Retrieve, Processing and Analysis of Global Positioning System Derived Ionospheric Total Electron Content Using IGS Products

J. R. K. Kumar Dabbakuti, Yenumala Kowshik Chandu, A. Sai Koushik Reddy, and A. V. Prabu

Abstract Analysis of ionospheric variability is imperative for developing the day-to-day ionospheric modeling and prediction services of the global navigation satellite system (GNSS) applications. The highest-quality GNSS information is provided by the International GNSS Service (IGS) on open access to users. The GNSS information that accompanies them also covers services in support of positioning, navigation and timing information, which benefits science and society. In this paper, retrieve, processing and analysis of Global Positioning System (GPS) derived ionospheric total electron content (TEC) using the IGS Hyderabad GNSS station (17.41° N, 78.55° E; geographical). The presented work would be useful for download, process and analysis of the IGS GNSS data.

Keywords Global navigation satellite system (GNSS) · Global Positioning System (GPS) · Total electron content (TEC) · International GNSS Service (IGS)

1 Introduction

Most functions of the global navigation satellite system (GNSS) necessitate high-precision GNSS information such as clocks, orbits and station positions. The International GNSS Service (IGS) analysis center produces these results on a regular basis by processing measurements from the GNSS station network [1]. For an extremely long time, the United States Global Positioning System (GPS) and, to a certain extent, the Russian Global Navigation Satellite System (GLONASS) have been the main GNSS in this processing effort. The IGS is a voluntary association of more than 200 support associations in more than 80 countries. The IGS Global Tracking Network (GTN) of more than 300 continuously operating GPS stations provides an abundant dataset to the IGS Analysis Centers, which produce precise products such as satellite clock and ephemeris solutions. IGS Real-Time Service (RTS) provides access to accurate

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real-time products such as orbits, clocks and code biases, which can be used as an alternative to breakthrough instant products in real-time applications.

Ionospheric variability analysis is crucial for developing ionospheric modeling and forecasting services for GNSS applications. Numerous empirical models have been built on the basis of the huge amount of GNSS IGS station datasets to stipulate the requirements of the scientific application. Empirical and semiempirical ionospheric models have been developed using data from IGS stations in the low latitude region of India, which are useful for understanding low latitude ionospheric morphology {Dabbakuti 2016 #88} [2–7]. This article is organized into three main sections. After the introduction, Sect. 2 illustrates in detail the raw observation approach (RINEX format) and illustrates the steps required to download the solution. In Sect. 3.2, the RINEX observation processing strategy by Gopi Seemala is implemented at Boston College. The resulting GNSS products are presented and evaluated using the MATLAB program in Sect. 3.3. Finally, Sect. 4 summarizes the main points and draws some conclusions.

2 Materials and Methods

One of the most important attributes of the raw observation approach is that it does not explicitly use a linear combination of observations. The ionosphere-free combination is typically used in GNSS processing to reduce the first-order ionospheric delay [8]. It is formed separately for code and phase measurements. This indicates that the ionospheric delay is individually suppressed for code and phase measurements. A related observation also shows that the standard deviation of GPS L1 or L2 frequency signals has increased by a factor of 3 [9]. The raw observation approach estimates the slant total electron content (sTEC) parameter [10–12] (Fig. 1).

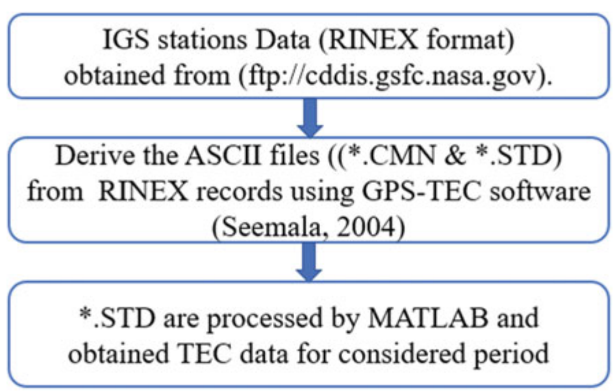

Fig. 1 Flowchart illustrating the processing and analysis of IGS GPS-TEC observables

This software converts RINEX files into ASCII files (*.CMN and *.STD). The data with the file name "STATddd-YYY-MM-DD.CMN", which is created in the same ASCII output record folder, is in 10 segments isolated by a tab. The ASCII output document is in 4 sections isolated by a tab, which is done in a similar organizer to the data with the same document name, except that the extension becomes *.CMN and *.STD [13].

3 Results and Discussion

3.1 Retrieve the Data from the CDDIS Anonymous FTP Site

The data of a receiver is usually transformed into three files, each with a particular task. The formats of these files are described in RINEX formats. The naming convention for these files is SSSSDDD #.YYC. where SSSS is the four-character site, ID; DDD is the three-digit day of the year; # is a session code; YY is the two-digit year; C is the file type designation; m = surface meteorological data; n = broadcast navigation message; o = lowercase letter O = observations; s = status. The GPS-TEC observations were recorded in Receiver Independent Exchange (RINEX) format and obtained from ("ftp://cddis.gsfc.nasa.gov"). Below program code shows the IGS data download program for the bash script file. It consists of instructions written in the Bash language and can be executed using key-up text commands within the shell command-line interface.

Program Code for IGS data download in bash language

```
  #!bash
  for i in {001..365}
  do
  for j in IGS station ID
  do
  wget-c
ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily/Year/"i"/Yo/
j"i"0.Yo.Z
  done
  done
```

3.2 Procedure for GPS-TEC Analysis from IGS RINEX File

To achieve the sTEC and vTEC measurements, GPS-RINEX observations were processed using GPS-TEC analysis software developed by Gopi Seemala at Boston College. This program can process the RINEX observation and navigation file for the observation date of any IGS station to estimate the azimuth and elevation angles of the satellites that are needed for the vTEC calculation. Satellite bias is also required, and the program uses Differential Code Bias (BCS) files obtained from the IGS Web site (ftp://unibe.ch/aiub/CODE/).

RINEX observation and navigation files can be obtained from the Web site (ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily). Select the period, and then the observation and navigation files are obtained as yyn/yy in the directory (here yy is a 2-digit year, "n" for navigation and "o" for observation). DCB files can be obtained from ftp://aiub.unibe.ch/CODE/; select the year and select the files P1C1yymm.DCB.Z and P1P2yymm.DCB.Z (Fig. 2). This software converts RINEX files into ASCII files (*.CMN and *.STD). The data with the file name "STATddd-YYY-MM-DD.CMN", which is created in the same ASCII output record folder, is in 10 segments isolated by a tab. The ASCII output document is in 4 sections isolated by a tab, which is done in a similar organizer to the data with the same document name, except that the extension becomes *.CMN and *.STD.

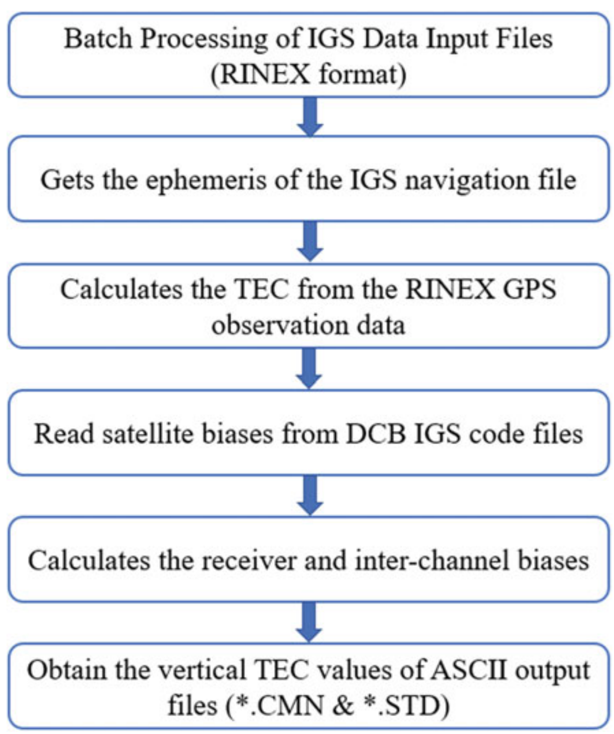

Fig. 2 Flowchart illustrating the processing of IGS RINEX data into ASCII output format

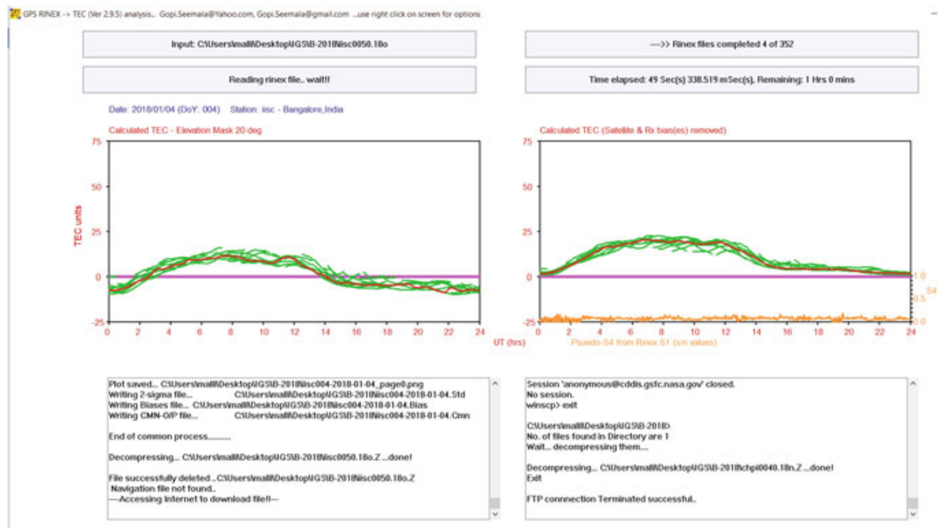

Fig. 3 GPS-TEC variations from GPS-TEC analysis software

From Fig. 3, the red line indicates the average TEC (iterated 2 sigma) on all PRNs (output file: *.std) and the green line indicates the vTEC (output file: *.cmn, it contains all elevation angles).

3.3 Processing and Analysis of ASCII File Using MATLAB®

The *.CMN and *.STD ASCII files are processed with MATLAB script to obtain the observed GPS-TEC data, and the code is as follows [14, 15].

Program Code for processing and analysis of GPS-TEC using MATLAB in MATLAB®

```
clc;
clear all;
FileList = dir('*.std/*.cnm ');
N = size(FileList,1);
for k = 1:N
    %get the file name:
   filename1{k}= FileList(k).name;
   disp(filename1);
 end
for k=1:N
filename=fopen(filename1{k});
mydata{k}=textscan(filename,'%s');
end
for i=1:length(mydata)
    for j=1:4
mydata1{i}(:,j)=mydata{i}{j};
    end
end
AA=[]
mydata2=[]
for i=1:length(mydata1)
       mydata2=[mydata2; mydata1{i}];
    if length(mydata2)==1440
      mydata2=mydata2;
else
    B=zeros(1440-length(mydata1{i}),4);
A=vertcat(mydata1{i});
mydata2=[A;num2cell(B)];
    end
    AA=[AA mydata2'];
end
  save ('IGSDATA','AA')
```

Figure 4 shows the surfing curves of the GPS-vTEC variations at the Hyderabad station for the period 2018. The GPS-vTEC variations show a stable increase to reach the maximum value in the afternoon and then start to decrease to reach the minimum value after the midnight period. It is observed that the GPS-vTEC daytime peaks exist between 07:00 and 15:00 UT, when it reaches the lowest value at night around 3:00 UT during the low solar phase (2018). The GPS-vTEC has an average minimum deviation from early morning (05:00–07:00 UT) and maximum deviations during the noon hours (13:00–14:00 UT). The maximum GPS-vTEC measurements were observed in March and September, and minimum values were observed between June and December. This is associated with Pre-Reversal Enhancement (PRE) in low latitude regions [16, 17].

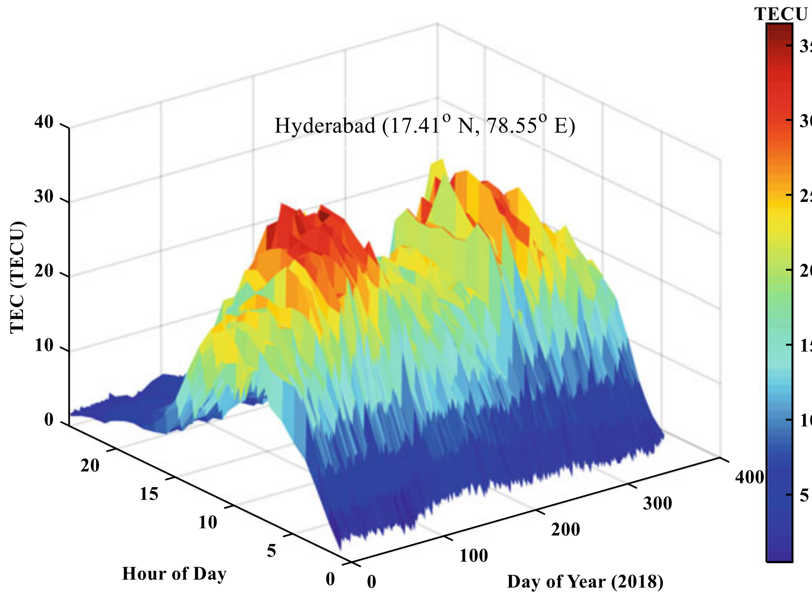

Fig. 4 GPS-vTEC variation at Hyderabad GNSS Station for the year 2018

4 Conclusion

In this paper, we presented methods for retrieval, processing and analysis of GPS-TEC data using different techniques. Three scenarios are used to obtain GPS-TEC data from the IGS network. First, raw observation in RINEX format retrieves data from the anonymous FTP site CDDIS using the Unix shell written in Bash language and can be executed by command-line interface approach. Secondly, the strategy of processing RINEX observation files by Gopi Seemala's TEC software is implemented at Boston College. Third, ASCII files from the GPS-TEC software are processed with the MATLAB script to obtain the observed GPS-TEC data.

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