Tutorial 3
Model components analysis

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

http://www.gage.upc.edu

Introduction

- This practical lecture is devoted to analyze and assess different issues associated with Standard and Precise Point Positioning with GPS data.

- The laboratory exercises will be developed with actual GPS measurements, and processed with the ESA/UPC GNSS-Lab Tool suite (gLAB), which is an interactive software package for GNSS data processing and analysis.

- Some examples of gLAB capabilities and usage will be shown before starting the laboratory session.

- All software tools (including *gLAB*) and associated files for the laboratory session are included in the USB stick delivered to lecture attendants.

- The laboratory session will consist in a set of exercises performing a glance assessment of the different model components involved on a Standard or Precise Positioning.

Model Components Analysis

Exercises 1 and 2.

They consist of simple exercises to assess the model components for Standard and Precise Point Positioning.

"Background information" slides are provided, summarizing the main concepts associated with these exercises.
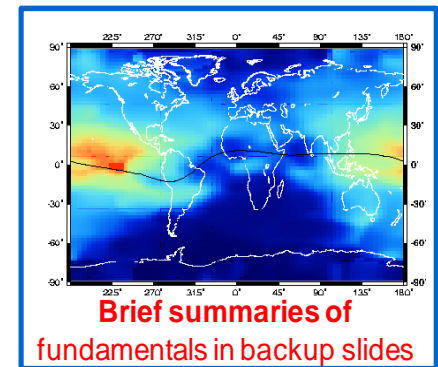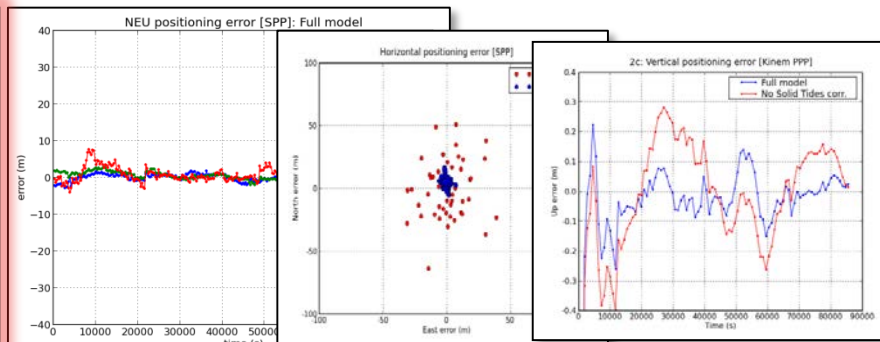
Brief summaries of fundamentals in backup slides

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Model Components Analysis

Exercise 1: Model components analysis for SPP

- This exercise is devoted to analyze the different model components of measurements (ionosphere, troposphere, relativity, etc.). This is done both in the Signal-In-Space (SIS) and User Domains.

Exercise 1: SPP Model components analysis

1. Compute SPP using files: `chpi0010.04o,brdc0010.04n`
   Cachoeira Paulista station (in the south of Brazil: λ=-22.7º, ϕ=-45.0º). January 1st 2004.

Set vertical range: -40, 40

gLAB.out

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

NEU Position Error plot from gLAB.out

Exercise 1: SPP Model components analysis
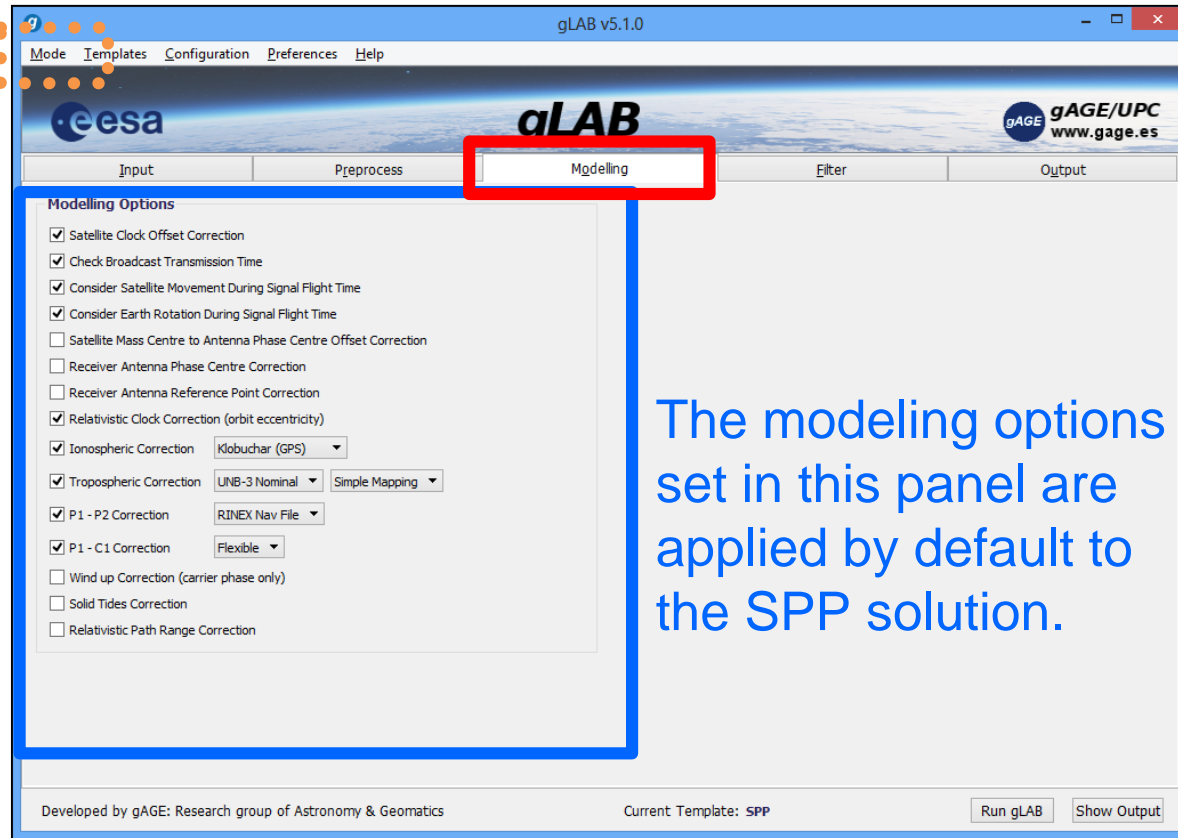
The different model components will be analyzed with gLAB:

- Using the previous data file, the impact of neglecting each model component will be evaluated in the Range and Position domains

- A baseline example of this analysis procedure for the ionospheric correction is provided as follows.

- The same scheme must be applied for all model terms.

Example of model component analysis: **IONO.**

Default configuration for SPP

The procedure explained here is applicable for all the cases: iono, tropo…

1. In Modeling panel, disable the model component to analyze.
   (in this example: disable Ionospheric correction)

1

Disable Ionospheric correction
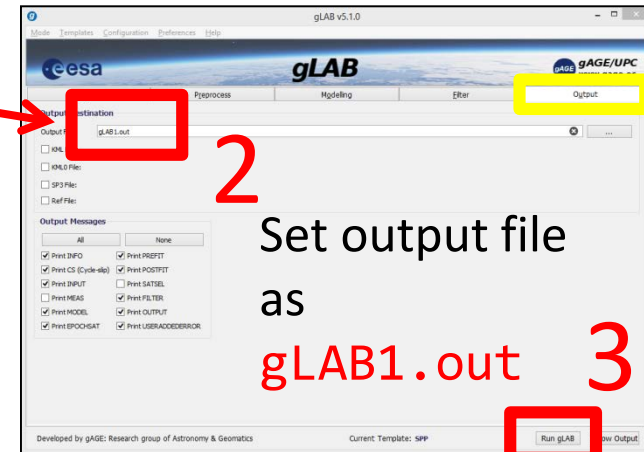
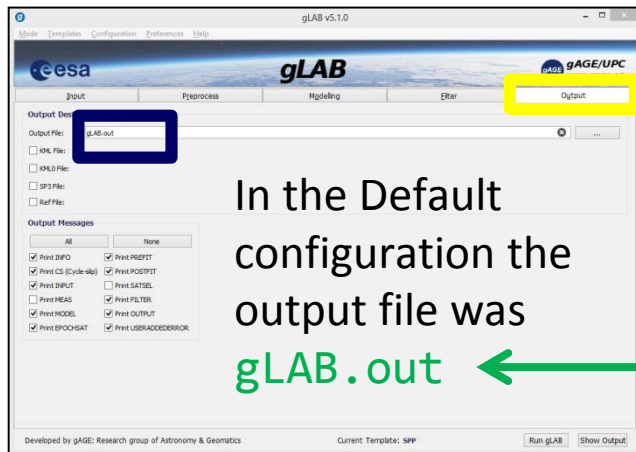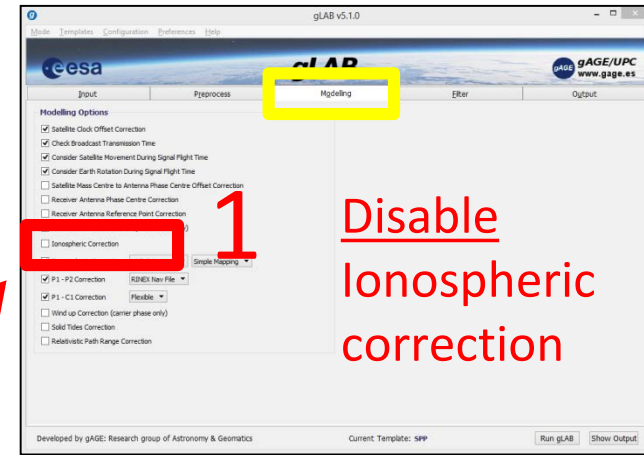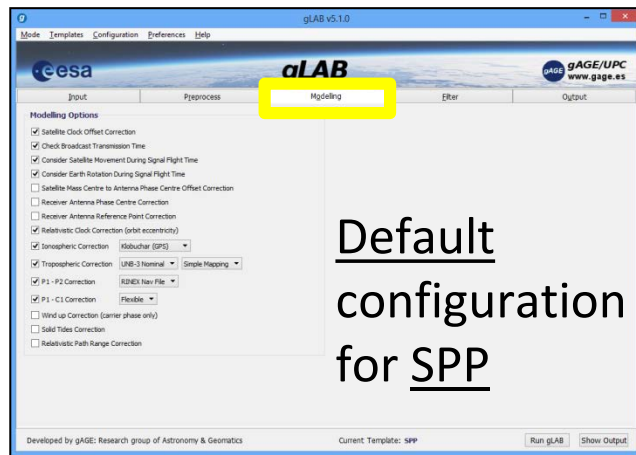2. Save as gLAB1.out the associated output file.

Notice that the gLAB.out file contains the processing results with the FULL model, as it was set in the default configuration.
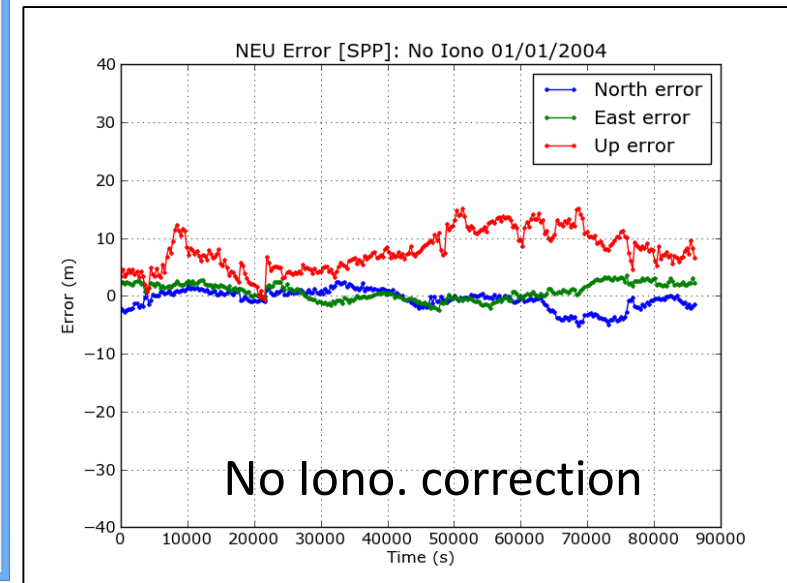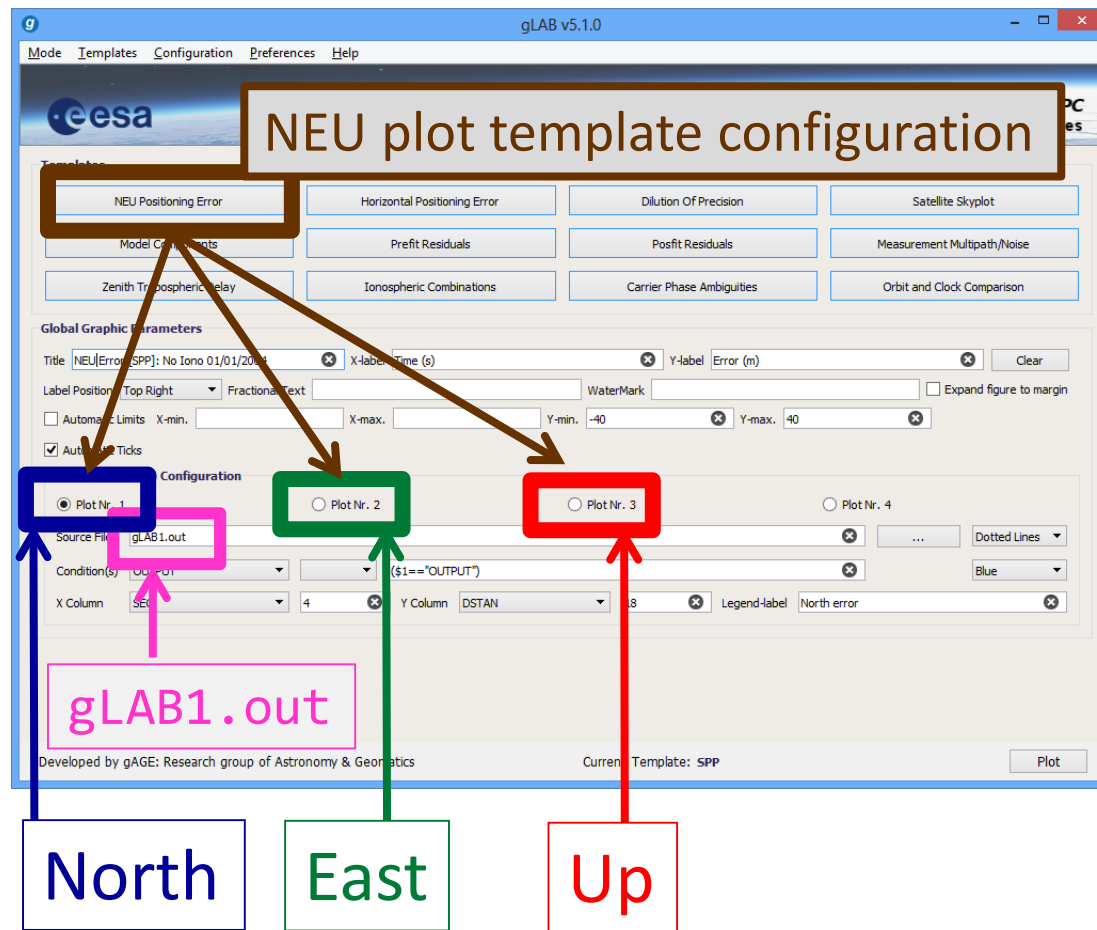

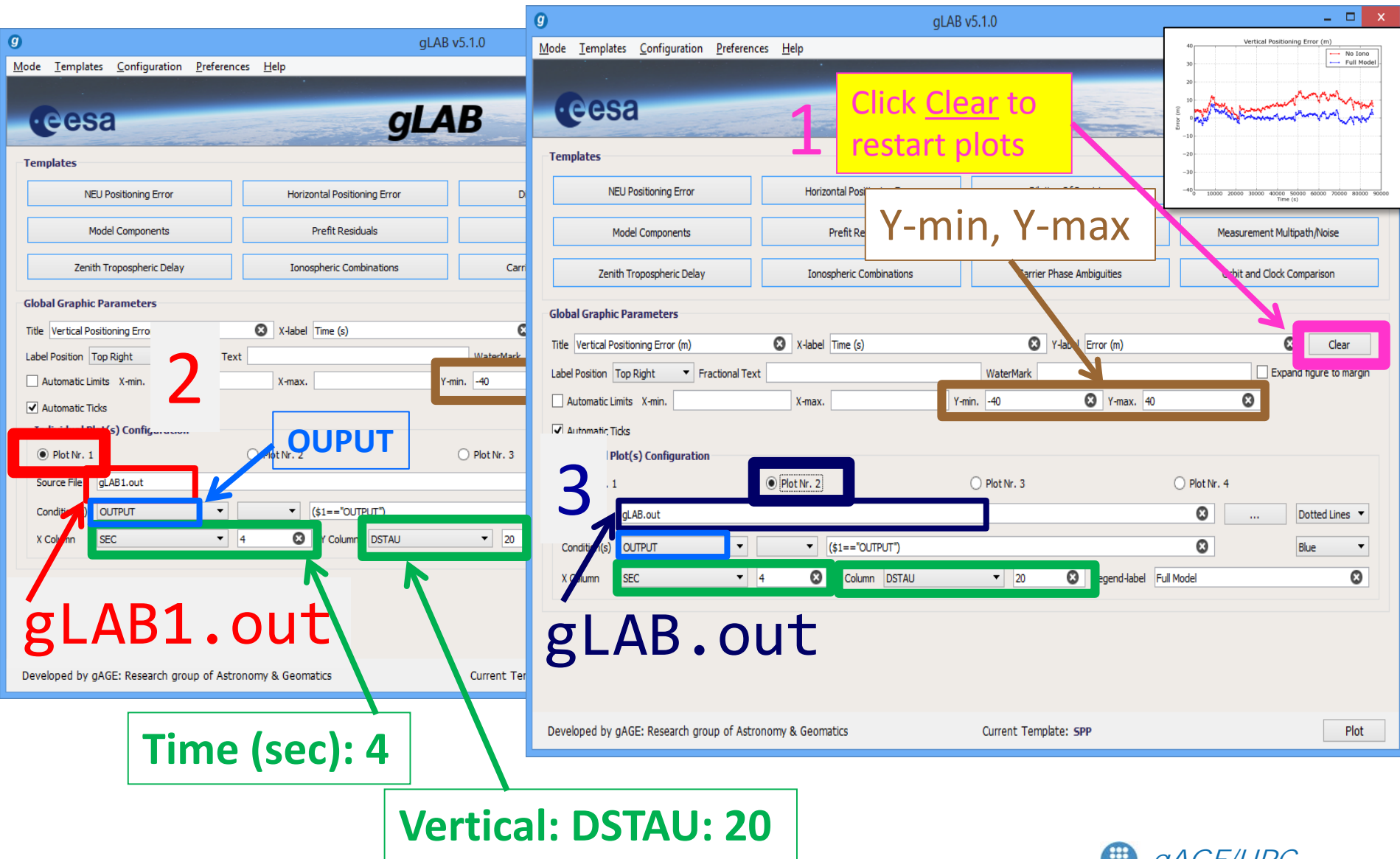In the Default configuration the output file was gLAB.out

2
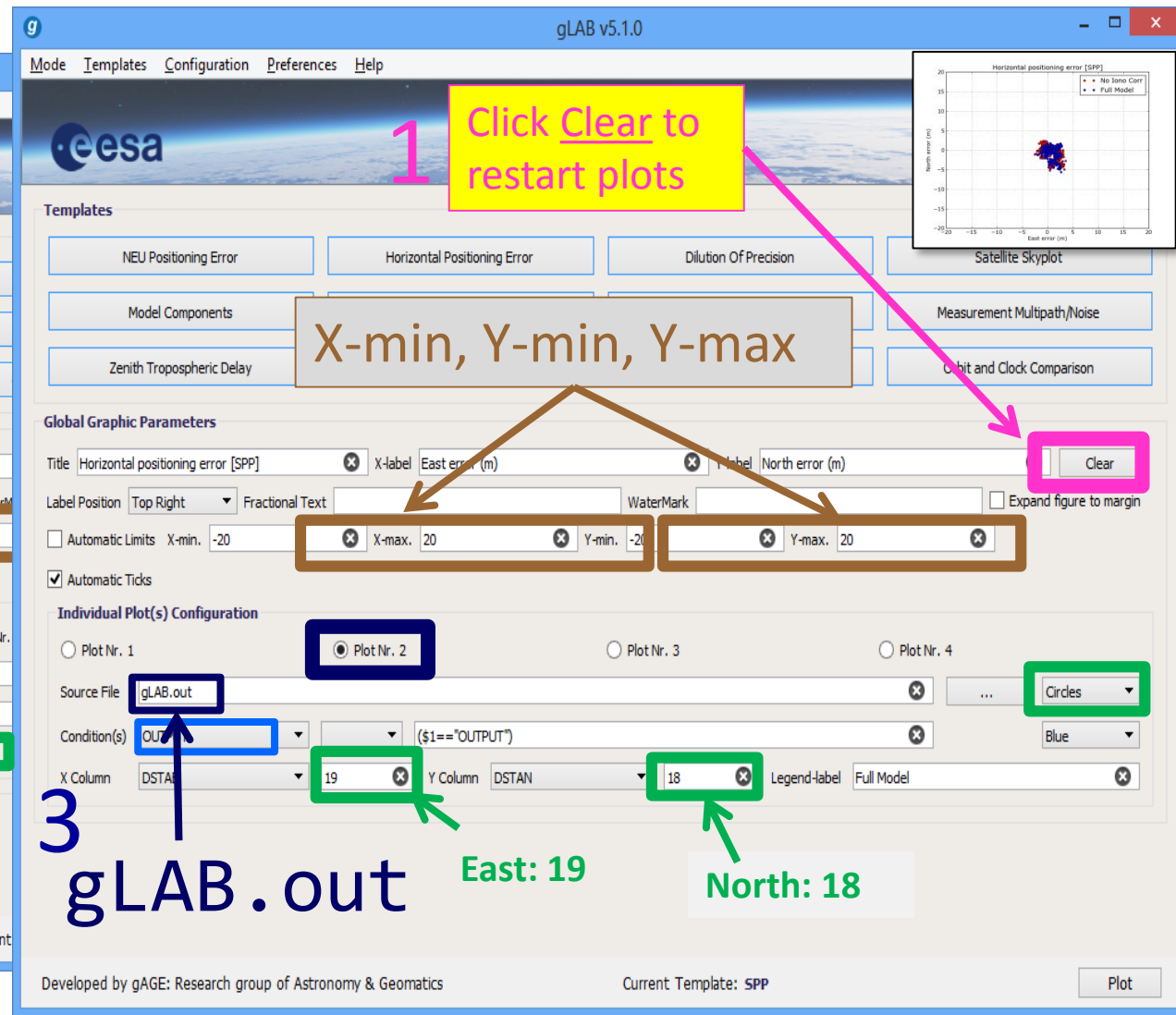
Set output file as

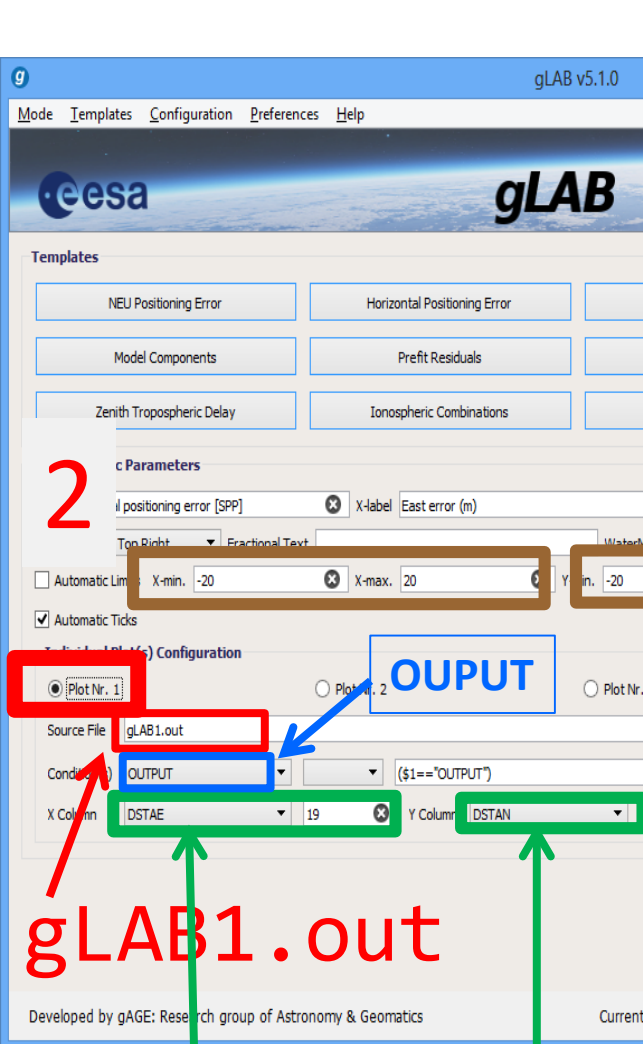gLAB1.out   **3**

NEU Position Error plot from **gLAB1.out**

NEU plot template configuration
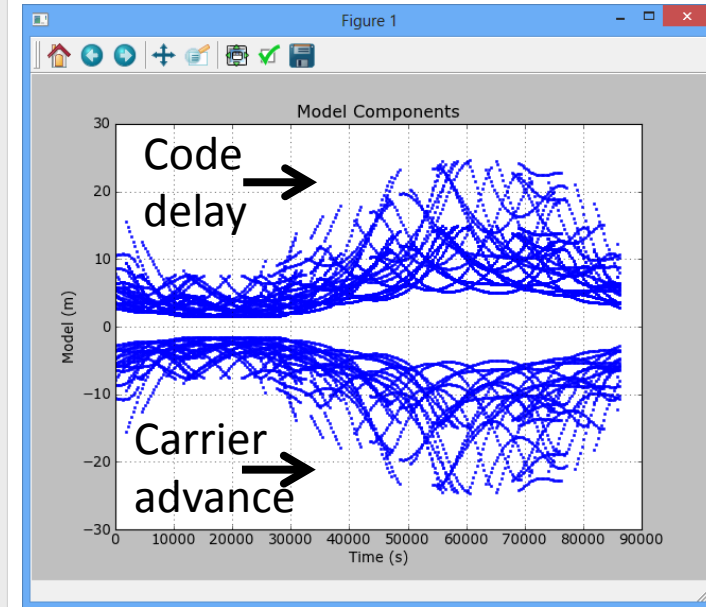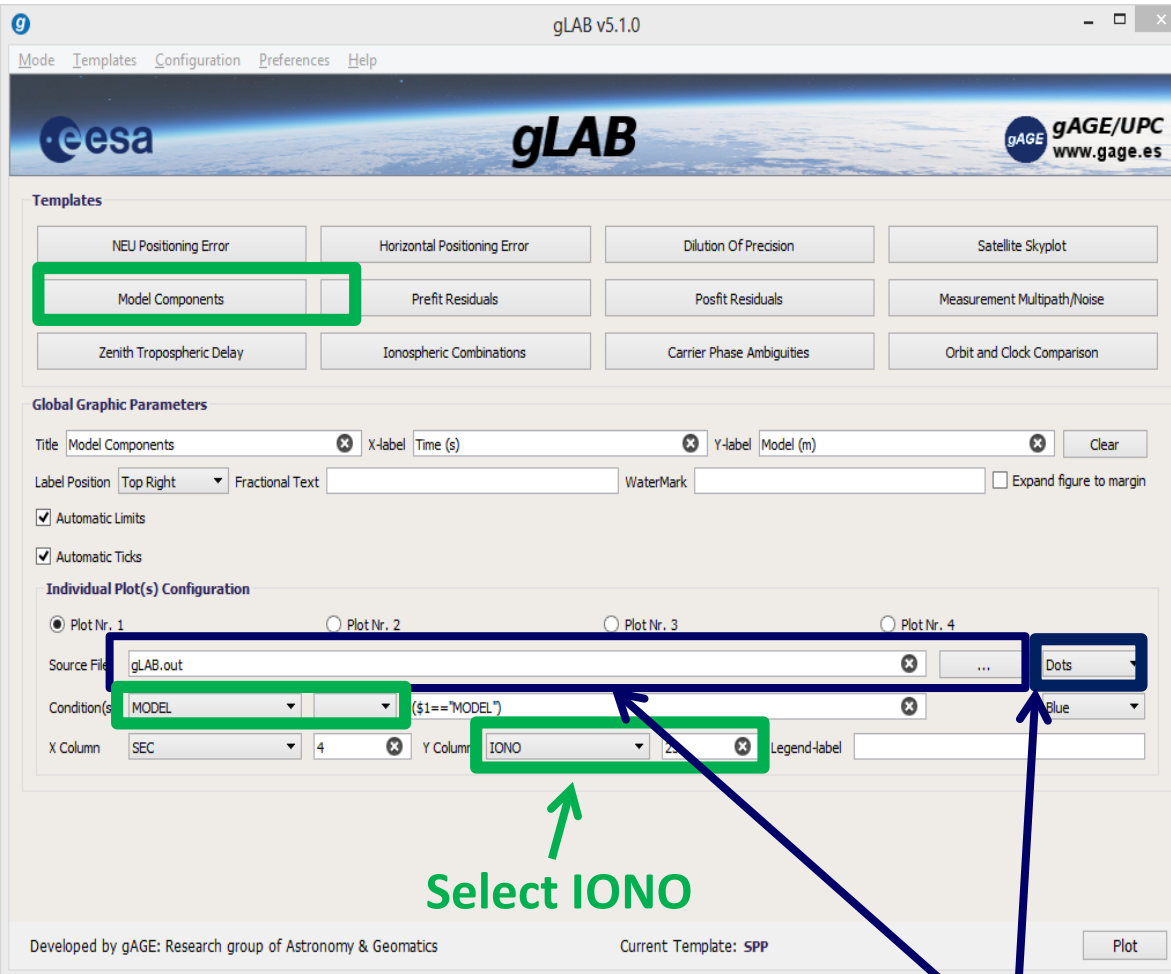
gLAB1.out

North

East

Up

Vertical Position Error plot from `gLAB.out, gLAB1.out`

Horizontal Position Error plot: **gLAB.out, gLAB1.out**
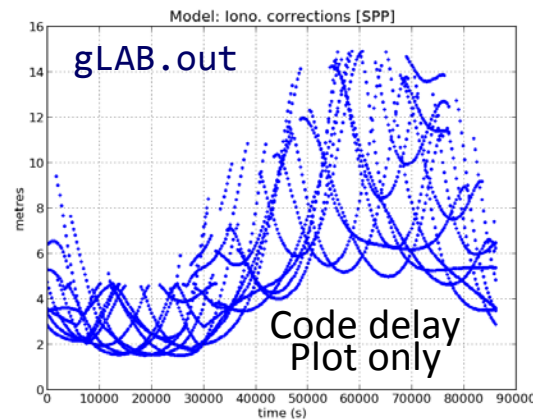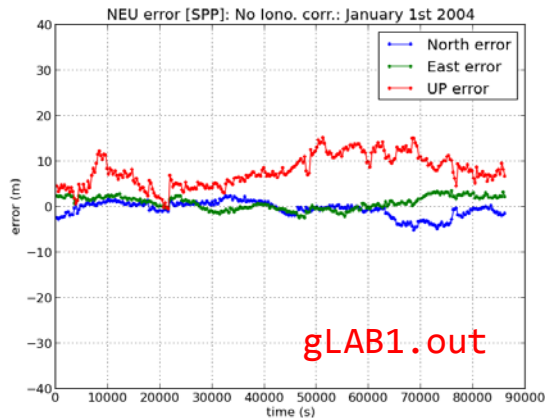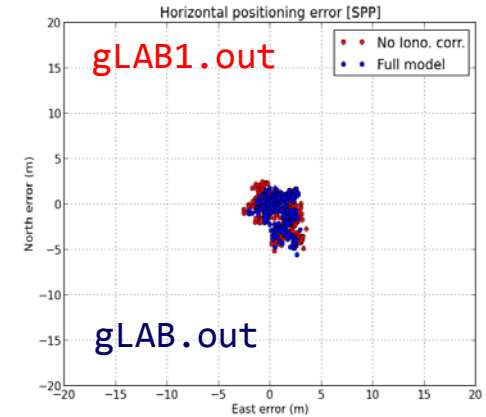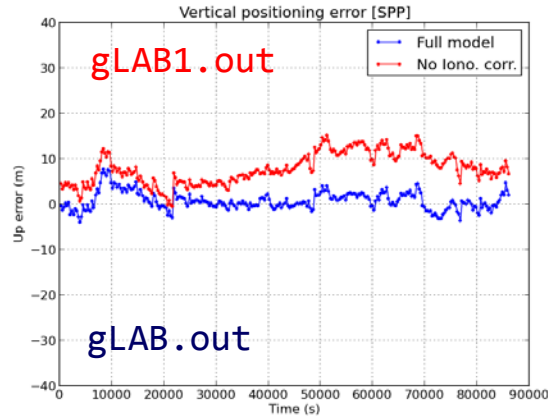
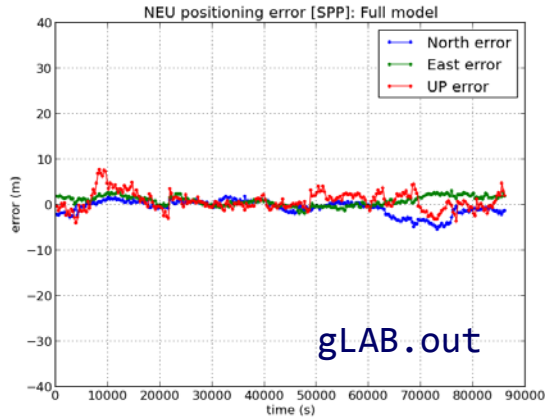# Ionospheric model component plot: `gLAB.out`

Ionosphere delays code and advances carrier measurements.

Note: **Use the `gLAB.out` file.** In `gLAB1.out` file this model component was switched off.

Select IONO

`gLAB.out`

Summary: Iono. model component analysis

NEU positioning error [SPP]: Full model — gLAB.out (North error, East error, UP error)

Vertical positioning error [SPP] — gLAB1.out / gLAB.out (Full model, No Iono. corr.)

Horizontal positioning error [SPP] — gLAB1.out / gLAB.out (No Iono. corr., Full model)

NEU error [SPP]: No Iono. corr.: January 1st 2004 — gLAB1.out (North error, East error, UP error)

Model: Iono. corrections [SPP] — gLAB.out — Code delay Plot only

Ionospheric correction (broadcast Klobuchar)

Ionospheric delays are larger at noon due to the higher insulation.

Large positioning errors (mainly in vertical) appear when neglecting iono. corr.

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Exercise 1: SPP Model components analysis

Ionospheric delay

The ionosphere extends from about 60 km over the Earth surface until more than 2000 km, with a sharp electron density maximum at around 350 km. The ionospheric refraction depends, among other things, of the location, local time and solar cycle (11 years).

- First order (~99.9%) ionospheric delay δ_{ion} depends $\delta_{ion} = \dfrac{40.3}{f^2} I$ on the inverse of squared frequency:

  where I is the number of electrons per area unit along ray path (STEC: Slant Total Electron Content). $I = \int N_e ds$

- Two-frequency receivers can remove this error source (up to 99.9%) using ionosphere-free combination of pseudoranges (PC) or carriers (LC). $LC = \dfrac{f_1^2 L1 - f_2^2 L2}{f_1^2 - f_2^2}$

- Single-frequency users can remove about a 50% of the ionospheric delay using the Klobuchar model, whose parameters are broadcast in the GPS navigation message.
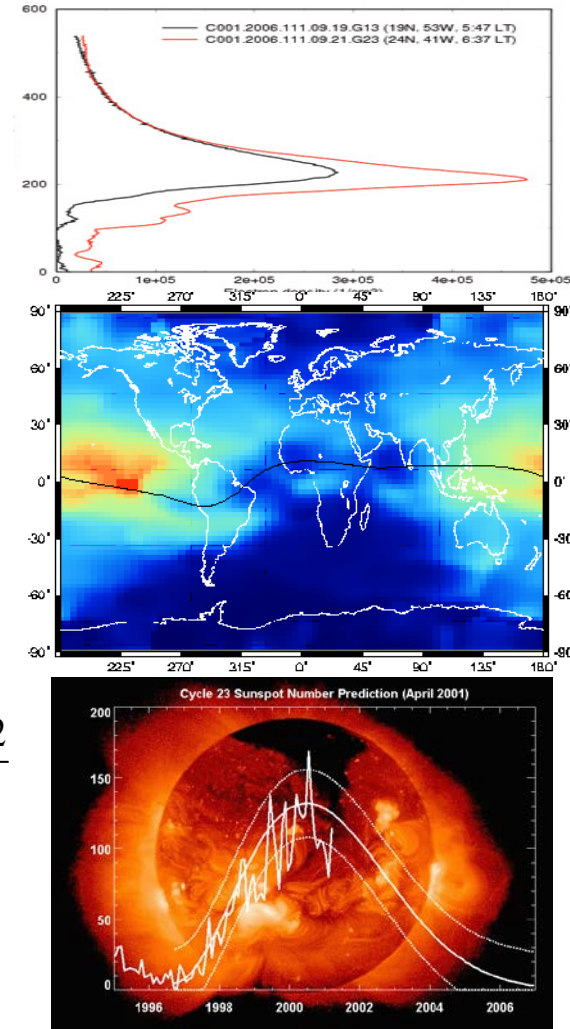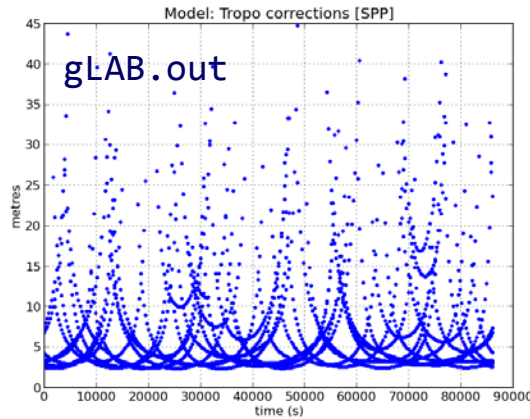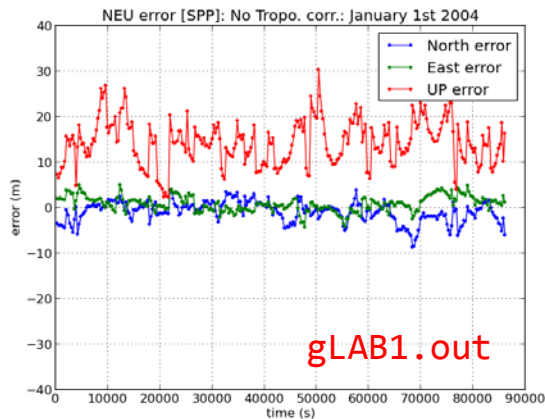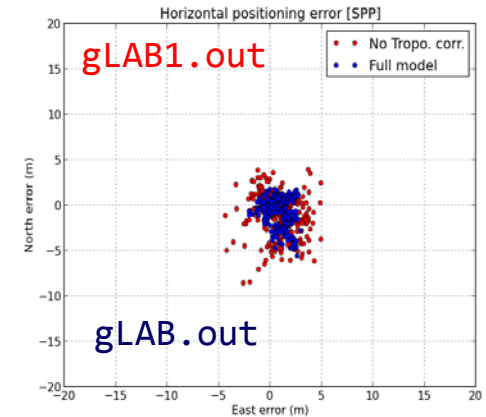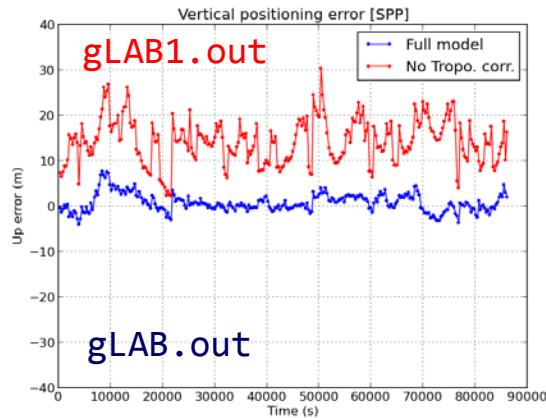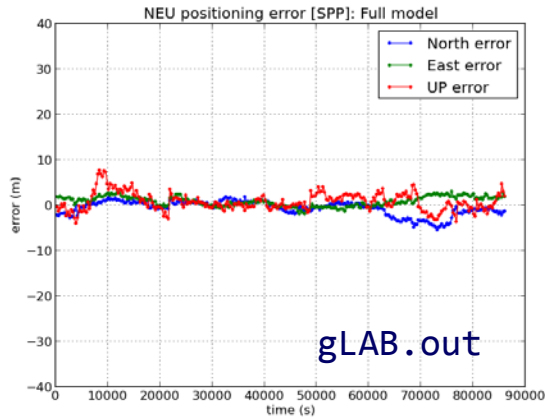
Example of model component analysis: **TROPO.**

The *gLAB* configuration can be set-up as follows, to <u>repeat the processing without applying the tropospheric correction</u> (but using the ionosphere again!):
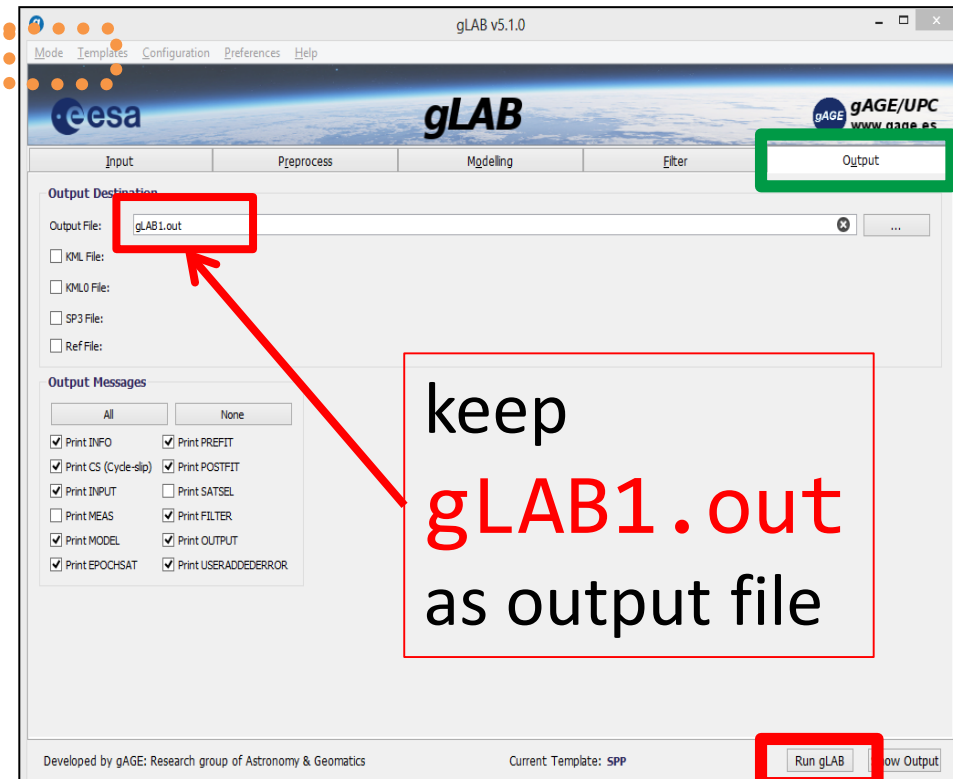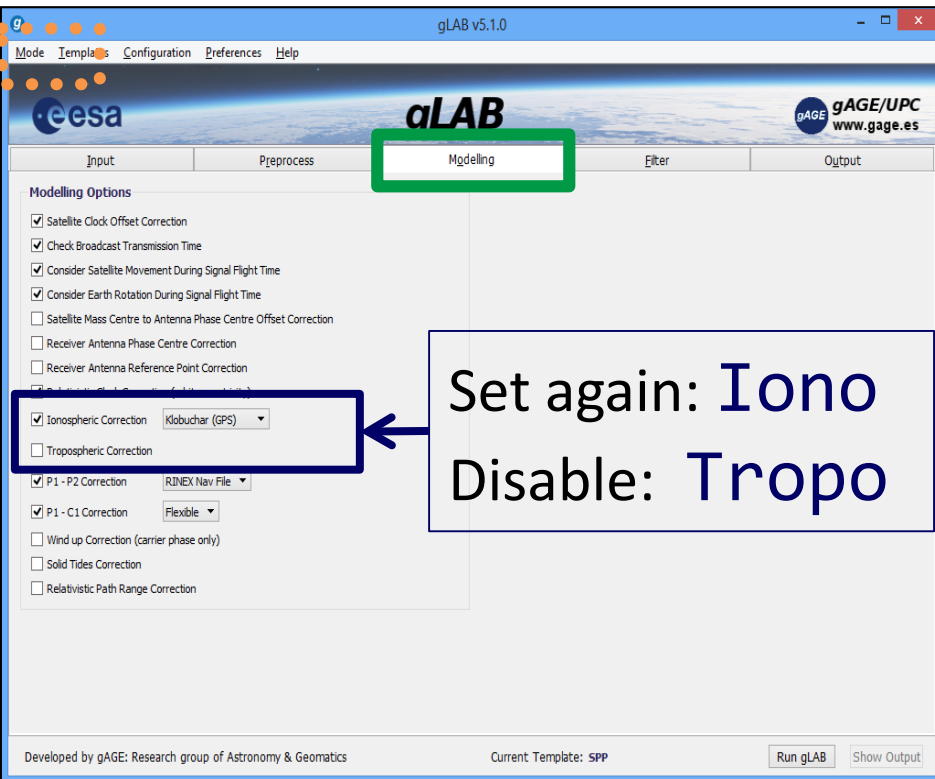
- The same scheme must be applied for all other model terms (TGDs, relat...)

Exercise 1: SPP Model components analysis

Title: NEU positioning error [SPP]: Full model

Legend: North error, East error, UP error

gLAB.out

Title: Vertical positioning error [SPP]

gLAB1.out

Legend: Full model, No Tropo. corr.

gLAB.out

Title: Horizontal positioning error [SPP]

gLAB1.out

Legend: No Tropo. corr., Full model

gLAB.out

Title: NEU error [SPP]: No Tropo. corr.: January 1st 2004

Legend: North error, East error, UP error

gLAB1.out

Title: Model: Tropo corrections [SPP]

gLAB.out

Tropospheric correction (blind model)

Tropospheric and vertical error are highly correlated.

A displacement of vertical component appears when neglecting tropospheric corrections.

gAGE/UPC

Research group of Astronomy & Geomatics
Technical University of Catalonia

# Exercise 1: SPP Model components analysis

Tropospheric delay

The troposphere is the atmospheric layer placed between Earth's surface and an altitude of about 60 km.

The effect of troposphere on GNSS signals appears as an extra delay in the measurement of the signal travelling from satellite to receiver.

The tropospheric delay does not depend on frequency and affects both the pseudorange (code) and carrier phases in the same way. It can be modeled by:

– An **hydrostatic component**, composed of dry gases (mainly nitrogen and oxygen) in hydrostatic equilibrium. This component can be treated as an ideal gas. Its effects vary with the temperature and atmospheric pressure in a quite predictable manner, and it is the responsible of about 90% of the delay.

– A **wet component** caused by the water vapor condensed in the form of clouds. It depends on the weather conditions and varies faster than the hydrostatic component and in a quite random way. For high accuracy positioning, this component must be estimated together with the coordinates and other parameters in the navigation filter.

Exercise 1: SPP Model components analysis
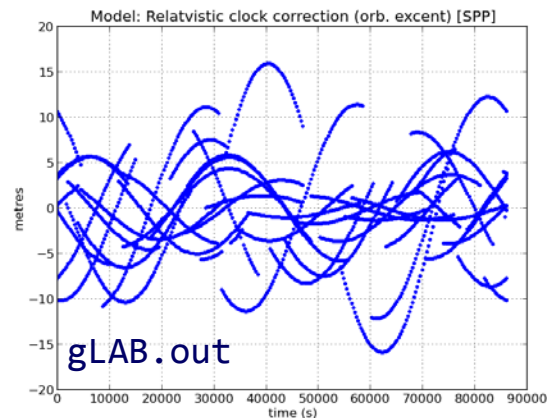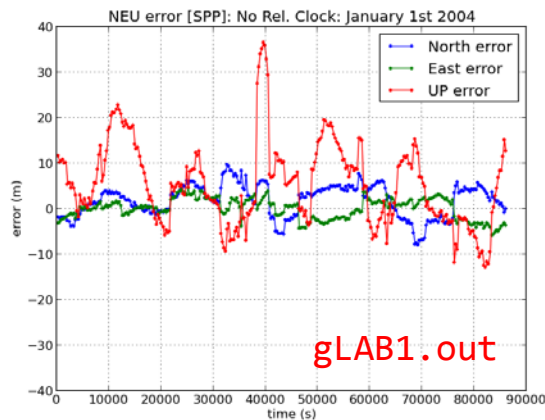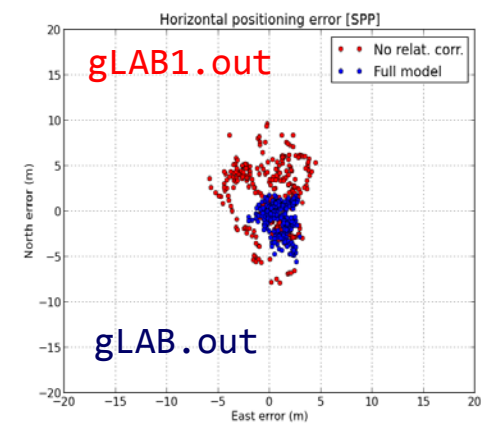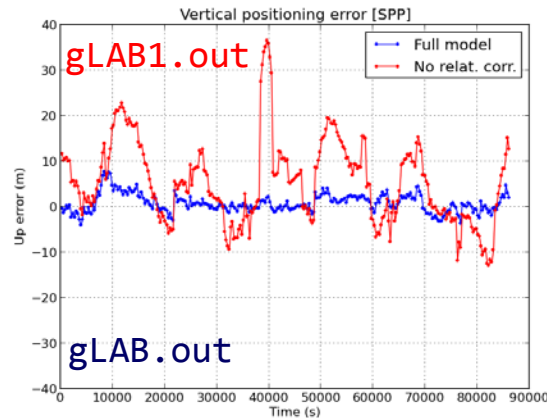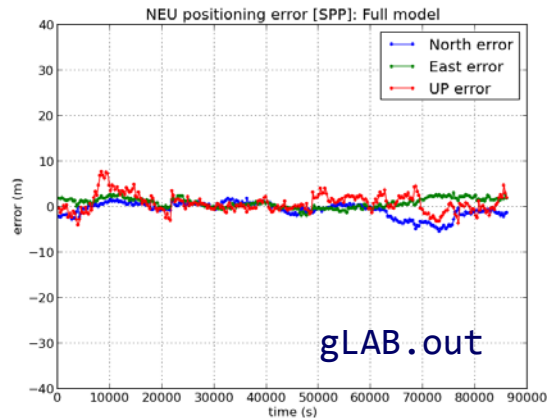
Relativistic correction on satellite clock due to orbit eccentricity.

This is an additional correction to apply at the receiver level. The satellite clock oscillator is modified on factory to compensate the main effect (~40μs/day).

Exercise 1: SPP Model components analysis

Relativistic clock correction

1) A constant component, depending only on nominal value of satellite's orbit major semi-axis. It is corrected modifying satellite's clock oscillator frequency:

$$\frac{f_0' - f_0}{f_0} = \frac{1}{2}\left(\frac{v}{c}\right)^2 + \frac{\Delta U}{c^2} = -4.464 \cdot 10^{-10}$$

being $f_0 = 10.23\ MHz$, we have $\Delta f = 4.464\ 10^{-10}\ f_0 = 4.57\ 10^{-3}\ Hz$. So, satellite should use $f'_0 = 10.22999999543\ MHz$.

2) A periodic component due to orbit eccentricity must be corrected by user receiver:

$$rel = -2\frac{\sqrt{\mu a}}{c}e\sin(E) = -2\frac{\mathbf{r}\cdot\mathbf{v}}{c}\ (meters)$$

Being $\mu = G\ M_E = 3.986005\ 10^{14}\ (m^3/s^2)$ the gravitational constant, c =299792458 (m/s) light speed in vacuum, a is orbit's major semi-axis, e is its eccentricity, E is satellite's eccentric anomaly, and r and v are satellite's geocentric position and speed in an inertial system.

Exercise 1: SPP Model components analysis

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Exercise 1: SPP Model components analysis
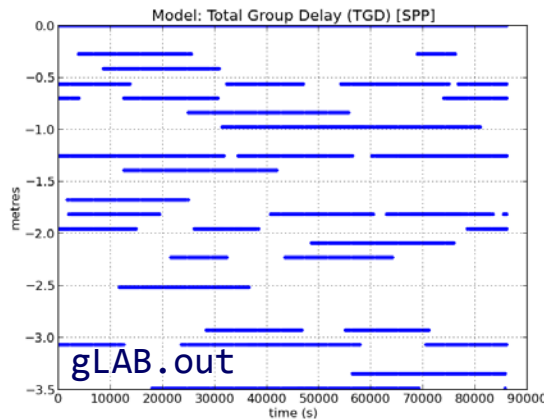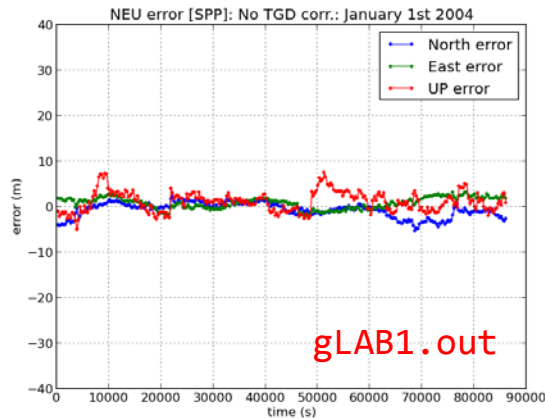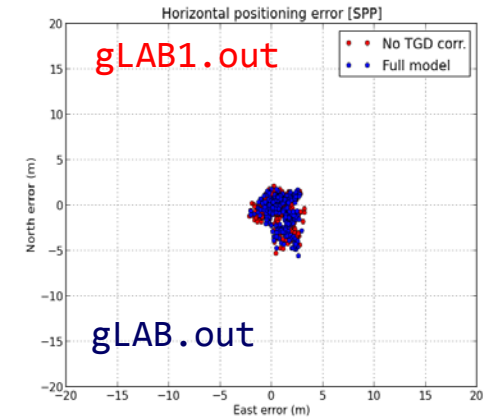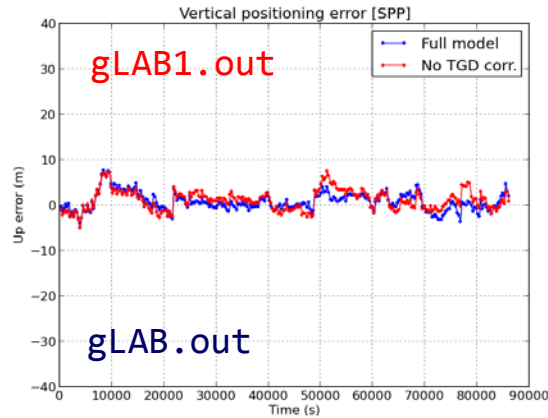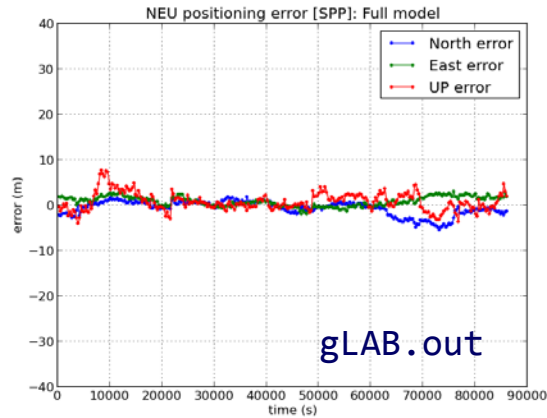
Total Group Delay correction (TGD)
(P2-P1 Differential Code Bias [DCB])

- Instrumental delays are associated to antennas, cables, as well as different filters used in receivers and satellites. They affect both code and carrier measurements.

- Code instrumental delays depend on the frequency and the codes used, and are different for the receiver and the satellites.

- Dual frequency users cancel such delays when using the ionosphere free combination of codes and carrier phases.

- For single frequency users, the satellite instrumental delays (TGDs) are broadcast in the navigation message. The receiver instrumental delay, on the other hand, is assimilated into the receiver clock estimation. That is, being common for all satellites, it is assumed as zero and it is included in the receiver clock offset estimation.

Exercise 1: SPP Model components analysis
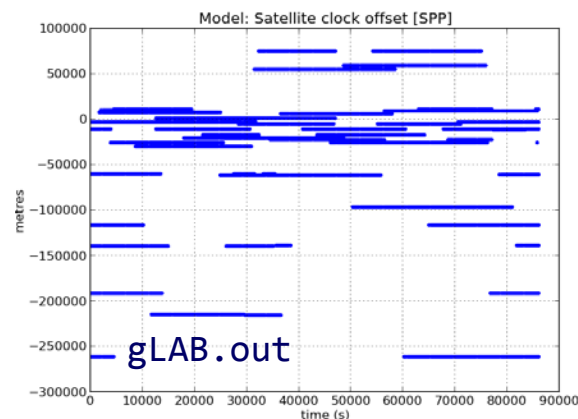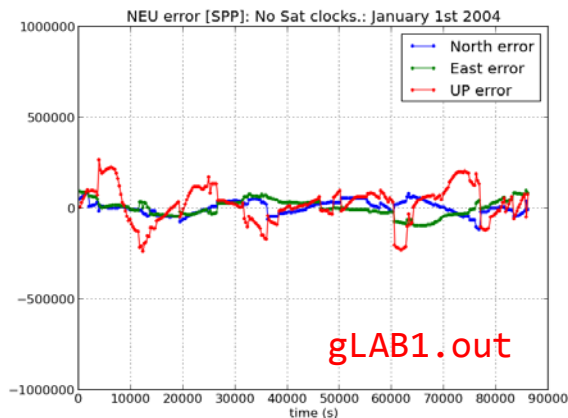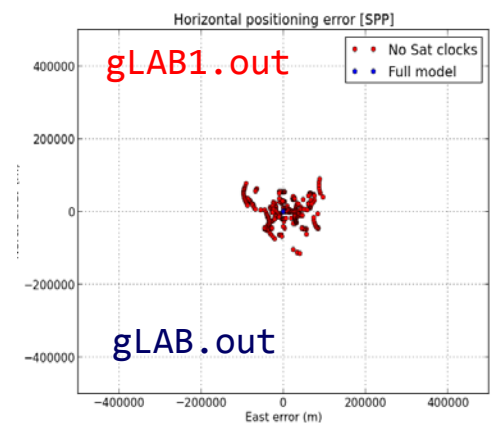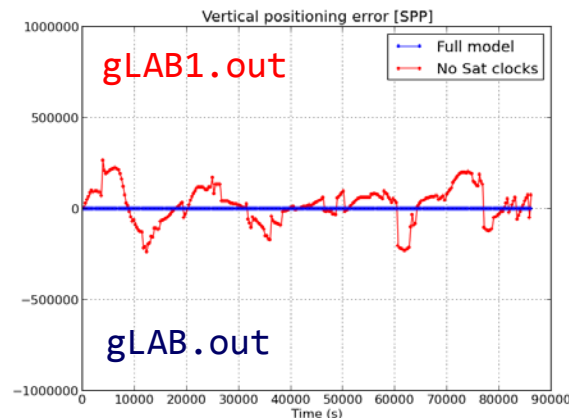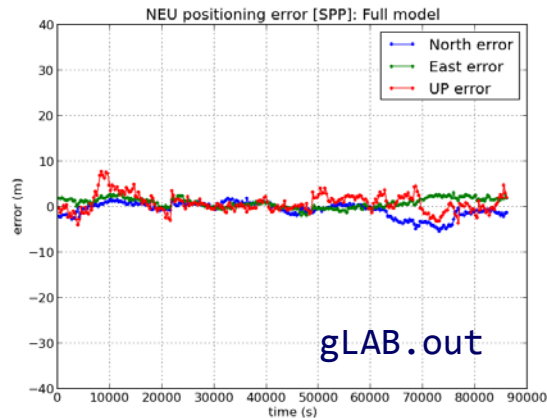
Exercise 1: SPP Model components analysis

Satellite clock offsets

- – They are time-offsets between satellite/receiver clocks time and GPS system time (provided by the ground control segment).

- – The receiver clock offset is estimated together with receiver coordinates.

- – Satellite clock offset values are provided:
  - In real-time, within the broadcast navigation message with a few meters of error

  or,
  - In post-process mode, by IGS precise products with centimeter-level accuracy.

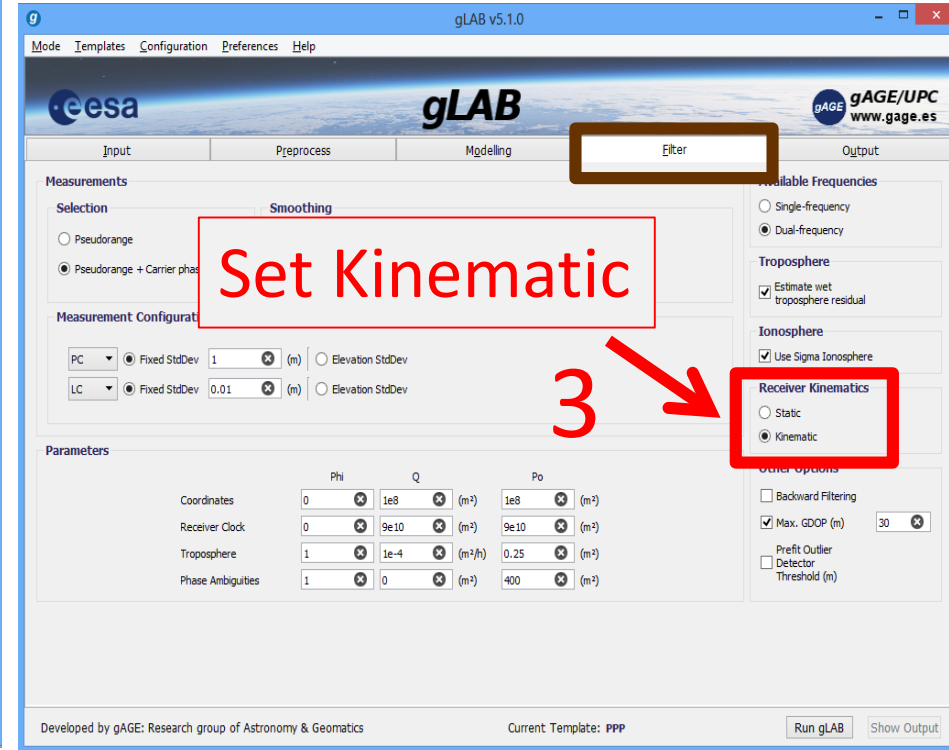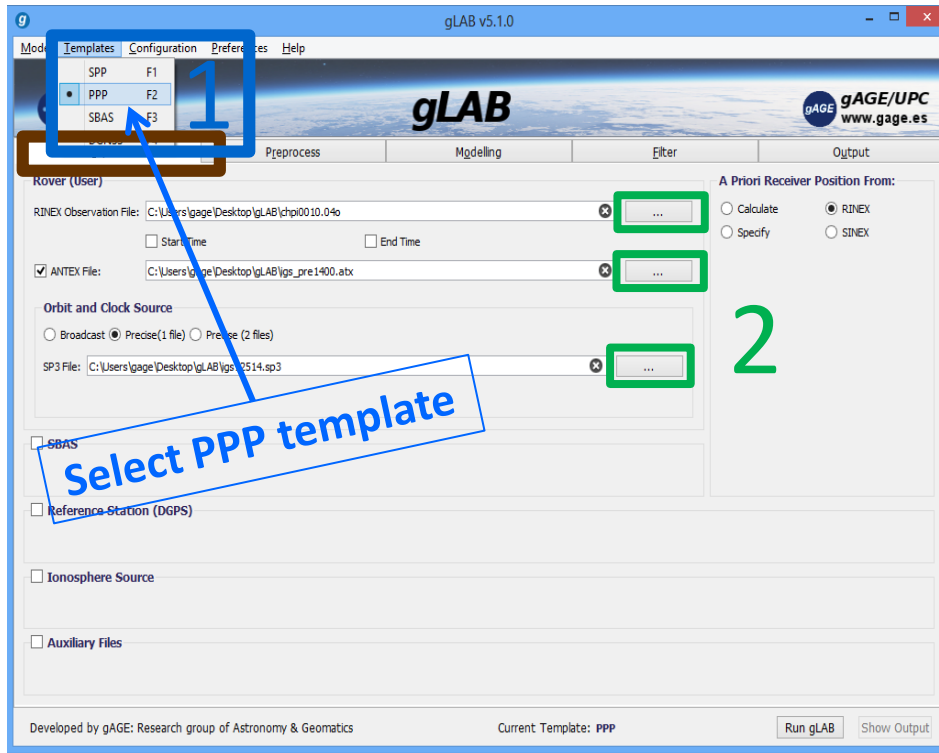# **Basic:** Introductory laboratory exercises

Exercise 2: Model components analysis for PPP

- – This exercise is devoted to analyse the additional model components used in Precise Point Positioning (the ones which are not required by SPP). This is done in Range and Position Domains.

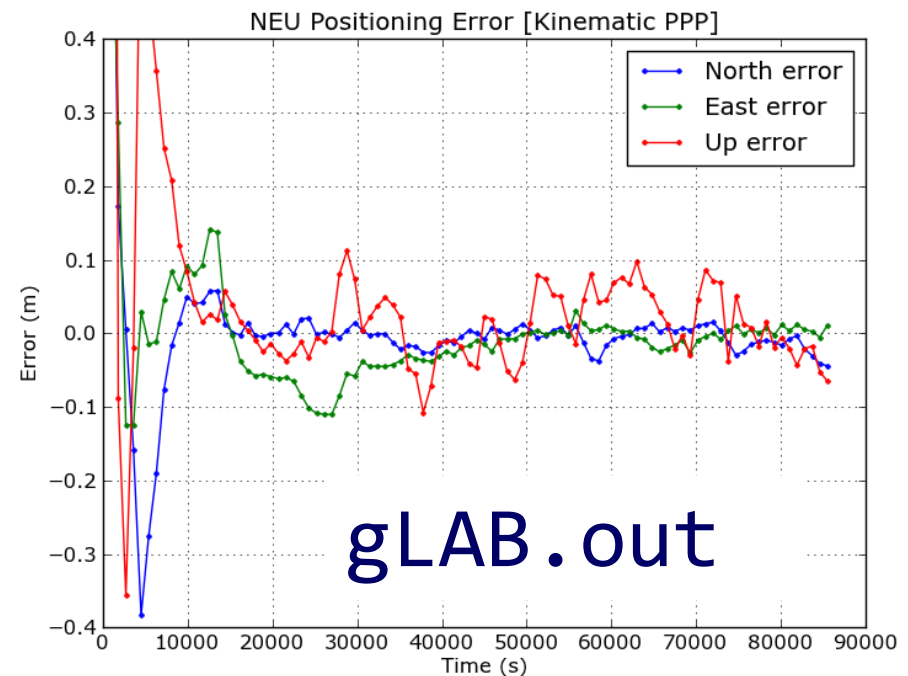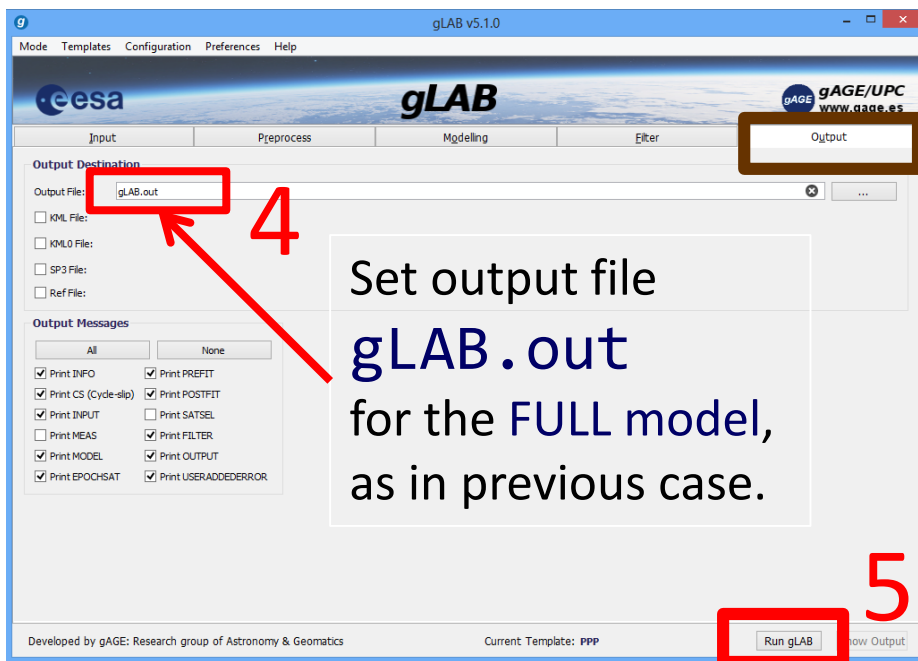# Exercise 2: PPP Model components analysis

- Compute the kinematic PPP solution using files:
  chpi0010.04o, igs_pre1400.atx, igs12514.sp3

*Note: The* igs_pre1400.atx *file contains the APC used by IGS before GPS week 1400.*

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Exercise 2: PPP Model components analysis

Kinematic PPP solution using files `chpi0010.04o,`
`igs_pre1400.atx, igs12514.sp3`

Set output file
gLAB.out
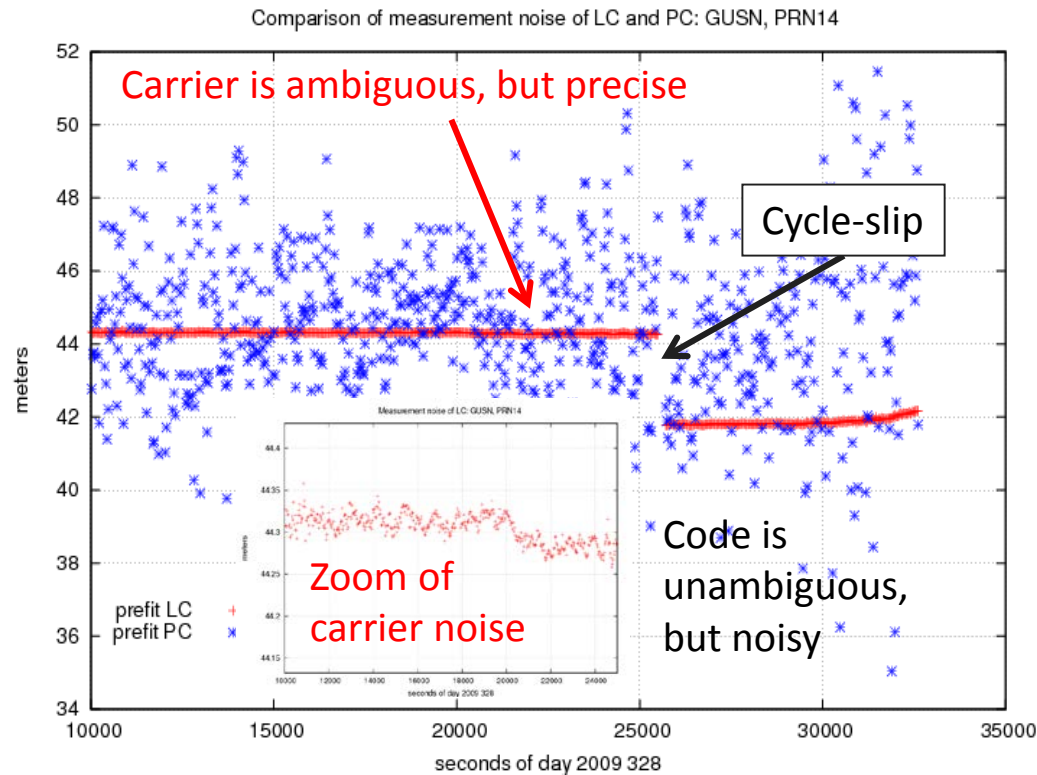for the FULL model,
as in previous case.

Exercise 2: PPP Model components analysis
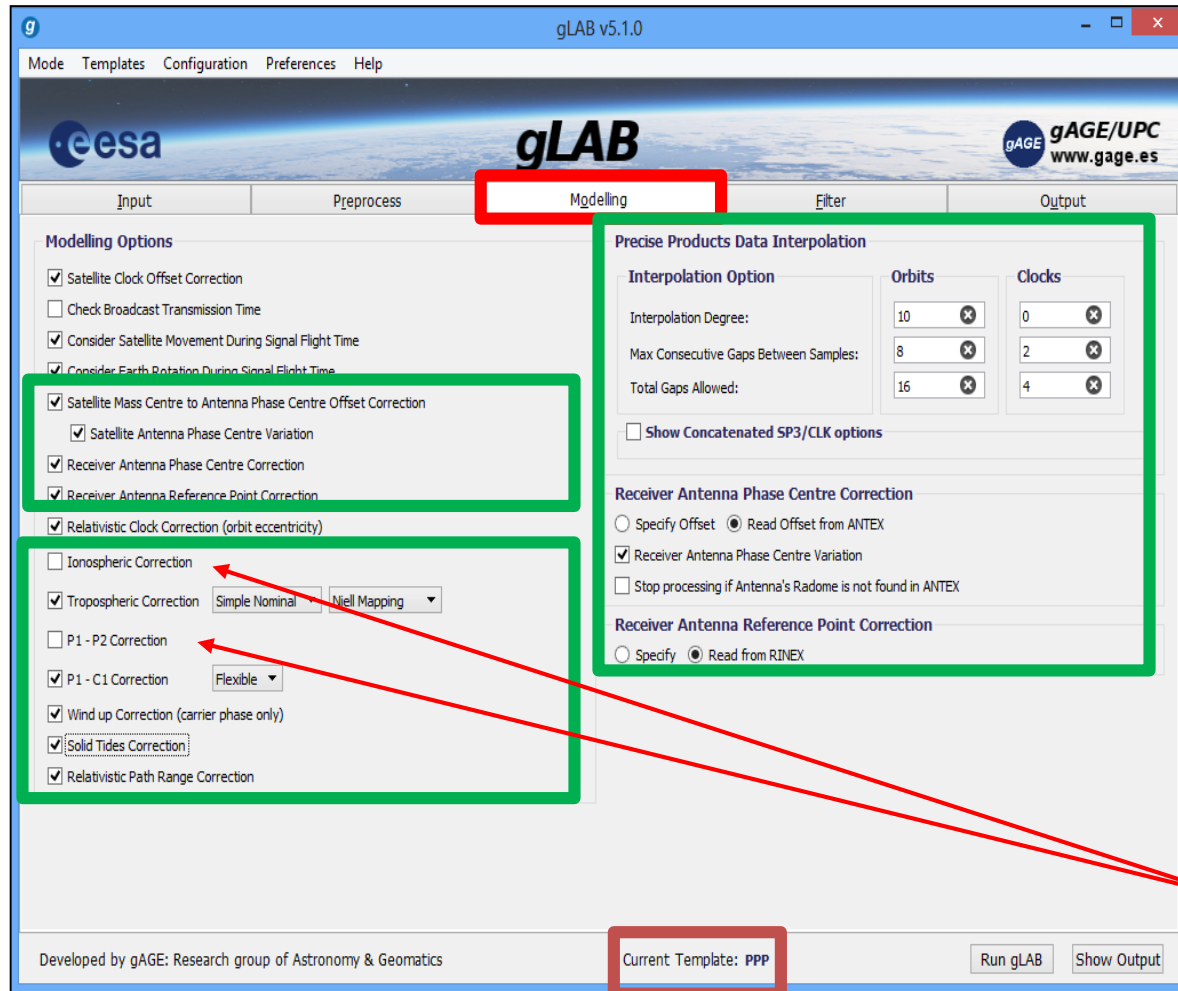
- Additional model components are used now in the FULL model to assure a <u>centimeter level modeling</u>.

- <u>Precise orbits and clocks</u> instead of broadcast ones.

- <u>Dual frequency Code and Carrier</u> data instead of only single frequency code.

- <u>Iono-free combination of</u> codes and carriers to remove ionospheric error and P1-P2 DCBs.

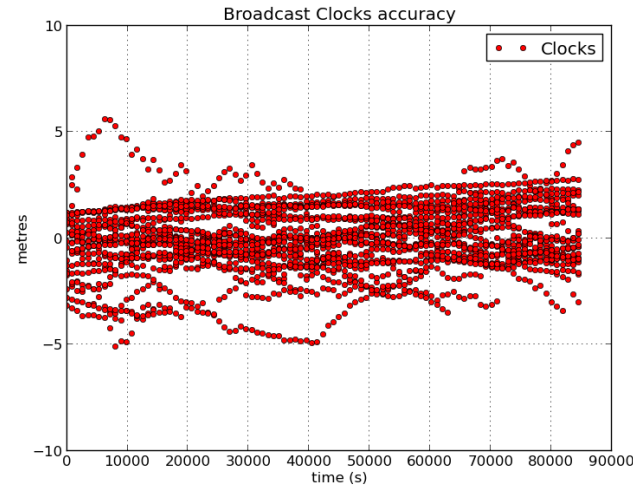# Exercise 2: PPP Model components analysis

Code and carrier Measurement noise

Comparison of measurement noise of LC and PC: GUSN, PRN14

Carrier is ambiguous, but precise

Cycle-slip

Zoom of carrier noise

Code is unambiguous, but noisy

prefit LC
prefit PC

seconds of day 2009 328

Note: Figure shows the noise of **code** and **carrier** prefit-residuals, which are the input data for navigation equations.

- Code measurements are unambiguous but noisy (meter level measurement noise).

- **Carrier measurements are precise but ambiguous**, meaning that they have some millimetres of noise, but also have unknown biases that could reach thousands of km.

- Carrier phase biases are estimated in the navigation filter along with the other parameters (coordinates, clock offsets, etc.). If these biases were fixed, measurements accurate to the level of few millimetres would be available for positioning. However, some time is needed to decorrelate such biases from the other parameters in the filter, and the estimated values are not fully unbiased.
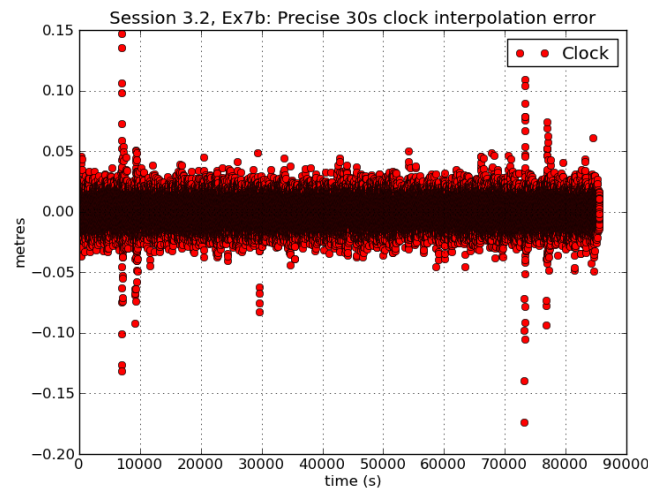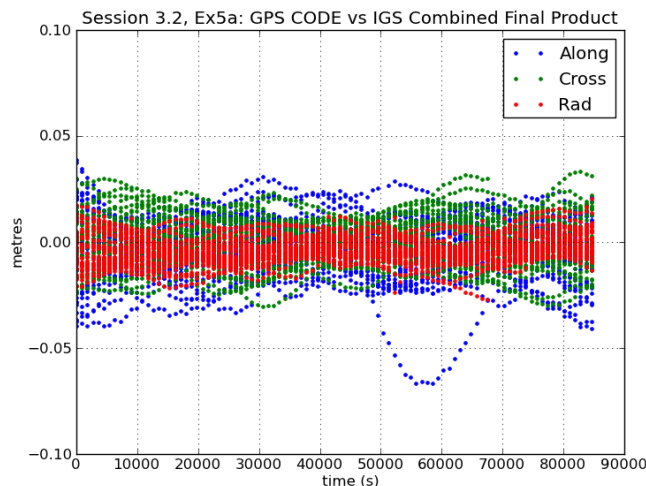
Exercise 2: PPP Model components analysis
Orbits & clocks accuracies
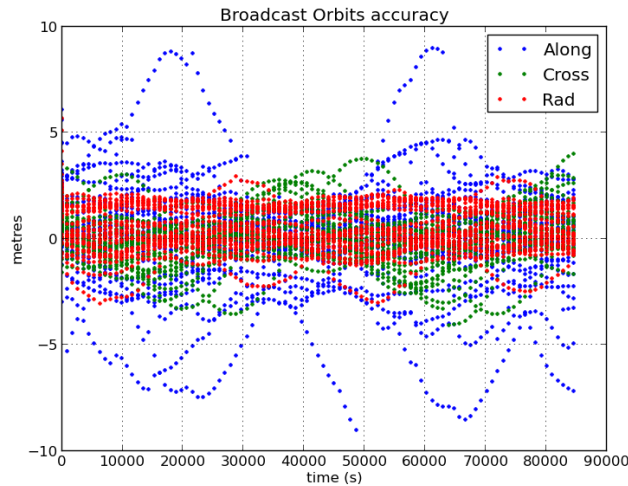
Broadcast:

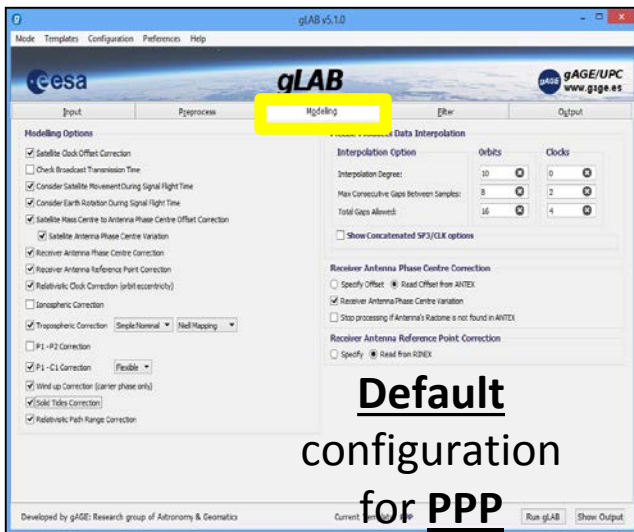- **Few metres** of accuracy for broadcast orbits and clocks

Precise:

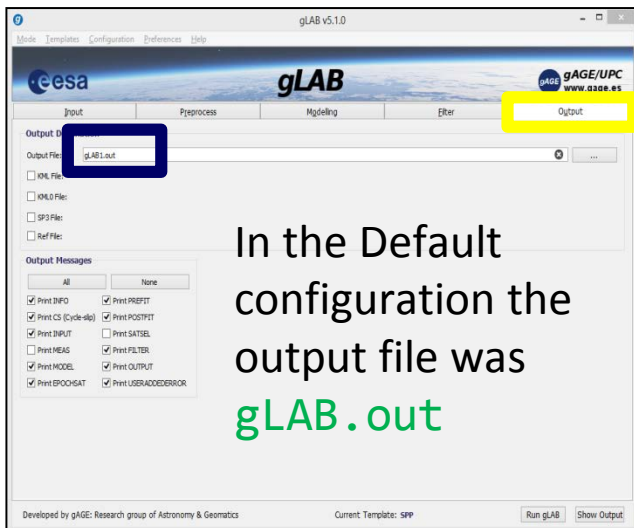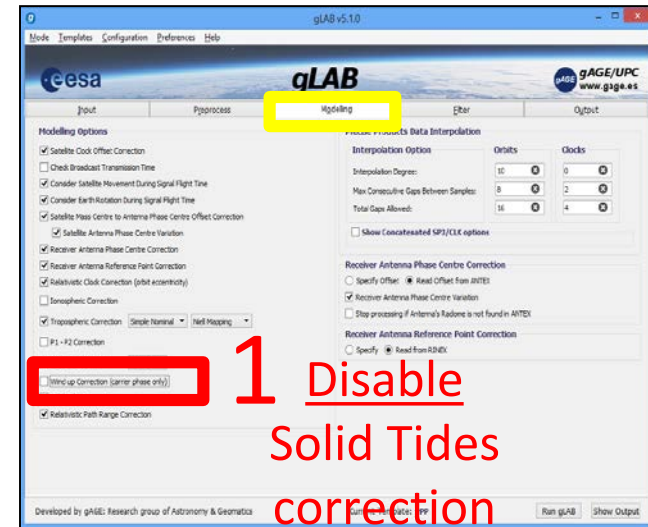- **Few centimetres** of accuracy for broadcast orbits and clocks

Example of model component analysis: **Solid Tides**

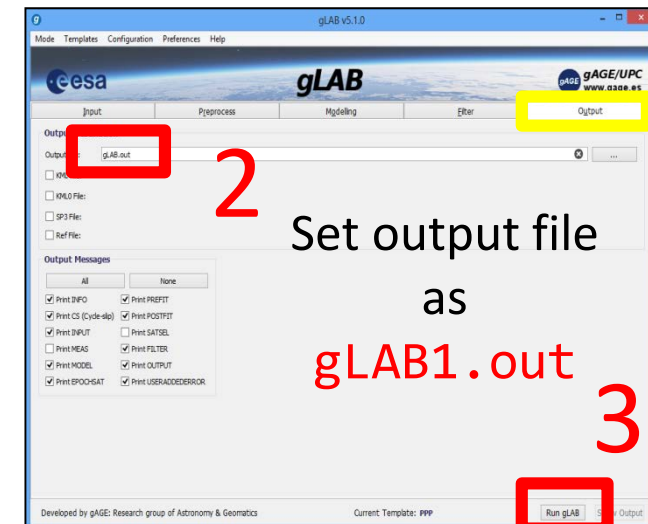**Default** configuration for **PPP**

1. **Disable Solid Tides correction**

Proceed as in the previous exercise:

1. In Modeling panel, <u>disable</u> the model component to analyze.

2. **Save** as `gLAB1.out` the associated output file.

Notice that the `gLAB.out` file contains the processing results with the <u>FULL model</u>, as it was set in the default configuration.

Make plots as in previous exercises (see slides 38-40).

In the Default configuration the output file was `gLAB.out`

2. **Set output file as `gLAB1.out`**

3.

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Vertical Position Error plot from gLAB.out, gLAB1.out

©gAGE/UPC

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

32

Horizontal Position Error plot: gLAB.out, gLAB1.out

East: DSTAE: 19

North: DSTAN: 18

1 Click Clear to restart plots

X-min, Y-min, Y-max

2

OUPUT

gLAB1.out

3 gLAB.out

East: 19

North: 18

Research group of Astronomy & Geomatics
Technical University of Catalonia

# Solid Tides model component plot: `gLAB.out`
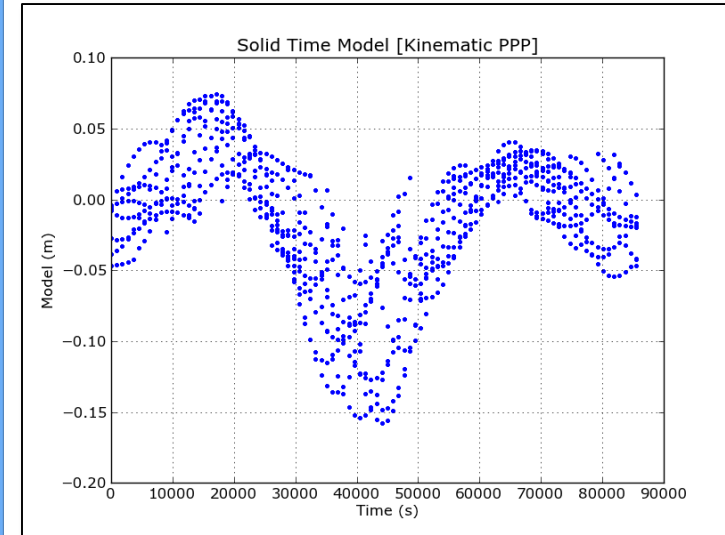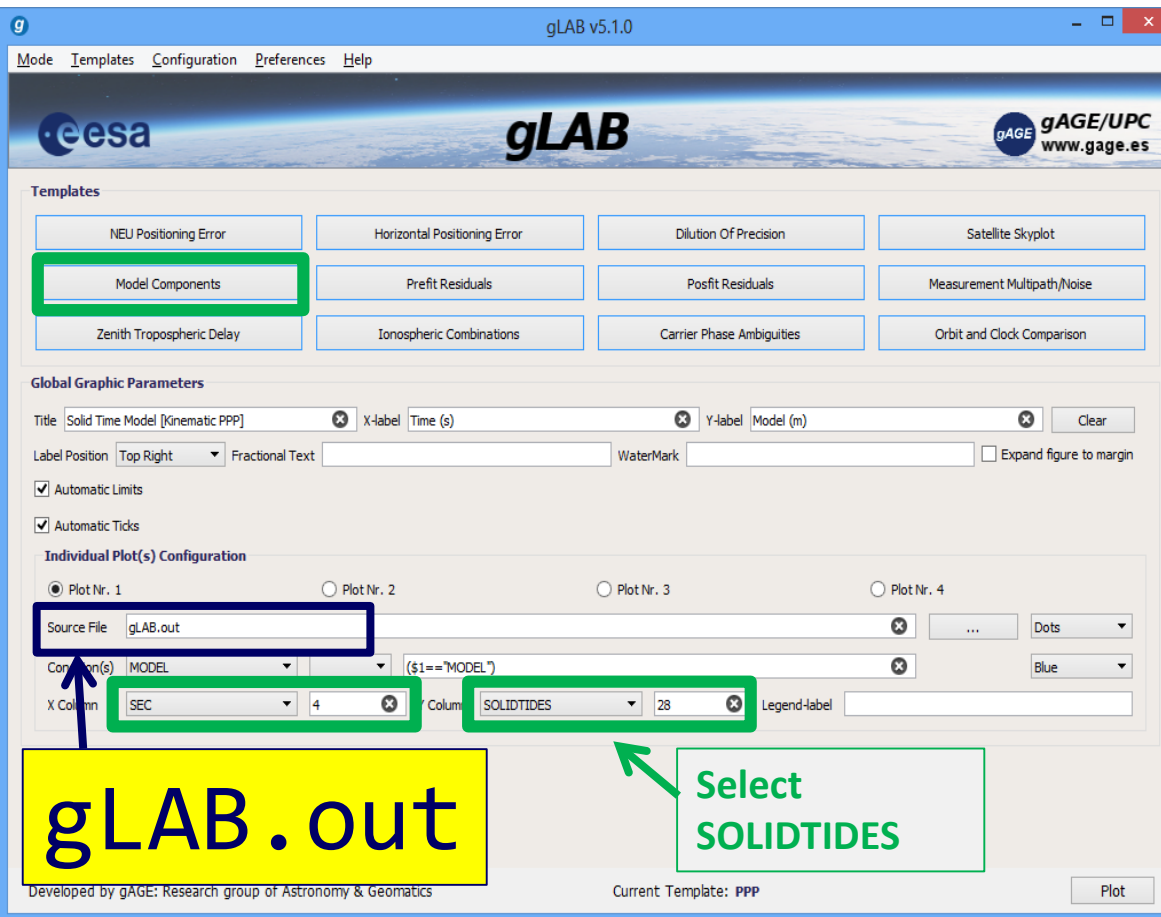
Solid Tides plot

Note: Use the `gLAB.out` file. In `gLAB1.out` file this model component was switched off.

Exercise 2: PPP Model components analysis

Solid Tides

It comprises the Earth's crust movement (and thence receiver coordinates variations) due to the gravitational attraction forces produced by external bodies, mainly the Sun and the Moon.
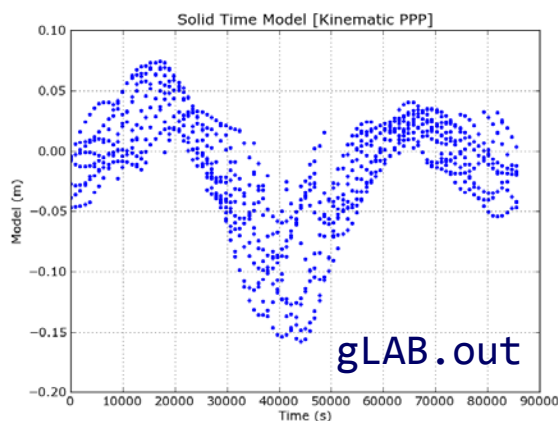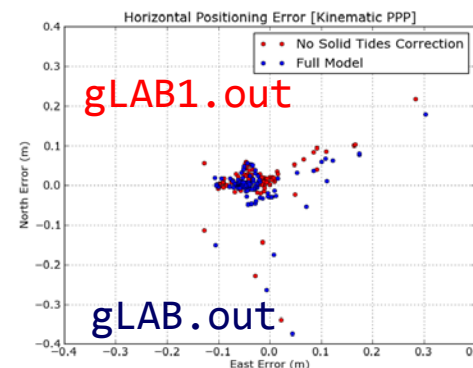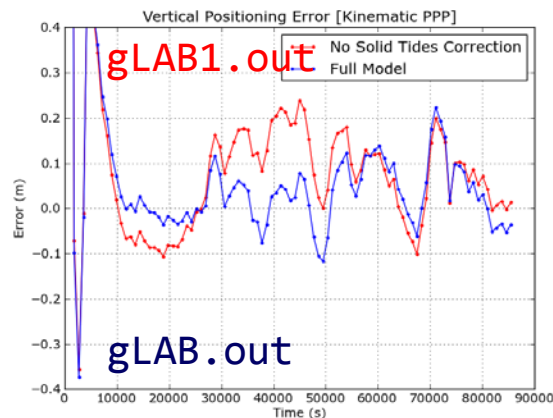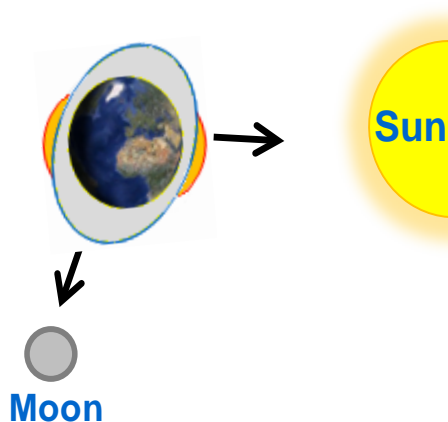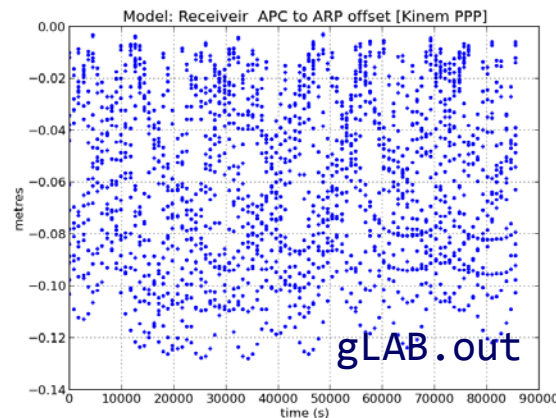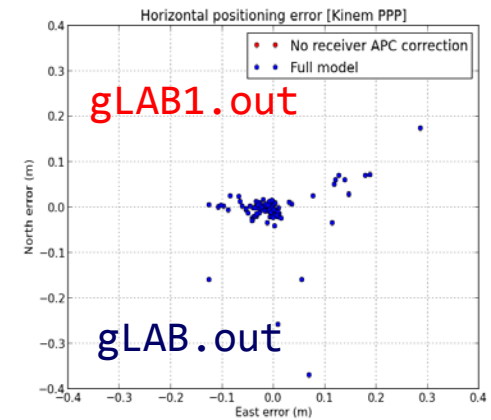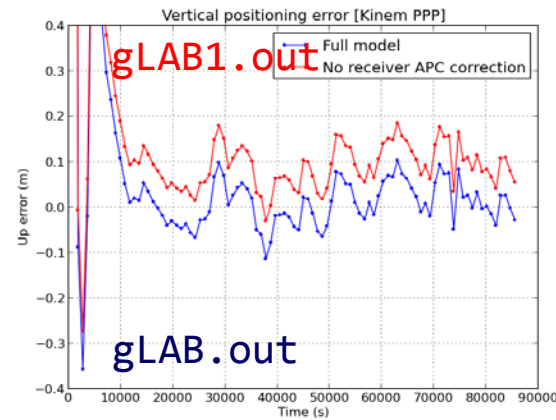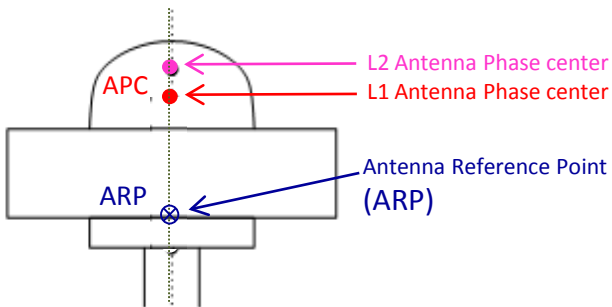

Solid Tides:

These effects do not affect the GNSS signals, but if they were not considered, the station coordinates would oscillate with relation to a mean value.

They produce vertical (mainly) and horizontal displacements.

Exercise 2: PPP Model components analysis

## Receiver Antenna Phase center (APC)

L2 Antenna Phase center
L1 Antenna Phase center
APC
ARP
Antenna Reference Point (ARP)

GNSS measurements are referred to the APC. This is not necessarily the geometric center of the antenna, and it depends on the signal frequency and the incoming radio signal direction.

For geodetic positioning a reference tied to the antenna (ARP) or to monument is used.

Vertical positioning error [Kinem PPP]
gLAB1.out
gLAB.out
Full model
No receiver APC correction

Horizontal positioning error [Kinem PPP]
gLAB1.out
gLAB.out
No receiver APC correction
Full model

Model: Receiveir APC to ARP offset [Kinem PPP]
gLAB.out

Receiver APC:

The antenna used for this experiment, has the APC position vertically shifted regarding ARP.
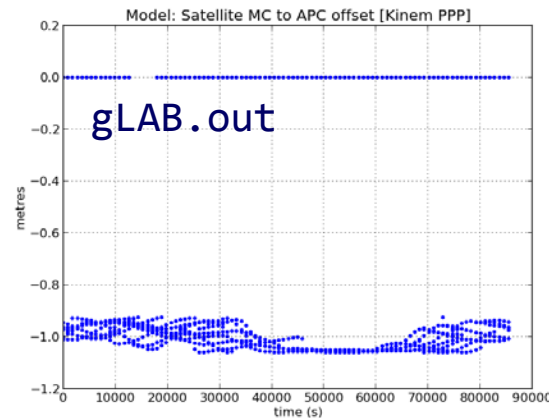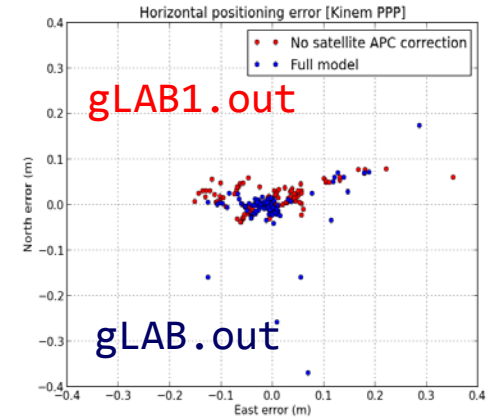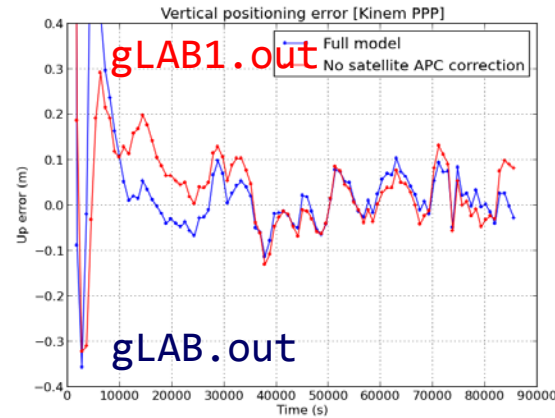
Thence, neglecting this correction, an error on the vertical component occurs, but not in the horizontal one.

Exercise 2: PPP Model components analysis

Satellite Mass Center to Antenna Phase Center

Satellite Antenna Phase Center (APC)

Satellite Mass Center (MC)
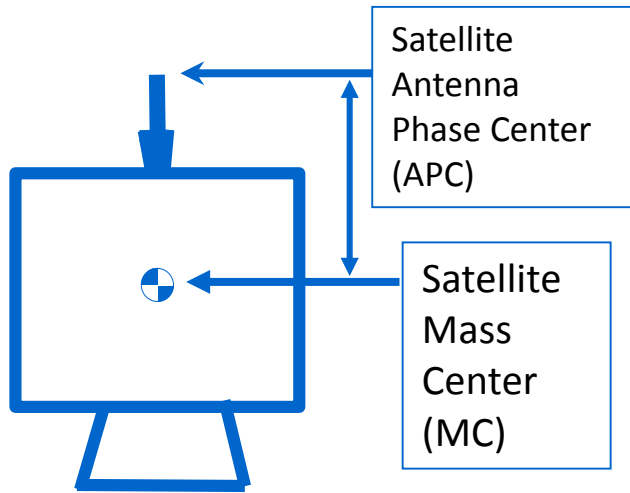
Broadcast orbits are referred to the antenna phase center, but IGS precise orbits are referred to the satellite mass center.

Vertical positioning error [Kinem PPP]
gLAB1.out
gLAB.out

Horizontal positioning error [Kinem PPP]
gLAB1.out
gLAB.out

Model: Satellite MC to APC offset [Kinem PPP]
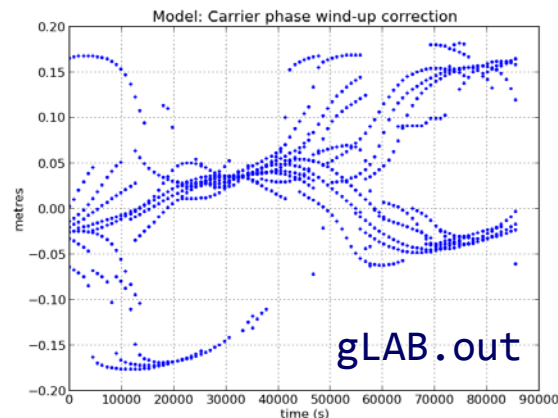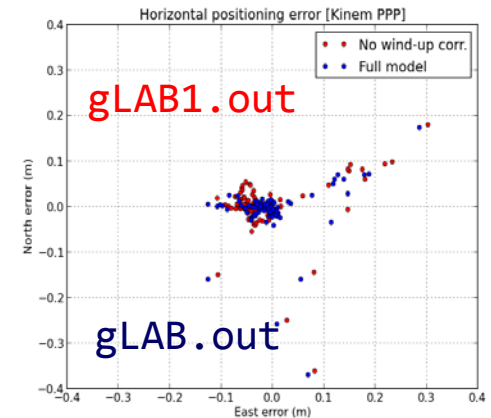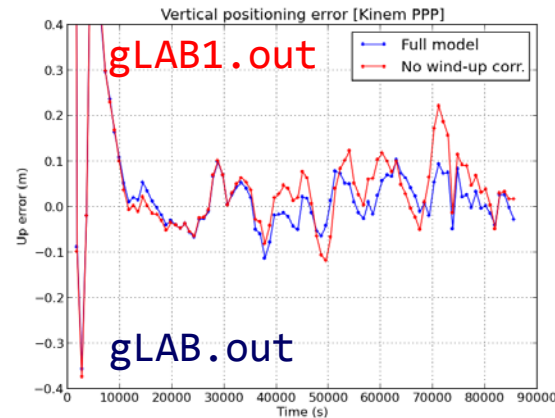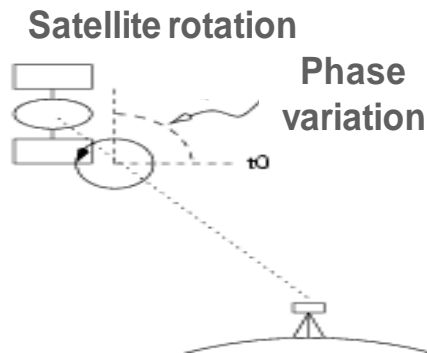gLAB.out

Satellite MC to APC:

The satellite MC to APC eccentricity vector depends on the satellite. The APC values used in the IGS orbits and clocks products are referred to the iono-free combination (LC, PC) . They are given in the IGS ANTEX files (e.g., `igs05.atx`).

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Exercise 2: PPP Model components analysis

Wind-up affects only carrier phase. It is due to the electromagnetic nature of circularly polarized waves of GNSS signals.

As the satellite moves along its orbital path, it performs a rotation to keep its solar panels pointing to the Sun direction. This rotation causes a carrier variation, and thence, a range measurement variation.

Satellite rotation

Phase variation

Vertical positioning error [Kinem PPP]
gLAB1.out
gLAB.out

Horizontal positioning error [Kinem PPP]
gLAB1.out
gLAB.out

Model: Carrier phase wind-up correction
gLAB.out

Wind-Up

Wind-up changes smoothly along continuous carrier phase arcs.

In the position domain, wind-up affects both vertical and horizontal components.

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

Thanks for your attention

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia

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.

gAGE/UPC
Research group of Astronomy & Geomatics
Technical University of Catalonia