DIFFERENT PPP STRATEGIES IN THE CASE OF NATURAL DISASTERS

M. De Agostino, M. Piras

Politecnico di Torino, Land, Environment and Geoengineering Department (DITAG)
24, Corso Duca degli Abruzzi, 10129 Torino, Italy - (mattia.deagostino, marco.piras)@polito.it

KEY WORDS: Land Use, Satellite Applications, Comparison, Data, Software, Accuracy

ABSTRACT:

Sometimes, there is the necessity to operate in parts of the world where a real time or a relative GNSS positioning is not available. Otherwise, it is very difficult to carry out any immediate action where the use of georeferencing data is required; this is the case of an UAV reconnaissance flight or the georeferencing of satellite images devoted to realize a new cartography. Under these particular conditions, it is necessary to operate immediately (<48h), for example, by preparing a map of the roads that can still be used.

The quality and congruence of GNSS products, devoted to precise positioning have increased considerably, considering the accuracy of the IGS05 reference system. The highest quality products are available, a precise positioning using a PPP approach (without the use of reference stations) is possible. This solution was also available in the past, but is it currently possible to obtain the same precision using shorter measurement sessions? This is the aim of this research.

A particular analysis was carried out to define a possible relationship between the accuracy and the length of campaign, considering different scenarios. During the tests, the positioning was obtained considering both precise and rapid ephemerides; in fact, these products are very interesting since they are available with only 17 hours of delay.

Two different software of calculus have been considered: Waypoint GrafNav and CSRS on-line service.

1. INTRODUCTION

In Global Navigation Satellite System (GNSS) positioning, a centrimetric accuracy can usually be obtained if an approach with differential observations is used, where the rover observations are combined with the data from one or more permanent reference stations. In most cases a relative positioning is realized. If the field conditions are favourable, it is also possible to consider a Real Time Kinematic (RTK) positioning, with a decrease of the length time of measurement sessions.

Sometimes, there is the necessity to operate in parts of the world where GNSS permanent stations are not available or the distance between the rover-permanent station is too long to realize a real time positioning or a relative positioning.

Another possibility is that a GNSS permanent station is available but, because of some particular conditions (i.e. violent natural phenomena, catastrophes), it is not possible to use it because the accessory services (internet connection, electric power) do not working.

The quality and congruence of GNSS products, devoted to precise positioning (i.e. precise ephemerides, clock errors, Earth rotation parameters, etc) have increased considerably. The improvement in IGS products has produced many benefits both in precise relative positioning, and in Precise Point Positioning (PPP). The highest quality products are available, a precise positioning using the PPP approach is possible. This solution was also available in the past, but a measurement campaign with long period of occupation (>30 hrs) was necessary.

This improvement is particularly due to the quality of the IGS05 reference system . This system is defined and realized using only GPS measurements, obtained from several IGS permanent stations (>100) located throughout the world. Nowadays, this is a standard reference system and each GNSS permanent station is referred to this reference system.

The accuracy of the PPP method is very important, therefore it is necessary to investigate how accurate the PPP is, in particular considering different realistic scenarios.

This research considers all the possible combinations between receivers, IGS products and length of session, in order to define the effective accuracy and precision of PPP positioning.

In particular, different temporal session lengths have been considered, and in particular: 1, 2, 3, 6, 12 and 24 hours. In a short period (< 6 hs) different parts of the day (morning, afternoon and evening) are considered, account for the different impacts of the ionospheric propagation delay on the GNSS observations.

Two different strategies of calculus have been considered, adopting a commercial software and a on line public service.

The first approach is GrafNav-Waypoint commercial software, which allows a precise point positioning to be made and to set some important parameters such as tropospheric delay value and velocity of the model.

The second one is the NRCan's PPP software, that is a free on-line post-processing service that allows GPS users to compute better-accuracy positions from their GPS raw observation data.

2. PRECISE POINT POSITIONG: A BRIEF DESCRIPTION

Relative positioning allows to obtain centrimetric accuracy (or better) estimating the distance between two receivers (baseline). Particular combination of differential observations are involved to achieve this accuracy. This operation permits to reduce (or sometimes to remove) the common errors which exist in the receivers. Unlikely these errors cannot be eliminated using the Precise Point Positioning, they can be modelled with respect to the space and the time. This solution is affected from different errors for example, geophysical phenomena as tectonic plate, Earth tides and ocean tides. Tropospheric and ionospheric effect are also included in the observation errors.

In addition, the observations are affected from other type of errors, which depend from the measurement. These errors can be included both in the satellite and in the receiver observations. Clock error, phase-centre variations, differential group delay and relativity are just some example of satellite errors. Receiver observations are affected from clock error, phase-centre variations and multipath.

The Precise Point Positioning solution needs to estimate the contribute of each error, (Witchayangkoon, 2000).

Adopting a dual frequency receiver, it is possible to consider the iono-free combination as the available observations. In this way, ionospheric propagation effects are reduced.

$$P_{IF} = \frac{f_1^2 P_1 - f_2^2 P_2}{f_1^2 - f_2^2} = \rho + cdt + d_{trop} + dm_{IF} + \delta\varepsilon_r + cdt_s + \varepsilon(P_{IF}) \qquad (1)$$

$$\Phi_{IF} = \frac{f_1^2 \Phi_1 - f_2^2 \Phi_2}{f_1^2 - f_2^2} = \rho + cdt + d_{trop} + \frac{cf_1\, N_1 - cf_2\, N_2}{f_1^2 - f_2^2} + \delta m_{IF} + \delta\varepsilon_r + cdt_s + \varepsilon(\Phi_{IF}) \qquad (2)$$

where:
P_i = pseudorange on L_i [m];
Φ_i = carrier phase on L_i [m];
ρ = geometrical distance [m];
c = light velocity [m/s];
dt = clock receiver error [s];
dt_s = clock satellite error [s];
$\delta\varepsilon_r$ = ephemerid error [m];
d_{trop}= tropospheric delay [m];
N_i = carrier phase ambiguity on L_i [cycle];
f_i = frequency of L_i band [Hz];
dm_i = multipath effect on pseudorange L_i [m];
δm_i = multipath effect on carrier phase Φ_i [m];
$\varepsilon(.)$ = noise [m].

Using precise ephemerides and clock products (.clk files), satellites clock and ephemerid errors can be removed from the previous equations.

Clock receiver error and tropospheric delay have to be still estimated.

3. CHARACTERICS OF THE MAIN MODEL USED IN THE PPP

3.1 Geophysical model

The Earth is primarily composed of three basic components: solid (e.g., rock), liquid (e.g., ocean), and atmosphere. These components make the Earth far from absolutely rigid. Therefore, in order to study the Earth's deformation, the more realistic Earth's model should be somewhere in between being rigid (all considered solid) and being liquid. The Earth must be seen as a deformable body over a wide range of time scales in response to changing surface loads in the atmosphere, ocean, and hydrosphere (Lambeck, 1989). In addition, we have the knowledge about the motion that the Earth revolves around the Sun, together with other planets. As well known, the Earth also rotates or spins around its instantaneous axis of rotation. The Earth's motions, combined with solar and lunar attraction forces, cause Earth tides, which are of interest regarding their effects on geocentric coordinates. In general, the Earth's temporal deformations occur locally as well as globally. Tidal deformations take place in the solid Earth, in the oceans, and in the atmosphere.

3.2 Atmospheric model

Satellite signals travel through the atmosphere, which affects the their integrity. The atmosphere effects are divided into two different components, the tropospheric propagation delay and the ionospheric one. Each effect influences the satellite signals differently. Since the troposphere is a non-dispersive medium, tropospheric refraction causes an identical effect on both code and phase modulation. The troposphere causes a signal delay of up to 30 meters for a horizontal path. Therefore, the effect from the troposphere is considered one of the major sources of errors imposed on the satellite signals. On the other hand, the ionosphere is a dispersive medium of the ionized atmosphere layer(s). Thus, the ionosphere affects the signal code and phase modulation in an opposing way. Moreover, the ionospheric effect is a function of carrier frequency. Fortunately, the ionospheric effect can be eliminated using dual frequency observations.

In this chapter, the emphasis will be given to the recent tropospheric model or so-called "global mapping function", that are used for global positioning analysis. For the ionospheric effect, the popular ionosphere-free linear combination is presented.

3.3 Tropospheric Models

Due to the significance of tropospheric effects on radio signal propagation, many studies to formulate tropospheric correction have been performed. Therefore, various tropospheric models exist. In addition, different mapping functions which illustrate signal delay as a function of elevation angle are also given.

3.4 Ionosphere Models

There are a few ionospheric models available to estimate ionospheric effects. Examples are the ionospheric plate model, daily cosine model, and ionospheric point model. In addition, ionospheric coefficient for the cosine model included in the GPS navigation message compensates approximately 50% of the actual group delay.

3.5 Receiver antenna models

A recent study about GPS antenna phase center offset has been conducted at the National Geodetic Survey (NGS) by (Mader, 1999). The effect occurs because a GPS range observation is measured from a satellite transmitted signal to the electrical phase center of the receiving antenna. The electrical Phase Center Variation (PCV) is a function of a particular antenna's phase pattern (Aloi, 1999).

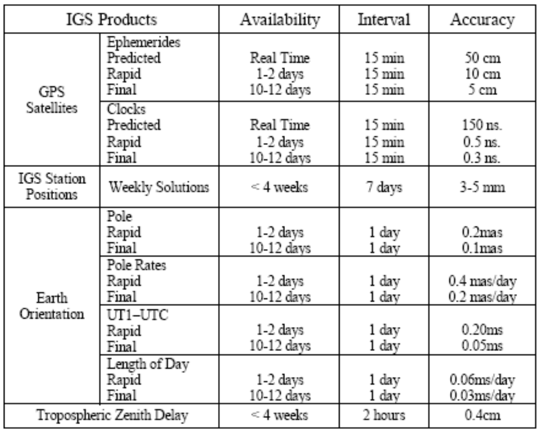
GPS antenna phase center is neither a single well-defined physical point nor stable spot, but rather varies with the changing direction of the incoming satellite signal. However, practically, users assume that the received signal point stays constant over the observation period, which is often referred to the phase center of the antenna.

The antenna phase center offset may reflect significant vertical positioning accuracy of up to 10 cm and sub-centimeter in the horizontal. However, it is not easy to model PCV variations due to high temporal correlation with signal reflection multipath and specific antenna. As a matter of simplicity by assuming azimuthal symmetry, one simple model is rather to assume that the phase center varies as a function of satellite elevation angle only.

4. IGS PRODUCTS FOR PRECISE POSITIONING

International GNSS Service (IGS) produces useful products devoted to precise static positioning and precise point positioning.

In particular, precise ephemerides for all available satellites (GPS and GLONASS), Earth orientation parameter (EOP) and clock corrections are the most important product employed in the Precise Point Positioning. This IGS service is completely free and it is based on a global network composed by several GNSS permanent stations (greater than 200) enable to transmit continuously their data to a control centre, in order to collect the raw data and to create different GNSS secondary products. The figure below shows the different IGS products, their availability, interval and average accuracy.



IGS Products		Availability	Interval	Accuracy
GPS Satellites	Ephemerides			
	Predicted	Real Time	15 min	50 cm
	Rapid	1-2 days	15 min	10 cm
	Final	10-12 days	15 min	5 cm
	Clocks			
	Predicted	Real Time	15 min	150 ns.
	Rapid	1-2 days	15 min	0.5 ns.
	Final	10-12 days	15 min	0.3 ns.
IGS Station Positions	Weekly Solutions	< 4 weeks	7 days	3-5 mm
Earth Orientation	Pole			
	Rapid	1-2 days	1 day	0.2mas
	Final	10-12 days	1 day	0.1mas
	Pole Rates			
	Rapid	1-2 days	1 day	0.4 mas/day
	Final	10-12 days	1 day	0.2 mas/day
	UT1–UTC			
	Rapid	1-2 days	1 day	0.20ms
	Final	10-12 days	1 day	0.05ms
	Length of Day			
	Rapid	1-2 days	1 day	0.06ms/day
	Final	10-12 days	1 day	0.03ms/day
Tropospheric Zenith Delay		< 4 weeks	2 hours	0.4cm

Figure 1. IGS products

5. REFERENCE SYSTEM (RS): AN IMPORTANT FACTOR

The ITRF (International Terrestrial Reference Frame) is internationally recognized as the standard reference system. It is continuously defined and updated, using different kinds of measurements deriving from spatial-geodetic techniques as Very Long Baseline Interferometry (VLBI), Lunar Laser Ranging (LLR) and Satellite Laser Ranging (SLR). GPS and Doppler (derived by DORIS satellite) data are also used to define this reference system. This reference system is periodically redefined with new releases, but the continuity between the different frames is guaranteed trough a set of 14 parameters (3 translations, 3 rotations, 1 scale factor and 7 velocities). Since 2002, the system IGbyy is working on parallel to ITRF reference frame. Nowadays the system IGbyy is became IGSyy: this reference system is defined using only GNSS measurements. In this way, the system is more consistent with respect to ITRF, where the observations involved are in different way weighted. Today, the IGSyy system is the standard used to define the RS of IGS products. There are different procedures devoted to transform a set of coordinates defined in a reference system into another one. The most rigorous procedure is that use Boucher-Altamimi equations (Boucher, Altamimi, 2001).

6. DEVELOPED TESTS

The purposes of this research are to analyze the effective potentiality of the Precise Point Positioning and to identify a good strategy to be used in case of emergency. The main factors that have to be considered in our analysis are:

- type of receiver (dual frequency);
- receiver clock (internal or external);
- ephemerides (precise or broadcast);
- length of observations (1, 2, 3, 6, 12 and 24 hrs);
- IGS products available.

The GNSS observations used in the test derive from the VERC permanent station, located in the II Faculty of the Politecnico di Torino in Vercelli, Italy. In this site a Topcon Odyssey receiver is working and a rubidium atomic clock (AC) is connected. This station has been defined in IGS05 reference system and in ETRF89, using a Helmert's transformation. The coordinates of the site are semiannual defined, using the test network located in Piedmont and which belongs to the Politecnico di Torino (Figure 2). For the same site, observations with and without the atomic clock connected to the receiver are available, in two different periods.

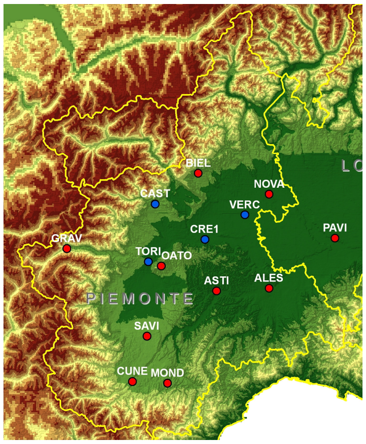


Figure 2. Network of Piedmont (Italy)

The summary of tests carried out, considering the type of observations, used approach, length of session and date are reported in the Table 1.

Type of Observations	*Products Used*	*Length of session*	*Date*
Dual Freq. with AC	*IGS - SP3 e Clk (precise)*	*1,2, 3, 6, 12, 24 h*	*07/05/2008*
Dual Freq. without AC	*IGS - SP3 e Clk (precise)*	*1,2, 3, 6, 12, 24 h*	*20/05/2007*
Dual Freq. with AC	*IGS - SP3 e Clk (rapid)*	*1,2, 3, 6, 12, 24 h*	*07/05/2008*
Dual Freq. without AC	*IGS - SP3 e Clk (rapid)*	*1,2, 3, 6, 12, 24 h*	*20/05/2007*
Dual Freq. with AC	*CSRS*	*1,2, 3, 6, 12 h*	*07/05/2008*
Dual Freq. without AC	*CSRS*	*1,2, 3, 6, 12 h*	*20/05/2007*

Table 1. List of tests

Two different software are used to elaborate the data: the first one is a commercial software, called Waypoint GrafNav v. 8.10, which use a not differential and combined approach. It allows to consider precise and rapid ephemerides, clock satellite model, ionospheric and tropospheric model, DCB (Differential Code Bias) values and data dynamic model (through a Kalman filter, combining the forward and the reverse solution in order to improve the quality of the final result).

The second procedure is the Natural Research Canada on-line service, called CSRS-PPP (Natural Resources Canada, 2004). In this case the user cannot define any parameter, because the best product will be directly selected by the on-line procedure. It is also a not differential and combined approach and it has been sponsored for long time in several technical papers. Thanks to brief time of analysis and the rapid time to obtain the results, the on-line service are becoming an interesting and accurate product, in particular for not expert users.

Same data and same length of session have been elaborated using both procedures. The results already obtained have been compared.

7. RESULTS

The results obtained considering all available combinations are described in this chapter. The data have been organized with respect the session length and the type of observation (atomic clock or not atomic clock). The results obtained with Waypoint's software are divided in two different sections: rapid and precise products. Rapid product are available only 17 hours after the event, instead the second one only after 13 days. Considering CSRS, this separation is not possible because the procedure automatically applies the best product available. The quantity of the results denies the singular description for each case but, to give a general point of view about the final result, bar diagrams were been used in the following sections. Figure 3 and Figure 4 contain two of the several plots realized, in order to give to the reader what there is beyond each value of the bar diagram. For each test, coordinate differences (accuracies) and precisions have been estimated, as described in Tables 2 and 3.

	ΔE [m]	ΔN [m]	Δh [m]
Rapid	-0.023	0.018	-0.053
Precise	-0.063	-0.008	0.008

	σE [m]	σN [m]	σh [m]
Rapid	0.072	0.032	0.054
Precise	0.016	0.004	0.009

Table 2. Solutions with 1 hour of data and atomic clock – Grafnav

ΔE [m]	ΔN [m]	Δh [m]
0.041	0.004	-0.059

σE [m]	σN [m]	σh [m]
0.028	0.011	0.026

Table 3. Solutions with 1 hour of data and atomic clock – CSRS

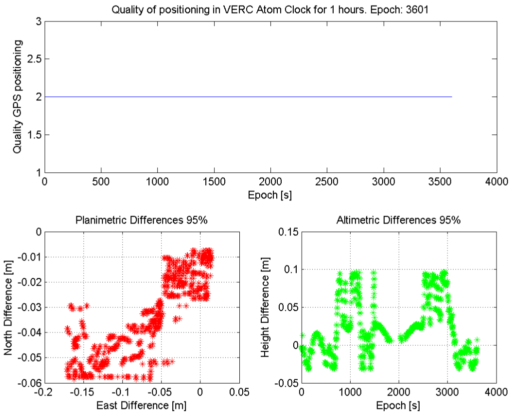


Figure 3. Accuracy with Precise Ephemerides

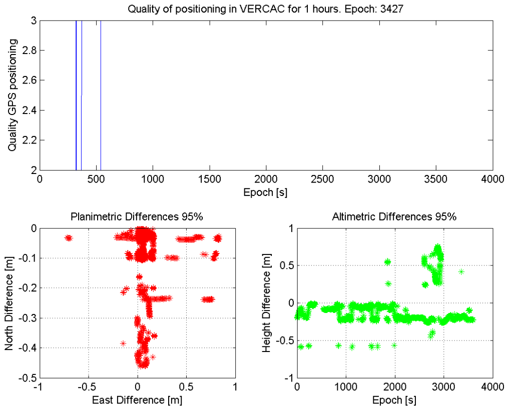


Figure 4. Accuracy with Rapid Ephemerides

In this paper, the Authors prefer to give a complete point of view about the PPP approach, paying more attention to the importance of the method, and putting in second order the single solutions. In the next parts, the different results will be resumed, considering at the beginning the test developed with the atomic clock and after that those developed without it.

7.1 Tests with Atomic Clock

Considering an Atomic Clock (AC), the accuracy of the solution is quite good, also when short period (1h) is considered. This aspect is very interesting, because this kind of result were not possible 10 years ago, when the quality of the product and the model was not so good. Centimetrical accuracy is obtained with all procedures, but the standard deviation value changes sensitively if rapid or precise ephemerides are used (Figure 6).

The main differences between the developed tests is only denoted between the analysis with 1 hour and the rest of the dataset. In this case, considering the rapid ephemerides, the results have a standard deviations greater than the accuracy.

Analyzing the results, the CSRS solution has a good stability. In fact, the level of accuracy is quite the same, also changing the length of the measurement session. The precisions of the different solutions are comparable in the short period, whereas, for session length longer than 6 hours, only precise and CSRS solutions are similar. The precisions of the solution obtained using rapid products increase if the length of the session grows, but there is a fall passing from 6 hour to 12 hours (Figure 5).

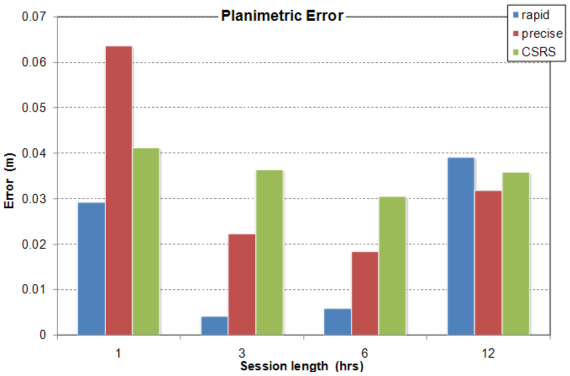


Figure 5. Planimetric error

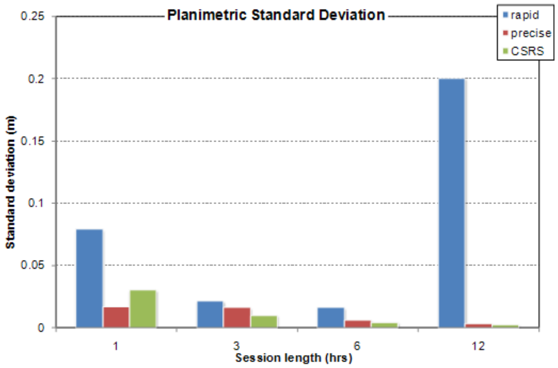


Figure 6. Planimetric standard deviation

Similar considerations can be make analyzing the altimetric component. In fact, the results, resumed in Figure 6 and 7, have a similar behavior as above.

In this case the CSRS procedure not has the same stability denoted before, but the solution also has both a good accuracy and precision.

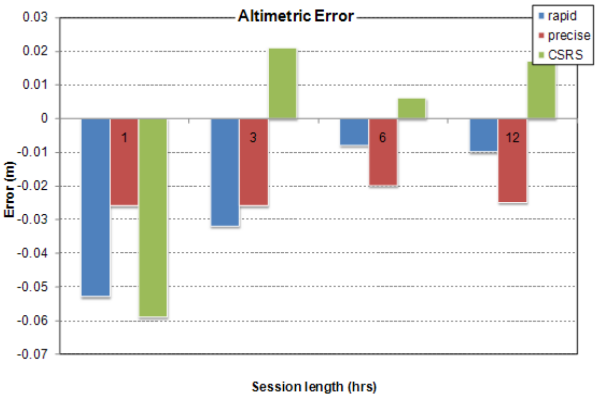


Figure 7. Altimetric error

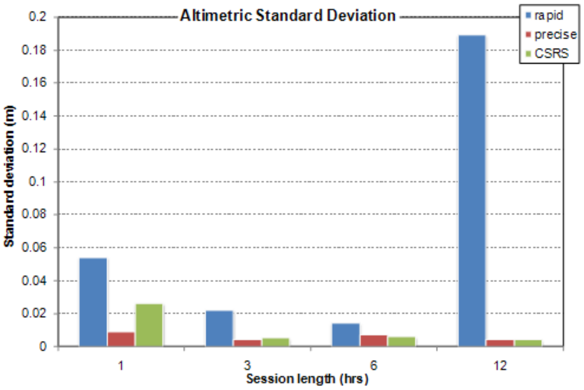


Figure 8. Altimetric standard deviation

The good quality of the IGS products or more generally of products for PPP allows to obtain a centimetric accuracy also with a short length of data. It means that this approach is very powerful when a rapid and accurate solution is necessary. Nowadays, low cost atomic clocks are available on the market, then they can be installed in a semi-permanent station GNSS. This kind of receiver could be used as a reference for each activities which needs a real time positioning or a georeferencing.

7.2 Test without Atomic Clock

In this case, the dataset with only 1 hour of data brings to have a decimetrical accuracy and precision, in particular if rapid products are involved. The accuracy increase if longer periods are considered, reaching always a centimetrical accuracy. In the other hand, a centimetric level is assumed by the precision only in precise and CSRS solution. Rapid solution achieves only decimetric values. In this case is evident as the contribute of clock receiver model plays an important role; in particular, it allows to obtain a centimetric solution also with short period of data and considering rapid products.

Also in this case, similar consideration can be make about the altimetric component. In fact, the results resumed in Figure 11 and 12, have a similar behavior as above.

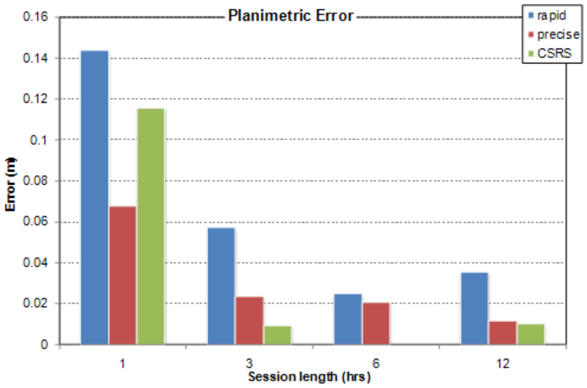


Figure 9. Planimetric error

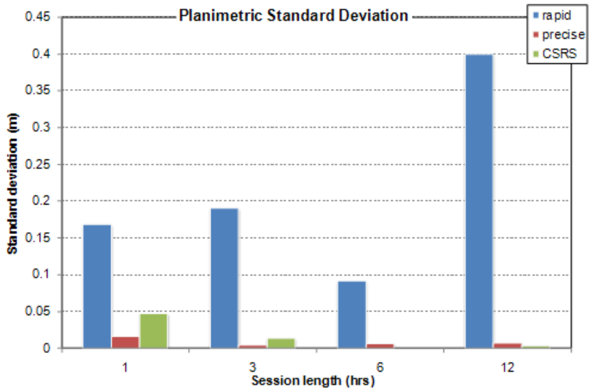


Figure 10. Planimetric standard deviation

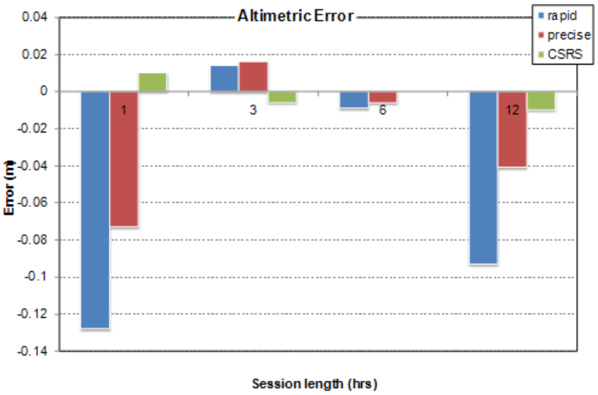


Figure 11. Altimetric error

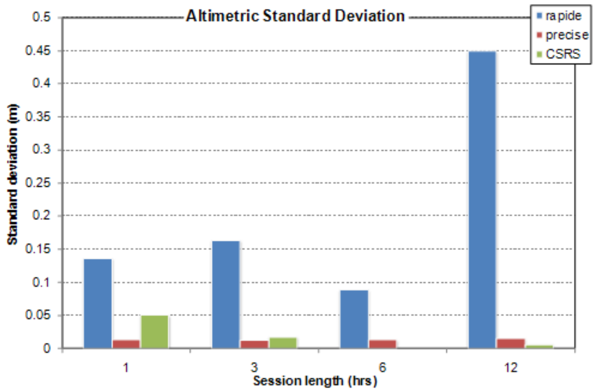


Figure 12. Altimetric standard deviation

This test is closer to the real operative conditions therefore it is more interesting for application which concern natural disaster. PPP allows to obtain a decimetrical solution which can be enough for an early operation. An immediate semi-permanent station GNSS could be located in the site interested by the natural disaster and to have rapidly a reference position. In some case, for large natural disaster the first 24-48 hrs are fundamental in order to save the largest number of life.

8. CONCLUSIONS

The use of rapid products allows to obtain a centimetrical accuracy also considering short session of data (3-6 hrs). Both the procedure considered are enough easy to use, but the CSRS on-line service is easier, more immediate and rapid. Planimetric components are more precise with respect to altimetric component.

The characteristics of accuracy obtained using these approaches are completely compatible and useful with the accuracy needs in some extraordinary cases. An example is natural disasters, where an immediate positioning solution is required.
In fact, the PPP positioning may be used as a basis for defining the coordinates of a semi-permanent station, that can be used on the ground an RTK positioning or for the use of UAVs for reconnaissance fleets or photogrammetric survey. The use of short sessions also limits the presence of cycle slips within the data. The use of an atomic clock is certainly advantageous to be associated with specific products, but especially to rapid products. It denotes a substantial decrease in the accuracy of the hot-fix when long sessions of data (> 12 hours) are used.

This phenomenon could be related both to the receiver clock model and to ionosphere overcorrection phenomenon, but everything is still in the process of analysis and study.

ACKNOWLEDGMENTS

This research is supported by the Italian "Ministero dell'Università e della Ricerca" (MIUR) under the PRIN 2005 project *"Reti di stazioni permanenti GPS: architettura, gestione e fruizione dei dati per rilevamenti topo-cartografici e monitoraggio del territorio"*.

REFERENCES

Aloi, D. N., 1999. "Phase Center Variation (PCV) Determination of the Ohio University Dipole Array Using GPS Data". *Proceedings of the ION GPS 1999*, Nashville.

Betti B., Biagi L., Passoni D., Tornatore V., Cina A. Pesenti M., Piras M., Barrile V., Meduri G. (2007), "Interoperabilità e integrazione tra reti NRTK interagenti e inserimento nei sistemi geodetici e cartografici ufficiali", *Proceedings of the ASITA conference*, Turin, 6-9 November 2007.

Boucher, C., Altamimi, Z., 2001. "Memo: Specification for reference frame fixing in the analysis of a EUREF GPS campaign". Version 5: 12-04-01. http://etrs89.ensg.ign.fr/memo.pdf (accessed 26 Nov. 2009).

Lambeck, K., 1989. *The Earth's Variable Rotation: Geophysical Causes and Consequences*. Cambridge Univ. Press, England.

Mader, G. L., 1999. *GPS Antenna Calibration at the National Geodetic Survey*. GPS Solutions, 3(1), pp. 50-58.

Natural Resources Canada, 2004. *CSRS-PPP (Precise Point Positioning) Service: "How to Use" Document*. http://ess.nrcan.gc.ca/2002_2006/gnd/csrs_e.php (accessed 26 Nov. 2009).

Witchayangkoon, B. 2000. *Elements of GPS precise point positioning*, PhD Thesis, The University of Maine. http://www.cctechnol.com/uploads/167_0.pdf (accessed 26 Nov. 2009).