Tutorial 3
Model components analysis

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Authorship statement

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Introduction

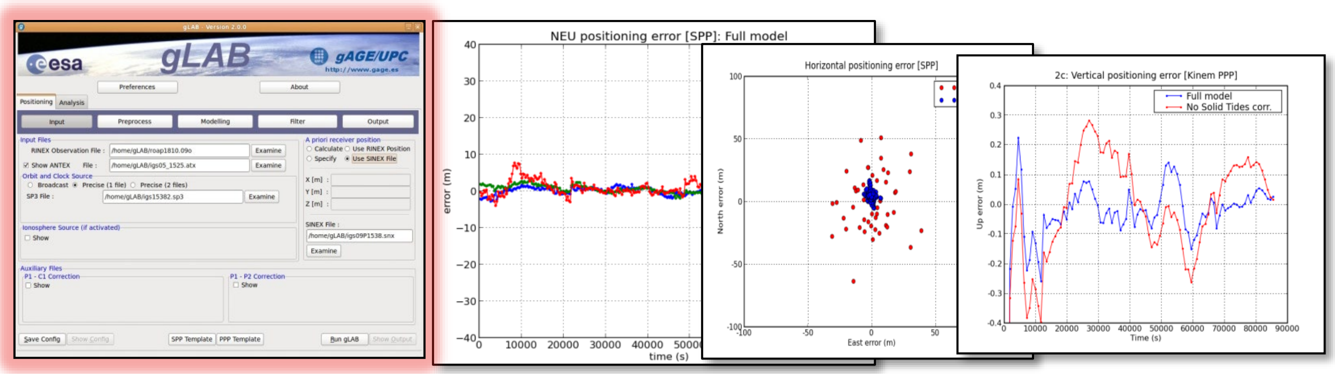
- This practical lecture is devoted to analyze and assess different issues associated with Standard and Precise Point Positioning with GPS data.
- The laboratory exercises will be developed with actual GPS measurements, and processed with the ESA/UPC GNSS-Lab Tool suite (gLAB), which is an interactive 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.

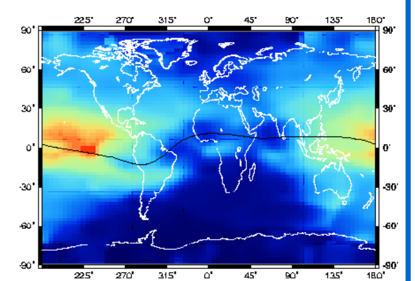
Model Components Analysis

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

Model Components Analysis

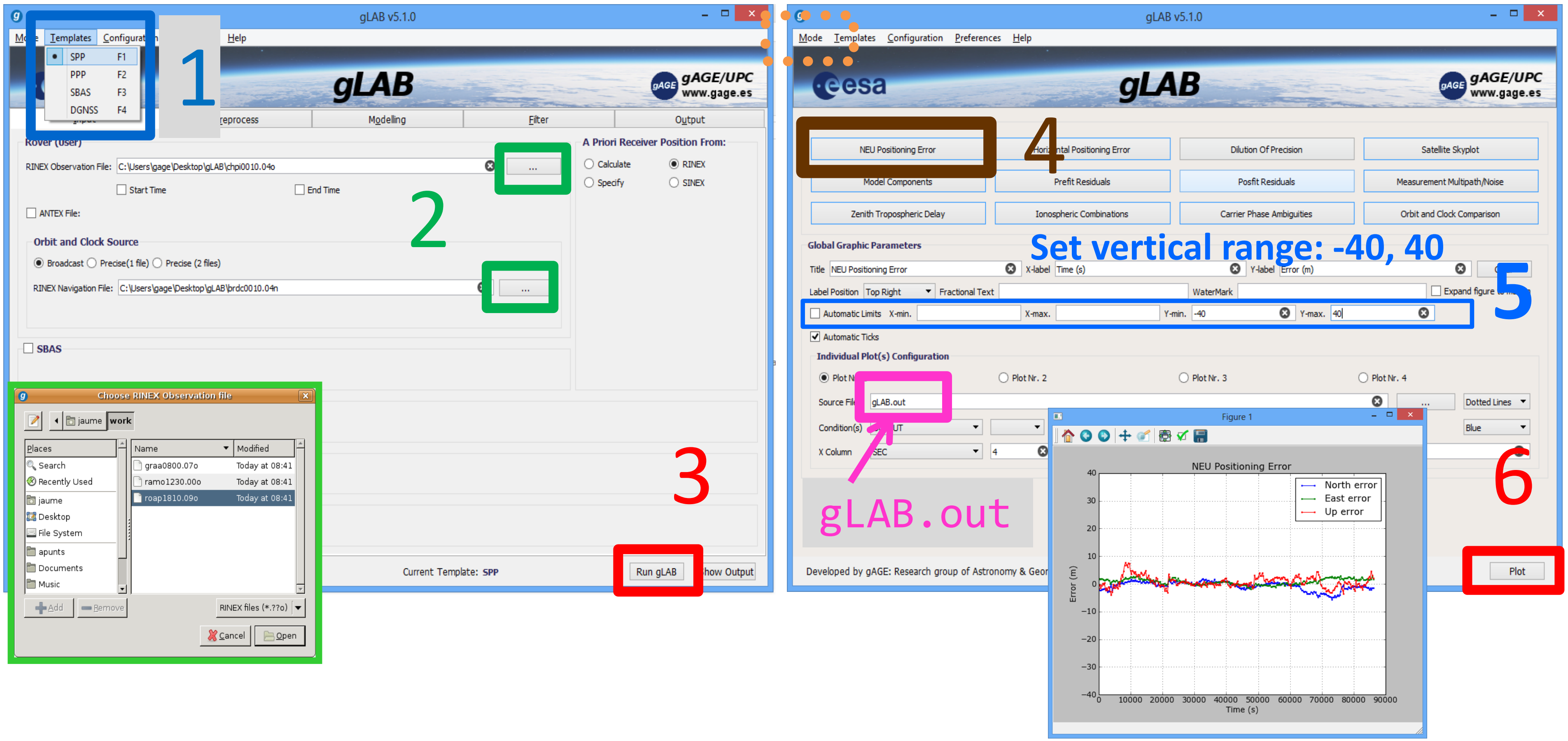
Exercise 1: Model components analysis for SPP

- 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.

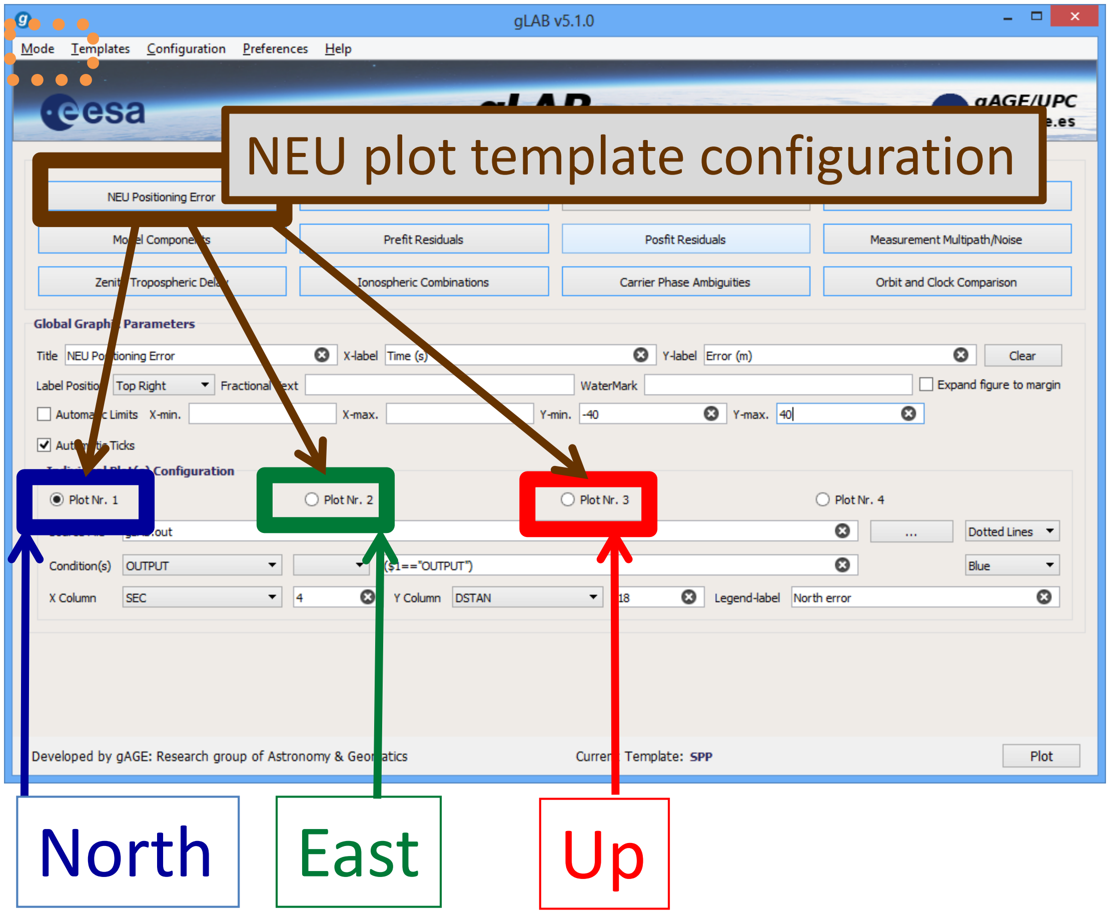
Exercise 1: SPP Model components analysis

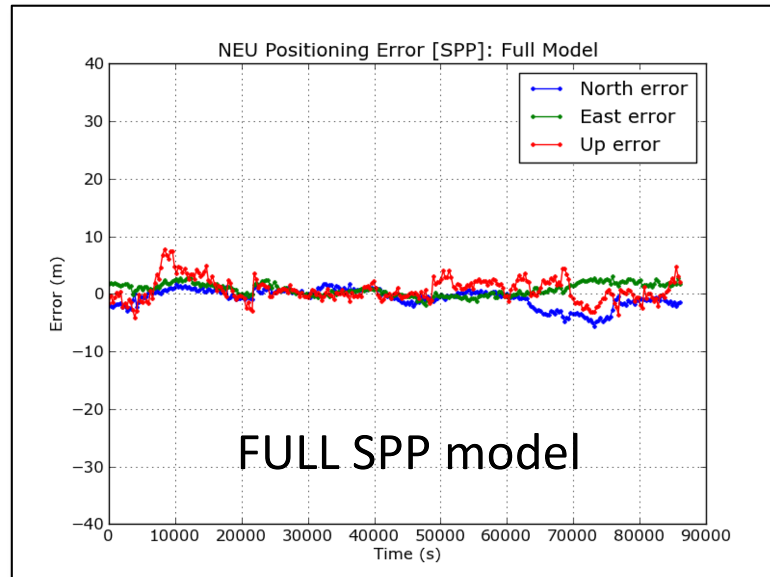
1. Compute SPP using files: `chpi0010.04o,brdc0010.04n`

Cachoeira Paulista station (in the south of Brazil: λ=-22.7º, ϕ=-45.0º). January 1st 2004.

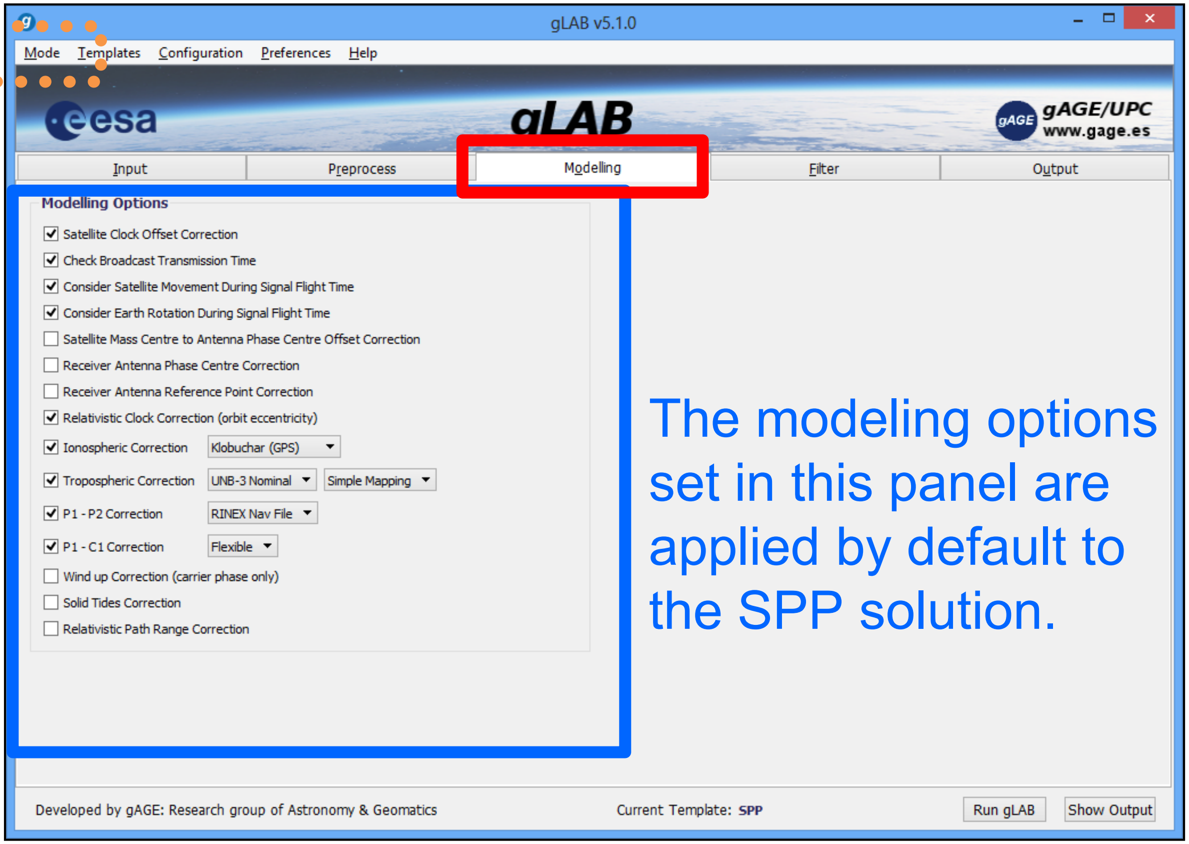


NEU Position Error plot from gLAB.out





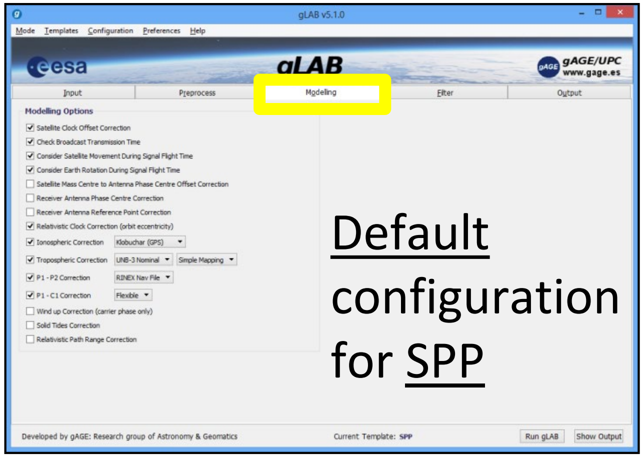
Exercise 1: SPP Model components analysis



The different model components will be analyzed with gLAB:

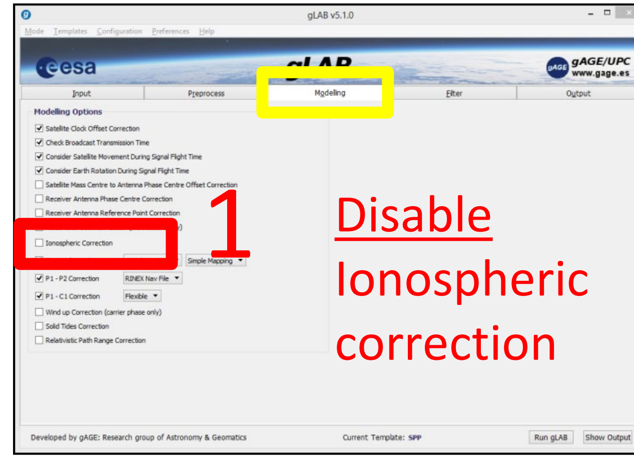
- Using the previous data file, the impact of neglecting each model component will be evaluated in the Range and Position domains
- A baseline example of this analysis procedure for the ionospheric correction is provided as follows.
- The same scheme must be applied for all model terms.

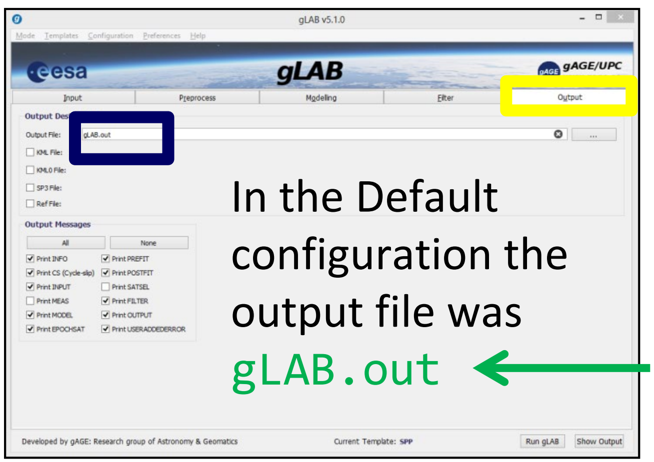
Example of model component analysis: **IONO.**



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

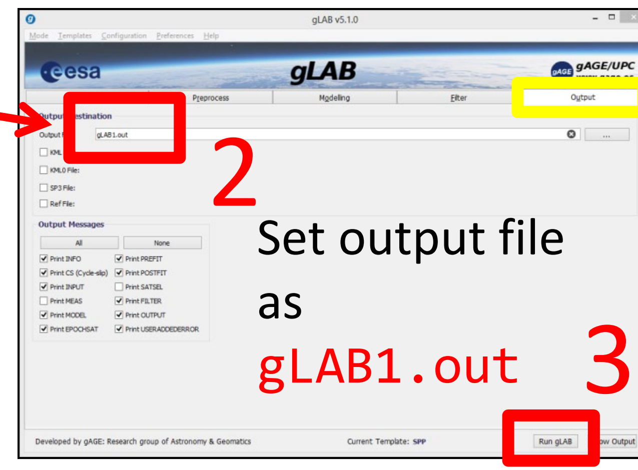
1. In Modeling panel, disable the model component to analyze.
   (in this example: disable Ionospheric correction)



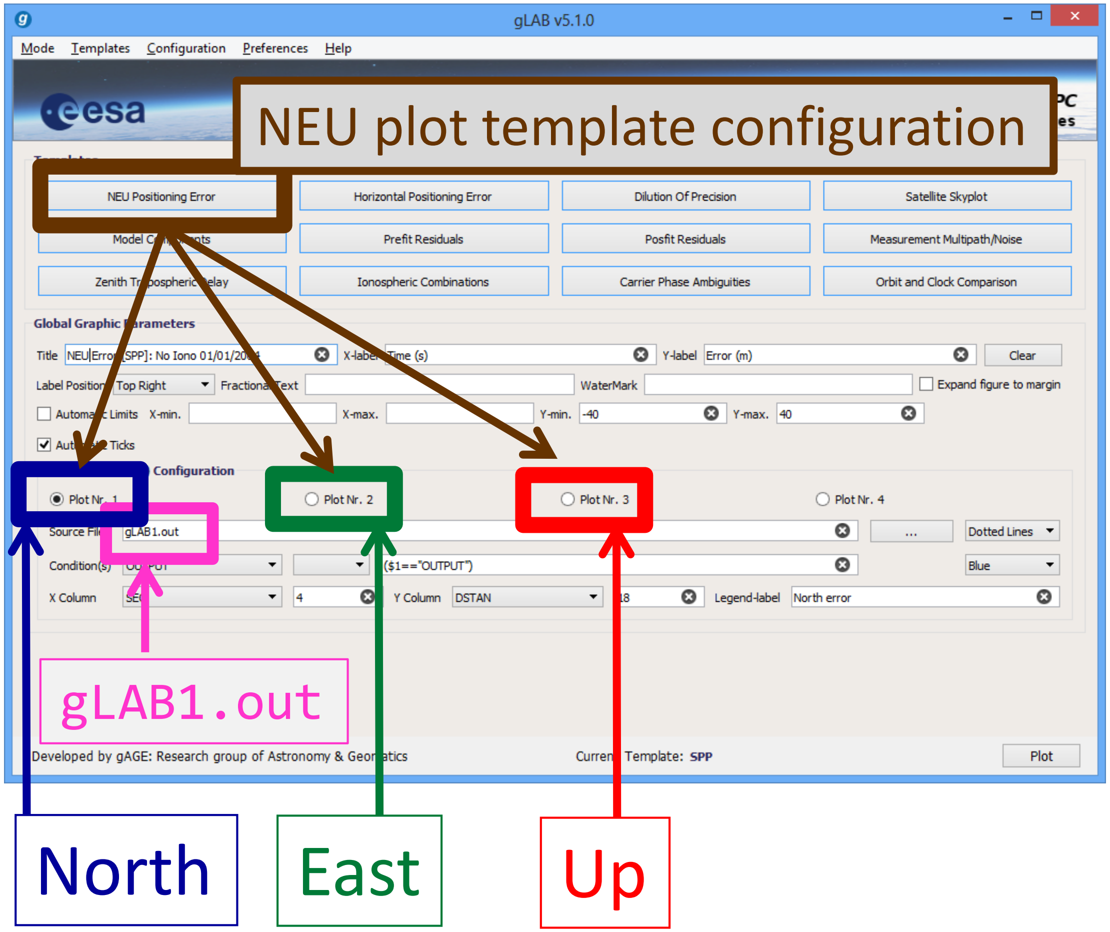


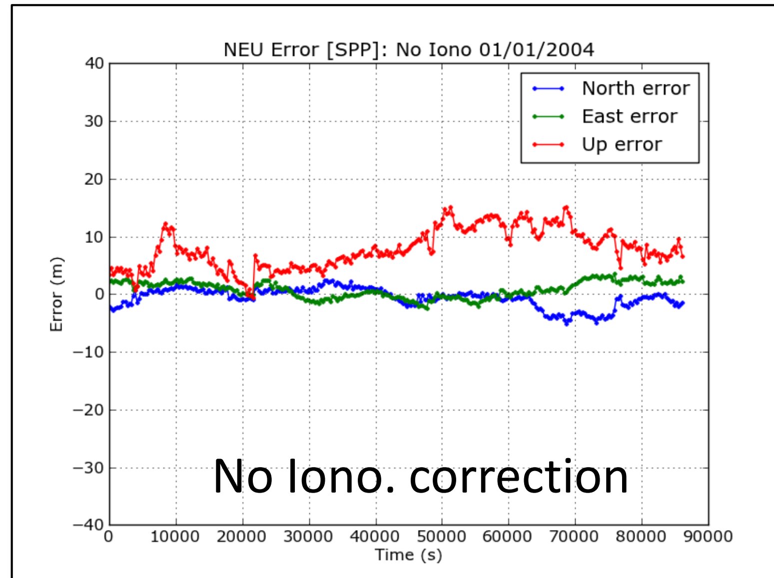
2. Save as `gLAB1.out` the associated output file.

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

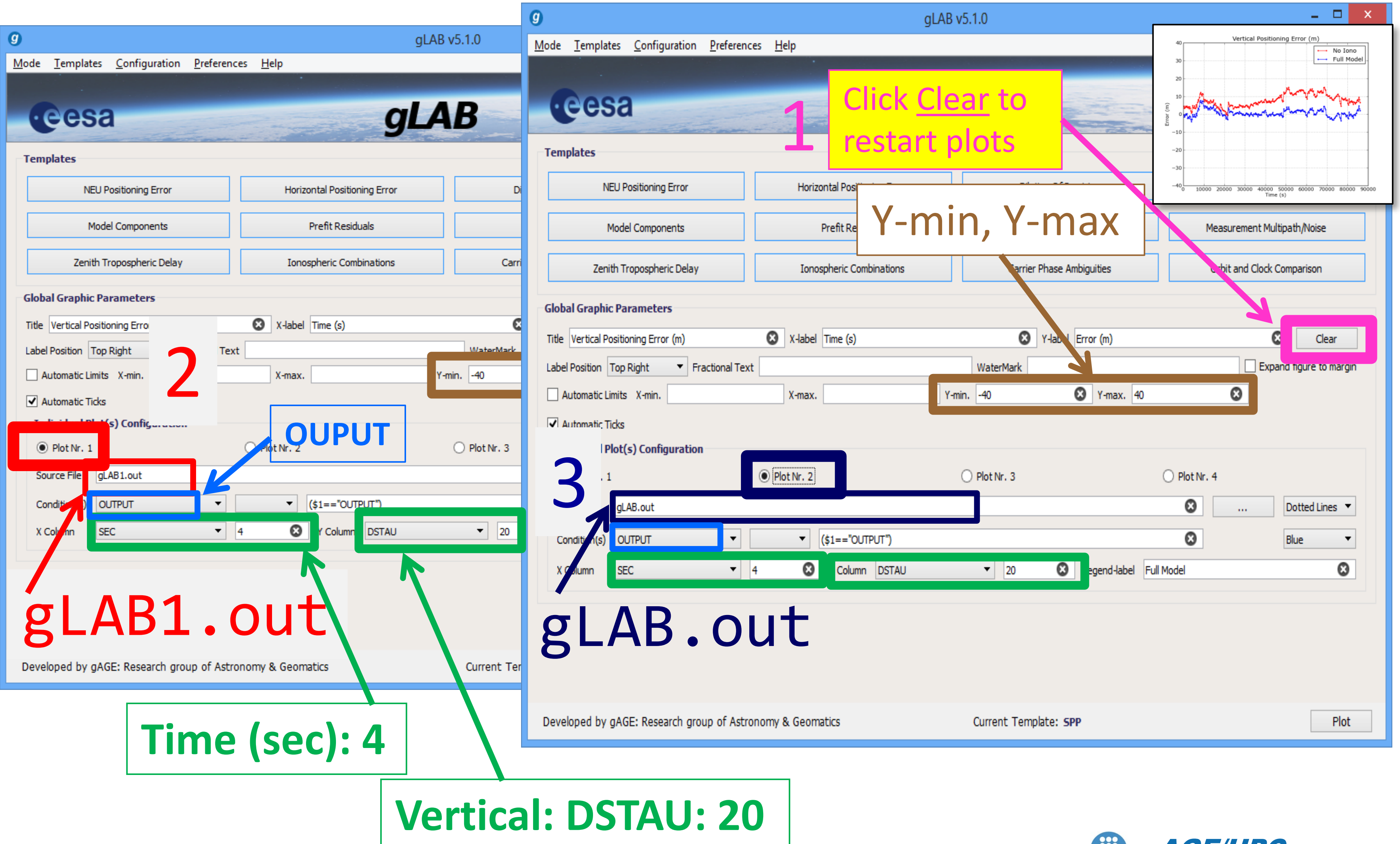


NEU Position Error plot from gLAB1.out

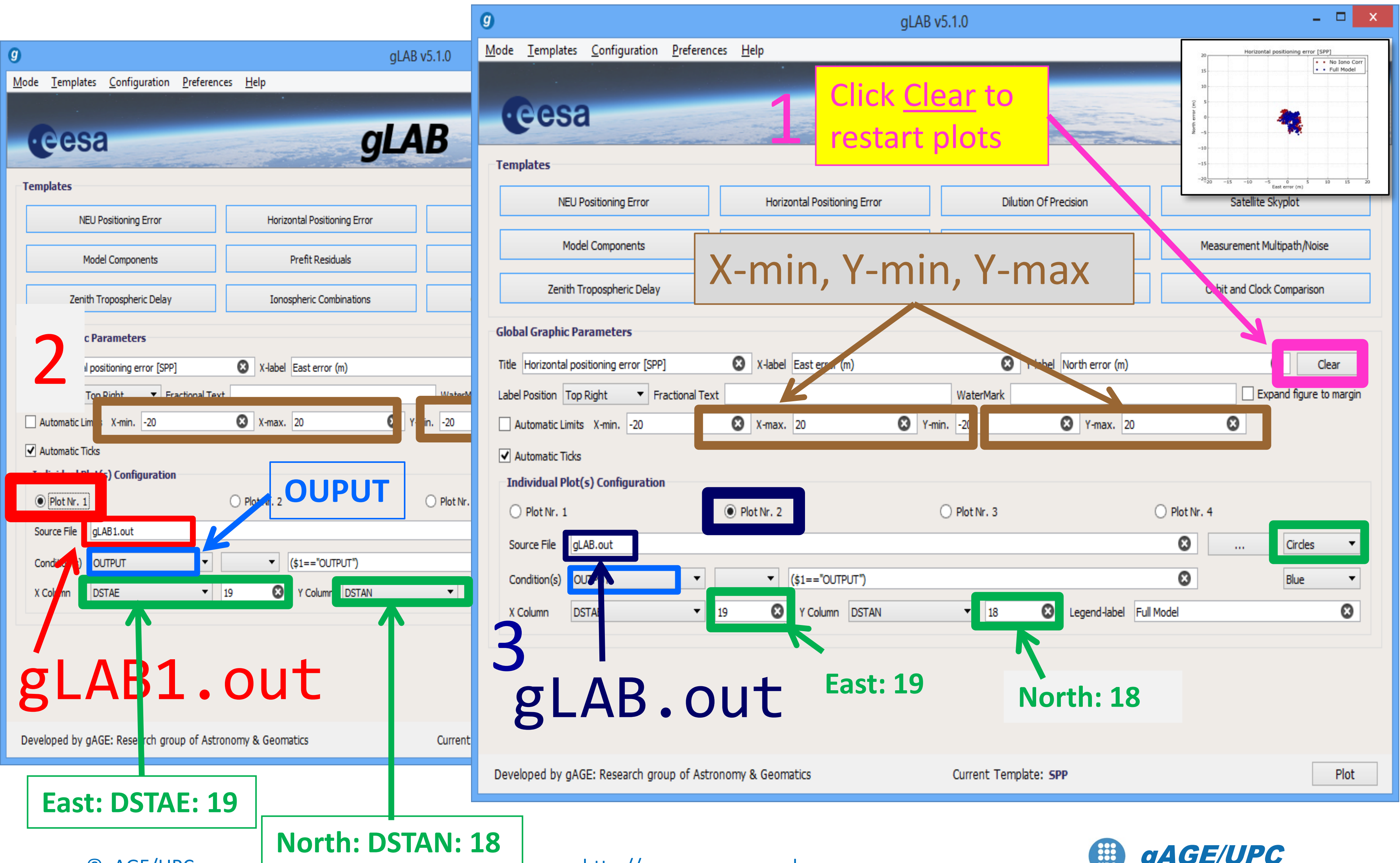




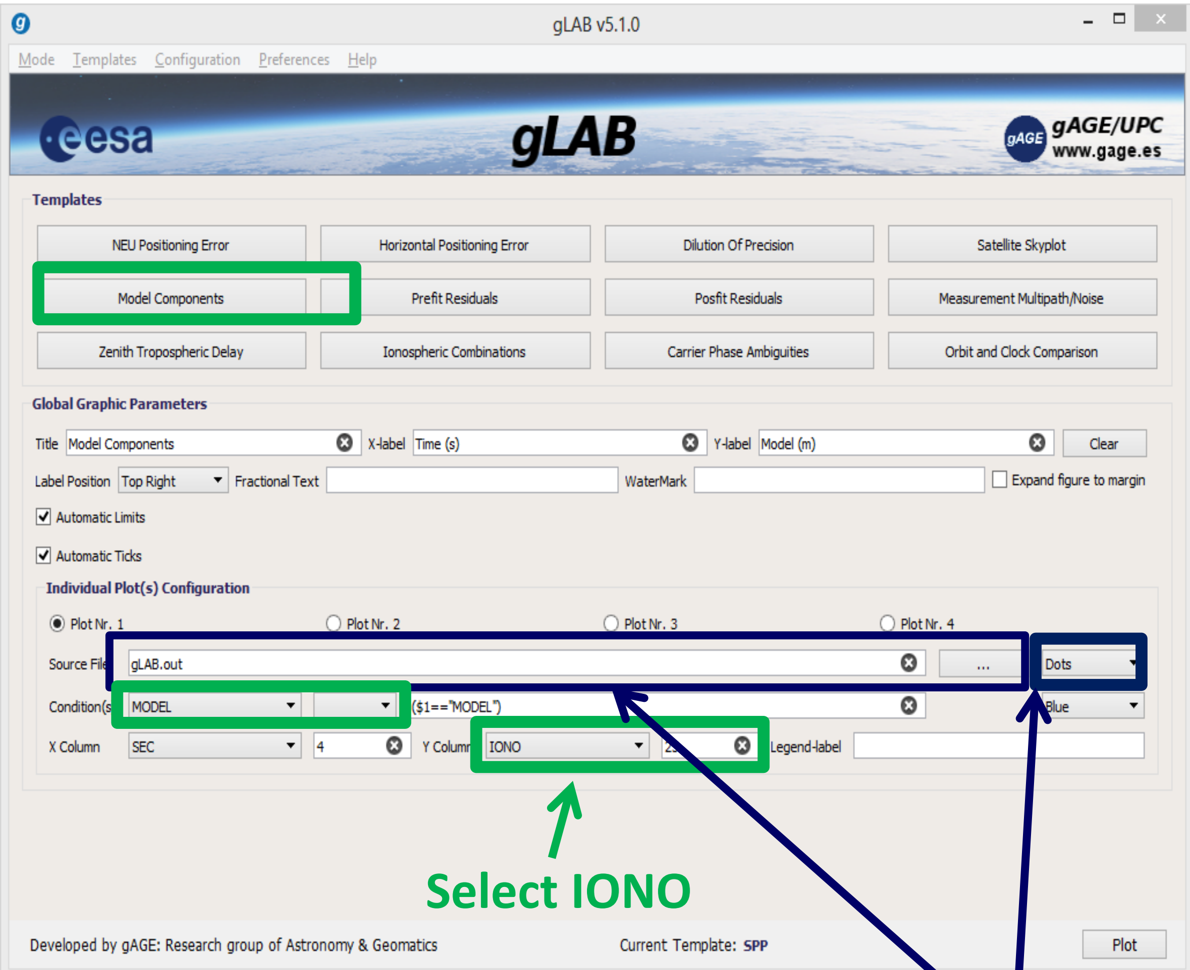
Vertical Position Error plot from gLAB.out, gLAB1.out

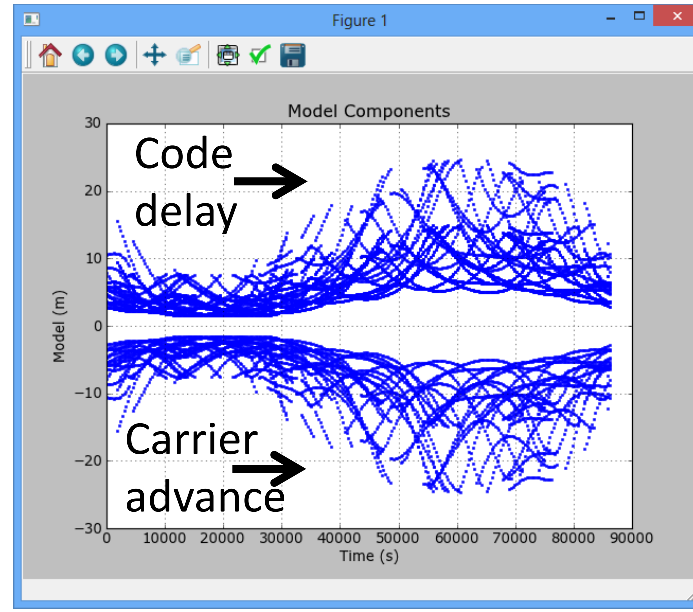


Horizontal Position Error plot: gLAB.out, gLAB1.out



Ionospheric model component plot: **gLAB.out**





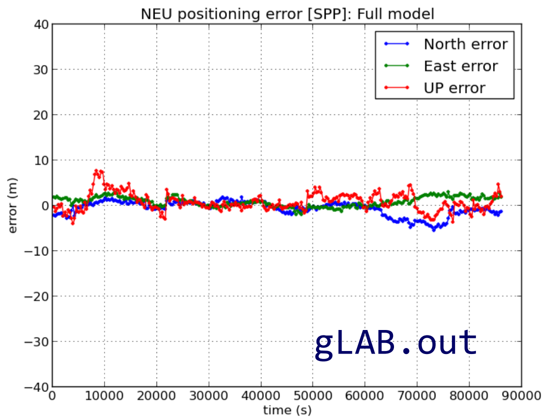
Select IONO

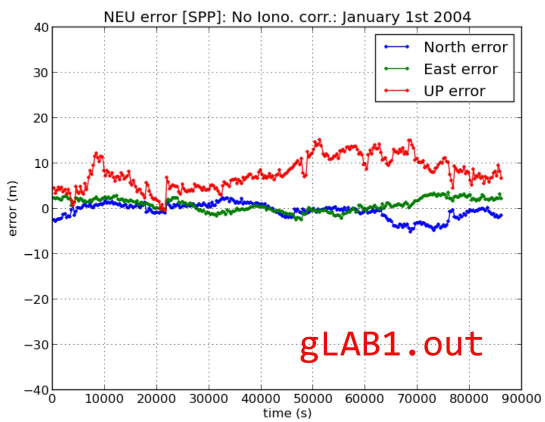
gLAB.out

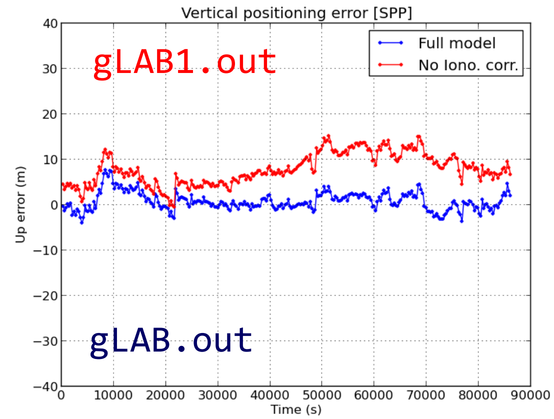
Ionosphere delays code and advances carrier measurements.

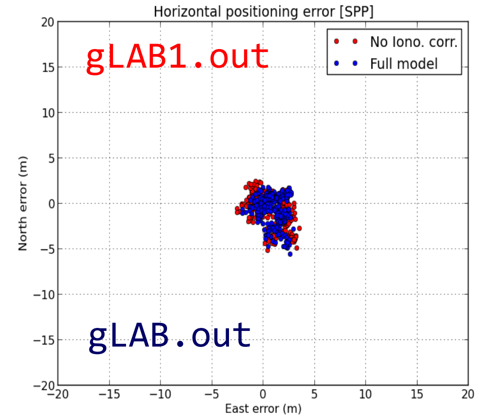
Note: **Use the gLAB.out** file. In **gLAB1.out** file this model component was switched off.

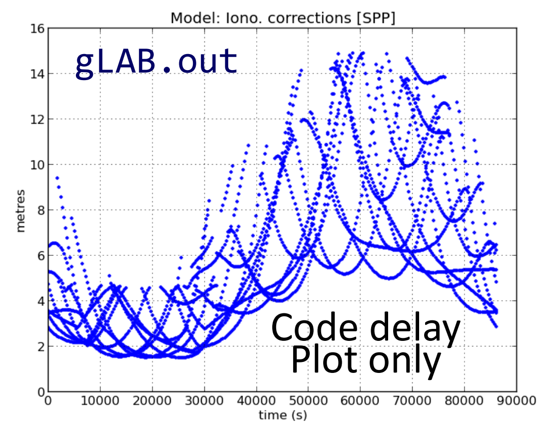
Summary: Iono. model component analysis











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.

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 on the inverse of squared frequency:

$$\delta_{ion} = \frac{40.3}{f^2} I$$

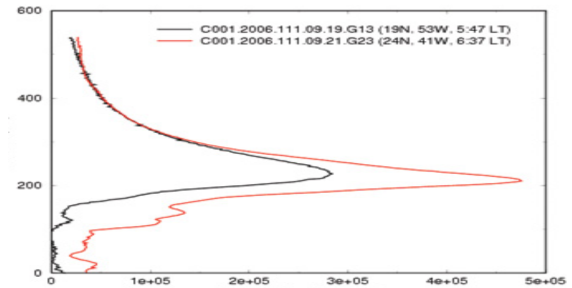
  where I is the number of electrons per area unit along ray path (STEC: Slant Total Electron Content).

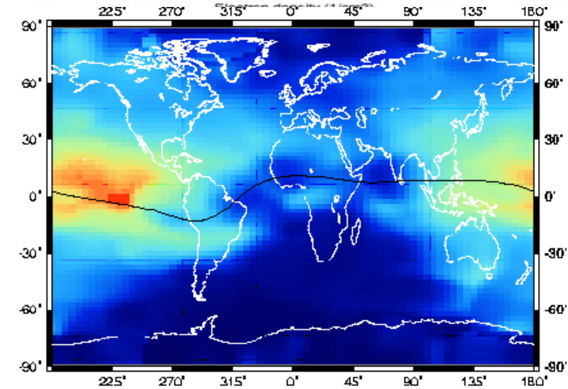
$$I = \int N_e ds$$

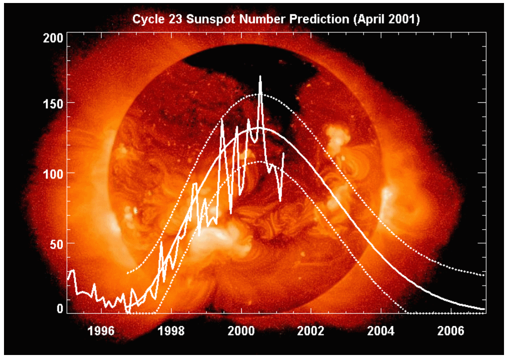
- Two-frequency receivers can remove this error source (up to 99.9%) using ionosphere-free combination of pseudoranges (PC) or carriers (LC).

$$LC = \frac{f_1^2 L1 - f_2^2 L2}{f_1^2 - f_2^2}$$

- 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.

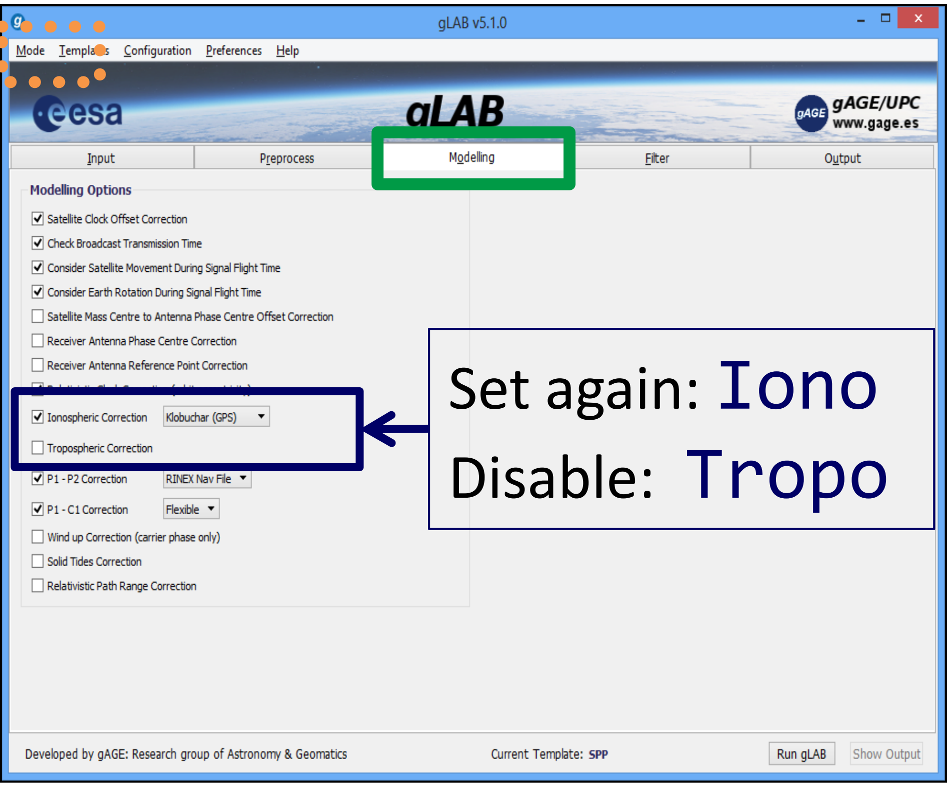


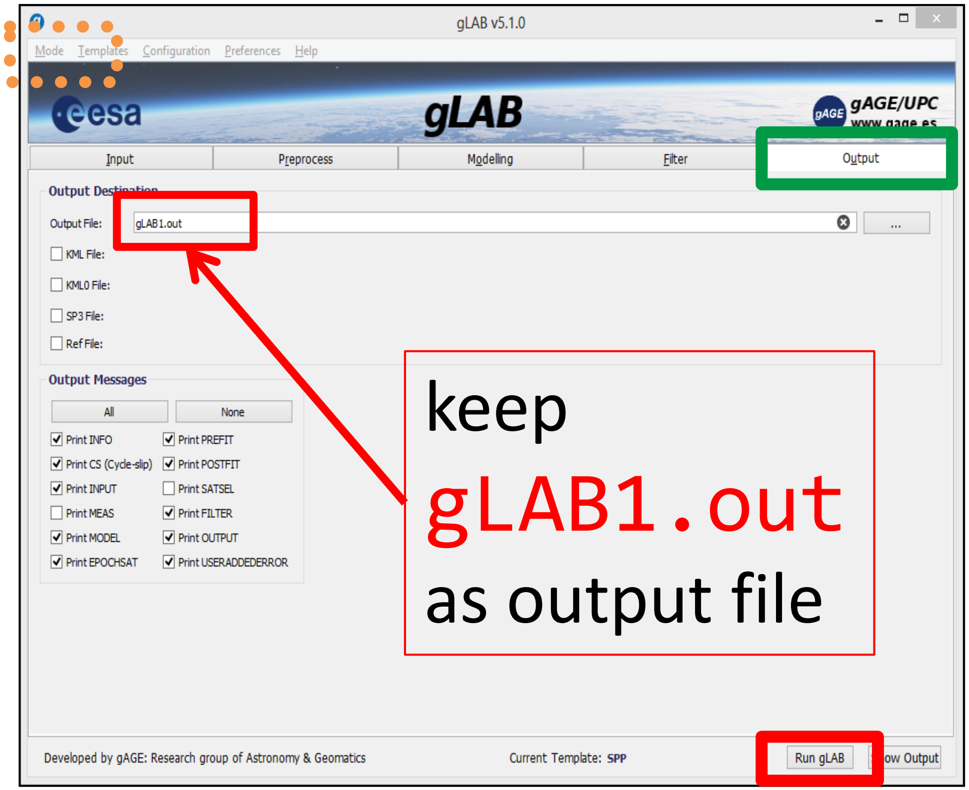




Example of model component analysis: **TROPO.**

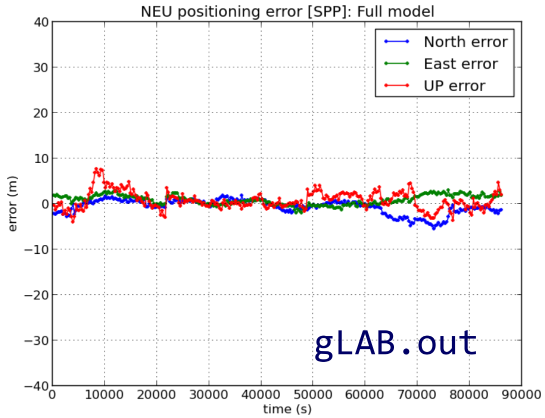
The *gLAB* configuration can be set-up as follows, to repeat the processing without applying the tropospheric correction (but using the ionosphere again!):

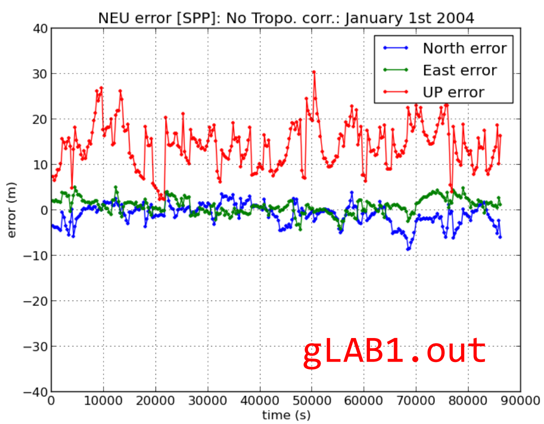


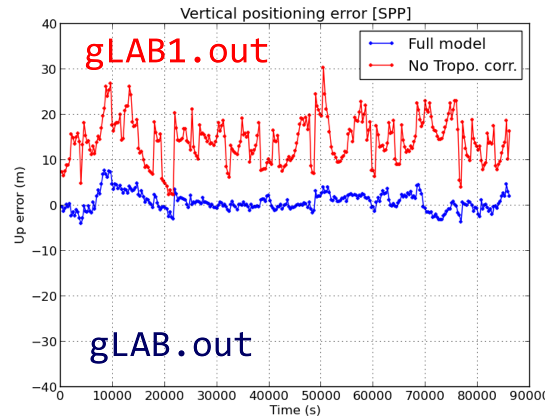


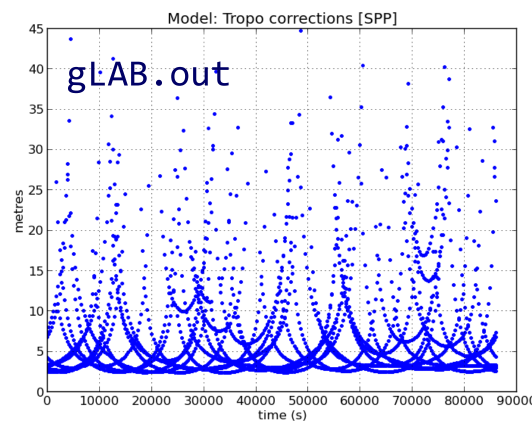
- The same scheme must be applied for all other model terms (TGDs, relat...)

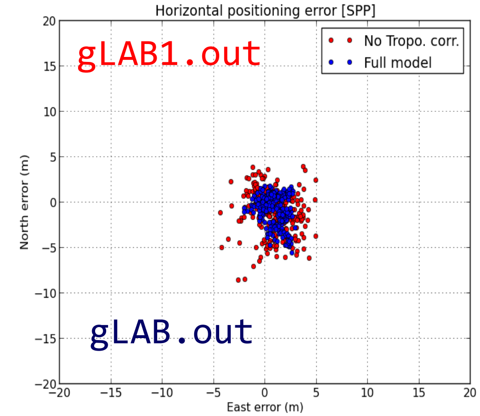
Exercise 1: SPP Model components analysis











Tropospheric correction
(blind model)

Tropospheric and vertical error are highly correlated.

A displacement of vertical component appears when neglecting tropospheric corrections.

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.

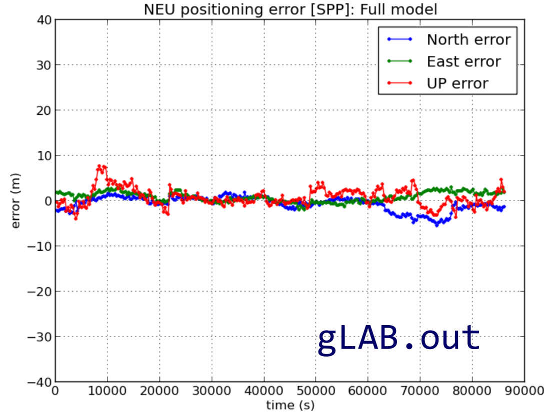
The effect of troposphere on GNSS signals appears as an extra delay in the measurement of the signal travelling from satellite to receiver.

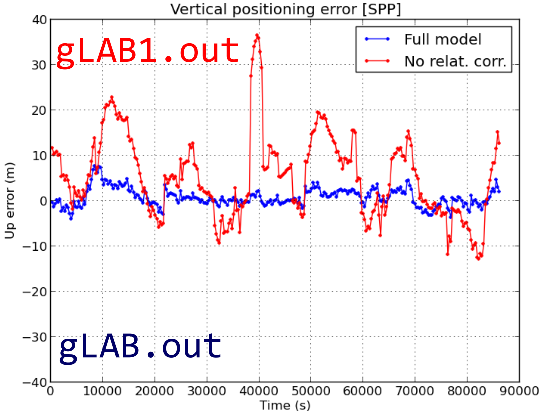
The tropospheric delay does not depend on frequency and affects both the pseudorange (code) and carrier phases in the same way. It can be modeled by:

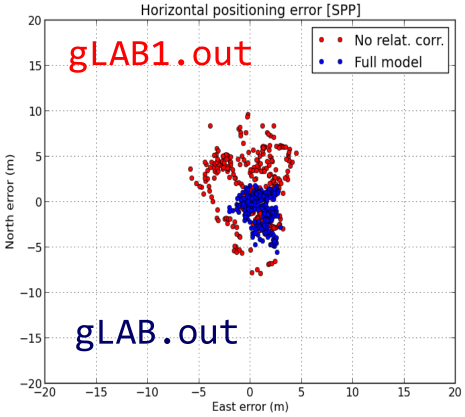
– An **hydrostatic component**, composed of dry gases (mainly nitrogen and oxygen) in hydrostatic equilibrium. This component can be treated as an ideal gas. Its effects vary with the temperature and atmospheric pressure in a quite predictable manner, and it is the responsible of about 90% of the delay.

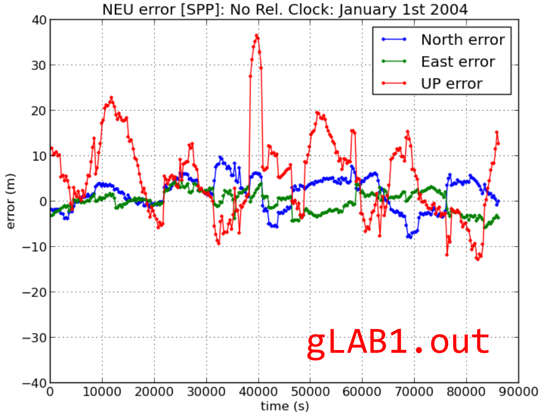
– A **wet component** caused by the water vapor condensed in the form of clouds. It depends on the weather conditions and varies faster than the hydrostatic component and in a quite random way. For high accuracy positioning, this component must be estimated together with the coordinates and other parameters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

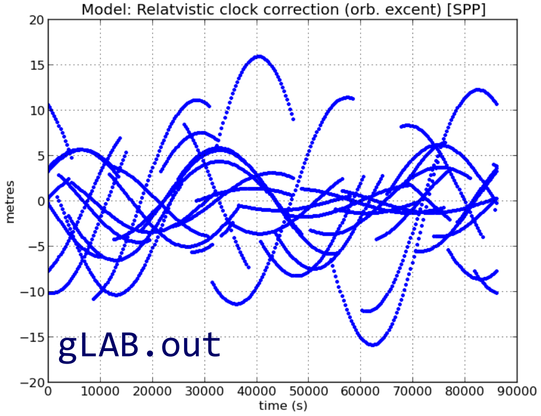
Exercise 1: SPP Model components analysis











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 $f'_0 = 10.22999999543\ MHz$.

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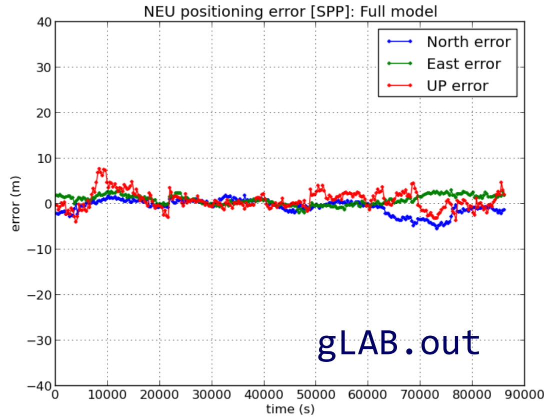
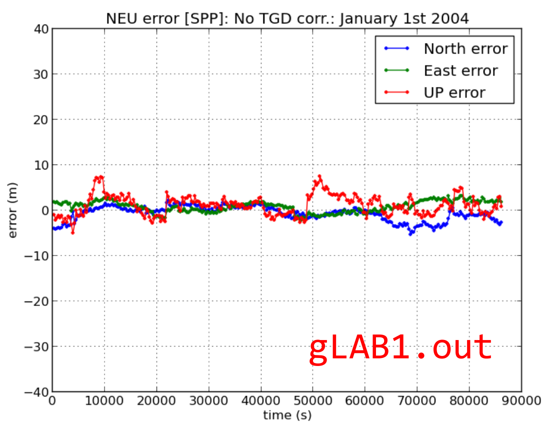
2) A periodic component due to orbit eccentricity must be corrected by user receiver:

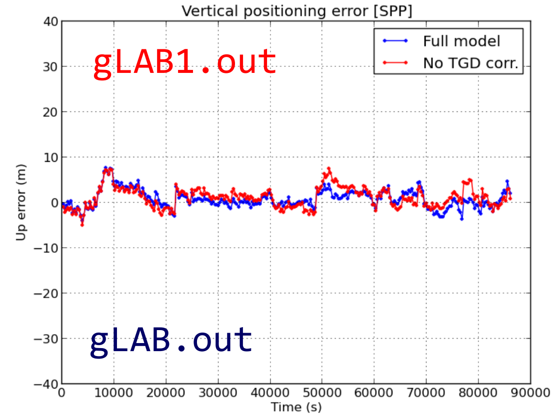
$$rel = -2\frac{\sqrt{\mu a}}{c} e \sin(E) = -2\frac{\mathbf{r} \cdot \mathbf{v}}{c}\ (meters)$$

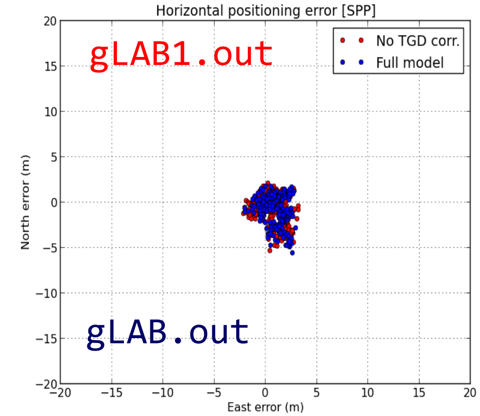
Being $\mu = G\ M_E = 3.986005\ 10^{14}\ (m^3/s^2)$ the gravitational constant, c =299792458 (m/s) light speed in vacuum, a is orbit's major semi-axis, e is its eccentricity, E is satellite's eccentric anomaly, and r and v are satellite's geocentric position and speed in an inertial system.

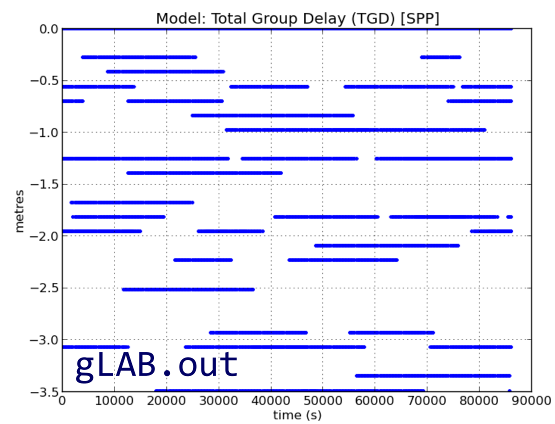
Exercise 1: SPP Model components analysis











P2-P1 Differential Code Bias (Total Group Delay [TGD]) correction.

These instrumental delays can affect up to few meters, being the satellite TGDs broadcast in the navigation message for single frequency users.

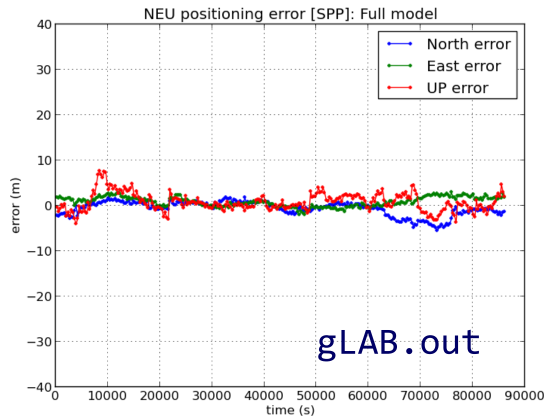
Exercise 1: SPP Model components analysis

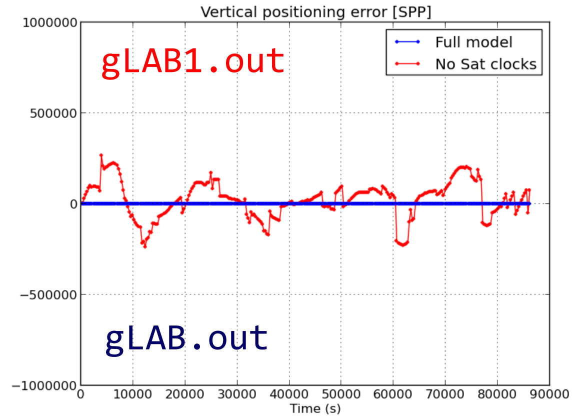
Total Group Delay correction (TGD)

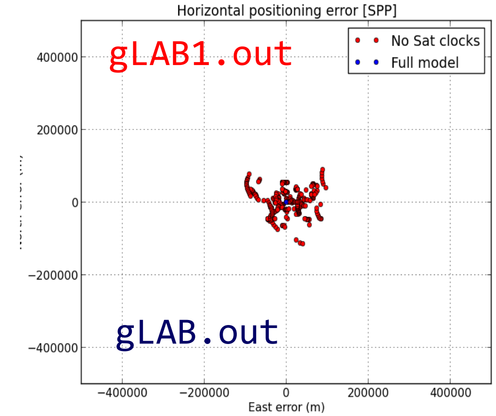
(P2-P1 Differential Code Bias [DCB])

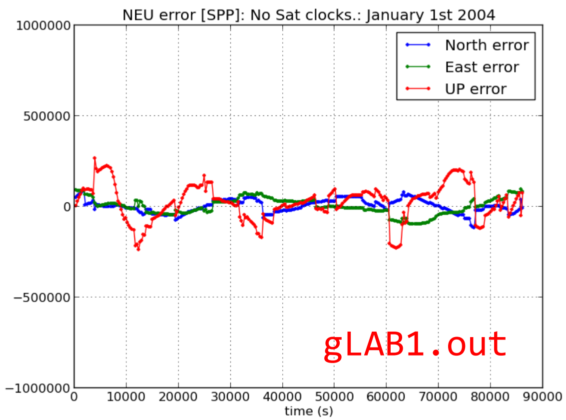
- Instrumental delays are associated to antennas, cables, as well as different filters used in receivers and satellites. They affect both code and carrier measurements.
- Code instrumental delays depend on the frequency and the codes used, and are different for the receiver and the satellites.
- Dual 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.

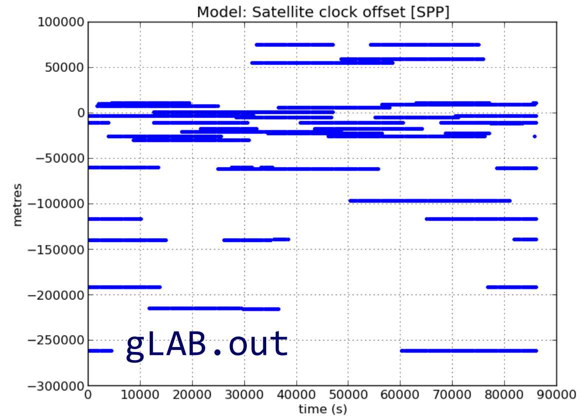
Exercise 1: SPP Model components analysis











Satellite clock offsets

This is the largest error source, and it may introduce errors up to a thousand kilometers.

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

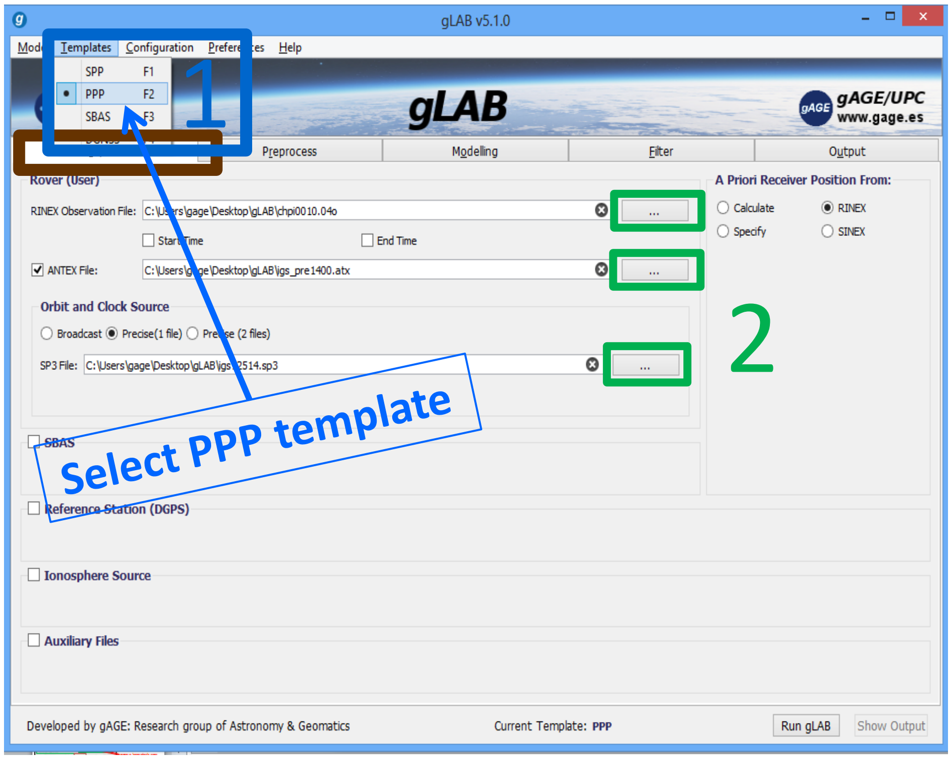
Exercise 2: Model components analysis for PPP

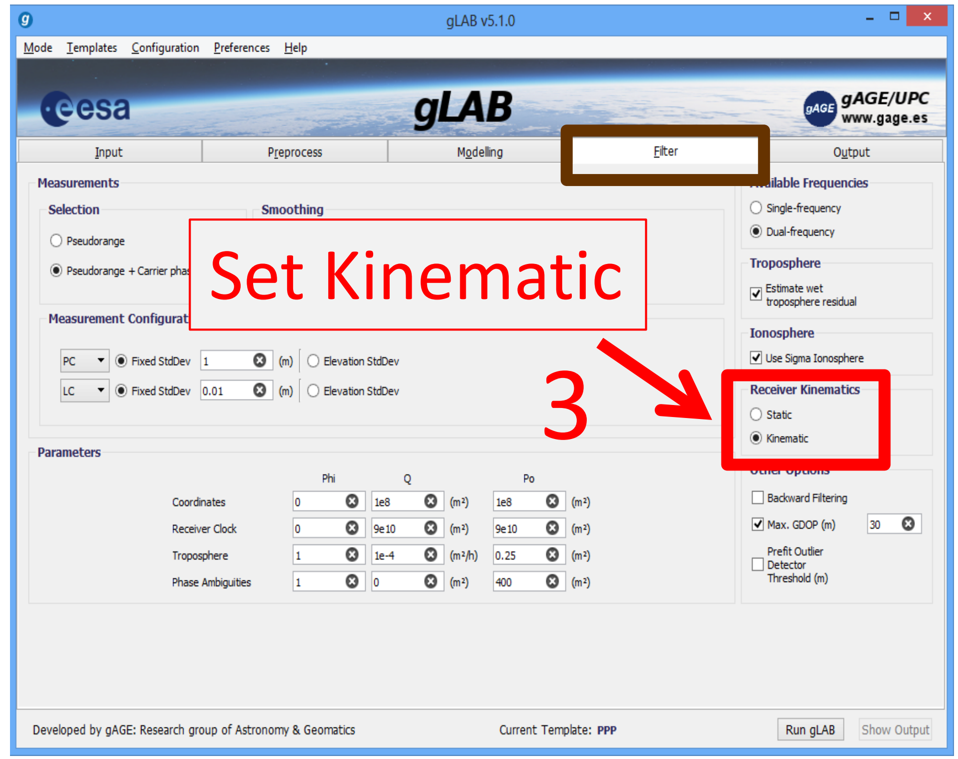
- This exercise is devoted to analyse the additional model components used in Precise Point Positioning (the ones which are not required by SPP). This is done in Range and Position Domains.

Exercise 2: PPP Model components analysis

- Compute the kinematic PPP solution using files:

  `chpi0010.04o, igs_pre1400.atx, igs12514.sp3`

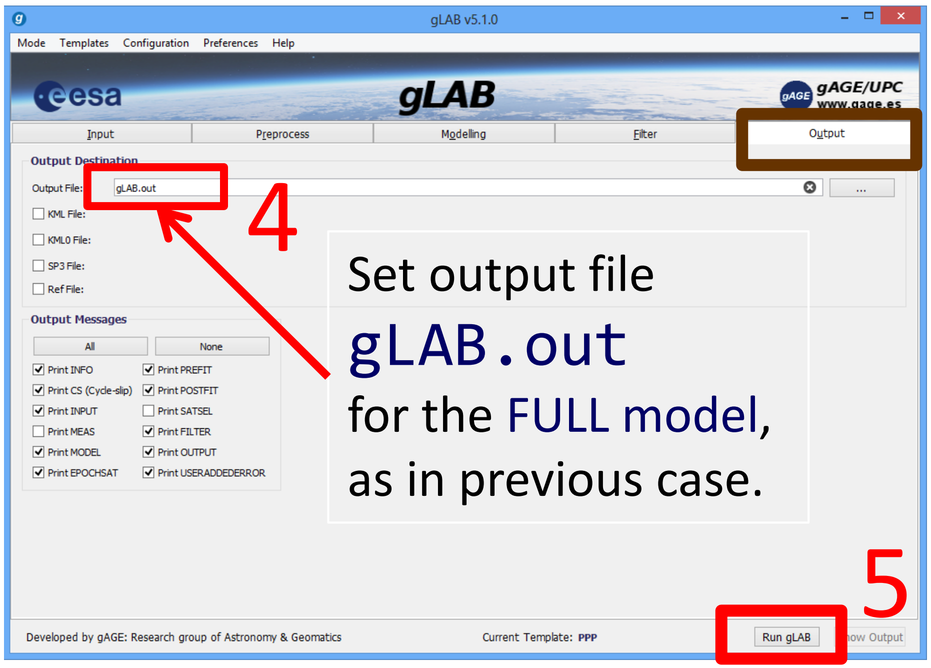


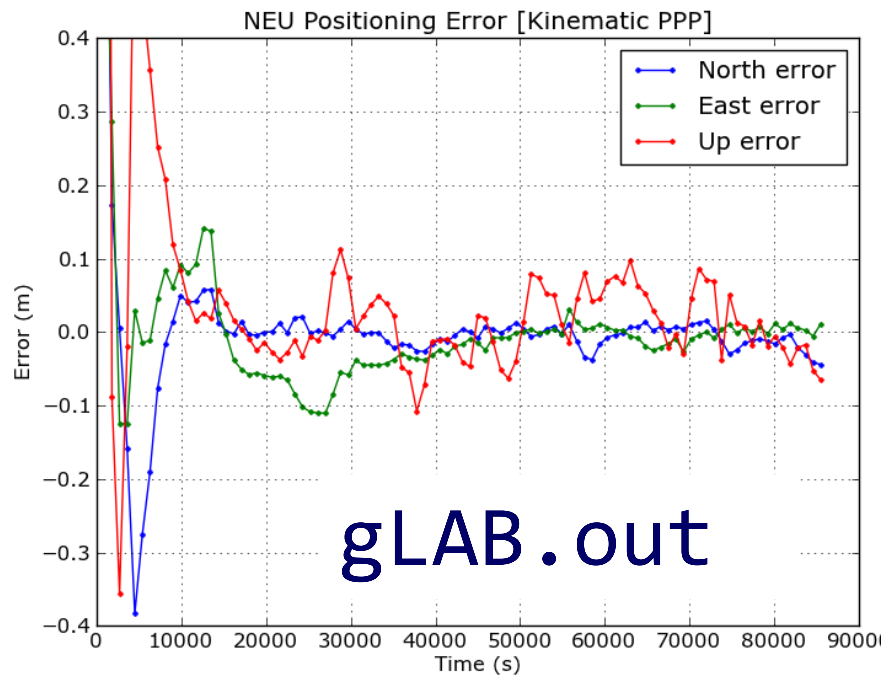


Note: The `igs_pre1400.atx` file contains the APC used by IGS before GPS week 1400.

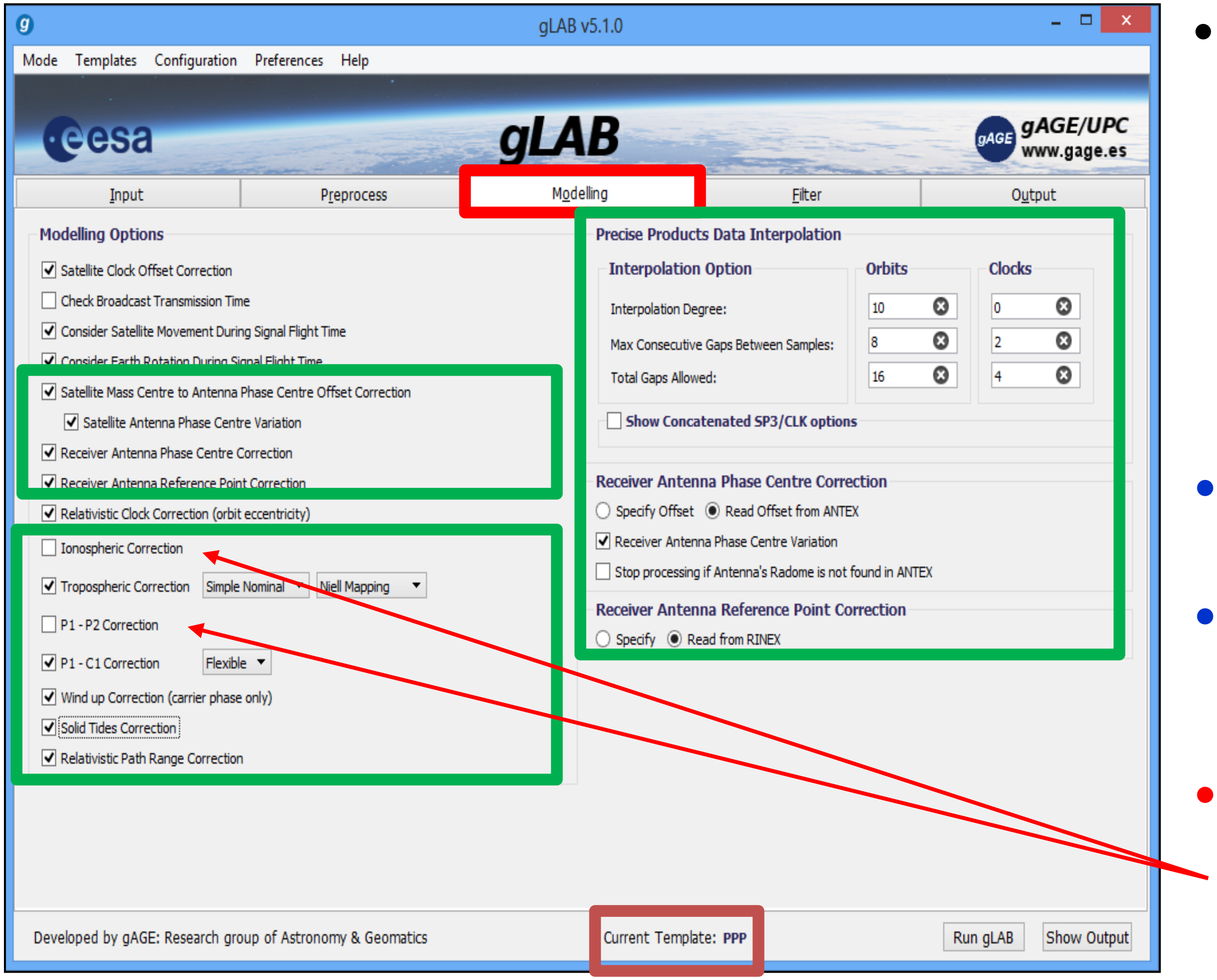
Exercise 2: PPP Model components analysis

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





Exercise 2: PPP Model components analysis



- Additional model components are used now in the FULL model to assure a <u>centimeter level modeling</u>.

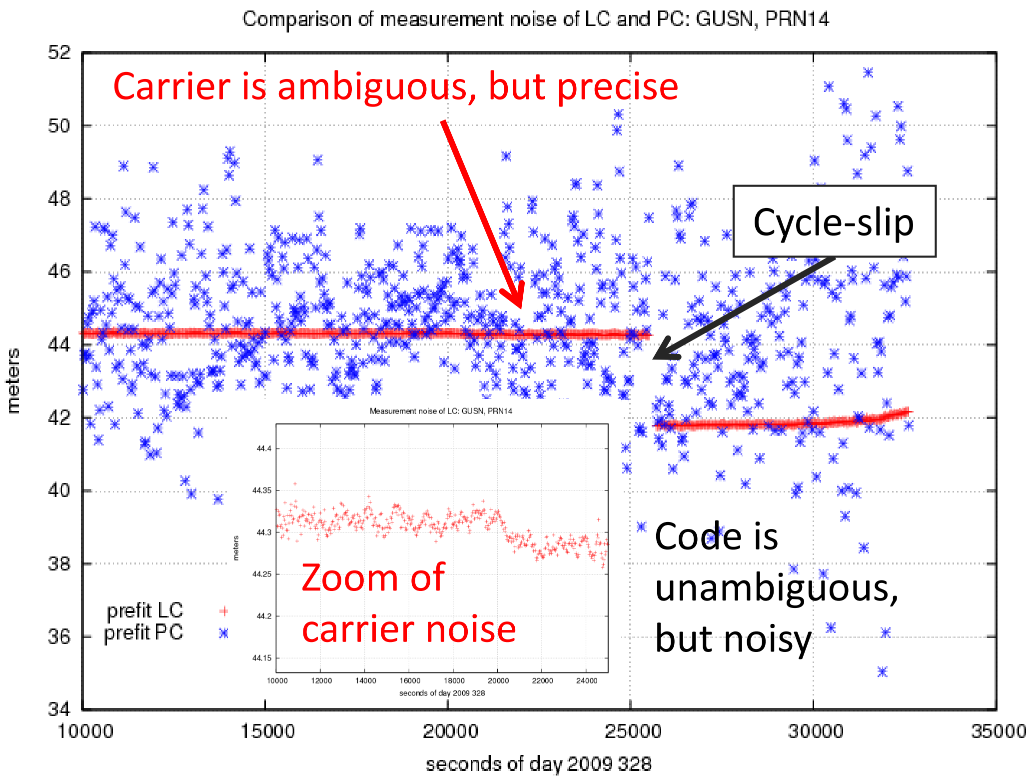
- <u>Precise orbits and clocks</u> instead of broadcast ones.

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

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

Exercise 2: PPP Model components analysis

Code and carrier Measurement noise

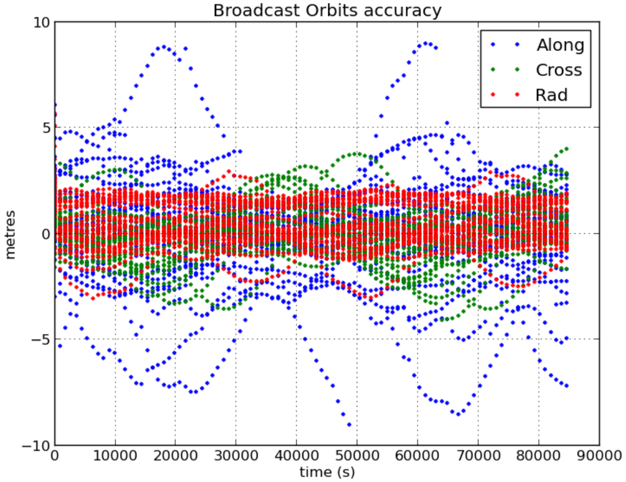


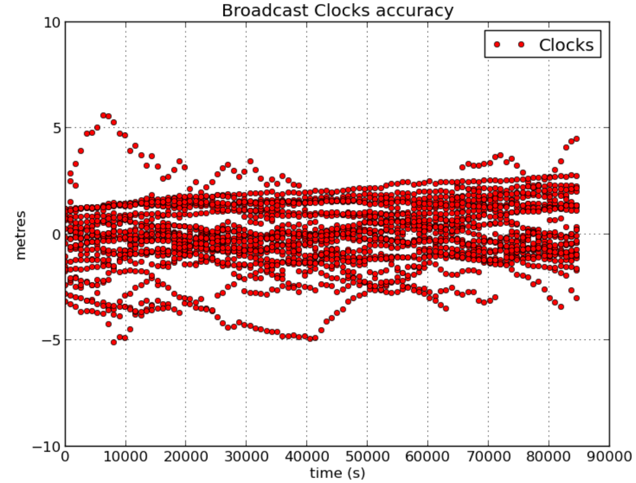
Note: Figure shows the noise of **code** and **carrier** prefit-residuals, which are the input data for navigation equations.

- 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

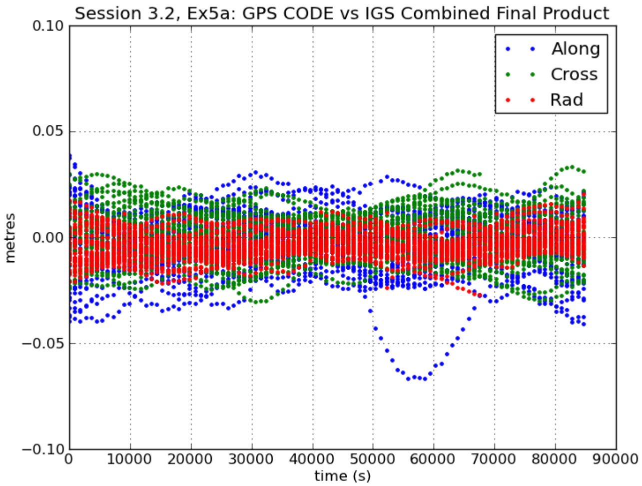
Orbits & clocks accuracies

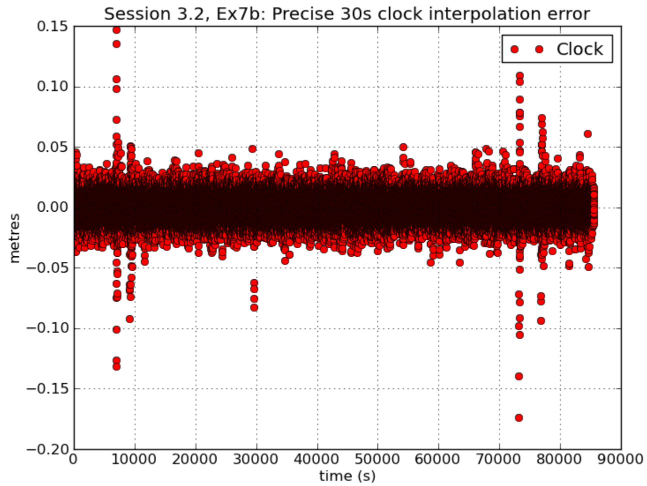




Broadcast:

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

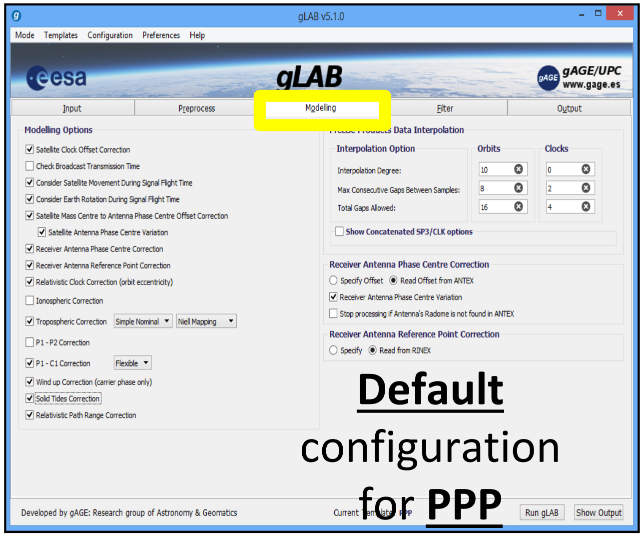




Precise:

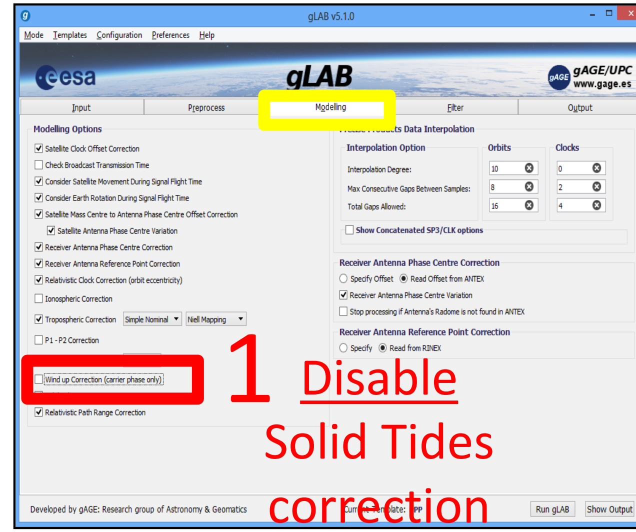
- **Few centimetres** of accuracy for broadcast orbits and clocks

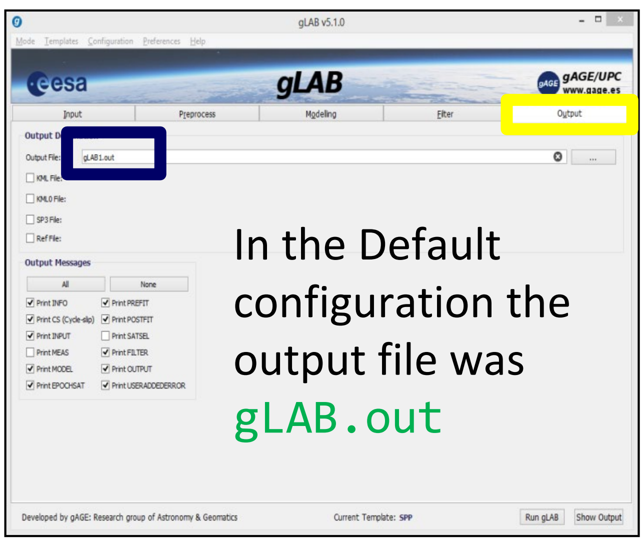
Example of model component analysis: **Solid Tides**



Proceed as in the previous exercise:

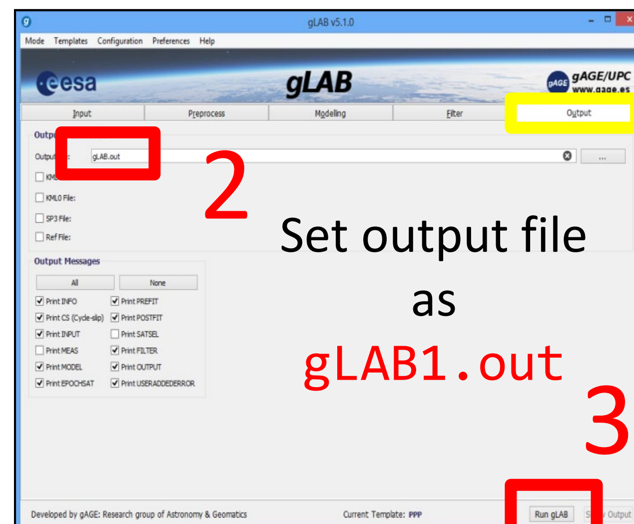
1. In Modeling panel, disable the model component to analyze.
2. Save as `gLAB1.out` the associated output file.



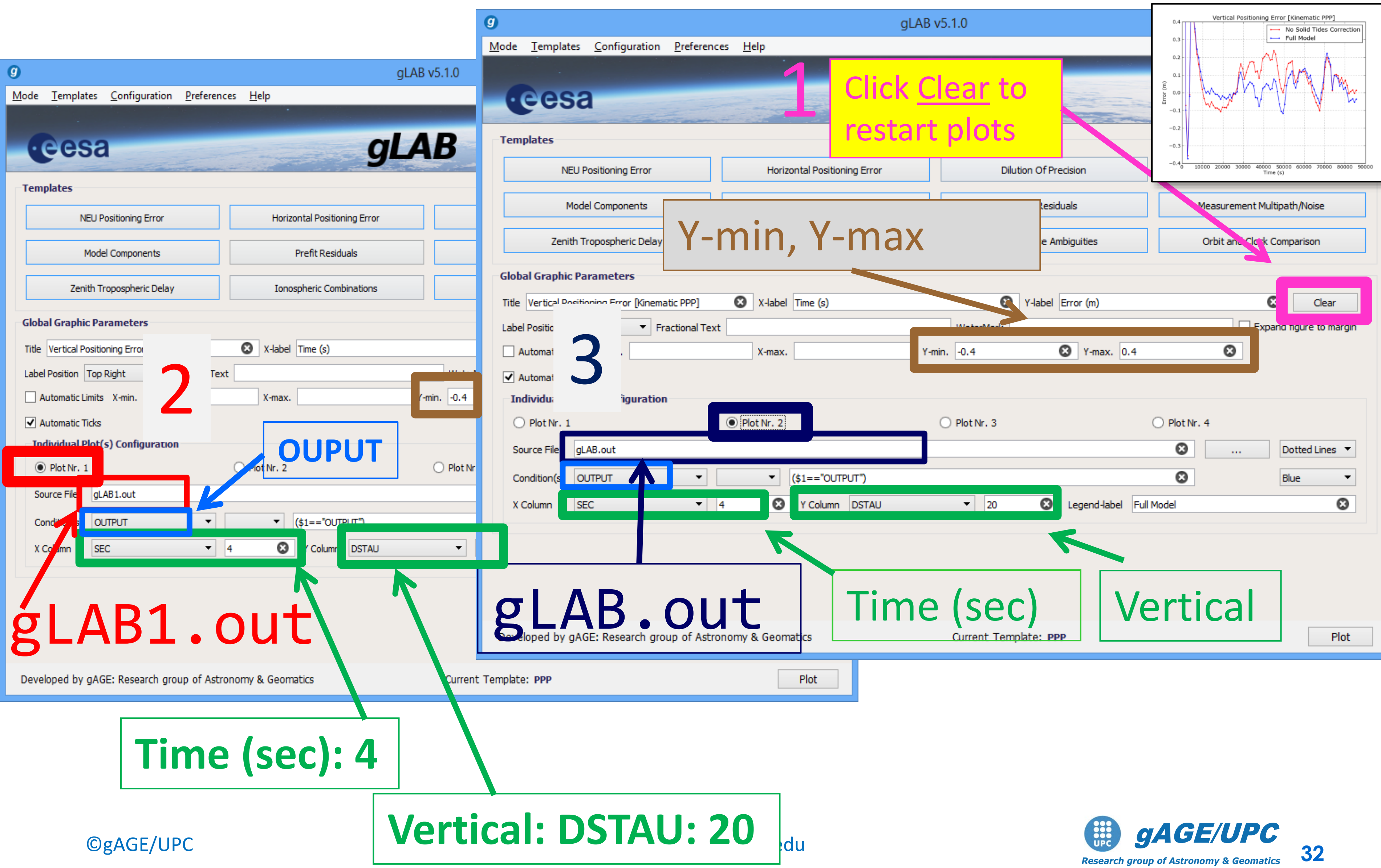


Notice that the `gLAB.out` file contains the processing results with the FULL model, as it was set in the default configuration.

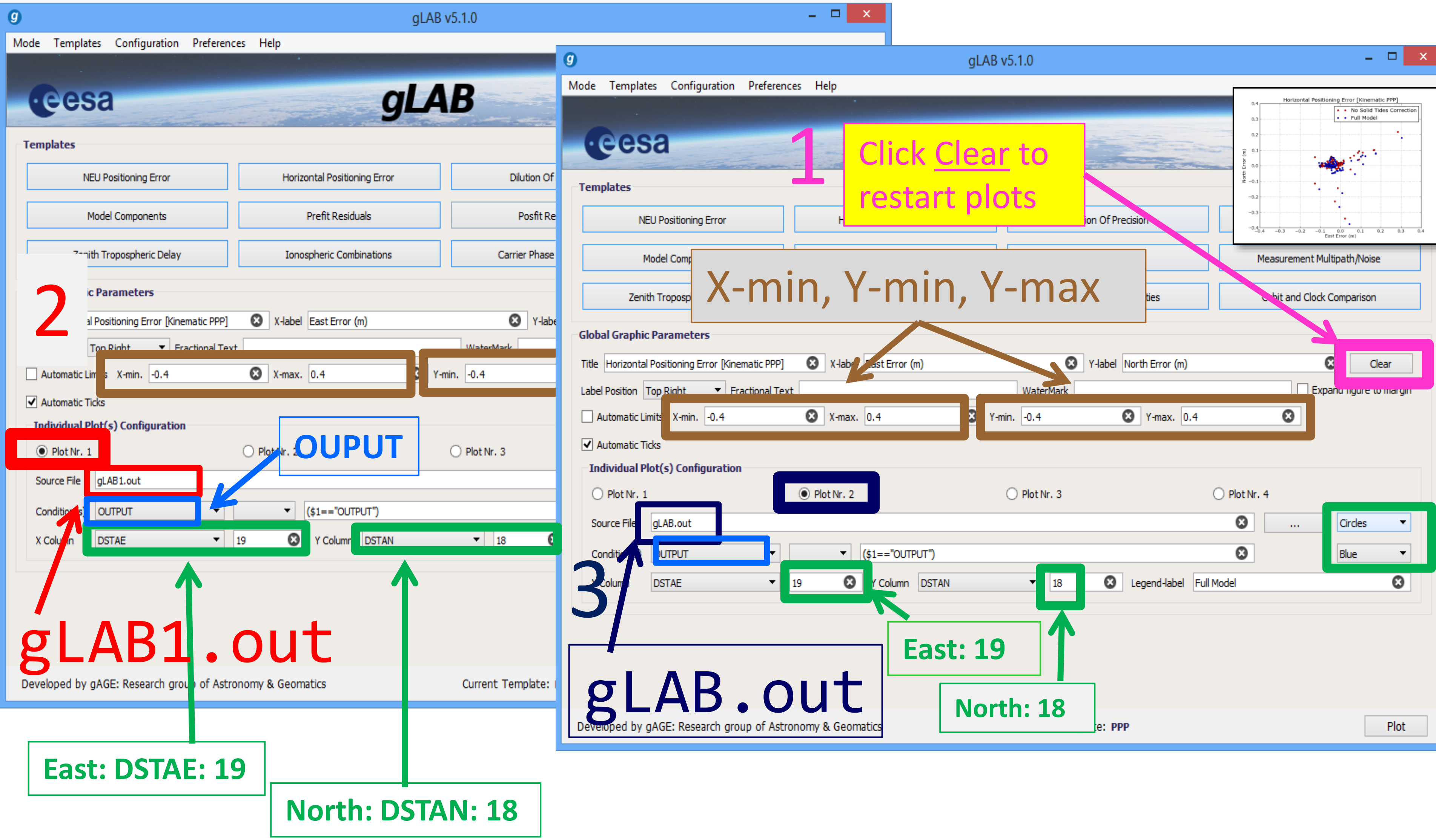
Make plots as in previous exercises (see slides 38-40).



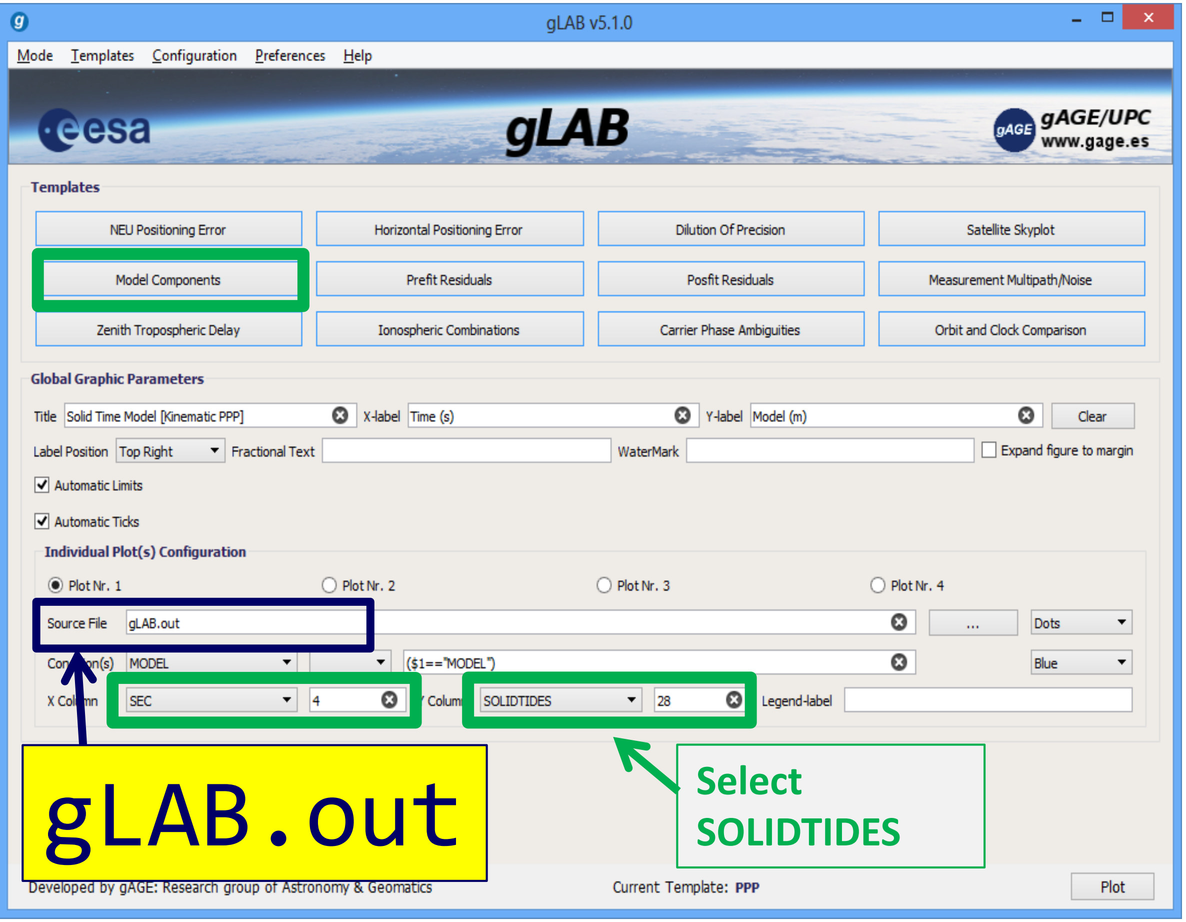
Vertical Position Error plot from gLAB.out, gLAB1.out

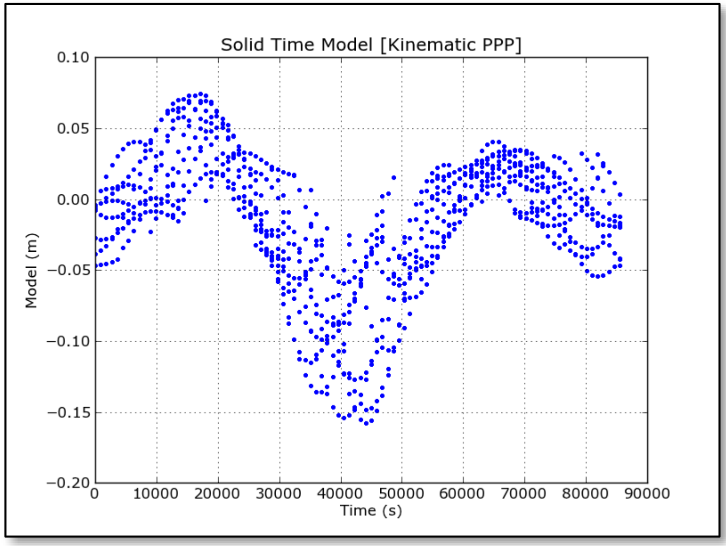


Horizontal Position Error plot: gLAB.out, gLAB1.out



Solid Tides model component plot: gLAB.out





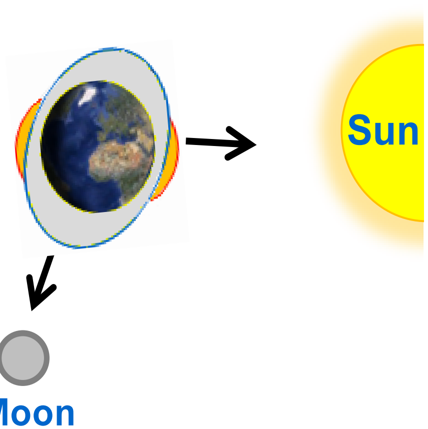
Solid Tides plot

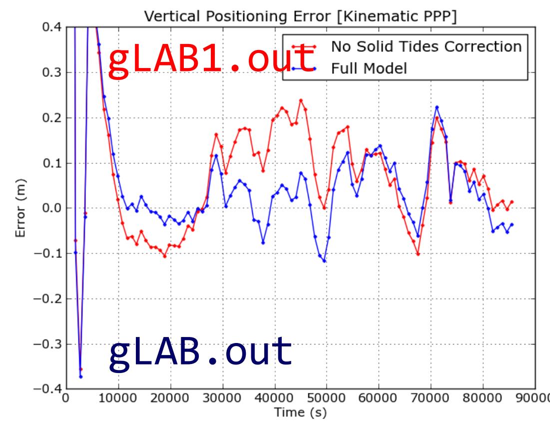
Note: Use the gLAB.out file. In gLAB1.out file this model component was switched off.

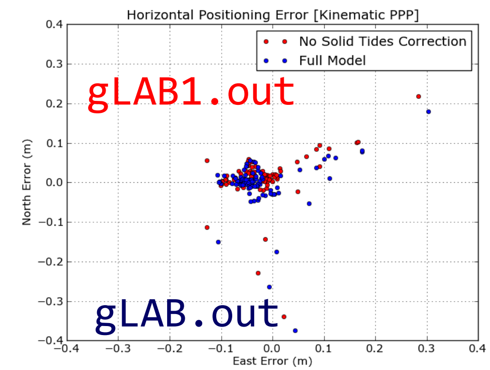
Exercise 2: PPP Model components analysis

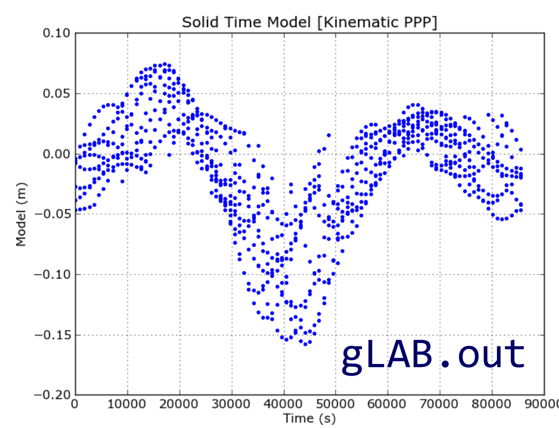
Solid Tides

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.









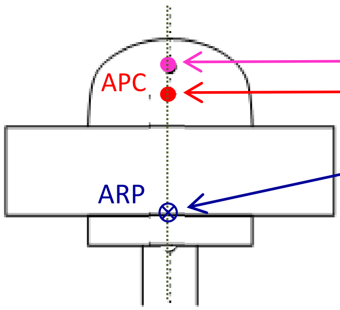
Solid Tides:

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.

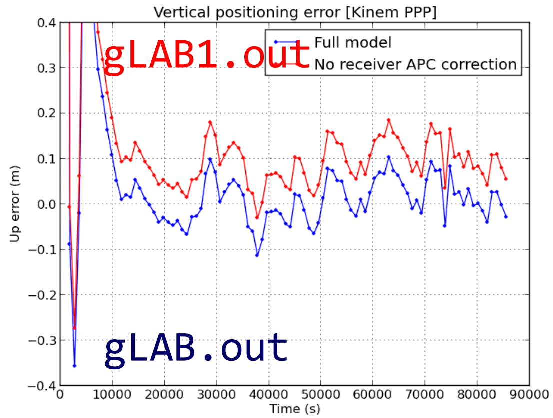
Exercise 2: PPP Model components analysis

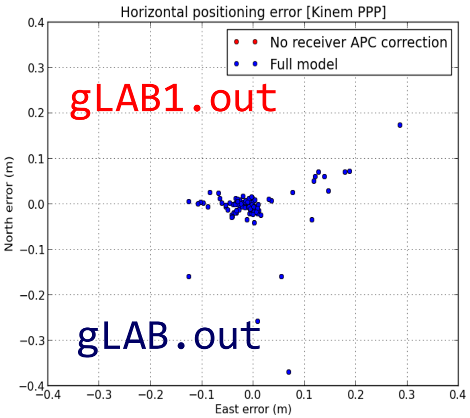
Receiver Antenna Phase center (APC)

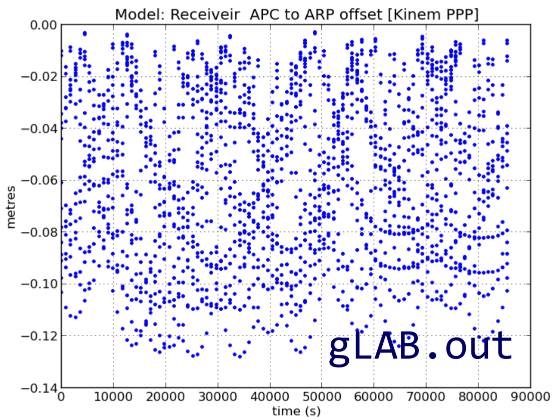


GNSS measurements are referred to the APC. This is not necessarily the geometric center of the antenna, and it depends on the signal frequency and the incoming radio signal direction.

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







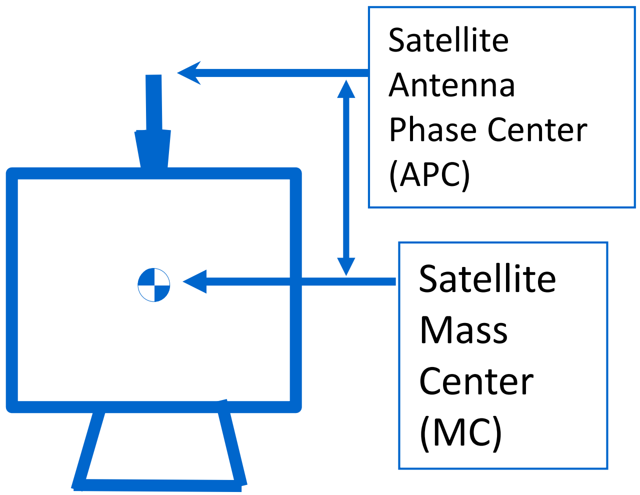
Receiver APC:

The antenna used for this experiment, has the APC position vertically shifted regarding ARP.

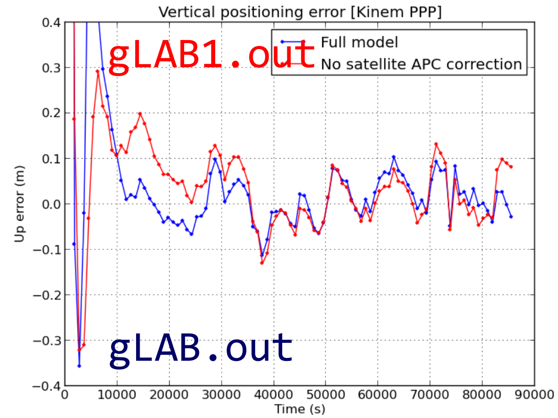
Thence, neglecting this correction, an error on the vertical component occurs, but not in the horizontal one.

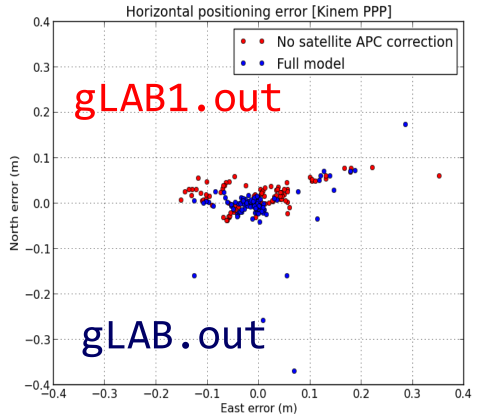
Exercise 2: PPP Model components analysis

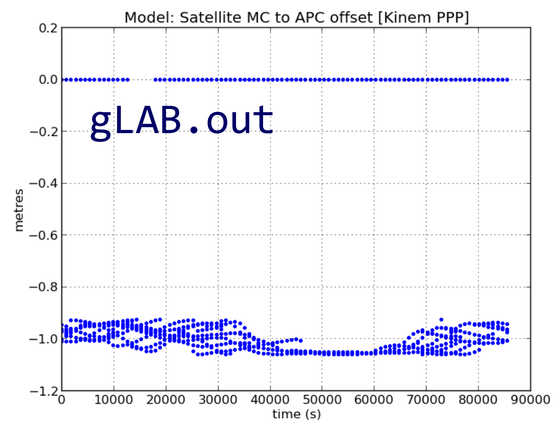
Satellite Mass Center to Antenna Phase Center



Broadcast orbits are referred to the antenna phase center, but IGS precise orbits are referred to the satellite mass center.







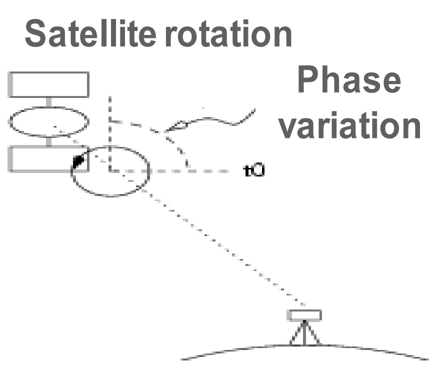
Satellite MC to APC:

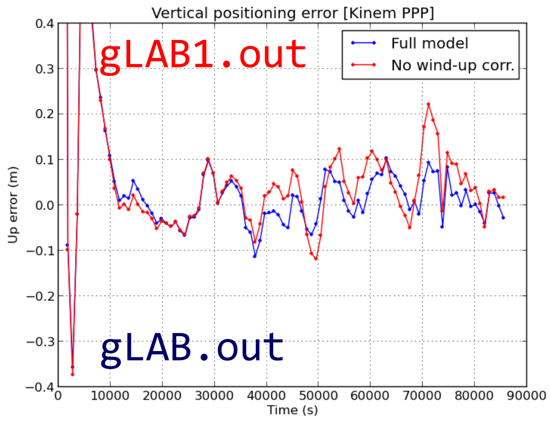
The satellite MC to APC eccentricity vector depends on the satellite. The APC values used in the IGS orbits and clocks products are referred to the iono-free combination (LC, PC) . They are given in the IGS ANTEX files (e.g., `igs05.atx`).

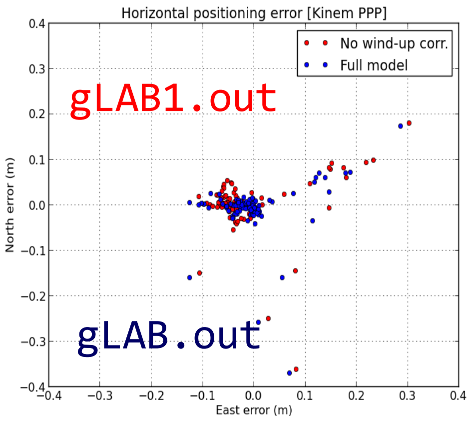
Exercise 2: PPP Model components analysis

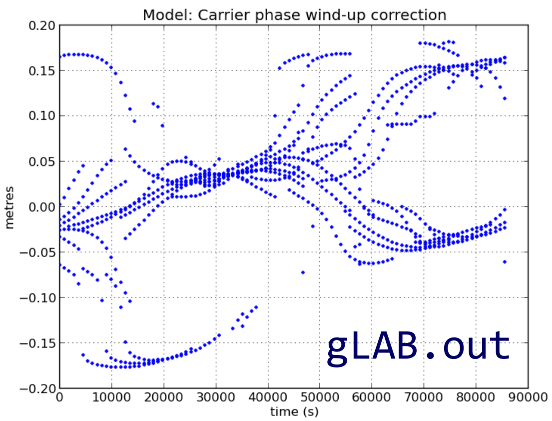
Wind-up affects only carrier phase. It is due to the electromagnetic nature of circularly polarized waves of GNSS signals.

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.









Wind-Up

Wind-up changes smoothly along continuous carrier phase arcs.

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

Thanks for your attention

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- Iono. Corrections
- Iono. Disturb. Mitig.
- Receiver orientation

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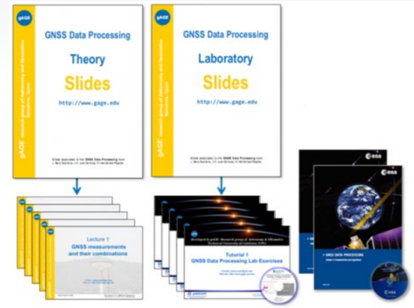

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  - About the course
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    - Lecture 1: GNSS measurements and their combinations
    - Lecture 2: Satellite orbits and clocks computation accuracy
    - Lecture 3: Position estimation with pseudoranges
    - 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
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    - Tutorial 5: Analysis of propagation effects from GNSS observables based on laboratory exercises
    - Tutorial 6: Differential positioning and carrier ambiguity fixing
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    - 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.

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- Log in using OpenID
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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, Mac and LINUX installable versions for this tutorial.