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Full Length Research Paper

Design and testing of a web-based automatic high precision GPS data processing environment

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While GPS (Global Positioning System) has been in daily life in form a navigation tool for nearly three decades, its applications have been matured to provide valuable information for a wide range of areas requiring very high precision such as geophysical and seismological studies, earthquake prediction, deformation monitoring. High-precision GPS data processing requires incorporating elaborate models of numerous physical phenomena such as ocean loading, solid earth tides, troposphere and ionosphere modeling, water-vapor modeling, robust phase ambiguity resolution. Commercial software has limited applications and often lacks such fine and complex modeling capabilities which are usually developed and applied in research institutes and universities. The academic software developed in universities and research institutes are generally highly complicated lacking a user-friendly environment and an easy learning curve. On the other hand, today's engineering requirements is constantly increasing and more precise GPS data processing methods are needed. In this study, we present a web-based approach to high precision GPS data processing which integrates the complex data modeling methods in the server side with the user-friendly interface in the client side. A complete application was also given in details.

Key words: Global positioning system, data processing, web-based positioning.

INTRODUCTION

Early applications of GPS have been limited to navigation without any user interaction or any post-processing or further modeling (Seeber, 1993; Rizos, 1997). Growing applications of GPS have also improved the error models and baseline precision of up to 0.01 ppm has been obtained (El-Rabbany, 2006; Herring, 1999). In this respect, most studies focused on improving the precision of GPS observations through post-processing and modeling and such efforts led to sophisticated research software packages such as GAMIT/GLOBK (King and Bock, 1998) and Bernese (Beutler et al., 2001), GIPSY (Zumberge et al., 1997). Complex and impractical nature of such research software has always been avoided by commercial applications. However, such today's applications demand more precise results and new technologies were need to reconcile the differences between high-precision research efforts and practical applications (Langley, 1993).

Following the establishment of national continuous networks, online positioning services have been proposed such as in Canada (Heroux et al., 1993), in USA (Weston et al., 2007a; Weston et al., 2007b; Soler et al., 2006) in Australia (Dowson et al., 2002) . In such studies, main focus is generally rapid-static surveys (Erickson, 1992) and the reference sites are usually fixed and the service is controlled centrally by the national mapping authority. In addition, an abstraction is applied which does not allow the full control of the computing process. Establishment of continuous networks eventually resulted in real-time continuous networks. Real-time continuous networks have provided instant access to moderate precision but still lack the necessary

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precision for demanding applications such as deformation monitoring. Today, both the static continuous and Real-Time Kinematic (RTK) continuous networks are getting more and more popular and position computation is now theoretically possible within a few centimeters.

For the most precise applications, the user still has to use complicated scientific research software which also require a sufficient technical background and a long training. The alternative models and strategies available in such software should be exercised with caution and could lead to large differences. On the other hand, high-precision GPS results are also needed by many people in various fields without the necessary technical background. In this respect, a practical tool is needed to provide high-precision GPS results practically. Moreover, such a tool should be independent of the operating system of the users which is the one of major drawbacks of scientific software in practice.

The service centrally provided by the few national institutions should be extended to allow for near-real time applications and more user interaction. In this study, the design and implementation of such a positioning system is presented. The proposed online system has the advantage of ultra high precision as well as a user-friendly interface and practicality. Background processing engine has been chosen as GAMIT/GLOBK 10.34 software which incorporates state-of-art models (Maraş, 2010). Some of the original modules of GAMIT/GLOBK software has been modified so as to work efficiently in the proposed online positioning system. Since the proposed service will be web-based, the user does not have to allocate a Unix/Linux computer to process data which is the only platform GAMIT/GLOBK can run.

Another advantage of the proposed system is that the reference network has been designed as scalable. In this respect, the user can also add stations to the reference network. If the user prefers not to get into the details about the network, the application was so designed that the optimal set of network stations are used in the system. In this configuration, even a single observation file is sufficient to obtain millimeter level precision. The available reference network can optionally be designed in hierarchical manner such that the user can choose the remoter station with better accuracy or nearer ones with relatively lower accuracy. In any case, user supplied observations are processed by the processing engine simultaneously. The server runs in Linux Debian 2.6.24-etchnhalf.1-686 platform.

DESIGN AND IMPLEMENTATION OF THE POSITIONING SERVICE

Workflow and employed technologies

The interface of the web-based positioning service was deliberately designed in pure HTML pages to avoid dependency of the third-party products (Adobe Flash, Microsoft Silverlight etc.) and make the service platform (Mac OS, Windows, Linux etc.) independent. The service allows the user to input GPS observation data in RINEX format and to obtain high-precision coordinates in return (Maraş, 2010). Since the reference sites of the network are well stationed and collect all the available data, the only requirement for high precision results is dictated by the user observation such as the length and the number of locked satellites. The general workflow of the service can be summarized as follows:

(i) Obtaining user data and user choices through web interface.
(ii) Checking data integrity and updating default settings.
(iii) Processing the data through the engine.
(iv) Presenting the results to the user in numerical and graphical format.

Various technologies and methods have been employed for the design of the positioning system. The tools were chosen as much flexible as possible and are shown in Table 1.

User preferences and settings

The user preferences and settings have been designed to work without any input from the user. Such a procedure helps the novice user with an appropriate list of default choices. The default settings were also carefully adjustment to meet the requirements of a practical user. The user interface for the preferences is given in Figure 1. The options offered to the users are as follows:

(a) Solution type: The user can choose between different strategies for the solution (L1&L2, L1_ONLY, L2_ONLY, LC_ONLY, L1_L2_INDEPEND, LC_AUTCLN) which has an impact on the solution. For instance, L1_ONLY is the best choice for short baselines (< 5 km). Similarly more precise results can only be obtained with LC_AUTCLN option. The user choice is collected in a temporary file then input to the processing engine (Herring et al., 2006). A general difference between the algorithms is about handling the ionosphere constraints (Wanninger, 2004).
(b) Zenith delay estimation: The user can opt for estimating the zenith delays explicitly in the processing. Most commercial software uses modeled delays. Default value is “Yes” to better model the troposphere. In typical zenith delay estimation, a stochastic quantity is estimated in addition to the deterministic part in order to account for the unmodeled effects, in particular for the effects for water vapor which is difficult to model (Bisnath et al., 1997).
(c) Atmospheric gradient: This option is also related with the zenith delay estimation. In addition to the zenith delay estimation, the user can put stochastic constraints on the spatial distribution of the estimated quantities. The options in this list are Yes/No. The details of the gradient modeling can be found in (Mendes and Langley, 1994).
(d) Atmospheric loading: Atmospheric loading can also have an impact on the results. The main grid files are applied as given in Tregoning and van Dam (2005). In particular, the weighted root-mean-square of the vertical component can be reduced significantly.
(e) Tropospheric constraint: This option is useful when the user decides to estimate the zenith delays explicitly. In this case, a constraint is applied to the residual zenith delays to improve the estimation.
(f) Elevation mask: In general, elevation mask is applied at the observations level. For instance, the GPS receiver equipment can be set to collect data at higher than a specified elevation angle.

Table 1. The employed technologies for various stages of the service.

Modules	Web technology
User interface	PHP, HTML, JavaScript
System settings	PHP, HTML, JavaScript
Data input/output	PHP
Data checking/Integrity monitoring	Flash, ShellScript
IGS data/products/FTP process	ShellScript, Flash
Data processing	ShellScript, Flash, GAMIT
Kalman filtering	ShellScript, GLOBK
Preliminary results/visualization and mapping	PHP, HTML, JavaScript, Google Maps
Coordinate transformations	Perl, C++
E-mail services	ShellScript

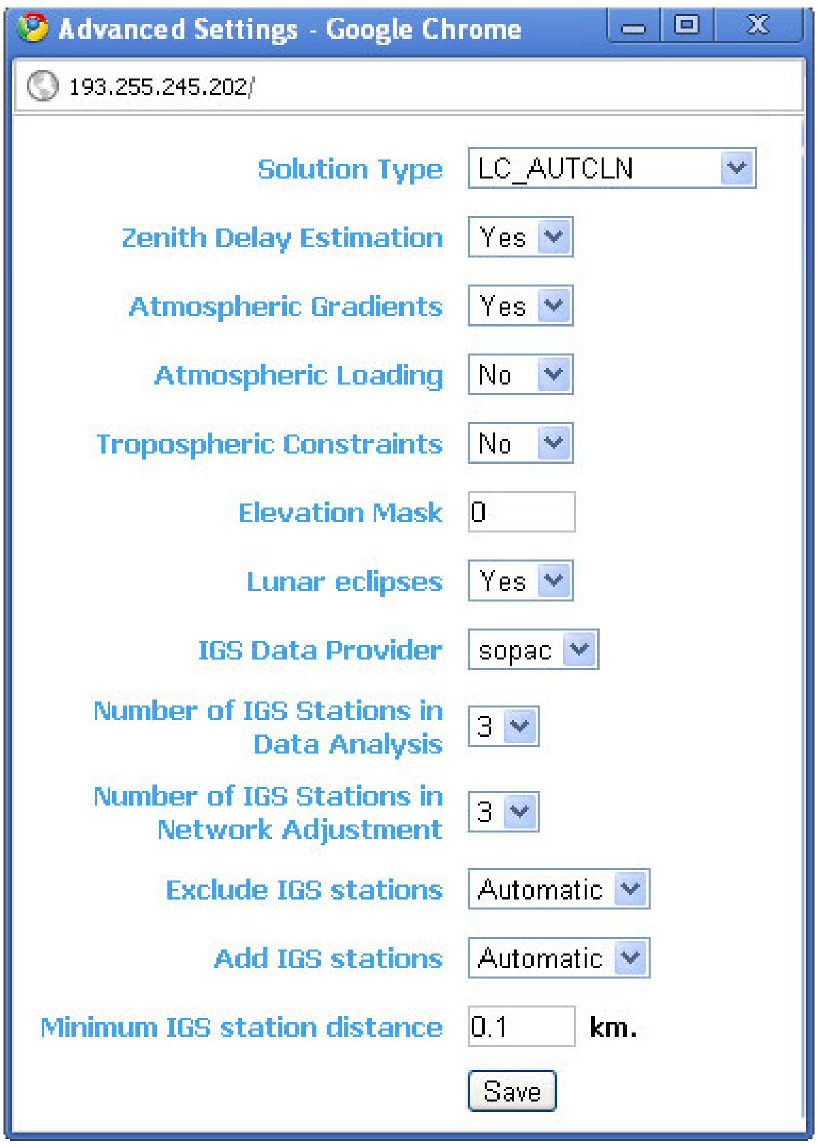

Figure 1. Settings for the users.

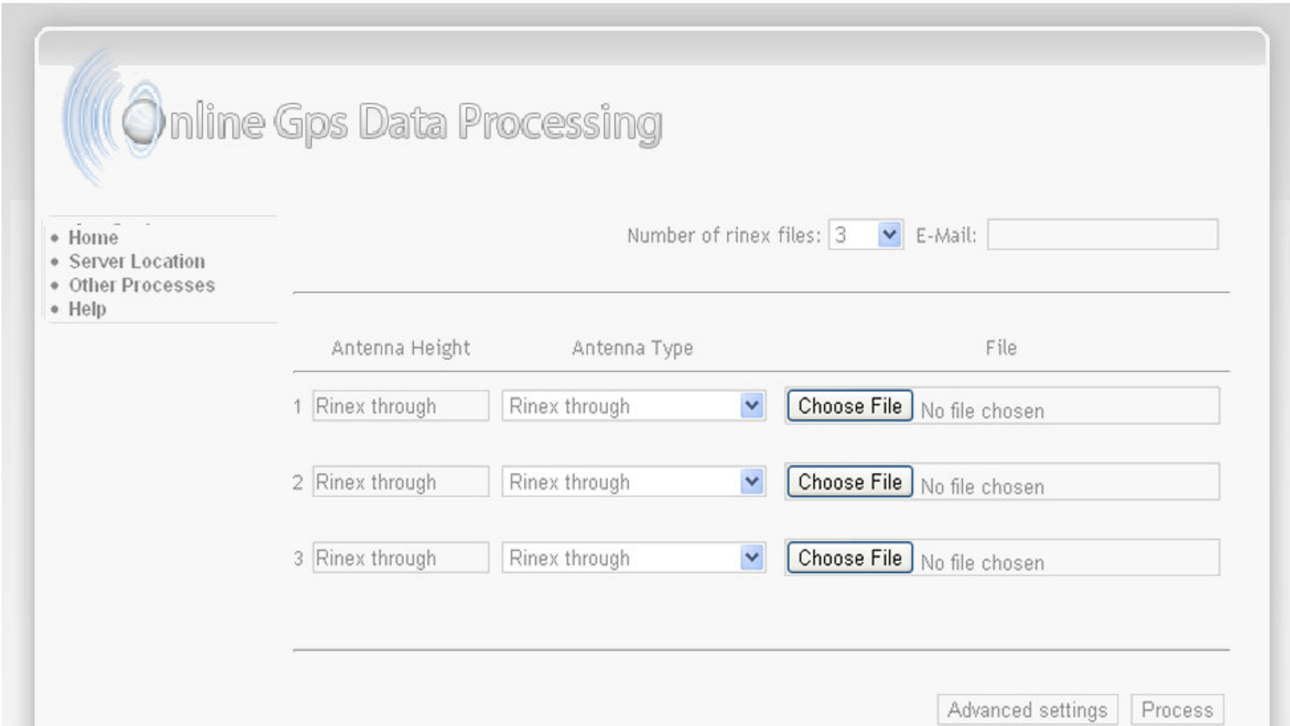

Figure 2. Introduction page.

Typically such threshold is 10 to 15°. However, for short data spans or limited satellite visibility, even the satellite data from a lower elevation can help resolve ambiguities and strengthen the estimation. This option is for those who want to do a fine-tuning about the elevation mask.

(g) IGS data provider: International Global Navigation Satellite Systems Service (IGS) consists of data and analysis centers. The IGS products such as precise orbits are provided to the users via the data centers (Kouba, 2009). However, each analysis center also has its own products before final combination. Moreover, some internet connections to the specific data centers can be slow. This option offers the user to choose the IGS data provider. The online positioning system then uses the related configuration to download the necessary data from the specified IGS data center.

(h) Number of IGS stations in data analysis: The processing service can be configured to run with as many reference stations as available. However, the user can choose fewer stations to minimize the computation time.

(i) Number of IGS stations in network adjustment: The processing service was configured to run with at least three reference stations. However, the user can choose fewer stations. Such an approach can have an advantage in the network adjustment phase in which the user can choose a subset of stations with the most precise coordinates.

(j) Exclude IGS stations: In this option, the user can exclude certain IGS stations from the analysis for testing purposes or to be able to use only the nearest reference station. Alternatively, the user can exclude stations which appear to noisier.

(k) Minimum IGS station distance: The errors of the GPS observations in double-difference processing are a function of baseline length. In this respect, remote stations can be excluded from the analysis based on the distances.

Graphical user interface

The introduction page was designed in pure HTML. The introduction page is shown in Figure 2. Since the user is supposed to provide the service with various inputs such as antenna height and antenna type, HTML form objects are formed in run-time through PHP based scripts. In the second part of the introduction page, the user can upload his/her own data through the service provided by the online positioning system. The most popular format for GPS observations is the Receiver Independent Exchange (RINEX) Format (Gurtner, 1994). However to minimize the file size, they are often kept in compressed form such as (*.Z), (*.gz). The positioning system is smart enough to uncompress the compressed observation files before the data processing. The upload service supports uploading of up to 7 files simultaneously.

Following the uploading of the files, the system checks if the meta-data about the observations in the RINEX format is consistent with those provided by user. Those provided by the user directly overrides those given in RINEX observation file(s). Specifically antenna type and antenna height are the most important inputs. Antennas have a variation of electrical phase center with respect to the physical phase center. Such variation is often modeled as a function of elevation and azimuth. Antenna manufacturers often provide calibration reports for the antennas and the online positioning service make use of the calibration values in the computation process. For the case of antenna heights, they are often measured in slant heights which should be reduced to vertical heights taking the antenna size into account. The proposed positioning service treats the data with the antenna properly as long as the meta-data is provided by the user. If the user does not provide the meta-data, then positioning service look for the necessary information in the observation files.

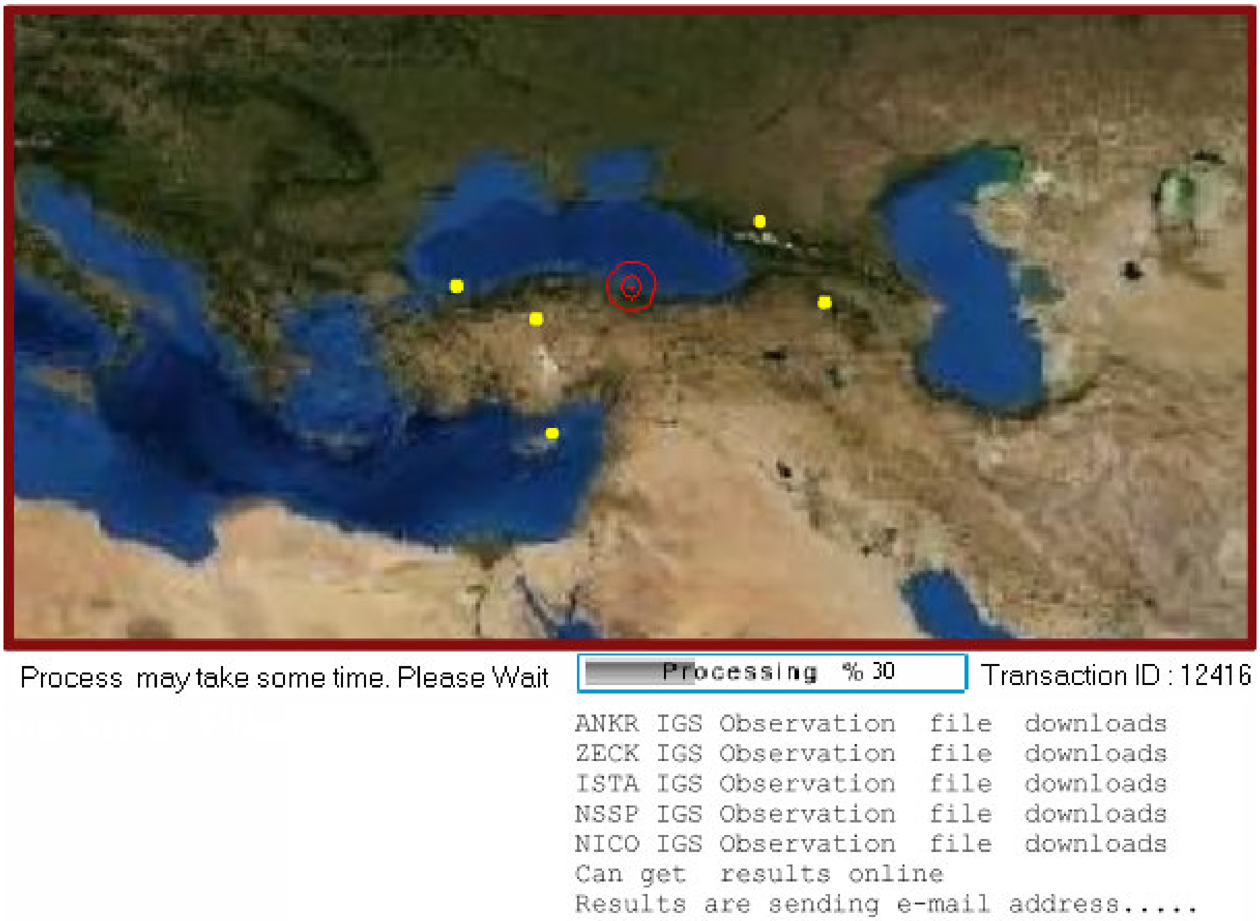

Figure 3. Downloading the IGS data through ftp and progress bar.

Automated processing

The data processing is initiated through the button located on the main page. This is the minimal necessary interaction provided by the online processing service. After uploading the observation files, the user can initiate the basic solution. The processing service will run with the pre-configured default values and will produce an optimal solution. The average processing time depends on the number and the size of RINEX observation files, internet bandwidth of the user and the number of the simultaneous users. After submitting the files, a concise report is sent to the user verifying the integrity of the observation files and giving a process ID. The processing service appoints a unique process ID for each submission. Since the process-dependent input files are necessary for each job, the service automatically creates temporary directories to handle the preferences of each user independently. Another useful property of the positioning service is the automatic quality checking of the GPS observations.

The approximate coordinates given in the header of the RINEX observation are used to display the distribution of the sites on a map. All the available IGS stations were analyzed for selecting the nearest stations and the necessary observation files of the selected subset of the stations are searched at the IGS data centers such as SOPAC, CDDIS, UNAVCO and are downloaded through File Transfer Protocol (FTP). The submitted stations along the IGS stations are marked on the map as shown in Figure 3. After completion of the data, processing engine is started and the progress bar is shown as in Figure 3.

The actual process time depends on the content of the submitted files. The results can be shown online and/or through e-mail. Even in the case that the internet connection is lost or the user closes the browser, the results are still sent to the user via e-mail. The baselines and neighboring reference stations are also displayed on the screen through Google Maps as shown in Figure 4. The processing time for a single station of 24 h is under 3 min. The duration depends on how busy the IGS data providers and the accessible internet bandwidth.

The statistics provided by the positioning service is an important indication of the quality of the results. The final evaluation of the results can be done by checking the normalized root-mean-square (NRMS) of the overall data processing. Any discrepancy between the ambiguity-fixed and ambiguity-free solutions can be traced back to a problem with the ambiguity fixing procedure. For a 24 h observation the results should be similar. The popup window giving quality indicators and the statistics is shown in Figure 5.

Computed coordinates of the stations are also displayed graphically as shown in Figure 6. Both Cartesian and geodetic coordinates are supported and the coordinates of any site can be

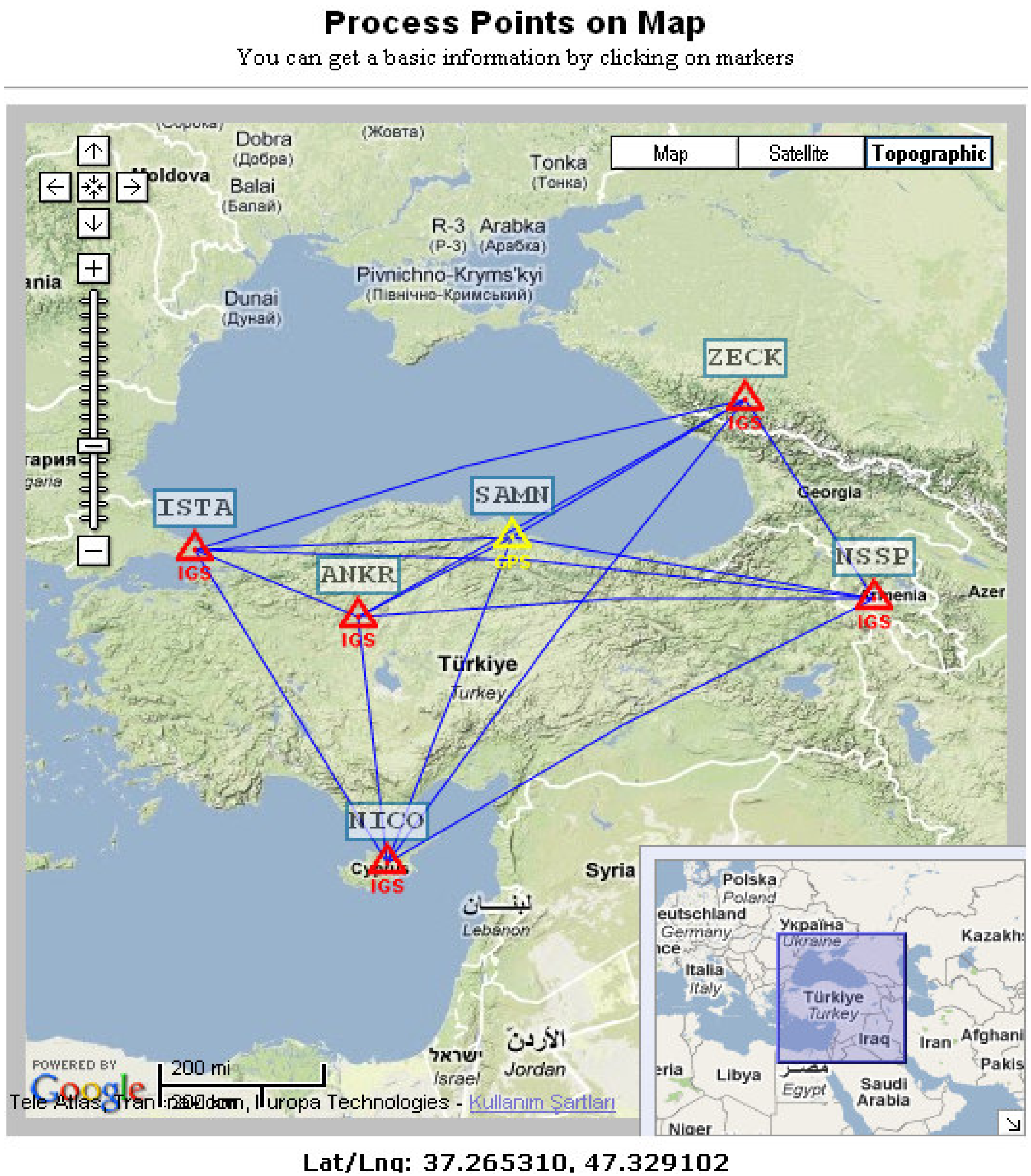

Figure 4. The display of the baselines and the nearest stations.

accessed by simple clicking.

RESULTS

The quality of the results was also analyzed. Since the coordinate precision is a function of the observation duration, results are presented as a function of observation span as shown in Figure 7. Performance of observations with durations less than three hours heavily relies on baseline lengths. Since the main objective is to investigate the performance of the web based positioning

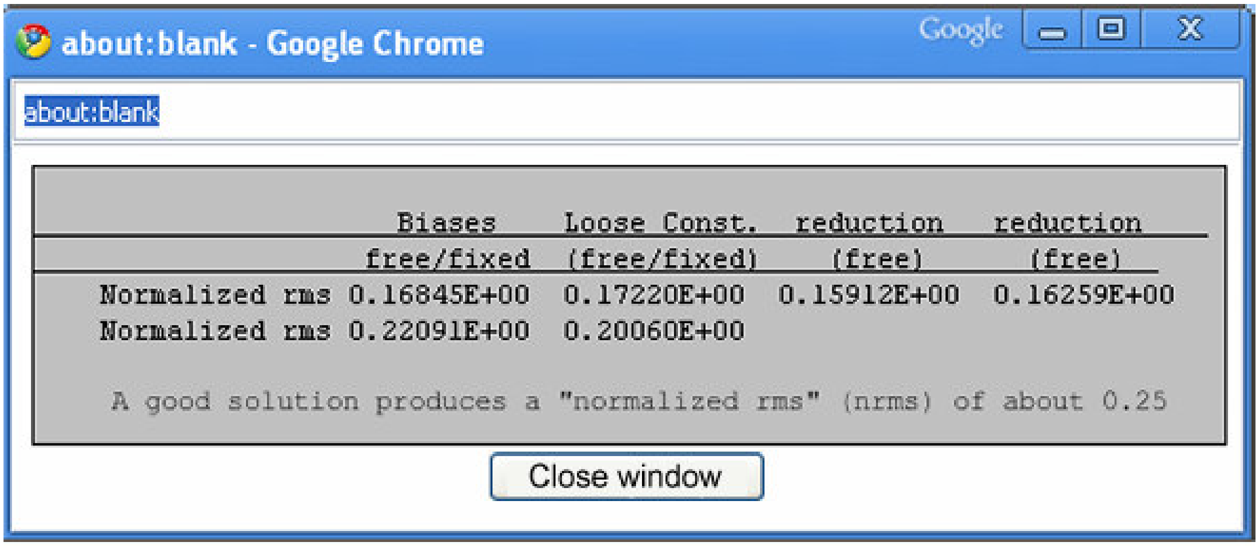

Figure 5. Quality indicators and statistics.

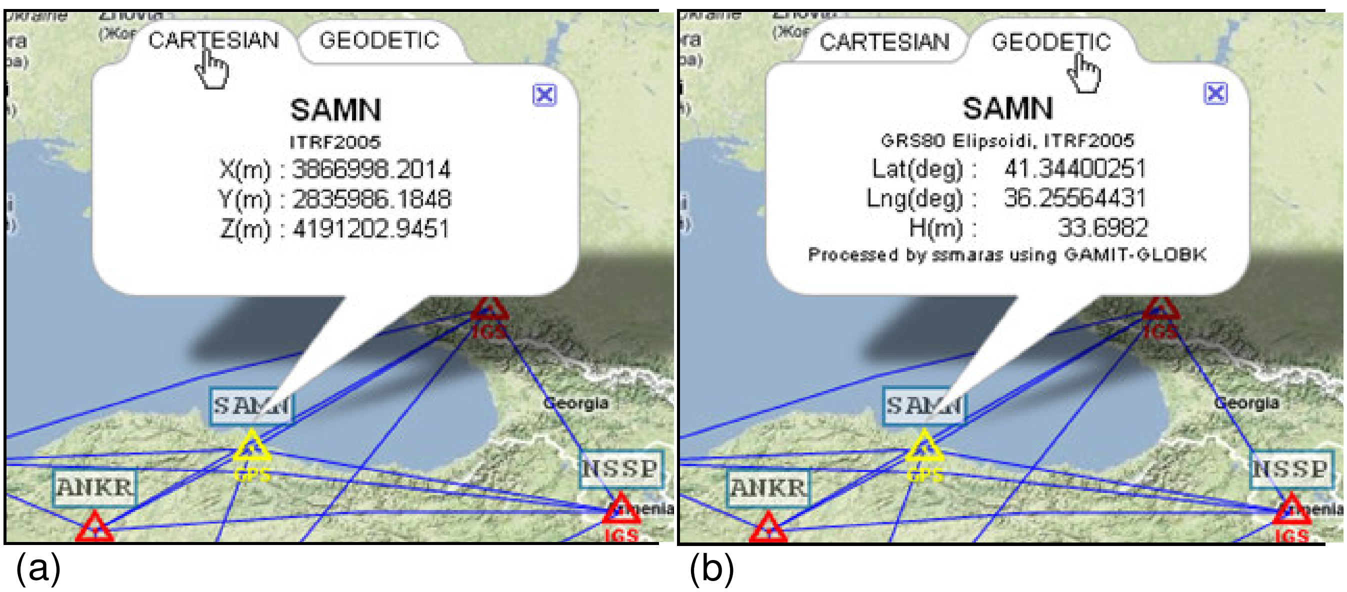

Figure 6. Display of the different coordinate systems (a) Cartesian (b) Geodetic.

service and the baseline length specified by the station submitted by the user, a long baseline was selected as a worst scenario and the analysis was carried out based on the observation span rather than the baseline length.

Several researchers have also investigated the performance of data processing in terms of observation time (Eckl et al., 2001; Psimoulis et al., 2004; Snay et al., 2002; Soler et al., 2006; Weston et al., 2009). The results show that the proposed online positioning service provides the users with comparable even better precision.

Conclusion

Web-based online positioning services have several advantages: (1) homogenization of the produced coordinate sets (2) cost-efficiency due to the required

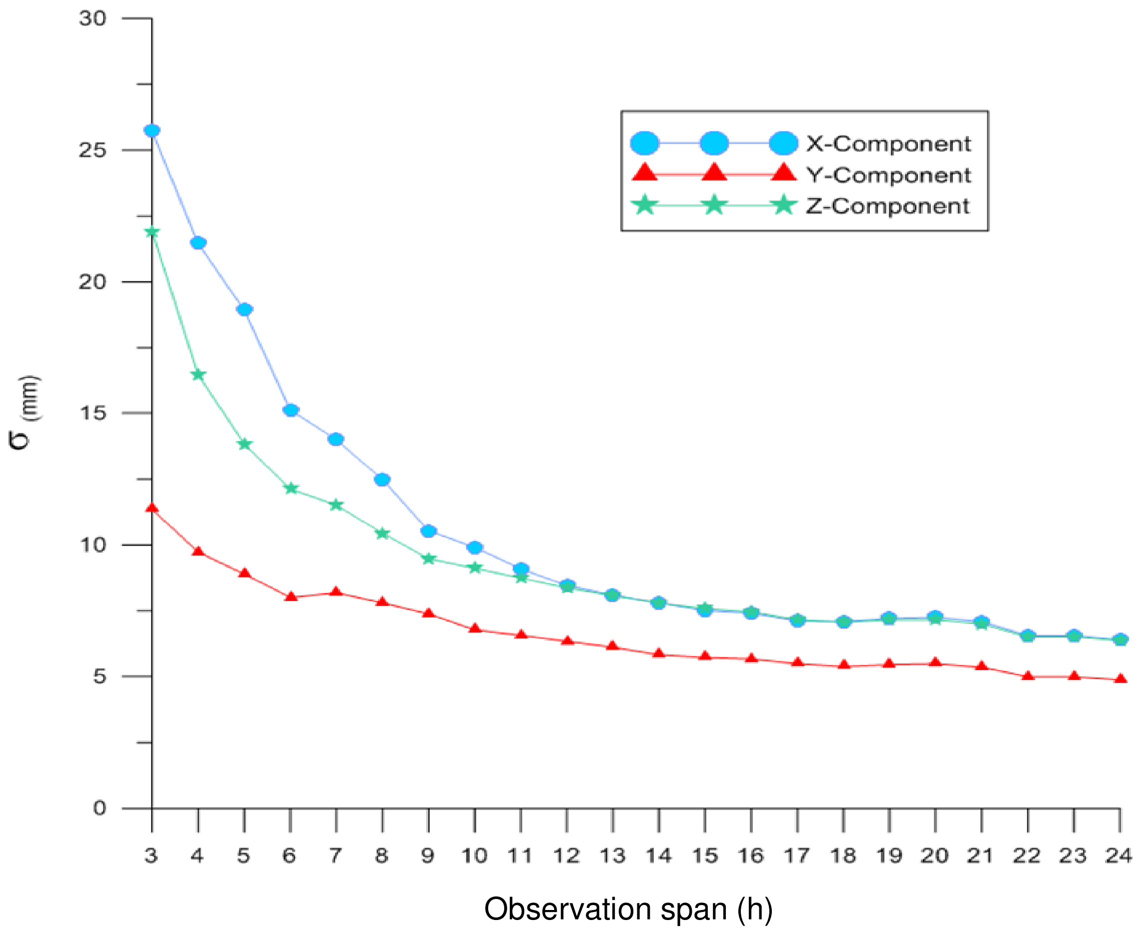

Figure 7. Obtained precision as a function of observation span.

minimal hardware (2) minimizing the training to make use of high-end processing software (4) Instant Visualization of the results (5) Correct application of newest error models (6) Detailed reporting (7) Automation. Minimization of the user interaction together with well-configured default settings has the potential of producing high precision coordinates in a very short time. On the other hand, the proposed positioning service has also the necessary tools for fine tuning. Many complex modeling such as atmospheric modeling of tropospheric delays, zenith delays, atmospheric loading can be applied with or without any user interaction. The custom selection of the reference network to be incorporated into the analysis is also found to be very useful. The proposed positioning service is designed to be scalable to networks of any dimension. The working principles of the design were deliberately made flexible to enable easy adaptation.

The performance of the proposed system can be examined in two distinct terms. The required process time of the service is much less than a desktop computing system due to the fact that the service runs at central high performance server. In this respect, only uploading of the files into to system depends on the bandwidth of the user. The second term is about the precision. Since the provided service can process complex error models, the obtained results are not surprising and positioning service has the potential of producing ±5 mm precision for the coordinate components even over several hundred kilometers baselines.

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