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GPS-TEC data processing from multiple sources

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Introduction

- GPS stands for Global Positioning System, a system for locating ourselves on earth. It is a satellite-based navigation system created and controlled by the US Department of Defense (DoD), initially for military purposes but extended later for civilian usage.

- Though GPS radio signals are subjected to effects, which degrade its accuracy in all three layers of the atmosphere (troposphere, stratosphere, ionosphere), the effects of accuracy degradation in the ionosphere are the most significant.

- The largest effect that ionosphere has on GPS accuracy is group time delay which is proportional to the total electron content (TEC).

- Generally the ionospheric delay is of the order of 5m to 15m, but can reach over 40-60m during the periods of high sunspot activity and large space weather events such as geomagnetic and solar disturbances.

- Hence, the measurements of TEC have gained importance with the increasing demand for the GPS based navigation applications in trans-ionospheric communications with space borne vehicles such as satellites, aircrafts and surface transportations.

Introduction

…cont. 2

TEC measurement from Dual frequency receiver:

- The ionosphere is a dispersive medium, hence the GPS frequencies L1 (1575.42 MHz) and L2 (1227.6 MHz) experience different group delays and phase advances.

- TEC from group delay from pseudo-range measurements is given by

  $TEC_{group} = 1/40.3 * (1/f_1^2 - 1/f_2^2)^{-1} * (P_1 - P_2)$

  Where f_1 & f_2 are L1 and L2 carrier frequencies, and P_1 & P_2 are pseudo-range observables

- TEC from carrier phase measurements is given by

  $TEC_{phase} = (C_1 - C_2) * 2.852$

  Where C_1 & C_2 are phase measurements in nano-seconds.

- Calculation of TEC from group delay measurement is absolute and noisy. The relative phase delay between the two carrier frequencies gives a more precise measure of relative TEC, but is ambiguous because the actual number of cycles of phase is unknown. These two estimates can be combined to form an improved estimate for absolute TEC.

Data collection

Data recorded from the GPS receiver is in various formats

- Rinex format (ascii): popular & receiver independent, mostly used for sharing between various groups or publishing data.
- Novatel format (binary): Novatel receiver dependent, there are different formats depending on the type of observables to record.
- Leica format (binary): Leica receiver dependent
- AER format (ascii): Ashtech receiver dependent

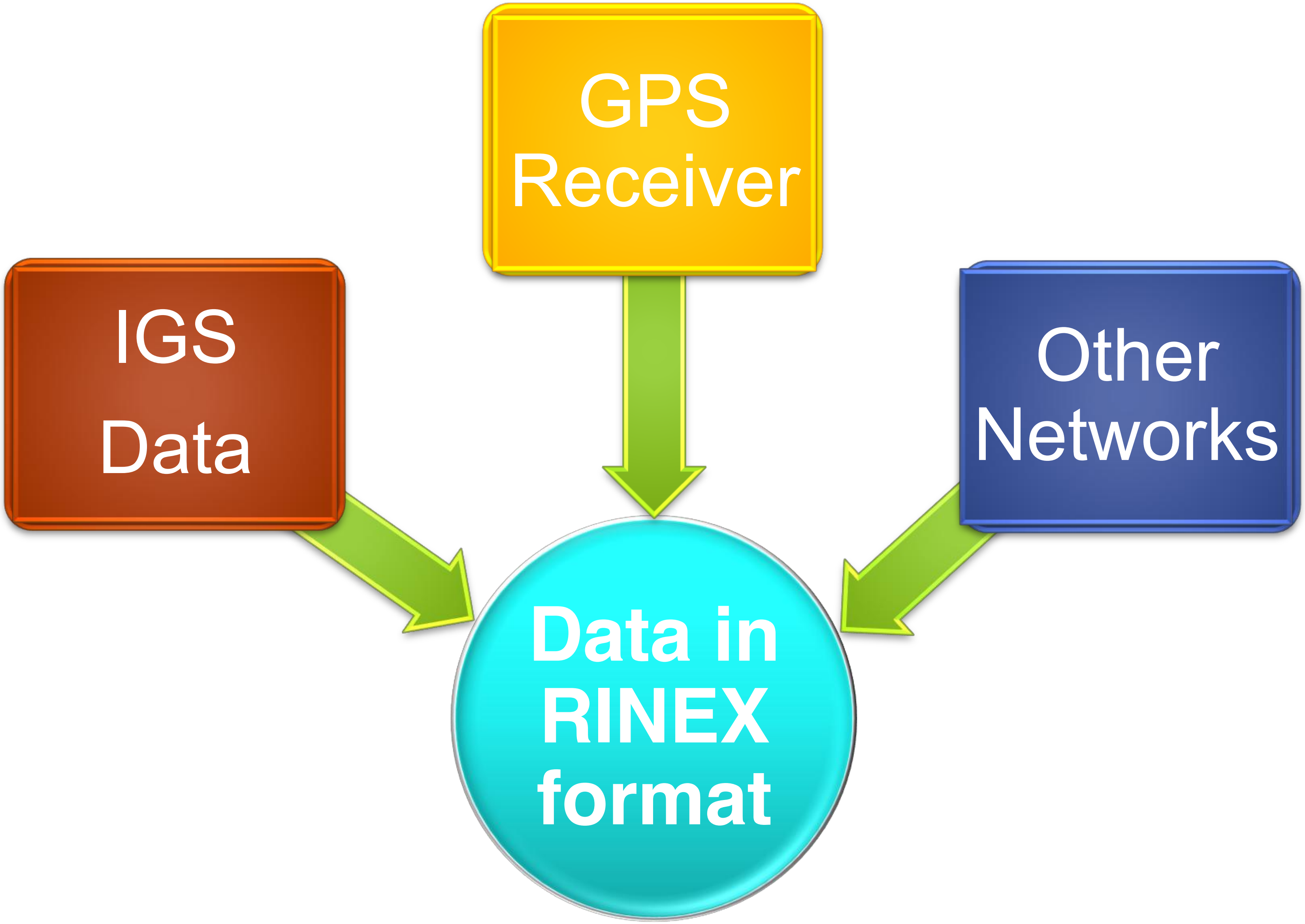
Besides above formats, there are many other data formats available to be recorded from GPS receivers.

To measure TEC, the following GPS observables are required from the receiver:

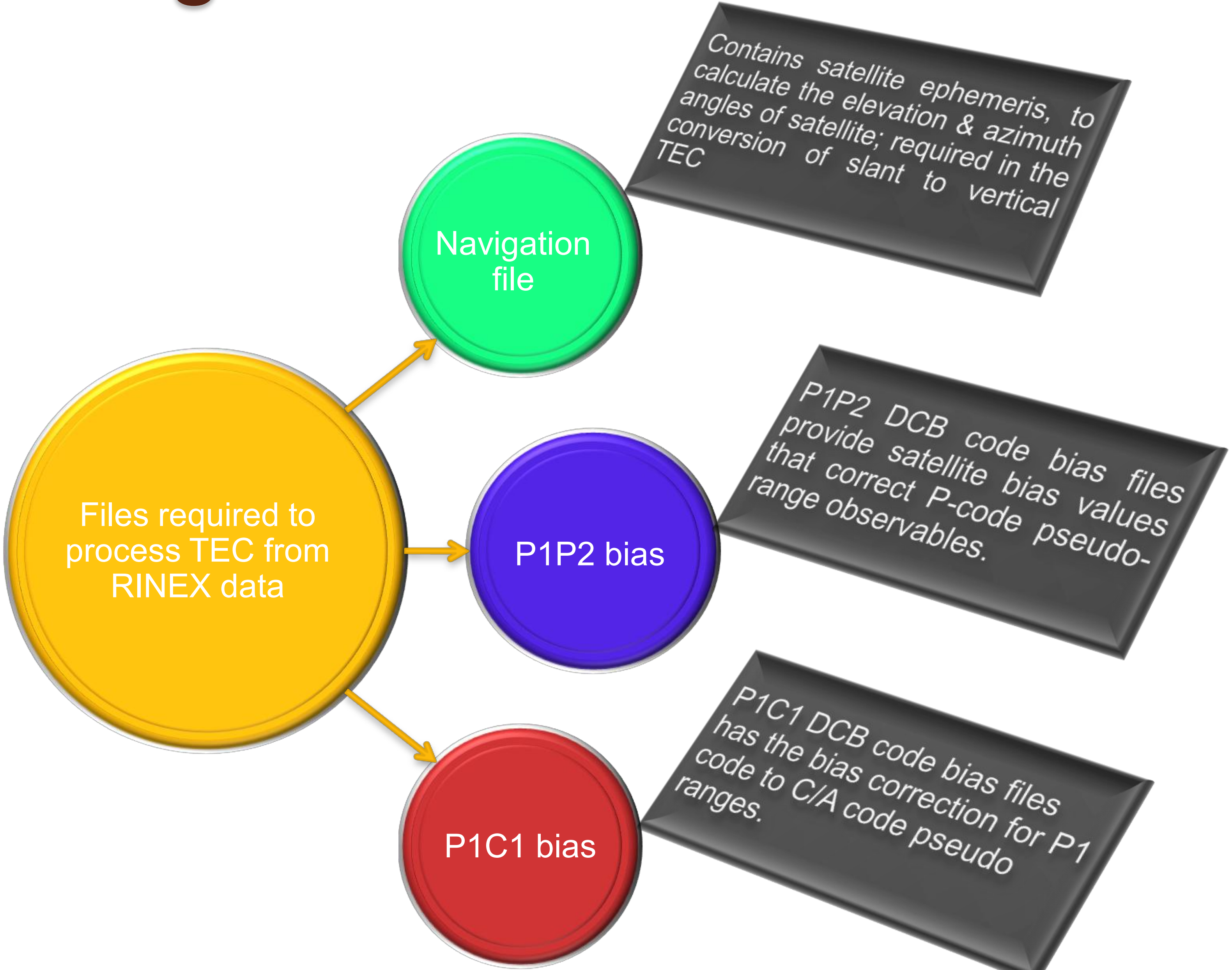
- L1, L2 – Carrier phase measurements in L1,L2 cycles respectively (1,2 represent frequencies 1.575, 1.227 GHz)
- P1, P2 – P-Code or pseudo-range measurements
- C1, C2 – C/A & L2C code measurements (optional)

Data collection

…cont. 2



Navigation and bias files



Ephemeris analysis

1

- **Ephemeris for each PRN are obtained from the RINEX Navigation files (from receiver or IGS site)**

2

- **The station coordinates should be known to calculate the elevation and azimuth angles of the satellite with respect to station, from the ephemeris at the given time.**

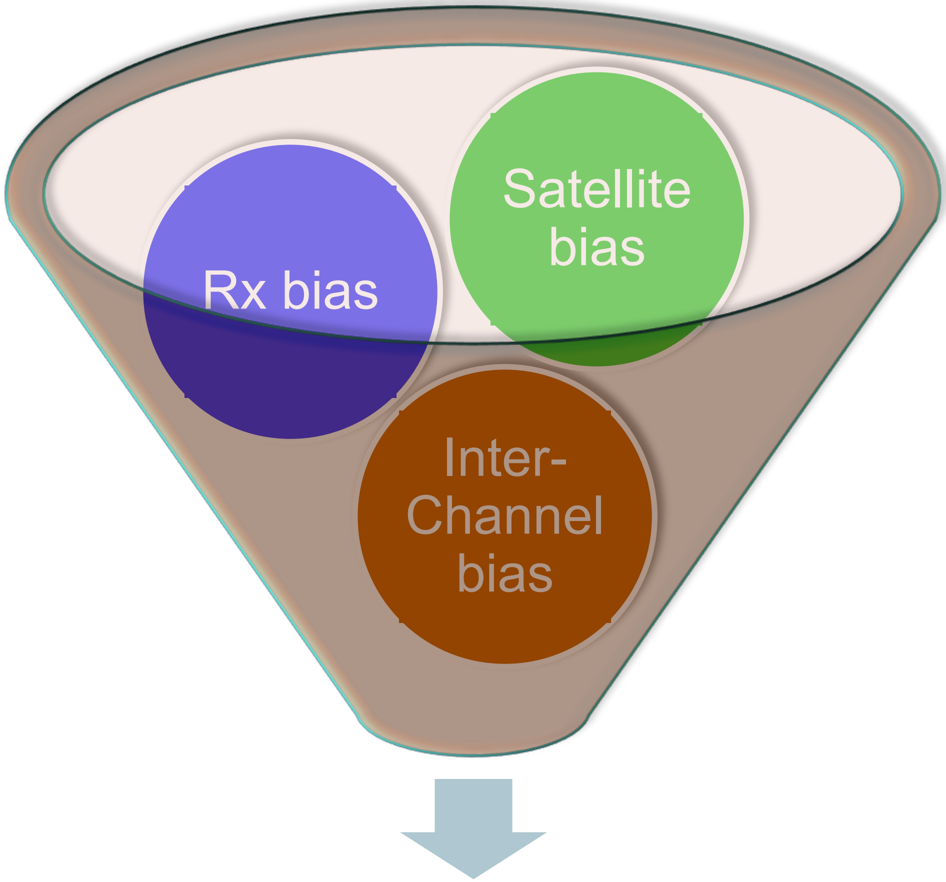
3

- These elevation and azimuth angles are used in the calculation of vertical TEC from the slant TEC

Raw data processing

1. Read TEC observables (L1,L2, P1, P2) from file
2. Calculate Group and Phase TEC values
3. Correction of cycle slips in phase TEC values
4. Estimate absolute TEC from phase & group TEC
5. Remove the hardware biases, and convert slant to vertical TEC

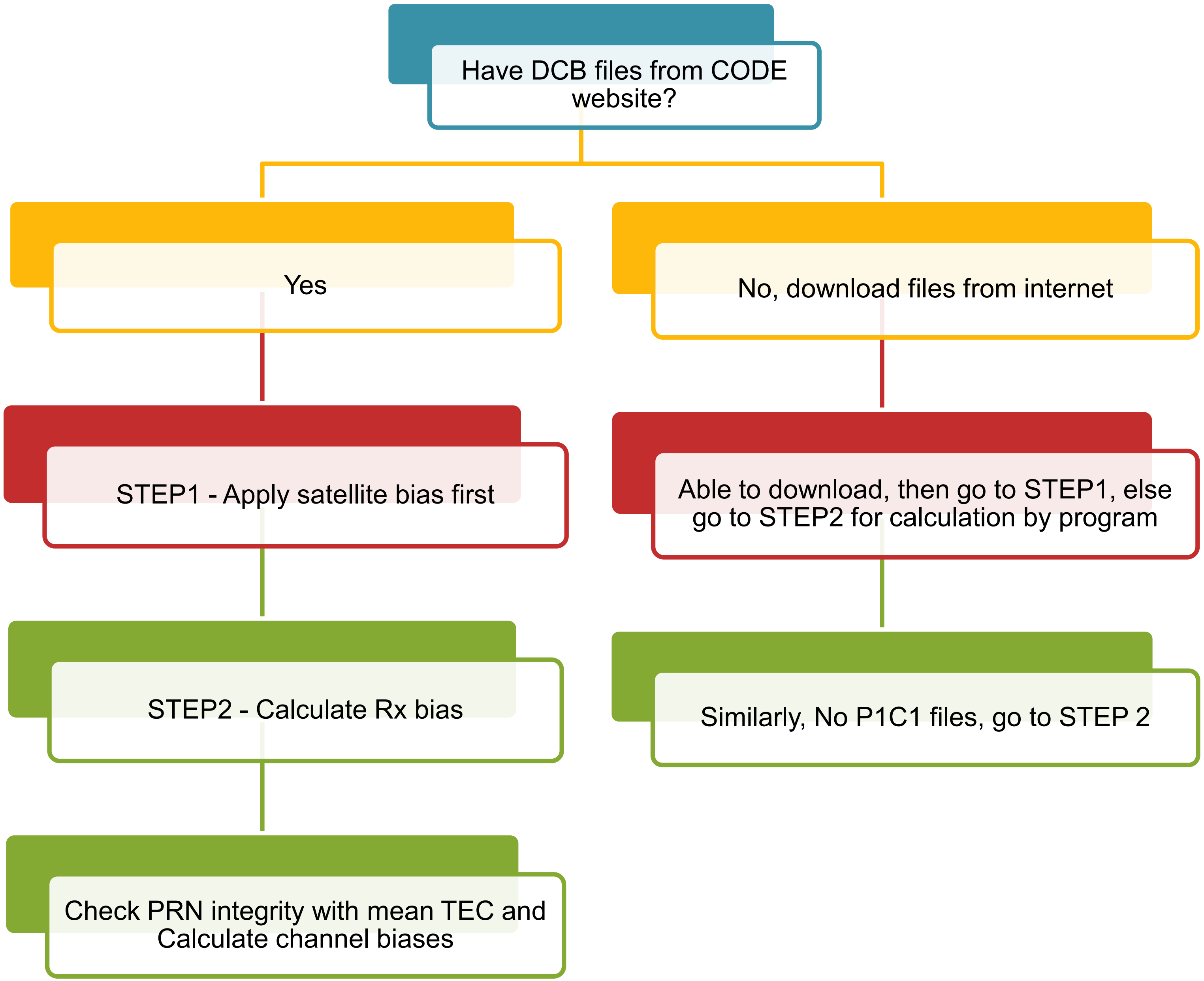
Bias calculation



Total Bias

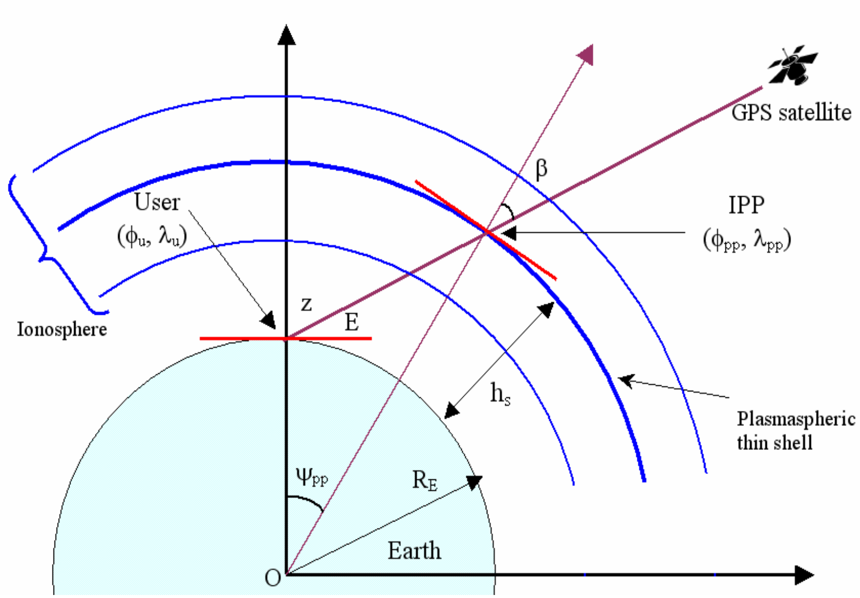
Bias calculation

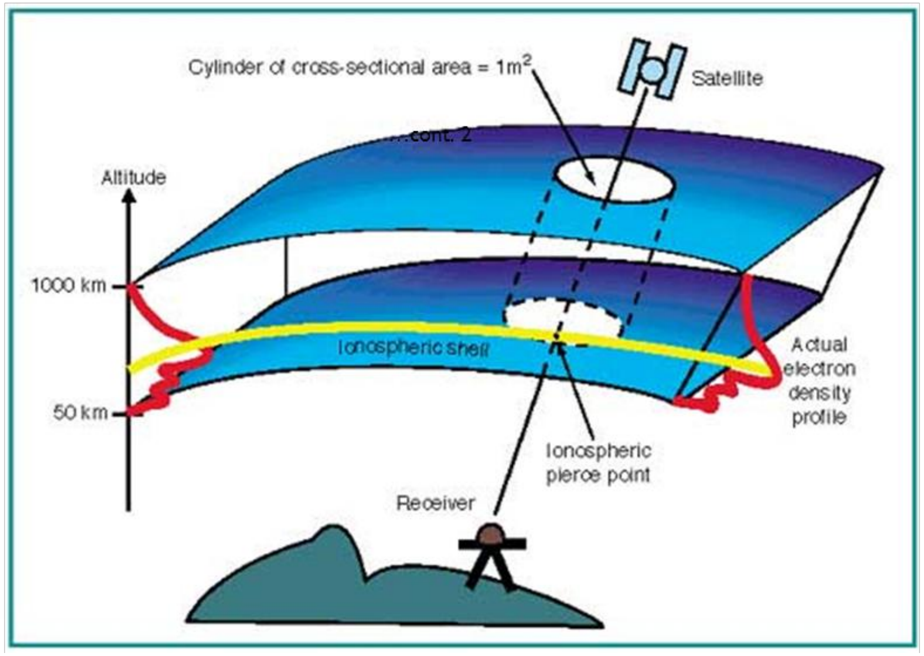
...cont. 2



Vertical TEC conversion

$$Z = [\sin^{-1}(.94792*\cos(elev)]$$





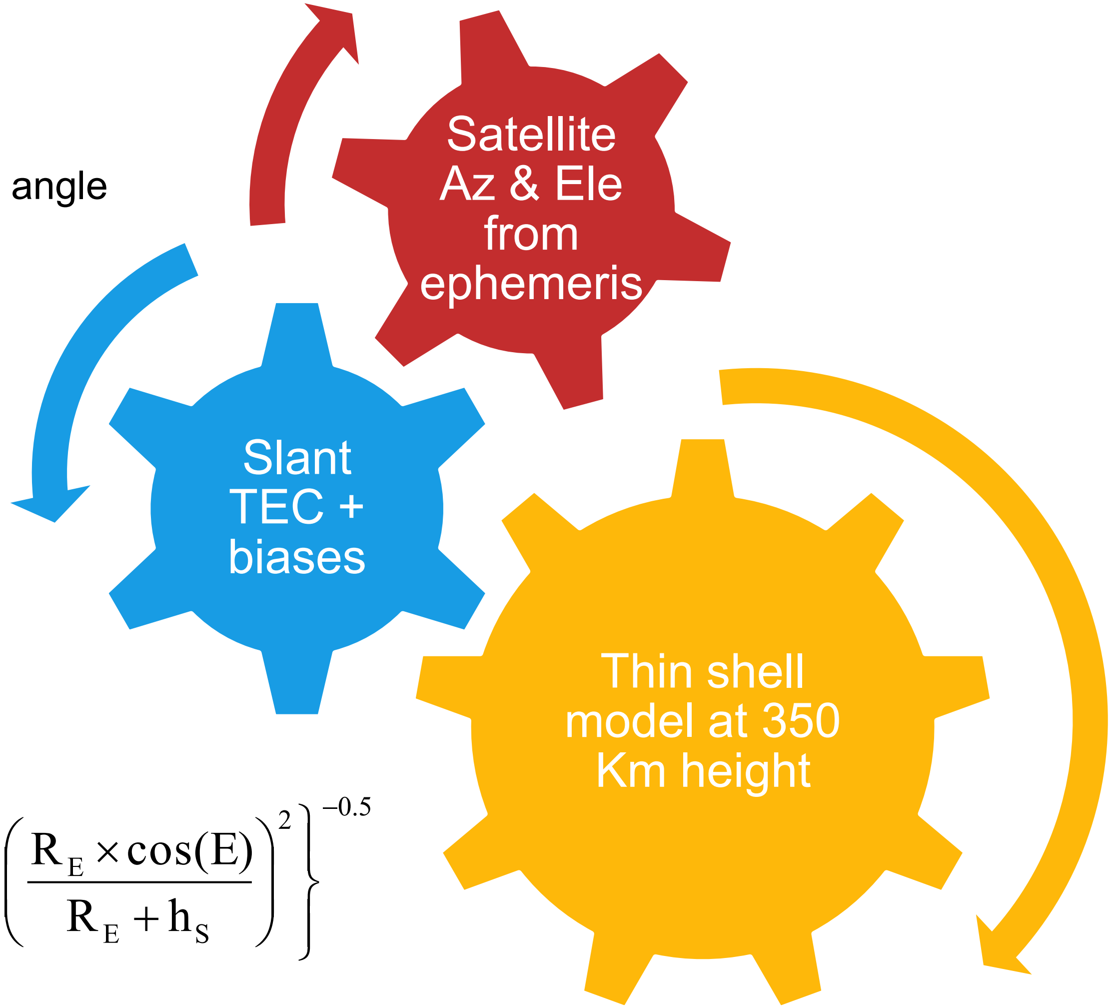
To calculate the vTEC, it was assumed that the ionosphere (and the protonosphere) is spatially uniform, and further it is simplified to a thin layer at an altitude of h_S = 350 km above the earth's surface. This is the thin shell model and its height is the effective height or centroid of the plasmasphere (ionosphere and protonosphere collectively called plasmasphere).

Vertical TEC conversion ...cont. 2

$$VTEC = [STEC - (b_R + b_S)] / S(E)$$

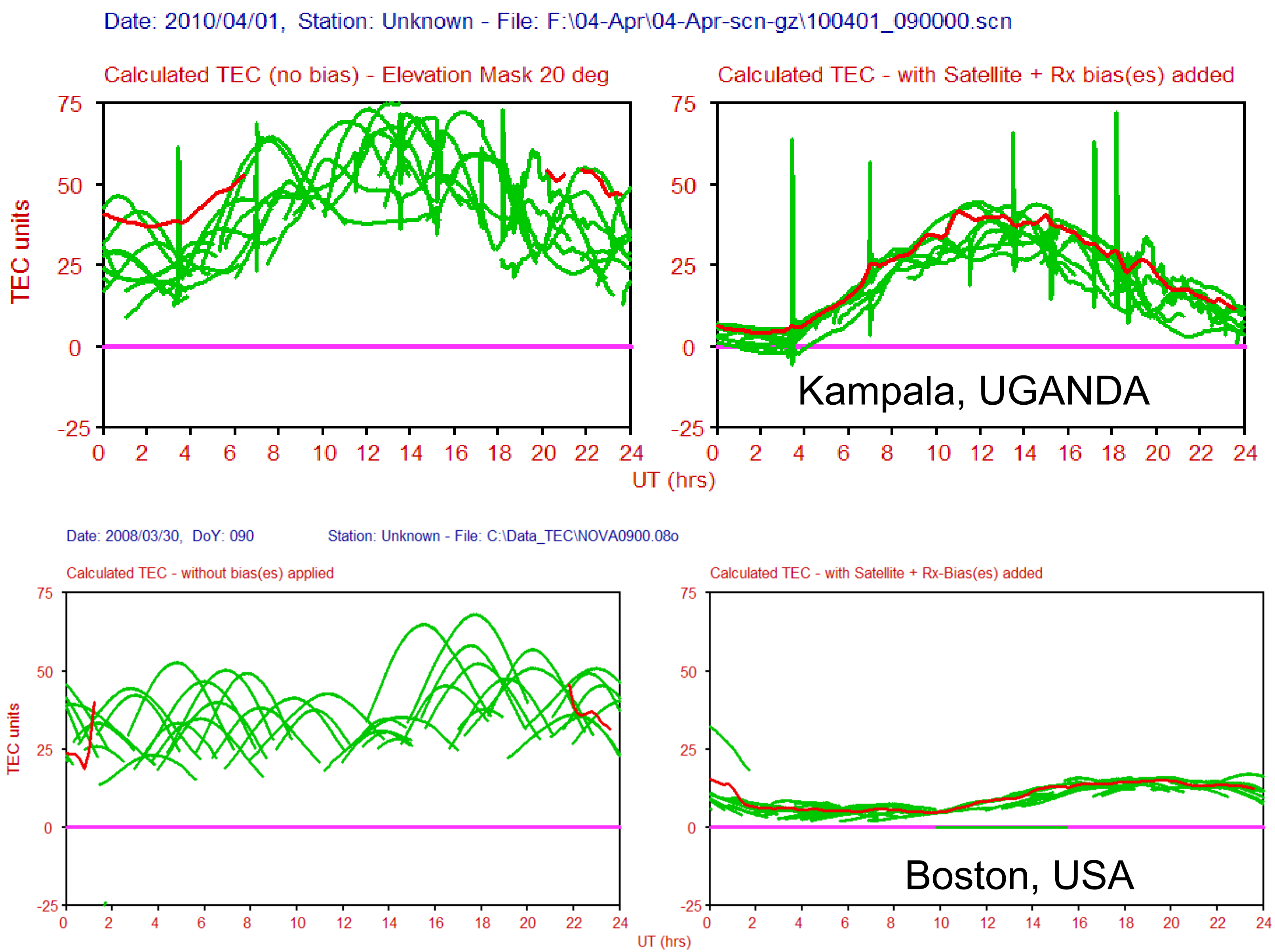
Here
VTEC = vertical TEC
STEC = slant TEC
S(E) is the projection angle given below

RE = radius of earth
E = elevation angle



$$S(E) = \frac{1}{\cos(z)} = \left\{1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S}\right)^2\right\}^{-0.5}$$

Vertical TEC conversion ...cont. 3



Downloading Rinex Navigation & DCB files from FTP

Screen shot of the program downloading Navigation and DCB code bias files

```
By using this program you are agreed to the above!
© 2009 Gopi Seemala

No file was selected or dropped into program
You can Open file using Right click anywhere on window..
The file chosen by you was   C:\Data_TEC\NOVA0900.08o

Navigation file not found..
—Accessing Internet to download file!!—

Navigation file is..C:\Data_TEC\chpi0900.08n

DCB file(s) not found..
—Accessing Internet to download file!!—
```

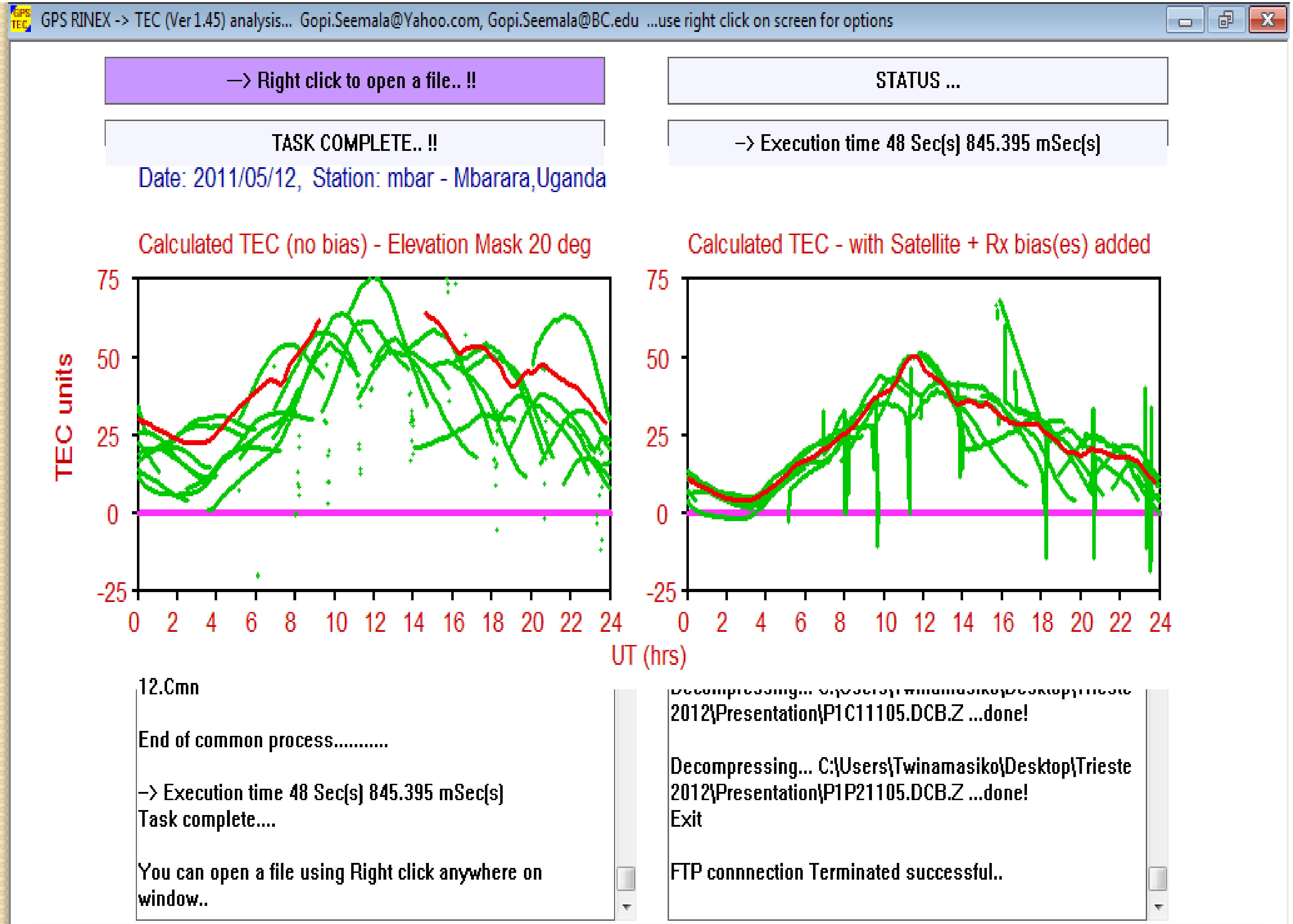
```
Connected
Starting the session...
Reading remote directory...
Session started.
Active session: [1] anonymous@ftp.unibe.ch
winscp> option transfer binary
transfer     binary
winscp> cd aiub/CODE
/aiub/CODE
winscp> cd 2008
/aiub/CODE/2008
winscp> get -preservetime P1P20803*.* "C:\Data_TEC\"
P1P20803.DCB.Z          |        0 KiB |    0.0 KiB/s | binary | 100%
P1P20803_ALL.DCB.Z      |        4 KiB |    4.5 KiB/s | binary | 100%
winscp> get -preservetime P1C10803.DCB.Z "C:\Data_TEC\"
P1C10803.DCB.Z          |        0 KiB |    0.0 KiB/s | binary | 100%
```

Manually downloading the files into the data directory

FTP address for Rinex Navigation files
ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily/
Select year → select day number → select "<YY>n" directory → download a station file "<STAT><ddd>0.<YY>n"

FTP address for DCB code files
ftp://ftp.unibe.ch/aiub/CODE/
Select year → download the following files
"P1P2<YY><MM>_DCB.z
"P1C1<YY><MM>_DCB.z

<YY> two digit year, <MM> two digit month, <ddd> day number, <STAT> four letter station code



Screen shot of the program, analyzing data set of stations. Plot on screen shows the VTEC of GPS receiver at St. Clements hall, Boston College

Processed data file output

Output file -> <station code> + <day number> + <yyyy-mm-dd> . <cmn>

Path -> same directory of the rinex data file

contents in output file:

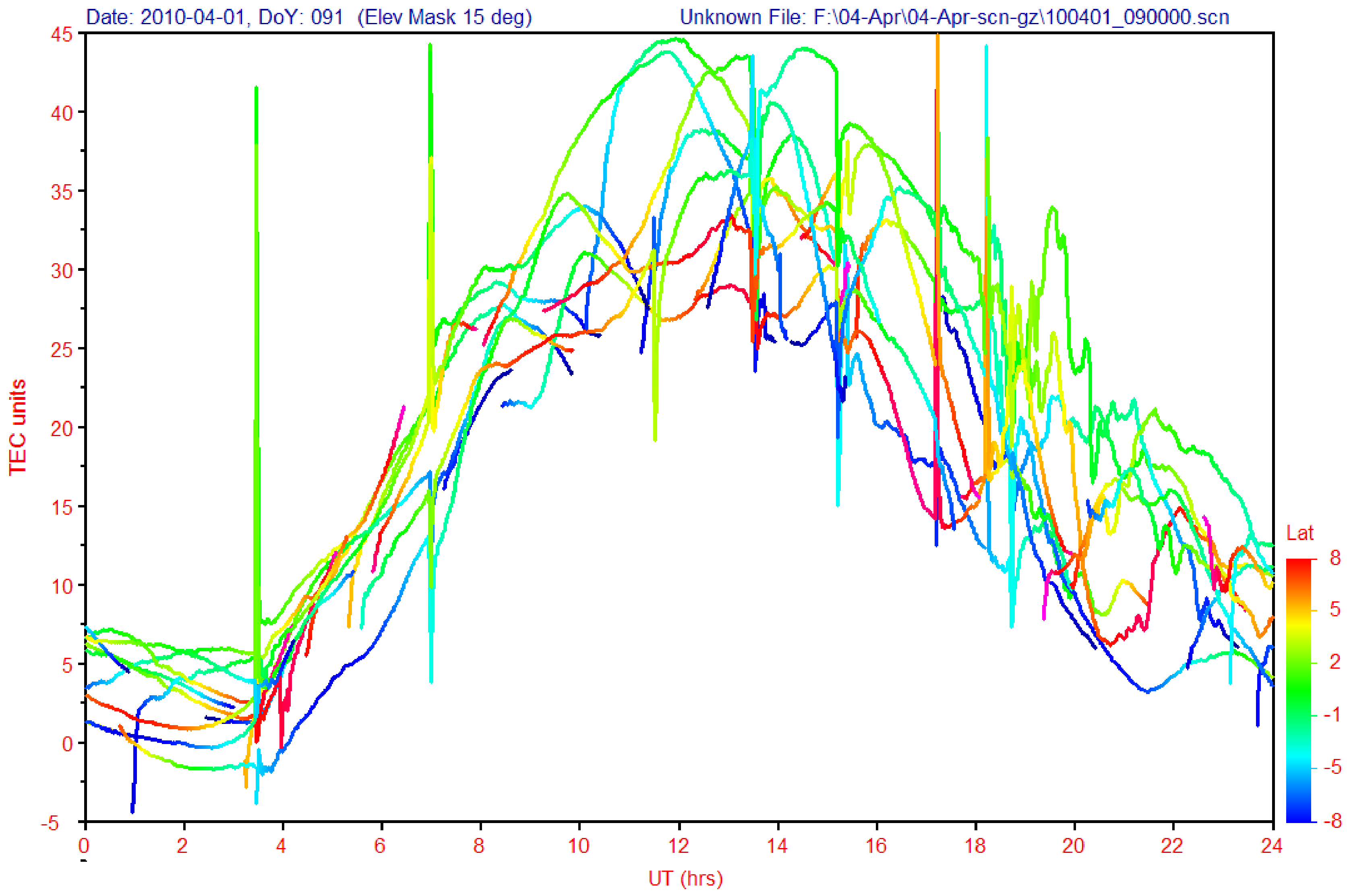
JulianDay +time	UT	PRN	Azimuth	Elevaion	Latitude	Longitude	STEC	VTEC	S4 index
2454550.873958	8.97	2	219.77	10.99	-19.73	275.75	16.35	5.98	-99.000
2454550.874653	8.98	2	219.92	11.33	-19.58	275.85	15.93	5.87	-99.000
2454550.875347	9.00	2	220.07	11.68	-19.44	275.95	15.95	5.93	-99.000
2454550.878125	9.07	2	220.72	13.04	-18.90	276.31	15.50	5.94	-99.000
2454550.878819	9.08	2	220.89	13.38	-18.77	276.39	15.49	5.99	-99.000
2454550.879514	9.10	2	221.07	13.72	-18.64	276.47	15.37	5.99	-99.000
2454550.880208	9.12	2	221.25	14.05	-18.52	276.55	15.36	6.03	-99.000
2454550.880903	9.13	2	221.43	14.39	-18.40	276.63	15.25	6.04	-99.000
2454550.881597	9.15	2	221.62	14.73	-18.28	276.70	15.24	6.09	-99.000
2454550.882292	9.17	2	221.81	15.06	-18.17	276.78	15.13	6.09	-99.000
2454550.882986	9.18	2	222.01	15.40	-18.05	276.85	15.15	6.15	-99.000

***The output file is sorted in PRNs then Time**

Summary

- The program developed eases the GPS-TEC data analysis by taking multiple formats as the input files (Rinex, Novatel, Leica, AER formats)
- It applies the necessary receiver, satellite, and inter-channel bias corrections; also shows the applied bias corrections in program for later verification.
- It downloads the required navigation files, DCB files from internet automatically if it doesn't find them in the data directory.
  - For example: If you download an IGS station rinex observation file and give this as input to the program (no need to give any other files) it does download necessary files (decompresses them) and gives the output files including the plot image.
- The output ascii files are easily machine and human readable

Graphs Obtained



Links: http://sopac.ucsd.edu/cgi-bin/dbDataBySite.cgi

See You in the Lab

Any Question?

Save 'em for the Lab

Thank You for Listening