2007 Comparison Testing of LTPP Profilers

Final Report

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1.0 INTRODUCTION

In the Long Term Pavement Performance (LTPP) Program, profile data at General Pavement Studies (GPS) and Specific Pavement Studies (SPS) sections are collected by four Regional Support Contractors. Each Regional Support Contractor (RSC) uses an International Cybernetics Corporation (ICC) MDR 4083 inertial profiler to collect profile data. These profilers are equipped with three laser sensors that collect data along the left and right wheelpaths, and along the center of the lane. Profile data are collected at 25 mm intervals along each of these paths.

After completion of data collection, the ProQual software is used to obtain profile data at 150 mm intervals along the left and right wheelpaths. This software applies a 300 mm moving average on the profile data collected at 25 mm intervals, and then saves the data at 150 mm intervals. After quality assurance checks, these data are uploaded to the LTPP database. The profile data collected at 25 mm intervals are stored as part of the LTPP Ancillary Information Management System (AIMS).

A comparison test among the four ICC profilers used by the LTPP RSC's was performed from May 14 to 17, 2007. The comparison test was performed at the Mn/ROAD facility in Albertville, Minnesota. This was the second comparison of the four LTPP ICC profilers after they went into operation in August 2002. The previous profiler comparison was held at the Mn/ROAD facility in July 2003. The LTPP K. J. Law T-6600 profiler that was purchased by the Federal Highway Administration in 1996 and currently operated by the North Central RSC also took part in the comparison. This profiler is equipped with three infrared sensors that collect data along the left and right wheelpaths, and along the center of the lane. This profiler also collects profile data at 25 mm intervals. Figure 1.1 shows the five profilers that took part in the comparison.

Figure 1.1. Five profilers that took part in the comparison.

The profiler comparison was carried out using the procedures described in the LTPP Manual for Profile Measurements and Processing, Version 4.1[1] (hereafter referred to as the Profile Manual). Six test sections were used for profile testing and one test section was used to evaluate the accuracy of the Distance Measuring Instrument (DMI).

The purpose of the profiler comparison was to: (1) evaluate the static accuracy of the height sensors in the profilers, (2) evaluate the results from the bounce test, (3) evaluate the accuracy of the DMI, (4) compare International Roughness Index (IRI) values obtained by the LTPP profilers with those from the Dipstick, (5) compare the IRI values among the profilers, and (6) compare the profiles obtained by the profilers.

After completion of the profiler comparison, each RSC summarized the results obtained for their profiler, and forwarded them to the FHWA and its Technical Support Services Contractor (TSSC). This report summarizes the activities that were conducted during the profiler comparison and presents the results of the inter-regional comparison among the LTPP profilers.

2.0 TEST PLAN AND TEST SECTIONS

2.1 Test Plan

The following tests were carried out during the profiler comparison:

1. Static Height Sensor Test: This test was performed to evaluate the precision and bias of the profiler height sensors in the static mode.

2. Bounce Test: This test was performed to see if the height sensors and the accelerometers in the profiler were functioning properly.

3. DMI Test: This test was performed to evaluate the precision and bias of the DMI.

4. Profiling of Test Sections: Six test sections were profiled for the comparison test. Dipstick measurements were obtained at five of these sections.

2.2 Test Sections

One test section was established for DMI testing, and six test sections were established for profile testing. The sections established for profile testing were two smooth asphalt concrete (AC) sections, a rough AC section, a smooth portland cement concrete (PCC) section, a rough PCC section, and a chip seal section. Only five test sections are required for profile testing according to the guidelines presented in the Profile Manual (a smooth AC section, a rough AC section, a smooth PCC section, a rough PCC section, and a chip seal section).

The DMI section was established on the low volume loop at Mn/ROAD. Three of the profile test sections were surfaced AC, while the other two were surfaced with portland cement concrete (PCC). The remaining profile test section had a chip seal. All profile test sections were 152.4 m long. Table 2.1 lists the test sections that were used as profile sections, and they are described immediately afterwards. Profile measurements were performed at all six sections, while Dipstick measurements were performed at five sections (sections 2 through 6).

Table 2.1. Profile test sections.

Test Section	Surface Type	Location	Roughness Level
1	AC	Mn/ROAD Low Volume Road	Smooth
2	AC	Mn/ROAD Mainline	Rough
3	PCC	Mn/ROAD Low Volume Road	Smooth
4	PCC	Mn/ROAD Low Volume Road	Medium Rough
5	Chip Seal	Access road to Mn/ROAD Office	Rough
6	AC	Mn/ROAD Low Volume Road	Smooth

Section 1 (Smooth AC): This section was located in the outside lane of cell 30. This section had no distress except for low severity rutting. A flexible microsurfacing was placed on this section in 2005.

Section 2 (Rough AC): The passing lane of cell 18 in the mainline was used as section 2. Transverse cracks were located throughout the test section. Most of these cracks had been repaired with a patching material. However, depressions were noted adjacent to the cracks. This section also had low to medium severity rutting.

Section 3 (Smooth PCC): This test section was located on the outside lane of the low volume road, with the start of the section being approximately 89.6 m east of the west end of cell 37. There were no distresses within the test section.

Section 4 (Medium Rough PCC): This test section was located on the inside lane of the low volume road, with the start of the section being approximately 87.8 m east of the west end of cell 38. There were no distresses within the test section.

Section 5 (Chip Seal): This section was located on the road outside the entrance gate to the Mn/ROAD facility. This section had low to medium severity transverse cracks throughout the section. Some of the material was worn away with areas of stone loss.

Section 6 (Smooth AC): This section was located on the inside lane of the low volume road, with the start of the section being 45.7 m west of the west end of cell 28. This section had no distress except for low severity rutting.

Photographs of the test sections are included in Appendix A. Paint marks were placed on the approach to the test section as well as within the test sections to aid the driver in aligning the profiler along the path to be tested and to maintain the path within the test section.

3.0 STATIC HEIGHT SENSOR TEST

3.1 Overview

The purpose of performing the static height sensor test is to evaluate the precision and bias of the height sensors of the profiler in the static mode. The specified requirements outlined in the Profile Manual are that the bias is within 0.25 mm and the precision be less than 0.125 mm.

3.2 Test Procedure

The static height sensor test was performed on each height sensor using the following procedure.

1. Measure distance from the ground to the glass face of the height sensor, and record the reading for each height sensor.

2. Drive the vehicle so that all four tires rest on support blocks. The height of each support block is 76 mm.

3. Place a calibration base plate on the ground under each laser sensor. Place a calibration surface plate on top of each base plate. Let computer take at least 500 readings.

4. Place a block on each base plate such that the 25 mm side of the block is vertical. Place a calibration surface plate on top of each block. Let computer take at least 500 readings and then record value shown for ‘Dif Ht’ on the computer screen for each sensor.

6. Repeat steps 3 and 4 four more times and record readings.

5. Repeat steps 3 through 6 for block heights of 50, 75, and 100 mm. For the 100 mm block height, place two blocks on top of each other such that the 50 mm sides are vertical to get a block height of 100 mm.

The sensors in the K. J. Law profiler were calibrated prior to performing the static height sensor test. The laser sensors in the ICC profilers cannot be calibrated by the user. The height sensor test on the K. J. Law profiler was performed for three block heights (i.e., 25, 50, and 75 mm). The height sensors in the K. J. Law profiler have a lower measuring range than the sensors in the ICC profilers, and hence the sensor test at 100 mm cannot be performed on the K. J. Law profiler.

3.3 Test Results

The data obtained from the static height sensor test are included in Appendix B. The bias and precision of each height sensor for block heights of 25, 50, 75, and 100 mm were computed from the data included in Appendix B for the four ICC profilers. For the K. J. Law profiler, results were computed for block heights of 25, 50, and 75 mm. For example, at the 25 mm block position, the bias of the height sensor is the difference between the average of the five readings obtained from the five repeat tests and the actual height of the block, while the precision of the height sensor is the standard deviation of the heights obtained at this position for the five tests.

Tables 3.1 and 3.2, respectively, present the bias and precision values for the three height sensors in each profiler corresponding to the 25, 50, 75, and 100 mm heights. (Results for the K. J. Law profiler show values for the three block positions of 25, 50, and 75 mm). These bias and precision values are shown graphically in figures 3.1 and 3.2.

The LTPP specified criteria are that the bias of the sensors be within 0.25-mm and that the precision of the sensors be less than 0.125-mm. The cases that did not satisfy each criterion are shown in bold in tables 3.1 and 3.2.

All sensors in the Southern, Western, and K. J. Law profiler met the bias criterion. The following sensors did not meet the specified bias criterion:

- North Atlantic Profiler: Center sensor at 50 mm (bias of 0.26 mm), 75 mm (bias of 0.43 mm), and 100 mm (bias of 0.50 mm) positions.

- North Central Profiler: Left sensor at 100 mm position (bias of 0.40 mm) and center sensor at 25 mm position (bias of 0.28 mm).

Table 3.1. Bias values from the static height sensor test.

Position	Sensor	Region				
		North Atlantic	North Central	Southern	Western	K. J. Law
25 mm	Left	0.11	0.12	0.11	0.09	0.16
	Center	0.16	**0.28**	-0.05	0.04	-0.11
	Right	0.10	0.15	0.11	0.14	-0.11
50 mm	Left	0.02	0.16	0.10	0.07	0.14
	Center	**0.26**	0.12	-0.06	0.01	-0.18
	Right	0.09	0.10	0.08	0.11	-0.01
75 mm	Left	0.09	0.06	0.21	0.17	-0.06
	Center	**0.43**	0.04	0.01	0.15	-0.10
	Right	0.16	0.15	0.24	0.10	0.15
100 mm	Left	0.04	**0.40**	0.25	0.17	N/A
	Center	**0.50**	0.09	0.09	0.08	N/A
	Right	0.20	0.07	0.17	-0.02	N/A

Table 3.2. Precision values from the static height sensor test.

Position	Sensor	Region				
		North Atlantic	North Central	Southern	Western	K. J. Law
25 mm	Left	0.060	0.054	0.053	0.079	0.076
	Center	0.043	0.113	0.034	0.069	0.018
	Right	0.091	**0.146**	0.041	0.107	**0.180**
50 mm	Left	0.050	0.116	0.050	0.061	**0.175**
	Center	0.039	0.069	**0.180**	0.092	0.069
	Right	0.044	0.091	0.084	0.115	**0.132**
75 mm	Left	0.076	**0.489**	0.036	0.059	0.124
	Center	0.044	**0.143**	0.060	0.116	0.050
	Right	0.049	0.086	0.066	**0.177**	0.083
100 mm	Left	0.062	0.067	0.068	0.024	N/A
	Center	0.055	**0.145**	**0.127**	0.109	N/A
	Right	0.121	0.102	0.068	**0.168**	N/A

All sensors in the North Atlantic profiler met the precision criterion. The following sensors did not meet the specified precision criterion:

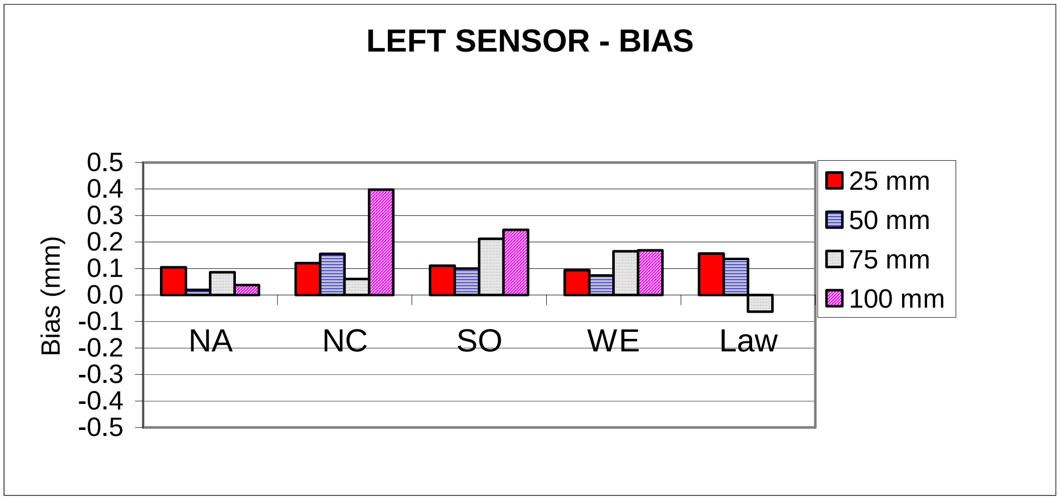
- North Central Profiler: Left sensor at 75 mm position (precision of 0.489); right sensor at 25 mm position (precision of 0.146 mm); and center sensor at 75 mm position (precision of 0.143 mm) and 100 mm position (precision of 0.145 mm). For all cases, one high value or one low value during the test caused the high precision value.

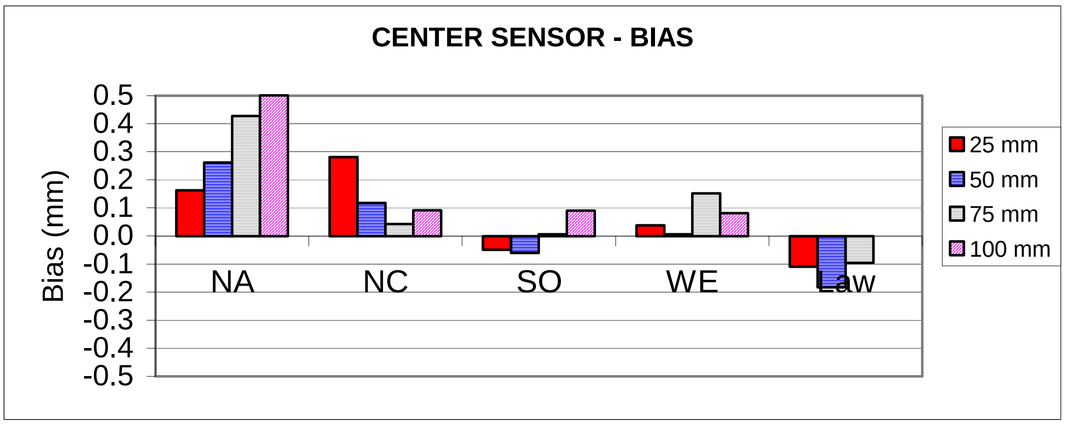
- Southern Profiler: Center sensor at 50 mm position (precision of 0.180 mm) and 100 mm position (precision of 0.127 mm). For both cases, one high value during the test caused the high precision value.

- Western Profiler: Right sensor at 75 mm position (precision of 0.177 mm) and 100 mm position (precision of 0.168 mm). For both cases, one low value during the test caused the high precision value.

- K. J. Law Profiler: Left sensor at 50 mm position (precision of 0.175 mm) and right sensor at 25 mm position (precision of 0.180 mm) and 50 mm position (precision of 0.132 mm). For all cases, one high value or one low value during the test caused the high precision value.

Each RSC was also requested to measure the distance from the ground to the sensor glass of the height sensor when the vehicle was off the blocks. These results are presented in table 3.3.





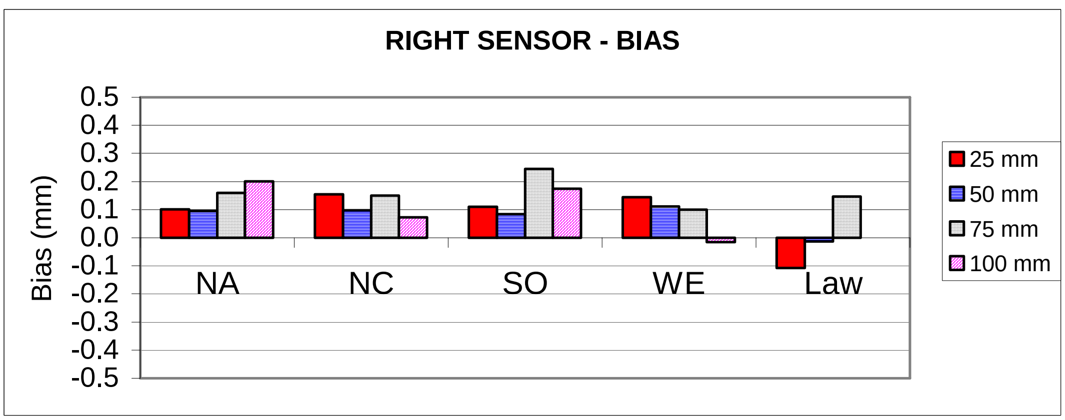


Figure 3.1. Bias values from static height sensor test (NA- North Atlantic, NC – North Central, SO – Southern, WE – Western).

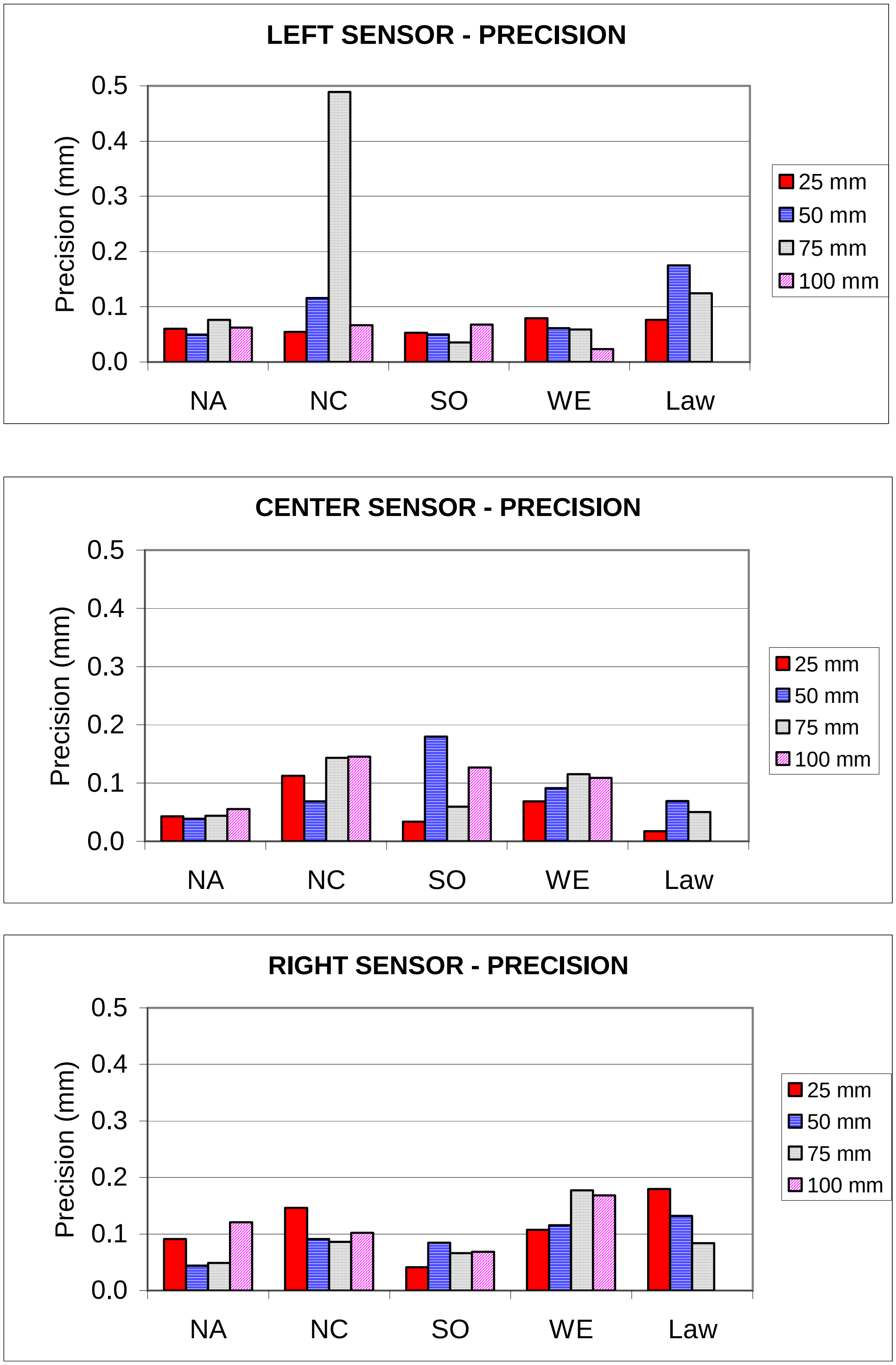


Figure 3.2. Precision values for height sensors from static height sensor test (NA- North Atlantic, NC – North Central, SO – Southern, WE – Western).

According to the Profile Manual, the distance from the ground to the glass face of the height sensor should be 325 $\pm$ 5 mm for the ICC profilers. All three sensors on all ICC profilers were within the specified limit.

Table 3.3. Distance from ground to sensor glass.

Profiler	Distance From Ground to Sensor Glass (mm)		
	Left Sensor	Center Sensor	Right Sensor
North Atlantic – ICC	320	320	325
North Central – ICC	324	325	326
Southern – ICC	325	323	325
Western – ICC	329	329	328
K. J. Law	278	281	281

4.0 BOUNCE TEST RESULTS

A bounce test was performed on all profilers after the static height sensor test was completed following the procedures outlined the Profile Manual. The bounce test consists of a static test and a dynamic bounce test. The static test is performed to evaluate the noise in the sensors. In this test, the bounce test procedures are followed, but no motion is induced on the vehicle. During the dynamic bounce test, a bouncing motion is induced on the profiler. The profile recorded during the static test and dynamic bounce test is used to compute an IRI value for each test. The Southern RSC did not record the bounce test values for the tests performed at Mn/ROAD. However, they performed a bounce test later on August 14th, 2007 and provided the values to the TSSC. Table 4.1 presents the IRI values from the static and dynamic bounce test, as well as the difference in IRI value between the dynamic and static test for all profilers.

Table 4.1. IRI values from bounce test.

Profiler	IRI Value (m/km)								
	Static Test			Dynamic Test			Dynamic - Static		
	Left	Center	Right	Left	Center	Right	Left	Center	Right
North Atlantic	0.02	0.05	0.05	0.06	0.05	0.06	0.04	0.00	0.01
North Central	0.02	0.03	0.05	0.05	0.04	0.05	0.03	0.01	0.00
Southern	0.07	0.05	0.05	0.09	0.07	0.09	0.02	0.02	0.04
Western	0.05	0.05	0.05	0.10	0.12	0.13	0.05	0.07	0.08
K. J. Law	0.07	N/A	0.06	0.12	N/A	0.15	0.05	N/A	0.09
N/A: The center sensor IRI is not displayed in the K. J. Law profiler.									

According to the criteria presented in the Profile Manual, the static test IRI value should be less than 0.08 m/km, while the difference in IRI value between the dynamic bounce and static test should be less than 0.10 m/km. All sensors in all profilers satisfied the required criteria. It was noted that in the North Central and the North Atlantic profilers, the dynamic bounce test IRI values were very close to the static values, and for some cases the dynamic value was the same as the static value. It is not clear if the low dynamic bounce test values were caused because the operators were not inducing a displacement that was lower than the specified amount during the bounce test, or if it is a characteristic of the profiler. The Profile Manual indicates that when performing the bounce test the displacement of the rear bumper must be 25 mm (i.e., distance of bumper from highest point to lowest point during bouncing must be 25 mm).

5.0 DMI TEST RESULTS

5.1 Overview

The purpose of the DMI test is to evaluate the bias and precision of the DMI in the profiler. The specified criteria are that the DMI bias is within 0.05% of the distance and that DMI precision is less than 0.025% of the distance (see Section 6 of the Profile Manual). A 300 m long section was laid out as the DMI section. For a 300 m long test section, the bias and precision values are 0.15 and 0.075 m, respectively.

5.2 Test Procedure

All profilers calibrated their DMI at the DMI section following the procedures outlined in the Profile Manual prior to obtaining profile measurements. Immediately after the DMI was calibrated, each profiler performed six runs on the DMI section and recorded the distance measured between the start and the end of the section. After profiling all test sections, each profiler again performed six repeat runs at the DMI section and recorded the distance between the start and end of the section. The purpose of obtaining the second set of measurements was to evaluate the stability of the DMI over time.

5.3 Test Results

Table 5.1 presents the results obtained from the DMI tests that were conducted immediately after calibrating the DMI. Table 5.1 shows the tire pressure before and after testing, the air temperature noted from the temperature probe in the profiler before and after testing, the DMI reading for each run, average of DMI readings, the standard deviation of DMI readings, and indicates whether or not the profiler met the bias and the precision criterion. All five profilers met the bias as well as the precision criterion.

Table 5.2 presents the results of the verification testing of DMI that was performed after the profilers completed data collection at the six profile test sections. All profilers except for the North Atlantic profiler and the K. J. Law profiler passed both the bias and precision criterion. The North Atlantic profiler failed the bias criterion, but passed the precision criterion. The K. J. Law profiler failed both the bias and precision criterion.

Table 5.1. Results of DMI test performed immediately after calibration.

Description	Region				
	North Atlantic	North Central	Southern	Western	K. J. Law
DMI Reading - Run 1 (m)	300.115	300.138	299.906	299.985	299.980
DMI Reading - Run 2 (m)	299.998	300.119	299.926	300.063	299.970
DMI Reading - Run 3 (m)	300.115	300.003	300.044	299.966	299.970
DMI Reading - Run 4 (m)	300.017	300.100	299.867	300.005	299.890
DMI Reading - Run 5 (m)	300.076	300.119	299.847	300.082	299.920
DMI Reading - Run 6 (m)	300.017	300.041	299.906	300.005	299.890
Average (m)	**300.06**	**300.09**	**299.92**	**300.02**	**299.94**
Length of Section (m)	**300.00**	**300.00**	**300.00**	**300.00**	**300.00**
Bias (m)	**0.06**	**0.09**	**-0.08**	**0.02**	**-0.06**
Standard Deviation (m)	**0.052**	**0.053**	**0.069**	**0.045**	**0.042**
Bias Criterion Satisfied?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Precision Criterion Satisfied?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Left rear tire pressure before test (psi)	80	80	82	82	55
Left rear tire pressure after test (psi)	80	80	82	82	55
Right rear tire pressure before test (psi)	80	80	82	82	55
Right rear tire pressure after test (psi)	80	80	82	82	55
Before measurements - Air Temp. (°C)	11.3	7.5	14.2	11.4	8.5
After measurements - Air Temp. (°C)	11.1	8.3	15.4	11.8	9.3

Table 5.2. Results of DMI tests performed after profiling the test sections.

Description	Region				
	North Atlantic	North Central	Southern	Western	K. J. Law
DMI Reading - Run 1 (m)	299.809	299.956	300.162	299.868	299.260
DMI Reading - Run 2 (m)	299.653	299.917	300.103	299.849	299.350
DMI Reading - Run 3 (m)	299.653	299.936	300.103	299.868	299.460
DMI Reading - Run 4 (m)	299.711	299.878	300.182	299.868	299.250
DMI Reading - Run 5 (m)	299.653	299.898	300.143	299.888	299.350
DMI Reading - Run 6 (m)	299.633	299.878	300.162	299.849	299.320
Average	**299.685**	**299.911**	**300.143**	**299.865**	**299.332**
Length of Section (m)	**300.00**	**300.00**	**300.00**	**300.00**	**300.00**
Bias (m)	**-0.31**	**-0.09**	**0.14**	**-0.14**	**-0.67**
Standard Deviation (m)	**0.066**	**0.032**	**0.033**	**0.015**	**0.076**
Bias Criterion Satisfied?	**No**	**Yes**	**Yes**	**Yes**	**No**
Precision Criterion Satisfied?	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Left rear tire pressure before test (psi)	80	80	82	85	55
Left rear tire pressure after test (psi)	80	80	82	85	55
Right rear tire pressure before test (psi)	80	80	83	85	55
Right rear tire pressure after test (psi)	80	80	83	85	55
Before measurements - Air Temp. (°C)	14.2	13.5	17.6	15.3	11.5
After measurements – Air Temp. (°C)	14.7	13.9	17.1	15.7	11.9

6.0 COMPARISON OF IRI VALUES

6.1 Overview

This section describes the following: (1) data collection activities that were carried out at the test sections, (2) IRI values obtained from Dipstick measurements, (3) evaluation of repeatability of IRI values obtained by the profilers, (4) comparison of IRI values obtained by the profilers, and (5) comparison of IRI values obtained by the profilers with IRI obtained from Dipstick measurements. In the tables and graphs presented in this section, the following notations are used for the profilers: NA – North Atlantic, NC – North Central, SO – Southern, WE –Western, and Law – K. J. Law.

6.2 Dipstick Data Collection

Dipstick data were collected at five test sections (sections 2 through 6). The original plan was to collect Dipstick data on the afternoon of May 14th. However, due to the prevailing weather conditions, it was decided to postpone the data collection to the 15th. Dipstick measurements were obtained along both wheelpaths at five of the test sections on May 15th using the procedures described in the Profile Manual. Ideally, the measurements on the PCC test sections should be obtained after noon to minimize the effect of slab curling on the obtained measurements. However, due to time constraints, the measurements had to be performed around 10 AM. Table 6.1 presents the following information for each test section—regional contractor who performed Dipstick measurements, Dipstick model used for testing, and the start and end time of testing.

Table 6.1. Dipstick testing at test sections.

Section Number	Region Performing Measurements	Dipstick Used For Measurements	Start Time	End Time
2	Southern	Southern, Model 2000, Serial No. 32107	10:00	11:32
3	Northern	North Central, Model 2200, Serial No. 33006	10:00	11:25
4	Northern	North Central, Model 2000, Serial No. 22137	10:00	11:30
5	Northern	North Central, Model 2000, Serial No. 22137	14:45	16:00
6	Western	Western, Model 2000, Serial No 32108	10:00	11:15

Table 6.2 shows the Dipstick closure error at each test section, as well as the surface type and the roughness level. According to the Profile Manual, the closure error should be within 76 mm. The closure error was not within the specified value at Section 6, which is a smooth AC section. Usually the closure error requirement is easily met at a smooth AC sections. Therefore, the Dipstick measurements were repeated at this section. The closure error obtained for the repeat measurements was also outside the specified limit. The Mn/ROAD personnel at the site office indicated the surface on this section was a flexible microsurfacing. This was not known when the section was laid out. It appears that the flexible micosurfacing was displacing under the footpads

of the Dipstick when the Dipstick was rotated during measurements, which resulted in the closure error being greater than the specified value.

Table 6.2. Dipstick closure error at the test sections.

Section Number	Surface Type	Roughness Level	Closure Error (mm)
2	AC	Rough	96.5
3	PCC	Smooth	17.3
4	PCC	Medium Rough	44.7
5	Chip Seal	Rough	72.8
6	AC	Smooth	100.3

6.3 Profile Data Collection

The five profilers performed profile measurements at the six test sections. The test sections were profiled according to the procedures outlined in the Profile Manual. Profile measurements on PCC sections were performed after about 10 AM (which is the time when Dipstick measurements were started). Each RSC processed the data collected by their profiler using the current version of the ProQual software. Each region selected five profile runs for each test section for the IRI comparison, and submitted the IRI values of the selected runs to the FHWA and the TSSC. Table 6.3 shows the profile runs that were selected by the regions for the IRI comparison.

Table 6.3. Profile runs selected for analysis.

Region	Profile Runs Selected for Analysis					
	Test Section					
	1	2	3	4	5	6
North Atlantic	1, 2, 3, 5, 7	1, 2, 5, 7, 8	1, 2, 5, 7, 9	1, 3, 4, 5, 9	2, 3, 6, 8, 9	3, 4, 5, 6, 9
North Central	2, 3, 4, 8, 9	1, 5, 6, 8, 9	1, 5, 6, 7, 8	4, 5, 6, 7, 8	1, 4, 6, 7, 8	2, 4, 6, 7, 8
Southern	2, 3, 4, 8, 9	2, 4, 7, 8, 9	2, 4, 5, 7, 8	3, 4, 5, 7, 9	1, 2, 6, 8, 9	1, 5, 6, 7, 12
Western	1, 3, 6, 7, 8	2, 3, 4, 6, 7	1, 3, 6, 7, 8	1, 2, 6, 7, 9	2, 4, 5,7, 9	1, 2, 4, 5, 7
K. J. Law	1, 3, 4, 5, 6	1, 2, 4, 5, 6	2, 3, 4, 5, 6	2, 3, 5, 8, 9	2, 3, 4, 6, 7	4, 5, 6, 7, 8

6.4 IRI from Dipstick Measurements

The RSC that collected the Dipstick data entered the data into ProQual, computed IRI values, and then submitted the values to the TSSC. The TSSC used the raw Dipstick data recorded in the field to create the elevation profile for each wheelpath, and then used ProVAL software to compute the IRI values for all sections. The IRI values computed from ProVAL and ProQual agreed only for one test section. When ProQual computes IRI from Dipstick data, it first applies a filter that has an upper wavelength cut-off of 100 m, and then uses the filtered data to compute the IRI. There are two filtering options in ProQual to apply the 100 m filter, Surface Dynamics filter and ICC filter. The IRI values obtained from ProQual for the cases where the Dipstick data were filtered with the ICC filter did not agree with the ProVAL IRI values. For the case where the data were filtered in ProQual with the Surface Dynamics filter, the IRI from ProVAL and ProQual showed excellent agreement. (The Profile Manual indicates that the Surface Dynamics filter should be used to process longitudinal Dipstick data.) The Northern region used ProQual to re-process Dipstick data collected by all regions, with the Surface Dynamics filter being applied on the data, and computed the IRI values which are shown in table 6.4. The IRI values shown in table 6.4 were used for analysis.

Table 6.4. IRI values from Dipstick Measurements.

Section Number	**Dipstick IRI (m/km)**	
	Left Wheelpath	**Right Wheelpath**
2	2.90	2.81
3	0.93	0.99
4	1.20	1.28
5	3.26	3.24
6	1.18	1.42

6.5 Analysis of IRI Values

The IRI values computed from profile measurements were used to perform the following analyses.

1. Evaluate repeatability of IRI values obtained by the profilers.
2. Compare Dipstick IRI with profiler IRI.
3. Compare IRI values obtained by the profilers.

6.5.1 Repeatability of IRI Values

The left and right wheelpath IRI values obtained by the profilers for the profile runs selected at the test sections (see table 6.3) are presented in Appendix C. The five IRI values obtained at each test section were used to compute the standard deviation of IRI for the left and right wheelpaths. The computed standard deviations are shown in table 6.5, and are also shown graphically in figures 6.1 and 6.2, respectively. The precision criterion for IRI indicated in the Profile Manual is that the standard deviation of IRI for each wheelpath computed from five runs at a section should be less than 0.04 m/km. Cases that did not meet this criterion are shown in bold in table 6.5.

The following observations were noted for the standard deviation values.

- All profilers met the precision criterion for both wheelpaths of section 1 and 4.

Table 6.5. Standard deviation of IRI.

Wheelpath	Profiler	Standard Deviation of IRI (m/km) Test Section					
		1	2	3	4	5	6
Left	NA - ICC	0.015	0.027	0.018	0.007	0.015	0.034
	NC – ICC	0.017	**0.116**	0.013	0.009	**0.042**	**0.048**
	SO – ICC	0.005	**0.165**	0.016	0.015	**0.077**	0.015
	WE - ICC	0.010	**0.104**	0.018	0.037	0.014	0.009
	K. J. Law	0.007	**0.099**	0.013	0.011	0.029	**0.046**
Right	NA - ICC	0.009	0.028	0.012	0.021	0.013	**0.083**
	NC – ICC	0.011	**0.072**	**0.058**	0.039	**0.055**	0.026
	SO – ICC	0.019	0.015	0.027	0.021	**0.044**	0.019
	WE - ICC	0.011	**0.044**	**0.068**	0.022	**0.044**	0.024
	K. J. Law	0.020	**0.081**	0.035	0.032	**0.040**	0.063
Note: NA - North Atlantic, NC - North Central, SO - Southern, WE – Western							

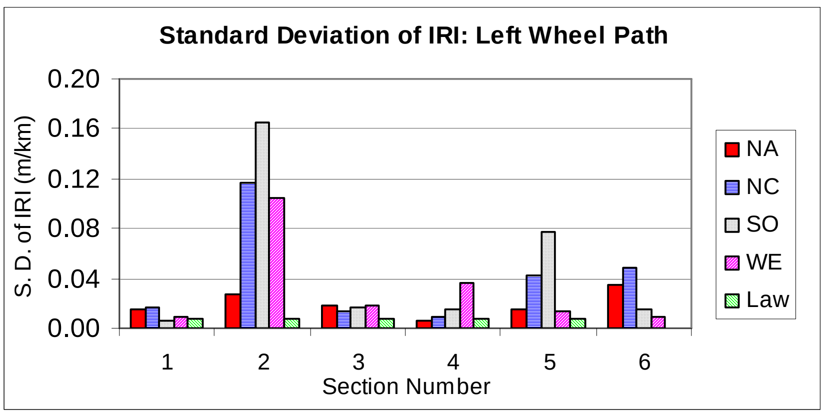


Figure 6.1. Standard deviation of IRI – left wheelpath.

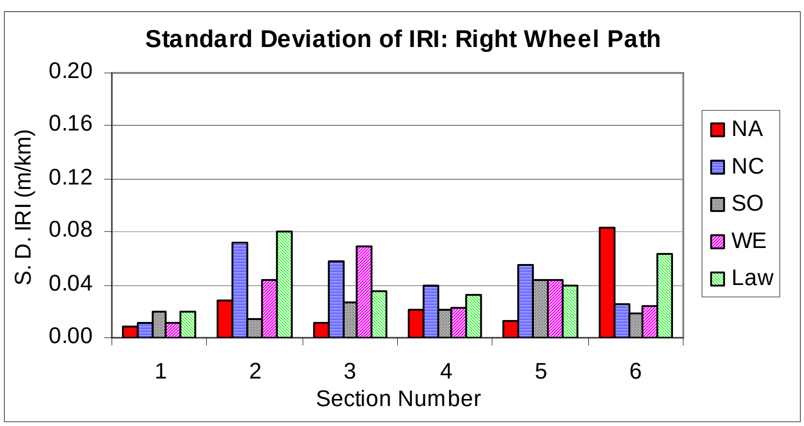


Figure 6.2 Standard deviation of IRI – right wheelpath.

- At section 2, the only cases that satisfied the precision criterion were the North Atlantic profiler (left and right wheelpaths) and the Southern profiler (right wheelpath). This section is rough and has many transverse cracks. The rut depths observed at this section during a survey performed in April 2006 were 0.29 and 0.19 mm for the left and the right wheelpaths respectively. Evaluation of the profile data indicated that the variability in the paths followed by the profilers was the likely cause for the standard deviation to exceed the specified value.

- At section 3, the only cases that failed the precision criterion were the North Central profiler (right wheelpath) and western profiler (right wheelpath). Evaluation of the profile data indicated that the variability in the paths followed by the profilers was the likely cause for the standard deviation to exceed the specified value.

- At section 5, the North Central and the Southern profilers failed the precision criterion along the left wheelpath, while all profilers except for the North Atlantic profiler failed the precision criterion along the right wheelpath. This section is rough and has many transverse cracks with some areas exhibiting raveling and stone loss. Evaluation of the profile data indicated that the variability in the paths followed by the profilers was the likely cause for the standard deviation to exceed the specified value.

- At section 6, the only cases that failed the precision criterion were the North Central profiler (left wheelpath), K. J. Law profiler (left wheelpath), and the North Atlantic profiler (right wheelpath). Evaluation of the profile data indicated that the variability in the paths followed by the profilers was the likely cause for the standard deviation to exceed the specified value.

6.5.2 Comparison of IRI Values among the Profilers

The left and right wheelpath IRI values of the five runs that were used for analysis at the test sections for all profilers are included in Appendix C. Table 6.6 shows the range of the IRI values (average of the five submitted runs) obtained at each test section along the left and the right wheelpaths by the four ICC profilers. As seen in this table, at sections 1, 3, 4, and 6 the difference between the maximum and minimum IRI along a wheelpath was less than 0.1 m/km. The difference was between 0.12 and 0.18 m/km for the right wheelpath at section 2, and left and right wheelpaths of section 5. The highest difference was observed along the left wheelpath of section 2, where the difference between the maximum and minimum IRI was 0.66 m/km. Section 2 and 5 have transverse cracking throughout the section, while section 2 also has rutting. These distresses can have a significant impact on IRI due to lateral variability of the profiled path. It appears that the lateral variability in the paths followed by the profilers caused the high range of IRI value seen at sections 2 and 5.

Table 6.7 shows the range of the IRI values obtained at each section along the left and the right wheelpaths when all five profilers were considered. The ranges shown in this table are identical to the values shown in table 6.6 for the majority of the cases, and vary from the values shown in table 6.6 by a small amount for a few of the cases. These observations indicate that the IRI values obtained by the K. J. Law profiler are comparable to those obtained by the four ICC profilers.

Table 6.6. Range of IRI values for the four ICC profilers.

Section No	Range for IRI Values (m/km)	
	Wheelpath	
	Left	Right
1	1.88 – 1.89	1.63 – 1.68
2	2.51 – 3.17	2.55 – 2.67
3	0.86 – 0.88	1.02 – 1.10
4	1.37 – 1.42	1.33 – 1.39
5	3.19 – 3.33	3.55 – 3.73
6	1.08 – 1.15	1.37 – 1.45

Table 6.7. Range of IRI values for all five profilers.

Section No	Range for IRI Values (m/km)	
	Wheelpath	
	Left	Right
1	1.88 – 1.92	1.63 – 1.68
2	2.51 – 3.17	2.51 – 2.67
3	0.86 – 0.90	1.02 – 1.10
4	1.37 – 1.42	1.33 – 1.42
5	3.19 – 3.33	3.55 – 3.73
6	1.08 – 1.17	1.37 – 1.45

6.5.3 Comparison of IRI Values from Profilers and Dipstick

The average IRI value along each wheelpath for each profiler at each test section computed from the IRI values of the five runs selected for analysis is shown in table 6.8. This table also includes the IRI computed from Dipstick data. The IRI values are shown graphically for the left and right wheelpaths in figures 6.3 and 6.4, respectively.

The difference between the average profiler IRI value and the IRI value obtained from the Dipstick (i.e., average profiler IRI – Dipstick IRI) at each test section for each wheelpath are shown in table 6.9. These values are presented graphically in figures 6.5 and 6.6 for the left and the right wheelpath, respectively. The Profiler Manual specifies that the difference between the profiler IRI and the Dipstick IRI should be within ± 0.16 m/km for each wheelpath. Cases that failed the criterion are shown in bold in Table 6.9.

Table 6.8. Average IRI values.

Wheelpath	**Profiler**	**Average IRI (m/km)**					
		Test Section					
		1	**2**	**3**	**4**	**5**	**6**
Left	Dipstick	N/A	2.90	0.93	1.20	3.26	1.18
	NA – ICC	1.88	2.58	0.88	1.42	3.21	1.12
	NC – ICC	1.89	2.51	0.88	1.37	3.19	1.08
	SO – ICC	1.89	2.91	0.87	1.41	3.33	1.15
	WE – ICC	1.88	3.17	0.86	1.38	3.27	1.14
	K. J. Law	1.92	2.52	0.90	1.42	3.27	1.17
Right	Dipstick	N/A	2.81	0.99	1.28	3.24	1.42
	NA – ICC	1.68	2.66	1.02	1.39	3.72	1.42
	NC – ICC	1.63	2.55	1.10	1.33	3.73	1.44
	SO – ICC	1.67	2.67	1.03	1.37	3.71	1.45
	WE – ICC	1.63	2.58	1.07	1.34	3.55	1.37
	K. J. Law	1.66	2.51	1.04	1.42	3.65	1.39

Note: Dipstick IRI obtained from a single run, NA – North Atlantic, NC – North Central, SO – Southern, WE – Western

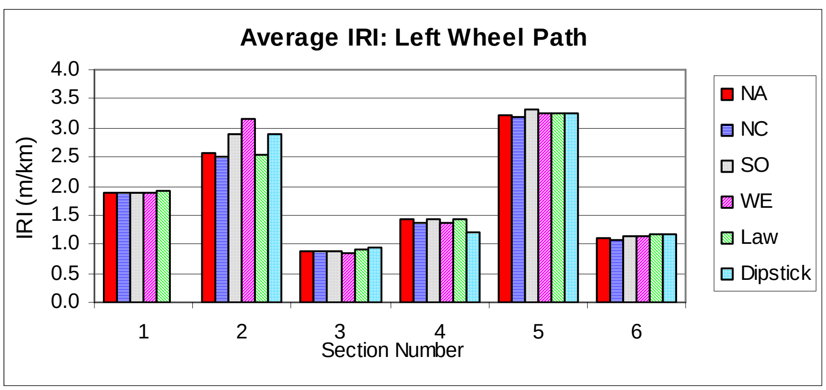


Figure 6.3. Left wheelpath IRI values.

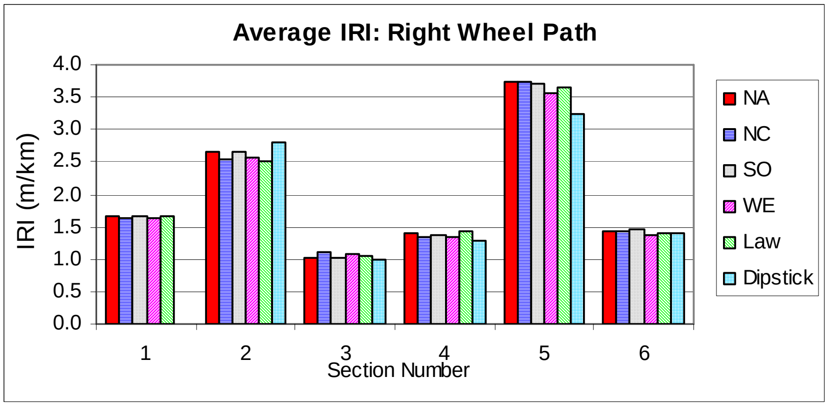


Figure 6.4. Right wheelpath IRI values.

Table 6.9. Difference between profiler and Dipstick IRI.

Wheelpath	Profiler	Avg. Profiler IRI - Dipstick IRI (m/km)				
		Test Section				
		2	**3**	**4**	**5**	**6**
Left	NA – ICC	**-0.32**	-0.05	**0.22**	-0.05	-0.06
	NC – ICC	**-0.39**	-0.05	**0.17**	-0.07	-0.10
	SO – ICC	0.01	-0.06	**0.21**	0.07	-0.03
	WE – ICC	**0.27**	-0.07	**0.18**	0.01	-0.04
	K. J. Law	**-0.38**	-0.03	**0.22**	0.01	-0.01
Right	NA – ICC	-0.15	0.03	0.11	**0.48**	0.00
	NC – ICC	**-0.26**	0.11	0.05	**0.49**	0.02
	SO – ICC	-0.14	0.04	0.09	**0.47**	0.03
	WE – ICC	**-0.23**	0.08	0.06	**0.31**	-0.05
	K. J. Law	**-0.30**	0.05	0.14	**0.41**	-0.03

NA – North Atlantic, NC – North Central, SO – Southern, WE – Western

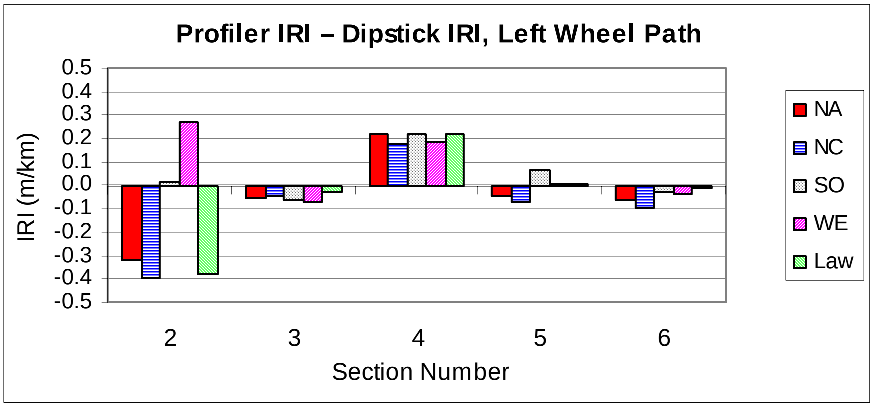


Figure 6.5. Difference between profiler and Dipstick IRI, left wheelpath.

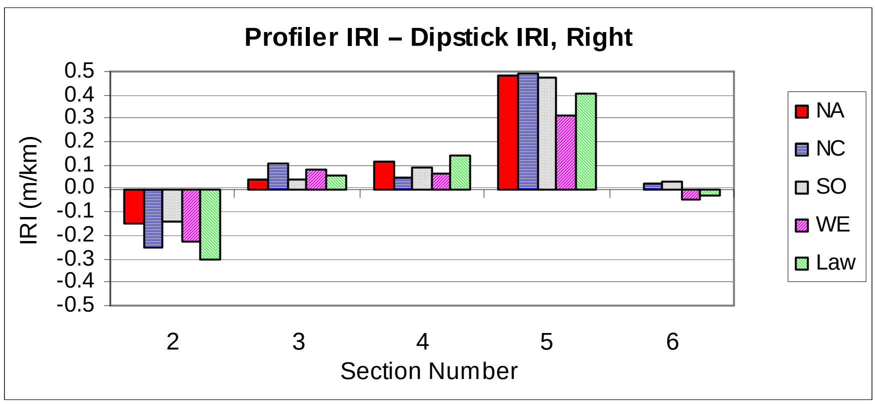


Figure 6.6. Difference between profiler and Dipstick IRI, right wheelpath.

The following observations were noted for the difference between profiler and Dipstick IRI:

- Section 2: The only cases that satisfied the specified criterion were the left and right wheelpath of the Southern profiler, and the right wheelpath of the North Atlantic profiler. This section is a rough section with transverse cracks present throughout the section. A slight dip was noted at each crack. It appears that the profilers failed to meet the specified criterion because of lateral variations in the paths followed by the profilers.

- Section 3: The specified criterion was satisfied by all profilers for both wheelpaths.

- Section 4: All profilers satisfied the specified criterion along the right wheelpath, but failed it along the left wheelpath. Along the left wheelpath the IRI obtained by the profilers were greater than the IRI from the Dipstick for all cases. The cause for the difference in IRI is not clear.

- Section 5: All profilers satisfied the specified criterion along the left wheelpath but failed it along the right wheelpath. The IRI obtained by all profilers were higher than that obtained by the Dipstick along the right wheelpath. This section had transverse cracks throughout the section. The crack openings were greater along the pavement edge when compared to the area adjacent to the centerline of the pavement. Lateral variability in the paths followed by the profilers and profilers picking up features that are not measured by the Dipstick (because of bridging effect of the footpad and higher sampling interval for Dipstick) are possible reasons that caused the profiler IRI values to be higher than the Dipstick IRI.

- Section 6: The specified criterion was satisfied by all profilers for both wheelpaths. The Dipstick closure error at this section was greater than the specified amount. However, it does not seem to have affected the IRI values.

7.0 EVALUATION OF PROFILE PLOTS

7.1 Overview

Two types of analyses were performed. In the first analysis, the overlaid profile plots that showed the replicate profile runs collected by a profiler at each section were reviewed to evaluate the repeatability of the profilers. In the second analysis, a representative profile was selected from each profiler at each test section, and the profiles for the left and right wheelpaths were compared among the profilers. Power spectral density plots generated from the profile data were also reviewed.

7.2 Evaluation of Replicate Profile Runs Collected by the Profilers

A visual evaluation was performed on the replicate profile runs collected by each profiler at each test section to evaluate the repeatability of profile data. This evaluation was performed separately for the left, right, and center sensor data. Appendix D contains the overlaid profile plots for all profilers along the left and right wheelpaths at all test sections. Separate plots are presented for the left and right wheelpath data. The five profile runs shown on each plot are the profile runs that were used in the IRI analysis. A review of these plots did not show any problems for all five profilers, with good repeatability being observed for all.

Appendix E includes the overlaid profile plots for the center sensor. Separate plots are presented for each profiler and each test section. A review of these plots did not show any problems with the ICC profiler data, with good repeatability being observed for all profilers. The K. J. Law profiler showed good repeatability of profile data except for the data collected at section 1. Significant variability was seen among the repeat runs obtained at this section.

7.3 Comparison of Profiles Among the Profilers

A representative profile for each ICC profiler was selected at each test section by evaluating the five replicate profile runs. Thereafter, the selected profiles at each test section were overlaid separately for the left and the right wheelpaths to compare the profile plots. The profiles from the K. J. Law profiler were not used in this evaluation as a previous study indicated there were differences between profiles collected by the ICC and K. J. Law profilers.(2) The differences in profiles collected by these two profilers occur due to differences in the long wavelength cut-off filter. Appendix F contains the overlaid profile plots from the four ICC profilers as well as offset profile plots. The Roadruf software was used to generate these plots, as this software has a feature to create offset profile plots. The overlaid profile plots indicate reasonable agreement in profiles among the four ICC profilers, with no profiler showing a profile shape that is not in agreement with the other profilers. The offset plots show that all four profilers appear to be capturing similar profile features present on the pavement.

7.4 Power Spectral Density Plots

Power spectral density (PSD) plots were created from the profile data, and these plots are included in appendix G. The plots were examined to detect potential problems in the collected data. No problems were detected in the data, and all four profilers appear to be collecting similar data. The variability among the profilers that were seen for very short wavelengths is attributed to variability in the paths followed by the profilers.

8.0 PHOTOCELL OFFSET VALUES

The K. J. Law T-6600 profilers that were used in the LTPP program to collect profile data from 1996 to August 2002 obtained the first data point at a distance of 114 mm from the leave edge of the section start stripe. When the data collected by the ICC profilers are processed by ProQual, in order to be consistent with the data collection procedure used by the K. J. Law T-6600 profilers, the first data point in the test section is assigned a location that is 114 mm from the leave edge of the section start stripe. ProQual needs a parameter called the photocell offset in order process the profile data such that the first data point is at the previously indicated location.

A test was performed during the profiler comparison to determine the photocell offset values for the vertical and horizontal photocells in the ICC profilers. This test was performed according to the procedures specified in Appendix E of the Profile Manual. The collected data were analyzed by each RSC to compute the horizontal and vertical photocell offset values. The RSC's submitted the computed values to the FHWA and TSSC.

Table 7.1 shows the photocell offset values that were submitted by the RSC's. This table also shows the previous photocell offset values used by the RSC and the test date corresponding to those values.

Table 7.1. Photocell offset values.

Profiler	Photocell Offset (mm)				Date of Test For Previous Value
	Determined at Mn/ROAD		Previous Value		
	Vertical	Horizontal	Vertical	Horizontal	
North Atlantic	100	275	125	250	July 2004
North Central	75	250	125	200	July 2004
Southern	75	250	75	250	July 2004
Western	75	250	75	250	April 2007

9.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, the results from the profiler comparison indicated the four ICC profilers that are currently collecting data for the LTPP program are performing satisfactorily. The K. J. Law profiler is also capable of collecting satisfactory data. A brief summary of the results obtained for each of the analysis performed on the data are presented separately.

Static Height Sensor Test

The specified criteria for this test are that the bias should be within ± 0.25 mm and the precision should be less than 0.125 mm.

All sensors in all profilers passed the bias criterion except for: (1) the center sensor on the North Atlantic profiler that had bias values of 0.26, 0.43, and 0.50 mm at the 50, 75, and 100 mm positions respectively, (2) the left sensor on the North Central profiler that had a bias value of 0.40 mm at the 100 mm position, and (3) the center sensor on the North Central profiler that had a bias value of 0.28 mm at the 25 mm position. The bias values for the center sensor in the North Atlantic profiler indicate a potential problem with that sensor. However, as the center sensor data are not uploaded to the LTPP database, the failure of the bias criterion for this sensor has no impact on the data that are uploaded to the database. In the North Central profiler, the left sensor at the 100 mm position and the center sensor at the 25 mm position failed the bias criterion. During data collection, at most sections (except for very rough sections), the vertical movement of the height sensor due to vehicle movement will be within ± 25 mm. The 25 and 100 mm positions used for the block test (with the profiler up on the blocks) check areas of the measuring range that will not be used for most sections, except for very rough sections. Therefore, the failure of the bias criterion at the two positions described previously should not have a significant impact on the quality of the data.

The North Atlantic profiler passed the precision criterion for all cases. However, at least one sensor in the other profilers failed the precision criterion at one or more positions. The precision criterion was not met for the following cases: (1) North Central profiler: left sensor at the 75 mm position, the right sensor at the 25 mm position, and the center sensor at the 75 and 100 mm positions where the precision values were 0.489, 0.146, 0.143, and 0.145 mm respectively, (2) Southern profiler: the center sensor at the 50 and 100 mm positions where the precision values were 0.180 and 0.127 mm respectively, (3) Western profiler: the right sensor at the 75 and 100 mm positions where the precision values were 0.177 and 0.168 mm, respectively, and (4) K. J. Law profiler: the left sensor at the 50 mm position, and the right sensor at the 25 and 50 mm positions where the precision values were 0.175, 0.180, and 0.132 mm respectively. In all these cases, the failure of the precision criterion was caused by one data point being either lower or higher than the rest of the readings. The failure of the precision criterion may have been caused by the operator coming in contact with the vehicle (which induces movement in the vehicle) when the readings were taken or due to warping of the blocks, which can result in variable readings if the block is not placed at the same position when obtaining replicate measurements. A review of the data for all of the cases that failed the precision criterion did not show any erratic behavior in the sensor. Therefore, based on the review of the readings and the magnitude of the precision values there is no evidence to suggest there is a problem with the repeatability of readings obtained by a sensor in the static mode.

Bounce Test Results

All three sensors of the four ICC profilers met the static and dynamic bounce test requirements outlined in the Profile Manual. The left and the right sensors of the K. J. Law profiler also met the bounce test criteria. It was noted that in the North Central and the North Atlantic profilers, the dynamic bounce test IRI values were very close to the static values, and for some cases the dynamic value was the same as the static value. It is not clear if the low dynamic bounce test values were caused because the operators were not inducing a displacement that was lower than the specified amount during the bounce test, or if it is a characteristic of the profiler. The Profile Manual indicates when performing the bounce test the displacement of the rear bumper must be 25 mm (i.e., distance of bumper from highest point to lowest point during bouncing must be 25 mm). The operators of these profilers must ensure the specified displacement is induced when performing the bounce test.

DMI Test Results

Results from the DMI test that was performed immediately after calibration of the DMI indicated the DMI in all five profilers met the specified bias criterion (bias within ±0.15 m) and the precision criterion (precision to be less than 0.075 m). All profilers except for the North Atlantic profiler and the K. J. Law profiler passed both the bias and precision criterion for the DMI verification test that was performed after data collection was completed at the profile test sections. In the verification test, the North Atlantic profiler failed the bias criterion, but passed the precision criterion, while the K. J. Law profiler failed both the bias and precision criterion. The results from the monthly DMI calibration for the North Atlantic and K. J. Law profiler should be compared with previous values to evaluate the stability of the DMI. If a potential problem is detected, the DMI should be calibrated at a more frequent interval or the DMI should be examined to identify and correct the problem.

Precision of IRI from Profilers

Overall, all profilers appear to be obtaining repeatable IRI values. The IRI values did not indicate that a particular profiler was behaving differently than the other profilers. The Profile Manual indicates the standard deviation of IRI obtained for each wheelpath from five repeat runs (precision criterion) at a section must be less than 0.04 m/km. However, sometimes this criterion cannot be met if distresses are present along the wheelpath, because even a slight shift in the profiled path can have a significant impact on the IRI.

All profilers met the precision criterion for both wheelpaths of section 1 and 4. At section 3, the only cases that failed the criterion were the North Central profiler (right wheelpath) and the Western profiler (right wheelpath). At section 6, the only cases that failed the precision criterion were the North Central profiler (left wheelpath), K. J. Law profiler (left wheelpath), and the North Atlantic profiler (right wheelpath). At section 2, the only cases that satisfied the precision criterion were the North Atlantic profiler (left and right wheelpaths) and the Southern profiler (right wheelpath). At section 5, the North Central and the Southern profilers failed the precision criterion along the left wheelpath, while all profilers except for the North Atlantic profiler failed the precision criterion along the right wheelpath. Section 2 and 5 are rough sections with transverse cracks located throughout the section. Section 2 also has low to medium severity rutting. Hence, at sections 2 and 5, lateral variability in the path followed during a profile run can have a significant effect on IRI. The failure of the precision criterion at these two sections is attributed to lateral variability during profiling. Evaluation of profile data for the cases that failed the precision criterion at section 3 and 6 did not show a clear reason why the precision criterion was not met. Variability in the paths followed during the repeat runs is a possible cause for failing the precision criterion at these two sections.

IRI Values Obtained by Profilers

Comparison of IRI values obtained by the ICC profilers indicated at sections 1, 3, 4, and 6 the difference between the maximum and minimum IRI along a wheelpath (average of five runs) obtained by the four profilers was less than 0.1 m/km, which indicates very good agreement in IRI values. The difference was between 0.12 and 0.18 m/km for the right wheelpath at section 2, and left and right wheelpaths of section 5. The highest difference was observed along the left wheelpath of section 2, where the difference between the maximum and minimum IRI was 0.66 m/km. Sections 2 and 5 have significant amount of distress, and lateral variability in the paths followed by the profilers appear to have been the cause for the high range in IRI at these sections. The IRI values obtained by the K. J. Law profiler fell within the range of IRI values obtained by the ICC profilers for most cases, and was outside the range by a small amount for few cases. This indicates the IRI values obtained by the K. J. Law profiler is comparable to those obtained by the ICC profilers.

Difference between Profiler and Dipstick IRI

In order to obtain good agreement between the profiler IRI and the Dipstick IRI, the profiler must collect data along the exact path where the Dipstick measurements were made. At smooth sections where no distresses are present, lateral variability in the path followed by the profiler does not usually have a significant impact on IRI. However, if distresses are present along the wheepaths, even a slight lateral shift in the path profiled can have a significant impact on IRI. Except at the rough sections (section 2 and 5), good agreement between profiler IRI and Dipstick IRI was noted for the majority of the cases The Profile Manual indicates the difference between the Dipstick IRI and profiler IRI should be within $\pm$ 0.16 m/km for each wheelpath. This criterion was satisfied by all profilers for both wheelpaths at sections 3 and 6. This criterion was not satisfied for the following cases: (1) section 2 – all cases except for left and right wheelpath of the Southern profiler, and the right wheelpath of the North Atlantic profiler, (2) section 4 – left wheelpath for all profilers, and (3) section 5 – right wheelpath for all profilers. As indicated previously, sections 2 and 5 had significant distress, and a profiler not following the path along which Dipstick measurements were obtained can result in significant differences in IRI values obtained by the two devices. In addition, the profiler will pick-up features that are not measured by the Dipstick due to the high sampling rate of the profiler when compared to the Dipstick (25 mm vs. 304.8 mm) and also because of the bridging effect of the Dipstick footpads over cracks, which can also contribute to differences in IRI. At section 5, it was noted that the profilers were picking up deep cracks and localized depressions along the right wheelpath that were not being measured by the Dipstick because of the bridging effect of the Dipstick footpads and the higher sampling distance of the Dipstick. The reason for the profilers to obtain a higher IRI than the Dipstick at section 4 along the right wheelpath is not clear.

Evaluation of Profile Plots

Overlaid profile plots of profile data collected by each profiler along the left as well as the right wheelpath showed that all profilers were collecting repeatable data, and no problems were observed. A similar observation was noted for the data collected by the center sensor in the ICC profilers. The center sensor in the K. J. Law profiler showed good repeatability except at one section. The data collected by the center sensor in the K. J. Law profiler should be evaluated carefully to see if there are any problems with the data.

A comparison of profiles obtained by the four ICC profilers at all test sections indicated that all four profilers are capturing similar profile features, thus confirming that all four ICC profilers are collecting similar data. The K. J. Law profiler profiles were not compared with those from the ICC profilers as previous studies have shown that the profiles among the devices are different because of differences in the long wavelength filter that is applied on the profile data.(2)

Power Spectral Density Plots

Power spectral density plots of the profile data were created and examined to detect potential problems in the collected data. No data problems were noted.

10.0 REFERENCES

1. R.W. Perera, S.D. Kohn, and G.R. Rada, LTPP Manual for Profile Measurements and Processing, Version 4.1, Federal Highway Administration, 2004.

2. R.W. Perera and S.D. Kohn, Quantification of Smoothness Index Differences Related to LTPP Equipment Type, Report No. FHWA-HRT-05-054, Federal Highway Administration, September 2005.

APPENDIX A

PHOTOGRAPHS OF TEST SECTIONS

Test section 2.

Test section 3.

Test section 4.

Test section 5.

Test section 6.

APPENDIX B

STATIC HEIGHT SENSOR TEST RESULTS

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: North Atlantic
Date: 5/14/2007

Distance from Ground to Sensor Glass (mm): Left: 320 mm Center 320 mm Right 325 mm

Left Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	143.56	143.44	143.39	143.37	143.33	143.418	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.024	25.166	25.159	25.165	25.133	25.1294	25.024	0.11	0.060
Base Plate + 50 mm Block + Calibration Plate	50.021	49.991	49.978	50.023	50.106	50.0238	50.005	0.02	0.050
Base Plate + 75 mm Block + Calibration Plate	75.180	75.118	75.118	75.007	75.008	75.0862	75.001	0.09	0.076
Base Plate + 100 mm Block + Calibration Plate	100.149	100.063	100.045	100.038	99.976	100.054	100.017	0.04	0.062

Center Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	145.92	145.83	145.82	145.84	145.75	145.832	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.175	25.131	25.188	25.221	25.115	25.166	25.003	0.16	0.043
Base Plate + 50 mm Block + Calibration Plate	50.268	50.254	50.238	50.336	50.250	50.2692	50.007	**0.26**	0.039
Base Plate + 75 mm Block + Calibration Plate	75.364	75.484	75.427	75.452	75.429	75.4312	75.004	**0.43**	0.044
Base Plate + 100 mm Block + Calibration Plate	100.607	100.666	100.670	100.537	100.645	100.625	100.124	**0.50**	0.055

Right Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	148.71	148.54	148.57	148.48	148.52	148.564	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.214	25.026	25.193	25.037	25.184	25.1308	25.030	0.10	0.091
Base Plate + 50 mm Block + Calibration Plate	50.068	50.172	50.089	50.107	50.063	50.100	50.005	0.09	0.044
Base Plate + 75 mm Block + Calibration Plate	75.169	75.113	75.121	75.221	75.208	75.1664	75.006	0.16	0.049
Base Plate + 100 mm Block + Calibration Plate	100.003	100.146	100.324	100.250	100.203	100.185	99.984	0.20	0.121

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: North Central
Date: 5/14/2007

Distance from Ground to Sensor Glass (mm): Left: 324 mm Center 325 mm Right 326 mm

Left Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	146.79	146.7	146.58	146.62	146.51	146.640	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.095	25.105	25.130	25.208	25.205	25.149	25.028	0.12	0.054
Base Plate + 50 mm Block + Calibration Plate	50.123	50.228	50.295	49.995	50.214	50.171	50.015	0.16	0.116
Base Plate + 75 mm Block + Calibration Plate	74.208	75.365	75.082	75.281	75.357	75.059	74.998	0.06	**0.489**
Base Plate + 100 mm Block + Calibration Plate	100.454	100.524	100.399	100.361	100.377	100.423	100.026	**0.40**	0.067

Center Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	153.27	153.27	153.24	153.16	153.17	153.222	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.382	25.377	25.414	25.187	25.187	25.309	25.028	**0.28**	0.113
Base Plate + 50 mm Block + Calibration Plate	50.150	50.221	50.167	50.063	50.064	50.133	50.015	0.12	0.069
Base Plate + 75 mm Block + Calibration Plate	75.219	75.086	74.821	75.041	75.034	75.040	74.998	0.04	**0.143**
Base Plate + 100 mm Block + Calibration Plate	100.340	100.173	100.074	99.966	100.033	100.117	100.026	0.09	**0.145**

Right Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value for Height 1)	155.52	155.47	155.34	155.44	155.35	155.424	N/A	N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.072	25.138	25.119	25.142	25.439	25.182	25.028	0.15	**0.146**
Base Plate + 50 mm Block + Calibration Plate	50.003	50.242	50.149	50.122	50.057	50.115	50.017	0.10	0.091
Base Plate + 75 mm Block + Calibration Plate	75.143	75.023	75.227	75.230	75.118	75.148	74.998	0.15	0.086
Base Plate + 100 mm Block + Calibration Plate	99.960	100.079	100.055	100.211	100.186	100.098	100.026	0.07	0.102

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: Southern
Date: 5/14/2007

Distance from Ground to Sensor Glass (mm): Left: 325 mm Center 323 mm Right 325 mm

Left Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	25.138	25.109	25.114	25.091	25.225	25.1354	25.024	0.11	0.053
Base Plate + 50 mm Block + Calibration Plate	50.096	50.132	50.124	50.035	50.17	50.1114	50.012	0.10	0.050
Base Plate + 75 mm Block + Calibration Plate	75.224	75.241	75.226	75.168	75.265	75.2248	75.013	0.21	0.036
Base Plate + 100 mm Block + Calibration Plate	100.384	100.269	100.202	100.263	100.243	100.2722	100.027	0.25	0.068

Center Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	24.994	24.919	24.974	24.984	25.006	24.9754	25.025	-0.05	0.034
Base Plate + 50 mm Block + Calibration Plate	49.909	49.701	50.189	50.045	49.938	49.9564	50.017	-0.06	**0.180**
Base Plate + 75 mm Block + Calibration Plate	75.07	75.062	75.069	74.938	74.988	75.0254	75.019	0.01	0.060
Base Plate + 100 mm Block + Calibration Plate	100.27	100.227	99.981	100.039	100.052	100.1138	100.024	0.09	**0.127**

Right Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	25.157	25.16	25.174	25.086	25.092	25.1338	25.024	0.11	0.041
Base Plate + 50 mm Block + Calibration Plate	50.052	50.238	50.023	50.104	50.064	50.0962	50.012	0.08	0.084
Base Plate + 75 mm Block + Calibration Plate	75.295	75.351	75.247	75.182	75.218	75.2586	75.014	0.24	0.066
Base Plate + 100 mm Block + Calibration Plate	100.261	100.276	100.206	100.126	100.139	100.2016	100.027	0.17	0.068

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: Western RSC
Date: 5/14/07

Distance from Ground to Sensor Glass (mm): Left: 329 mm Center: 329 mm Right: 328 mm

Left Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown for Height 1)	165.51	165.12	165.08	165.95	165.77	165.49		N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.233	25.062	25.110	25.031	25.150	25.117	25.023	0.09	0.079
Base Plate + 50 mm Block + Calibration Plate	50.082	50.153	50.045	50.015	50.147	50.088	50.015	0.07	0.061
Base Plate + 75 mm Block + Calibration Plate	75.181	75.216	75.177	75.156	75.060	75.158	74.993	0.17	0.059
Base Plate + 100 mm Block + Calibration Plate	100.224	100.169	100.210	100.194	100.173	100.194	100.025	0.17	0.024

Center Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	155.93	155.73	155.69	155.99	155.82	155.83		N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.058	24.962	25.024	25.100	25.141	25.057	25.019	0.04	0.069
Base Plate + 50 mm Block + Calibration Plate	50.149	49.979	50.083	49.930	49.964	50.021	50.015	0.01	0.092
Base Plate + 75 mm Block + Calibration Plate	75.236	75.246	75.198	75.044	74.997	75.144	74.993	0.15	0.116
Base Plate + 100 mm Block + Calibration Plate	100.267	100.100	100.104	99.961	100.083	100.103	100.022	0.08	0.109

Right Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base + Calibration Plate (Value shown in Height 1)	159.44	159.40	158.82	158.34	158.05	158.81		N/A	N/A
Base Plate + 25 mm Block + Calibration Plate	25.144	25.025	25.287	25.257	25.112	25.165	25.021	0.14	0.107
Base Plate + 50 mm Block + Calibration Plate	49.978	50.186	50.128	50.279	50.060	50.126	50.015	0.11	0.115
Base Plate + 75 mm Block + Calibration Plate	75.236	75.137	75.071	74.798	75.220	75.092	74.993	0.10	**0.177**
Base Plate + 100 mm Block + Calibration Plate	100.152	100.200	99.969	99.787	99.935	100.009	100.025	-0.02	**0.168**

Note: Values outside tolerance are shown in bold

STATIC HEIGHT SENSOR MEASUREMENTS

RSC: North Central, K.J. Law
Date: 5/16/2007

Distance from Ground to Sensor Glass (mm): Left: 278 mm Center 281 mm Right 281 mm

Left Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Std Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	25.143	25.207	25.155	25.040	25.240	25.157	25	0.16	0.076
Base Plate + 50 mm Block + Calibration Plate	50.226	50.182	50.222	49.825	50.227	50.136	50	0.14	**0.175**
Base Plate + 75 mm Block + Calibration Plate	75.076	74.887	74.867	74.797	75.062	74.938	75	-0.06	0.124
Base Plate + 100 mm Block + Calibration Plate									

Center Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	24.874	24.878	24.888	24.893	24.919	24.890	25	-0.11	0.018
Base Plate + 50 mm Block + Calibration Plate	49.785	49.781	49.937	49.769	49.814	49.817	50	-0.18	0.069
Base Plate + 75 mm Block + Calibration Plate	74.886	74.986	74.850	74.905	74.896	74.905	75	-0.10	0.050
Base Plate + 100 mm Block + Calibration Plate									

Right Sensor

Position	Measured Height (mm)					Avg. of Heights (mm)	Actual Block Height (mm)	Average Minus Actual (mm)	Standard Dev. of Heights (mm)
	Test 1	Test 2	Test 3	Test 4	Test 5				
Base Plate + 25 mm Block + Calibration Plate	24.755	24.848	24.761	25.194	24.906	24.893	25	-0.11	**0.180**
Base Plate + 50 mm Block + Calibration Plate	49.816	50.023	49.924	50.175	49.992	49.986	50	-0.01	**0.132**
Base Plate + 75 mm Block + Calibration Plate	75.114	75.099	75.051	75.248	75.218	75.146	75	0.15	0.083
Base Plate + 100 mm Block + Calibration Plate									

Note: Values outside tolerance are shown in bold

APPENDIX C

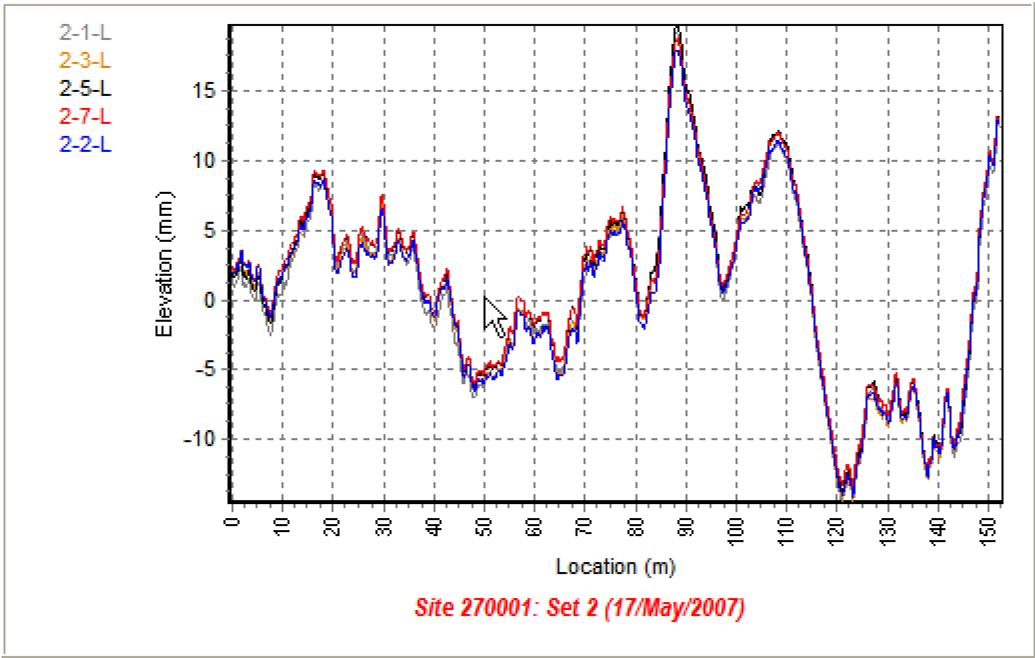
IRI VALUES

Test Section	Profiler	Left Wheel Path IRI (m/km)							Right Wheel Path IRI (m/km)						
		Run Number							Run Number						
		1	2	3	4	5	Avg	S.D	1	2	3	4	5	Avg	S.D.
1	NA - ICC	1.89	1.86	1.87	1.90	1.86	1.88	0.015	1.67	1.67	1.69	1.68	1.67	1.68	0.009
1	NC - ICC	1.92	1.88	1.87	1.88	1.89	1.89	0.017	1.64	1.61	1.62	1.63	1.64	1.63	0.011
1	SO - ICC	1.89	1.89	1.90	1.90	1.90	1.89	0.005	1.68	1.68	1.69	1.64	1.68	1.67	0.019
1	WE - ICC	1.89	1.88	1.88	1.88	1.90	1.88	0.010	1.62	1.63	1.62	1.64	1.64	1.63	0.011
1	K.J. Law	1.92	1.93	1.92	1.91	1.93	1.92	0.007	1.64	1.67	1.65	1.69	1.65	1.66	0.020
2	NA - ICC	2.59	2.57	2.55	2.62	2.57	2.58	0.027	2.66	2.64	2.66	2.65	2.71	2.66	0.028
2	NC - ICC	2.52	2.39	2.39	2.59	2.64	2.51	0.116	2.61	2.49	2.48	2.56	2.64	2.55	0.072
2	SO - ICC	2.68	2.84	3.12	2.90	3.00	2.91	0.165	2.68	2.67	2.66	2.65	2.69	2.67	0.015
2	WE - ICC	3.13	3.02	3.29	3.22	3.20	3.17	0.104	2.54	2.64	2.61	2.54	2.57	2.58	0.044
2	K.J. Law	2.42	2.52	2.49	2.69	2.51	2.52	0.099	2.44	2.49	2.46	2.65	2.49	2.51	0.081
3	NA - ICC	0.87	0.87	0.87	0.91	0.87	0.88	0.018	1.01	1.03	1.02	1.03	1.03	1.02	0.012
3	NC - ICC	0.88	0.86	0.90	0.88	0.89	0.88	0.013	1.16	1.03	1.13	1.04	1.13	1.10	0.058
3	SO - ICC	0.89	0.84	0.86	0.87	0.87	0.87	0.016	1.01	1.08	1.03	1.01	1.02	1.03	0.027
3	WE - ICC	0.84	0.86	0.84	0.88	0.87	0.86	0.018	1.00	1.12	0.99	1.13	1.10	1.07	0.068
3	K.J. Law	0.90	0.92	0.91	0.88	0.91	0.90	0.013	1.03	1.08	1.08	1.00	1.03	1.04	0.035
4	NA - ICC	1.41	1.43	1.41	1.42	1.42	1.42	0.007	1.39	1.37	1.42	1.40	1.38	1.39	0.021
4	NC - ICC	1.38	1.36	1.38	1.37	1.36	1.37	0.009	1.31	1.40	1.30	1.32	1.31	1.33	0.039
4	SO - ICC	1.39	1.41	1.43	1.42	1.42	1.41	0.015	1.40	1.37	1.39	1.34	1.36	1.37	0.021
4	WE - ICC	1.34	1.34	1.42	1.40	1.40	1.38	0.037	1.33	1.33	1.38	1.34	1.33	1.34	0.022
4	K.J. Law	1.41	1.42	1.43	1.43	1.40	1.42	0.011	1.37	1.41	1.43	1.46	1.43	1.42	0.032
5	NA - ICC	3.20	3.21	3.22	3.23	3.19	3.21	0.015	3.72	3.72	3.74	3.72	3.71	3.72	0.013
5	NC - ICC	3.20	3.23	3.22	3.17	3.13	3.19	0.042	3.70	3.67	3.81	3.77	3.72	3.73	0.055
5	SO - ICC	3.25	3.35	3.25	3.37	3.43	3.33	0.077	3.66	3.69	3.72	3.71	3.78	3.71	0.044
5	WE - ICC	3.28	3.28	3.25	3.27	3.26	3.27	0.014	3.52	3.56	3.58	3.50	3.61	3.55	0.044
5	K.J. Law	3.24	3.24	3.31	3.28	3.26	3.27	0.029	3.69	3.63	3.60	3.64	3.69	3.65	0.040
6	NA - ICC	1.10	1.12	1.07	1.12	1.17	1.12	0.034	1.29	1.44	1.39	1.50	1.48	1.42	0.083
6	NC - ICC	1.07	1.09	1.01	1.12	1.13	1.08	0.048	1.45	1.48	1.41	1.44	1.45	1.44	0.026
6	SO - ICC	1.15	1.14	1.17	1.13	1.16	1.15	0.015	1.44	1.43	1.48	1.45	1.46	1.45	0.019
6	WE - ICC	1.13	1.15	1.14	1.14	1.14	1.14	0.009	1.34	1.37	1.36	1.40	1.40	1.37	0.024
6	K.J. Law	1.21	1.16	1.18	1.09	1.20	1.17	0.046	1.42	1.29	1.40	1.39	1.45	1.39	0.063

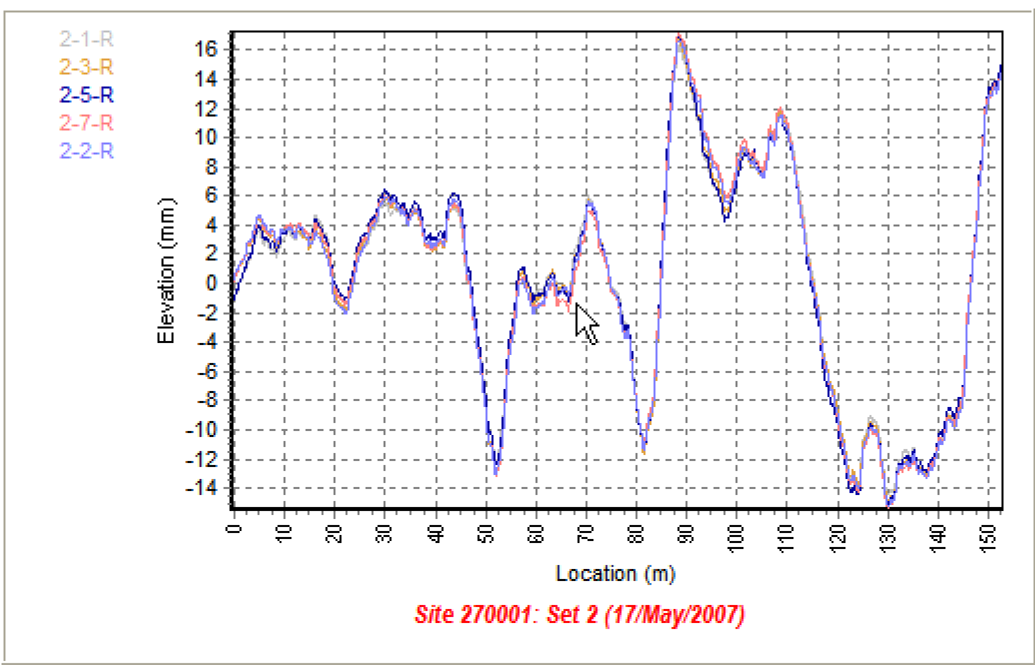
Note: SD - Standard Deviation, Avg - Average, NA - North Atlantic, NC - North Central, SO - Southern, WE - Western

APPENDIX D

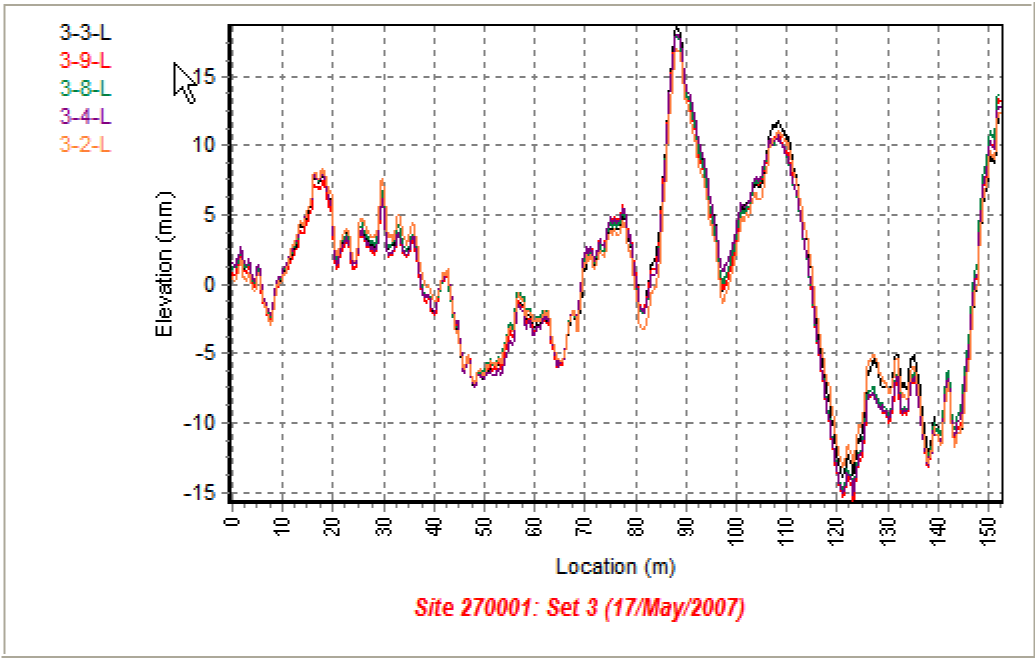
PLOTS OF REPLICATE PROFILE RUNS OBTAINED BY THE PROFILERS ALONG THE LEFT AND RIGHT WHEELPATHS



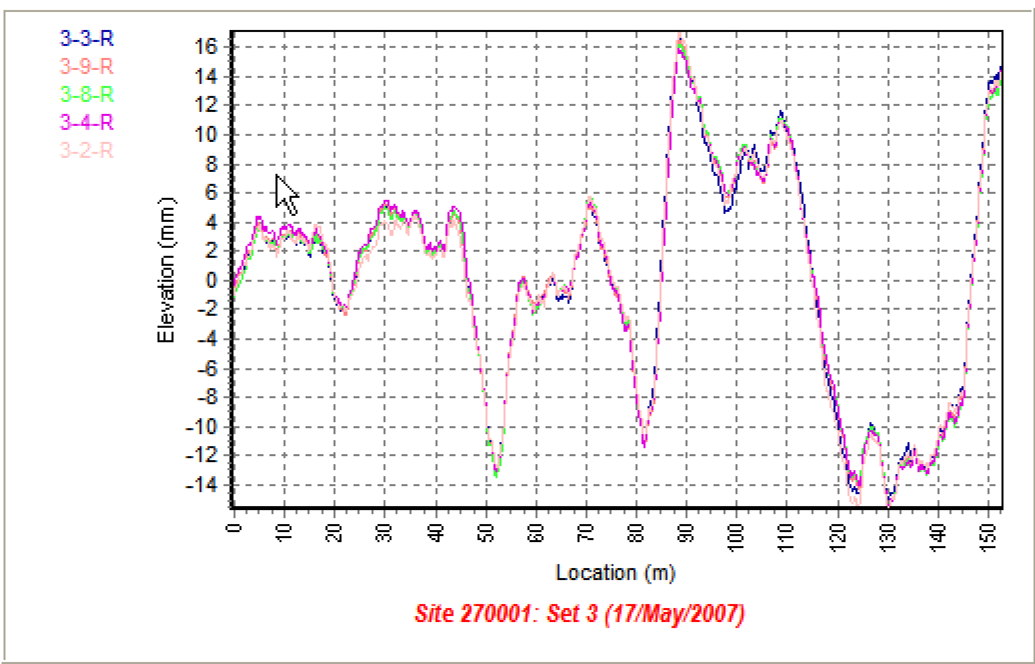
Section 1 – North Atlantic – Left Wheelpath.



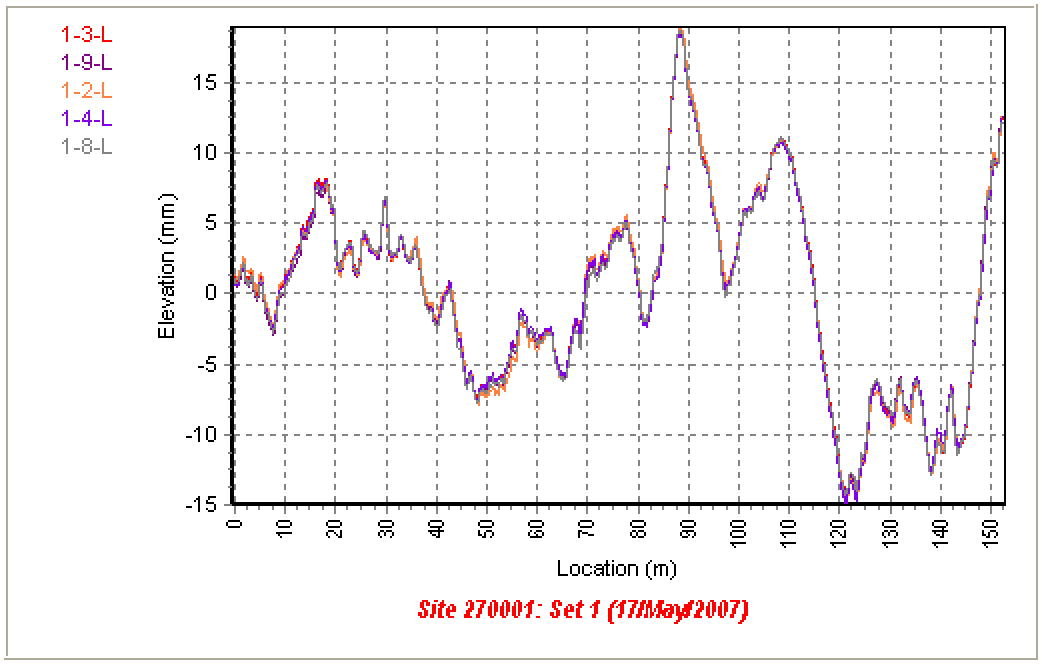
Section 1 - North Atlantic – Right Wheelpath.



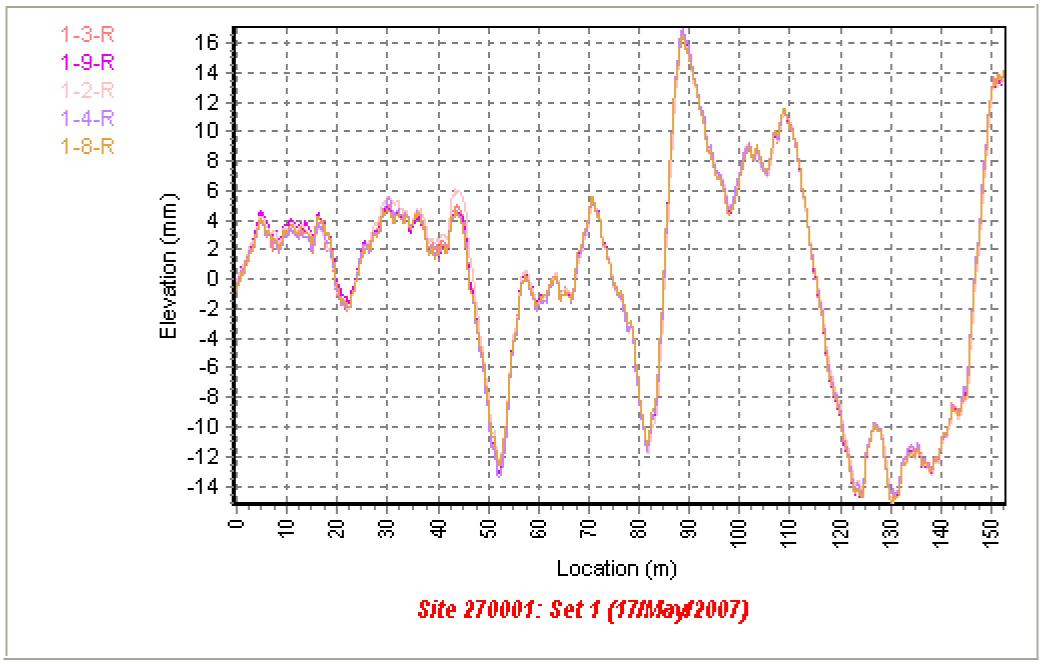
Section 1 – North Central – Left Wheelpath.



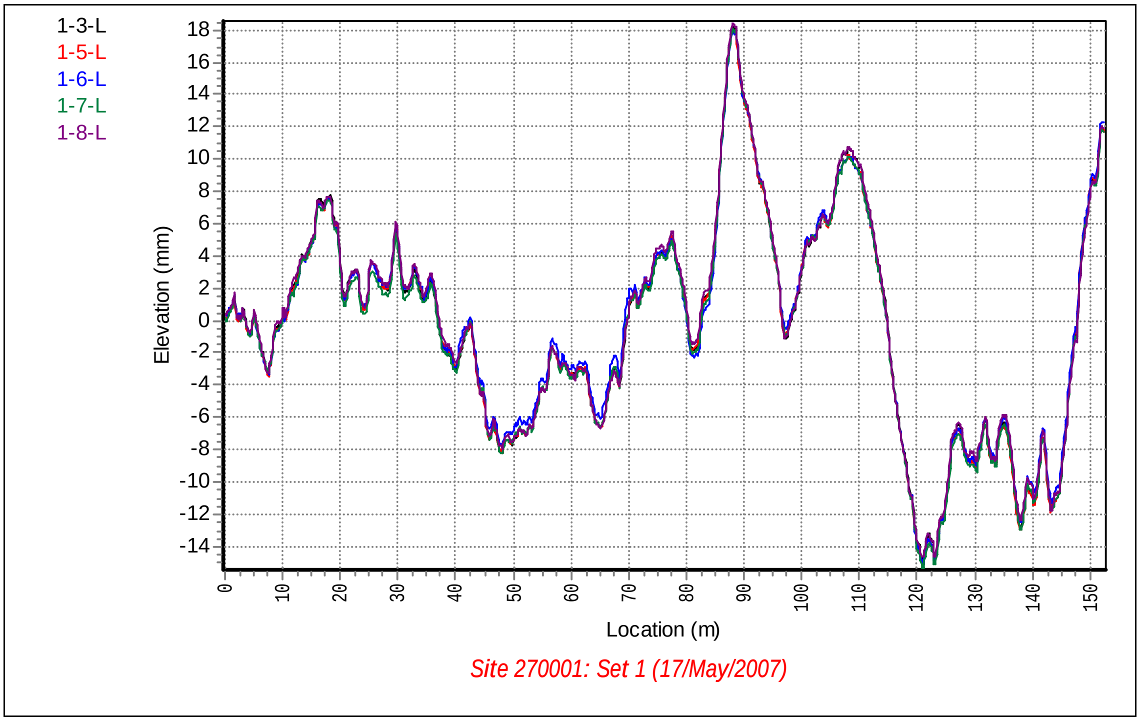
Section 1 – North Central – Right Wheelpath.



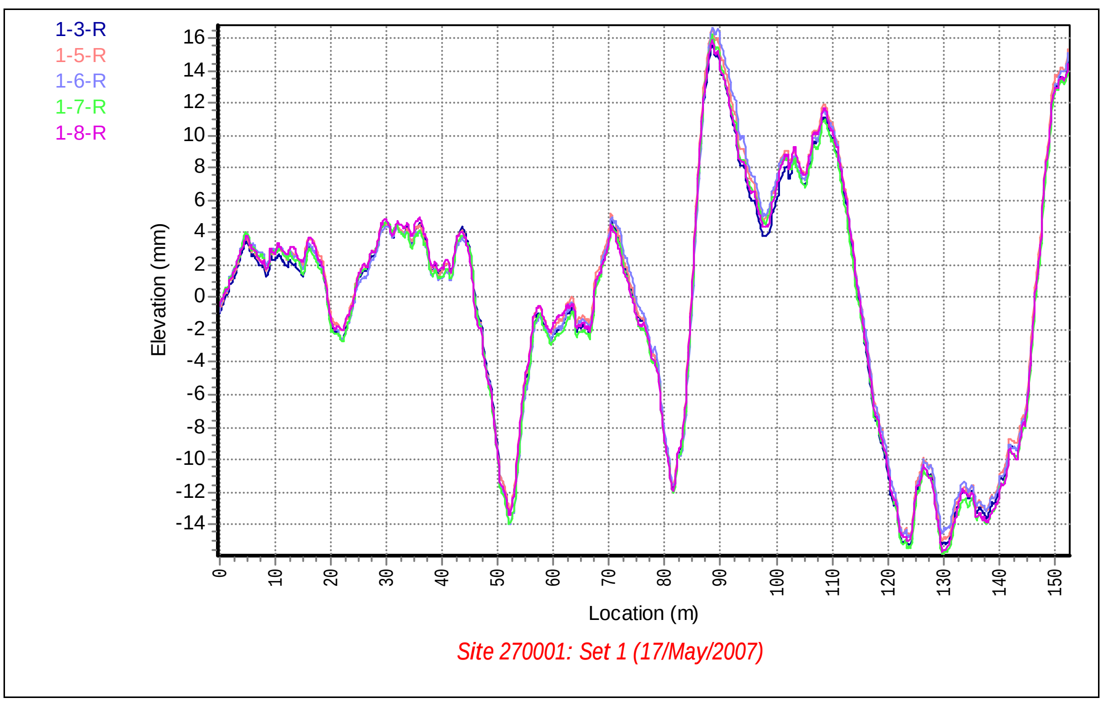
Section 1 – Southern – Left Wheelpath.



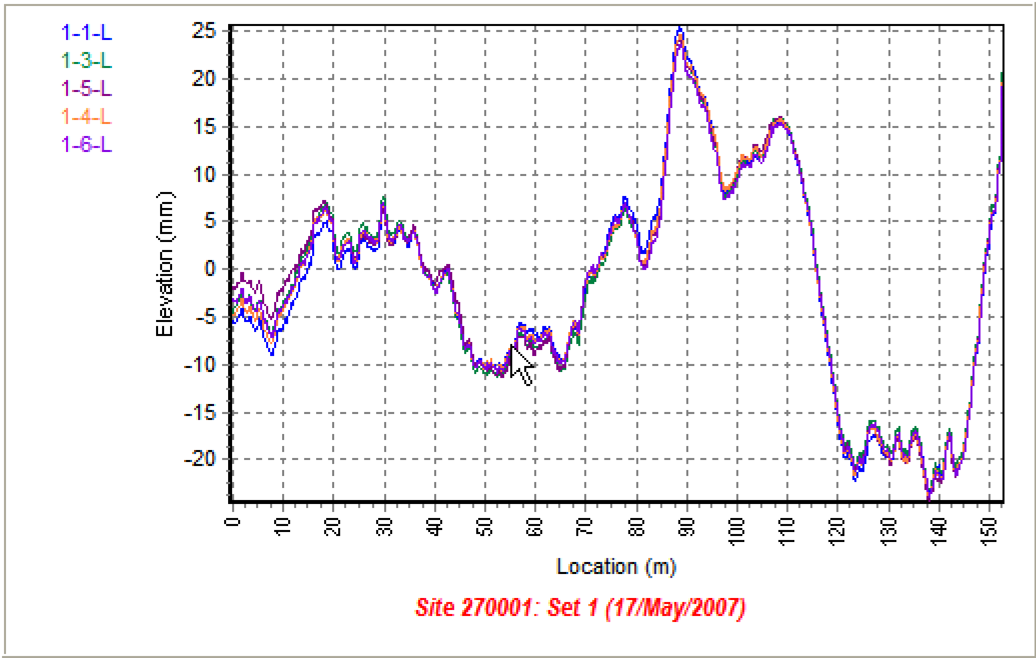
Section 1 – Southern – Right Wheelpath.



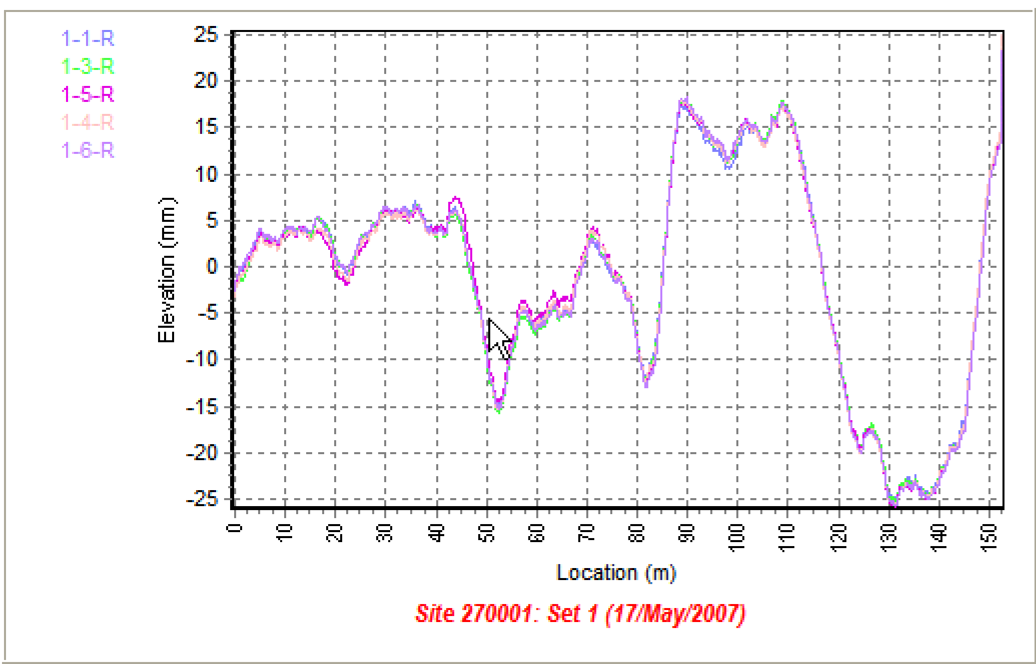
Section 1 – Western – Left Wheelpath.



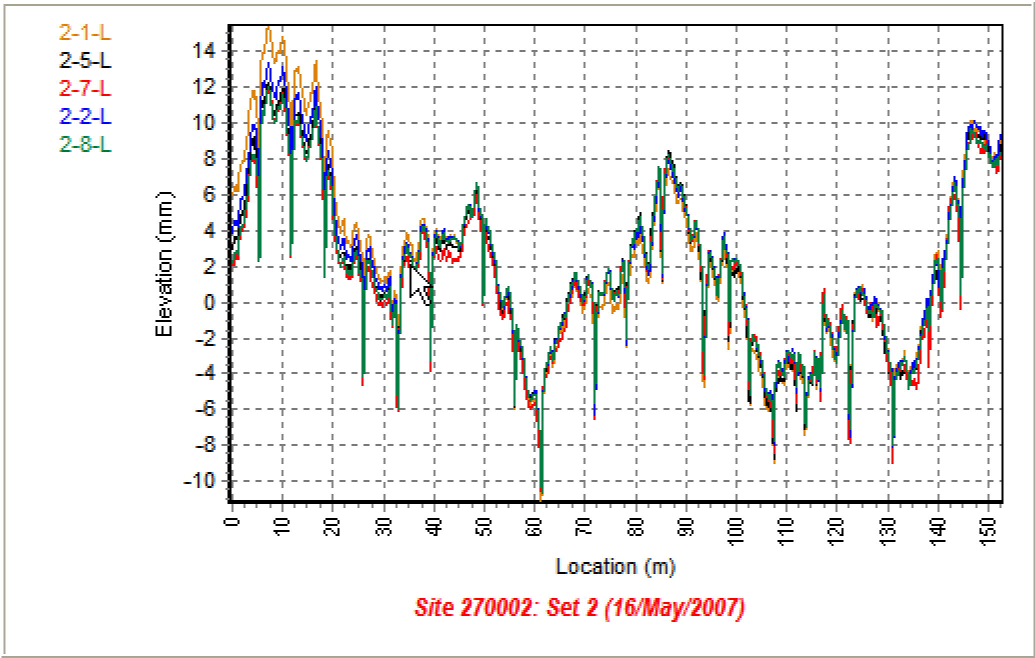
Site 1 – Western - Right Wheelpath.



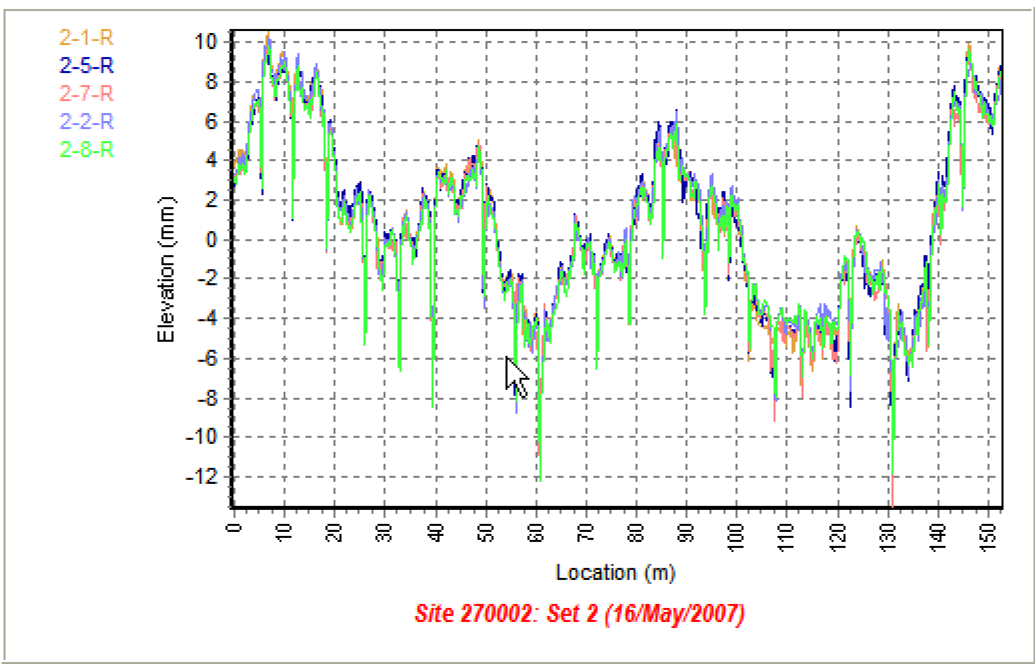
Site 1 - K. J. Law – Left Wheelpath.



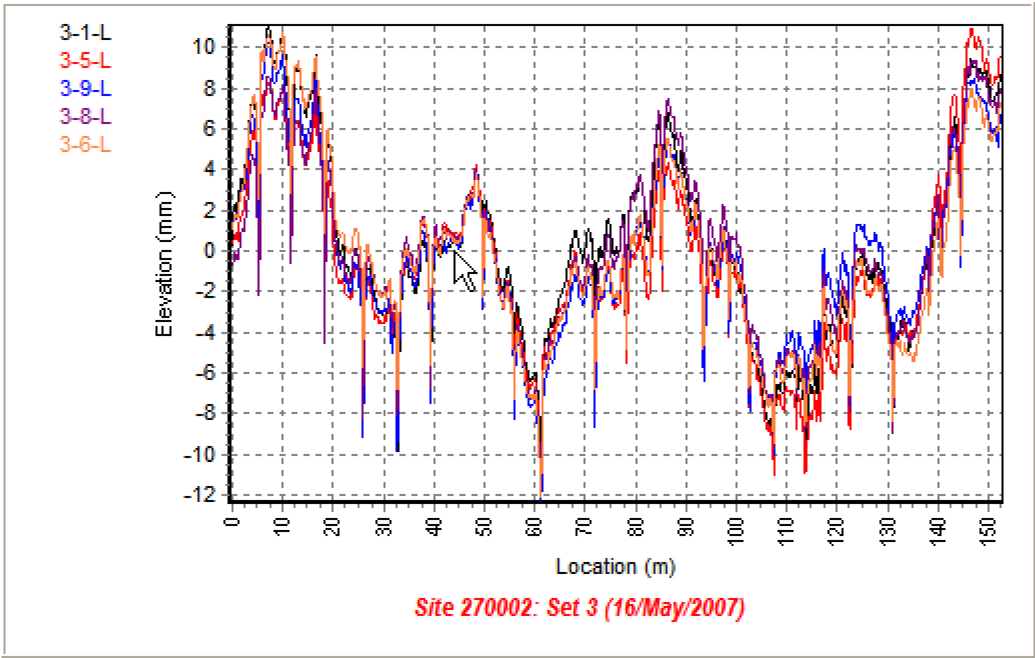
Section 1 – K. J. Law – Right Wheelpath.



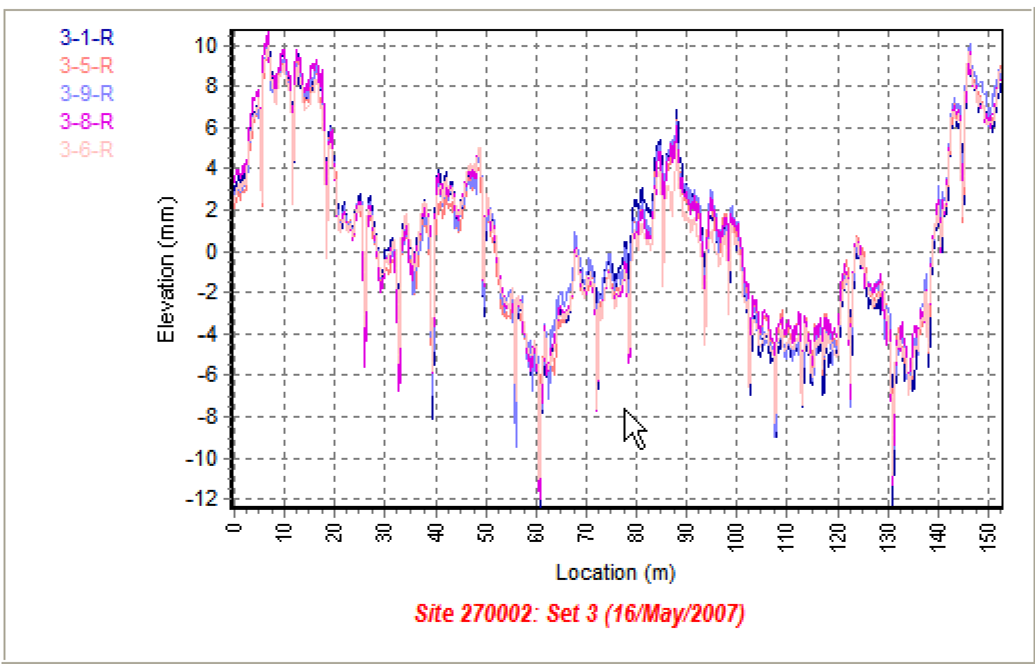
Section 2 – North Atlantic – Left Wheelpath.



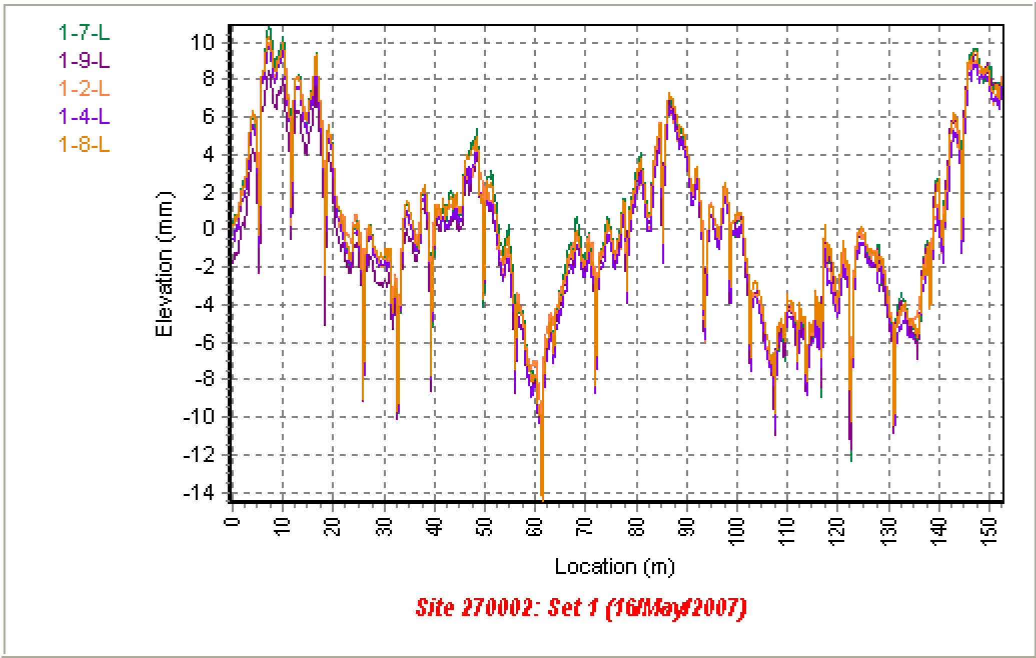
Section 2 – North Atlantic – Right Wheelpath.



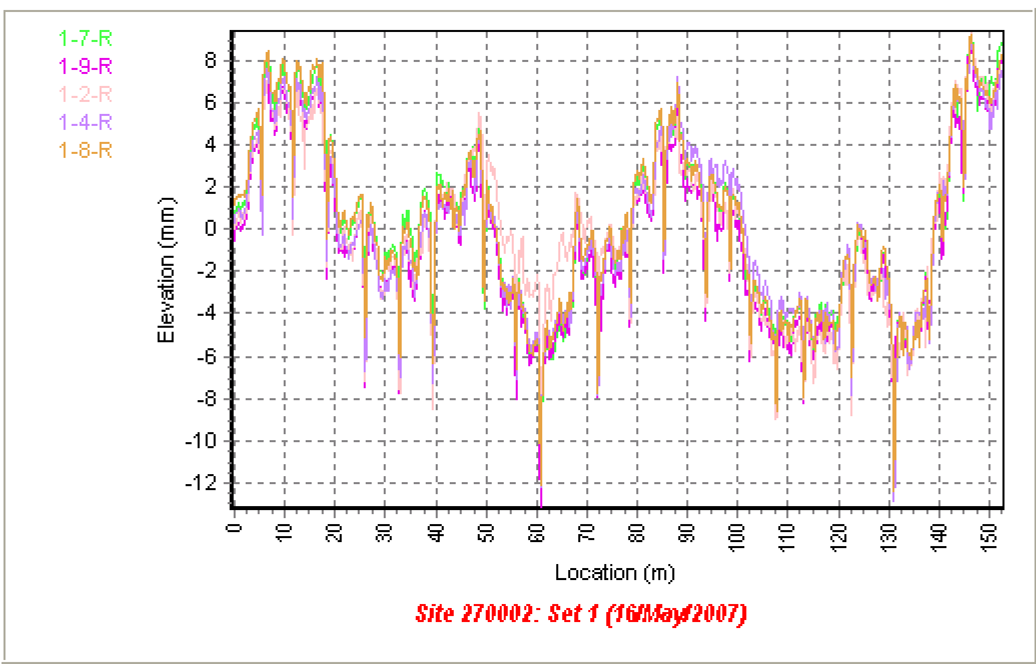
Section 2 – North Central – Left Wheelpath.



Section 2 – North Central – Right Wheelpath.



Section 2 – Southern – Left Wheelpath.



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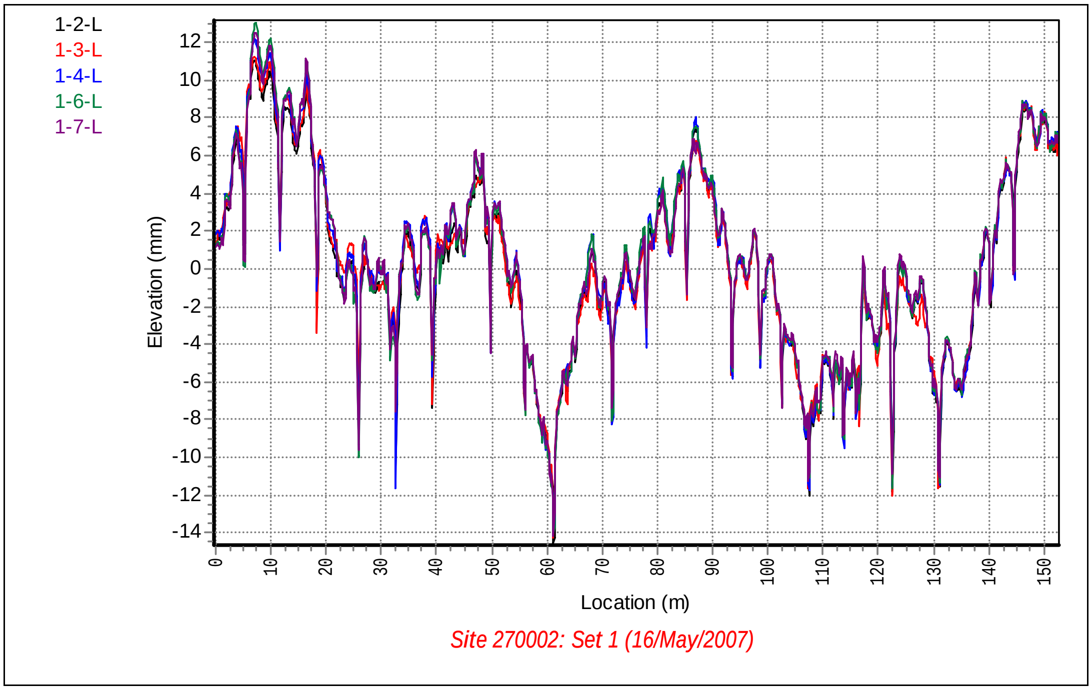
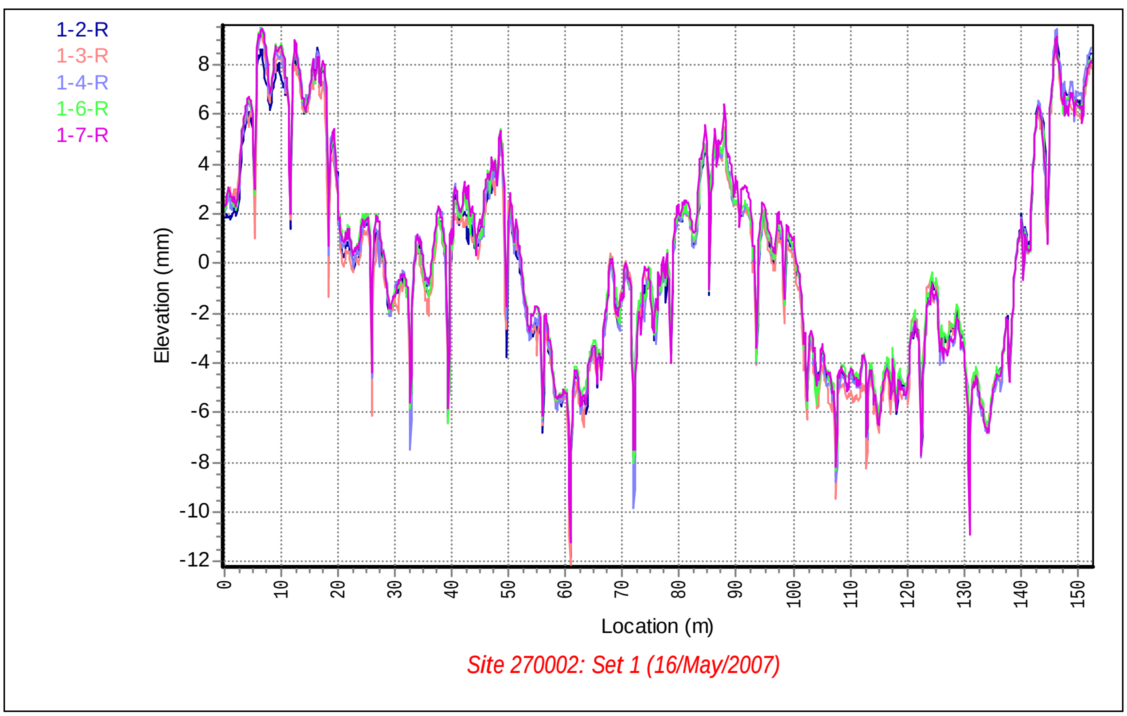
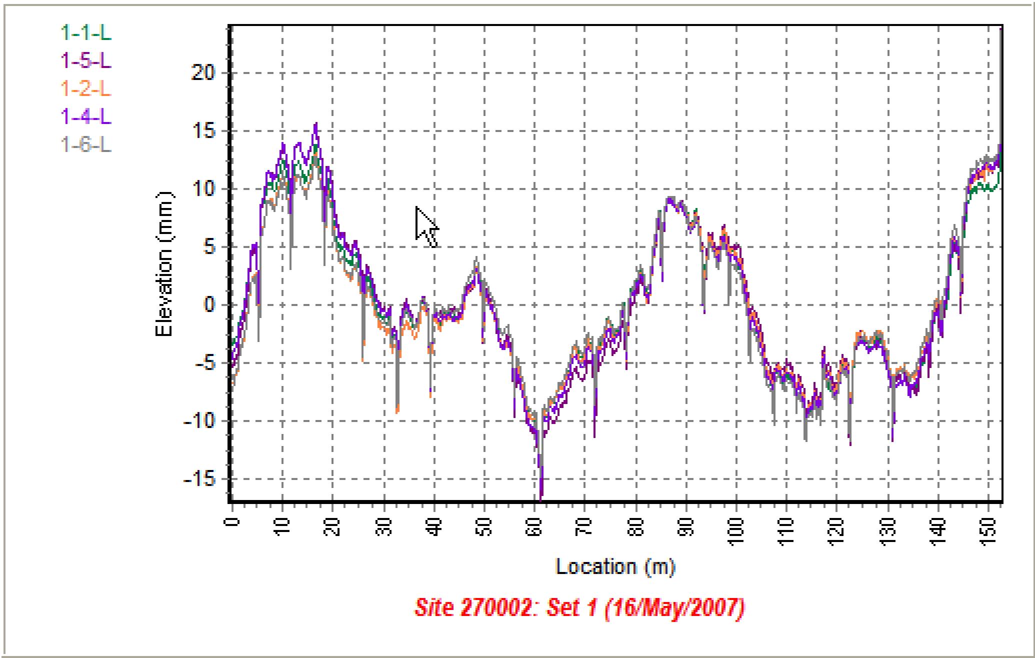


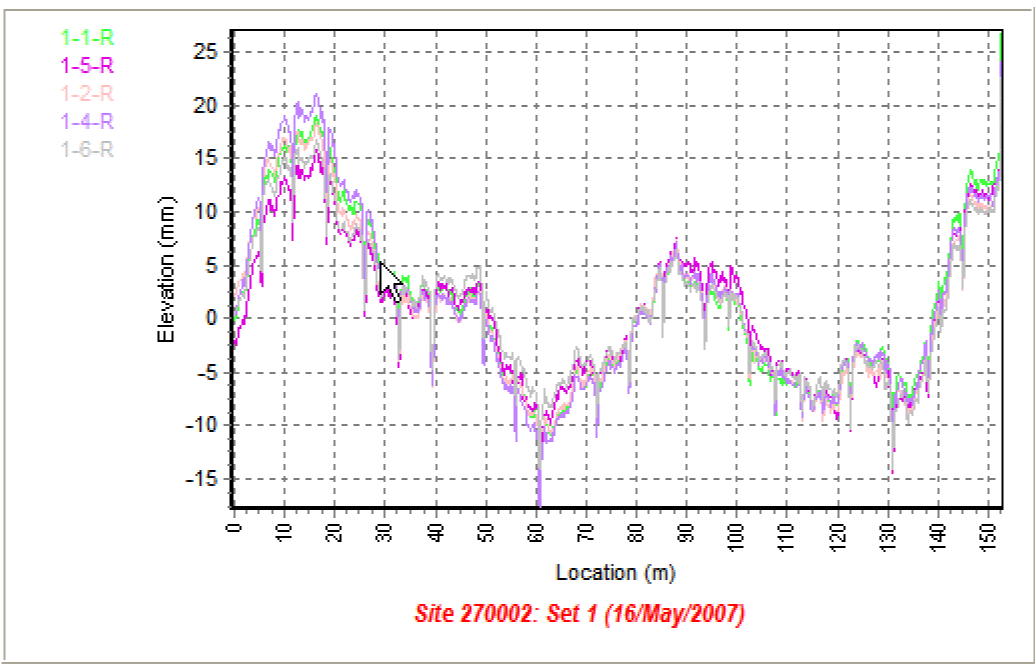
Section 2 – Western – Left Wheelpath.



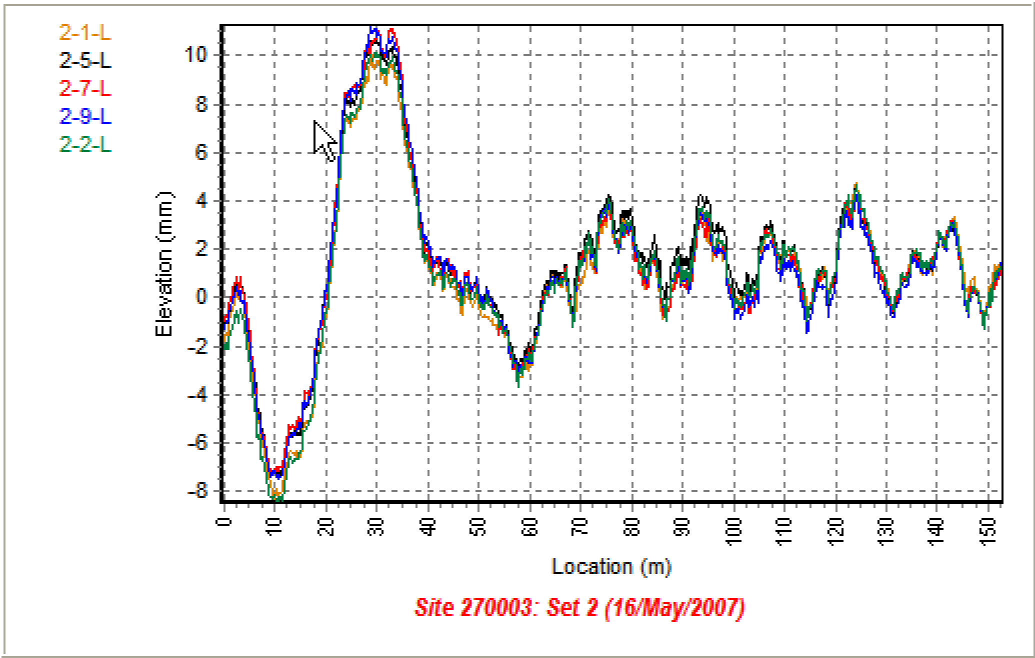
Section 2 – Western – Right Wheelpath.



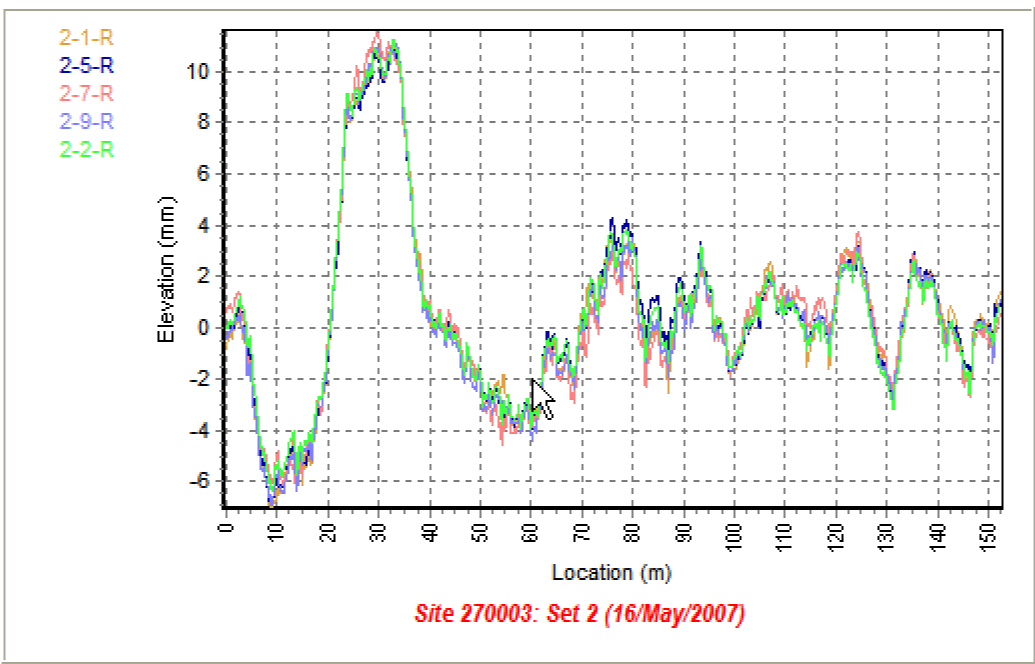
Section 2 – K. J. Law – Left Wheelpath.



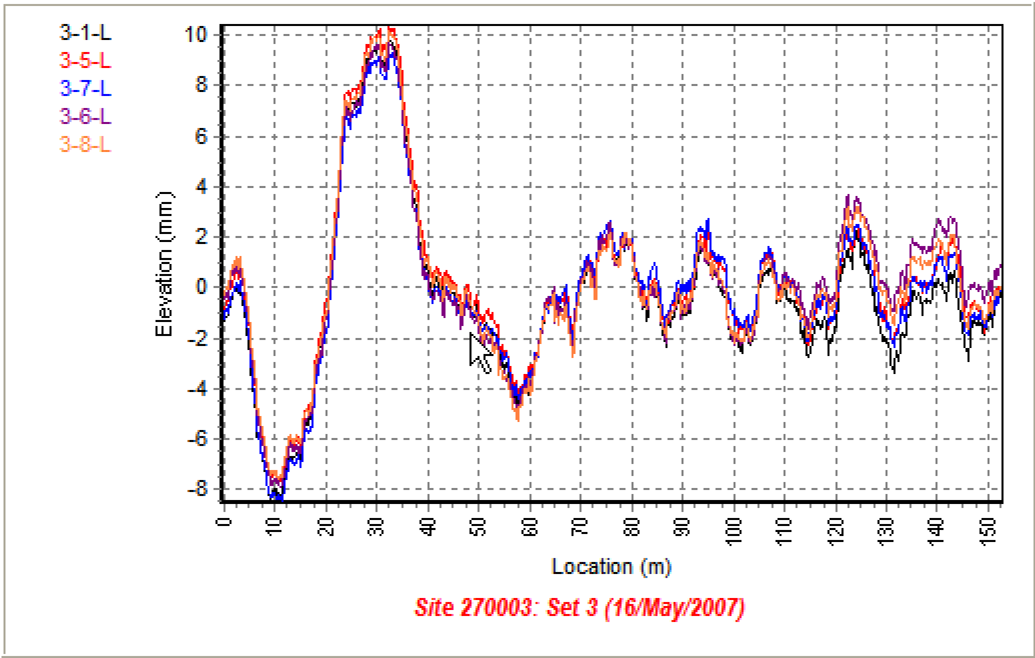
Section 2 – K. J. Law – Right Wheelpath.



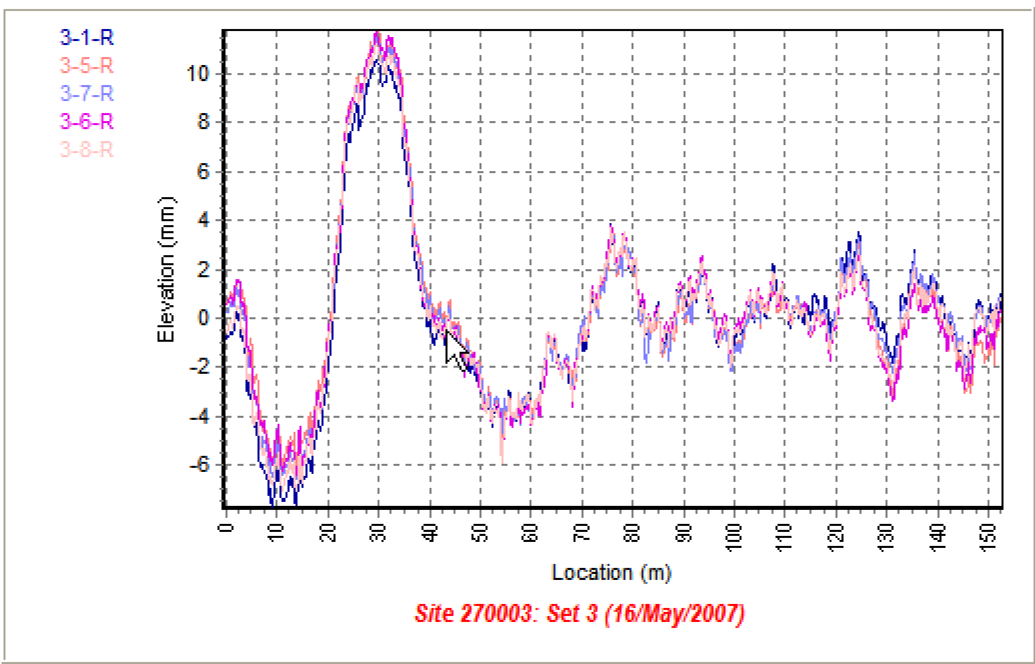
Section 3 – North Atlantic – Left Wheelpath.



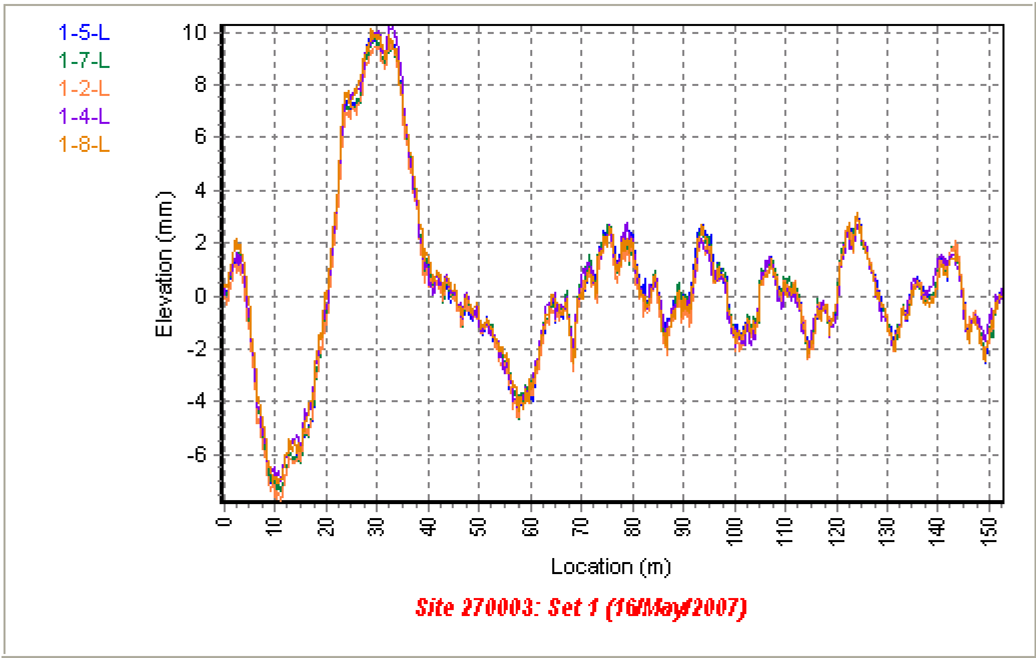
Section 3 – North Atlantic – Right Wheelpath.



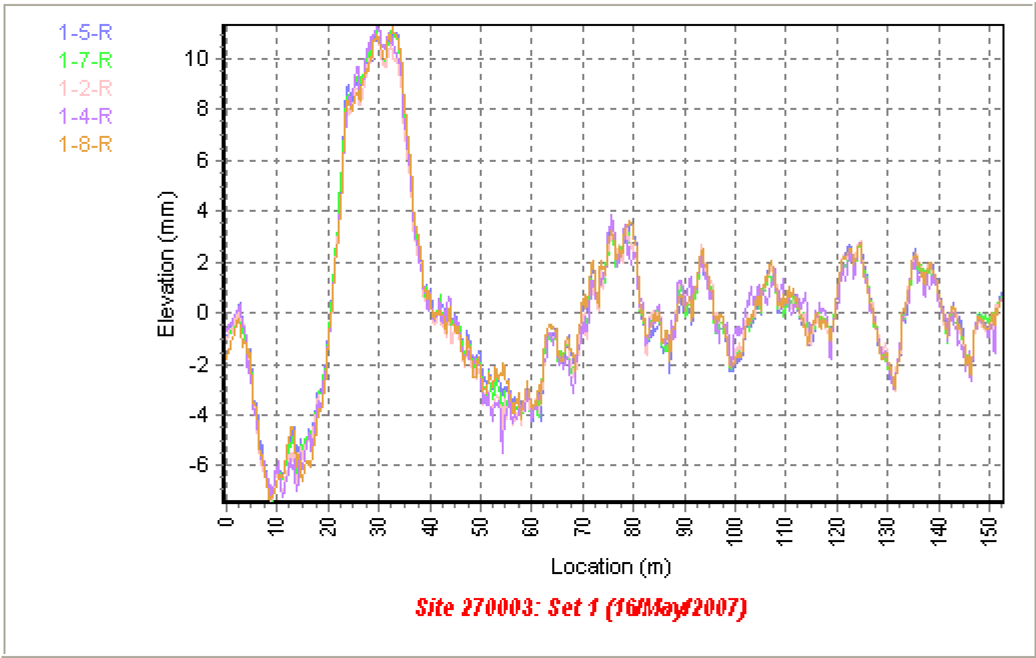
Section 3 – North Central – Left Wheelpath.



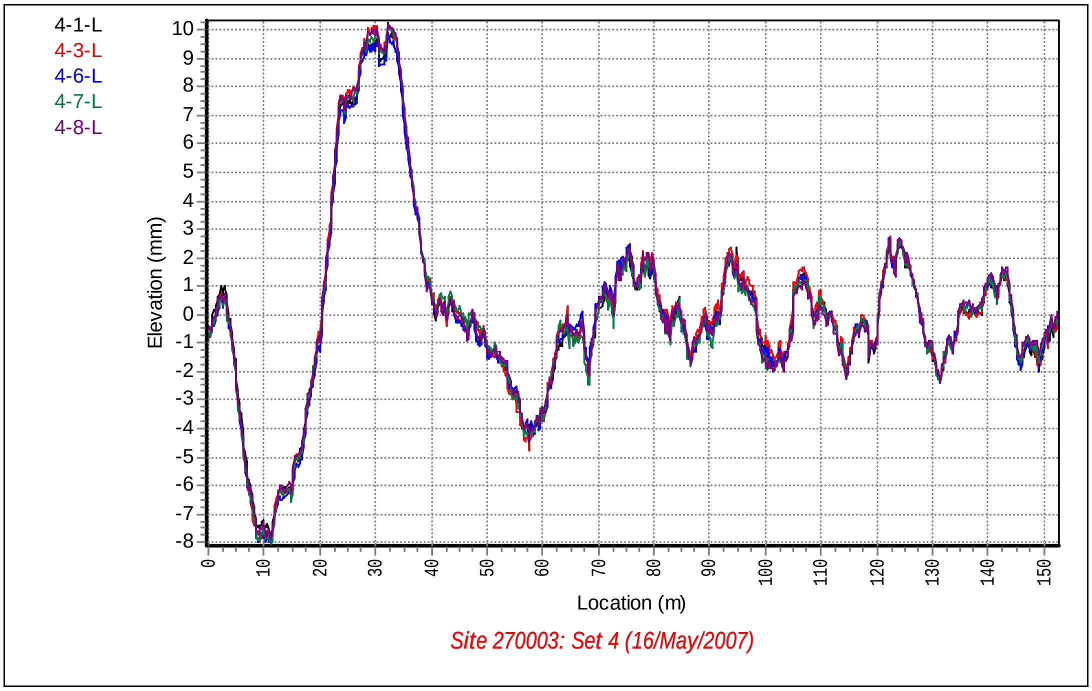
Section 3 – North Central – Right Wheelpath.



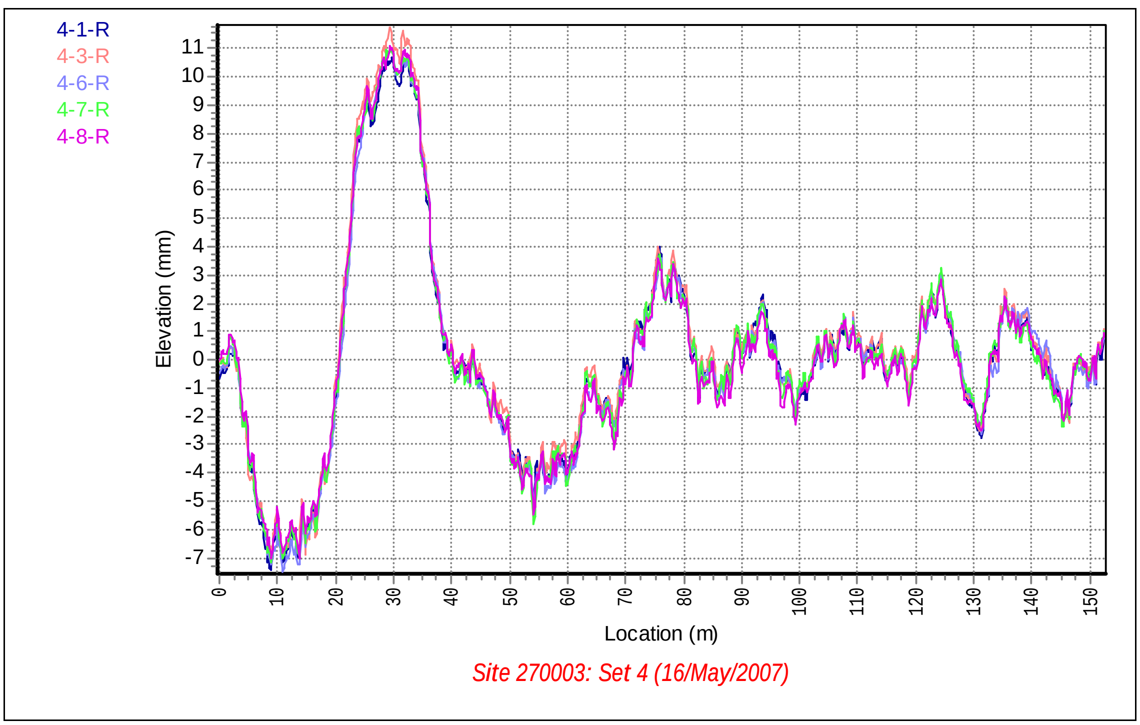
Section 3 – Southern – Left Wheelpath.



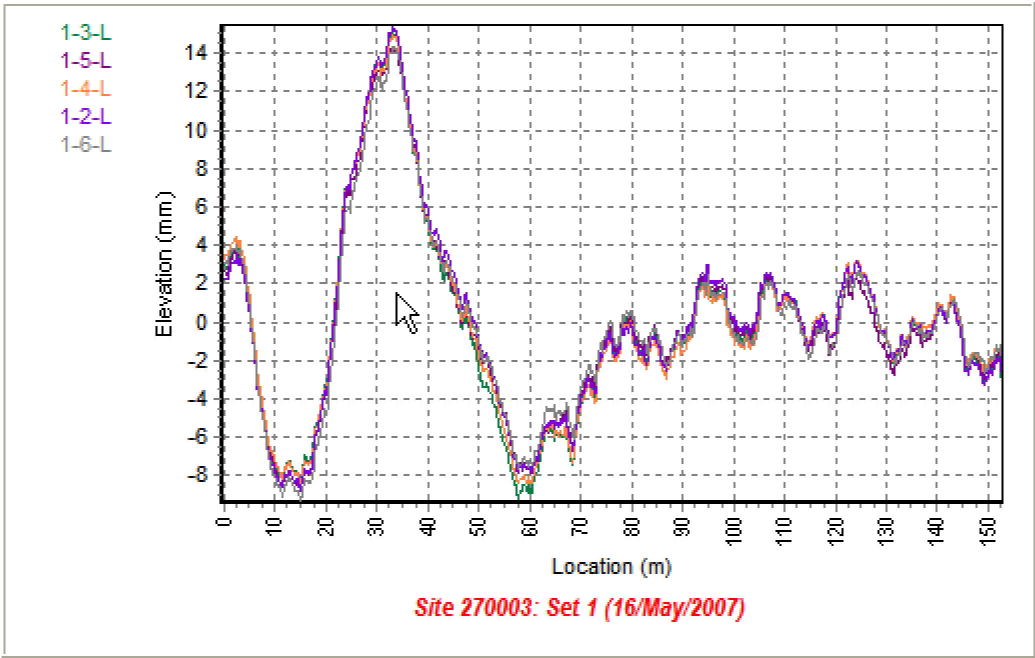
Section 3 – Southern – Right Wheelpath.



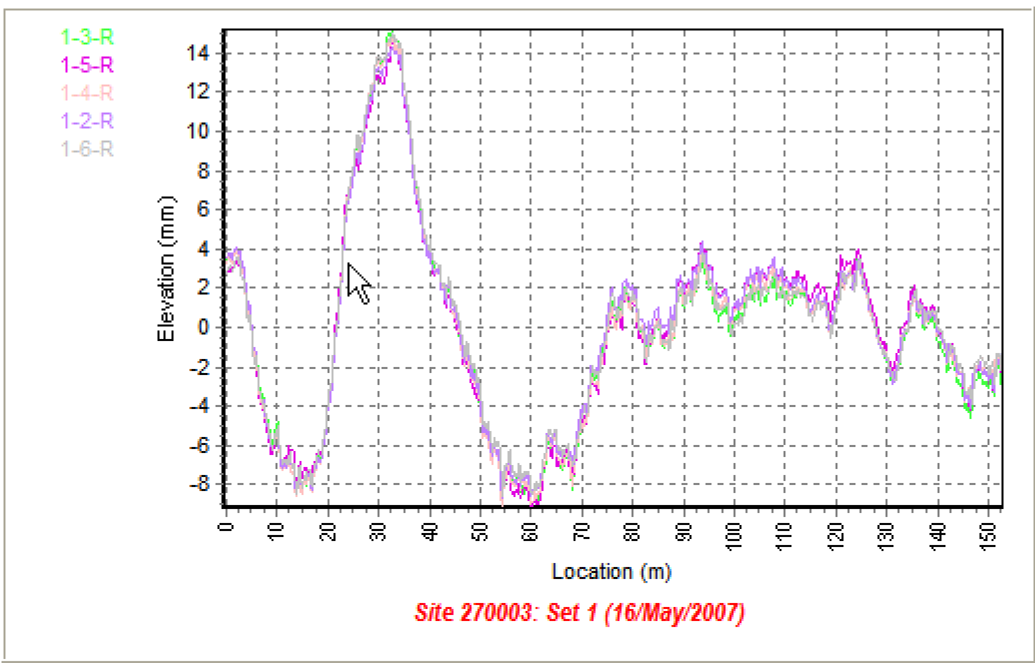
Section 3 – Western – Left Wheelpath.



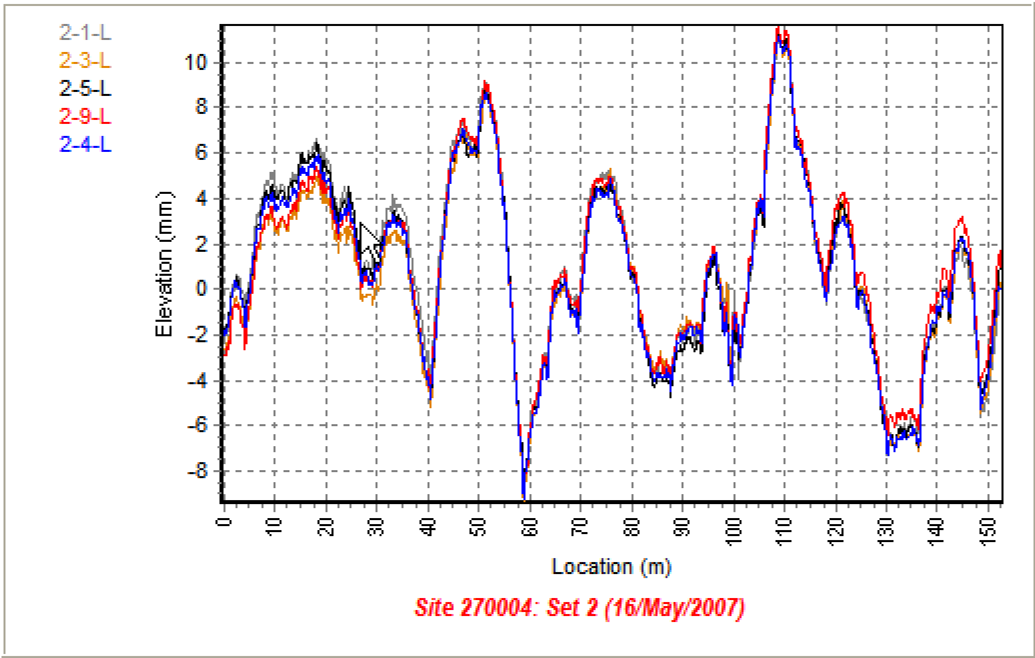
Section 3 – Western – Right Wheelpath.



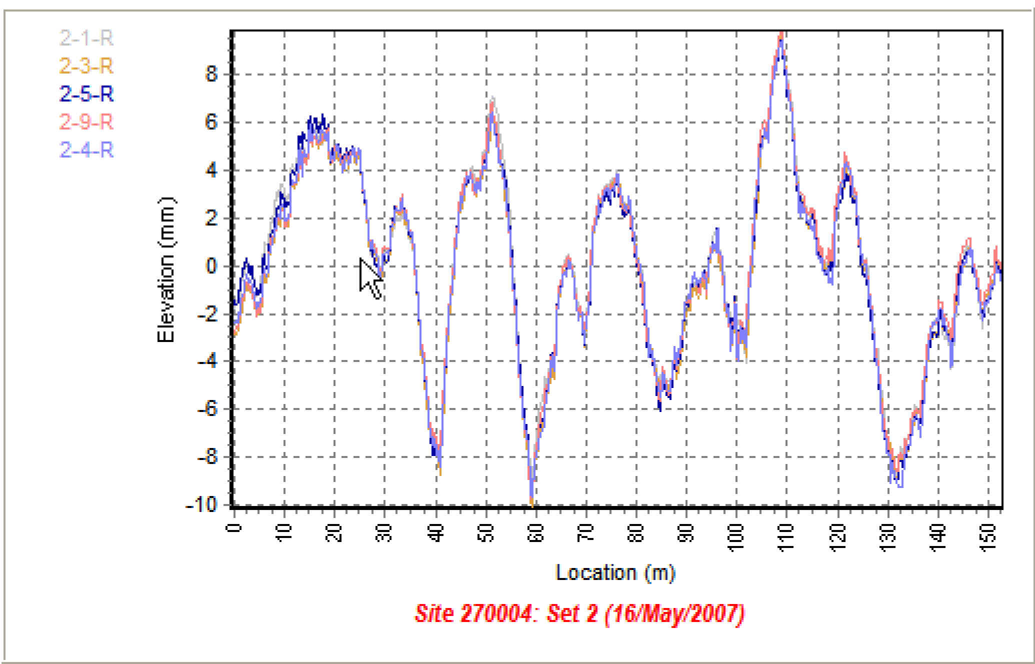
Section 3 – K. J. Law – Left Wheelpath.



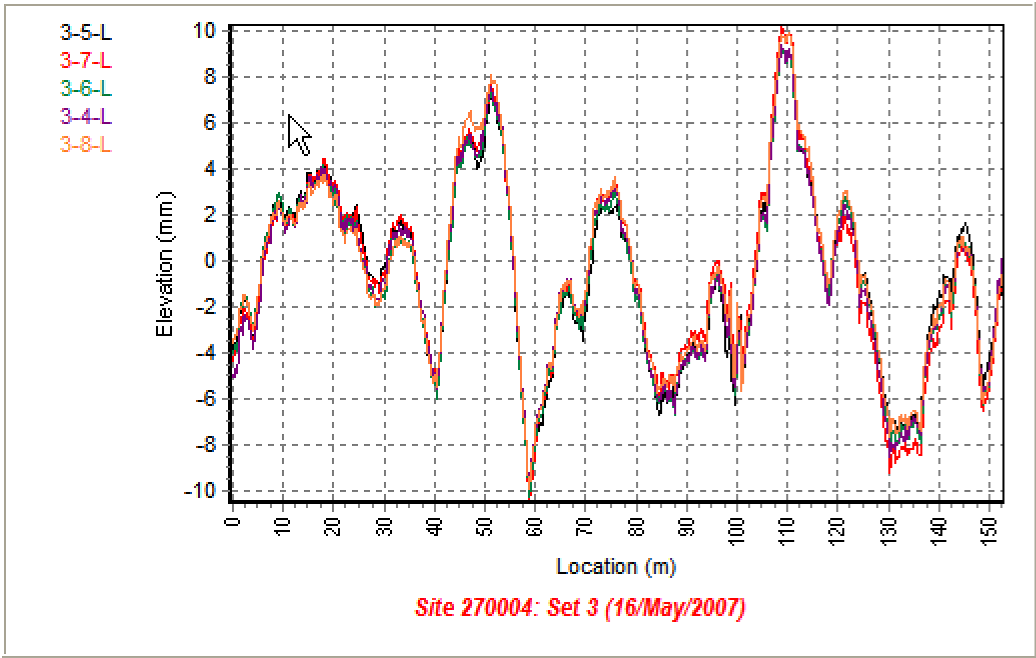
Section 3 – K. J. Law – Right Wheelpath.



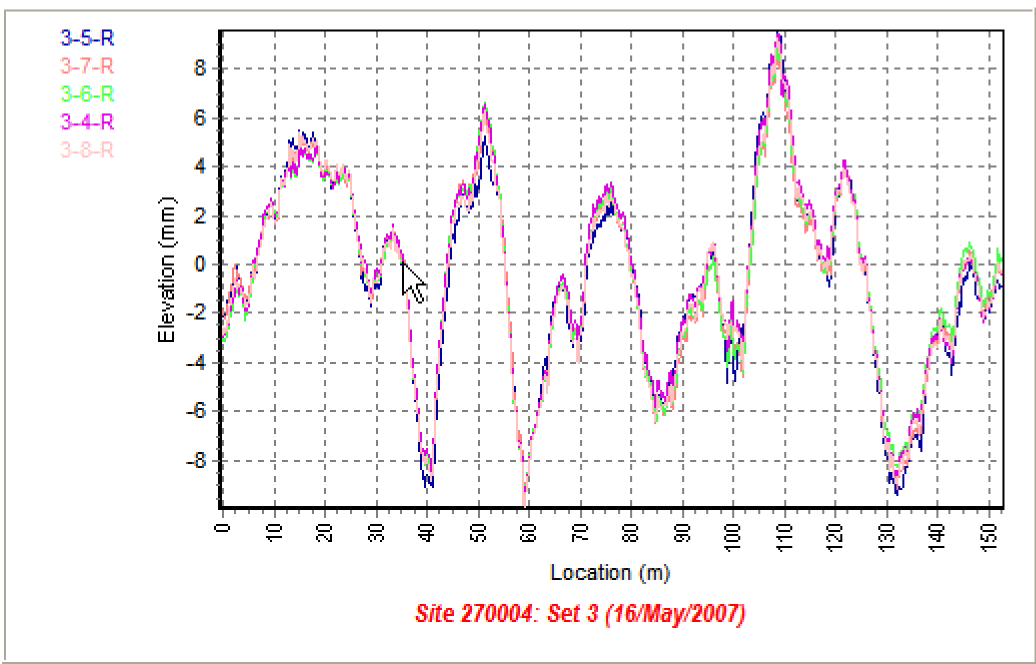
Section 4 - North Atlantic – Left Wheelpath.



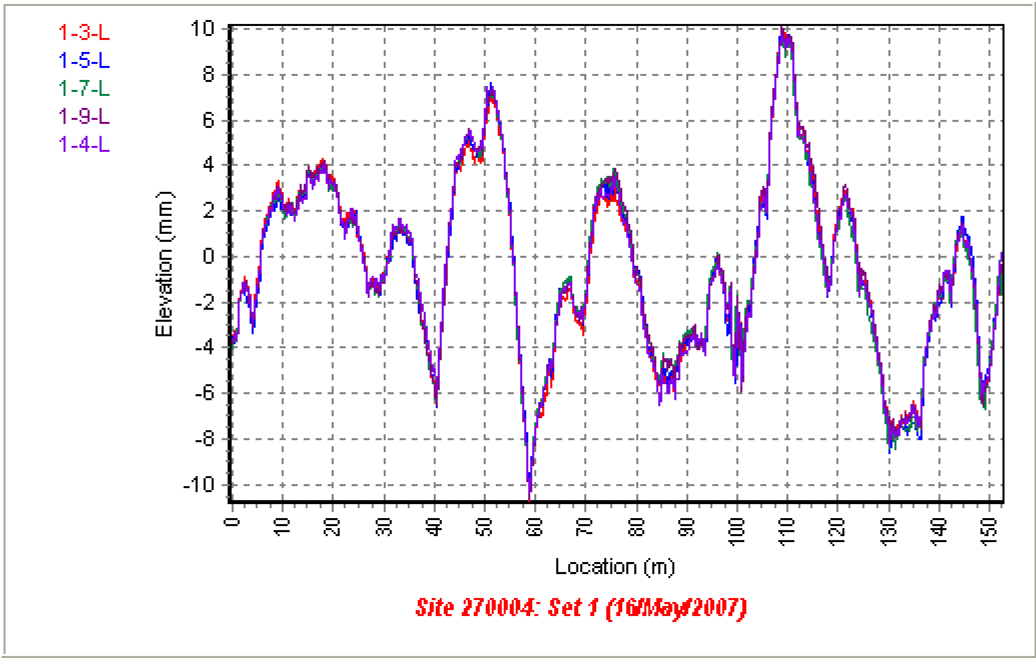
Section 4 – North Atlantic – Right Wheelpath.



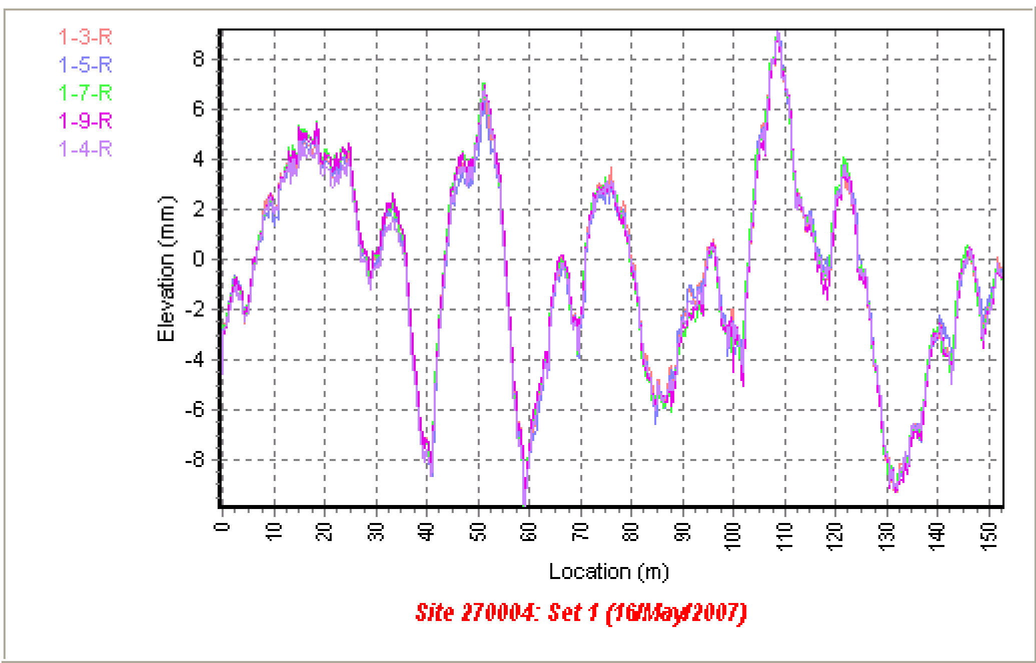
Section 4 – North Central – Left Wheelpath.



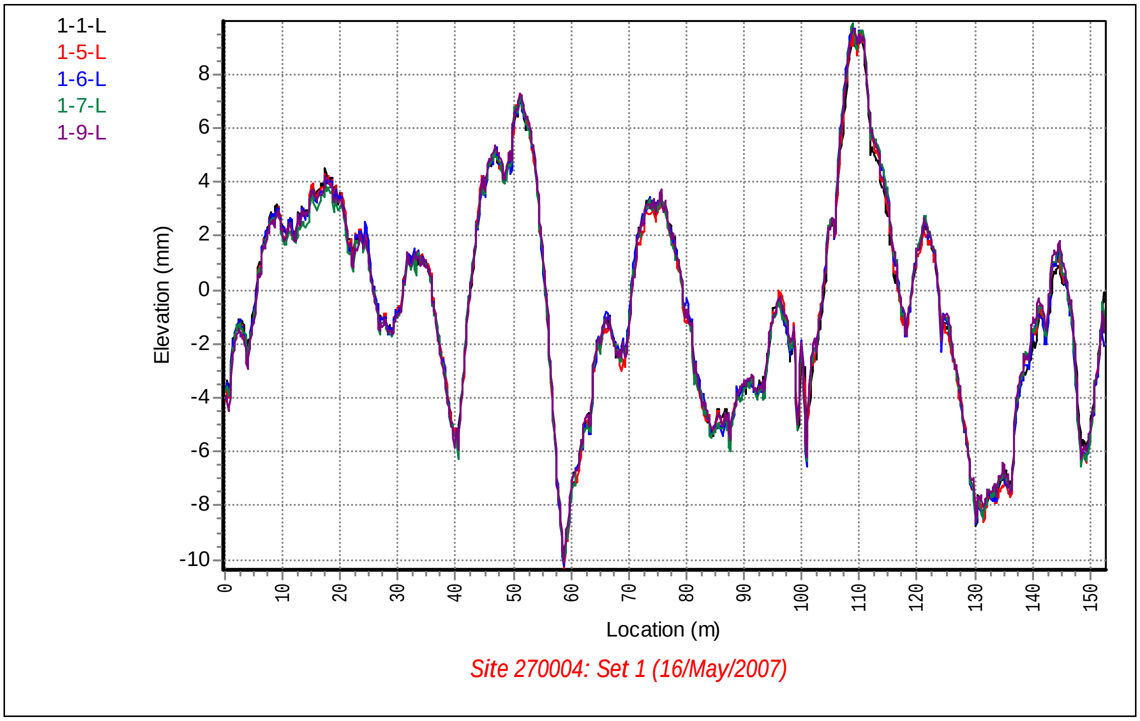
Section 4 – North Central – Right Wheelpath.



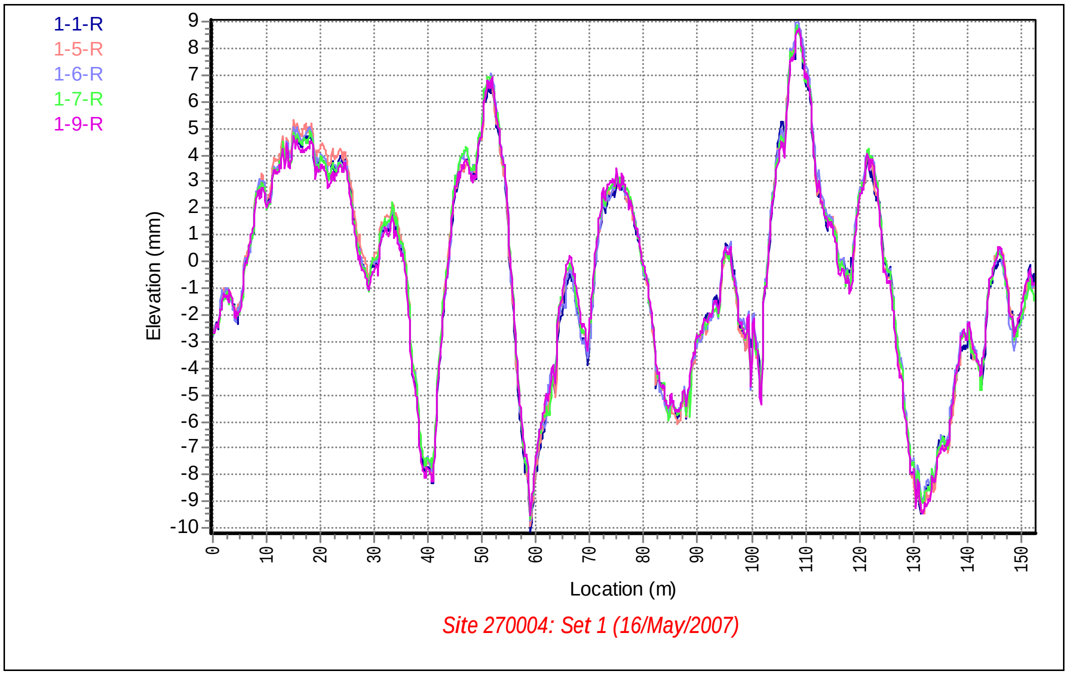
Section 4 – Southern – Left Wheelpath.



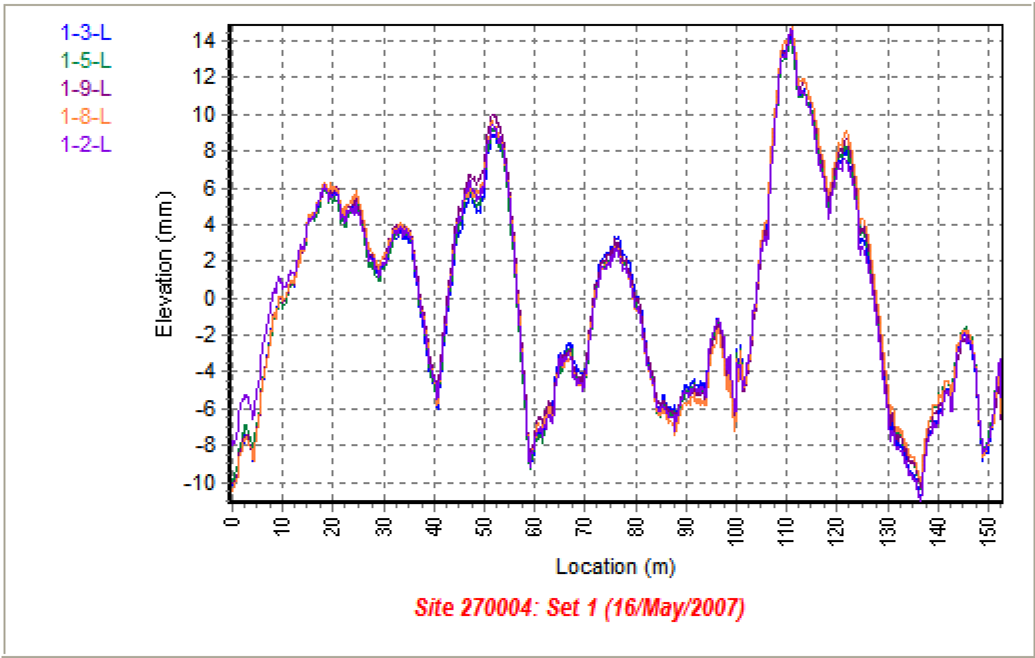
Section 4 – Southern – Right Wheelpath.



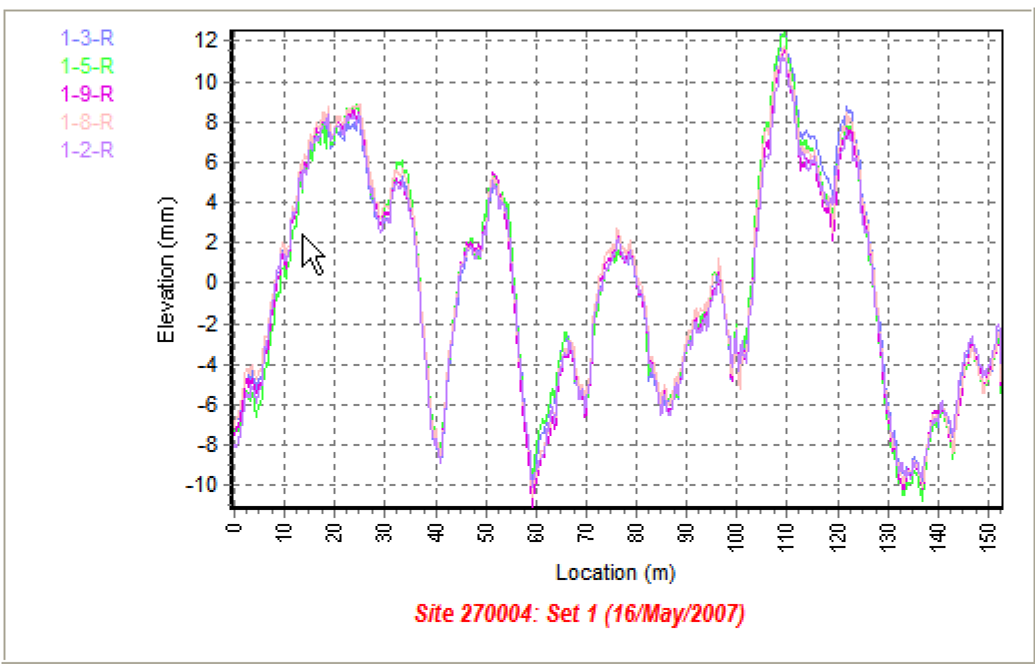
Section 4 – Western – Left Wheelpath.



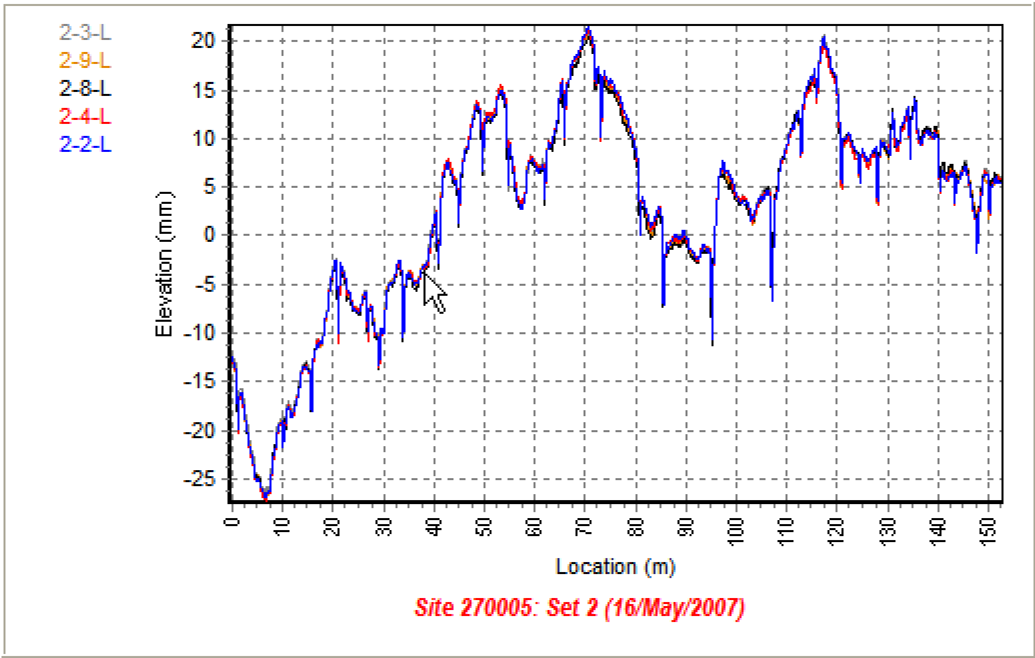
Section 4 – Western – Right Wheelpath.



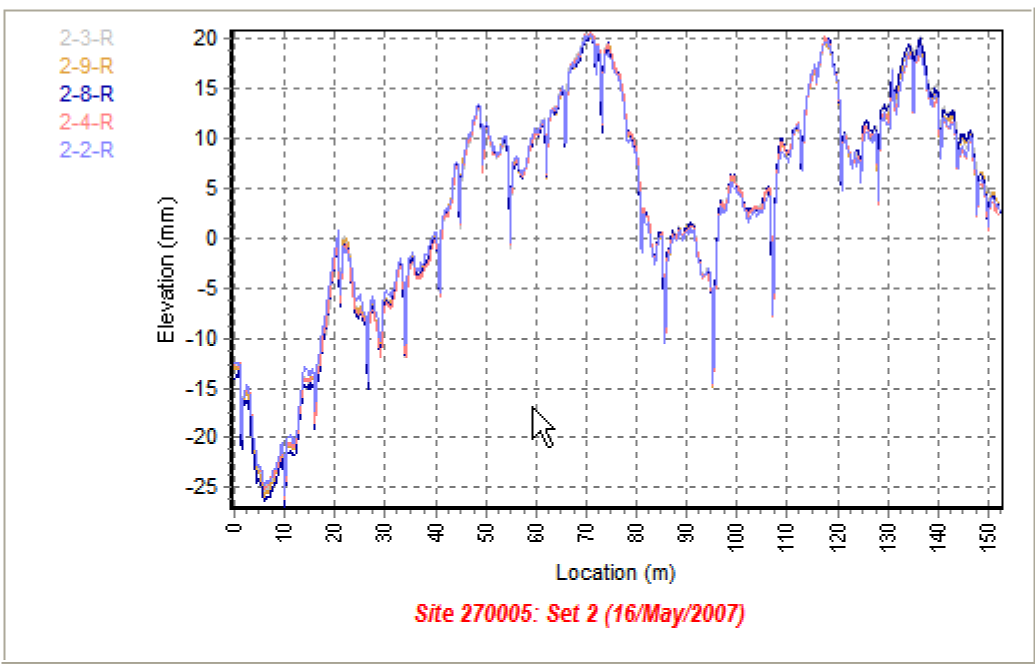
Section 4 – K. J. Law – Left Wheelpath.



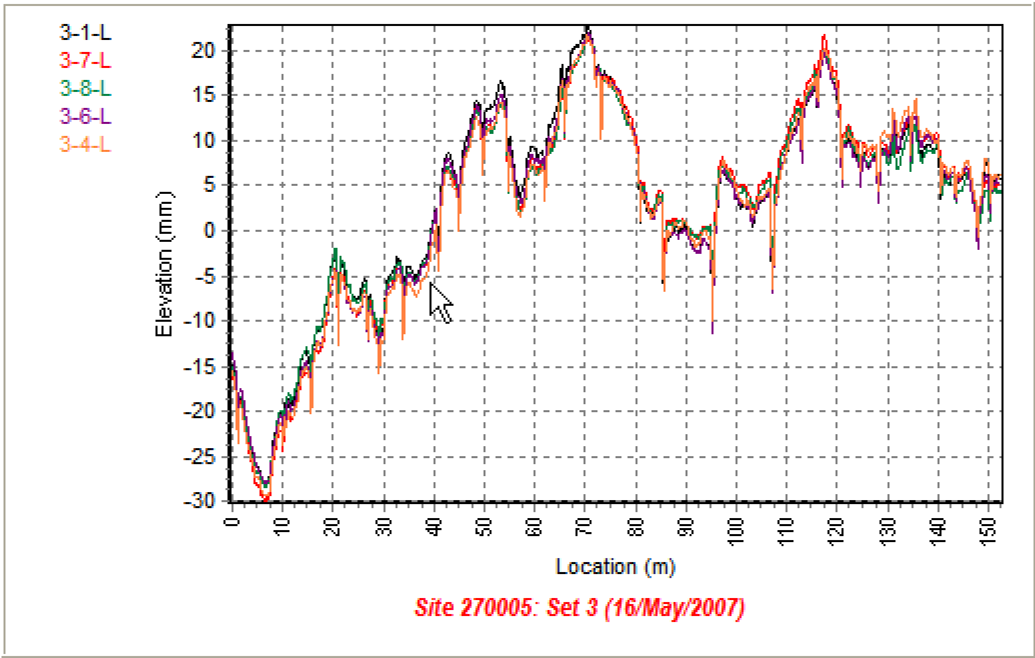
Section 4 – K. J. Law – Right Wheelpath.



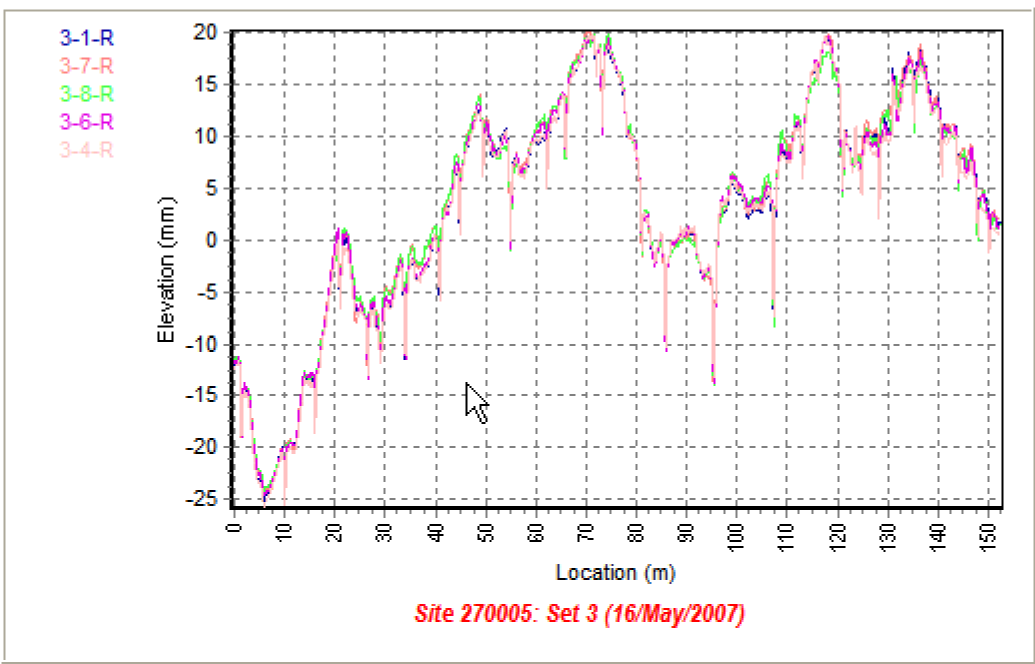
Section 5 – North Atlantic – Left Wheelpath.



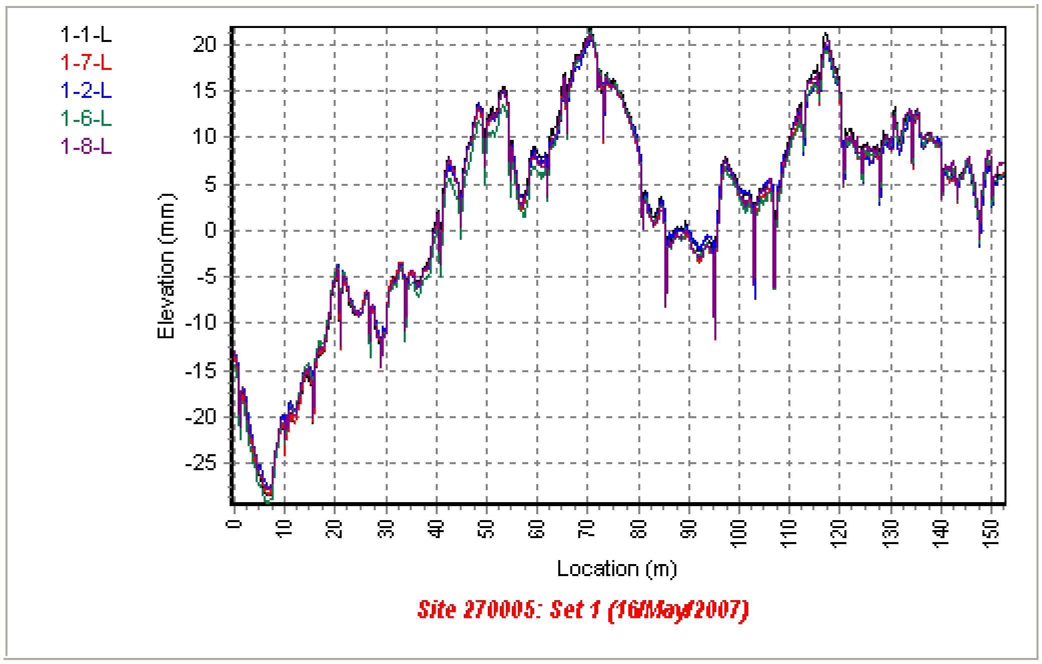
Section 5 – North Atlantic – Right Wheelpath.



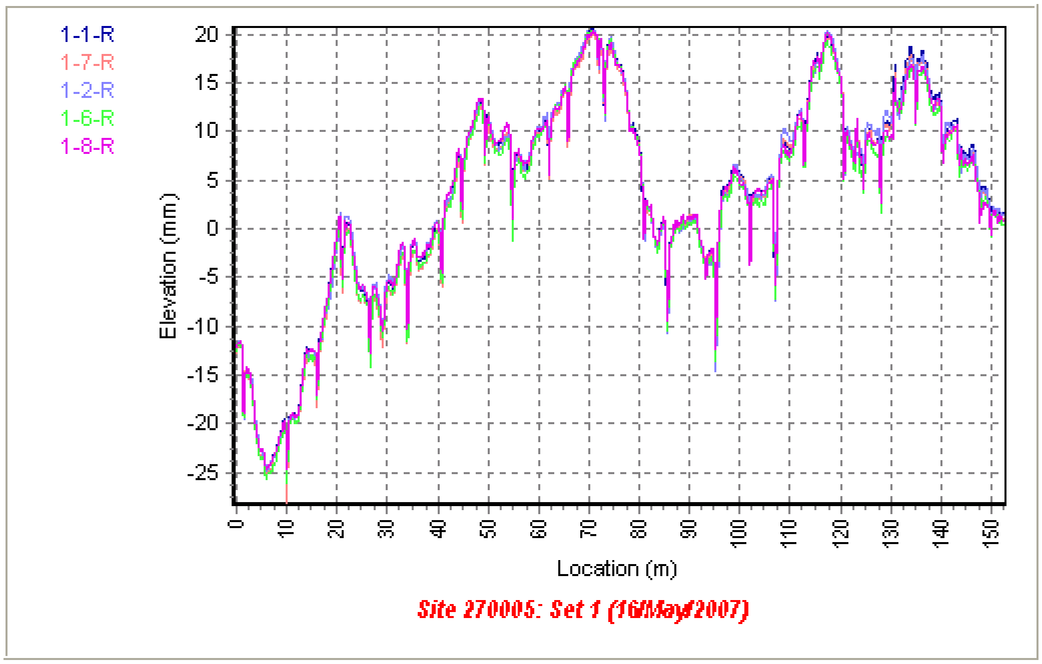
Section 5 – North Central – Left Wheelpath.



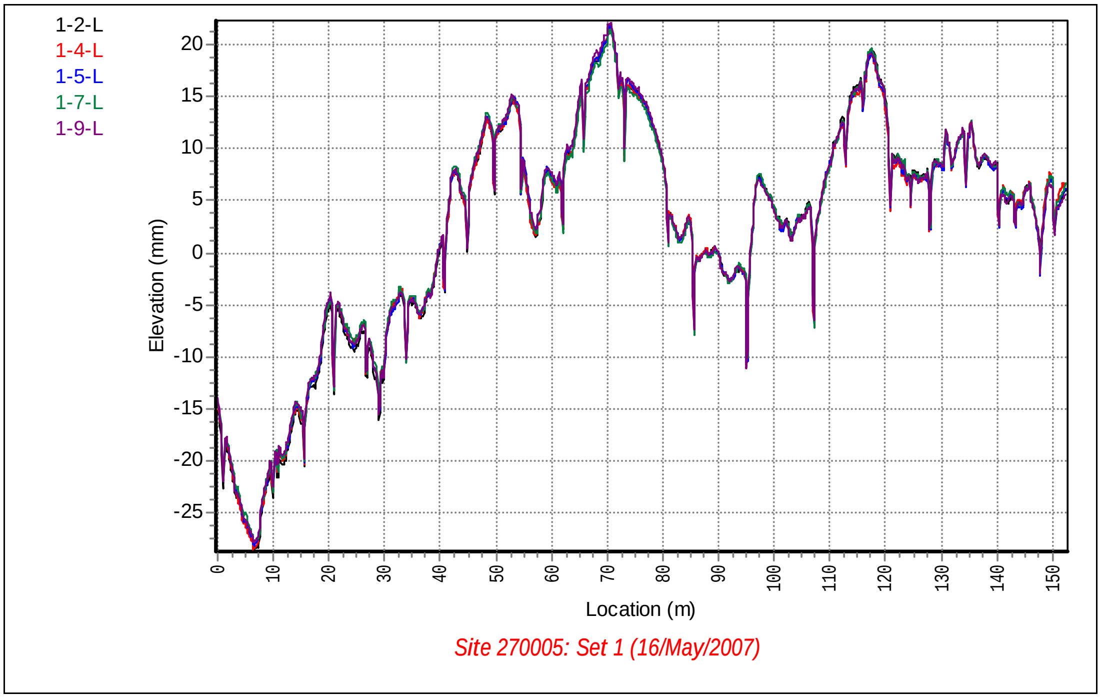
Section 5 – North Central – Right Wheelpath.



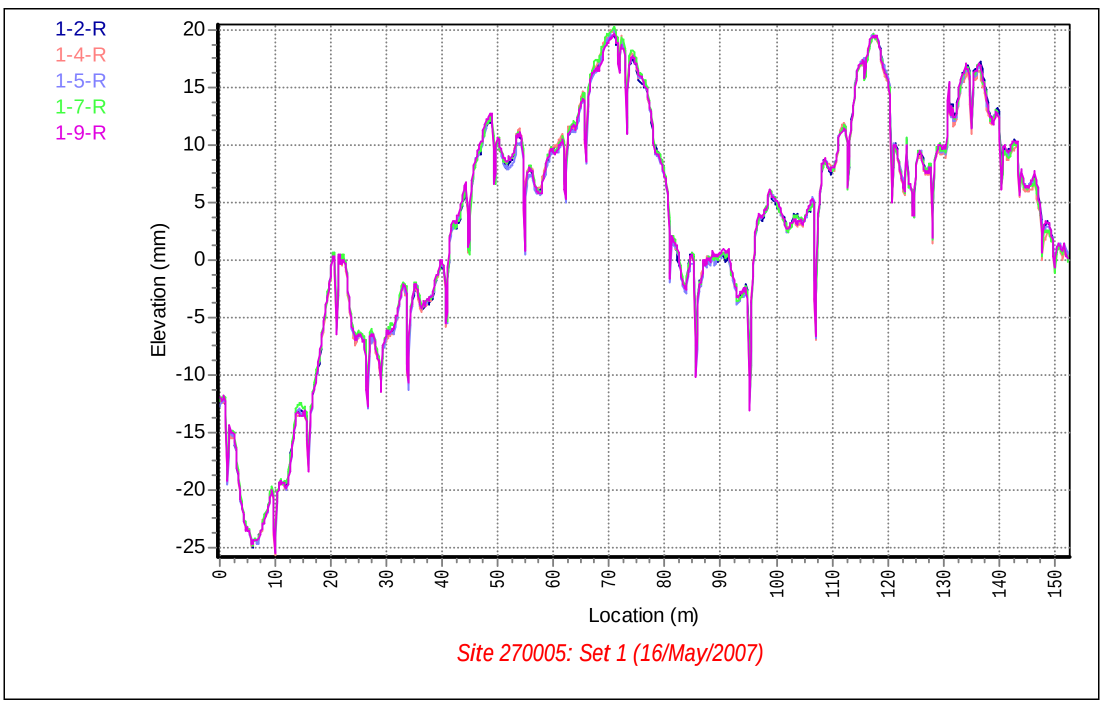
Section 5 – Southern – Left Wheelpath.



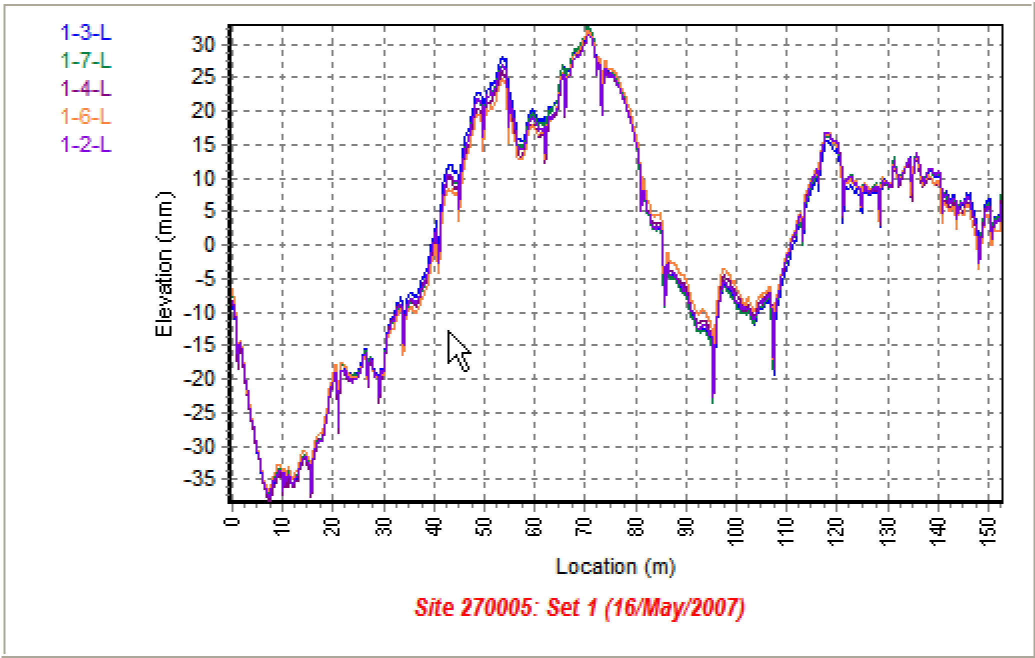
Section 5 – Southern – Right Wheelpath.



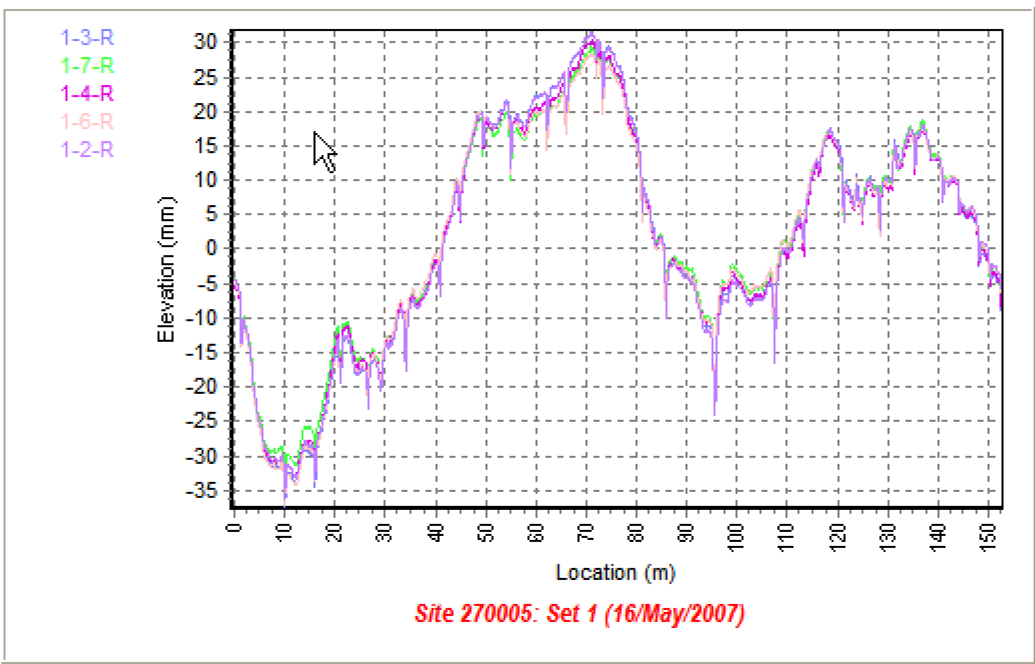
Section 5 – Western – Left Wheelpath.



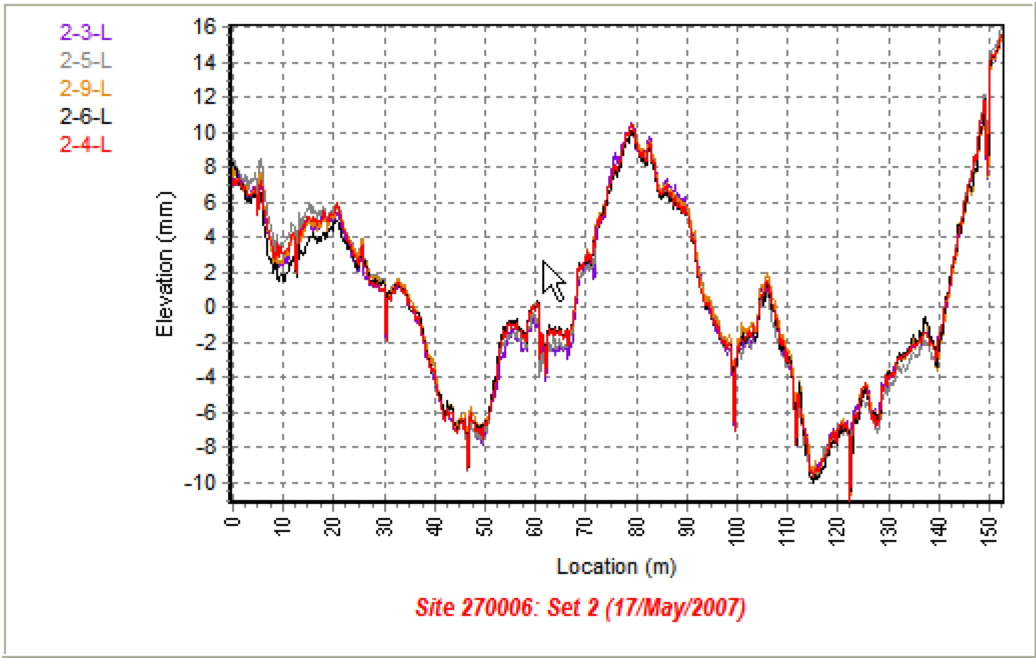
Section 5 – Western – Right Wheelpath.



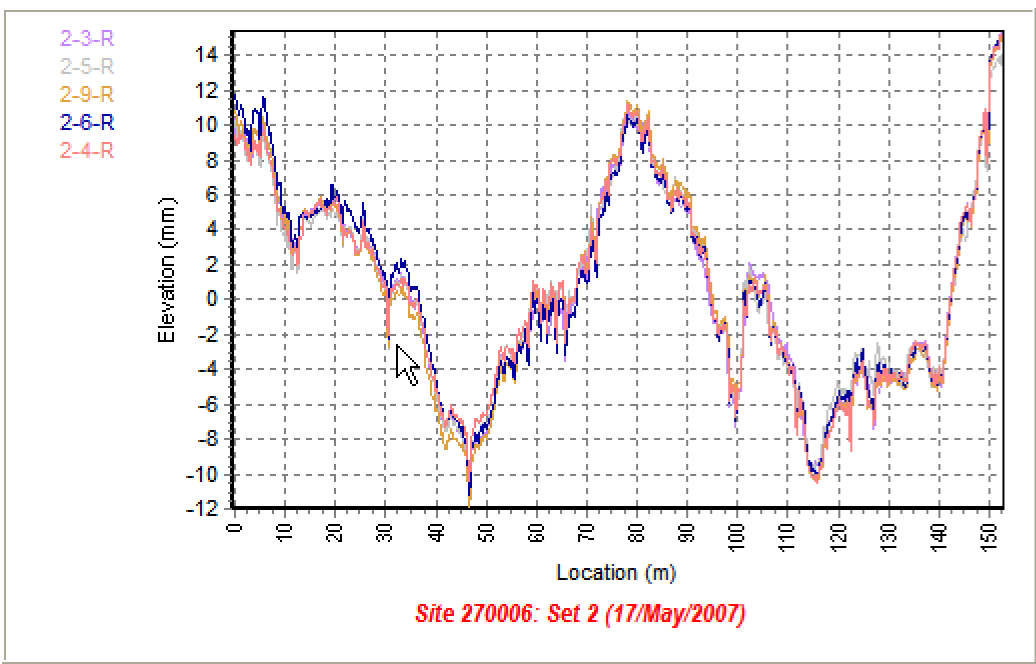
Section 5 – K. J. Law – Left Wheelpath.



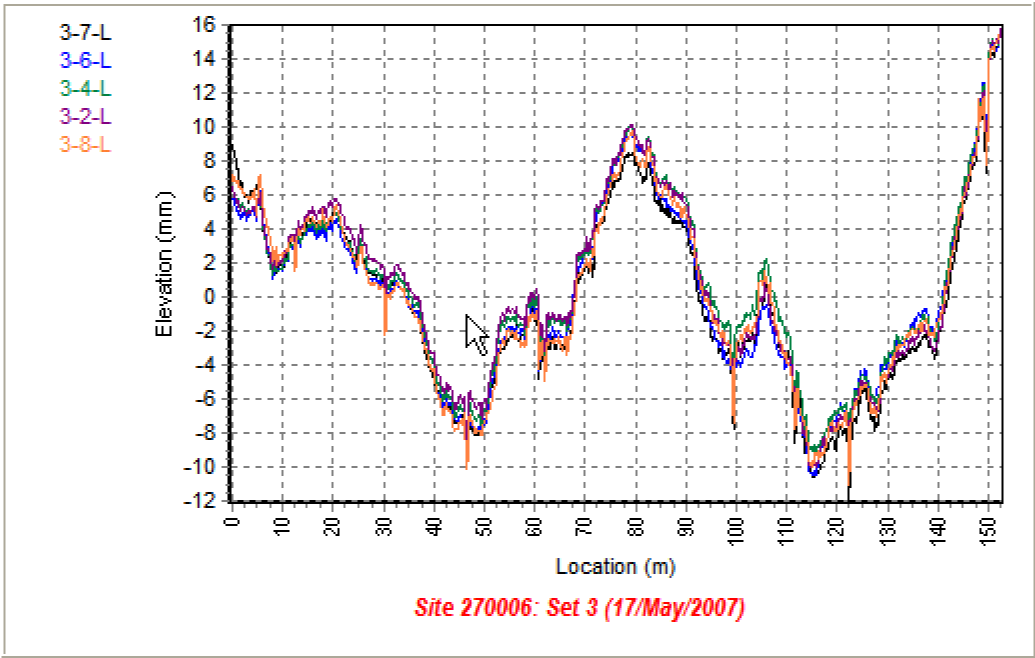
Section 5 – K. J. Law – Right Wheelpath.



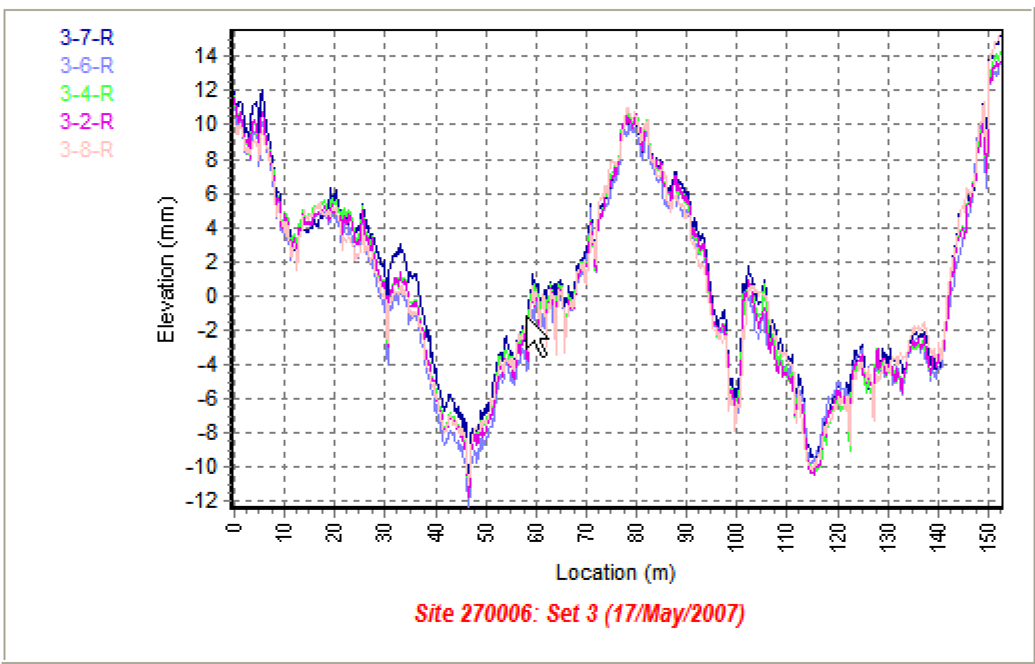
Section 6 – North Atlantic – Left Wheelpath.



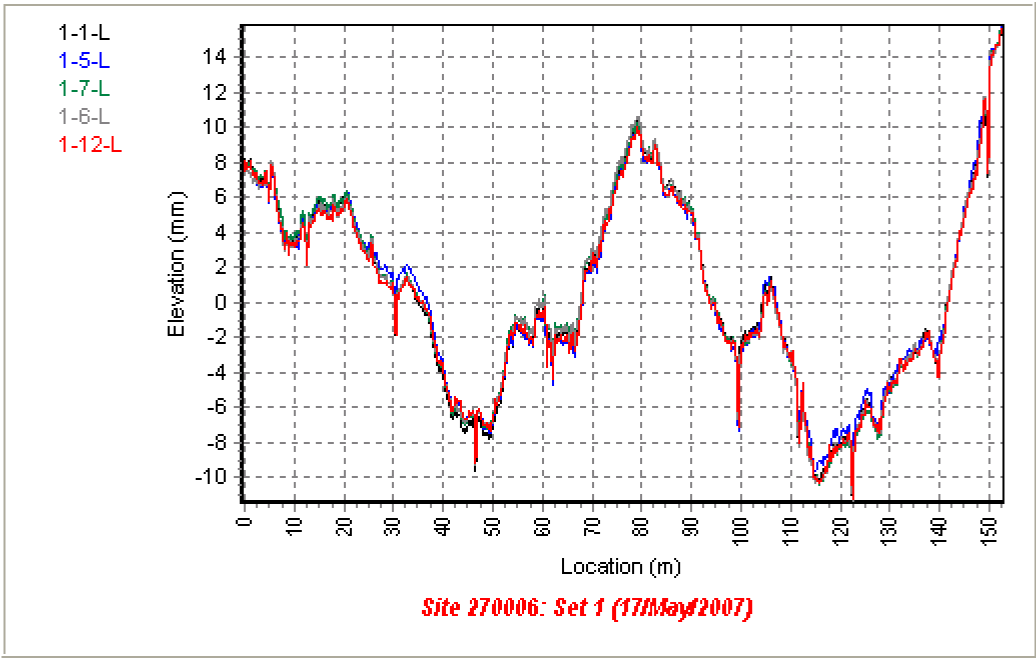
Section 6 - North Atlantic – Right Wheelpath.



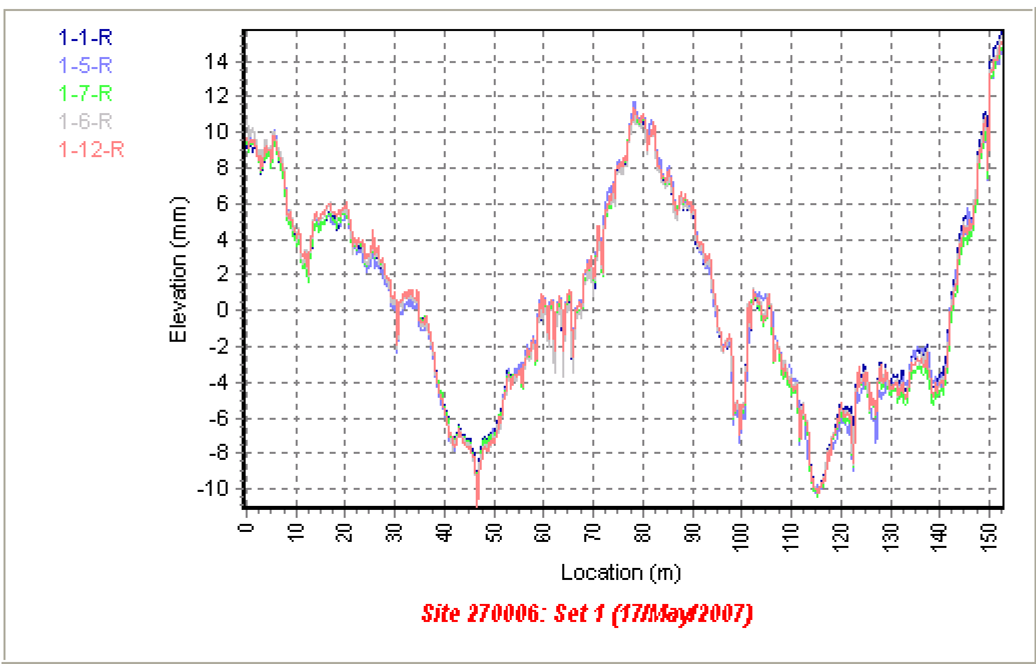
Section 6 – North Central – Left Wheelpath.



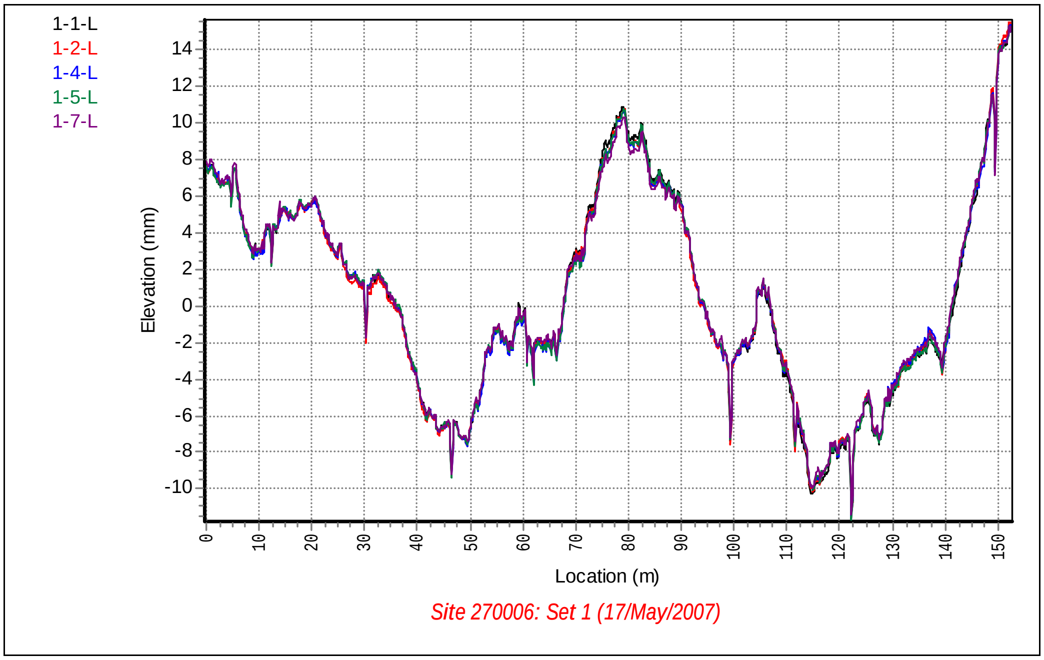
Section 6 – North Central – Right Wheelpath.



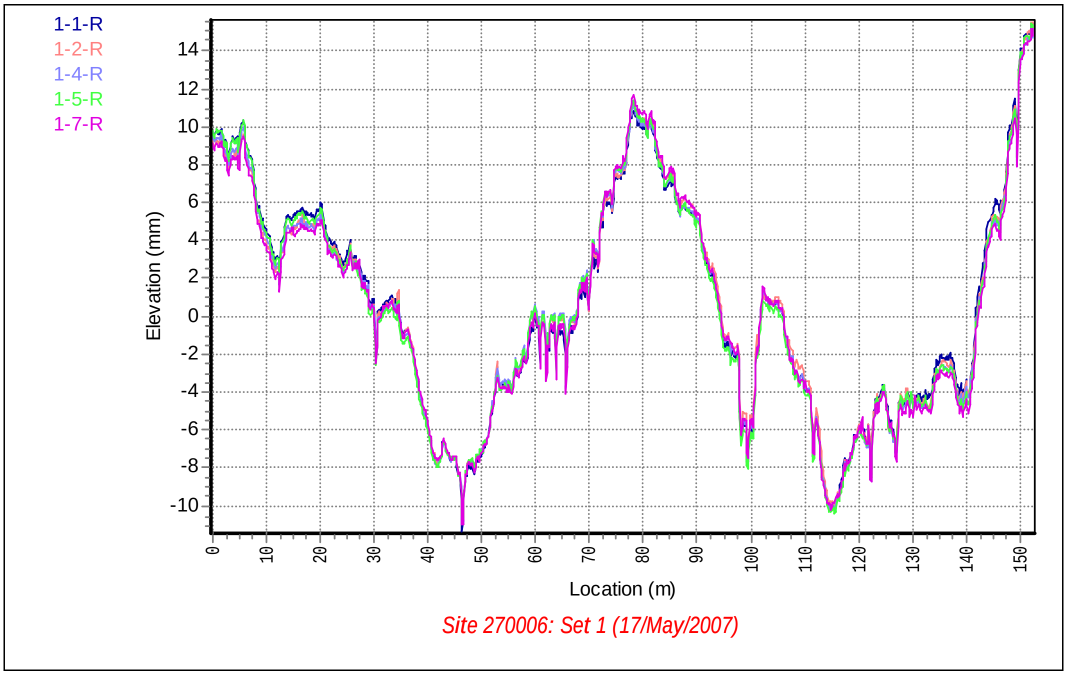
Section 6 – Southern – Left Wheelpath.



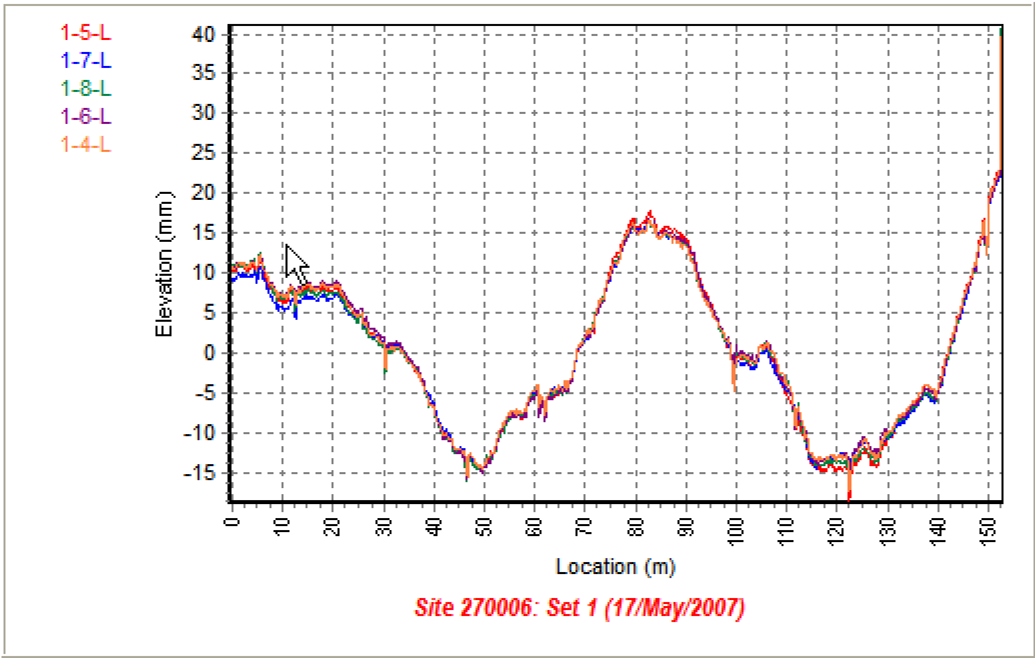
Section 6 – Southern – Right Wheelpath.



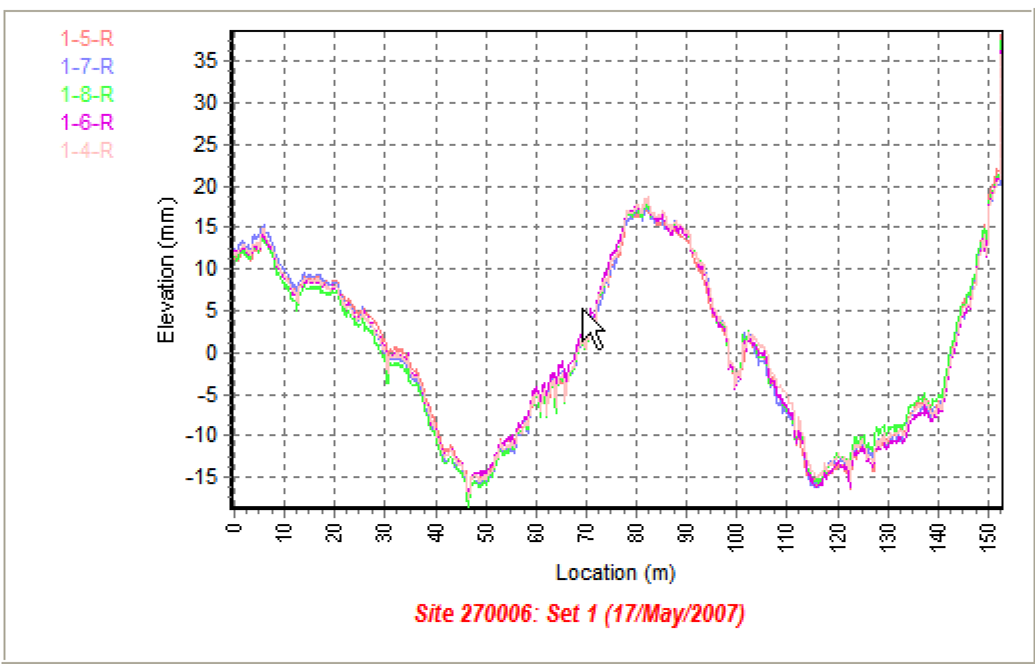
Section 6 – Western – Left Wheelpath.



Section 6 – Western - Right Wheelpath.



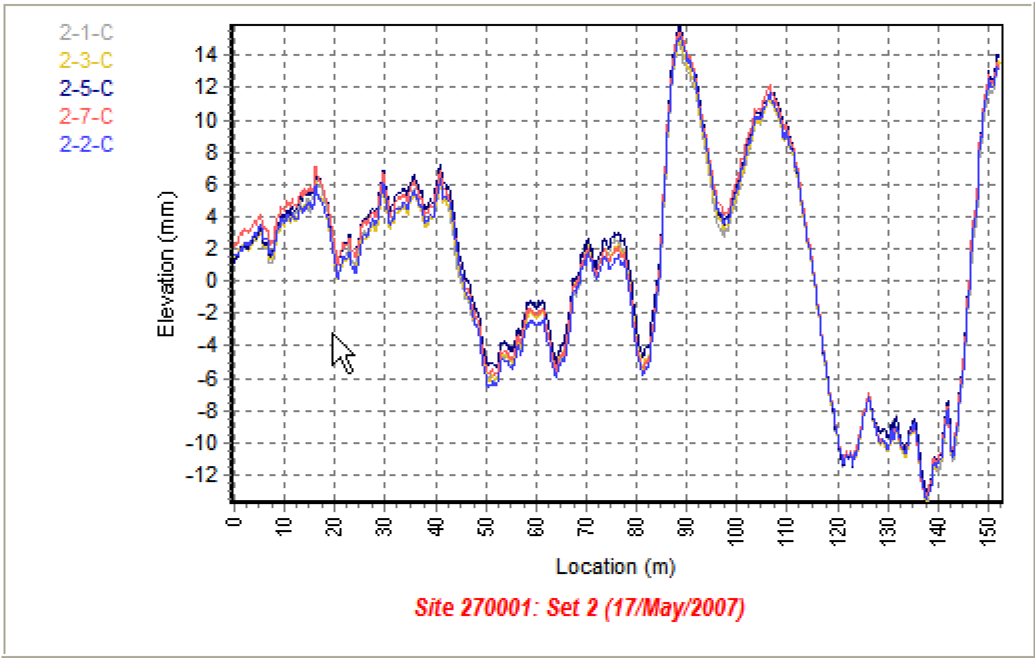
Section 6 - K. J. Law – Left Wheelpath.



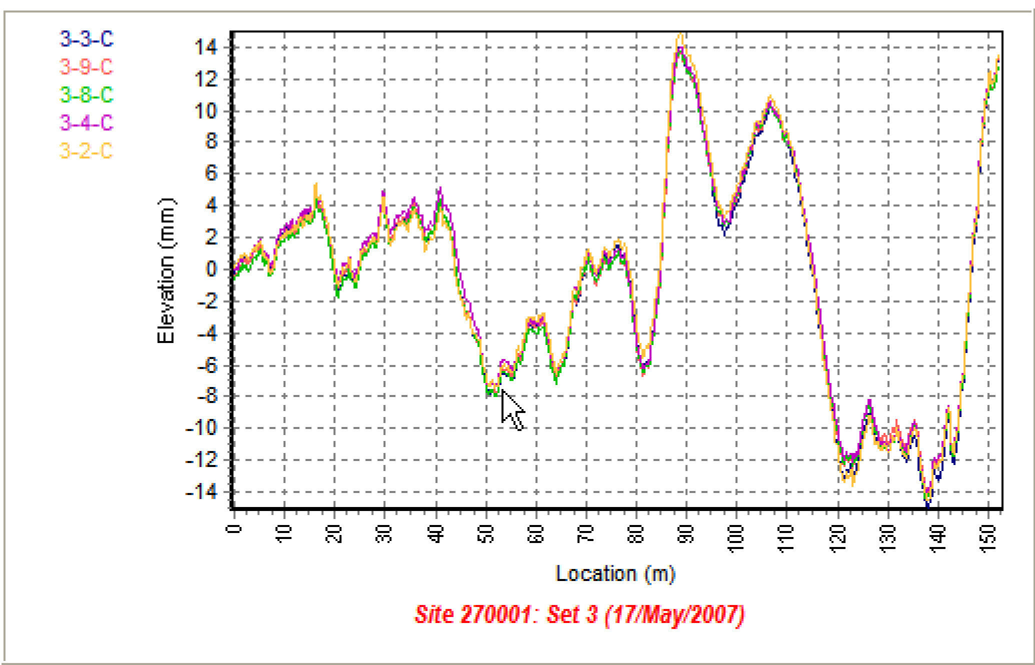
Section 6 – K. J. Law – Right Wheelpath.

APPENDIX E

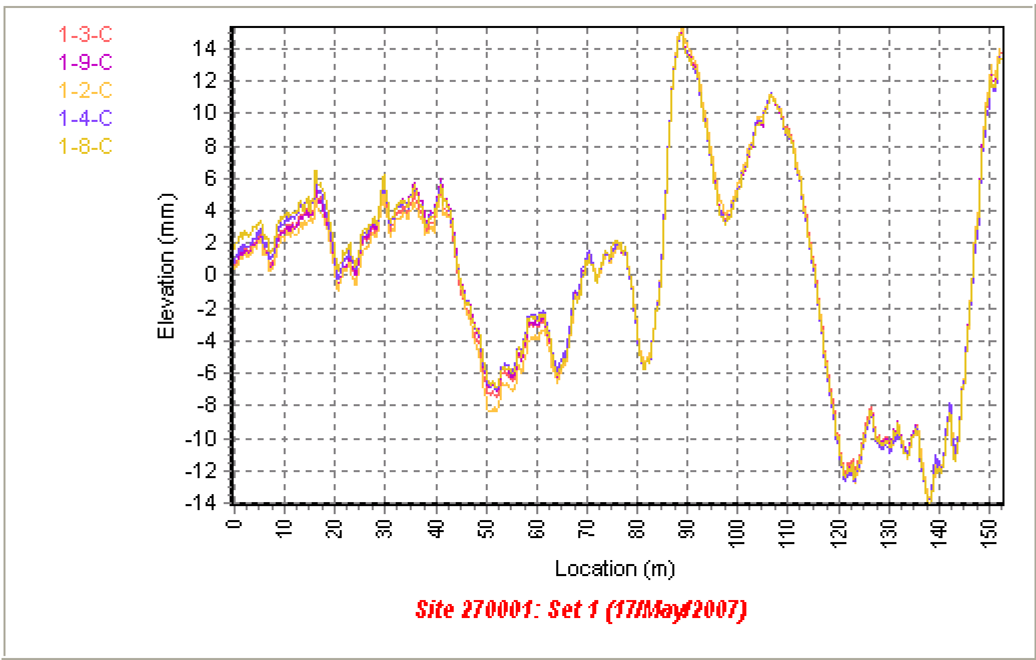
PLOTS OF REPLICATE CENTER SENSOR PROFILES OBTAINED BY PROFILERS



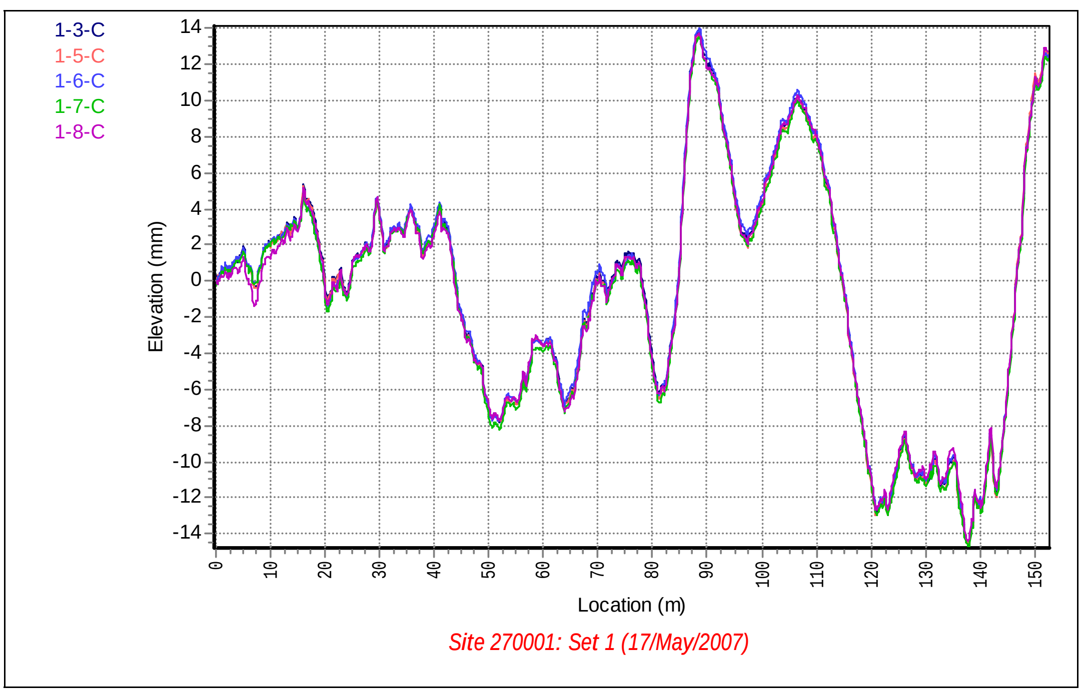
Section 1 – North Atlantic.



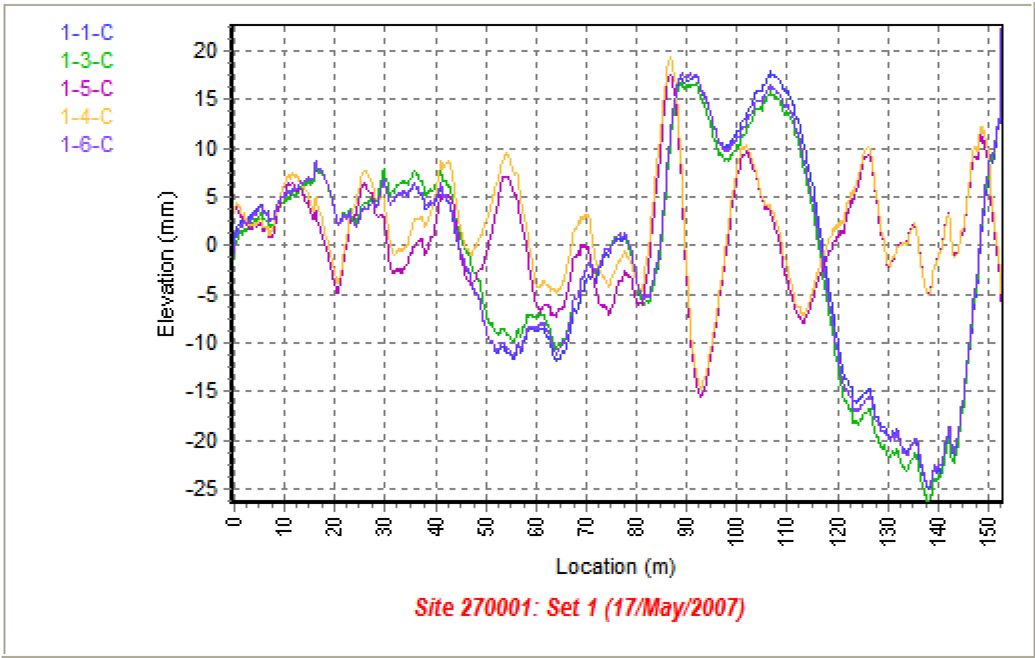
Section 1 – North Central.



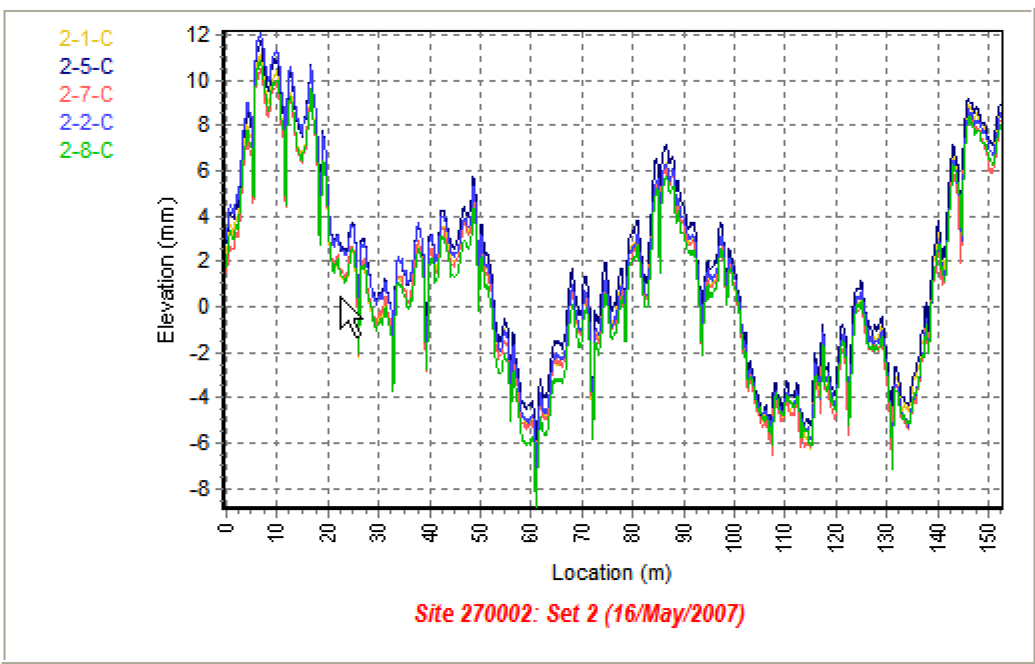
Section 1 – Southern.



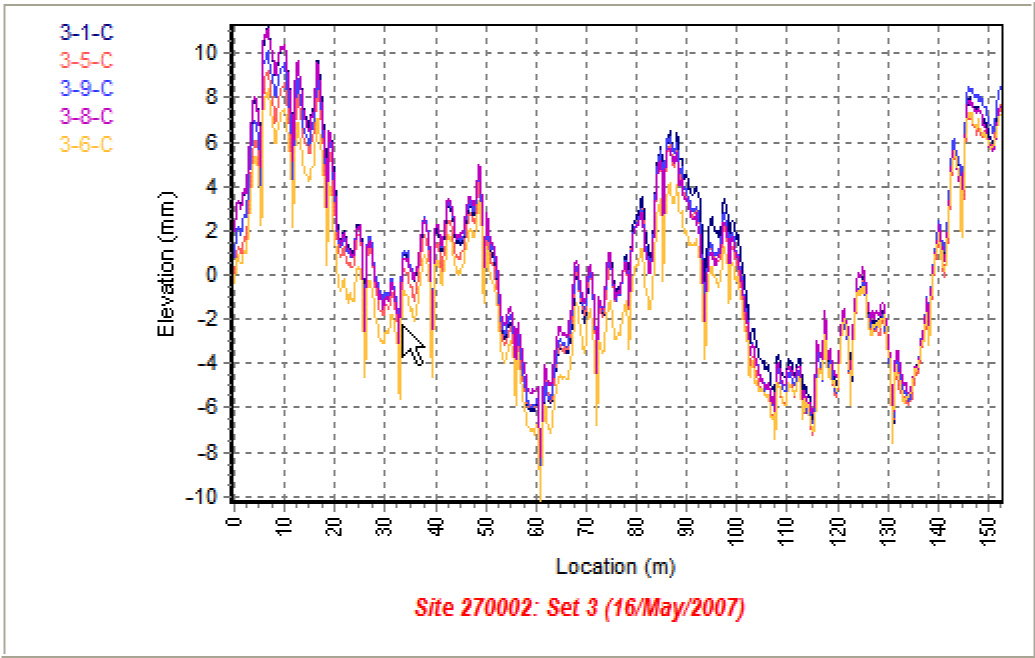
Section 1 – Western.



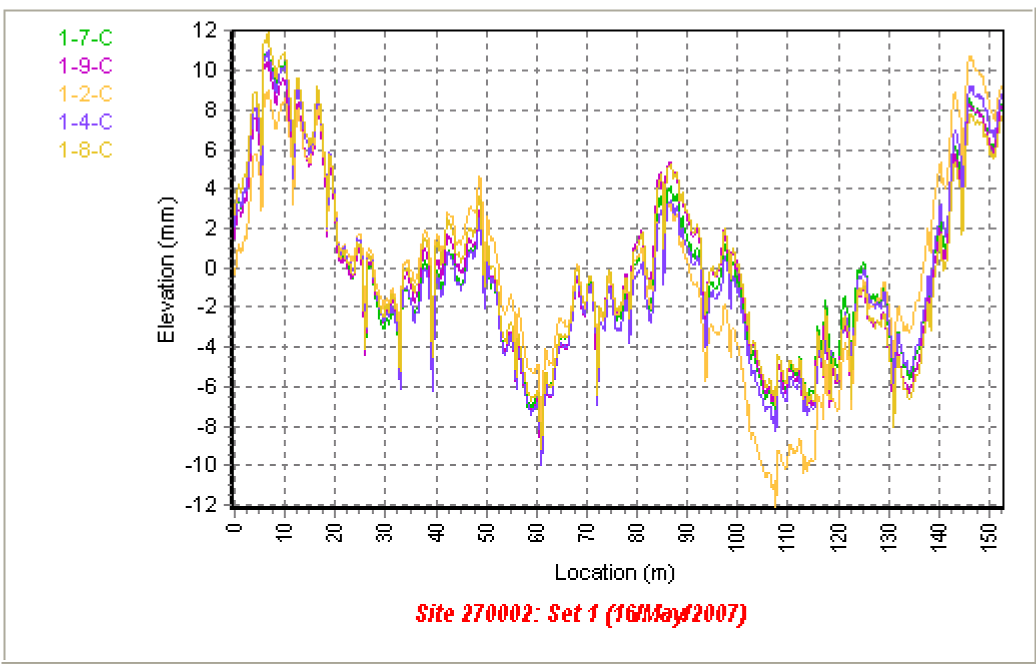
Section 1 – K. J. Law.



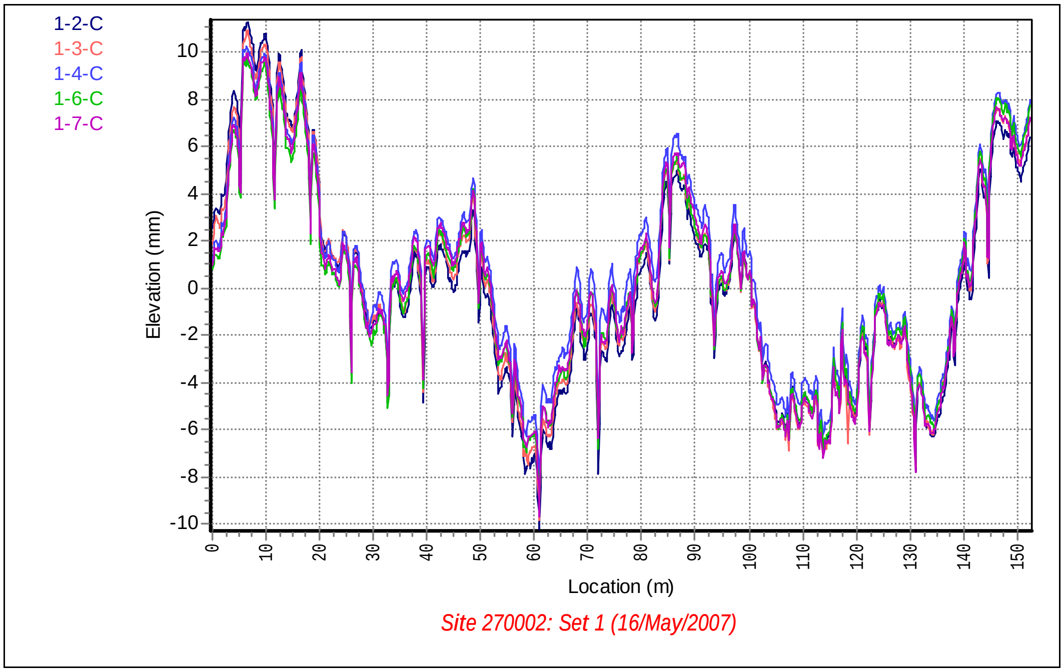
Section 2 – North Atlantic.



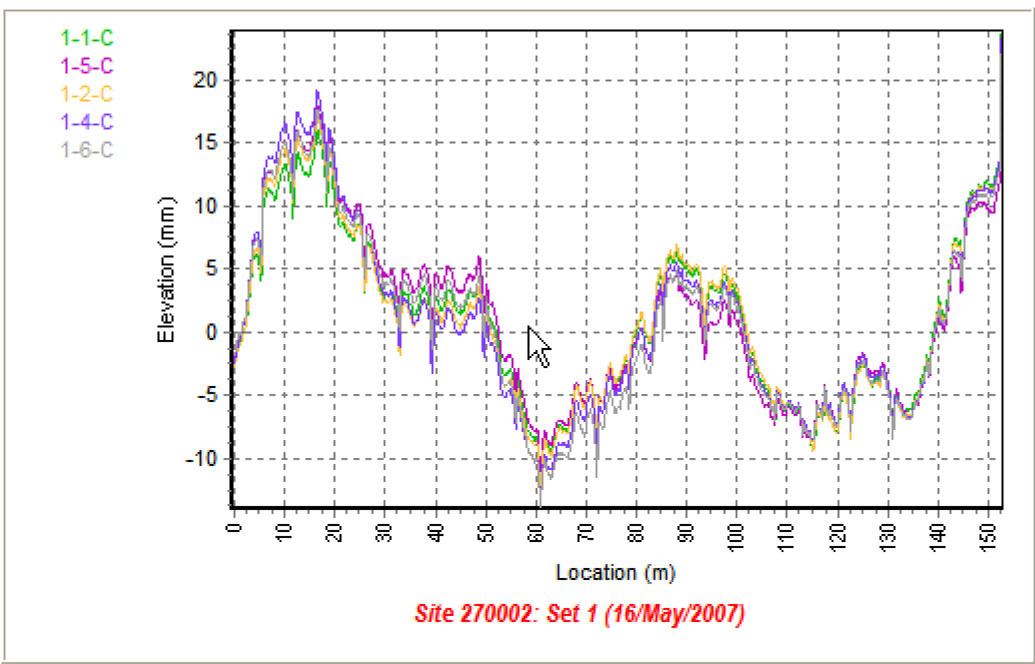
Section 2 – North Central.



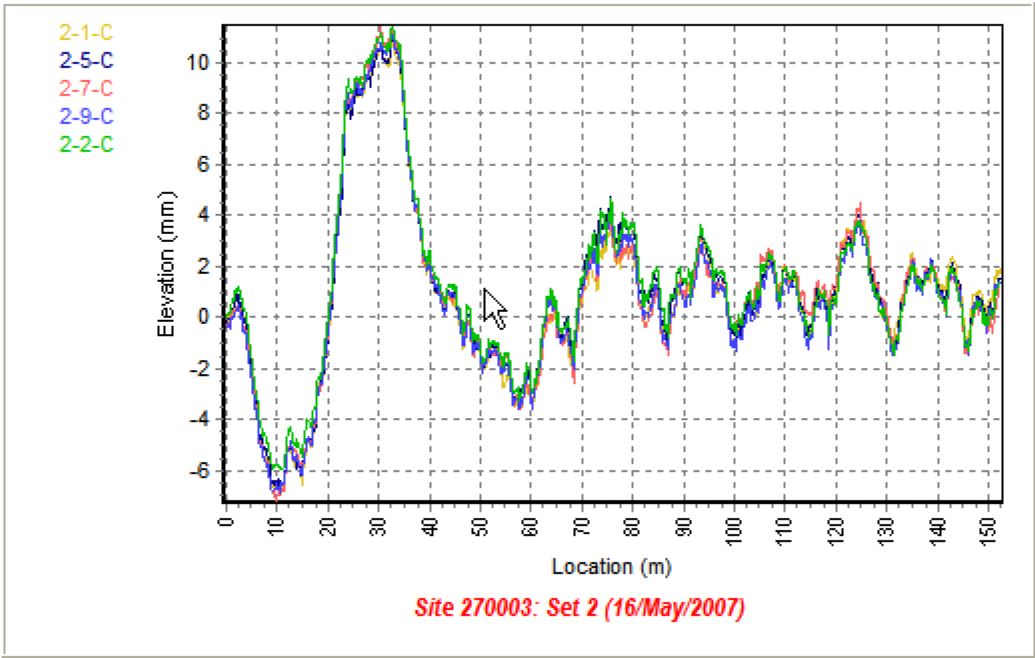
Section 2 – Southern.



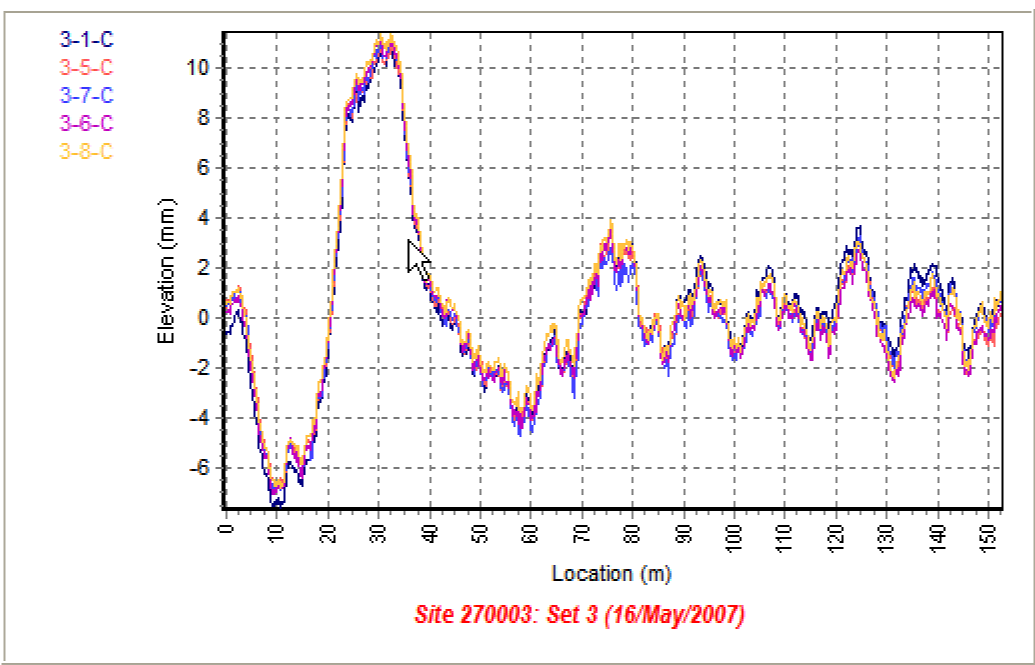
Section 2 – Western.



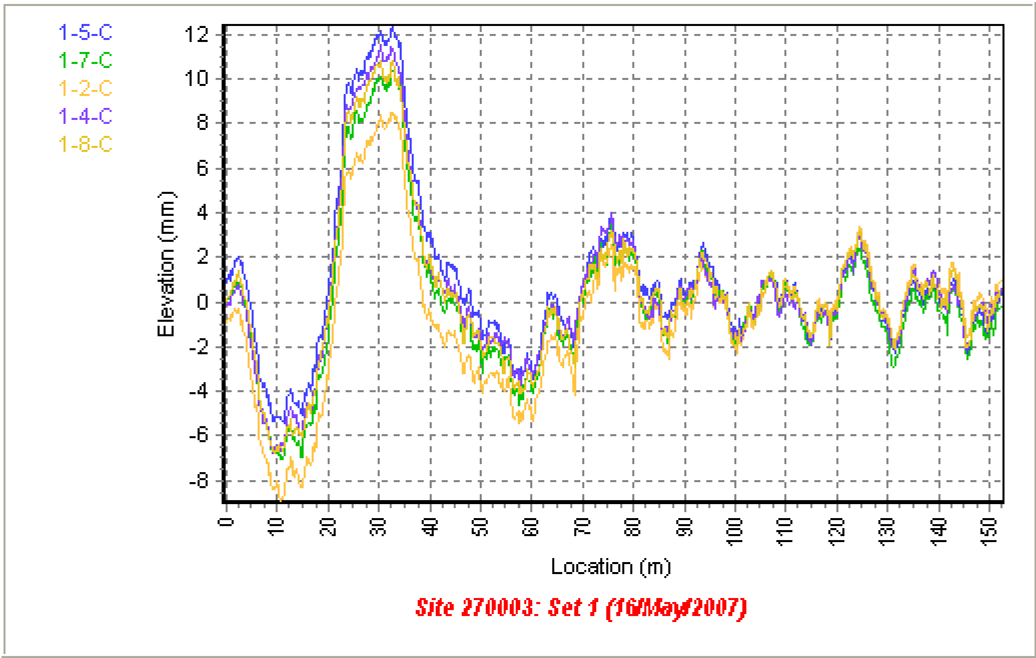
Section 2 – K. J. Law.



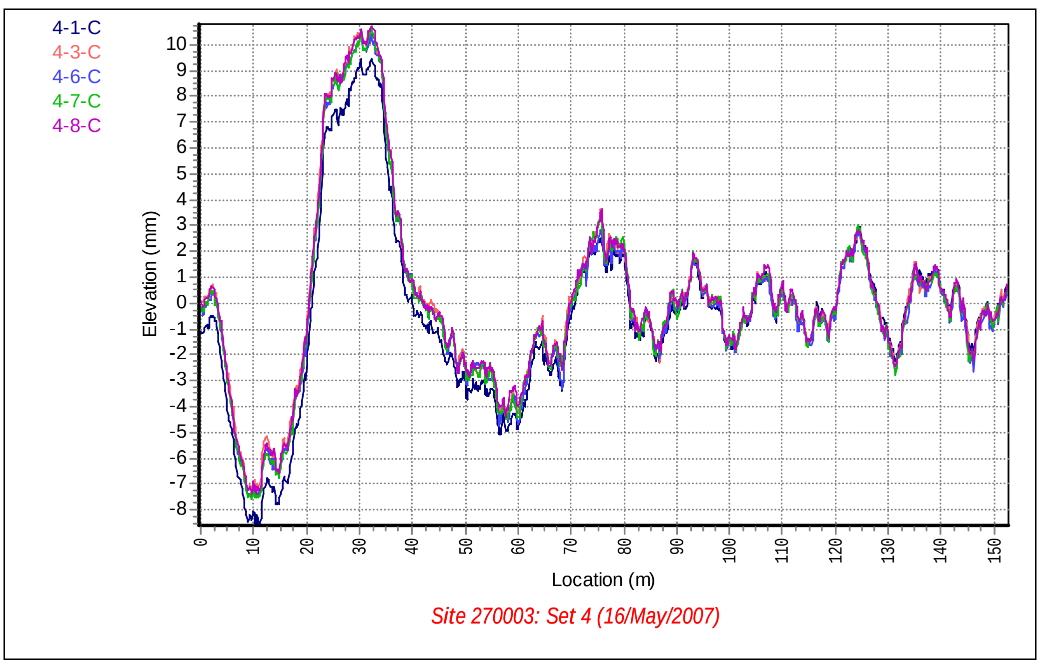
Section 3 – North Atlantic.



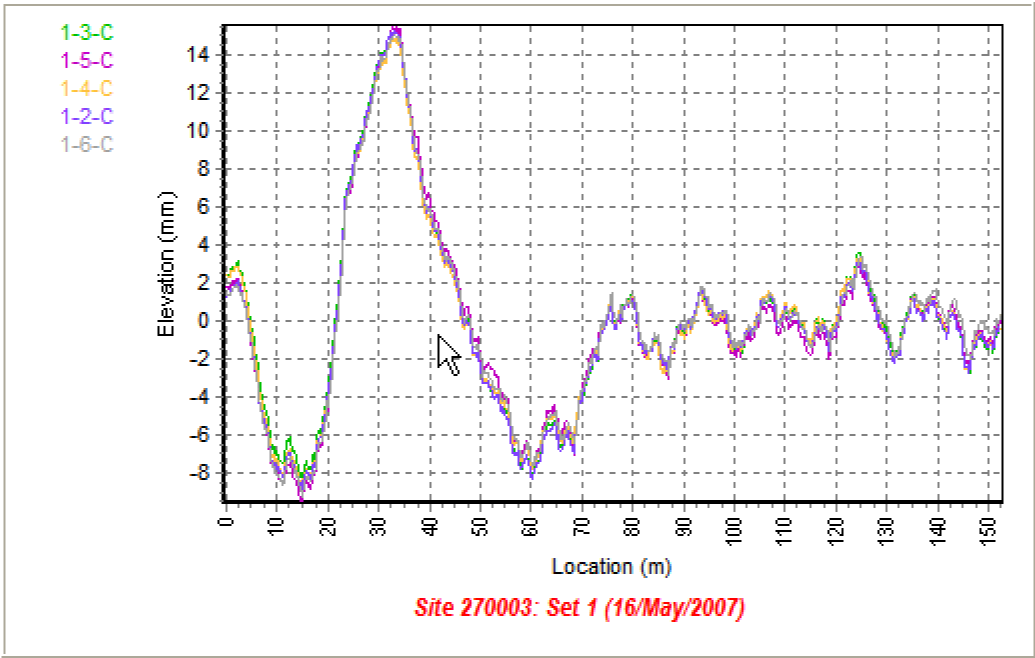
Section 3 – North Central.



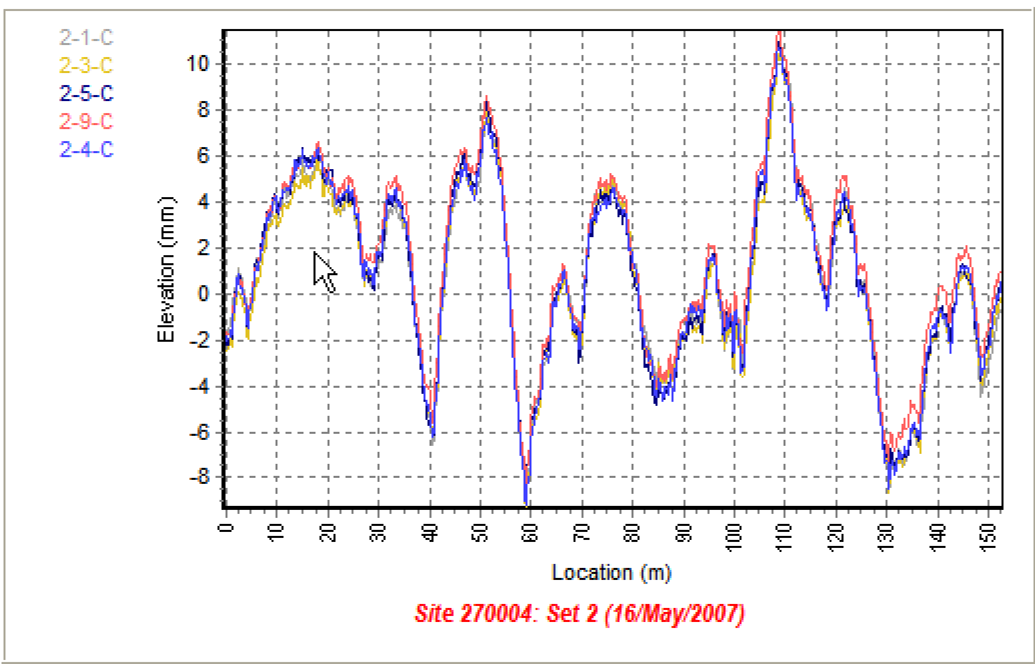
Section 3 – Southern.



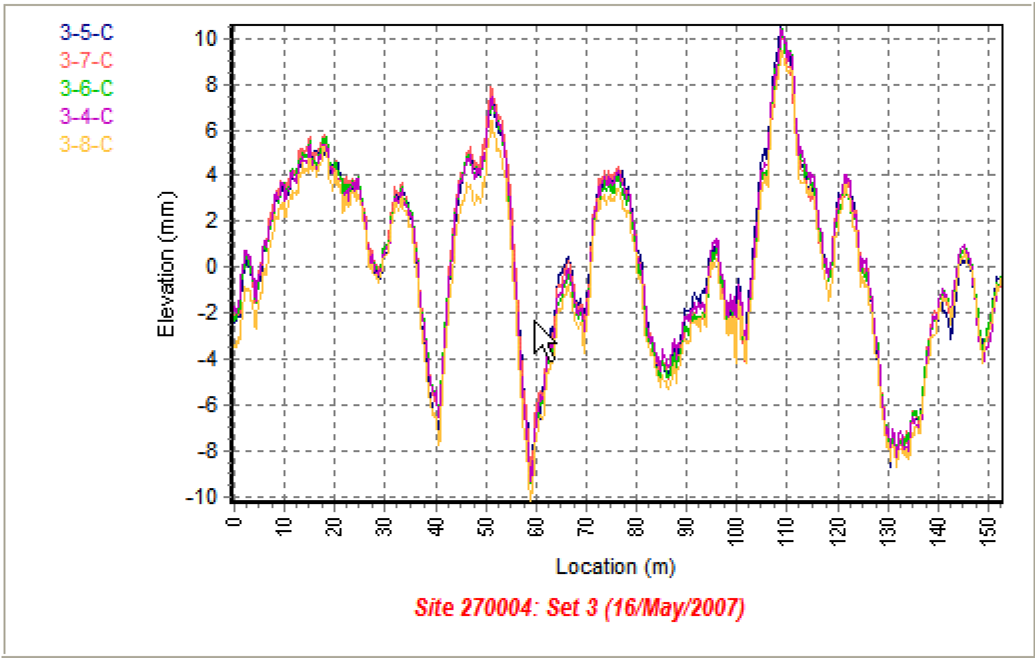
Section 3 – Western.



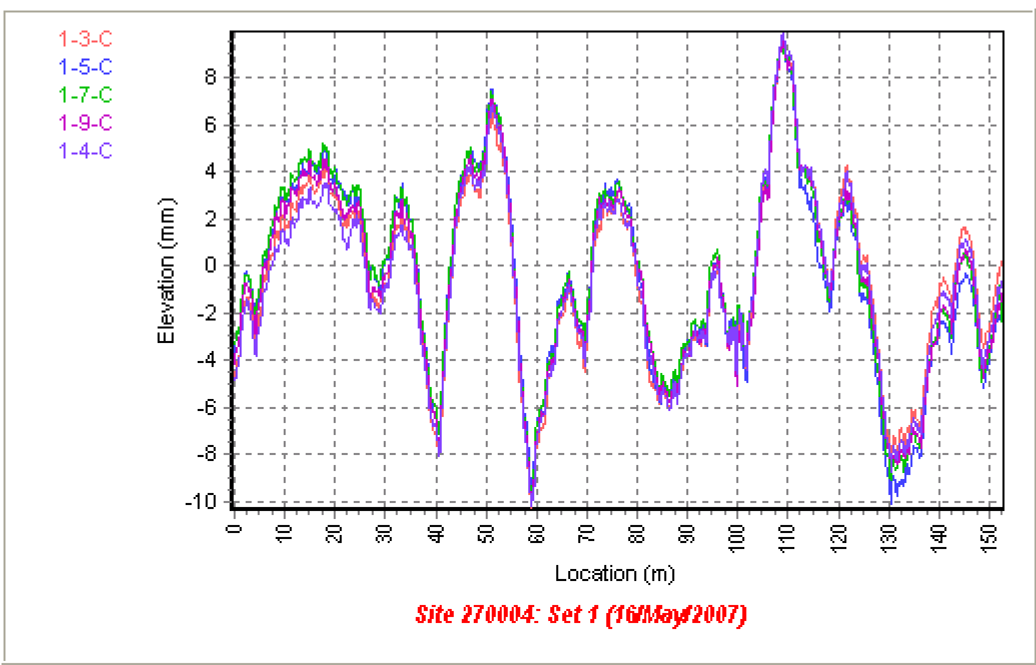
Section 3 – K. J. Law.



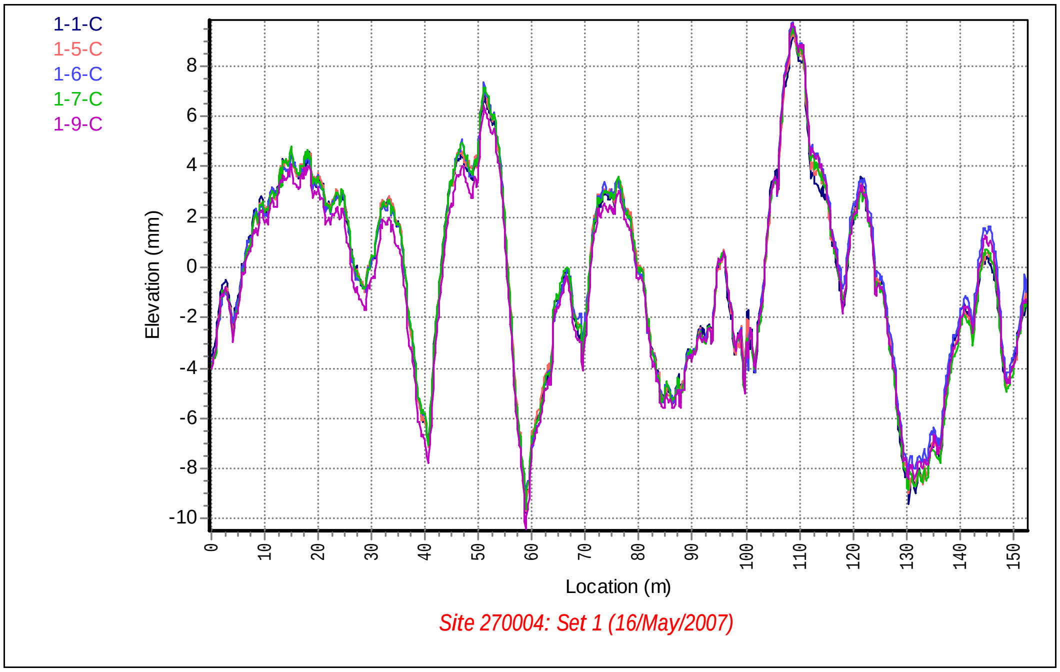
Section 4 – North Atlantic.



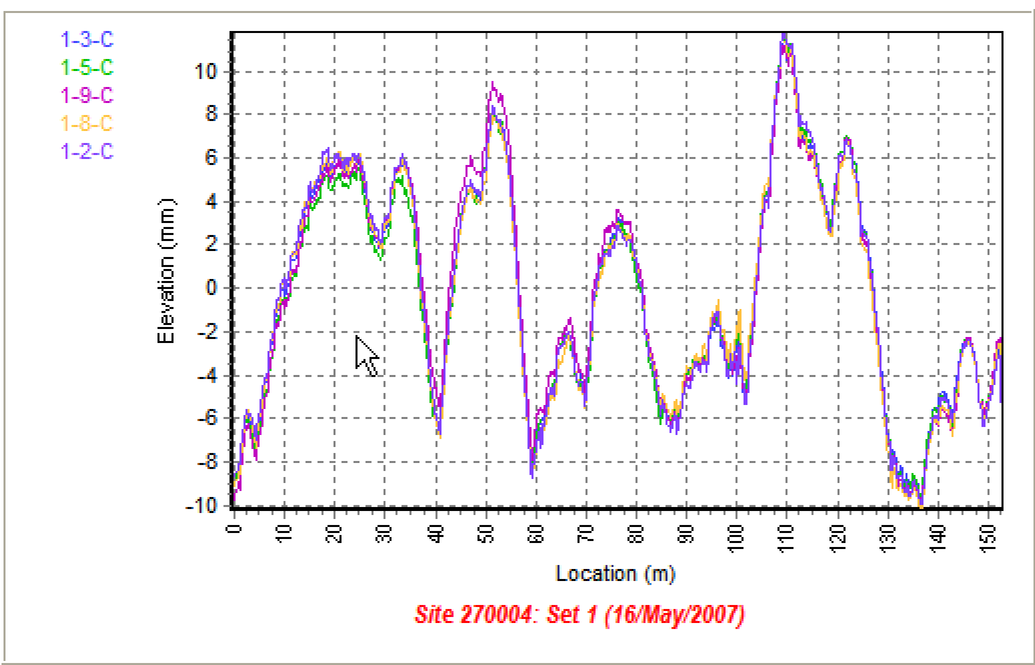
Section 4 – North Central.



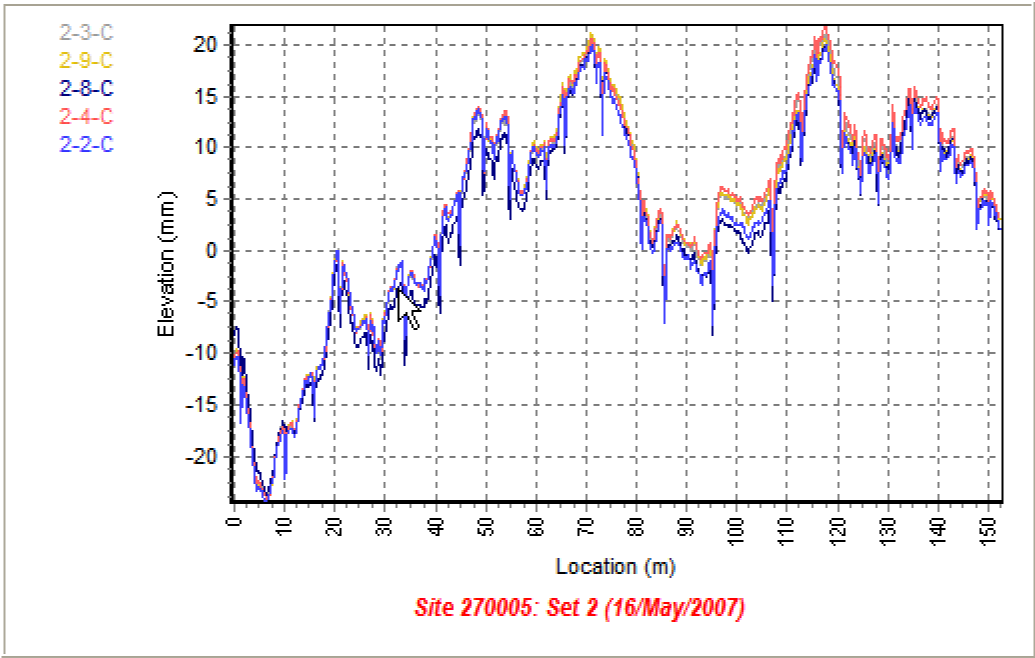
Section 4 – Southern.



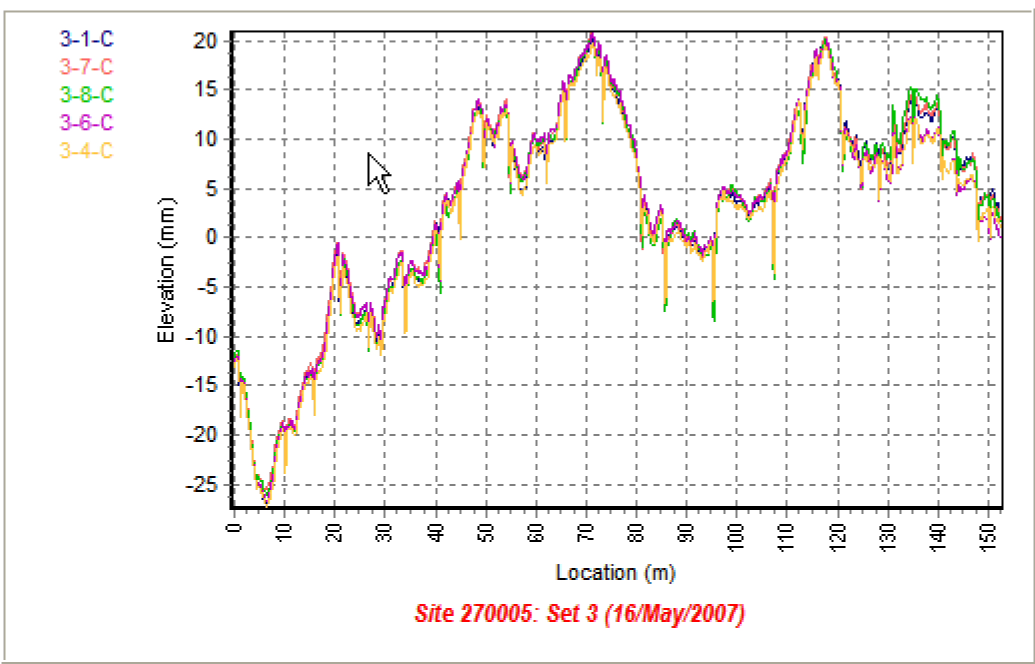
Section 4 – Western.



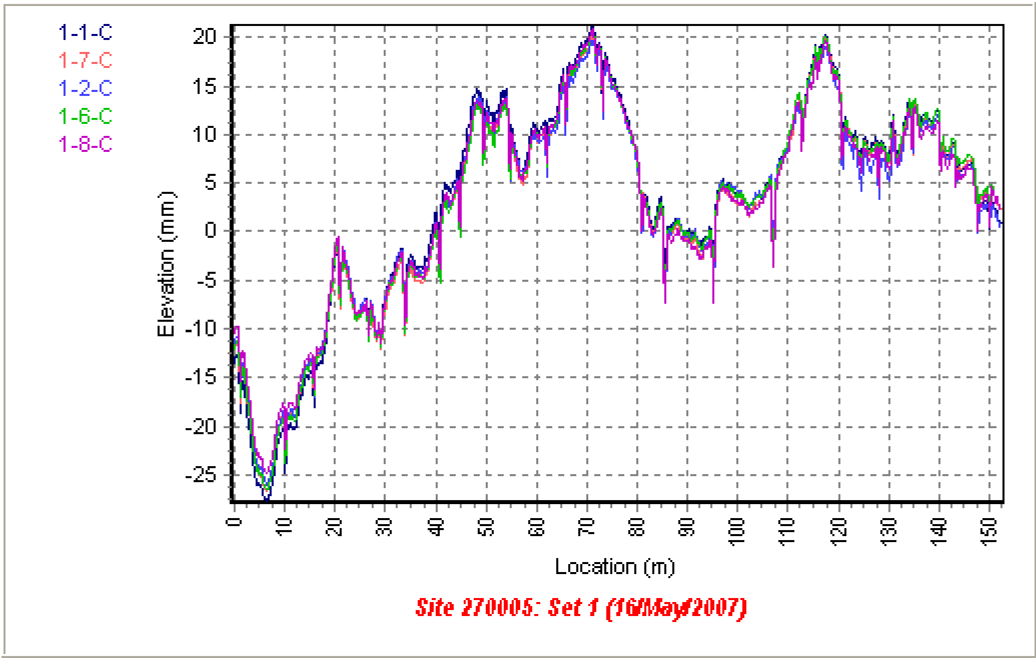
Section 4 – K. J. Law.



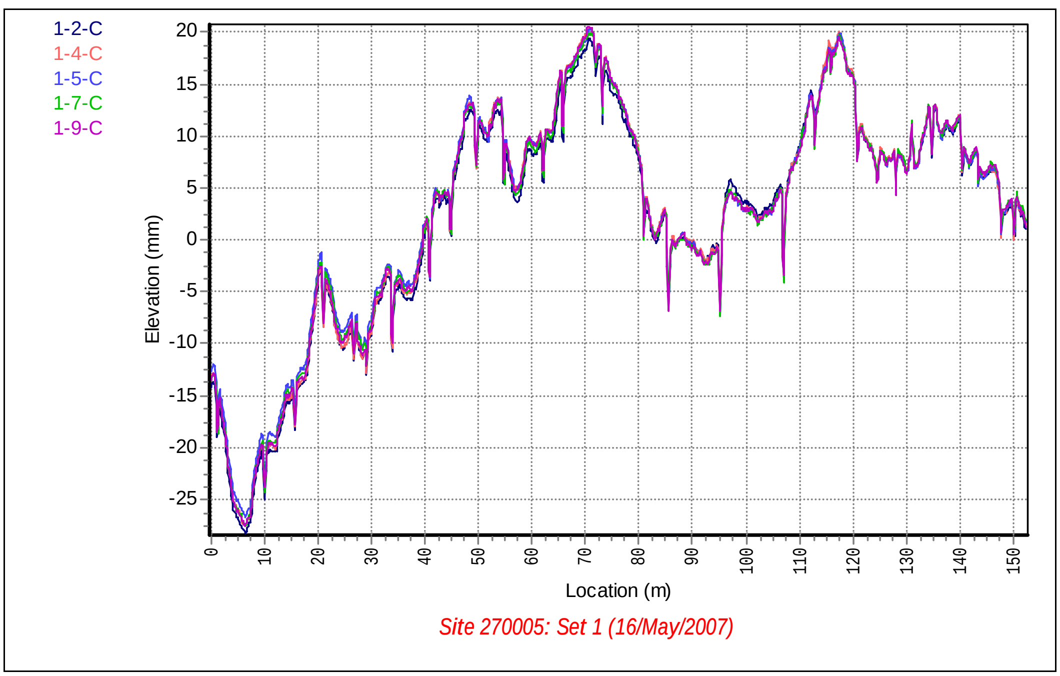
Section 5 – North Atlantic.



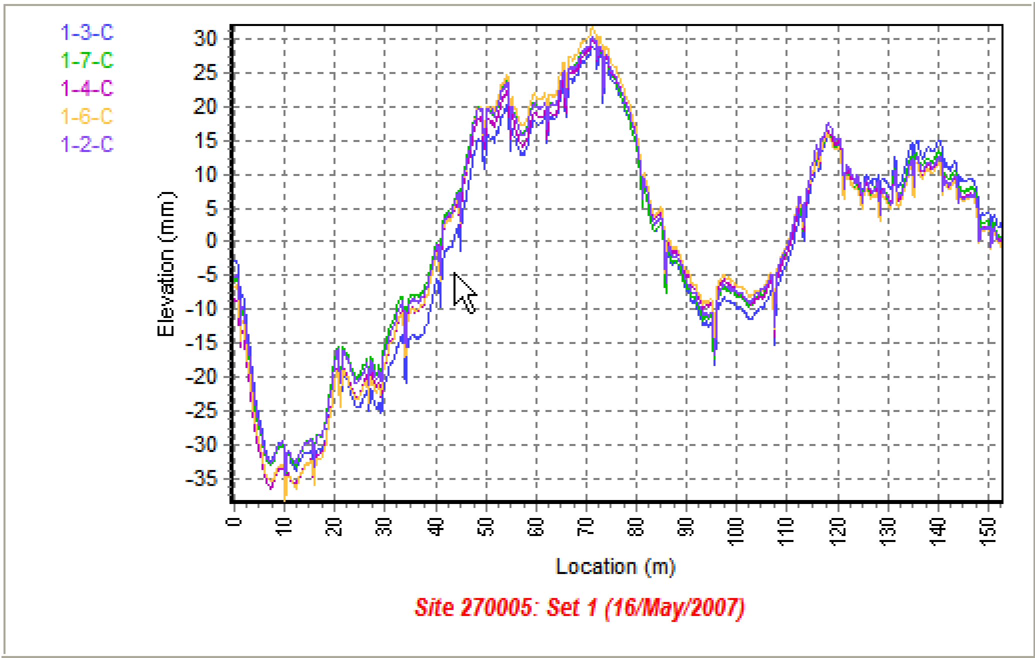
Section 5 – North Central.



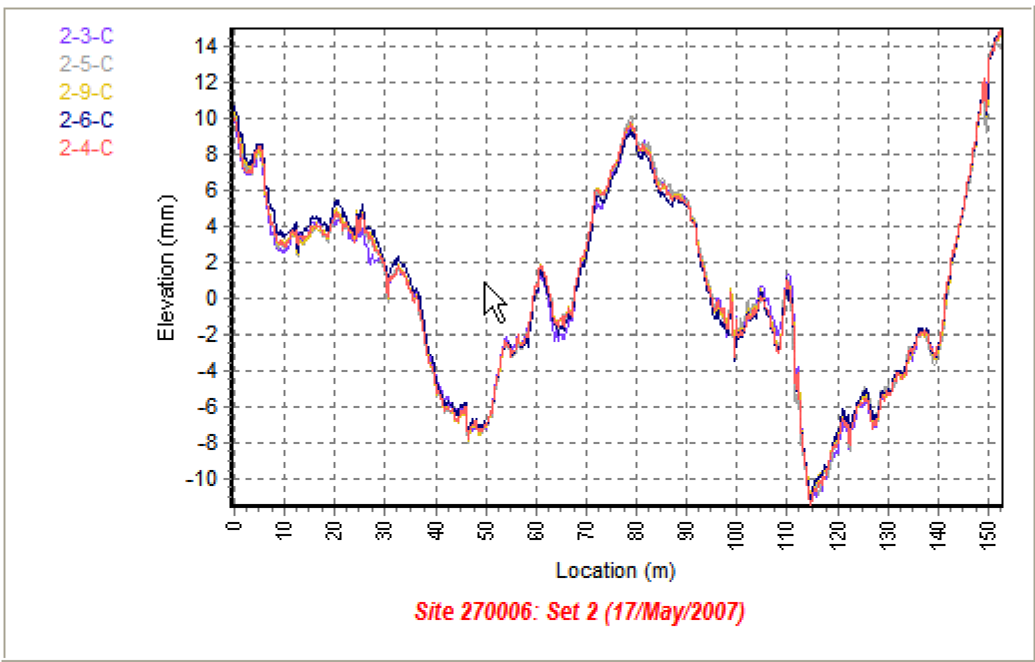
Section 5 – Southern.



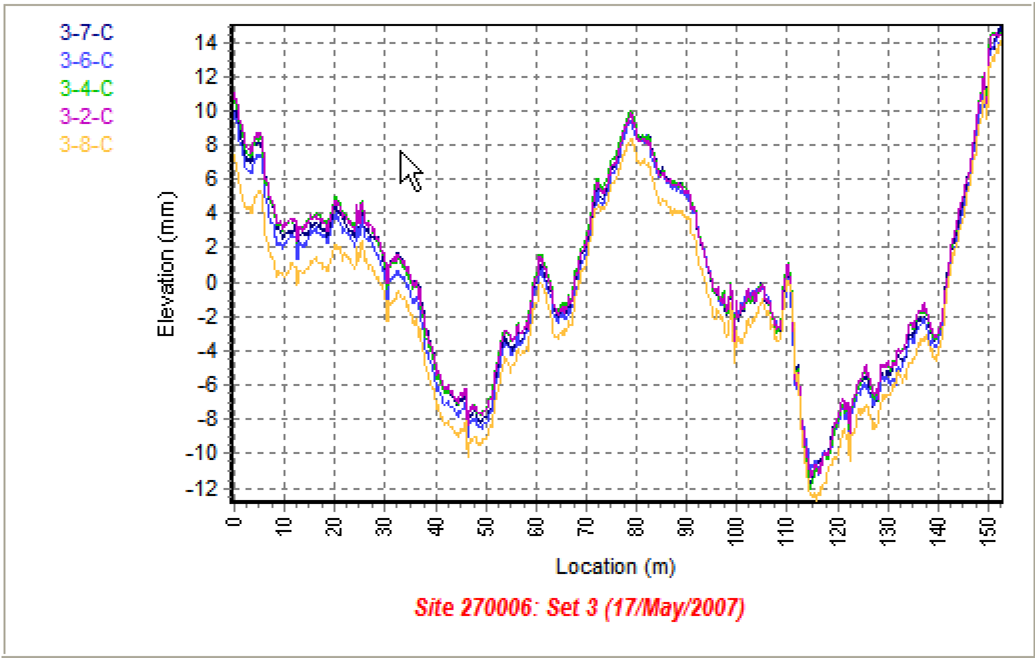
Section 5 – Western.



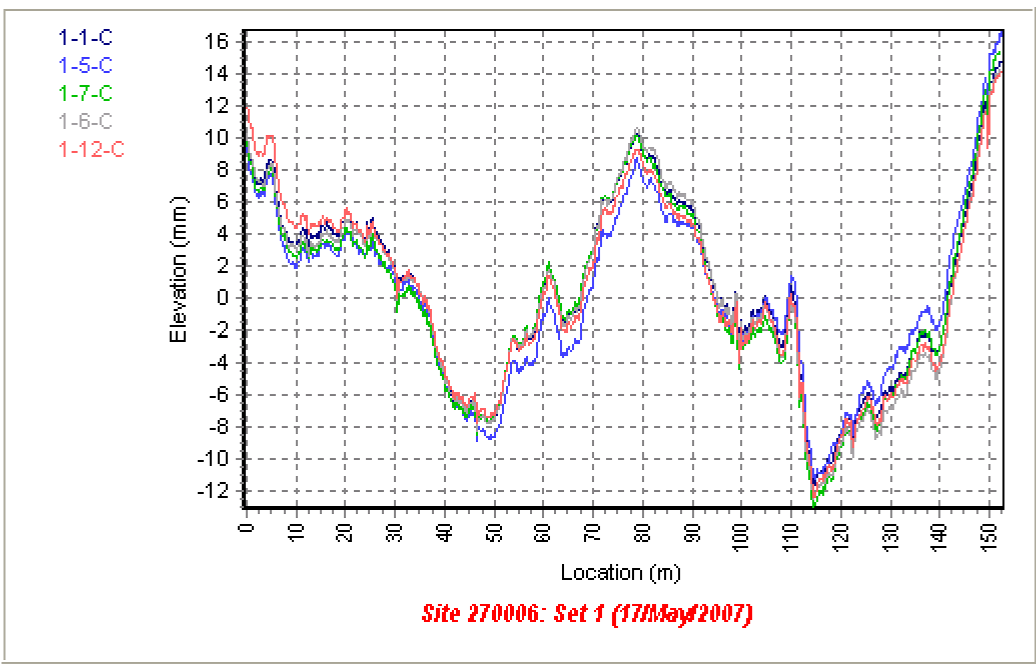
Section 5 – K. J. Law.



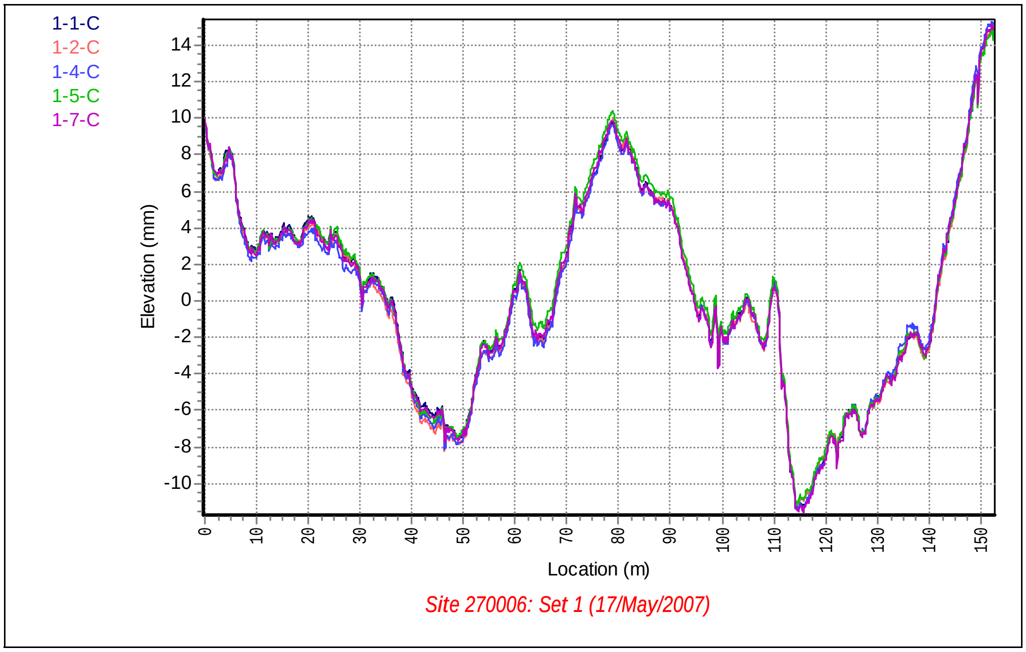
Section 6 – North Atlantic.



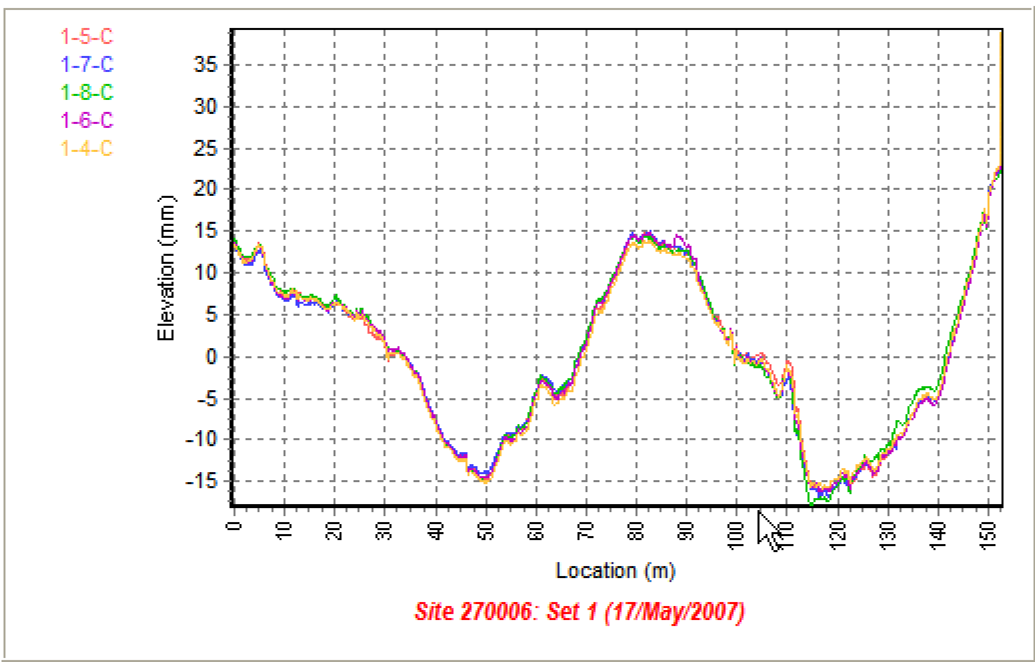
Section 6 – North Central.



Section 6 – Southern.



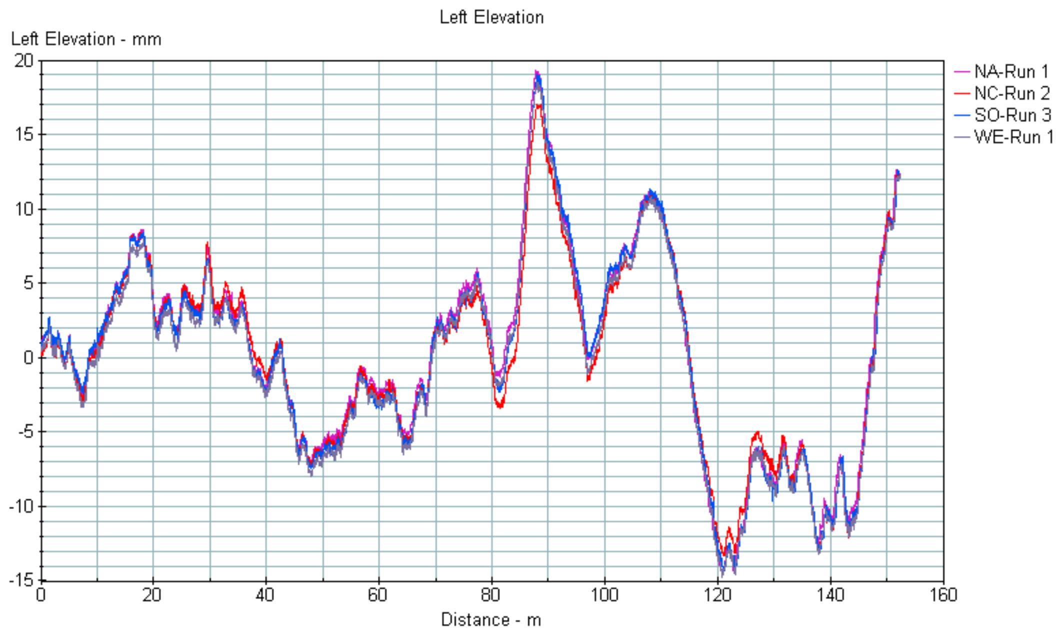
Section 6 – Western.

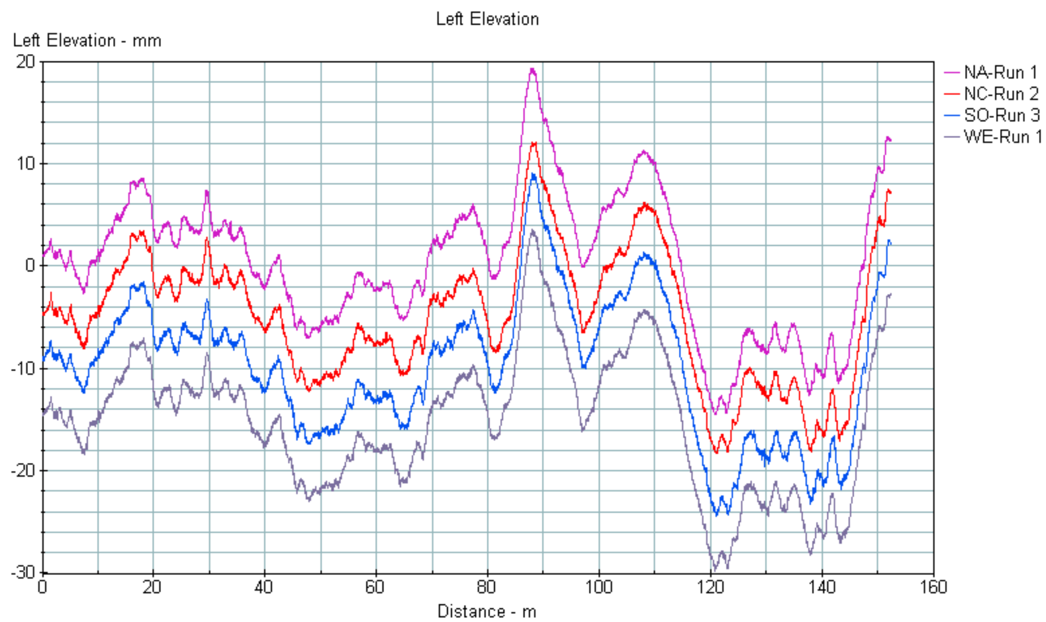


Section 6 – K. J. Law.

APPENDIX F

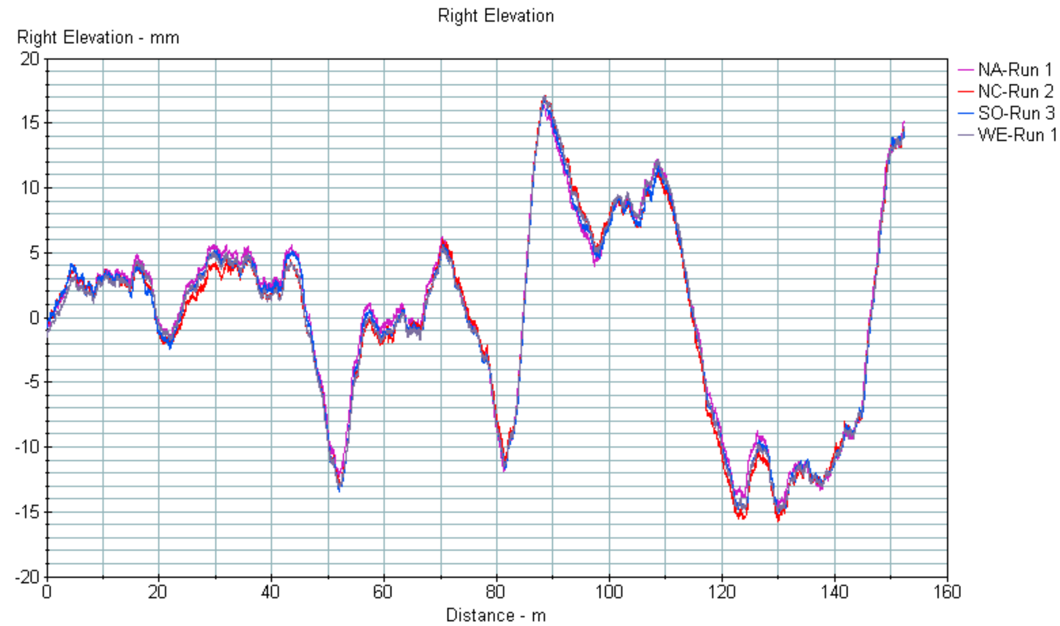
COMPARISON OF PROFILE PLOTS AMONG THE FOUR ICC PROFILERS

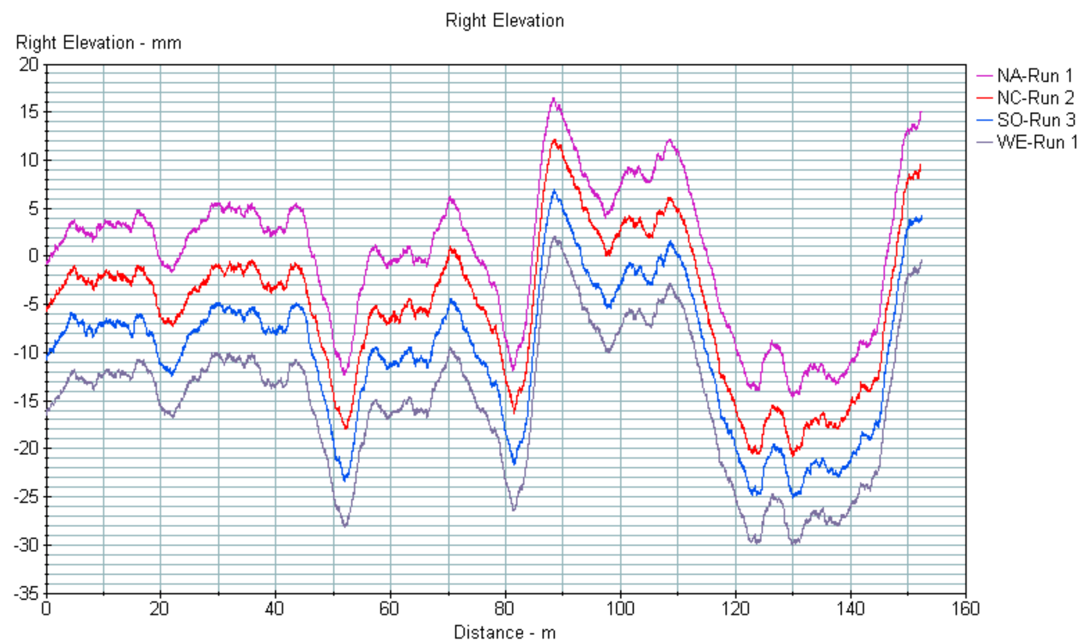




Section 1 – Left Wheelpsth.

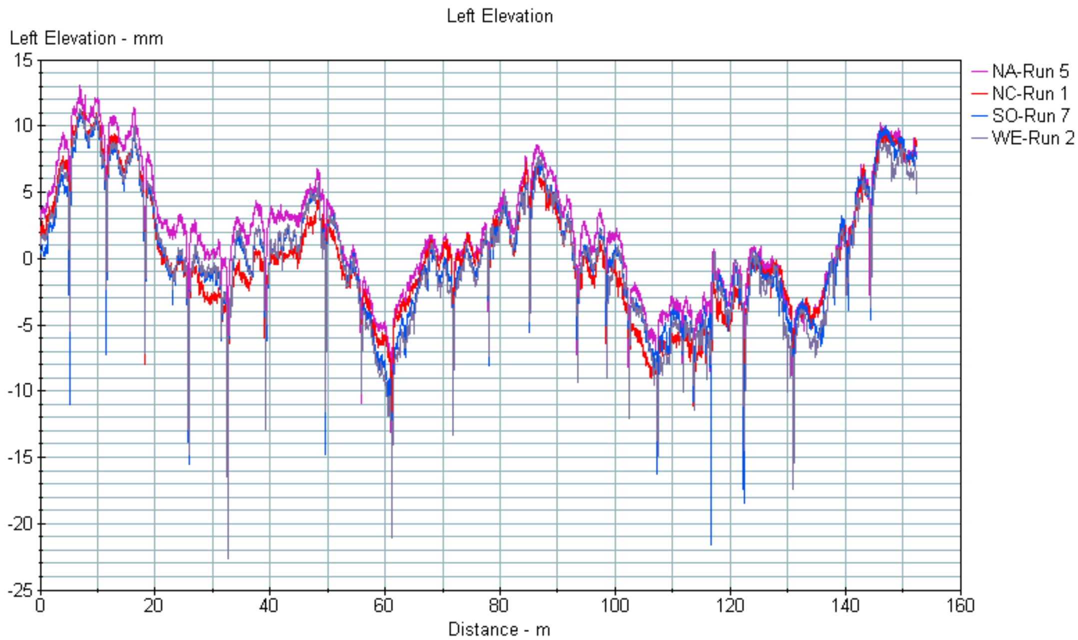
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

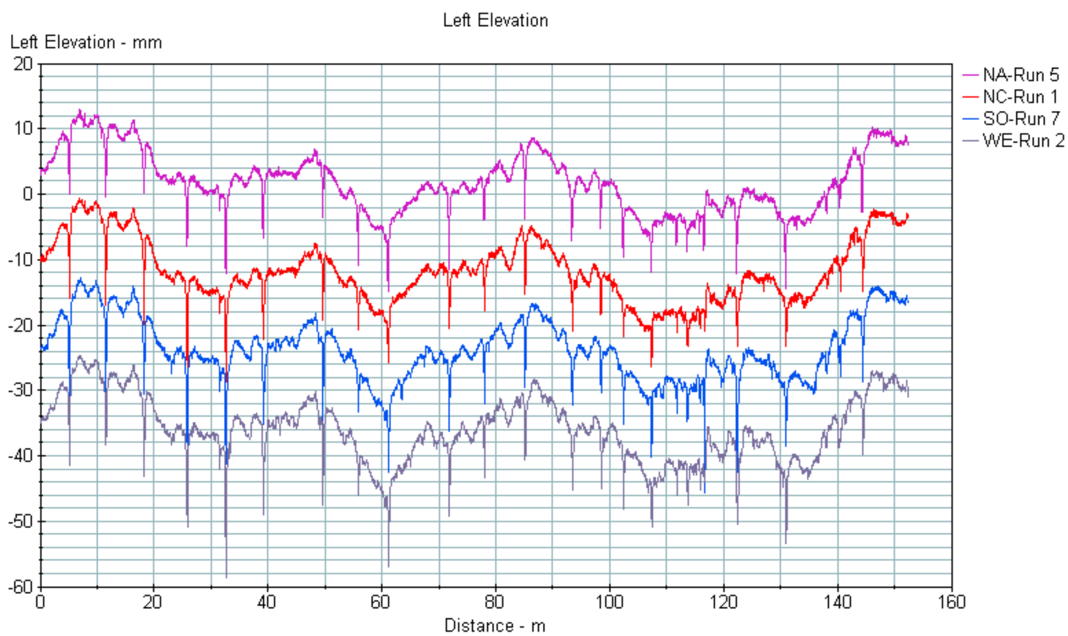




Section 1 – Right Wheelpath.

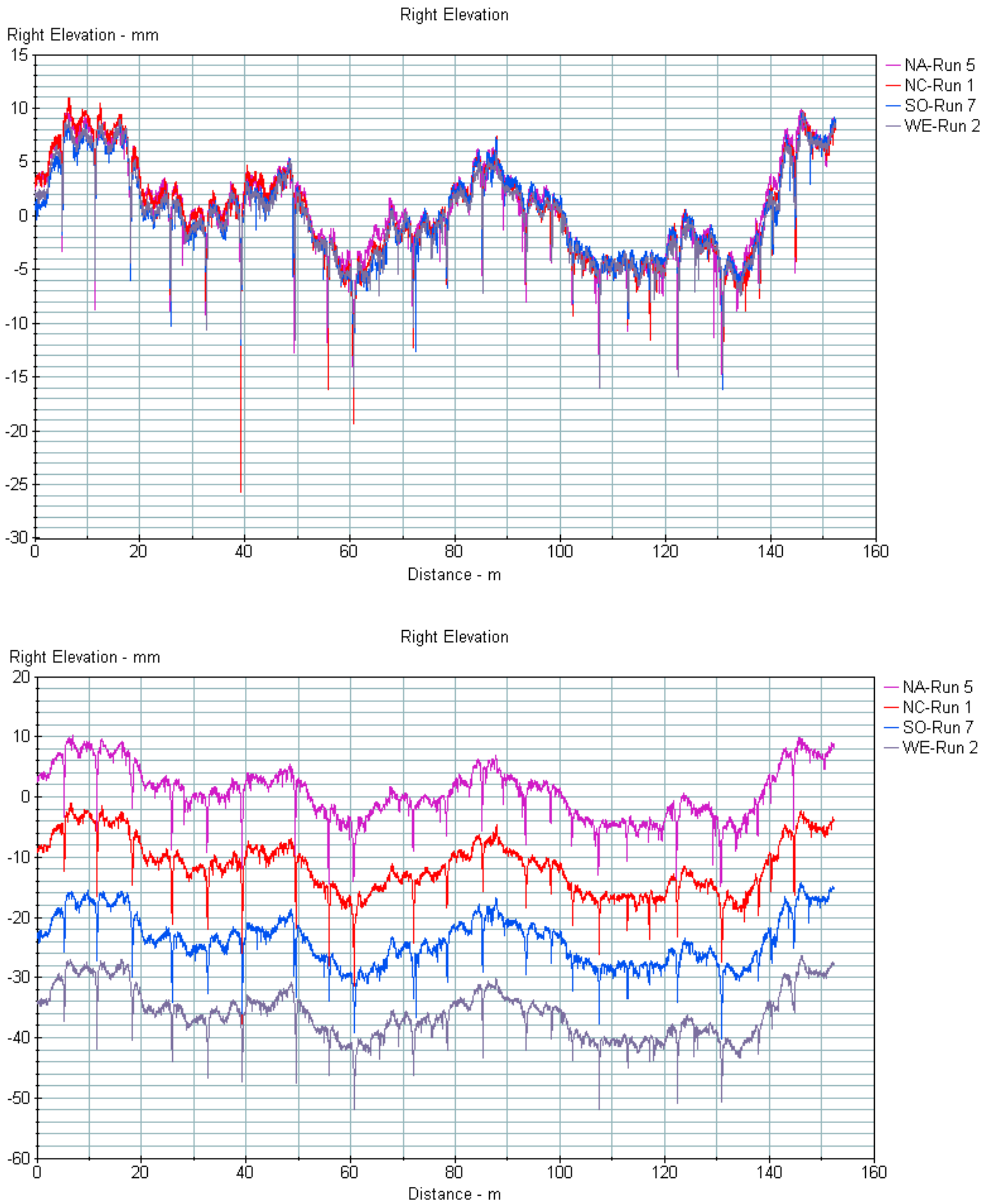
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.





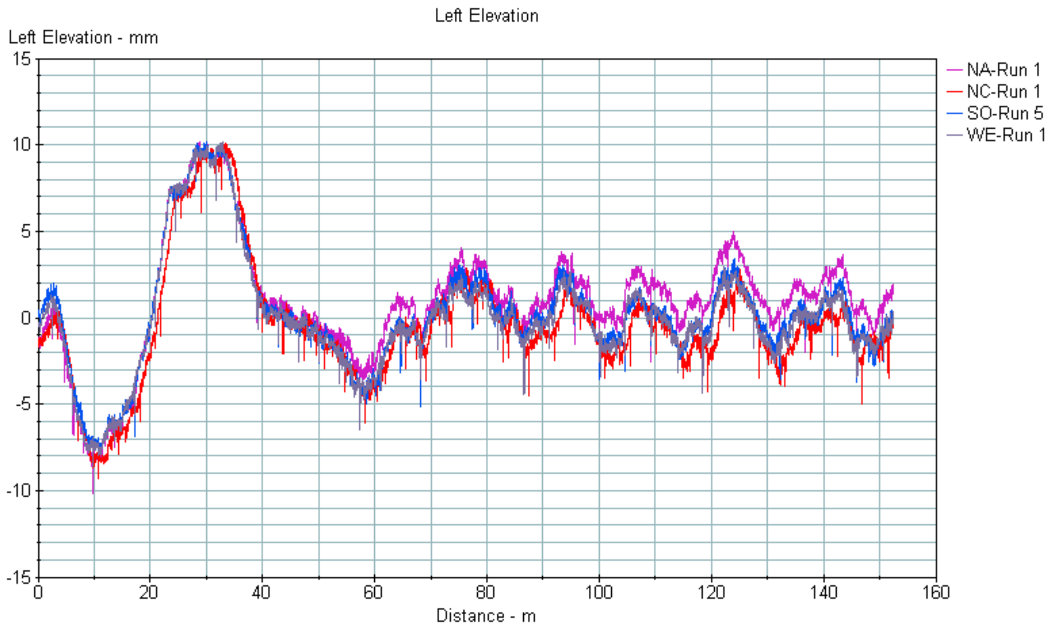
Section 2 – Left Wheelpath.

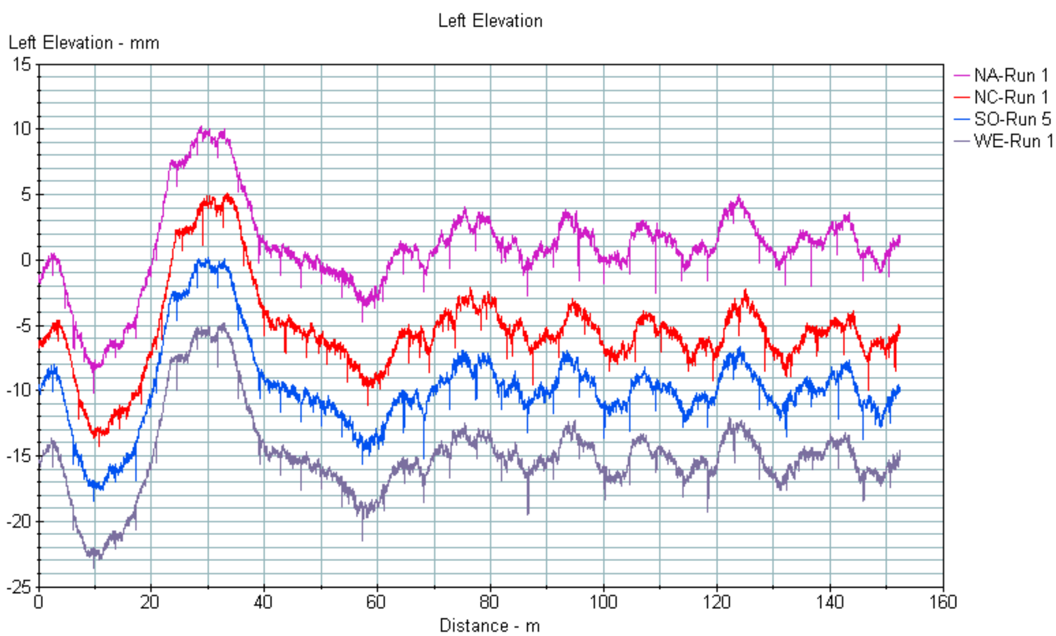
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.



Section 2 – Right Wheelpath.

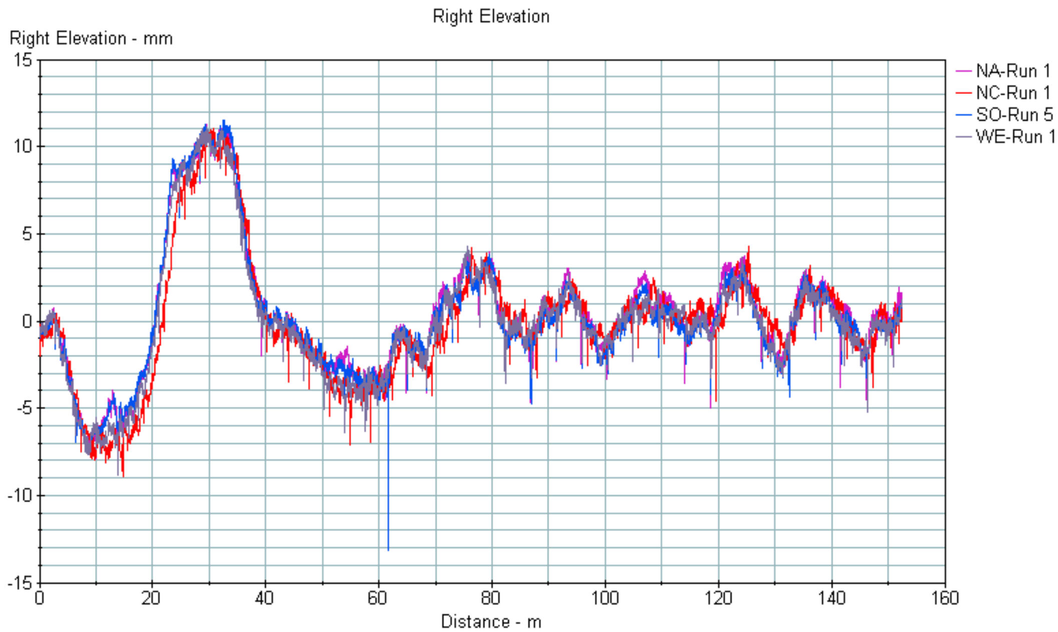
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

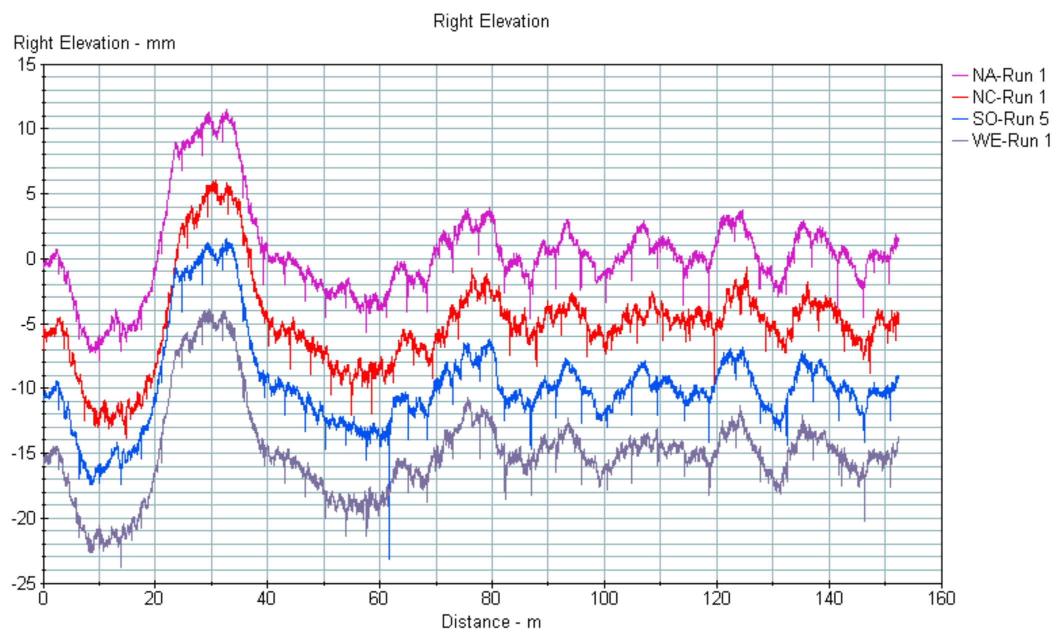




Section 3 – Left Wheelpath.

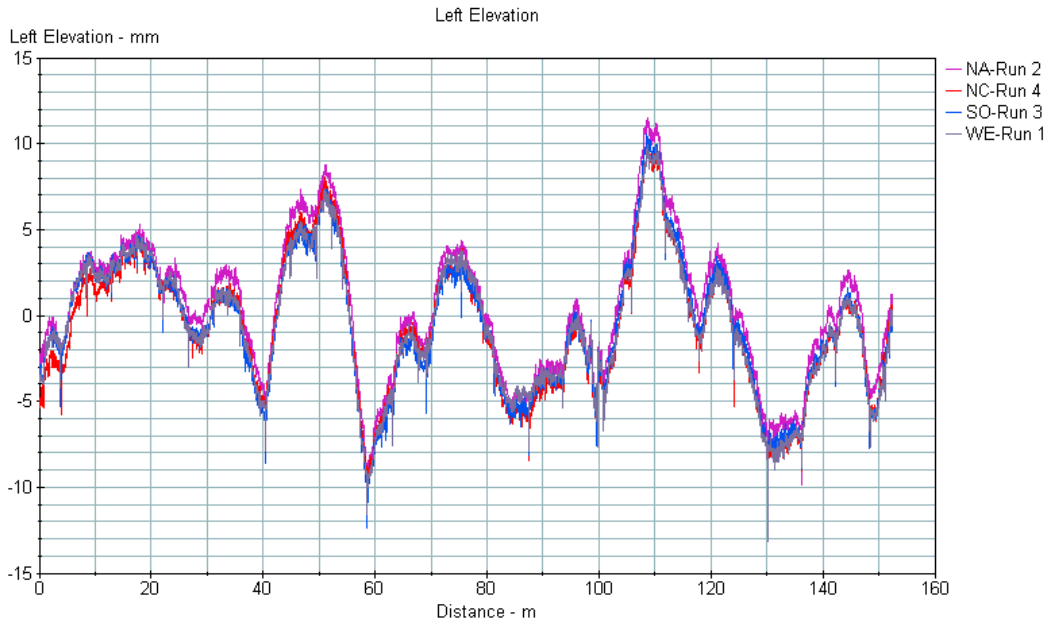
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

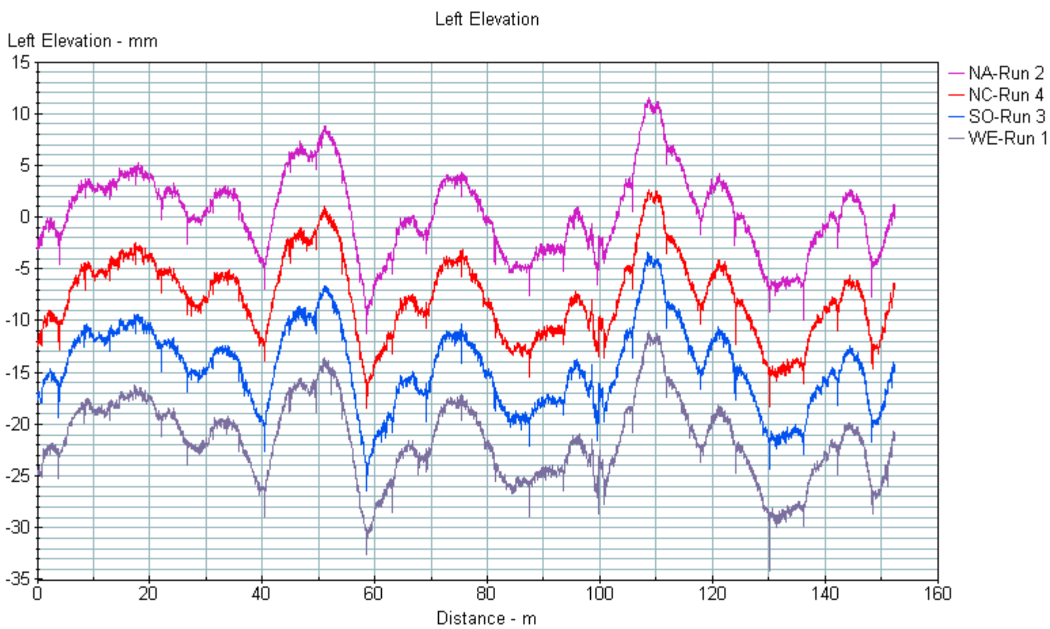




Section 3 – Right Wheelpath.

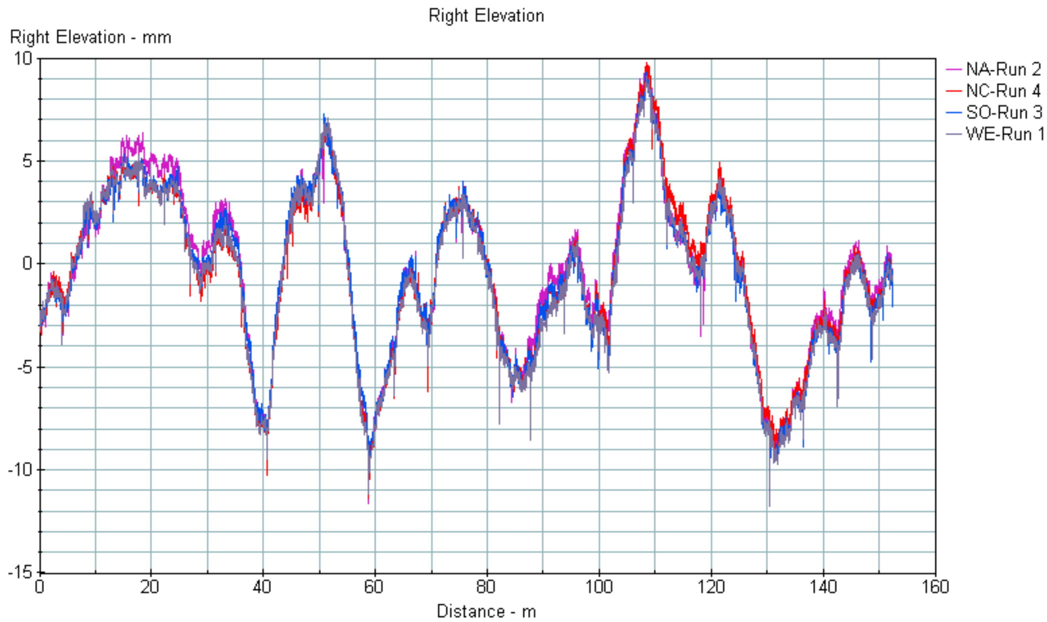
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

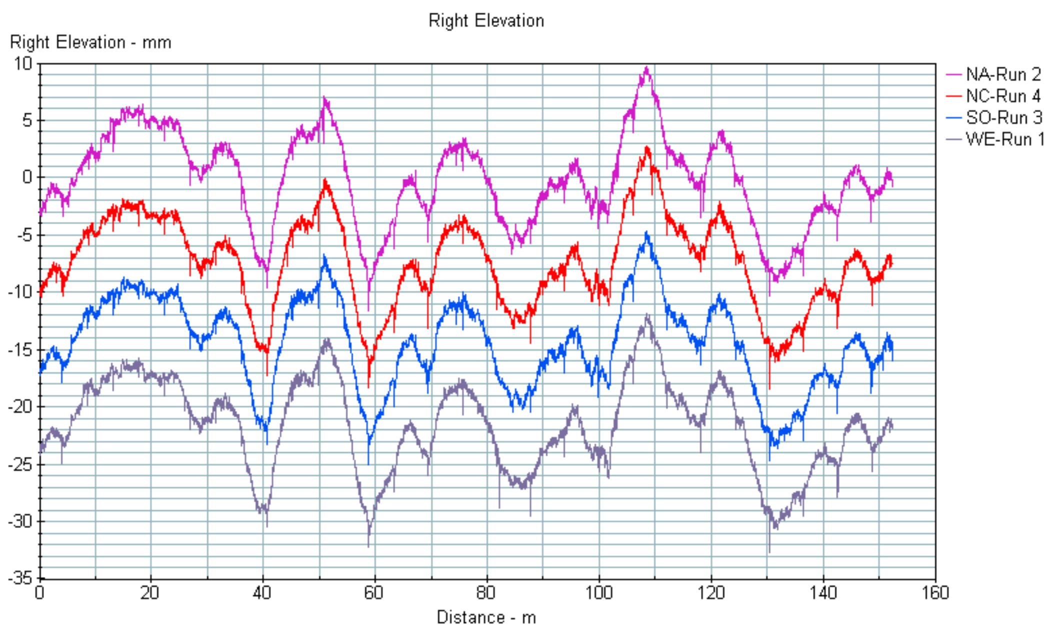




Section 4 – Left Wheelpath.

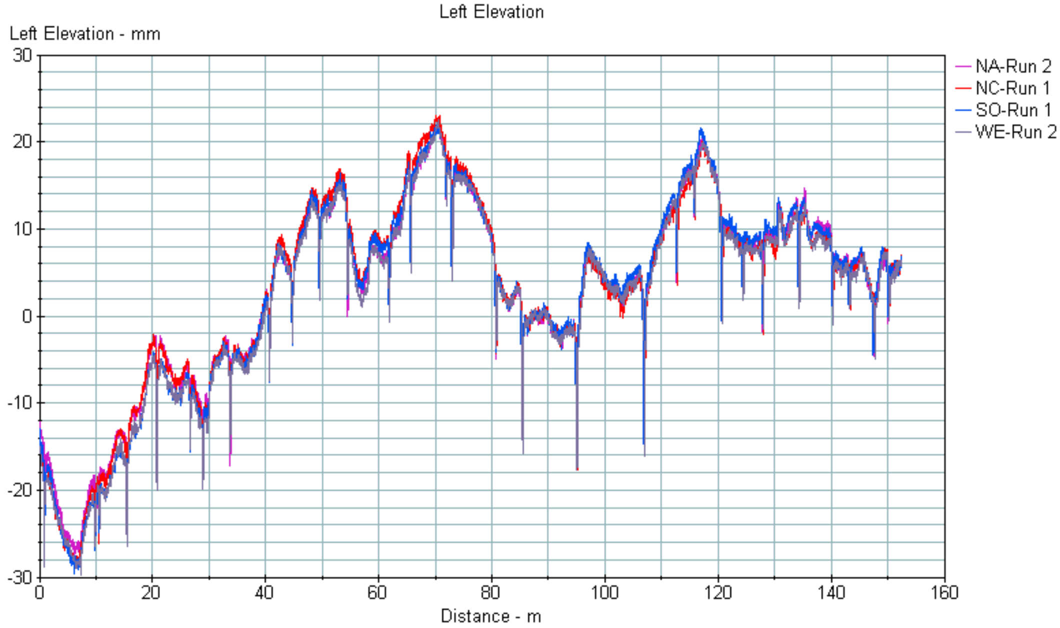
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

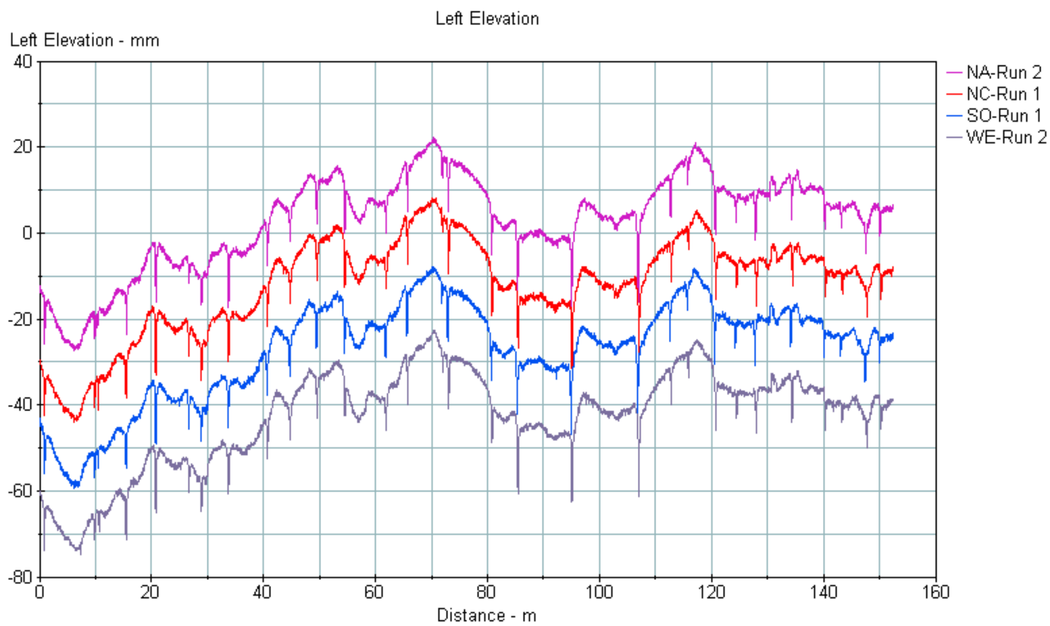




Section 4 – Right Wheelpath.

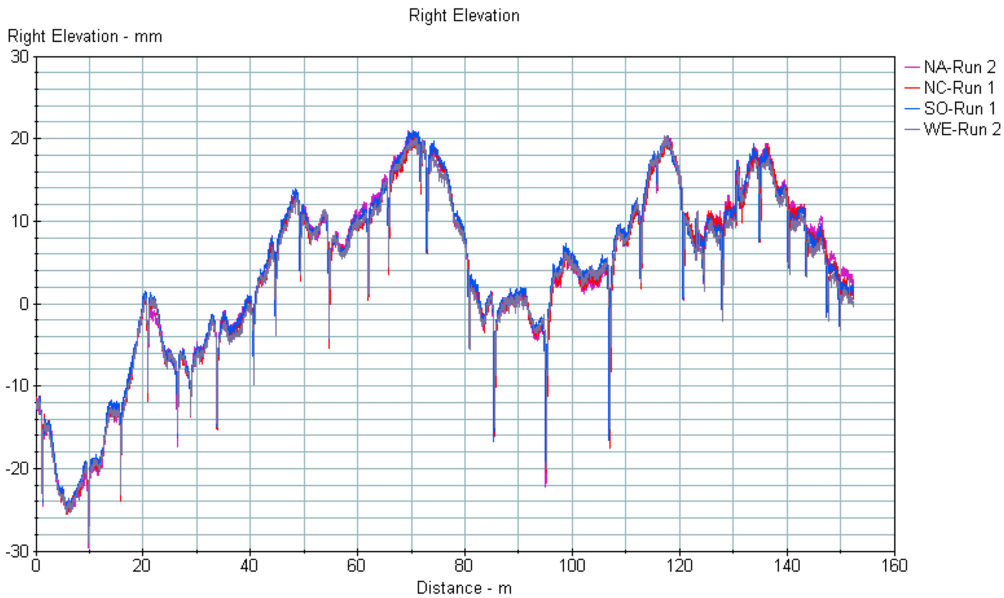
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

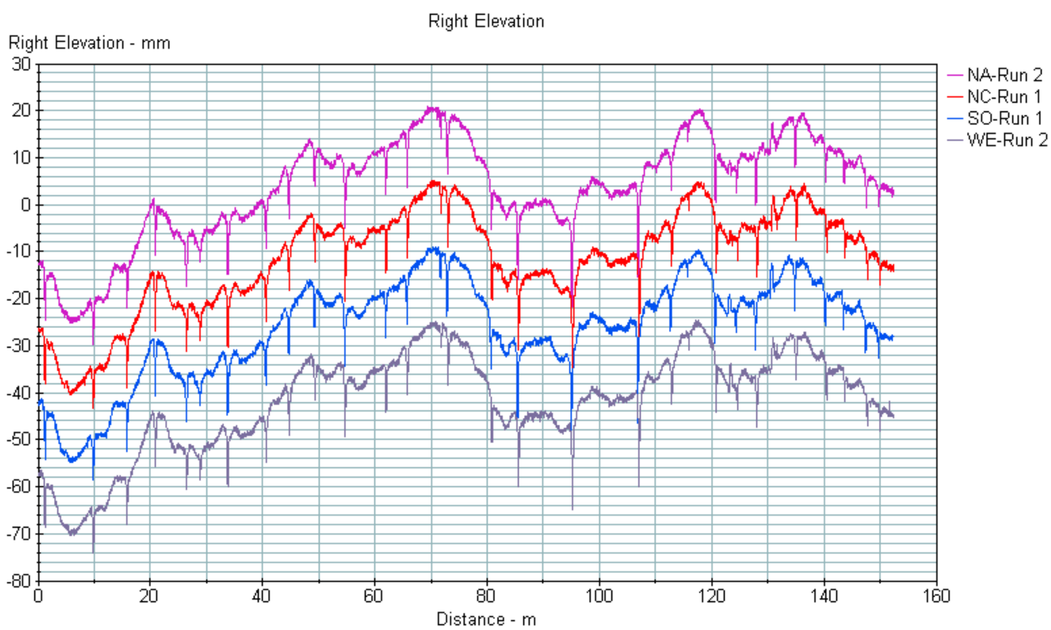




Section 5 – Left Wheelpath.

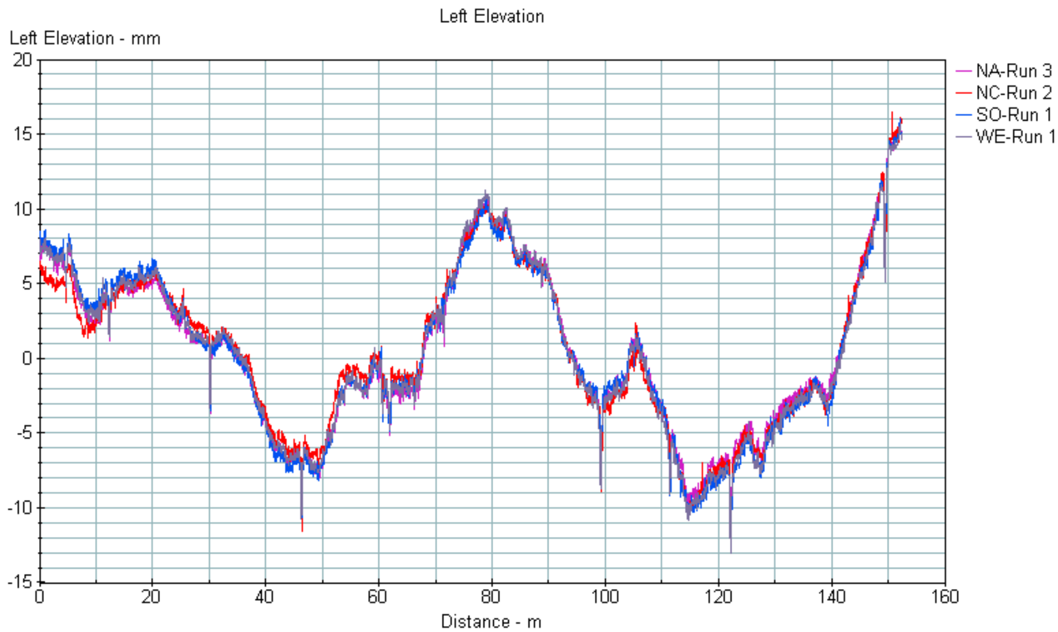
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

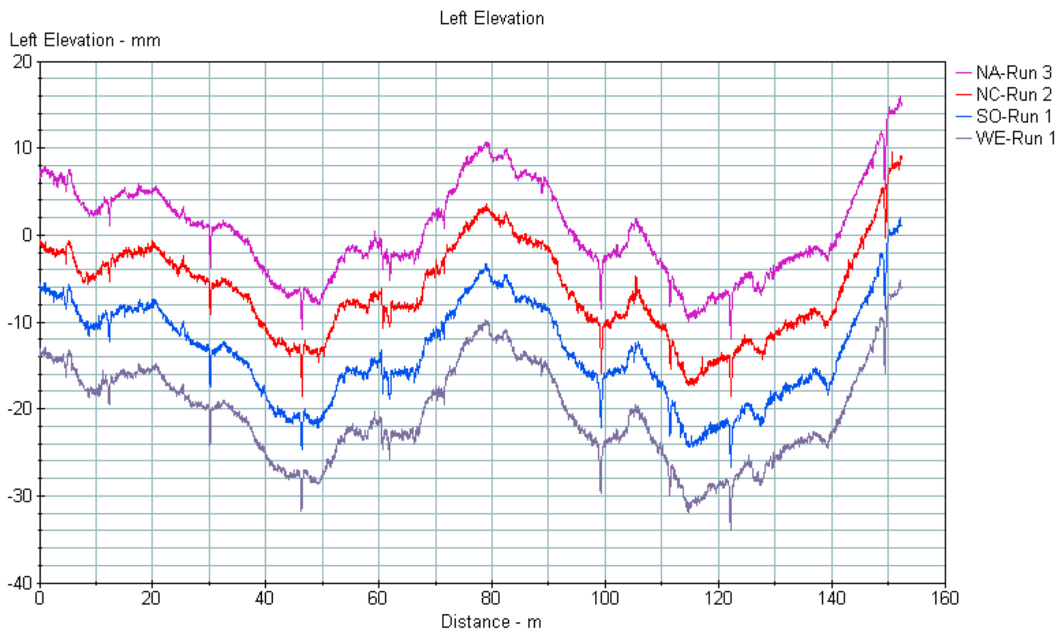




Section 5 – Right Wheelpath.

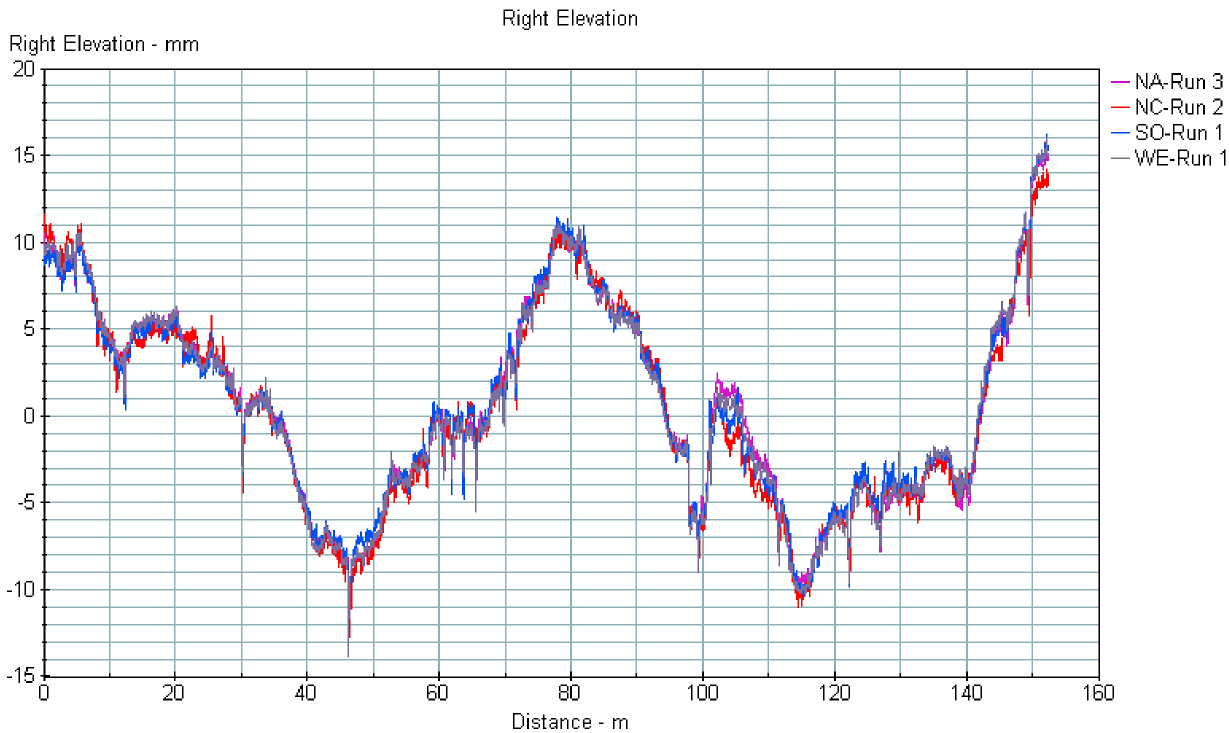
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

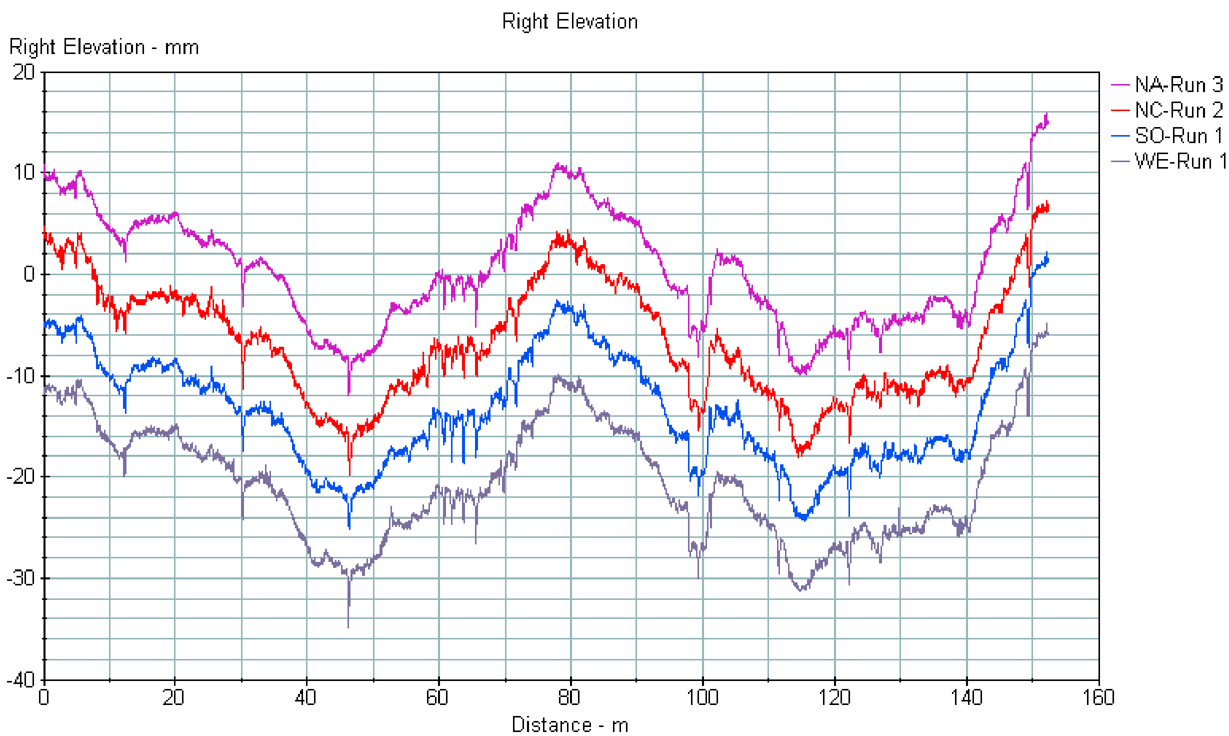




Section 6 – Left Wheelpath.

Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.



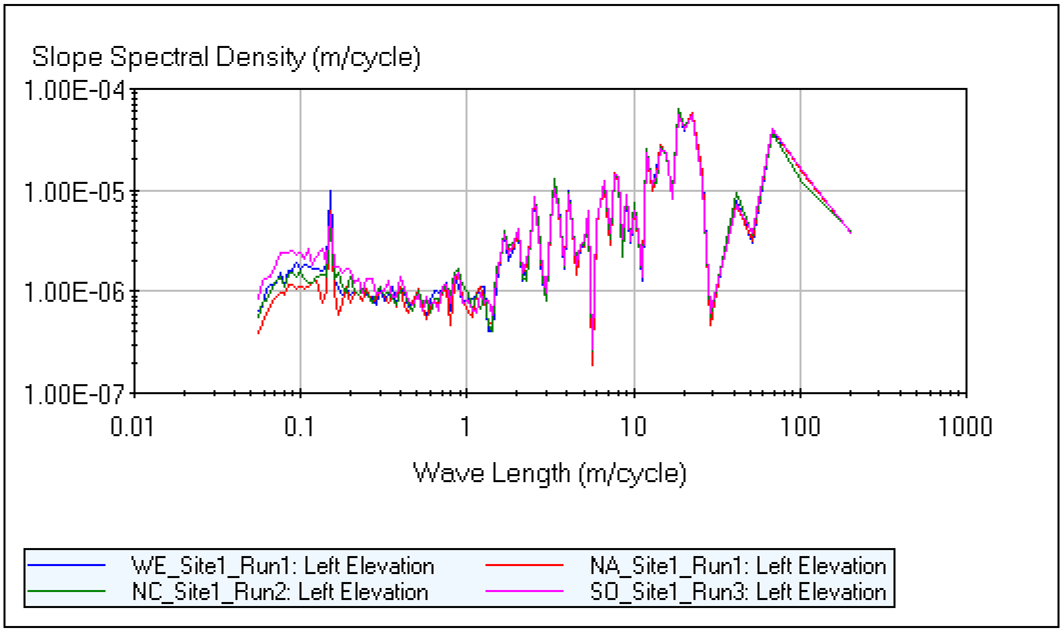


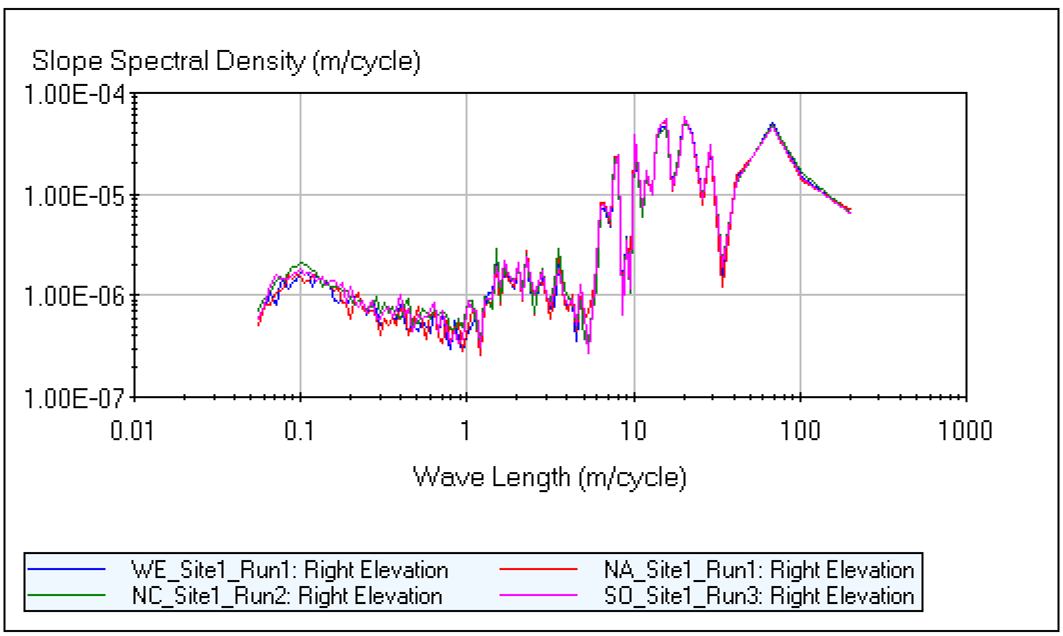
Section 6 – Right Wheelpath.

Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.

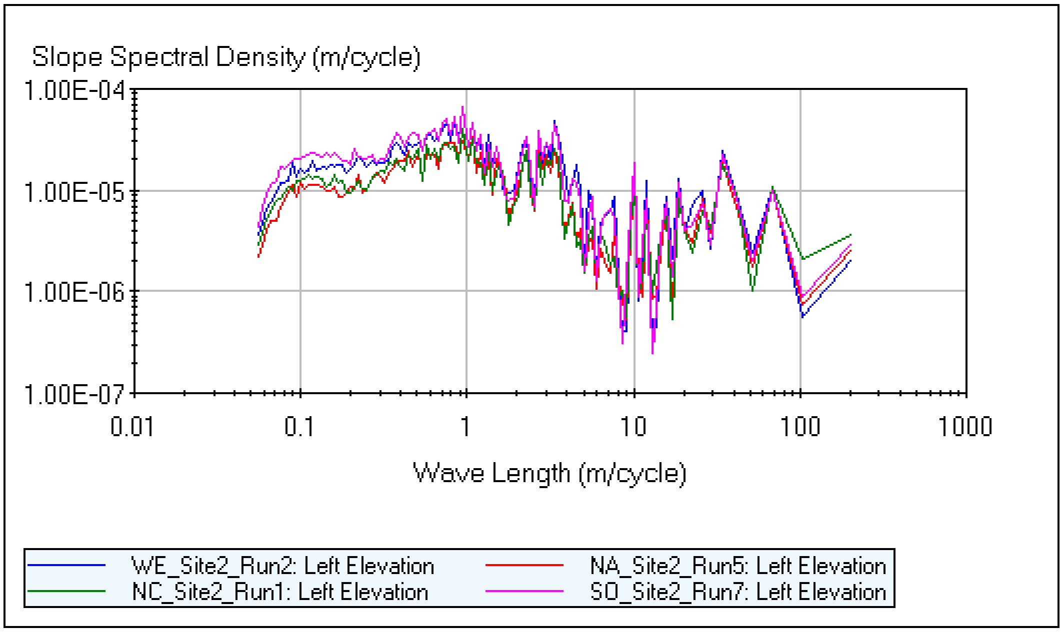
APPENDIX G

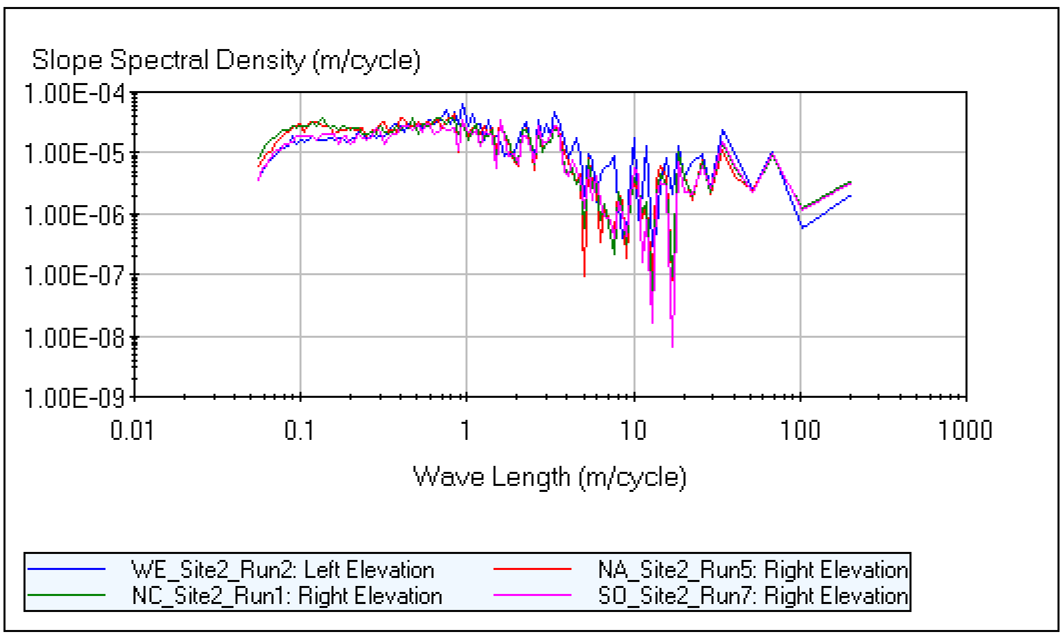
POWER SPECTRAL DENSITY PLOTS OF PROFILE DATA



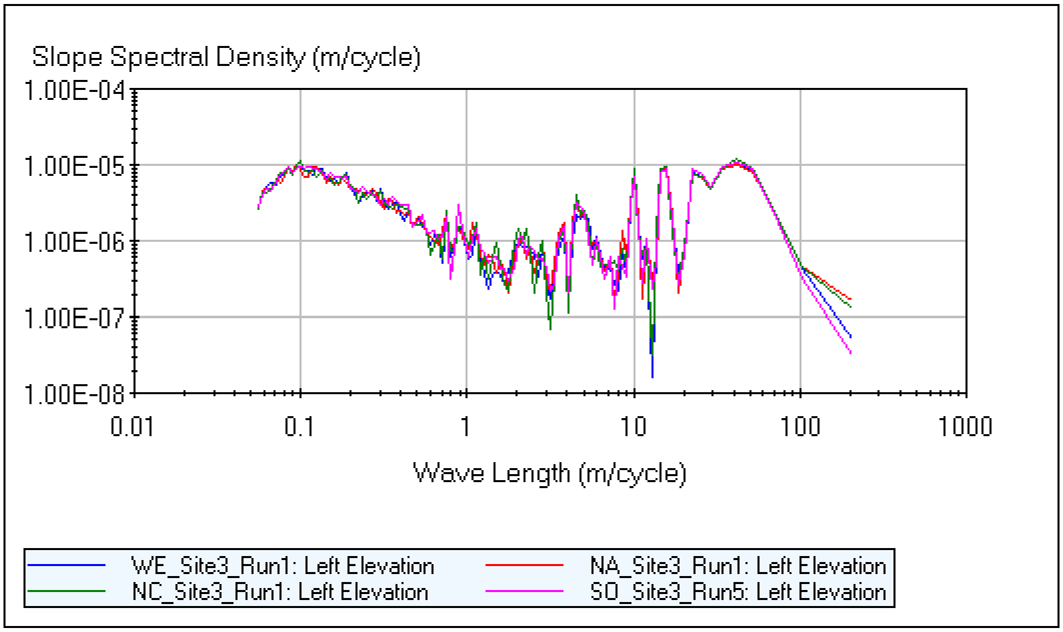


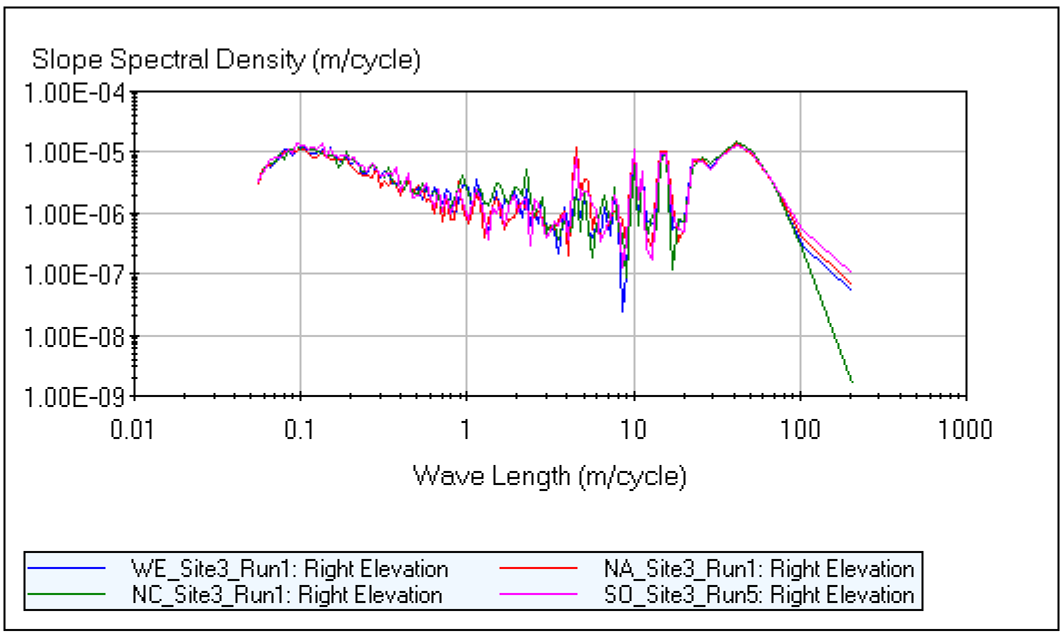
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.



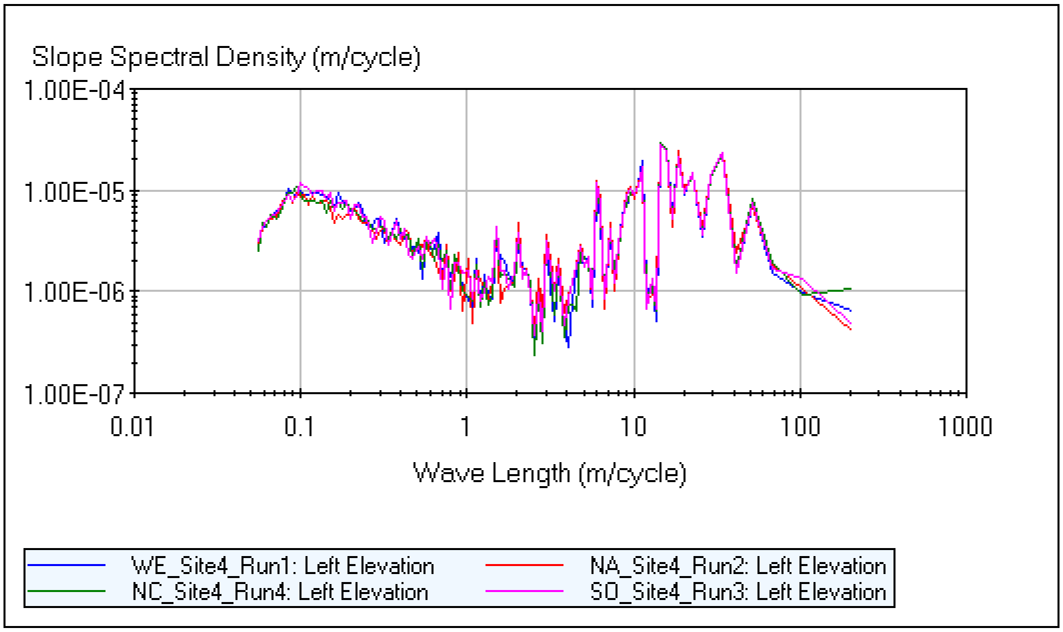


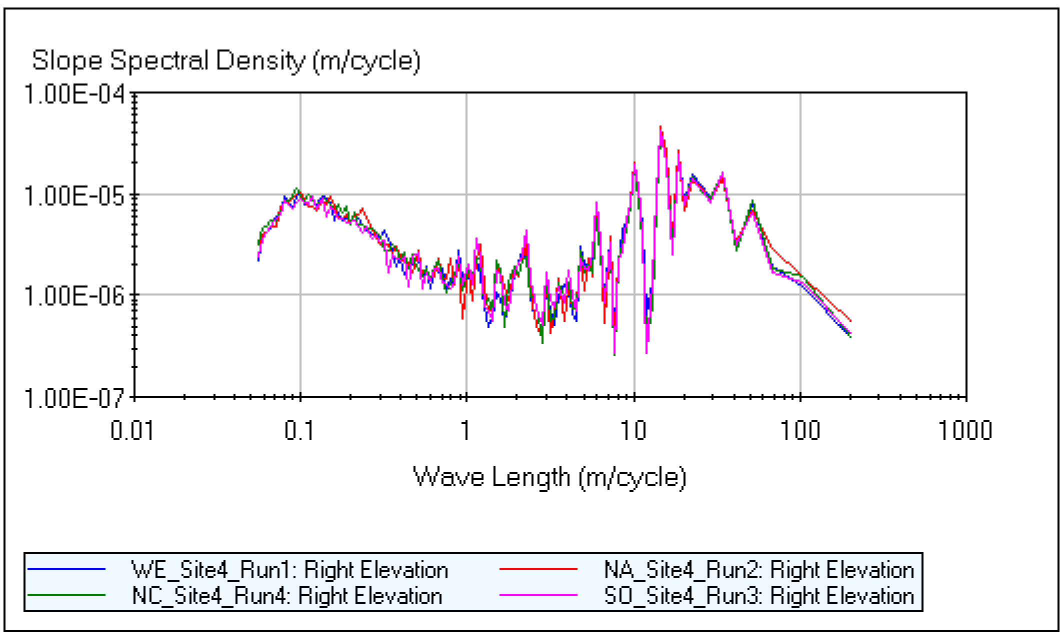
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.



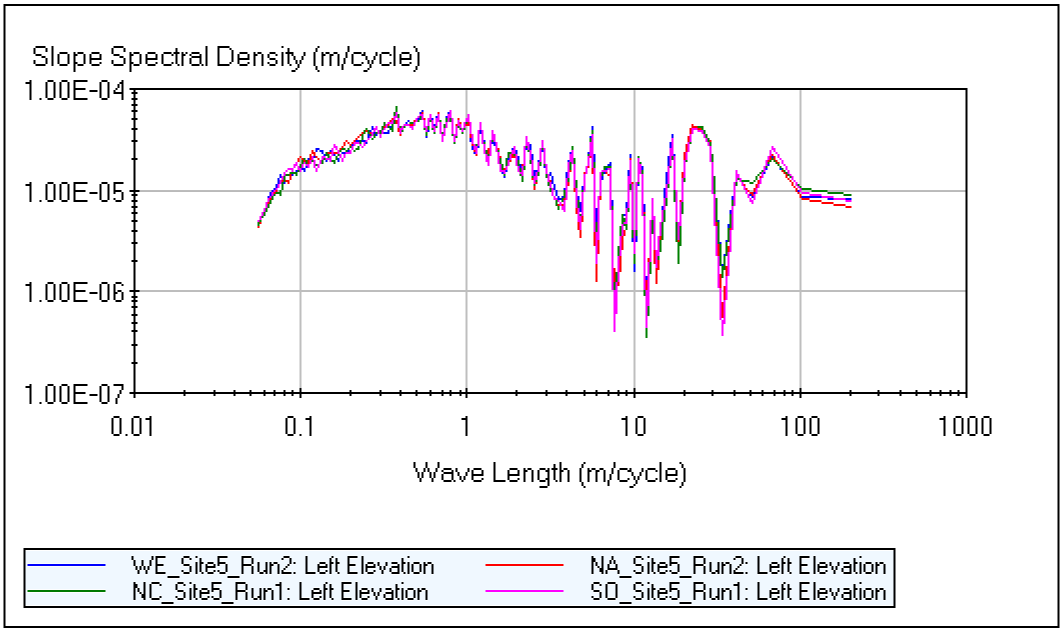


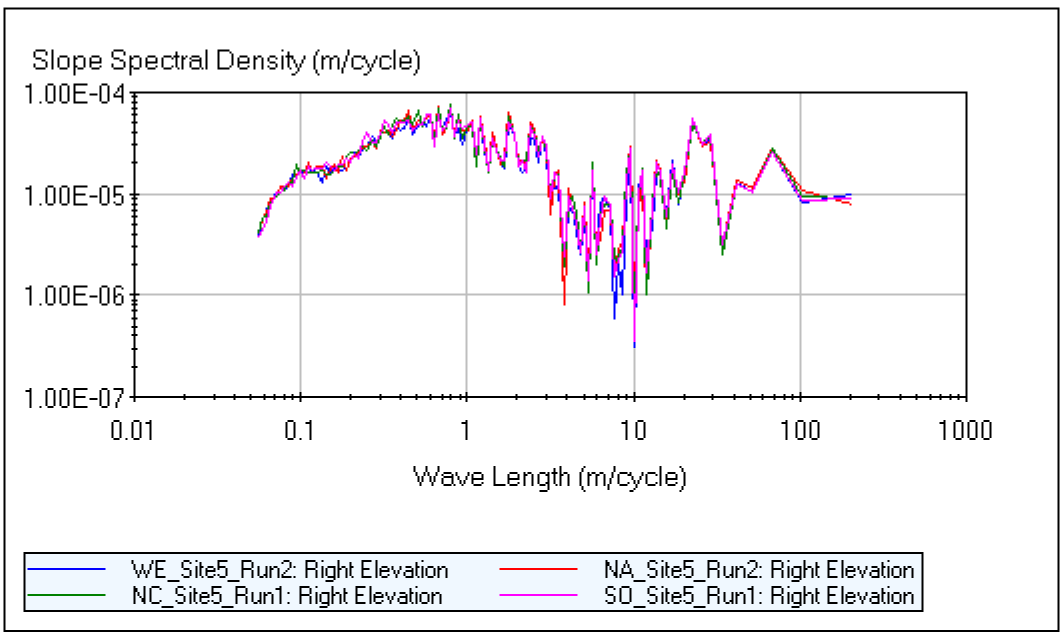
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.



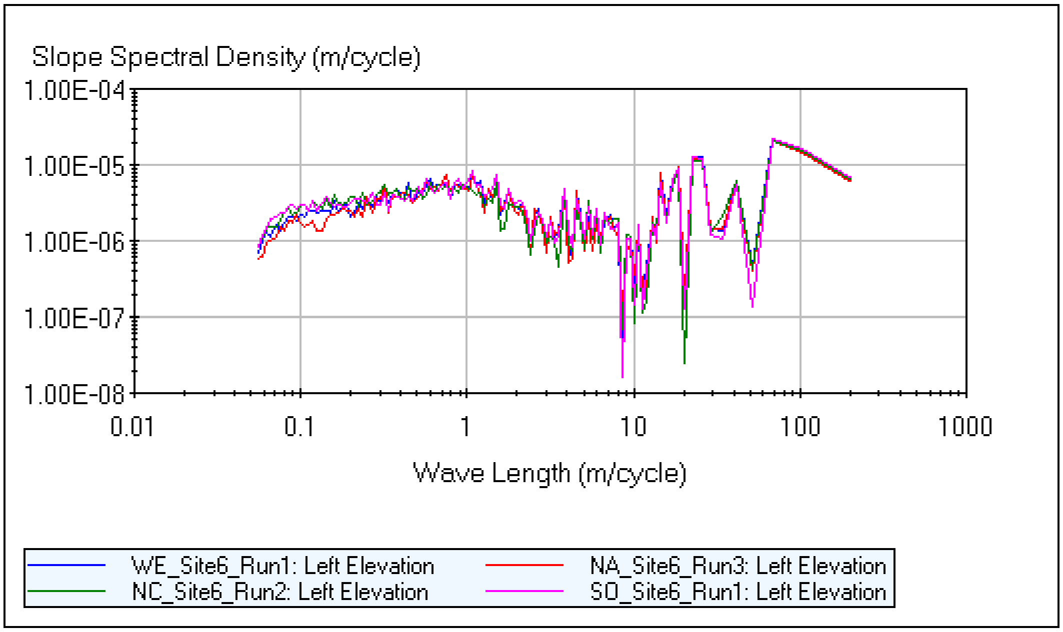


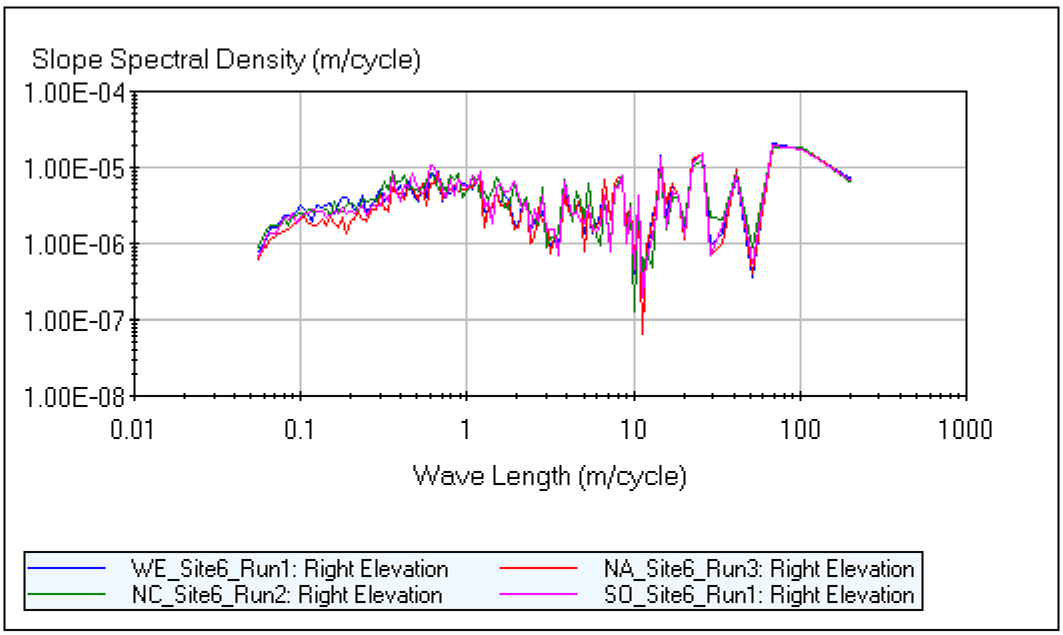
Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.





Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.





Note: NA – North Atlantic, NC – North Central, SO – Southern, WE – Western.