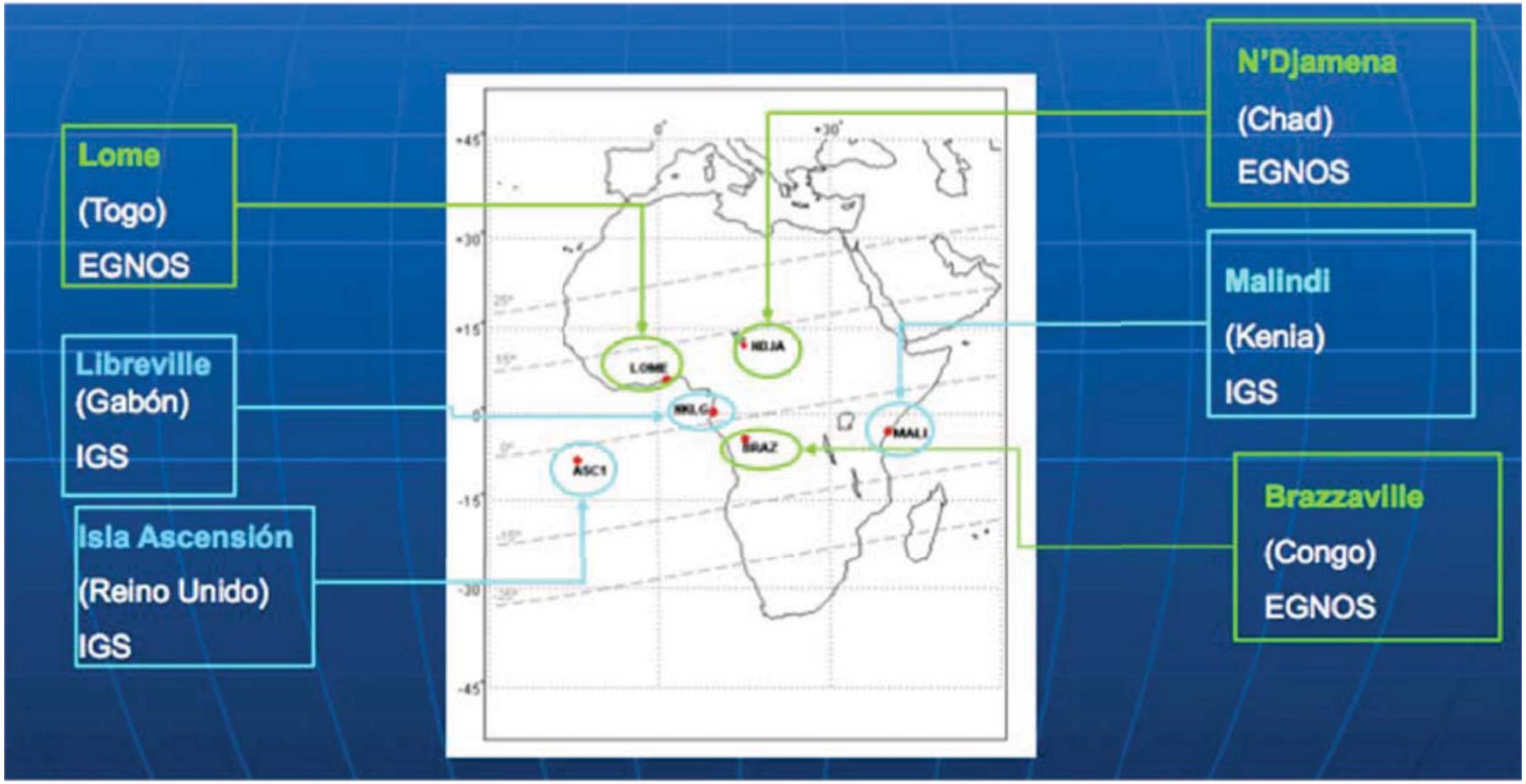
$$n(x,y,z)/n_0(x,y,z) < 1$$

- *Size*: tenth to hundreds of km perpendicular to the geomagnetic field
- *Shape*: close to cylindrical with axes along the geomagnetic field ("banana shape")
- *Dynamics*: rise to heights up to1000 km

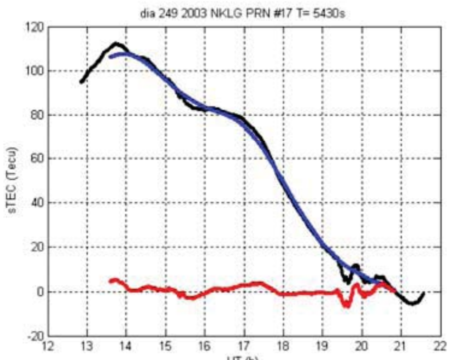
  eastward drift (50-100 m/s, lower at higher altitude)

  branching of do to internal electric field
- *Physical process*: F-region plasma density irregularities and upward plasma drifts in the equatorial ionosphere that evolve nonlinearly by means of the Rayleigh-Taylor instability.
- Seen in GPS derived TEC data
- Are related to scintillation occurrence

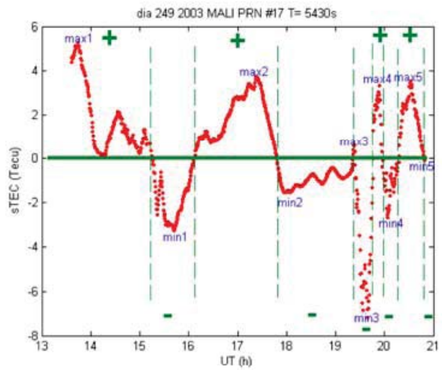
African Stations used



The method of bubbles detection

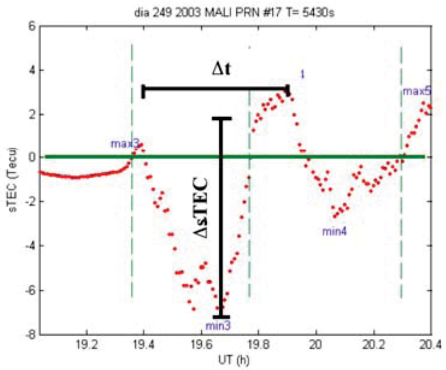


1. Load data, moving average calculation in 90 min period, and sTEC-average subtraction

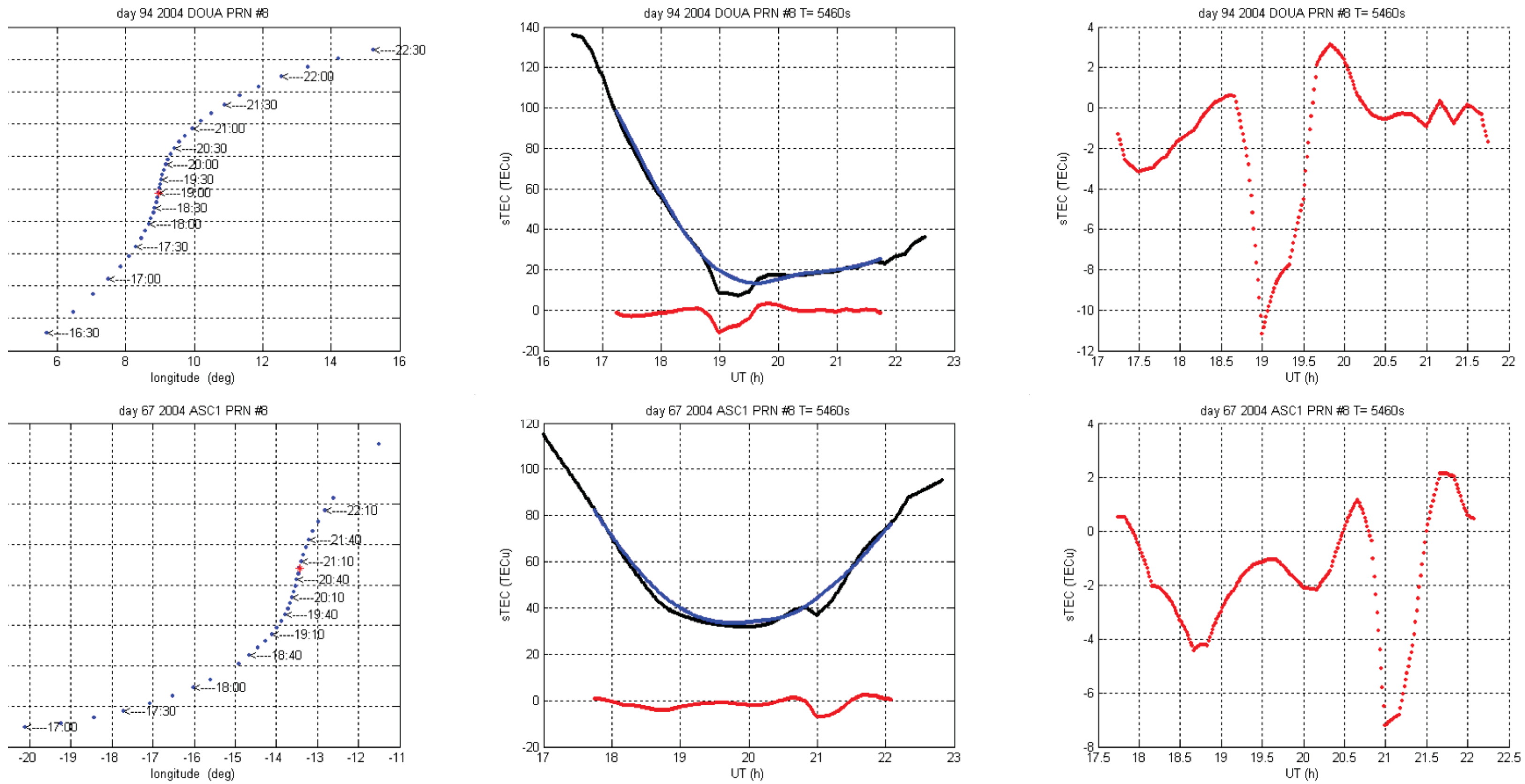


2. For every sTEC-average subtraction curve:
2.1 Local minima calculation if differences <0
2.2 Local maxima calculation if differences >0

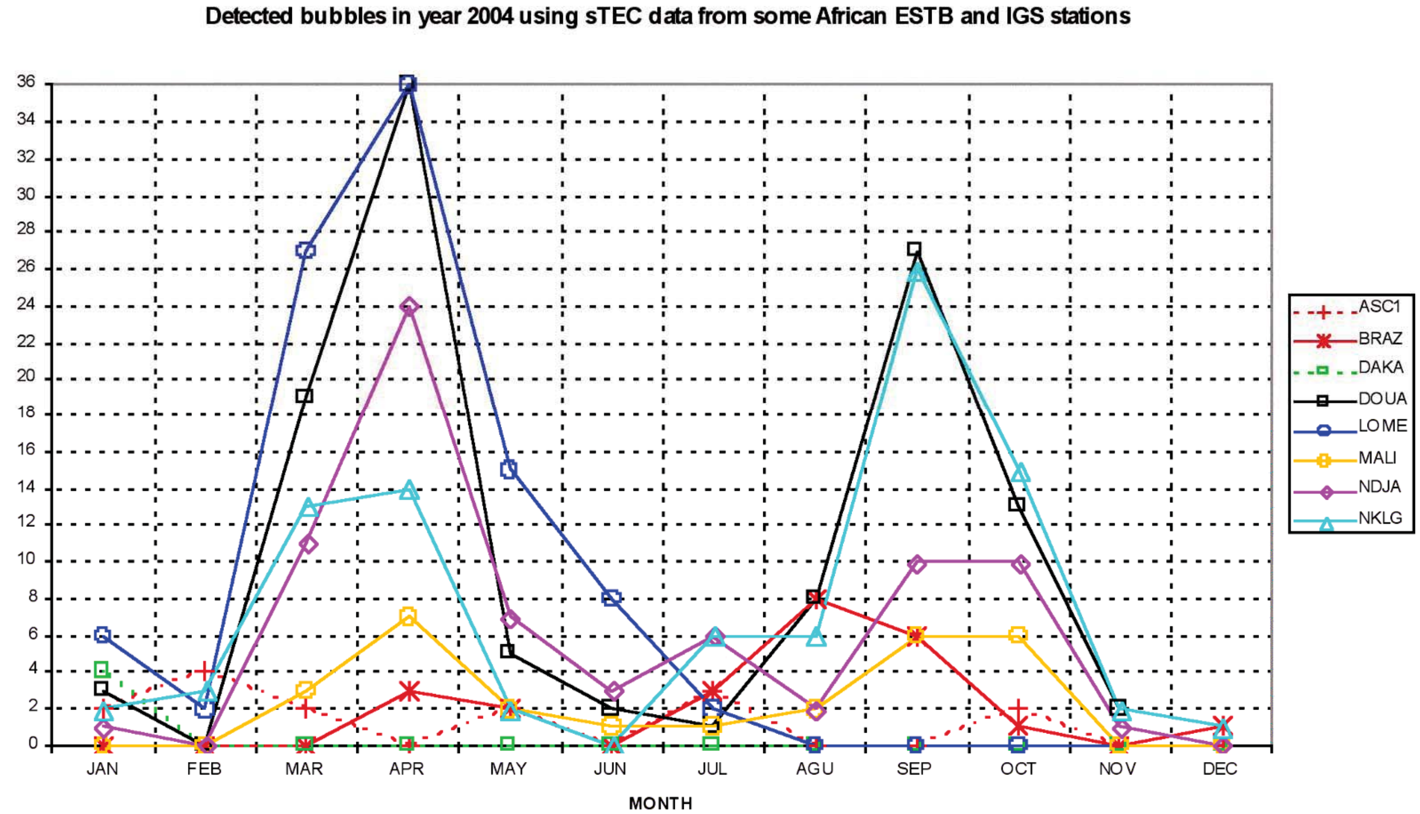
3. There is a bubble if
a. 60 s<Δt=UT(MAX(i+1))-UT(MAX(i))<1 h
b. sTEC(MAX(i+1))< 5tecus; sTEC(MAX(i))< 5tecus
c. sTEC(min(i))< -5tecus



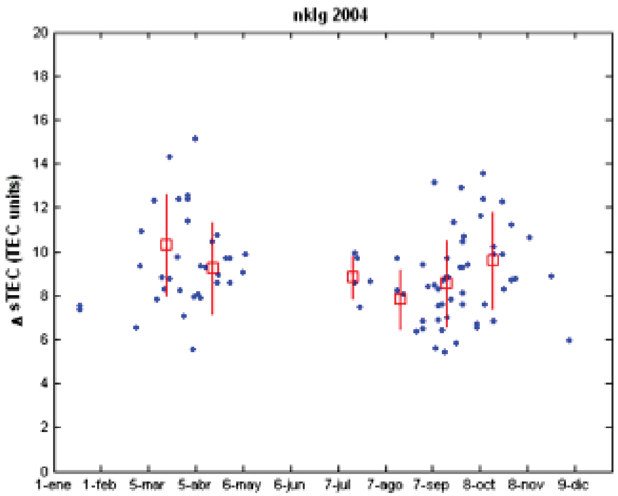
Examples of bubbles over Africa

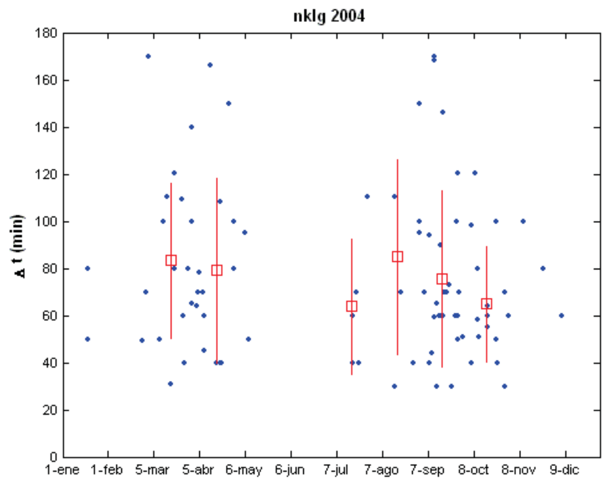


Bubble occurrence over African stations in 2004

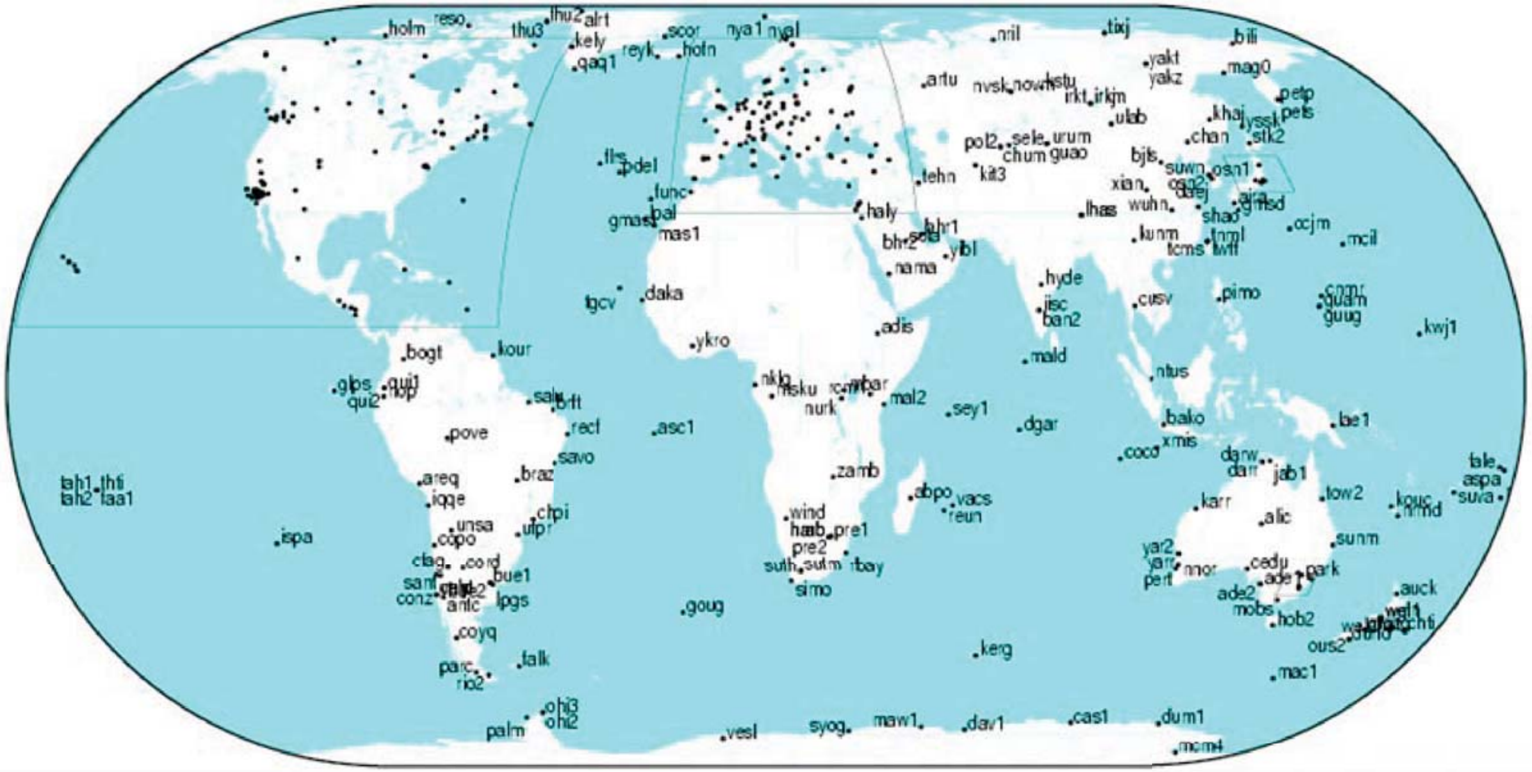


Bubble occurrence over African stations in 2004





What kind of research can be started with what is already available (past and present data), waiting for more instruments to be installed in the region?



The IGS Tracking Network

Possible lines of research: objectives

- To characterize the vertical TEC as a function of modip over Africa, in terms of:
  - Solar activity
  - Seasonal variation
  - Diurnal variation
  - Day-to-day variability
  - Short term variations (inter-hour variability)
  - Differences between station values and values extracted from global maps of vertical TEC for the same location.
  - Effects of geomagnetic activity vs. quiet conditions variability

Possible lines of research: objectives (cont.)

- To characterize bubbles as observed in slant TEC data in terms of:
  - Occurrence
  - Depth
  - Duration
  - Location of the bubble (assuming the bubble at a pierce point)
  - Multiple occurrence from more than one station.

Possible lines of research: objectives (cont.)

- To investigate slant TEC rate of change in terms of:
  - Location (modip)
  - Solar activity
  - Seasonal variation
  - Diurnal variation
  - Day-to-day variability

Acknowledgements

Part of this lecture is based on the work carried out by the ICTP-ARPL under a contract with the European GNSS Supervisory Authority.

The chapter on electron density bubbles was based on a work carried out in collaboration with the Universidad Complutense of Madrid

The TEC and TEC rate of change data used in this lecture have been processed by L. Ciraolo.

THANK YOU FOR YOUR ATTENTION