

The ESA/UPC GNSS-Lab Tool (gLAB)

An advanced educational and professional package for GNSS data processing and analysis

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Abstract—The GNSS-Lab Tool suite (gLAB) is an advanced interactive educational multipurpose package to process and analyse GNSS data. The first release of this software package allows full processing capability of GPS data, and partial handling of Galileo and GLONASS data.

The gLAB software tool performs a precise modelling of the GNSS observables (code and phase) at the centimetre level, allowing GPS standard and precise positioning (SPS, PPP). gLAB also implements full processing capabilities for GPS data and is prepared to allocate future module updates, such as the expansion to Galileo and GLONASS systems, EGNOS and differential processing. It is capable of read a variety of standard formats RINEX-3.00, SP3, ANTEX or SINEX files, among others. Moreover, functionality is also included for GPS, Galileo and GLONASS, being able to perform some data analysis with real multi-constellation data.

gLAB is flexible, able to run under Linux and Windows operating systems (OS) and it is provided free of charge by the European Space Agency (ESA) to Universities and GNSS professionals.

GNSS software tool; Precise Point Positioning; gLAB; open source; GPS; Galileo; GNSS data processing

I. INTRODUCTION

Satellite Navigation has become a keystone for the development of Europe and its citizens. It is then essential to provide adequate educational programmes so to ensure a prepared workforce for the GNSS sector in Europe. In this context, ESA has launched a complete Satellite Navigation Educational program, called EDUNAV, aiming at providing up-to-date GNSS based educational material and educational tools. EDUNAV includes, among other initiatives, the provision of updated on-line technical GNSS material (as for example the recently opened ESA NAVIPEDIA dedicated GNSS wiki [1]) and the provision of hands-on educational SW tools. The GNSS-Lab (gLAB) Educational Software Tool is a fundamental part of this ESA EDUNAV initiative and the subject of this article.

gLAB, developed under ESA Contract by the research

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group of Astronomy and Geomatics (gAGE) from the Universitat Politecnica de Catalunya (UPC), is an interactive educational multipurpose package to process and analyse GNSS data. gLAB performs precise modeling of GNSS observables (pseudorange and carrier phase) at the centimetre level, with precise positioning (PPP) capability. Every single error contributor may be assessed independently, which provides a major educational benefit.

The requested Educational GNSS Software Tool constitutes a step forward in the ESA-Education Office aim at fostering the transfer of knowledge in GNSS through the provision of GNSS-based educational utilities. The good consecution of this objective will help to enhance the GNSS knowledge of European students and professionals.

This software package targets following groups of users:

- Education professionals aiming to teach GNSS from both a theoretical and practical points of view.
- Standalone students and professionals with basic knowledge on GNSS as a self-learning tool.
- Professionals with more in deep knowledge on GNSS who want an easy and user-friendly tool with high accuracy positioning capability.

The gLAB tool is distributed within a learning material package containing the following components:

- Software: A set of binary files able to read GPS RINEX data, process it and show the results in the form of data files and graphics. The processing options are fully parametrizable through a Graphic User Interface (GUI) that eases to understand the tool and its different options.
- Tutorial: A practical lecture can be found in [2] on GNSS fundamentals, with several exercises covering from the basics of data processing, to more complex processes like positioning a rover and analyzing the results¹.
- Data: The data sets files used in the exercises.

¹ A new practical book [3] on GNSS data processing fundamentals and algorithms (Vol-I) and laboratory exercises (Vol-II) based in gLAB is expected to be published by the end of this year by the ESA Publications Division.

II. GENERAL SOFTWARE CHARACTERISTICS

The current release of this software package implements full processing capabilities for GPS data and it is prepared to incorporate future module updates, such as an expansion to Galileo and GLONASS systems, EGNOS and differential processing.

The tool is able to run under Linux and Windows operating systems (OS). It is programmed in C and Python languages and is divided in three main software modules:

1. The Data Processing Core (DPC),
2. The Data Analysis Tool (DAT), and
3. The Graphic User Interface (GUI).

The DPC implements all the data processing algorithms and can be executed in command line. The DAT provides a plotting tool for the data analysis. The GUI consists in different graphic panels for a user friendly managing of both the DPC and DAT. Both the DPC and DAT modules may be used independently of the GUI, including them in batch files to automatically process GNSS data.

A. Main gLAB features

The gLAB tool features a wide range of characteristics only available in advanced GNSS data processing software. The main features are mentioned here, where a more detailed list may be found in the Software User Manual [4].

- **High Accuracy** Positioning capability: This software tool implements a precise modelling of the GNSS measurements (code and carrier phase) at the centimetre level, allowing both standalone GPS positioning and PPP.
- **Fully configurable:** gLAB is driven by a configuration file, where the different internal parameters are set. These range from input/output and data processing options such as Kalman filter. This ASCII configuration file can be generated from the Graphic User Interface (GUI) as well as by any experienced user, with a text editor.
- **Easy to use:** gLAB includes an intuitive GUI, with tooltips and a lot of explanations over the different options to select. Guidelines and several error and warning messages are also provided, as well as, templates and carefully chosen defaults for pre-configured processing modes.
- **Access to internal computations:** A wide tracking of internal computations is provided by gLAB through different output messages.
- **Open source:** gLAB source code is distributed under the Apache License Version 2.0. This allows the user to develop both free and commercial GNSS data processing tools using gLAB as a library.
- Able to be executed in command-line and to be included in **batch processing**.

B. Minimum hardware requirements

The gLAB requires computational hardware requirements are relatively modest:

- 256 MB of memory.
- CPU with at least 1GHz.
- 200MB of hard disk free space.
- Screen resolution of at least 1024x768 is recommended. In order to cope with small screens, scrollbars can be displayed in the preferences button. This requirement may be waived when just the DPC and DAT modules are used.

III. GLAB GRAPHIC USER INTERFACE (GUI)

The GUI is an interface between the other two components (DPC and DAT). It allows the user to change parameters, and execute the other two programs with proper arguments.

The initial screen can be seen in Fig. 1, where two main tabs may be found:

- **Positioning:** interfaces with the DPC tool, and allows selecting the different processing options.
- **Analysis:** interfaces with the DAT tool, and allows selecting the plotting options.

A. Positioning tab

The positioning tab is split into 5 different sections, which correspond to 5 different modules inside the DPC:

- **INPUT:** It is like a "driver" between the input data and the rest of the program. This module implements all the input reading capabilities and stores data into the appropriate internal structures.
- **PREPROCESS:** This module prepares the data for the next module (MODEL). It checks for cycle-slips, pseudorange-carrier phase inconsistencies and decimates the data (if required).



Figure 1. gLAB GUI initial screen.

- **MODEL:** This module has all the functions to fully model the receiver measurements. It implements several kinds of models, which can be enabled or disabled at will. Fig. 2 shows the screen corresponding to the MODEL module.
- **FILTER:** This module implements a fully configurable Kalman filter, and obtains the estimations of the required parameters.
- **OUTPUT:** This module outputs the data obtained from the FILTER.

It is very important to notice that the GUI provides to the novice user a couple of “data processing templates”, shown as buttons in the lower centre part of the interface with labels “SPP Template” and “PPP Template”.

Those “templates” automatically configure the appropriate options to carry out the desired data processing strategy. In the case of the “SPP Template”, the configuration corresponds to the GPS Standard Positioning Service defined in [5], while the “PPP Template” configures gLAB to carry out the Precise Point Positioning strategy as defined by [6]. For instance, Fig. 2 shows how the PPP model is configured by the PPP Template.

This feature must not be underestimated, because it provides the novice user with a quick and friendly way to setup the processing, reducing the learning curve slope. Once the basics are mastered, the user may easily explore the effects of modifying some aspects of the original provided strategies.

Another item to ease the use of the tool are the tooltips. When the user hovers the mouse over a given option, a small box with information about the item is automatically displayed, as shown in Fig 3. These tooltips help the user to understand which processing is being done. They are activated by default but they can be deactivated on the preferences button (on the left top part of the GUI). Together with the tooltips several error and warning messages will be displayed along the GUI.



Figure 3. Tooltip and error example in Preprocess module.

B. Analysis tab

The analysis tab allows configuring all the visualization options for the DAT, as shown in Fig. 4. There are two different areas. On the upper part, the user finds all the templates buttons. In this case, the templates are a set of preconfigured plotting options for the Graphic Details section. Clicking on any button will load all the corresponding options, allowing modifying or plotting them directly.

On the lower part, the user can configure a plot from scratch using the “Global Graphic Parameters” section below the templates. The GUI can accommodate up to four plots, (i.e. four different data series in the same graphic) although the DAT program has no plot number limitation when executed independently from the command line.

Finally, it is only to be remarked that while there are some common data that needs to be uploaded only once per graphic, user can fine tune different options of the individual plots, providing full flexibility.



Figure 2. gLAB Model module configured by the PPP template.



Figure 4. gLAB Analysis tab.

IV. GLAB DATA PROCESSING CORE (DPC)

The DPC is the processing tool of gLAB, and it has been programmed in C. The DPC is:

- Easy to use for an advanced user.
- Modularized, in order to incorporate future updates.
- Optimized for CPU and memory usage.

The options of the DPC and GUI are basically the same with some exceptions that provide further flexibility. The DPC can be executed with the '-help' argument, which provides detailed information of the possible arguments. It is also worth mentioning that the DPC can also read the processing options from a configuration file, allowing an easy repeatability of results and automatic batch processing.

A. Work modes

gLAB can work in four different modes:

- **Positioning Mode:** 'Standard' mode, where all the processing is done and the position solution for a receiver is provided as OUTPUT messages. The minimum parameters required for this mode are an input observation file and orbit and clock products (broadcast or precise). Using precise products will also require the use of an ANTEX file.
- **Show Input Mode:** This mode only reads an input RINEX observation file and prints its measurements. No orbit nor clock products should be provided (if provided, gLAB will switch to Positioning Mode).
- **Product Comparison Mode:** This mode reads and compares two different sources of orbit and clock products. In order to use this mode, two different orbit and clock products should be provided. This mode outputs the SATDIFF, SATSTAT and SATSTATTOT messages.
- **Show Product Mode:** This mode reads a single source of orbit and clock products. In order to use this mode, a single orbit and clock product should be provided. This mode output SAT messages.

V. GLAB DATA ANALYSIS TOOL (DAT)

The DAT is an advanced plotting utility prepared to graph different combinations of columns taking into account several user-defined conditions. The DAT, as the DPC, is highly configurable with multiple options available to set scale, titles, ranges, styles, colours, plotting conditions, etc.

An important additional feature of DAT module is the capability to output multiple image formats, including png, jpeg, pdf, eps, svg, among others.

VI. DATA PROCESSING EXAMPLES

A. Static PPP vs SINEX

First example gives an overview of a simple processing using the gLAB DPC component. A Precise Point Positioning

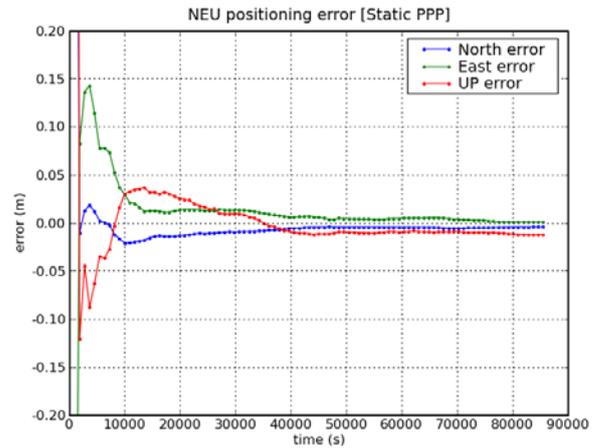


Figure 5. Static PPP results.

processing in static mode will obtain the precise coordinates of a given station (ROAP). Those coordinates are then compared against the International GNSS Service (IGS) provided solution in the corresponding SINEX file and the "North", "East" and "Up" differences are plot in Fig. 5.

- Input files: Observation file roap1810.09o, Precise ephemeris files: igs15382.SP3, Antenna phase centres file: igs05_1525.atx, SINEX file: igs09P1538.snx

Please note that the positioning errors are below 1 cm, with convergence time (errors below 10 cm) of about 1 h. This performance is comparable with the best PPP processing suites currently available.

B. Zenith Tropospheric Delay estimation

The Zenith Tropospheric Delay (ZTD) is estimated in the PPP solution, together with the receiver coordinates and its clock offset from GPS time (among the floated carrier phase ambiguities). Fig 6 shows a comparison of the ZTD obtained with gLAB with respect to the IGS estimation from file roap1810.09zpd.

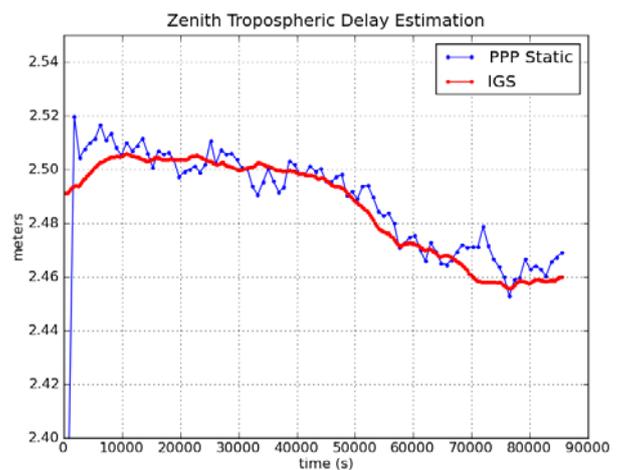


Figure 6. gLAB ZTD estimation with IGS value.

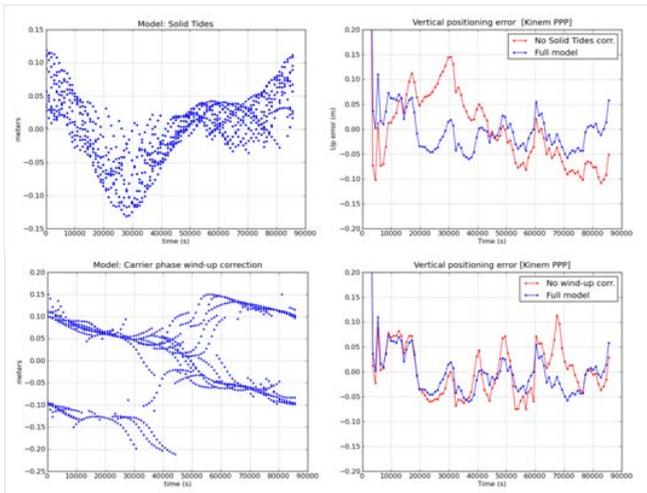


Figure 7. Solid tides and wind up model together with the effect in the user domain (vertical component) of neglecting such terms.

C. PPP Model Components Assessment.

gLAB permits easily the assessment of the different model components of measurements (ionosphere, troposphere, relativity, etc.). This can be done both in the Signal-In-Space (SIS) and User Domains. By disconnecting any term of the model, the user can assess the modelling needs in terms of the GPS positioning service accuracy. Fig 7 shows two examples of the impact on the user position of neglecting such model component.

D. Kinematic LEO processing.

Fig 8 shows an example of an advanced GNSS data processing exercise included in the tutorial [2]. The LEO satellite GRACE-A is cinematically positioned using the GRAPHIC combination [6]. The positioning errors are plot in the radial, along track and cross track directions, using the GRACE-A Precise Reference Orbit determinations

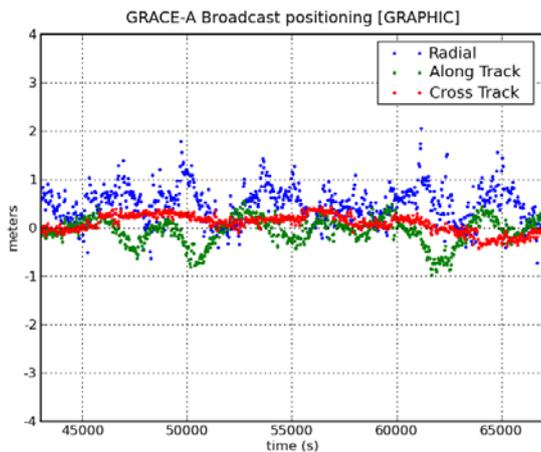


Figure 8. GRACE-A positioning using GRAPHIC combination.

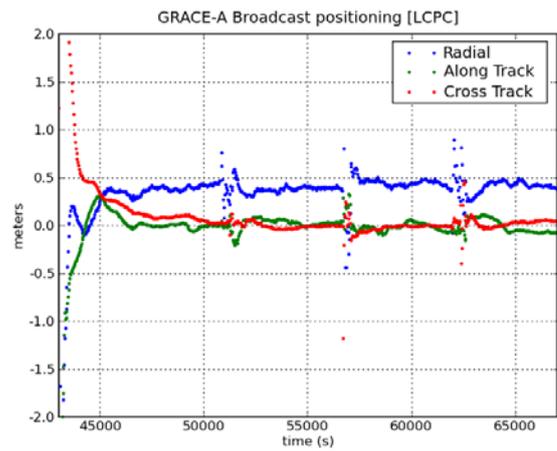


Figure 9. GRACE-A positioning using kinematic PPP.

from the JPL Propulsion Laboratory as reference.

- Input files: Observation file: graa0800.07o, Precise ephemeris files: cod14193.sp3, cod14193.clk, Antenna Phase Centre file: igs05_1402.atx.

As it can be seen, very good results can be achieved with gLAB following a simple procedure.

An even better solution is shown in Fig. 9, obtained using code and carrier dual-frequency ionosphere-free combinations (PC, LC) together with precise orbits and clocks in PPP kinematic mode.

It is interesting to note that the bias in the Radial direction corresponds to GRACE-A antenna phase centre position with respect to satellite's centre of mass (0.414 m), confirming the accuracy of the gLAB-based solution.

Google Earth® tool can be used to plot the results obtained with gLAB for several GRACE-A ground tracks. Fig. 10 is easily obtained by inserting the OUTPUT messages from gLAB into a kml file.



Figure 10. GRACE-A ground tracks obtained with gLAB.

VII. LEARNING PACKAGE ON THE WEBSITE

gLAB and all the related material can be found in the following website <http://www.gage.upc.edu/gLAB>. Here the user can find not only the gLAB latest source code version and its associated Software User Manual, but also a Frequent Answered Questions (FAQ), available to gather solved questions to the gLAB community.

As mentioned at the beginning and in previous work [8], gLAB is released within a learning package. All of these complementary parts are also available in the gLAB's website. These learning material comprise, for instance the referred GNSS tutorial [2] which is entirely based in gLAB. This tutorial was initially developed for the ESA Summer School and it has been taught in its 2010 and 2011 editions.

The above mentioned website contains a section devoted to GNSS Standard Format data files. This section aims to provide the GNSS community a reliable and powerful tool which explains these standards in an easy and friendly way. Some data files such as RINEX, ANTEX, IONEX, SP3 have been converted into HTML files, so any web browser is suitable to open them. As with the tooltips of gLAB, an explanatory help message is automatically triggered to describe the field content, units and format. Fig. 11 shows how these files look like.

Although gLAB is able to run in both Windows and Linux, the Linux (Ubuntu) has been selected as a baseline for the laboratory exercises in the tutorial [2]. Thence in order to help the user working in this platform and to avoid the need of installing Linux, a specific in-built solution has been developed.

This application, called GNSS Laboratory under Ubuntu Environment (gLUE) consists of the necessary files and instructions to generate a bootable live USB stick with a full environment ready to use (based on Linux Ubuntu OS).

Once the USB is successfully burned, the user can convert any PC on a working station with a fully prepared environment, by booting the computer from the live USB. This will leave the PC unaltered. At this point gLAB and all necessary files to execute the exercises of [2] are ready to use, see Fig 12.



Figure 12. gLUE Snapshot, where gLAB and a terminal are ready to use.

VIII. SUMMARY

The GNSS-Lab Tool suite (gLAB) is an advanced interactive educational multipurpose package to process and analyze GNSS data. The current release allows full processing capability of GPS data, and partial handling of Galileo and GLONASS. In addition, the tool is prepared to allocate future updates, such as a complete expansion for Galileo and GLONASS systems, as well as for EGNOS.

From an operative point view, this tool is conceived to support a practical GNSS course, by means:

- as part of a GNSS course with practical exercises integrated following a manual, or
- experimenting around with contextual help with hyperlinks for more information, or
- to use the SPP or PPP solutions for specific research or GNSS applications development.

The GNSS-Lab Tool suite (gLAB), developed under a contract with ESA Education Office, is intended to fill an educational gap supporting European university students and professionals in GNSS data processing.

IX. ACKNOWLEDGMENTS

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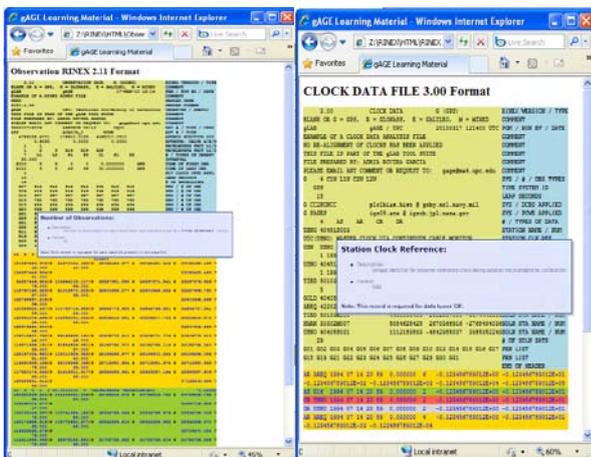


Figure 11. Example of the GNSS Format Descriptions utility.

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