TP 14220E

# Effect of Surface Conditions on the Friction Coefficients Measured on Winter Surfaces

Prepared for
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On behalf of
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Transport Canada

March 2003

by

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by

G. Comfort
BMT Fleet Technology Limited

March 2003

# DISCLAIMER



Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

*Un sommaire français se trouve avant la table des matières.*

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16. Abstract


Data obtained from the Joint Winter Runway Friction Measurement Program (JWRFMP) were used to investigate the effect of surface conditions on the friction coefficient measured by the Electronic Recording Decelerometer (ERD), the Surface Friction Tester device owned by Transport Canada (TC SFT'79), and the Instrument de Mesure Automatique de la Glissance (IMAG). Two types of analyses were conducted:

1. Analyses for individual surfaces – where possible, the friction coefficients obtained from the devices were compared to the guideline Canadian Runway Friction Index (CRFI) given in the Aeronautical Information Publication (AIP)
2. Correlations among the devices

The results varied from device to device and surface to surface, which makes it difficult to infer general conclusions.

This project should be followed up with more detailed quantitative analyses to investigate issues such as the variability among the results for different surfaces, and the degree of confidence that one could have in friction coefficients inferred solely from surface descriptions, in comparison to data obtained with friction-measuring devices.


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16. Résumé


Des données recueillies au cours du Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH) ont été utilisées pour étudier l'effet de l'état de la surface sur le coefficient de frottement mesuré au moyen du décéléromètre électronique (ERD, pour *Electronic Recording Decelerometer*), du glissancemètre de Transports Canada (TC SFT'79) et de l'Instrument de mesure automatique de la glissance (IMAG). Deux types d'analyses ont été effectuées :

1. Analyses portant sur chaque surface – là où c'était possible, les coefficients de frottement obtenus à l'aide des appareils de mesure ont été comparés aux mesures du Coefficient canadien de frottement sur piste (CRFI, pour *Canadian Runway Friction Index*) données dans la Publication d'information aéronautique (AIP, pour *Aeronautical Information Publication*).
2. Analyses de corrélation entre les appareils de mesure.

Les résultats variaient d'un appareil à l'autre et d'une surface à l'autre, ce qui a empêché de tirer des conclusions générales.

Comme suite à ces travaux, il y aurait lieu d'effectuer des analyses quantitatives plus détaillées afin de mieux cerner des questions comme la variabilité des résultats obtenus sur divers états de piste, et le niveau de confiance que l'on peut avoir dans des coefficients de frottement déduits uniquement des caractéristiques de la piste, par opposition à des coefficients de frottement mesurés par des appareils.


| | |
|---|---|
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Brahim Djimet carried out the database searches used for these analyses.

# EXECUTIVE SUMMARY

Testing has been under way at North Bay and elsewhere since 1996 as part of the Joint Winter Runway Friction Measurement Program (JWRFMP). The main research objectives are to:

- Compare friction readings from various devices
- Evaluate the relationship between ground vehicle and aircraft friction coefficients

The results of this testing have led to the generation of a large information database regarding friction coefficients on winter surfaces.

The general objective of this project was to investigate the effect of surface conditions on friction coefficients. The work comprised two general parts: analyses for individual surfaces and correlation analyses.

**Analyses for Individual Surfaces**

This work investigated the friction coefficients measured for various surface types such as ice, snow, packed snow, and dry and wet pavement. Three devices were analyzed:

1. Electronic Recording Decelerometer (ERD)
2. Transport Canada's Surface Friction Tester (TC SFT'79)
3. Instrument de Mesure Automatique de la Glissance (IMAG)

The following issues were examined:

- Range and distribution of friction coefficient values by surface and friction-measuring device
- Effect of surface temperature
- Effect of snow depth for surfaces with loose snow

The results were compared to the Canadian Runway Friction Index (CRFI) guidelines given in the Aeronautical Information Publication (AIP). The results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions. It was, however, commonly observed that the ranges of values observed in the JWRFMP were larger than those given in the AIP.

**Correlation Analyses**

This work evaluated the effects of surface conditions on correlations between measurements recorded by the above devices.

Again, the results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions. However, it was noted that:

- ERD readings on contaminated surfaces were generally higher and more scattered on contaminated surfaces than those for the TC SFT'79 and the IMAG. This probably reflects the fact that the ERD is a locked-wheel test.
- TC SFT'79 and the IMAG showed good correlation for all surfaces.

## Recommendations

This was an exploratory project to investigate general trends and relationships. The results obtained here should be followed up with more detailed quantitative analyses to investigate issues such as:

- Variability among the results for different surfaces.
- Degree of confidence that one could have in friction coefficients inferred solely from surface descriptions, in comparison to data obtained with friction-measuring devices.

## SOMMAIRE

### Introduction

Depuis 1996, des essais ont lieu dans le cadre du Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH). Ces essais, qui ont lieu à North Bay et ailleurs dans le monde, ont comme grands objectifs:

- de comparer les valeurs de frottement obtenues à l'aide de divers appareils de mesure
- d'évaluer la relation entre les coefficients de frottement établis à l'aide de véhicules au sol et d'aéronefs

**Ces essais ont permis d'accumuler une imposante base de données concernant les coefficients de frottement sur des surfaces contaminées par des précipitations hivernales.**

L'objectif principal de ce projet était d'étudier l'effet de l'état de la surface sur les coefficients de frottement mesurés sur celle-ci. Les travaux comportaient deux volets: des analyses portant sur chaque surface et des analyses de corrélation entre les appareils de mesure.

### Analyses portant sur chaque surface

Ce travail a consisté à analyser les coefficients de frottement mesurés sur divers états de piste: piste couverte de glace, de neige et de neige compactée, piste sèche et piste mouillée. Trois appareils ont été utilisés:

1. le décéléromètre électronique (ERD, pour *Electronic Recording Decelerometer*)
2. le glissancemètre de Transports Canada (TC SFT'79)
3. l'Instrument de mesure automatique de la glissance (IMAG)

Les questions suivantes ont été examinées:

- Étendue et distribution des valeurs du coefficient de frottement selon la surface et l'appareil de mesure
- Effet de la température de la surface
- Effet de l'épaisseur de la neige, dans le cas de surfaces couvertes de neige folle

Les résultats ont été mis en relation avec les mesures du Coefficient canadien de frottement sur piste (CRFI, pour *Canadian Runway Friction Index*) contenues dans la Publication d'information aéronautique (AIP, pour *Aeronautical Information Publication*). Comme les résultats variaient d'un appareil à l'autre et d'une surface à l'autre, il n'a pas été possible de tirer de conclusion générale. On a toutefois couramment observé que la gamme des valeurs issues du PCRGCAH était plus étendue que celle des valeurs données par l'AIP.

### Analyses de corrélation

Cette partie du travail a consisté à évaluer les effets de l'état de la surface sur la corrélation entre les mesures enregistrées par les divers appareils susmentionnés.

Encore une fois, les résultats variaient d'un appareil à l'autre et d'une surface à l'autre, ce qui n'a pas permis de tirer de conclusion générale. Il a toutefois été possible de noter ce qui suit:

- Sur les surfaces contaminées, les lectures faites par l'ERD étaient généralement supérieures à celles obtenues à l'aide du glissancemètre de TC et de l'IMAG, et elles étaient aussi plus dispersées. Cela est probablement attribuable au fait que l'ERD est un appareil qui prend ses mesures avec la roue bloquée.
- Le glissancemètre de TC et l'IMAG ont affiché une bonne corrélation pour toutes les surfaces.

**Recommandations**

Ce projet à caractère exploratoire visait à cerner des tendances et des liens généraux. Les résultats obtenus ici devraient faire l'objet d'analyses quantitatives plus détaillées afin de clarifier des questions comme:

- la variabilité entre les résultats obtenus pour différents états de piste.
- le niveau de confiance que l'on peut avoir dans les coefficients de frottement déduits uniquement des caractéristiques de la piste, par opposition à des coefficients de frottement mesurés par des appareils.

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# GLOSSARY OF TERMS

| | |
|---|---|
| AIP | Aeronautical Information Publication |
| CRFI | Canadian Runway Friction Index |
| ERD | Electronic Recording Decelerometer |
| IMAG | Instrument de Mesure Automatique de la Glissance (French acronym for friction-measuring device manufactured by the French Civil Aviation Authority) |
| IRV | IRFI Reference Vehicle |
| IRFI | International Runway Friction Index |
| JWRFMP | Joint Winter Runway Friction Measurement Program |
| TC SFT'79 | Surface Friction Tester device owned by Transport Canada |

# 1. INTRODUCTION

## 1.1 Background

Testing has been under way at North Bay and elsewhere since 1996 as part of the Joint Winter Runway Friction Measurement Program (JWRFMP). The main research objectives are as follows:

- to compare friction readings from various devices
- to evaluate the relationship between ground vehicle and aircraft friction coefficients

The results of this testing have led to the generation of a large information database [1] regarding friction coefficients on winter surfaces.

## 1.2 Objective

The general objective of this project was to investigate the effect of surface conditions on friction coefficients. The work comprised two general parts:

[1] Analyses for Individual Surfaces – This work investigated the friction coefficients measured for various surface types such as ice, compacted snow, and others. The results were also compared to the Canadian Runway Friction Index (CRFI) guidelines given in the Aeronautical Information Publication (AIP) [2]. The work investigated the following issues:

(a) Range and distribution of values by surface and friction-measuring device – the surfaces evaluated included those given in the AIP [2]. Three devices were analyzed:
   i. Electronic Recording Decelerometer (ERD)
   ii. Transport Canada's Surface Friction Tester (TC SFT'79)
   iii. Instrument de Mesure Automatique de la Glissance (IMAG)

(b) Effect of surface temperature

(c) Effect of snow depth for surfaces with loose snow

[2] Correlation Analyses – This work evaluated the effects of surface conditions on correlations between measurements recorded by the above devices.

# 2. METHOD AND DATABASE SEARCH PARAMETERS

## 2.1 Overall Summary

Database search parameters were specified as follows:

- Year and site – All years and sites were included in all searches to maximize the size of the data set.

- Speed – All speeds were included in all searches. This was done as previous analyses (e.g., [3]) have shown that friction coefficients on winter surfaces are not greatly dependent on speed. The data set was maximized by including all speeds.

- Surface and base conditions – Several cases were investigated as described in section 2.2.

- Devices – The analyses were limited to the friction coefficients measured by the ERD, the TC SFT'79 and the IMAG (section 2.3). The IMAG was investigated rather than the IRFI Reference Vehicle (IRV) as the IMAG was tested over a longer time span during the JWRFMP.

- Maintenance action – In most cases, the searches were made for surfaces that had not been treated with any maintenance action. However, a few searches were made for sanded ice (see section 2.2).

- Time interval between individual friction readings – All readings were included. The results were not partitioned by time interval.

- Track section on which the average friction coefficient is computed – The analyses were done using average friction coefficients for the whole track section, as opposed to 100 m sections (which is the other option in the search wizard). This selection was made because it maximized the size of the data set, as only "whole track" data were recorded during the early years of the JWRFMP.

## 2.2 Surfaces Evaluated

### 2.2.1 Surfaces Evaluated

The search wizard in the database [1] allows the user to specify various combinations of base and surface conditions. See Figure 2.1. Efforts were made to select the same surfaces given in the AIP [2] (Figure 2.2) to the extent possible. The surfaces evaluated are listed in Table 2.1.

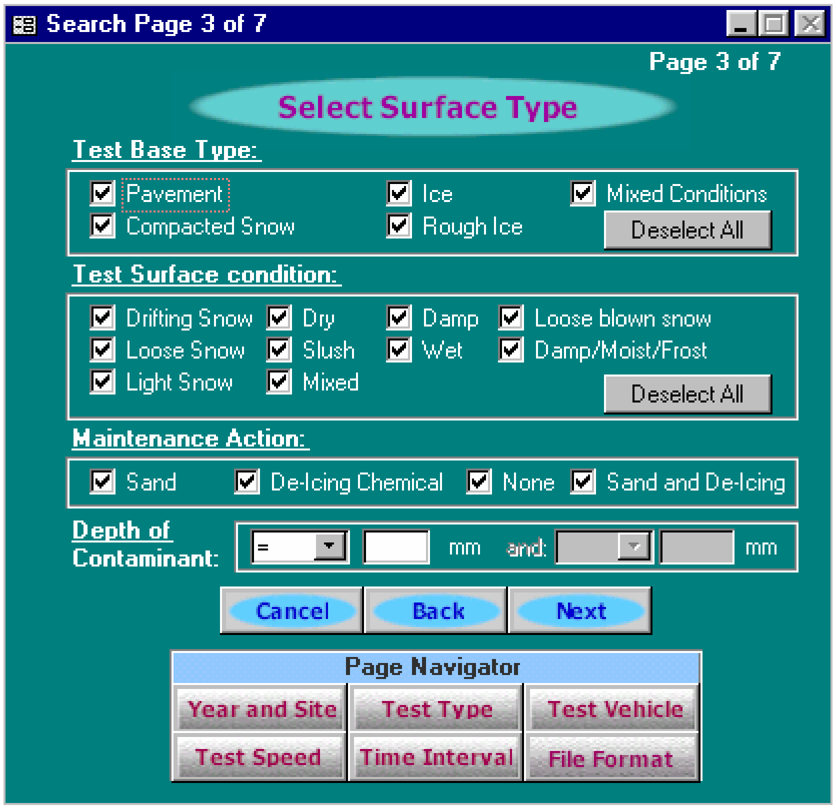



**Figure 2.1: Selectable Base and Surface Conditions in the Database Search Wizard [1]**

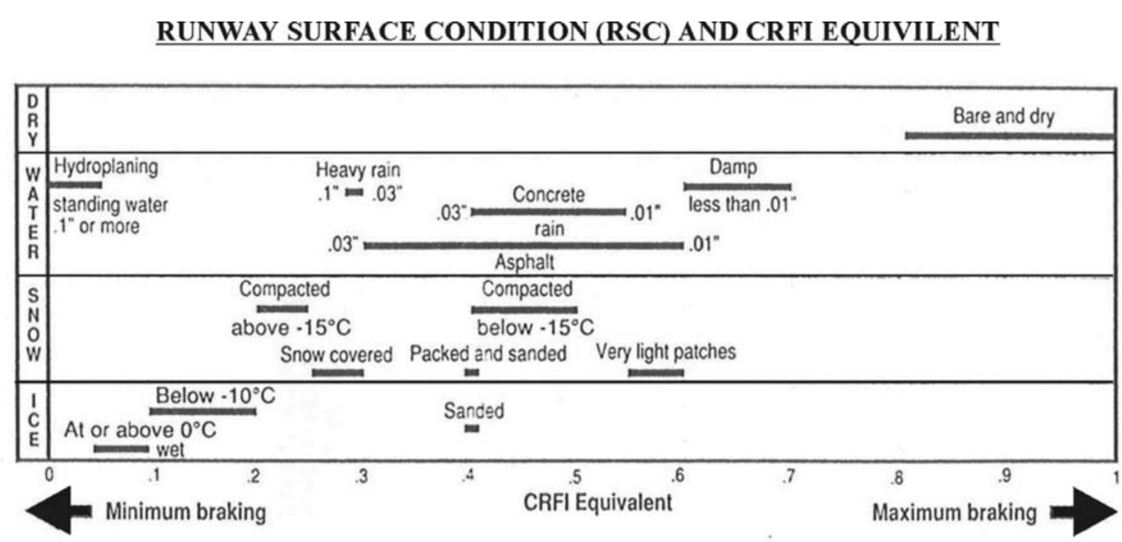



**Figure 2.2: CRFIs Given in the AIP for Various Surfaces [2]**

**Table 2.1: Database Search Summary**

| Surface | ERD | TC SFT'79 – all Cs[1] | TC SFT'79 – C3[1] | IMAG – All Cs[1] | IMAG C3C7[1] |
|---|---|---|---|---|---|
| Bare Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Bare Ice and Rough Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Sanded Bare Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Sanded Bare Ice and Rough Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | No data | √ | √ |
| Bare Packed Snow:<br>• > -15°C<br>• <= -15°C | √ | √ | √ | √ | √ |
| Snow on Pavement:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Snow on Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Snow on Rough Ice:<br>• >= 0°C<br>• 0°C to -10°C<br>• <= -10°C | √ | √ | √ | √ | √ |
| Snow on Packed Snow:<br>• > -15°C<br>• <= -15°C | √ | √ | √ | √ | √ |
| Bare Pavement | √ | √ | √ | √ | √ |
| Wet or Damp Pavement:<br>• Wet Pavement<br>• Damp Pavement | <br>√<br>√ | | <br>√ | | <br>√ |
| Slush on any base | √ | √ | √ | √ | √ |

1: Legend (See Table 2.2 for a description of the configurations below):

- TC SFT'79 – all Cs: all configurations for the TC SFT'79
- TC SFT'79 – C3: configuration 3 for the TC SFT'79
- IMAG – all Cs: all configurations for the IMAG
- IMAG – C3C7: configurations 3 and 7 for the IMAG

### 2.2.2 Effect of Snow Depth

The friction coefficients for snow-covered surfaces were also evaluated, although these are not included in the AIP guideline (Figure 2.2). It is well known that snow depth affects measured friction coefficients. Consequently, the effect of snow depth was investigated to assess the most appropriate way to partition the data set.

The effect of snow depth is shown in Figures 2.3 to 2.9 for the devices evaluated. The devices that were evaluated and corresponding configurations are described in section 2.3.

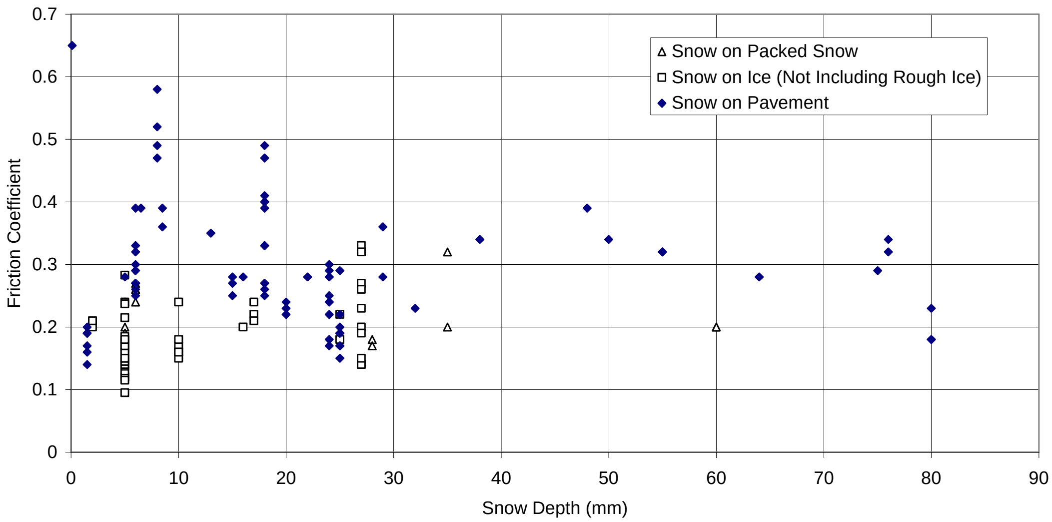



**Figure 2.3: Effect of Snow Depth on ERD Readings**

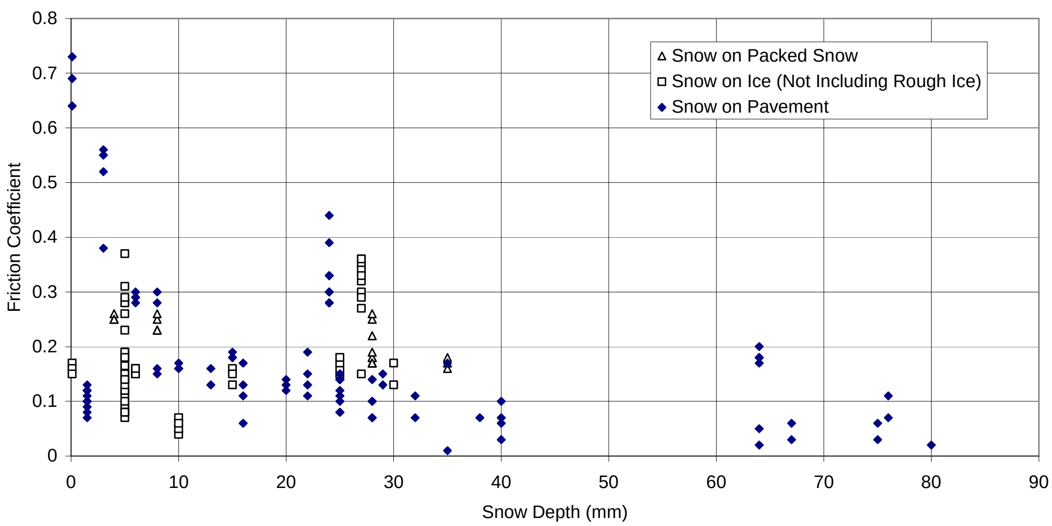



**Figure 2.4: Effect of Snow Depth on TC SFT'79 Readings (All Configurations)**

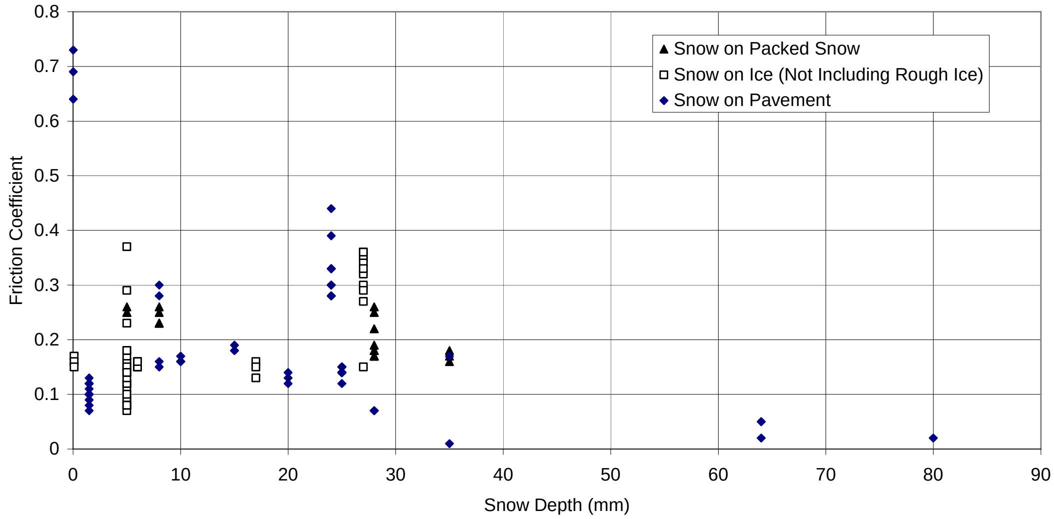



**Figure 2.5: Effect of Snow Depth on TC SFT'79 Readings (Configuration 3)**

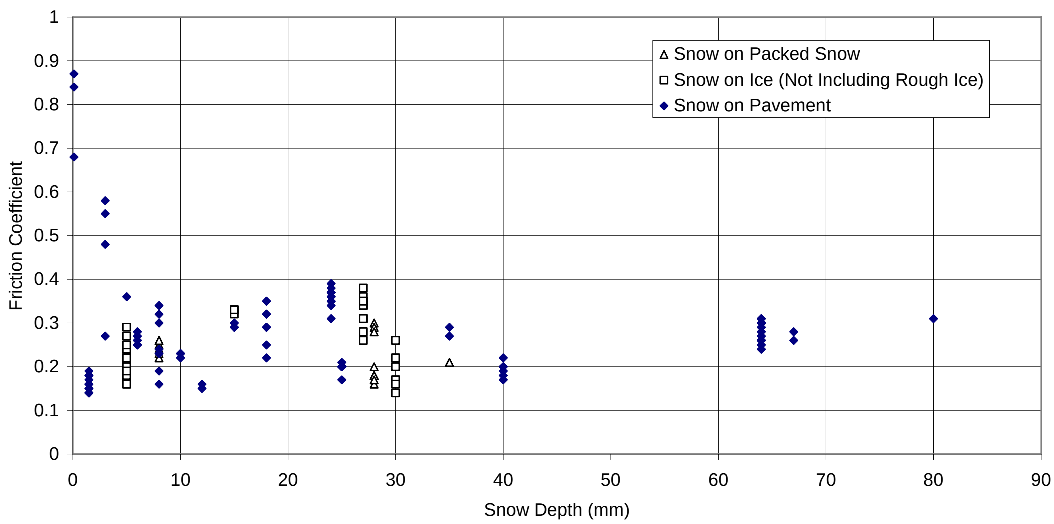



**Figure 2.6: Effect of Snow Depth on IMAG Force Readings (All Configurations)**

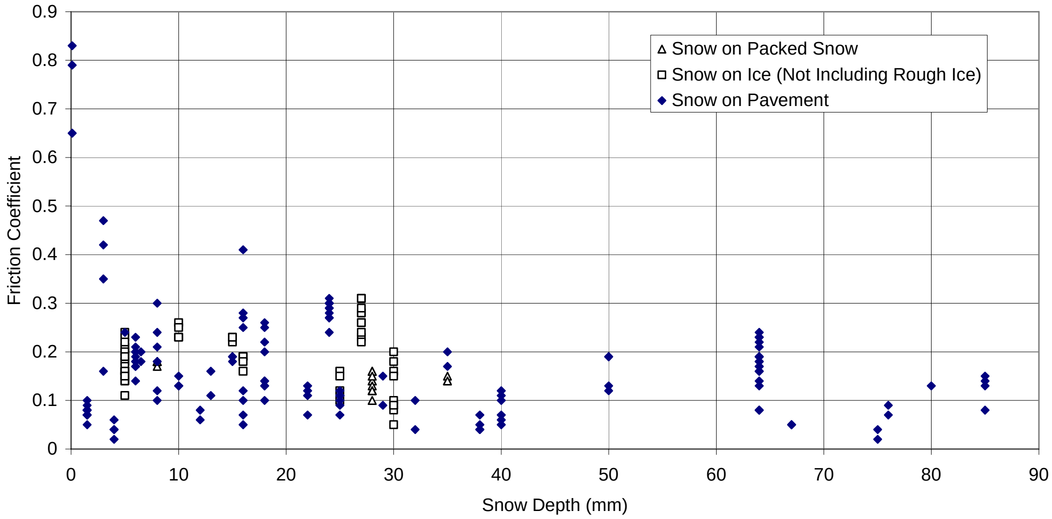



**Figure 2.7: Effect of Snow Depth on IMAG Torque Readings (All Configurations)**

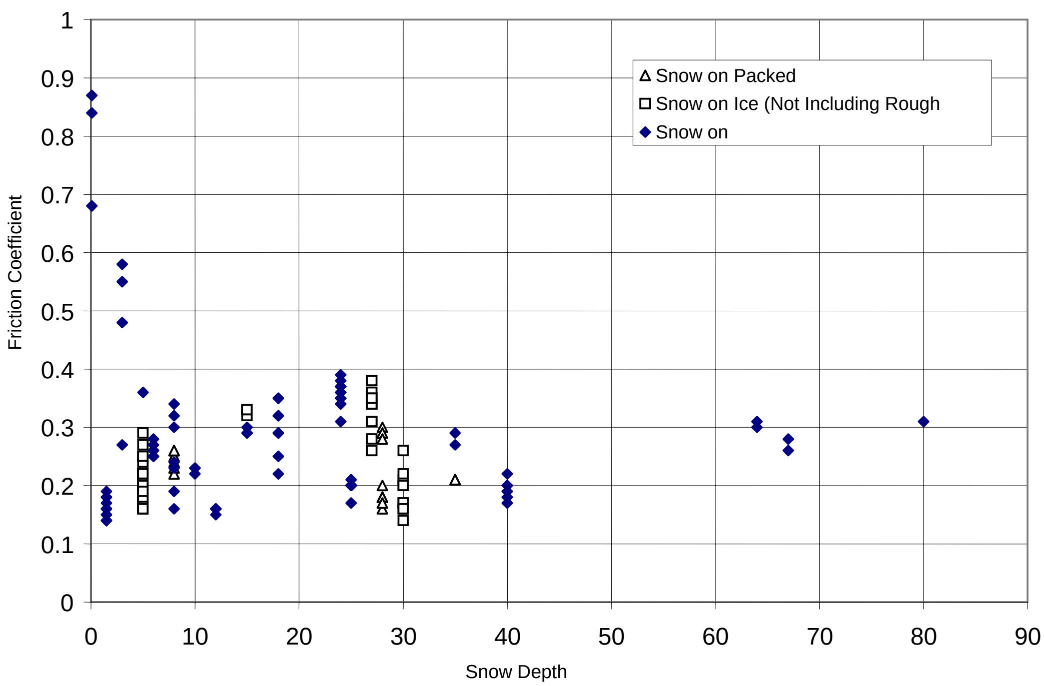



**Figure 2.8: Effect of Snow Depth on IMAG Force Readings (Configurations 3 and 7)**

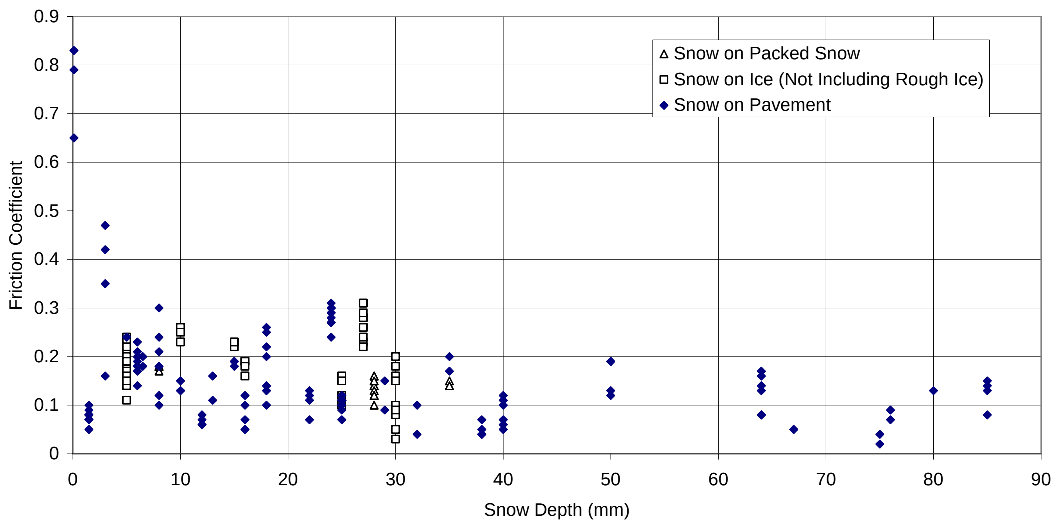



**Figure 2.9: Effect of Snow Depth on IMAG Torque Readings (Configurations 3 and 7)**

The effect of snow depth depends on the device and surface under consideration as summarized below:

(1) ERD (shown in Figure 2.3)

a. Snow on Ice – Although the relationship is scattered, the ERD reading tends to increase with increasing snow depth. This probably reflects an increasing amount of contaminant drag as the snow depth is increased.

b. Snow on Packed Snow – Only a few data points are available, which makes it difficult to define trends.

c. Snow on Pavement – The ERD reading tends to level off (thus becoming independent of snow depth) at depths exceeding 10-20 mm. At lower snow depths, the ERD reading varies significantly from values near those expected for bare pavement to those expected for bare packed snow. This range may reflect differences in snow coverage over the pavement. Alternatively, it may indicate that the vehicle wheels were breaking through the snow cover to reach bare pavement during friction measurements.

(2) TC SFT'79 (shown in Figures 2.4 and 2.5)

a. Snow on Ice – Although the relationship is scattered, the friction coefficient tends to increase with increasing snow depth. This probably reflects an increasing amount of contaminant drag as the snow depth is increased.

b. Snow on Packed Snow – The friction coefficient tends to decrease with increasing snow depth for both cases evaluated (i.e., all configurations of the TC SFT'79, and only configuration 3). This trend may reflect increased bonding between the snow on the surface to the packed snow base for deeper depths, which would cause the TC SFT'79 to tend to see a snow surface at deeper snow depths.

c. Snow on Pavement – The TC SFT'79 reading decreases exponentially as the snow depth is increased. As for the "snow on packed snow" case above, this trend may reflect increased bonding between the snow on the surface to the pavement base for deeper depths. This would cause the TC SFT'79 to tend to see a snow surface at deeper snow depths.

(3) IMAG (shown in Figures 2.6 to 2.9)

a. Snow on Ice – As for the ERD and the TC SFT'79, the friction coefficient tends to increase with increasing snow depth. This probably reflects an increasing amount of contaminant drag as the snow depth is increased.

b. Snow on Packed Snow – Only a few data are available, which makes it difficult to identify trends. However, the data tend to indicate that the friction coefficient does not change greatly with increasing snow depth.

c. Snow on Pavement – As for the TC SFT'79, the IMAG reading decreases exponentially as the snow depth is increased. As for the "snow on packed snow" case above, this trend may reflect increased bonding between the snow on the surface to the pavement base for deeper depths. This would cause the IMAG to tend to see a snow surface at deeper snow depths.

In conclusion, it is evident that all three devices exhibited different trends depending on the surface being considered. This makes it difficult to identify a cut-off snow depth below which the readings were not affected significantly. To allow the analyses to proceed, two cases were analyzed:

(a) All snow depths
(b) Snow depths of 10 mm or less

These two snow depth cases were analyzed partly because the size of the data set was quite small for snow depths of 10 mm or less. Often, snow depth data were not available for various sets of friction data (although general surface classifications were available), which necessitated these data sets being eliminated from the data subset being analyzed.

The "all snow depths" case includes data for snow depths exceeding 25 mm (1 inch). See Figures 2.3 to 2.9. It is noted that Transport Canada advises that CRFIs not be taken in snow exceeding this depth. It would be useful to further partition the data set to remove the friction values for snow depths exceeding 25 mm (1 inch).

## 2.3 Friction Measuring Devices Analyzed

Friction coefficients were evaluated in this project for the following devices:

(1) The ERD

(2) The TC SFT'79 – Two cases were analyzed as follows:
   a. All configurations (Table 2.2) – It should be noted that two of the configurations apply to the case where the self-wetting system is on (i.e., configurations 5 and 6 – Table 2.2). Data for these configurations were not included in the results presented here as these configurations would not be used in wintertime conditions. However, the data for these configurations were included in the overall data quantity evaluations that were made (section 2.4).
   b. Configuration 3 (Table 2.2) – This configuration was evaluated separately as it was the most common one used during the JWRFMP.

(3) The IMAG – Two cases were analyzed as follows:
   a. All configurations (Table 2.2)
   b. Configurations 3 and 7 (Table 2.2) – These two configurations were evaluated separately as they were the most common ones used during the JWRFMP.

**Table 2.2: List of Configurations**

| Device | Config'n | Tire Type | Inflation Press (kPa) | Vertical Load (kN) | Slip Ratio (%) | Self-Wetting On? |
|---|---|---|---|---|---|---|
| TC SFT '79 | 1 | ASTM E1551 Ribbed | 210 | 1400 | 12 | no |
| TC SFT '79 | 2 | ASTM E1551 Ribbed | 690 | 1400 | 12 | no |
| TC SFT '79 | 3 | ASTM E1551 Smooth | 690 | 1400 | 12 | no |
| TC SFT '79 | 4 | AERO Smooth Tread | 690 | 1400 | 12 | no |
| TC SFT '79 | 5 | ASTM E1551 Smooth Tread | 690 | 1400 | 12 | yes |
| TC SFT '79 | 6 | AERO Smooth Tread | 690 | 1400 | 12 | yes |
| TC SFT '79 | 7 | ASTM E1551 Ribbed | 690 | 1400 | 12 | no |
| | | | | | | |
| IMAG | 1 | PIARC Smooth | 150 | 1800 | 20 | no |
| IMAG | 2 | PIARC Smooth | 150 | 1800 | 5 | no |
| IMAG | 3 | PIARC Smooth | 150 | 1800 | 15 | no |
| IMAG | 4 | PIARC Smooth | 150 | 1800 | 12 | no |
| IMAG | 5 | PIARC Smooth | 150 | 1800 | 50 | no |
| IMAG | 6 | PIARC Smooth | 150 | 1800 | 10 | no |
| IMAG | 7 | PIARC Smooth | 165 | 1800 | 15 | no |
| IMAG | 8 | PIARC Smooth | 150 | 1800 | 15 | no |
| IMAG | 9 | PIARC Smooth | 150 | 1800 | 0 | no |
| IMAG | 10 | PIARC Smooth (note) | 165 | 1800 | 15 | no |
| IMAG | 11 | PIARC Smooth | 165 | 1800 | 30 | no |
| IMAG | 12 | PIARC Smooth | 165 | 1800 | 45 | no |
| IMAG | 13 | PIARC Smooth | 165 | 1800 | 60 | no |
| IMAG | 14 | PIARC Smooth | 165 | 1800 | 75 | no |
| IMAG | 15 | PIARC Smooth | 150 | 1800 | 30 | no |
| IMAG | 16 | PIARC Smooth | 150 | 1800 | 60 | no |
| IMAG | 17 | PIARC Smooth | 150 | 1800 | 90 | no |
| IMAG | 18 | PIARC Smooth | 150 | 1800 | 40 | no |

NOTE: Swapped tires with IRV

## 2.4 Number of Records

The number of records was checked at the start of the work as this provides an indication of the strength of the conclusions that may be obtained from various analyses. The total number of records for all surfaces and cases was 884, 1029, 938, and 1151 for the ERD, TC SFT'79, IMAG Force, and IMAG Torque, respectively. As expected, the number of records was reduced as the data set was partitioned. See Tables 2.3 to 2.5.

**Table 2.3: Data Quantities and Breakdown for the ERD**

| Configuration Number[1] | Year and Site | Time Interval[2] | Speed[2] | Surface Parameters | | | | Track Section | Number of Data Points |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Base | Surface | Depth[2] | Maintenance Action | | |
| All | All | Blank | Blank | All | All | Blank | None | Whole | 884 |
| All | All | Blank | Blank | Ice | All | Blank | None | Whole | 328 |
| All | All | Blank | Blank | Ice and Rough Ice | All | Blank | None | Whole | 408 |
| All | All | Blank | Blank | Ice | Dry | Blank | None | Whole | 196 |
| All | All | Blank | Blank | Ice and Rough Ice | Dry | Blank | None | Whole | 239 |
| All | All | Blank | Blank | Packed Snow | All | Blank | None | Whole | 223 |
| All | All | Blank | Blank | Packed Snow | Dry | Blank | None | Whole | 186 |
| All | All | Blank | Blank | Pavement | All | Blank | None | Whole | 183 |
| All | All | Blank | Blank | Pavement | Dry | Blank | None | Whole | 13 |

Notes:

1. The ERD only has one configuration.
2. By leaving this field blank, the program will include all data.

## Table 2.4: Data Quantities and Breakdown for the TC SFT'79

| Configuration Number | Year and Site | Time Interval[1] | Speed[1] | Surface Parameters | | | | Track Section | Number of Data Points |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Base | Surface | Depth[1] | Maintenance Action | | |
| All[2] | All | Blank | Blank | All | All | Blank | None | Whole | 1029 |
| All[2] | All | Blank | Blank | Ice | All | Blank | None | Whole | 390 |
| All[2] | All | Blank | Blank | Ice and Rough Ice | All | Blank | None | Whole | 465 |
| All[2] | All | Blank | Blank | Ice | Dry | Blank | None | Whole | 212 |
| All[2] | All | Blank | Blank | Ice and Rough Ice | Dry | Blank | None | Whole | 226 |
| All[2] | All | Blank | Blank | Packed Snow | All | Blank | None | Whole | 258 |
| All[2] | All | Blank | Blank | Packed Snow | Dry | Blank | None | Whole | 191 |
| All[2] | All | Blank | Blank | Pavement | All | Blank | None | Whole | 249 |
| All[2] | All | Blank | Blank | Pavement | Dry | Blank | None | Whole | 79 |
| | | | | | | | | | |
| 3 | All | Blank | Blank | All | All | Blank | None | Whole | 760 |
| 3 | All | Blank | Blank | Ice | All | Blank | None | Whole | 314 |
| 3 | All | Blank | Blank | Ice and Rough Ice | All | Blank | None | Whole | 381 |
| 3 | All | Blank | Blank | Ice | Dry | Blank | None | Whole | 174 |
| 3 | All | Blank | Blank | Ice and Rough Ice | Dry | Blank | None | Whole | 188 |
| 3 | All | Blank | Blank | Packed Snow | All | Blank | None | Whole | 214 |
| 3 | All | Blank | Blank | Packed Snow | Dry | Blank | None | Whole | 151 |
| 3 | All | Blank | Blank | Pavement | All | Blank | None | Whole | 131 |
| 3 | All | Blank | Blank | Pavement | Dry | Blank | None | Whole | 24 |

Notes:

1. By leaving this field blank, the database search wizard will include all data.
2. These data quantities include the data for configurations 5 and 6, which are the ones with the self-wetting system on (Table 2.2). However, the friction data for configurations 5 and 6 were not included in the results presented in section 3 for "all configurations" of the TC SFT'79.

**Table 2.5: Data Quantities and Breakdown for the IMAG**

| Configuration Number | Year and Site | Time Interval[1] | Speed[1] | Surface Parameters: Base | Surface | Depth[1] | Maintenance Action | Track Section | Number of Points (IMAG Force/IMAG Torque) |
|---|---|---|---|---|---|---|---|---|---|
| All | All | Blank | Blank | All | All | Blank | None | Whole | 938/1151 |
| All | All | Blank | Blank | Ice | All | Blank | None | Whole | 372/448 |
| All | All | Blank | Blank | Ice and Rough Ice | All | Blank | None | Whole | 460/562 |
| All | All | Blank | Blank | Ice | Dry | Blank | None | Whole | 211/247 |
| All | All | Blank | Blank | Ice and Rough Ice | Dry | Blank | None | Whole | 254/298 |
| All | All | Blank | Blank | Packed Snow | All | Blank | None | Whole | 218/253 |
| All | All | Blank | Blank | Packed Snow | Dry | Blank | None | Whole | 158/189 |
| All | All | Blank | Blank | Pavement | All | Blank | None | Whole | 215/265 |
| All | All | Blank | Blank | Pavement | Dry | Blank | None | Whole | 46/48 |
| | | | | | | | | | |
| 3 and 7 | All | Blank | Blank | All | All | Blank | None | Whole | 881/1082 |
| 3 and 7 | All | Blank | Blank | Ice | All | Blank | None | Whole | 331/407 |
| 3 and 7 | All | Blank | Blank | Ice and Rough Ice | All | Blank | None | Whole | 413/515 |
| 3 and 7 | All | Blank | Blank | Ice | Dry | Blank | None | Whole | 174/210 |
| 3 and 7 | All | Blank | Blank | Ice and Rough Ice | Dry | Blank | None | Whole | 211/255 |
| 3 and 7 | All | Blank | Blank | Packed Snow | All | Blank | None | Whole | 208/235 |
| 3 and 7 | All | Blank | Blank | Packed Snow | Dry | Blank | None | Whole | 148/171 |
| 3 and 7 | All | Blank | Blank | Pavement | All | Blank | None | Whole | 215/261 |
| 3 and 7 | All | Blank | Blank | Pavement | Dry | Blank | None | Whole | 46/48 |

Notes:

1. By leaving this field blank, the database search wizard will include all data.

# 3. ANALYSES FOR INDIVIDUAL SURFACES

## 3.1 Surfaces Quantified in the AIP

The analyses were focused on the surfaces given in the AIP [2], as it is of interest to compare the friction coefficients measured during the JWRFMP with the CRFIs given in the AIP.

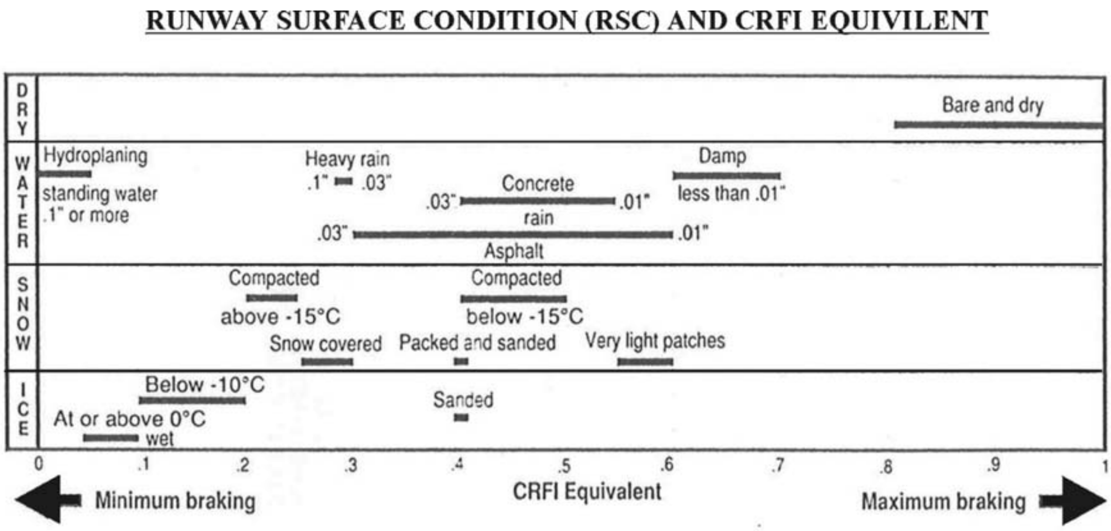



**Figure 3.1: CRFIs Given in the AIP for Various Surfaces [2]**
**(repeated from Figure 2.2)**

Summary results are presented in Figures 3.7 to 3.22. It should be noted that, for formatting reasons, all remaining figures associated with section 3 are presented at the end of section 3.

## 3.2 Bare Ice and Bare Packed Snow

### 3.2.1 Bare Ice

Figures 3.7 and 3.8 provide summary results for bare ice not including and including rough ice. Summary results are tabulated in Table 3.1. Detailed results are plotted in Appendix A.

The following observations can be made:

(1) Comparison to AIP
   a. Friction coefficients at or above 0°C – The AIP suggests values that tend to be lower than those measured by the devices.
   b. Friction coefficients below -10°C – The values suggested by the AIP are in reasonable agreement with the means measured by the devices.
   c. Overall comparison – The ranges of values suggested by the AIP tend to be smaller than those measured by the devices. In almost all cases, the devices measured values that were both lower than and higher than the lower-bound and upper-bound values suggested by the AIP, respectively.

(2) Effect of Including or Not Including Rough Ice Data – As expected, the inclusion of the rough ice data causes an increase in friction coefficient. However, the increase is relatively

slight, in relation to the overall variation between the maximum and minimum values recorded. Consequently, the conclusions drawn from the analyses will not be affected greatly by whether the rough ice data are included.

This result may be partly due to the fact that the quantity of rough ice data is relatively small compared to that for the smooth ice data. This will cause the friction statistics to be controlled by the smooth ice data.

(3) Effect of Surface Temperature – The friction coefficients measured by each of the devices were not greatly affected by the surface temperature (Appendix A.2).

3.2.2 Bare Packed Snow

Figure 3.9 shows summary results for bare packed snow. Summary results are tabulated in Table 3.2. Detailed results are plotted in Appendix B.

The following observations can be made:

[1] Comparison to AIP
  a. Friction coefficient below -15°C: All of the friction coefficients measured by the devices were substantially less than the values given in the AIP.
  b. Friction coefficient above -15°C: The friction coefficients measured by all of the devices were in general agreement with the range of values in the AIP.
  c. Ranges of friction coefficients: The devices measured a much wider range of friction factors than that given in the AIP.

[2] Effect of Surface Temperature – Typically, there are many more data for surface temperatures above -15°C than below it (Table 3.2), which makes it difficult to infer trends from the summary values listed in Table 3.2. Consequently, the trend plots presented in Appendix B.2 were used to assess the significance of surface temperature. The friction coefficients measured by each of the devices were not greatly affected by the surface temperature (Appendix B.2).

# Table 3.1: Summary Results for Bare Ice

| Device | | Not Including Rough Ice | | | | | Including Rough Ice | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ERD | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| | mean | 0.12 | 0.111506849 | 0.2 | 0.119439 | | 0.131818 | 0.112440476 | 0.19125 | 0.12364 |
| | st dev | 0.039441 | 0.046321104 | 0.132212 | 0.054448 | | 0.045318 | 0.04404335 | 0.111411 | 0.052914 |
| | maximum | 0.21 | 0.289999992 | 0.45 | 0.45 | | 0.24 | 0.289999992 | 0.45 | 0.45 |
| | minimum | 0.08 | 0.050000001 | 0.08 | 0.05 | | 0.08 | 0.050000001 | 0.1 | 0.05 |
| | no of obs | 10 | 146 | 6 | 196 | | 22 | 168 | 8 | 239 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (All Configs) | mean | 0.183333 | 0.128797468 | 0.097273 | 0.138624 | | 0.178571 | 0.129127517 | 0.101667 | 0.139956 |
| | st dev | 0.060625 | 0.057621183 | 0.031966 | 0.067071 | | 0.057652 | 0.05883937 | 0.029951 | 0.067201 |
| | maximum | 0.28 | 0.289999992 | 0.14 | 0.42 | | 0.28 | 0.289999992 | 0.16 | 0.42 |
| | minimum | 0.05 | 0.029999999 | 0.05 | 0.03 | | 0.05 | 0.029999999 | 0.05 | 0.03 |
| | no of obs | 24 | 158 | 11 | 218 | | 28 | 149 | 18 | 226 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (Config 3) | mean | 0.175625 | 0.1225 | No Data | 0.132126 | | 0.18 | 0.12337931 | 0.09 | 0.133351 |
| | st dev | 0.029205 | 0.055587768 | No Data | 0.062432 | | 0.024202 | 0.055417865 | No data | 0.062454 |
| | maximum | 0.21 | 0.289999992 | 0 | 0.42 | | 0.21 | 0.289999992 | 0.09 | 0.42 |
| | minimum | 0.11 | 0.029999999 | 0 | 0.03 | | 0.13 | 0.029999999 | 0.09 | 0.03 |
| | no of obs | 16 | 136 | 0 | 174 | | 15 | 145 | 1 | 188 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (All Configs) | mean | 0.237667 | 0.184367816 | No Data | 0.203415 | | 0.260204 | 0.196111111 | 0.21 | 0.215645 |
| | st dev | 0.033803 | 0.041699398 | No Data | 0.052758 | | 0.042793 | 0.045980877 | No data | 0.056565 |
| | maximum | 0.3 | 0.319999993 | 0 | 0.4 | | 0.34 | 0.319999993 | 0.21 | 0.4 |
| | minimum | 0.17 | 0.090000004 | 0 | 0.09 | | 0.17 | 0.109999999 | 0.21 | 0.09 |
| | no of obs | 30 | 87 | 0 | 205 | | 49 | 72 | 1 | 248 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (All Configs) | mean | 0.155238 | 0.151214954 | 0.114 | 0.146166 | | 0.165652 | 0.153200001 | 0.165652 | 0.150625 |
| | st dev | 0.034587 | 0.038820104 | 0.014298 | 0.053049 | | 0.034406 | 0.04014821 | 0.128446 | 0.050515 |
| | maximum | 0.22 | 0.25999999 | 0.14 | 0.68 | | 0.23 | 0.25999999 | 0.68 | 0.68 |
| | minimum | 0.07 | 0.07 | 0.1 | 0.07 | | 0.07 | 0.07 | 0.1 | 0.07 |
| | no of obs | 42 | 107 | 10 | 253 | | 69 | 100 | 23 | 304 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (Configs 3 & 7) | mean | 0.235 | 0.18654321 | 0.168 | 0.205238 | | 0.258919 | 0.191744186 | 0.14 | 0.217463 |
| | st dev | 0.0373 | 0.040686621 | 0.040249 | 0.045068 | | 0.048177 | 0.043876615 | 0.014142 | 0.050627 |
| | maximum | 0.3 | 0.319999993 | 0.21 | 0.37 | | 0.34 | 0.319999993 | 0.16 | 0.37 |
| | minimum | 0.17 | 0.109999999 | 0.13 | 0.11 | | 0.17 | 0.109999999 | 0.13 | 0.11 |
| | no of obs | 24 | 81 | 5 | 168 | | 37 | 86 | 4 | 205 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (Configs 3 & 7) | mean | 0.157714 | 0.152475248 | 0.172941 | 0.149259 | | 0.165614 | 0.153867925 | 0.171875 | 0.153218 |
| | st dev | 0.034733 | 0.038688653 | 0.149489 | 0.054894 | | 0.03713 | 0.038360961 | 0.154713 | 0.051891 |
| | maximum | 0.22 | 0.25999999 | 0.68 | 0.68 | | 0.23 | 0.25999999 | 0.68 | 0.68 |
| | minimum | 0.07 | 0.079999998 | 0.1 | 0.07 | | 0.07 | 0.079999998 | 0.1 | 0.07 |
| | no of obs | 35 | 101 | 17 | 216 | | 57 | 106 | 16 | 261 |

**Table 3.2: Summary Results for Bare Packed Snow**

| Device | | Friction Coefficient by Temperature | | |
|---|---|---|---|---|
| ERD | | <=-15°C | >-15°C | All Temperatures |
| | mean | 0.2875 | 0.184638 | 0.198817205 |
| | st dev | 0.005 | 0.063501 | 0.066346338 |
| | maximum | 0.29 | 0.63 | 0.629999995 |
| | minimum | 0.28 | 0.09 | 0.090000004 |
| | no of obs | 4 | 138 | 186 |
| | | | | |
| TC SFT'79 | | <=-15°C | >-15°C | All Temperatures |
| (All Configs) | mean | 0.239375 | 0.219478 | 0.226073298 |
| | st dev | 0.045088 | 0.038202 | 0.042436019 |
| | maximum | 0.29 | 0.35 | 0.349999994 |
| | minimum | 0.16 | 0.13 | 0.119999997 |
| | no of obs | 16 | 115 | 191 |
| | | | | |
| TC SFT'79 | | <=-15°C | >-15°C | All Temperatures |
| (Config 3) | mean | No Data | 0.219333 | 0.227483444 |
| | st dev | No Data | 0.029622 | 0.042758525 |
| | maximum | 0 | 0.33 | 0.349999994 |
| | minimum | 0 | 0.14 | 0.119999997 |
| | no of obs | 0 | 105 | 151 |
| | | | | |
| IMAG | | <=-15°C | >-15°C | All Temperatures |
| Force (All Configs) | mean | 0.275714 | 0.250851 | 0.263903449 |
| | st dev | 0.019101 | 0.054054 | 0.053789886 |
| | maximum | 0.3 | 0.37 | 0.372999996 |
| | minimum | 0.25 | 0.15 | 0.150000006 |
| | no of obs | 14 | 94 | 145 |
| | | | | |
| IMAG | | <=-15°C | >-15°C | All Temperatures |
| Torque (All Configs) | mean | 0.18 | 0.183511 | 0.189168318 |
| | st dev | 0.021034 | 0.040704 | 0.042460064 |
| | maximum | 0.22 | 0.31 | 0.310000002 |
| | minimum | 0.14 | 0.1 | 0.100000001 |
| | no of obs | 34 | 131 | 202 |
| | | | | |
| IMAG | | <=-15°C | >-15°C | All Temperatures |
| Force (Configs 3 & 7) | mean | 0.28375 | 0.251429 | 0.265525927 |
| | st dev | 0.020659 | 0.054845 | 0.05479471 |
| | maximum | 0.3 | 0.37 | 0.372999996 |
| | minimum | 0.25 | 0.15 | 0.150000006 |
| | no of obs | 8 | 91 | 135 |
| | | | | |
| IMAG | | <=-15°C | >-15°C | All Temperatures |
| Torque (Configs 3 & 7) | mean | 0.1792 | 0.183171 | 0.190391305 |
| | st dev | 0.023965 | 0.041038 | 0.043324031 |
| | maximum | 0.23 | 0.31 | 0.310000002 |
| | minimum | 0.14 | 0.1 | 0.100000001 |
| | no of obs | 25 | 123 | 184 |

## 3.3 Sanded Ice

Figures 3.10 and 3.11 provide summary results for bare ice not including and including rough ice. Summary results are tabulated in Table 3.3. Detailed results are plotted in Appendix C.

The data set for sanded ice is quite small (Table 3.3), which limits the strength of the conclusions that can be drawn. Nevertheless, the following preliminary observations can be made:

(1) Comparison to AIP – The measured friction coefficients span a much wider range of values than that given in the AIP.

(2) Comparison to Un-Sanded Ice – The friction coefficients for sanded ice tend to be higher than those for un-sanded ice.

(3) Effect of Including or Not Including Rough Ice Data – This had no significant effect.

(4) Effect of Surface Temperature – The friction coefficient was not greatly affected by the surface temperature (Appendix C.1).

## 3.4 Snow on Ice, Pavement and Packed Snow

### 3.4.1 Snow-Covered Ice

Figures 3.12 and 3.13 provide summary results for snow-covered ice (not including rough ice) for all snow depths, and for snow depths of 10 mm or less, respectively. Figures 3.14 and 3.15 provide summary results for bare ice (including rough ice) for all snow depths, and for snow depths of 10 mm or less, respectively. Summary results are tabulated in Tables 3.4 and 3.5 for bare ice not including and including rough ice, respectively. Detailed results are plotted in Appendix E.

The following observations can be made:

(1) Comparison to AIP – Comparisons are not possible because this case is not covered by the AIP.

(2) Effect of Including or Not Including Rough Ice Data – This did not affect the conclusions significantly due to the large ranges of variation that were measured.

(3) Effect of Including All Snow Depths vs. Limiting the Analyses to Snow Depths of 10 mm or Less – Wider ranges of variation were observed for the full data set. However, the mean friction coefficients were generally similar for each case.

(4) Effect of Surface Temperature – The trends for the whole data set were highly scattered (Appendix D.2), which is partly due to the fact that all snow depths were mixed. However, the plots produced for the data subset with snow depths of 10 mm or less were also scattered (Appendix E.5), which indicates that the friction coefficients were not greatly affected by the surface temperature.

# Table 3.3: Summary Results for Sanded Ice

| Device | | Sanded Ice Not Including Rough Ice | | | | | Sanded Ice Including Rough Ice | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ERD | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| | mean | 0.3 | 0.263333331 | 0.23 | 0.241667 | | 0.221111 | 0.254285714 | 0.23 | 0.2325 |
| | st dev | No Data | 0.092915735 | No Data | 0.051316 | | 0.038873 | 0.067788186 | No Data | 0.046368 |
| | maximum | 0.3 | 0.340000004 | 0.23 | 0.34 | | 0.3 | 0.340000004 | 0.23 | 0.34 |
| | minimum | 0.3 | 0.159999996 | 0.23 | 0.16 | | 0.17 | 0.159999996 | 0.23 | 0.16 |
| | no of obs | 1 | 3 | 1 | 12 | | 9 | 7 | 1 | 24 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (All Configs) | mean | No Data | 0.636666665 | 0.11 | 0.426 | | No Data | 0.636666665 | 0.11 | 0.426 |
| | st dev | No Data | 0.073936908 | 0.040825 | 0.278496 | | No Data | 0.073936908 | 0.040825 | 0.278496 |
| | maximum | 0 | 0.699999988 | 0.17 | 0.7 | | 0 | 0.699999988 | 0.17 | 0.7 |
| | minimum | 0 | 0.5 | 0.08 | 0.08 | | 0 | 0.5 | 0.08 | 0.08 |
| | no of obs | 0 | 6 | 4 | 10 | | 0 | 6 | 4 | 10 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (Config 3) | mean | No Data | 0.636666665 | No Data | 0.636667 | | No Data | 0.636666665 | No Data | 0.636667 |
| | st dev | No Data | 0.073936908 | No Data | 0.073937 | | No Data | 0.073936908 | No Data | 0.073937 |
| | maximum | 0 | 0.699999988 | 0 | 0.7 | | 0 | 0.699999988 | 0 | 0.7 |
| | minimum | 0 | 0.5 | 0 | 0.5 | | 0 | 0.5 | 0 | 0.5 |
| | no of obs | 0 | 6 | 0 | 6 | | 0 | 6 | 0 | 6 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (All Configs) | mean | No Data | 0.556666662 | No Data | 0.556667 | | 0.3525 | 0.556666662 | No Data | 0.44 |
| | st dev | No Data | 0.089591669 | No Data | 0.089592 | | 0.027646 | 0.089591669 | No Data | 0.120384 |
| | maximum | 0 | 0.639999986 | 0 | 0.64 | | 0.39 | 0.639999986 | 0 | 0.64 |
| | minimum | 0 | 0.419999987 | 0 | 0.42 | | 0.31 | 0.419999987 | 0 | 0.31 |
| | no of obs | 0 | 6 | 0 | 6 | | 8 | 6 | 0 | 14 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (All Configs) | mean | No Data | 0.49666667 | 0.2075 | 0.381 | | 0.24625 | 0.292083335 | 0.2075 | 0.2725 |
| | st dev | No Data | 0.093523619 | 0.051881 | 0.167495 | | 0.025036 | 0.13493893 | 0.051881 | 0.115 |
| | maximum | 0 | 0.579999983 | 0.28 | 0.58 | | 0.28 | 0.579999983 | 0.28 | 0.58 |
| | minimum | 0 | 0.349999994 | 0.17 | 0.17 | | 0.21 | 0.150000006 | 0.17 | 0.15 |
| | no of obs | 0 | 6 | 4 | 10 | | 8 | 24 | 4 | 36 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (Configs 3 & 7) | mean | No Data | 0.556666662 | #DIV/0! | 0.556667 | | 0.3525 | 0.556666662 | No Data | 0.44 |
| | st dev | No Data | 0.089591669 | #DIV/0! | 0.089592 | | 0.027646 | 0.089591669 | No Data | 0.120384 |
| | maximum | 0 | 0.639999986 | 0 | 0.64 | | 0.39 | 0.639999986 | 0 | 0.64 |
| | minimum | 0 | 0.419999987 | 0 | 0.42 | | 0.31 | 0.419999987 | 0 | 0.31 |
| | no of obs | 0 | 6 | 0 | 6 | | 8 | 6 | 0 | 14 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (Configs 3 & 7) | mean | No Data | 0.49666667 | 0.2075 | 0.381 | | 0.24625 | 0.292083335 | 0.2075 | 0.2725 |
| | st dev | No Data | 0.093523619 | 0.051881 | 0.167495 | | 0.025036 | 0.13493893 | 0.051881 | 0.115 |
| | maximum | 0 | 0.579999983 | 0.28 | 0.58 | | 0.28 | 0.579999983 | 0.28 | 0.58 |
| | minimum | 0 | 0.349999994 | 0.17 | 0.17 | | 0.21 | 0.150000006 | 0.17 | 0.15 |
| | no of obs | 0 | 6 | 4 | 10 | | 8 | 24 | 4 | 36 |

## Table 3.4: Summary Results for Snow-Covered Ice – Not Including Rough Ice

| **Device** | | **Any Snow Depth** | | | | | **Snow Depth < 10 mm** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ERD | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| | mean | 0.178889 | 0.17455072 | No Data | 0.192358 | | 0.24 | 0.165764706 | No Data | 0.169889 |
| | st dev | 0.05819 | 0.05930022 | No Data | 0.073699 | | 0 | 0.037315249 | No Data | 0.040128 |
| | maximum | 0.24 | 0.33000001 | 0 | 0.39 | | 0.24 | 0.282999992 | 0 | 0.283 |
| | minimum | 0.1 | 0.07 | 0 | 0.07 | | 0.24 | 0.094999999 | 0 | 0.095 |
| | no of obs | 9 | 69 | 0 | 95 | | 2 | 34 | 0 | 36 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (All | mean | 0.177391 | 0.1614486 | No Data | 0.166341 | | 0.166364 | 0.150121952 | No Data | 0.153558 |
| Configs) | st dev | 0.093479 | 0.07975792 | No Data | 0.081864 | | 0.102788 | 0.056018834 | No Data | 0.067659 |
| | maximum | 0.33 | 0.37 | 0 | 0.37 | | 0.31 | 0.370000005 | 0 | 0.37 |
| | minimum | 0.04 | 0.04 | 0 | 0.04 | | 0.04 | 0.07 | 0 | 0.04 |
| | no of obs | 23 | 107 | 0 | 138 | | 11 | 41 | 0 | 52 |
| | | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (Config 3) | mean | 0.16 | 0.15716495 | No Data | 0.156394 | | 0.16 | 0.144571429 | No Data | 0.145789 |
| | st dev | 0.01 | 0.08041853 | No Data | 0.077774 | | 0.01 | 0.058828908 | No Data | 0.056599 |
| | maximum | 0.17 | 0.37 | 0 | 0.37 | | 0.17 | 0.370000005 | 0 | 0.37 |
| | minimum | 0.15 | 0.04 | 0 | 0.04 | | 0.15 | 0.07 | 0 | 0.07 |
| | no of obs | 3 | 97 | 0 | 104 | | 3 | 35 | 0 | 38 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force | mean | 0.246333 | 0.21557895 | No Data | 0.22296 | | No Data | 0.203333334 | No Data | 0.203333 |
| (All | st dev | 0.047669 | 0.07286998 | No Data | 0.06878 | | No Data | 0.03396831 | No Data | 0.033968 |
| Configs) | maximum | 0.33 | 0.38 | 0 | 0.38 | | 0 | 0.289999992 | 0 | 0.29 |
| | minimum | 0.18 | 0.09 | 0 | 0.09 | | 0 | 0.159999996 | 0 | 0.16 |
| | no of obs | 30 | 95 | 0 | 125 | | 0 | 27 | 0 | 27 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque | mean | 0.1638 | 0.1653271 | No Data | 0.165217 | | 0.21375 | 0.172222222 | No Data | 0.181714 |
| (All | st dev | 0.053486 | 0.06402119 | No Data | 0.060011 | | 0.035832 | 0.030801264 | No Data | 0.036095 |
| Configs) | maximum | 0.26 | 0.31 | 0 | 0.31 | | 0.26 | 0.239999995 | 0 | 0.26 |
| | minimum | 0.06 | 0.03 | 0 | 0.03 | | 0.15 | 0.109999999 | 0 | 0.11 |
| | no of obs | 50 | 107 | 0 | 161 | | 8 | 27 | 0 | 35 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force | mean | 0.253333 | 0.21553192 | No Data | 0.223967 | | 0.22 | 0.202692308 | No Data | 0.203333 |
| (Configs | st dev | 0.045234 | 0.07325926 | No Data | 0.06966 | | No Data | 0.03447407 | No Data | 0.033968 |
| 3 & 7) | maximum | 0.33 | 0.38 | 0 | 0.38 | | 0.22 | 0.289999992 | 0 | 0.29 |
| | minimum | 0.19 | 0.09 | 0 | 0.09 | | 0.22 | 0.159999996 | 0 | 0.16 |
| | no of obs | 27 | 94 | 0 | 121 | | 1 | 26 | 0 | 27 |
| | | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10 | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque | mean | 0.167234 | 0.16584906 | No Data | 0.166624 | | 0.202222 | 0.174615385 | No Data | 0.181714 |
| (Configs | st dev | 0.053312 | 0.06409618 | No Data | 0.060102 | | 0.048161 | 0.028737538 | No Data | 0.036095 |
| 3 & 7) | maximum | 0.26 | 0.31 | 0 | 0.31 | | 0.26 | 0.239999995 | 0 | 0.26 |
| | minimum | 0.06 | 0.03 | 0 | 0.03 | | 0.11 | 0.140000001 | 0 | 0.11 |
| | no of obs | 47 | 106 | 0 | 157 | | 9 | 26 | 0 | 35 |

## Table 3.5: Summary Results for Snow-Covered Ice – Including Rough Ice

| Device | | Any Snow Depth | | | | | Snow Depth < 10 mm | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ERD | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| | mean | 0.149444 | 0.180695652 | No Data | 0.188326 | | 0.253333 | 0.16910204 | No Data | 0.173887 |
| | st dev | 0.065212 | 0.058113898 | No Data | 0.070961 | | 0.023094 | 0.038762226 | No Data | 0.042349 |
| | maximum | 0.28 | 0.330000013 | 0 | 0.39 | | 0.28 | 0.282999992 | 0 | 0.283 |
| | minimum | 0.09 | 0.07 | 0 | 0.07 | | 0.24 | 0.094999999 | 0 | 0.095 |
| | no of obs | 18 | 92 | 0 | 129 | | 3 | 49 | 0 | 53 |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (All Configs) | mean | 0.191111 | 0.166007463 | 0.1025 | 0.168636 | | 0.194 | 0.164402986 | No Data | 0.169817 |
| | st dev | 0.092584 | 0.076595265 | 0.023629 | 0.076791 | | 0.099484 | 0.059838941 | No Data | 0.068998 |
| | maximum | 0.33 | 0.370000005 | 0.12 | 0.37 | | 0.31 | 0.370000005 | 0 | 0.37 |
| | minimum | 0.04 | 0.039999999 | 0.07 | 0.04 | | 0.04 | 0.07 | 0 | 0.04 |
| | no of obs | 27 | 134 | 4 | 187 | | 15 | 67 | 0 | 82 |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (Config 3) | mean | 0.170714 | 0.160826772 | No Data | 0.161069 | | 0.1775 | 0.1615 | No Data | 0.1625 |
| | st dev | 0.020178 | 0.076492463 | No Data | 0.072005 | | 0.03594 | 0.062309371 | No Data | 0.060932 |
| | maximum | 0.23 | 0.370000005 | 0 | 0.37 | | 0.23 | 0.370000005 | 0 | 0.37 |
| | minimum | 0.15 | 0.039999999 | 0 | 0.04 | | 0.15 | 0.07 | 0 | 0.07 |
| | no of obs | 14 | 127 | 0 | 145 | | 4 | 60 | 0 | 64 |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (All Configs) | mean | 0.250526 | 0.211491229 | No Data | 0.222911 | | No Data | 0.198260869 | No Data | 0.205962 |
| | st dev | 0.043243 | 0.06952726 | No Data | 0.065368 | | No Data | 0.039231751 | No Data | 0.042898 |
| | maximum | 0.33 | 0.379999995 | 0 | 0.38 | | 0 | 0.289999992 | 0 | 0.29 |
| | minimum | 0.18 | 0.090000004 | 0 | 0.09 | | 0 | 0.140000001 | 0 | 0.14 |
| | no of obs | 38 | 114 | 0 | 158 | | 0 | 46 | 0 | 52 |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (All Configs) | mean | 0.159848 | 0.16 | No Data | 0.160991 | | 0.205 | 0.153913044 | No Data | 0.16625 |
| | st dev | 0.055206 | 0.059603628 | No Data | 0.056923 | | 0.03451 | 0.038208682 | No Data | 0.041077 |
| | maximum | 0.26 | 0.310000002 | 0 | 0.31 | | 0.26 | 0.239999995 | 0 | 0.26 |
| | minimum | 0.02 | 0.029999999 | 0 | 0.02 | | 0.15 | 0.100000001 | 0 | 0.1 |
| | no of obs | 66 | 136 | 0 | 212 | | 12 | 46 | 0 | 64 |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (Configs 3 & 7) | mean | 0.256286 | 0.21141593 | No Data | 0.223701 | | 0.22 | 0.197777778 | No Data | 0.205962 |
| | st dev | 0.040226 | 0.06983229 | No Data | 0.066006 | | No Data | 0.039536453 | No Data | 0.042898 |
| | maximum | 0.33 | 0.379999995 | 0 | 0.38 | | 0.22 | 0.289999992 | 0 | 0.29 |
| | minimum | 0.19 | 0.090000004 | 0 | 0.09 | | 0.22 | 0.140000001 | 0 | 0.14 |
| | no of obs | 35 | 113 | 0 | 154 | | 1 | 45 | 0 | 52 |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (Configs 3 & 7) | mean | 0.162222 | 0.16037037 | No Data | 0.161971 | | 0.197692 | 0.154888889 | No Data | 0.16625 |
| | st dev | 0.055371 | 0.059668329 | No Data | 0.057015 | | 0.04226 | 0.038056311 | No Data | 0.041077 |
| | maximum | 0.26 | 0.310000002 | 0 | 0.31 | | 0.26 | 0.239999995 | 0 | 0.26 |
| | minimum | 0.02 | 0.029999999 | 0 | 0.02 | | 0.11 | 0.100000001 | 0 | 0.1 |
| | no of obs | 63 | 135 | 0 | 208 | | 13 | 45 | 0 | 64 |

### 3.4.2 Snow-Covered Pavement

Figures 3.16 and 3.17 provide summary results for snow-covered pavement for all snow depths, and for snow depths of 10 mm or less, respectively. Summary results are tabulated in Table 3.6. Detailed results are plotted in Appendix D.

The following observations can be made:

(1) Comparison to AIP – Comparisons are not possible, as the AIP does not provide guideline CRFI values for this case.

(2) Ranges of Values – The measured values span a wide range for each device and each snow depth case analyzed.

(3) Effect of Limiting the Analyses to Snow Depths of 10 mm or Less – The friction coefficients were lower for the “10 mm or Less” case, particularly with respect to mean values.

(4) Effect of Surface Temperature – Typically, there are many more data for surface temperatures in the range of 0°C to -10°C than for the other temperature ranges (Table 3.6), which makes it difficult to infer trends from the summary values listed in Table 3.6. Consequently, the trend plots presented in Appendices D.2 and D.5 were used to assess the significance of surface temperature. The plots are highly scattered for both snow depth cases (Appendices D.2 and D.5), which indicates that the friction coefficients are not strongly related to the surface temperature.

### 3.4.3 Snow-Covered Packed Snow

Figures 3.18 and 3.19 provide summary results for snow-covered packed snow for all snow depths, and for snow depths of 10 mm or less, respectively. Summary results are tabulated in Table 3.7. Detailed results are plotted in Appendix F.

The following observations can be made:

(1) Comparison to AIP – The measured friction coefficients are in reasonable agreement with the values in the AIP. Furthermore, the ranges of variation are generally similar.

(2) Effect of Including All Snow Depths vs. Limiting the Analyses to Snow Depths of 10 mm or Less – The friction coefficients are lower for the “10 mm or Less” case. As well, the ranges of variation are much smaller than the “10 mm or Less” case.

(3) Effect of Surface Temperature – The plots are quite scattered (Appendices F.2 and F.5), which indicates that the friction coefficients are not greatly affected by the surface temperature.

## Table 3.6: Summary Results for Snow on Pavement

| Device | | All Snow Depths | | | | Snow Depths of 10 mm or Less | | | |
|---|---|---|---|---|---|---|---|---|---|
| ERD | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| | mean | 0.298571 | 0.279827588 | 0.515 | 0.306116 | 0.29 | 0.294999999 | 0.515 | 0.33 |
| | st dev | 0.040591 | 0.110286571 | 0.047958 | 0.10447 | #DIV/0! | 0.111897504 | 0.047958 | 0.130352 |
| | maximum | 0.36 | 0.660000026 | 0.58 | 0.66 | 0.29 | 0.649999976 | 0.58 | 0.65 |
| | minimum | 0.23 | 0.140000001 | 0.47 | 0.14 | 0.29 | 0.140000001 | 0.47 | 0.14 |
| | no of obs | 7 | 58 | 4 | 121 | 1 | 20 | 4 | 25 |
| | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (All Configs) | mean | 0.195833 | 0.188472223 | 0.2225 | 0.171626 | 0.29 | 0.263636363 | 0.2225 | 0.261667 |
| | st dev | 0.077748 | 0.15936193 | 0.078475 | 0.131631 | 0.008165 | 0.232185178 | 0.078475 | 0.200019 |
| | maximum | 0.3 | 0.730000019 | 0.3 | 0.73 | 0.3 | 0.730000019 | 0.3 | 0.73 |
| | minimum | 0.07 | 0.01 | 0.15 | 0.01 | 0.28 | 0.07 | 0.15 | 0.07 |
| | no of obs | 12 | 72 | 4 | 123 | 4 | 22 | 4 | 30 |
| | | | | | | | | | |
| TC SFT'79 | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| (Config 3) | mean | No Data | 0.200000001 | 0.2225 | 0.17974 | No Data | 0.210555555 | 0.2225 | 0.212727 |
| | st dev | No Data | 0.158972767 | 0.078475 | 0.133515 | No Data | 0.221265671 | 0.078475 | 0.201333 |
| | maximum | 0 | 0.730000019 | 0.3 | 0.73 | 0 | 0.730000019 | 0.3 | 0.73 |
| | minimum | 0 | 0.01 | 0.15 | 0.01 | 0 | 0.07 | 0.15 | 0.07 |
| | no of obs | 0 | 48 | 4 | 77 | 0 | 18 | 4 | 22 |
| | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (All Configs) | mean | No Data | 0.282753624 | 0.265 | 0.277944 | No Data | 0.303448276 | 0.254286 | 0.293889 |
| | st dev | No Data | 0.145419109 | 0.057975 | 0.120891 | No Data | 0.207231336 | 0.067788 | 0.188502 |
| | maximum | 0 | 0.870000005 | 0.34 | 0.87 | 0 | 0.870000005 | 0.34 | 0.87 |
| | minimum | 0 | 0.140000001 | 0.16 | 0.14 | 0 | 0.140000001 | 0.16 | 0.14 |
| | no of obs | 0 | 69 | 10 | 107 | 0 | 29 | 7 | 36 |
| | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (All Configs) | mean | 0.161667 | 0.174731183 | 0.17 | 0.163333 | 0.188333 | 0.197575756 | 0.19 | 0.195217 |
| | st dev | 0.048399 | 0.142756949 | 0.06532 | 0.117002 | 0.031885 | 0.208851475 | 0.068557 | 0.178248 |
| | maximum | 0.23 | 0.829999983 | 0.3 | 0.83 | 0.23 | 0.829999983 | 0.3 | 0.83 |
| | minimum | 0.08 | 0.02 | 0.1 | 0.02 | 0.14 | 0.02 | 0.1 | 0.02 |
| | no of obs | 12 | 93 | 10 | 159 | 6 | 33 | 7 | 46 |
| | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Force (Configs 3 & 7) | mean | No Data | 0.282941177 | 0.265 | 0.277944 | No Data | 0.303448276 | 0.254286 | 0.293889 |
| | st dev | No Data | 0.146491899 | 0.057975 | 0.120891 | No Data | 0.207231336 | 0.067788 | 0.188502 |
| | maximum | 0 | 0.870000005 | 0.34 | 0.87 | 0 | 0.870000005 | 0.34 | 0.87 |
| | minimum | 0 | 0.140000001 | 0.16 | 0.14 | 0 | 0.140000001 | 0.16 | 0.14 |
| | no of obs | 0 | 68 | 10 | 107 | 0 | 29 | 7 | 36 |
| | | | | | | | | | |
| IMAG | | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps | <=-10°C | <0°C to >-10°C | >= 0°C | All Temps |
| Torque (Configs 3 & 7) | mean | 0.161667 | 0.174761905 | 0.17 | 0.166516 | 0.188333 | 0.219310344 | 0.19 | 0.21 |
| | st dev | 0.048399 | 0.143941723 | 0.06532 | 0.116767 | 0.031885 | 0.213974814 | 0.068557 | 0.179661 |
| | maximum | 0.23 | 0.829999983 | 0.3 | 0.83 | 0.23 | 0.829999983 | 0.3 | 0.83 |
| | minimum | 0.08 | 0.050000001 | 0.1 | 0.02 | 0.14 | 0.050000001 | 0.1 | 0.05 |
| | no of obs | 12 | 84 | 10 | 155 | 6 | 29 | 7 | 42 |

**Table 3.7: Summary Results for Snow-Covered Packed Snow**

| Device | | All Snow Depths | | | | Snow Depths of 10 mm or Less | | |
|---|---|---|---|---|---|---|---|---|
| ERD | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| | mean | No Data | 0.201818 | 0.211481 | | No Data | 0.22125 | 0.22125 |
| | st dev | No Data | 0.047972 | 0.047935 | | No Data | 0.04051 | 0.04051 |
| | maximum | 0 | 0.32 | 0.32 | | 0 | 0.27 | 0.27 |
| | minimum | 0 | 0.12 | 0.12 | | 0 | 0.17 | 0.17 |
| | no of obs | 0 | 22 | 27 | | 0 | 8 | 8 |
| | | | | | | | | |
| TC SFT'79 | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| (All Configs) | mean | No Data | 0.204815 | 0.205625 | | No Data | 0.246 | 0.246 |
| | st dev | No Data | 0.057135 | 0.052667 | | No Data | 0.011738 | 0.011738 |
| | maximum | 0 | 0.33 | 0.33 | | 0 | 0.26 | 0.26 |
| | minimum | 0 | 0.09 | 0.09 | | 0 | 0.23 | 0.23 |
| | no of obs | 0 | 27 | 32 | | 0 | 10 | 10 |
| | | | | | | | | |
| TC SFT'79 | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| (Config 3) | mean | No Data | 0.221304 | 0.219286 | | No Data | 0.246 | 0.246 |
| | st dev | No Data | 0.043621 | 0.040086 | | No Data | 0.011738 | 0.011738 |
| | maximum | 0 | 0.33 | 0.33 | | 0 | 0.26 | 0.26 |
| | minimum | 0 | 0.16 | 0.16 | | 0 | 0.23 | 0.23 |
| | no of obs | 0 | 23 | 28 | | 0 | 10 | 10 |
| | | | | | | | | |
| IMAG | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| Force (All Configs) | mean | No Data | 0.233684 | 0.241667 | | No Data | 0.243333 | 0.243333 |
| | st dev | No Data | 0.059462 | 0.05522 | | No Data | 0.01633 | 0.01633 |
| | maximum | 0 | 0.41 | 0.41 | | 0 | 0.26 | 0.26 |
| | minimum | 0 | 0.16 | 0.16 | | 0 | 0.22 | 0.22 |
| | no of obs | 0 | 19 | 24 | | 0 | 6 | 6 |
| | | | | | | | | |
| IMAG | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| Torque (All Configs) | mean | No Data | 0.154783 | 0.161429 | | No Data | 0.178333 | 0.178333 |
| | st dev | No Data | 0.045614 | 0.043861 | | No Data | 0.004082 | 0.004082 |
| | maximum | 0 | 0.33 | 0.33 | | 0 | 0.18 | 0.18 |
| | minimum | 0 | 0.1 | 0.1 | | 0 | 0.17 | 0.17 |
| | no of obs | 0 | 23 | 28 | | 0 | 6 | 6 |
| | | | | | | | | |
| IMAG | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| Force (Configs 3 & 7) | mean | No Data | 0.233684 | 0.241667 | | No Data | 0.243333 | 0.243333 |
| | st dev | No Data | 0.059462 | 0.05522 | | No Data | 0.01633 | 0.01633 |
| | maximum | 0 | 0.41 | 0.41 | | 0 | 0.26 | 0.26 |
| | minimum | 0 | 0.16 | 0.16 | | 0 | 0.22 | 0.22 |
| | no of obs | 0 | 19 | 24 | | 0 | 6 | 6 |
| | | | | | | | | |
| IMAG | | <=-15°C | > -15°C | All Temps | | <=-15°C | > -15°C | All Temps |
| Torque (Configs 3 & 7) | mean | No Data | 0.154783 | 0.161429 | | No Data | 0.178333 | 0.178333 |
| | st dev | No Data | 0.045614 | 0.043861 | | No Data | 0.004082 | 0.004082 |
| | maximum | 0 | 0.33 | 0.33 | | 0 | 0.18 | 0.18 |
| | minimum | 0 | 0.1 | 0.1 | | 0 | 0.17 | 0.17 |
| | no of obs | 0 | 23 | 28 | | 0 | 6 | 6 |

### 3.5 Slush on Any Base Surface

Figure 3.20 provides summary results for slush on any base surface. Summary results are tabulated in Table 3.8. Detailed results are plotted in Appendix G.

Only a few data points are available, which limits the strength of the conclusions that can be drawn (Table 3.8). Furthermore, only very limited slush depth data are available. For the ERD results, slush depth data are available for only 10 of the 34 friction observations. The measured depths are highly variable, ranging from 8 mm to 50 mm. No slush depth data are available for correlation with the TC SFT'79 and IMAG friction data. This further limits the strength of the conclusions that can be drawn. Nevertheless, some preliminary observations can be made as follows:

(1) Ranges of Variation – The measured friction coefficients span a wide range for each device.
(2) Friction Coefficient Magnitudes – These tend to be higher than those for bare ice or bare packed snow.

### 3.6 Wet Pavement

Figure 3.21 provides summary results for wet pavement. Summary results are tabulated in Table 3.8. Detailed results are plotted in Appendix H. Only a few data points are available, which limits the strength of the conclusions that can be drawn (Table 3.8). Nevertheless, some preliminary observations can be made as follows:

(1) Comparison to AIP – The measured friction coefficients are generally higher than those in the AIP.
(2) Ranges of Variation – The measured friction coefficients span a wide range for each device.

### 3.7 Dry Pavement

Figure 3.22 provides summary results for dry pavement. Summary results are tabulated in Table 3.8. Detailed results are plotted in Appendix I. Although only a few data points are available (Table 3.8), some preliminary observations can be made as follows:

(1) Comparison to AIP – The measured friction factors are lower than those in the AIP.
(2) Ranges of Variation – The ranges for each device are similar to those in the AIP.
(3) Wet vs. Dry Pavement – The ERD indicated higher friction on average for wet pavement than for dry pavement (Table 3.8). This may reflect variations in texture among the different sites included in the observations used to establish the average.

**Table 3.8: Summary Results for Slush, Wet Pavement and Dry Pavement**

| Device | | Slush on Any Base Surface | | Wet Pavement | | Dry Pavement |
|---|---|---|---|---|---|---|
| ERD | | All Temperatures | | All Temperatures | | All Temperatures |
| | mean | 0.305882352 | | 0.709130445 | | 0.696923082 |
| | st dev | 0.121508638 | | 0.079252929 | | 0.065368777 |
| | maximum | 0.629999995 | | 0.829999983 | | 0.810000002 |
| | minimum | 0.090000004 | | 0.540000021 | | 0.589999974 |
| | no of obs | 34 | | 23 | | 13 |
| | | | | | | |
| TC SFT'79 | | All Temperatures | | | | All Temperatures |
| (All Configs) | mean | 0.229999997 | | | | 0.875344826 |
| | st dev | 0.152970581 | | | | 0.048130506 |
| | maximum | 0.569999993 | | | | 1 |
| | minimum | 0.079999998 | | | | 0.779999971 |
| | no of obs | 17 | | | | 58 |
| | | | | | | |
| TC SFT'79 | | All Temperatures | | All Temperatures | | All Temperatures |
| (Config 3) | mean | 0.236153843 | | 0.807619049 | | 0.905833331 |
| | st dev | 0.174381687 | | 0.059405784 | | 0.03752294 |
| | maximum | 0.569999993 | | 0.920000017 | | 1 |
| | minimum | 0.079999998 | | 0.680000007 | | 0.850000024 |
| | no of obs | 13 | | 21 | | 24 |
| | | | | | | |
| IMAG | | All Temperatures | | | | All Temperatures |
| Force (All Configs) | mean | 0.27625 | | | | 0.735652179 |
| | st dev | 0.149883289 | | | | 0.063092598 |
| | maximum | 0.680000007 | | | | 0.910000026 |
| | minimum | 0.109999999 | | | | 0.589999974 |
| | no of obs | 16 | | | | 46 |
| | | | | | | |
| IMAG | | All Temperatures | | | | All Temperatures |
| Torque (All Configs) | mean | 0.218 | | | | 0.69333333 |
| | st dev | 0.127510577 | | | | 0.056052157 |
| | maximum | 0.629999995 | | | | 0.860000014 |
| | minimum | 0.109999999 | | | | 0.589999974 |
| | no of obs | 20 | | | | 48 |
| | | | | | | |
| IMAG | | All Temperatures | | All Temperatures | | All Temperatures |
| Force (Configs 3 & 7) | mean | 0.27625 | | 0.690638295 | | 0.735652179 |
| | st dev | 0.149883289 | | 0.049537173 | | 0.063092598 |
| | maximum | 0.680000007 | | 0.839999974 | | 0.910000026 |
| | minimum | 0.109999999 | | 0.589999974 | | 0.589999974 |
| | no of obs | 16 | | 47 | | 46 |
| | | | | | | |
| IMAG | | All Temperatures | | All Temperatures | | All Temperatures |
| Torque (Configs 3 & 7) | mean | 0.218 | | 0.624705884 | | 0.69333333 |
| | st dev | 0.127510577 | | 0.172108722 | | 0.056052157 |
| | maximum | 0.629999995 | | 0.819999993 | | 0.860000014 |
| | minimum | 0.109999999 | | 0.050000001 | | 0.589999974 |
| | no of obs | 20 | | 51 | | 48 |

## 3.8 Direct Comparisons with the CRFI Values in the AIP

### 3.8.1 Presentation of Results

Figures 3.2 to 3.5 show summary results for the ERD, the TC SFT'79 in configuration 3, the IMAG Force in configurations 3 or 7, and the IMAG Torque in configurations 3 or 7, respectively. For reference, the CRFI values currently in the AIP are re-plotted in Figure 3.22.

### 3.8.2 Ice Surfaces

The following comments can be made:

(a) "Cold" (below -10°C) vs. "Warm" (at or above 0°C) Ice – The AIP values indicate a sharp distinction between cold and warm ice, with higher CRFIs for warm ice.

The devices do not show such a distinction. The ERD, the TC SFT'79 (configuration 3) and the IMAG Torque (configurations 3 or 7) all show higher CRFIs for warm ice than cold ice. The IMAG Force (configurations 3 or 7) indicates similar CRFIs for warm and cold ice.

(b) Sanded Ice – The AIP indicates that sanded ice can be expected to have a CRFI that is much larger than bare ice. Furthermore, it indicates that the CRFI for sanded ice will lie in a narrow range.

The devices gave CRFI values that spanned a wide range. The range of CRFIs measured for sanded ice was similar to that for bare ice.

### 3.8.3 Packed Snow

The following comments can be made:

(a) Effect of Temperature – The CRFIs in the AIP are much higher for "cold" packed snow (i.e., below -15°C).

The ERD and the IMAG both measured CRFIs that are not greatly different over the full range of temperatures. Data are not available for the TC SFT'79 at below -15°C, and thus, comparisons cannot be made for it.

(b) Packed Snow vs. Bare Ice – The CRFIs in the AIP are significantly higher for packed snow than for bare ice.

The measured values do not exhibit a clear difference between bare ice and bare packed snow, although they are slightly higher for packed snow.

(c) Snow on a Packed Snow Base – The AIP indicates that the CRFI for snow-covered packed snow will lie between the values for bare "warm" and "cold" packed snow.

The measured values for snow-covered packed snow are similar to those for bare packed snow.

### 3.8.4 Wet Pavement

The measured CRFIs are generally similar to those given in the AIP for damp pavement.

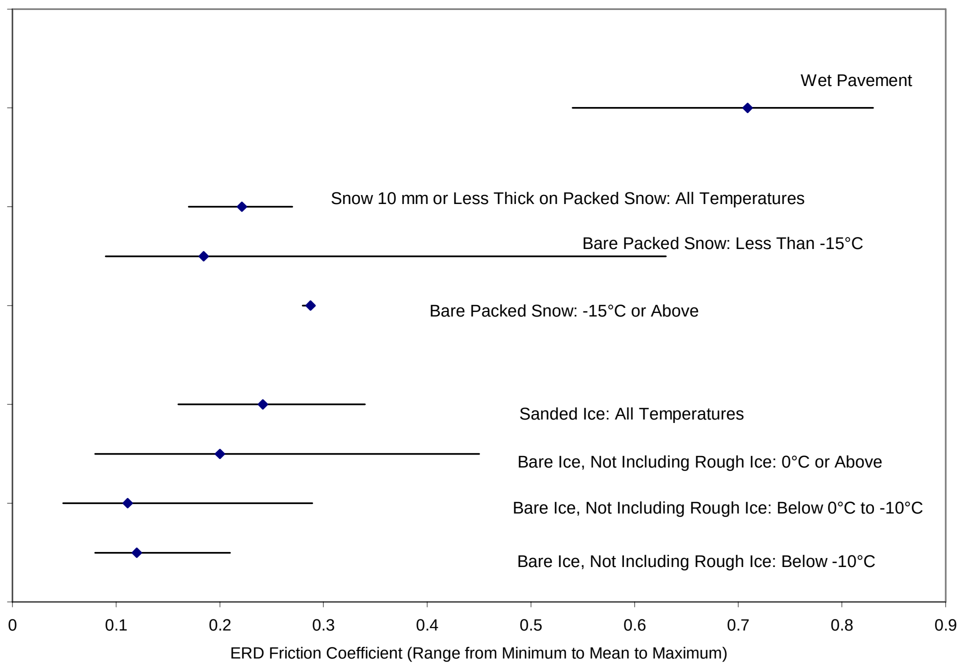



**Figure 3.2: Summary Results for the ERD**

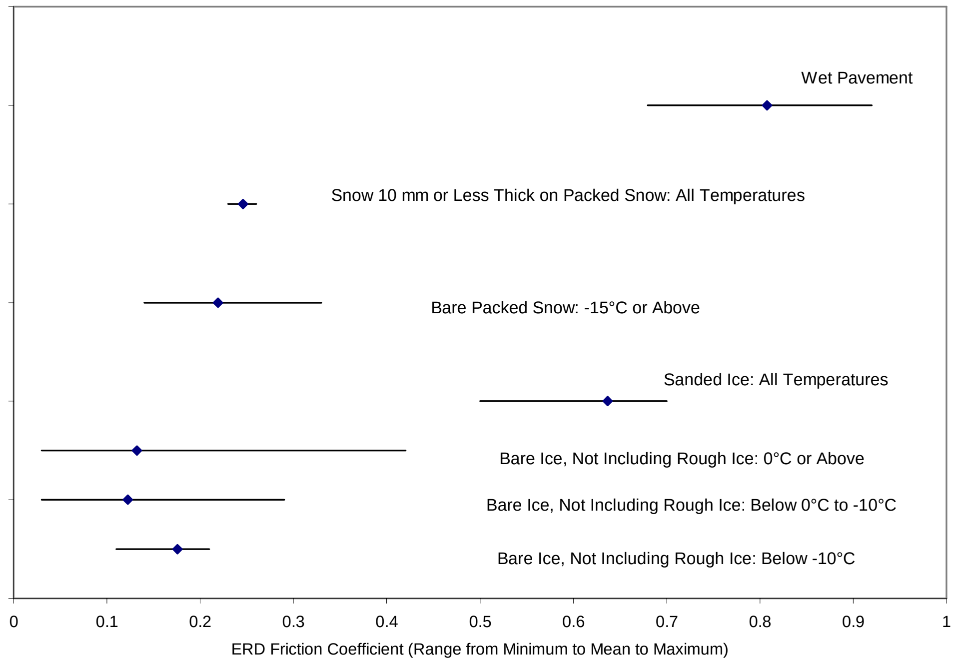



**Figure 3.3: Summary Results for the TC SFT'79 in Configuration 3**

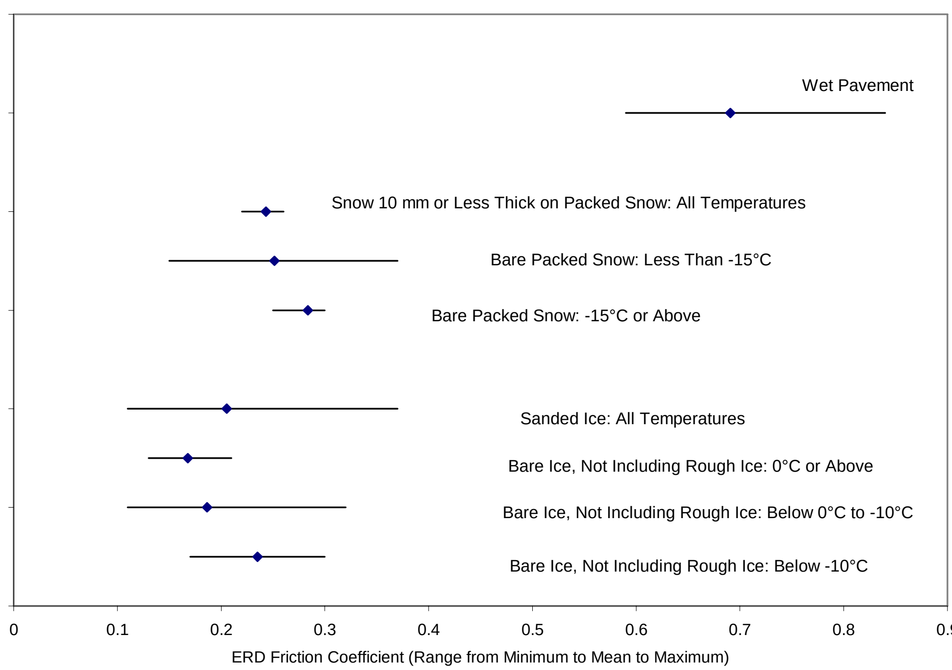



**Figure 3.4: Summary Results for the IMAG Force in Configuration 3 or 7**

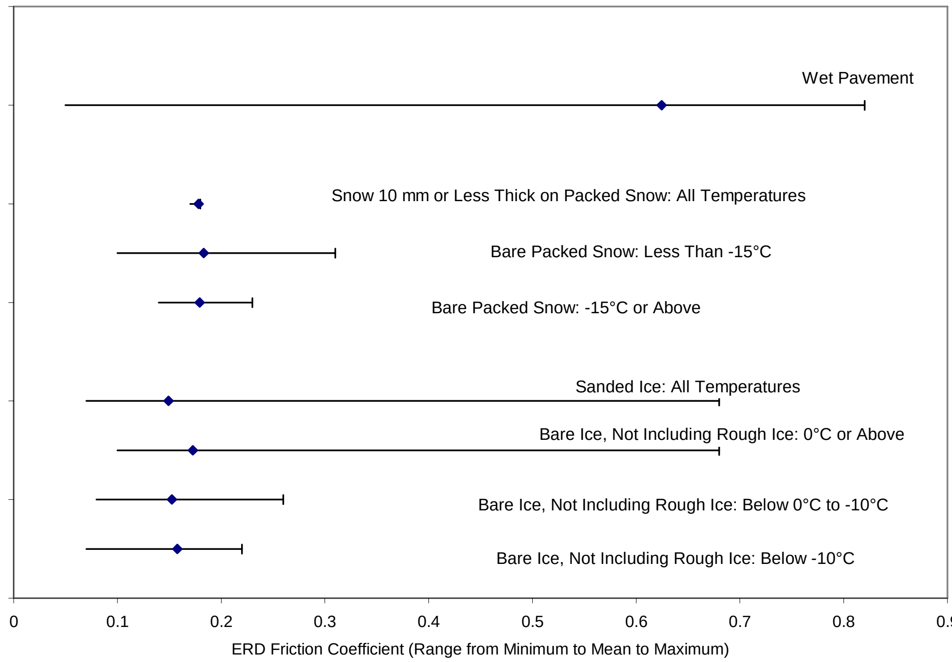



**Figure 3.5: Summary Results for the IMAG Torque in Configuration 3 or 7**

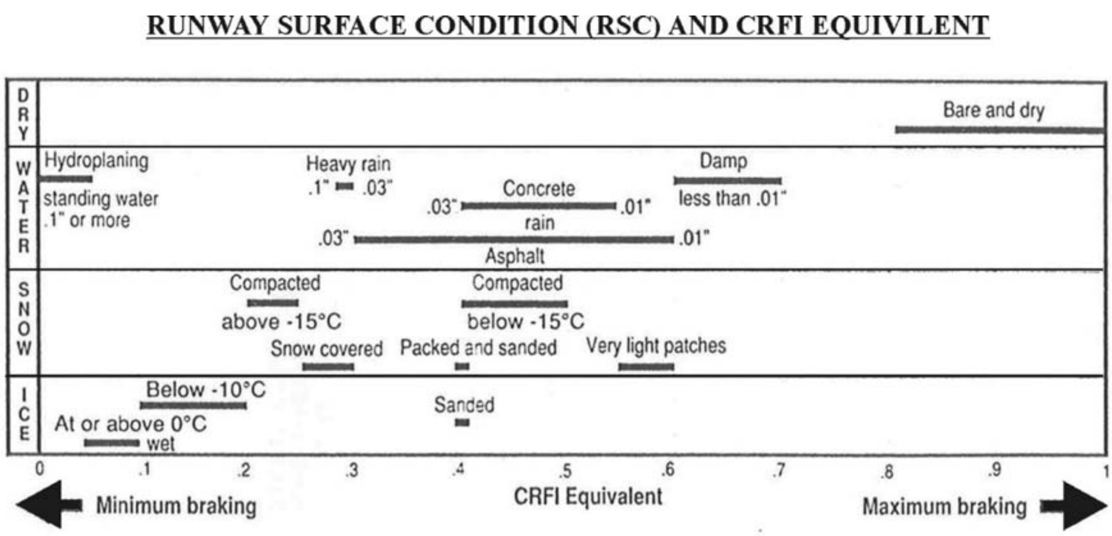



**Figure 3.6: CRFIs Given in the AIP for Various Surfaces [2] (repeated from Figure 2.2)**

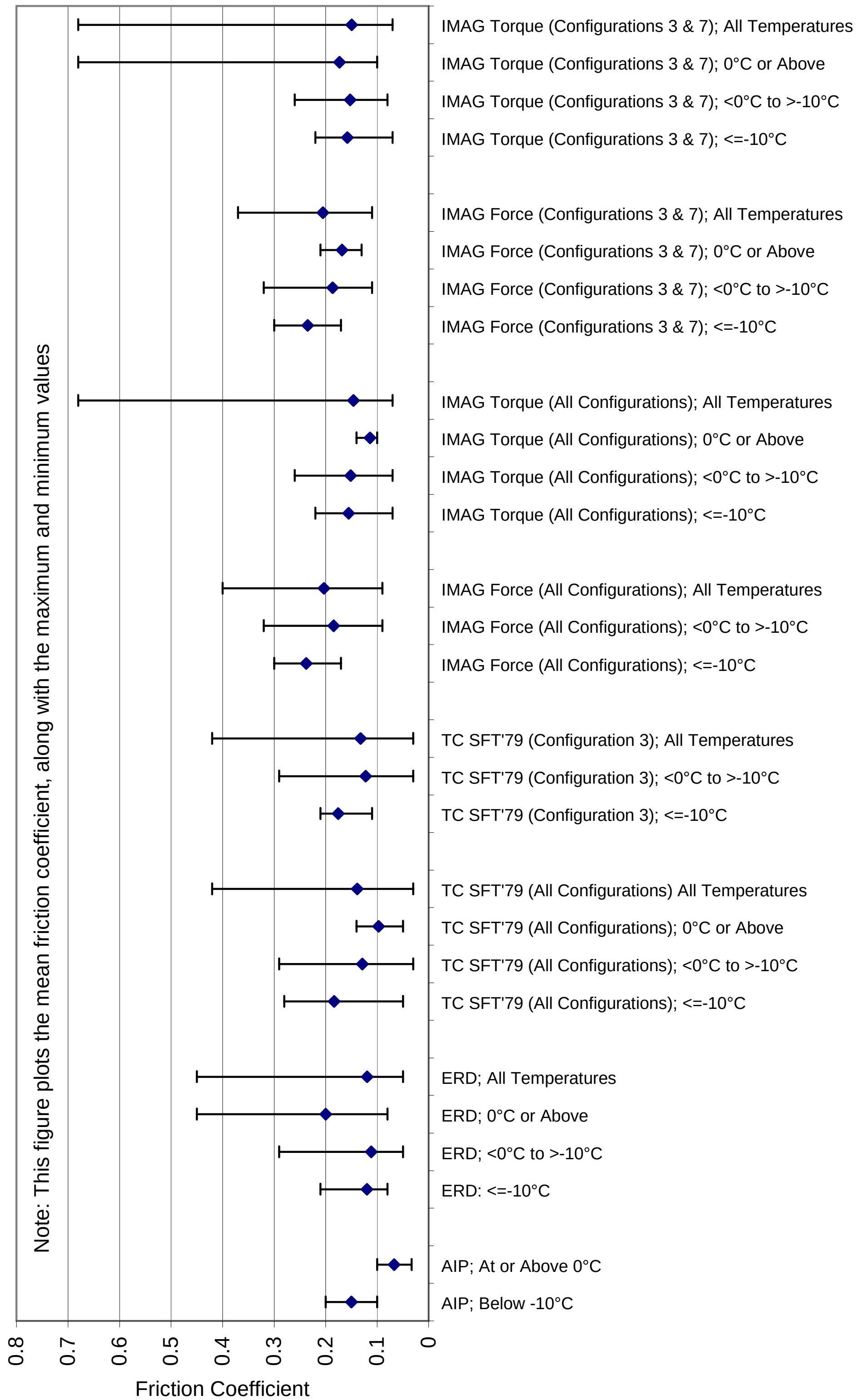



**Figure 3.7: Friction Coefficients on Bare Ice: Summary Results**

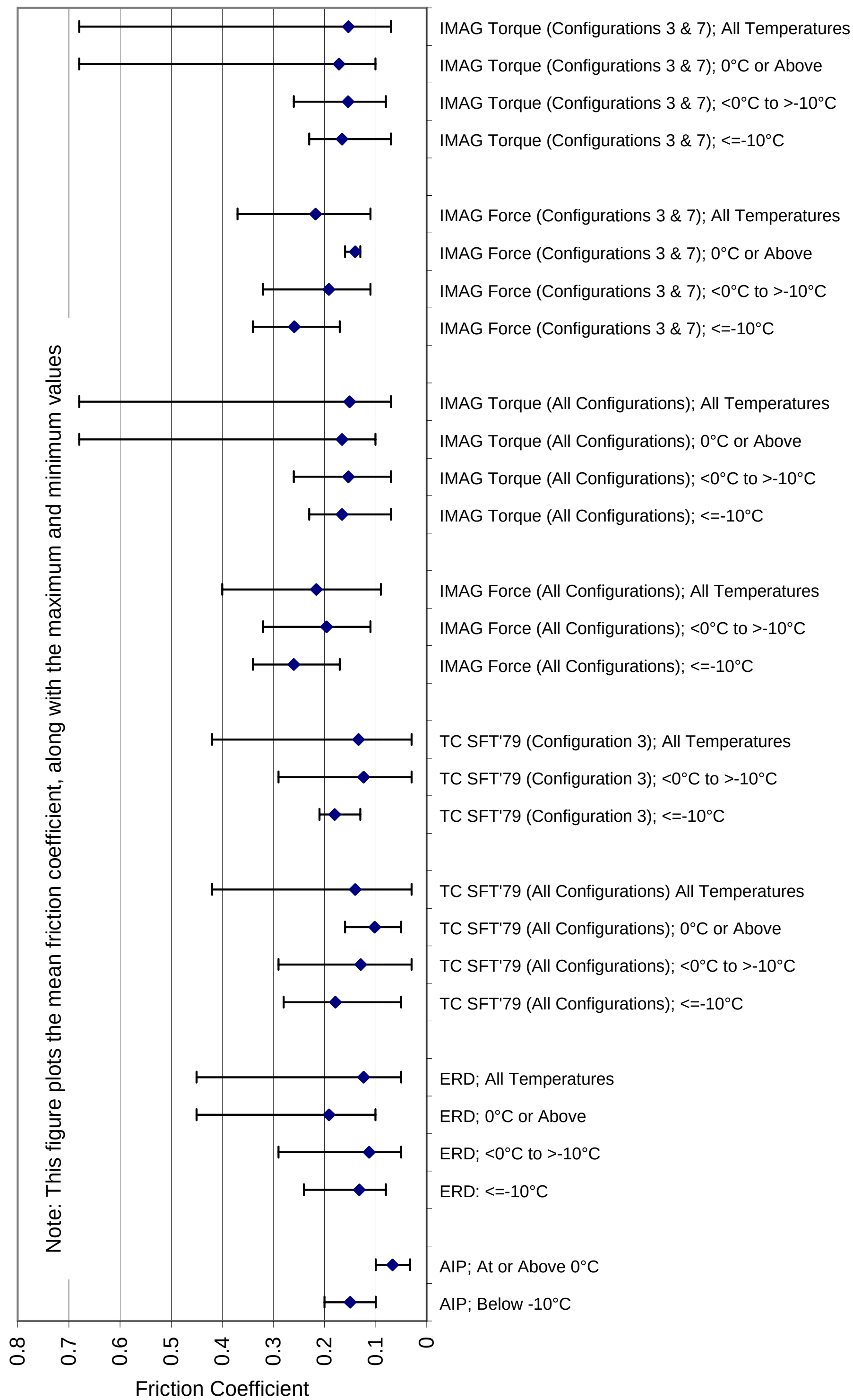



**Figure 3.8: Friction Coefficients on Bare Ice Including Rough Ice: Summary Results**

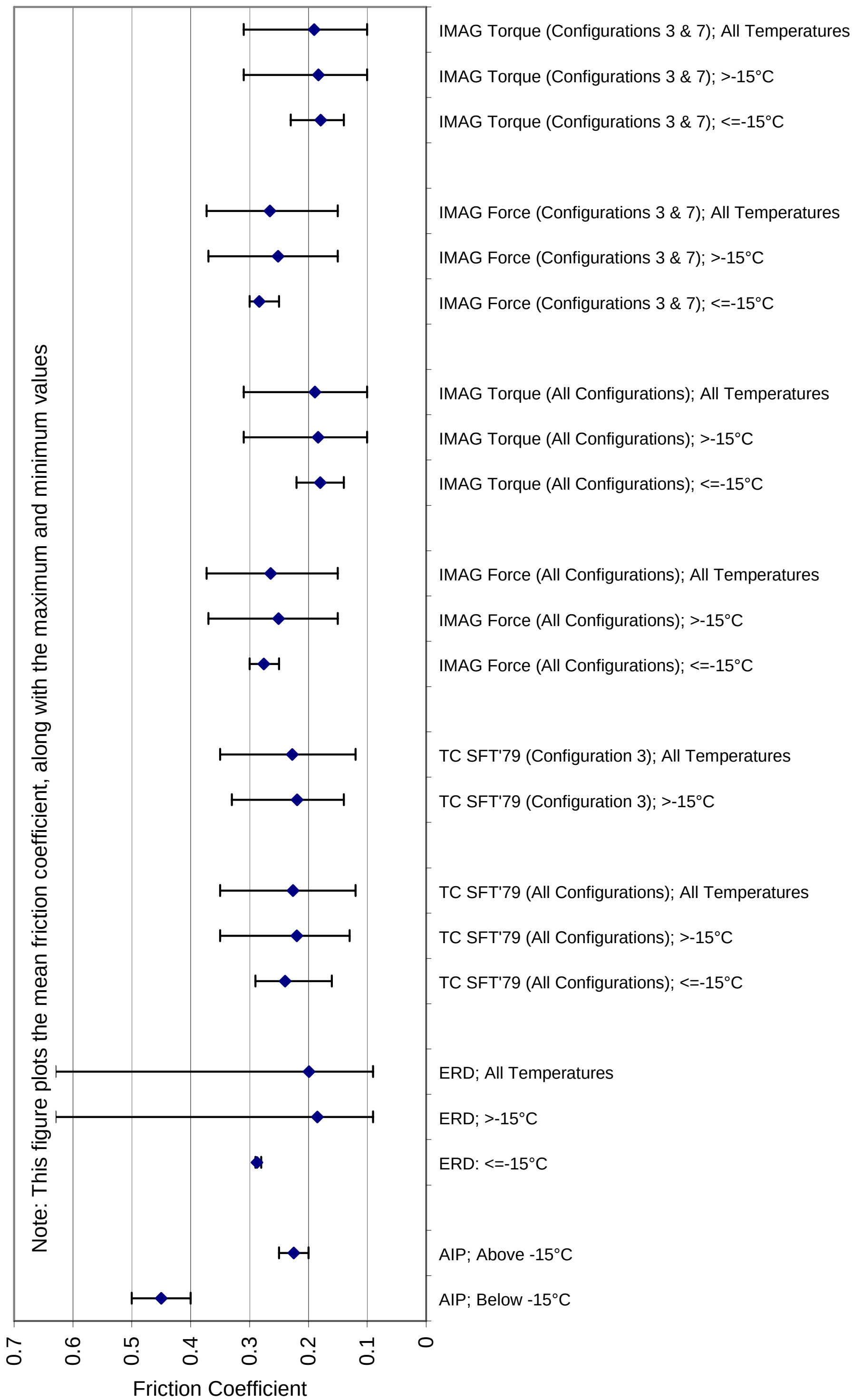



**Figure 3.9: Friction Coefficients on Bare Packed Snow: Summary Results**

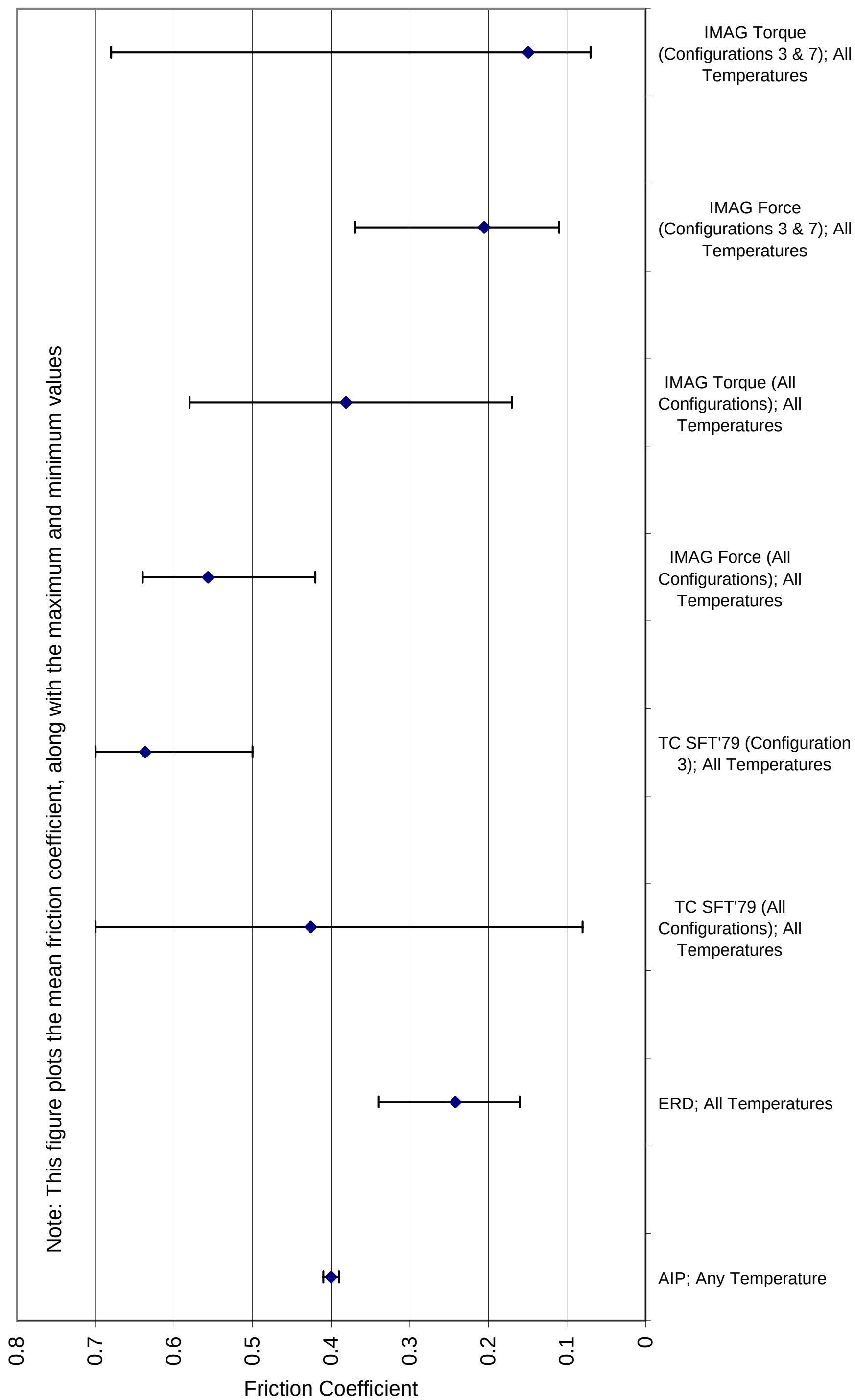



**Figure 3.10: Friction Coefficients on Sanded Ice: Summary Results**

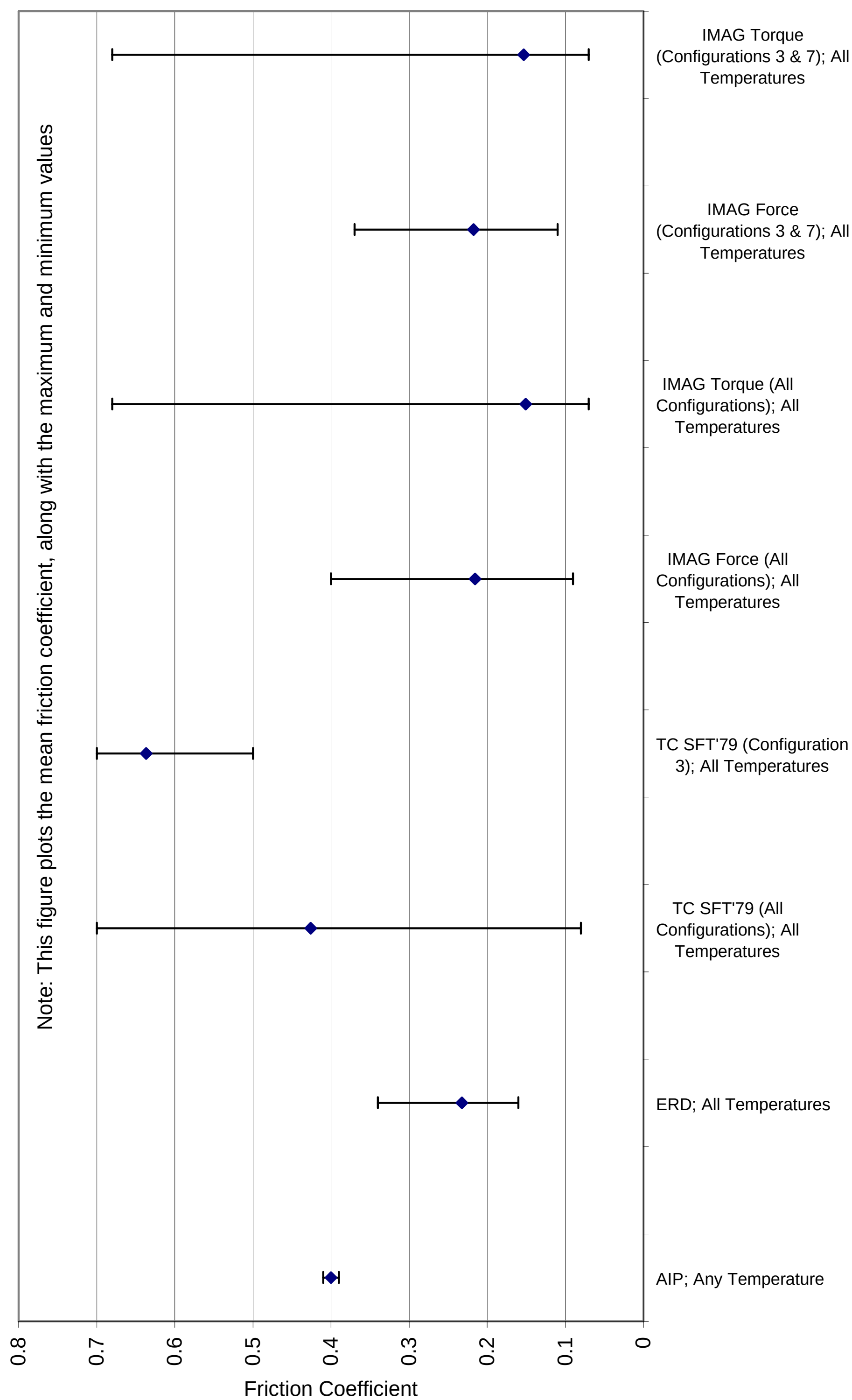



**Figure 3.11: Friction Coefficients on Sanded Ice Including Rough Ice: Summary Results**

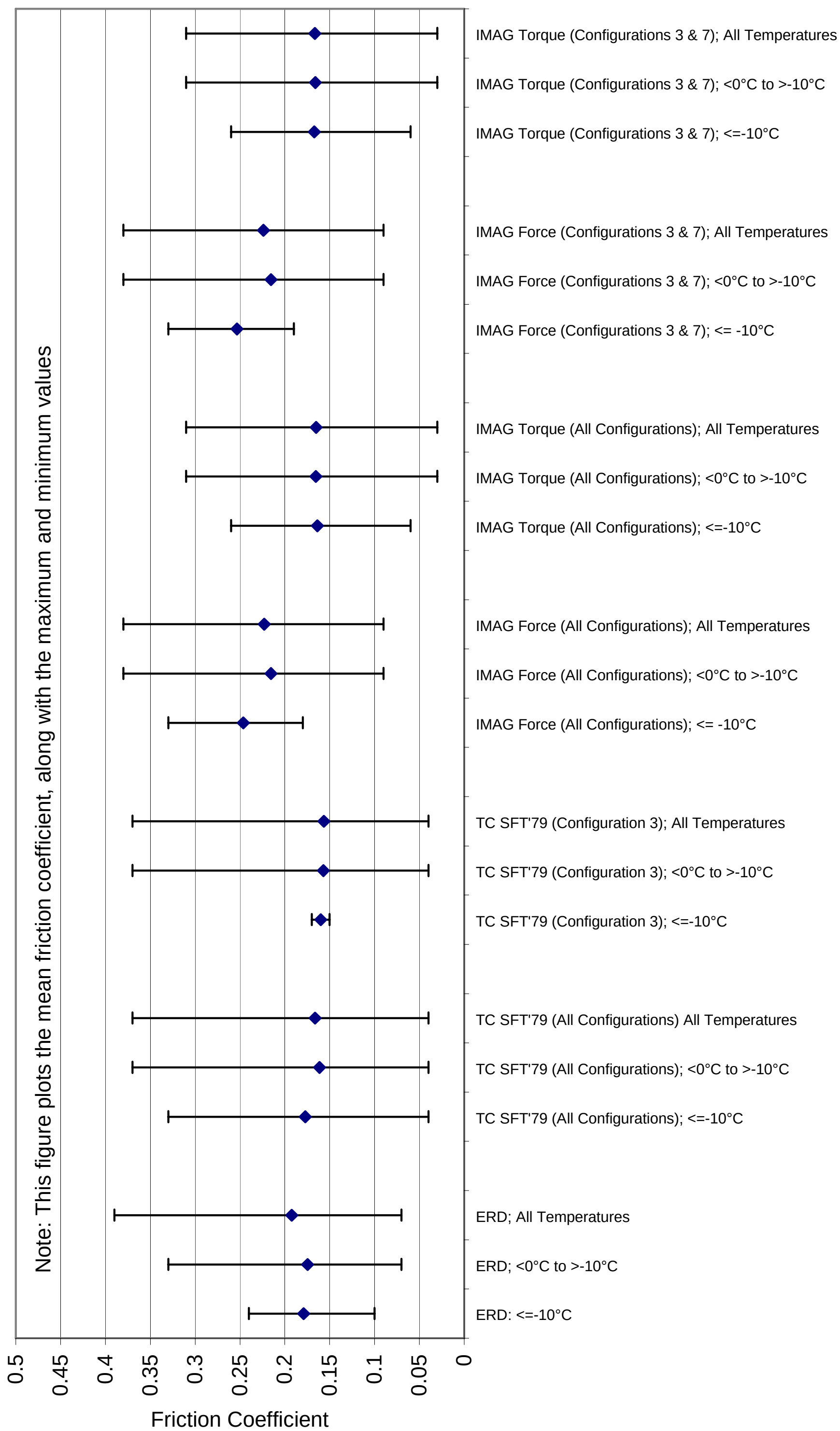



**Figure 3.12: Friction Coefficients on Snow Covered Ice (All Depths of Snow Cover): Summary Results**

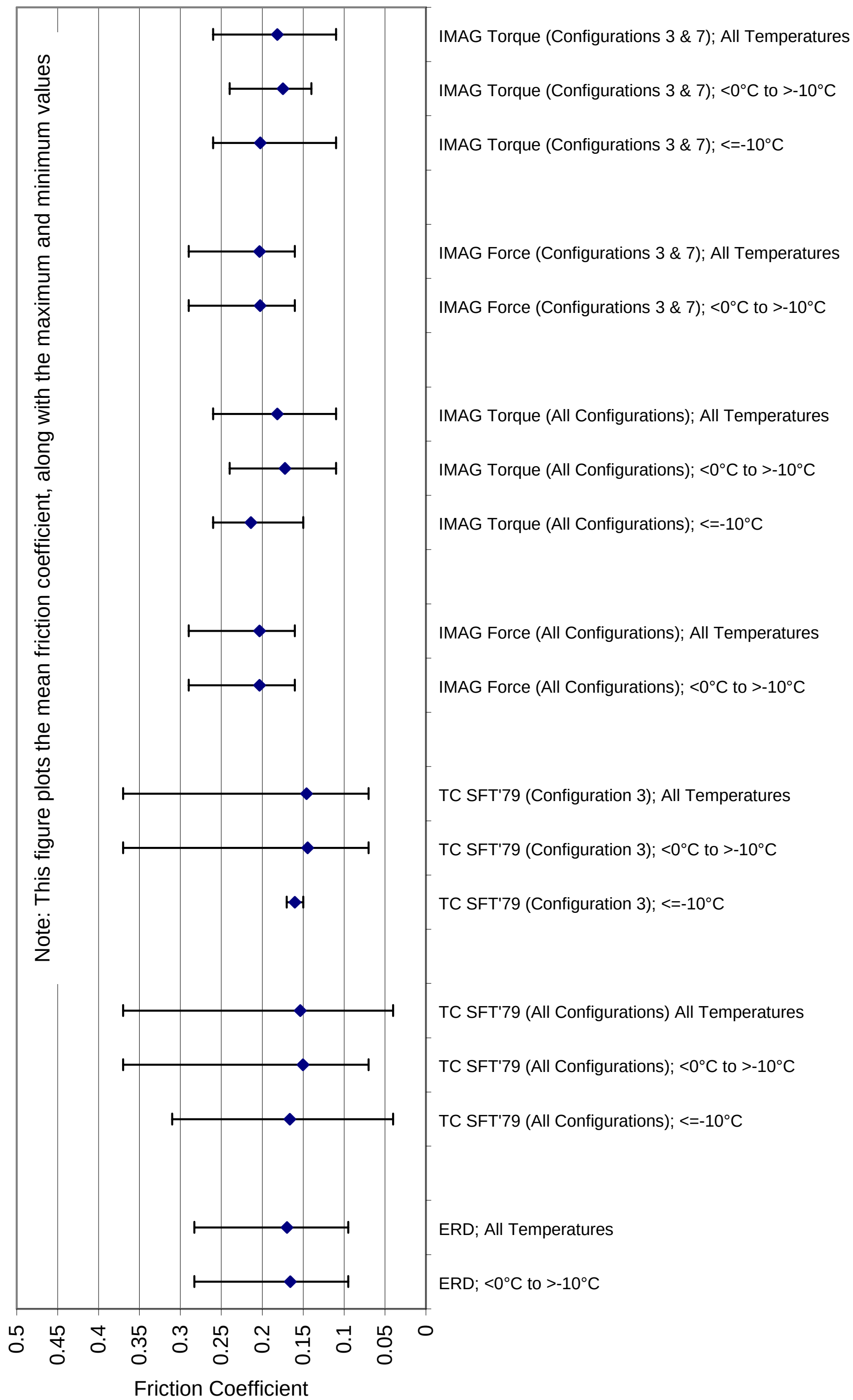



**Figure 3.13: Friction Coefficient on Snow Covered Ice (Snow Cover 10 mm or Less Thick):**
**Summary Results**

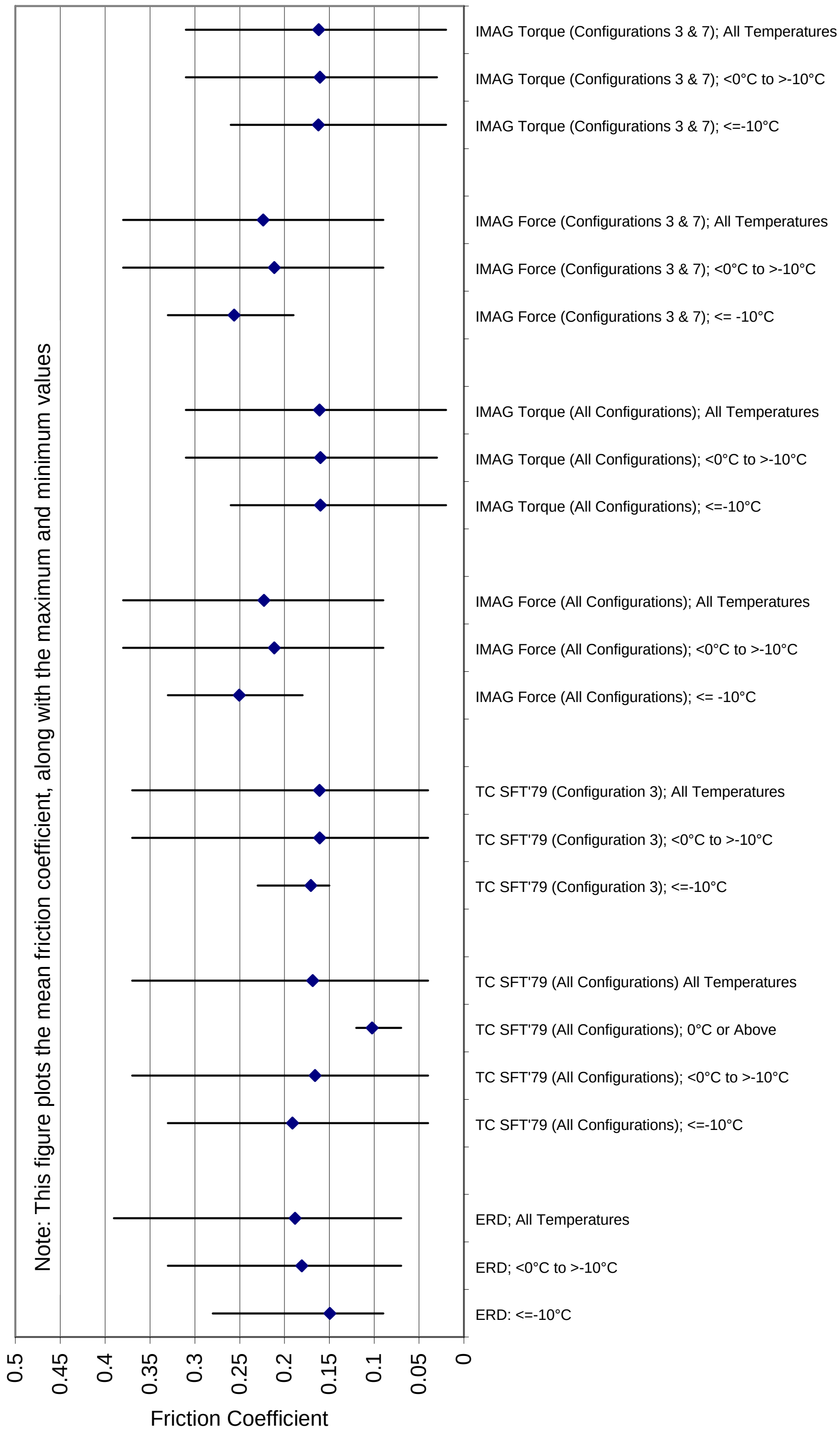



**Figure 3.14: Friction Coefficients on Snow Covered Ice Including Rough Ice (All Depths of Snow Cover): Summary Results**

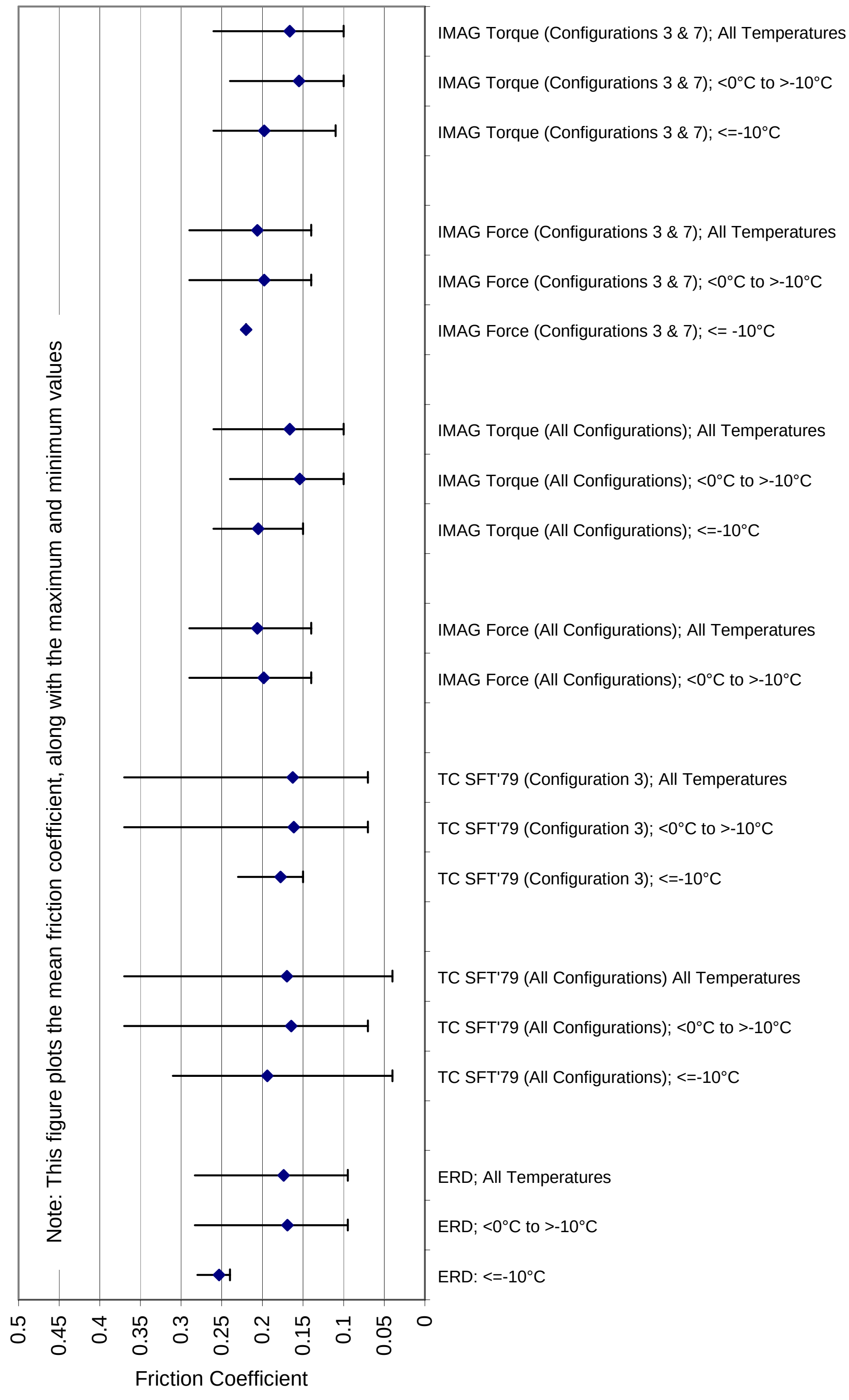



**Figure 3.15: Friction Coefficients on Snow Covered Ice Including Rough Ice (Snow Cover 10 mm or Less Thick): Summary Results**

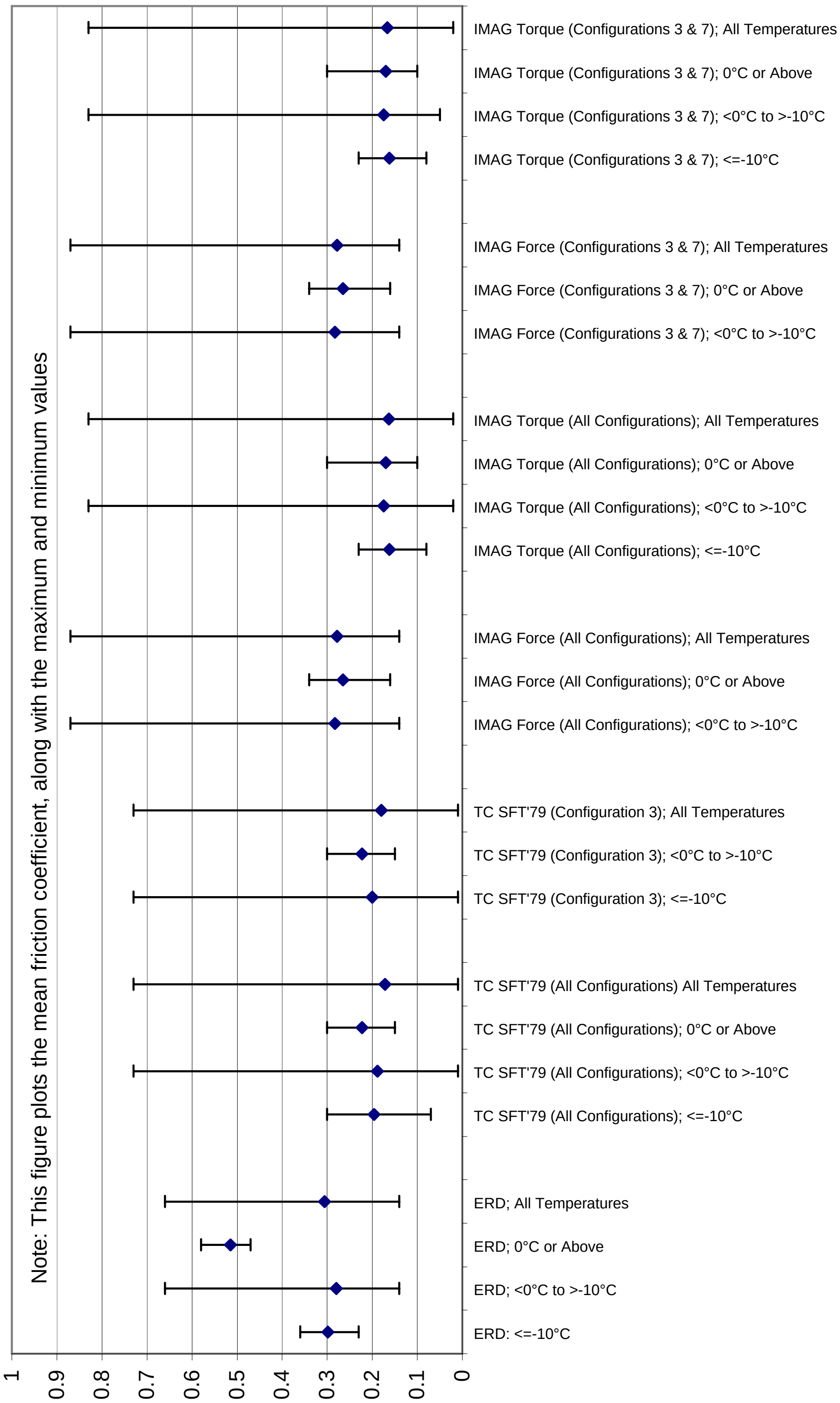



**Figure 3.16: Friction Coefficients on Snow Covered Pavement (All Depths of Snow Cover): Summary Results**

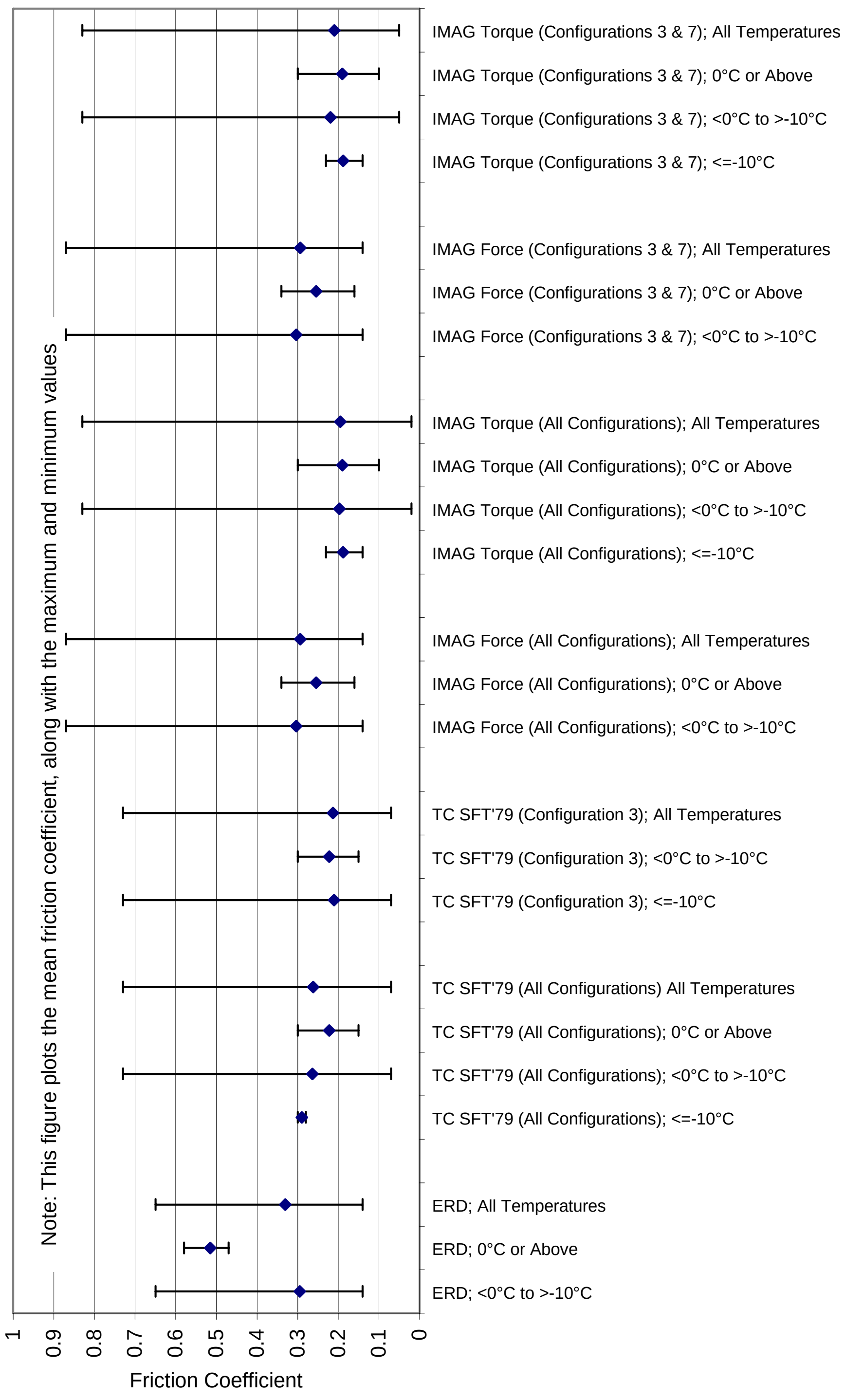



**Figure 3.17: Friction Coefficients on Snow Covered Pavement (Snow Cover 10 mm or Less Thick): Summary Results**

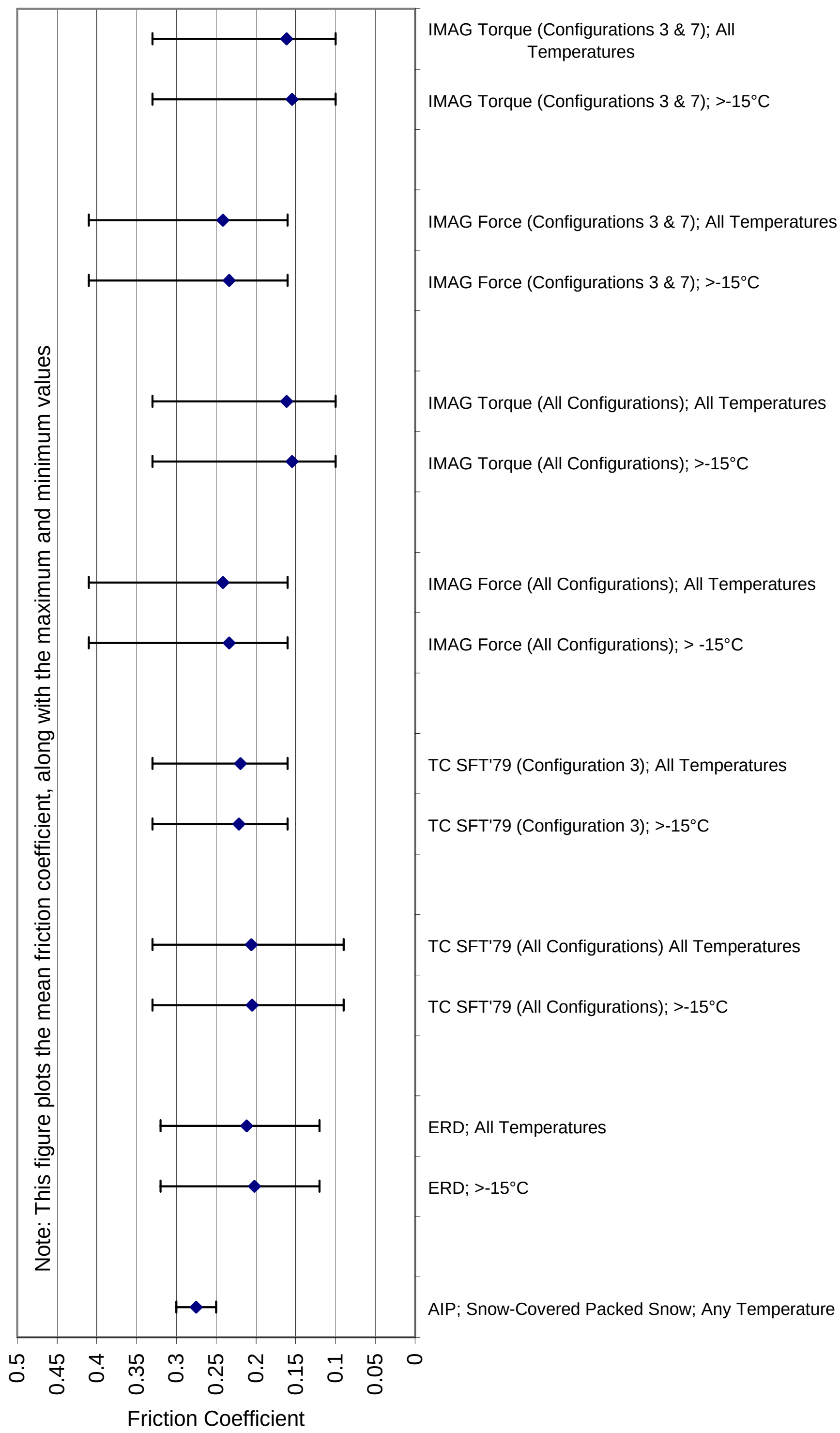



**Figure 3.18: Friction Coefficients on Snow Covered Packed Snow (All Depths of Snow Cover): Summary Results**

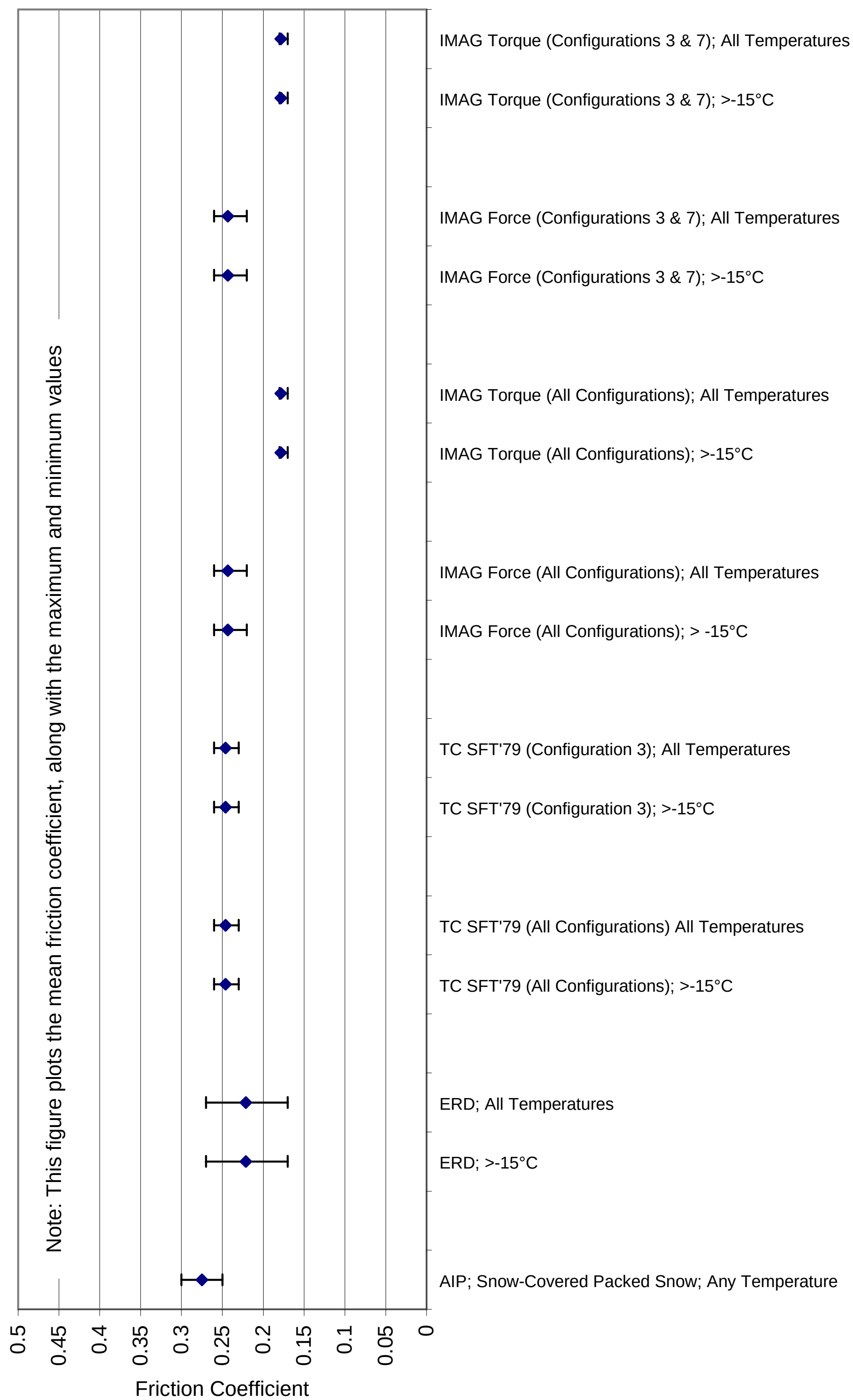



**Figure 3.19: Friction Coefficients on Snow Covered Packed Snow (Snow Cover 10 mm or Less Thick): Summary Results**

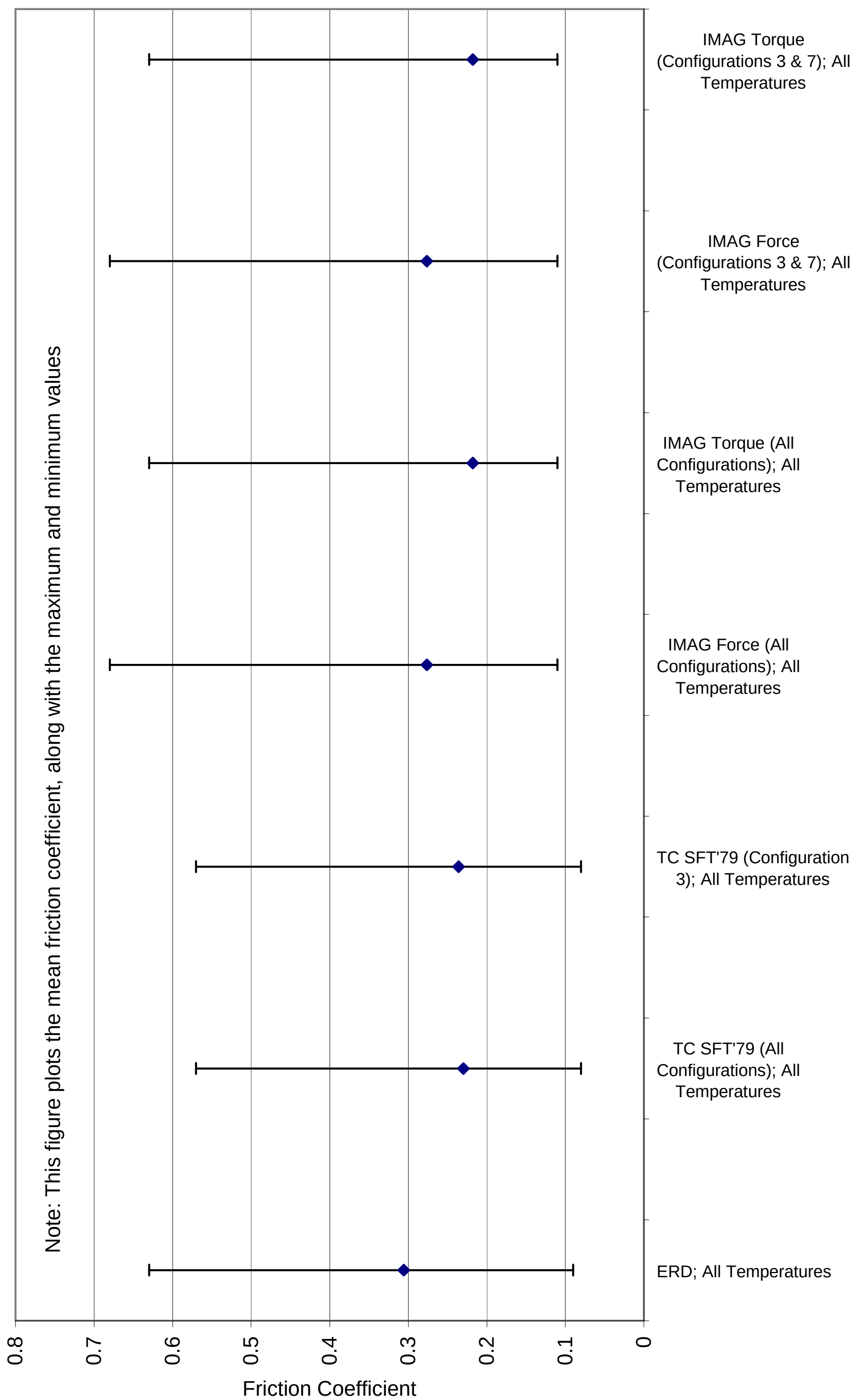



**Figure 3.20: Friction Coefficients for Slush on any Base Surface: Summary Results**

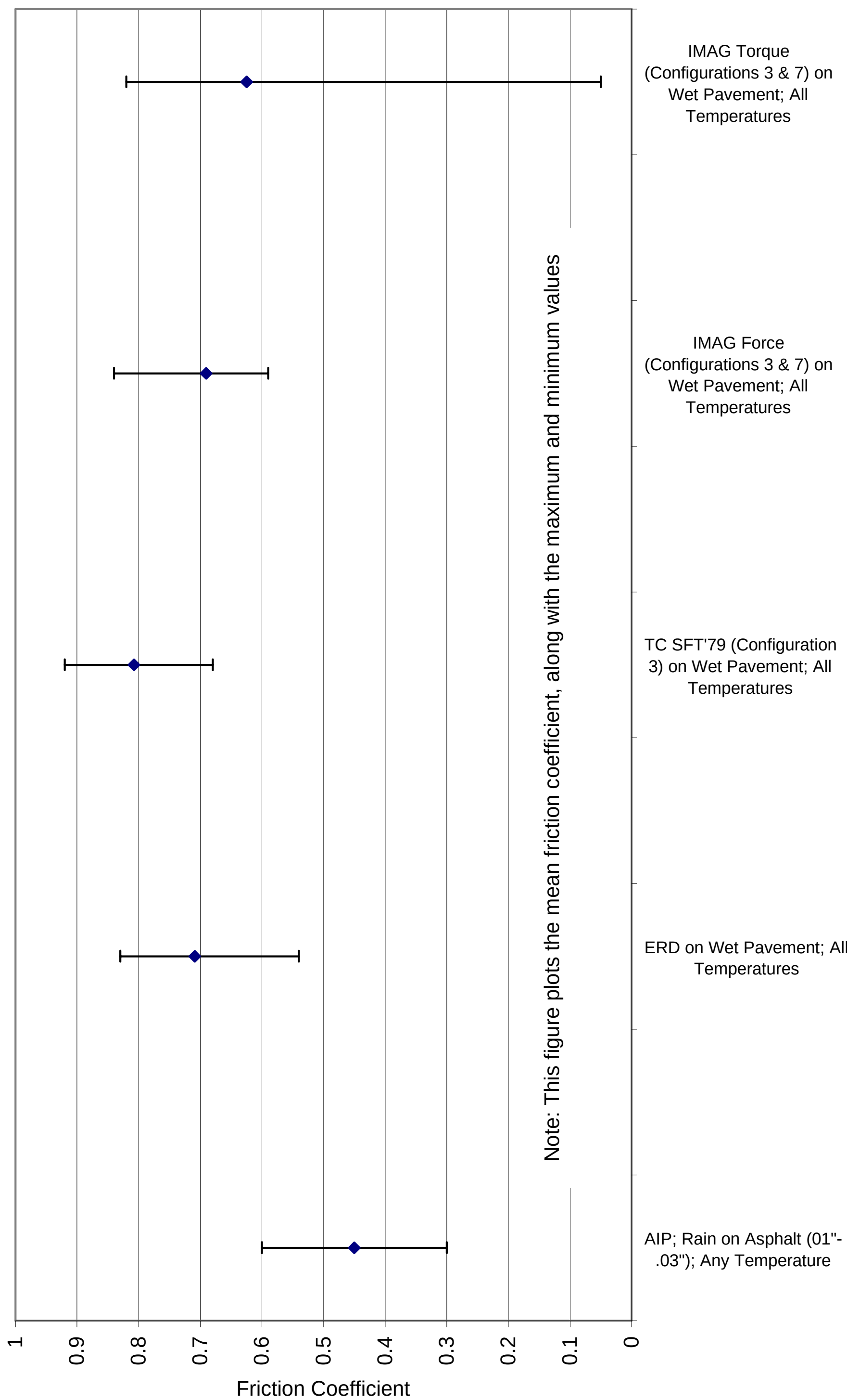



**Figure 3.21: Friction Coefficients on Wet Pavement: Summary Results**

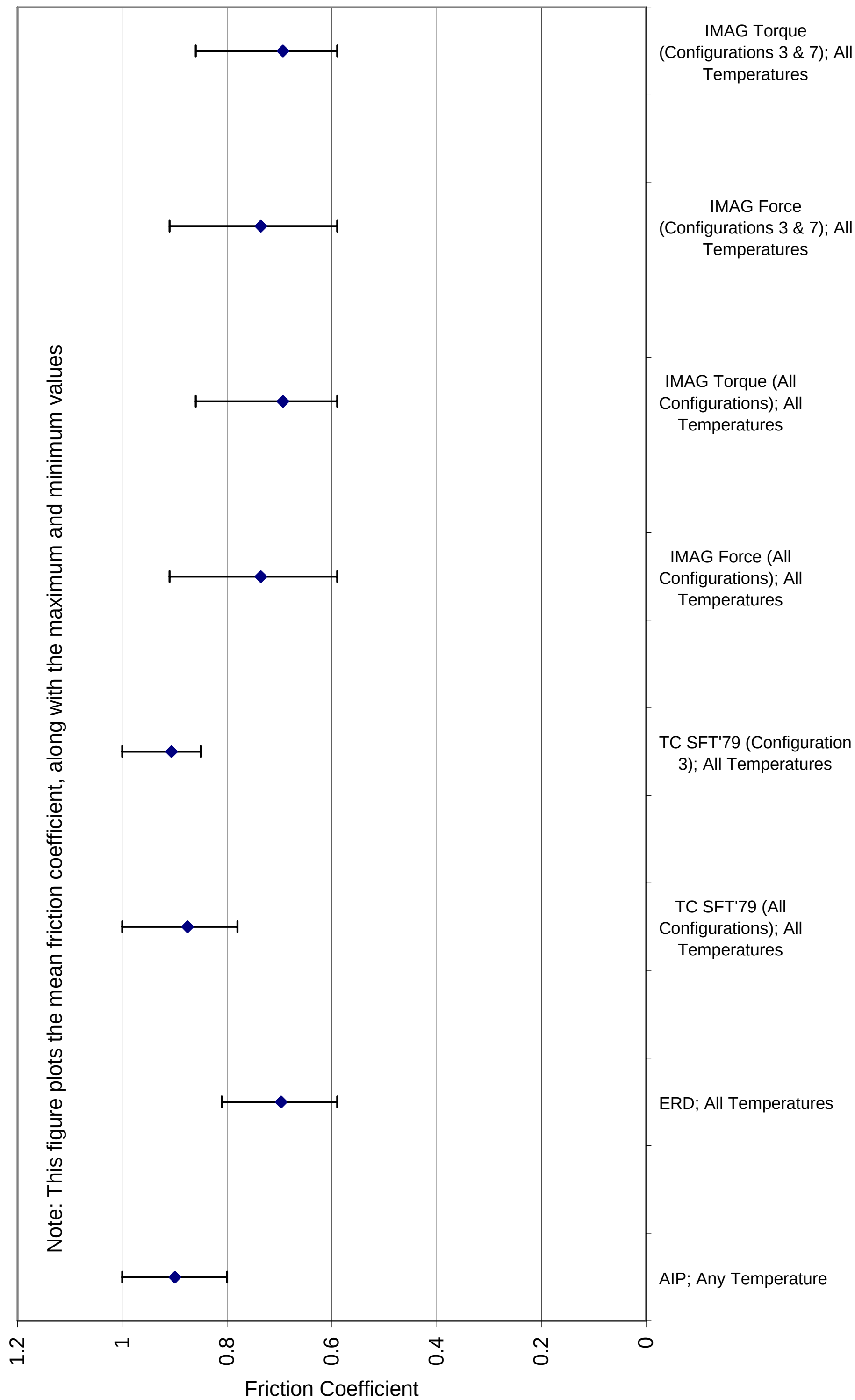



**Figure 3.22: Friction Coefficients on Dry Pavement: Summary Results**

# 4. CORRELATION AMONG DEVICES BY SURFACE TYPE

## 4.1 Results: ERD vs. TC SFT'79

Figures 4.1, 4.2, and 4.3 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix J, showing a breakdown by surface type and base type. General comparisons are shown in Table 4.1.

It is evident that the largest scatter occurs for the contaminated surfaces. Compare Figures 4.2 and 4.3. This probably reflects forces due to contaminant drag that are likely to be more significant for the ERD (as it is a locked-wheel test).

**Table 4.1: Summary Comparison: ERD vs. TC SFT'79**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | All friction levels | TC SFT'79 readings about 10% higher than the ERD ones |
| Contaminated | Less than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read higher than did the TC SFT'79 |
| Contaminated | Greater than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read lower than did the TC SFT'79 |

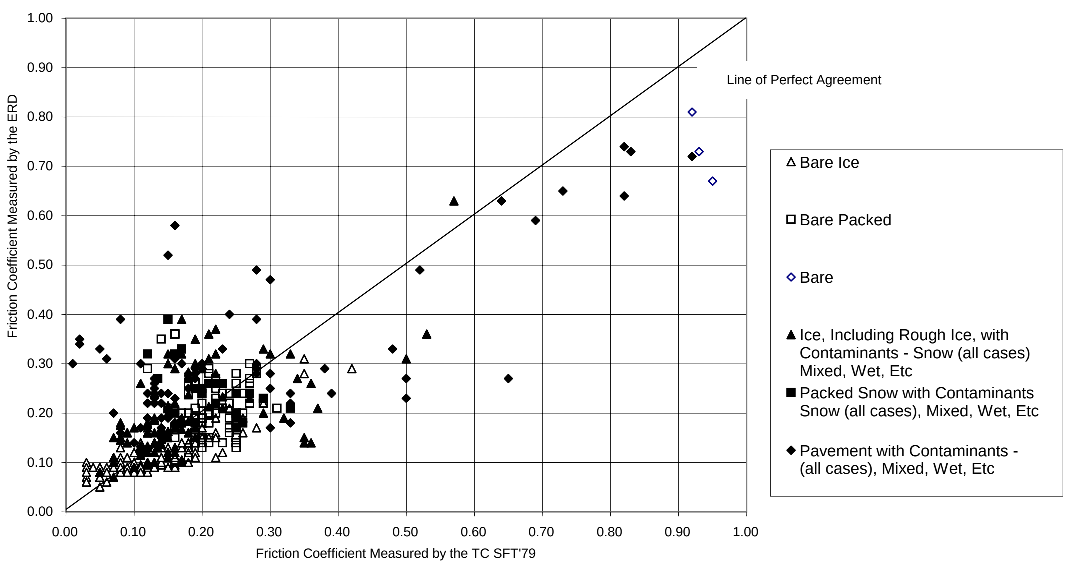



**Figure 4.1: Correlation of ERD to TC SFT'79: All Surfaces**

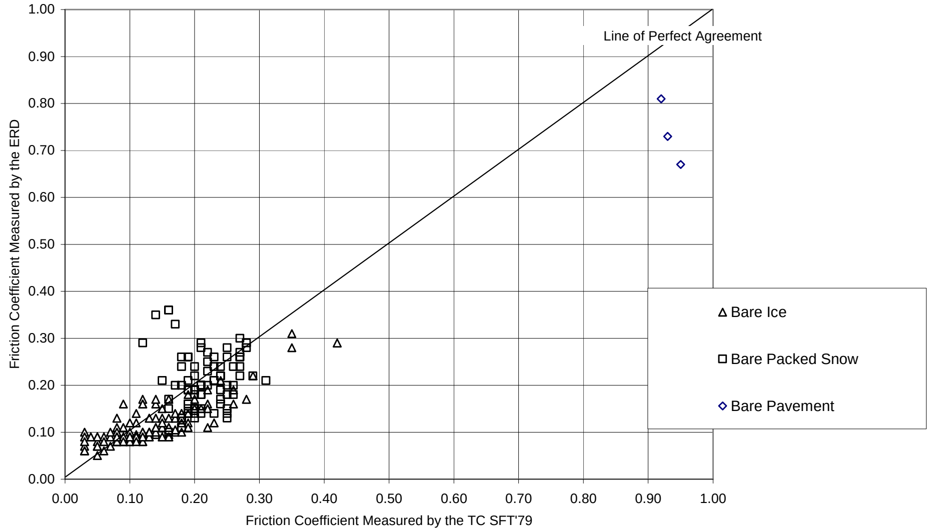



**Figure 4.2: Correlation of ERD to TC SFT'79: Bare Surfaces**

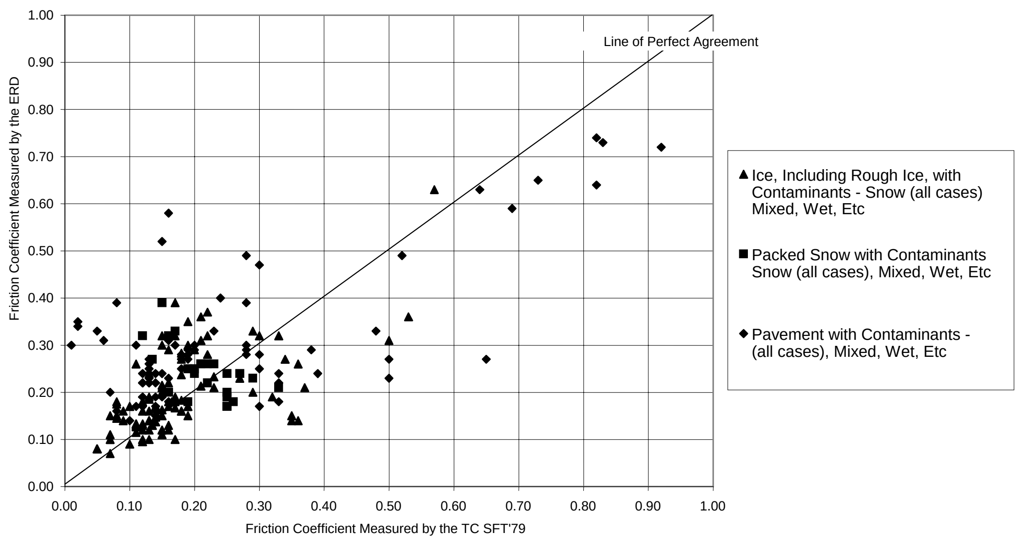



**Figure 4.3: Correlation of ERD to TC SFT'79: Contaminated Surfaces**

### 4.2 Results: ERD vs. IMAG Force

Figures 4.4, 4.5, and 4.6 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix K, showing a breakdown by surface type and base type. General comparisons are shown in Table 4.2.

As was the case for the TC SFT'79, the largest scatter occurs for the contaminated surfaces. Compare Figures 4.5 and 4.6. This probably reflects forces due to contaminant drag that are likely to be more significant for the ERD (as it is a locked-wheel test).

**Table 4.2: Summary Comparison: ERD vs. IMAG Force**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | All friction levels | IMAG Force readings about 10% higher than the ERD ones |
| Contaminated | Less than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read higher than did the IMAG Force |
| Contaminated | Greater than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read lower than did the IMAG Force |

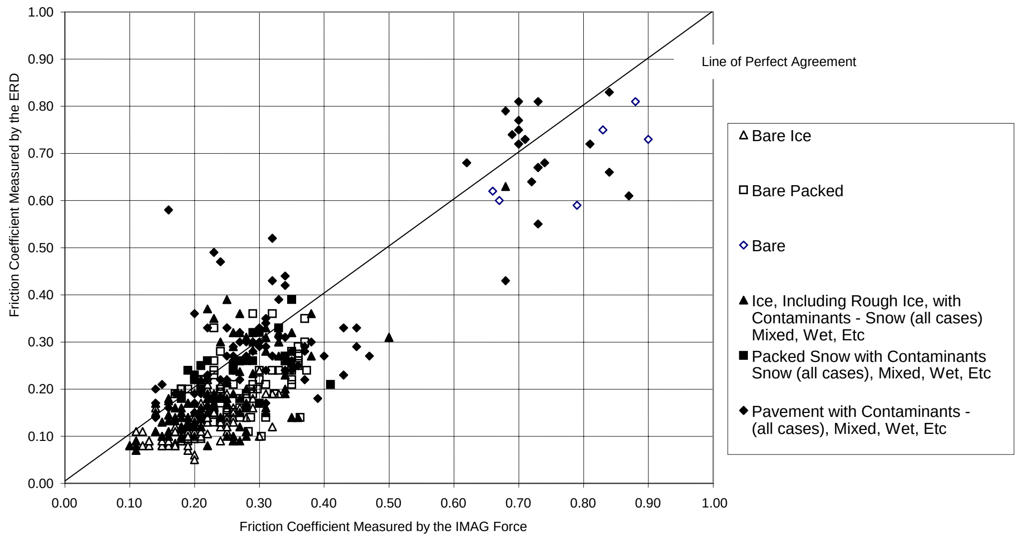



**Figure 4.4: Correlation of ERD to IMAG Force: All Surfaces**

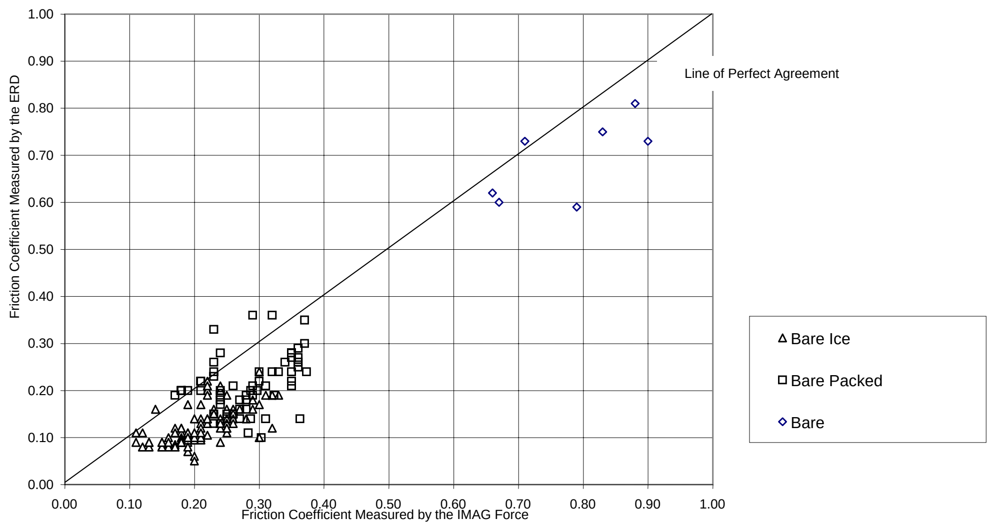



**Figure 4.5: Correlation of ERD to IMAG Force: Bare Surfaces**

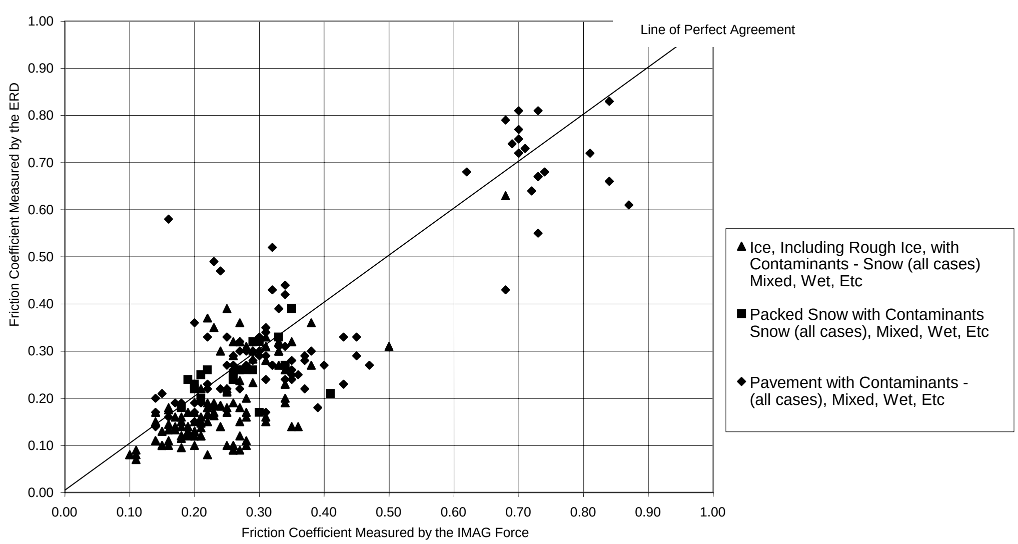



**Figure 4.6: Correlation of ERD to IMAG Force: Contaminated Surfaces**

## 4.3 Results: ERD vs. IMAG Torque

Figures 4.7, 4.8, and 4.9 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix L, showing a breakdown by surface type and base type. General comparisons are shown in Table 4.3.

As was the case for the other comparisons made to date, the largest scatter occurs for the contaminated surfaces. Compare Figures 4.8 and 4.9. This probably reflects forces due to contaminant drag that are likely to be more significant for the ERD (as it is a locked-wheel test).

**Table 4.3: Summary Comparison: ERD vs. IMAG Torque**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | All friction levels | IMAG Torque readings slightly higher (less than 10%) than the ERD ones |
| Contaminated | Less than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read higher than did the IMAG Torque |
| Contaminated | Greater than about 0.4 | • Relationship is highly scattered<br>• Generally, the ERD read lower than did the IMAG Torque |

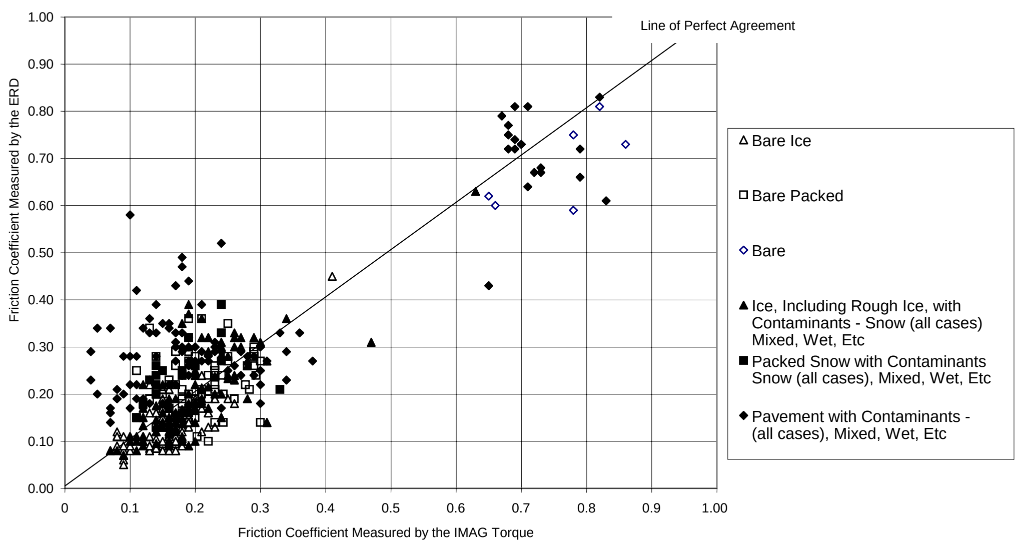



**Figure 4.7: Correlation of ERD to IMAG Torque: All Surfaces**

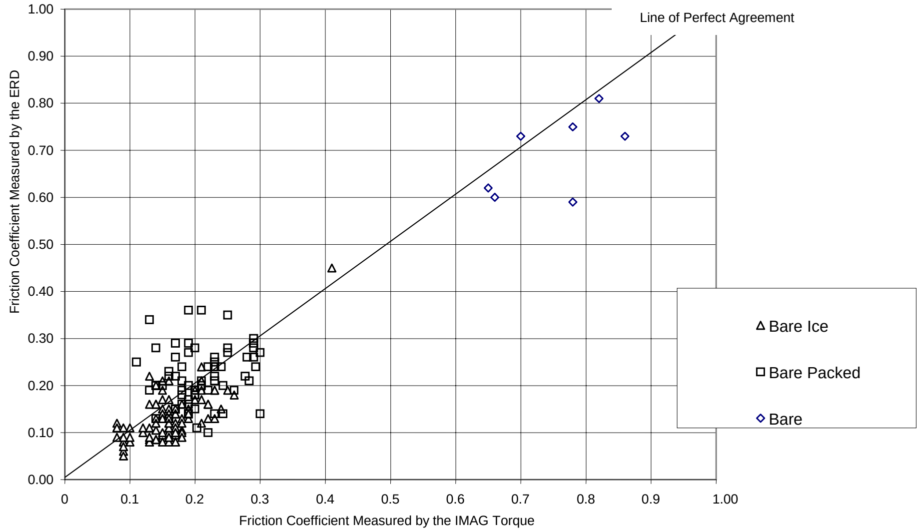



**Figure 4.8: Correlation of ERD to IMAG Torque: Bare Surfaces**

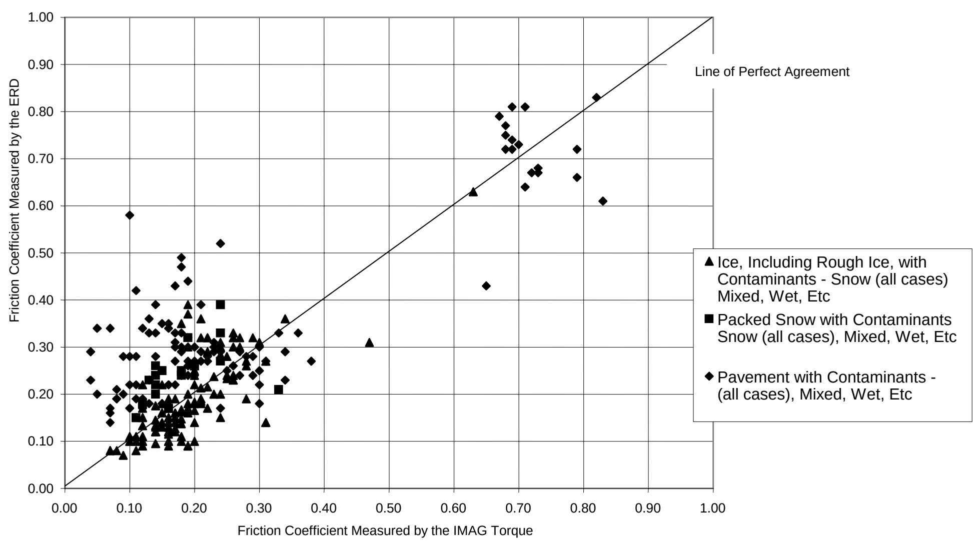



**Figure 4.9: Correlation of ERD to IMAG Torque: Contaminated Surfaces**

## 4.4 Results: TC SFT'79 vs. IMAG Force

Figures 4.10, 4.11, and 4.12 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix M, showing a breakdown by surface type and base type. General comparisons are shown in Table 4.4.

The scatter is considerably less for this comparison than for all of the ones made with the ERD. Furthermore, the scatter is not significantly different between the contaminated and the bare surfaces. Compare Figures 4.11 and 4.12. This probably reflects the fact that both of these devices utilize a rolling, braked wheel to measure friction, and thus they are better able to "process" contaminants than is the ERD.

**Table 4.4: Summary Comparison: TC SFT'79 vs. IMAG Force**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | Less than about 0.4 | IMAG Force readings generally lower than the TC SFT'79 ones |
| Bare | Greater than about 0.4 | IMAG Force readings generally higher than the TC SFT'79 ones |
| Contaminated | Less than about 0.4 | Generally, the TC SFT'79 read higher than did the IMAG Force |
| Contaminated | Greater than about 0.4 | Generally, the TC SFT'79 read lower than did the IMAG Force |

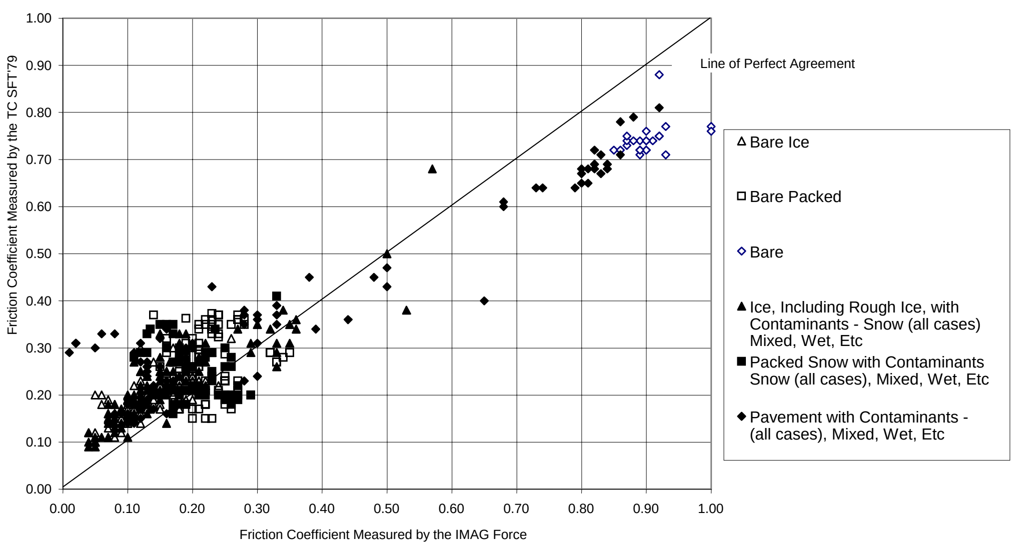



**Figure 4.10: Correlation of TC SFT'79 to IMAG Force: All Surfaces**

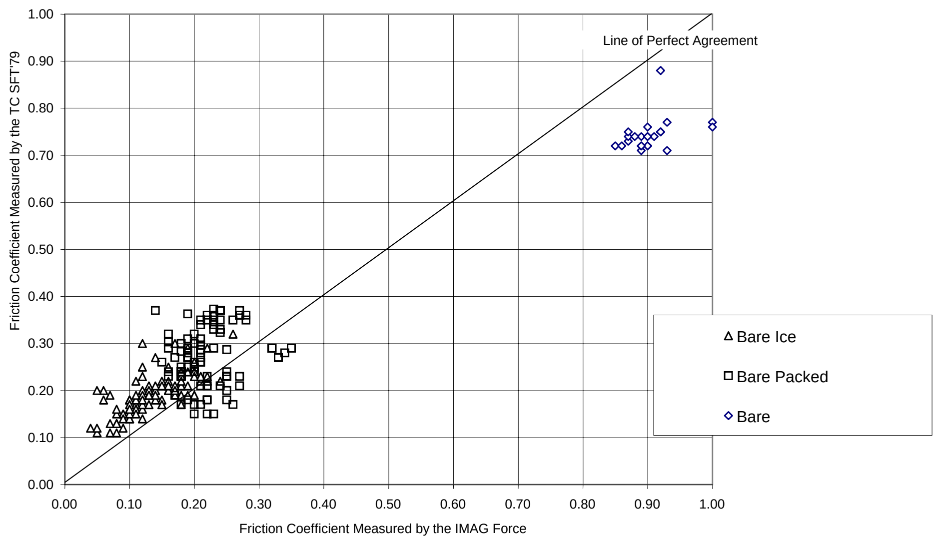



**Figure 4.11: Correlation of TC SFT'79 to IMAG Force: Bare Surfaces**

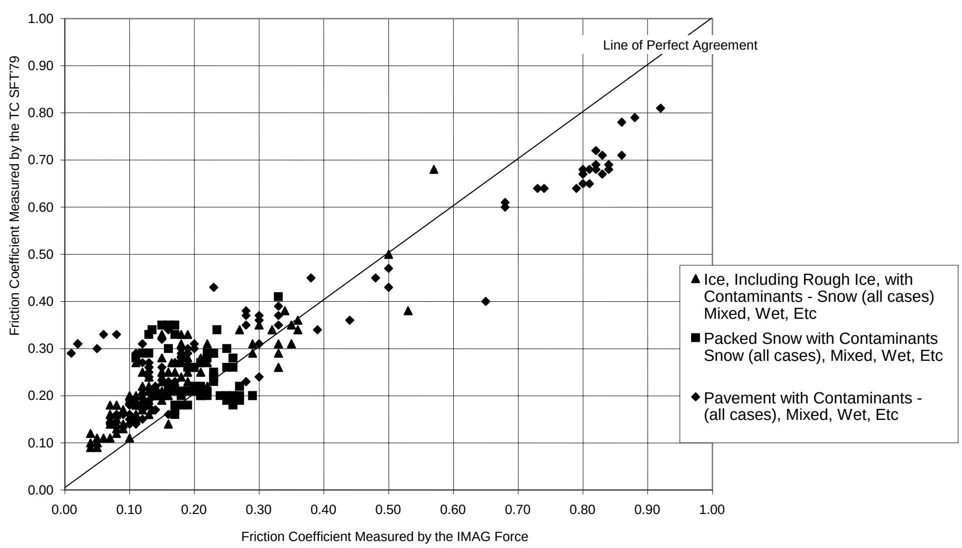



**Figure 4.12: Correlation of TC SFT'79 to IMAG Force: Contaminated Surfaces**

## 4.5 Results: TC SFT'79 vs. IMAG Torque

Figures 4.13, 4.14, and 4.15 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix N, showing a breakdown by surface and base type. General comparisons are shown in Table 4.5.

As was the case for the IMAG force (section 4.4), the scatter is considerably less for this comparison than for all those made with the ERD. Furthermore, the scatter is not significantly different between the contaminated and the bare surfaces. Compare Figures 4.14 and 4.15. This probably reflects the fact that both of these devices utilize a rolling, braked wheel to measure friction, and thus they are better able to "process" contaminants than is the ERD.

**Table 4.5: Summary Comparison: TC SFT'79 vs. IMAG Torque**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | All friction levels | IMAG Torque readings generally higher than the TC SFT'79 ones |
| Contaminated | All friction levels | IMAG Torque readings generally higher than the TC SFT'79 ones |

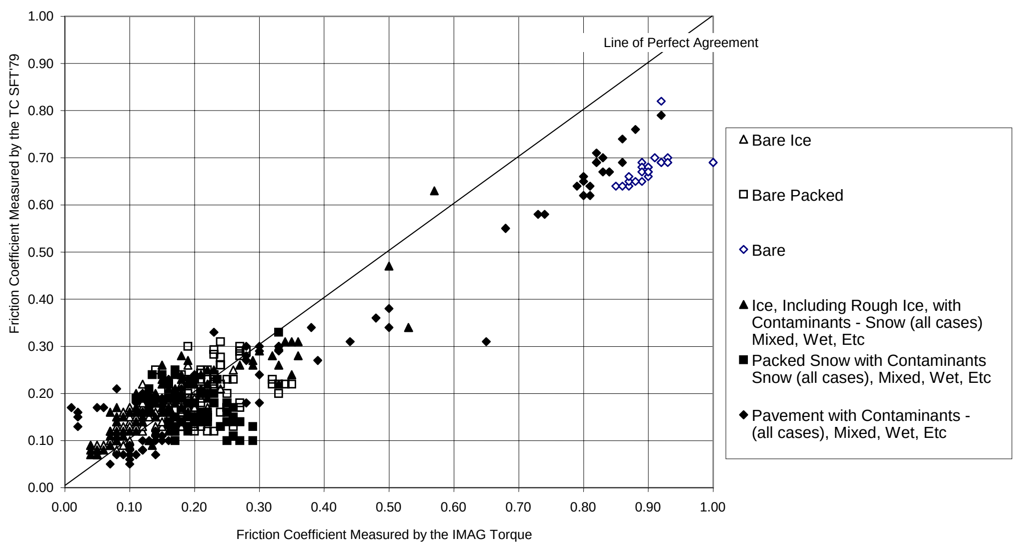



**Figure 4.13: Correlation of TC SFT'79 to IMAG Torque: All Surfaces**

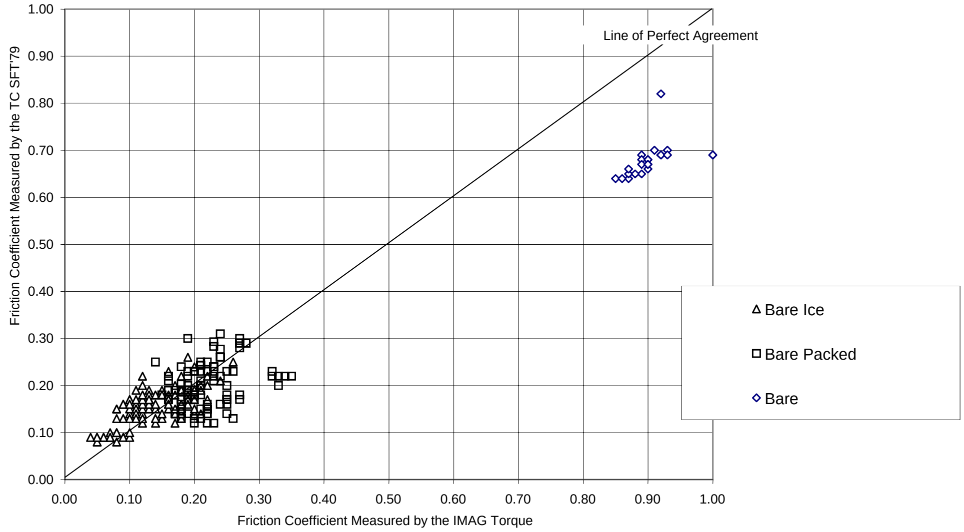



**Figure 4.14: Correlation of TC SFT'79 to IMAG Torque: Bare Surfaces**

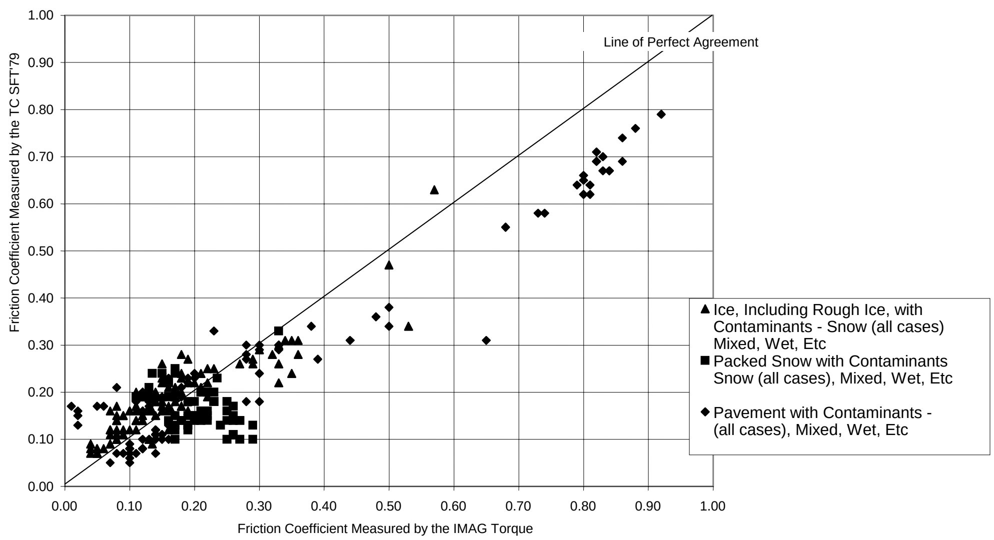



**Figure 4.15: Correlation of TC SFT'79 to IMAG Torque: Contaminated Surfaces**

### 4.6 Results: IMAG Force vs. IMAG Torque

Figures 4.16, 4.17, and 4.18 show results for all surfaces, bare surfaces only, and contaminated surfaces only, respectively. More detailed plots are contained in Appendix O, showing a breakdown by surface type and base type. General comparisons are shown in Table 4.6. This comparison showed the least scatter, probably because:

(a) IMAG Force and IMAG Torque are both part of the same device.
(b) IMAG utilizes a rolling, braked wheel to measure friction, which allows it to "process" contaminants. This is probably the reason the scatter is not significantly different between the contaminated and the bare surfaces. Compare Figures 4.17 and 4.18.

**Table 4.6: Summary Comparison: IMAG Force vs. IMAG Torque**

| Surface Type | Friction Level | Comparison |
|---|---|---|
| Bare | All friction levels | IMAG Torque readings always lower than the IMAG Force ones |
| Contaminated | All friction levels | IMAG Torque readings always lower than the IMAG Force ones |

It is also evident that:

(a) IMAG Force and IMAG Torque are highly correlated to each other.
(b) The IMAG Force reading is always higher than the IMAG Torque one. This is to be expected as the IMAG Force reading is determined by adding the contaminant drag to the horizontal braking forces applied to the measuring wheel. It is noteworthy that the relationship between the IMAG Torque and IMAG Force is generally similar for both the bare and the contaminated surfaces. (Figures 4.17 and 4.18). This suggests that the contaminant drag is an important part of the total horizontal forces applied to the measuring wheel even for the bare surfaces.

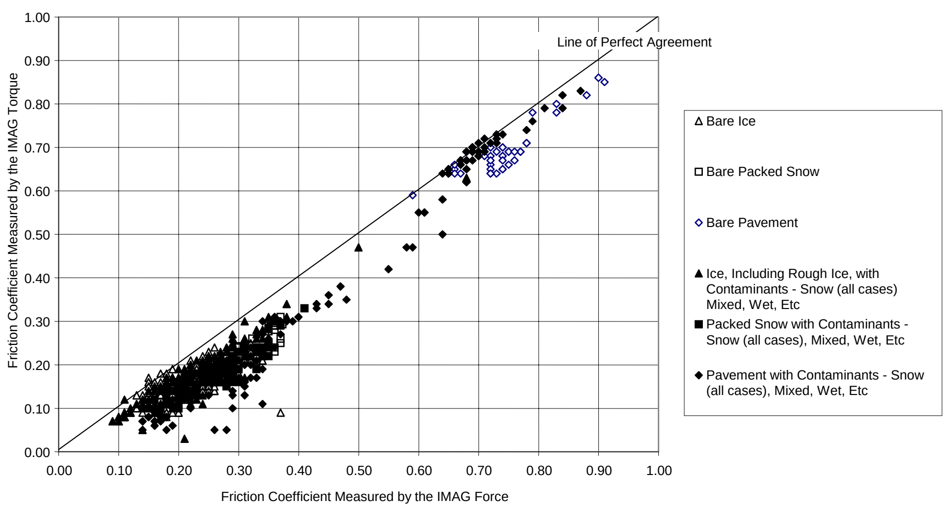



**Figure 4.16: Correlation of IMAG Force to IMAG Torque: All Surfaces**

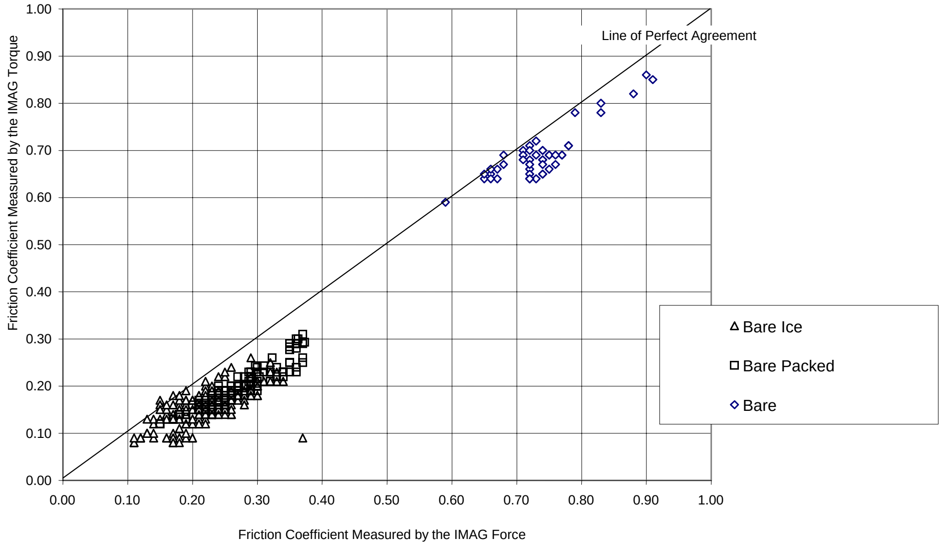



**Figure 4.17: Correlation of IMAG Force to IMAG Torque: Bare Surfaces**

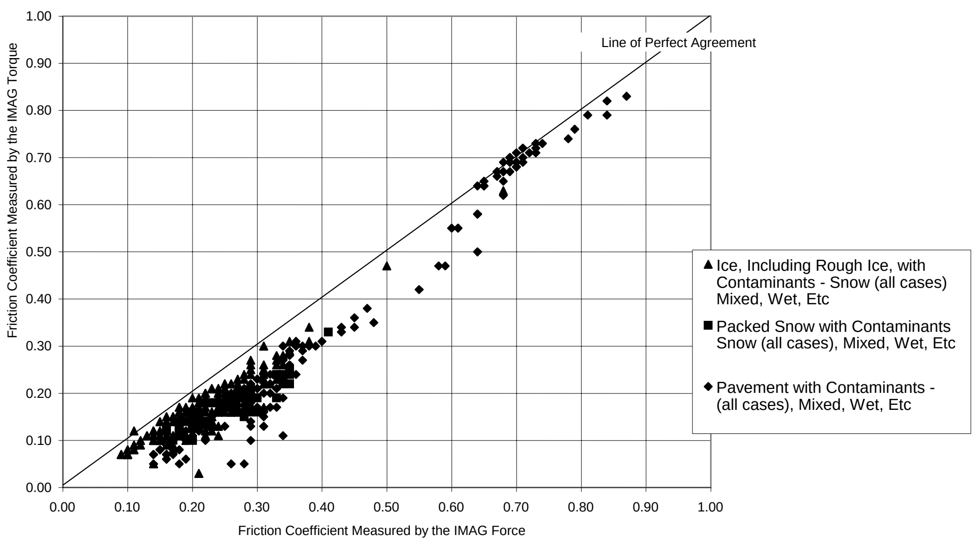



**Figure 4.18: Correlation of IMAG Force to IMAG Torque: Contaminated Surfaces**

# 5. CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The results obtained from the JWRFMP were used to investigate the effect of surface conditions on the friction coefficient measured by the ERD, the TC SFT'79, and the IMAG. Two types of analyses were conducted as follows:

(a) Analyses for individual surfaces – Where possible, the friction coefficients obtained from the devices were compared to the guideline CRFIs given in the AIP.
(b) Correlations among the devices.

### 5.1.1 Analyses for Individual Surfaces

The results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions.

It was commonly observed that the ranges of values observed in the JWRFMP were larger than those given in the AIP.

### 5.1.2 Correlations among the Devices

The results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions.

It was noted that:

(a) ERD readings on contaminated surfaces were generally higher and more scattered on contaminated surfaces than those for the TC SFT'79 and the IMAG. This probably reflects the fact that the ERD is locked-wheel test.
(b) TC SFT'79 and the IMAG showed good correlation for all surfaces.

## 5.2 Recommendations

This was an exploratory project that was aimed at investigating general trends and relationships. The results obtained here should be followed up with more detailed quantitative analyses to investigate issues such as:

(a) Variability among the results for different surfaces.

(b) Degree of confidence that one could have in friction coefficients inferred solely from surface descriptions, in comparison to data obtained with friction-measuring devices.

## REFERENCES

[1] Comfort, G., and Trott, B., 2002, *Joint Winter Runway Friction Test Program Database Manual*, prepared by Fleet Technology Limited for the Transportation Development Centre on behalf of Aerodrome Safety Branch of Civil Aviation, Transport Canada.

[2] AIP, 2002, *Aeronautical Information Publication*, Air 1-15, Table 4, TP 2300.

[3] Comfort, G., and Gong, Y., 1998, *Analysis of the Friction Factors Measured by the Ground Vehicles at the 1998 North Bay Trials*, TP 13366E Transportation Development Centre, Transport Canada.

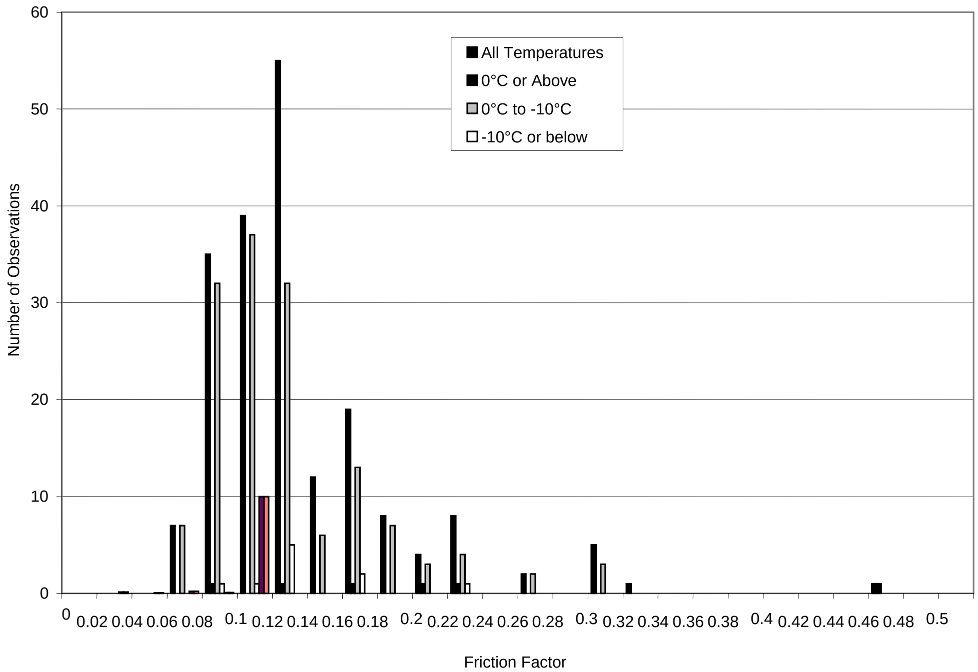
**APPENDIX A**

**RESULTS FOR BARE ICE**

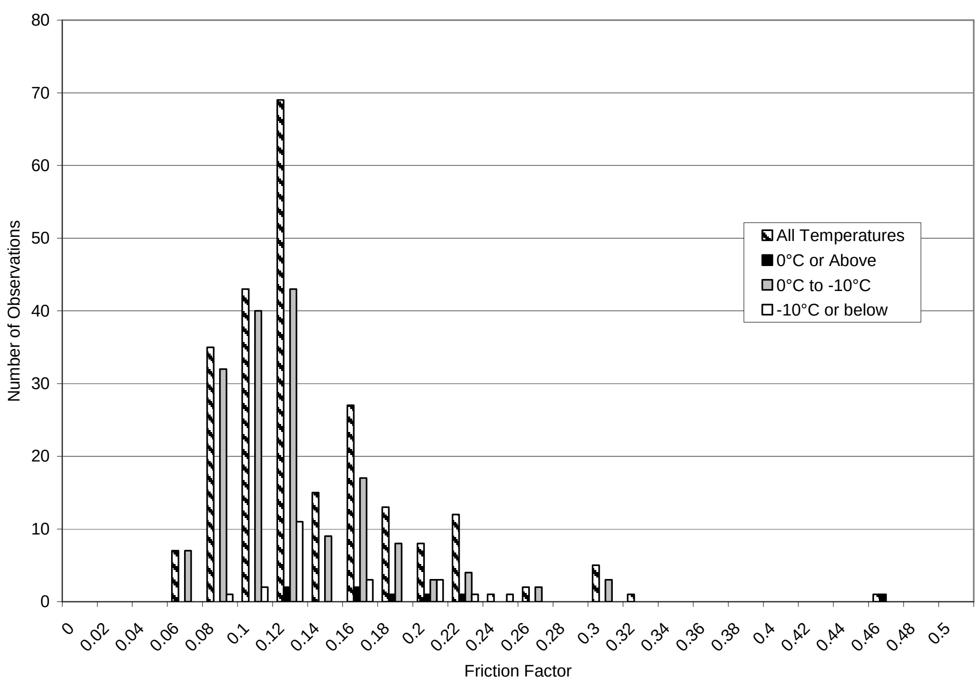
Contents

# APPENDIX A.1

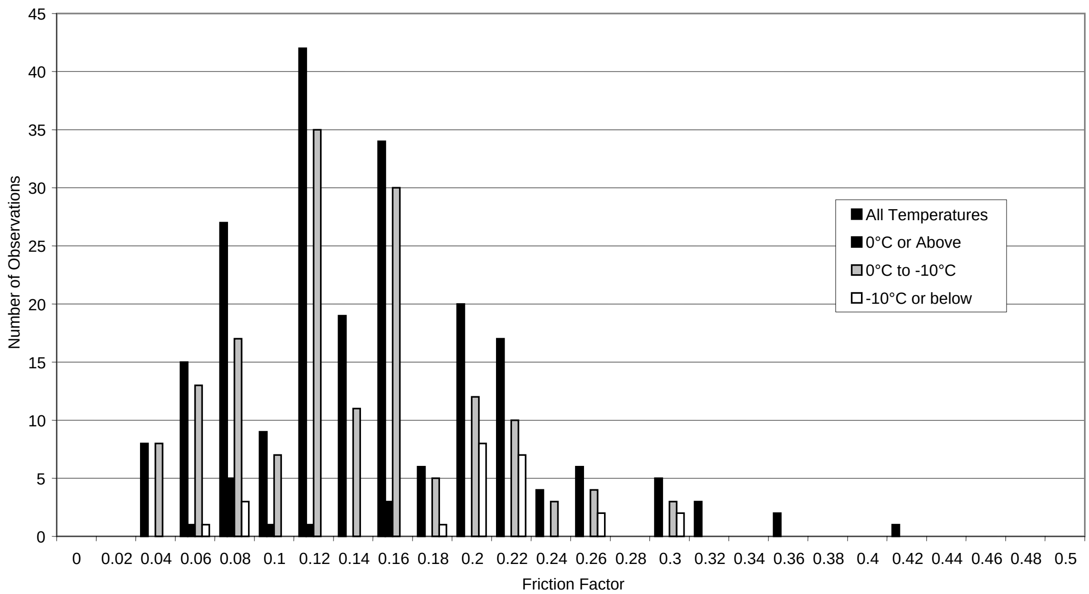
# HISTOGRAMS



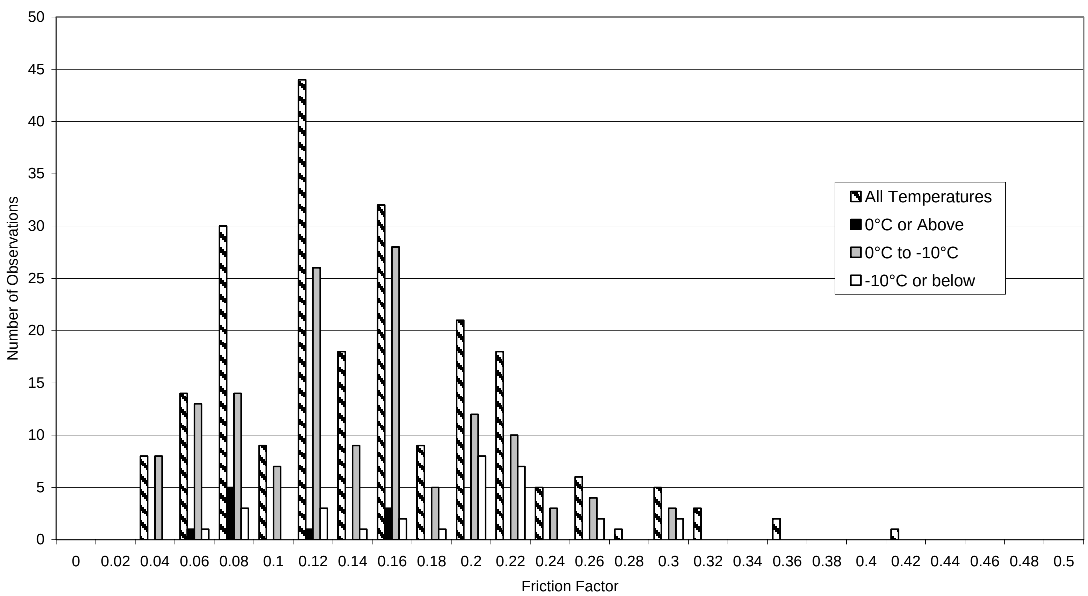

**A.1-1: ERD Readings on Bare Ice: Effect of Temperature**



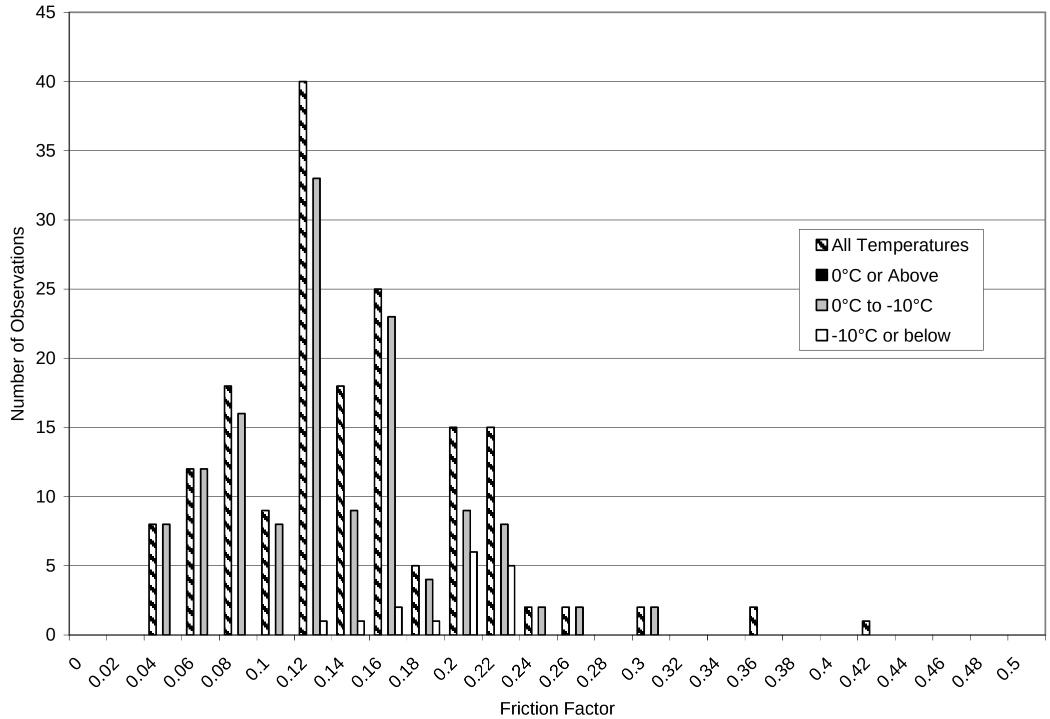

**A.1-2: ERD Readings on Bare Ice and Rough Ice: Effect of Temperature**



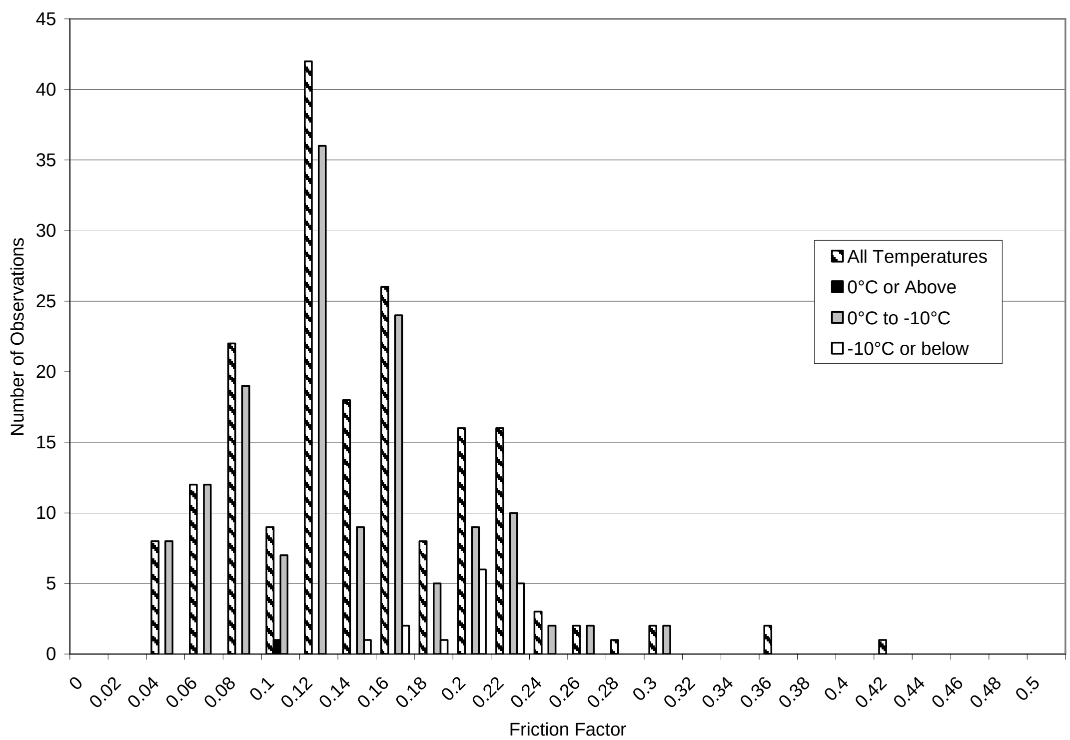

**A.1-3: ERD TC SFT'79 (All Configurations) Readings on Bare Ice: Effect of Temperature**



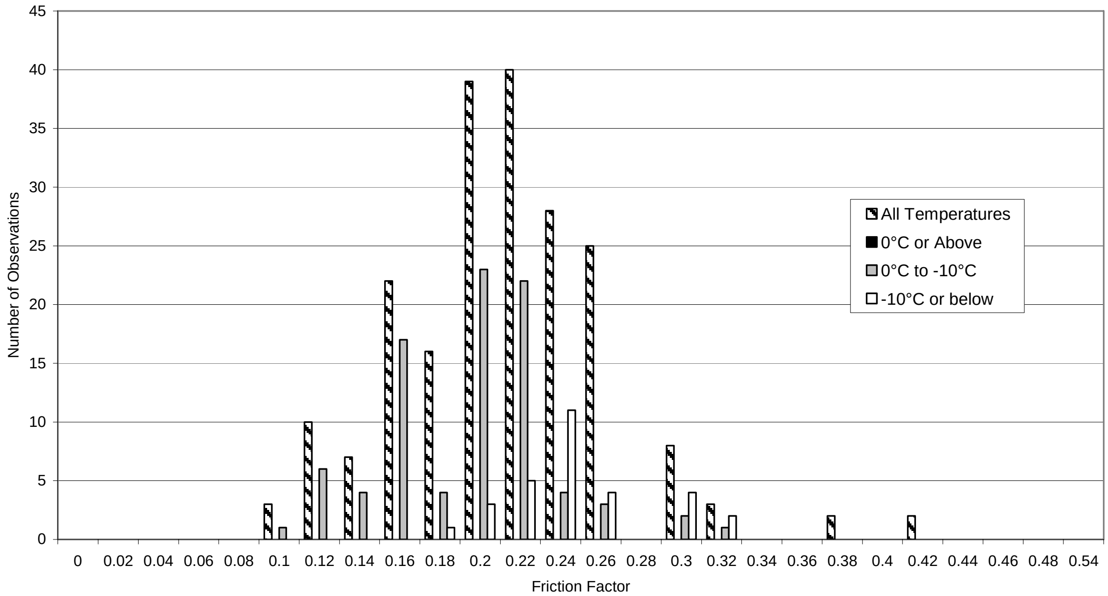

**A.1-4: ERD TC SFT'79 (All Configurations) Readings on Bare and Rough Ice: Effect of Temperature**



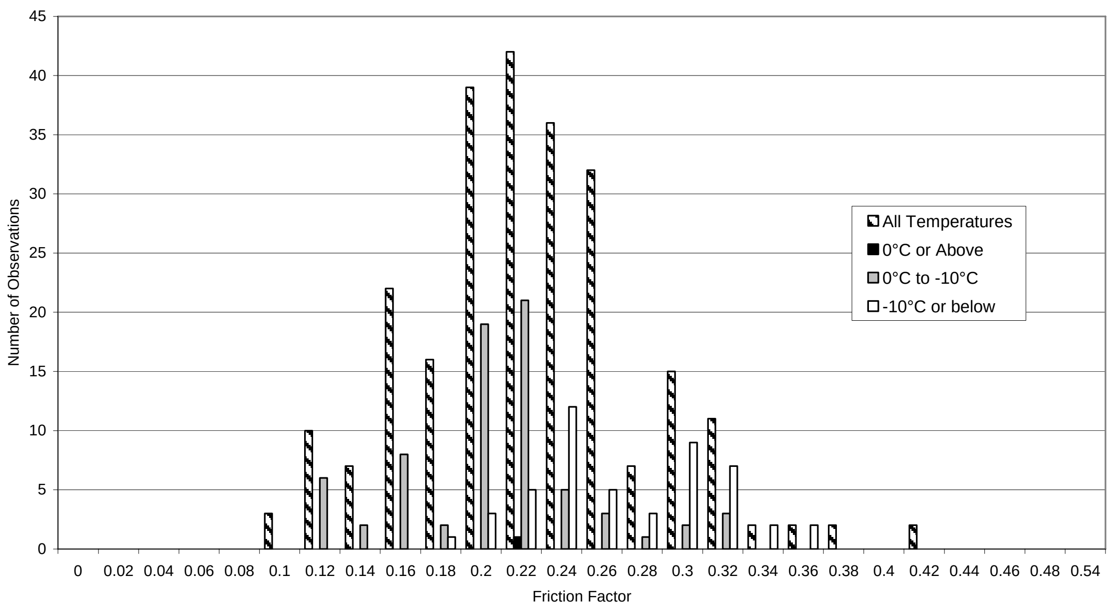

**A.1-5: TC SFT'79 (Configuration 3) Readings on Bare Ice: Effect of Temperature**



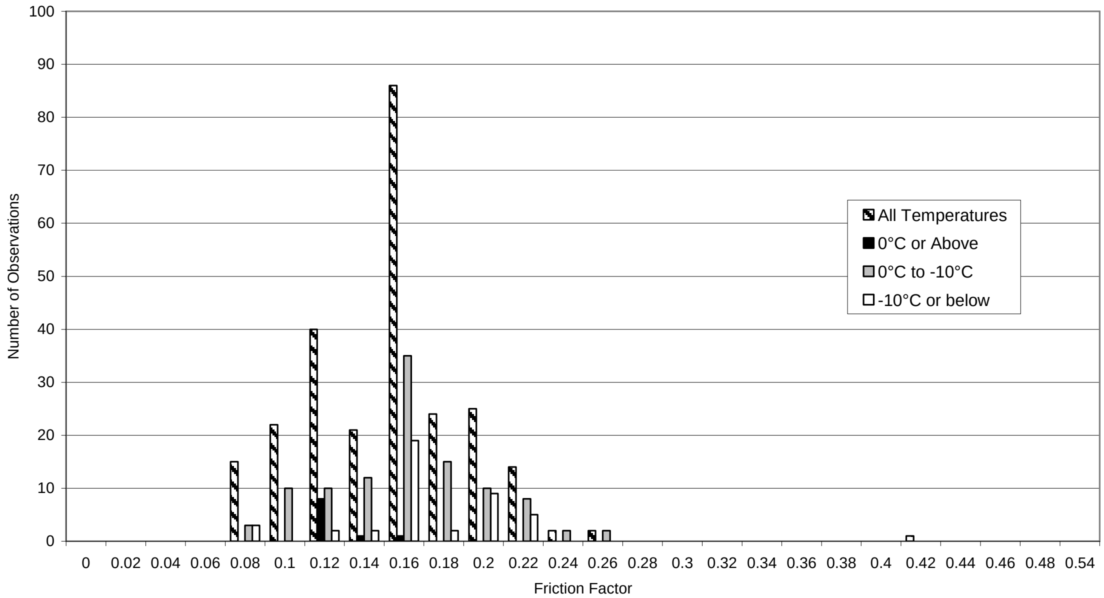

**A.1-6: TC SFT'79 (Configuration 3) Readings on Bare and Rough Ice: Effect of Temperature**



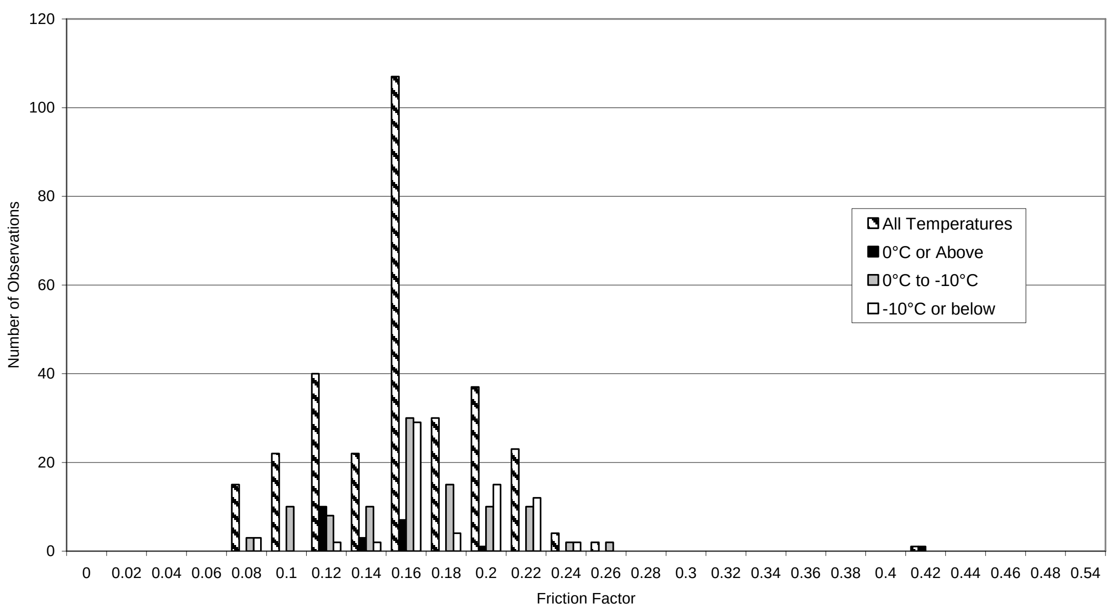

**A.1-7: IMAG Force (All Configurations) Readings on Bare Ice: Effect of Temperature**



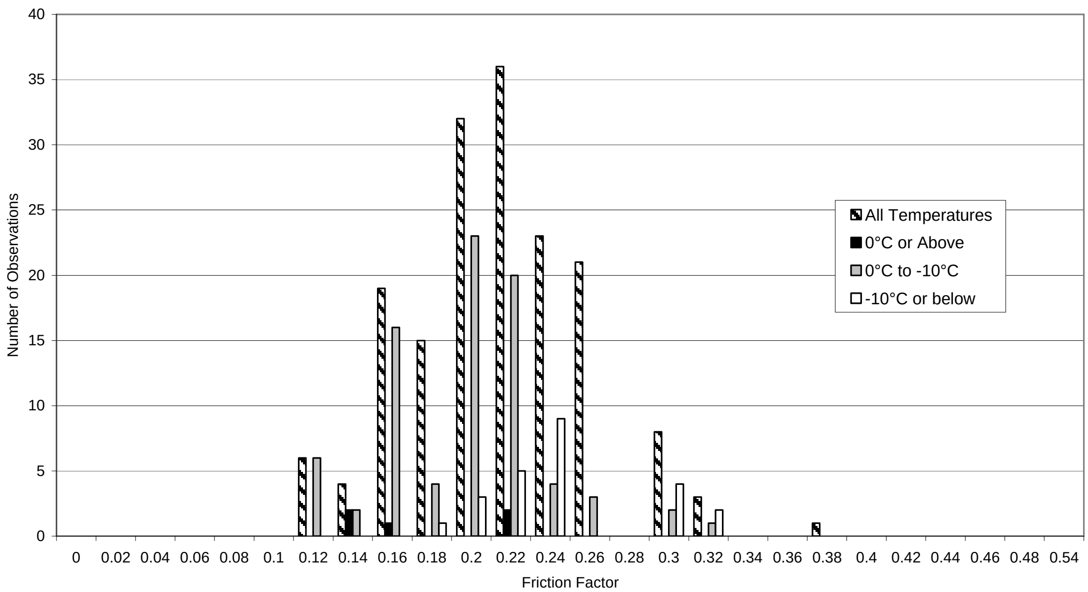

**A.1-8: IMAG Force (All Configurations) Readings on Bare and Rough Ice: Effect of Temperature**



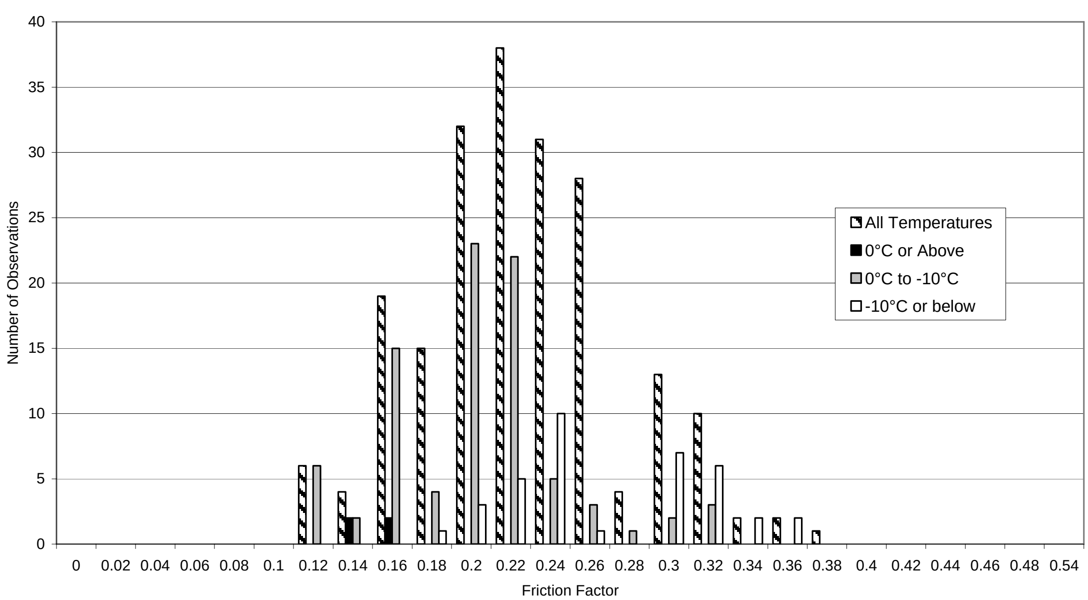

**A.1-9: IMAG Torque (All Configurations) Readings on Bare Ice: Effect of Temperature**



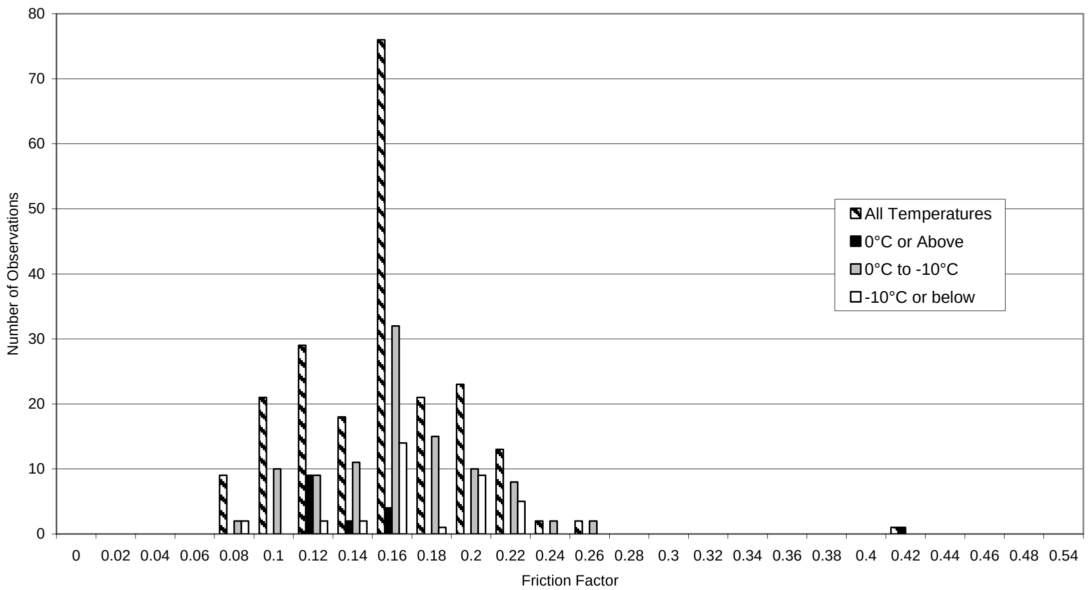

**A.1-10: IMAG Torque (All Configurations) Readings on Bare and Rough Ice: Effect of Temperature**



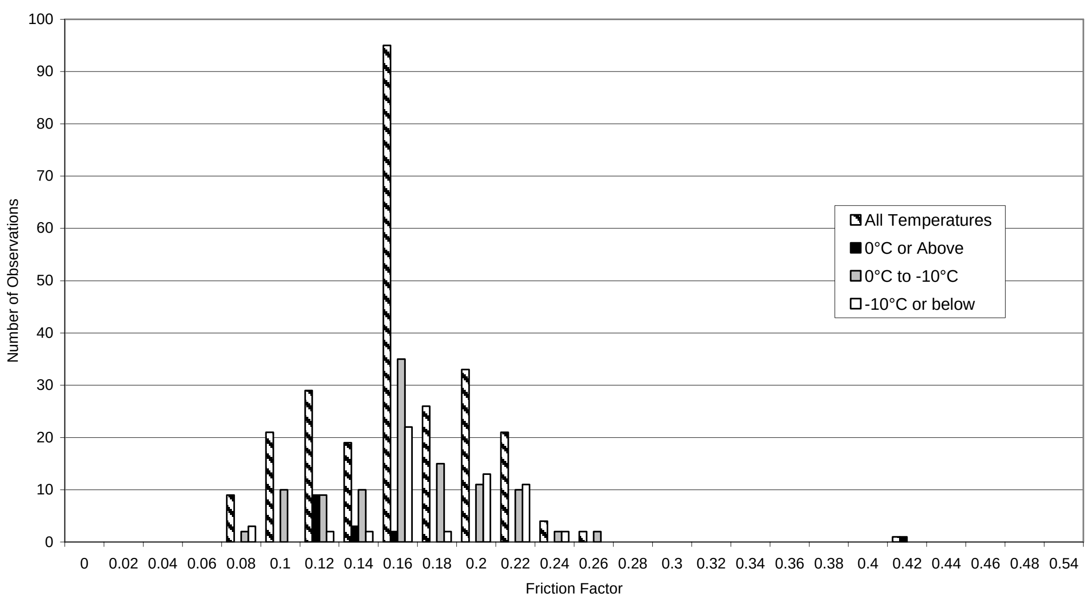

**A.1-11: IMAG Force (Configurations 3 and 7) Readings on Bare Ice: Effect of Temperature**




**A.1-12: IMAG Force (Configurations 3 and 7) Readings on Bare and Rough Ice: Effect of Temperature**



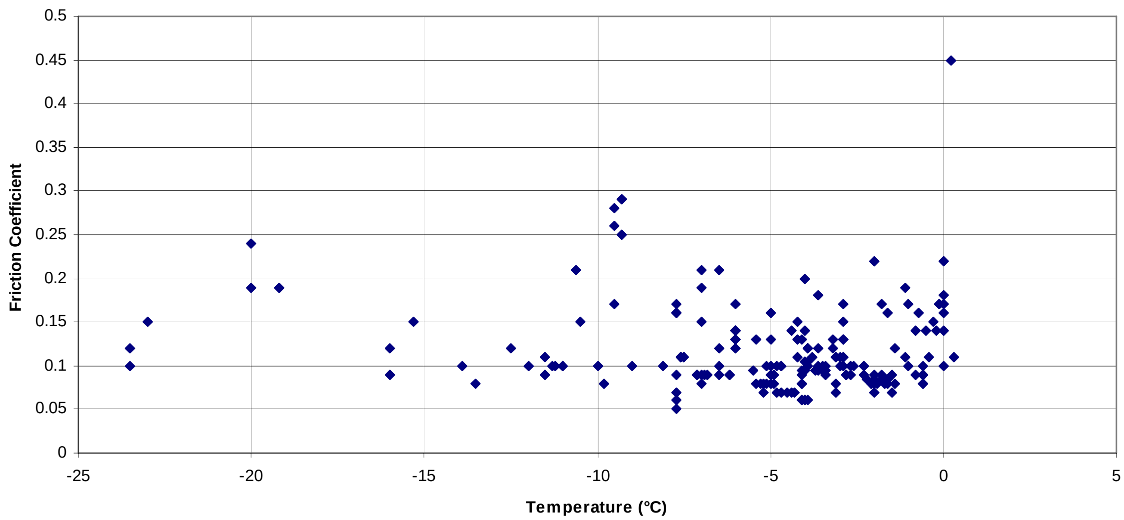

**A.1-13: IMAG Torque (Configurations 3 and 7) Readings on Bare Ice: Effect of Temperature**



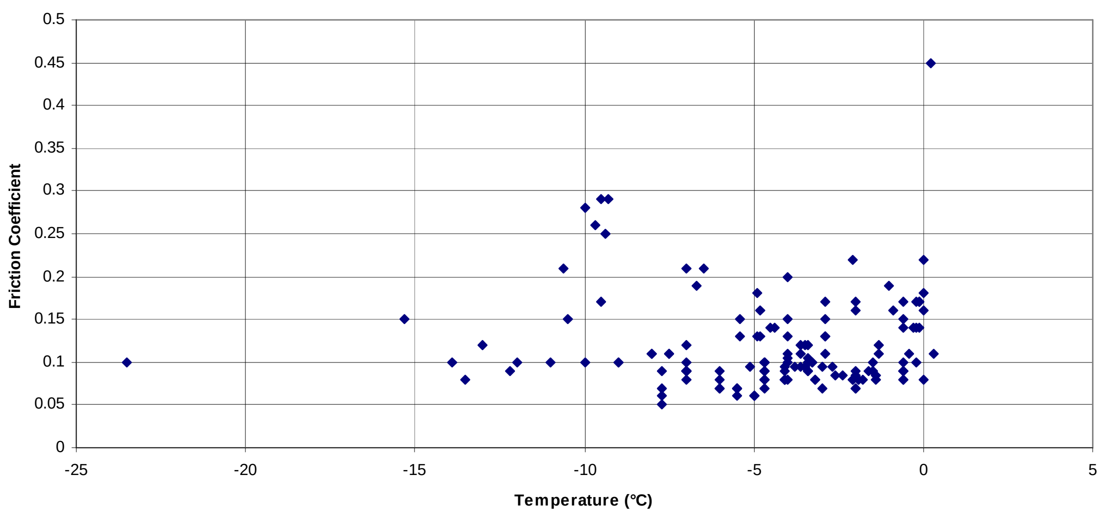

**A.1-14: IMAG Force (Configurations 3 and 7) Readings on Bare and Rough Ice: Effect of Temperature**

# APPENDIX A.2

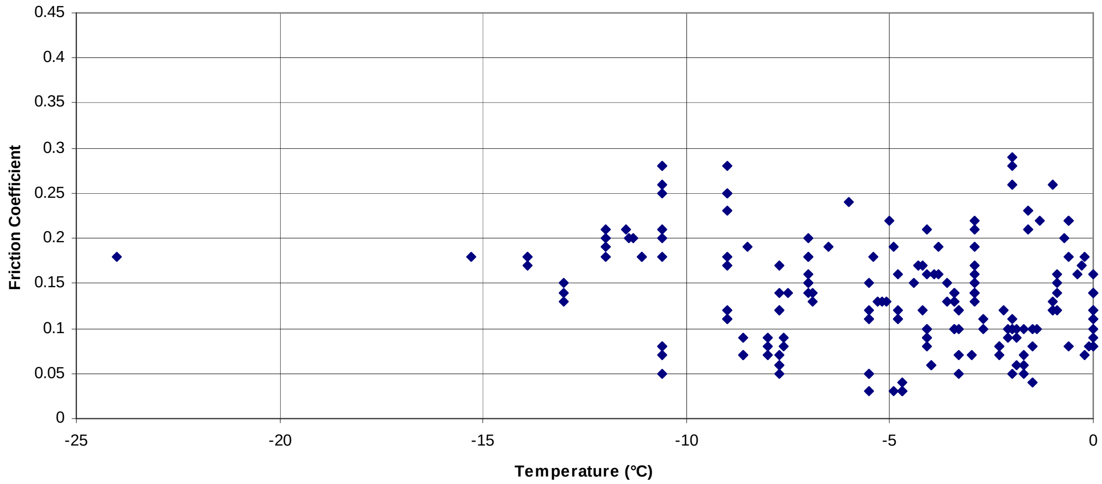
# TREND PLOTS VS. SURFACE TEMPERATURE



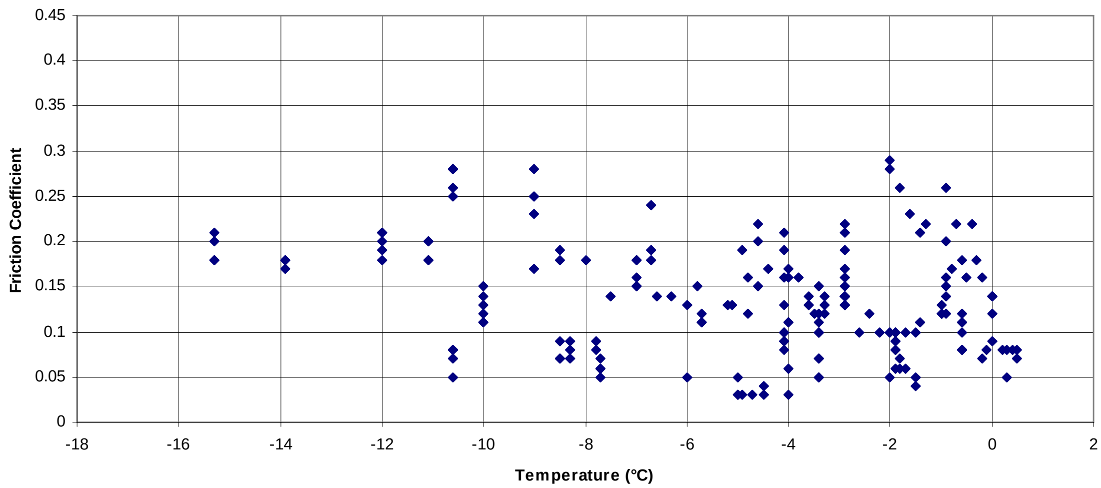

**A.2-1: Effect of Temperature: ERD Readings on Bare Ice and Rough Ice**



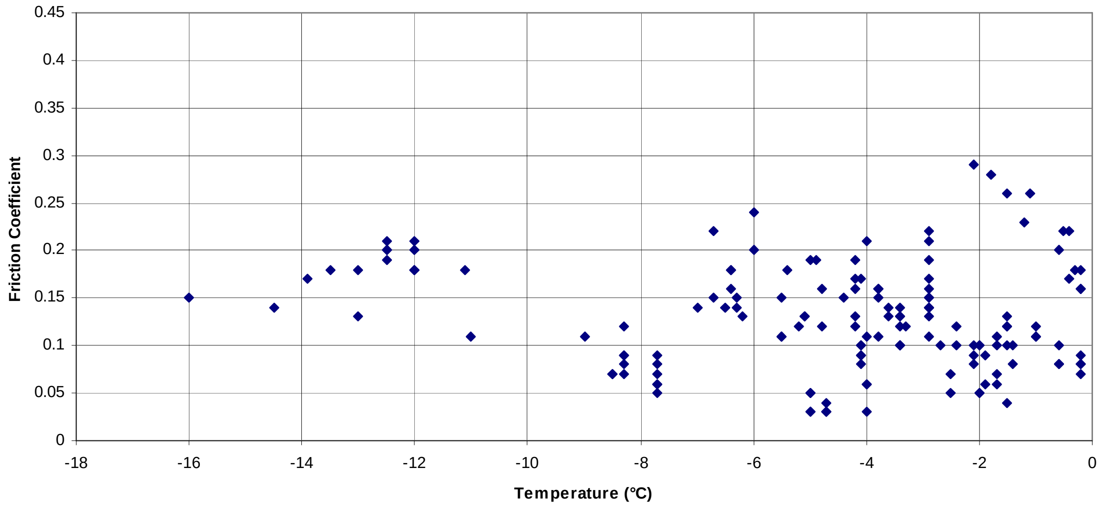

**A.2-2: Effect of Temperature: ERD Readings on Bare Ice**



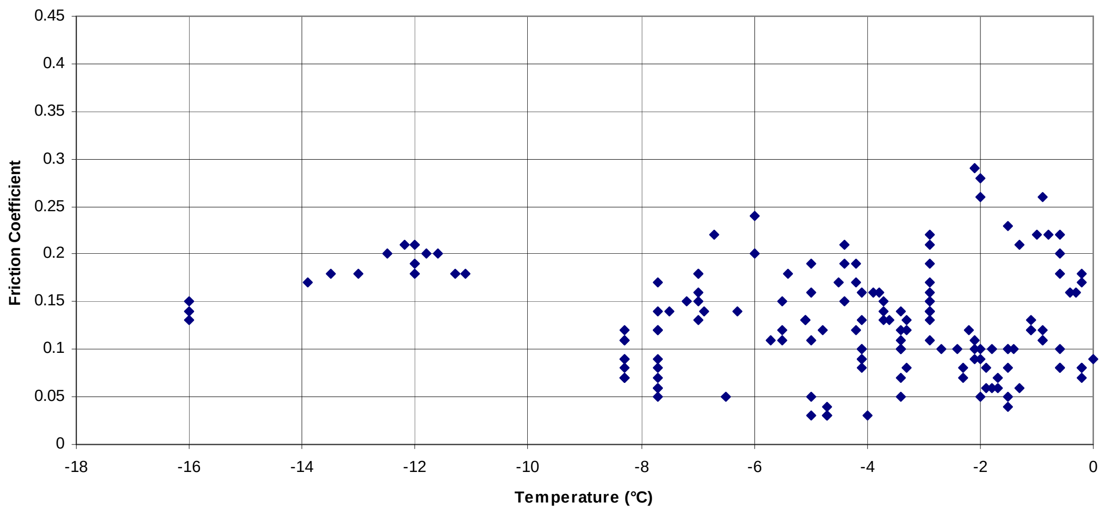

**A.2-3: Effect of Temperature: TC SFT'79 (All Configurations) Readings on Bare and Rough Ice**



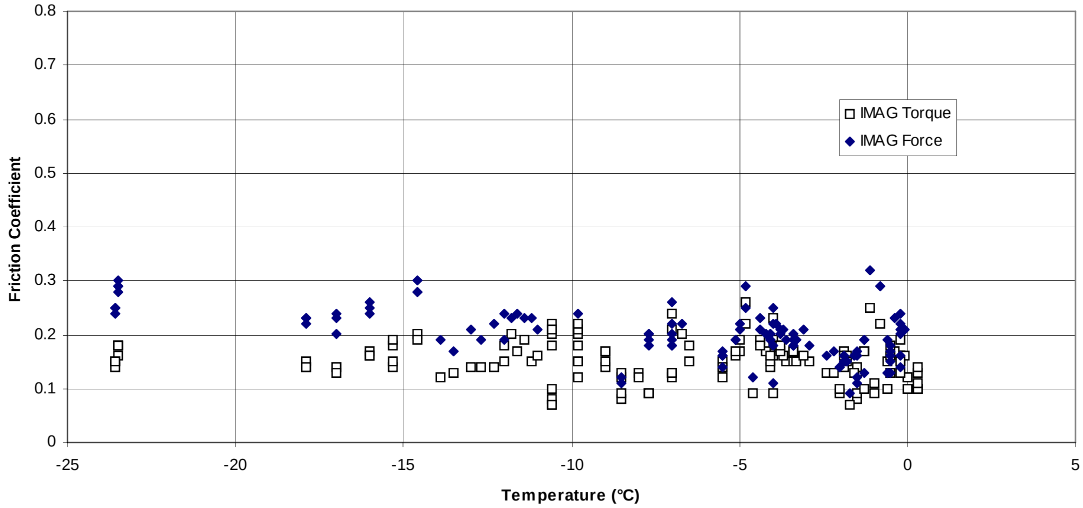

**A.2-4: Effect of Temperature: TC SFT'79 (All Configurations) Readings on Bare Ice**



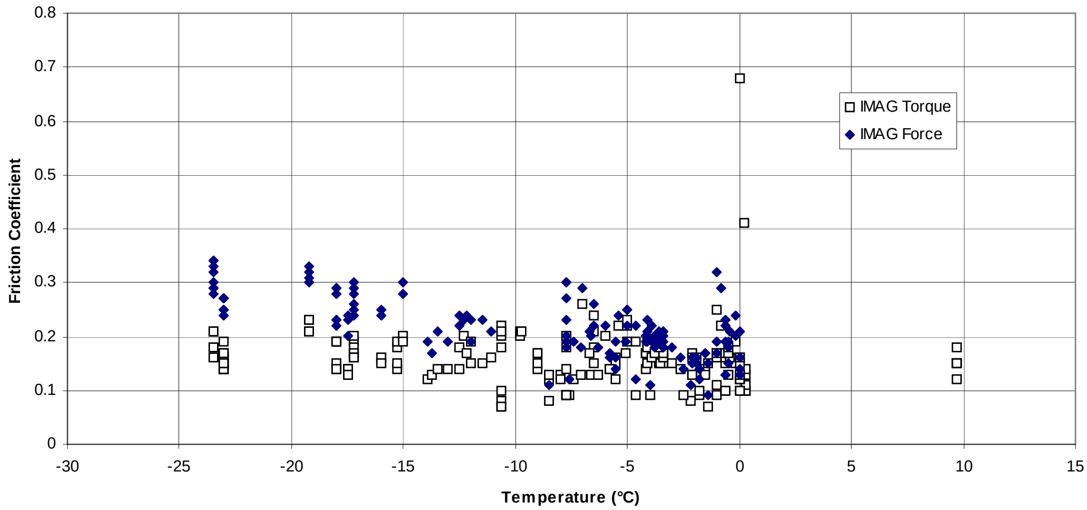

**A.2-5: Effect of Temperature: TC SFT'79 (Configuration 3) Readings on Bare Ice**



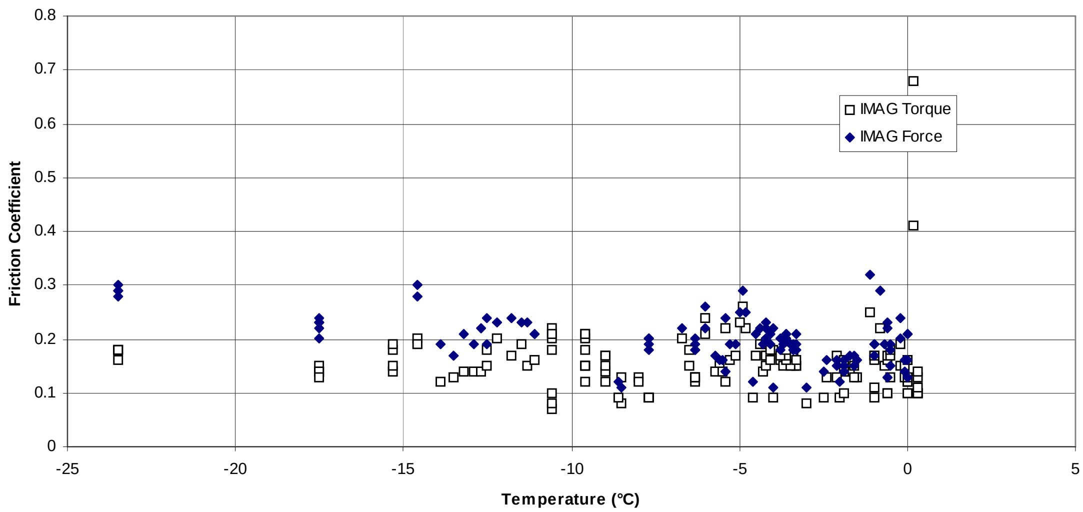

**A.2-6: Effect of Temperature: TC SFT'79 (Configuration 3) Readings on Bare and Rough Ice**



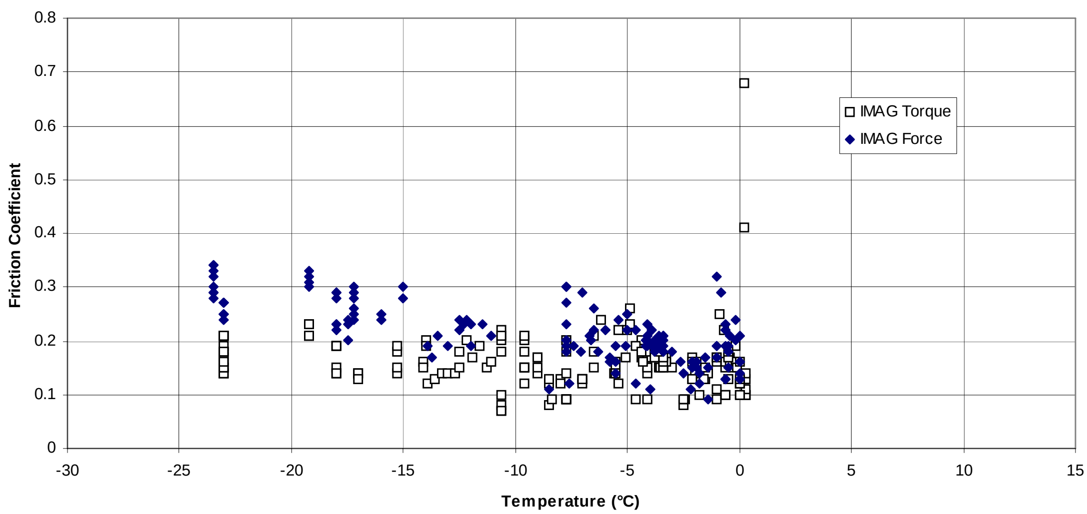

**A.2-7: Effect of Temperature: IMAG (All Configurations) Readings on Bare Ice**




**A.2-8: Effect of Temperature: IMAG (All Configurations) Readings on Bare and Rough Ice**




**A.2-9: Effect of Temperature: IMAG (Configurations 3 and 7) Readings on Bare Ice**




**A.2-10: Effect of Temperature: IMAG (Configurations 3 and 7) Readings on Bare and Rough Ice**

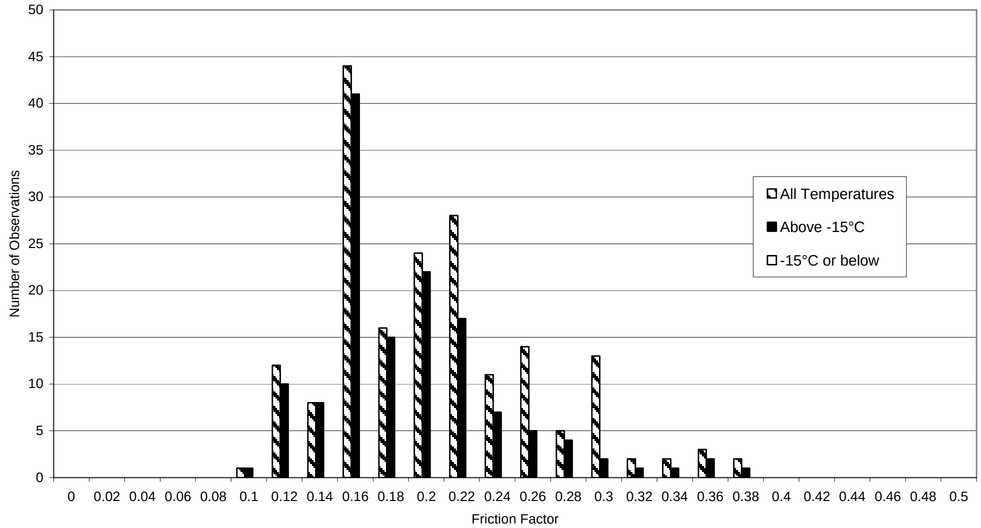
# APPENDIX B

# RESULTS FOR BARE PACKED SNOW

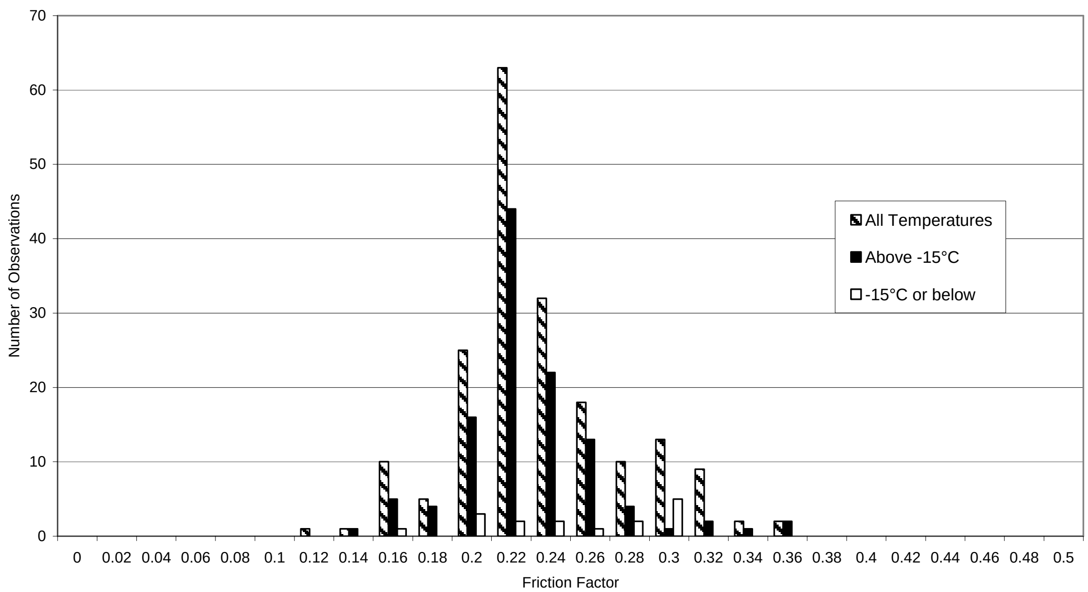
Contents

# APPENDIX B.1

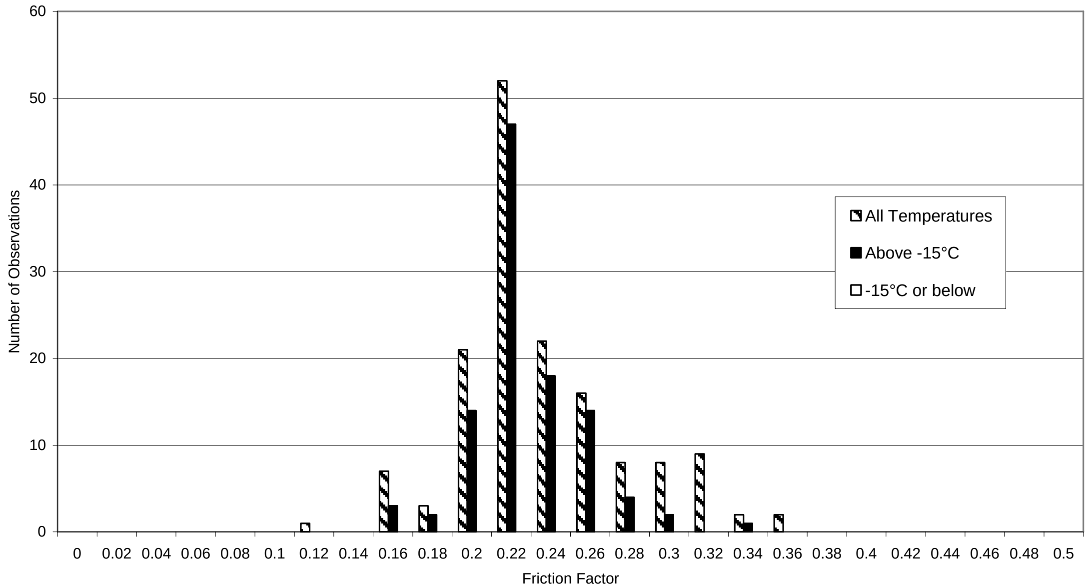
# HISTOGRAMS



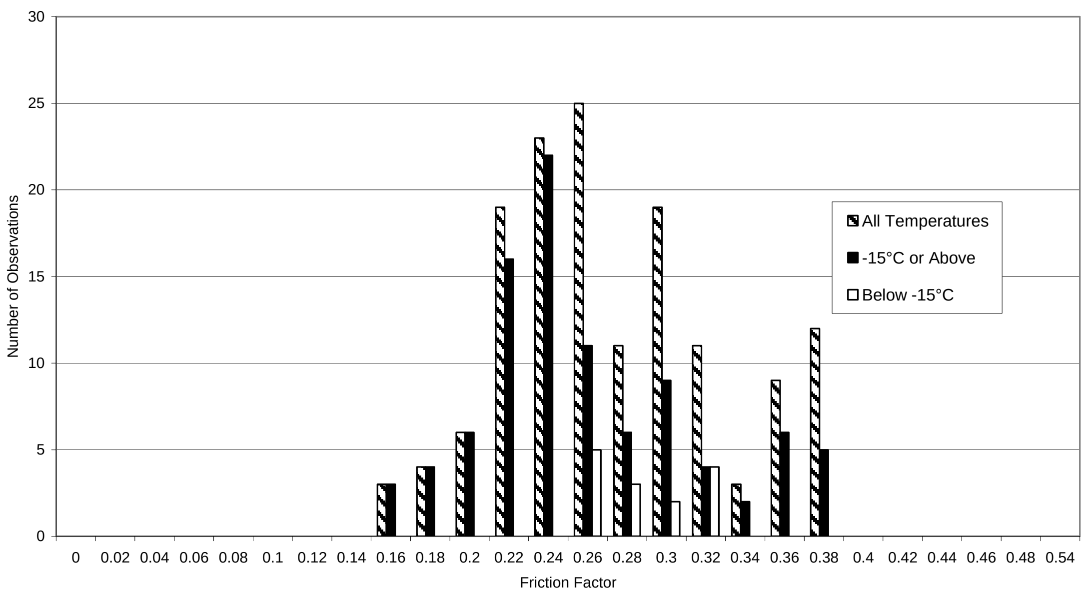

**B.1-1: ERD Readings on Bare Packed Snow: Effect of Temperature**



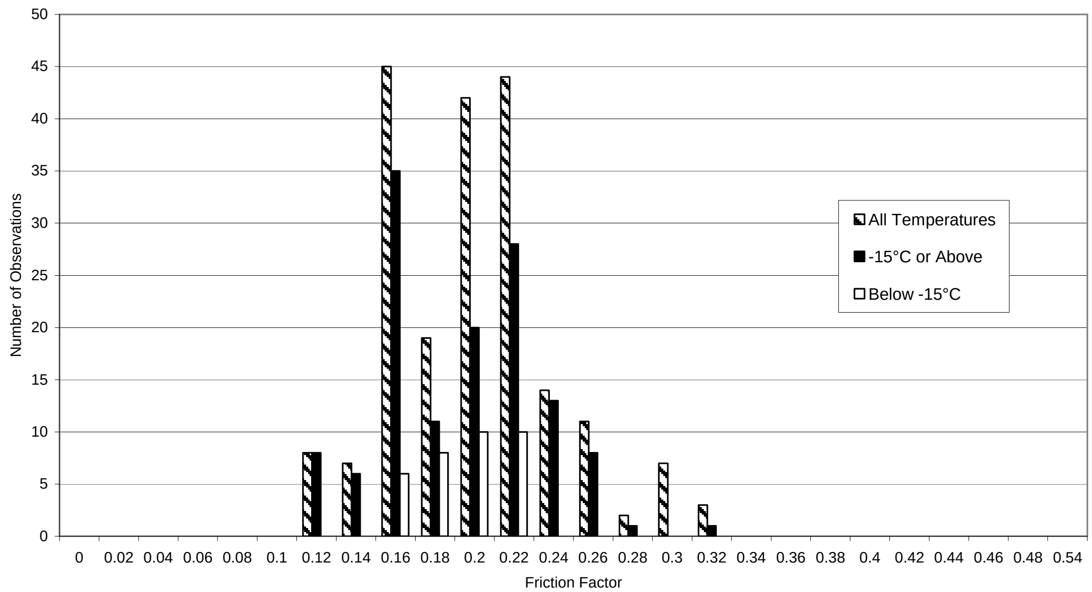

**B.1-2: TC SFT'79 (All Configurations) Readings on Bare Packed Snow: Effect of Temperature**



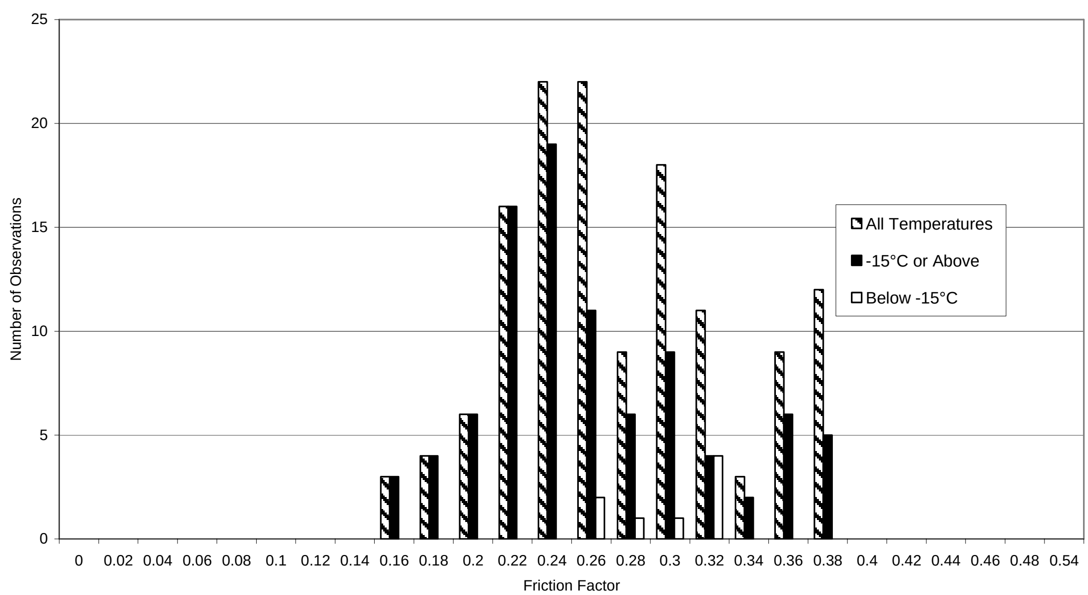

**B.1-3: TC SFT'79 (Configuration 3) Readings on Bare Packed Snow: Effect of Temperature**



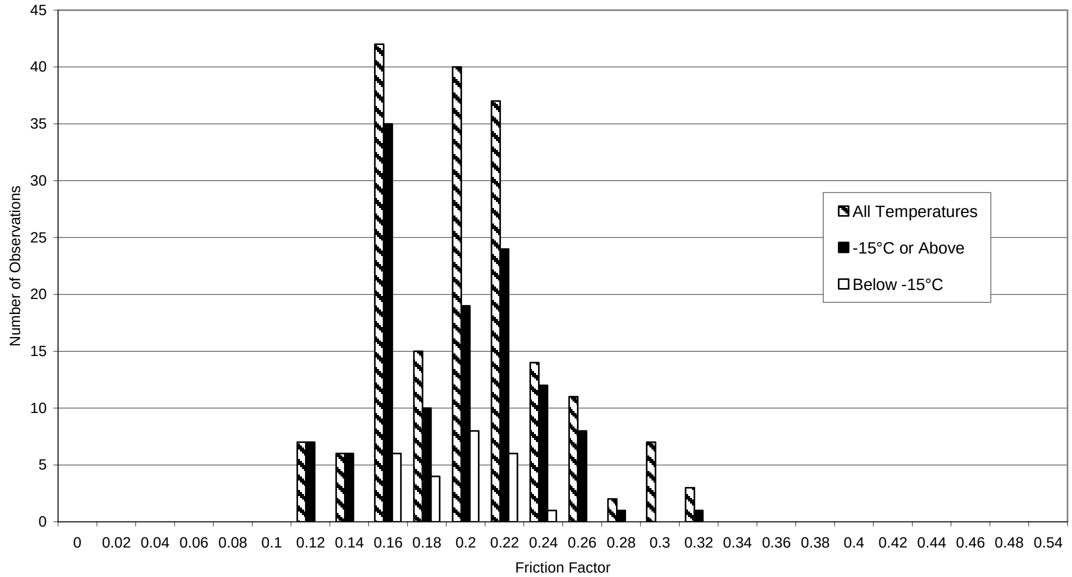

**B.1-4: IMAG Forces (All Configurations) Readings on Bare Packed Snow: Effect of Temperature**




**B.1-5: IMAG Torque (All Configurations) Readings on Bare Packed Snow: Effect of Temperature**



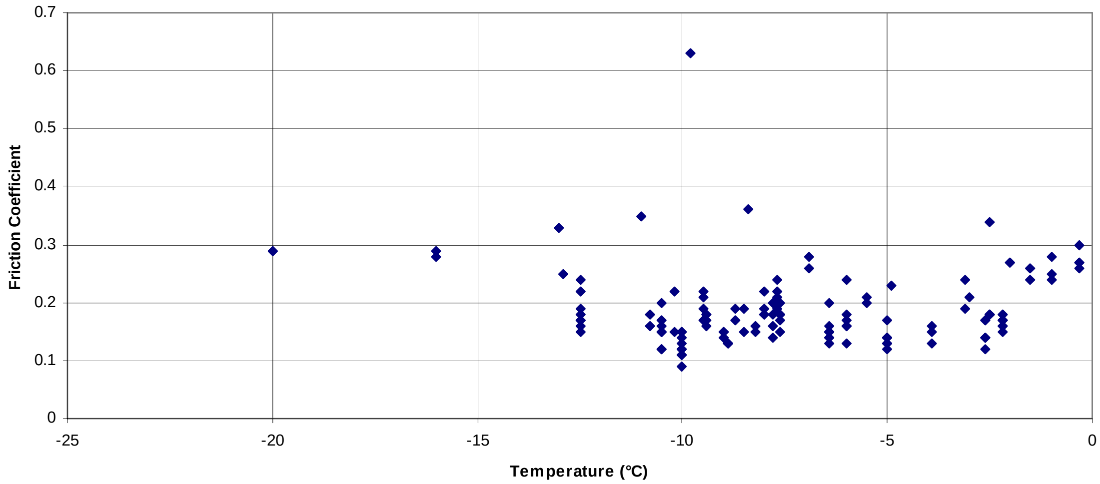

**B.1-6: IMAG Forces (Configurations 3 and 7) Readings on Bare Packed Snow: Effect of Temperature**



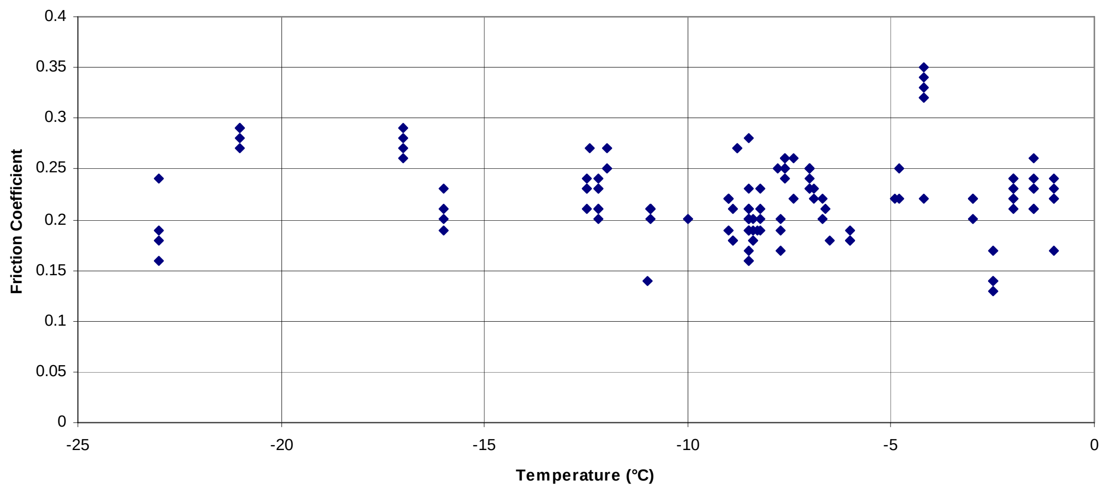

**B.1-7: IMAG Forces (Configurations 3 and 7) Readings on Bare Packed Snow: Effect of Temperature**

# APPENDIX B.2

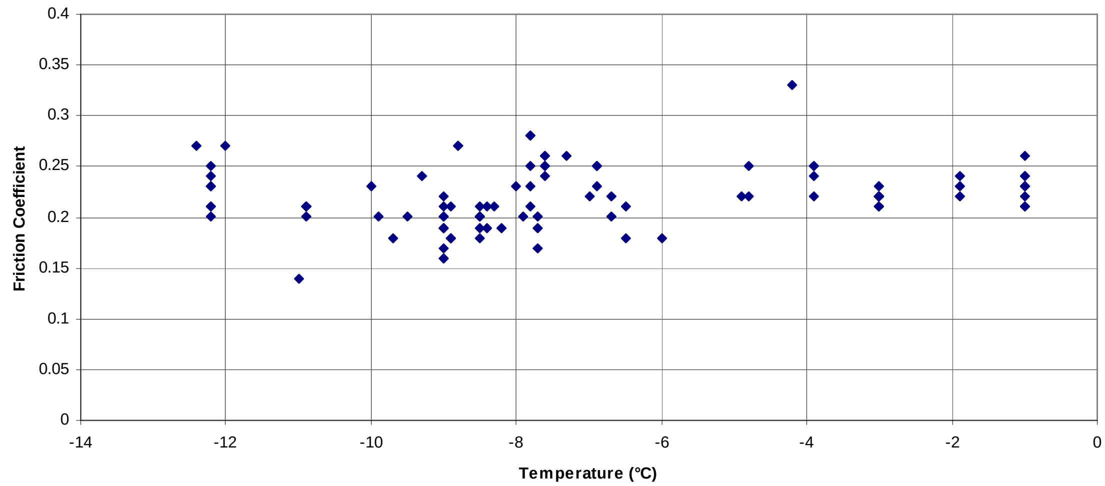
# TREND PLOTS VS. SURFACE TEMPERATURE



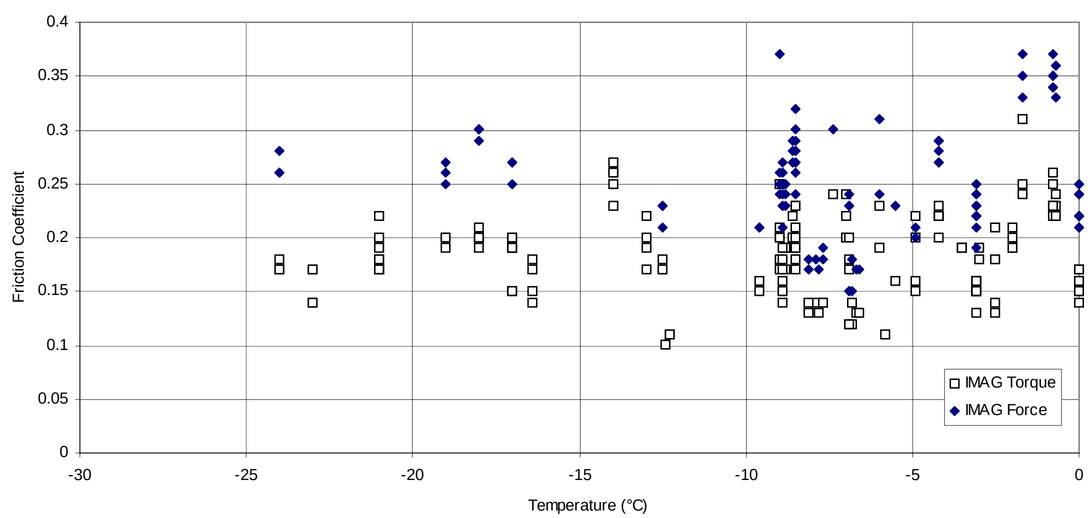

**B.2-1: Effect of Temperature: ERD Readings on Bare Packed Snow**



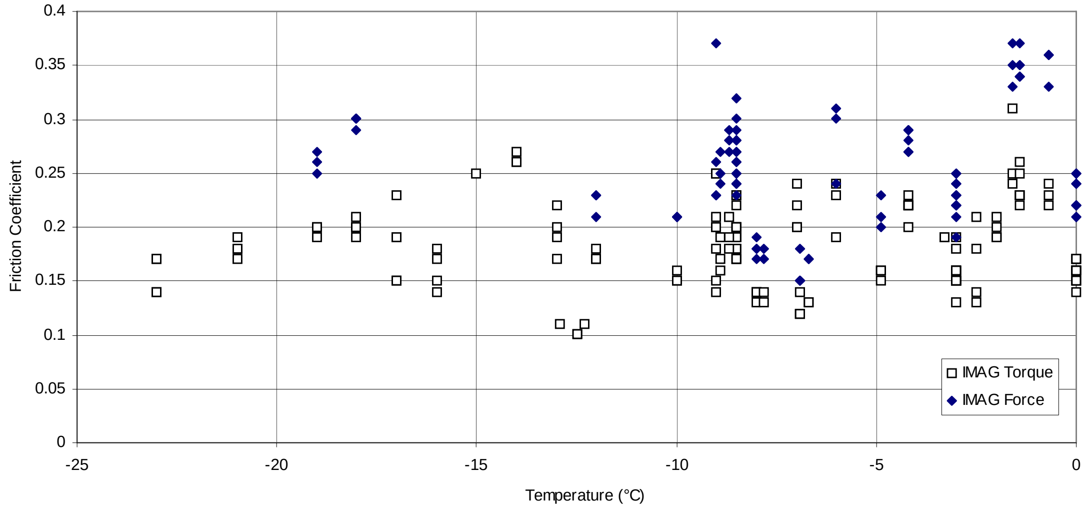

**B.2-2: Effect of Temperature: TC SFT'79 (All Configurations) Readings on Bare Packed Snow**




**B.2-3: Effect of Temperature: TC SFT'79 (Configuration 3) Readings on Bare Packed Snow**




**B.2-4: Effect of Temperature: IMAG (All Configurations) Readings on Bare Packed Snow**




**B.2-5: Effect of Temperature: IMAG (Configurations 3 and 7) Readings on Bare Packed Snow**

# APPENDIX C

# RESULTS FOR SANDED BARE ICE

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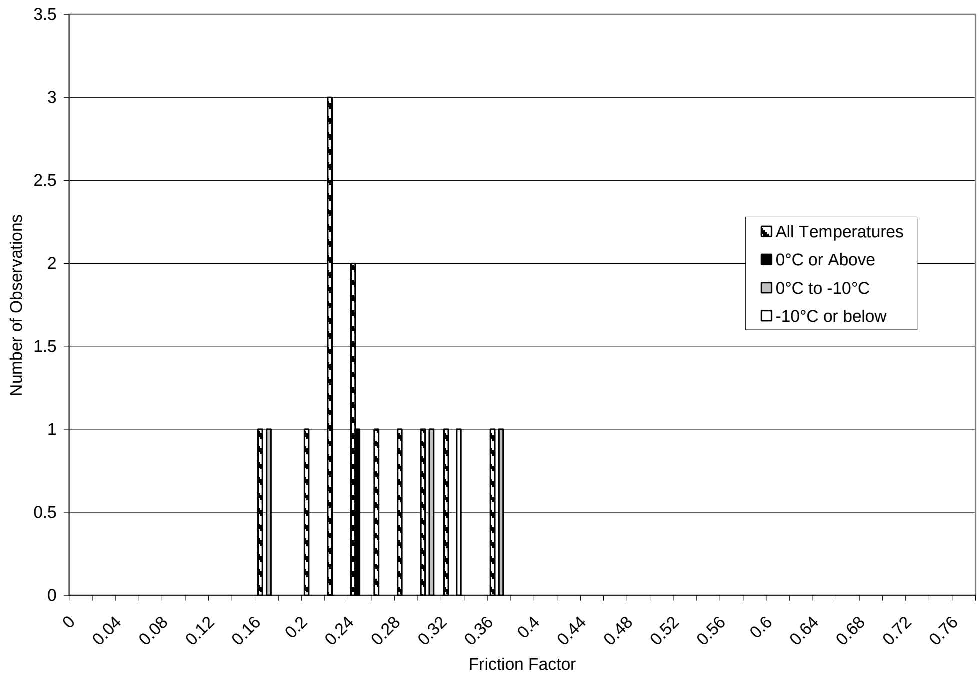
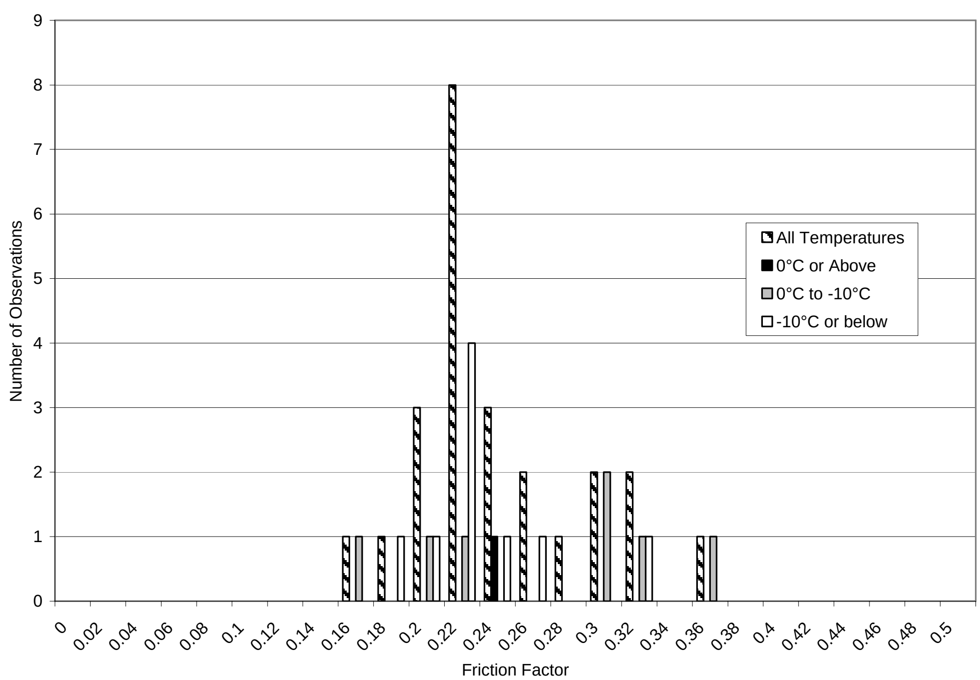
# APPENDIX C.1

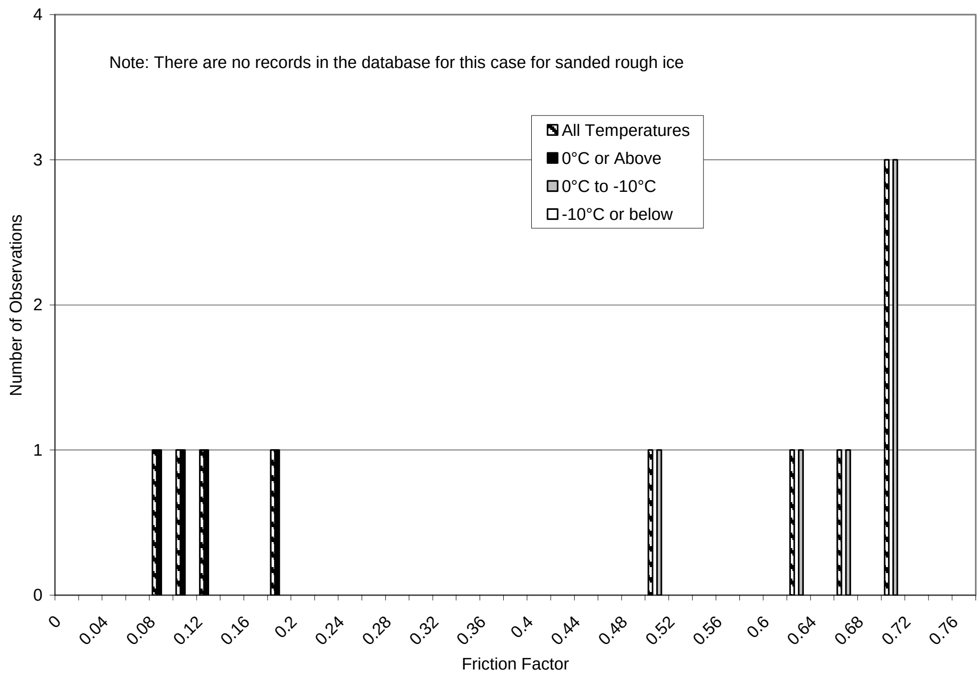
# HISTOGRAMS



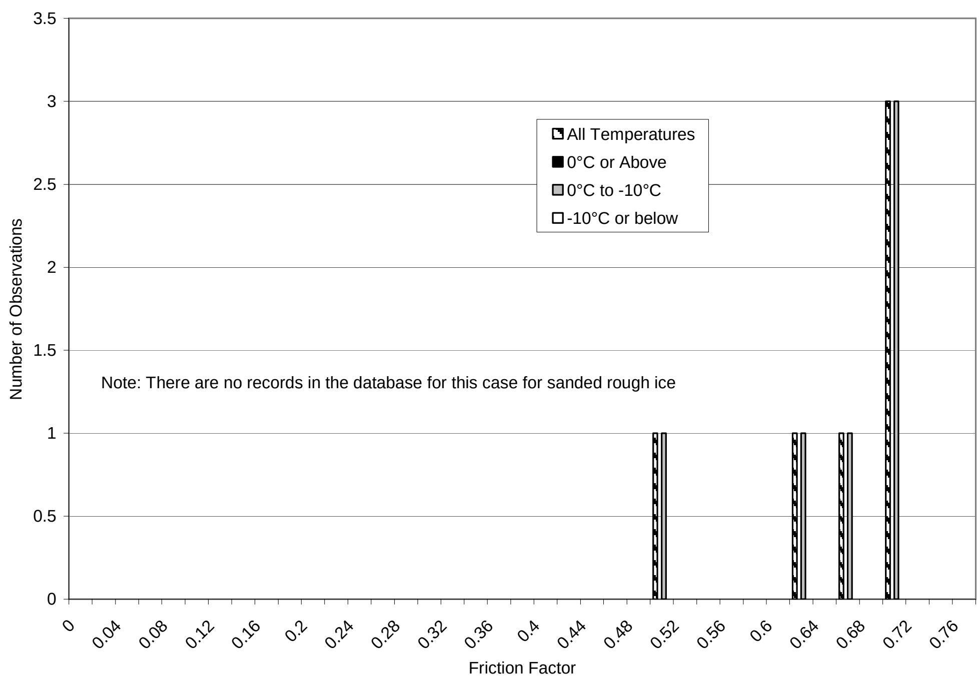

**C.1-1: ERD Readings on Bare Sanded Ice: Effect of Temperature**



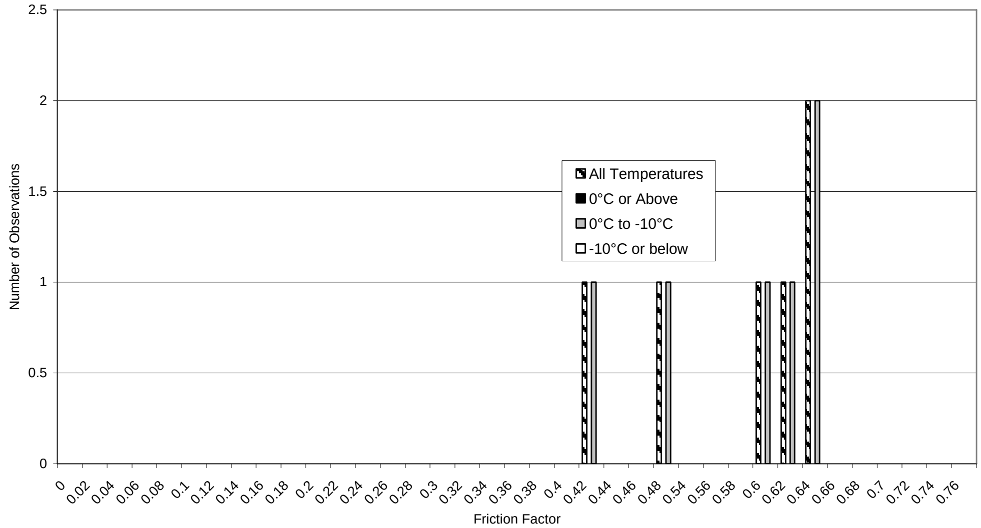

**C.1-2: ERD Readings on Sanded Bare Ice and Sanded Rough Ice: Effect of Temperature**



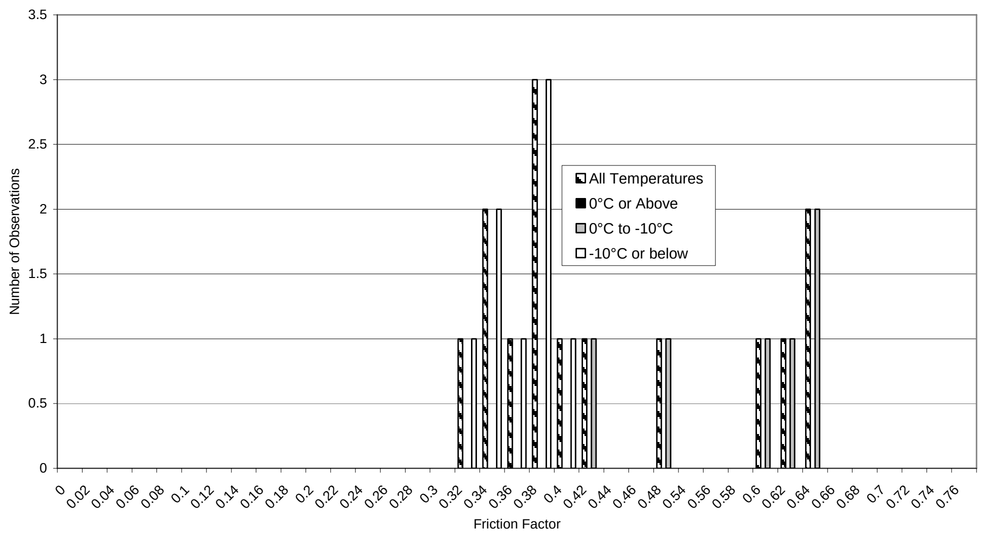

**C.1-3: TC SFT'79 (All Configurations) Readings on Bare Sanded Ice: Effect of Temperature**



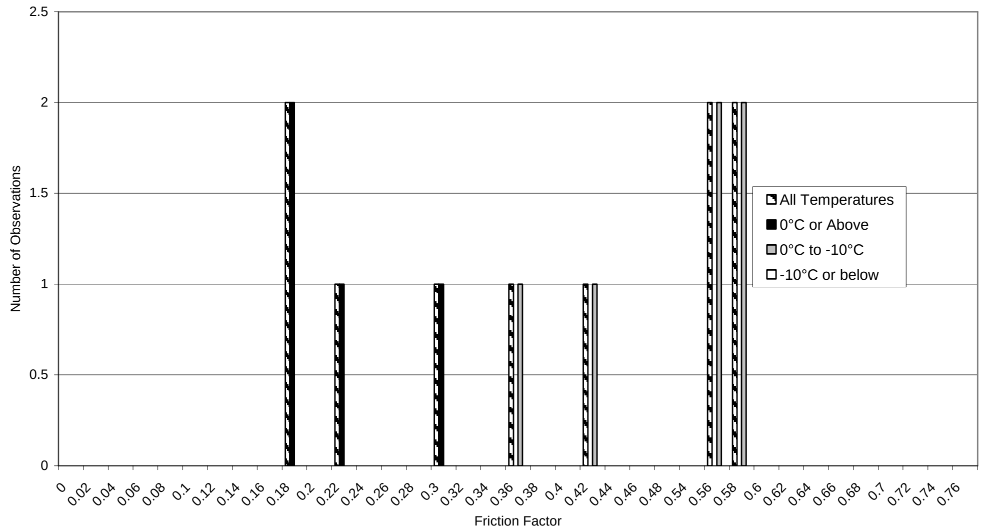

**C.1-4: TC SFT'79 (Configuration 3) Readings on Bare Sanded Ice: Effect of Temperature**



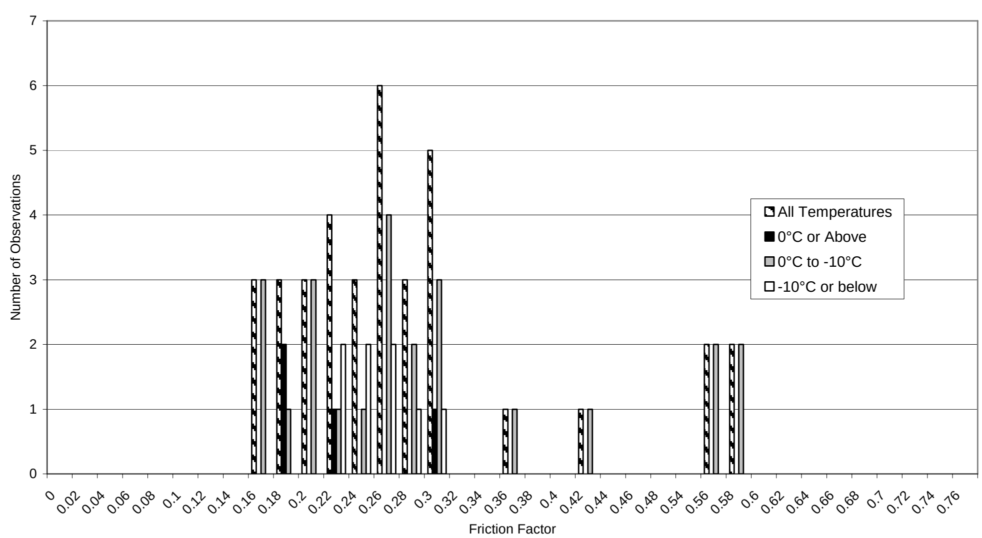

**C.1-5: IMAG Force (All Configurations) Readings on Bare Sanded Ice: Effect of Temperature**



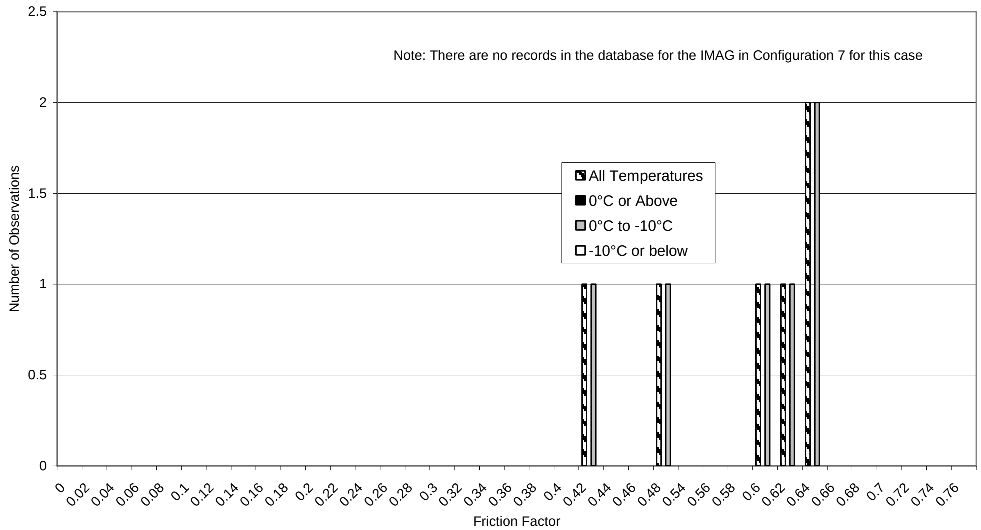

**C.1-6: IMAG Force (All Configurations) Readings on Bare Sanded Ice and Rough Ice: Effect of Temperature**



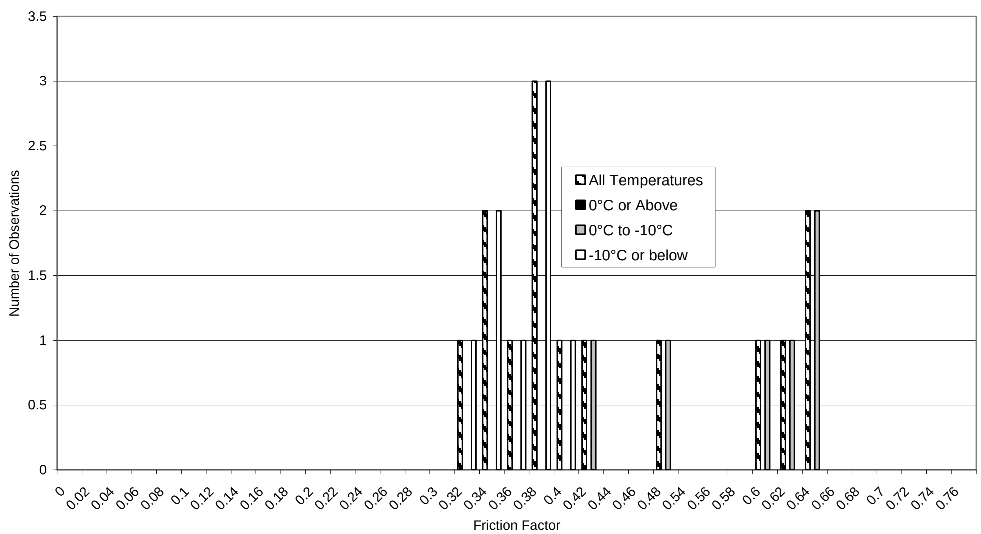

**C.1-7: IMAG Torque (All Configurations) Readings on Bare Sanded Ice: Effect of Temperature**



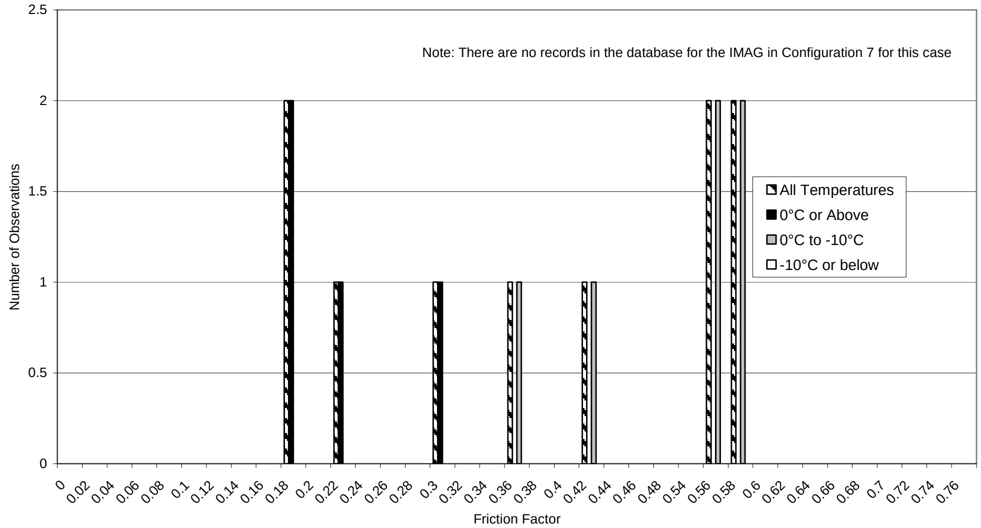

**C.1-8: IMAG Torque (All Configurations) Readings on Bare Sanded Ice and Rough Ice: Effect of Temperature**



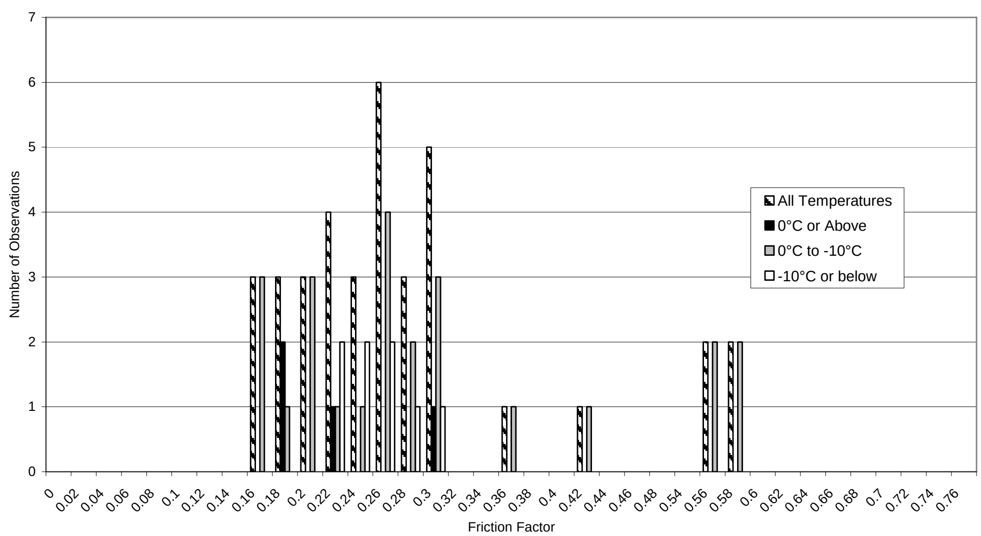

**C.1-9: IMAG Force (Configuration 3) Readings on Bare Sanded Ice: Effect of Temperature**




**C.1-10: IMAG Force (Configuration 3) Readings on Bare Sanded Ice and Rough Ice: Effect of Temperature**




**C.1-11: IMAG Torque (Configuration 3) Readings on Bare Sanded Ice: Effect of Temperature**




**C.1-12: IMAG Torque (Configuration 3) Readings on Bare Sanded Ice and Rough Ice: Effect of Temperature**

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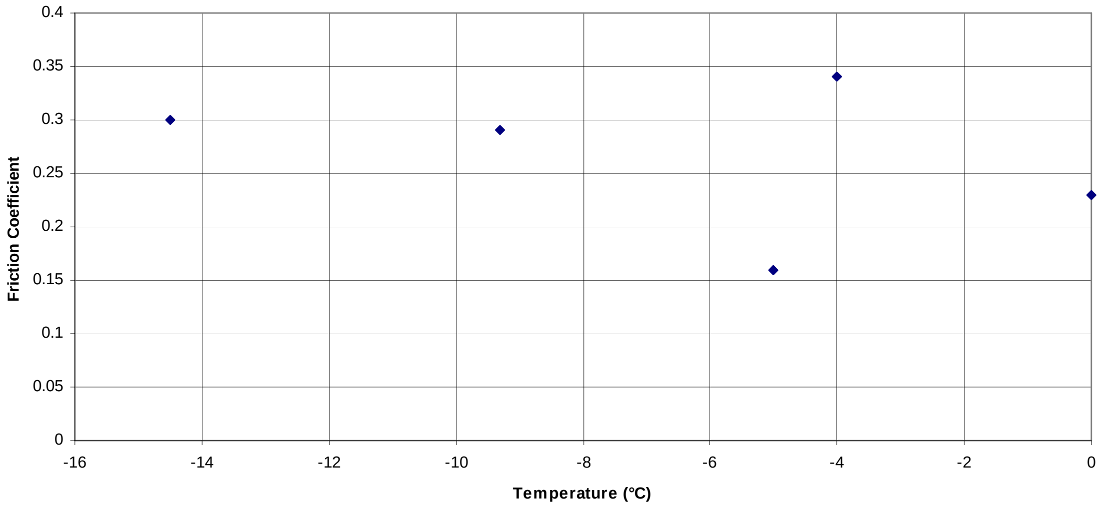
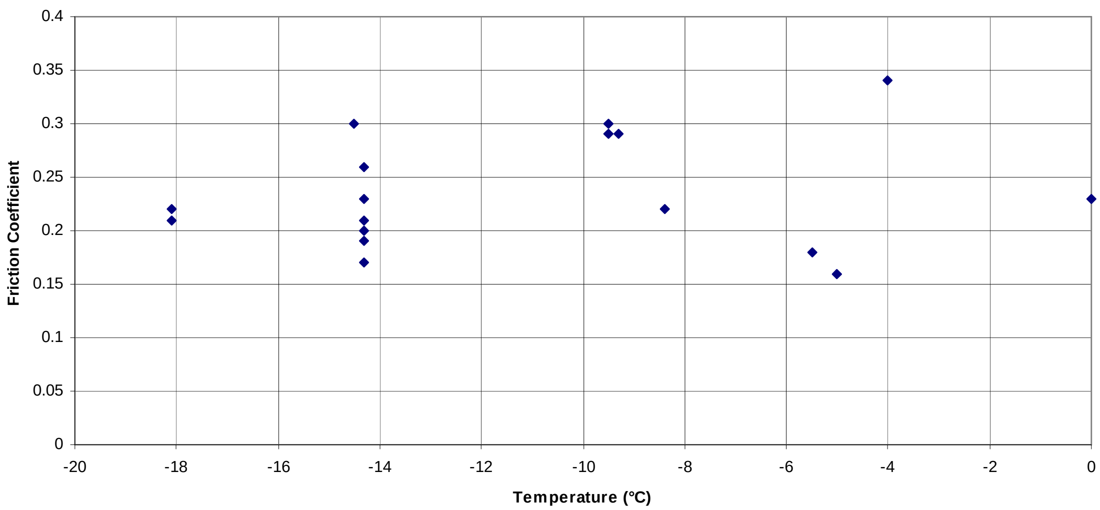
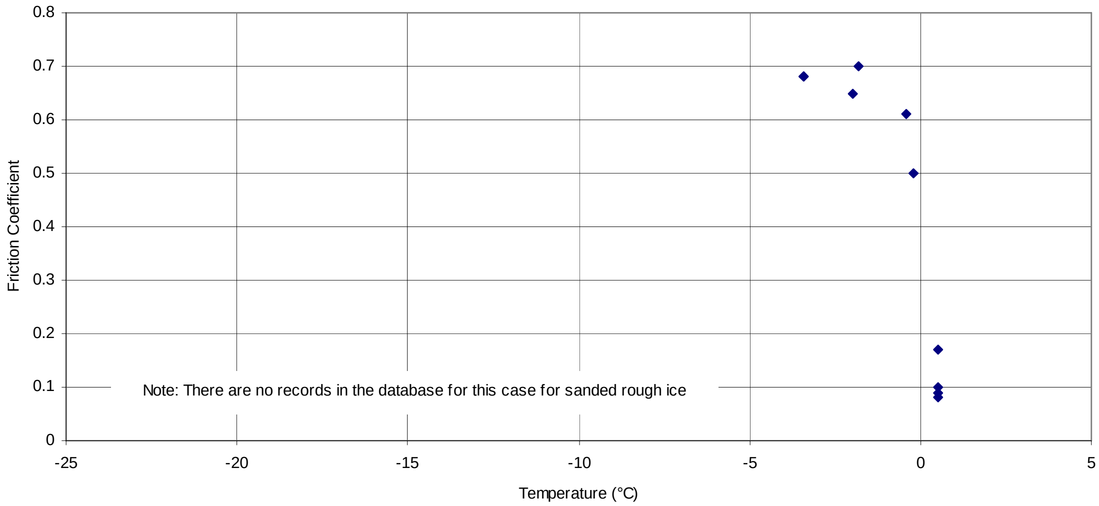


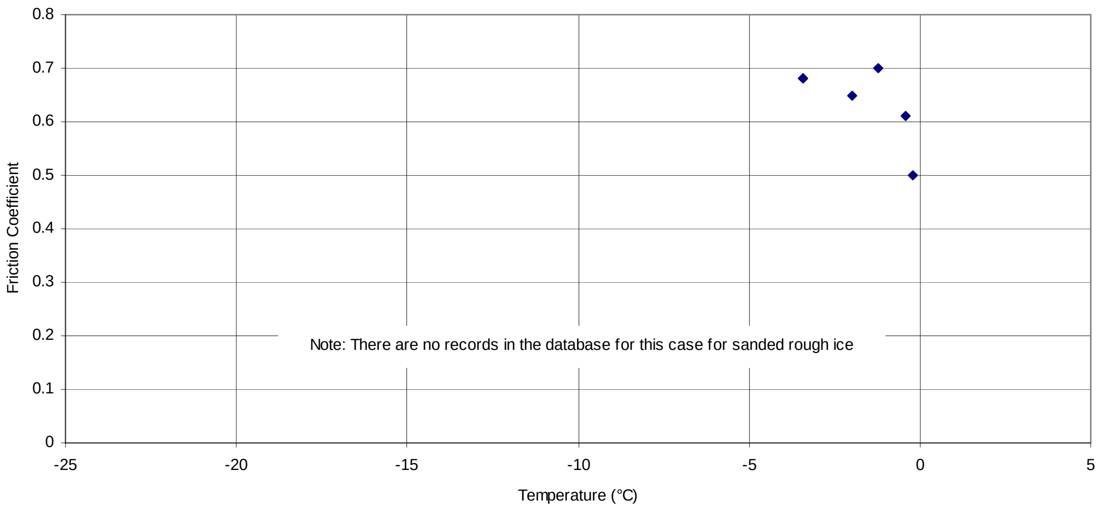

**C.2-1: Effect of Temperature: ERD Readings on Bare Sanded Ice**



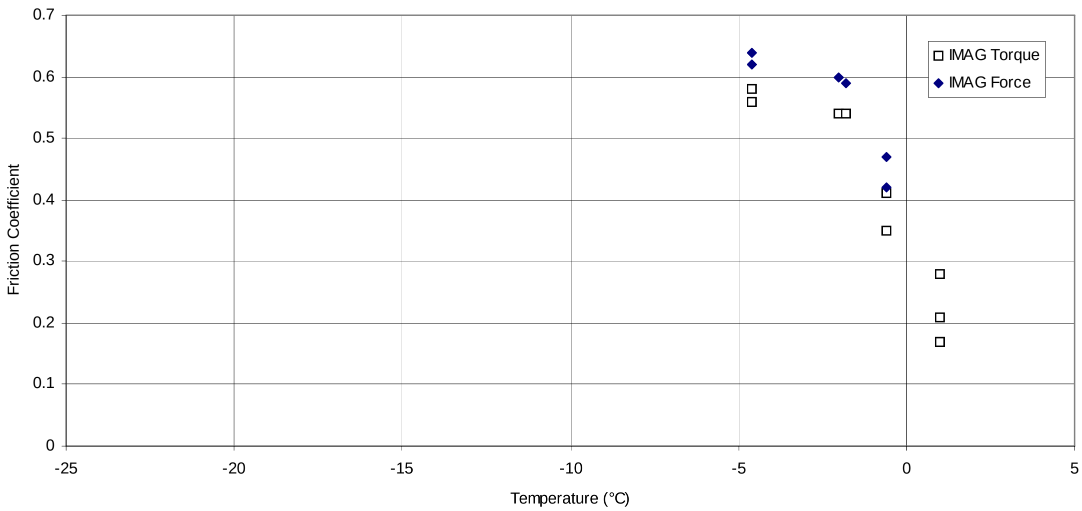

**C.2-2: Effect of Temperature: ERD Readings on Bare Sanded Ice and Sanded Rough Ice**



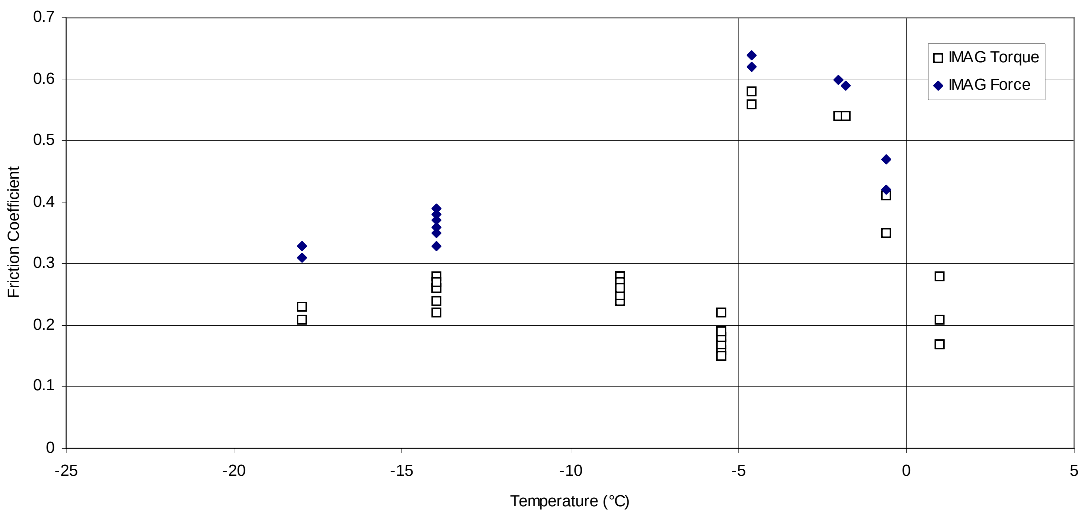

**C.2-3: Effect of Temperature: TC SFT'79 (All Configurations) Readings on Bare Sanded Ice**



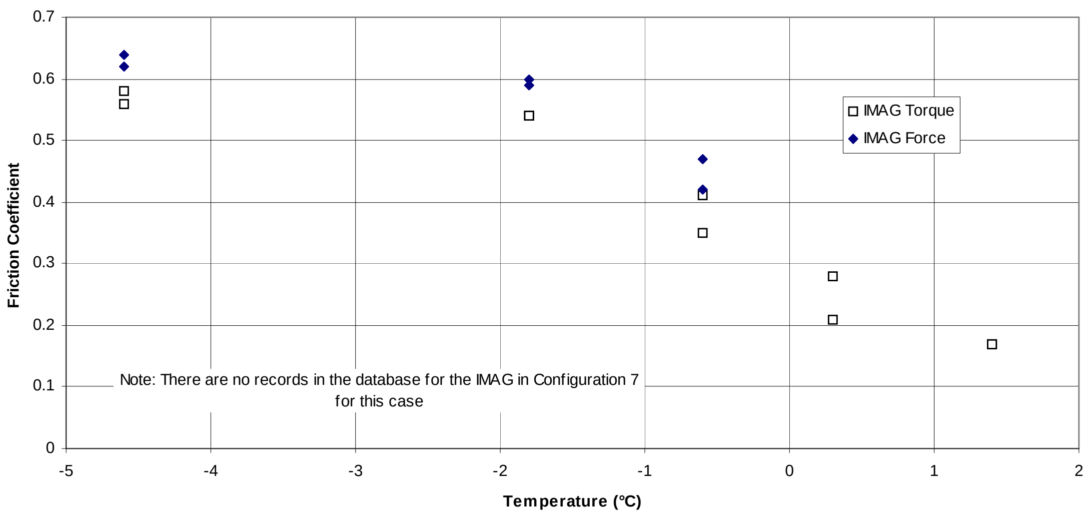

**C.2-4: Effect of Temperature: TC SFT'79 (Configuration 3) Readings on Bare Sanded Ice**



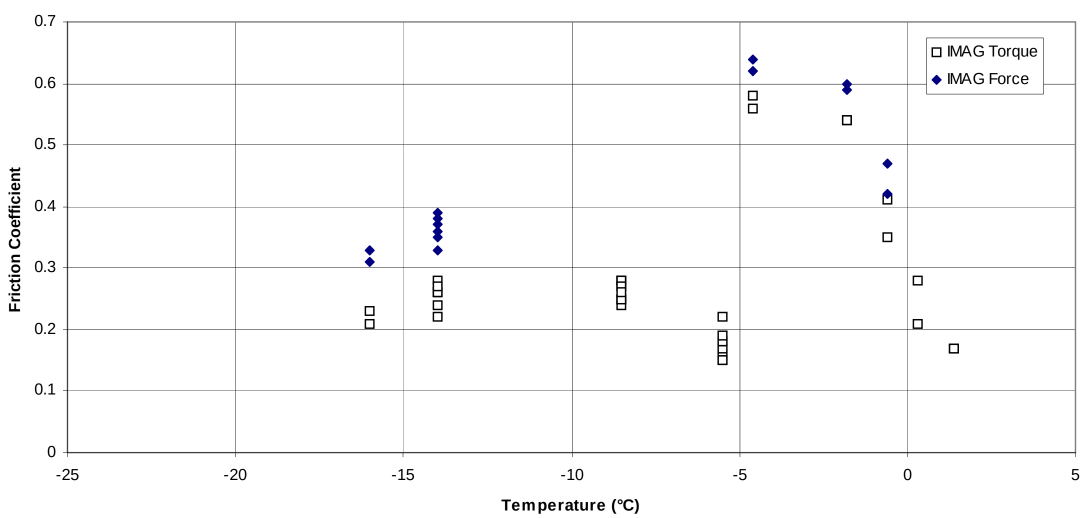

**C.2-5: Effect of Temperature: IMAG (All Configurations) Readings on Bare Sanded Ice**




**C.2-6: Effect of Temperature: IMAG (All Configurations) Readings on Bare Sanded Ice and Rough Ice**




**C.2-7: Effect of Temperature: IMAG (Configuration 3) Readings on Bare Sanded Ice**




**C.2-8: Effect of Temperature: IMAG (Configurations 3 and 7) Readings on Bare Sanded Ice and Rough Ice**

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# RESULTS FOR SNOW ON PAVEMENT

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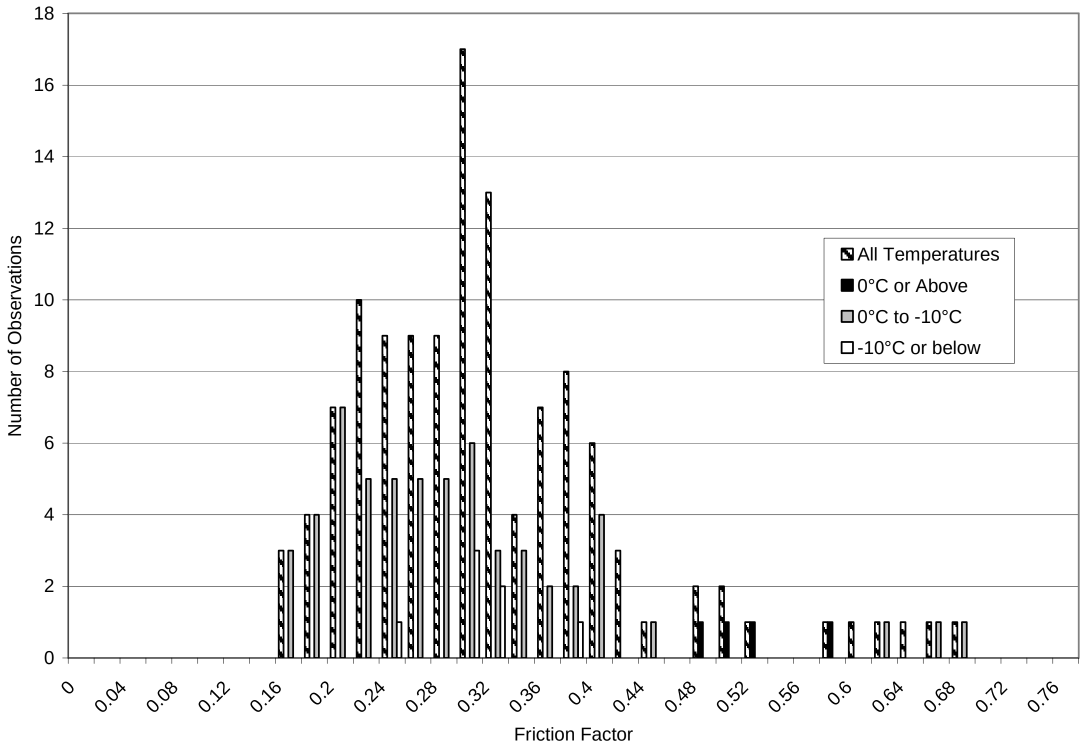
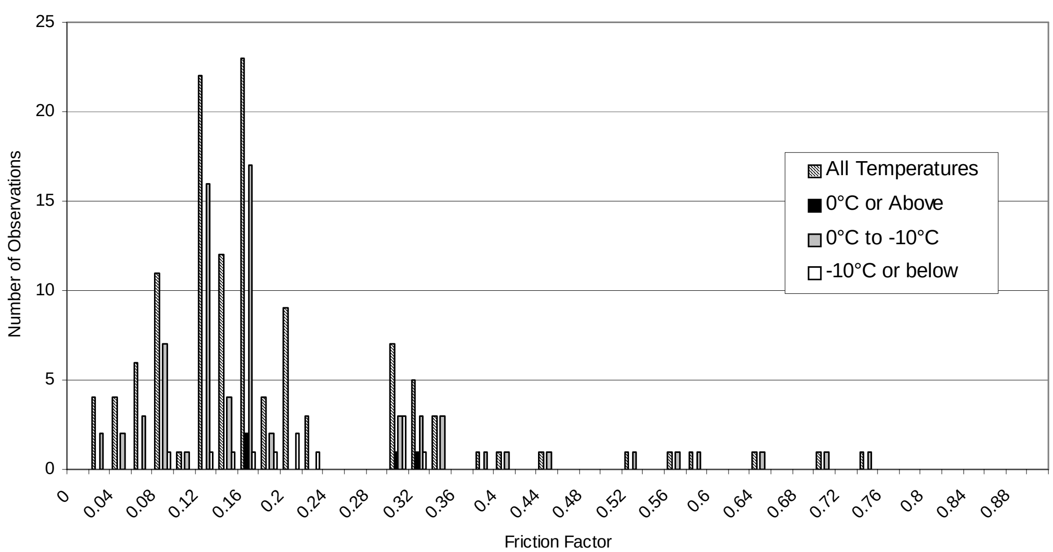
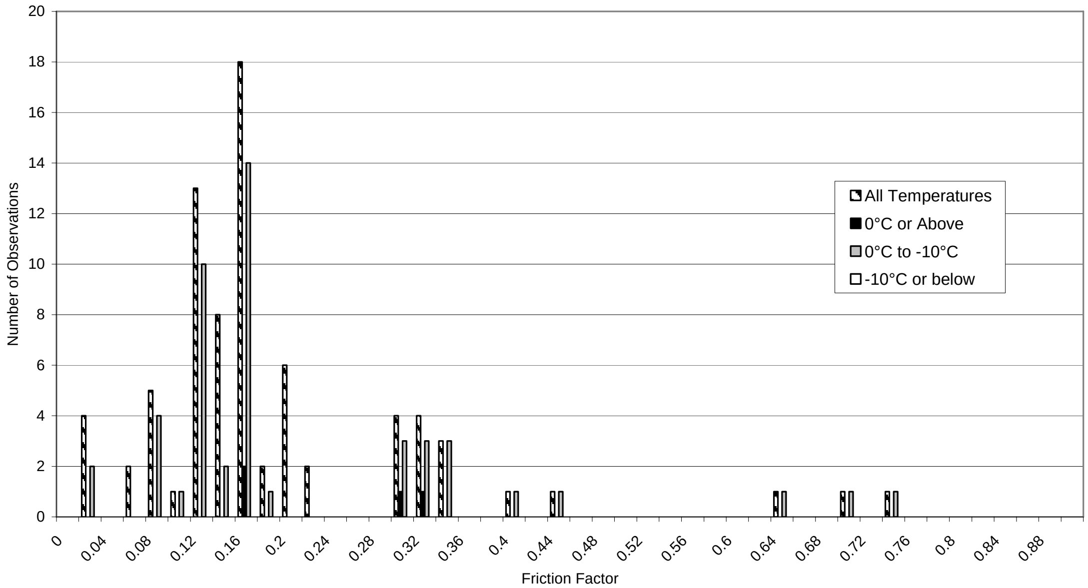


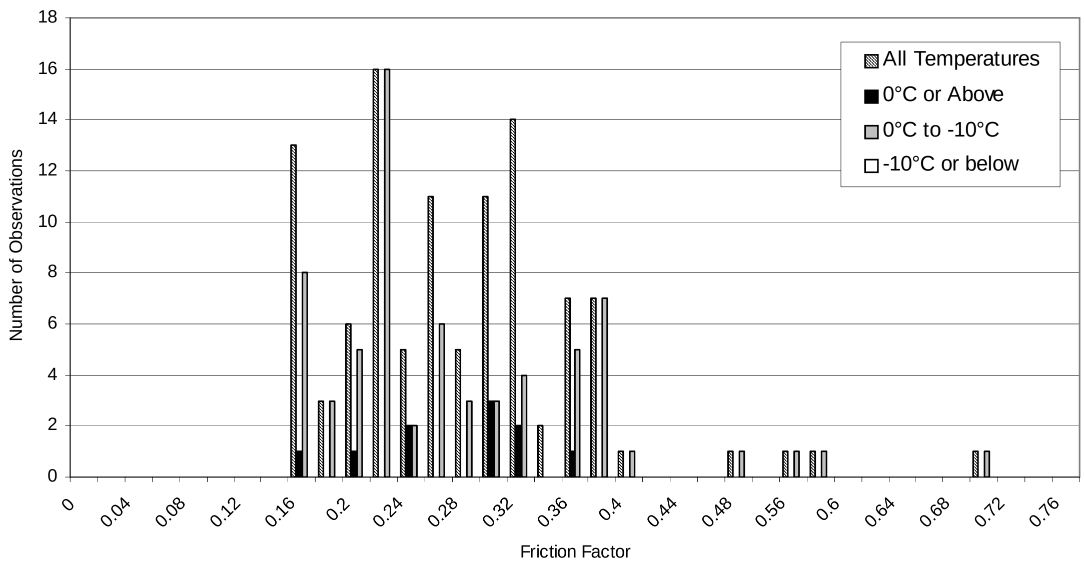

**D.1-1: ERD Readings for Snow on Pavement: Effect of Temperature**



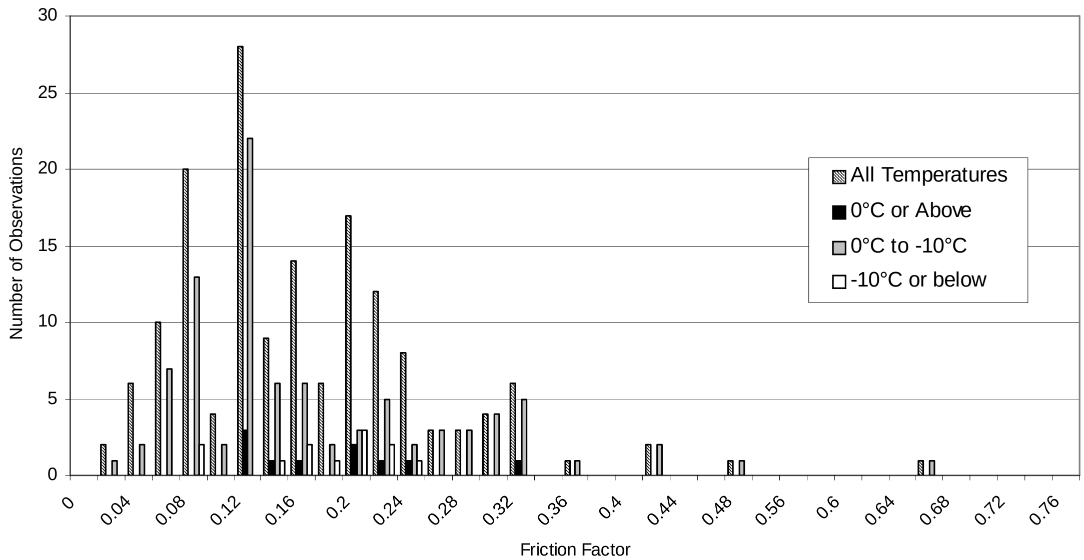

**D.1-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Temperature**



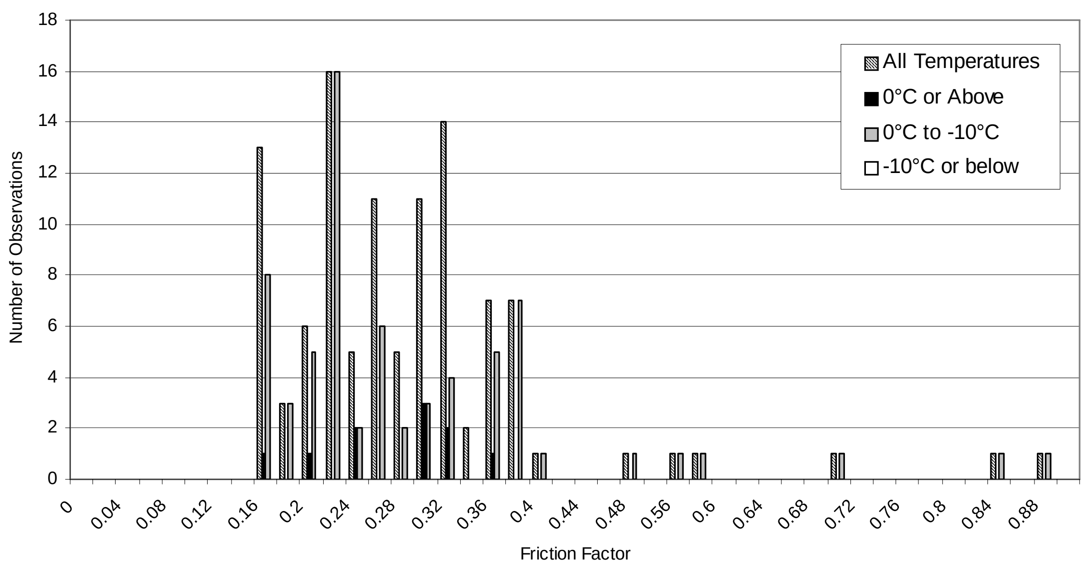

**D.1-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Temperature**



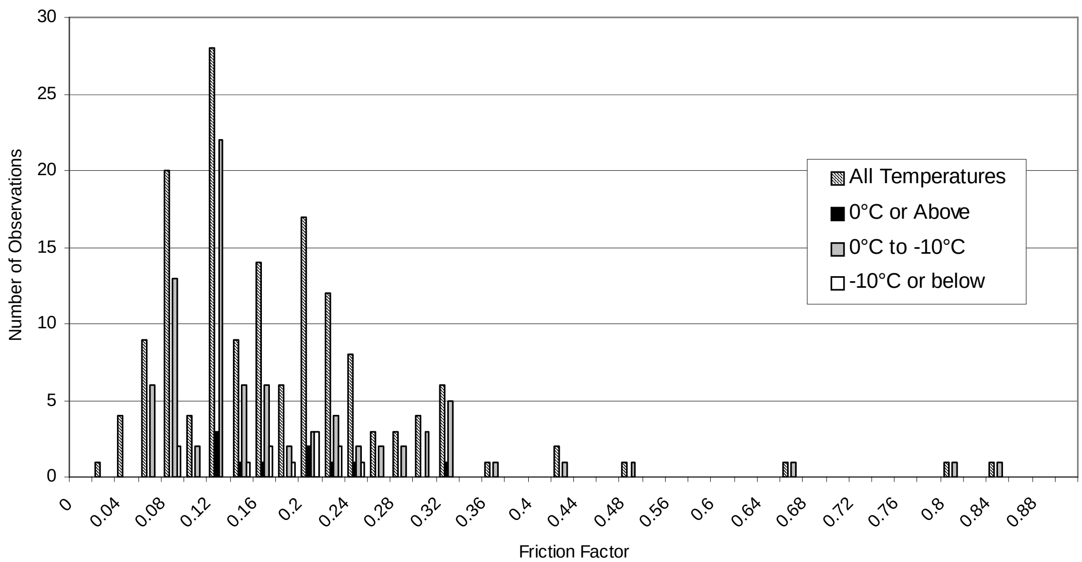

**D.1-4: IMAG Force (All Configurations) Readings for Snow on Pavement: Effect of Temperature**




**D.1-5: IMAG Torque (All Configurations) Readings for Snow on Pavement: Effect of Temperature**



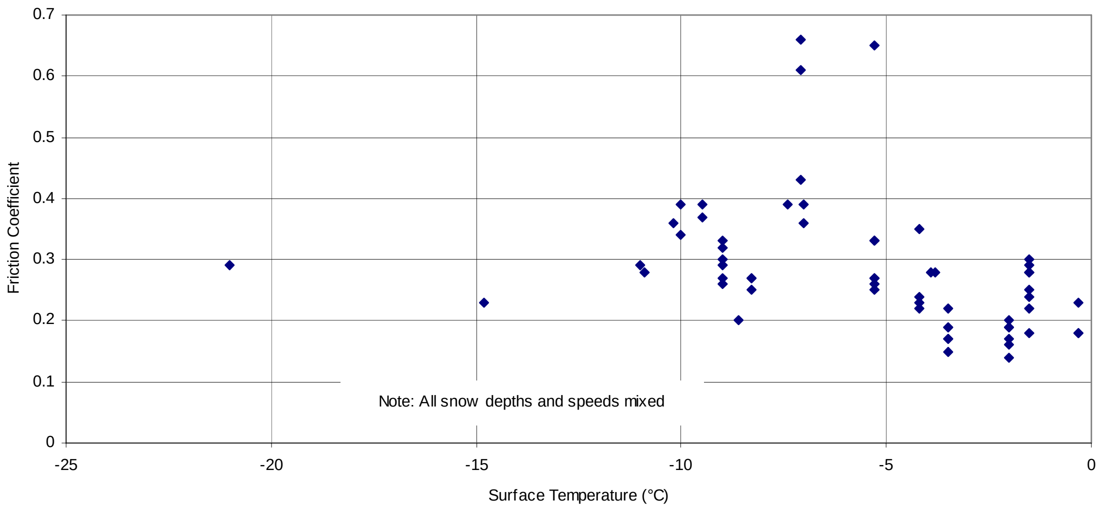

**D.1-6: IMAG Force (Configurations 3 and 7) Readings for Snow on Pavement: Effect of Temperature**



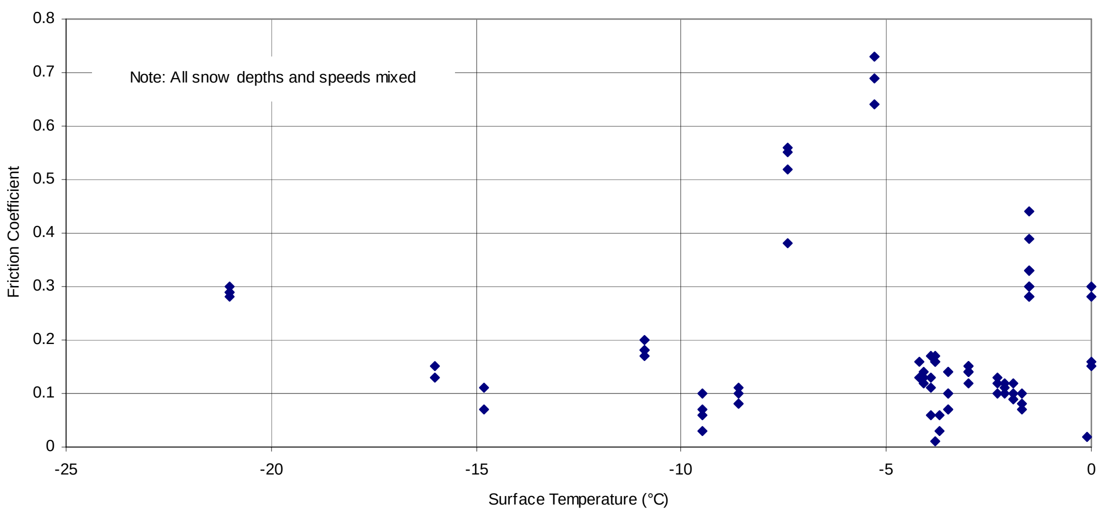

**D.1-7: IMAG Torque (Configurations 3 and 7) Readings for Snow on Pavement: Effect of Temperature**

# APPENDIX D.2

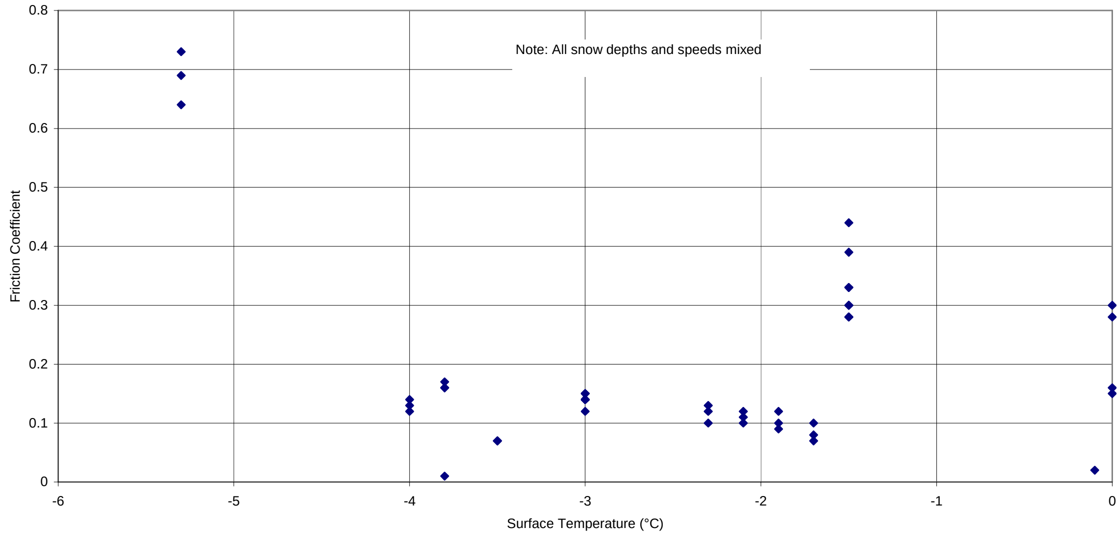
# TREND PLOTS VS. SURFACE TEMPERATURE
(ALL SNOW DEPTHS)



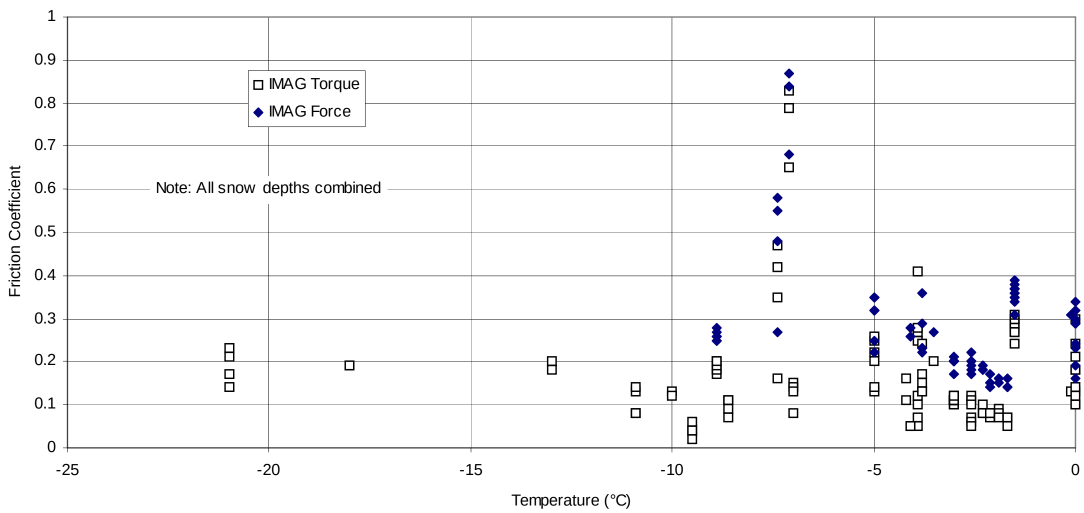

**D.2-1: ERD Readings for Snow on Pavement: Effect of Surface Temperature**



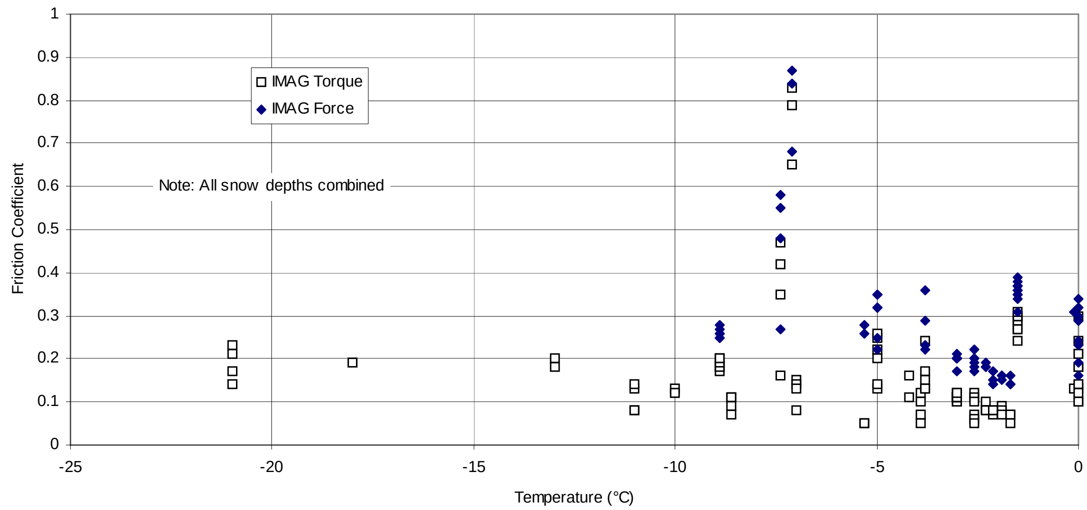

**D.2-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Surface Temperature**




**D.2-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Surface Temperature**



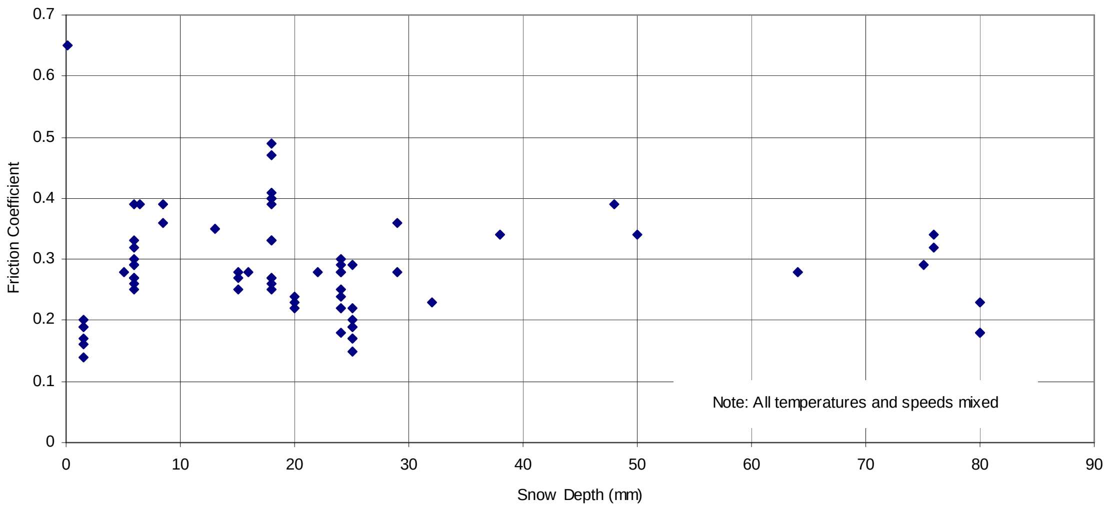

**D.2-4: Effects of Temperature: IMAG (All Configurations) Readings for Snow on Pavement**



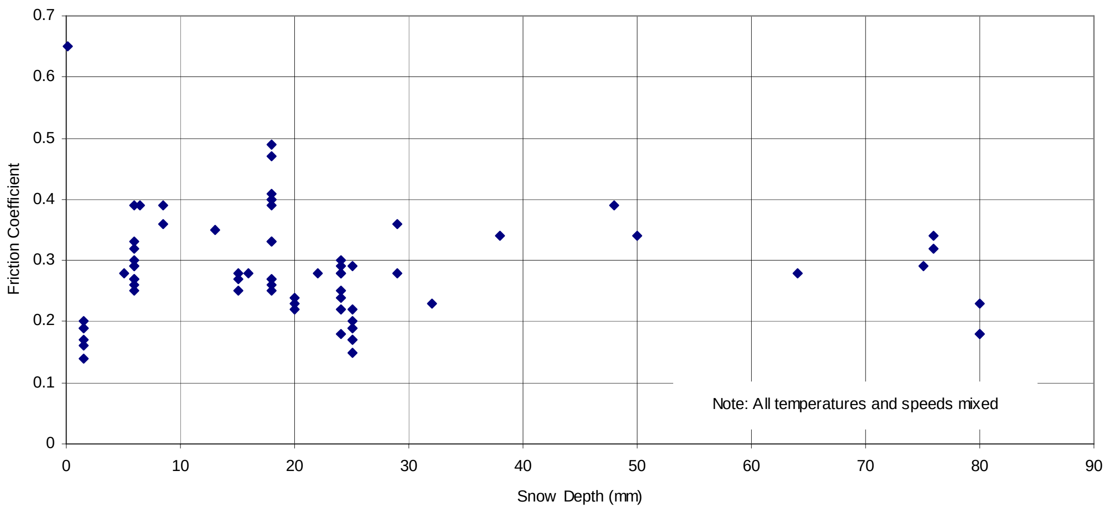

**D.2-5: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Pavement**

# APPENDIX D.3

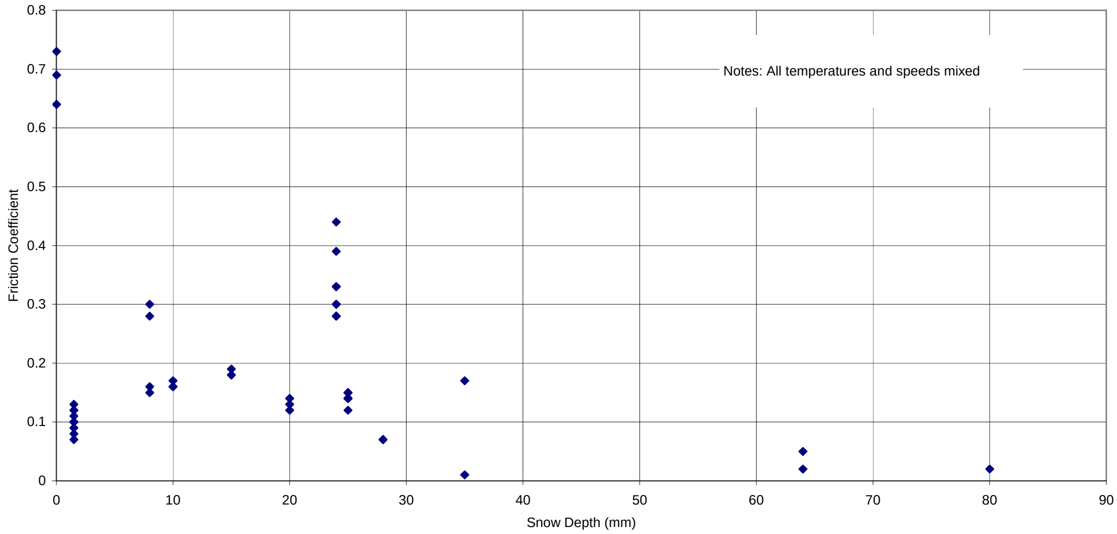
# TREND PLOTS VS. SNOW DEPTH
# (ALL SNOW DEPTHS)



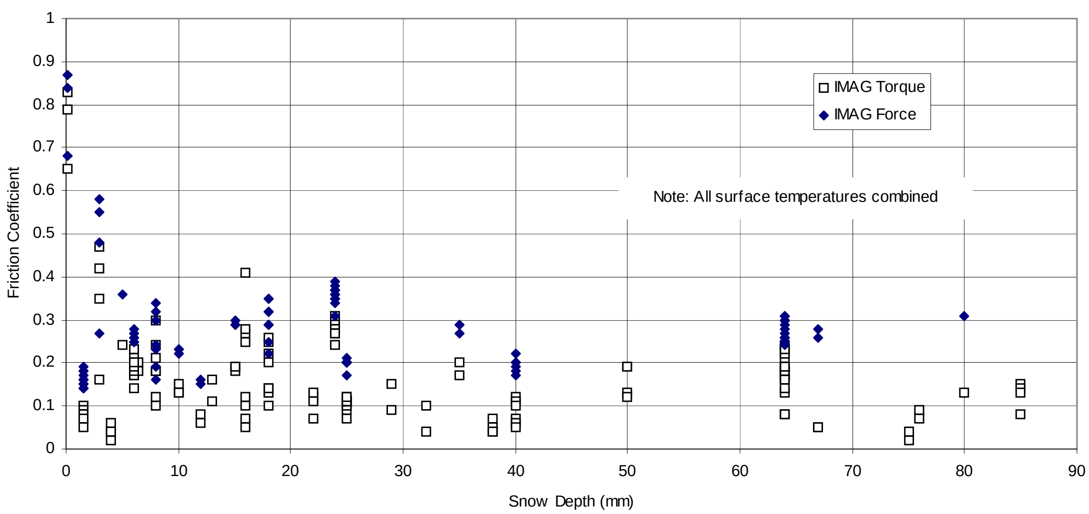

**D.3-1: ERD Readings for Snow on Pavement: Effect of Snow Depth**



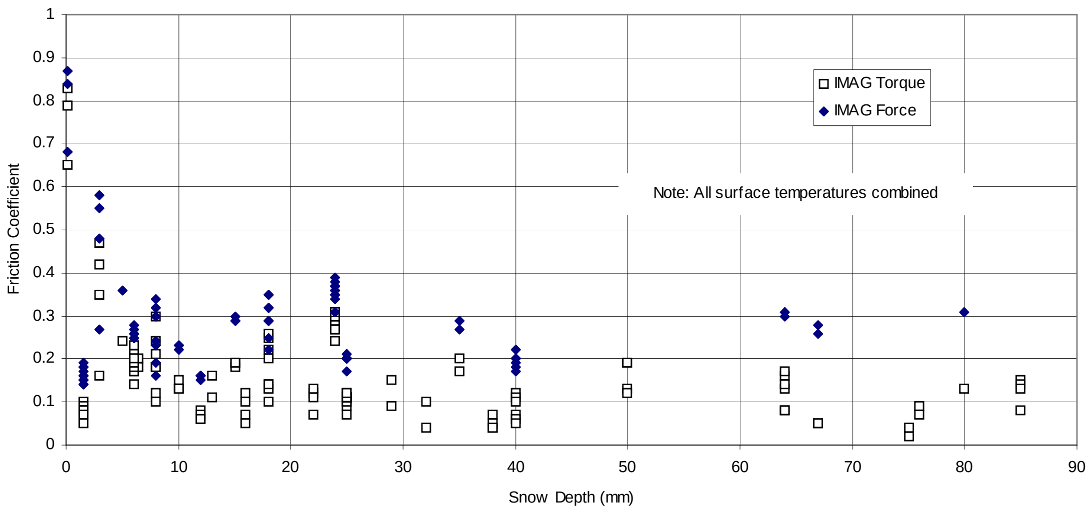

**D.3-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Snow Depth**




**D.3-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Snow Depth**



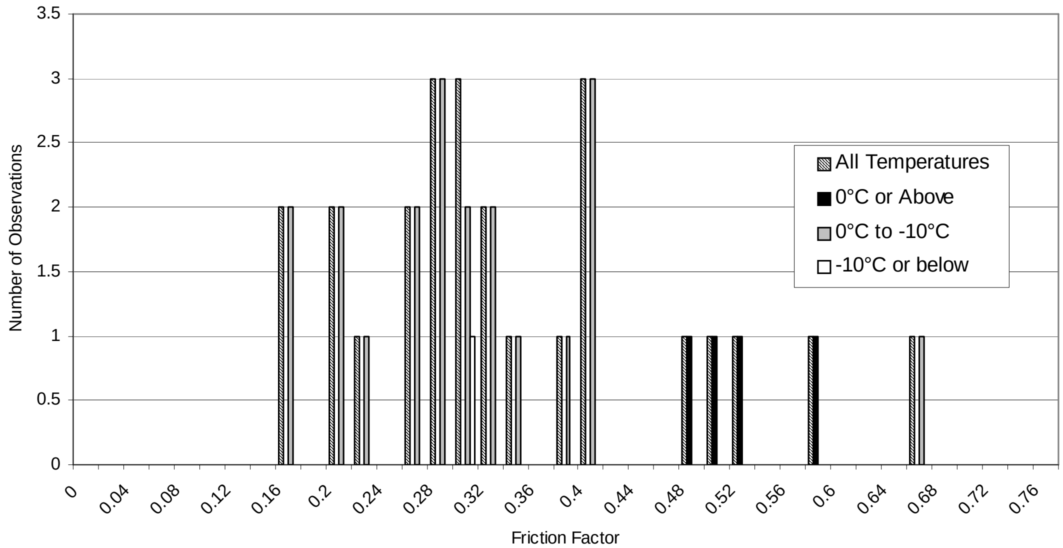

**D.3-4: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Pavement**



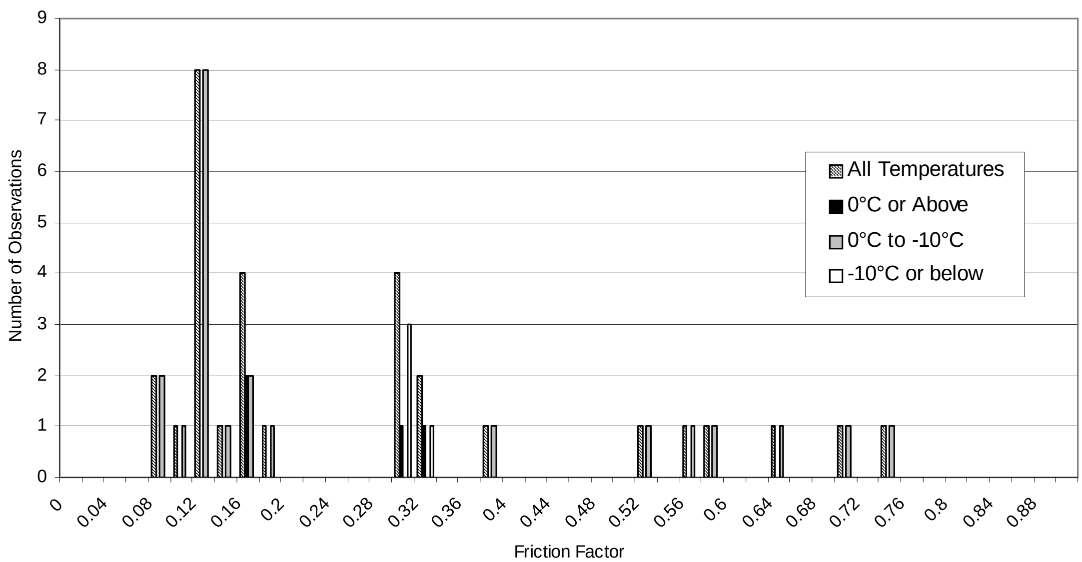

**D.3-5: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Pavement**

# APPENDIX D.4

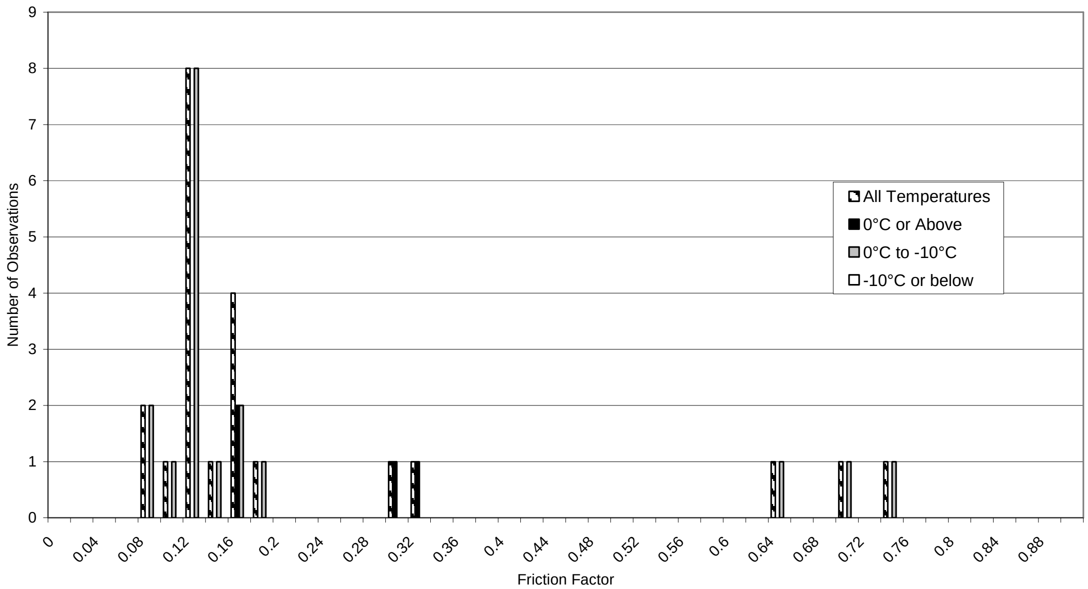
# HISTOGRAMS FOR SNOW ON PAVEMENT
(SNOW DEPTHS 10 MM OR LESS)



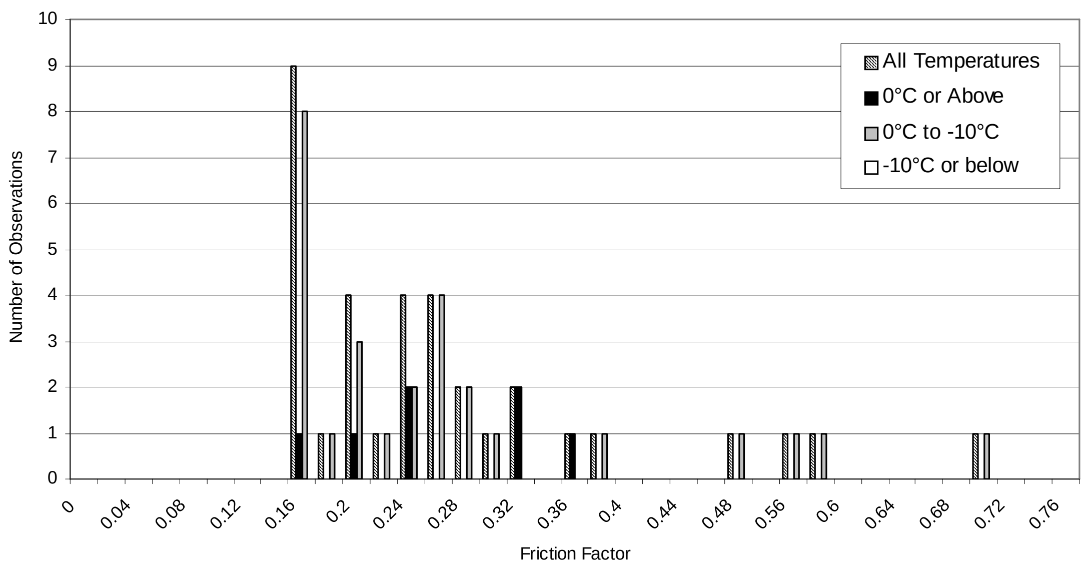

**D.4-1: ERD Readings for Snow on Pavement: Effect of Temperature**



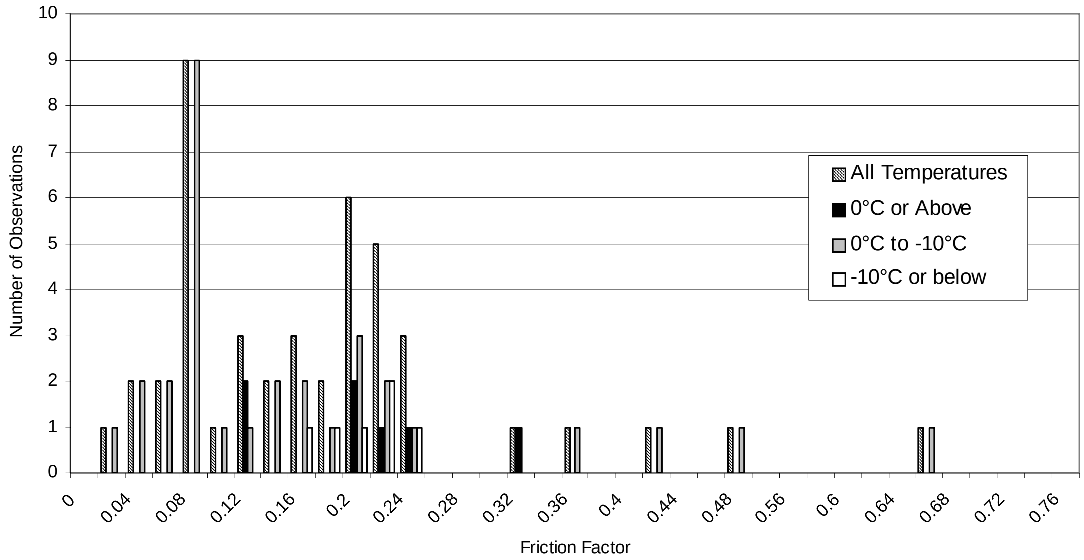

**D.4-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Temperature**



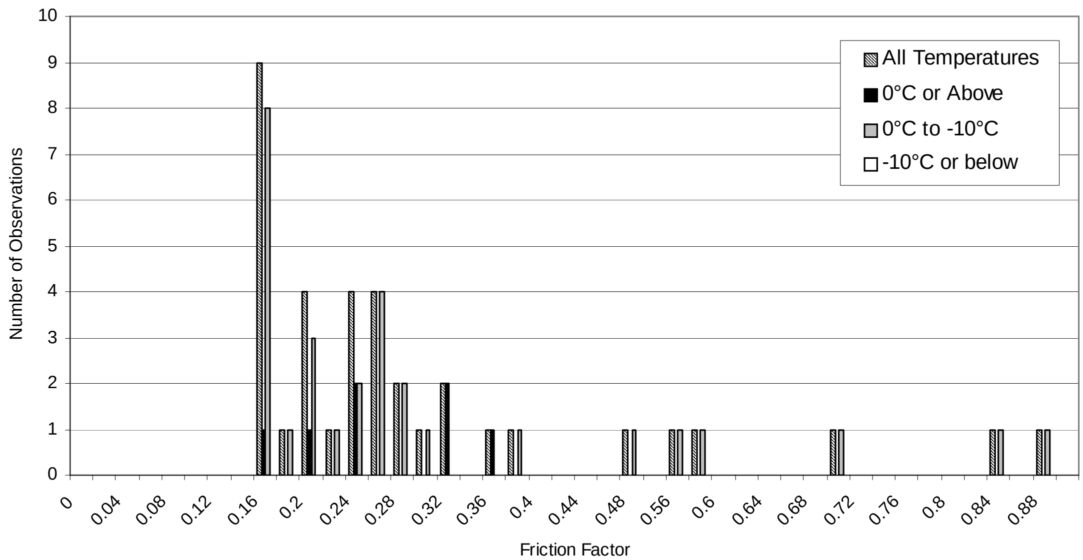

**D.4-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Temperature**



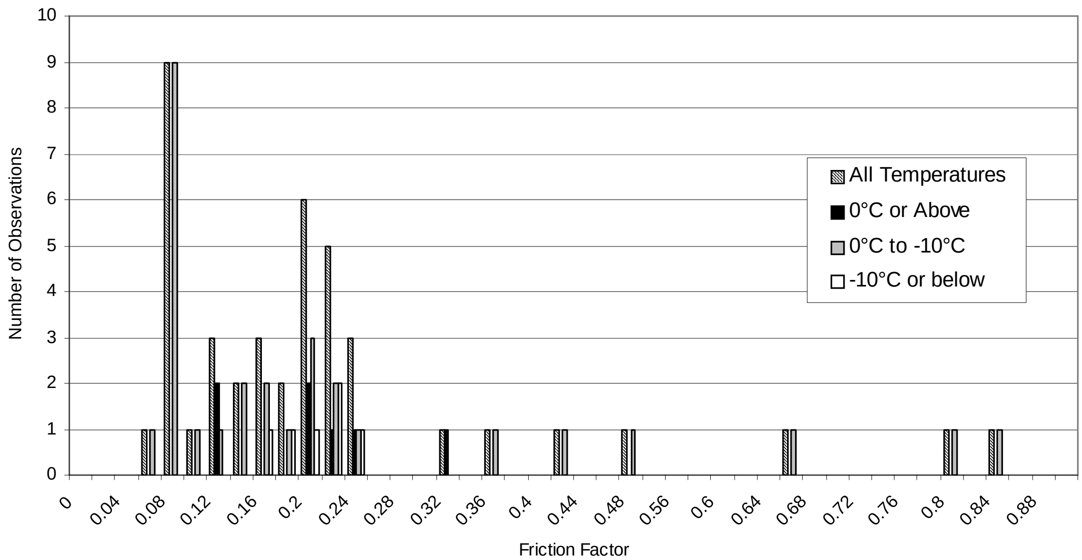

**D.4-4: IMAG Force (All Configurations) Readings for Snow on Pavement: Effect of Temperature**




**D.4-5: IMAG Torque (All Configurations) Readings for Snow on Pavement: Effect of Temperature**



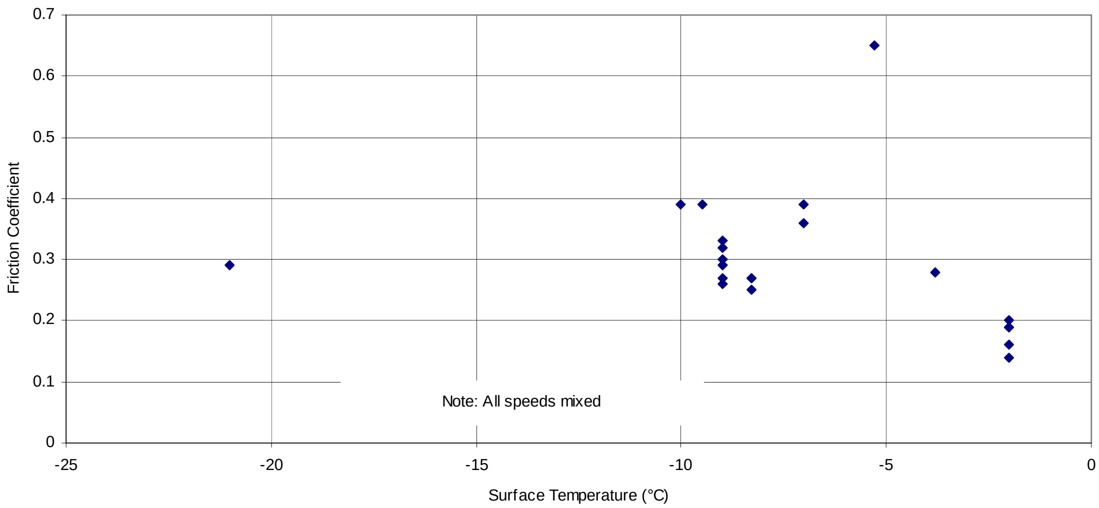

**D.4-6: IMAG Force (Configurations 3 and 7) Readings for Snow on Pavement: Effect of Temperature**



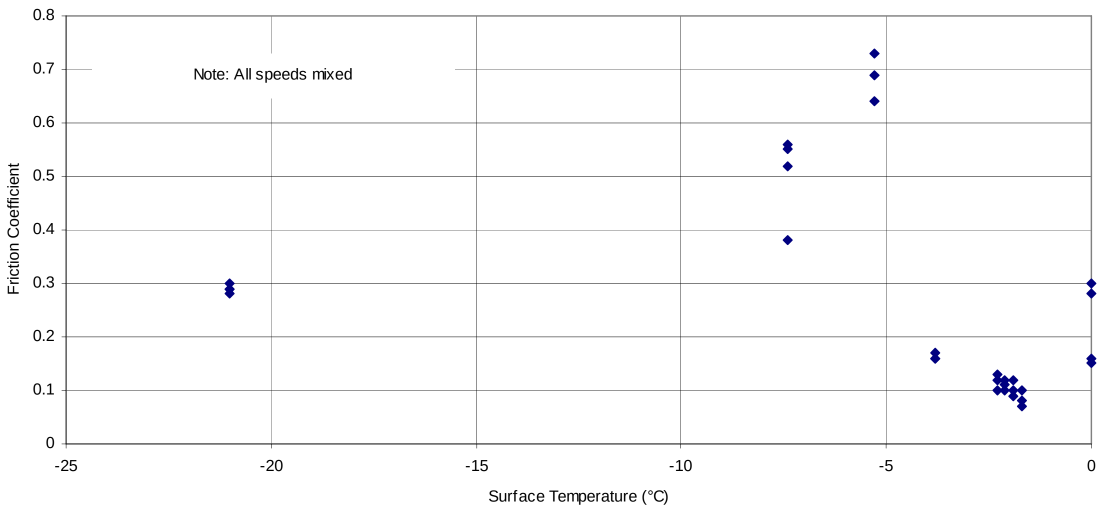

**D.4-7: IMAG Torque (Configurations 3 and 7) Readings for Snow on Pavement: Effect of Temperature**

# APPENDIX D.5

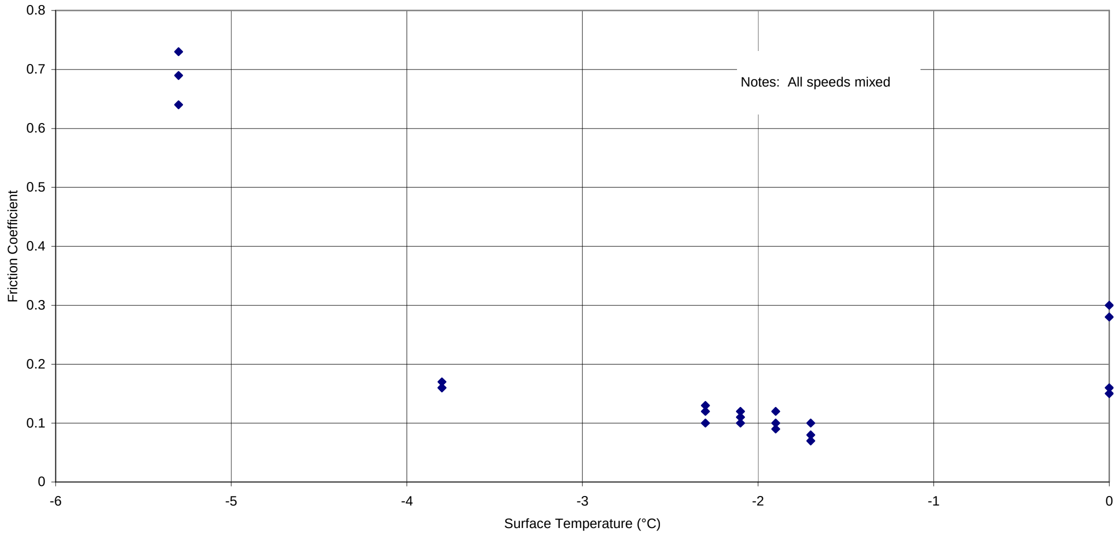
# TREND PLOTS VS. SURFACE TEMPERATURE
# (SNOW DEPTHS 10 MM OR LESS)



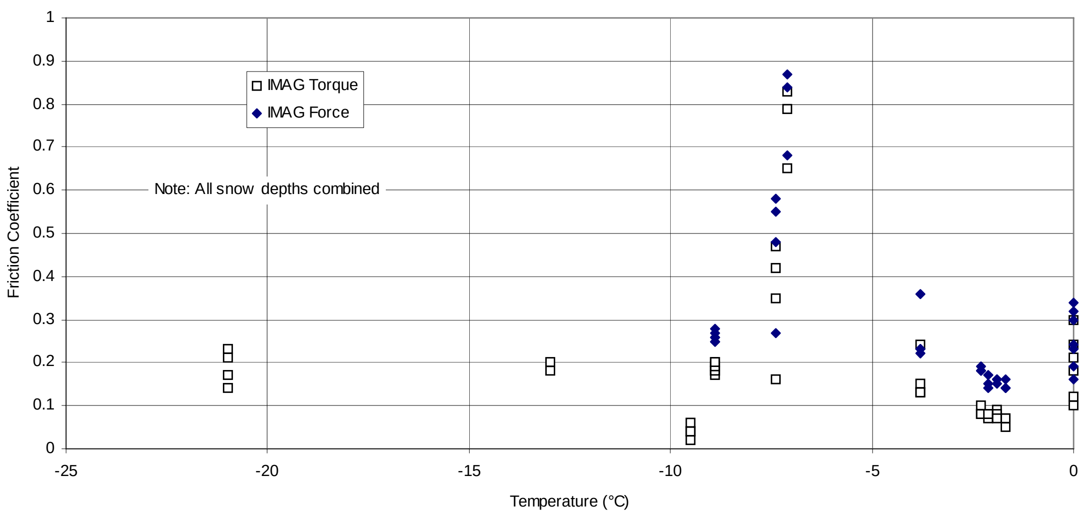

**D.5-1: ERD Readings for Snow on Pavement: Effect of Surface Temperature**



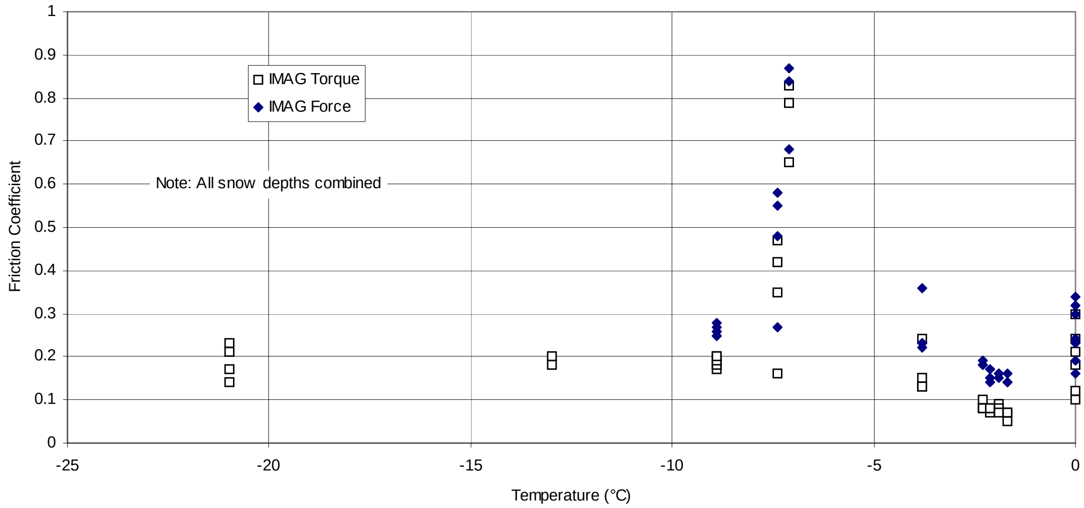

**D.5-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Surface Temperature**




**D.5-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Surface Temperature**



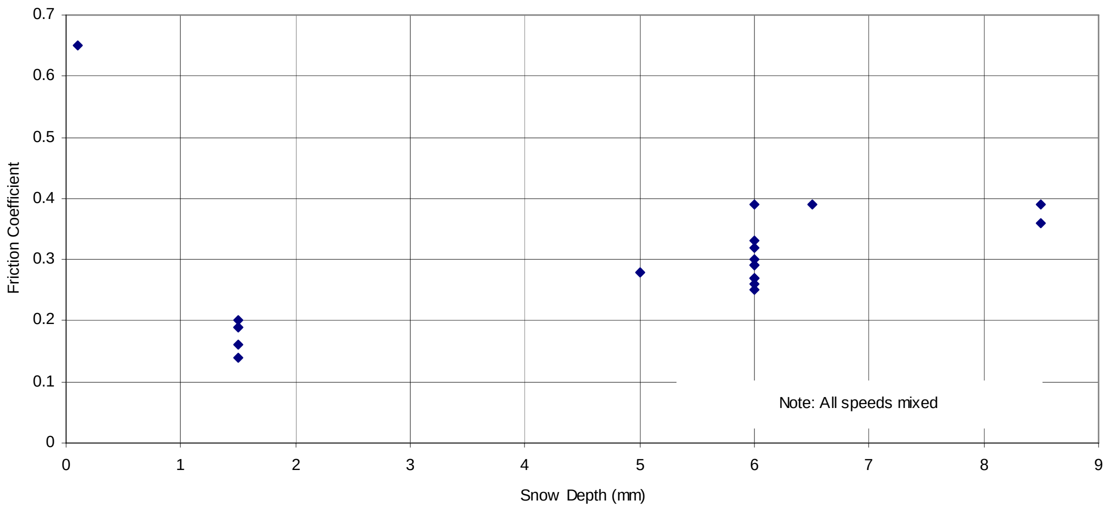

**D.5-4: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Pavement**



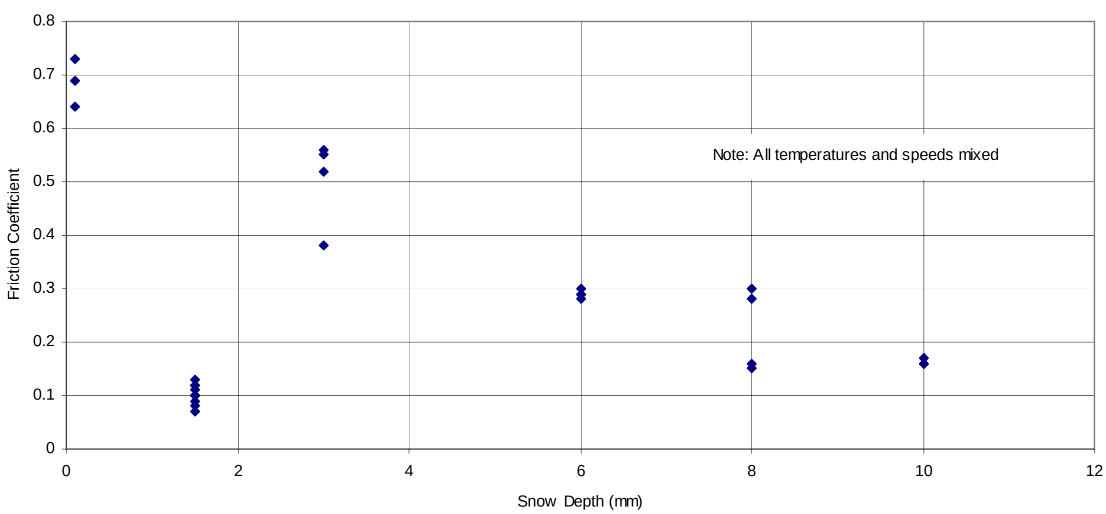

**D.5-5: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Pavement**

# APPENDIX D.6

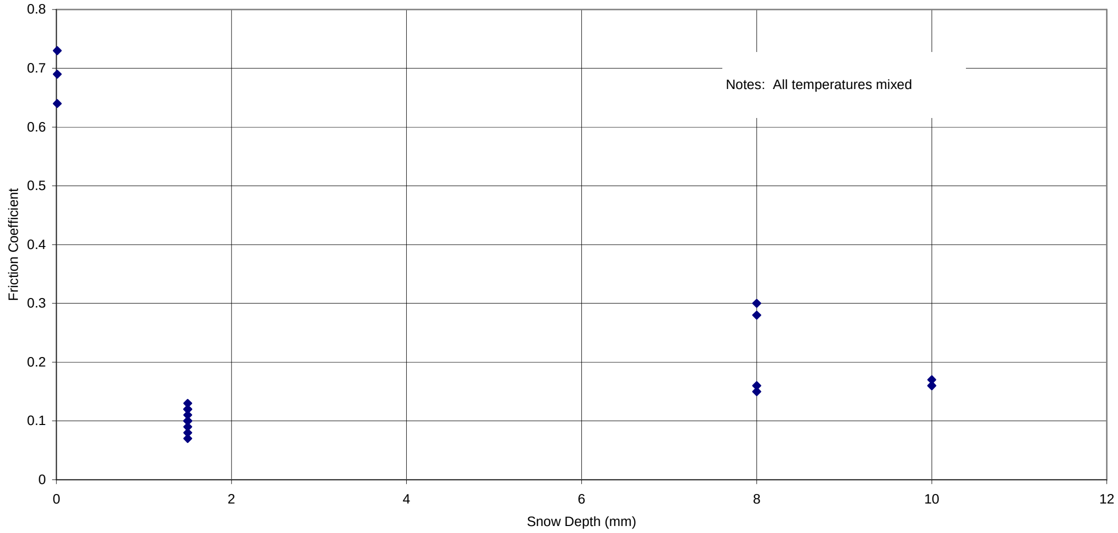
## TREND PLOTS VS. SNOW DEPTH
## (SNOW DEPTHS 10 MM OR LESS)



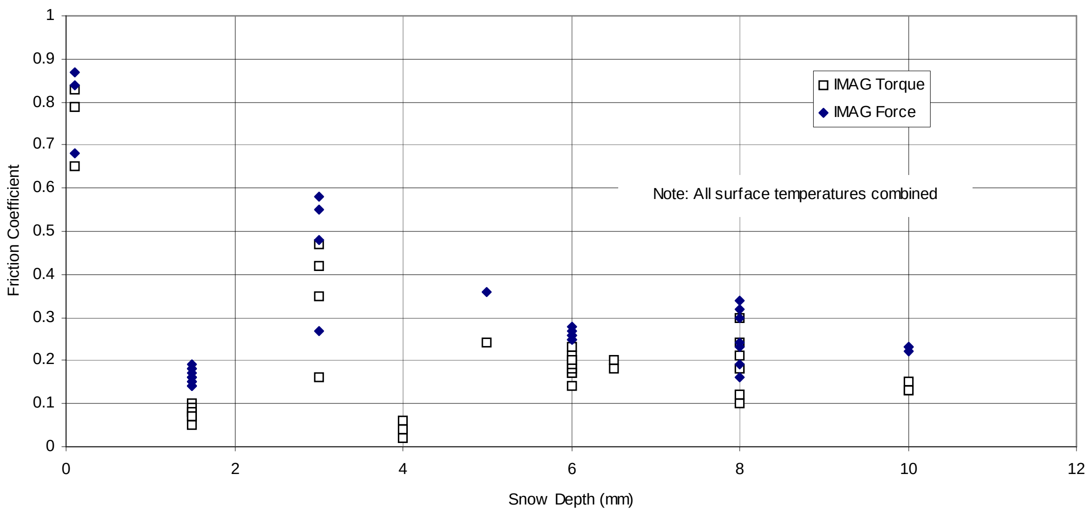

**D.6-1: ERD Readings for Snow on Pavement: Effect of Snow Depth**



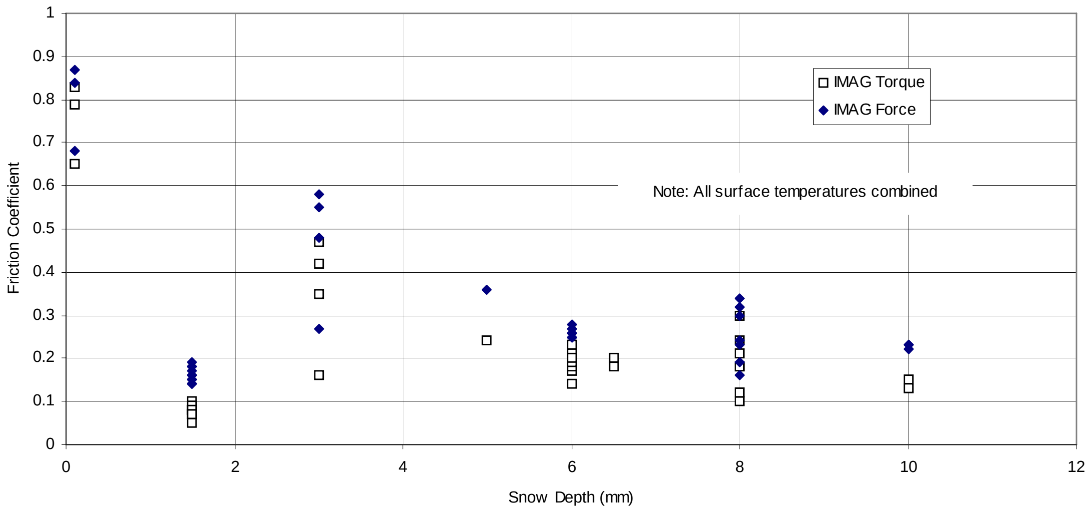

**D.6-2: TC SFT'79 (All Configurations) Readings for Snow on Pavement: Effect of Snow Depth**




**D.6-3: TC SFT'79 (Configuration 3) Readings for Snow on Pavement: Effect of Snow Depth**




**D.6-4: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Pavement**




**D.6-5: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Pavement**

# APPENDIX E

# RESULTS FOR SNOW ON ICE

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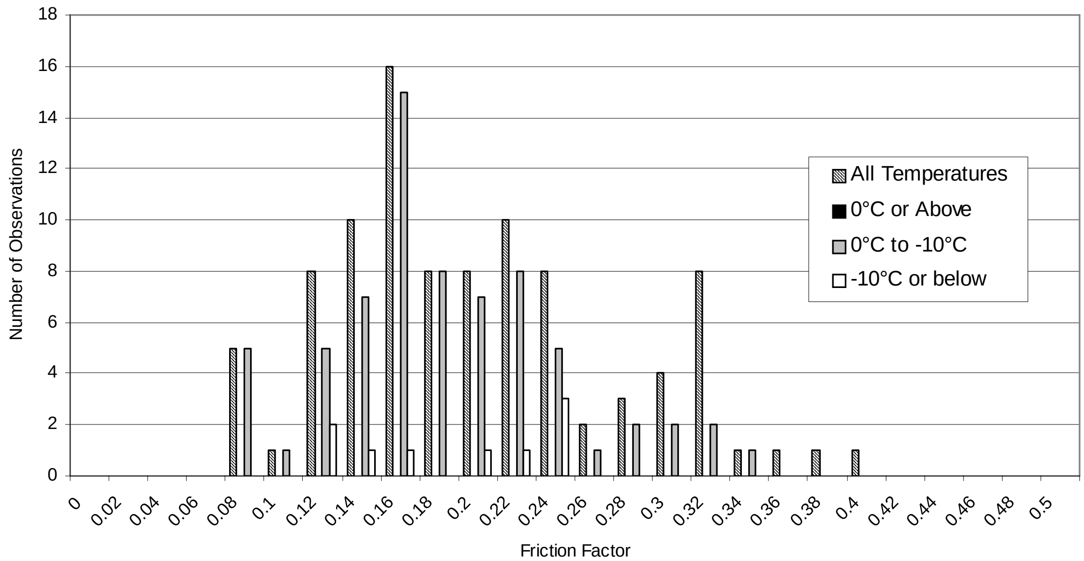
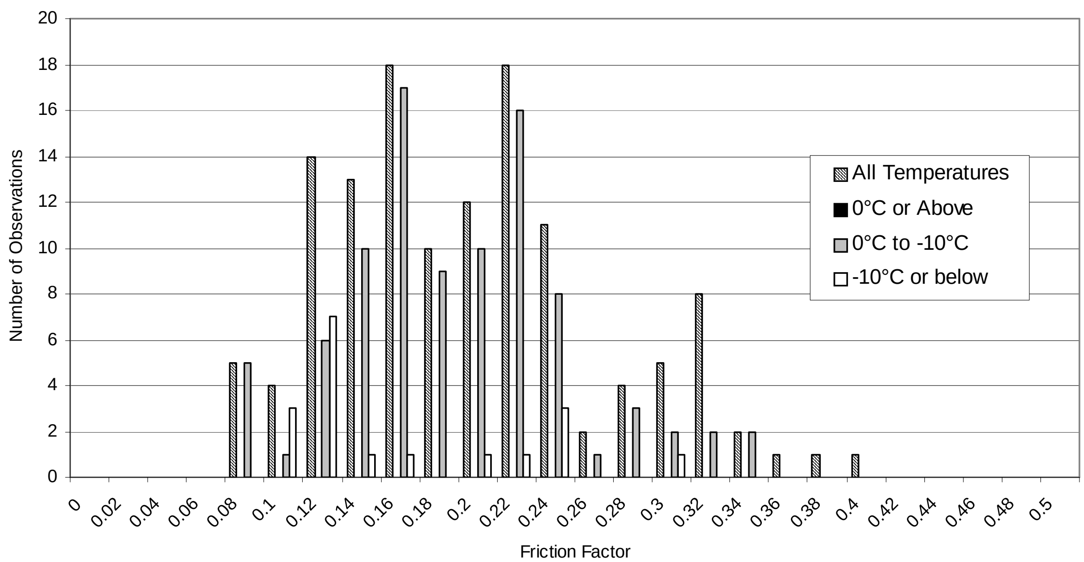
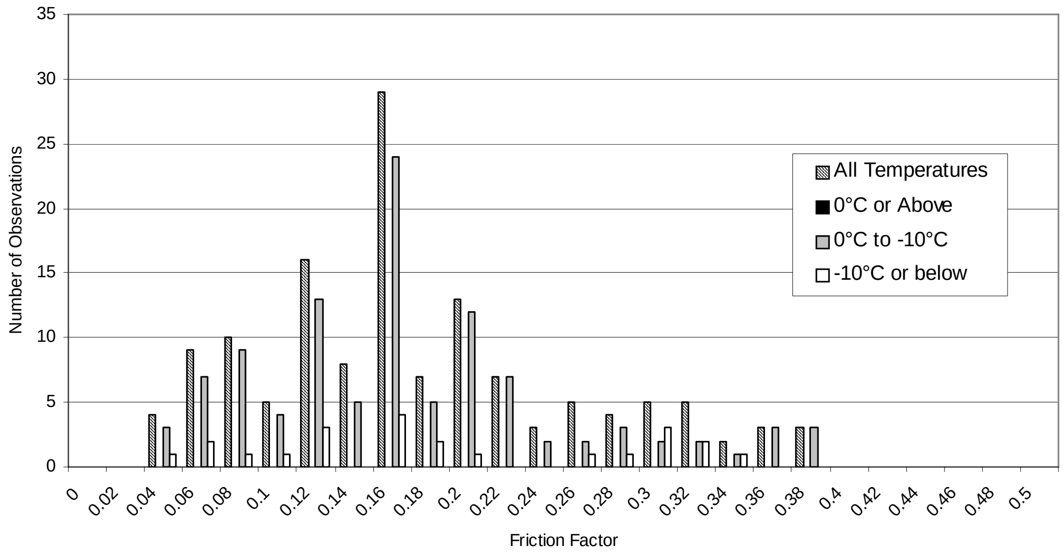


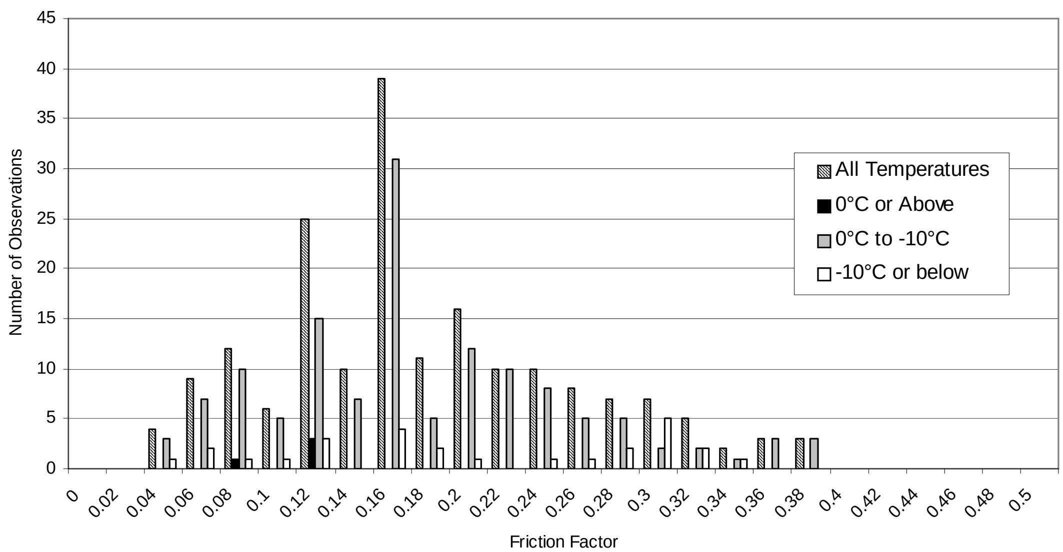

**E.1-1: ERD Readings for Snow on an Ice Base: Effect of Temperature**



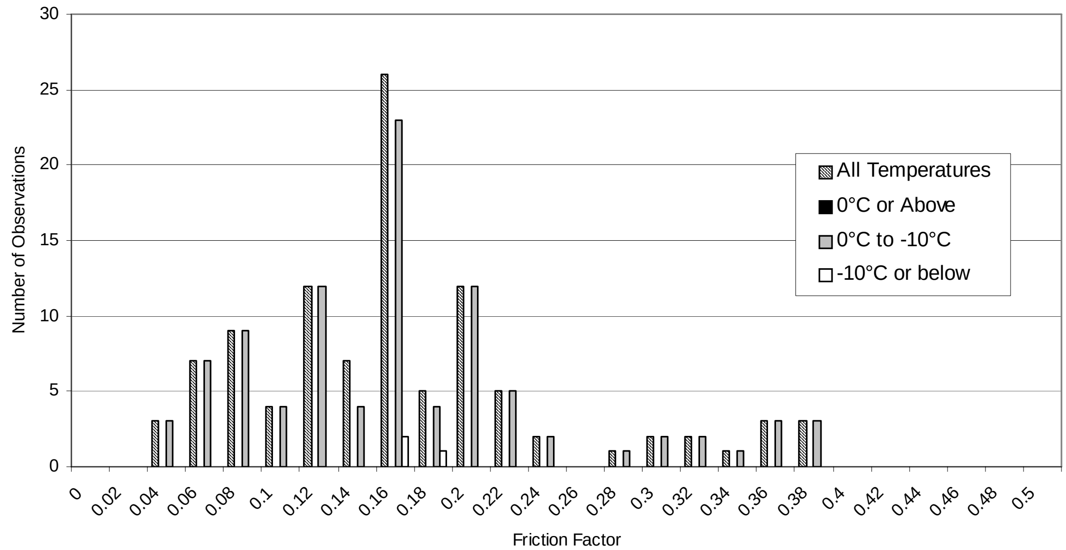

**E.1-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



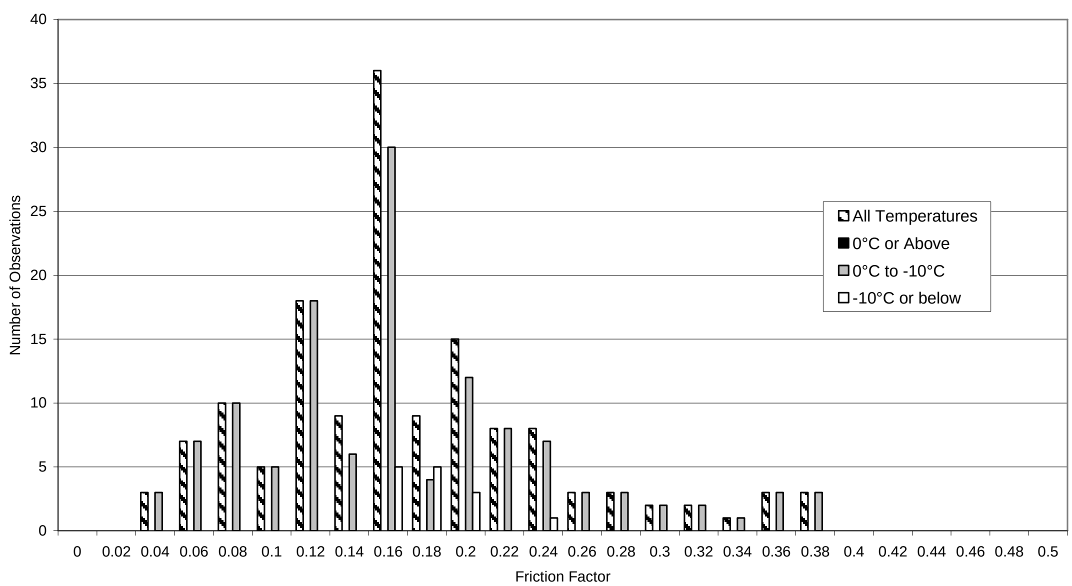

**E.1-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Temperature**



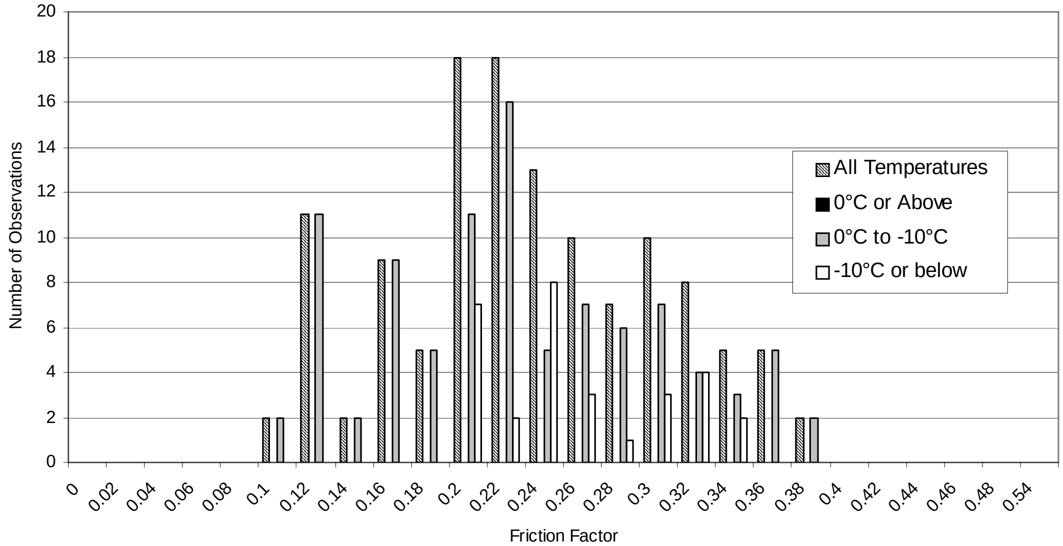

**E.1-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



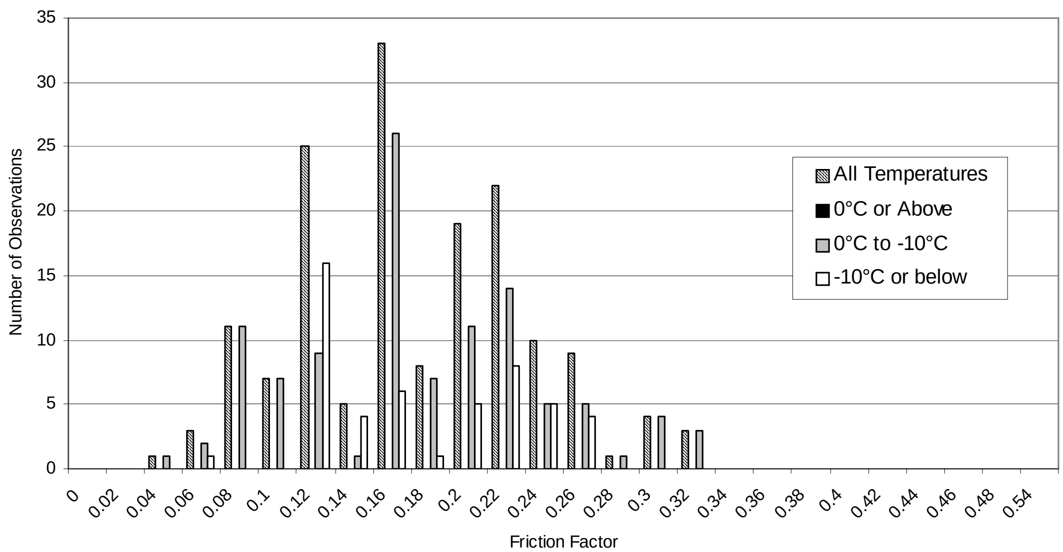

**E.1-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Temperature**



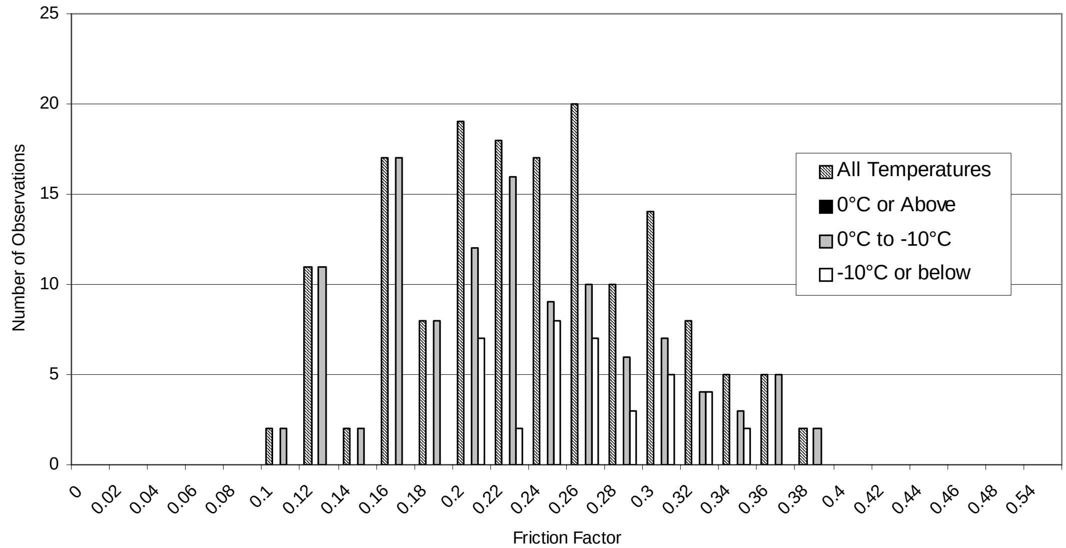

**E.1-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



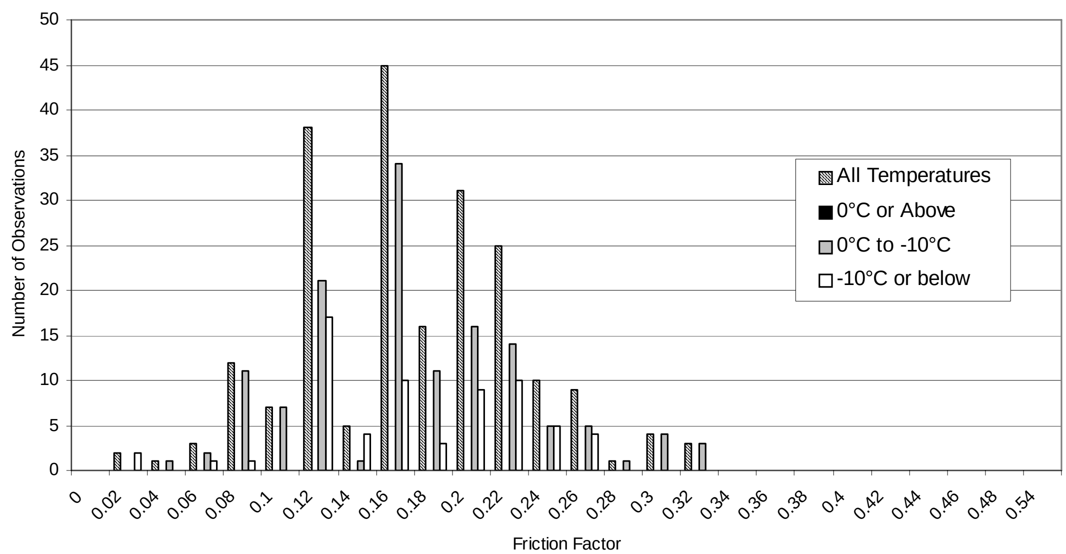

**E.1-7: IMAG Force (All Configurations) Readings for Snow on Bare Ice: Effect of Temperature**



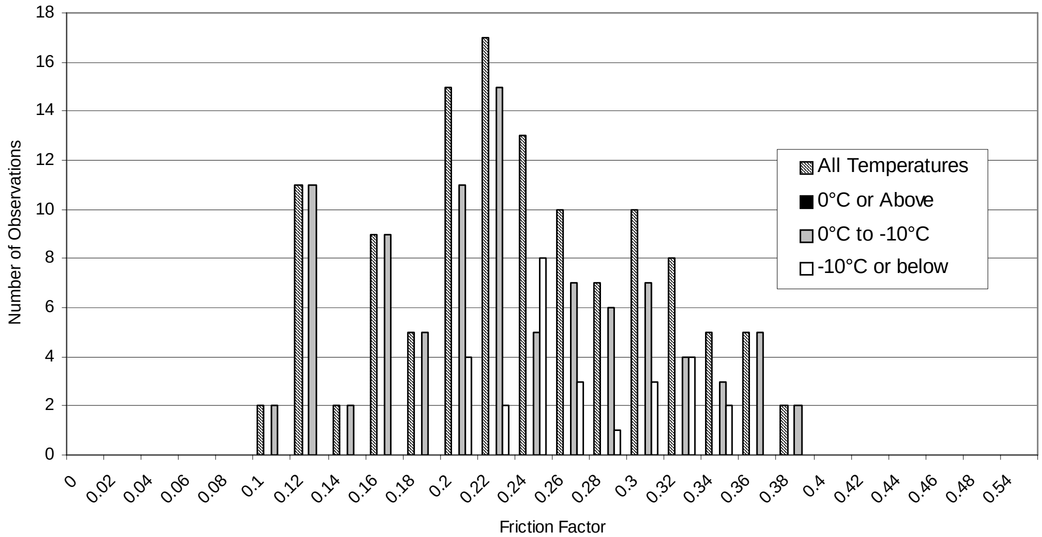

**E.1-8: IMAG Torque (All Configurations) Readings for Snow on Bare Ice: Effect of Temperature**



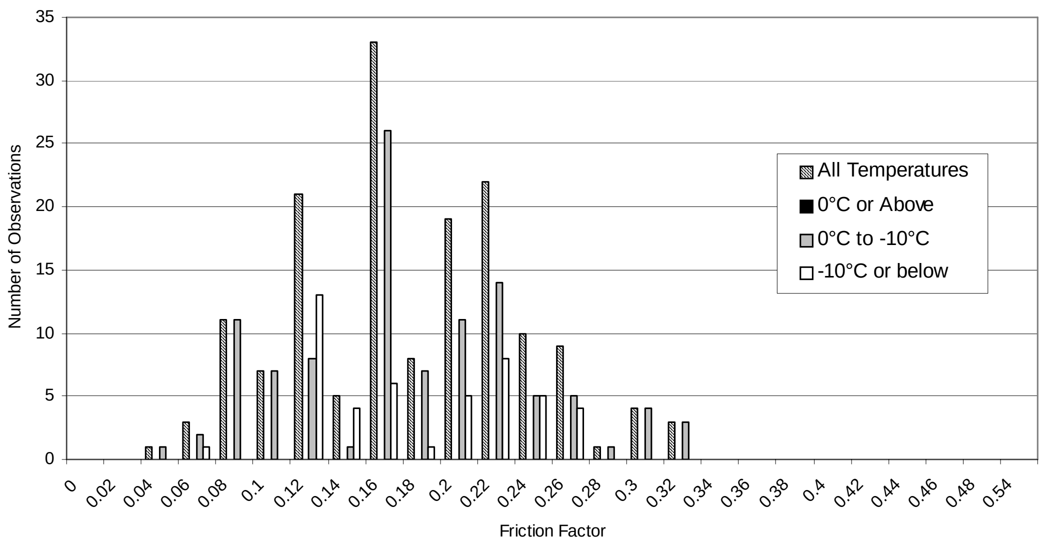

**E.1-9: IMAG Force (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



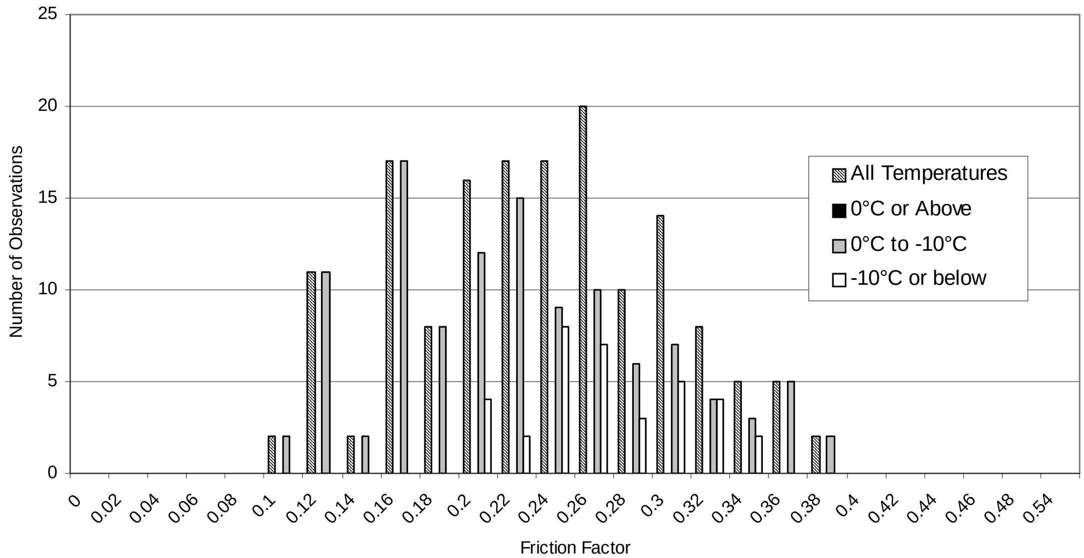

**E.1-10: IMAG Torque (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



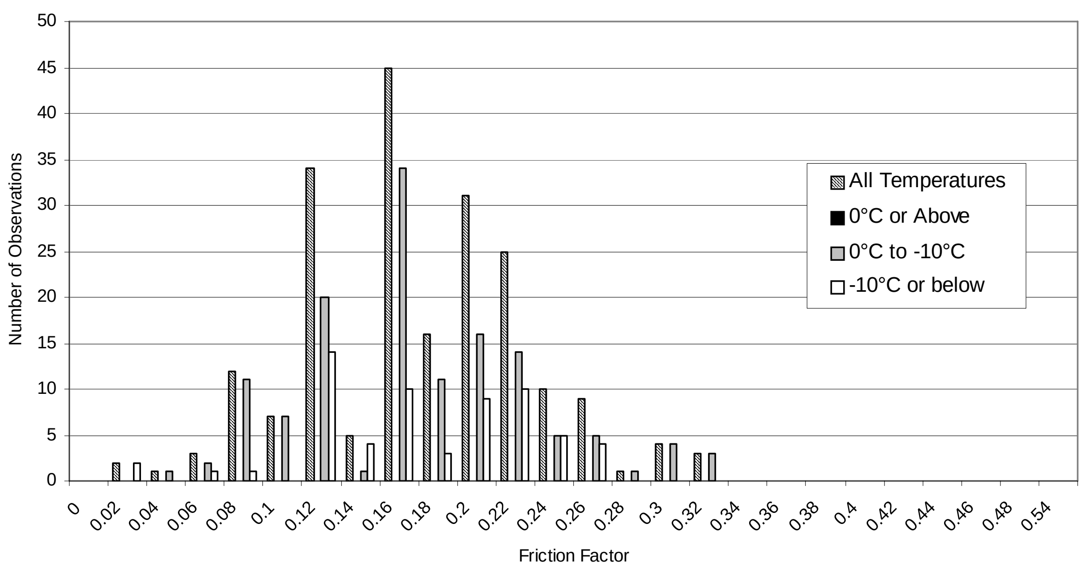

**E.1-11: IMAG Force (Configurations 3 and 7) Readings for Snow on Bare Ice: Effect of Temperature**




**E.1-12: IMAG Torque (Configurations 3 and 7) Readings for Snow on Bare Ice: Effect of Temperature**



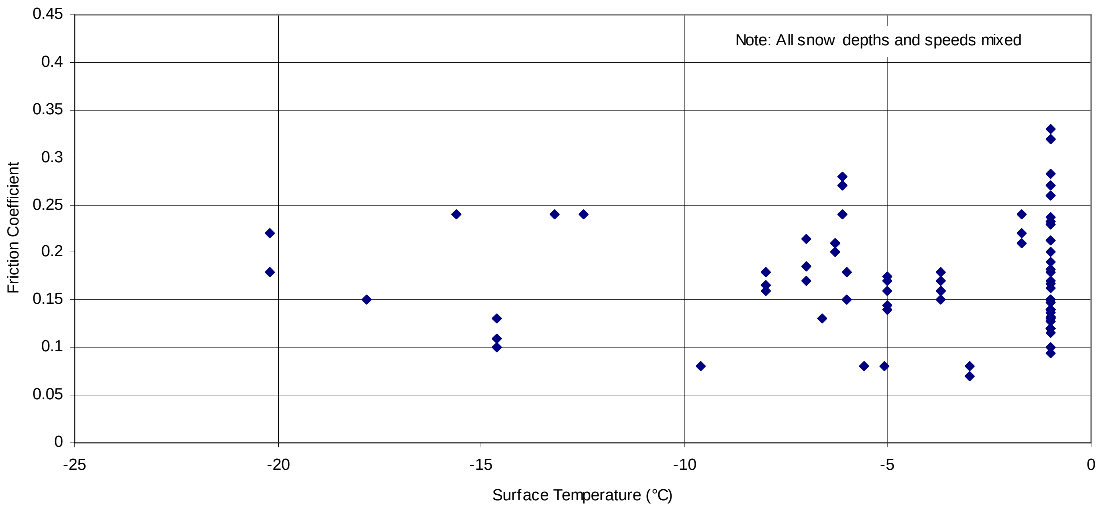

**E.1-13: IMAG Force (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



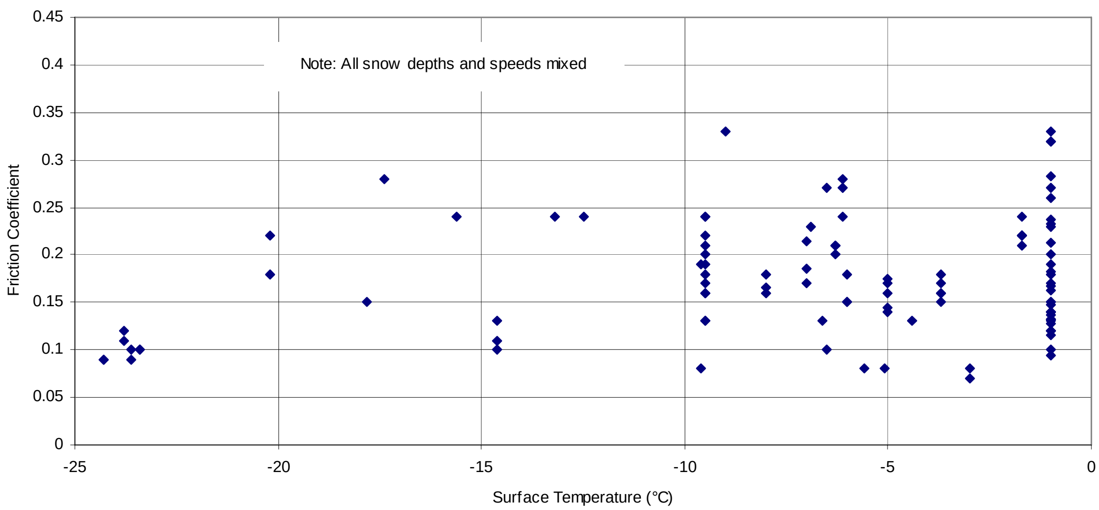

**E.1-14: IMAG Torque (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**

# APPENDIX E.2

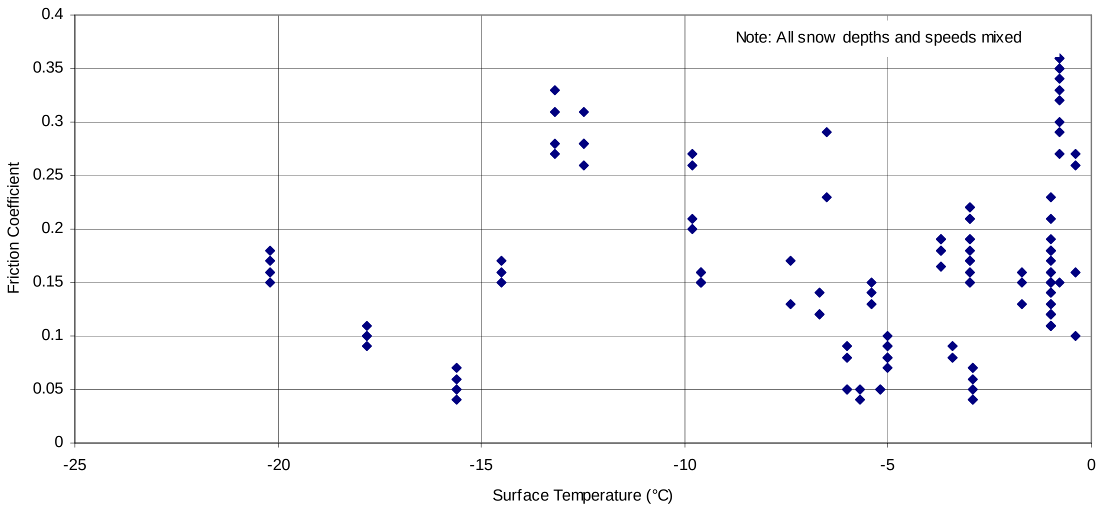
# TREND PLOTS VS. SURFACE TEMPERATURE
# (ALL SNOW DEPTHS)



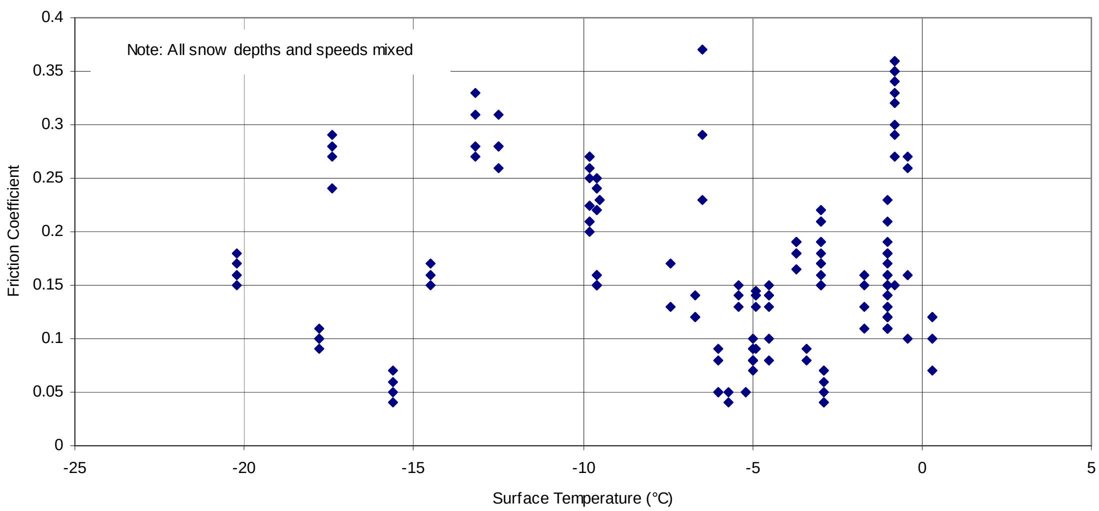

**E.2-1: ERD Readings for Snow on an Ice Base: Effect of Surface Temperature**



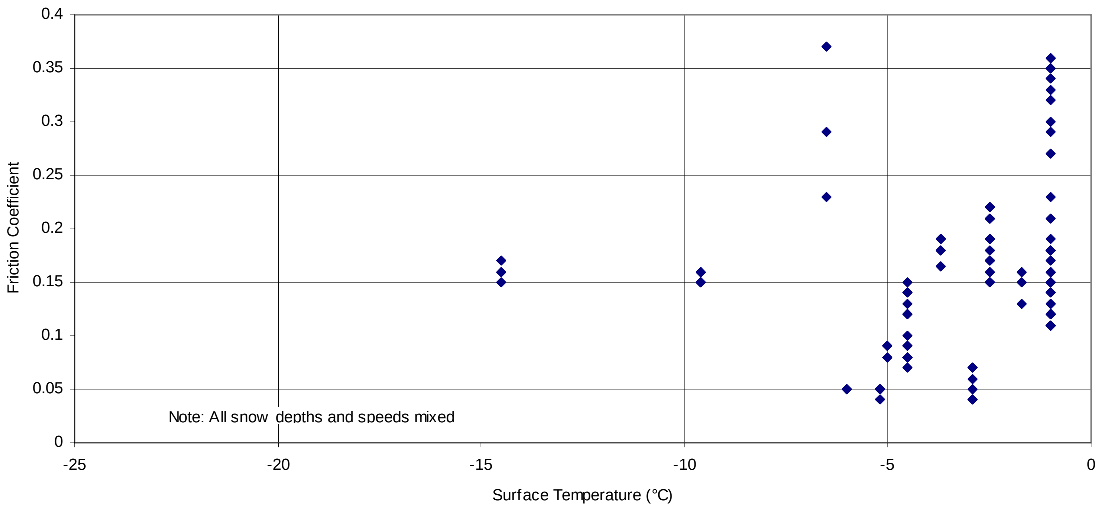

**E.2-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



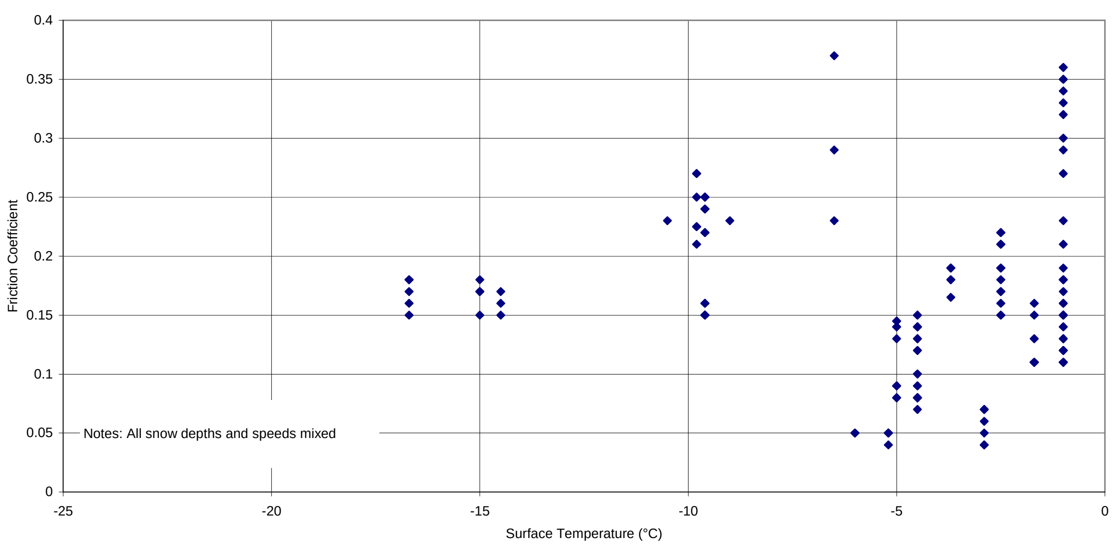

**E.2-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Surface Temperature**



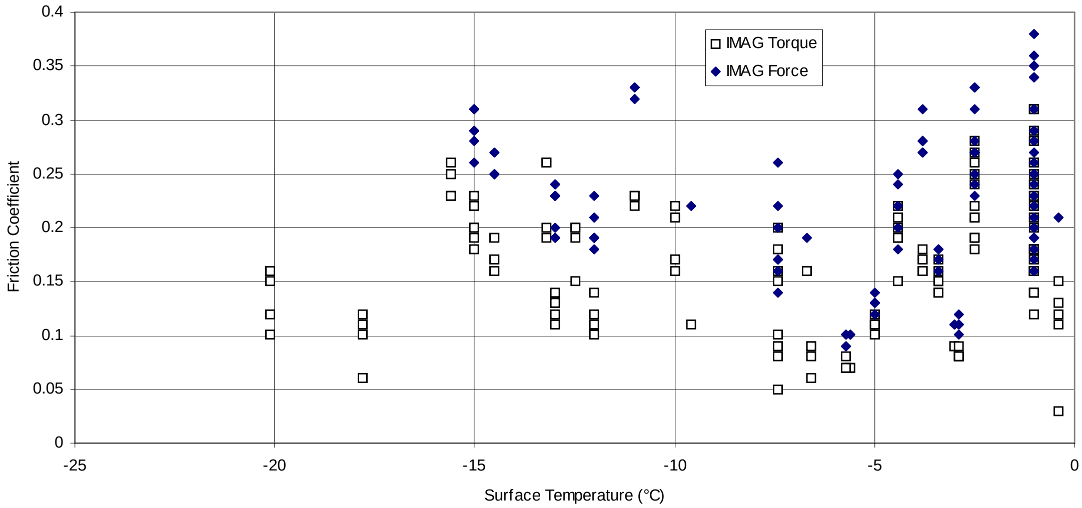

**E.2-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



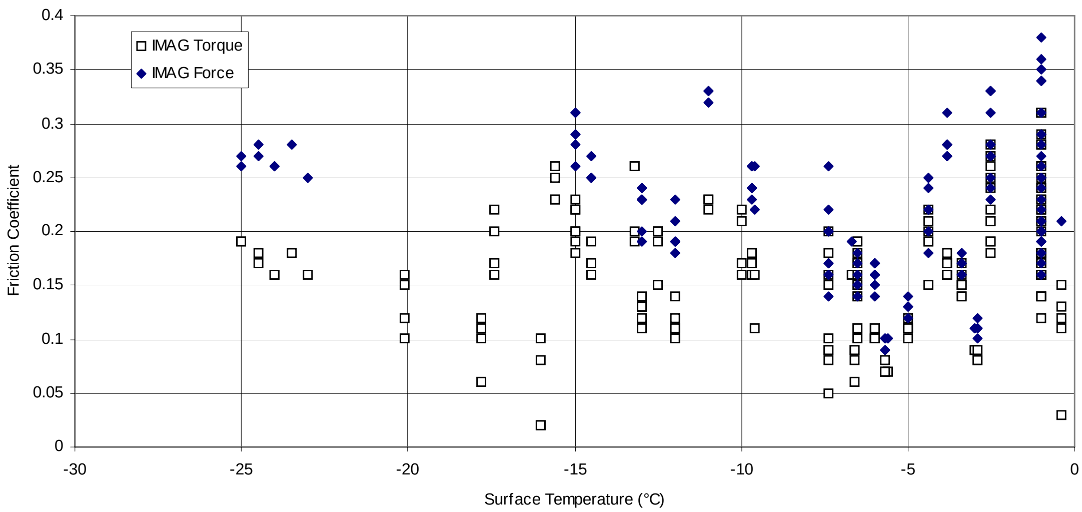

**E.2-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Surface Temperature**



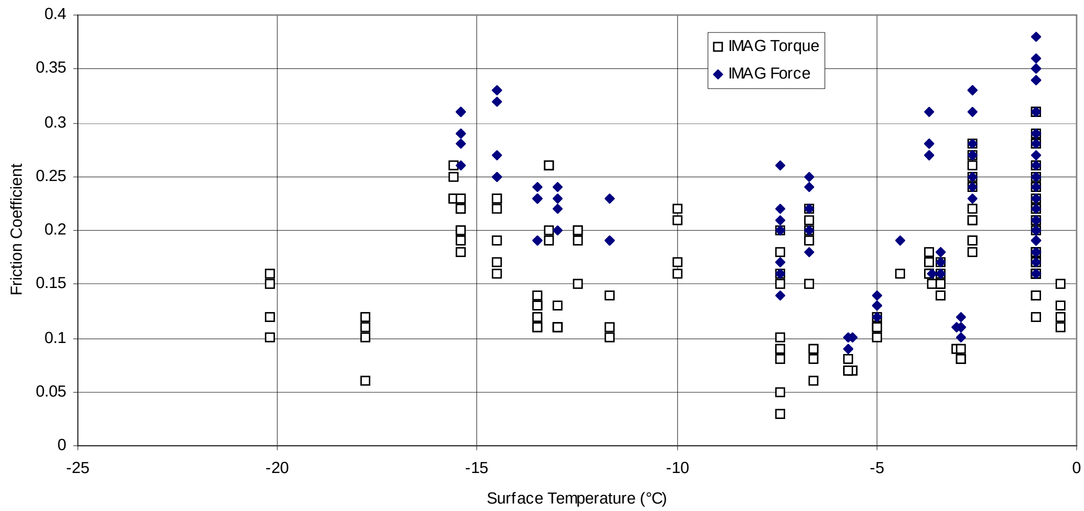

**E.2-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



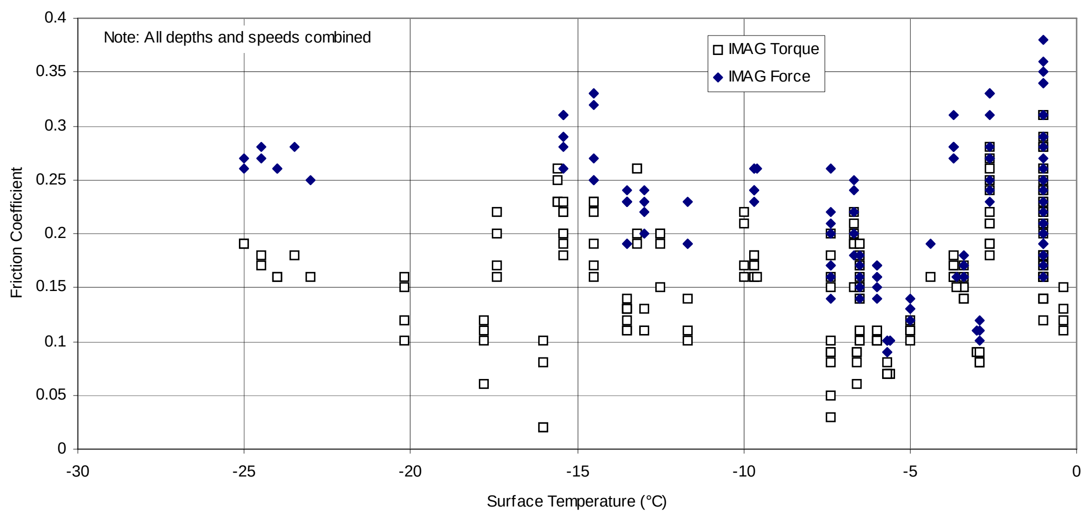

**E.2-7: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Ice**




**E.2-8: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Ice Including Rough Ice**



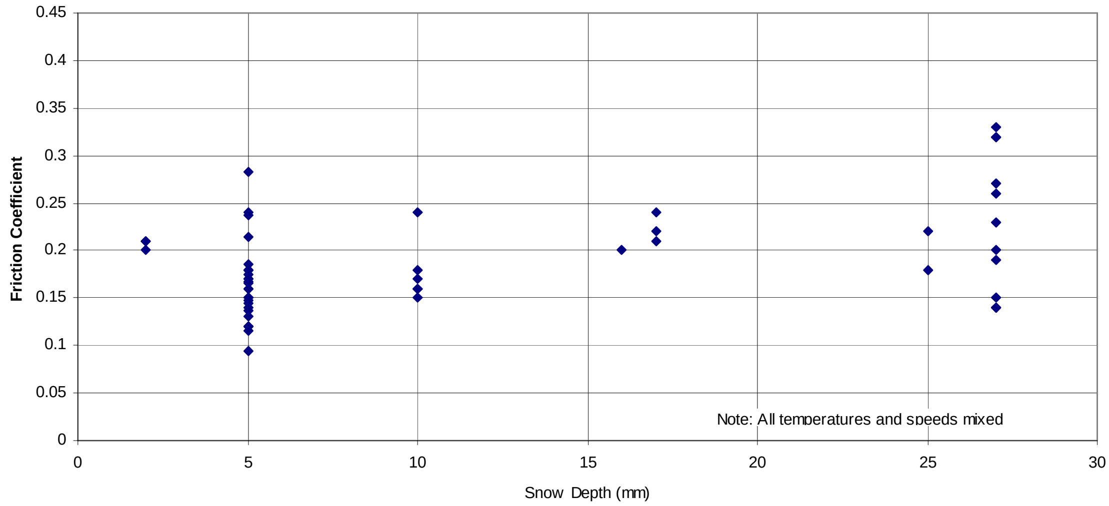

**E.2-9: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Ice**



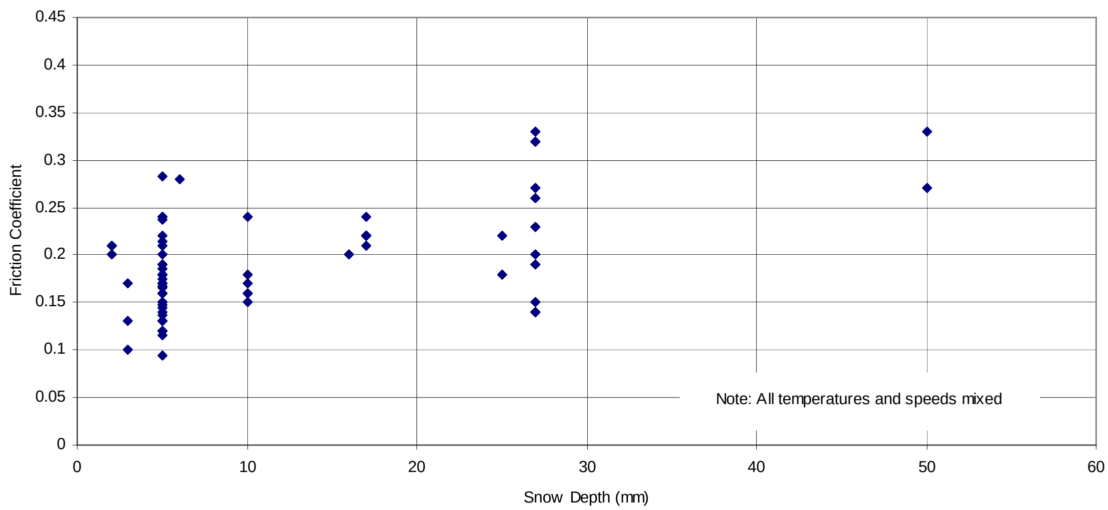

**E.2-10: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice**

# APPENDIX E.3

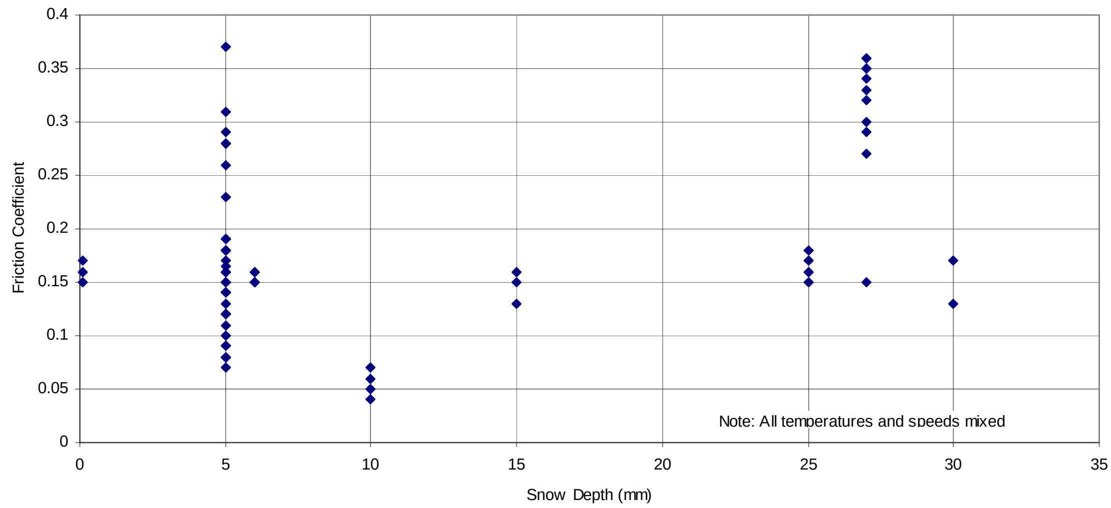
## TREND PLOTS VS. SNOW DEPTH
## (ALL SNOW DEPTHS)



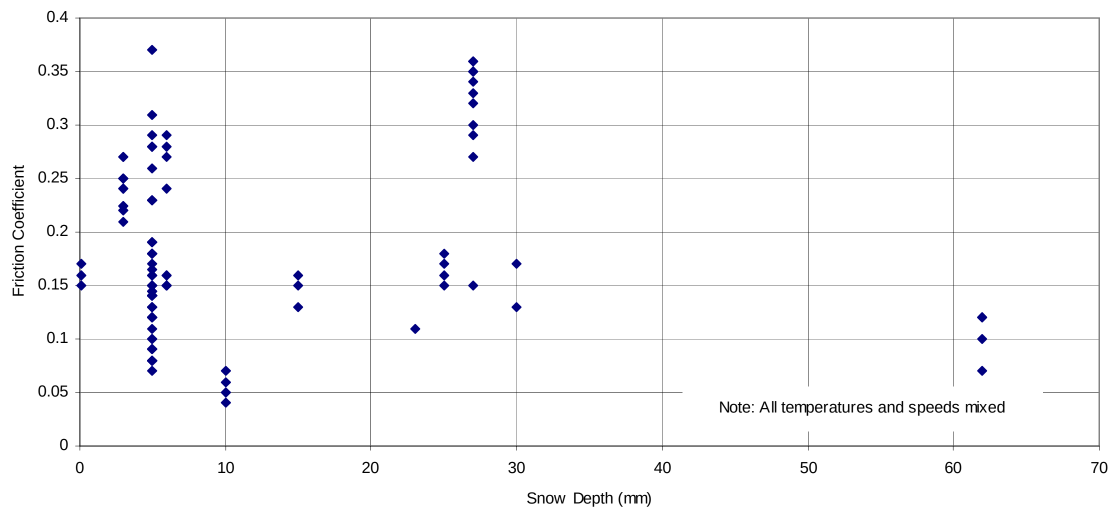

**E.3-1: ERD Readings for Snow on an Ice Base: Effect of Snow Base**



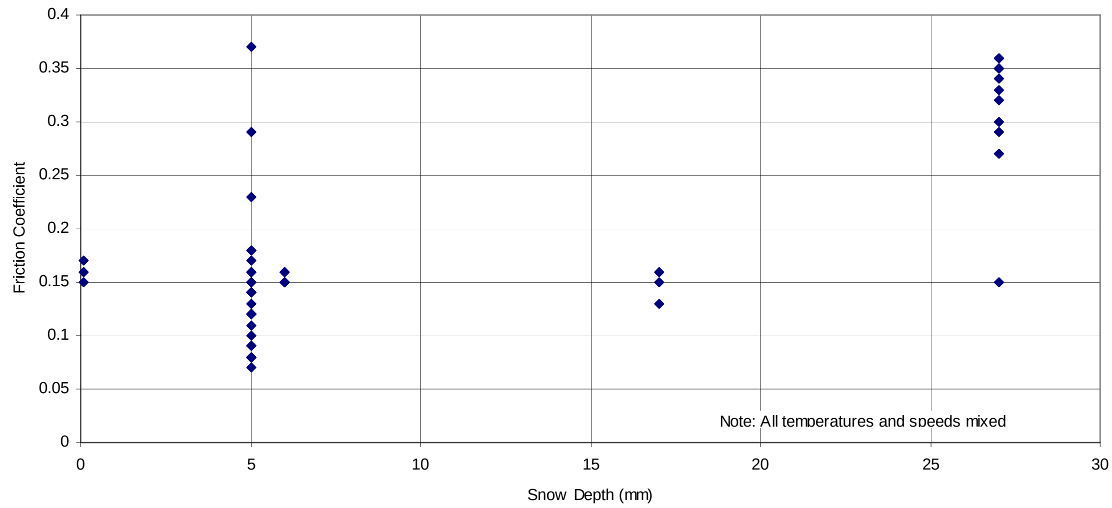

**E.3-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



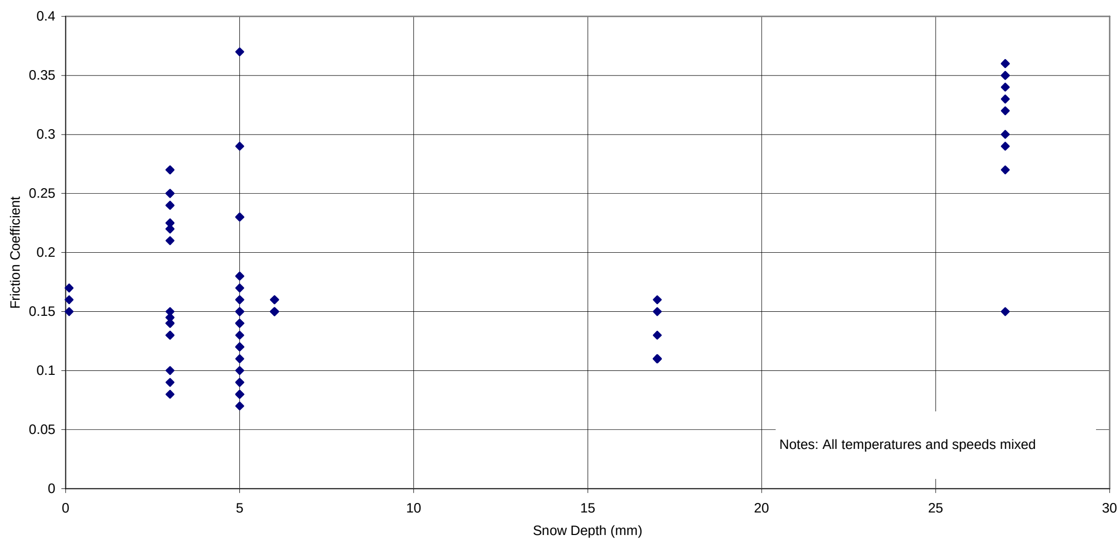

**E.3-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Snow Depth**



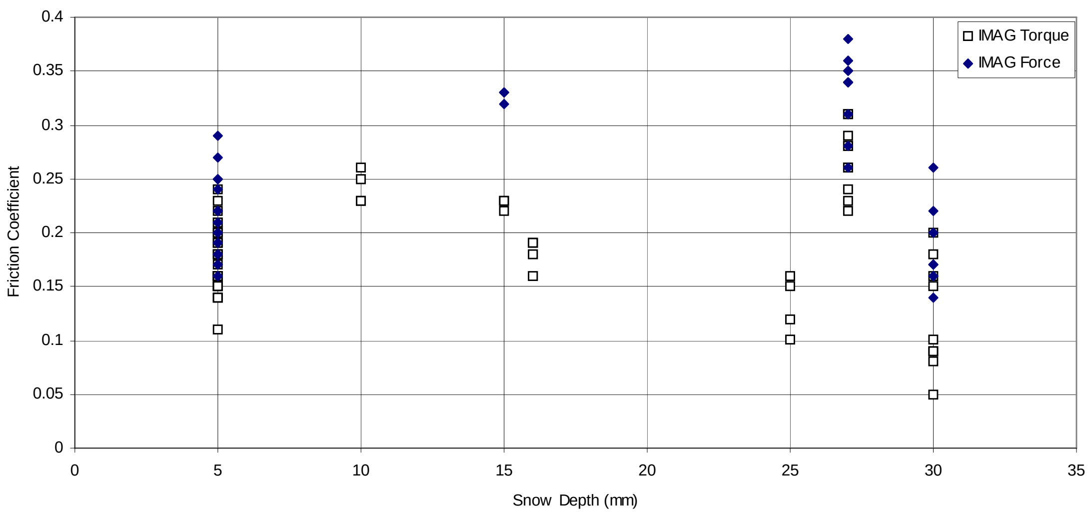

**E.3-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



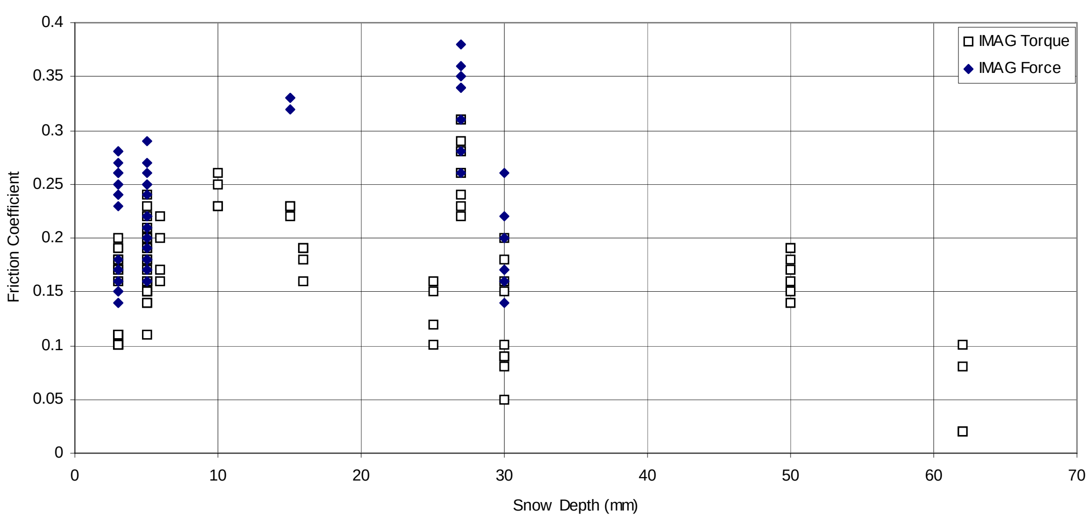

**E.3-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Snow Depth**



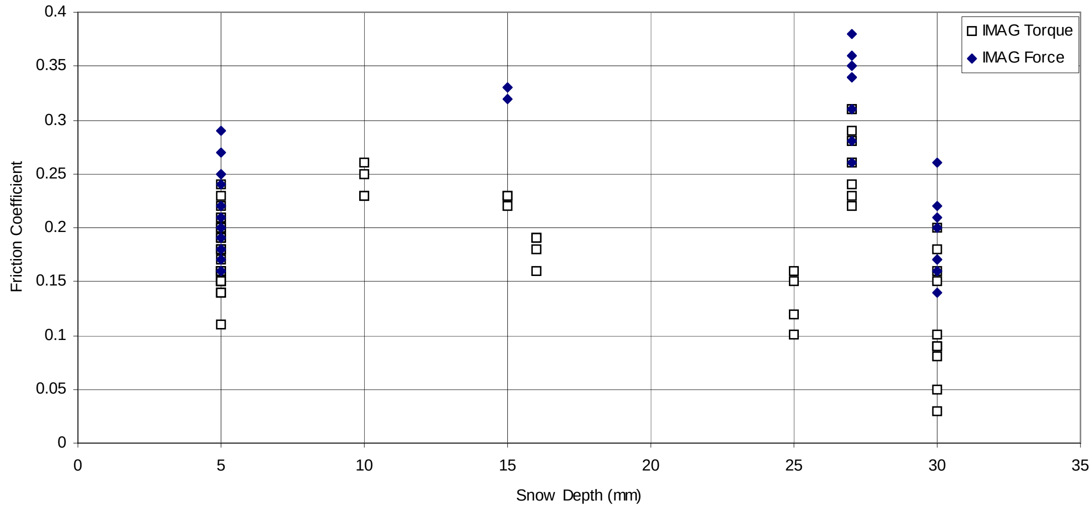

**E.3-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



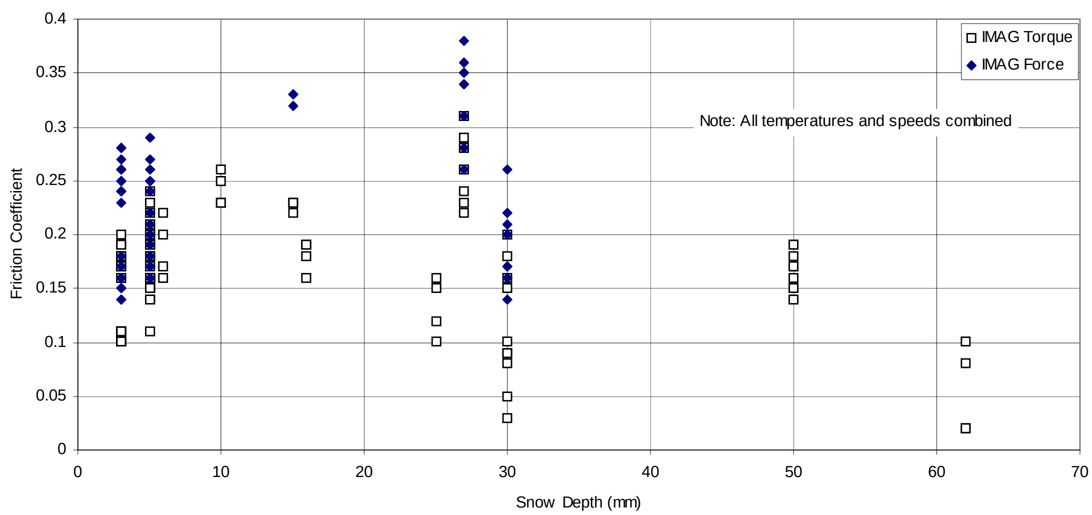

**E.3-7: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Ice**




**E.3-8: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Ice Including Rough Ice**



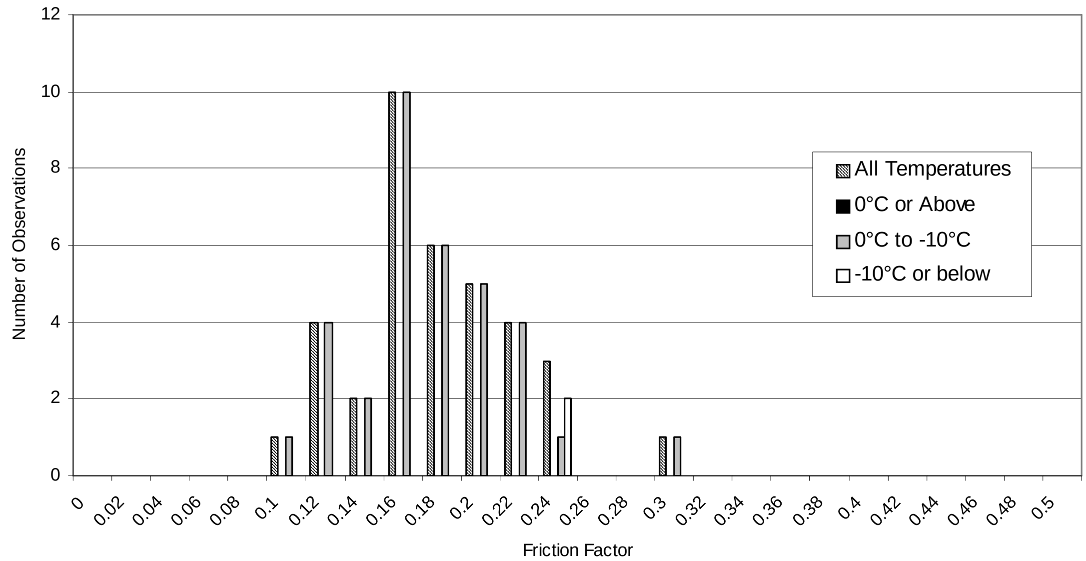

**E.3-9: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Ice**



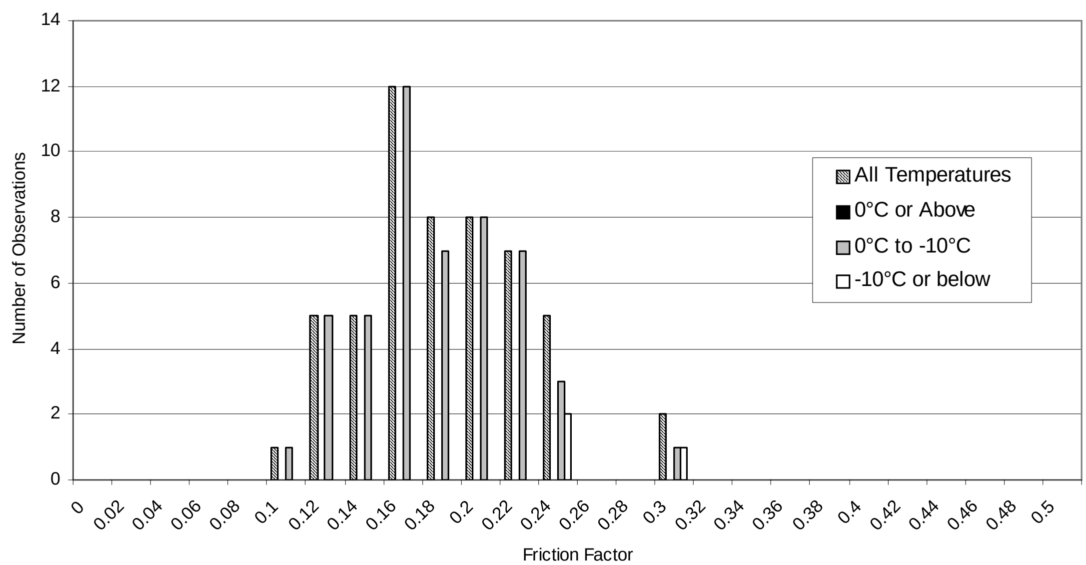

**E.3-10: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice**

# APPENDIX E.4

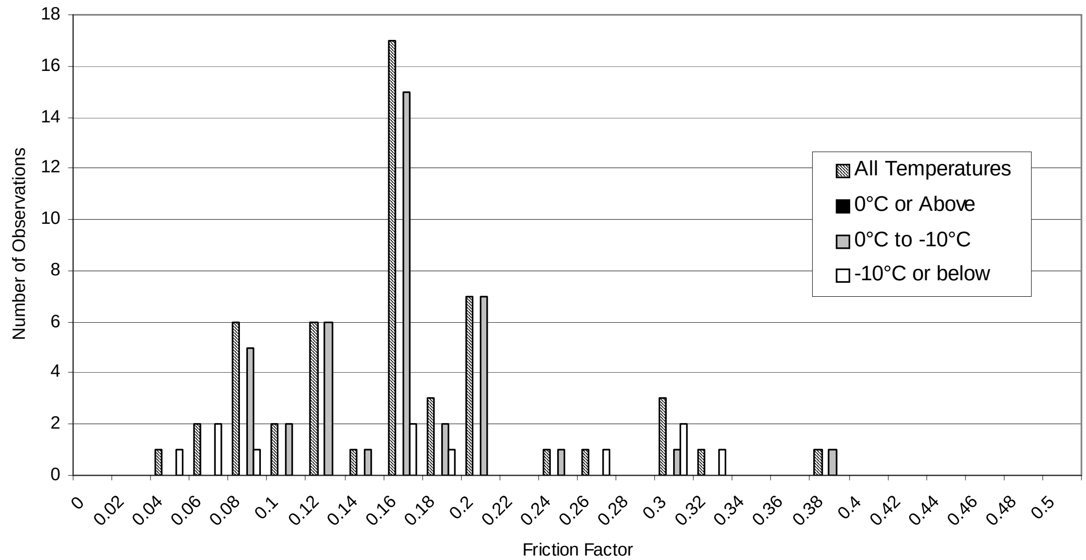
# HISTOGRAMS FOR SNOW ON ICE
# (SNOW DEPTHS 10 MM OR LESS)



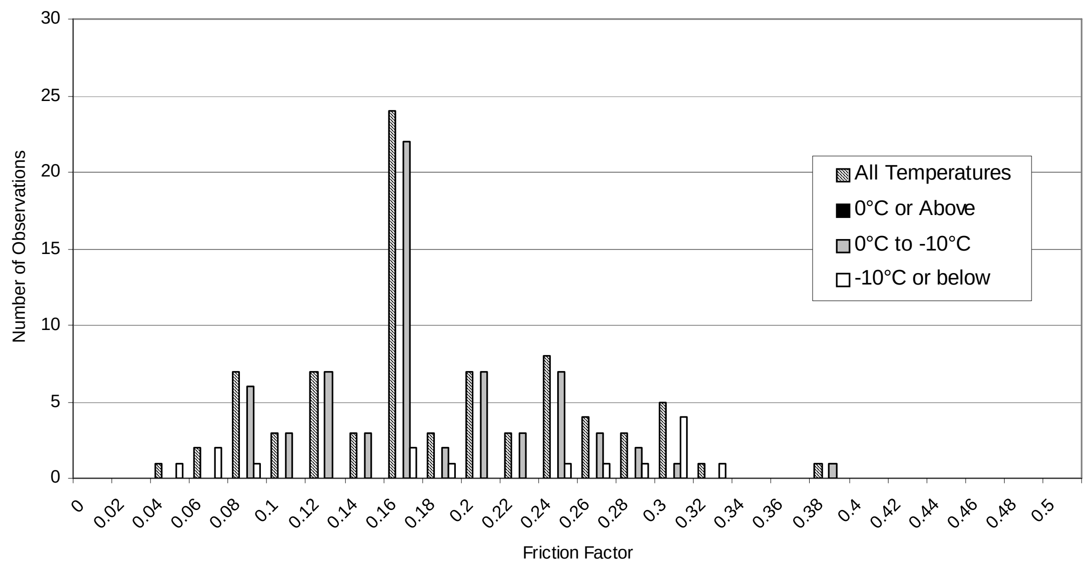

**E.4-1: ERD Readings for Snow on an Ice Base: Effect of Temperature**



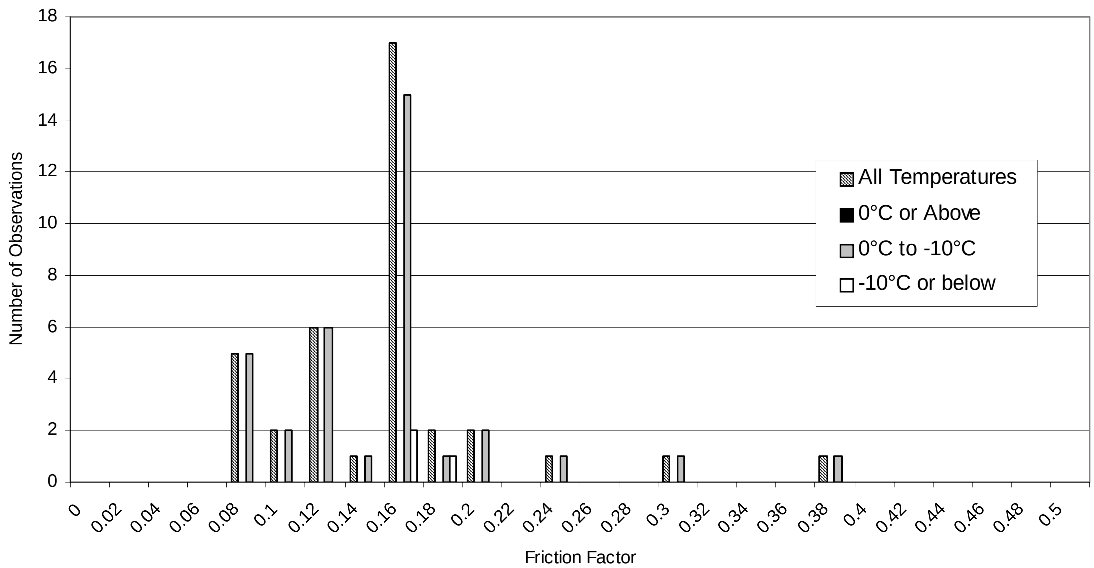

**E.4-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



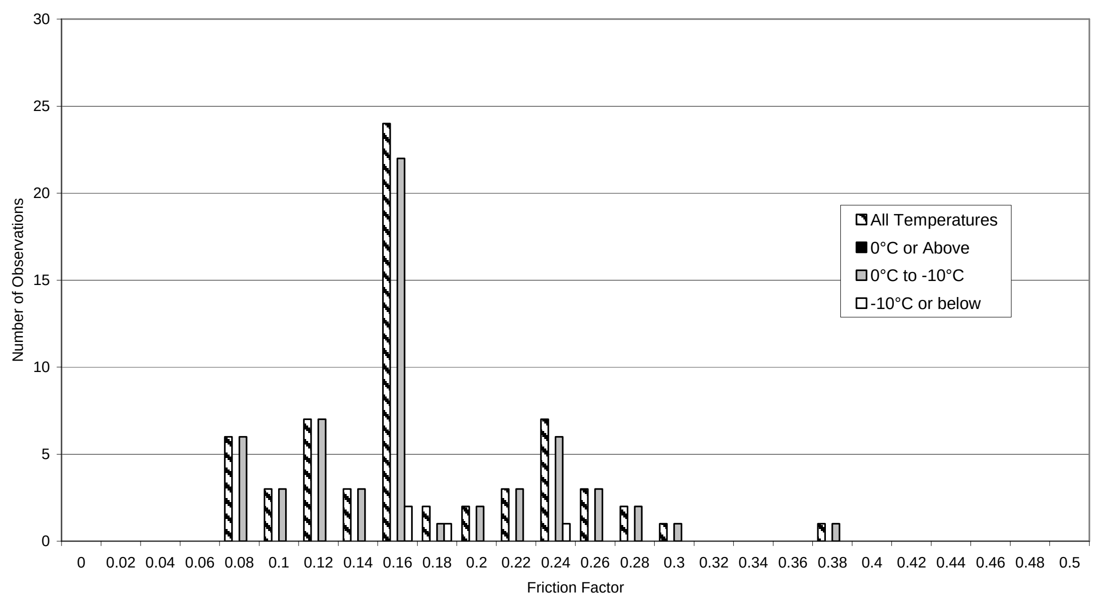

**E.4-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Temperature**



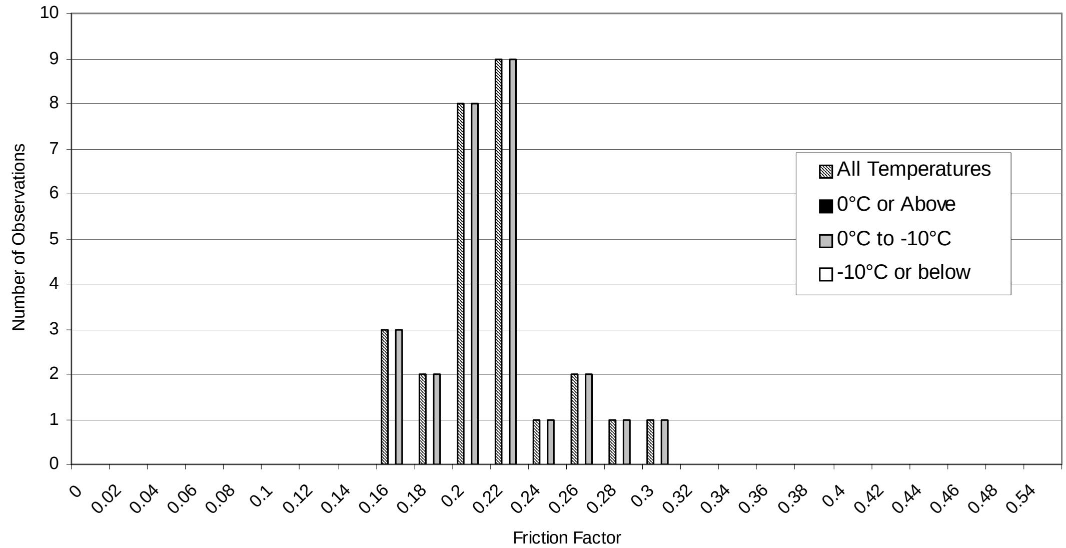

**E.4-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



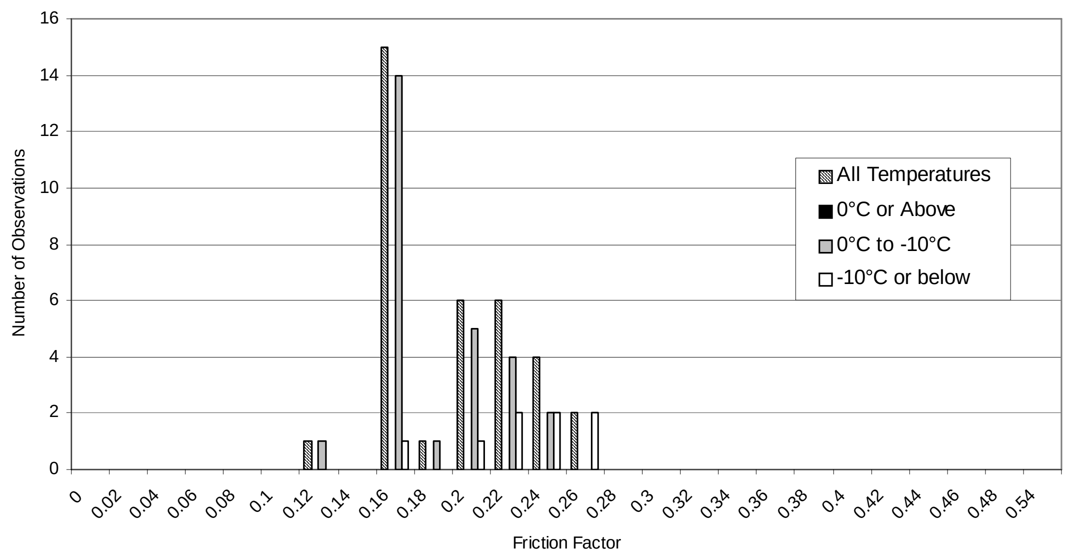

**E.4-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Temperature**



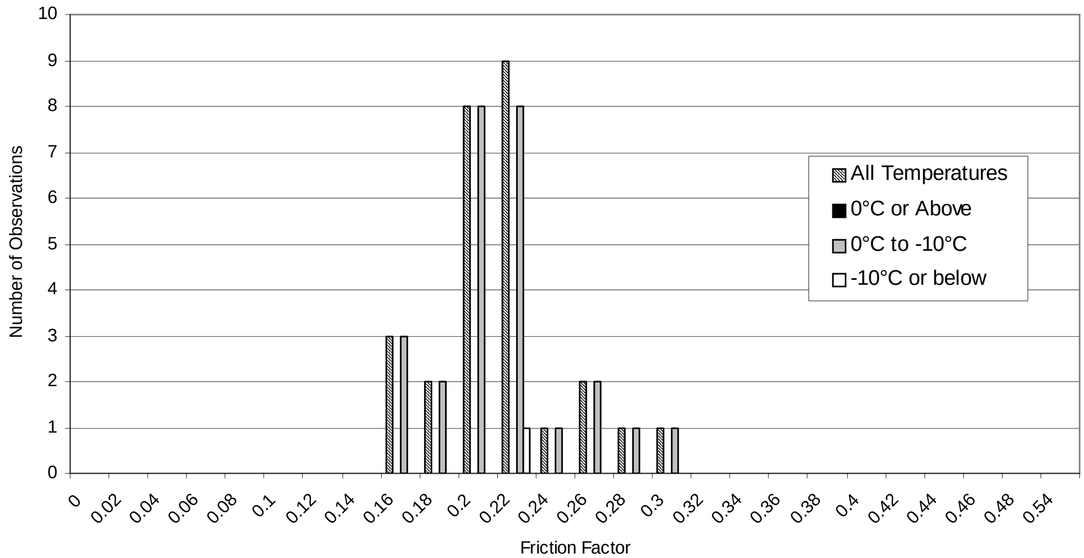

**E.4-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Temperature**



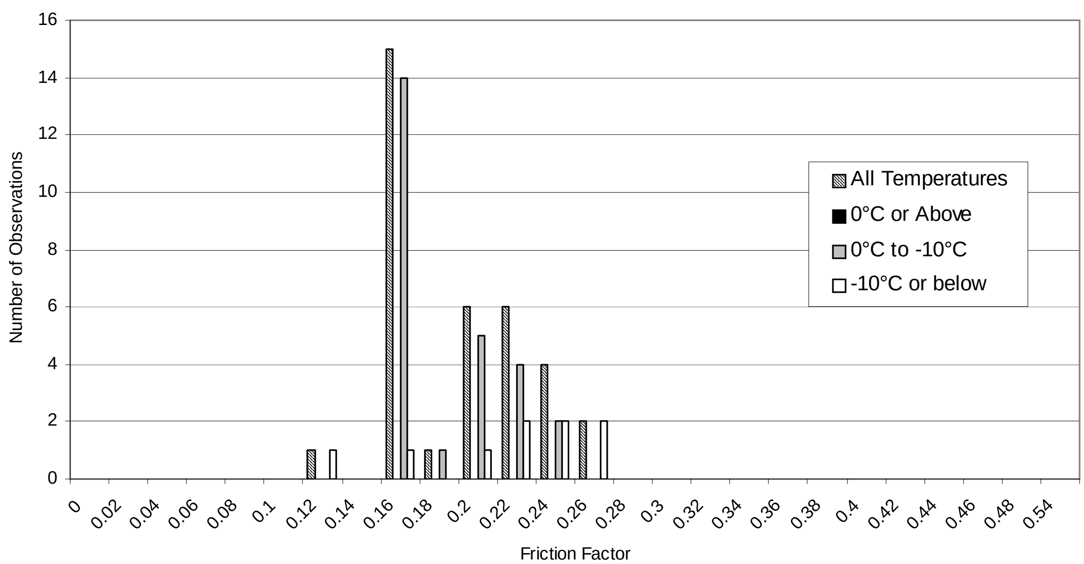

**E.4-7: IMAG Force (All Configurations) Readings for Snow on Bare Ice: Effect of Temperature**




**E.4-8: IMAG Torque (All Configurations) Readings for Snow on Bare Ice: Effect of Temperature**



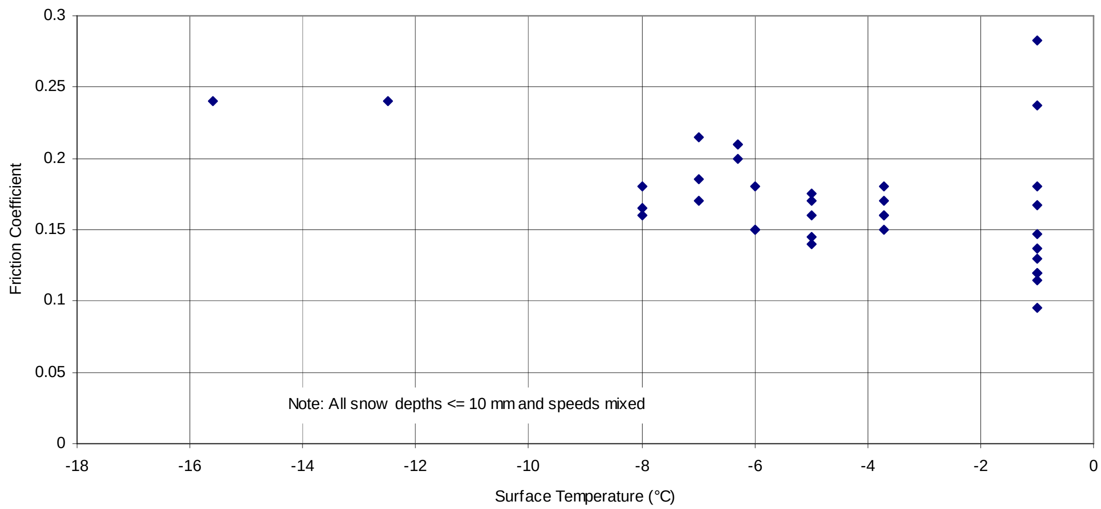

**E.4-9: IMAG Force (Configurations 3 and 7) Readings for Snow on Bare Ice: Effect of Temperature**



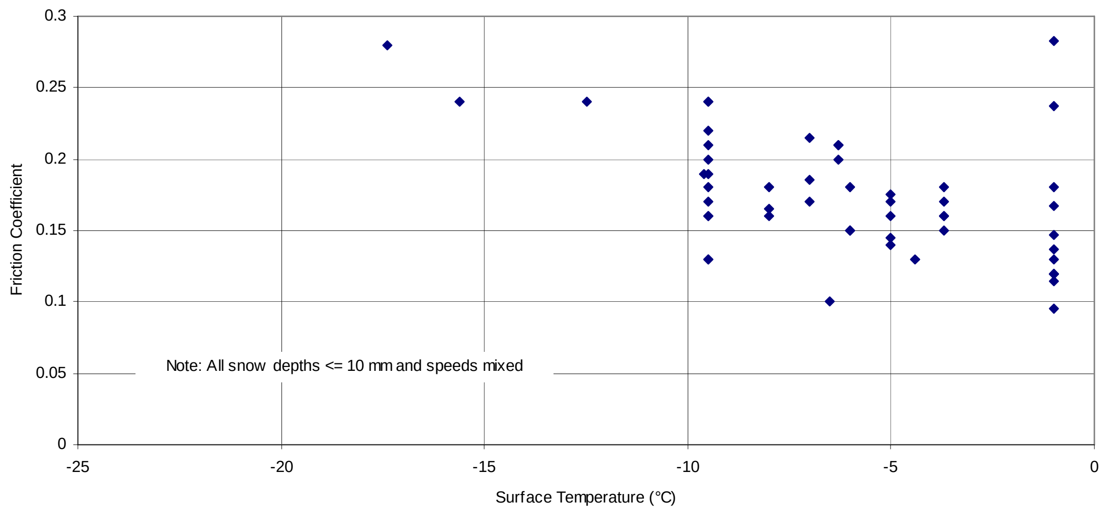

**E.4-10: IMAG Torque (Configurations 3 and 7) Readings for Snow on Bare Ice: Effect of Temperature**

APPENDIX E.5

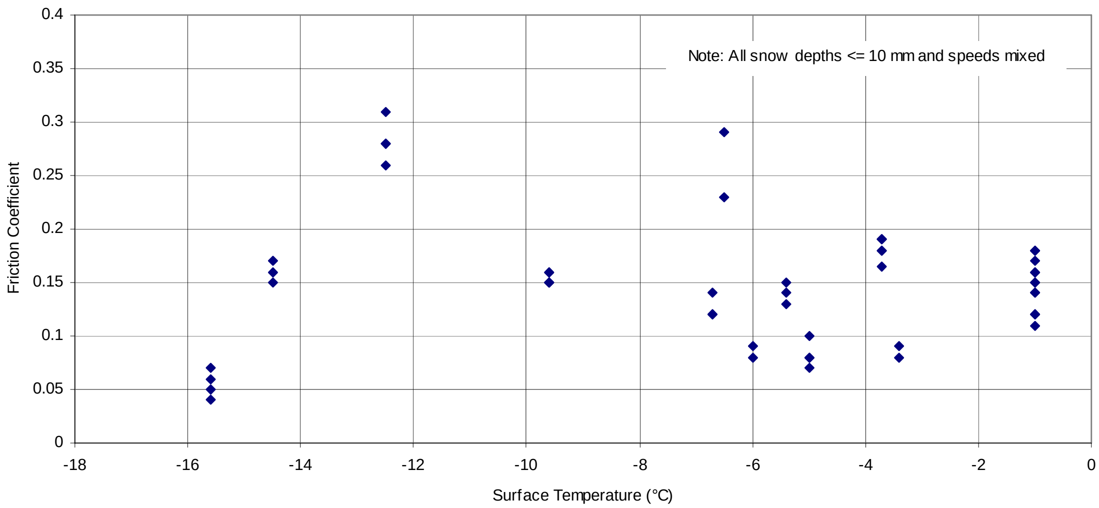
TREND PLOTS VS. SURFACE TEMPERATURE
(SNOW DEPTHS 10 MM OR LESS)



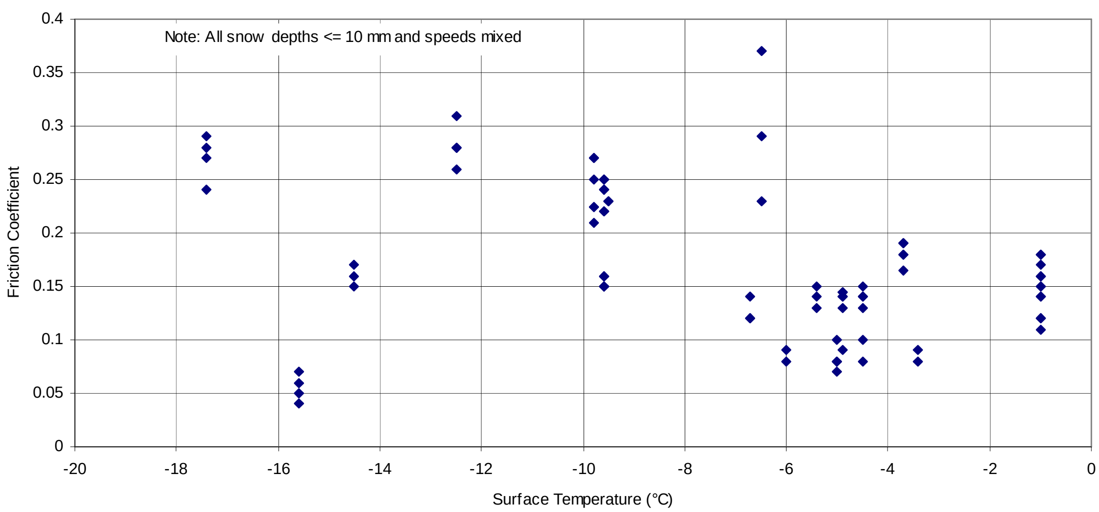

**E.5-1: ERD Readings for Snow on an Ice Base: Effect of Surface Temperature**



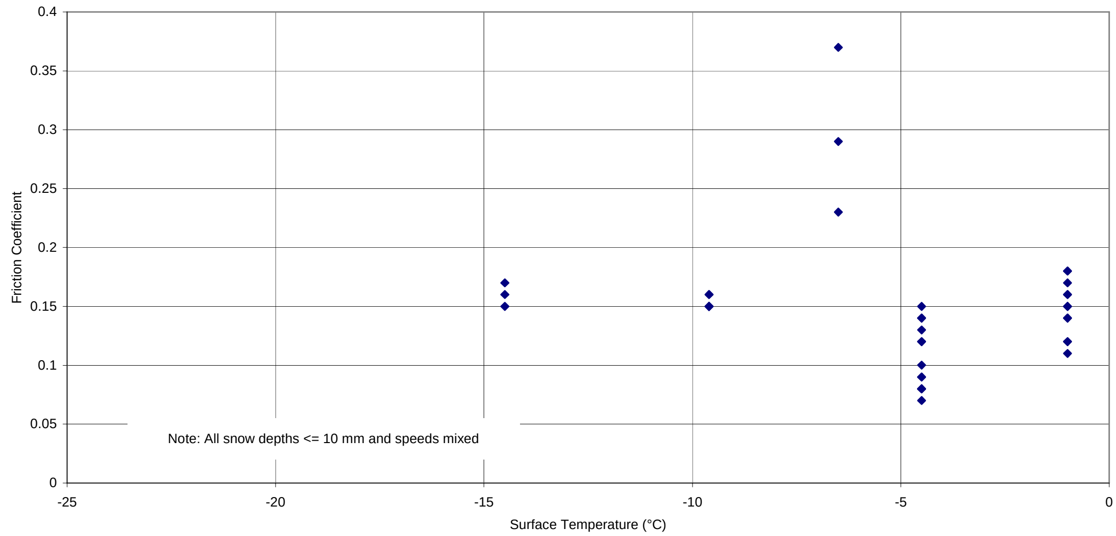

**E.5-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



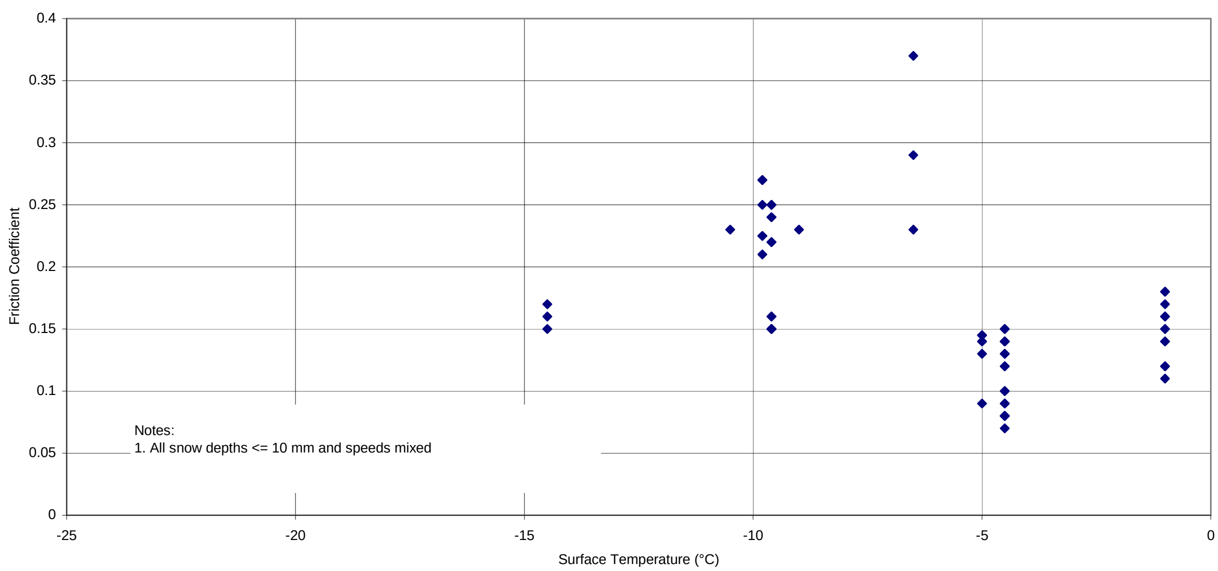

**E.5-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Surface Temperature**



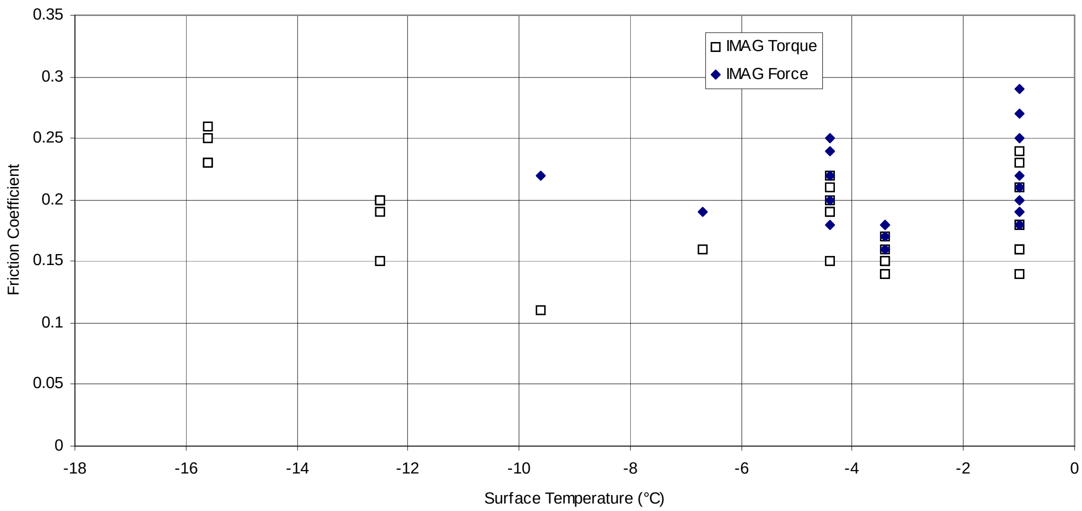

**E.5-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



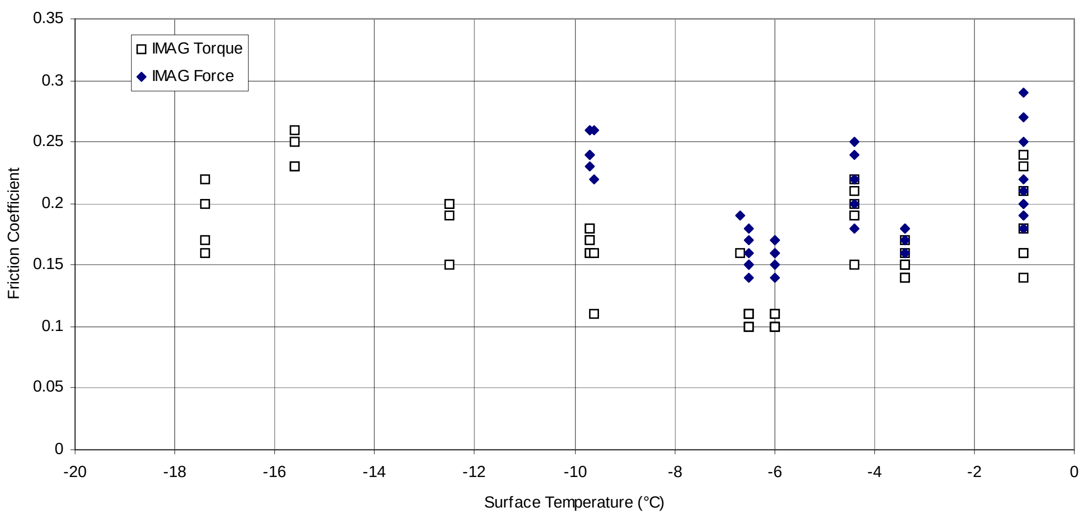

**E.5-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Surface Temperature**



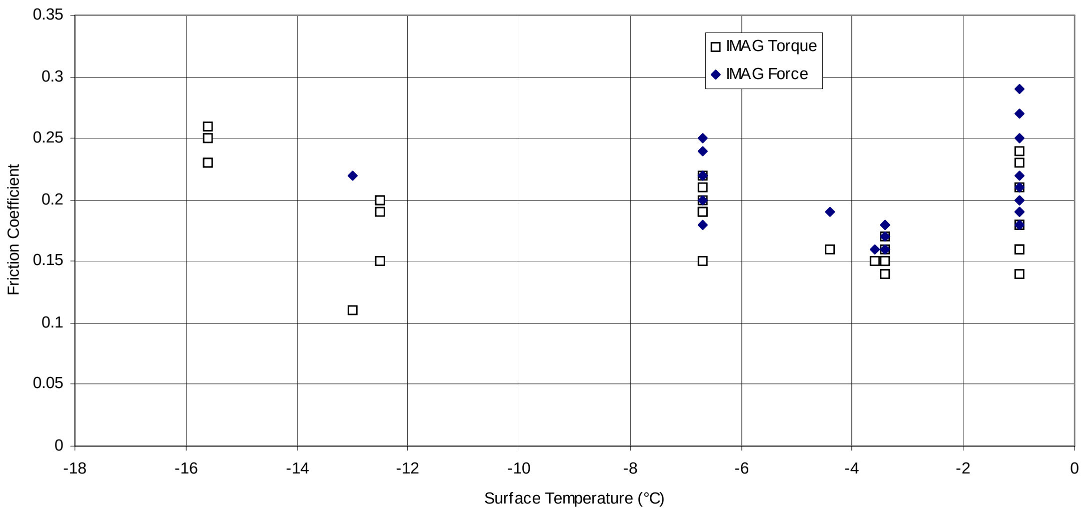

**E.5-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Surface Temperature**



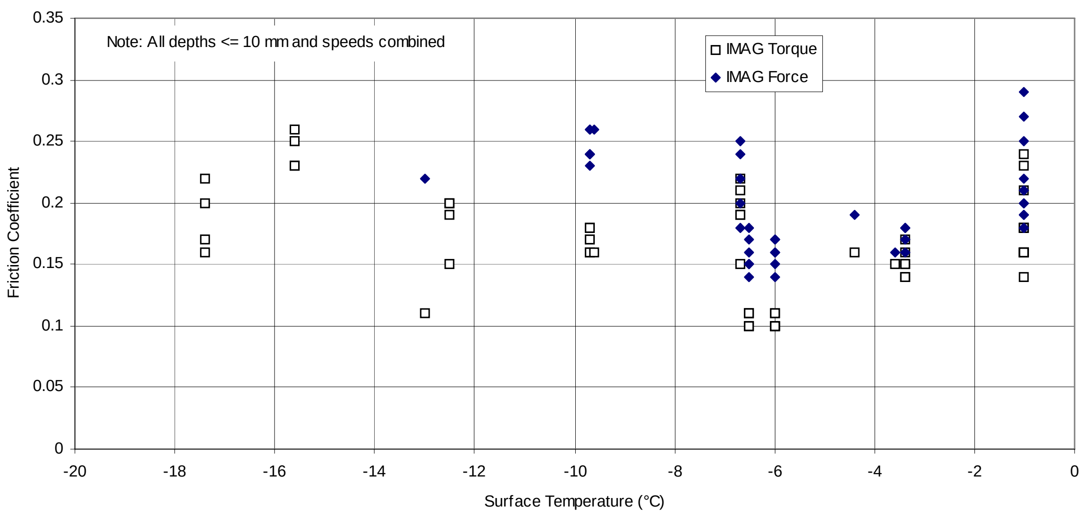

**E.5-7: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Ice**




**E.5-8: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Ice Including Rough Ice**



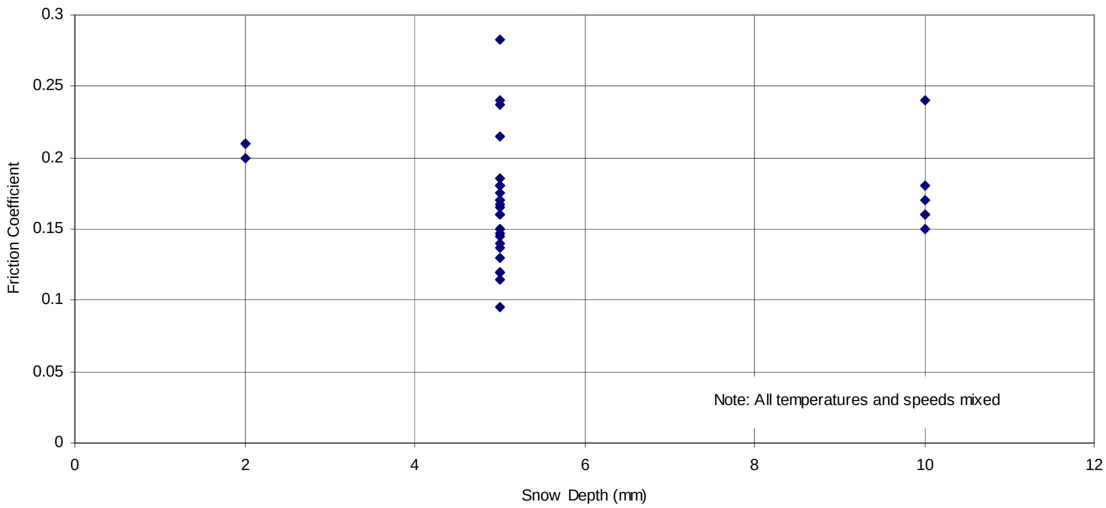

**E.5-9: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Ice**



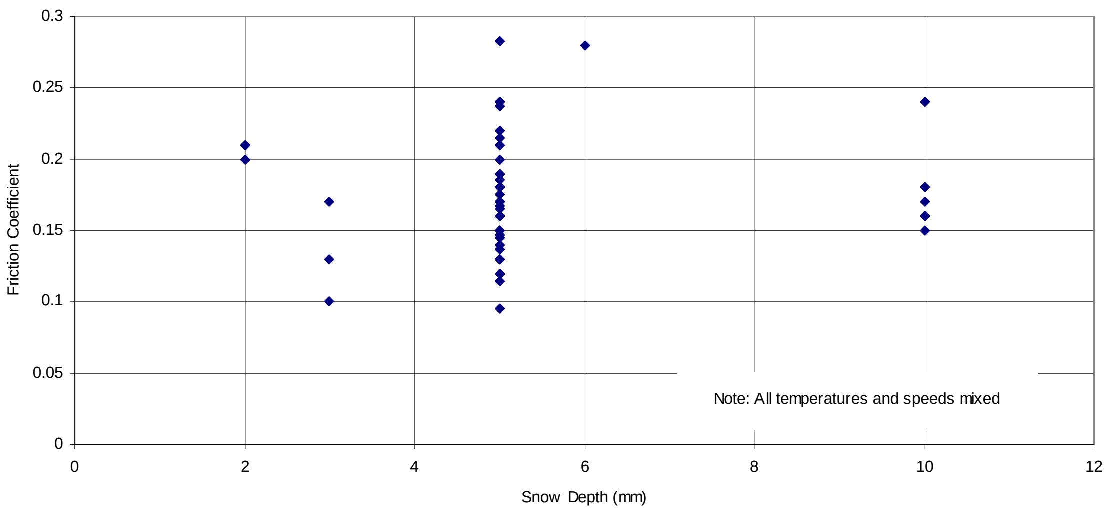

**E.5-10: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice**

# APPENDIX E.6

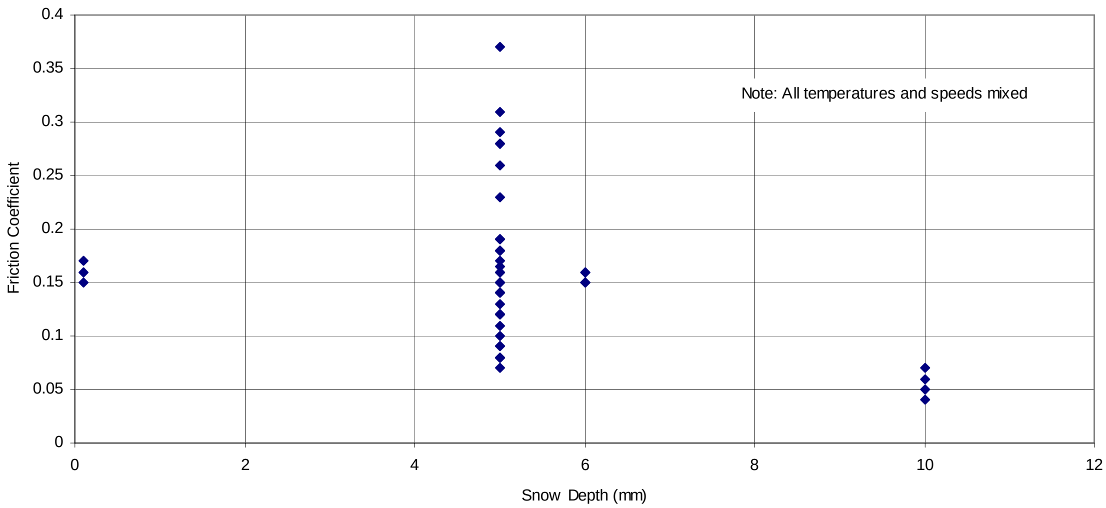
# TREND PLOTS VS. SNOW DEPTH
# (SNOW DEPTHS 10 MM OR LESS)



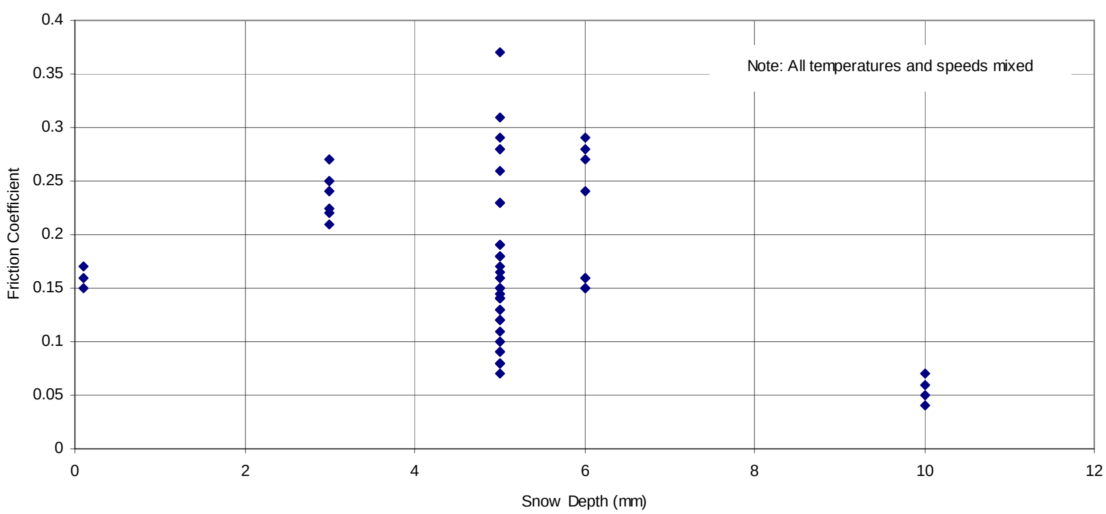

**E.6-1: ERD Readings for Snow on an Ice Base: Effect of Snow Depth**



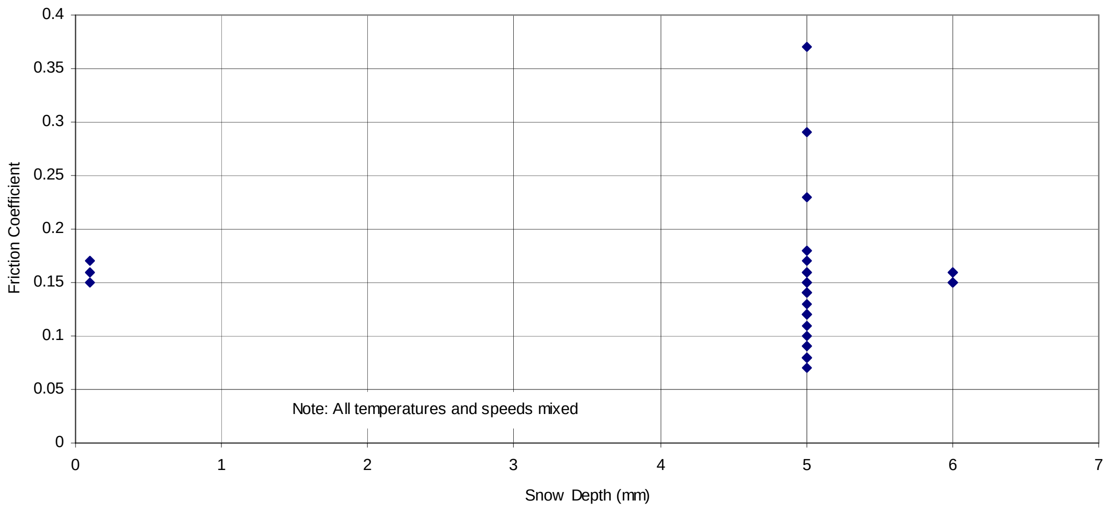

**E.6-2: ERD Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



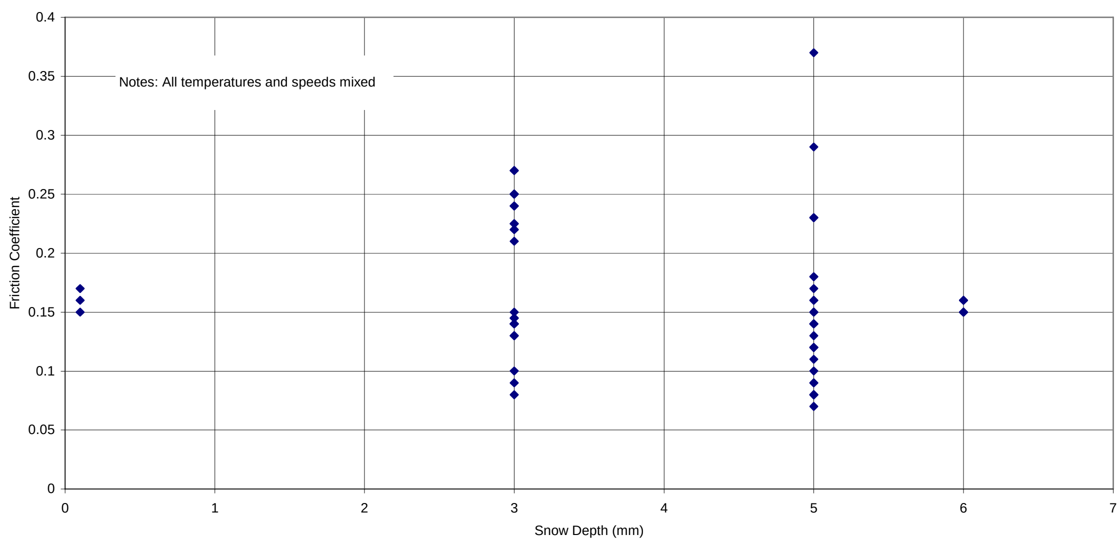

**E.6-3: TC SFT'79 (All Configurations) Readings for Snow on an Ice Base: Effect of Snow Depth**



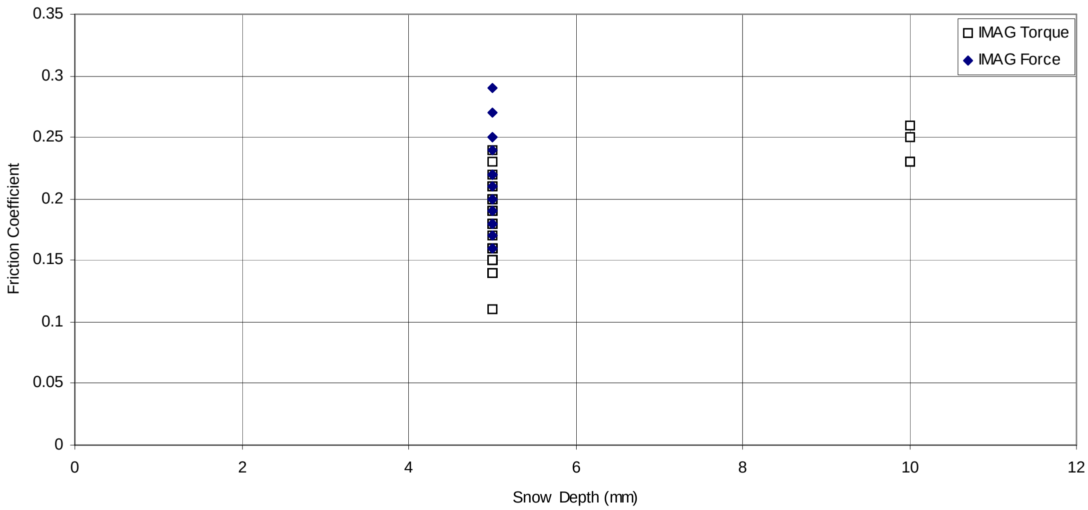

**E.6-4: TC SFT'79 (All Configurations) Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



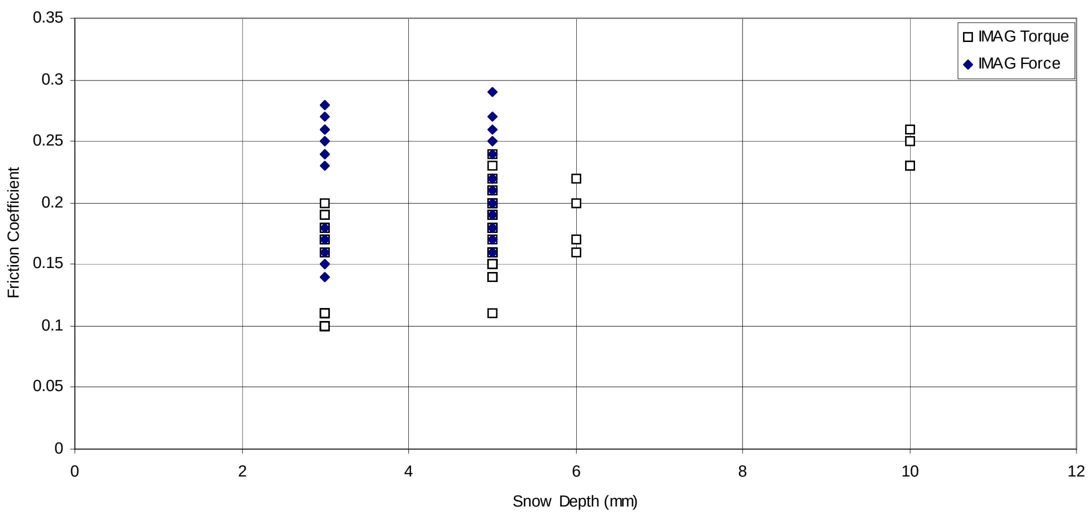

**E.6-5: TC SFT'79 (Configuration 3) Readings for Snow on an Ice Base: Effect of Snow Depth**



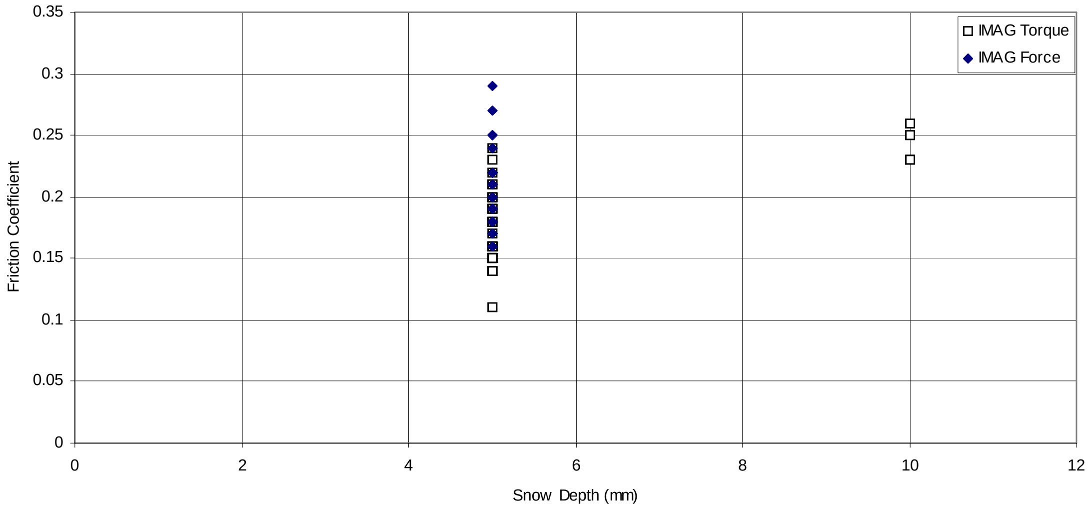

**E.6-6: TC SFT'79 (Configuration 3) Readings for Snow on Ice Including Rough Ice: Effect of Snow Depth**



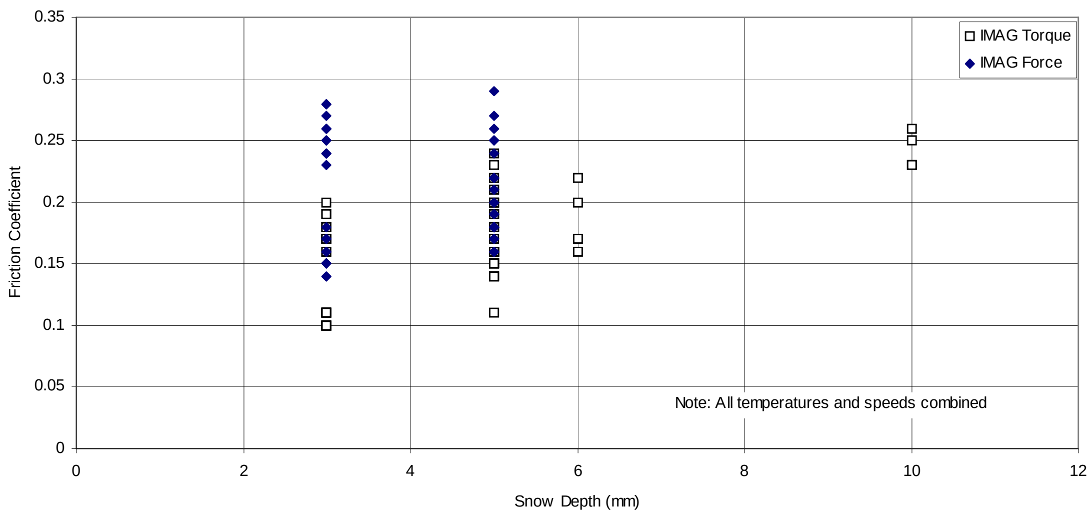

**E.6-7: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Ice**




**E.6-8: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Ice Including Rough Ice**




**E.6-9: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Ice**




**E.6-10: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Ice Including Rough Ice**

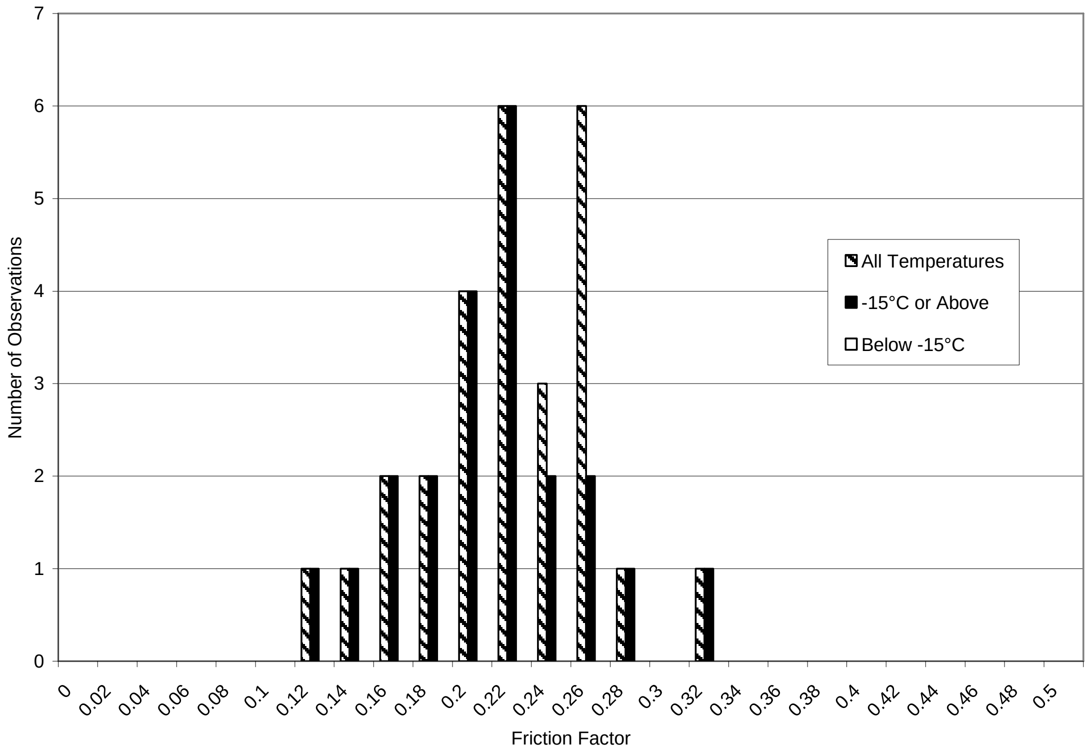
# APPENDIX F

## RESULTS FOR SNOW ON PACKED SNOW

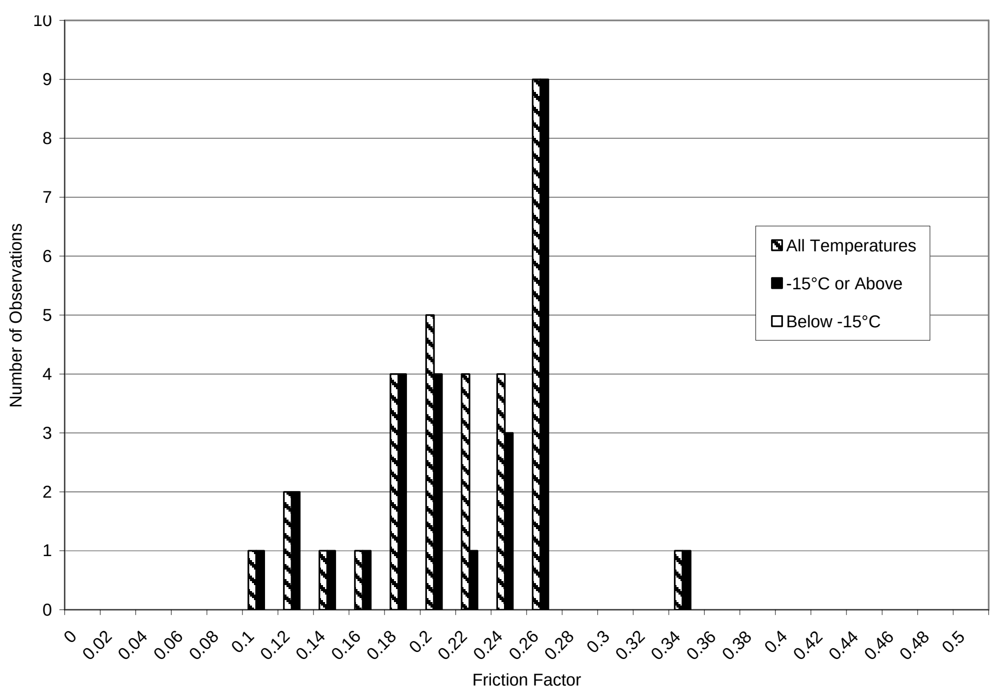
Contents

APPENDIX F.1

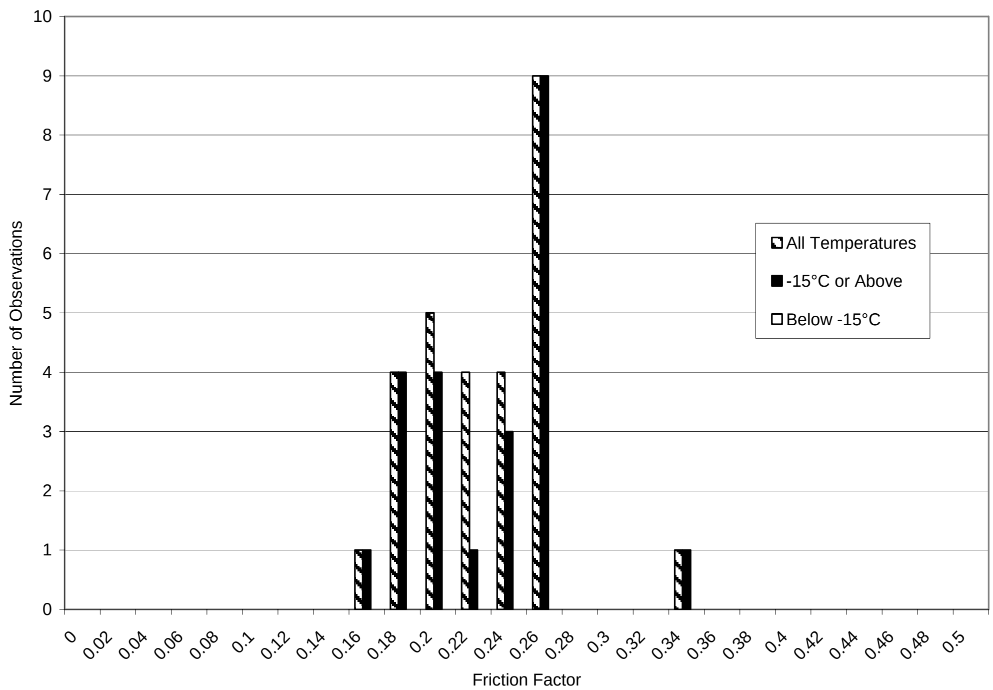
HISTOGRAMS
(ALL SNOW DEPTHS)



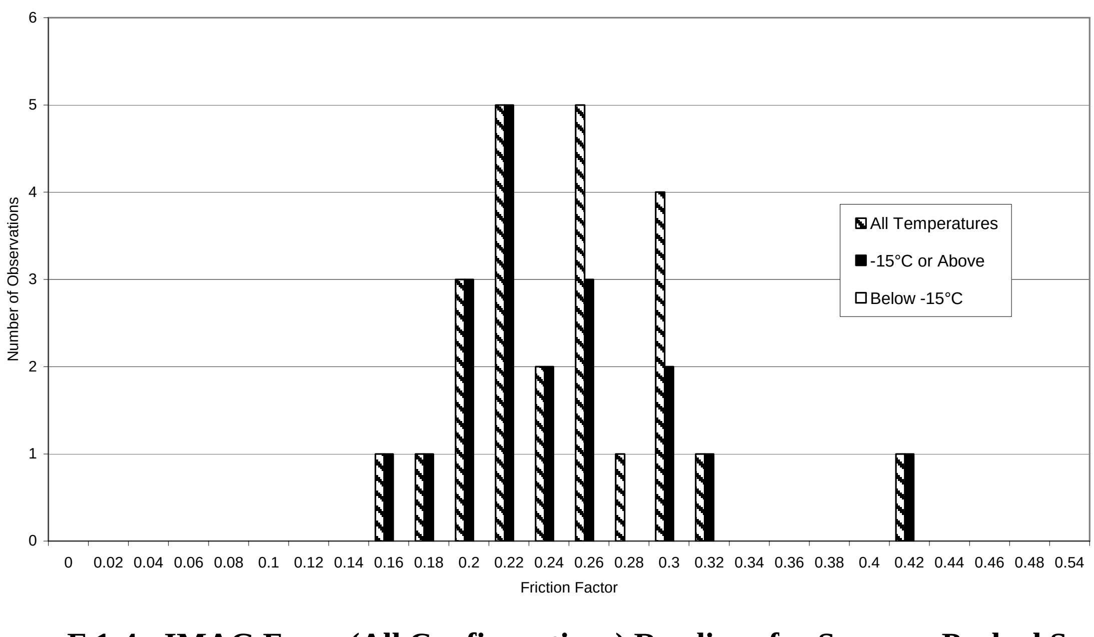

**F.1-1: ERD Readings for Snow on a Packed Snow Base: Effect of Temperature**



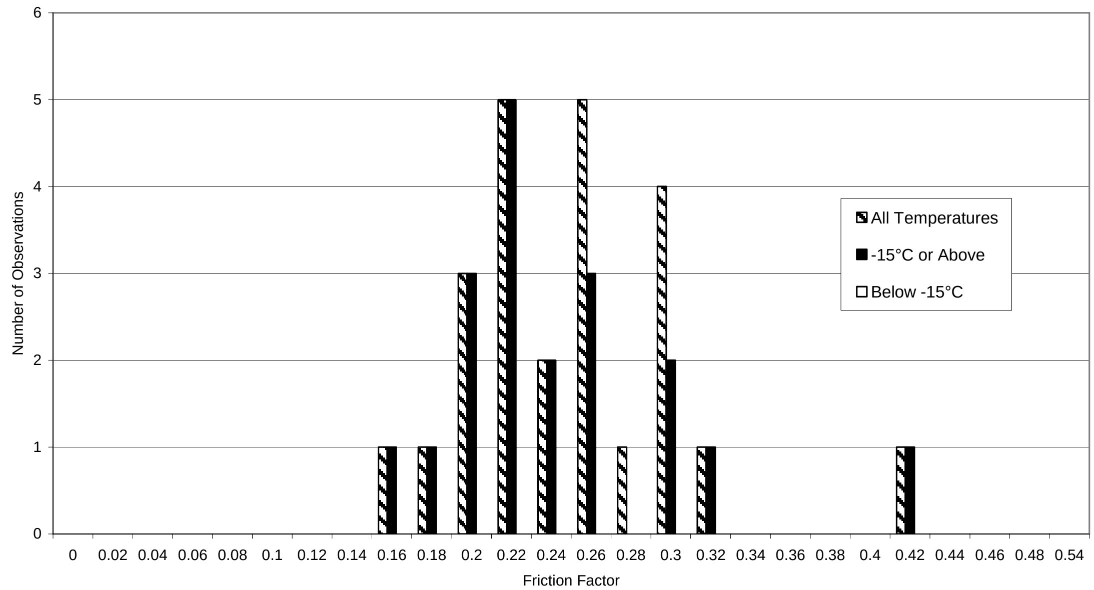

**F.1-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Temperature**



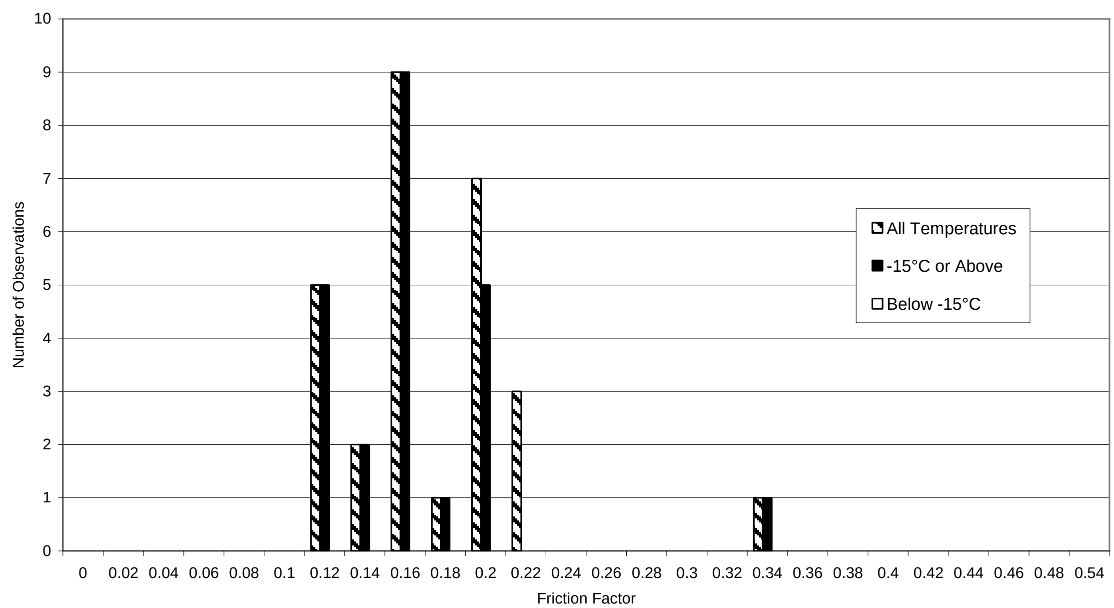

**F.1-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Temperature**



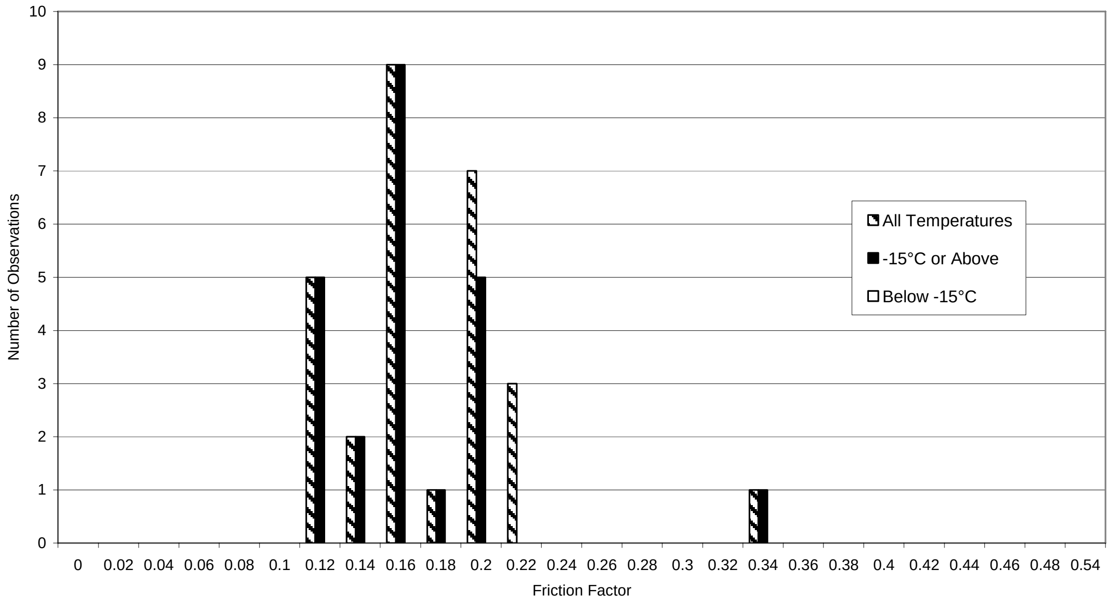

**F.1-4: IMAG Force (All Configurations) Readings for Snow on Packed Snow: Effect of Temperature**




**F.1-5: IMAG Force (Configurations 3 and 7) Readings for Snow on Packed Snow: Effect of Temperature**



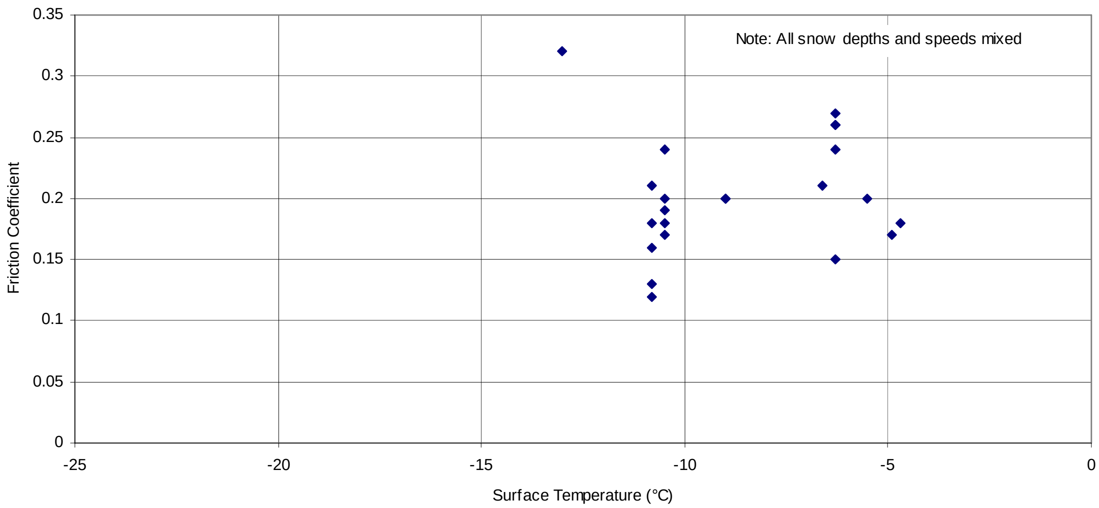

**F.1-6: IMAG Torque (All Configurations) Readings for Snow on Packed Snow: Effect of Temperature**



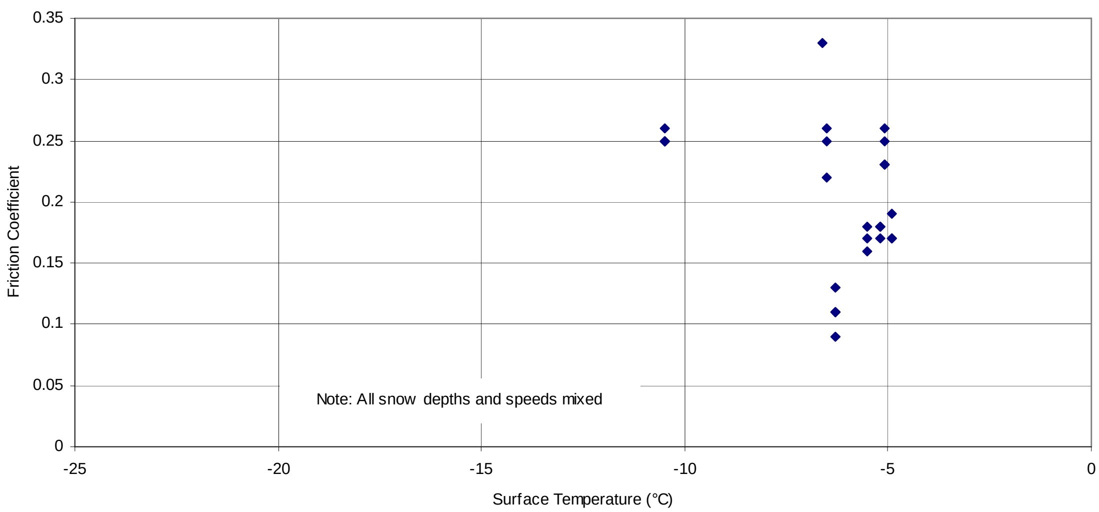

**F.1-7: IMAG Torque (Configurations 3 and 7) Readings for Snow on Packed Snow: Effect of Temperature**

APPENDIX F.2

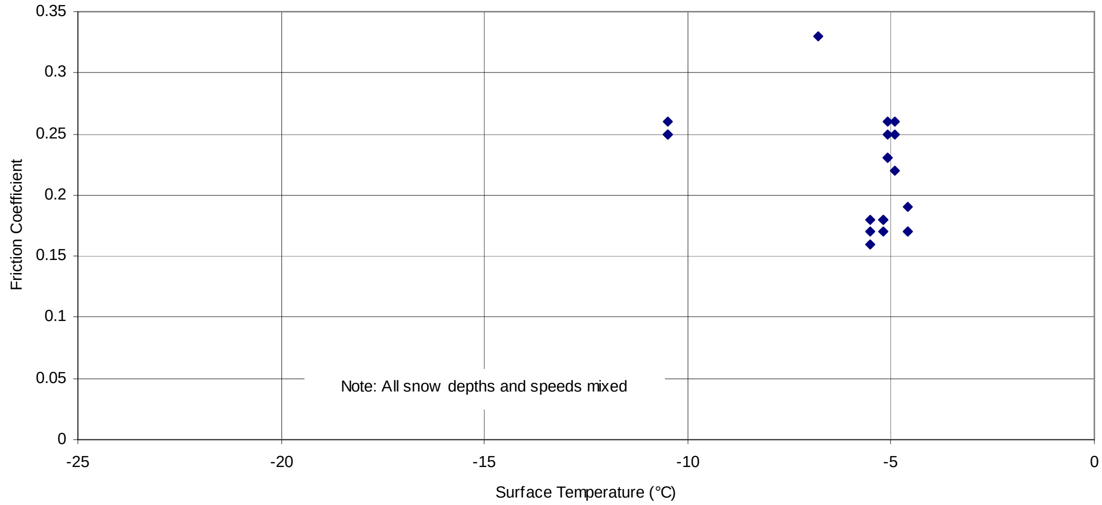
TREND PLOTS VS. SURFACE TEMPERATURE
(ALL SNOW DEPTHS)



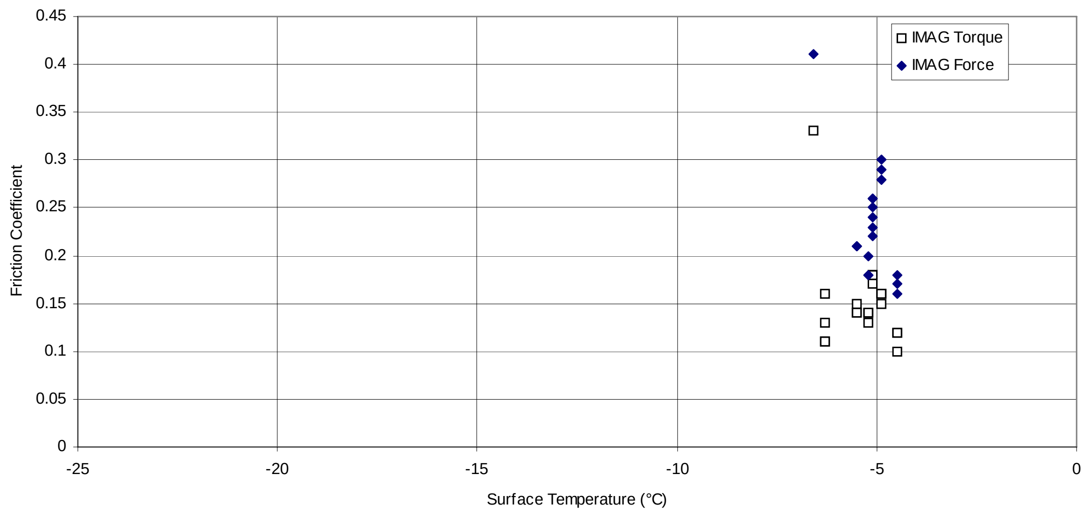

**F.2-1: ERD Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**



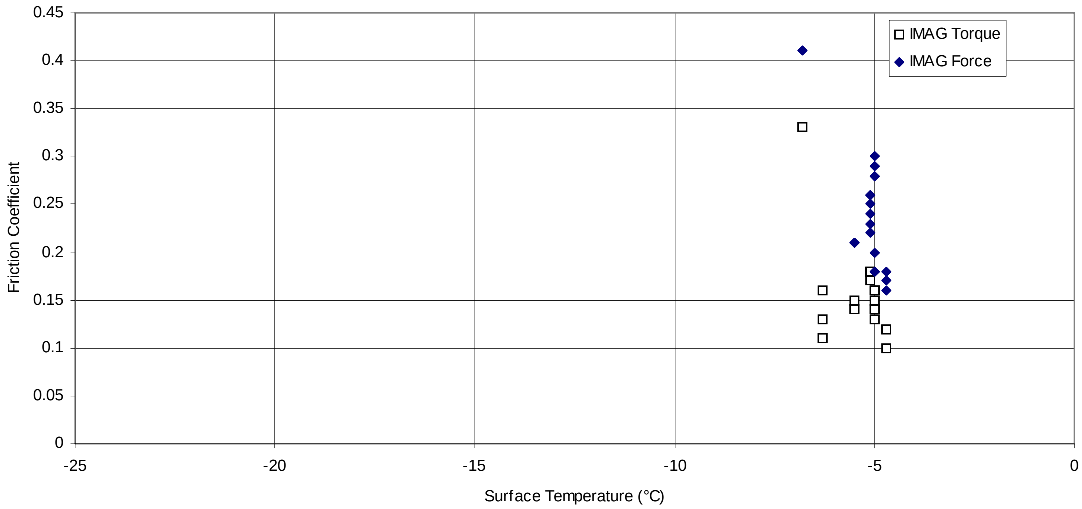

**F.2-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**




**F.2-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**



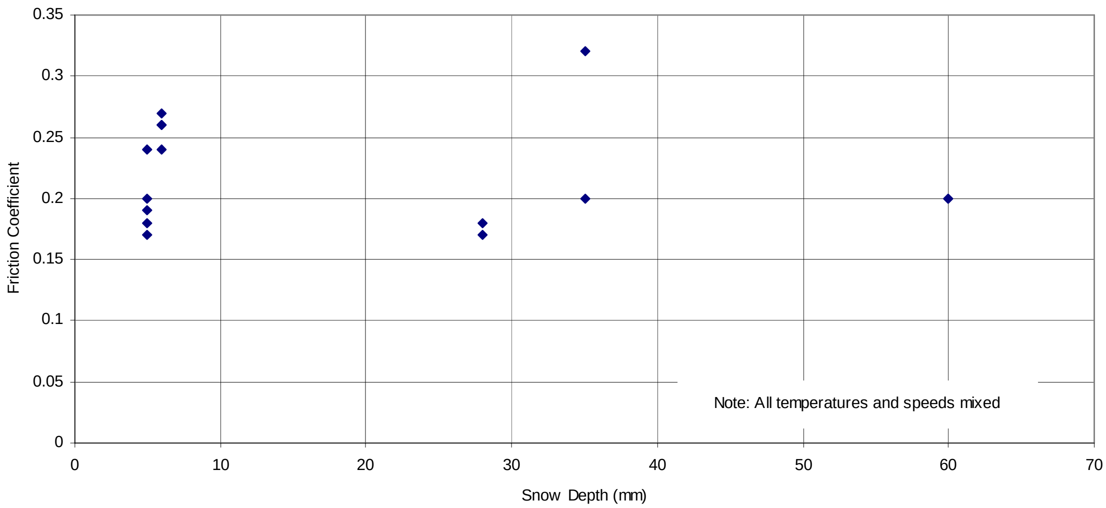

**F.2-4: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Packed Snow**



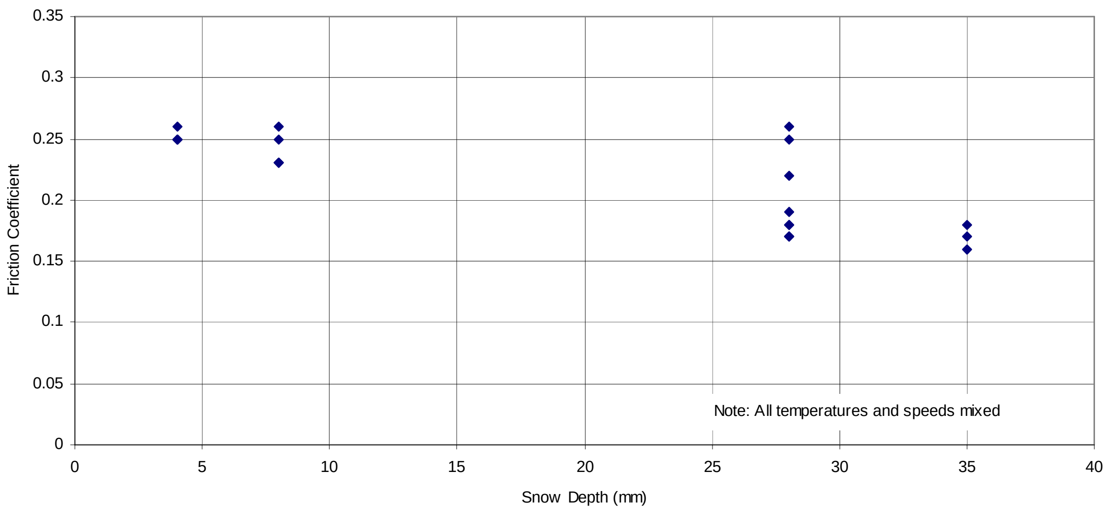

**F.2-5: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Packed Snow**

# APPENDIX F.3

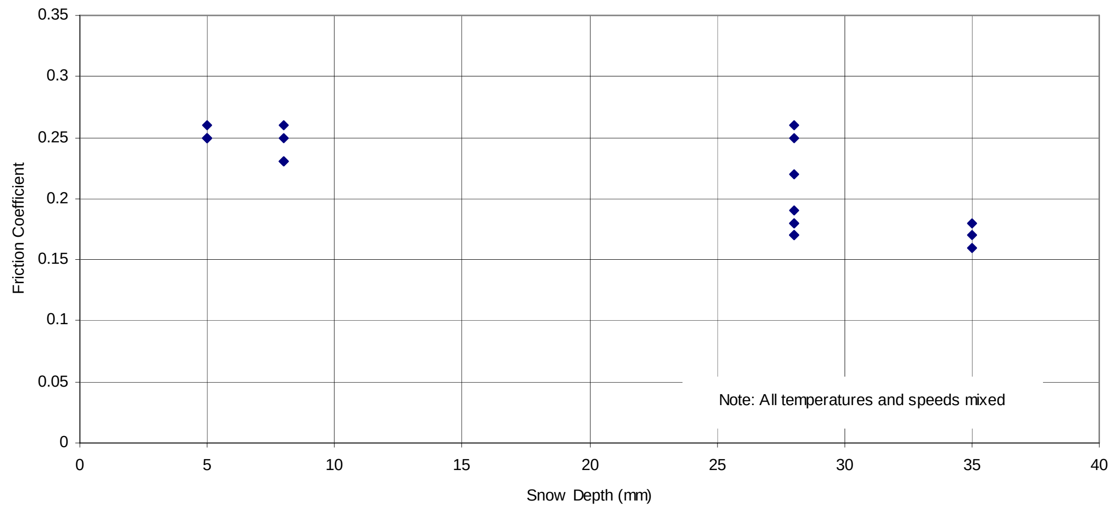
## TREND PLOTS VS. SNOW DEPTH
## (ALL SNOW DEPTHS)



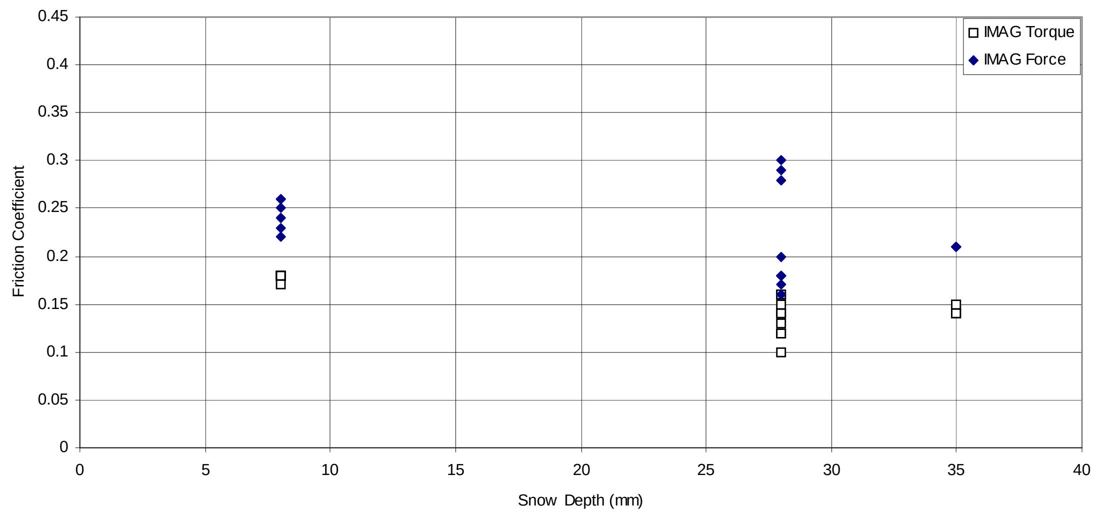

**F.3-1: ERD Readings for Snow on a Packed Snow Base: Effect of Snow Depth**



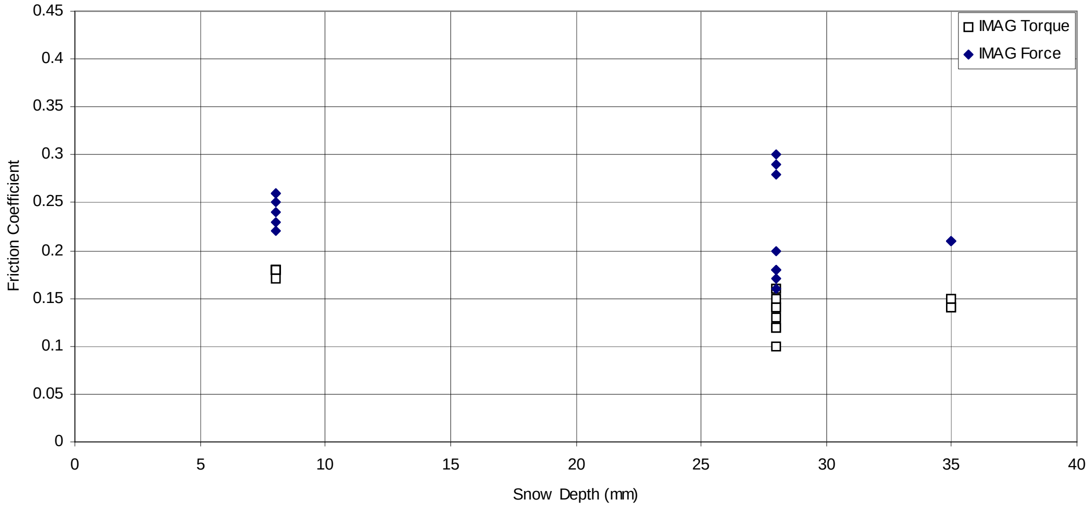

**F.3-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Snow Depth**




**F.3-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Snow Depth**



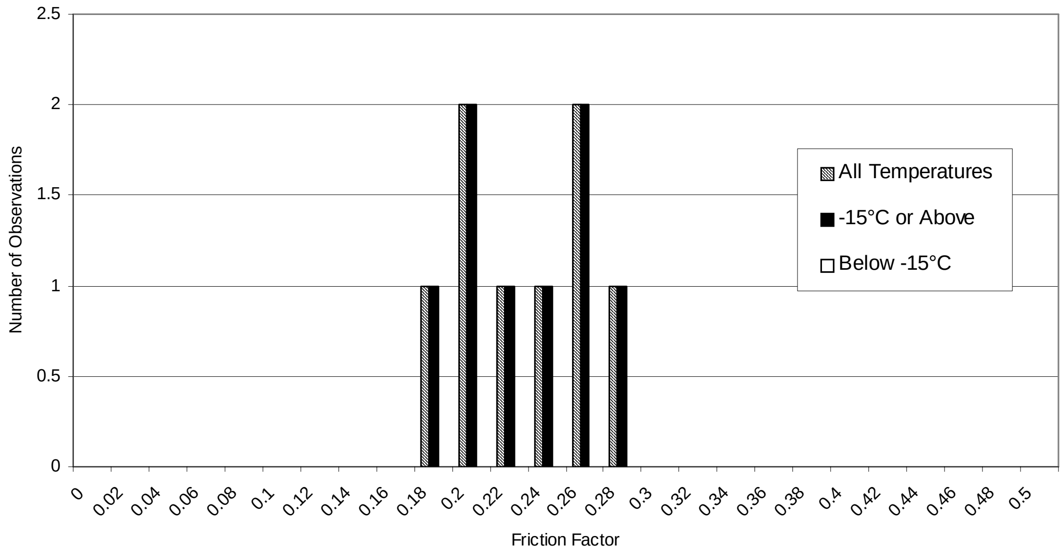

**F.3-4: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Packed Snow**



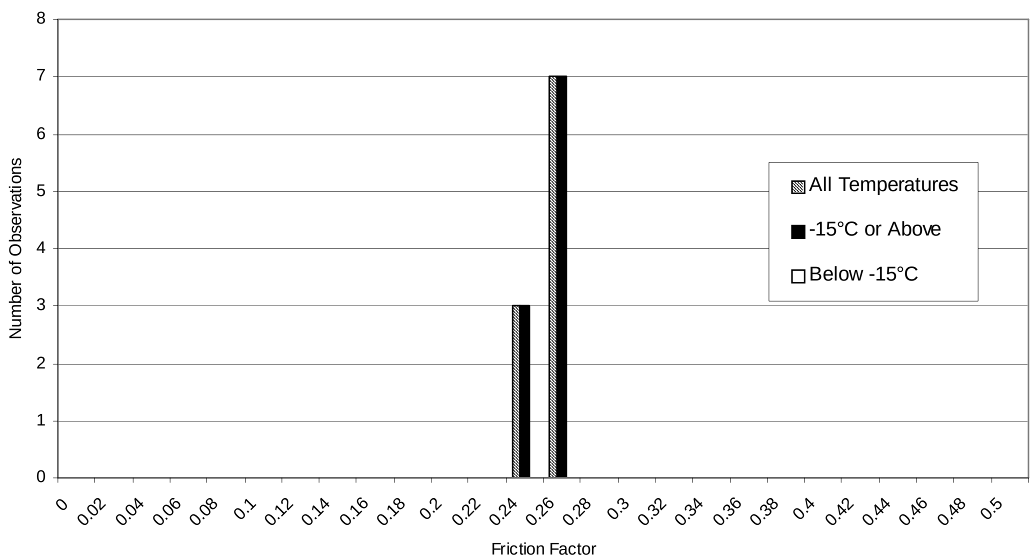

**F.3-5: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Packed Snow**

# APPENDIX F.4

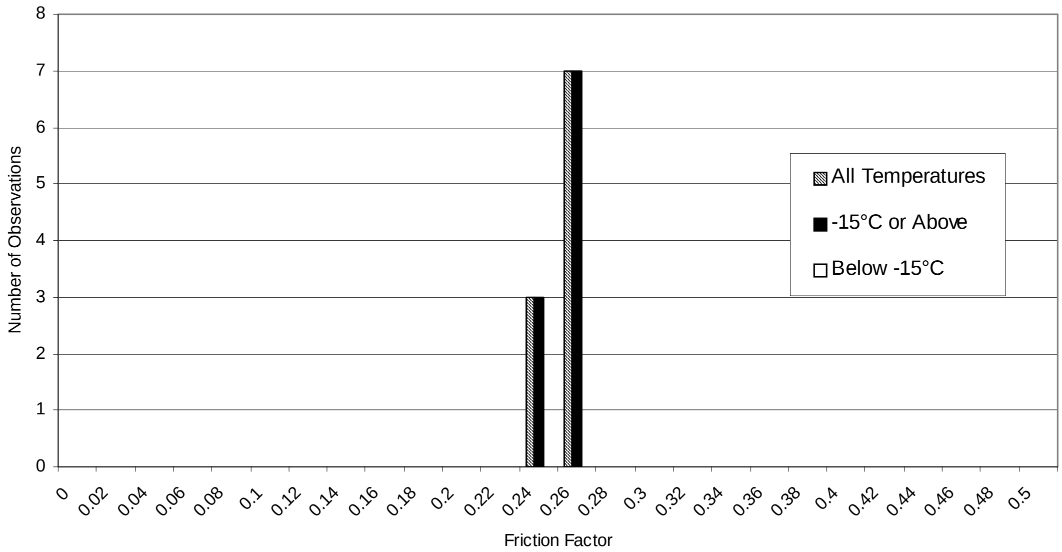
## HISTOGRAMS FOR SNOW ON PACKED SNOW
## (SNOW DEPTHS 10 MM OR LESS)



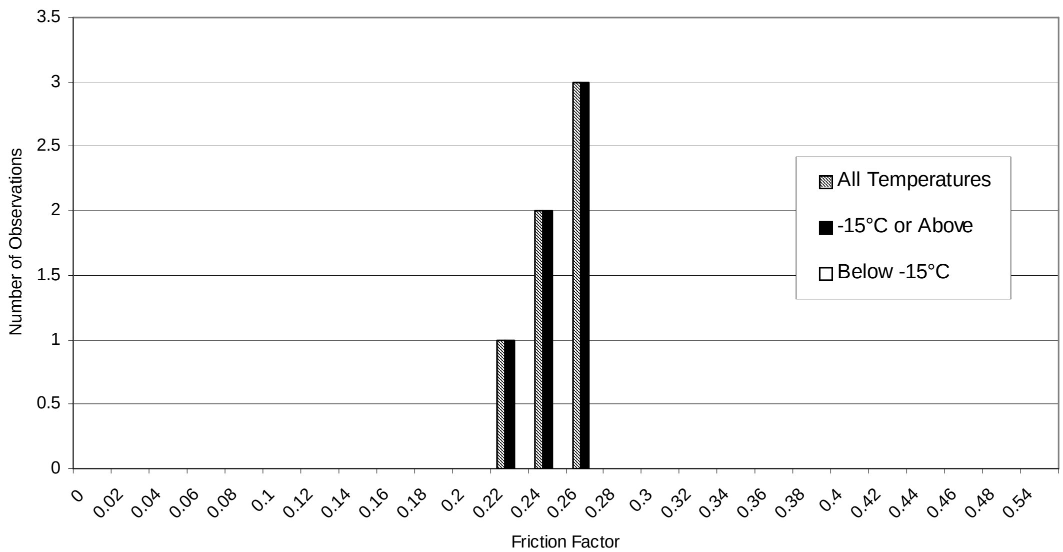

**F.4-1: ERD Readings for Snow on a Packed Snow Base: Effect of Temperature**



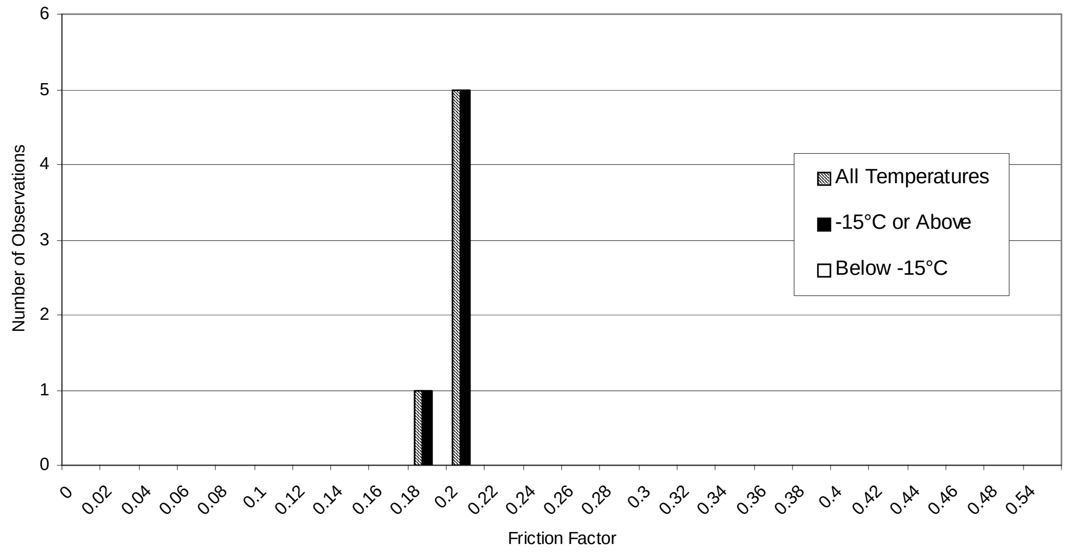

**F.4-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Temperature**



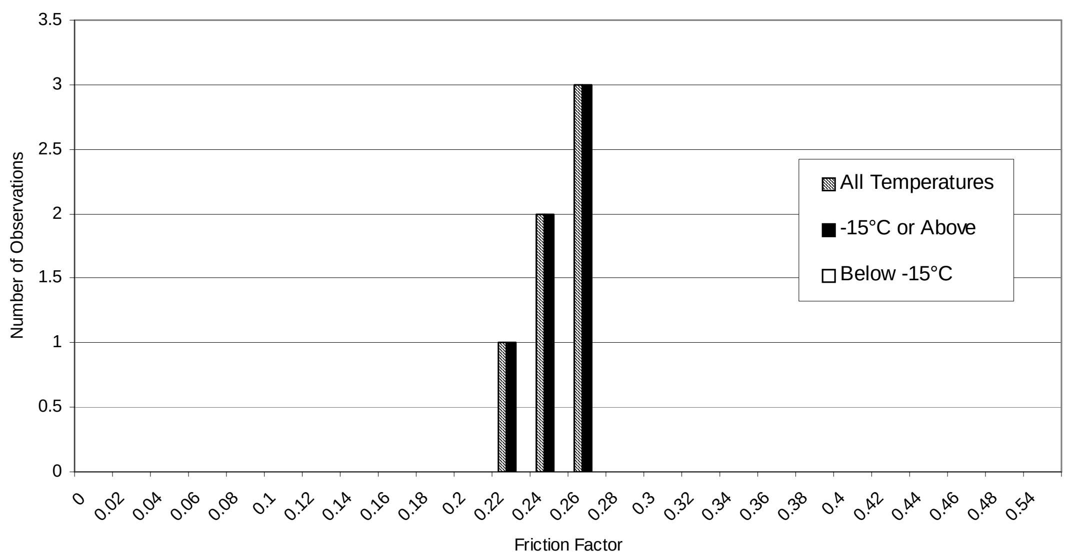

**F.4-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Temperature**



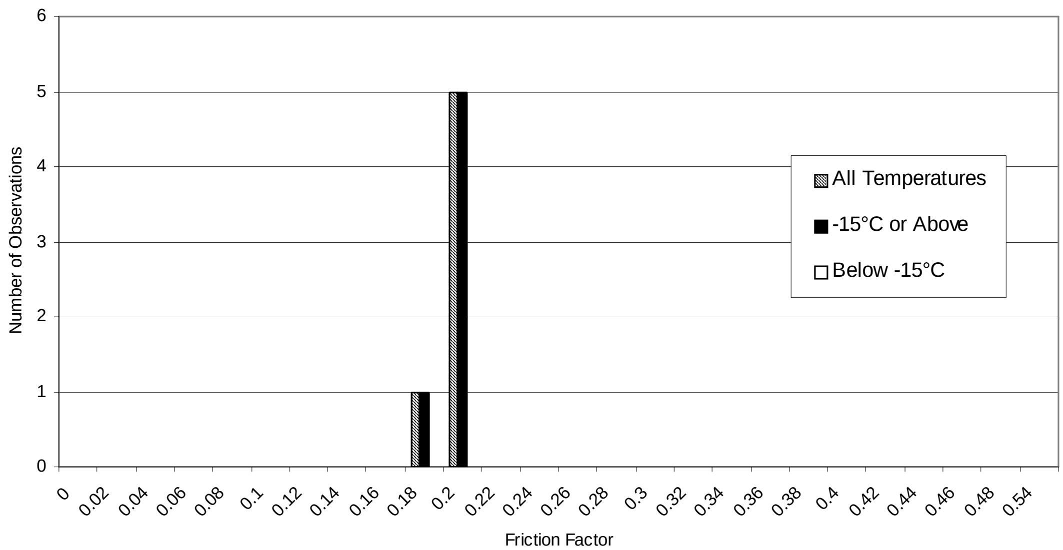

**F.4-4: IMAG Force (All Configurations) Readings for Snow on Packed Snow: Effect of Temperature**




**F.4-5: IMAG Torque (All Configurations) Readings for Snow on Packed Snow: Effect of Temperature**



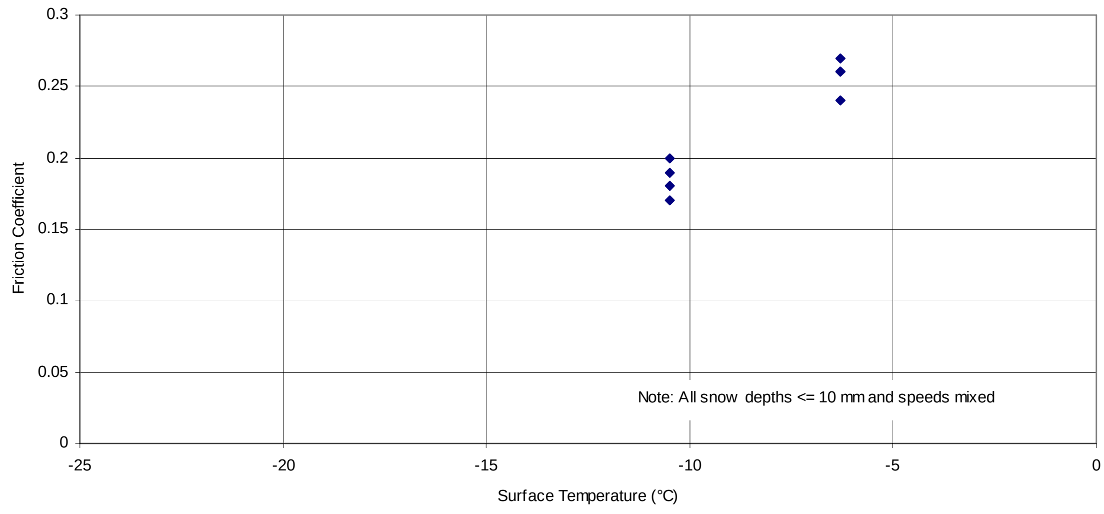

**F.4-6: IMAG Force (Configurations 3 and 7) Readings for Snow on Packed Snow: Effect of Temperature**



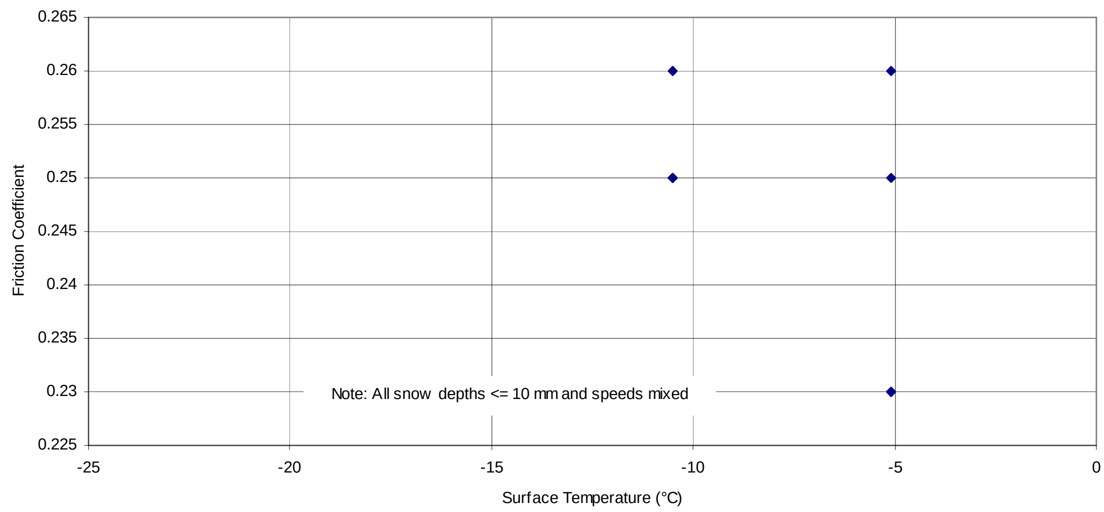

**F.4-7: IMAG Torque (Configurations 3 and 7) Readings for Snow on a Packed Snow: Effect of Temperature**

# APPENDIX F.5

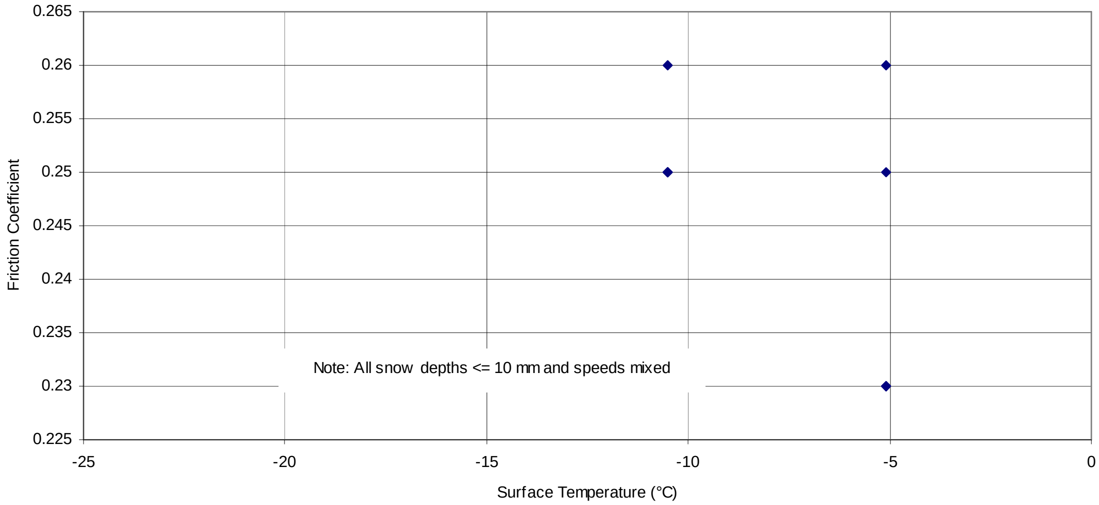
# TREND PLOTS VS. SURFACE TEMPERATURE
(SNOW DEPTHS 10 MM OR LESS)



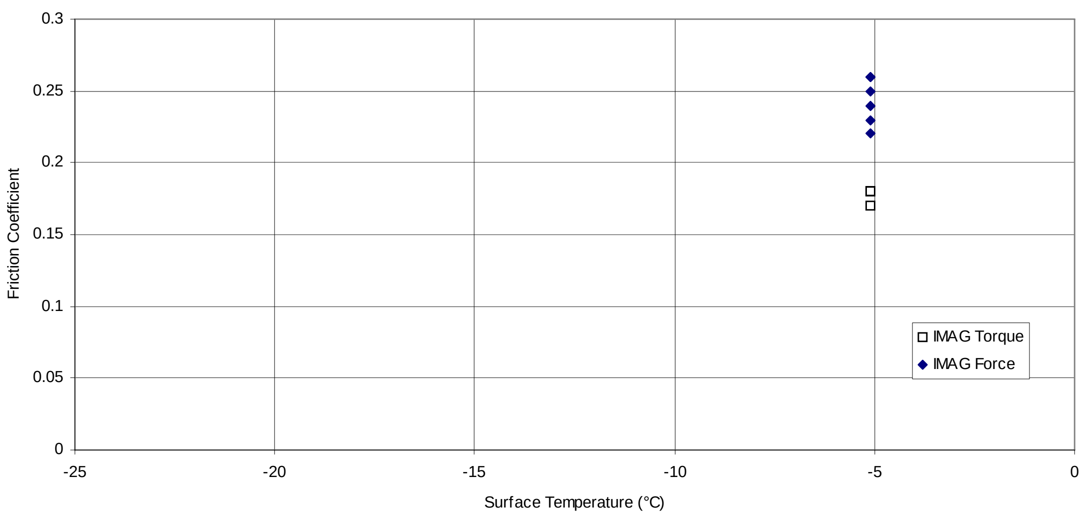

**F.5-1: ERD Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**



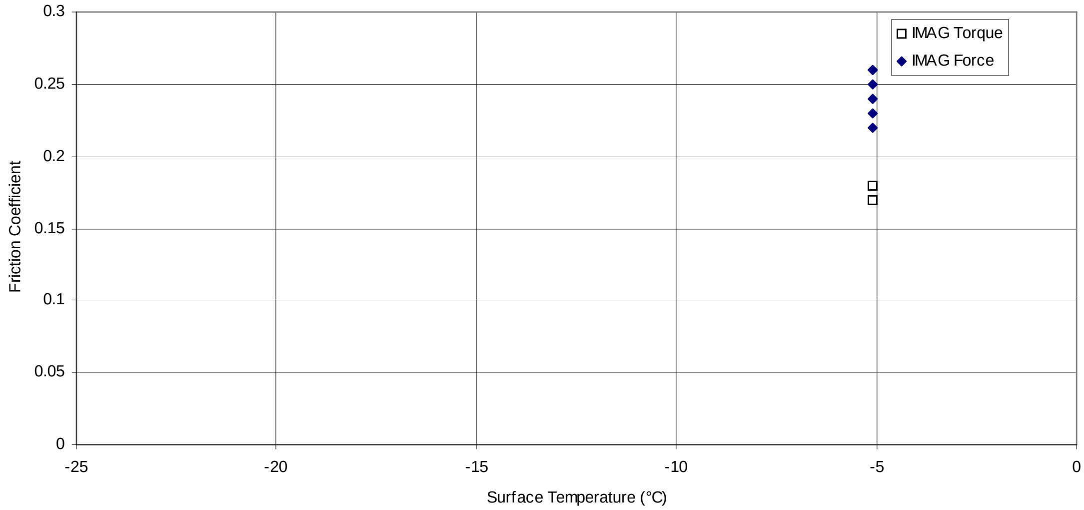

**F.5-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**




**F.5-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Surface Temperature**



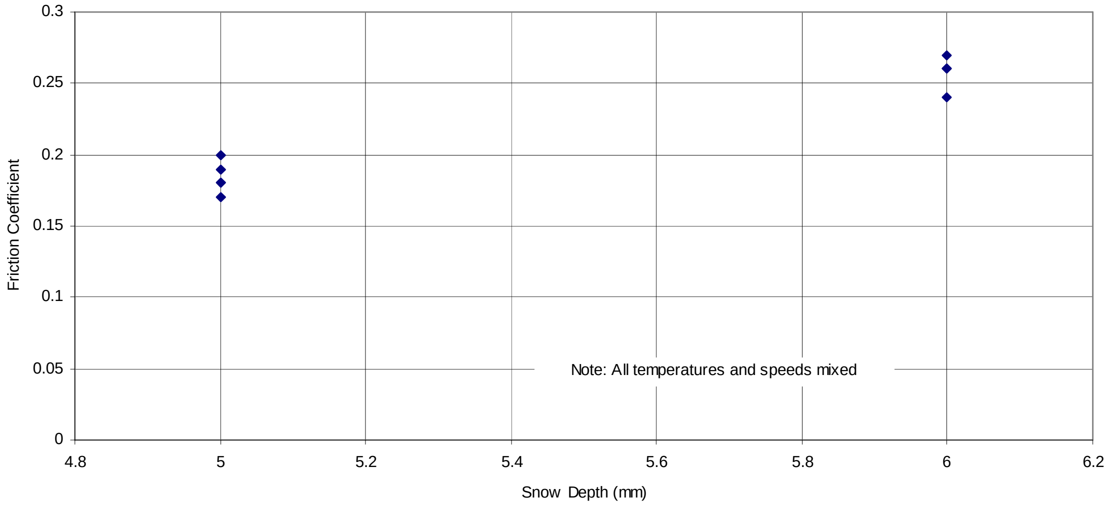

**F.5-4: Effect of Temperature: IMAG (All Configurations) Readings for Snow on Packed Snow**



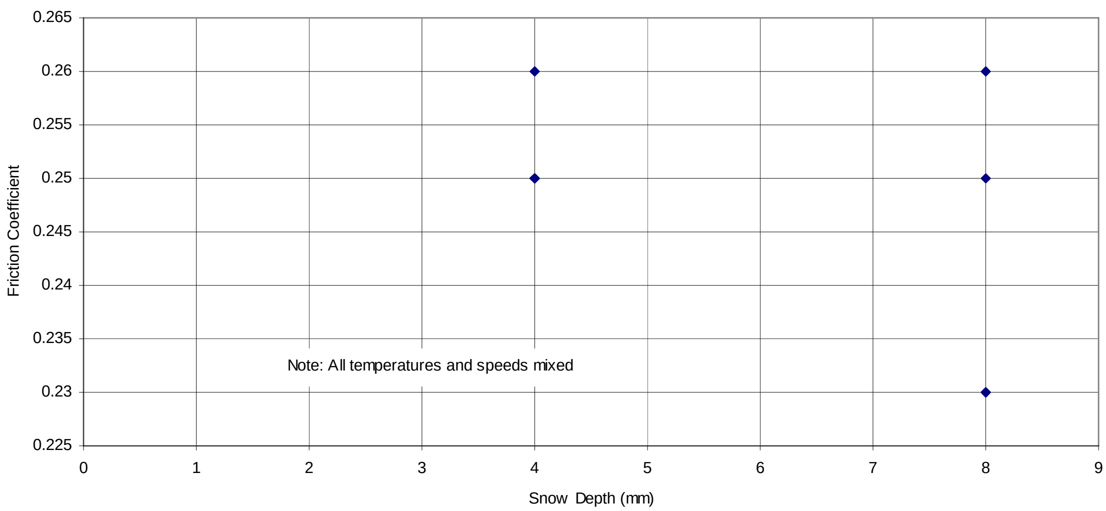

**F.5-5: Effect of Temperature: IMAG (Configurations 3 and 7) Readings for Snow on Packed Snow**

# APPENDIX F.6

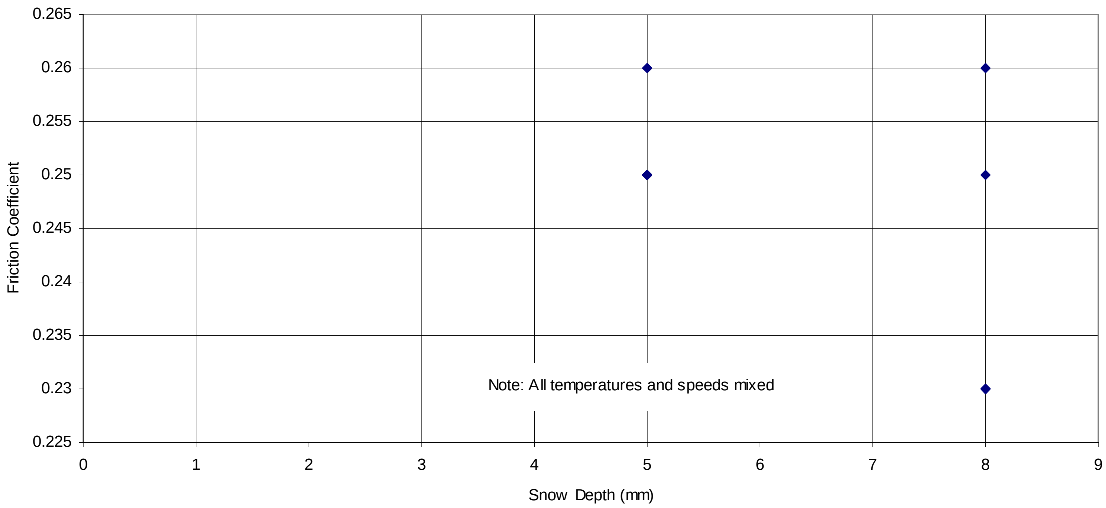
## TREND PLOTS VS. SNOW DEPTH
## (SNOW DEPTHS 10 MM OR LESS)



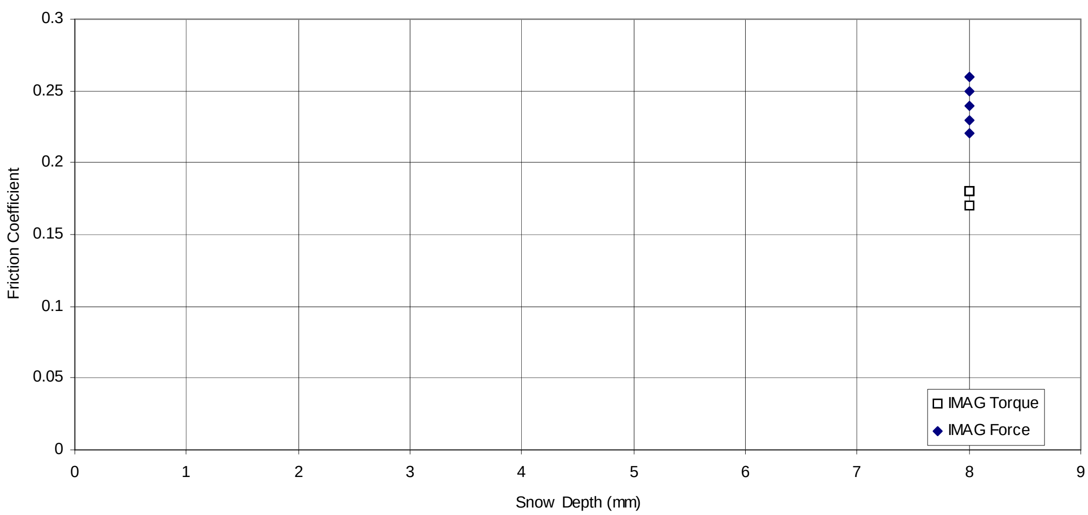

**F.6-1: ERD Readings for Snow on a Packed Snow Base: Effect of Snow Depth**



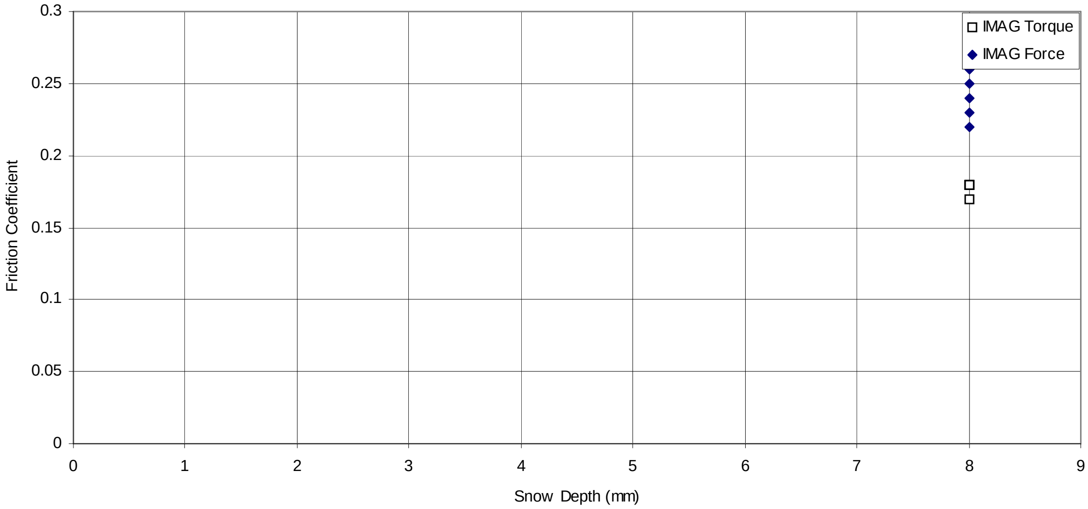

**F.6-2: TC SFT'79 (All Configurations) Readings for Snow on a Packed Snow Base: Effect of Snow Depth**




**F.6-3: TC SFT'79 (Configuration 3) Readings for Snow on a Packed Snow Base: Effect of Snow Depth**



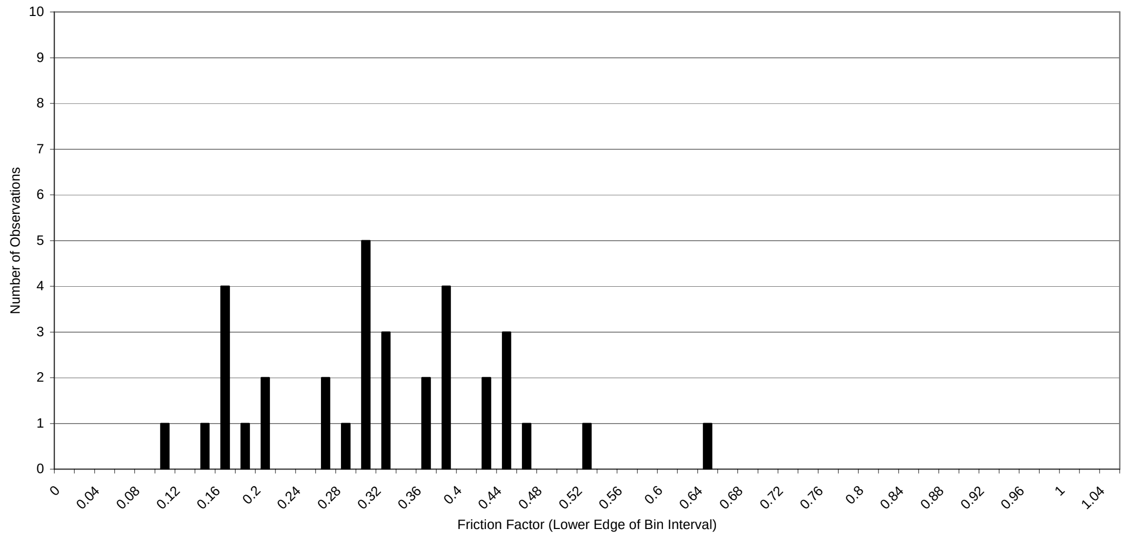

**F.6-4: Effect of Snow Depth: IMAG (All Configurations) Readings for Snow on Packed Snow**



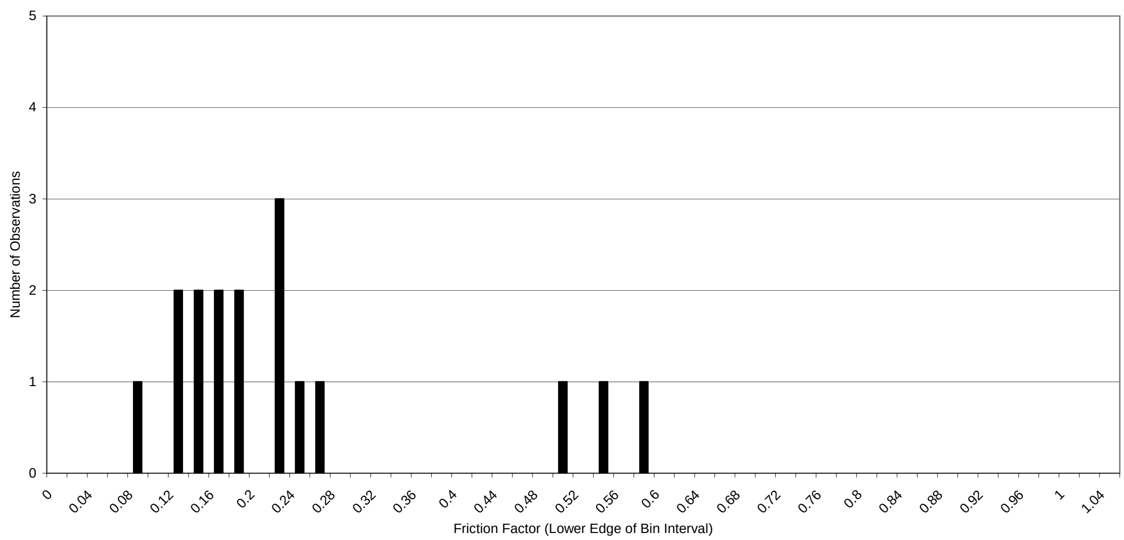

**F.6-5: Effect of Snow Depth: IMAG (Configurations 3 and 7) Readings for Snow on Packed Snow**

# APPENDIX G

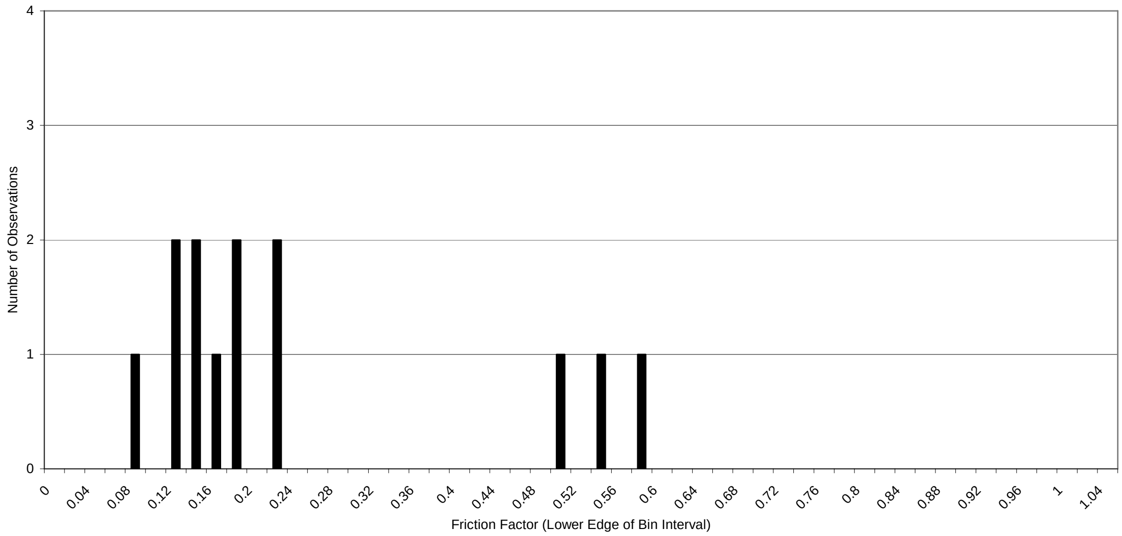
# RESULTS FOR SLUSH ON ANY BASE SURFACE



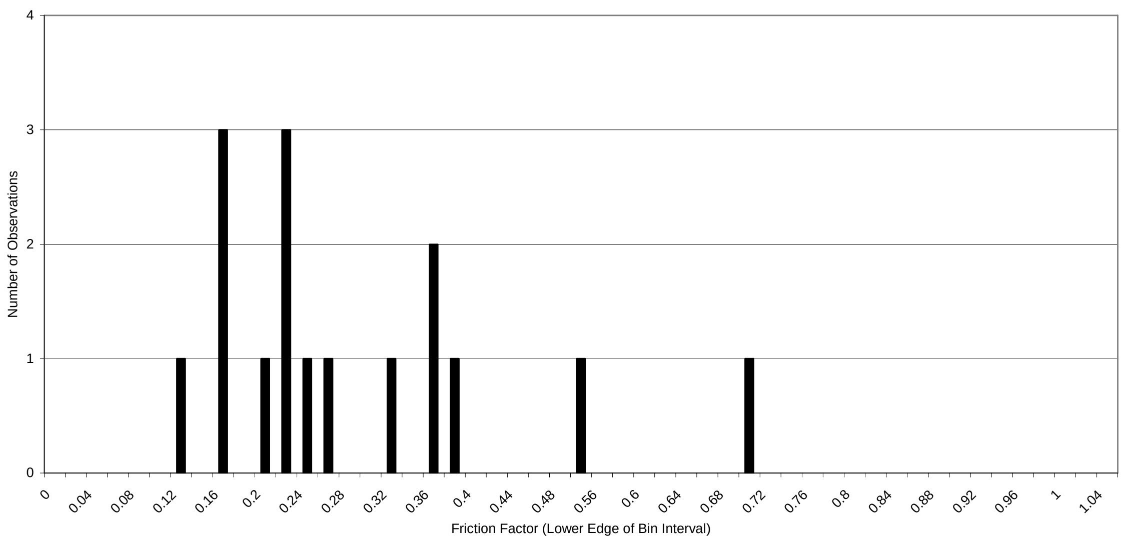

**G-1: ERD Readings on Slush (on all bases): All Temperatures Included**



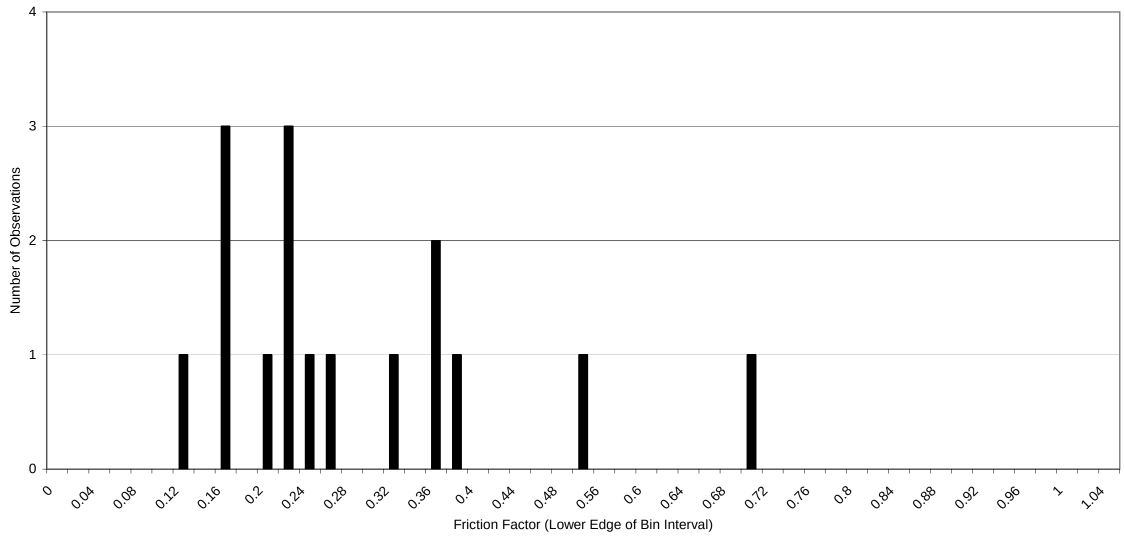

**G-2: TC SFT'79 (All Configurations) Readings on Slush (on all bases): All Temperatures Included**



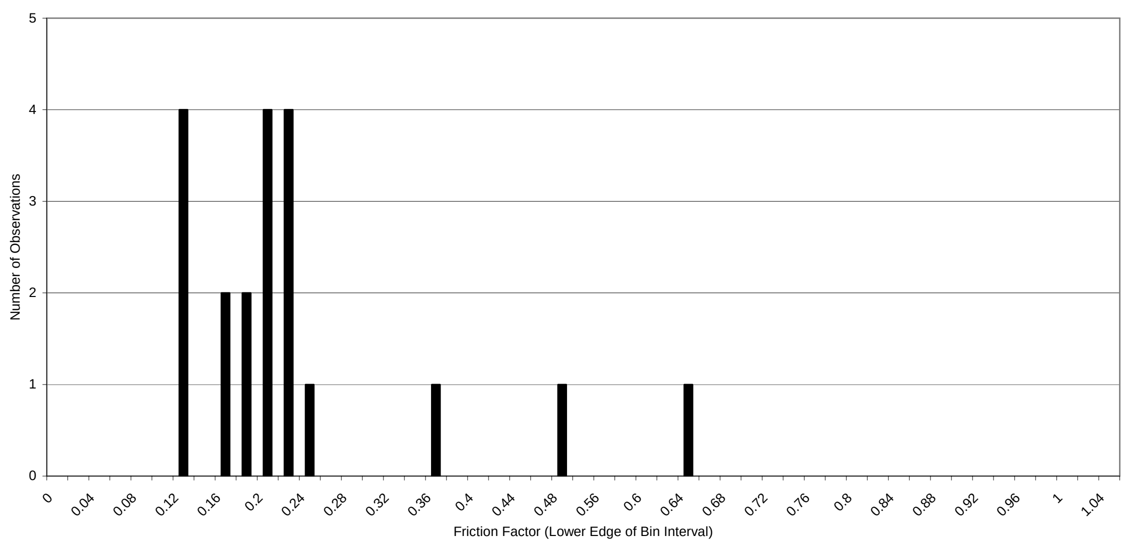

**G-3: TC SFT'79 (Configuration 3) Readings on Slush (on all bases): All Temperatures Included**



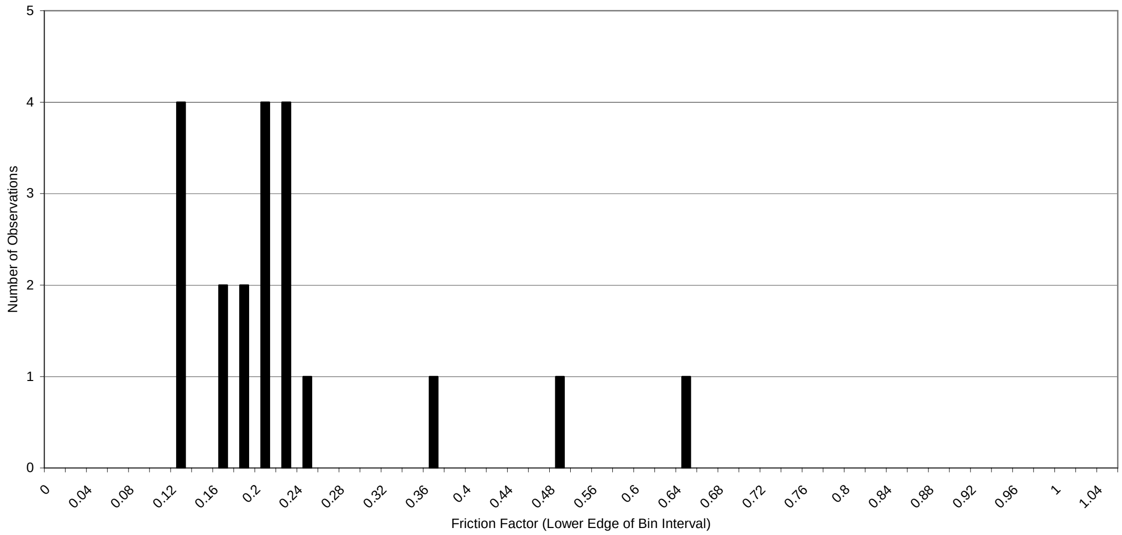

**G-4: IMAG Force (All Configurations) Readings on Slush (on all bases): All Temperatures Included**




**G-5: IMAG Force (Configurations 3 and 7) Readings on Slush (on all bases): All Temperatures Included**



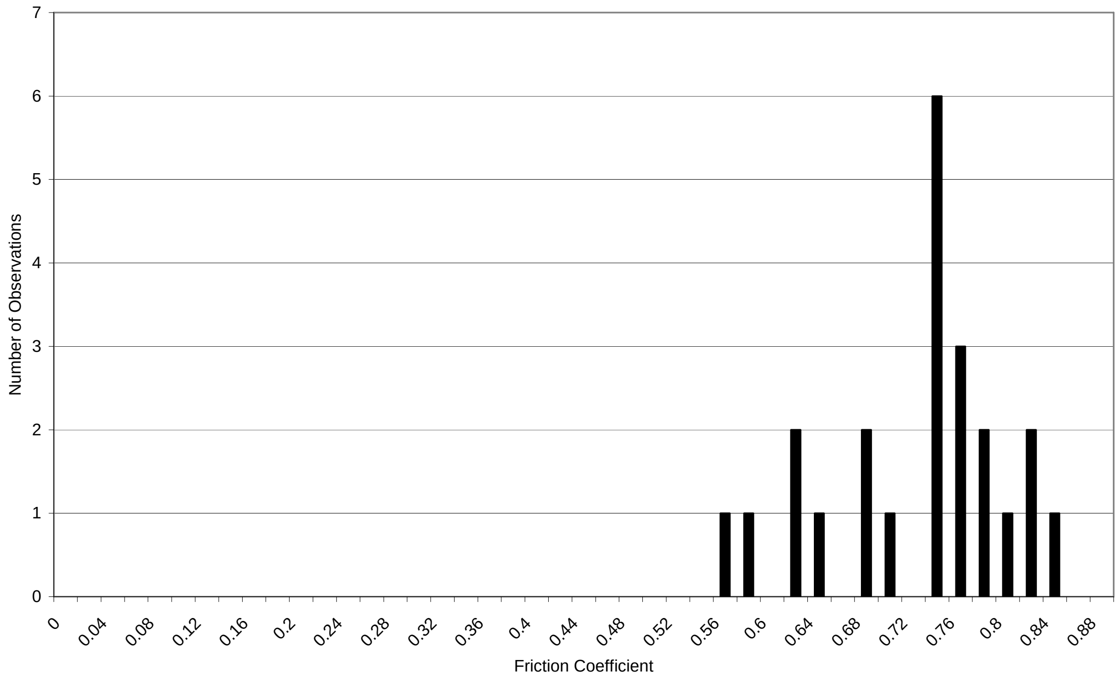

**G-6: IMAG Torque (All Configurations) Readings on Slush (on all bases): All Temperatures Included**



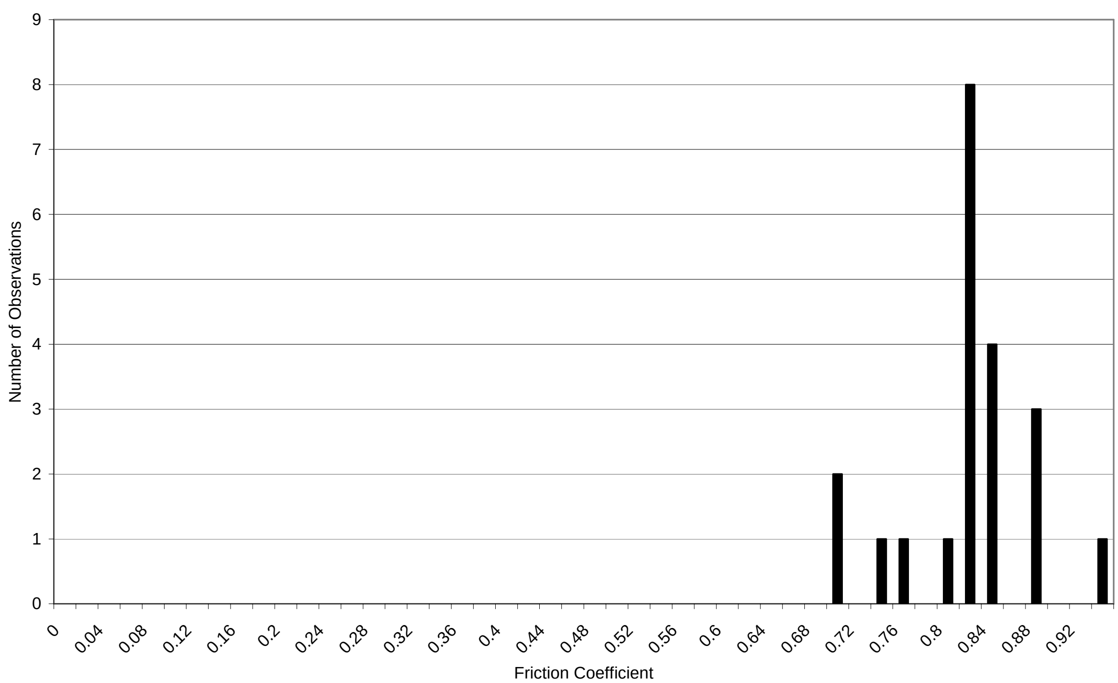

**G-7: IMAG Torque (Configurations 3 and 7) Readings on Slush (on all bases): All Temperatures Included**

# APPENDIX H

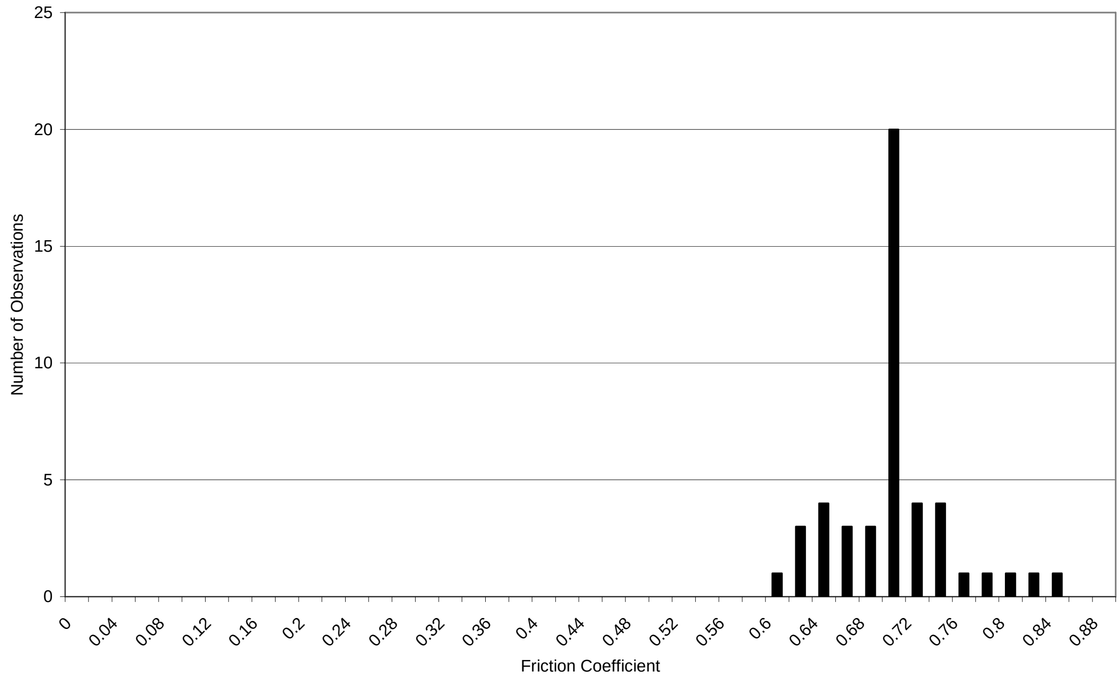
# RESULTS FOR WET OR DAMP PAVEMENT



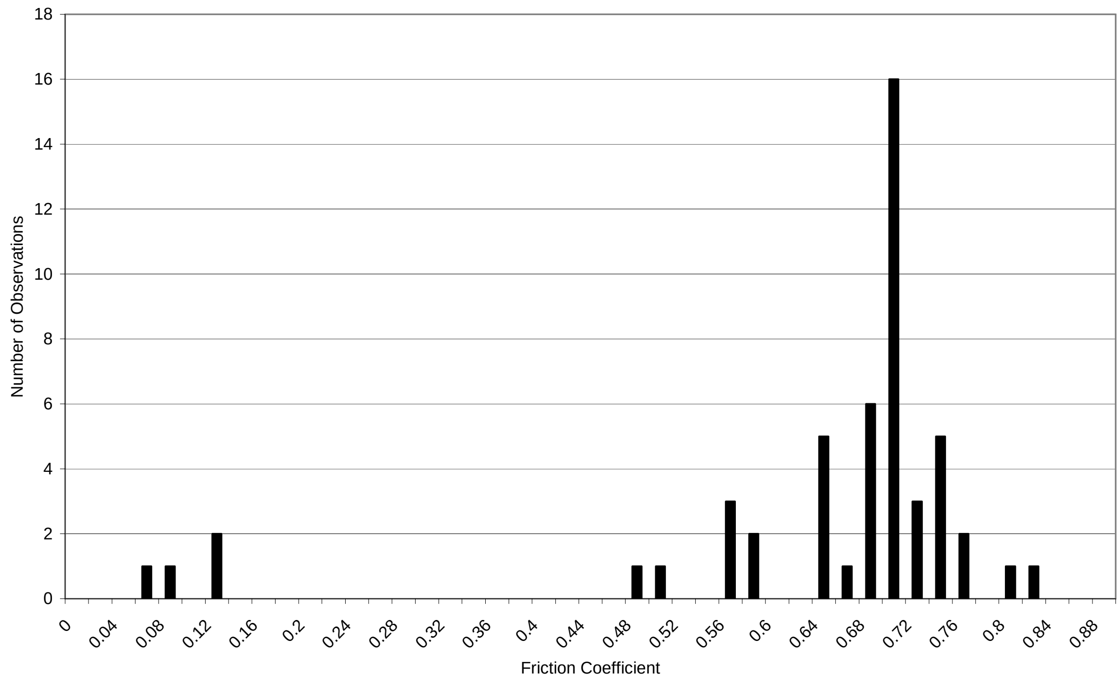

**H-1: ERD Readings on Wet Pavement: All Speeds Combined**




**H-2: TC SFT'79 (Configuration 3) Readings on Wet Pavement: All Speeds Combined**



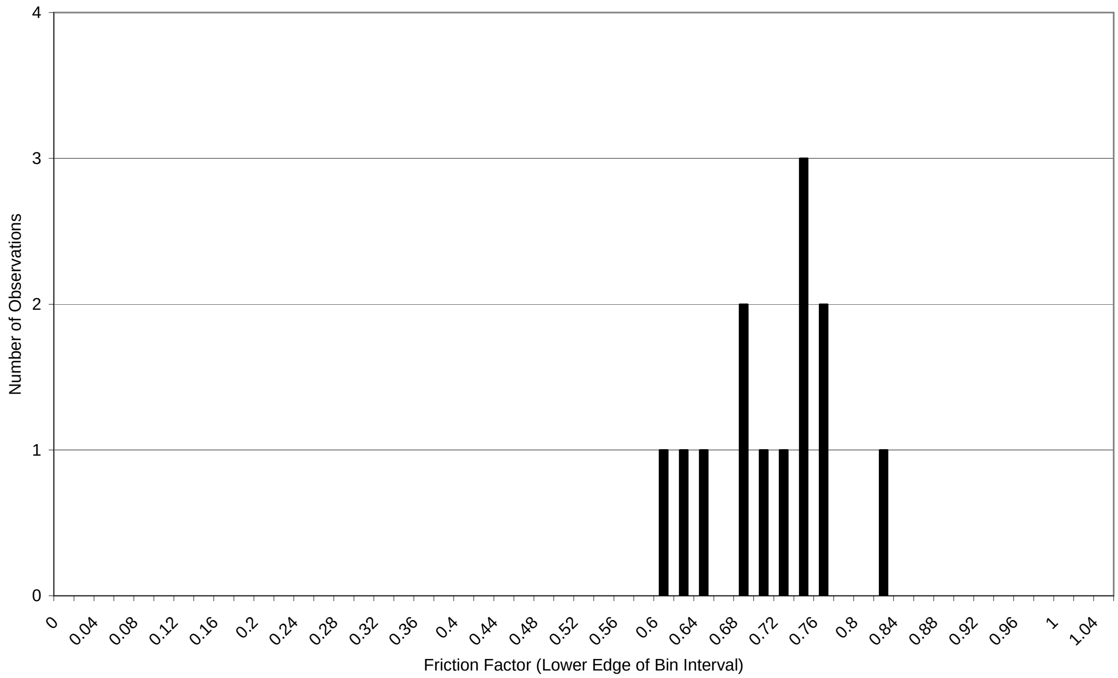

**H-3: IMAG Force (Configurations 3 and 7) Readings on Wet Pavement: All Speeds Combined**



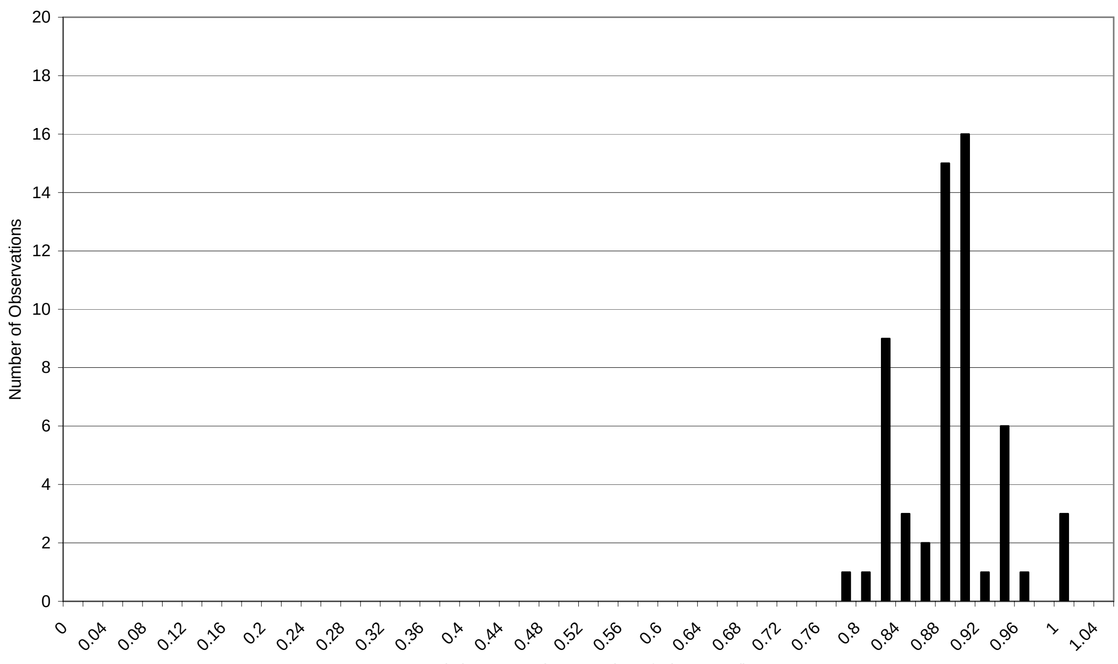

**H-4: IMAG Torque (Configurations 3 and 7) Readings on Wet Pavement: All Speeds Combined**

# APPENDIX I

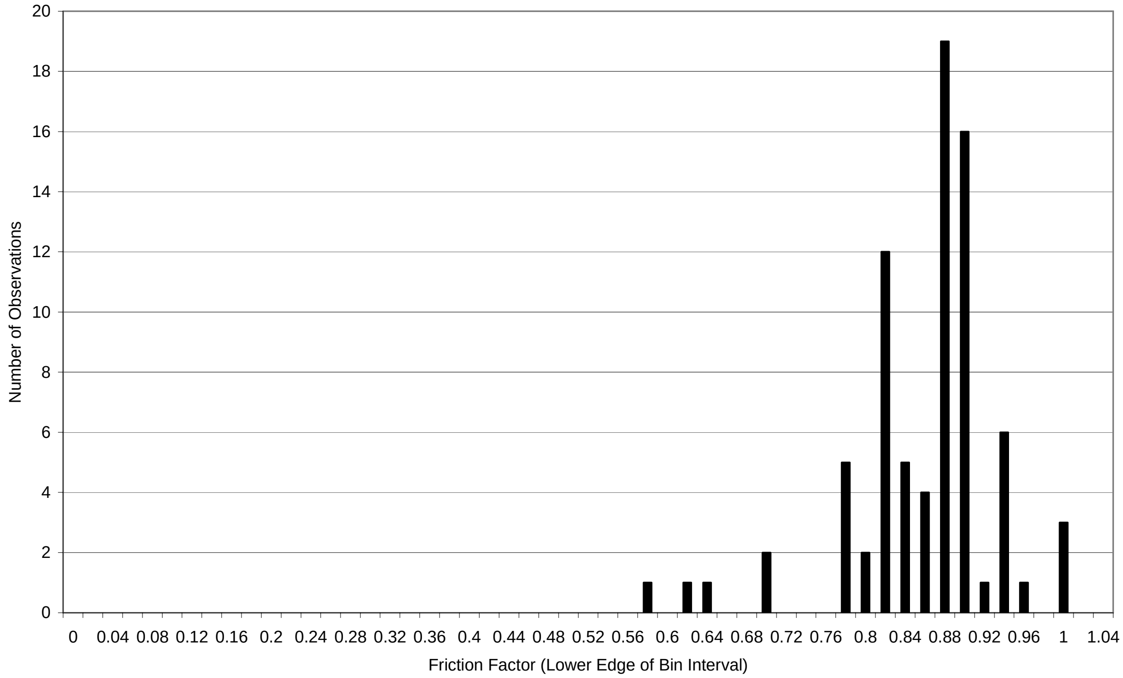
# RESULTS FOR DRY PAVEMENT



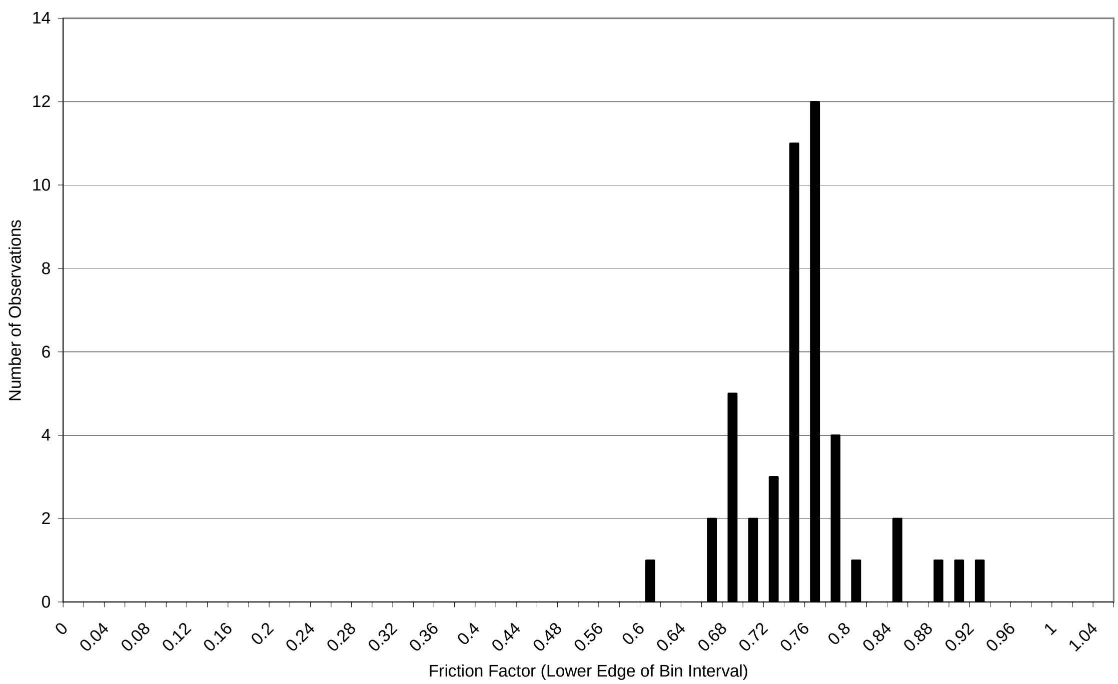

**I-1: ERD Readings on Bare Pavement: All Temperatures Included**



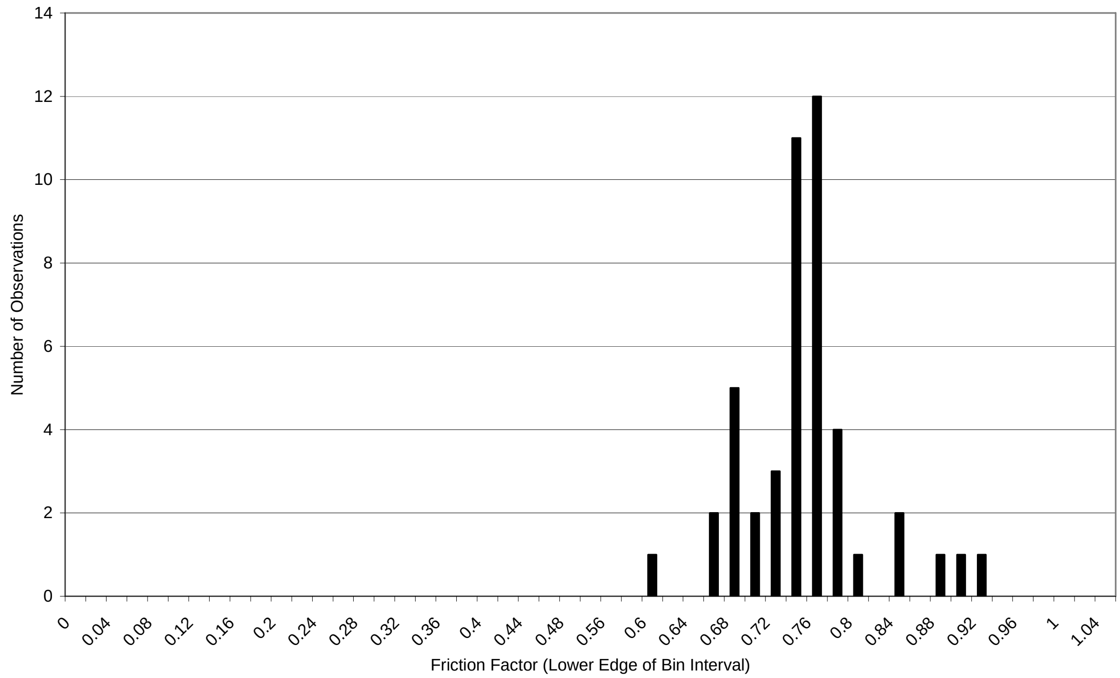

**I-2: TC SFT'79 (All Configurations) Readings on Bare Pavement: All Temperatures Included**



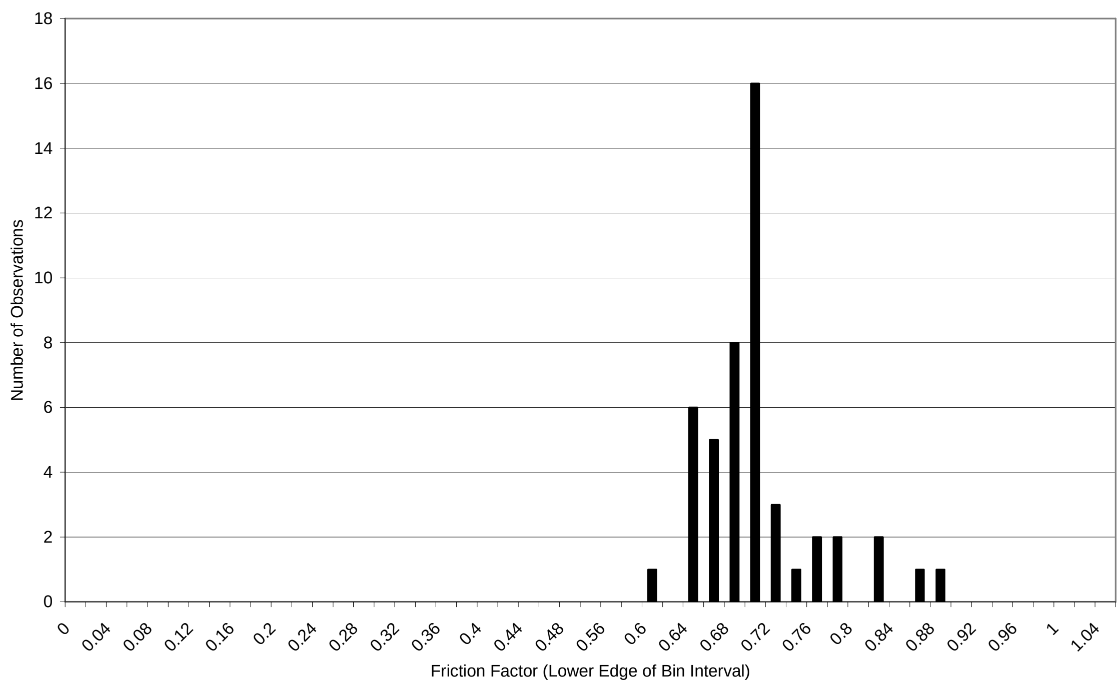

**I-3: TC SFT'79 (Configuration 3) Readings on Bare Pavement: All Temperatures Included**



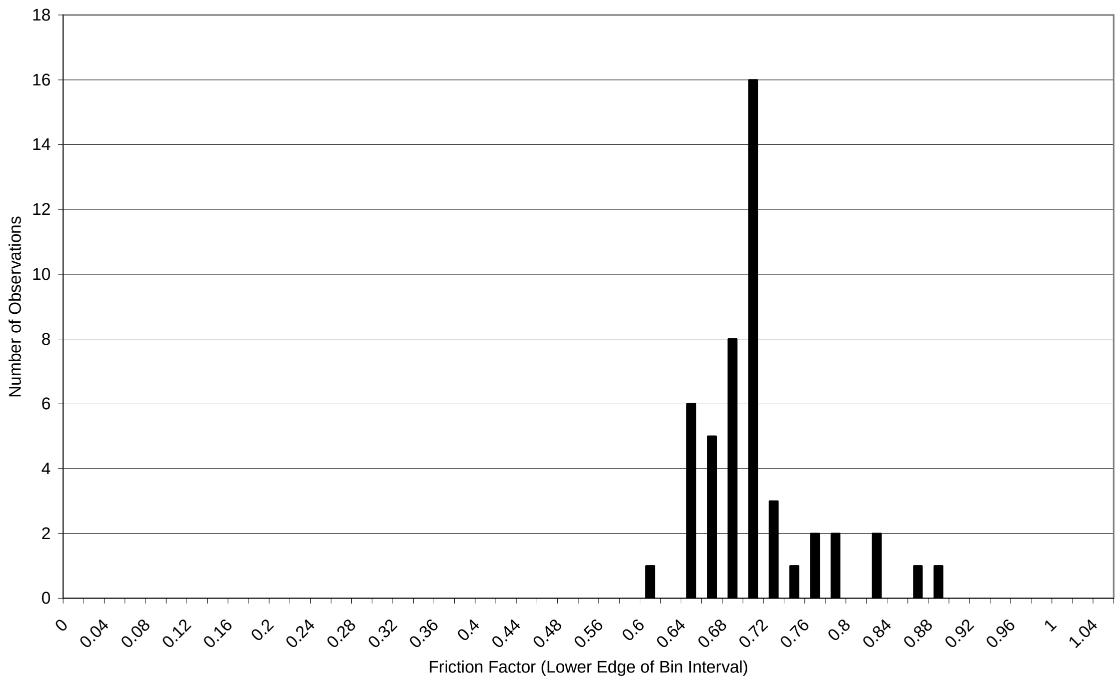

**I-4: IMAG Force (All Configurations) Readings on Bare Pavement: All Temperatures Included**




**I-5: IMAG Force (Configurations 3 and 7) Readings on Bare Pavement: All Temperatures Included**



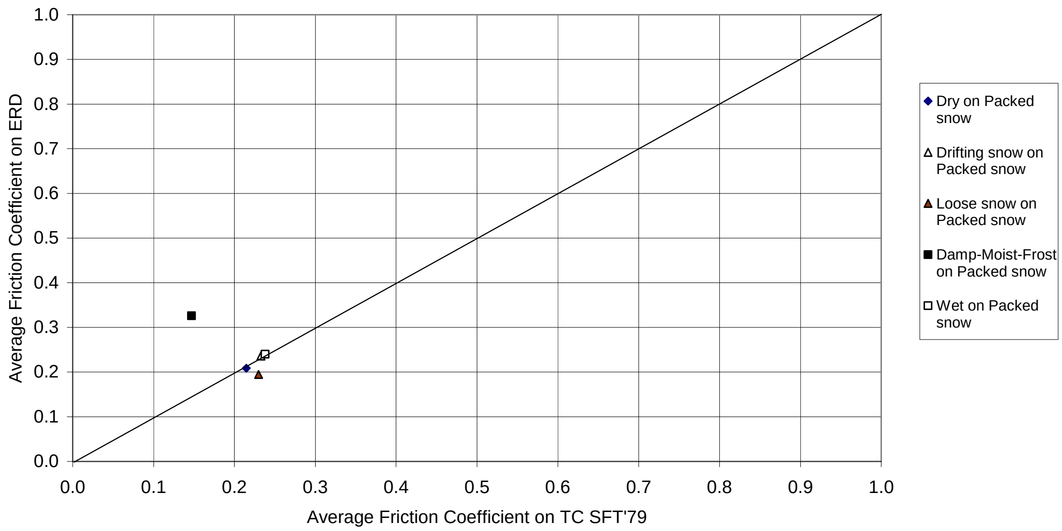

**I-6: IMAG Torque (All Configurations) Readings on Bare Pavement: All Temperatures Included**



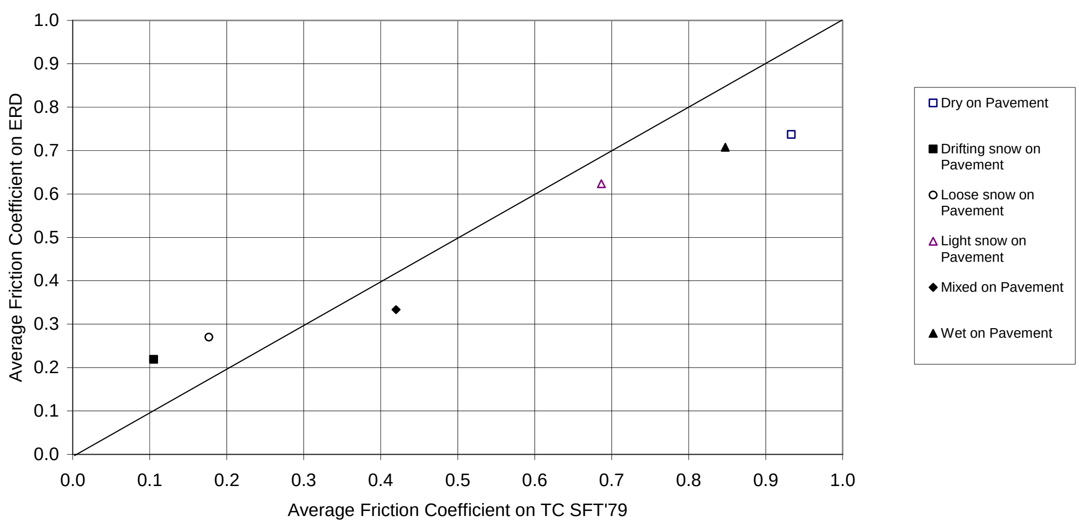

**I-7: IMAG Torque (Configurations 3 and 7) Readings on Bare Pavement: All Temperatures Included**

# APPENDIX J

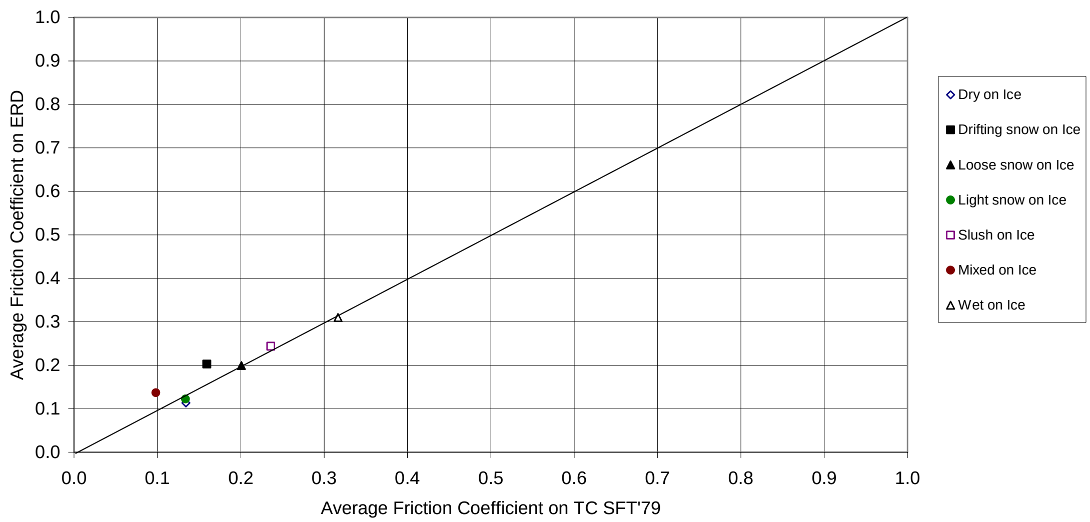
# CORRELATION PLOTS: ERD VS. TC SFT'79



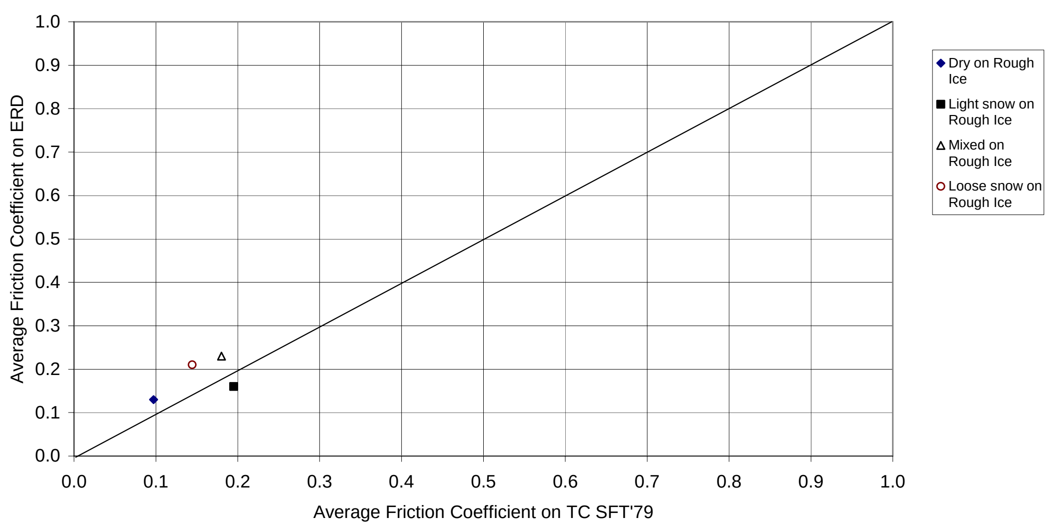

**J-1: Correlation of ERD to TC SFT'79 (Configuration 3) on Packed Snow**



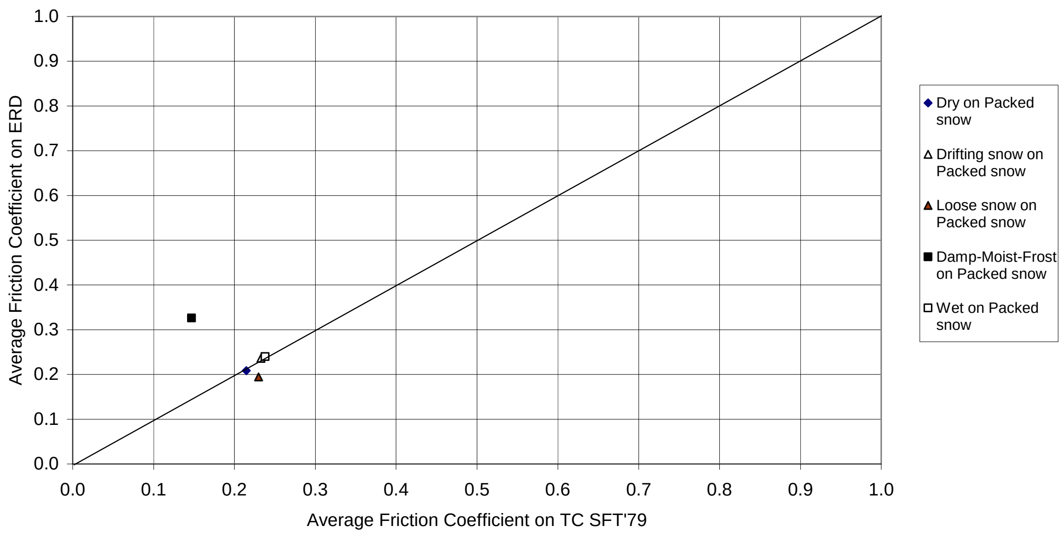

**J-2: Correlation of ERD to TC SFT'79 (Configuration 3) on a Pavement Base**



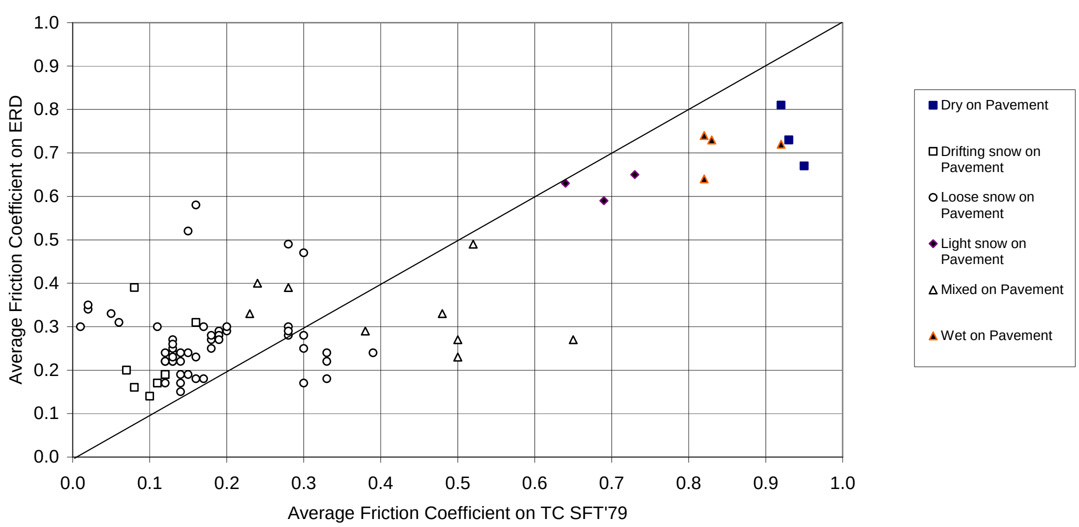

**J-3: Correlation of ERD to TC SFT'79 (Configuration 3) on Ice Base**



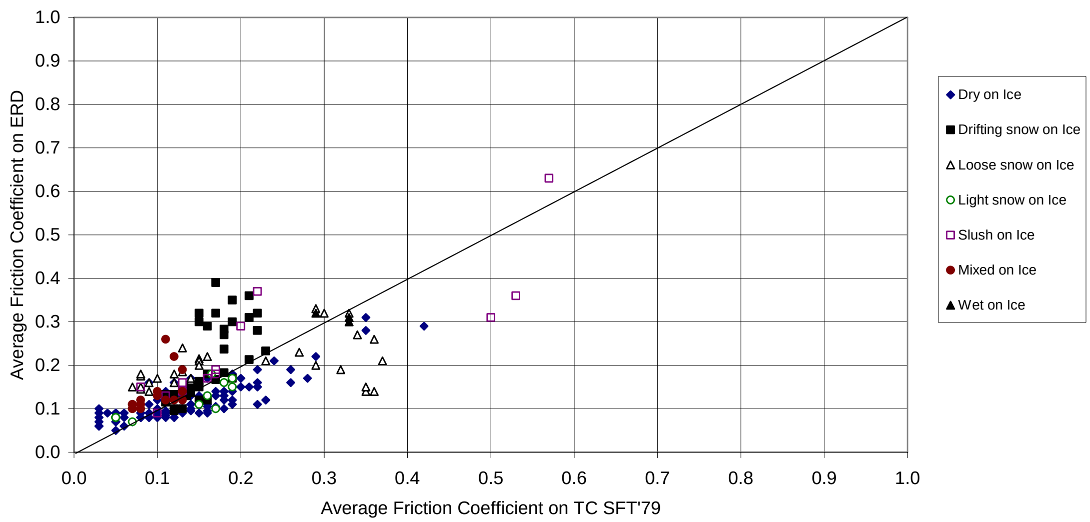

**J-4: Correlation of ERD to TC SFT'79 (Configuration 3) on a Rough Ice Base**



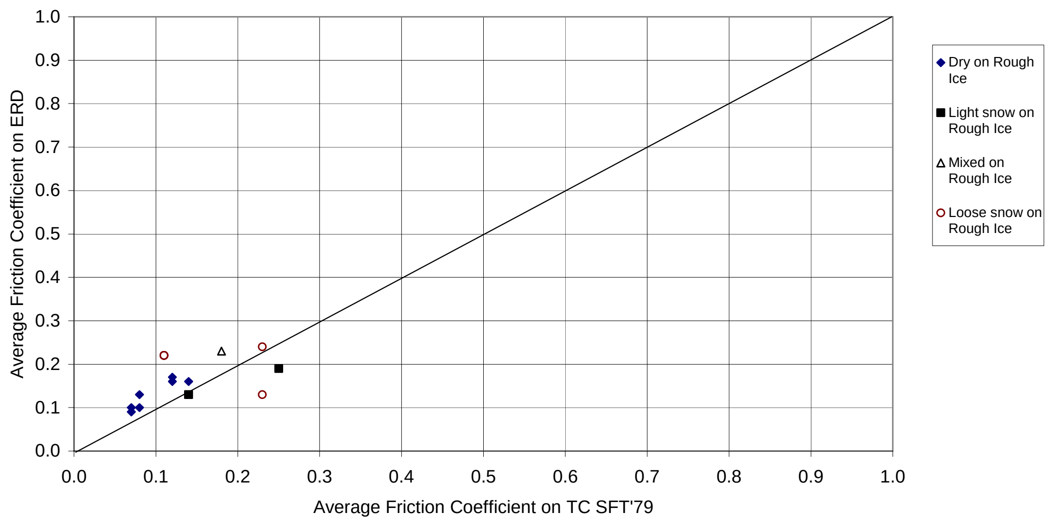

**J-5: Correlation of ERD to TC SFT'79 (Configuration 3) on Packed Snow**



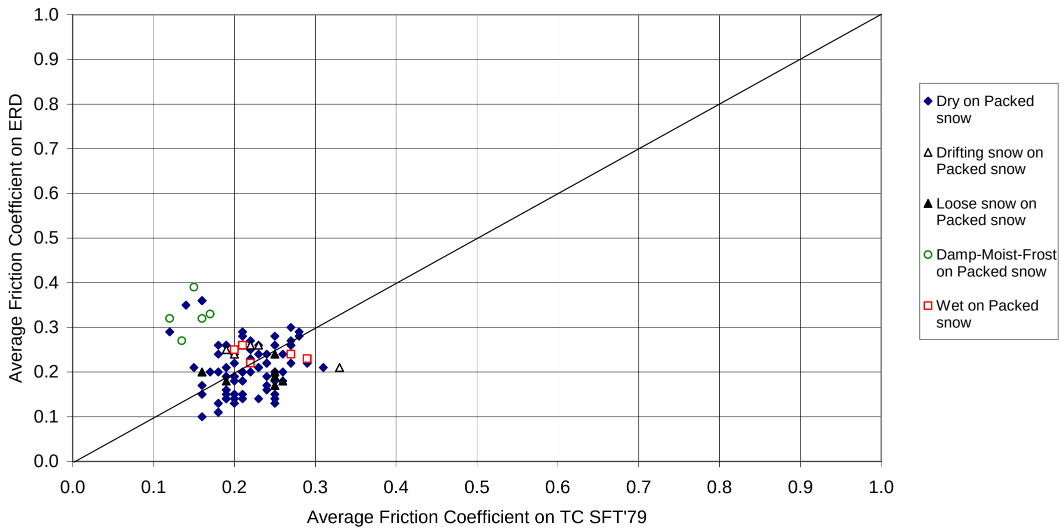

**J-6: Correlation of ERD to TC SFT'79 (Configuration 3) on a Pavement Base**




**J-7: Correlation of ERD to TC SFT'79 (Configuration 3) on an Ice Base**



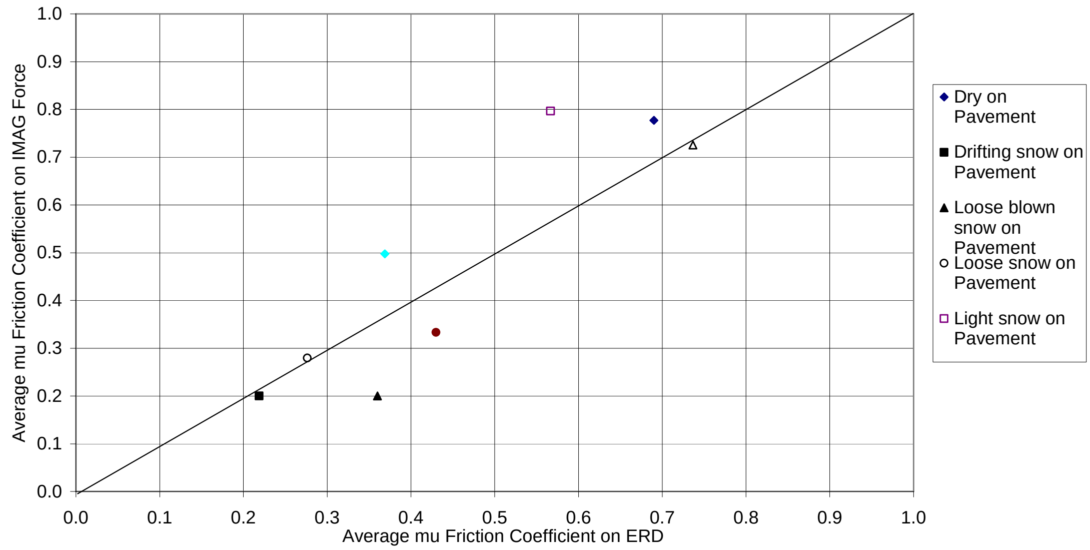

**J-8: Correlation of ERD to TC SFT'79 (Configuration 3) on a Rough Ice Base**



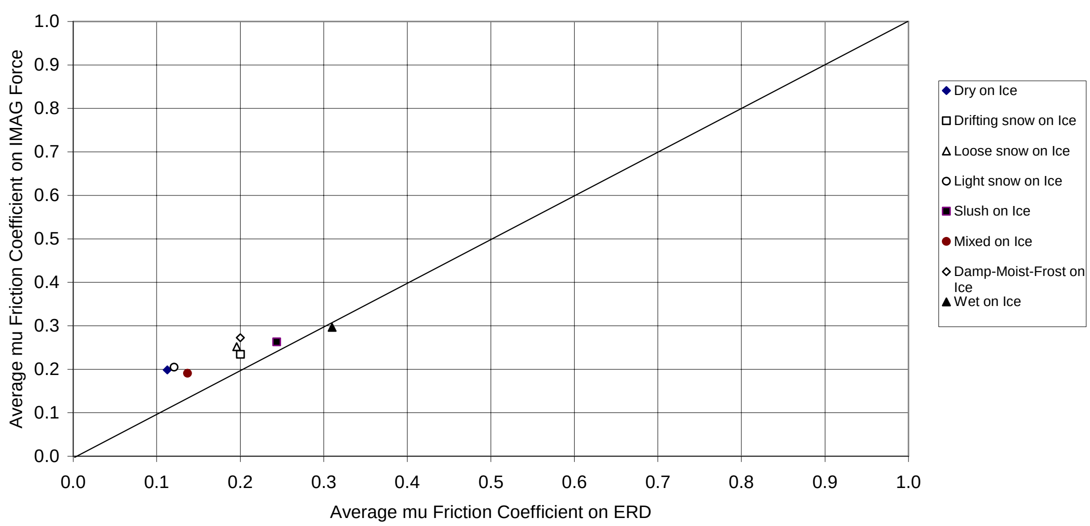

**J-9: Correlation of ERD to TC SFT'79 (Configuration 3) on Packed Snow**

# APPENDIX K

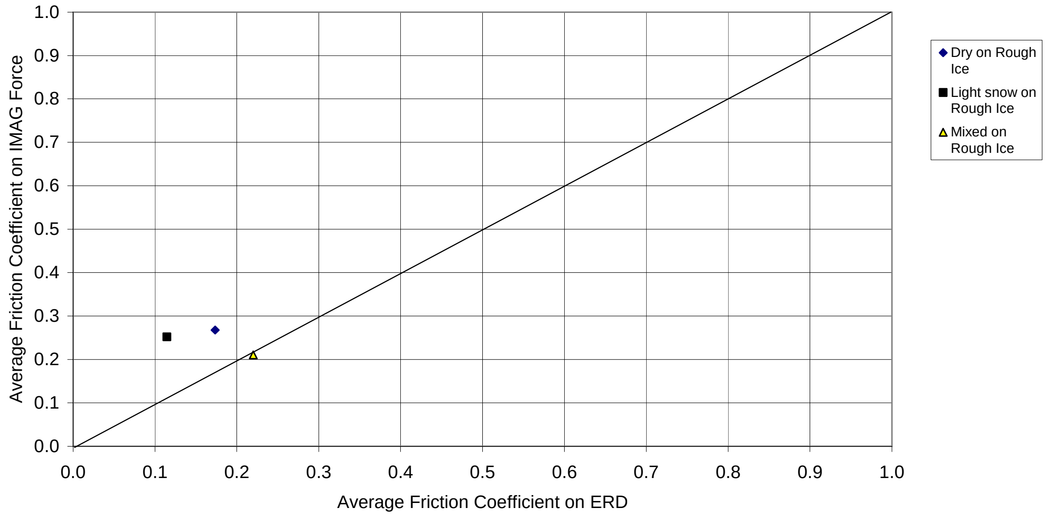
# CORRELATION PLOTS: ERD VS. IMAG FORCE



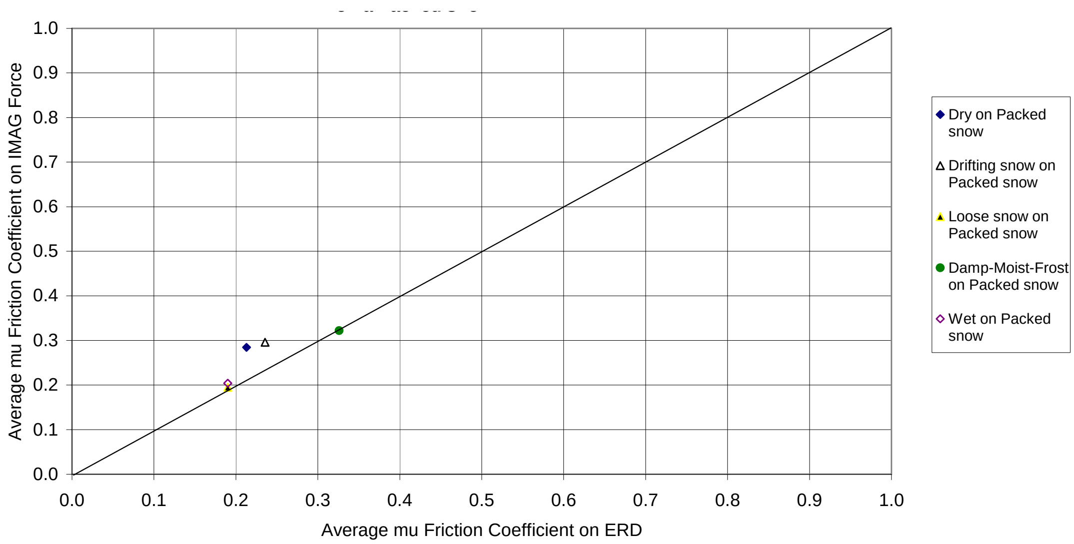

**K-1: Correlation of ERD to IMAG Force (Configurations 3 and 7) on a Pavement Base**



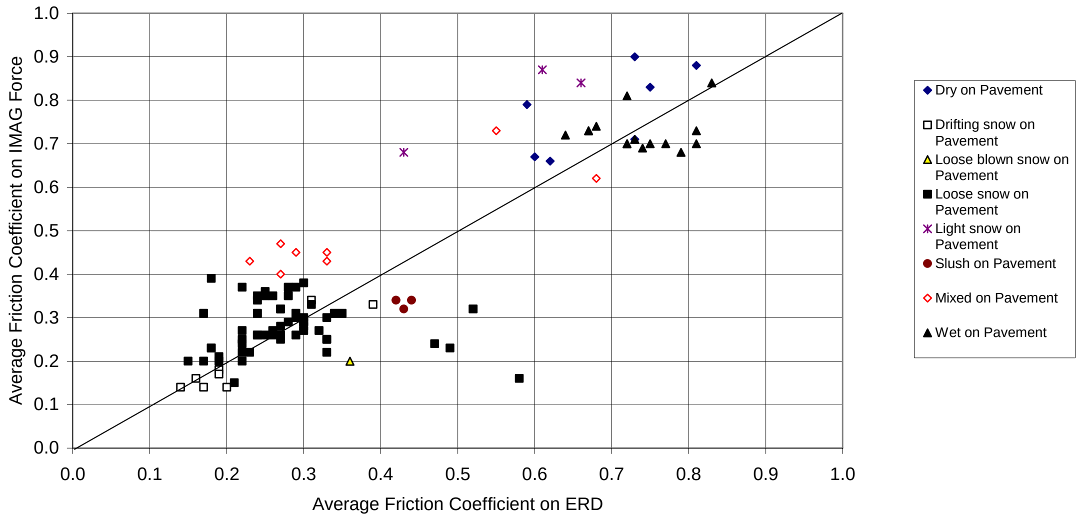

**K-2: Correlation of ERD to IMAG Force (Configurations 3 and 7) on an Ice Base**



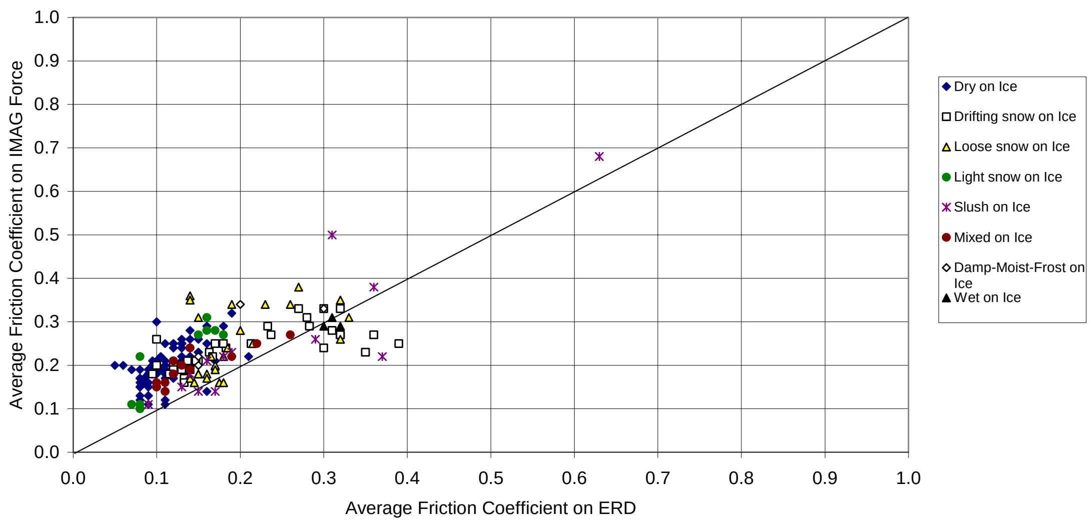

**K-3: Correlation of ERD to IMAG Force (Configurations 3 and 7) on a Rough Ice Base**



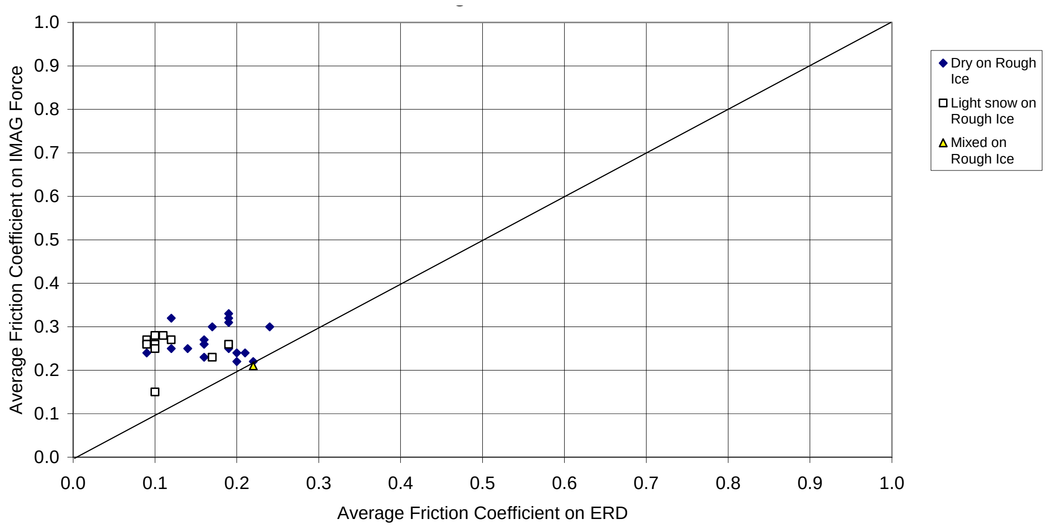

**K-4: Correlation of ERD to IMAG Force (Configurations 3 and 7) on Packed Snow**



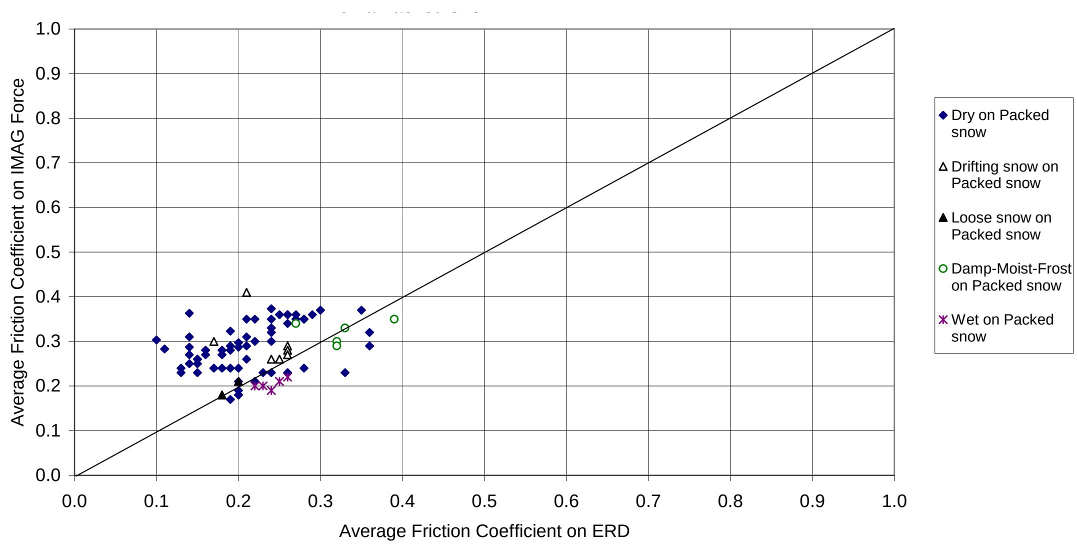

**K-5: Correlation of ERD to IMAG Force (Configurations 3 and 7) on a Pavement Base**




**K-6: Correlation of ERD to IMAG Force (Configurations 3 and 7) on an Ice Base**



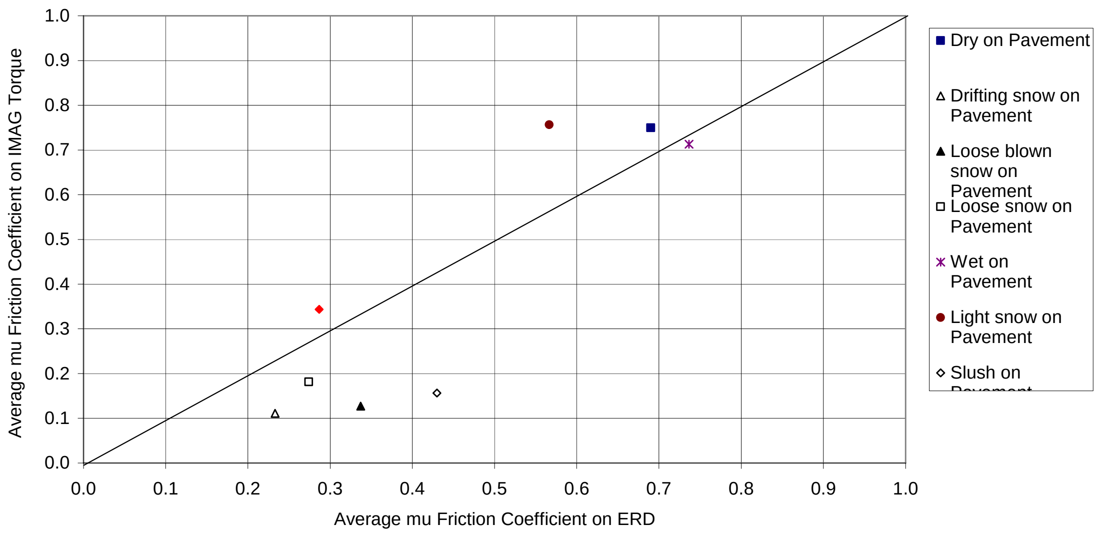

**K-7: Correlation of ERD to IMAG Force (Configurations 3 and 7) on a Rough Ice Base**



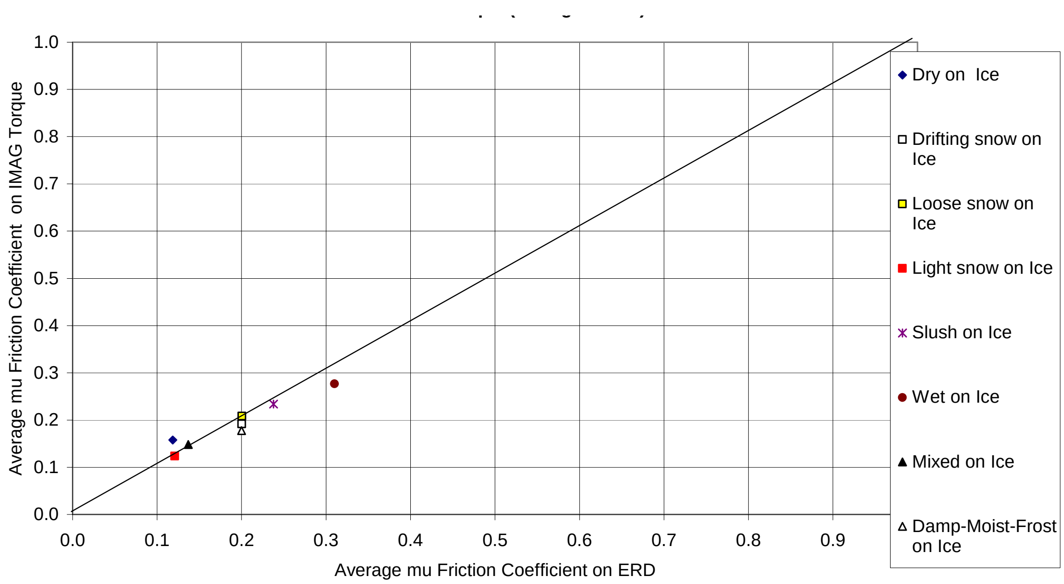

**K-8: Correlation of ERD to IMAG Force (Configurations 3 and 7) on Packed Snow**

# APPENDIX L

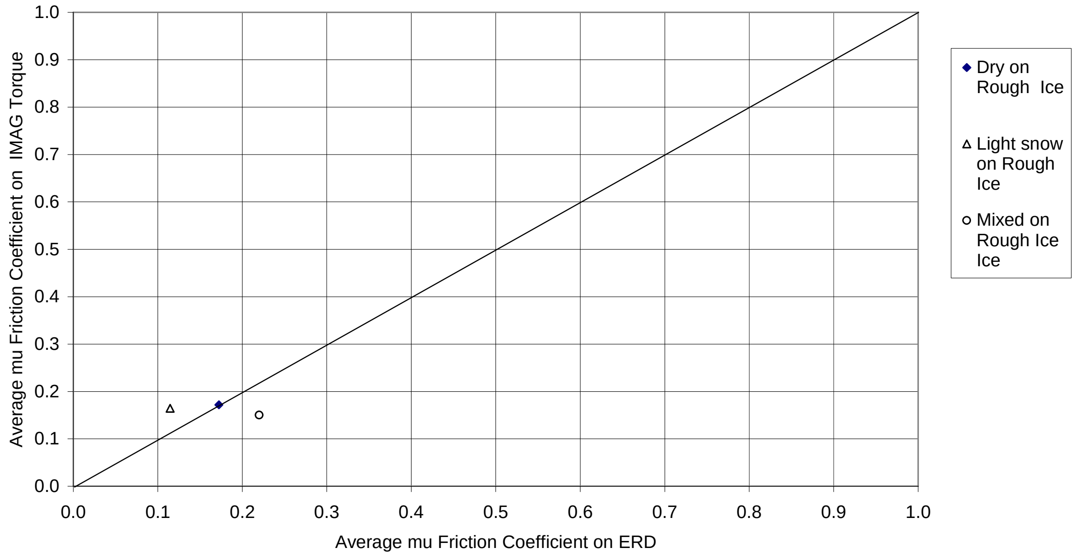
## CORRELATION PLOTS: ERD VS. IMAG TORQUE



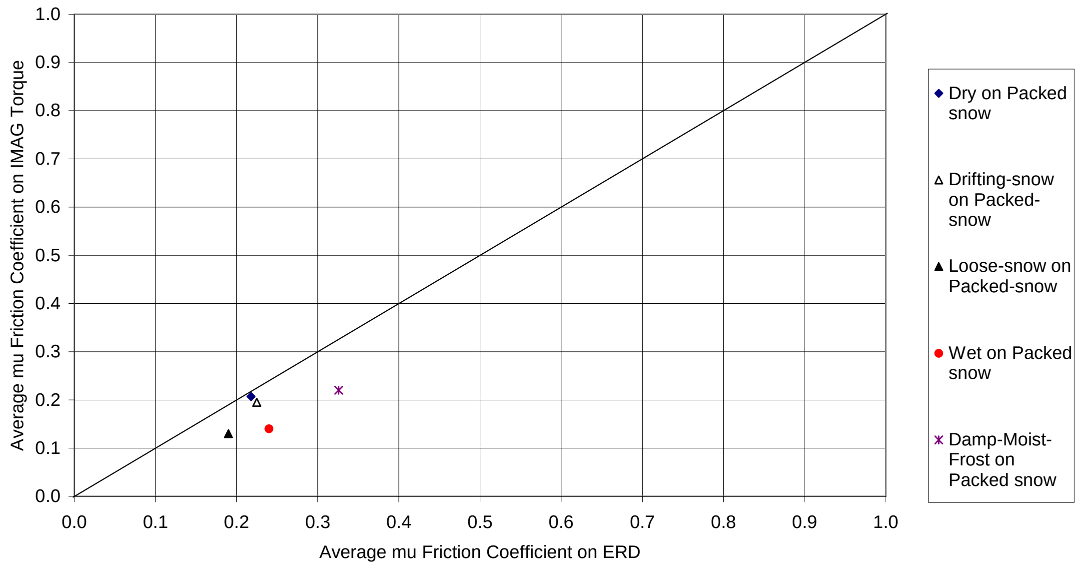

**L-1: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Pavement Base**



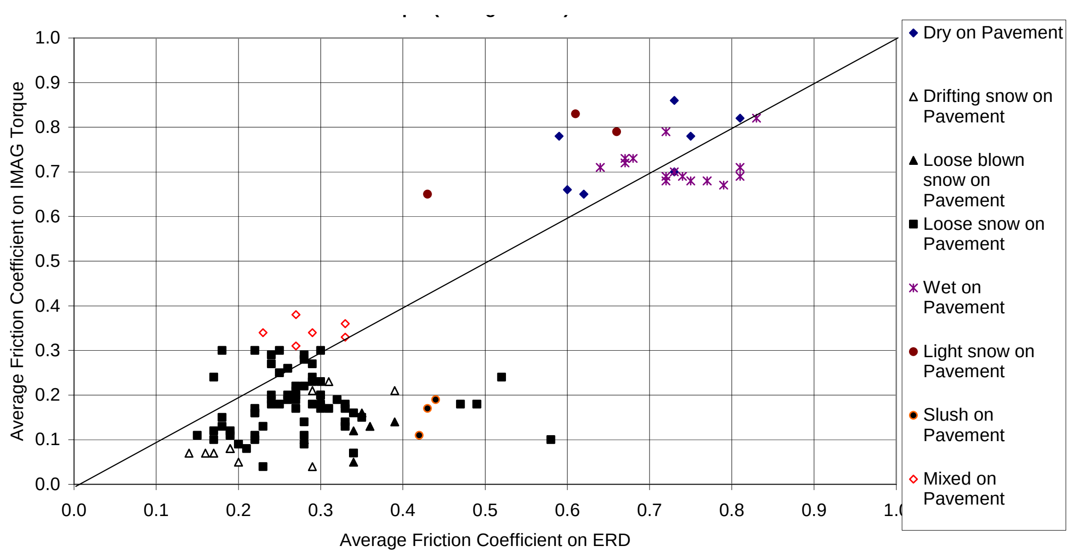

**L-2: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on an Ice Base**



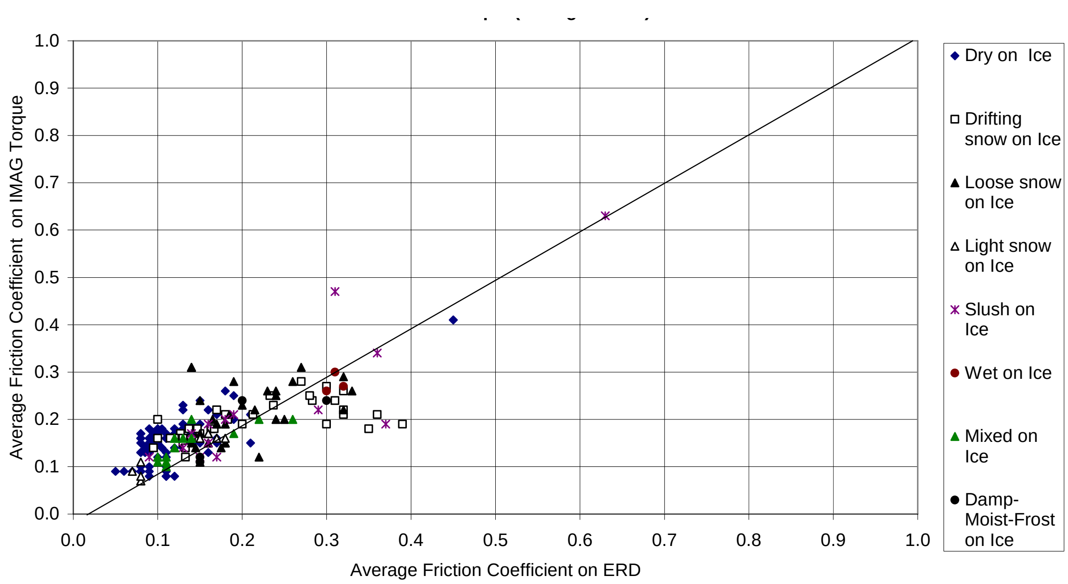

**L-3: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**



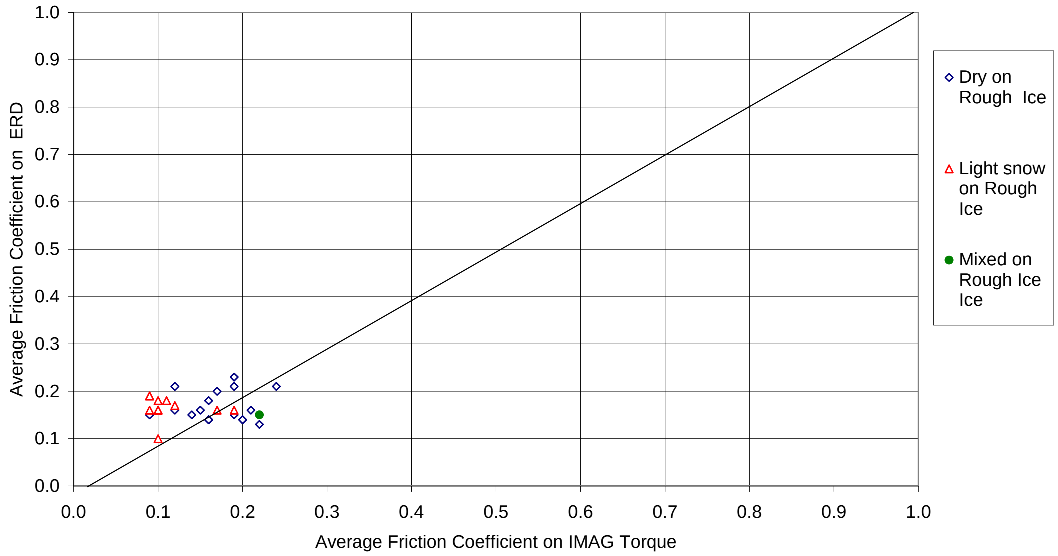

**L-4: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Packed Snow Base**



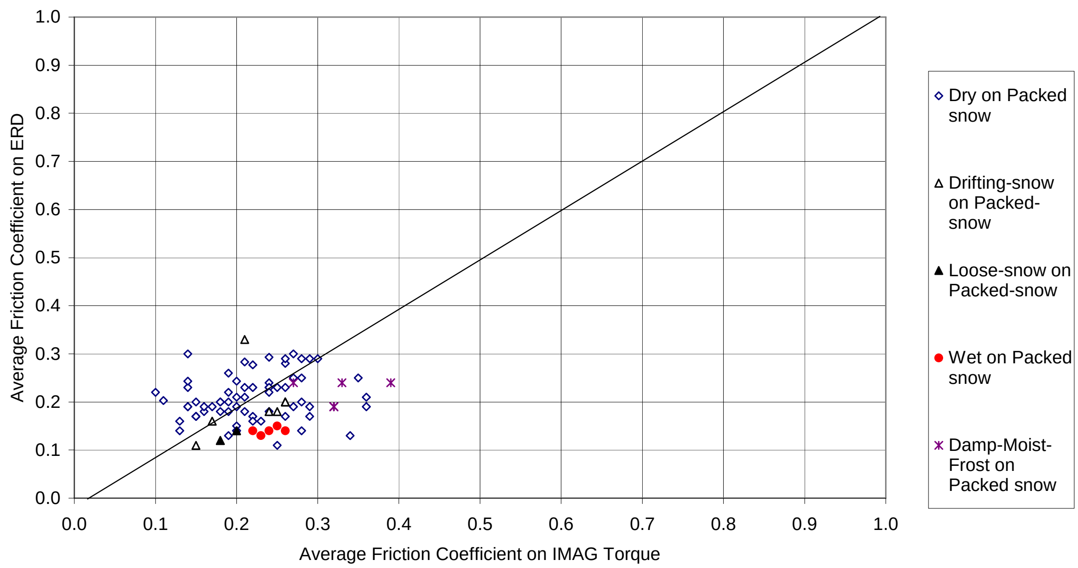

**L-5: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Pavement Base**




**L-6: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on an Ice Base**



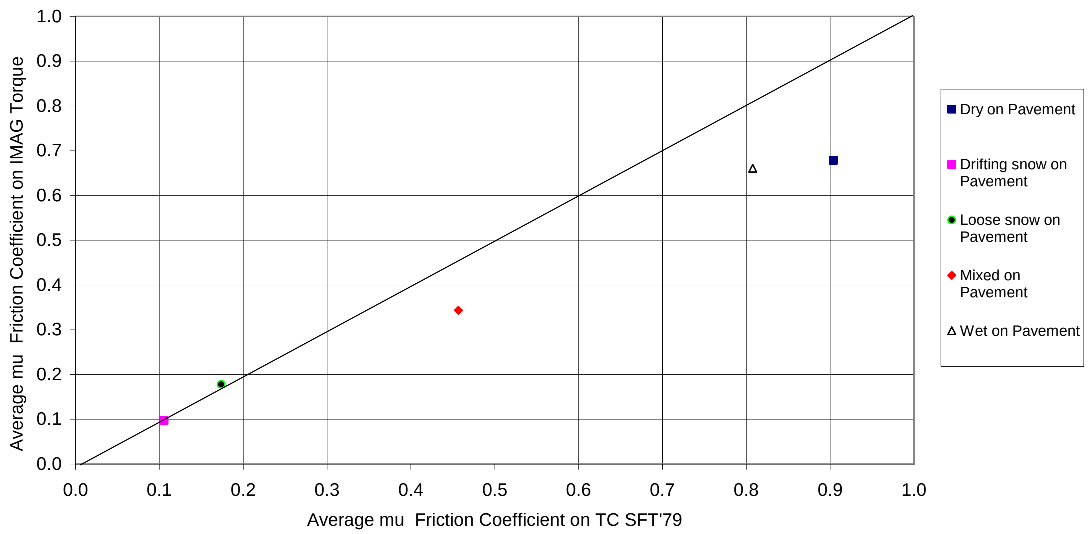

**L-7: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**



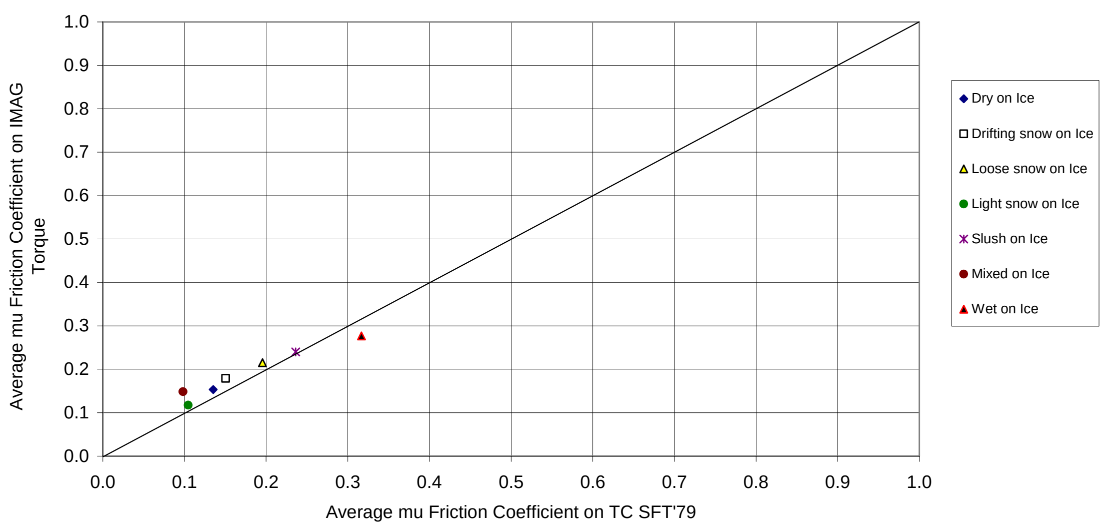

**L-8: Correlation of ERD to IMAG Torque (Configurations 3 and 7) on a Packed Snow Base**

# APPENDIX M

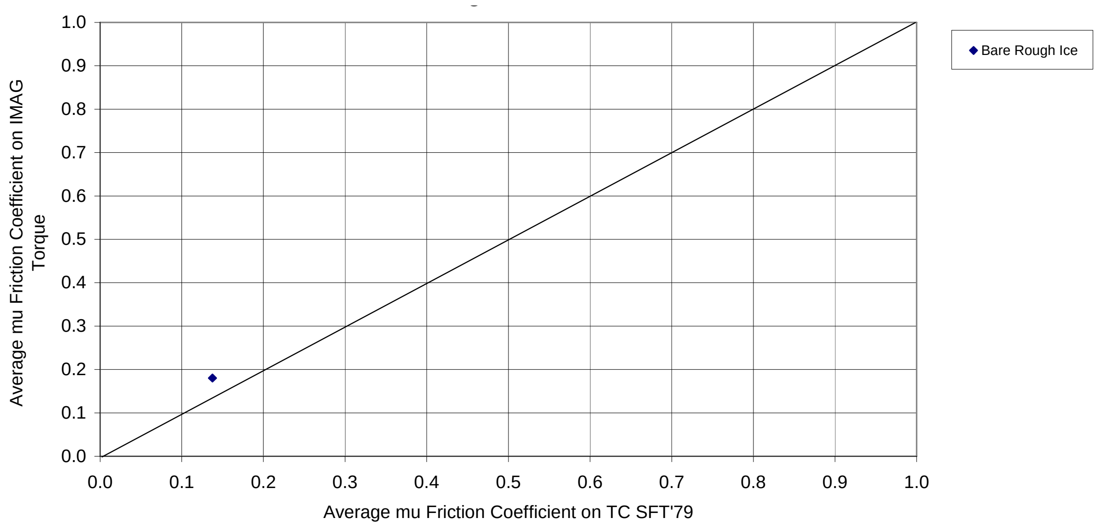
# CORRELATION PLOTS: TC SFT’79 VS. IMAG TORQUE



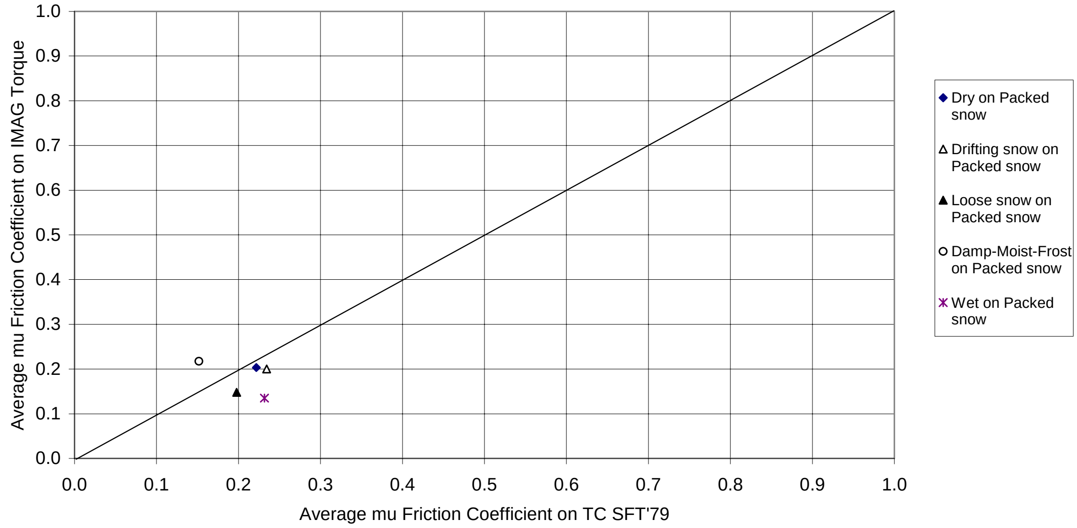

**M-1: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on a Pavement Base**



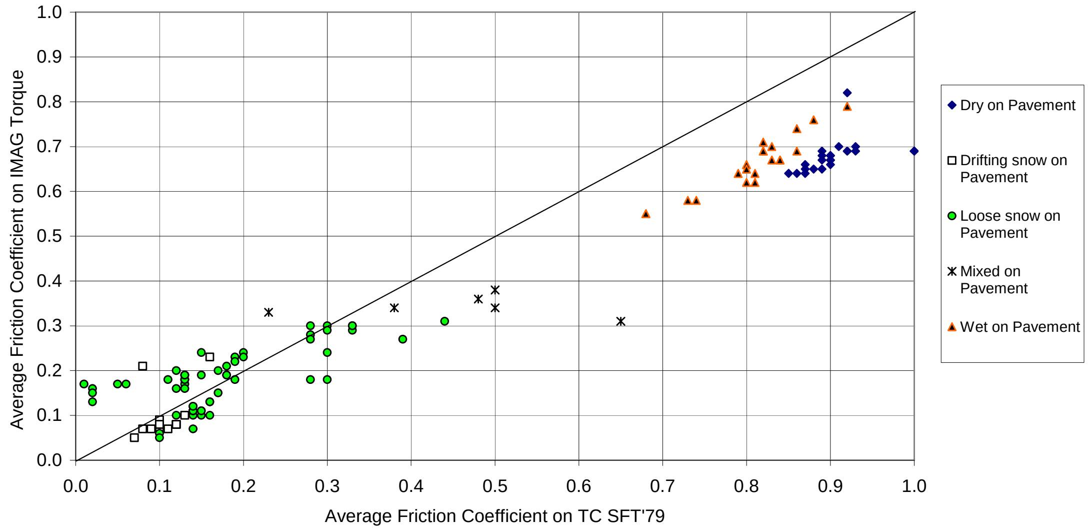

**M-2: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on an Ice Base**



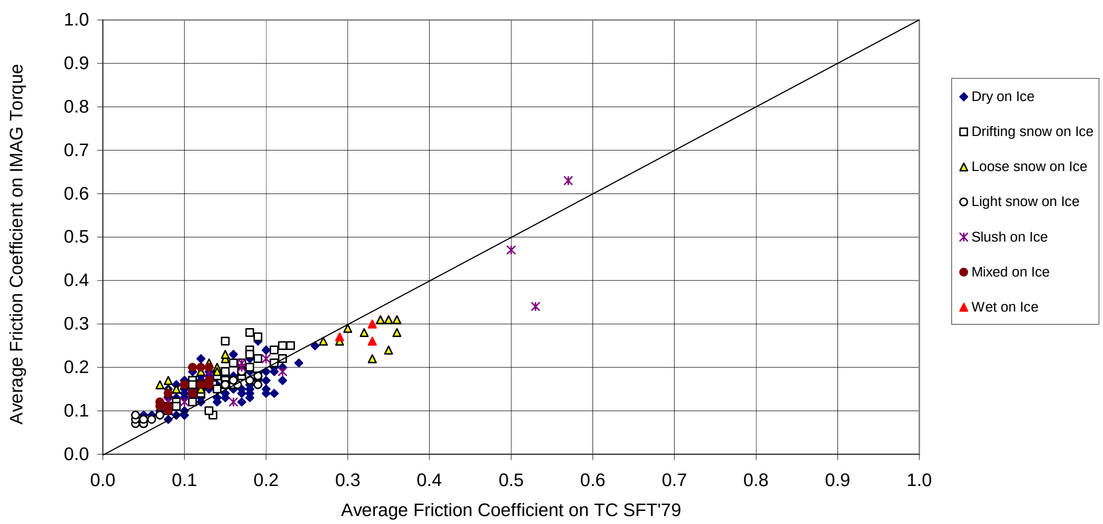

**M-3: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**



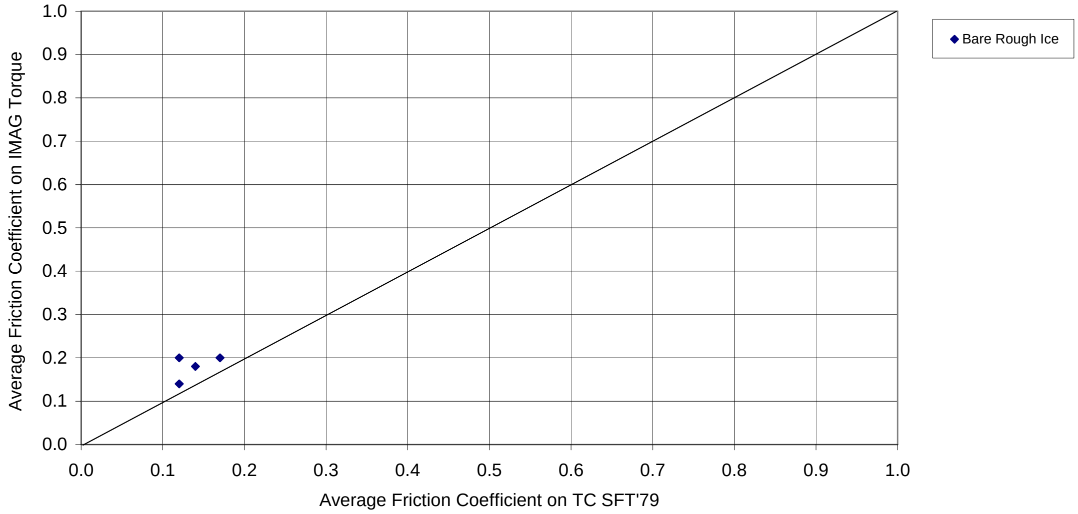

**M-4: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on Packed Snow**



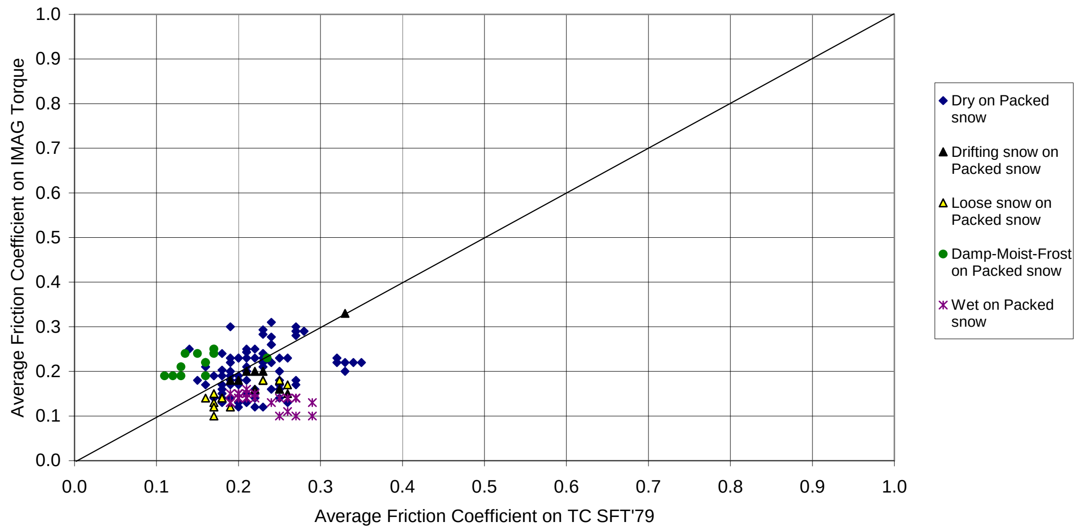

**M-5: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on a Pavement Base**




**M-6: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on an Ice Base**



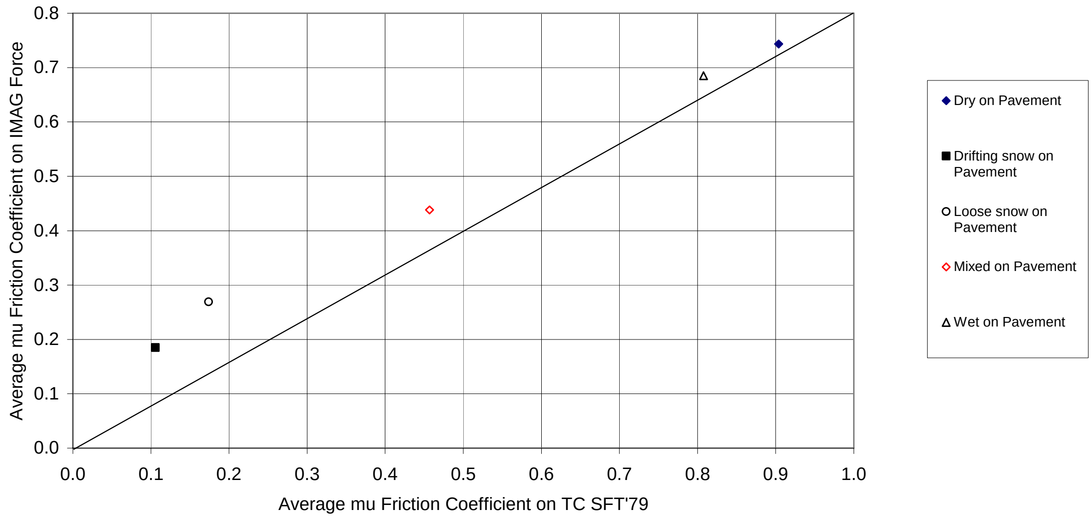

**M-7: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**



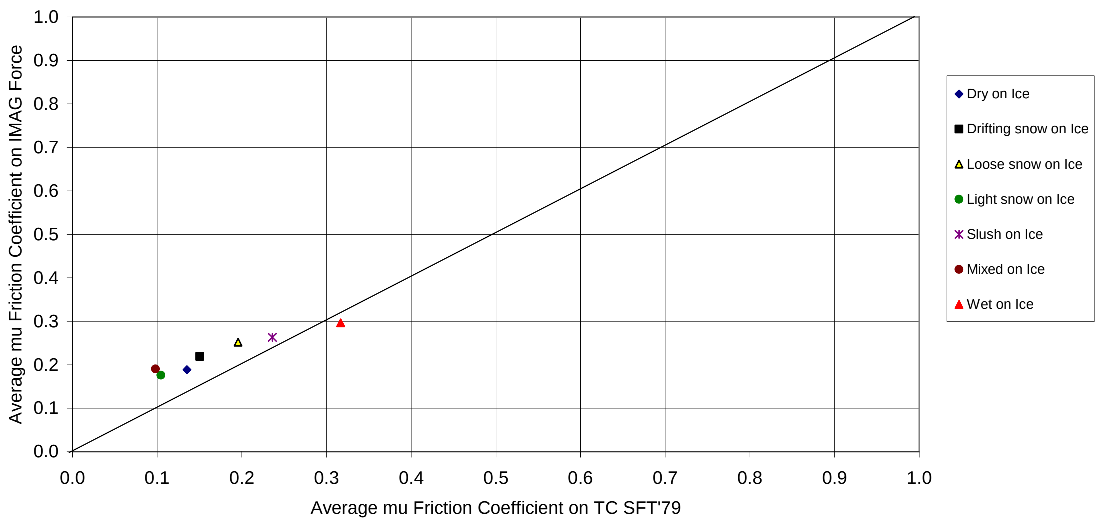

**M-8: Correlation of TC SFT'79 to IMAG Torque (Configurations 3 and 7) on Packed Snow**

# APPENDIX N

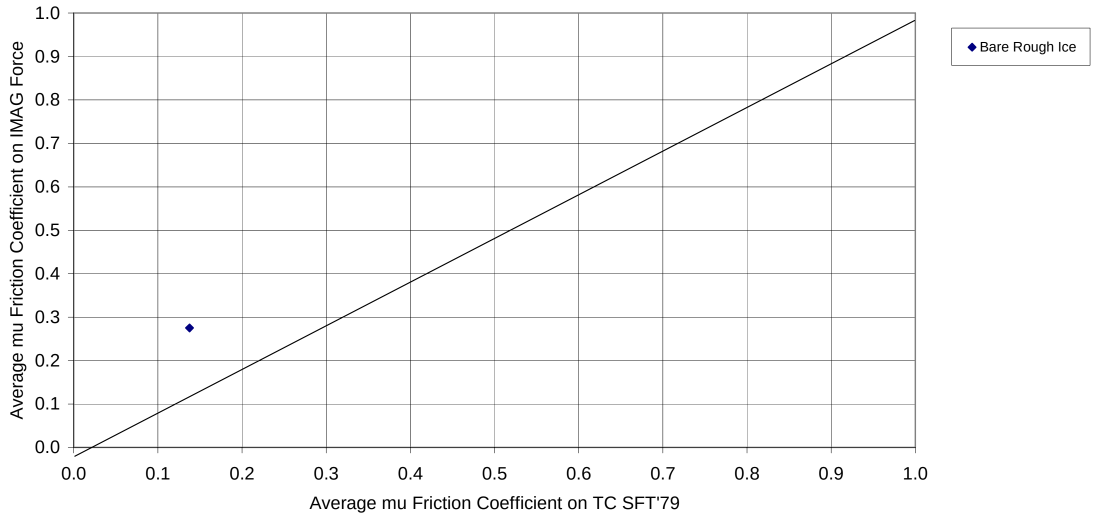
# CORRELATION PLOTS: TC SFT’79 VS. IMAG FORCE



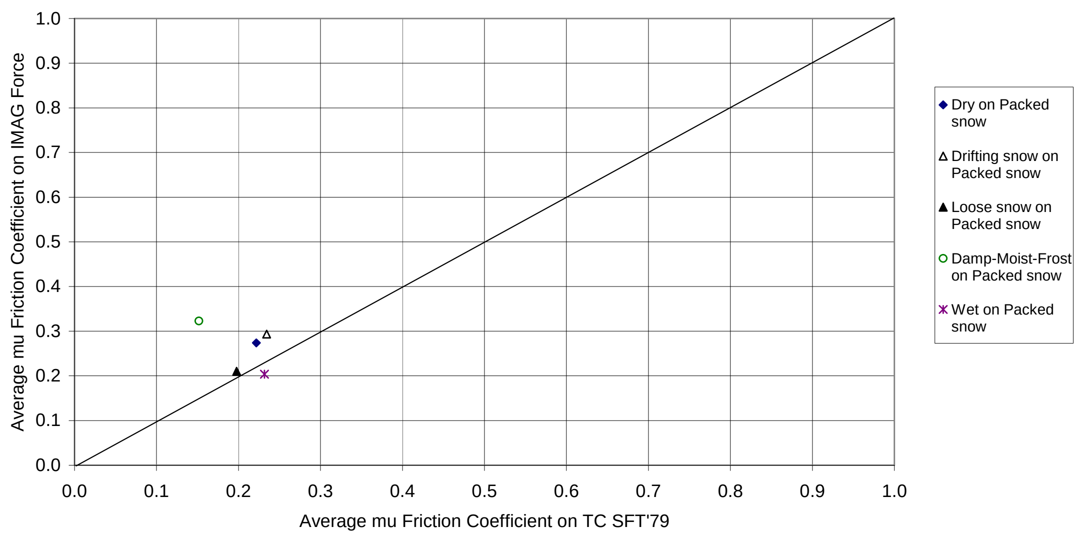

**N-1: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on a Pavement Base**



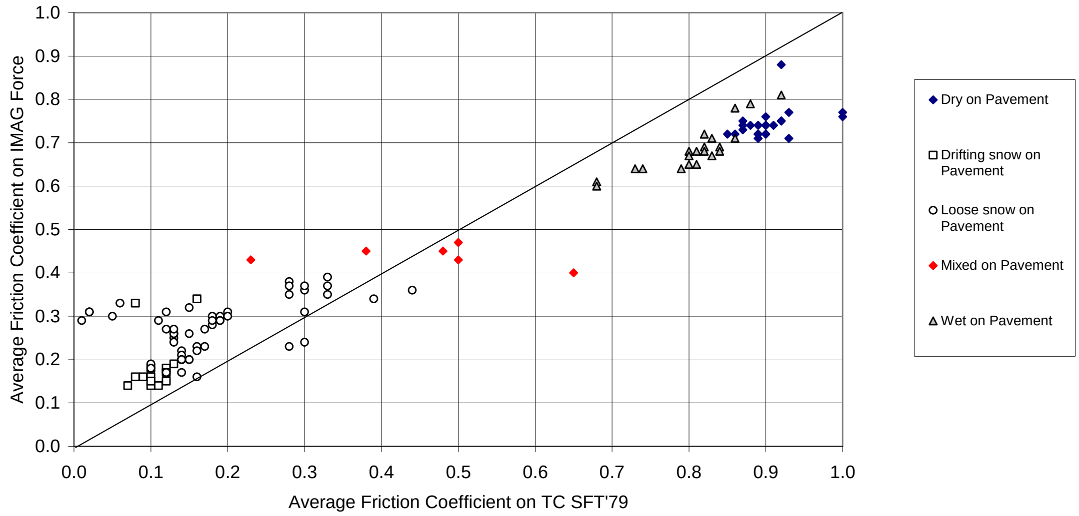

**N-2: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on an Ice Base**



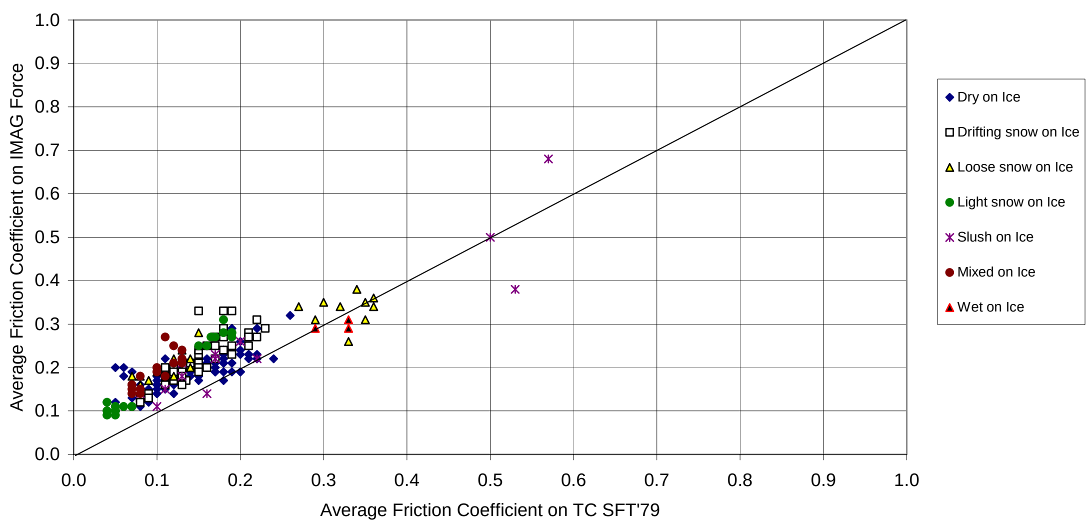

**N-3: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on a Rough Ice Base**



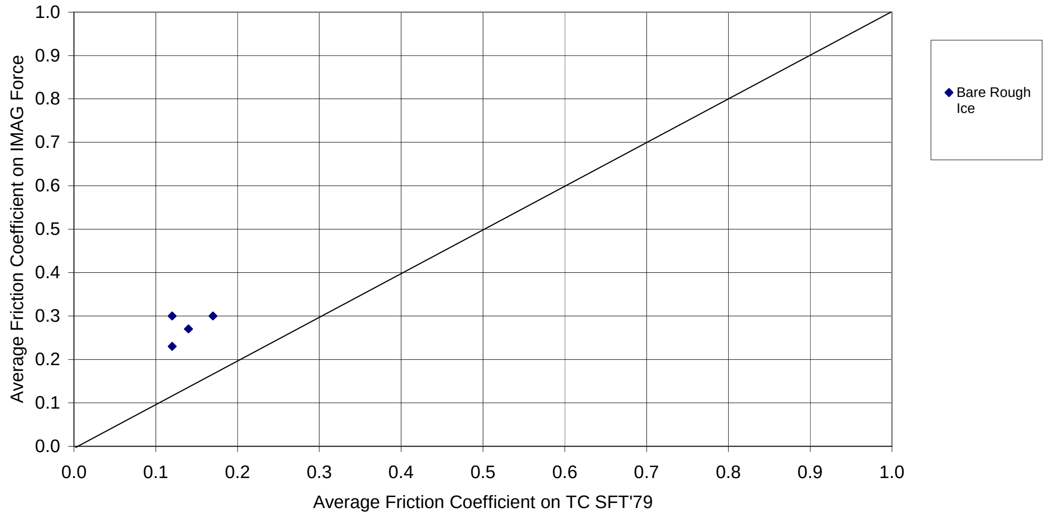

**N-4: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on Packed Snow**



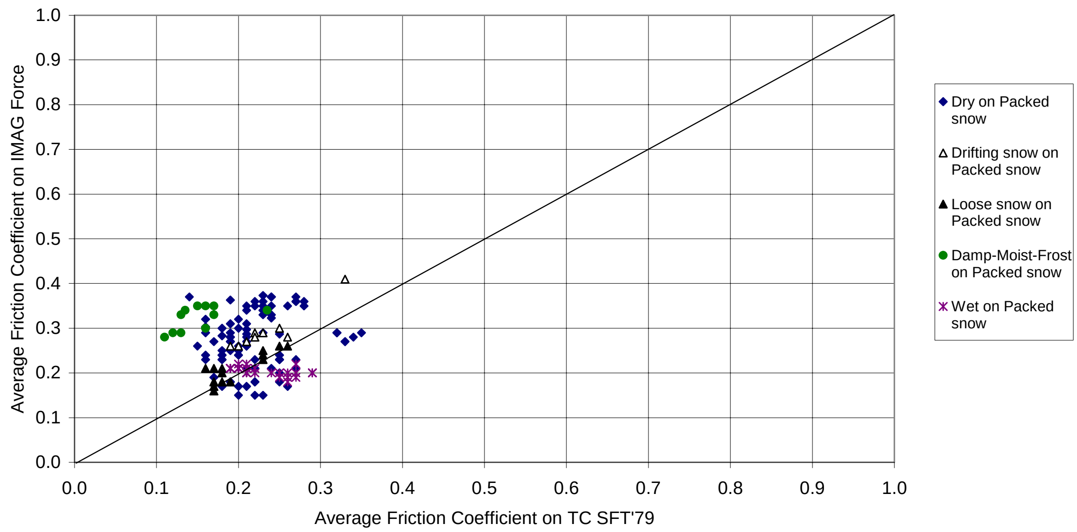

**N-5: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on a Pavement Base**




**N-6: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on an Ice Base**



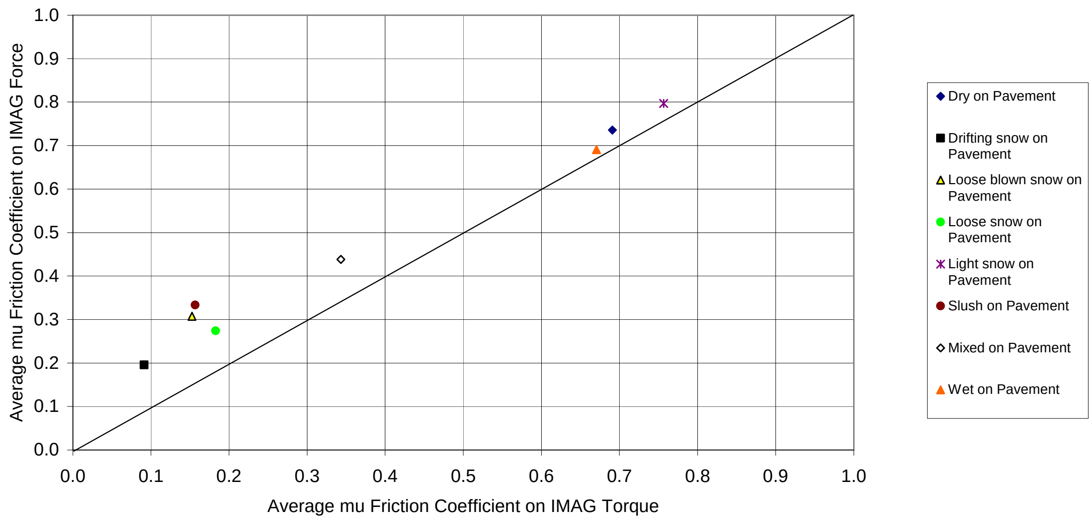

**N-7: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on a Rough Ice Base**



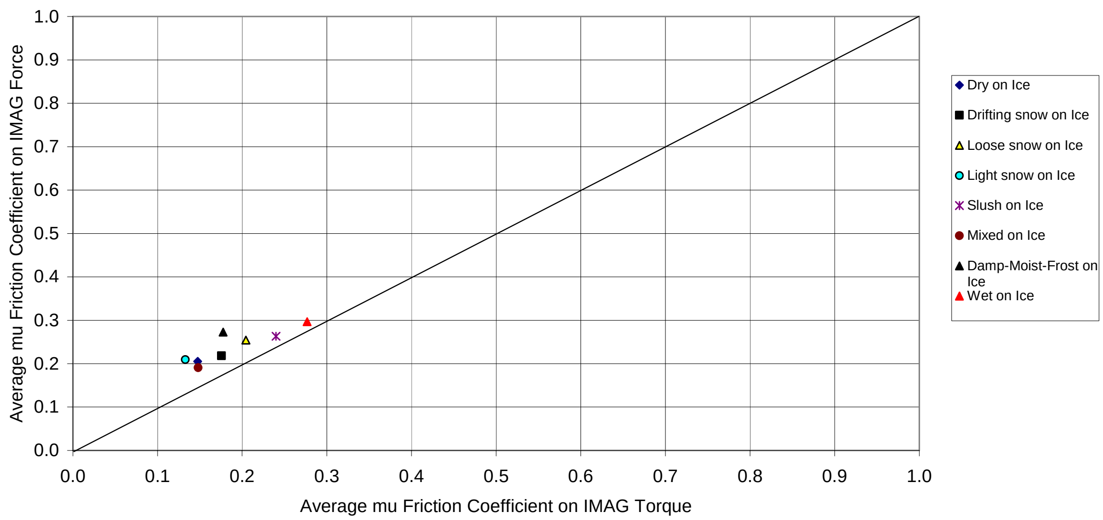

**N-8: Correlation of TC SFT'79 to IMAG Force (Configurations 3 and 7) on Packed Snow**

# APPENDIX O

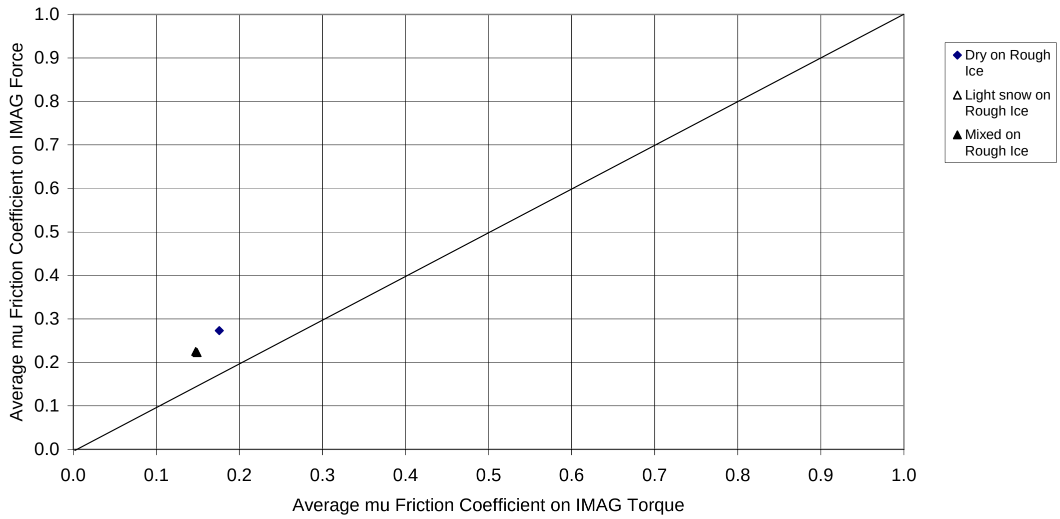
# CORRELATION PLOTS: IMAG TORQUE VS. IMAG FORCE



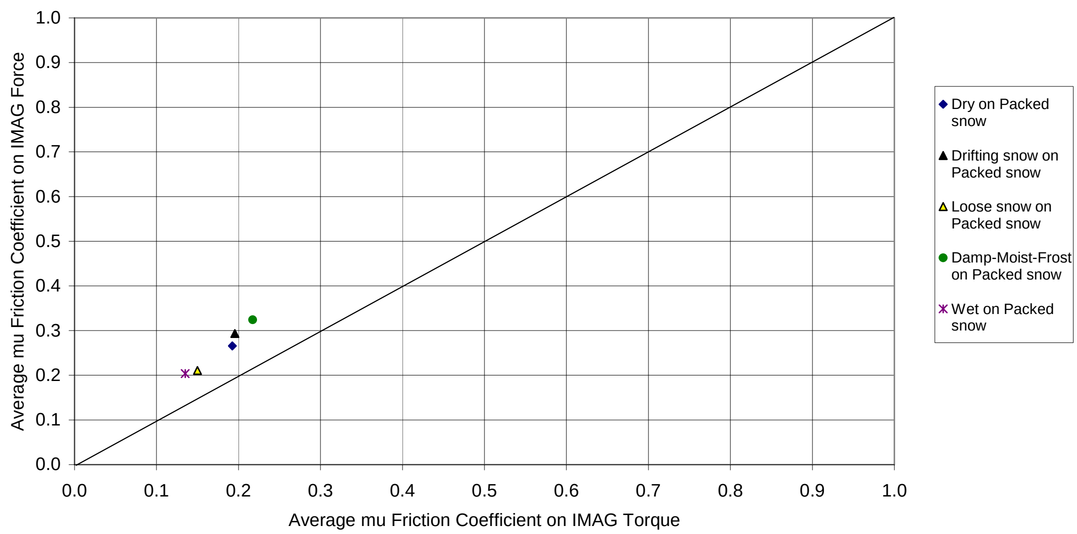

**O-1: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on a Pavement Base**



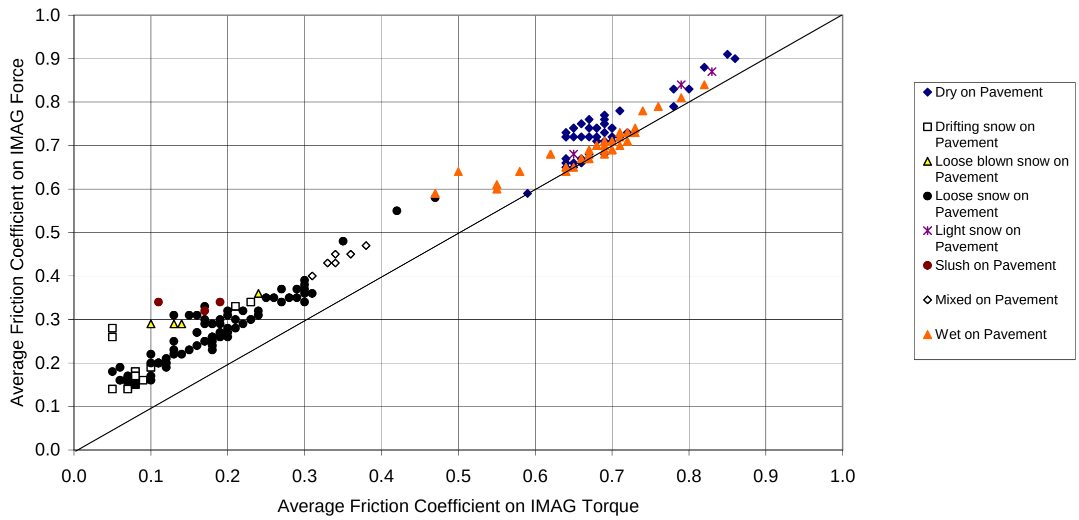

**O-2: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on an Ice Base**



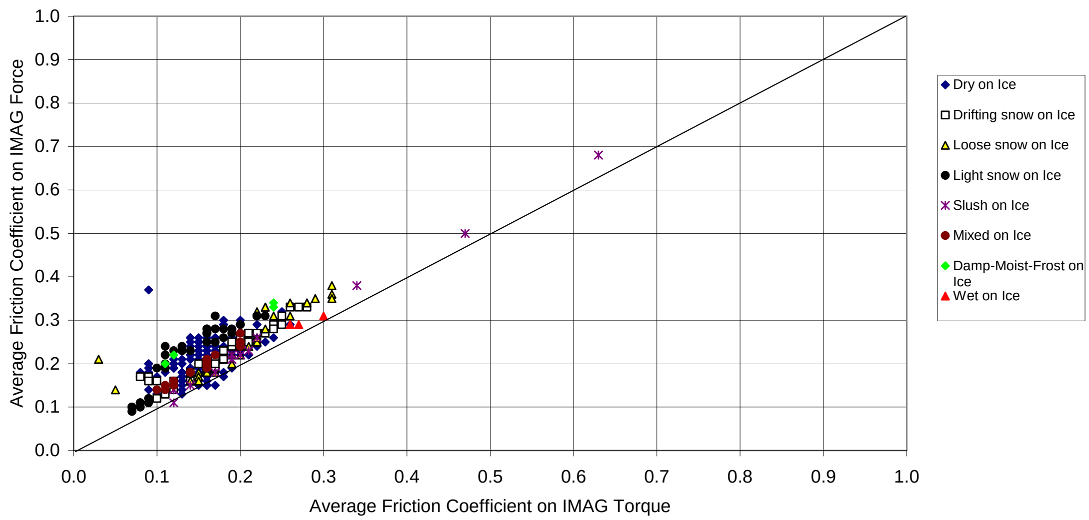

**O-3: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**



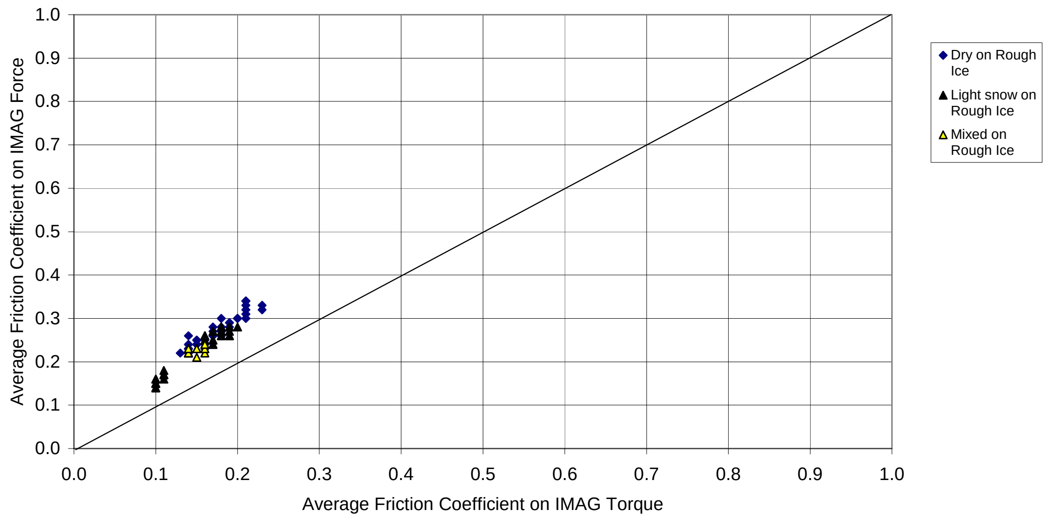

**O-4: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on Packed Snow**



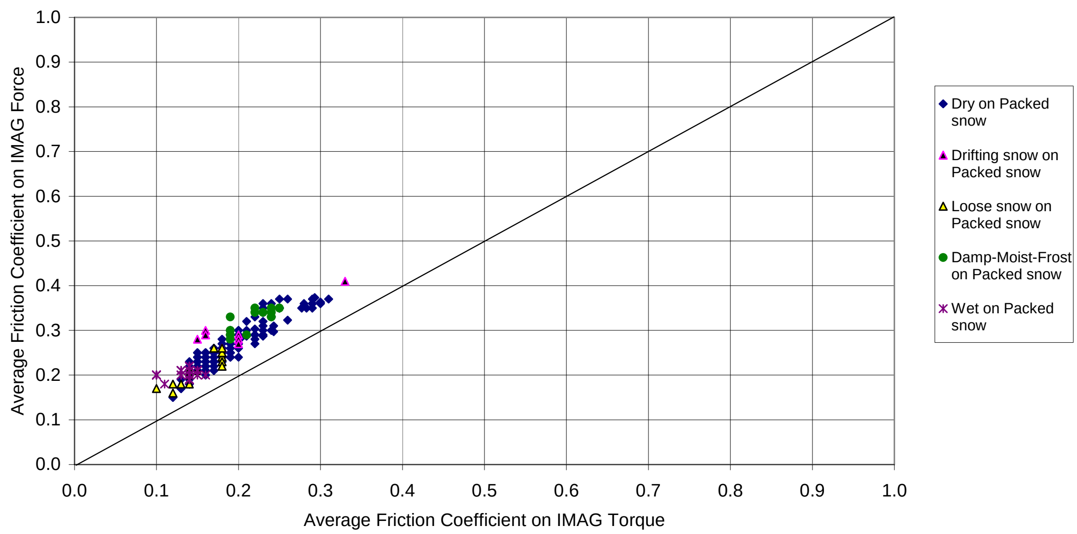

**O-5: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on a Pavement Base**




**O-6: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on an Ice Base**




**O-7: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on a Rough Ice Base**




**O-8: Correlation of IMAG Force to IMAG Torque (Configurations 3 and 7) on Packed Snow**