Modelling TEC over Africa: Neural Network Approach (AfriTEC)

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Centre for Atmospheric Research

Outline

Introduction

Data & Methods

Results/Demonstration of Use

On-going/Future work

Introduction (Detailed Resources)

Quiet time

https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JA027065

JGR Space Physics

RESEARCH ARTICLE
10.1029/2019JA027065

Key Points:
- The first regional TEC model over the entire African region using empirical observations is developed
- The model offers opportunities to conduct high spatial resolution investigations over the African region
- EIA occurrence is reduced during the June solstice, and the anomaly

A Neural Network-Based Ionospheric Model Over Africa From Constellation Observing System for Meteorology, Ionosphere, and Climate and Ground Global Positioning System Observations

Daniel Okoh[1,2], Gopi Seemala[2], Babatunde Rabiu[1], John Bosco Habarulema[3,4], Shuanggen Jin[5,6], Kazuo Shiokawa[7], Yuichi Otsuka[7], Malini Aggarwal[2], Jean Uwamahoro[8], Patrick Mungufeni[9], Bolaji Segun[10], Aderonke Obafaye[1], Nada Ellahony[11], Chinelo Okonkwo[12], Mpho Tshisaphungo[3], and Dadaso Shetti[13]

Storm time

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020SW002525

Space Weather

RESEARCH ARTICLE
10.1029/2020SW002525

Key Points:
- First report on storm-time modeling of TEC across the entire African region is presented
- Inclusion of time history of geomagnetic activity indicators improved TEC modeling by about

Storm-Time Modeling of the African Regional Ionospheric Total Electron Content Using Artificial Neural Networks

Daniel Okoh[1,2,3], John Bosco Habarulema[2,4], Babatunde Rabiu[1,3], Gopi Seemala[5], Joshua Benjamin Wisdom[6], Joseph Olwendo[7], Olivier Obrou[8], and Tshimangadzo Merline Matamba[2]

Introduction

AfriTEC is acronym for African regional ionospheric Total Electron Content. It is a model of the ionosphere over the entire African region.

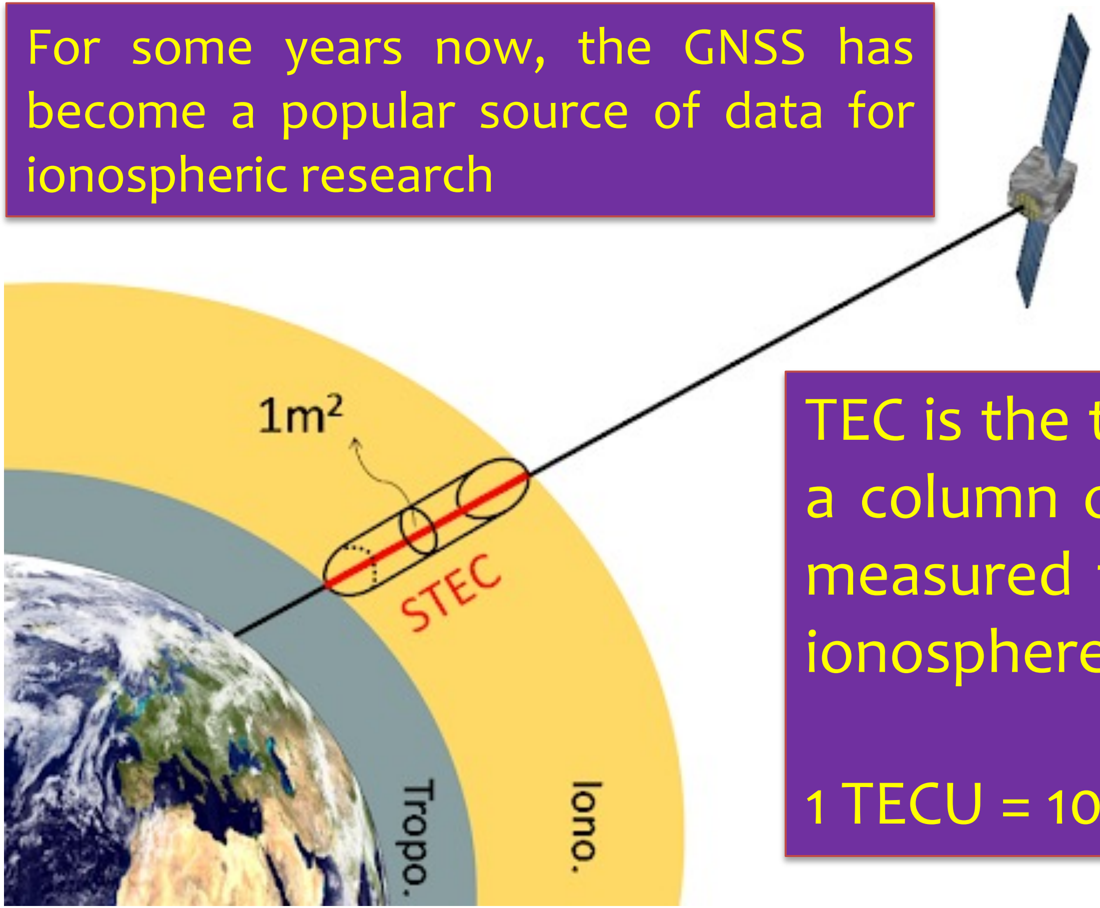
Motivation for developing the AfriTEC is based on the fact that the African region is least studied. This is obviously due to paucity of data available from the region.

Knowledge of the ionosphere, especially for lesser known areas like the African sector, is required to enhance understanding and exploitation of it.

Introduction

For some years now, the GNSS has become a popular source of data for ionospheric research

The parameter of interest is the Total Electron Content (TEC)



TEC is the total number of electrons in a column of unit cross sectional area, measured from top to bottom of the ionosphere.

1 TECU = 10^{16} electrons/m^2

Data & Methods

Data used in this work include:

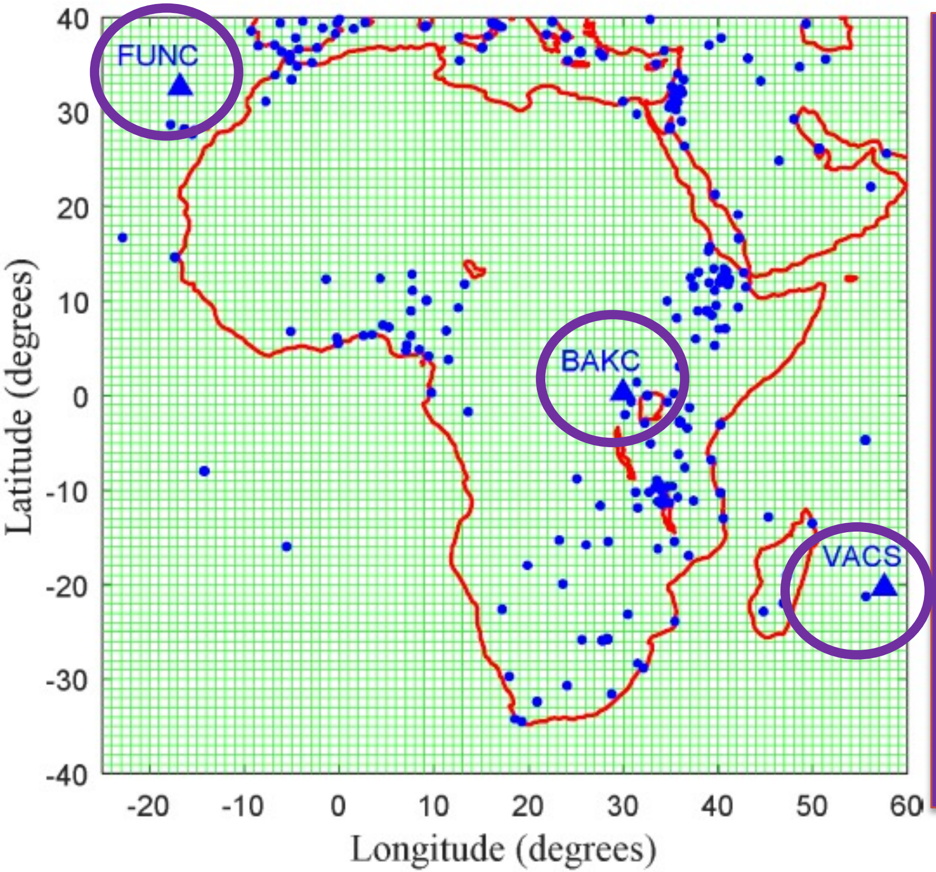
- GNSS data from ground based receivers
- GNSS data from satellite based receivers (COSMIC Radio Occultation (RO))
- Indices for solar and geomagnetic activities
- Data from other ionospheric models (IRI-Plas, NeQuick, and GIM (Global Ionospheric Maps))

Data & Methods

Ground based GNSS Data used in this work was obtained from the following sources (**Total: 269 stations**):

- The African Geodetic Reference Frame (AFREF, http://afrefdata.org)
- The Nigeria GNSS Reference Network (NIGNET, www.nignet.net)
- The South African network of continuously operating GNSS base stations (TRIGNET, http://www.trignet.co.za)
- The University of California, San Diego, SOPAC & CSRC GARNER GPS Archive (ftp://garner.ucsd.edu)
- The National Aeronautics and Space Administration's CDDIS Archive of GNSS products (ftp://cddis.gsfc.nasa.gov)
- The Global Data Center of the International GNSS Service (ftp://igs.ensg.ign.fr)
- The UNAVCO Archive of GNSS Data (ftp://data-out.unavco.org)
- The Geodetic Data Archiving Facility (ftp://geodaf.mt.asi.it)

Data & Methods

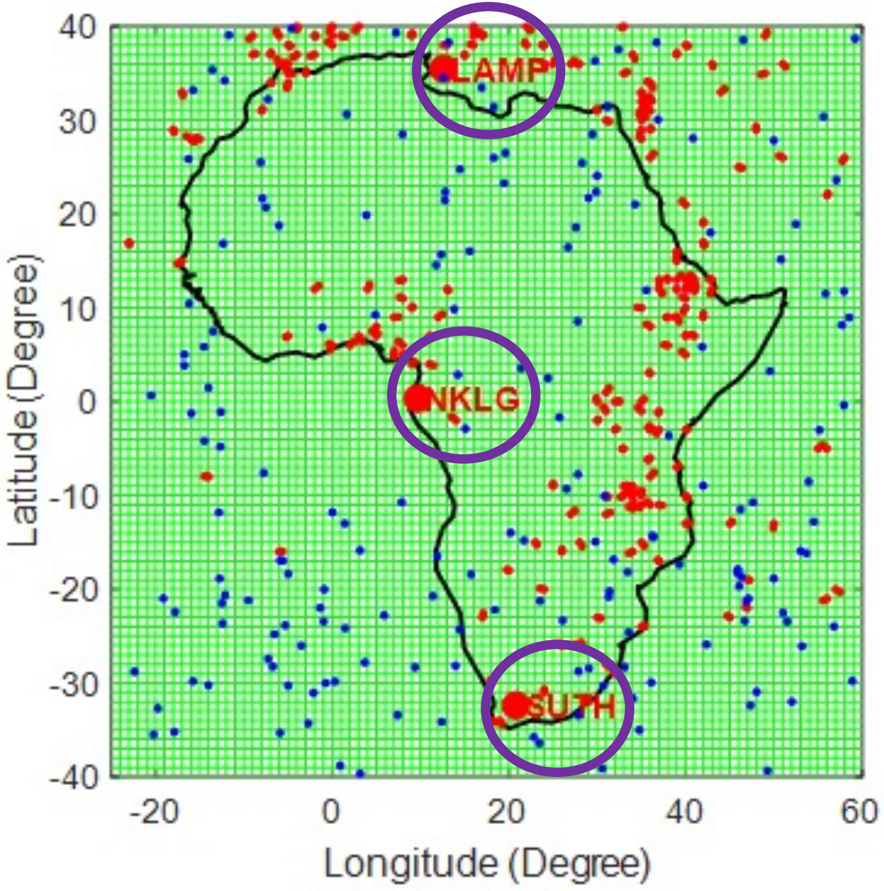


Map of Africa showing locations of ground based GNSS receivers used in this work.

Stations marked in triangles (and labeled using the 4-digit station codes) were used for testing the spatial performance of the networks.

The green background lines show 1° × 1° grids of longitude and latitude used to bin the final observations.

Data & Methods

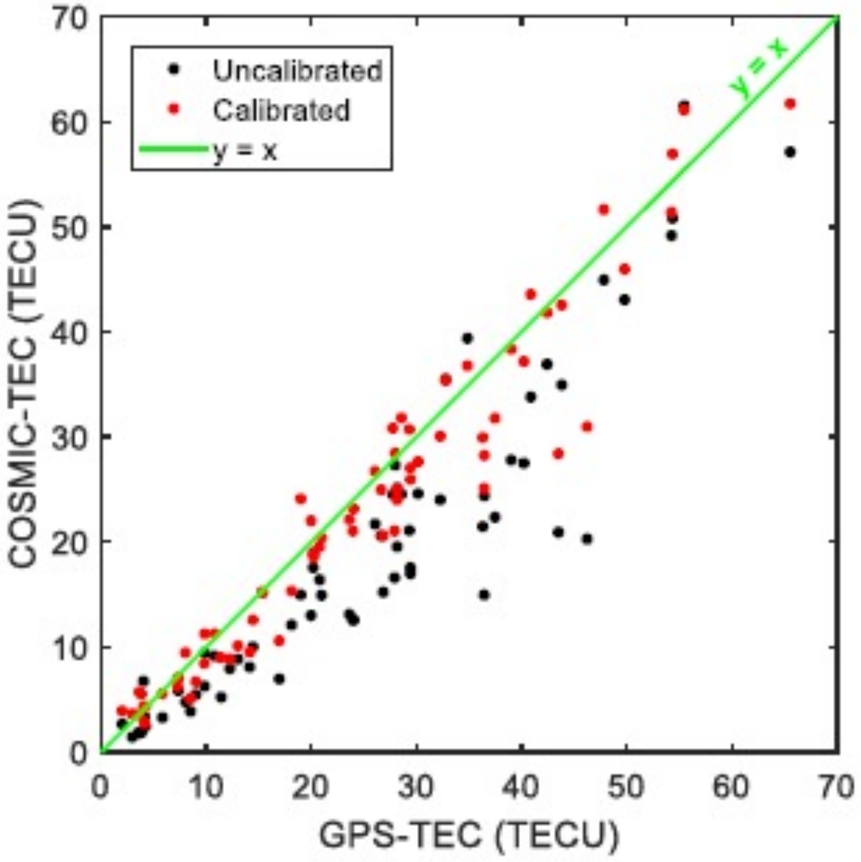


Configuration for storm time model:

Red dots: Ground based GNSS receivers.

Blue dots: COSMIC data (locations of maximum electron densities in various RO events) during the storm period of 7-9 March 2012.

Data & Methods



Calibration of COSMIC Data:

This was necessary considering the disparity between the datasets, especially with regards to the upper integration limit.

GPS: ~20,200 km
COSMIC: ~800 km

An illustration of how the calibrated and un-calibrated COSMIC-TECs compare with ground GPS-TEC at the 1° × 1° grid cell of NKLG station

Data & Methods

All available data covering the periods from year 2000 to year 2018 were used.

GNSS data was obtained in RINEX (Receiver Independent Exchange) format and processed into TEC information using the most recent version of the GPS-TEC analysis application software (version 2.9.5) developed by Gopi Seemala (Seemala and Valladares, 2011) which can be downloaded from the webpage https://seemala.blogspot.com.

To reduce the volume of data and to smoothen out data spikes, the computed VTEC data was averaged in 1-hour interval. And to minimize multipath errors, we excluded VTEC computed from satellites with elevation angles less than or equal to 30°.

Data & Methods

•SSN data was obtained from the WDC-SILSO, Royal Observatory of Belgium, Brussels (website: http://www.sidc.be/silso/datafiles).

•F10.7 data was obtained from the National Oceanic and Atmospheric Administration, NOAA (ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-radio/noontime-flux/penticton/penticton_observed/listings/).

•Solar UV flux data was obtained from the University of South California Dornsife (https://dornsifecms.usc.edu/space-sciences-center/download-sem-data).

•Dst and Kp indices were obtained from NASA's OMNIWeb (https://omniweb.sci.gsfc.nasa.gov/form/dx1.html).

For quiet model: |Dst|<=20 nT

For storm model: |Dst|>=50 nT or Kp>=4

Data & Methods

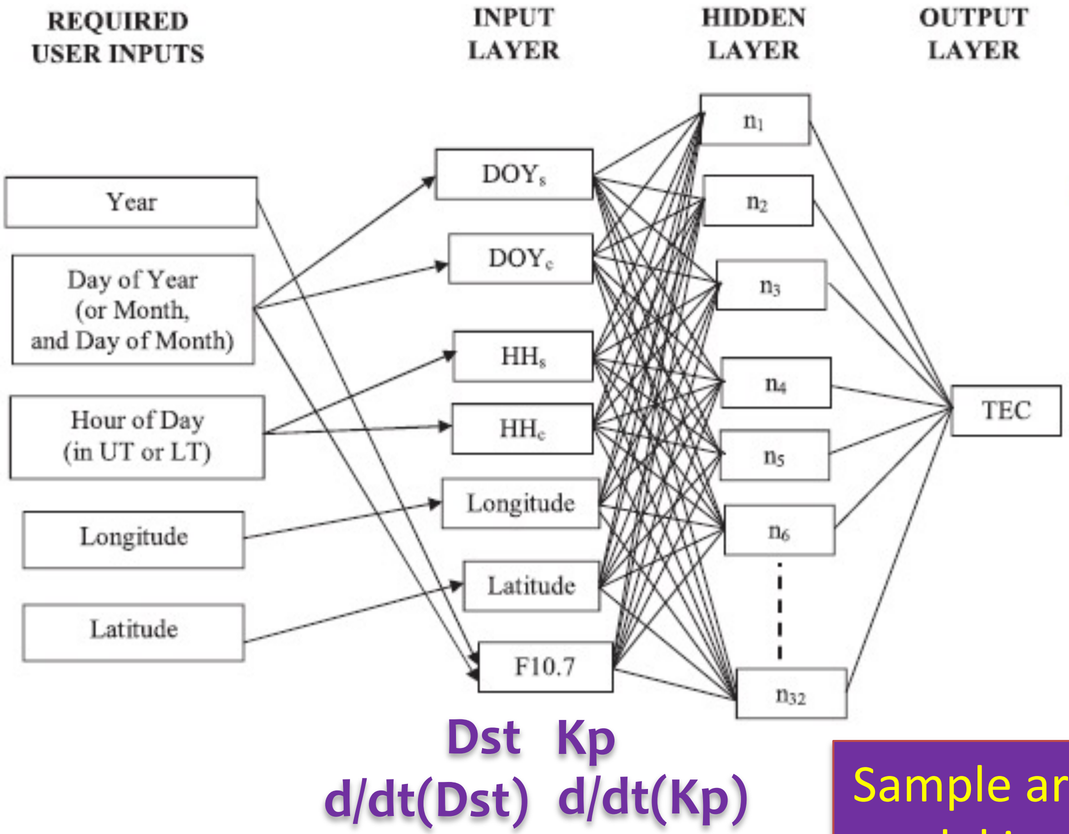
Computer neural networks were used for the TEC modeling in this work.

- They are a system of information processing techniques inspired by the manner in which the human brain works; they can learn trends and patterns in data and consequently be able to predict future trends in the data. For this reason, they are hugely applied in predictive modeling .

Computer neural networks have been demonstrated by several authors (e.g. Habarulema et al., 2009; Habarulema, 2010; Okoh et. al, 2016) as very efficient tools for ionospheric modeling in parts of the continent.

The strengths and advantages of neural networks derive from their ability to represent both linear and non-linear relationships directly from the data being modeled.

Data & Methods



$$DOY_s = \sin\left(\frac{2\pi \times DOY}{365.25}\right) \qquad DOY_c = \cos\left(\frac{2\pi \times DOY}{365.25}\right),$$

$$HH_s = \sin\left(\frac{2\pi \times HH}{24}\right) \qquad HH_c = \cos\left(\frac{2\pi \times HH}{24}\right),$$

$$LT = UT + Long/15,$$

Sample architecture of the neural network model implemented in this work

Data & Methods

$$H_m = \tanh(I_{wm} \times I_m + B_1)$$

$$O_m = \tanh(H_{wm} \times H_m + B_2)$$

The hyperbolic tangent function is intentionally used as transfer function between the hidden and output layer so as to provide a boundary for the TEC output which should not be negative by physical definition.

I_m, H_m, and O_m are respectively variable matrices for the input, hidden, and output layers.

I_{wm} and H_{wm} are respectively weight matrices for the input and hidden layers.

B_1 and B_2 are the bias vectors.

Results & Discussions

AfriTEC Availability

Since the AfriTEC model is developed for real-world applications, the model is made available for research, education, and other non commercial applications in the following web pages:

- Website of the Centre for Atmospheric Research (http://carnasrda.com/tec_models)

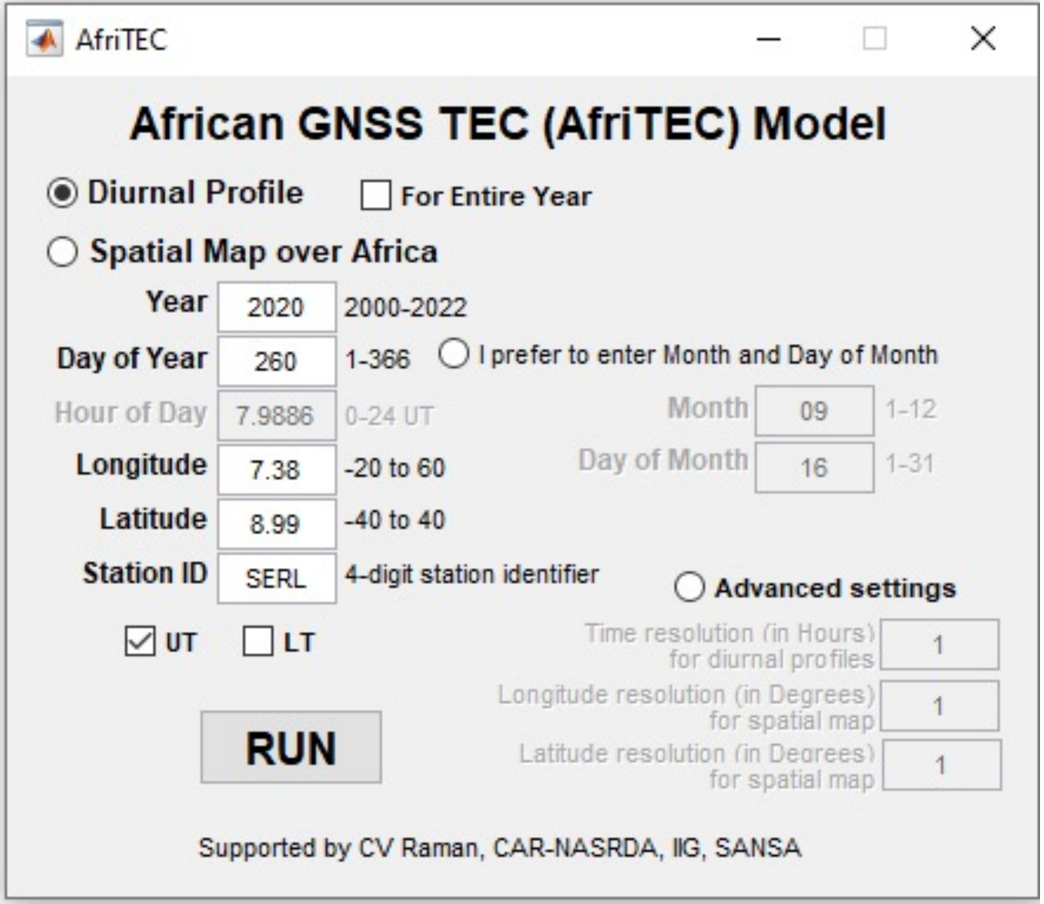
- MATLAB Central website (https://www.mathworks.com/matlabcentral/fileexchange/69257-african-gnss-tec-afritec-model?s_tid=prof_contriblnk)

Results & Discussions

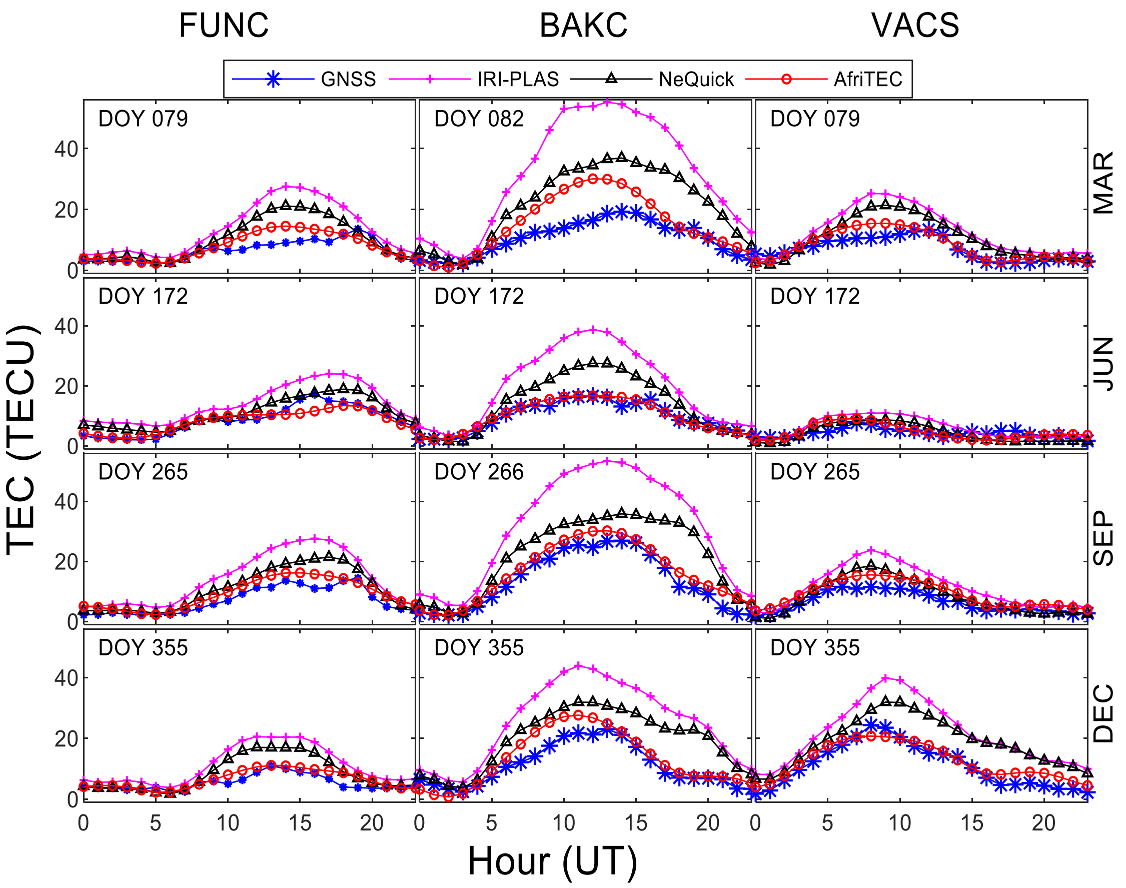
User Interface

For user friendliness, a graphical user interface is developed.

Detailed information on how to use the AfriTEC model is given on the model web pages



Results & Discussions



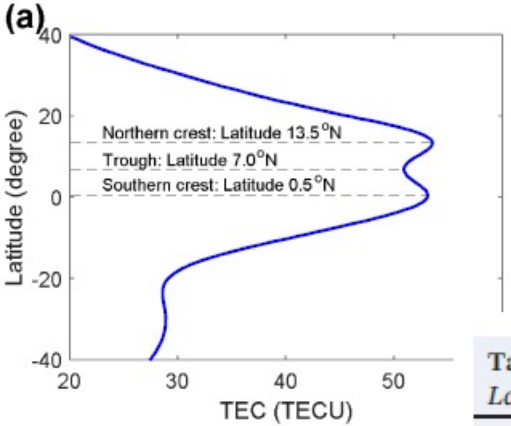
With reference to GPS-TEC;

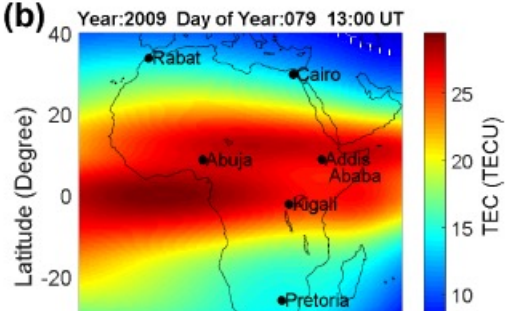
AfriTEC RMSE = 3.76 TECU

NeQuick = 6.65 TECU

IRI-Plas = 10.44 TECU

Results & Discussions





Separation between crests increase with increasing level of solar activity

- Maximum during December solstice

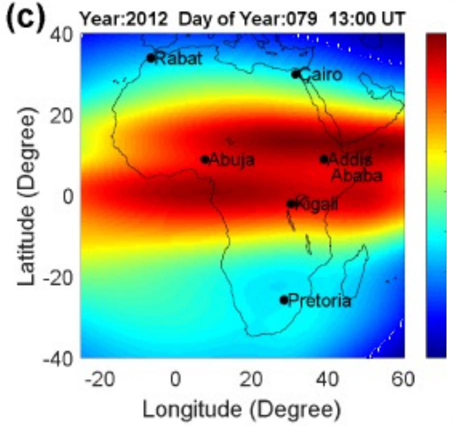
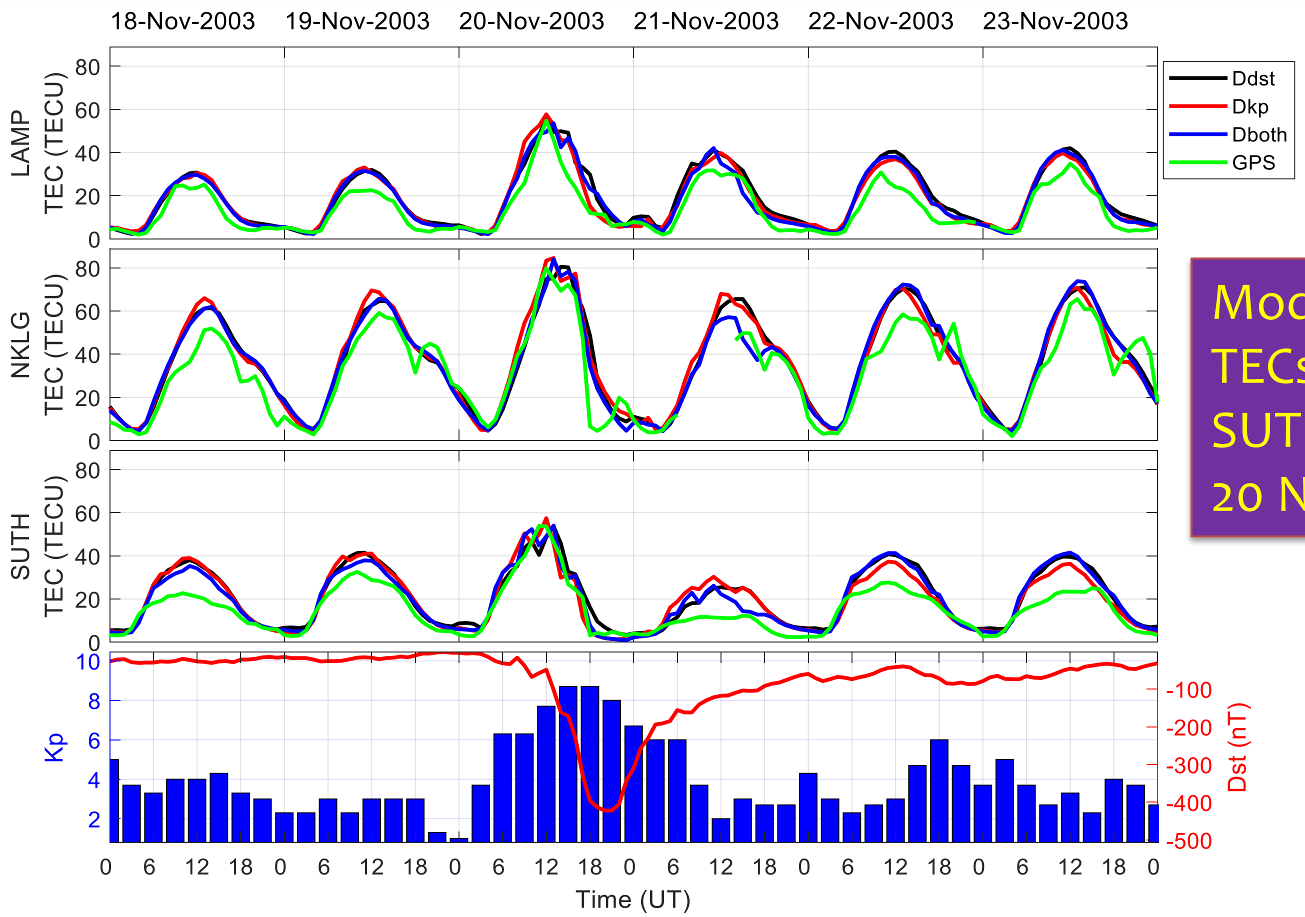


Table 1

Latitudinal Locations of the Equatorial Anomaly Crests and Troughs Measured Along the Meridian of Longitude 20°E

Season/Year	Latitude of northern crest (±0.5°)	Latitude of trough (±0.5°)	Latitude of southern crest (±0.5°)	Latitudinal separation between crests (±1.0°)
Classification by seasons of year 2012				
March equinox (F10.7 = 101)	13.5	7.0	0.5	13.0
September equinox (F10.7 = 125)	15.0	6.5	1.0	14.0
December solstice (F10.7 = 111)	13.5	5.5	−2.5	16.0
Classification by years of varying solar activity during March equinoxes				
2009 (F10.7 = 68)	12.0	6.0	0.5	11.5
2012 (F10.7 = 101)	13.5	7.0	0.5	13.0
2014 (F10.7 = 150)	15.5	7.5	0.5	15.0

Results & Discussions



Modeled TECs versus GPS TECs at LAMP, NKLG, and SUTH, during the storm of 20 November 2003.

On-going/Future work

A global 3-D electron density reconstruction model based on radio occultation data and neural networks

ELSEVIER

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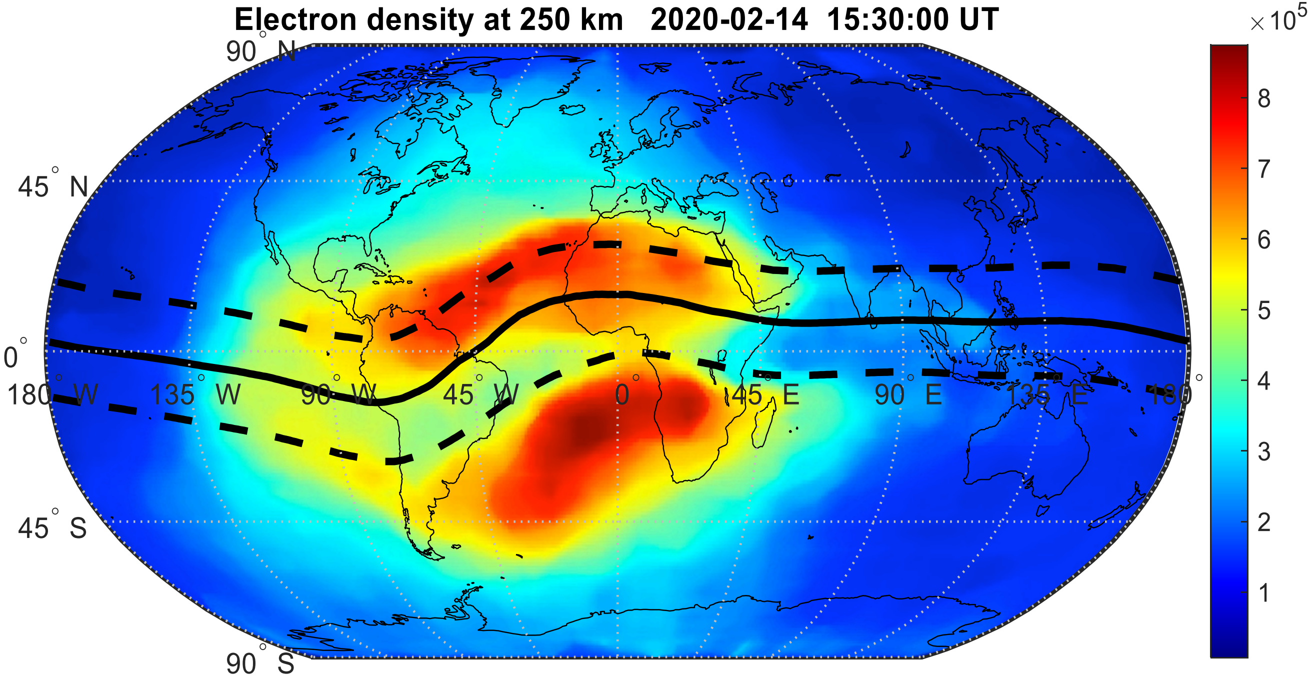

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Thank you for Listening