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XY466 Atmospheric Delay Reduction using Ray Tracing Technique through Meso-scale Numerical Weather Data for Space Geodesy

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1. Introduction

We have developed a state-of-art 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, 2008b]. 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. Hobiger et al. [2008a] preliminarily compared precise point positioning (PPP) estimates using KARAT with that using the Global Mapping Function (GMF)[Boehm et al., 2006a] based on GPS data of the GPS Earth Observation Network System (GEONET) operated by Geographical Survey Institute (GSI). Under the various atmospheric conditions the results imply that the performance of KARAT is almost equal to the solution which is obtained by applying the GMF with gradients.

In our study, we have compared PPP processed position solutions using KARAT with those using state-of-the-art mapping functions in order to evaluate the present KARAT potential for longer time periods. In our comparison 57 stations of GEONET during the year of 2008 were processed.

The grid interval of the MANAL data was updated from 10km to 5km on April 7 2009. We have also assessed the impacts of data scheme improvement by comparison between the KARAT-based PPP solutions with the PPP solutions using the Vienna Mapping Function 1 (VMF1) [Boehm and Schuh, 2004; Boehm et al., 2006b] during June 2009.

2. Eikonal Solver and PPP Results for GEONET Stations

The KARAT can estimate atmospheric slant delays by three different calculation scheme as shown in Figure 1. 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 can include small scale variability of atmosphere in the horizontal component, it has a significant disadvantage due to the massive computational load.

In order to compare KARAT processing and modern mapping functions we analyzed data sets of GEONET, which is a nationwide GPS network operated by GSI. In our comparison 57 stations from GEONET of the year 2008 were considered for processing. We selected the stations which were not affected by crustal deformations caused by seismic activities. Figure 2 shows the locations of the selected stations in our study. Since these stations are distributed over the whole Japan islands evenly, we can investigate effects of various weather conditions on the processing. In addition, we can avoid uncertainties due to the individual difference of equipments in term of the same type of antenna-receiver set in GEONET. The precise point positioning (PPP) processing were carried out using GPSTOOLS [Takasu and Kasai, 2005].

3. Examples of Time Series

Figure 3 represents two examples of station positions time series at Tsukuba and Koganei during the year 2008. In this figure two cases of solutions for each component are shown, i.e. KARAT solution using Eikonal solver with respect to the VMF1 solution and VMF1 with gradient solution [Chen and Herring, 1997] with respect to the VMF1 solution. The large amplitudes due to high water vapor variability, which mean poorest repeatabilities, are presented during summer season (from June to August). The time series at both stations agree very well in both amplitude and phase through one year in spite of such high variability. The differences of both time series for each station are less than 0.2 mm in all coordinates. This means slant delay estimations using Eikonal solver and those using VMF1 with gradient are almost identical.

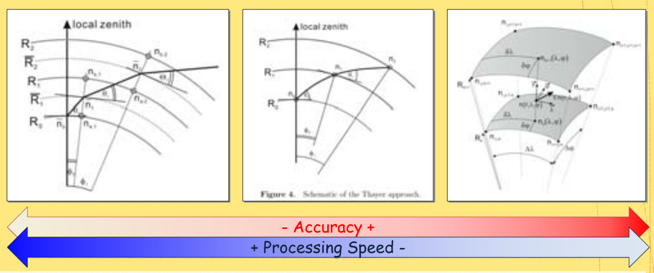

Figure 1. Three schemes of KARAT calculation ([1] piece-wise linear, [2] Thayer model, [3] Eikonal solution strategy).

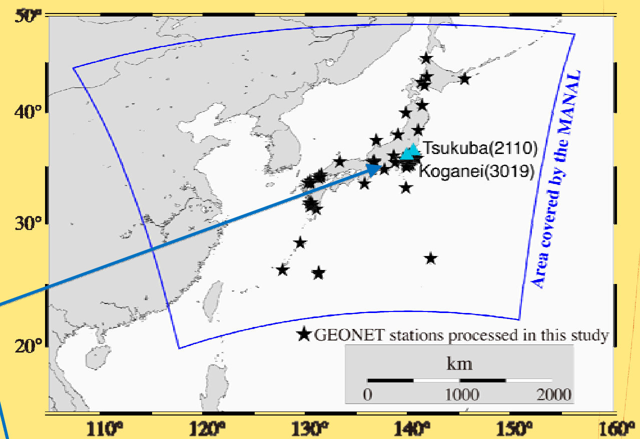

Figure 2 GEONET stations processed in this study. The boundary of JMA meso-scale analysis (MANAL) data is also shown (blue line).

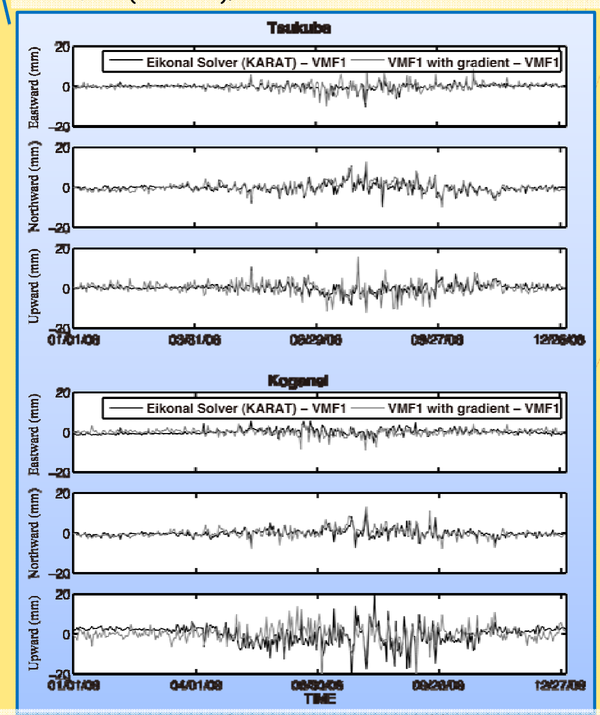

Figure 3. Time series of station position differences at Tsukuba (Upper) and Koganei (Lower) during the year of 2008 (Station locations are indicated in Figure 2). The position differences for solutions using Eikonal solver and VMF1 with gradient model with respect to the VMF1 solutions are represented, respectively.

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4. Monthly Averaged Repeatability

In order to examine the position error magnitude the monthly averaged repetabilities for each coordinate component at both stations are displayed in Figure 4. In this figure five cases of solutions (i.e. KARAT solution using Eikonal solver, KARAT solution using the Thayer model, VMF1 solution with gradient, VMF1 solution without gradient, GMF with gradient) are shown. The results of VMF1 without gradient reveal the largest repeatability value for all components at both stations during the summer season (July, August, and September), as one would expect.

Tsukuba and Koganei have undergone severe heavy rainfall event during August 26-31, 2008. Especially, the total rainfall around Tsukuba was about 300 mm during these 6 days. The north-south position errors were caused by steep water vapor gradient associated with an EW rain band which lies around both stations. Such large position errors are partly reduced using the modern mapping functions with gradient model as shown in Figure 4.

On the other hand, the results of KARAT solutions (both the Eikonal solver and the Thayer model) are much better for the north-south component at the both station during the July and August. These suggest that the both KARAT solutions are quite competitive to the modern mapping functions with gradient model.

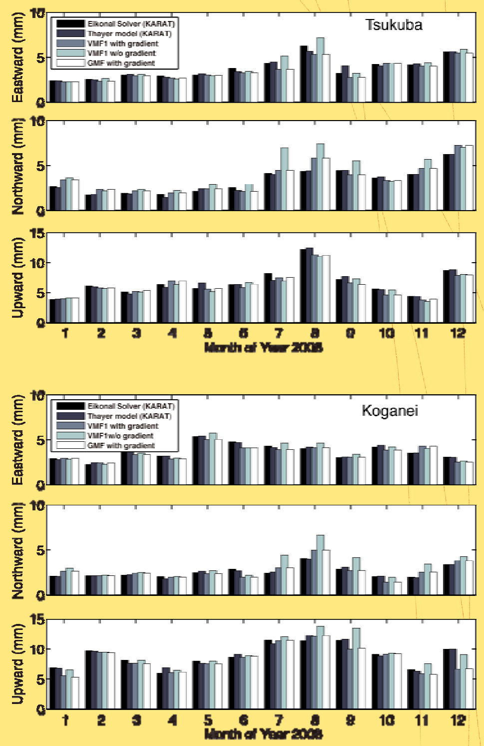

Figure 4. Monthly averaged repeatabilities of station positions at Tsukuba (upper) and Koganei (lower) during year of 2008.

5. Yearly Averaged Repeatability

Finally, Figure 5 shows the averaged repeatabilities for all 57 stations. In this figure the results for each coordinate component for all six solutions (i.e. Eikonal solver, Thayer model, VMF1 with gradient, VMF1 without gradient, GMF with gradient, and GMF without gradient) are represented. It indicates that both KARAT solutions are slightly better than the modern mapping functions with gradient solution. However, there are no significant differences between the Eikonal solver and the Thayer model.

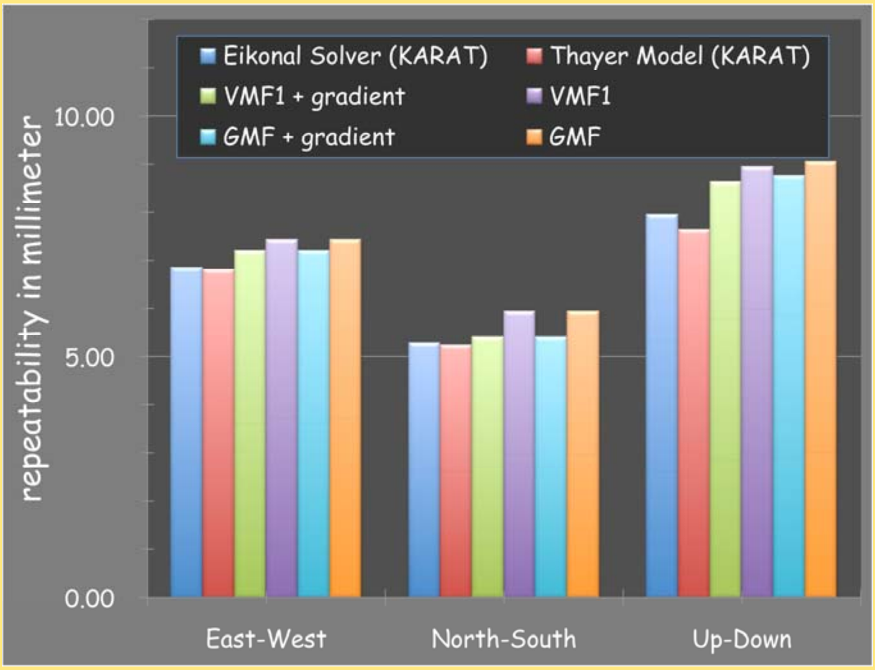

Figure 5. Averaged repeatability of station position during year of 2008 for 57 GEONET stations shown in Figure 2.

6. MANAL Scheme Improvement

The grid interval of the MANAL data was updated from 10km to 5km on April 7 2009 (see Figure 6 for example). We have assessed the impacts of data scheme improvement on the KARAT-based PPP solutions by the similar comparison as described above. In this preliminary comparison it is not clear the impact of scheme improvement as shown in Figure 7. The relatively high elevation cut off angle (10 deg.) may cause such results.

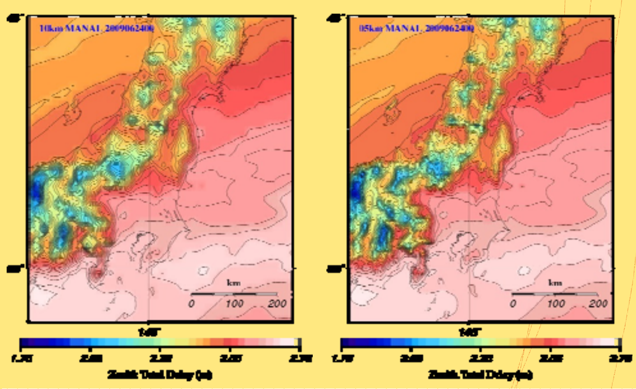

Figure 6. Examples of Zenith Total Delay on 00UT of June 24th, 2009: 10km MANAL (left) and 5km MANAL (right).

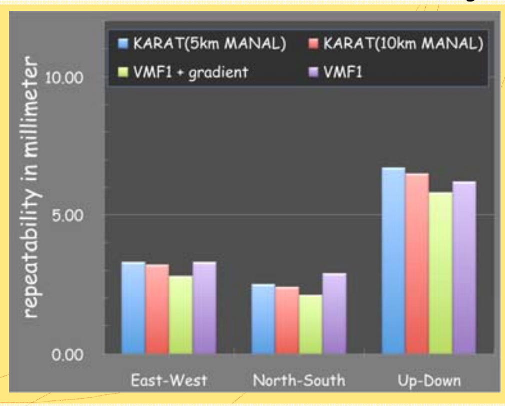

Figure 7. Averaged repeatability of station position during June 2009 for 1214 GEONET stations.

7. Summary and Outlook

The KARAT solution is almost identical to the solution using VMF1 (Vienna mapping function 1) with linear gradient model and some cases tends to be slightly better. On the other hand, the impact of the MANAL scheme improvement on KARAT solutions is not clear at present. We need further investigations to evaluate the capability of KARAT to reduce atmospheric path delays under various topographic and meteorological regimes.

One advantage of KARAT is that the reduction of atmospheric path delay will become more accurate each time the numerical weather model are improved (i.e. time and spatial resolution, including new observation data). On October 27, 2009 the JMA started data assimilation of zenith wet delay obtained by the GEONET for meso-scale numerical weather prediction. We are now preparing to evaluate the impacts of the assimilation strategy change on the slant delay reduction.

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