BEST PRACTICES FOR ASSESSING NEXTMAP® EUROPE DATA QUALITY AND ACCURACY

Stephen Cliffen, IV&V Manager
Graham Weeden, IV&V Team Lead
Intermap Technologies
2 Gurdwara Rd., Suite 200
Ottawa, ON K2E1A2
scliffen@intermap.com
gweeden@intermap.com

ABSTRACT

In April 2009, Intermap Technologies completed its NEXTMap® Europe 3D mapping program. Using proprietary Interferometric Synthetic Aperture RADAR (IFSAR) technology, Intermap has successfully created a high resolution, highly accurate and homogeneous digital elevation database consisting of approximately 2.4 million km² covering 20 countries in Western Europe. This paper reports on the best practices utilized to independently assess the quality and accuracy of the NEXTMap® Europe database at a regional scale. This assessment was accomplished via Intermap's Independent Verification and Validation (IV&V) process which operates separately from Intermap's Production and Quality Control processes to ensure that analyses are conducted from an objective and unbiased point of view. All IV&V analyses are reported back to internal stakeholders to ensure that data meets published specifications and to highlight any potential improvement opportunities. To assess data quality and accuracy, an understanding of the published specifications of the NEXTMap® data as outlined in Intermap's Core Product Handbook was required. The vertical accuracy of the NEXTMap® Europe database was assessed using highly accurate reference data, which served as a reliable measurement of ground elevations. Tens of thousands of Vertical Check Points (VCPs) were obtained and/or purchased from various mapping agencies throughout Western Europe to support the quality and accuracy assessment. In addition to VCPs, this quality assessment also included comparisons to other ancillary Digital Elevation Models (DEMs) such as LiDAR and National DEMs where available. While the spatial extents or accuracies of the ancillary DEMs were not sufficient to fully complement the VCP accuracy assessment, they provided some insight into general product quality and relative consistency.

Key words: NEXTMap®, Europe, Elevation, Accuracy, IFSAR

INTRODUCTION

Intermap Technologies is a leading provider of large scale high resolution mapping products and services to facilitate a broad range of geospatial applications. The data is acquired from airborne platforms using Interferometric Synthetic Aperture RADAR (IFSAR) technology. The Intermap Core Products discussed in this paper include the Digital Surface Model (DSM) and Digital Terrain Model (DTM). The DSM represents the elevation of the first surface identified by the RADAR, including natural and cultural features. The DTM is a "bare-earth" product that is generated from the DSM after trees, buildings and other cultural features have been digitally removed from the elevation model during an interactive editing process.

Intermap has proactively remapped entire countries under its NEXTMap® 3D Mapping Program. A major milestone was accomplished in April 2009 when Intermap Technologies announced the completion and commercial availability of NEXTMap® Europe. Intermap's NEXTMap Europe database now offers uniform national databases, consisting of affordably priced Orthorectified RADAR Imagery (ORI) and Digital Elevation Models at unprecedented accuracy for Western Europe. Intermap's NEXTMap Europe database includes complete nationwide digital maps for: Andorra, Austria, Czech Republic, Denmark, France, Germany, Gibraltar, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Portugal, San Marino, Spain, Switzerland, Vatican City and the United Kingdom.

Evaluating such an immense database for data quality and assessing the vertical accuracy, specifically, can be a daunting task. In addition to internal quality control checks and balances throughout the enterprise workflow at

Intermap, an Independent Verification and Validation (IV&V) group in the Customer Care division was established to perform unbiased evaluations for data quality and adherence to data specifications. As data is produced, samples are "audited" by IV&V. The target for these internal product audits is for IV&V to review 5-10% of all NEXTMap® data available for purchase. One of the most important tasks outlined for IV&V is to validate the vertical accuracy of NEXTMap® data. This paper will focus on the methodologies and the results observed by IV&V in assessing NEXTMap® Europe vertical accuracy.

VERTICAL ACCURACY SPECIFICATIONS

In order to validate vertical accuracy, the first step is to understand the specifications of the data. Table 1, copied directly from Intermap's Product Handbook & Quick Start Guide v4.3, describes the vertical accuracy specifications associated with the DSM and DTM. The majority of the NEXTMap® Europe database consists of Intermap's "Type II" Product Type. The accuracy specification for Type II DSM and DTM data is 1m RMSE. In the table there is a footnote associated with the RMSE statistic. This footnote, as described in the Product Handbook, stipulates that this vertical accuracy specification is based on evaluation conducted in unobstructed slopes less than 10 degrees. This clarifies that in bare open terrain free from objects obstructing the ground view of the IFSAR sensor, such as vegetation or cultural features, and in modest slope conditions, the root mean square error for the dataset is within 1m. Sections in the handbook go on to describe how certain factors can influence data quality and accuracy. These factors include slope, obstructed areas and artifacts. Accuracy in higher slopes, generally, is expected to decrease but there are many factors contributing to variable results including the magnitude of the slope, whether the slope is positive or negative, the aspect angle and where it lies in the RADAR swath (look angle). Accuracy is also expected to decrease in obstructed areas. In small obstructed areas, particularly in low slope areas, it is likely the data is very close to or within a 1m RMSE accuracy range. However, in large obstructed areas, such as closed canopy forests or very dense urbanized areas, there are not enough ground measurements acquired by the sensor to expect the same 1m RMSE as in unobstructed low slope conditions. In these areas a Fully Integrated Terrain Solution (FITS) algorithm is applied during the creation of the DTM. FITS utilizes ancillary DEM information to help derive a viable ground surface. This is not a "cut and paste" solution but rather a complex algorithm which manipulates the ancillary DEM surface by adjusting it to transition seamlessly with the more accurate unobstructed surrounding terrain from the IFSAR data. This manipulation process is applied to small localized areas, removing any bias or tilt and warping the data to match the IFSAR elevations. In addition, this process is performed prior to the interactive edit where editors are validating that the obstructed areas in the DTM are consistent with what is seen in a stereo model based on DSM elevations. In other words, the opportunity exists to identify where poor ancillary data requires further editing due to temporal changes and/or a general lack of terrain resolution. In addition to slope and obstructed areas, there are a number of artifacts inherent with IFSAR data acquisition and processing (as well as other remote sensing technologies) that can affect accuracy. These artifacts may include layover, shadow, signal saturation, decorrelation, motion ripples, missing data and image tone consistency. For more details, the handbook can be reviewed and/or downloaded from the Resource Center found at www.intermap.com in the Quick Links section. Efforts are taken throughout Intermap's production process to reduce the occurrence of these artifacts, however they have been known to impact accuracy in some localized areas. While there are no detailed numeric specifications described for accuracy in outside the unobstructed slopes less than 10 degrees, the handbook explains that the error should be expected to increase. In other words, an accuracy of 1m RMSE in high slopes and/or obstructed areas would be a false expectation. In addition to validating the vertical accuracy in unobstructed slopes less than 10 degrees, the IV&V group set out to evaluate accuracy in high slope and obstructed areas in hopes to provide a better understanding of potential data limitations. It is very difficult to assess product accuracy in fully

Table 1. Vertical Accuracy Specifications

DSM	Measures of Accuracy Specifications		Pixel Size / Post Spacing
Product Type	RMSE[1]	LE95[2]	
I	0.5 m	1.0 m	5 m
II	1.0 m	2.0 m	5 m
III	3.0 m	6.0 m	5 m

DTM	Measures of Accuracy Specifications		Pixel Size / Post Spacing
Product Type	RMSE[1]	LE95[2]	
I	0.7 m	1.5 m	5 m
II	1.0 m	2.0 m	5 m

obstructed areas (forests especially). Due to technical and cost limitations, there are very few highly accurate reference datasets available for comparison in densely obstructed areas. Some localized comparisons to LiDAR datasets were conducted to help provide some insight into the expected accuracies in obstructed areas. LiDAR technologies however, face some of the same challenges as IFSAR in these areas so there remains low level of confidence in the reference data as being absolute "truth". One example of a localized comparison to LiDAR data conducted in the NEXTMap® Europe evaluation is discussed in this paper. However, the majority of the reference data used to validate NEXTMap® Europe vertical accuracy specifications was in the form of thousands of independently collected Vertical Check Points (VCPs).

IV&V VCP DATABASE

The IV&V VCP database is a collection of over 20,000 highly accurate ground measurements throughout Western Europe. The data was negotiated for use and/or purchased from various private and government mapping agencies. Limiting factors such as the availability of existing data and cost made the collection of VCPs challenging. The end result, however, was an impressive sample size; one that was certainly adequate for a regional assessment. Figure 1 illustrates the spatial distribution of the VCP database. Points were only collected for the larger countries that make up the NEXTMap® Europe database, including: Austria, Belgium, Czech Republic, Denmark, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain and Switzerland. NOTE: No VCPs were collected in the UK by the IV&V group as this area was evaluated externally before the group was established. The VCP point density covering all countries where VCPs were collected was approximately 1 point per 110km^2. The average minimum linear distance between all points in the VCP database for NEXTMap® Europe was less than 6km (point density in countries like Spain and the Czech Republic heavily influenced this average).

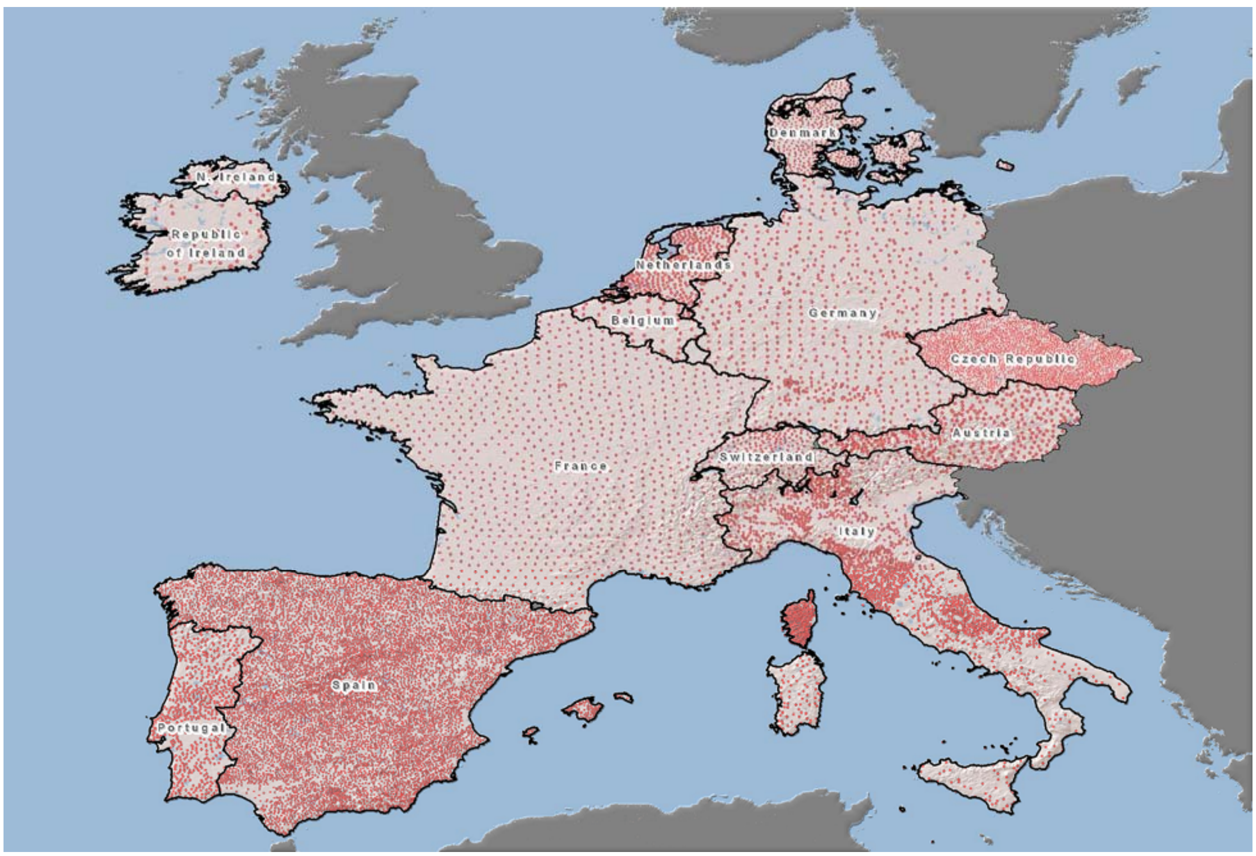


Figure 1. VCP Spatial Distribution (red dots).

The IV&V VCP database consists of surveyed control points with expected accuracies better than 10cm. While requests were originally submitted to external mapping agencies for points primarily in unobstructed low slope areas (to validate the vertical accuracy specification of the DSM and DTM), often what was delivered was a mixture of points in a range of land cover and terrain types. Some points were simply not usable for this particular evaluation, such as points on top of structures like churches with no offset information for an accurate ground measurement. As data was acquired from the various mapping agencies, an interactive review was conducted on the majority of the points to ensure they were valid ground measurements and suitable for validating vertical accuracy specifications. During the interactive review, descriptions and/or survey drawings in datasheets supplied with many of the points were reviewed to determine the point suitability. Where there were no datasheets, the point locations were reviewed with the DSM and Orthorectified RADAR Image (ORI) as well as using available online ancillary imagery sources to gauge point suitability. Beyond qualifying each point as being located in or out of areas defined by the vertical accuracy specification, additional information was also noted to justify the decision regarding point suitability.

Figure 2. NEXTMap® Europe Processing Blocks.

As milestones were completed in the NEXTMap® Europe program and large data processing "blocks" were completed, IV&V set out to evaluate the accuracy for each of these areas. The coordination of VCP collection was based on the Production schedule and anticipated availability of data processing blocks. As the data in these blocks were processed independently it was at that level the IV&V group was required to begin to validate vertical accuracy to ensure the program was progressing as expected with respect to data quality. It should be noted however that steps were taken during the editing process to ensure the data was consistent and seamless throughout the entire database. The sizes of processing blocks in NEXTMap® Europe ranged from approximately 5000 km^2 to 80,000 km^2 with an average of 35,000 km^2, see Figure 2. By evaluating VCP locations block by block, IV&V took a systematic approach for a more manageable review process. This enabled IV&V to deliver timely feedback and track data quality trends as the NEXTMap® Europe program progressed. Once all blocks intersecting entire countries were completed, IV&V would formulate an accuracy evaluation for each country based on the work completed at the block level. Finally, as all countries were completed, IV&V was able to examine the NEXTMap® Europe database at a regional scale.

NEXTMap® EUROPE VCP ANALYSIS & RESULTS

A systematic approach was used in the evaluation of vertical accuracy for NEXTMap® Europe. As NEXTMap processing blocks passed through the Production QC stages and were delivered to the Core Product Repository, IV&V copied the data to external hard drives to compare elevations against the VCP database on local workstations. This made data processing more manageable. Global Mapper was the primary software package used in the VCP evaluation process. DSM and DTM elevations were extracted using Global Mapper. The elevations from a number of other DEM sources and information layers were also extracted at VCP locations for comparison purposes and to demonstrate what data quality advantage the NEXTMap® Europe database could offer. The other DEM sources incorporated in the evaluation included SRTM, ASTER and the original elevations from the National DEMs used as ancillary information in the creation of the DTM in obstructed areas ("ANC"). The Shuttle Radar Topography Mission (SRTM) dataset is a first surface product available for free in Europe at 3 arc-second resolution (~90m). Another dataset publicly available is the Advanced Spaceborne Thermal Emmision and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM). Also a first surface product, the ASTER GDEM is available for download at 30m resolution. A business partner of Intermap, Global Mapper was the preferred software package as it is capable of reading large amounts of geospatial data in native formats (including the various data formats used by Intermap throughout the data production process). With such large volumes of data to include in the evaluation, any steps to reduce intermediate files or reformatting increased the efficiency so more time could be focused on the analysis. As the interpolated (bilinear) elevation values for the DSM and DTM were extracted, they were copied into a master Microsoft Excel spreadsheet which would eventually contain all VCP points. A VCP database tool was designed by the IV&V group, consisting of several Excel macros, so the raw data could be very quickly analyzed with a variety of filter criteria, see Figure 3. The IV&V VCP database tool contains several drop-down filter options

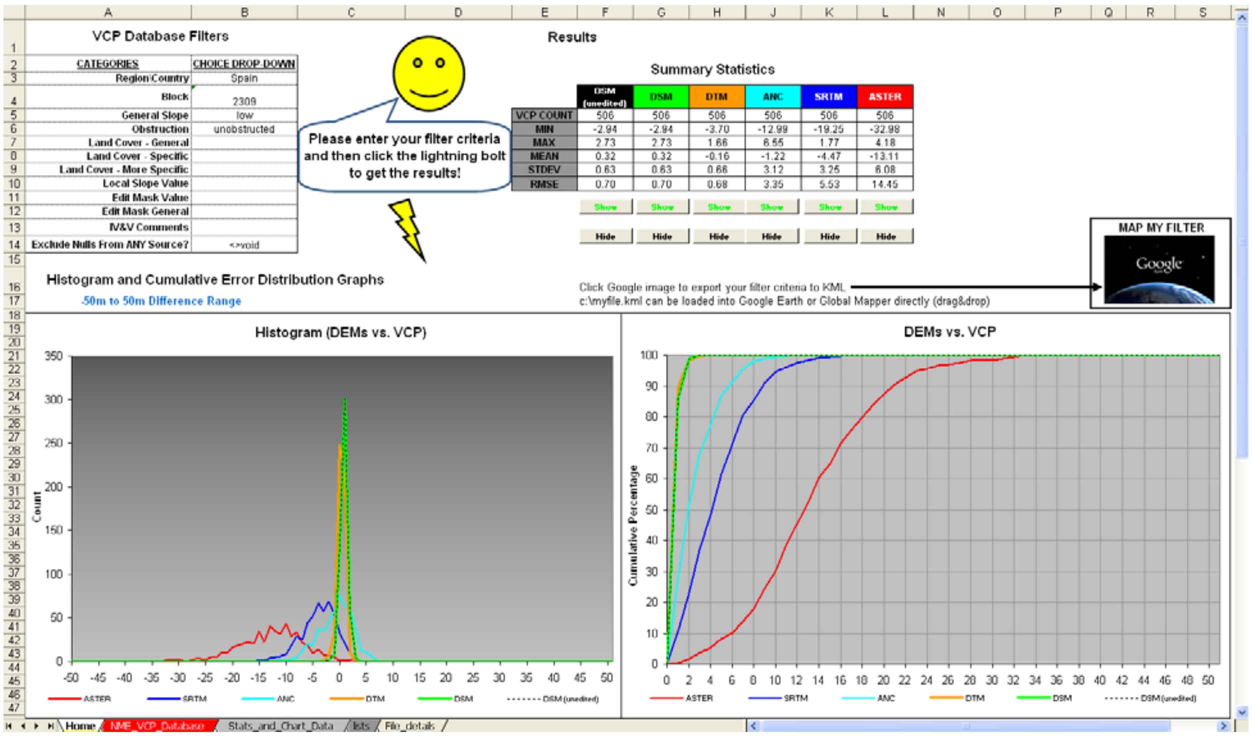


Figure 3. IV&V VCP Database Tool.

so the NEXTMap® Europe database accuracy results could be evaluated in specific regions and/or in specific land cover and terrain types. Processing blocks could be queried individually as could specific countries. Queries for high or low slope as well as obstructed and unobstructed points were possible using the General Slope and Obstruction drop down filters. Land cover information was extracted from the CORINE 2000 dataset (http://www.eea.europa.eu/themes/landuse/clc-download) with the intent to be able to relate vertical accuracy to land cover classes. A European Environment Agency program, the Coordination of information on the environment (CORINE) is a land cover layer derived from satellite imagery. The 100m resolution of the CORINE raster data, however, was not well-suited for comparison to the 5-meter resolution of the NEXTMap® Europe database. Early in the evaluation, it became clear that the resolution of the land cover layer was not sufficient to draw any conclusions about expected accuracy in specific land cover classifications. Slope values or ranges derived from DTM could be queried using the database tool, as could information collected in an edit mask that is generated during the production of the DTM. The IV&V Comments drop down filter listed information input by IV&V during the interactive review of VCP suitability. And finally, the last drop down item allowed for making “apples to apples” comparisons between all DEM sources. In order to compare the DEMs relative to each other, the same VCPs needed to be used (this filter would exclude any points containing null values for **any** DEM). Once the filter criteria were set, the filter macro button could be clicked to retrieve the results. The summary statistics updated and recalculated automatically, as did the two charts displaying histograms and cumulative percentage plots for the various DEM sources. Macros were added to the tool to hide or show whichever combinations of DEM sources were desired for display in the charts. Finally, another macro was designed to export the filter criteria to a KML file which could be loaded into Google Earth, Global Mapper or other software to visualize the spatial distribution of the points selected. Explanations on how to interpret the charts in the database tool are described as follows. The histograms showed the distribution of error of the dataset(s) compared to the truth (VCPs). A desirable result was a tight distribution centered on 0m (showing no significant bias either negative or positive) and a symmetrical Gaussian or bell curve. The histogram complemented the summary statistics because it provided a good visualization of the quantities of the errors. This could be helpful if there were significantly large outliers in the summary statistics table described by the min and max values (outliers which could be skewing the statistical results). The cumulative percentage plots were another visualization of the error distribution in the data. However, those plots displayed absolute vertical difference between the dataset(s) compared to the truth (VCPs). They helped to visualize what percentage of data could be expected within the error range on the x axis. A desirable result for the cumulative percentage plots was a steep rise at the beginning of the plot showing that a large percentage of the data had very small absolute linear error associated with it. As the data trailed off at the top of the chart (showing outliers), it was evident at what error level the data fell at a 95 percent confidence for example. Using the VCP database tool, IV&V was able quickly evaluate the vertical accuracy based on a number of filter criteria. The following are results from four different filter criteria.

Filter #1: Specification Validation (Unobstructed Slopes Less Than 10 Degrees)

IV&V's primary task was to validate that the DSM and DTM met the Core Product vertical accuracy specifications. The following statistics and charts were derived from the VCP database tool:

Table 2. Summary Statistics in Unobstructed Low Slopes (DSM and DTM)

	DSM	DTM
VCP COUNT	8296	8296
MIN	-3.95	-5.74
MAX	4.77	4.43
MEAN	0.03	-0.27
STDEV	0.61	0.63
RMSE	0.61	0.69

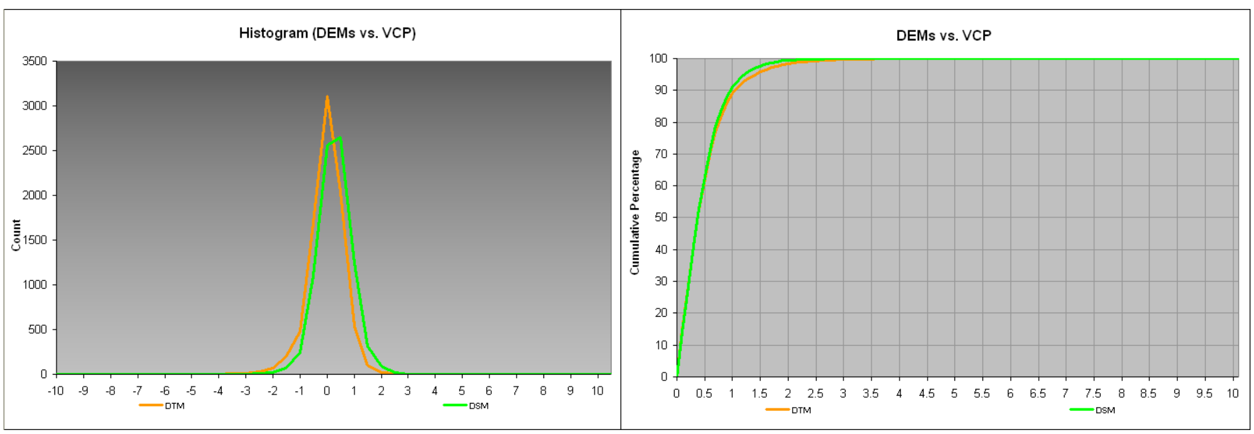


Figure 4. Histogram and Cumulative Percentage Plot in Unobstructed Low Slopes (DSM and DTM).

Table 3. Summary Statistics in Unobstructed Low Slopes (All DEMs)

	DSM	DTM	ANC	SRTM	ASTER
VCP COUNT	7196	7196	7196	7196	7196
MIN	-3.95	-5.74	-131.69	-29.02	-48.42
MAX	4.77	4.43	208.60	12.20	25.22
MEAN	0.04	-0.28	-1.06	-3.62	-11.07
STDEV	0.61	0.63	5.69	3.17	6.77
RMSE	0.61	0.69	5.79	4.82	12.97

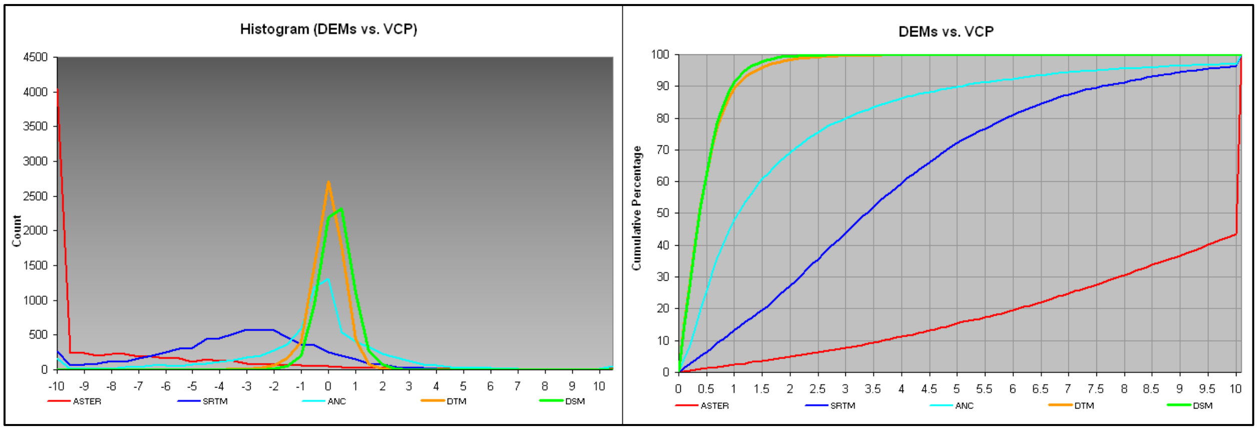


Figure 5. Histogram and Cumulative Percentage Plot in Unobstructed Low Slopes (All DEMs).

As seen in Table 2 and Figure 4, using 8,296 vertical check points throughout NEXTMap® Europe, the RMSE for the DSM and DTM was tested to be 61cm and 69cm respectively. The histogram showed a tight distribution of error and the cumulative percentage plot confirmed that the majority of the data contained very few outliers. Both DSM and DTM met the 1m RMSE vertical accuracy specifications. Relative to other DEMs, as seen in Table 3 and Figure 5, the VCP analysis revealed that the NEXTMap® Europe database significantly outperformed all other DEM sources in unobstructed low slopes. The difference in the number of VCPs used in Table 2 and Table 3 reflect the exclusion of any VCPs with null values in any of the other DEM sources. The "other" DEM sources are somewhat self explanatory with the column labels in the summary statistics tables, however for review, as previously described, the ANC column reflected the accuracy results found when comparing the VCPs to the original elevations of the various national DEMs that were used to help approximate ground elevations for the DTM in obstructed terrain. The ANC outperformed both the SRTM and ASTER DEMs but the DSM and DTM provided the best results by a significant margin (as seen in Figure 5). This is a good example why visualizing the error distributions can provide information hidden in the summary statistics. Due to the extreme outliers in the ANC, the RMSE for the SRTM indicated it provided better results however when plotting the distribution of error, clearly the ANC outperforms SRTM. The overall specification validation results provided a good final chapter to an already successful NEXTMap® Europe story. Those results did not come as a surprise to internal stakeholders at Intermap, however, since IV&V had been providing interim reports on a country wide scale as the program progressed. Table 4 lists the accuracy results for many of the NEXTMap® Europe countries. The Land Area column was the number of square kilometers of unobstructed low slope terrain in each country and what percentage of the whole country that represented. The number of VCPs in those areas for each country was provided as well as the RMSE value for the DSM and DTM. At a regional scale the DSM and DTM met specifications and at a national level, all NEXTMap® Europe countries met vertical accuracy specifications as well.

Table 4. RMSE Results by Country

	Unobstructed Low Slope (Spec.)				
	Land Area (km²/%)		VCPs	DSM	DTM
Germany	156,000	44%	690	0.68	0.69
France	214,772	40%	987	0.53	0.63
Italy	92,561	31%	703	0.61	0.87
Spain	231,429	47%	2619	0.70	0.78
Belgium	12,379	41%	53	0.61	0.58
Neth.	17,633	52%	253	0.57	0.65
Austria	18,561	22%	142	0.55	0.67
Czech. Rep.	31,187	41%	2289	0.54	0.53
Switzerland	7,364	18%	83	0.49	0.46
Denmark	26,000	60%	263	0.52	0.63
Portugal	32,229	37%	163	0.47	0.75

Filter #2: Unobstructed Slopes Greater Than 10 Degrees

As described earlier, and in more detail in Intermap's Product Handbook, the accuracy in high slopes is not expected to be 1m RMSE. However, Intermap does not commit to a specification to validate against. There are a number of factors that can influence results in higher slopes. Magnitude of the slope, whether the slope is positive or negative, the aspect angle and where it lies in the RADAR swath (look angle) are all factors that contribute to variable accuracy results in slopes greater than 10 degrees. Taking advantage of the large sample size of the VCP database, IV&V looked at points in slopes greater than 10 degrees to better understand what accuracy range could be expected in those areas in the NEXTMap® Europe database. Further evaluations are underway to look at breaking down the high slope points further into the other slope factors that could affect accuracy but this evaluation was just a general high slope query. The following statistics and charts were derived from the VCP database tool using an "unobstructed slopes greater than 10 degrees" filter:

Table 5. Unobstructed Slopes Greater Than 10 Degrees (All DEMs)

	DSM	DTM	ANC	SRTM	ASTER
VCP COUNT	4129	4129	4129	4129	4129
MIN	-58.96	-59.61	-120.01	-530.73	-296.22
MAX	76.06	76.64	77.38	84.45	91.44
MEAN	-1.13	-3.00	-6.49	-16.92	-23.74
STDEV	2.77	3.22	10.71	15.88	18.31
RMSE	2.99	4.40	12.52	23.20	29.98

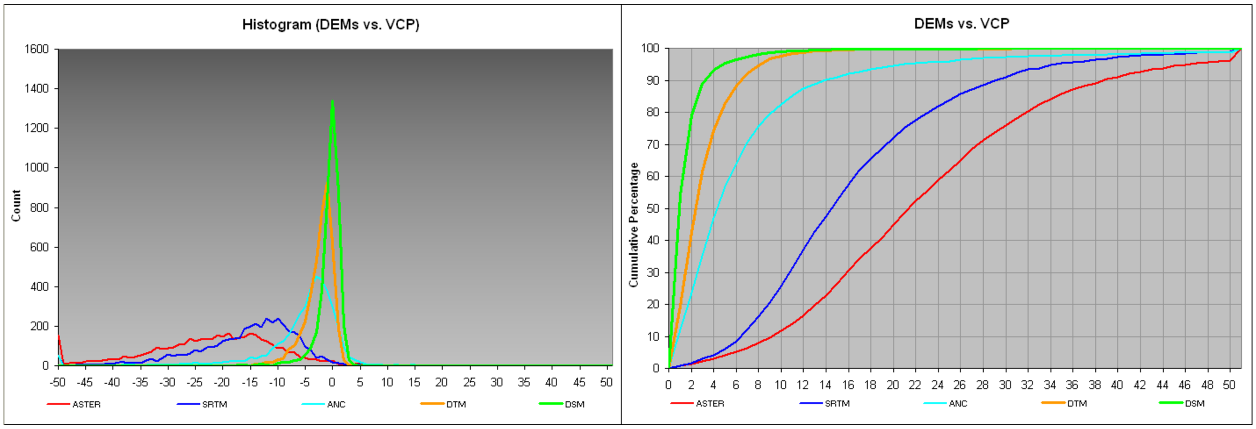


Figure 6. Histogram and Cumulative Percentage Plot in Unobstructed High Slopes (All DEMs).

As seen in Table 5 and Figure 6, at just less than 3 meters RMSE, the DSM yielded the best results in unobstructed slopes greater than 10 degrees. In high slopes a relatively small negative bias found in the DSM was found to be further compounded in the DTM and reduced the RMSE to just over 4 meters. This was clearly evident in the offset between the DSM and DTM in the histogram in Figure 6. The cause for the decrease in accuracy in these unobstructed high slopes was attributed to the process in which the DTM was derived from the DSM. The DSM contains a certain amount of noise inherent in RADAR based remote sensing technologies. The DTM statistics contains smoothing on ridges and valleys where many ground control points were located and thus the difference between DSM and DTM. The RMSE and distributions of error confirm that the NEXTMap is the best data available.

Filter #3: Obstructed Slopes Greater Than 10 Degrees

The "obstructed slopes greater than 10 degrees" filter really began to isolate the most challenging areas for DSM and DTM performance with respect to absolute accuracy. While the accuracy of the unobstructed areas is not attainable in this challenging terrain, at National or Pan-European scale, the NEXTMap® Europe database continues to offer the best available product. The following statistics and charts were derived from the VCP database tool using an "obstructed slopes greater than 10 degrees" filter:

Table 6. Summary Statistics in Obstructed Slopes Greater Than 10 Degrees (All DEMs)

	DSM	DTM	ANC	SRTM	ASTER
VCP COUNT	3148	3148	3148	3148	3148
MIN	-93.55	-96.65	-388.24	-325.33	-266.67
MAX	22.80	23.05	749.21	19.58	26.10
MEAN	-1.43	-5.82	-7.56	-14.01	-21.33
STDEV	4.86	6.16	21.03	15.20	17.47
RMSE	5.06	8.48	22.35	20.67	27.57

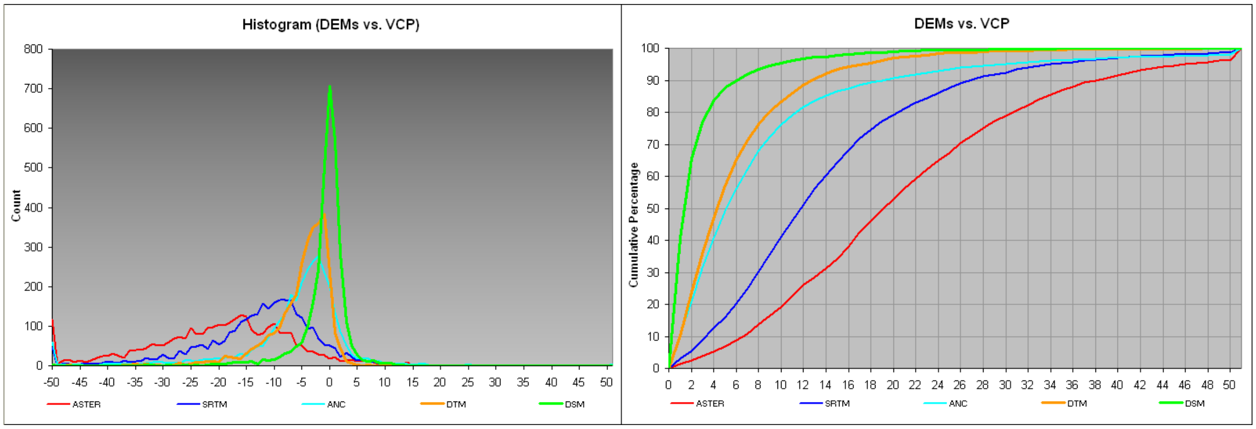


Figure 7. Histogram and Cumulative Percentage Plot in Obstructed High Slopes (All DEMs).

Errors observed in unobstructed high slopes were found to be nearly double in obstructed high slopes. Areas of dense canopy vegetation specifically, where there was very little penetration to ground elevations from the side looking IFSAR sensor, made producing a DTM from the DSM very challenging. If in the data production process the edit technicians were unable to visualize the ground through the trees, that scenario made it very difficult to estimate a ground surface in the DTM. Ancillary DEM sources were heavily relied upon to help create the DTM in those challenging areas and unfortunately suffer from similar technical challenges and the error from the Ancillary DEM sources were in some cases transferred in the DTM in obstructed high slope areas.

Filter #4: VCP Results in FITS Locations

As previously described, in large densely obstructed areas, ancillary DEM sources were utilized to help estimate the ground surface in the DTM. This was not simply a substitution of data. The Fully Integrated Terrain Solution (FITS) utilized unobstructed surrounding terrain as well as input from edit technicians to improve upon the original elevation values from ancillary DEM sources. IV&V was able to use an information layer captured in the Production process that identified the locations where ancillary data was utilized to determine how much the Fully Integrated Terrain Solution improved the accuracy from the original ancillary DEMs. The VCP database consisted of 6,730 locations where FITS was used in the DTM edit process. As Table 7 describes, overall within the NEXTMap® Europe database, the DTM was tested to be 2.5 times more accurate than the original ancillary DEM sources used in obstructed areas. The following statistics and charts were derived from the VCP database tool using a filter to select only those points that fell within FITS areas:

Table 7. Summary Statistics in FITS Areas (DTM & ANC)

	DTM	ANC
VCP COUNT	6730	6730
MIN	-96.65	-341.36
MAX	7.46	749.21
MEAN	-3.55	-4.20
STDEV	5.09	14.89
RMSE	6.21	15.47

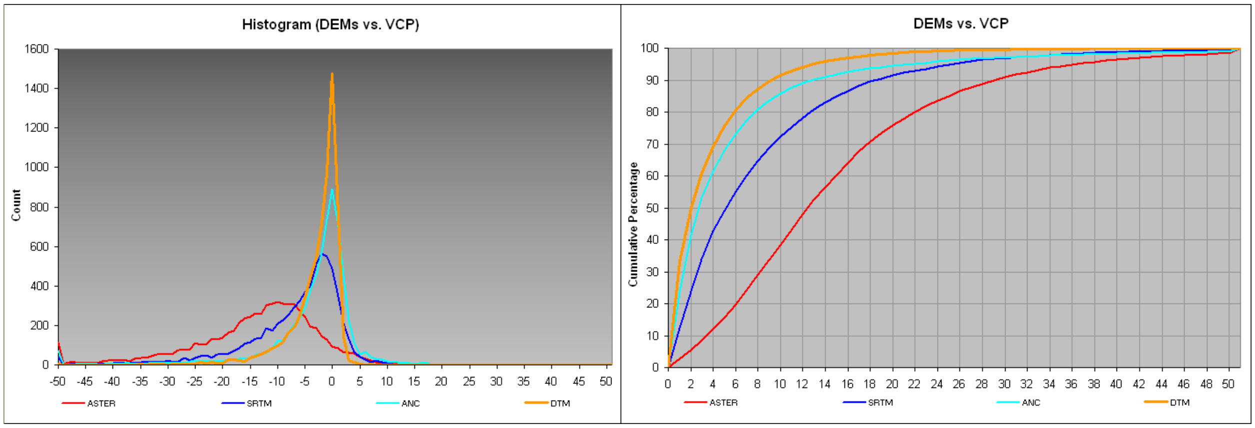


Figure 8. Histogram and Cumulative Percentage Plot in Obstructed High Slopes (All DEMs).

The histogram and cumulative percentage plots in Figure 8 visualize information found in the summary statistics table. They clearly demonstrated that at the locations of the 6,730 VCPs found in locations where ancillary data was used, FITS had improved the DTM from the original ancillary DEM sources.

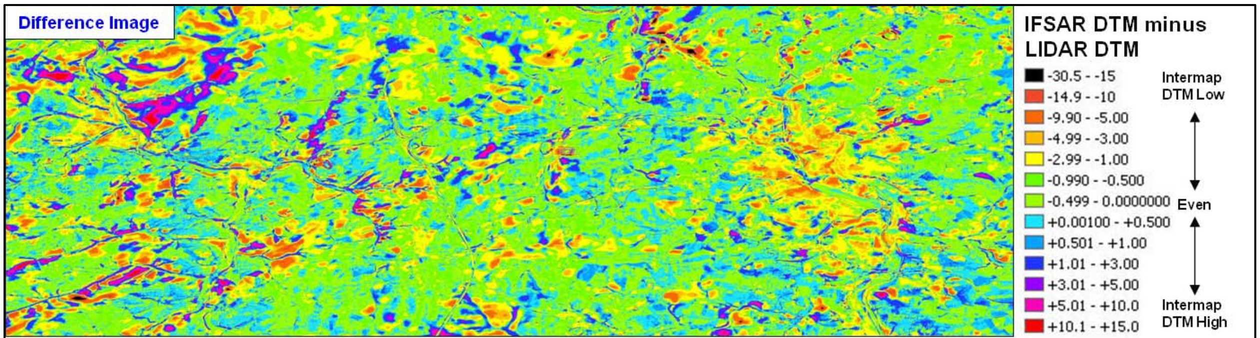
To summarize information from the 4 filters examined from the IV&V VCP database,

- The DSM and DTM met the 1m RMSE vertical accuracy specification (unobstructed low slopes) testing at 61cm and 69cm respectively
- In unobstructed high slopes the NEXTMap® Europe database accuracy was tested to be in the 3-4 meters RMSE range
- Obstructed high slope accuracy results were found to be double that of unobstructed high slopes
- The Fully Integrated Terrain Solution successfully improved DTM accuracy (2.5x) compared to the original ancillary DEM sources used to estimate ground elevations in obstructed areas.

One of the challenges in using VCPs to evaluate product accuracy, especially in obstructed areas, was a limited sample size relative to the number of elevation posts being evaluated. Whenever possible, IV&V acquired other highly accurate DEM sources to supplement the VCP accuracy evaluation. The following section of the paper shares more accuracy results as they relate to comparisons to other highly accurate elevation data.

LOCAL COMPARISON RESULTS TO LiDAR

To complement the VCP analysis conducted in the NEXTMap® Europe accuracy evaluation, IV&V was able to obtain some LiDAR sample data for localized comparisons to the DTM. One such LiDAR sample was received from a Bavarian State Agency Survey which included roughly 230km^2 of DTM data. This highly accurate data was acquired around the city of Hof and included a variety of land cover and terrain types. While LiDAR also has some limitations in terms of what accuracies can be achieved in obstructed areas, a comparison in both unobstructed and obstructed areas offered more insight in terms of data quality and consistency in the NEXTMap® DTM. Figure 9 illustrates some of the analysis conducted using the Bavarian State Agency Survey LiDAR sample:



Distribution of DTM Differences (Unobstructed Areas)

Difference Range [m]	Count [# of Pixels]	Distribution	Total Distribution			
-3 to -4	3716	0.05%				
-2 to -3	12034	0.16%				
-1 to -2	160649	2.17%				
-1 to 0 to 1	7101236	96.01%	96.01%	99.57%	99.82%	99.90%
1 to 2	102905	1.39%				
2 to 3	6239	0.08%				
3 to 4	1941	0.03%				

Min	-29.86
Max	27.56
Mean	-0.13
St Dev.	0.56

Distribution of DTM Differences (Obstructed Areas)

Difference Range [m]	Count [# of Pixels]	Distribution	Total Distribution			
-3 to -4	536296	5.77%				
-2 to -3	910923	9.80%				
-1 to -2	1610892	17.34%				
-1 to 0 to 1	4153923	44.70%	44.70%	68.19%	80.69%	87.90%
1 to 2	571218	6.15%				
2 to 3	251324	2.70%				
3 to 4	133494	1.44%				

Min	-30.49
Max	22.03
Mean	-0.95
St Dev.	2.61

Figure 9. Bavaria State Agency Survey LiDAR vs. IFSAR DTM Difference Image (units in meters).

The difference image above provided some indication of the correlation between elevations in the IFSAR and LiDAR DTMs. Upon closer examination, some of the larger differences were attributed to temporal change (mining operations). In looking at the distribution tables in unobstructed areas (left) it was clear that a large percentage of the datasets shared similar elevations. Over 96% of IFSAR DTM values were within ±1m of the LiDAR elevations (this included over 7 million DEM posts), and over 99% fell within ±2m. The LiDAR dataset also contains errors, however if considered “truth”, the IFSAR DTM accuracy in unobstructed terrain was estimated to be 57cm RMSE. This was another source of data that could confirm that in this localized area, the NEXTMap® Europe dataset met vertical accuracy specifications. In obstructed areas, where the larger variations existed, the IFSAR DTM accuracy was tested to be 2.78m RMSE compared to the LiDAR. Those results were much better (at least 2 times) than previously reported in the VCP analysis (from the obstructed high slopes or FITS filters). Those differences in results could be attributed several possibilities (or a combination of them all) including:

1. More obstructed terrain posts were evaluated in this LiDAR comparison (over 8 million DEM posts) compared to VCPs that fell within obstructed areas (approximately 8,000). It is possible these results were more representative of data quality in obstructed areas. A large portion of the VCP locations in obstructed areas were typically situated on hilltops where the error in the DTM may be found to be the largest in the entire obstructed area. The LiDAR comparison was applied over entirely obstructed areas which included a mix of terrain conditions which when average out produced better results.
2. Since the VCPs were known to be of higher accuracy than LiDAR in obstructed areas, it is also possible that the VCP results were more representative of data quality in obstructed areas. This possibility would imply that both the IFSAR and LiDAR have similar errors in obstructed areas as the correlation in this sample was relatively close.
3. This small localized area in the DTM was of unusually high quality compared the majority of the NEXTMap® Europe database. Every attempt is made through the Production process to create a consistent product. Obstructed areas however, are the most challenging area to maintain consistency. This is due to various ancillary DEM sources utilized through the NEXTMap® Europe database, as well as the DTM editor’s inability to accurately visualize the ground in densely obstructed areas.

CONCLUSION

This paper has reported on the best practices utilized to independently assess the quality and accuracy of the NEXTMap® Europe database at a regional scale. Intermap's NEXTMap® Europe program was not only a success from a data acquisition and processing perspective but as described through this data validation story, it offers the greatest accuracy of any homogeneous Pan-European digital elevation datasets on the market. The IV&V group was able to use a systematic approach to verify data quality throughout the NEXTMap® Europe program. This evaluation relied heavily upon acquiring highly accurate vertical check points as well as any available digital elevation datasets for comparison. IV&V was successful in collecting a VCP database with over 20,000 points with vertical accuracies better than 10cm. Once the VCP database was fully populated with all data extracted by IV&V throughout the NEXTMap® Europe program, a database tool with advanced filter capabilities enabled IV&V to quickly create summary statistics and dynamic charts to visualize the error distributions. Using these methods, IV&V was able to confidently validate that the 1m RMSE vertical accuracy specification was achieved. Additionally, IV&V was able to provide some empirical data to better understand the accuracies in areas outside those defined in the vertical accuracy specification. VCP assessments and comparisons to LiDAR helped to gain insight into performance of the data in obstructed and/or high slopes. The NEXTMap® Europe database, relative to the other digital elevation sources evaluated, offers a superior product in Western Europe.

REFERENCES

Product Handbook & Quick Start Guide, Standard Edition v4.3, Intermap Technologies Inc., Denver, CO, section 6.