2nd Satellite Navigation Science and Technology for Africa

6 April – 24 April 2010

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

- **Receiver Independent Exchange 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

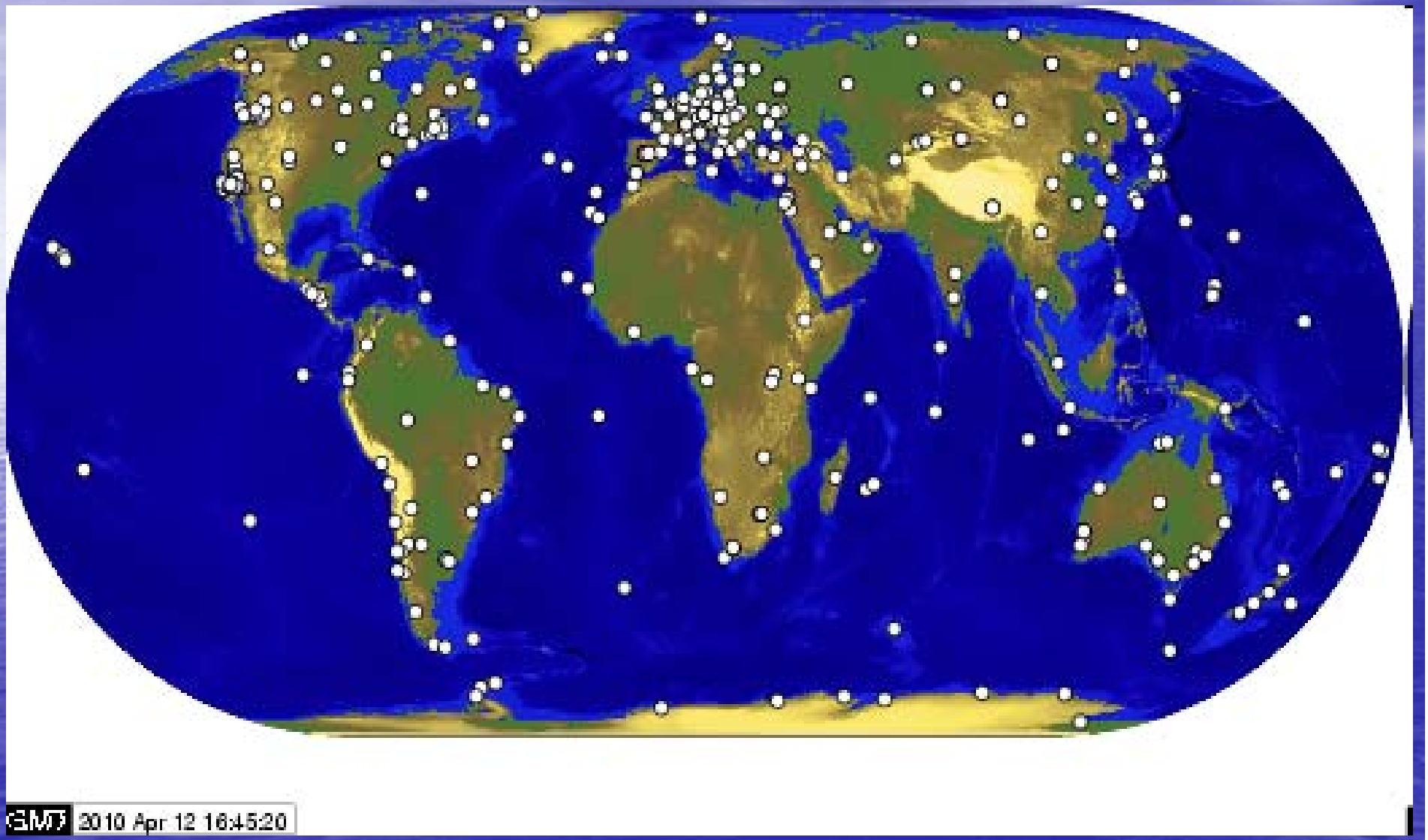
File Type	Containing Information
Observation Data File	GPS Measurements
GPS Navigation Message File	Ephemeris (Orbit information)
CODE bias files	Satellite Biases

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



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

Continuously Operating Reference Stations

National Geodetic Survey

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

Helpful URLS:

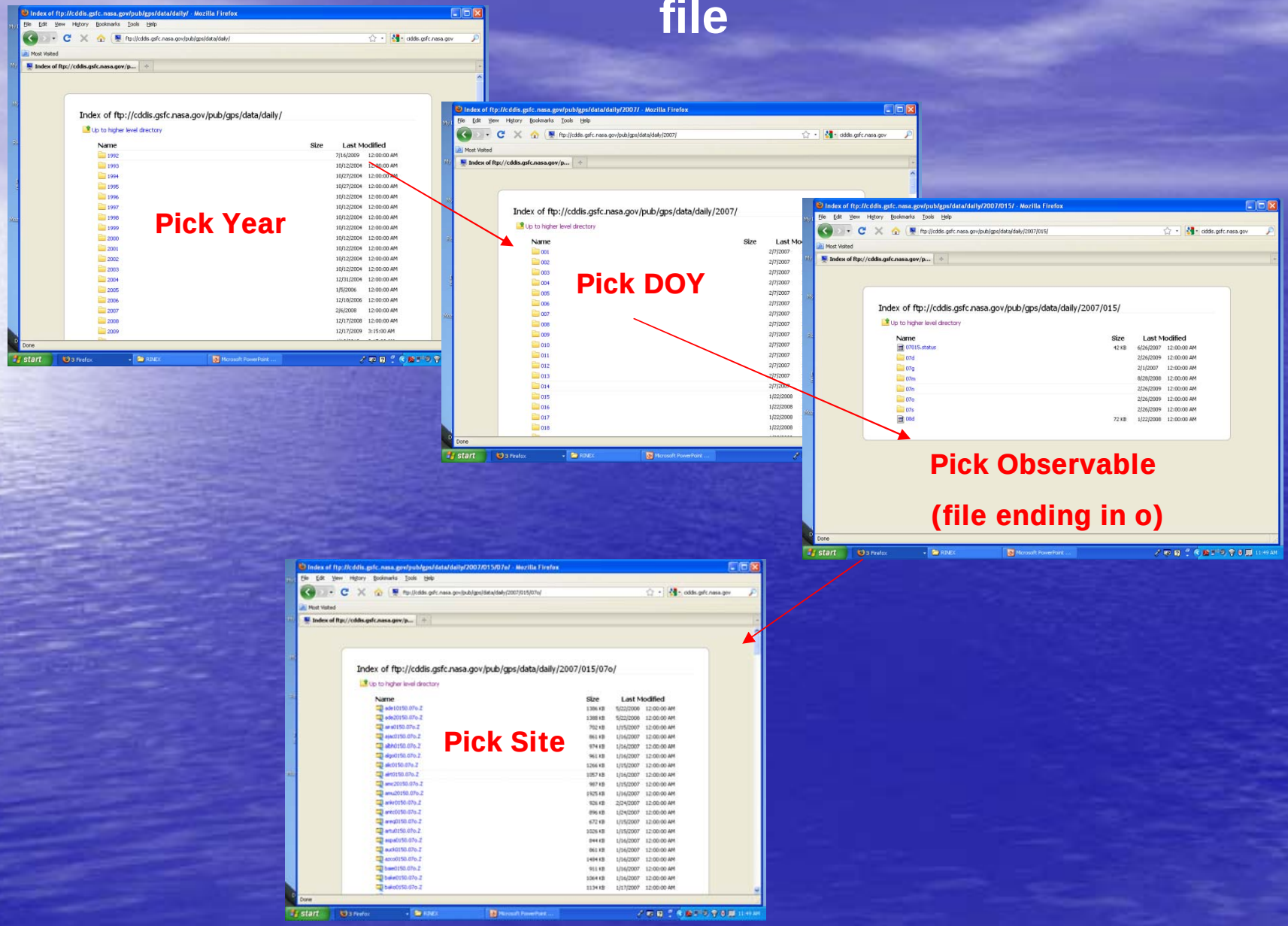
- **IGS Stations**
  - http://igscb.jpl.nasa.gov/network/netindex.html
  - global overview of stations; latitude and longitude of station
- **CODE info**
  - http://www.aiub.unibe.ch/download/CODE/
  - differential code biases
    - P1C1yymm.DCB and P1P2yymm.DCB
      - where yy=year, mm=month
- **Ap/Kp 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

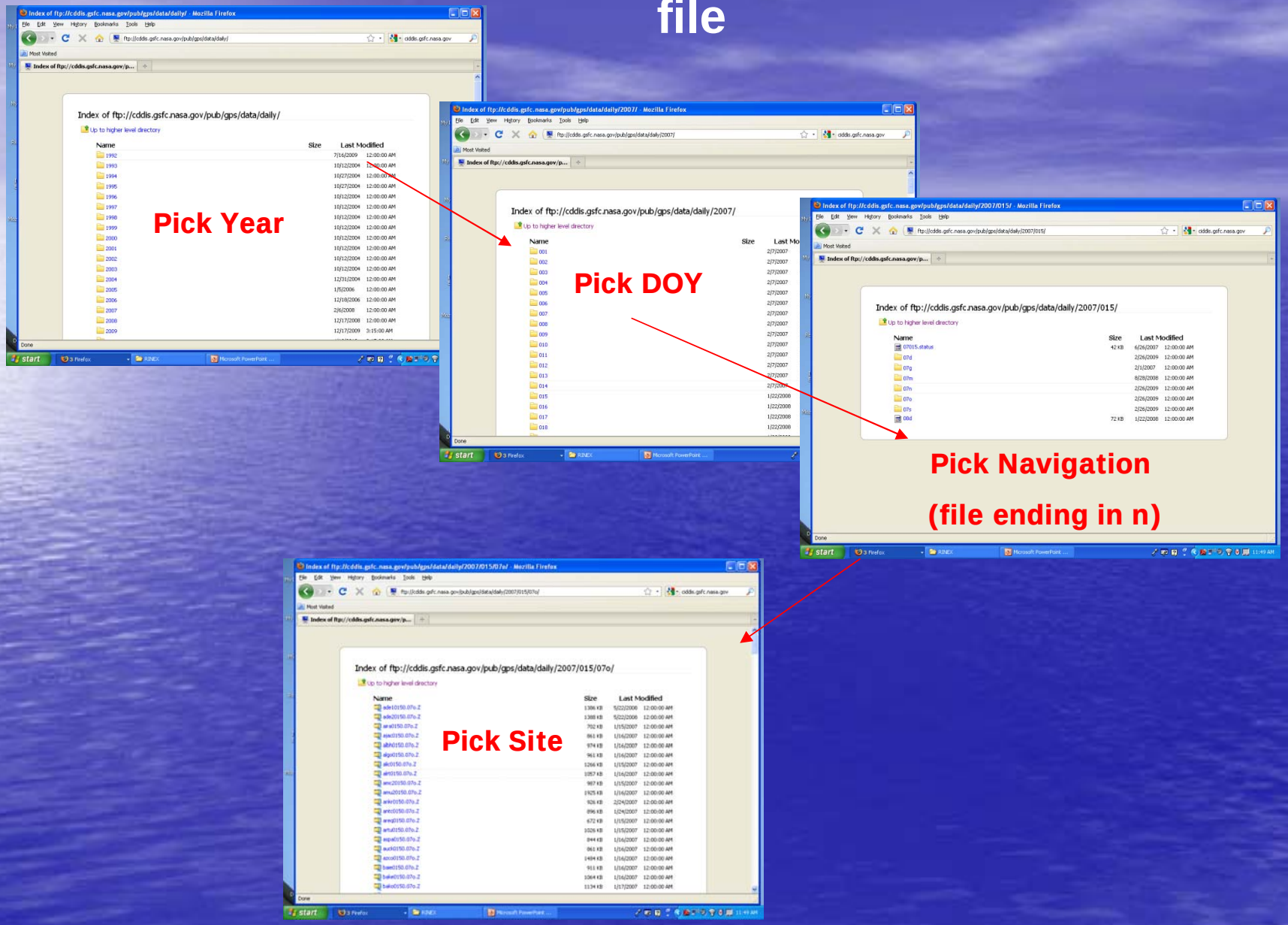
Retrieve Data for Input

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

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

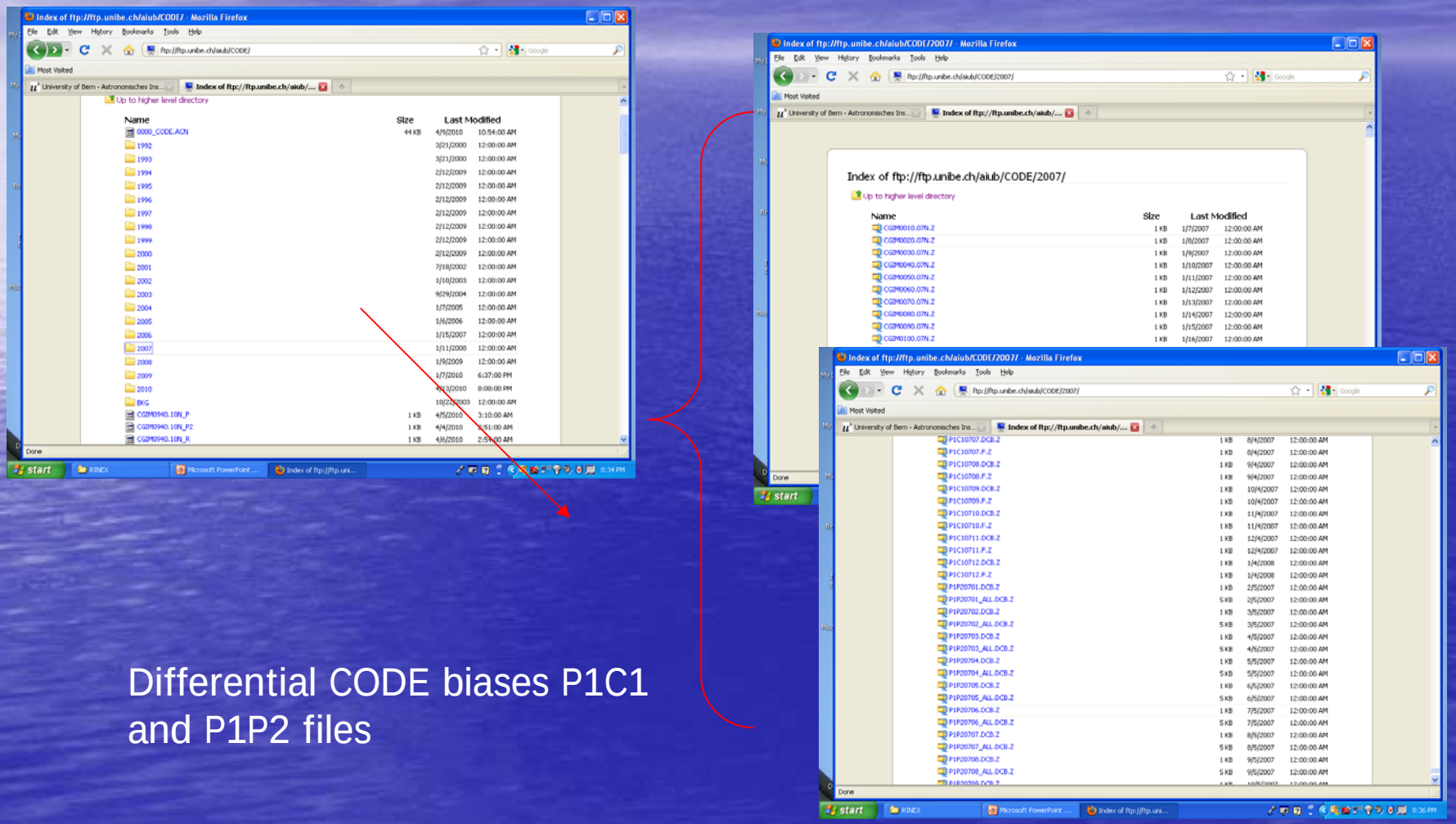


Using ciddis.gsfc.nasa.gov/gps/data/daily to get navigation file



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

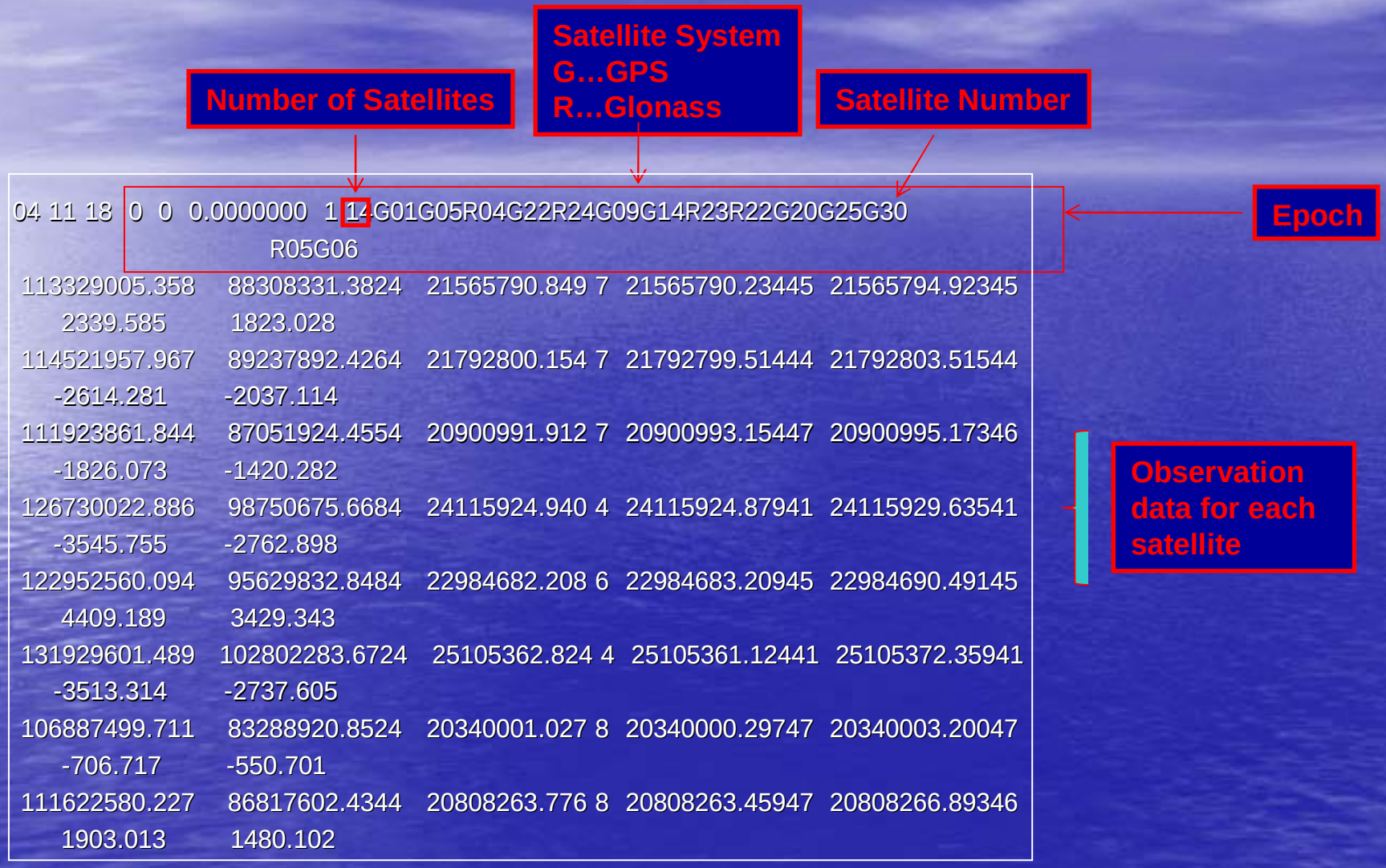
11 November 2004

```
2           OBSERVATION DATA    M (MIXED)           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
```

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

PGM/ RUN BY / DATE	Program, Agency, date of creating the file
REC # / TYPE / VERS	Receiver Number, type, version
ANT # / TYPE	Antenna Number, TYPE
APPROX POSITION XYZ	Approximation marker position (in WGS84)
ANTENNA: DELTA H/E/N	Antenna height, Eccentricities of antenna centre relative to marker in east and north (in meters)
WAVELENGTH FACT L1/2	Wavelength factors for L1 and L2
# / TYPES OF OBSERV	Number of observation types, observation types
TIME OF FIRST OBS	Time of first observation record

RINEX Observation File: Data 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
 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
```

RINEX Observation File: Data Section

L1	L2	C1	P1	P2
113329005.358	88308331.3824	21565790.849	7	21565790.23445
21565794.92345				

D1	D2
2339.585	1823.028

LL1

IP

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

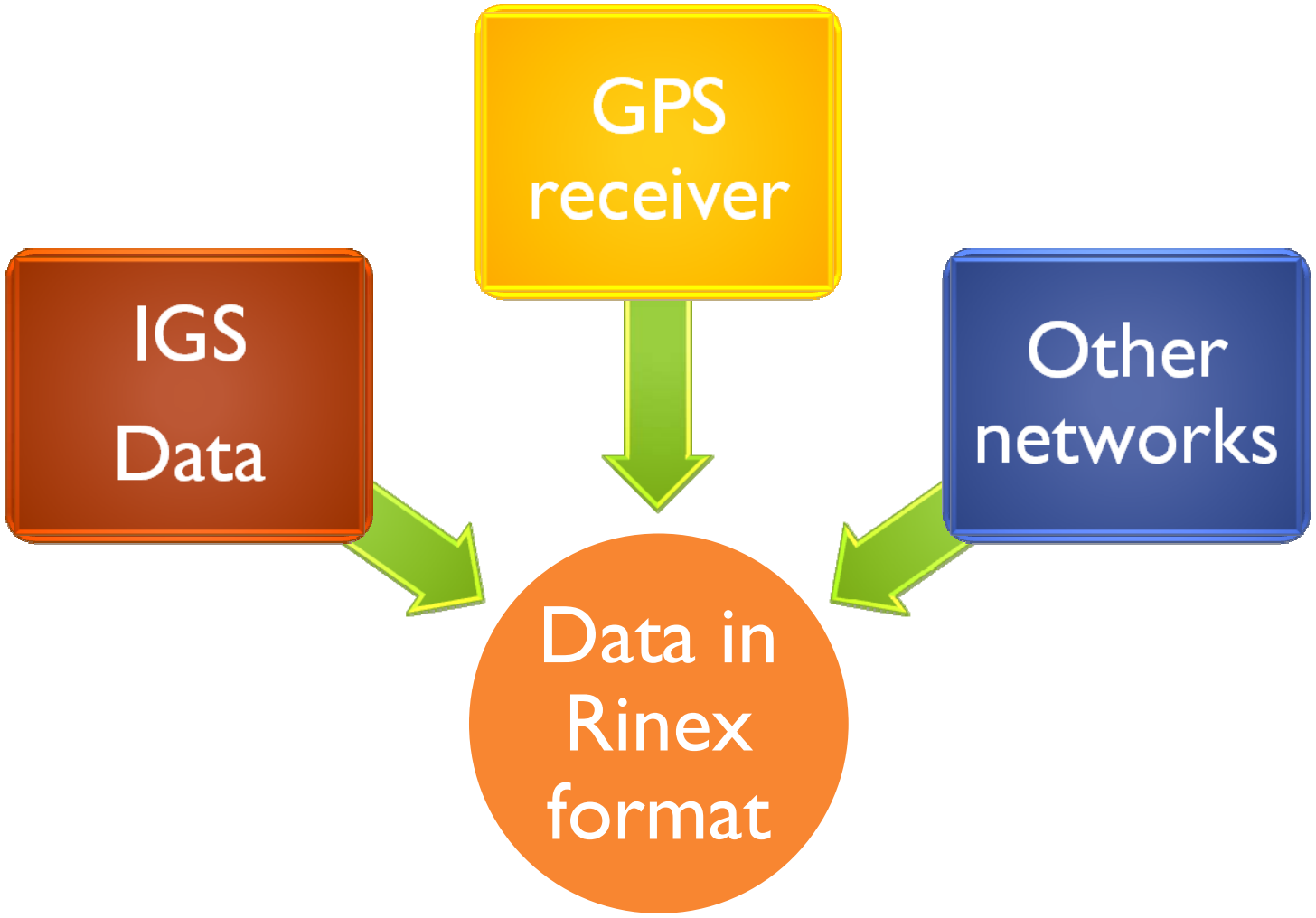
Besides above formats, there are many other data formats available to be recorded from GPS receivers.

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

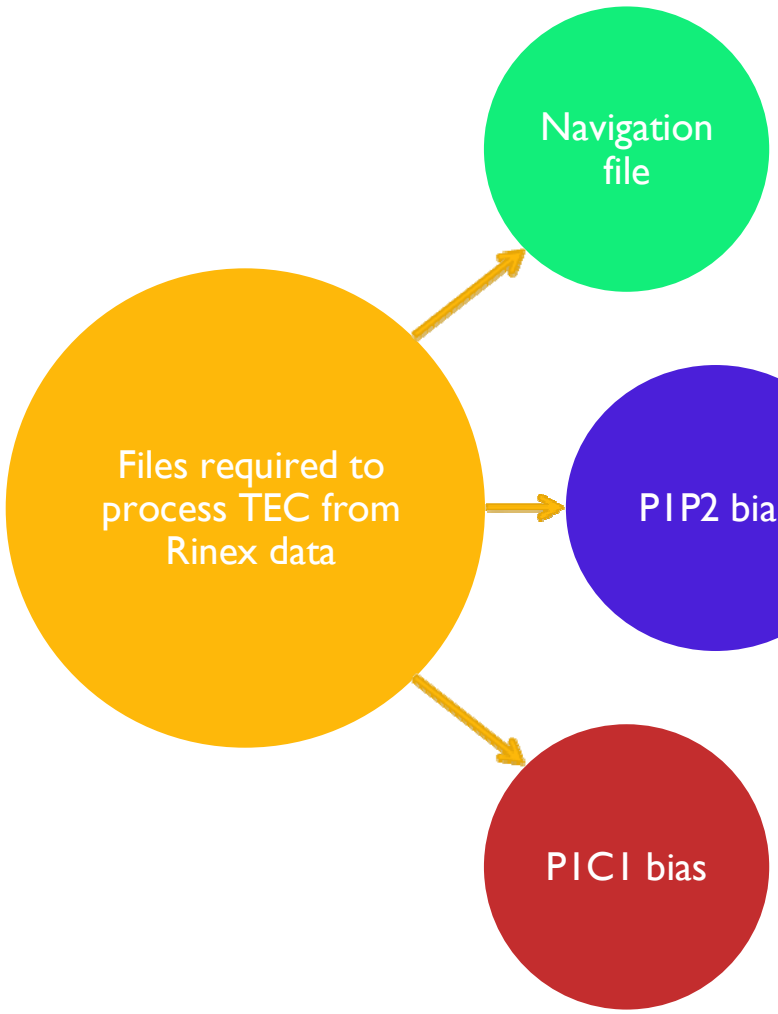
- L1, L2 – Carrier phase measurements in L1,L2 cycles respectively (1,2 represent frequencies 1.575, 1.227 GHz)
- P1, P2 – P-Code or pseudo-range measurements
- C1, C2 – C/A & L2C code measurements (optional)

Data collection

…cont. 2



Navigation and bias files



Contains satellite ephemeris, to calculate the elevation & azimuth angles of satellite; required in the conversion of slant to vertical TEC

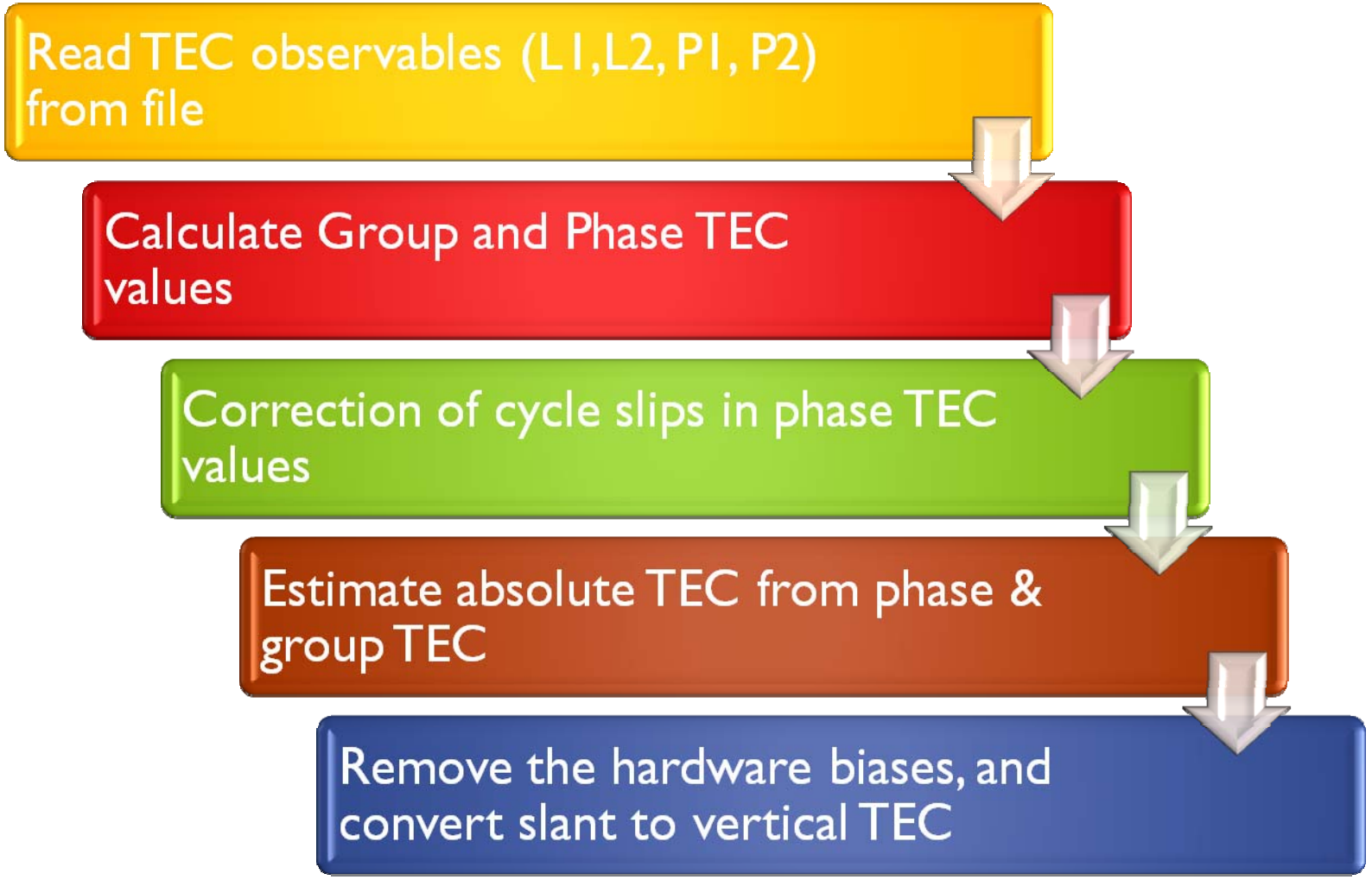
P1P2 DCB code bias files provide satellite bias values that correct P-code pseudo-range observables.

P1C1 DCB code bias files has the bias correction for P1 code to C/A code pseudo ranges.

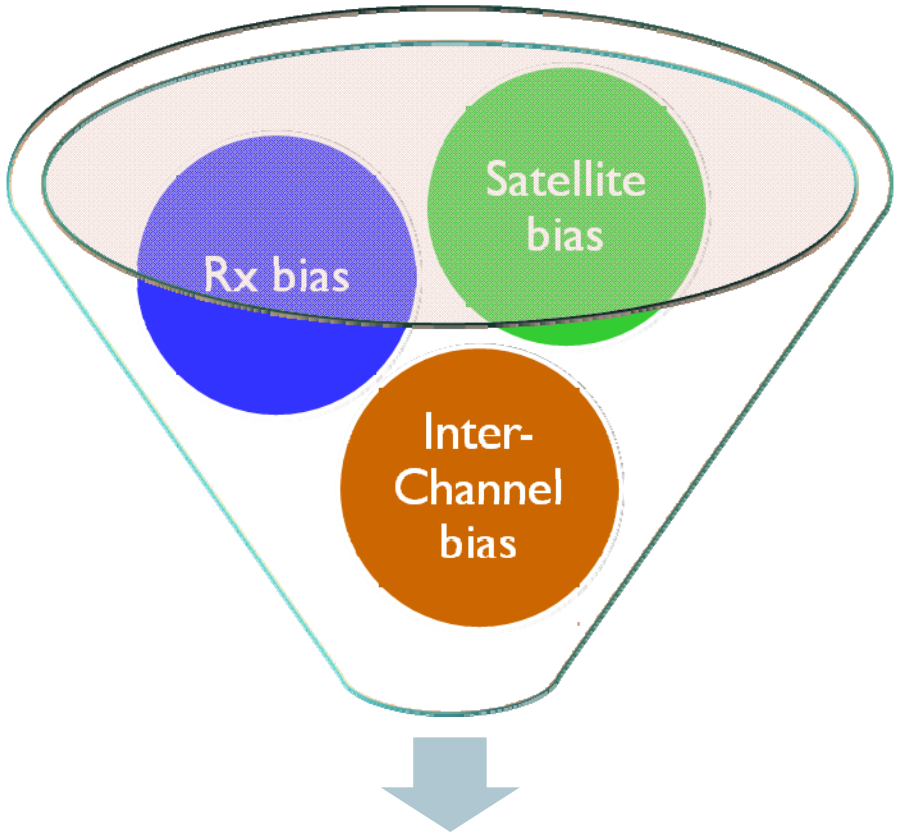
Ephemeris analysis

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

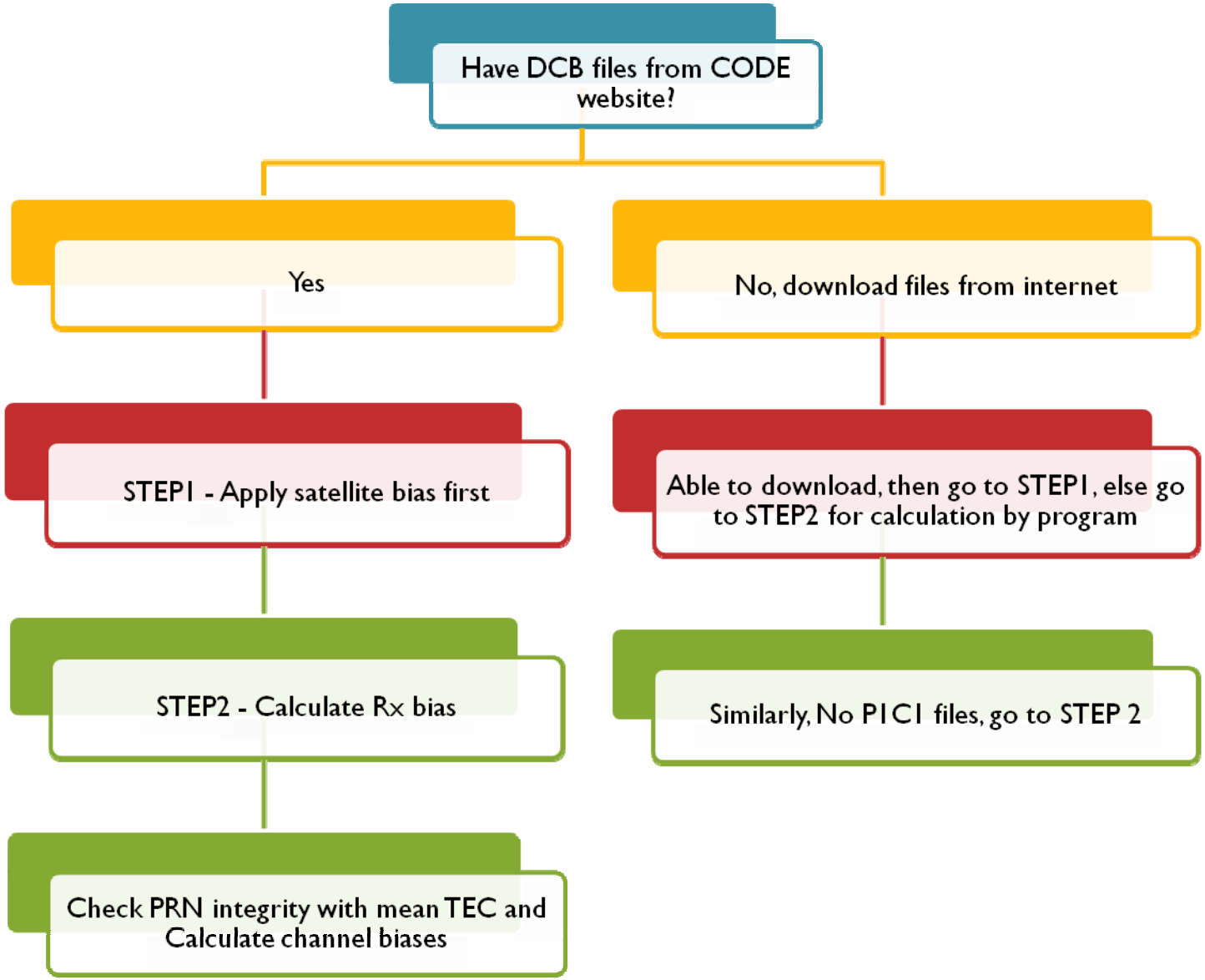


Bias calculation

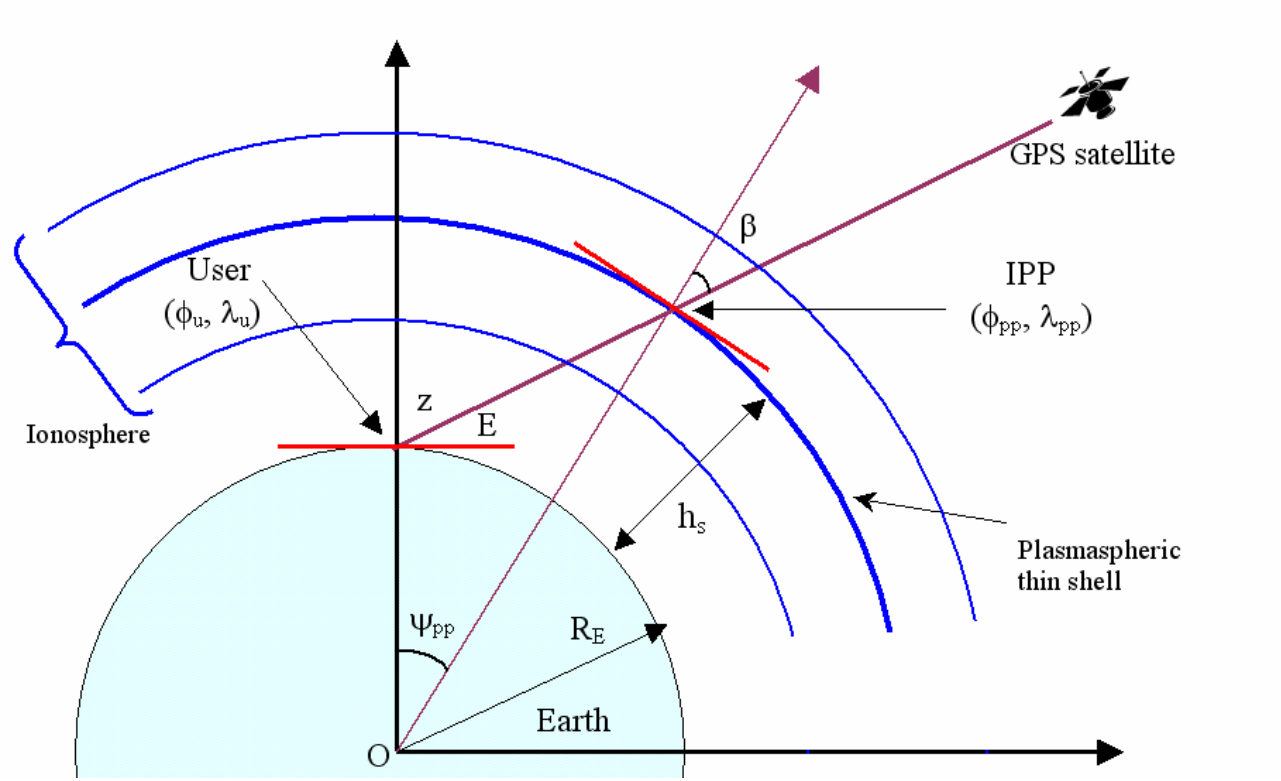


Bias calculation

…cont. 2



Vertical TEC conversion



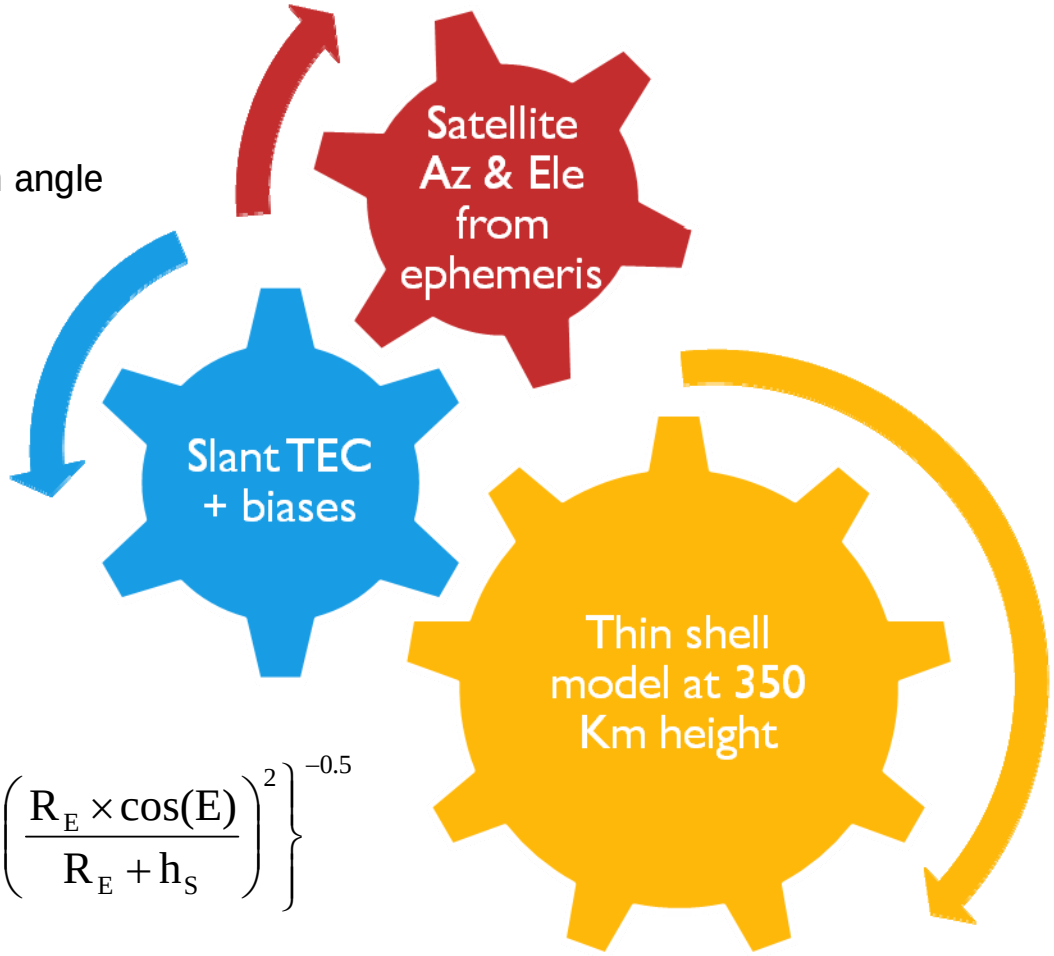
To calculate the VTEC, it was assumed that the ionosphere (and the protonosphere) is spatially uniform, and further it is simplified to a thin layer at an altitude of h_S= 350 km above the earth's surface. This is the thin shell model and its height is the effective height or centroid of the plasmasphere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

Vertical TEC conversion …cont. 2

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

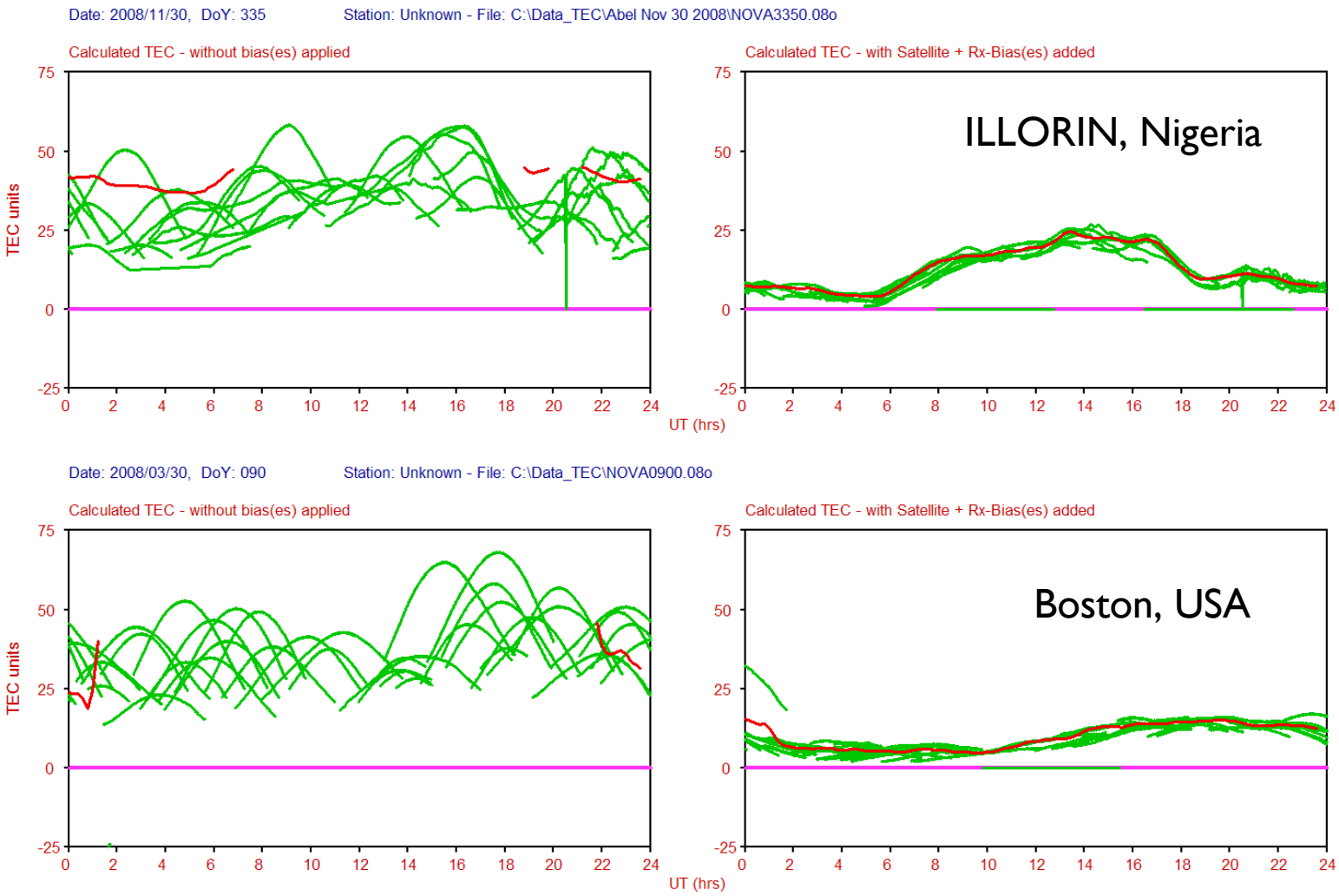
Here
VTEC = vertical TEC
STEC = slant TEC
S(E) is the projection angle given below

RE = radius of earth
E = elevation angle



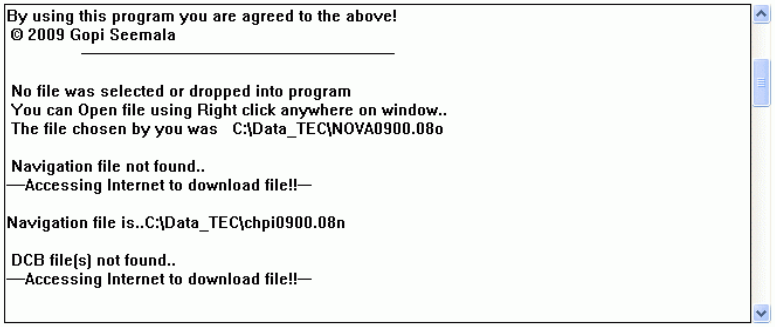
$$S(E) = \frac{1}{\cos(z)} = \left\{1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S}\right)^2\right\}^{-0.5}$$

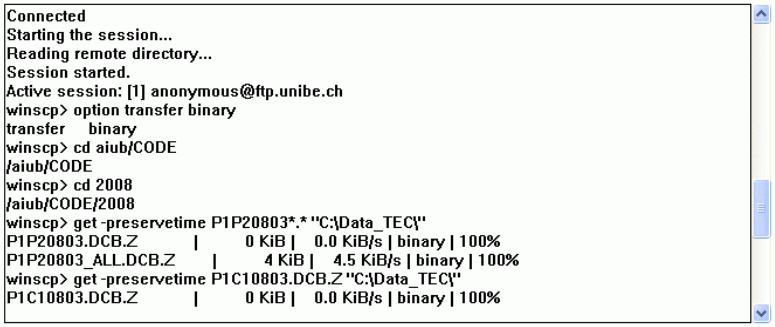
Vertical TEC conversion …cont. 3



Downloading Rinex Navigation & DCB files from FTP

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



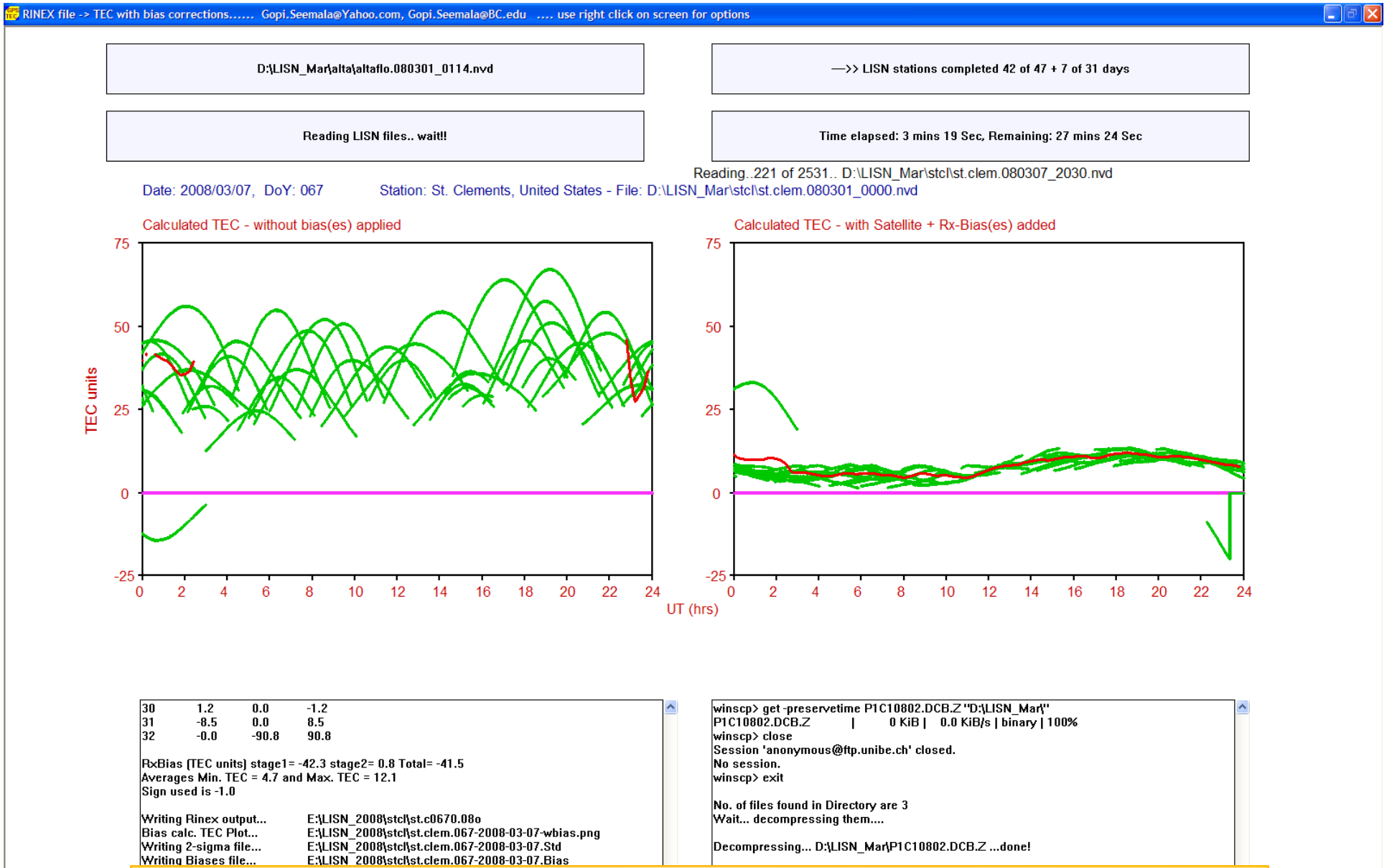


Manually downloading the files into the data directory

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 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..