ERDC/CRREL TR-13-11

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National Science Foundation, Arctic Sciences Program (ARC)

Site Assessment and Feasibility of a New Operations Base on the Greenland Ice Sheet

Amy M. Burzynski, Sandy Wong, Jennifer L. Mercer, Elias J. Deeb, and Stephen D. Newman

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Abstract

The National Science Foundation is moving forward with plans to convert Summit Station, Greenland, into a clean air/clean snow research facility. Plans include reducing the size of the station and minimizing both research and operations activities. To continue support of scientific research that does not require a clean air/snow environment, an alternate site needs to be identified and assessed for feasibility of operations, scientific viability (at or easily reachable from the new site), and traversability between there and the existing Summit Station. Additionally, the 109th Airlift Wing of the Air National Guard is seeking a new training site in Greenland; increased melt along the margin of the ice sheet is encroaching upon their current site, Raven. Here we present the results of our site selection analysis to identify target locations for a new operations base serving science research and support and 109th training facilities. Recently, NSF has shifted focus to a new site, "Isi," located about 3 miles north of Summit, closer to the actual peak elevation of the ice sheet, to house a proposed telescope. This site assessment and the geographic information system (GIS) we built will be used primarily to identify an alternate training location for the 109th. Once specific target sites are identified, we recommend satellite imagery analysis and further consideration of ice stability factors (i.e., velocity and crevassing) that may affect construction viability, as well as weather station installation and monitoring to assess local climatic factors. A site visit for in-depth physical inspection should follow.

Contents

Illustrations

Figures

Preface

This work was funded by the National Science Foundation, Office of Polar Programs—Arctic Research Support and Logistics Program under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ARC-11-19.

The work was performed by Amy M. Burzynski, Sandy Wong, and Dr. Jennifer L. Mercer (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief) and Dr. Elias J. Deeb and Stephen D. Newman (Remote Sensing/GIS and Water Resources Branch, Timothy Pangburn, Chief) of the US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Justin Berman was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

The authors acknowledge and thank the Summit stakeholders for their critical contributions to this work, continued support and guidance, and insightful dialogue: CH2M Hill Polar Services (CPS)/Polar Field Services (PFS); the New York Air National Guard 109th Airlift Wing; the Government of Greenland; the Summit Science Coordination Office (SCO); and the wider science community, particularly Dr. J. P. Steffensen from the University of Copenhagen.

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Acronyms

ASIAA	Academia Sinica Institute of Astronomy and Astrophysics
CPS	CH2M Hill Polar Services
CRREL	Cold Regions Research and Engineering Laboratory
DEM	Digital Elevation Model
ERDC	US Army Engineer Research and Development Center
GC-Net	Greenland Climate Network
GIS	Geographic Information System
GISP2	Greenland Ice Sheet Project 2
GoG	Government of Greenland
MIT	Massachusetts Institute of Technology
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NROA	National Radio Astronomy Observatory
NSF	National Science Foundation
NYANG	New York Air National Guard
PFS	CH2M Hill Polar Field Services
SAO	Smithsonian Astrophysical Observatory
SCO	Summit Science Coordination Office
UAV	Unmanned Aerial Vehicles
VLBI	Very Long Baseline Interferometry

Unit Conversion Factors

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters

1 Introduction

Since its establishment in 1989 for the deep ice coring efforts of the Greenland Ice Sheet Project 2 (GISP2), Summit Station (72°36'N, 38°25'W, 3200 m.a.s.l.) has been a central hub of science research on the Greenland ice sheet. Research and operations at the station have continued to expand, and summertime population has grown accordingly (Barna et al. 2011). To maintain the integrity of environmentally sensitive science projects at this site, the National Science Foundation (NSF) is moving forward with plans to convert Summit Station into a clean air/clean snow research facility. NSF seeks to limit the size of the station and to minimize both research and operational impacts. An alternate site needs to be identified to continue supporting science activity and operations that do not require a clean air/snow environment.

Concurrently, the New York Air National Guard (NYANG) 109th Airlift Wing has expressed desire to move its current training facility from Raven (66°29'N, 46°17'W, 2100 m.a.s.l.) to a location on the ice sheet less prone to melt. The current facility is located about 35 minutes flying time outside of Kangerlussuaq and is used for conducting training for air drops, open snow landings, and landings on minimally groomed skiways. It is also used as an alternative landing site when weather prohibits safe landing at Kangerlussuaq. In recent years, the 109th has observed encroaching melt ponds, a rain event, and crevasses on the skiway at Raven (Mercer 2012).

In consideration of these stakeholders, NSF initiated a search for a new operations base on the Greenland ice sheet in 2010. This site would support science research and operations that do not require a clean air/clean snow environment and would serve as a training facility for the 109th. NSF and its primary arctic research support and logistics contractor (CH2MHill/Polar Field Services) have supported this effort with crucial input from the Greenland Science Community and from the Summit Science Coordination Office (SCO), the NYANG 109th, the Government of Greenland (GoG), and NSF's partnering agencies: the US Army Cold Regions Research and Engineering Laboratory (ERDC-CRREL), the National Oceanic and Atmospheric Administration (NOAA), and the National Renewable Energy Laboratory (NREL).

Through Greenland Planning Conferences, hosted by the NYANG 109th in 2011 and 2012, and regular teleconferences, we identified specific stakeholder requirements: (a) proximity to Kangerlussuaq and Summit Station for ease of logistics and (b) a high and dry location, ideal both for the 109th and for much of the science conducted at Summit.

Here we present a site assessment using GIS (geographic information system) analysis to identify a target region on the ice sheet that meets stakeholder requirements. We also highlight weather trends at several long-term climate-monitoring sites on the ice sheet.

Recently NSF has shifted focus to Isi, a proposed site about 3 miles north of Summit Station, closer to the highest elevation on the ice sheet, to support a proposed telescope. Isi, pronounced *eeshee*, means “eye” in Greenlandic. The installation of a 12-m diameter, sub-millimeter telescope would be a joint effort between the Smithsonian Astrophysical Observatory (SAO); the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), an institution based in Taiwan; the Massachusetts Institute of Technology (MIT) Haystack Observatory; and the National Radio Astronomy Observatory (NROA), which is an NSF facility. The two primary scientific drivers for placing the telescope at Isi are (a) to make millimeter-wave, Very Long Baseline Interferometry (VLBI) observations of the super-massive black hole in galaxy M-87 and (b) to make sub-millimeter and terahertz observations, which require atmospheric conditions present at Isi's high altitude and high latitude location (Greenland Telescope 2013).

The 109th has renewed interest in moving Raven after cracks formed in the ice on and near the skiway during summer 2012 (Mercer 2012). The analysis presented here will be informative in their search for an alternate training facility site; future assessment scenarios may be easily tailored to the specific requirements and preferences of the 109th.

2 Approach

2.1 Information gathering from stakeholders

The primary stakeholders in this search for a new operational site on the Greenland ice sheet are NSF and its arctic research support and logistics contractor (CH2M Hill Polar Field Services), the NYANG 109th Airlift Wing, GoG, NOAA, SCO, and the wider Greenland science community. Regular teleconferences and Greenland Planning Conferences hosted by the NYANG 109th in 2011 and 2012 supported ongoing dialogue among these stakeholders.

When NSF identified the need to minimize environmental impacts at Summit and to move most operations and research activities to another site, they reached out to the Greenland science community for input. Polar Field Services (PFS) sent a questionnaire to science community members stating the intention to minimize impacts at Summit and requesting specific details and needs of proposed and funded research projects (Appendix A).

2.2 Target sites: weather trends and traversability

NSF, CRREL, CH2M Hill/PFS, and SCO identified initial regions of interest and potential target sites based on general stakeholder requirements of high elevation and proximity to Kangerlussuaq and Summit Station (Fig. 2). We then analyzed data from Greenland Climate Network weather stations near the target sites to address concerns about temperature, prevailing winds, humidity, and snow accumulation (Steffen et al. 1996).

To address questions about traversability, we built a GIS and then calculated the distance from each intital target site to Summit at a travel rate of approximately 50 miles per day (Burnside 2011).

2.3 Site selection: GIS analysis

Based on specific quantitative stakeholder requirements listed below, we conducted GIS site selection analysis (Fig. 1) to identify a target region on the ice sheet. We derived elevation and slope values from the GLAS/ICESat 1-km digital elevation model (DEM) (DiMarzio et al. 2007). Appendix B presents a comparison of this dataset and the Byrd Polar Research Center 1-km DEM at Summit (Byrd Polar Research Center, n.d.). Of these two elevation models, we chose to use GLAS/ICESat because of its higher estimated accuracy.

Site Requirements:

1. Slope < 0.28°, the estimated current slope at Raven.
2. Elevation > 2100 m. High elevation is required by the Summit science community and reduces risk of melt for the 109th.
3. Elevation < 2745 m. Above this altitude, the 109th would need to use supplemental oxygen for their training activities (Bernasconi 2012).
4. ≤ 45 minute flight to Kangerlussuaq to serve as an alternate landing site for the 109th.
5. Position between Summit and Kangerlussuaq for science support and logistics.

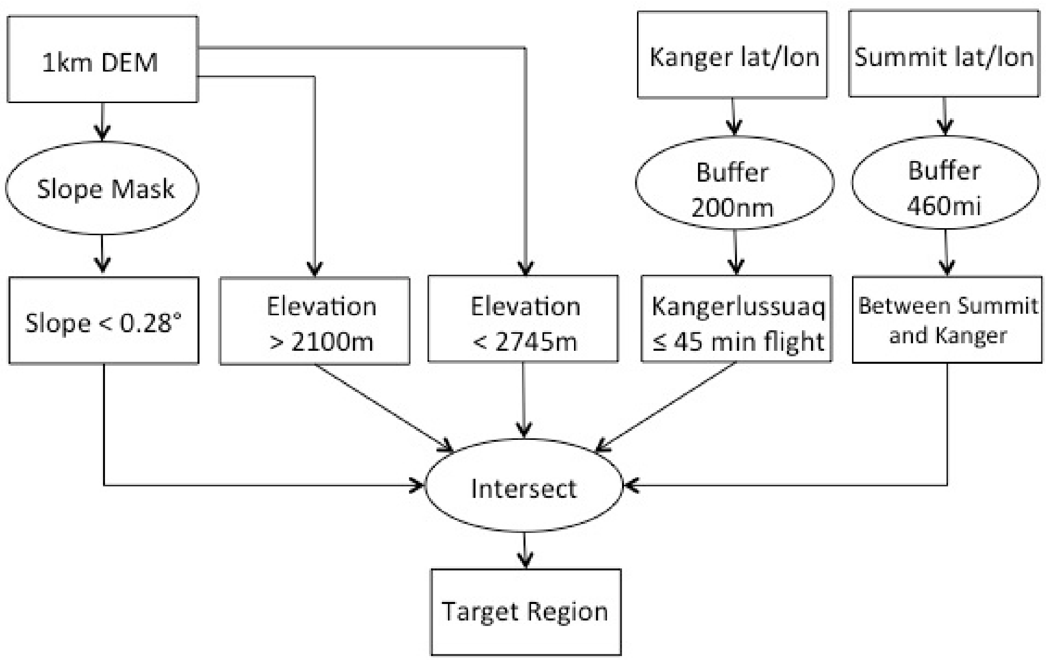

Figure 1. Methodology flowchart.

3 Report of Findings

3.1 Stakeholder requirements

We gathered stakeholder requirements, organized below, to guide the identification and development of a new research and operations base on the Greenland ice sheet.

3.1.1 NSF and its logistics support contractor (CH2MHill/PFS)

Summit Camp has been the hub of Greenland science research; but to maintain the integrity of climate research (i.e., “clean air/clean snow”) conducted at Summit, the station must minimize the environmental impact of both research and operations activities. Thus, the size of Summit Camp must also be reduced. NSF recognizes that another site should be identified for activities on the Greenland Ice Cap. Particular requirements for a new site include that it

- Be at a high altitude.
- Be an alternate flight landing spot.
- Be located between Kangerlussuaq and Summit.
- Be traversable to Summit.
- Allow access to more areas of Greenland for science.
- Have consistent prevailing winds.
- Be above 2100 m or at a higher latitude to compensate for predicted temperature increases.

3.1.2 NYANG (109th)

The NYANG has indicated a possible desire to move their current training facility from Raven to a site higher up on the ice sheet or further north. This is because of environmental changes in the area, including rain events, ice cracks, melt events, and the continued increase and advancement of melt pools towards the current Raven location (66°29'N, 46°17'W, 2100 m.a.s.l.) in recent years. Particular requirements for a new site include

- An uninhibited area for training.
- A maintained skiway.
- An open snow field area.

- A drop-zone area for air-drop training.
- A 30–45 min flight time to Kangerlussuaq.
- An altitude of 6000–8000 (updated to 9000 ft maximum).
- Less slope across area than Raven.
- C130 Fuel.

3.1.3 Science community

Summit science activities generally fall into one of two categories: “clean air” or “non-clean air.” Similarly, Greenland science focuses generally on “melt/ice motion” or “dry snow/stable pristine environments.” It is possible that a new operations site could serve as a launching point for mobile science accessing locations to study either of the general Greenland science categories. Additionally, the new site could serve as a test site for any unproven science equipment or methods. Some examples of possible science activities to occur at the new site location include testing unmanned aerial vehicles (UAVs), testing drill prototypes, collecting surface snow samples, conducting pit coring, etc.

3.1.4 Government of Greenland

Any area chosen for this new site will need an allotment and approval from the GoG.

3.2 Target sites: weather trends and traversability

The primary stakeholder group identified target regions based on general requirements of high elevation and proximity to Kangerlussuaq and Summit Station (shown as red ovals in Fig. 2). Within these regions of interest, we identified six initial target locations for the new operations base (Fig. 2). Target sites 1, 2, 3, and 5 are located along the ridge south of Summit, in the saddle between the two highest points on the ice sheet. Target 4, near Crawford Point, was suggested as a potential launching site for mobile science expeditions to reach either lower, wetter climes or higher, dryer snow and ice regimes. The 109th selected Target 6, “ANG,” because it has a slightly higher elevation than Crawford Point and is further away from the Jacobshaven trough.

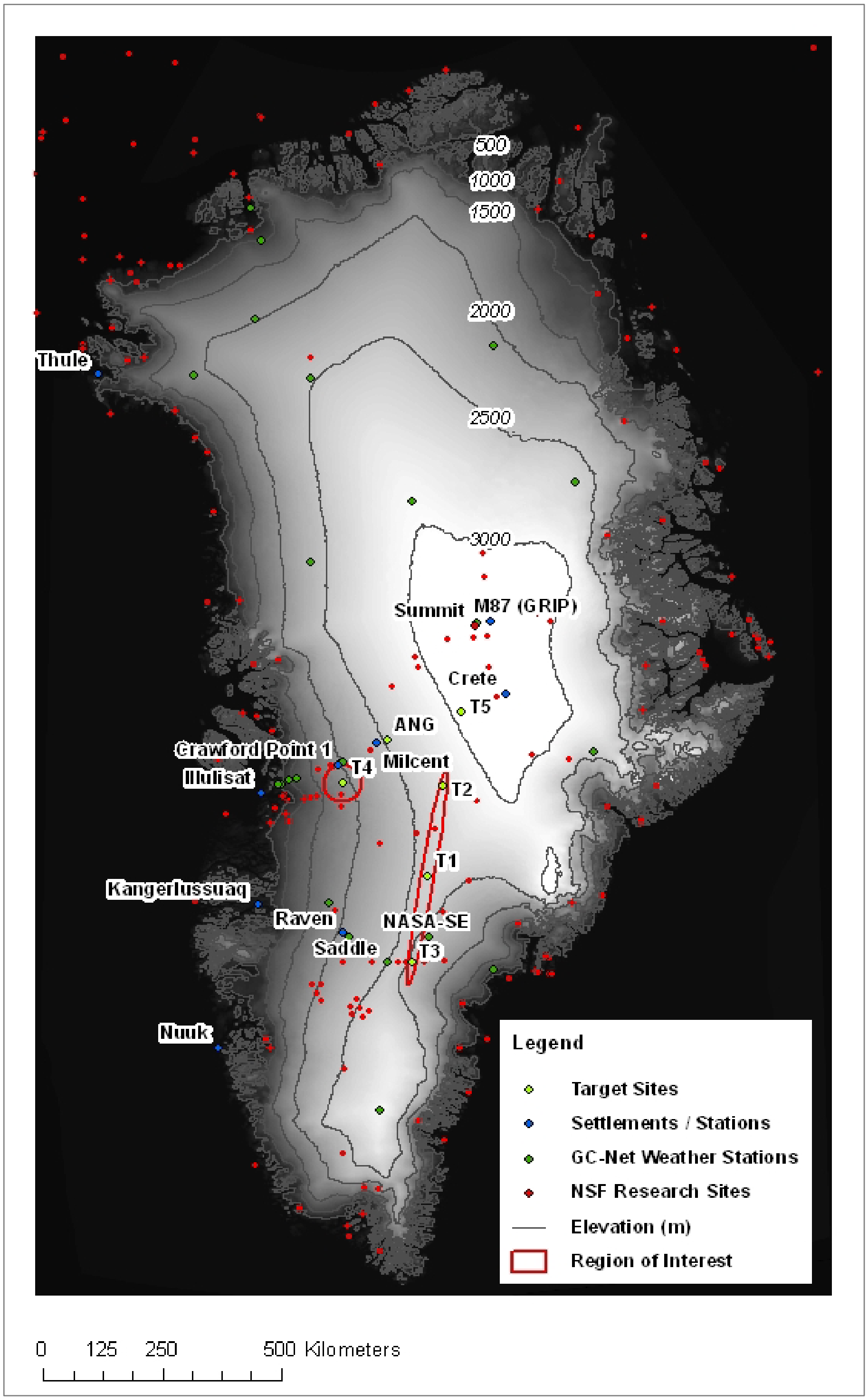

Figure 2. Map of proposed regions (red ovals) and potential target sites for a new operations base on the Greenland ice sheet, based on general stakeholder requirements of high elevation and proximity to Kangerlussuaq and Summit (DiMarzio et al. 2007; Gaylord et al. 2012; Steffen et al. 1996).

To address NSF's requirement that the new operations site be traversable to Summit, we calculated the distance between each target site and Summit. Assuming an average traverse speed of approximately 50 miles per day (Burnside 2011), we calculated traverse times to each site, ranging from 2.5 days (Target 5) to 9.5 days (Target 3) (Fig. 3).

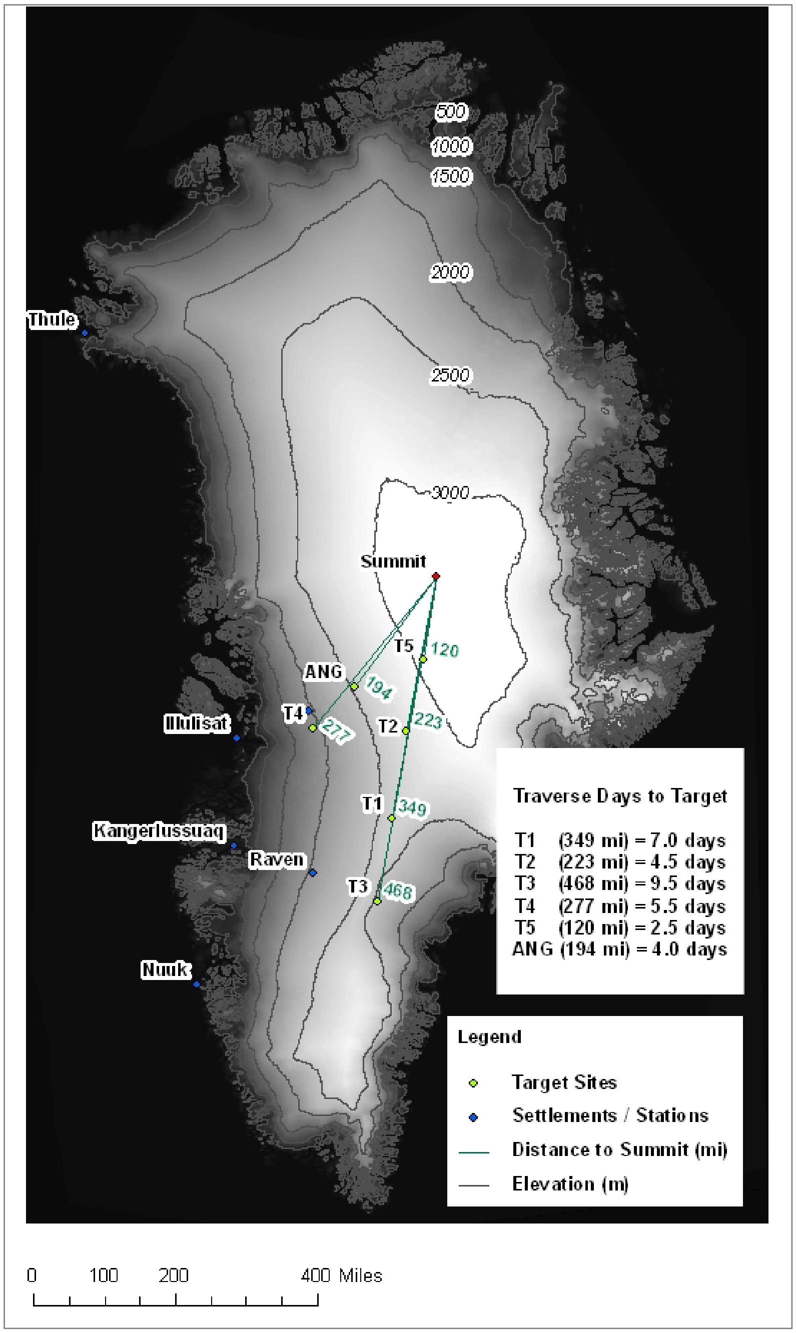

Figure 3. Distance and traverse time between target sites and Summit Station, assuming a traverse speed of approximately 50 miles per day (Burnside 2011).

Near the target sites, Greenland Climate Network (GC-Net) automatic weather stations have collected climate information since 1995 (locations shown in Fig. 2) (Steffen et al. 1996; Steffen and Box 2001). The array of GC-Net stations enables near-real-time monitoring of weather conditions on the Greenland ice sheet (Steffen et al. 1996) and yields insight into the spatial and temporal variability of climate trends (Box 2002). Data from these weather stations are applied to improve climate models (Box and Rinke 2003); to ground truth and supplement satellite measurements (Comisco 2003); and to better understand ice sheet mass balance, flow, and melt dynamics (Zwally et al. 2002; Hanna et al. 2005; Box et al. 2006; Hanna et al. 2008). We analyzed historical weather data trends at three GC-Net sites to address stakeholder concerns about prevailing winds, temperature, humidity, and snow accumulation: Crawford Point-1 (69°52'47"N, 46°59'12"W, 2022 m), NASA-SE (66°28'52"N, 42°19'20"W, 2360 m), and Saddle (66°00'02"N, 44°30'05"W, 2559 m).

Wind speeds (Fig. 4) average between 4 and 8 m/s at all three sites with a range between near zero and 24 m/s throughout the year. Average wind speeds are slightly higher at Crawford Point, compared to NASA-SE and Saddle. Monthly wind speeds show a seasonal cycle; maximum winds speeds peak during winter and reach a minimum during the summer. The strongest recorded winds in this study occur at Saddle. GC-Net automatic weather stations measure winds using a RM Young propeller-type Vane with 0.1 m/s accuracy (Steffen and Box 2001).

Air temperature (Fig. 5) averages between −30°C and −5°C at all sites. The lowest temperatures occur in February and the highest in July, in agreement with Steffen and Box (2001, Table 3a and Fig. 4). Temperatures range between −50°C and −10°C in winter and between −20°C and 8°C in summer. The widest range of air temperatures and the lowest winter temperatures were observed at Crawford Point. GC-Net automatic weather stations measure air temperature with Vaisala CS-500 probes and Type-E thermocouples with an accuracy of 0.1°C (Steffen and Box 2001).

Relative humidity (Fig. 6) averages around 85–95% at all sites. Humidity varies seasonally; highest humidity occurs in the winter months (November–February) and reaches a minimum in the summer (June–July). The greatest range of humidity occurs in summer, from 50 to 100%. Observations are very similar at all sites though NASA-SE and Saddle show lower minimum humidity than Crawford Point. GC-Net automatic weather stations measure humidity with Vaisala Intercap transmitters with an accuracy of 5% when under 90% humidity and of 10% when over 90% humidity (Steffen and Box 2001).

Relative snow surface height (Fig. 7) represents the cumulative effects of “precipitation, firn compaction, redistribution of snow by drifting, and sublimation/condensation” (Steffen and Box 2001). All three sites show peak accumulation (i.e., increasing surface height) in winter and a decrease in surface height during the warmer spring and summer months. Accumulation value estimates need to account for firn compaction effects (Herron and Langway 1980; Steffen and Box 2001). The seasonal cycle of surface height change is most pronounced at NASA-SE with an annual range spanning nearly 1.4 m. Crawford Point also shows a strong seasonal cycle with a range spanning just under 1.1 m. Saddle exhibits a subtler seasonal cycle with an annual range of about 0.6 m. GC-Net automatic weather systems measure snow surface height with Campbell SR-50 sonic ranging sensors at an accuracy of 1 mm (Steffen and Box 2001).

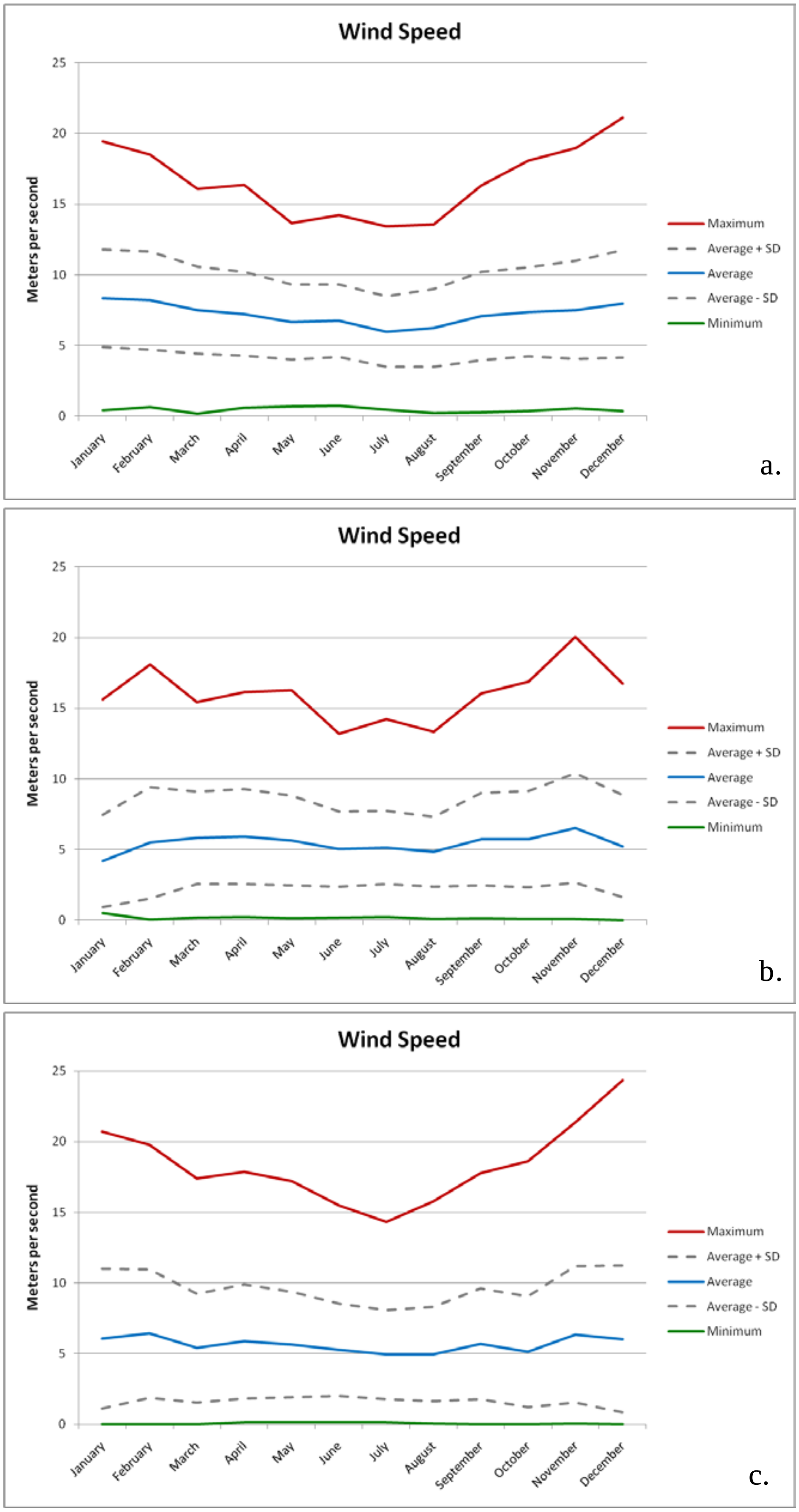

Figure 4. Wind speed at target sites (a) Crawford Point, 1995–2010; (b) NASA-SE, 1998–2012; and (c) Saddle, 1997–2009.

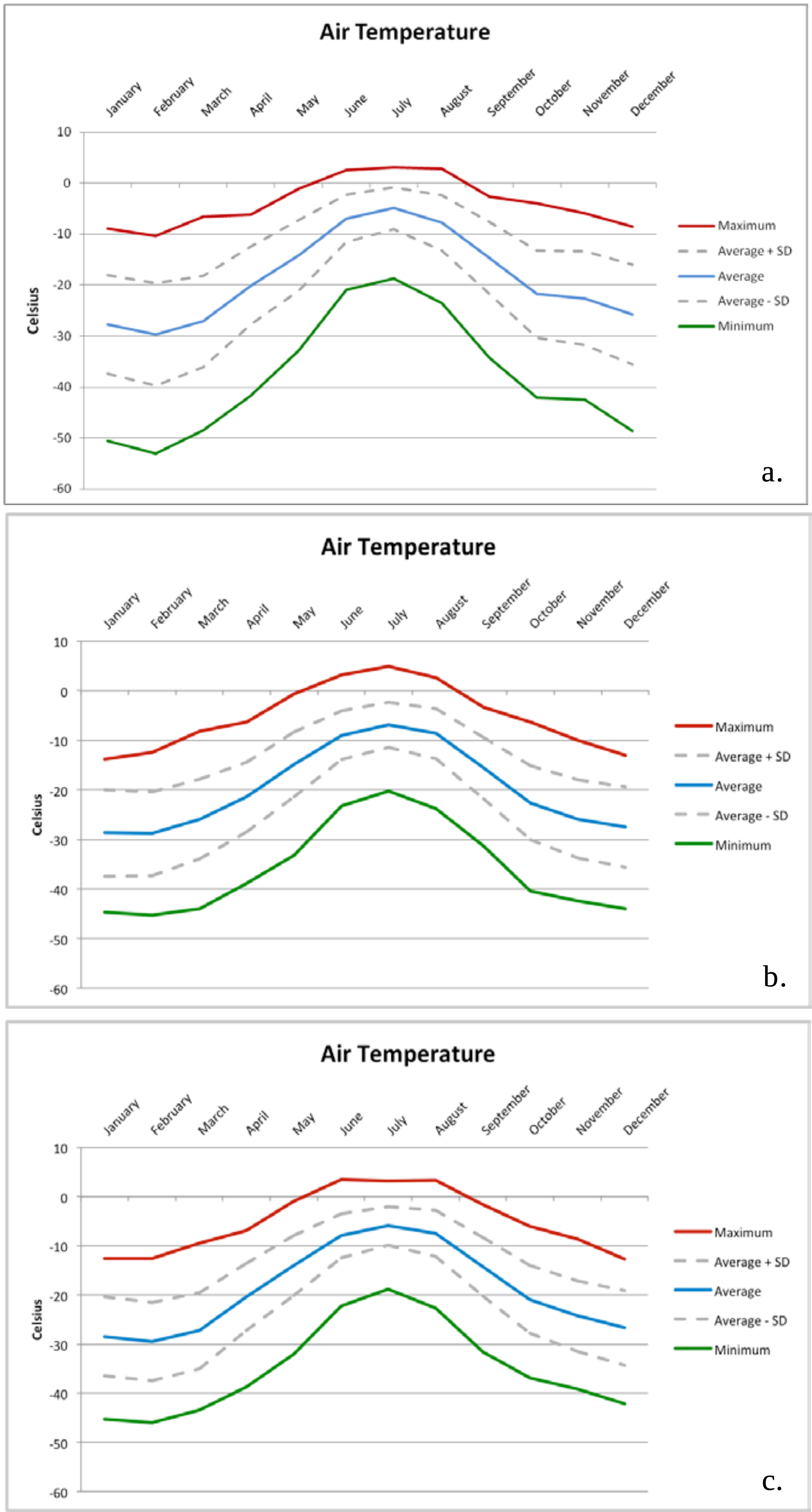

Figure 5. Air temperature at target sites (a) Crawford Point, 1995–2010; (b) NASA-SE, 1998–2012; and (c) Saddle, 1997–2009.

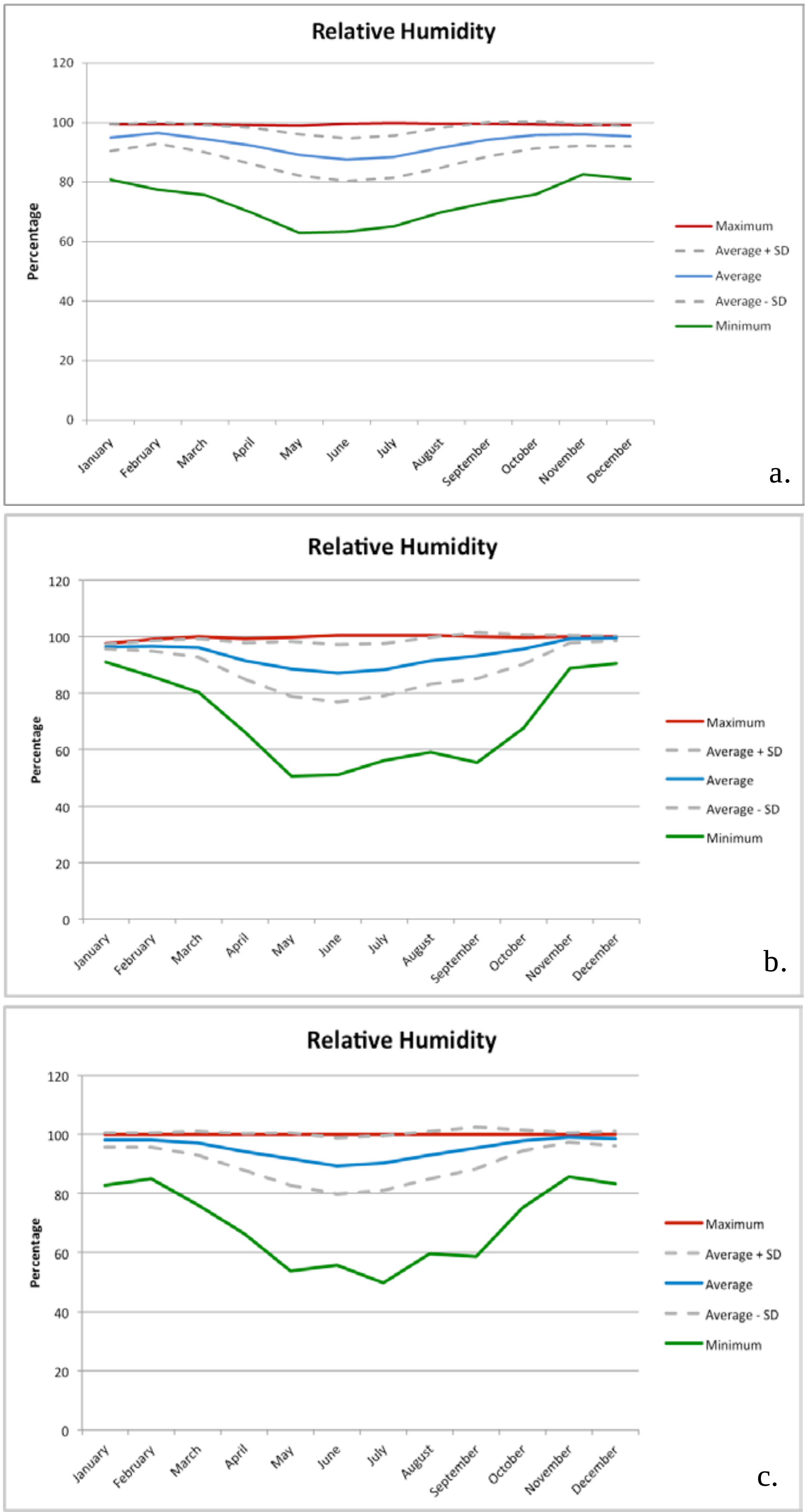

Figure 6. Relative humidity at target sites (a) Crawford Point, 1995–2010; (b) NASA-SE, 1998–2012; and (c) Saddle, 1997–2009.

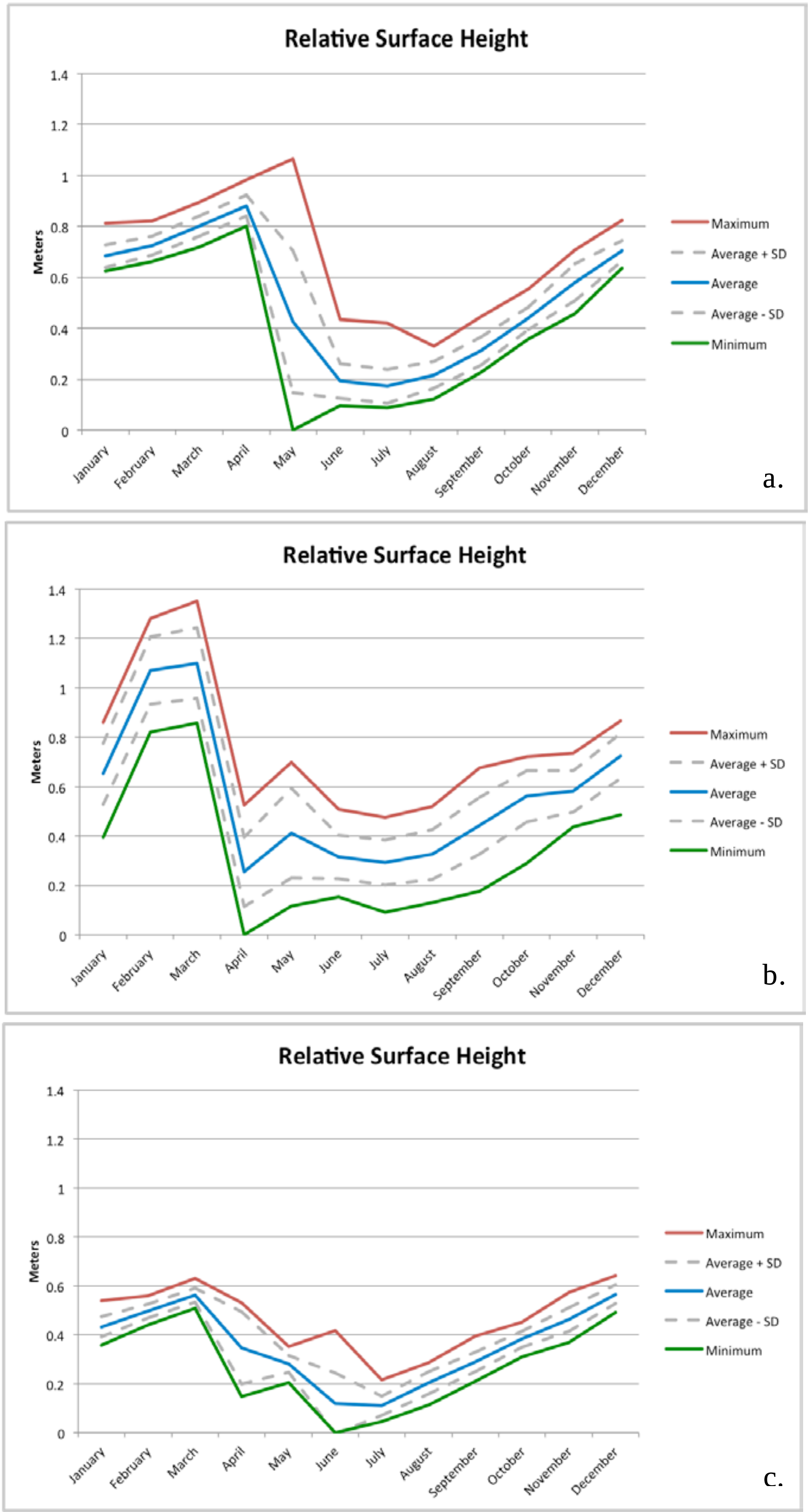

Figure 7. Relative monthly surface height at target sites (a) Crawford Point, 1995–2010; (b) NASA-SE, 1998–2012; and (c) Saddle, 1997–2006.

3.3 Geographic site selection

Figures 8–12 show the input parameters for GIS site selection analysis. These parameters are based on specific quantitative stakeholder requirements of low slope, elevation range, proximity to Kangerlussuaq, and position between Kangerlussuaq and Summit. Figure 13 highlights the area satisfying all requirements.

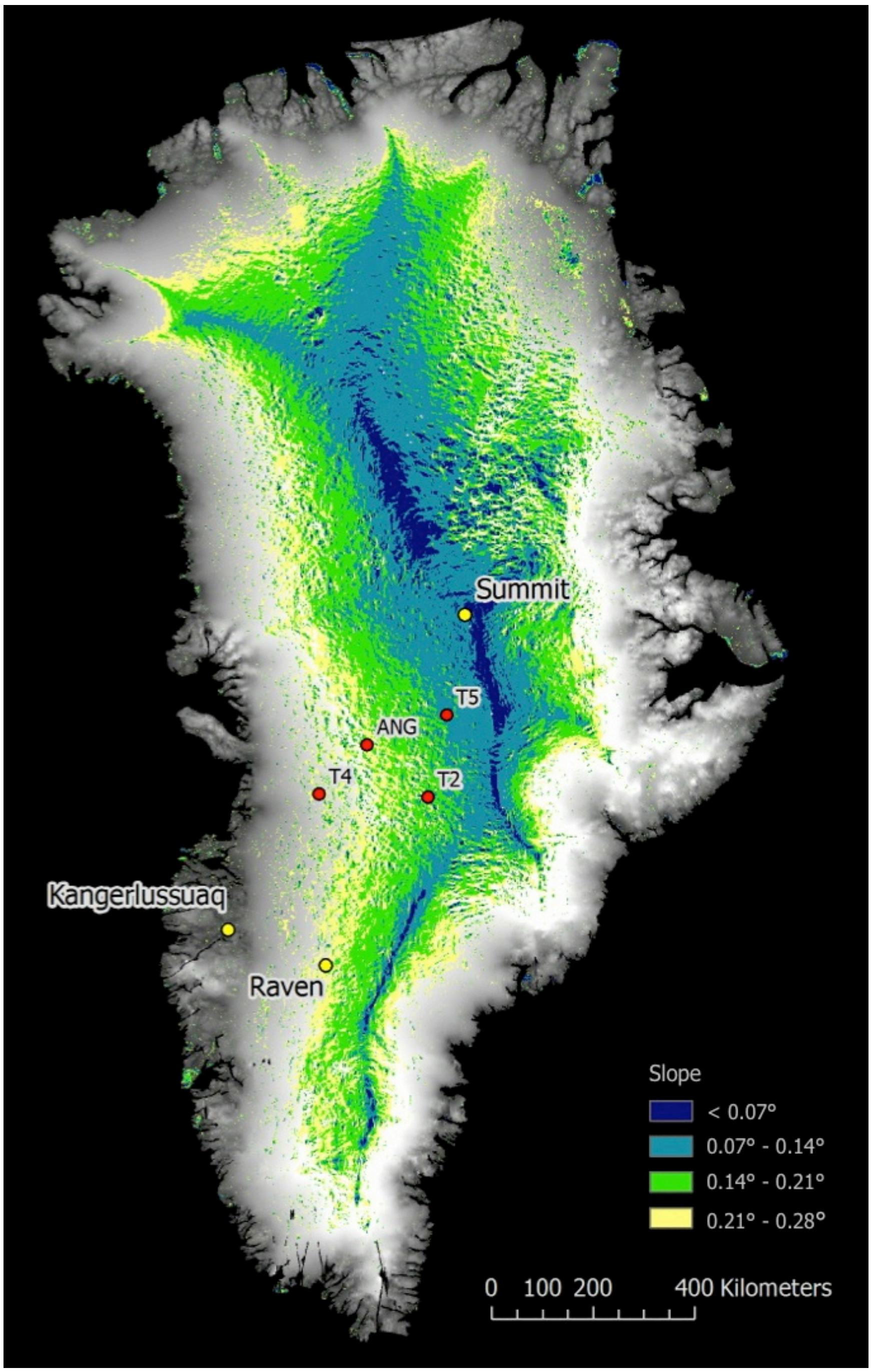

Figure 8. Slope ≤ 0.28°, the estimated current slope at Raven.

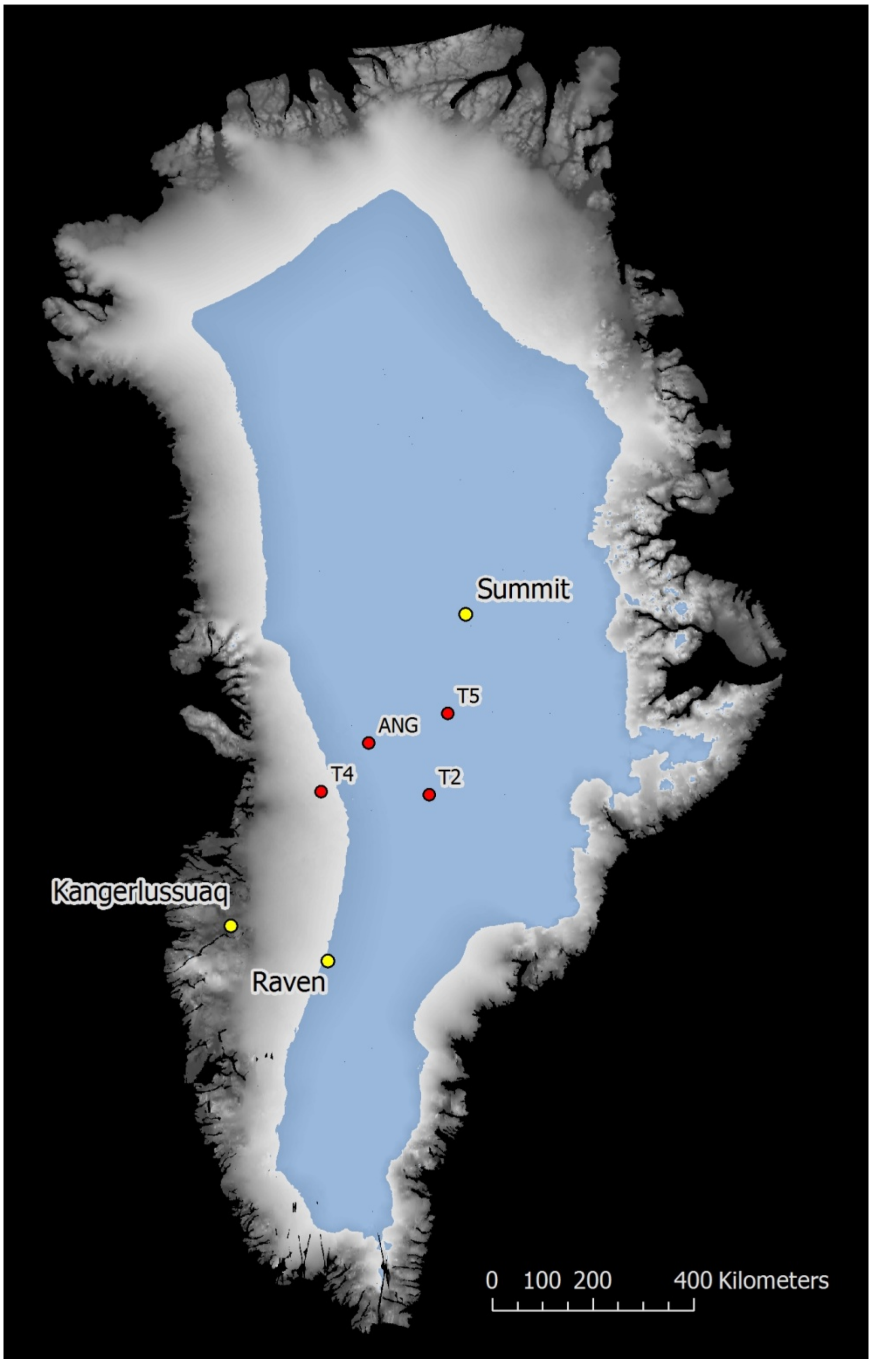

Figure 9. Elevation ≥ 2100 m shown in blue. High elevation is required by the Summit science community and it also reduces risk of melt for the 109th.

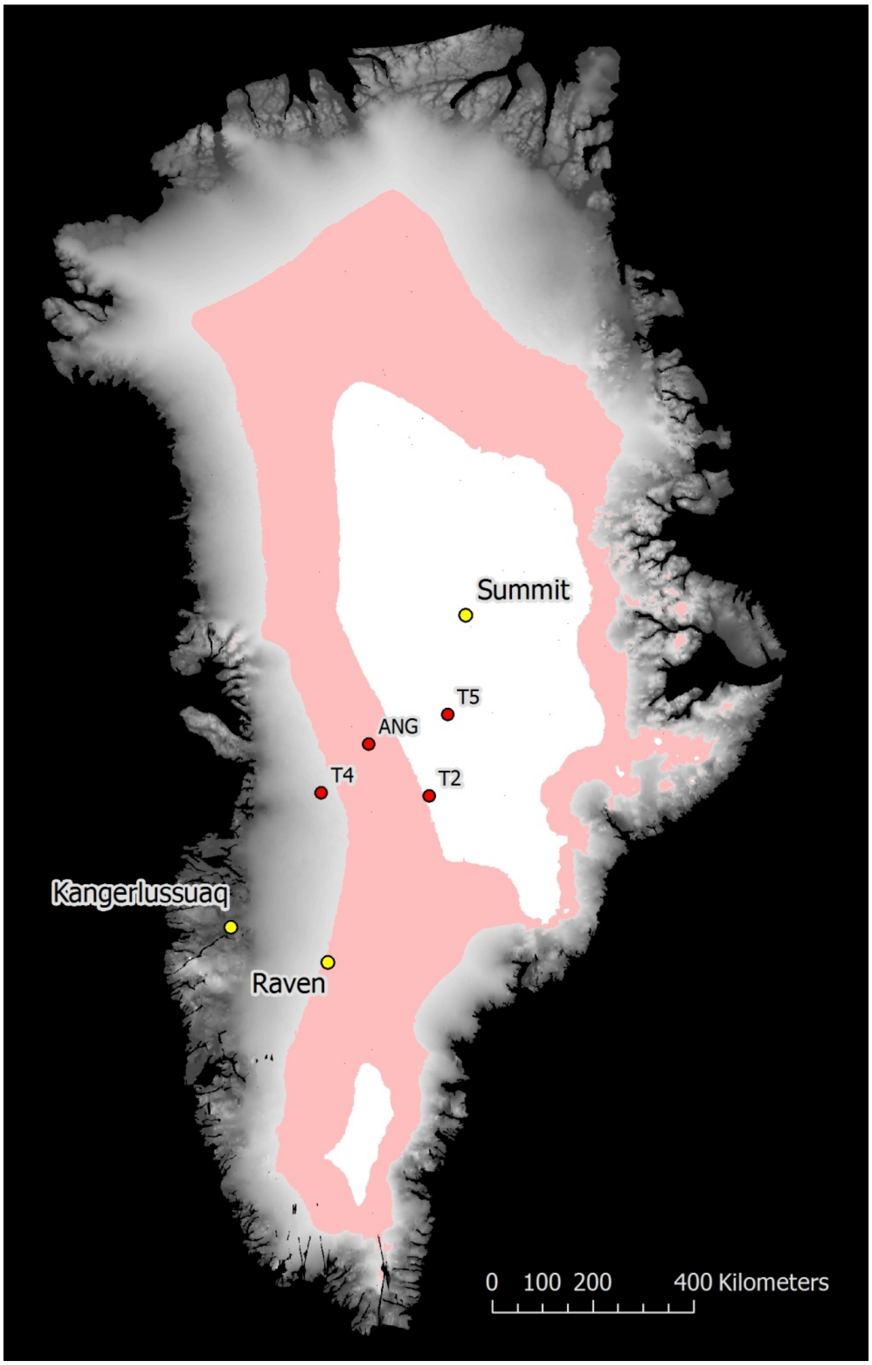

Figure 10. Elevation of 2100–2745 m (about 9000 ft) shown in pink. Above this altitude, the 109th would need to use supplemental oxygen for their training activities.

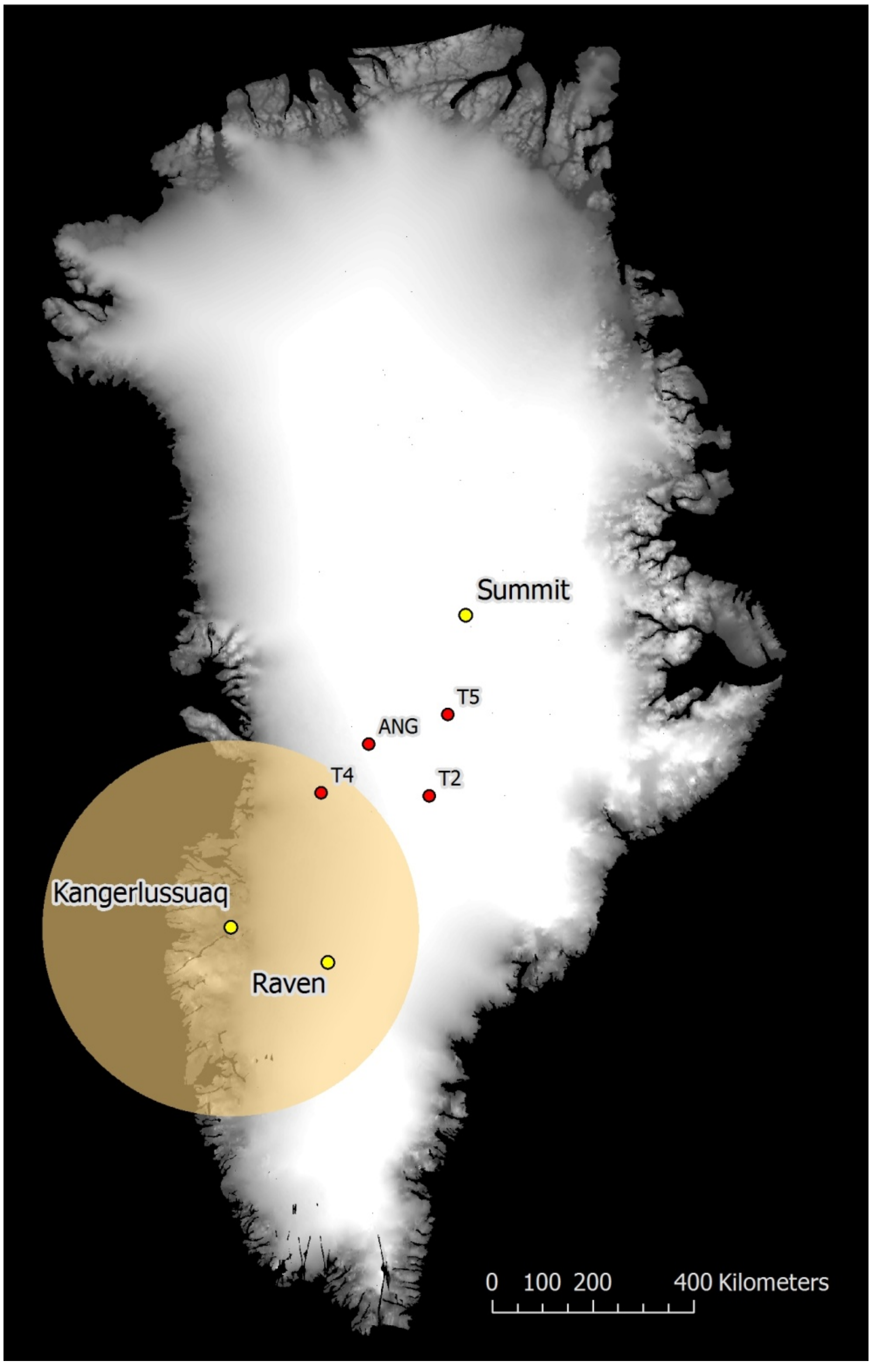

Figure 11. Shown in gold, a ≤ 45-minute flight to and from Kangerlussuaq to serve as an alternate landing site for the 109th.

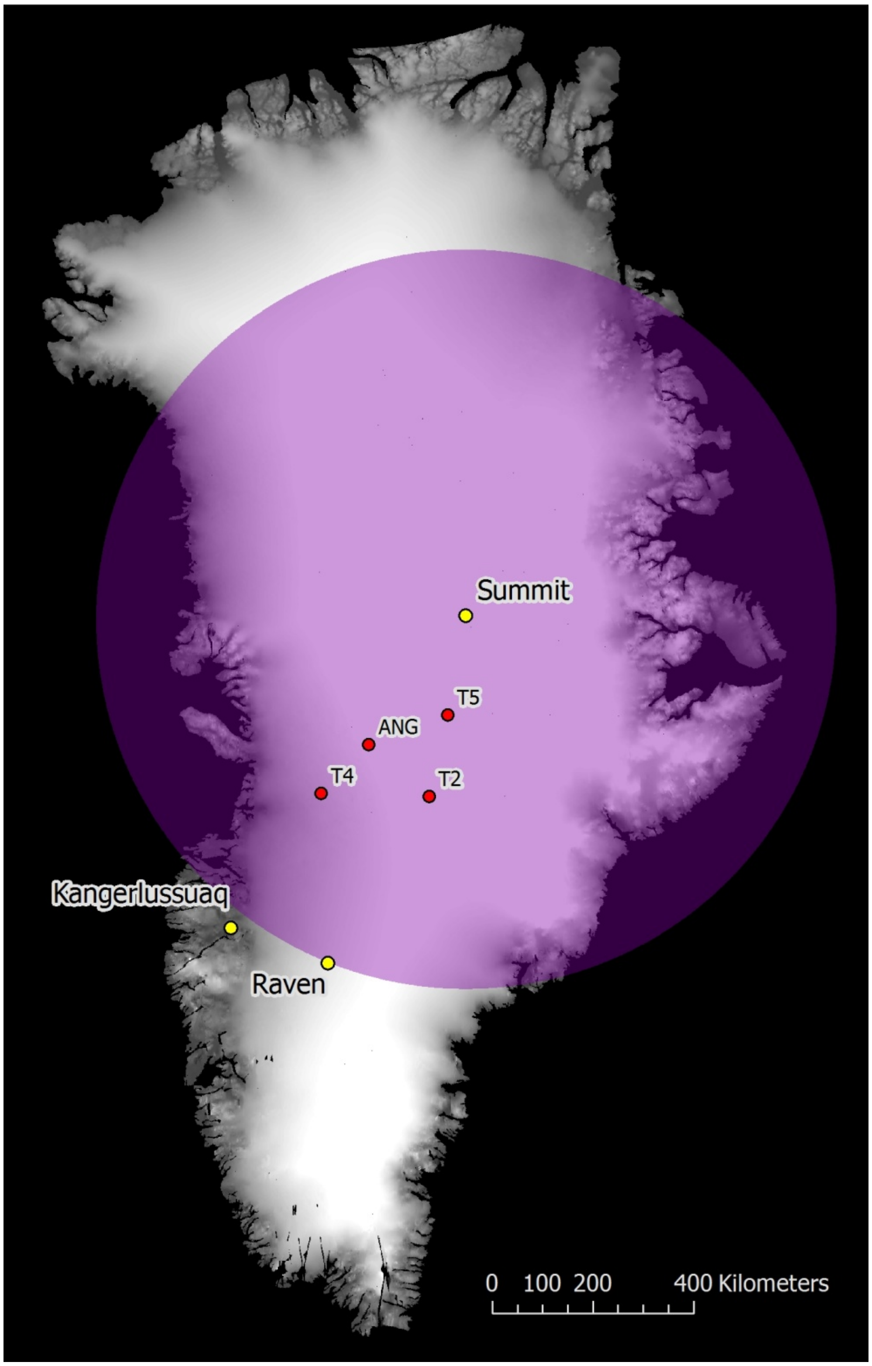

Figure 12. Shown in purple, the position between Kangerlussuaq and Summit Station for science support and logistics.

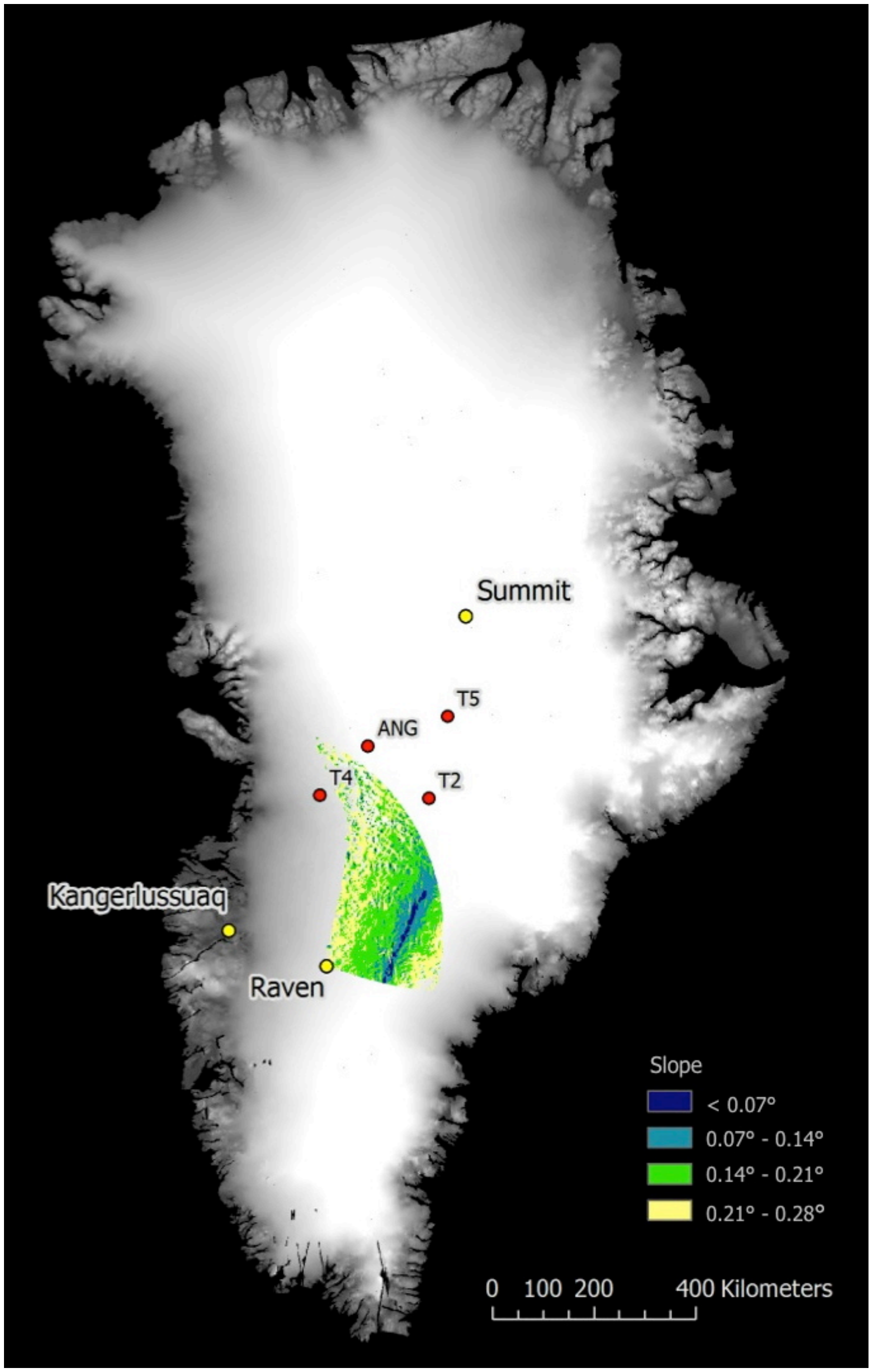

Figure 13. Output target region, where all stakeholder requirements intersect, overlaid with slope map.

4 Conclusions and Future Considerations

In an effort to identify a site on the Greenland ice sheet that can provide science and operational support for NSF and training facilities for the 109th Airlift Wing of the Air National Guard, we gathered stakeholder requirements; identified initial potential target sites; analyzed weather data; and built a GIS to spatially analyze quantitative requirements for the site's elevation, slope, and proximity to Kangerlussuaq and Summit Station. The resulting target region is located along a high-elevation, flat spine of the ice sheet north and east of Raven.

As NSF has shifted its focus to Isi, a site about three miles north of Summit, this assessment and analysis will primarily be used by the 109th to select an alternate training facility site. The GIS variables can be tailored to reflect the specific needs and preferences of the 109th to visualize various scenarios. The science community has a strong interest in this site and in modifications to Summit Station and construction of the proposed Isi station.

Once specific sites have been identified within the target area of interest, we recommend analyzing satellite imagery to characterize the area in more detail (e.g., look for crevasses and melt pools) and carefully considering ice stability factors (e.g., velocity, crevassing, and melt rates) that may affect construction viability. We recommend installing a weather station to monitor local meteorology and prevailing winds in addition to considering historical trends. A site visit for an in-depth physical inspection is necessary before initiating construction plans.

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Appendix A: Science Community Questionnaire

Summit and Related Locations - Requirement Gathering Questionnaire

The purpose of this document is to capture the details of proposed and funded projects that require a location at Summit. The primary motivation for operating Summit as a year round station is to provide a platform for the long-term measurement of climate relevant parameters, thus NSF-OPP, CPS, and the community of climate researchers working at Summit are dedicated to making the environmental impact of the station itself as small as possible. Proposed new or continuing research at Summit should be:

- Directly relevant to understanding current climate and documenting change (but not duplicating current efforts)
- Or, focused on adding value and rigor to the interpretation of the Summit ice core records
- Or, reliant on data records and/or data streams that are unique to Summit

The SCO will assist in defining if research fits the Summit criteria.
Investigations that could be successfully undertaken at a location similar to Summit but do not meet criteria above will be encouraged to consider alternative locations. Innovative approaches to supporting projects at locations other than Summit are being developed.

PIs proposing to National Science Foundation solicitations should be prepared to provide a strong science justification within their proposal outlining why the research should be conducted at Summit. Non-NSF funded researchers wishing to work at Summit will likely be asked to provide similar justifications to the NSF before their work is approved.

This document is used as a tool to help identify potential costs, and it not a binding agreement in terms of resources that will be provided. It will be updated throughout the life of a project to reflect changes in scope and impact.

Updated 2/28/2011

1. General Information

1.1 Project Details

Grant/Proposal #:
Point of Contact:
Instrument/Experiment:
Funding Source:
Collaborators:

1.2 Science Coordination Office

Science activities at Summit Station are conducted under the guidance of the Science Coordination Office (SCO). It is requested that you contact the SCO (sco@summitcamp.org) during your planning process in order to assure the appropriate integration of your project into other activities at Summit Station. The SCO also has links to related research and resources that might save you time and expense in the planning process.

Have you contacted the SCO?

1.3 Deployment Details

Is your experiment campaign or year round?

What is the duration/lifetime of the project?

Please outline a proposed deployment schedule in the table below. Attach a supplemental table for larger groups.

Member	Routing	Date In	Date Out

Updated 2/28/2011

polar FIELD SERVICES

1.4 Cargo Requirements

Please outline your estimated cargo requirements using the table below. Attach a supplemental table for large shipments. Include items shipping directly from vendors (e.g. gas cylinders).

Item	Origin	Routing	Weight	Dimensions	Special Handling*

‘*”Do Not Freeze”; “Keep Frozen”; “Hazard Cargo”; “Extremely Fragile”; etc.

2. Experiment Requirements

2.1 Science Tech Support

Please describe the frequency and duration of science tech support required for this project, (hrs/wk).

Is support required on a seasonal (summer and/or winter) basis?

Is support required at night?

If you already have written protocols, please include them as an attachment with this document.

Please describe any specific technical skills that a science tech would need to support your experiment (e.g. low voltage wiring/soldering, computer networking, etc.).

2.2 Location

Please describe the preferred location for your installation or experiment (e.g. on station, clean air lab, off station, clean snow area, etc.):

Have you discussed this location with the SCO?

Updated 2/28/2011

For off station work, including traversing work, please describe the general area, distances, time required off station and goals:

If you do not have a preferred location, please describe the following:
- Inside, outside, or both?
- Tower mounting? YES/NO
- Access to the power grid? YES/NO
- Unobstructed skyview? YES/NO
- Isolated from turbulent disturbances? YES/NO
- Clean room? YES/NO
- Access to clean snow? YES/NO
- Access to the clean air sector? YES/NO
- Do you need a temporary shelter? If so, describe interior dimensions.

2.3 Installation Details

2.3.1 Interior

If available, please include a sketch or image of interior installation.

Please provide the following information describing the **interior** installation requirements for your experiment:

Installation	Mounting: Bench, Rack, Floor, Wall	Installation Dimensions (L, W, H)	Clearance Distances (sides, overhead, other)	Access to Wall, Roof Penetration (dimensions)	Maximum Distance to Wall, Roof Penetration

Please further describe any apertures or penetration requirements associated with your installation or experiment (e.g. wall penetration for power cable, maximum turning radius for optical cabling, roof aperture for optical instrument, etc).

Please indicate how much additional space you will require for work space, temporary assembly, office space, etc. during your experiment:

Updated 2/28/2011

2.3.2 Exterior

Please provide the following information describing the **exterior** installation requirements for your experiment:

Installation	Mounting: Roof, Wall, Tower, Ground, other	Installation Dimensions (L, W, H)	Installation Weight (lbs)	Clearance Distances (sides, overhead, other)	Maximum Distance to Wall, Roof Penetration

Please further describe any **exterior** requirements for your experiment (i.e. heated conduit, buried lines, overhead lines, etc.):

Please describe any access requirements (e.g. sky view) or unacceptable obstructions (e.g. air flow, shading, etc.):

Does your installation or experiment require special electrical, compressed gas or piping fittings? Are the fittings U.S. or European? Please explain:

2.4 Environmental

Please provide the environmental operating requirements for your installation or experiment:

Installation	Optimal Operating temperature [°C]	Minimum Operating temperature [°C]	Minimum Storage temperature [°C]	Minimum Operating humidity [°C]

Is your instrument or experiment sensitive to external environmental factors such as vibration, radio interference, noise, or exhaust from internal combustion sources?

Updated 2/28/2011

2.5 Power

Energy conservation is important objective at Summit Station. Please let us know if you would like any technical assistance in managing your power requirements.

Please provide your power requirements, by installation including peripherals:

Installation	Power, Continuous (kW)	Power, Peak (kW)	Duration of Peak (hr/wk)	Voltage (V), AC/DC	Frequency (Hz)	UPS required?

Does your instrument or experiment require clean power or can it operate on power with some harmonics?

3. Materials

3.1 Chemical/Hazardous

Please provide MSDS and/or appropriate descriptions of any chemicals required for your experiment.

Does your project require shipment of hazardous materials and/or chemicals (including flammables, compressed gases, radioactive sources, or batteries)? If so, please list the type and amount.

Does your experiment require local storage of hazardous materials and/or chemicals (including flammables, compressed gases, radioactive sources, or batteries)? If so, please list the type, amount, and containment requirements.

Does your experiment/instrument produce any waste that must be stored and shipped out of camp?

Does your experiment require liquid nitrogen or any special calibration gases?

Updated 2/28/2011

Is clean or ultra pure water required for your instrument or experiment? If so, please specify the amount and frequency?

4. Allocations

4.1 Laboratory/Storage

Does your experiment need to be located in a clean room? If so, please describe requirements (e.g. clean level, laminar flow bench, filters, etc).

Do you need access to a wet lab?

Do you need access to bench space?

Does your experiment require any special ventilation or pressurization? If so, please describe requirements.

Do you need local "Do Not Freeze" storage? If so, please provide temperature requirements.

Do you need cold storage for samples? If so, please provide temperature requirements.

Do you need any ice core boxes, eutectics, core tubes or lay flat tubing?

Do you need portable generators?

Do you need any custom excavations (trenches, pits, etc.)

4.2 Communications

Please describe any networking or remote communication requirements (e.g. static IP, bandwidth, VHF, etc.).

Updated 2/28/2011

Does your installation have its own computer, or does it require a serial/modem/etc connection to a camp laptop for configuration, calibration, or downloads?

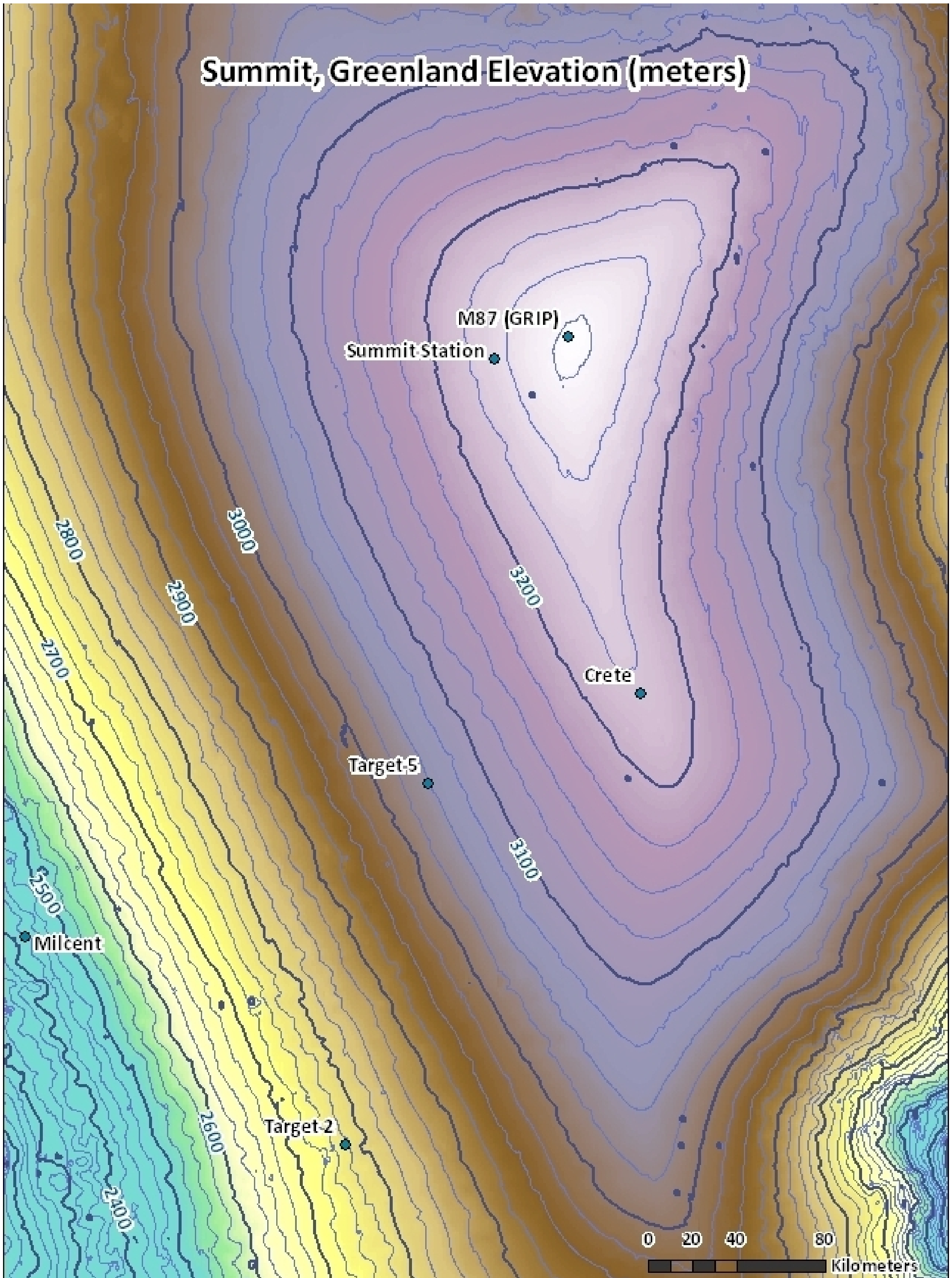
Do you need remote communication equipment for off-station travel (e.g. handheld GPS, Iridium phone, Personal Locator Beacon, etc)?

4.3 Vehicles

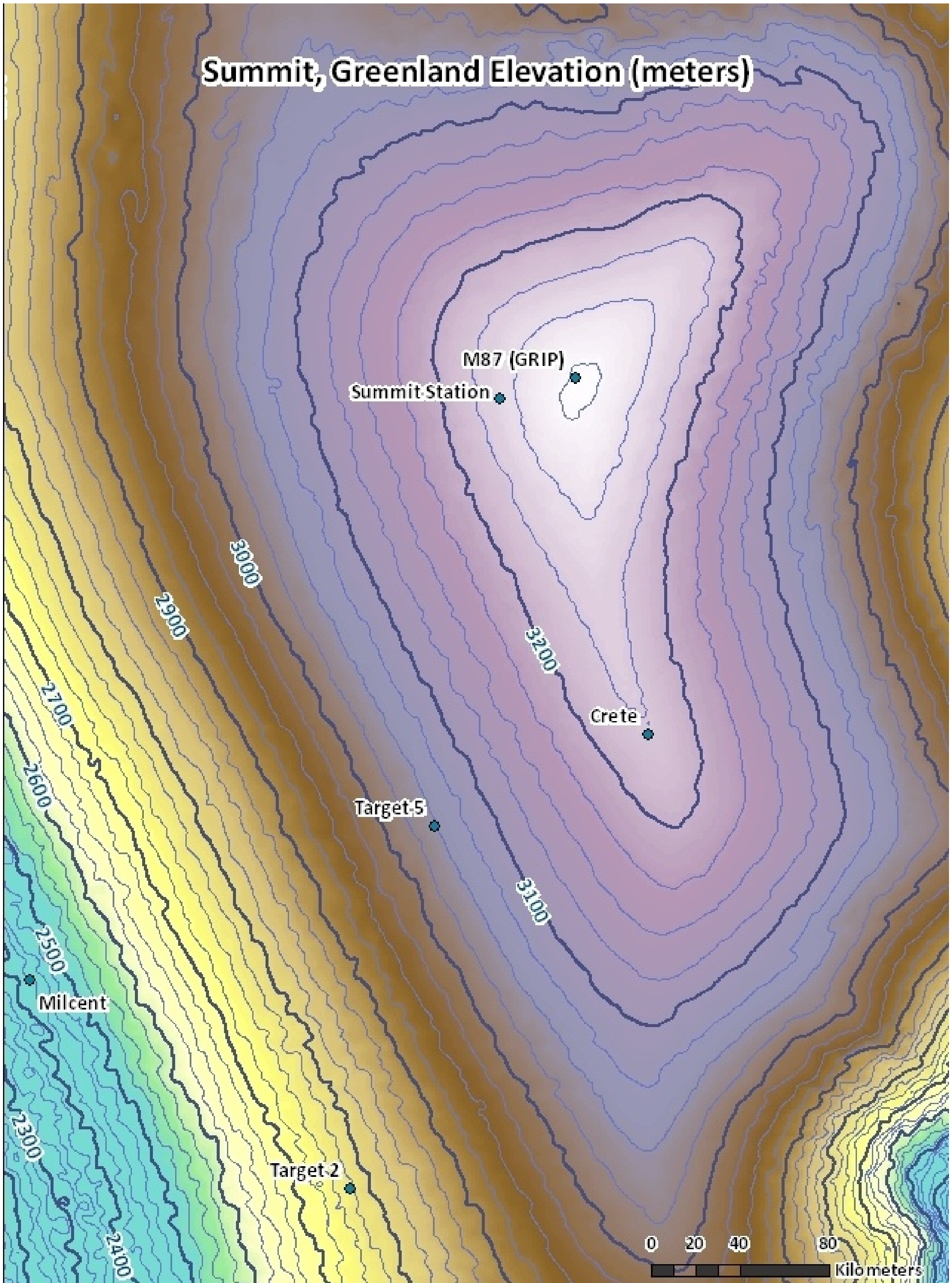
Do you need access to any vehicles (e.g. snowmobiles or electric vehicles)? If so, please describe the vehicle, payload, and usage schedule.

Do you need access to any cargo hauling sleds? If so, please describe the load that needs to be hauled, distances required and usage schedule.

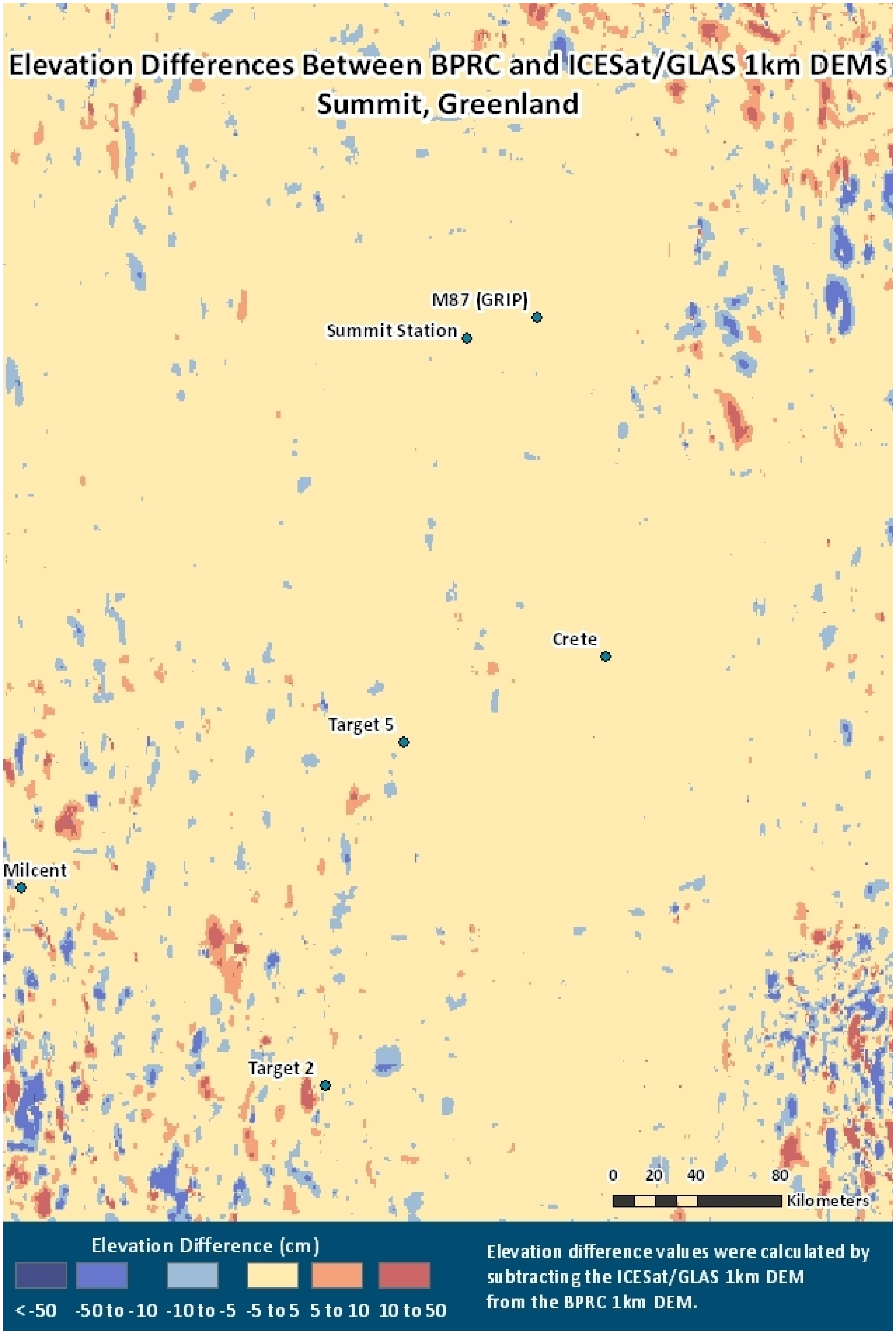
Appendix B: Comparing Digital Elevation Models



Data Source: DiMarzio, J., A. Brenner, R. Schutz, C. A. Shuman, and H. J. Zwally. 2007. GLAS/ICESat 1 km laser altimetry digital elevation model of Greenland. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media. <http://nsidc.org/data/nsidc-0305.html>
Accuracy Statement from NSIDC, ICESat/GLAS FAQs: The laser altimeter on the GLAS instrument measures height from the spacecraft to the ice sheet with an intrinsic precision of better than 10 cm with a 60 m surface spot size. Vertical accuracy of the 1 km DEM is estimated to be within +/- 1 meter.



Data Source: Byrd Polar Research Center, Greenland 1 km DEM
<http://bprc.osu.edu/rsl/greenland_data/dem/1km%20greenland%20DEM.html>
Accuracy Statement from Metadata of 1 km DEM: "The grid values in the ice sheet represent the mean elevation of a region approximately 2.5 km in diameter centered on the grid point, with an accuracy of +/- 3 meters."


Elevation Differences Between BPRC and ICESat/GLAS 1km DEMs
Summit, Greenland
M87 (GRIP)
Summit Station
Crete
Target 5
Milcent
Target 2
0 20 40 80
Kilometers
Elevation Difference (cm)
< -50
-50 to -10
-10 to -5
-5 to 5
5 to 10
10 to 50
Elevation difference values were calculated by subtracting the ICESat/GLAS 1km DEM from the BPRC 1km DEM.

<table>
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Site Assessment and Feasibility of a New Operations Base on the Greenland Ice Sheet</td><td colspan="3">5a. CONTRACT NUMBER
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<tr><td colspan="6">14. ABSTRACT
The National Science Foundation is moving forward with plans to convert Summit Station, Greenland, into a clean air/clean snow research facility. Plans include reducing the size of the station and minimizing both research and operations activities. To continue support of scientific research that does not require a clean air/snow environment, an alternate site needs to be identified and assessed for feasibility of operations, scientific viability (at or easily reachable from the new site), and traversability between there and the existing Summit Station. Additionally, the 109th Airlift Wing of the Air National Guard is seeking a new training site in Greenland; increased melt along the margin of the ice sheet is encroaching upon their current site, Raven. Here we present the results of our site selection analysis to identify target locations for a new operations base serving science research and support and 109th training facilities. Recently, NSF has shifted focus to a new site, "Isi," located about 3 miles north of Summit, closer to the actual peak elevation of the ice sheet, to house a proposed telescope. This site assessment and the geographic information system (GIS) we built will be used primarily to identify an alternate training location for the 109th. Once specific target sites are identified, we recommend satellite imagery analysis and further consideration of ice stability factors (i.e., velocity and crevassing) that may affect construction viability, as well as weather station installation and monitoring to assess local climatic factors. A site visit for in-depth physical inspection should follow.</td></tr>
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