# 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).

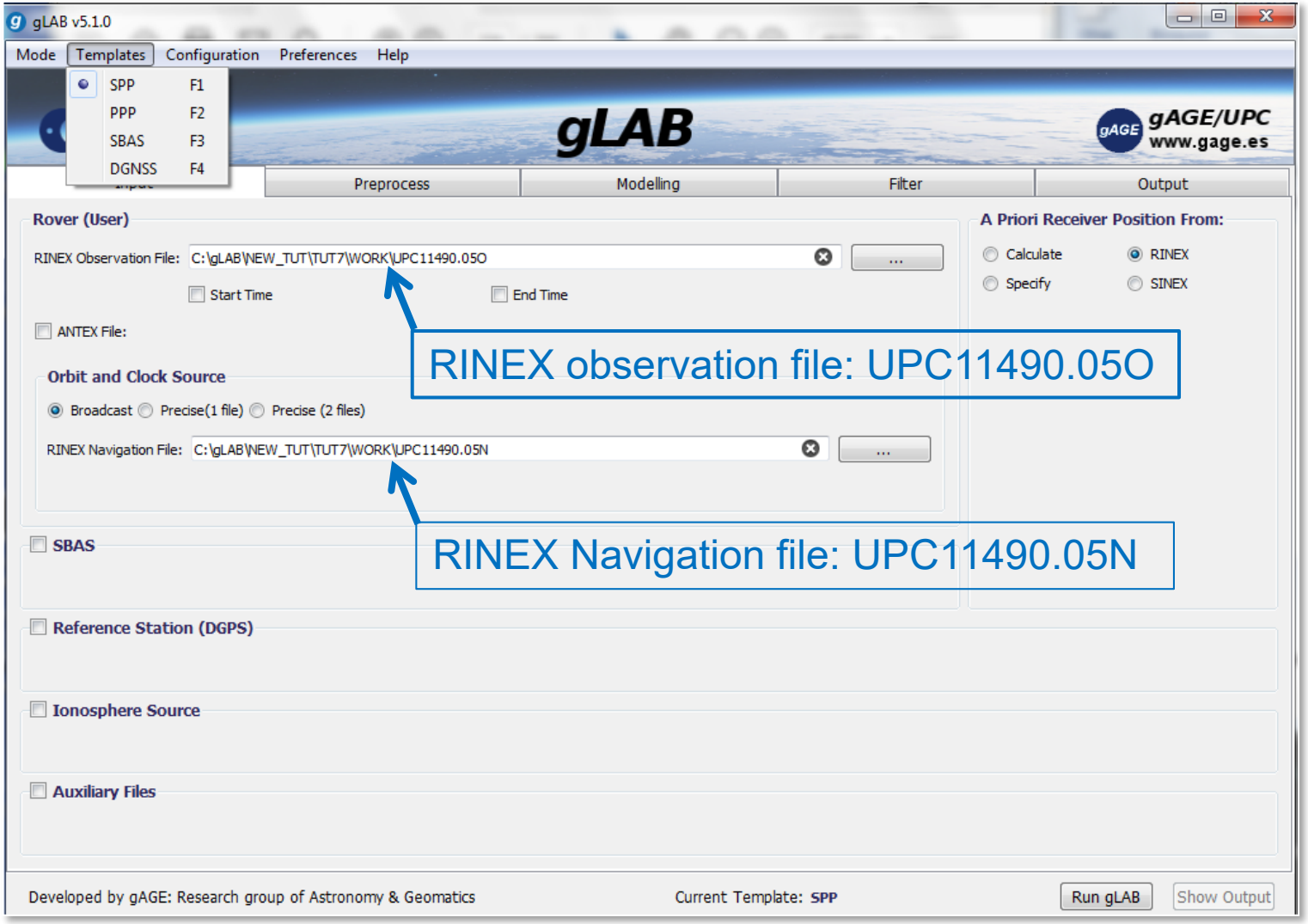
$$C1_{rec}^{sat}[\text{modelled}] = \rho_{0,rec}^{sat} - c\left(\overline{dt}^{sat} + \Delta rel^{sat}\right) + Trop_{rec}^{sat} + Ion_{1rec}^{sat} + TGD^{sat}$$

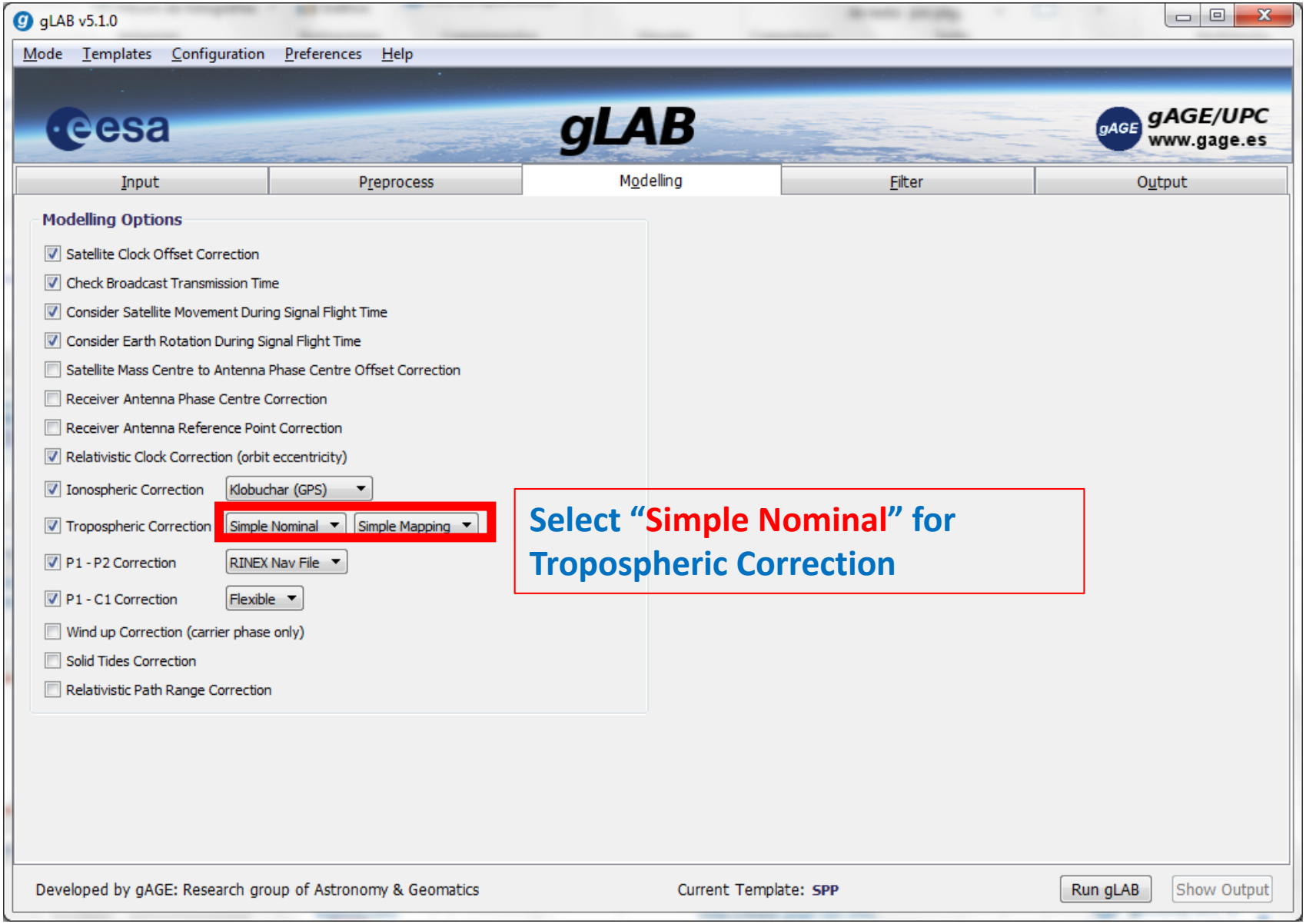
Compare the results with gLAB.

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

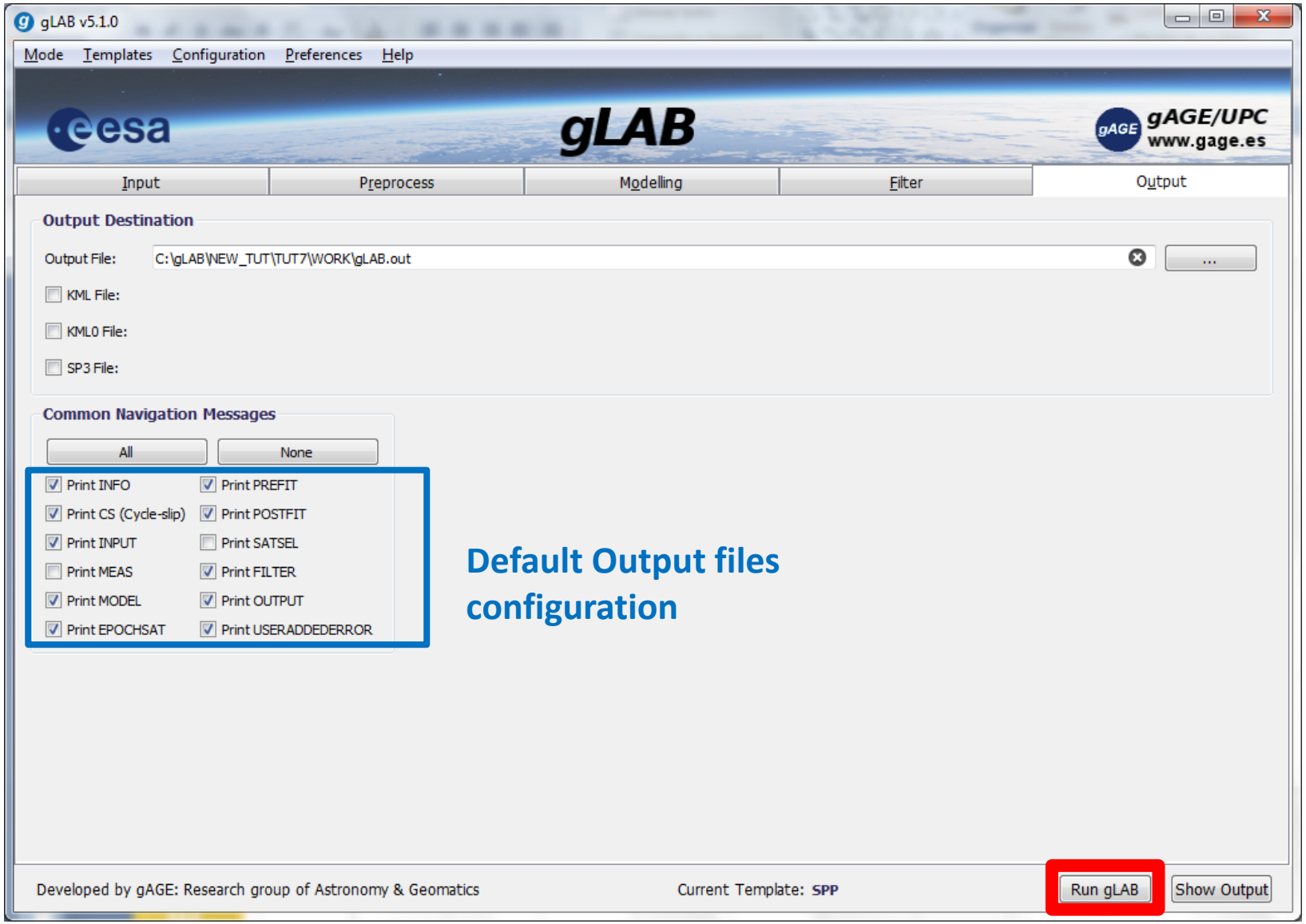
Follow next steps:

# 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:

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

# 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 UPC11490.05O, 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

# 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-07-2.689                0 1.396983861923E-07
 9.492799                00000E+02-1.460408709553E+00-8.100337411567E-09
-3.643008                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
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User manuals
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File Standards
File formats description
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GNSS Calendar
GNSS Date Converter
GNSS Coordinate Converter
GNSS Data Processing Book
GNSS Master Course
Check for updates

Input | Filter | Output

Measurements
Selection
Pseudorange
Pseudorange + Carrier phase
Measurement Configuration and Noise
C1C Fixed StdDev 1
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 | | |

Inputs

OK

## 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*

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

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

```
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*

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

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

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

# Cross-checking results with gLAB

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


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

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

# 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

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

## Cross-checking results with gLAB

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


TGD = -7.450580596924E-09 (in seconds)

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

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

# 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* )**

```
Jaume@Jaume-PC:/cygdrive/c/gLAB/NEW_TUT/TUT7/WORK
     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
```

$(x_{0,rec}, y_{0,rec}, Z_{0,rec})$

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

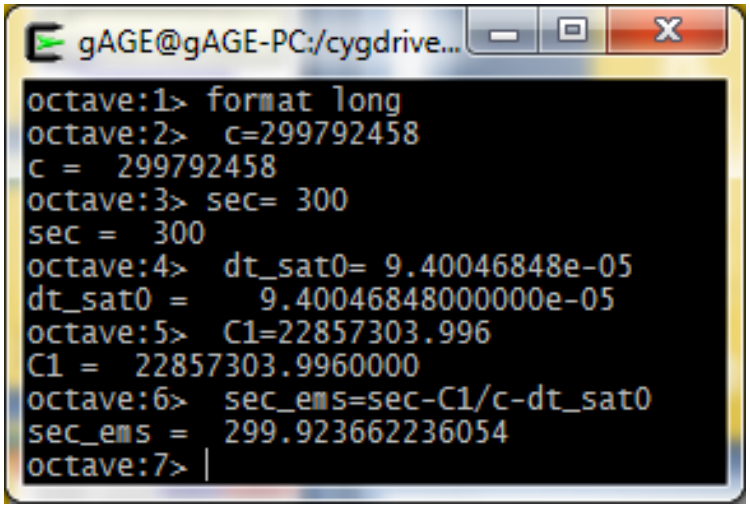
Ephemeris file
**UPC11490.05N**

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

Thence, the emission time in GPS satellite clock is:

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

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




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= 21 851 197.941 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].*

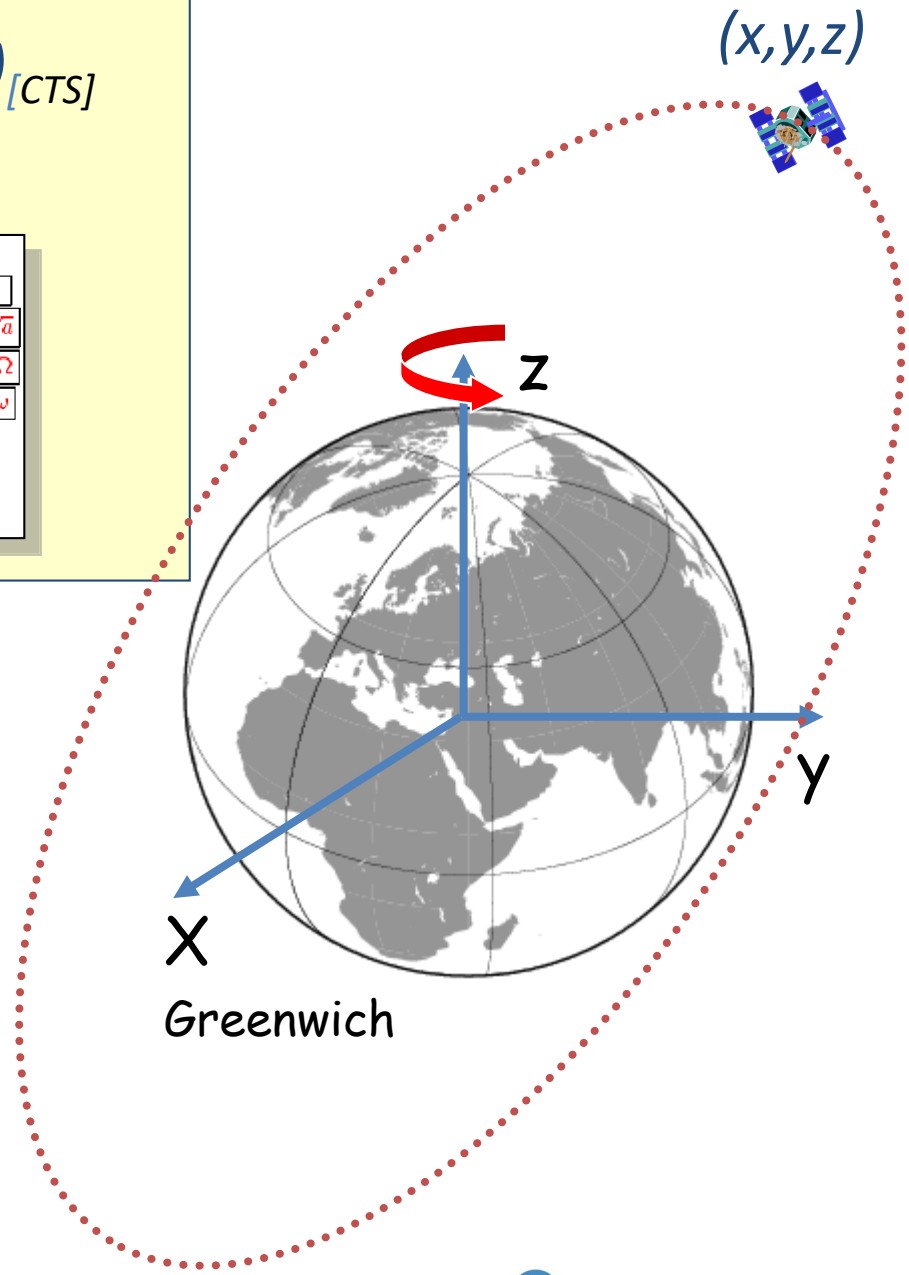
$$(x^{sat},y^{sat},z^{sat})_{CTS[reception]} = R_3(\omega_E \Delta t).(x^{sat},y^{sat},z^{sat})_{CTS[emission]}$$

$t \longrightarrow$ **GPSxyz** $\longrightarrow (x,y,z)_{[CTS]}$

```
03 00  5 30 10  0 40.0+7.855705916882E-06+3.524291969370E-12+0.000000000000E+00
   +1.010000000000E+02+6.500000000000E+01+5.456298524109E-09+5.530285585107E-01  Mo
   +3.475695848465E-06+1.308503560722E-03+2.641230821609E-06+5.153678266525E+03  e, √a
   +2.088000000000E+05+1.117587089539E-08+7.472176136643E-01-1.862645149231E-09  TOE,Ω
   +9.412719852649E-01+3.163750000000E+02+1.125448382894E+00-8.826796182859E-09  io, ω
   +1.239337382719E-10+1.000000000000E+00+1.064000000000E+03+0.000000000000E+00
   +4.000000000000E+00+0.000000000000E+00-4.190951585770E-09+6.130000000000E+02  TGD
   +2.044980000000E+05+0.000000000000E+00+0.000000000000E+00+0.000000000000E+00
```

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 $\Omega_k$ (Greenwich), from longitude $\Omega_0$ 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 $u_k$, $i_k$, $\Omega_k$) :

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

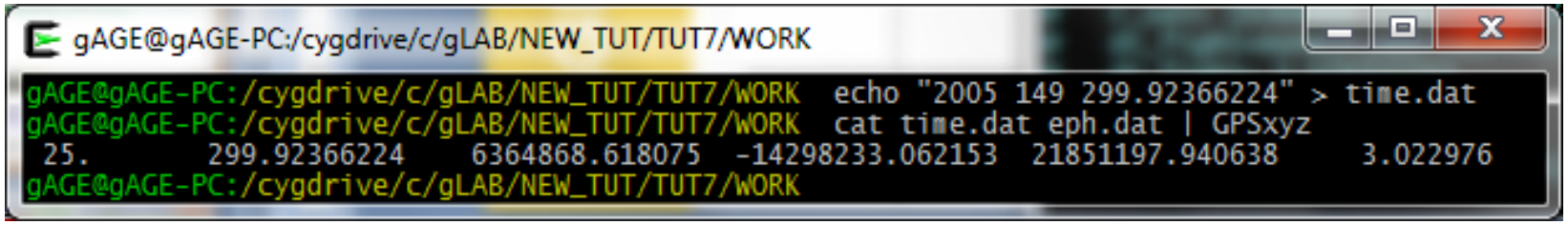
## Computation of satellite coordinates in an Earth-Fixed reference frame (CTS) at *t=T[emission]*= 299.92366 s.

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
```




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]*

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

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

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

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

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

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

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

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

An approximate value is enough to compute $\Delta t$.

**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   0.000000000000
  -0.000005566633934   0.999999999984506   0.000000000000
   0.000000000000000   0.000000000000000   1.000000000000

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]**

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

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

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

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

## 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:

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

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

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

"Approximate" receiver coordinates at reception time.

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

# 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
```

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

# 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)*

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

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

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

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

## 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, $r_{sta}$, $r^{sat}$ α0,α1,α2,α3,β0,β1,β2,β3) ➔[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
```

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

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

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

Approximate values for receiver or satellite coordinates are enough

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

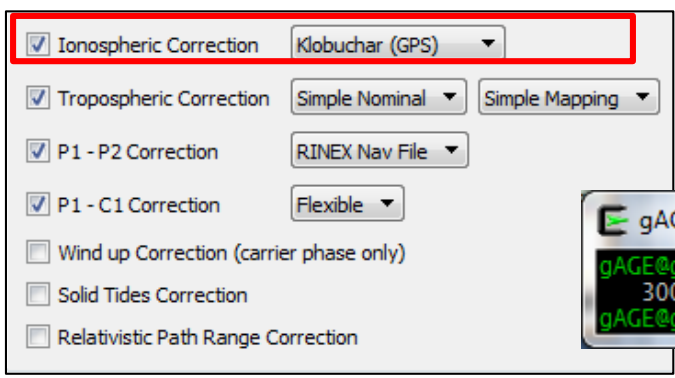
# 6. Ionospheric correction

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.

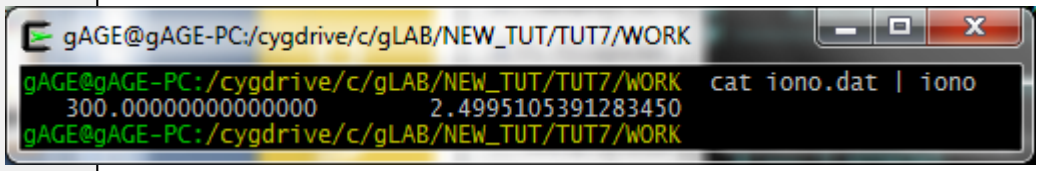
Note: the algorithms are given in the GNSS book, Volume-1.
The Fortran code **iono.f** and C code **Model.c** are available in the CD-ROM, Volume -2




Execute

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

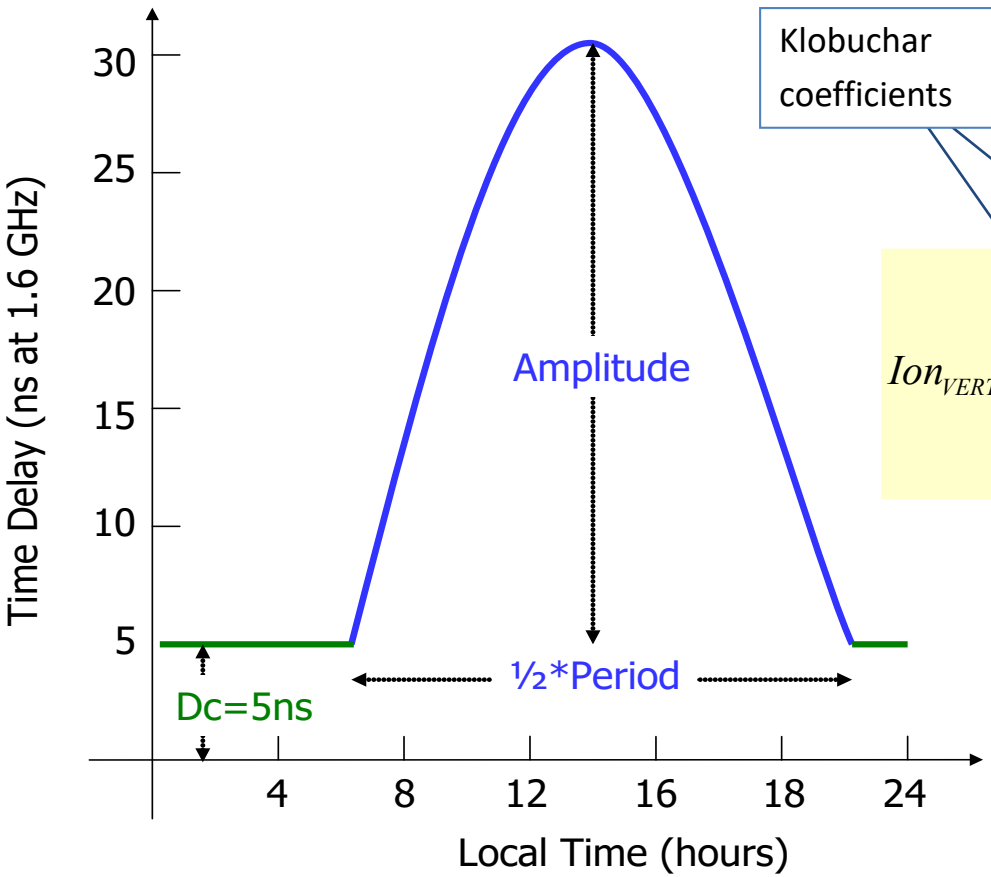
➔**2.47 m L1 delay**



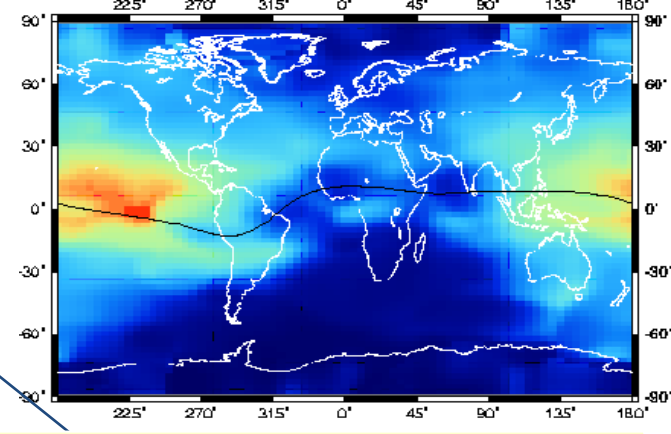
$$(\text{time}, \underbrace{r_{sta}, r^{sat}}_{elev,\ \phi}, \alpha 0, \alpha 1, \alpha 2, \alpha 3, \beta 0, \beta 1, \beta 2, \beta 3) \rightarrow \boxed{\text{iono}}$$

```
 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




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**

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

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

Where:

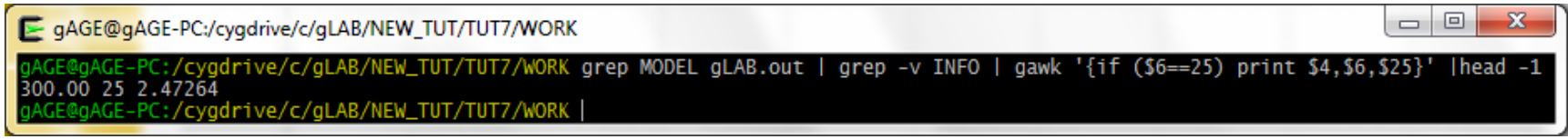
$DC$= 5ns

$\Phi$= 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
```




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

*Solution:*

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

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

# 7. Tropospheric correction

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

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

$$d_{wet} = 0.1m$$

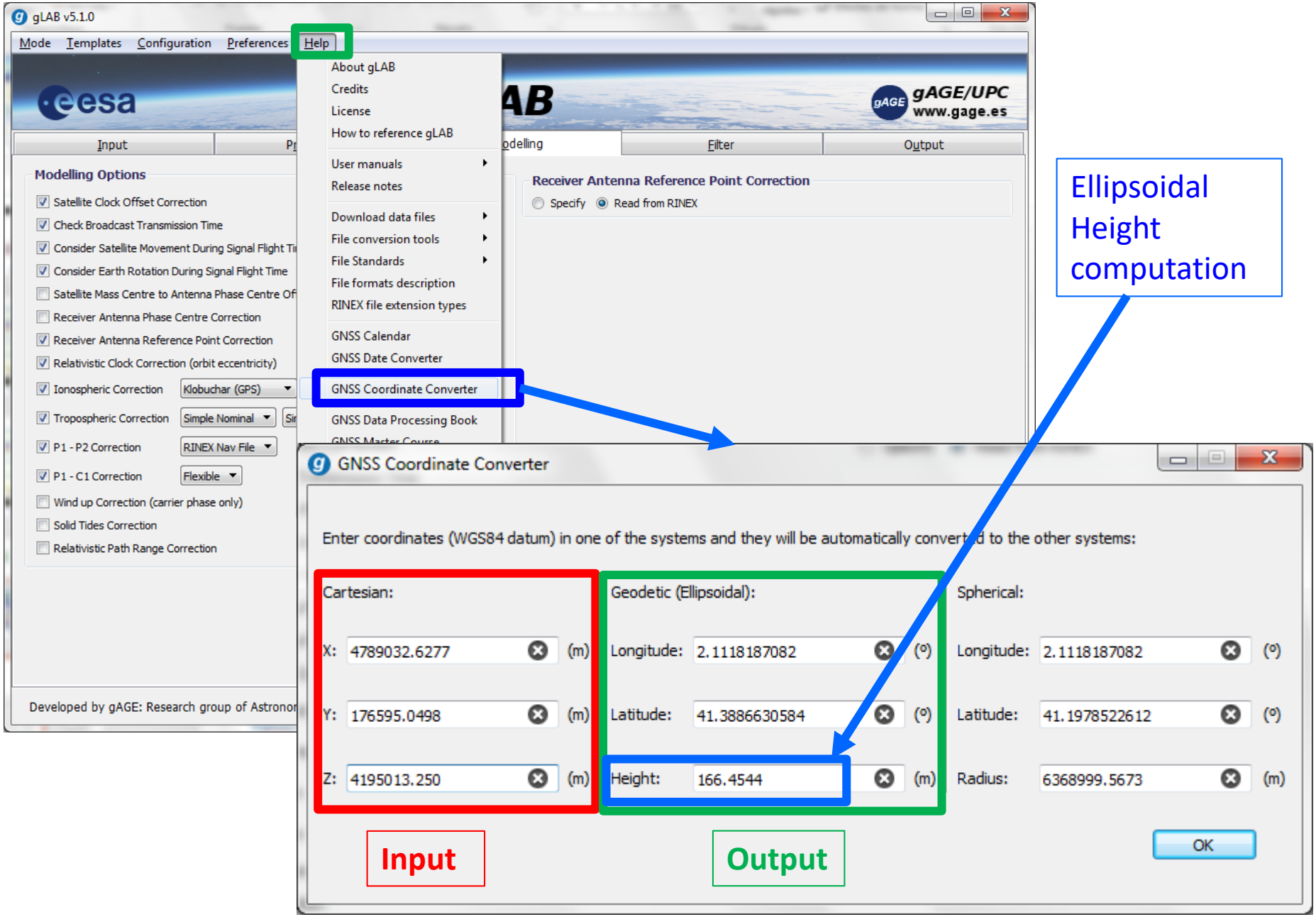
$$m(elev) = \frac{1.001}{\sqrt{0.002001 + \sin^2(elev)}}$$

**See next slides**

$elev$ : *satellite elevation*

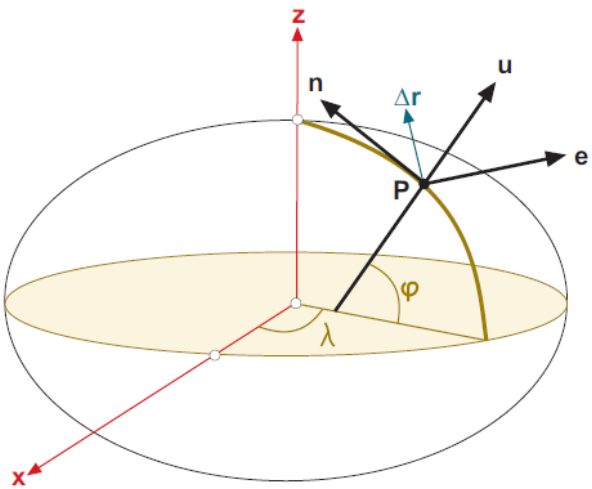
$H$ = *height over the ellipsoid*

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




Ellipsoidal Height computation

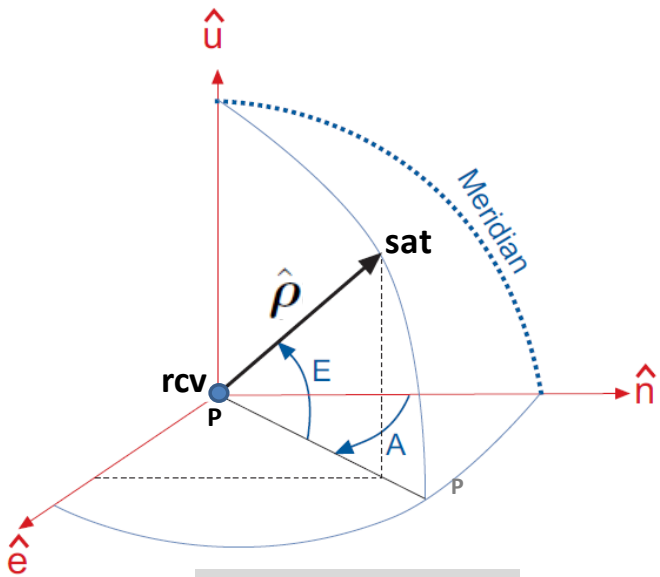
# Satellite Elevation and Azimuth computation




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

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

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




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

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

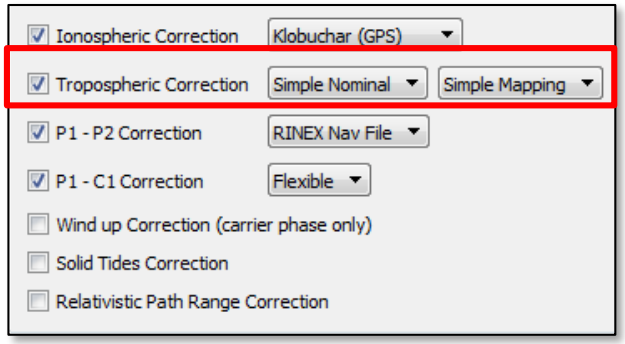
## Computation of satellite elevation

```
# 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)
```

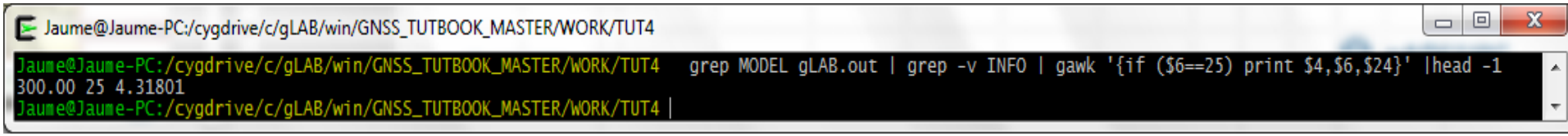
# Computation of Tropospheric delay

```
# 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
```




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

# 8. Compute the modeled pseudorange

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

$$\rho_{0,rec}^{sat} = 22\,885\,487.554\,\text{m}$$

$$\overline{dt}^{sat} = 9.400 \cdot 10^{-5}\, c = 28181.896\,\text{m}$$

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

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

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

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

$$\rightarrow C1_{rec}^{sat}[\text{modelled}] = 22\,857\,311.201\text{m}$$

## 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

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

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

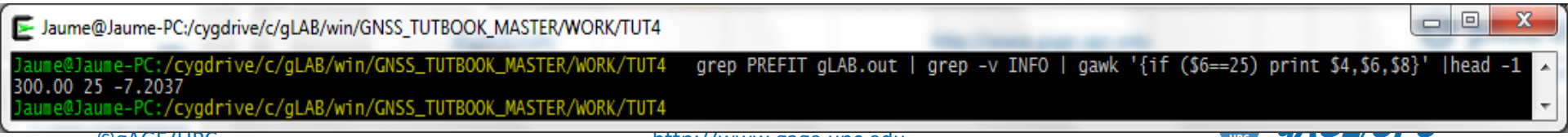
Pref= 22857303.996 - 22857311.201 = -7.205 m

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
```



# 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

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- Library
  - GNSS Books
  - GNSS Course and associated Tutorials
  - GNSS Format Descriptions
  - GNSS Webinars
- Software Tools

## Projects

- gAGE/UPC
- gAGE-NAV, S.L.

## Patents

- WARTK
- Fast-PPP
- Iono. Corrections
- Iono. Disturb. Mitig.
- Receiver orientation

## GNSS Tutorials


- **GNSS Course** (associated to the **GNSS Data Processing Book**)
  - About the course
  - **GNSS Data Processing: Theory Slides (Full compendium)**
    - Lecture 0: Introduction
    - Lecture 1: GNSS measurements and their combinations
    - Lecture 2: Satellite orbits and clocks computation accuracy
    - Lecture 3: Position estimation with pseudoranges
    - Lecture 4: Introduction to DGNSS
    - Lecture 5: Precise positioning with carrier phase (PPP)
    - Lecture 6: Differential positioning with code pseudoranges
    - Lecture 7: Carrier based differential positioning. Ambiguity resolution techniques
  - **GNSS Data Processing: Laboratory Exercises (Full compendium)**
    - Tutorial 0: UNIX enviroment, tools and skills. GNSS standard file formats [Format files decription]
    - Tutorial 1: GNSS data processing laboratory exercises
    - Tutorial 2: Measurement analysis and error budget
    - Tutorial 3: Differential positioning with code measurements
    - Tutorial 4: Carrier ambiguity fixing
    - Tutorial 5: Analysis of propagation effects from GNSS observables based on laboratory exercises
    - Tutorial 6: Differential positioning and carrier ambiguity fixing
  - Associated **Software and Data Files (Linux)**
    - CDROM zipped tar file. How to install the CDROM [Linux]
    - CDROM ISO. How to install the CDROM [Linux]
  - Associated **Software and Data Files (Windows)**
    - **Instalable Toolkit (*gLAB* + Cygwin)**
    - **Data Files**
    - How to install the Software
  - **Bootable USB stick (Linux live)**
    - ***gAGE-GLUE*** (to buid-up a botable USB stick). How to burn the gAGE-GLUE. **How to use the bootable USB stick.**
    - **How to start-up the laboratory session.**
  - **Useful tools for Windows:** Windows users can install the next ports of Linux tools (instead of Cygwin) at gnuwin32.sourceforge.net/packages.html:

## About us

*gAGE is a research group of the Technical University of Catalonia (UPC).* UPC is a public university located in Barcelona, Spain.

**gAGE Brochure**

## Shortcuts

- GNSS Data Processing Book
- GNSS Course and associated Tutorials
- GNSS Webinars
- gLAB Tool Suite
- gAGE Products
- Useful GNSS links
- Master MAST (UPC)
- Master Of Science (ENAC)
- gAGE upload file facility

## User login

**Username:** *
jaume.sanz

**Password:** *
••••••••

Log in

- Log in using OpenID
- Request new password

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There are currently *0 users* and *8 guests* online.

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