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Real-time zenith tropospheric delays in support of numerical weather prediction applications

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Abstract

The Geodetic Observatory Pecný (GOP) routinely estimates near real-time zenith total delays (ZTD) from GPS permanent stations for assimilation in numerical weather prediction (NWP) models more than 12 years. Besides European regional, global and GPS and GLONASS solutions, we have recently developed real-time estimates aimed at supporting NWP nowcasting or severe weather event monitoring. While all previous solutions are based on data batch processing in a network mode, the real-time solution exploits real-time global orbits and clocks from the International GNSS Service (IGS) and Precise Point Positioning (PPP) processing strategy. New application G-Nut/Tefnut has been developed and real-time ZTDs have been continuously processed in the nine-month demonstration campaign (February–October, 2013) for selected 36 European and global stations. Resulting ZTDs can be characterized by mean standard deviations of 6–10 mm, but still remaining large biases up to 20 mm due to missing precise models in the software. These results fulfilled threshold requirements for the operational NWP nowcasting (i.e. 30 mm in ZTD). Since remaining ZTD biases can be effectively eliminated using the bias-reduction procedure prior to the assimilation, results are approaching the target requirements in terms of relative accuracy (i.e. 6 mm in ZTD). Real-time strategy and software are under the development and we foresee further improvements in reducing biases and in optimizing the accuracy within required timeliness. The real-time products from the International GNSS Service were found accurate and stable for supporting PPP-based tropospheric estimates for the NWP nowcasting.

Keywords: GNSS; Zenith tropospheric delay; Real-time analysis; Precise Point Positioning; Numerical weather prediction nowcasting

1. Introduction

The Geodetic Observatory Pecný (GOP) of the Research Institute of Geodesy, Topography and Cartography has been routinely estimating zenith total delay (ZTD) parameters from European GPS permanent stations in near real-time (NRT) since 2001 (Dousa, 2001). The GOP ZTD products are disseminated via the Global Telecommunication System of the World Meteorological Organization to meteorological institutions worldwide. The products are currently assimilated into numerical weather prediction (NWP) models in Météo France and the UK Met Office and exploited in other ways at some other agencies. In 2010, first hourly global ZTD solution (Dousa and Bennitt, 2013) was developed at GOP in support of global NWPs. One year later, after the product thorough evaluation, it was officially switched to the operational mode and it started to be routinely assimilated into operational global NWP models. In 2009, along with the developing ultra-rapid GLONASS orbits for the International GNSS Service (IGS) (Dow et al., 2009), GOP implemented near real-time GPS + GLONASS solution. It has been routinely provided since 2011 after adopting the IGS08 antenna phase center model which reduced

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well-known GPS – GLONASS biases in ZTD (Dach et al., 2011; Dousa, 2012). Based on this product we could state that GNSS ultra-rapid orbit products, provided so far by the IGS unofficially, have proven to be reliable for operational ZTD retrievals too.

All the above mentioned ZTD solutions are based on data analysis in a batch network mode using the least-square adjustment and double-difference observations. The Bernese GNSS software V5.0 (Dach et al., 2007) was used for the processing together with support of the IGS ultra-rapid orbits (Springer and Hugentobler, 2001). We did not utilize the Precise Point Positioning (PPP) method developed by Zumberge et al. (1997) which required an access to precise satellite clocks along with predicted orbits. Gendt et al. (2004) demonstrated that ZTD using PPP, supported with hourly updated precise satellite clocks, gives results comparable to those from the network solution. The precise clock product usable for NRT solution was, however, not publicly available at that time. The situation changed with the definition of the state-space correction format for real-time dissemination that was standardized by the Radio Technical Commission for Maritime Service (RTCM, 2013). During last years, the IGS coordinated development of global real-time orbit and clock products exploiting individual contributions from several institutions in order to guarantee its high robustness and availability. At the end of 2012, the IGS launched its Real-Time Service (RTS) (Caissy et al., 2012) and declared the product as official. Thanks to these developments, PPP could have been implemented and recently used at GOP.

One of the well-known disadvantages of the PPP method, however, still remains – a long convergence interval of about 20–30 min. It is related to the difficulty of integer ambiguity resolution due to the presence of so called uncalibrated phase biases (Ge et al., 2008). Several strategies has been implemented in order to speed up the PPP convergence, but they require additional products, such as uncalibrated phase delays used in Ge et al. (2008) and Geng et al. (2010) or integer-clock corrections, see e.g. (Mervart et al., 2008; Laurichesse et al., 2009; Collins et al., 2010). The integer ambiguity resolution is thus available and the convergence time was reduced to about 10 min. The resolution of narrow-lane ambiguities, which are highly correlated with the other parameters such as receiver clocks, coordinates and tropospheric parameters, remained difficult using a shorter interval. Another recent studies overcame the PPP limitation by providing additional products, such as undifferenced L1 and L2 regional augmentation corrections from several reference stations up to a distance of 80–150 kilometers (Ge et al., 2012). Li et al. (2014) demonstrated the PPP Regional Augmentation (PPP-RA) for the instantaneous ambiguity resolution if supported with additional corrections derived from a regional reference network. This was already able to compete with the network RTK systems in terms of the first-time-to-fix interval when supporting even longer distances to reference stations.

In this paper we present a new GOP solution of real-time ZTD estimates that applies the PPP approach and un-differenced observations. The G-Nut/Tefnut software was developed for this purpose as a PPP client that uses global precise products publicly available from the internet. Ambiguities are not resolved to integer values, but ZTDs from a convergence interval after data gap can be eliminated since they are showing high formal errors.

Motivations for using the PPP consisted of several advantages when compared to the standard network processing strategy

1. highly efficient solution that may be processed for each station separately or, alternatively, in a decentralized mode provided that relevant products and software are distributed,
2. approach suitable for epoch-wise real-time filtering and supporting high-resolution tropospheric parameters,
3. direct support of absolute tropospheric zenith total delay estimates as well as additional parameters for monitoring atmospheric asymmetry around the stations – horizontal gradients or slant delays.

In particular the parameters of asymmetry modeling are considered as rewarding products for future support of NWP nowcasting or severe weather event monitoring.

After this introduction, the second section introduces the software development used in this work. The third section summarizes initial results from the new approach analyzing a time-limited benchmark campaign in an offline mode. The fourth section describes a demonstration campaign provided for the assessment of a routine real-time solution. The results are summarized in the last section.

2. Software development

The results, presented in the paper, were achieved using the in-house application named Tefnut which was derived from the G-Nut software library developed at GOP (Vaclavovic et al., 2013). The G-Nut library is designed primarily for the GNSS data analyses, but recently we introduced modules for the processing of selected data from numerical weather models. The library aims at supporting all GNSS constellations, real-time and offline processing mode, epoch-wise filtering as well as batch least-square adjustment. For a high flexibility, the library is written in C++ taking advantage of the object-oriented concept.

While the pre-processing of carrier-phase observation has been properly implemented, the first stage of the library development missed several models for a high-accuracy analysis. These are foreseen for completing in the second development phase. Available models in the G-Nut/Tefnut application include solid earth tides, phase wind-up effect, receiver and satellite antenna phase center offsets and