

Tutorial 2

Model components analysis

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June 2022

Introduction

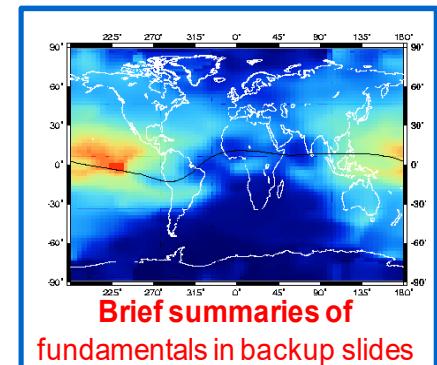
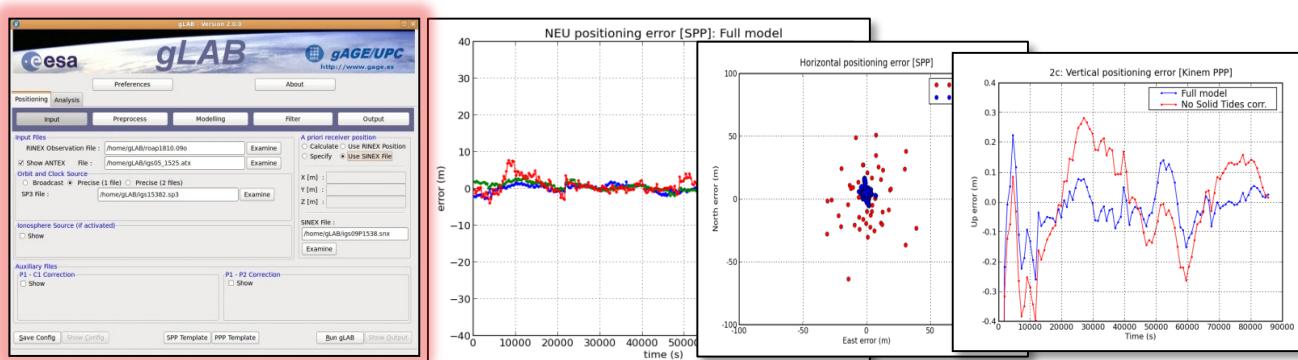
- This practical lecture is devoted to analyze and assess different issues associated with Standard and Precise Point Positioning with GPS data.
- The laboratory exercises will be developed with actual GPS measurements, and processed with the ESA/UPC GNSS-Lab Tool suite (*gLAB*), which is an interactive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



Model Components Analysis

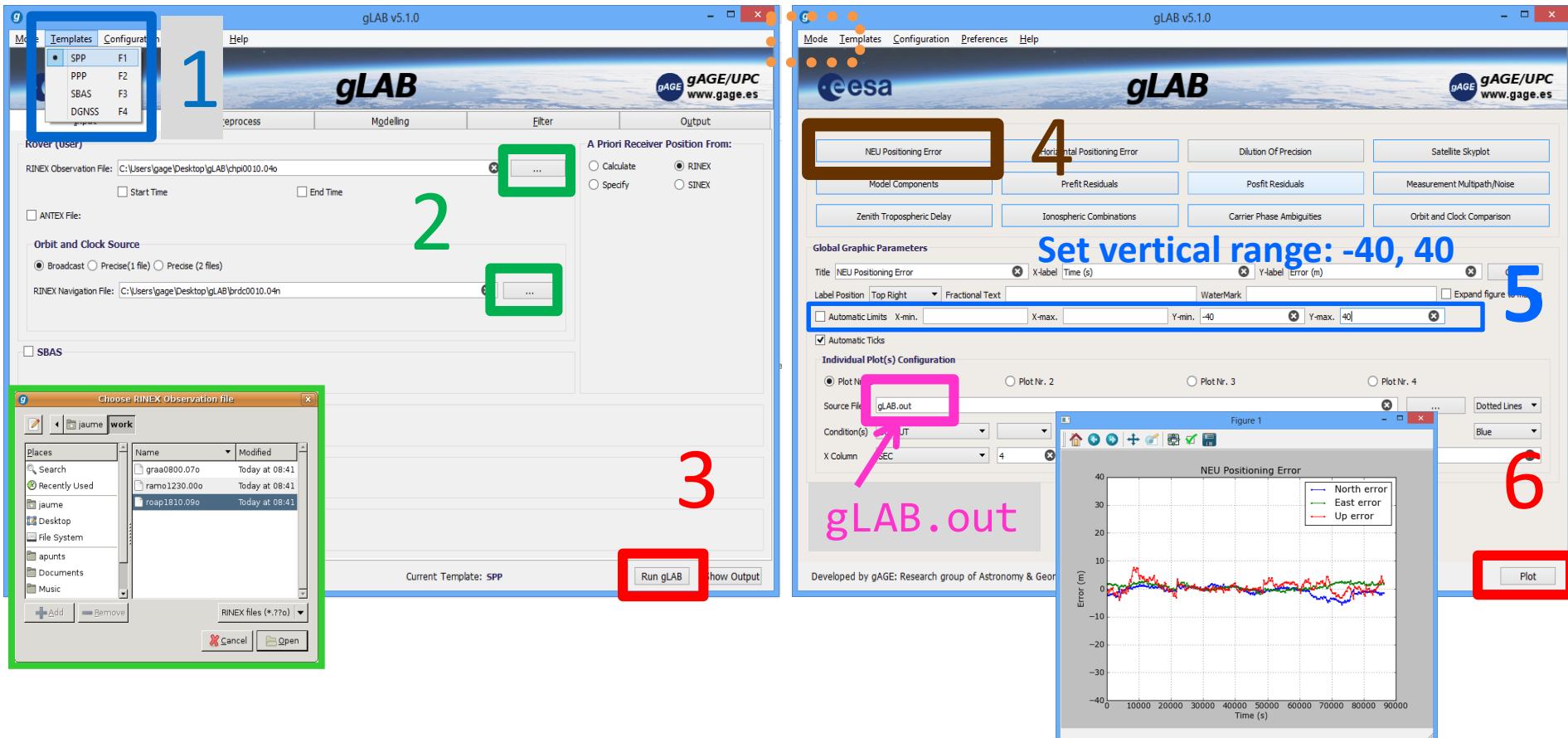
Exercise 1: Model components analysis for SPP

- 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.

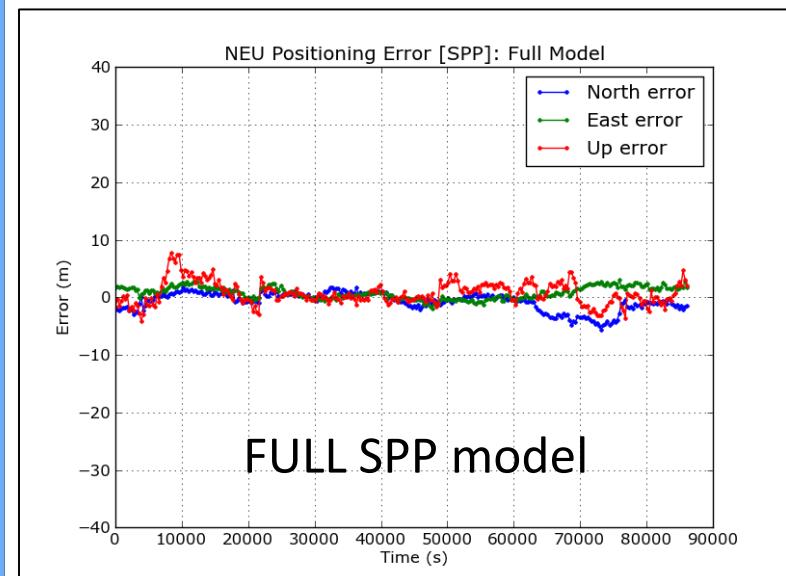
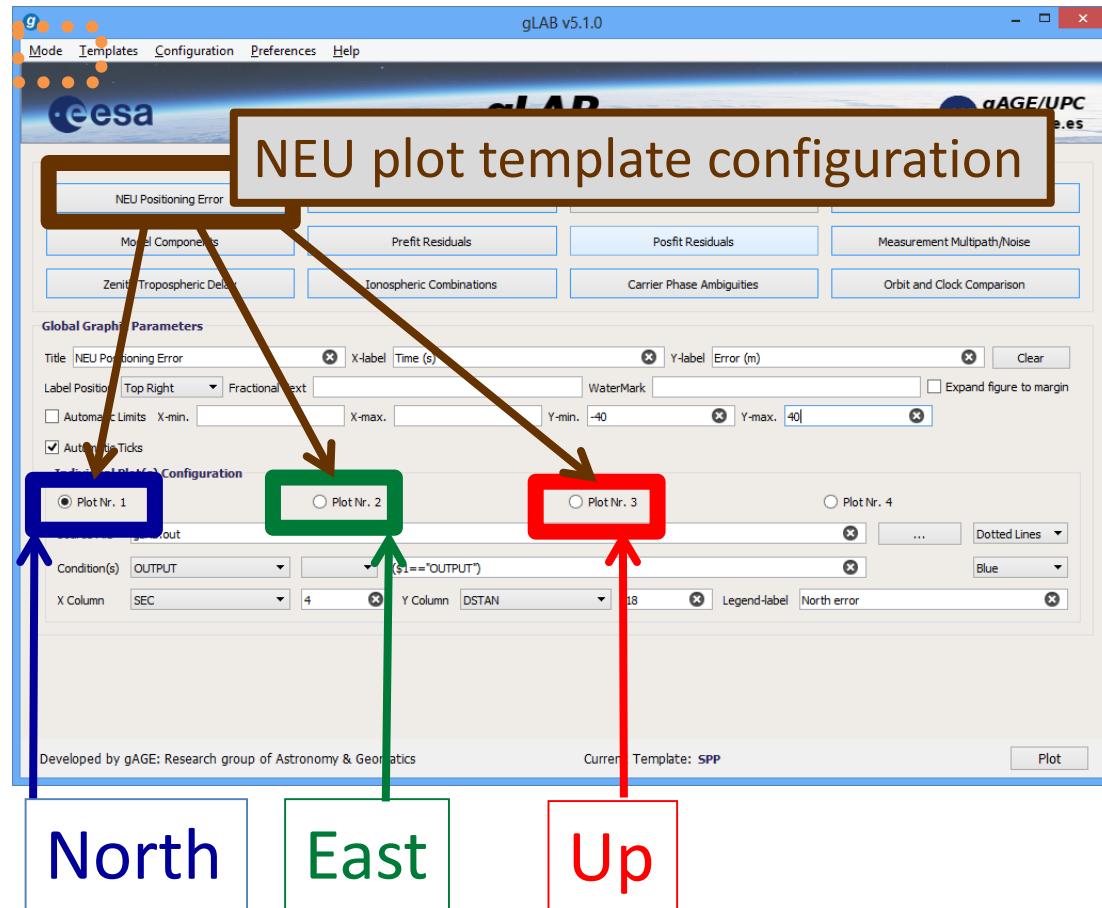
Exercise 1: SPP Model components analysis

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

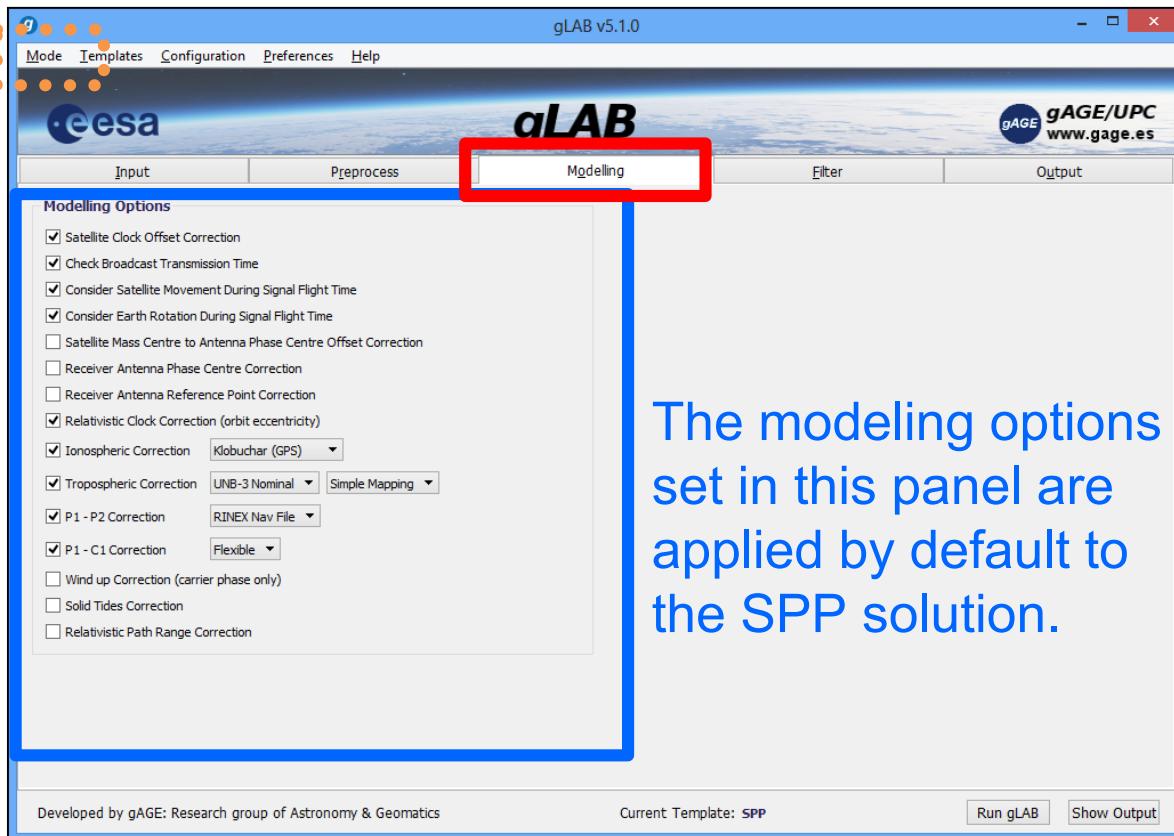
Cachoeira Paulista station (in the south of Brazil: $\lambda=-22.7^\circ$, $\phi=-45.0^\circ$). January 1st 2004.



NEU Position Error plot from gLAB.out



Exercise 1: SPP Model components analysis



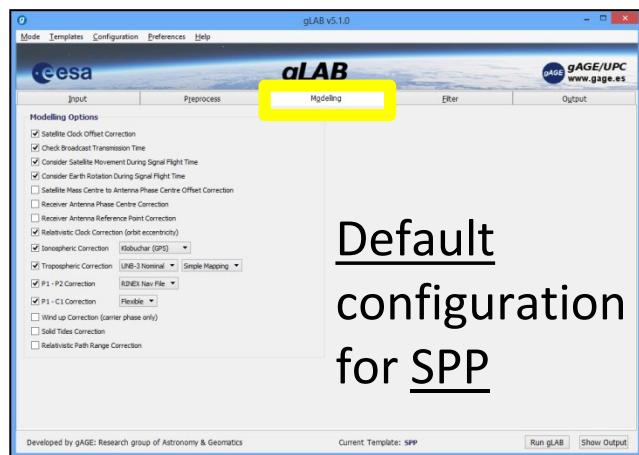
The modeling options set in this panel are applied by default to the SPP solution.

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.

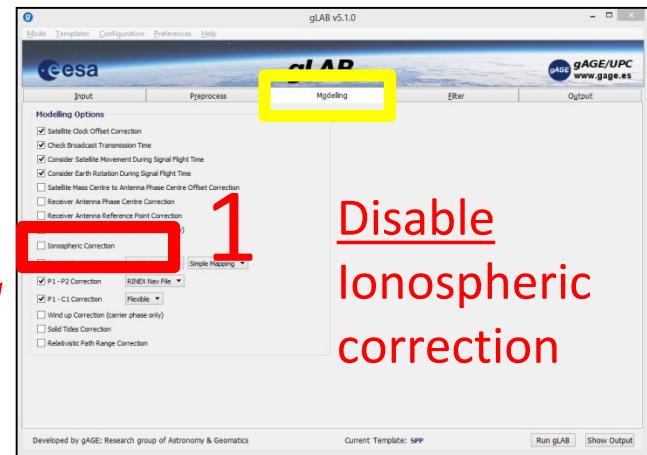
Example of model component analysis: IONO.

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



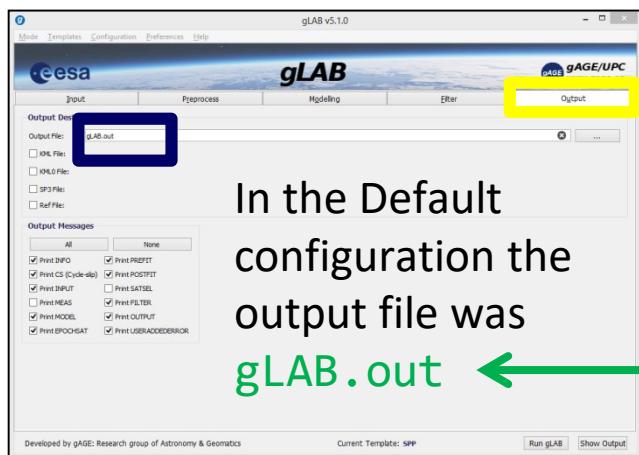
Default
configuration
for SPP

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



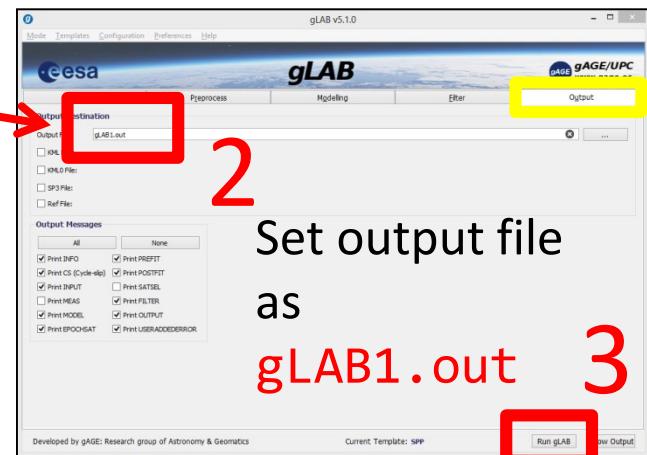
Disable
Ionospheric
correction

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



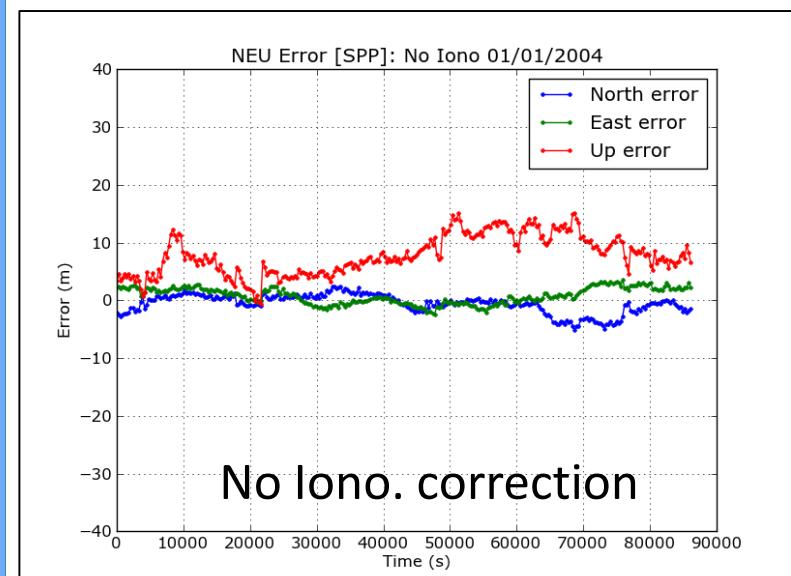
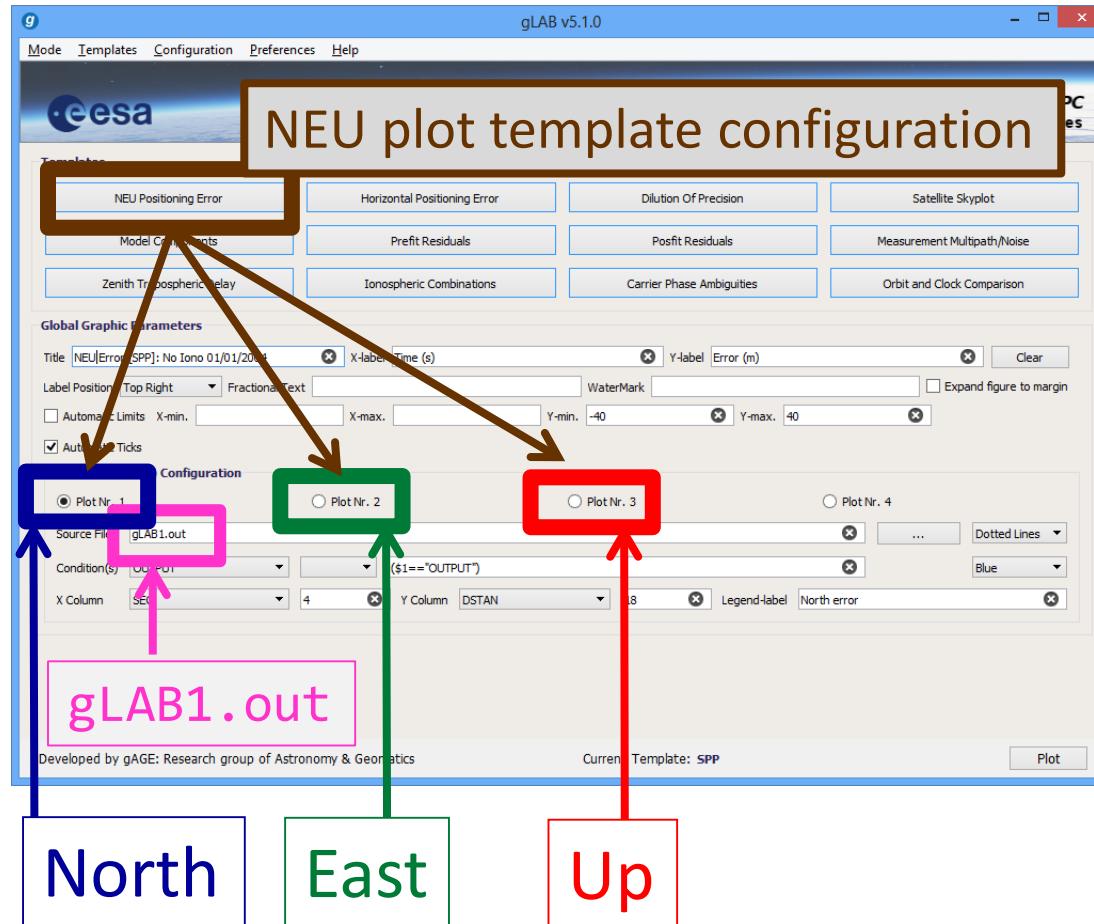
In the Default configuration the output file was **gLAB.out** ←

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

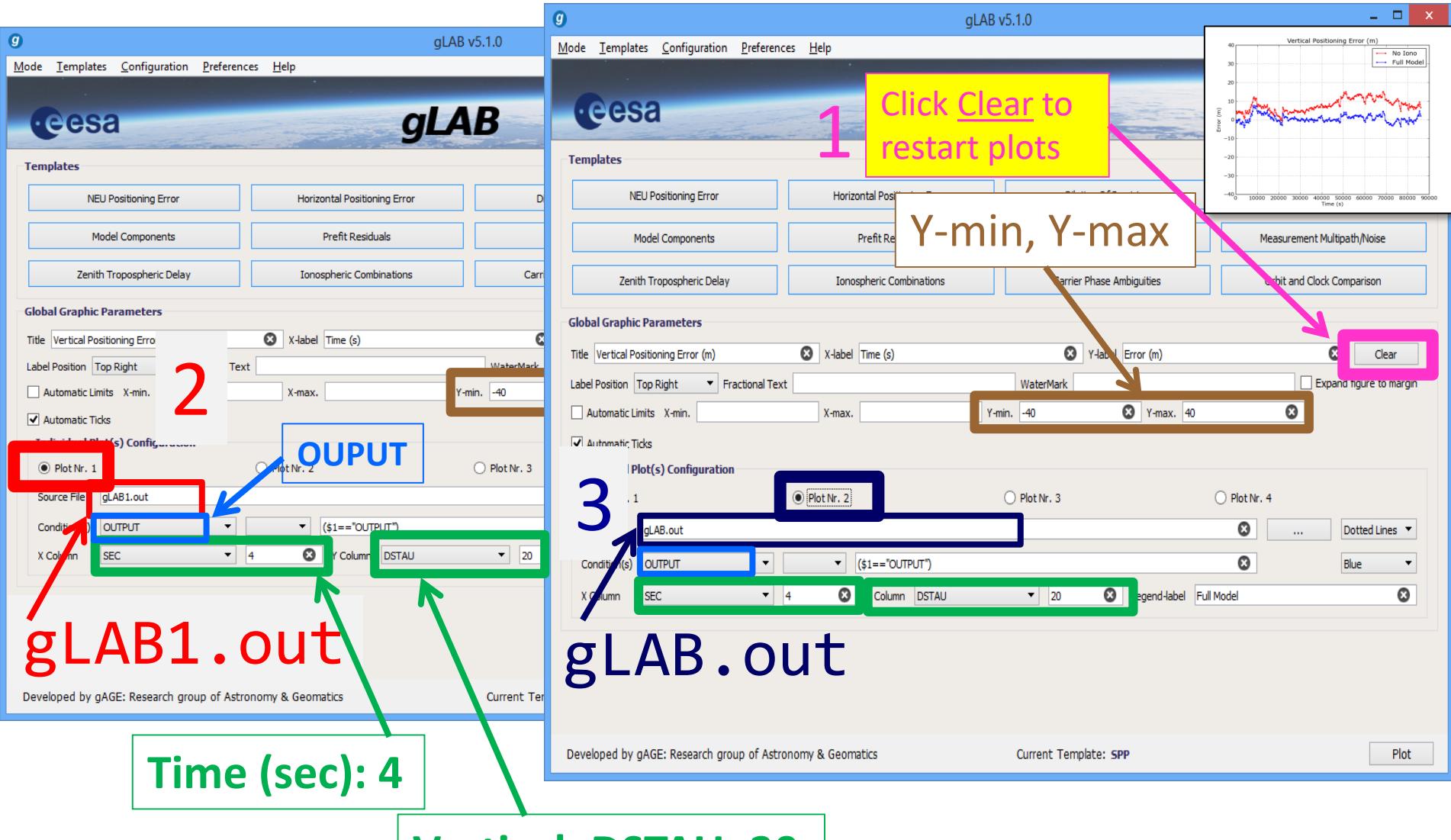


Set output file as **gLAB1.out** 3

NEU Position Error plot from gLAB1.out



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



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

gLAB v5.1.0

gLAB

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Model Components
- Prefit Residuals
- Zenith Tropospheric Delay
- Ionospheric Combinations

c Parameters

Horizontal positioning error [SPP]

X-label: East error (m)

Y-label: North error (m)

Top Right Fractional Text

Automatic Limits: X-min: -20, X-max: 20, Y-min: -20, Y-max: 20

Automatic Ticks

Individual Plot(s) Configuration

Plot Nr. 1 (Selected)

Source File: gLAB1.out

Condition(s): OUTPUT (\$1=="OUTPUT")

X Column: DSTAE, Y Column: DSTAN

Plot Nr. 2

Source File: gLAB.out

Condition(s): OUTPUT (\$1=="OUTPUT")

X Column: DSTAE, Y Column: DSTAN

Plot Nr. 3

Plot Nr. 4

Legend-label: Full Model

Current Template: SPP

Plot

gLAB v5.1.0

Mode Templates Configuration Preferences Help

1 Click Clear to restart plots

X-min, Y-min, Y-max

Title: Horizontal positioning error [SPP]

X-label: East error (m)

Y-label: North error (m)

Label Position: Top Right

Automatic Limits: X-min: -20, X-max: 20, Y-min: -20, Y-max: 20

Automatic Ticks

Individual Plot(s) Configuration

Plot Nr. 1

Source File: gLAB.out

Condition(s): OUTPUT (\$1=="OUTPUT")

X Column: DSTAE, Y Column: DSTAN

Plot Nr. 2 (Selected)

Source File: gLAB.out

Condition(s): OUTPUT (\$1=="OUTPUT")

X Column: DSTAE, Y Column: DSTAN

Plot Nr. 3

Plot Nr. 4

Legend-label: Full Model

Current Template: SPP

Plot

gLAB1.out

gLAB.out

East: DSTAE: 19

North: DSTAN: 18

East: 19

North: 18

Clear

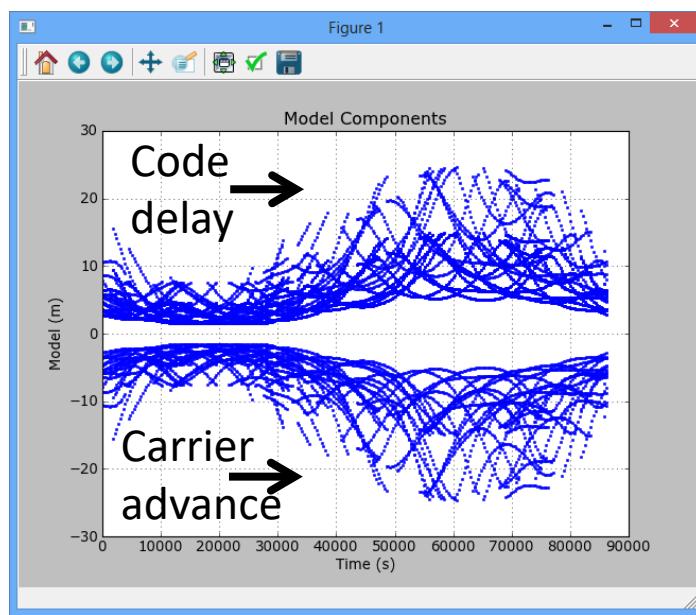
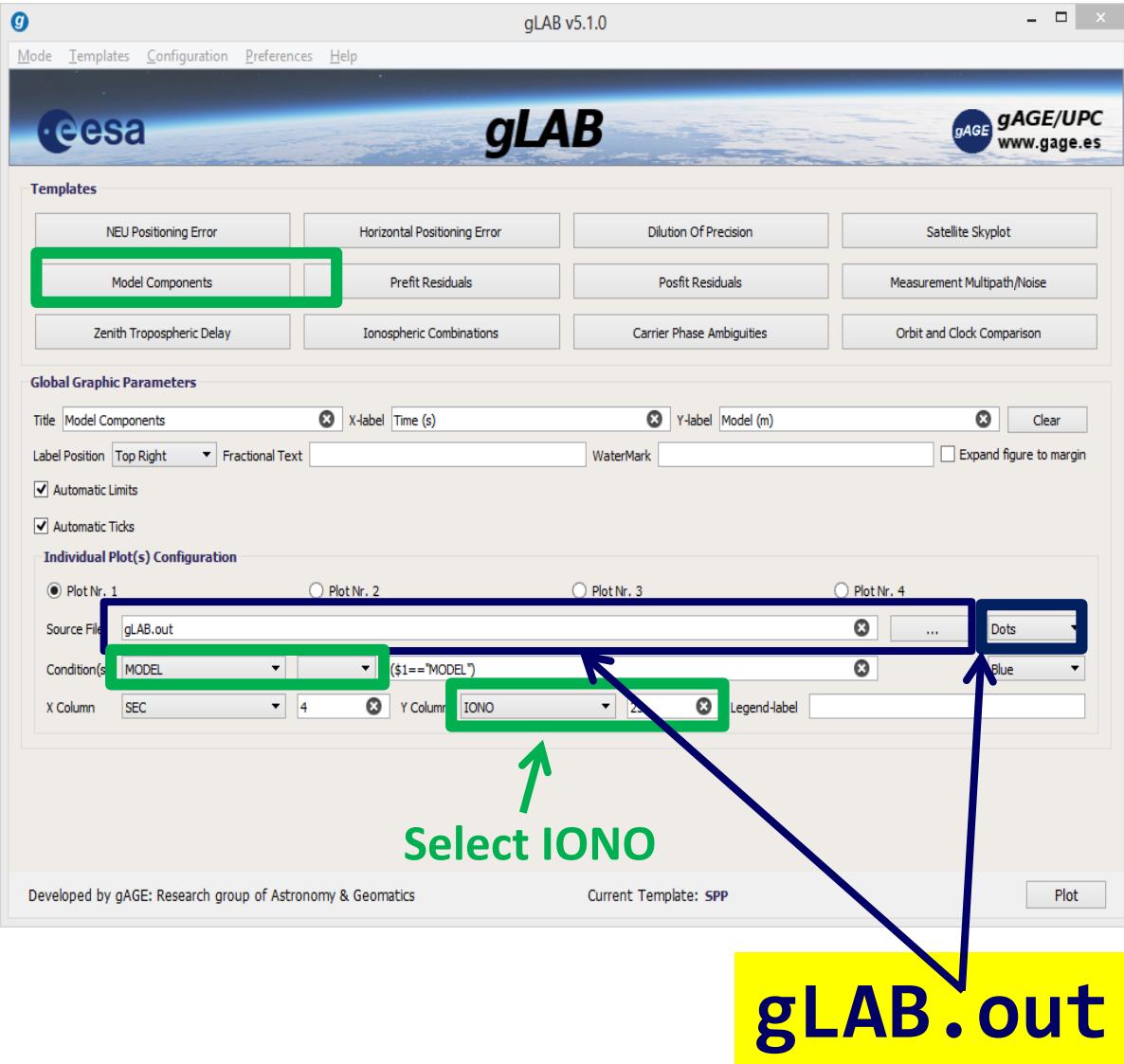
Expand figure to margin

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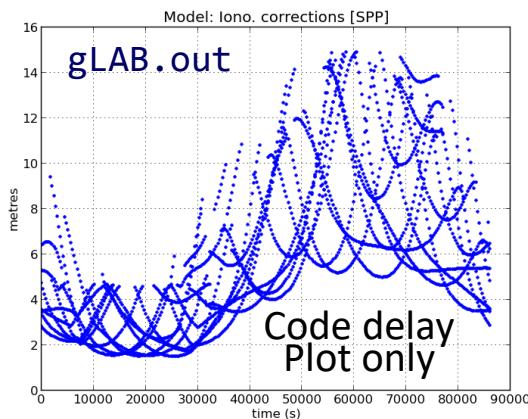
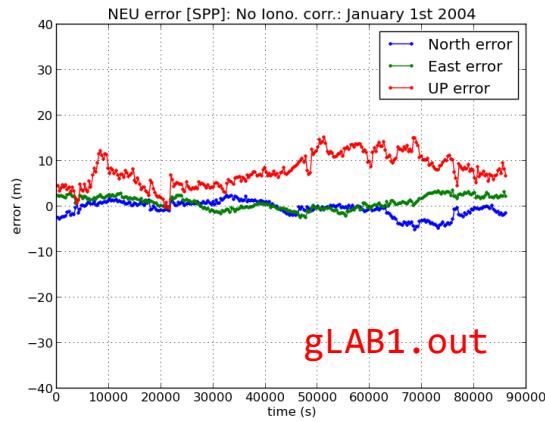
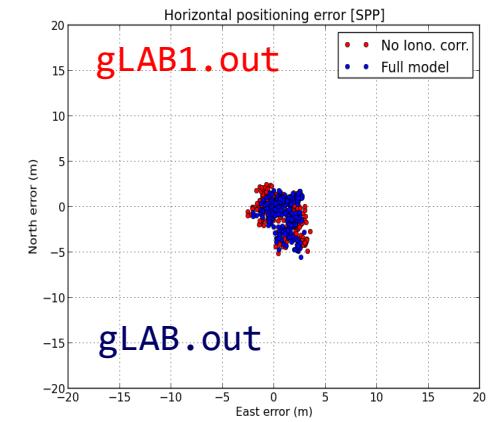
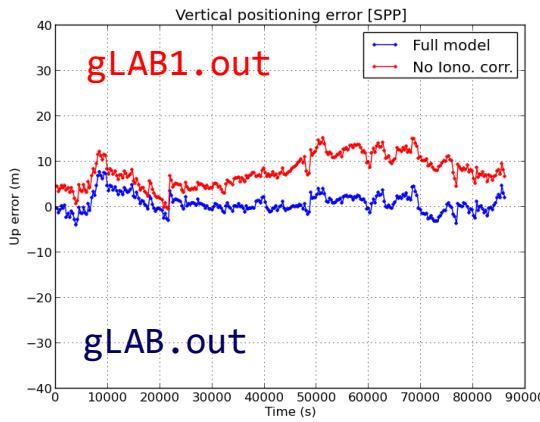
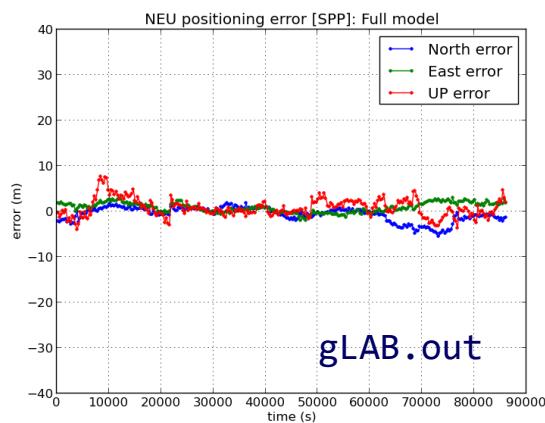
Ionospheric model component plot: gLAB.out



Ionosphere delays code and advances carrier measurements.

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

Summary: Iono. model component analysis



Ionospheric correction (broadcast Klobuchar)

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

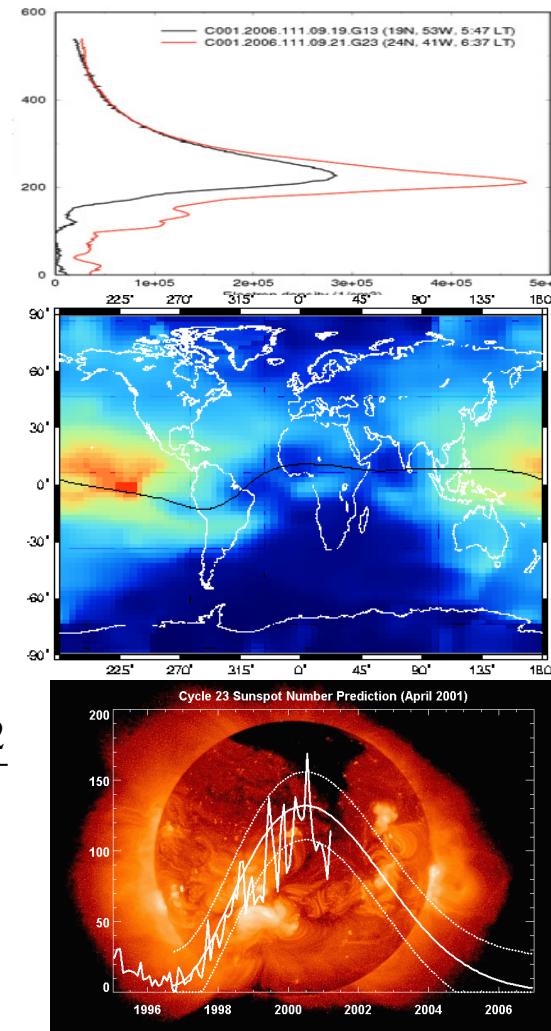
Large positioning errors (mainly in vertical) appear when neglecting iono. corr.

Exercise 1: SPP Model components analysis

Ionospheric delay

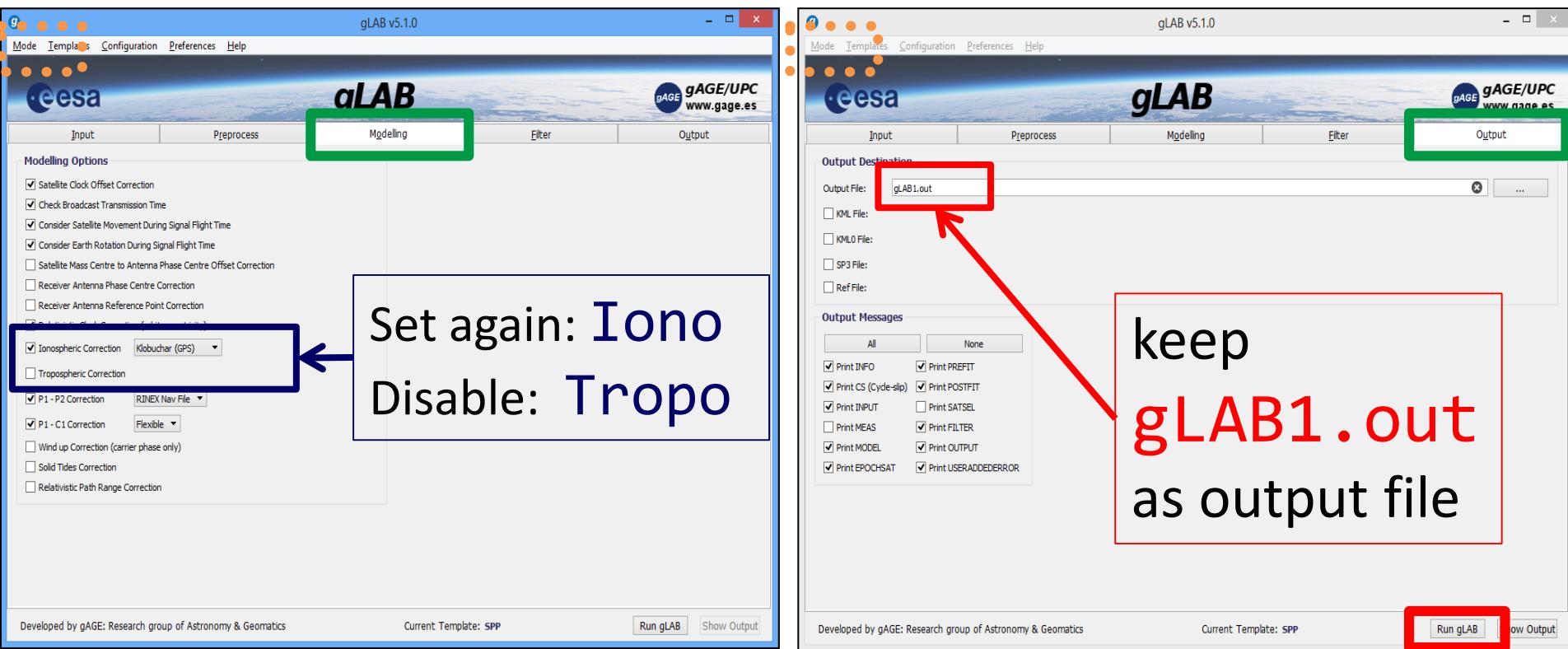
The ionosphere extends from about 60 km over the Earth surface until more than 2000 km, with a sharp electron density maximum at around 350 km. The ionospheric refraction depends, among other things, of the location, local time and solar cycle (11 years).

- First order (~99.9%) ionospheric delay δ_{ion} depends $\delta_{ion} = \frac{40.3}{f^2} I$ 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). $LC = \frac{f_1^2 L_1 - f_2^2 L_2}{f_1^2 - f_2^2}$
- 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.



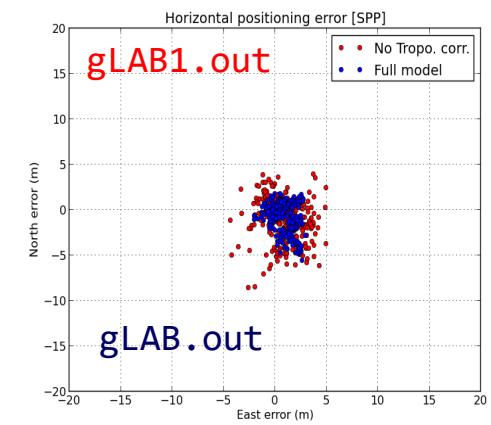
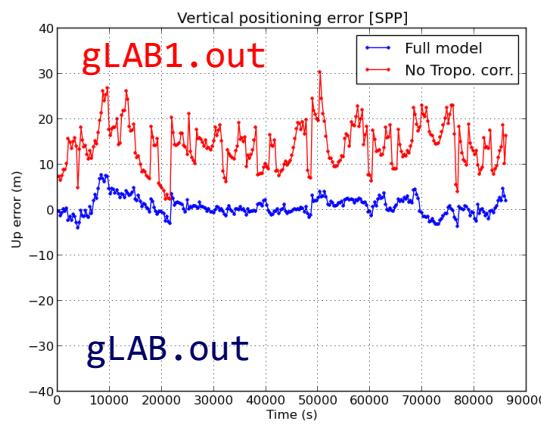
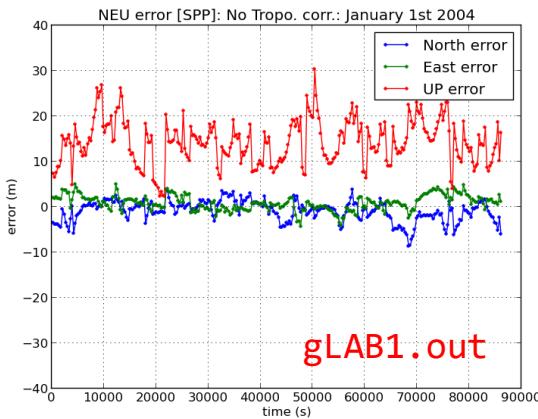
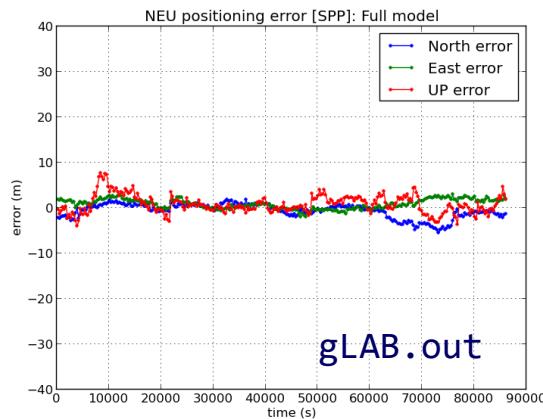
Example of model component analysis: TROPO.

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



Exercise 1: SPP Model components analysis

Tropospheric delay

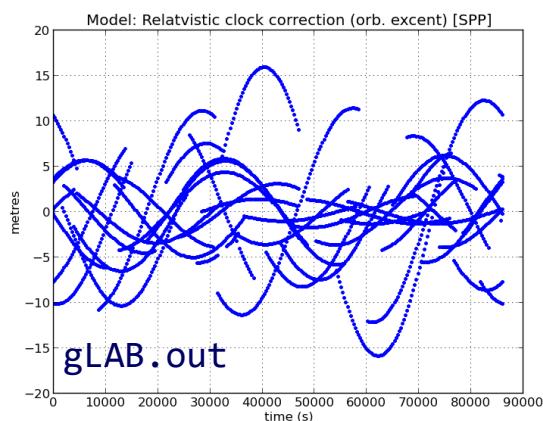
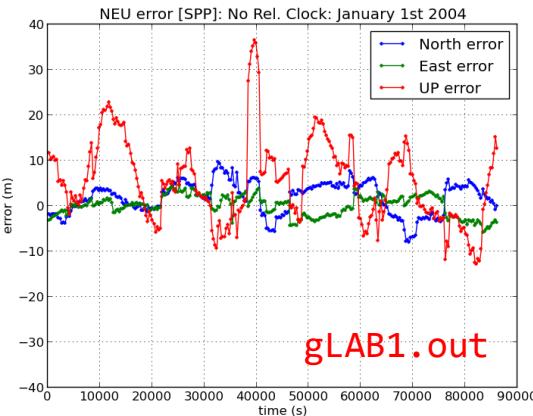
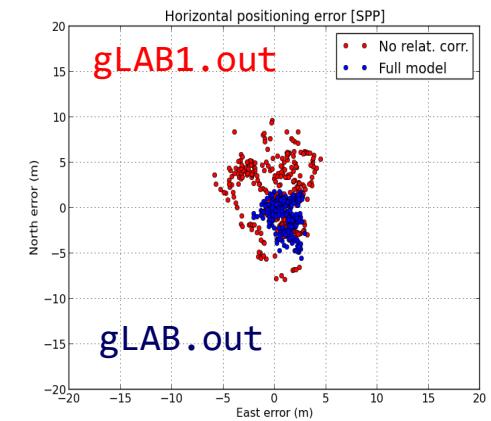
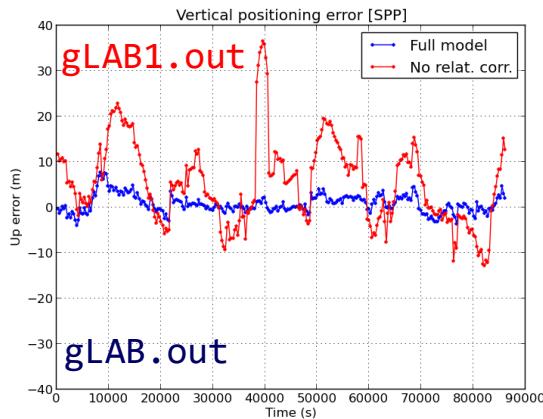
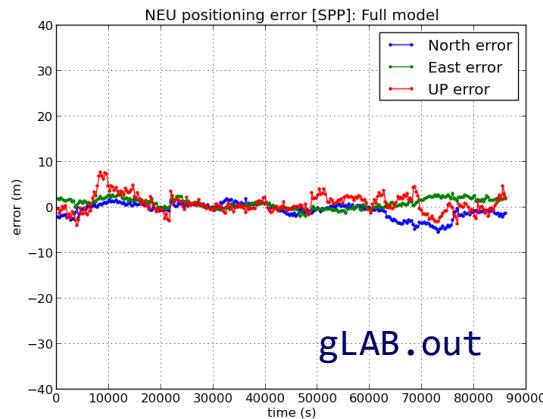
The troposphere is the atmospheric layer placed between Earth's surface and an altitude of about 60 km.

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 ($\sim 40\mu\text{s/day}$).

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:

$$\frac{f'_0 - f_0}{f_0} = \frac{1}{2} \left(\frac{v}{c} \right)^2 + \frac{\Delta U}{c^2} = -4.464 \cdot 10^{-10}$$

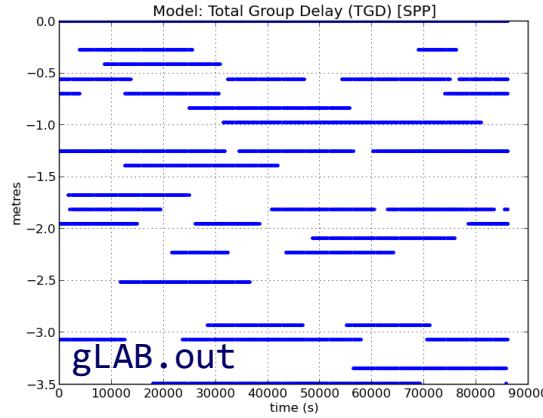
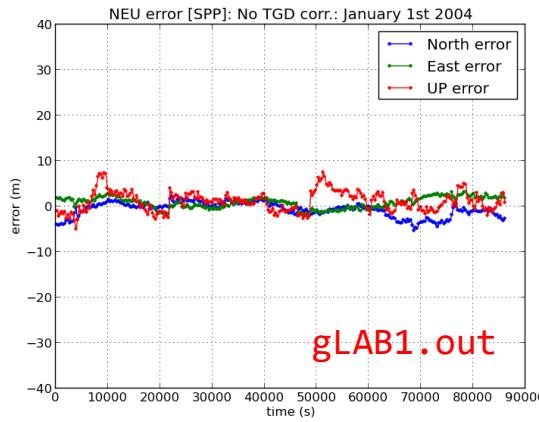
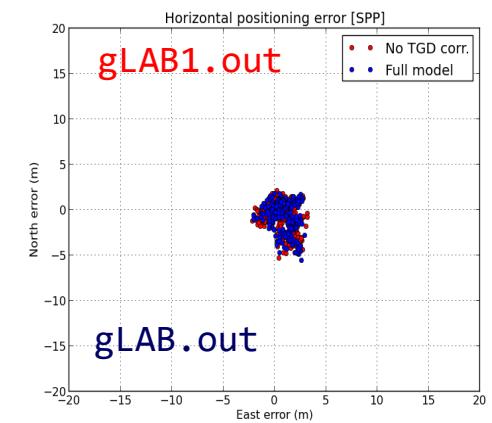
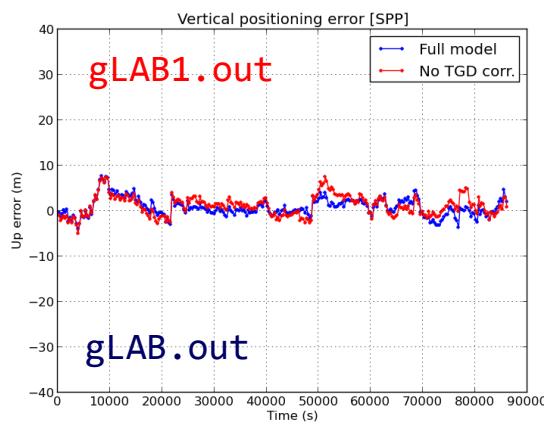
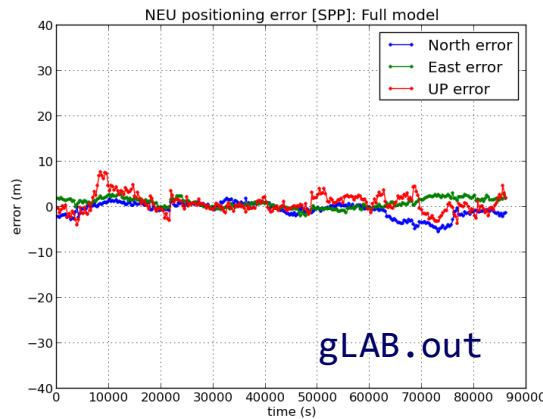
being $f_0 = 10.23 \text{ MHz}$, we have $\Delta f = 4.464 \cdot 10^{-10} f_0 = 4.57 \cdot 10^{-3} \text{ Hz}$. So, satellite should use $f'_0 = 10.22999999543 \text{ MHz}$.

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

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

Being $\mu = G M_E = 3.986005 \cdot 10^{14} \text{ (m}^3/\text{s}^2)$ the gravitational constant, $c = 299792458 \text{ (m/s)}$ 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.

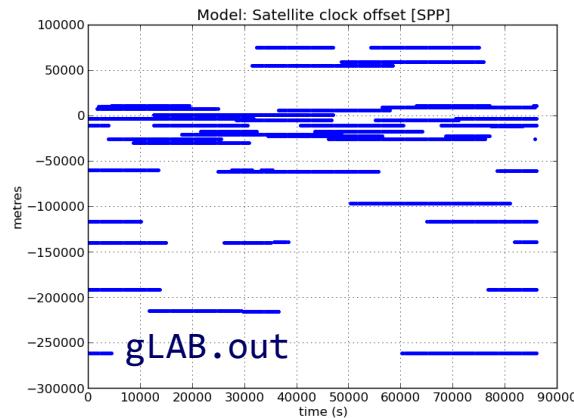
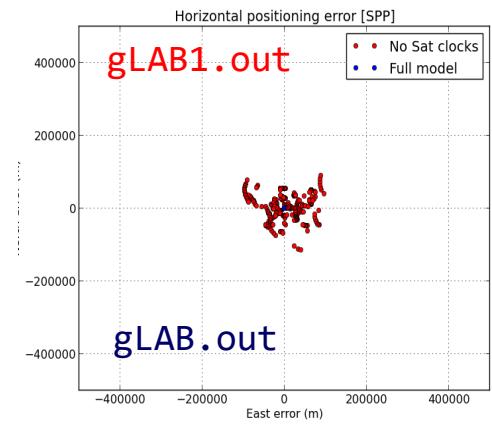
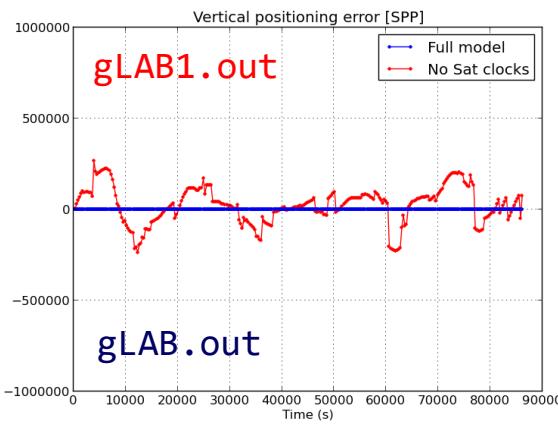
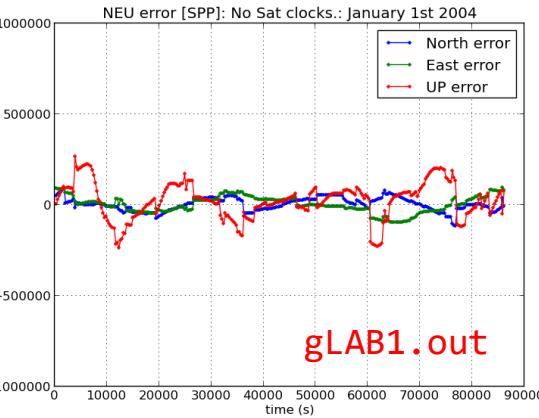
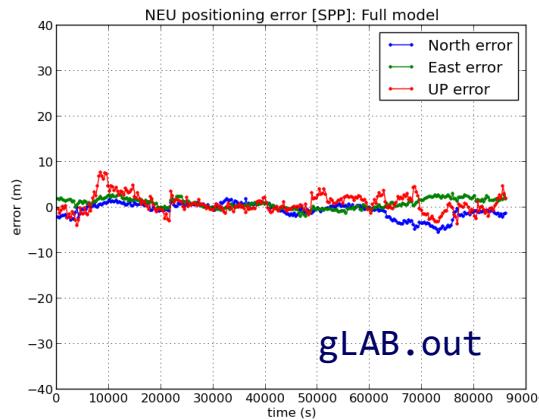
Exercise 1: SPP Model components analysis

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.

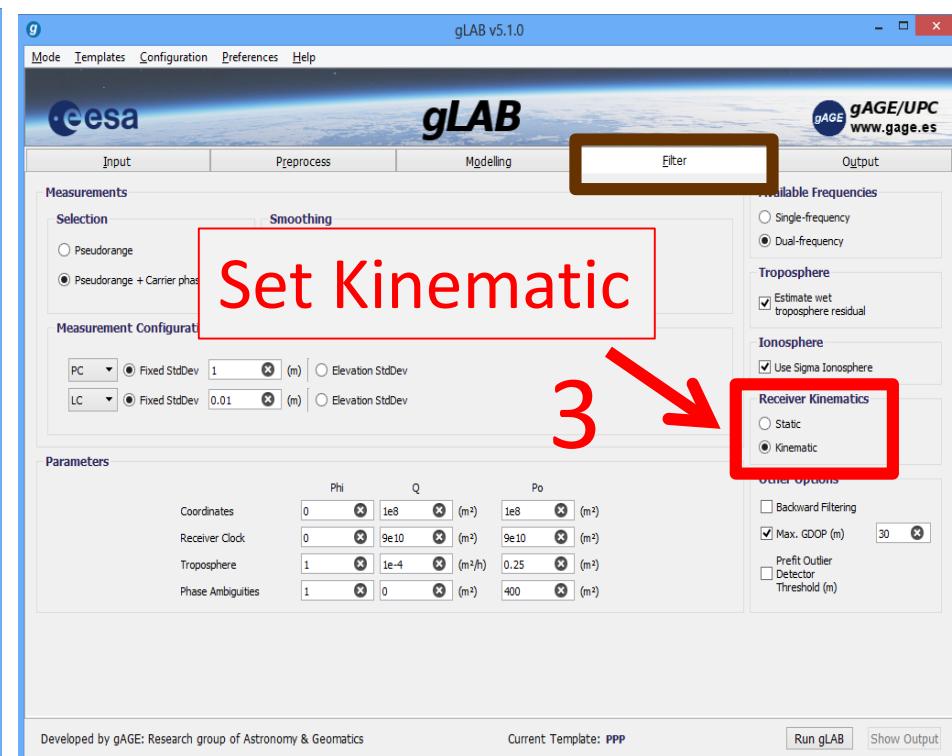
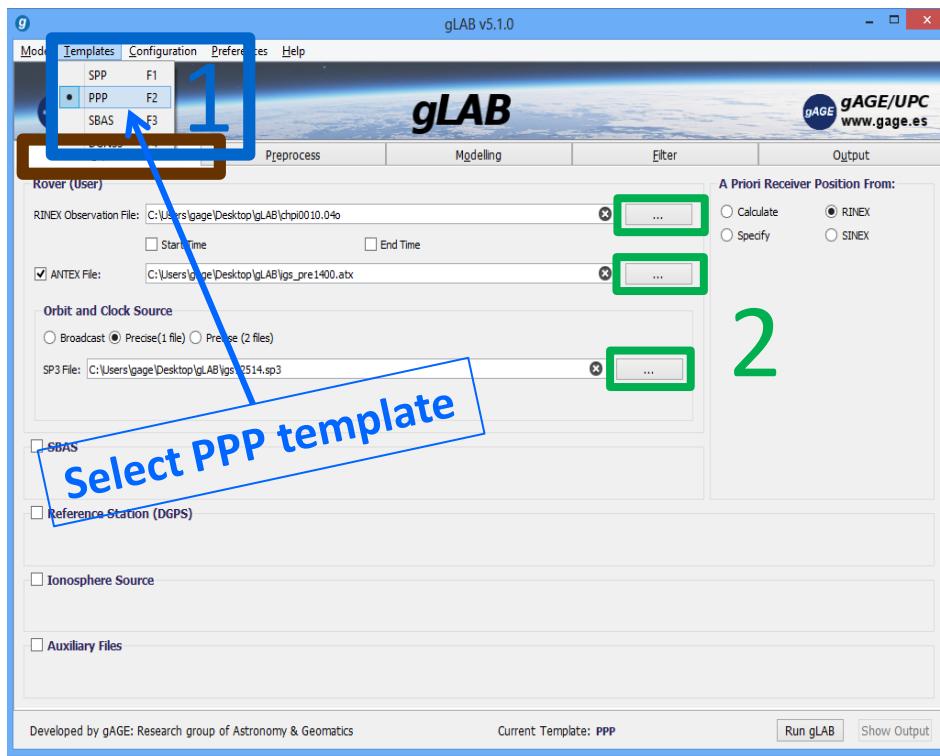
Basic: Introductory laboratory exercises

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

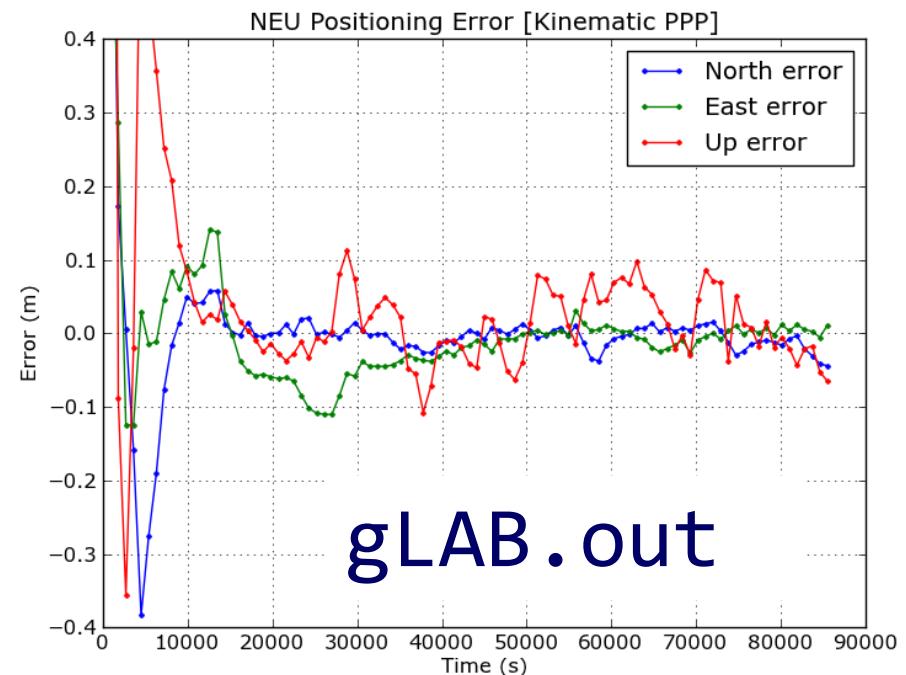
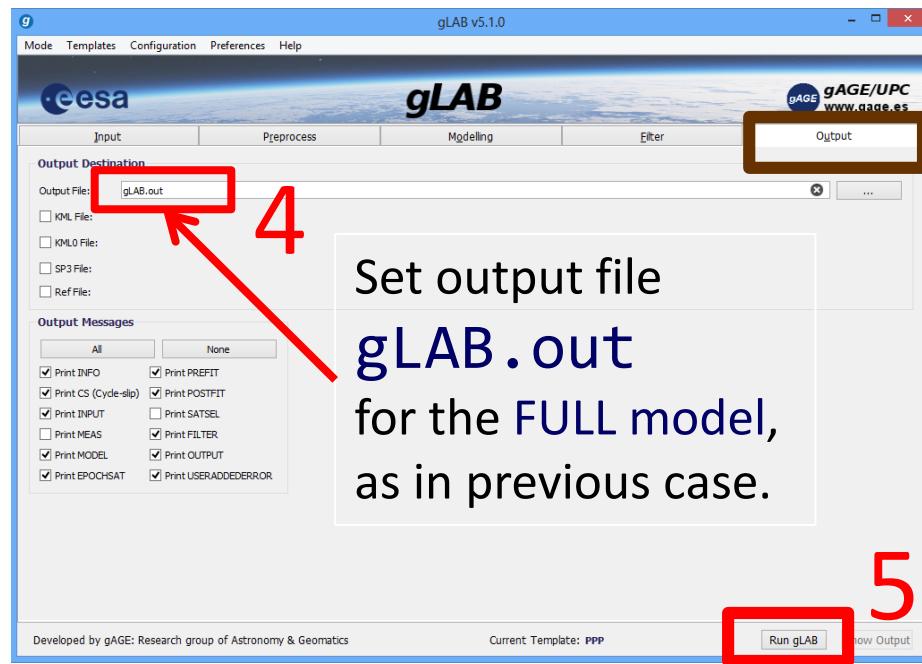
- Compute the kinematic PPP solution using files:
`chpi0010.04o, igs_pre1400.atx, igs12514.sp3`



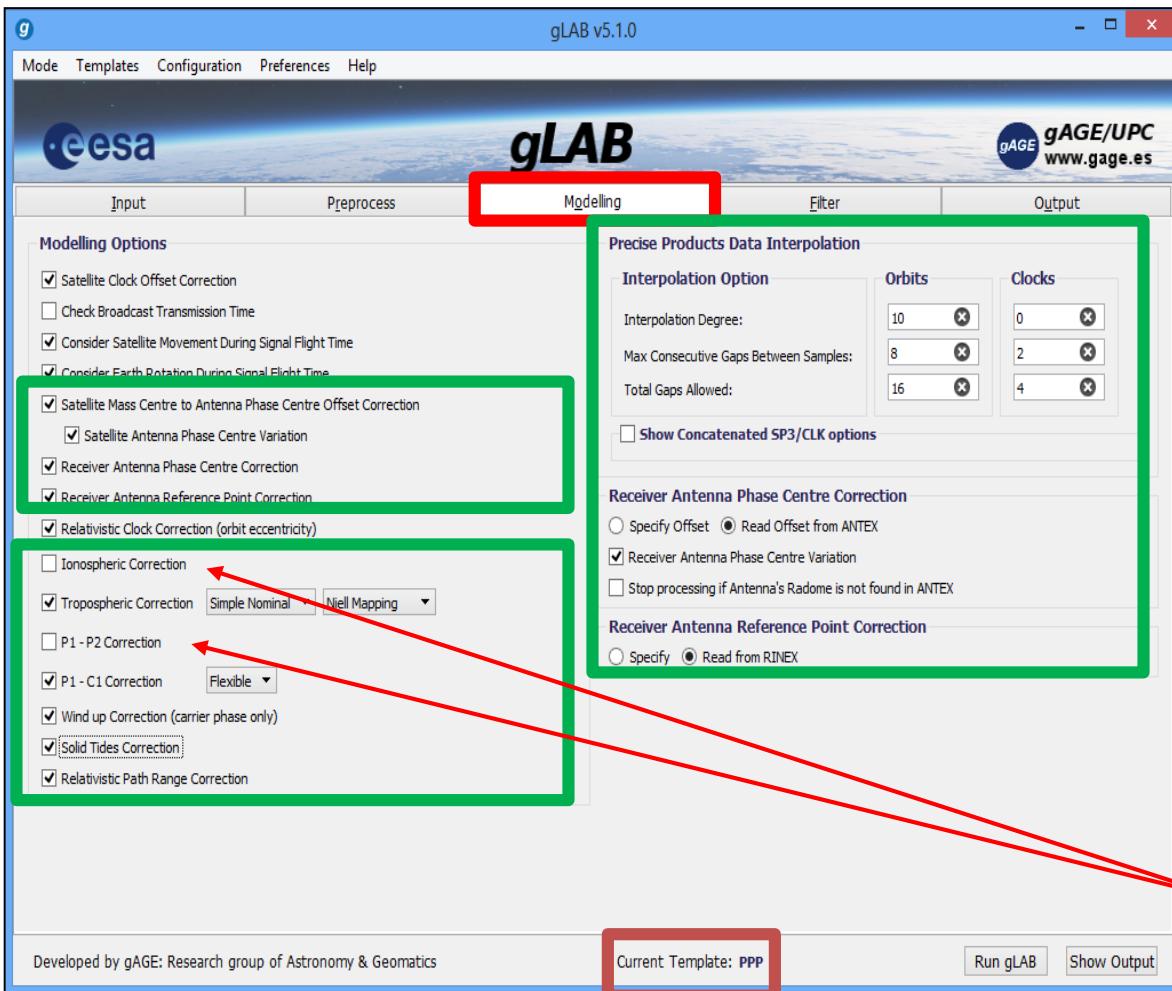
Note: The `igs_pre1400.atx` file contains the APC used by IGS before GPS week 1400.

Exercise 2: PPP Model components analysis

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



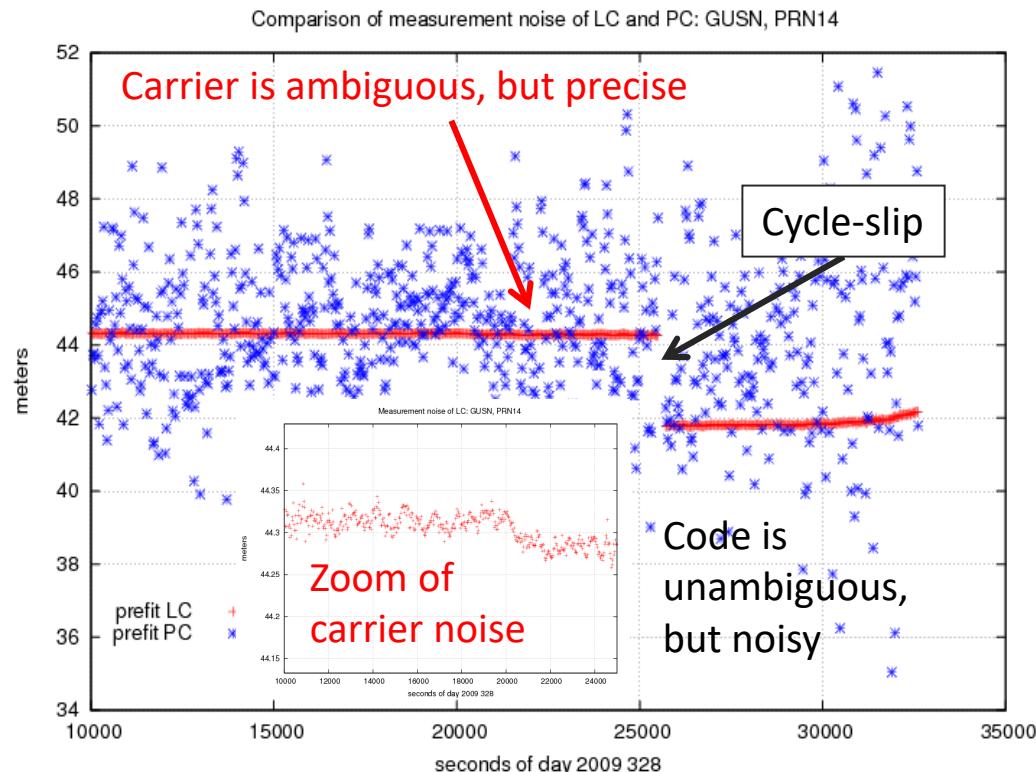
Exercise 2: PPP Model components analysis



- Additional model components are used now in the **FULL** model to assure a centimeter level modeling.
- Precise orbits and clocks instead of broadcast ones.
- Dual frequency Code and Carrier data instead of only single frequency code.
- Iono-free combination of codes and carriers to remove ionospheric error and P1-P2 DCBs.

Exercise 2: PPP Model components analysis

Code and carrier Measurement noise

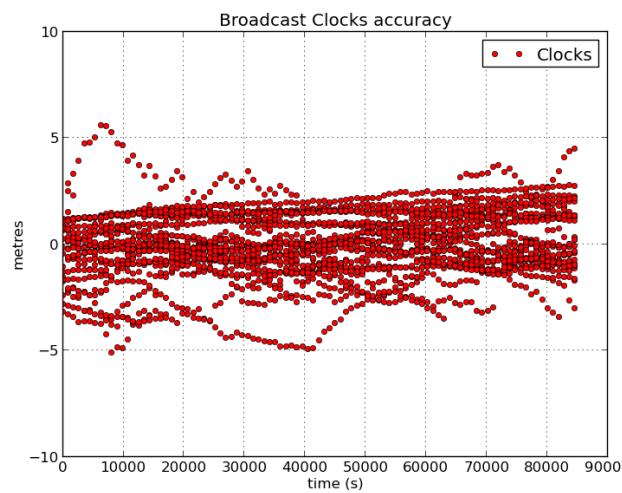
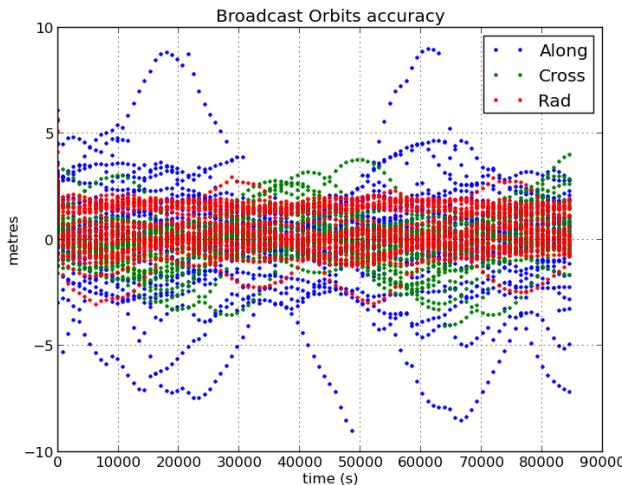


- Code measurements are unambiguous but noisy (meter level measurement noise).
- **Carrier measurements are precise but ambiguous**, meaning that they have some millimetres of noise, but also have unknown biases that could reach thousands of km.
- Carrier phase biases are estimated in the navigation 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.

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

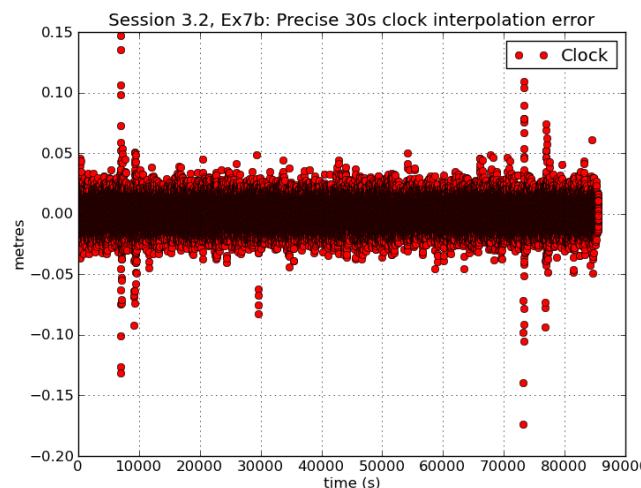
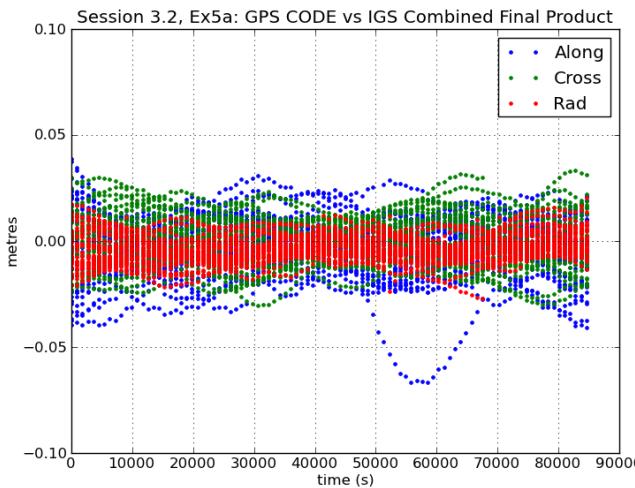
Exercise 2: PPP Model components analysis

Orbits & clocks accuracies



Broadcast:

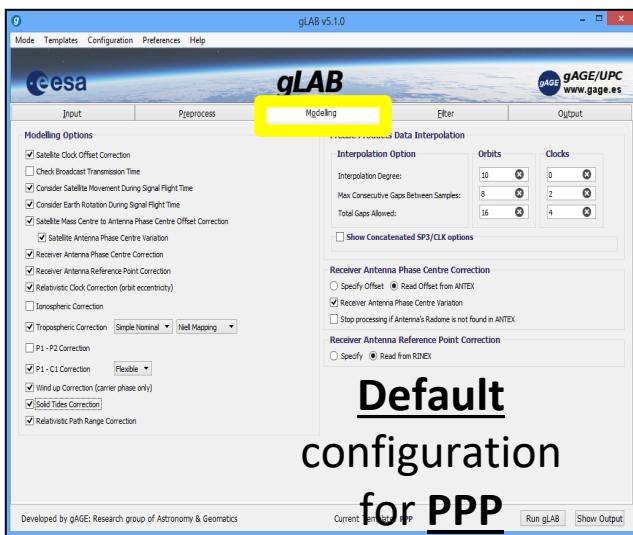
- Few metres of accuracy for broadcast orbits and clocks



Precise:

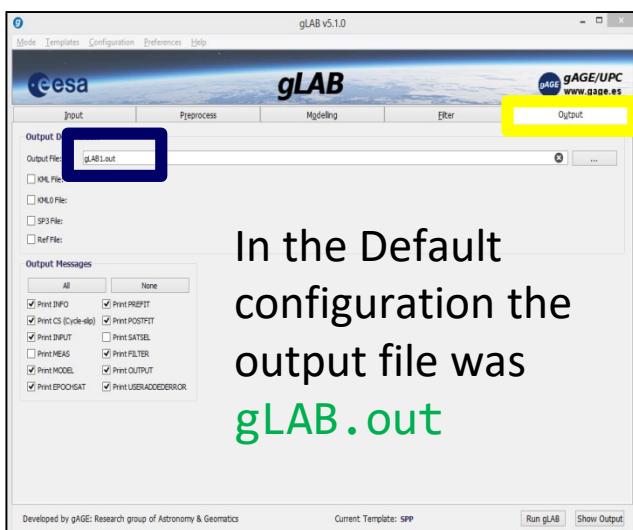
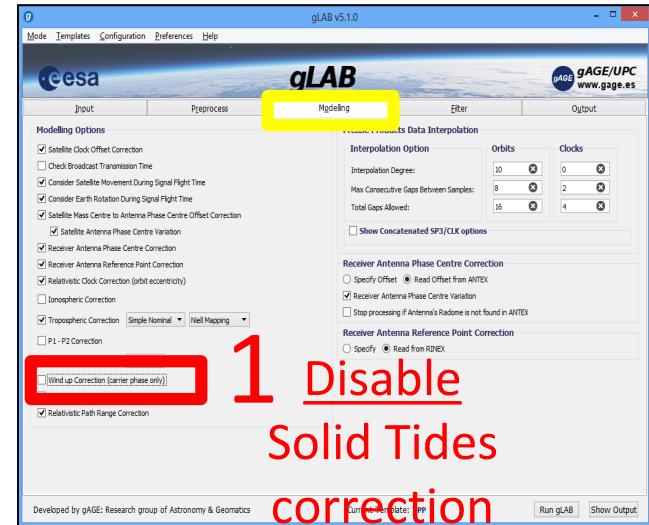
- Few centimetres of accuracy for broadcast orbits and clocks

Example of model component analysis: Solid Tides

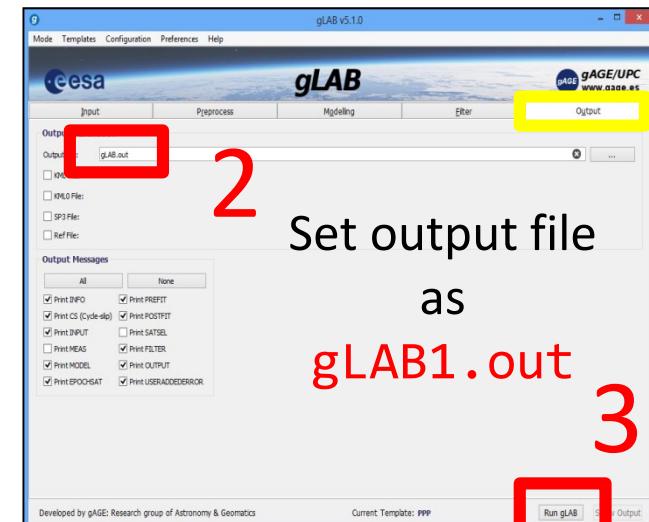


Proceed as in the previous exercise:

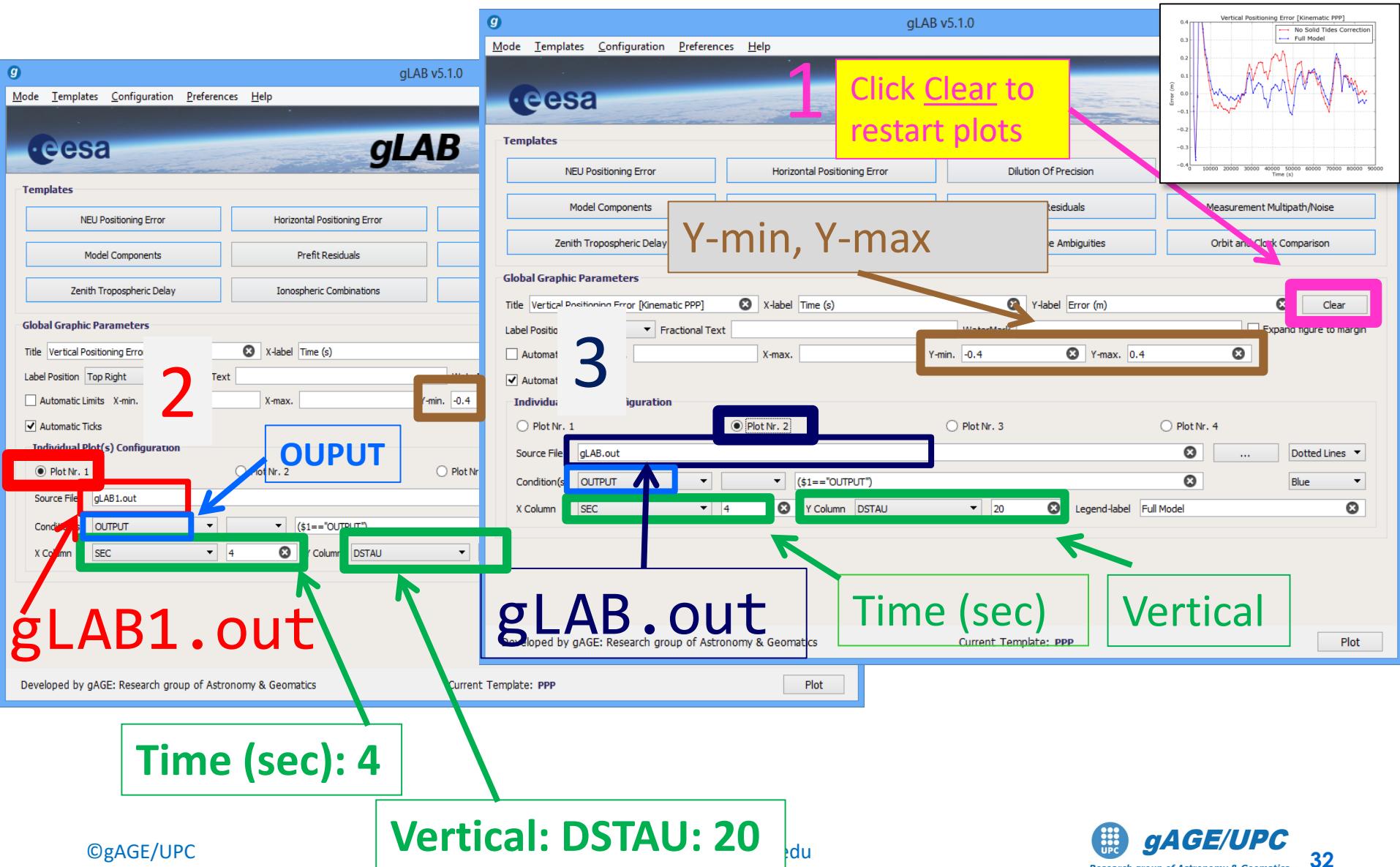
1. In **Modeling** panel, disable the model component to analyze.
2. Save as **gLAB1.out** the associated output file.



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

gLAB v5.1.0 - Left Screenshot (gLAB1.out):

- Plot Nr. 1:** Selected.
- Source File:** gLAB1.out (highlighted with a red box).
- Conditions:** OUTPUT (highlighted with a blue box).
- X Column:** DSTAE (highlighted with a green box), value: 19.
- Y Column:** DSTAN (highlighted with a green box), value: 18.
- Global Graphic Parameters:** X-min: -0.4, X-max: 0.4, Y-min: -0.4, Y-max: 0.4.

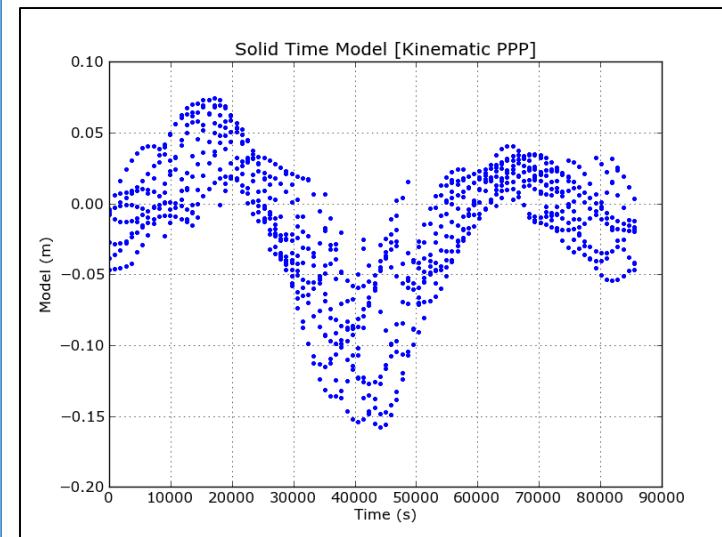
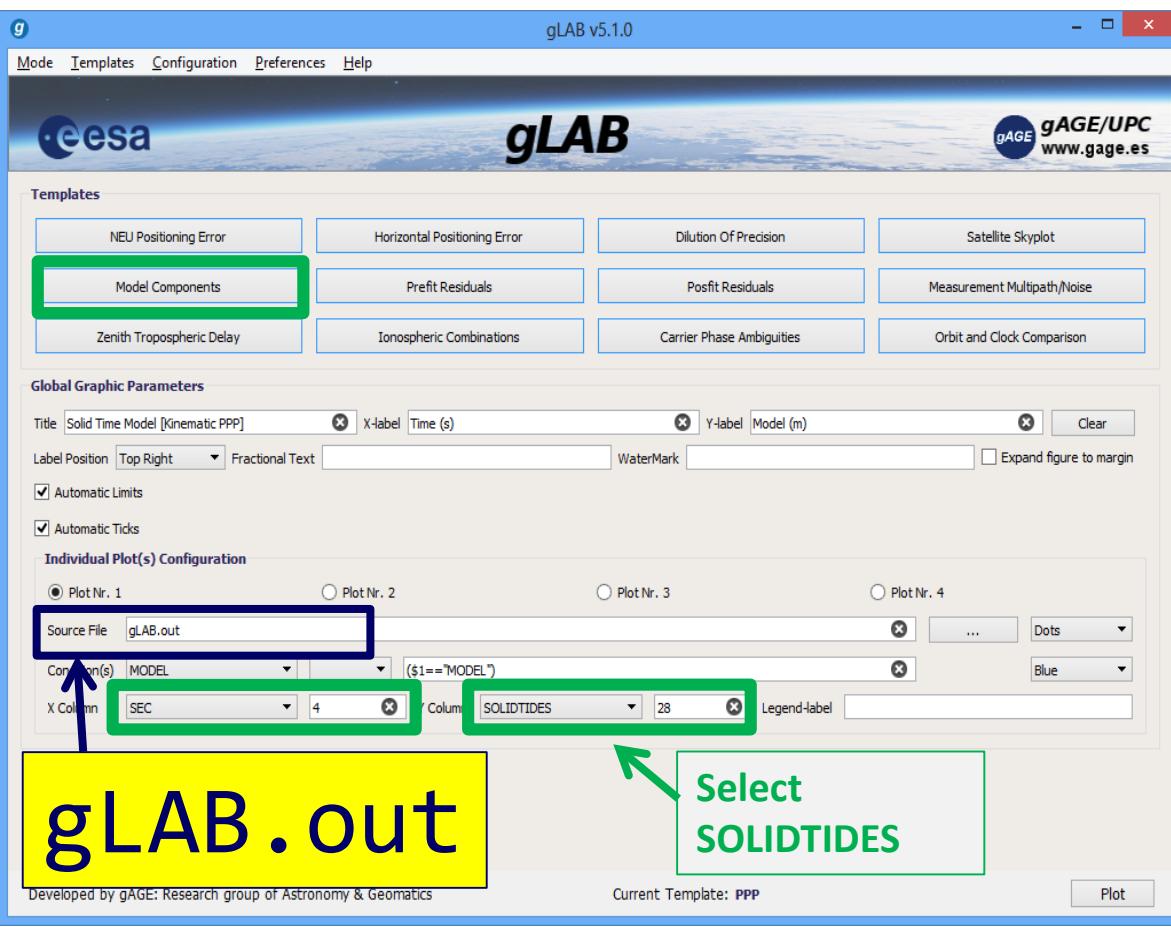
gLAB v5.1.0 - Right Screenshot (gLAB.out):

- Plot Nr. 2:** Selected.
- Source File:** gLAB.out (highlighted with a blue box).
- Conditions:** OUTPUT (highlighted with a blue box).
- X Column:** DSTAE (highlighted with a green box), value: 19.
- Y Column:** DSTAN (highlighted with a green box), value: 18.
- Global Graphic Parameters:** X-min: -0.4, X-max: 0.4, Y-min: -0.4, Y-max: 0.4.
- Legend-label:** Full Model.
- Plot Type:** Circles, Blue.

Annotations:

- Red Number 2:** Points to the 'Plot Nr. 1' radio button in the left screenshot.
- Blue Box:** Surrounds the 'OUTPUT' condition in the 'Conditions' dropdown of both screenshots.
- Green Boxes:** Surround the 'X Column' and 'Y Column' dropdowns in both screenshots.
- Yellow Boxes:**
 - 1:** Points to the 'Clear' button in the top right of the right screenshot.
 - X-min, Y-min, Y-max:** Points to the global graphic parameter boxes in the right screenshot.
 - East: 19:** Points to the 'X Column' value 19 in the right screenshot.
 - North: 18:** Points to the 'Y Column' value 18 in the right screenshot.
- Pink Boxes:** Surround the 'X-min' and 'X-max' boxes in the global graphic parameter section of the right screenshot.

Solid Tides model component plot: gLAB.out



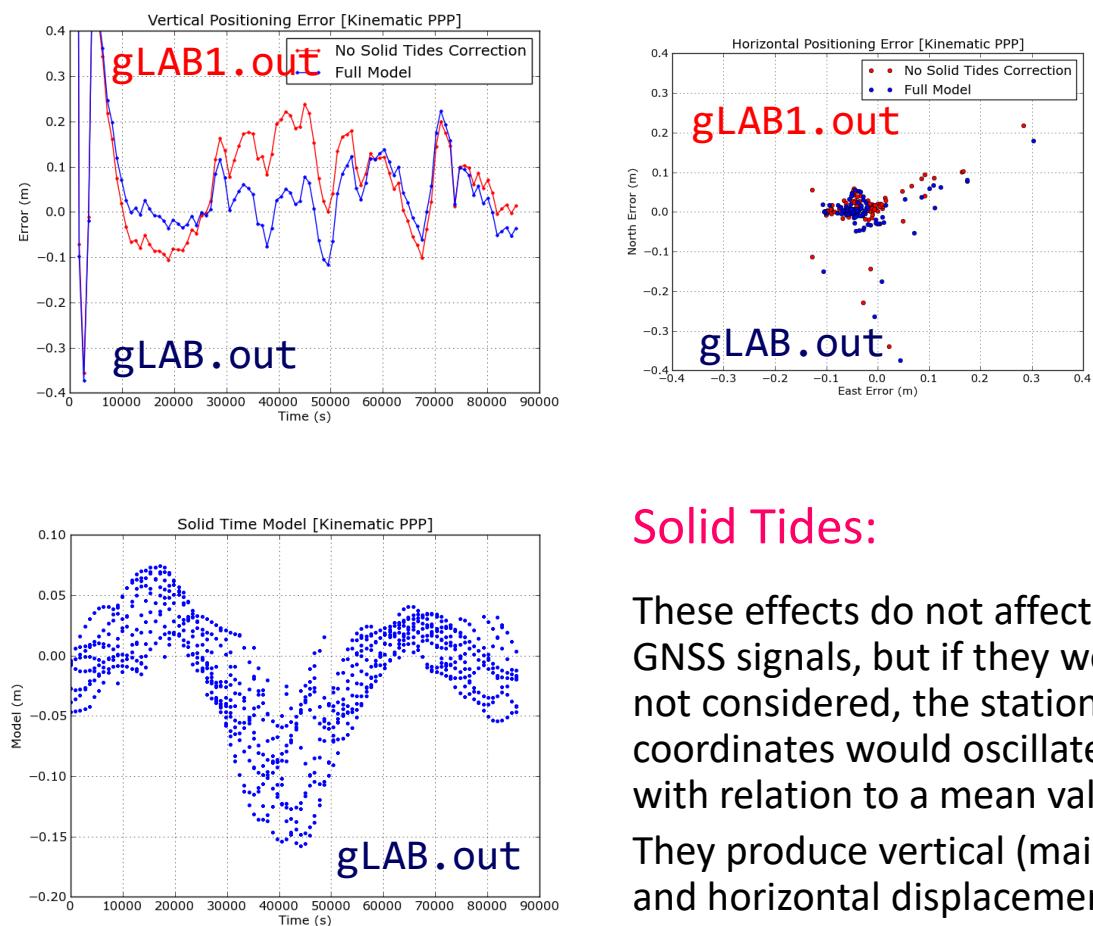
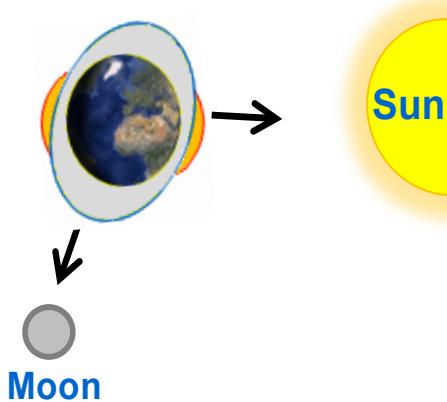
Solid Tides plot

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.

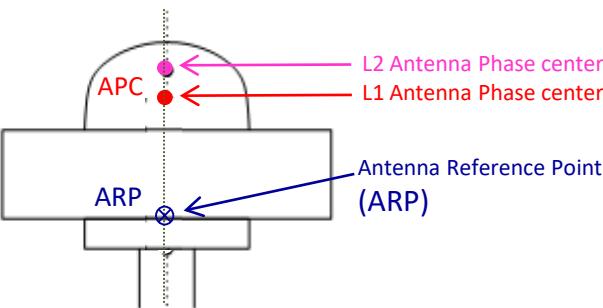


Solid Tides:

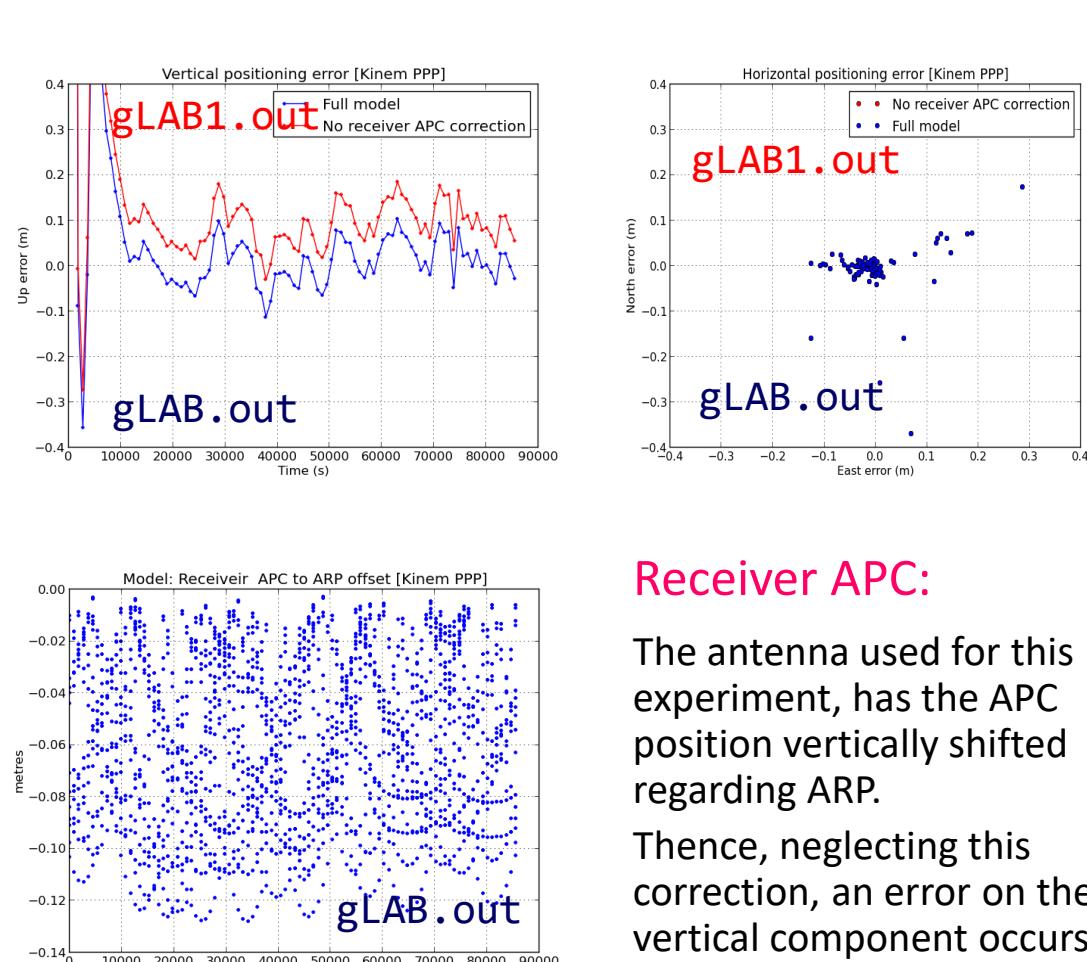
These effects do not affect the GNSS signals, but if they were not considered, the station coordinates would oscillate with relation to a mean value. They produce vertical (mainly) and horizontal displacements.

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.

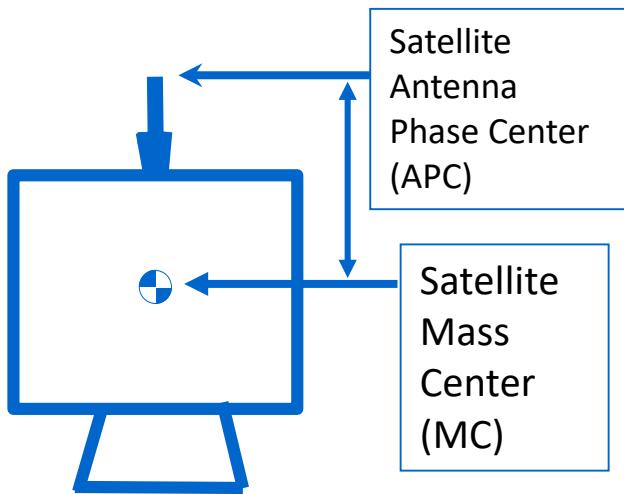


Receiver APC:

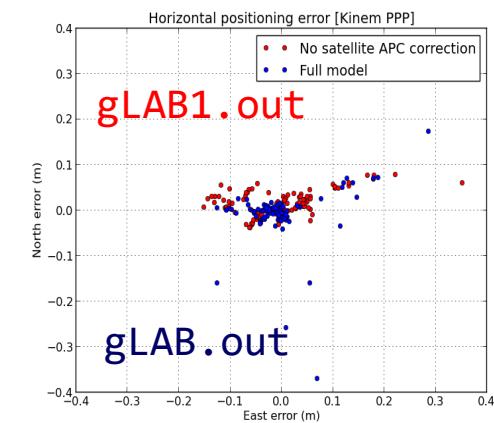
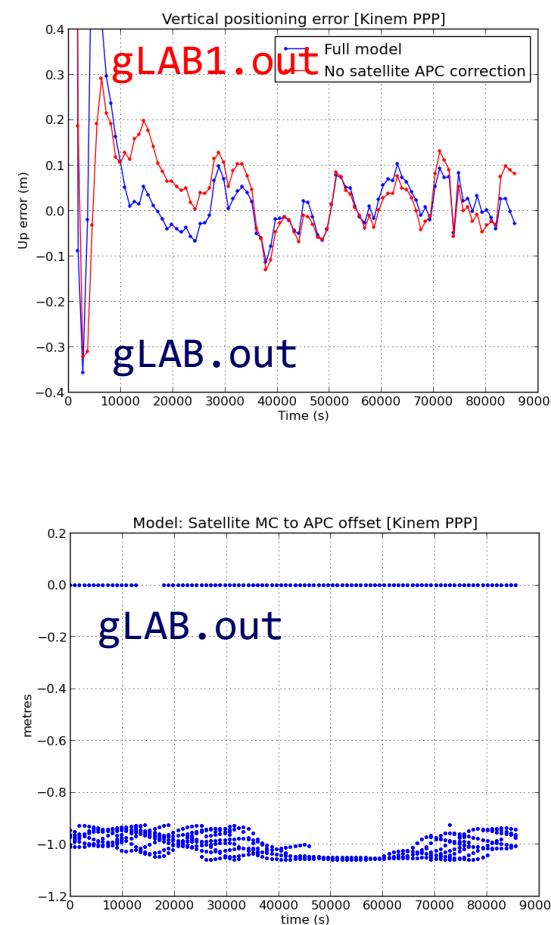
The antenna used for this experiment, has the APC position vertically shifted regarding ARP. Thence, neglecting this correction, an error on the vertical component occurs, but not in the horizontal one.

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.



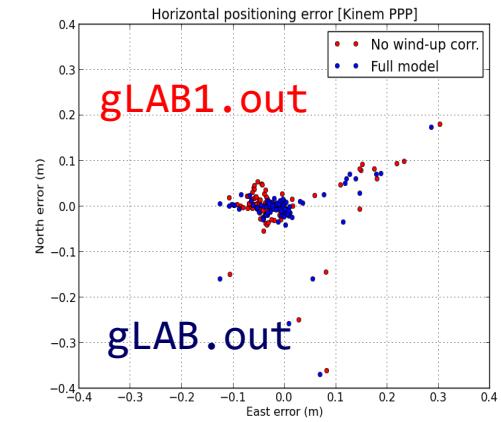
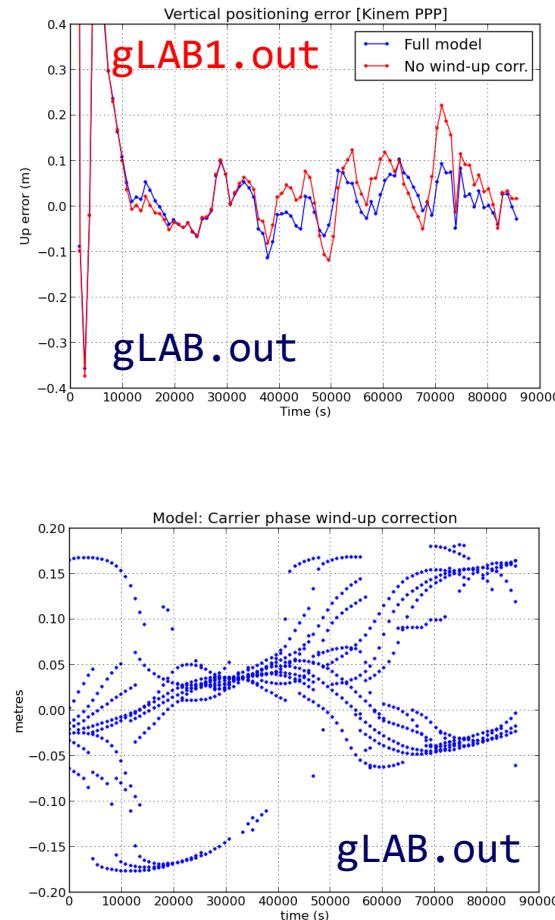
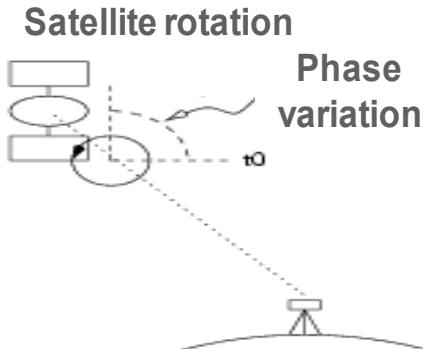
Satellite MC to APC:

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

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

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GNSS Tutorials | gAGE : Research group of the Technical University of Catalonia (UPC)

www.gage.es/tutorials

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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 environment, tools and skills. GNSS standard file formats [Format files description]
 - 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 build-up a bootable 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](#):

The image shows two presentation slides for GNSS Data Processing. The left slide is titled 'GNSS Data Processing Theory Slides' and the right slide is titled 'GNSS Data Processing Laboratory Slides'. Both slides feature the gAGE logo and provide links to the respective resources.

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 using OpenID

Request new password

Who's online

There are currently 0 users and 8 guests online.

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).
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- To Deimos Ibáñez for his contribution to gLAB updating and making the Windows, Mac and LINUX installable versions for this tutorial.