Single-Frequency Precise Point Positioning Using USTEC Ionospheric Model

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Introduction

Precise Point Positioning (PPP) technique can achieve positioning accuracy at the centimeter level for static applications and at the decimeter level for kinematic applications, when dual frequency receivers are used. This, however, is not the case with low-cost single-frequency GPS receivers, which are limited by the effect of ionospheric delay. A number of mitigation techniques have been proposed by the scientific community to account for the effect of ionospheric delay for single-frequency users. Unfortunately, however, most of those mitigation techniques are not suitable for precise point positioning (PPP). More recently, the US Total Electron Content (USTEC) product has been developed by NOAA, which describes the ionospheric total electron content with high resolution over most of North America. This article investigates the performance of USTEC and studies its effect on single-frequency PPP solution. A performance comparison with two widely used ionospheric mitigation techniques, namely the International GNSS Service (IGS) final global ionospheric maps (GIM) and the CODE-generated Klobuchar-style models, is also presented.

A well known empirical method to account for the effect of ionospheric delay is the Klobuchar model, whose coefficients are transmitted as part of the navigation message (Klobuchar, 1991). Although this model can be implemented in real time, it can only correct for 50%-60% of the total ionospheric effect. The Centre for Orbit Determination in Europe (CODE) has been producing Klobuchar-style ionospheric coefficients since 2000 (CODE, 2012). The coefficients are estimated through best fitting of CODE-produced IONosphere map EXchange (IONEX) data. CODE performed a validation study, which showed that Klobuchar-style ionospheric coefficients outperform those of the standard Klobuchar model (CODE, 2012).

The GIM product provided by the IGS offers an alternative way to mitigate the ionospheric delay. The two-dimensional GIM file contains the vertical total electron content (TEC) grid values and the differential code biases (DCBs) of the satellites and stations in the IONEX format (Schaer et al., 1998). IGS provides two different ionospheric TEC grid products, namely the final and the rapid. The final product is accurate to 2 to 8 TEC units (i.e., $2*10^{16}$ to $8*10^{16}$ electrons/m^2) with a latency of 11 days, while the rapid product is accurate to 2 to 9 TEC units with a latency of less than 24 hours (IGS, 2012). Both final and rapid GIM have a temporal resolution of 2 hours and a spatial resolution of 5° in longitude and 2.5° in latitude.

More recently, the US National Oceanic and Atmospheric Administration (NOAA) used a regional network to provide maps of the TEC values over the Continental US. The product, which is known as the US Total Electron Content, or USTEC, provides vertical TEC and slant path values of the line-of-sight electron content to the GPS satellites in view (Araujo-Pradere et al., 2007).

NOAA Ionospheric Mitigation Model - USTEC

The US National Oceanic and Atmospheric Administration, through collaboration of different offices, used a regional network of CORS, GPS/Met and IGS reference stations to produce maps of TEC values over the Continental US (Araujo-Pradere et al., 2007). The product, which is known as the US Total Electron Content, or USTEC, provides vertical TEC as well as line-of-sight TEC values to the GPS satellites in view of the reference stations at the time. The USTEC product is based on a data assimilation model, which uses Kalman filtering for parameter estimation (Spencer et al., 2004).

The files are produced every 15 minutes and cover all the satellites in view of the network. The USTEC maps have a spatial resolution of 1° by 1° and cover regions across the US, which extend from latitude 10° to 60° North, and from longitude 50° to 150° West. The expected accuracy of the USTEC maps is in the range of 1 to 3 TEC units. To estimate the ionospheric correction using the USTEC (and also the GIM), it is necessary that a two-dimensional spatial interpolation function be applied to match the station location. In addition, a temporal interpolation function is needed to obtain the ionospheric correction at a particular time. In this research, we used the Lagrange interpolation method (Spiegel, 1999).

Results and Analysis

In order to evaluate the USTEC, Natural Resources Canada (NRCan) GPSPace PPP software was modified to facilitate single frequency GPS data processing with USTEC ionospheric modelling. Data from four North American IGS reference stations representing different latitudes (Figure 1) were downloaded and used in our analysis. The data sets were selected to represent three different seasons (January, July, and October), each for three days of the year 2011, which reflect the seasonal variations of the ionospheric delay. The values of slant ionospheric delays were estimated using NOAA USTEC, Klobuchar-style, and GIM models.

The PPP solution convergence and the root-mean-square

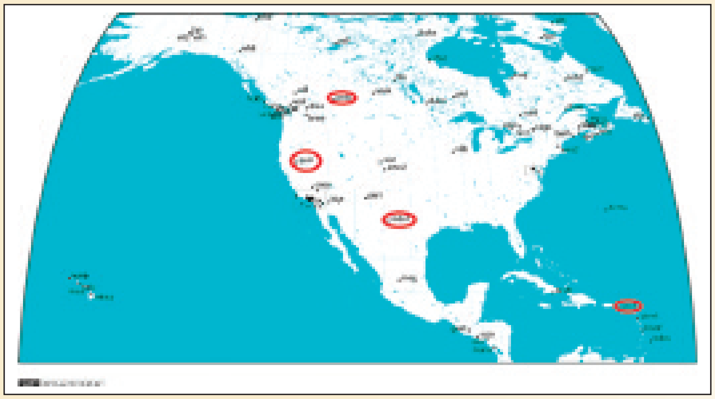

Figure 1: IGS stations used in data analysis

error (RMSE) of the positioning residuals were calculated for each station and compared with those of dual frequency results. Figures 2 to 4 show the positioning solution (latitude, longitude and height) for the NOAA, Klobuchar-style and the GIM models for station MOD1 on October 30, 2011, as an example.

Figures 5 and figure 6 show summary results of the RMSE of the positioning residuals for stations CRO1 and QUIN respectively in various seasons.

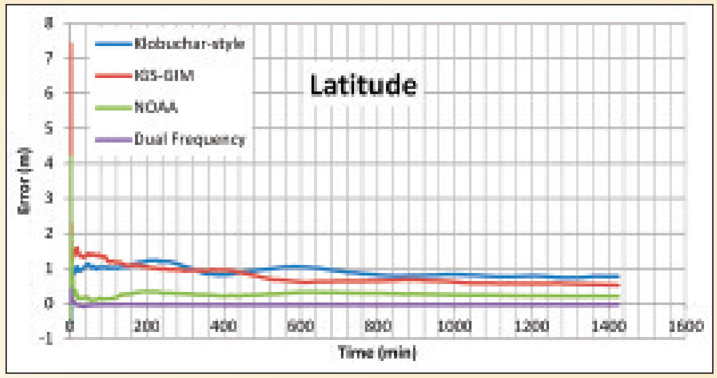

Figure 2: Latitude accuracy and convergence for station MOD1 on October 30, 2011

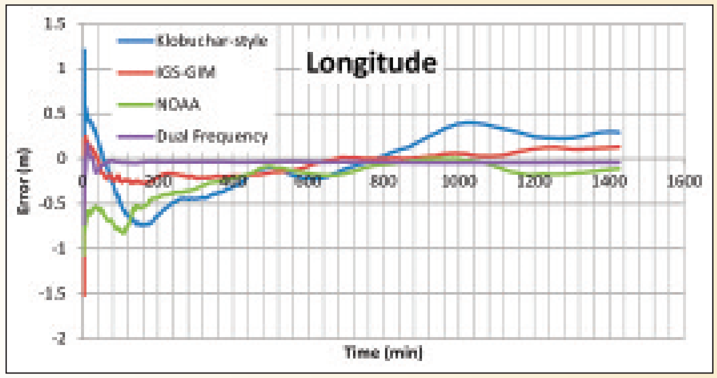

Figure 3: Longitude accuracy and convergence for station MOD1 on October 30, 2011

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It can be clearly seen from these figures that the use of the NOAA model improved the positioning accuracy to decimeter-level and speeded up the convergence time in comparison with the GIM and Klobuchar-style models. The GIM model is capable of attaining sub-metre level accuracy. The Klobuchar-style model performed poorly in comparison with other models and was capable of only achieving metre-level accuracy. This is particularly clear in the height component. In general, the values of the RMSE are smallest in the January results and largest in the October results, which suggest that the performance of the models are seasonal-dependent.

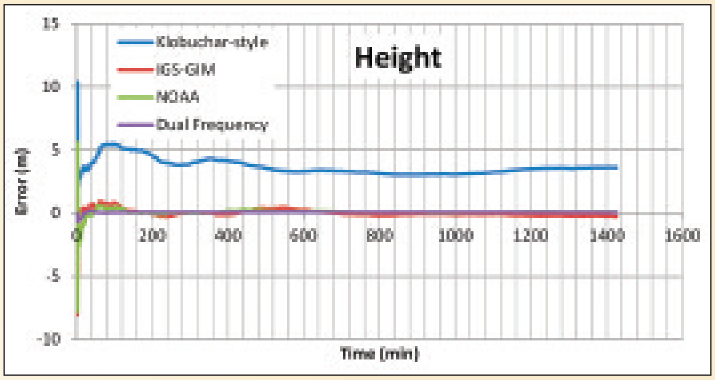

Figure 4: Height accuracy and convergence for station MOD1 on October 30, 2011

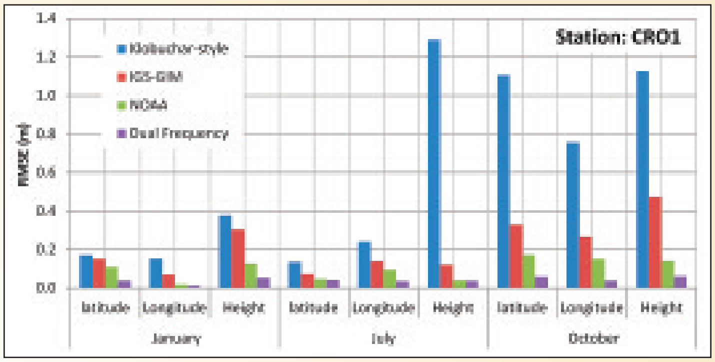

Figure 5: RMSE of positioning residuals for station CRO1

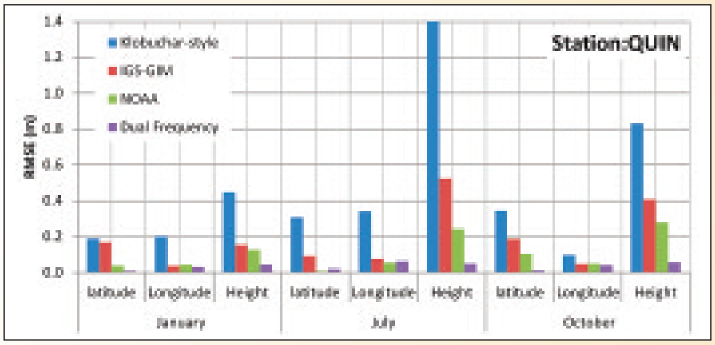

Figure 6: RMSE of positioning residuals for station QUIN

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Calendar of Events

February 4 to 6, 2014
11th Annual ORCGA Damage Prevention Symposium
Collingwood, Ontario
www.orcga.com

February 17 to 19, 2014
International LiDAR Mapping Forum
Denver, Colorado
http://www.lidarmap.org/international

February 26 to 28, 2014
122nd AOLS Annual General Meeting
Tomorrow is Now
Niagara Falls, Ontario
www.aols.org

March 23 to 27, 2014
ASPRS 2014 Annual Conference
Geospatial Power in Our Pockets
Louisville, Kentucky
www.asprs.org

May 28 to 29, 2014
GEO Business 2014
London, England
www.geobusinessshow.com

June 16 to 21, 2014
XXV FIG International Congress
Engaging the Challenges, Enhancing the Relevance
Kuala Lumpur, Malaysia
www.fig.net/fig2014