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Evaluation of NRTK-based heighting techniques from different operational GNSS networks in Greece

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1. Objective

The scope of this paper is to present preliminary results from several field tests that were conducted by the Department of Geodesy and Surveying of the Aristotle University of Thessaloniki in order to evaluate the heighting accuracy from different commercial providers of NRTK-based positioning services in Greece. Our aim is to investigate the actual positional quality of the vertical component from an end-user's point of view in relation to the:

- choice of the applied correction method (VRS or MAC)
- number of in-view satellites and their geometry (PDOP)
- data sampling rate and the duration of station occupancy

The validation of our results is based on high-quality height information that was independently obtained by precise spirit leveling, in double-traverse mode, over the test network (see Fig. 1).

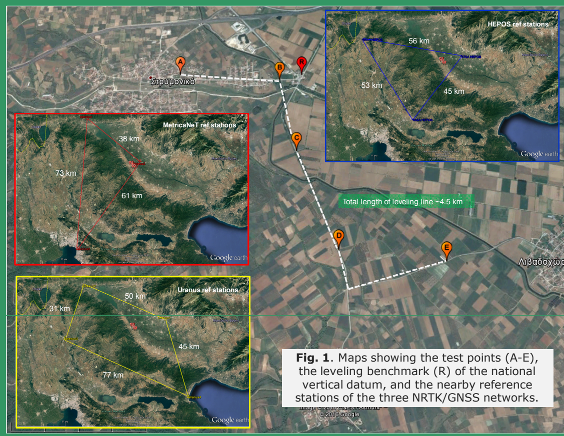

Fig. 1. Maps showing the test points (A-E), the leveling benchmark (R) of the national vertical datum, and the nearby reference stations of the three NRTK/GNSS networks.

2. Data – Methodology

To evaluate the NRTK-based performance in the vertical component, a test network of 5 points (A-E) was established in the area of Strymoniko near the city of Serres in Greece. The test points were placed along the main road network at successive distances of ~1 km (see Fig. 1). Their spatial positions with respect to the Hellenic Terrestrial Reference System 2007 were determined via different nationwide commercial GNSS positioning services, namely MetricaNet (GPS/GLONASS), Uranus (GPS/GLONASS) and HEPOS (GPS only), using both the VRS and MAC correction methods. For each NRTK scenario a separate ensemble of GNSS measurements was obtained at a sampling rate of 1Hz for different durations of station occupancy (see Table 1). Three different Leica Viva dual-frequency GPS/GLONASS receivers were used for the data collection in the following manner: GS08plus (MetricaNet), GS08 (Uranus) and GS14 (HEPOS).

The (orthometric) heights of the test points were obtained by each NRTK positioning provider/method on the basis of a corresponding built-in geoid model, and they were tested against their precise spirit-leveled heights which were transferred from a known nearby benchmark of the Hellenic vertical datum (see Fig. 1). All leveling measurements were performed by a Leica Sprinter 150 digital level, and the achieved (relative) height accuracy was in the range of few mm.

Table 1. *Details of the NRTK-heighting tests that were performed.*

Test Point	Network Service	Method	Duration (sec)
A	MetricaNet/Uranus/HEPOS	VRS / MAC	50/100/200
B	MetricaNet/Uranus/HEPOS	VRS / MAC	50/100/200
C	MetricaNet/Uranus/HEPOS	VRS / MAC	50/100/200
D	MetricaNet/Uranus/HEPOS	VRS / MAC	50/100/200
E	MetricaNet/Uranus/HEPOS	VRS / MAC	50/100/200

3. Results

Firstly, our results show that the three NRTK positioning services seem to offer similar accuracy level for vertical positioning regardless of the applied correction method (MAC or VRS). Both methods appear to behave similarly with regard to the determination of orthometric heights, and they present statistically comparable differences in relation to the spirit-leveled heights (with the exception of Uranus). Note that the differences in vertical positioning performance among the three NRTK providers reach a few cm (see Table 2) which can be considered significant at least for a number of precise surveying engineering applications.

The NRTK-derived heights seem to be biased by several cm with respect to the spirit-leveled heights which were transferred from the national leveling benchmark R. This is evident in the results shown in the following figures, as well as in the "*Avg*" values given in Table 2. Such an effect is most likely caused by a systematic offset between the adopted geoid model of each NRTK positioning service and the Hellenic vertical datum over our test area.

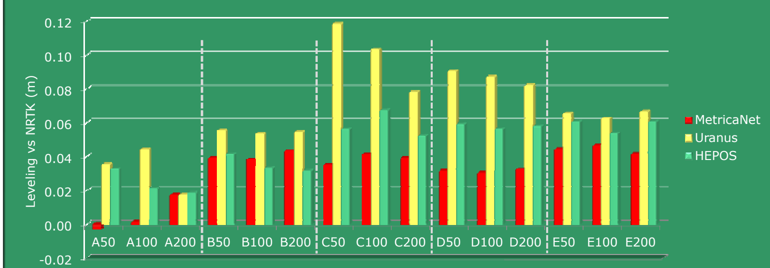

Fig. 2. *Differences between the **NRTK/MAC-derived heights** (for station occupancies of 50/100/200 sec) and the spirit-leveled heights from R.*

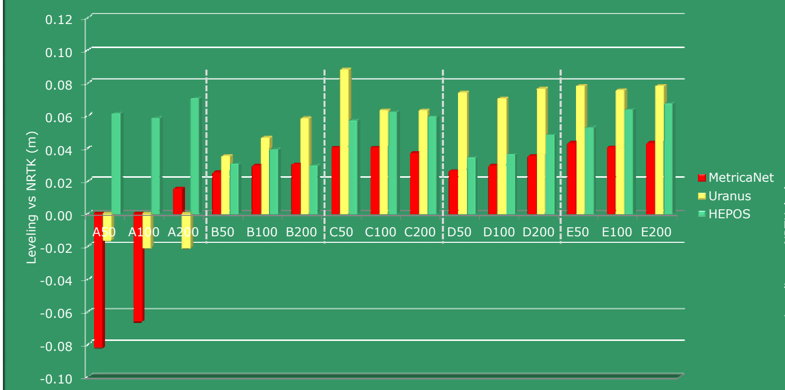

Fig. 3. *Differences between the **NRTK/VRS-derived heights** (for station occupancies of 50/100/200 sec) and the spirit-leveled heights from R.*

As shown in the above figures, the duration of station occupancy (50/100/200 sec) does not seem to have a sizeable effect on the vertical positioning performance, either for the MAC or the VRS correction method. The noticeable different behavior in the test point A is probably due to bad observing conditions at the time of the GNSS measurements.

Table 2. *Statistics of the differences between the **NRTK-derived heights** (for station occupancy 200 sec) and the **spirit-leveled heights** from R. All values in cm.*

	MetricaNet		Uranus		HEPOS	
	MAC	*VRS*	*MAC*	*VRS*	*MAC*	*VRS*
Min	1.7	1.5	1.7	-2.2	1.8	2.9
Max	4.3	4.4	8.2	7.9	6.1	7.0
Avg	3.5	3.2	6.0	5.1	4.4	5.5
Sigma	1.1	1.1	2.6	4.1	1.8	1.7

Relative, instead of absolute, height determination is more important for a large number of surveying applications. The evaluation of the NRTK positioning services in terms of relative height determination at our test stations is given in Table 3. Interestingly enough, there are still remaining biases (> 1 cm) with respect to the spirit-leveled height differences, mainly in the results by Uranus (MAC/VRS) and HEPOS (MAC only). The statistical accuracy of relative height determination seems also to vary considerably among the three NRTK-based positioning services.

Table 3. *Statistics of the differences between the **NRTK-derived height differences** (for station occupancy 200 sec) and the **spirit-leveled height differences** over all observed baselines in our test network. All values in cm.*

	MetricaNet		Uranus		HEPOS	
	MAC	*VRS*	*MAC*	*VRS*	*MAC*	*VRS*
Min	-0.7	-0.2	-1.6	0.2	0.2	-4.3
Max	2.4	1.3	3.5	7.8	2.1	3.0
Avg	0.6	0.7	1.2	2.5	1.0	-0.1
Sigma	1.4	0.6	2.2	3.6	0.8	3.3

There is no visible correlation between the GNSS satellite geometry and the vertical positioning performance of the NRTK-based heighting. Note that HEPOS supports only GPS satellite tracking, a fact which is reflected in Fig. 4 by the larger PDOP values compared to MetricaNet and Uranus.

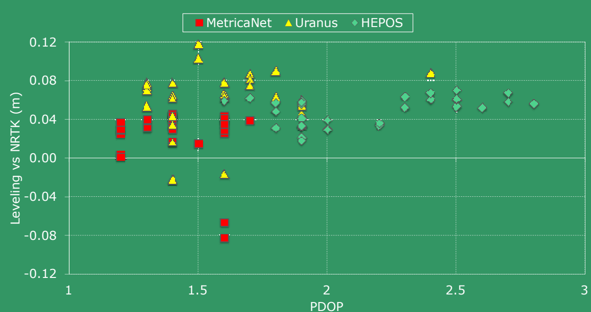

Fig. 4. *PDOP-dependency of the differences between the NRTK-derived heights and the spirit-leveled heights as obtained in our tests at the five measured points.*

(*) Note that the results from these evaluation tests reflect only the vertical performance of the NRTK-based positioning techniques in the particular area for the actual observation period. All measurements were performed on 16/4/2016.