Single Frequency PPP Using Real-Time Regional Broadcast Corrections via NTRIP for the Australian GDA94 Datum

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Abstract

The possibility of Real-Time Precise Point Positioning directly in the Australian GDA94 datum has become possible through the availability of Real-Time Broadcast Corrections (BCs) provided by the IGS Real-Time Pilot-Project. Generation of BCs for the GDA94 datum has some pitfalls which are identified in this contribution. It is shown that it is impossible to obtain identical positioning results using either the BCs in ITRF or BCs in GDA94 due to scale differences between both systems. A new user-friendly RBC-approach is introduced, which deals with the scale-induced biases in the current approach. The user-friendly RBC-approach eliminates the user-need of having to apply the ITRF-to-GDA94 transformation, while still giving correct horizontal PPP positions in GDA94. For users that additionally require precise height information in GDA94 as well, a simple constant height-correction, valid for the complete Australian continent, is all that is needed to obtain the correct full 3D PPP position.

1 Introduction

Precise Point Positioning (PPP) (Zumberge et al. 1997; Kouba and Heroux 2001; Bisnath and Gao 2008) traditionally gives users positions in the reference frame of the precise orbits. For IGS products, the reference frame is the IGS realisation of the ITRF. IGS05 was the realisation which was aligned to ITRF2005 and since April 2011 IGS08 (aligned to ITRF2008) is the reference frame for IGS products. To enable PPP in Real-Time (RT), Broadcast Corrections (BC) have become available through the Real-Time IGS Pilot and the EUREF Real-Time Analysis Projects Söhne (2010). Two types of BC are currently available via the BKG IGS Data Center BKG (2010). The first type of BC, the Global Broadcast Correction (GBC), gives RT PPP users the necessary correction to Broadcast Ephemeris to obtain Precise Orbit and Clocks in the IGS Global Reference Frame (GRF) (Ge et al. 2011; Hauschild and Montenbruck 2009; Weber et al. 2007). The second BC, available since 2010, are the Regional Broadcast Corrections (RBC). They give the Precise Orbits directly in a Regional Reference Frame (RRF), such as GDA94 (Australia), ETRF2000 (Europe), etc. The goal of the RBC is to enable users to obtain their position directly in the RRF, without the need of having to apply the GRF-to-RRF transformation. This contribution analyses the applicability and limitations of the current GDA94 RBC. Section 2 describes the GBC-concept. The existing RBC-concept is introduced in Sect. 3. Here we also analyze the difference in the positioning results of both approaches and identify the source of these differences. A new user-friendly RBC, which is bias-free for the horizotal component is introduced in Sect. 4 and the last section gives conclusions.

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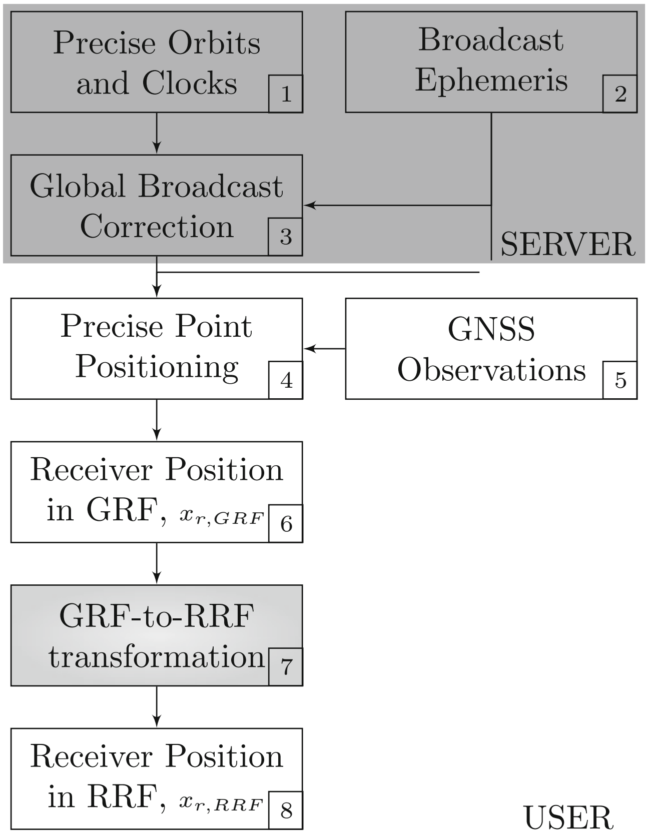

Fig. 1 Flow-diagram for obtaining a PPP position in GDA94 using the GBC-concept

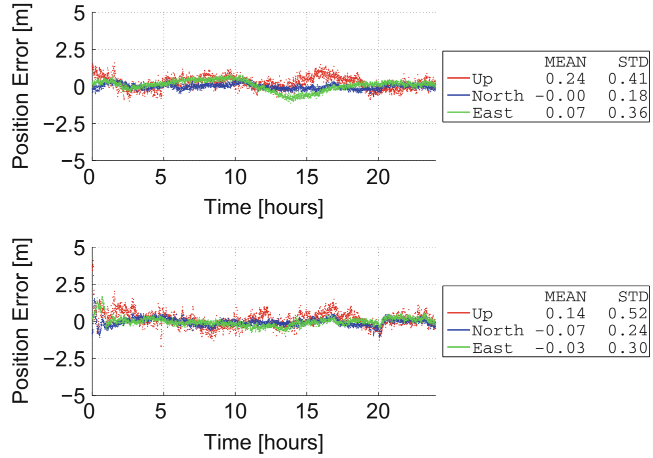

Fig. 2 Typical position errors for our real-time kinematic single-frequency PPP using the CLK10 broadcast corrections from BKG. *Top figure* ionosphere corrected with GIM, *bottom figure* ionosphere eliminated through code + phase linear combination

2 Real-Time PPP with Broadcast Corrections

The process of obtaining positions in a RRF using the GBC-concept is shown in Fig. 1. Precise Orbits and Clocks (box 1) are used to generate Global Broadcast Corrections (box 3) to the Broadcast Ephemeris (box 2). The PPP-algorithm (box 4) uses these GBCs and the Broadcast Ephemeris together with the GNSS Observations (box 5) to compute a precise Receiver Position in the GRF (box 6). A GRF-to-RRF Coordinate Transformation (box 7) is needed to obtain the Receiver Position in the required RRF (box 8). Typical position errors for our Real-Time Single-Frequency PPP (Le and Tiberius 2007; van Bree and Tiberius 2011) using the CLK10 Broadcast Corrections, which are based on IGS ultra-rapid predicted orbtis and real-time BKG clocks (BKG 2011; Weber et al. 2007) are shown in Fig. 2. Besides the Broadcast Corrections the other models and a-priori corrections used in the algorithm are: solid earth tide correction, tropospheric delay correction (Saastamoinen with Ifadis mapping function), carrier-phase wind up, differential phase and code biases (CODE) and satellite antenna phase center offsets (igs05.atx). The ionosphere is either corrected using predicted-Global Ionospheric Maps (GIM) (Schaer 1999) as in Øvstedal (2002) or eliminated as in Montenbruck (2003). The 1 Hz observation data used in this contribution is from the APREF-station CUT0, doy 79 year 2011. CUT0 is located at Curtin University and equipped with a Trimble NetR9 receiver which is connected to a TRM59800.00 GNSS choke-ring antenna covered with a UNVACO SCIS radome. In this set-up typical empirical standard deviations for the position are a few decimeter in the horizontal components and less than 5 dm for the vertical component.

3 Global Versus Regional Broadcast Corrections

The main difference of the RBC with the GBC is that the transformation between the reference frames is performed at the Server that computes the BC instead of transformation by the User. This is illustrated in Fig. 3. Both the GBC- and the RBC-concept intend to give a position in the RRF, GDA94 in this contribution. The GDA94 coordinates obtained for CUT0 using the CLK10-product for the GBC-approach and the CLK43-product for the RBC-approach are compared in Fig. 4. Both the CLK10 and CLK43 products are based on the BKG clocks. The ITRF-to-GDA94 transformation, with transformation parameters obtained from Dawson and Woods (2010), is done at the Server for the RBC-approach (BKG 2011), while the transformation was applied at the User for the GBC-approach. Where one would expect identical results for the GDA94 coordinates, a height difference of 60–80 mm is observed in the height component as well as differences of up to 10 mm in the horizontal components. The origin of this difference lies in the difference in

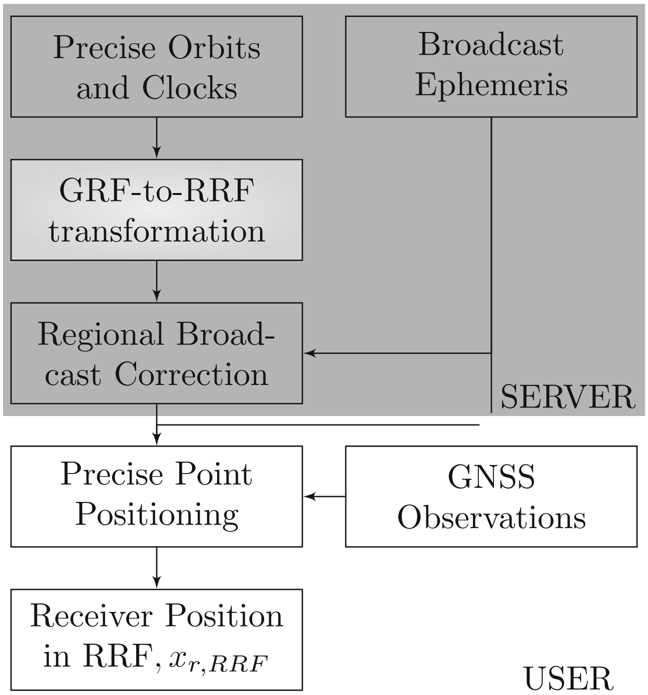

Fig. 3 Flow-diagram for obtaining a PPP position in GDA94 using the RBC-concept, compare with Fig. 1

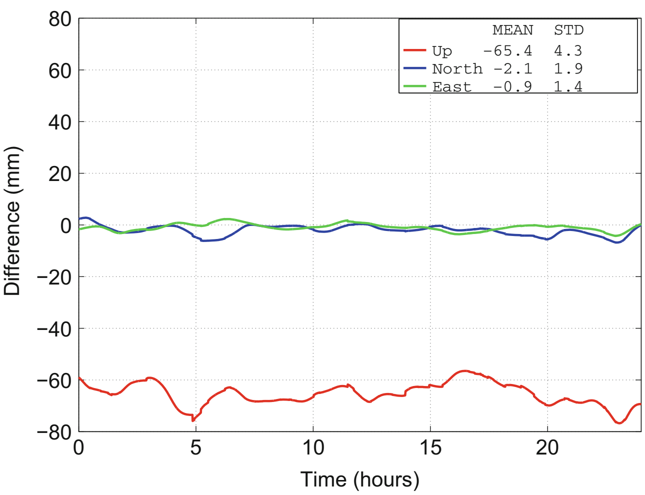

Fig. 4 Single-frequency PPP RRF-coordinate differences between using the GBC-concept and the RBC-concept

scale-factor of GDA94 and ITRF2005, which was 11.7 ppb at the time of observations. As the receiver-satellite range ρ_r^s is invariant for translation and rotation, but not for scale, the differences shown in Fig. 4 are caused by the scale factor λ that exists between the reference frames (GRF vs. RRF). The scale λ affects the computation of ρ_r^s, because $\rho_{r,1}^s = ||\mathbf{x}_1^s - \mathbf{x}_{r,1}|| = \frac{1}{\lambda}||\mathbf{x}_2^s - \mathbf{x}_{r,2}|| = \frac{1}{\lambda}\rho_{r,2}^s$, in which $\mathbf{x}_1^s$, $\mathbf{x}_2^s$ are the satellite position vectors in the GRF and RRF frames, respectively, with $\mathbf{x}_{r,1}$, $\mathbf{x}_{r,2}$ the corresponding receiver position vectors. Hence, if the scale is not properly taken into account, the outcome of the PPP algorithm will result in a position bias. Since its impact depends on the changing receiver-satellite geometry, this bias varies with time as shown in Fig. 4. To eliminate this scale-generated bias, the effect of λ on ρ_r^s has to be corrected in the PPP algorithm by the user.

4 User Friendly Regional Broadcast Corrections

As shown in the previous section of this contribution, it is not possible to obtain correct user positions without elimination of the scale-factor between the GRF and the RRF in the PPP-algorithm at the User. The scale effect causes a receiver-satellite geometry-dependent bias in the position solution. The correction for the scale effect in the user's PPP algorithm is not practical as users often do not have access to the source code of their software. Here we propose a user-friendly Regional Broadcast Correction, where the scale-factor is eliminated from the RBC by excluding it in the transformation. Effectively, as is shown in Fig. 5, in our user-friendly RBC, only the GRF-to-RRF Rotation and Translation are applied at the Server side. Although, as shown in Fig. 6, the scale-omission at the Server side results in a position dependent bias, for all practical purposes this bias can be treated to be a simple constant ellipsoidal height-offset δh, valid for the complete Australian continent. Hence, the application of a simple constant height-correction is then all that is needed to obtain the 3D PPP position in the RRF. No correction at all is needed for users that are only interested in the horizontal position. To confirm that the user-friendly RBC-approach results in identical positions as the GBC-concept we have applied the scale correction as given in the last box in Fig. 5. The resulting position differences are indeed zero, as shown in Fig. 7. Hence, the GBC- and user-friendly RBC-concept give identical results, the key to realizing identical results is omitting the scale at the Server side and introducing it at the User side.

5 Conclusions

We have introduced a user-friendly Regional Broadcast Correction which takes care of the scale-factor induced effects on PPP positioning. The user-friendly RBC is an alternative to the existing RBC that is affected by the difference in scale-factor between Global and Regional Reference Frames. It is possible to use the user-friendly RBC in existing PPP-software. Users that are only interested in horizontal positions obtain a practically bias-free position

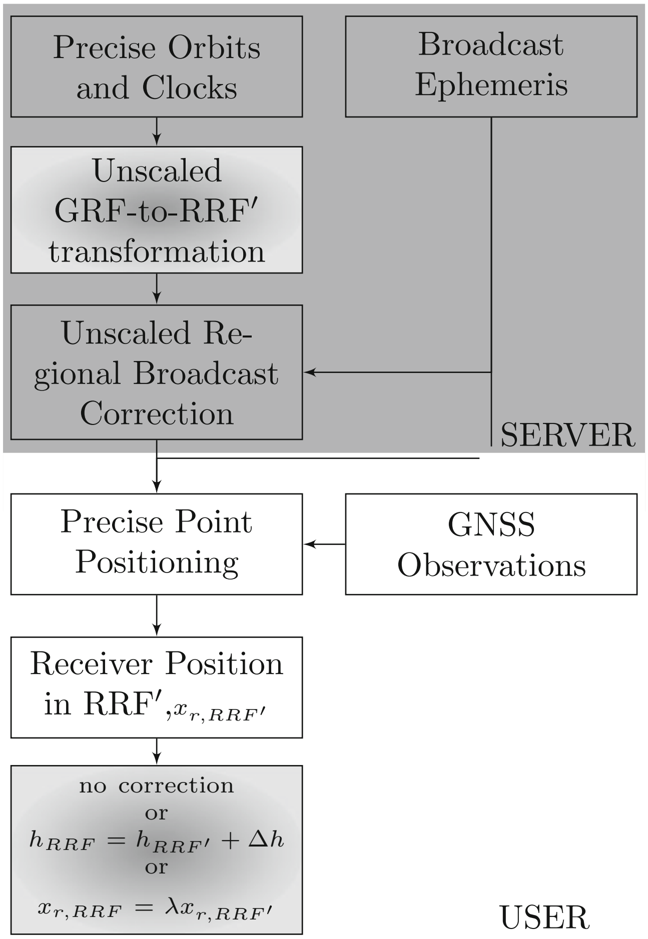

Fig. 5 Flow-diagram for obtaining a PPP position in GDA94 using the user friendly RBC-concept, compare with Figs. 1 and 3

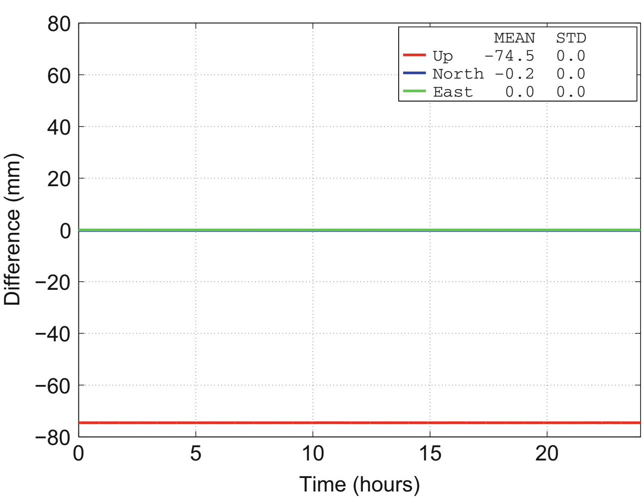

Fig. 6 Difference between receiver positions in the RRF from SF-PPP using the user friendly RBC compared to using the GBC. There are no differences in the horizontal components, the height offset is a constant bias

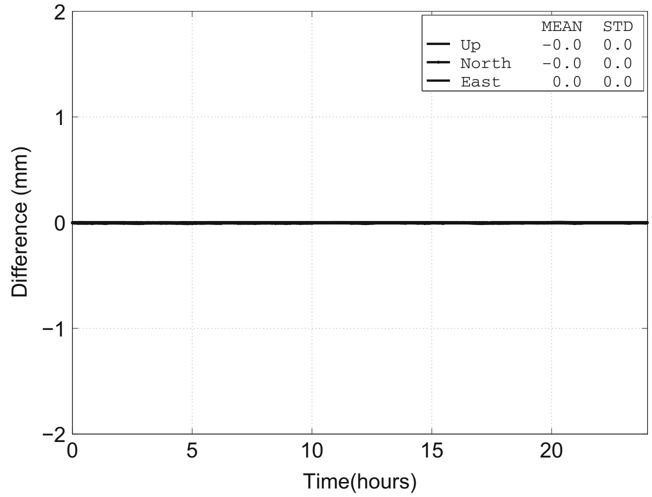

Fig. 7 Single-frequency PPP RRF-coordinate differences between using the GBC-concept and our, scale-corrected, user friendly RBC-concept. There are no differences between the coordinates obtained with the two methods

using the suggested approach, while users interested in a 3D-position only have to apply a height-bias correction instead of a 14-parameter transformation when using the GBC-approach.

A similar analysis as done in the present contribution for GDA94 can be performed for other RRFs, such as ETRF2000 and NAD83, as well.

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