Estimation of precipitable water vapour using kinematic GNSS precise point positioning over an altitude range of 1 km

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1. Introduction :

• Atmospheric water vapour is a key quantity in meteorology and climate studies.

• To improve the ability of Numerical Weather Models (NWM) to account for its presence, it must be characterised as representatively as possible. To accurately constrain NWM at ever increasing spatial resolution requires ever more observations. Although models provide more reliable and representative forecasts in areas with dense sensor networks, they are limited in their performance in data sparse areas such as deserts, mountains and oceans.

• A solution to this problem would be to use GNSS water vapour estimation with an absolute solution (not limited by distance from a base station), on kinematic platforms (e.g. ships, airplanes, trains).

• The following work builds on previous shipborne studies (e.g. Rocken et al. 1995), and explores the effect of altitude change in the estimation of Zenith Wet Delay (ZWD) from GNSS.

• Data was collected from a moving platform with a repeatable trajectory over a long time span to assess the ability of kinematic GNSS to retrieve PWV. Interpolated ZWD from sites at the lateral and vertical extremities of the trajectory acts as a reference, allowing a robust analysis of the GNSS solution. ZWD estimates from a GPS double difference solution and a NWM were also tested, as additional control.

2. Data set :

• A GNSS receiver and pressure sensor were installed on to a carriage (SNTR) of the Snowdon Mountain Railway (SMR).

• The SMR has an altitude range of ~950 m (115 – 1065 m above MSL) and covers a plan distance of ~6 km.

• Continuously operating static GNSS receivers and co-located pressure sensors were installed at the extremities of the railway (SNLB and SNSU).

• Data were collected between 30th Aug – 16th Oct 2011. Up to four daily ascents were possible, between 08:00 and 18:00 local time, with a top speed of 2 m s^{-1}.

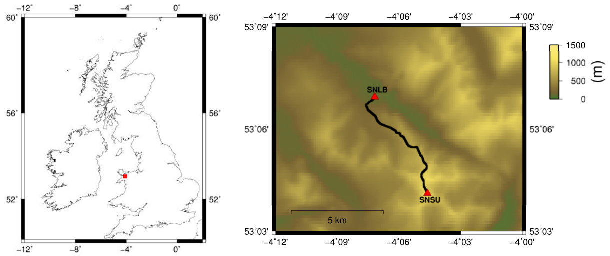

FIG. 1. *Site location (red box) within the UK (left); local topography of the SMR (right).*

4. Results :

ZWD comparisons were made between the interpolated ZWD reference, the GNSS estimates and the Unified Model NWM output every 15 minutes. ZWD estimates were only included in the comparison when SNTR is outside the stations and therefore truly kinematic.

• The statistics relating to the differences are displayed in Table 1.

• An example day showing the ZWD estimates, and ZWD differences can be seen in Fig 2.

• Correlation plots of the ZWD estimates compared to the interpolated reference are displayed in Fig 3.

• To assess variation in the performance of the different techniques with height, the ZWD differences were computed in 100 m altitude bins, with the RMS differences shown in Fig. 4.

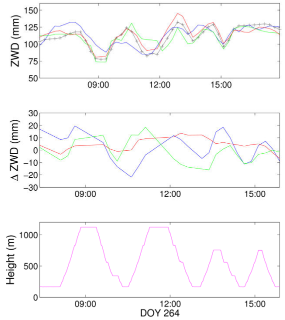

FIG. 2. *ZWD time series from kinematic PPP GNSS (blue), kinematic relative GPS (green), Unified Model (red) for SNTR on day 264 of 2011. In the upper pane, GIPSY-based interpolated reference ZWD values are shown in grey with crosses representing comparison epochs; the middle pane shows the differences from this reference . Bottom pane shows the altitude of SNTR.*

TABLE 1. *RMS, STD and median of the differences between ZWD estimates and the GIPSY-estimated interpolated reference values for SNTR . All quantities are expressed in mm.*

	RMS	STD	Median
Kinematic PPP GNSS	12.3	12.2	1.9
Kinematic relative GPS	13.6	13.6	-1.2
Unified model	11.2	9.7	4.9

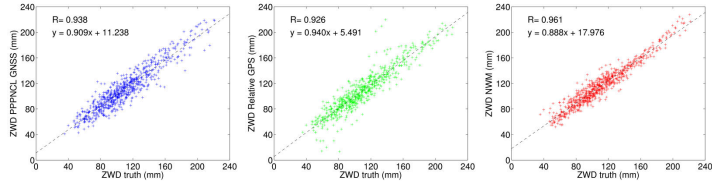

FIG. 3. *Correlation plots of ZWD per kinematic estimation method versus the interpolated GIPSY-based static ZWD reference values for SNTR. From left to right the plots consist of kinematic PPP GNSS; kinematic relative GPS; the Unified Model.*

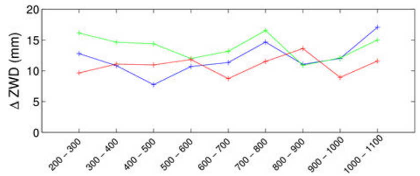

FIG. 4. *ZWD RMS differences (in 100 m altitude bins) between the GIPSY-based reference and each of the estimation methods: kinematic PPP GNSS (blue), kinematic relative GPS(green), and the Unified Model (red).*

3. Tropospheric Comparators :

• **Interpolated Reference** - ZWD estimates from GIPSY static PPP solutions were obtained for SNLB and SNSU. At each epoch, the estimated ZWD was interpolated from these locations to the height of SNTR by varying the exponential coefficient in the extrapolation method of Kouba (2008).

• **Kinematic PPP GNSS** - A back-smoothed kinematic PPP solution using both GPS and GLONASS data from SNTR, processed with PPP software developed at Newcastle University (Martin, 2013). ZWD was estimated as a random walk process.

• **Unified Model** - ZWD was extracted from a local run of the Met Office Unified Model. The model was configured with one-way nested domains with horizontal grid lengths of 4 km (UK), 1 km (100km × 100km), 333 m (50km × 50km) and 100 m (20km × 20km).

• **Kinematic relative GPS** – A back-smoothed double difference GPS solution for SNTR, processed with the GAMIT module Track, relative to static site SNLB using a 'levered' approach to estimate ZWD.

5. Conclusions :

• Three ZWD estimation techniques were compared and validated against a static GPS reference, for a kinematic platform undergoing nearly 1 km of height change per trajectory over a 50 day period.

• The RMS ZWD difference between the NWM and the GIPSY-based reference is 11 mm, demonstrating the high quality of the high resolution Unified Model.

• The RMS ZWD difference between kinematic PPP GNSS and the reference is 12 mm. This is equivalent to < 2mm of PWV - similar to previous shipborne studies.

• The high correlation coefficient of each method compared to the reference gives further confidence in the use of kinematic PPP GNSS in the collection of PWV.

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