Analysis of the Accuracy of GMF, NMF, and VMF1 Mapping Functions with GPT 50 a Priori Zenith Constraint in Tropospheric Delay Modelling

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Abstract
When modelling the tropospheric delay in Global Positioning System (GPS), the zenith delay is mapped to the slant with numerous mapping functions. The accuracy of the modelled tropospheric delay will be affected by the kind of mapping function used. Fixing the a priori zenith constraint as Global Temperature Pressure Humidity 50 (GPT 50), this paper compares the accuracy of the different mapping. Global Mapping Function (GMF), Niell Mapping Function (NMF) and Updated Vienna Mapping Function (VMF1), the update of Vienna Mapping Function (VMF) are the mapping functions studied. All these are used with the saastamoinen tropospheric delay model which is used in the GPS Analysis Software for the Massachusetts Institute of Technology software (GAMIT_GLOBK). For the north and east offsets these mapping functions achieved the same accuracy and can therefore be used interchangeably in modelling of the tropospheric delay effect in the planner. However, for the up offsets VMF1 achieved better accuracy compared to GMF and NMF however, being more consistent with GMF than NMF. In the future, if more mapping functions are incorporated in GAMIT_GLOBK, the accuracy of these new mapping functions should be investigated and use another a priori zenith constraint – meteorological data, which will improve positioning using Global Navigation Satellite System (GNSS).

Key words: GPT50, GPS, GMF, NMF, VMF1.

1.0 Introduction

Mapping functions of tropospheric delay models based on data from the numerical weather models have now been developed. Mapping functions use information about the vertical distribution of the refractivity therefore they can assess the thickness of the troposphere which is a basis for the determining of the value for the mapping function (Niell, 1996). Even though these mapping functions have been available for some years now, many analysts still use NMF because it depends only on the station latitude, height and the day of the year thus can be easily implemented in GPS software (Niell, 1996). However when NMF was compared withVMF1 it was discovered that it has deficiencies in the temporal behaviour and large static deficiencies in certain areas. Therefore GMF was developed similar to NMF as it is determined from the station latitude, height and day of the year. However GMF is based on spherical harmonics up to degree and order 9 and the aim is to make it more consistent with VMF1 than NMF. Boehm et al. (2006a) used the rigorous ray trace at 3^0 elevation to determine VMF1. VMF1 is available on a 2.5 X 2.0 degree grid with a grid of 0.25x0.20 degree at some places at a temporal resolution of 6hours with planned reduction in this temporal resolution. GMF and NMF have larger standard deviations because they contain only a seasonal term and thus cannot reproduce the short-term variations sampled by VMF1 and IMF which have 6 hour temporal resolution (Boehm et al, 2008). In GAMIT_GLOBK software, a priori zenith constraint is modelled first then the mapping functions are applied. GPT 50 is based on spherical harmonics up to degree and order nine and provides pressure and temperature at any site in the vicinity of the Earth's surface. It is used for geodetic applications such as the determination of a priori hydrostatic zenith delays and reference pressure values for atmospheric loading (Kouba, 2009). When modelling the tropospheric delay in GPS, the tropospheric zenith delay is mapped to the slant with numerous mapping functions. The accuracy of the modelled Tropospheric delay will be affected by the kind of mapping function used. New mapping functions are now based on numerical weather models compared to the earlier ones based station latitude, height and the day of the year. The accuracy of the new mapping functions is compared to that of the earlier ones for easting, northing and height of points. In this research we analyse the accuracy of GMF, NMF, and VMF1 mapping functions with GPT 50 a priori zenith constraint and investigate the application of VMF1 in tropospheric delay modelling.

2.0 Study Area

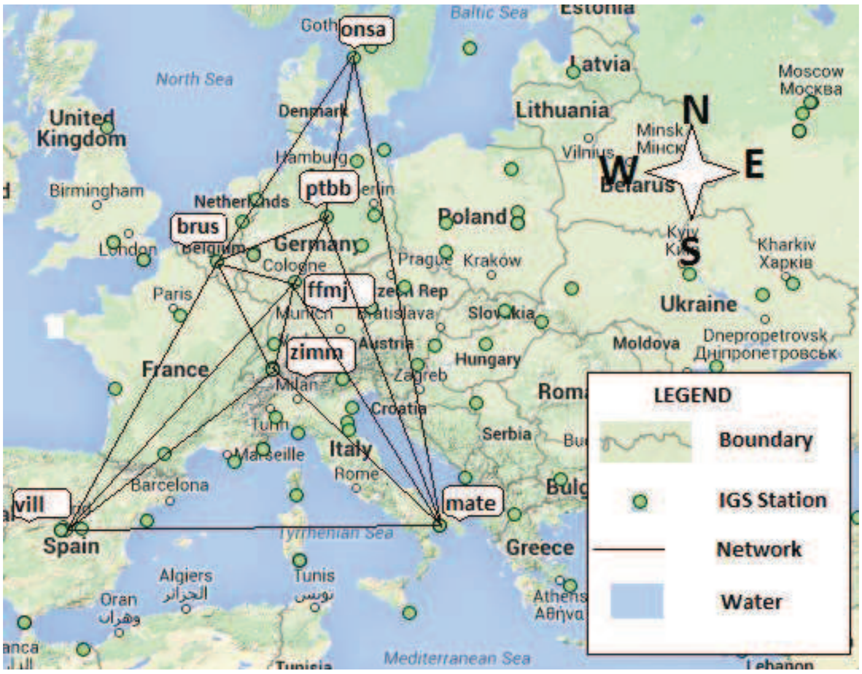

Figure 2 IGS stations used in the network

GPS data for six years was collected from seven International GNSS Station (IGS) stations located in Europe as shown in figure 1 above. The network was tested and found to be stable and sufficient for this study. These stations were Zimmerwand (zimm) - Switzerland, Villafranca (vill) - Spain, Braunschweig (ptbb) - Germany, Onsala (onsa) - Sweden, Matera (mate) - Italy, Frankfurt (ffmj) - Germany and Brussels (brus) – Belgium (figure 1).

3.0 METHOD

GPT 50 a priori zenith constraint was used with GMF, NMF and VMF1 mapping functions one at a time as shown in figure 2. GPT 50 was used because it is the default a priori zenith constraint that is used in the GAMIT_GLOBK software. During the processing all the other GPS errors were efficiently modeled so that the error that would propagate to the fixed GPS points would only be due to applied mapping functions. Two gradients were modeled each day for the azimuth effect on the tropospheric delay. The other errors modeled included the atmospheric loading, multipath, ionosphere (including the higher order effects) - The higher order error terms do not cancel out in the (first order) ionospherically corrected observable and as such, when not accounted for, they can degrade the accuracy of GNSS positioning, depending on the level of the solar activity and geomagnetic and ionospheric conditions (Hoque and Jakowski, 2007) and the antenna phase center. Repeatability graphs were plotted to show the accuracy of the fixed GPS points. These repeatability graphs were plotted for each combination of a priori zenith constraint and mapping function. The Weighted Root Mean Square (WRMs) from the repeatability graphs for each IGS stations were extracted and plotted for each a priori zenith constraint and mapping function combination figure 3, 4 and 5.

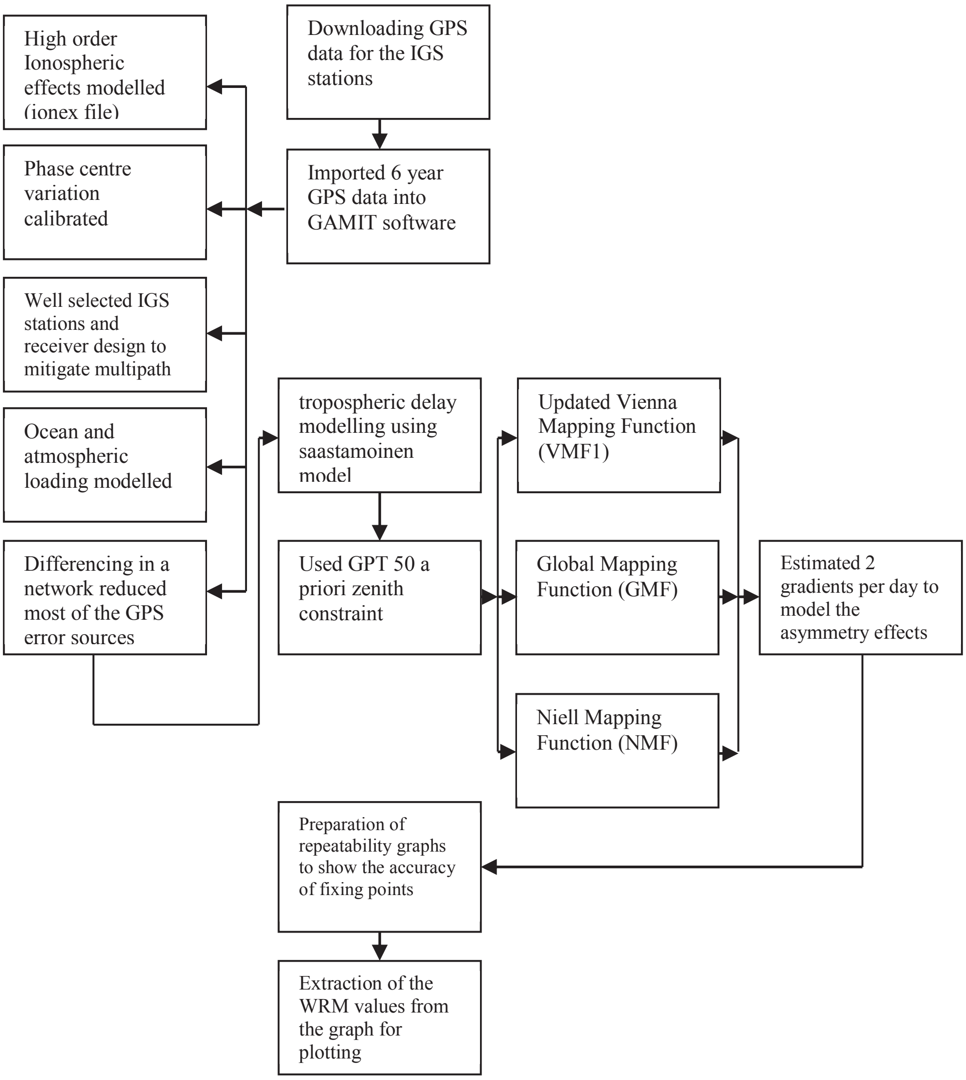

Figure 3 Methodology used in the research

4.0 RESULTS PRESENTATION AND ANALYSIS

The WRMs for the seven stations are all below 2mm for the north offset, implying that the north offset for all these points have been well fixed. zimm was fixed with the highest accuracy while brus was fixed with the lowest accuracy. During the processing of the GPS data, instability was noticed in the planar coordinates of brus IGS station, this is shown in figure 3 as the station has a WRMs of 1.7 mm for all the mapping functions. VMF1-GPT50, GMF-GPT50, NMF-GPT50 combinations have the same WRMs for the north offset. This implies that the NMF, GMF and VMF1 mapping functions achieve the same accuracy when modelling the north offset. This is because the effect of the tropospheric delay has minimal effect on the planner coordinates of points.

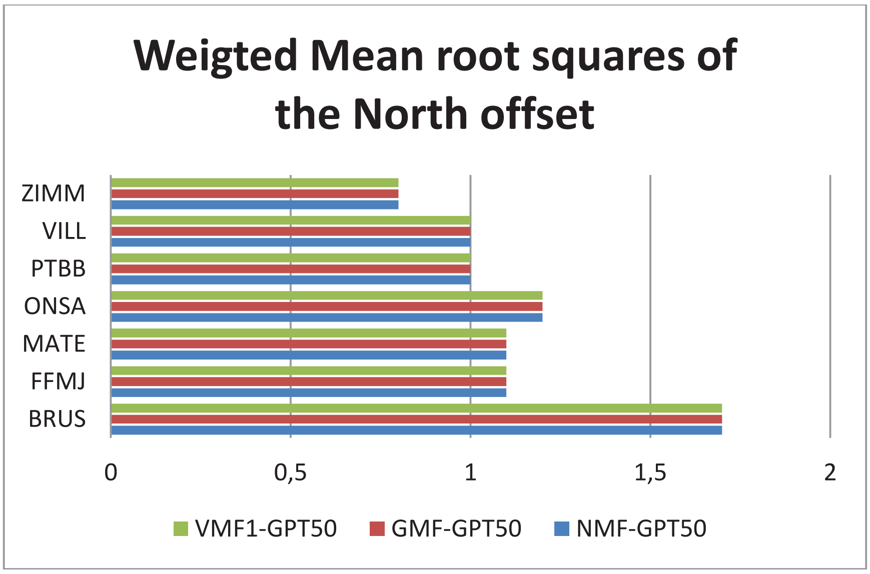

Figure 4 Repeatability graph for the North offset

The case for the east offset is similar to that of the north offset where the WRMs for all the seven IGS stations are below 2mm hence showing that the east offset of these stations are well fixed. Stations zimm and ptbb are fixed with high accuracy compared to brus fixed with a low accuracy again as seen in figure 4 and figure 3 previously. VMF1-GPT50, GMF-GPT50 and NMF-GPT50 combinations all achieve the same WRMs for the east offsets again showing that the effect of the tropospheric delay is minimal to the east coordinates.

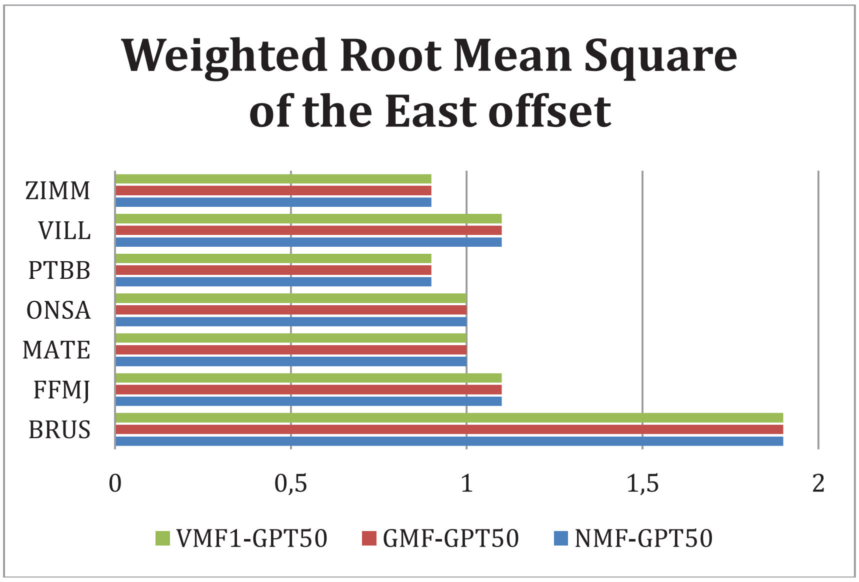

Figure 5 Repeatability graph for the East Offset

The WRMs for the fixed up offsets for all the seven IGS stations are below 10mm. This shows that the up offset for all the IGS stations are well fixed. The WRMs acceptable for the up offset are larger than those for the north and east offset because GPS achieves results better in the planar than in the vertical. This is due to the fact that the GPS error sources in the planar counsel due to symmetry as the satellites are traced from horizon to horizon while this is not possible for the vertical as the symmetrical errors won't counsel as GPS receivers cannot trace the GPS satellites both above and below the horizon.

The VMF1-GPT50 combination attains the least WRMs for the up offset at zimm, vill, onsa and ffmj IGS stations (figure 5). The mapping functions achieve different accuracies in this instance because the residual range errors from the tropospheric delay propagate most to the heights of the points compared to the planner coordinates, this implies the tropospheric delay affects the fixed heights of the GPS points more than the planner coordinates (Rothacher,2002). The VMF1-GPT50 combination attains the best accuracy here because it is based on data from numerical weather models, unlike the other mapping functions, it uses information about the vertical distribution of the refractivity and thus can assess the thickness of the troposphere which is a measure for the value of the mapping functions (Neil, 1996) and it is has a grid separation (2.0 x 2.5 degrees) small enough and a high temporal resolution of 6 hours (Boehm et al. 2006b).
GMF-GPT50 combination attains the same accuracy as VMF1-GPT50 for IGS stations ptbb, mate and brus (figure 5). This is because GMF mapping function is based on spherical harmonics up to degree and order 9 and the aim was to make it more consistent with VMF1 during its creation. Though when we compare GMF to VMF1, GMF is easily implemented into GPS software compared to VMF1 because it depends on station coordinates and the day of the year, then if it attains the same accuracy as VMF1 at some stations it could be used as a substitute for VMF1 in software where implementation of the VMF1 mapping function is not possible.

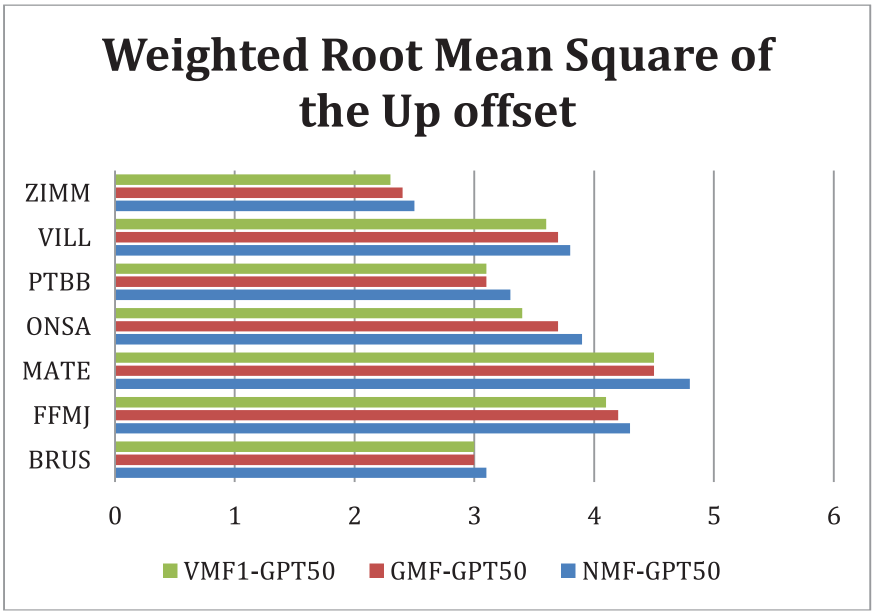

Figure 6 Repeatability graph for the up offset

NMF-GPT50 combination achieves the lowest accuracy for all the IGS stations used in this case study. Though NMF can also be easily implemented into the available GPS software because of its dependence on station coordinates and day of the year, when compared with VMF1 it was discovered that it had deficiencies in the temporal behaviour and large static deficiencies in certain areas.

5.0 Conclusions and Recommendations

5.1 Conclusion

- The accuracy achieved modeling the tropospheric delay from the mapping functions based on data from numerical weather models (VMF1) is greater than that from mapping functions that depend only on station latitude, height and day of the year (GMF and NMF) when fixing the heights of points. Though the later, due to the data they are based on, station latitude, height and day of the year they are easily implemented in GPS software than their counterparts based on data from numerical weather models (VMF1). Those based on data from numerical weather models achieve better accuracy because they use information about the vertical distribution of the refractivity and thus can assess the thickness of the troposphere which is a measure for the value of the mapping function.

- For the east and north offsets, there is no significant accuracy differences as it is in the up offsets where VMF1 is more consistent with GMF than NMF but VMF1 being more accurate overall for the up offsets. GMF is more consistent with VMF1 than NMF because it is based on spherical harmonics up to degree and order 9 developed with the goal to be more consistent with VMF1.

5.2 Recommendations

- More mapping functions will be incorporated in GAMIT_GLOBK (i.e. IMF). They should be investigated to determine how well they model the tropospheric delay using GPT 50. VMF1 has been implemented in few GPS software, though its behaviour could be investigated in other GPS software. The VMF1 grid is becoming smaller as more meteorological data is collected with the increase in the IGS stations, investigations could be carried out with such smaller grids to determine the improvement in the accuracy of modelling the tropospheric delay using VMF1.

- All the mapping functions could be compared using meteorological files (met files) as the a priori constraints. This is when Temperature, Pressure and Humidity are locally recorded at the IGS stations.

- This research could be done in the future modelling more than two gradients a day when determining the effects of the azimuth on the tropospheric delay.

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