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An Evaluation of the Performance of Network RTK GNSS Services in Ireland

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SUMMARY

The national Geodetic infrastructure for the island of Ireland has developed rapidly to a fully GNSS compatible coordinate reference system - Irish Transverse Mercator (ITM) which is realised through a Continuously Operating Reference System (CORS) network of active GNSS stations. The National Mapping Authority's CORS network provides data for post processing and streamed raw data for real-time network (NRTK) solutions. This NRTK raw data is currently being used by both Leica and Topcon to provide independent NRTK solutions. A second CORS network, known as VRS Now Ireland, with both RINEX and NRTK capabilities, was established in 2008 by Trimble and provides users with a third supplier of real-time GNSS solutions.

This study is the first in the public domain to evaluate the performance of NRTK services in Ireland and is intended to provide guideline information for geo-spatial practitioners. Based on collecting NRTK data at nine locations within a 50 km radius of Dublin City, and using 'normal' observing and processing methods, an accuracy of 22 mm ±8 mm with respect to published IRENET 2D coordinates and 29 mm ±14 mm with respect to the IRENET-derived orthometric heights was achieved. The three systems were shown to be generally comparable although some initialization problems were experienced. The addition of GLONASS observables made no significant difference to the results.

An Evaluation of the Performance of Network RTK GNSS Services in Ireland

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1. INTRODUCTION

The national Geodetic Infrastructure for the island of Ireland has developed from a passive network of triangulation stations based on a modified Airy ellipsoid and a Transverse Mercator Projection developed in the 1950's, and known as Irish National Grid (ING), to a fully GNSS compatible coordinate reference system,Irish Transverse Mercator (ITM), which is realised through a Continuously Operating Reference System (CORS) network of active GNSS stations. This development began in 1994 when Ordnance Survey Ireland (OSi) and Ordnance Survey Northern Ireland (OSNI) agreed to establish a new geodetic control network based on ETRS89 which complied with international standards. The passive realisation of ETRS89 in 1995 was known as IRENET and consisted of 12 Zero Order control points used for scientific purposes only (8 in the Republic of Ireland, 3 in Northern Ireland and 1 in the Isle of Man and 173 densification stations (D001 – D173) with an accuracy quoted as ±20 mm in x, y and z in ETRS89 (OSi and OSNI, 1999). At this time transformation parameters between ING and ETRS89 were determined.

In 2001, an extensive GPS observation campaign (IRENET02) was undertaken to ensure all positioning standards, both existing and developing, were compatible. IRENET02 consisted of an Active GPS network of 16 stations (10 OSi, 3 OSNI and 3 Commissioner for Irish Lights stations) and was determined to a similar accuracy as the Zero Order Passive network. At this time the need to maintain the accuracy of surveys undertaken using GNSS techniques also led to the development of the Irish Transverse Mercator (ITM) projection, a GNSS compatible coordinate reference system which ensured that both the survey and the mapping were based on the same control network and datum. ITM was realised in 2002 when ITM coordinates were first published on the OSi geodetic website (www.osi.ie). A link between ING and ITM horizontal positioning is maintained using transformation parameters embedded in the OSi online software Grid InQuest. Conversions of GNSS ellipsoidal heights to their orthometric equivalent, relative to Malin Head in the Republic of Ireland and Belfast Lough in Northern Ireland, was achieved through the development of a new Ordnance Survey Geoid model known as OSGM02. This signalled the end of the traditional levelling networks in Ireland, excluding the Fundamental Benchmarks.

The original CORS network in Ireland, IRENET02, was based on a GPS campaign consisting of 80 sessions, each of a 24 hour period. The shortest observation period was 66 sessions, with all other positions being based on more than 70 sessions. This campaign also included the IRENET Zero Order stations, the EUVN points and a number of densification points and whilst the campaign was designed, completed and processed to the standards required by

EUREF, the 2002 results were not submitted to EUREF for ratification. The data were processed by IESSG, Nottingham University, UK and resulted in a plan and height accuracy of better than ±10 mm for all IRENET02 stations (OSi, 2011). The network was based on Leica Geosystems technology. It was designed to enable users to avail of post processing data via RINEX ftp downloads from the OSi website and has undergone significant development phases. Initially, due to the poor GSM telecommunications network, the real-time positioning option was only available in the region around Dublin. It was served by 4 active stations. In 2004 a new Active OSi GPS network was established, this comprised of 12 stations which extended the real-time option to most of the country reflecting the improved communications infrastructure however, the western and north-western areas were poorly serviced. This network only operated in 'beta testing' mode and was available free of charge. The network software solution adopted at the time was Leica GNSMART and Leica Hardware (CR500 dual frequency geodetic receivers with Choke Ring Antennae) was installed at each active station (Greenway and Bray, 2004). This system was upgraded in 2006 to provide users with GPRS access to the NRTK solution. (Greenway and Bray, 2006).

The system was further upgraded in 2009 when Leica Geosystems extended its Smartnet RTK network in Ireland to GPS and GLONASS enabled stations. Four new receiver sites were added to the active network and a further station was relocated to improve coverage and redundancy, and to provide full traceability with real-time data stream links to the OSi and OSNI. A further OSi observation campaign was carried out in 2009 as part of a greater Ireland and United Kingdom GNSS campaign (OS IE/UK09). The coordinates from this campaign differ from those computed in the IRENET02 campaign at the mm level and will be introduced following computation of an updated Geoid model and software transformation utility (OSi, 2011). There are also plans to increase the density of the National Mapping Authority's (NMA) Active GNSS network in Ireland in late 2011 and 2012 to facilitate redundancy within the associated IT systems which will provide provide additional contingency in the event of a systems failure. This will also enhance the data available for associated GNSS services in Ireland (OSi, 2011).

2. NRTK

2.1 NRTK in Ireland

The current NMA CORS network consists of 23 stations (17 OSi and 6 OSNI) illustrated in Figure 1. These stations currently provide RINEX data for post processing and streamed raw data for real-time network solutions for dynamic surveys nationally.

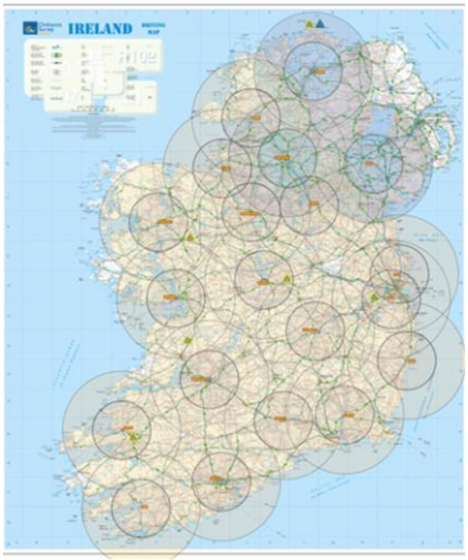

Fig 1: Ordnance Survey Ireland CORS Network
Source: OSi www.osi.ie/en/geodeticservices/map-of-active-stations.aspx

In 2008, Trimble established a second CORS network, VRS Now Ireland, with RINEX and NRTK capabilities as an extension to their VRS Now international network of 150 Trimble VRS Now networks currently operating worldwide. This Trimble network consists of 22 CORS stations positioned relative to the OSi CORS network. Coordinates for the new Trimble CORS stations were processed from 6 days of data for all OSi and Trimble reference stations whereby OSi CORS coordinates were fixed in the network adjustment. Thus ensuring that the Trimble VRS Now network was established in the official Irish coordinate frame. The VRS Now Ireland system is constantly monitored and system availability for the network has been above 99.9 % (24/7) over the last number of years (Wegner, 2011). The spatial distribution of the VRS Now Ireland network is shown in Figure 2.

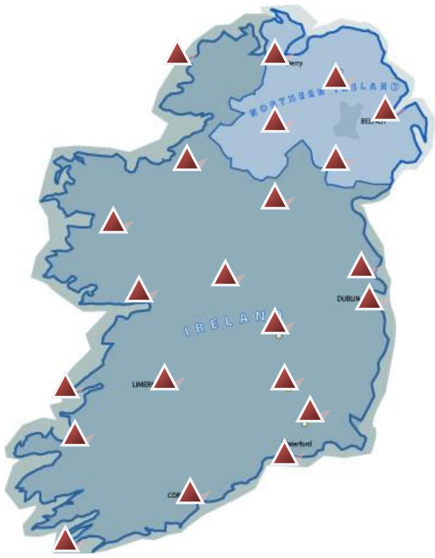

Fig 2: Trimble VRSNow Ireland CORS Network
Adapted from Trimble www.trimble.com/vrsnow-IE_coverage.shtml

A third NRTK supplier entered the Irish market in 2010 when Topcon Ireland established TopNET+. Similar to the Leica solution, Topcon utilizes raw data streamed from the NMAs CORS infrastructure. The TopNET+ solution is however based on the VRS correctional method, similar to Trimbles' VRS Now, and provides a Modelled Reference Station (MRS) solution. As all processing is done in a dedicated Topcon server the rover only requires to transmit its position via a GGA message to the server and subsequently receive the correctional signal back (Murray, 2011).

Thus there are currently three different NRTK systems in operation in Ireland: SmartNet, established by Leica Geosystems in 2006 is managed by Survey Instrument Services (SIS) and mainly operates in the area of geodetic surveying and engineering; VRS Now Ireland, established by Trimble is managed by Korec Ireland also predominately services the survey and engineering market; and TopNET+ which is managed by Topcon Ireland who have a significant stakehold in the construction and utilities market in Ireland. All three service providers envisage signifiant growth in NRTK in the areas of agriculture, utilities and mobile mapping. Table 1 briefly summarizes the characteristics of each of these NRTK systems.

Table 1: Network RTK Systems Currently in Operation in Ireland†.

System	**SmartNet**	**VRSNow**	**TopNET**
Provider	Leica GeoSystems	Trimble	Topcon
Irish Supplier	Survey Instrument Services (SIS)	Korec Ireland	Topcon Ireland
CORS Network	OSi	Trimble	OSi
Network Correction using:	GPS, GPS & GLONASS	GPS & GLONASS	GPS, GPS & GLONASS
Solution Type	MAC	VRS	MRS (VRS)
Data Transmission method	GPRS, GSM, 3G & Broadcast radio	NTRIP, GPRS, 3G, EDGE, Rebroadcast	NTRIP, GPRS, EDGE, Rebroadcast
Mobile Communications	All	All	All
Claimed Network			
Accuracy: Control (2 sets of 3-min observations)			
Horizontal, m	0.010 – 0.015	0.010 – 0.015	0.010 – 0.020
Vertical, m	0.010 – 0.030	0.020 – 0.030	0.015 – 0.030
Integrity controls	Yes	Yes	Yes
Cost			
Annual Licence	€2000(unlimited)	€1950 (unlimited)	€1500 (unlimited)
Limited access	€1200 (40hrs/m)	€795 (150 hrs/quater)	€1000 (40hrs/m)

† *Adapted from Engineering Surveying Showcase March 2011*

As can be seen from Table 1 differences in the three systems exist in the origin of the synchronised observations for NRTK corrections i.e. NMA CORS network or Trimble CORS network and also in the NRTK solution used to model the network biases and interpolate them for the rover location.

2.2 NRTK Concepts

All NRTK positioning solutions are used to overcome distance dependent biases, resolve carrier-phase ambiguities and generate atmospheric corrections within a CORS network. The solutions differ mainly in the manner in which the network corrections are interpolated and transmitted. Both Trimble (VRS Now) and Topcon (TopNET+) operate a Virtual Reference Station (VRS) solution whereby the server generates a virtual station close to the user and network corrections are interpolated at this virtual station which in turn transmits corrections across a very short single baseline to the roving receiver (Janssen, 2009). In this approach area corrections are applied at the network server thus simplifying the work done at the rover.

The Master-Auxiliary-Concept (MAC) introduced by Euler *et al.* (2001) and marketed by Leica as MAX consists of one master station, usually the closest, which generates master-auxiliary corrections from the other auxiliary reference stations, typically five other stations, within a Smartnet Leica network. Full corrections generated for the master station and correction and coordinate differences generated for auxiliary stations are then sent to the rover using the RTCM 3.1 format. The MAC concept differs from that of VRS in that it moves the computing burden from the network server to the roving receiver which requires specific software (Brown *et al*,. 2006). For legacy Leica receivers unable to access the MAX corrections using the RTCM format, modelled data for the master network station is created in the network server and transmitted to the rover using older versions of the RTCM format. These corrections are known as individualised-master-auxiliary (i-MAX) solutions and are comparative with the VRS approach described above however, i-MAX solutions do not employ a virtual station (Janssen, 2009).

2.3 Data Communication

The selection of an NRTK solution and also the number of visible satellites will affect the amount of data which has to be transmitted. The VRS solution broadcasts small quantities of data as the heavy processing takes place within the server whereas, the MAC approach requires up to three times greater bandwidth to transmit the raw data and this increases significantly with increasing number of reference stations (Janssen, 2009). When using mobile internet for data transfer bandwidth this is not an issue. The standard Radio Technical Commission for Maritime Services (RTCM) v3.1 data format is typically used by all service providers to transmit the real-time observations and corrections via a mobile phone or wireless internet. Most GNSS receiver manufacturers incorporate RTCM SC-104 standard RTK message types into their RTK systems and this enables interoperability between different receivers.

Latency of the signal at the rover is also a function of the quantity of data being broadcast and the quality of the communications network. The many small delays that may occur during data transmission between the reference stations and the server, and the server and the data port do not generally affect the solution. The communications network is generally the point at which most latency occurs and accurate NRTK solutions are therefore dependent on the existing mobile communications infrastructure available in a region (Leica, 2011). Network

RTK providers do not specify particular mobile networks and the choice of mobile network rests with the user and is usually based on local knowledge of coverage within an area. Figure 3 illustrates the mobile network coverage for Vodaphone Ireland and is indicative of current mobile coverage in Ireland.

Fig 3: Vodaphone coverage map
Source: www.Vodaphone.ie

The recent development of Smart SIM cards, whereby receivers automatically select the strongest mobile network in a specific area, should to some extent improve NRTK availability in some currently compromised data transmission locations. However, to be advantageous to the user this process should be seamless and have a centralised billing system.

2.4 NRTK System Performance

NRTK is comprised of three components: firstly, the CORS survey infrastructure, secondly the network solution applied and thirdly the data transmission format and protocol used. System performance is a function of these three components and when measured using accuracy and reliability indicators, is subject to a number of anomalies due to multipath, obstructions, satellite geometry and atmospheric conditions. All service providers specify that good survey procedures are essential when undertaking an NRTK survey and best practice guidelines for GNSS surveys outline the practical operational procedures which should be adopted when undertaking dynamic GNSS surveys including NRTK (SCS, 2010). The attainment of adopted standards must also be proven without doubt when surveys are performed for legal boundary surveys, land registration and for court appearances (IIS, 2009) furthermore, equipment must be field tested (ISO 17123 part 8) (Martin, 2008). However, issues pertaining to the traceability of all NRTK data and computational methods employed remain as both the VRS/iMAX and the MAC solutions are validated differently. Data provided by the network service provider for VRS/iMAX solutions can be authenticated once for all users whereas, this facility rests with the users' receiver firmware for MAC solutions which provide complete information on the error sources.

A number of previous comparative studies (Edwards *et al*., 2010, Jansen, 2009, and Brown *et al*., 2006) have shown that VRS and MAC solutions provide very similar results independent of network size. Each method has inherent advantages and disadvantages but their respective solutions provide results of similar accuracy and reliability when correctional data are streamed from a single CORS network. Results of NRTK solutions originating from correctional data streamed from independent CORS networks in the same area, such as those in Ireland, have not yet been assessed. Although no standard criteria currently exist for NRTK performance assessment Wang *et al*., (2010) tabularized the common manufacturers RTK initialization and accuracy performance specifications and experimental results, and additional performance assessment parameters identified by Feng and Wang (2008) include RTK Availability and ambiguity resolution.

In this paper a regional study to evaluate the currently available Network RTK systems in Ireland, *viz.* Leica Smartnet, Trimble VRS-Now and Topcon TopNET+, with respect to positional accuracy and efficacy was undertaken. Factors that are hypothesized to affect positional accuracy include observation time, elevation difference between observation points and NRTK base stations, observation point positional geometry relative to base station layout and solution algorithm variation between service providers. The intention of this study is to provide the required information to enable practitioners to make informed decisions when selecting a NRTK system.

3.0 METHODOLOGY

GNSS positional data were collected at nine OSi passive IRENET control points in May 2011. The IRENET points were selected to represent a range of scenarios with respect to NRTK performance, *viz.* points within the NRTK networks, points on the margins of the NRTK networks, points outside the NRTK networks and a point at a considerable altitude above the two CORS networks in Ireland, Osi and Trimble. The IRENET points were also chosen for their convenience from Dublin city and are, by their nature, located in open ground with good satellite visibility. Figure 4 shows the selected IRENET station locations.

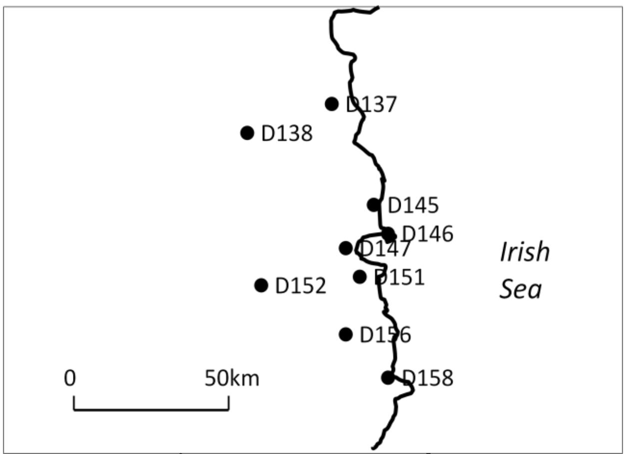

Fig. 4: IRENET station locations.

Some receiver issues were apparent with respect to the results and, accordingly, two locations, D145 and D147, were resurveyed in October 2011 using the Leica and the Topcon receivers. The relationships of the IRENET locations to the SmartNet and VRSNow networks can be seen by comparing Figure 4 with Figure 1 and Figure 2. Note that point D156 at an altitude of 488 m whereas the remaining points are at altitudes below 100 m. At each location, a tripod was set-up and centred over the IRENET control point. A purpose-built bracket capable of supporting three GNSS receivers was fixed to the tripod, the configuration is shown in Figure 5.

Fig. 5: Bracket allowing simultaneous observation with three receivers.

From Figure 5 it can be seen that the middle receiver is centred over the IRENET point while the remaining two receivers are offset by 0.250 m, respectively, from the central receiver. This arrangement allows for simultaneous data collection by the three receivers. The receivers used were a Leica Viva NetRover, a Topcon GRS-1 and a Trimble R8. These receivers are GPS and GLONASS-enabled and are their respective manufacturer's current (2011) products intended for NRTK surveys. As this study is concerned with NRTK performance in 'normal' use, the receivers were used as supplied by their manufacturer's agents, i.e. they were presumed to be in standard hire fleet-ready configuration.

At each location, the coordinates of the offset receivers were determined by coordinating a point some distance from the IRENET point and precisely aligning the bracket towards that point. The bearing of the bracket could then be determined and coordinates computed for the offset receiver locations. The height of the receivers above the IRENET point was determined by direct measurement. The receivers were set to record at 5" epochs with a 10° cut-off angle for approximately 45 minutes with GPS+GLONASS reception enabled and for a further approximately 45 minutes with GPS-only reception enabled. The receivers were configured, by default, to record plan coordinates in the GNSS-compatible Irish Transverse Mercator (ITM) grid system. Heights were recorded as orthometric heights. The orthometric heights were derived in real-time on the associated survey controller by application of the OSGM02 geoid separation model.

The data were downloaded as .txt files from the controllers without any further processing on the controllers. For each location there were two files per receiver, *viz* a 'GPS+GLONASS' and 'GPS only' file. Each file consisted of Point Number, ITM Easting, ITM Northing, Orthometric Height. The recorded coordinates were compared to the reference coordinates as published on the OSi website. The recorded heights were compared to the reference heights which were determined by converting the published ellipsoidal heights of the IRENET points to orthometric heights using the OSi GridInquest software. Recorded coordinates that, by inspection, were clearly subject to gross error were excluded from further processing. For each file, and for each remaining 3D component therein, *viz*. Easting, Northing and Height, the following statistics were generated: Count, Maximum, Minimum, Range, Standard Deviation, Mean, Standard Error and Root Mean Squared error (RMSE). Furthermore, the Easting RMSE's and the Northing RMSE's were combined to produce an RMSE of the 2D difference vector.

4.0 RESULTS

There are a number of outcomes from this study that collectively represent a 'snapshot' of the performance of the commercial NRTK systems available in Ireland. Accuracy determinations are with respect to existing IRENET stations. The results of the separate tests are summarized below:

4.1 2D RMSE with GLONASS included

The results of the 2D RMSE test with c. 45 minutes observing time and GLONASS included are shown if Figure 6.

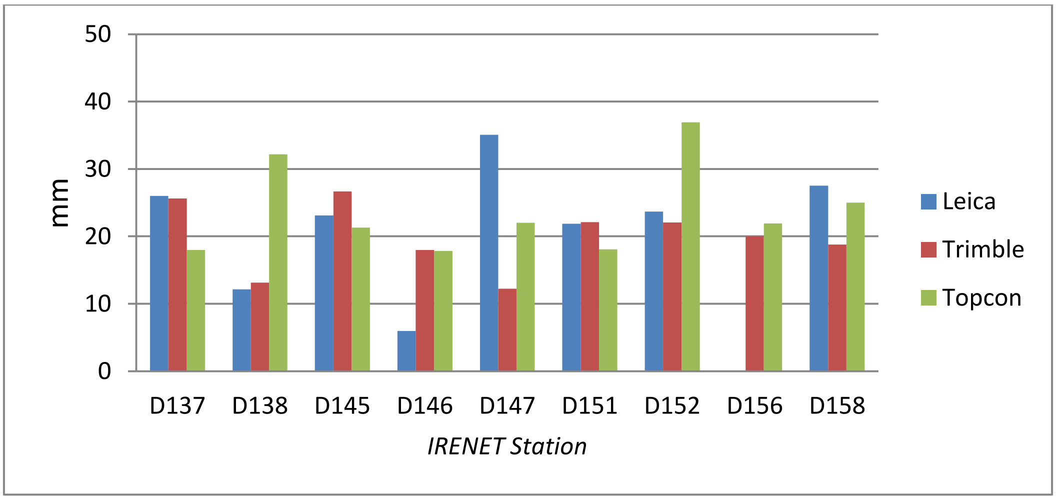

Fig. 6: 2D RMSE test with c. 45 minutes observing time and GLONASS included.

From Figure 6 it can be seen that, with respect to the IRENET coordinates, the 2D RMSE's range from 6 mm to 37 mm with an overall mean of 22 mm. While some variablilty is evident generally, no significant difference is apparent between manufacturers and/or solution types. Note that at D156 the Leica receiver was unable to initialize.

4.2 2D RMSE with GLONASS excluded

The results of the 2D RMSE test with c. 45 minutes observing time and GLONASS not included are shown in Figure 7.

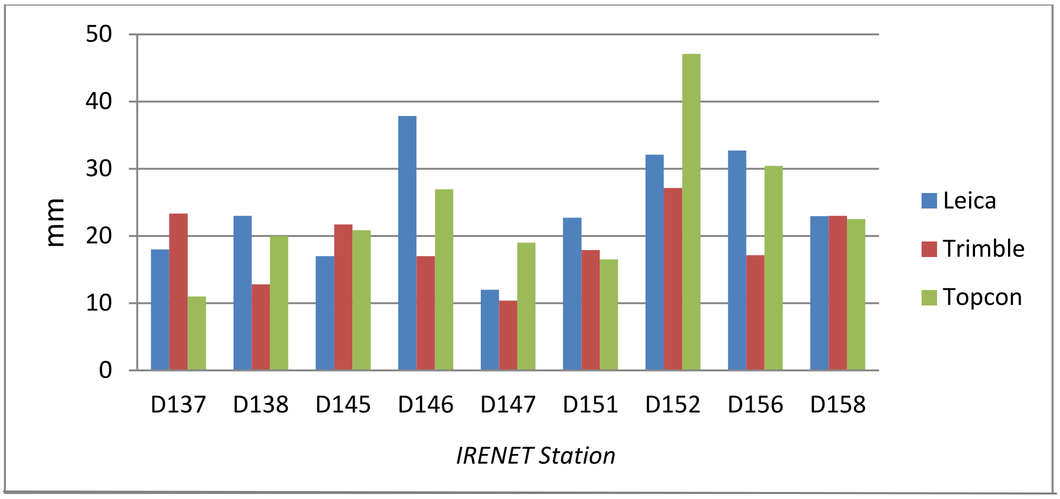

Fig. 7: 2D RMSE test with c. 45 minutes observing time and GLONASS included.

From Figure 7 it can be seen that, with respect to the IRENET coordinates, the 2D RMSE's range from 10 mm to 47 mm with an overall mean of 22 mm. While some variablilty is evident generally, no significant difference is apparent between manufacturers and/or solution types.

4.3 Contribution of GLONASS

The effect of including/excluding GLONASS in the each manufacturer's solution is shown in Figure 8.

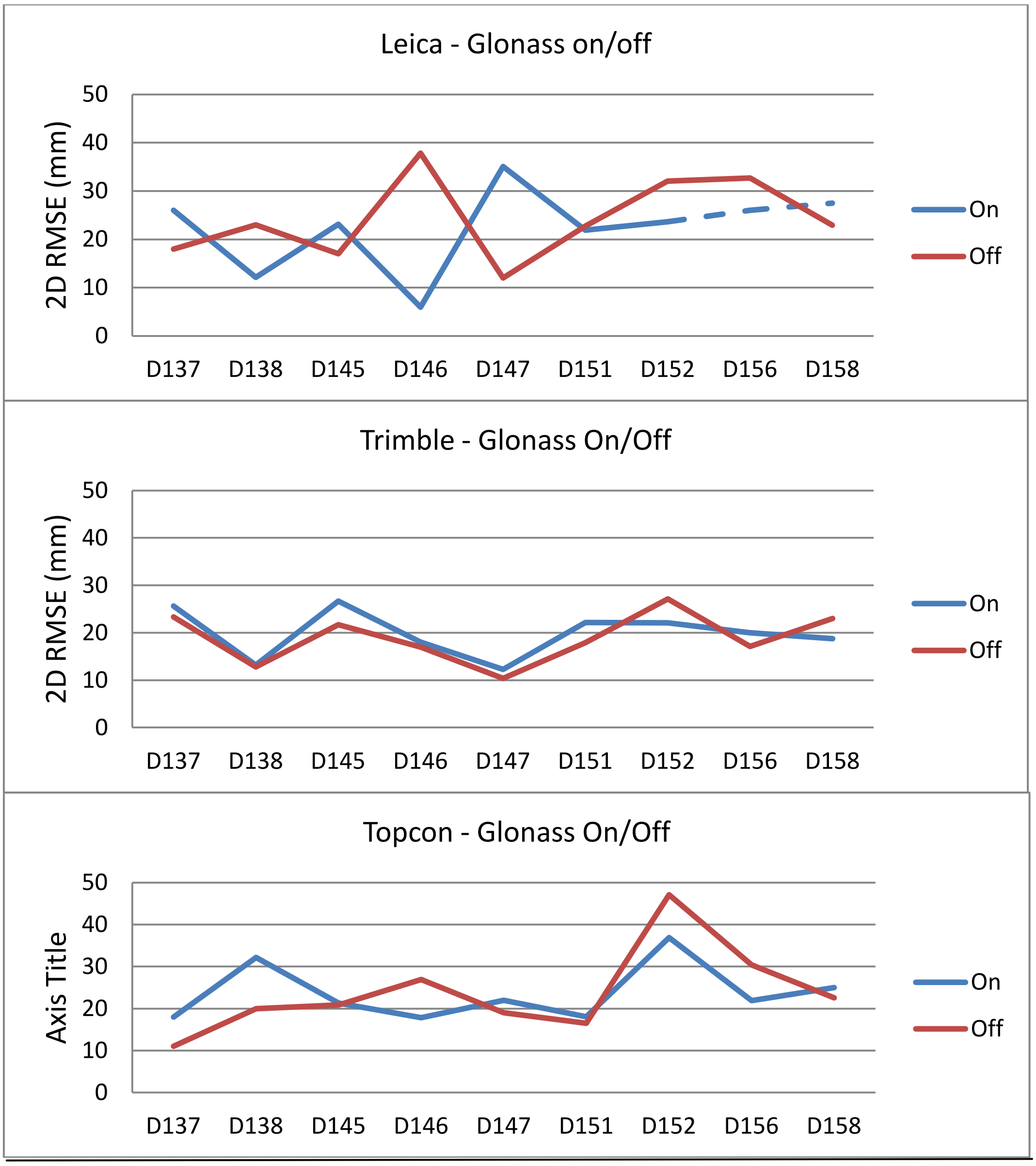

Fig. 8: The effect of including/excluding GLONASS in the each manufacturer's 2D solution.

From Figure 8 it can be seen that, at the selected locations, the addition of GLONASS observables had no significant impact on the results. It should be noted that the selected locations, being IRENET stations, are in relatively open ground. Note, also, that at D156 the Leica receiver was unable to initialize.

4.4 Height RMSE with GLONASS included

The results of the Height RMSE test with c. 45 minutes observing time and GLONASS included are shown in Figure 9.

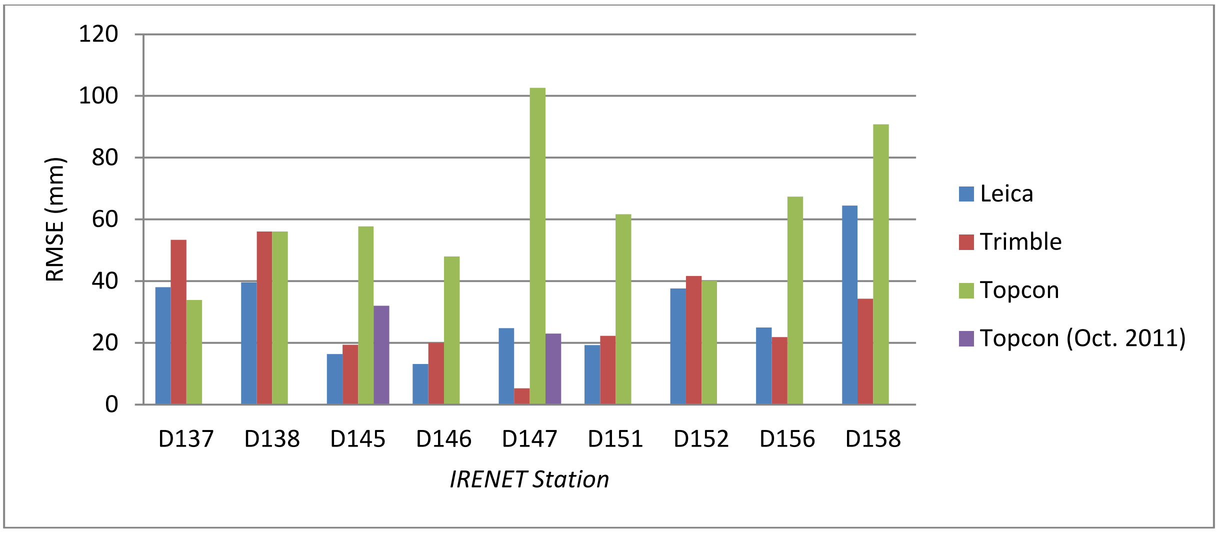

Fig. 9: Height RMSE test with c. 45 minutes observing time and GLONASS included. Note Topcon heights shown in green were subject to an incorrect receiver setting.

From Figure 9 it can be seen that, with respect to the IRENET-based orthometric heights, the height RMSE's range from 2 mm to 103 mm. However, it should be noted that the Topcon height values shown in green are subject to an incorrect receiver setting. A subsequent check in October 2011 at points D145 and D147 using the same methodology yielded RMSE's of 32 mm and 23 mm, respectively, as can be seen in Figure 9. Time constraints prohibited further rechecks at the remaining locations.

4.5 Height RMSE with GLONASS excluded

The results of the Height RMSE test with c. 45 minutes observing time and GLONASS excluded are shown in Figure 10.

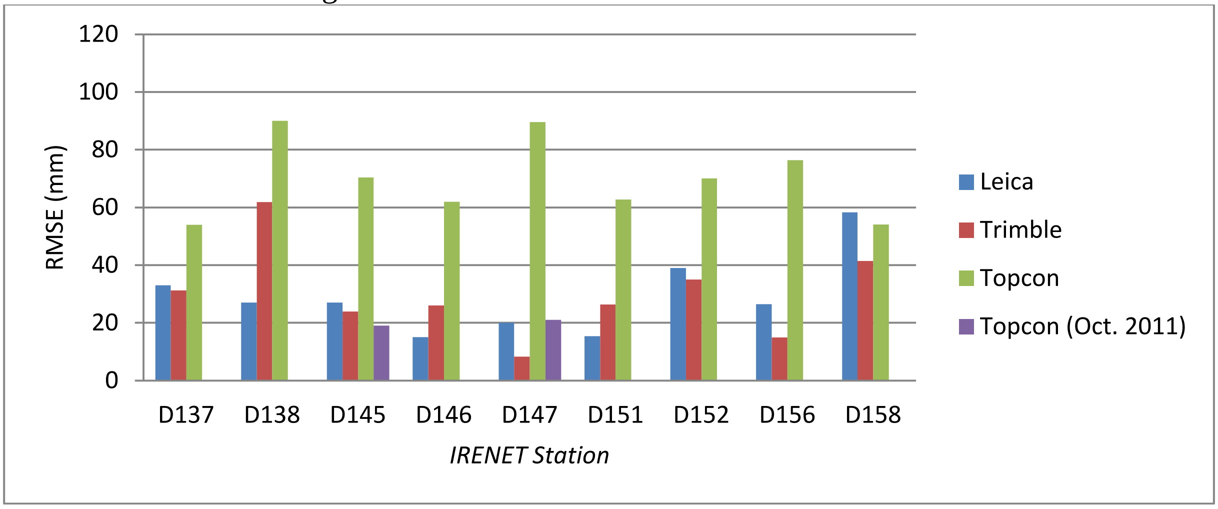

Fig. 10: Height RMSE test with c. 45 minutes observing time and GLONASS not included. Note Topcon heights shown in green were subject to an incorrect receiver setting.

From Figure 10 it can be seen that, with respect to the IRENET-based orthometric heights, the height RMSE's range from 8 mm to 90 mm with an overall mean of 42 mm. The Topcon RMSE's average at 70 mm whereas the Leica and Trimble RMSE's average at 30 mm. The reason for this difference in the 'GLONASS not included' data is an incorrect setting in the Topcon receiver. A subsequent recheck in October 2011 at points D145 and D147 using the same methodology yielded RMSE's of 19 mm and 21 mm, respectively as can be seen in Figure 10. Time constraints prohibited further rechecks at the remaining locations. .

4.6 Contribution of GLONASS to heighting

The effect on heighting of selecting/deselecting GLONASS satellites is shown in Figure 11.

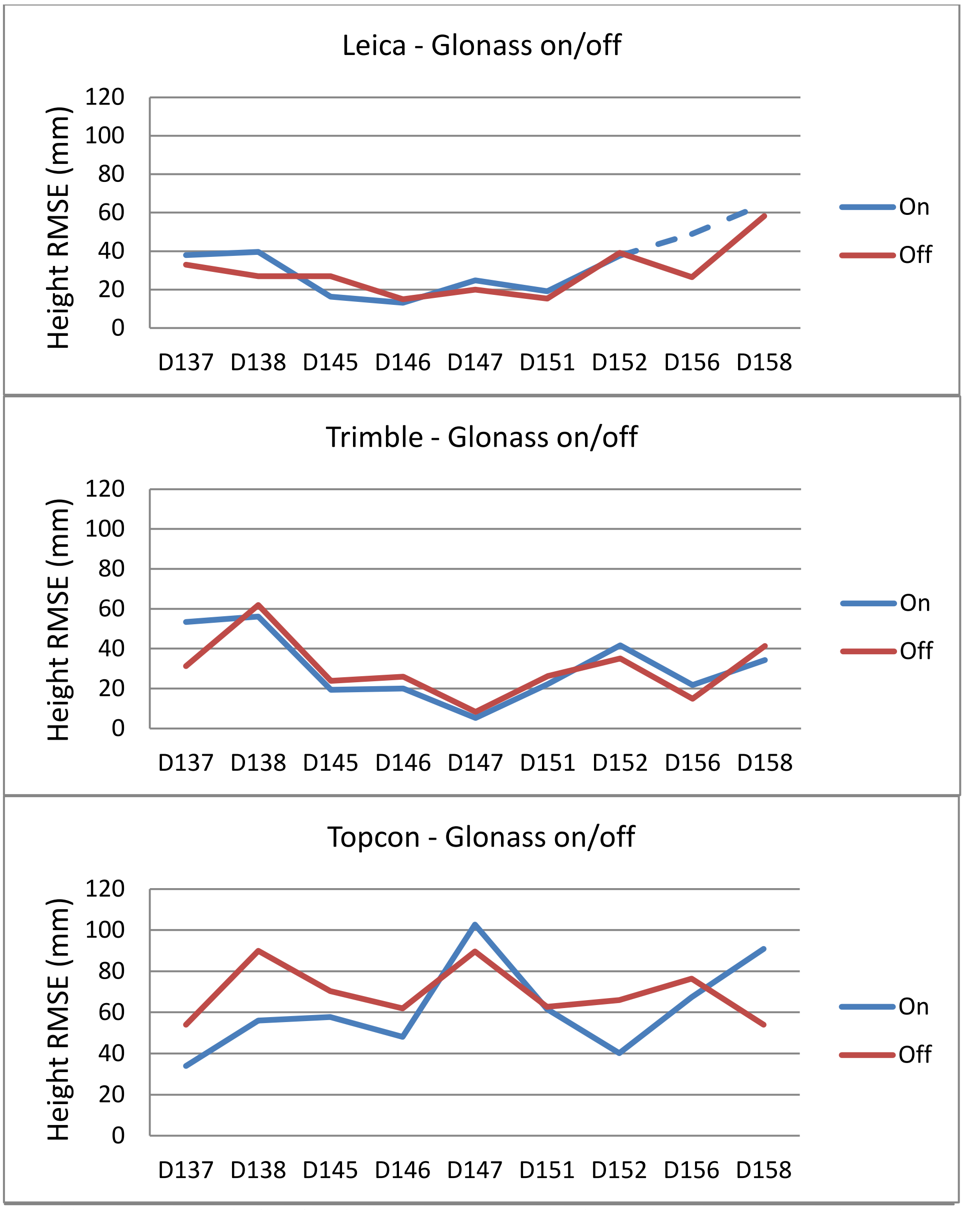

Fig. 11: The effect of including/excluding GLONASS in the each manufacturer's height solution.

From Figure 11 it can be seen that, for the Leica and the Trimble solutions, the addition of GLONASS observables had no significant impact on the heighting results. Note that at D156 the Leica receiver was unable to initialize. For the Topcon solution the inclusion of GLONASS observables would appear, in general, to improve the results although the issues with the Topcon heighting as referred to above should be noted.

4.7 Initialization issues

Generally, rapid initializations were achieved by the three receivers. Nevertheless, a number of observing sessions were affected by lost or incorrect initializations. An example is shown is Figure 12.

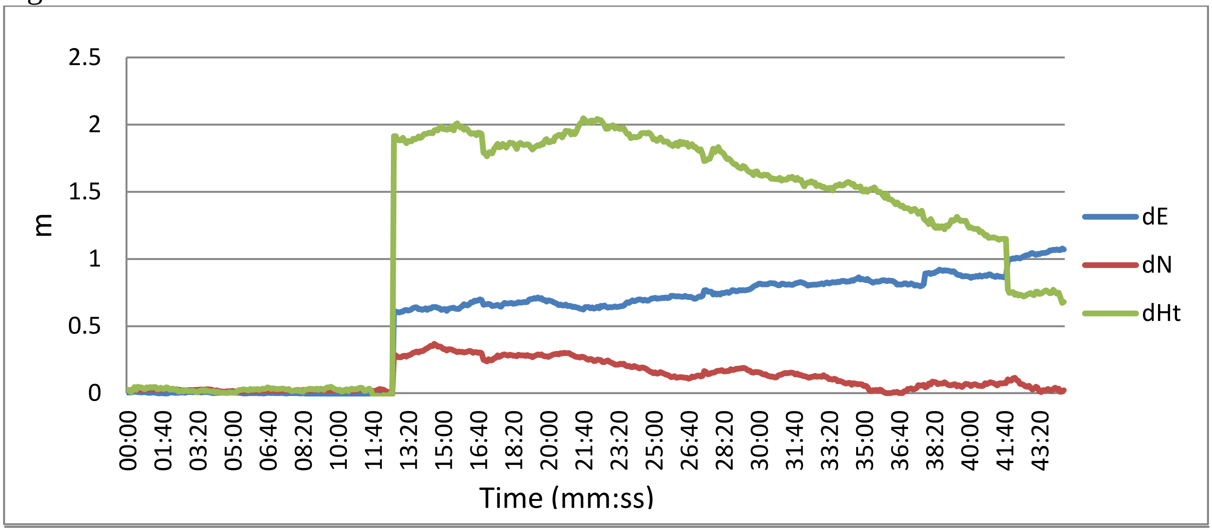

Fig. 12: Example of a loss of lock and failure to correctly reinitialize at D138.

Of the 18 sessions observed in May 2011 using the Leica system, 4 sessions were subject to significant initialization issues. The percentages of all Leica-recorded points that were clearly impaired, and thus removed before further analysis, were 12 % for GLONASS-included and 18 % for GLONASS-excluded. Included in those percentages was one full session when the receiver was unable to correctly initialize. Of the 18 sessions observed in May 2011 using the Topcon system 2 sessions were subject to significant initialization issues. The percentages of all Topcon-recorded points that were clearly impaired, and thus removed before further analysis, were 0% for GLONASS-included and 6% for GLONASS-excluded. The reasons for these difficulties are unclear. Cell phone coverage is a possible reason although most of the IRENET points used are located in, or around, large towns where good cell phone coverage would be expected. CORS station outages are another possibility. SmartNet (Leica) and TopNET (Topcon) use the same CORS stations so SmartNET CORS station outages would be expected to affect both systems simultaneously and this was not the case. This would suggest that CORS station outages were not the reason. The Trimble system was not subject to initialisation issues. A follow-up survey at two of the IRENET locations was carried out in October 2011 with the Leica and the Topcon systems, using the same methodology as before, and no initialization issues were encountered.

4.8 Windowing and Averaging

The options of 'windowing' and averaging were examined. 'Windowing' is the suggested procedure of taking a number of relatively short observing sessions at the same point, at different times, to produce mean coordinates of comparable accuracy to a single, longer observing session, thus improving efficiency. Data from all the observing sessions was examined to assess the viability of 'windowing'. Figure 13, as an example, shows the data collected at D137 by the Leica receiver with GLONASS excluded.

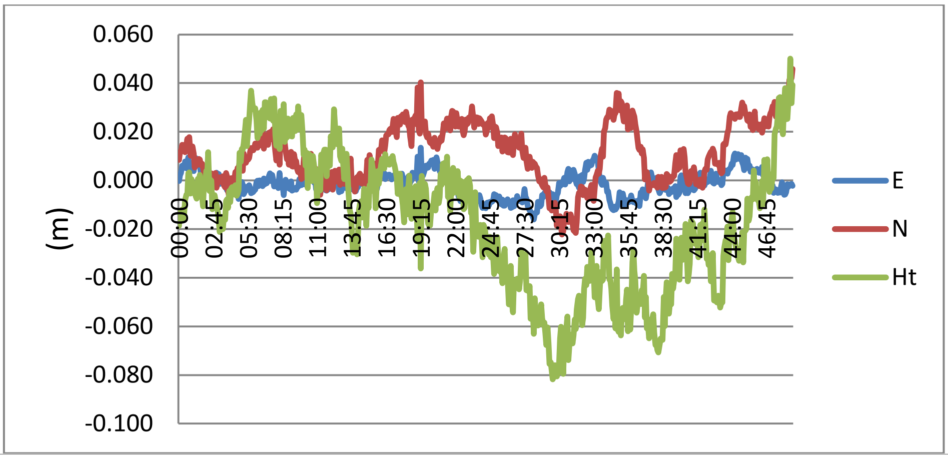

Fig. 13: Example of variability of coordinate residuals with time for one observing session**.**

From Figure 13 it can be seen that the coordinate residuals, and hence the coordinates themselves, exhibit trends but the variability of the trends appears chaotic. It was concluded, therefore, from an inspection of Figure 13, and the data from the other observing sessions, that it is not possible to select in advance a windowing strategy that will function as intended. The data was studied to determine whether averaging over time would improve the accuracy of the coordinates. Figure 14 shows the accumulated means for the same observing session as shown in Figure 13 and is typical of the other observing sessions.

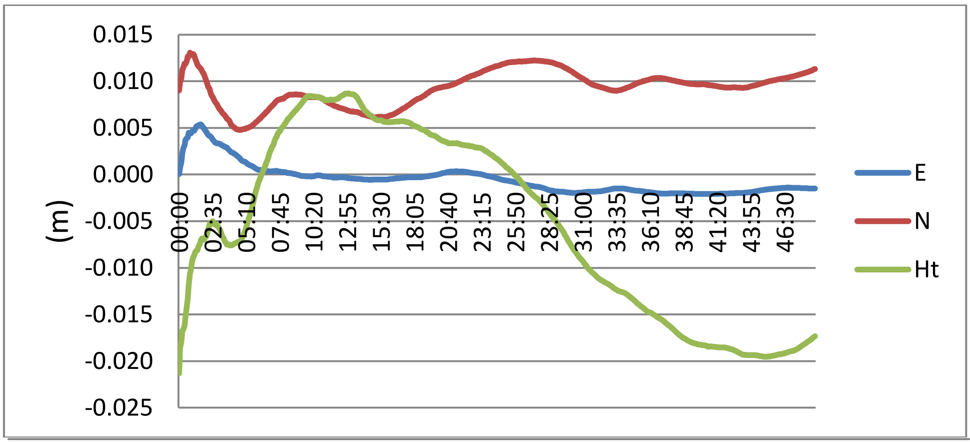

Fig. 14: Example of accumulated mean residuals for one observing session.

From Figure 14 it can be seen that the accumulated mean residuals (i) do not converge on the reference value and (ii) do not necessarily settle over time. It can be concluded, therefore, that no minimum or maximum recording time can be suggested to achieve optimal results.

4.8 Effect of elevation difference.

IRENET point D156 is located in the Wicklow Mountains at an elevation of 488 m which is considerably higher than the other IRENET points and the regional CORS stations. From the data presented in Figure 6, Figure 7, Figure 9 and Figure 10 it can be seen that results for D156 were comparable to those achieved at the other stations and so it was concluded that the substantial elevation difference did not have a significant effect on the solutions. In Figure 6, however, it can be seen that no results are presented for the Leica receiver because for that observing session the Leica unit was unable to initialize.

5.0 CONCLUSION

Network RTK is used regularly in Ireland today by, *inter alia*, surveyors, hydrographers, engineers and geoscientists. There is, however, a lack of information available concerning the performance of NRTK. This study addresses the deficit of knowledge available regarding the performance of the three commercial NRTK services in Ireland, *viz.* SmartNet, VRS Now Ireland and TopNET+. Notwithstanding some highlighted issues with signal lock robustness and heighting, it was found that the three systems delivered comparable planimetric and heighting accuracies. It was shown that, for the open locations used, the addition of the GLONASS observables to the solutions did not make a significant difference. Accordingly, combining all the available data, an overall figure for the planimetric (2D) accuracy of NRTK at the locations selected, and with respect to the published IRENET coordinates, was ±22 mm with a standard deviation of ±8 mm. Excluding the erroneous height determinations that were highlighted, an overall figure for the heighting accuracy of NRTK at the locations selected, and with respect to the IRENET-derived orthometric heights, was ±29 mm with a standard deviation of ±14 mm.

This study is the first in the public domain to evaluate the performance of NRTK services in Ireland. It is intended to provide guideline information for practitioners and, as such, has generated significant interest from the geospatial community in Ireland. A logical development would be to undertake a nationwide study using rigorous methodologies so that a more definitive assessment could be achieved.

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