

Tutorial 2

Model components analysis

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Technical University of Catalonia

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5 July 2021

Introduction

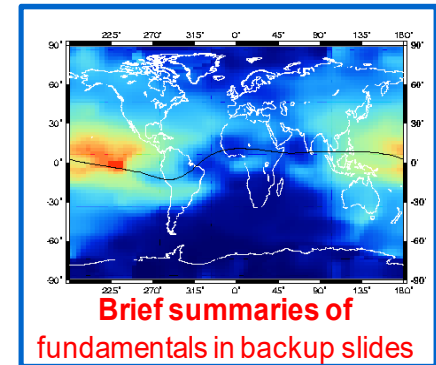
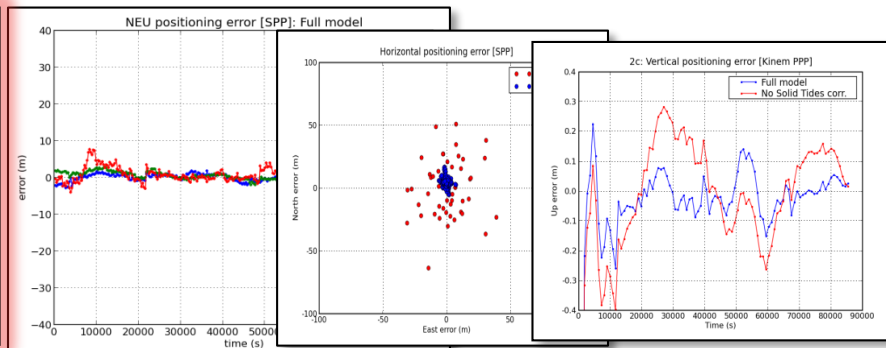
- This practical lecture is devoted to analyze and assess different issues associated with Standard and Precise Point Positioning with GPS data.
- The laboratory exercises will be developed with actual GPS measurements, and processed with the ESA/UPC GNSS-Lab Tool suite (gLAB), which is an interactive 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: $\lambda=-22.7^\circ$, $\phi=-45.0^\circ$). January 1st 2004.

The image displays the gLAB v5.1.0 software interface, divided into two main panels. The left panel shows the 'gLAB' main window with the 'Templates' menu open, highlighting 'SPP' (F1). The 'RINEX Observation File' and 'RINEX Navigation File' fields are highlighted with green boxes, and the 'Run gLAB' button is highlighted with a red box. A file explorer window is open, showing the selection of 'rosp1810.09o' as the RINEX Observation file. The right panel shows the 'NEU Positioning Error' configuration window. The 'NEU Positioning Error' button is highlighted with a brown box. The 'Global Graphic Parameters' section shows the 'Y-min' and 'Y-max' values set to -40 and 40, respectively, highlighted with a blue box. The 'Source File' is set to 'gLAB.out', highlighted with a pink box. The 'Plot' button is highlighted with a red box. A plot window titled 'Figure 1' shows the 'NEU Positioning Error' plot, with the Y-axis labeled 'Error (m)' ranging from -40 to 40 and the X-axis labeled 'Time (s)' ranging from 0 to 90000. The plot shows three data series: North error (blue), East error (green), and Up error (red). The plot is highlighted with a red box.

1. Templates menu (SPP selected)

2. RINEX Observation File and RINEX Navigation File fields

3. Run gLAB button

4. NEU Positioning Error button

5. Global Graphic Parameters (Y-min: -40, Y-max: 40)

6. Plot button

gLAB.out

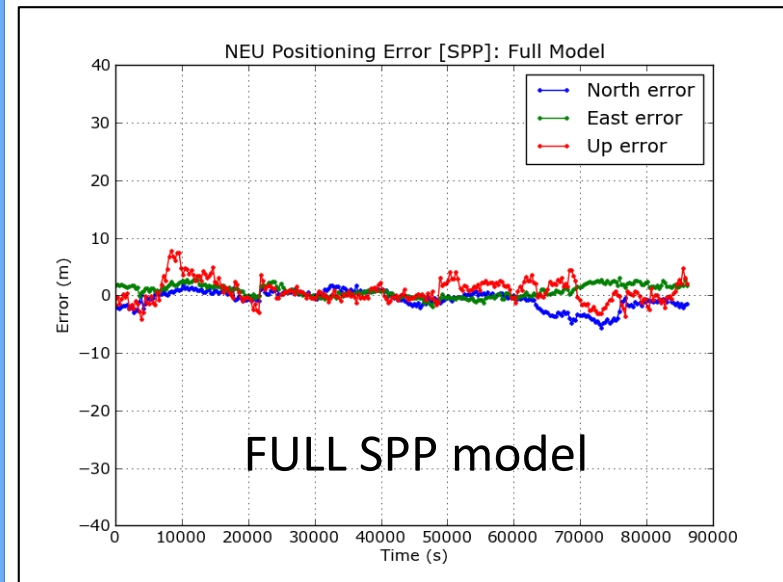
NEU Position Error plot from gLAB.out

The screenshot shows the gLAB v5.1.0 software interface. A large text box labeled "NEU plot template configuration" is overlaid on the top part of the window. Below it, the "Global Graph Parameters" section is visible. The "Title" is set to "NEU Positioning Error". The "X-label" is "Time (s)" and the "Y-label" is "Error (m)". The "Y-min" is -40 and the "Y-max" is 40. In the "Plot Configuration" section, three radio buttons are visible: "Plot Nr. 1" (selected), "Plot Nr. 2", and "Plot Nr. 3". Below these, the "Condition(s)" is "OUTPUT", the "X Column" is "SEC", and the "Y Column" is "DSTAN". The "Legend-label" is "North error".

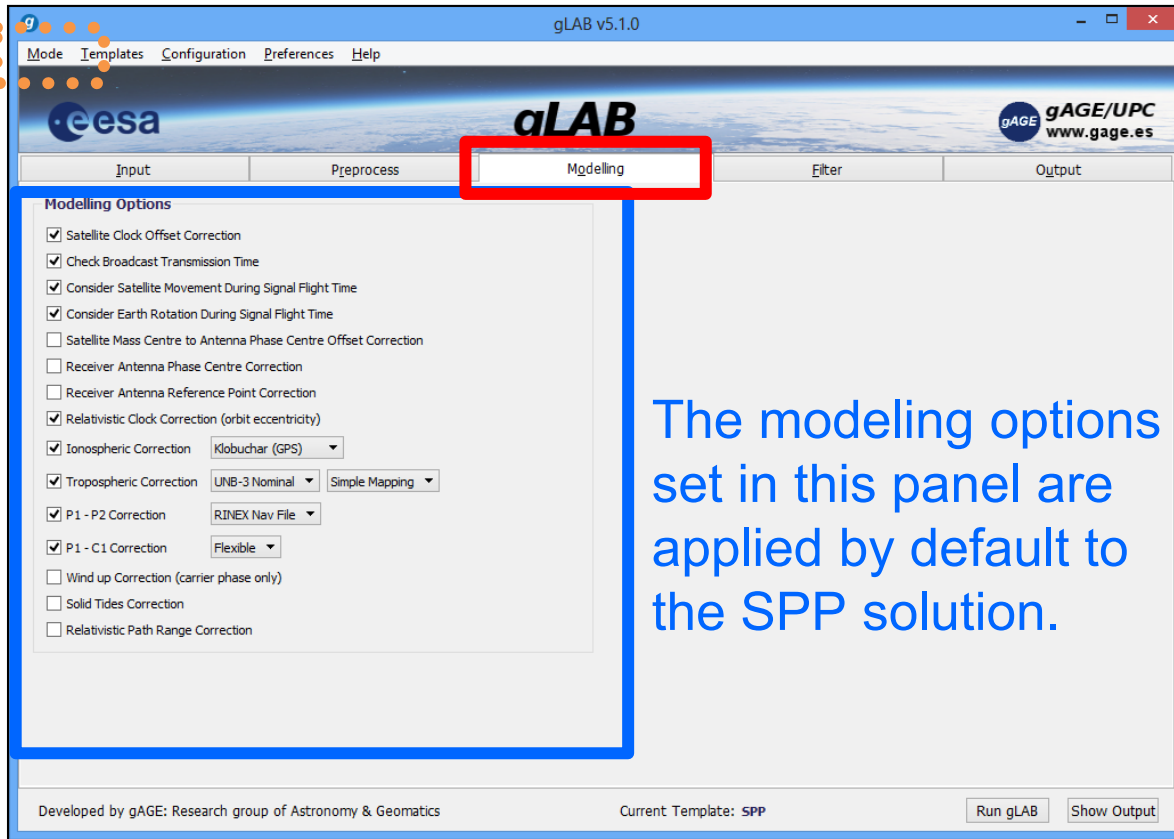
North

East

Up



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)

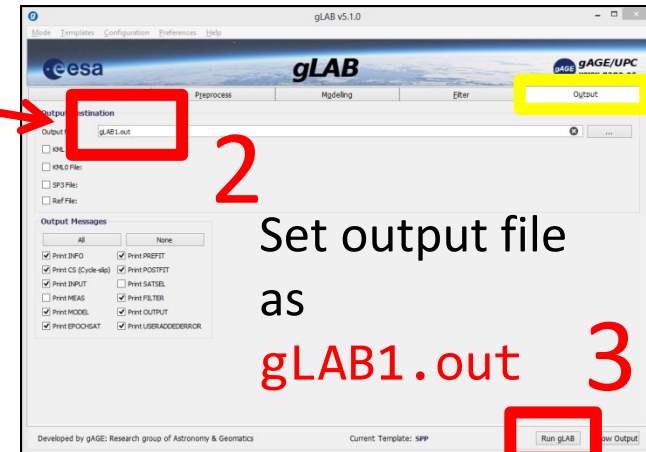
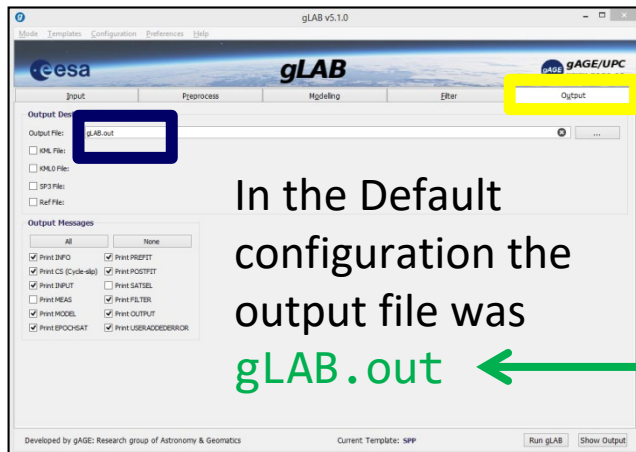
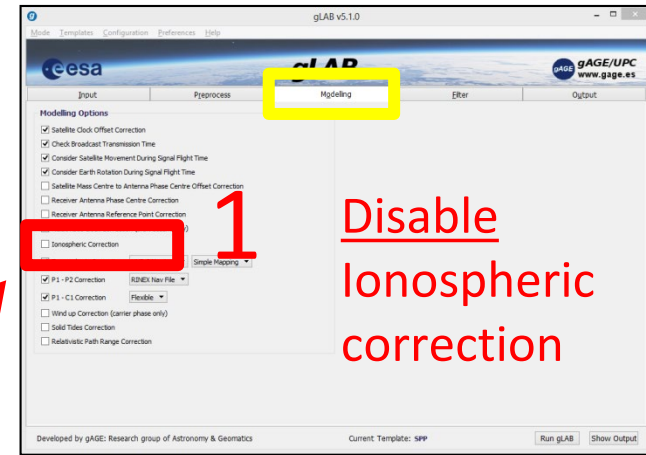
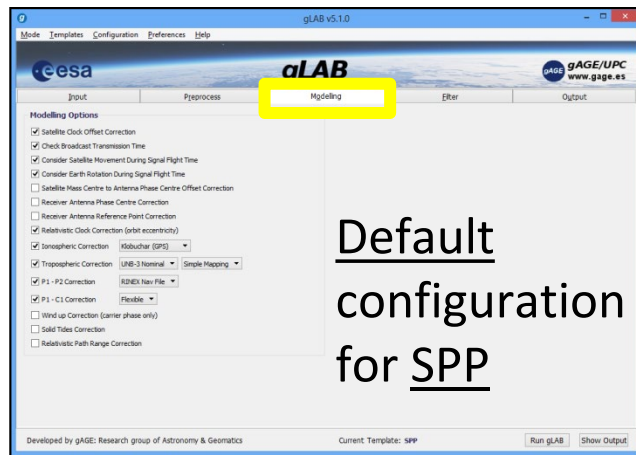
2. Save as gLAB1.out the associated output file.

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

Default
configuration
for SPP

Disable
Ionospheric
correction

Set output file
as
gLAB1.out



NEU Position Error plot from gLAB1.out

gLAB v5.1.0

Mode Templates Configuration Preferences Help

NEU plot template configuration

NEU Positioning Error

Horizontal Positioning Error

Dilution Of Precision

Satellite Skyplot

Model Corrections

Prefit Residuals

Posfit Residuals

Measurement Multipath/Noise

Zenith Tropospheric Delay

Ionospheric Combinations

Carrier Phase Ambiguities

Orbit and Clock Comparison

Global Graphic Parameters

Title: NEU[Error [SPP]: No Iono 01/01/2004

X-label: Time (s)

Y-label: Error (m)

Label Position: Top Right

Automatic Limits: X-min. X-max. Y-min. -40 Y-max. 40

Configuration

Plot Nr. 1

Plot Nr. 2

Plot Nr. 3

Plot Nr. 4

Source File: gLAB1.out

Condition(s): (S1=="OUTPUT")

X Column: SE Y Column: DSTAN

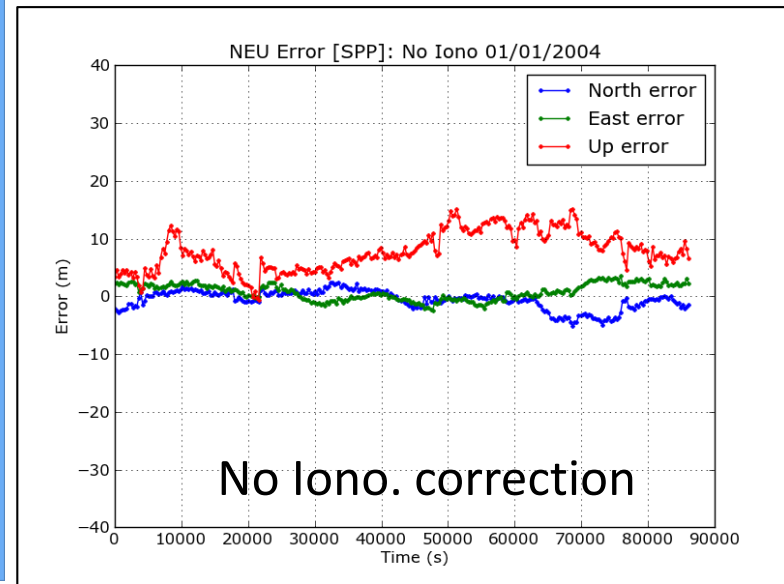
Legend-label: North error

gLAB1.out

Developed by gAGE: Research group of Astronomy & Geomatics

Current Template: SPP

Plot



North

East

Up

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

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Model Components
- Profit Residuals
- Zenith Tropospheric Delay
- Ionospheric Combinations
- Carrier Phase Ambiguities
- Measurement Multipath/Noise
- Orbit and Clock Comparison

Global Graphic Parameters

Title: Vertical Positioning Error X-label: Time (s)

Label Position: Top Right

Y-min: -40 Y-max: 40

Plot(s) Configuration

- Plot Nr. 1
- Source File: gLAB1.out
- Condition(s): OUTPUT (\$1=="OUTPUT")
- X Column: SEC 4
- Y Column: DSTAU 20

gLAB1.out

Time (sec): 4

Vertical: DSTAU: 20

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Model Components
- Profit Residuals
- Zenith Tropospheric Delay
- Ionospheric Combinations
- Carrier Phase Ambiguities
- Measurement Multipath/Noise
- Orbit and Clock Comparison

Global Graphic Parameters

Title: Vertical Positioning Error (m) X-label: Time (s) Y-label: Error (m)

Label Position: Top Right

Y-min: -40 Y-max: 40

Plot(s) Configuration

- Plot Nr. 2
- Source File: gLAB.out
- Condition(s): OUTPUT (\$1=="OUTPUT")
- X Column: SEC 4
- Y Column: DSTAU 20
- Legend-label: Full Model

gLAB.out

Vertical Positioning Error (m)

Time (s)

Error (m)

Legend: No Ionosphere, Full Model

1 Click Clear to restart plots

Y-min, Y-max

3

Clear

Developed by gAGE: Research group of Astronomy & Geomatics

Current Template: SPP

Plot

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

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB

Templates

NEU Positioning Error Horizontal Positioning Error Dilution Of Precision

Model Components Prefit Residuals

Zenith Tropospheric Delay Ionospheric Combinations

2 c Parameters

Horizontal positioning error [SPP] X-label East error (m) Y-label North error (m)

Top Right Fractional Text WaterMark Expand figure to margin

X-min: -20 X-max: 20 Y-min: -20 Y-max: 20

Automatic Limits Automatic Ticks

Configuration

Plot Nr. 1 Plot Nr. 2 Plot Nr. 3 Plot Nr. 4

Source File gLAB1.out gLAB.out

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

X Column DSTAE 19 Y Column DSTAN 18

Legend-label Full Model

Legend-type Circles Legend-color Blue

Plot

Developed by gAGE: Research group of Astronomy & Geomatics

Current Template: SPP

1 Click Clear to restart plots

X-min, Y-min, Y-max

3 gLAB.out East: 19 North: 18

gLAB1.out

OUTPUT

East: DSTAE: 19

North: DSTAN: 18

Ionospheric model component plot: gLAB.out

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB gAGE/UPC www.gage.es

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Dilution Of Precision
- Satellite Skyplot
- Model Components**
- Profit Residuals
- Posfit Residuals
- Measurement Multipath/Noise
- Zenith Tropospheric Delay
- Ionospheric Combinations
- Carrier Phase Ambiguities
- Orbit and Clock Comparison

Global Graphic Parameters

Title: Model Components X-label: Time (s) Y-label: Model (m)

Label Position: Top Right Fractional Text: WaterMark: Expand figure to margin:

Automatic Limits Automatic Ticks

Individual Plot(s) Configuration

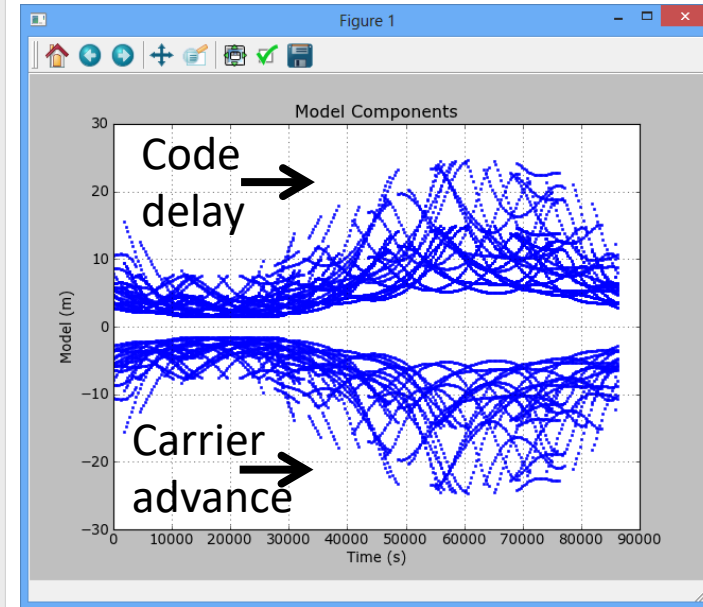
Plot Nr. 1 Plot Nr. 2 Plot Nr. 3 Plot Nr. 4

Source File: gLAB.out Dots: Blue

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

X Column: SEC 4 Y Column: IONO Legend-label:

Developed by gAGE: Research group of Astronomy & Geomatics Current Template: SPP Plot

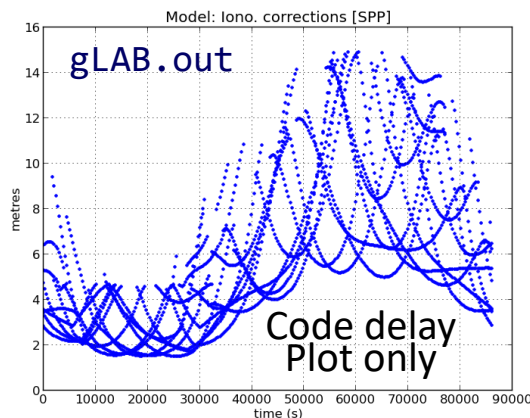
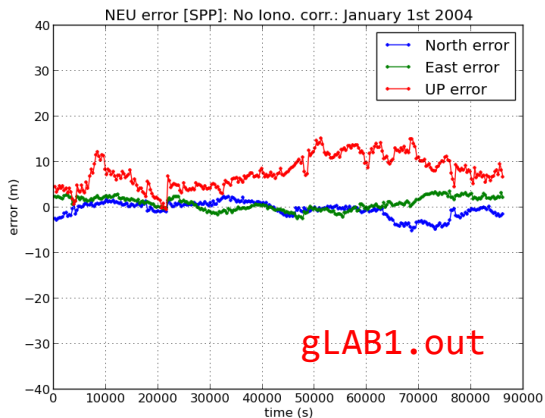
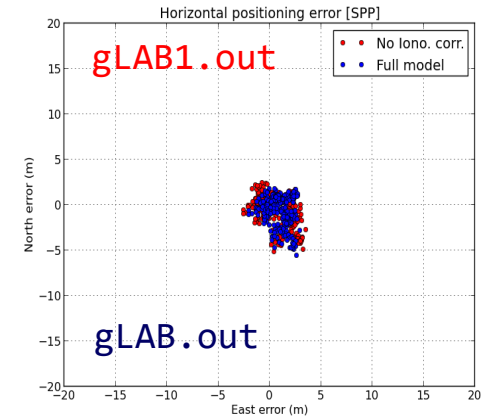
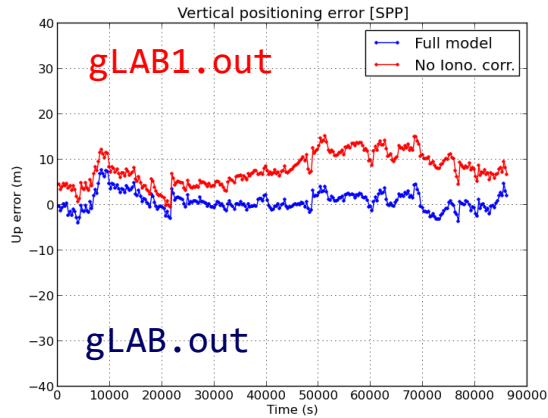
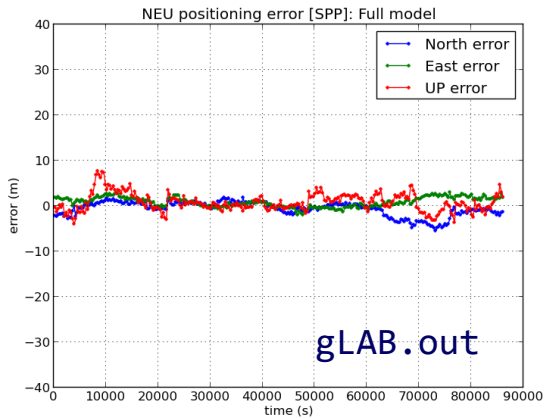


Ionosphere delays code and advances carrier measurements.

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

gLAB.out

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

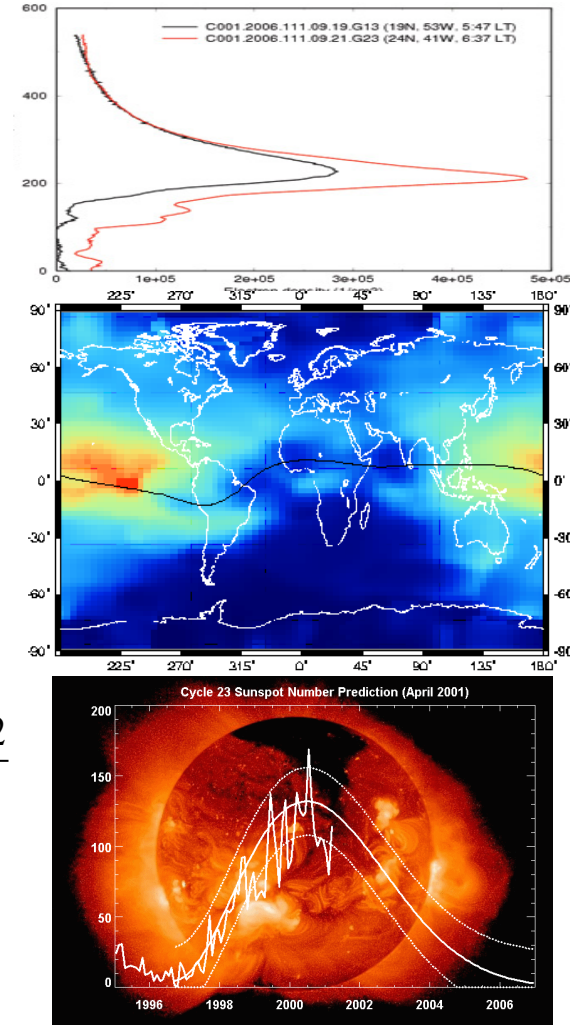
The ionosphere extends from about 60 km over the Earth surface until more than 2000 km, with a sharp electron density maximum at around 350 km. The ionospheric refraction depends, among other things, of the location, local time and solar cycle (11 years).

- 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).

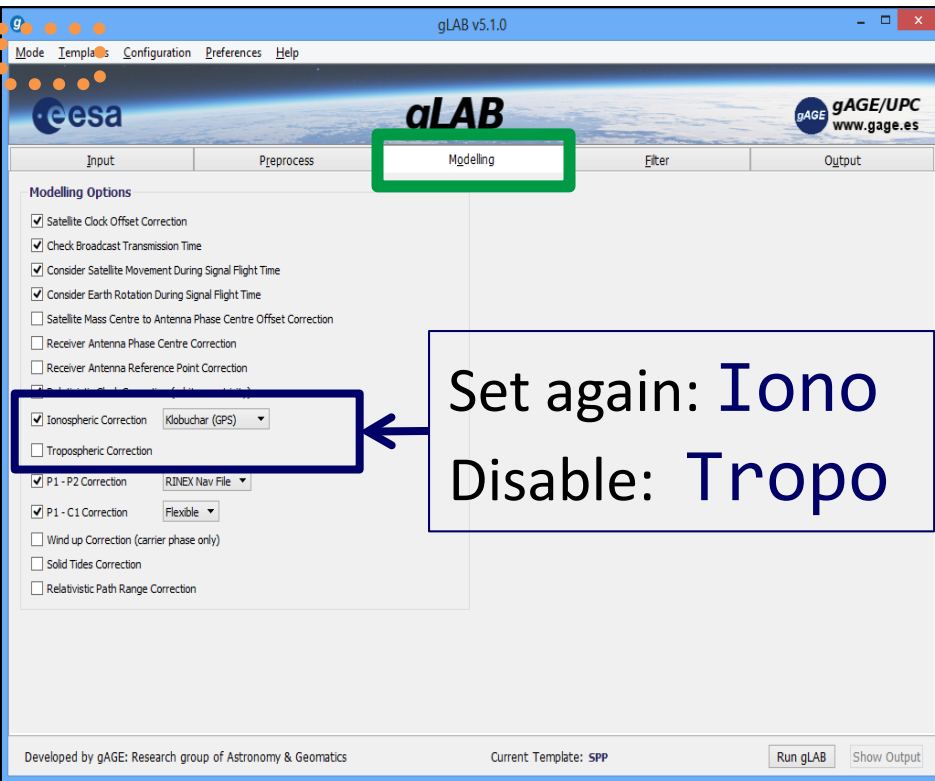
$$I = \int N_e ds$$
- Two-frequency receivers can remove this error source (up to 99.9%) using ionosphere-free combination of pseudoranges (PC) or carriers (LC).

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

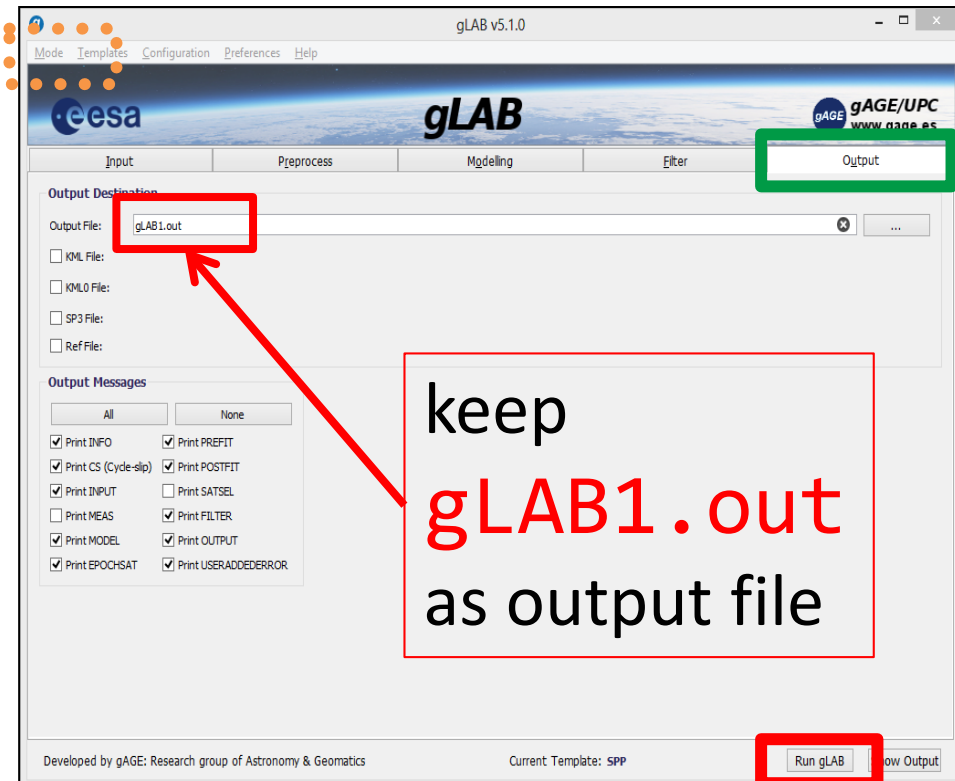


Example of model component analysis: TROPO.

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



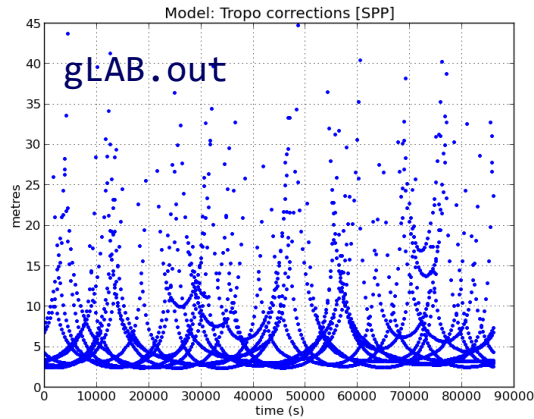
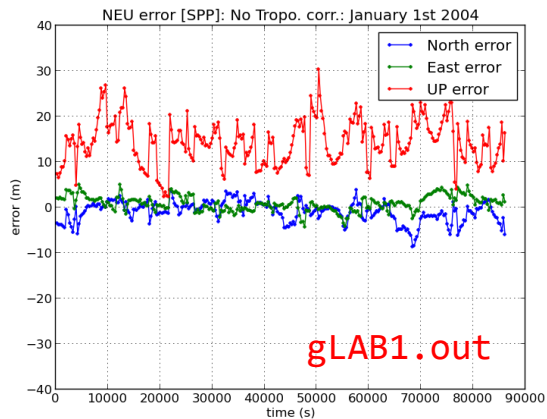
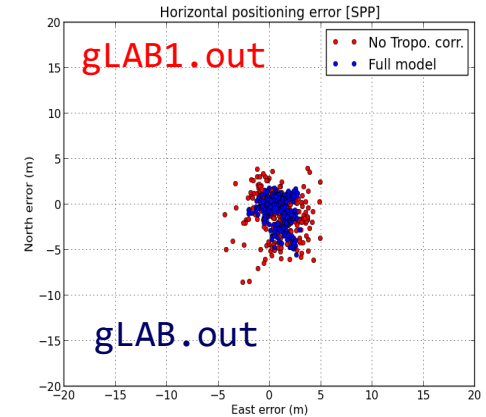
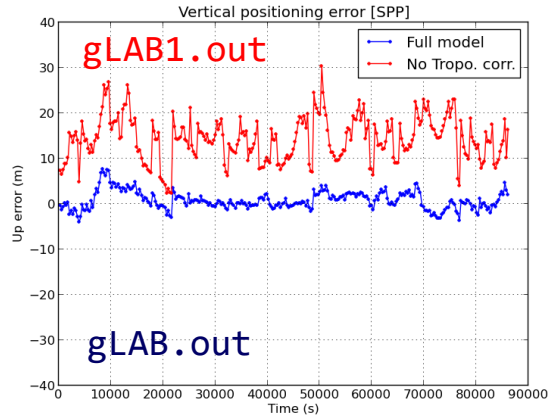
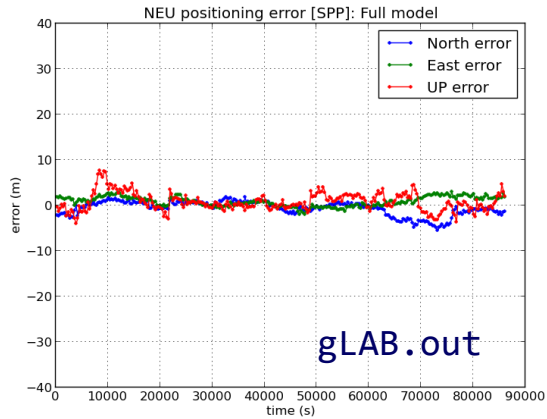
Set again: Iono
Disable: Tropo



keep
gLAB1.out
as output file

- 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

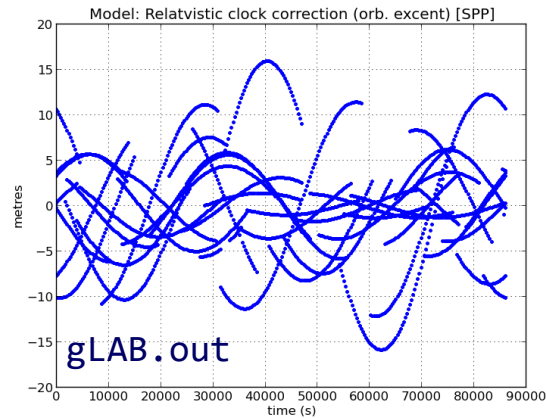
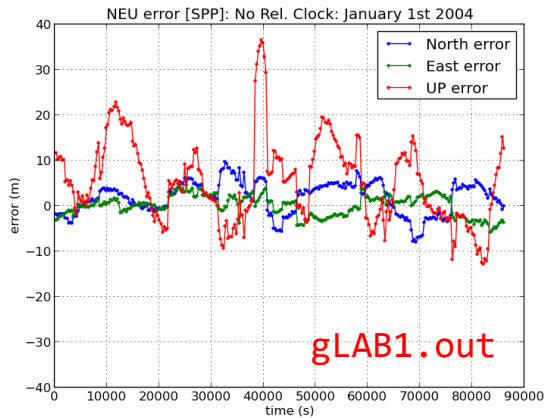
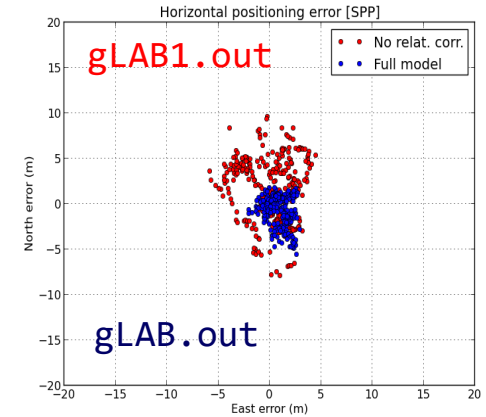
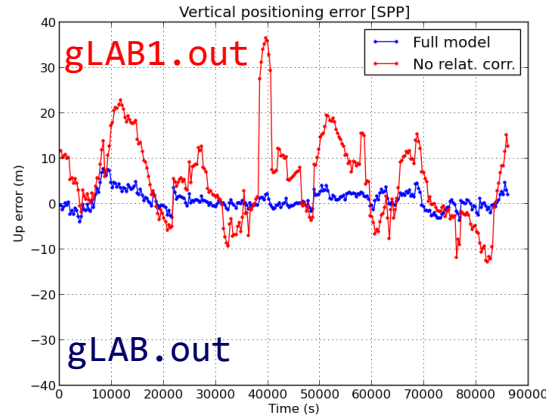
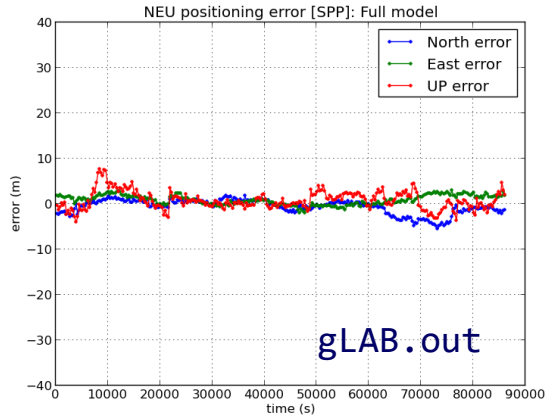
The troposphere is the atmospheric layer placed between Earth's surface and an altitude of about 60 km.

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

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:

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

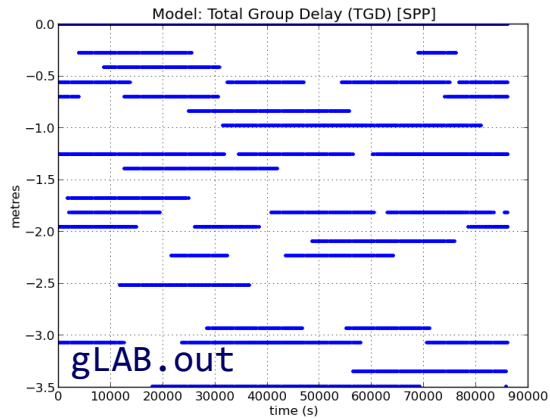
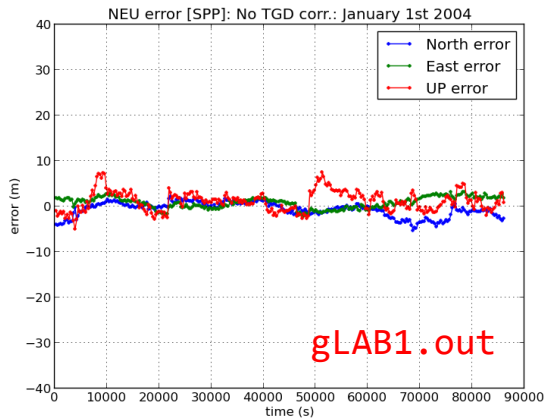
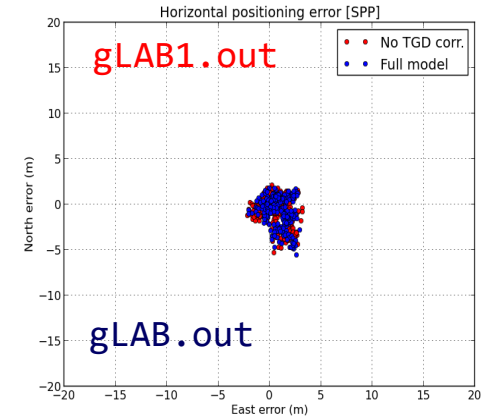
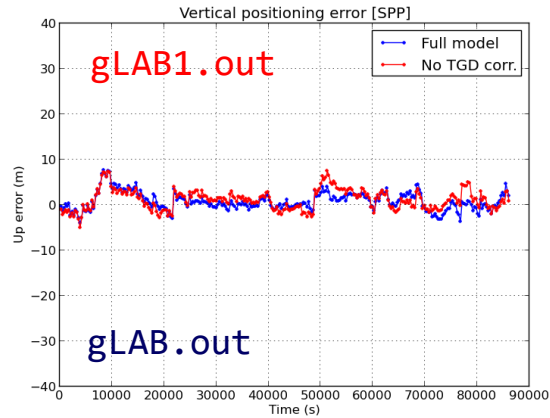
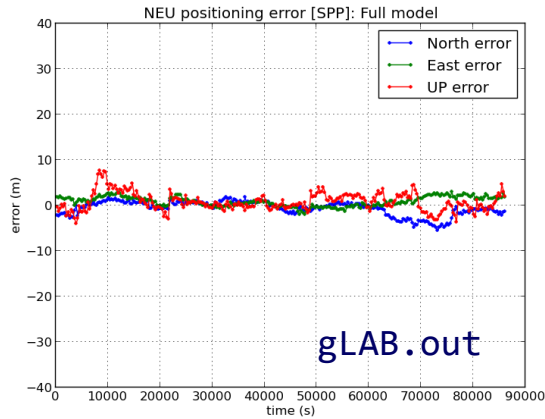
being $f_0 = 10.23 \text{ MHz}$, we have $\Delta f = 4.464 \cdot 10^{-10} f_0 = 4.57 \cdot 10^{-3} \text{ Hz}$. So, satellite should use $f_0' = 10.22999999543 \text{ MHz}$.

- 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.

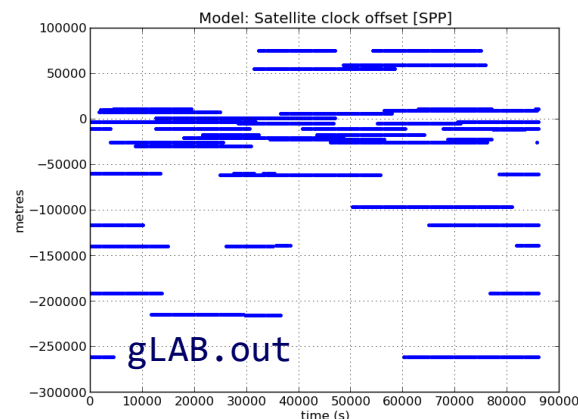
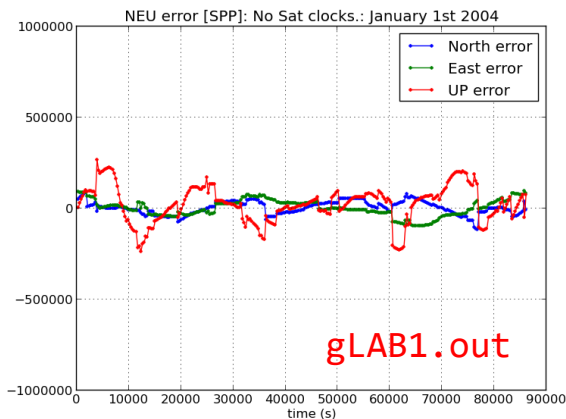
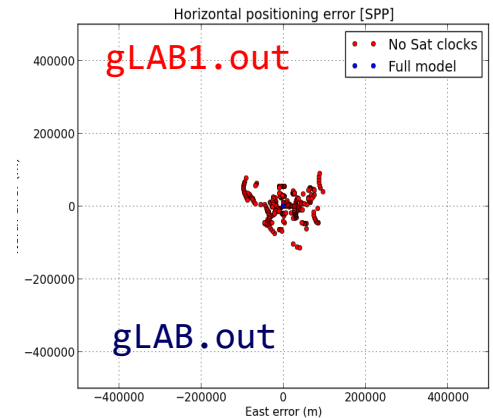
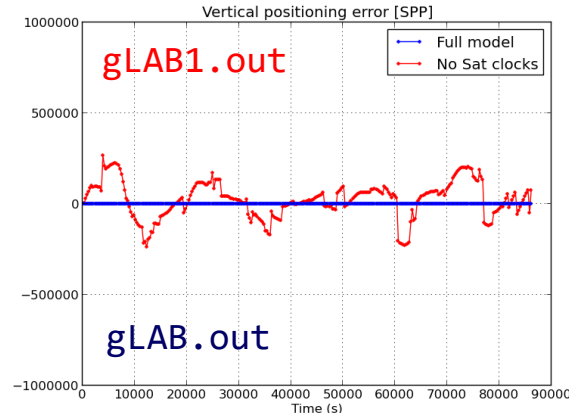
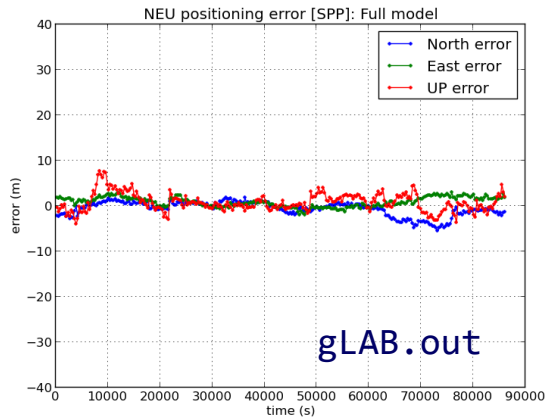
Exercise 1: SPP Model components analysis

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

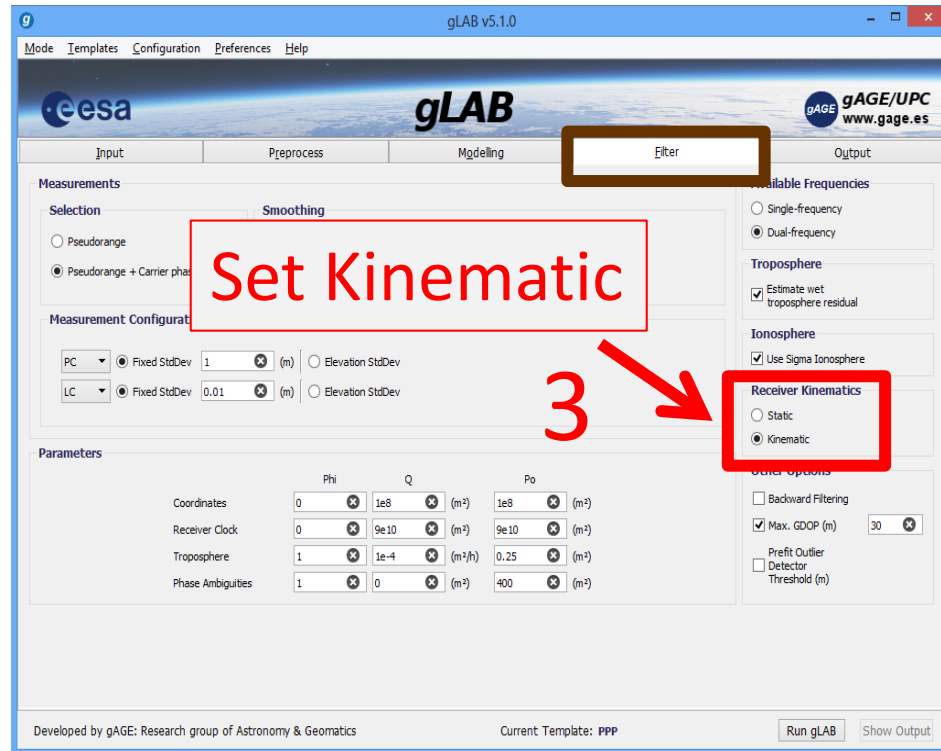
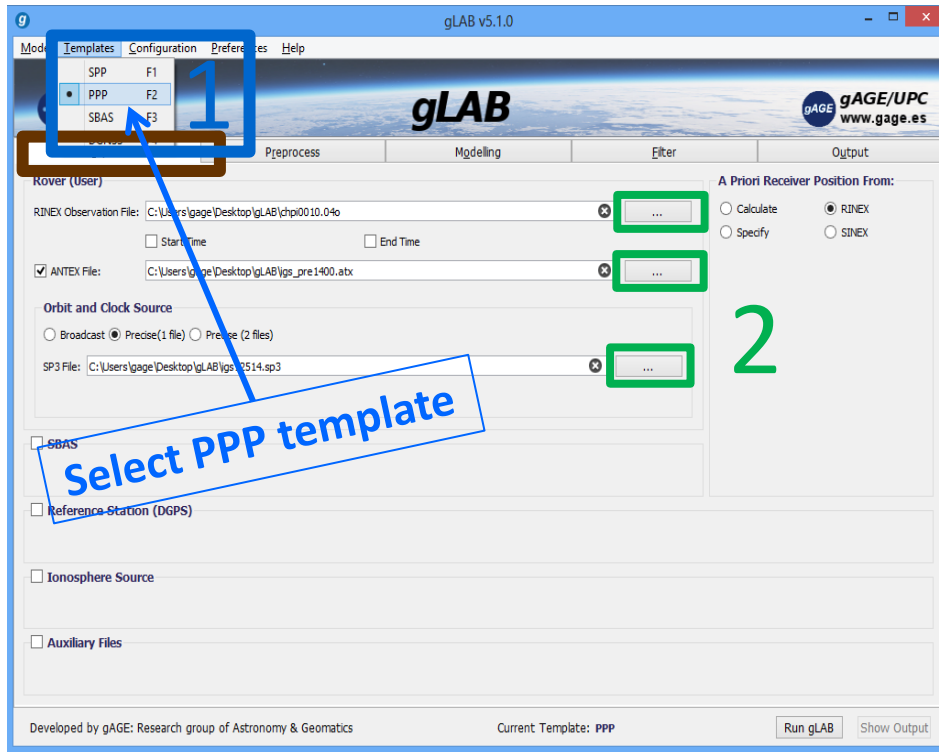
Basic: Introductory laboratory exercises

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`

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa **gLAB** gAGE/UPC www.gage.es

Input Preprocess Modelling Filter **Output**

Output Destination

Output File: **gLAB.out** 4

KML File:
 KML0 File:
 SP3 File:
 Ref File:

Output Messages

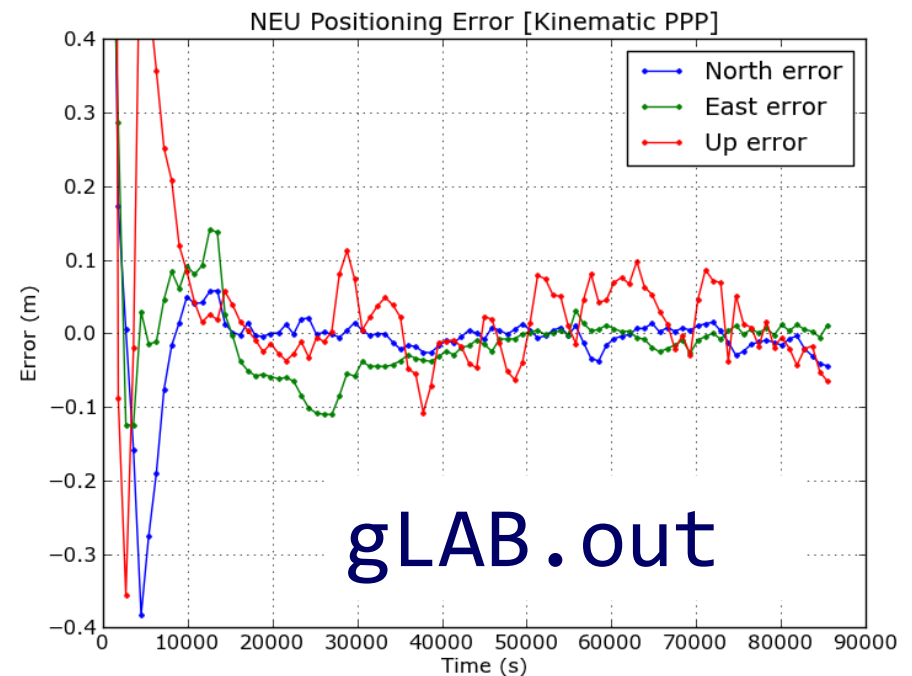
All None

Print INFO Print PREFIT
 Print CS (Cycle-slip) Print POSTFIT
 Print INPUT Print SATSEL
 Print MEAS Print FILTER
 Print MODEL Print OUTPUT
 Print EPOCHSAT Print USERADDEDERROR

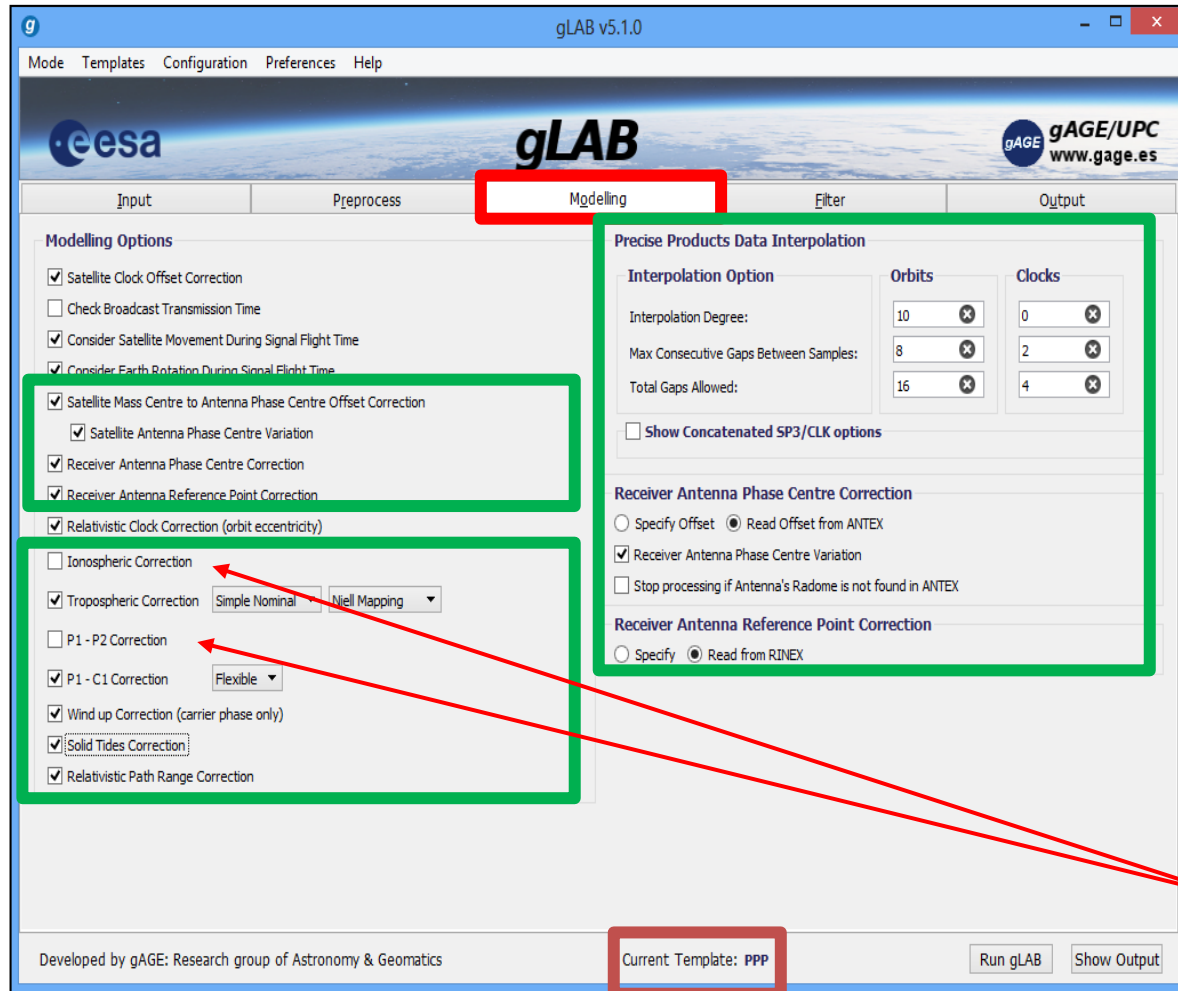
Set output file **gLAB.out** for the FULL model, as in previous case.

Run gLAB 5

Developed by gAGE: Research group of Astronomy & Geomatics Current Template: PPP Show Output



Exercise 2: PPP Model components analysis

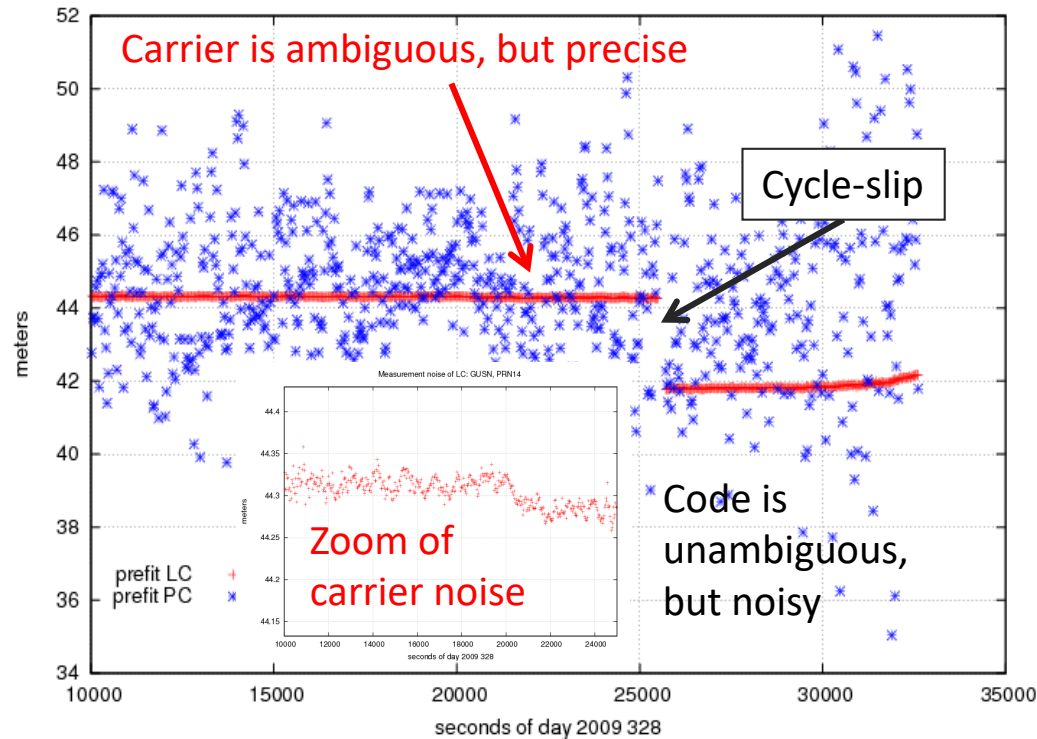


- Additional model components are used now in the FULL model to assure a centimeter level modeling.
- Precise orbits and clocks instead of broadcast ones.
- Dual frequency Code and Carrier data instead of only single frequency code.
- Iono-free combination of codes and carriers to remove ionospheric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

Exercise 2: PPP Model components analysis

Code and carrier Measurement noise

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

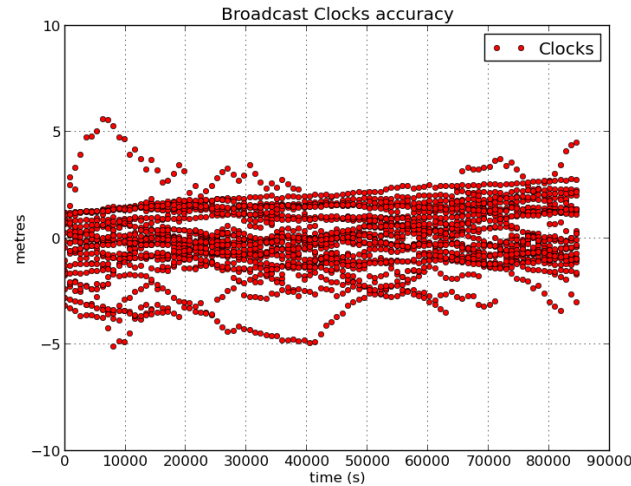
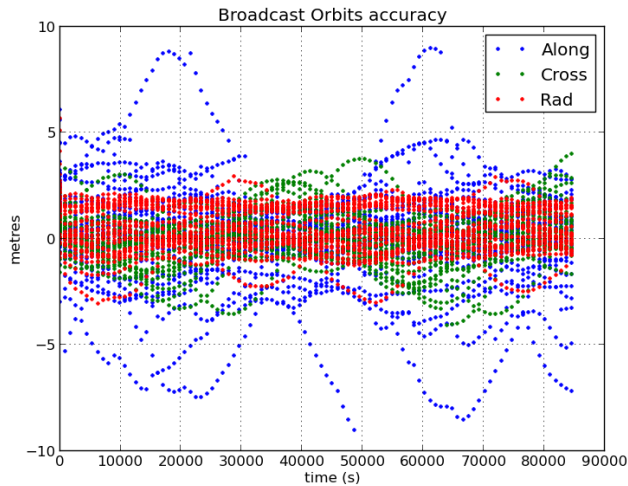


- Code measurements are unambiguous but noisy (meter level measurement noise).
- **Carrier measurements are precise but ambiguous**, meaning that they have some millimetres of noise, but also have unknown biases that could reach thousands of km.
- Carrier phase biases are estimated in the navigation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

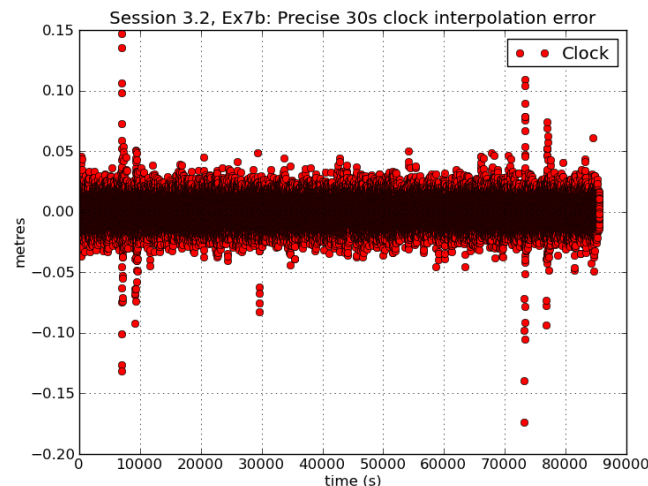
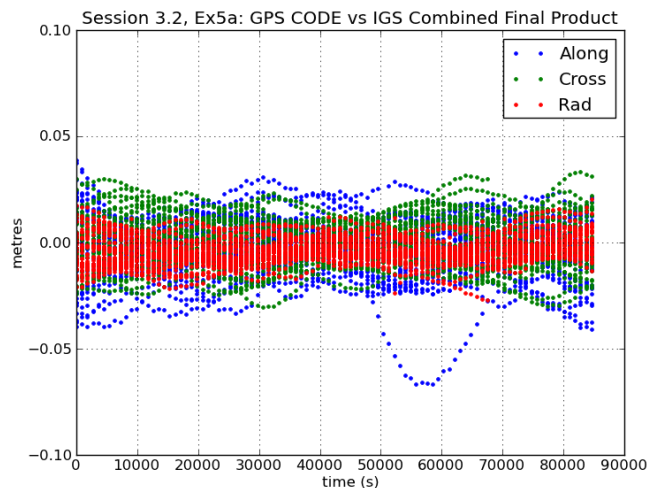
Exercise 2: PPP Model components analysis

Orbits & clocks accuracies



Broadcast:

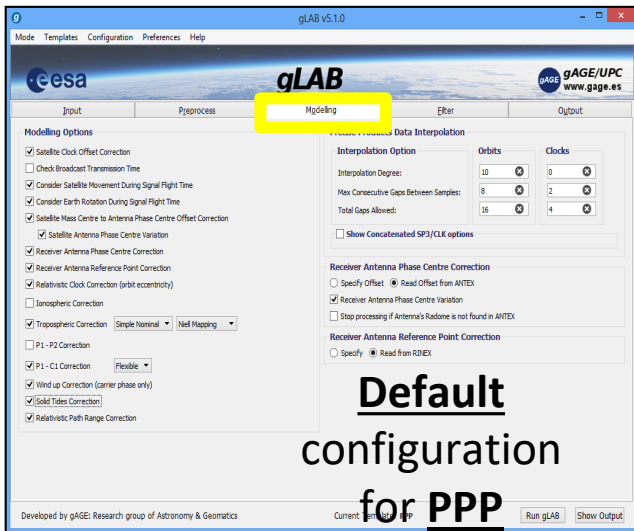
- Few metres of accuracy for broadcast orbits and clocks



Precise:

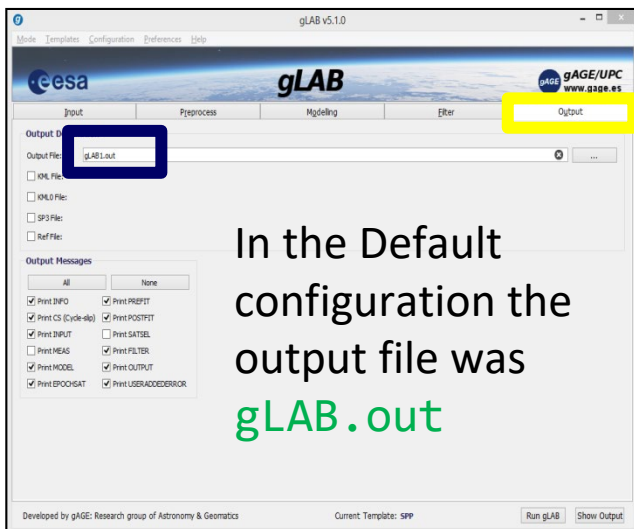
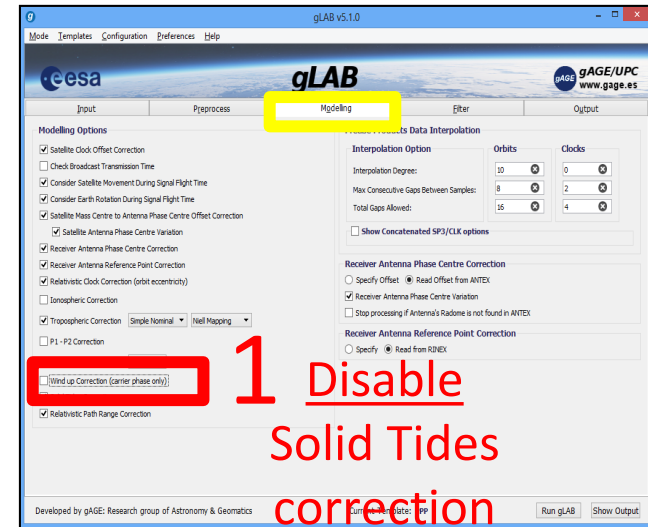
- Few centimetres of accuracy for broadcast orbits and clocks

Example of model component analysis: Solid Tides



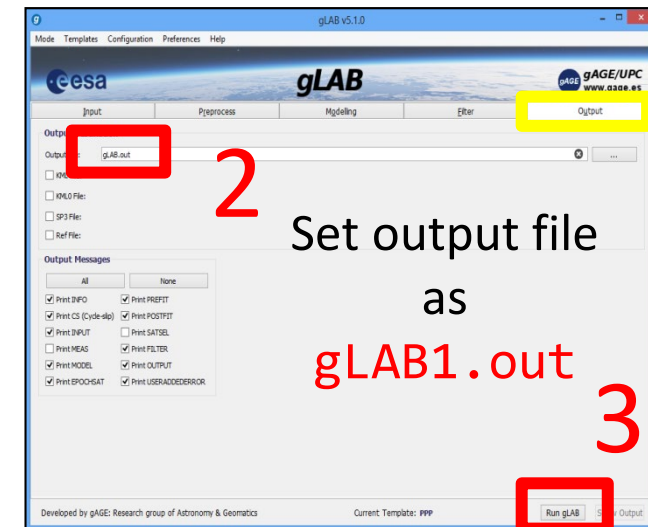
Proceed as in the previous exercise:

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

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Dilution Of Precision
- Model Components
- Residuals
- Zenith Tropospheric Delay
- Measurement Multipath/Noise
- Orbit and Clock Comparison

Global Graphic Parameters

Title: Vertical Positioning Error [Kinematic PPP] X-label: Time (s) Y-label: Error (m)

Label Position: Top Right

Automatic Limits: X-min: -0.4 X-max: 0.4 Y-min: -0.4 Y-max: 0.4

Automatic Ticks:

Individual Plot(s) Configuration

Plot Nr. 1 Plot Nr. 2 Plot Nr. 3 Plot Nr. 4

Source File: gLAB.out

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

X Column: SEC 4 Y Column: DSTAU 20 Legend-label: Full Model

Clear

Vertical Positioning Error [Kinematic PPP]

Error (m)

Time (s)

— No Solid Tides Correction

— Full Model

1 Click Clear to restart plots

2

3

OUTPUT

gLAB1.out

gLAB.out

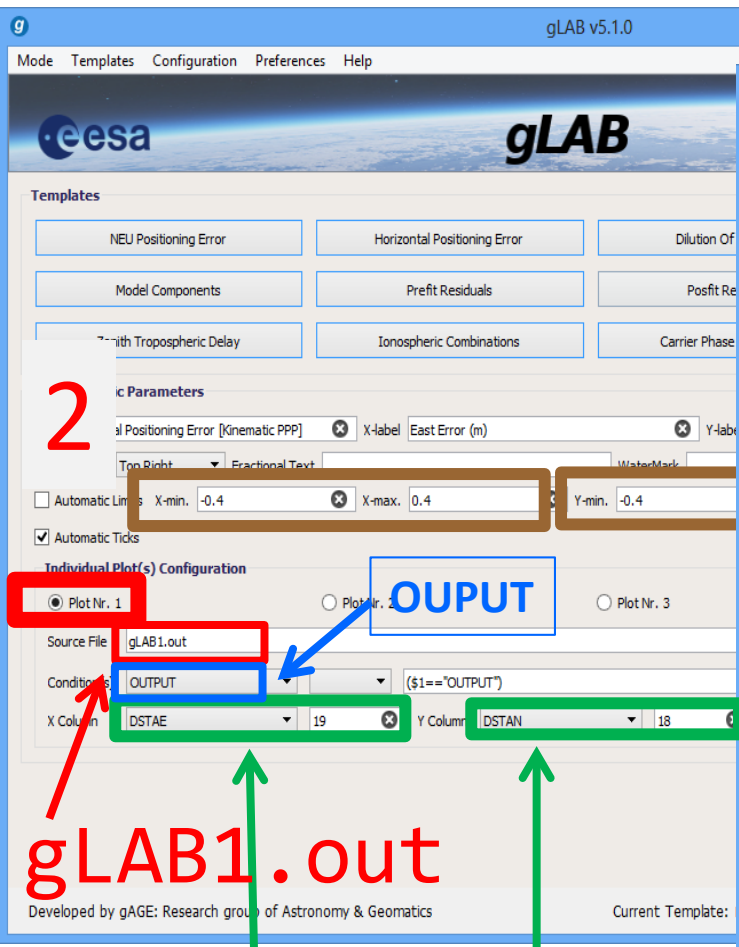
Time (sec)

Vertical

Time (sec): 4

Vertical: DSTAU: 20

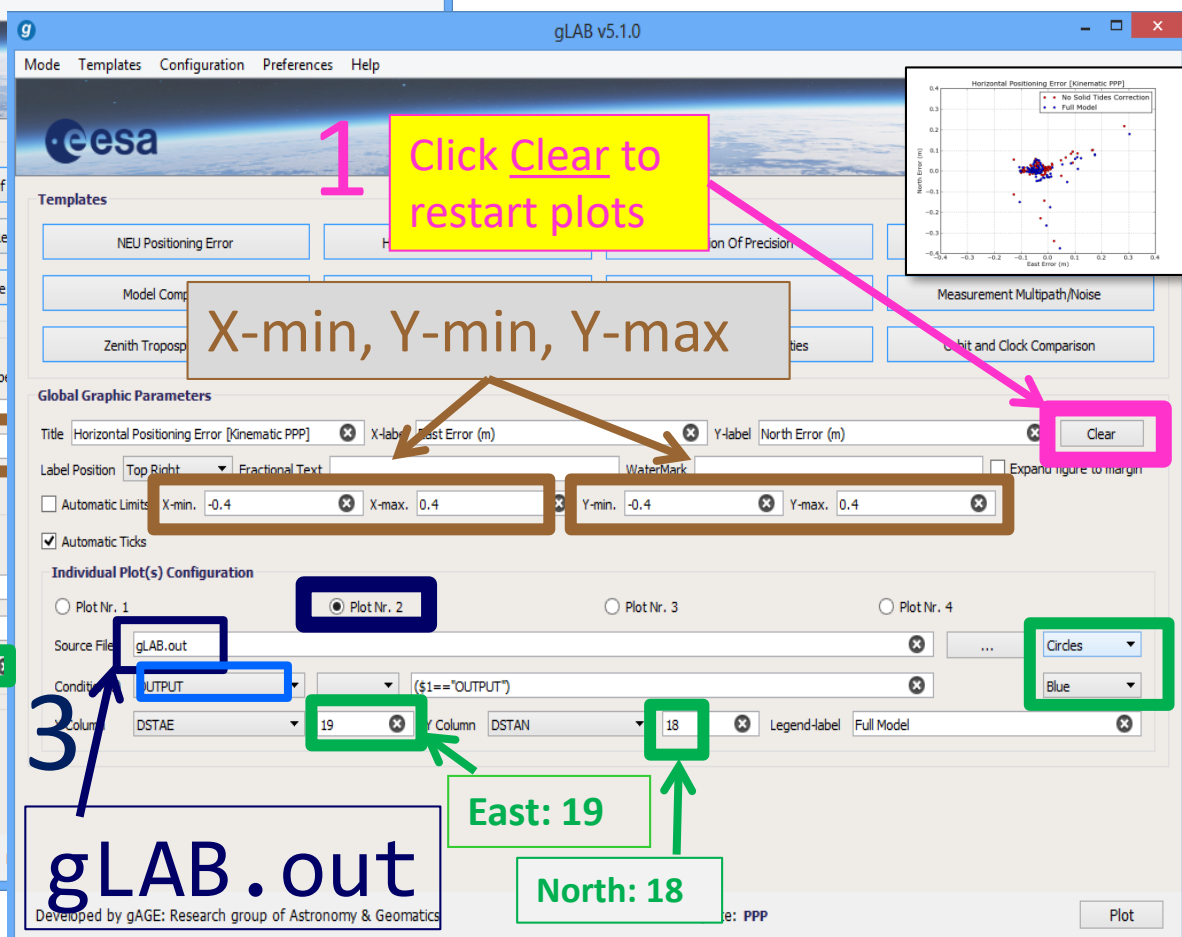
Horizontal Position Error plot: gLAB.out, gLAB1.out



gLAB1.out

East: DSTAE: 19

North: DSTAN: 18



1 Click Clear to restart plots

X-min, Y-min, Y-max

3

gLAB.out

East: 19

North: 18

Solid Tides model component plot: gLAB.out

gLAB v5.1.0

Mode Templates Configuration Preferences Help

eesa gLAB gAGE/UPC www.gage.es

Templates

- NEU Positioning Error
- Horizontal Positioning Error
- Dilution Of Precision
- Satellite Skyplot
- Model Components**
- Zenith Tropospheric Delay
- Ionospheric Combinations
- Carrier Phase Ambiguities
- Orbit and Clock Comparison
- Profit Residuals
- Posfit Residuals
- Measurement Multipath/Noise

Global Graphic Parameters

Title: Solid Time Model [Kinematic PPP] X-label: Time (s) Y-label: Model (m)

Label Position: Top Right Fractional Text: WaterMark: Expand figure to margin:

Automatic Limits Automatic Ticks

Individual Plot(s) Configuration

Plot Nr. 1 Plot Nr. 2 Plot Nr. 3 Plot Nr. 4

Source File: gLAB.out

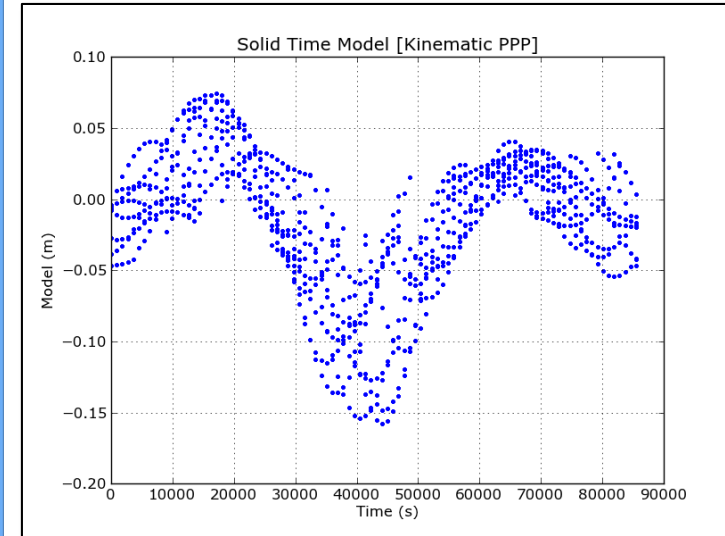
Component(s): MODEL (\$1=="MODEL")

X Column: SEC 4 Column: SOLIDTIDES 28 Legend-label:

gLAB.out

Select SOLIDTIDES

Current Template: PPP Plot



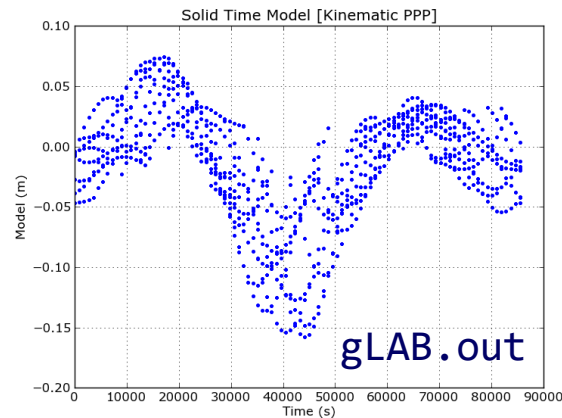
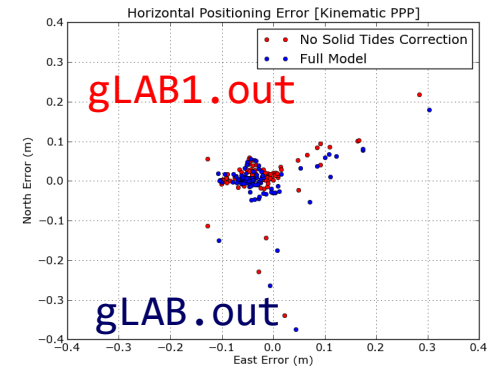
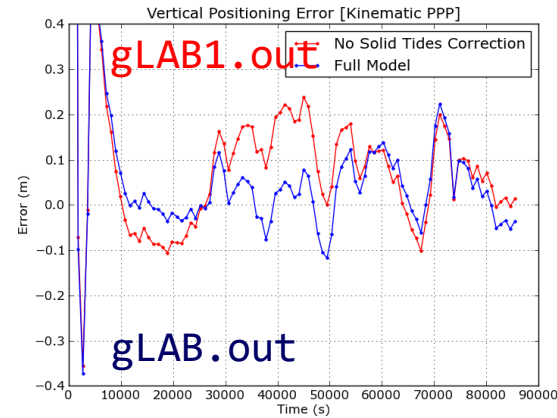
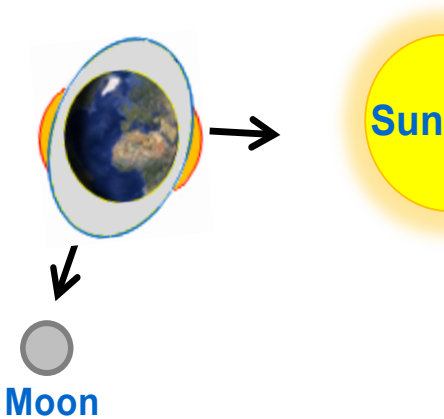
Solid Tides plot

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.

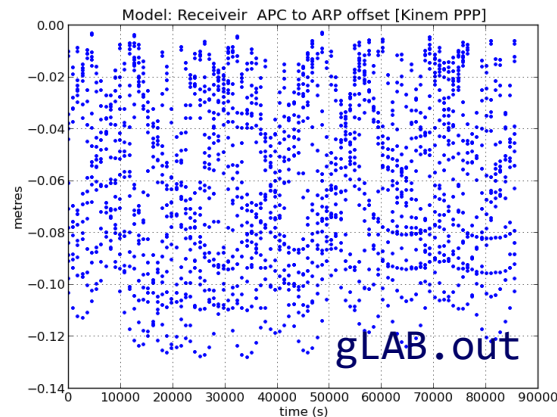
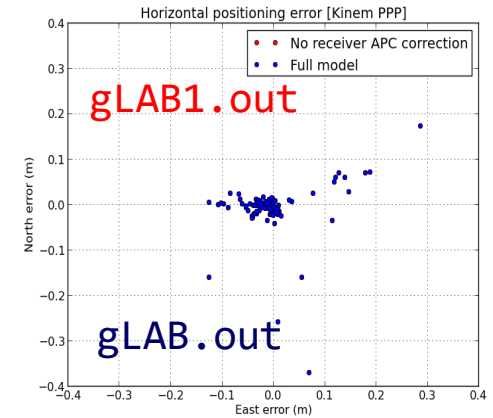
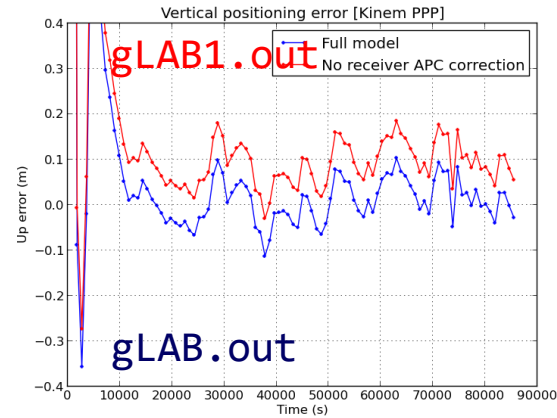
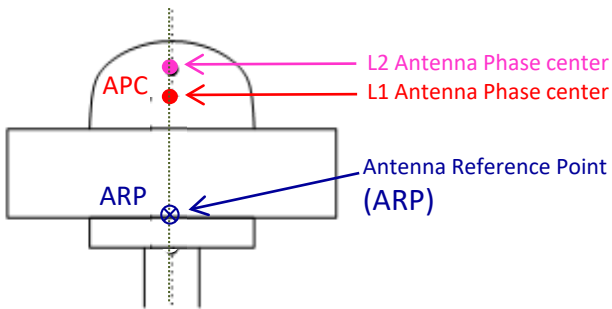


Solid Tides:

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)



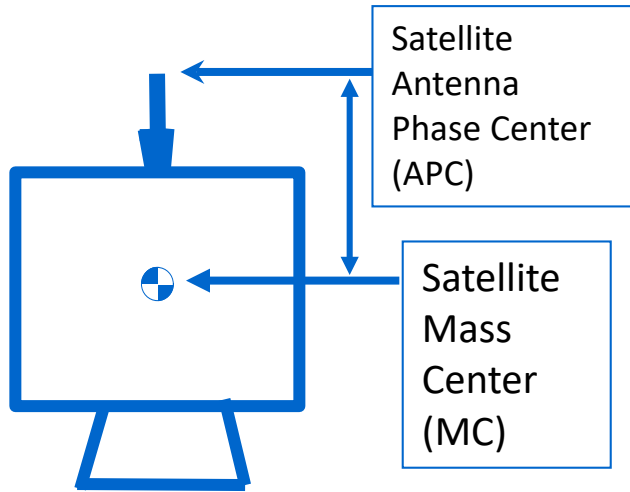
Receiver APC:

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

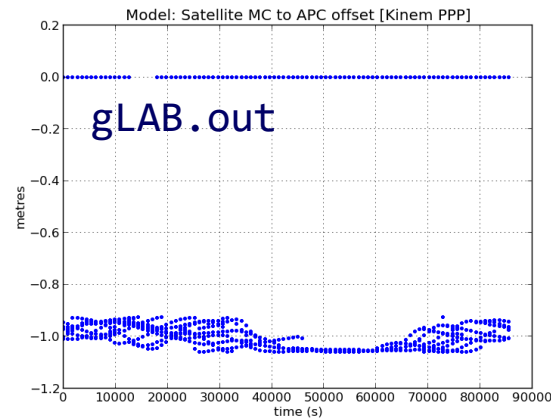
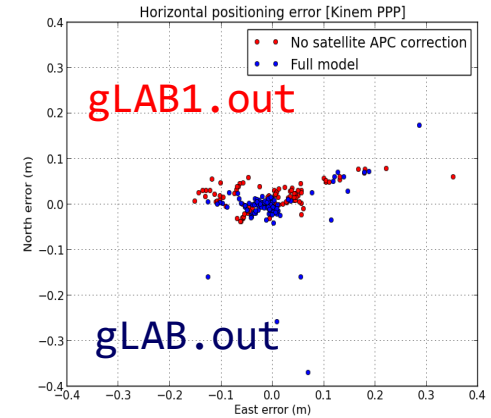
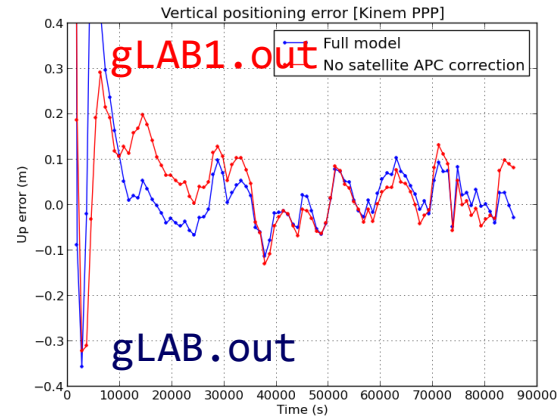
Thence, neglecting this correction, an error on the vertical component occurs, but not in the horizontal one.

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.



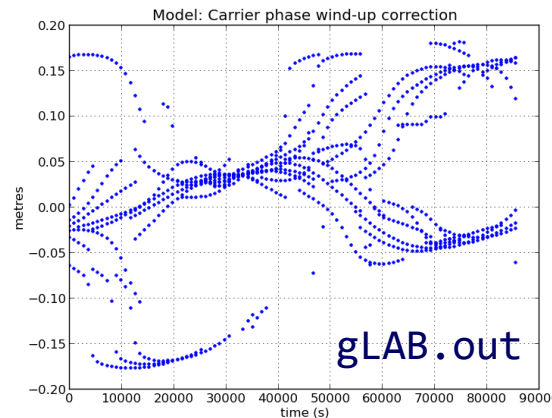
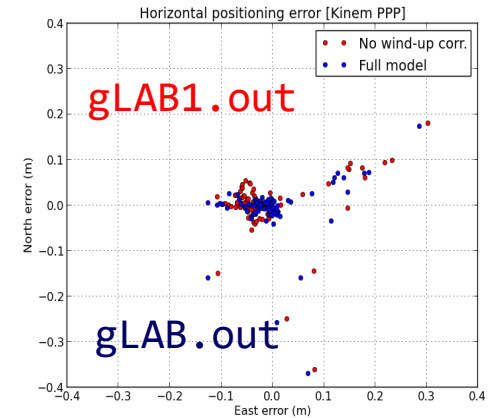
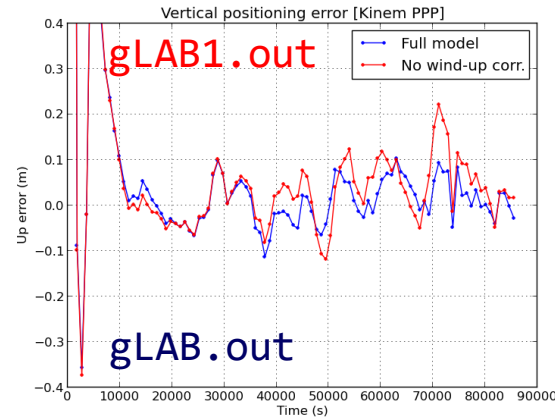
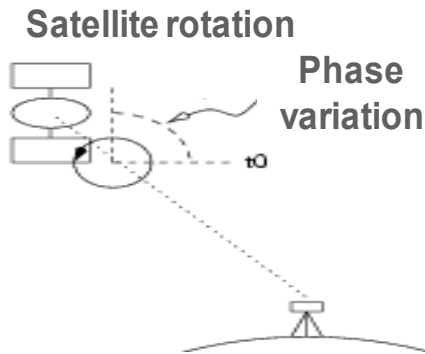
Satellite MC to APC:

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>

The screenshot shows a web browser window displaying the gAGE website. The browser's address bar shows www.gage.es/tutorials. The page content is organized into several sections:

- Personnel:** Includes links for Permanent Staff, Researchers, and Former Researches.
- Publications:** Includes links for Peer Reviewed Papers, Meeting Proceedings, Culture & Society, and PhD Dissertations.
- Learning Material:** Includes a Library section with links for GNSS Books, GNSS Course and associated Tutorials, GNSS Format Descriptions, GNSS Webinars, and Software Tools.
- Projects:** Includes links for gAGE/UPC and gAGE-NAV, S.L.
- Patents:** Includes links for WARTK, Fast-PPP, Iono. Corrections, Iono. Disturb. Mitig., and Receiver orientation.
- GNSS Tutorials:** The main content area, featuring a list of tutorials and associated materials. It includes:
 - GNSS Course (associated to the GNSS Data Processing Book):**
 - About the course
 - GNSS Data Processing: Theory Slides (Full compendium):** Includes lectures from 0 to 7, covering topics like GNSS measurements, satellite orbits, position estimation, DGNSS, PPP, differential positioning, and ambiguity resolution.
 - GNSS Data Processing: Laboratory Exercises (Full compendium):** Includes tutorials from 0 to 6, covering topics like UNIX environment, data processing exercises, measurement analysis, differential positioning, carrier ambiguity fixing, propagation effects, and differential positioning with ambiguity fixing.
 - Associated Software and Data Files (Linux):** Includes links for CDROM zipped tar file and CDROM ISO.
 - Associated Software and Data Files (Windows):** Includes links for an installable toolkit (gLAB + Cygwin), data files, and instructions on how to install the software.
 - Bootable USB stick (Linux live):** Includes links for gAGE-GLUE (instructions on how to burn and use the bootable USB stick) and instructions on how to start-up the laboratory session.
 - Useful tools for Windows:** A link to instructions for installing Linux tools on Windows.
- About us:** A brief description of gAGE as a research group at UPC.
- Shortcuts:** A list of quick links to various resources, with "GNSS Course and associated Tutorials" highlighted by a red box.
- User login:** A form with fields for Username (jaume.sanz) and Password, and a Log in button.
- Who's online:** A status report showing 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).
- 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.