

2nd Satellite Navigation Science and Technology for Africa



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GNSS TEC DATA PROCESSING

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TEC (Total Electron Content)

- > an important descriptive quantity for the ionosphere
- > key parameter for ionospheric studies
- > key parameter for the correction of ionospheric effects which degrade GNSS positioning accuracy.
- > GPS dual frequency measurements can be used to reconstruct the Total Electron Content

http://gpsweather.meteo.be/ionosphere/total_electron_content

RINEX

- **R**eceiver **I**ndependent **E**xchange Format
- Developed by the Astronomical Institute of the University of Berne in 1989
- For the easy exchange of the GPS data
- For processing in various software

Consists of 3 ASCII file types

File Type	Containing Information
Observation Data File	GPS Measurements
GPS Navigation Message File	Ephemeris (Orbit information)
CODE bias files	Satellite Biases

Program Process

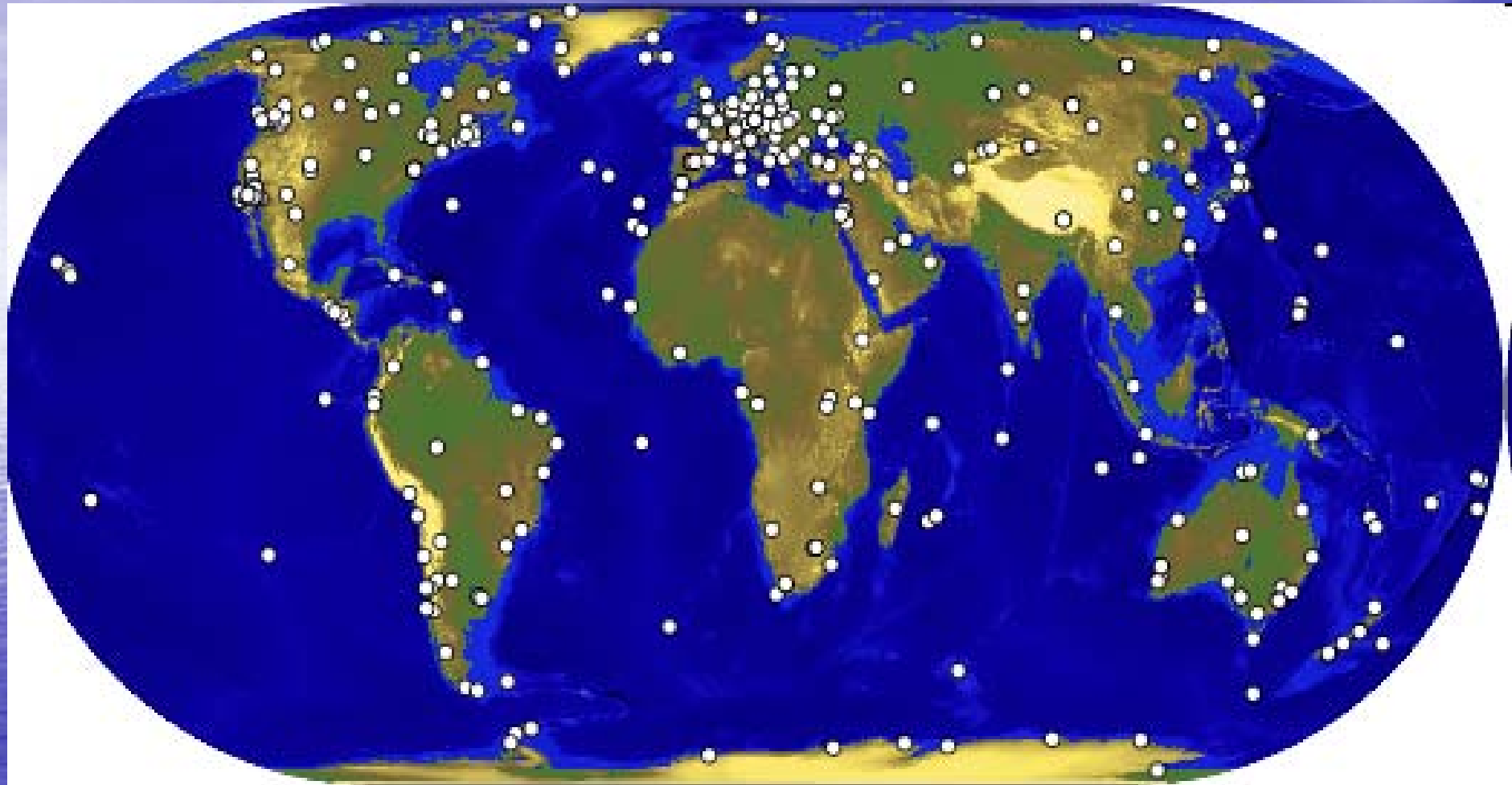
- Calculate preliminary slant TEC from phase and pseudorange
 - RINEX data files include a header with site information and a
 - data section including:
 - 1) phase in cycles of L1 and L2 carriers
 - 2) pseudorange in meters using C/A codes on L1 and P-code on L1&L2
 - 3) SNR in receiver dependent units for L1 and L2 carriers
- Cycle Slip Detection and Removal
- Leveling the phase to the pseudorange to get an **absolute** measurement
- Remove the satellite T_{gd} biases
- Apply the mapping function to convert the slant measurements to equivalent vertical
- Estimate and remove the hardware bias
- Identify and remove bad data (local interference, receiver glitches)



DATA

SOURCES

IGS TRACKING NETWORKS



©IM7 2010 Apr 12 16:45:20

<http://igscb.jpl.nasa.gov/>

Continuously Operating Reference Stations National Geodetic Survey



<http://www.ngs.noaa.gov/CORS/cors-data.html>

Helpful URLs:

- **IGS Stations**

- <http://igscb.jpl.nasa.gov/network/netindex.html>
- global overview of stations; latitude and longitude of station

- **CODE info**

- <http://www.aiub.unibe.ch/download/CODE/>
- differential code biases
 - P1C1yymm.DCB and P1P2yymm.DCB
 - where yy=year, mm=month

- **Ap/Kp indices**

- ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/
- Ap/Kp indices ... planetary Kp indices and related Ap indices measure worldwide geomagnetic activity

- **GPS data**

- <ftp://cddis.gsfc.nasa.gov/gps/data/daily/>
- observation files

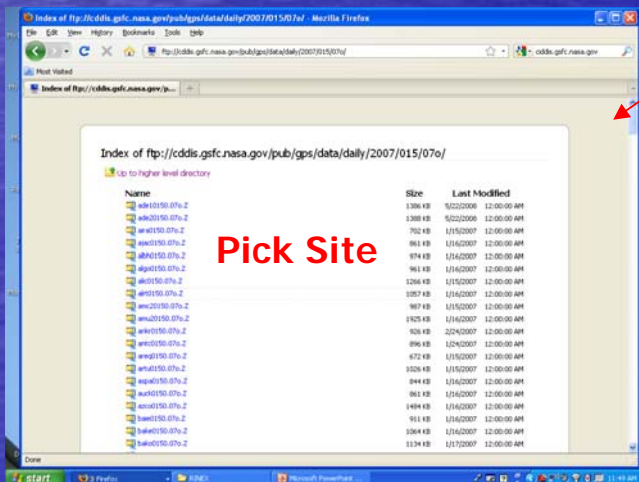
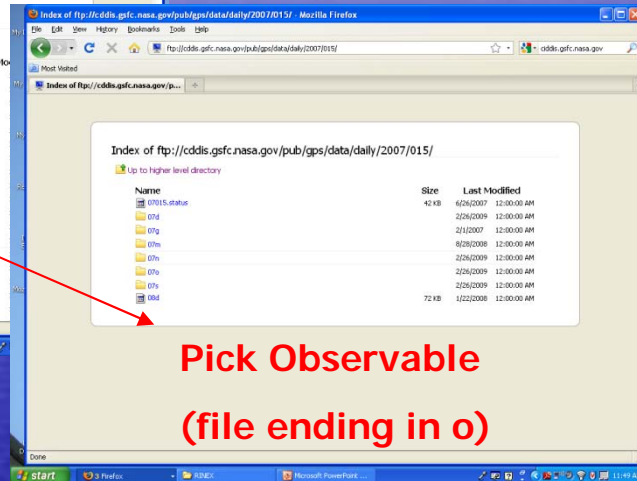
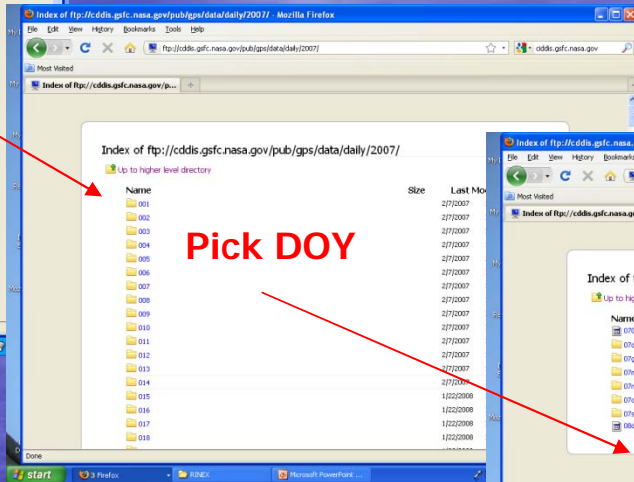
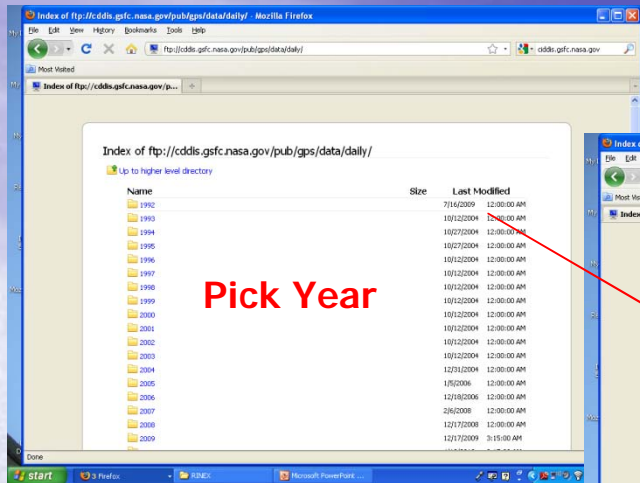


Processing GPS Data

Retrieve Data for Input

- Retrieve either *yyo* or *yyd* data from *cddis* site (*yy=year*)
- Retrieve *yn* data from *cddis* site
- Retrieve P1C1 and P1P2 differential code bias data from *CODE* site

Using cddis.gsfc.nasa.gov/gps/data/daily to get observable file



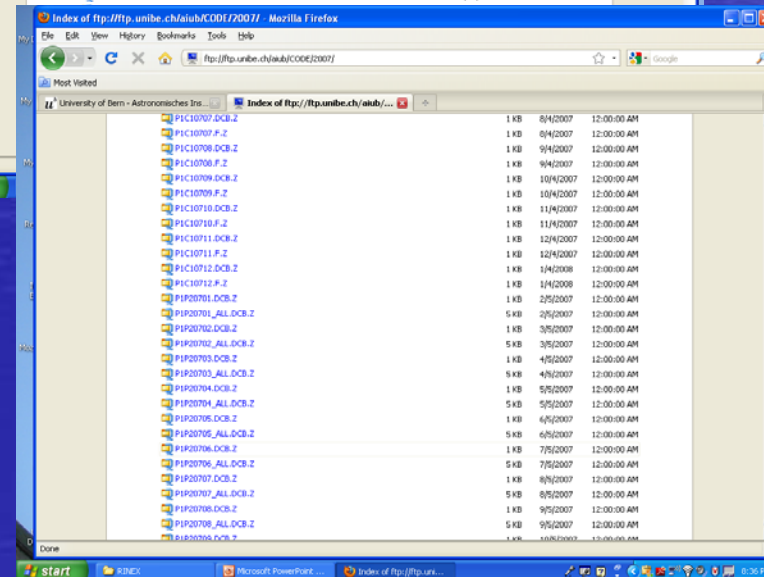
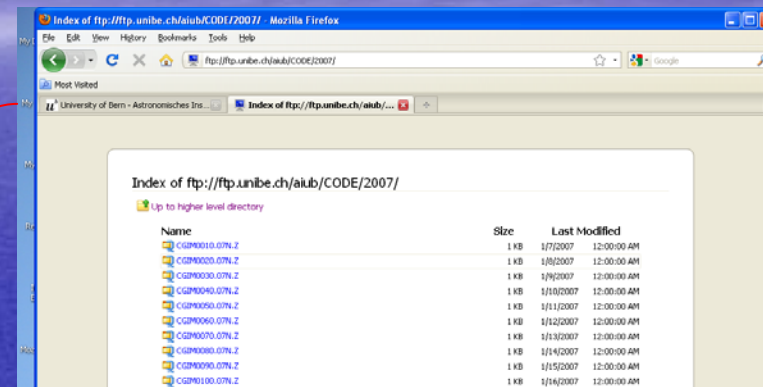
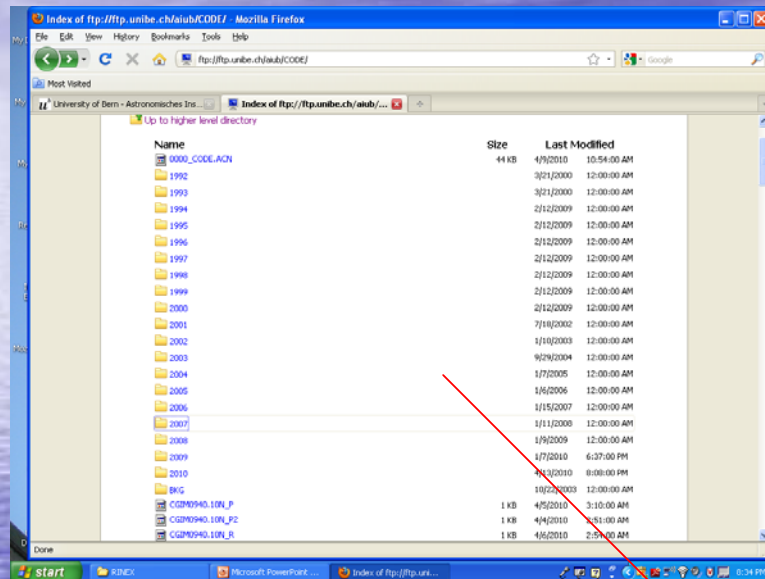
Using ciddis.gsfc.nasa.gov/gps/data/daily to get navigation file

The process is shown in four sequential screenshots of a Mozilla Firefox browser window:

- Step 1:** The browser shows the root directory index: `Index of ftp://ciddis.gsfc.nasa.gov/pub/gps/data/daily/`. A table lists years from 1992 to 2009. A red arrow points to the year 2007, with the text **Pick Year**.
- Step 2:** The browser shows the 2007 directory index: `Index of ftp://ciddis.gsfc.nasa.gov/pub/gps/data/daily/2007/`. A table lists days of the year (DOY) from 001 to 019. A red arrow points to DOY 015, with the text **Pick DOY**.
- Step 3:** The browser shows the 2007/015 directory index: `Index of ftp://ciddis.gsfc.nasa.gov/pub/gps/data/daily/2007/015/`. A table lists files, including `07015.status` and `07015`. A red arrow points to the file `07015`, with the text **Pick Navigation (file ending in n)**.
- Step 4:** The browser shows the 2007/015/070 directory index: `Index of ftp://ciddis.gsfc.nasa.gov/pub/gps/data/daily/2007/015/070/`. A table lists site-specific files like `ab410150.070.2`. A red arrow points to the first file, with the text **Pick Site**.

Retrieve Differential CODE Bias Files:

<http://www.aiub.unibe.ch/download/CODE>



Differential CODE biases P1C1 and P1P2 files

RINEX Observation File

11 November 2004

```
2      OBSERVATION DATA  M (MIXED)      RINEX VERSION / TYPE
CCRINEXO V2.3.1 LH IMVP      19-NOV-04 06:10  PGM / RUN BY / DATE
JPS2RIN 1.05  IMVP      19-NOV-04 06:10  COMMENT
BUILD AUGUST 17, 2000      COMMENT
KHAJ0153.JPS      COMMENT
KHAJ      MARKER NAME
12361M001      MARKER NUMBER
          VNIIFTI, KHABAROVSK      OBSERVER / AGENCY
2079      JPS LEGACY      2.3 APR,28,2004 P4  REC # / TYPE / VERS
RA0032      JPSREGANT_SD_E NONE  ANT # / TYPE
-2995267.0389 2990444.2408 4755577.9936  APPROX POSITION XYZ
          0.0000  0.0000  0.0000  ANTENNA: DELTA H/E/N
          1  1      WAVELENGTH FACT L1/2
          7  L1  L2  C1  P1  P2  D1  D2  # / TYPES OF OBSERV
          30      INTERVAL
          2004 11 18  0  0  0.000000  GPS  TIME OF FIRST OBS
          END OF HEADER
```

**Header
Section**

```
04 11 18 0 0 0.0000000 1 14G01G05R04G22R24G09G14R23R22G20G25G30
          R05G06
113329005.358 88308331.3824 21565790.849 7 21565790.23445 21565794.92345
          2339.585 1823.028
114521957.967 89237892.4264 21792800.154 7 21792799.51444 21792803.51544
          -2614.281 -2037.114
111923861.844 87051924.4554 20900991.912 7 20900993.15447 20900995.17346
          -1826.073 -1420.282
126730022.886 98750675.6684 24115924.940 4 24115924.87941 24115929.63541
          -3545.755 -2762.898
122952560.094 95629832.8484 22984682.208 6 22984683.20945 22984690.49145
          4409.189 3429.343
131929601.489 102802283.6724 25105362.824 4 25105361.12441 25105372.35941
          -3513.314 -2737.605
```

**Data
Section**

RINEX Observation File: Header

11 November 2004

```
2      OBSERVATION DATA  M (MIXED)
CCRINEXO V2.3.1 LH IMVP      19-NOV-04 06:10
JPS2RIN 1.05    IMVP      19-NOV-04 06:10
BUILD AUGUST 17, 2000
KHAJ0153.JPS
KHAJ
12361M001
      VNIIFTI, KHABAROVSK
2079      JPS LEGACY      2.3 APR,28,2004 P4
RA0032      JPSREGANT_SD_E NONE
-2995267.0389 2990444.2408 4755577.9936
      0.0000      0.0000      0.0000
      1      1
      7 L1 L2 C1 P1 P2 D1 D2
      30
2004 11 18 0 0 0.000000 GPS
```

```
RINEX VERSION / TYPE
PGM / RUN BY / DATE
COMMENT
COMMENT
COMMENT
MARKER NAME
MARKER NUMBER
OBSERVER / AGENCY
REC # / TYPE / VERS
ANT # / TYPE
APPROX POSITION XYZ
ANTENNA: DELTA H/E/N
WAVELENGTH FACT L1/2
# / TYPES OF OBSERV
INTERVAL
TIME OF FIRST OBS
END OF HEADER
```

```
PGM/ RUN BY / DATE
REC # / TYPE / VERS
ANT # / TYPE
APPROX POSITION XYZ
ANTENNA: DELTA H/E/N

WAVELENGTH FACT L1/2
# / TYPES OF OBSERV
TIME OF FIRST OBS
```

```
Program, Agency, date of creating the file
Receiver Number, type, version
Antenna Number, TYPE
Approximation marker position (in WGS84)
Antenna height, Eccentricities of antenna centre
relative to marker in east and north (in meters)
Wavelength factors for L1 and L2
Number of observation types, observation types
Time of first observation record
```

L1 : Phase measurements on L1
L2 : Phase measurements on L2
C1 : Pseudorange using C/A code on L1
P1 : Pseudorange using P-Code on L1
P2 : Pseudorange using P-Code on L2
D1 : Doppler frequency on L1
D2 : Doppler frequency on L2

RINEX Observation File: Data Section

Number of Satellites		Satellite System G...GPS R...Glonass		Satellite Number		Epoch			
04	11	18	0	0	0.0000000	1	14	G01G05R04G22R24G09G14R23R22G20G25G30	
								R05G06	
113329005.358	88308331.3824	21565790.849	7	21565790.23445	21565794.92345				
2339.585	1823.028								
114521957.967	89237892.4264	21792800.154	7	21792799.51444	21792803.51544				
-2614.281	-2037.114								
111923861.844	87051924.4554	20900991.912	7	20900993.15447	20900995.17346				
-1826.073	-1420.282								
126730022.886	98750675.6684	24115924.940	4	24115924.87941	24115929.63541				
-3545.755	-2762.898								
122952560.094	95629832.8484	22984682.208	6	22984683.20945	22984690.49145				
4409.189	3429.343								
131929601.489	102802283.6724	25105362.824	4	25105361.12441	25105372.35941				
-3513.314	-2737.605								
106887499.711	83288920.8524	20340001.027	8	20340000.29747	20340003.20047				
-706.717	-550.701								
111622580.227	86817602.4344	20808263.776	8	20808263.45947	20808266.89346				
1903.013	1480.102								

Observation data for each satellite

RINEX Observation File: Data Section

L1	L2	C1	P1	P2
113329005.358	88308331.3824	21565790.849 7	21565790.23445	
21565794.92345				
D1	D2	LL1	IP	
2339.585	1823.028			

LLI (Loss of Lock Indicator)

0: OK

1: Cycle Slip

4: Antispoofing

Blank: not known

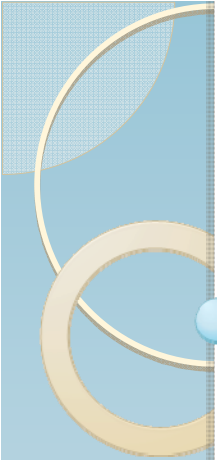
Signal Strength (IP)

-Interval 1-9

1: minimum possible signal strength

9: maximum possible signal strength

0 or blank: not known



GPS-TEC data processing from multiple sources

Introduction

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
 - $TEC_{\text{group}} = 1/40.3 * (1/f_1^2 - 1/f_2^2)^{-1} * (P_1 - P_2)$
 - 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
 - $TEC_{\text{phase}} = (C_1 - C_2) * 2.852$
 - 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

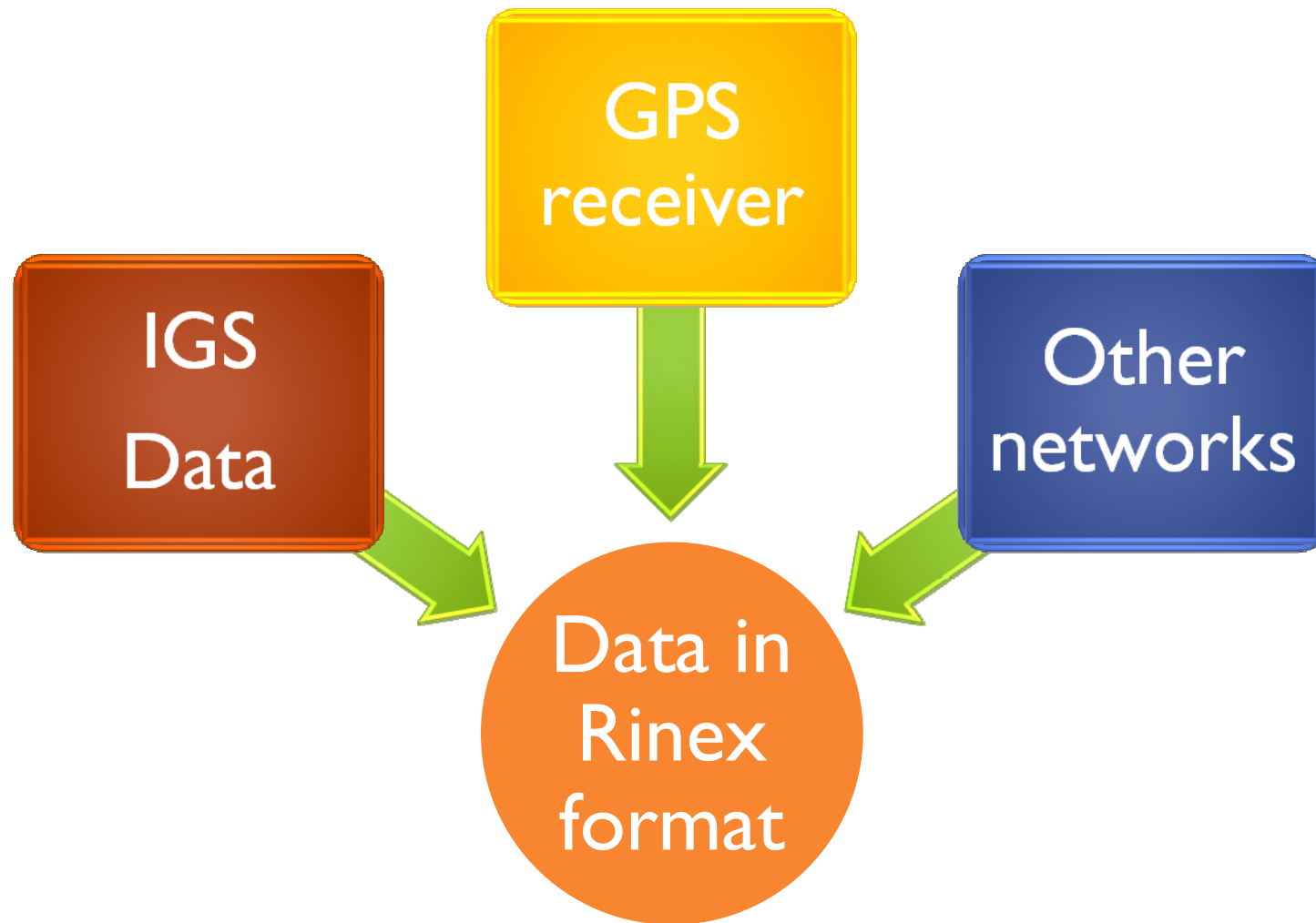
Besides above formats, there are many other data formats available to be recorded from GPS receivers.

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

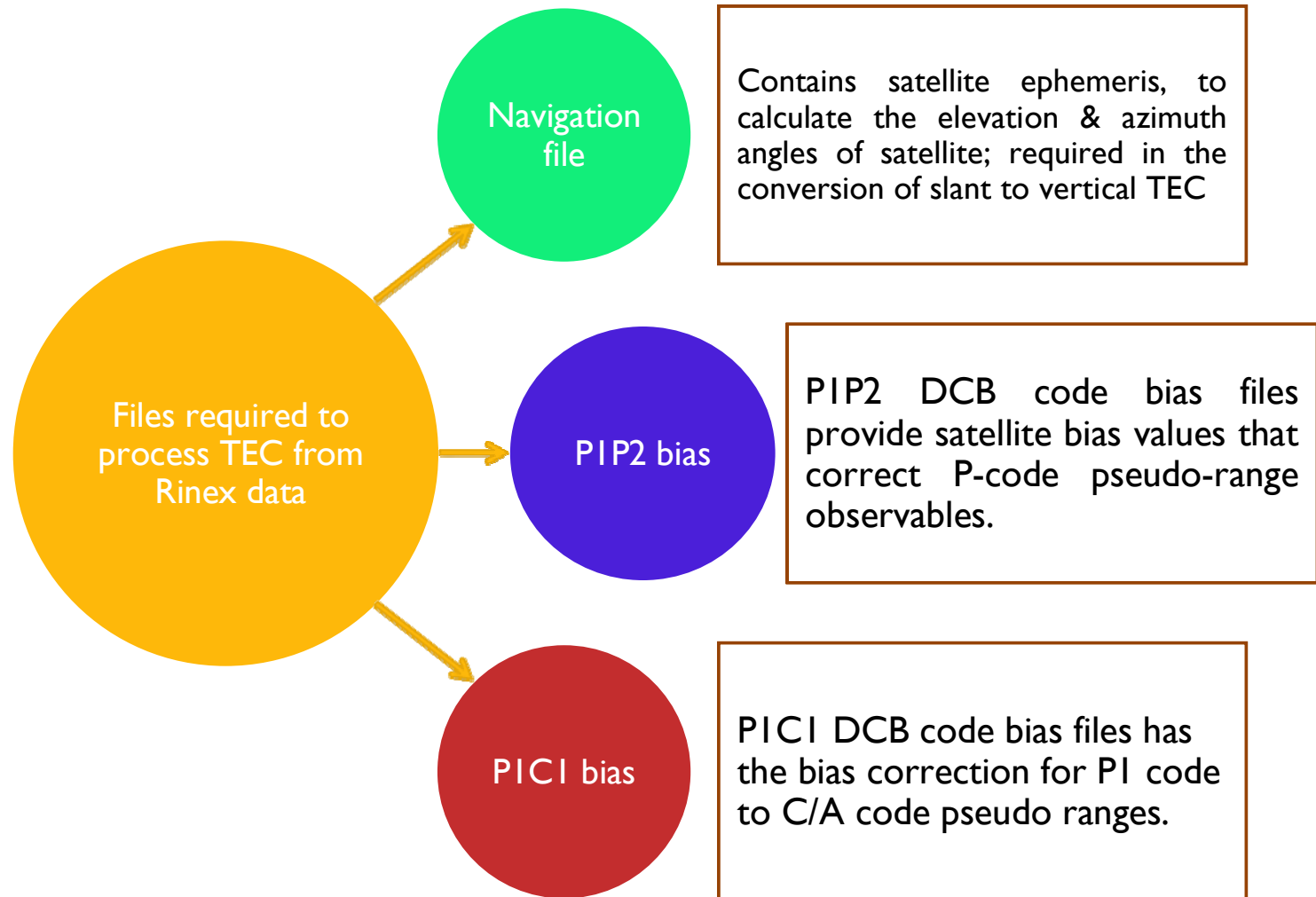
- **L1, L2** – Carrier phase measurements in L1,L2 cycles respectively (L1,L2 represent frequencies 1.575, 1.227 GHz)
- **P1, P2** – P-Code or pseudo-range measurements
- **C1, C2** – C/A & L2C code measurements (optional)

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

Read TEC observables (L1, L2, P1, P2) from file

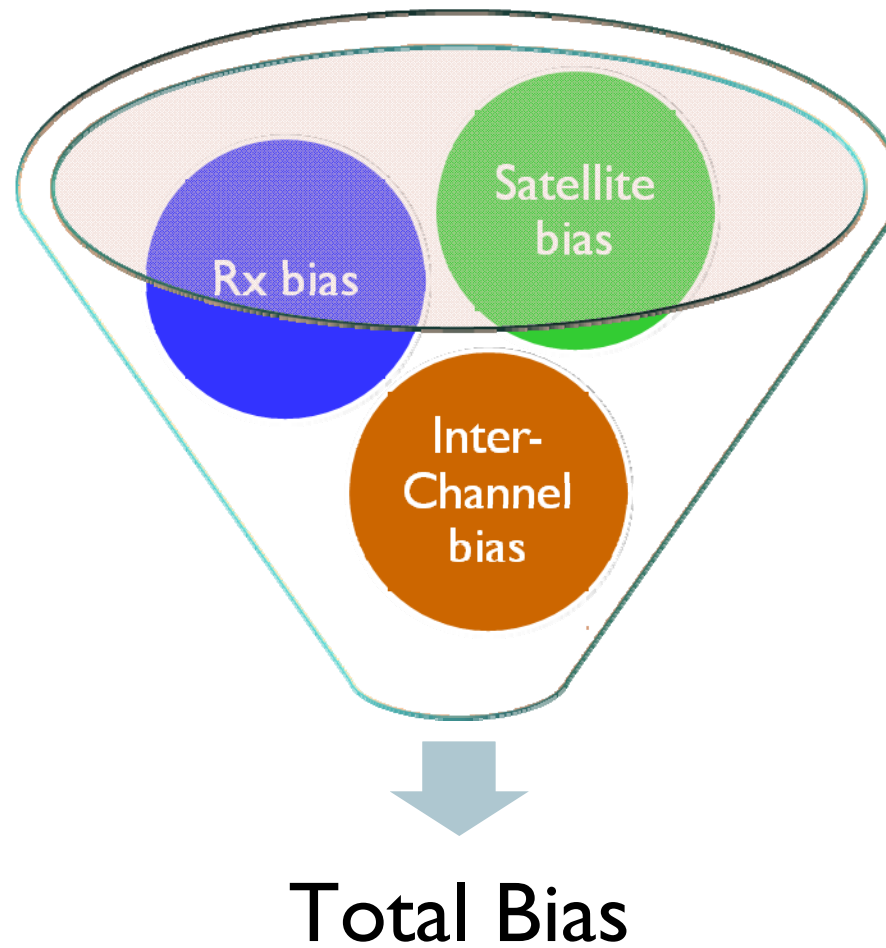
Calculate Group and Phase TEC values

Correction of cycle slips in phase TEC values

Estimate absolute TEC from phase & group TEC

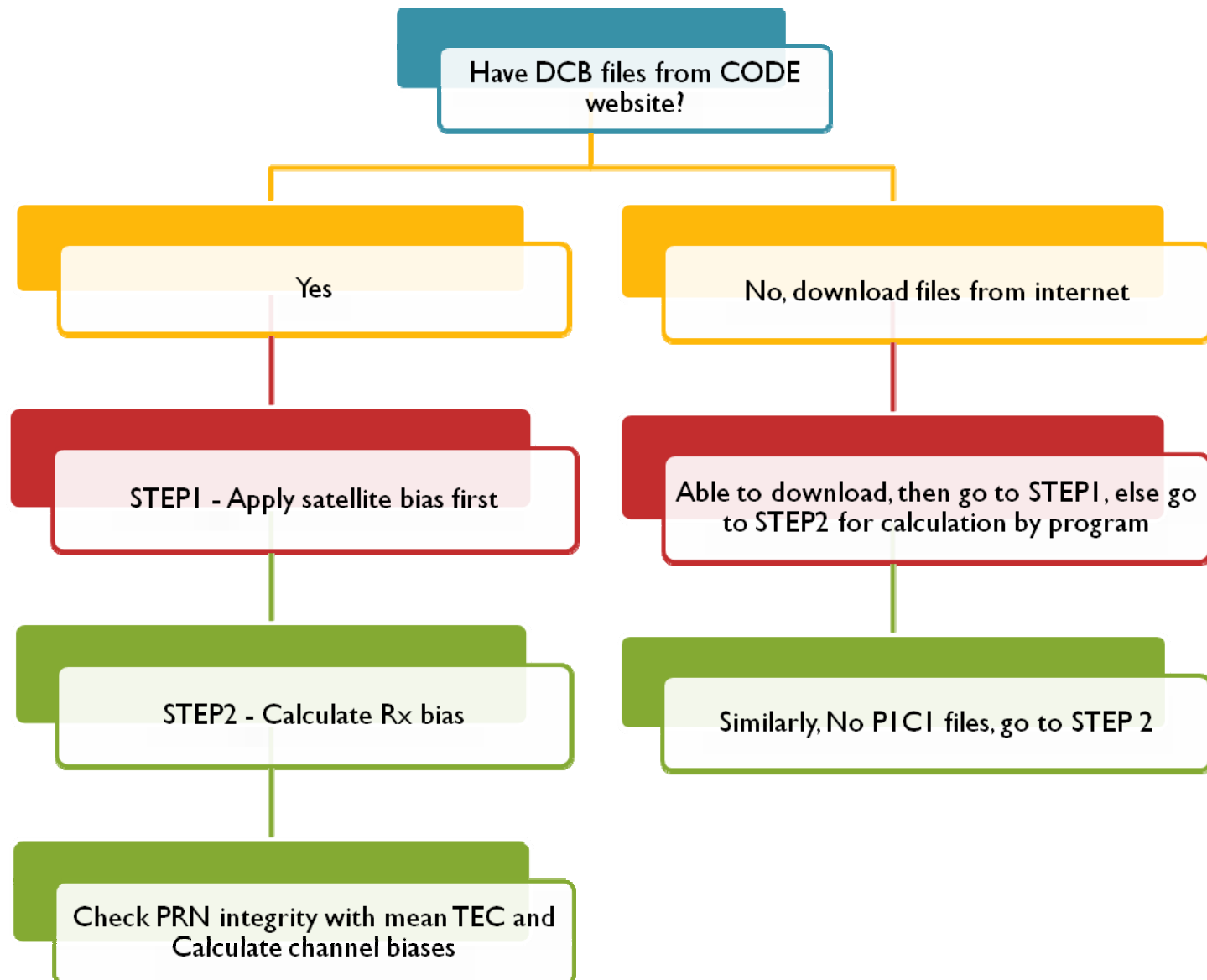
Remove the hardware biases, and convert slant to vertical TEC

Bias calculation

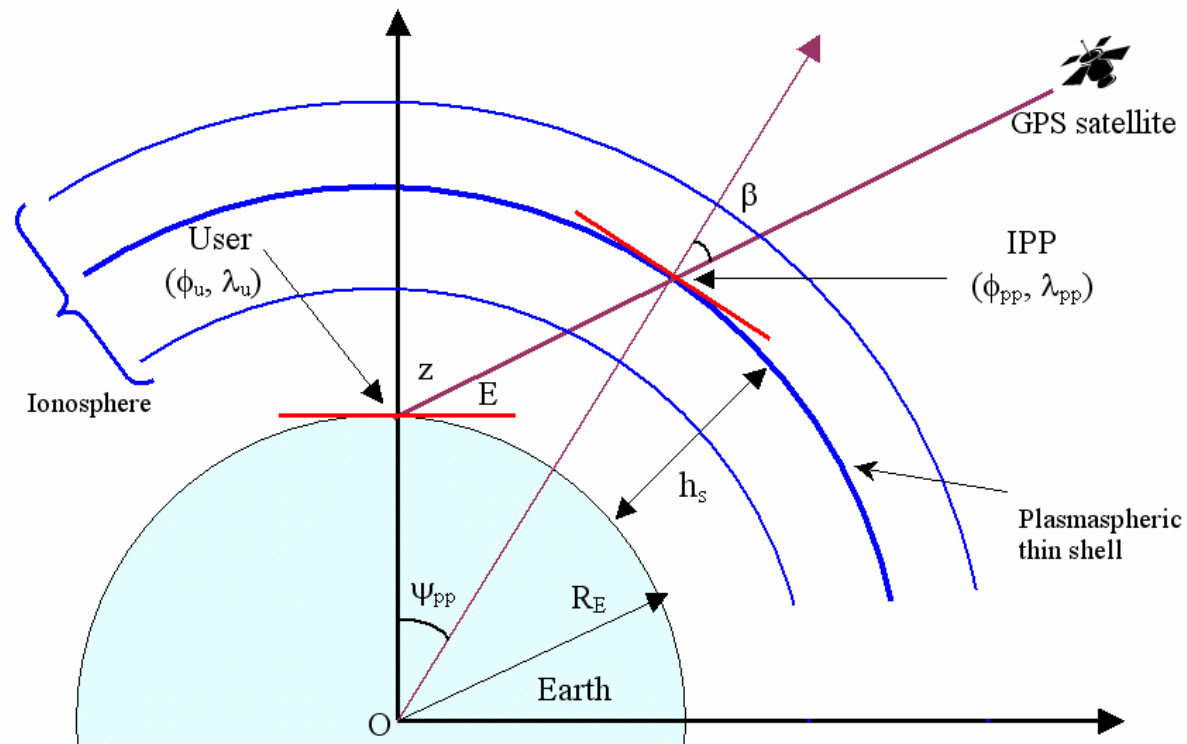


Bias calculation

...cont. 2



Vertical TEC conversion



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

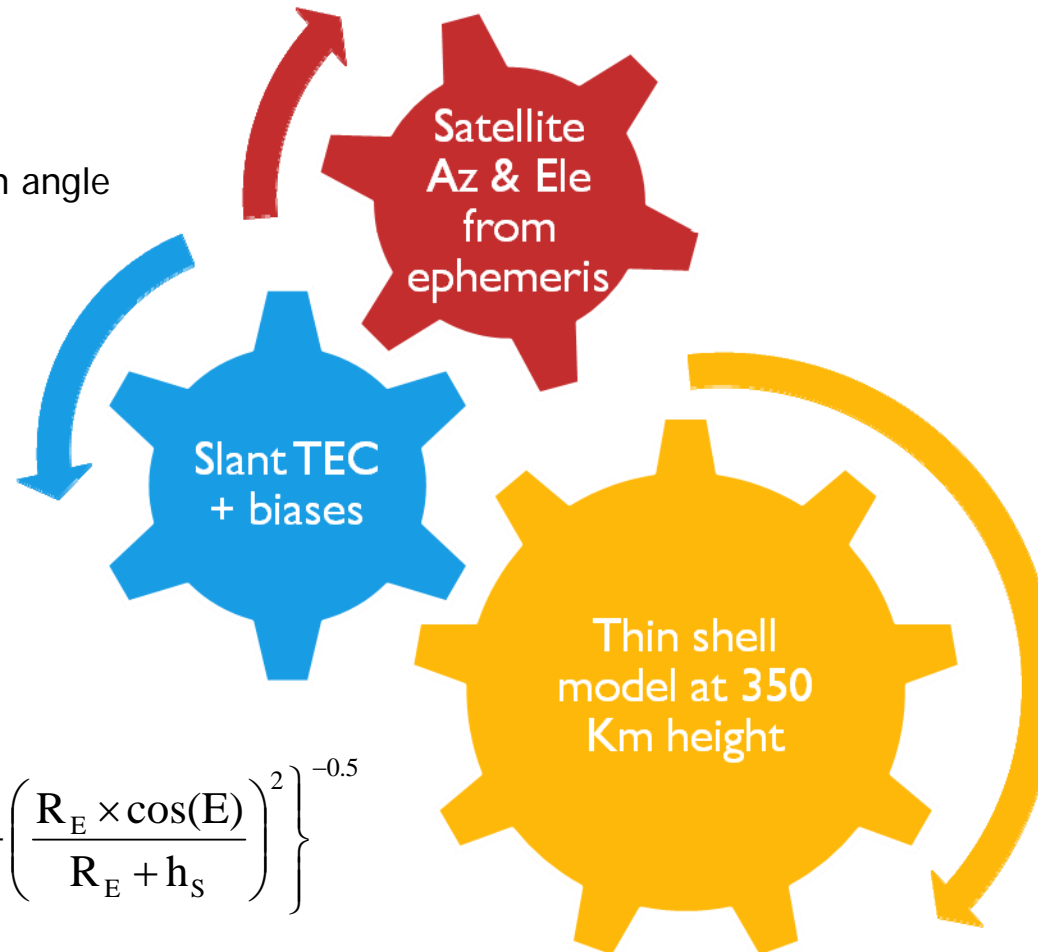
VTEC = vertical TEC

STEC = slant TEC

S(E) is the projection angle
given below

RE = radius of earth

E = elevation angle

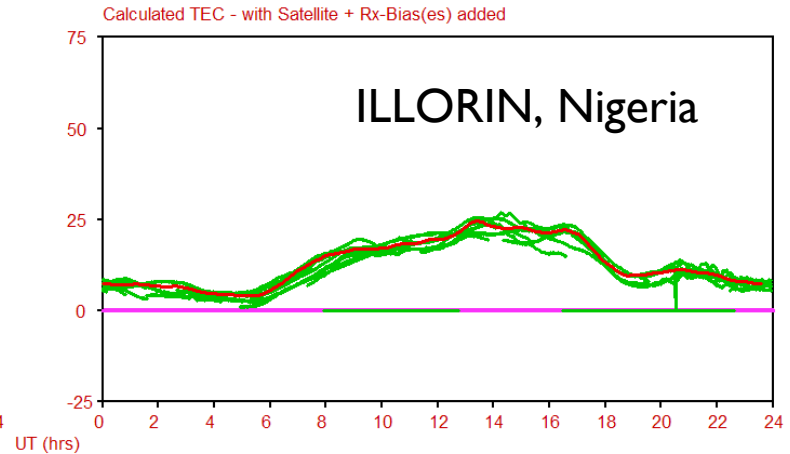
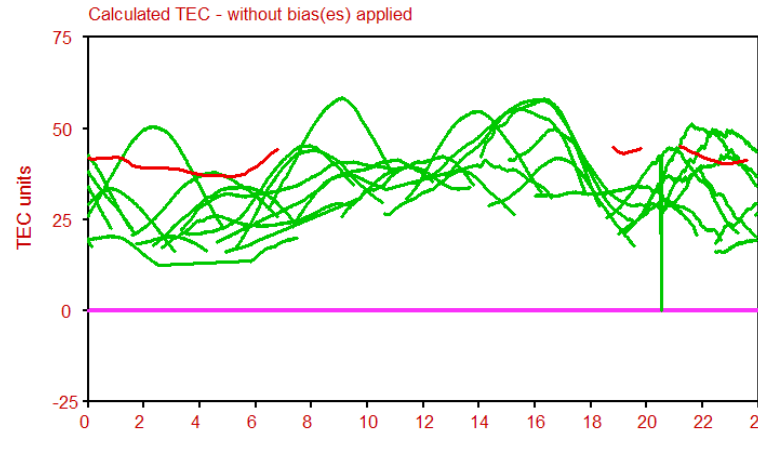


$$S(E) = \frac{1}{\cos(z)} = \left\{ 1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S} \right)^2 \right\}^{-0.5}$$

Vertical TEC conversion ...cont. 3

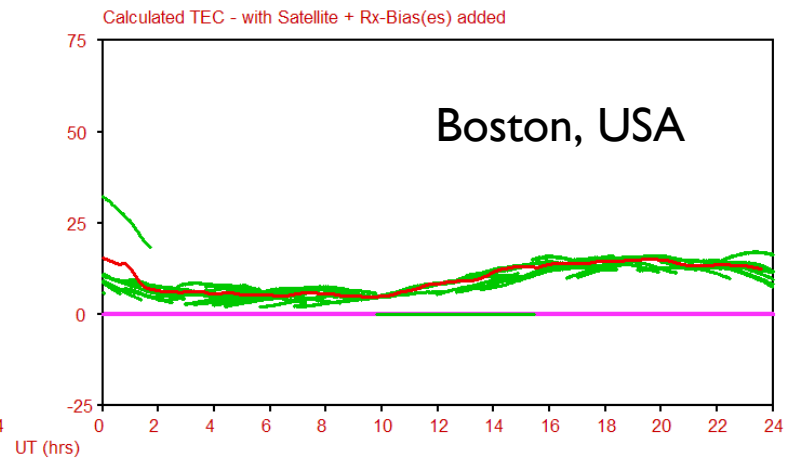
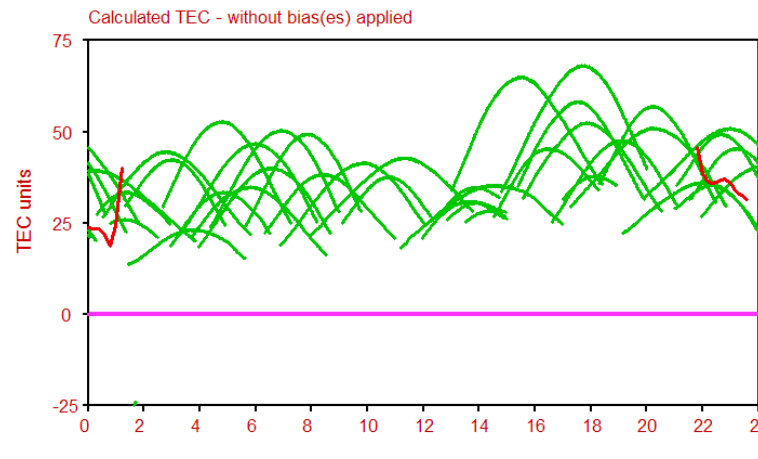
Date: 2008/11/30, DoY: 335

Station: Unknown - File: C:\Data_TEC\Abel Nov 30 2008\NOVA3350.08o



Date: 2008/03/30, DoY: 090

Station: Unknown - File: C:\Data_TEC\NOVA0900.08o



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

“PIP2<YY><MM>_DCB.z

“PICI<YY><MM>_DCB.z

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

D:\LISN_Mar\alta\altaflo.080301_0114.nvd

—>> LISN stations completed 42 of 47 + 7 of 31 days

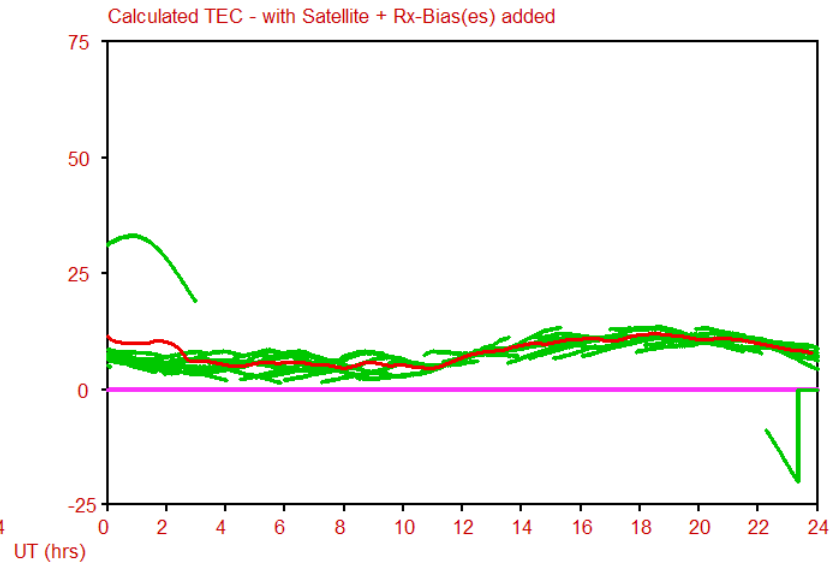
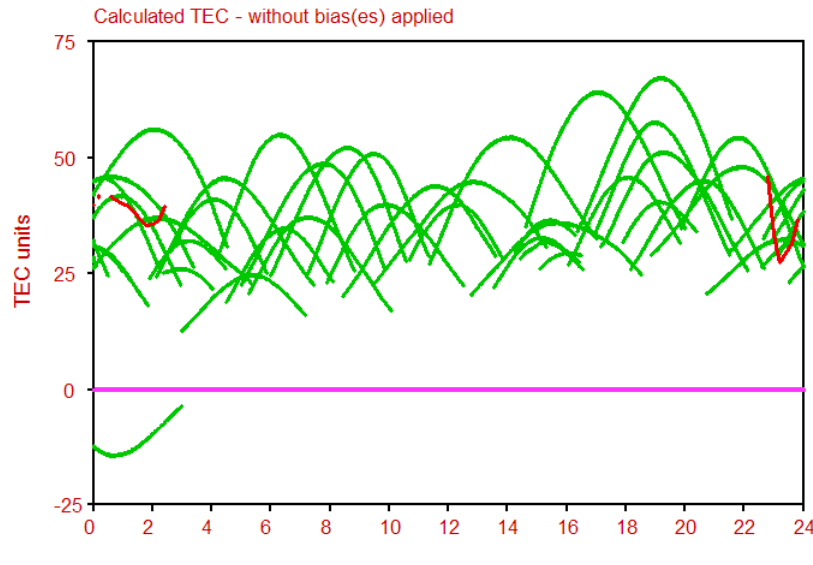
Reading LISN files.. wait!!

Time elapsed: 3 mins 19 Sec, Remaining: 27 mins 24 Sec

Date: 2008/03/07, DoY: 067

Station: St. Clements, United States - File: D:\LISN_Mar\stcl\st.clem.080301_0000.nvd

Reading .221 of 2531.. D:\LISN_Mar\stcl\st.clem.080307_2030.nvd



30	1.2	0.0	-1.2
31	-8.5	0.0	8.5
32	-0.0	-90.8	90.8

RxBias [TEC units] stage1= -42.3 stage2= 0.8 Total= -41.5
 Averages Min. TEC = 4.7 and Max. TEC = 12.1
 Sign used is -1.0

Writing Rinex output... E:\LISN_2008\stcl\st.c0670.08o
 Bias calc. TEC Plot... E:\LISN_2008\stcl\st.clem.067-2008-03-07-wbias.png
 Writing 2-sigma file... E:\LISN_2008\stcl\st.clem.067-2008-03-07.Std
 Writing Biases file... E:\LISN_2008\stcl\st.clem.067-2008-03-07.Bias

```
winscp> get -preservetime P1C10802.DCB.Z "D:\LISN_Mar"
P1C10802.DCB.Z | 0 KIB | 0.0 KiB/s | binary | 100%
winscp> close
Session 'anonymous@ftp.unibe.ch' closed.
No session.
winscp> exit

No. of files found in Directory are 3
Wait... decompressing them....

Decompressing... D:\LISN_Mar\P1C10802.DCB.Z ...done!
```

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 file and 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



Thank you..