Terry Fox resistance tests: Phase III (PMM) ITTC Experimental Uncertainty Analysis Iniative

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SUMMARY:

This is the 3rd phase of a research program designed to develop a procedure for Experimental Uncertainty Analysis (EUA) for ship resistance testing in an ice tank. The latter is a task for the 23rd and 24th ITTC specialist committee on ice.

In this report, the results of Phase III ship resistance in ice test program were documented and used to formulate the EUA procedure. One of the objectives of Phase III test program is to compare the test results using the tow post (Phase I) with those using the PMM (Phase III).

The procedure for EUA, presented in this report, validates the applicability of the preliminary EUA procedure (previously, proposed by Derradji-Aouat, 2002) to the laboratory measurements from both phases of testing. Consequently, this EUA procedure will be recommended to the 24th ITTC (during its upcoming meeting in Scotland, 2005).

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TERRY FOX RESISTANCE TESTS – PHASE III (PMM) TESTING

ITTC EXPERIMENTAL UNCERTAINTY ANALYSIS INITIATIVE

TR-2004-05

Ahmed Derradji-Aouat and Amy van Thiel

April 2004

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ITTC Experimental Uncertainty Analysis Initiative

1. Introduction

Experiments for ship model resistance in ice were conducted at the Institute for Ocean Technology of the National Research Council of Canada (www.iot-ito.nrc-cnrc.gc.ca/). These tests were conducted for the ITTC 23rd and 24th specialty committee on ice[1] (mandate period 1999-2002 and 2002-2005, respectively). One of the committee's main objectives is to develop a procedure for Experimental Uncertainty Analysis (EUA) in ice tank testing. So far, three phases of testing have been completed. From project management point of view, the Terry Fox test program was divided into several phases to accommodate the project planning for opportunity testing in the ice tank.

In this report, Phase III test program, test results, and calculations of uncertainties in the test results are presented. However, for clarity and completeness, the following short summary regarding all three phases of the test program is given.

Phase I test program was documented by Derradji-Aouat et al. (2002) and Derradji-Aouat (2002) in two (2) internal technical reports: These are: TR-2002-01 and TR-2002-04, the first report dealt with presenting the experimental program and test results, while the second report dealt with developing a preliminary methodology to quantify Experimental Uncertainties (EU) in the test results.

Similarly, the documentation for Phase II testing program is presented in two (2) internal reports (Derradji-Aouat and Coëffé, 2003, and Derradji-Aouat, 2003). In the first report, Phase II test program and test results are presented. In the second report calculations for EU in Phase II test results are given. Note that both reports provide comparisons between Phase I and Phase II test results.

In Phase II, the same test matrix as in Phase I was repeated. The only difference is the target thickness of the ice sheets. In Phase I, all tests were conducted for only one target ice thickness (40 mm), while Phase II tests were conducted for two additional target ice thicknesses (25 mm and 55 mm). In a way, Phase II test program is a continuation of Phase I. Together, both phases provided information for three different ice sheet thicknesses.

In Phase III, the same test matrix as in Phase I was completed. All tests were conducted for only one target ice thickness (40 mm). The difference between phase I and phase III test programs is that in phase I, the model was attached to the carriage using the tow post (Figure 1.a), while in phase III, the model was attached to the carriage using the PMM (Planar Motion Mechanism, Figure 1.b). One of the objectives of phase III test

[1] ITTC = International Towing Tank Conference

program is to compare test results using the tow post (Phase I) with the test results using the PMM (Phase III).

In all phases of testing, tests in ice involved a total of sixteen (16) different ice sheets. Phase I of testing required four (4) different ice sheets, all four ice sheets had nominal thickness of 40 mm and nominal flexural strength value of 35kPa. Phase II of testing, however, required eight (8) different ice sheets, four ice sheets had nominal thickness of 25 mm and the other four ice sheets had nominal thickness of 55 mm. All Phase II ice sheets had nominal flexural strength value of 35 kPa. Phase III of testing required four (4) different ice sheets, all four ice sheets had nominal thickness of 40 mm and target nominal flexural strength value of 35kPa.

All phases involved experiments in both ice and calm open water. In all phases, all experiments were conducted using a model for the Canadian Icebreaker, "Terry Fox", shown in Figure 2. The latter is the IOT standard icebreaker model (IOT Model # 417, scale ≈1:21.8), its particulars and hydrostatics are given in Appendix 1. During Phases I and II, the ship model motions (heave, pitch and roll), tow force and carriage speed were measured. The same parameters were measured during Phase III, with the exception of roll (PMM tests were fixed in roll). During Phase III, sway and yaw were also measured.

2. Experimental Uncertainty Analysis (EUA)

A literature review for the history and development of EUA in marine/ocean testing facilities was given by Derradji-Aouat (2002).

2.1 Basic Formulation

Mathematically, the EUA procedure presented in this report is based on the equations provided by Coleman and Steel (1998). The latter is in harmony with the guidelines of ISO (1995), ASME (PTC-19.1, 1998), and GUM (2003).

2.2 Uncertainty Components and Bias Effects in Ice Tank Testing

In a typical experiment, the total uncertainty (U) is the geometric sum of a bias uncertainty component (B) and a random uncertainty component (P):

$$U = \pm \sqrt{\left(B^2 + P^2 \right)} \tag{1a}$$

The bias component (B) deals with uncertainties in instrumentation and equipment calibrations. Examples of bias uncertainty sources are the load cells, RVDT's (Rotary Variable Differential Transformers), yoyo potentiometers and Data Acquisition System (DAS). However, the precision component (P) deals with environmental and human factors that may effect the repeatability of the test results (<u>i.e. if a test was to be repeated several times, would the same results be obtained each time?</u>). Examples of random uncertainty sources are the changing test environment (such as fluctuations in room temperature during testing), small misalignments in the initial test setup, human factors, …etc.

Derradji-Aouat (2002) showed that in a typical ice tank ship resistance test, the bias uncertainty component (B) is much smaller than the random one (P), he reported that, in Phase I ship model tests in ice, the value of (B) is at least one order of magnitude smaller than the value of (P). He concluded, therefore, that; in routine ship resistance ice tank testing, the total uncertainty (U) can be taken as equal to the random one. Simply, without a loss of accuracy, the bias uncertainty component can be neglected. It follows that:

$$U = \pm P \tag{1b}$$

3. Test Setup

In these tests, the main components of the test set up are: The Terry Fox ship model, the PMM (Figure 3), data acquisition system (DAS) and video cameras.

Marineering Limited (1997) provided details on the development and commissioning of the PMM. Originally, the PMM was designed to study maneuvering of ships in both ice and open water. The PMM dynamometer has 4 cantilever type load cells for measuring surge force, sway force and yaw moment. Surge is measured by two load cells aligned along the x-axis. Sway force is measured by two other load cells aligned along the y-axis. Yaw moment is determined by all four load cells.

4. Data Acquisition System (DAS)

Eleven channels were used to record the data. The test program required measurements of the following 11 items:

- **i.** FWD Sway (N)………………………………… Channel # 2.
- **ii.** AFT Sway (N)…………………………………. Channel # 3.
- **iii.** Surge Center 2 (N)……………….…………. Channel # 4.
- **iv.** X-Pull (N)……………………………………… Channel # 5.
- **v.** Y-Pull (N)……………………………………… Channel # 6.
- **vi.** Yaw (degrees).…………………….………… Channel # 9.
- **vii.** FWD Heave (mm)………..……….………… Channel # 10.
- **viii.** AFT Heave (mm).……………………………... Channel # 11.
- **ix.** Pitch (degrees).………………………………… Channel # 28.
- **x.** Carriage Position (ITC o/p) (m)……………….. Channel # 31.
- **xi.** Carriage Velocity (ITC o/p) (m/s)……………... Channel # 32.

All acquired analog DC signals were low pass filtered at 10 Hz., amplified as required and digitized at 50 Hz. (details given at the IOT quality system standard document for Data Acquisition, Verification and Storage, IOT standard # 42-8595-S/GM-2).

In this project, it was required that all measurements need to be accurate to about ± 2% of the instrumentation range (specifications are given in the Project Initiation Plan “PIP” document).

5. Instrumentation and Calibrations

All details regarding the instrumentations used in this test program and their calibration sheets are given in Appendix 2.

6. Description of the Experimental Program

6.1 Ice Type and Ice Properties

The program required four (4) different ice sheets. Non-bubbly ice was used.

The procedures followed to prepare the ice tank, seed and grow the ice sheet are given in the IOT work procedures TNK 22, TNK 23, and TNK37, respectively. All work procedures are given in the IOT documentations for the quality system.

The mechanical properties of the ice are determined according to the following work procedures: TNK 26 (for measurements of the flexural strength), TNK 27 (for measurements of the elastic modulus), TNK 28 (for measurements of the compressive strength), and TNK 30 (for measurements of the ice density).

Measurements of ice thickness are performed as per the work procedure TNK 25.

A summary of the ice sheets (seeding, growth and warm-up) and the measurements of the necessary ice properties, tempering curves, and schematics for the location of ice samples used for the flexural strength tests are presented in Appendix 3 (summaries for all 4 ice sheets are included).

It should be noted that all of the above work procedures are valid for both bubbly ice and non-bubbly ice. Simply, in the case of non-bubbly ice, the bubbler system is not used (the bubbler system is turned off).

6.2 Test Matrix and Run Sequence

The overall test matrix is given in Appendix 4. Broadly speaking, two (2) different types of experiments were performed. These are experiments in ice and experiments in open water.

- ***<u>Experiments in Ice:</u>***
  - 1.a: Experiments in level ice sheets (continuous, unbroken ice sheets).
  - 1.b: Experiments in pre-sawn ice sheets.
  - 1.c: Experiments in pack ice (broken ice, the ice sheet was broken, manually, and ice blocks were re-distributed in the tank to achieve various ice concentrations).

All tests in ice were conducted with no turbulent stimulation studs.

- ***Resistance Experiments in Open Water:***
    - 2.a: Standard resistance experiments in open water (ship model is equipped with turbulent stimulation studs and beach absorbers were used).
    - 2.b: Baseline experiments in open water (constant speed through the length of the tank, turbulent stimulation studs were not used).

Note that all of the open water tests were conducted in the ice tank, for calm water conditions (no waves).

6.3 Description of the Experiments in Ice

The test program involved the use of four (4) different ice sheets. All ice sheets had the same target thickness (40 mm) and the same target flexural strength (35 kPa). All tests were conducted at approximately 0°C air temperature.

As indicated in Appendix 4, ship model speeds of 0.1 m/s, 0.2 m/s, 0.4 m/s and 0.6 m/s were selected. Each ice sheet was tested for only one speed. Ice sheet # 1 was tested for speed of 0.1 m/s, ice sheet # 2 was tested for speed 0.2 m/s, ice sheet # 3 was tested for speed of 0.4 m/s and ice sheet # 4 was tested for speed 0.6 m/s.

In each ice sheet, six (6) different test runs were performed. The first three runs were conducted in continuous "unbroken" ice, while the last three runs were conducted in pack "broken" ice.

Figure 4 shows a schematic for the first three (3) test runs:

Run # 1: This run was performed in a level "unbroken" ice sheet, along the centerline of the tank (central channel, CC). The carriage speed was kept constant along most of the entire useable length of the ice tank (the entire usable length is ≈ 76 m, each test run uses ≈ 65 m).

<u>Note that after the completion of Run # 1, an open water channel along the centerline of the tank is created.</u>

Run # 2: After the completion of the first run, the model was moved to the South Quarter Point (SQP) of the tank. The south half of the ice sheet was constrained (using pegs), and the ice was pre-sawn along the SQP straight path. A resistance test run was performed in the pre-sawn ice at constant speed (same speed as Run # 1) along most of the entire useable length of the ice tank.

Run # 3: The model was moved to the North Quarter Point (NQP) of the tank. The north half of the ice sheet was neither pre-sawn nor constrained (no pegs, the ice sheet had a free boundary). Resistance test run was performed in the ice sheet at constant speed (same speed as Run # 1) along most of the entire useable length of the ice tank.

The last three runs (Runs # 4, # 5 and # 6) were performed in broken ice. After the completion of the first three runs, the ice sheet was broken (manually) into small blocks (the ice was broken slowly to avoid rafting) with arbitrary shapes. The ice blocks were re-distributed in the tank, manually, to achieve the desired pack ice concentration. Three (3) different pack ice concentrations were targeted; these are the $9/10^{ths}$, $8/10^{ths}$ and $6/10^{ths}$. These ice concentrations were chosen to reflect actual "existing" pack ice environment. Note that ice concentration less than about $6/10^{th}$ yields behavior equivalent to that of baseline open water tests.

The three test runs in pack ice are:

Run # 4: Test run in $9/10^{ths}$ ice concentration. The ship model was towed along the NQP at a constant speed (same speed as in Run # 1).

Run # 5: Test run in $8/10^{ths}$ ice concentration. The model was towed along the CC of the ice tank at a constant speed (same speed as in Run # 1).

Run # 6: Test run in $6/10^{ths}$ ice concentration. The ship model was towed along the SQP at a constant speed (same speed as in Run # 1).

After the completion each test run, a creeping test was performed in the remaining portion of the ice sheet. A creeping test run is a resistance test at very low ship speed (≈ 0.02 m/s) for at least one ship length.

The above six test runs (Run # 1 to Run # 6) were repeated for each ice sheet, with the exception of the first ice sheet (Run # 6 was not completed due to time constraints). A total of 23 resistance test runs in ice were conducted.

Figures 5a and 5b show pictures of typical test runs in ice.

6.4 Description of the Experiments in Open Water

- ***<u>Standard Resistance Experiments in Open Water:</u>***

Six (6) standard open water resistance tests were performed in the ice tank. In all six tests, turbulent stimulation studs were placed on the model. Also, beach absorbers were used. In these test, ship speeds from 0.3 m/s to 1.7 m/s were covered.

- ***<u>Baseline Resistance Experiments in Open Water:</u>***

For these tests, the turbulent studs and beach absorbers were removed. In each test, the model was towed in calm open water at constant velocity along the entire length of the ice tank (same as in the case for ice tests). Velocities of 0.1 m/s, 0.2 m/s, 0.4 m/s and 0.6 m/s were selected. Tests for each velocity were repeated several times (see test matrix in Appendix 4). A total of (26) baseline open water resistance tests were conducted.

7. Data Storage and Resistance Calculations

All test results (data-files and test plots) are stored in the IOT computer system under the directory name “PJ02953” on Mickey server.

A summary of the completed test matrix and the data file naming convention are given in Appendix 4.

Plots for typical test results are given in Appendix 5. These plots include:

- Typical results for resistance experiments in ice:
  P3_S3_NQP_R3_0P4_038

- Typical results for the baseline resistance experiments in open water:
  P3_OW_V8_008

- Typical Results for the standard resistance experiments in open water:
  P3_OW_V2_082

8. Phase III Results

8.1 Resistance in Baseline Open Water Tests

The test results are given in Figure 6a. The numerical values for the mean tow force at each speed are:

Model velocity (m/s)	0.1	0.2	0.4	0.6
Number of tests repeated	7	4	4	11
Mean Tow Force (N)	0.319371	1.016385	3.4846	7.392555
Standard deviation	0.053471	0.066705	0.109116	0.032734

The resistance in baseline open water tests ($R_{Baseline}$) is obtained from the regression line in Figure 6a:

$$\left(R_{Baseline}\right) = 18.125 * V^2 + 1.5342 * V - 0.0153 \quad (2a)$$

8.2. Resistance in Standard Open Water Tests

Figure 6b shows the results from the six different tests conducted in the ice tank. The resistance (R_{STD_OW}) is obtained from the regression line in Figure 6b:

$$\left(R_{STD\_OW}\right) = 42.343 * V^2 - 34.193 * V + 11.573 \quad (2b)$$

8.3 Resistance in Ice Tests

- ***Tow Force versus velocity in continuous ice***

Figure 7a shows the measured tow force versus velocity curves for all tests in continuous ice (Runs # 1, 2 and 3). All curves exhibit the same general trends.

- ***Tow Force versus velocity in broken ice***

All measured tow force versus velocity curves in broken ice tests are given in Figure 7b. The results show that the $9/10^{ths}$ and $8/10^{ths}$ ice coverage tests, resistance curves are almost linear (very low level of non-linearity). However, in the $6/10^{ths}$ ice coverage, the tow force versus velocity curves are highly non-linear (approach open water resistance in Fig. 6a).

8.4 Comparison of Test Results

8.4.1 Tow Force in Baseline Open Water Tests

- ***Comparison between tests from Phases I, II and III***

The general trend of the curves for resistance versus model speed is the same for both phases (Figures 8a and 8b). The differences in mean resistances for Phases I and III are:

Approx. Speed	Phase I Mean Tow Force	Phase III Mean Tow Force	% Difference
0.1	0.319371429	0.613016	62.99%
0.2	1.016385	1.0396	2.26%
0.4	3.4846	3.5894	2.96%
0.6	7.392554545	7.6602	3.56%

Note that for all tests, except for tests at a speed of 0.1 m/s (an outlier), there is a very small difference between the results from the two phases. At very low speed (0.1 m/s), it appears that noise levels are too high. This data point is considered an outlier.

8.4.2 Resistance in Standard Open Water Tests

- ***Comparison between tests from Phases I and III***

Figures 9a and 9b provides a comparison between the measured tow force values in Phases I, II and III, each is plotted for tow force versus velocity. There is no significant difference between the results in all phases.

8.4.3 Resistance in Ice Tests

Tables 1 and 2 present the mean and maximum tow forces measured in Phases I and III, respectively. Figures 10a and 10b provide a comparison between the measured tow forces in Phase I testing and those from Phase III testing. Implicitly, the tables show the effects of the tow post and PMM on the test results. The main conclusions drawn from the comparisons are:

- **Mean Tow Forces**

From Table 1, mean tow forces for Phase I are generally larger than the Phase III values (Figure 10a). The difference averages 22.22% and ranges from 5.38% to 50.15%. However, at tow forces less than 20N, no significant difference is observed.

- **Maximum Tow Forces**

In Table 2, maximum tow forces for Phase I are generally smaller than the Phase III values (Figure 10b). The difference averages 26.6% and ranges from 1.79% to 51.09%. At tow forces lower than 100N, no significant difference is observed.

The source of the differences in the measured tow forces in Phase I and those in Phase III is, basically, unknown. However, one possibility is the effects of the test set up (the PMM test set up is much different than that of the tow post). Another possibility is that the PMM is not rigid enough as compared to the tow post.

9. Components for Ship Model Resistance In Ice

Since the objective of the test program is to develop a procedure for EUA-ship resistance tests in ice tanks, a summary of the resistance calculations is given in this section.

The standards for ship resistance in ice (ITTC-4.9-03-03-04.2.1) and (IOT/42-8595-S/TM7) give formulas for the total resistance in ice as the sum of four individual components:

$$R_t = R_{br} + R_c + R_b + R_{ow} \qquad (3a)$$

where R_t is the total resistance, R_{br} is the resistance component due to breaking the ice, R_c is the component due to clearing the ice, R_b is the component due to buoyancy of the ice and R_{ow} is the resistance in open water. In order to quantify each component, the following test plan is to be conducted (ITTC-4.9-03-03-04.2.1):

Standard open water tests provide values for R_{ow}, while the creeping speed tests give R_b:

$$R_t = R_{ow} \quad \text{(in standard open water tests)},$$
$$R_t = R_b \quad \text{(in the creeping speed tests)} \qquad (3b)$$

In the pre-sawn ice tests (Runs #2), the ice breaking component $R_{br} = 0$, and therefore:

$$R_t = R_c + R_b + R_{ow} \quad \text{(in pre-sawn ice tests)} \qquad (3c)$$

Since both R_{ow} and R_b are already known from Eq. 3b, R_c is:

$$R_c = R_t - R_b - R_{ow} \tag{3d}$$

where R_t, in Eq. 3d, is the measured resistance in the pre-sawn ice test runs.

From tests in level ice sheets, the total resistance R_t is measured, and the ice breaking component, R_{br}, is calculated as (from Eq. 3a):

$$R_{br} = R_t - R_c - R_b - R_{ow} \tag{3e}$$

where R_t, in Eq. 3e, is the measured resistance in the level continuous ice (Run #1 tests).

Theoretically, in the ship ice resistance main equation (Eq. 3a), the superposition principle is used, which implies that the total resistance in ice is equal to the sum of four separate components. One may argue against the use of the superposition principle and the applicability of Eq. 3a to actual ship-ice interactions (since ice breaking and clearing processes are highly non-linear and dynamic, and superposition principles are applied to linear and static problems). However, this argument is beyond the scope of this report.

10. EUA for ice tank testing – A Procedure Development

10.1 Segmentation Hypothesis

For the ice test runs, several reasons have contributed to the decision for keeping the speed of the ship model constant throughout most of the useable length of the ice tank (≈ 65 m). The main one is the hypothesis that the time history from one long ice test run can be divided into segments, and each segment can be analyzed as a statically independent test. The hypothesis states that (Derradji-Aouat, 2004):

> *"The history for a measured parameter (such as tow force versus time) can be divided into 10 (or more) segments, and each segment is analyzed as a statistically independent test. Therefore, the 10 segments in one long test run in ice are regarded as 10 individual (independent but identical) tests."*

Coleman and Steel (1998) reported that, in statistical uncertainty analysis, a population of at least 10 measurements (10 data points) is needed. Precision uncertainty is calculated using the mean and the standard deviation of that population.

However, in ice tank testing, it is recognized that conducting the same test 10 times is very costly and very time consuming. Therefore, the principle of segmenting a time history of a measured parameter over a long test run (such as 65 m) into 10 (or more) segments, results in significant savings in project costs and efforts. By demonstrating that each segment can be analyzed as a statistically independent test, uncertainties are calculated from the means and standard deviations of the individual segments.

To further illustrate the segmentation hypothesis, an example is given in Figure 11. In the example, the measured tow force history in test run # 1 (nominal speed of 0.2

m/s) in ice sheet # 2 of Phase III (nominal ice thickness of 40 mm) is presented to illustrate the basic steps followed to develop the procedure on how to calculate the uncertainties in ice tank testing. The time history given in Figure 11a was divided into 10 equal (more or less equal) segments, as illustrated in Figures 11b.

In this report, only calculations of uncertainties in measured tow forces (given in Figure 11a) are presented. The same calculation steps are valid for all other measured parameters (heave, pitch, carriage speed, yaw, sway).

Using the tow force segments, in Fig. 11b, the first calculation step is to obtain mean and standard deviation for each segment. The second step is to calculate the mean of the means and the standard deviation of the means. The mean of the means and standard deviation of the means are needed to compute random uncertainties in the results of the test run (as it will be shown in the subsequent sections). These two basic calculations steps are repeated for all six (6) test runs (Run # 1 to Run # 6), in all four (4) ice sheets.

It should be cautioned that the segmentation hypothesis is valid only if the following three conditions are satisfied (Derradji-Aouat, 2004):

1. Each segment should span over 1.5 to 2.5 times the length of the ship model,
2. Each segment should include at least 10 events for ice breaking (10 load peaks) or at least 10 collision events (in the case of pack ice test runs), and
3. General trends (of a measured parameter such as tow force versus time) are repeated in each segment.

Condition # 1 is based on the fact that the ITTC procedure for resistance tests in level ice (ITTC-4.9-03-03-04.2.1) requires that a test run should span over at least 1.5 times the model length. For high model speeds (> 1 m/s), however, the ITTC procedure requires test spans of 2.5 times the model length.

Condition # 2 is based on the fact that in EUA, for an independent test, a population of at least 10 data points is needed to achieve the minimum value for the factor t (in the t distribution Table A.2, Coleman and Steele, 1998). For tests in ice tanks, 10 to 15 segments are recommended. The gain in any further reduction in the value of t (by having more than 10 to 15 segments) is minimum.

Condition # 3 is introduced to ensure that the overall trends in a measurement (such as tow force versus time) are repeated in each segment. This condition serves to provide further assurance into the main hypothesis ("*…Therefore, the 10 segments in one long test run are regarded as 10 individual, independent but identical, tests"*). Fundamentally, if the trends are not, reasonably, repeated, then the segments could not be analyzed as "*independent but identical*" tests.

It is important to emphasize the fact that the division of the time history of a measured parameter into consecutive segments is valid only for long test runs at constant speed and heading. If the model speed or heading is changed during the test run, then the segments cannot be analyzed as "identical".

Note that the time histories measured in creeping speed test are not subjected to the segmentation hypothesis.

Furthermore, it is recognized that the division of the results of a test run into segments is valid only for the steady state portion of the measured data. Only, the steady state portion of the measured time history is to be used. This is required to eliminate the effects of the initial ship penetration into the ice (transient stage) and the effects of the slowdown and full stop of the carriage during the final stages of the test run.

10.2 Steady State Requirements

In ice tank testing, for any given ice sheet, the ice properties are not completely (100%) uniform (same thickness) and homogeneous (same mechanical properties) all over the ice sheet. This is attributed, mainly, to the ice growing processes and refrigeration system in the ice tank. An example to illustrate the special variability of the material properties is given in Appendix 6.

In addition to the spatial variability of the material properties of ice, during an ice test run, the carriage speed may (or may not) be maintained at exactly the required nominal constant speed[2]. Because of this inherent non-uniformity of ice sheets, the non-homogeneity of ice properties and the small fluctuations in the carriage speed, steady state condition in the time history of a measurement may not be achieved. For example, in Fig. 11, the tow force did not become completely steady after the initial transient stage.

Theoretically, if the time history of a measured parameter is changing drastically, then the segments could not be analyzed as "identical" tests (condition # 3). The steady state requirement, therefore, calls for a corrective action to account for the effects of non-uniform ice thickness, non-homogenous ice mechanical properties and small fluctuations in carriage speed on the test measurements.

To identify whether or not the time history for a measured parameter has reached its steady state, the following procedure was recommended (Derradji-Aouat, 2002). The measured time histories for all parameters, in all 23 ice test runs, were plotted along with their linear trend lines. A linear trend line with zero slope (or very close to zero) indicates that a steady state in a measured parameter is achieved.

So far, in this project, all three phases of testing generated a total of 498 time histories (there are 95 ice test runs, and in each test run five parameters are measured for Phases I and II[3] and six parameters are measured in Phase III[4]). For example, Fig. 12

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[2] The control system maintains the carriage speed constant. However, when ice breaks, small fluctuations in carriage speed may take place.
[3] Tow force, carriage speed and three ship model motions (heave, pitch and roll).
[4] Tow force, carriage speed and four ship model motions (heave, pitch, sway and yaw).

shows the time histories for the measured tow forces in Phase III testing. Time histories for Phases I and II testing were provided in previous reports by Derradji-Aouat (2002) and Derradji-Aouat (2003), respectively.

After drawing the linear trend lines through all measured tow forces, it was observed that, in the majority of cases, a <u>true</u> steady state was never achieved (Table 3a). For example, the linear trend lines (in Fig. 12) show that the tow force time histories runs changed over a range of 0.002% (for PICE-2 – Run # 3) to 5.2% (for PICE-4 – Run # 1). The sloping trend lines reflect the fact that the time histories never reached their steady state.

As shown in Table 3b, it is interesting to show that, although the slopes of the trend lines varied within only 5.2%, they led to some significant changes in the tow forces over the 65 m towing distance (up to 121% in PICE-1, Run # 5).

Therefore, in this work, it is suggested that the non-steady state condition may be attributed to one (or all) of the following three factors:

- **i.** A changing carriage speed (or small fluctuations in carriage speed) during testing,
- **ii.** Non-uniform ice thickness,
- **iii.** Non-uniform mechanical properties of the ice (flexural/compressive strengths, elastic modulus and density of ice).

The contribution of each factor is further investigated as follows:

10.2.1 Effects of changing carriage speed

Figure 13 shows the time histories for the measured carriage speed histories in Phase III testing. The results, for Phases I and II testing, were already given by Derradji-Aouat (2002, 2003). The linear trend lines point to the fact that, during testing, the actual changes in the carriage speeds were very small, and consequently, they can be neglected. Trend lines through the carriage speed histories had slopes between $1 \text{ X } 10^{-8}$ (for PICE-3 - Run # 5) to $6 \text{ X } 10^{-6}$ (for PICE-4 - Run # 3). Table 3d shows that, over the ≈ 65 m towing distance, changes in the carriage speed ranged between 0.0003% (PICE-3, Run # 5) and 0.53% (PICE-1, Run # 1) with a mean of about 0.18%.

Over the ≈ 65 m towing distance, the changes in the carriage speed were extremely small (Table 3d), they are several orders of magnitude smaller than the changes in tow forces (Table 3b). By and large, the carriage speed is very much steady, and therefore, it was assumed that the contribution of the changing carriage speed into the development of non-steady state time history of the measured parameters can be ignored. Consequently, no corrections for carriage speed fluctuations are needed. The same conclusions were reached in previous phases of testing (Derradji-Aouat, 2002 and 2003).

10.2.2 Effects of non-uniform ice thickness

Measured ice thickness profiles along the length of the ice tank are given in Figure 14a. In each ice sheet, three thickness profiles were measured (these are: the CC, the NQP and the SQP profiles). Each profile consisted of a series of ice thickness measurements (every 2 m) along the length of the ice tank.

Mean ice thickness profiles are given in Fig. 14b, each mean profile is the average of the three measured ice thickness profiles (CC, NQP and SQP profiles). The linear trend lines, through the mean profiles, indicate that the ice thickness varied within the range of 0.69% (in PICE-1) to 2.64% (in PICE-2), as can be calculated from Table 4.

In Phase I testing, mean ice thickness profiles increased progressively from the east side to the west side of the tank (all ice sheets show thickness profiles with increased trend lines). However, in Phase III tests, the changes in mean ice thickness profiles were, somewhat, random (as compared to Phase I testing).

To correct for the effects of non-uniform ice thickness on the test measurements, the following correction methodology and rational are used (Derradji-Aouat, 2002):

a. Uncertainty analyses for both mean and maximum tow forces are calculated. In ice engineering, maximum tow forces are indicators for maximum ice loads on the ship structure, while mean tow forces are used in the standard ship resistance calculations.

b. In the following discussion, mean ice resistance values are used to show how the EUA method is conceptualized and developed. The same procedure and equations are used for maximum ice resistance values (Derradji-Aouat, 2002).

c. Ice thickness corrections are applied only to the resistance of ice. In ice resistance analysis, the total ice resistance ($R_{Total\ Ice}$) is equal to the measured resistance in ice tests ($R_{Measured}$) minus the resistance measured in the baseline open water tests ($R_{Open\ Water}$).

$$\left(R_{Total\ \ Ice}\right)_{Mean} = \left(R_{Measured}\right)_{Mean} - \left(R_{Open\ Water}\right) \tag{4a}$$

where ($R_{Open\ Water}$) is obtained from the correlation obtained from the baseline open water test results (Eq. 2a).

d. For a given ice sheet, with nominal thickness h_o, the following equation is used to calculate mean total ice resistance (Derradji-Aouat, 2003):

$$\left(R_{Total\ \ Ice}\right)_{Correct\ \ Mean} = \left(R_{Total\ \ Ice}\right)_{Measured\ \ Mean} * \left(\frac{h_o}{h_m}\right) \tag{4b}$$

where $(R_{Total\ Ice})_{Correct\ Mean}$ is the corrected total ice resistance for the nominal ice thickness h_o, $(R_{Total\ Ice})_{Measured\ Mean}$ is the measured total ice resistance for the nominal ice thickness h_o (h_o = 40 mm). The parameter h_m is the measured ice thickness at a distance D (D is the distance from the east end of the tank to where the calculation is made, which ranges from 0 m to 76 m).

Note that Eqs. 4a and 4b are also valid when using maximum ice resistance values. This is achieved by substituting the subscript "mean", in Eqs. 4a and 4b by the subscript "max".

Figures 15 and 16 show plots for corrected versus measured (uncorrected) mean and maximum tow force, respectively.

Note that only the results of tests in continuous ice (Run # 1, # 2 and # 3) were subjected to ice thickness corrections. In broken ice test results (Run # 4, # 5 and # 6), no corrections were necessary. This stems from the fact that, in broken ice tests, the original ice thickness profiles are not maintained (not conserved).

Note, also, that the time histories measured in the creeping speed test runs are not subjected to corrections for ice thickness variation. The length of each creeping speed test run is small (only one ship length ≈ 3.8 m), the variation of ice thickness over this small length can be ignored.

10.2.3 Effects of non-homogeneous ice properties

Measured flexural strength profiles along the length of the ice tank are given in Figure 17a. In each ice sheet, two flexural strength profiles along the SQP and NQP are measured (actual measurements were performed every 15 m along the longitudinal axis of the tank). Mean flexural strength profiles are given in Figure 17b.

In-situ cantilever beam flexural strength tests were conducted along the tank. The beam dimensions have the proportions of 1:2:5 (thickness: width: length). The flexural strength σ_f is calculated as:

$$\sigma_f = \frac{6PL}{wh_f^{\ 2}} \tag{5a}$$

where *L is* the length of the beam, *w is* its width, and h_f is its thickness. *P* is the load.

The uncertainty in the measured flexural strength is $U_{\sigma f}$:

$$U\sigma_f = \sqrt{U_P^2 + U_L^2 + U_W^2 + 2U_{hf}^2} \tag{5b}$$

where U_L, U_W, and U_{hf} are the uncertainties is the measured dimensions (*L*, *w and* h_f).
U_p is the uncertainty in the measured point load.

The uncertainties in the flexural strength profiles are calculated using Eq. 5b, they are given in Tables 5a and 5b. Uncertainties varied between 38.62% and 64.98%. Derradji-Aouat (2002) reported that any data correction for ice thickness includes, implicitly, the correction for the flexural strength of the ice. This is due to the fact that ice thickness is a fundamental measurement while the flexural strength is a calculated material property (flexural strength is calculated from measurements of applied point load and dimensions of the ice cantilever beam). Since this work deals with EUA of actual "fundamental" measurements, it is recognized that if corrections were to be made for both ice thickness and flexural strength, double correction (double counting) would take place, and the final uncertainty values would be overestimated. The same argument is valid for corrections for the comprehensive strength of ice (the latter is calculated from applied axial load and measurements of actual dimensions of the ice sample).

Measured ice density profiles along the length of the ice tank are given in Figure 18. The density of ice, ρ_i, is:

$$\rho_{\mathrm{i}} = \rho_{\mathrm{w}} - \frac{\mathrm{M}}{\mathrm{V}} \qquad (6a)$$

where ρ_w is the density of water. M is the mass of the ice sample. The volume, V, is calculated from the sample dimensions (length, L, width, W, and thickness, H). The uncertainty in the ice density is:

$$U_{\rho_i} = \sqrt{U_H^2 + U_L^2 + U_W^2 + U_M^2} \qquad (6b)$$

The value of U_M is ignored because it is considered a bias uncertainty.

The variation of density along the centre line of the tank was 4.58% to 8.60%, measured values and experimental uncertainty calculations are given in Table 6. To a large extent, this is a reflection of the uniformity of non-bubbly ice. From the ice tank operational point of view, in non-bubbly ice sheets, density value could not be controlled but its uniformity is reasonably assured. In bubbly ice, however, the inverse is true, the target density values can be achieved but the spatial uniformity of ice density is compromised.

From the above three subsections, it is obvious that the most critical correction to be made is the correction for ice thickness variation. However, it should be re-emphasized that, ice thickness corrections need to be applied only to tests in continuous ice (Runs # 1, # 2 and # 3). In broken ice tests (Runs # 4, # 5 and # 6) and in creeping speed ice tests, no corrections are necessary.

11. Calculations for Random Uncertainties

The plot for the tow force history, in Figure 11a, is used as an example to illustrate the method used to calculate random uncertainties. The plot was divided into 10 segments (Figure 11b and Table 7). Mean tow force (TF_{Mean}) and maximum tow force (TF_{Max}) were obtained for each segment. Consequently, a population of 10 data points for (TF_{Mean}) and a population of 10 data points for (TF_{Max}) are obtained. Random uncertainties in mean tow force and in maximum tow force are given in Tables 7 and 8, respectively.

The following discussion will be focused on the mean tow force history. The same procedure is applicable for maximum tow force history.

As shown in Table 7, each ice test run is divided into about 10 segments. Mean tow force (TF_{Mean}) is obtained for each segment.

The following discussion will be focused on the mean tow force history obtained in ice sheet # 2 for Run #1 (Figures 11a and 11b). The same procedure is applicable for all other ice sheets.

For Run #1 in ice sheet # 2, the mean of the 10 means ($Mean\_TF_{Mean}$) and the standard deviation of the 10 means (STD_TF_{Mean}) were calculated. Random uncertainties in mean tow forces $U(TF_{Mean})$ are calculated in three steps:

Step # 1: In Table 7, after the calculations of the mean of means ($Mean\_TF_{Mean}$) and standard deviation of means (STD_TF_{Mean}), the Chauvenet's criterion was applied to identify the outliers (outliers are discarded data points). The Chauvenet number for mean tow forces is $(Chauv\ \#)_{Mean}$:

$$(\text{Chauv }\#)_{Mean} = \left| \frac{TF_{Mean} - (Mean\_TF_{Mean})}{(STD\_TF_{Mean})} \right| \quad (7a)$$

The Chauvenet's criterion dictates that the Chauv # for each data point should not exceed a certain prescribed value (Coleman and Steele, 1998). For 10 to 15 segments, the Chauv # should not exceed 1.96 to 2.13. In Table 7, data points with Chauv # greater than 1.96 were disregarded. For example, the data from segment # 13 of Run # 1 in ice sheet # 2 was disregarded (that segment has a Chauvenet # of 2.43, which is larger than 1.96).

A new mean of means and a new standard deviation of means were then calculated from the remaining data points (remaining segments).

Step # 2: After calculating the new mean of the means and the new standard deviation of the means (from the remaining segments - data points), random uncertainties in the mean tow force are:

$$\left(U(TF_{Mean}) \right) = \frac{t^*(STD\_TF_{Mean})}{\sqrt{N}} \quad (7b)$$

where $t \approx 2$, and N is the number of the remaining data points (segments).

Step # 3: Random uncertainties, calculated using Eq. 7b, are expressed in terms of uncertainty percentage (UP):

$$\left(UP(TF_{Mean}) \right) = \frac{U(TF_{Mean})}{Mean\_TF_{Mean}} * 100 \quad (7c)$$

Note that the above three steps (Eqs. 7a, 7b and 7c) are also used to calculate random uncertainties in maximum tow forces. This is achieved by substituting (TF_{Mean}), ($Mean\_TF_{Mean}$), $(Chauv\ \#)_{Mean}$, and (STD_TF_{Mean}) with (TF_{Max}), ($Mean\_TF_{Max}$), $(Chauv\ \#)_{Max}$, and (STD_TF_{Max}), respectively.

The magnitudes of the ($Mean\_TF_{Mean}$) as a function of the model speed and as a function of the test run # are given in Figures 19a and 19b, respectively. Similarly, the magnitudes of the ($Mean\_TF_{Max}$) as a function of the model speed and as a function of the test run # are given in Figures 20a and 20b, respectively. The overall trends seem reasonable, and the same conclusions as those given in Phase I report (Derradji-Aouat, 2002) are reached.

It is important to note that the above procedure (segmentation of measured time history, correction for ice thickness, the use of the three calculation steps) is valid for calculating random uncertainties in all other measured ship motion parameters (pitch, heave, yaw and sway).

11.1 Random Uncertainties in Mean Tow Force

Figures 21a and 21b show the calculated random uncertainties in mean resistance ($Mean\_TF_{Mean}$) as a function of test run type (in Fig. 21a) and as a function of ice sheet number (in Fig. 21b). The main results are:

- In level (continuous, unbroken) ice test runs (Run # 1, # 2 and # 3), Figs. 21a and 20b and Table 7 show that, the calculated random uncertainties in mean tow forces are less than 6%. In fact, all uncertainties were below 4%, except for two data points (PICE-1, Run # 2 and PICE-4, Run # 3), where uncertainties were 5.84% and 4.08%, respectively.

- In broken ice test runs (Run # 4, # 5 and # 6), Fig. 21a, 21b and Table 7 show that all random uncertainties were below 18%, except for test run # 5 in PICE-1, where the uncertainty value was 25.94 %. It should be emphasized that in broken ice tests, no corrections for ice thickness profiles were made.

11.2 Random Uncertainties in Maximum Tow Force

Calculations of uncertainties in maximum tow force are given in Table 8 (same calculation procedure as for the uncertainties in mean tow force in Table 7). Figures 22a and 22b show plots for the calculated uncertainties in maximum tow force ($Mean\_TF_{Max}$)

as a function of test run # (Fig. 22a) and as a function of the model speed (Fig. 22b). The main results are:

- In continuous (unbroken) ice test runs (Run # 1, # 2 and # 3), Figs. 22a and 22b and Table 8 show that, all calculated random uncertainties are less than 14%. In fact, all uncertainties were below 10%, except for three data points (PICE-2-Run # 1, PICE-3-Run # 1 and PICE-4-Run # 3), where uncertainties were 10.71%, 13.83% and 11.17 %, respectively.

- In broken ice test runs (Run # 4, # 5 and # 6), Fig. 22a and 22b and Table 8 show that all random uncertainties were below 14 %. It should be re-emphasized that in broken ice tests, no corrections for ice thickness profiles were made.

11.3 Effect of Correction for Ice Thickness on Random Uncertainties

Corrections for variations in ice thickness profiles (using Eq. 4b) are made only for tests in continuous ice (Runs # 1, # 2 and # 3). Figure 23a shows comparisons between corrected versus uncorrected random uncertainties in mean tow force. It is clear that the change in ice thickness did affect much the values of $U(TF_{Mean})$. This is a different conclusion than those reached in the previous two phases of testing.

11.4 Effects of Data Reduction Equation

Equation 4b was proposed to correct for effects of ice thickness variations on the values of random uncertainties. It should be recognized that the corrected resistance curves are not direct laboratory measurements, but they are calculated from the analytical equation (Eq. 4b). The process of using analytical equations to correct measured parameters is called “Application of Data Reduction Equations, DRE”.

In EUA, there are additional random uncertainties involved in the application of the DRE. The uncertainty involved in using Eq. 4b is:

$$\left(\frac{UR}{R}\right) = \left(\left(\frac{UR_0}{R_0}\right)^2 + \left(\frac{U_h}{h_0}\right)^2\right)^{\frac{1}{2}} \qquad (8)$$

In the above equation, (U_R/R) is the total uncertainty in resistance, R. Both (UR_0/R_0) and (U_h/h_0) are the relative uncertainty in the measured ice resistance (as calculated in Tables 7 and 8) and the relative uncertainty in the measured ice thickness, respectively (the uncertainties in ice thickness are shown in Table 4). Note that, in Eq. 8, the value of (U_h/h_0) is an additional relative uncertainty, which is induced by the use and application of the DRE. The total relative uncertainty is the geometric sum of both relative uncertainties (UR_0/R_0) and (U_h/h_0).

Tables 9a and 10a give the values for mean and maximum tow forces (mean of the means and means of maximums), respectively. Tables 9b and 10b show the calculated uncertainties in mean and in maximum tow forces before the use of the data reduction equation. Tables 9c and 10c show the calculated uncertainties in mean and in maximum tow forces after including the additional uncertainty due to the use of DRE.

After adding the effect of the DRE, in mean tow force, all final uncertainties were below 18%, except for test Run # 5 in PICE-1, where the uncertainty value was 25.94 %. In maximum tow force, all calculated random uncertainties are less than 15%.

Application of the DRE does not affect the uncertainties in broken ice test runs. No ice thickness corrections were applied to the results from broken ice tests.

11.5 Comparison of Uncertainties in Continuous Ice and in Broken Ice

In continuous ice (including presawn ice sheets), random uncertainties were mainly under 10%. This is valid for both maximum and mean resistance measurements.

However, in broken ice tests, uncertainties of less than 14% were obtained (except in 2 cases). The value of 14% is higher than the magnitude of uncertainty in continuous ice (10%). The difference between uncertainties in continuous ice and those in broken ice are attributed to several factors (the details were given by Derradji-Aouat, 2002).

11.6 Comparison of Uncertainties in Mean and Maximum Tow Forces

Figures 24a and 24b show comparisons between random uncertainties in mean tow forces and those in maximum tow forces as a function of the test run number (Fig. 24a) and as a function of the model speed (through the ice sheet # in Fig. 24b).

In continuous ice tests, random uncertainties in maximum tow forces are higher than those in mean tow forces (ratio of up to 5:1 for PICE-3, Run # 1). However, no conclusion has been reached in broken ice tests, random uncertainties in mean tow force are both higher and lower than those in maximum tow forces.

12. Bias and Total Uncertainties

In ice tank testing bias uncertainties are neglected (Derradji-Aouat, 2002), and therefore, the total uncertainties are taken as equal to the random ones.

13. Comparison of Phase I and III Uncertainties

Tables 11 and 12 present the mean and maximum tow force uncertainties calculated from the results of Phase I and Phase III test programs, respectively. Figures 25a and 25b provide a comparison between uncertainties calculated in Phase I testing and those calculated in Phase III testing. Implicitly, the tables show the effects of the tow post and PMM on random uncertainties. More comparisons between the analyses of test results in Phase I and those in Phase III are provided in Appendix 7.

The main conclusions drawn from the comparisons in Tables 11 and 12 are:

13.1 Uncertainties in Mean Resistance

- In level (continuous, unbroken) ice test runs (Run # 1, # 2 and # 3), the calculated random uncertainties are less than 10% (Table 11). The values for uncertainties in mean tow force in Phase I are generally larger than those of Phase III (Figure 25a).

- In broken ice test runs (Run # 4, # 5 and # 6), all random uncertainties were below 20%, except for Run # 5 in sheet # 1 of Phase III where the uncertainty was 25.94%. The equivalent test in Phase I also experienced the highest uncertainty for that phase at 19.97%.

13.2 Uncertainties in Maximum Resistance

- In the continuous (unbroken) ice test runs (Run # 1, # 2 and # 3) for both phases, all calculated random uncertainties are less than 15% (Table 12), except for one data point at 15.98% (Run # 2 in ice sheet # 4 from Phase I).

- In broken ice test runs (Run # 4, # 5 and # 6), all random uncertainties were below 15 %, except for one data point at 16% (run #5 in ice sheet #2 from Phase I).

14. Summary, Conclusions and Recommendations

- In continuous ice test runs, the uncertainty range of 3% to 10% was obtained. This is consistent with the range of uncertainties obtained in Phases I and II test programs. The range is also consistent with the previously reported studies (in the literature) using different ship models, in different ice tanks, in different countries over a time span of 10 to 12 years (Derradji-Aouat, 2002).

- In broken ice, the uncertainties ranged from to 3% to 26%. This is also consistent with the calculated range obtained in Phases I and II test programs. The large uncertainties are possible (and sometimes expected) in randomly broken ice.

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Tables

Table 1: Percentage Difference in Phase I and Phase Mean Tow Forces.

Run #	Speed (m/s)	Phase 1: Tow Post	Phase 3: PMM	% Difference
1	0.1	34.54	27.77	21.73%
	0.2	46.00	33.45	31.59%
	0.4	56.49	46.47	19.46%
	0.6	63.96	52.07	20.49%
2	0.1	11.58	2.11	138.35%
	0.2	13.18	11.24	15.92%
	0.4	20.50	13.41	41.83%
	0.6	29.76	27.80	6.82%
3	0.1	25.11	18.01	32.96%
	0.2	34.65	20.76	50.15%
	0.4	44.30	27.71	46.06%
	0.6	52.22	35.44	38.28%
4	0.1	7.06	5.67	21.85%
	0.2	8.99	8.49	5.75%
	0.4	14.50	12.24	16.87%
	0.6	20.14	17.78	12.45%
5	0.1	5.11	4.04	23.50%
	0.2	7.58	5.37	34.11%
	0.4	9.50	10.02	5.38%
	0.6	16.41	15.43	6.14%
6	0.1	2.21	n/a	n/a
	0.2	4.71	5.29	11.67%
	0.4	9.23	7.59	19.49%
	0.6	13.23	12.41	6.38%

Table 2: Percentage Difference in Phase I and Phase III Maximum Tow Force.

Run #	Speed (m/s)	Phase 1: Tow Post	Phase 3: PMM	% Difference
1	0.1	67.7	79.95	16.59%
	0.2	121.34	144.78	17.62%
	0.4	203.66	321.75	44.95%
	0.6	261.71	433.82	49.49%
2	0.1	45.1	21.55	70.67%
	0.2	45.48	34.82	26.55%
	0.4	53.55	60.61	12.37%
	0.6	65.91	94.71	35.86%
3	0.1	54.47	63.42	15.18%
	0.2	93.96	65.26	36.05%
	0.4	154.22	219.12	34.77%
	0.6	242.18	358.09	38.62%
4	0.1	37.48	25.51	38.00%
	0.2	30.78	29.20	5.28%
	0.4	39.39	45.62	14.65%
	0.6	50.87	85.78	51.09%
5	0.1	21.03	20.66	1.79%
	0.2	20.52	21.02	2.42%
	0.4	25.89	32.85	23.70%
	0.6	36.2	56.04	43.01%
6	0.1	36.37	n/a	n/a
	0.2	25.13	19.78	23.81%
	0.4	27.99	31.37	11.40%
	0.6	33.88	51.92	42.06%

Note: The shaded data points are outliers.

Table 3a: Slope for tow force time histories.

Ice Sheet	Continuous Ice Tests			Broken Ice Tests		
	Run # 1: Level Ice	Run # 2: Pre-sawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	0.50%	0.11%	1.00%	0.28%	0.92%	n/a
PICE-2	1.57%	0.03%	0.002%	0.67%	1.40%	0.76%
PICE-3	1.09%	0.14%	1.38%	0.74%	0.91%	1.58%
PICE-4	5.19%	1.31%	1.22%	1.75%	1.89%	2.27%

Table 3b: Change in measured tow force during the long test runs (~65m).

Ice Sheet	Continuous Ice Tests			Broken Ice Tests		
	Run # 1: Level Ice	Run # 2: Pre-sawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	9.66%	27.16%	2.87%	23.87%	121.57%	n/a
PICE-2	12.03%	0.73%	0.026%	21.40%	68.72%	40.63%
PICE-3	3.03%	1.35%	6.19%	7.98%	12.10%	28.47%
PICE-4	8.77%	4.24%	2.91%	8.50%	10.80%	15.76%

Table 3c: Slope for carriage speed time histories.

Ice Sheet	Continuous Ice Tests			Broken Ice Tests		
	Run # 1: Level Ice	Run # 2: Pre-sawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	1.E-06	1.E-06	8.E-07	1.E-06	1.E-06	n/a
PICE-2	2.E-06	2.E-06	2.E-06	2.E-06	8.E-07	4.E-07
PICE-3	5.E-07	2.E-07	8.E-07	1.E-07	1.E-08	4.E-06
PICE-4	2.E-06	6.E-07	6.E-06	3.E-06	2.E-06	3.E-06

Table 3d: Change in measured carriage speed during the long test runs (~65m).

Ice Sheet	Continuous Ice Tests			Broken Ice Tests		
	Run # 1: Level Ice	Run # 2: Pre-sawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	0.53%	0.50%	0.41%	0.48%	0.52%	n/a
PICE-2	0.26%	0.27%	0.27%	0.27%	0.11%	0.055%
PICE-3	0.016%	0.006%	0.025%	0.003%	0.0003%	0.14%
PICE-4	0.029%	0.009%	0.085%	0.043%	0.030%	0.044%

Table 4: Experimental Uncertainty Calculations for Ice Sheet Thickness Profiles.

Tank Position (m)	Thickness (mm)			
	PICE-1	PICE-2	PICE-3	PICE-4
0	38.5			
2	38.35	37.58333	38.51667	38.18333
4	38.66667	38.21667	38.6	38.4
6	39.08333	39.01667	39.23333	38.6
8	39.65	39.7	40	38.95
10	39.98333	39.88333	40.36667	39.08333
12	39.98333	39.66667	39.86667	39.2
14	39.76667	39.1	39.55	39.1
16	39.73333	39.06667	39.36667	39.2
18	39.91667	39.93333	39.5	38.68333
20	40.46667	40.05	39.93333	39.38333
22	40.18333	39.23333	39.75	39.63333
24	39.86667	38.98333	39.35	39.48333
26	39.43333	38.81667	39.26667	39.05
28	39.18333	38.93333	39.38333	39.05
30	39.53333	38.61667	39.26667	38.95
32	39.61667	38.23333	39.11667	38.75
34	39.56667	38.3	38.81667	38.71667
36	39.75	38.98333	39.23333	39.23333
38	40.3	39.21667	39.6	39.81667
40	40.01667	38.76667	39.48333	39.8
42	39.6	38.25	38.85	39.23333
44	39.23333	38	38.3	38.75
46	39.3	38.18333	38.55	38.56667
48	39.61667	38.36667	38.66667	38.8
50	39.95	39.28333	38.9	39.31667
52	40.55	40.33333	39.2	40.05
54	40.53333	40.31667	39.46667	40.65
56	40.08333	39.21667	39.36667	40.16667
58	39.7	38.63333	38.8	39.45
60	39.68333	38.66667	38.76667	39.38333
62	40	38.5	39.38333	39.63333
64		38.86667	39.25	40
66		38.25		
H mean	39.72419	38.94444	39.2043	39.18118
STDEV	0.479561	0.684332	0.434549	0.530259
Uh(N)	0.959121	1.368664	0.869098	1.060518
Uh(%)	2.41%	3.51%	2.22%	2.71%

Note: The details for the Chauvenet rejection criteria are hidden but taken into account.

Table 5a: Ice Flexural Strength Components (measured values and experimental uncertainty calculations).

PICE-1				
Location	Length (m)	Width (m)	Thickness (m)	Load (N)
15N	0.2030	0.0885	0.0396	2.79
	0.1960	0.0835	0.0397	2.70
	0.2010	0.0869	0.0394	2.60
15S	0.2050	0.0976	0.0388	3.68
	0.1950	0.1080	0.0399	3.53
	0.2000	0.1000	0.0405	3.58
31N	0.2080	0.0930	0.0390	2.79
	0.1970	0.0842	0.0390	2.50
	0.1950	0.0869	0.0393	2.79
31S	0.2080	0.0843	0.0394	2.94
	0.2150	0.0845	0.0391	2.60
	0.2050	0.0812	0.0392	2.84
38N	0.1500	0.0852	0.0405	1.47
	0.2050	0.0848	0.0407	1.72
	0.2050	0.0850	0.0414	1.96
	0.1950	0.0839	0.0411	1.37
38S	0.2000	0.0822	0.0409	1.37
	0.2000	0.0834	0.0405	1.47
	0.2000	0.0755	0.0405	0.98
	0.1850	0.0794	0.0414	1.03
39N	0.1940	0.0893	0.0404	2.45
	0.1980	0.0841	0.0405	2.40
	0.1850	0.0829	0.0404	2.35
	0.2080	0.0867	0.0405	2.45
39S	0.2000	0.0874	0.0406	2.50
	0.2100	0.0746	0.0406	1.47
	0.2000	0.0865	0.0405	2.70
	0.2000	0.0865	0.0405	2.70
60N	0.2000	0.0879	0.0403	3.92
	0.2120	0.0898	0.0395	3.04
	0.1980	0.0845	0.0396	2.94
60S	0.2050	0.0842	0.0393	3.38
	0.2000	0.0811	0.0389	3.48
	0.2050	0.0799	0.0399	1.72
Mean	0.201	0.0853152	0.0400412	2.4767647
STDEV	0.0065717	0.0051048	0.0007382	0.7841796
U (%)	6.54%	11.97%	3.69%	63.32%

PICE-2				
Location	Length (m)	Width (m)	Thickness (m)	Load (N)
15N	0.2000	0.0851	0.0387	2.60
	0.2050	0.0815	0.0388	2.60
	0.2100	0.0795	0.0387	2.89
15S	0.2100	0.0854	0.0385	2.53
	0.1950	0.0834	0.0387	2.01
	0.2050	0.0822	0.0389	1.96
30N	0.1950	0.0937	0.0385	2.30
	0.1920	0.0931	0.0387	2.06
	0.1850	0.0770	0.0385	2.11
30S	0.1950	0.0761	0.0390	2.06
	0.1950	0.0808	0.0389	2.26
	0.1900	0.0850	0.0386	2.65
38N	0.1250	0.0820	0.0392	1.23
	0.1880	0.0815	0.0398	1.18
	0.2100	0.0865	0.0393	1.18
	0.2000	0.0826	0.0395	1.18
38S	0.2000	0.0805	0.0407	1.03
	0.1800	0.0835	0.0400	1.03
	0.2000	0.0786	0.0405	0.83
	0.2080	0.0771	0.0397	1.18
39N	0.1920	0.0881	0.0387	1.86
	0.2080	0.0870	0.0388	1.91
	0.2050	0.0893	0.0391	2.21
	0.1900	0.0865	0.0387	2.11
39S	0.1850	0.0835	0.0400	2.06
	0.2000	0.0797	0.0395	1.86
	0.1950	0.0830	0.0397	1.96
	0.1600	0.0827	0.0393	2.65
40N	0.2050	0.0837	0.0382	2.84
	0.2050	0.0832	0.0389	2.72
	0.2050	0.0781	0.0389	3.04
	0.2100	0.0815	0.0399	3.19
40S	0.2100	0.0883	0.0399	3.09
	0.1900	0.0828	0.0383	2.79
	0.1900	0.0846	0.0395	3.14
	0.2000	0.0866	0.0385	2.06
60N	0.2000	0.0815	0.0390	2.75
	0.2000	0.0827	0.0385	2.89
	0.1920	0.0826	0.0385	2.84
60S	0.1900	0.0849	0.0381	2.75
	0.1950	0.0846	0.0379	3.04
	0.2000	0.0832	0.0383	3.14
Mean	0.19825	0.08291	0.0389927	2.232619
STDEV	0.0079928	0.0031143	0.0006006	0.6812258
U (%)	8.06%	7.51%	3.08%	61.02%

Note: The details for the Chauvenet rejection criteria are hidden but taken into account.

Table 5b: Ice Flexural Strength Components (measured values and experimental uncertainty calculations).

PICE-3				
Location	Length (m)	Width (m)	Thickness (m)	Load (N)
15N	0.2000	0.0779	0.0397	3.43
	0.1950	0.0750	0.0401	2.94
	0.2070	0.0812	0.0394	3.38
15S	0.2070	0.0831	0.0400	3.24
	0.1980	0.0845	0.0391	3.63
	0.1950	0.0792	0.0397	3.48
30N	0.2000	0.0814	0.0403	2.40
	0.2000	0.0814	0.0391	2.99
	0.2020	0.0812	0.0400	3.14
30S	0.1980	0.0790	0.0393	2.84
	0.2030	0.0806	0.0393	3.19
	0.2080	0.0832	0.0389	2.84
38N	0.2050	0.0815	0.0398	2.06
	0.2250	0.0809	0.0398	2.30
	0.2150	0.0754	0.0405	1.27
	0.2100	0.0806	0.0401	2.65
38S	0.2000	0.0868	0.0396	2.50
	0.1930	0.0833	0.0396	2.55
	0.2040	0.0788	0.0397	2.50
	0.2150	0.0800	0.0396	2.35
39N	0.1850	0.0805	0.0397	2.70
	0.1950	0.0855	0.0395	2.84
	0.1950	0.0822	0.0396	2.21
	0.2080	0.0834	0.0395	2.45
39S	0.2050	0.0834	0.0395	1.52
	0.2050	0.0843	0.0401	3.29
	0.2100	0.0833	0.0404	3.14
	0.1850	0.0754	0.0405	1.03
40N	0.2050	0.0845	0.0390	3.29
	0.2000	0.0878	0.0390	3.53
	0.1980	0.0841	0.0390	2.99
	0.2180	0.0894	0.0390	3.92
40S	0.2040	0.0813	0.0393	3.50
	0.2040	0.0769	0.0394	2.89
	0.1940	0.0832	0.0395	4.02
	0.2040	0.0806	0.0391	3.73
60N	0.2050	0.0955	0.0385	3.82
	0.2040	0.0845	0.0386	3.43
	0.2080	0.0842	0.0385	3.53
60S	0.2080	0.0876	0.0385	3.63
	0.2040	0.0875	0.0390	3.48
	0.2120	0.0830	0.0387	3.09
Mean	0.2027073	0.0821366	0.0394643	3.03525
STDEV	0.0071633	0.0033629	0.0005418	0.5596014
U (%)	7.07%	8.19%	2.75%	36.87%

PICE-4				
Location	Length (m)	Width (m)	Thickness (m)	Load (N)
15N	0.2080	0.0789	0.0392	3.09
	0.2030	0.0813	0.0388	3.29
	0.2060	0.0765	0.0391	2.60
15S	0.1950	0.0852	0.0393	2.89
	0.1900	0.0869	0.0387	3.19
	0.2050	0.0858	0.0386	3.24
30N	0.1780	0.0760	0.0393	2.11
	0.1930	0.0830	0.0384	1.81
	0.2150	0.0772	0.0394	2.11
30S	0.1950	0.0788	0.0398	2.84
	0.2000	0.0777	0.0396	2.65
	0.2100	0.0771	0.0396	2.70
35N	0.1400	0.0811	0.0392	1.67
	0.2030	0.0814	0.0394	2.06
	0.1840	0.0796	0.0386	2.01
35S	0.1980	0.0854	0.0394	2.16
	0.1910	0.0800	0.0384	1.62
	0.1890	0.0853	0.0393	1.86
	0.1980	0.0801	0.0394	1.77
36N	0.2180	0.0856	0.0390	1.86
	0.2030	0.0785	0.0393	1.67
	0.1850	0.0828	0.0392	2.06
	0.2040	0.0861	0.0391	2.01
36S	0.2100	0.0813	0.0391	2.16
	0.2100	0.0812	0.0401	2.45
	0.1950	0.0844	0.0400	2.30
40N	0.1850	0.0858	0.0392	2.94
	0.1980	0.0866	0.0391	3.48
	0.2040	0.0923	0.0391	3.33
	0.2070	0.0799	0.0394	3.19
40S	0.2100	0.0843	0.0390	3.14
	0.2100	0.0871	0.0395	3.44
	0.2100	0.0828	0.0392	1.96
	0.2150	0.0797	0.0392	2.99
60N	0.1750	0.0886	0.0390	3.73
	0.2030	0.0883	0.0390	3.43
	0.2030	0.0785	0.0391	3.24
60S	0.2000	0.0899	0.0401	3.24
	0.2100	0.0852	0.0392	3.68
	0.1900	0.0836	0.0394	3.78
Mean	0.2001538	0.0825	0.03922	2.64365
STDEV	0.0103582	0.0037225	0.0003897	0.6713282
U (%)	10.35%	9.02%	1.99%	50.79%

Note: The details for the Chauvenet rejection criteria are hidden but taken into account.

Table 6: Ice Density Components (measured values and experimental uncertainty calculations)

	Location (m)		Length (m)	Width (m)	Thickness (m)	Submergence Force (g)
PICE-1	15	North	0.1063	0.1062	0.0390	27.5
		South	0.1009	0.1023	0.0397	27
	30	North	0.1066	0.1016	0.0389	25.4
		South	0.0977	0.0988	0.0397	23.1
	40	North	0.1043	0.1100	0.0400	28.9
		South	0.1037	0.1022	0.0396	26
	60	North	0.1020	0.1031	0.0394	25.8
		South	0.1036	0.0986	0.0392	25.1
		MEAN	0.103125	0.10182143	0.039440625	26.1
		STDEV	0.00292175	0.00261277	0.000390269	1.740279124
		U(%)	5.67%	5.13%	1.98%	13.34%
	Location (m)		Length (m)	Width (m)	Thickness (m)	Submergence Force (g)
PICE-2	15	North	0.1041	0.1015	0.0384	26.3
		South	0.1053	0.1024	0.0386	26.4
	30	North	0.1077	0.1059	0.0384	26.2
		South	0.1015	0.1019	0.0389	23.9
	40	North	0.1029	0.1041	0.0388	25.8
		South	0.1060	0.1006	0.0389	25.9
	60	North	0.0983	0.1001	0.0387	23.4
		South	0.1025	0.1012	0.0387	24.9
		MEAN	0.10353125	0.10166786	0.03866875	25.35
		STDEV	0.00292974	0.00131107	0.00019168	1.155112858
		U(%)	5.66%	2.58%	0.99%	9.11%
	Location (m)		Length (m)	Width (m)	Thickness (m)	Submergence Force (g)
PICE-3	15	North	0.1045	0.0997	0.0397	25.4
		South	0.0105	0.1054	0.0389	26.1
	30	North	0.1022	0.1035	0.0390	26.8
		South	0.1006	0.1012	0.0388	25.2
	40	North	0.1013	0.1020	0.0391	25.9
		South	0.1023	0.1018	0.0397	25.5
	60	North	0.1004	0.1015	0.0383	25
		South	0.0999	0.1009	0.0386	25.1
		MEAN	0.10158571	0.10150357	0.039009375	25.45714286
		STDEV	0.00156584	0.00117504	0.000481615	0.411732692
		U(%)	3.08%	2.32%	2.47%	3.23%
	Location (m)		Length (m)	Width (m)	Thickness (m)	Submergence Force (g)
PICE-4	15	North	0.1017	0.1025	0.0397	26.5
		South	0.1061	0.1021	0.0389	26.7
	30	North	0.1037	0.1044	0.0388	27
		South	0.0980	0.1005	0.0387	24.3
	40	North	0.0981	0.1040	0.0395	25.4
		South	0.1003	0.1000	0.0397	26.2
	60	North	0.1087	0.1038	0.0395	28
		South	0.1048	0.1054	0.0390	26.1
		MEAN	0.1026625	0.10284688	0.039209375	26.275
		STDEV	0.00383685	0.00191584	0.00040332	1.09772492
		U(%)	7.47%	3.73%	2.06%	8.36%

Note: The details for the Chauvenet rejection criteria are hidden but taken into account

Table 7a: Random Uncertainties in mean tow force – Run #1, all ice sheets.

Mean Tow Force: Continuous Ice Sheet - Run #1									
Ice Sheet #	Segment #	TF-mean (N)	Mean Rt_corr	STD mean (N)	Chauv #	New mean TF mean	New STD mean	Uncertainty Value (N)	Uncertainty %
PICE-1	2	26.50	27.98	1.47	0.70			0.93	**3.32%**
	3	28.12	27.98	1.47	0.38				
	4	26.80	27.98	1.47	0.57				
	5	27.12	27.98	1.47	0.39				
	6	25.84	27.98	1.47	1.30				
	7	26.69	27.98	1.47	0.76				
	8	27.45	27.98	1.47	0.28				
	9	28.39	27.98	1.47	0.33				
	10	30.30	27.98	1.47	1.60				
	11	30.44	27.98	1.47	1.69				
PICE-2	4	31.74	34.96	2.43	1.02	34.30	1.34	0.89	**2.60%**
	5	34.33	34.96	2.43	0.08				
	6	33.94	34.96	2.43	0.08				
	7	33.74	34.96	2.43	0.16				
	8	32.21	34.96	2.43	0.79				
	9	31.69	34.96	2.43	1.00				
	10	34.54	34.96	2.43	0.21				
	11	33.57	34.96	2.43	0.19				
	12	35.27	34.96	2.43	0.53				
	13	39.74	34.96	2.43	2.43				
PICE-3	4	46.35	47.24	1.03	0.30			0.78	**1.65%**
	5	48.42	47.24	1.03	1.79				
	6	47.32	47.24	1.03	0.77				
	7	45.99	47.24	1.03	0.48				
	8	45.34	47.24	1.03	1.06				
	9	45.46	47.24	1.03	0.87				
	10	46.42	47.24	1.03	0.15				
PICE-4	4	50.35	53.01	2.44	0.52			1.84	**3.48%**
	5	52.62	53.01	2.44	0.38				
	6	49.64	53.01	2.44	0.95				
	7	49.20	53.01	2.44	1.20				
	8	52.24	53.01	2.44	0.01				
	9	53.80	53.01	2.44	0.58				
	10	56.61	53.01	2.44	1.70				

Correction for Ice Thickness							
Speed (m/s)	TF_BL (N)	Ice (N) Resistance	D (m)	hm (mm)	ho (mm)	R_corr (N)	Rt_corr (N)
0.1	0.31937	26.18	5.01	39.33	40	26.63	26.95
0.1	0.31937	27.80	10.87	39.41	40	28.22	28.54
0.1	0.31937	26.48	16.49	39.49	40	26.82	27.14
0.1	0.31937	26.80	23.37	39.58	40	27.08	27.40
0.1	0.31937	25.52	29.15	39.66	40	25.74	26.06
0.1	0.31937	26.37	36.10	39.75	40	26.54	26.86
0.1	0.31937	27.13	42.97	39.84	40	27.24	27.56
0.1	0.31937	28.07	47.19	39.90	40	28.14	28.46
0.1	0.31937	29.98	51.48	39.95	40	30.01	30.33
0.1	0.31937	30.12	53.75	39.99	40	30.14	30.46
0.2	1.01654	30.73	4.82	39.07	40	31.46	32.47
0.2	1.01654	33.31	9.63	39.05	40	34.12	35.14
0.2	1.01654	32.92	15.20	39.02	40	33.74	34.76
0.2	1.01654	32.72	20.76	39.00	40	33.56	34.57
0.2	1.01654	31.19	26.18	38.98	40	32.01	33.03
0.2	1.01654	30.67	31.82	38.95	40	31.50	32.52
0.2	1.01654	33.52	37.31	38.93	40	34.44	35.46
0.2	1.01654	32.55	42.80	38.91	40	33.47	34.49
0.2	1.01654	34.25	48.37	38.88	40	35.23	36.25
0.2	1.01654	38.72	53.81	38.86	40	39.86	40.87
0.4	3.49838	42.85	5.28	39.47	40	43.42	46.92
0.4	3.49838	44.92	11.76	39.42	40	45.58	49.08
0.4	3.49838	43.82	18.61	39.36	40	44.54	48.03
0.4	3.49838	42.49	26.22	39.30	40	43.25	46.74
0.4	3.49838	41.84	32.95	39.24	40	42.65	46.14
0.4	3.49838	41.96	40.67	39.18	40	42.84	46.34
0.4	3.49838	42.92	47.90	39.12	40	43.89	47.39
0.6	7.43022	42.92	5.48	38.75	40	44.31	51.74
0.6	7.43022	45.19	12.69	38.87	40	46.50	53.93
0.6	7.43022	42.21	22.23	39.04	40	43.25	50.68
0.6	7.43022	41.77	29.79	39.17	40	42.66	50.09
0.6	7.43022	44.81	37.89	39.31	40	45.60	53.03
0.6	7.43022	46.37	46.72	39.46	40	47.00	54.43
0.6	7.43022	49.18	51.94	39.56	40	49.73	57.16

Note: The shaded data points are Chauvenet outliers.

Table 7b: Random Uncertainties in Mean Tow Force – Run #2, all ice sheets.

Mean Tow Force: Presawn Ice Sheet - Run #2									
Ice Sheet #	Segment #	TF-mean (N)	Mean Rt_corr	STD mean (N)	Chauv #	New mean TF mean	New STD mean	Uncertainty Value (N)	Uncertainty %
PICE-1	2	1.49	2.08	0.26	2.13				
	3	1.88	2.08	0.26	0.64	2.13	0.21	0.12	**5.84%**
	4	2.12	2.08	0.26	0.24				
	5	2.16	2.08	0.26	0.41				
	6	2.07	2.08	0.26	0.05				
	7	1.97	2.08	0.26	0.33				
	8	2.25	2.08	0.26	0.72				
	9	2.12	2.08	0.26	0.20				
	10	2.46	2.08	0.26	1.48				
	11	1.71	2.08	0.26	1.36				
	12	2.17	2.08	0.26	0.38				
	13	2.34	2.08	0.26	0.99				
PICE-2	3	10.71	11.48	0.55	0.98			0.35	**3.04%**
	4	10.91	11.48	0.55	0.60				
	5	10.82	11.48	0.55	0.77				
	6	11.50	11.48	0.55	0.50				
	7	11.88	11.48	0.55	1.24				
	8	12.14	11.48	0.55	1.72				
	9	11.69	11.48	0.55	0.89				
	10	10.80	11.48	0.55	0.74				
	11	10.70	11.48	0.55	0.93				
	12	11.01	11.48	0.55	0.34				
PICE-3	4	13.74	13.59	0.24	1.18			0.19	**1.36%**
	5	13.69	13.59	0.24	1.05				
	6	13.37	13.59	0.24	0.22				
	7	12.98	13.59	0.24	1.77				
	8	13.26	13.59	0.24	0.52				
	9	13.41	13.59	0.24	0.19				
	10	13.38	13.59	0.24	0.09				
PICE-4	2	27.70	28.20	0.47	0.33			0.30	**1.05%**
	3	27.36	28.20	0.47	0.51				
	4	27.18	28.20	0.47	1.01				
	5	27.52	28.20	0.47	0.36				
	6	26.88	28.20	0.47	1.87				
	7	28.05	28.20	0.47	0.57				
	8	28.35	28.20	0.47	1.08				
	9	27.99	28.20	0.47	0.18				
	10	27.96	28.20	0.47	0.02				
	11	28.71	28.20	0.47	1.57				

Correction for Ice Thickness							
Speed (m/s)	TF_OW (N)	Ice (N) Resistance	D (m)	hm (mm)	ho (mm)	R_corr (N)	Rt_corr (N)
0.1	0.31937	1.17543	5.6464	39.341	40	1.20	1.51
0.1	0.31937	1.56	10.23	39.40	40	1.59	1.91
0.1	0.31937	1.80	14.93	39.47	40	1.82	2.14
0.1	0.31937	1.84	19.51	39.53	40	1.87	2.19
0.1	0.31937	1.75	23.40	39.58	40	1.77	2.09
0.1	0.31937	1.66	27.66	39.64	40	1.67	1.99
0.1	0.31937	1.93	31.74	39.69	40	1.95	2.27
0.1	0.31937	1.80	35.75	39.74	40	1.81	2.13
0.1	0.31937	2.14	40.02	39.80	40	2.15	2.47
0.1	0.31937	1.39	44.54	39.86	40	1.40	1.72
0.1	0.31937	1.85	48.43	39.91	40	1.86	2.18
0.1	0.31937	2.02	52.31	39.97	40	2.02	2.34
0.2	1.01654	9.69	5.12	39.07	40	9.92	10.94
0.2	1.01654	9.90	9.09	39.05	40	10.14	11.15
0.2	1.01654	9.80	13.69	39.03	40	10.04	11.06
0.2	1.01654	10.48	18.67	39.01	40	10.74	11.76
0.2	1.01654	10.87	23.81	38.99	40	11.15	12.17
0.2	1.01654	11.12	29.50	38.96	40	11.42	12.43
0.2	1.01654	10.67	35.03	38.94	40	10.96	11.98
0.2	1.01654	9.79	40.64	38.92	40	10.06	11.08
0.2	1.01654	9.68	46.33	38.89	40	9.95	10.97
0.2	1.01654	9.99	51.86	38.87	40	10.28	11.30
0.4	3.49838	10.24	6.78	39.46	40	10.38	13.88
0.4	3.49838	10.19	13.78	39.40	40	10.35	13.84
0.4	3.49838	9.87	21.68	39.34	40	10.03	13.53
0.4	3.49838	9.48	29.69	39.27	40	9.65	13.15
0.4	3.49838	9.76	39.71	39.18	40	9.96	13.46
0.4	3.49838	9.91	47.38	39.12	40	10.13	13.63
0.4	3.49838	9.88	52.05	39.08	40	10.11	13.61
0.6	7.43022	20.27	4.59	38.73	40	20.93	28.36
0.6	7.43022	19.93	9.71	38.82	40	20.54	27.97
0.6	7.43022	19.75	14.68	38.91	40	20.30	27.73
0.6	7.43022	20.09	20.60	39.01	40	20.60	28.03
0.6	7.43022	19.45	26.20	39.11	40	19.90	27.33
0.6	7.43022	20.62	31.80	39.21	40	21.04	28.47
0.6	7.43022	20.92	38.52	39.32	40	21.28	28.71
0.6	7.43022	20.56	44.60	39.43	40	20.86	28.29
0.6	7.43022	20.53	49.25	39.51	40	20.78	28.21
0.6	7.43022	21.28	53.40	39.58	40	21.50	28.94

Note: The shaded data points are Chauvenet outliers.

Table 7c: Random Uncertainties in Mean Tow Force – Run #3, all ice sheets.

Mean Tow Force: Unsupported Ice Sheet - Run #3									
Ice Sheet #	**Segment #**	**TF-mean (N)**	**Mean Rt_corr**	**STD mean (N)**	**Chauv #**	**New mean TF mean**	**New STD mean**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-1	2	16.70	18.26	0.86	1.50			0.57	**3.14%**
	3	18.21	18.26	0.86	0.24				
	4	18.39	18.26	0.86	0.41				
	5	19.11	18.26	0.86	1.23				
	6	19.04	18.26	0.86	1.09				
	7	16.79	18.26	0.86	1.59				
	8	18.59	18.26	0.86	0.47				
	9	18.07	18.26	0.86	0.17				
	10	18.09	18.26	0.86	0.19				
PICE-2	3	19.18	21.28	0.97	1.73			0.61	**2.87%**
	4	22.00	21.28	0.97	1.28				
	5	21.49	21.28	0.97	0.75				
	6	21.98	21.28	0.97	1.27				
	7	20.43	21.28	0.97	0.35				
	8	21.10	21.28	0.97	0.37				
	9	20.18	21.28	0.97	0.60				
	10	20.26	21.28	0.97	0.50				
	11	19.77	21.28	0.97	1.01				
	12	21.21	21.28	0.97	0.53				
PICE-3	4	27.83	28.31	1.02	0.15			0.77	**2.71%**
	5	29.39	28.31	1.02	1.45				
	6	28.09	28.31	1.02	0.20				
	7	28.06	28.31	1.02	0.22				
	8	26.35	28.31	1.02	1.45				
	9	26.74	28.31	1.02	1.03				
	10	28.51	28.31	1.02	0.77				
PICE-4	4	34.54	36.17	1.95	0.39			1.48	**4.08%**
	5	37.06	36.17	1.95	0.90				
	6	37.56	36.17	1.95	1.11				
	7	34.30	36.17	1.95	0.66				
	8	33.49	36.17	1.95	1.15				
	9	34.02	36.17	1.95	0.91				
	10	37.98	36.17	1.95	1.10				

Correction for Ice Thickness							
Speed (m/s)	**TF_OW (N)**	**Ice (N) Resistance**	**D (m)**	**hm (mm)**	**ho (mm)**	**R_corr (N)**	**Rt_corr (N)**
0.1	0.31937	16.38	5.76	39.34	40	16.65	16.97
0.1	0.31937	17.89	11.17	39.41	40	18.15	18.47
0.1	0.31937	18.07	16.59	39.49	40	18.30	18.62
0.1	0.31937	18.79	21.61	39.55	40	19.00	19.32
0.1	0.31937	18.72	28.50	39.65	40	18.89	19.21
0.1	0.31937	16.47	35.32	39.74	40	16.57	16.89
0.1	0.31937	18.27	41.94	39.83	40	18.35	18.67
0.1	0.31937	17.75	47.22	39.90	40	17.80	18.12
0.1	0.31937	17.77	51.63	39.96	40	17.78	18.10
0.2	1.01654	18.16	5.25	39.07	40	18.59	19.61
0.2	1.01654	20.99	9.67	39.05	40	21.50	22.51
0.2	1.01654	20.48	14.35	39.03	40	20.99	22.00
0.2	1.01654	20.96	19.02	39.01	40	21.49	22.51
0.2	1.01654	19.42	23.87	38.99	40	19.92	20.94
0.2	1.01654	20.08	28.87	38.97	40	20.61	21.63
0.2	1.01654	19.16	33.13	38.95	40	19.68	20.69
0.2	1.01654	19.24	38.47	38.92	40	19.77	20.79
0.2	1.01654	18.75	44.07	38.90	40	19.28	20.30
0.2	1.01654	20.19	50.16	38.87	40	20.77	21.79
0.4	3.49838	24.33	5.90	39.47	40	24.66	28.16
0.4	3.49838	25.90	13.58	39.40	40	26.29	29.79
0.4	3.49838	24.59	22.48	39.33	40	25.01	28.51
0.4	3.49838	24.57	32.38	39.25	40	25.04	28.54
0.4	3.49838	22.85	41.39	39.17	40	23.34	26.83
0.4	3.49838	23.24	48.18	39.11	40	23.76	27.26
0.4	3.49838	25.01	52.41	39.08	40	25.60	29.10
0.6	7.43022	27.11	6.44	38.76	40	27.98	35.41
0.6	7.43022	29.63	11.56	38.85	40	30.50	37.93
0.6	7.43022	30.13	20.05	39.00	40	30.90	38.33
0.6	7.43022	26.87	30.14	39.18	40	27.44	34.87
0.6	7.43022	26.06	39.26	39.34	40	26.50	33.93
0.6	7.43022	26.59	46.94	39.47	40	26.95	34.38
0.6	7.43022	30.55	52.06	39.56	40	30.89	38.32

Table 7d: Random Uncertainties in Mean Tow Force – Run #4, all ice sheets.

Mean Tow Force: 9/10th Ice Concentration Broken Ice - Run #4									
Ice Sheet #	**Segment #**	**TF-mean (N)**	**Mean TF mean**	**STD mean (N)**	**Chauv #**	**New mean TF mean**	**New STD mean**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-1	2	5.15	5.67	0.70	0.74			0.44	**7.77%**
	3	4.42	5.67	0.70	1.80				
	4	5.48	5.67	0.70	0.27				
	5	6.31	5.67	0.70	0.93				
	6	6.91	5.67	0.70	1.79				
	7	6.26	5.67	0.70	0.85				
	8	5.68	5.67	0.70	0.01				
	9	5.72	5.67	0.70	0.07				
	10	5.42	5.67	0.70	0.36				
	11	5.34	5.67	0.70	0.47				
PICE-2	3	6.63	8.49	0.96	1.93			0.61	**7.15%**
	4	7.32	8.49	0.96	1.22				
	5	8.89	8.49	0.96	0.42				
	6	9.12	8.49	0.96	0.66				
	7	7.88	8.49	0.96	0.64				
	8	8.94	8.49	0.96	0.48				
	9	9.12	8.49	0.96	0.66				
	10	9.69	8.49	0.96	1.25				
	11	9.11	8.49	0.96	0.65				
	12	8.17	8.49	0.96	0.34				
PICE-3	4	11.36	12.24	0.56	1.57			0.42	**3.45%**
	5	11.93	12.24	0.56	0.55				
	6	12.81	12.24	0.56	1.01				
	7	12.47	12.24	0.56	0.40				
	8	11.94	12.24	0.56	0.54				
	9	12.21	12.24	0.56	0.06				
	10	12.98	12.24	0.56	1.32				
PICE-4	4	16.09	17.78	1.06	1.59			0.75	**4.22%**
	5	19.52	17.78	1.06	1.64				
	6	18.63	17.78	1.06	0.80				
	7	17.08	17.78	1.06	0.66				
	8	17.44	17.78	1.06	0.33				
	9	17.26	17.78	1.06	0.49				
	10	18.42	17.78	1.06	0.60				
	11	17.81	17.78	1.06	0.03				

Table 7e: Random Uncertainties in Mean Tow Force – Run #5, all ice sheets.

Mean Tow Force: 8/10th Ice Concentration Broken Ice - Run #5									
Ice Sheet #	**Segment #**	**TF-mean (N)**	**Mean TF mean**	**STD mean (N)**	**Chauv #**	**New mean TF mean**	**New STD mean**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-1	2	2.28	4.04	1.65	1.06			1.05	**25.94%**
	3	2.07	4.04	1.65	1.19				
	4	2.87	4.04	1.65	0.70				
	5	3.23	4.04	1.65	0.49				
	6	2.98	4.04	1.65	0.64				
	7	3.43	4.04	1.65	0.37				
	8	5.43	4.04	1.65	0.85				
	9	6.38	4.04	1.65	1.42				
	10	5.47	4.04	1.65	0.87				
	11	6.21	4.04	1.65	1.31				
PICE-2	3	6.00	5.37	1.53	0.41			0.97	**17.99%**
	4	3.61	5.37	1.53	1.15				
	5	3.68	5.37	1.53	1.10				
	6	4.30	5.37	1.53	0.70				
	7	4.61	5.37	1.53	0.50				
	8	4.18	5.37	1.53	0.78				
	9	5.48	5.37	1.53	0.07				
	10	7.26	5.37	1.53	1.24				
	11	7.82	5.37	1.53	1.60				
	12	6.77	5.37	1.53	0.92				
PICE-3	4	9.10	10.02	1.09	0.85			0.69	**6.88%**
	5	10.36	10.02	1.09	0.31				
	6	11.18	10.02	1.09	1.06				
	7	8.62	10.02	1.09	1.29				
	8	9.09	10.02	1.09	0.85				
	9	9.33	10.02	1.09	0.64				
	10	11.47	10.02	1.09	1.33				
	11	11.54	10.02	1.09	1.39				
	12	9.25	10.02	1.09	0.71				
	13	10.30	10.02	1.09	0.26				
PICE-4	4	16.96	15.43	1.54	0.99			0.97	**6.31%**
	5	13.81	15.43	1.54	1.05				
	6	15.44	15.43	1.54	0.01				
	7	14.47	15.43	1.54	0.62				
	8	12.81	15.43	1.54	1.70				
	9	14.52	15.43	1.54	0.59				
	10	16.37	15.43	1.54	0.61				
	11	15.39	15.43	1.54	0.03				
	12	17.07	15.43	1.54	1.06				
	13	17.48	15.43	1.54	1.33				

Table 7f: Random Uncertainties in Mean Tow Force – Run #6, all ice sheets.

Mean Tow Force: 6/10th Ice Concentration Broken Ice - Run #6									
Ice Sheet #	Segment #	TF-mean (N)	Mean TF mean	STD mean (N)	Chauv #	New mean TF mean	New STD mean	Uncertainty Value (N)	Uncertainty %
PICE-2	3	4.65	5.04	0.92	0.43	5.29	0.47	0.32	**5.97%**
	4	2.77	5.04	0.92	2.48				
	5	4.89	5.04	0.92	0.17				
	6	4.80	5.04	0.92	0.26				
	7	5.16	5.04	0.92	0.13				
	8	5.30	5.04	0.92	0.28				
	9	5.60	5.04	0.92	0.61				
	10	5.54	5.04	0.92	0.55				
	11	5.55	5.04	0.92	0.56				
	12	6.15	5.04	0.92	1.21				
PICE-3	4	3.91	7.60	1.74	2.12				
	5	7.96	7.60	1.74	0.21	7.59	0.57	0.38	**5.03%**
	6	6.73	7.60	1.74	0.50				
	7	8.08	7.60	1.74	0.28				
	8	7.80	7.60	1.74	0.12				
	9	7.56	7.60	1.74	0.02				
	10	7.08	7.60	1.74	0.30				
	11	7.99	7.60	1.74	0.23				
	12	8.28	7.60	1.74	0.39				
	13	6.83	7.60	1.74	0.44				
	14	11.33	7.60	1.74	2.15				
PICE-4	4	8.60	12.41	2.43	1.57			1.54	**12.40%**
	5	10.69	12.41	2.43	0.71				
	6	14.83	12.41	2.43	1.00				
	7	14.28	12.41	2.43	0.77				
	8	9.35	12.41	2.43	1.26				
	9	13.06	12.41	2.43	0.26				
	10	16.43	12.41	2.43	1.65				
	11	12.32	12.41	2.43	0.04				
	12	12.73	12.41	2.43	0.13				
	13	11.83	12.41	2.43	0.24				

Note: The shaded data points are Chauvenet outliers.

Table 8a: Random Uncertainties in Maximum Tow Force – Run #1, all ice sheets.

Max Tow Force: Continuous Ice Sheet - Run #1									
Ice Sheet #	Segment #	TF-max (N)	Mean Rt_corr	STD max (N)	Chauv #	New mean TF max	New STD max	Uncertainty Value (N)	Uncertainty %
PICE-1	2	75.77	82.84	8.49	0.68	80.64	5.14	3.43	**4.25%**
	3	86.02	82.84	8.49	0.52				
	4	82.81	82.84	8.49	0.12				
	5	70.18	82.84	8.49	1.40				
	6	77.57	82.84	8.49	0.54				
	7	76.50	82.84	8.49	0.69				
	8	83.80	82.84	8.49	0.15				
	9	83.80	82.84	8.49	0.14				
	10	83.14	82.84	8.49	0.05				
	11	102.64	82.84	8.49	2.34				
PICE-2	4	115.49	148.61	25.16	1.21			15.91	**10.71%**
	5	185.67	148.61	25.16	1.65				
	6	137.42	148.61	25.16	0.31				
	7	138.76	148.61	25.16	0.25				
	8	137.82	148.61	25.16	0.29				
	9	109.20	148.61	25.16	1.45				
	10	130.84	148.61	25.16	0.56				
	11	165.20	148.61	25.16	0.84				
	12	156.07	148.61	25.16	0.47				
	13	171.29	148.61	25.16	1.10				
PICE-3	4	276.83	327.35	59.90	0.78			45.28	**13.83%**
	5	407.14	327.35	59.90	1.43				
	6	407.14	327.35	59.90	1.44				
	7	302.80	327.35	59.90	0.32				
	8	302.80	327.35	59.90	0.31				
	9	279.42	327.35	59.90	0.70				
	10	276.10	327.35	59.90	0.75				
PICE-4	4	392.26	442.85	49.64	0.77			37.53	**8.47%**
	5	403.32	442.85	49.64	0.56				
	6	515.02	442.85	49.64	1.71				
	7	425.88	442.85	49.64	0.16				
	8	435.01	442.85	49.64	0.01				
	9	381.48	442.85	49.64	1.13				
	10	483.77	442.85	49.64	0.93				

Correction for Ice Thickness							
Speed (m/s)	TF_OW (N)	Ice (N) Resistance	D (m)	hm (mm)	ho (mm)	R_corr (N)	Rt_corr (N)
0.1	0.31937	75.45	5.01	39.33	40	76.73	77.05
0.1	0.31937	85.70	10.87	39.41	40	86.98	87.30
0.1	0.31937	82.49	16.49	39.49	40	83.56	83.88
0.1	0.31937	69.86	23.37	39.58	40	70.61	70.93
0.1	0.31937	77.25	29.15	39.66	40	77.92	78.24
0.1	0.31937	76.18	36.10	39.75	40	76.66	76.98
0.1	0.31937	83.48	42.97	39.84	40	83.81	84.13
0.1	0.31937	83.48	47.19	39.90	40	83.69	84.01
0.1	0.31937	82.82	51.48	39.95	40	82.91	83.23
0.1	0.31937	102.32	53.75	39.99	40	102.36	102.68
0.2	1.01654	114.47	4.82	39.07	40	117.20	118.22
0.2	1.01654	184.65	9.63	39.05	40	189.15	190.17
0.2	1.01654	136.40	15.20	39.02	40	139.81	140.83
0.2	1.01654	137.74	20.76	39.00	40	141.27	142.29
0.2	1.01654	136.80	26.18	38.98	40	140.39	141.41
0.2	1.01654	108.18	31.82	38.95	40	111.09	112.11
0.2	1.01654	129.82	37.31	38.93	40	133.39	134.41
0.2	1.01654	164.18	42.80	38.91	40	168.80	169.82
0.2	1.01654	155.05	48.37	38.88	40	159.51	160.53
0.2	1.01654	170.27	53.81	38.86	40	175.27	176.29
0.4	3.49838	273.33	5.28	39.47	40	276.98	280.47
0.4	3.49838	403.64	11.76	39.42	40	409.59	413.09
0.4	3.49838	403.64	18.61	39.36	40	410.19	413.69
0.4	3.49838	299.30	26.22	39.30	40	304.65	308.15
0.4	3.49838	299.30	32.95	39.24	40	305.09	308.59
0.4	3.49838	275.92	40.67	39.18	40	281.72	285.22
0.4	3.49838	272.60	47.90	39.12	40	278.77	282.26
0.6	7.43022	384.83	5.48	38.75	40	397.27	404.70
0.6	7.43022	395.89	12.69	38.87	40	407.37	414.80
0.6	7.43022	507.59	22.23	39.04	40	520.09	527.52
0.6	7.43022	418.45	29.79	39.17	40	427.31	434.74
0.6	7.43022	427.58	37.89	39.31	40	435.07	442.50
0.6	7.43022	374.05	46.72	39.46	40	379.12	386.55
0.6	7.43022	476.34	51.94	39.56	40	481.69	489.12

Note: The shaded data points are Chauvenet outliers.

Table 8b: Random Uncertainties in Maximum Tow Force – Run #2, all ice sheets.

Max Tow Force: Presawn Ice Sheet - Run #2									
Ice Sheet #	**Segment #**	**TF-max (N)**	**Mean Rt_corr**	**STD max (N)**	**Chauv #**	**New mean TF max**	**New STD max**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-1	2	19.71	21.73	2.20	0.77			1.27	**5.84%**
	3	23.09	21.73	2.20	0.78				
	4	20.30	21.73	2.20	0.53				
	5	20.30	21.73	2.20	0.54				
	6	21.53	21.73	2.20	0.01				
	7	21.07	21.73	2.20	0.22				
	8	25.03	21.73	2.20	1.59				
	9	25.03	21.73	2.20	1.57				
	10	21.45	21.73	2.20	0.08				
	11	17.57	21.73	2.20	1.86				
	12	23.07	21.73	2.20	0.63				
	13	20.48	21.73	2.20	0.56				
PICE-2	3	34.97	37.25	6.06	0.24	35.71	3.82	2.55	**7.14%**
	4	29.69	37.25	6.06	1.13				
	5	30.57	37.25	6.06	0.98				
	6	35.58	37.25	6.06	0.13				
	7	40.93	37.25	6.06	0.78				
	8	38.84	37.25	6.06	0.43				
	9	49.79	37.25	6.06	2.29				
	10	33.34	37.25	6.06	0.50				
	11	32.55	37.25	6.06	0.63				
	12	36.93	37.25	6.06	0.12				
PICE-3	4	63.59	61.68	3.37	0.81			2.55	**4.13%**
	5	63.81	61.68	3.37	0.90				
	6	56.78	61.68	3.37	1.19				
	7	62.32	61.68	3.37	0.51				
	8	55.10	61.68	3.37	1.63				
	9	61.35	61.68	3.37	0.29				
	10	61.35	61.68	3.37	0.31				
PICE-4	2	90.10	96.54	17.05	0.22			10.79	**11.17%**
	3	77.80	96.54	17.05	0.97				
	4	73.82	96.54	17.05	1.22				
	5	93.66	96.54	17.05	0.04				
	6	101.07	96.54	17.05	0.39				
	7	122.67	96.54	17.05	1.67				
	8	122.67	96.54	17.05	1.65				
	9	80.44	96.54	17.05	0.88				
	10	93.02	96.54	17.05	0.14				
	11	91.83	96.54	17.05	0.22				

Correction for Ice Thickness							
Speed (m/s)	**TF_OW (N)**	**Ice (N) Resistance**	**D (m)**	**hm (mm)**	**ho (mm)**	**R_corr (N)**	**Rt_corr (N)**
0.1	0.31937	19.39	5.65	39.34	40	19.71	20.03
0.1	0.31937	22.77	10.23	39.40	40	23.12	23.44
0.1	0.31937	19.98	14.93	39.47	40	20.25	20.57
0.1	0.31937	19.98	19.51	39.53	40	20.22	20.54
0.1	0.31937	21.21	23.40	39.58	40	21.44	21.76
0.1	0.31937	20.75	27.66	39.64	40	20.94	21.26
0.1	0.31937	24.71	31.74	39.69	40	24.90	25.22
0.1	0.31937	24.71	35.75	39.74	40	24.87	25.19
0.1	0.31937	21.13	40.02	39.80	40	21.23	21.55
0.1	0.31937	17.25	44.54	39.86	40	17.31	17.63
0.1	0.31937	22.75	48.43	39.91	40	22.80	23.12
0.1	0.31937	20.16	52.31	39.97	40	20.17	20.49
0.2	1.01654	33.95	5.12	39.07	40	34.76	35.78
0.2	1.01654	28.67	9.09	39.05	40	29.37	30.39
0.2	1.01654	29.55	13.69	39.03	40	30.29	31.30
0.2	1.01654	34.57	18.67	39.01	40	35.44	36.46
0.2	1.01654	39.92	23.81	38.99	40	40.95	41.97
0.2	1.01654	37.82	29.50	38.96	40	38.83	39.84
0.2	1.01654	48.77	35.03	38.94	40	50.10	51.12
0.2	1.01654	32.32	40.64	38.92	40	33.22	34.24
0.2	1.01654	31.53	46.33	38.89	40	32.43	33.45
0.2	1.01654	35.91	51.86	38.87	40	36.96	37.97
0.4	3.49838	60.09	6.78	39.46	40	60.91	64.41
0.4	3.49838	60.31	13.78	39.40	40	61.23	64.73
0.4	3.49838	53.28	21.68	39.34	40	54.18	57.67
0.4	3.49838	58.82	29.69	39.27	40	59.91	63.41
0.4	3.49838	51.60	39.71	39.18	40	52.68	56.18
0.4	3.49838	57.85	47.38	39.12	40	59.15	62.65
0.4	3.49838	57.85	52.05	39.08	40	59.21	62.71
0.6	7.43022	82.66	4.59	38.73	40	85.37	92.80
0.6	7.43022	70.37	9.71	38.82	40	72.51	79.94
0.6	7.43022	66.39	14.68	38.91	40	68.25	75.68
0.6	7.43022	86.23	20.60	39.01	40	88.42	95.85
0.6	7.43022	93.64	26.20	39.11	40	95.78	103.21
0.6	7.43022	115.24	31.80	39.21	40	117.58	125.01
0.6	7.43022	115.24	38.52	39.32	40	117.23	124.66
0.6	7.43022	73.01	44.60	39.43	40	74.07	81.50
0.6	7.43022	85.59	49.25	39.51	40	86.65	94.08
0.6	7.43022	84.40	53.40	39.58	40	85.30	92.73

Note: The shaded data points are Chauvenet outliers.

Table 8c: Random Uncertainties in Maximum Tow Force –Run #3, all ice sheets.

Max Tow Force: Unsupported Ice Sheet - Run #3									
Ice Sheet #	**Segment #**	**TF-max (N)**	**Mean Rt_corr**	**STD max (N)**	**Chauv #**	**New mean TF max**	**New STD max**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-1	2	64.54	63.95	8.11	0.20			5.41	**8.45%**
	3	56.93	63.95	8.11	0.76				
	4	62.01	63.95	8.11	0.14				
	5	48.81	63.95	8.11	1.80				
	6	69.07	63.95	8.11	0.71				
	7	61.92	63.95	8.11	0.20				
	8	61.42	63.95	8.11	0.28				
	9	67.49	63.95	8.11	0.46				
	10	78.59	63.95	8.11	1.81				
PICE-2	3	56.53	66.96	9.48	0.96			5.99	**8.95%**
	4	59.64	66.96	9.48	0.62				
	5	56.56	66.96	9.48	0.95				
	6	71.14	66.96	9.48	0.63				
	7	60.69	66.96	9.48	0.50				
	8	58.43	66.96	9.48	0.74				
	9	67.33	66.96	9.48	0.23				
	10	77.05	66.96	9.48	1.29				
	11	83.08	66.96	9.48	1.95				
	12	62.14	66.96	9.48	0.32				
PICE-3	4	227.42	223.19	17.28	0.42			13.07	**5.85%**
	5	227.42	223.19	17.28	0.44				
	6	189.42	223.19	17.28	1.77				
	7	223.46	223.19	17.28	0.26				
	8	232.59	223.19	17.28	0.82				
	9	232.59	223.19	17.28	0.84				
	10	200.94	223.19	17.28	1.02				
PICE-4	4	298.01	356.67	26.76	1.85				
	5	364.23	356.67	26.76	0.68	364.91	17.04	13.91	**3.81%**
	6	325.26	356.67	26.76	0.87				
	7	349.96	356.67	26.76	0.02				
	8	367.77	356.67	26.76	0.64				
	9	367.77	356.67	26.76	0.60				
	10	373.54	356.67	26.76	0.78				

Correction for Ice Thickness							
Speed (m/s)	**TF_BL (N)**	**Ice (N) Resistance**	**D (m)**	**hm (mm)**	**ho (mm)**	**R_corr (N)**	**Rt_corr (N)**
0.1	0.31937	64.22	5.76	39.34	40	65.29	65.61
0.1	0.31937	56.61	11.17	39.41	40	57.45	57.77
0.1	0.31937	61.69	16.59	39.49	40	62.49	62.81
0.1	0.31937	48.49	21.61	39.55	40	49.04	49.36
0.1	0.31937	68.75	28.50	39.65	40	69.36	69.68
0.1	0.31937	61.60	35.32	39.74	40	62.01	62.33
0.1	0.31937	61.10	41.94	39.83	40	61.36	61.68
0.1	0.31937	67.17	47.22	39.90	40	67.34	67.66
0.1	0.31937	78.27	51.63	39.96	40	78.35	78.67
0.2	1.01654	55.52	5.25	39.07	40	56.84	57.86
0.2	1.01654	58.62	9.67	39.05	40	60.05	61.06
0.2	1.01654	55.54	14.35	39.03	40	56.92	57.94
0.2	1.01654	70.12	19.02	39.01	40	71.90	72.92
0.2	1.01654	59.67	23.87	38.99	40	61.22	62.24
0.2	1.01654	57.41	28.87	38.97	40	58.93	59.95
0.2	1.01654	66.32	33.13	38.95	40	68.11	69.13
0.2	1.01654	76.04	38.47	38.92	40	78.14	79.15
0.2	1.01654	82.06	44.07	38.90	40	84.38	85.40
0.2	1.01654	61.13	50.16	38.87	40	62.90	63.91
0.4	3.49838	223.92	5.90	39.47	40	226.94	230.44
0.4	3.49838	223.92	13.58	39.40	40	227.31	230.81
0.4	3.49838	185.92	22.48	39.33	40	189.09	192.59
0.4	3.49838	219.96	32.38	39.25	40	224.19	227.69
0.4	3.49838	229.09	41.39	39.17	40	233.94	237.44
0.4	3.49838	229.09	48.18	39.11	40	234.29	237.78
0.4	3.49838	197.44	52.41	39.08	40	202.10	205.60
0.6	7.43022	290.58	6.44	38.76	40	299.84	307.27
0.6	7.43022	356.80	11.56	38.85	40	367.33	374.76
0.6	7.43022	317.83	20.05	39.00	40	325.97	333.40
0.6	7.43022	342.53	30.14	39.18	40	349.73	357.16
0.6	7.43022	360.34	39.26	39.34	40	366.43	373.86
0.6	7.43022	360.34	46.94	39.47	40	365.19	372.62
0.6	7.43022	366.11	52.06	39.56	40	370.20	377.63

Note: The shaded data points are Chauvenet outliers.

Table 8d: Random Uncertainties in Maximum Tow Force – Run #4, all ice sheets.

Max Tow Force: 9/10th Ice Concentration Broken Ice - Run #4									
Ice Sheet #	Segment #	TF-max (N)	Mean TF max	STD max (N)	Chauv #	New mean TF max	New STD max	Uncertainty Value (N)	Uncertainty %
PICE-1	2	24.31	25.51	2.87	0.42			1.82	**7.12%**
	3	23.10	25.51	2.87	0.84				
	4	26.15	25.51	2.87	0.22				
	5	29.98	25.51	2.87	1.56				
	6	29.98	25.51	2.87	1.56				
	7	24.28	25.51	2.87	0.43				
	8	24.28	25.51	2.87	0.43				
	9	27.10	25.51	2.87	0.55				
	10	24.97	25.51	2.87	0.19				
	11	20.96	25.51	2.87	1.58				
PICE-2	3	30.68	29.20	2.08	0.71			1.32	**4.51%**
	4	29.03	29.20	2.08	0.08				
	5	29.91	29.20	2.08	0.34				
	6	31.94	29.20	2.08	1.32				
	7	26.72	29.20	2.08	1.19				
	8	25.93	29.20	2.08	1.57				
	9	28.24	29.20	2.08	0.46				
	10	32.36	29.20	2.08	1.52				
	11	28.97	29.20	2.08	0.11				
	12	28.18	29.20	2.08	0.49				
PICE-3	4	37.32	45.62	4.72	1.76			3.57	**7.82%**
	5	50.05	45.62	4.72	0.94				
	6	49.66	45.62	4.72	0.86				
	7	49.66	45.62	4.72	0.86				
	8	44.14	45.62	4.72	0.31				
	9	42.46	45.62	4.72	0.67				
	10	46.03	45.62	4.72	0.09				
PICE-4	4	82.54	85.78	5.25	0.62			3.71	**4.33%**
	5	82.54	85.78	5.25	0.62				
	6	91.86	85.78	5.25	1.16				
	7	91.86	85.78	5.25	1.16				
	8	79.04	85.78	5.25	1.28				
	9	84.47	85.78	5.25	0.25				
	10	82.05	85.78	5.25	0.71				
	11	91.86	85.78	5.25	1.16				

Table 8e: Random Uncertainties in Maximum Tow Force – Run #5, all ice sheets.

Max Tow Force: 8/10th Ice Concentration Broken Ice - Run #5									
Ice Sheet #	Segment #	TF-max (N)	Mean TF max	STD max (N)	Chauv #	New mean TF max	New STD max	Uncertainty Value (N)	Uncertainty %
PICE-1	2	15.79	21.71	4.67	1.27	20.66	3.47	2.31	**11.19%**
	3	14.74	21.71	4.67	1.49				
	4	18.67	21.71	4.67	0.65				
	5	22.28	21.71	4.67	0.12				
	6	22.48	21.71	4.67	0.16				
	7	22.48	21.71	4.67	0.16				
	8	21.40	21.71	4.67	0.07				
	9	24.65	21.71	4.67	0.63				
	10	23.42	21.71	4.67	0.37				
	11	31.21	21.71	4.67	2.03				
PICE-2	3	22.04	21.02	3.46	0.29			2.19	**10.40%**
	4	18.52	21.02	3.46	0.72				
	5	20.74	21.02	3.46	0.08				
	6	17.00	21.02	3.46	1.16				
	7	24.00	21.02	3.46	0.86				
	8	15.31	21.02	3.46	1.65				
	9	19.14	21.02	3.46	0.55				
	10	25.84	21.02	3.46	1.39				
	11	24.00	21.02	3.46	0.86				
	12	23.65	21.02	3.46	0.76				
PICE-3	4	30.27	32.85	6.13	0.42			3.88	**11.81%**
	5	40.45	32.85	6.13	1.24				
	6	42.36	32.85	6.13	1.55				
	7	32.22	32.85	6.13	0.10				
	8	32.22	32.85	6.13	0.10				
	9	24.53	32.85	6.13	1.36				
	10	34.51	32.85	6.13	0.27				
	11	38.62	32.85	6.13	0.94				
	12	26.04	32.85	6.13	1.11				
	13	27.27	32.85	6.13	0.91				
PICE-4	4	94.92	59.92	15.69	2.23				
	5	50.75	59.92	15.69	0.58	56.04	10.34	6.89	**12.30%**
	6	69.87	59.92	15.69	0.63				
	7	62.56	59.92	15.69	0.17				
	8	64.90	59.92	15.69	0.32				
	9	45.19	59.92	15.69	0.94				
	10	68.83	59.92	15.69	0.57				
	11	48.29	59.92	15.69	0.74				
	12	49.15	59.92	15.69	0.69				
	13	44.79	59.92	15.69	0.96				

Note: The shaded data points are Chauvenet outliers.

Table 8f: Random Uncertainties in Maximum Tow Force – Run #6, all ice sheets.

Max Tow Force: 6/10th Ice Concentration Broken Ice - Run #6									
Ice Sheet #	**Segment #**	**TF-max (N)**	**Mean TF max**	**STD max (N)**	**Chauv #**	**New mean TF max**	**New STD max**	**Uncertainty Value (N)**	**Uncertainty %**
PICE-2	3	17.99	19.78	4.08	0.44			2.58	**13.03%**
	4	13.04	19.78	4.08	1.65				
	5	25.55	19.78	4.08	1.42				
	6	17.75	19.78	4.08	0.50				
	7	16.65	19.78	4.08	0.77				
	8	20.56	19.78	4.08	0.19				
	9	18.30	19.78	4.08	0.37				
	10	21.18	19.78	4.08	0.34				
	11	26.76	19.78	4.08	1.71				
	12	20.08	19.78	4.08	0.07				
PICE-3	4	26.20	31.37	3.59	1.44			2.16	**6.90%**
	5	32.73	31.37	3.59	0.38				
	6	32.73	31.37	3.59	0.38				
	7	34.16	31.37	3.59	0.78				
	8	28.57	31.37	3.59	0.78				
	9	25.89	31.37	3.59	1.53				
	10	29.45	31.37	3.59	0.54				
	11	37.57	31.37	3.59	1.73				
	12	34.14	31.37	3.59	0.77				
	13	30.73	31.37	3.59	0.18				
	14	32.95	31.37	3.59	0.44				
PICE-4	4	50.06	51.92	8.03	0.23			5.08	**9.78%**
	5	41.40	51.92	8.03	1.31				
	6	52.72	51.92	8.03	0.10				
	7	64.23	51.92	8.03	1.53				
	8	51.34	51.92	8.03	0.07				
	9	39.51	51.92	8.03	1.55				
	10	58.02	51.92	8.03	0.76				
	11	52.50	51.92	8.03	0.07				
	12	47.45	51.92	8.03	0.56				
	13	62.00	51.92	8.03	1.26				

Table 9a: Corrected Mean of Means in Tow Force (N).

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	27.98	2.13	18.26	5.67	4.04	n/a
PICE-2	34.30	11.48	21.28	8.49	5.37	5.29
PICE-3	47.24	13.59	28.31	12.24	10.02	7.59
PICE-4	53.01	28.20	36.17	17.78	15.43	12.41

Table 9b: Random uncertainties in corrected mean tow force before DRE

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	3.32%	5.84%	3.14%	7.77%	25.94%	n/a
PICE-2	2.60%	3.04%	2.87%	7.15%	17.99%	5.97%
PICE-3	1.65%	1.36%	2.71%	3.45%	6.88%	5.03%
PICE-4	3.48%	1.05%	4.08%	4.22%	6.31%	12.40%

Table 9c: Random uncertainties in corrected mean tow force after DRE.

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	4.10%	6.32%	3.96%	7.77%	25.94%	n/a
PICE-2	4.37%	4.64%	4.54%	7.15%	17.99%	5.97%
PICE-3	2.76%	2.60%	3.50%	3.45%	6.88%	5.03%
PICE-4	4.41%	2.90%	4.90%	4.22%	6.31%	12.40%

Table 10a: Corrected Mean of Maximums in Tow Force (N)

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	80.64	21.73	63.95	25.51	20.66	n/a
PICE-2	148.61	35.71	66.96	29.20	21.02	19.78
PICE-3	327.35	61.68	223.19	45.62	32.85	31.37
PICE-4	442.85	96.54	364.91	85.78	56.04	51.92

Table 10b: Random uncertainties in corrected maximum tow force before DRE.

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	4.25%	5.84%	8.45%	7.12%	11.19%	n/a
PICE-2	10.71%	7.14%	8.95%	4.51%	10.40%	13.03%
PICE-3	13.83%	4.13%	5.85%	7.82%	11.81%	6.90%
PICE-4	8.47%	11.17%	3.81%	4.33%	12.30%	9.78%

Table 10c: Random uncertainties in corrected maximum tow force after DRE.

Ice Sheet	Run # 1: Level Ice	Run #2: Presawn	Run # 3: Unsupported	Run # 4: 9/10th	Run # 5: 8/10th	Run # 6: 6/10th
PICE-1	4.89%	6.32%	8.79%	7.12%	11.19%	n/a
PICE-2	11.27%	7.96%	9.62%	4.51%	10.40%	13.03%
PICE-3	14.01%	4.69%	6.26%	7.82%	11.81%	6.90%
PICE-4	8.90%	11.49%	4.68%	4.33%	12.30%	9.78%

Table 11: Comparison of Phase I and Phase III (Uncertainties in Mean Tow Forces)

Experimental Uncertainty for the Mean Tow Force After Data Reduction Equation: Phase I (Tow Post) and Phase III (PMM) Results							
Ice Sheet #	Speed (m/s)	Continious Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	8.95%	7.65%	9.58%	4.20%	19.97%	16.44%
	0.2	4.37%	3.47%	4.09%	3.53%	16.56%	13.06%
	0.4	5.30%	3.68%	4.37%	3.01%	14.79%	9.20%
	0.6	4.88%	4.89%	5.90%	4.07%	10.14%	4.25%
Phase 3: PMM	0.1	4.10%	6.32%	3.96%	7.77%	25.94%	n/a
	0.2	4.37%	4.64%	4.54%	7.15%	17.99%	5.97%
	0.4	2.76%	2.60%	3.50%	3.45%	6.88%	5.03%
	0.6	4.41%	2.90%	4.90%	4.22%	6.31%	12.40%

Table 12: Comparison of Phase I and Phase III (Uncertainties in Maximum Tow Forces)

Experimental Uncertainty for the Max Tow Force After Data Reduction Equation: Phase I (Tow Post) and Phase III (PMM) Results							
Ice Sheet #	Speed (m/s)	Continious Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	10.10%	8.01%	8.14%	8.26%	9.86%	6.82%
	0.2	5.62%	13.01%	10.78%	10.38%	16.00%	12.81%
	0.4	5.30%	7.14%	9.30%	6.58%	14.51%	7.87%
	0.6	4.78%	15.98%	8.25%	5.59%	11.70%	6.22%
Phase 3: PMM	0.1	4.89%	6.32%	8.79%	7.12%	11.19%	n/a
	0.2	11.27%	7.96%	9.62%	4.51%	10.40%	13.03%
	0.4	14.01%	4.69%	6.26%	7.82%	11.81%	6.90%
	0.6	8.90%	11.49%	4.68%	4.33%	12.30%	9.78%

Note: More comparisons are given in Appendix 7.

Figures

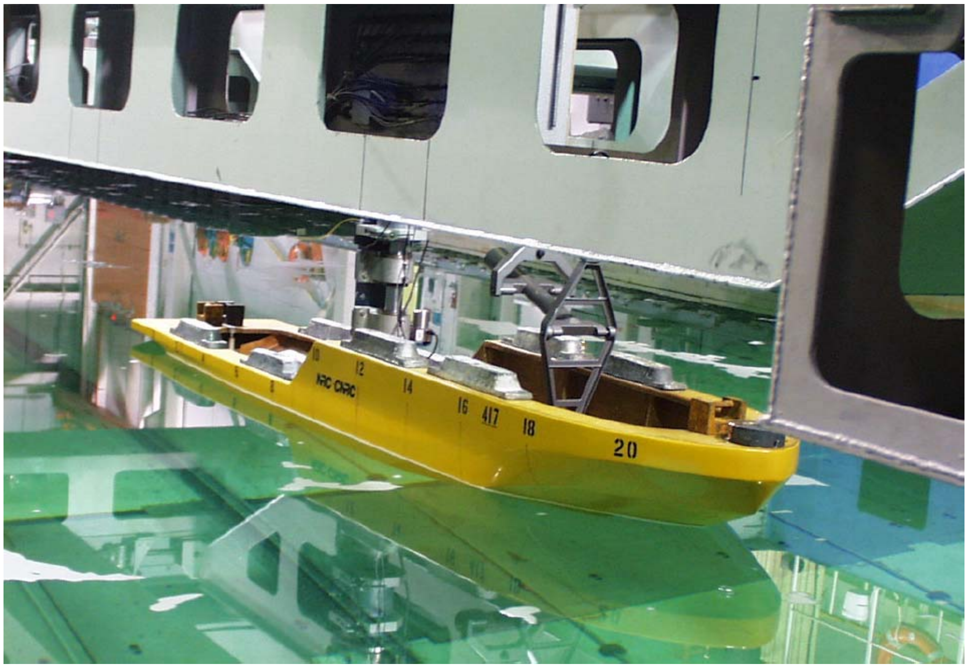


Figure 1a: Tow Post Test Setup.

Figure 1b: Planar Motion Mechanism (PMM) Test Setup.

Figure 2a: Terry Fox Model on the Shop Floor (model in its wooden cradle).

Figure 2b: Terry Fox Model on the swing frame on the Shop Floor.

Figure 3a: Actual Planar Motion Mechanism on the Shop Floor.

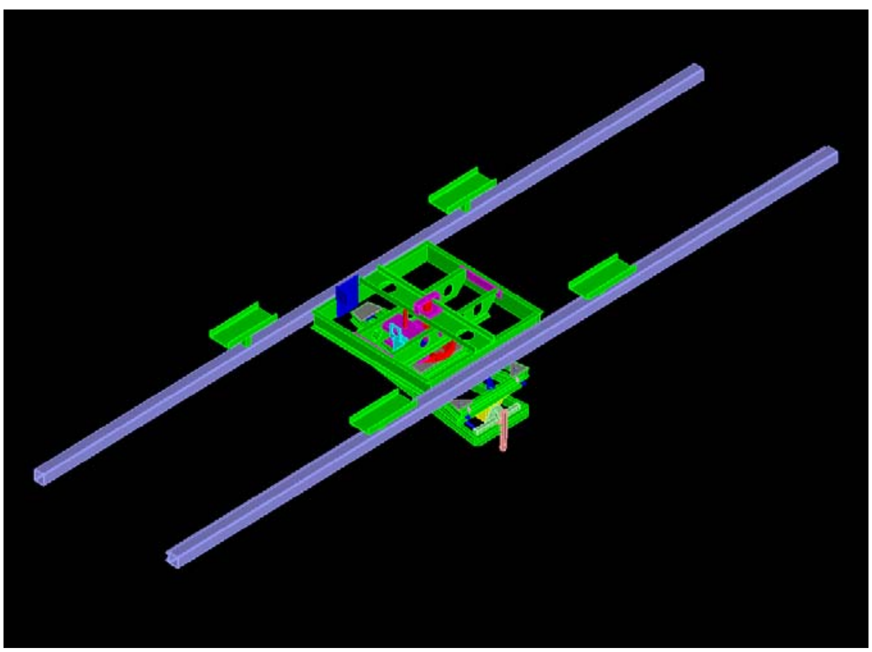


Figure 3b: CAD- top isometric - view for the Planar Motion Mechanism.

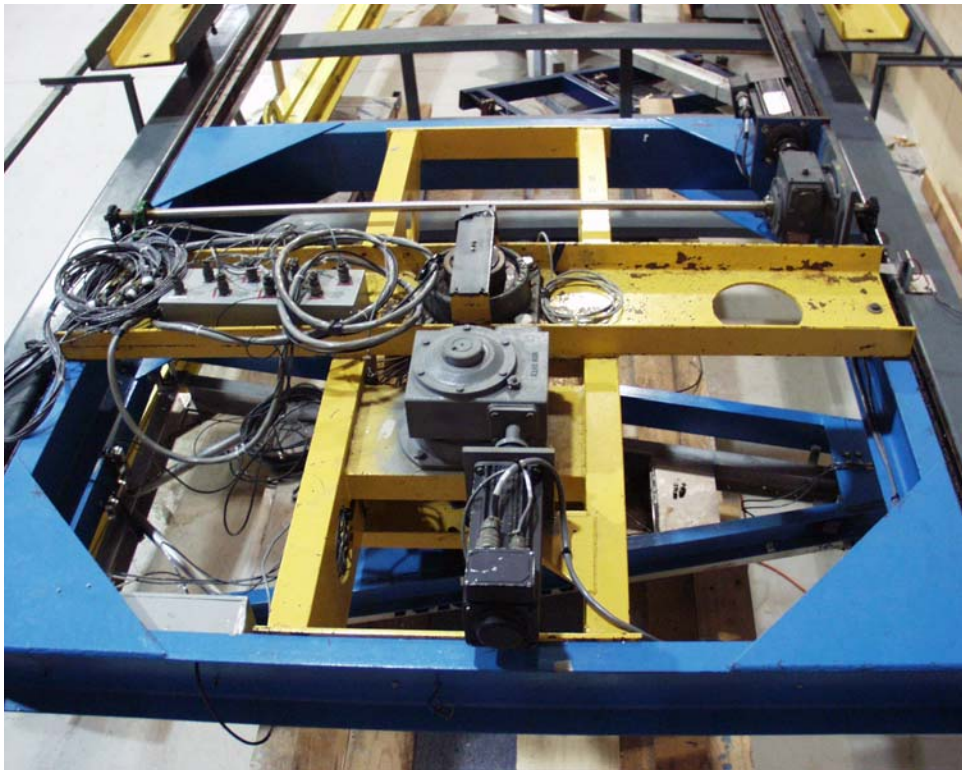


Figure 3c: Actual Planar Motion Mechanism (top view).

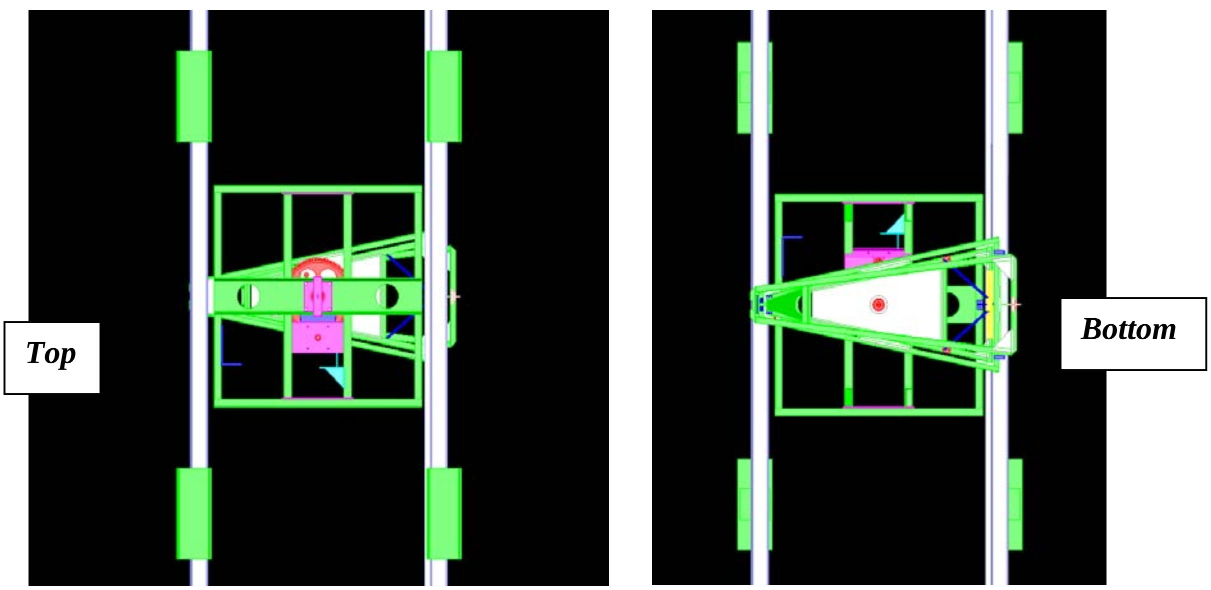


Figure 3d: Top and Bottom CAD views of the PMM.

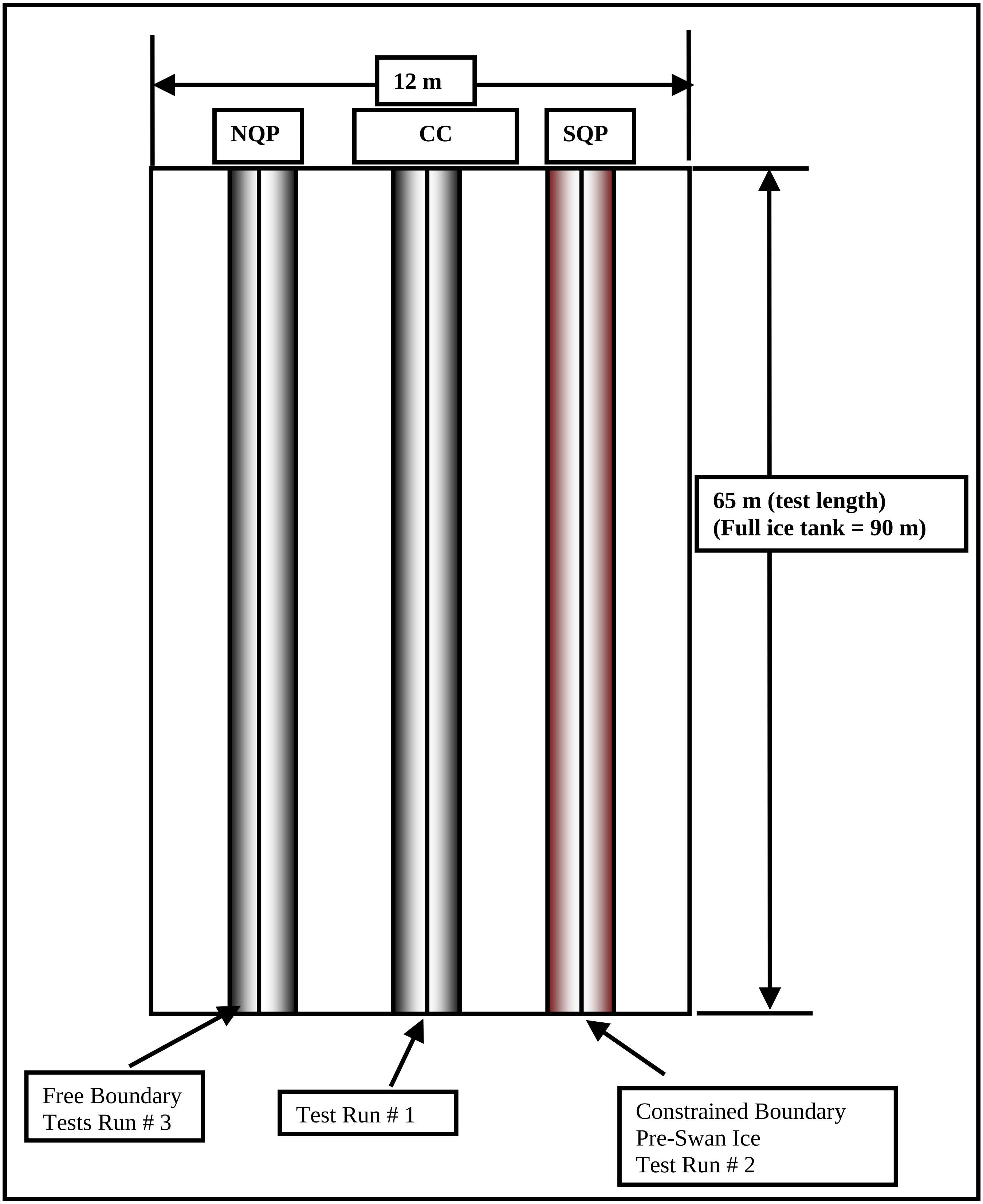


Figure 4: A schematic for Run # 1, Run # 2 and Run # 3.

Figure 5a: Typical test run in continuous ice (Phase III).

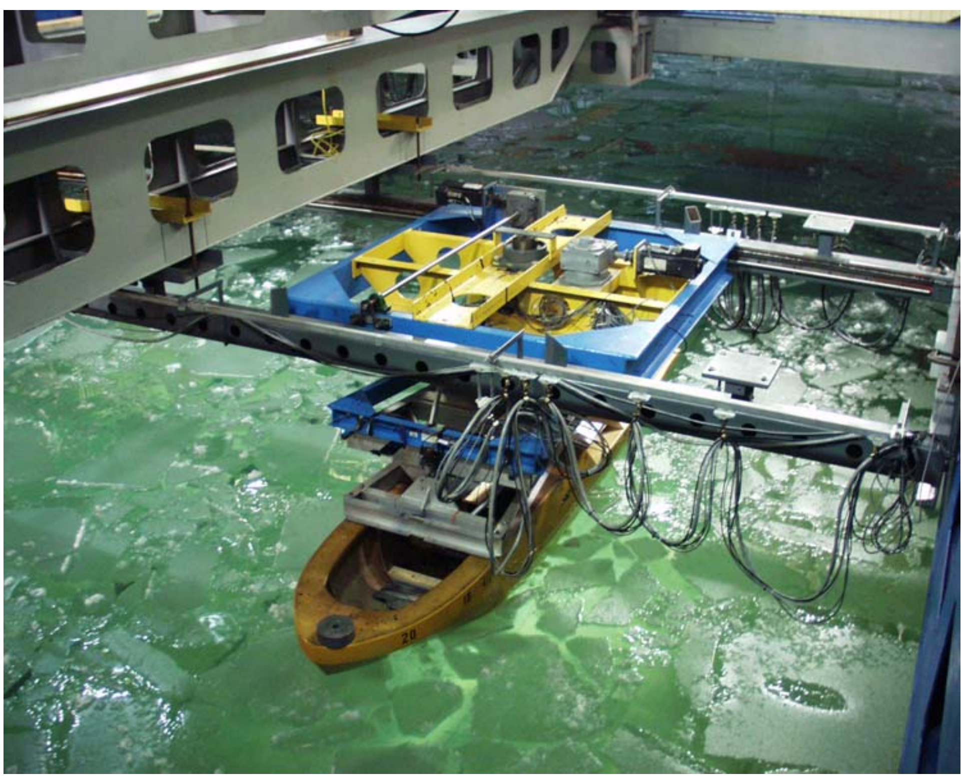


Figure 5b: Typical test run in broken ice (Phase III).

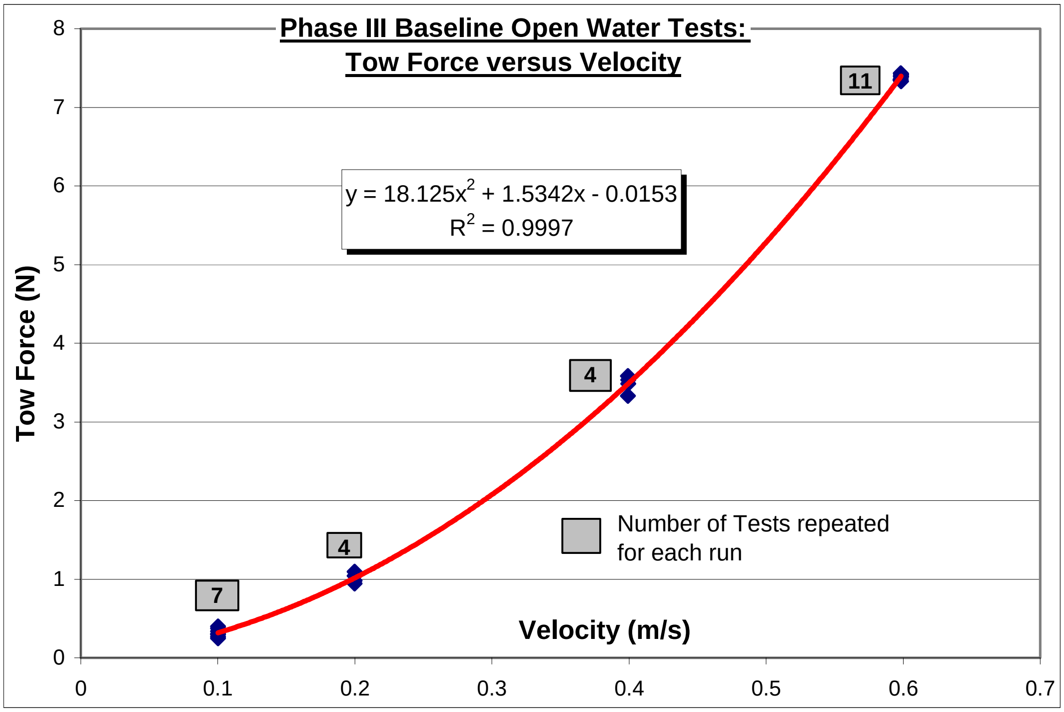


Figure 6a: Results from baseline open water tests – Measured tow force versus velocity.

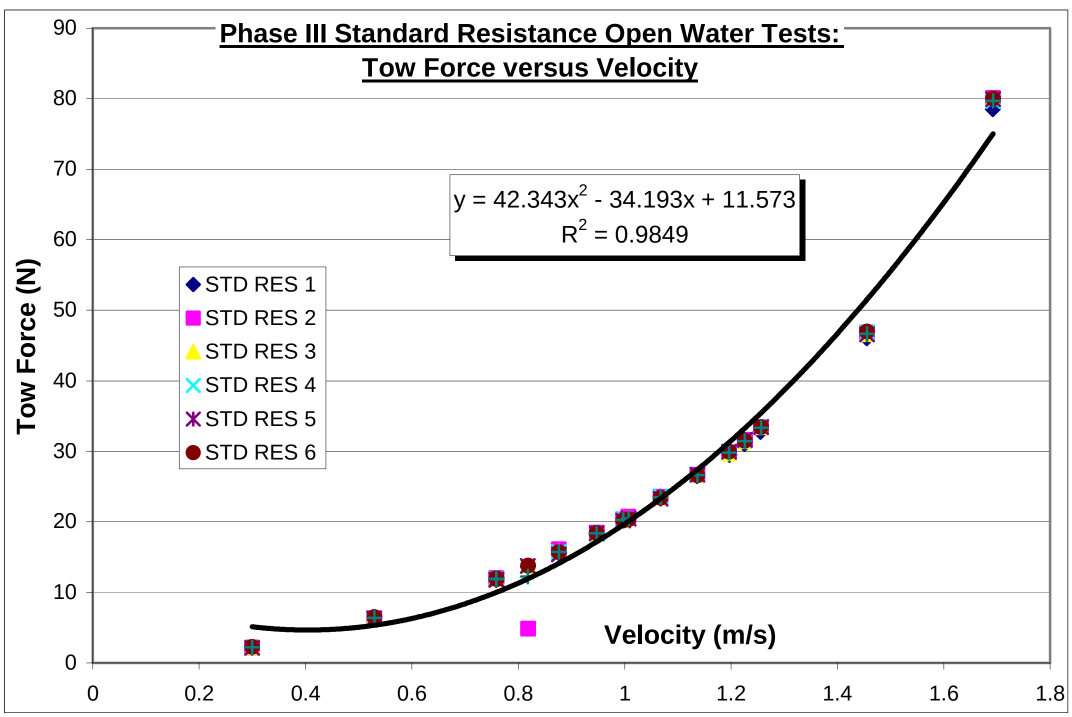


Figure 6b: Results from standard open water tests – Measured tow force versus Velocity.

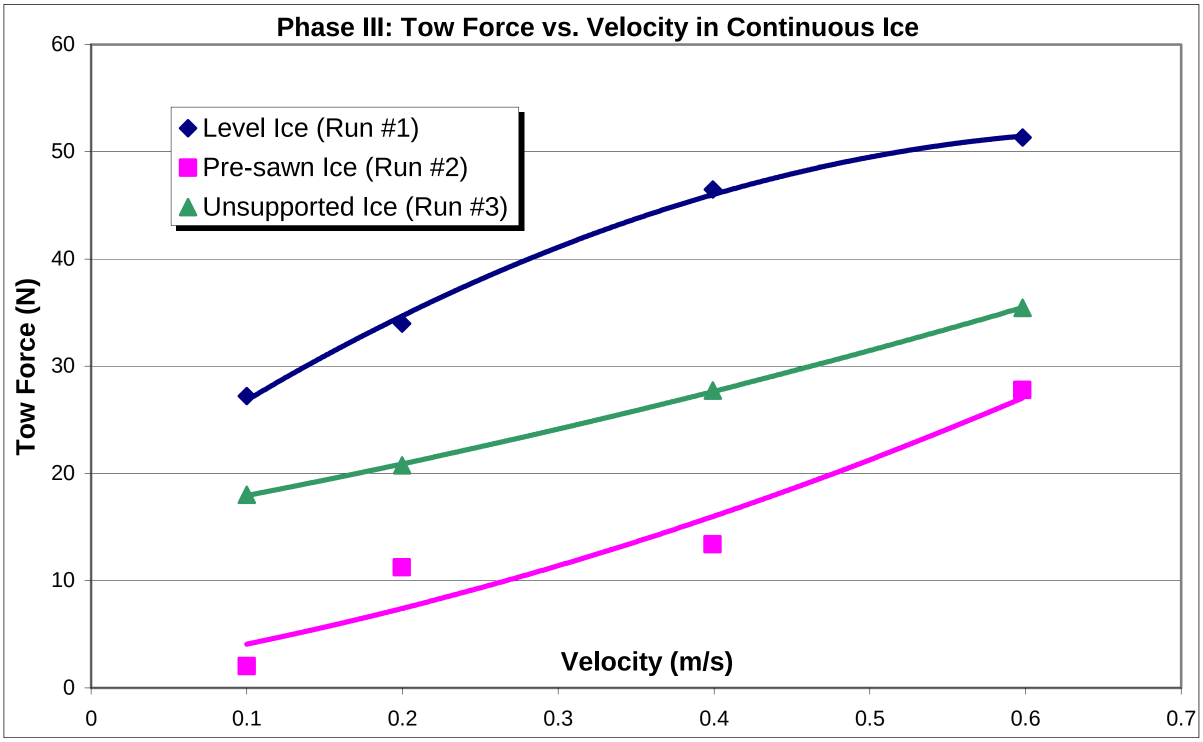


Figure 7a: Measured Tow Force in Continuous Ice Test Runs.

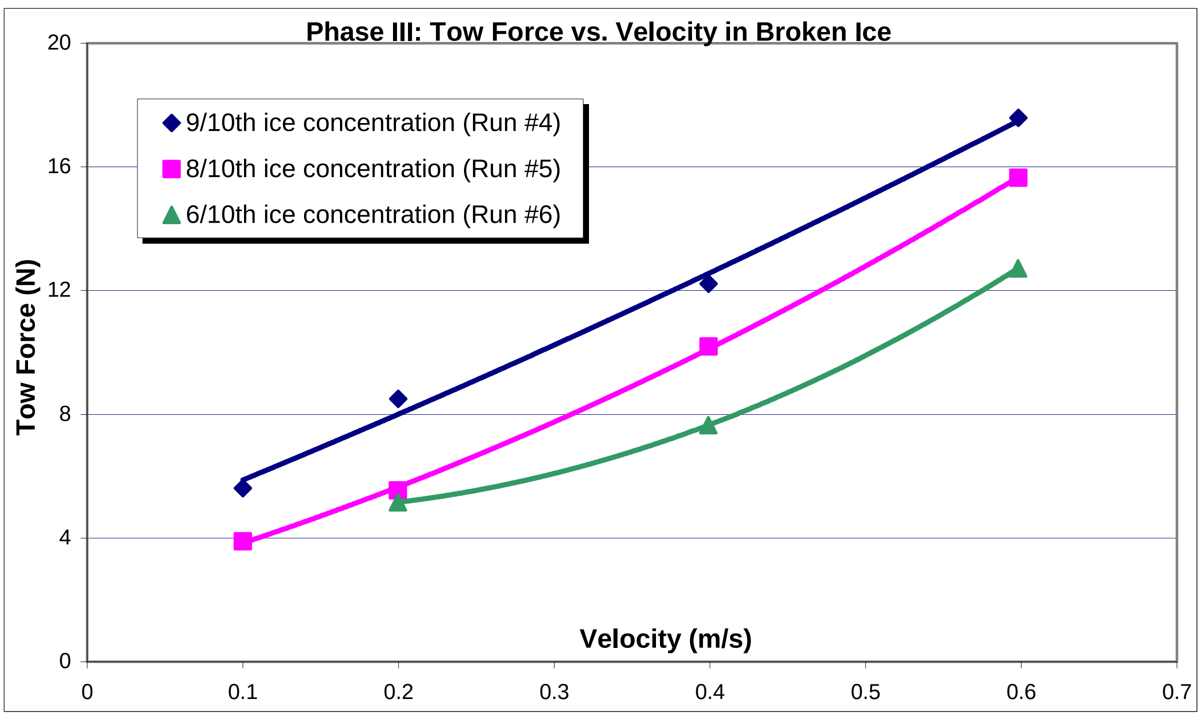


Figure 7b: Measured Tow Force in Broken Ice Test Runs

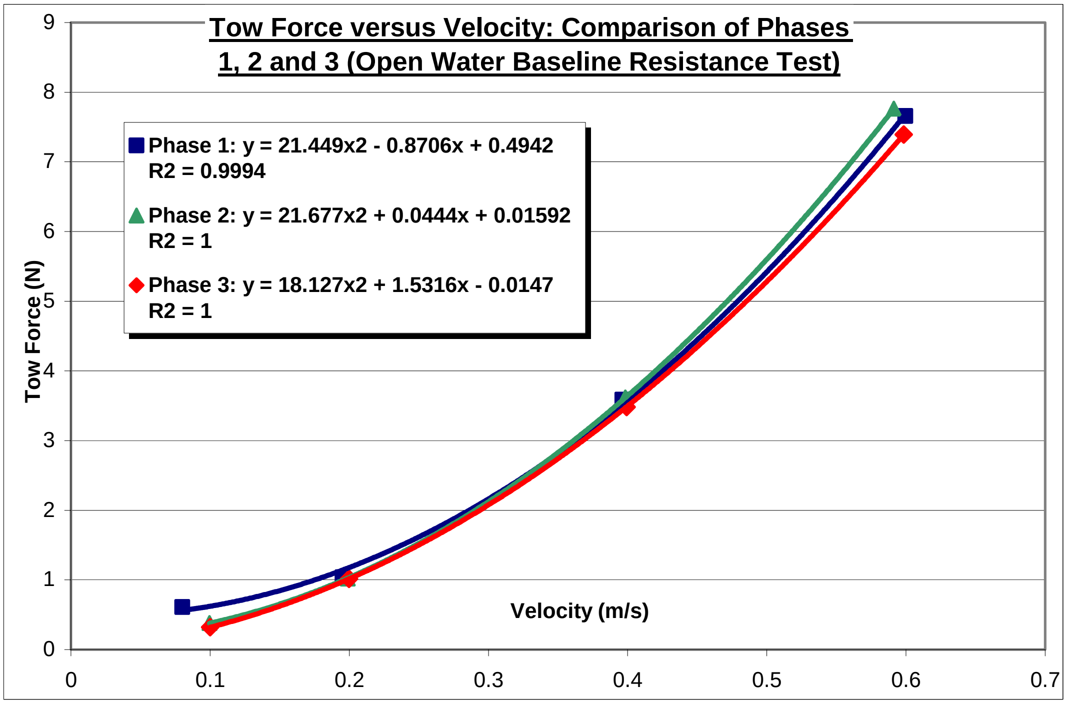


Figure 8a: Baseline open water tests (comparison between phases I, II and III).

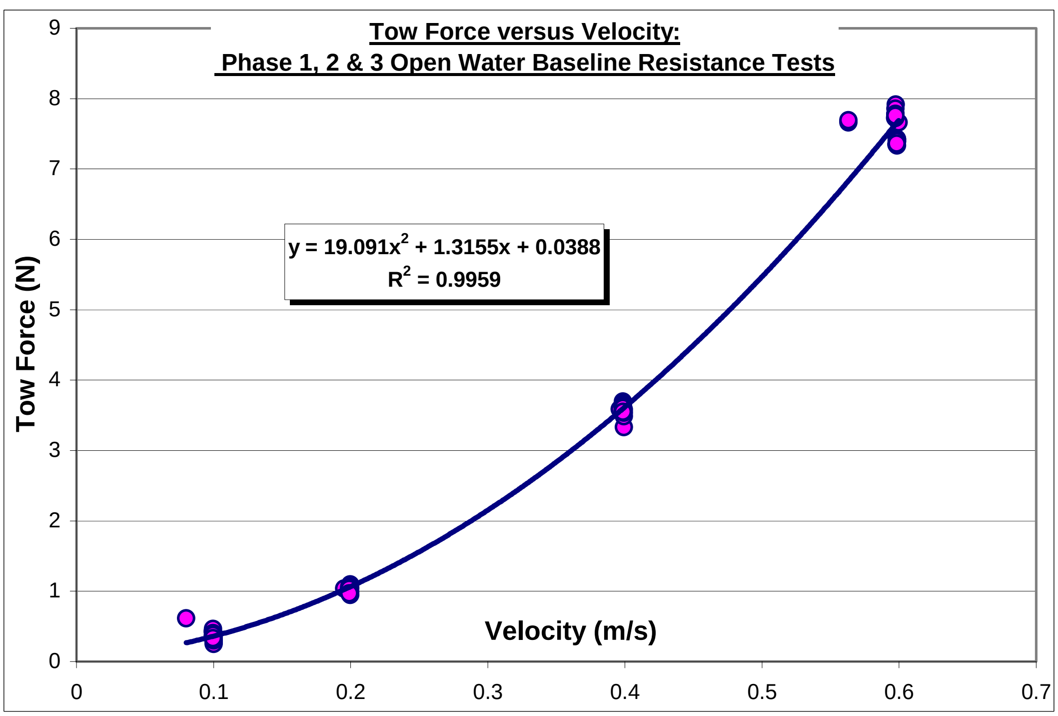


Figure 8b: Baseline open water tests (best fit for all phases of testing).

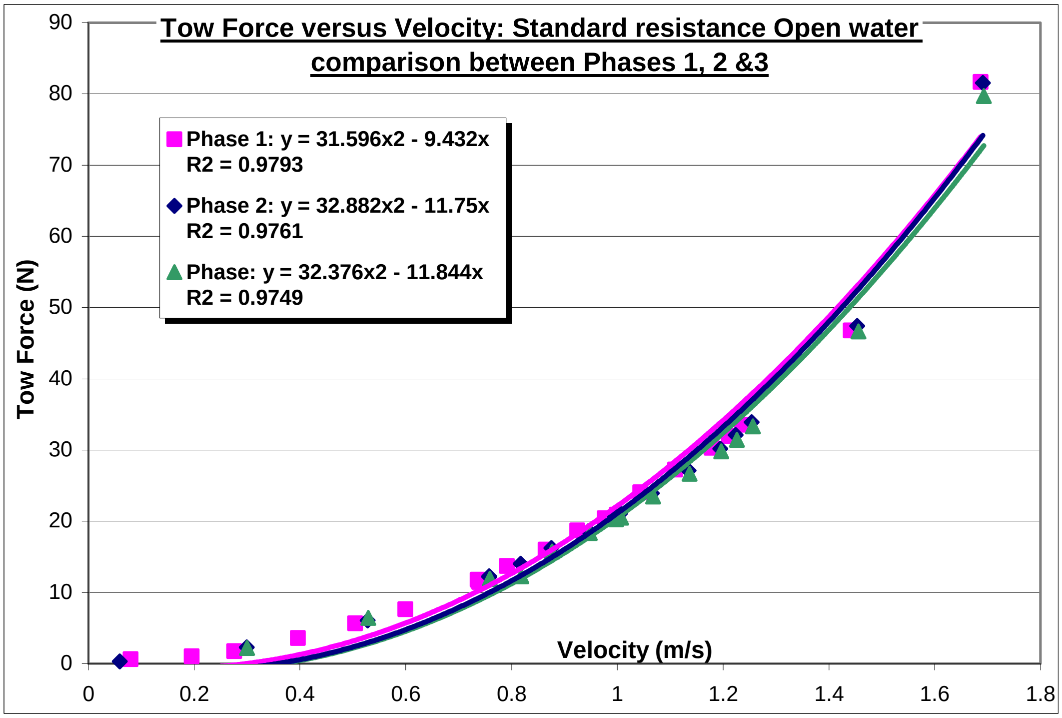


Figure 9a: Standard open water tests (comparison between phases I, II and III).

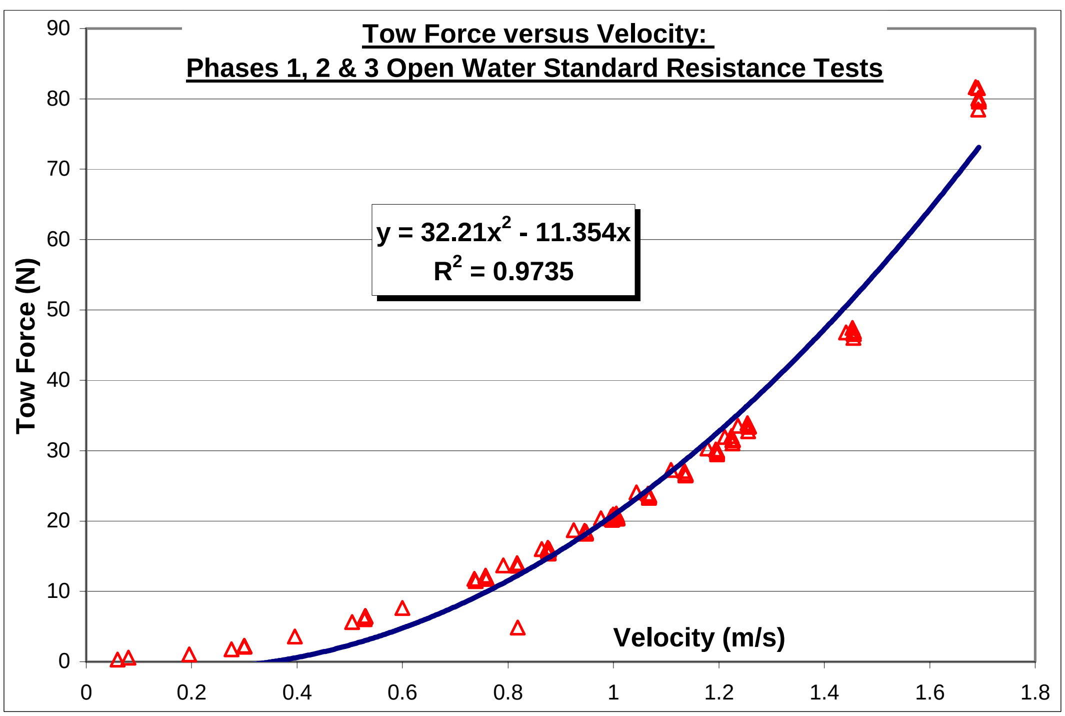


Figure 9b: Standard open water tests (best fit for all phases of testing).

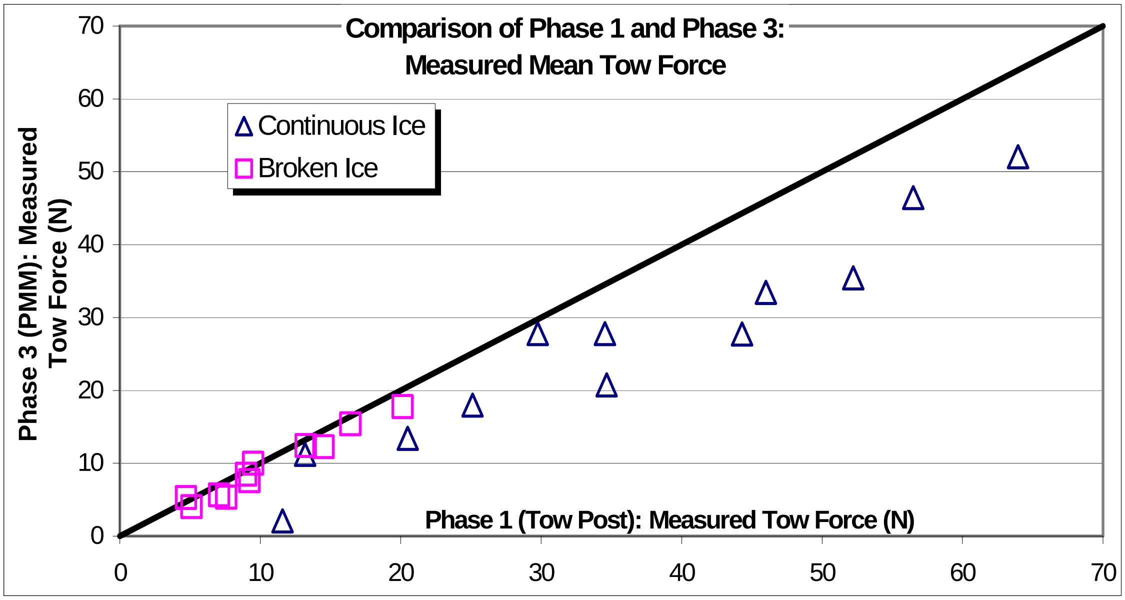


Figure 10a: Comparison of Phase I and Phase III Measured Mean Tow Force.

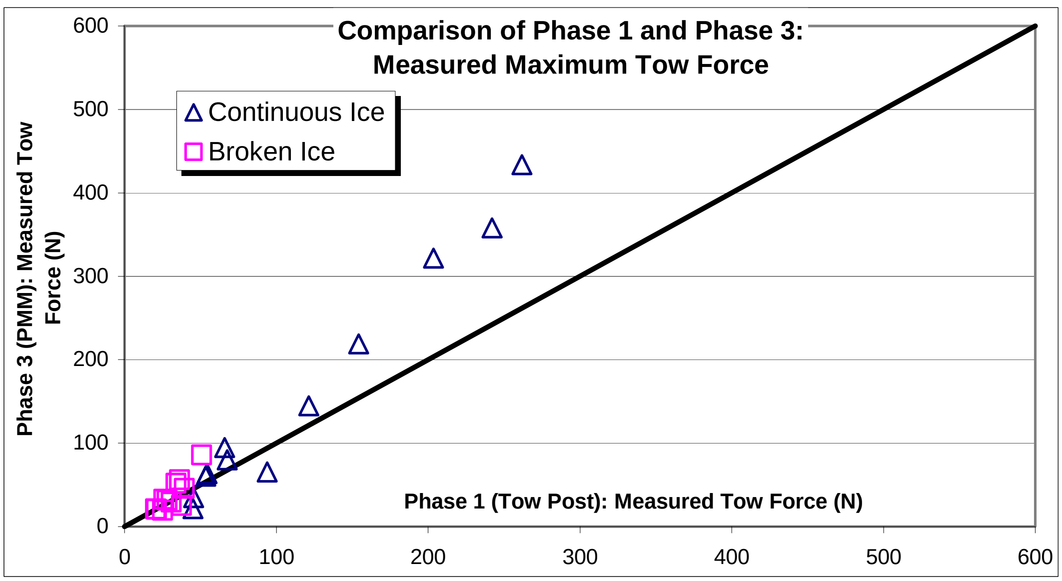
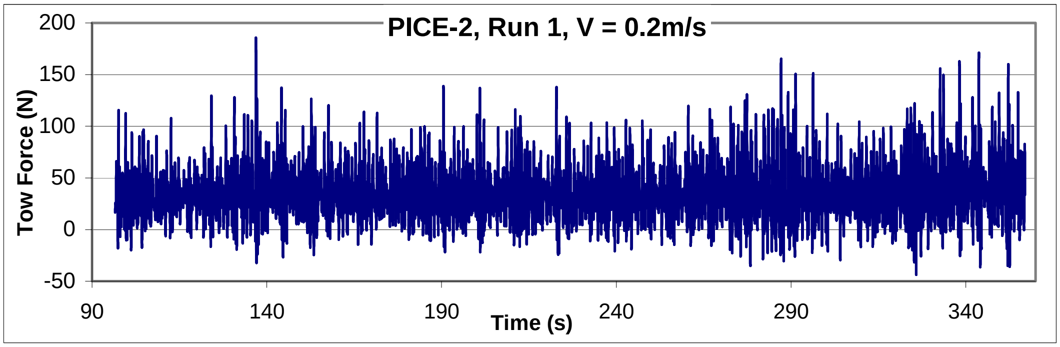


Figure 10b: Comparison of Phase I and Phase III Measured Maximum Tow Force.



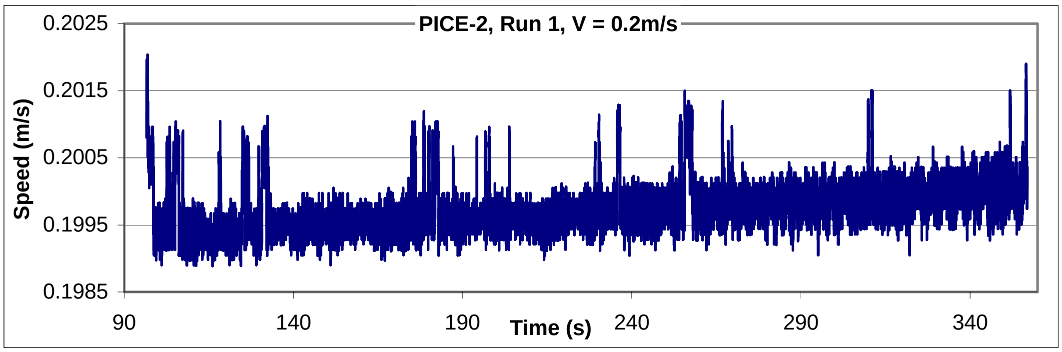


Figure 11a: Measured Tow Force versus Time and Measured Speed versus Time.

- **Note 1:** This is an example of laboratory measurements in a typical resistance test in ice (Phase III, ice sheet #2, Run #1, nominal speed = 0.2m/s).

- **Note 2:** In the speed time history (bottom figure), the stepping fluctuation of the curve is only the plotting effects generated by a new digital control system in the ice tank carriage.

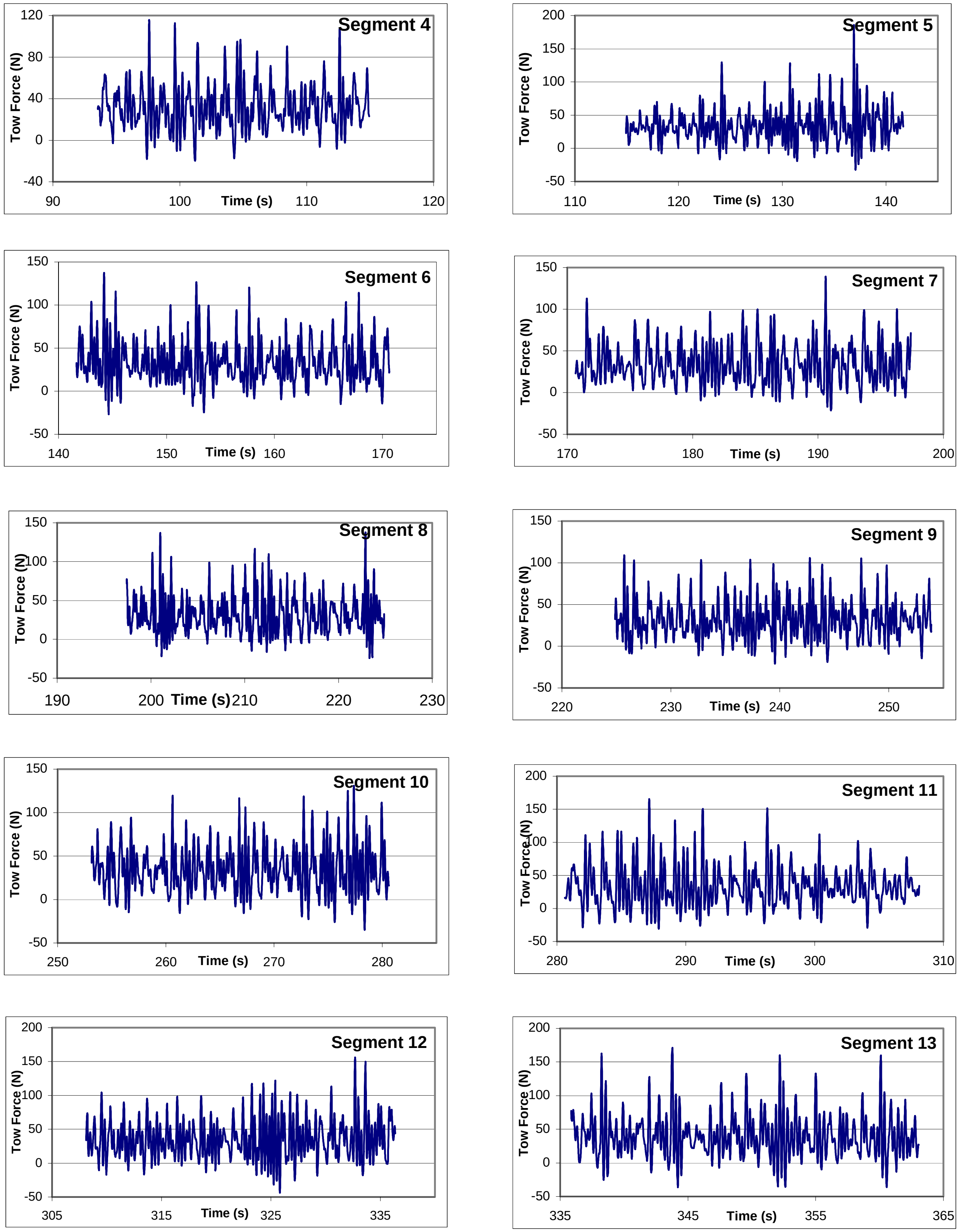


Figure 11b: Subdivision of the tow force time history test data (in Fig. 11a) into segments.

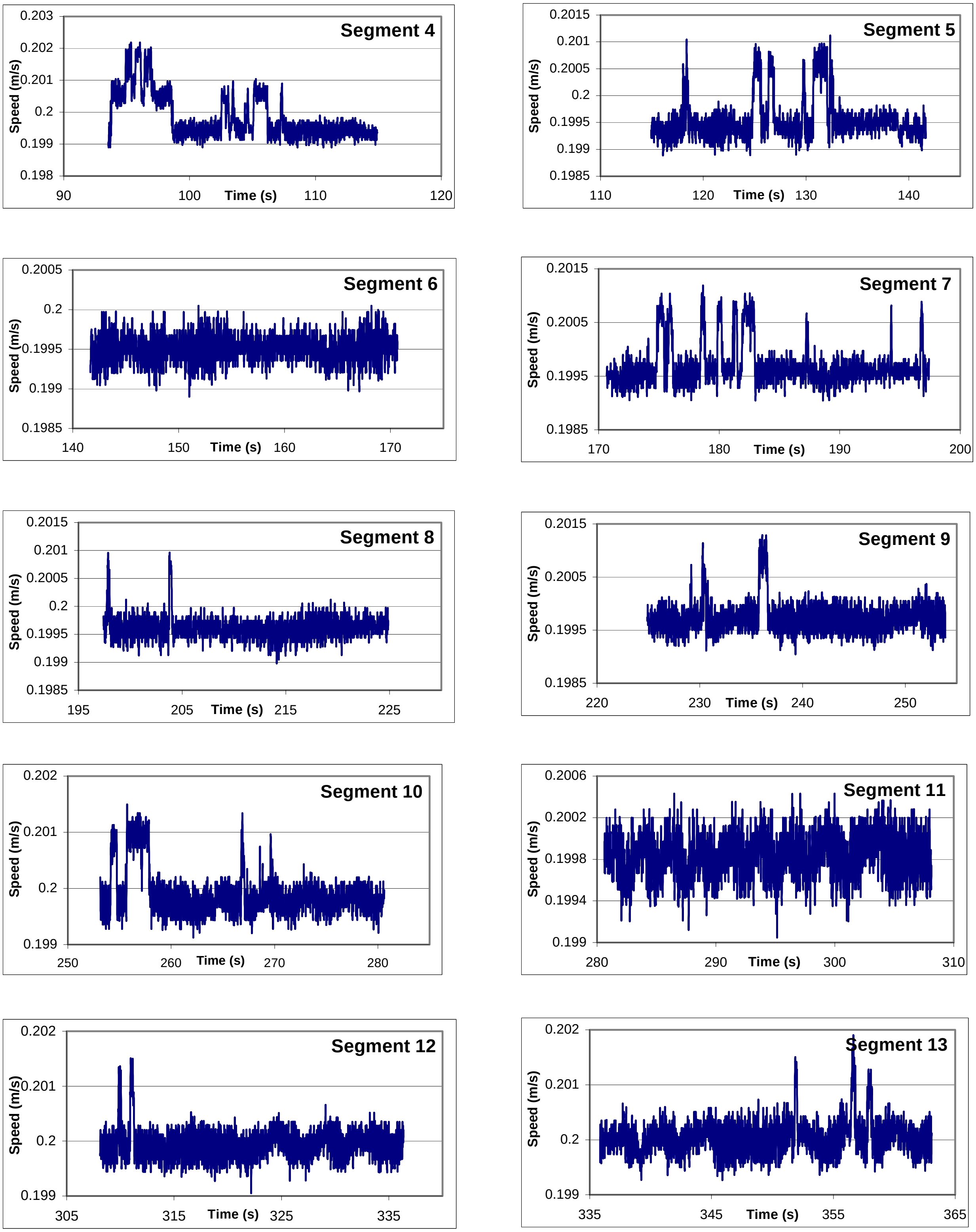


Figure 11c: Subdivision of the speed time history test data in Fig. 11a) into segments.

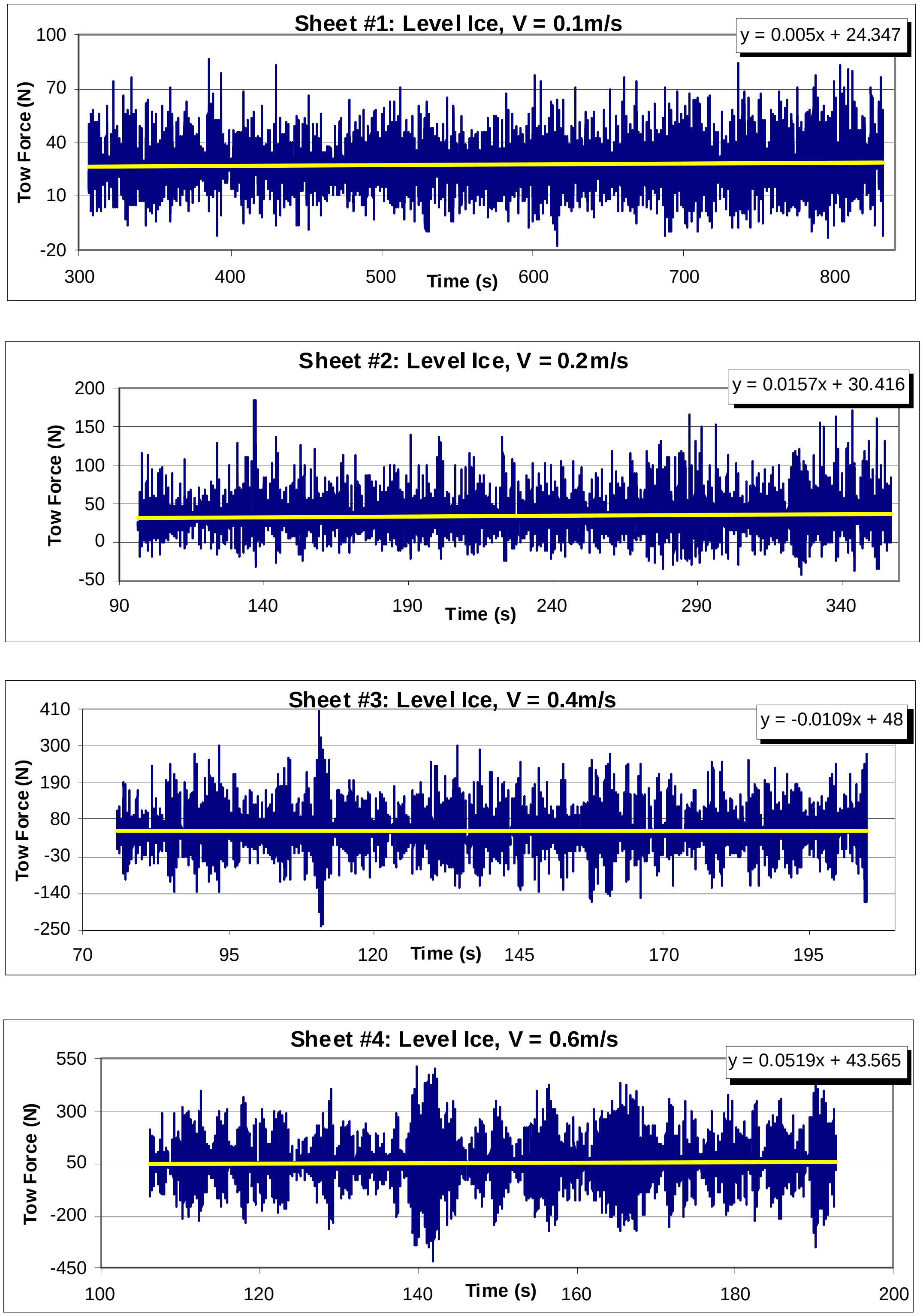
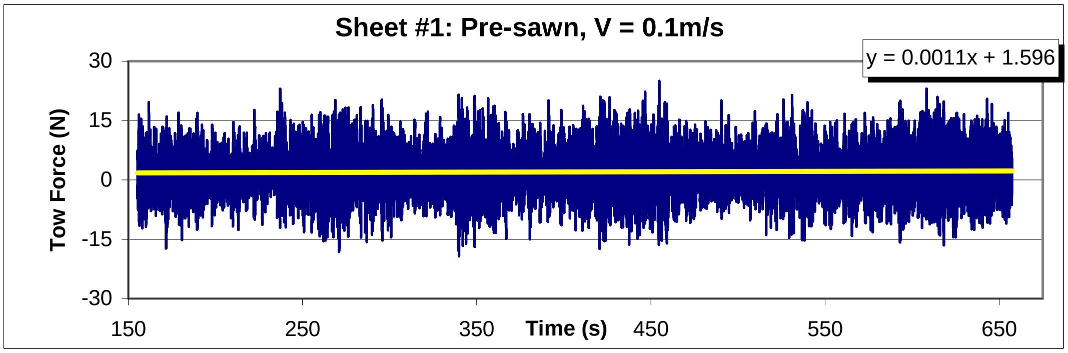
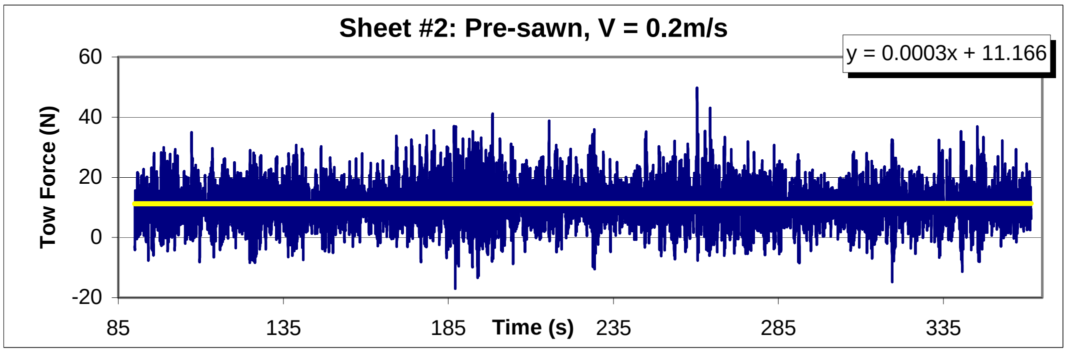
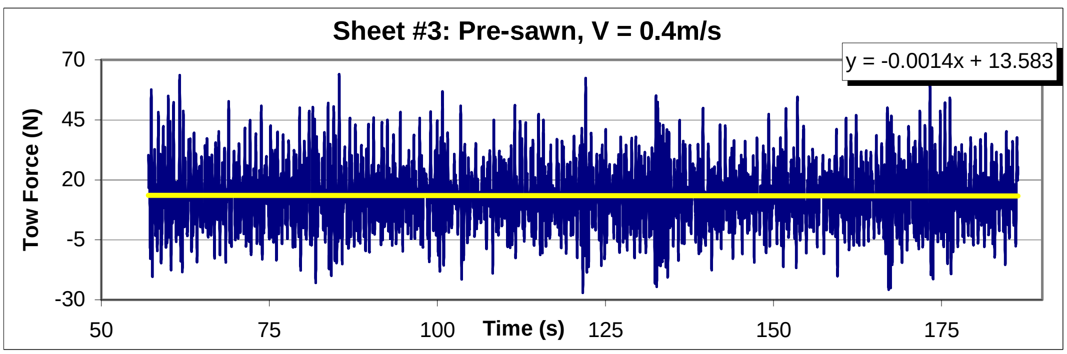


Figure 12a: Measured tow force versus time (Level ice sheet, Run #1).







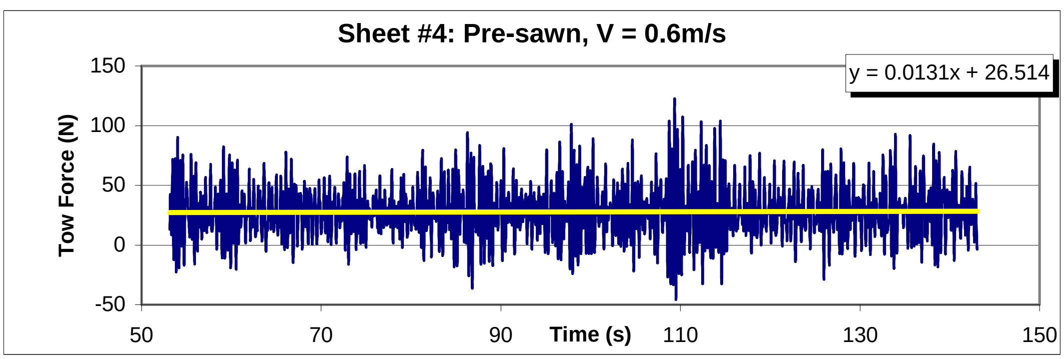
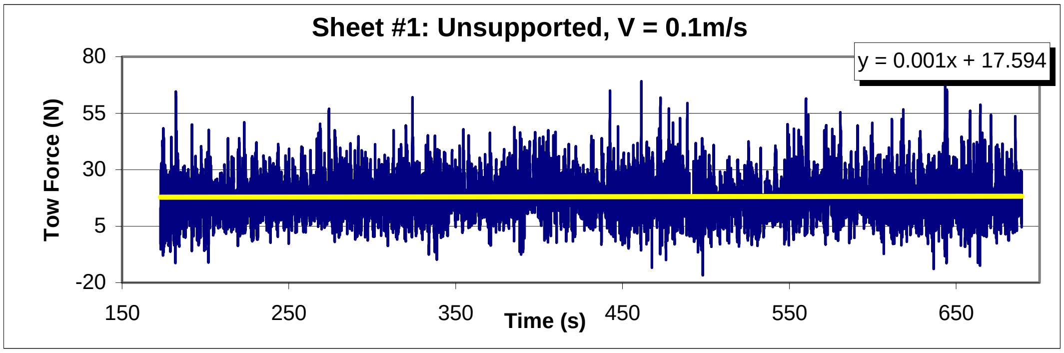
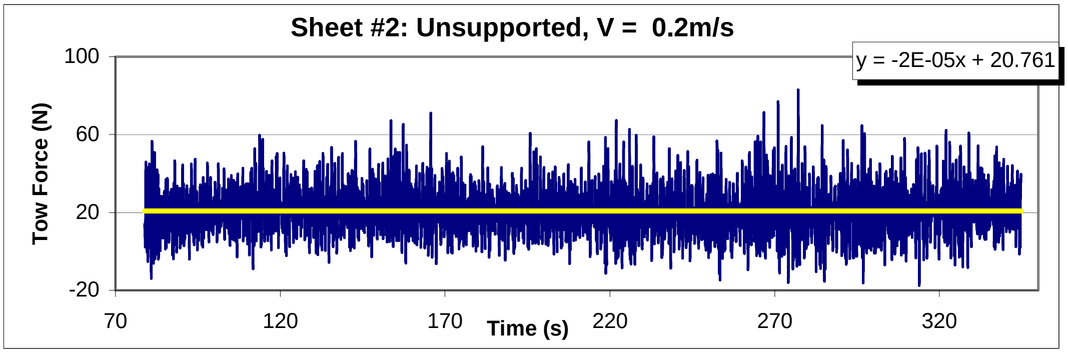
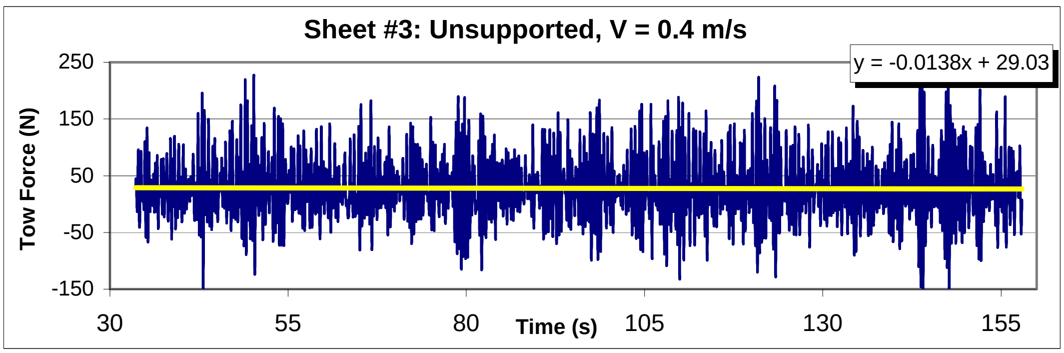


Figure 12b: Measured tow force versus time (Presawn ice sheet, Run #2).







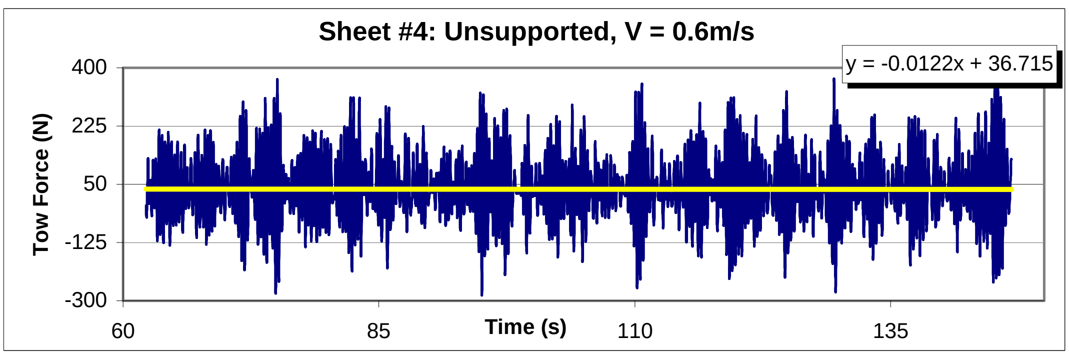


Figure 12c: Measured tow force versus time (Unsupported ice sheet, Run #3).

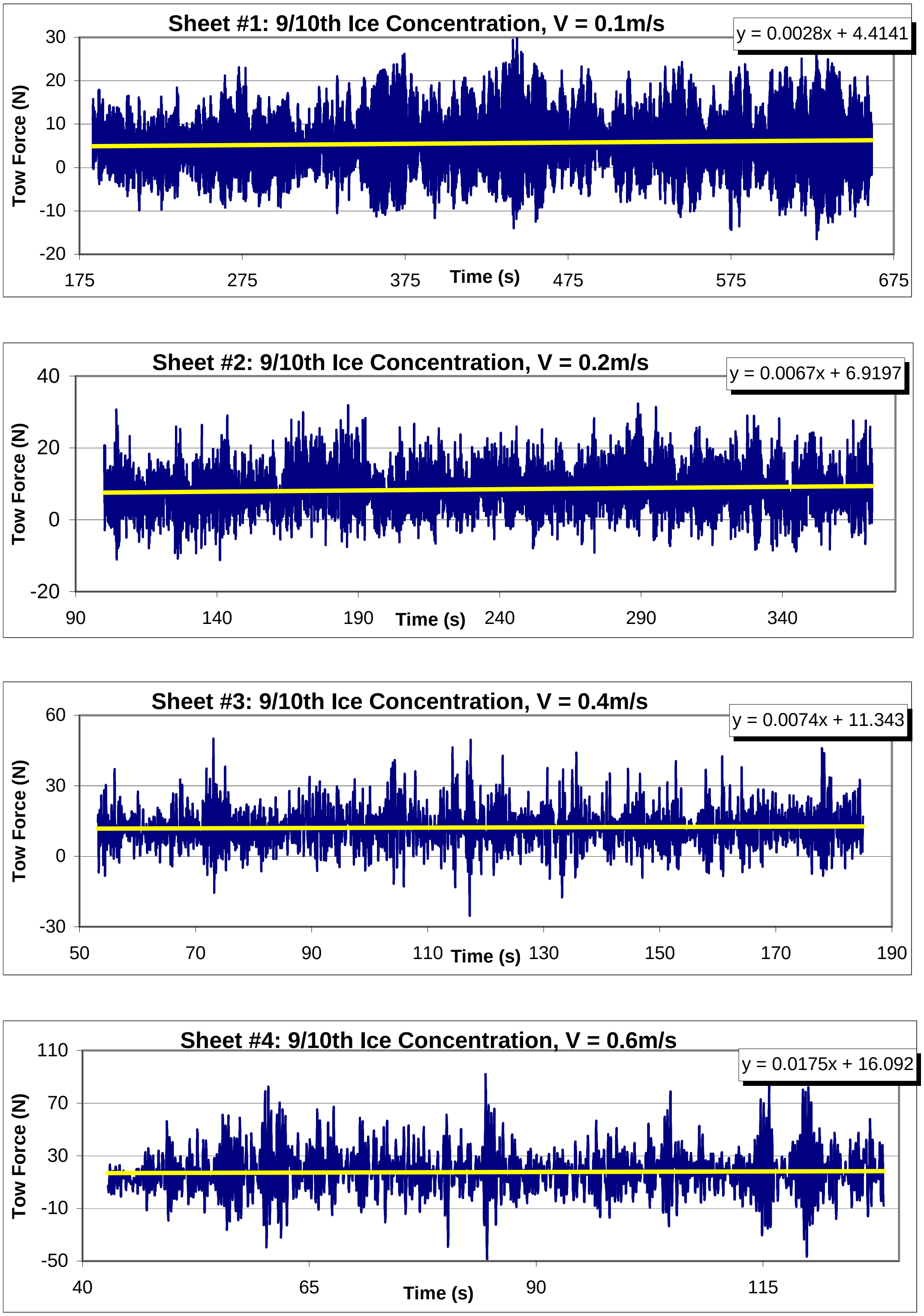


Figure 12d: Measured tow force versus time (9/10th Ice Concentration, Run #4).

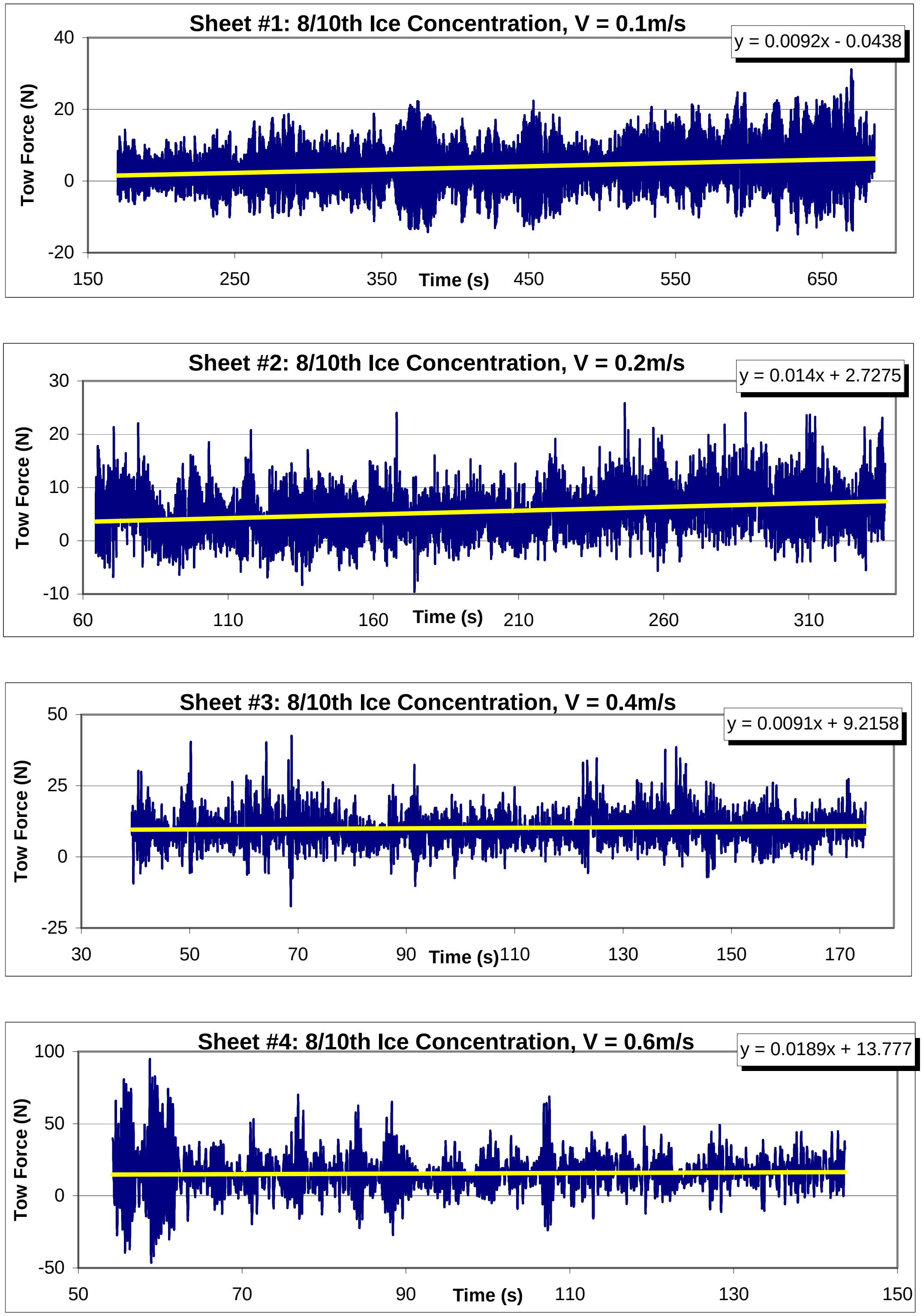


Figure 12e: Measured tow force versus time (8/10th Ice Concentration, Run #5).

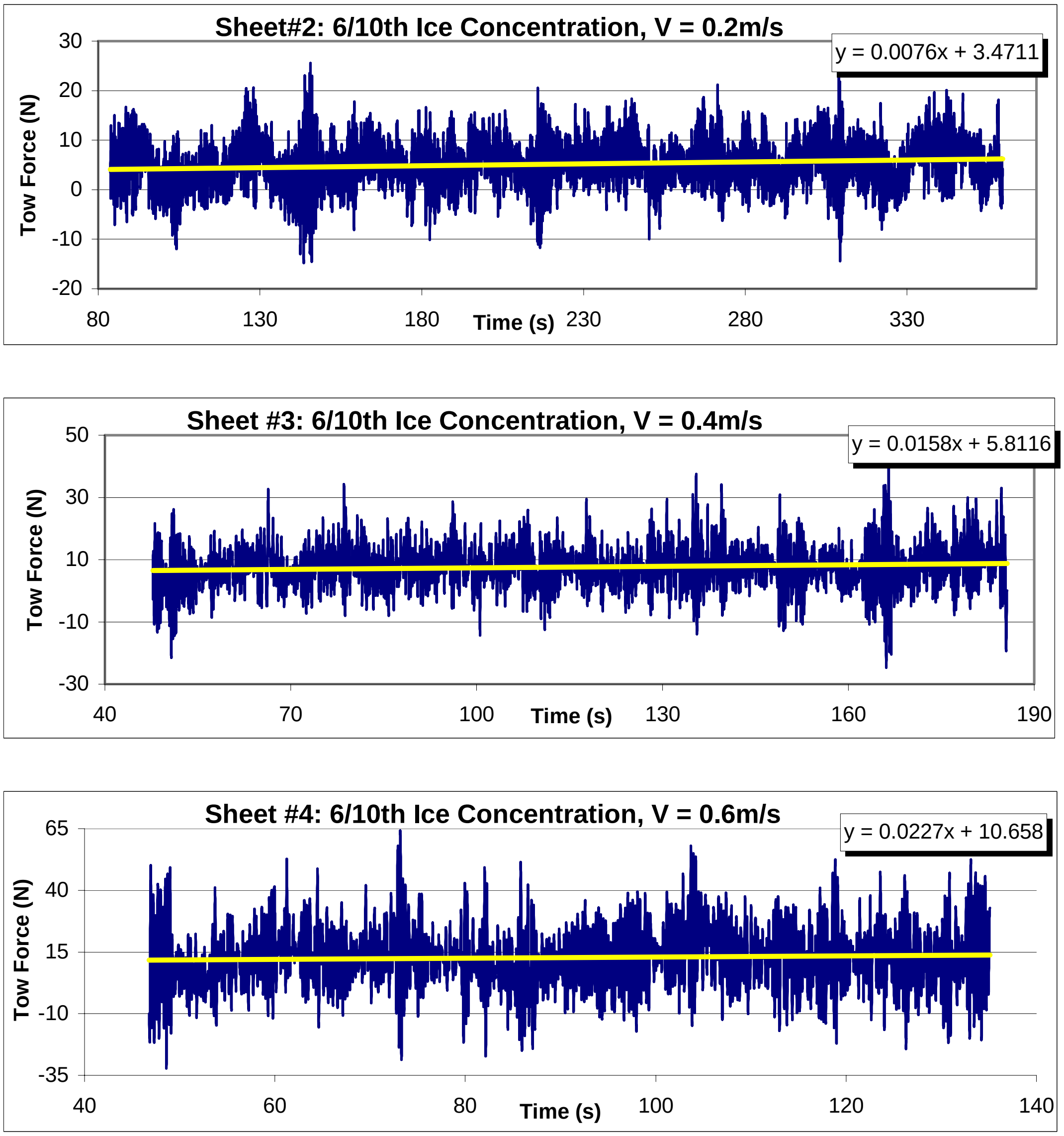


Figure 12f: Measured tow force versus time (6/10th Ice Concentration, Run #6).

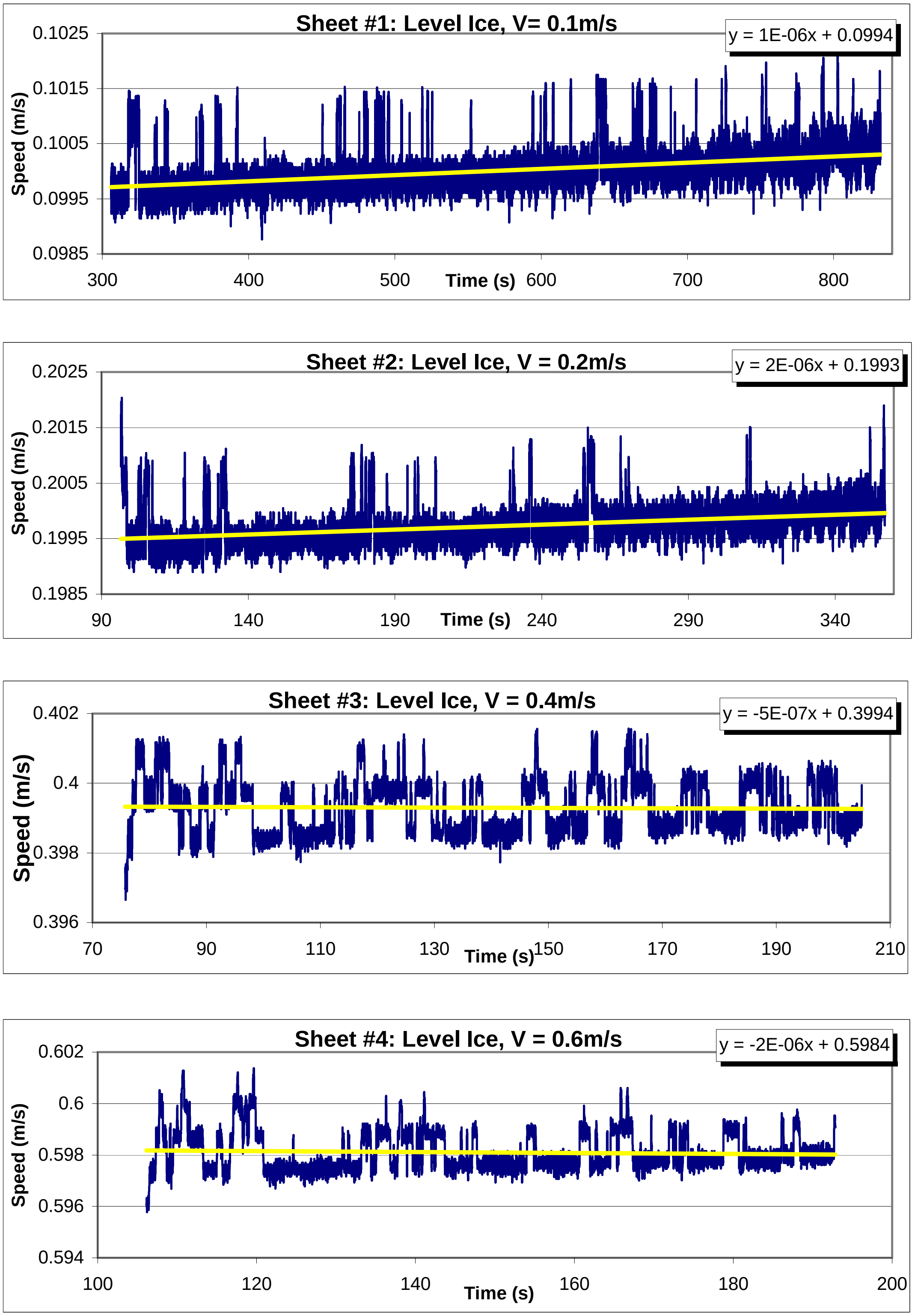


Figure 13a: Measured speed versus time (Level Ice, Run #1).

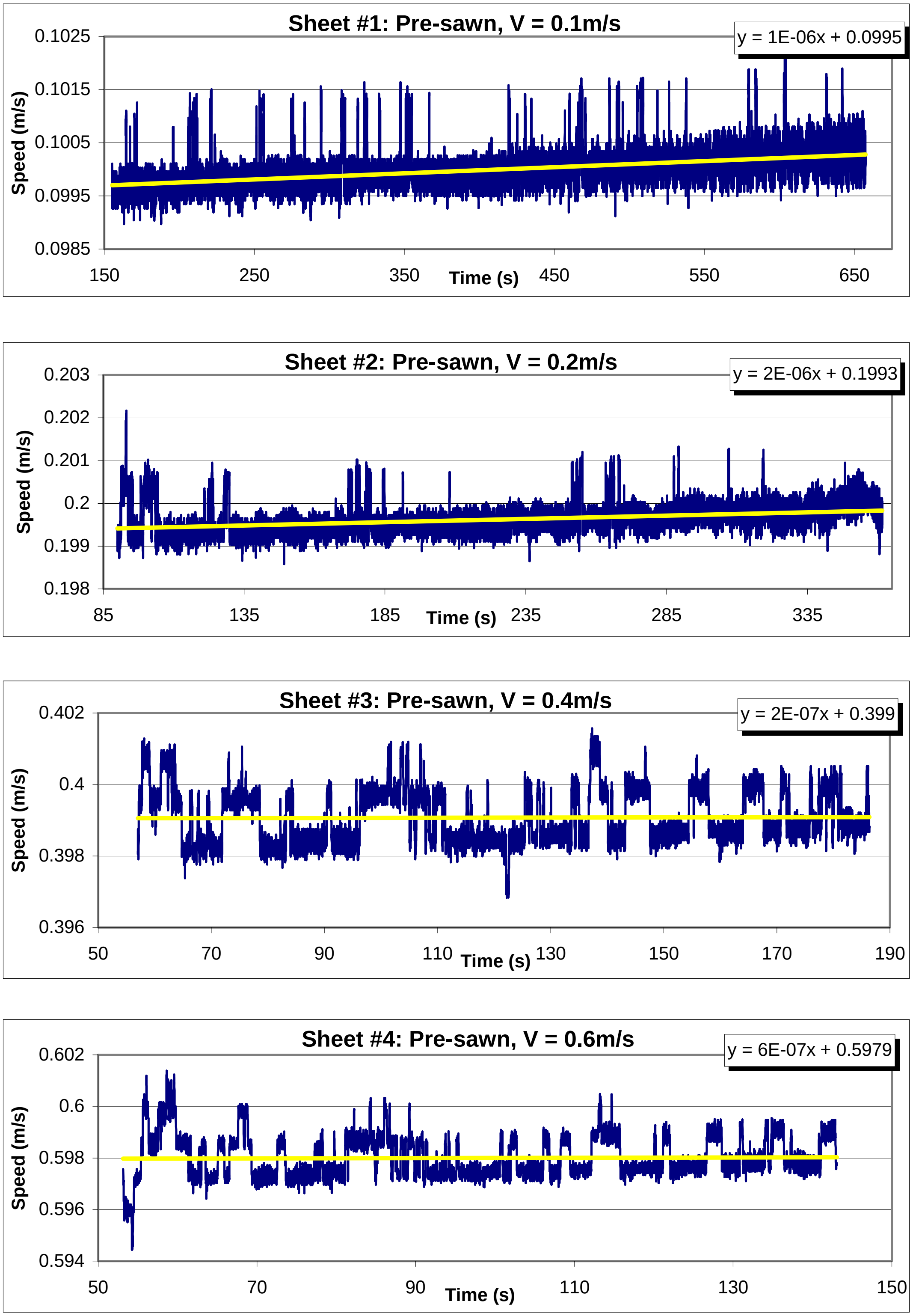


Figure 13b: Measured speed versus time (Presawn Ice, Run #2).

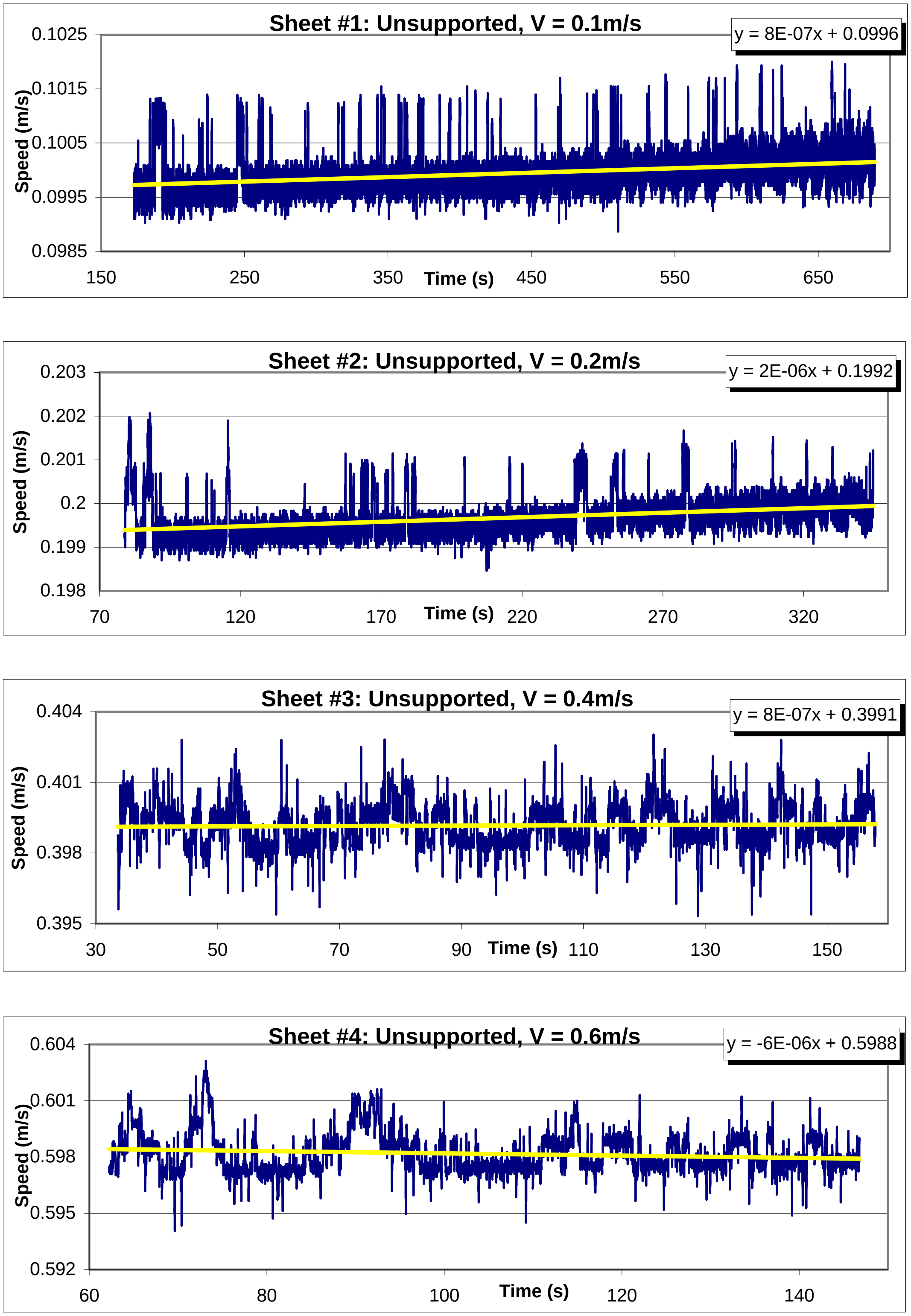


Figure 13c: Measured speed versus time (Unsupported Ice, Run #3).

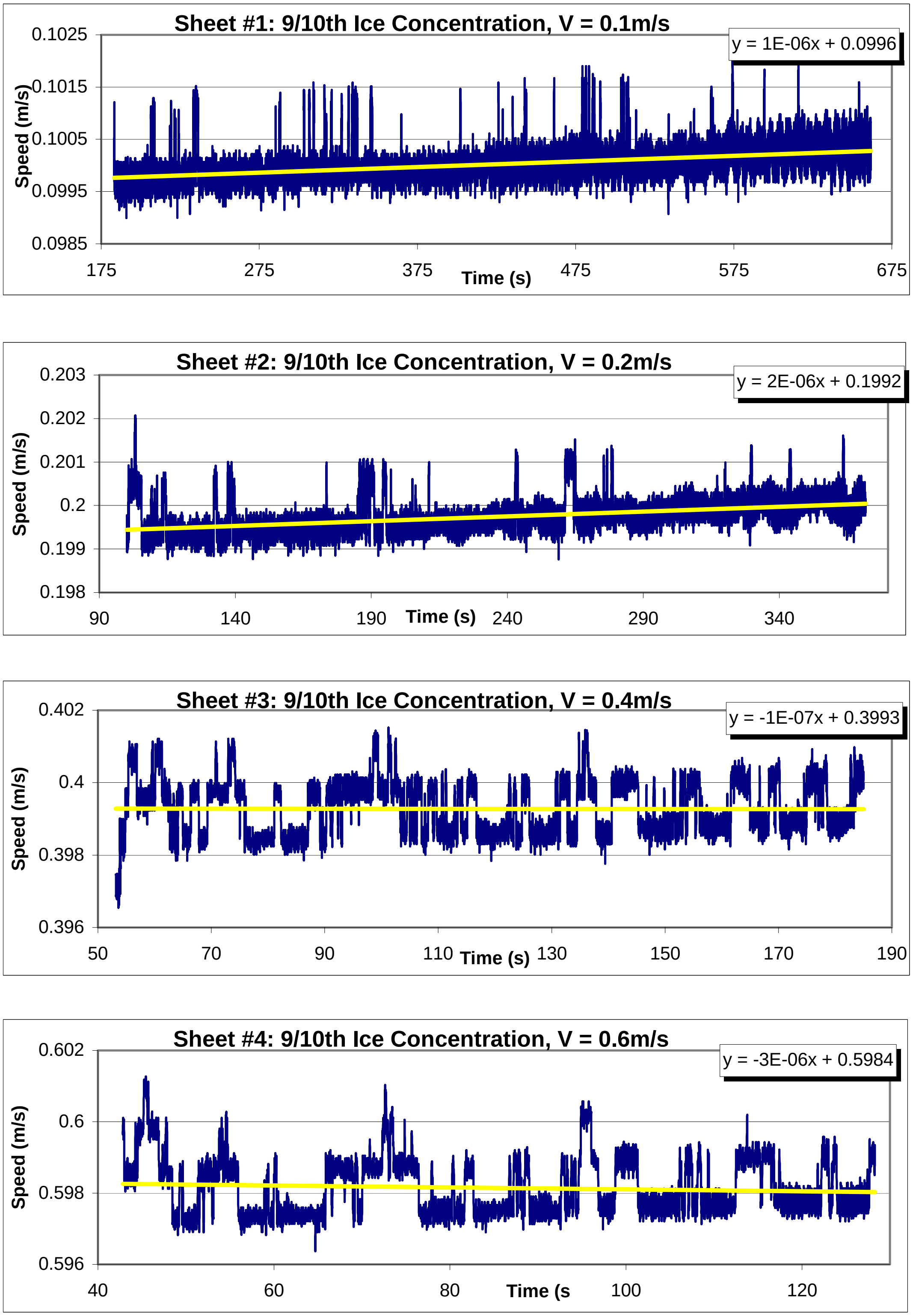


Figure 13d: Measured speed versus time (9/10th Ice Concentration, Run #4).

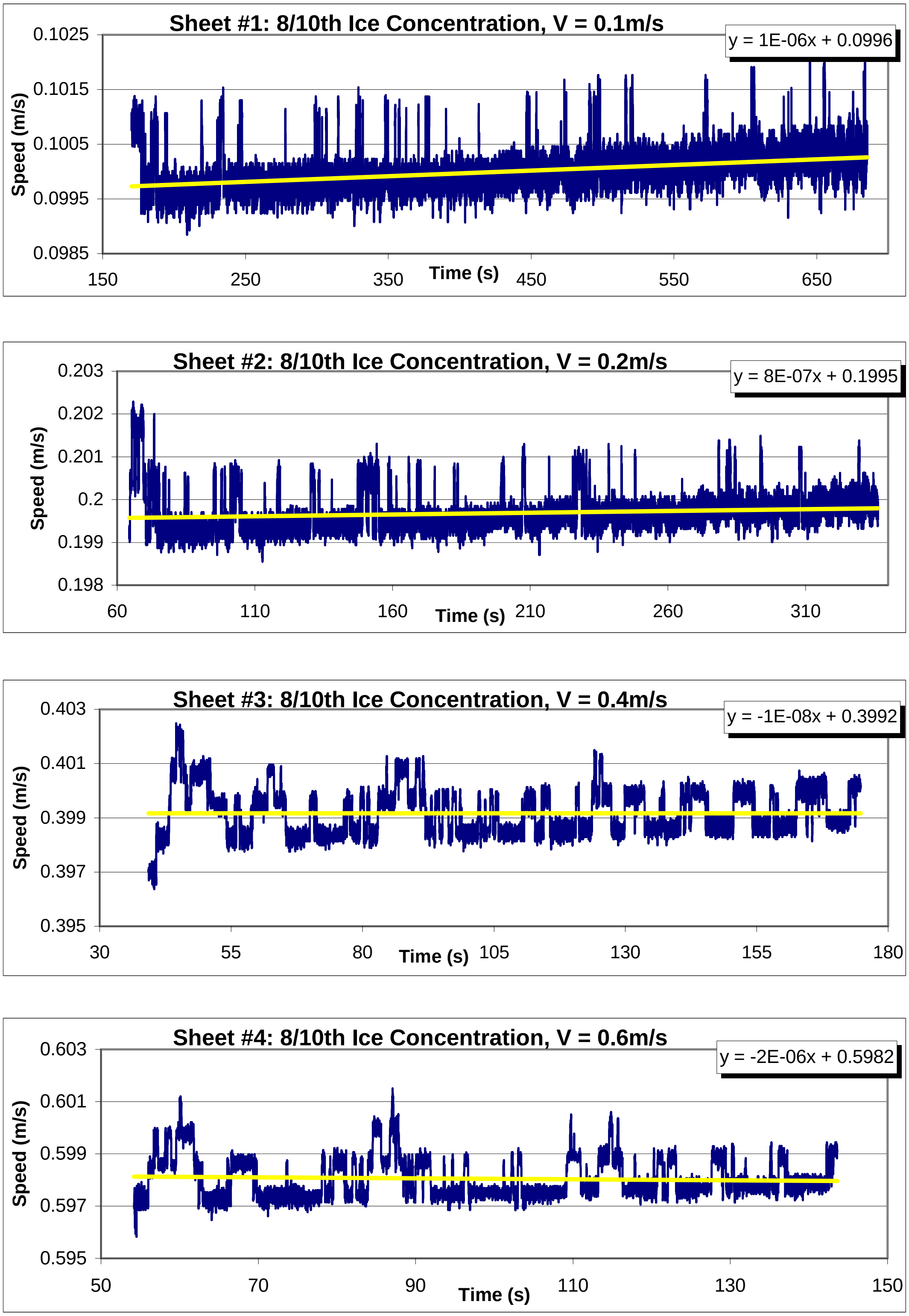


Figure 13e: Measured speed versus time (8/10th Ice Concentration, Run #5).

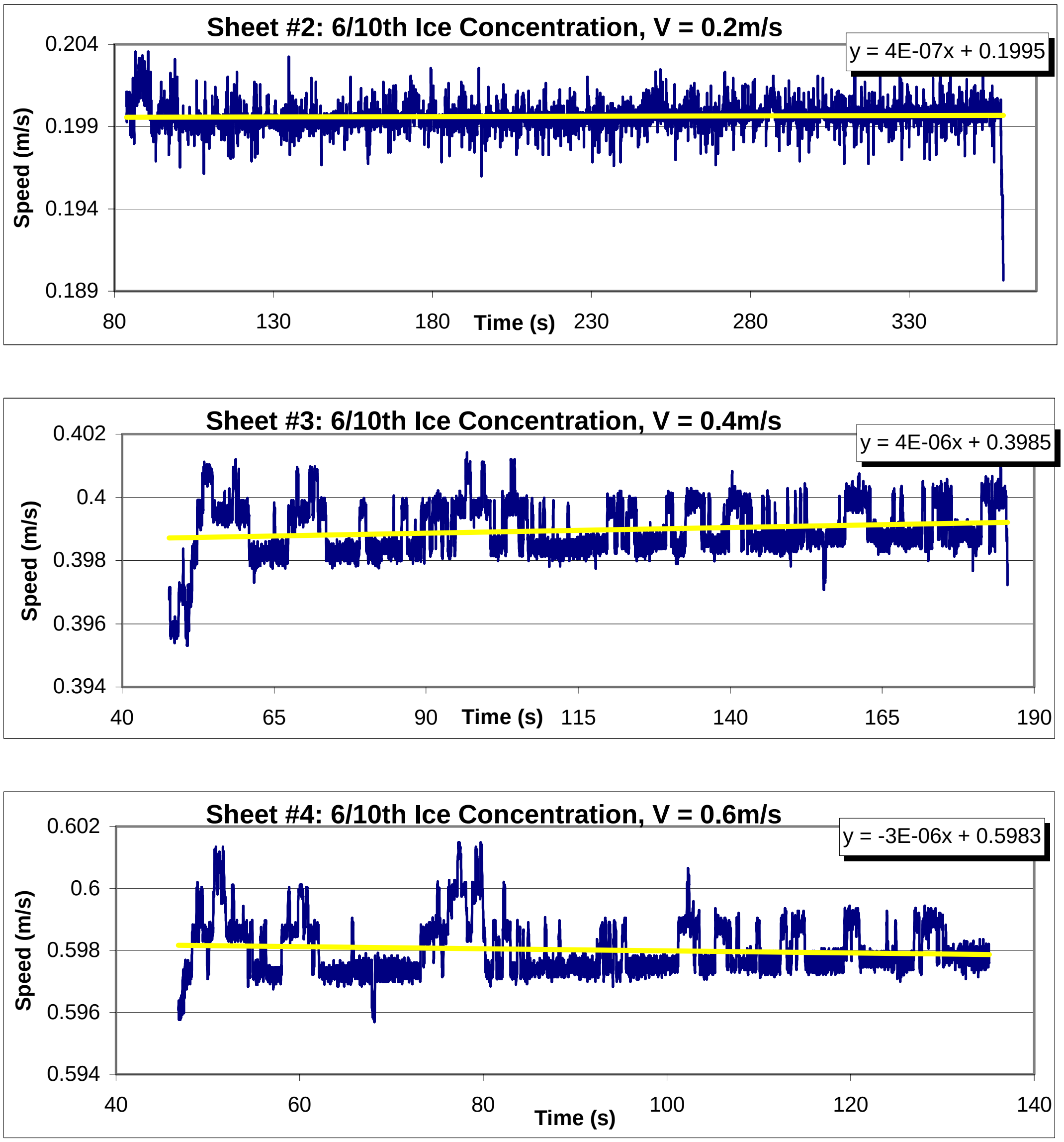


Figure 13f: Measured speed versus time (6/10th Ice Concentration, Run #6).

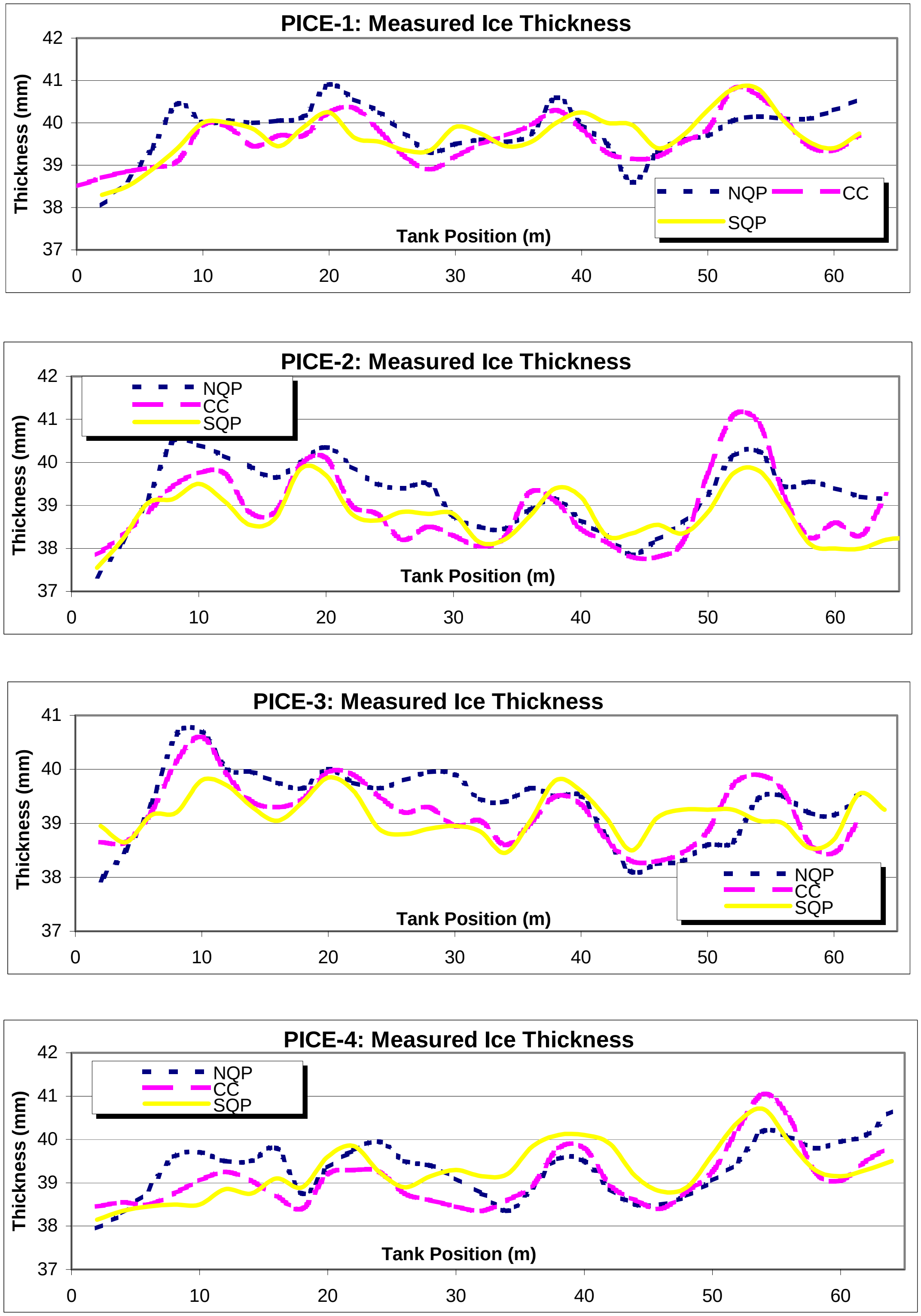


Figure 14a: Measured Thickness Profiles.

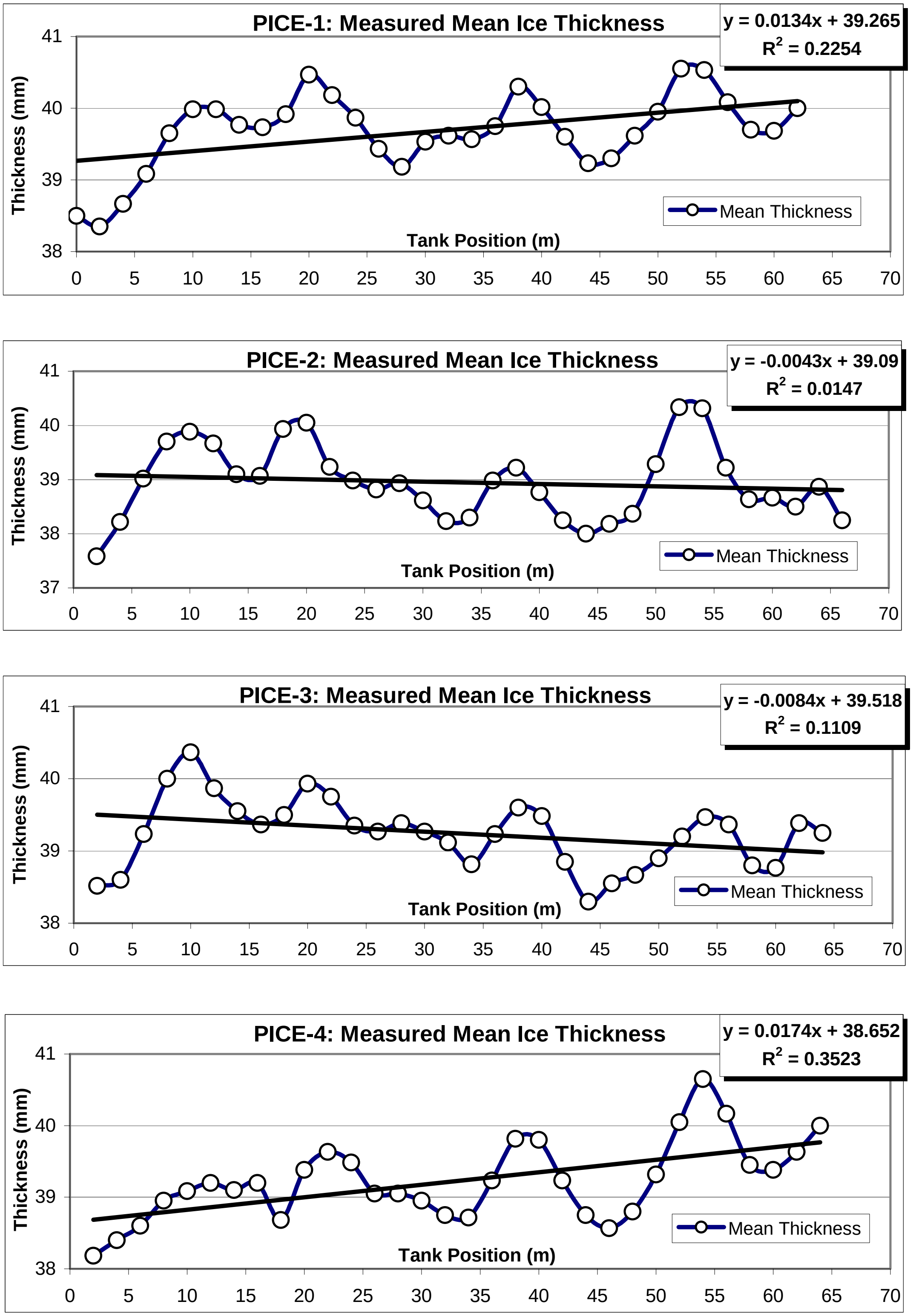


Figure 14b: Mean Thickness profiles and the linear trends.

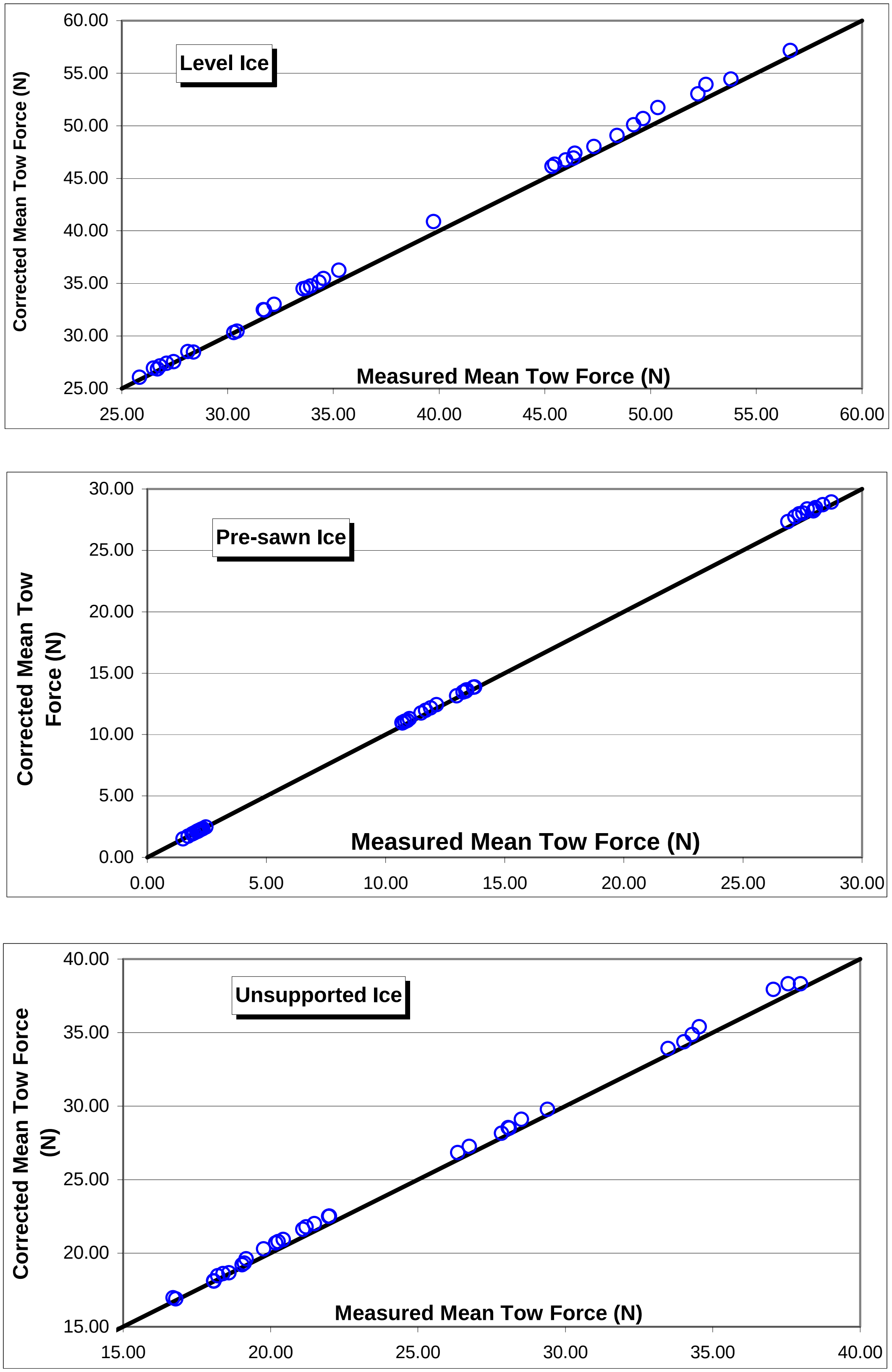


Figure 15: Corrected versus measured mean tow force (N).

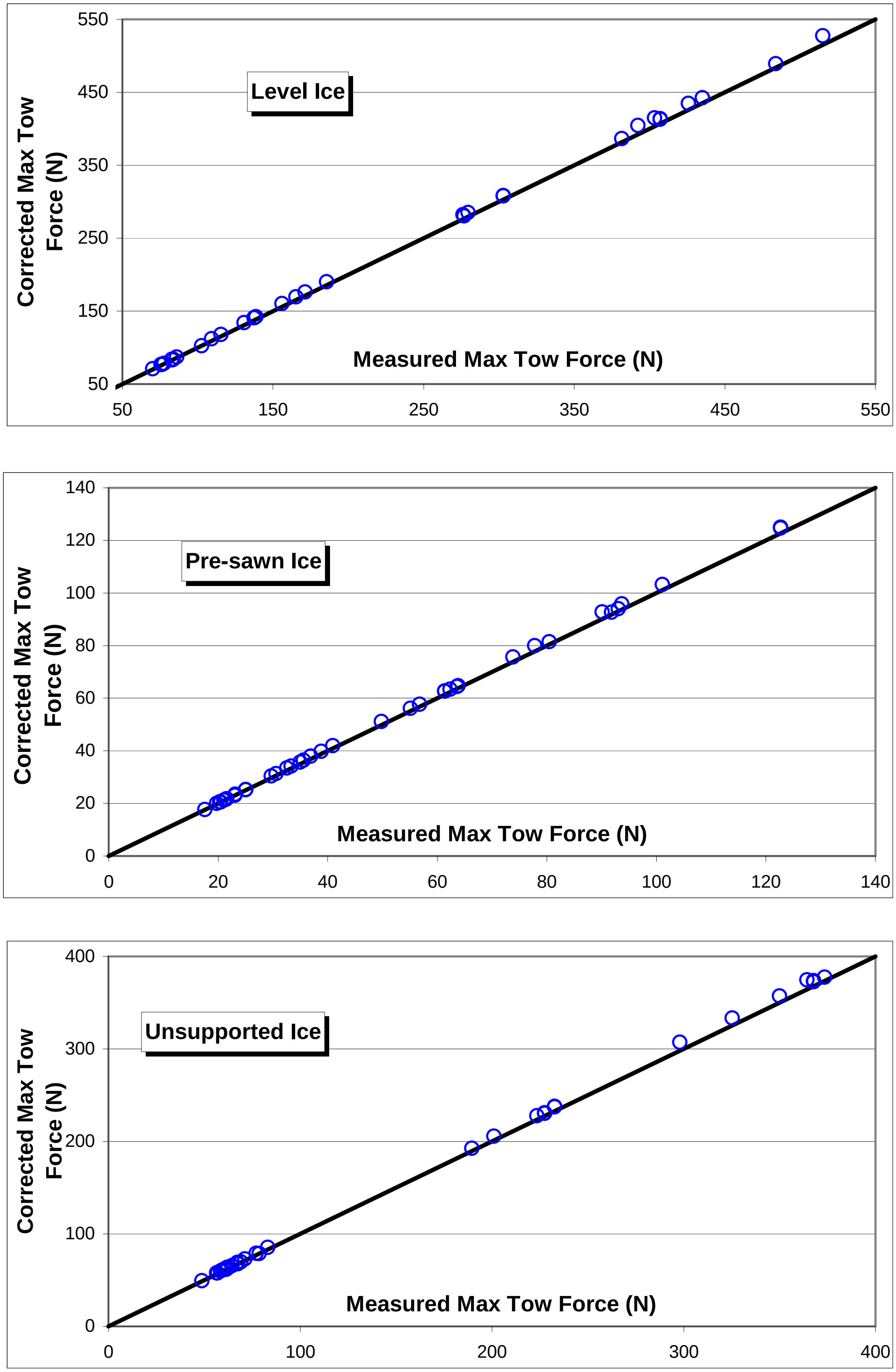


Figure 16: Corrected versus measured max Tow Force (N).

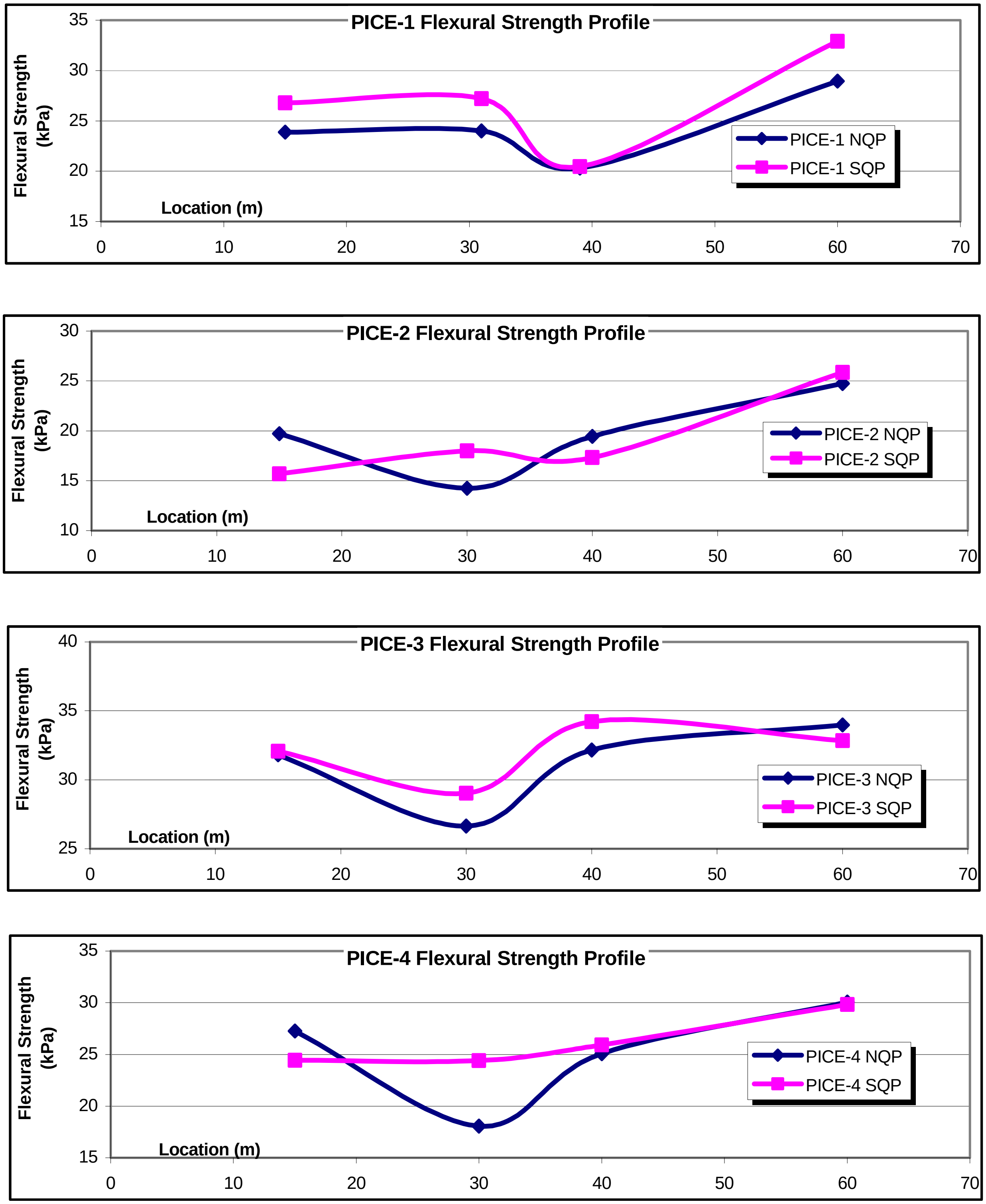


Figure 17a: Measured flexural strength profiles.

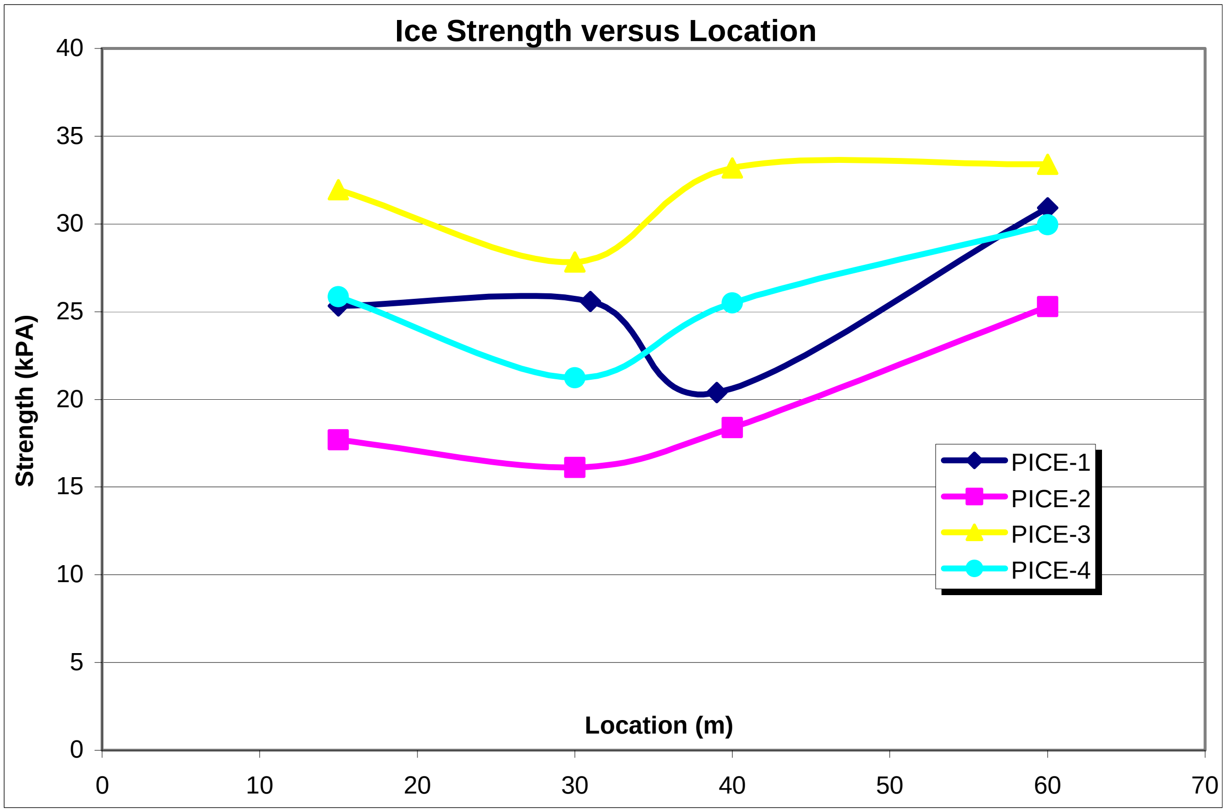


Figure 17b: Mean profiles for the measured flexural strength profiles.

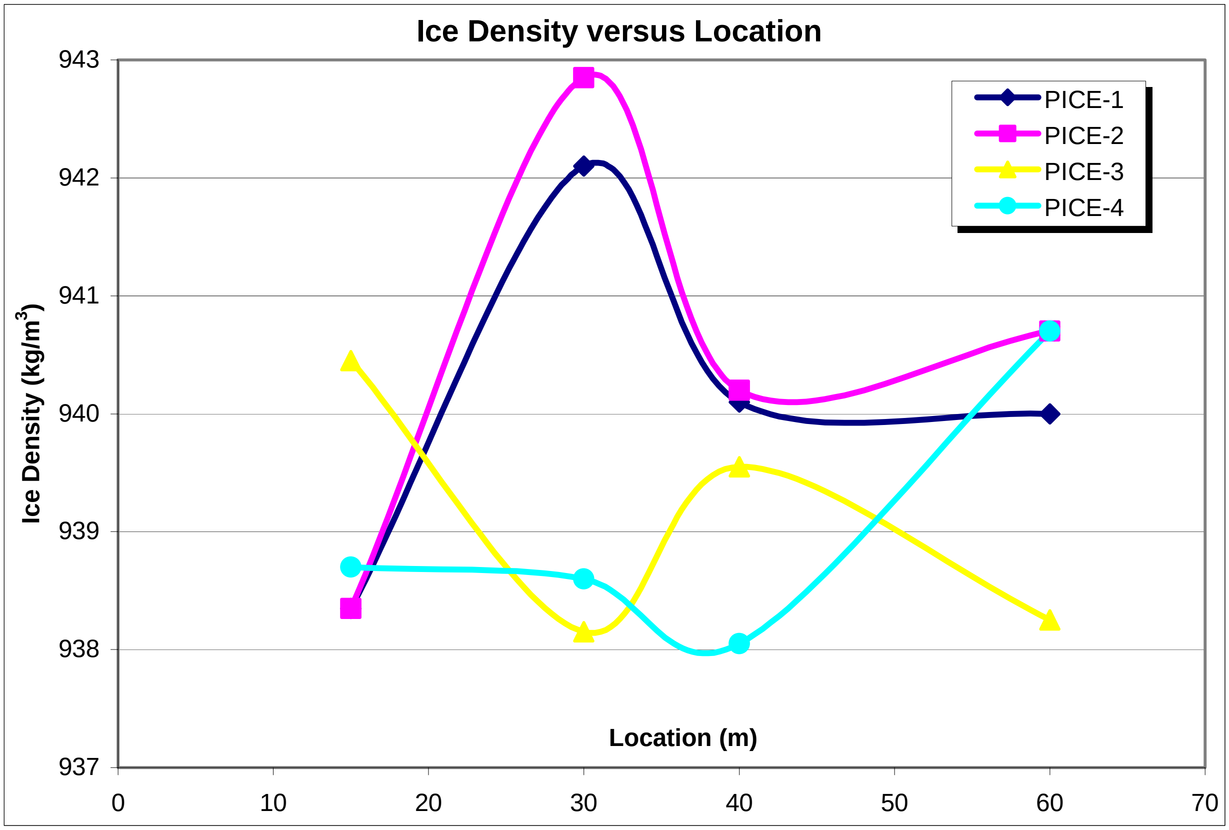


Figure 18: Measured ice density profiles.

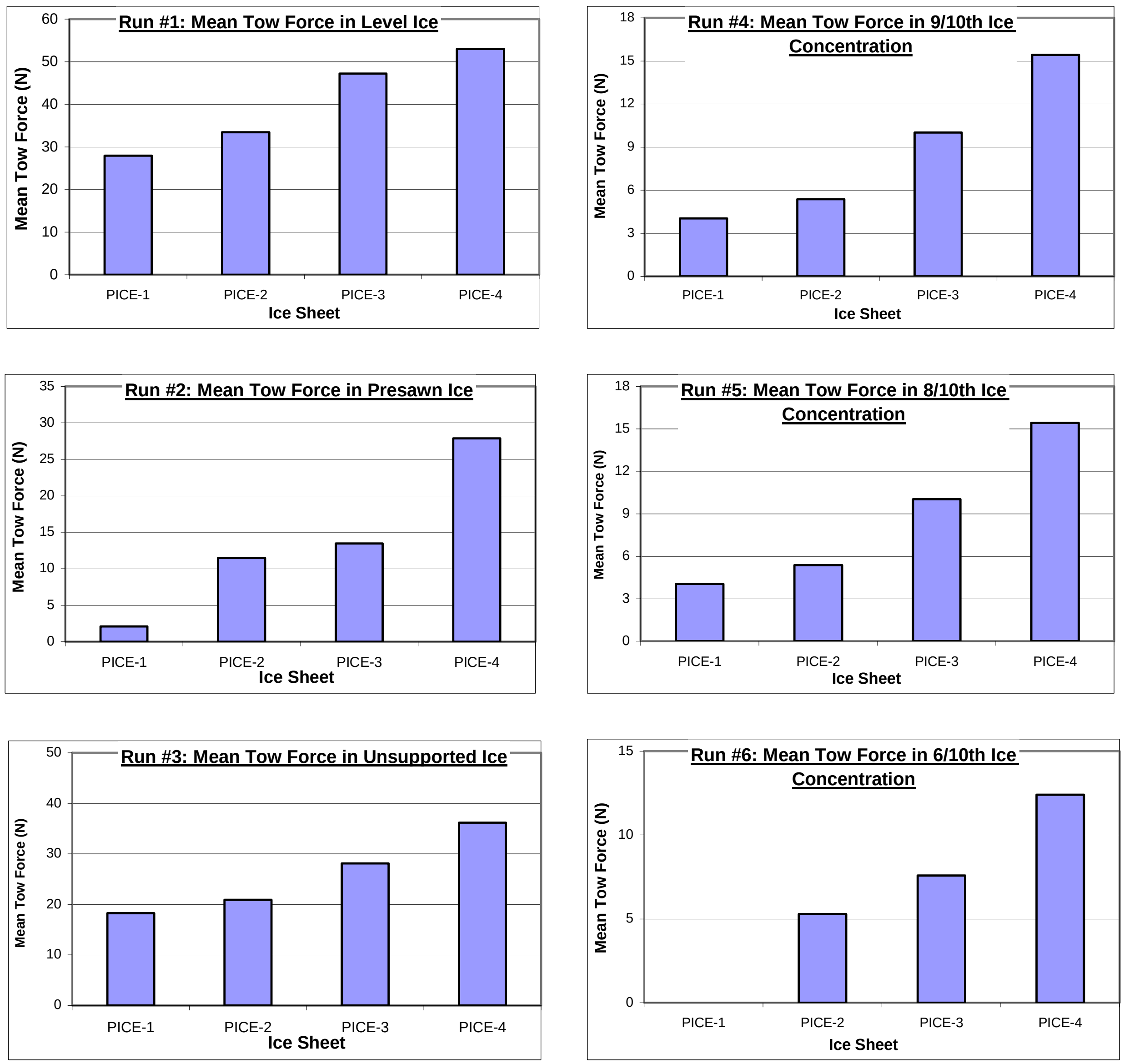


Figure 19a: Mean of Means for tow force versus ice sheet number.

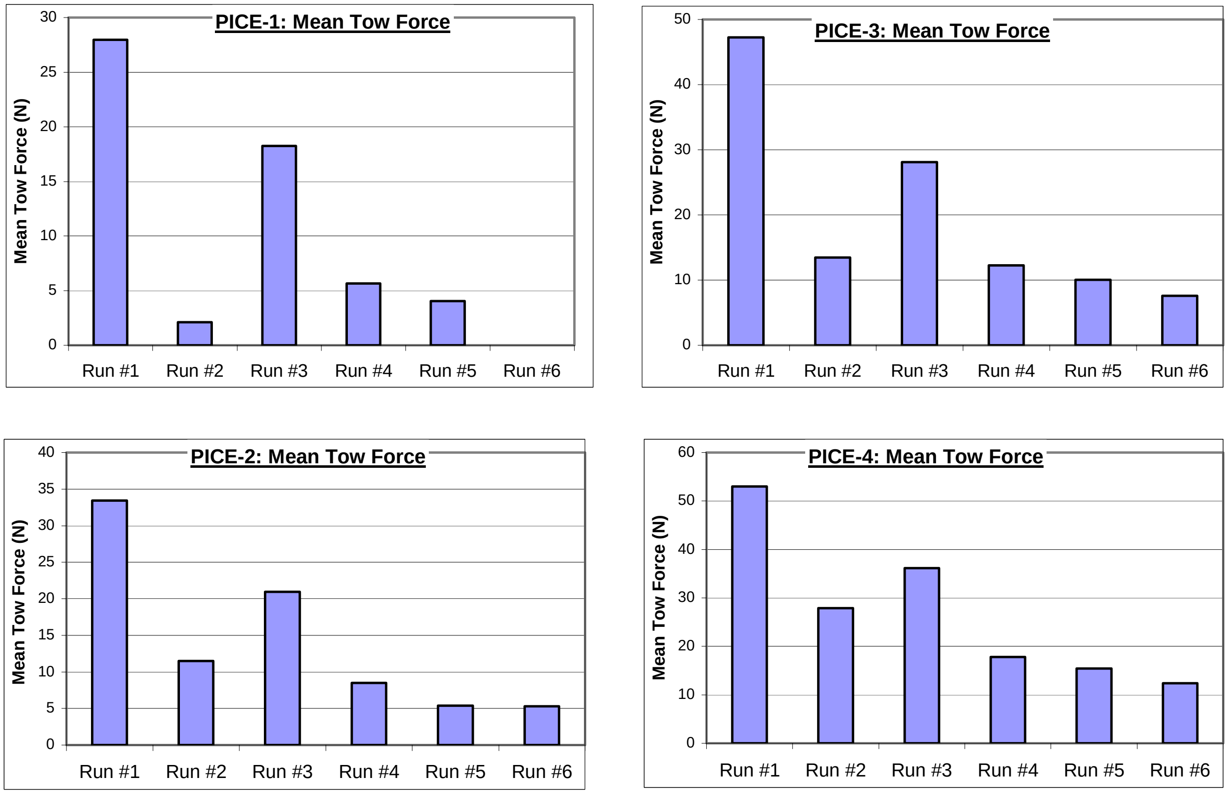


Figure 19b: Mean of means of tow force versus run number.

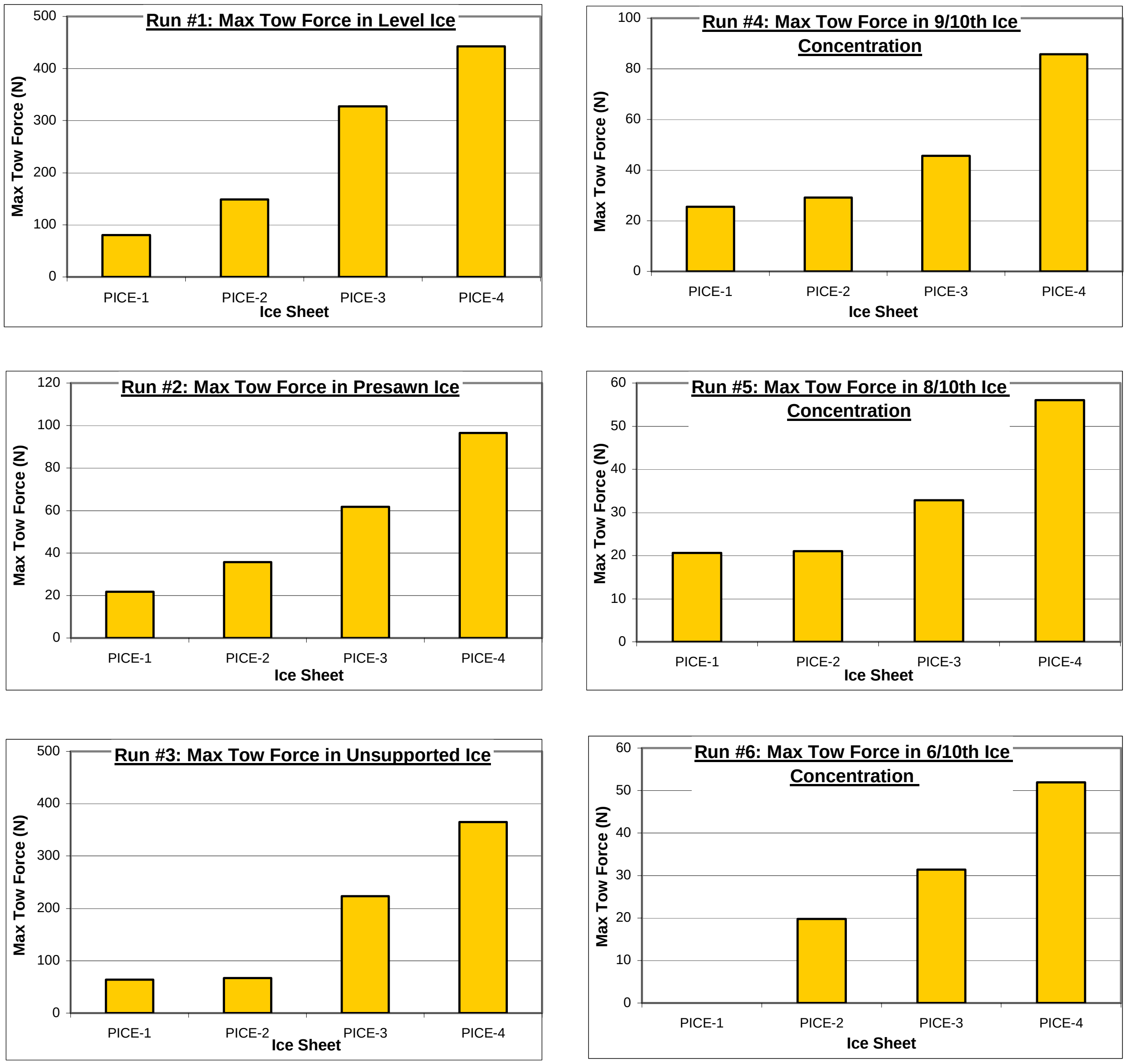


Figure20a: Mean of Maximums of tow force versus ice sheet number.

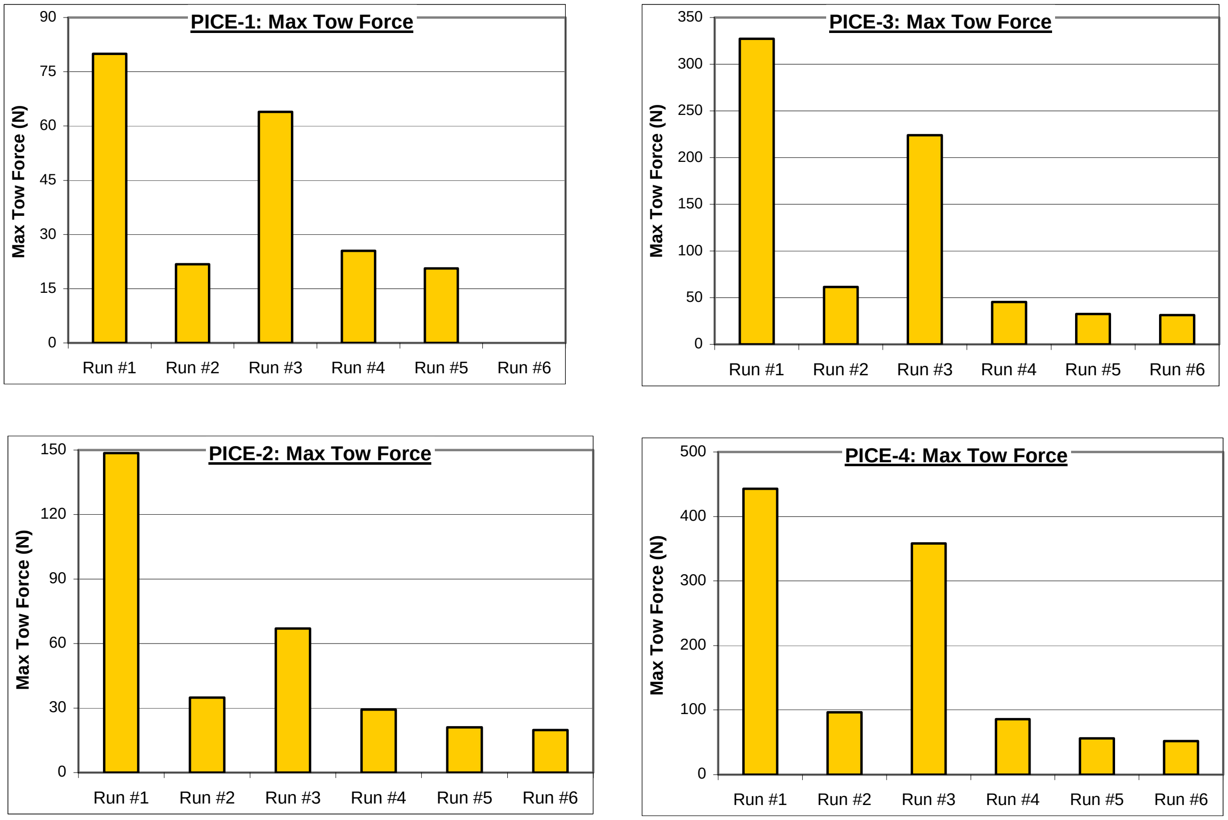


Figure 20b: Mean of Maximums of tow force versus run number.

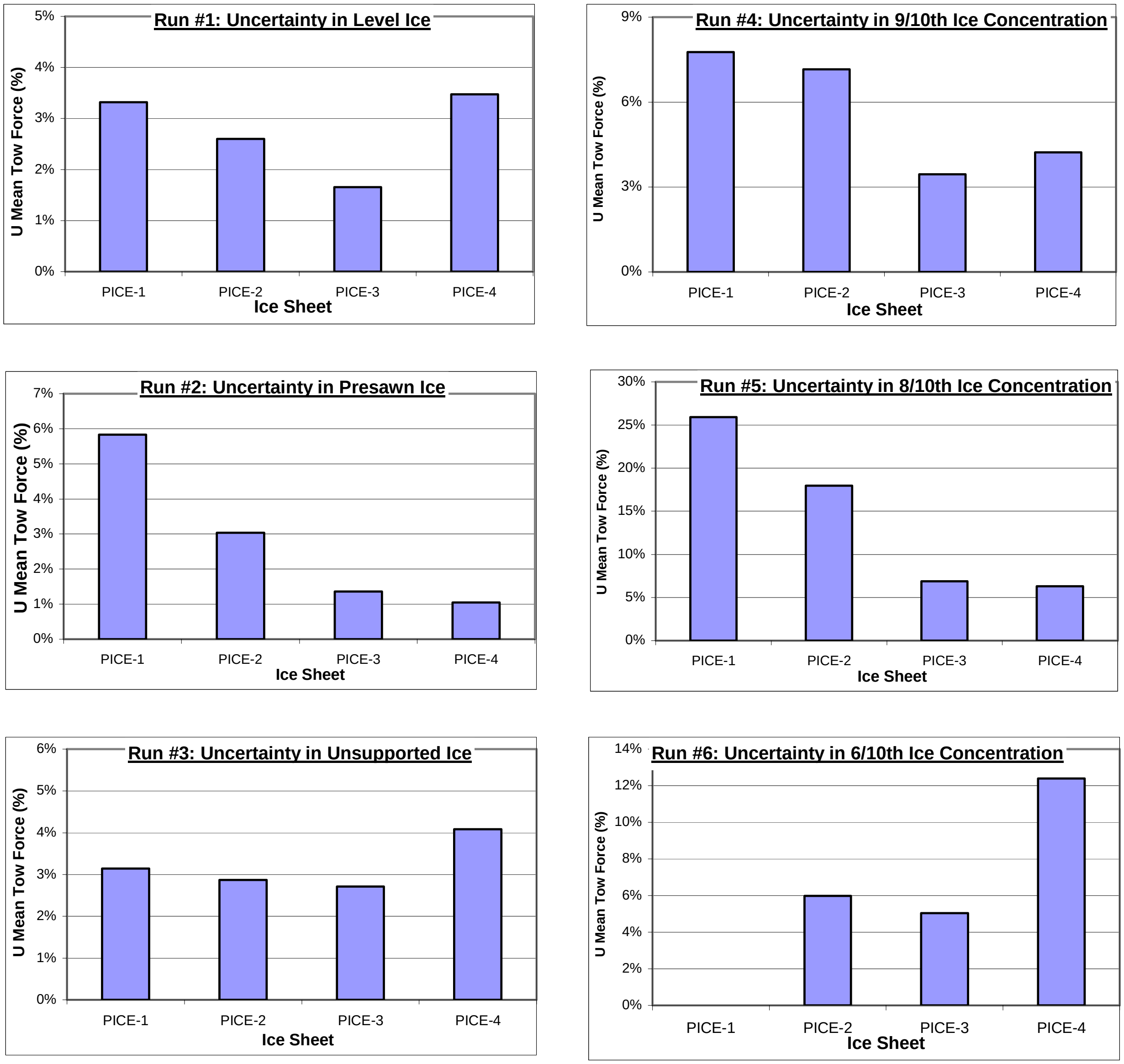


Figure 21a: Uncertainty in the mean of means for tow force versus ice sheet number before data reduction equation.

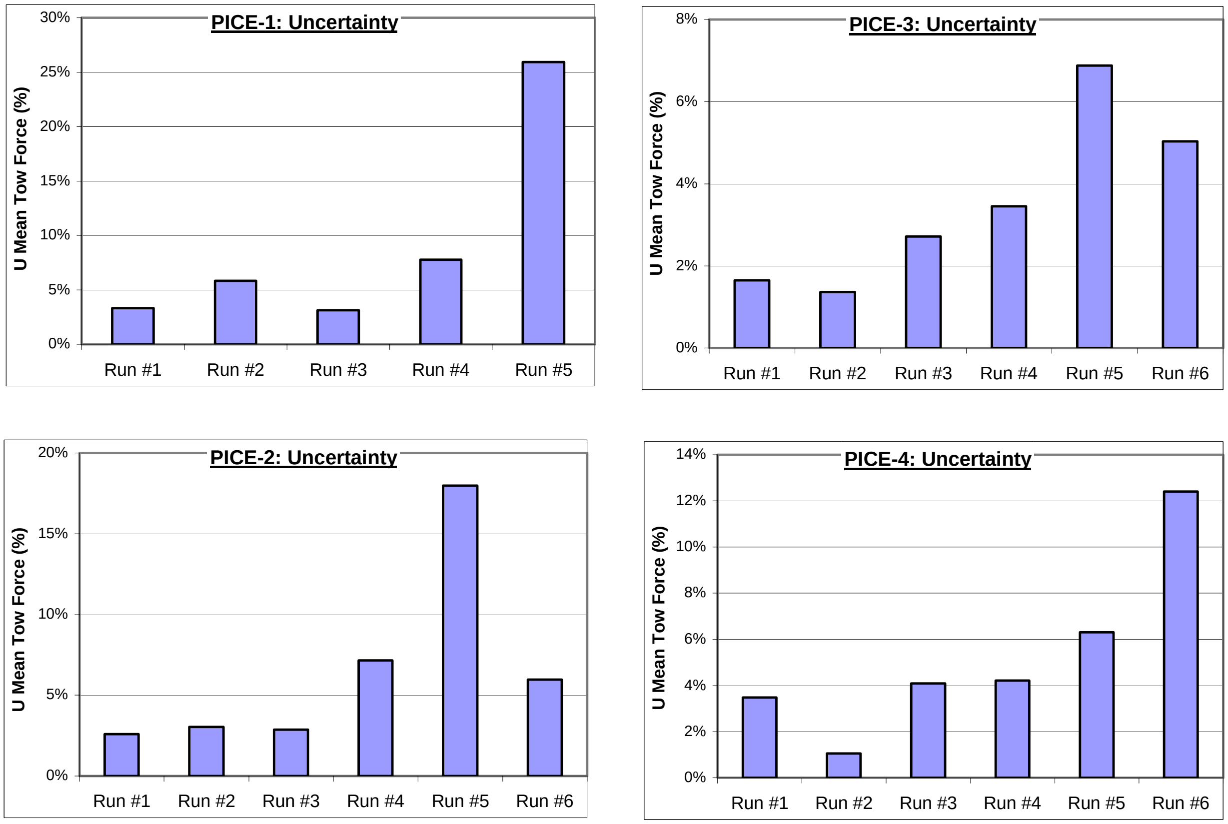


Figure 21b: Uncertainty in the mean of means for tow force versus test run number before data reduction equation.

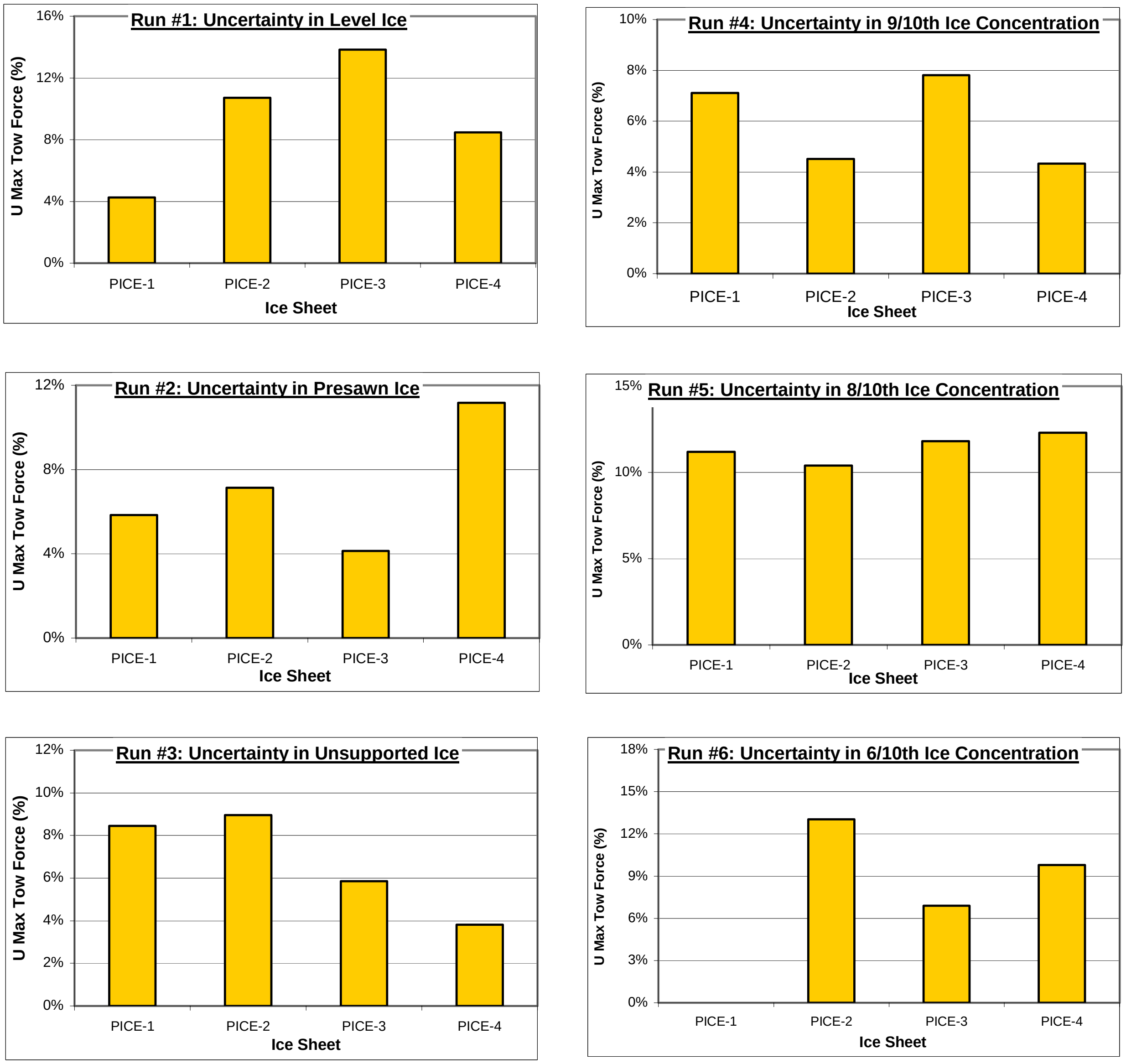


Figure 22a: Uncertainty in the mean of maximums for tow force versus ice sheet number before data reduction equation.

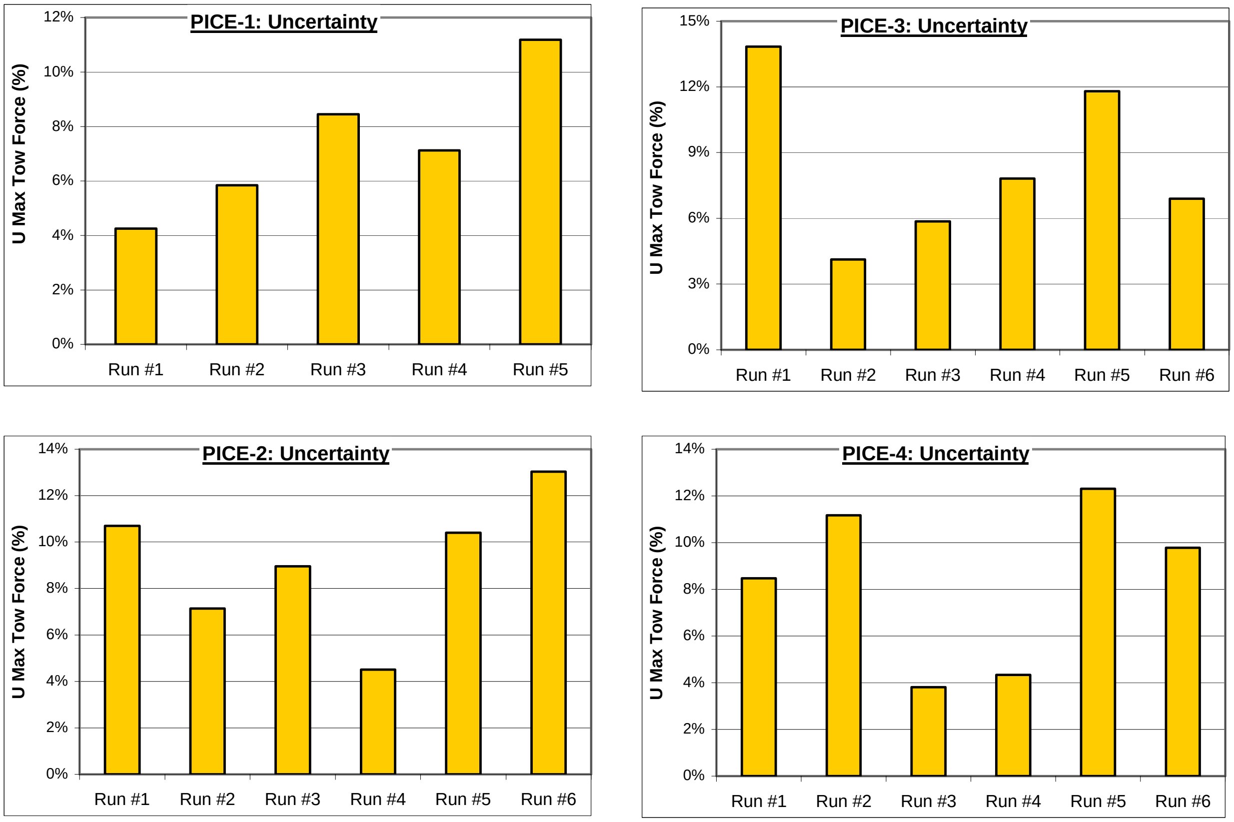


Figure 22b: Uncertainty in the mean of maximums for tow force versus test run number before data reduction equation.

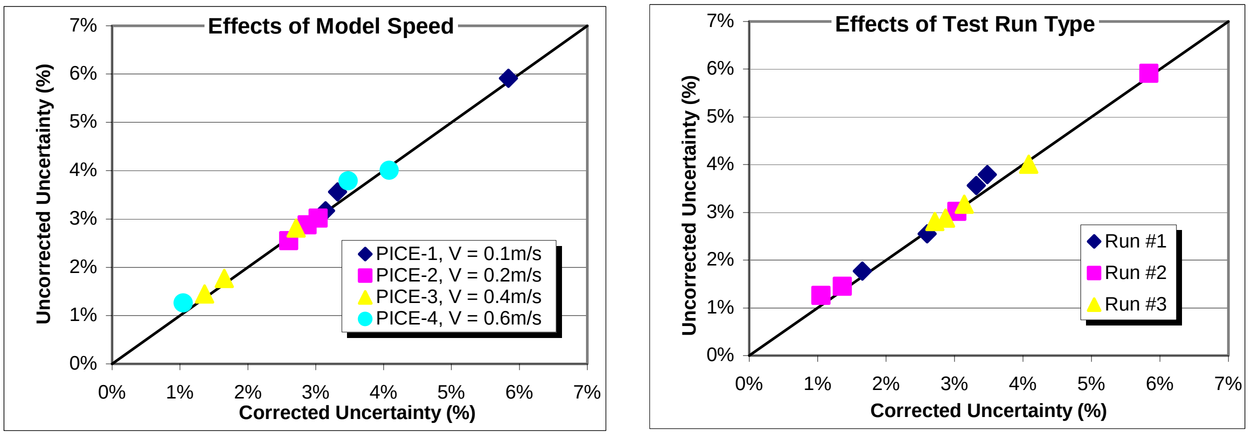


Figure 23a: Effect of correction on uncertainty in mean ice resistance for ice thickness variations.

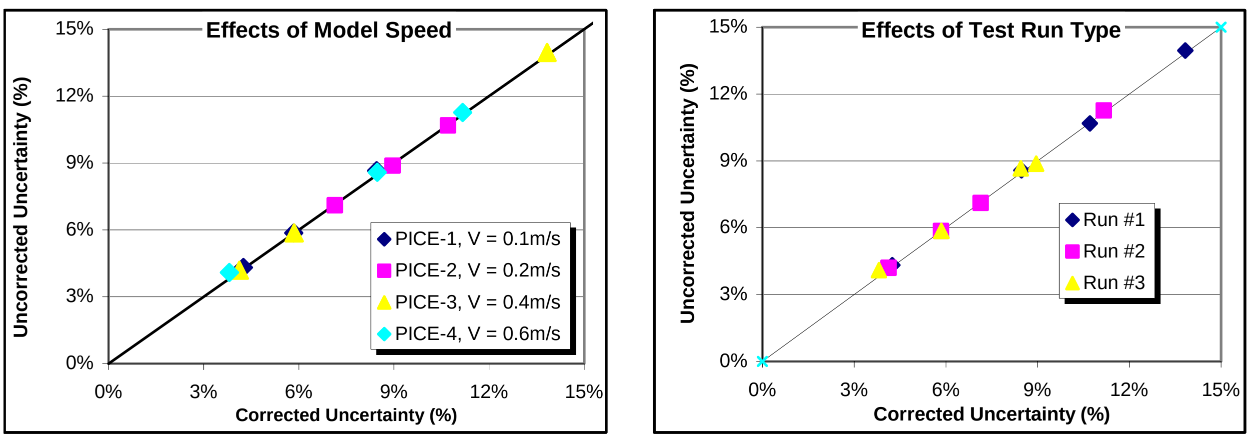


Figure 23b: Effect on correction of uncertainty in maximum ice resistance for ice thickness variations.

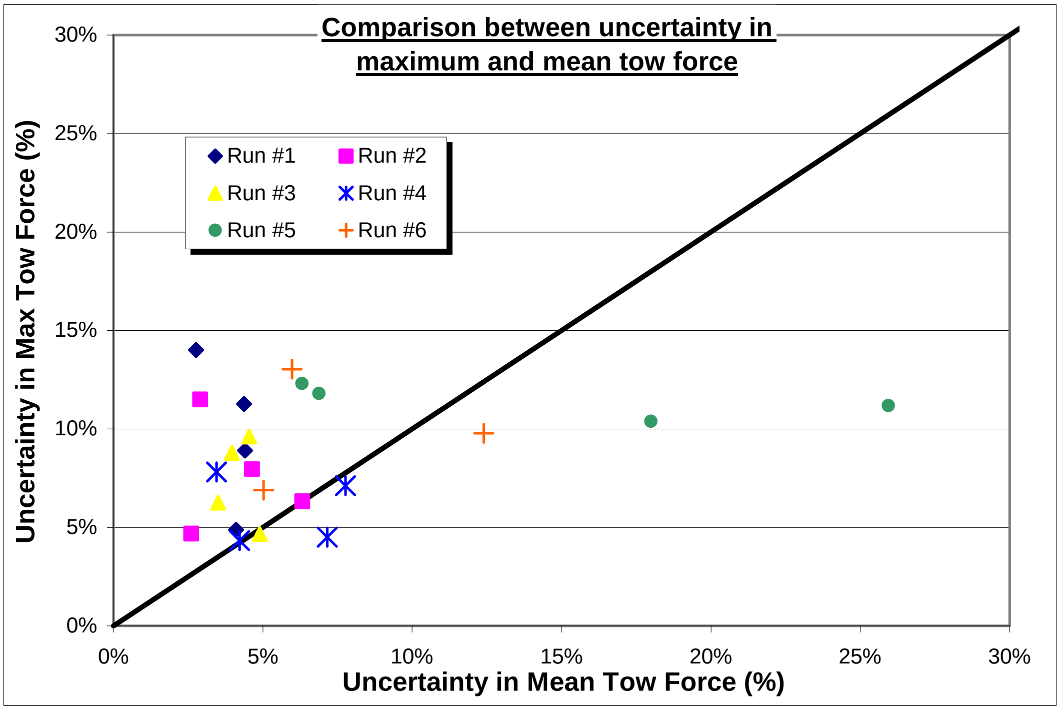


Figure 24a: Uncertainties in maximum tow forces versus uncertainties in mean tow force after data reduction equation, effect of test run type.

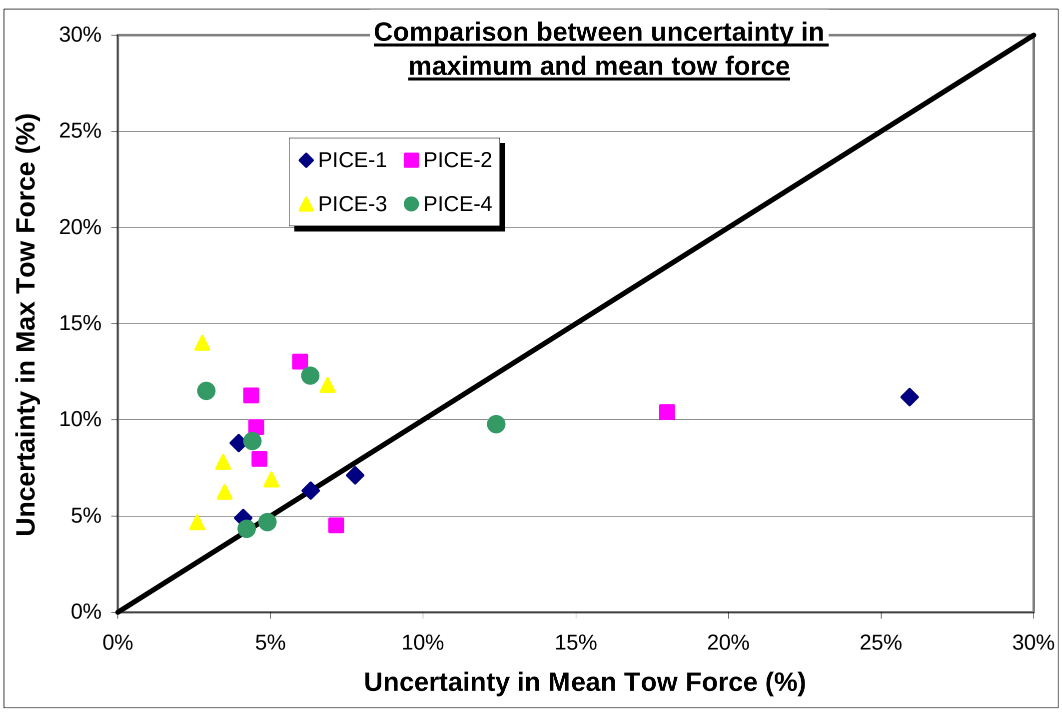


Figure 24b: Uncertainties in maximum tow forces versus uncertainties in mean tow force after data reduction equation, effect of speed.

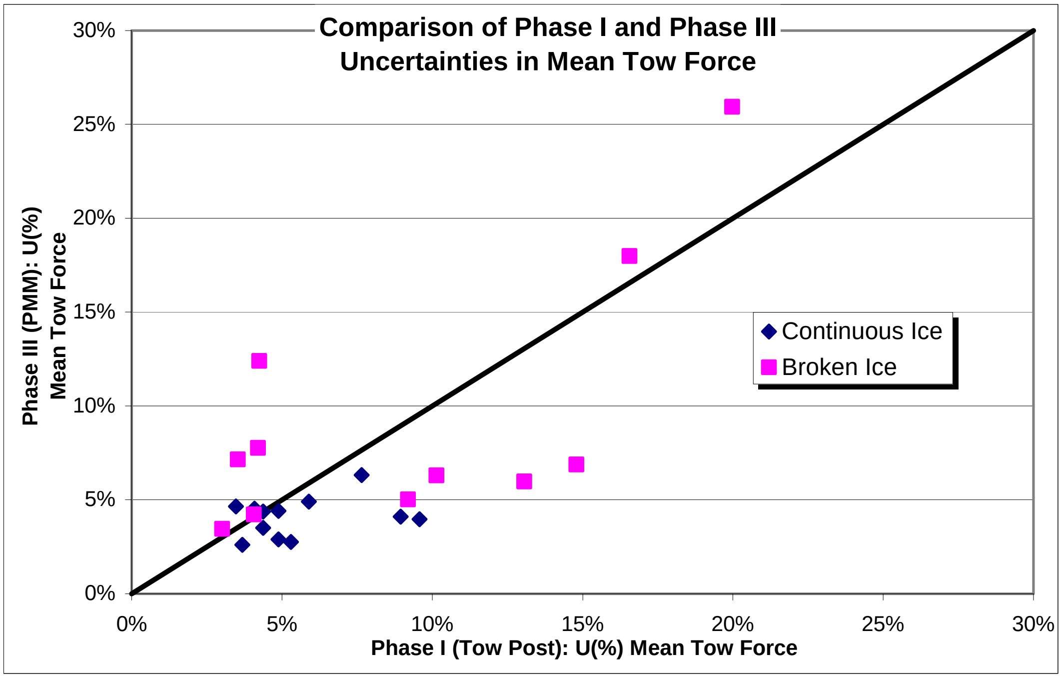


Figure 25a: Comparison of Phase I and Phase III uncertainty in mean tow force after data reduction equation.

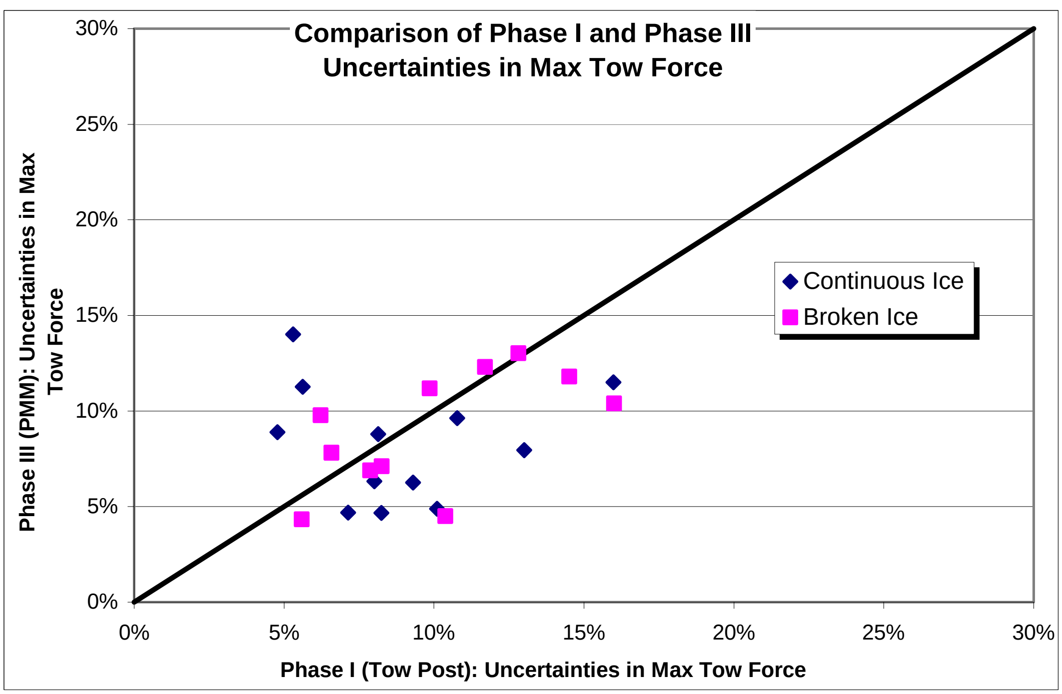


Figure 25b: Comparison of Phase I and Phase III uncertainty in maximum tow force after data reduction equation.

Appendix 1:

Hydrostatics and Particulars of the Terry Fox Model

Model # IMD 417

APPENDIX 1:

Model Scale Particulars (Note 1)

IMD model # 417, scale 1/ 21.8, without appendages	
Length between perpendiculars (LPP)	3.440 m
Length on waterline (LWL)	3.739 m
Waterline beam at mid-ship	0.789 m
Waterline beam at maximum section	0.789 m
Maximum waterline beam	0.789 m
Draught at mid-ship	0.368 m
Draught at maximum section	0.368 m
Maximum draught	0.368 m
Draught above datum	0.368 m
Maximum section forward of mid-ship	-0.344 m
Parallel middle body: From aft of mid-ship To forward of mid-ship	0.344 m 0.344 m
Area of mid-ship station	0.264 m^2
Area of maximum station	0.264 m^2
Center of buoyancy forward of mid-ship (LCB)	-0.070 m
Center of aft body buoyancy forward of mid-ship	-0.676 m
Center of fore body buoyancy forward of mid-ship	0.594 m
Center of buoyancy above datum	0.214 m
Wetted surface area	3.984 m^2
Volume of displacement	0.627 m^3
Displacement of fresh water	625.800 kg
Center of floatation forward of mid-ship (LCF)	-0.188 m
Center of floatation (aft body), forward of mid-ship	-0.927m
Center of floatation (fore body), forward of mid-ship	0.737m
Area of waterline plane	2.565 m^2
Transverse meta-centric radius (BM)	0.185 m
Longitudinal meta-centric radius (BML)	3.845 m
Center of area of profile plane forward of mid-ship (CLR)	-0.017 m
Center of area of profile plane above datum	0.206 m
Area of profile plane	1.017 m^2

Note 1: Reference: IMD report #: TR-AVR-12.

(Appendix 1, Continued)

Full Scale Particulars (Note 1)

8.02 m draught, level trim, without appendages	
Length between perpendiculars (LPP)	75.00 m
Length on waterline (LWL)	81.51 m
Waterline beam at mid-ship	17.20 m
Waterline beam at maximum section	17.20 m
Maximum waterline beam	17.20 m
Draught at mid-ship	8.02 m
Draught at maximum section	8.02 m
Maximum draught	8.02 m
Draught above datum	8.02 m
Maximum section forward of mid-ship	- 7.50 m
Parallel middle body: From, aft of mid-ship To forward of mid-ship	7.50 m 7.50 m
Area of mid-ship station	125.43 m^2
Area of maximum station	125.43 m^2
Center of buoyancy forward of mid-ship (LCB)	-1.52 m
Center of aft body buoyancy forward of mid-ship	-14.73 m
Center of fore body buoyancy forward of mid-ships	12.95 m
Center of buoyancy above datum	4.66 m
Wetted surface area	1893.36 m^2
Volume of displacement	6491.33 m^3
Displacement of salt water	6659.00 t
Center of floatation forward of mid-ship (LCF)	-4.09 m
Center of floatation (aft body), forward of mid-ship	-20.20 m
Center of floatation (fore body), forward of mid-ship	16.07 m
Area of waterline plane	1218.93 m^2
Transverse meta-centric radius (BM)	4.03 m
Longitudinal meta-centric radius (BML)	83.82 m
Center of area of profile plane forward of mid-ship (CLR)	- 0.37 m
Center of area of profile plane above datum	4.49 m
Area of profile plane	483.25 m^2

Appendix 2:

Instrumentations and Calibrations

Test Configuration January 22, 2004

DACON File: PJ953_PMM_APR03 **Facility:** ICETANK

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Model:** N/A

Configuration 1, Group 1 (ICEDAS, 50Hz)

Channel No.	Sensor Name	Sensor Model	Serial No.	Data Description
2	FWD SWAY	SSB-AJ-500	C65397	Force (N)
3	AFT SWAY	SSB-AJ-500	C65391	Force (N)
4	surge center2	c40115	A11667	Force (N)
5	XPULL	6000-1	0003211	Force (N)
6	YPULL	6001-A100-1000	732494	Force (N)
9	YAW	PMM YAW		Angle (deg)
10	FWD Heave	Intertech. A67930	A10329	Displacement (mm)
11	AFT Heave	Celesco	A10806	Displacement (mm)
28	Pitch	43878	018683	Angle (deg)
31	Carriage Position (ITC o/p)	ITC Carriage A/D Output (CnE)		Displacement (m)
32	Carriage Velocity (ITC o/p)	Carriage A/D Output (CnE)		Velocity (m/s)

Calibration of ICEDAS Channel 1 — 12:04 14 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: SURGE CENTER **Model:** SSB-HN-500 **Serial Number:** C23054

Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

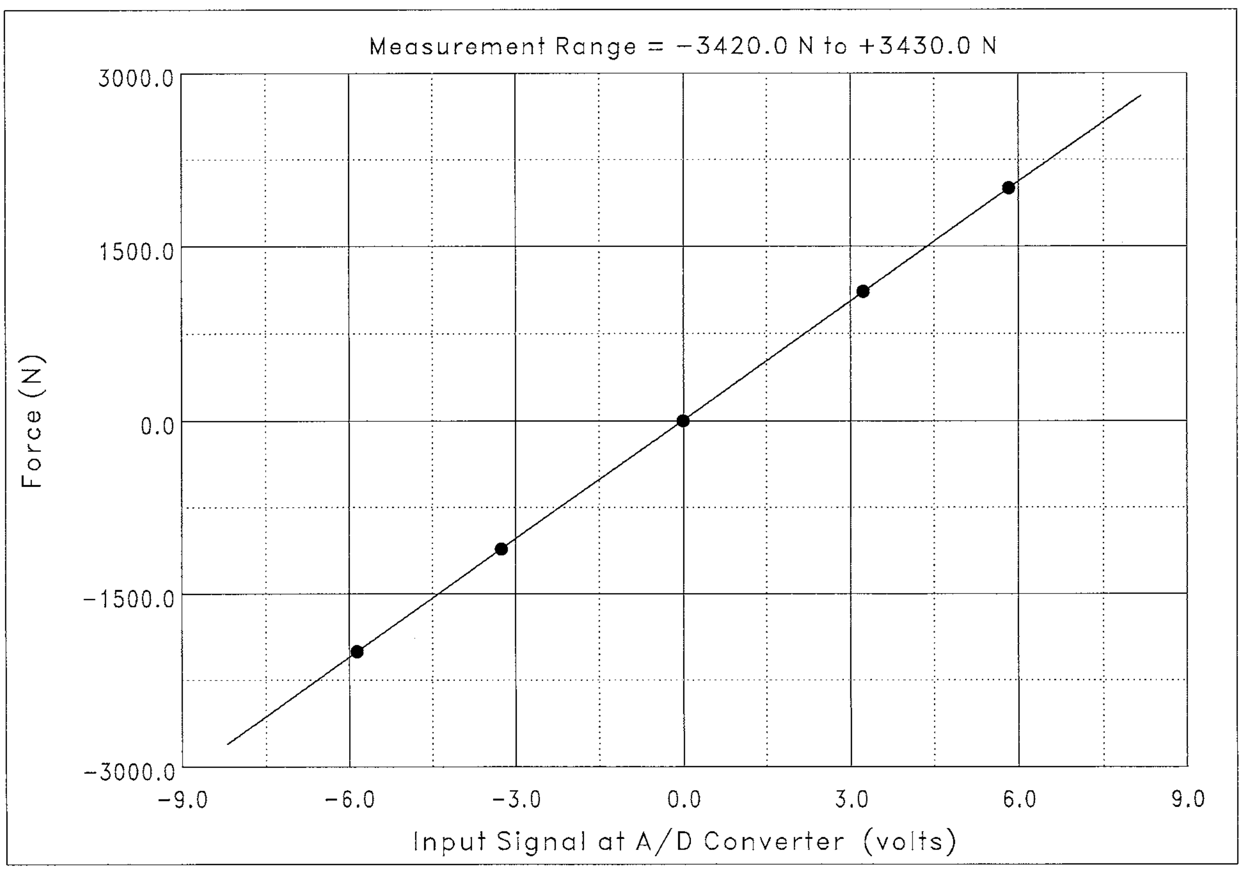
Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	−5.858	−2001.7	−2001.8	−0.12402	⇐ Maximum Error
2	−3.260	−1112.1	−1112.0	0.10498	
3	−0.012	0.0	0.1	0.10538	
4	3.234	1112.1	1112.0	−0.04590	
5	5.832	2001.7	2001.7	−0.04041	
Maximum Error = −0.00310 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 4.34642 N,
and C_1 = 342.456 N/volt .



Calibration of ICEDAS Channel 2 12:16 14 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: FWD SWAY **Model:** SSB-AJ-500 **Serial Number:** C65397

Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

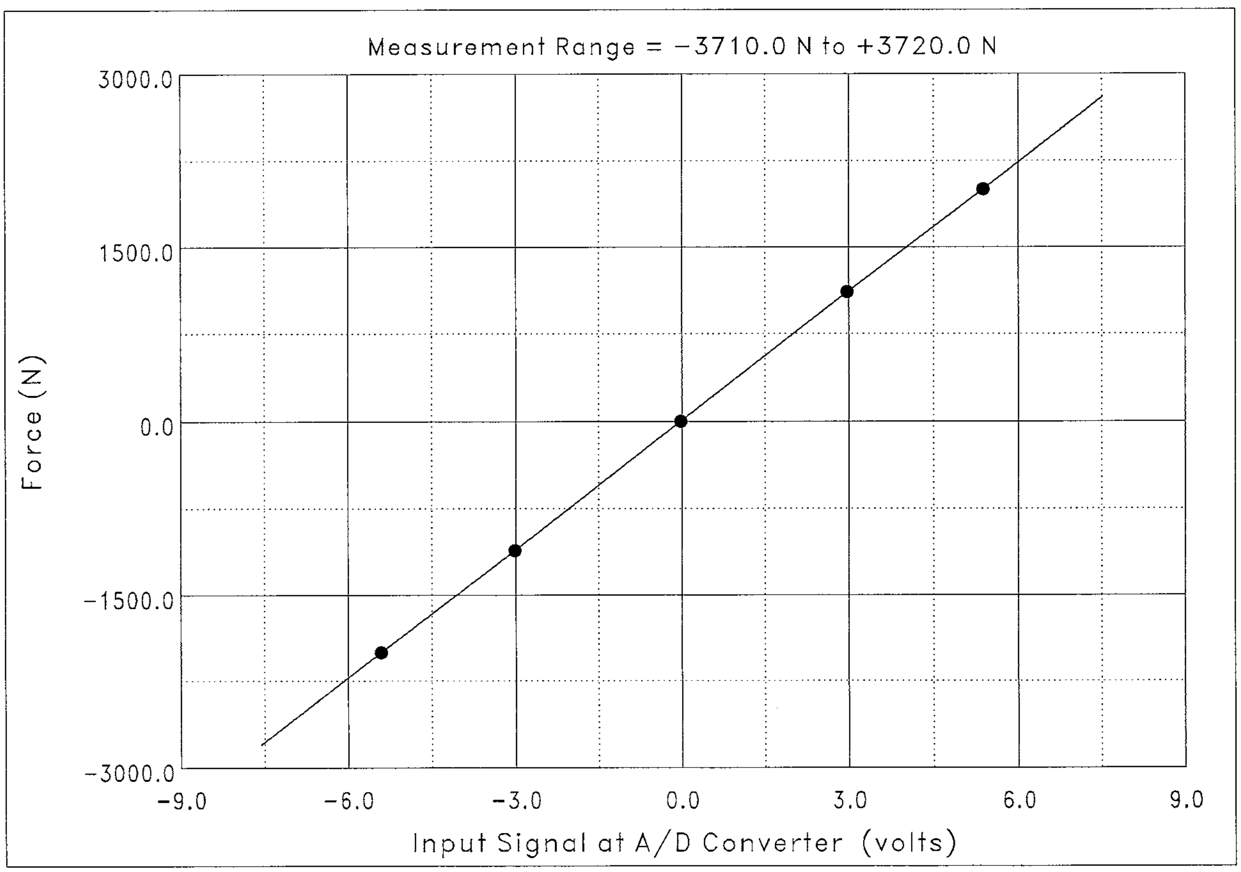
Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	−5.406	−2001.7	−2001.0	0.6815	
2	−3.013	−1112.1	−1112.2	−0.0972	
3	−0.021	0.0	−0.7	−0.6941	
4	5.373	2001.7	2003.0	1.2704	⇐ Maximum Error
5	2.971	1112.1	1110.9	−1.1606	
Maximum Error = 0.0317 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 7.15649 N,
and C_1 = 371.444 N/volt .



Calibration of ICEDAS Channel 3 12:24 14 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: AFT SWAY **Model:** SSB-AJ-500 **Serial Number:** C65391

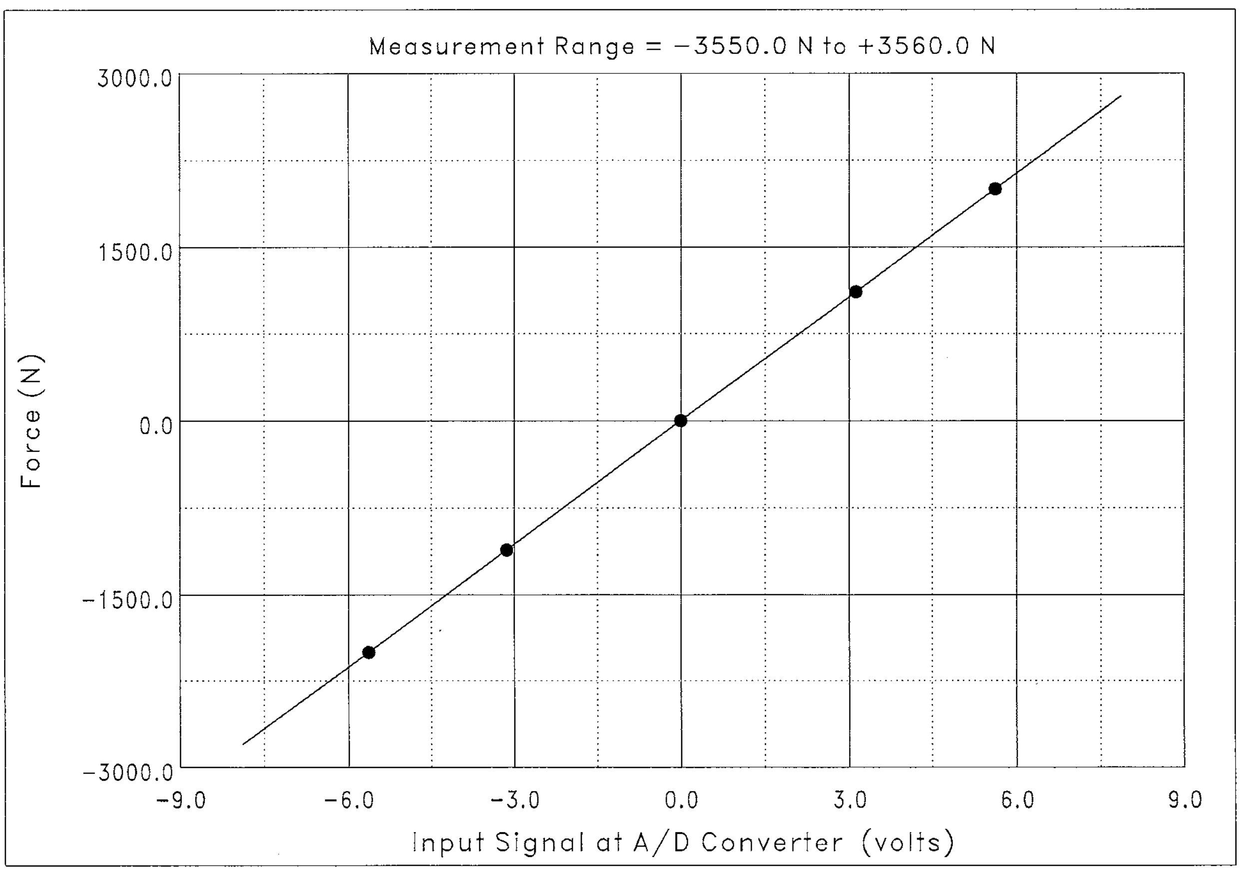
Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	−3.138	−1112.1	−1112.2	−0.09216	
2	−0.011	0.0	0.0	−0.02131	
3	−5.639	−2001.7	−2001.7	0.03809	
4	3.117	1112.1	1112.3	0.19971	⇐ Maximum Error
5	5.618	2001.7	2001.6	−0.12402	
Maximum Error = 0.00499 % of Calibration Range.					

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 3.78438 N,
and C_1 = 355.635 N/volt .



Calibration of ICEDAS Channel 4 09:50 23 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: surge center2 **Model:** c40115 **Serial Number:** A11667

Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	0.629	0.00	−0.27	−0.27114	
2	1.991	98.07	97.89	−0.17513	
3	3.363	196.13	196.73	0.59792	⇐ Maximum Error
4	4.723	294.20	294.73	0.53317	
5	6.070	392.27	391.83	−0.43414	
6	1.314	49.03	49.06	0.02264	
7	2.673	147.10	146.98	−0.11768	
8	4.038	245.17	245.35	0.18492	
9	5.391	343.23	342.89	−0.34052	
Maximum Error = 0.152 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

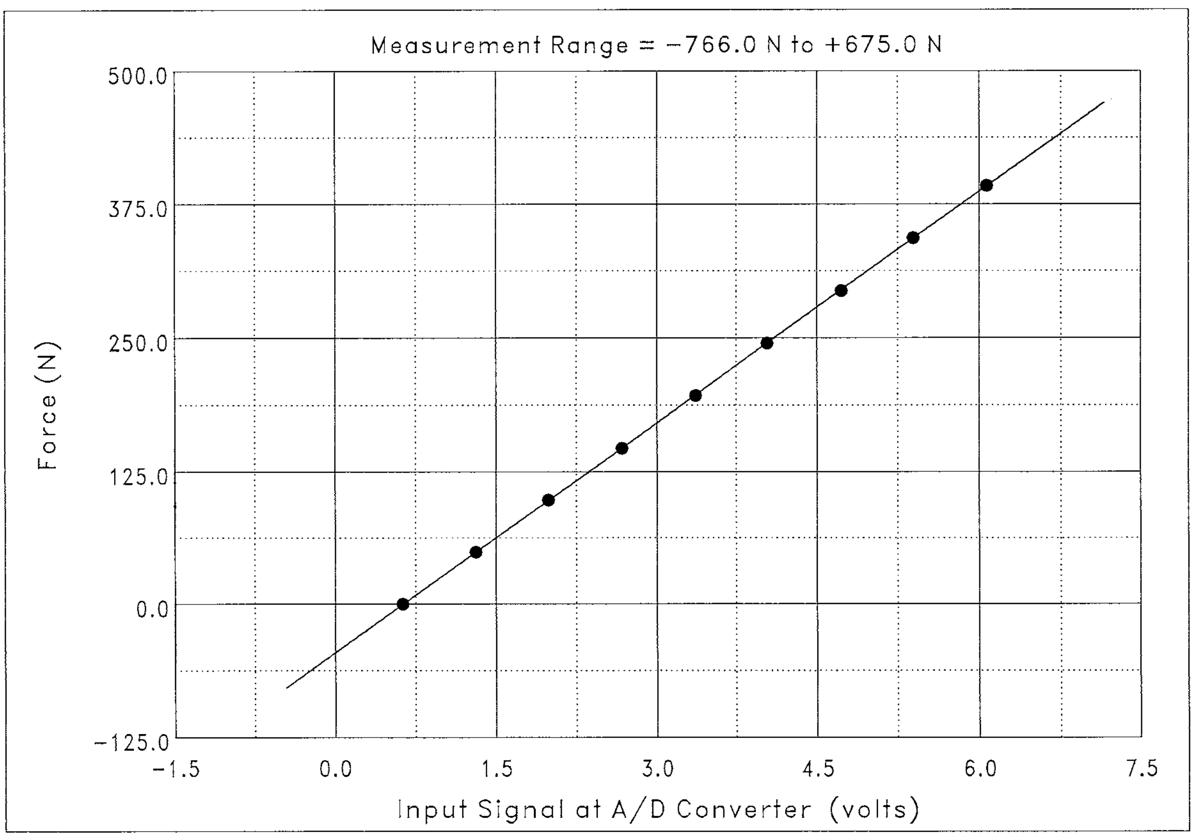
$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),

$V(t)$ = input signal at A/D converter (volts),

C_0 = -45.6230 N,

and C_1 = 72.0674 N/volt.



Calibration of ICEDAS Channel 5 13:50 14 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: XPULL **Model:** 6000-1 **Serial Number:** 0003211

Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	0.525	0.00	0.00	−0.00147	
2	1.190	49.04	48.96	−0.07512	
3	3.858	245.20	245.37	0.17003	
4	5.184	343.28	343.06	−0.21582	⇐ Maximum Error
5	1.856	98.08	97.98	−0.10178	
6	3.192	196.16	196.36	0.20012	
7	4.522	294.24	294.27	0.02817	
8	5.853	392.32	392.32	−0.00409	
Maximum Error = −0.0550 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

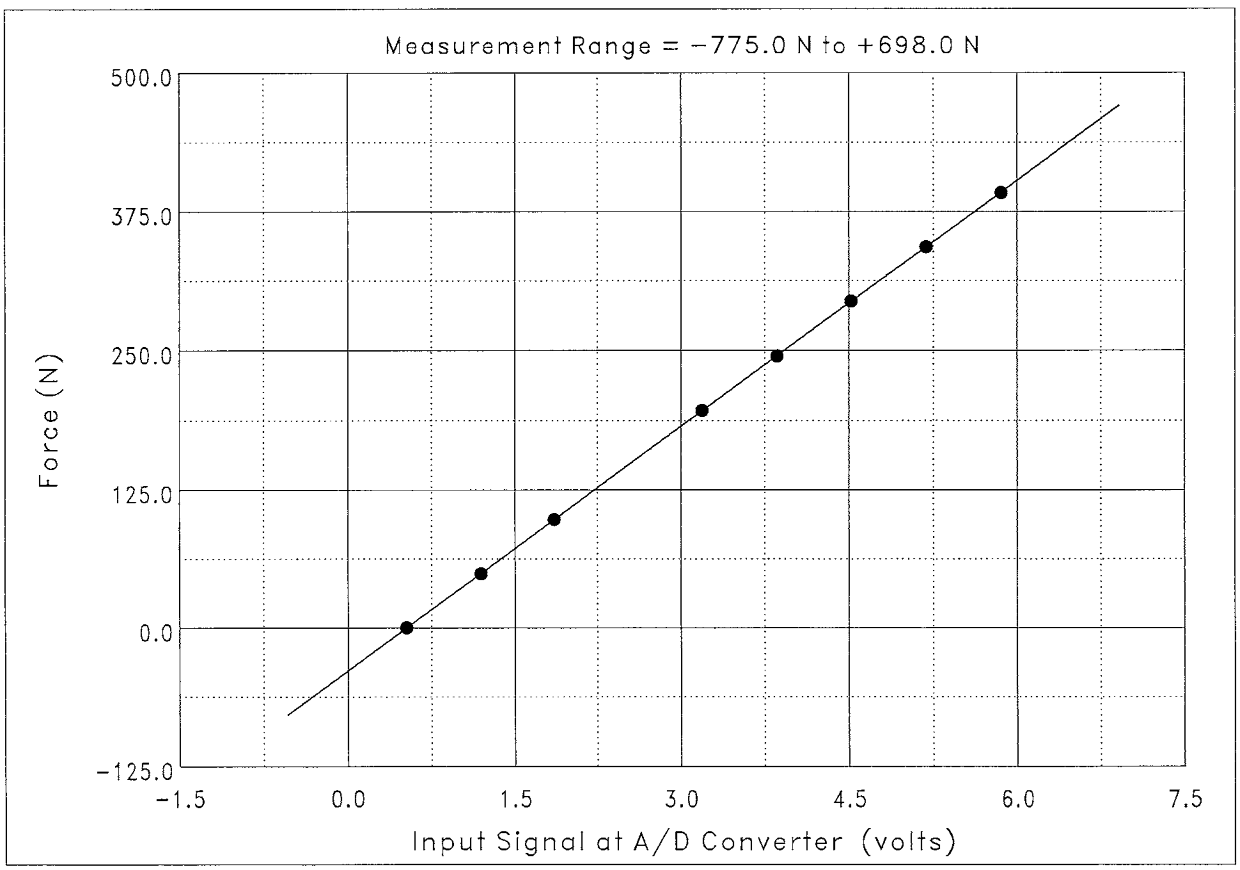
$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),

$V(t)$ = input signal at A/D converter (volts),

C_0 = -38.6794 N,

and C_1 = 73.6341 N/volt .



Calibration of ICEDAS Channel 6 13:50 14 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: YPULL **Model:** 6001-A100-1000 **Serial Number:** 732494

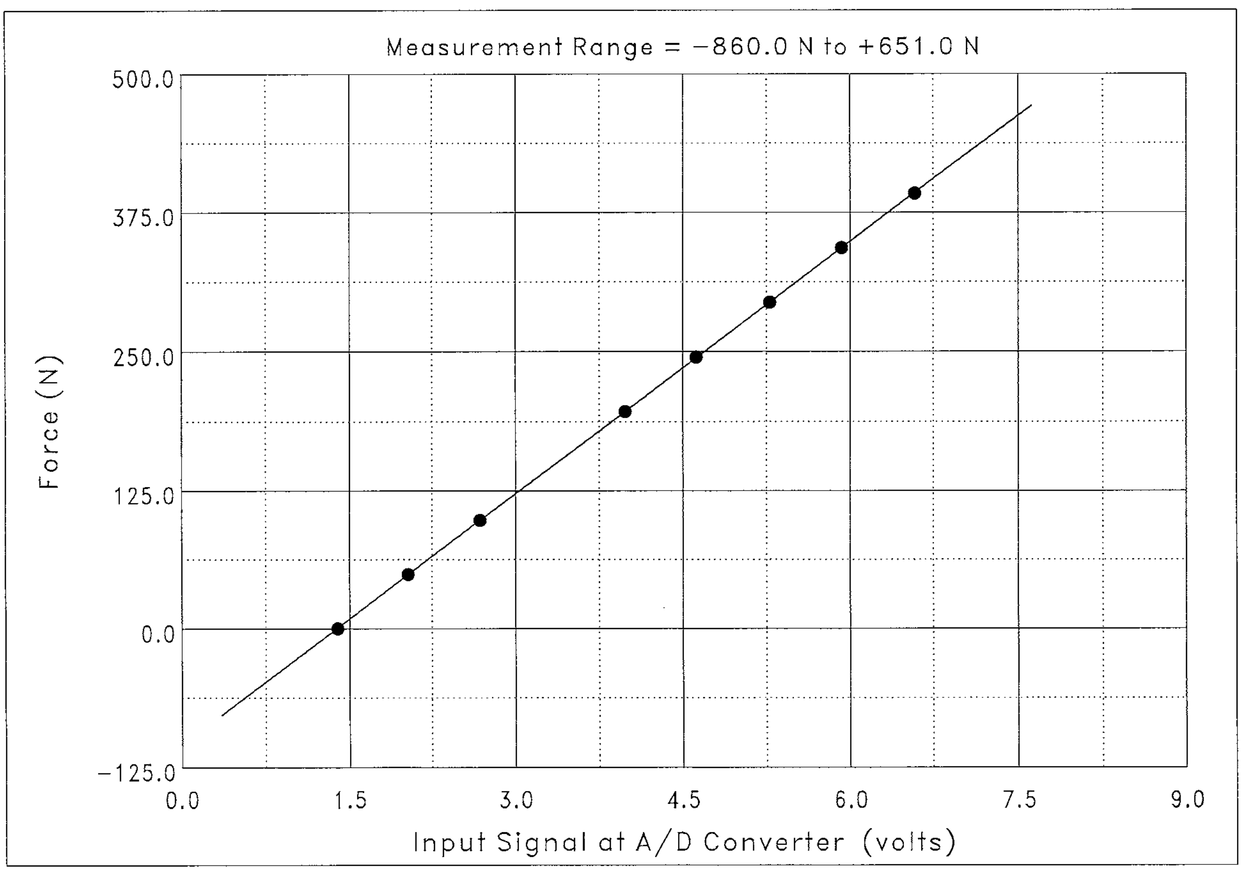
Programmable Gain: 1 **Plug-In Gain:** 200 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	1.390	0.00	0.45	0.45496	
2	2.028	49.04	48.68	−0.35783	
3	4.619	245.20	244.47	−0.73376	⇐ Maximum Error
4	5.923	343.28	343.05	−0.23358	
5	2.683	98.08	98.18	0.10095	
6	3.982	196.16	196.30	0.14253	
7	5.279	294.24	294.31	0.07498	
8	6.583	392.32	392.87	0.55176	
Maximum Error = −0.187 % of Calibration Range.					

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),
$V(t)$ = input signal at A/D converter (volts),
C_0 = -104.593 N,
and C_1 = 75.5720 N/volt.



Calibration of ICEDAS Channel 9 09:34 15 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: YAW **Model:** PMM YAW **Serial Number:** N/A

Programmable Gain: 1 **Plug-In Gain:** 1

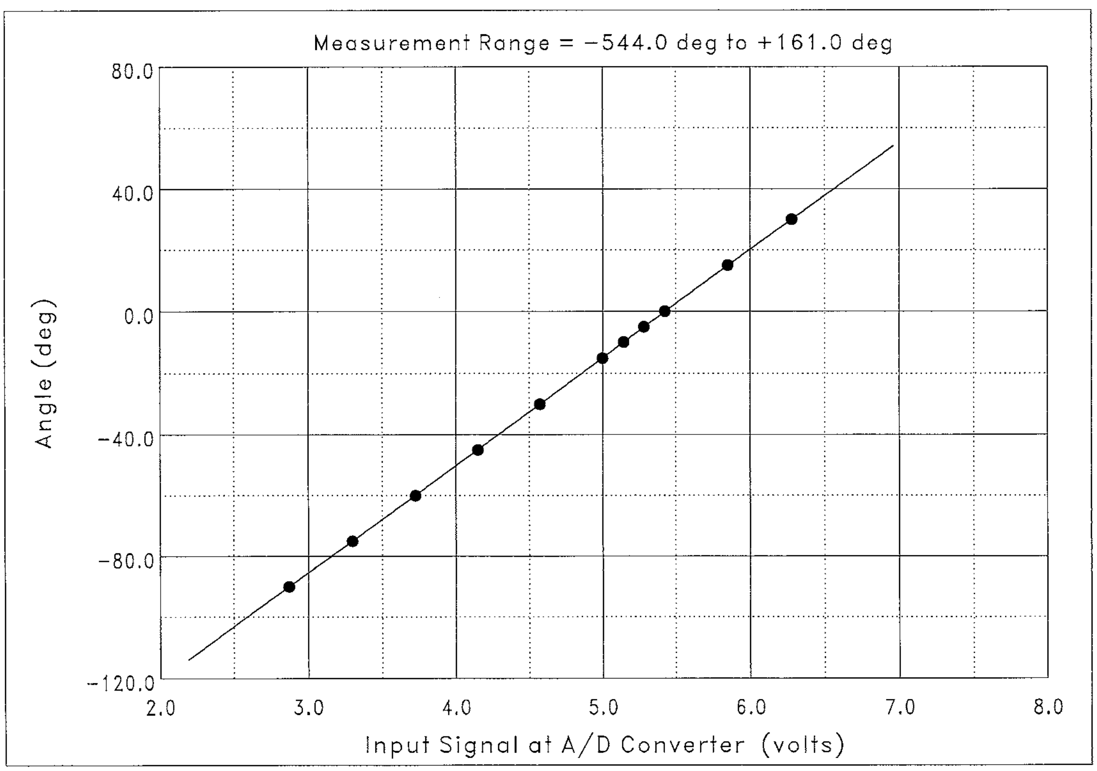
Data Point No.	Input Signal (volts)	Physical Value (deg)	Fitted Curve Value (deg)	Error (deg)	
1	5.426	0.000	−0.017	−0.016846	
2	5.284	−5.000	−4.992	0.008133	
3	5.142	−10.000	−10.008	−0.008179	
4	5.000	−15.000	−14.997	0.003220	
5	4.573	−30.000	−30.043	−0.043121	
6	4.151	−45.000	−44.926	0.074448	⇐ Maximum Error
7	3.724	−60.000	−59.957	0.043335	
8	3.297	−75.000	−75.026	−0.025787	
9	2.871	−90.000	−90.030	−0.030113	
10	5.852	15.000	14.989	−0.010803	
11	6.278	30.000	30.006	0.005692	
Maximum Error = 0.0620 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Angle (deg),
$V(t)$ = input signal at A/D converter (volts),
C_0 = −191.177 deg,
and C_1 = 35.2329 deg/volt .



Calibration of ICEDAS Channel 10 — 10:12 24 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: FWD Heave **Model:** Intertech. A67930 **Serial Number:** A10329

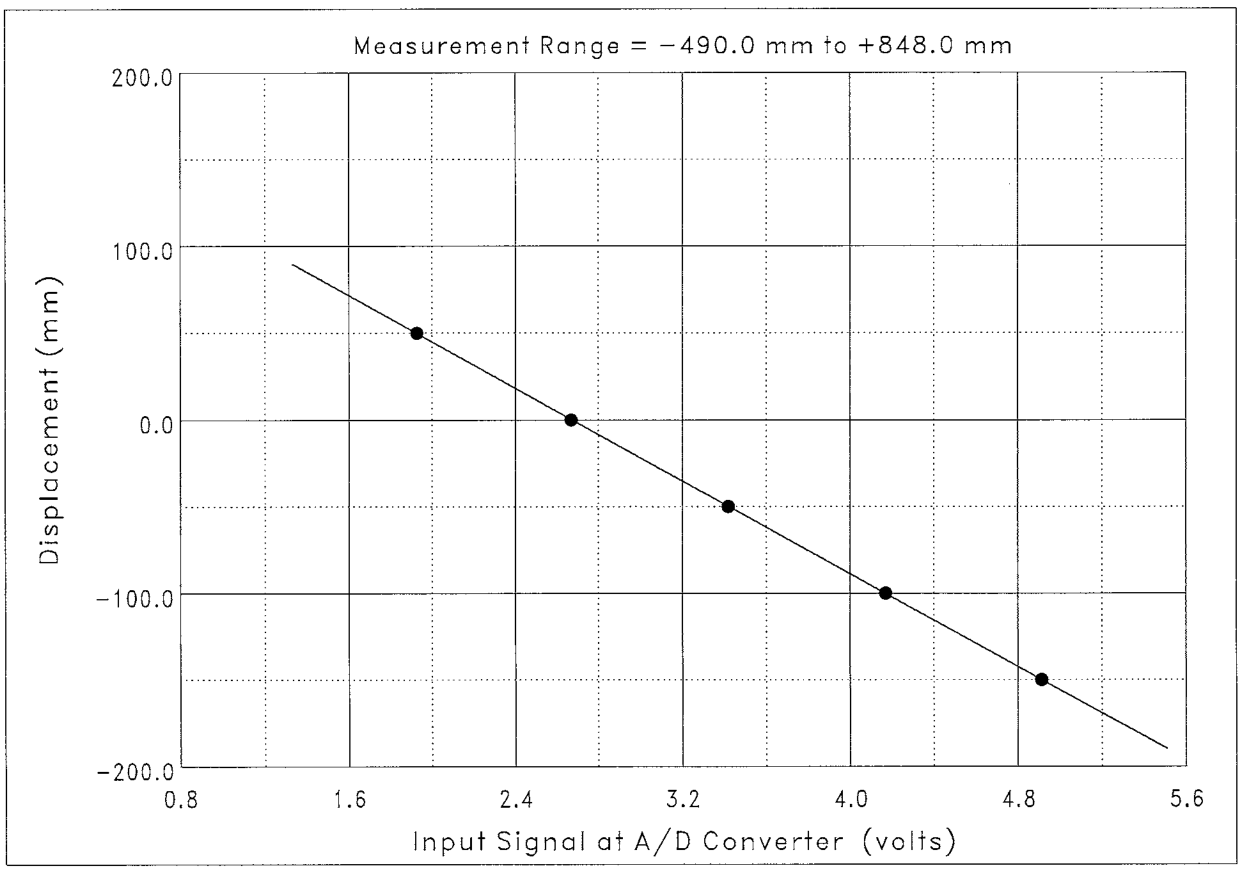
Programmable Gain: 2 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (mm)	Fitted Curve Value (mm)	Error (mm)	
1	2.669	0.00	0.23	0.22588	⇐ Maximum Error
2	3.419	−50.00	−49.96	0.04477	
3	4.171	−100.00	−100.22	−0.22202	
4	4.914	−150.00	−149.91	0.08829	
5	1.927	50.00	49.86	−0.13695	
Maximum Error = 0.113 % of Calibration Range.					

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Displacement (mm),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 178.815 mm,
and C_1 = −66.9017 mm/volt .



Calibration of ICEDAS Channel 11 — 10:05 24 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: AFT Heave **Model:** Celesco **Serial Number:** A10806

Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

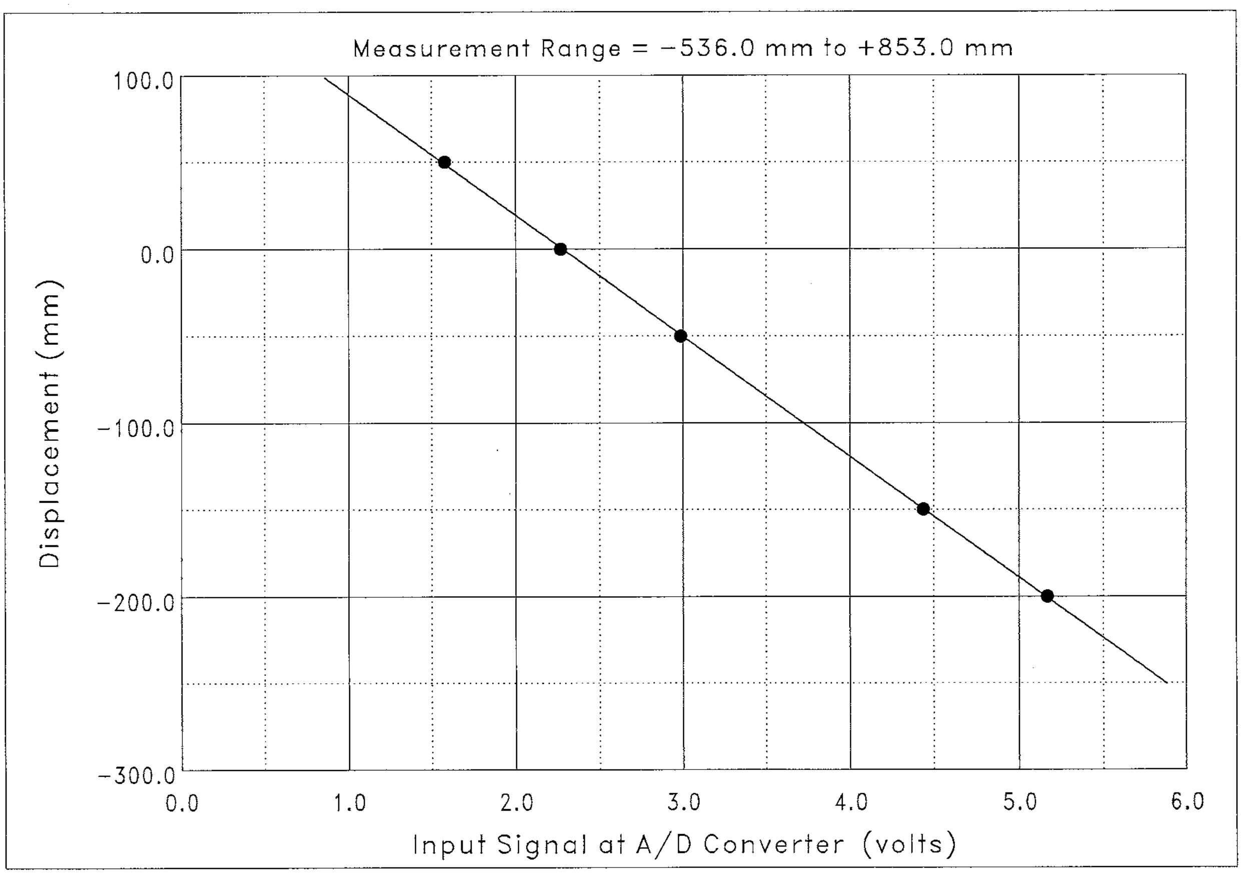
Data Point No.	Input Signal (volts)	Physical Value (mm)	Fitted Curve Value (mm)	Error (mm)	
1	2.265	0.00	0.98	0.9753	
2	2.987	−50.00	−49.14	0.8643	
3	4.437	−150.00	−149.87	0.1318	
4	5.168	−200.00	−200.63	−0.6306	
5	1.579	50.00	48.66	−1.3408	⇐ Maximum Error

Maximum Error = −0.536 % of Calibration Range.

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Displacement (mm),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 158.356 mm,
and C_1 = −69.4695 mm/volt .



Calibration of ICEDAS Channel 28 10:18 24 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: Pitch **Model:** 43878 **Serial Number:** 018683

Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

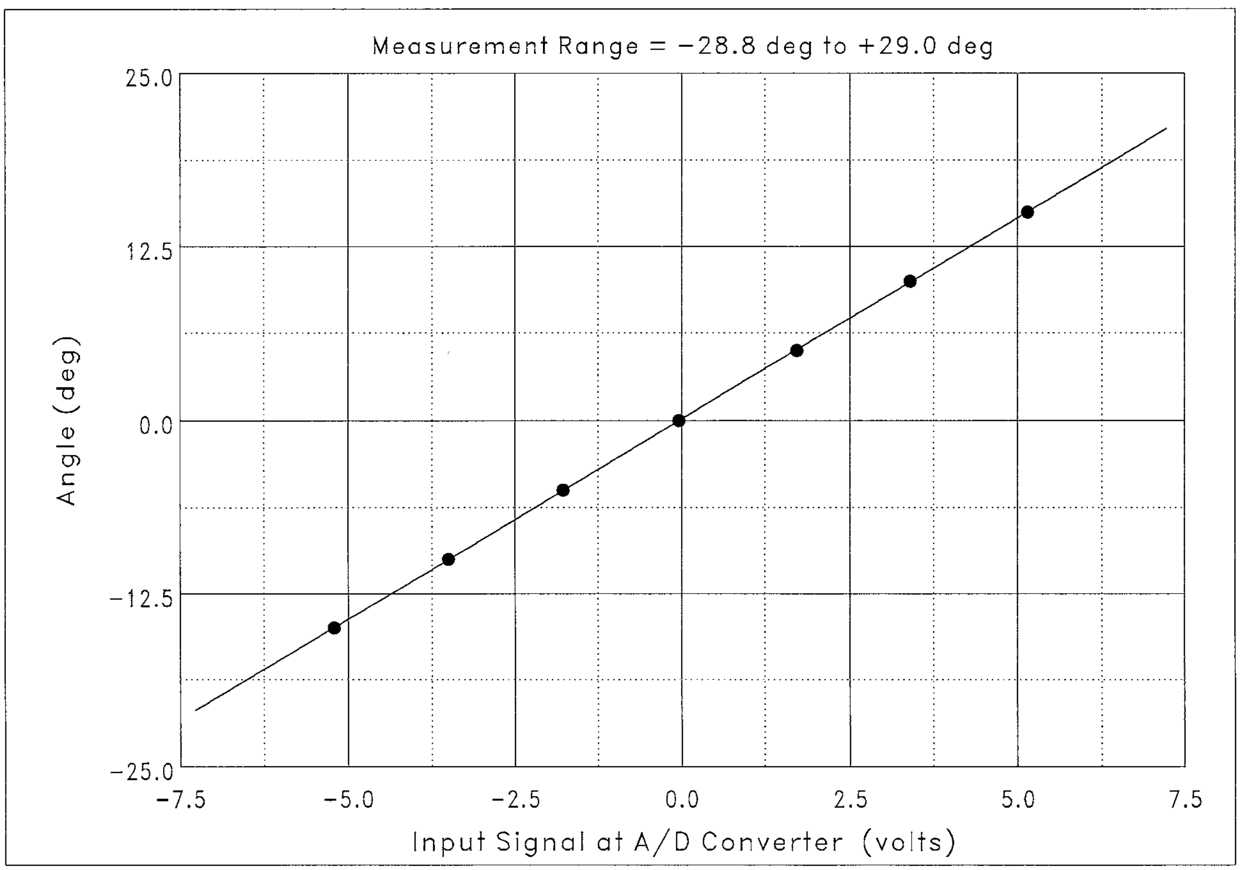
Data Point No.	Input Signal (volts)	Physical Value (deg)	Fitted Curve Value (deg)	Error (deg)	
1	−0.042	0.000	−0.017	−0.017141	
2	1.723	5.000	5.090	0.089720	⇐ Maximum Error
3	3.398	10.000	9.937	−0.063009	
4	5.154	15.000	15.019	0.018658	
5	−5.205	−15.000	−14.961	0.039056	
6	−3.500	−10.000	−10.027	−0.026895	
7	−1.777	−5.000	−5.040	−0.040389	
Maximum Error = 0.299 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Angle (deg),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 0.103378 deg,
and C_1 = 2.89418 deg/volt .



Calibration of ICEDAS Channel 29 13:35 10 April 2003

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: Carriage Velocity (F/V) **Model:** Ono Sokki 132 Wheel en & fv-801 **Serial Number:** 60302876

Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

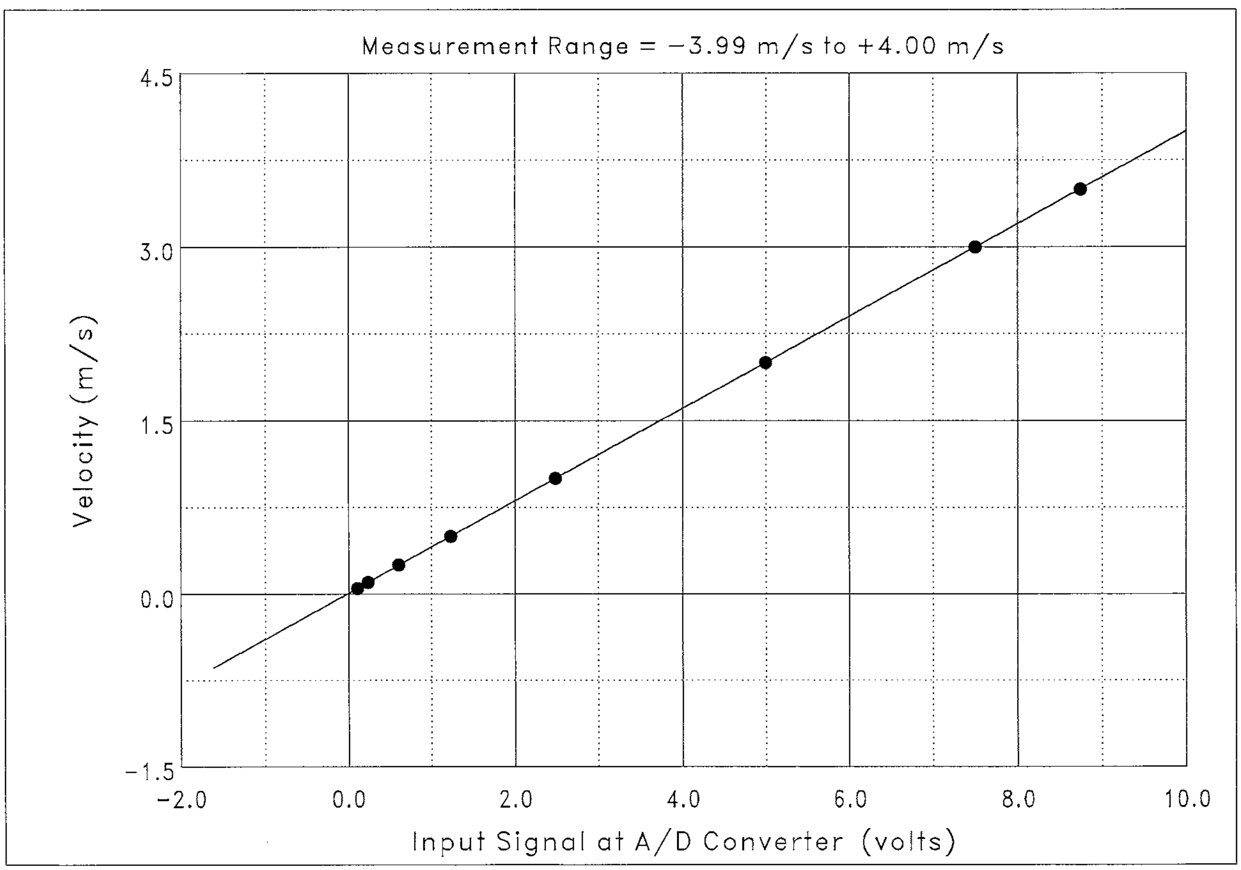
Data Point No.	Input Signal (volts)	Physical Value (m/s)	Fitted Curve Value (m/s)	Error (m/s)	
1	2.485	1.0000	0.9993	−0.00071013	
2	8.745	3.5000	3.4993	−0.00074339	
3	4.992	2.0000	2.0005	0.00045466	
4	7.497	3.0000	3.0009	0.00088620	⇐ Maximum Error
5	1.233	0.5000	0.4995	−0.00049827	
6	0.607	0.2500	0.2496	−0.00038593	
7	0.235	0.1000	0.1007	0.00073279	
8	0.108	0.0500	0.0503	0.00026403	
Maximum Error = 0.0257 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Velocity (m/s),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 0.00704321 m/s,
and C_1 = 0.399323 (m/s)/volt.



Calibration of ICEDAS Channel 31 09:51 01 May 2002

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: Carriage Position (ITC o/p) **Model:** ITC Carriage A/D Output (CnE) **Serial Number:** N/A

Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

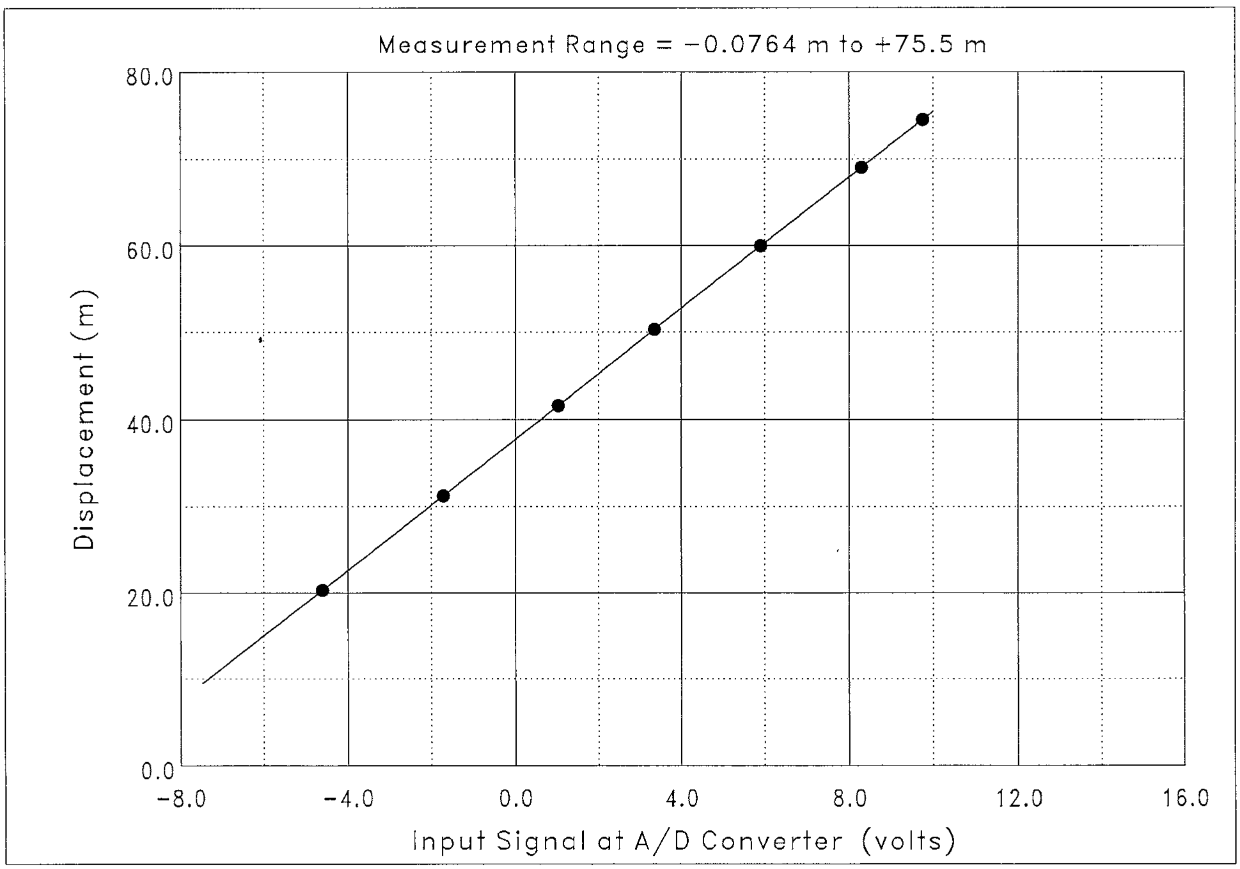
Data Point No.	Input Signal (volts)	Physical Value (m)	Fitted Curve Value (m)	Error (m)	
1	−4.603	20.311	20.312	0.000803	
2	−1.712	31.221	31.229	0.007864	
3	1.024	41.570	41.566	−0.003807	
4	3.348	50.349	50.345	−0.003899	
5	5.901	59.997	59.988	−0.009239	
6	8.295	69.037	69.032	−0.005470	
7	9.745	74.494	74.508	0.013756	⇐ Maximum Error
Maximum Error = 0.0254 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Displacement (m),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 37.6973 m,
and C_1 = 3.77737 m/volt .



Calibration of ICEDAS Channel 32 — 14:10 27 November 2002

Project: EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM **Facility:** ICETANK

Sensor: Carriage Velocity (ITC o/p) **Model:** Carriage A/D Output (CnE) **Serial Number:** N/A

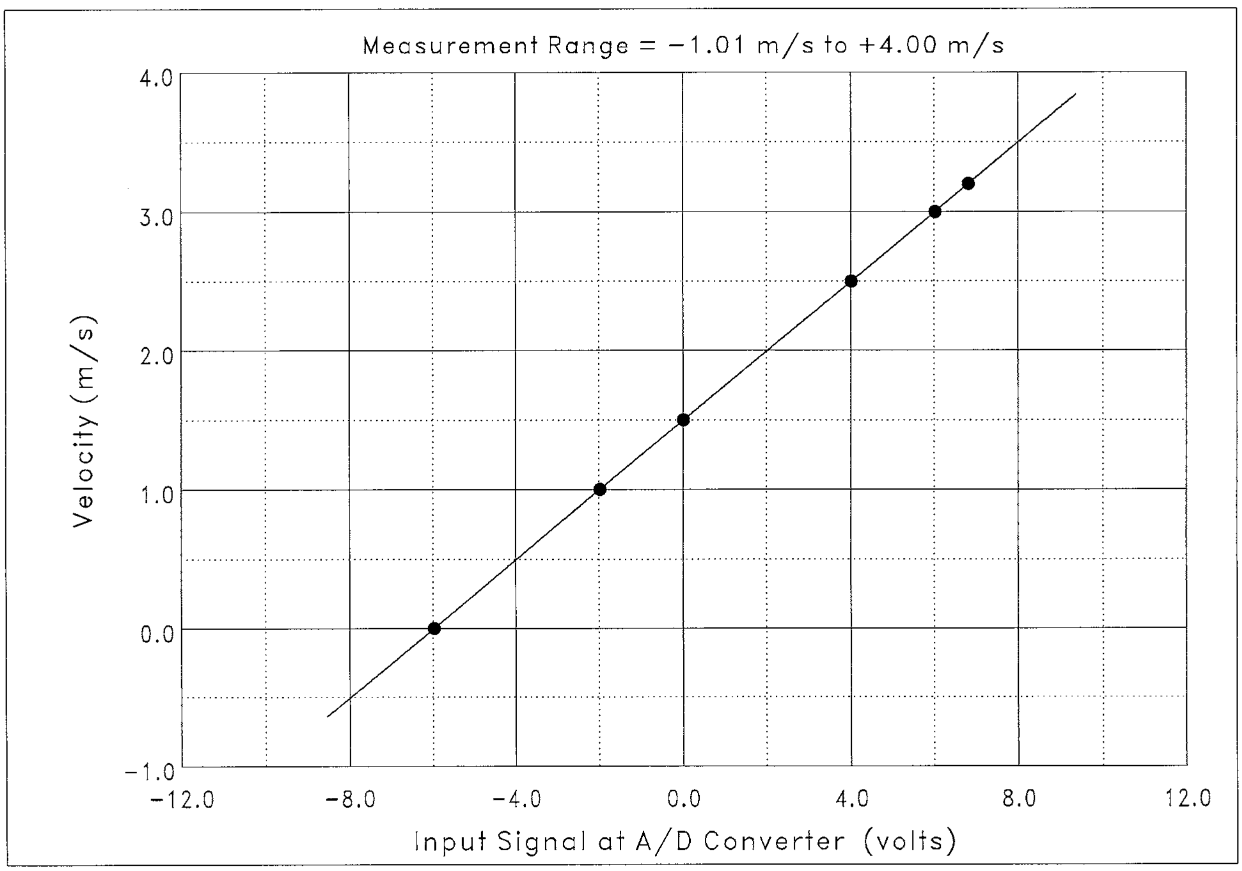
Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (m/s)	Fitted Curve Value (m/s)	Error (m/s)	
1	−1.978	1.0000	1.0000	−0.000016153	
2	−5.976	0.0000	0.0000	0.000016212	
3	4.019	2.5000	2.5001	0.000068426	⇐ Maximum Error
4	6.018	3.0000	3.0000	0.000034809	
5	6.817	3.2000	3.1999	−0.000060797	
6	0.021	1.5000	1.5000	−0.000041962	
Maximum Error = 0.00214 % of Calibration Range.					

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Velocity (m/s),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 1.49479 m/s,
and C_1 = 0.250143 (m/s)/volt.



Appendix 3:

Ice Sheets Summaries and Material Properties

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ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: PICE1

Project Number: 953

Target ice thickness(mm): 40.

EG/AD/S: (%) .39/.036/.04

Target ice strength(kPa): 35

Ice Type: M

SEEDING:

Air temp.(max/min) C: -18.0/-14.7
Seeding completed at 0933 29-APR-2003
Seed volume: l 30.9
Humidity: tank(%) 78
room(%) 57

Tank water temp. C: 0.06
Seed duration: (min) 30.
Seed water temp.: C 32.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -20.0
Avg temp. of freeze cycle C -19.9
Total negative deg. hours 246.2
Avg growth rate: (mm/hr) 2.393

Time to target temp. hrs: 0.9
Duration of plateau hrs: 11.5
Duration of freeze cycle hrs: 12.4
Thickness at end of freeze:(mm) 29.7
Avg growth rate: (mm/fdh) .121

WARM-UP:

Warm-up commenced at 2155 29-APR-2003
Time to tempering temp: (hrs) 3.8
Final ice thickness: (mm) 39.8
Total growth rate: (mm/hr) 3.205

Length of warm-up: (hrs) 17.
Avg tempering temperature: (C) 2.0
Ice growth during warm-up: (mm) 10.1
Total growth rate: (mm/fdh) .162

* thickness at end of freeze was estimated

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE1 Project Number: 953

Warm up commenced: 21:55 29-APR-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0855	11.00	N	37.8± 0.7 n= 3									
		S	39.3± 0.7 n= 3									
0926	11.51	40S	39.8		35.	25.2	741	8.8				
		40C	39.8		34.	23.7	698	8.7				
0938	11.71	40S	39.6	34.± 3.4								
			39.4	16.(u/d 48%)								
0945	11.83	40N	39.9	30.± 3.0								
			40.1	16.(u/d 53%)								
1005	12.16	40S	39.6									.941
1010	12.25	40N	40.0									.940
1030	12.58	15N	39.0									.940
1035	12.66	15S	39.7									.937
1049	12.90	30N	38.9									.942
1052	12.95	30S	39.7									.942
1109	13.23	60N	39.4									.940
1112	13.28	60S	39.2									.940
1216	14.35	N	39.6± 0.5 n=31									
		S	39.7± 0.6 n=31									
1347	15.86	N	39.5± 0.6 n=31									
		S	40.0± 0.7 n=31									
1400	16.08	38S	40.8	11.± 2.1								
			40.0	12.(u/d110%)								
1403	16.13	38N	41.1	14.± 2.7								
			40.6	14.(u/d 98%)								
1442	16.78	N	39.9± 0.6 n=31									
		S	39.8± 0.7 n=31									

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ICE SHEET PROPERTIES AND LOCATION DIAGRAM

ICE SHEET: PICE 1

DATE: 04/30/03

TEST-TIME: 11:30

Flexural strength @ Test-time

	North		South	
0				
5				
10				
15	23.89 ± 0.7, n = 3	ρ = .940	26.77 ± 3.4, n = 3	ρ = .937
20				
25				
30	23.99 ± 0.8, n = 3	ρ = .942	27.19 ± 1.2, n = 3	ρ = .942
NORTH 35				
40	20.30 ± 1, n = 4	ρ = .941	20.47 ± 3.7, n = 4	ρ = .941
	40 = 37.8 ± 0.7, n = 3		40 = 39.3 ± 0.7, n = 3	
45				
50				
55				
60	28.95 ± 3.5, n = 3	ρ = .940	32.90 ± 1.4, n = 2	ρ = .940
65				
70				

ρ_i = .940 ± .0016

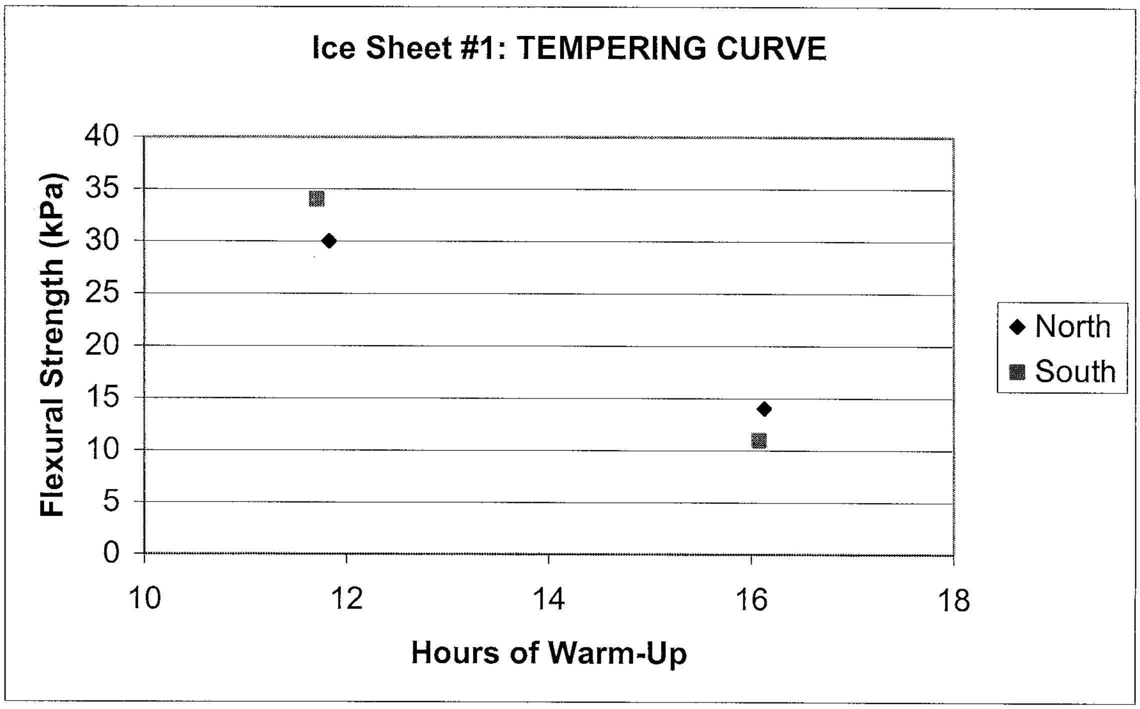
h_i (Center) = 39.62 ± .54, n = 62

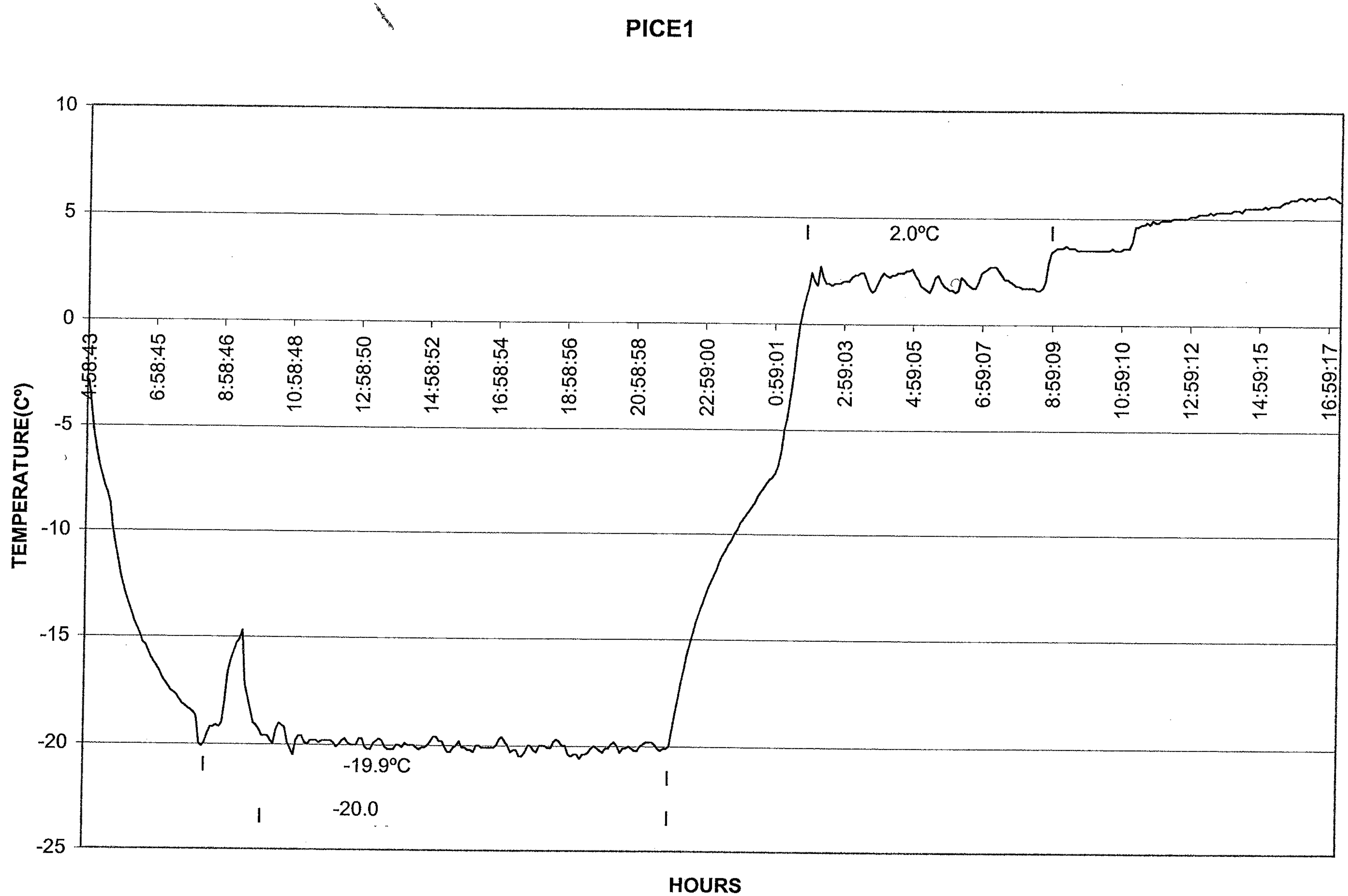
h_i (SQP) = 39.73 ± .67, n = 62

h_i (NQP) = 39.83 ± .62, n = 62

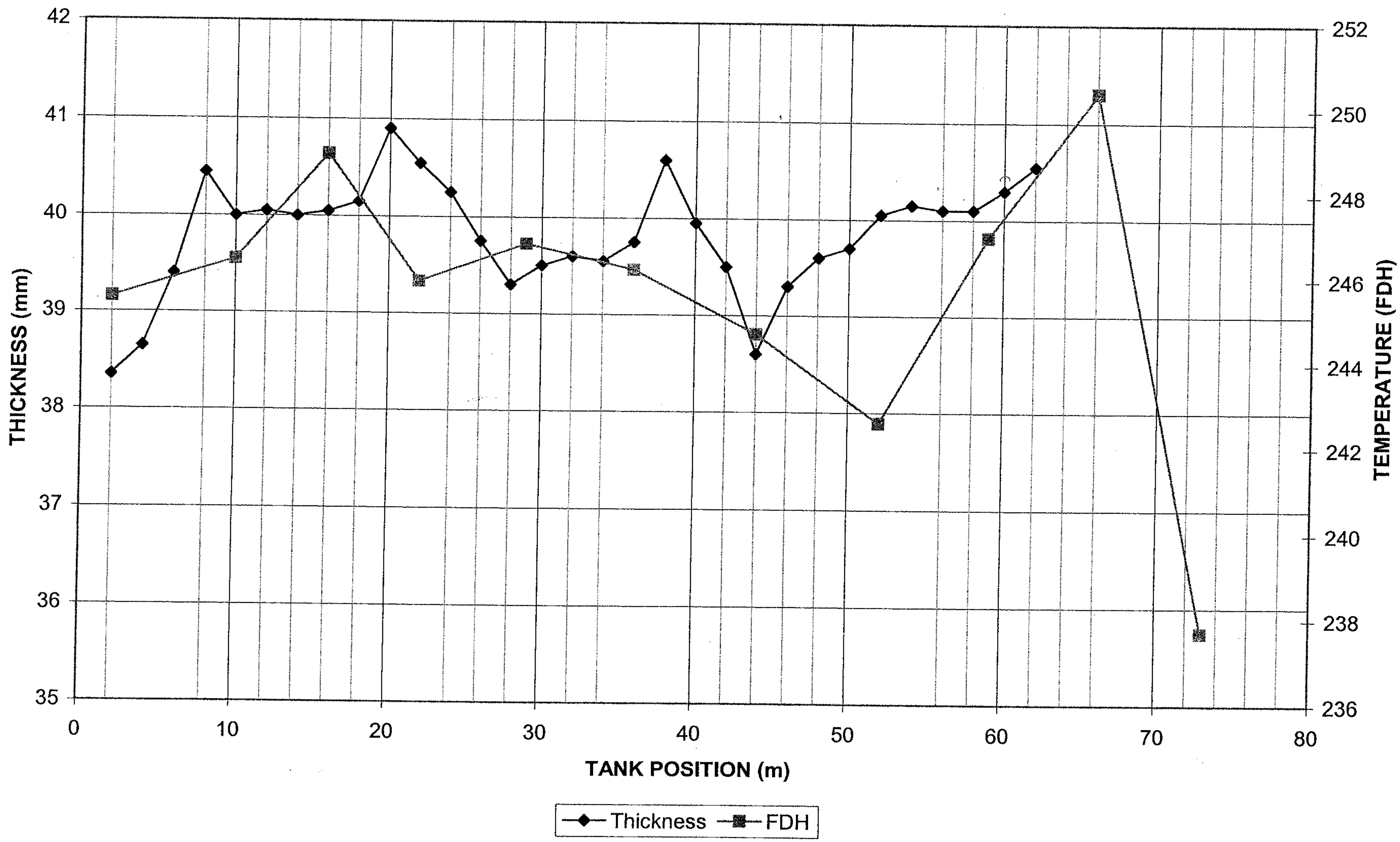
σ_F = 24.2 ± 4.5, n = 26

Run #	Date	Time	Flexural Strength		
			North	South	Mean
CC LEV ICE	04/30/2003	1130	20.2	18.1	19.2
SQP PRESAWN	04/30/2003	1312	20.1	17.9	19.0
NQP LEV ICE	04/30/2003	1412	20.1	17.8	18.9

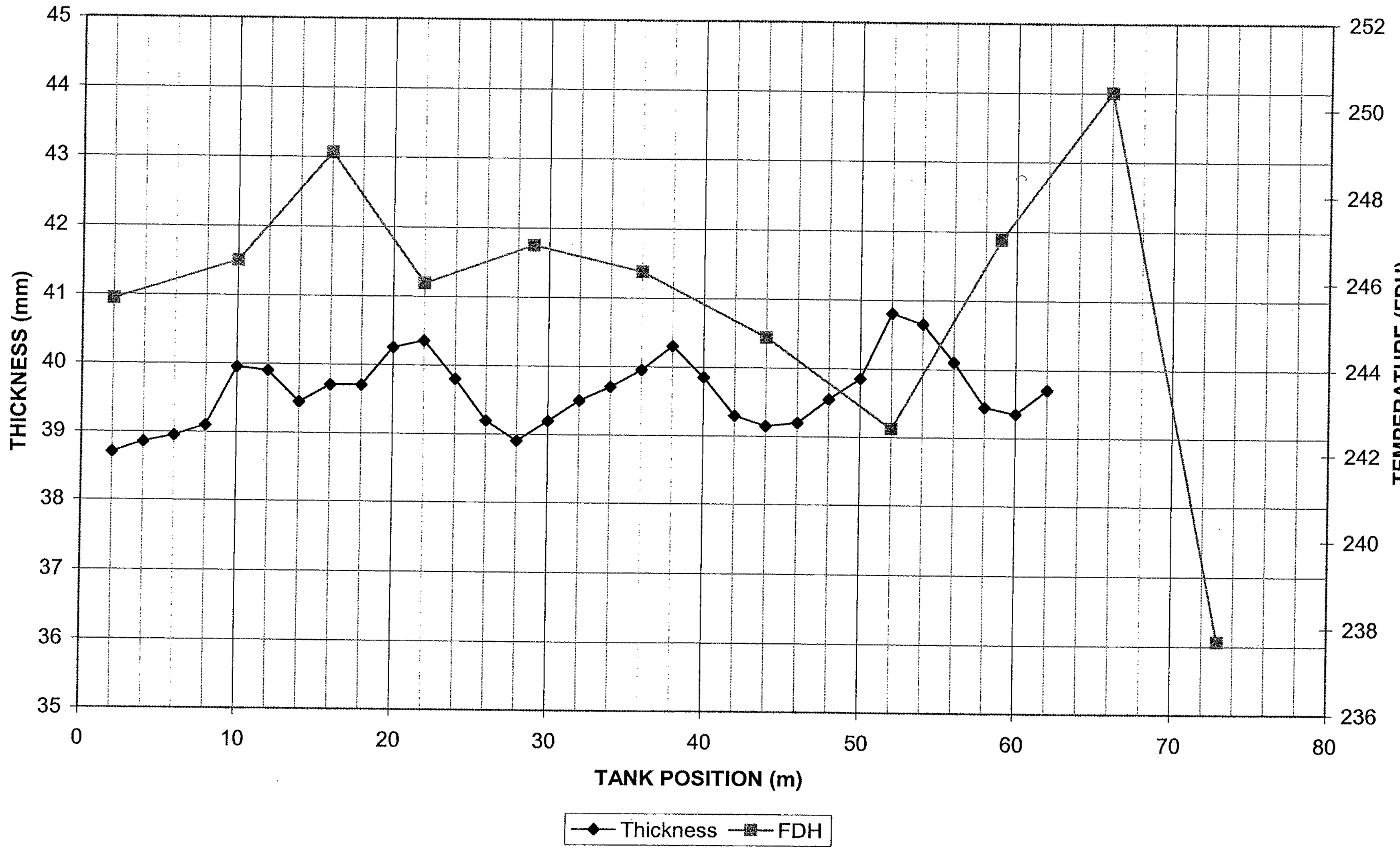


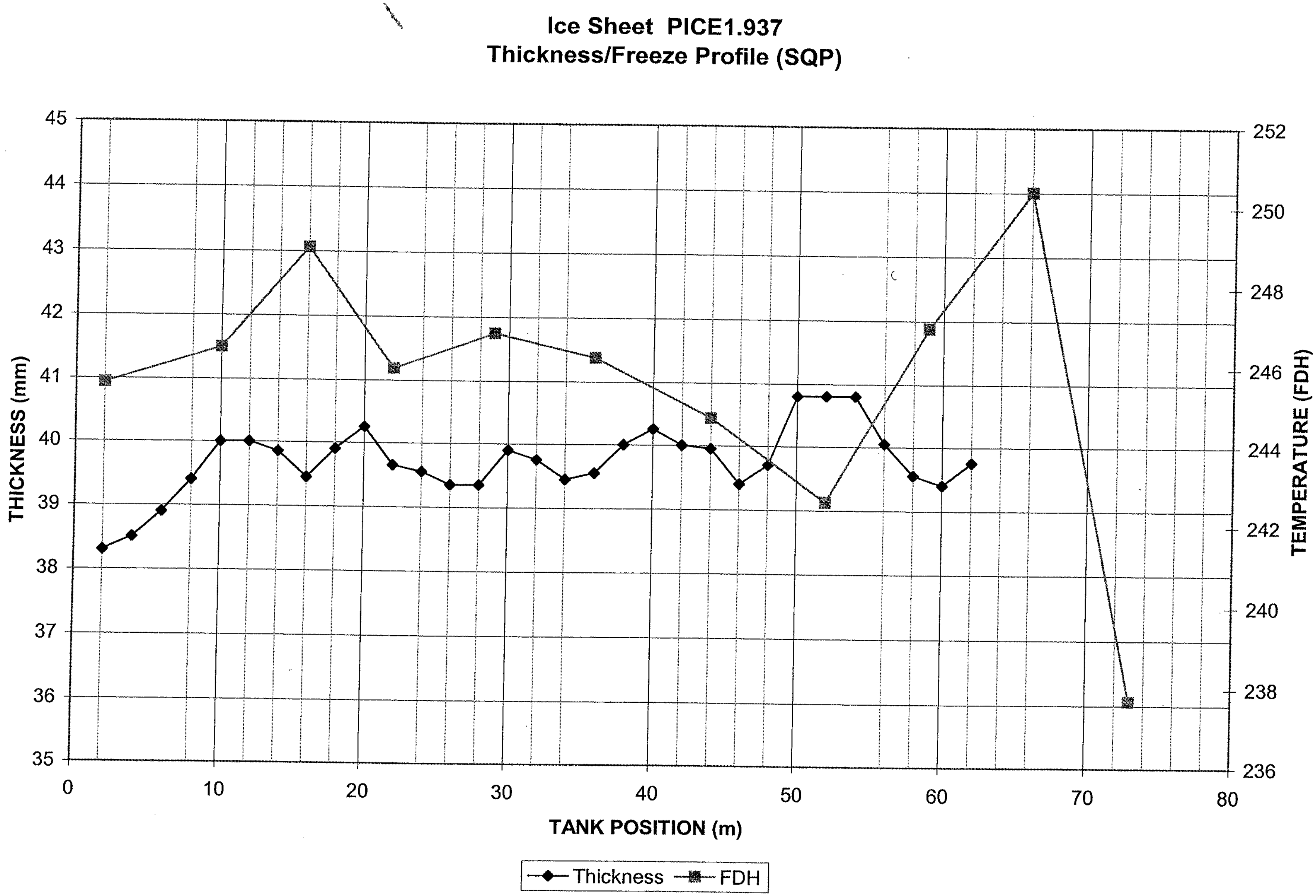

PICE1
TEMPERATURE(C°)
10
5
0
-5
-10
-15
-20
-25
4:58:43
6:58:45
8:58:46
10:58:48
12:58:50
14:58:52
16:58:54
18:58:56
20:58:58
22:59:00
0:59:01
2:59:03
4:59:05
6:59:07
8:59:09
10:59:10
12:59:12
14:59:15
16:59:17
2.0ºC
-19.9ºC
-20.0
HOURS

Ice Sheet PICE1.937
Thickness/Freeze Profile (NQP)



Ice Sheet 936,PIF21
Thickness/Freeze Profile (CC)




Ice Sheet PICE1.937
Thickness/Freeze Profile (SQP)
THICKNESS (mm)
TEMPERATURE (FDH)
TANK POSITION (m)
45
44
43
42
41
40
39
38
37
36
35
252
250
248
246
244
242
240
238
236
0
10
20
30
40
50
60
70
80
Thickness
FDH

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ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: PICE2

Project Number: 4295310

Target ice thickness(mm): 40.

EG/AD/S: (%) .39/.036/.04

Target ice strength(kPa): 35

Ice Type: M

SEEDING:

Air temp.(max/min) C: -19.5/-14.2
Seeding completed at 0947 1-MAY-2003
Seed volume: l 31.7
Humidity: tank(%) 80
room(%) 50

Tank water temp. C: -.04
Seed duration: (min) 35.
Seed water temp.: C 32.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -19.7
Avg temp. of freeze cycle C -19.6
Total negative deg. hours 244.4
Avg growth rate: (mm/hr) 2.374

Time to target temp. hrs: 1.6
Duration of plateau hrs: 10.9
Duration of freeze cycle hrs: 12.5
Thickness at end of freeze:(mm) 29.7
Avg growth rate: (mm/fdh) .121

ARM-UP:

Warm-up commenced at 2219 1-MAY-2003
Time to tempering temp: (hrs) 3.6
Final ice thickness: (mm) 39.2
Total growth rate: (mm/hr) 3.133

Length of warm-up: (hrs) 15.
Avg tempering temperature: (C) 2.0
Ice growth during warm-up: (mm) 9.5
Total growth rate: (mm/fdh) .160

* thickness at end of freeze was estimated

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE2 Project Number: 4295310

Warm up commenced: 22:19 1-MAY-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0845	10.43	N	38.2 ± 1.0 n= 3									
		S	38.4 ± 1.2 n= 3									
0857	10.63	40C	38.6		34.	25.2	915	8.9				
0914	10.91	40N	39.0	30. ± 2.2								
			39.1	12. (u/d 40%)								
0918	10.98	40S	39.1	25. ± 3.9								
			38.5	12. (u/d 46%)								
0926	11.11	40S	38.9									.940
0931	11.20	40N	38.8									.941
0942	11.38	15S	38.6									.939
0946	11.45	15N	38.4									.938
1005	11.76	30N	38.4									.943
1010	11.85	30S	38.9									.943
1025	12.10	60S	38.7									.941
1035	12.26	60N	38.7									.941
1100	12.68	N	38.9 ± 0.9 n=32									
		S	38.9 ± 0.9 n=32									
1112	12.88	39N	38.8	18. ± 1.5								
			38.8	12. (u/d 66%)								
1118	12.98	39S	39.6	18. ± 1.4								
			39.4	18. (u/d 97%)								
1235	14.26	N	38.9 ± 0.7 n=33									
		S	38.6 ± 0.6 n=33									
1256	14.61	38S	40.2	9. ± 1.9								
			39.5	8. (u/d 80%)								
1301	14.70	38N	39.5	10. ± 1.8								
			39.8	7. (u/d 73%)								

1330	15.18	N	39.2± 0.8 n=32
		S	39.2± 0.8 n=32

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ICE SHEET PROPERTIES AND LOCATION DIAGRAM

ICE SHEET: PICE 2

DATE: 05/02/03

TEST-TIME: 10:41

Flexural strength @ Test-time

NORTH	N	S
0		
5		
10		
15	19.71 ± 2.3, n=3 ρ=.938	15.68 ± 2.6, n=3 ρ=.939
20		
25		
30	19.24 ± 1.3, n=3 ρ=.943	17.99 ± 1.3, n=3 ρ=.943
35		
40	19.45, ± 1.5, n=4 ρ=.940	17.32 ± 2.7, n=4 ρ=.941
45		
50		
55		
60	24.73, ± 0.9, n=3 ρ=.94	25.85 ± 2.5, n=3 ρ=.941
65		
70		

$\rho = .940 \pm .0018, n = 8$

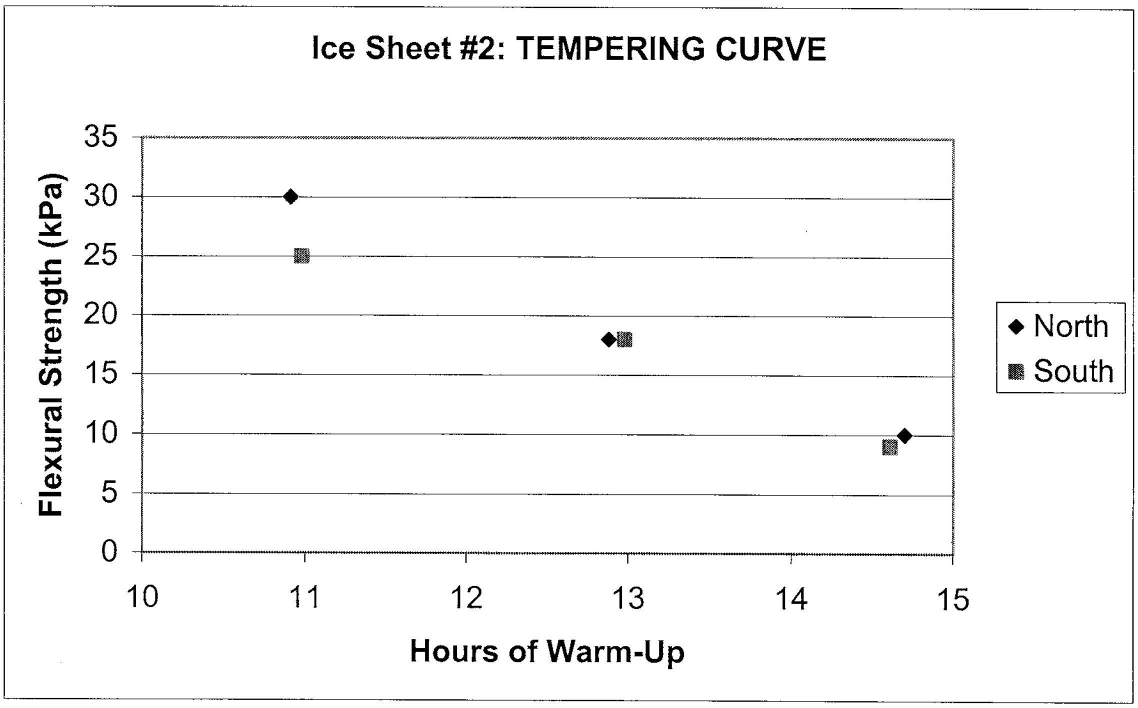
$h_i(CC) = 38.9 \pm .88, n = 64$

$h_i(SQP) = 38.75 \pm .62, n = 66$

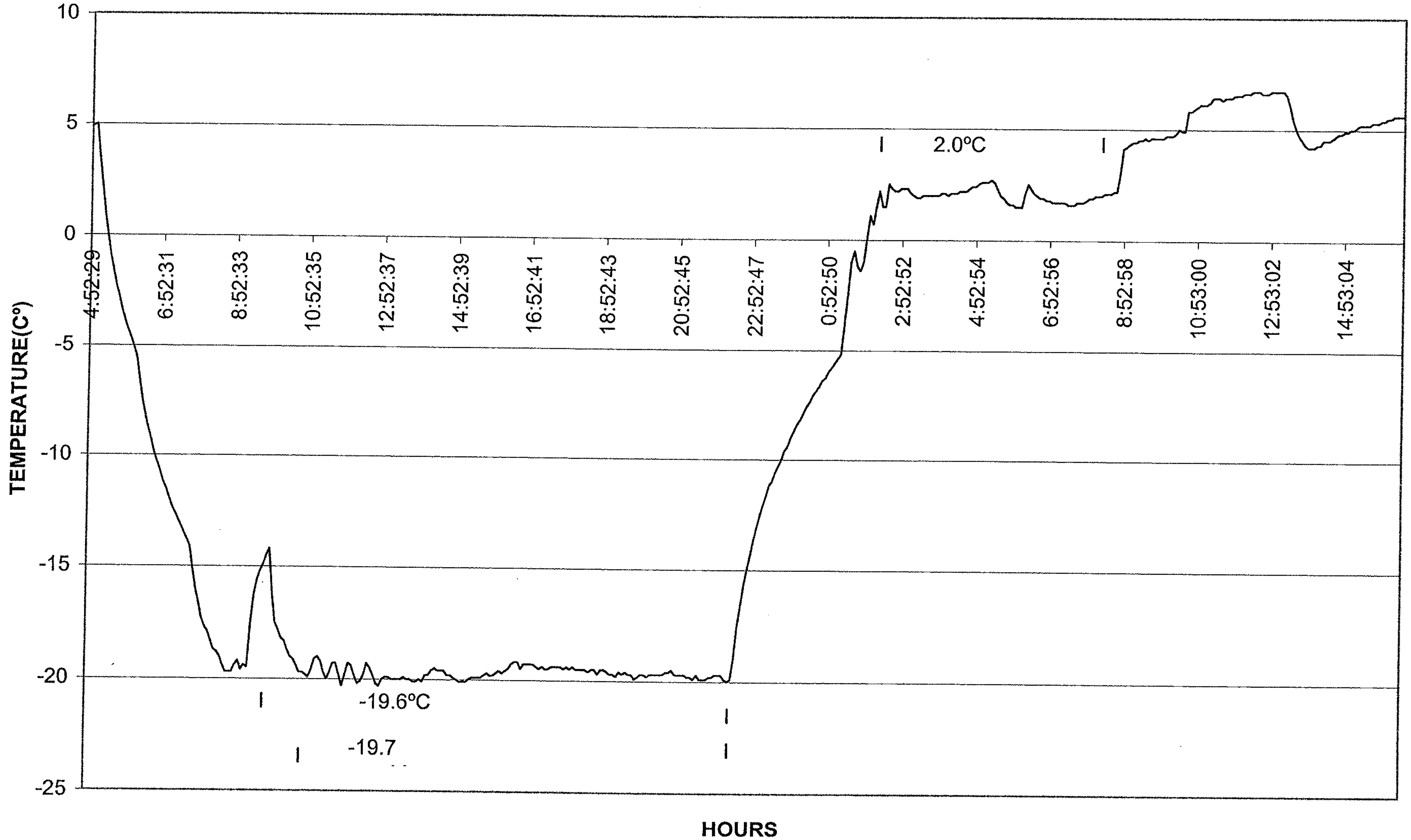
$h_i(NQP) = 39.24 \pm .80, n = 66$

$\alpha_F = 18.03 \pm 5.52, n = 26$

Run #	Date	Time	Flexural Strength		
			North	South	Mean
CC LEV ICE	02/05/2003	1040	20.1	18.6	19.4
SQP PRESAWN	02/05/2003	1205	13.4	12.8	19.0
NQP LEV ICE	02/05/2003	1308	9.9	9.6	18.9

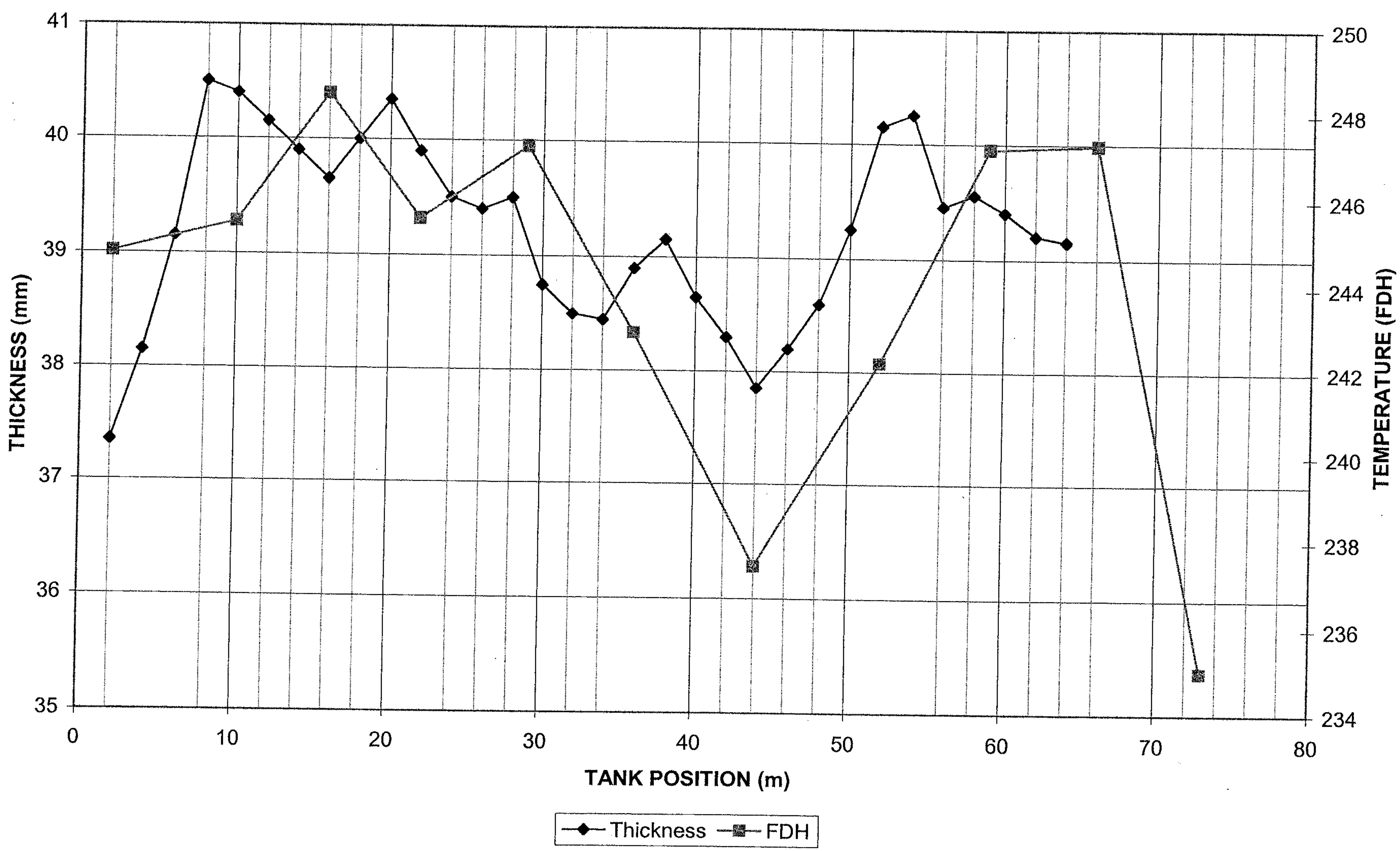


PICE2.938

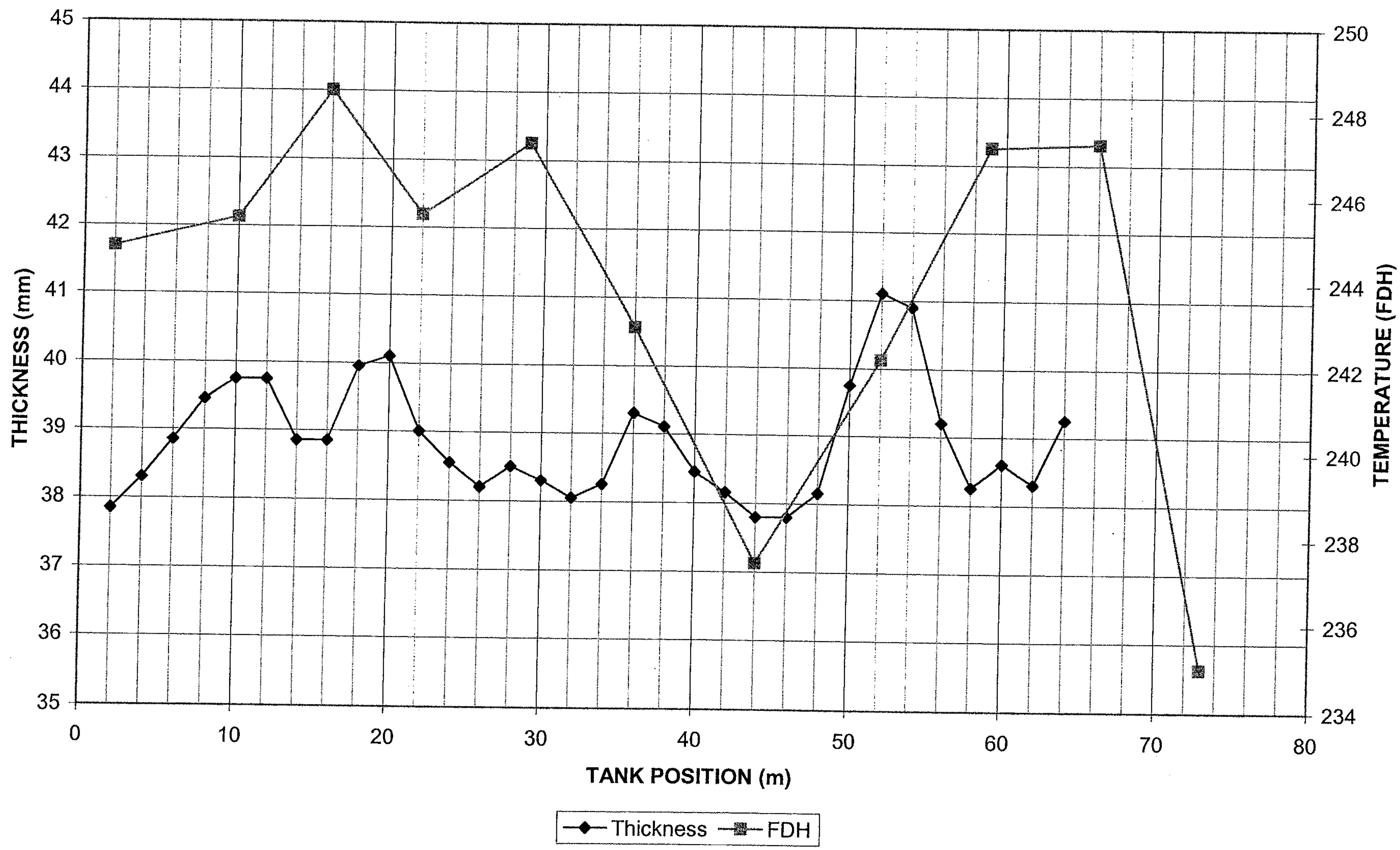


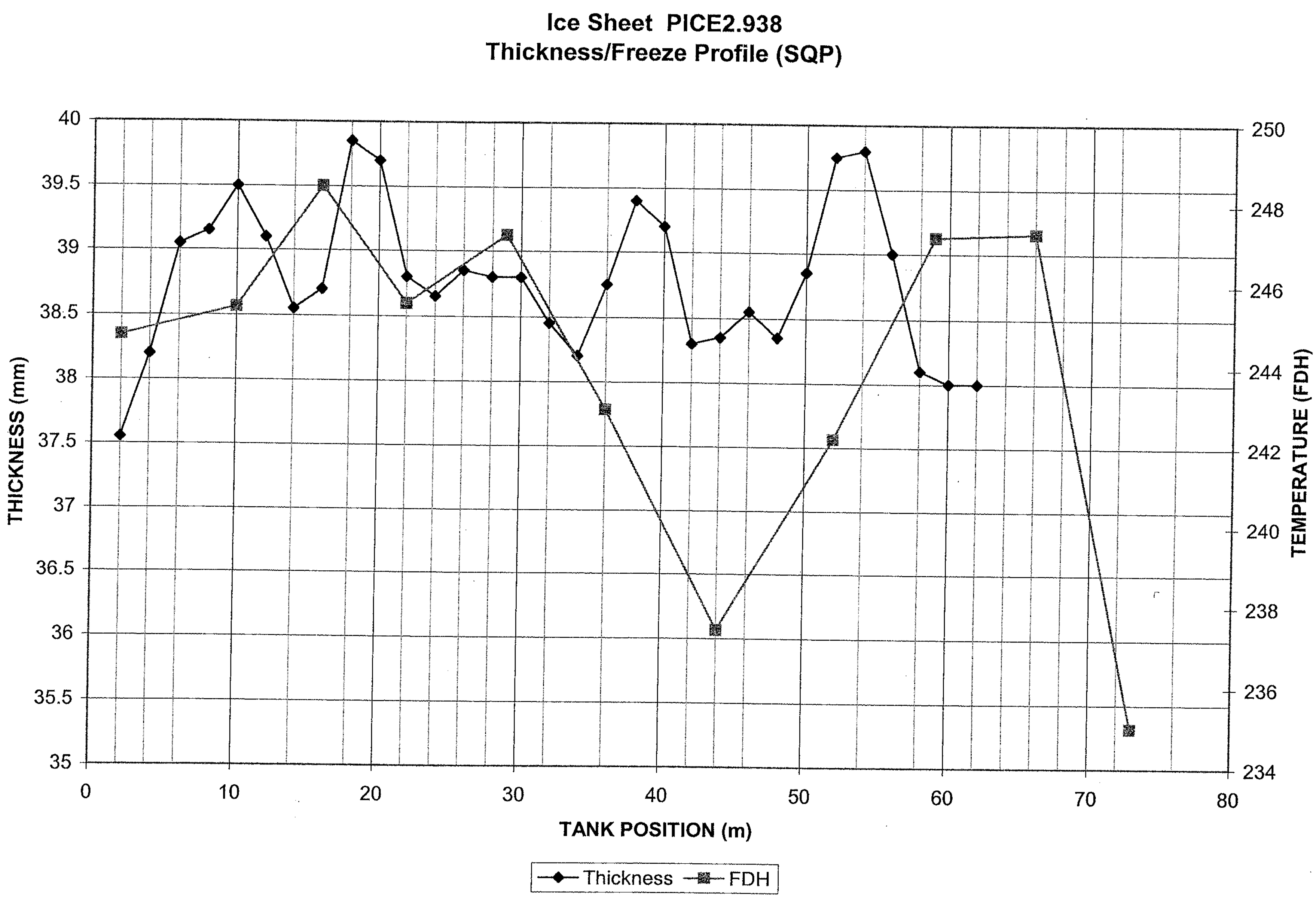
10
5
0
-5
-10
-15
-20
-25
TEMPERATURE(C°)
4:52:29
6:52:31
8:52:33
10:52:35
12:52:37
14:52:39
16:52:41
18:52:43
20:52:45
22:52:47
0:52:50
2:52:52
4:52:54
6:52:56
8:52:58
10:53:00
12:53:02
14:53:04
2.0ºC
-19.6ºC
-19.7
HOURS

Ice Sheet PICE2.938
Thickness/Freeze Profile (NQP)



Ice Sheet PICE2.938
Thickness/Freeze Profile (CC)




Ice Sheet PICE2.938
Thickness/Freeze Profile (SQP)
THICKNESS (mm)
40
39.5
39
38.5
38
37.5
37
36.5
36
35.5
35
TEMPERATURE (FDH)
250
248
246
244
242
240
238
236
234
0
10
20
30
40
50
60
70
80
TANK POSITION (m)
Thickness
FDH

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ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: PICE3

Project Number: 4295310

Target ice thickness(mm): 40.

EG/AD/S: (%) .39/.036/.04

Target ice strength(kPa): 35

Ice Type: M

SEEDING:

Air temp.(max/min) C: -19.4/-14.7
Seeding completed at 0927 5-MAY-2003
Seed volume: l 32.0
Humidity: tank(%) 80
room(%) 52

Tank water temp. C: 0.04
Seed duration: (min) 35.
Seed water temp.: C 32.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -19.2
Avg temp. of freeze cycle C -19.0
Total negative deg. hours 245.5
Avg growth rate: (mm/hr) 2.318

Time to target temp. hrs: 1.8
Duration of plateau hrs: 11.2
Duration of freeze cycle hrs: 12.9
Thickness at end of freeze:(mm) 29.9
Avg growth rate: (mm/fdh) .122

WARM-UP:

Warm-up commenced at 2221 5-MAY-2003
Time to tempering temp: (hrs) 3.7
Final ice thickness: (mm) 39.6
Total growth rate: (mm/hr) 3.067

Length of warm-up: (hrs) 15.
Avg tempering temperature: (C) 1.8
Ice growth during warm-up: (mm) 9.7
Total growth rate: (mm/fdh) .161

* thickness at end of freeze was estimated

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE3

Project Number: 4295310

Warm up commenced: 22:21 5-MAY-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0842	10.35	N S	37.5± 0.8 n= 3 39.6± 1.1 n= 3									
0905	10.73	40C	38.6		35.	26.6	710	9.0				
0935	11.23	40N	39.0 39.1	32.± 4.1 14.(u/d 42%)								
0940	11.32	40S	39.3 39.4	34.± 3.3 14.(u/d 41%)								
0947	11.43	40S	39.7									.941
0950	11.48	40N	39.1									.938
1003	11.70	15S	38.9									.940
1006	11.75	15N	39.7									.941
1019	11.97	30S	38.8									.939
1021	12.00	30N	39.0									.938
1031	12.17	60S	38.6									.938
1033	12.20	60N	38.3									.938
1102	12.68	N S	39.3± 0.6 n=31 39.2± 0.6 n=31									
1116	12.92	39S	40.1 39.6	20.±11.9 8.(u/d 40%)								
1120	12.98	39N	39.6 39.6	23.± 2.1 11.(u/d 48%)								
1212	13.85	N S	39.4± 0.4 n=32 38.9± 0.4 n=32									
1224	14.05	38S	39.6 39.5	23.± 1.2 11.(u/d 47%)								
1226	14.08	38N	40.0 40.8	21.± 5.6 6.(u/d 29%)								

1250	14.48	N	39.3± 0.7 n=31	
		S	39.5± 0.7 n=31	
1305	14.73	36N	39.7	16.± 1.9
			39.5	11. (u/d 72%)
1309	14.80	36S	39.6	18.± 4.9
			39.5	7. (u/d 39%)

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ICE SHEET PROPERTIES AND LOCATION DIAGRAM

ICE SHEET: PICE3

DATE: 05/08/2003

TEST-TIME: 10:52

Flexural strength @ Test-time

NORTH

	N	S
0		
5		
10		
15	31.81 ± 2.8, n=3 ρ=.940	32.07 ± 1.6, n=3 ρ=.940
20		
25		
30	26.64 ± 4.2, n=3 ρ=.938	29.02 ± 1.9, n=3 ρ=.939
35		
40	32.17 ± 4.1, n=4 ρ=.938	34.21 ± 3.3, n=4 ρ=.941
45		
50		
55		
60	33.97 ± 1.2, n=3 ρ=.938	32.83 ± 1.8, n=3 ρ=.938
65		
70		

ρ = .939 ± .0014, n=8

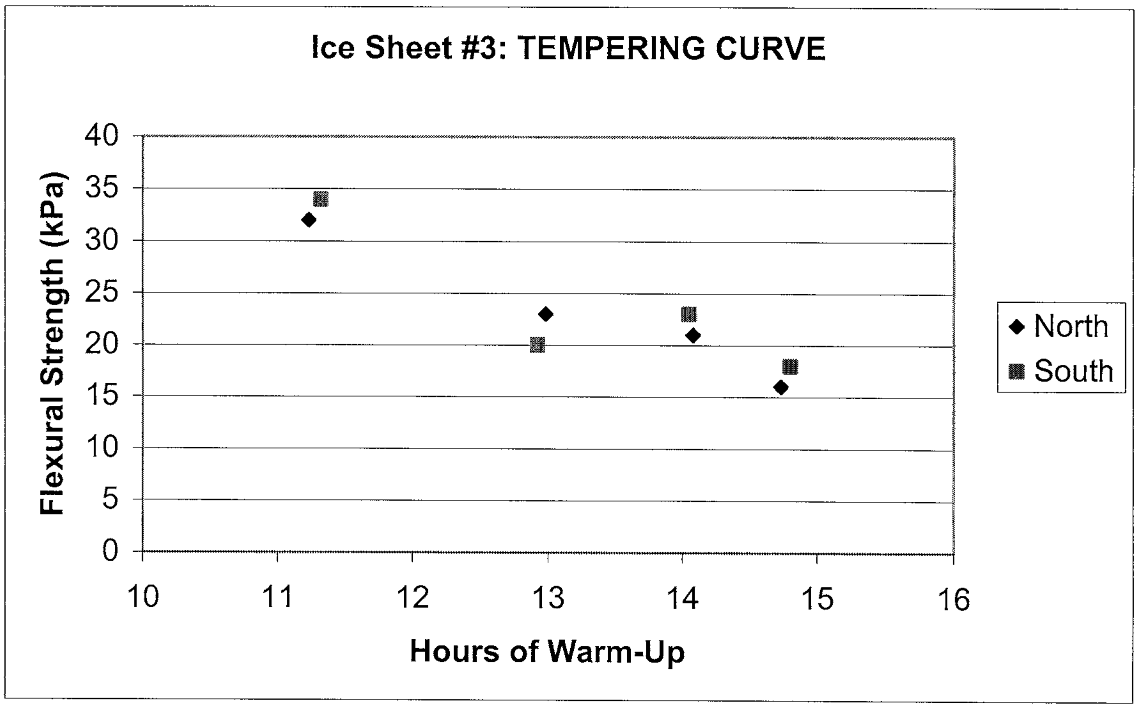
h_iCC = 39.14 ± .49, n=62

h_iSQP = 39.14 ± .49, n=62

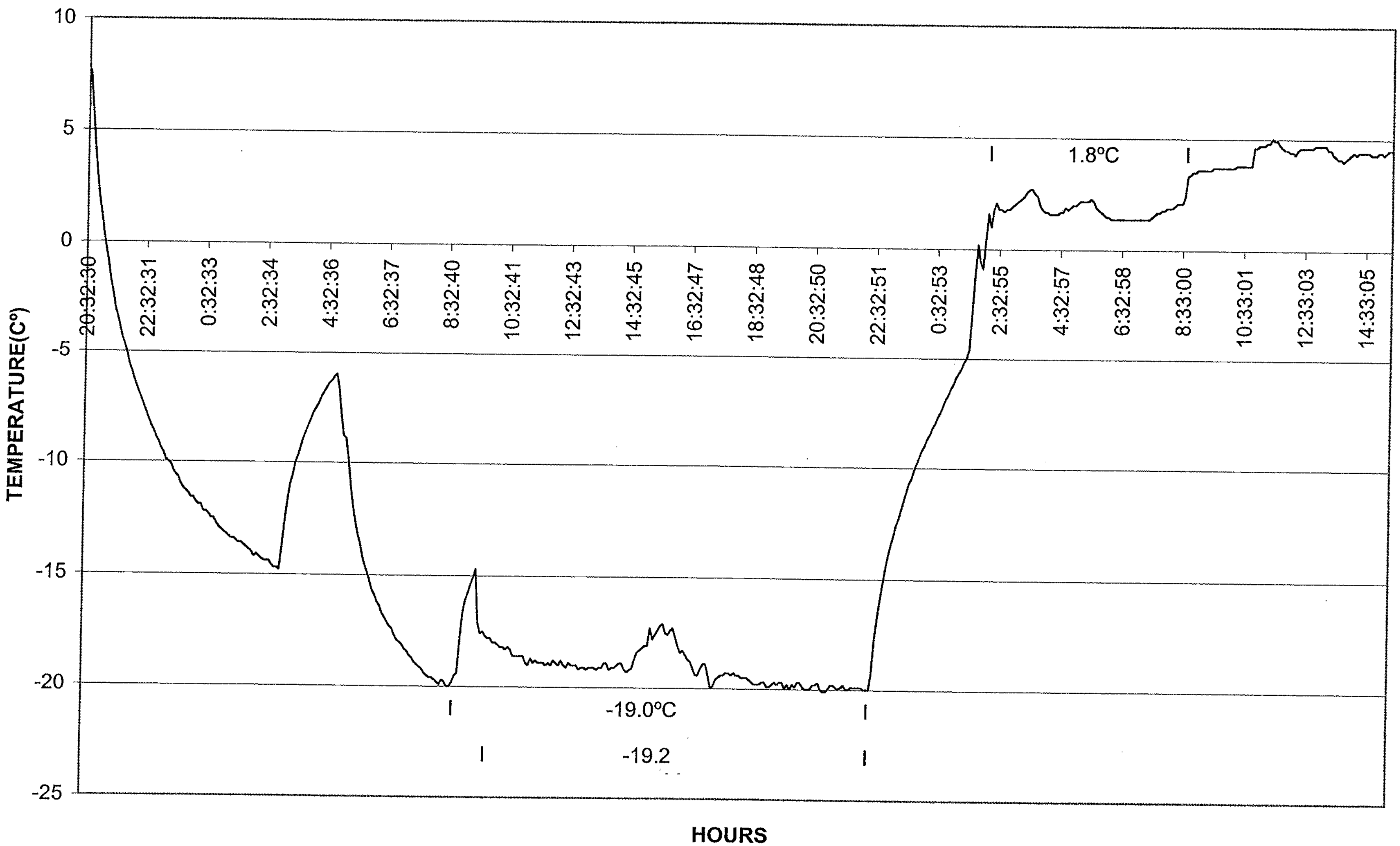
h_iNQP = 39.39 ± 0.70, n=62

σ_F = 31.71 ± 3.46, n=26

Run #	Date	Time	Flexural Strength		
			North	South	Mean
CC LEV ICE	06/05/2003	1052	25.3	26.2	25.8
SQP PRESAWN	06/05/2003	1155	20.7	22.3	21.5
NQP LEV ICE	06/05/2003	1232	18.4	20.3	19.3

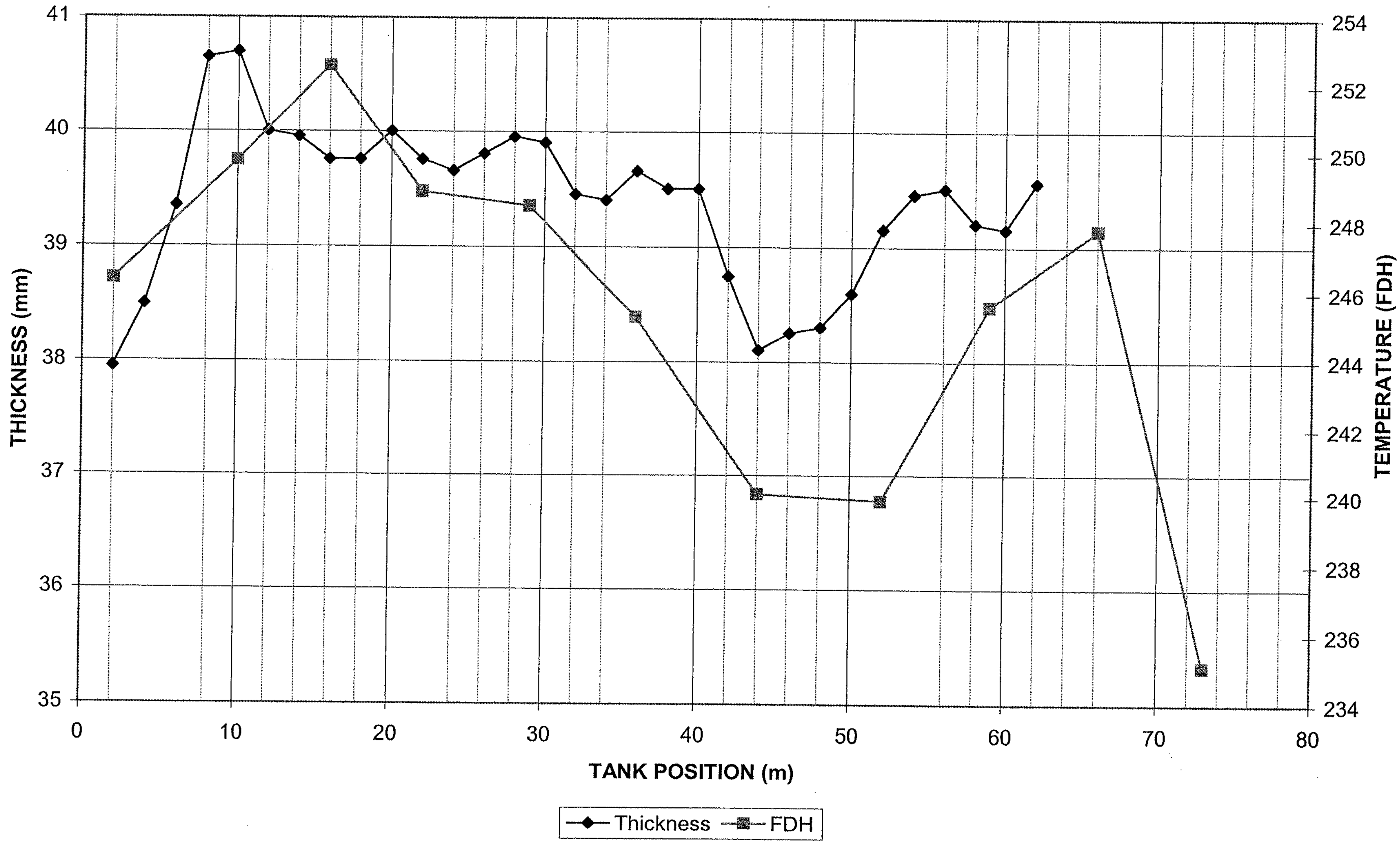


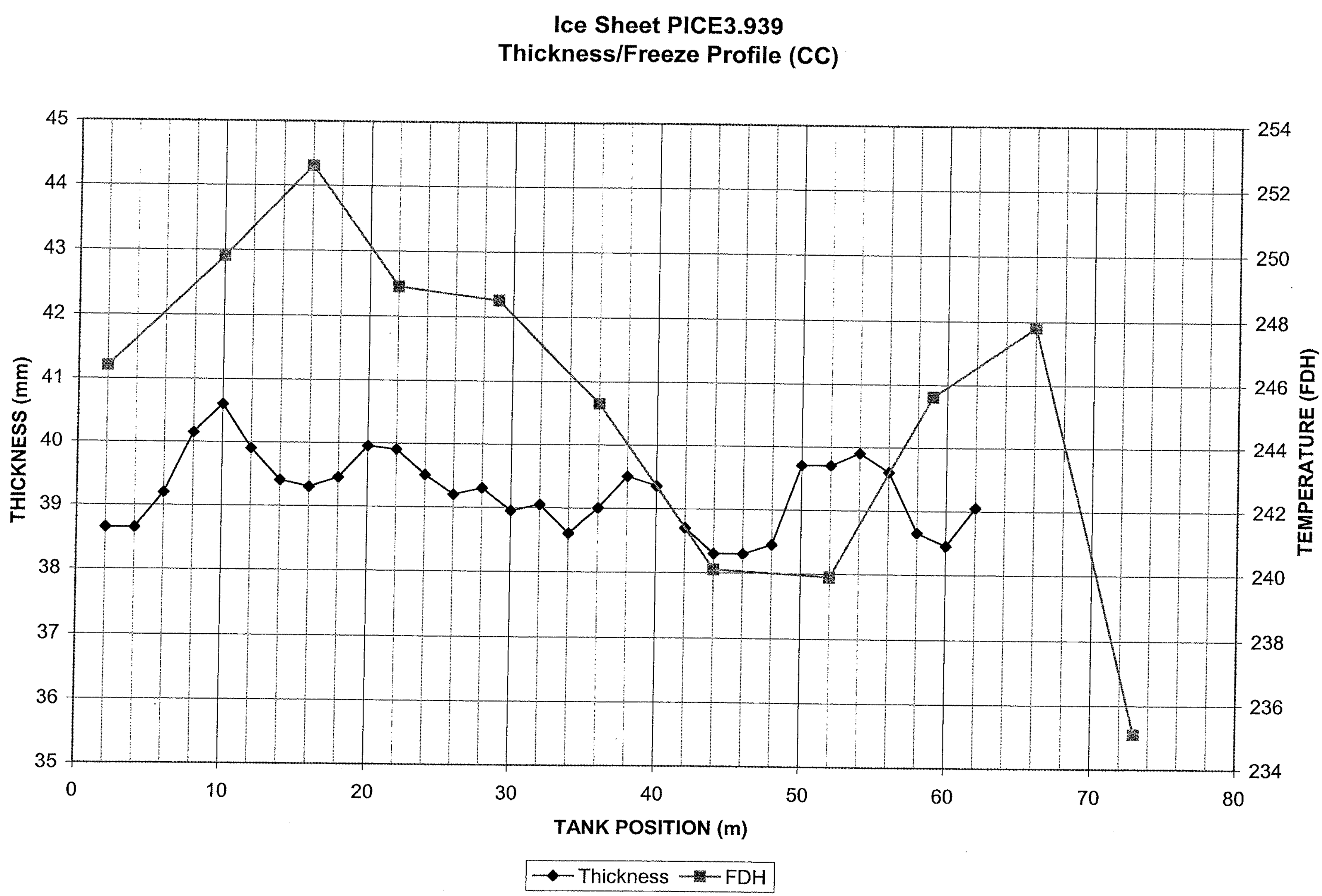
PICE3.939



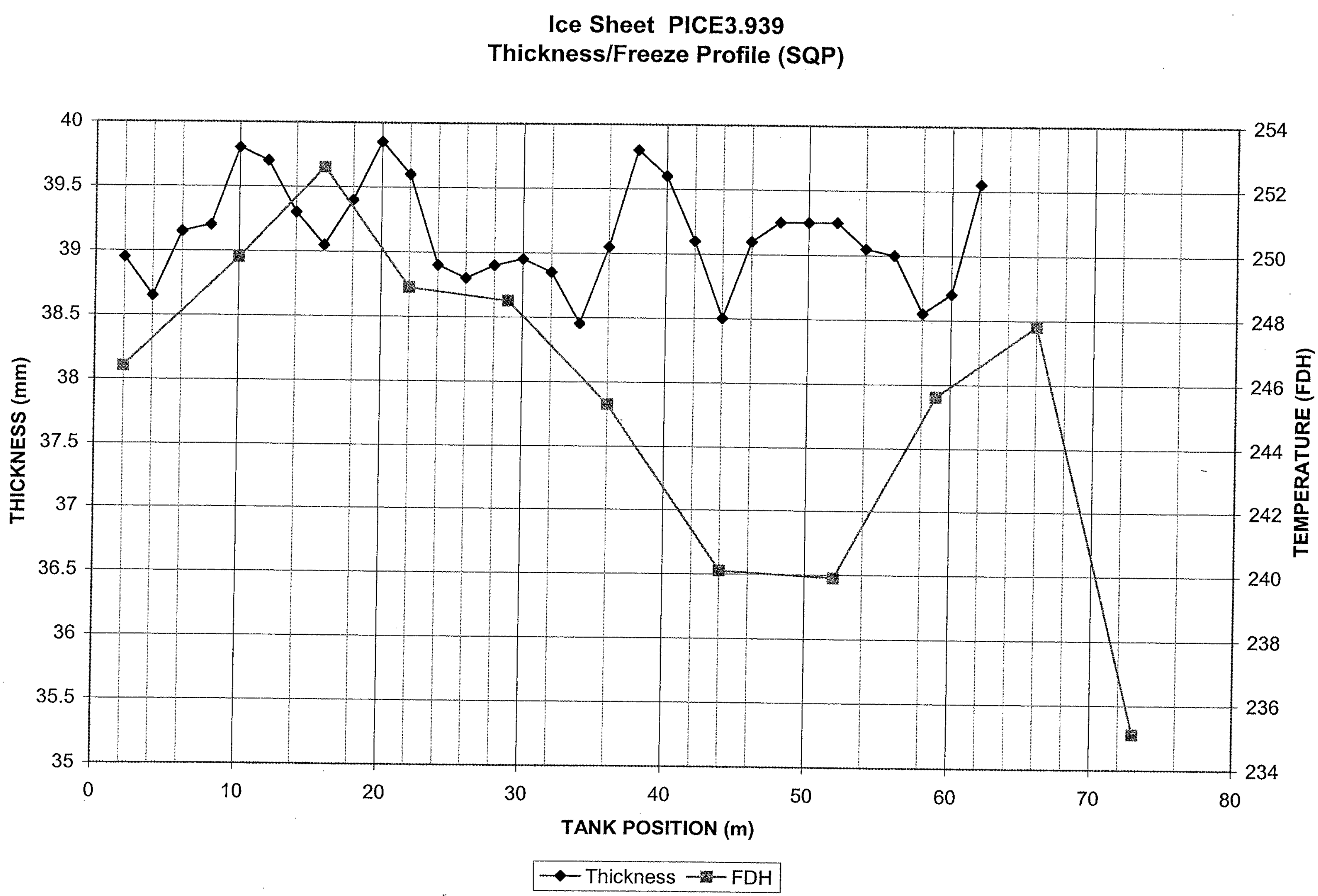
TEMPERATURE(C°)
10
5
0
-5
-10
-15
-20
-25
20:32:30
22:32:31
0:32:33
2:32:34
4:32:36
6:32:37
8:32:40
10:32:41
12:32:43
14:32:45
16:32:47
18:32:48
20:32:50
22:32:51
0:32:53
2:32:55
4:32:57
6:32:58
8:33:00
10:33:01
12:33:03
14:33:05
1.8ºC
-19.0ºC
-19.2
HOURS

Ice Sheet PICE3.939
Thickness/Freeze Profile (NQP)





Ice Sheet PICE3.939
Thickness/Freeze Profile (CC)
THICKNESS (mm)
45
44
43
42
41
40
39
38
37
36
35
TEMPERATURE (FDH)
254
252
250
248
246
244
242
240
238
236
234
0
10
20
30
40
50
60
70
80
TANK POSITION (m)
Thickness
FDH


Ice Sheet PICE3.939
Thickness/Freeze Profile (SQP)
THICKNESS (mm)
40
39.5
39
38.5
38
37.5
37
36.5
36
35.5
35
TEMPERATURE (FDH)
254
252
250
248
246
244
242
240
238
236
234
0
10
20
30
40
50
60
70
80
TANK POSITION (m)
Thickness
FDH

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ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: PICE4

Project Number: 4295310

Target ice thickness(mm): 40.

EG/AD/S: (%) .39/.036/.04

Target ice strength(kPa): 35

Ice Type: M

SEEDING:

Air temp.(max/min) C: -19.2/-14.0
Seeding completed at 0938 7-MAY-2003
Seed volume: l 33.3
Humidity: tank(%) 76
room(%) 21

Tank water temp. C: -.05
Seed duration: (min) 40.
Seed water temp.: C 32.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -19.9
Avg temp. of freeze cycle C -19.7
Total negative deg. hours 245.7
Avg growth rate: (mm/hr) 2.478

Time to target temp. hrs: 0.9
Duration of plateau hrs: 11.5
Duration of freeze cycle hrs: 12.4
Thickness at end of freeze:(mm) 30.8
Avg growth rate: (mm/fdh) .125

WARM-UP:

Warm-up commenced at 2200 7-MAY-2003
Time to tempering temp: (hrs) 3.3
Final ice thickness: (mm) 39.5
Total growth rate: (mm/hr) 3.180

Length of warm-up: (hrs) 15.
Avg tempering temperature: (C) 2.0
Ice growth during warm-up: (mm) 8.7
Total growth rate: (mm/fdh) .161

* thickness at end of freeze was estimated

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE4 Project Number: 4295310

Warm up commenced: 22:00 7-MAY-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0830	10.50	N	39.0± 0.8 n= 3									
		S	39.8± 1.3 n= 3									
0844	10.73	40C	38.8		33.	20.6	612	8.4				
0908	11.13	40S	39.2	31.± 0.5								
			39.6	11. (u/d 35%)								
0910	11.17	40N	39.2	29.± 3.2								
			39.3	17. (u/d 59%)								
0915	11.25	40N	39.5									.939
0918	11.30	40S	39.7									.937
0930	11.50	15S	38.9									.939
0935	11.58	15N	39.7									.938
0943	11.72	30S	38.7									.939
0948	11.80	30N	38.8									.938
0958	11.97	60S	39.0									.942
1002	12.03	60N	39.5									.940
1030	12.50	N	39.1± 0.7 n=32									
		S	39.1± 0.7 n=32									
1041	12.60											
1041	12.68	38N	39.6	23.± 1.6								
			39.7	12. (u/d 53%)								
1042	12.70	38S	40.3	24.± 1.0								
			40.8	11. (u/d 46%)								
1132	13.53	N	39.2± 0.6 n=32									
		S	39.3± 0.6 n=32									
1144	13.73	36N	39.1	18.± 0.9								
			39.4	11. (u/d 59%)								
1146	13.77	36S	39.7	22.± 1.8								

			40.1	13.(u/d 61%)
1203	14.05	N	39.3± 0.7 n=32	
		S	39.2± 0.7 n=32	
1224	14.40	35S	39.4	17.± 1.9
			39.3	12.(u/d 71%)
1225	14.42	35N	39.0	19.± 0.8
			40.0	14.(u/d 71%)

Run #	Date	Time	Hours from Warm-up	Flexural Strength north	Flexural Strength south	Flexural Strength mean
1	05/08/2003	1014	12.23	24.1	25.6	24.8
2	05/08/2003	1114	13.23	19.4	21.5	20.4
3	05/08/2003	1154	13.90	17.6	21.3	19.5

ATIONAL RESEARCH COUNCIL - INSTITUTE FOR MARINE DYNAMICS

ICE SHEET PROPERTIES AND LOCATION DIAGRAM

ICE SHEET: PICE4

DATE: May 8/2003

TEST-TIME: 10:14

Flexural strength @ Test-time

NORTH

	N	S
0		
5		
10		
15	27.27±2.5, n=3 ρ=.938	24.44±2.4, n=3 ρ=.939
20		
25		
30	18.06±2.6, n=3 ρ=.938	24.41±0.9, n=3 ρ=.939
35		
40	25.07±2.8, n=4 ρ=.939	25.91±0.4, n=3 ρ=.937
45		
50		
55		
60	30.08±2.1, n=3 ρ=.940	29.84±4.1, n=3 ρ=.942
65		
70		

ρ_i = .939 ± .0015, n=8

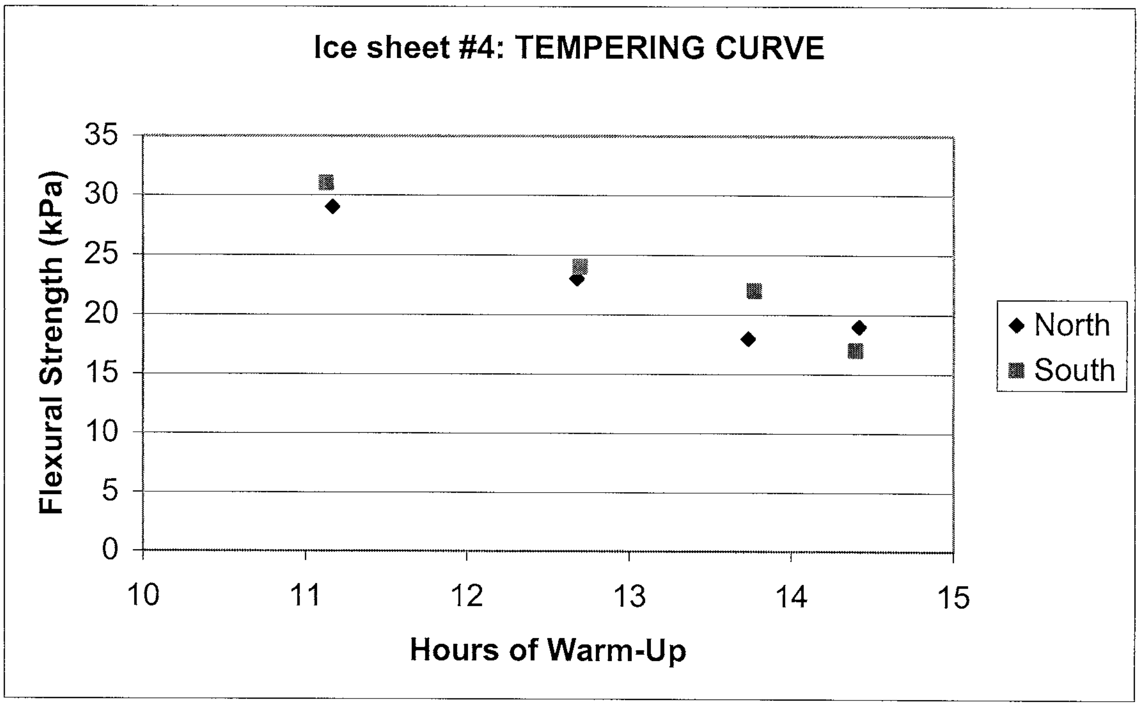
h_i CC = 39.29 ± .67, n=64

h_i SQP = 39.26 ± .64, n=64

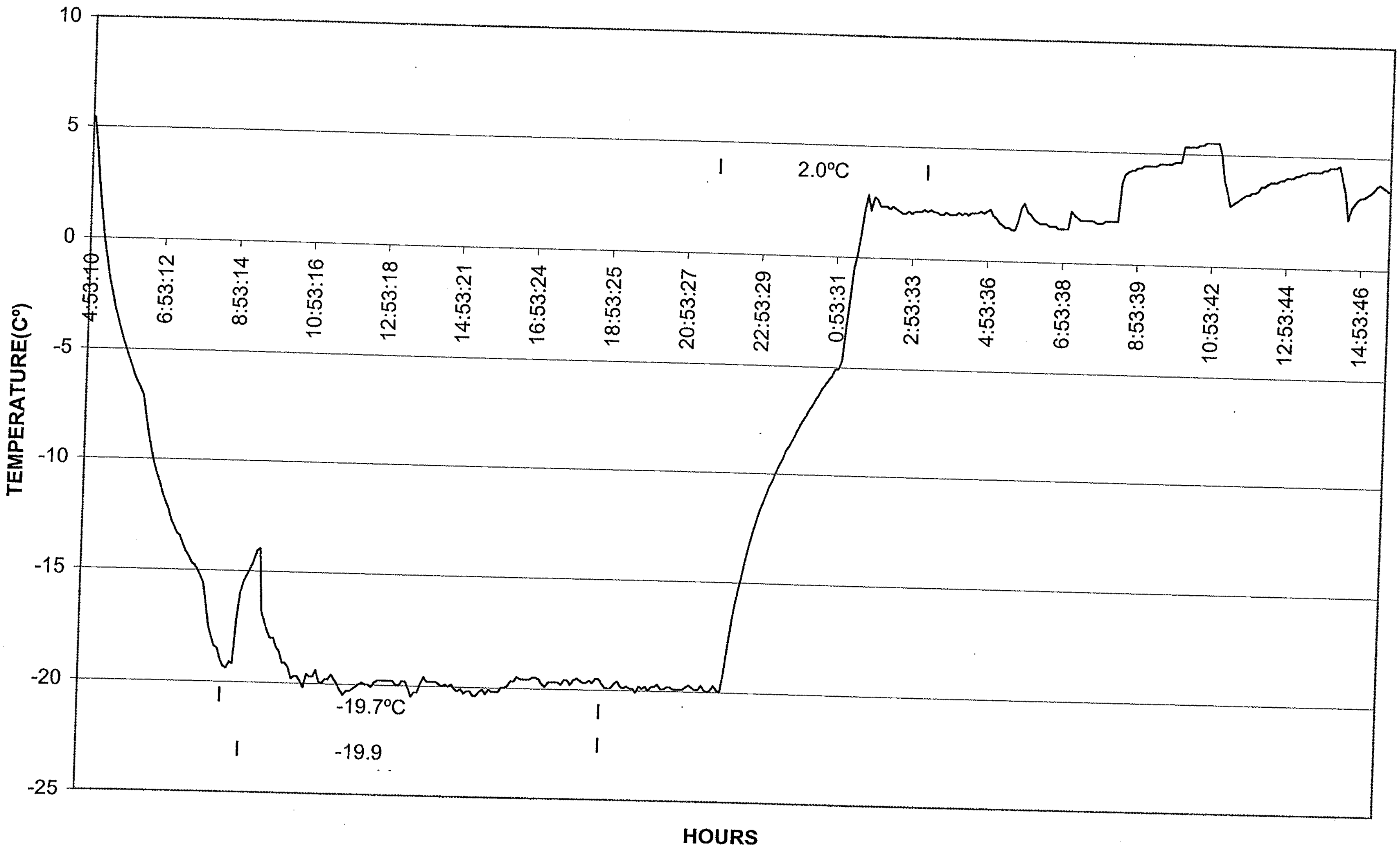
h_i NQP = 39.29 ± .69, n=64

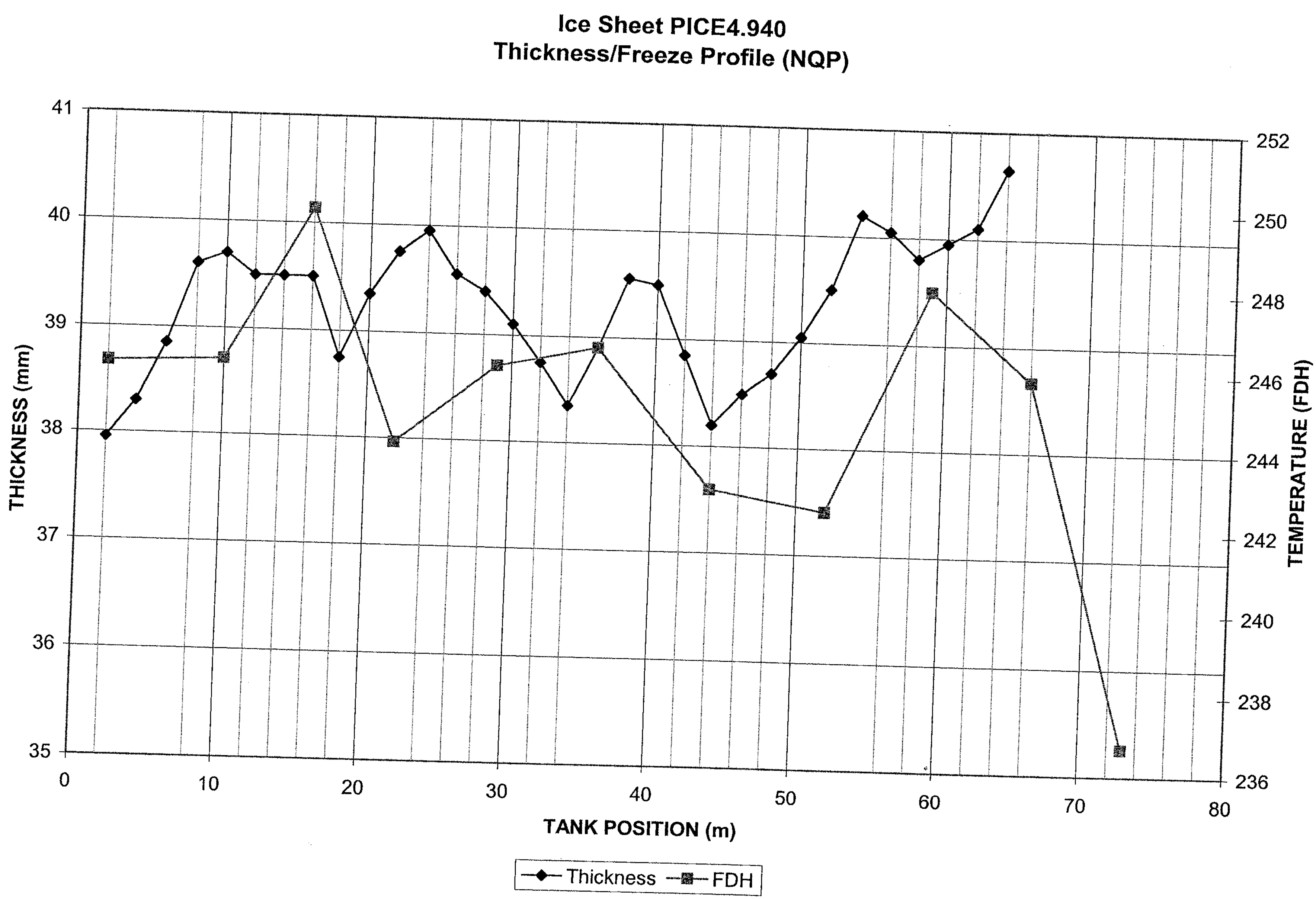
σ_F = 25.61 ± 4.12, n=25

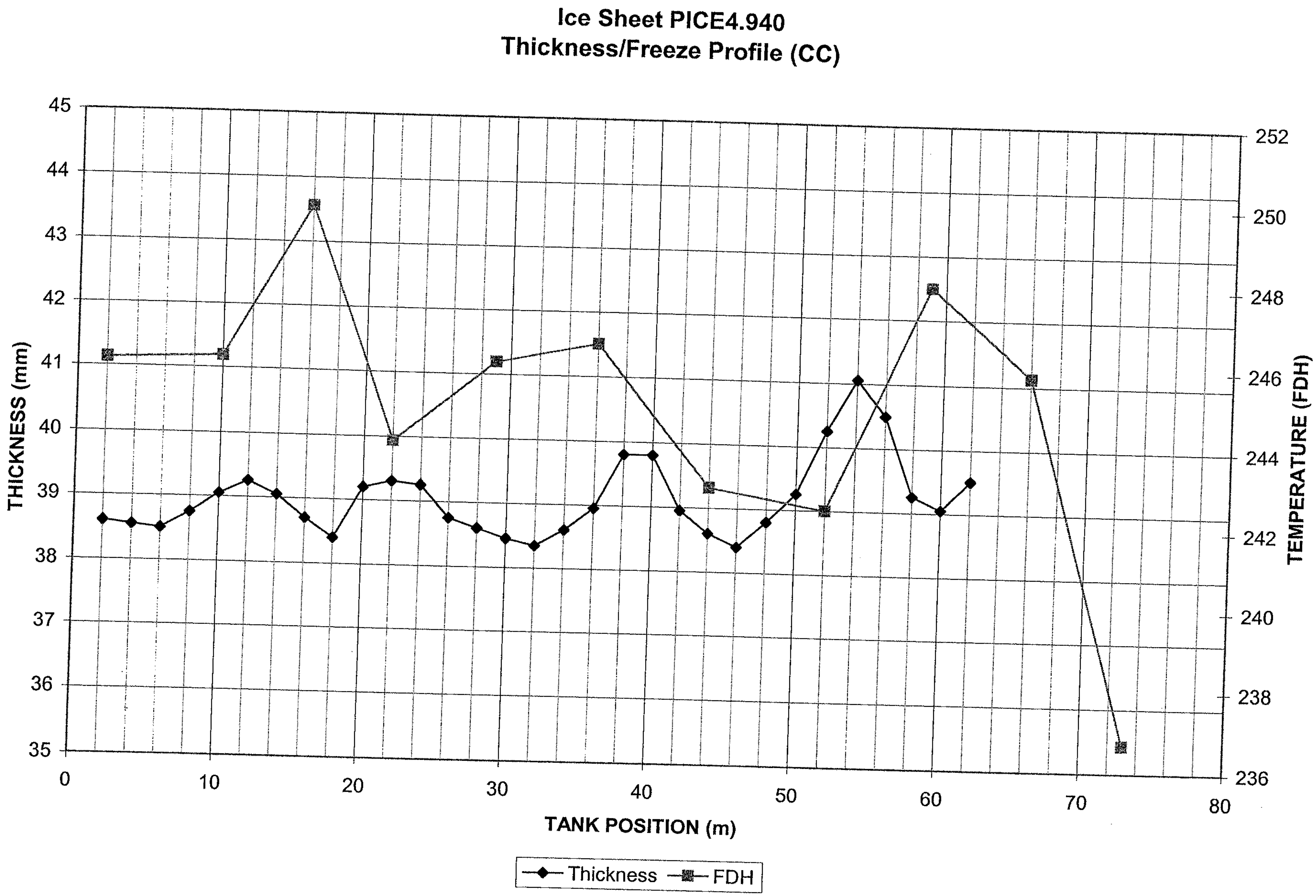
Run #	Date	Time	Flexural Strength		
			North	South	Mean
CC LEV ICE	08/05/2003	1014	n/a	n/a	n/a
SQP PRESAWN	08/05/2003	1114	n/a	n/a	n/a
NQP LEV ICE	08/05/2003	1154	n/a	n/a	n/a

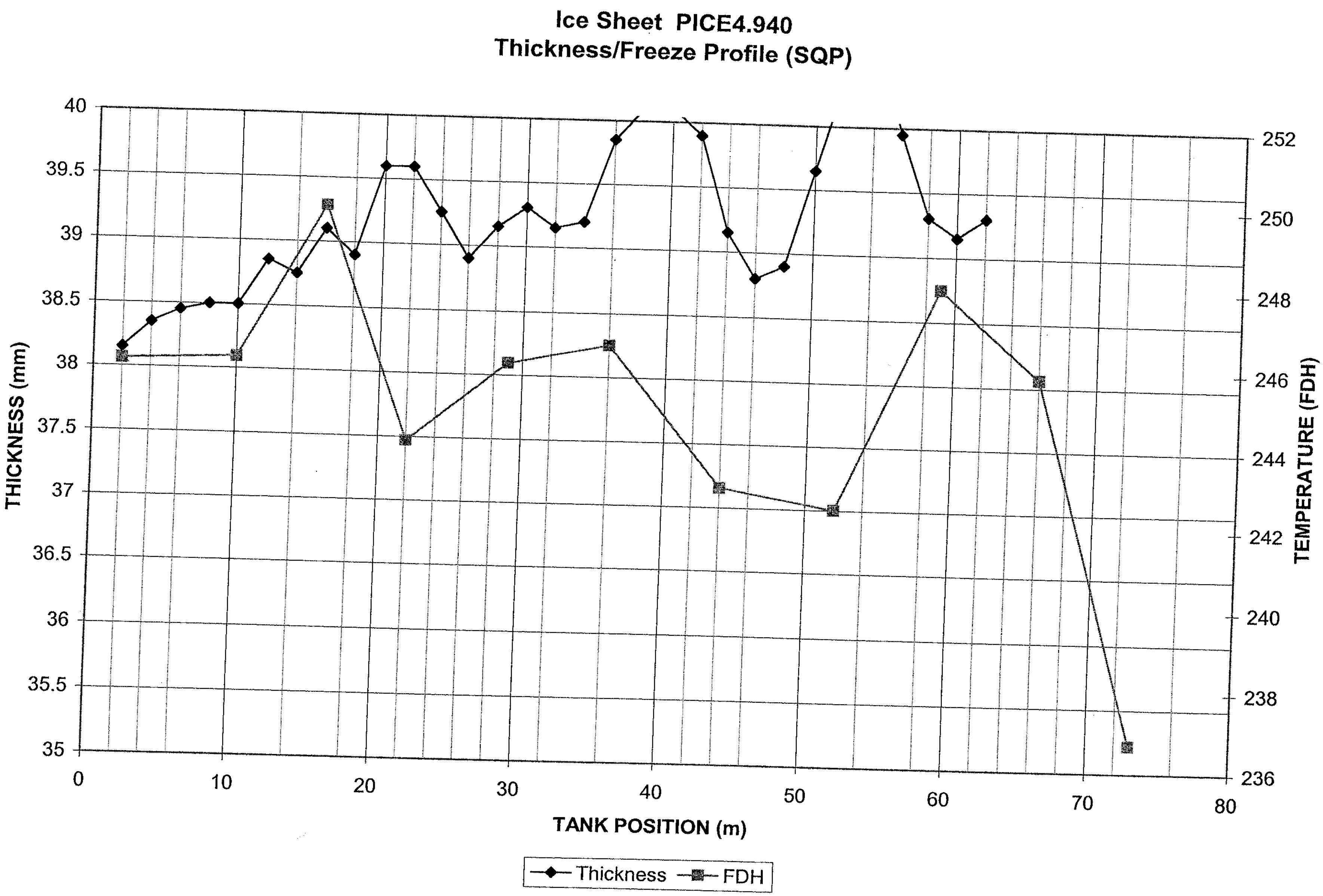


PICE4.940


10
5
0
-5
-10
-15
-20
-25
TEMPERATURE(C°)
4:53:10
6:53:12
8:53:14
10:53:16
12:53:18
14:53:21
16:53:24
18:53:25
20:53:27
22:53:29
0:53:31
2:53:33
4:53:36
6:53:38
8:53:39
10:53:42
12:53:44
14:53:46
2.0ºC
-19.7ºC
-19.9
HOURS


Ice Sheet PICE4.940
Thickness/Freeze Profile (NQP)
THICKNESS (mm)
41
40
39
38
37
36
35
TEMPERATURE (FDH)
252
250
248
246
244
242
240
238
236
0
10
20
30
40
50
60
70
80
TANK POSITION (m)
Thickness
FDH


Ice Sheet PICE4.940
Thickness/Freeze Profile (CC)
45
44
43
42
41
40
39
38
37
36
35
THICKNESS (mm)
252
250
248
246
244
242
240
238
236
TEMPERATURE (FDH)
0
10
20
30
40
50
60
70
80
TANK POSITION (m)
Thickness
FDH


Ice Sheet PICE4.940
Thickness/Freeze Profile (SQP)
THICKNESS (mm)
40
39.5
39
38.5
38
37.5
37
36.5
36
35.5
35
TEMPERATURE (FDH)
252
250
248
246
244
242
240
238
236
TANK POSITION (m)
0
10
20
30
40
50
60
70
80
Thickness
FDH

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ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: PICE5

Project Number: 593

Target ice thickness(mm): 40.

EG/AD/S: (%) .39/.036/.04

Target ice strength(kPa): 35

Ice Type: M

SEEDING:

Air temp.(max/min) C: -19.2/-14.0
Seeding completed at 0938 13-MAY-2003
Seed volume: l 31.0
Humidity: tank(%) 79
room(%) 59

Tank water temp. C: 0.02
Seed duration: (min) 40.
Seed water temp.: C 32.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -19.9
Avg temp. of freeze cycle C -19.7
Total negative deg. hours 245.7
Avg growth rate: (mm/hr) 2.498

Time to target temp. hrs: 1.3
Duration of plateau hrs: 11.2
Duration of freeze cycle hrs: 12.4
Thickness at end of freeze:(mm) 31.0
Avg growth rate: (mm/fdh) .126

ıRM-UP:

Warm-up commenced at 2200 13-MAY-2003
Time to tempering temp: (hrs) 3.2
Final ice thickness: (mm) 40.7
Total growth rate: (mm/hr) 3.277

Length of warm-up: (hrs) 17.
Avg tempering temperature: (C) 2.0
Ice growth during warm-up: (mm) 9.7
Total growth rate: (mm/fdh) .166

* thickness at end of freeze was estimated

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE5

Project Number: 593

Warm up commenced: 22:00 13-MAY-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0905	11.08	40S	39.5 39.7	31.± 7.2 14.(u/d 44%)								
0908	11.13	40N	40.0 39.4	41.± 4.6 10.(u/d 24%)								
0958	11.97	39N	40.1 40.1	26.± 5.1 10.(u/d 37%)								
0959	11.98	39S	40.1 40.2	23.± 3.2 12.(u/d 52%)								
1055	12.92	37N	40.8 40.4	24.± 6.2 9.(u/d 38%)								
1100	13.00	37S	40.4 40.7	24.± 3.1 8.(u/d 34%)								
1137	13.62	40N	39.5									.936
1139	13.65	40C	39.8									.939
1142	13.70	40S	39.9									.939
1204	14.07	38S	40.8 40.7	16.± 1.2 11.(u/d 65%)								
1205	14.08	38N	40.7 40.5	23.± 3.2 7.(u/d 29%)								
1422	16.37	34N	40.1 40.4	6.± 1.0 5.(u/d 73%)								
1426	16.43	34S	40.4 40.3	16.± 0.7 10.(u/d 61%)								
1505	17.08	36S	40.7 40.1	21.± 1.8 10.(u/d 49%)								
1510	17.17	36N	40.6 40.8	14.± 1.1 9.(u/d 63%)								

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ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: PICE5

Project Number: K♣K♣

Warm up commenced: 00:00 13-MAY-2003

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
****	11.08											
****	11.13											
****	11.97	39N	40.1± 0.0 n= 2									
		39N	*****±**** n= 1									
****	11.98											
1055	12.92	37N	40.8	24.± 6.2								
			40.4	9.(u/d 38%)								
1100	13.00	37S	40.4	24.± 3.1								
			40.7	8.(u/d 34%)								
1109	13.15	10S	40.6									.940
1113	13.22	10C	41.0									.937
1115	13.25	10N	40.4									.938
1118	13.30	20N	40.3									.938
1121	13.35	20C	39.9									.938
1125	13.42	20S	40.1									.940
1129	13.48	30S	39.6									.941
1131	13.52	30C	38.9									.942
1134	13.57	30N	39.5									.938
1137	13.62	40N	39.5									.936
1139	13.65	40C	39.8									.939
1142	13.70	40S	39.9									.939
1145	13.75	50N	39.6									.936
1147	13.78	50C	40.2									.936
1149	13.82	50S	40.6									.939
1153	13.88	60S	40.7									.939

1155	13.92	60N	41.3		
1157	13.95	60C	40.6		.939
1204	14.07	38S	40.8 40.7	16.± 1.2 11.(u/d 65%)	.939
1205	14.08	38N	40.7 40.5	23.± 3.2 7.(u/d 29%)	
1325	15.42	5S	38.6		
1328	15.47	5N	38.9		.942
1331	15.52	5C	39.1		.940
1335	15.58	15S	40.0		.945
1337	15.62	15C	40.5		.944
1340	15.67	15N	39.8		.941
1343	15.72	25S	39.3		.943
1345	15.75	25C	40.1		.943
1347	15.78				.942
****	15.80				
****	15.87	35C	40.3		
1355	15.92	35N	40.1		.943
1356	15.93	45S	40.3		.945
1359	15.98	45C	40.2		.943
1401	16.02				.944
1422	16.37	34N	40.1 40.4	6.± 1.0 5.(u/d 73%)	
1426	16.43	34S	40.4 40.3	16.± 0.7 10.(u/d 61%)	
1505	17.08	36S	40.7 40.1	21.± 1.8 10.(u/d 49%)	
1510	17.17	36N	40.6 40.8	14.± 1.1 9.(u/d 63%)	
****	0.00				

...TIONAL RESEARCH COUNCIL – INSTITUTE FOR MARINE DYNAMICS

ICE SHEET PROPERTIES AND LOCATION DIAGRAM

ICE SHEET: PICES

DATE: 05/14/03

TEST-TIME: 10:00

N C S

Flexural strength @ Test-time

NORTH

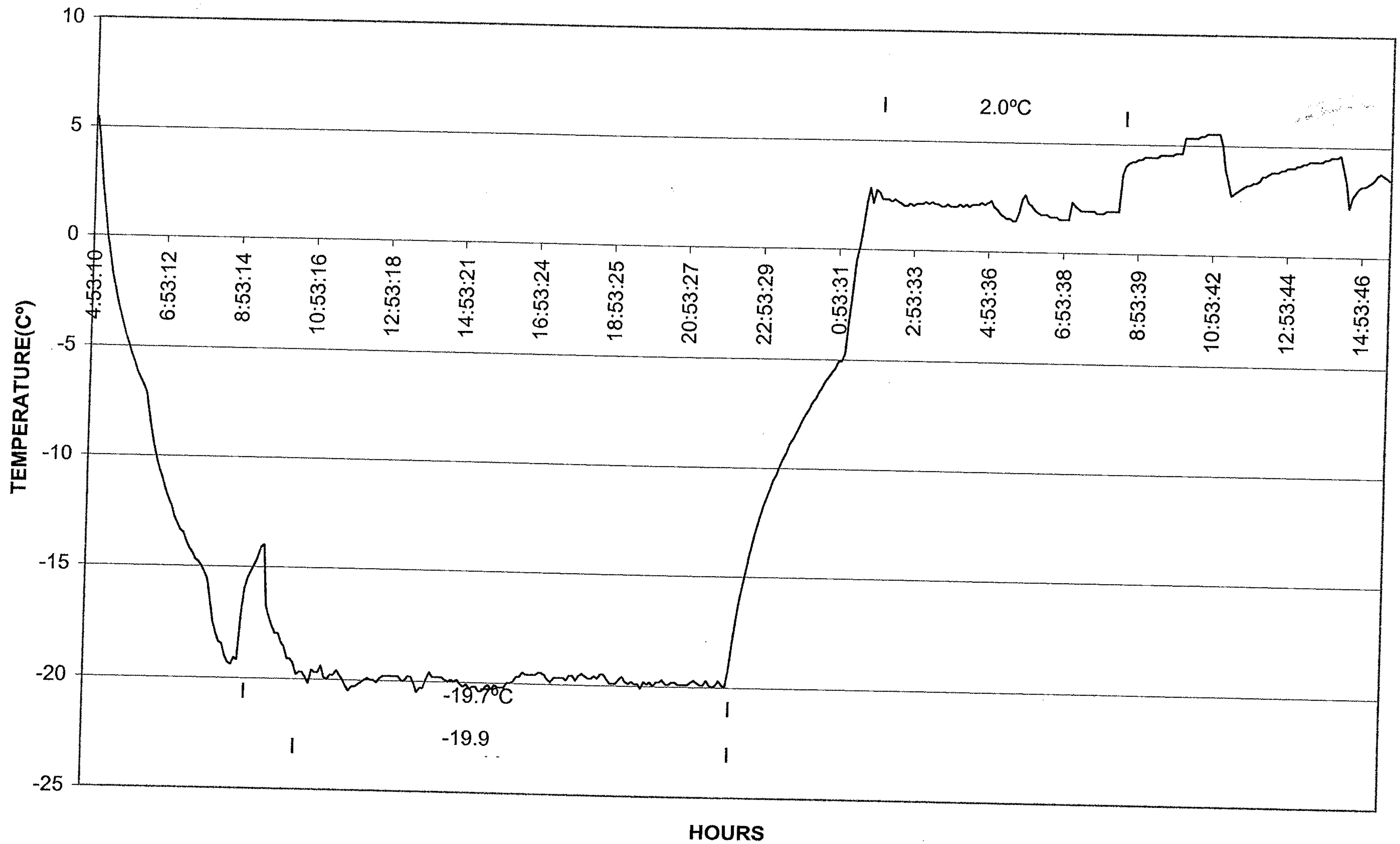
0	
5	ρ = .940, .945, .942
10	ρ = .938, .937, .940
15	ρ = .943, .941, .944
20	ρ = .938, .938, .940
25	ρ = .942, .943, .942
30	ρ = .938, .942, .941
35	ρ = .945, .943, .942
40	ρ = .936, .939, .939
45	ρ = .947, .944, .943
50	ρ = .936, .934, .939
55	ρ .944, .943, .941
60	ρ = .939, .939, .939
65	ρ = .944, .944, .947
70	

$\rho = 0.941 \pm .0029, n = 39$

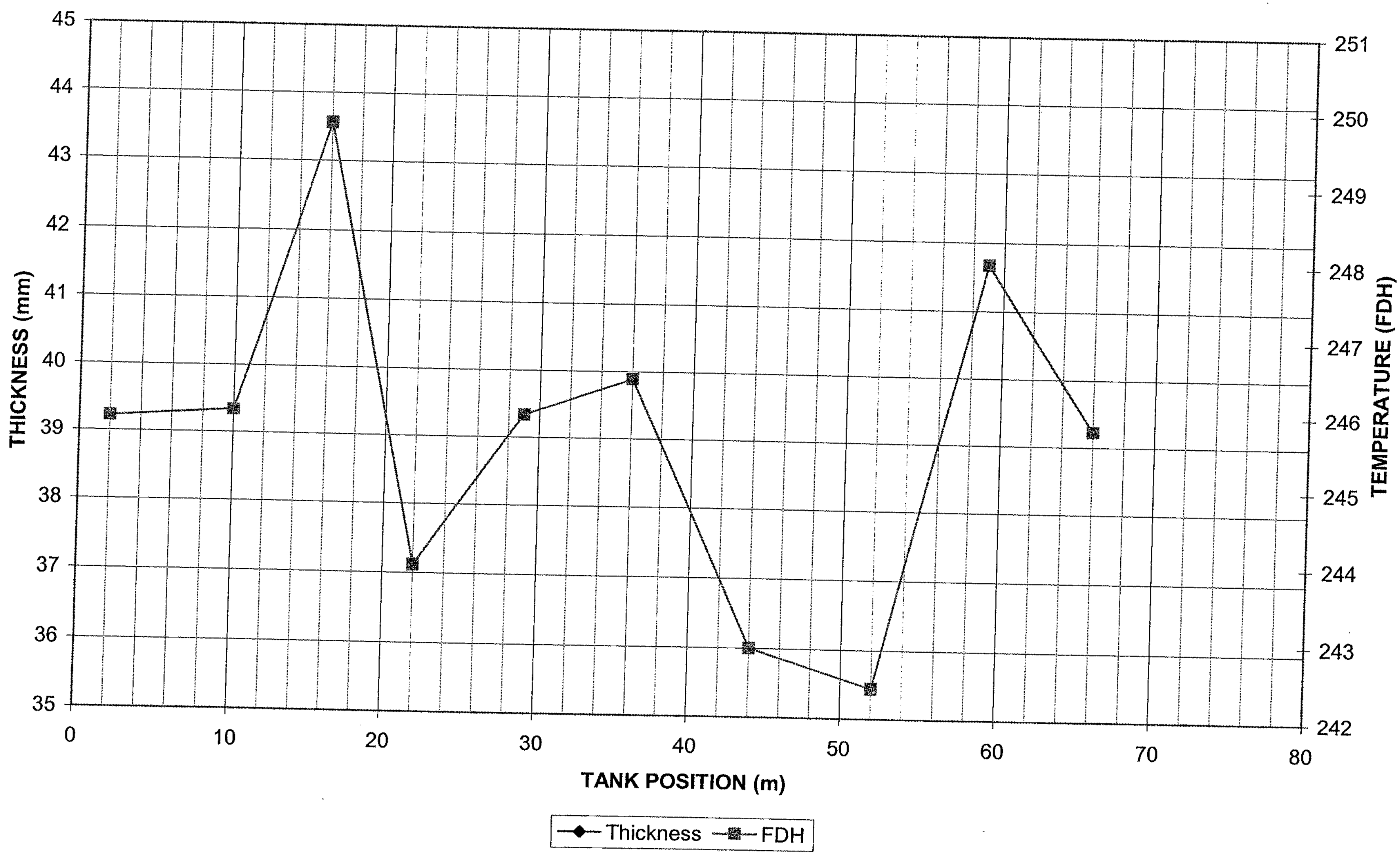
$\alpha_F = 34.14 \pm 7.0, n = 39$

$h_i = 40.0 \pm 3.9, n = 108$

PICE5.941


10
5
0
-5
-10
-15
-20
-25
TEMPERATURE(C°)
4:53:10
6:53:12
8:53:14
10:53:16
12:53:18
14:53:21
16:53:24
18:53:25
20:53:27
22:53:29
0:53:31
2:53:33
4:53:36
6:53:38
8:53:39
10:53:42
12:53:44
14:53:46
2.0°C
-19.7°C
-19.9
HOURS

Ice Sheet PICE5.941
Thickness/Freeze Profile (CC)



Appendix 4:

Test Matrix,

File Naming Convention,

Resistance Calculations

APPENDIX 4:

Types of Experiments:

Three types of experiments are needed. These are:

a) Resistance experiments in open water
b) Resistance experiments in level ice
c) Resistance experiment in pack ice

Experiments in Open Water:

<u>Standard Resistance Experiments in Open Water</u>

- The ship model is equipped with turbulent stimulation studs and uses beach absorbers (speeds from 0.3m/s to 1.7 m/s). All tests conducted in the center channel.
- Test repeated six times.

Test	Model Speed (m/s)
V1	0.76 0.88 1.01
V2	1.14 1.26
V3	0.82 0.95
V4	1.07 1.2
V5	0.53 1.0 1.46
V6	0.3 0.76 1.23
V7	1.7

<u>Baseline Experiments in Open Water</u>

- Same model speeds as in the ice tests (0.1 m/s, 0.2 m/s, 0.4 m/s and 0.6 m/s).
- Constant speed along the entire useable length of the ice tank.
- No disturbance stimulators and no beach absorbers.
- Repeat tests as much as possible.
- Completed the following tests:

Case #	Model Speed, m/s
1	0.1 (CC, 7 times)
2	0.2 (CC 2 times, NQP and SQP 1 time each)
3	0.4 (CC 2 times, NQP and SQP 1 time each)
4	0.6 (CC, 11 times)

Completed Tests in Open Water:

Test Designation	Test Name or Constant Speed Value	# Of tests
Open Water Standard Resistance Tests in the Ice Tank (Note 1)		
V_1	P3_OW_V1_Sequence #	6
V_2	P3_OW_V2_Sequence #	6
V_3	P3_OW_V3_Sequence #	6
V_4	P3_OW_V4_Sequence #	6
V_5	P3_OW_V5_Sequence #	6
V_6	P3_OW_V6_Sequence #	6
V_7	P3_OW_V7_Sequence #	6
Open Water baseline Resistance Tests in the Ice Tank		
V_8	Speed = 0.1 m/s	7 *(Note 2)*
V_9	Speed = 0.2 m/s	4 *(Note 3)*
V_10	Speed = 0.4 m/s	4 *(Note 4)*
V_11	Speed = 0.6 m/s	11 *(Note 5)*

- Note 1: Test repeated six (6) times (speeds from 0.3m/s to 1.7 m/s).
- Note 2: Test repeated seven (7) times, all in the Central Channel (CC).
- Note 3: Test repeated four (4) times: 1 test along the NQP, 1 test along the SQP and 2 tests along the CC.
- Note 4: Test repeated four (4) times: 1 test along the NQP, 1 test along the SQP and 2 tests along the CC.
- Note 5: Test repeated eleven (11) times, all along the CC.

Experiments in Ice:

In the ice tank, the Terry Fox model (scale ≈1:21.8) will be towed in four (4) different ice sheets. In each ice sheet, the model will be towed in ice at a constant speed along the entire useable length of the ice tank (≈ 65 m). In all ice sheets, the target flexural strength of the ice is ≈ 35 kPa.

Ice Sheet #	Model Speed, m/s	Ice Thickness, mm	Strength, kPa
1	0.1	40	35
2	0.2	40	35
3	0.4	40	35
4	0.6	40	35

Test Sequence

For each ice sheet, six (6) different test runs should be performed, with the exception of the first ice sheet (only runs #1 to #5 were completed). These are three (3) runs in level ice (non-broken ice) and three (3) runs in pack ice (broken ice).

Resistance Experiments in Level Ice:

1.a: Experiments in level ice sheets along the CC (Central Channel).

1.b: Experiments in pre-sawn ice sheets (pegged ice sheet, restricted boundaries) along the SQP.

1.c: Experiments in level free ice sheets (no pegs, free boundary) along the NQP.

Resistance Experiments in Broken Ice:

1.d: Experiments in broken ice (9/10th concentration).

1.e: Experiments in broken ice (8/10th concentration).

1.f: Experiments in broken ice (6/10th concentration).

Note that all of the above six test runs (1.a to 1.f) are repeated for:

- Four different ship model speeds (0.1 m/s, 0.2 m/s, 0.4 m/s, and 0.6 m/s), with the exception of ice sheet #1 (0.1m/s) the first five runs are completed (1.a to 1.e).

Completed Tests in Ice:

Ice sheet #	**Test Run #** (Notes 1 and 2)	**Constant ship Speed** (Note 3)	**# of tests**	**Creeping test**
# 1	Runs # 1 to # 3	Speed = 0.1 m/s	3	Yes
(PICE1)	Runs # 4 to # 5	Speed = 0.1 m/s	2	Yes
# 2	Runs # 1 to # 3	Speed = 0.2 m/s	3	Yes
(PICE2)	Runs # 4 to # 6	Speed = 0.2 m/s	3	Yes
# 3	Runs # 1 to # 3	Speed = 0.4 m/s	3	Yes
(PICE3)	Runs # 4 to # 6	Speed = 0.4 m/s	3	Yes
# 4	Runs # 1 to # 3	Speed = 0.6 m/s	3	Yes
(PICE4)	Runs # 4 to # 6	Speed = 0.6 m/s	3	Yes

Note 1: Runs # 1 to # 3 are in level ice, they are in CC, SQP and NQP, respectively.
Note 2: Runs # 4 to # 6 are in pack ice, they are for 9/10, 8/10 and 6/10 ice coverage respectively.
Note 3: Ship speed is constant throughout the useable length of the ice tank (≈ 65 m)

Summary of Completed Tests:

Total # of Tests in Open Water	28	0
Total # of Tests in Ice	23	23
Total # of Tests	51	23
	74	

File Naming Convention:

<table>
<tr><th>Test type</th><th>Name</th></tr>
<tr><td>Ice Runs</td><td>Name: 'P3'_'S#'_'Channel'_'R#'_'V_m'_Inc.dac
• P3 = Phase # 3
• S# = Ice sheet # 1.
• Channel= Channel (CC, SQP, or NQP).
o CC = Center Channel.
o SQP = South Quarter Point.
o NQP = North Quarter Point.
• R# = Run # (1to 6)
• V_m = Velocity of the model (example: 0P1 = 0.1 m/s)
• Inc = Incremented File Number (automatically)
• dac = extension for GEDAP files.

Example: P3_S4_NQP_R3_0P6_047
• Phase 3, Ice Sheet # 4, North Quarter Point, Run #3, Model Speed = 0.6 m/s, 47th run sequence.</td></tr>
<tr><td>Open Water Runs</td><td>Name: 'P3'_OW_'V'_inc.dac
• P3 = Phase # 3
• OW = Open Water
• V# = Model Speeds
• Inc = Incremented File Number

Example: ‘P3’_’OW’_’V5_085’.dac
• Phase 3, Standard Open Water, Speeds of 0.53m/s, 1.0m/s and 1.46m/s, 85th run.</td></tr>
</table>

Appendix 5:

Typical Test Results

Example of Results from
Ice Resistance Experiments:

Phase 3

Ice Sheet: PICE3

Test #: P3_S3_NQP_R3_0P4_038

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 6-MAY-2003 12:47:42
Acquired: 6-MAY-2003 12:32:01

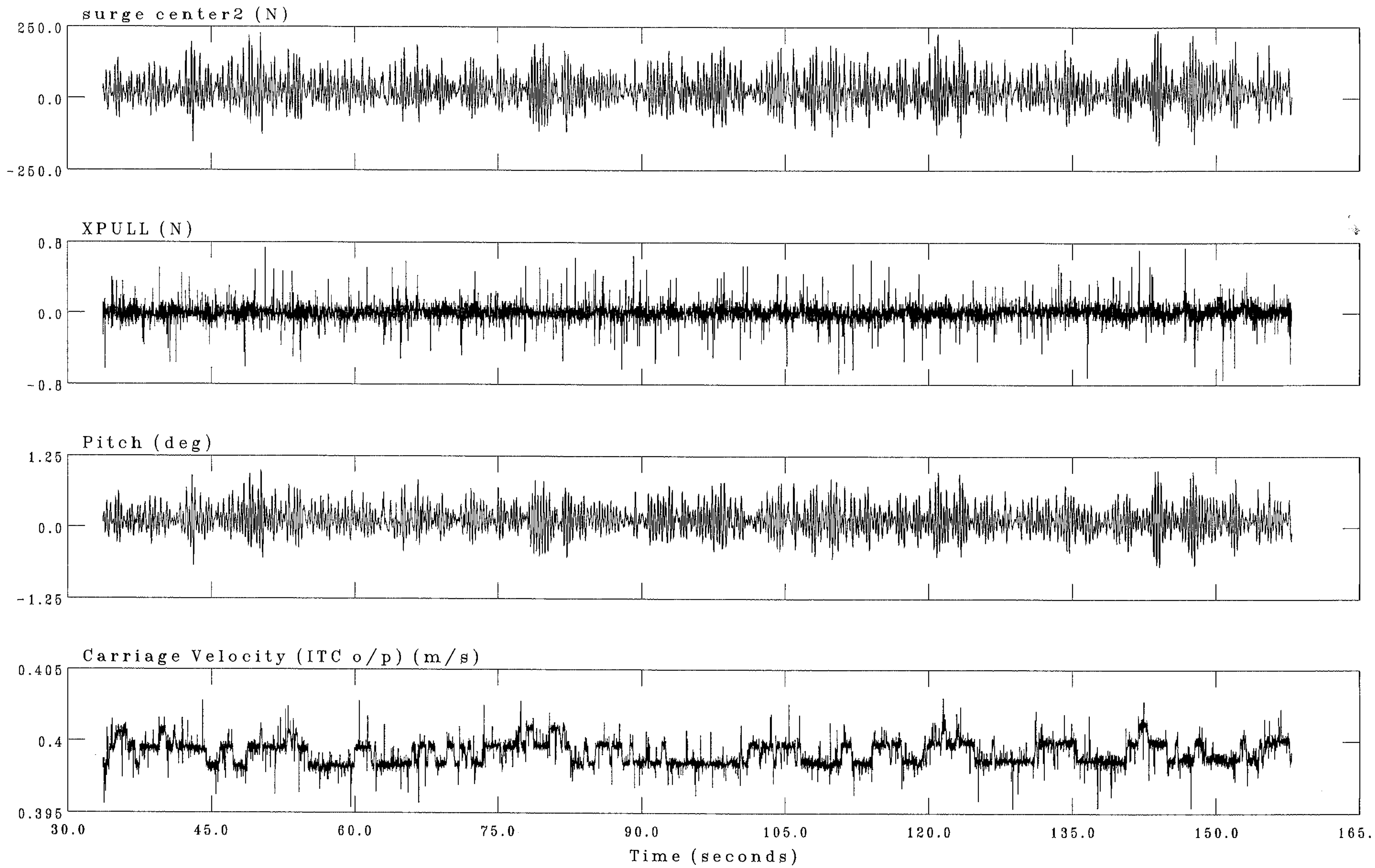


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Figure 2 P3_S3_nqp_r3_0p4_038

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 6-MAY-2003 12:47:42
Acquired: 6-MAY-2003 12:32:01

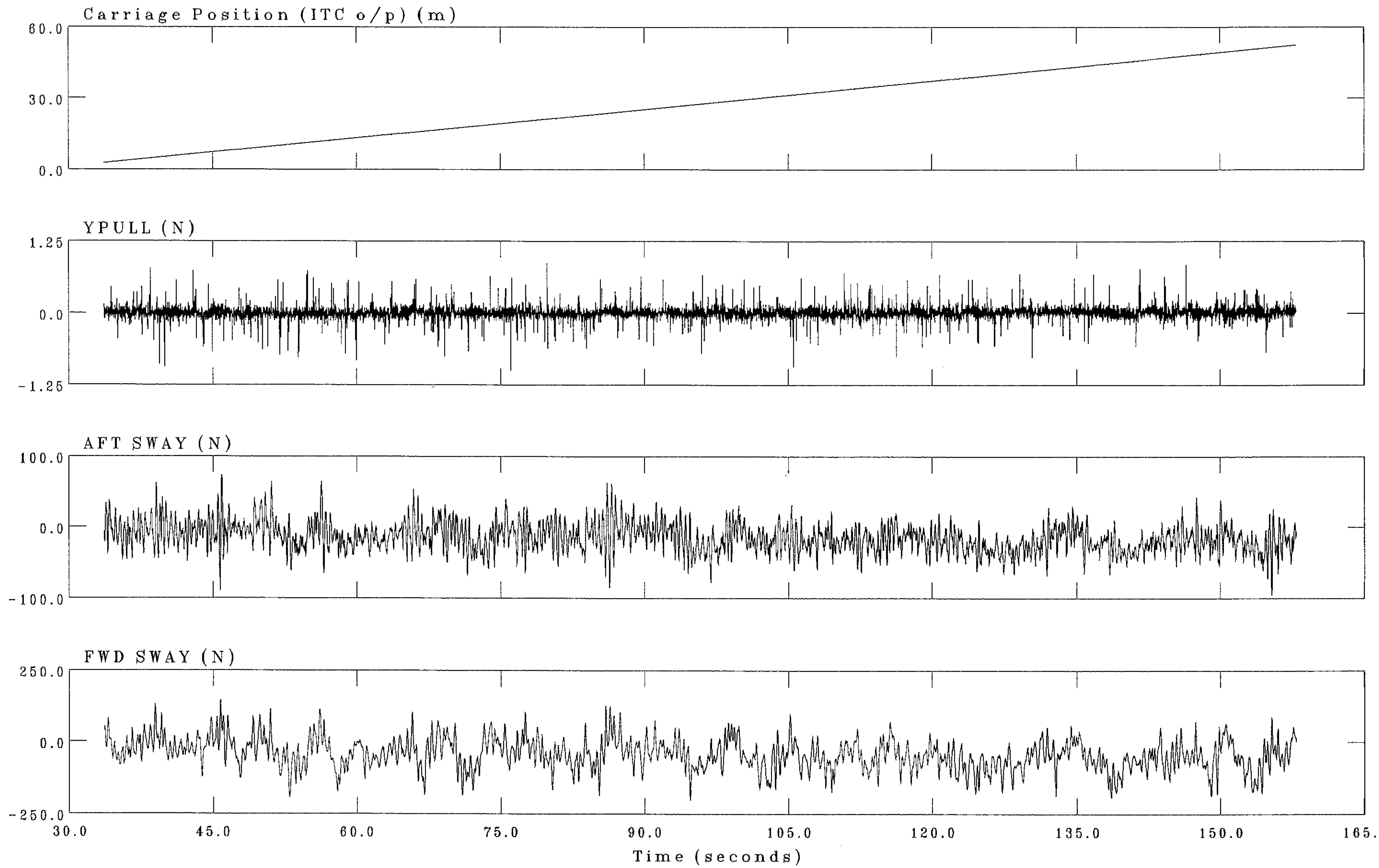

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Figure 3 P3_S3_nqp_r3_0p4_038

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3 IMD

Analyzed: 6-MAY-2003 12:47:42
Acquired: 6-MAY-2003 12:32:01

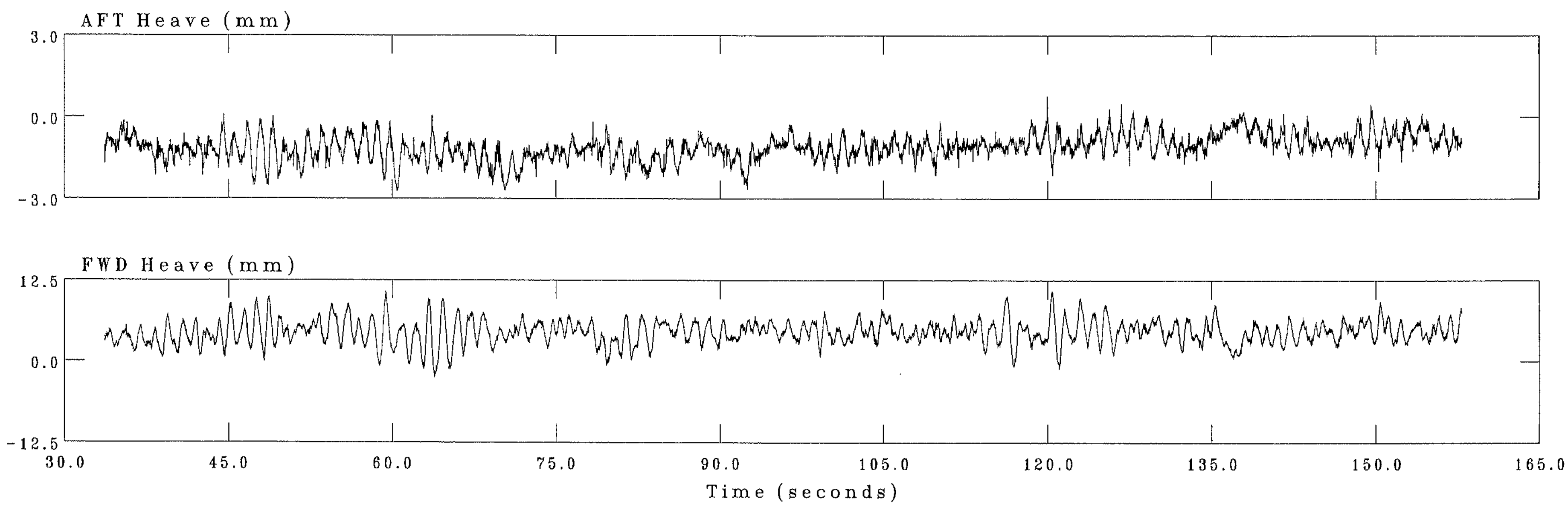

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Figure 4 P3_S3_nqp_r3_0p4_038

Example of Results from Baseline Open Water Experiments:

Phase 3

Test #: P3_OW_V8_008

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3 IMD

Analyzed: 28-APR-2003 15:48:44
Acquired: 28-APR-2003 15:33:47

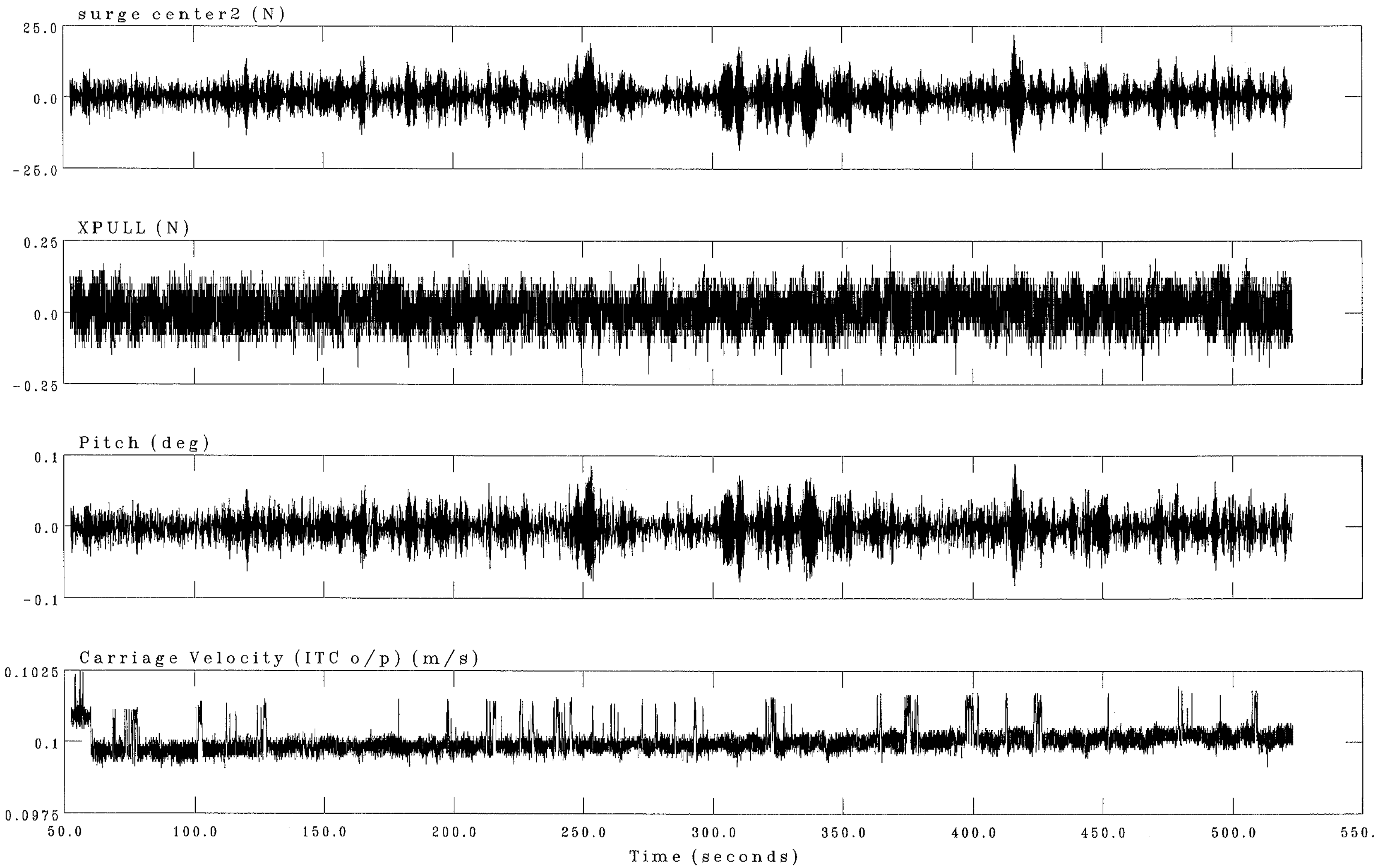

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Figure 2 P3_ow_v8_008

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 28-APR-2003 15:48:44
Acquired: 28-APR-2003 15:33:47

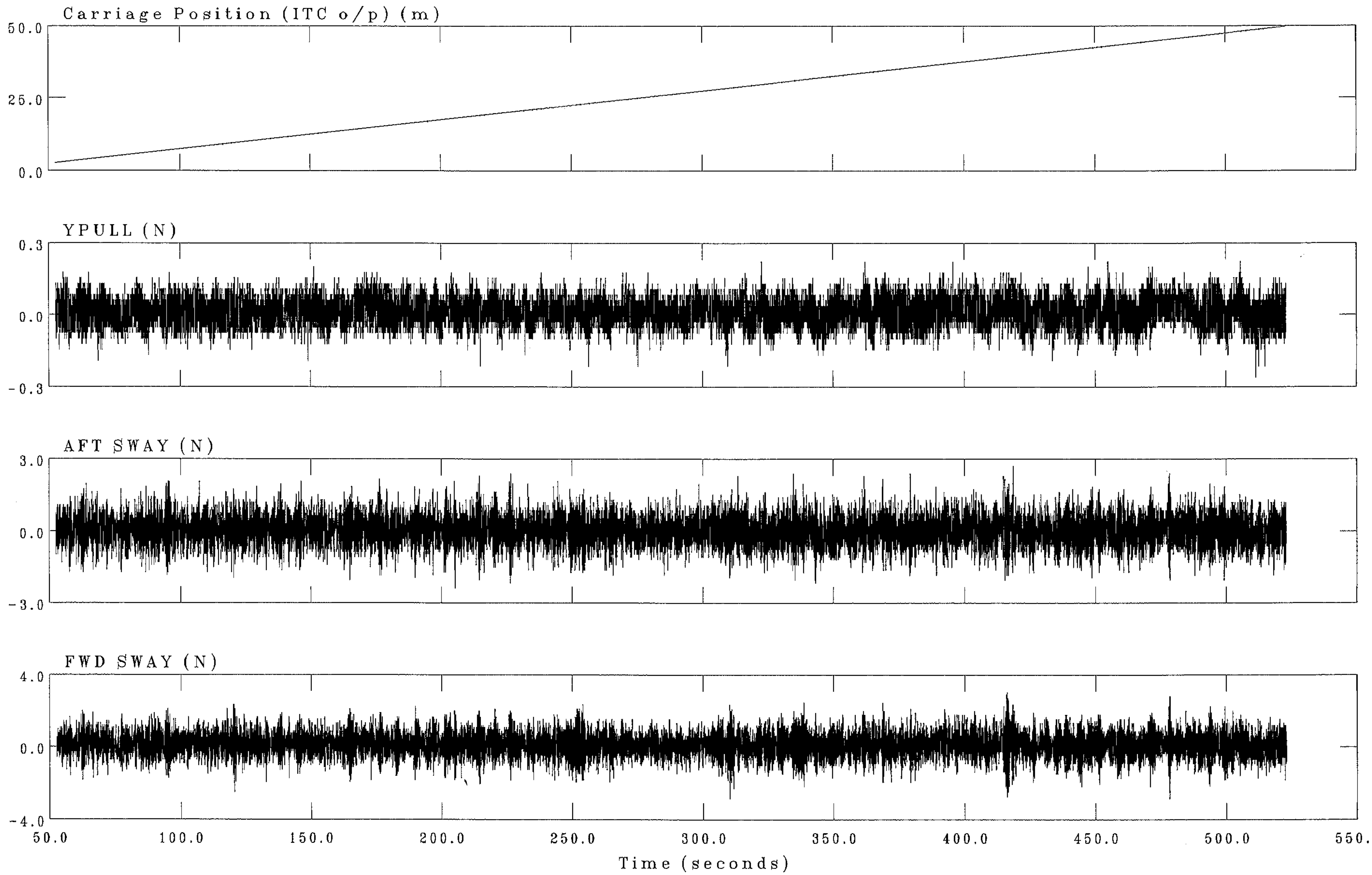

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Figure 3 P3_ow_v9_008

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 28-APR-2003 15:48:44
Acquired: 28-APR-2003 15:33:47

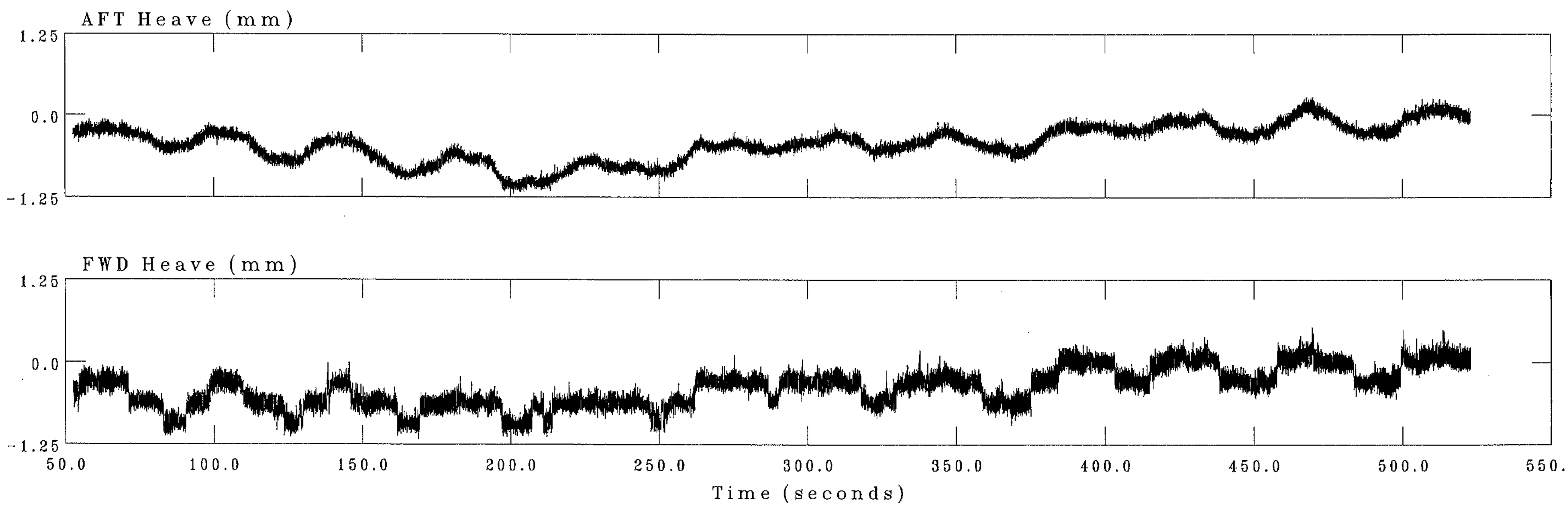

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Figure 4 P3_ow_v9_008

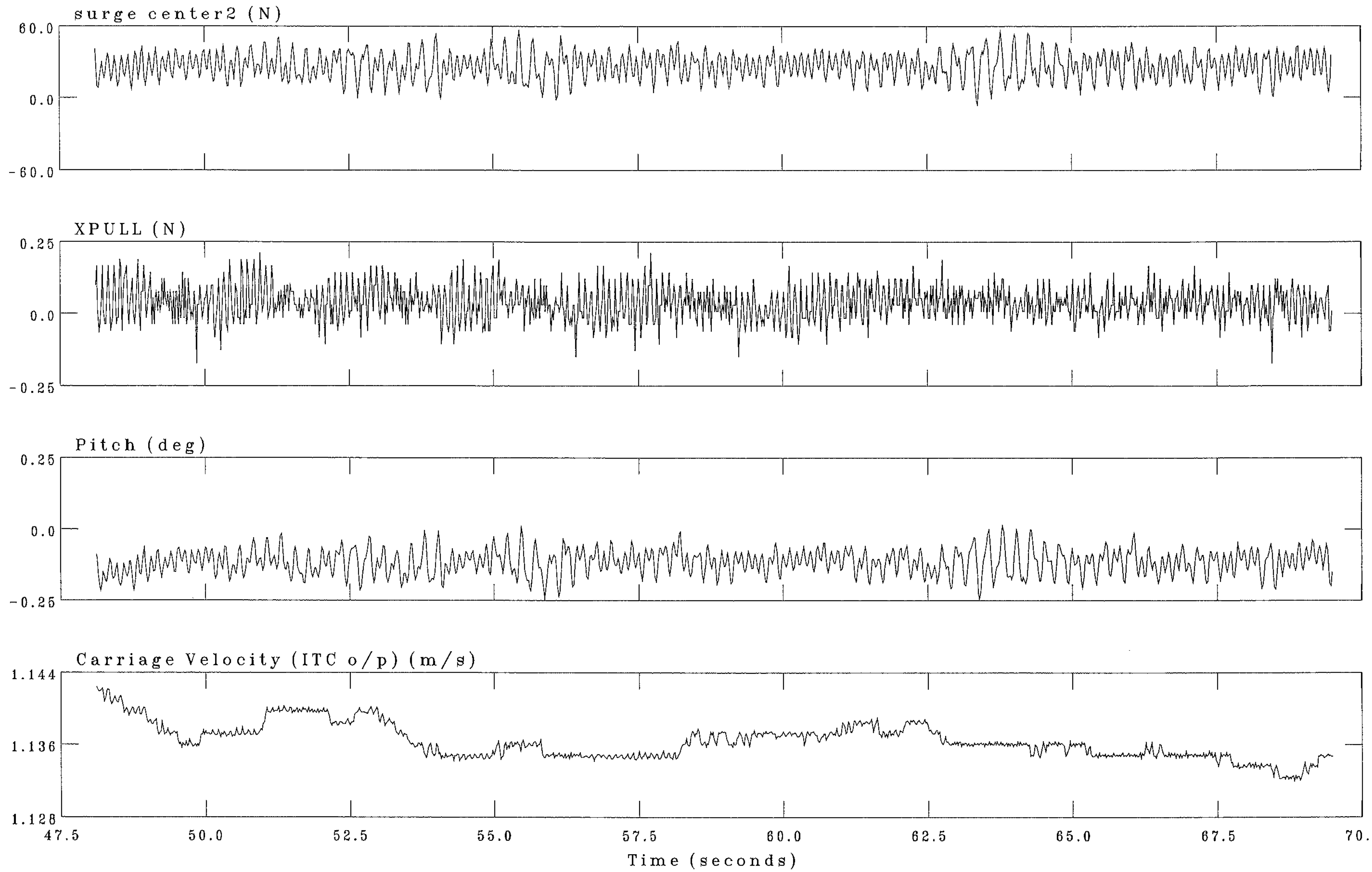
Example of Results from Standard Open Water Experiments:

Phase 3

Test #: P3_OW_V2_082

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3 IMD

Analyzed: 15-MAY-2003 14:28:28
Acquired: 15-MAY-2003 14:25:30



National Research Council Canada Institute for Marine Dynamics	GENERATED BY: MEADUSC	CHECKED BY:	APPROVED BY:
	Figure 2 P3_ow_v2_082		

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 15-MAY-2003 14:28:28
Acquired: 15-MAY-2003 14:25:30

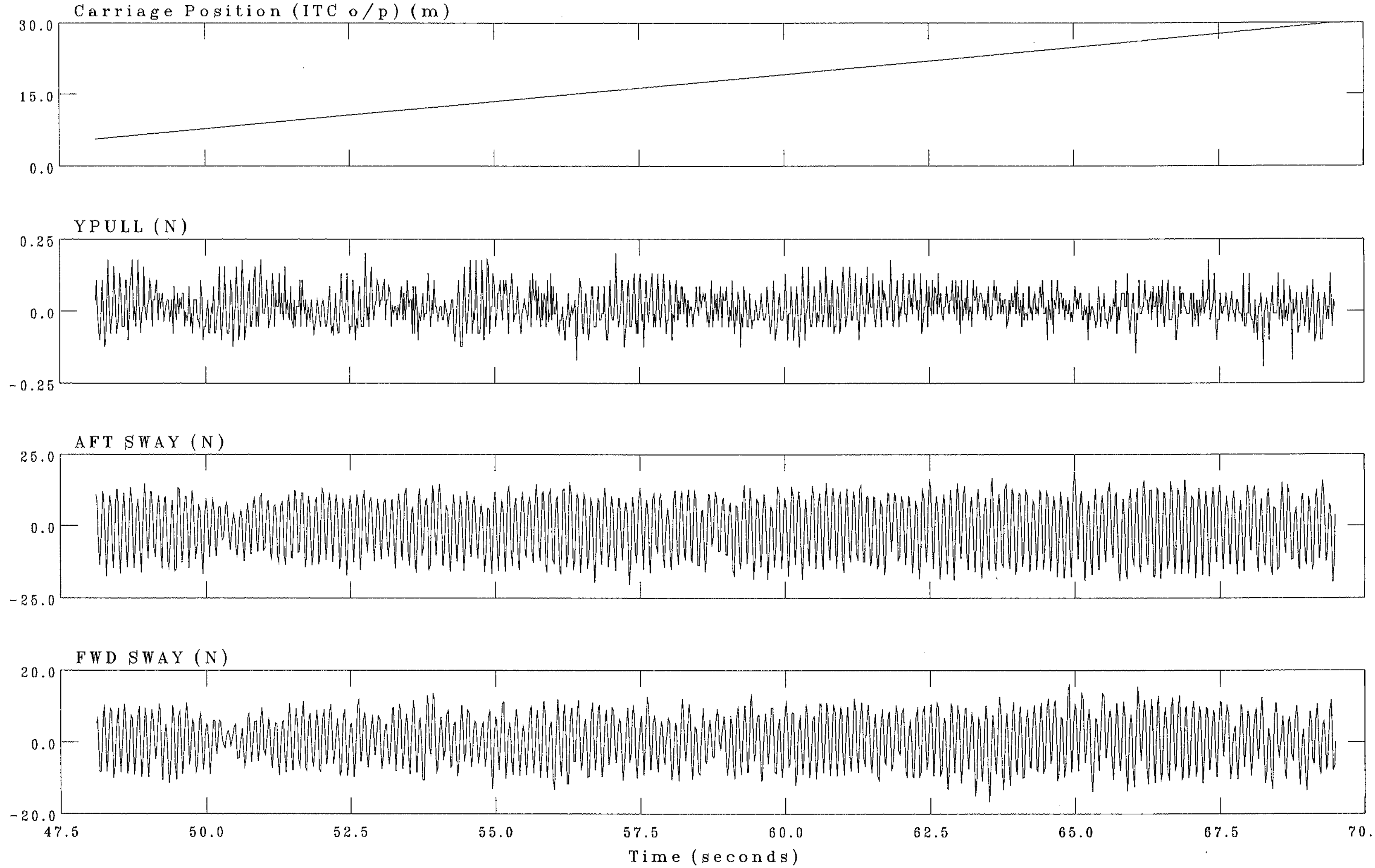


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Figure 3 P3_ow_v2_082

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 15-MAY-2003 14:28:28
Acquired: 15-MAY-2003 14:25:30

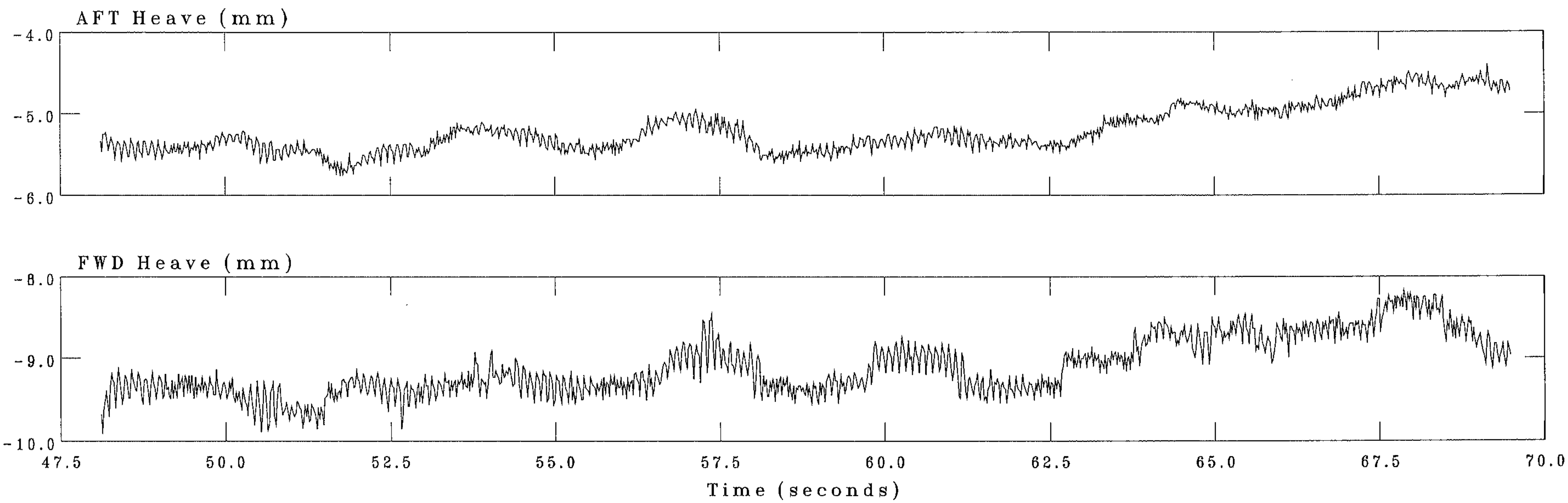

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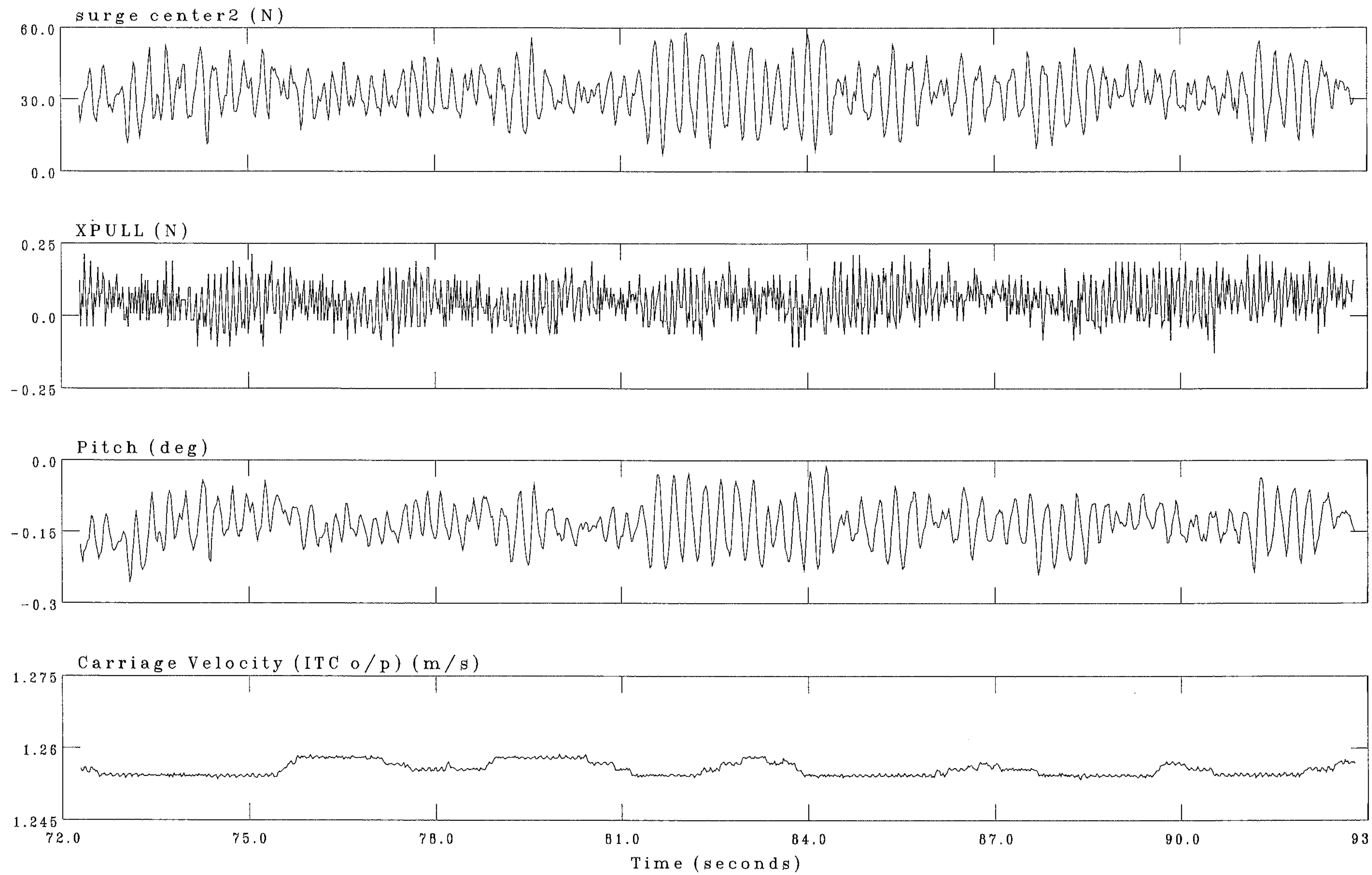
Figure 4 P3_ow_v2_082

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 15-MAY-2003 14:29:29
Acquired: 15-MAY-2003 14:25:30



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APPROVED BY:

Figure 5 P3_ow_v2_082

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 15-MAY-2003 14:29:29
Acquired: 15-MAY-2003 14:25:30

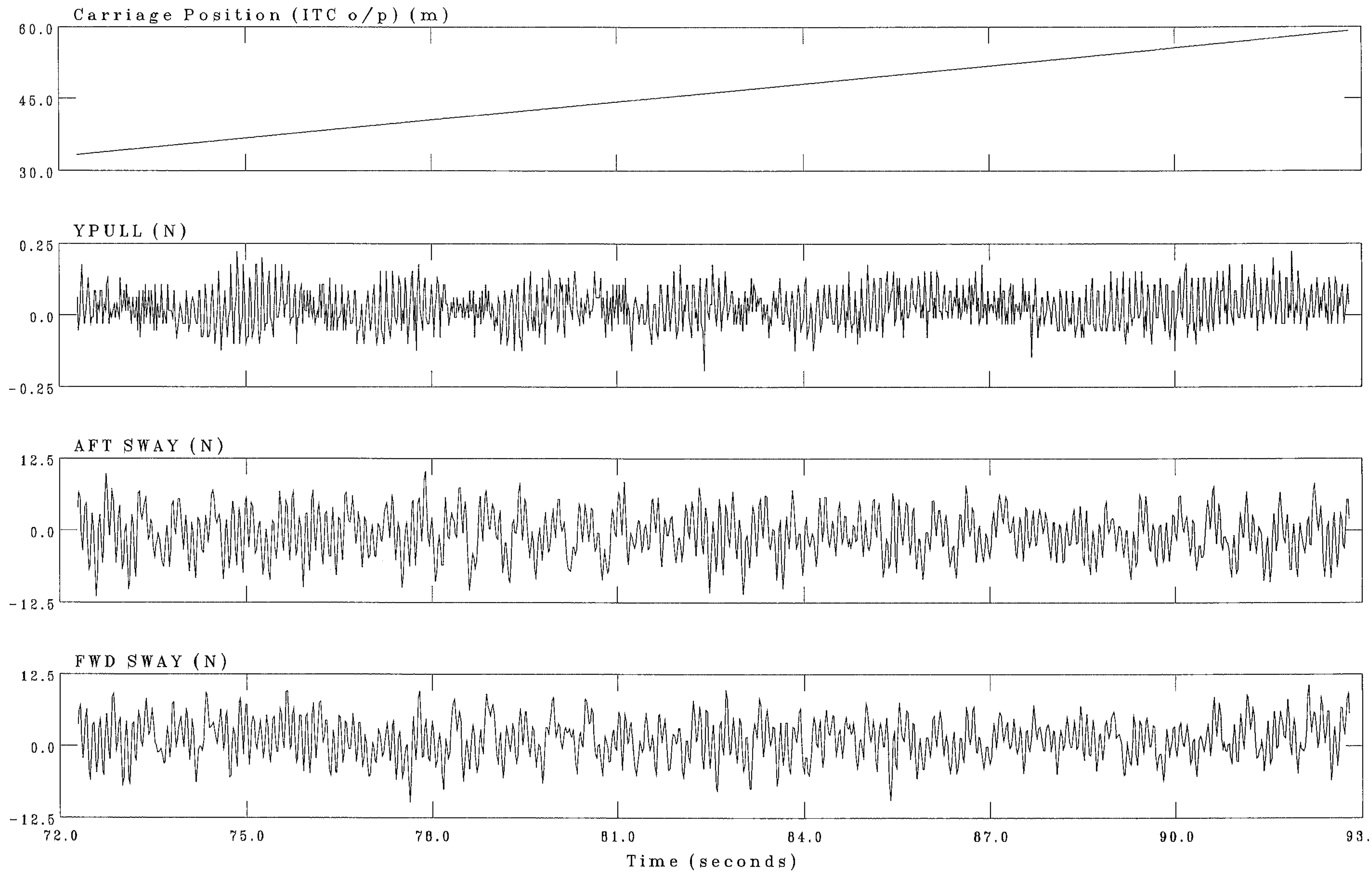

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Figure 6 P3_ow_v2_082

EXPERIMENTAL UNCERTAINTY ANALYSIS PHASE 3:PMM
Phase3
IMD

Analyzed: 15-MAY-2003 14:29:29
Acquired: 15-MAY-2003 14:25:30

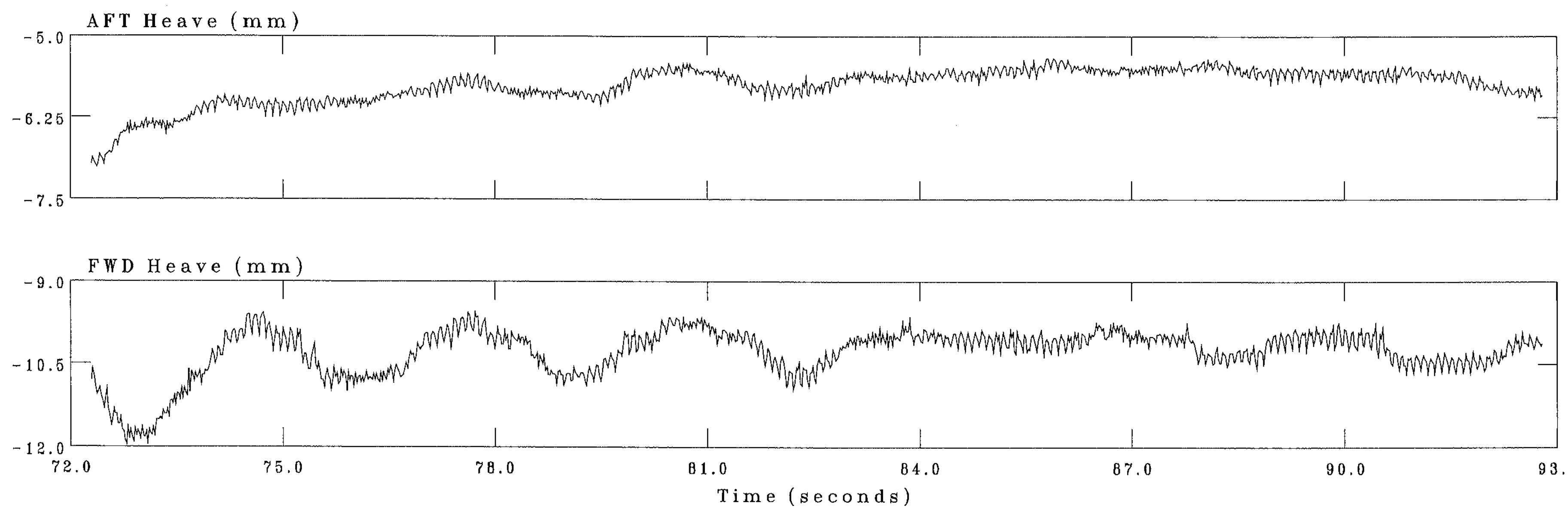

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Figure 7 P3_ow_v2_082

Appendix 6:

Analysis of the Spatial Distribution of the Properties of Model Ice In the IOT Ice Tank

APPENDIX 6:

In addition to the four ice sheets used to complete the test program, a fifth ice sheet was used, it is called PICE-5. The purpose of PICE-5 was to examine in more details the spatial distribution of the properties of the model ice.

Measurements of ice thickness, ice density and ice flexural strengths were made along both the longitudinal and the lateral directions of the ice tank. The results in a map indicating peaks and valleys of the materials properties of model ice over the surface of the water in the ice tank.

Thickness Distribution

Figure A1.a shows the measured thickness profiles (Table A.1). The mean thickness profile (Figure A1.b) shows an upward sloping trend line, indicating the ice thickness increases along the longitudinal direction of the tank (about 0.062%). The random uncertainty of the measured thickness is 3.27%. Figure A1.c shows a 3-D plot of the thickness peaks and valleys.

Density

Figure A2.a shows the measured density profiles (Table A.1). The mean density profile (Figure A2.b) shows an upward sloping trend line, indicating the ice density increases along the tank by 0.0047%. The random uncertainty of the measured density is 7.22%, which is calculated using Eq. 6b. A 3-D plot of the density peaks and valleys is shown in Figure A.2c.

Flexural Strength

Figure A3.a shows the calculated flexural strength profiles obtained for PICE-5 (Table A.1). The mean strength profile (Figure A3.b) shows an upward sloping trend line, indicating the flexural strength increases along the tank by 4.69%. The random uncertainty of the measured strength is 21.36%, which is calculated using Eq. 5b. A 3-D plot of the measured strength peaks and valleys is shown in Figure A3.c.

Table A.1: PICE-5 Ice Properties

Location		Thickness	Density				Strength			
		Thickness (mm)	Length (m)	Width (m)	Thickness (m)	Submergence Force (g)	Length (m)	Width (m)	Thickness (m)	Load (N)
5	SQP	38.55	0.1008	0.1027	0.0386	24.2	0.1960	0.0775	0.0381	2.713
	CC	39.13	0.1035	0.1018	0.0391	23.9	0.2063	0.0842	0.0381	2.793
	NQP	38.93	0.1022	0.1031	0.0389	25.5	0.2017	0.0795	0.0381	3.170
10	SQP	40.55	0.1000	0.1011	0.0406	25.7	0.1960	0.0769	0.0399	2.957
	CC	40.95	0.1014	0.1025	0.0410	28.1	0.2100	0.0866	0.0399	3.333
	NQP	40.40	0.0992	0.1013	0.0404	26.3	0.2017	0.0811	0.0400	3.450
15	SQP	40.03	0.0991	0.1003	0.0400	23.1	0.1990	0.0805	0.0391	3.123
	CC	40.50	0.1043	0.0998	0.0405	25.8	0.2107	0.0862	0.0391	3.480
	NQP	39.83	0.0964	0.1006	0.0398	22.8	0.2033	0.0834	0.0532	3.237
20	SQP	40.15	0.1001	0.1020	0.0402	25.7	0.1987	0.0788	0.0397	2.600
	CC	39.90	0.1009	0.1008	0.0399	25.9	0.2113	0.0862	0.0394	3.400
	NQP	40.25	0.0999	0.1013	0.0403	26.2	0.2033	0.0805	0.0405	2.877
25	SQP	39.25	0.0994	0.1006	0.0393	23.5	0.1927	0.0824	0.0389	2.843
	CC	40.08	0.1047	0.1008	0.0401	25.4	0.2090	0.0861	0.0393	3.203
	NQP	40.45	0.0983	0.1017	0.0405	23.4	0.2033	0.0806	0.0399	3.220
30	SQP	39.63	0.1050	0.1036	0.0396	26.4	0.2000	0.0820	0.0393	2.843
	CC	38.85	0.1042	0.1023	0.0389	24.9	0.2010	0.0836	0.0386	3.253
	NQP	39.50	0.0974	0.0965	0.0395	24	0.2050	0.0808	0.0396	2.910
35	SQP	40.35	0.1009	0.0991	0.0404	24.4	0.1917	0.0809	0.0399	2.940
	CC	40.25	0.1003	0.1051	0.0403	25.1	0.2143	0.0852	0.0399	3.547
	NQP	40.08	0.0981	0.1034	0.0401	23.5	0.2000	0.0812	0.0395	2.730
40	SQP	39.85	0.1033	0.1002	0.0399	26	0.2061	0.0771	0.0395	3.125
	CC	39.78	0.1048	0.1005	0.0398	26.7	0.2068	0.0779	0.0397	3.610
	NQP	39.48	0.0976	0.0976	0.0395	24.8	0.2075	0.0787	0.0400	4.095
45	SQP	40.25	0.0996	0.1031	0.0403	24.5	0.2057	0.0807	0.0402	2.747
	CC	40.15	0.0976	0.1004	0.0402	23	0.2130	0.0850	0.0394	3.450
	NQP	38.95	0.1050	0.1030	0.0390	23.4	0.2117	0.0814	0.0391	2.730
50	SQP	40.60	0.1025	0.1018	0.0406	26.8	0.2007	0.0860	0.0401	2.890
	CC	40.20	0.1051	0.0966	0.0402	27.3	0.2143	0.0873	0.0403	3.350
	NQP	39.63	0.1002	0.1022	0.0396	27	0.2033	0.0788	0.0397	3.090
55	SQP	41.28	0.1024	0.0991	0.0413	25.7	0.2017	0.0823	0.0407	2.940
	CC	41.03	0.1018	0.0982	0.0410	24.2	0.2083	0.0862	0.0405	3.397
	NQP	40.35	0.0993	0.1038	0.0404	24.1	0.2073	0.0816	0.0406	3.580
60	SQP	40.65	0.1047	0.1015	0.0407	27.4	0.2017	0.0808	0.0409	3.547
	CC	40.50	0.1031	0.0985	0.0406	26.3	0.1833	0.0853	0.0403	2.977
	NQP	41.30	0.0991	0.1037	0.0413	26.9	0.2077	0.0813	0.0400	3.270
65	SQP	40.73	0.1032	0.1009	0.0407	23.7	0.2047	0.0817	0.0403	3.170
	CC	40.35	0.0973	0.1004	0.0404	22.9	0.2130	0.0882	0.0400	3.530
	NQP	40.38	0.0994	0.0988	0.0404	23.3	0.2033	0.0809	0.0401	4.153
Mean		0.040079487	0.101066	0.101029	0.0400795	25.07179487	0.20452	0.082187	0.039688	3.13581
STDEV		0.00065554	0.002567	0.001993	0.0006555	1.46304454	0.005693	0.00304	0.0006972	0.29153
U(%)		3.27%	5.08%	3.95%	3.27%	11.67%	5.57%	7.40%	3.51%	18.59%

Note: The details for the Chauvenet rejection criteria are hidden but taken into account.

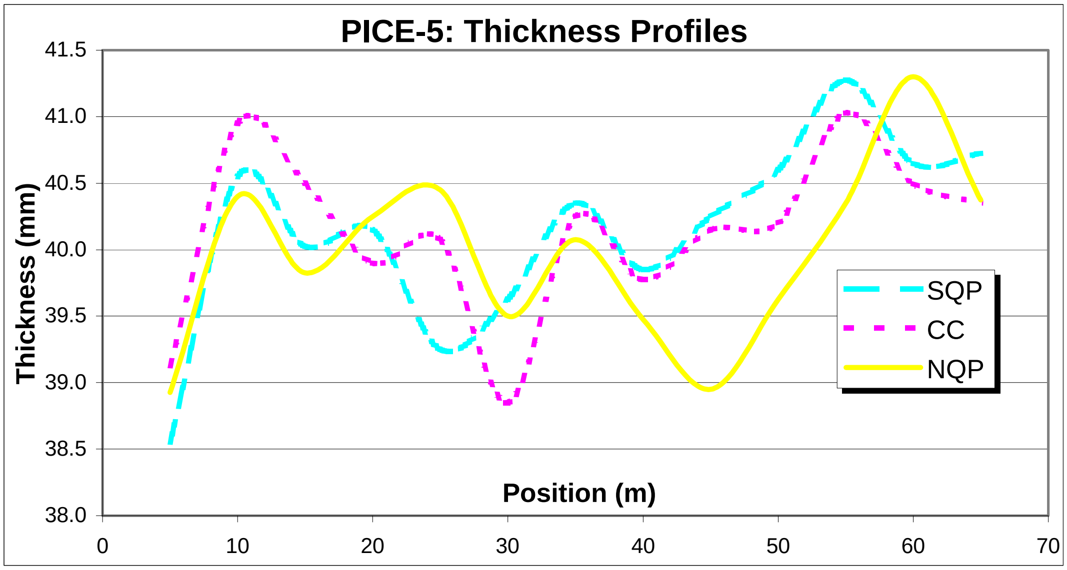

Figure A.1a: Measured thickness profiles for PICE-5.

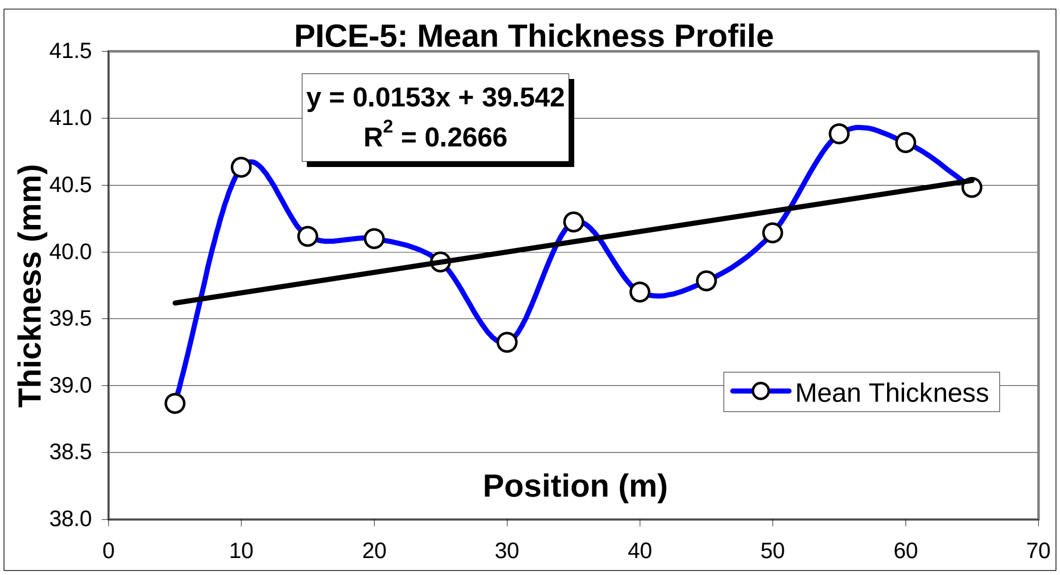

Figure A. 1b: Mean thickness profile for PICE-5, and its linear trend line.

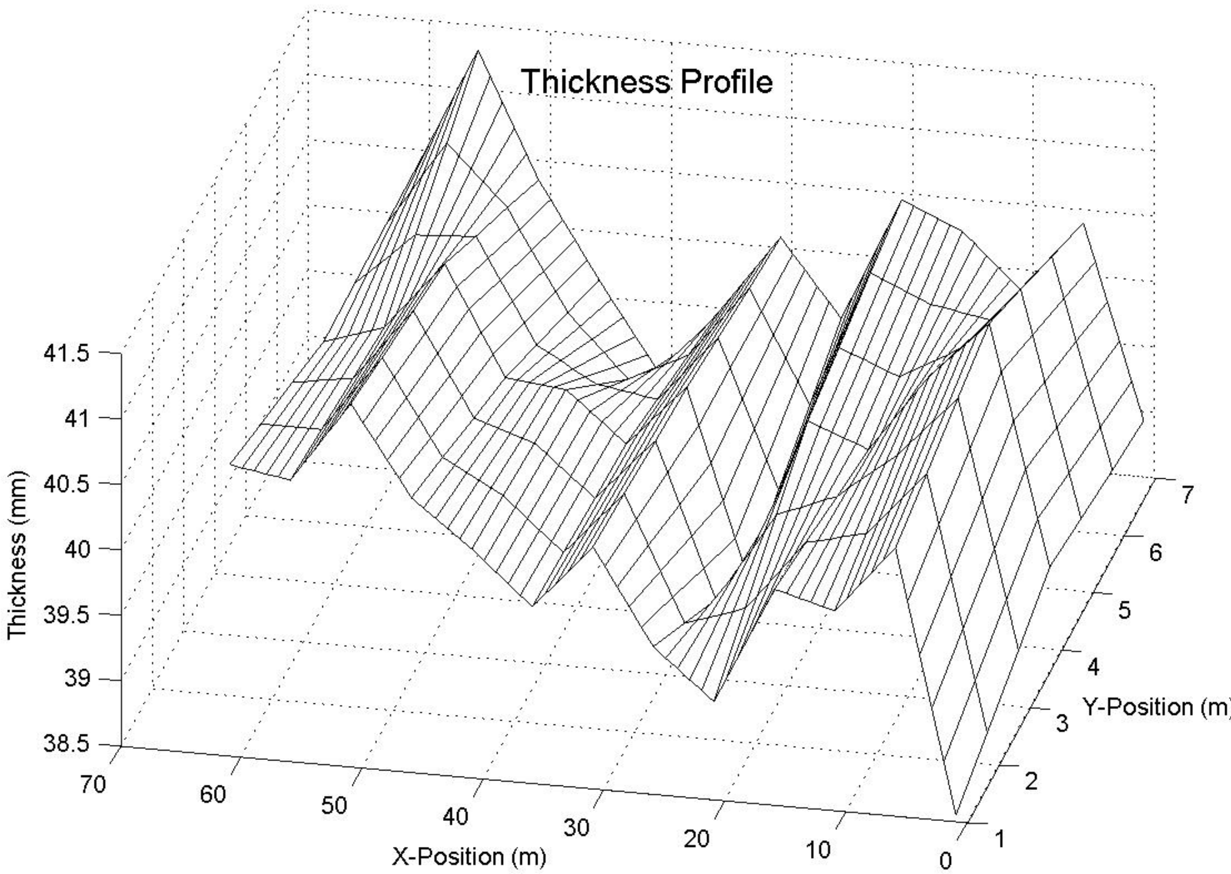

Figure A. 1c: 3-D Plot of thickness profile in PICE-5.

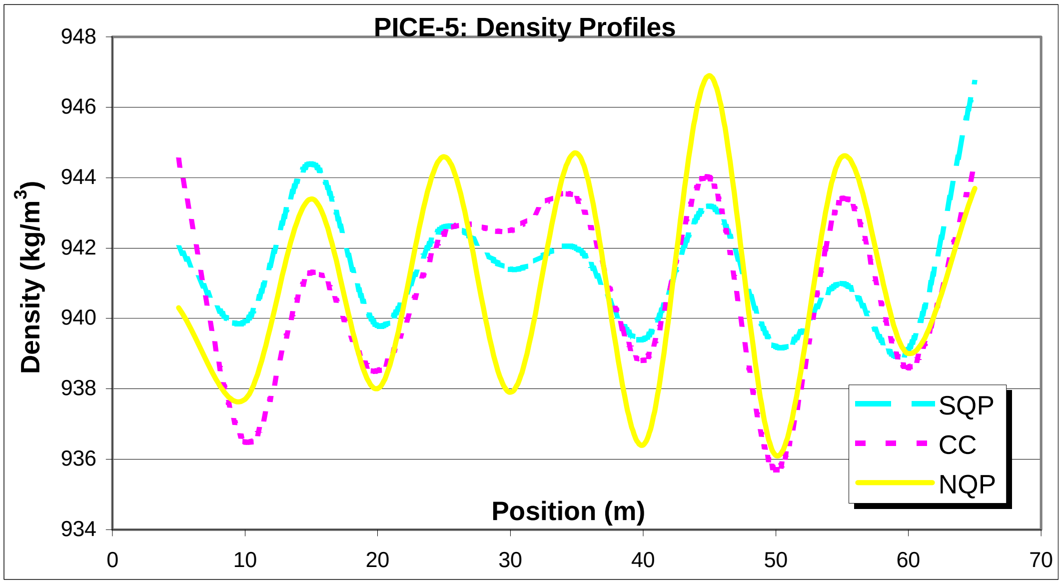

Figure A2. a: Measured density profiles for PICE-5.

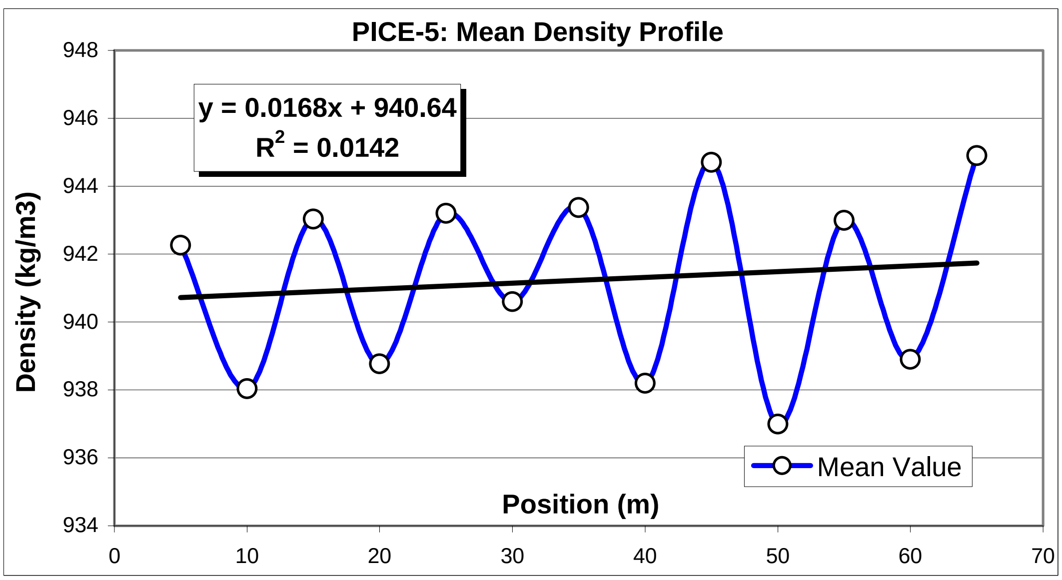

Figure A2. b: Mean density profile for PICE-5, and its linear trend line.

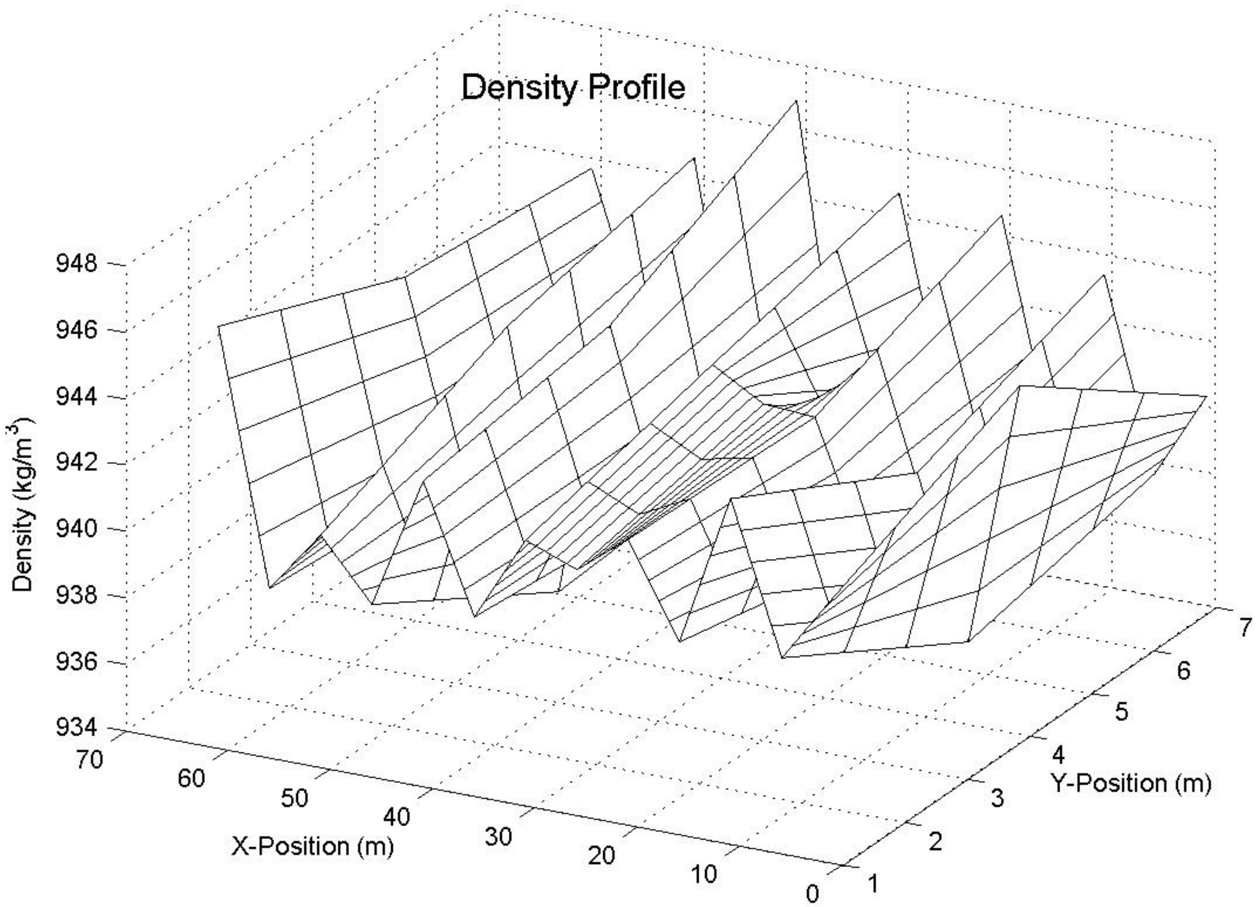

Figure A2. c: 3- D Plot of density profile for PICE-5.

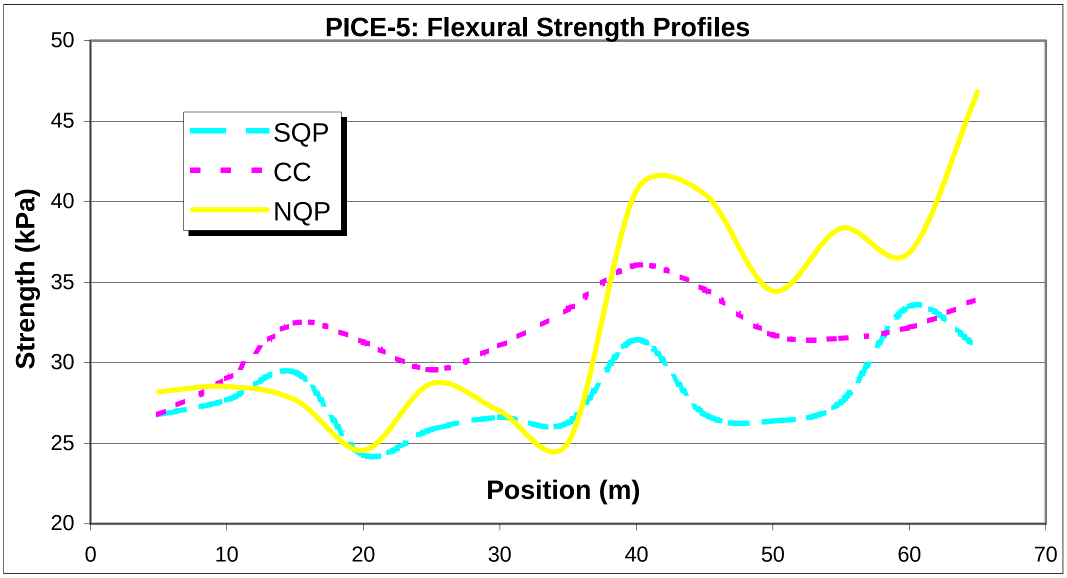

Figure A3. a: Measured flexural strength profile for PICE-5.

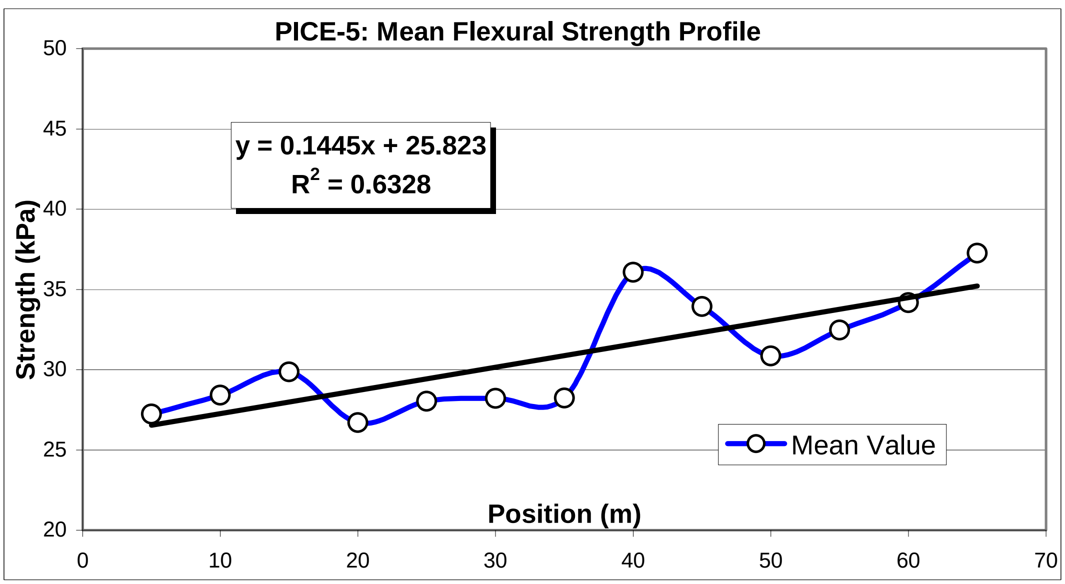

Figure A3. b: Mean flexural strength profile for PICE-5.

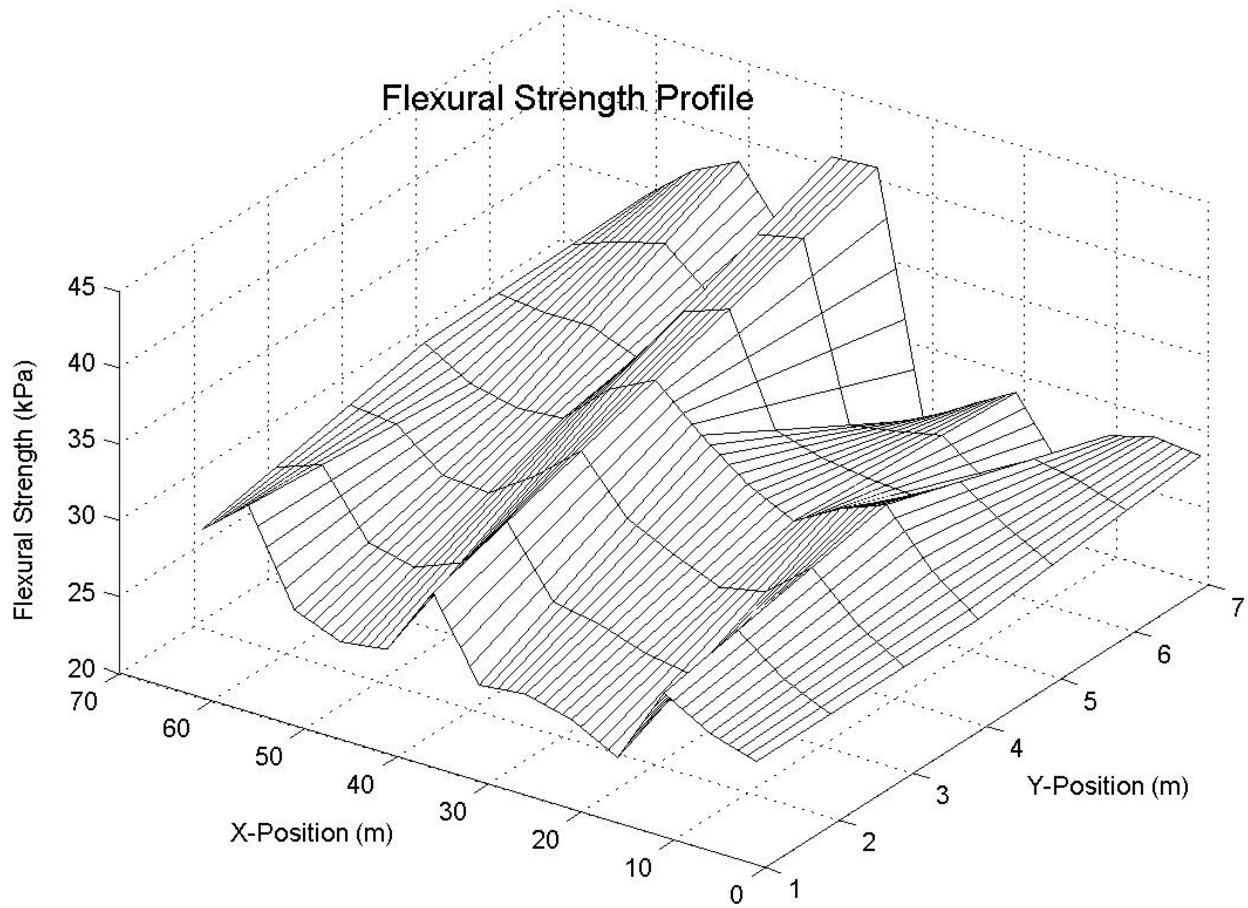

Figure A3. c: 3D Plot of Strength Profile.

Appendix 7:

Comparison of the Tow Post (Phase I) and the PMM (Phase III) Test Results and Uncertainties

APPENDIX 7:

In this appendix, the details for the comparisons between the results of Phase I testing (using the Tow Post) and those of Phase III testing (using the PMM).

Test Results for Measured Mean Tow Force: Phase I (Tow Post) and Phase III (PMM)							
Phase	Speed (m/s)	Continuous Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	34.54	11.58	25.11	7.06	5.11	2.21
	0.2	46.00	13.18	34.65	8.99	7.58	4.71
	0.4	56.49	20.50	44.30	14.50	9.50	9.23
	0.6	63.96	29.76	52.22	20.14	16.41	13.23
Phase 3: PMM	0.1	27.77	2.11	18.01	5.67	4.04	n/a
	0.2	33.45	11.24	20.76	8.49	5.37	5.29
	0.4	46.47	13.41	27.71	12.24	10.02	7.59
	0.6	52.07	27.80	35.44	17.78	15.43	12.41

Table A1: Comparison of Phase I and Phase III Measured Mean Tow Force.

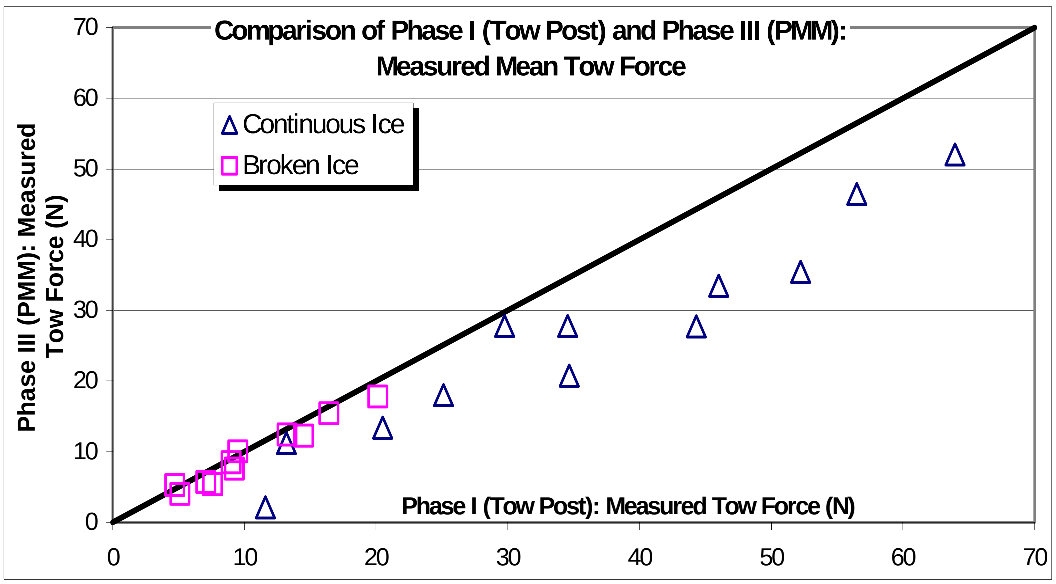

Figure A1: Comparison of Phase I and Phase III Measured Mean Tow Force.

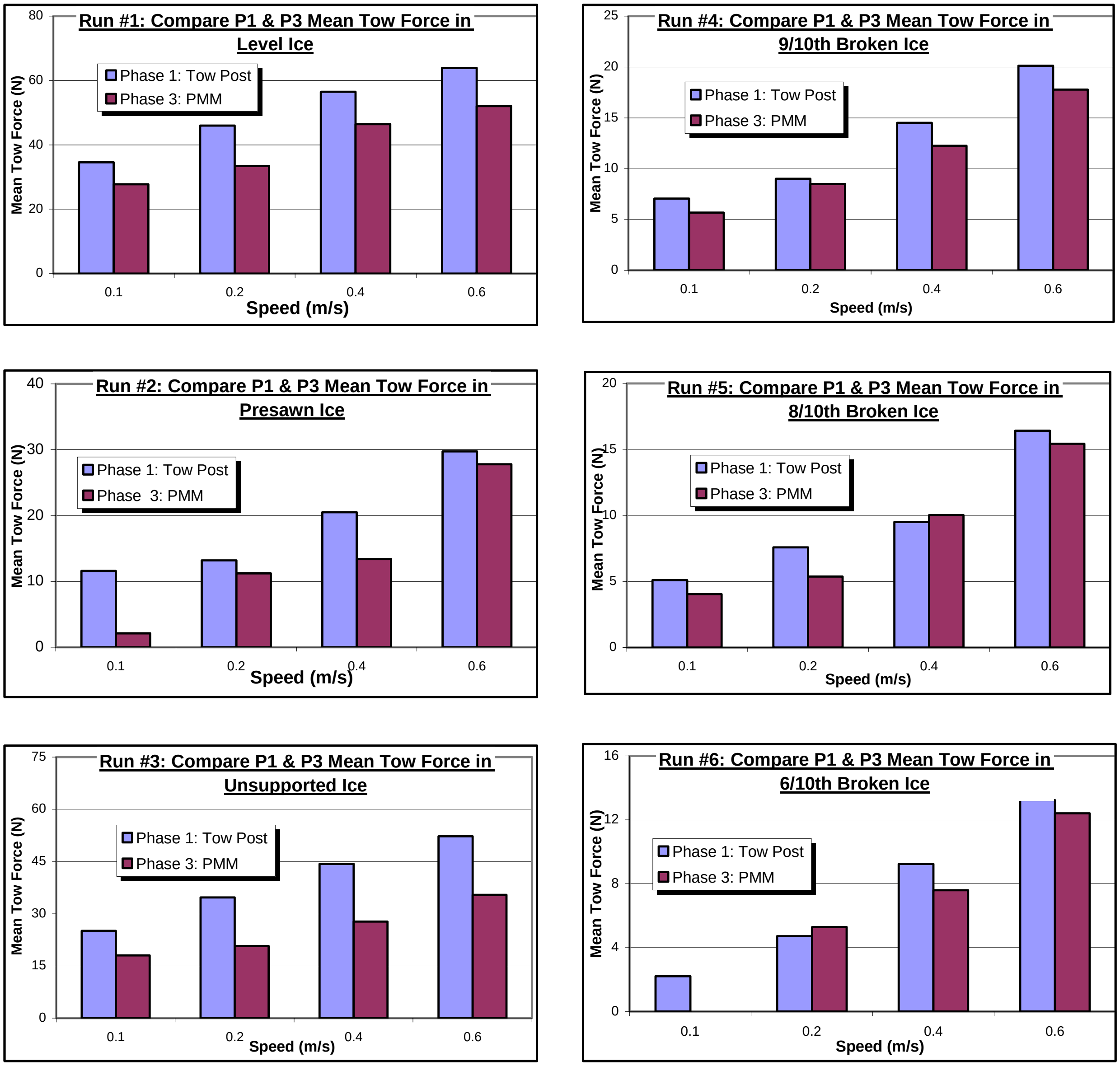

Figure A2: Comparison of Test Results in Mean Two Force using the Tow Post (Phase I) and the PMM (Phase III) versus Model Speed.

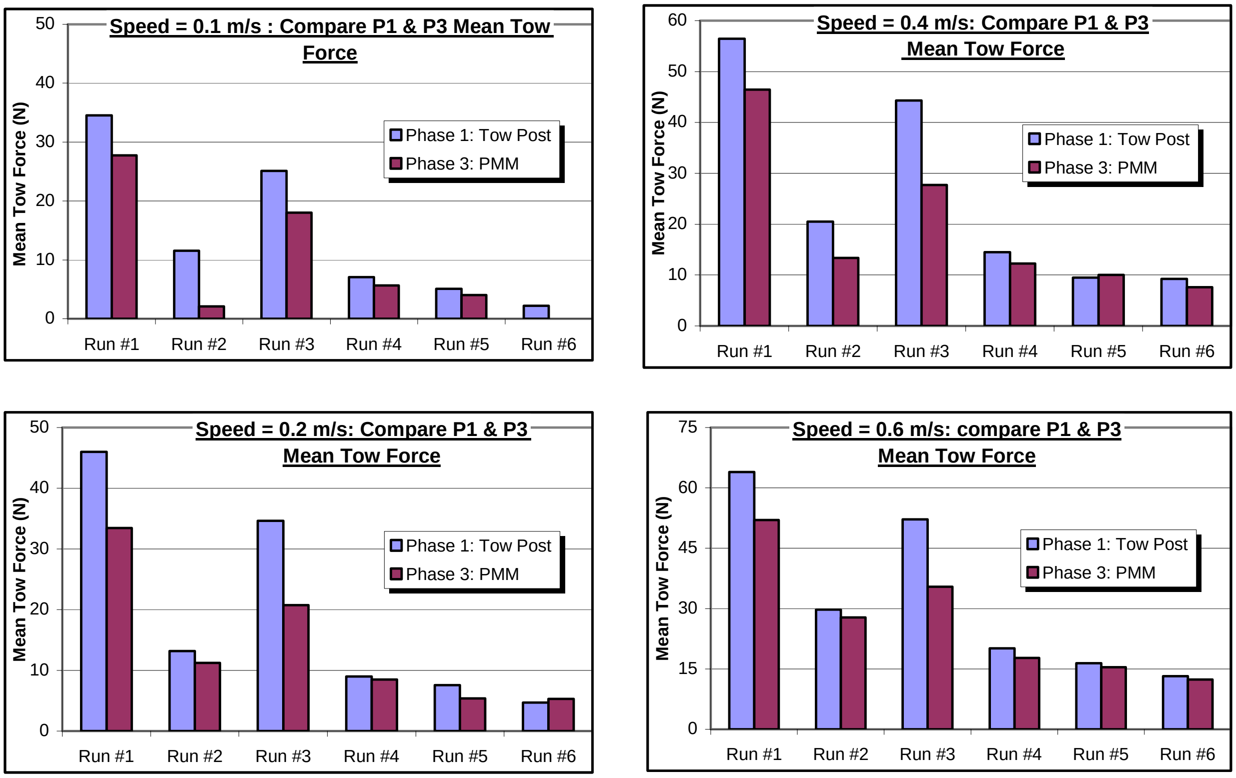

Figure A3: Comparison of Test Results in Mean Tow Force using the Tow Post (Phase I) and the PMM (Phase III) versus Run Number.

Test Results for Measured Maximum Tow Force: Phase I (Tow Post) and Phase III (PMM)							
Phase	Speed (m/s)	Continuous Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	67.7	45.1	54.47	37.48	21.03	36.37
	0.2	121.34	45.48	93.96	30.78	20.52	25.13
	0.4	203.66	53.55	154.22	39.39	25.89	27.99
	0.6	261.71	65.91	242.18	50.87	36.2	33.88
Phase 3: PMM	0.1	79.95	21.55	63.42	25.51	20.66	n/a
	0.2	144.78	34.82	65.26	29.20	21.02	19.78
	0.4	321.75	60.61	219.12	45.62	32.85	31.37
	0.6	433.82	94.71	358.09	85.78	56.04	51.92

Table A2: Comparison of Phase I and Phase III Measured Maximum Tow Force.

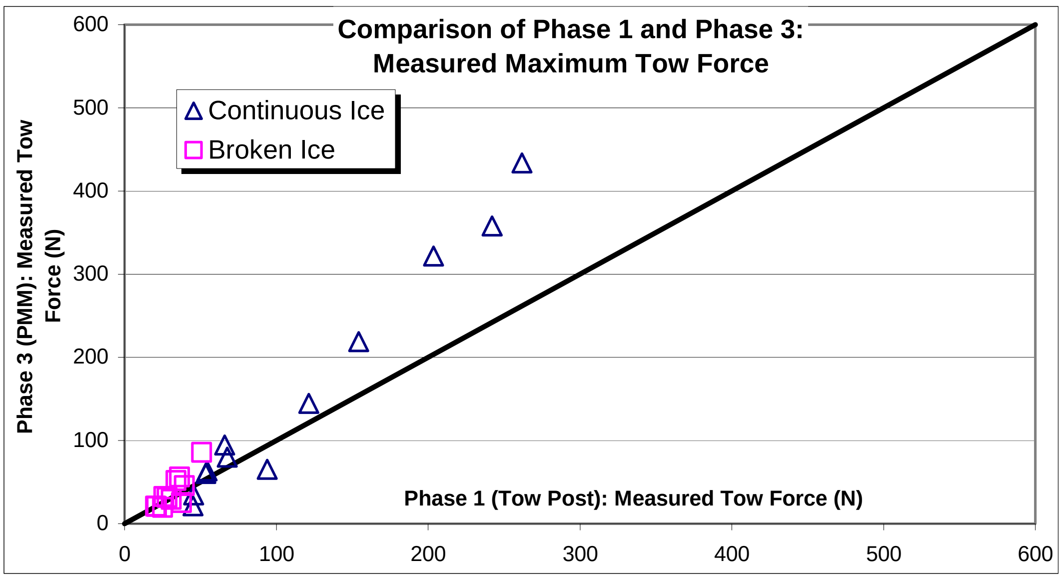

Figure A4: Comparison of Phase I and Phase III Measured Maximum Tow Force.

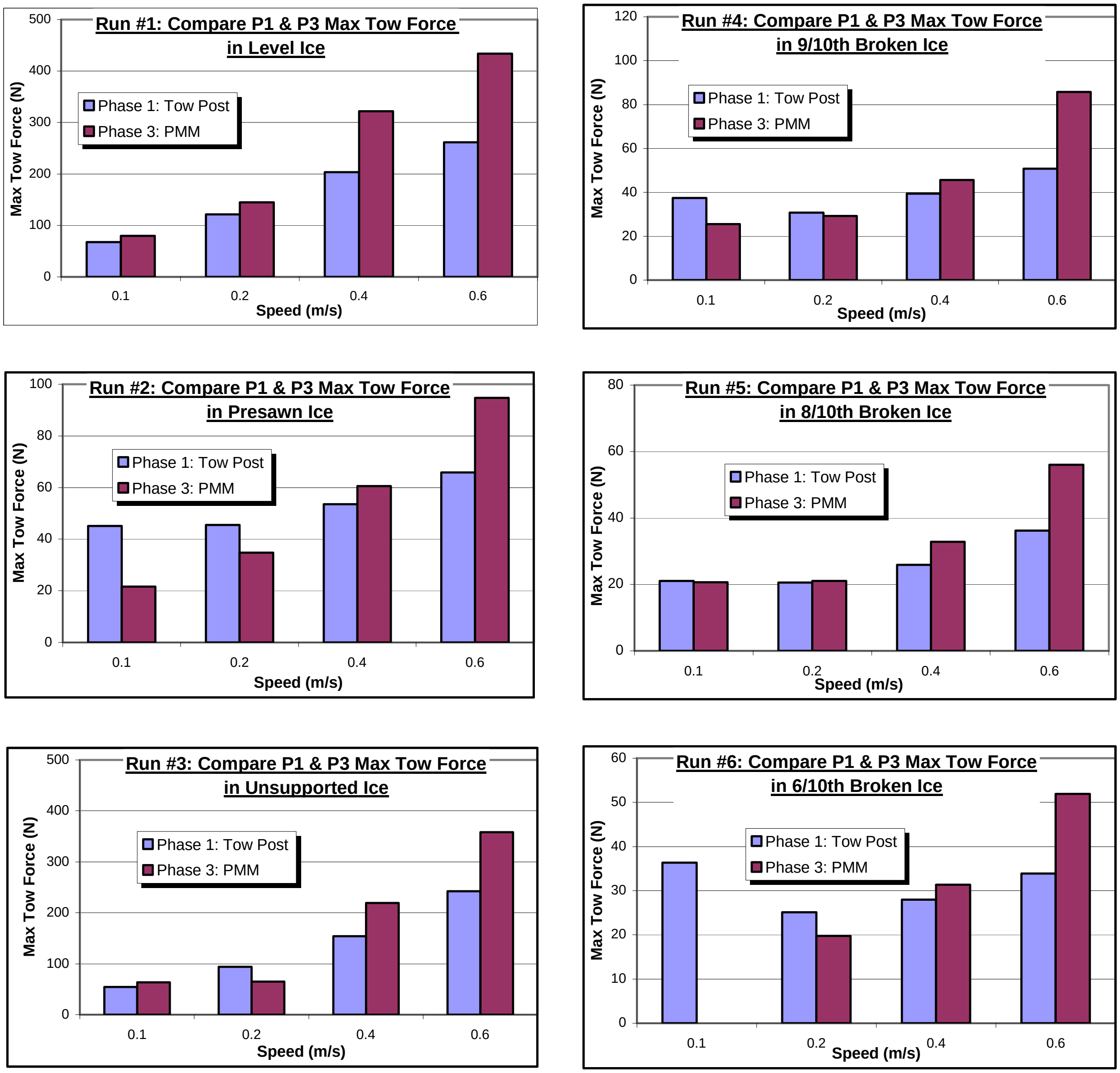

Figure A5: Comparison of Test Results in Maximum Two Force using the Tow Post (Phase I) and the PMM (Phase III) versus Model Speed.

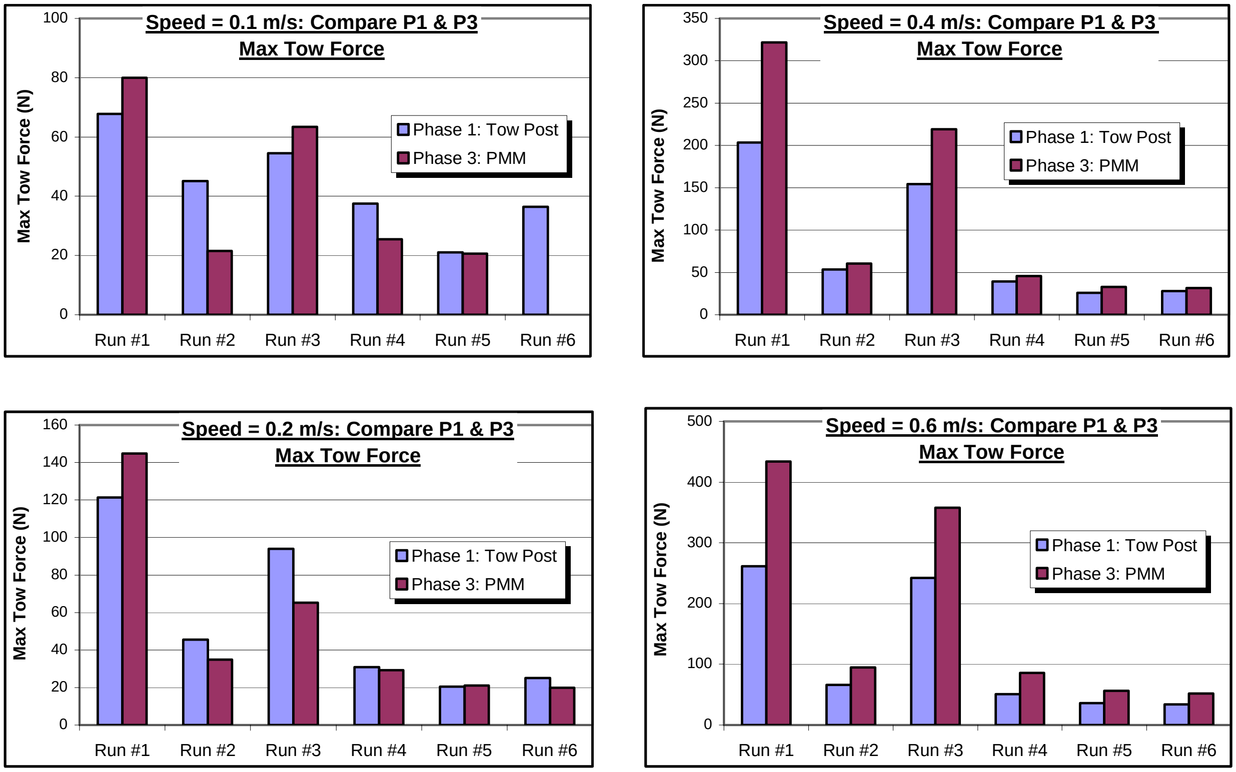

Figure A6: Comparison of Test Results in Maximum Tow Force using the Tow Post (Phase I) and the PMM (Phase III) versus Run Number.

Experimental Uncertainty for the Mean Tow Force After Data Reduction Equation: Phase I (Tow Post) and Phase III (PMM) Results							
Ice Sheet #	Speed (m/s)	Continuous Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	8.95%	7.65%	9.58%	4.20%	19.97%	16.44%
	0.2	4.37%	3.47%	4.09%	3.53%	16.56%	13.06%
	0.4	5.30%	3.68%	4.37%	3.01%	14.79%	9.20%
	0.6	4.88%	4.89%	5.90%	4.07%	10.14%	4.25%
Phase 3: PMM	0.1	4.10%	6.32%	3.96%	7.77%	25.94%	n/a
	0.2	4.37%	4.64%	4.54%	7.15%	17.99%	5.97%
	0.4	2.76%	2.60%	3.50%	3.45%	6.88%	5.03%
	0.6	4.41%	2.90%	4.90%	4.22%	6.31%	12.40%

Table A.3: Comparison of Phase I and Phase III Experimental Uncertainties in Mean Tow Force

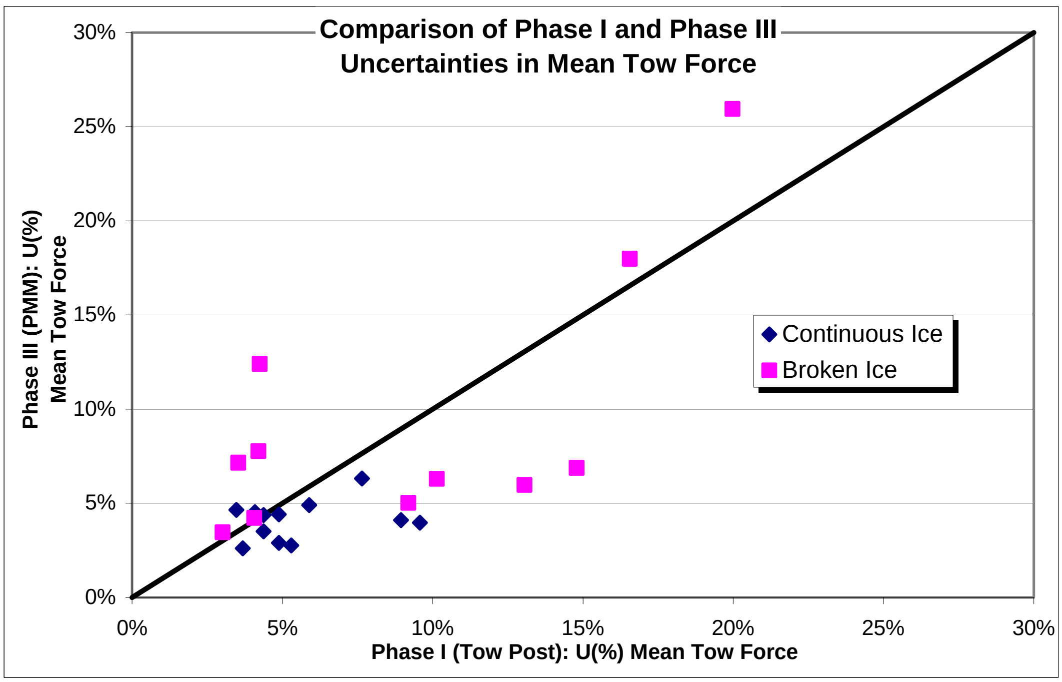

Figure A7: Comparison of Phase I and Phase III Uncertainty in Mean Tow Force after DRE.

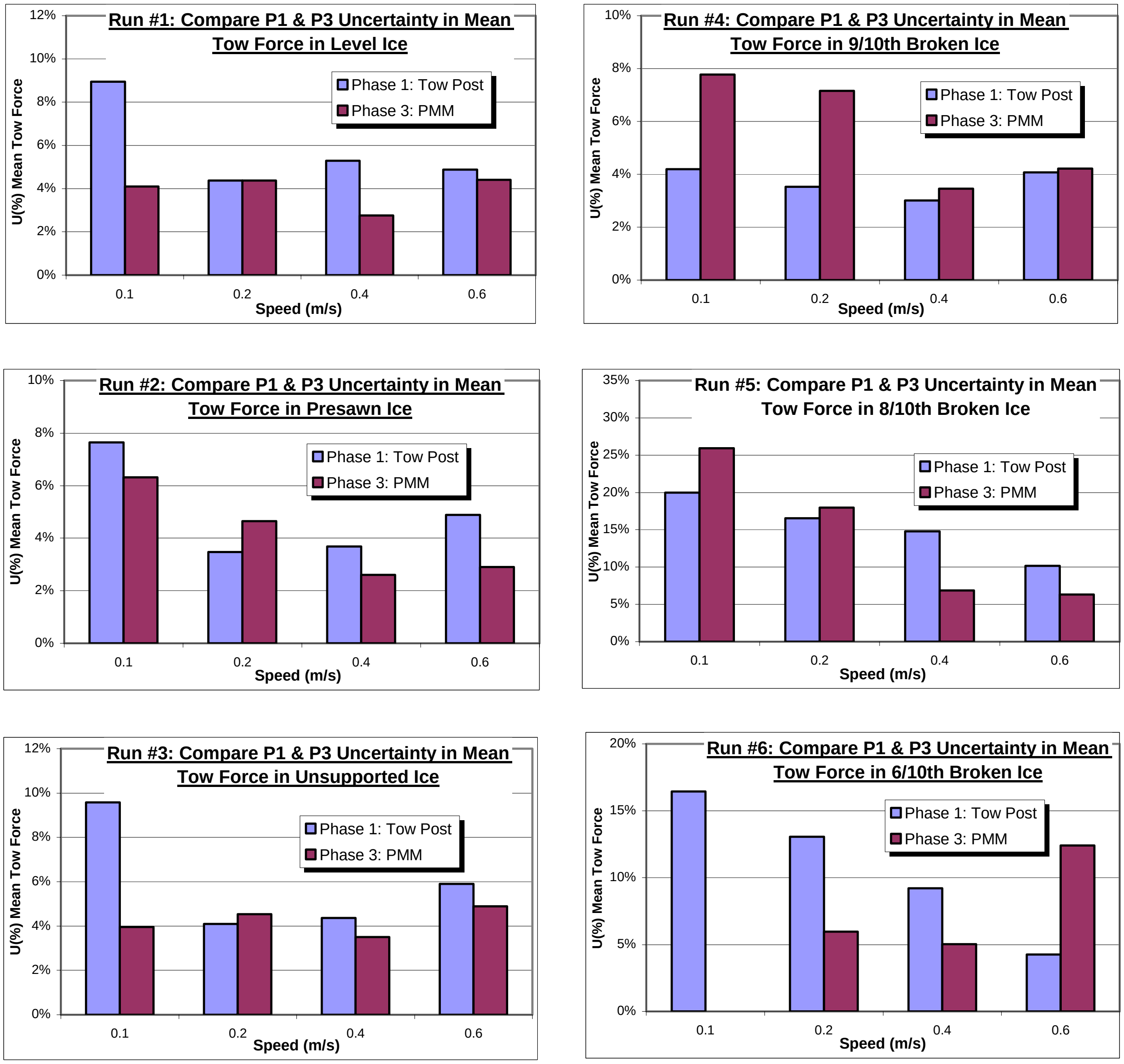

Figure A8: Comparison of Uncertainties in Mean Two Force using the Tow Post (Phase I) and the PMM (Phase III) versus Model Speed

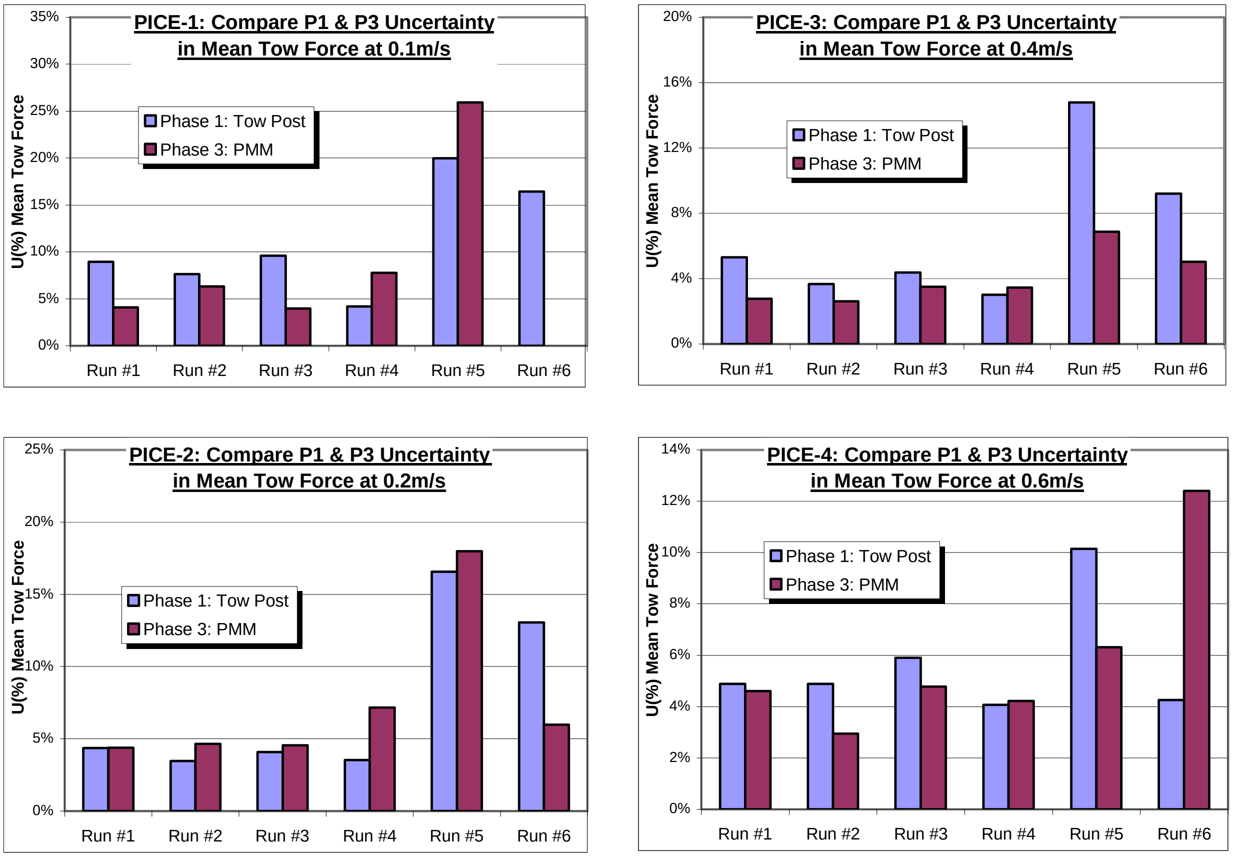

Figure A9: Comparison of Uncertainties in Mean Tow Force using the Tow Post (Phase I) and the PMM (Phase III) versus Run Number.

Experimental Uncertainty for the Max Tow Force After Data Reduction Equation: Phase I (Tow Post) and Phase III (PMM) Results							
Ice Sheet #	Speed (m/s)	Continuous Ice			Broken Ice		
		Run #1	Run #2	Run #3	Run #4	Run #5	Run #6
Phase 1: Tow Post	0.1	10.10%	8.01%	8.14%	8.26%	9.86%	6.82%
	0.2	5.62%	13.01%	10.78%	10.38%	16.00%	12.81%
	0.4	5.30%	7.14%	9.30%	6.58%	14.51%	7.87%
	0.6	4.78%	15.98%	8.25%	5.59%	11.70%	6.22%
Phase 3: PMM	0.1	4.89%	6.32%	8.79%	7.12%	11.19%	n/a
	0.2	11.27%	7.96%	9.62%	4.51%	10.40%	13.03%
	0.4	14.01%	4.69%	6.26%	7.82%	11.81%	6.90%
	0.6	8.90%	11.49%	4.68%	4.33%	12.30%	9.78%

Table A4: Comparison of Phase I and Phase III Experimental Uncertainties in Maximum Tow Force

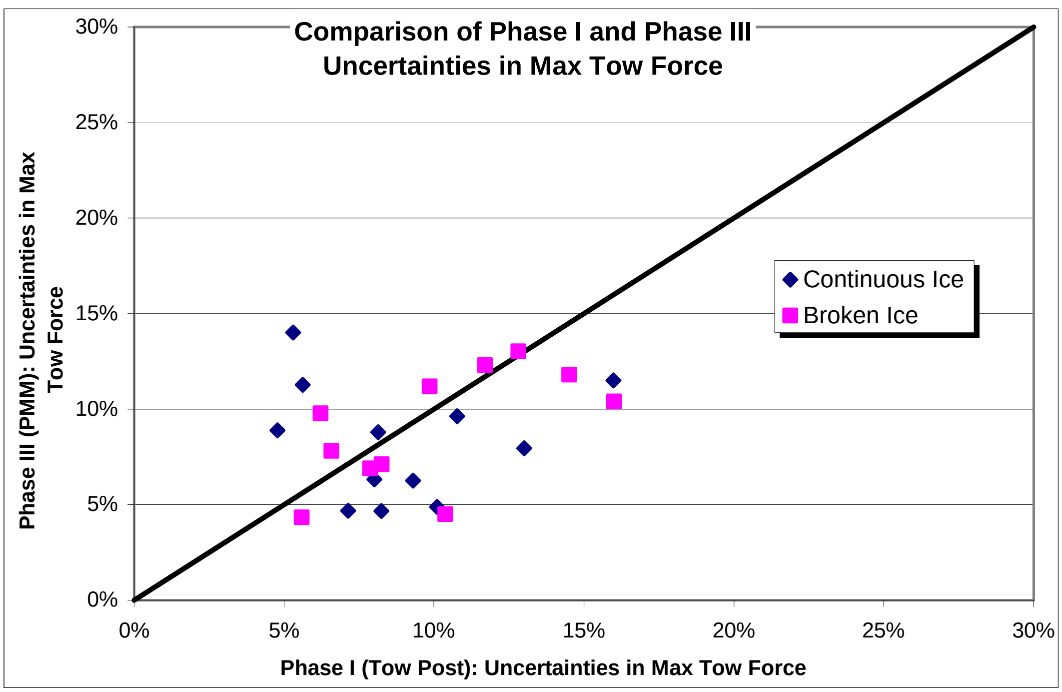

Figure A10: Comparison of Phase I and Phase III Uncertainty in Maximum Tow Force after DRE

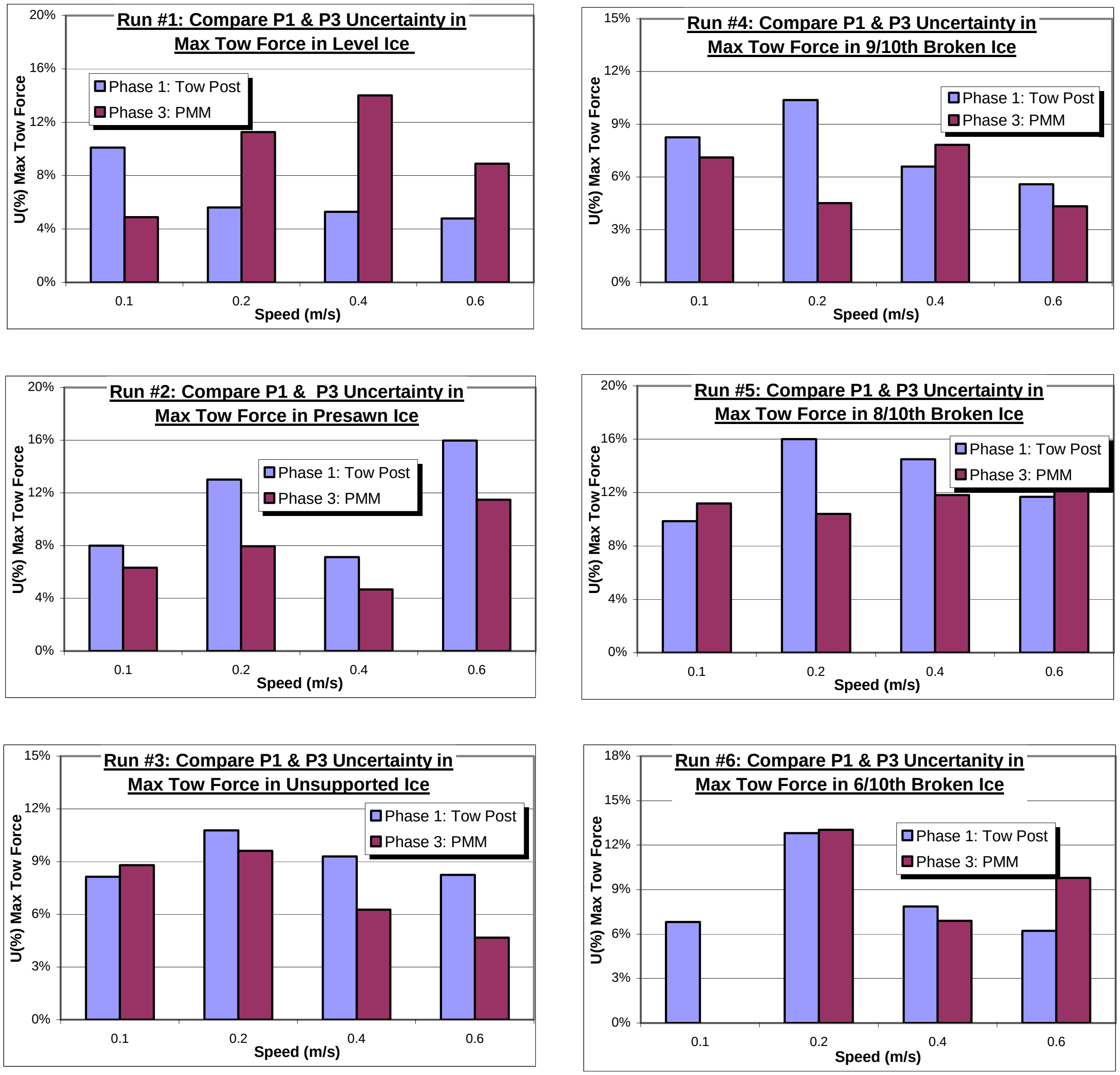

Figure A11: Comparison of Uncertainties in Maximum Tow Force using Tow Post (Phase I) and the PMM (Phase III) versus Model Speed.

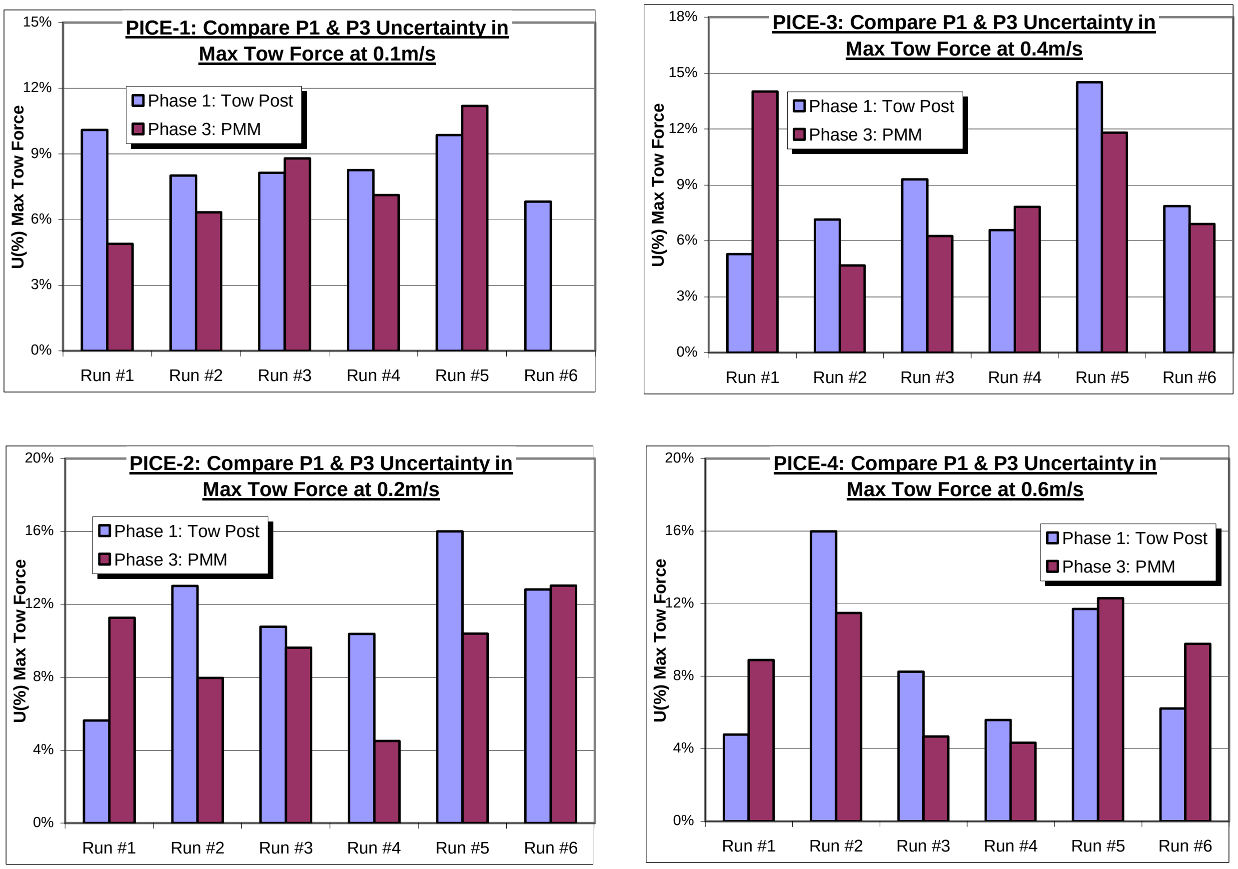

Figure A12: Comparison of Uncertainties in Maximum Tow Force using the Tow Post (Phase I) and the PMM (Phase III) versus Run Number.