Tutorial 4

Detailed code measurements modelling

Professors Dr. Jaume Sanz Subirana, Dr. J. M. Juan Zornoza

and Dr. Adrià Rovira Garcia

Research group of Astronomy & Geomatics (gAGE)
Universitat Politècnica de Catalunya (UPC)
Barcelona, Spain

gAGE/UPC

Research group of Astronomy & Geomatics
Technical University of Catalonia

Detailed Computation of modeled pseudorange

Using files **UPC11490.05O** and **UPC11490.05N** compute the SPP solution.

Afterwards, calculate by hand the modelled C1 pseudo-range and the pre-fit residual for satellite PRN25 at time **t = 300** seconds of day 29 May 2005 (Day Of Year 149).

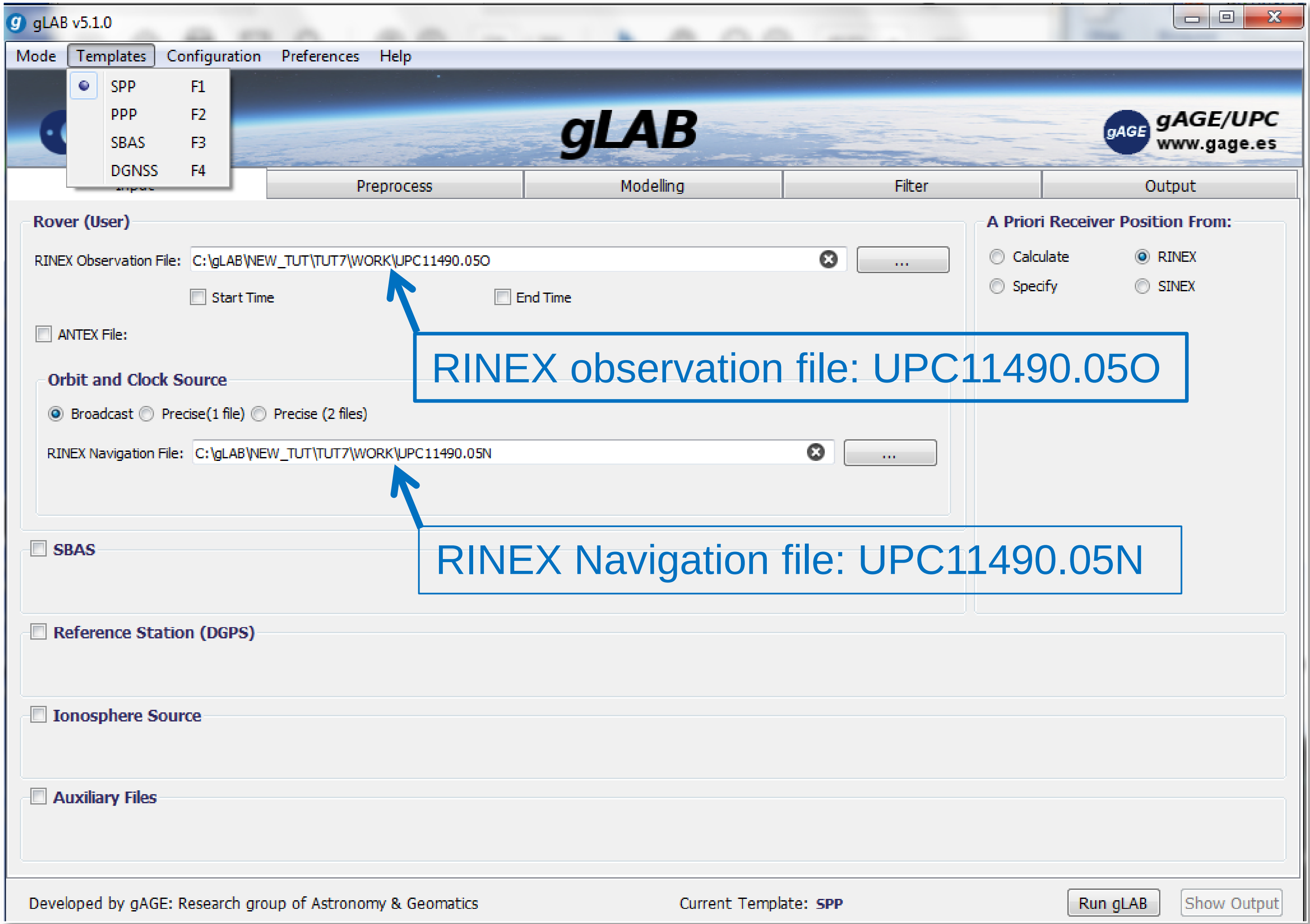
$$\boxed{C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}}$$

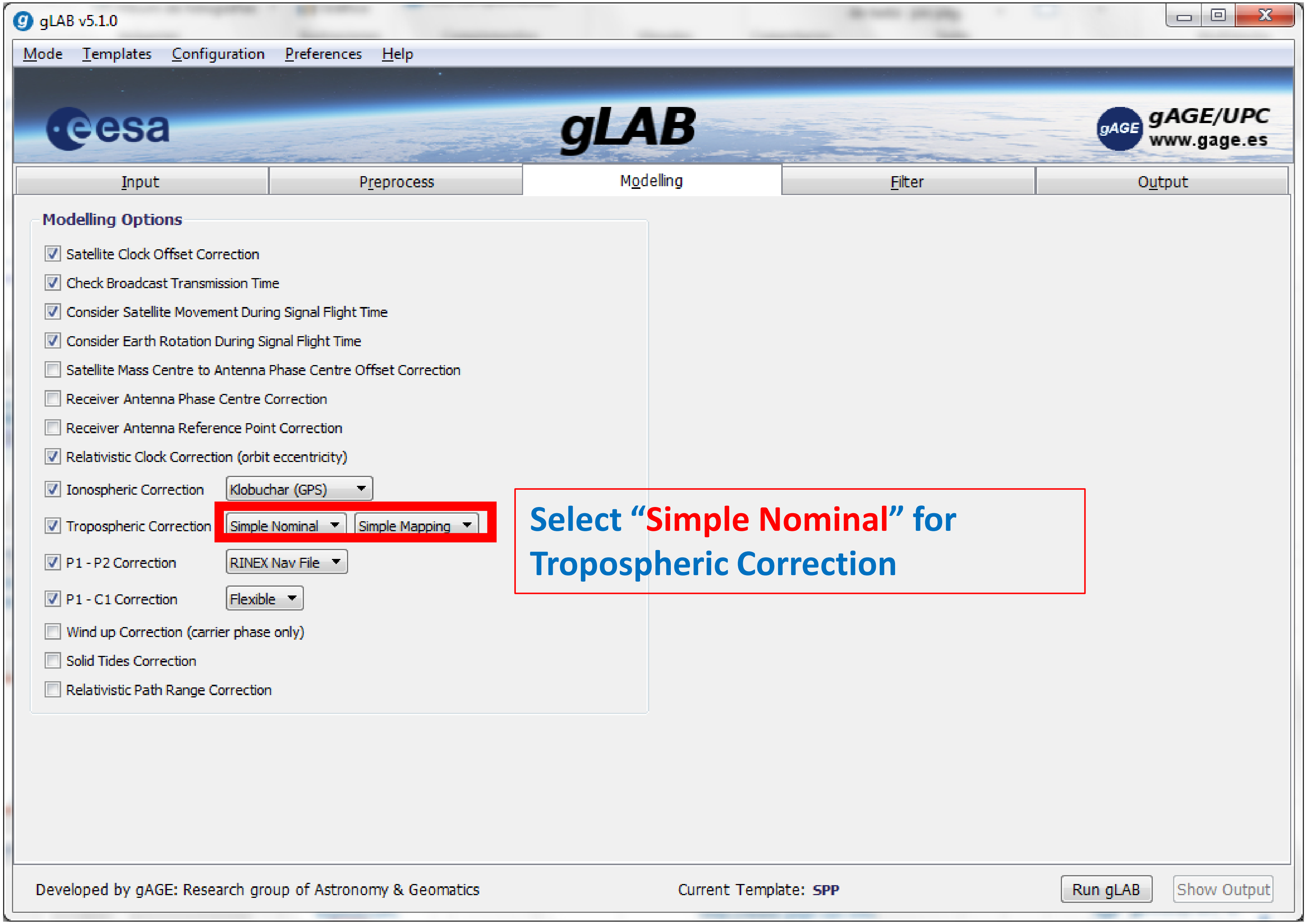
Compare the results with gLAB.

NOTE: use the Simple Nominal Model an Mapping for Tropospheric Correction.

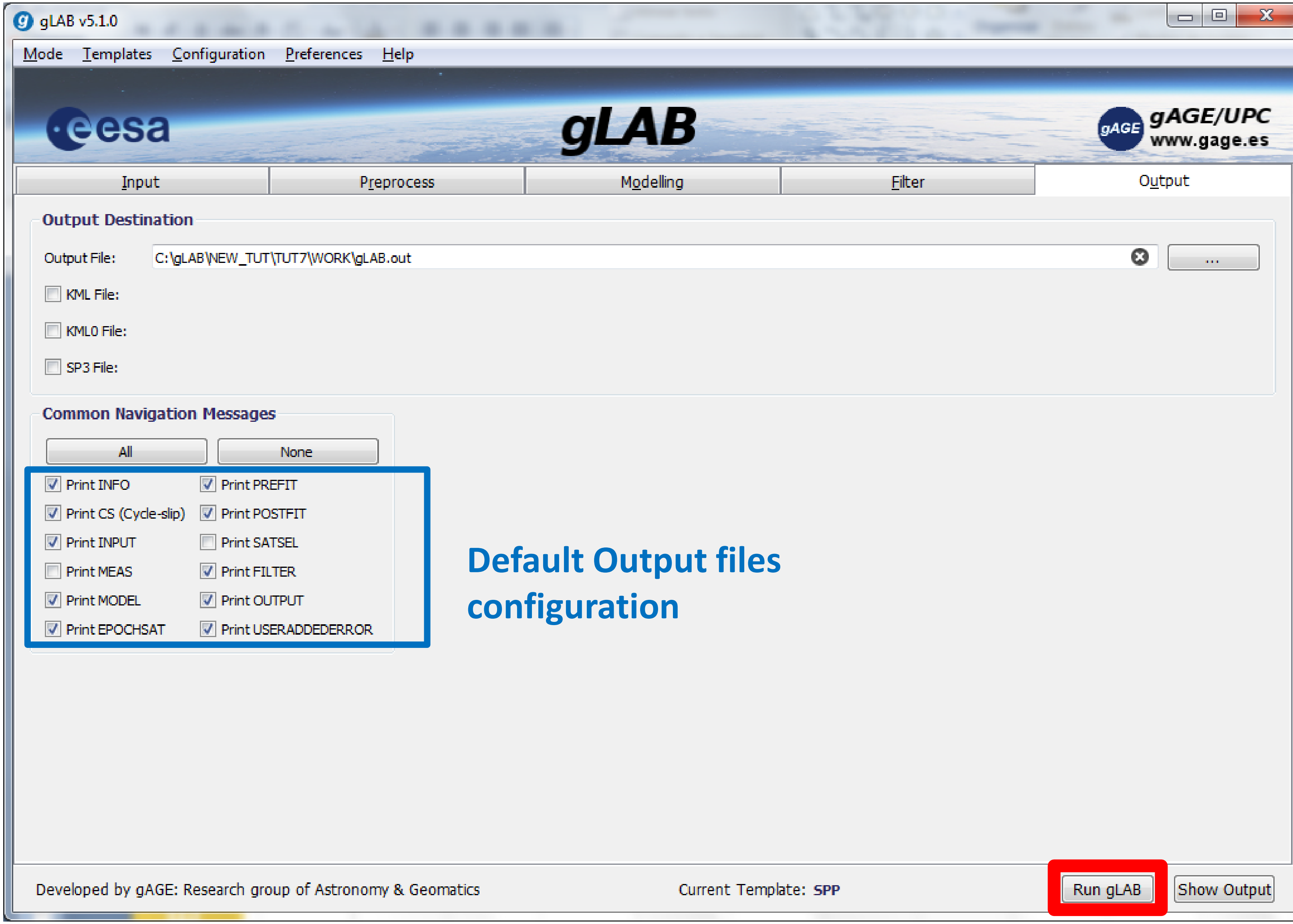
Follow next steps:

Process the data files using the default SPP mode:





Select “Simple Nominal” for Tropospheric Correction



Default Output files configuration

0. Select pseudorange C1 for PRN25, at t=300 seconds.
1. Select orbital elements closest to t=300 seconds
2. Compute satellite clock offset
3. Compute satellite instrumental delay (TGD)
4. Compute satellite-receiver aprox. geometric range:

   3.1 Compute emission time from receiver (reception) time-tags and code pseudorange.

   3.2 Compute satellite coordinates at emission time

   3.3 Compute approximate geometric range.
5. Compute relativistic satellite clock correction
6. Compute ionospheric delay
7. Compute tropospheric delay
8. Compute modeled pseudorange from previous values:

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\overline{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

0. Select pseudorange C1 for PRN25, at t=300 seconds.

t = 300 sec= 0h 05m 0.000000s

RINEX meas. file **UPC11490.05O**

```
Jaume@Portatil_Jaume:/cygdrive/c/gLAB/win/Professional_training/WO...
 05  5 29  0  5  0.0000000  0  8G25G09G06G01G02G05G30G14
  22857303.996    22857301.3054  120115969.49948  93596862.76546      2723.29048
       2122.09146
  24466601.337    24466601.6684  128572940.94147 100186651.00844     -3729.38047
     -2905.98944
  20405995.011    20405993.9894  107234297.78349  83559175.41846      1058.26649
        824.62446
  22758443.914    22758442.9824  119596458.09448  93192027.40946       221.51848
        172.61946
  22847797.979    22847793.9524  120066006.91748  93557939.31646      -597.92448
       -465.90346
  22038213.121    22038210.8494  115811711.44948  90242946.64646     -2309.52148
      -1799.62646
  20171035.530    20171033.5794  105999650.93349  82597114.84546      -377.07249
       -293.81446
  22567004.856    22567003.4674  118590435.21148  92408144.24746     -2193.61648
      -1709.30346
 05  5 29  0  5 30.0000000  0  8G25G09G06G01G02G05G30G14
  22841780.362    22841777.9824  120034393.69248  93533297.24445      2715.16248
       2115.71845
  24487903.545    24487901.6274  128684880.96348 100273876.88342     -3732.94148
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4  head -190 UPC11490.050
```

0. Select pseudorange C1 for PRN25, at t=300 seconds.

From RINEX measurement file **UPC11490.05O**, select the *C1* pseudorange measurement at receiver time-tag for PRN25:

t = 300 sec= 0h 05m 0.000000s

from file UPC11490.050, C1 = 22857303.996 m at $t = 300$ s.

```
 5  5 29  0  5  0.0000000  0  9G25G 9G 6G 1G21G 2G 5G30G14
22857303.996    22857301.3054  120115969.49948  93596862.76546     2723.29048
    2122.09146
24466601.337    24466601.6684  128572940.94147 100186651.00844    -3729.38047
   -2905.98944
20405995.011    20405993.9894  107234297.78349  83559175.41846     1058.26649
     824.62446
22758443.914    22758442.9824  119596458.09448  93192027.40946      221.51848
     172.61946
```

Thence:

Measurement file **UPC11490.05O** → Pseudorange *C1* at receiver time-tag t=300: *C1*= 22857303.996 m

1. Selection of orbital elements:

For **PRN25**, select from file **UPC11490.05N** the last transmitted navigation message, before **t = 300** seconds of DoY 149 of year 2005.

Transmission time:

1325 18 → 2005/05/29 00:00:18

PRN

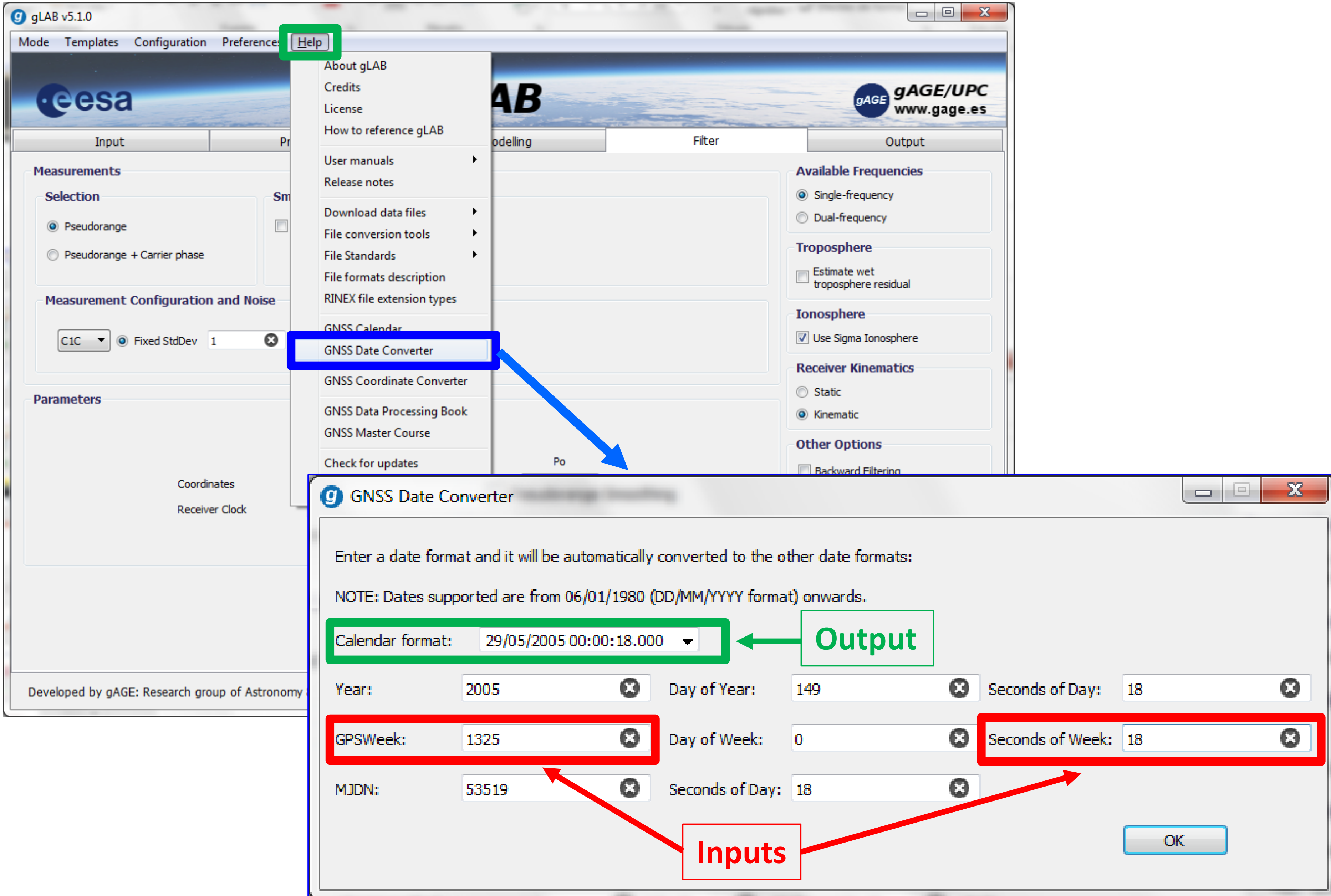
```
25  5  5 29  2  0  0.0 9.401096031070E-05 9.094947017729E-13 0.000000000000E+00
 8.400000000000E+01-1.061875000000E+02 4.825915304457E-09-2.255215633503E+00
-5.284324288368E-06 1.204112719279E-02 5.686655640602E-06 5.153704689026E+03
 7.200000000000E+03 2.011656761169E-07-2.68            0 1.396983861923E-07
 9.4927995             00000E+02-1.460408709553E+00-8.100337411567E-09
-3.6430088             00000E+00 1.325000000000E+03 0.000000000000E+00
 2.800000000000E+00 0.000000000000E+00-7.450580596924E-09 8.520000000000E+02
 1.800000000000E+01 0.000000000000E+00 1.000000000000E+00 0.000000000000E+00
```

GPS week

GPS sec of week

These data were transmitted by PRN25 at second 18 of GPS week 1325 (i.e. 1.800000000000E+01, 1.325000000000E+03 in the message).

The associated Y Y:MM:DD:hh:mm:ss with this transmission time can be computed using the `GNSS Date Converter` tool of **gLAB** as follows:


gLAB v5.1.0
Mode
Templates
Configuration
Preferences
Help
About gLAB
Credits
License
How to reference gLAB
User manuals
Release notes
Download data files
File conversion tools
File Standards
File formats description
RINEX file extension types
GNSS Calendar
GNSS Date Converter
GNSS Coordinate Converter
GNSS Data Processing Book
GNSS Master Course
Check for updates
gAGE/UPC
www.gage.es
Input
Filter
Output
Measurements
Selection
Pseudorange
Pseudorange + Carrier phase
Measurement Configuration and Noise
C1C
Fixed StdDev
Parameters
Coordinates
Receiver Clock
Available Frequencies
Single-frequency
Dual-frequency
Troposphere
Estimate wet troposphere residual
Ionosphere
Use Sigma Ionosphere
Receiver Kinematics
Static
Kinematic
Other Options
Backward Filtering
Developed by gAGE: Research group of Astronomy
GNSS Date Converter
Enter a date format and it will be automatically converted to the other date formats:
NOTE: Dates supported are from 06/01/1980 (DD/MM/YYYY format) onwards.
Calendar format: 29/05/2005 00:00:18.000
Output
Year: 2005
Day of Year: 149
Seconds of Day: 18
GPSWeek: 1325
Day of Week: 0
Seconds of Week: 18
MJDN: 53519
Seconds of Day: 18
OK
Inputs

2. Satellite clock offset computation:

From file **UPC11490.05N**, compute satellite clock offset at time **t=300 s** for **PRN25**:

PRN t_0 a_0 a_1 a_2

```
25  5  5 29  2  0  0.0 9.401096031070E-05 9.094947017729E-13 0.000000000000E+00
    8.400000000000E+01-1.061875000000E+02 4.825915304457E-09-2.255215633503E+00
   -5.284324288368E-06 1.204112719279E-02 5.686655640602E-06 5.153704689026E+03
    7.200000000000E+03 2.011656761169E-07-2.689273653419E+00 1.396983861923E-07
    9.492799505545E-01 2.625625000000E+02-1.460408709553E+00-8.100337411567E-09
   -3.643008888800E-11 1.000000000000E+00 1.325000000000E+03 0.000000000000E+00
    2.800000000000E+00 0.000000000000E+00-7.450580596924E-09 8.520000000000E+02
    1.800000000000E+01 0.000000000000E+00 1.000000000000E+00 0.000000000000E+00
```

t = 300sec

t_0= 2h 0m 0s= 7200 s

$$d\bar{t}^{sat} = a_0 + a_1(t-t_0) + a_2(t-t_0)^2 = 9.400 \cdot 10^{-5}\,\mathrm{s}$$

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(\boxed{d\bar{t}^{sat}} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7...
octave:1>  format long
octave:2>  c=299792458
c =  299792458
octave:3>  sec= 300
sec =  300
octave:4>  toc= 2*3600+ 0*60 +0
toc =  7200
octave:5>  a0= 9.401096031070E-05
a0 =    9.40109603107000e-05
octave:6>  a1= 9.094947017729E-13
a1 =    9.09494701772900e-13
octave:7>  a2= 0
a2 = 0
octave:8>  dt_sat0=a0+a1*(sec-toc)+a2*(sec-toc)**2
dt_sat0 =    9.40046847972578e-05
octave:9>  c*dt_sat0
ans =  28181.8955188851
octave:10>
```

Satellite clock offset computation with MATLAB (octave)

$t = 300sec$

$$t_0 = 2\,\mathrm{h}\ 0\,\mathrm{min}\ 0\,\mathrm{s} = 7200\,\mathrm{s},$$

$$a_0 = 9.401096031070\mathrm{E}{-}05 \quad a_1 = 9.094947017729\mathrm{E}{-}13,$$
$$a_2 = 0.000000000000\mathrm{E}{+}00 \quad (\text{use also } c = 299\,792\,458\,\mathrm{m/s}).$$

$$\boxed{d\bar{t}^{\,sat} = a_0 + a_1(t - t_0) + a_2(t - t_0)^2 = 9.400\cdot 10^{-5}\,\mathrm{s}}$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
              awk '{if ($6==25) print $4,$6,$18}' |head -1
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4   grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$18}' |head -1
300.00 25 -28181.89550
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
```

$$\boxed{d\bar{t}^{\,sat} = 9.400\,468\,48 \cdot 10^{-5}\ \mathrm{s}} \Longrightarrow -c\,d\bar{t}^{\,sat} = -28\,181.895\,51\mathrm{m}.$$

$$\boxed{C1_{rec}^{sat}[\mathrm{modelled}] = \rho_{0,rec}^{sat} - c\left(\boxed{d\bar{t}^{\,sat}} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}}$$

3. Satellite Instrumental delay (TGD)

From file **UPC11490.05N**, compute the Total Group Delay for **PRN25**:

PRN

TGD (in sec)

```
25  5  5 29  2  0  0.0 9.401096031070E-05 9.094947017729E-13 0.000000000000E+00
    8.400000000000E+01-1.061875000000E+02 4.825915304457E-09-2.255215633503E+00
   -5.284324288368E-06 1.204112719279E-02 5.686655640602E-06 5.153704689026E+03
    7.200000000000E+03 2.011656761169E-07-2.689273653419E+00 1.396983861923E-07
    9.492799505545E-01 2.625625000000E+02-1.460408709553E+00-8.100337411567E-09
   -3.643008888800E-11 1.000000000000E+00 1.325000000000E+03 0.000000000000E+00
    2.800000000000E+00 0.000000000000E+00-7.450580596924E-09 8.520000000000E+02
    1.800000000000E+01 0.000000000000E+00 1.000000000000E+00 0.000000000000E+00
```

TGD= -7.450580596924E-09 * c= -2.23363m

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + \boxed{TGD^{sat}}$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
              awk '{if ($6==25) print $4,$6,$27}' | head -1
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4  grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$27}' |head -1
300.00 25 -2.23363
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
```

TGD = -7.450580596924E-09 (in seconds)

Thus: $\boxed{\mathrm{TGD} = -7.450580596924\mathrm{E}-09 \times c = -2.233\,63\ \mathrm{m}}$.

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + \boxed{TGD^{sat}}$$

4. Satellite-receiver geometric range computation:

Use the following values **(4789032.6277, 176595.0498, 4195013.2503)** as approximate coordinates.

4.1: Emission time computation from receiver time-tag and code pseudorange:

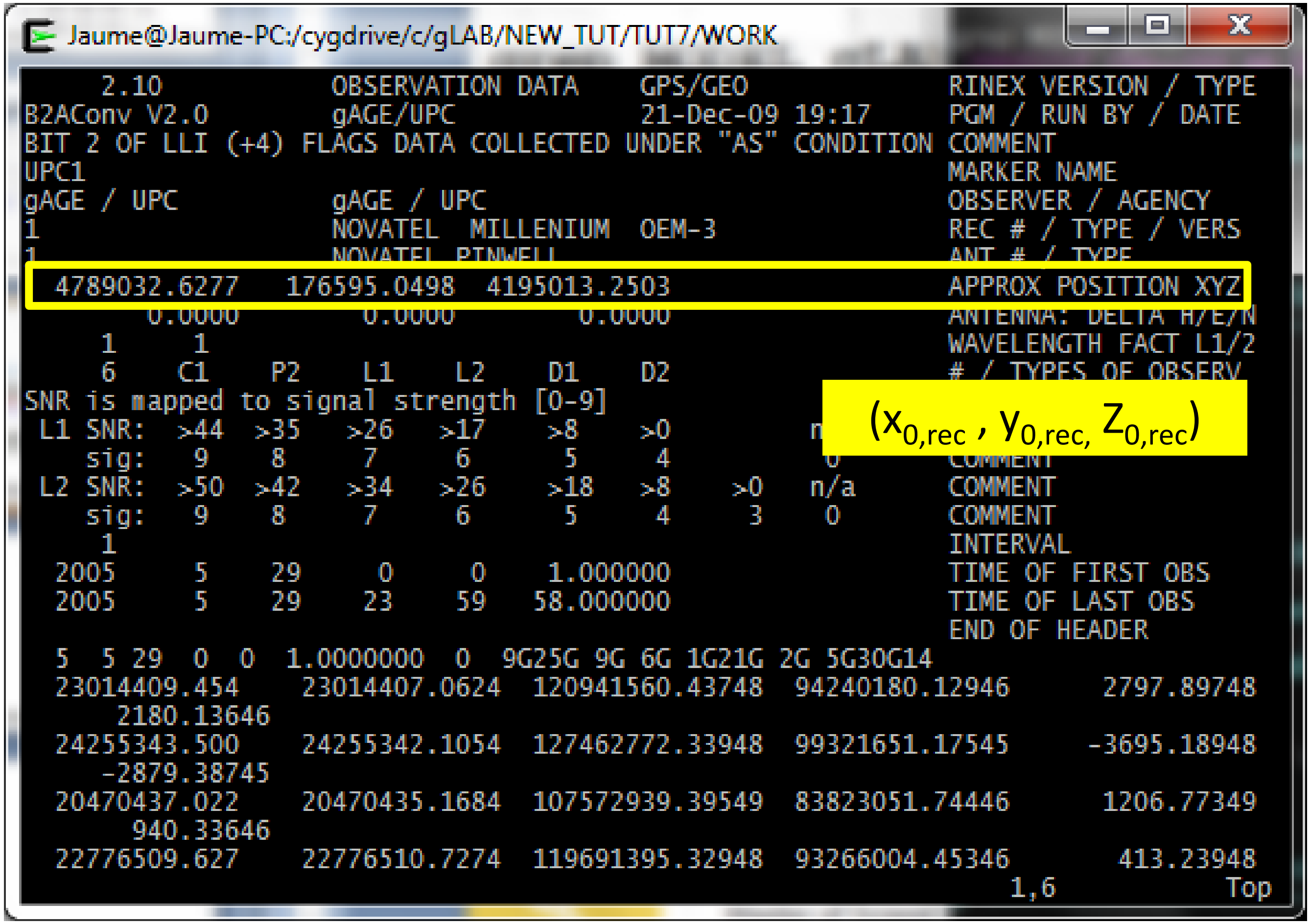
$$T[ems]= t_{rec}(T_R)-(C1/c + dt^{sat})$$

Measurement file **UPC11490.05O**	→	Pseudorange *C1* at receiver time-tag t=300: *C1*= 22857303.996 m
Ephemeris file **UPC11490.05N**	→	Satellite clock offset at t=38230 s dt^{sat}= 9.40046848e-05 s (see previous results)

Thence, the emission time in GPS satellite clock is:

$$T[ems]= 300s - (22857303.996m\ /c + 9.40\ 10^{-5}s)$$

$$= 299.923662236054s$$ **(where *c=299792458 m/s*)**




```
     2.10           OBSERVATION DATA    GPS/GEO             RINEX VERSION / TYPE
B2AConv V2.0        gAGE/UPC            21-Dec-09 19:17     PGM / RUN BY / DATE
BIT 2 OF LLI (+4) FLAGS DATA COLLECTED UNDER "AS" CONDITION COMMENT
UPC1                                                        MARKER NAME
gAGE / UPC          gAGE / UPC                              OBSERVER / AGENCY
1                   NOVATEL  MILLENIUM  OEM-3               REC # / TYPE / VERS
1                   NOVATEL  PINWELL                        ANT # / TYPE
  4789032.6277   176595.0498  4195013.2503                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
     6    C1    P2    L1    L2    D1    D2                  # / TYPES OF OBSERV
SNR is mapped to signal strength [0-9]
 L1 SNR:  >44  >35  >26  >17   >8   >0         n
    sig:    9    8    7    6    5    4         0            COMMENT
 L2 SNR:  >50  >42  >34  >26  >18   >8   >0   n/a           COMMENT
    sig:    9    8    7    6    5    4    3    0            COMMENT
     1                                                      INTERVAL
  2005     5    29     0     0    1.000000                  TIME OF FIRST OBS
  2005     5    29    23    59   58.000000                  TIME OF LAST OBS
                                                            END OF HEADER
  5  5 29  0  0  1.0000000  0  9G25G 9G 6G 1G21G 2G 5G30G14
  23014409.454    23014407.0624  120941560.43748  94240180.12946      2797.89748
      2180.13646
  24255343.500    24255342.1054  127462772.33948  99321651.17545     -3695.18948
     -2879.38745
  20470437.022    20470435.1684  107572939.39549  83823051.74446      1206.77349
       940.33646
  22776509.627    22776510.7274  119691395.32948  93266004.45346       413.23948
                                                                 1,6          Top
```

Approximate Receiver coordinates given in the RINEX file header

$x_{0,rec}$ =4789032.6277
$y_{0,rec}$ = 176595.0498
$z_{0,rec}$ =4195013.2503

Measurement file UPC11490.05O

t = 300 sec= 0h 05m 0.000000s

Jaume@Portatil_Jaume:/cygdrive/c/gLAB/win/Professional_training/WO...

```
 05  5 29  0  5  0.0000000  0  8G25G09G06G01G02G05G30G14
  22857303.996    22857301.3054  120115969.49948  93596862.76546      2723.29048
      2122.09146
  24466601.337    24466601.6684  128572940.94147 100186651.00844     -3729.38047
     -2905.98944
  20405995.011    20405993.9894  107234297.78349  83559175.41846      1058.26649
       824.62446
  22758443.914    22758442.9824  119596458.09448  93192027.40946       221.51848
       172.61946
  22847797.979    22847793.9524  120066006.91748  93557939.31646      -597.92448
      -465.90346
  22038213.121    22038210.8494  115811711.44948  90242946.64646     -2309.52148
     -1799.62646
  20171035.530    20171033.5794  105999650.93349  82597114.84546      -377.07249
      -293.81446
  22567004.856    22567003.4674  118590435.21148  92408144.24746     -2193.61648
     -1709.30346
 05  5 29  0  5 30.0000000  0  8G25G09G06G01G02G05G30G14
  22841780.362    22841777.9824  120034393.69248  93533297.24445      2715.16248
      2115.71845
  24487903.545    24487901.6274  128684880.96348 100273876.88342     -3732.94148
```

Note:

From RINEX measurement file **UPC11490.05O**, select the *C1* pseudorange measurement at receiver time-tag for PRN25:

t = 300 sec= 0h 05m 0.000000s

from file UPC11490.05O, C1 = 22857303.996 m at $t = 300$ s.

```
5  5 29  0  5  0.0000000  0   9G25G 9G 6G 1G21G 2G 5G30G14
22857303.996    22857301.3054  120115969.49948  93596862.76546     2723.29048
    2122.09146
24466601.337    24466601.6684  128572940.94147 100186651.00844    -3729.38047
   -2905.98944
20405995.011    20405993.9894  107234297.78349  83559175.41846     1058.26649
     824.62446
22758443.914    22758442.9824  119596458.09448  93192027.40946      221.51848
     172.61946
```

Thence:

Measurement file **UPC11490.05O**	Pseudorange *C1* at receiver time-tag t=300: *C1*= 22857303.996 m

$$T[ems] = t_{rec}(T_R) - (C1/c + dt^{sat})$$

Measurement file
UPC11490.05O

Pseudorange *C1* at receiver time-tag
t=300: *C1*= 22857303.996 m

Ephemeris file
UPC11490.05N

Satellite clock offset at t=300 s
dt^{sat}= 9.40046848e-05 s

Thence, the emission time in GPS satellite clock is:

$$T[ems] = 300\text{s} - (22857303.996\text{m}\ /c + 9.40\ 10^{-5}\text{s})$$

$$= 299.92366223605\text{4s}$$ **(where *c=299792458*)**

gAGE@gAGE-PC:/cygdrive...

```
octave:1> format long
octave:2>  c=299792458
c =  299792458
octave:3> sec= 300
sec =  300
octave:4>  dt_sat0= 9.40046848e-05
dt_sat0 =    9.40046848000000e-05
octave:5>  C1=22857303.996
C1 =  22857303.9960000
octave:6>  sec_ems=sec-C1/c-dt_sat0
sec_ems =  299.923662236054
octave:7> |
```

Emission time computation
with MATLAB (octave)

4.2: Satellite coordinates at emission time pseudorange:

T[emission]= 299.92366 sec → **GPSxyz** →

x= 6 364 868.618 m
y= 14 298 233.062 m
z= 851 197.941 m
CTS [emission]

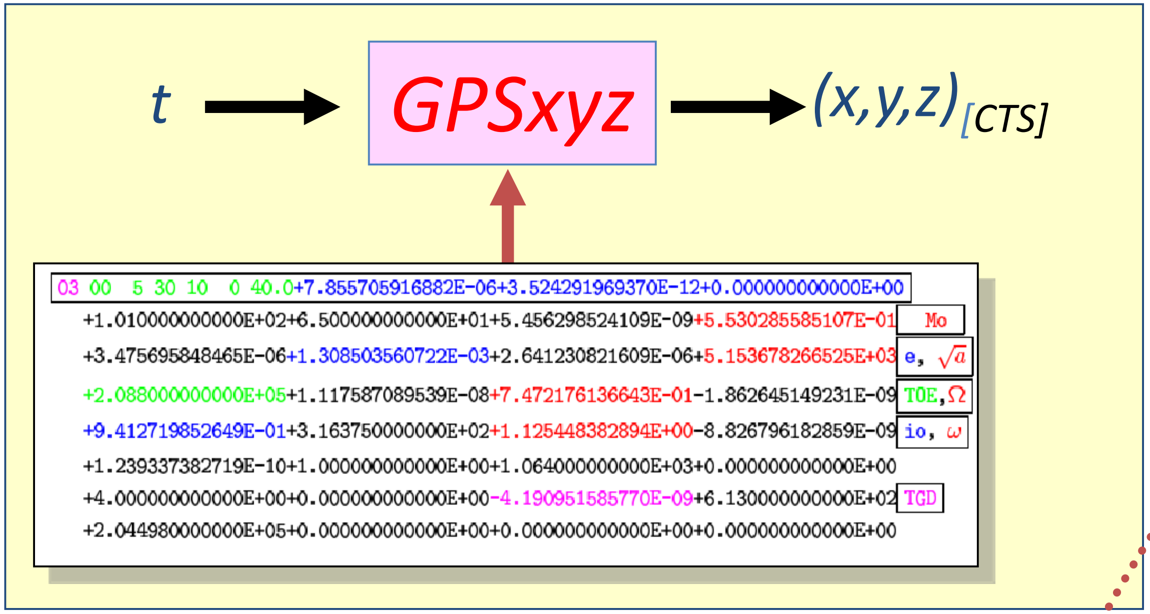
↑

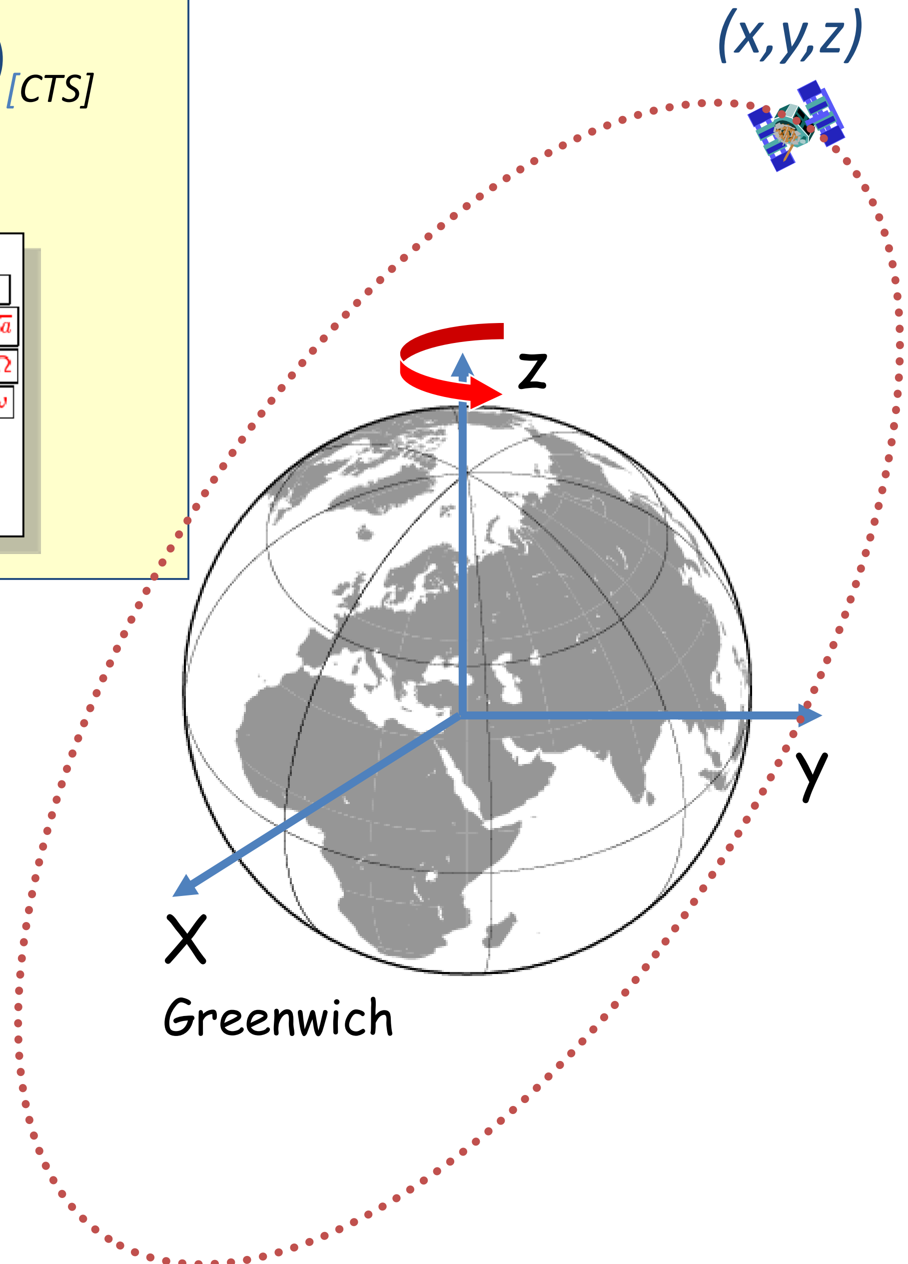
Use the selected ephemeris for PRN25 (from file **UPC11490.05N**)

The obtained coordinates are given in an Earth-fixed reference frame (CTS) at *t=T[emission]=* 299.92366 s.

This reference frame rotates by un amount "$\omega_E\, \Delta t$" during traveling time $\Delta t=T[reception]-T[emission]$.

$$(x^{sat},y^{sat},z^{sat})_{CTS[reception]} = R_3(\omega_E\, \Delta t).(x^{sat},y^{sat},z^{sat})_{CTS[emission]}$$





Conventional Terrestrial Reference System (CTS):

Earth Centered, Earth-Fixed (ECEF) ➔

the reference system rotates with Earth.

Computation of satellite coordinates from navigation message (**GPSxyz.f**)

- Computation of t_k time since ephemerids reference epoch t_{oe} (t and t_{oe} are given in GPS seconds of week):

$$t_k = t - t_{oe}$$

- Computation of mean anomaly M_k for t_k,

$$M_k = M_0 + \left(\frac{\sqrt{\mu}}{\sqrt{a^3}} + \Delta n \right) t_k$$

- Iterative resolution of Kepler's equation in order to compute eccentric anomaly E_k :

$$M_k = E_k - e \sin E_k$$

- Calculation of true anomaly v_k :

$$v_k = \arctan \left(\frac{\sqrt{1-e^2} \sin E_k}{\cos E_k - e} \right)$$

- Computation of latitude argument u_k from perigee argument W, true anomaly v_k and corrections c_{uc} and c_{us}:

$$u_k = \omega + v_k + c_{uc} \cos 2(\omega + v_k) + c_{us} \sin 2(\omega + v_k)$$

Computation of satellite coordinates from navigation message (**GPSxyz.f**)

- Computation of radial distance r_k, taking into consideration corrections c_{rc} and c_{rs}:

$$r_k = a\left(1 - 2\cos E_k\right) + c_{rc}\cos 2\left(\omega + v_k\right) + c_{rs}\sin 2\left(\omega + v_k\right)$$

- Calculation of orbital plane inclination i_k from inclination i_o at reference epoch t_{oe} and corrections c_{ic} and c_{is} :

$$i_k = i_0 + it_k + c_{ic}\cos 2\left(\omega + v_k\right) + c_{is}\sin 2\left(\omega + v_k\right)$$

- Computation of ascending node longitude Ω_k (Greenwich), from longitude Ω_0 at start of GPS week, corrected from apparent variation of sidereal time at Greenwich between start of week and and reference time $t_k=t-t_{oe}$, and also corrected from change of ascending node longitude since reference epoch t_{oe}.

$$\Omega_k = \Omega_0 + \left(\Omega - \omega_E\right)t_k - \omega_E t_{oe}$$

- Calculation of coordinates in CTS system, applying three rotations (around u_k, i_k, Ω_k) :

$$\begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} = \mathbf{R}_3(-\Omega_k)\mathbf{R}_1(-i_k)\mathbf{R}_3(-u_k)\begin{bmatrix} r_k \\ 0 \\ 0 \end{bmatrix}$$

Computation of satellite coordinates in an Earth-Fixed reference frame (CTS) at *t=T[emission]*= 299.92366 s.

x= 6 364 868.618 m

y= -14 298 233.062 m

z= 21851 197.941 m

CTS [emission]

```
echo "2005 149 299.92366224" > time.dat
cat time.dat eph.dat | GPSxyz
```

Note: use the file "`eph.dat`" (with the selected Nav. Message)

```
Result: [25. 299.92366224  ← time
         6364868.618075 -14298233.062153  21851197.940638 ← coord
         3.022976] ← Excentric anomaly Ek
```

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK  echo "2005 149 299.92366224" > time.dat
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK  cat time.dat eph.dat | GPSxyz
 25.        299.92366224     6364868.618075  -14298233.062153  21851197.940638     3.022976
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
```

These coordinates are given in an

t=T[emission]= 299.92366 s, i.e *CTS [emission]*

Next step is to transform these coordinates to *CTS [reception]*

$$(x^{sat},y^{sat},z^{sat})_{CTS[reception]} = R_3(\omega_E\, \Delta t).(x^{sat},y^{sat},z^{sat})_{CTS[emission]}$$

$$(x^{sat}, y^{sat}, z^{sat})_{CTS[reception]} = R_3(\omega_E\, \Delta t) \cdot (x^{sat}, y^{sat}, z^{sat})_{CTS[emission]}$$

$$\boxed{\underset{CTS[reception]}{\begin{pmatrix} 6364789.025 \\ -14298268.493 \\ 21851197.941 \end{pmatrix}}} = \begin{pmatrix} \cos(\omega_E \Delta t) & \sin(\omega_E \Delta t) & 0 \\ -\sin(\omega_E \Delta t) & \cos(\omega_E \Delta t) & 0 \\ 0 & 0 & 1 \end{pmatrix} \underset{CTS[emission]}{\begin{pmatrix} 6\,364\,868.618 \\ -14\,298\,233.062 \\ 21851\,197.941 \end{pmatrix}}$$

$$(x,y,z)^{satellite} \approx (6364868.618\ ,\ -14298233.062\ ,\ 21851197.940)$$

$$(x_0, y_0, z_0)_{receiver} \approx (4789032.628,\ \ 176595.050,\ 4195013.250)$$

$$\rho_{0,rec}^{sat} = \sqrt{\left(x^{sat} - x_{0,rec}\right)^2 + \left(y^{sat} - y_{0,rec}\right)^2 + \left(z^{sat} - z_{0,rec}\right)^2} \approx 22885470.626m$$

$$\Delta t = \frac{\rho_{0,rec}^{sat}}{c} = 0.0763\sec$$

$$\omega_E \Delta t = 5.56 \cdot 10^{-6}\, rad. \quad (where \quad \omega_E = 7.2921151467 \cdot 10^{-5}\, rad/sec)$$

An approximate value is enough to compute Δt.

Note: Both satellite and receiver coordinates must be given in the same reference system!

➔the CTS[reception] will be used to build navigation equations.

Transformation of satellite coordinates form *CTS [emission]* to *CTS [reception]* with MATLAB (octave)

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
octave:1> format long
octave:2>  r0_rcv=[4789032.6277      176595.0498    4195013.2503]
r0_rcv =

   4789032.627700000    176595.049800000   4195013.250300000

octave:3> r_sat= [6364868.61807  -14298233.06215  21851197.94064]
r_sat =

    6364868.61807000  -14298233.06215000   21851197.94064000

octave:4>  c=299792458
c =  299792458
octave:5>  dt_fight=norm(r_sat-r0_rcv,2)/c
dt_fight =  0.0763377130243576
octave:6>   we= 7.2921151467e-5
we =    7.29211514670000e-05
octave:7>  theta=we*dt_fight
theta =    5.56663393409356e-06
octave:8>  R=[cos(theta) sin(theta) 0 ; -sin(theta) cos(theta) 0 ; 0 0 1]
R =

   0.999999999984506   0.000005566633934   0.00000000000
  -0.000005566633934   0.999999999984506   0.00000000000
   0.000000000000000   0.000000000000000   1.00000000000

octave:9>  r_sat_ems=(R*r_sat')'
r_sat_ems =

    6364789.02494202  -14298268.49282210   21851197.94064000

octave:10> |
```

**r0_rcv=[4789032.6277
176595.0498
4195013.2503]**
(from RINEX header)

**r_sat= [6364868.61807
-14298233.06215
21851197.94064]**
CTS [emission]

$$\rho_{0,receiver}^{satellite} = \sqrt{\left(x^{sat} - x_{0,rec}\right)^2 + \left(y^{sat} - y_{0,rec}\right)^2 + \left(z^{sat} - z_{0,rec}\right)^2}$$

$$\Delta t = \frac{\rho_{0,rec}^{sat}}{c}$$

$$\underbrace{\begin{pmatrix} 6364789.025 \\ -14298268.493 \\ 21851197.941 \end{pmatrix}}_{CTS[reception]} = \begin{pmatrix} \cos(\omega_E \Delta t) & \sin(\omega_E \Delta t) & 0 \\ -\sin(\omega_E \Delta t) & \cos(\omega_E \Delta t) & 0 \\ 0 & 0 & 1 \end{pmatrix} \underbrace{\begin{pmatrix} 6\,364\,868.618 \\ -14\,298\,233.062 \\ 21851\,197.941 \end{pmatrix}}_{CTS[emission]}$$

$$\omega_E = 7.2921151467 \cdot 10^{-5}\, rad / \sec$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO
     | gawk '{if ($6==25) print $4,$6,$11,$12,$13}'|head -1
```

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$11,$12,$13}'|head -1
300.00 25 6364789.0249 -14298268.4928 21851197.9406
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK |
```

4.3: Geometric range computation

The geometric range between satellite coordinates at emission time and the "approximate position of the receiver" at reception time *both coordinates given in the same reference system [for instance the CTS system at reception time])* is computed by:

$$\rho_{0,rec}^{sat} = \sqrt{\left(x^{sat} - x_{0,rec}\right)^2 + \left(y^{sat} - y_{0,rec}\right)^2 + \left(z^{sat} - z_{0,rec}\right)^2} \approx 22885487.555m$$

$$(x,y,z)^{satellite} = (6364789.0249 \;\; -14298268.4928 \;\; 21851197.9406)_{CTS[reception]}$$

$$\boxed{(x_0,y_0,z_0)_{receiver}} = (4789032.6277 \quad 176595.0498 \quad 4195013.2503\,)_{CTS[reception]}$$

"Approximate" receiver coordinates at reception time.

$$C1_{rec}^{sat}[\text{modelled}] = \boxed{\rho_{0,rec}^{sat}} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

Geometric range computation with octave (MATLAB)

r0_rcv=[4789032.6277 176595.0498 4195013.250] ← from RINEX header

r_sat_ems=[6364789.0249 -14298268.4928 21851197.9406] ← *CTS [reception]*

from previous computations

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
octave:1> format long
octave:2> r_sat_ems=[6364789.02494205  -14298268.49282209   21851197.94064000]
r_sat_ems =

   6364789.02494205  -14298268.49282209   21851197.94064000

octave:3>  r0_rcv=[4789032.6277      176595.0498     4195013.2503]
r0_rcv =

   4789032.627700000    176595.049800000   4195013.250300000

octave:4> rho=norm(r_sat_ems-r0_rcv,2)
rho =  22885487.5547884
octave:5> |
```

$$\rho_{0,receiver}^{satellite} = \sqrt{\left(x^{sat} - x_{0,rec}\right)^2 + \left(y^{sat} - y_{0,rec}\right)^2 + \left(z^{sat} - z_{0,rec}\right)^2}$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
            gawk '{if ($6==25) print $4,$6,$17}' |head -1
```

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK  grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$17}' |head -1
300.00 25 22885487.5548
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK |
```

$$C1_{rec}^{sat}[\text{modelled}] = \boxed{\rho_{0,rec}^{sat}} - c\left(d\bar{t}^{sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

5. Relativistic clock correction:

PRN

e

sqrt(a)

```
25  5  5 29  2  0   0.0 9.401096031070E-05 9.094947017729E-13 0.000000000000E+00
   8.400000000000E+01-1.061875000000E+02 4.825915304457E-09-2.255215633503E+00
  -5.284324288368E-06 1.204112719279E-02 5.686655640602E-06 5.153704689026E+03
   7.200000000000E+03 2.011656761169E-07-2.689273653419E+00 1.396983861923E-07
   9.492799505545E-01 2.625625000000E+02-1.460408709553E+00-8.100337411567E-09
  -3.643008888800E-11 1.000000000000E+00 1.325000000000E+03 0.000000000000E+00
   2.800000000000E+00 0.000000000000E+00-7.450580596924E-09 8.520000000000E+02
   1.800000000000E+01 0.000000000000E+00 1.000000000000E+00 0.000000000000E+00
```

T[emission] = 299.92366224 s → **GPSxyz** → **E = 3.022976 rad.** *(eccentric anomaly)*

$$\Delta rel^{sat} = -2\frac{\sqrt{\mu a}}{c^2}\, e \sin(E) = -3.28\cdot 10^{-9}\,\mathrm{s}$$

$$\mu = 3.986005\cdot 10^{14} \quad m^3 s^{-2}$$
$$c = 299792458 \quad m\, s^{-1}$$

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{\,sat} + \boxed{\Delta rel^{sat}}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

Relativistic clock correction computation with MATLAB (octave)

gAGE@gAGE-PC:/cygdrive/c/gLAB/N...

```
octave:1> format long
octave:2>  a12= 5.153704689026E+03
a12 =  5153.70468902600
octave:3> a=a12*a12
a =  26560672.0216886
octave:4>  mu= 3986004.418e8
mu =  398600441800000
octave:5>  c= 299792458
c =  299792458
octave:6>  e= 1.204112719279E-02
e =  0.0120411271927900
octave:7>  E= 3.022976
E =  3.02297600000000
octave:8> dt_rel= -2*sqrt(mu*a)/c*e*sin(E)
dt_rel = -0.978118852131222
octave:9>
```

$$\Delta rel^{sat} = -2\frac{\sqrt{\mu a}}{c^2}\, e\sin(E) = -3.28\cdot 10^{-9}\,\mathrm{s}$$

sqrt(a)= 5.153704689026E+03

e= 1.204112719279E-02

E = 3.022976 rad.

(eccentric anomaly)

From previous computations

$$\mu = 3.986005\cdot 10^{14} \quad m^3 s^{-2}$$

$$c = 299792458 \quad m\, s^{-1}$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
             gawk '{if ($6==25) print $4,$6,$22}' |head -1
```

gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$22}' |head -1
300.00 25 0.98343
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK |
```

Note: gLAB computes this relativistic correction using a different algorithm: **dt_rel= -2*r_sat_ems*v'/c/c** (see GNSS book). Where the velocity is estimated from coordinates variation from two close epochs. This is the reason of the small discrepancy.

6. Ionospheric correction

(time, r_{sta}, r^{sat}, $\alpha0,\alpha1,\alpha2,\alpha3,\beta0,\beta1,\beta2,\beta3$) → [iono] → Iono=2.49m

```
2.10              N: GPS NAV DATA                          RINEX VERSION / TYPE
B2AConv V2.0           gAGE/UPC             21-Dec-09 19:17     PGM / RUN BY   / DATE
REALTIME EPHEMERIS FILE                                         COMMENT
    1.0245E-08  2.2352E-08 -5.9605E-08 -1.1921E-07              ION ALPHA
    9.6256E+04  1.3107E+05 -6.5536E+04 -5.8982E+05              ION BETA
    3.725290298462E-09 9.769962616701E-15   319488     1325 DELTA-UTC: A0,A1,T,W
    13                                                          LEAP SECONDS
                                                                END OF HEADER
```

$$t = 300\,\text{sec}$$

$$(x,y,z)^{satellite} = (6364789.0249 \quad -14298268.4928 \quad 21851197.9406)_{CTS[reception]}$$

$$(x_0,y_0,z_0)_{receiver} = (4789032.6277 \quad 176595.0498 \quad 4195013.2503\ )_{CTS[reception]}$$

Approximate values for receiver or satellite coordinates are enough

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\overline{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + \boxed{Ion_{1rec}^{sat}} + TGD^{sat}$$

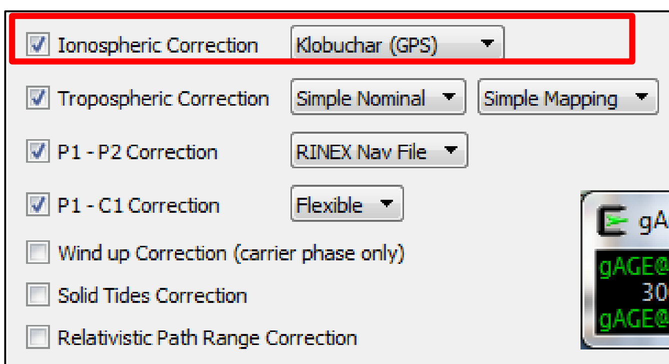
6. Ionospheric correction

File **iono.dat** contents the **measurement time** and the **receiver and satellite PRN25 coordinates**:

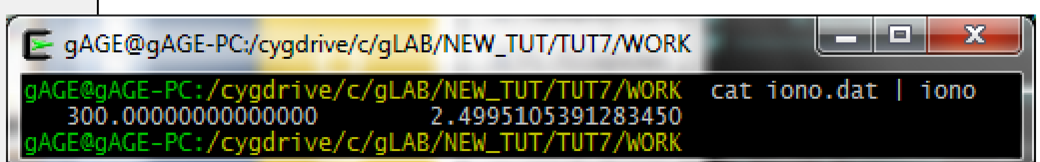
```
.................. iono.dat ........................
300     4789032.6277    176595.0498   4195013.2503 <- rec. coord
        6364789.0249 -14298268.4928  21851197.9406 <- sat. coord
        1.0245E-08  2.2352E-08 -5.9605E-08 -1.1921E-07 <- ALPHAs
        9.6256E+04  1.3107E+05 -6.5536E+04 -5.8982E+05 <- BETAs
....................................................
```

The FORTRAN program **iono.f** implements the Klobuchar ionospheric model selected by default in gLAB.

Note: the algorithms are given in the GNSS book, Volume-1.
The Fortran code **iono.f** and C code **Model.c** are available in the CD-ROM, Volume -2



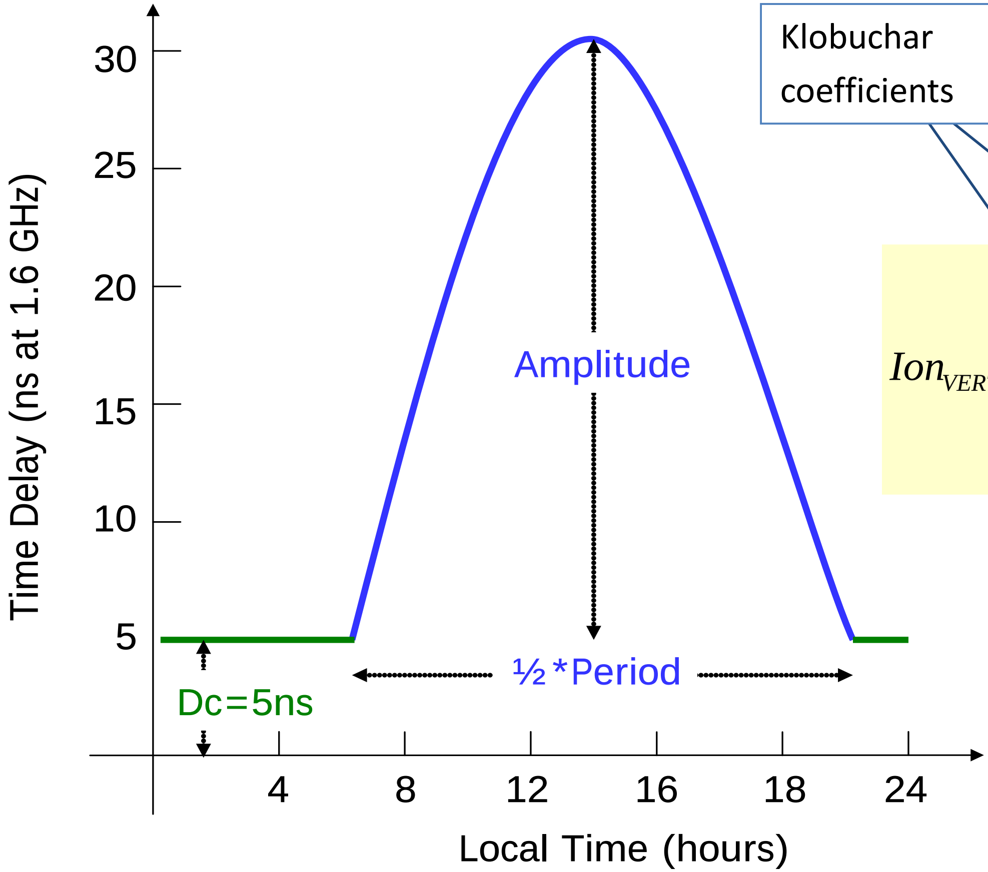
Execute
cat iono.dat | iono
→2.47 m L1 delay



$$(time, \underbrace{r_{sta}, r^{sat}}_{elev,\ \phi}, \alpha 0, \alpha 1, \alpha 2, \alpha 3, \beta 0, \beta 1, \beta 2, \beta 3) \rightarrow \boxed{iono}$$

```
 2              NAVIGATION DATA                       RINEX VERSION / TYPE
CCRINEXN V1.5.2 UX  CDDIS               24-MAR- 0 00:23     PGM / RUN BY / DATE
IGS BROADCAST EPHEMERIS FILE                                COMMENT
    0.3167D-07  0.4051D-07 -0.2347D-06  0.1732D-06          ION ALPHA
   -0.2842D+05 -0.2150D+05 -0.1096D+06  0.4301D+06          ION BETA
   -0.121071934700D-07-0.488498130835D-13   319488     1002 DELTA-UTC: A0,A1,T,W
    13                                                      LEAP SECONDS
                                                            END OF HEADER
 1 99  3 23  0  0  0.0 0.783577561379D-04 0.113686837722D-11 0.000000000000D+00
    0.191000000000D+03-0.106250000000D+01 0.487163149444D-08-0.123716752769D+01
   -0.540167093277D-07 0.476544268895D-02 0.713579356670D-05 0.515433833885D+04
    0.172800000000D+06-0.260770320892D-07-0.850753478531D+00 0.763684511185D-07
    0.957259887797D+00 0.241437500000D+03-0.167990552187D+01-0.823998608564D-08
    0.174650132022D-09 0.100000000000D+01 0.100200000000D+04 0.000000000000D+00
    0.320000000000D+02 0.000000000000D+00 0.465661287308D-09 0.191000000000D+03
    0.172800000000D+06 0.000000000000D+00 0.000000000000D+00 0.000000000000D+00
```

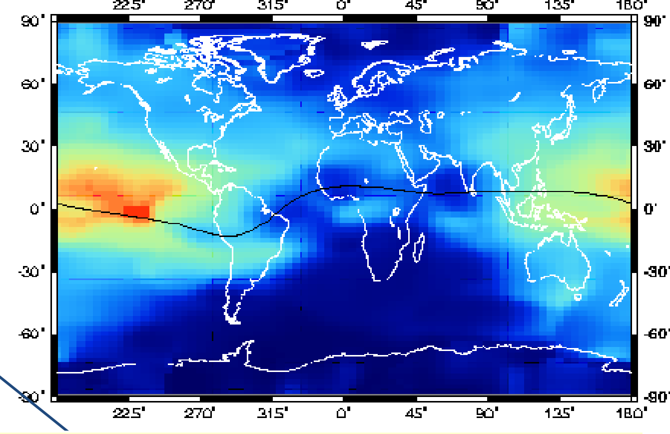
Klobuchar model



$$Ion_{SLANT} = Ion_{VERT}\ m(elev)$$

$$m(elev) = \left[1 - \left(\frac{R_E}{R_E + h}\cos(elev)\right)^2\right]^{-1/2}$$

Klobuchar coefficients



$$Ion_{VERT} = \begin{cases} DC + A\cos\left[\dfrac{2\pi(t-\Phi)}{P}\right] & (day) \\ DC \quad ;\ if \left[\dfrac{2\pi(t-\Phi)}{P}\right] > \dfrac{\pi}{2} & (night) \end{cases}$$

$Being:$

$$A = \sum_{n=0}^{3} \alpha_n \varphi^n \quad ; \quad P = \sum_{n=0}^{3} \beta_n \varphi^n$$

φ = Geomagnetic Latitude

Where:

DC= 5ns

Φ= 14 (ctt. phase offset)

t = Local Time

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
        gawk '{if ($6==25) print $4,$6,$25}' |head -1
```

```
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$25}' |head -1
300.00 25 2.47264
gAGE@gAGE-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
```

```
cat iono.dat | iono
```

Solution:

$I_1 = 2.472\,64\,\mathrm{m}$ of L1 delay.

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(\overline{dt}^{sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + \boxed{Ion_{1rec}^{sat}} + TGD^{sat}$$

7. Tropospheric correction

$$Trop_{rec}^{sat} = \left(d_{dry} + d_{wet}\right) m(elev) = 4.319m$$

$$d_{dry} = 2.3\,\mathrm{e}^{-0.116\cdot 10^{-3}\,H}$$

$$d_{wet} = 0.1m$$

$$m(elev) = \frac{1.001}{\sqrt{0.002001 + \sin^2(elev)}}$$

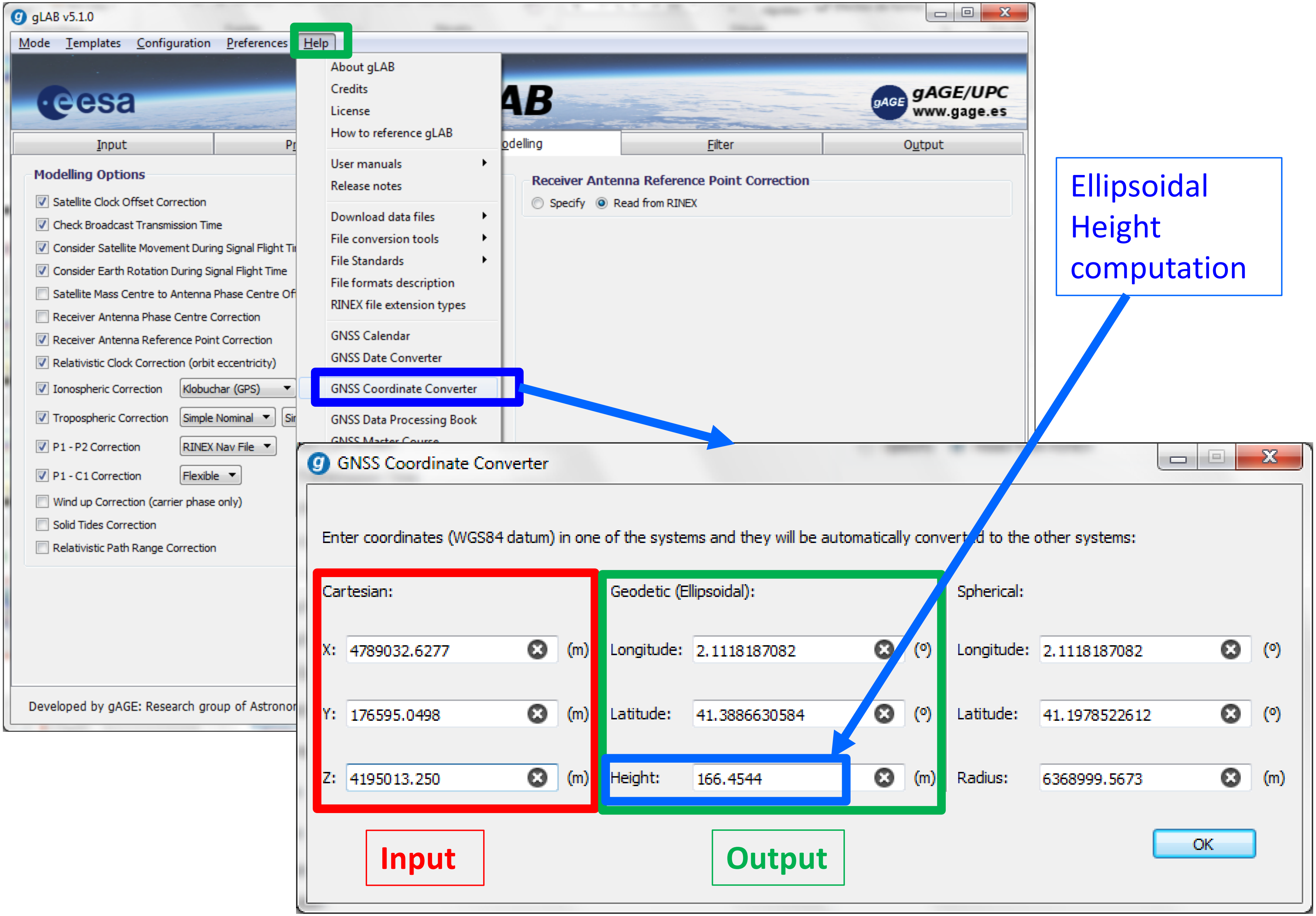
See next slides

$elev: satellite\ elevation$

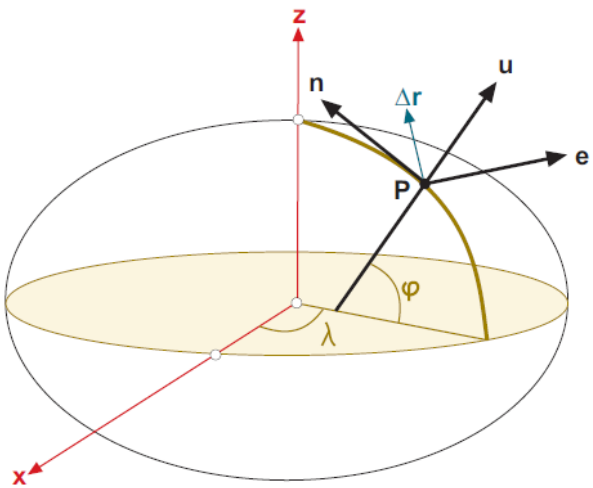
$H = height\ \ over\ the\ ellipsoid$

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + \boxed{Trop_{rec}^{sat}} + Ion_{1rec}^{sat} + TGD^{sat}$$

Ellipsoidal Height computation

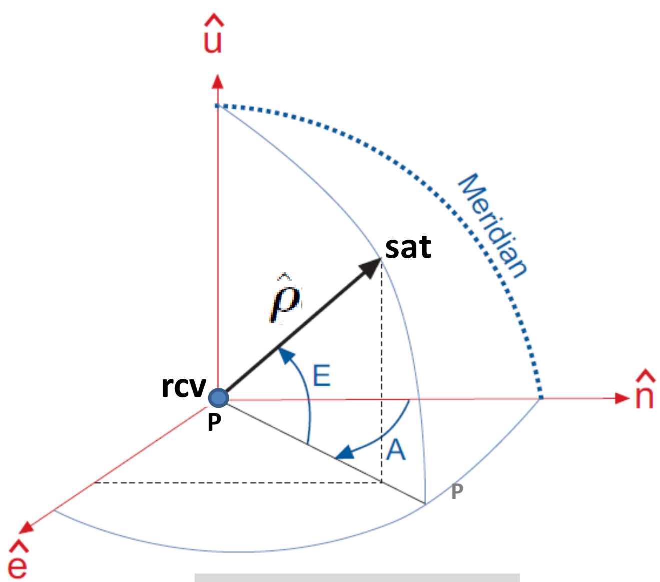


Satellite Elevation and Azimuth computation



The unit vectors in the local east, north and up directions as expressed in ECEF Cartesian coordinates are given by

$$\hat{\mathbf{e}} = (-\sin\lambda\,,\ \cos\lambda\,,\ 0)$$
$$\hat{\mathbf{n}} = (-\cos\lambda\sin\varphi\,,\ -\sin\lambda\sin\varphi\,,\ \cos\varphi)$$
$$\hat{\mathbf{u}} = (\cos\lambda\cos\varphi\,,\ \sin\lambda\ \cos\varphi\,,\ \sin\varphi)$$



$$\hat{\boldsymbol{\rho}} = \frac{\mathbf{r}^{sat} - \mathbf{r}_{rcv}}{\left\|\mathbf{r}^{sat} - \mathbf{r}_{rcv}\right\|}$$

$$\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{e}} = \cos E \sin A$$
$$\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{n}} = \cos E \cos A$$
$$\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{u}} = \sin E$$

$$\boxed{\begin{aligned} E &= \arcsin(\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{u}}) \\ A &= \arctan\left(\frac{\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{e}}}{\hat{\boldsymbol{\rho}}\cdot\hat{\mathbf{n}}}\right) \end{aligned}}$$

BACKUP SLIDE

Computation of satellite elevation

```
# Using Octave or MATLAB compute:
# ///////////////////////////////
  octave
  format long
  l=2.1118187082
  f= 41.3886630584
  l=l*pi/180
  f=f*pi/180

  u=[cos(l)*cos(f);sin(l)*cos(f);sin(f)]

     r0_rcv=[4789032.6277    176595.0498   4195013.250]
  r_sat_ems=[6364789.0249 -14298268.4928 21851197.9406]

  rho=r_sat_ems-r0_rcv
  rho=rho/norm(rho)

  elev=asin(rho*u)
  # ==> elev=0.575464444394506 (rad)
```

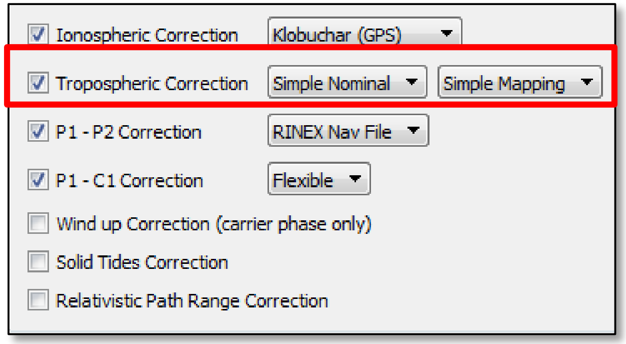
Computation of Tropospheric delay

```
# Using Octave or MATLAB compute:
# ///////////////////////////////
  octave
  format long
  H=166.4544
  elev=0.575464444394506


  dry=2.3*exp(-0.116e-3*H)
  wet=0.1
  m=1.001/sqrt(0.002001+sin(elev)**2)

  Tropo=(dry+wet)*m
  # ==> Tropo= 4.31889 (metres)
  exit
# //////////////////////////////
```

Cross-checking results with gLAB




```
grep MODEL gLAB.out | grep -v INFO |
      gawk '{if ($6==25) print $4,$6,$24}' |head -1
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4   grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$24}' |head -1
300.00 25 4.31801
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4 |
```

```
cat tropo.dat | tropo
```

Solution:

$T = 4.465\,83\ \mathrm{m}.$

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(d\bar{t}^{sat} + \Delta rel^{sat}\right) + \boxed{Trop_{rec}^{sat}} + Ion_{1rec}^{sat} + TGD^{sat}$$

8. Compute the modeled pseudorange

$$C1_{rec}^{sat}[\text{modelled}] = \rho_{rec,0}^{sat} - c\left(d\bar{t}^{\,sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

$$\rho_{0,rec}^{sat} = 22885487.554\,\text{m}$$

$$d\bar{t}^{\,sat} = 9.400 \cdot 10^{-5}\, c = 28181.896\,\text{m}$$

$$c\,\Delta rel^{sat} = -3.28 \cdot 10^{-9}\, c = -0.0983\text{m}$$

$$Trop_{rec}^{sat} = 4.319\,\text{m}$$

$$Ion_{1rec}^{sat} = 2.473\,\text{m}$$

$$TGD^{sat} = -2.234\,\text{m}$$

$$\rightarrow C1_{rec}^{sat}[\text{modelled}] = 22857311.201\text{m}$$

Cross-checking results with gLAB

```
grep MODEL gLAB.out | grep -v INFO |
                    awk '{if ($6==25) print $4,$6,$10}' |head -1
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4  grep MODEL gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$10}' |head -1
300.00 25 22857311.1997
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
```

9. Pre-fit residual:

Is the difference between measured and modeled pseudorange

$$\mathrm{Pref}_{rec}^{sat} = \boxed{C1_{rec}^{sat} - C1[\mathrm{mod}]_{rec}^{sat}} = \boxed{\rho_{rec}^{sat} - \rho_{0,rec}^{sat} + c\,dt_{rec} + K_{1rec} + \varepsilon}$$

In the previous example (PRN25 at t= 300 s):

Pref= $\boxed{22857303.996 - 22857311.201}$ = $\boxed{-7.205 \text{ m}}$

From measurement file

Previously calculated

Cross-checking results with gLAB

```
grep PREFIT gLAB.out | grep -v INFO |
              gawk '{if ($6==25) print $4,$6,$8}' |head -1
```

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4   grep PREFIT gLAB.out | grep -v INFO | gawk '{if ($6==25) print $4,$6,$8}' |head -1
300.00 25 -7.2037
Jaume@Jaume-PC:/cygdrive/c/gLAB/win/GNSS_TUTBOOK_MASTER/WORK/TUT4
```

Thank you

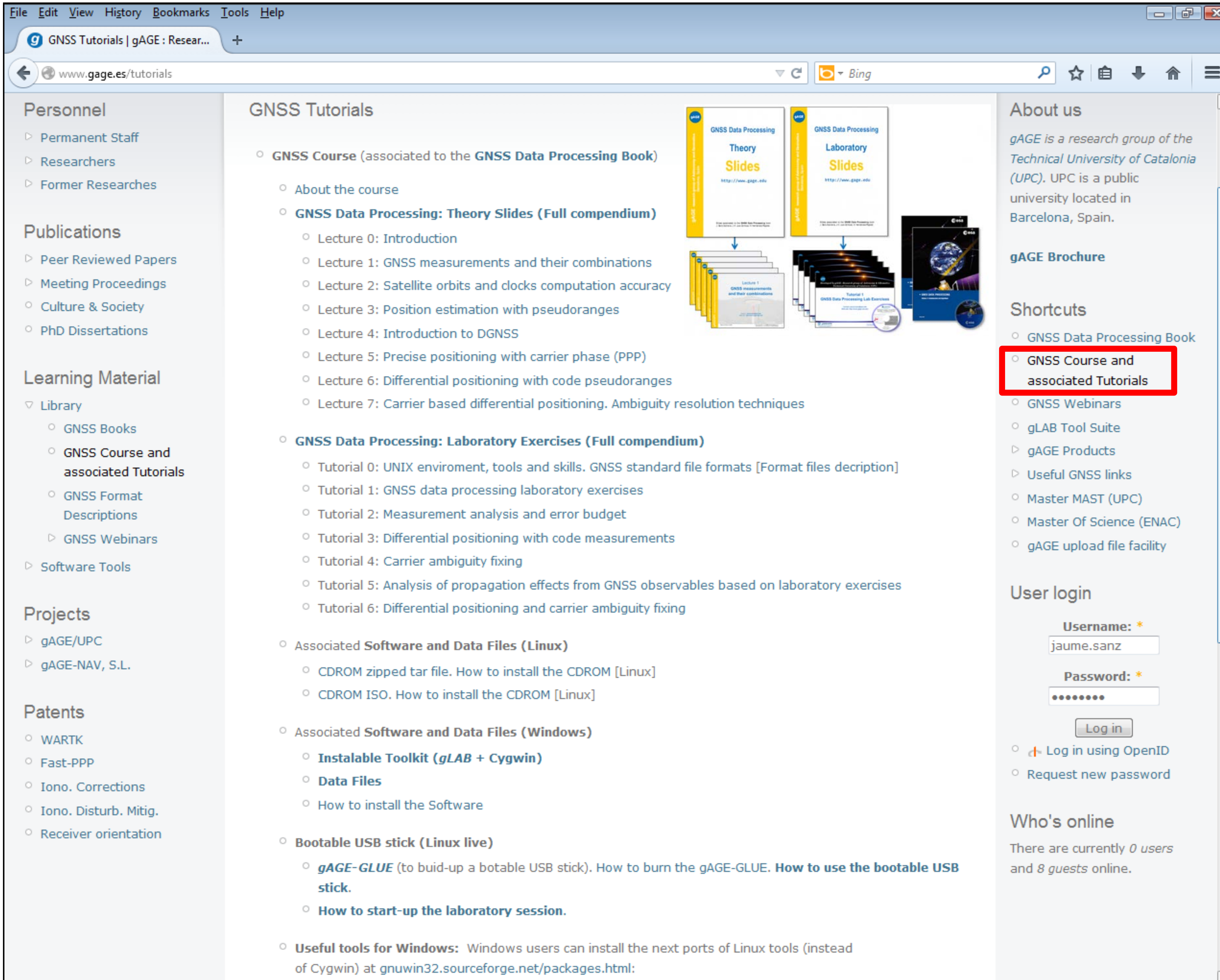
References

[RD-1] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 1: Fundamentals and Algorithms. ESA TM-23/1. ESA Communications, 2013.

[RD-2] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 2: Laboratory Exercises. ESA TM-23/2. ESA Communications, 2013.

[RD-3] Pratap Misra, Per Enge. Global Positioning System. Signals, Measurements, and Performance. Ganga –Jamuna Press, 2004.

[RD-4] B. Hofmann-Wellenhof et al. GPS, Theory and Practice. Springer-Verlag. Wien, New York, 1994.



Other Tutorials are available at
http://www.gage.upc.edu

Acknowledgements

- The ESA/UPC GNSS-Lab Tool suit (gLAB) has been developed under the ESA Education Office contract N. P1081434.
- The data set of GRACE-A LEO satellite was obtained from the NASA Physical Oceanography Distributed Active Archive Center at the Jet Propulsion Laboratory, California Institute of Technology.
- The other data files used in this study were acquired as part of NASA's Earth Science Data Systems and archived and distributed by the Crustal Dynamics Data Information System (CDDIS).
- To Pere Ramos-Bosch for his fully and generous disposition to perform gLAB updates in his afterhours.
- To Adrià Rovira-Garcia for his contribution to the edition of this material and gLAB updating.
- To Deimos Ibáñez for his contribution to gLAB updating and making the Windows installable version for this tutorial.