Impact of Atmospheric Delay Reduction using KARAT on GPS/PPP Analysis

Ichikawa R.,[1] T. Hobiger,[2] Koyama Y.,[2] and Kondo T.[2,3]

Abstract. We have been developing a state-of-art tool to obtain the delays by ray-tracing through the meso-scale analysis (MANAL data) data for numerical weather prediction developed by Japan Meteorological Agency (JMA). The tool, which we have named 'KAshima RAytracing Tools (KARAT)', is capable of calculating total slant delays and ray- bending angles considering real atmospheric phenomena. According to Hobiger et al. [2008a], the KARAT solutions are better than the solutions using the Global Mapping Function (GMF) with gradient during a period of 4 months. We also compared PPP processed position solution using KARAT with that using the GMF for the data sets of GEONET (GPS Earth Observation Network System) operated by Geographical Survey Institute (GSI). In our comparison about 1360 stations of GEONET data during July 1st - August 31st of 2007 were processed. The averaged repeatabilitiy differences of height component indicate the KARAT solution is worse than the GMF with gradient solution. The largest repeatabilities more than 10 mm, which occur in Kyushu and Shikoku islands which are located in the west of Japan. During the whole processed period southwest Japan has undergone severe heavy rain fall event due to the Baiu front and the typhoon 'MAN-YI' passing and cumulative precipitation amounts ranging 500 - 1100 mm. Under the extreme atmospheric condition such as the concerned period, our results imply that the performance of KARAT is almost equal to the solution using the GMF with gradient. The KARAT can estimate atmospheric slant delays by three different calculation scheme. These are (1) a piece-wise linear propagation, (2) an analytical 2-D ray-propagation model by Thayer [1967], and (3) a 3-D Eikonal equation [Hobiger et al., 2008b]. Though the third scheme gives the most accurate solution, it has a significant disadvantage due to a computational load. So far, we have not yet applied the Eikonal equation method for reducing the atmospheric delays from GPS data sets. According to our preliminary computation, slant delay differences between the Eikonal calculation and Thayer model are up to 5 millimeters at the elevation of 5 degrees. In addition, the Eikonal calculation can predict small scale perturbations which are not retrieved using both Thayer and linear models. These result suggest that the higer order variations of slant delays can be reduced from the GPS data using JMA/MANAL data. We are now performing KARAT calculation using Eikonal model for longer duration of GPS data sets and we will present these results.

1. Introduction

Radio signal delay associated with the neutral atmosphere is one of the major error sources in GNSS, VLBI, In-SAR measurements. Recently, several anisotropic mapping functions have been developed for the purpose of a better modeling of these propagation delays, thereby improving the repeatability of horizontal site coordinates (MacMillan, 1995; Chen and Herring, 1997). The anisotropic mapping function is a powerful tool for removing or calibrating the effects of horizontal variability of atmosphere within GNSS and VLBI analyses. Atmospheric gradients are assumed to have a simple linear form modeled by the anisotropic mapping function. However, it has been suggested that this assumption is not always appropriate in the context of intense mesoscale phenomena such as the passing of a cold front, heavy rainfall, or severe storms. We have developed a new tool to obtain atmospheric slant path delays by ray-tracing through the meso-scale analysis data from numerical weather prediction with 10 km horizontal resolution provided by the Japan Meteorological Agency (JMA) (Hobiger et al., 2008a) (hereafter, we call this "JMA 10km MANAL data"). These data are operationally used weather forecast and are considered for our study. We have created ray-tracing routines and named the tools "KAshima RAytracing Tools (KARAT)" resolution (Hobiger et al., 2008a). First, we compared empirical mapping functions, developed for space geodesy, with KARAT slant delays. Next, we estimated position changes caused by the horizontal variability of the atmosphere by running simulations using the ray-traced slant delays in order to examine the position error magnitude and its behavior under meso-scale atmospheric disturbances. Finally, we carried out a preliminary comparison between position repeatabilities of precise point positioning (PPP) estimates using KARAT and those using the latest mapping function.

[1]Kashima Space Research Center, National Institute of Information and Communications, Kashima, Ibaraki, JAPAN
[2]National Institute of Information and Communications, Kashima, Ibaraki, JAPAN
[3]Ajou University, Swon, Korea

2. KARAT

KARAT have been developed at the National Institute of Information and Communications Technology (NICT), Japan and is capable of calculating total slant delays and ray-bending angles. We perform a successive 19 months run of KARAT calculations from March 2006 to September 2007. The JMA 10km MANAL data which we used in our study provides temperature, humidity, and pressure values at the surface and at 21 pressure levels (which are equal to steps of several meters to kilometers up to about 31 km), for each node in a 10 km by 10 km grid that covers all Japanese islands, the surrounding ocean and Eastern Asia (Saito et al., 2006). Figure 1 shows the distribution of the total zenith delays retrieved from the JMA 10-km MANAL data at 1600 UT of July 22nd, 2006. We first resample the original JMA grid to a modified grid which allows to run the new ray tracing algorithms using analytic expressions. At present the 3-hourly operational products are only available by JMA. Thus, a linear time interpolation is used to obtain results at arbitrary epochs what allows also to evaluate temporal change of estimates. The details of KARAT is described in another paper (Hobiger et al., 2008a). Numerical weather model data are based on the physical/dynamical equations that govern the atmospheric flow. The JMA 10 km MANAL data are obtained by combining short model forecasts with new observations (a process called data assimilation). Therefore, the ZTD obtained from KARAT can be considered to be the most realistic empirical value of the real atmosphere.

3. Precise Point Positioning Results for GEONET Stations

In order to compare KARAT processing and empirical mapping functions we analyzed whole data sets of GEONET (GPS Earth Observation Network System), which is a nationwide GPS network operated by Geographical Survey Institute (GSI). In our comparison about 1360 stations of GEONET data during July 9th ? 23rd of 2007 were processed. At first, precise point positioning (PPP) estimates covering the whole period shown above were obtained for all sites using GPSTOOLS (Takasu and Kasai, 2005). The troposphere delays have been modeled by dry (using the Saastamoinen [1972] model) and wet constituents, whereas the latter one were estimated as unknown parameters using the GMF together with linear gradients. The daily position estimates from this solution acts a reference to which the ray-traced solutions can be compared (see Hobiger et al., [2008c] in detail.). In our comparison, PPP estimations using the GMF without linear gradient were also performed. Changes in the mapping functions primarily cause changes of the station heights in general. According to Hobiger et al. (2008a), the KARAT solutions are better than the solutions using GMF with gradient during a period of 4 months. In our comparison, the averaged vertical repeatabilities of all solutions demonstrate a similar nation-wide pattern as shown in Figure 7. The largest repeatabilities more than 10 mm, which occur in Kyushu and Shikoku islands which are located in the west of Japan, are reflected in all three figures. In addition, Figure 8, which shows the repeatabilities for each coordinate component (i.e. the north, east, and vertical errors) for all three solutions, indicates that the KARAT solution is slightly worse than the GMF with gradient solution. On the other hand, KARAT solution is better than the GMF without gradient solution for horizontal component. These characteristics are also presented in Table 2. During the whole processed period both Kyushu and Shikoku islands have undergone severe heavy rain fall event due to the Baiu front and the tyhoon "MAN-YI" passing and cumulating in precipitation amounts ranging 500 - 1100 mm. The time-resolution of the JMA 10km MANAL data is three hours, whereas the PPP processing including gradient estimation was performed for 300 seconds interval. Under the extreme atmospheric condition such as the concerned period, our results imply that the performance of KARAT is almost equal to the solution using the GMF with gradient. We need to extend the processing period for our comparison in order to evaluate a KARAT capability in a reduction of atmospheric path delay.

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