

## **POST-PROCESS GPS NAVIGATION SOFTWARE DEVELOPMENT**

The laboratory work is to develop the necessary software to solve receiver coordinates for each observation epoch stored in the corresponding RINEX file using the navigation RINEX file.

P2 pseudoranges to the GPS satellites are used as observations and the results are saved to a .txt file, the corresponding graphs should be generated and the solution will be plotted directly to google maps.

The process has three distinct steps that must be linked to solve the system equations.

### **1 Observation RINEX file reading**

89090590.11o file (a car kinematic observation).

The software should read:

- a) Header:
  - APPROX POSITION XYZ
  - ANTENNA: DELTA H/E/N
  - # / TYPES OF OBSERV (a variable should be generated to store the P2 position)
  - TIME OF FIRST OBS
- b) Observations:
  - Beginning of the epoch line/s (if more than 12 satellites have been observed there will be more than one line)
    - Read Epoch
    - Read OK flag
    - Number satellites per epoch
    - Satellite identifier (letter and number)
  - Observations line/s for every satellite (if there is more than 5 observations, two lines per satellite will be used). RINEX format:  
<ftp://igscb.jpl.nasa.gov/pub/data/format/>

<http://gage14.upc.es/gLAB/HTML/LaunchHTML.html>

As an idea, an output file with all the observations can be generated with the format below:

Epoch hour min. Sec. Num\_sats OK\_flag PRN observations

(If there is no a specific observation in the RINEX file for a satellite a “none” should be introduced in the corresponding cell).

## 2 Navigation RINEX file Reading

Coordinates of the satellites ( $X_{Sat}$ ,  $Y_{Sat}$ ,  $Z_{Sat}$ ) in the emission time should be computed (for every epoch and satellite) from brdc0590.11n or 89090590.11n file.

The inputs of this part of the software are the observation epoch, the satellite identification and the P2 observation.

The software could read:

- a) LEAP SECONDS and Alpha and Beta coefficients for the ionospheric delay correction from the header.
- b) Navigation RINEX files enter the orbital parameters for each satellite every two hours and, sometimes, in a random way (this is not the usual if a brdc file is used). The first step is to find the appropriate satellite parameters epoch for the corresponding observation. After that, the reading should be done properly ( $D$  should be replaced by  $e$  in the numerical formats) :
  - <ftp://igscb.jpl.nasa.gov/pub/data/format/>
  - <http://gage14.upc.es/gLAB/HTML/LaunchHTML.html>

The computational procedure can be followed from:

- [http://www.navipedia.net/index.php/GPS\\_and\\_Galileo\\_Satellite\\_Coordinates\\_Computation](http://www.navipedia.net/index.php/GPS_and_Galileo_Satellite_Coordinates_Computation).
- [http://ccar.colorado.edu/asen5050/projects/projects\\_2008/xiaofanli/](http://ccar.colorado.edu/asen5050/projects/projects_2008/xiaofanli/)

Special attention in the calculation of the emission epoch is required, the procedure is:

$$T_{Emis1} = \left( T_{Rec} - \frac{P2}{c} \right) - Toe$$

$T_{Rec}$  is the reception time in GPS week seconds and  $c$  is the speed of light.

If  $T_{Emis1} > 302400$ ,  $T_{Emis1} = T_{Emis1} - 604800$ ; If  $T_{Emis1} < 302400$ ,  $T_{Emis1} = T_{Emis1} + 604800$

In order to correct possible jumps in the GPS week due to the interpolation.

After that, the correction to the satellite clock with respect to the GPS time should be computed using  $a_0$ ,  $a_1$ , and  $a_2$  parameters from the ephemeris file:

$$T_{Corr1} = a_0 + a_1(T_{Emis1}) + a_2(T_{Emis1})^2$$

Where  $Toe$  is the reference time (GPS week seconds) for the orbital ephemeris parameters.

A second computation of the emission time will be performed using this correction:

$$T_{Emis2} = \left( T_{Rec} - \frac{P2}{c} - T_{corr1} \right) - Toe$$

If  $T_{Emis2} > 302400$ ,  $T_{Emis2} = T_{Emis2} - 604800$ ; If  $T_{Emis2} < 302400$ ,  $T_{Emis2} = T_{Emis2} + 604800$

A second calculation of the satellite clock correction is needed:

$$T_{Corr2} = a_0 + a_1(T_{Emis2}) + a_2(T_{Emis2})^2$$

Finally, the emission time is:

$$T_{Emis} = \left( T_{Rec} - \frac{P2}{c} - T_{corr2} \right) - Toe$$

If  $T_{Emis} > 302400$ ,  $T_{Emis} = T_{Emis} - 604800$ ; If  $T_{Emis} < 302400$ ,  $T_{Emis} = T_{Emis} + 604800$

This time ( $T_{Emis}$ ) is the one used to compute the satellite coordinates.

The sequence of computation is:

Semi-Major axis of the satellite orbit (Ephemeris RINEX file gives only the square root):

$$a = (\sqrt{a})^2$$

The mean motion is computed as:

$$n = \sqrt{\frac{\mu}{a^3}} + \Delta n$$

Where  $\mu$  is the geocentric gravitational constant (3.986005e14).

$\Delta n$  is the mean motion difference from computed value, and can be obtained from the navigation RINEX file.

The mean anomaly is found as:

$$M = M_0 + n * T_{Emis}$$

$M_0$  is the Mean anomaly at a reference time, and can be obtained from the navigation RINEX file.

Eccentric anomaly can be found through iterative calculation as:

$$E = M + e * \sin E$$

Where  $E=M$  in the first iteration.  $e$  is the eccentricity of the satellite orbit, and can be obtained from the navigation RINEX file.

The true anomaly is calculated as:

$$\nu = \tan^{-1} \left[ \frac{(\sqrt{1 - e^2} * \sin E)}{(cos E - e)} \right]$$

The argument of latitude is found as:

$$\phi_0 = \nu + \omega$$

Where  $\omega$  is the argument of the perigee and can be obtained from the RINEX navigation file.

The orbital correction terms are:

$$\begin{aligned}\delta u &= C_{us} * \sin 2\phi + C_{uc} * \cos 2\phi \\ \delta r &= C_{rs} * \sin 2\phi + C_{rc} * \cos 2\phi \\ \delta i &= C_{is} * \sin 2\phi + C_{i\bar{s}} * \cos 2\phi\end{aligned}$$

All C terms can be obtained from the RINEX navigation file.

The argument of latitude, radius and inclination are corrected as:

$$\begin{aligned}\phi &= \phi_0 + du \\ r &= a(1 - e * \cos E) + dr \\ i &= i_0 + di + \dot{i} * T_{Emis}\end{aligned}$$

Where  $i_0$  is the inclination angle at reference time and  $\dot{i}$  is the rate of inclination angle, both can be obtained from the RINEX navigation file.

The position in the orbital plane is:

$$\begin{aligned}x_{op} &= r * \cos \phi \\ y_{op} &= r * \sin \phi\end{aligned}$$

The corrected longitude of ascending node is:

$$\Omega = \Omega_0 + (\dot{\Omega} - \Omega_e) * T_{Emis} - \Omega_e * Toe$$

Where  $\Omega_0$  is the longitude of ascending node of the orbit plane at weekly epoch,  $\dot{\Omega}$  is the rate of right ascension (from the navigation RINEX file) and  $\Omega_e$  is the value of the Earth's rotation rate (7.2921151467e-5).

Finally, the satellite coordinates are:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x_{op} * \cos \Omega - y_{op} * \cos i * \sin \Omega \\ x_{op} * \sin \Omega + y_{op} * \cos i * \cos \Omega \\ y_{op} * \sin i \end{bmatrix}$$

Two final corrections should be applied to the computed  $T_{Corr2}$  in order to obtain the final correction to the satellite clock ( $T_{Corr}$ ) to be used in the navigation equations. The first one is a relativistic effect due to the orbit eccentricity:

$$\Delta t_{rel} = -2 \frac{\sqrt{\mu a}}{c} e \sin E$$

Where  $\mu$  is the geocentric gravitational constant (3.986005e14),  $a$  is the semimajor axis,  $e$  is the eccentricity and  $E$  the eccentric anomaly of the satellite orbit.

The second one is the Total Group Delay (TGD), or satellite instrumental bias, the satellites broadcast in their navigation messages this number in seconds for the L1 frequency, so, in order to use it for the L2 frequency the following expression should be used:

$$\Delta t_{TGD}^{L2} = \left(\frac{f_1}{f_2}\right)^2 \Delta t_{TGD}^{L1} = 1.65 \Delta t_{TGD}^{L1}$$

Finally, the clock correction to be used in the equations is:

$$T_{corr} = T_{corr2} + \Delta t_{rel} - \Delta t_{TGD}^{L2}$$

As an idea, ECEF satellite coordinates can be added to the previous output file, including  $T_{corr}$  and  $Sec\_of\_Week$  in each line ("none" in the satellite coordinates if a GLONASS satellite is observed).

### 3 Main module: solving the system equations for every epoch

Only epochs with  $OK\_flag=0$  should be solved.

The process consist of 6 iterations to solve the coordinates of the navigation point for every epoch. The approximate unkowns for the first iteration will be the coordinates and receiver clock correction obtained in the previous epoch and, for the first epoch, the APPROX POSITION XYZ from the observation file and zero for the receiver clock.

The first step, in the iteration process, is to transform the satellite coordinates from the system tied to the earth at "emission time" to the system tied to the earth at "reception time" (which is common for all measurements). In order to do so, one must consider the earth rotation during the time interval that the signal takes to propagate from the satellite to the receiver:

$$\omega\tau = \omega * travel\_time$$

$$travel\_time = \frac{\sqrt{(X_{Sat\_rot} - X_{Est.})^2 + (Y_{Sat\_rot} - Y_{Est.})^2 + (Z_{Sat\_rot} - Z_{Est.})^2}}{c}$$

$$\omega = 7.2921151467e-5 \text{ (Earth rotation speed)}$$

$$R3 = \begin{pmatrix} \cos(\omega\tau) & \sin(\omega\tau) & 0 \\ -\sin(\omega\tau) & \cos(\omega\tau) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} X_{Sat\_rot} \\ Y_{Sat\_rot} \\ Z_{Sat\_rot} \end{pmatrix} = R3 * \begin{pmatrix} X_{Sat} \\ Y_{Sat} \\ Z_{Sat} \end{pmatrix}$$

The elevation and azimuth for every satellite at every epoch should be computed (coordinate transformation from X, Y, Z to Latitude, Longitude and elliposoidal height, and transformation to horizontal coordinates: dN, dE, dh, elevation and azimuth), only satellites with an elevation higher than 10 degrees will form an equation.

Tropospheric delay should be computed using the Saastamoinen method ((Hoffmann, Lichtenegger, Wasle (2008): GNSS global navigation satellite systems, pg. 135)):

$$d_{Tropo} = \frac{0.002277}{\cos(z)} \left[ p + \left( \frac{1255}{T} + 0.05 \right) e - B \tan^2(z) \right] + dR$$

Where  $z$  is the satellite zenith angle, and the theoretical values for pressure,  $p$  (in Millibars), temperature,  $T$  (in Kelvin degrees), and  $e$  the partial pressure of water vapor (in Millibars) can be obtained from:

$$\text{Pres} = 1013.25 * (1 - 0.000065 * h_{ECEF})^{**}(5.225)$$

$$\text{Temp} = 291.15 - 0.0065 * h_{ECEF}$$

$$H = 50 * \text{numpy.exp}(-0.0006396 * h_{ECEF})$$

$$e_{wp} = (H * 0.01) * \text{numpy.exp}(-37.2465 + 0.213166 * \text{Temp} + 0.000256908 * \text{Temp}^2))$$

$H$  is the humidity in % and the orthometric height is assumed to be the ellipsoidal height.

$dR$  correction will not be implemented and  $B$  parameter (a correction which depends on the station height), can be computed from the table below:

| High (Km) | B (mb) |
|-----------|--------|
| 0.0       | 1.156  |
| 0.5       | 1.079  |
| 1.0       | 1.006  |
| 1.5       | 0.938  |
| 2.0       | 0.874  |
| 2.5       | 0.813  |
| 3.0       | 0.757  |
| 4.0       | 0.654  |
| 5.0       | 0.563  |

Finally, the ionospheric delay ( $d_{ion}$ ), should be taken into account using the Klobuchar model:

- [http://www.navipedia.net/index.php/Klobuchar\\_Ionospheric\\_Model](http://www.navipedia.net/index.php/Klobuchar_Ionospheric_Model)

The sequence for the calculation is:

1.- Calculate the Earth-center angle (elevation E in semicircles: E(in degrees/180)

$$\psi = \frac{0.0137}{E + 0.11} - 0.022 \quad (\text{semicircles})$$

2.- Compute the latitude of the ionospheric Pierce Point (IPP). A is the azimuth of the satellite (in radians) and  $\phi_u$  is the geodetic latitude (in semicircles: latitude in degrees / 180) of the user (rover receiver).

$$\phi_i = \phi_u + \psi \cos A \quad (\text{semicircles})$$

$$\begin{aligned} &\text{if } \phi_1 > 0.416 \rightarrow \phi_1 = 0.416 \\ &\text{if } \phi_1 < -0.416 \rightarrow \phi_1 = -0.416 \end{aligned}$$

3.- Compute the longitude of the IPP.  $\lambda_u$  is the geodetic longitude (in semicircles: longitude in degrees / 180) of the user (rover receiver). A and  $\phi_i$  in radians.

$$\lambda_i = \lambda_u + \frac{\psi \sin A}{\cos \phi_i} \quad (\text{semicircles})$$

4.- Find the geomagnetic latitude of the IPP. ( $\lambda_i - 1.617$ ) should be multiplied by  $\pi$  in order to transform to radians for the calculation of the cosinus.

$$\phi_m = \phi_i + 0.064 \cos(\lambda_i - 1.617) \quad (\text{semicircles})$$

5.- Find the local time at the IPP.

$$t = 43200 * \lambda_i + t_{\text{sec of week}} \quad (\text{seconds})$$

where  $t \leq 86400$ ,

therefore: if  $t \geq 86400$ , subtract 86400. If  $t < 0$ , add 86400

6.- Compute the amplitude of ionospheric delay.

$$A_i = \sum_{n=0}^3 \alpha_n \phi_m^n \text{ (seconds)}$$

If  $A_i < 0$ , thence  $A_i = 0$

7.- Compute the period of ionospheric delay.

$$P_i = \sum_{n=0}^3 \beta_n \phi_m^n \text{ (seconds)}$$

If  $P_i < 72000$ , thence  $P_i = 72000$

8.- Compute the phase of ionospheric delay.

$$X_i = \frac{2\pi(t - 50400)}{P_i} \text{ (radians)}$$

9.- Compute the slant factor (elevation  $E$  in semicircles)

$$F = 1.0 + 16.0(0.53 - E)^3$$

10.- Compute the ionospheric time delay.

$$I_{L1} = \begin{cases} \left[ 5 \cdot 10^{-9} + A_i \left( 1 - \frac{X_I^2}{2} + \frac{X_I^4}{24} \right) \right] * F & ; |X_i| \leq 1.57 \\ 5 \cdot 10^{-9} & ; |X_i| \geq 1.57 \end{cases}$$

11.- Compute the ionospheric time delay for L2 (seconds).

$$I_{L2} = \left( \frac{f_{L1}}{f_{L2}} \right)^2 * I_{L1} = 1.65 * I_{L1}$$

12.- Transform to meters ( $c$  is the speed of light):

$$I_{L2}(m) = I_{L2}(s) * c$$

In the system equations for every epoch, each satellite generates the following equation:

$$\begin{aligned} & \left[ -\frac{(X_{Sat\_rot} - X_{Sta})}{Dist} - \frac{(Y_{Sat\_rot} - Y_{Sta})}{Dist} - \frac{(Z_{Sat\_rot} - Z_{Sta})}{Dist} \quad 1 \right] \\ & = [P2 - Dist - dT_{Pre.Ite.}^{Rec.} + c * T_{corr} - d_{Trop} - d_{Ion}] \end{aligned}$$

Where  $Dist. = \sqrt{(X_{Sat\_rot} - X_{Sta.})^2 + (Y_{Sat\_rot} - Y_{Sta.})^2 + (Z_{Sat\_rot} - Z_{Sta.})^2}$

And the weight is:

$$Pi = \frac{\sin(el_i)^2}{e_{P2}^2}$$

Where  $e_{P2}$  is equal to  $1.5 * (0.30)$  meters (Hofmann et al. 2008).

The parameters to be solved are the coordinates of the navigation point, and the delay of the receiver clock (the solution will be obtained in meters, for a time units the solution should be divided by the speed of light).

The final solution should will be saved in a file with the following columns:

Hour Min. Sec. X Y Z Xerror Yerror Zerror Lat. Lon. h

Only the solutions with an error less than 1.5 multiplied by the mean error of all the navigation points (máximum error value again), will be plotted using matplotlib library. The plots to be generated are: (X, Y, X), (Lat., Lon.) and (h).

Finally, the .html file will be generated using Pygmaps library, placing a circle for every navigation epoch on google maps. The web navigator should be open directly from the software using webbrowser library.

## 4 Partial Results

### Orbital Parameters

epoch 1

```

satellite= 2.0
hour_ref (navigation file hour-epoch hour)= 0.469444444444
jde= 2455621.0637731482275
sec_of_week= 135110.000007
TEmis1= 135109.924863
Toe= 136800.0
dt_eph0(TEmis1-Toe)= -1690.07513741
TCorr1= 0.000322746571865

```

dt\_eph1((T<sub>Emis1</sub>-T<sub>Corr1</sub>)-Toe)= -1690.07546015  
T\_coor2= 0.000322746571864  
dt\_eph2((T<sub>Emis1</sub>-T<sub>Corr2</sub>)-Toe)= -1690.07546015  
mean motion= 0.000145856177504  
mean anomaly= -1.49519531165  
ano\_ecc= -1.50522458968  
true\_ano= -1.51525734066  
phi= -4.58635680549  
T<sub>rel</sub>= 2.29639815455e-08  
T<sub>Corr</sub>= 0.000322797964467  
du= -2.69086694427e-06  
dr= -238.072496744  
di= 1.25158610262e-09  
u\_eph= -4.58635949635  
r\_eph= 26543000.1928  
i\_eph= 0.939351632001  
omega= -9.23134314432  
x1= -3336352.10533  
y1= 1 26332482.1061  
sat\_x= 6262234.04949  
sat\_y= -14613110.9779  
sat\_z= 21254935.2267

satellite= 4.0  
hour ref= (navigation file hour-epoch hour)=(14:00:00-  
13:31:50)=0.469444444444  
jde= 2455621. 0637731482275  
sec\_of\_week= 135110.000007  
T<sub>Emis1</sub>= 135109.931313  
toe= 136800.0  
dt\_eph0(T<sub>Emis1</sub>-Toe )= -1690.06868701  
T<sub>Corr1</sub> = 4.78864889998e-05  
dt\_eph1 ((T<sub>Emis1</sub>-T<sub>Corr1</sub>)-Toe)= -1690.06873489  
T<sub>Corr2</sub>= 4.78864889998e-05  
dt\_eph2 ((T<sub>Emis1</sub>-T<sub>Corr2</sub>)-Toe)= -1690.06873489  
T<sub>rel</sub>= -2.19797297574e-08  
T<sub>Corr</sub>= 4.78744977042e-05  
mean\_motion= 0.00014586579188  
mean\_anomaly= 1.52824192856  
ano\_ecc= 1.5378415543  
true\_ano= 1.54744284698  
phi= 2.25971282235  
du= -7.11183316323e-06  
dr= -67.0188662344  
di= 2.45406585183e-08  
u\_eph= 2.25970571052  
r\_eph= 26551099.9286  
i\_eph= 0.93843559198  
omega= -9.21384712706

```

x1= -16878419.2681
y1= 20495850.0782
sat_x= 19040662.0127
sat_y= -8311756.52015
sat_z= 16532658.6212
...
...
...
satellite= 23.0
hour ref= (navigation file hour-epoch hour)=(14:00:00-
13:31:50)=0.469444444444
jde= 2455621. 0637731482275
sec_of_week= 135110.000007
TEmis1= 135109.927325
toe= 136800.0
dt_eph0 (TEmis1-Toe)= -1690.07267501
TCorr1= 0.000323132455779
dt_eph1((TEmis1-TCorr1)-Toe)= -1690.07299814
TCorr2= 0.000323132455779
dt_eph2 ((TEmis1-TCorr2)-Toe)= -1690.07299814
Trel=1.59123485071e-08
Tcorr=0.000323181406797
mean_motion= 0.000145865413454
mean_anomaly= -1.44951718329
ano_ecc= -1.45646690052
true_ano= -1.46341944901
phi= 1.66630620623
du= -5.12121056468e-06
dr= -204.234152066
di= 5.67837878201e-08
u_eph= 1.66630108502
r_eph= 26538062.5133
i_eph= 0.965516493005
omega= -7.10926601189
x1= -2530660.05432
y1= 26417125.5373
sat_x= 9336918.79375
sat_y= 12048291.2834
sat_z= 21723935.7979

```

## **Parameters for the system equations**

Epoch 1

itera = 1

Satellite values:

sat\_id=G02  
omegatau= 5.49875083649e-06  
sat\_x\_rot= 6262153.69554  
sat\_y\_rot= -14613145.4121  
sat\_z\_rot= 21254935.2267  
el\_sat= 32.1926877409  
aci\_sat= 310.365695268

troposphere:

relative\_humidity= 9.88283763309  
corr\_trop= 4.43538019603

ionosphere:

psi= 0.0254297465115  
lat\_i= 0.235810850931  
lon\_i= -0.0281147580174  
lat\_gm= 0.263987676582  
l\_t= 47495.4424605  
sf= 1.69279450999  
A\_i= 1.50664711795e-08  
per= 87300.3907406  
dIon= 10.0170140051  
dIon\*1.65= 16.528073108

sat\_id=G04

Satellite Values:

omegatau= 5.00833545146e-06  
sat\_x\_rot= 19040620.3844  
sat\_y\_rot= -8311851.88207  
sat\_z\_rot= 16532658.6212  
el\_sat= 66.4528487462  
aci\_sat= 274.491856591

Troposphere:

Relative\_humidity= 9.88283763309  
corr\_trop= 2.57901336887

ionosphere:

psi= 0.0065903600385  
lat\_i= 0.21985706383  
lon\_i= -0.0103812917082  
lat\_gm= 0.244790455634  
l\_t= 48261.5282051  
sf= 1.06654569398

A\_i= 1.48442380443e-08  
per= 89756.3764061  
dIon= 6.29196077549  
dIon\*1.65= 10.381735279

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sat\_id=G23

satellite values:

omegatau= 5.31922601949e-06  
sat\_x\_rot= 9336982.8812  
sat\_y\_rot= 12048241.6181  
sat\_z\_rot= 21723935.7979  
el\_sat= 41.8680881185  
aci\_sat= 48.0022627314

Troposphere:

Relative\_humidity= 9.88283763309  
corr\_trop= 3.54108651306

ionosphere:

psi= 0.0179882674368  
lat\_i= 0.231376896304  
lon\_i= 0.0160327171571  
lat\_gm= 0.251338857388  
l\_t= 49402.613388  
sf= 1.42086298444  
A\_i= 1.49162920008e-08  
per= 88927.9419704  
dIon= 8.46785344086  
dIon\*1.65= 13.971958177

...

...

...

itera = 6

sat\_id=G02

Satellite values:

omegatau= 5.4987512563e-06  
sat\_x\_rot= 6262153.69553  
sat\_y\_rot= -14613145.4122  
sat\_z\_rot= 21254935.2267  
el\_sat= 32.1926980946  
aci\_sat= 310.365692316

Troposphere:

Relative\_humidity= 9.92074206773

corr\_trop= 4.44133822047

ionosphere:  
psi= 0.0254297370664  
lat\_i= 0.235810867169  
lon\_i= -0.0281147459783  
lat\_gm= 0.263987690647  
l\_t= 47495.4429806  
sf= 1.69279416954  
A\_i= 1.09129771063e-08  
per= 87300.3889115  
dIon= 7.95505738179  
dIon\*1.65= 13.1258446799

Sat\_id=G04

Satellite values:  
omegatau= 5.00833626485e-06  
sat\_x\_rot= 19040620.3844  
sat\_y\_rot= -8311851.88208  
sat\_z\_rot= 16532658.6212  
el\_sat= 66.4528523773  
aci\_sat= 274.491844111

Troposphere:

Relative\_humidity = 9.92074206773  
corr\_trop= 2.58247726226

Ionosphere:  
psi= 0.00659035883489  
lat\_i= 0.219857085659  
lon\_i= -0.0103812861186  
lat\_gm= 0.244790476427  
l\_t= 48261.5284465  
sf= 1.06654566894  
A\_i= 1.12728645771e-08  
per= 89756.3737914  
dIon= 5.16281244185  
dIon\*1.65= 8.51864052906

...

...

...

Sat\_id=G23

Satellite values:  
omegatau= 5.31922654288e-06  
sat\_x\_rot= 9336982.8812  
sat\_y\_rot= 12048241.6181  
sat\_z\_rot= 21723935.7979

el\_sat= 41.8680991394  
aci\_sat= 48.0022667268

Troposphere:

Relative\_humidity = 9.92074206773  
corr\_trop= 3.54584303856

ionosphere:

psi= 0.0179882602904  
lat\_i= 0.231376913944  
lon\_i= 0.0160327167164  
lat\_gm= 0.251338875112  
l\_t= 49402.613369  
sf= 1.42086272451  
A\_i= 1.11512868845e-08  
per= 88927.9397148  
dIon= 6.86807603209  
dIon\*1.65= 11.332325453

## Final coordinates

| Hour | minute | second | X             | Y              | Z             | Satellite number |                 |         |
|------|--------|--------|---------------|----------------|---------------|------------------|-----------------|---------|
| 13   | 31     | 50.0   | 4929474.94651 | -28766.5668131 | 4033738.32092 | 9                |                 |         |
|      |        |        | eX            | eY             | eZ            | Latitude         | Longitude       | h       |
|      |        |        | 0.7737        | 0.3694         | 0.5796        | 39.4813705133    | -0.334352883046 | 48.7464 |
| Hour | minute | second | X             | Y              | Z             | Satellite number |                 |         |
| 13   | 31     | 55.0   | 4929475.16583 | -28766.257238  | 4033738.30884 | 9                |                 |         |
|      |        |        | eX            | eY             | eZ            | Latitude         | Longitude       | h       |
|      |        |        | 1.0261        | 0.4900         | 0.7689        | 39.4813691837    | -0.334349270071 | 48.9066 |
| ...  |        |        |               |                |               |                  |                 |         |
| ...  |        |        |               |                |               |                  |                 |         |
| Hour | minute | second | X             | Y              | Z             | Satellite number |                 |         |
| 14   | 4      | 20.0   | 4929472.01463 | -28762.8753547 | 4033740.09682 | 9                |                 |         |
|      |        |        | eX            | eY             | eZ            | Latitude         | Longitude       | h       |
|      |        |        | 1.2659        | 0.5950         | 1.0507        | 39.4813997726    | -0.33431017715  | 47.5961 |
| Hour | minute | second | X             | Y              | Z             | Satellite number |                 |         |
| 14   | 4      | 25.0   | 4929471.37283 | -28762.8722439 | 4033739.80181 | 9                |                 |         |
|      |        |        | eX            | eY             | eZ            | Latitude         | Longitude       | h       |
|      |        |        | 1.3494        | 0.6341         | 1.1202        | 39.4814013973    | -0.334310184518 | 46.9131 |