ERDC/CRREL TR-17-3

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

2010/11 McMurdo Station Snow-Road Strength and Maintenance

Terry D. Melendy and Sally Shoop

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Abstract

During the 2010/11 Antarctic field season, the Cold Regions Research and Engineering Laboratory (CRREL) conducted a snow roads and transportation study for a second year at McMurdo Station. Part of this study included tracking the road maintenance and temperature and testing the road strength at predetermined mile markers along the 13 miles of snow roads located on a permanent ice shelf that connects the (now closed) Pegasus Airfield to McMurdo Station. These data were recorded for each lane of road at six locations over 5 months. A Clegg Impact Hammer and a Rammsonde snow cone penetrometer were used to capture both the surface strength and the strength of the road with regard to depth. The team collected temperature data by using a temperature probe inserted into the snow to measure temperature of the air, snow surface, 7.6 cm down from surface, and 15.2 cm down from surface.

Analysis of the data provides insight as to the direct effects of various maintenance and environmental factors on the strength of the roads. Understanding the effects of these variables will ensure the roads are kept operational for as long as possible and will increase the efficiency of the McMurdo Station transportation infrastructure. The data also contributed to the creation of standard operating procedures for maintaining the snow roads at McMurdo Station.

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Preface

This study was conducted for the National Science Foundation, Office of Polar Programs (NSF-OPP), Antarctic Infrastructure and Logistics Program, under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-12-05, "Snow Roads and Transportation." At the time the work was conducted, the technical monitor was George Blaisdell, NSF. It could not have been completed without the outstanding assistance received from many staff with the Antarctic Support Contract, at the time Raytheon Polar Services staff.

The work was performed by the Force Projection and Sustainment Branch (CEERD-RRH), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Sarah Kopczynski was Chief, CEERD-RRH, and Janet Hardy was the program manager for EPOLAR Antarctica. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

The authors appreciate the contributions of Margaret Knuth (NSF) for her insight, tireless fieldwork, and review.

COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms and Abbreviations

CBR	California Bearing Ratio
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations, Logistics and Research
ERDC	Engineer Research and Development Center
HEOs	Heavy-Equipment Operators
HMW	High Molecular Weight
NSF	National Science Foundation
OPP	Office of Polar Programs
USAP	United States Antarctic Program

Unit Conversion Factors

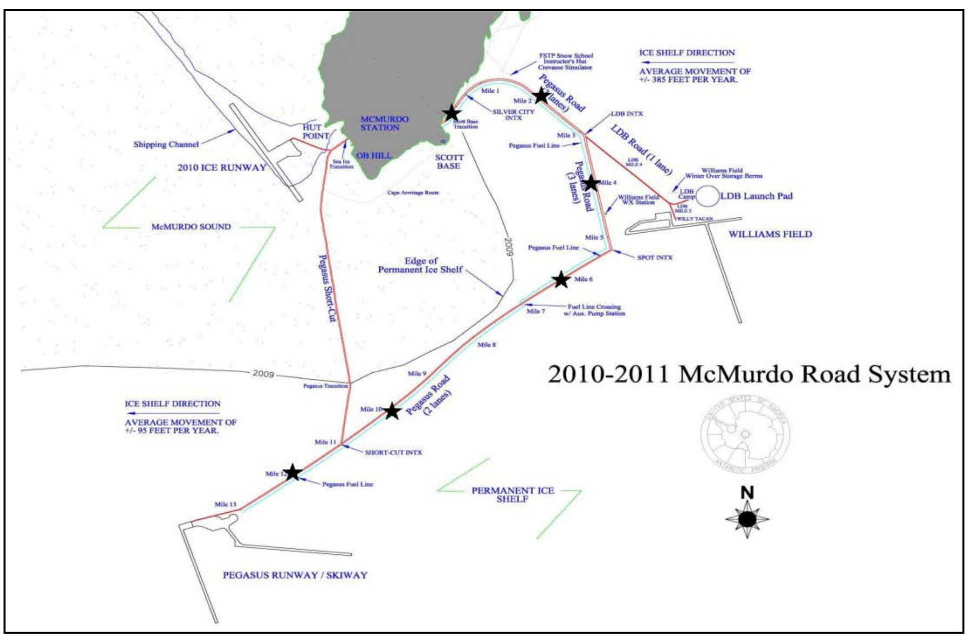
Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (mass)	0.45359237	kilograms

1 Introduction

1.1 Background

McMurdo Station, Antarctica, serves as the most heavily populated research station in the United States Antarctic Program (USAP). Over 1100 scientists, engineers, military personnel, and support staff are stationed here at any one time during the austral summer from October to February. At the time of this study, the Pegasus airfield served as the main runway for inter- and intracontinental air traffic from December to February with as many as three C-17 flights a week and daily LC-130, Twin Otter, and Basler flights. Pegasus airfield was located 15 miles from McMurdo Station for the 2010/11 season with 13 of those miles travelling across snow roads and 2 miles on dirt and gravel roads (Figure 1). This snow road was a critical asset, providing the main avenue of transportation going to and from McMurdo Station.

Figure 1. Map of McMurdo Station road and airfield; test site locations for the 2010/11 season are marked by stars.



1.2 Objective

During the 2010/11 austral summer, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) conducted a second summer season of studying snow roads at McMurdo Station. This is a follow up to the

2002/03 study, as described in Shoop et al. (2016), looking at snow-road construction, maintenance, and usage. The 2010/11 work focused on tracking road maintenance (i.e., what, when, and where each piece of road equipment was used), temperature, and road strength. The goal was to collect data that would be able to determine road-strength trends that can be used in future years to increase the reliability of the transportation system. The snow roads historically have been a very time consuming area for heavy equipment, and the performance has resulted in increased travel time to and from the runways.

1.3 Approach

The 2010/11 data were tracked at six different locations: Mile Points 0.5, 2.0, 4.0, 6.0, 10.0, and 12.0. The snow road has two to three wheeled lanes and one tracked lane on the ice shelf to the airfield. CRREL collected the data on each lane at each of the six locations two to three times per week. The collection of data took place at various times, depending on weather conditions, which was the driving factor for taking probe temperatures at each location at the same time as the strength test. Heavy-equipment tracking occurred daily by the operators detailing what task they were performing and where along the snow roads.

2 Current Equipment

2.1 Prime movers

There are multiple types of prime movers used on station for various aspects of maintaining the snow roads on the permanent ice shelf. The machines in highest demand during the summer season are the Challenger tractors (Figure 2). Challenger is a Caterpillar product outfitted with rubber tracks for low ground pressure and is capable of pulling implements over 60,000 lb. When conditions allow, the Challenger can pull implements at speeds in excess of 15 mph. They pull compacting, smoothing, and planing implements. Bulldozers are the second preferred method for snow-road construction and maintenance. There are multiple sizes of bulldozers on site; but the primary ones used are the Caterpillar D-7H (Figure 3) and D-8R models, which are stationed on the permanent ice shelf and are responsible for assisting with pulling implements and with constructing the transition (the section of road that connects the permanent ice shelf to Ross Island). The drawback to using bulldozers is their inability to travel at speeds above 7 mph. However, they are capable of pulling heavy implements and loads, including compacting, smoothing, planing, and some in tandem to improve efficiency (Figure 4). Delta vehicles (Figure 5) are used for tire compacting and pulling drags when equipment and heavy-equipment operators (HEOs) are limited. They can also travel at speeds of 20–25 mph.

Figure 2. Caterpillar Challenger 95E at McMurdo, January 2014.

Figure 3. Caterpillar D-7 bulldozer with 50,000 lb cart at McMurdo Station, November 2011.

Figure 4. Caterpillar D-7 bulldozer with sheepsfoot and drag at McMurdo Station, November 2011.

Figure 5. Delta transporting cargo at McMurdo Station, November 2010.

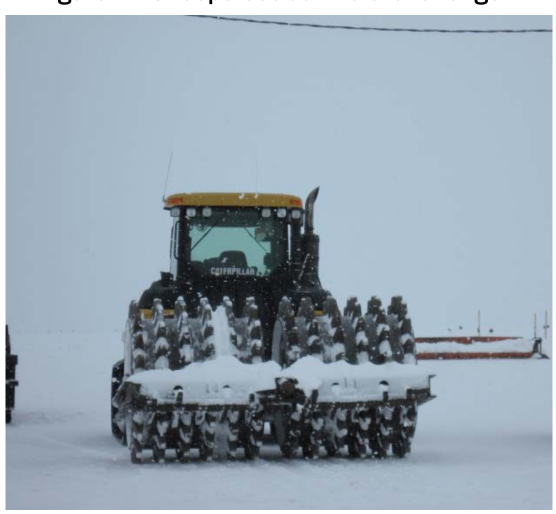
2.2 Implements

The snow road implements currently used at McMurdo Station fall into three different groups: compaction, smoothing, and planing equipment. Each category of attachments is necessary in the process of constructing and maintaining snow roads.

Compaction implements include ox carts (Figure 6) with pneumatic tires and can be loaded in excess of 60,000 lb. They not only apply high ground pressure to the snow surface but also are capable of kneading the snow to achieve deeper compaction (Melendy et al. 2011). The sheepsfoot roller (Figure 7) weighs approximately 15,000 lb and has two steel drums with 6 in. tines. These drums can be weighted by adding a non-freezing fluid, such as glycol, which increases compaction capability. In soft snow conditions, the sheepsfoot can be used to precompact the snow road; and often (but not always) use of an ox cart will follow. The use of a high molecular weight (HMW) polyethylene sheet loaded with miscellaneous weight has been used when snow conditions are too weak for tire compaction towed behind a prime mover. This type of compaction is commonly referred to as a magic carpet.

Figure 6. Ox cart behind a Challenger.

Figure 7. Sheepsfoot behind a Challenger.



Smoothing attachments used are steel drags (Figure 8) that can be towed solo or in tandem behind a compaction implement. The drags are typically 15 to 20 ft wide. Planing equipment includes gooses (Figure 9) that are capable of removing bumps (also referred to as *rollers*) or large snowdrifts. A goose has a 15 ft wide serrated cutting blade with skis to slide along the road surface. Artsway (Figure 10) and Eversman land planes are bump-removal implements similar to the goose but have 24 to 30 ft serrated cutting blades and are capable of removing longer wavelength oscillations on the snow surface. The removal of these bumps is important because they can lead to potholes or blowouts caused by vehicles bouncing. Bumps are also particularly dangerous to operators in flat light conditions where determining the location of the horizon becomes blurred and details in the snow surface are all but lost.

Figure 8. Steel Drag behind a Challenger.

Figure 9. Goose behind a Challenger.

Figure 10. Artsway behind a Challenger.

An experimental implement designed by Michigan Tech Keweenaw Research Center and evaluated by CRREL over the course of the 2010/11 summer season is the Snow Miller or Snow Paver (Figure 11). The Snow Paver was designed to be capable of smoothing, grading, milling, and compacting in one pass. This would historically take three passes to complete the same tasks. During testing, the proof of concept could not produce enough hydraulic pressure and flow to operate all of the different functions at once but proved effective for plate vibratory compaction of the surface and for grading. The Keweenaw Research Center designed and installed an onboard power pack on the attachment with limited success due to data collection issues (Shoop et al. 2014a).

Figure 11. Snow Paver at McMurdo, November 2010.

3 Data Collected

Over the course of the 2010/11 summer season at McMurdo Station, CRREL research staff collected snow-road data at six different locations, Mile Points 0.5, 2.0, 4.0, 6.0, 10.0, and 12.0, a minimum of two times per week. Data collected for each of these locations included snow strength, temperature, maintenance, and weather events. Strength data were collected by two different methods: Rammsonde snow penetrometer and Clegg Impact Hammer. Temperature was measured above the surface (air); at the surface; and at 2, 4, and 6 in. below the surface. HEOs recorded their daily activities, including which piece of equipment they operated, what implement they pulled, the location of work, and how many passes were made. CRREL personnel recorded weather events and road conditions, such as snow drifting, roughness, and potholes, at each of the mile-marker test points.

3.1 Rammsonde data

CRREL machined Rammsonde cone penetrometers that could be used with either a 30° or 60° conical tip (Figure 12). The Rammsonde measures snow strength with respect to depth, accurately separating snow strength into layers. It is important to be able to understand which layers are affected by various maintenance events and how the warming part of the season affects the snow roads below the surface. At each test location, CRREL personnel performed three independent tests to a depth of 60 cm on each of the travel lanes (Figure 13); the data were then averaged to produce one data set for each lane at each test location. The travel lanes typically included wheeled lanes A, B, and C for pneumatic tired vehicle and a track lane for heavy equipment. Once collected, the data were separated into two distinct snow layers, 0–15 cm and 15–30 cm, and plotted with time (Figure 14). Data were taken to 60 cm but was not analyzed in as much detail because the expected compaction impact depth does not exceed 30 cm. Separating the strength data into two layers provides a comparison over the course of the season between the surface and subsurface. Figure 14 shows Lane A at Mile Point 2.0 from October to February. The recorded strength at the start of the main body (station opening for research usually in October) season was very high for the 15–30 cm layer and then dropped along with the surface layer until the end of December; then the strength began to increase once again. This pattern is typical of all wheeled lanes at various mile points.

Figure 12. Typical Rammsonde used to measure snow-road strength.

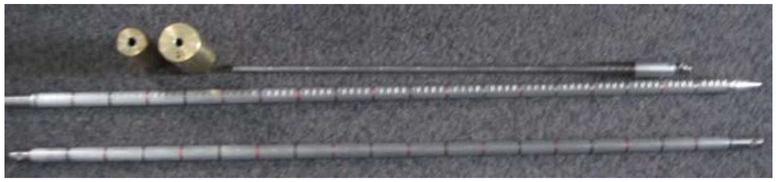
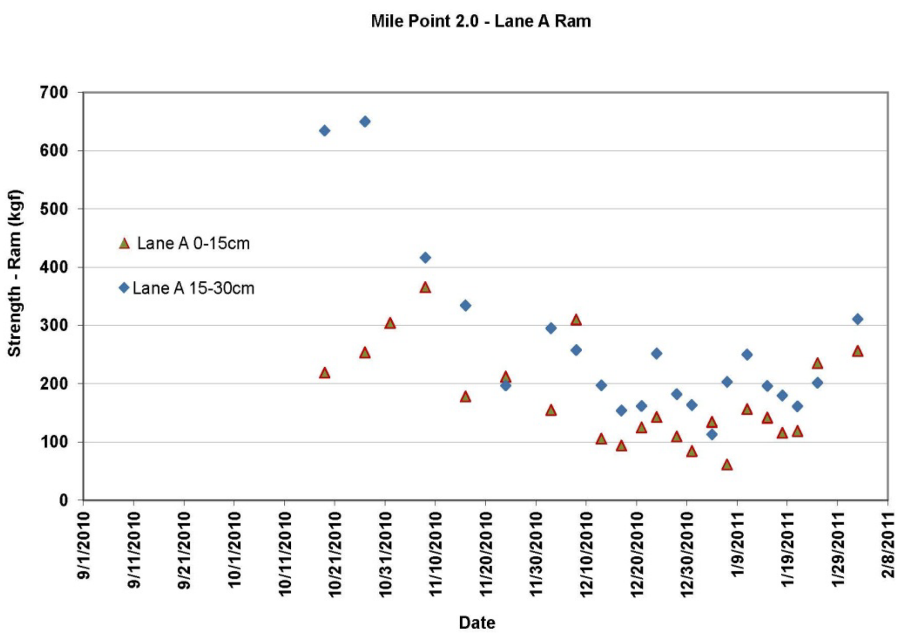


Figure 13. Rammsonde in use at McMurdo.

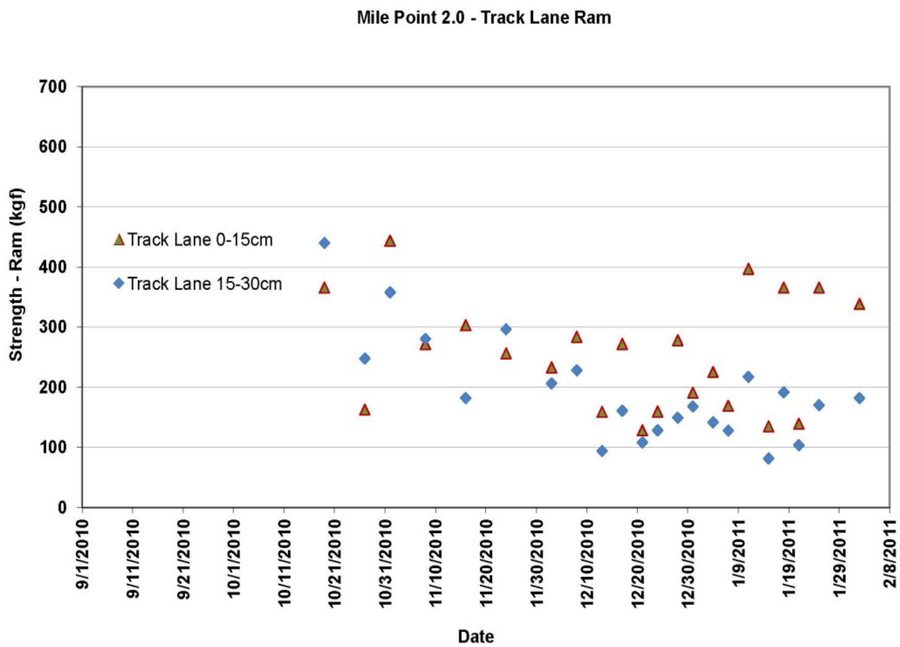
Figure 14. Mile Point 2.0, Lane, A Rammsonde data.



In Figure 15, the Mile Point 2.0 Track Lane shows a different trend in the snow layers; the surface layer never drops below a Rammsonde value of

100 kgf as was seen in Figure 14 on the wheeled vehicle lane on multiple occasions from December to January. The surface layer (0–15 cm) actually shows higher strength than the subsurface layer over most of the season. The surface layer averaged 50 kgf higher than the subsurface. The strength of both layers does decrease in December in comparison to October measurements; this could be due to rising temperatures in December. The surface strength generally increases from January to February and once again could be tied to the decreasing temperatures at this time. This trend is typical of the Track Lane at many of the test locations over the 13 miles of snow roads. The data provided many questions, such as how much impact does snow-road maintenance have, how important is it for the snow road to sinter (harden) after smoothing and compaction events, and can we distinguish which maintenance routine works best. The results section of this report addresses these questions.

Figure 15. Mile Point 2.0, Track Lane, Rammsonde data.



3.2 Clegg Impact Hammer data

CRREL used the Clegg (Figure 16) to measure the surface strength of the snow roads. At each of the six test locations, we established a test matrix similar to that for the Rammsonde; we conducted a series of three independent tests on each lane. The data were then averaged to produce one data set for each lane at each test site. The Clegg Hammer was dropped six times for each test. Drops 3 to 5 were averaged for each test; all three tests for a lane were then averaged to produce one data set for each lane at each test mile point. Several sizes of Cleggs exist. We used the one with a 2.25 kg mass, which we determined to yield the best results for snow roads (Shoop et al. 2014b). Strength measurements for the Clegg are recorded in Clegg Impact Values, which can be converted to the California Bearing Ratio (CBR) using the equation below:

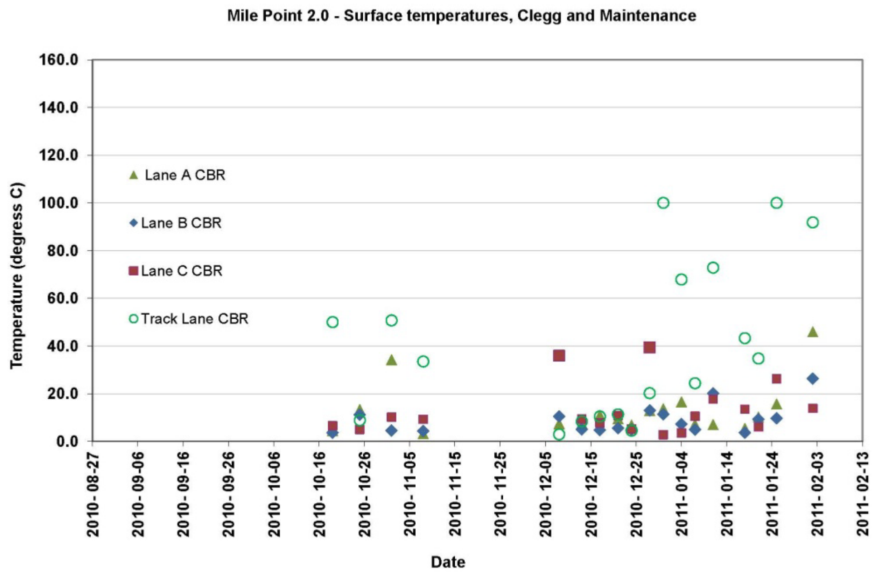
$$\%CBR = e^{\left[\frac{10x-14.936}{79.523}\right]}$$

where x = the peak decelerations in C_{max} for the third drop of the medium Clegg Hammer from a height of 0.45 m and with an r^2 value of 0.932 (MVMBNI JV 2003; Shoop et al. 2012).

Figure 16. A 2.25 kg Clegg Impact Hammer being used on the McMurdo Snow Roads.

The data from each monitoring location were graphed to compare trends in the surface strength with maintenance events throughout the season. Figure 17 is a typical example of the trends in Clegg data as reported at Mile Point 2.0 across the A, B, C, and Track Lane. The Track Lane was recorded as having the highest average surface strength over the course of the 2010/11 field season regardless of the instrument used to collect the data. Lane C at this location was recorded as having the highest strength at two points during the season, which are questionable data because of the lack of similar trends at other mile points. The Rammsonde data in comparison to the Clegg on the Track Lane display the same trends at the same timing, such as in December with a drop in strength followed by an increase in strength moving into late January.

Figure 17. Clegg data at Mile Point 2.0 for Lanes A, B, C, and Track.



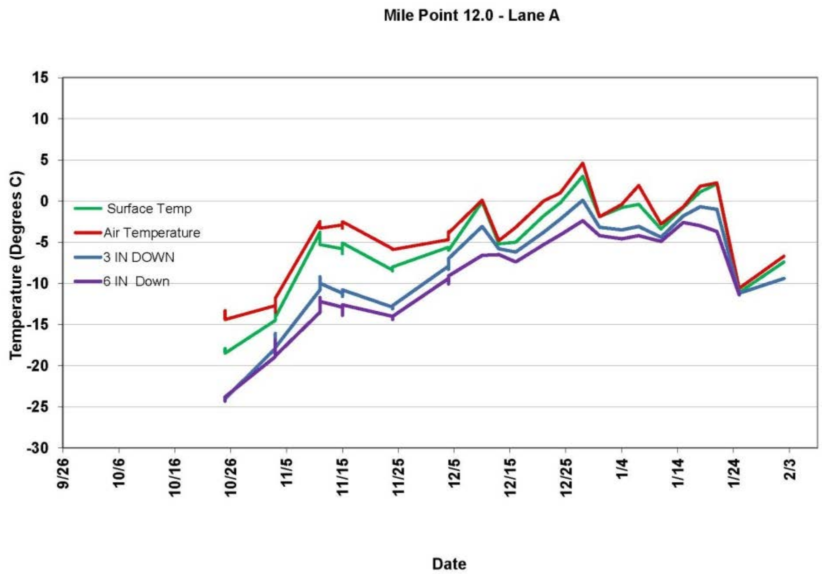
4 Data Analysis

4.1 Temperature vs. road strength

The CRREL team collected temperatures at each test location by using a CRREL-manufactured temperature probe (Figure 18). The probe captured the temperature at four vertical locations during each measurement: (1) in the air at 3 in. above the snow, (2) at the snow surface, (3) at 3 in. below the surface, and (4) at 6 in. below the surface. Typically, the air temperature was highest, and temperatures below the surface at −3 and −6 in were the lowest recorded temperatures (Figure 19). This was likely because the measurements were made during the warming part of the day. We determined that the air and surface temperatures were the most important for snow strength because melting temperatures are an independent variable (Gow and Ramsier 1964). Temperatures at Mile Point 12.0 followed similar trends at all of the test locations and lanes; from October to December, the temperature was rising, during January the temperatures would level off, and then they started to drop in late January. The maximum recorded temperature at Mile Point 12.0 was 5°C from the air sensor, proving that during the warmest part of the season, melting is possible at the surface.

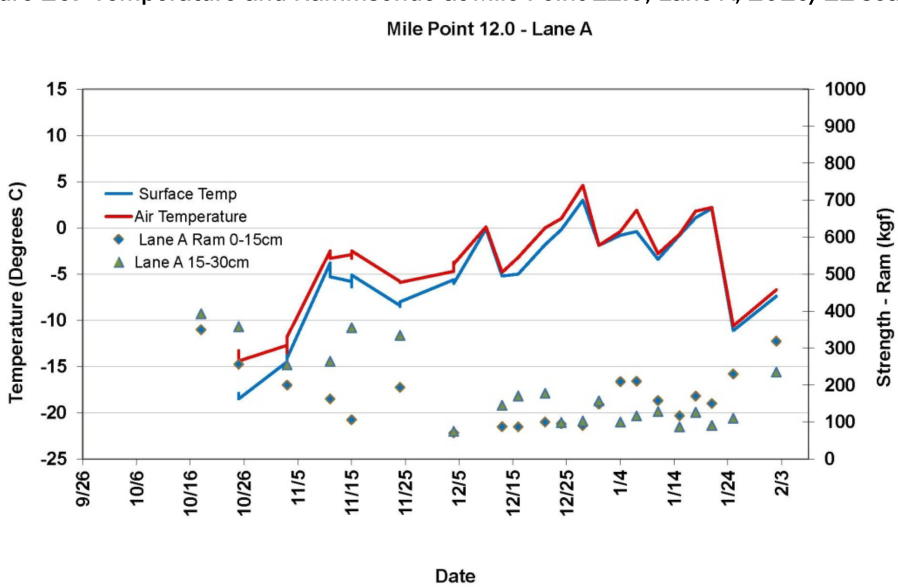
Figure 18. CRREL-manufactured temperature probe.

Figure 19. Temperature at Mile Point 12.0, Lane A, 2010/11 season.



As shown in Figure 20 for Mile Point 12.0, Lane A, Rammsonde measurements plotted along with temperature, we see a relationship between strength and temperature. As the temperature increases, the strength recorded at both the 0–15 cm and 15–30 cm layers decreases from 400 kgf in October to 90 kgf in December. The subsurface 15–30 cm layer during this time period was stronger than the surface because of the delayed effects of rising temperatures (whiplash effect) with depth. This plot does not take into account the maintenance being performed as a variable and assumes limited snowfall.

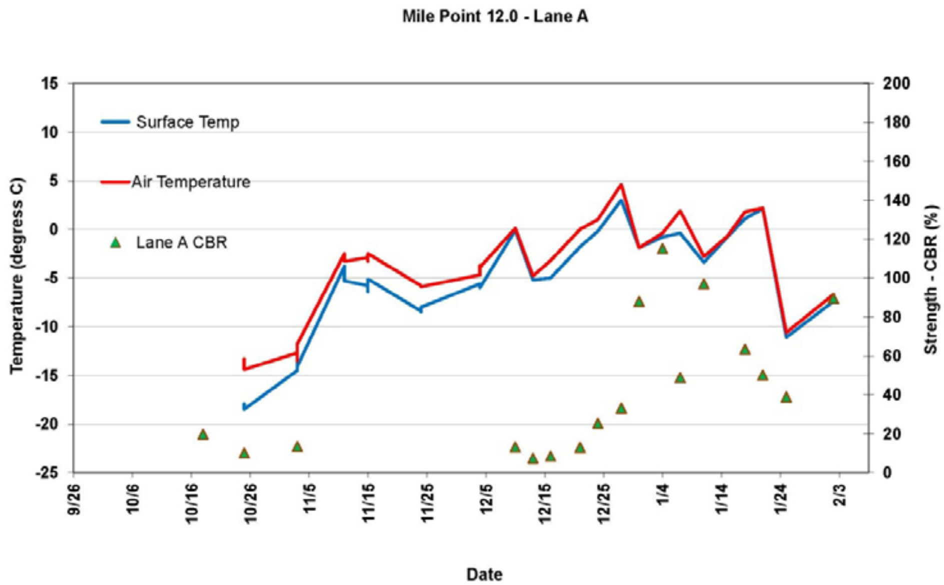
Figure 20. Temperature and Rammsonde at Mile Point 12.0, Lane A, 2010/11 season.



The ideal snow-construction air temperature range is −5°C to −10°C (Shoop 2010; Abele 1990) to have a balance between ultimate strength and sintering time. Snow construction can be completed at temperatures lower and higher than this range, but the time to achieve higher strengths will take longer. As the temperatures at Mile Point 12.0 hovered around the 0°C mark from December to January, the recorded snow-road strength in both road layers stayed consistently low until the temperatures began to drop once again. The subsurface layer (15–30 cm) is critical for determining overall snow-road conditions because heavy-ground-pressure vehicles often break through the surface layer (0–15 cm); and if there is relatively low strength in the subsurface layer, the vehicles will become immobilized. A weaker 15–30 cm layer resulted in vehicles becoming stuck and requiring assistance to reach their destination due to lack of snow bonding similar to corn kernels in a cup. Once the temperatures started to decrease at the end of January, the snow-road strengths at all mile points began to increase in excess of 250 kgf as recorded by the Rammsonde. Determining an optimal road strength is key for deciding which maintenance procedures to complete and at what time. Knuth et al. (2013) showed that strengths above 150 kgf reduce LC-130 slides (takeoff attempts) on the skiway at Summit Station, Greenland. This information provided a rough order of magnitude for a minimum baseline for snow-road strength to reduce the number of immobilized vehicles and trip time to and from the airfield. Strengths recorded at or above 250 kgf, as seen on the Track Lane for most of the season, correlated to serviceable roads that could safely handle wheeled traffic with few problems.

Clegg strength versus air and surface temperature (Figure 21) portrays a different trend than the Rammsonde data. The Clegg surface strength does not decrease with increasing temperatures while the Rammsonde data show a trend of decreasing strength with increasing temperature. The surface strength actually increases in warmer temperatures. This could be associated with the method in which the Clegg drops a wider contact area on the surface and physically pounds the surface down. The method in which Clegg was used is detailed by Shoop et al. in their 2012 report. The corresponding measurement of strength calculated from the Clegg is more reflective of the surface strengths. Lane A was subjected to repeat trafficking, resulting in a thin cap on the surface of the snow road. This hard surface was evident as the Challenger fleet was capable of driving on top of the snow roads, pulling heavy loads with little sinking; however, once the tracks started to dig in below the surface, the Challengers would become immobilized. Rammsonde data support these surface-capping events, showing weaker subsurface layers during the warmest parts of the season. This similar trend can be seen on over 75% of the Clegg data collected over the season, including at all mile points and lanes.

Figure 21. Temperature and Clegg at Mile Point 12.0, Lane A, 2010/11 season.



Comparison between lanes (both Rammsonde and Clegg) revealed the Track Lane as the strongest over the entire season at all six test locations for both surface and subsurface depths. Mile Point 12.0, Rammsonde data for the 0–15 cm layer, indicate that all three of the lanes followed similar trends of dropping in strength as the temperature increased (Figure 22; Appendix A), yet the Clegg data did not follow the same trend.

Taking a more in-depth look at Figure 22 shows the Track Lane did differ from both Lanes A and B by not dropping below 100 kgf and averaged 200 kgf during the month of December. The Track Lane gained strength at a faster rate than both A and B during January, which still had high temperatures above −5°C. Mile Points 2.0, 4.0, 6.0, 10.0, and 12.0 (Figures 23–27) consistently had low strength (CBR below 10) from 10 November to 12 December across all lanes; and only the Track Lane consistently showed increases in strength from 20 December to 24 January. After 24 January, the temperatures began to drop once again; and all lanes started to gain strength. We should note that Delta cargo vehicles equipped with aggressive tires used the Track Lane, and Delta cargo vehicles equipped with smooth tires used Lanes A and B.

Figure 22. Temperature and Rammsonde at Mile Point 12.0, all lanes, 2010/11 season.

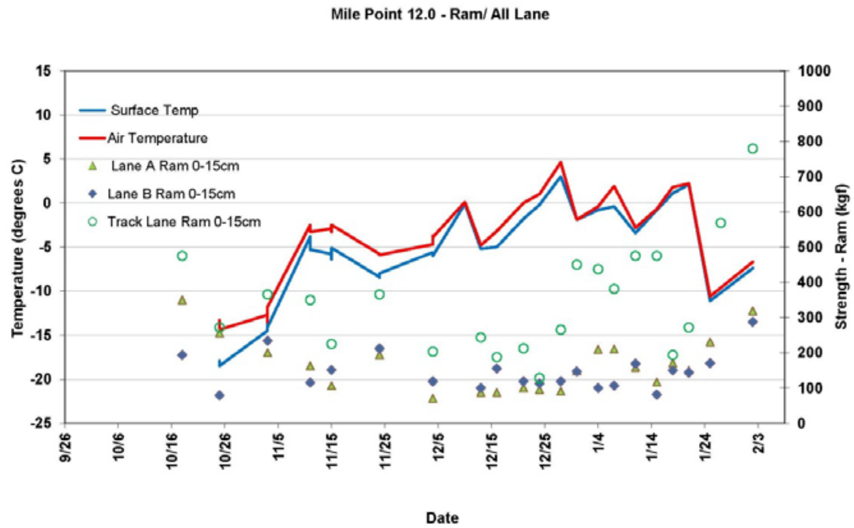


Figure 23. Temperature and Clegg at Mile Point 2.0, all lanes, 2010/11 season.

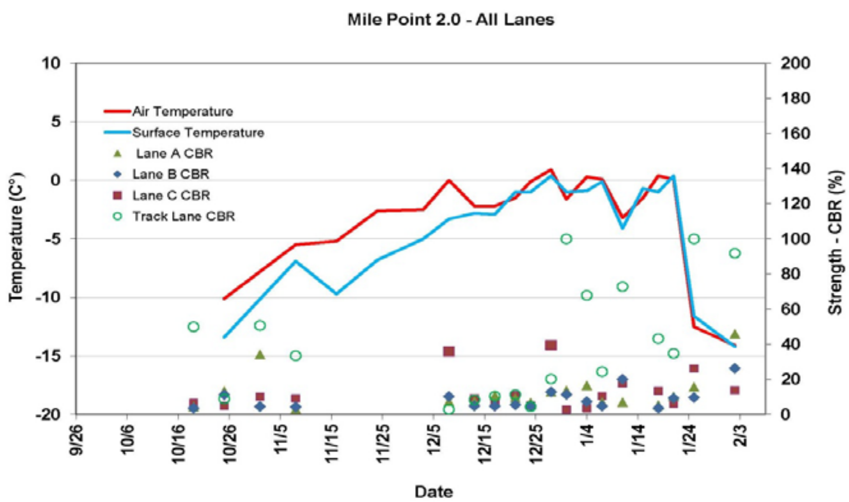


Figure 24. Temperature and Clegg at Mile Point 4.0, all lanes, 2010/11 season.

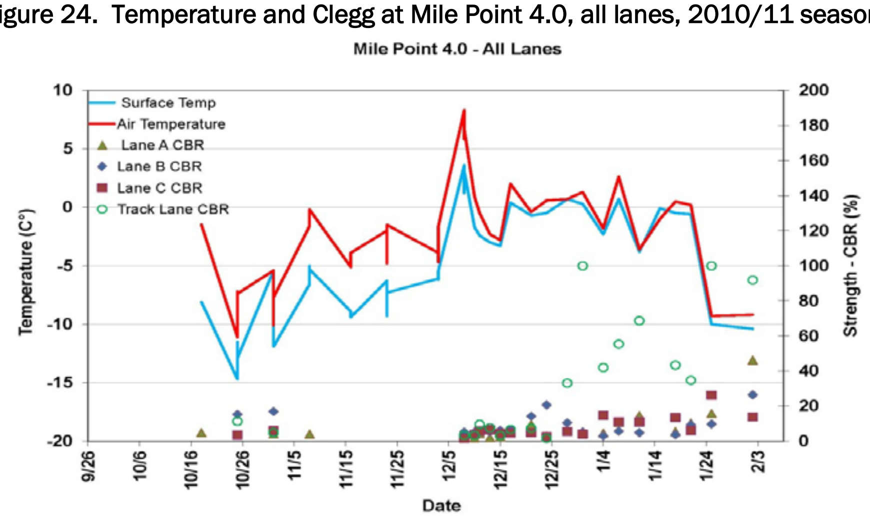


Figure 25. Temperature and Clegg at Mile Point 6.0, all lanes, 2010/11 season.

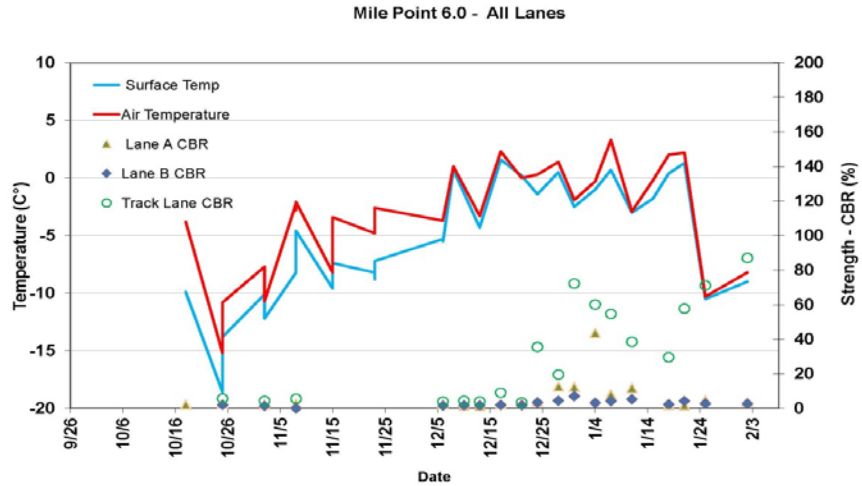


Figure 26. Temperature and Clegg at Mile Point 10.0, all lanes, 2010/11 season.

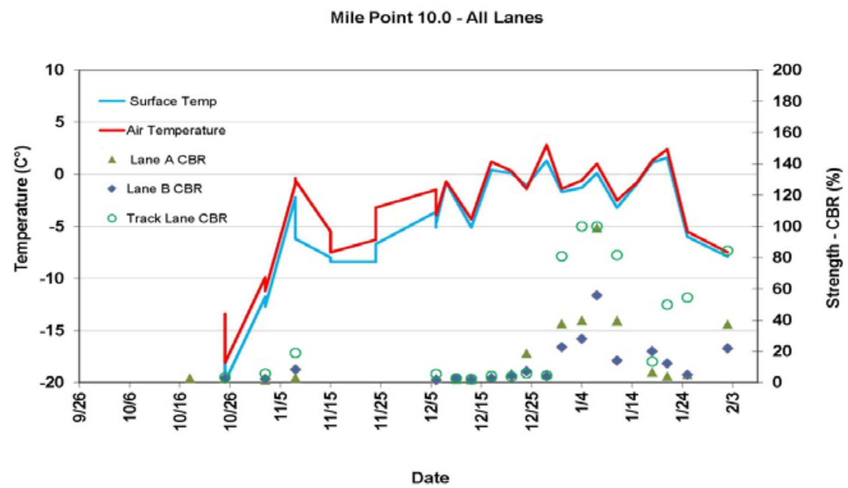
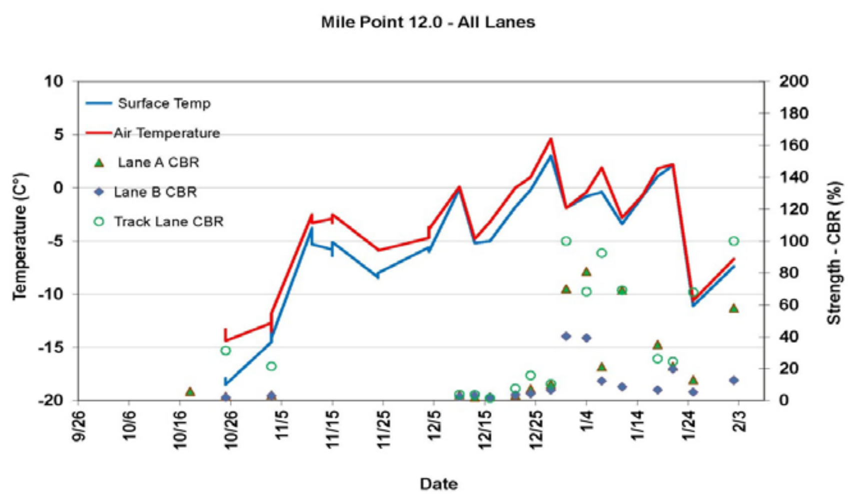


Figure 27. Temperature and Clegg at Mile Point 12.0, all lanes, 2010/11 season.



The hypothesis for higher Track Lane strengths in comparison to the other lanes is that continuous traversing over the lane with heavy tracked and wheeled equipment regardless of the temperatures resulted in increased strengths over the whole season. These vehicles compacted the surface of the Track Lane during high temperatures, enabling the Track Lane to establish a stronger snow pack at the surface. Once the two-wheeled lanes (A and B) began to fail and create large ruts between 10 and 18 in.in depth, all vehicles were directed to travel on the Track Lane. Rutting was evident across all lanes during the temperature peak of the season; however, the recorded strengths for the Track Lane were generally higher in comparison to the other lanes.

4.2 Maintenance vs. road strength

CRREL and maintenance staff tracked the construction and maintenance events during the 2010/11 summer season to determine the effects of various pieces of equipment and implements on snow-road strength. In conjunction with Rammsonde and Clegg data, the equipment events provided information to optimize equipment use. Figure 28 shows the entire season of compaction events. The red ovals point out periods where little to no maintenance was performed on the snow roads, which could have led to potential road issues. Compaction events used four different methods, including the weight cart (both light and heavy versions), sheepsfoot, Deltas, and the proof-of-concept Snow Paver. Two different crews maintained the snow road, resulting in different patterns of compaction events from the 0 to 5 mile marker and 6 to 12 markers.

While compaction events are most effective when temperatures are between −5°C and −10°C (Abele 1990; Gow and Ramsier 1964), often it is difficult to perform maintenance events on a set schedule because of machine breakdowns and limited availability of implements, resulting in compaction events occurring sporadically over the course of the 2010/11 field season. When temperatures are lower than −10°C, compaction events still result in increased surface strength; the difference is that it takes longer to reach the same strength than when temperatures are more favorable. There has been little research to determine the full effects of strength events on the surface and subsurfaces in temperatures higher than −5°C.

Figure 28. All compaction events on snow roads, 2010/11 season. The *red ovals* point out periods where little to no maintenance was performed on the snow roads.

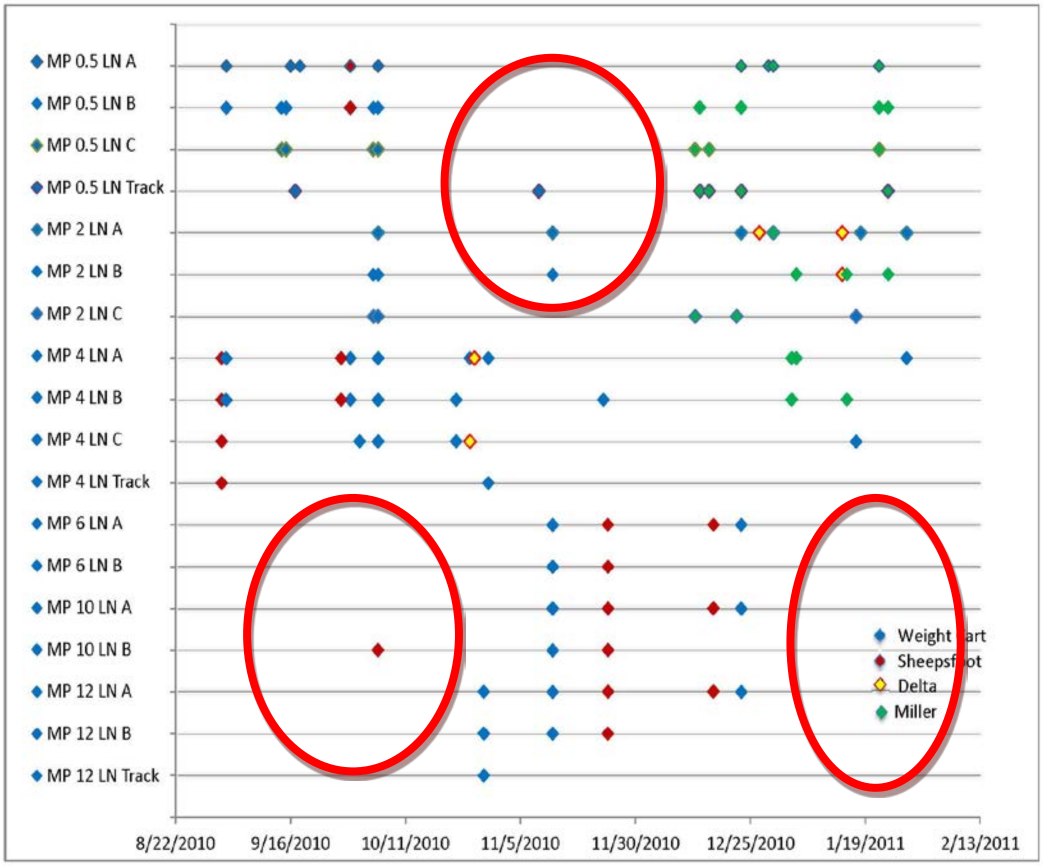


Figure 29 shows the maintenance in Lane A at Mile Point 10.0. The top of the chart states when various maintenance events took place for the corresponding dates on the horizontal axis (date of event). There were only two recorded sheepsfoot compaction events and no other compaction events performed on Lane A at Mile Point 10.0 for the entire season. The lack of compaction left the snow road susceptible to losing strength at both the surface and subsurface layers. The lack of compaction resulted in a lower-than-potential strength than if more compaction had occurred. When compaction events were performed at a higher frequency (Figure 30), the Rammsonde strengths were consistently higher for the 15–30 cm layer. At Mile Point 2.0, Lane A's 15–30 cm layer never dropped below 100 kgf and averaged 150 kgf during the end of December. Compare this to Mile Point 10.0, Lane A, which averaged 75 kgf at the same time. Mile Point 2.0 was maintained on a different schedule than Mile Point 10.0 and received 15 compaction events over the course of the season, ranging from weight carting to snow miller vibratory compaction and Delta tire packing. The effect of having a stronger subsurface layer (15–30 cm) was that rutting did not typically occur at deeper depths and that the road was passable by wheeled vehicles for a majority of the road open period. A similar result was reported by Abele and Frankenstein 1967. The snow roads from McMurdo to Pegasus Airfield have distinct differences in conditions from mile point to mile point, with Mile Points 10.0 on to Pegasus being the worst because of drifting snow and different maintenance procedures. These differences resulted in a majority of the vehicle mobility problems, including becoming stuck, and was a risk to safety.

One specific compaction event at Mile Point 2.0, Lane A, appears to have affected the strength; and this occurred on 23 December 2010. The event was a weight carting (marked with a red circle in Figures 30 and 31) that increased the strength of both the surface and subsurface layers at different timings. The Rammsonde and Clegg were both tested on 24 December 2010. The Clegg values (Figure 31) show that the surface continued to decrease in strength in the first 24 hr and then rapidly increased in the days that followed. The surface strength drops after the compaction event because the surface was disrupted, rearranging the snow structure; and in the following days, the strength increased to levels higher than before the compaction event took place (as shown by the blue circle). A second variable that affected on the snow strength was the temperature, which is typically at its peak from late December to mid-January. Figures 30 and 31 combined show the effects of a compaction event at both the surface and subsurface layers. Compaction, even in weaker snow conditions, can increase strength if it is allowed to sit after the event approximately 48 hr. Therefore, we focused on compaction implements to improve the strength as the dragging and leveling equipment affects only the surface of the snow and has little effect on the snow density and strength. The goosing and dragging events at both Mile Points 10.0 and 2.0 were completed at least twice per compaction event. The reasons for this could be associated with implement availability, snow surface conditions, or working time permitted.

Figure 29. Rammsonde vs. maintenance at Mile Point 10.0, Lane A, 2010/11 season.

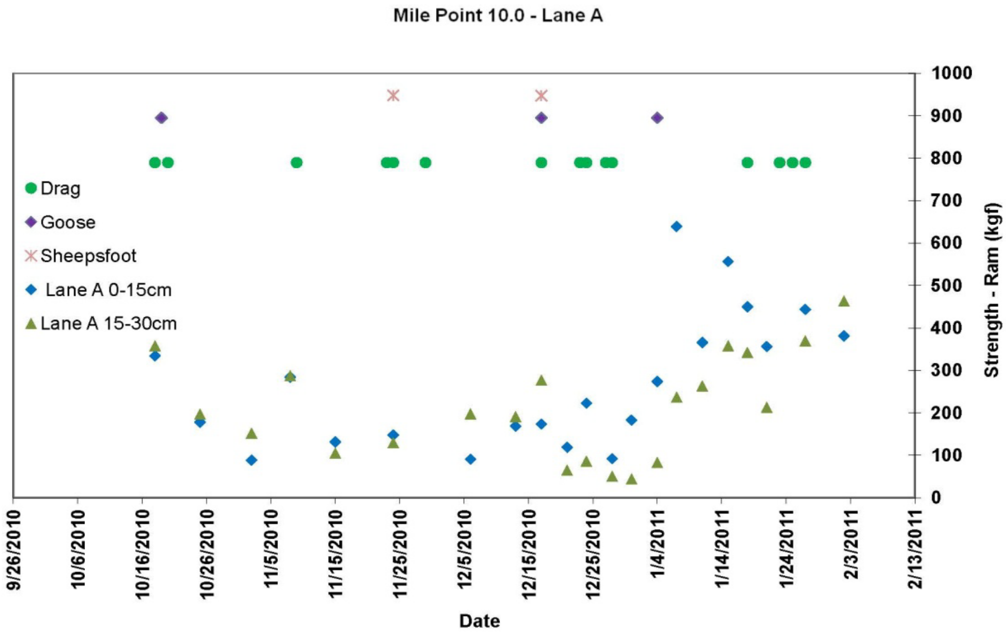


Figure 30. Rammsonde vs. maintenance at Mile Point 2.0, Lane A, 2010/11 season.

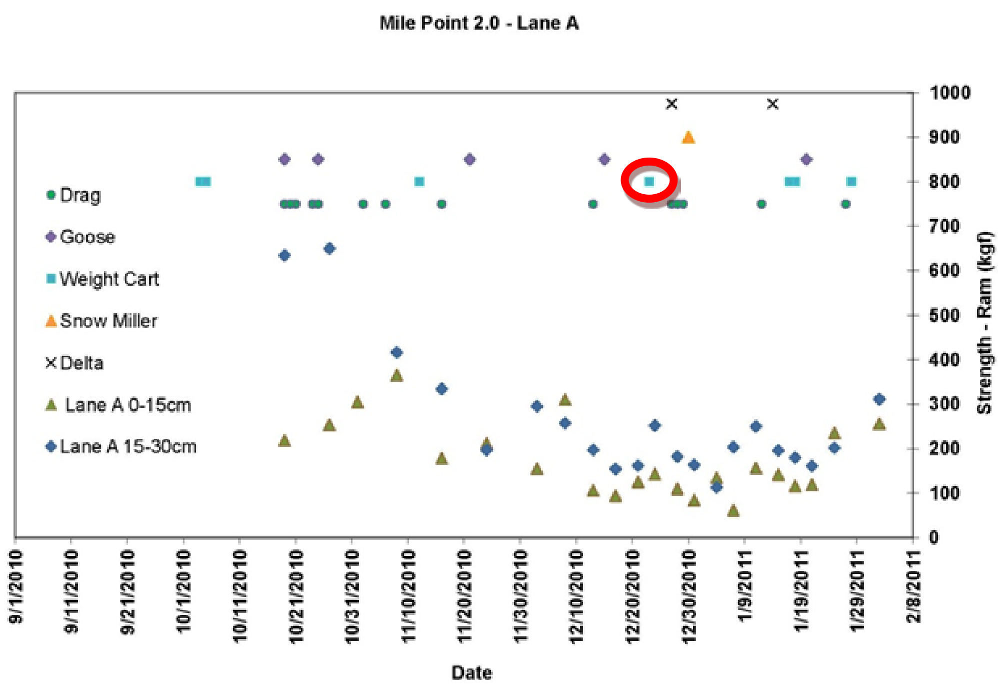
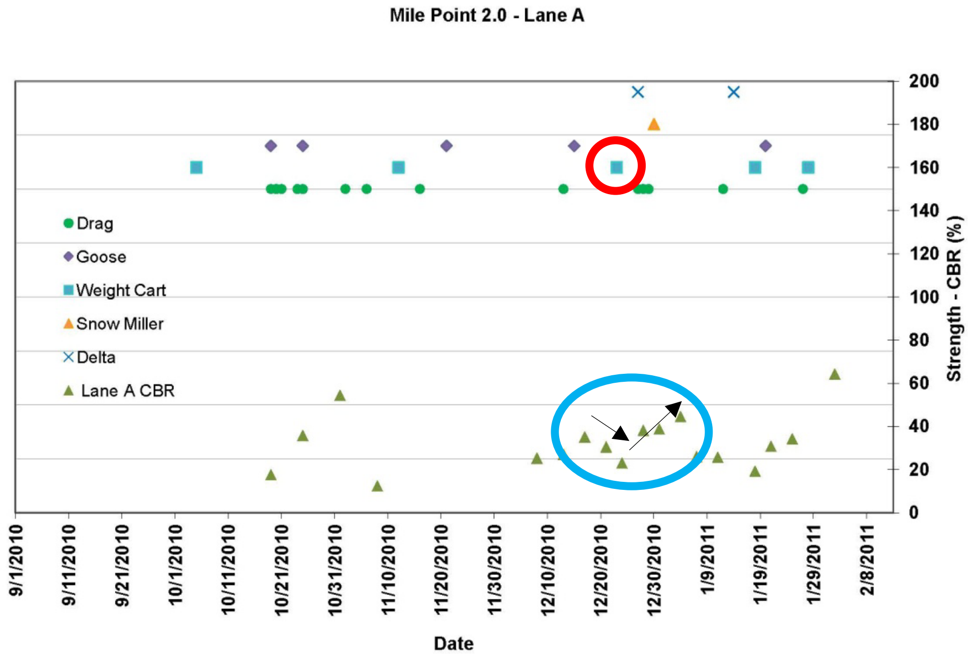


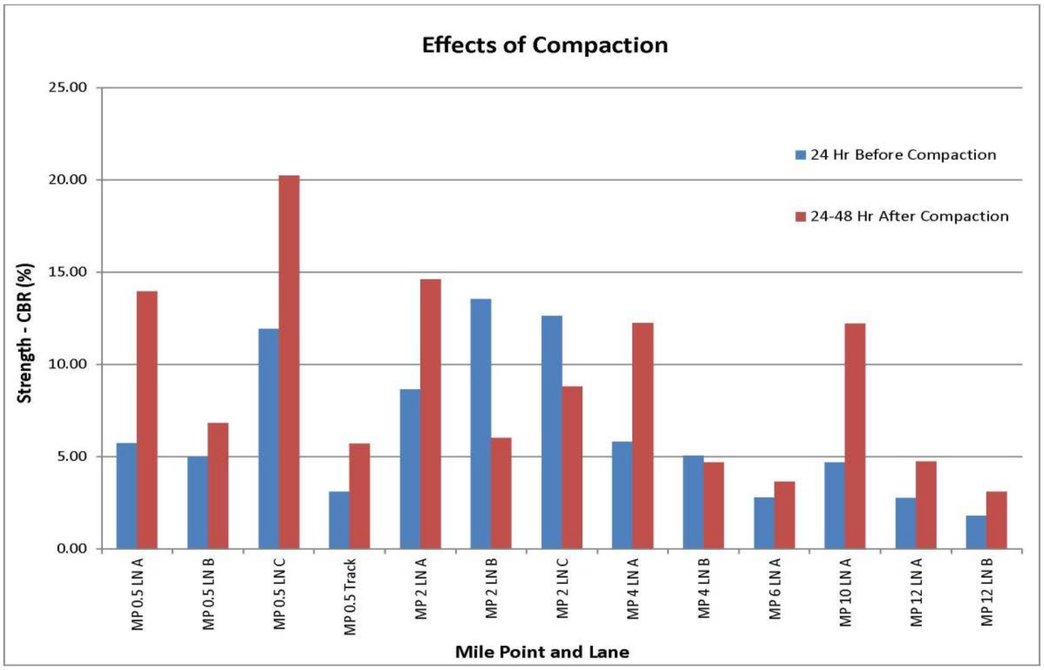
Figure 31. Clegg vs. maintenance at Mile Point 2.0, Lane A, 2010/11 season.



The effects of compaction on the snow roads were that 76% of the events resulted in an increase in surface strength (Figure 32). Because almost all compaction that takes place at McMurdo is by surface implements, we used the Clegg data to compare before and after compaction events. The baseline data before compaction were taken within 24 hr of the event, and the resulting effect was measured within 24–48 hr. Figure 32 is based on 49 different compaction events from October to January. The results show an increase in strength a majority of the time regardless of the temperature at the time of the event, the mile point, or lane. Mile Point 2.0, Lanes B and C, which do not follow the trend. This could be explained by having higher surface strength before compaction, and the snow could have required more time to sinter to exhibit higher strength. The reason for not having data for all of the lanes is that the available strength data were not always collected within the small time window at each location.

Age hardening was a key factor in determining the optimum amount of time after compaction for measuring the resulting strength. At 72 hr after the compaction, 50% of the optimum strength gain is typically achieved (Wuori 1963). The remaining 50% strength gain typically is reached after 28 days, assuming temperature fluctuations or increases will be limited.

Figure 32. Clegg results showing the effects of compaction, 2010/11 season.



5 Recommendations

Maintaining the snow roads in safe operational condition is vital for the current logistics requirements at McMurdo Station. For this to happen, compaction events (using a sheepsfoot, weight carts, wheel/track compacting, or a weighted magic carpet) should be completed early in the season (October) to establish a hard surface at cold temperatures and continued throughout the rest of the season, including during the warmer parts. The ideal ratio between grooming and compacting events should be one to one. This could result in stronger snow surfaces that are more likely to stand up to the warming conditions that occur in December to January.

The positive effects that heavy compacting has on the snow roads during the season, regardless of the temperature, suggest that there is a benefit to alternating the Track Lane between all three of the lanes over the course of the summer season. This would allow heavy equipment to compact all lanes on a more regular basis. Another possibility is the construction and maintenance of only two lanes. This would reduce the amount on work for heavy-equipment operators and would allow for more concentrated maintenance on the two lanes. Because the lanes are currently 50 ft wide, two-way traffic within each lane would still be possible if one lane needed to be shut down for cold sinking or sintering. The current reasoning for having a track lane is so that heavy equipment does not destroy the surface for wheeled vehicles; however, the effects of compacting outweigh this concern.

Compaction equipment currently used at McMurdo has an unknown effective depth and should be researched to determine the most effective frequency of use for the sheepsfoot, weight carts, and weighted magic carpet. Layered compaction, the compaction of snow in small lifts as it accumulates from drifting and snowfall, is also a possibility over the course of the season and should be tested as well. Vibratory compaction should also be reintroduced to the maintenance fleet as it has historically been the most effective at increasing snow surface strength (Abele 1990).

The airfield currently takes priority in regards to regular maintenance due to the importance of logistics and personnel transfer. Snow-road work should be completed on as similar a schedule as possible to the runways due to the impact on the logistics cycle. Allowing the roads to go unmaintained leads to larger issues in December–January when the temperatures reach yearly highs. More frequent maintenance events could improve the roads' performance. The peak transport period to and from the airfield at Pegasus or any airfield on the ice shelf is from December to February; the snow roads need to be in their best operational state to reduce trip time and vehicle maintenance and to ensure operator safety.

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Appendix A: Maintenance, Strength, and Temperature Charts

Figure A-1. Rammsonde at Mile Point 2.0, Lane A.

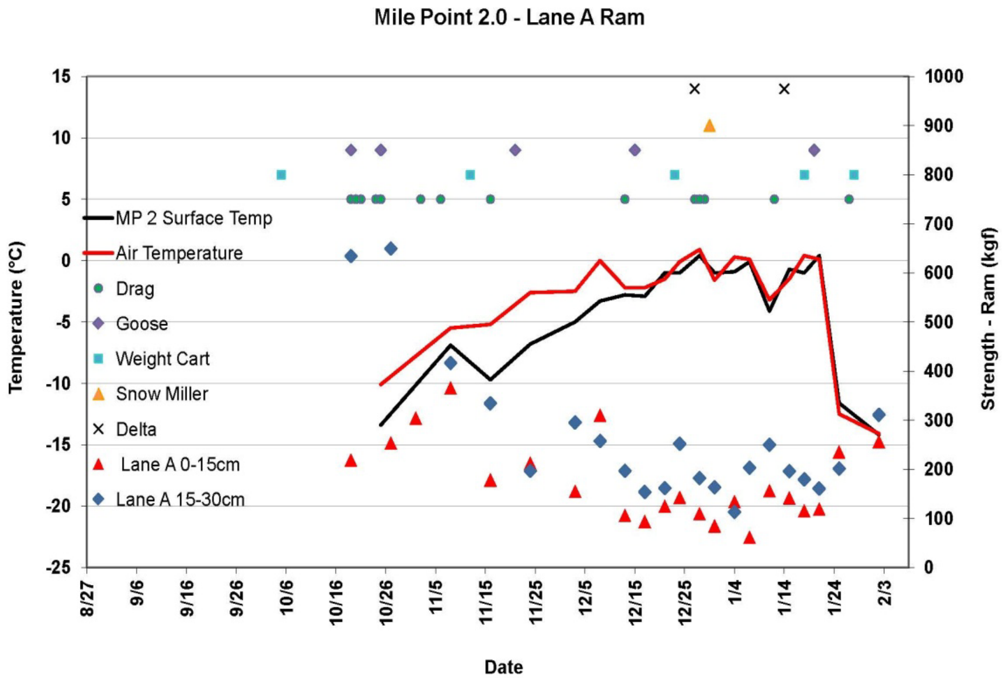


Figure A-2. Rammsonde at Mile Point 2.0, Lane B.

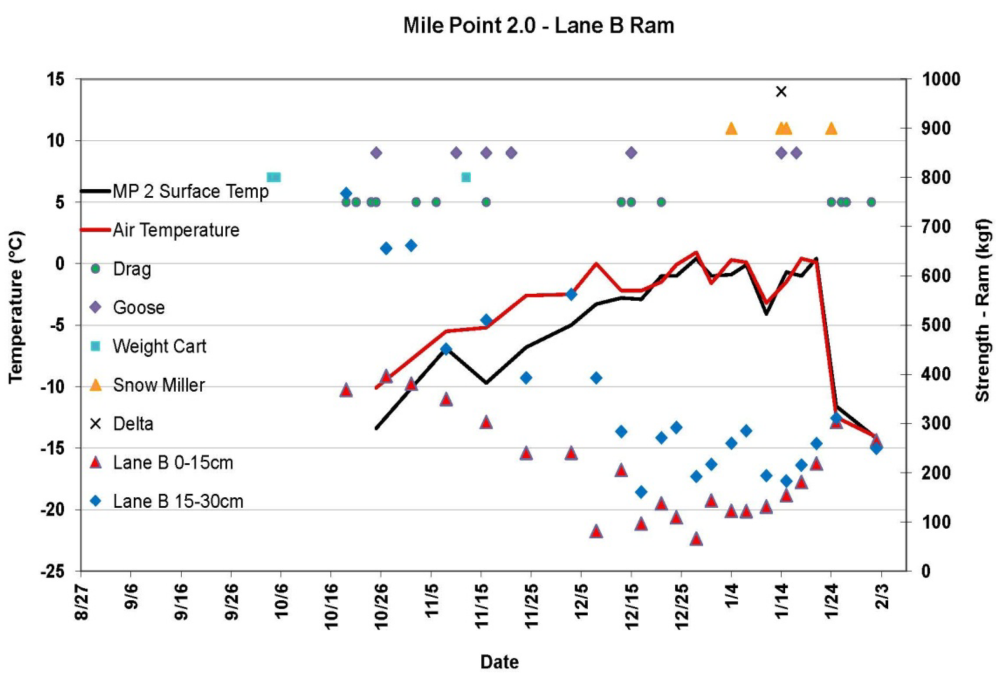


Figure A-3. Rammsonde at Mile Point 2.0, Lane C.

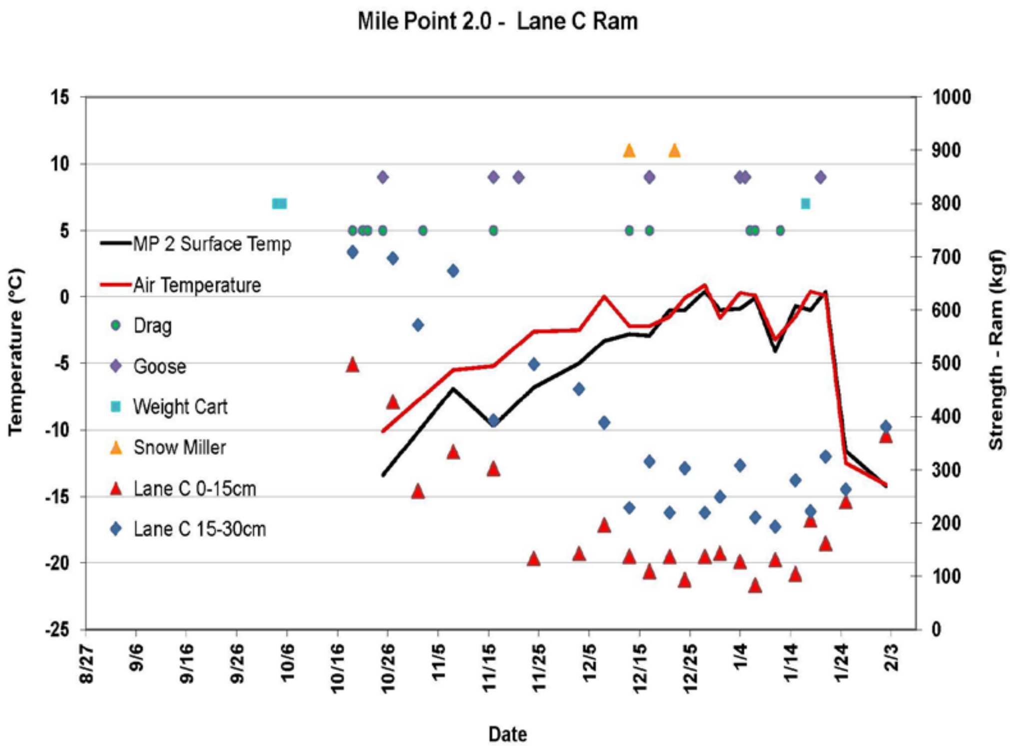


Figure A-4. Rammsonde at Mile Point 2.0, Track Lane.

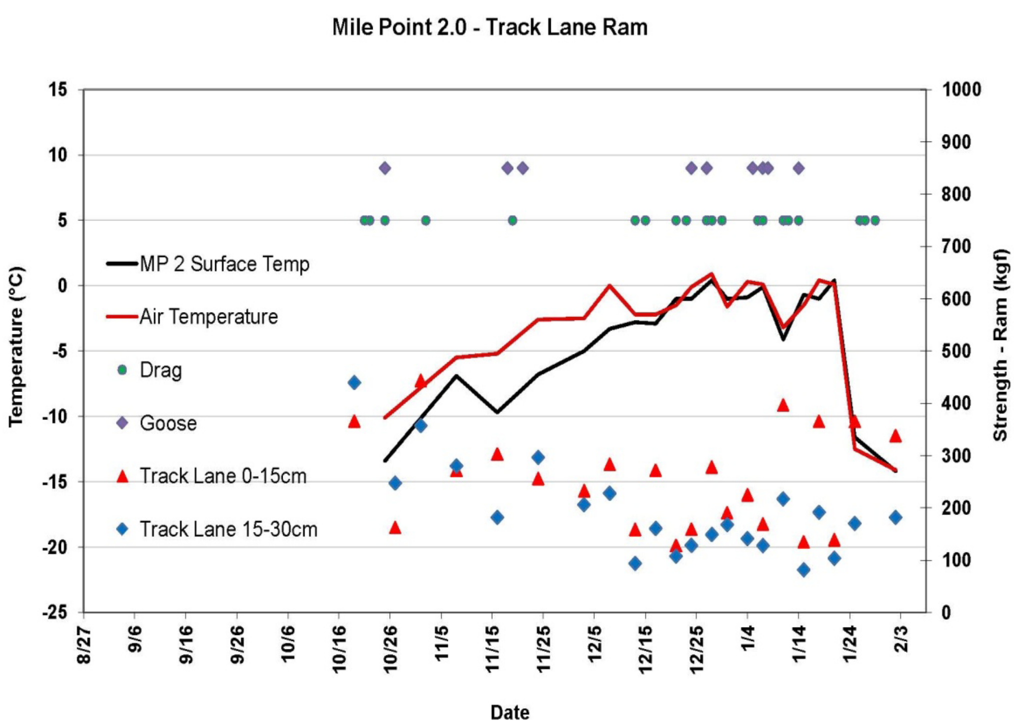


Figure A-5. Rammsonde at Mile Point 4.0, Lane A.

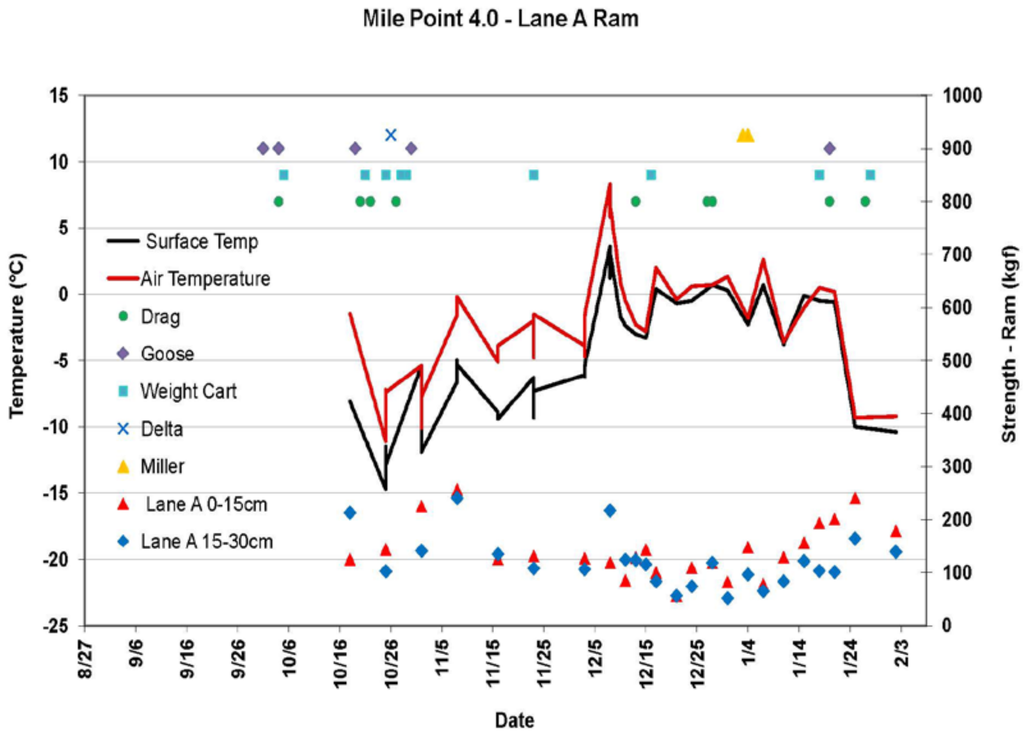


Figure A-6. Rammsonde at Mile Point 4.0, Lane B.

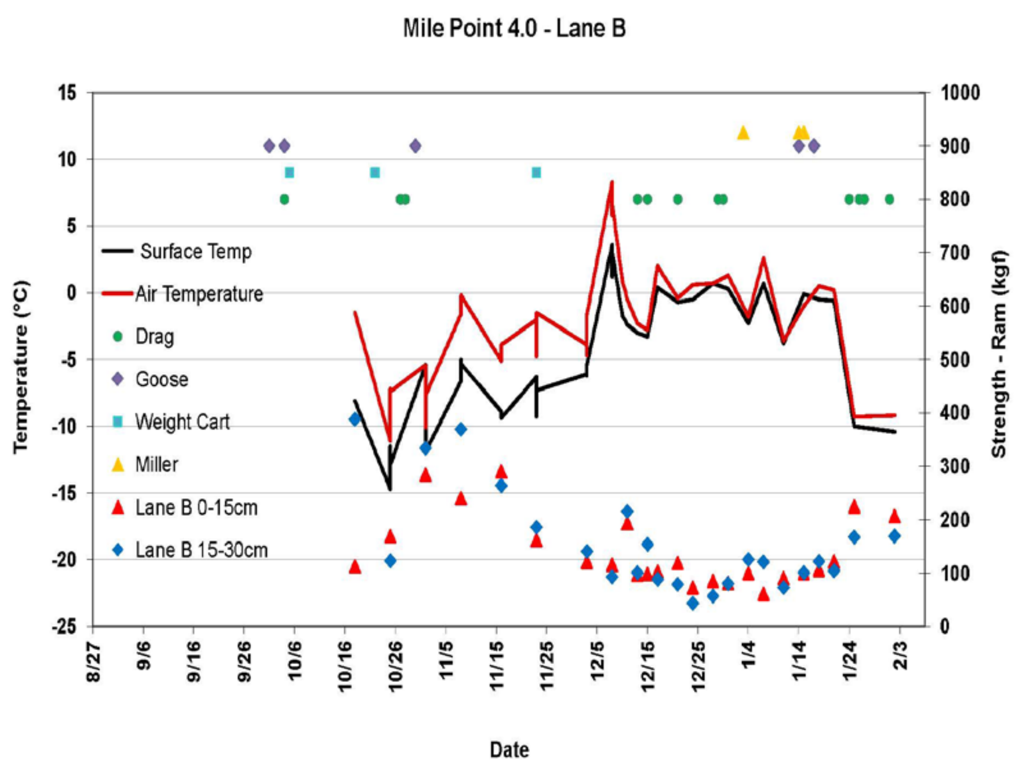


Figure A-7. Rammsonde at Mile Point 4.0, Lane C.

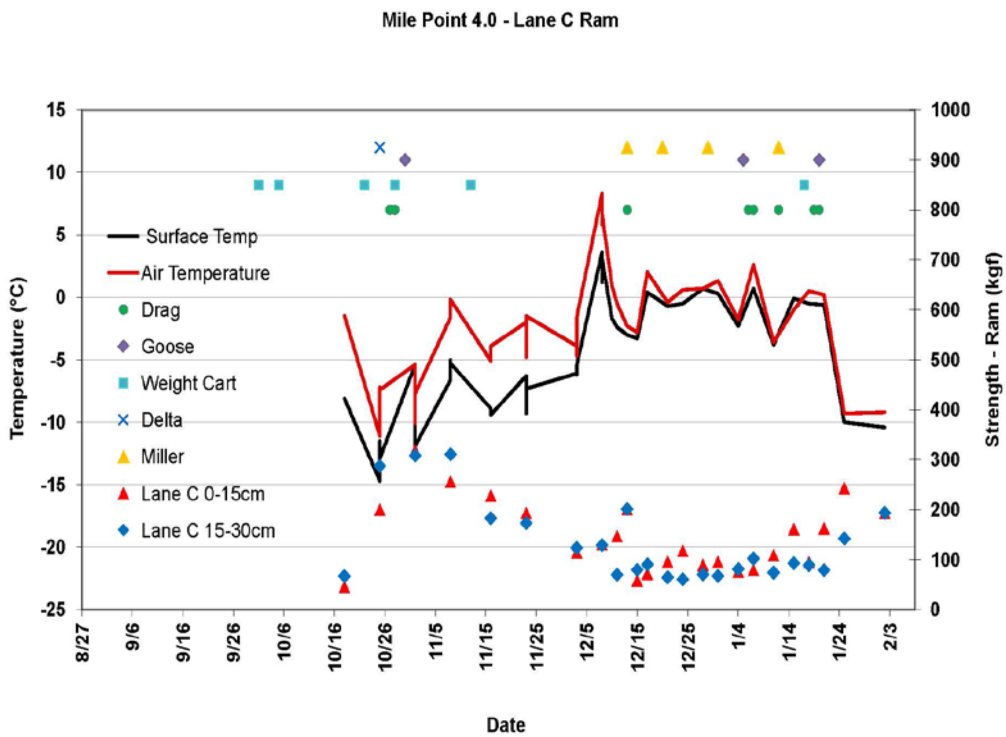


Figure A-8. Rammsonde at Mile Point 4.0, Track Lane.

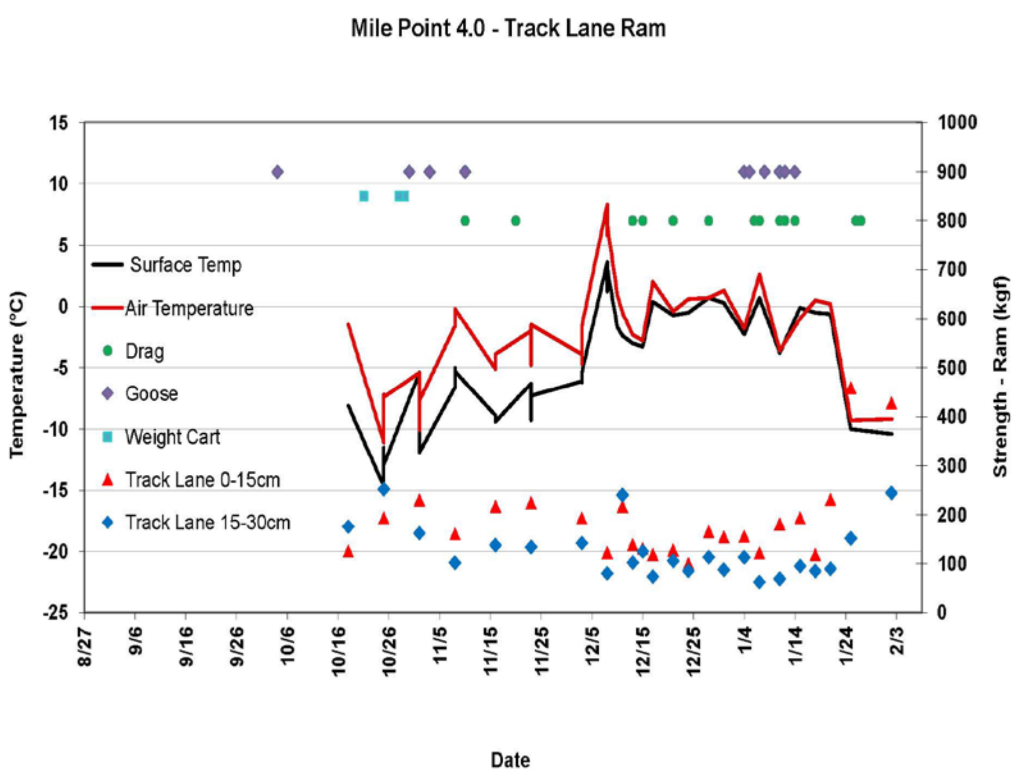


Figure A-9. Rammsonde at Mile Point 6.0, Lane A.

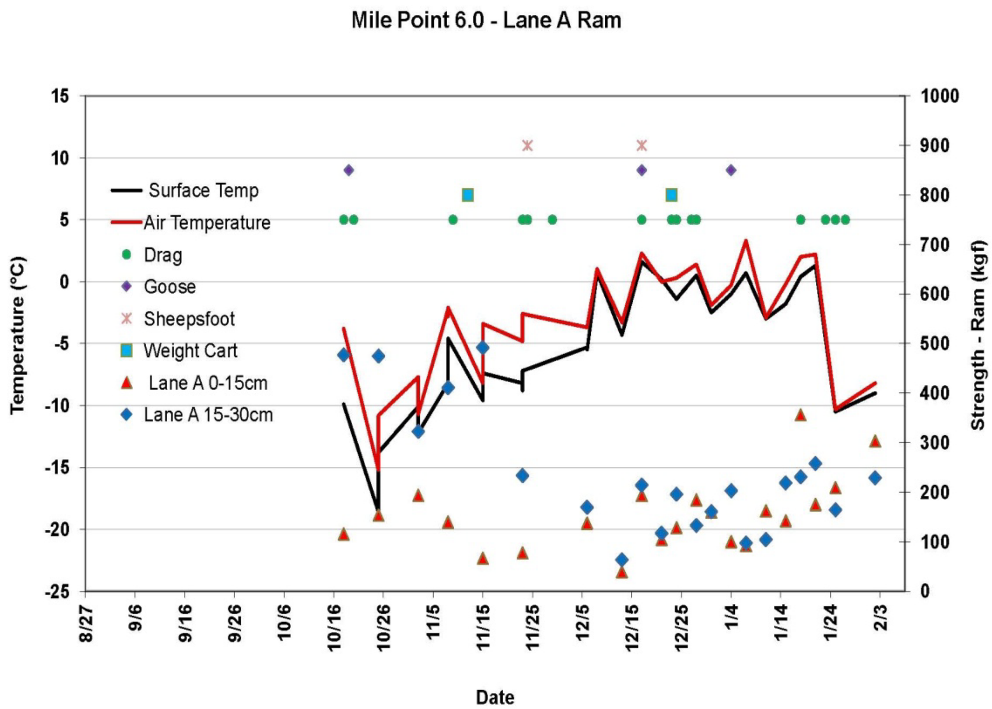


Figure A-10. Rammsonde at Mile Point 6.0, Lane B.

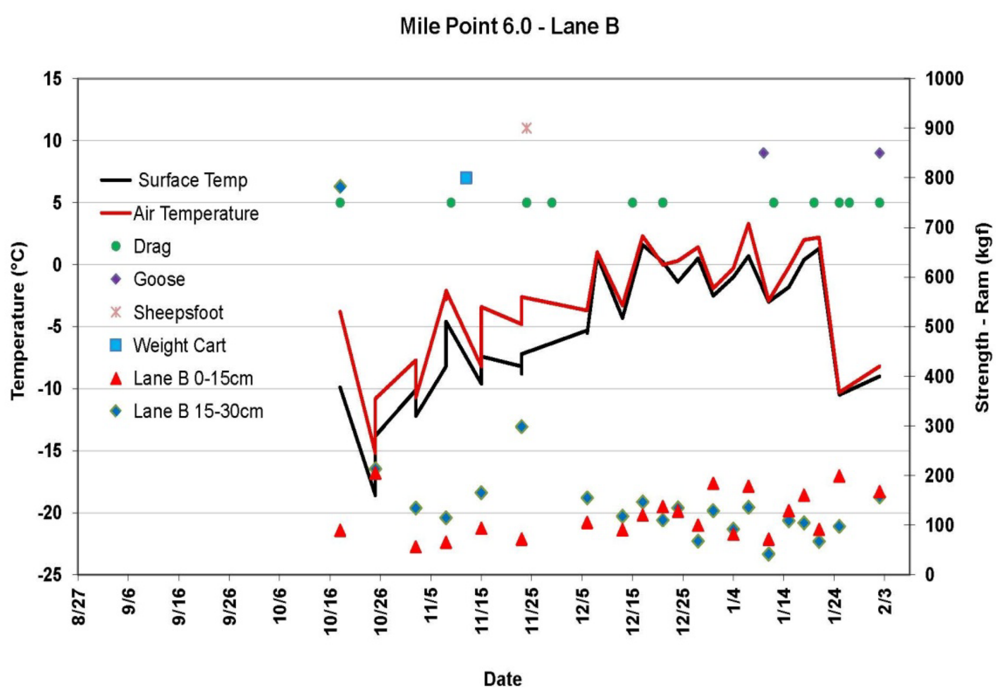


Figure A-11. Rammsonde at Mile Point 6.0, Track Lane.

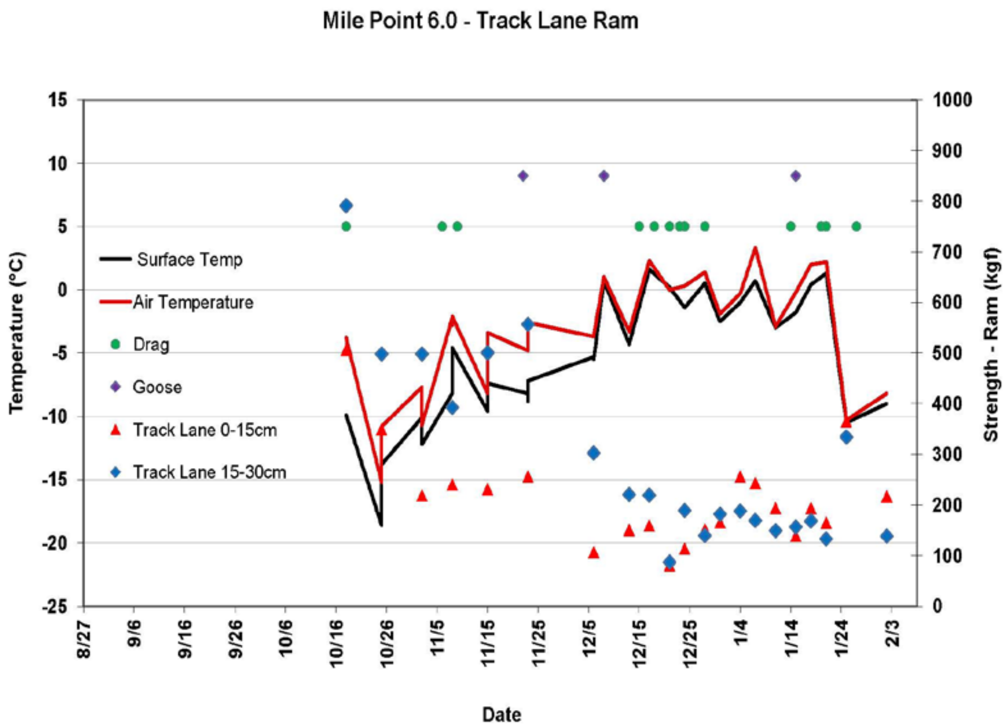


Figure A-12. Rammsonde at Mile Point 10.0, Lane A.

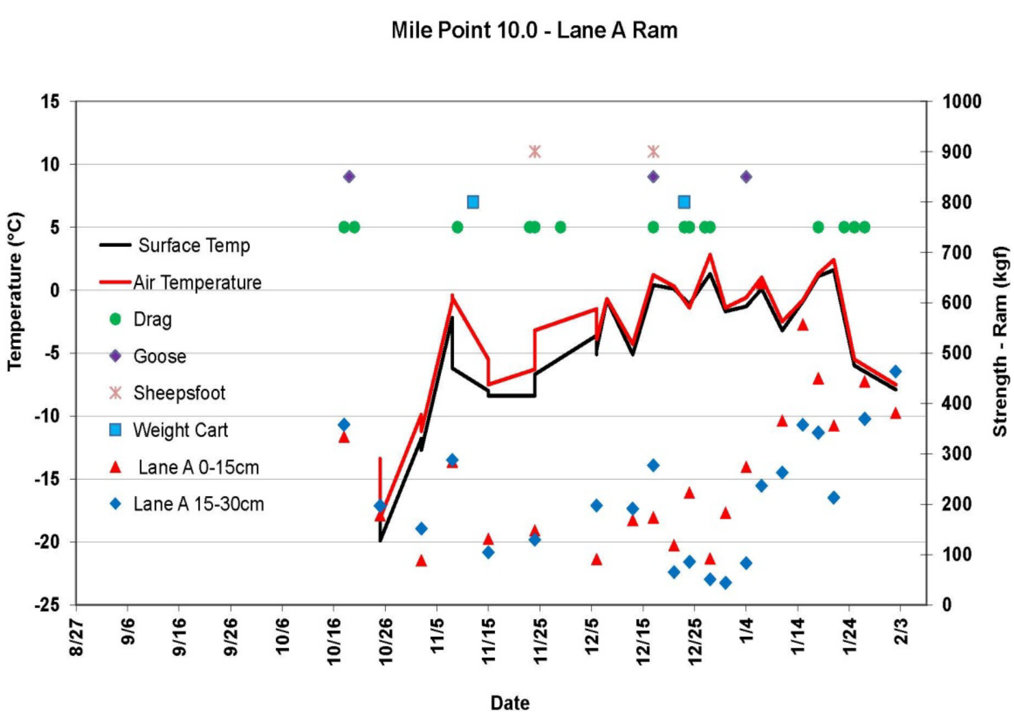


Figure A-13. Rammsonde at Mile Point 10.0, Lane B.

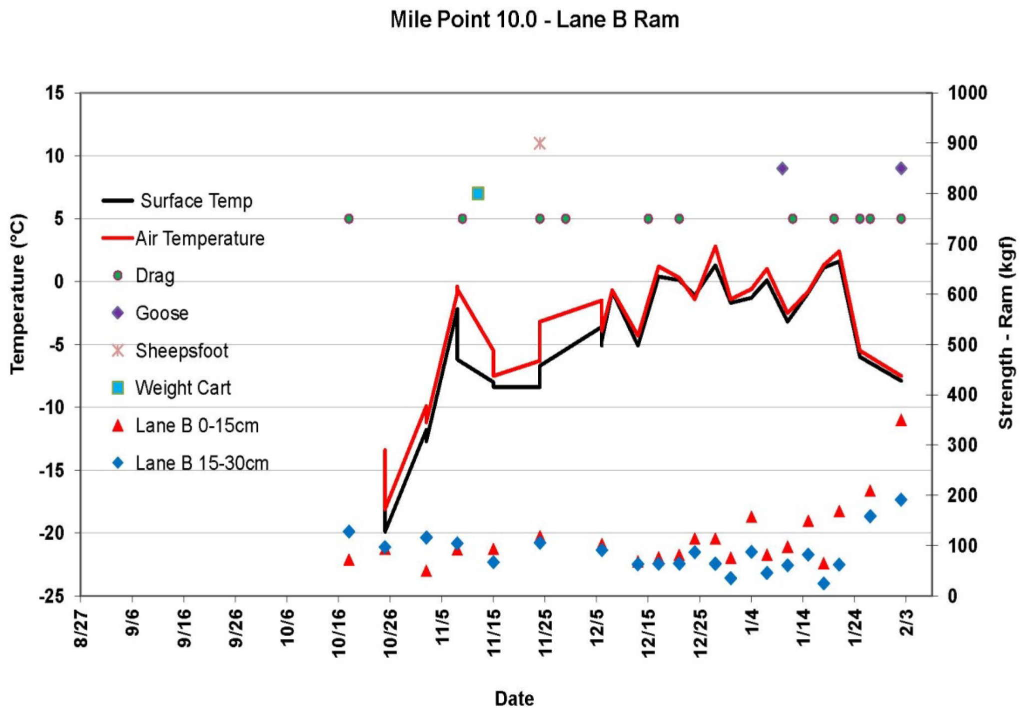


Figure A-14. Rammsonde at Mile Point 10.0, Track Lane.

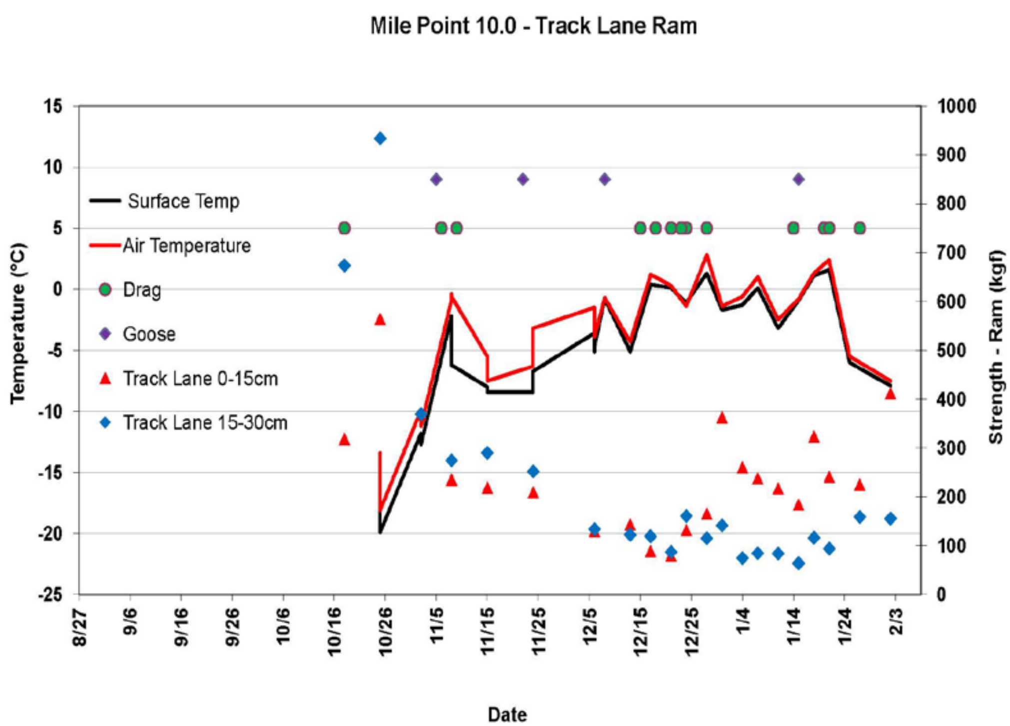


Figure A-15. Rammsonde at Mile Point 12.0, Lane A.

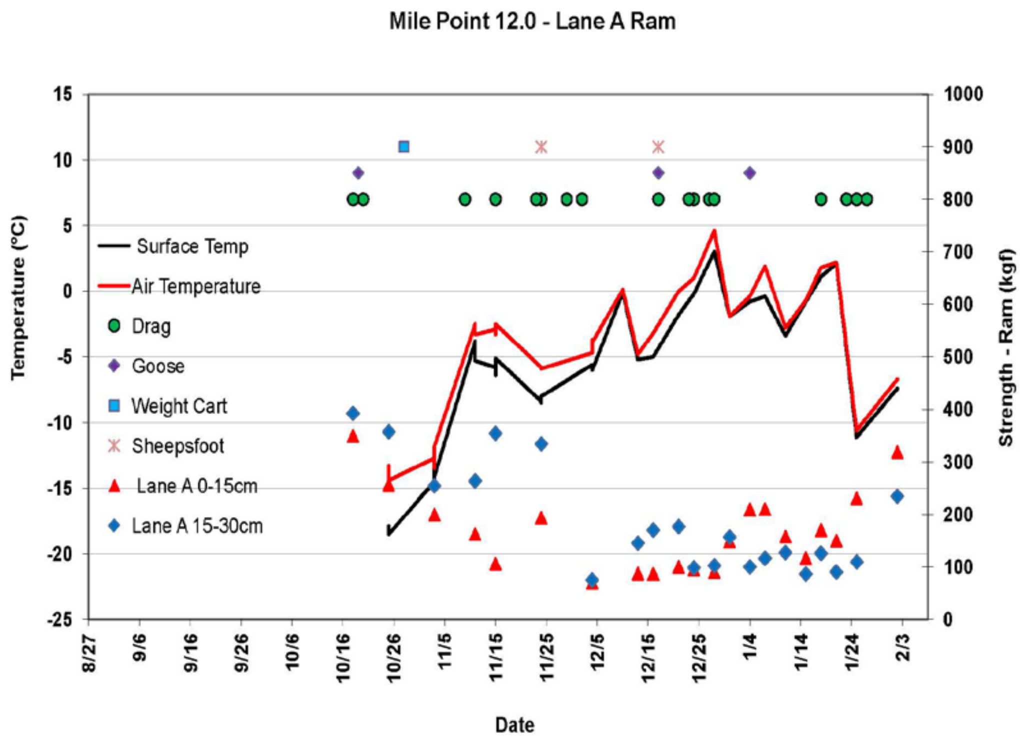


Figure A-16. Rammsonde at Mile Point 12.0, Lane B.

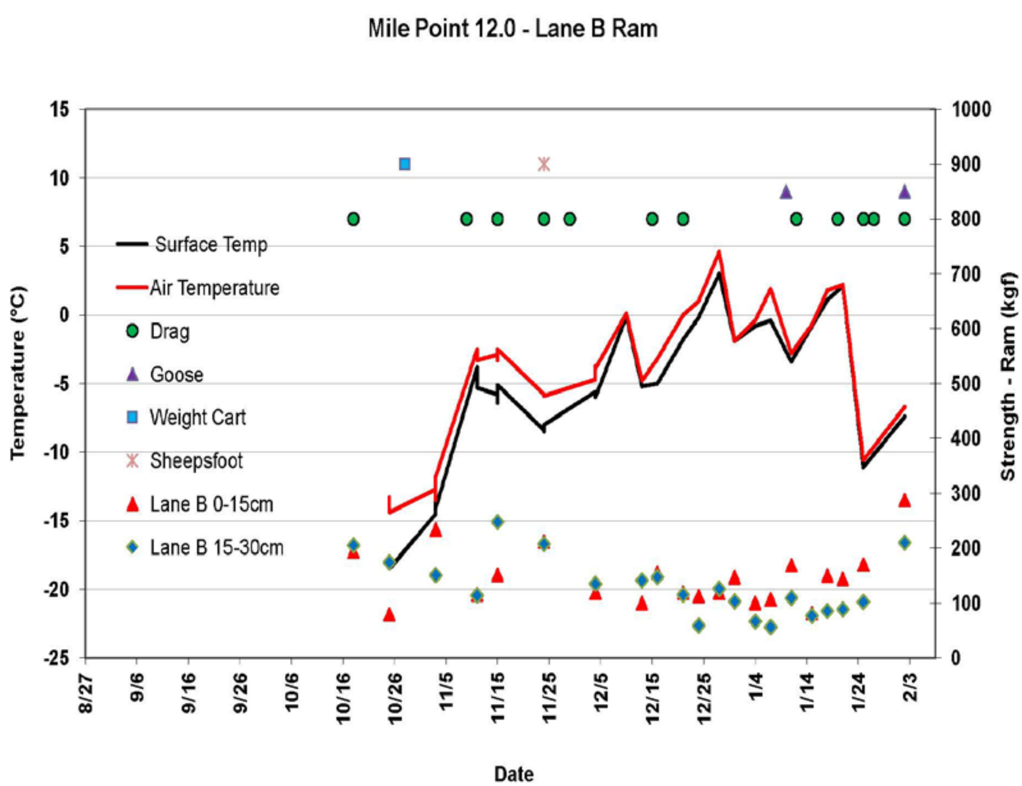
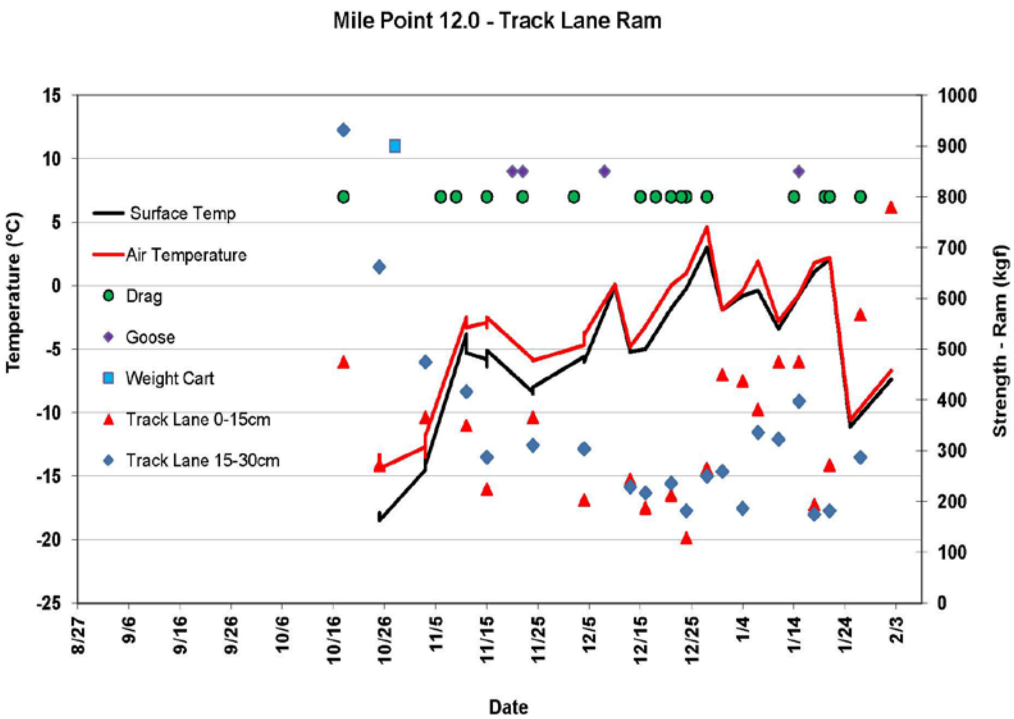


Figure A-17. Rammsonde at Mile Point 12.0, Track Lane.



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14. ABSTRACT
During the 2010/11 Antarctic field season, the Cold Regions Research and Engineering Laboratory (CRREL) conducted a snow roads and transportation study for a second year at McMurdo Station. Part of this study included tracking the road maintenance and temperature and testing the road strength at predetermined mile markers along the 13 miles of snow roads located on a permanent ice shelf that connects the (now closed) Pegasus Airfield to McMurdo Station. These data were recorded for each lane of road at six locations over 5 months. A Clegg Impact Hammer and a Rammsonde snow cone penetrometer were used to capture both the surface strength and the strength of the road with regard to depth. The team collected temperature data by using a temperature probe inserted into the snow to measure temperature of the air, snow surface, 7.6 cm down from surface, and 15.2 cm down from surface.

Analysis of the data provides insight as to the direct effects of various maintenance and environmental factors on the strength of the roads. Understanding the effects of these variables will ensure the roads are kept operational for as long as possible and will increase the efficiency of the McMurdo Station transportation infrastructure. The data also contributed to the creation of standard operating procedures for maintaining the snow roads at McMurdo Station.

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