Workshop Summary

for the
Weather, Climate, Snow, Ice and Permafrost Scoping Workshop for the Arctic Parklands of the National Park Service

held in
Bodega Bay, California
7-9 December 2006

Executive Summary

This document describes the results of a workshop sponsored by the National Park Service (NPS) and University of Alaska Fairbanks to which 20 arctic scientists were invited to identify a plan to monitor three 'vital signs' that relate primarily to climate and its impacts on the physical landscape of Arctic Network (ARCN) of NPS. The primary charge of workshop participants was to write protocol summaries and scope standard operating procedures (SOPs) for these three vital signs (which had been previously selected in other workshops): "Climate and Weather", "Snow and Ice", and "Permafrost and Active Layer". The consensus view of workshop participants was that the workshop itself was quite successful and that each of the three vital signs now has a viable long-term monitoring strategy as described in the protocol summaries included below; these protocol summaries are the primary output of this workshop.

This document contains:

- A description of the workshop, including participants, agenda, and summary of some of the philosophical considerations discussed (pages 2-8);
- The protocol summaries that contain the consensus views of the workshop participants on the monitoring plans themselves (page 9-17);
- A pre-workshop primer document annotated with participant comments, questions, and concerns (pages 18-64); and
- A transcription of Matt Nolan's notes taken during the workshop (pages 65-71).

This document was circulated to and approved by all workshop participants.

Workshop Summary

The workshop was held in at the Bodega Bay Lodge over a three day period. The location provided a retreat from the distractions of civilization and allowed the participants to focus on the workshop in a pleasant and scenic environment. Participants all slept, ate, and convened at the Lodge during the workshop, which enhanced the opportunities for continuing discussions and other interactions. All commented that this venue played a key role in its success.

Several weeks before the workshop, each participant was sent a document which provided background on the protocol development process and put a number of issues on the table for discussion (this pre-workshop document can be found on pages 18-64 of this document). Participants were invited to comment on these issues digitally, and their comments were compiled and incorporated into a common version of the document which was then redistributed electronically before the meeting and provided in paper form in a workshop binder that also included maps and other background material. This revised document formed the basis for discussions at the workshop. The mix of participant expertise proved successful, with most discussions having significant input from most participants, as hoped.

The workshop goals presented at the start of the meeting were:

1) Review, discuss, and revise the current draft 'vital signs' related to weather, climate, snow, ice and permafrost in the Arctic Network (ARCN) of the National Park Service (NPS);
2) Develop preliminary protocols and protocol summaries for sustainable, long-term monitoring of these vital signs;
3) Identify the particular Standard Operating Procedures (SOPs) required to create these protocols; and
4) Provide sufficient working knowledge of the issues that need to be considered when creating these SOPs for ARCN

The discussions were essentially an attempt to optimize many competing factors. For example, the desire to construct the 'dream network' of weather stations was balanced against logistical, economic, and wilderness value concerns. As another example, the desire to measure snow fall and snow pack was balanced against the limitations of the current techniques and the huge spatial scale and heterogeneity involved. A few general guiding principles emerged as well. For example, make the best use of prior experience and research to guide new protocols; solicit broad end-user participation to ensure long-term viability; and for long-term study its better to make measurements at fewer sites more reliably than to have a lot of sites with poorer reliability. These principles are reflected in the "Ten Climate Monitoring Principles" (developed by Thomas Karl et al of NOAA in 1995), and included below; while we did not have a copy of these at hand during the workshop nearly all of these points were discussed, and both NOAA and other NPS networks have adopted them in their protocols. For practical purposes, there is essentially no climate monitoring currently being conducted within the huge area of the ARCN, and thus there was consensus that there was a great need and urgency for such monitoring and that the sooner monitoring could start the better. There was also unanimous approval and support for the NPS in taking action to develop and implement these plans, noting that the Arctic National Parklands and North Slope are now undergoing possibly the greatest changes in air temperature of any location in the world yet discovered (based on modeling and nearby measurements) and that NPS is the only federal agency currently funded and acting in more than an *ad hoc* way in this region. Due to its importance globally, the weather station network here should be held to the highest standards possible.

The first day focused on "Climate and Weather". Discussions ranged over the full breadth of considerations necessary, from sensor inter-comparisons to long-term data archival. The primary philosophical discussions resulted in the following consensus views: 1) climate monitoring is more important to ARCN's goals than weather monitoring in terms of funding priority, but that as much as possible real-time weather data should be telemetered and distributed publicly to increase the user-base for these stations; 2) a flexible and adaptable station network design is required to optimize economics and need; 3) the NPS should avoid station duplication with other agencies (which tend to favor populated areas) by locating its stations in as many remote locations as it can afford; 4) it is essential to consider the needs of modelers when designing the network, as modeling is the only means to provide sufficient spatial coverage; 5) new digital elevation models (DEMs) are essential to spatial extrapolation and nearly all ARCN vital sign protocols will benefit from having them so they should be acquired as soon as possible; 6) understanding prior climate is essential to understanding current and future trajectories; and 7) insufficient background climate data currently exists to guide other vital sign monitoring protocols. As example of the latter, a synoptic climatology over the region has never been completed or written, and this is a necessary and straightforward component of an overall plan. A map of suggested locations for primary long-term stations was created and consensus was that this selection was of sufficient density and distribution, as well as being a reasonable optimization between a 'dream network' and an economically viable one. The workshop was adjourned this day with a homework assignment – to annotate a map of each park unit with suggested temporary station locations designed to better understand spatial gradients, such as coastal-inland or highland-lowland; these maps are currently being compiled and used in the planning and permitting process.

The second day focused on "Snow and Ice" and "Permafrost and Active Layer", which are so closely linked with "Climate and Weather" that much of the discussions from the previous day applied to them as well. There was general consensus that snowfall is the most difficult climate variable to measure accurately in the Arctic, especially at remote and unmanned stations, but that nevertheless something should be done. The consensus was that a combination of weather station measurements and snow machine transects would capture a reasonable mix of temporal and spatial variations. Further, annual snow machine traverses could provide economical access to remote weather stations for maintenance and upkeep. River ice breakup and discharge were considered to be more valuable to monitor than lake ice dynamics (though both are important), as rivers integrate not only the seasonal impacts but large spatial scales as well, and the Noatak River was proposed as the most valuable target due to its size , extent (encompassing both NOAT and GAAR) and because the preserve is mandated for scientific inquiry. Aufeis measurements were added to the protocol as well, as they can yield valuable information on changes in groundwater hydrology over time in an economical way. Given the recent changes in permafrost temperatures just north of ARCN, consensus view was that new boreholes are vital to NPS interests. Participants also agreed that major ecosystem disturbances such as widespread thermokarst are likely (as have been observed in some locations) and need to be monitored. The afternoon ended with a tour of a local NOAA weather station and visits with local farmers and scientists involved in climate and climate change measurement.

The final day was spent summarizing our results. Much of these can be found in this summary and in the protocol summaries, but many details not included here will be found in the SOP's which have not yet been drafted. The homework project of map annotations were turned in by most of the participants, and this information will also be included in the SOPs. The workshop ended with a lot of smiling faces expressing satisfaction and approval of the workshop and the results it produced. This document was sent in draft form to all of the participants for comments and corrections before being finalized.

Ten Climate Monitoring Principles

Suggested as guiding principles by the workshop and adapted from Karl, T.R., V. Derr, D. Hofmann, D.R. Easterling, C. Folland, S. Levitus, N. Nicholls, D. Parker, and G.W. Withee, 1995: Critical Issues for Long-term Climate Monitoring. Climatic Change, 31, 185-221.

1. Management of Network Change: Assess how and the extent to which a proposed change could influence the existing and future climatology obtainable from the system, particularly with respect to climate variability and change. Changes in observing times will adversely affect time series. Without adequate transfer functions, spatial changes and spatially dependent changes will adversely affect the mapping of climate elements.

2. Parallel Testing: Operate the old system simultaneously with the replacement system over a sufficiently long time period to observe the behavior of the two systems over the full range of variation of the climate variable observed. This testing should allow the derivation of a transfer function to convert between climatic data taken before and after the change. When the observing system is of sufficient scope and importance, the results of parallel testing should be documented in peer-reviewed literature.

3. Metadata: Fully document each observing system and its operating procedures. This is particularly important immediately prior to and following any contemplated change. Relevant information includes: instruments, instrument sampling time, calibration, validation, station location, exposure, local environmental conditions, and other platform specifics that could influence the data history. The recording should be a mandatory part of the observing routine and should be archived with the original data. Algorithms used to process observations need proper documentation. Documentation of changes and improvements in the algorithms should be carried along with the data throughout the archiving process.

4. Data Quality and Continuity: Assess data quality and homogeneity as a part of routine operating procedures. This assessment should focus on the requirements for measuring climate variability and change, including routine evaluation of the long-term, high-resolution data capable of revealing and documenting important extreme weather events.

5. Integrated Environmental Assessment: Anticipate the use of the data in the development of environmental assessments, particularly those pertaining to climate variability and change, as part of a climate observing system's strategic plan. National climate assessments and international assessments (e.g., international ozone or IPCC) are critical to evaluating and maintaining overall consistency of climate data sets. A system's participation in an integrated environmental monitoring program can also be quite beneficial for maintaining climate relevancy. Time series of data achieve value only with regular scientific analysis.

6. Historical Significance: Maintain operation of observing systems that have provided homogeneous data sets over a period of many decades to a century or more. A list of protected sites within each major observing system should be developed, based on their prioritized contribution to documenting the long-term record.

7. Complementary Data: Give the highest priority in the design and implementation of new sites or instruments within an observing system to data-poor regions, poorly observed variables, regions sensitive to change, and key measurements with inadequate temporal resolution. Data sets archived in non-electronic format should be converted for efficient electronic access.

8. Climate Requirements: Give network designers, operators, and instrument engineers the climate monitoring requirements at the outset of network design. Instruments must have adequate accuracies with biases sufficiently small to resolve climate variations and changes of primary interest. Modeling and theoretical studies must identify spatial and temporal resolution requirements.

9. Continuity of Purpose: Maintain a stable, long-term commitment to these observations, and develop a clear transition plan from serving research needs to serving operational purposes.

10. Data and Metadata Access: Develop data management systems that facilitate access, use, and interpretation of the data and data products by users. Freedom of access, low cost mechanisms that facilitate use (directories, catalogs, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.), and quality control should be an integral part of data management. International cooperation is critical for successful data management.

Workshop Participants

Standing, left to right:
- **Matt Nolan**, UAF. Workshop leader. Expertise: arctic weather stations, glaciology.
- **Tom Heinlein,** NPS BELA Superintendent. Expertise: Local knowledge, permitting.
- Bruce Peterson, MBL. Expertise: arctic hydrology, aquatic beogeochemistry.
- Mary Booth, NPS. Expertise: Terrestrial Ecology.
- Chris Daly. Expertise: GIS, PRISM model developer.
- Bruce Baker, NOAA. Expertise: running NOAA's Climate Reference Network.
- **Darrell Kaufman**, Northern Arizona University. Expertise: arctic paleoclimate
- **John Cassano**, U Colorado Boulder. Expertise: regional climate modeling in Alaska.
- **Kenji Yoshikawa**, UAF. Expertise: arctic groundwater dynamics, permafrost, pingos.

Kneeling, left to right:
- **Diane Sanzone**, NPS ARCN coordinator, workshop leader. Expertise: aquatic ecology.
- Andrew Balser, UAF. Expertise: GIS, remote sensing.
- **Frank Urban**, USGS. Expertise: permafrost boreholes, arctic AWS.
- Cathy Cahill, UAF. Expertise: atmospheric chemistry.
- **Bud Rice**, NPS Regional Office AKRO. Expertise: compliance issues
- Jason Geck, UAF. Glacier volume change in the Brooks Range.
- Matthew Sturm, CRREL. Expertise: arctic snow dynamics and snow/vegetation dynamics, also representing UAF's NOAA RISA program.
- **Martha Shulski,** UAF. Expertise: Alaska climate patterns and trends.

Not in picture:
- **Pam Sousanes,** NPS CAKN. Expertise: Climate and Weather for CAKN.
- Kelly Redmond, WRCC, Expertise: network design, data archival and distribution
- Tom Hamilton. Expertise: glacial geology, arctic landscape evolution.

AGENDA

Thursday, 07 Dec 06
8 – 9:15 AM Buffet Breakfast (concurrent with meeting)
8:30 – 9:15 AM Introductions

- Who are we?
- Why are we here?
- What do we hope to accomplish?

9:15 – 9:30 AM Break
9:30 – 11:45 AM Climate and Weather Scoping

- Protocol summary straw-man – what's on the table?
- The bottom line – what are our constraints (budget, compliance, and logistics)?
- Weather vs. Climate – what questions are we trying to answer and why?
- Point measurements vs. extrapolation – what's the best use of our time and money?
- Field vs. remote sensing – what's the best use of our time and money?
- Science vs. Monitoring – what's the difference and how does this affect our plans?

11:45 – Noon Break
Noon – 1 PM Buffet Lunch & self-organized discussions
1 – 3:15 PM Climate and Weather Scoping (continued)

- Synoptic climatology – what's the weather like in this region?
- Future predictions – what are we expecting to change?
- Climate vs. climate change – how do these affect our plans?
- Station density – how many stations does it take to do what we want to do?
- Instruments – which to use?

3:15 – 3:45 PM Break
4 – 5:30 PM Climate and Weather Scoping (continued)

- Deployment – locations, timeline, and costs
- Long-term issues – data management, QA/QC, and data archival
- Basic data products – what analyses do we want to provide at a minimum?
- More long-term issues – funding and partnerships

5:30 – 6:30 PM Break
6:30 – 7:30 PM Buffet Dinner & Self-organized discussions
7:30 PM Onwards Self-organized discussions on hiking trails, swimming pool and Egret Suite

Friday, 08 Dec 06
8 – 9:15 AM Buffet Breakfast (concurrent with meeting)
8:15 – 9:15 AM Permafrost Scoping
9:15 – 9:30 AM Break
9:30 – 10AM Permafrost Scoping (continued)
10 – Noon Snow and Ice Scoping
Noon – 1 PM Buffet Lunch
1 -5 PM Break Out Sessions

- 1 – 2 PM Bodega Bay NOAA Weather Station visit – discussions on instruments, maintenance, coastal climates, local weather station networks

- 2 – 3 PM Travel to local farm (Cline vineyards)– self-organized discussions
- 3 – 5 PM Visit with local grape farmers – discussions on spatial climate variations, climate-vegetation interactions, climate measurements, and climate change

5:30 – 7:30 PM Group dinner in Petaluma (Semolina's – 600 E Washington, 707 766 6976)

8PM Return to Lodge

Saturday, 08 Dec 06

8 – 9:15 AM Buffet Breakfast (concurrent with meeting)

8:15 – 9:15 AM Summary of break-out sessions

9:15 – 9:30 AM Break

9:30 – 11:45 AM Protocol Summaries – Create final workshop drafts

- Climate and Weather
- Permafrost
- Snow and Ice

11:45 – Noon Break

Noon – 1:15 PM Plated Lunch with discussions on Next Steps and Wrap Up

1:15 PM Workshop Adjourns

Protocol Summary: Climate and Weather

"Climate and Weather"Description: Climate is a general term that usually refers to the long-term average, or typical, weather of a region. Weather describes the state of the atmosphere at a particular place and time. Thus to measure climate, it is necessary to measure weather as well, but the infrastructure and SOPs necessary for measuring them differ. For example, maintaining real-time access to weather measurements with 100% uptime requires the ability to service weather stations at any time of year in any weather as often as required, whereas most uses of climate data can tolerate a lag in reporting or short gaps in acquisition. Of primary concern to the ARCN is climate and climate change. The station network described here will thus be of sufficient quality to ensure that future changes and variations in primary measurements at specific sites can be monitored without the need for uncertain adjustments and corrections to the data and that the network will provide adequate spatial coverage to monitor the anticipated trends in future Arctic climate. When logistically and economically convenient these SOPs allow for real-time access to weather measurements for public use.

Significance: Climate is widely recognized as a fundamental driver of ecosystem change in the Arctic and thus nearly all ARCN natural resources are affected by it. Most climate models indicate that the rate of climate change in the Arctic will match or exceed that of anywhere on earth over the next 100 years, yet there are no long-term climate monitoring sites within ARCN (an area the size of Massachusetts, New Hampshire, and Vermont combined). With mean annual temperatures here typically below freezing and the ground covered by snow more than 6 months per year, any increases in temperature and or changes in precipitation could have great impact on ecosystem structure and dynamics as well as major impacts on the land surface through changes in glaciers and permafrost. Without climate data, it is impossible to understand the causes of a variety of ecosystem changes now underway because changes in climate are largely driving those changes.

Monitoring questions and objectives:

1. Overarching Question:

- What is the spatial and temporal variability in weather and long-term climate trend (c.1850AD – 2050 AD) in ARCN units?

2. Specific Questions on Prior Climate to be Answered Through Climate Modeling:

- What is the synoptic climatology of this region and how has it changed over the past 50 years?
- Where is the 0ºC mean annual and 10ºC summer air temperature isotherm currently, and has there been a trend over the past 50 years?
- What are the trends in changes in air temperatures, precipitation, cloud cover, relative humidity, wind speed and direction, storm frequency and soil moisture over the past 50 years? Do they have seasonal trends that differ from annual trends?

3. Specific Questions on Prior Climate to be Answered Through Paleoclimate Studies:

- How do short term temperature and precipitation trends of the past 50 years fit into longer-term trends of the past 1000 years, such as through lake-sediment and glacial-ice coring.

4. Specific Questions on Modern and Future Climate to be Answered using a New Weather Station Network:

- Is the synoptic climatology of this region changing?
- Are the 0ºC and 10ºC (or any other) isotherms changing?

- Is there a trend in air temperature greater than 0.1ºC per decade or a trend in precipitation greater than 2% per decade?
- What are the dominant climate gradients in the region? E.g., how do the weather parameters of interest change from coastal to inland regions or from lowlands to highlands?
- How is discharge varying on the Noatak River over time?

5. Sample Questions on Current Weather to be Answered by Users:

- Can our weather stations aid in improved operational 3 to 5 day weather forecasts within ARCN or in aircraft or backcountry safety?
- Can our weather stations aid in real-time tracking and prediction of animal migrations and dynamics within ARCN?
- Can our weather stations aid in real-time monitoring of break-up, freeze-up, and other weather events of significance to ARCN ecosystem dynamics and management?

Monitoring plan overview: The questions above were selected to provide a climate-monitoring infrastructure that not only monitors climate but also facilitates monitoring of other ARCN vital signs through improved climate information. The overarching question addresses the importance of both spatial and temporal variability in climate and weather, as well as the need to understand recent climate to better understand current climate trajectories; the most natural break for ‘recent’ prior change is the end of the Little Ice Age conditions in the late 19th century, thus we need to under conditions prior to this to understand the change. **The second group of questions** focuses on the last 50 years as the primary baseline against which to compare future change, as this period is when we have global climate reanalysis data sets available and beyond this period any sort of spatial extrapolations are of questionable value for this purpose due to the sparseness of measurement. The answers to these questions are intended to provide sufficient background information on climate within ARCN for use in all vital sign protocols. For example, to properly design a strategy to monitor aquatic ecosystem dynamics, it would be useful to have a basic understanding of the dominant weather patterns in the region, how these may have changed over the past 50 years, and how they may change in the future. These answers will also help guide in development of a new network of weather stations within ARCN. **The third group of questions** focuses on understanding our current climate within longer-term trends (past 1000 years) using various paleoclimate proxies, such as lake sediments, tree-rings, and glacial geology (moraines). Because a variety of tree-ring and geological data already exists, new work would likely focus on coring lake sediments and glacier ice; the types of questions that can be answered with such studies are necessarily limited in temporal and spatial extent. Such lake and ice coring projects can extend into the past on-going modern process studies (e.g., river and lake sedimentation rates) as part of other vital signs. **The fourth group of questions** focuses on the use of a new network of weather stations, providing a means to bridge the transition from prior climate to future climate. The constraints on detecting trends in air temperature and precipitation come from NOAA’s Climate Reference Network and are based on trends reported over the past century in the 2001 IPCC report. A priority in network design is integration with modeling studies, as the network will never be dense enough to provide sufficient spatial coverage without extrapolation. Thus questions regarding isotherm mapping would be answered through modeling driven by real station data. To accomplish this, an important part of the long-term monitoring plan is short-term deployment of additional weather stations to understand local gradients, such as inversions and coastal-inland transitions, so that these dynamics can be incorporated into the models accurately. A final integrating parameter for all of these measurement and modeling efforts is measuring discharge on the Noatak River, which also facilitates regional-scale water balance questions and evapotranspiration estimates. **The final group of questions** on weather would utilize weather stations with near real-time telemetry. The primary motivation for telemetry is to determine functionality of the station, to provide quicker access to the data, and to provide an off-site means to back-up the data in near real-time. Once the data is telemetered, however, it is available for analysis in a variety of ways, as suggested by the sample research questions; answering questions of this type are currently outside of the scope of the ARCN vital sign monitoring and are provided only as examples of community usage.

Weather station network design and philosophy: To achieve our monitoring goals, the station network will consist of three general types of weather stations, with the number of sensors on each type of station varying depending on location and purpose. **Primary stations** are intended to support long-term climate monitoring and are defined by their rigor, performance, and priority as the core stations to maintain in case of future budgetary limitations.
Ten primary stations are planned to be distributed throughout ARCN, as studies have shown this to likely be sufficient to meet the accuracy required for the specified trend detection. Sensor redundancy is a primary design feature of these stations to ensure sensor reliability, data reliability, and temporal continuity. For example, each primary station will measure at least air temperature, using replicated sensors on at least one height on a suitable re-calibration schedule. After temperature, solid and liquid precipitation and wind are the next most important variables for typical deployment. Similar to air temperature, measurements would be made redundantly and, in the case of snow, by multiple sensor types (such as sonic ranger, mass collection, tipping bucket, and camera). The primary stations will be towers anchored in bedrock or set in concrete (with suitable frost jacking protection) and will serve as long-term, permitted sites to facilitate a variety of future expansion, including measurement of solar radiation, relative humidity, soil temperature and soil moisture, or improved sensor design (especially for snow). Partnerships with other agencies and organizations will be sought to ensure long-term continuity and cost-sharing for these stations; for example, another agency may wish to measure additional variables (e.g., four-component radiation) and they could be allowed to hang their own data logger and sensor on a primary station’s tower, in exchange for a service which would enhance the ARCN network efficiency in some way. Telemetry is planned for these stations. **Tertiary stations** are defined by their purpose and are designed to be temporary (1 to 3 years). Their purpose is to better understand the spatial representativeness of primary stations or spatial trends in a particular gradient, such as coastal-inland or elevational-inversions. Fifty stations are planned to be redeployed as needed and where possible to co-locate them to directly facilitate the monitoring of other vital signs. Air temperature, wind, rain, and incoming solar radiation are typical measurement possibilities for tertiary stations. Telemetry is possible but not mandatory for these.
Secondary stations are defined by their location and expected to arise as a result of monitoring conducted using tertiary stations. Thus they would become long-term sites of a lower funding priority than primary sites. For example, a tertiary study may find the dynamics of a particular site are not being captured by primary sites, yet that it is valuable for long-term climate monitoring (e.g., at an elevation that captures inversion dynamics well). The anchoring and instrumentation of this new secondary site would then be improved (as well as possibly the permitting) to capture long-term temporal trends.

Current Monitoring: There is no climate monitoring currently on NPS ground that is suitable for accurate and reliable long-term monitoring, though several weather stations do exist on or within 50 km of park lands.

Implementation schedule: Site selections and initial deployments will begin in 2007, with 2 to 3 primary sites installed each year until 2010 or as funding allows. Analysis of climate of the past 50 years will begin in 2007 and continued until finished. Tertiary station deployments are expected on a limited basis in 2007, with the first large-scale deployments in 2008.

Data archival: Weather station data will be archived at national repositories on a yearly basis (if not telemetered) or in near-real time (if telemetered) to national databases used by NOAA and other NPS networks (such as the Western Regional Climate Center).

Linked Vital Signs: Nearly all vital signs are linked to “Climate and Weather” in ARCN, due to the magnitude and rates of recent climate change in the Arctic. However, the implementation plans for this vital sign will be closely linked with “Snow and Ice” and “Permafrost and Thermokarst”.

Standard Operating Procedures to be developed (drafts by December 2007, final in 2008):

- Site selection
- Instrumentation selection and calibrations (for primary, secondary and tertiary stations)
- Data logger programming
- Deployment
- Field maintenance
- Data handling, metadata, and reporting
- Data quality assurance and control
- Data reduction
- Standard annual analyses and distribution
- Contingency planning for long-term funding
- Use of tertiary stations in other vital signs monitoring projects

Protocol Summary: Snow and Ice

"Snow and Ice" Description: This vital sign is primarily concerned with seasonal snow, seasonal river and lake ice, seasonal to inter-annual aufeis, and long-term glacial ice; sea ice is treated in a separate protocol.

Significance: Seasonal snow, seasonal river ice, seasonal lake ice, and long-term glacial ice are dominant ecosystem system influences in ARCN. Snow affects landscape vegetation patterns, drainage patterns, nutrient cycling, water quality, productivity of plants and animals, the degree and types of disturbance events, the timing of migratory and breeding events of organisms, predator-prey relationships, and the distribution of plants and animals. River and lake ice formation, thickness, and breakup are also key indicators of regional climate, especially in the data-sparse regions that characterize much of the network, and they exert dominant controls on aquatic productivity and aquatic ecosystem dynamics. The most massive changes to ARCN landscapes are caused by changes in glacier ice, and these changes influence both terrestrial ecosystems through their area change and microclimates as well as stream ecosystems through their timing and flux of freshwater and sediments. Without some indication of trends in snow cover, lake ice cover, and glacial ice cover, we cannot understand the causes of change in a wide variety of biotic ecosystem components. Snow and lake ice are seasonal features which give us integrative information on the duration and severity of winter. Glaciers are persistent landscape features that give us integrative information of the decadal-scale climate trends. Comprehensively, measurements of all these features give us information on intra- and inter-annual climate trends that cannot be achieved through weather stations alone.

Monitoring questions and objectives:

1. Snow Monitoring Questions:

- Are spatial patterns of snow thickness, timing, and extent changing over time?
- What weather patterns and other climate factors control these variables?

2. Glacier Monitoring Questions:

- What can glaciers tell us about the climate of the past?
- How are glacier extents and volume continuing to change, and what does this tell us about current climate?
- If current climate trends continue, when will the glaciers disappear?

3. Lake and River Ice Monitoring Questions:

- Is the timing, duration and thickness of ice on lakes and rivers changing?
- Where does aufeis typically occur in ARCN, how has this varied in the past, and what does this imply about groundwater baseflow?

4. Example vital sign linkage questions:

- What feedbacks exist between snow and vegetation and how are these influencing ecosystem form and dynamics?
- How does glacier loss and its associated reduction in sediment flux affect aquatic ecosystems?
- How is earlier lake and river ice breakup impacting aquatic ecosystems and biogeochemistry?

Monitoring plan overview and philosophy:

The monitoring plan for "Snow and Ice" is designed to not only address these features as park resources themselves, but their impact on the overall ARCN ecosystem and other vital signs. Like the other vital signs, the plan is an optimization process, considering economics, logistics,

wilderness values, and reliability of measurements. Because of the spatial scales involved, the necessity for human involvement in measurements, and the relative simplicity of some measurement types, this plan incorporates more use of local residents than many other vital signs.
Snow. Measurement of arctic snow is expensive and difficult to measure even when human observers are available, thus this plan focuses on optimizing automated and human measurements and prioritizes the integrative metrics that can be measured most accurately. For example, while snowfall is a valuable parameter, it is difficult to measure accurately, whereas end-of-winter snow thickness and water equivalent are comparatively easy to measure and are perhaps even more valuable for ARCN needs. To improve quality assurance and control as well as failure redundancy, automated weather stations will utilize more than one type of sensor typically, such as a sonic ranger to measure snow thickness, a Geonor or other mass collection device shielded by an Alter or double-Alter shield (or possibly Wyoming-style shield), and an automated camera taking pictures of a snow stake. To understand overall snow-pack and long-term temporal trends, a snow-machine traverse is planned planned each year in late spring, with a route such as from Nome to Barrow, where snow thickness, snow water equivalent, and snow chemistry will be made at index sites. Prior research has found that information from such traverses can be extrapolated over broad regions, as snowpacks tend to vary primarily with latitude. Snow-vegetation interactions will also be monitored at index sites. This traverse will also serve as a primary weather station deployment/maintenance mission, as overland travel is much easier in winter than summer and is significantly cheaper than alternatives involving aircraft. Field surveys of aerial snow stakes may occur via airplane one or more times per winter to increase temporal coverage and spatially extrapolate weather station measurements.
River and Lake Ice. The logistics associated with the spatial scales involved make a comprehensive study of lake ice impossible. Lake ice monitoring will thus occur as a nested study and focus on ice thickness as a simple integrative metric which indicates the severity of winter, with the most intensive measurements being made in coordination with a lake-sediment coring project. Here water temperature and weather information will be collected along with ice thickness. Other lake ice thickness measurements will be made as part of the snow machine traverse, and a more distributed set of measurements made at lakes near villages in coordination with local observers. Field data will be used to calibrate models to predict or hindcast lake ice freeze-up and break-up dates. River ice breakups dates provide an integrative measure of both winter and spring severity, and this would be monitored by villagers, who already have an existing interest in this for transportation needs. Both river and lake ice monitoring will be supplemented by automated cameras and remote sensing (such as Modis and SAR).
Glacial Ice. Glacier ice dynamics is closely linked with long-term climate dynamics and thus can serve as both a repository for climate information and an indicator of climate change. This plan focuses on comprehensively monitoring all glaciers through the easiest metrics of area and volume change, with intensive studies on just one or several glaciers to understand the mechanisms of these changes. A baseline monitoring project will photographically document the size and shape of all glaciers in ARCN through a combination of aerial and ground-based photography. New digital elevation models will be acquired to supplement other recently-acquired ones to determine ice volume change through comparisons with USGS maps and will serve as a baseline for future volume change monitoring, to occur every 10 years or so. A representative glacier (or set) will be selected for more intensive glacier-climate interaction study, such as mass balance monitoring, and one or more of these will be cored for paleoclimate investigation. Comparisons will be made between these ARCN glaciers and McCall Glacier in the eastern Brooks Range, which is the only glacier in arctic Alaska with a long-term history of research.

Current Monitoring: There is no ongoing snow or ice monitoring within ARCN. Nearby Kanuti currently has an aerial snow marker course and there are SNOTEL sites at four locations on the eastern boundary of ARCN (Imnaviat Creek, Atigun Pass, Coldfoot, and Gobblers Knob) and one site between Noatak National Preserve and Cape Krusenstern National Monument (Ikalukrok Creek). There are no ongoing glacier monitoring projects in ARCN, though several glaciers have been studied in the past.

Linked Vital Signs: Climate and Weather, Sea Ice, Terrestrial Landscape Patterns and Dynamics, Terrestrial Vegetation and Soils, Surface Water Dynamics and Distribution, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems

Standard Operating Procedures to be developed (draft in 2007, final by 2008):

- Snow machine traverse
- Lake ice timing, duration, and thickness
- River ice timing, duration, and thickness
- Aufeis inventorying and monitoring
- Glacial ice photography, volume change, and mass balance
- Data quality assurance, quality control, and archival
- Data reduction and annual reporting

Protocol Description: Permafrost and Active Layer

"Permafrost and Active Layer" Description: Most of ARCN is underlain by continuous or discontinuous permafrost because mean annual air temperatures are typically well below freezing. Above the permafrost is the seasonally unfrozen ground of the active layer, with perhaps an unfrozen talik between them. Various disturbances and changes in surface energy balance can affect permafrost, causing thermokarst, solifluction, and other surface disturbances. This vital sign focuses on monitoring long-term changes in permafrost extent and temperature, active layer depths, and the evolution of permafrost landscapes whether due to climate change or other processes.

Significance: Permafrost extent and thickness is largely controlled by air temperature, snow thickness and duration, and vegetative cover – each of these parameters is currently changing and so must be affecting permafrost. This anticipated change in permafrost will have broad impacts on regional hydrology, soils, biogeochemistry, trace gas emissions, and vegetation patterns and therefore on large-scale ecosystem structure and function. Extensive thermokarst will lead to altered soil nutrient dynamics in ARCN parklands as soil organic matter reservoirs formerly icebound become available for redistribution. Thermokarst will likely have significant effects on carbon sequestration in wetter areas, and loss of permafrost may cause drier, more aerobic soil conditions in upland areas.

Monitoring Questions:

- What is the extent, thickness and temperature of permafrost within ARCN and how are these changing over time?
- What can permafrost temperatures tell us about past and current climate?
- What surface disturbances (e.g., thermokarst, solifluction) are occurring and what are their causes?
- Example vital sign linkage question: What are the impacts of melting permafrost on nutrient cycling, element transport to aquatic ecosystems, and hydrologic networks in ARCN?

Monitoring Plan Overview and Philosophy: The overall intent of this monitoring plan is to understand the current thermal state of ARCN ground, to understand how this is changing over time (past 150 years to future), to monitor changes to the land surface, to determine whether these are caused by climate change or not, and to use this knowledge to facilitate monitoring of other vital signs such as terrestrial vegetation and aquatic ecosystem dynamics. As with all vital signs, developing this monitoring plan is an optimization process, and as such focuses on economical metrics which integrate seasonal or annual impacts. Similar to the Climate and Weather monitoring plan, monitoring permafrost temperatures is based on a tiered approach, with one or two deep boreholes (to at least 60 m) surrounded by a series of spatially-distributed inexpensive shallow boreholes (to about 6 m) with continuously logging thermistor strings. The deep boreholes would be associated with primary weather stations and the shallow holes associated with any other weather stations throughout ARCN. The deep boreholes can provide information on recent climate changes by modeling the temperature distribution with depth in the holes and will provide an integrative metric to assess the impact of future changes in climate. Coupled with the climate modeling infrastructure developed in the "Climate and Weather" protocol, spatial extents and anticipated changes in permafrost will be assessed largely through modeling. To monitor surface disturbances, airborne and space-borne remote sensing would provide baseline information on total extent, morphology, and expansion rates of thermokarst through imagery and elevation measurement, on a decadal basis over large areas and more frequently if possible at known hot spots. Field campaigns, in association with other monitoring efforts when feasible, would measure ground temperatures, surface elevation, and active layer depths at index sites as often as every year. In associations with other vital sign monitoring, organic thickness accumulation, sediment flux, fire-soil interactions, and other metrics will be monitored as opportunity and need arises.

Current Monitoring: ARCN baseline study of thermokarst development in the Noatak Basin (2006, 2007).

Linked Vital Signs: Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems, Weather and Climate, Snow and Ice, Terrestrial Vegetation and Soils, Coastal Erosion, Surface Water Dynamics and Distribution

Standard Operating Procedures to be developed (by 2008):

- Deep borehole installation, measurement and maintenance
- Shallow borehole installation, measurement and maintenance
- Active layer monitoring
- Thermokarst inventory (linked with vegetation and soils protocols)
- Remote sensing monitoring
- Data quality assurance, quality control, and archival
- Data reduction and annual reporting

Pre-Workshop Materials and Notes

Overview (added after the workshop)

This section describes the goals and related background information for the workshop. The initial draft was made by Matt Nolan and Diane Sanzone, who sent it to workshop participants by email about one month prior to the workshop. Participants were asked to annotate the text in any ways they thought reasonable, such as with questions, comments, concerns, additions or corrections. Responses were compiled into a single document and sent to participants shortly before the workshop as well as presented to them at the workshop in hard-copy form. These comments are included in this document, highlighted by gray and preceded with the participant's name in CAPS. After the workshop ended, handwritten notes on the discussions were also transcribed and added to this end of this document. Note that many parts of the original text end in ellipsis (…) or are highlighted in yellow, indicating the need for group input, and that this section is left in this unfinished form. The original intention of this document was to use the annotations and workshop discussions to revise the text into the final workshop proceedings, but later it was decided to be more valuable in its original form with annotations added separately.

Background -- Where are we in the scoping process?

This section provides a brief overview of the history of the Inventorying and Monitoring Program and the scoping process for the Arctic Network (ARCN).

The National Park Service's Inventory and Monitoring (I&M) Program was formed in 1992 to:

(1) gather baseline information about park ecosystems,
(2) develop techniques and strategies for monitoring ecological communities, and
(3) provide crucial scientific information to park managers so that better-informed scientifically sound management decisions can be made.

The success and implementation of the I&M throughout the system varied, perhaps largely due to funding issues, but recently was revitalized when Congress reinforced these goals in the text of the FY2000 Appropriations Bill:

> The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data.

One result of this was to organize the 270 NPS units into 32 biome-based networks. Four networks were established in Alaska, including the Arctic Network (ARCN) which is the focus of this document (see Figures 1 and 2). The ARCN consists of five units:

- Bering Land Bridge National Preserve (BELA),
- Cape Krusenstern National Monument (CAKR),
- Gates of the Arctic National Park and Preserve (GAAR),
- Kobuk Valley National Park (KOVA), and
- Noatak National Preserve (NOAT).

RICE: Advise participants of purposes and values for which these park units were established in the Alaska National Interest Lands Conservation Act on 1980 (ANILCA).

Pending continued congressional support over the next 50 years, the NPS, and its networks such as ARCN, are now committed to a developing a long-term monitoring program. Before implementation of such a program can occur, however, the scope of measurements and their protocols must be determined. As each network is unique in its character and needs, each network is developing its own plans using a similar 3 phase strategy. As the networks were not all established at the same times, some are further along in this process than other. ARCN was one of the later networks to be funded, (see discussion below), and is currently entering into Phase Three of development of a monitoring plan..

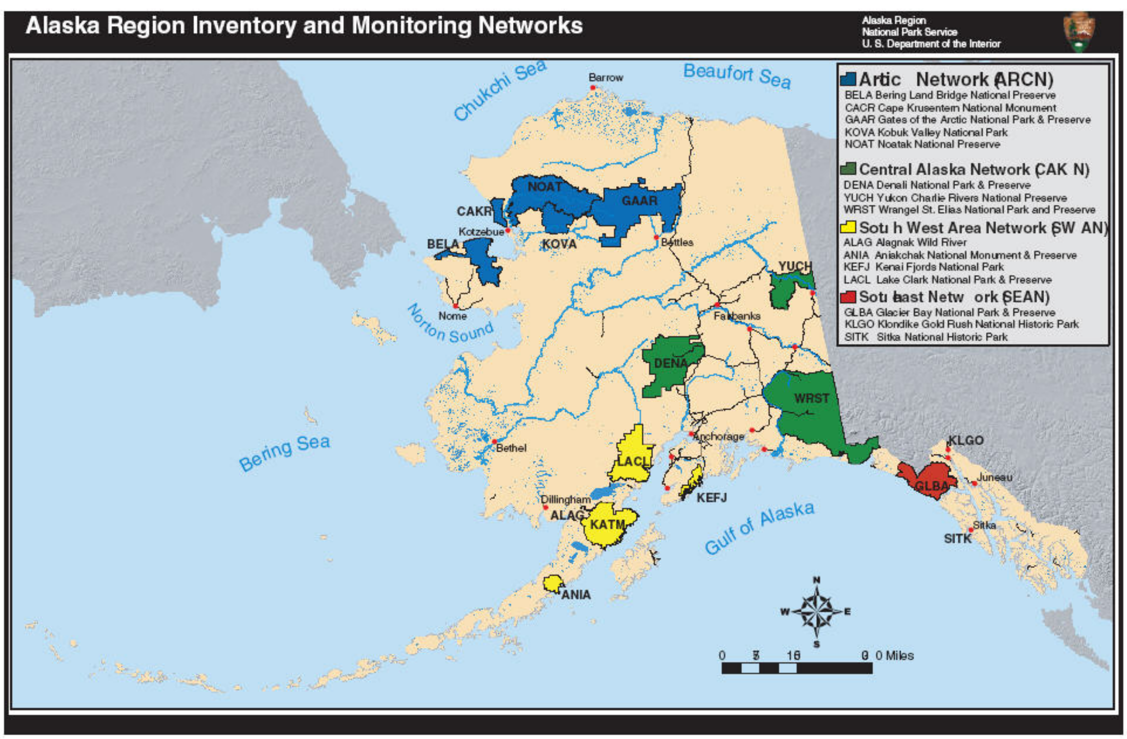


Figure 1. Location map of all 4 NPS networks in Alaska.

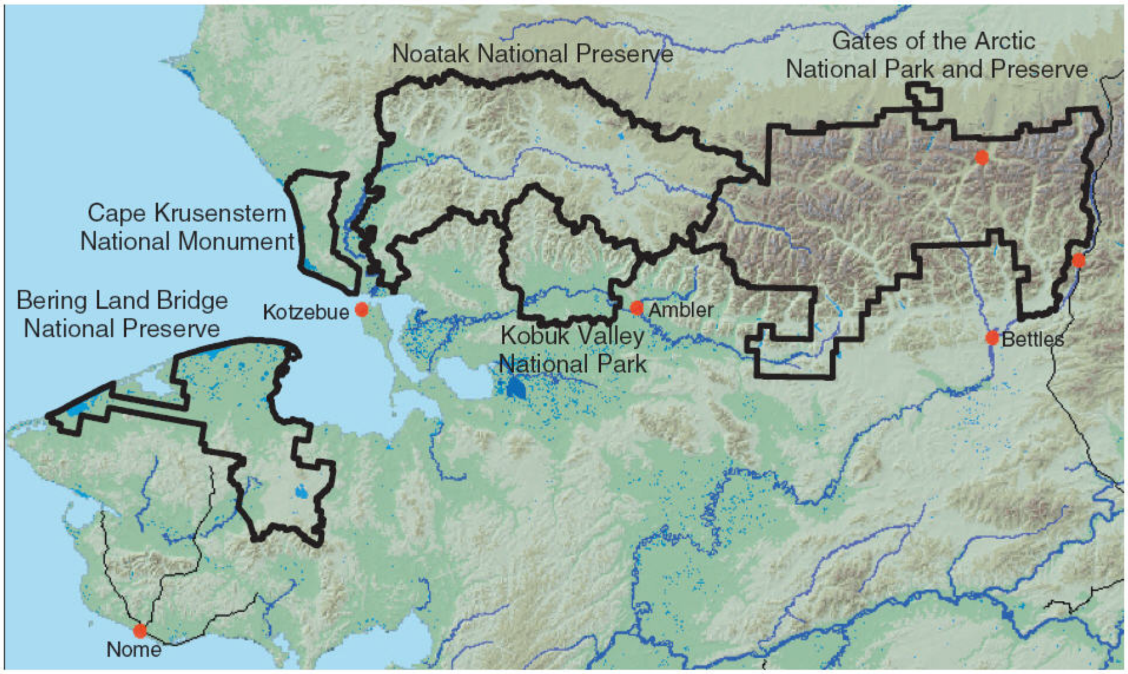


Figure 2. Location map of ARCN units.

Background information (weather, flora, fauna, geology, etc) on ARCN units can be found in the Appendix, along with a variety of detailed maps. A few interesting notes on the ARCN:

- The five units of the ARCN comprise 25% of the US National Park Service lands.
- In total they cover 77,000 km^2. This is roughly the size of New Hampshire, Vermont, and Massachusetts combined (there are 109 operational weather stations in these 3 states that report to national database and none in ARCN)
- These five units are the least visited and most remote park units in the US.
- Of the networks in the Alaska, this is the only one where the units essentially form one large contiguous area, straddling the central and western Brooks Range and continuing on to the coast and the Seward Peninsula.
- The arctic is experiencing the highest rates of climate change globally and the impacts of these changes will impact ARCN as much if not more than other networks due to its location and widespread continuous permafrost.

RICE: Though no weather stations on ARCN lands, Anaktuvuk Pass is surrounded by GAAR, and other village and airport weather stations are near these parks. Somewhere this document needs to identify primary and secondary weather stations near the parks in the overall region.

Between 2003 and 2006, a series of four workshops were held by ARCN:

- Terrestrial Ecosystems Workshop (Summer 2004)
- Coastal-Influenced Ecosystems Workshop (Fall 2004)
- Terrestrial Ecosystems Workshop (Spring 2005)

- Land-Air-Water Linkages (January 2006)

These workshops gathered together leading local, national, and international experts to help the ARCN identify the major scientific and management gaps and to suggest a way forward. The fourth workshop condensed and prioritized the results of the first three workshops to develop a list of ecological indicators or “Vital Signs” which could be used to monitor change. A complete description of each vital sign is included in the Appendix (please note these descriptions are in draft form and will be later turned into protocol summaries); below is a listing of these vital signs (in no particular order) followed by a summary of their scope (organized by convenient groupings of their objectives):

Table 1: Draft Indicators or “Vital Signs”

1) Air Contaminants
2) Aquatic Invertebrates
3) Bird Assemblages
4) Brown Bears (*Ursus arctos*)
5) Caribou (*Rangifer tarandus*)
6) Climate and Weather
7) Coastal Erosion/Sedimentation/Deposition
8) Dall’s Sheep (*Ovis dalli*)
9) Fire Extent and Severity
10) Fish Assemblages
11) Invasive/Exotic Species and Diseases
12) Lagoon Communities and Ecosystems
13) Lake Communities and Ecosystems
14) Moose (*Alces alces*)
15) Muskoxen (*Ovibos moschatus*)
16) Permafrost, Peatland Soils, and Thermokarsting/Solifluction
17) Small Mammal Assemblages
18) Surface Water Dynamics and Distribution
19) Terrestrial Landscape Patterns and Dynamics
20) Human Effects: Point Source Pollution
21) Rare and Unique Species/Communities/Habitats/Ecosystems
22) Stream Communities and Ecosystems
23) Subsistence/Harvest
24) Terrestrial Vegetation and Soils
25) Wet and Dry Deposition of Various Pollutants
26) Water Quality
27) Sea Ice
28) Snow and Ice (not including sea ice)

Table 2. Draft general monitoring objectives and overarching themes for ARCN

Climate and Weather

Objective 1: Understand the natural variation in weather and climate patterns across ARCN using past and current data

CASSANO: Over what time period(s)? – Use paleo data, satellite data, atmospheric reanalyses, in-situ data (any available?)

Objective 2: Analyze current trends in climate and weather patterns

CASSANO: What time period is of interest for current trends (20th century, 1957-present, other?)? What weather and climate parameters are of interest (temperature (avg., min, max, extreme warm and cold events), precipitation (snow, rain), storms (how defined?), clouds, wind, radiation

Objective 3: Predict future trends in climate and weather patterns in ARCN

Objective 4: Understand the natural variability in depth, phenology and distribution of snow and ice in ARCN

Objective 5: Determine how the extent, duration and timing of snow and ice cover are changing in the ARCN

Air Quality and the Deposition and Accumulation of Pollutants

Objective 1: Determine the main components of air pollution in ARCN

Objective 2: Determine if air quality is changing

Objective 3: Determine the contaminant levels in freshwater, coastal-influenced, and terrestrial ecosystems

RICE: (WACAP will inform this by spring 2007 for Noatak River drainage basin.

Landscape Processes and Dynamics

Objective 1: Determine what large landscape-level changes are occurring

Objective 2: Understand the changes in volume and distribution of water

Objective 3: Determine the extent and distribution of thermokarsts

Objective 4: Determine changes in land cover and terrestrial vegetation composition and distribution across the landscape

Objective 5: Determine if migratory and invasive species are replacing native plants and animals

RICE: According to Jeff Heys, invasive plant species are not evident yet in these park units, except near the road corridor east of GAAR.

Freshwater Ecosystems: Freshwater Lakes and Wadeable Streams

RICE: Why limit ourselves to wadeable streams, why not rivers? What about wetlands, or are they considered under peatlands? Not all wetlands are "peatlands."

Objective 1: Understand the patterns and long-term trends in the physical, chemical, and biological characteristics of streams, lakes, and surrounding watersheds

Objective 2: Understand how landscape components interact at various spatial and temporal scales to affect freshwater ecosystems

Coastal Ecosystems: Coastal Lagoons, Estuaries, Sandy beaches, Tundra Bluffs, and Rocky Shores

Objective 1: Understand the patterns and long-term trends in the physical, chemical, and biological characteristics of coastal lagoons, estuaries, sandy beaches, tundra bluffs, and rocky shores

Objective 2: Understand how landscape components interact at various spatial and temporal scales to affect arctic coastal ecosystems

Terrestrial Ecosystems: Tundra and Boreal Forest Ecosystems

Objective 1: Determine the status and long-term trends of vegetation and soils of tundra and boreal forest ecosystems within ARCN parklands

Objective 2: Determine the extent of tree line advance and shrub-line expansion due to accelerated climate change

Objective 3: Understand interactions between landscape components at various spatial and temporal scales and their effects on terrestrial ecosystems

Biological Diversity and Ecosystem Resilience

Objective 1: Document the rates and changes in biological diversity in terrestrial, aquatic, and coastal ecosystems

Objective 2: Understand the ecosystem consequences to shifts in biological diversity

Population Trends in Species of Interest

Objective 1: Determine the current abundance and distribution of selected species of interest

Objective 2: Monitor the productivity, recruitment, and mortality of selected species of interest
Objective 3: Understand the effects of human presence and development on selected species of interest

Consumptive Use of Resources

Objective 1: Understand the temporal and spatial trends in consumptive uses of mammals, birds, fishes, and plants in ARCN
Objective 2: Determine how local human populations are impacted by changes in subsistence resources

Within this scoping process, we are nearing the end of Phase 2 in NPS terminology, and a draft Phase 2 report has now been written and posted online at the ARCN web page (http://www.nature.nps.gov/im/units/arcn/index.cfm). This document summarizes the workshop efforts and recommends a list of the vital signs selected for long-term monitoring. While draft descriptions of these vital signs were created for the Phase Two report, considerable work remains to define their scope and develop specific protocols for their monitoring plans, which will be included in the Phase Three monitoring plan due in draft form in December of 2007. The final peer-reviewed document is due September 2008.

The purpose of this document, and the workshop associated with it, is to accomplish the next stage of this process: outline the protocols necessary to implement three of these vital signs: “Climate and Weather”, “Snow and Ice”, and “Permafrost, Peatlands, and Thermokarst/Solifluction”. These vital signs are closely related and represent the vital signs that primarily relate to the physical, non-biological ecosystem elements. These vital signs are also largely those upon which the plans of other vital signs depend, as a proper understanding of the physical landscape and climate are fundamental to our understanding of all biological processes in the Arctic. Because of the large-scale climate changes that the Arctic is currently experiencing and the impact these changes are having on not only the physical landscape but also the entire arctic ecosystem, we thought it important to hold a workshop to help ensure that long-term monitoring of these foundational vital signs would be based on as much scientific expertise and vigor as possible. That is, although the national I&M program has recommended starting points for some of the SOP’s related to Weather and Climate, ARCN is unique in that no other NPS I&M network has such large, remote areas or such large recent and predicted changes in climate. For this reason, ARCN instrumentation, deployment and maintenance will require an additional level of thoughtfulness.

What are protocol summaries, protocols, and SOPs? The purpose of the protocols and SOPs are to help guide the monitoring process over the next 50 years by articulating a clear vision for establishing sustainable monitoring networks which address tangible concerns (like weather station design) and intangible concerns (uncertainties in future funding, relationships with other NPS networks or agencies), as well as maintain a consistent methodology including documentation of any changes to this methodology (such as might be based on new or improved technologies) so they can be tracked over time. Developing a protocol summary is the first step in the process, as this outlines the scope and nature of the final protocol. The protocol is the actual monitoring plan, including the Standard Operating Procedures that will guide the actual activity. The goal of this document and its workshop is to develop a reasonable first draft of the protocol summaries for three ARCN vital signs and outline the likely SOPs with enough depth that all of the major considerations are addressed.

The next step after this in this scoping process is to take the plans, outlines, and discussions on protocols found in this document and turn them into official SOPs. This document has been designed to facilitate that through its organization. The remaining sections are thus organized around the three vital signs of relevance here, and each vital sign section includes some background needed for the protocol along with a list of necessary SOPs that the workshop deemed appropriate, along with a summary of the discussions on those SOPs. In some cases, it is anticipated that more than one SOP will result from those listed. The final version of these protocols and SOPs are due in draft form December of 2007, so there will be plenty of opportunity for comments from the broader community on the scope and content of these protocols, and the outcomes of this workshop are just an important first step in this process.
RICE: This paragraph is a bit confusing in terms of where we are in the planning process for this I&M effort.

Our questions:
Was this clear?
What additional background information can we provide to further develop discussions?
RICE: Participants need to know up front the ANILCA purposes and values for which the parks were established, the goals of NPOMA, NEPA and Wilderness Act requirements.

Your questions and comments:
RICE: Can we obtain TEK information for this effort? What about local knowledge, expertise, and observations?
See other comments sprinkled throughout body of document.

STURM: WHILE LAUDABLE, I DOUBT THAT NPS OR ANY OTHER FEDERAL ENTITY CAN ACTUALLY TAKE A 50-YEAR VIEW. SO I THINK OUR GROUP MUST SPEND SOME TIME ANAYLZING POSSIBLE FUTURE FUNDING SCENARIOS. WE NEED PERHAPS TO DEVELOP 3: 50 YEARS OF FUNDING. 5 YEARSOF FUNDING THEN A CRASH. 15 YEARS OF FUNDING AND A TAPER. ANYWAY YOU GET THE IDEA. THESE MIGHT INFLUENCE THE SYSTEM WE DESIGN. **WE MUST BE THINKING ABOUT CONTINUITY AND WORKING ON HOW TO ENSURE THE MEASUREMENTS CONTINUE A LONG TIME.**

Vital Sign: Weather and Climate

<u>Discussion on "Weather" vs. "Climate" and Other Prioritizations</u>

The vital sign addressed here is "Weather and Climate", and the network deployed must have some elements of both, but networks designed to measure just weather or just climate could look quite different. For example, a network of weather stations used in daily operational forecasting or in pilot weather briefings might need 100% uptime, with repair technicians deployed at the first sign of trouble year-round. Climate stations, however, can tolerate some gaps in the record and the data only really become valuable after 5 years or more of record. Similarly, operational weather forecasting prefers wind speeds and directions measured at the top of mountains, whereas climate monitoring stations are more appropriate near the valley bottoms where more life exists and more snow accumulates. The differences relate to time-scales of measurements as well. For example, for climate studies we might find that monthly or weekly precipitation. integrated over 20 years is exactly the sort of metric we need, but not hourly measurements. Similarly, it be great to know how the cold wave moves down through the active layer, but maybe all we need for climate change is the maximum depth of freeze. We need to be clear on which parameters we are collecting at what frequency and why. We may find our temporal needs are driven by high-end models that might be able to use ECFMW hind-casts, but we need to be sure of this and other considerations before we say we need to make a specific type of measurement. These are not easy questions to answer.

Thus before a protocol summary or its SOPs can be developed, some fundamental questions must be asked and answered, like What is the purpose of this network?. Should we be most interested in weather, or in climate? Or a mixture of both? What questions are we trying to answer with these weather stations? Who is going to actually use the data to answer these questions? To keep such a network operational and questions being answered, individuals need to be identified (along with their funding) that will feel some ownership of the project and its long-term success. The protocol summary and the SOPs below take stabs at these questions, but they clearly need further discussions.

A flexible solution to station design that we have been considering thus far and that could be applied to any answers of these questions might be to deploy a mixed network, with some stations meeting both goals and some only one or the other. For example, we might consider some stations as "Primary" and include on them all of the equipment necessary to understand both weather and climate, siting them in a mixture of locations, possibly following the design and protocols of NOAA's Climate Reference Network (CRN). If these Primary stations show signs of problems through telemetry, they would be fixed as soon as possible. A set of "Secondary" stations might have fewer instruments and be used primarily for weather (and so have telemetry) but only be repaired on a regular maintenance schedule (or as budget opportunities arise), and should they survive through the long-term serve as climate stations as well, possibly following the design and protocols of the RAWS fire service network which other Alaska NPS networks have decided to use. A final set of low-cost "Tertiary" stations (with perhaps only air temperature, wind, rain, or incoming solar) could be deployed in large number to understand climatic-gradients (as discussed below); these would not need to be telemetered and could be redeployed every few years to develop new spatial trend relationships. Should funding decline in subsequent years, prioritization of resources would follow these same levels of Primary, Secondary, and Tertiary.

For other ideas on the format of the protocol summary, similar summaries for the CAKN and SWAN networks in Alaska have been included in the Appendix.

Our questions:

- More input on the group is needed as to the differences in potential design of these two types (climate or weather) of networks and the questions we should be asking and answering prior to designing the network itself.
- What do others think about the three level system? How about the naming convention for it? (We didn't want to use "first order", etc, since that's already being used for other things)

Your questions:

STURM: GOOD. WE NEED TO HAVE THIS DISCUSSION RIGHT UP FRONT OR ELSE WE ARE LIKELY TO HAVE A MIXED SYSTEM…A CLIMATE NETWORK THAT DOESN'T SOLVE OPERATIONAL PROBLEMS, OR A WEATHER SYSTEM THAT COSTS SO MUCH TO MAINTAIN IT LASTS ONLY A FEW YEARS. VERY IMPORTANT TOPIC!

CASSANO: Do we want to think about additional data besides AWS? – satellite data, model data (reanalyses, targeted model simulations), other?
What are the current weather data needs in ARCN? How are they currently being met? What additional weather needs are there, or do we really only need to worry about climate monitoring?

RICE:

1) I like the nomenclature of primary, secondary, and tertiary met stations.
2) I like the idea of tying stations to funding priorities.
3) Locating and maintaining facilities in remote Wilderness could be problematic, but possible. We need to collocate such facilities with other installations or proposed installations such as radio repeaters, PBO, seismometers, cabins, lodges, etc. and to establish partners with other agencies and private landowners.

Overview and Draft Protocol Summary

The "Weather and Climate" vital sign is perhaps unique for ARCN because changes in nearly all other vital signs are related to changes in weather and climate, and the changes anticipated here are likely higher here than any other NPS network. For convenience, this section of the report deals exclusively with designing, implementing and managing a network of remote, automated weather stations and the use of this data in climate models. Though important parts of an overall climate monitoring plan, the monitoring snow packs, lake ice, and glaciers are treated in subsequent sections of this document.

Similarly the use of glaciers and permafrost to understand prior climate trends are treated in these subsequent sections.

A protocol for addressing the Climate and Weather Vital Sign for the ARCN must include consideration of the following:

- **Prioritization of "weather" vs. "climate" measurements,** that is, the network design for operational weather measurements is not necessarily the same as for climate measurements (e.g., weather measurements need hourly telemetry but climate does not; winds for weather should be measured on mountain tops rather than valley bottoms for climate);

RICE: How about mountain passes, which are more important for FAA and aviators?

- **Siting new equipment locations**, which must include considerations of the weather and climate patterns intended to be studied, the locations of existing or planned weather stations, logistical access, how to spatially extrapolate the point data, relevance to other ARCN vital signs, what needs to be measured (perhaps not the same everywhere), what data end-users are expecting, the methods of other NPS monitoring networks, and the individual characters of the five NPS management units within ARCN:
- **Meteorological instrumentation**, including which sensors to use, what telemetry systems to use, and considerations of compatibility with existing sensor networks;

STURM: MAYBE WE NEED TO HAVE A SERIES OF CRITERIA THAT WE CONSIDER AS WE REVIEW EACH INSTRUMENT: DOES IT SATND ALONE? IS IT ROBUST? WHAT IS ITS DATA STREAM?

-
- **Deployment,** including considerations of standardized methods, access, timing, and funding;
- **Maintenance**, including standard metadata formats and sensor calibrations;
- **Data handling and distribution**, including which national or international data networks to subscribe to, metadata creation and formats, and interfacing with other NPS networks,
- **Data reduction and analysis**, including ensuring that the data is in a form easily accessible to end-users, that summary products are made available in a timely manner and that someone will be using these data to answer some of the big questions and gaps (such as synoptic climatologies, future climate predictions, etc), and interfacing ARCN results with those of other NPS networks;
- **Long-term partnerships and contingencies**, including plans for intra- and inter-agency partnerships and considerations on what happens to the network should NPS funding be cut.

STURM: UNLESS WE EXPLICITLY CONSIDER COST AND DIFFICULTY AS WE MOVE THROUGH THIS EXERCISE, THE LAUNDRY LIST WILL BE TOO BIG AND TOO EXPENSIVE, AND CERTAINLY UNLIKELY TO HAVE LONG CONTINUITY. WE OUGHT TO BE ASKING QUESTIONS LIKE "HOW VALUABLE IS THIS MEASUREMENT IN LIGHT OF THE EFFORT TO GET IT AND THE COST?"

CASSANO: Might consider looking at University of Wisconsin Antarctic AWS data management model or University of Colorado Greenland AWS network.
Should store data at AWS as well as transmit so if transmit capability fails we can still retrieve the data for archive.

Many of these items will require more than one Standard Operating Procedure.

You can find a draft description of Weather and Climate vital sign in the Appendix, taken from the Phase Two ARCN report. Below is a version of that description expanded into a *draft* protocol summary to start discussions at the workshop:

Draft Protocol Summary for Climate and Weather

Description: Climate is widely recognized as a fundamental driver of ecosystem change in the Arctic. With mean annual temperatures here typically below freezing and the ground covered by snow more than 6 months per year, any slight changes in temperature and precipitation can have great impact on ecosystem form and dynamics as well as major impacts on the land surface through changes in glaciers and permafrost. Snow and ice heavily influence all ecosystem components in freshwater, coastal, and terrestrial ecosystems. For example, the extent and degree of ice and snow cover transforms land surfaces, increases surface albedo, and reduces solar energy absorption. Altered albedo over the parks changes the frequency and types of clouds occurring in the region, further influencing surface energy balance, and precipitation frequency. These factors affect solar radiation and precipitation and may ultimately lead to altered duration of the growing season. Basic climate data for most of ARCN is sparse or nonexistent because there are simply no weather stations here.

RICE: Can't we monitor albedo with satellites?

Significance: Because climate is a basic driver of all ecological systems, these measurements are important for understanding the relationship between climate and other components of biotic and abiotic systems. Without climate data, it is impossible to understand the causes of a variety of ecosystem changes because changes in climate are largely driving those changes. Basic climatological measurements lacking for most of ARCN include temperature, cloud cover, precipitation, wind (speed and direction), relative humidity, ice and snow cover, snow depth, and soil temperature.

Overarching Question:

- What is the natural variability in weather and the long-term climate trend in ARCN units?

Specific Questions on Prior Climate to be Answered Through Climate Modeling:

- What is the synoptic climatology of this region and how has it changed over the past 50 years?
- Where is the 0ºC mean annual air temperature isotherm currently and has there been a trend over the past 50 years?
- Where is the 10ºC summer isotherm currently and has there been a trend over the past 50 years?
- What are the trends in changes in air temperatures, precipitation, cloud cover, relative humidity, wind speed and direction, storm frequency and soil moisture over the past 50 years? Do they have seasonal trends that differ from annual trends?

Specific Questions on Prior Climate to be Answered Through Paleoclimate Studies:

- How does the short term trend of the past 50 years fit into longer-term trends of the past 100-10,000 years?

Specific Questions on Modern and Future Climate to be Answered Through New Weather Stations:

- Is the synoptic climatology of this region changing?
- Are the 0ºC and 10ºC isotherms changing?
- Is there a trend in air temperature greater than 0.1ºC/decade or a trend in precipitation greater than 2%/decade?
- How do the weather parameters of interest change from coastal to inland regions?
- How do the weather parameters of interest change from lowlands to mountain regions?

CASSANO: How do the trends from in-situ observations compare to trends from other data sources (satellite, reanalyses, other?).

Specific Questions on Current Weather:

- Can our weather stations aid in improved operational 3 to 5 day weather forecasts within ARCN?

CASSANO: Surface pressure and accurate elevation are the most useful surface weather data for assimilation into weather forecasting models. Most other surface variables are too dependent on the local site to be of real value for assimilation.

-
- Can our weather stations aid in real-time tracking and prediction of animal migrations and dynamics within ARCN?
- Can our weather stations aid in real-time monitoring of break-up, freeze-up, and other weather events of significance to ARCN ecosystem dynamics and management?

Proposed Metrics: Air temperature, cloud cover (tough to measure well from automatic station), precipitation, relative humidity, wind (speed and direction), solar radiation, longwave radiation, surface albedo, storm frequency (defined by what parameter(s)?), soil temperature, and moisture

Specific Methods, Spatial Scale, and Frequency of Measurement: Questions on prior recent change will be answered through analysis of climate models, such as reanalysis models like ERA40 (coarse resolution but long 50+ year record, question regarding accuracy of ERA40 data at specific points), regional climate models (good for physically based downscaling but can be very computationally expensive at high resolution, will include model errors), and GIS based extrapolation models (lower computational cost than RCMs but less physically based, need good data for statistical relationships). These questions will help guide us in development of a new network of weather stations within ARCN. The network will be designed to answer different questions using different equipment in a three tiered network approach utilizing Primary, Secondary and Tertiary stations. Primary stations are modeled after NOAA's Climate Reference Network stations, largely using their protocols, of sufficient spatial density to detect trends of interest in temperature and precipitation. Secondary stations are modeled after fire services' RAWS stations, and are the weather stations largely deployed by other NPS networks. Tertiary stations are low-cost stations designed for 1 to 3 year re-deployments, using Onset Computer Corp (or similar) equipment, to measure specific gradients of interest at high spatial resolution (what do you consider high spatial resolution?). Primary stations will be telemetered to the internet for operational, near real-time use; Secondary and Tiertiary stations may or may not be telemetered depending on their specific deployments. Partnerships with other agencies and organizations will be sought to ensure long-term continuity and cost-sharing. For example,

NOAA may have an interest in direct funding of some of our Primary sites, and BLM may have an interest in funding some of our RAWS sites or perhaps just their telemetry.
Current Monitoring: National Weather Service stations located in communities adjacent to ARCN parklands; RAWS Stations; See map.
Implementation schedule: Site selections and initial deployments in 2007, continued deployments through 2009.
Data archival: Weather station data will be archived at national repositories on a yearly basis (if not telemetered) or in near-real time (if telemetered) to national databases used by NOAA and other NPS networks (such as the Western Regional Climate Center).
Linked Vital Signs: Nearly all vital signs are linked to Climate and Weather in ARCN, due to the magnitude and rates of recent climate change in the Arctic.

Our questions:

- Does this plan seem reasonable?
- What other questions need to be addressed?

Your questions and comments:

DALY: In the end, the monitoring system established here will be far less than what is needed to accurately characterize the spatial and temporal variation in climate. In fact, the needs could really be called infinite. Therefore, there is a need to establish a baseline level of support for installation and ongoing costs, and work backwards from there. I think portable tertiary stations will be key to sampling the full range of variability in just a few areas, if nothing else to assess what is being missed.

RAWS tipping bucket precipitation gauges are mostly worthless except in the core summer months. Precipitation will be by far the most difficult and expensive element to measure accurately. My experience in working with Alaskan precipitation data has been that only shielded gauges (such as those used by SNOTEL) and snow courses are really very useful. Unshielded gauges under catch by 100% or more.

The ongoing cost of data QC is a sleeper, here, in that it is usually just lumped in with archival costs. In actuality, good QC requires sophisticated processes that must be developed and performed on a routine basis, and the results routed back the monitoring groups for assessment and possible corrective action.

RICE

1) What spatial densities of all 3 levels of weather stations are acceptable/optimal?
2) What are limits to deployment and access in the 5 ARCN units and what collocations of facilities are possible?

HAMILTON: The 50-yr span cited is appropriate for climate modeling. It needs to be made clear, however, that climate reconstructions over a span of 100-120 yr are also feasible, and would take off from a more significant episode-the close of the Little Ice Age.

SOP: Creation of Synoptic Climatology and Study of Recent Climate Change in this Region as We Understand It Now and Predicted Changes

One component of designing a network of weather stations needs to be an assessment of the spatial scale of the weather systems we are trying to capture and where their gradients are largest and least known. Unfortunately, a true synoptic climatology of this huge region has never been fully described. This section presents an overview of some of what's known about the synoptic climatology of the ARCN region and what it should include, and might also serve as a primer for workshop discussions on other SOPs.

A major problem facing ARCN park managers and scientists is we do not have adequate knowledge to even define the dominant boundaries of climatic zones in Alaska except on a very coarse scale (see Figure). Any weather station network designed for ARCN needs to have defining these boundaries (as they relate to the ARCN boundaries) as one of its goals, since the Arctic, Maritime and Continental regimes intersect above the parks.

RICE: Can we use land/vegetation cover to help define climate zones and boundaries?

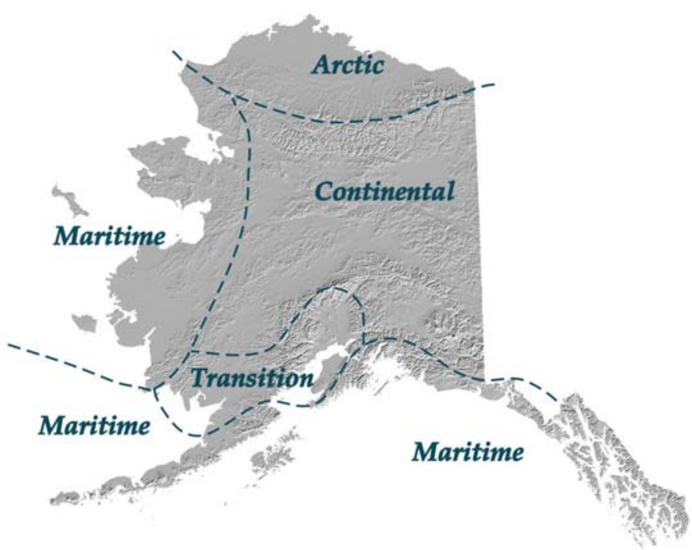


Figure 3. Sketch of major climatic zones in Alaska.

RICE: Indicate the original/source of this sketch map. Show location oaf ARCN units on the sketch/map.

STURM: THIS DESCRIPTION IS A LITTLE MISLEADING BECAUSE THE ZONES MOVE FROM SUMMER TO WINTER. THE ARCTIC FRONT MAY BE A USEFUL INDEX FOR DIVIDING THE REGION.

Descriptions of approximate air temperatures and precipitation rates for each ARCN unit are presented in the Appendix. The dominant picture is of course that coastal units are characterized by coastal weather and interior units are characterized by dry and cold conditions, but most of the climate observing stations currently operating in Arctic Alaska are along the coast therefore the climate history of this area is somewhat biased. A dominant feature for coastal areas is high winds that are predominantly from an easterly direction, which are associated with the Beaufort high pressure system. These frequent high winds tend to diminish the influence of the low-level temperature inversion that is common during winter elsewhere. As such, air temperatures in winter, while they can reach extreme low values, are not as low as those found inland. Precipitation is light, averaging about 10cm per year, and is likely underreported due to the problem of under catch. Snowfall occurs at any time of year but the seasonal snowpack is normally established in September, with snowmelt occurring in June. Snowfall totals are relatively low, averaging about 76cm a season [source?]. The short summer brings frequent low stratus-type cloud cover to coastal areas due to moisture influx from the bordering ice-free ocean. In addition, a sea breeze has been documented to occur along the coast due to the surface thermal imbalance. Interestingly, there is no reverse phenomena, or land breeze, because of the near constant surface heating from continuous daylight. For inland areas, such as Umiat, summers are noticeably warmer than at the coast with less cloud cover and abundant surface heating. Daytime highs above 20°C are not uncommon and while thunderstorms are rare, they have been reported in this region.

CASSANO: do you see land breezes during the **winter** months?.

RICE: Can we show wind roses for various parts of ARCN? I know Red Dog Mine EIS has such data, and presumably we can get this for villages like Anaktuvuk, Bettles, etc.

Long-term station data are sparse in Alaska, with only five stations (Fairbanks, Nome, Juneau, Barrow …) having a record of about 100 years (Figure 4). More stations exist with records of approximately 20-50 years (Figure 5)… The low elevation bias of these stations is obvious, with most stations existing either on the coast, river valleys, or a few mountain passes (Figure 6).

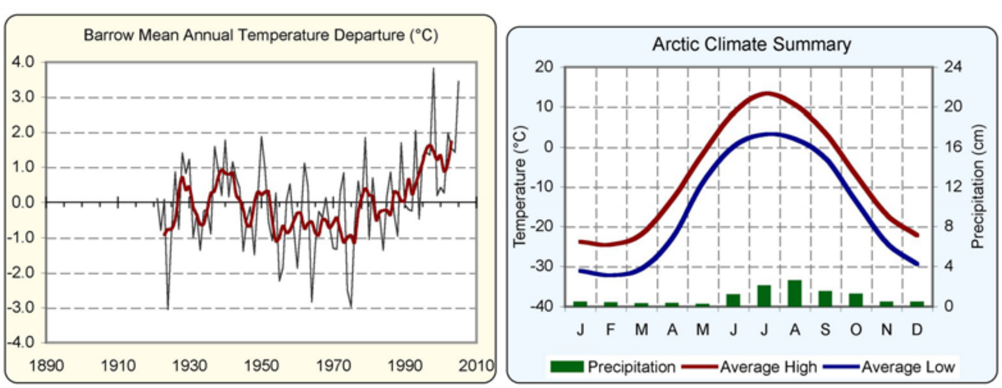


Figure 4. Long term climate records from Barrow.

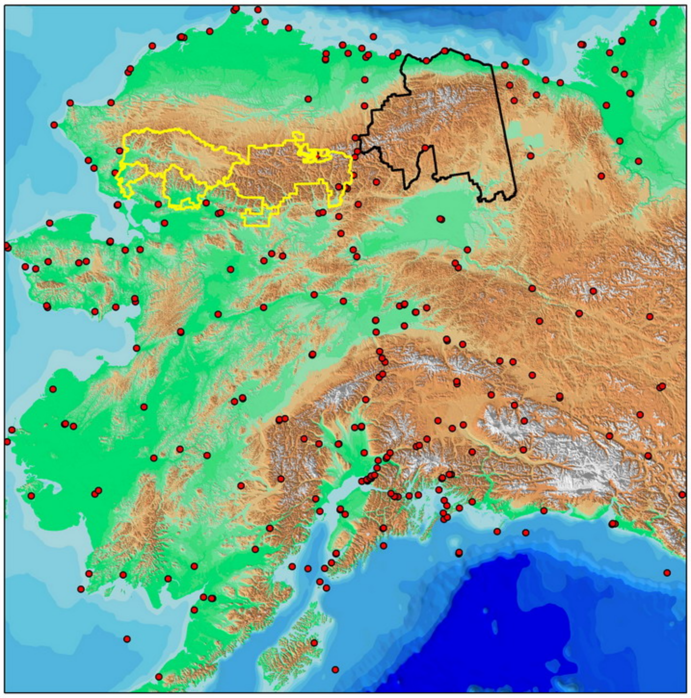
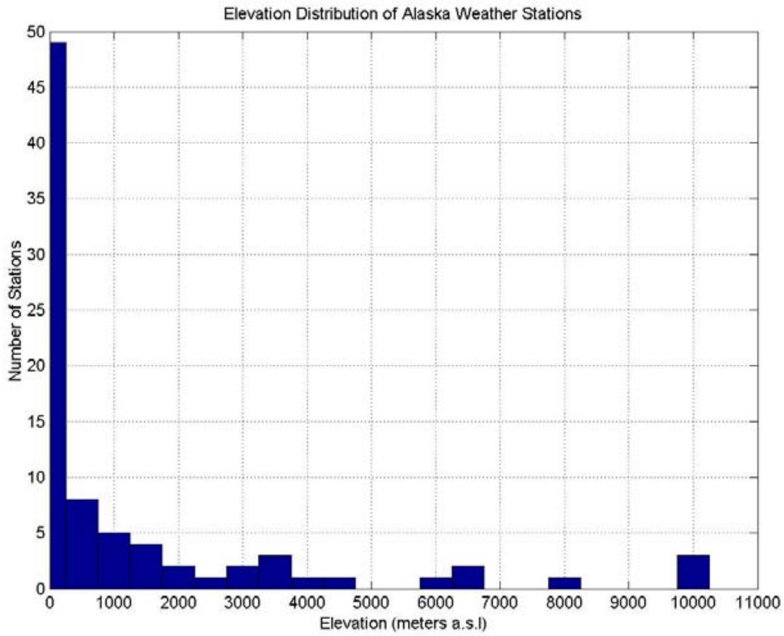


Figure 5. Locations of weather stations that have reported to the national networks in the past 50 years. Yellow outlines are ARCN units and black outline is ANWR. Red dots have reported nationally, white dots are part of UAF mesonets. (note: I'd like to replace this figure with one showing current stations with a marker size that is dependent on age of station)

RICE: *Good change!*



RICE: *Note 10,000 meters is above Mt Everest. Where are these stations?*
NOLAN: *Excellent observation, just making sure someone is paying attention. Should be feet... Atigun, Isabel, Chandalar Shelf, and Eureka fall in that bar. Though that seems high in feet also...*

Figure 6. Histogram of weather station elevations in Alaska. Note that most stations are located along the coast or in low elevation river valleys or mountain passes.

Though air temperature and precipitation (and temporal changes in them) are the two parameters that most ARCN workshop participants indicated as most important to their models and other vital signs, inter-annual changes in them are driven largely by changes in storm tracks (local effects due to changing snow-cover duration will be discussed in a subsequent section).

A thorough synoptic climatology for this region has never been completed, to our knowledge, largely due to the lack of weather stations here, though there is sufficient information to describe some of the dominant trends. There are two primary types of synoptic patterns that influence this area during the cold seasons, arctic high pressure or an eastward moving low. The high can either dominate much of mainland Alaska, bringing extreme low temperatures or be balanced by a low to the southwest with a stationary frontal boundary between. There can also be a strong low pressure system that moves in from the west, although the strongest influence is usually western and southern coastal areas of Alaska.

CASSANO: Can create synoptic climatology using self-organizing map technique using ERA40 and Polar MM5 output – my group has already done this with the goal of looking at precip in the Mackenzie and Yukon basins as related to varying surface weather patterns.

Climate signals such as the Pacific Decadal Oscillation (PDO) and Arctic Oscillation (AO) have been shown to influence weather patterns for this area. Although some are skeptical as to where these represent new signals rather than a regional composite or manifestation of ENSO (PDO) and the North Atlantic Oscillation (AO), their influence on this part of Alaska is nonetheless apparent. Both the PDO and AO are best expressed, and therefore have the greatest influence, during the winter, the time at which there is the greatest equator to pole temperature difference. While the these signals might not have a large influence day to day weather patterns, their most significant impact is likely on the longer-term climatological characteristics, decadal-scale regimes, and trends.

The PDO index itself reflects variability in the mean monthly sea surface temperatures for the north Pacific basin. Surface winds in this area show distinct patterns with predominantly southerly flow coming into Alaska from the Gulf with an intensification of the Aleutian Low, which is the warm phase. During the cool phase, the opposite occurs and northerly flow predominates. The significance of this index on Alaska weather and climate lies with the synoptic-scale patterns. Advection of relatively warm and moist Pacific air occurs during the positive phase, which brings striking positive temperature anomalies for much of Alaska. In a study by Hartmann and Wendler (2005), significant changes were noted in temperature, precipitation, winds, and cloudiness between the positive and negative PDO phase. Historic observations of the PDO index show decadal scale variability with a predominantly positive mode since 1976, negative phase from about 1945 to 1976 and mostly positive previous to 1945. In addition, mean annual temperature anomalies in Alaska show a strong correlation to the PDO index.

CASSANO: Can perform SOM synoptic climatology analysis for different phases of PDO, AO, etc to identify changes in frequency of daily weather patterns.

The pattern of AO variability is found in the strength of the circumpolar stratospheric vortex, which is reflected through the troposphere and down to the surface. A primary characteristic of the AO is a see-saw between centers of action of the North Atlantic and North Pacific, with the strongest being the former. The variability of the AO is on a shorter time scale than the PDO and has been in a positive phase for much of the 1990's. Of importance for Alaska is the variability in sea level pressure and storm tracks, and the response of sea ice thickness and extent in the Bering Sea and Arctic Ocean to trends in the AO.

Mean annual temperatures for all the long-term observing stations in this area show a warming, however, the change has been highly non-linear with the records exhibiting both low and high frequency variability. Moreover, the greatest changes have been seen in the cold seasons, more specifically the winter and spring, with the least change in summer. While other areas of Alaska south of the Brooks Range have shown a correlation to the Pacific Decadal Oscillation, this area does not seem to have a strong influence from this particular climate signal. Of importance for this region are the current and predicted oceanic changes, such as the decline in sea ice extent in the Arctic as well as the timing of ice establishment in the autumn. If there is no landfast or shorefast sea ice protecting coastal areas then the vulnerability to erosion, storm surge, and flooding is significant. Currently, areas along the Seward Peninsula and northwest coast are already experiencing these effects.

Changes in jet stream…

There have been several climate reanalysis modeling projects, such as ERA40 and NCEP, which make use of most existing surface, upper air and satellite data over the past 50 years to create a reasonably consistent picture of global climate. These models have output on the order of 1 to 3 degrees of latitude/longitude, and so are coarse for our interests here. However, they are essentially the substitute we have for our lack of local weather station measurements in ARCN. Fortunately, these data can be used to drive regional climate models of higher resolution (down to several square kilometers) with reasonable results. As with all models, real measurements are required to calibrate or validate them…

Nolan analyzed the ERA40 model output for grid nodes north of 60N in an effort to understand climate changes over the past 50 years and how they relate to the rest of the Arctic. The first step was extracting 10 surface parameters from the data set and placing these into 8600 separate ascii text files for easy access by terrestrial researchers unfamiliar with the unix-based file formats used by climate modelers. These surface parameters have 4 data points per day, running from 1957 to 2002, and include air temperature, precipitation, wind speed and direction, relative humidity, surface radiation, among others. A corresponding 8600 web pages were created plotting each of these variables to easily scan for trends, and a 3D graphical user interface developed using Earth SLOT and Google Earth so that researchers could find their study site of interest and the corresponding ERA40 grid node.

CASSANO: My group has completed Polar MM5 simulations with 50 km horizontal grid spacing over all of Alaska for 1957-2002. I would be happy to provide you with this data for similar access as the ERA40 data described above.

One of the trends that is immediately apparent from these plots is that air temperatures in ARCN units were strongly affected by a PDO shift in 1976 and that the impact in arctic Alaska was perhaps more important than anywhere else (Figure 7). Within ARCN, prior to 1976 there was a decreasing trend in air temperature, whereas afterwards there was an increasing trend. The magnitude of this increase around 1976 explains most of the increase in air temperature over the past 50 years, demonstrating that abrupt changes in weather patterns can have significant, abrupt changes in local weather and long-term climate here. Understanding such trends is important both to designing weather station networks and to properly interpreting ecosystem changes on the ground. For example, ecosystem respond differently to a gradual change than they do to a step change, and it is therefore important to capture these driving signals in order to properly model their impacts.

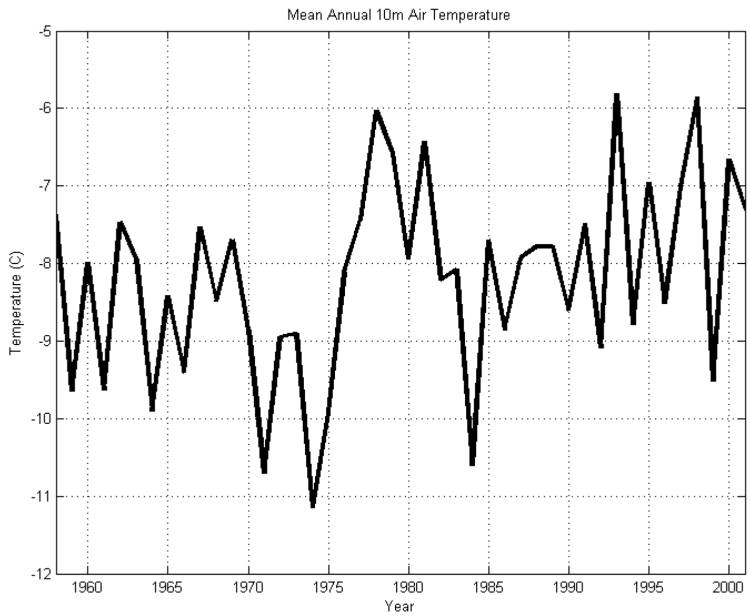


Figure 7a. *Mean annual temperature for a grid node over Gates of the Arctic. Note that prior to 1976, air temperatures were decreasing, whereas after 1976 there is a slight increasing trend. You can find this plot at http://www.earthslot.org/era40/era40.php?node=6261along with the others for this node.*

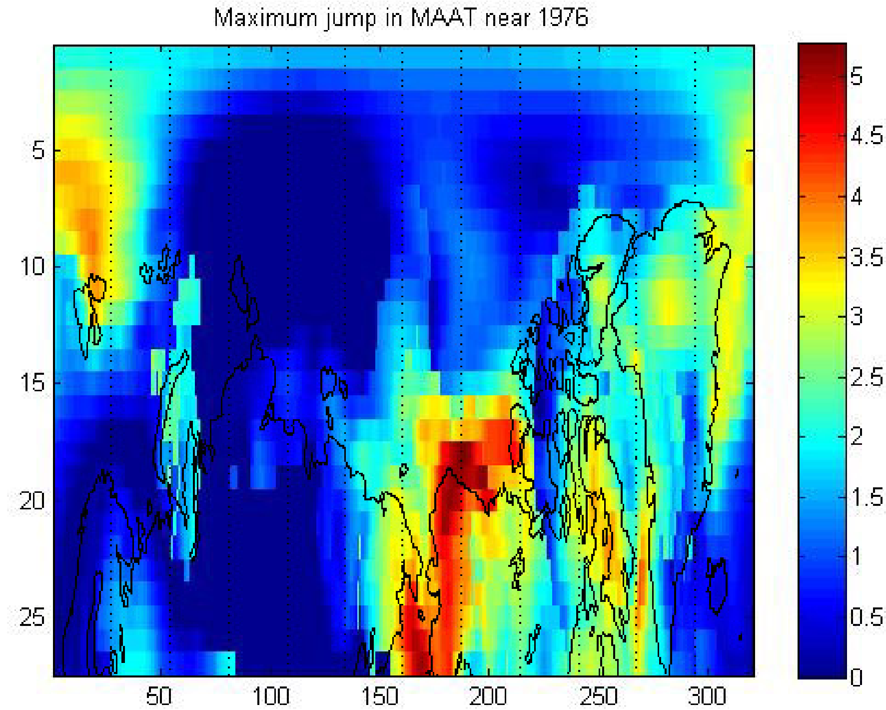


Figure 7b. *This figure plots the maximum jump in mean annual air temperatures around 1976. For example, in preceding grid node, this jump lasted from 1974 to 1978; the jump around 1976 was the only example of 3 consecutive years or more that had an increasing trend in nearly all of the 8600 ERA40 nodes. Arctic and western Alaska show the largest change.*

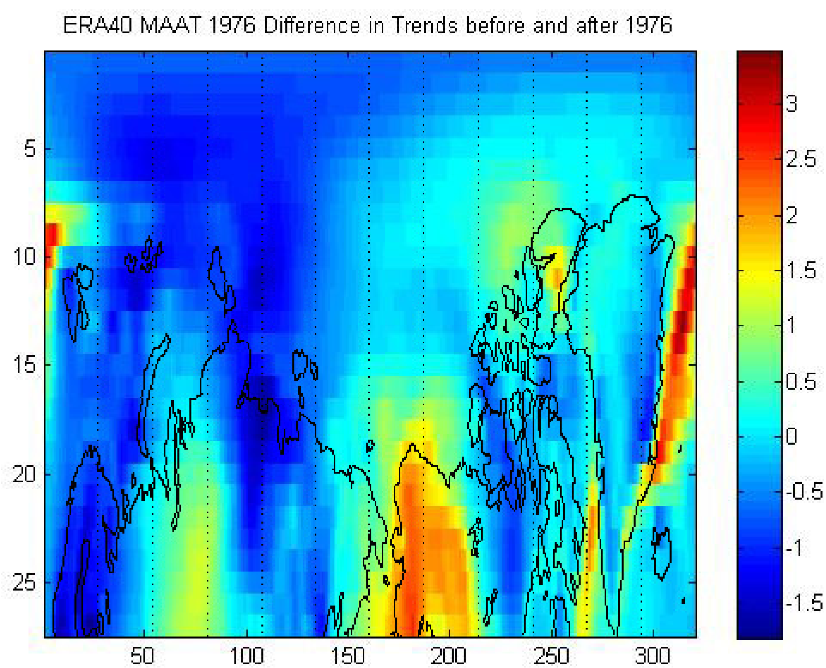


Figure 7c. This figure is similar to the preceding one, but rather than the maximum jump, it is the difference in linear trends fit to1957-1975 and 1977-2001 at 1976. All of Alaska appears significantly impacted, but arctic Alaska less so than in the preceding figure.

IPCC and ACIA have both looked at future scenarios…

Our questions:
What else do we need to know about climate?
Can someone improve the modeling section?

Your questions and comments:
STURM: MOST OF THE ARCTIC PARKS HAVE SIMILAR CLIMATES, AT LEAST IN WINTER. I THINK ACTUALLY IT IS THE LOCAL VARIATIONS, CHANGES WITH ALTITUDE AND GEOGRAPHY THAT THE NPS REALLY WANTS TO KNOW. SO EVEN IF PUTTING ALL THE STATIONS IN ONE PARK MADE SENSE FROM THE STANDPOINT OF DEFINING CLIMATE GRADIENTS, IT WOULD MISS THIS LATTER ISSUE, AND PROBABLY BE POLITICALLY UNACCEPTABLE. IF THIS IS TRUE, WE OUGHT TO ACCEPT IT AT THE ONSET OF THE DISCUSSIONS. IT IMPACTS THE DISCUSSION ON WEATHER VS. CLIMATE AS WELL AS THE WHAT THE GOAL OF THE NETWORK IS.

RICE: What do IPCC and ACIA say about climate change in the ARCN part of the arctic? Can we summarize?

SOP: Determine New Equipment Location

Statistical Approaches to Station Density for Climate Change Measurement

Given our current understanding of the scale of the weather systems and their trends, how many stations do we need to adequately capture the details of interest for climate change purposes? Should they be uniformly distributed or non-uniformly distributed? Does this change based on the how accurate we want to capture certain trends? These sorts of questions have been answered in the past for the continental US in a series of papers, some of which will be described here as background.

Janis et al (2002) took a close look existing US weather station data and developed methods to answer questions like "What minimum weather station separation is necessary to capture National trends in air temperature at 0.05ºC/decade and 1.5%/decade in precipitation?" The basic approach was to selectively reduce existing station density (that is, pretend they did not exist) to determine whether the remaining network was dense enough to capture the trends of interest. Their overall findings are shown in the table below:

Precipitation Trend (% median/decade)	Number of Stations needed in Lower 48	Temperature Trend (°C/decade)	Number of Stations needed in Lower 48
1.0	900	0.050	622
1.5	490	0.075	338
2.0	**293**	**0.100**	**233**
2.5	218	0.125	167
1 station per grid cell	115	1 station per grid cell	114

Table 1. Analysis of station density require to capture particular trends. As can be seen, the tighter the trend-detection tolerance, the more stations that are required. Grid cells for this study were 2.5º latitude x 3.5 º longitude.

NOAA's Climate Reference Network adopted the results of this study into their plan, calling for a protocol defined by the ability to measure a 2% change in precipitation per decade and a 0.1 º C change in air temperature per decade. These numbers were chosen largely through IPCC model predictions. This resulted in a planned station density of 322 stations, with a typical separation of 175-200km. The distribution within grid cells varied considerably, however, based on the regional weather patterns. The western US, for example, required a much smaller station separation than did the eastern US.

While such a study would be useful in Alaska, the existing station network is likely not dense enough or spatially representative enough to conduct such an analysis. Given that there are so few weather stations in Alaska and none within the ARCN (an area roughly the size of Vermont, Massachusetts, and New Hampshire combined), it seems wise in lieu of a new to study to adopt the most conservative guidelines based on the CRN study, which is roughly a station separation of 100 km. This density is roughly 1 station per 1º x 1º of lat/lon, and equates to approximately 8 stations within ARCN. By comparison, no other region of continental has a density this low, as reported in CLIM81 dataset, and the 3 states mentioned above have over 100 stations. Nevertheless, based on the Janis et al (2002) study, this minimum density would have a good chance of capturing trends on the order of 0.1C/decade and 2%/decade in precipitation, and perhaps a bit better. When the harsh climate that these remote, self-powered stations is considered, a factor safety of twice this density is probably a wise precaution.

Our questions:
Do we need to fund a rigorous study on statistical station density even though it's likely to fail?
CASSANO: No, I don't think that this makes sense.

What else do we need to know about climate?
What trend tolerance should we be shooting for?

Your questions and comments:

STURM: NICE BUT I THINK FOR SNOW ON GROUND, THIS DEGRADES AND STATION DENSITY NEEDS TO BE HIGHER (NOT THAT IT IS ANYWHERE IN THE U.S.)
I THINK WE NEED TO SEPARATE TEMPERATURE FROM PRECIPITATION AND BE THINKING ABOUT THESE AS TWO NETWORKS. TEMP. IS EASY AND WE COULD POSTULATE 10X MORE STATIONS THAN WE COULD FOR PRECIP. (MAYBE EVEN 50X). WE WANT TO BE SURE NOT TO DRAG DOWN ONE NETWORK WITH THE OTHER.

DALY: Adding to Matt's comment above, the Janis study assumed that the current network was sufficient to capture all details of temperature and precipitation trends and variability in the US, and the question was how many could you do without. This premise is likely false for mountainous areas, and certainly will be for the ARCN. Not only should temp and ppt be considered differently in terms of the cost to monitor, but in terms of their known or suspected spatial heterogeneity. My feeling is that long-term temperature trends and variations often have a finer spatial scale than those of precipitation, thus requiring increased spatial density. Overcoming under catch in the measurement of frozen precipitation will be very expensive.

RICE: As a back-up, can we use weather station data from sites proximal to ARCN areas such as Anaktuvuk Pass, Red Dog Mine, Noatak, Kivalina, Kiana, Ambler, Bettles, Shishmaref, Coldfoot/Wiseman, etc?

Other ARCN Vital Signs

Nearly all of the other ARCN Vital Signs require some use of the data recorded as part of this Climate and Weather monitoring effort so it makes sense to consider their needs when designing a network. That is, the statistical approach to weather station density offers no guidance on exact equipment location just average instrument separation, so other criteria can take over at smaller spatial scales. As a simple example, the snow pack, glacier, lake ice and permafrost monitoring described below all require local weather data, so why not collocate instruments between projects if feasible? Since monitoring for these vital signs are all being discussed and designed by the same working group, plans for this are described below. Similarly, the needs of those studying Air Quality, Water Quality, Coastal Erosion, Flora and Fauna should be considered, since it could be possible to collocate equipment and share instrument and logistical costs while at the same time improving the science itself. Conversely, in the future it may be advisable for projects related to other vital signs to choose study locations based on proximity to weather stations.

Our questions:

We need some guidance from NPS on project locations, but they have not been determined yet. Can we get rough ideas from biome and biota distributions?

Your questions and comments:

STURM: IT IS ESSENTIAL THAT THE POLITICAL REALITIES BE CANDIDLY ADDRESSED AT THE OUTSET. FOR EXAMPLE, IF NPS HAS SENSITIVE AREAS (KOBUK SAND DUNES) WHERE THERE IS GOING TO BE A SITE NO MATTER WHAT WE DECIDE, WE NEED TO KNOW THAT RIGHT AWAY. SAVES TIME DESIGNING A FANTASY NETWORK.

DALY: As I mention in may comments below under Spatial Extrapolation, using proxies for climate such as biome and biota distributions is good idea, and can not only suggest station placement, but also help evaluate draft climate maps of the region by identifying patterns that should have a climatic basis but are not reflected in the maps. However, this is only possible if the spatial uncertainty in the biome/biota distributions is known and reasonable low. This means comparing these distributions with other spatial data sets to try to establish an accumulation of evidence for a postulated climate pattern.

RICE: What other existing facilities or proposed facilities are in ARCN for collocation of weather/met stations?

Other NPS Networks

At least two other NPS networks in Alaska have gone through this process, and it seems reasonable to draw from their experience in siting new stations. The site selection process of CAKN and SWAN seemed to have been based mostly on consideration of existing stations in or near their units and how to best capture weather from biomes and landscapes which were under-represented. Thus their criteria in choosing sites did not rely so much as selecting sites that were representative of regional climate, but on selecting sites that could later be used as index sites of climate change, and where future researchers could draw their own conclusions on which sites were most representative for a particular research purpose. For example, sites were selected based on whether near-surface temperature inversions were likely or not (highlands or lowlands) and often coupled to capture both within a region. To determine how well these stations represent a region, other stations are required within that region (at least temporarily) to draw such conclusions, but this adds expense and complexity to the monitoring program. A major difference between the other networks in Alaska and ARCN is that the ARCN area is nearly all contiguous, whereas units within other networks are more spatially spread, making consistent synoptic and regional scale measurements more difficult to manage within an NPS program. That is, the ARCN covers a huge, contiguous land area, creating new opportunities and challenges for network design.

There are also some national recommendations for SOPs for many aspects of Weather and Climate; for more information on the national recommendations go to www.wrcc.dri.edu/nps...

Our questions:

- What lessons can we learn from prior station siting strategies to guide the ARCN process?
- The index site philosophy is a simple, reasonable approach – is it sufficient here?

Your questions:
DALY: I think the point made above regarding the sampling of above and below inversion temperatures is critical. This is likely to be a major gradient (almost a step function) in both the spatial and temporal variability of temperature.

The Need of Spatial Extrapolation
CASSANO: Would want to have short duration (1-2 years) of high in-situ observation data density. Could then develop statistical/physical relationships between the sites so that future monitoring could use a reduced network size.
One possibility would be to tie this into a synoptic climatology type approach, where different statistical relationships are derived for different synoptic weather patterns. In doing this the point measurements would be related to the larger scale circulation and thus provide more information for the statistical relationships between sites.

Point data recorded by weather stations are not sufficient for the monitoring needs of many ARCN vital signs, so methods and data requirements for spatial extrapolation need to be considered. For example, tree line migration is though to be crudely related to the 10ºC isotherm in July, but determining the location of this isotherm can only be determined through spatial extrapolation of point data, as our station density will never be high enough to determine this otherwise throughout the entire ARCN. As another example, determining the extents of continuous permafrost will require an understanding of the 0ºC isotherm.

Extrapolation of station data is not straightforward in our case, and the degree of difficulty depends on the parameter. For example, the relationship of barometric pressure with elevation is well known but the relationship of air temperature and elevation varies widely in this region, based not just on weather systems dynamics across this huge, mountain/coastal area, but also on strong low-elevation inversions. Thus there are a lot of unknowns when trying to design an extrapolation scheme, the biggest of which relate to the interior reach of coastal weather (east to west, in this case) and the vertical differences across mountain ranges (north to south, in this case).

CASSANO: Do we want to consider more than just weather station data – satellites, reanalyses, dedicated regional models

Extrapolation schemes also have the benefit of serving as a backup plan in case future funding declines or reprioritizations prevent maintenance of the full network. For example, once we have several years of operation with a full network, we may have enough cross-correlation information and spatial trend information to create more reliable extrapolations of a reduced point network consisting only of our Primary weather stations (which presumably would be deployed in such a way to reduce their cross-correlations to capture the broadest variety of weather trends). That is, as the Secondary and Tertiary stations might be sited close to the Primary stations, once their differences are assessed their similarities may be found duplicative enough with Primary stations to eliminate them.

CASSANO: Yes, this is an important point.

Extrapolation schemes come in two basic varieties. First, and simplest, are GIS-based schemes which incorporate certain rules and metrics to do a true spatial extrapolation. An example of such rules might be to define the inland extent of coastal influence or prescribe an adiabatic lapse rate with elevation. Second are fluid dynamics models which are significantly more complex, tracking air masses through physical rules and attempting to simulate the climate system itself. Both have their strengths and weaknesses, and both can be useful to the ARCN's goals, as described below.

Chris Daly's model …
DALY:

How spatial extrapolation can support monitoring decisions

An important first step in understanding the spatial climate of a region is to develop maps that reflect our best understanding of long-term average conditions. This usually involves defining a 30-year climatological period (i.e., 1971-2000) and using all data available during that period to create mean monthly maps of temperature and precipitation (the two base climate elements). One advantage of starting with long-term averages is that vegetation, soils, terrestrial and aquatic species habitats, and others often respond to long-term climatic conditions, and thus can be used as proxy indicators to inform the spatial climate analysis. Since the ARCN has few to no historical stations, the use of expert input (based on experiences) will be especially vital. People tend to understand long-term climatic averages well, and have historically made excellent reviewers of long-term maps we have created for Alaska and elsewhere, especially mean annual precipitation.

As a way to jump start the process, I suggest that existing PRISM analyses of temperature and precipitation for the period 1961-1990 (developed in 2000) be used as a starting point for an updated mapping activity. They are the best representations of the spatial climate patterns for Alaska currently available, and have been extensively reviewed. However, the ARCN was not a focus, and the exceedingly sparse data strongly suggests that these maps will not be very accurate in the ARCN. These maps could be reviewed by a team with experience in the ARCN parks, inaccuracies identified, and recommendations given as to where stations should be located to quantify particularly weak areas. This may also allow weaknesses in modeling system to be identified, weaknesses that may be reduced by engaging other approaches discussed in this workshop.

Once maps that reflect our best knowledge of the spatial patterns of long-term climate have been created, these maps can be used as a basis from which many other maps can be statistically derived. These include time series of temperature and precipitation across many years, and long term means and time series of important derivative variables such as snowfall, the average and extreme dates of the first last freeze, number of days above a given temperature, record and mean extreme minimum and maximum temperatures, etc. Several such derivations have already been performed for Alaska using the 1961-90 maps as a base.

The spatial climate maps should be thought of as "living documents" that reflect (and allow one to visualize) the current state of knowledge. As monitoring proceeds in the ARCN, the maps should be updated periodically to reflect new data and knowledge gained.

Importance of DEMs

The key input into any interpolation scheme that cares about topography is a digital elevation model (DEM). Good DEMs at resolutions finer than about 1 km are typically not available for Alaska, and even the 1 km DEMs are suspect in many northern regions. This will be a major limitation on the spatial extrapolation of climate elements across the ARCN. If this has not already been done, I recommend engaging the topographic remote sensing people at UAF to get their recommendations on the best available sources of elevation data and their limitation so we can be realistic about what is possible with spatial extrapolation.

PRISM Overview

Here is a short overview of PRISM, which mostly points to other sources of information. PRISM (Parameter-elevation Regressions on Independent Slopes Model) is an in-house, knowledge-based system for spatial climate modeling. It has been continuously developed and refined by Oregon State University's PRISM Group since 1991. PRISM climate maps produced by the PRISM Group are considered the standard in the US, and are the official climate maps of the USDA. PRISM spatial climate data sets for the US, China, and elsewhere are in widespread use worldwide (see, for example, Daly et al., 1994, 2001, 2002, 2003, Daly and Hannaway 2005, Daly 2006, Daly and Johnson 1999, Johnson et al., 2000)

PRISM adopts the assumption that for a localized region, elevation is the most important factor in the distribution of temperature and precipitation (Daly et al., 2002). PRISM calculates a linear climate-elevation relationship for each DEM grid cell, but the slope of this line changes locally with elevation as dictated by the data points. Beyond the lowest or highest station, the function can be extrapolated linearly as far as needed. A simple, rather than multiple, regression model was chosen because controlling and interpreting the complex relationships between multiple independent variables and climate is difficult. Instead, weighting the data points (discussed later) controls the effects of variables other than elevation.

The climate-elevation regression is developed from x,y pairs of elevation and climate observations supplied by station data. A moving-window procedure is used to calculate a unique climate-elevation regression function for each grid cell. The simple linear regression has the form

$$Y = \beta_1 X + \beta_0$$

where Y is the predicted climate element, β_1 and β_0 are the regression slope and intercept, respectively, and X is the DEM elevation at the target grid cell.

Upon entering the regression function, each station is assigned a weight that is based on several factors. In the general PRISM formulation, the combined weight of a station is a function of distance, elevation, cluster, vertical layer, topographic facet, coastal proximity, effective terrain, and topographic index weights, respectively. The combined weight W of a station is a function of the following:

$$W = f\{ W_d, W_z, W_c, W_f, W_p, W_l, W_e, W_t \}$$

where W_d, W_z, W_c, W_f, W_p, W_l, W_e and W_t are the distance, elevation, cluster, topographic facet, coastal proximity, vertical layer, effective terrain, and topographic index weights, respectively. Distance, elevation, and cluster weighting are relatively straightforward in concept. A station is down-weighted when it is relatively distant or at a much different elevation than the target grid cell, or when it is clustered with other stations (which leads to over-representation). Coastal proximity weighting is used to define gradients in precipitation or temperature that may occur due to proximity to large water bodies (Daly et al. 2003, Daly 2006). Facet weighting effectively groups stations into individual hill slopes (or facets), at a variety of scales, to account for sharp changes in climate regime that can occur across facet boundaries (Daly et al. 2002). Vertical layer weighting is used to simulate situations where rapid changes, or even reversals, in the relationship between climate and elevation are possible (i.e., temperature inversions). When the potential for such situations exists, the climate stations entering the regression are divided into two vertical layers, and regressions run on each separately. Layer 1 represents the boundary layer, and layer 2 represents the free atmosphere above it (Daly et al. 2002). Effective terrain weighting accounts for differences in the ability of terrain features to enhance precipitation through mechanical uplift of moisture-bearing air. Features having relatively steep, bulky profiles typically produce strong precipitation-elevation relationships; while low, gently rolling features have weaker relationships (Daly 2002, Daly et al. 2002). Topographic index weighting favors stations having topographic positions (e.g., valley bottom, ridge top) similar to that of the target grid cell. This is especially useful when interpolating temperature in regions where terrain configuration affects the spatial patterns of climate, such as the case of nocturnal cold air drainage and ponding (Daly et al. 2006).

Details on the PRISM station weighting functions are available through Daly (2002), and Daly et al. (2002, 2003, 2006).

Details on the PRISM Alaska maps and data used in their creation are available in a journal article in Artic:
http://www.ocs.oregonstate.edu/pub/prism/docs/ComparingMapsFinalProof.pdf
Animated graphics of the maps by Bill Manley can be viewed at:
http://instaar.colorado.edu/QGISL/AGCA/index.html

A Powerpoint presentation I gave to a Nature Conservancy salmon habitat workshop in Anchorage that introduces PRISM and describes the AK data sets is at: http://www.ocs.orst.edu/pub/daly/tnc/Daly_PRISM_TNC_051806.ppt

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Johnson, G.L., C. Daly, C.L. Hanson, Y.Y. Lu and G.H. Taylor. 2000. Spatial variability and interpolation of stochastic weather simulation model parameters. Journal of Applied Meteorology 39(6): 778-796.

David Atkinson's model …

John CASSANO's model…

Mesoscale regional atmospheric model:

- Could run 5-10 km horizontal grid spacing for multiple decades, but higher resolution increases computational cost significantly, so simulations with

horizontal resolution of ~1 km could only be done for limited times and small areas
- Is there a need for real-time regional model simulations or just retrospective simulations?

Synoptic climatology
- Use self-organizing maps technique for objective climatology creation
- Could be useful tied into GIS / statistical downscaling approach

In all of the methods, better information is needed to guide or validate their results. The two biggest unknowns are the coastal/inland gradients and the vertical valley/mountain gradients, in air temperature, cloudiness, and precipitation. Without new, local information, our ability to accurately spatially-extrapolate station data will be reduced.

Designing a network with spatial extrapolation in mind also allows us to better understand the representativeness of our individual stations. For example, if surrounding each of the Primary stations there were also several Secondary and Tertiary stations, we would arrive at a much better understanding of the spatial variances surrounding that Primary station.

Our questions:
- Are there other gradients we should be considering? Perhaps mountains to coastal plain?
RICE: Yes!

Your questions and comments:
RICE: Can we have regional villages and airports as primary stations, add 8 RAWS type stations as secondary stations, and have tertiary sites with data-loggers?

STURM: VALIDATION: THERE ARE TWO WAYS TO VALIDATE EXTRAPOLATIONS. 1) MET SITES THAT YOU PREDICT TIME SERIES FOR AND THEN COMPARE, AND 2) INTENSIVE CAMPAIGNS THAT MEASURE SPATIAL FIELDS (SNOW DEPTH) AGAINST WHICH THE MODEL OUTPUT CAN BE COMPARED. THESE ARE VERY DIFFERENT METHODS, REQUIRING COMPLETELY DIFFERENT EXPENDITURE OF FUNDS. WHICH ARE WE DOING? WHY?
DALY: Spatial and temporal trends are interrelated. It is possible to get one right (i.e., long-term mean) and other (i.e., temporal variation) wrong. This argues for the necessity of both primary and second stations; wherever primary stations are sited, they will still represent only a point on the landscape with unknown relationships with the surrounding region. These relationships will need to be quantified if the primary stations are to be interpreted correctly.

There is a very strong coastal proximity effect in northwest Alaska that will need to be characterized.

Individual Needs of ARCN Parks

Each of the five Parks and Preserves likely has unique needs for operational weather monitoring. For example, there may be a heavily used air strip, a unique cultural feature, or a unique weather anomaly.

Our questions:
- We need some guidance from NPS on this.

Your questions and comments:
STURM: WE ABSOLUTELY NEED A BALLPARK FIGURE ON SITES…5, 50 OR 500? OTHERWISE WE MAY FLOUNDER IN OUR DISCUSSIONS.

CASSANO: What is currently being used for operational weather data?
What additional real-time weather data is needed/wanted?

RICE: Locating weather stations @ airstrips, cabins, lodges, or other installations makes good sense and makes possible the sharing of logistics and costs for servicing.

Leveraging with Other Agencies or Projects

A reasonable approach to developing a new weather station network in this region is to start with a plan based on science, then determine which stakeholders in this plan may be able to contribute towards its development. Here we identify many of these potential stake-holders and outline ways in which we may be able to work together towards implementing this plan.

NOAA Climate Reference Network. Our Primary stations could be designed based on the CRN protocols, such that these new stations could be considered part of the official CRN network…Could there be cost sharing?

National Weather Service Forecasting.

North Slope Borough.

USGS.

NOAA RISA Program.

Academic Climate Change Research.

Oil field services.

BLM and State wildfire services. Our Secondary stations could be designed based on the RAWS protocols, such that these new stations could be considered part of the official RAWS network…Could there be cost sharing?

FAA/NOAA (ASOS and AWOS). Our primary or secondary stations could be designed based on the ASOS/AWOS protocols…

NRCS (SNOTEL).

Our questions:

- Input from other participants is requested to fill in these blanks.
- Are there other partners we should identify?

Your questions and comments:
STURM: I THINK THAT THE ISSUE ISN'T WHAT PARTNERS ARE OUT THERE, BUT RATHER WHAT ARE THE INSTITUTIONAL CONSTRAINTS THAT PREVENT MESHING NETWORKS. TRADITIONALLY, THIS HAS BEEN VIRTUALLY AN IMPOSSIBLE AREA TO BREAK DOWN BARRIERS. DO YOU WANT TO SPEND MEETING TIME ON THE ISSUE? IF SO, RATHER THAN IDENTIFYING NETWORKS, LETS DISCUSS HOW WE MIGHT BREAKDOWN BARRIERS THAT PREVENT NETWORK INTEGRATION.

SOP: Instrumentation

The selection of instrumentation depends closely on the goals of the station that they are placed at. Following the Primary, Secondary, and Tertiary model described previously, here are the major considerations for instrumentation selection.

Primary Stations. Perhaps the best model to follow here is the NOAA CRN station design. The CRN station design has already undergone extensive peer review and more than 200 such stations have already been deployed in the lower 48, with 20-30 planned for Alaska. Following their plan represents an excellent means for inter-agency collaboration and cost-sharing, both by not duplicating their scoping effort and by incorporating our locations and data into their network. Their stations were designed, however, for non-arctic locations that typically have AC power or sunshine throughout the year, so some modifications will be necessary. These modifications will need to occur for most of their Alaska stations and so in nothing peculiar to the NPS. These stations measure air temperature (2 groups of 3 sensors within 2 separate aspirated shields CASSANO:– are these measured at two separate heights?), precipitation (using a Geonor collector inside of a modified Wyoming gage fence), rain (using a tipping bucket inside of an Alter shield), incoming solar radiation (silicon pyranometer), wind speed, and wetness. Due to NPS needs and the lack of any other automated weather observations in this region, we may also want to add a 4 component radiometer (Kipp and Zonen CNR1), barometric pressure CASSANO: (this would be the most useful variable for data assimilation into weather forecasting models), and air quality instrumentation. Hardware costs are approximately $20,000, not including the power system or extra instrumentation.

Secondary Stations. Perhaps the best model to follow here is the RAWS designed used by BLM and DNR fire weather predictors. These are typically made from stock Campbell Scientific instrumentation, and complete RAWS systems are now available from them as stocked unit with pre-wired dataloggers and color-coded instrument hook-ups to the exterior of the logger box. Typical measurements include air temperature, relative humidity, rain, and … and costs are closer to $10,000. In terms of network design, since these stations are useful to fire weather predictors (who might also be willing to share costs), it might be reasonable to site these stations in low lands, and place the CRN's snow fences at these locations rather than mountain tops where wind measurements are more useful but snow scour and collection is a major problem.

Tertiary Stations. Perhaps the best model to follow here are stock units from Onset Computer Corporation. These range from simple stations measuring air temperature only for about $300/each to more sophisticated stations measuring air temperature, relative humidity, incoming solar, wind, and rain for about $3000. Sensor hookups are plug-and-play style (no wiring) and programming is quite simple, as the dataloggers automatically recognize the sensor type and the user only needs to choose a sampling rate. Satellite telemetry can be added to the more sophisticated station for about $1000.

Our questions:

- Does this seem like a good starting point for discussion?
- Have other NPS networks pursued or had any luck with cost sharing?
- How important is it to duplicate the station designs of other NPS units, compared with CRN?
- With limited funds to purchase and maintain stations, how should we prioritize weather and climate stations?

Your questions and comments:

RICE: What is the expected overall level of funding?

Can we swap out CRN sites for village/airport and focus installations inside ARCN to secondary and tertiary stations?

SOP: Deployment, Permitting, and Maintenance

Each instrumentation package will need its own deployment SOP. These should be straightforward to create, as each of the systems described above already have the foundations of such documentation created. The level of complication and manpower decreases from Primary to Tertiary stations.

An important aspect of deployment is permitting…

Questions of logistics are also important to consider as part of an SOP, as regulations on helicopter use vary between NPS units…

RICE: Policies, not regulations?

A comprehensive plan for deployment will also consider funding and timing issues. For example, we know that we cannot fund the full network deployment with first year funds and will likely never be able to fund the ideal network anyway, so a phased-deployment plan will be necessary. So once the locations are determined for the overall network, prioritization will need to occur as to which sites to instrument first.

Before the stations are deployed, several issues of long-term maintenance need to be addressed. For example, if telemetry shows that a station or instrument is non-functional, should it be repaired immediately, or as part of a regularly-planned mission? It is likely that each station will need at least one-visit per year, and this would likely occur in summer due to safety and logistical concerns. What sort of manpower and logistics are necessary for this? Maintenance procedures will also vary by weather station type. Fortunately, a good start on downloading and maintaining SOPs already exist for Primary and Secondary station designs, and Tertiary stations are so simple that similar SOPs are straightforward to create.

Our questions:
What else?
What lessons can be learned from other NPS networks?
- If NPS hires someone to help with ARCN's climate monitoring, what 'level' should this person be at? (e.g., technician, professional, PhD?)

Your questions and comments:
STURM: MOUNTINGS, RIMING AND THER ENVIRONMENTAL ISSUES/POWER/POWER/POWER

ISN'T PERMITTING EASY SINCE IT IS AN NPS PROJECT IN NPS PARKS?

SOP: Data handling and distribution

How the data will be handled after collection will depend considerably on the type of station it was collected from. For example, Primary stations are telemetered hourly and the data need to be ingested into national weather forecast systems in near real time.

Ideally, both Primary and Secondary stations will draw extensively on existing SOPs for similar data management. Some secondary and most Tertiary data will likely not feed into such systems, as it is used solely for long-term climate analysis and improvement of models, and so would have a quite different SOP with data downloaded on an annual basis…

The Western Regional Climate Center is an obvious choice for data archival…

Our questions:
- Seems like we need to get further along with answering basic questions of what we are trying to measure and what types of stations we will deploy before spending too much time on this.

Your questions and comments:

SOP: Data Analysis

Several types of data analysis need to be established. First, quality control must be performed on the data to ensure that it has been reliably delivered. Second, monthly and annual compilations of the data should be performed. Third, the compilations and raw data must be made available in easily digested formats and potential users and stake-holders need to be made aware of where the data is located and how to access it. Finally, we need to ensure that several analysis projects are making use of the data, including those related to spatial extrapolation, synoptic climatologies, prediction of future climate trends, and the questions addressed in the protocol summary.

Our questions:

- Do we need to identify these users now?
- What can we learn from other NPS networks?
- Again, before getting to much into data analysis, we need to determine and prioritize what questions we are trying to answer.

Your questions and comments:
RICE: Data users may be climate/weather researchers and modelers, aviators, subsistence hunters, travelers/Recreationists, park managers, wildlife biologists, ecologists, etc.

SOP: Long-term management strategies

Continued operation of this network is dependent on good planning and continued funding. A plan needs to be in place regarding long-term stewardship of this network within the ARCN and its partners. Further, in the unfortunate case that NPS funding is decreased for these efforts, back-up plans should be identified that can keep the network going. This may require inter-agency agreements …

Our questions:
- We need a lot of help with this one, but it's probably premature to speculate until we have a more solid set of goals.

Your questions and comments:
RICE: Work closely with NOAA – RISA, FAA, State of Alaska (ADOT), Native Corp's, and other private landowners.

SOP: Others?...

Vital Sign: Snow and Ice

Discussion on prioritization

Similar to “Climate and Weather”, a protocol for long-term monitoring of Snow and Ice can take a lot of different forms. Before creating a protocol, we must consider which of the aspects of snow and ice are most important for NPS to monitor. For example, do we measure snow thickness or snow water equivalent? We must also consider the spatial scales involved and consider what is logistically manageable. For example, do we choose an in-depth field index site, or try to use remote sensing methods? We must also consider the value of integrative methods vs. process studies. For example, do we monitor the growth and formation of lake ice growth throughout the year, or just make an end-of-winter measurement of ice depth measurement? We must also consider what other funding sources have to offer and make the best use of NPS resources. For example, NSF will never fund long-term monitoring of glacier mass balance, but they will fund an analysis of the relationship between an existing mass balance and climate records. Similar to Climate and Weather, the full suite of life-cycle components must be considered in the form of SOPs, including instrument deployment, data management and archival, data analysis, and long-term viability.

Overview and draft protocol summary

You can find a draft description of the Snow and Ice vital sign in the Appendix, taken from the draft Phase Two ARCN report. Below is a version of that description expanded into a *draft* protocol summary to start discussions at the workshop:

> ***Description:*** Snow and ice are dominant system influences in ARCN. Snow affects landscape vegetation patterns, drainage patterns, nutrient cycling, water quality, productivity of plants and animals, the degree and types of disturbance events, the timing of migratory and breeding events of organisms, predator-prey relationships, and the distribution of plants and animals. Lake ice formation, thickness, and breakup are also key indicators of regional climate, especially in the data-sparse regions that characterize much of the network, and exert dominant controls on lake productivity and aquatic ecosystem dynamics. The most massive changes to ARCN landscapes are caused by changes in glacier ice, and these changes influence both terrestrial ecosystems through their size and microclimates and stream ecosystems through their timing and volume of freshwater and sediment flux.
> ***Significance:*** Without some indication of trends in snow cover, lake ice cover, and glacial ice cover, we cannot understand the causes of change in a wide variety of biotic ecosystem components. Snow and lake ice are seasonal features which give us integrative information on the duration and severity of winter. Glaciers are persistent landscape features that give us integrative information of the decadal-scale climate trends. Comprehensively, measurements of all three features give us information on intra- and inter-annual climate trends that cannot be achieved through weather stations alone.
> ***Snow Monitoring Questions:***
> - Are patterns of snow deposition, timing, and extent changing?
> - What is the depth, phenology, and distribution of snow pack in ARCN?
> - What climatic factors control (precipitation, wind, weather patterns, etc.) the depth, phenology, and distribution of snow in ARCN?

- What feedbacks exist between snow and vegetation and how are these influencing ecosystem form and dynamics?

Glacier Monitoring Questions:

- What can glaciers tell us about the climate of the past 150 years?
- What can glaciers tell us about the climate of the past 150,000 years?
- How are glacier extents and volume continuing to change, and what does this tell us about current climate?

Lake and River Ice Monitoring Questions:

- What are the annual thickness and duration of ice and snow cover in lakes and lagoons?
- Is the duration and thickness of ice on lakes and streams changing?
- Where does aufice typically occur in ARCN?

Proposed Metrics: Snow: thickness, water equivalent, extent and timing; Lake ice: thickness, duration, spatial variability; River ice: freeze-up and break-up dates; Glacier ice: extent and volume change, mass balance.

Specific Methods, Spatial Scale, and Frequency of Measurement: Field, modeling and remote sensing methods

Current Monitoring: Kanuti currently has an aerial snow marker course. There are SNOTEL sites at four locations on the eastern boundary of ARCN (Imnaviat Creek, Atigun Pass, Coldfoot, and Gobblers Knob) and one site between Noatak National Preserve and Cape Krusenstern National Monument (Ikalukrok Creek).

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Linked Vital Signs: Climate and Weather, Sea Ice, Terrestrial Landscape Patterns and Dynamics, Terrestrial Vegetation and Soils, Surface Water Dynamics and Distribution, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems

Our questions:

Your questions and comments:

STURM: IT STRIKES ME THAT WHILE OTHER VITAL SIGNS ARE IN THE MONITORING PHASE, SOME OF THE SNOW, ICE PERMAFROST IS STILL IN THE INVENTORY STAGE: WHAT IS IN THESE PARKS? THIS INVENTORYING CAN BE TIED TO IOPS TO THAT CAN BE SUED TO VALIDATE EXTRAPOLATION METHODS.

RICE:

1) What NRCS snow courses are measured in or near ARCN units?
2) Should we consider hardness and temperature gradients in snow packs? These may be important for wildlife and vegetation.

3) I think a tiering of snow measurements should parallel weather stations, such as NPRCS monthly snow surveys and other sampling near primary weather stations, Snotels near secondary sites, and snow stakes near tertiary sites.

HAMILTON: "Aufeis" is misspelled. In addition to "Where does it occur", we might also ask "What controls its distribution" and "Is aufeis decreasing in thickness or extent as climate warms". Using revegetation studies of formerly more extensive aufeis fields, we should be able to trace aufeis dimensions back 100-120 yr.

SOP: Long-term temporal patterns in snow cover at index sites
Measurements, modeling, remote sensing (including airborne Lidar (temporal change) and the need for good DEMs)…

SOP: Spatial extent, thickness, and duration of snow cover with ARCN
Same…

SOP: Others?...

Our questions:

Your questions and comments:

SOP: Glaciers extent and volume change
Glaciers in the ARCN are currently undergoing massive wastage and represent the single largest landscape-change feature within ARCN and Alaska. The reasons for this volume loss are clearly related to climate change over the past 150 years. Through field work, modeling, and remote sensing, we have the opportunity to both understand the history of climate change in this region, but we can also use glaciers as an integrative measure to understand the impacts of temperature and precipitation changes for the future.

A simple, low-cost approach to long-term inventorying and monitoring is through repeat photography. It also has the added advantage of being something easy for the public and policy-makers to understand with little ambiguity. All of the glaciers in the park should be photographed, both from the air and the ground, with perspectives and clarity that will serve as benchmarks for the next 100 years. This means choosing photo locations that can capture variations that include major retreat and major advance. Included with this photographic survey should be the deglaciated glacier forelands with an emphasis on ecosystem evolution there. Having a pleasing scenic and compositional quality is also an important aspect of this quite visual method. Periodic repeat photography should occur on time-scales of not longer than 20 years, with perhaps a tiered approach where some interesting and logistically convenient glaciers are photographed every year and others every 5 to 10 years.

While repeat-photography *qualitatively* captures the long-term changes of interest, volume change is the next simplest integrative measure that actually *quantifies* the impacts of climate change on the glaciated landscape. Here repeat surface elevation measurements are used to determine the actual amount of ice lost or gained over a time period. As with repeat photography, an initial survey should calculate volume change over all of the glaciers over the past 50 years through comparison with USGS maps. Then a temporally-tiered monitoring program can track changes throughout the future, with a complete volume change study occurring every 20 years, key index glaciers measured every year, and perhaps 5 to 10 more measured every few years. On the 20-year schedule, new topographic maps are required of each glacier to properly capture their changing hypsometries. Higher frequency measurements can be made with one or more transects, either measured from the ground with GPS or from the air with laser range finding.

To properly relate the changes in ice volume to changes in climate (including the past 150 years), long-term field studies need to occur on 1 to 3 glaciers. Here local measurements of weather and glacier mass balance are combined with flow and mass balance modeling to develop a complete understanding of the long-term evolution of these landscape features. Knowledge learned from these studies can then be extrapolated across ARCN for better understanding of both current and prior glaciations and thus the influence the exert over ARCN ecology. On site measurements would include the establishment of a stake network (3 to 5 stakes) for mass balance and velocity, co-locating studies with long-term climate measurements, establishment of several on-ice weather stations to understand the micro-climatology (and its long-term evolution), ice thickness measurements, and other required process studies. Should a suitable candidate be found, extraction of ice cores could be used to better understand prior climate. Similarly, knowledge learned here can be used to hindcast the climates necessary to generate the massive moraine features of prior ice ages through modeling.

Our questions:
- Does this seem like a reasonable plan?

Your questions and comments:
HAMILTON: The 100-yr interval in 2nd par. seems at first read to be inconsistent with the 50-yr interval cited on p. 11. I know these are as different as apples and oranges, but a few extra words might make the distinction more clear. Also in the 2nd par., we should stress opportunities to determine other changes (talus, accumulation, foreland vegetation changes, etc.) from repeat photos.

SOP: Lake and River Ice

The duration and thickness of river and lake ice cover exerts strong controls on the landscape and ecology, but due to their large numbers and huge spatial distribution with ARCN, it will be impossible to measure any substantial number of them. Thus the best solution might be a two phased monitoring approach involving field work, remote cameras, satellite remote sensing, and modeling.

The long-term strategy would be to establish 1 to 3 long-term index sites where lake ice thickness is monitored at the end of winter. Ice thickness is an easy parameter to measure in the field and is essentially an integrate measure of the impact of the severity of the previous winter. The lakes should be located near to existing weather stations with a reliable means of extrapolation to the lake surface. A time-lapse camera would document the onset of lake ice formation and the mechanisms and timing of lake-ice melt, through daily photographs.

The short-term strategy would be to conduct similar studies at a diverse set of lakes throughout ARCN, covering a broad distribution of sizes, depths, climatic regimes, and local influences (such as inflows and outflows), on about 10 lakes total. Here several ice thickness measurements could be made throughout the year, and these used to calibrate or validate lake ice modeling. Once the spatial patterns in lake ice cover are determined and the lake ice model deemed sufficient to capture the dynamics, the several sites that will become long-term index sites can be selected.

There are variety of good reasons to collocate some of these long-term sites with existing or planned sediment coring studies…

RICE: Use Matcharak and Burial Lakes in Noatak drainage with WACAP sediment cores and dating.

The strategy for river ice monitoring would be quite similar to lake ice monitoring, with the exception that rive ice modeling is much more complicated and likely not as cost-effective. Here, local site knowledge will be very important to determining a strategy, as river ice breakup in highly non-uniform and ice jams tend to develop at the same locations year after year. Here, the monitoring strategy may be to establish several web-cams along the largest rivers (Noatak, Kobuk, etc.), prioritizing for locations where ice jams tend to develop. A few long-term thickness measurement locations could be established, perhaps in proximity to village infrastructures which both reduce logistical costs and leverage with natural hazard needs.

RICE: Absolutely, see previous comments throughout!

<u>Our questions:</u>

- What other studies already exist within the ARCN?
- Does this seem like a reasonable strategy?

Your questions and comments:

STURM: ONLY 3 LAKES! IT SEEMS LIKE WE WANT A MORE EXTENSIVE NETWORK OF EASIER TO OBTAIN DATA. INSTEAD OF TIME SERIES MONITORING, ANNUAL OR SEASONAL MEASUREMENTS BUT IN MORE PLACES. IN GENERAL LAKES OFFER A LESS AMBIGUUS METRIC FOR BREAK-UP THAN RIVERS. WHAT ABOUT AN ANNUAL SPRING TRIP, OR IKONOS IMAGERY TO DOCUMENT THIS SEASONAL DATE WIDELY.

RICE: WACAP will have final reports in spring 2007.

HAMILTON: We need to include local observers in recording river breakup and other natural phenomena. Natives need to be brought in as partners in monitoring.

Vital Sign: Permafrost, Peatland Soils, and Thermokarsting/Solifluction

Discussion on prioritization

Similar to the previous two vital signs, a protocol for monitoring permafrost, peatland soils, thermokarst and solifluction can take many forms. Before creating a protocol, we must consider which of the aspects of these are most important for NPS to monitor. For example, do we measure permafrost thickness or just near surface temperature, or both? We must also consider the spatial scales involved and consider what is logistically manageable. For example, do we drill thousands of boreholes to measure permafrost thickness or rely more on modeling? We must also consider the value of integrative methods vs. process studies. For example, do we monitor the growth of the cold wave through the active layer, or just maximum active layer thickness? We must also consider what other funding sources have to offer and make the best use of NPS resources. For example, NSF will likely never fund a long-term borehole-temperature monitoring effort, but they might fund development of a model that uses such temperatures to reconstruct climate. Similar to Climate and Weather, the full suite of life-cycle components must be considered in the form of SOPs, including instrument deployment, data management and archival, data analysis, and long-term viability.

Overview and draft protocol summary

You can find a draft description of the Permafrost vital sign in the Appendix, taken from the draft Phase Two ARCN report. Below is a version of that description expanded into a *draft* protocol summary to start discussions at the workshop:

> ***Description:*** Permafrost extent and thickness is largely controlled by air temperature, snow thickness and duration, and vegetative cover – we know that each of these is changing, and so must be affecting permafrost. This anticipated change in permafrost will have broad impacts on regional hydrology, peatland soils, biogeochemistry, and vegetation patterns and therefore on large-scale ecosystem structure and function. Thermokarst could lead to altered soil nutrient dynamics in ARCN parklands with their extensive, and largely icebound, soil organic matter reservoirs (peatlands). Thermokarst will likely have significant effects on carbon sequestration in wetter areas, and loss of permafrost may cause drier, more aerobic soil conditions in upland areas. Monitoring changes in permafrost presence (and depth to permafrost) would provide a simple indicator of interactions between climate and soil.
> ***Significance:*** Changes in permafrost will have large effects on hydrology, water quality, soils, vegetation, and trace gas emissions.
> ***Monitoring Questions:***
>
> - What is the extent, thickness and temperature of permafrost within ARCN and how are these changing over time?
> - What can permafrost temperatures tell us about past and current climate?
> - Is widespread thermokarsting occurring and what are its causes?
> - What are the impacts of melting permafrost on nutrient cycling, element transport to aquatic ecosystems, and hydrologic networks in ARCN?
>
> ***Proposed Metrics:*** Deep and shallow borehole temperatures, temperatures of ground surface and permafrost, surface topography, amount of thaw settlement, active-layer depths, groundwater depths, organic thickness accumulation, total extent of thermokarst using

remote sensing, total extent of differing types of thermokarst, and lateral rates of thermokarst, time since fire

Specific Methods, Spatial Scale, and Frequency of Measurement: A permafrost monitoring network would involve five types of efforts: (1) deep permafrost temperatures would be measured at a few regionally representative sites each year; (2) field monitoring of shallow ground temperatures, surface topography, thaw depths, and groundwater depths would be measured at a network of approximately 10 monitoring transects every three years; (3) baseline ground ice and carbon stratigraphy would be measured at three to five cores per transect; (4) remote sensing would use high-resolution imagery at the monitoring sites to measure total extent of thermokarst, total extent of differing types of thermokarst, and lateral rates of thermokarst every 10 years; and (5) high-resolution aerial photographs would be acquired at 300 to 500 points across ARCN to quantify extent and type of permafrost degradation every 10 years.

Current Monitoring: ARCN baseline study of thermokarsting in the Noatak Basin (2006).

Key References:

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Osterkamp, T. E., and A. H. Lachenbruch. 1990. Thermal Regime of Permafrost in Alaska and Predicted Global Warming. Journal of Cold Regions Engineering **4**:38-42.

Linked Vital Signs: Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems, Weather and Climate, Snow and Ice, Terrestrial Vegetation and Soils, Coastal Erosion, Surface Water Dynamics and Distribution

Background

With most of the ARCN underlain by potentially unstable permafrost, there comprehensive monitoring plan is needed…

What we know about permafrost here…

What we don't know about permafrost here…

What we know/don't know about thermokarst here…

SOP: Permafrost temperature monitoring

Similar to the weather station network, a tiered approach is perhaps best for monitoring temperatures, with several index sites with deep boreholes at logistically convenient locations and preferably in association with Primary weather stations, and numerous sites with shallow, inexpensive boreholes distributed throughout the ARCN hopefully in association with Tertiary weather stations…

SOP: Mapping temporal changes in permafrost extent

Modeling constrained by measurement…

SOP: Detection and measurement of thermokarsting

New methods of rapidly and accurately detecting changes in surface elevation due to thermokarst are now available and ready to be implemented. Specifically, the capabilities of repeat mapping of surface elevation with airborne and ground-based lidar are such that changes on the order of a few centimeters are detectable through differencing of the digital elevation models (DEMs) that they create. Airborne Lidar operates by collecting a swath of elevation data (typically about 1 km wide) with a spatial resolution and vertical accuracy of about 10 cm, easily capable of detecting and delineating thermokarsts, which typically occur on spatial scales of 10s of meters and vertical scales of up to several meters. Airborne Lidar transects made each year over selected areas can track the onset and evolution of these unstable landscape features, and map them optically with an associated camera. Similar, ground based Lidar can be placed on a tripod within a depression and the unit swings through 360 degrees, mapping anything within 300 m. An associated camera can automatically image the depression with a 470 megapixel camera. Thus another two-tiered plan could develop, where the airborne sensor collects broad area information in areas selected for their diversity within the ARCN and the ground-based sensor could be deployed at several index sites to monitor their long-term growth in higher resolution. The combination of technique should offer great insight into the thermokarst process and the ecological changes that result from it. A comprehensive airborne survey should be conducted as soon as possible of as large an area as possible, and repeated on a 10 to 20 year intervals. Ground surveys could be conducted more frequently.

YOSHIKAWA: We should including ground water and winter base flow monitoring of Major Rivers such as Noatak River. Groundwater/ winter base flow will be one of the response incidents by the absent or present of the permafrost. Groundwater monitoring well will be easier comparing with base flow discharge measurements. USGS have some site near Kivalina (see http://pubs.usgs.gov/wdr/2005/wdr-ak-05-1/regions/northwest/index.php). However, no well monitoring at Northwest. It will be nice well and discharge monitoring at least one at Noatak.

HAMILTON: "Thermokarsting" is not a word (no more than would be "karsting" in limestone terrains). The process is "thaw of ice-rich permafrost", or the short but inexact "permafrost thaw". In limestone terrains, the process is "solution". Thermokarst is great as a noun, and is a fine adjective ("thermokarst ponds", thermokarst gullies", etc.), but it is not a verb.

<u>Our questions:</u>

- What other studies already exist within the ARCN?

Your questions and comments:

YOSHIKAWA: The density of the borehole monitoring network will depend on a resolution of the modeling or other goal issue. Most of the permafrost model is not high enough to associate slope aspect or vegetation distribution which is most important factors of the permafrost condition in warm area. If we need regional (local) scale model, it definitely requires a lot of monitoring sites, which cannot make deep as reality. I would say the depth of the boreholes should go zero annual amplitude depth. It will be nice to have deep borehole (maybe warmest and coldest site in the each park?). It makes to understand long-term temperature trends and local heat flow rate.

Geophysical investigation will be a one of the potentials for filling in the borehole network. I attached old proposal, you can take some paragraph for background and SOP. Also under this SOP, we should classify and measure organic layer, thermal conductivity. The area most likely will have wildfire for long-term scope. Surface condition change / disturbance strongly affect this SOP.

HAMILTON: In discussing permafrost observations, some attention should be paid to geophysical approaches. Very difficult for permafrost thickness, but fine for delineation of its upper surface and for detecting taliks. Also, it should be emphasized more strongly that active layer thickness varies with soil material (shallow in peat, thicker in silt, thickest in gravel). Monitoring should be via transects across different materials. ~~In discussing permafrost observations, some attention should be paid to geophysical approaches. Very difficult for permafrost thickness, but fine for delineation of its upper surface and for detecting taliks. Also, it should be emphasized more strongly that active layer thickness varies with soil material (shallow in peat, thicker in silt, thickest in gravel). Monitoring should be via transects across different materials.~~

Matt Nolan's notes from the NPS Bodega Bay Workshop 7-9 Dec 2006

(note: I'm no secretary and was also trying to lead and contribute to the discussions while taking these notes, so that are not meant to be comprehensive, just indicative of what was being discussed.)

Thursday 7 Dec 06
"Climate and Weather Protocol"

10AM

Nolan: Should we focus on measuring weather or climate?

Sturm: fewer stations with better maintenance is better than more stations with poorer maintenance

Redmond: agrees, "consistency to the rescue" – good protocols vital

Shulski: National Weather Service would be heavy users of any data telemetered in real time, they would notice problems sooner than we would because they would look several times per day, unlike climate scientists once per month or year

Baker: The highest priority is to describe the state of environment, at the best temporal resolution; telemetry important but secondary priority

Cahill: Co-location of weather stations with other measurements is important for science and logistics

Sturm: Need for ARCN network has two driving attributes: 1) the largest changes on the plan in temperature and precipitation are likely happening here and 2) this may be the sparsest coverage of nearly anywhere

Redmond: Weather station networks have several attributes: 1) physical attributes (sensors etc), 2) a monitoring system is social system too (money, personalities, etc), and 3) time-scales (sample rates, station longevity)

Redmond: Most networks fail

Daly: new resources are clearly needed that have solid constituencies to ensure longevity. What is the risk factor – NPS funding future?

Sanzone: the more people that care, the more weight is carried for funding priorities. The NPS funding for this is a line-item, so the risk is real.

Hamilton: Consider constituent base (e.g. native corps, manual observations etc), e.g. ~~Alakaket's~~ Allakaket's long term record (with gaps)

Heinlein: Need strong high level support; the more collocation the better.

Sousanes: Collocation important – makes for good watchdogs as other users are in area and can check for problems; forecasters make the best watchdogs

Urban: Telemetry is useful for sharing data and helping check for problems with their sites, also opens options for short and long term support; can let forecaster use evolve naturally

Rice: All sites require permitting, there are wilderness issues to consider, EA's must be written; NEPA – good way to contact constituents

Redmond: need to survey public attitudes on stations here and get public support. It is possible to camouflage stations.

Rice: Camouflage is good idea for mitigation

Hamilton: Proper signage is important to deter vandalism and gain public support

Booth: Helicopters are the primary problem

Cahill: Need to go point-by-point through enabling legislation for justification support; scientific use is supported there

Baker: Start with science to justify logistics

Sturm: Synoptic scale – what are we not resolving currently?

Cassano: New stations are not going to improve climate models (e.g. MM5), but will help resolve local impacts

Daly: Networking to find existing data will help improve models and need to survey the parks for prior climate data. Important to span spatial scale – meso to micro. Cassano's work is critical. How do we downscale? Need both top down and bottom up models.

Cassano: Can get at variability using high resolution (1 km) regional model, but only for limited duration due to CPU time. Can use ground stations to validate or inform.

Booth: 2 options – pure climate research or weather data. Can we do it? Need to collocate and prioritize with other needs.

Sturm: Two tracks: 1) core sites – high constituency with 50 year lifespan, 2) intensive observing campaigns (5-10 year life)

Daly: We may find that we may not want to move Hobo stations – transfer functions not stationary sometimes.

Redmond: What is the minimal set of stations?

Sousanes: In CAKN installed 15 new stations and 5 new Snotel sites, Snotel critical; keep RAWS sites going, 100 total stations between partners. Maintenance about $2000 per station per year.

Baker: CRN maintenance is about $5000 per station per year.

Sousanes: Perhaps NPS networks can share technicians, maintenance supplies, etc.

Sanzone: Visitor numbers are down in parks, only a few thousand visitors per year in ARCN. Questions about ARCN (e.g. climate change) are driven by public not necessarily by visitors. There are about 10 vital signs and about $1M for monitoring, so about $100k each. A quarter of last year's budget was spent on logistics. It costs $3000 just to go to Feniak lake.

Urban: Logistics are biggest costs for USGS north slope stations.

Baker: How to use old station sites and data with new stations – continue long term trend.

1:30 PM

Daly: Coastal gradients may change over time

Sturm: Seward Peninsula has strong north-south gradient

Redmond: Put long-term stations in transition areas

Nolan: Use of time-lapse cameras or web cams should be standard weather station equipment

Yoshikawa: Hobos are great – cheap and high resolution

Sturm: Let's put dots on map together and see where we would all want to have primary stations – I bet we could converge rapidly on locations.

Sanzone: What defines a primary station?

Baker: CRN sites use 3 air temp sensors in a single aspirated shield and have 2 precipitation gages. Most important is to have NIST traceable calibrations.

HOMEWORK: Put dots and lines on Map for tertiary stations.

3:30 PM

Nolan: Sounds like we have consensus that a tiered system is a good idea, and better to have a few stations maintained well than many poorly maintained ones.

Nolan: How can tertiary network integrate with other monitoring?

Sanzone: Gives overview of existing vital signs

Booth: overview of vegetation studies.

Nolan: Tertiary systems can be reduced to secondary systems – those tertiary sites that we don't have the heart to demobilize.

Sanzone: ARCN is different than any other network. E.g., tree line and shrub expansion is rapid and ongoing

Sturm: Tertiary measurements need to be made at the scale of the process of interest

Rice: Noatak drainage travels through several parks, good tertiary studies

Nolan: Float trip deployments – save logistical costs.

Sturm: What are climate needs for spatial extrapolation?

Friday 8 Jan 06

"Permafrost and Active Layer" Protocol
8:15AM

Sturm: Are we inventorying or monitoring permafrost?

Hamilton: Very little is known about permafrost within ARCN. It can't be studied with remote sensing, needs detailed ground studies.

Sturm: Needs well informed ground studies.

Yoshikawa: Resolution is biggest problem. Modeling is difficult.

Daly: PRISM model could output something useful. Need good DEMs.

Hamilton: Thermal lag introduces response time, need to understand

Urban: overview of USGS borehole studies. GTN-P: 30m and 120 m boreholes, met stations. Huge recent changes.

Yoshikawa: overview of his shallow borehole network at schools. Proposes 1 or 2 deep holes and many shallow holes. Cost about $350 per site.

Balser: Thermokarst is extensive. Mapped 197 in a small area this summer. Found 4 types of these. Need to collect air photos ever 5 to 10 years.

Hamilton: Native observations are useful. Use stakes to monitor thermokarst expansion.

Kaufman: Solifluction? Need to assess stream ecology impacts.

Hamilton: Most solifluction happening in spring when surface is wettest.

Yoshikawa: Remote sensing shows water color in streams (sediment load). Important linkages to stream ecology. Need to consider many things when siting boreholes – inversion, aspect, free of trees.

"Snow and Ice" Protocol

Nolan: Glaciers are important park resource. Most massive changes in landscape. Impacts on local landscape and also streams and lakes. Good for climate change impact studies and paleo.

Kaufman: Several lakes close to glaciers in ARCN. Glaciers have scenic value as park resource.

Geck: Need new DEMs in ARCN. USGS are out of date and inaccurate.

Kaufman: Only 2-3 good glacial lake targets for paleoclimate study
Sturm: Break up dates of lake ice have been useful, trends have been found in other studies.
Hamilton: River ice break up dates also useful. These provide regional perspective vrs. more local significance of lake-ice records.
Sturm: Noatak and Anaktuvuk river ice break up, observations by locals. Rivers have strong hydrological control – good climate signal (probably better than lakes).
Peterson: Can use Modis for lake ice timing breakup, maybe also on Koyuk and Noatak rivers. River discharge measurements very valuable.

11AM
Sturm: Describes prior snow studies and what is important. Most parameters (snow fall, interception, wind transport, sublimation) difficult to measure; snow thickness and SWE are easy to measure in the field.
Sturm: Two measurement types: weather stations and field campaigns. Weather stations monitor temporal component by gages, sonic rangers, cameras, and soil and snow temp – most have issues. Snow courses at each site are good ideas. Field campaigns – have to be done on the ground. Can design snow machine traverse to maintain weather stations. Need to occur at end of winter at minimum, more often would be useful.
Sousanes: Aerial markers can be used.

Saturday 9 Dec 06

Break out session review
9AM
Sanzone: What about two test sites?
Baker: "Functional testing"
Sturm: Just get going doing something in the field. Try something of everything for prototyping.
Hamilton: For primary station with concrete pads, place on gravelly soils which do not heave.
Rice: Some precedents for temporary siting permits, radio repeaters in Denali, 3 year testing
Baker: Telemetry – try GOES w/ full backend data delivery of CRN. Use a phased approach to test and deploy. Try scalable systems – put in 3 m tower now but include capability to increase to 10 m. Consider flexible instrumentation – no need to install everything at once.
Nolan: Agrees – NPS can get sites going, allowing partners to hang their own instruments, build constituent base for long-term
Hamilton: Nice to have up-front partnerships. In the foothills, BLM, North Slope Borough, Native Corps.
Nolan: Have been in contact with NSB biologists
Sturm: NSSB has been trying for years to make collective effort, but getting no where so far.
Booth: Primary stations – too many?

Cahill: Primary stations should feed models.
Nolan: Tertiary climate sites design to improve extrapolations
Sturm: Red stars (primary sites) have reasons for being there. Issues will drive some locations. The Park service is the only agency with money for this right now – can make its own decisions. Just get going now. This plan is exciting – its more than just towers, it's a model for implementation. This is THE place in Alaska that needs a network now.
Rice: Stick with Noatak park for initial permitting –easier there as science is integral. Do lots of recon this summer and get permitting underway. May take a year.
Sturm: Snow machine traverses are great for logistics – took 4 tons of gear on last trip.
Hamilton: Good sites for met stations are very sparse and have likely been used prehistorically. Be alert to potential archeological impacts.
Nolan: Let's hear more on synoptic climatology of the area.
Cassano: describes NAO, AO, etc., weather patterns change and have big impacts, need better topography. No synoptic climatology currently, but is possible to do with ERA40 etc
Sturm: Agrees – need a synoptic climatology suitable for terrestrial researchers.
Cassano: Uses Polar MM5 1957-2004. Have completed 50 km resolution of all Alaska. Can make synoptic climatology from this, AGU talk on this next week. Combine this with info from weather forecasters, ERA40 analyses, etc.

Wrap-up – consensus views
Noon

<u>"Climate and Weather" protocol</u>

- overarching question: "What is the natural spatial and temporal variability in weather and the long-term (from LIA to +50 years) climate trend in ARCN units?"
- tiered system is a good idea (spatially scaled by level, as well as by rigor and longevity)
    - primary station – defined by permanence and rigor (not just by the suite of sensors).
    - Tertiary stations – for climate and weather, these would help define spatial trends for both modeling and representativness of primary sites (e.g. winter precip, AT), designed to be temporary. When possible, collocate with other vital signs studies.
    - Secondary – could be tertiary sites we cant bring ourselves to remove (possibility for long-term temporal)
- collocation is a high priority, but need to be careful depending on particular variable
- station design: goals for detection limits: 1C/decade and 2%/decade
- temporal redundancy for reliability and uncertainty (QA/QC), failures, different gadgets, multiple gadgets, storage/telemetry, communications,
- spatial redundancy – 2^{nd} and 3^{rd} tiered station
- capture high elevation stations, not just low, contaminants

- create a synoptic climatology that captures weather system dynamics and interpretation of trends
- need to create the modeling infrastructure to create isotherm maps, precip maps, long-term averages, monthly Tmin, Tmax, Tav, link PRISM with MM5
- a priority in network design should be feeding spatial models
- SOPs to support other vital signs, e.g. with tertiary stations
- Functional requirement document – limit liability?
- Weather is not our priority – climate is our highest priority
- Updated synoptic climatologies – annual; putting trends and variability of climate into the context of trends and variability of synoptic types
- ARCN web pages for facilitating data access related to parks (e.g. NAO indices)
- Data management and delivery, metadata
- Data analysis summaries
- Lake paleoclimate study SOP (1000BP to now), grading into future monitoring project
- Noatak river discharge and base flow, as integration of weather (precip, etc)

<u>"Snow and Ice" Protocol</u>

- Snow – site measurements coupled with field measurements (snowmachine and aerial surveys), plus snow chemistry
- Aufeis – extent and thickness links with climate change; possible future research projects through other agencies; need to inventory first; relationship to water budget and winter base flow, revegetation record
- Lake ice – remote sensing, coordination with lake sediment coring projects, or other collocations, nested study, thickness (local, more spatially variable)
- River ice – break up dates, coordination with local villages
- Glaciers – photographic surveys, volume change (new DEMs and GPS studies), long-term mass balance
- Discharge for snow melt and hydrology

<u>"Permafrost and Active Layer" Protocol</u>

- permafrost— spatial distribution, modeling (0C isotherm variations, with shading (i.e. equivalent lat)), continuous vs. discontinuous, lake taliks – define boundaries
- permafrost temperatures – a few deep boreholes supplemented by many shallow (<6m) boreholes (for zero amplitude depth), collocated with other stations, and active layer (temp, soil moisture) and CALM
- tiered approach – mimic weather network design, with SOPs to guide other projects
- active layer monitoring important (coordinate with other vital signs, help with SOPs)
- thermokarst – inventory of current situation, change with warming/precip, archival air photos (back to 1940s), steady state thermokarst vs. climate warming
- thermokarst/solifluction – impact on ecosystems, stream sedimentation, vegetation plots, what happens to them in the future?
- Closed/open taliks beneath lakes and rivers

General network design and issues

- use prior intensive research to guide network design
- new digital elevation models are required for nearly all vital signs monitoring
- use differences in scales to cross-check and discover new linkages
- get input from experienced arctic types to guide plans