PPP: Precise Point Positioning – Constraints and Opportunities

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Key words PPP, GNSS, positioning, low-cost

SUMMARY

Precise Point Positioning (PPP) is a satellite based positioning technique aiming at highest accuracy in close to real-time. First investigations using dual frequency data from a single GPS receiver data for a few cm-positioning in post-processing mode have been published in 1997 by JPL. Utilizing the ionosphere free linear combination the remaining required model information like precise orbits and clocks issued by the IGS has been used. Within the last decade a number of approaches have been carried out to serve applications in close to real-time by this technique. In comparison with common techniques like DGPS or RTK, the costs are reduced, because no base stations and no simultaneous observations are necessary. On the other hand the necessary models have to be fetched either from globally acting services like IGS (orbits, satellite clocks) or from regional GNSS service providers (atmospheric delays) and standard interfaces (e.g. RTCM) have to be developed to forward this information to the rover. Further problems still to be solved are coordinate convergence periods of up to 2 hours as well as ambiguity resolution, which are harmed by non-integer calibration phase biases. These biases vanish only in difference mode and have to be determined a priori.

The main focus of the research presented in this paper is to enhance the actual achievable accuracy of PPP and to reduce convergence time. Therefore detailed investigations on new PPP algorithms and methods are carried out within the project RA-PPP (Rapid Precise Point Positioning) focusing on the derivation of improved ionospheric models providing a better accuracy for single frequency users and on the use of “regional clocks” - a method to further enhance the positioning accuracy. Furthermore, linear combinations making use of new GNSS signals are investigated to improve the noise behavior with respect to commonly used linear combinations.

Additionally, a PPP software module that applies the developed algorithms and techniques to real GNSS data is developed during the research project. PPP is performed by means of a commercial GNSS receiver supported by a small processing device, but much improved accuracies than operating in standard positioning mode can be achieved. Several testing and verification routines evaluate the performance of applied algorithms and individual calculation steps. Also a later modification with regard to GNSS modernization (new signals) is considered.

Finally several fields of application, where the PPP technique is nowadays used and can be used in the future are presented.

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1. GENERAL ASPECTS OF PPP

1.1 Motivation

As reported by the European GNSS Supervisor Authority (GSA) the GNSS market has been growing enormously in the last decade (http://www.gsa.europa.eu/go/the-market/studies-and-forecasts): The value of the GNSS worldwide market of all applications is evaluated to be worth around 40 Billion USD in 2006 and expected to pass the 90 Billions USD by 2011. Some 3 billion satellite navigation receivers should be in service by 2020. GNSS applications vary from transport and communication over land survey to agriculture and tourism.
Nowadays the majority of GNSS users have sensors available at low prices. Normally those single frequency (SF) low-cost sensors perform single point positioning with code, which allows estimating a position with a horizontal accuracy ≤13 m and a vertical accuracy ≤22 m (GPS standard positioning service (SPS) specifications) or even better.

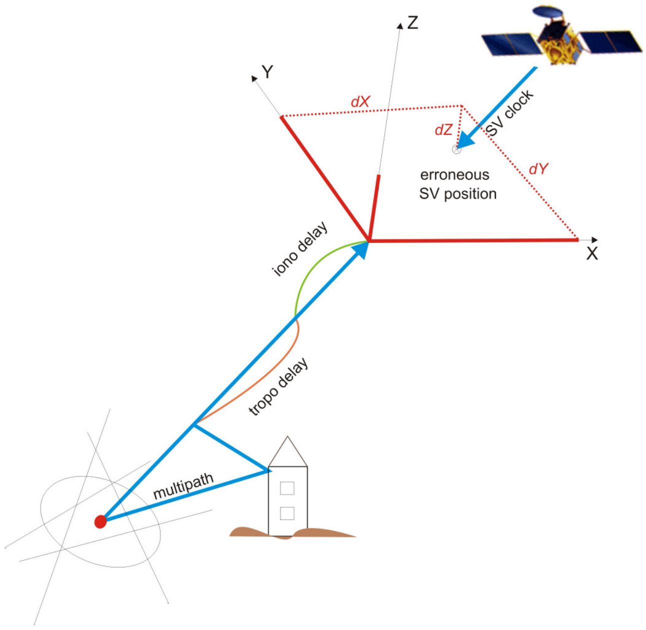

Figure 1: Main GNSS error sources

The main limiting factors of GNSS positioning accuracy are errors in broadcast satellite orbits, clock errors and atmospheric influences which are in general made up of ionospheric and tropospheric refraction (Figure 1).

Precise Point Positioning (PPP) however is an enhanced single point positioning technique for code or phase measurements using precise orbits and clocks instead of broadcast data. To compensate for ionospheric effects, dual frequency measurements are used for an ionosphere free combination (see equations (1) and (2)). In the case of single frequency observations some kind of ionosphere modeling has to be applied. The precise data and ionospheric models are provided by organizations like the International GNSS Service (IGS). PPP is considered as a rather cost efficient technique as it enables precise positioning with a single GNSS receiver. By applying PPP to dual frequency measurements even centimeter to decimeter accuracies can be achieved.

1.2 Principles

The concept of PPP was first introduced in the 1970's, whereby the theoretical foundation of PPP is documented in Zumberge et. al. (1997). Following Hofmann-Wellenhof et. al. (2008) the basic mathematical model underlying dual frequency PPP is defined by the desired ionosphere free combination of code pseudoranges

$$\frac{R_1 f_1^2}{f_1^2 - f_2^2} - \frac{R_2 f_2^2}{f_1^2 - f_2^2} = \rho + c dt_r + \Delta_{trp} \tag{1}$$

and carrier phases

$$\frac{\lambda_1 \Phi_1 f_1^2}{f_1^2 - f_2^2} - \frac{\lambda_2 \Phi_2 f_2^2}{f_1^2 - f_2^2} = \rho + c dt_r + \Delta_{trp} + \frac{\lambda_1 N_1 f_1^2}{f_1^2 - f_2^2} - \frac{\lambda_2 N_2 f_2^2}{f_1^2 - f_2^2} . \tag{2}$$

The unknown parameters to be determined are the point position contained in ρ, the receiver clock dt_r, the tropospheric delay Δ_{trp}, and the ambiguities N.

Compared to DGPS (differential GPS) and RTK (real-time kinematic) systems, PPP has several advantages: a PPP client is completely independent, since no base station or network of base stations is necessary. Therefore PPP can save a lot of time, resources and data volumes which have to be usually transferred between reference and rover. There is no need for simultaneous observations and no tight limit in range thanks to globally and regionally valid correction data (satellite orbits, clock corrections, ionospheric delays in case of SF data). Thus, it is imaginable that in the near future PPP will be able to substitute not only post-processing of network solutions but also real-time differential GPS or even RTK in many applications.

Nowadays PPP is used in the agricultural industry for precision farming, in hydrography and deformation monitoring. Further PPP applications are sensor positioning in seafloor mapping and marine construction as well as airborne mapping (Bisnath et. al. (2009).

1.3 Data providers and PPP products

For PPP processing high accuracy ephemerides and clock data is necessary. These data is freely provided by, e.g., the IGS. A detailed list of products provided by IGS can be found on http://igscb.jpl.nasa.gov/.

At the moment a variety of commercial and even online PPP engines can be found. Online services provide the possibility to upload RINEX (Receiver Independent Exchange Format) observation files to let them process fully automated on a server. The results are returned via email or ftp just within a short while.

In the run-up to the RA-PPP project the above mentioned PPP processors were tested with real GPS data regarding usability, possible settings, and results. These data consists of RINEX observation files (RINEX 2.10) from 3 stations for 3 subsequent days in 2008. All observations were made with a dual frequency receiver in static mode.

In the following, the different software packages and internet platforms are briefly described.

CSRS-PPP

NRCan's (Natural Resources Canada's) PPP, also known as CSRS-PPP (Canadian Spatial Reference System) is a free online global PPP service for GPS data post-processing, available since 2003 (http://www.geod.nrcan.gc.ca/products-produits/ppp_e.php). CSRS-PPP allows GPS users to submit single or dual frequency, static or kinematic GPS raw observation data files via the internet. In the case of static applications, world wide accuracy at the centimeter level can be achieved for the dual frequency approach as well as for single frequency receivers, using code and carrier measurements. For kinematic applications, sub decimeter accuracy is only achievable in the case of dual frequency receivers.

GAPS by UNB

The University of New Brunswick (UNB) developed the GPS Analysis and Positioning Software (GAPS). According to Leandro et. al. (2007) the algorithms used in GAPS follow more or less standard PPP approaches. GAPS is available as an online processing engine via the web page http://gaps.gge.unb.ca/ppp/. Static as well as kinematic processing is possible.

GrafNav by Waypoint

GrafNav is a kinematic trajectory processing tool for airborne applications, which provides a feature for PPP. The software is able to process single and dual frequency code and phase observations as well as precise orbit and clock files. According to Waypoint (2006), accuracies of 10-20 cm can be achieved for typical airborne surveys.

Bernese Software v5.0 (BSW)

Although traditionally a double-differencing processing tool, the Bernese software (BSW) v5.0 (http://www.bernese.unibe.ch/), developed at the Astronomical Institute at the University of Bern (AIUB), is also capable of analyzing undifferenced GNSS measurements in post processing mode. BSW PPP is very fast and efficient in generating cm-level accuracy station coordinates. Nevertheless, it is not possible to reach a coordinate quality as obtained from a network analysis.

Results

In the following the static PPP results from different software packages for the station of Graz on 20th July 2008 are compared. Thereby an observation data rate of 15s has been used. The resulting positions are expressed in plain coordinates with the a priori station coordinates as origin (Figure 2, Figure 3). Unless otherwise noted, IGS clock products with a data rate of 5 minutes have been used. For comparison also a network solution with 30s precise clocks calculated with Bernese post-processing software is visualized.

As illustrated in Figure 3, CSRS and GAPS are the PPP engines achieving the highest accuracies in height. The results are settled within an area of 1-2 cm compared to the a priori known station height. The horizontal positions (see Figure 2) show accuracies within the same range as the height component. The network solution provides similar results in height but comes closer to the a priori horizontal components. The GrafNav results show the influence of the clock products' data rate on height accuracies: The height resulting from 5 min clocks is much worse than the ones from 30s and 5s clock products. Because of the 15s observation data, there is no detectable difference in results from 30s and 5s clocks, which is also shown by the results of the Bernese software.

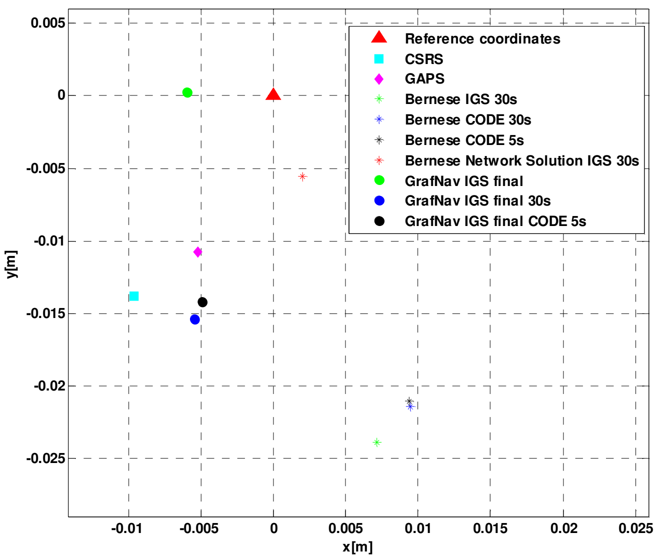

Figure 2: Plain coordinates x and y referenced to the a priori station coordinates

Among the tested PPP services and packages only the Bernese PPP post-processing engine allows advanced PPP settings and also the use of modified routines. Therefore it was rated to be the most promising tool for further investigations in PPP algorithms.
Furthermore different precise orbit and clock products were used for testing. It showed that the use of 30 s clock products should be preferred compared to the 5 min clocks, whereas there is no significant difference between 30 s and 5 s clock products. Also orbit and clock data from IGS and single analysis centers as for example CODE (Center for Orbit Determination in Europe) are rather equivalent. Concluding, the achieved PPP results from the software tests were within a few centimeters from the known station coordinates.

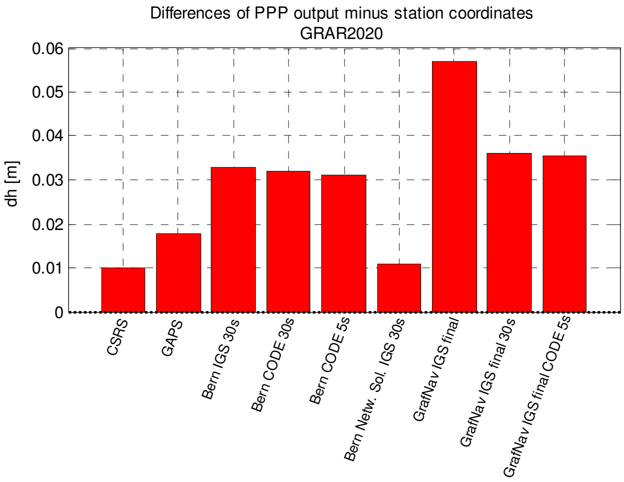

Figure 3: Height referenced compared to station height

1.4 Constraints and Limitations

Although PPP is a promising technique for future applications, it still underlies some limitations:

Since PPP is a technique with only one GNSS receiver, no differences between two receivers can be built to eliminate satellite specific errors such as clock and orbital errors. Therefore it is necessary to use the most precise satellite clock corrections and satellite orbits. Relevant products, available even in real-time, are for example IGS ultra rapid precise ephemerides ensuring an orbital representation of 10-15 cm and better than 1.5 ns clock accuracy over a prediction period of 2 hours and more.

Single frequency PPP users are requested to obtain external information on the ionospheric delay. This ionospheric delay can be obtained in real-time from models delivered for example by the IGS, SBAS services or regional service providers. The accuracy of global and regional total electron content (TEC) models derived from GPS data is currently at the ±2-8 TEC-level with a time resolution of one hour. This uncertainty maps into range errors in the order of 30 cm up to 1 m.

Beyond that the use of the non-integer ionosphere free linear combinations leads to further effects. The combined code and phase noise is amplified compared to the noise of isolated signals. Furthermore, the integer characteristics of the phase ambiguities get lost and ambiguity fixing is prevented, which leads to even longer convergence times. Convergence times are the time spans from start to a stably accurate solution. The convergence time to reach decimeter accuracy is typically about 30 minutes under normal conditions. To reach centimeter accuracies the PPP processor needs significantly longer.

Altogether the mentioned constraints still limit the usability of PPP. Especially applications with a need for real-time positioning make no use of the PPP technique by now. PPP would be able to replace other GNSS techniques in those kinds of applications, if just some of the problems could be resolved or at least reduced.

2. RA-PPP PROJECT

2.1 Project aims

RA-PPP stands for Rapid Precise Point Positioning, which denotes the wish for faster and more accurate algorithms for PPP. The project consortium consists of two Austrian research institutions, the Institute for Navigation and Satellite Geodesy (Graz University of Technology) and the Institute of Geodesy and Geophysics (Vienna University of Technology). Additionally, TeleConsult Austria GmbH and Wienstrom GmbH are part of the project consortium.

The main aims of the RA-PPP project are the identification of strengths and deficiencies of currently used PPP processing algorithms and thorough investigations in preparation for the development of new methods and algorithms based on the following four approaches:

- derivation of improved TEC models for single frequency users,
- use of "regional clocks"
- use of new ionospheric free linear combinations with reduced phase noise, and
- simulation to solve for ambiguities under special conditions.

Further a PPP user client for single and dual frequency processing is implemented using the newly developed PPP algorithms. The client's output parameters consist of positions and quality parameters of static and moving (kinematic) users. For the purpose of testing the developed user module and the algorithms' performance concerning convergence time, accuracy, and availability a test environment will be built up.

The aforementioned single approaches are shortly covered in the following. Investigations concerning the TEC models as well as on the "regional clocks" are presented in detail later in this section.

2.1.1 <u>Derivation of improved TEC models for single frequency users</u>

In the case of single frequency observations the user needs additional information on ionospheric refraction, since the ionospheric influence cannot be eliminated as in the case of dual frequency measurements. Hence the derivation of accurate TEC models is a necessity towards enhanced position accuracy for single frequency PPP.

2.1.2 Use of “regional clocks”

To improve the convergence time for dual frequency users it is possible to introduce clock differences between the satellites clocks and one regional reference station clock that additionally covers regional effects. These clock products are called “regional clocks” and are described later in detail. Furthermore, the use of regional clock parameters promises to enhance accuracy of PPP.

2.1.3 Use of new ionosphere free linear combinations with reduced phase noise

The third approach evaluated in this project is the use of new linear combinations (LC) since the standard ionosphere free combination used for dual frequency PPP with GPS (2) amplifies the code- and phase noise significantly compared to the noise of isolated signals.
Due to new carrier bands and signals in the near future, advantages for the data processing are expected. It is obvious that the use of new Galileo signals or the new civil signal at GPS L5 will allow the formation of additional linear combinations with phase and code based on three to five individual frequencies. This will allow better ambiguity resolution as well as reduced noise amplification within the combination of different signals.
Investigations concerning the noise behavior using the new L5 signal are under way but due to the known problems of GPS SVN49 (cf. Langley (2009)) are not finished yet.

2.1.4 Simulation to solve for ambiguities under special conditions

The probably most effective approach to improve convergence time of PPP solutions is the determination of the initial satellite and station bias parameters and to subsequently fix the remaining integer ambiguities like described in Ge et. al. (2006). For this case, simulations are conducted and will be presented in the near future.

2.2 Approaches

Consecutively two of the above mentioned four approaches to improve PPP with respect to convergence times and accuracy will be presented in detail.

2.2.1 Improved TEC models for single frequency users

Modeling

To provide corrections of the ionospheric delay for single frequency users a series of various model types have to be evaluated. These models are high resolution spherical harmonic (SH) expansions as well as Taylor series of the electron content derived from a regional reference station network. Since 2005 the Institute of Geodesy and Geophysics at Vienna University of Technology (IGG) calculates daily ionospheric delay models based on GPS/GLONASS as well as altimeter data (see Figure 4).

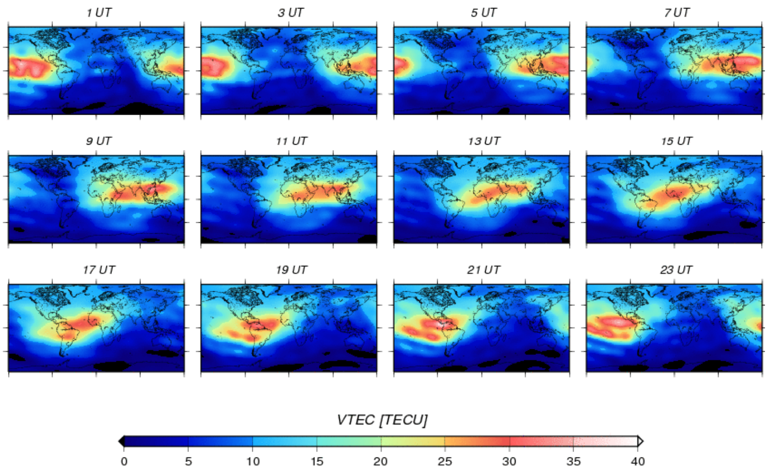

Figure 4: Map of VTEC calculated at IGG (DOY 182/2006)

The Vertical Electron Content (VTEC) at the ionosphere pierce point (IPP) can be derived from the SH expansion. The SH models are of degree and order 15 or 30 which is still too sparse (wavelength > 1500 km) to cover high resolution features of the ionospheric delay, but they allow to catch a time varying scale factor over extended regions. The quality of these models is at the few TECU level (1 TECU ≈ 0.16 m) which maps by a factor of 3 into low elevation observations.

Taylor series are able to catch smaller features of the ionospheric delay (ionospheric disturbances / TIDs). Series coefficients of the VTEC are usually derived up to a low degree and order (e.g. degree and order 2) from GPS zero-difference observations of a regional reference station network. Figure 5 presents a time series of the E_{00} coefficient (mean VTEC; 2h parameter validity) over a period of 21 days in July 2008 over the area of Vienna. VTEC values vary from 2-15 TECU (please note the scale).

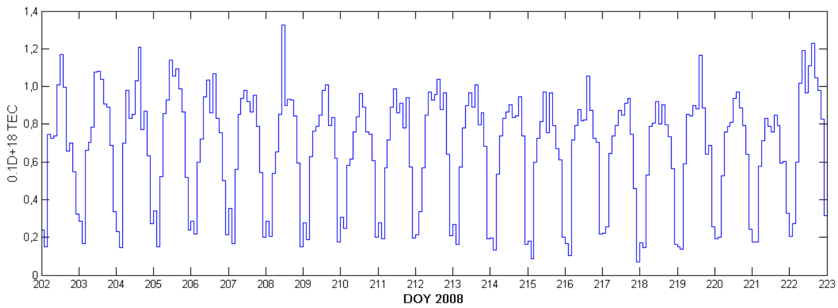

Figure 5: Time series of the E_{00} coefficient (mean VTEC; 2h parameter validity) over a period of 21 days in July 2008

The quality of the interpolated VTEC values depends on the validity area of the regional model and subsequently on the distance between the reference stations which provide data to establish this model (spatial resolution). It has to be ensured that the model is valid for all IPPs, even in case of low elevation signals. Furthermore, the quality also depends on the update rate of the model coefficients.

Comparison of different ionospheric models

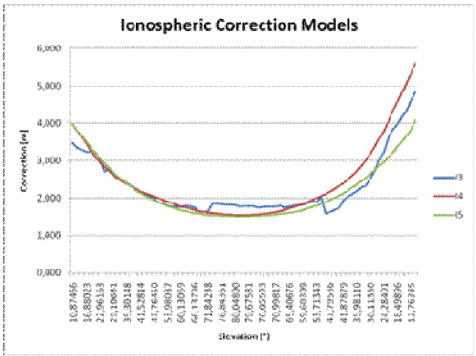

Figure 6: Comparison of different ionospheric correction models

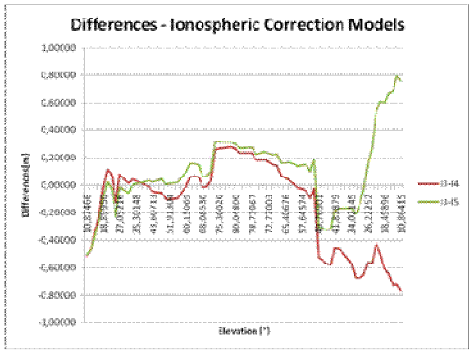

Figure 7: Comparison of ionospheric correction models' differences

Figure 6 and Figure 7 display the influence of the ionospheric delay calculated from 3 well known models, which are: I5 – the Klobuchar model issued by the GPS almanac information, I4 – a SH expansion of degree 30 of the VTEC (cf. Figure 4) as described above and I3 – the EGNOS model. These models have been evaluated for a typical path of satellite PRN 12 (16^{th} September 2009) and plotted with respect to the satellites elevation angle. In Figure 7 differences with respect to the I3 model are displayed. These models differ for low elevation observations by an amount of up to a meter, which corresponds to about 2 decimeters (+/-1-2 TECU) in zenith direction. It can be concluded that applying ionospheric corrections derived either from a high order SH expansion or a regional Taylor series will in general improve the calculated PPP position of the rover compared to a sole single frequency solution, but will still leave us with remaining range residuals at the few decimeter level which map onto the rover position and harm convergence of the solution.

2.2.2 “Regional clocks”

Under the precondition of at least two successfully tracked signals at different carrier frequencies we start with the ionosphere free linear combination ϕ_{if} . A linearization by means of approximate values and a slight reformulation of formula (2) leaves us with

$$\phi_{if} - \rho^0 - \Delta^0_{trp} - \lambda_{if} N^0_{if} = c(dt_s - dt_r) + \delta G + \delta\Delta_{trp} + \lambda_{if} \delta N_{if} + m + n \qquad (3)$$

where the index ^{0} indicates approximate values for geometric effects like orbits and tropospheric delay as well as an initial bias parameter N per individual satellite. On the right hand side we solve for the satellite clock with respect to the receiver clock and we note residual effects like orbit errors δG , remaining tropospheric delay $\delta\Delta_{trp}$ and a residual bias parameter δN_{if} . m denotes the environmental multipath and n the measurement noise. Since the only parameters to solve for are the clocks, all further effects on the right hand side map into these parameters. This procedure leaves us with a kind of virtual clock differences, but these clocks cover regional effects and are therefore clearly correlated with clocks at nearby stations (see Figure 8). Therefore we call these clock differences "regional clocks", which are clearly different from clock solutions provided for instance by IGS. When introducing the "regional clocks" via a PPP solution to process the coordinates of a nearby isolated station (slave station) we get rid of the remaining master station clock which will be absorbed by the slave station clock. The satellite specific bias at the master station will be absorbed as well by the ambiguity parameter at the slave station.

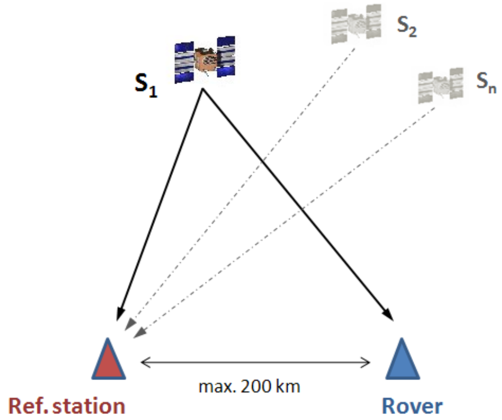

Figure 8: Spatial correlation of atmospheric and orbit effects

In terms of convergence time, which will be reduced in any case down to 30 minutes or less, this procedure is clearly favorable. The accuracy is quite comparable with state of the art PPP procedures and the concept can be applied both in post-processing and in real-time. Currently, this approach cannot compete in accuracy with double-difference post-processing approaches or network-RTK. Nevertheless, the correlation holds over hundreds of kilometers distance to our master station and the clock differences can easily be obtained, even in real-time.

Currently this approach is evaluated by feeding the PPP algorithm with "regional satellite clocks" recovered from a master station with observation data of well known rover stations in the vicinity (50 km up to 150 km distance) of the master station. Master and rover stations will be selected from the reference station network of the project partners.

Test calculations

First test calculations to qualify the "regional clocks" approach have been carried out. Provided accurate hourly estimates of the tropospheric zenith delay of reference station Leopoldau (LEOP) estimated by a baseline approach within our partners reference station network, we have mapped these tropospheric delays to the relevant elevation angle and subsequently converted to time differences to be applied to the satellite clock corrections issued by the IGS. These new "regional clocks" have been used to recalculate tropospheric zenith delays. Figure 9 shows that introducing these "manipulated" satellite clocks allows the reduction of the tropospheric delay estimates to almost zero for all stations in the vicinity of our reference station.

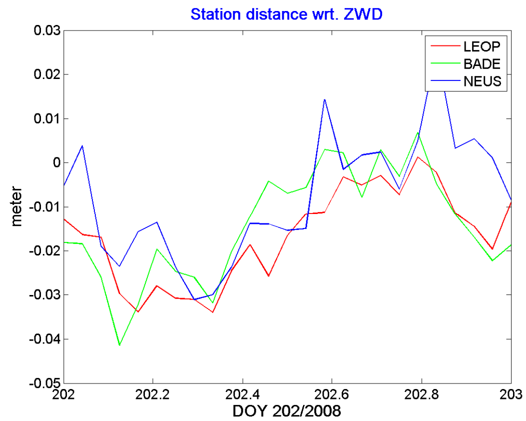

Figure 9: Remaining tropospheric delay (stations in about 50 km distance)

Concerning more distant stations (GRAZ about 160 km, WTZR about 400 km, DALA about 500 km) Figure 10 represents the de-correlation of the "regional clocks" effect with distance. While station GRAZ still shows a good correlation and tropospheric delays of up to 5 cm in zenith directions, which where not captured by the regional effect, the remaining stations in a few hundred km distance experience remaining delays of up to 15 cm. This leads to the assumption that the spatial validity of a set of "regional clocks" is about 150 km. The period of validity has still to be evaluated.

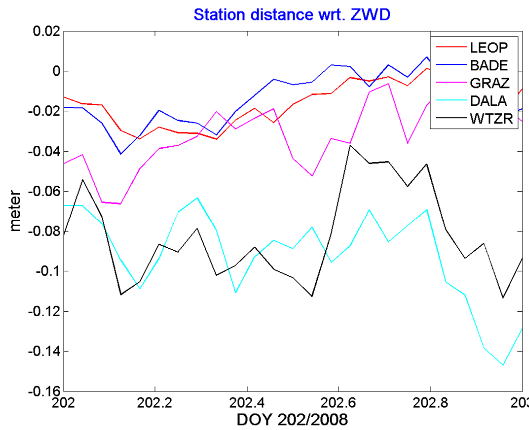

Figure 10: Remaining tropospheric delay (nearby and distant (> 150 km) stations)

2.3 Development of PPP client

Based on the previous described algorithms a PPP client is currently under development by TeleConsult Austria GmbH. For the purpose of testing the developed PPP client, Wienstrom GmbH provides the test facilities as well as the required input data for the evaluation.

The purpose of the RA-PPP client is the evaluation of the performance of the designed user algorithms and of different approaches. The main requirements for this client are:

- calculation of the position of a static or dynamic user,
- accuracy and quality parameters of the position solution,
- evaluation of the performance regarding convergence time, accuracy, and availability,
- various existing products as input, and
- indication of the performance which could be obtained in real-time.

The current design of the data flow and the overall system architecture of the RA-PPP project are shown in Figure 11.

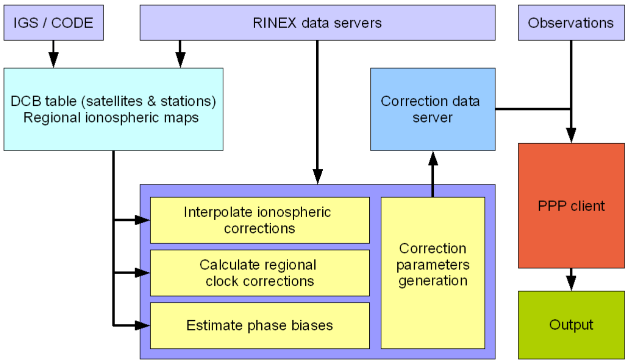

Figure 11: Data flow of the PPP processing chain

From IGS, CODE, and RINEX data servers DCB (differential code bias) tables, ionospheric maps and observation data can be obtained. These data are then fed into the correction data generation module. Within this module out of the ionospheric maps the actual ionospheric correction parameters are calculated. Additional the correction parameters for the "regional clock" concept are processed and the phase biases are estimated. These correction parameters are then uploaded to a correction data server.

The actual position computation takes place in the PPP client. Depending on the type of application (real-time or post-processing) either real-time measurements or RINEX files can be used as input source for the client. The heart of the RA-PPP user client is the processing module which includes the previously designed algorithms. The module will be capable of calculating the user's positions as well as quality parameters. An overview of the processing module is given in Figure 12.

The RA-PPP client is implemented in Matlab and C/C++, since advantages from both programming languages are used. The processing module is thereby developed in C++. It consists of two core modules – the correction computation and the PVT (Position, Velocity and Time) module. Before the actual computation takes place, all incoming data are converted into an internal format and plausibility checks are done. The correction module accesses the data server and requests the necessary correction parameters. As stated above, these corrections aim at the use of improved TEC models and the use of "regional clocks".

Depending on the user's input, different algorithms will be selected. Out of these parameters the corrections for each observation are calculated according to the previous mentioned algorithms. The corrected observations together with the computed satellite positions are then fed into the PVT module. Within this module the actual position calculation takes place. For evaluation purposes either a least squares adjustment or a Kalman filter algorithm can be used. Beside the position calculation, also accuracy and quality parameters as well as the convergence time are provided to the user. For the subsequent evaluation and for the comparison of different settings, the significant results and intermediate data are stored in files.

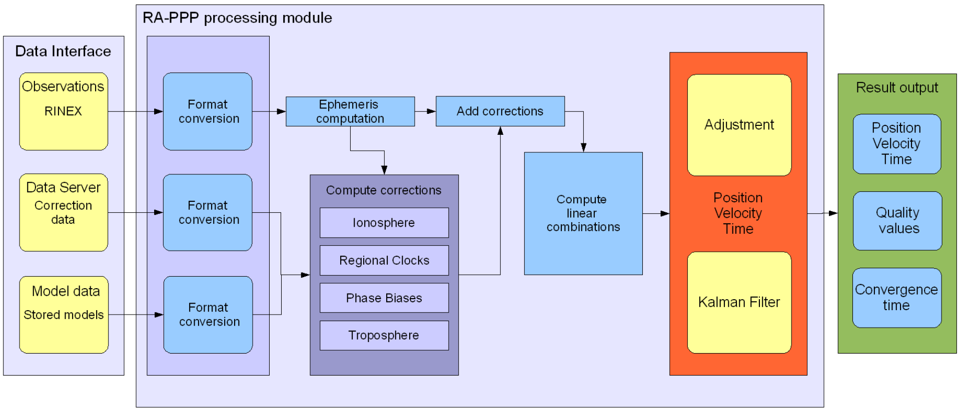

Figure 12: Architecture of the RA-PPP processing module

Currently the first version supports only post-processing and is under test. At the end of the project first tests regarding real-time capability will be accomplished.

3. CONCLUSIONS AND FIELDS OF APPLICATION

The RA-PPP Project demonstrated so far that there is still much room for improvement of PPP techniques. New GNSS signals like GPS L5 or the new Galileo system promise a better noise behavior for dual frequency PPP and therefore a reduction of convergence times. Further, there are methods to solve for ambiguities under special preconditions, which will also lead to a rapid PPP solution. Single frequency users can be supported by enhanced ionospheric modeling to achieve better accuracies. Plus, the new method of "regional clocks" promises improvement of convergence time and accuracy of PPP solutions.

These approaches are all aiming for a wider usability of PPP, which would be a gain for a wide range of applications currently lacking of a GNSS technique with no need for reference stations or further equipment and spatial limitations.

At the moment the PPP technique is used for several kinds of post processing applications. For example, hydrological survey in general is well suited for the application of PPP, since continuous dual frequency phase observations of one or more hours have to be processed. Under such conditions PPP is able to achieve centimeter accuracies. Further information can be found in Wanninger et. al. (2009).

An alternative field of PPP application is presented in Schwieger et. al. (2009). Thereby it is used as a processing method for kinematic GPS profiles of the German satellite mission TanDEM-X. This mission uses Synthetic Aperture Radar (SAR) to produce a global digital elevation model (DEM) with about 10 m vertical and horizontal accuracy. Additionally, airborne or at least moving platform based laser scanning is a field of application to calculate the trajectory of a GNSS sensor without the need of reference station data.

For the future many more applications are conceivable for PPP. Especially in case of restricted budgets and modest demands of position accuracy, PPP can be a promising approach for the gathering of geospatial data.

The RA-PPP project is still running and the test executions of the developed PPP user client have not been finished yet. If the evaluation of the new algorithms is successful, we have made a first step towards PPP as a cost effective alternative to GNSS techniques like DGPS or RTK. This would provide precise positioning with GNSS to a wider range of users.

ACKNOWLEDGEMENTS

RA-PPP is a research project financed by the Federal Ministry for Transport, Innovation and Technology, managed by the Austrian Research Promotion Agency (FFG) in the course of the 6th call of the Austrian Space Application Program (ASAP).

REFERENCES

Bisnath, S. B. and Gao, Y. (2009): Innovation: Precise Point Positioning – A Powerful Technique with a promising future, GPS World, April 2009

Ge, M., Gendt, G. and Rothacher, M. (2006): Integer ambiguity resolution for precise point positioning, Proceedings of the VI Hotine Marussi Symposium of Theoretical and Computational geodesy: Challenge and Role of Modern Geodesy, 2006, Wuhan, China.

Hofmann-Wellenhof, B., Lichtenegger, H. and Wasle, E. (2008): GNSS: Global Navigation Satellite Systems – GPS, GLONASS, GALILEO & more, SpringerWienNewYork

Langley, R. B. (2009): Cause identified for Pseudorange Error from New GPS Satellite SVN49, GPS WORLD – System Design & Test, July 13, 2009

Leandro, R.F., Santos, M.C. and Langley R.B. (2007): GAPS: The GPS Analysis and Positioning Software - A Brief Overview, Proceedings of ION GNSS 2007, Fort Worth, TX, September of 2007

Schwieger, V., Schweitzer, J. and Kosmann, D. (2009): GPS Precise Point Positioning as a Method to Evaluate Global TanDEM-X Digital Elevation Model, 7th FIG Regional Conference 2009, Spatial Data serving People: Land Governance and the Environment – Building the Capacity, Hanoi, Vietnam, 19-22 October 2009

Wanninger, L. and Heßelbarth, A. (2009): GNSS Precise Point Positioning und seine Anwendung in der Hydrographie, In: „Hydrographie – Neue Methoden von der Erfassung zum Produkt“, 89. DVW-Seminar, 06./07. Oktober 2009, Hamburg, DVW-Schriftenreihe Band 58/2009, S. 3-18, Wißner-Verlag, Augsburg

Waypoint Products Group (2006): Airborne Precise Point Positioning (PPP) in GrafNav 7.80 with Comparisons to Canadian Spatial Reference System (CSRS) Solutions, NovAtel Inc., December 2006

Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb (1997): Precise Point Processing for the Efficient and Robust Analysis of GPS Data from Large Networks, J. Geophys. Res., 102(B3), 5005-5017.

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