ASSESSMENT OF GEODETIC VELOCITIES USING CAMPAIGN MEASUREMENTS OVER LONG BASELINE LENGTH

ABSTRACT

GPS campaign measurements are frequently used in order to determine geophysical phenomena such as tectonic motion, fault zones, landslides, and volcanoes. When observation duration is shorter, the accuracy of coordinates are degraded and also the accuracy of point velocities are affected. The accuracies of the geodetic site velocities from a global network of the International GNSS Service (IGS) stations were previously investigated using only PPP. In this study, we extend that study in which site velocities will also be assessed including fundamental relative positioning. PPP derived results will also be evaluated to see the effect of JPL reprocessed products, single receiver ambiguity resolution, repeating survey campaigns minimum 3 days at the site, and eliminating noisier solution prior to the year 2000. Globally distributed 18 continuously operating IGS stations were chosen to create synthetic GPS campaigns. GPS data were processed comparatively using GAMIT/GLOBK v10.6 and GIPSY/OASIS II v6.3. The data of synthetic campaign GPS time series were processed using a regression model accounting for the linear and seasonal variation of the ground motion. Once accepting the velocities derived from 24 hour sessions as the truth, the results from sub-sessions were compared with the results of 24 hours and hypothesis testing was applied for the significance of the differences. The major outcome of this study is that at global scales (i.e. over long distances) with short observation sessions, the fundamental relative positioning produces results similar to PPP. The reliability of the velocity estimation for GPS horizontal baseline components has now been improved to about 85% on the average for observation durations of 12 h.

INTRODUCTION

GPS measurements were gathered from campaign surveys from the end of 80s through mid 90s. As of the emerge of continuous GPS in the early 90s and after the release of IGS offical orbit in 1994, campaign GPS measurements were combined with continuous GPS. By doing this, researchers wanted to take the advantage of episodic GPS measurements accumulated over the past 10 years. Campaign GPS measurements were mainly refered to monitor the global sea level in an attempt to decouple crustal motion from the actual sea level rise (Bingley et al. 2001) and to monitor tectonic motion (Zhang et al. 1997, Dixon et al. 2000, Reilinger et al. 1997).

Zhang et al. (1997) studied stochastic properties of continuous GPS (19-month long) data from permanent stations. They then extended their time series by extrapolation to 5 years and generated campaign GPS measurements. Velocities were estimated from those synthetically generated campaign measurements. Velocity estimation (i.e. standard) errors of campaign measurements were assesed employing white noise and colored noise models. The stochastic model derived from continuous measurements was recommended for finding the standard errors of deformation rates found from campaign measurements.

Dixon et al. (2000) used both campaign and continuous GPS to interpret the motion of Sierra Nevada Block. They followed a similar procedure as given in Zhang et al. (1997) and determined the stochastic model of their continuous measurements to later calibrate the velocity error of their combined time series. Bingley et al. (2001) followed a similar procedure in finding crustal motion in monitoring of the sea level, and velocities of campaign GPS measurements were computed in the combination model using the suggestions from Zhang et al. (1997) and Mao et al. (1999).

In the new milenium, many studies (Vernant et al. 2004, Serpelloni et al. 2007, Hollenstein et al. 2008, Chousianitis et al. 2015, Bitharis et al. 2016) in which GPS velocity fields have been used to facilitate tectonic and geodynamic research were performed applying the procedure detailed in Zhang et al. (1997), Mao et al. (1999), and Dixon et al. (2000). However, many others that employ campaign measurements were performed with the procedure; 1-day per year, collecting GPS measurements with only 8-10 hour observation session during the measurement day (Miranda et al., 2012; Elliot et al., 2010; Rontogianni et al., 2010; Ashurkov et al., 2011; Ozener et al., 2012; Tran et al., 2012; Catalão et al., 2011). Unluckily, the velocities from such campaigns vere estimated from only a couple of years (i.e. using only 2-3 estimates). Ambiguity resolution from the GPS baseline processing and hence the positioning accuracy as well as velocity estimation from the above campaigns were deteriorated due to the fact that GPS baseline solutions were produced for long baselines up to 2000 km with only 8-10 h of the data.

To critisize the above studies Akarsu et al. (2015) designed a global IGS study in which station velocities from 8-12 h GPS campaigns were assessed against those of the 24 h GPS campaigns.

Differing from the studies which aim to assess the "standard error level of estimated velocities" from campaign measurements (i.e. Zhang et al. 1997, Dixon et al. 2000, Mao et al. 1999), Akarsu et al. (2015) emphasized the term "accuracy of velocities" by which the accuracy of velocities estimated from 8-12 h observation time series is assessed against those of 24 h observations which are taken as the truth. They used the PPP online module of GIPSY/OASIS II (APPS) to analyze the GPS data. The results revealed that only 30-40% of the horizontal and none of the vertical velocities were comparable to the accuracy derived from 24h campaigns.

On the other hand, the analysis of Akarsu et al. (2015) at the time did not include some of the improvements due to recent developments in regard to the GIPSY/OASIS II processing, such as new JPL reprocessed products (i.e. orbits and clocks) and single receiver ambiguity solution. Considering those developments and adding some extra measures to the surveying procedure, we believe the success rate of estimated velocities from campaign GPS measurements will be improved. The extra measures mentioned above consider carrying out campaign GPS measurements in 3 consecutive days with overlapping sessions and including GPS days with ionospheric kappa index less than 4. Furthermore, the PPP results produced will be assessed with fundamental relative positioning using GAMIT/GLOBK analysis with the hypothesis "GPS relative positioning over long baseline lengths with short occupation durations should produce positioning information equivalent to PPP campaign results". To test this hypothesis a global network of 18 IGS stations were selected and the GPS data were analyzed using GAMIT and GIPSY. Synthetic GPS campaigns were created from the continuous observations with 8, 12- and 24-hour sessions. GPS data were processed for all sessions to form north, east and up campaign time series. Velocities derived from all three GPS components calculated from both 8- and 12-hours sub-sessions were compared with the velocities from 24-hours which were accepted as the truth. The differences from the truth were statistically tested and the result were interpreted.

2. METHODOLOGY

2.1 GPS Data Analysis

GPS data were downloaded in Receiver Independent Exchange (RINEX) format with 30 sec. intervals from the Scripps Orbit and Permanent Array Center (SOPAC) which is one of the data archives of the International GNSS Service (IGS) at http://sopac.ucsd.edu/. The IGS stations used in the study are demonstrated in Figure 1. First of all, to determine the horizontal velocities for each of the stations we selected three successive days in October each year for the years 2000 through 2015. Akarsu et. al. (2015) did the similar sampling using only 1 day in a year. This is the procedure followed by many of the GPS experiments using repeated surveys (Aktug et. al., 2009, 2013; Dogan et. al., 2014; Koulali et. al., 2015; McClusky et. al., 2000; Ozener et. al., 2010; Tatar et. al., 2012). Using 3 consecutive days here we believe we increased the reliability of the solutions. A treatment in regard to the solar activity, which was missing in Akarsu et. al. (2015), was also taken into consideration (i.e. days with kappa index ≤ 4) here. In addition, three successive days in every month were included for the processing of the vertical component. In order to model the significant annual plus semi-annual terms on GPS heights, here we did the sampling monthly. The GPS data were segmented into sub-sessions as listed in Table 1 in order to generate the repeated GPS measurements.

(i) GAMIT/GLOBK Processing

The GPS data were processed with GAMIT/GLOBK v10.6 software for relative point positioning (Herring et. al., 2006a, b) and with GIPSY/OASIS II, v6.3 for PPP (Zumberge et. al., 1997). The elevation cut-off angle was set to 7 degrees on both software.

The processing of the GPS data using GAMIT/GLOBK was conducted in three steps (Feigl et. al., 1993; McClusky et. al., 2000; Reilinger et. al., 2006; Tatar et. al., 2012; Dong et. al., 1998). We selected 18 globally scattered IGS stations. At first, the loosely constrained station coordinates, atmospheric zenith delays of each points, and Earth Orientation Parameters (EOP) were estimated using doubly differenced GPS phase measurements and IGS final products. Global Pressure and Temperature 2 (GPT2) mapping function developed by Lagler et al. (2013) was used to model the delay in the atmosphere. The ocean tide loading correction was applied using FES2004 model of Lyard et al. (2006).

Secondly, GLOBK was used to estimate the point coordinates and velocities from a combined solution comprising the daily loosely constrained estimates, EOP values, orbit data, and their covariance through Kalman Filtering. We used the IERS (International Earth Rotation and Reference Systems Service) Bulletin B values for Earth rotation parameters. Since our study was initially designed to be a global experiment, in this step we did not extra enlarge our network with more globally scattered and loosely constrained IGS stations.

In the last step, the reference frame was realized on each day through "generalized constraints". Iterations were applied on the initially chosen 18 IGS stations, and about 5 bad sites were eliminated after 4 iterations. The reference frame was realized on each day employing a reliable set of round 13 IGS stations in the ITRF2008 no-net-rotation (NNR) frame (Altamimi et. al., 2012). The reliability of the IGS stations was characterized with GPS days which do not contain the effect of bad ionospheric conditions with kappa index values smaller than 4, having at least 95% data coverage, being available on the common days, and repeating in 3 consecutive days with overlapping sessions.

The processing strategies described above were applied to each subset of sessions listed in Table 1. The coordinate values for all sub-sessions were transformed to the topocentric system consisting of East, North, and Up. The time series of the site ZIMM from relative positioning and PPP solutions for all sub-sessions were illustrated in Figure 2.

(ii) GIPSY/OASIS II Processing

We used JPL final precise (flinnR) orbits and clocks in the analysis. The (precise point positioning) PPP module of GIPSY/OASIS II v6.3 was developed by Zumberge et al. (1997). In GIPSY analysis, final orbits and clocks are determined from a global network solution. The results were represented using the International Earth Rotation Service's reference system ITRS (Petit and Luzum, 2010), as realized through the reference frame ITRF2008 (Altamimi et al., 2012). Tropospheric Zenith Wet Delay was modelled as a random-walk parameter with a variance rate of 5 mm^2 per hour and wet delay gradient with a variance rate of 0.5 mm^2 per hour. The dry troposphere was modelled using GPT2 mapping function a priori zenith conditions (Lagler et. al., 2013). Pseudo-range and carrier phase observations were employed to eliminate the ionospheric delay using L1 and L2 data combination. Kedar et al. (2003) model was used to eliminate the effect of second order ionosphere. Satellite and receiver antenna phase centre variation (APV) maps were automatically applied following the IGS standards (Haines et al., 2010). Desai (2002) model was used to eliminate the effect of ocean tide loading.

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