Experiments on the Ionospheric Models in GNSS

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Abstract In GNSS, one of the main error sources of the Standard Positioning Service (SPS) is introduced by the ionosphere. Although this error can be cancelled by combining two signals at different frequencies, most of the single-frequency mass-market receivers do not benefit from this cancellation. For that reason, a set of parameters is included in the navigation message in order to compute the ionospheric delay of any observation by the Klobuchar model. The Klobuchar model is a very simple model that is able to remove more than the 50% of the ionospheric delay. Recently, more accurate ionospheric models have been introduced such as Global Ionospheric Map (GIM) or the Fast Precise Point Positioning (FPPP) ionospheric model. In previous works, with data gathered in Europe, it was shown the advantage of the FPPP's ionospheric model. In this work, we conduct experiments to compare the performance of different ionospheric modelling methods including: Klobuchar, GIMs and FPPP. Our preliminary results show how FPPP and GIMs lead to better positioning precisions compared to the Klobuchar model. However, since data is not wide enough to cover different ionospheric conditions, more experiments will be carried out in our future work to validate the current results.

Key words GNSS, ionospheric, PPP, GIM, Klobuchar

1. Introduction

In GNSS, the accuracy of the broadcast orbits and clocks is at the level of 1 or 2 meters (see, for instance, http://igscb.jpl.nasa.gov/components/prods.html). Then, the main error source in the SPS is introduced by the ionospheric refraction [1], which can reach up to several tens of metres. Nevertheless, this error can be cancelled by combining two signals at different frequencies. This is done by building the so-called ionospheric-free combination (P3), which is not affected by the ionospheric refraction.

On the other hand, the use of P3 requires a dual frequency receiver while the mass market receivers, up to now, are single frequency receivers. For that reason, a set of parameters is included in the navigation message in order to compute the ionospheric delay of any observation by the Klobuchar model [3]. The Klobuchar model is a very simple model that is able to remove more than the 50% of the ionospheric delay [4].

On the 1st June, 1998 the International GNSS Service (IGS; [2]) started the Ionospheric Working Group (Iono-WG) with the aim of computing Global Ionospheric Maps (GIMs) with GPS data. Several institutions have contributed with their works in terms of computation and validation to generate a common, reliable and accurate IGS combined GIM on a daily basis. In this regard, GIMs have been represented in IONEX format with the grid solution 2h x 50 x 2.50 in Universal Time (UT), local time and latitude [5]. During the last decade, various research works have shown that GIMs are a reliable source of global ionospheric information.

Recently, a more precise ionospheric model has been introduced and integrated in the, so-called, Fast Precise Point Positioning (FPPP) method [5-6], which shows faster convergence time, and better positioning accuracy. Although FPPP was proposed for dual-frequency receivers, its ionospheric model can also benefit mass-market single frequency receivers by providing accurate ionospheric corrections.

In this paper, we investigate the benefit brought to the mass-market single frequency receivers thanks to using different ionospheric models including: Klobuchar, IGS GIMs, and FPPP.

2. Experiments and Results

As mentioned above, we conducted experiments to compare the performance of different ionospheric models including: Klobuchar, IGS GIMs and FPPP. The inputs for all the experiments are publicly available RINEX files. For the IGS GIMs, we used the global ionospheric maps in IONEX format provided through NASA's Crustal Dynamics Data Information System FTP site (CDDIS; **ftp://cddis.gsfc.nasa.gov/gps/products/ionex**). The below paragraphs provide the details on the experiments and their results.

Experiment 1 – Comparison of the performance of FPPP in the SEA region

In this section, the navigation performance of FPPP in the equatorial region of Sumatra (Indonesia) is presented. This scenario is more challenging than in European mid-latitudes since the Vertical Total Electron Content (VTEC) values are five times greater [6]. User navigation still benefits in terms of convergence time and accuracy from an accurate estimation of the ionosphere, and previous results in the European region, are only worsened by a factor two, where decimetre-level navigation was obtained for the classical PPP strategy after the best part of an hour.

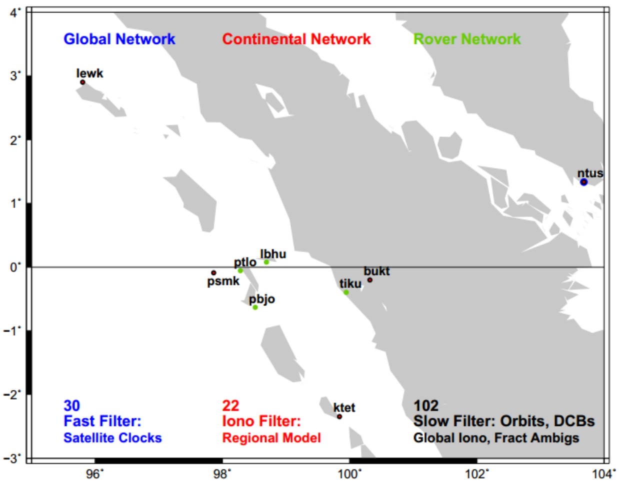
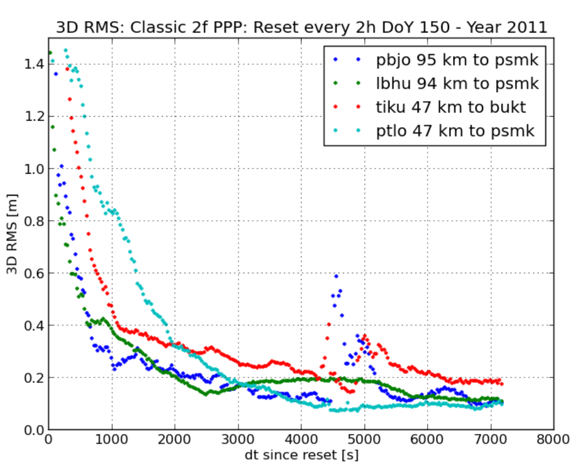


Figure 1. Location of rovers and reference stations used in experiment 1, DoY 150 of Year 2011.

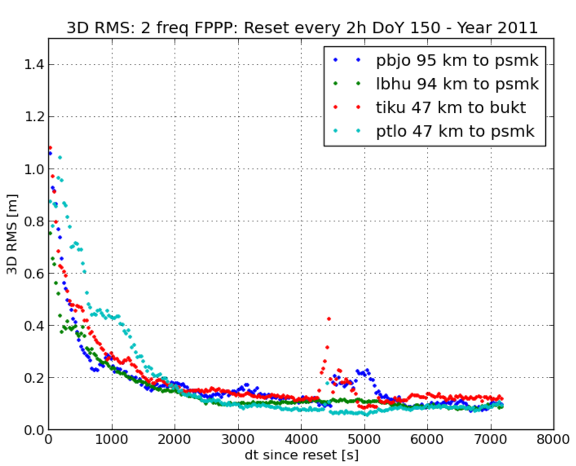
Fig.1 shows the rover location with respect to the nearest reference station. A total of 102 stations combining a selection of the globally distributed IGS network and the more local Sumatran GPS Array (SuGAr). The three different station networks are used by the Central Processing Facility (CPF) as follows.

Slow-varying parameters such as the satellite orbit corrections to IGS predicted products and the fractional part of the ambiguities are estimated every few minutes in a slow global filter. The coarse global ionosphere estimation enables the estimation of satellite Differential Code Biases (DCBs). Random white-noise-like parameters such as satellite clocks are computed with a much higher rate depending on satellite clock stability in a global high-rate filter. Finally, precise ionospheric corrections are computed in a devoted continental-slow filter.

Convergence of the double-frequency users is accelerated thanks to precise ionospheric information compared to the classical PPP strategy, where the first order ionospheric delay is removed algebraically with the ionospheric-free combination. This is illustrated in Fig.2 where the Root Mean Square (RMS) is computed from the user positioning applying resets every 2 hours. This convergence boost occurs for all rovers with different distances to the reference stations used to derive the ionospheric model.



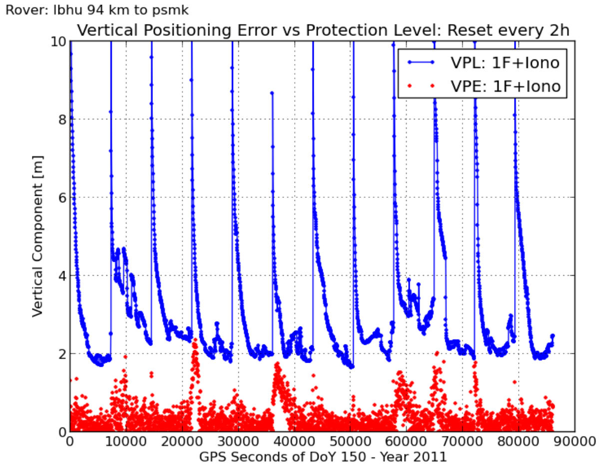
(a)



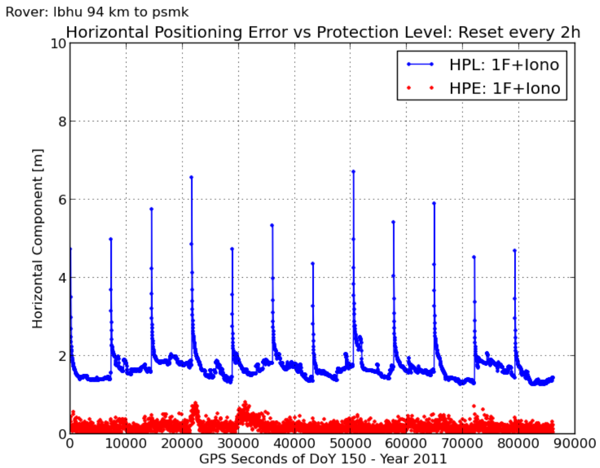
(b)

Figure 2. RMS of the 3D positioning error of the rovers when using two frequencies Classic PPP and Enhanced PPP (with ionosphere) with resets every 2 hours.

Accuracy of the mass-market single-frequency users is enhanced thanks to the accurate ionospheric modelling, as it is shown in the Vertical and Horizontal positioning errors of Fig.3. Since the corrections are broadcast together with their confidence values, the user can compute the associated Protection Level (PL). The integrity of the solution is maintained for all of the periods after each reset with a metre-level PL.



(a)

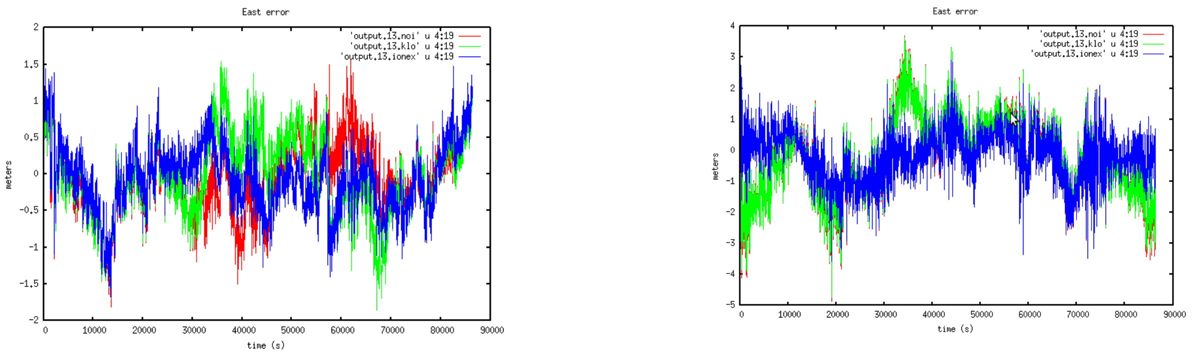


(b)

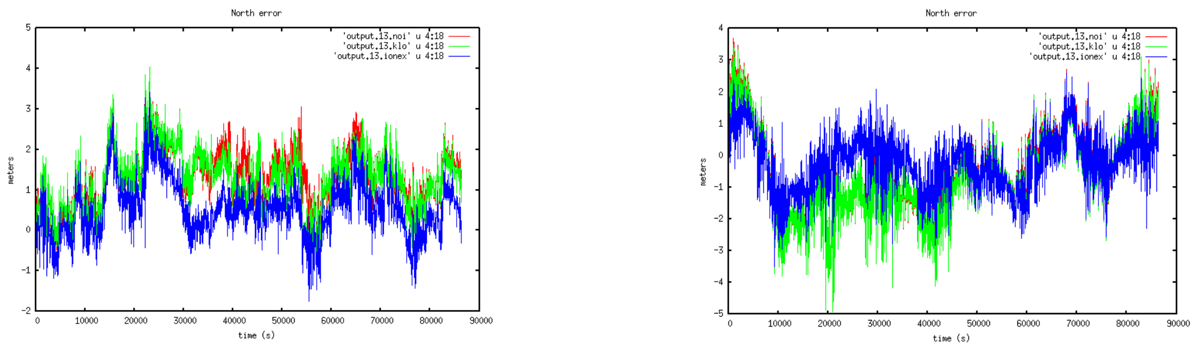
Figure 3. Vertical and Horizontal positioning errors and protection levels for single-frequency lbhu rover at 94 km of the nearest reference station.

Experiment 2 – Comparison between Klobuchar and IGS GIMs in one-frequency standard positioning.

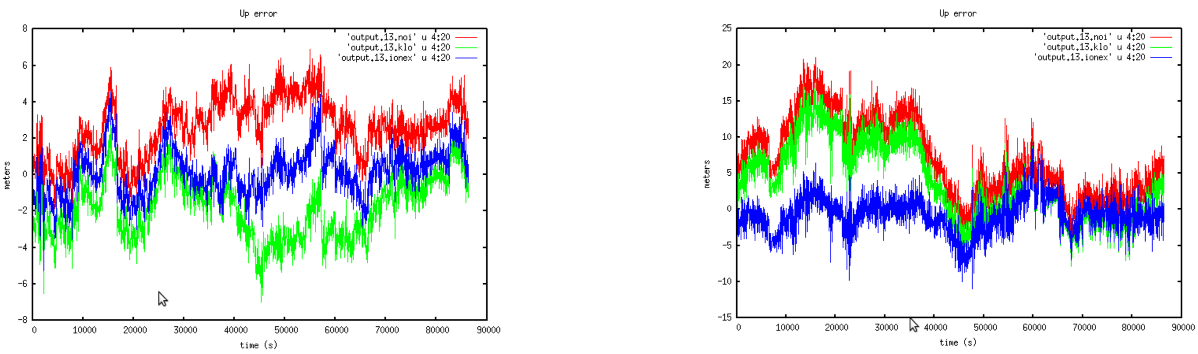
In this and the below experiments, we first computed the Ionospheric Pierce Point (IPP) coordinates then interpolated the slant Total Electron Content (STEC) at the IPP based on the GIMs grid VTEC values. The STEC interpolated values were used to correct the measurements before solving the receiver's positions. MORP (Europe) and PIMO (Philippines) stations were used in these experiments. Fig. 4 shows the positioning errors of the two stations. As it can be seen, for PIMO stations, the GIMs (blue lines) actually help to improve the error, especially in the vertical direction.



(a) East Error

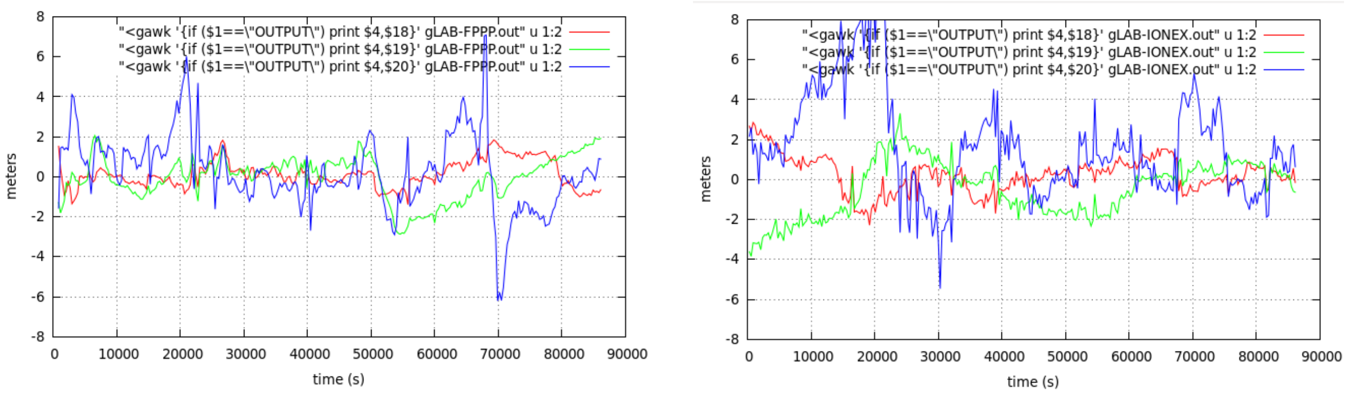


(b) North Error



(c) Up Error

Figure 4. ENU Positioning Error of MORP (left) and PIMO (right)



FPPP Ionospheric Model

Global Ionospheric Maps

Figure 5. Positioning Errors (GATH station): East (green), North (red), and Up (blue)

Experiment 3 – Comparison between IGS GIMs and FPPP in one-frequency standard positioning.

In spite of FPPP is thought to work using precise orbits and clocks, in this experiment, broadcast orbits and clocks are used for single-frequency users using the Standard Positing Service (SPS). In this regard, we demonstrated the benefit of the accurate ionospheric model generated using FPPP for mass-market single frequency receivers. First, the same steps as in the previous section were used to calculate the position with GIMs, and then we used gLAB [7, 8] to solve the position with FPPP ionospheric model.

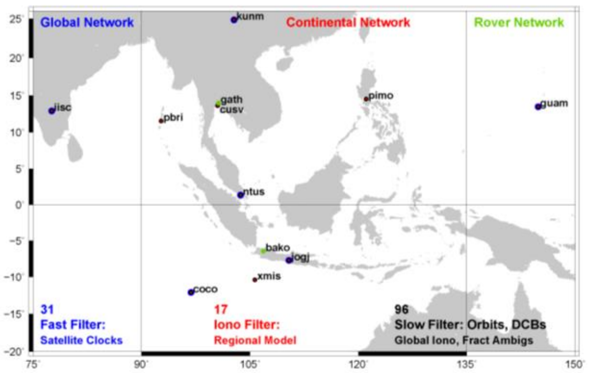


Figure 6. Location of rovers and reference stations used in Experiment 3, DoY 147 of Year 2011.

A total of 96 stations were used with the same strategy previously commented. Note that in this case not only fewer stations are involved in the computation of the regional ionospheric model, but also, there are larger baselines between reference stations (of around thousands of kilometres). This lack of stations is translated into a lower performance of the ionospheric model with respect to other scenarios such as the European mid-latitudes or Experiment 1 previously presented.

Fig.5 presents the errors of both methods. Note that rover BAKO and GATH are respectively 415 and 39 km from the nearest station. It can be shown statistically that FPPP provided better accuracy by a factor of 30% as it can be seen in the below table even in this much worse sounded and much more active ionospheric region.

3. Acknowledgements

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4.Conclusions

Results of the patent-protected [9] Fast Precise Point Positioning (FPPP) technique had been shown in this work. Equatorial South-East Asia (SEA) performances confirm previous obtained results for European mid-latitudes, with a Vertical Total Electron Content (VTEC) five times greater. Convergence of the dual frequency users is accelerated thanks to precise ionospheric information compared to the classical PPP strategy used nowadays. The experiments have proven that the use of interpolated values either from GIMs or from FPPP ionospheric model has improved the single-frequency positioning accuracy, which is often seen on mass-market receivers nowadays navigating with broadcast orbits and clocks. FPPP has shown better results than GIMs or broadcast Klobuchar model in all of our experiments., Using FPPP precise orbits and clocks, single-frequency sub-meter level positioning with meter-level protection levels are obtained even in the scenario where the availability of FPPP correction data was limited because of larger baselines between reference stations. Therefore, this preliminary result shows the potential of FPPP ionospheric model, even though further improvements and experiments should be conducted in order to validate the performance of FPPP over the South – East AsianSEA region.

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