Utilization of Indonesia's regional ionosphere model to improve the accuracy of GPS measurements to support disaster mitigation studies

A N Safi'i1*, Susilo1, D Ramdani1 and B Muslim2

1Geospatial Information Agency, Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor, 16911, Indonesia
2Space Science Center, National Institute Aeronautics and Space of Indonesia, Jl. DR. Djundjunan 133, Bandung 40137 Indonesia

E-mail: ayunursafi.10@gmail.com

Abstract. Ionospheric can cause severe degradation of GPS (Global Positioning System) functionality and decrease coordinate accuracy. Increasing the precision of GPS station coordinates will improve accuracy in many applications. Many applications can use GPS for deformation studies, such as geodynamic studies, active fault studies, volcanic deformation monitoring, land subsidence studies, and hazard mitigation studies. We can use global ionospheric correction to produce better coordinates by utilizing post-processing GPS data. With the increasing number of GPS stations in Indonesia, it is possible to develop regional ionosphere models. This study computes regional ionospheric models from real-time streaming GPS data and uses them in GPS processing. Regional ionospheric models can increase the accuracy of GPS station coordinates by 5% -10% compared to global ionosphere models (igsg and codg).

1. Introduction

The application of GPS (Global Positioning System) in hazard mitigation has improved positioning accuracy in the last decade. GPS provides navigation and time information worldwide. The GPS coordinates are available 24 hours, seven days a week. GPS will provide positioning accuracy from a few meters to a few centimeters or even millimeters, depending on the processing technique. Physical phenomena such as volcano monitoring [1], GPS meteorology [2], seismology [3] can rely on GPS.

Many applications used GPS for deformation studies, such as geodynamic study, active fault study, volcanic deformation monitoring, land subsidence studies, and hazard mitigation studies. The need for a position with high accuracy is challenging in Indonesia, which is located in the active tectonic plates with high atmospheric variation conditions. One of the error budgets that affected the GPS positioning is ionospheric delay [4]. Ionospheric delay will decrease the positioning accuracy in the standard positioning service [4,5]. The error budget from ionospheric delay can be minimized using an ionospheric model. The regional ionospheric model improves 40.4% over the global ionospheric model in terms of positioning accuracy for the kinematic positioning performance [6]. Using 24 hours GPS data and Egyptian Ionospheric model, achieved an improvement of up to 38%,28%, 24% and 32% 10%, 37% for accuracy of latitude, longitude, and altitude compared with using Klobuchar and Global ionospheric model [7]. This study created a regional ionosphere from real-time GPS data supported by
Ina-CORS (Indonesia Continuously Reference Stations). This regional ionosphere is used to calculate coordinates compared with the coordinates of the results from the global ionosphere models (igsg and codg).

2. Data and Methodology
This research uses 220 stations GPS data from Ina-CORS provided by the Indonesian Geospatial Information Agency (BIG). Our regional ionospheric model was determined using 60 GPS stations distributed over the Indonesian area (see Figure 1). The regional ionospheric model calculation does show in Figure 2, and this step was running in real-time. The output of the regional ionospheric model is the ionex file that can be used as input in the GPS processing and named as lpnd. The regional ionospheric model provided by Space Science Center - National Institute Aeronautics and Space of Indonesia (PUSAINSA-LAPAN) in the corporation with BIG.

Figure 1. The 60 GPS stations that use for determining the lpnd regional ionospheric model.

Figure 2. Real-time the lpnd regional ionospheric model calculation.
The GAMIT/GLOBK [8],[9] version 10.71 was used to process all GPS data, including 12 regional IGS stations (ALIC, COCO, DARW, DGAR, GUAM, HYDE, IISC, LHAZ, PIMO, PNGM, XMIS YARR). We processed GPS data for seven days with three ionospheric models; first, we processed GPS data using the global ionosphere model igsg second with codg, and third we used the regional ionospheric model (lpnd). Thus we have 3 coordinate solutions. Then we analyze these coordinates using the igsg and codg solutions as a reference with equation 1.

\[
AC(\%) = \frac{\sigma_{\text{NEU}}^i - \sigma_{\text{NEU}}^c}{\sigma_{\text{NEU}}^i} \times 100\%
\]  

(1)

with AC is the percentage of position accuracy in %, \(\sigma_{\text{NEU}}^i\) or \(\sigma_{\text{NEU}}^c\) are North East Up (NEU) coordinate accuracy using global ionosphere igsg (i) and codg(c), respectively. \(\sigma_{\text{NEU}}^l\) is NEU coordinate accuracy using lpnd. If the AC is less than 0, the coordinate accuracy using the regional ionospheric model is less than the coordinates' accuracy using the global ionospheric model and vice versa.

3. Result and Analysis

Our processing methods result in 3 topocentric coordinates in the NEU component. First, the NEU coordinate solution uses the igsg global ionosphere model; second, the NEU coordinate solution uses the codg global ionosphere model; and third, the NEU coordinate and accuracy solution uses the lpnd regional ionosphere model. The percentage accuracy of the NEU coordinate solutions using regional ionospheric models (igsg and codg) is shown in Figure 3 and Figure 4 to improve the coordinate accuracy between lpnd and igsg and lpnd and codg, respectively. There is a difference in resolution between the global ionosphere (2.5 degrees or 277.5 km) [10] and the local ionosphere (55.5 km).

Regional ionospheric model solutions show that most coordinate accuracy increases to 5%-10% and several stations increased until 20%. There are several stations with the coordinate accuracy decreasing until 10%. In our analysis, the coordinate accuracy using the regional ionospheric model depends on the quality of the lpnd regional model. In this study, the lpnd regional ionosphere model was calculated using real-time streaming GPS data. The quality of real-time streaming GPS data is highly dependent on the quality of data communication from the GPS station to the server. Because within 24 hours, communication problems can occur, so the regional ionosphere model of lpnd cannot calculate in total for 24 hours. Accuracy improvements can be seen in the computed coordinates with an uninterrupted ionospheric region for 24 hours. The difference in resolution from 277.5 km global ionosphere with 55.5 km regional ionosphere becomes the coordinates of the regional ionosphere for the better. Increasing the accuracy of GPS station coordinates will provide more accurate results in disaster mitigation studies.
**Figure 3.** The percentage improvement coordinate accuracy of GPS stations using lpnd regional ionospheric in comparison to the igsg global ionospheric model, a: east-west component; b: north-south component; c: up-down components
Figure 4. The percentage improvement coordinate accuracy of GPS stations using lpnd regional ionospheric compared to the codg global ionospheric model, a: east-west component; b: north-south component; c: up-down component.

4. Conclusions
In this study, regional ionospheric models lpnd and global ionosphere models (igsg and codg) have been used in GPS processing to determine GPS station coordinates and their accuracy. The accuracy of GPS
station coordinates increases by 5%-10% when processed using a regional ionosphere model that utilizes \textit{lpnd} data compared to using \textit{igsg} and \textit{codg} data.

5. Acknowledgments
We want to thank our colleagues from the Center for Geodesy and Geodynamic Control Networks for providing data, related documents, insights, and expert inputs that greatly assisted this research. Global Mapping Tools 6 (GMT6) was used to plot a portion of the image [11].

References
[1] Shimada S, Fujinawa Y, Sekiguchi S, Ohmi S 1990 Detection of a volcanic fracture opening in Japan using Global Positioning System measurements \textit{Nature}. \textbf{343} 631–633.
[2] Bevis M, Businger S, Herring T A 1992 GPS meteorology: remote sensing of atmospheric water vapor using the global positioning system \textit{Geophys. Res.} \textbf{97}.
[3] Larson K 2009 GPS Seismology \textit{Geod.} \textbf{83} 3–4.
[4] Klobuchar J A, Abdu M A 1989 Equatorial ionospheric irregularities produced by the Brazilian Ionospheric Modification Experiment (BIME) \textit{Geophys. Res. Lett.} \textbf{94}.
[5] Yuan Y, Huo X, Ou J, Zhang K, Chai Y, Wen D, Grenfell R 2008 Refining the Klobuchar ionospheric coefficients based on GPS observations, \textit{IEEE Trans. Aerosp. Electron. Syst.} \textbf{44} 1498–1510. https://doi.org/10.1109/TAES.2008.4667725.
[6] Park J, Sreeja V, Aquino M, Cesaroni C, Spogli L, Dodson A, De Franceschi G 2016 Performance of ionospheric maps in support of long-baseline GNSS kinematic positioning at low latitudes \textit{Radio Sci.} 429–442. https://doi.org/10.1002/2015RS005933.
[7] El Manaily E, Rabbou M A, El-shazly A, Baraka M 2018 Enhanced local ionosphere model for multi-constellations single frequency precise point positioning applications : egyptian case study \textit{Artif. Satell.} \textbf{53} 141–157. https://doi.org/10.2478/arsa-2018-0011.
[8] Herring T A, King R W, Floyd M A, McClusky S C 2018 GAMIT Reference Manual Release 10.7 Massachusetts Institute of Technology.
[9] Herring T A, King R W, Floyd M A, McClusky S C 2015 GLOBK Reference Manual Release 10.6 Massachusetts Institute of Technology.
[10] Schaeer S, Gurtner W, Feltens J 1998 IONEX: The IONosphere map exchange format version 1, \textit{Proc. IGS AC Work} pp. 233–247.
[11] Wessel P, Luis J F, Uieda L, Scharroo R, Wobbe F, Smith W H F, Tian D 2019 The Generic Mapping Tools version 6 \textit{Geochemistry, Geophys. Geosystems}. \textbf{20} 5556–5564. https://doi.org/https://doi.org/10.1029/2019GC008515.