GNSSGET and GNSSPLOT Platforms

Matlab GUIs for Retrieving GNSS Products and Visualizing GNSS Solutions

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Abstract: The emergence of new satellite systems such as Galileo and BeiDou, as well as the modernization of GPS and GLONASS, indicate dramatic changes in the field of satellite positioning. IGS initiated the MGEX (Multi-GNSS Experiment) campaign to overcome the challenges that scientific community has to face due to the arrival of new satellite systems. The variety of products improves and enhances the solution provided by multi-GNSS techniques. However, these heterogeneous products are provided by various Data Centers (DC) and Analysis Centers (AC) in many different locations. Users are therefore required to acquire their data across multiple FTP Servers, a rather cumbersome and time consuming task. The aim of the work described in this paper is to create a platform for the acquisition of GNSS data from heterogeneous sources, for performing high accuracy position solutions and building data visualizations concerning positioning error and solution accuracy. All of these tasks are essential for the purpose of making complex GNSS data more accessible, understandable and useful for precise point positioning, atmospheric research and other applications.

1 INTRODUCTION

Current satellite-based navigation systems include the following technologies: GPS (American), GLONASS (Russian), GALILEO (European), BeiDou (Chinese), QZSS (Japanese) and IRNSS (Indian). The number of satellites of the newly developed GNSS systems continues to increase, thus steadily improving accuracy and reliability in positioning (Li et al., 2015). New signals are more resistant to environmental conditions and multipath errors, while also enabling easier detection of low level signals (Hofmann-Wellenhof et al., 2008). In addition, the availability of non-encrypted signals at multiple frequencies gives a new dimension to resolving the ambiguity resolution and may also contribute to the analysis of ionosphere delays (Montenbruck et al., 2014). However, from the combination of multi-GNSS observations various other practical problems have emerged concerning the compatibility and interoperability between GNSS systems (Håkansson et al., 2016). To overcome these difficulties, various Analysis Centers of the International GNSS Service (IGS)

provide new products so as to improve and enhance the solution provided by multi-GNSS systems: tracking station data, coordinates and velocities, satellite ephemeris, earth rotation parameters, zenith tropospheric path delay estimates and global ionospheric maps. Among several institutes and agencies providing such products are: CODE (Center for Orbit Determination in Europe), GFZ (Geo Forschung Zentrum), CNES (Centre National d'Etudes Spatiales), TUM (Technische Universität München), WU (Wuhan University) and JAXA (Japan Aerospace Exploration Agency) (Guo et al., 2017). Over the past five years, the Multi-GNSS Experiment (MGEX) has been set-up by the IGS to track and analyze all available GNSS signals and to extend its services to GNSS user community by contributing multi-GNSS observations and data products from newly established or modernized monitoring IGS stations (Montenbruck et al., 2017). In this paper, we describe new software suitable for gathering distributed data needed for GNSS processing and visualization of the GNSS data solutions. This software works in full synergy with

the open source RTKLIB during the stage of data processing.

The remainder of the paper is structured as follows: The second section of the paper presents a brief introduction in GNSS positioning theory. The third section outlines the features of relevant GNSS processing software solutions and tools provided by GNSS receiver's manufacturers, universities, institutes and online services, pointing to their shortcomings with regard to the user effort required to retrieve various IGS products needed for processing and to visualize the processing results in a readily manner. In the fourth section, in lieu of a comparison, we present the newly created platforms, highlighting the added functionalities they provide to the end user. Finally, the fifth section concludes the paper with a summary of findings.

2 BASIC CONCEPTS IN GNSS DATA PROCESSING

A variety of applications such as environmental monitoring, earth-resource mapping and navigation require high resolution data. These data are derived from sensors, radars and satellite systems (Massinas et al., 2017, Protopapadakis et al., 2017).

GNSS positioning is based on the concept of trilateration, which is the method of determining the position of an unknown point by measuring distances to it from points at known coordinates. At a minimum, GNSS absolute positioning, requires four simultaneous "pseudoranges" to four satellites, in order to compute a receiver's coordinates (x_r, y_r, z_r) and time (t) (Figure 1).
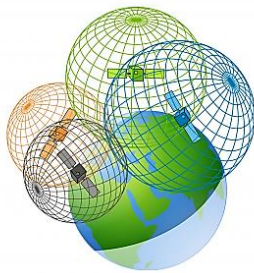

Figure 1: Geometric interpretation of absolute positioning (after http://gisgeography.com/trilateration-triangulation-gps/)

The transmitted signal from each satellite is encoded with the navigation message in the so-called broadcast ephemeris, which can be read by the user's GNSS receiver (Blewitt, 1997). The navigation message includes orbital parameters and other necessary information, from which the receiver can compute satellite coordinates (X^S, Y^S, Z^S). Knowing the signal travel time between receiver and satellite, the receiver coordinates could be computed with high accuracy depending on the availability of the various code and phase measurement observables.

The observation equations for code and phase measurements are (Teunissen et al., 2017):

$$p_r^s = \rho_r^s + c(dt_r - dt^s) + T_r^s + I_r^s + e_r^s \qquad (1)$$

$$\begin{aligned}\phi_r^s = \rho_r^s + c(dt_r - dt^s) \\ + T_r^s + I_r^s + \lambda M_r^s + \varepsilon_r^s\end{aligned} \qquad (2)$$

where, dt_r and dt^s are receiver and satellite clock offset from GNSS system time, T_r^S is troposphere delay, I_r^S is ionospheric delay, e_r^S and ε_r^S represent unmodeled errors, λ is the carrier wavelength, $M_r^S = N_r^S + \delta_r - \delta^S$ is the carrier phase-ambiguity with an integer part N_r^S and the instrumental receiver and satellite phase delays $\delta_r - \delta^S$ (cycles).
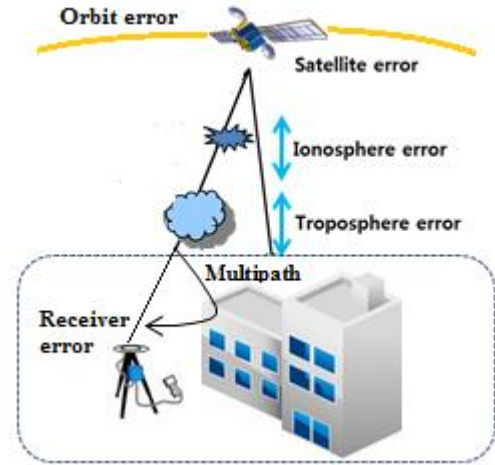

Figure 2: GNSS measurement errors

The code pseudoranges and phase-based ranges are affected by various systematic errors or biases and random noise effects. The error sources can be classified into three groups, namely satellite-related errors, propagation-medium-related errors, and receiver-related errors (Figure 2). Some of the systematic errors can be modelled and give rise to additional terms in the observation equations or can be eliminated by appropriate combinations of the observables (Hofmann-Wellenhof et al., 2008).

Through a least squares adjustment process of the available observations, during which all

corrections are made, the adjusted coordinates of the user receiver's position can be obtained as a time series depicting the convergence of the solution for each (X, Y, X or North, East, Up) coordinate (Figure 3), and similarly for other estimated parameters (e.g. tropospheric delays).
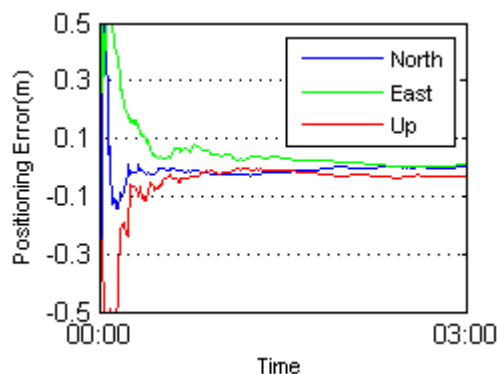

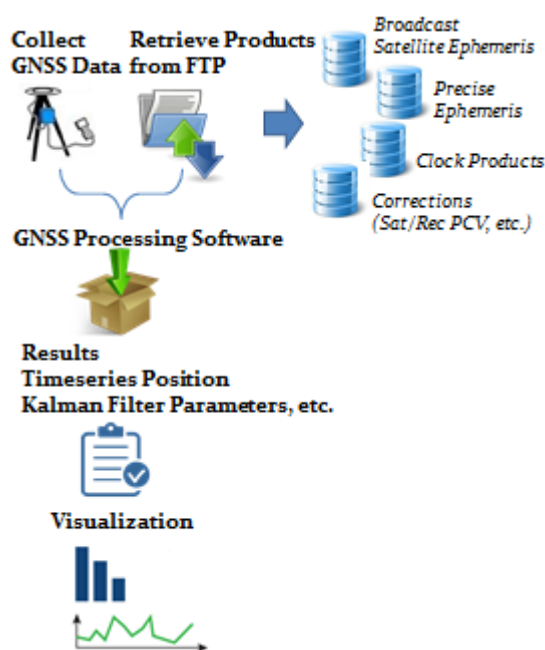Figure 3: GNSS positioning error

Figure 4: GNSS data processing workflow

Figure 4 presents schematically the field data collection and the subsequent computational procedure involved in order to come up in an accurate positioning solution, from a given set of GNSS observations and associated auxiliary IGS products. First, GNSS receivers collect observations, remaining in the field for a specific duration (from a few minutes to several hours or days). Then, the available products are gathered via FTP Servers. Having decided on the analysis mode to be applied

to the data, suitable processing is carried out in a software package with inputs all the data and available products. The output, in most cases, is a text file with the positioning solution results described by time series of various parameters, such as the estimated states of a Kalman filter, and residuals of the measurements. For interpreting and validating the processing results, visualization of the available position-related time series are used pervasively in order to enable a rapid visual assessment and to provide informative ways of understanding the data itself, as well as the quality of the positioning solutions obtained.

3 RELATED WORK

Currently, there are many software packages available for GNSS data processing and visualization. Most manufactures of GNSS receivers produce their own software for processing the observed field data in order to obtain adjusted results (Mohammed and Eldin, 2011). A typical shortcoming of available commercial software solutions is that they do not target many of the current GNSS data processing and analysis issues involved. On the other end, universities and research institutes have developed many high precision GNSS data processing packages, such as BERNESE (Dach et al., 2015), developed at the Astronomical Institute of the University of Bern (AIUB), GAMIT/GLOBK (MIT) and GIPSY-OASIS (JPL).

Although these packages provide high performance and high accuracy processing techniques, currently they only support processing of GPS and GLONASS observations. Furthermore, they are not addressed to all professionals and the average user, as they are not very easy to use. There are also online tools for post-processing GNSS data, including the CSRS-PPP (Canadian Spatial Reference System, Natural Resources Canada), the Australian GPS processing service AUSPOS, the GNSS analysis and positioning software GAPS provided by the University of New Brunswick, online service APPS (Jet Propulsion Laboratory), and the commercial magicGNSS by GMV and CenterPoint RTX post-processing service provided by Trimble. The processing method mostly used by many of these online services is based on the Precise Point Positioning (PPP) technique and the output is usually a positioning solution file solution and report is generated in ASCII format. Characteristically, most of the above services do not provide a user-oriented graphical interface platform for exploitation

of advanced GNSS algorithms and available IGS products. Furthermore, they don't provide the capability for interactive visualization of GNSS position tracks for each station, for the purpose of enabling the identification of temporal relationships, jumps or deviations from expected trends etc.

The RTKLIB (Takasu, 2013) suite is open source software for standard and high-precision positioning using observations from all currently available GNSS satellite systems (GPS, GLONASS, Galileo, BeiDou, QZSS). It was developed by T. Takasu at Tokyo University of Marine Sciences and Technology and has been available for free since 2006. The fact that RTKLIB code is accessible to users, allows code modification and improvement, meeting user's needs. Since 2006, major improvements have been made to the software (latest version v.2.4.2), both by its developers and RTKLIB users. RTKLIB consists of a portable program library and several APs (application programs) utilizing the library in order to facilitate satellite data processing and determine the exact station's location. In addition, RTKLIB supports several file formats, such as RINEX, RTCM, NTRIP, ANTEX, and IONEX files. Also provides limited capability to process and convert data, to visualize the visibility (azimuths and elevations) and the number of the used satellites against time, and to export position results. This paper targets to deal with RTKLIB's disadvantages by improving RTKLIB's platforms for data acquisition and visualization. One disadvantage is that RTKGET has a complex procedure for data acquisition, causing confusion in most of the users. RTKPLOT interface doesn't include statistics and metrics of computed solutions. Furthermore, RTKLIB's interface doesn't plot code and phase residuals.

4 THE GNSSGET AND GNSSPLOT PLATFORMS

The newly developed GNSSGET and GNSSPLOT platforms have been created with the aim to allow the user, in a more transparent way, to communicate with the RTKLIB software while retrieving data from FTP Servers and performing user-selected visualization tasks at the end of the data processing stage. The technology and programming techniques applied for the development of these platforms was based mainly on MATLAB which provides the ability to develop GUI applications through the GUIDE (Graphical User Interface Development Environment). GUIDE is a graphical environment where a developer can build a GUI application, by selecting various objects -included in the final application- and by selectively adjusting various application parameters related to the GUI. In that way, certain properties of the user interface and graphics components corresponding to a specific user action can be associated with specific call-back functions. This provides point-and-click control of software applications, eliminating the need to learn a language or type commands in order to run the application. These platforms aren't open source and freely available to the users as they have been developed with MATLAB 2008 version.

GNSSGET is essentially an Information Communication Technology (ICT) platform which acts like an umbrella, collecting information from distributed data sources. Products vary, based on parameters such as: time, space, file format, Analysis Centers and product type. Various IGS-coordinated Institutes and Data Centers provide GNSS data via communication protocol FTP. The objective of the application is to retrieve data from isolated data sources and store them in the local disk. This is accomplished by selecting few desired parameters. The application functions are: storage of GNSS observations and preview, retrieval of broadcast and post-fit precise orbital data and associated products and their storage on the local hard disk. GNSS data and products, retrieved from FTP Servers, are spatiotemporal big data, that is can be in high volumes, and in compressed or uncompressed form. Following the data collection, GNSS data processing is carried out, by communicating automatically the data to RTKLIB and applying appropriate models and methods for positioning and eventually generating position solution results.

The next stage is the visualization of the results which prompted us to build GNSSPLOT GUI. Visualization includes time series diagrams, statistics and metrics, plotting position history of each GNSS station or georeferenced ground tracks using Google Maps as background, Kalman filter residuals and parameters as a function of time.

These two interfaces aim to direct the user, minimizing errors from handling the available data. In order to achieve this goal, these platforms provide dynamic lists and warning messages to prevent the user from frequent or common mistakes. The most important functions are:

- Gathering isolated GNSS data and products via numerous FTP servers

- Capability of local data storage and decompression
- Positioning error time series visualization
- Code and phase residual visualization
- GNSS systems and satellites residuals isolation
- Kalman filter parameters visualization

These platforms cooperate fully with the RTKLIB software in order to provide the best possible result.

4.1 GNSSGET Platform

GNSSGET platform has the ability to gather the distributed information needed through separated servers. A major advantage is that GNSSGET platform is already interconnected with these FTPs, so user doesn't need to establish data communication links.

Figure 5: GNSSGET platform overview

The user has the ability to select a specific data time duration, which is necessary in order to pick the suitable data from the FTP servers. Also, the user should fill in the tab showing the local path where downloaded data will be stored (Figure 5).

In the next step, the user is required to select the desirable parameters concerning the observation data, through multiple sets of paired drop down lists. The option between selecting global or regional networks triggers different categories of available networks appearing in the pop-up menu that follows. Subsequently, the Data Centers pop-up menu changes dynamically, depending on the selected network. Each selected Data Center deals with data from stations in different countries. Having selected the preferred location (country), the associated stations list is displayed. Hence, the user selects via a menu with variable networks, the data bases containing specific types of data and the desirable location of each station. (Figure 6).

Selected observation and navigation files could be previewed, pressing the corresponding button. Also, the platform has the ability to inform the user in case of a missing file.

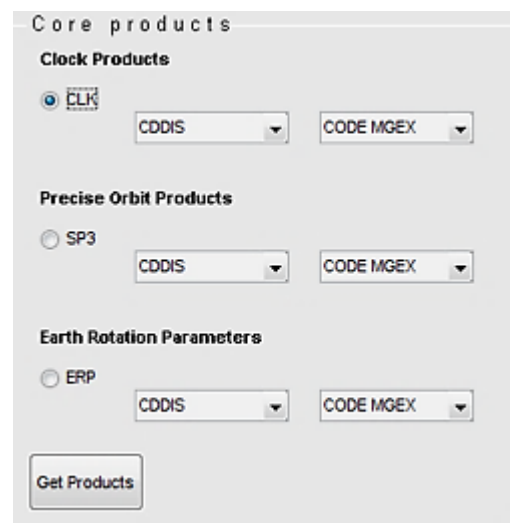Figure 6: Options for observation files selection

Figure 7: Selection of download data type products, in GNSSGET

From the tab named "Products", the user can choose through a variety of products such as: clock products, precise orbit ephemeris and earth rotation parameters, as they provided by various data bases and institutes that can be seen through the click-and-display menus (Figure 7). Among each product (CLK, SP3, ERP), a set of two paired select boxes

exists. User's selection in the first select box affects the options in the other select box. By pressing the button "Get Products", the desirable products are downloaded and stored in the local disk. When the process is finished, a suitable message appears on the white bar.

Figure 8: Introductory menu, in GNSSPLOT

4.2 GNSSPLOT Platform

GNSSPLOT is a platform for GNSS solutions visualization, including time series diagrams, statistics and metrics.
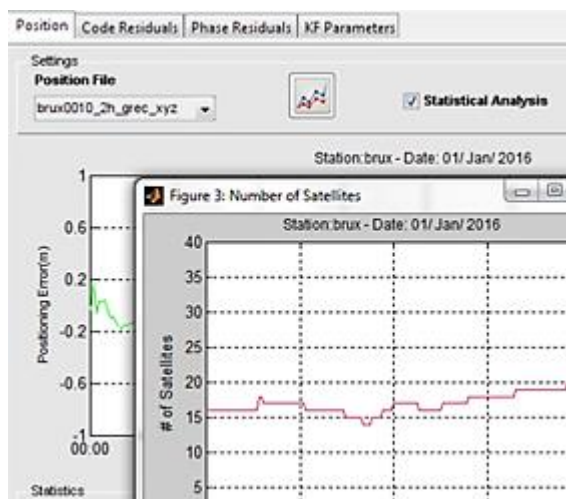

Figure 9: Tab "Position", in GNSSPLOT

Initially, an introductory menu is displayed as "welcome window", to allow the user to enter into the program. Platform has the capability to search the file folder as extracted from RTKLIB. The platform has been created to automatically recognize the number and useful types of files (.pos, .stat) that are contained in this folder. In the event that the folder does not contain files with .pos format, as extracted from RTKLIB, then a corresponding warning message appears on the screen (Figure 8).

On the other hand, GNSSPLOT reads positioning files (.pos) and status files (.stat) and stores their names in order to appear in the main interface, in a pop-up menu form. Then, a window with four tabs -displaying the main menu- opens. As already mentioned, the select box up-left contains the file names that exist in the specified folder. Thus, the activation of the first tab named "Position" (Figure 9) requires the existence of a positioning file in the specified folder.
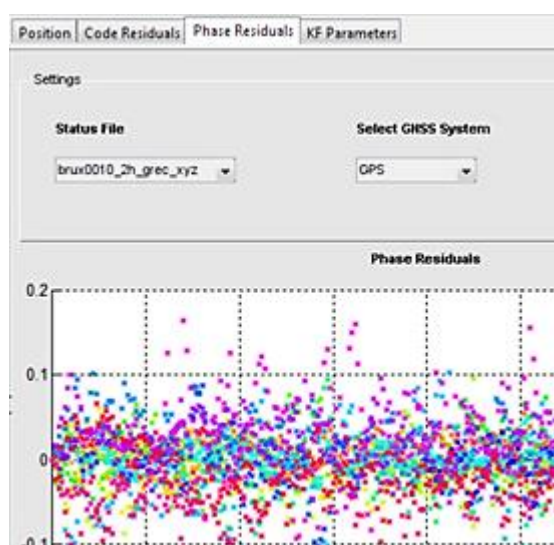

Figure 10: Code residuals visualization

Among GNSSPLOT's advantages, the visualization of positioning errors is included. Furthermore, statistics such as mean and standard deviation are computed. This platform also allows users to visualize the georeferenced ground track (by pressing the button "Ground Track"), in Google Maps background. GNSSPLOT provides the ability to easily display ground track at any scale, using the zoom in property, thus it is possible to visualize the ground track. In addition, the number of visible satellites over time can be plotted (by pressing the button "View of satellites").

Reading a status file, if it exists, code and phase residuals can be plotted, in the second (Figure 10) and the third tab.

Selecting a single GNSS system, from the second pop-up menu, the residuals from all observations to this satellite system are plotted (Figure 11).
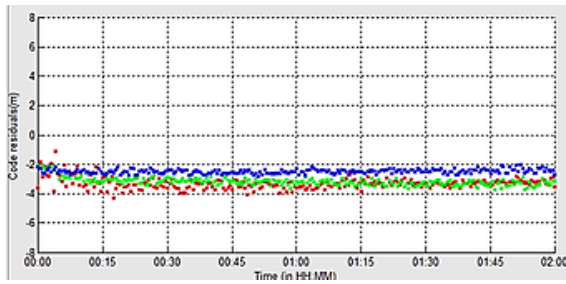
Figure 11: Code residuals for Galileo satellites, G31, on 1/1/2016

Also, there is the possibility of selecting a single satellite from the third pop-up menu (Figure 10). This way the errors from this specific satellite can be displayed (Figure 12).
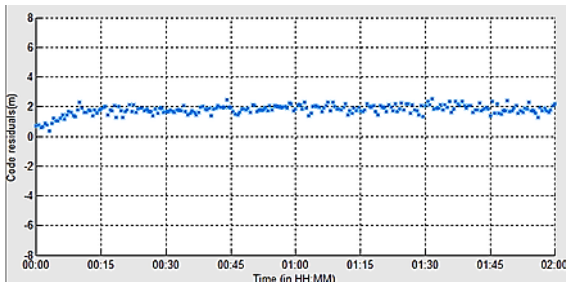

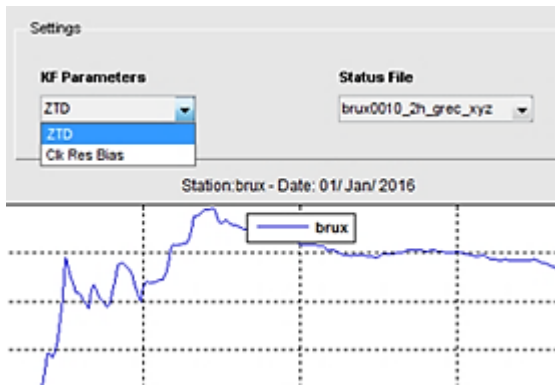Figure 12: Code residuals for GPS satellite, G31, on 1/1/2016

Figure 13: Kalman filter parameters visualization

Finally, zenith total delay (ZTD) and receiver clock bias are displayed in the fourth tab (Figure 13). In the first step, the user selects the type of data between ZTD and receiver clock bias in order to be plotted. In the next step, the user selects the status file name. Selecting any of the above-mentioned lists the plot is triggered.

All plots can be locally stored by pressing right-click on the image. Both newly developed platforms can be extracted in an application executable from MATLAB environment, thus providing a standalone application running in Windows. Necessary libraries needed for installation, are extracted from MATLAB and are installed together with a standard application installation.

5 CONCLUSIONS

The usage of multi-GNSS positioning systems offers several advantages for the user, mainly due to the increased number of available satellites and the enhanced user-to-satellites relative geometry (Cai et al., 2015, Li et al., 2015). As a result, the quality of positioning solutions is being improved, while the time required for field observations is being reduced. System interoperability is very important towards ensuring, higher accuracies in the future.

Many services and Analysis Centers provide products and observations from permanent stations which can be extremely useful in that respect. However, their proper usage is often confusing to the new users. To ease the tasks involved, GNSSGET is a platform, which can be used to download data and products from existing online databases through the FTP communication protocol.

Proposed platform provides the ability of data extraction among different Analysis Centers. This is achieved by selecting a desirable set of features provided by dynamically changing lists that communicate with each other and at the same time complement one another. Data are stored in a location per service, type of processing, and time, with the initial path for the storage of data indicated by the user. GNSSPLOT, focuses on visualizing solutions, derived from RTKLIB.

Unlike the extension of RTKLIB -RTKPLOT- which permits the visualization of a single set of solutions, the GNSSPLOT interface has the ability to visualize multiple sets of solutions by simply changing the options of a dynamic list. Furthermore, GNSSPLOT is a powerful tool to visualize GNSS position time series and other corrections and residuals.

The authors plan to create a web service in order to fully provide the platform's abilities to the users. This future service will include all the above mentioned functions that are provided through platforms GNSSGET and GNSSPLOT. Furthermore, the web service is more convenient as the installation of a standard application in the PC wouldn't be prerequisite. The exploitation of similar platforms should be considered in other applications as well (e.g. intangible cultural heritage digitization).

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