The Effect of Ambient and Permafrost Warming on Adfreeze VSM/Pile Design

Beez Hazen, Northern Engineering & Scientific
www.northern-engineering.com

November 4, 2022

USPA 20th Anniversary Celebration – Anchorage Workshop

Measured Soil Temperatures in Undisturbed Tundra

Geothermal Design Climate Data for Prudhoe

Predicted Soil Temperatures, 1976 through 2050

Effect of Soil Warming upon Adfreeze Pile/VSM Design

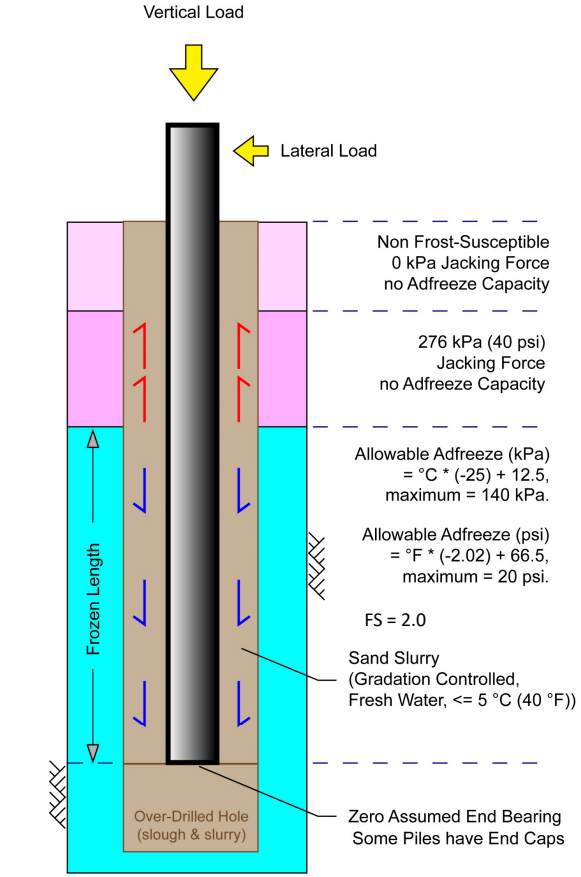
Summary

Note that some slides in this presentation were also presented in the keynote address prepared by Glen Pomeroy and Beez Hazen for the ***18th International Conference on Cold Regions Engineering & 8th Canadian Permafrost Conference, Quebec, 2019***. Those slides show BP's logo in the upper right corner of slides.

The keynote address can be downloaded from: www.northern-engineering.com.

Adfreeze Pile Design

Adfreeze Pile Design Schematic



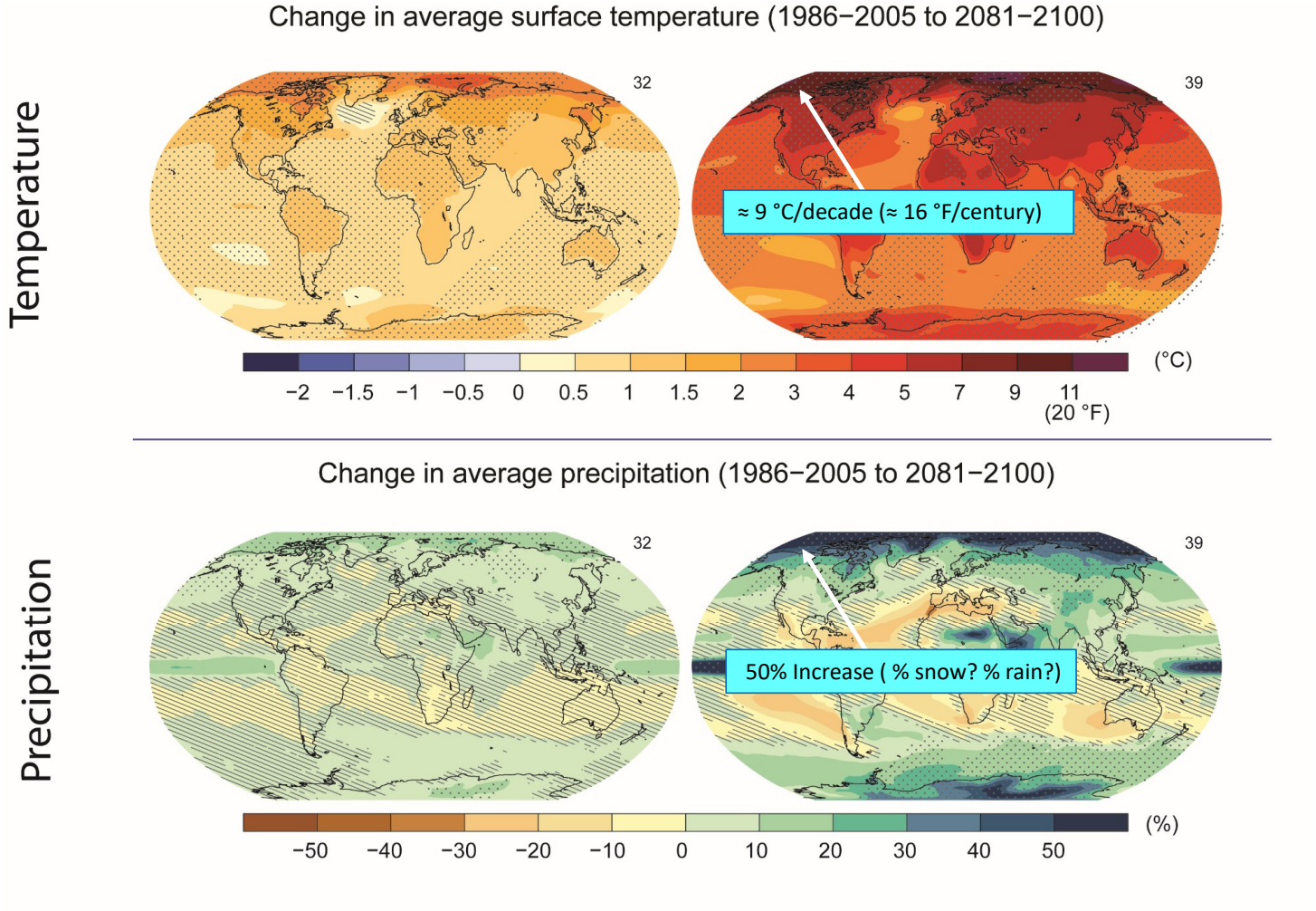
Adfreeze Capacity > Load
Adfreeze Capacity + Load > Jacking Force
Predicted Creep over Project Life Within Criteria

Note: the relationship between allowable adfreeze stress and temperature used for most North Slope facilities is based upon a pile load test conducted by SOHIO by Erv Long, et. al. It Remains proprietary.

Camps and Process Facilities Supported on Piles with 5’ to 7’ (1.5m to 2.1m) Air Gap Between Structure and Soil Surface

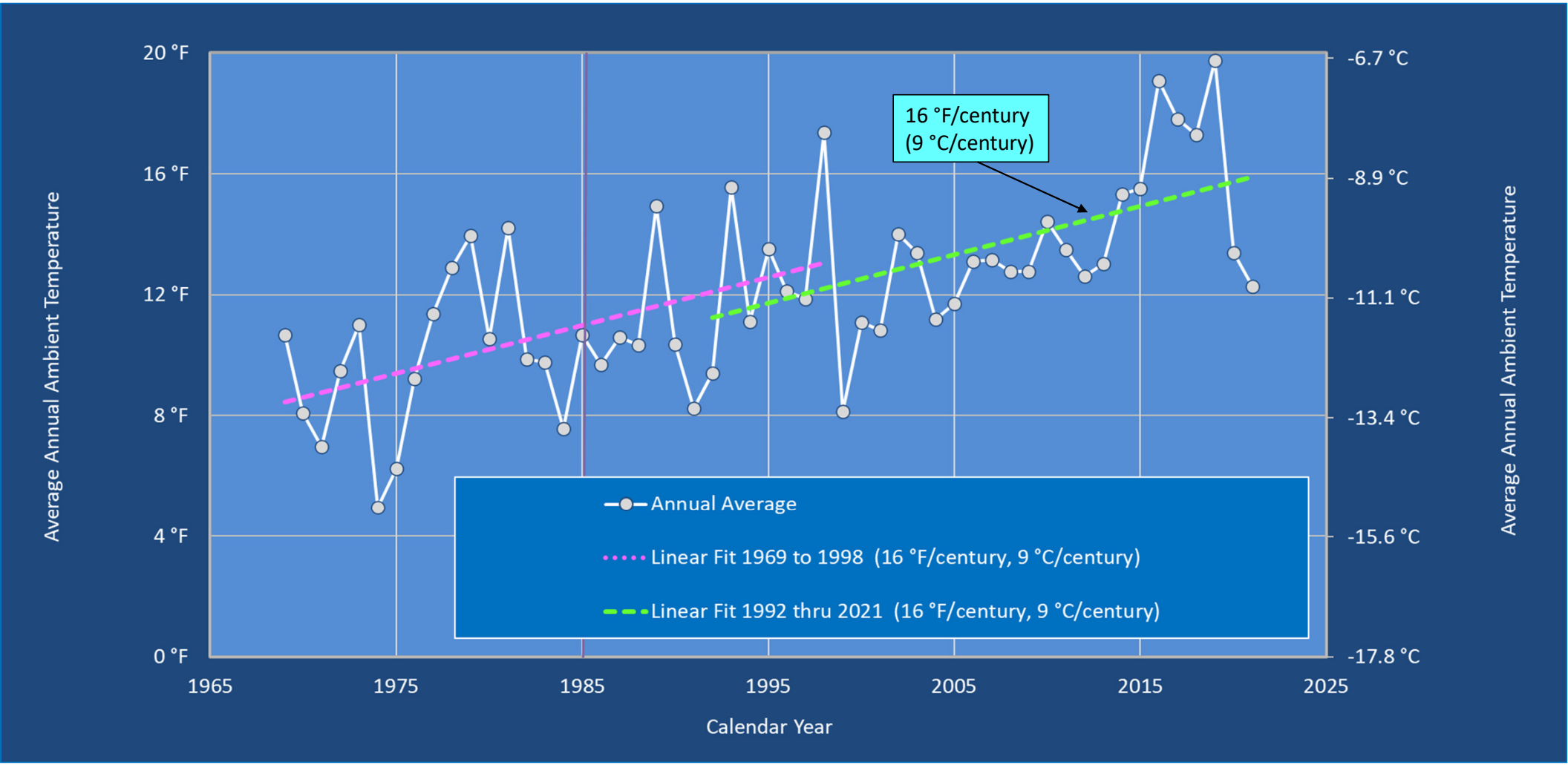
Pipes (Pipe Rack) Supported on Piles

Changing Climate



http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

Ambient Temperature Trends, Prudhoe (ARCO and NOAA Data)



Trends in Average Annual Winter Temperatures in Prudhoe/Deadhorse, October through April (“winter”)

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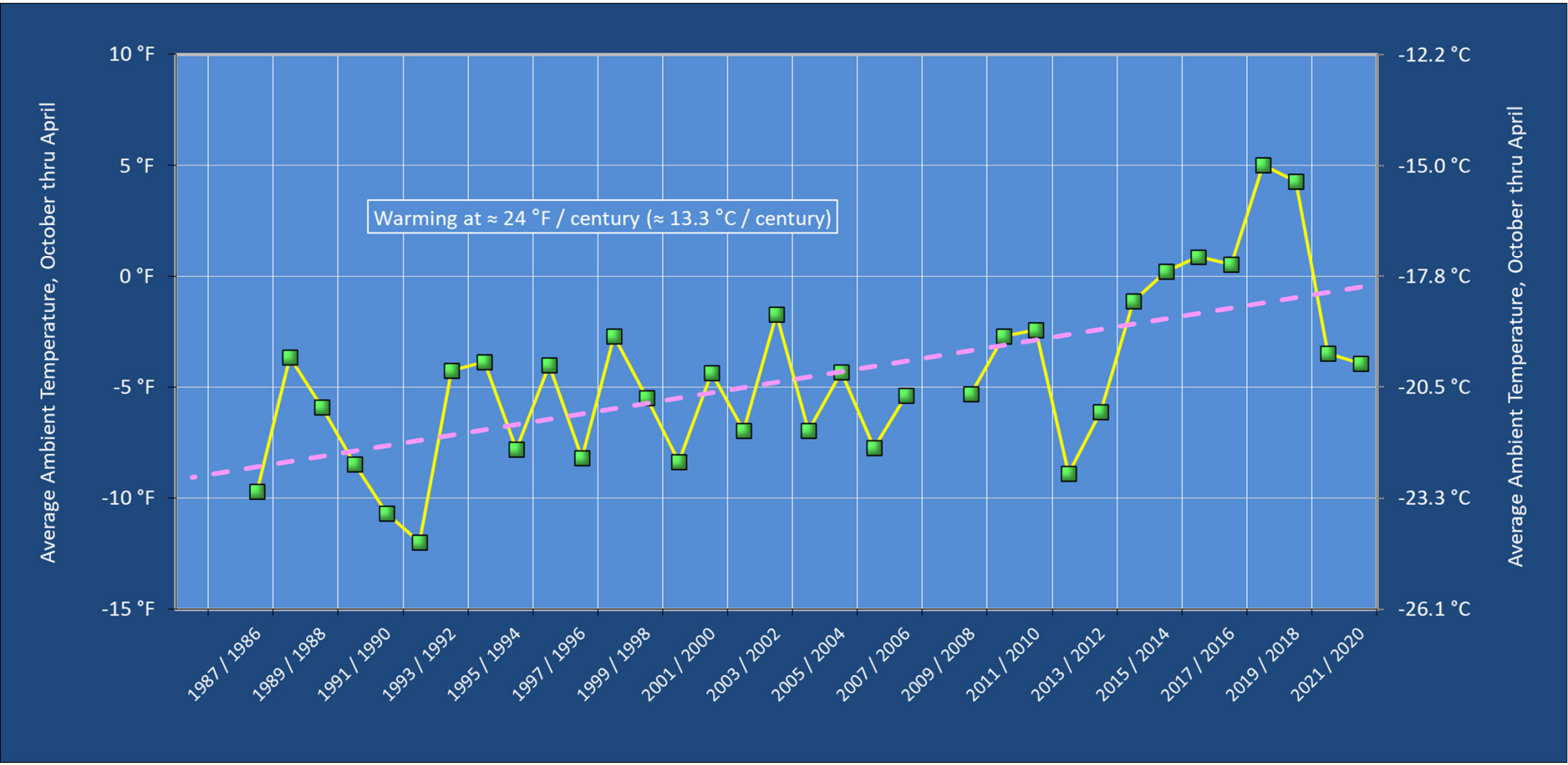
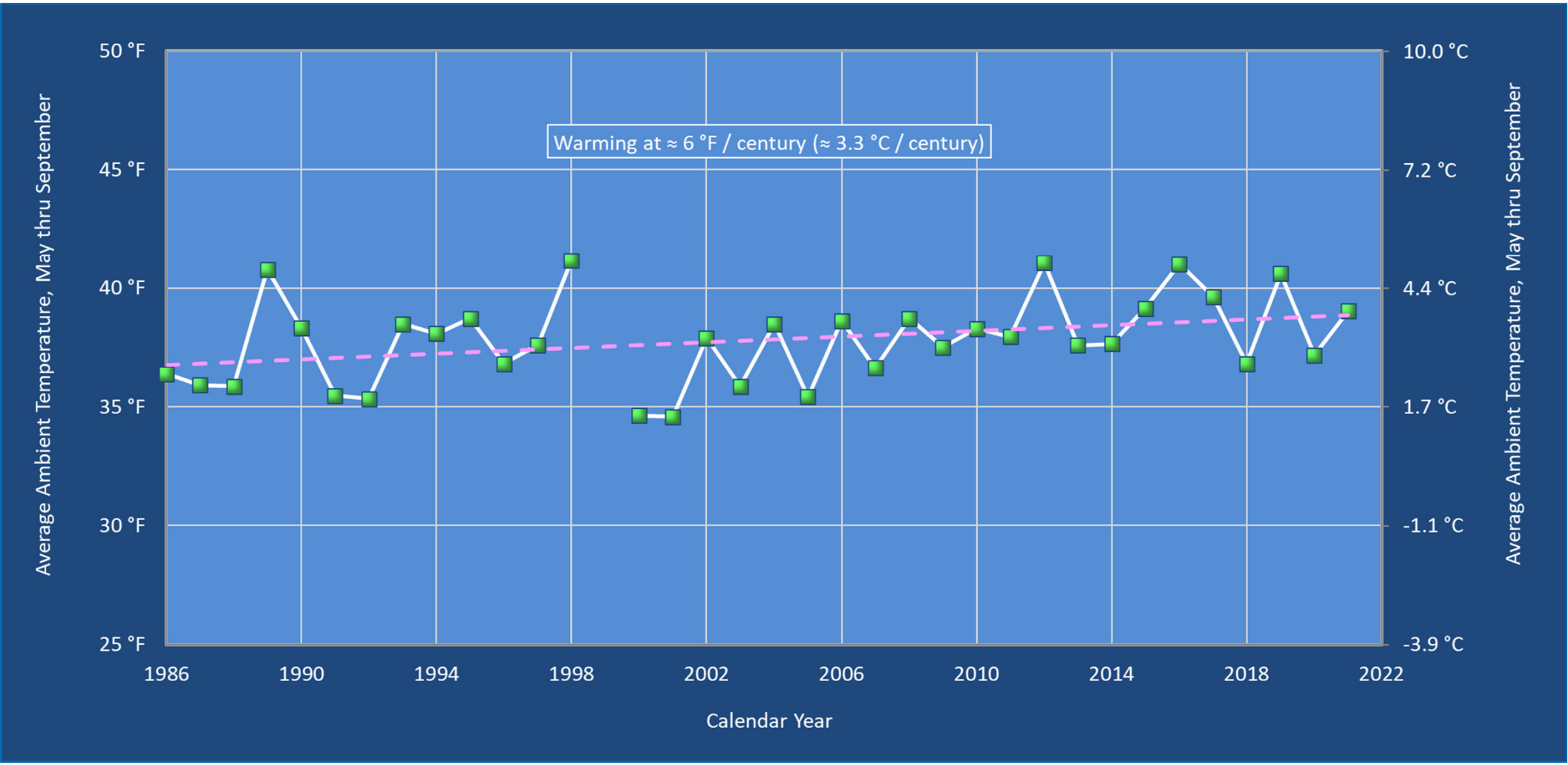
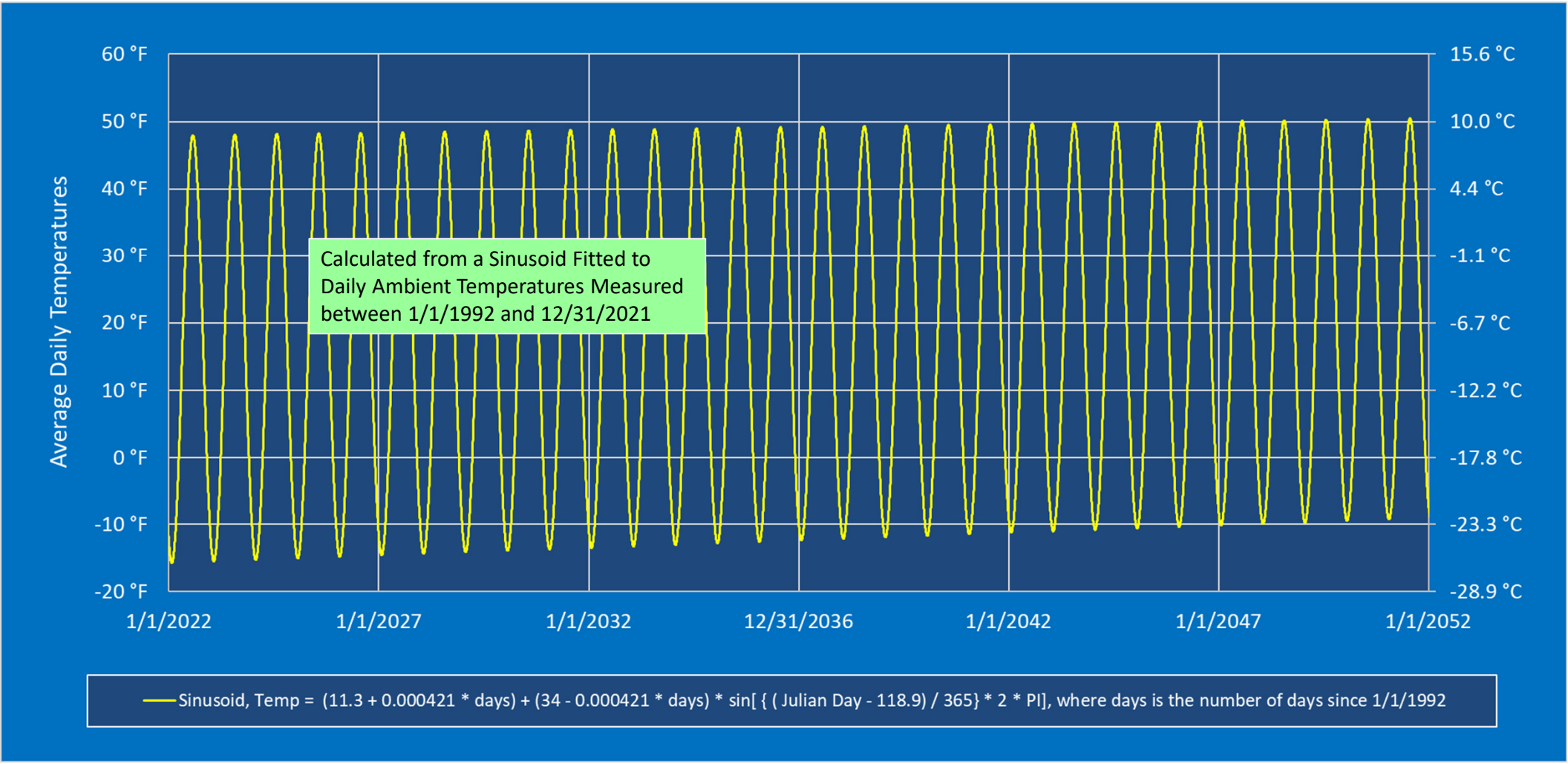


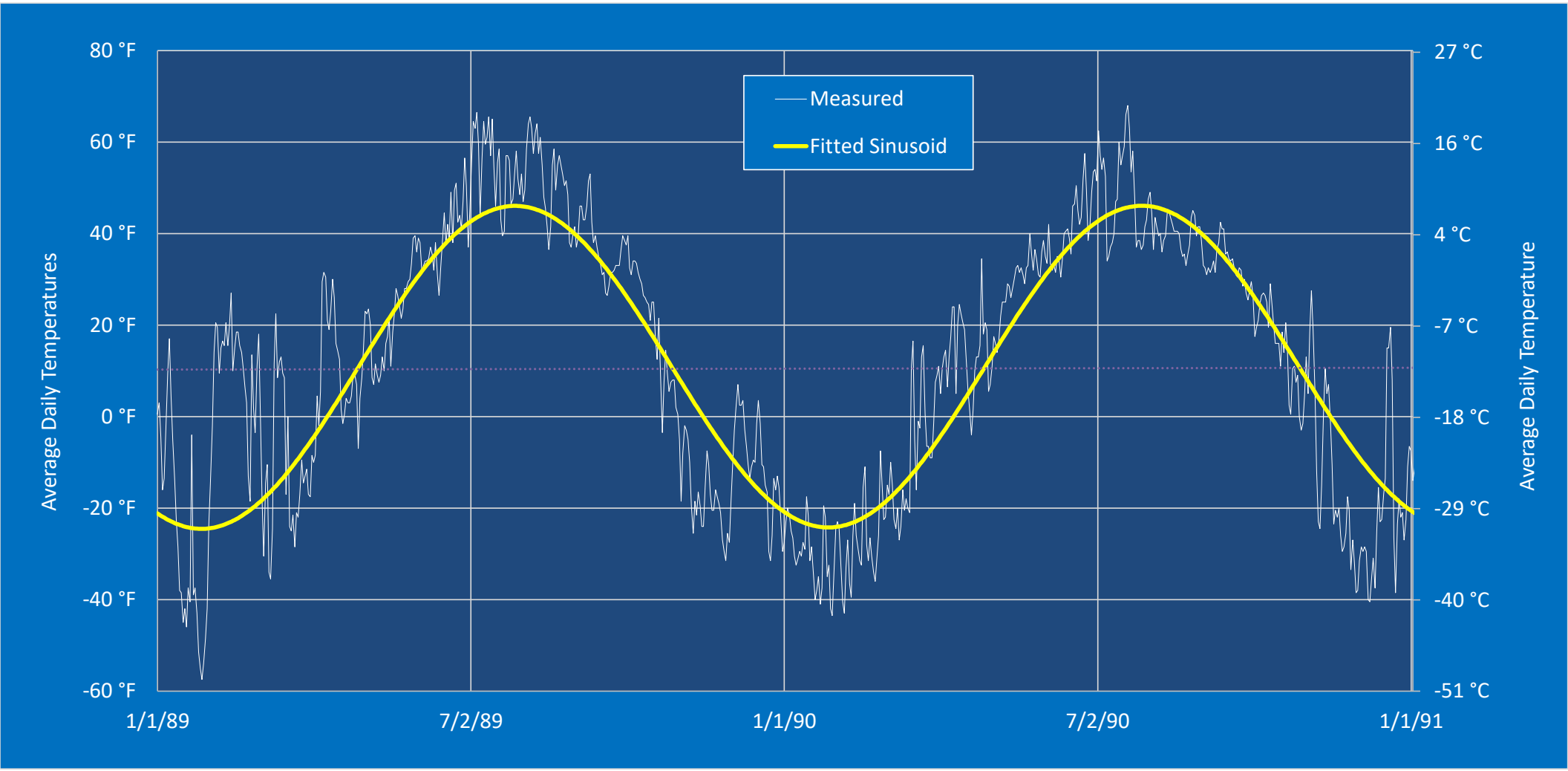
Trends in Average Annual Summer Temperatures in Prudhoe/Deadhorse, May through September ("summer")



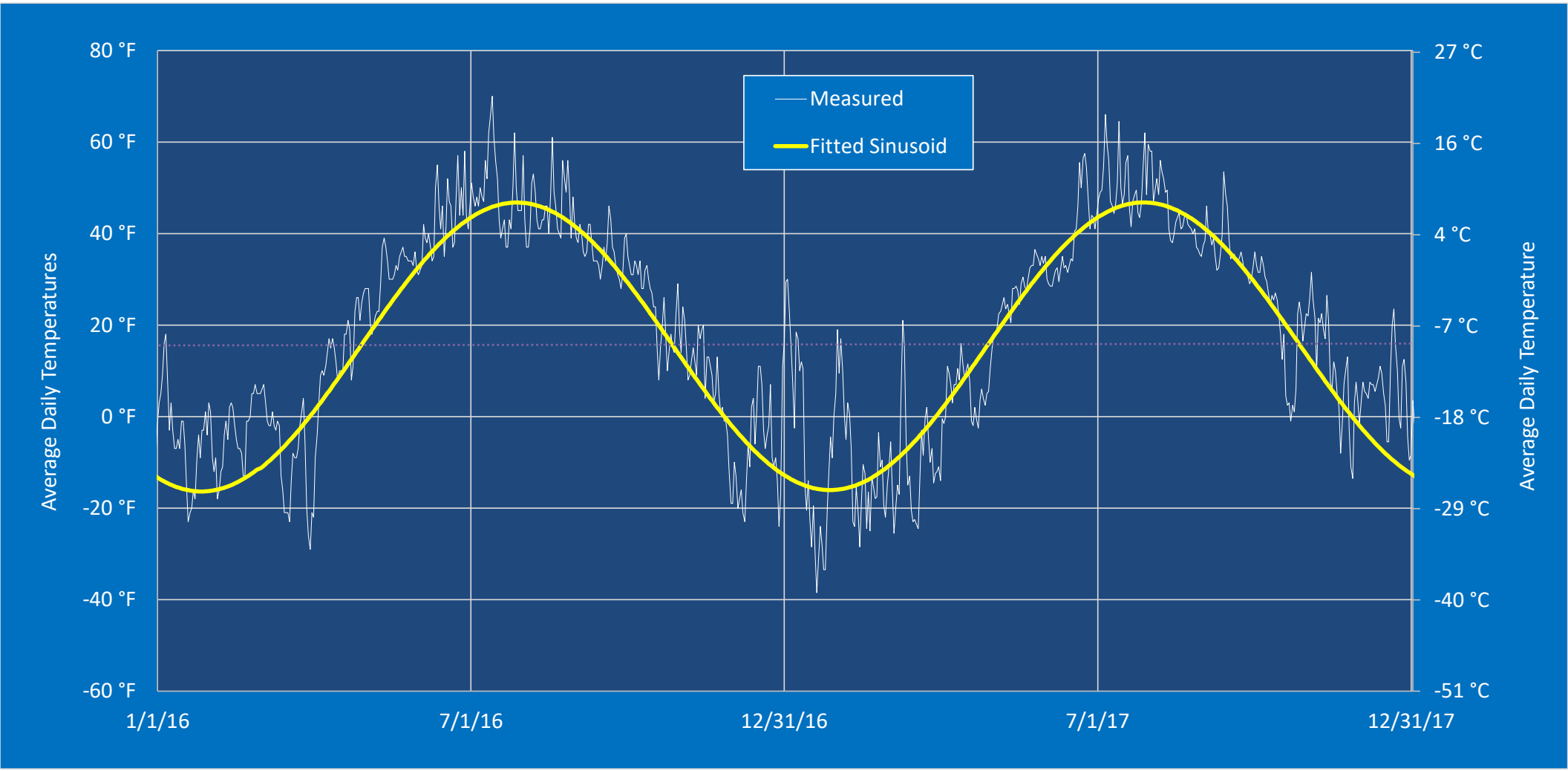
Fitted Average Daily Temperatures for Deadhorse, 2022 through 2052

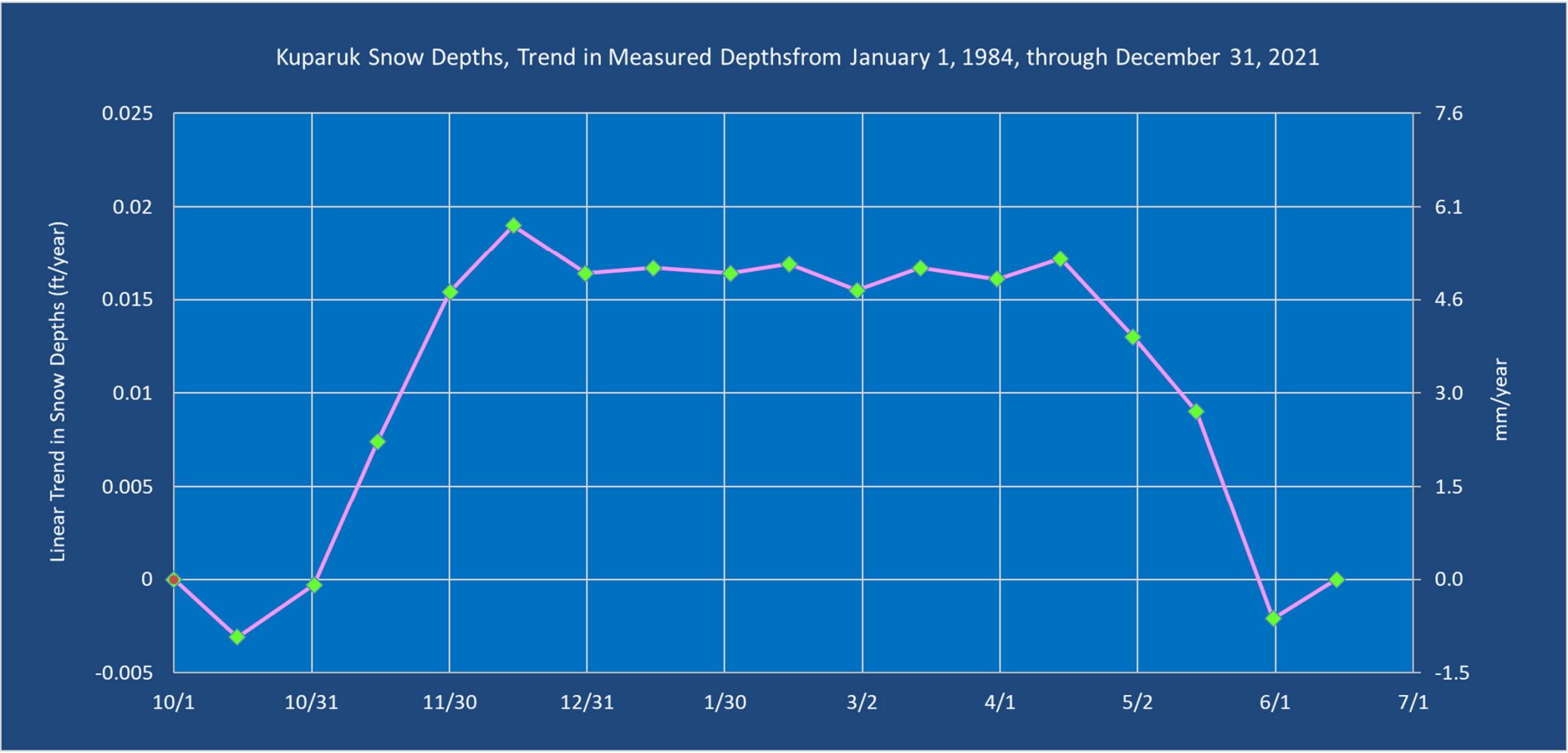


Comparison of Measured and Fitted Average Daily Temperature Measured at Deadhorse in 1989 and 1990

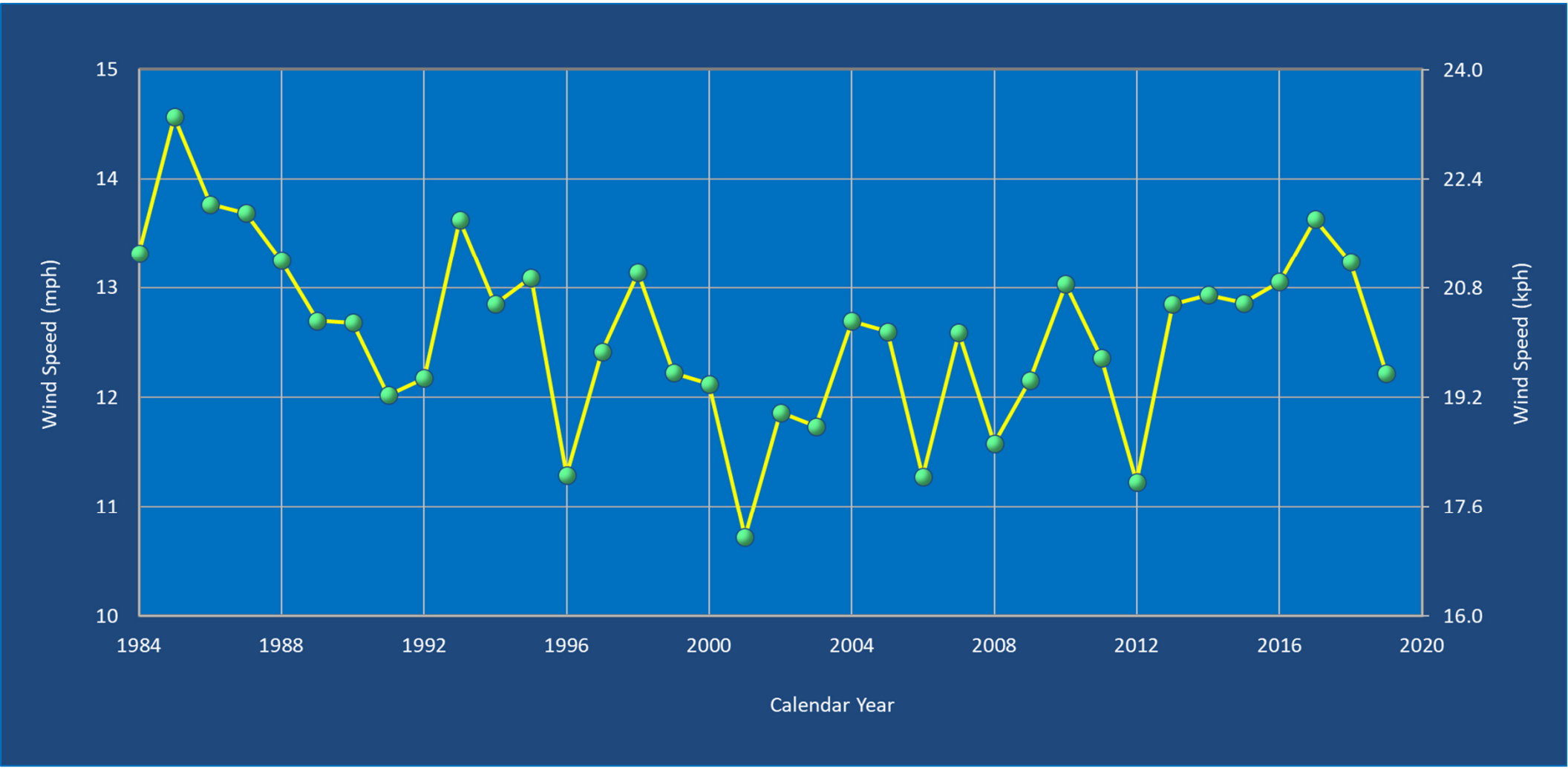


Comparison of Measured and Fitted Average Daily Temperature Measured at Deadhorse in 2016 and 2017




Kuparuk Snow Depths, Trend in Measured Depthsfrom January 1, 1984, through December 31, 2021
Linear Trend in Snow Depths (ft/year)
0.025
0.02
0.015
0.01
0.005
0
-0.005
7.6
6.1
4.6
3.0
1.5
0.0
-1.5
mm/year
10/1
10/31
11/30
12/31
1/30
3/2
4/1
5/2
6/1
7/1

Wind Speed Trends, Prudhoe (NOAA Data)



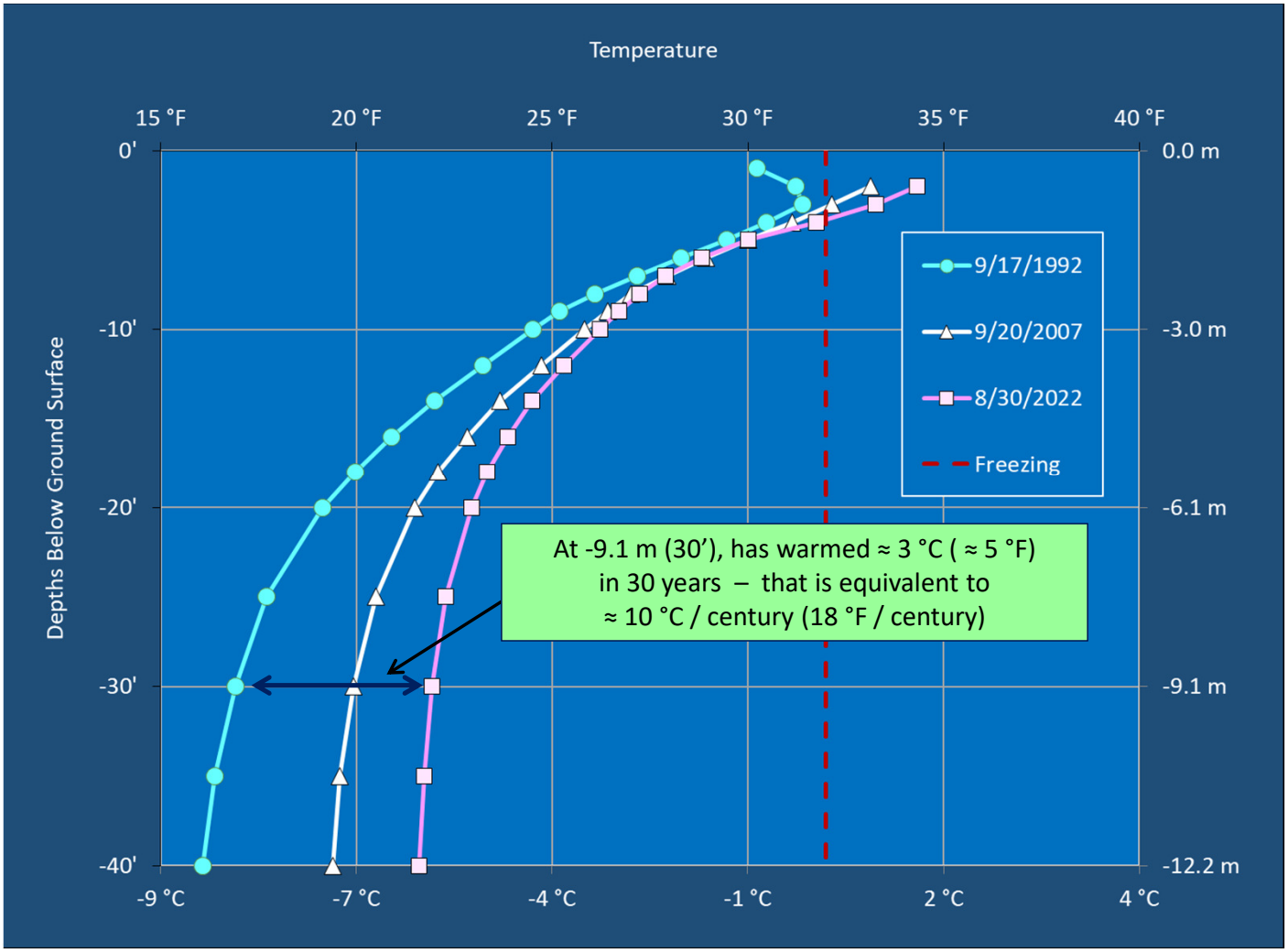
Warming Ground Temperatures

Undisturbed Tundra Soil Temperature Measurement Locations

CCP: 3 strings
AMDP: 3 strings
ESRDF: 2 strings
X-Pad: 2 strings

Deadhorse
West Dock

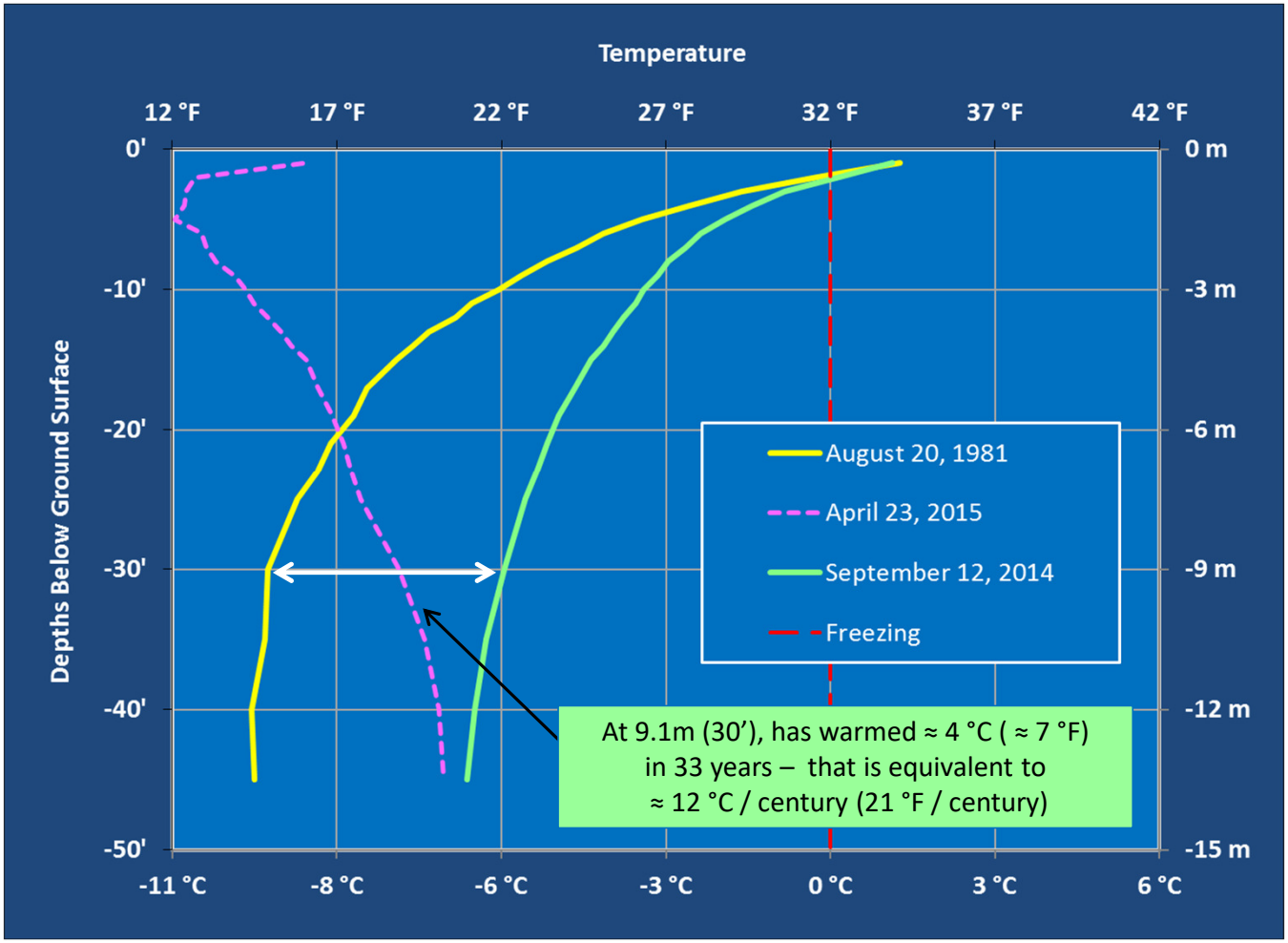
Temperature Profiles in Undisturbed Tundra at TE-1 near Drill Site 16



ESRDF Location (near DS16)

Photo of TS1, June 2013

Temperature Profiles in Undisturbed Tundra near the Central Compressor Plant



Near CCP

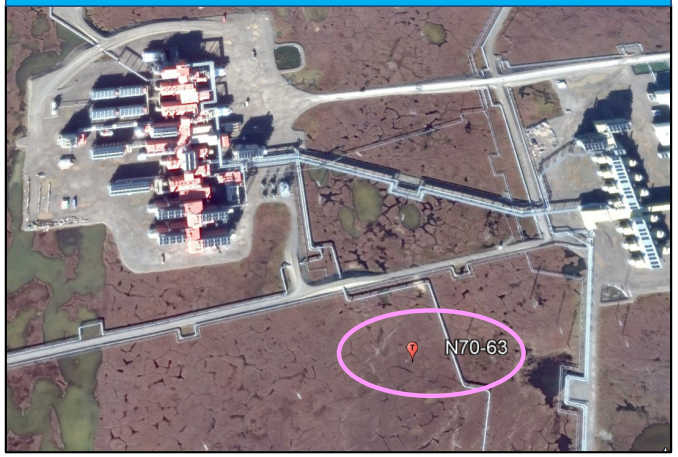
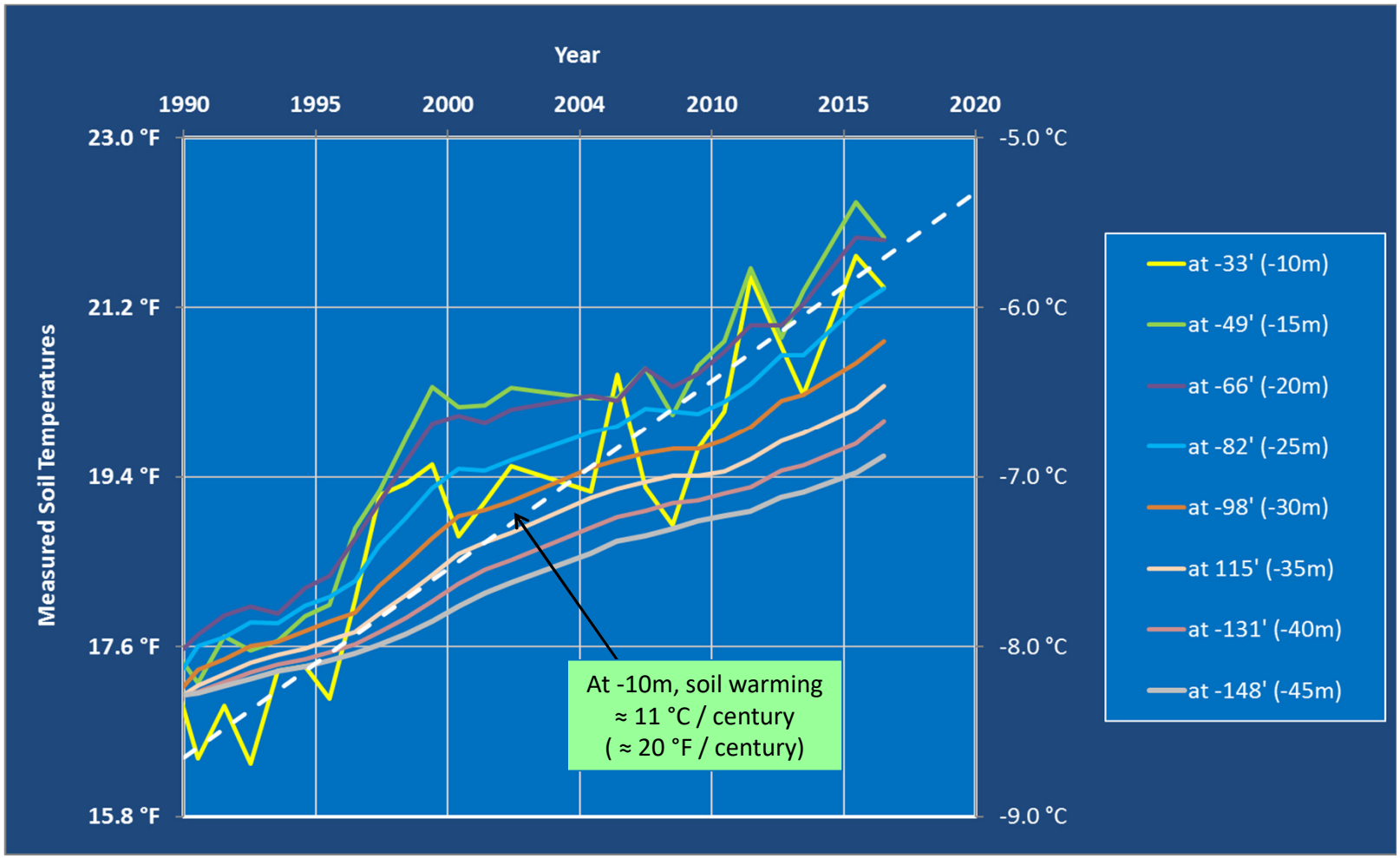


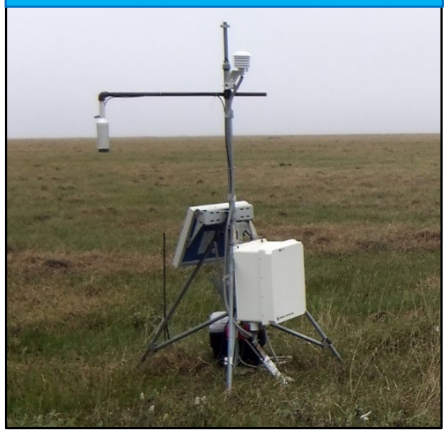
Photo of N70-63, June 2013

Undisturbed Tundra Measured Soil Temperatures, Prudhoe/Deadhorse, Alaska (Vlad Romanovsky, Tom Osterkamp)



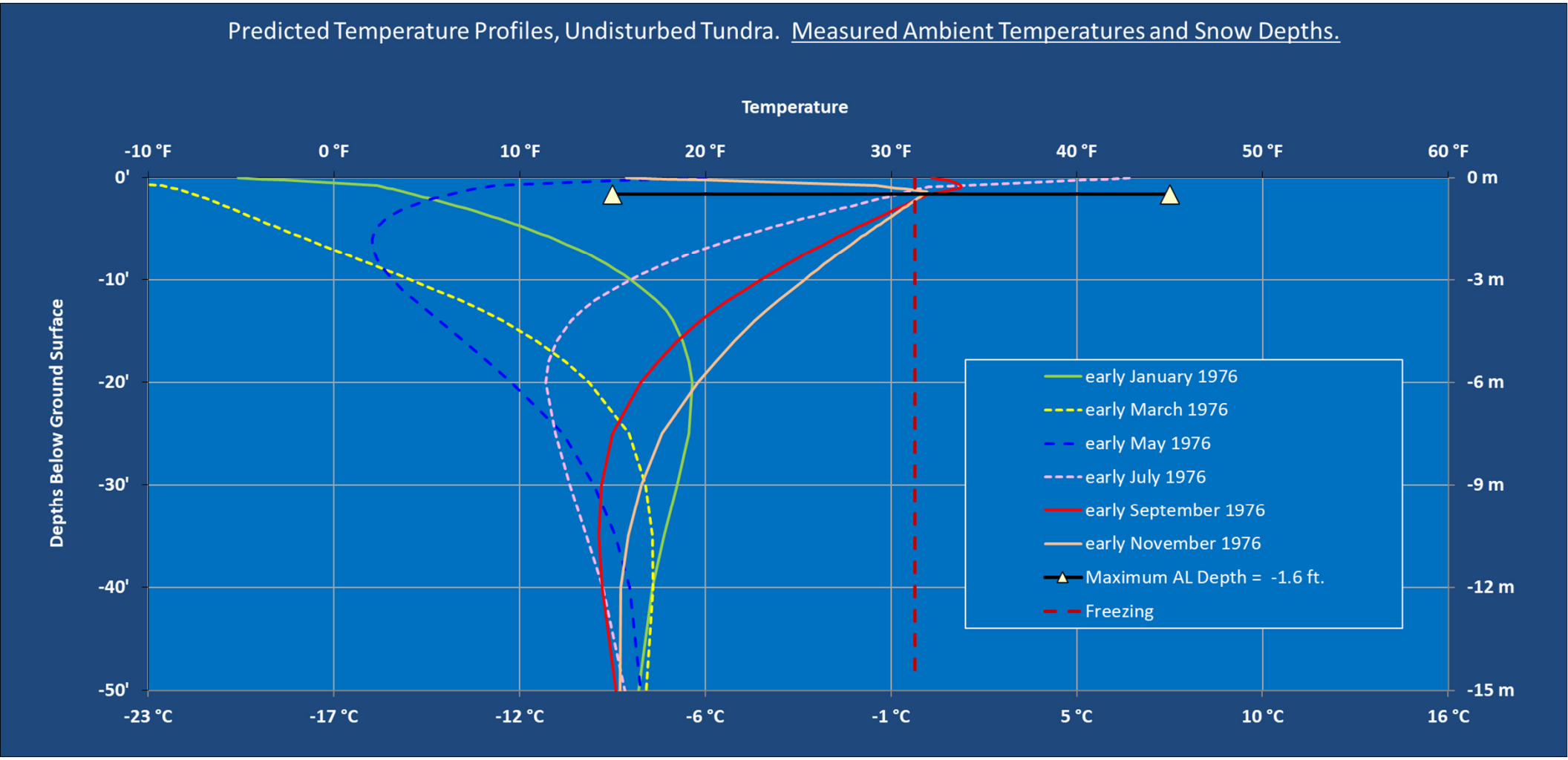
Site Location

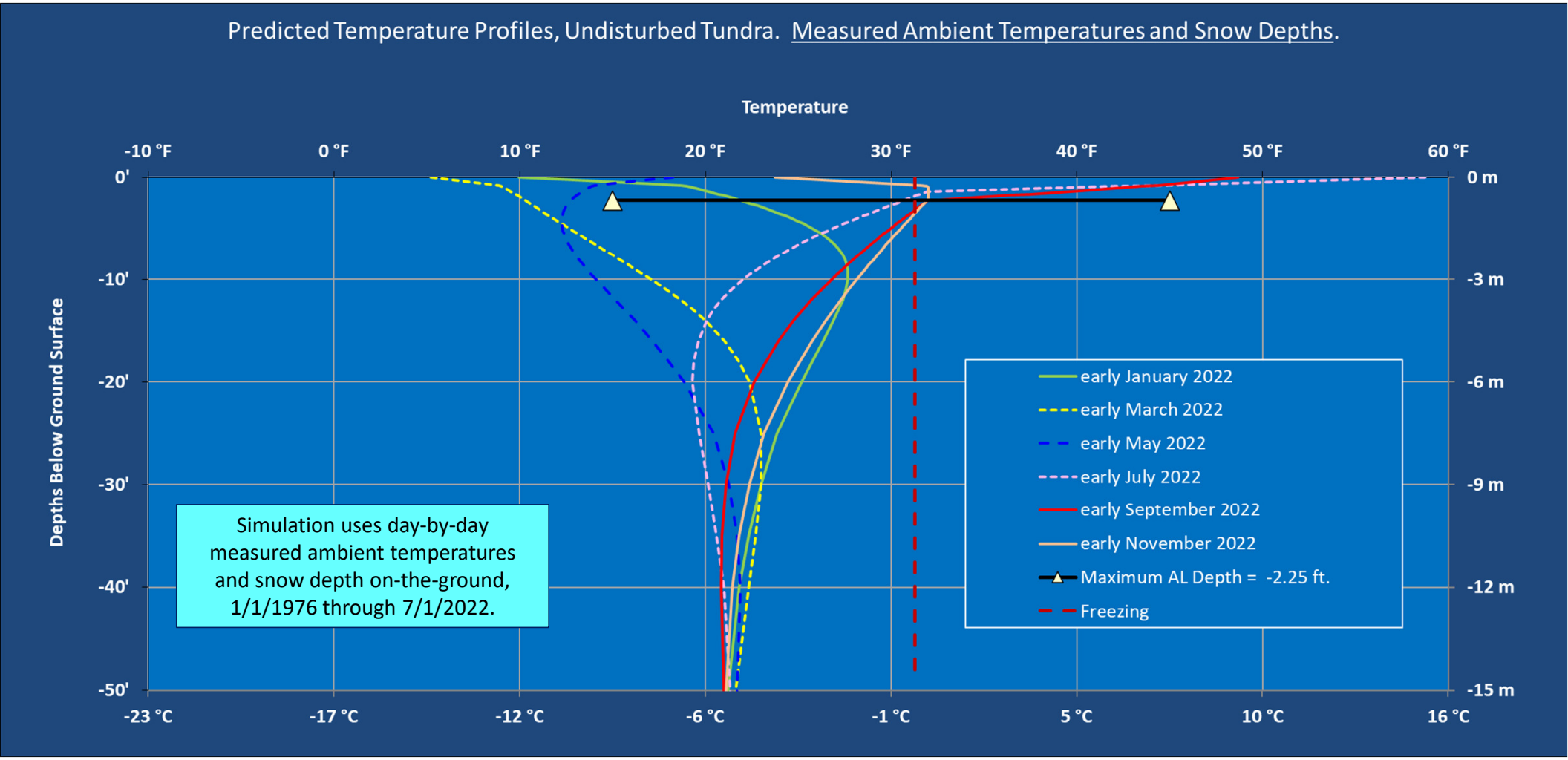
June 2013

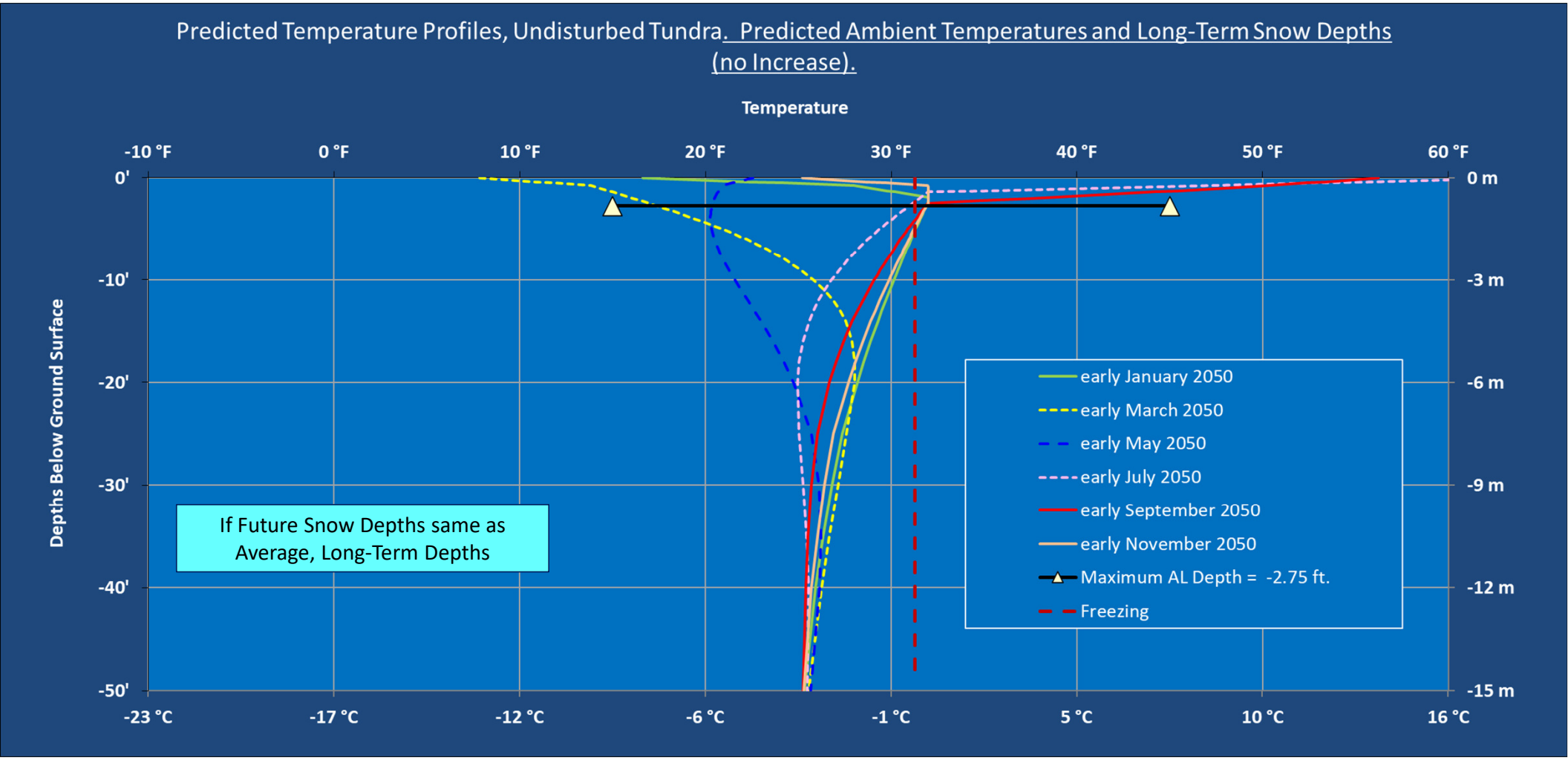


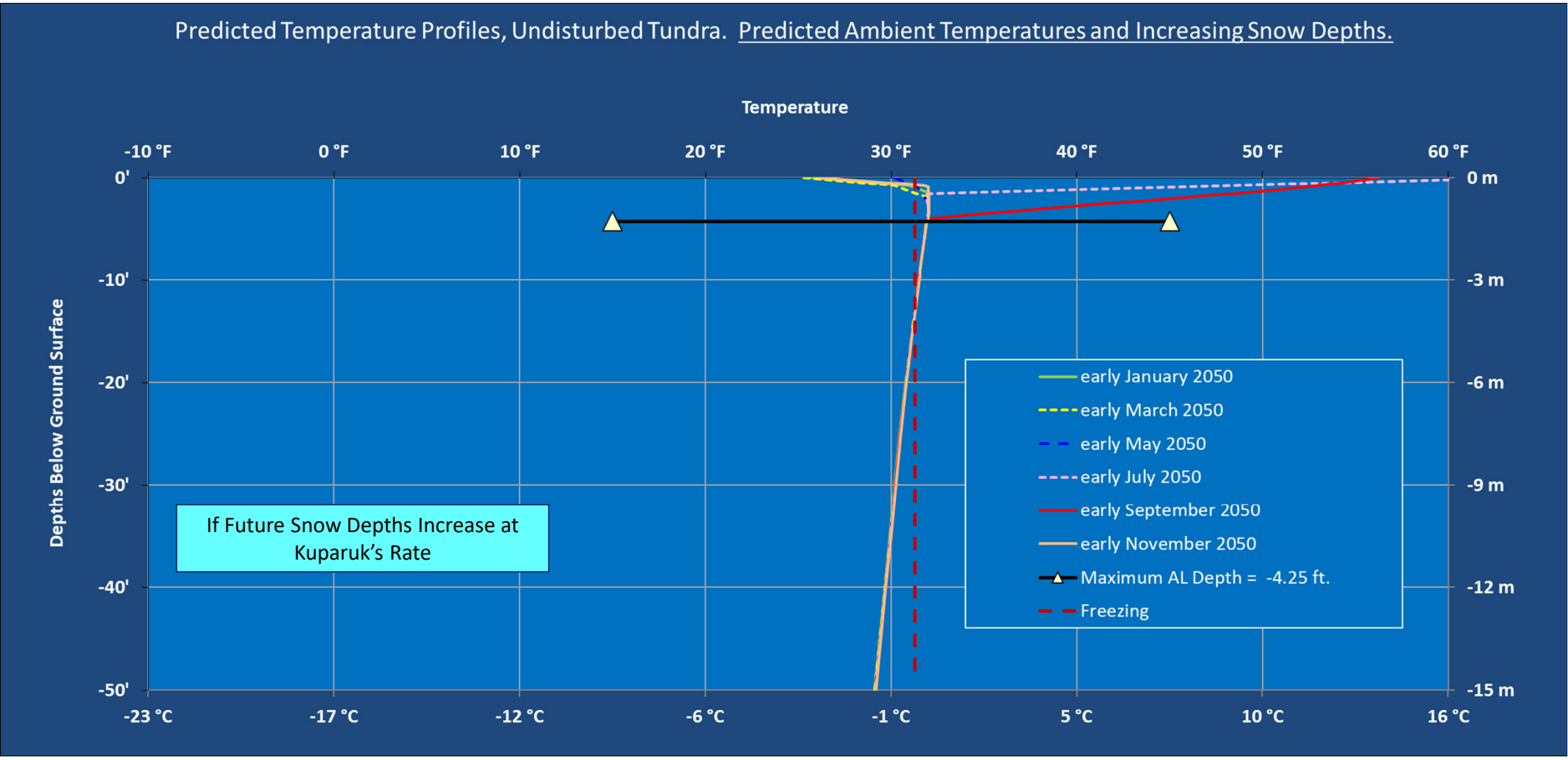
Predicted Undisturbed Tundra Soil Temperatures

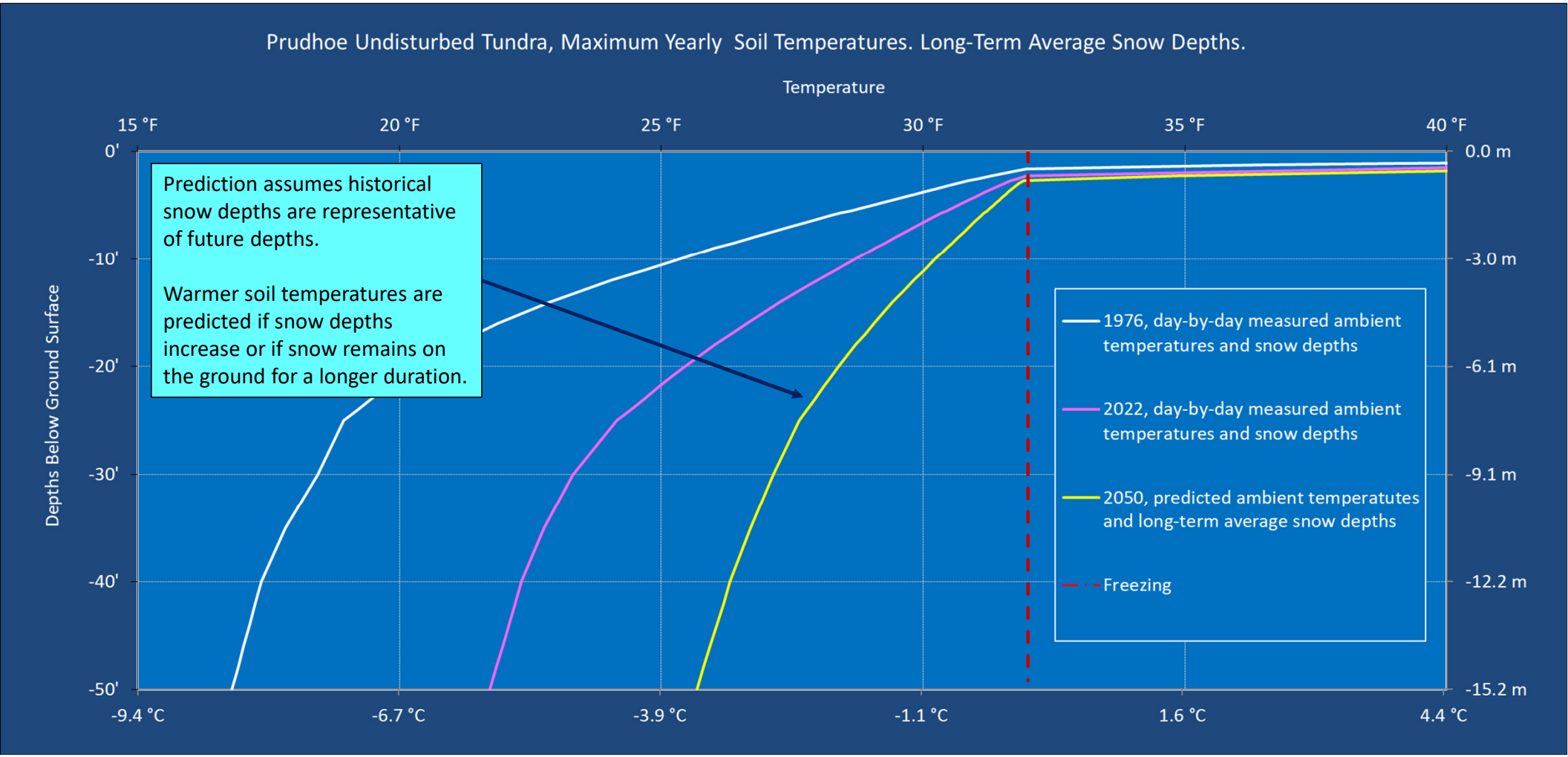
Predictions made by NES's TQUEST geothermal model using soil properties and stratigraphy from the borehole drilled at TS-1


Predicted Temperature Profiles, Undisturbed Tundra. Measured Ambient Temperatures and Snow Depths.
Temperature
-10 °F
0 °F
10 °F
20 °F
30 °F
40 °F
50 °F
60 °F
0'
-10'
-20'
-30'
-40'
-50'
0 m
-3 m
-6 m
-9 m
-12 m
-15 m
Depths Below Ground Surface
-23 °C
-17 °C
-12 °C
-6 °C
-1 °C
5 °C
10 °C
16 °C
early January 1976
early March 1976
early May 1976
early July 1976
early September 1976
early November 1976
Maximum AL Depth = -1.6 ft.
Freezing


Predicted Temperature Profiles, Undisturbed Tundra. Measured Ambient Temperatures and Snow Depths.
Temperature
-10 °F
0 °F
10 °F
20 °F
30 °F
40 °F
50 °F
60 °F
0'
-10'
-20'
-30'
-40'
-50'
0 m
-3 m
-6 m
-9 m
-12 m
-15 m
Depths Below Ground Surface
-23 °C
-17 °C
-12 °C
-6 °C
-1 °C
5 °C
10 °C
16 °C
Simulation uses day-by-day measured ambient temperatures and snow depth on-the-ground, 1/1/1976 through 7/1/2022.
early January 2022
early March 2022
early May 2022
early July 2022
early September 2022
early November 2022
Maximum AL Depth = -2.25 ft.
Freezing


Predicted Temperature Profiles, Undisturbed Tundra. Predicted Ambient Temperatures and Long-Term Snow Depths (no Increase).
Temperature
-10 °F
0 °F
10 °F
20 °F
30 °F
40 °F
50 °F
60 °F
0'
-10'
-20'
-30'
-40'
-50'
0 m
-3 m
-6 m
-9 m
-12 m
-15 m
Depths Below Ground Surface
-23 °C
-17 °C
-12 °C
-6 °C
-1 °C
5 °C
10 °C
16 °C
If Future Snow Depths same as Average, Long-Term Depths
early January 2050
early March 2050
early May 2050
early July 2050
early September 2050
early November 2050
Maximum AL Depth = -2.75 ft.
Freezing


Predicted Temperature Profiles, Undisturbed Tundra. Predicted Ambient Temperatures and Increasing Snow Depths.
Temperature
-10 °F
0 °F
10 °F
20 °F
30 °F
40 °F
50 °F
60 °F
0'
-10'
-20'
-30'
-40'
-50'
0 m
-3 m
-6 m
-9 m
-12 m
-15 m
-23 °C
-17 °C
-12 °C
-6 °C
-1 °C
5 °C
10 °C
16 °C
Depths Below Ground Surface
If Future Snow Depths Increase at Kuparuk's Rate
early January 2050
early March 2050
early May 2050
early July 2050
early September 2050
early November 2050
Maximum AL Depth = -4.25 ft.
Freezing


Prudhoe Undisturbed Tundra, Maximum Yearly Soil Temperatures. Long-Term Average Snow Depths.
Temperature
15 °F
20 °F
25 °F
30 °F
35 °F
40 °F
0'
-10'
-20'
-30'
-40'
-50'
0.0 m
-3.0 m
-6.1 m
-9.1 m
-12.2 m
-15.2 m
-9.4 °C
-6.7 °C
-3.9 °C
-1.1 °C
1.6 °C
4.4 °C
Depths Below Ground Surface
Prediction assumes historical snow depths are representative of future depths.
Warmer soil temperatures are predicted if snow depths increase or if snow remains on the ground for a longer duration.
1976, day-by-day measured ambient temperatures and snow depths
2022, day-by-day measured ambient temperatures and snow depths
2050, predicted ambient temperatutes and long-term average snow depths
Freezing

Predicted Maximum Yearly Soil Temperatures in Undisturbed Tundra. Using Snow Depths Increasing at Kuparuk's Rate (7/1/2022 thru 2050)

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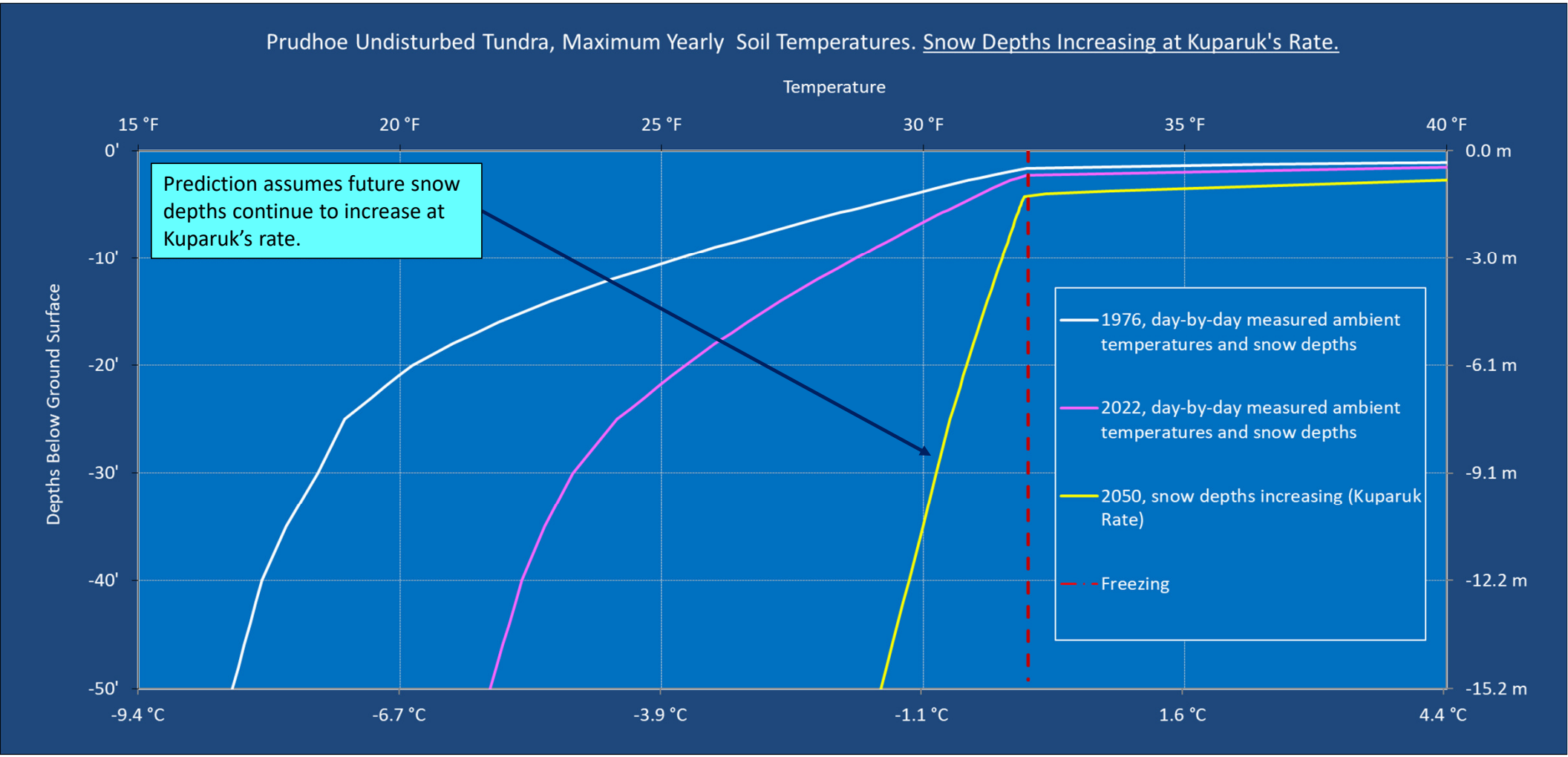
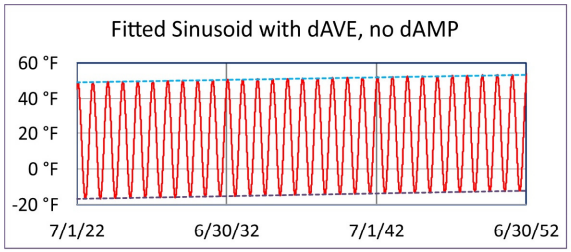
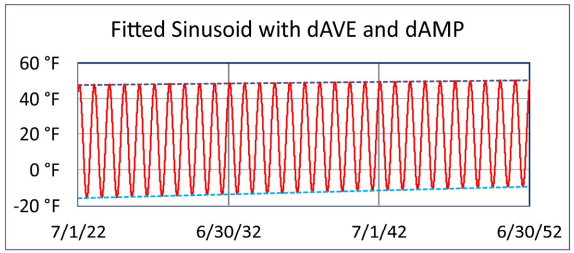
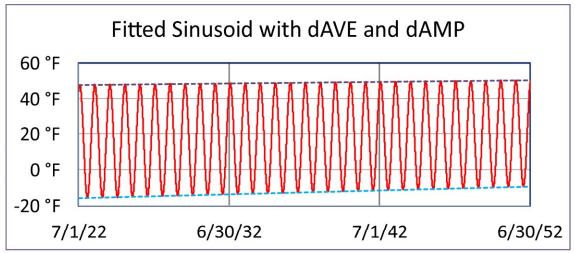
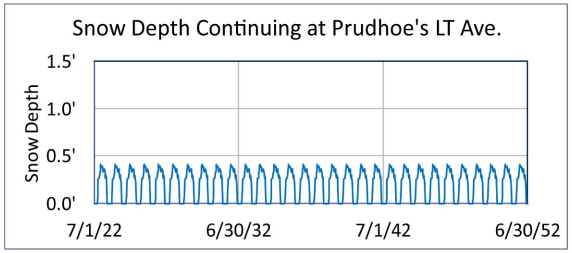


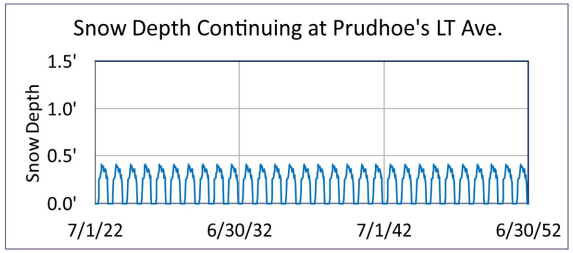
Effect of Warming Climate and Warming Soil Temperatures on Adfreeze Pile Design Lengths

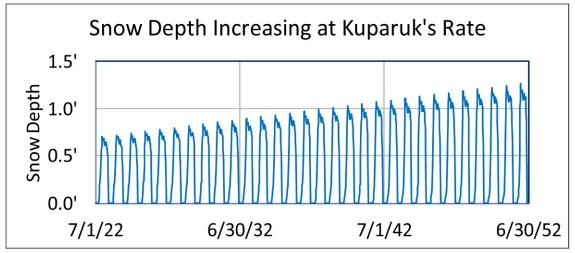












Effect of Warming Soil Temperatures upon Design Adfreeze Pile Lengths (30.5 cm dia. Pile, 445 kN design load)

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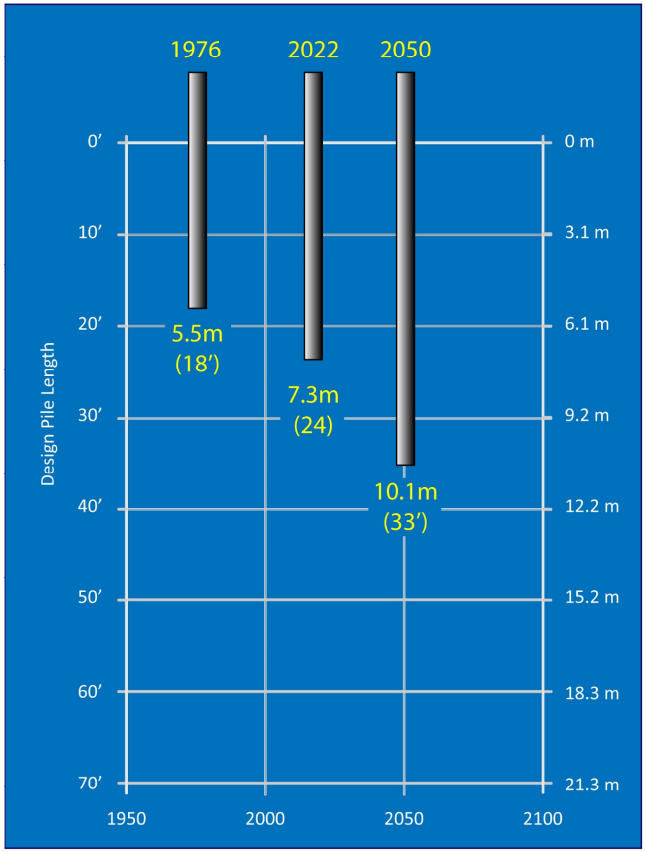
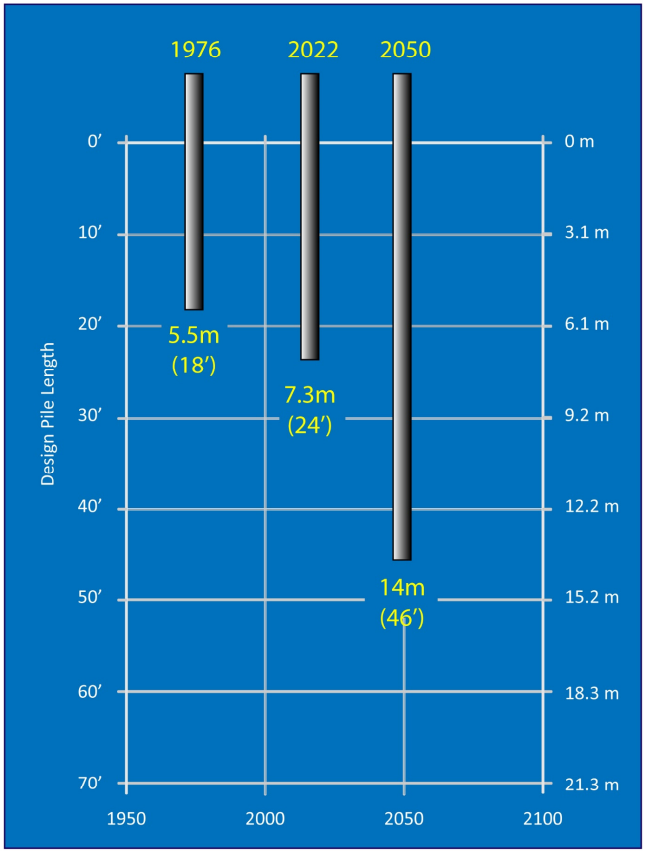
Future Ambient: Fitted Sinusoid with Warming Average

Future Snow: Long-Term Average, no Increase



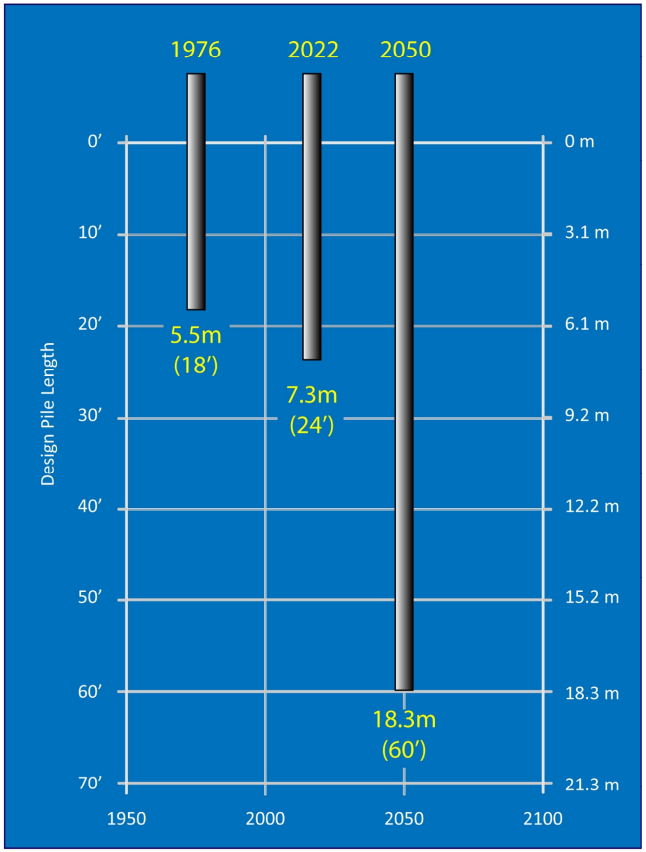
Future Ambient: Fitted Sinusoid with Warming Average and Decreasing Amplitude

Future Snow: Long-Term Average, no Increase



Future Ambient: Fitted Sinusoid with Warming Average and Decreasing Amplitude

Future Snow: Increasing at Kuparuk's Rate



/nes projects/USPA/pile_lengths_USPA.ai

Summary

Summary

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1. In the high Arctic, average annual ambient temperatures are warming rapidly: for the Prudhoe, Alaska, area, our current assumption is an average increase of 9°C (16 °F / century), which is approximately what is predicted by GCMs. Measured temperatures show that winters are warming about four times faster than summers, which affects active layer depth, passive heat extraction, pile design lengths, predicted settlements and frost jacking, mitigation designs, etc. Effectively all aspects of Arctic engineering and operations.
2. Changing climate affects the definition of the project design climate: should a project use a design climate predicted for the middle of a 30-year design life? The end of the design life? Factor of Safety = 1 at the end of the design life. Provisions to easily mitigate/adapt to more warming (VSM creep, surface settlement, etc.) than the design basis.
3. Some GCM predictions for the Alaskan High Arctic suggest less precipitation, and some predict more precipitation. Because snow is such a good insulator, increasing snow depth will significantly affect soil temperatures, i.e., decreasing beneficial wintertime soil cooling. Assuming that future snow depths increase using Kuparuk's rate, or that long-term average snow depths reasonably represent future depths, has a significant effect upon soil temperatures.
4. Presently, to calculate the frost-jacking force on a pile, we multiply the circumference of the pile by the assumed active layer depth, then by 276 kPa (40 psi). As the active layer deepens due to warming climate, does the design jacking force increase, too, or does it just apply for a longer duration?
5. BP's Applied Mitigation Demonstration Project (described in the Quebec keynote) demonstrated that retrofitting VSMs / piles with thermosyphons significantly reduced settlement rates, even for instances where adfreeze piles have settled up to 46 cm (18 inches). The same effect has been shown at many installations where shop/warehouses have settled due to pile/VSM creep in warming permafrost.
6. Put end plates on VSMs / piles so they can be refrigerated if necessary.
7. Get out into the field. Let the technicians who are collecting data know how their data are being used, and what to look for.

Thanks!