Arctic National Parks Evaluation:
Proposed Climate Monitoring Plan

Cottongrass. Gates of the Arctic. NPS Photo by Al Smith.

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Summary

The National Park Service (NPS) Inventory and Monitoring (I&M) Program Arctic Network (ARCN) has identified climate as an important vital sign, and proposed the establishment of a climate monitoring network for the five northernmost parks in the NPS system. These include Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Kobuk Valley National Park, Noatak National Preserve, and Gates of the Arctic National Park and Preserve. These parks encompass a vast area of 19 million acres and comprise a quarter of all NPS acreage. The severe climate of the Arctic is integral to the character of these park units, and imposes a significant influence on biological, cultural, and physical function. Climate change is expected to be greatly accentuated in the higher latitudes, and many forms of empirical evidence indicate that projected changes have begun. Information on climate for national park units is currently in wide-ranging demand by visitors, managers, the research community, and for routine operations by park staff. Only a few climate stations now exist in this immense region, and a large portion has no monitoring at all, resulting in the lowest spatial station density of all NPS units nationwide. The existing ARCN climate station network is currently inadequate to describe the spatial and temporal variations and trends with sufficient detail to understand the effects of fluctuations and slow changes in climate on ecological communities, hydrology, landscape alteration, and human activities. This report serves to: 1) perform an evaluation of the proposed station network, 2) examine the rationale behind various choices and suggestions, and 3) provide comments on the process followed. The latter comments address: 1) allowance for special circumstances such as the large amount of designated and de facto wilderness, 2) the stations themselves and their placement, and 3) the overall approach.

As a whole, the proposal is well written and well reasoned, incorporates lessons and experience from similar past efforts, and anticipates upcoming stages of further comment and review. The proposed network and activities will greatly improve knowledge and understanding of the climate in this region, and produce significant net benefits to park managers and visitors.

1. Introduction

The National Park Service (NPS) Arctic Network (ARCN), one of 32 such networks in the NPS Inventory and Monitoring (I&M) Program and one of four in Alaska, is considering the deployment of climate monitoring stations to provide direct on-the-ground measurements from within the five park units in that I&M region. The purpose of this report is to evaluate the process followed by ARCN in developing a list of candidate station locations and measurements, and the rationale behind the individual sites and the network as a whole.

The five park units include: Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Kobuk Valley National Park (KOVA), Noatak National Preserve (NOAT), and Gates of the Arctic National Park and Preserve (GAAR). In area, these total over 19 million acres and cover approximately one quarter of the entire area managed by NPS in the 50 states. Climate has extensive influences on ecological processes and human activities within this region, and in many important ways defines these areas (Davey et al., 2006).

This vast, varied, primitive, and astonishingly beautiful landscape presently is home to a mere handful of observing platforms, including three Remote Automated Weather Station (RAWS) fire-weather stations, and an FAA AWOS III (Automated Weather Observation Station) at the Anaktuvuk Pass airstrip. In order to address this lack of spatial coverage, a network of 17 surface stations has been proposed for ARCN by the I&M Program (Sousanes, 2009) The network includes 4 stations in BELA, 2 in CAKR, 1 in KOVA, 6 in NOAT, and 4 in GAAR. Materials examined in the preparation of this report included the site evaluation document, more extensive sets of digital photos of potential sites, a station inventory report for ARCN by Davey et al (2006), and discussions and presentations with NPS personnel in Fairbanks, Alaska during a visit in October 2009. Earlier evaluations of climate monitoring strategies and locations in other Alaska I&M regions (Central Alaska, CAKN, Redmond and Simeral, 2004; and Southwest Alaska, SWAN, Redmond et al., 2005) address issues that are very relevant to proposed ARCN activities.

2. Climate monitoring strategy process

Numerous trade-offs must be made in the development of a concrete proposal for the number of stations and their locations. Among these are:

- Acquisition cost
- Accessibility of site
- Maintenance
- Communications
- Reliability
- Aesthetics
- Knowledge gaps
- Representativeness of site
- Type of exposure
- Solar charging potential
- Wilderness issues
- Animal damage
- Density of stations
- Microclimate effects
- Potential constancy of site characteristics
- Future information needs

There is considerable evidence that previous experience and guidance have been incorporated into the strategy that resulted in the suggested number and placement of stations. It is also clear that careful thought went into the particular selection of station locales offered. The document describing the potential sites (Sousanes, 2009) is clearly written, straightforward, easy to follow, and along with the accompanying Powerpoint slides (easier to magnify and with more photos), yield descriptions that are quite adequate for the purpose intended.

A variety of circumstances particular to ARCN were taken into account. Comments on these are offered in individual sections below.

3. Existing stations

There are few existing weather or climate stations within these park units. Of the three contiguous parks, NOAT has two sites, KOVA has one, and GAAR has one (aviation weather). The total area of these three park units is 16.9 million acres. One more station is present in BELA, yielding an average density of one station per 3.8 million acres for all of ARCN.

Three stations (Kelly, Noatak, and Kavet Creek) are all RAWS stations managed by NPS as part of the larger interagency fire weather monitoring effort across the U.S. Data are received in real time and archived at the NOAA Western Regional Climate Center. Overall, these sites have functioned well through extremes of cold and dark in the harsh Arctic environment. From the track record at these sites, and RAWS sites elsewhere in Alaska, it is clear that well maintained stations can provide useful data and information even in this most challenging environment. These sites should continue to be maintained in the present manner for as long as practicable, along with any new sites emplaced. The remaining station in northeastern GAAR is a Federal Aviation Administration (FAA) AWOS III at the air strip at Anaktuvuk Pass intended for pilot use. Stations of this type are not necessarily intended to meet the more stringent standards of climate monitoring stations (Davey et al., 2006).

4. Sampling strategy

4.1 Spatial density

In the contiguous United States, the National Weather Service has strived for a minimum density of about one station per 25 miles (40 km) (NRC, 1998), or approximately one station per 625 mi^2 (about one per 1600 km^2 or one per 400,000 acres). Though a higher density is desired, this figure takes into account many practical considerations. This would result in about 48 stations in the 5 units of ARCN. Other studies (e.g., Janis et al., 2004) have shown that in topographically complex terrain, about twice this density is needed to identify regional climate signals as well as they can be extracted in flatter or more uniform terrain.

By contrast, the density of existing stations in ARCN is extremely low. Within the three contiguous parks (NOAT, KOVA, and GAAR), the present density is one per 4.2 million acres. Within KOVA the density is 1 station per 1.8 million acres, within NOAT the density is 3 stations per 6.5 million acres, and within GAAR the density is 1 station per 8.6 million acres.

To visualize, it is useful to note that the ARCN area (19.1 million acres), and the combined area of the three contiguous parks (NOAT, KOVA and GAAR) (16.8 million acres), are about the size of West Virginia (15.5 million acres) or the Navajo Nation (17.1 million acres). Yellowstone National Park, selected because of its familiarity to a wide swath of the public and NPS and because of its square shape, covers about 2.2 million acres, and is host to about 30 weather and climate monitoring stations of one type or another serving a variety of purposes (about one per 73,000 acres). GAAR alone is equivalent in size to about 3.9 Yellowstones, and NOAT another 3.0 Yellowstones. This comparison is shown visually in Figure 1. A similar density in NOAT-GAAR would yield over 200 surface measurement stations. Topographic complexity is similar in both regions. There are of course other issues in the ARCN park units to address relative to station density (discussed later), but these comparisons are offered to show just how extremely sparse the existing station "network" (to be generous) is. The proposed sites represent a density of one station per 1,124,000 acres in ARCN, and one station per 1,680,000 acres in NOAT-GAAR.

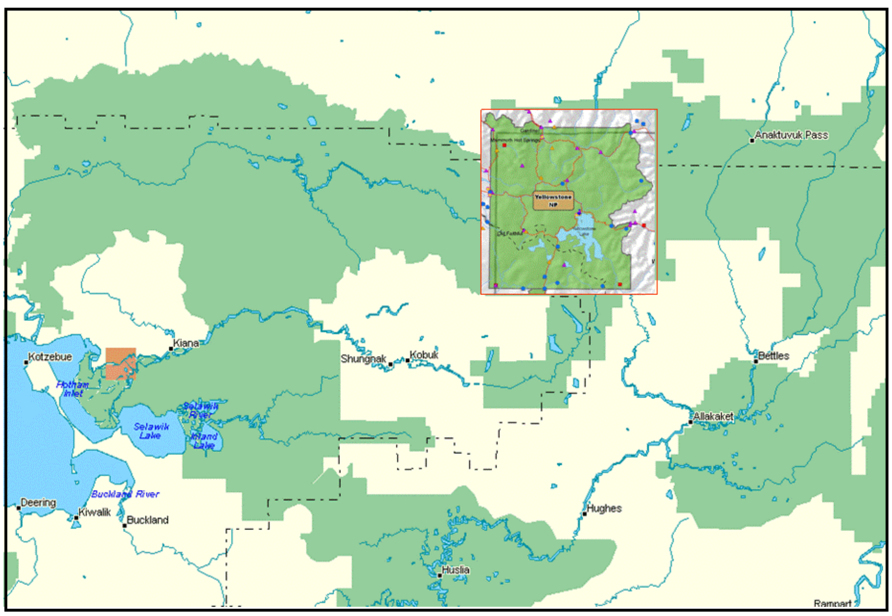

Figure 1. Relative sizes of Yellowstone National Park and the five ARCN parks. Symbols in Yellowstone map represent ongoing weather and climate measurements.

From the Arctic coastal plain south to interior Alaska, and from the coast east to the Haul Road, climatic characteristics exhibit changes similar to those seen in other settings of comparable topographic diversity. These changes occur somewhat gradually from west to east, and likely occur in more step-like fashion from north to south as successive mountain barriers are crossed. The station network should attempt to capture the broad features of such climatic transitions. The proposed network has an appropriate spacing to do so.

As noted above, with proper forethought stations of modest cost can be made to function reliably even in these severe environments. However, despite the best practical attention to maintenance, in the sometimes brutal conditions in which the ARCN stations must operate, station problems are inevitable. These may stem from effects of weather and climate itself, animals, or sensor and equipment malfunctions. A kind of delicate balance is needed in determining the desired station density, between *uniqueness* and *redundancy*. It is desirable that each station measure a climate somewhat different from that of its neighboring stations (uniqueness), but also sharing enough climatic similarities that data from one station could be used to provide an approximately correct estimate should a neighboring station malfunction (redundancy). In the case of the ARCN climate network, the primary emphasis should be on uniqueness, but it is expected that there will typically be a modest level of correlation between climate variations observed at adjoining pairs of stations. A record that is not continuous and reasonably complete really begins to lose value for a variety of applications, and some way of infilling missing records is advantageous. The ability to perform such infilling and other quality control is greatly facilitated by the availability of nearby data. From the standpoint of quality control considerations, there is little likelihood that adjoining stations will ever be considered “too close.”

4.2 Climatic representativeness

As noted above, there are broad east-west and north-south transitions in basic climate in the ARCN region. In addition, there are always local variations in long-term climate which can be considerable, even over very short distances. The most common is the difference between valleys and mountains. Temperature inversions form readily in this mountainous landscape, a result of radiation conditions that preferentially cool air near the surface: very low water vapor content, extended periods of snow cover, and low solar radiation input for much of the year. Consequently, valley locations are frequently much colder than adjoining higher ground. These vertical gradients in temperature can be substantial and can occur over extremely short distances, sometimes in just a few meters or tens of meters of elevation difference. Differences in slope aspect (and slope angle) at a given elevation can also create sharp horizontal and vertical differences in temperature. Furthermore, such circumstances are recurrent, and thus part of climate. This property of vertical thermal stratification is well known to human inhabitants and likely to larger fauna, and has been incorporated implicitly through genetic adaptation in the evolution of floral communities.

A variety of observational and theoretical arguments can be made that temporal climatic variability (such as from one year to another for a given segment of the year, e.g. January) need not be strictly similar at lowland and upland sites, even when in relatively close horizontal proximity to each other. The same may be true on longer time scales, such as those of interest for climate change. Thus, sound rationale exists for pairing of stations, one in lowland valleys and another in nearby upland locations which are less subject to local microclimatic influences. This strategy has been mentioned in many of the previous recommendations to NPS and others. There are also emerging discussions among climatologists and ecologists of the possibility that cold air pools may not respond similarly to regional climate change and variability as neighboring uplands, based on physical reasoning and small-scale measurement networks (e.g., Daly et al, 2007, 2009). This raises the possibility of “climate refugia” whereby biological organisms may remain, as overall regional climate changes, in smaller pockets that do not change as much or as soon (e.g., Ashcroft, et al., 2009). This concept could apply in many ARCN settings. A strategy that accounts for vertical as well as horizontal variations in climate has considerable merit.

Several of the 17 suggested sites are presented as station pairs, separated vertically by 1000-2000 feet (300-600 m) over relatively small horizontal distances of a few hundred meters to a few tens of kilometers. This constitutes a very viable and useful strategy, and is suggested at about the right fraction of the total sites. Following earlier guidance and advice, a main element of the strategy for the 17 suggested sites is a preference for higher elevations. Most previous systematic attempts to measure climate over long durations have taken place where people typically live and work, namely along rivers and streams or in lowlands, and upper elevations have consequently been greatly undersampled (CIRMOUNT, 2006). Most of the suggested sites are intended to help address this unintentional bias of the observed historical records.

The four stations suggested for GAAR have spacings of about 50, 70, 75, and 95 miles (80, 110, 120, and 150 km) from one to the next. At this scale, it is more desirable if the station exposures are all fairly similar (for example, all upland, or all lowland), so that differences between stations do not arise from elevational differences in exposure (lowland versus upland). At this coarse spacing, the sampling emphasis is on representing the overall patterns experienced by each park unit.

Lowlands tend to be representative of other nearby lowlands in similar topography (e.g., within a few tens of kilometers) and uplands tend to be representative of other nearby uplands. Especially, because wind is usually stronger at higher elevations, there is likely to be greater site-to-site similarity, for longer horizontal distances, at higher elevations than at lower elevations, where very local effects can exert strong individualized and location-specific influences.

The earlier discussion of station density in other parts of the United States was presented to provide context for reference purposes. It is recognized that there is essentially no possibility that such station density is possible in the ARCN region. The 17 suggested sites represent an effective and approximate inter-station spacing of about 40 miles (65 km). This number of stations and this density appear to be a very good compromise among a great variety of competing considerations, some discussed here and others discussed in reference material previously prepared for the Alaska park units and I&M networks. This number and density should greatly help to better define regional patterns of climate relevant to the needs of park units in this area.

There are practical reasons both for limiting the number of suggested monitoring sites and for increasing this number, in addition to more theoretical and intellectual reasons.

On balance, the suggested number of 17 represents a well-justified compromise.

5. Special circumstances within ARCN

Within the area encompassed by ARCN, there are several factors that are more relevant to this region that are not shared, or shared as strongly, by other I&M networks in the state. A few of these are discussed next.

5.1 Climatic effects on climate measurements

The station configurations and sensor complements include the main desired atmospheric elements. They rely on tried and tested instrumentation from reputable manufacturers, and do not excessively utilize delicate equipment that may be readily rendered inoperable by weather, animals, or other problems. By necessity many of the sites are in very exposed locations. Especially with the lack of vegetation in most locations, exposures are excellent for wind, temperature and humidity. Precipitation is all but impossible to measure in frozen form with the planned equipment, and without heroic effort and expense, but the liquid precipitation of summer can be observed adequately and is important. Only a Snotel type of setup would be expected to provide a good year-round record of precipitation. Admittedly, in semiarid to arid arctic regions, it may be very important to learn more about temporal variability characteristics of cold season precipitation, but in remote settings without power or visitation, this is very hard to achieve in practice.

At most of the suggested locations, winds will on occasion batter these exposed stations considerably. Such wind observations are particularly desirable in the ARCN region. As the Arctic sea ice recedes from the shore for greater portions of the year, the open water is expected to influence storm characteristics. Wind flow patterns may be consequently influenced some distance inland from the western and northern ocean. Most of the suggested sites are ideally situated for obtaining wind measurements, even with the rather short (10 foot / 3 meter) towers suggested (the world standard is 10 meters / 33 feet for general meteorological monitoring; shorter 10-foot towers are often used for agricultural networks). For multiple reasons, including logistical and wilderness issues (see below), and the general shortness of the vegetation, the planned anemometer height of 3 meters is acceptable for the ARCN monitoring program.

Battery charging is essential for successful station operation, and the sun is never very high in the sky at these high latitudes, and is even missing for part of winter, so solar exposure to the south must be, and is, considered in the siting decision. Fortunately, even with the very cold air, compared with wetter climates farther south in Alaska the prospects for riming and other ice accumulation are reduced in this region (with a possible exception near the western coast). The proposed instrumentation complement, including an ultrasonic snow depth sensor, is quite adequate. This suite of measurements is also sufficient to calculate approximate evapo-transpiration values. Similar configurations have been deployed at CAKN sites, and have functioned well since.

5.2 Climate Change

Much attention has been focused on the enhanced sensitivity of the Arctic to climate change compared with other latitudes, and on recent significant evidence that such changes have already begun (IPCC, 2007). This is amply documented in much of the support material from which the recommended strategy has been drawn, so there seems little need here to repeat this discussion or provide extensive references to such literature. Much of this is discussed in ACIA (2004) and IPCC (2007).

The Western Regional Climate Center is preparing a web-based North American Freezing Level Tracker, that makes use of Global Reanalysis data from 1948 to present, to help users track the history of freezing level through time in different months and seasons, throughout North America. One product from this tool is shown in Figure 2, revealing that in the last 10-20 years freezing levels over GAAR have been starting to rise, especially in the recent decade, indicative of probably surface warming as well, especially at higher elevations. Such changes would be expected have effects on biological organisms, ecological communities and ecotone boundary positions.

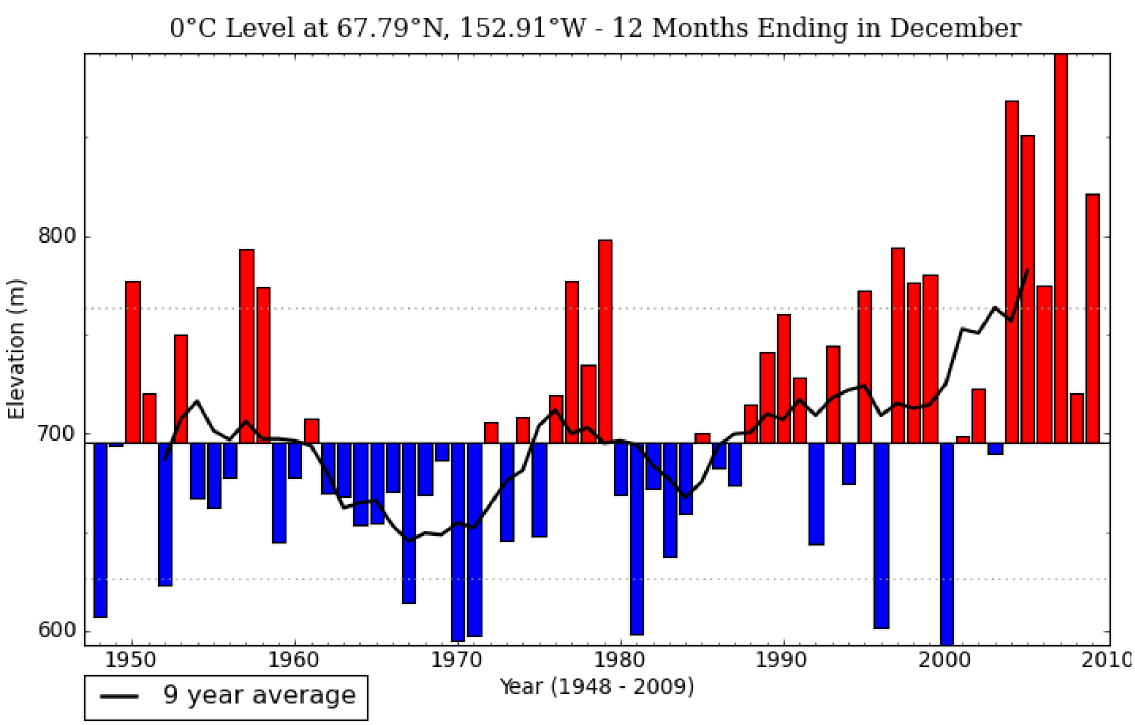

Figure 2. Annual mean of the elevation of the 0° C isotherm ("freezing level") in the free atmosphere over GAAR, based on Global Reanalysis data, 1948-2009.

This metric of change is interpolated from a coarse grid (2.5 x 2.5 degrees of latitude-longitude) and covers a wide area, and is in part informed by satellite and a few balloon measurements that sample the atmospheric temperature structure. Much more preferable, and necessary for many applications, are detailed on-the-ground measurements from surface stations to provide the required level of detail to interpret changes within the ARCN park units.

To serve climate tracking needs, for climate variability and climate change purposes, consistency through time is an absolute requirement: consistency in equipment, consistency in site characteristics, and consistency in sampling methodology. Apples today need to be compared with apples tomorrow. For each of the proposed sites, consideration was given to minimizing the potential effect of encroachment of bushes, trees, and other vegetation over coming decades. Sites that are now open tundra may develop thicker or taller vegetation cover, or become bushy or even forested. These effects will themselves change the apparent climate. For example, wind will slow as trees grow nearby, and brush growing up below thermometers can produce added solar absorption and a new source of heat. For the proposed network, a conscious effort was made to stay clear of nearby rising tree lines, for example, except in one case where that is part of the goal.

It is worth noting that Arctic sea ice continues to retreat and to thin (NSIDC, 2010). With climate change, the retreat of ice away from the Alaska shoreline may lead to increased ocean evaporation and humidification of the air during certain parts of the year. This may vary with distance from the ocean, as well as with changes in wind flow patterns that transport such moisture. In summer, increased plant growth and evapotranspiration, or increased precipitation (predicted for the Arctic in summer), could produce more water vapor in the atmosphere. Thus, gradual humidity changes may occur within ARCN units, and it would be helpful if at least some of the monitoring sites were less susceptible to local sources of humidity. The higher elevation sites favored in the proposed network are generally less subject to such effects. It is acknowledged that extremely accurate humidity measurements are difficult to obtain, but the sensors proposed can be sufficient for detection of moderate changes through time.

The ARCN park units are on the front lines of climate change. With changes of this magnitude already being seen at large scales, systematic monitoring to record these changes at sufficiently fine scales to adequately characterize spatial differences within these parks is urgently needed. This furnishes exceptionally strong motivation to deploy a surface station network that meets the needs of the I&M Program as rapidly as possible.

5.3 Remoteness

Most of the sites are very far from routine human visitation paths or airfields. The stations must be reliable enough to function for long periods without maintenance, especially in the cold half of the year. Other stations in this part of the state with similar instrumentation and communication have shown that they can indeed perform well throughout the winter with proper planning and sufficient maintenance resources.

Because the ARCN sites are remote from most human habitation, maintenance facilities, administrative headquarters, and recreational staging areas, the real-time availability of the data adds value to the monitoring program in other ways. Visits to these parks are seldom the result of impromptu decisions, and much access must be by air. Most modes of transportation are affected by the weather, and nearly all pilots express a desire for as much en route or destination weather conditions as they can obtain. Conditions in mountains can change rapidly, and routine (hourly) updating increases the value for aviation interests. Near real time weather information has many applications for park managers and staff for short term planning of routine activities in addition to aircraft operations. Such information is also very valuable during occasional search and rescue operations.

Visitors to these park units are essentially outdoors or in light shelter for their entire stay, and cannot rapidly return to inhabited areas even if desired. Most want to know what typical climatological conditions are like during visit planning. Typically they will also want to know conditions on the day of arrival. At WRCC extensive and detailed summaries of every long term daily National Weather Service coop station can be accessed by web, and nearly every national park unit has such a station. This information is very popular. Other data (such as from RAWS stations) can be summarized by potential visitors. Data from these ARCN sites will be made available through this same system (see below).

Those engaged in research activities and other ongoing activities can make more efficient use of their time by making use of current and recent climate observations. The goal here is to avoid unnecessary trips, which in this area are very expensive. Weather and climate measurements provide indications that certain thresholds of interest for a project (seasonal accumulations of degree days for example) have been met, or not, and that a visit to a research monitoring site is warranted and will be worth the trouble and expense.

In another important aspect, these five park units may seem “remote” but are in fact not. The air moving into, over, and out of the park contains greenhouse gasses and pollutants emitted throughout the Northern Hemisphere, and indeed the entire globe. In this sense, no place on earth can really be considered completely “remote” or “pristine” any more.

5.4 Wilderness

With a few exceptions (Anaktuvuk Pass, for example) GAAR is nearly entirely wilderness (following the particular definition in the Alaska National Interest Lands Conservation Act, ANILCA), and most of NOAT is also designated wilderness. Climate has been identified as a high priority vital sign for all Alaska park units (Davey et al, 2006). There is a spectrum of opinions on the necessity for surface monitoring equipment to support I&M Program goals inside these two park units (in particular), and to a somewhat lesser degree in the other three units of ARCN.

At one end of this spectrum, there is a viewpoint that monitoring equipment of any type, especially that with a lifetime beyond a short period, should be heavily discouraged, or even not allowed under any circumstances (again, subject to ANILCA wilderness definitions). The essence of this argument is that these lands represent the "purest" example of wilderness remaining on the North American continent, and that every effort should be made to keep them that way. The other end of this spectrum is actually poorly represented: there are few voices suggesting that an especially lenient interpretation be followed. On this spectrum, most parties with an interest in wilderness issues seem to be just modestly removed from the strictest possible interpretation, though they are often in general sympathy with that view, and would like to see it accommodated to the extent possible.

During this site evaluation, a timely report appeared (Landres et al., 2010) outlining a framework for how to evaluate science research proposals in wilderness areas in the United States. This document ("Framework Report") distills a great deal of careful thought spanning many decades, and, without being overly prescriptive, provides a practical pathway to assist those who must decide whether such an activity will go forward. The main concern of the Framework Report is not necessarily the decision outcome itself, but whether a certain process has been followed prior to that decision. A series of filters are applied to the proposed activity, and a Minimum Requirements Analysis (MRA) is undertaken as part of this process. The MRA addresses the question of whether everything possible has been done to meet wilderness values, without sacrificing the needs of the research effort to draw valid scientific conclusions. Those proposals that do not follow the process outlined in the Framework Report will either fare poorly or be summarily rejected. From this standpoint, the ARCN Site Evaluation report is very well written, has a practical orientation, and appears to accommodate the diverse choir of voices about as well as can be done.

The Framework Report notes that proposals prepared with knowledge of the contents of the report, and with anticipation of application of the filters described therein, will be in a better position that those proposals that do not. The ARCN proposal to install 17 stations appears to have adhered to the recommendations of the Framework Report, and to have anticipated the filters it contains. A subsequent and more formal process will determine whether this is actually the case before delivery to senior management.

There is wide agreement that the imprint of any monitoring should be as light upon the land as possible. The sites are to be anchored in a way that yields minimum disturbance to the substrate (by means of rods driven into the ground), rather than a typical concrete plug, for example. To avoid guy wires, the towers are shortened from the recommended WMO standard of 10 meters to 3 meters, typical of many tripod mounts. Climate stations deployed for CAKN are also 3 meter tripods. Stability is essential, and wind, animals, and occasionally other factors can topple or reorient a station, so some kind of strong tie to the substrate is necessary. This compromise is an explicit attempt to come closer to wilderness ideals, and seems quite reasonable.

Stations can be painted to blend in with surroundings, though unlike snowshoe hares one color scheme must suffice all year. The usual choice is the greenish colors of vegetative camouflage. Thermometer housings must remain as white as possible under all circumstances. Experience with other climate networks has shown that a carefully painted 10-meter tower can be surprisingly difficult to identify from even relatively close range (50-100 meters or more). In fact, network managers can have difficulty locating their own equipment even in treeless and nearly flat terrain. In large open tracts, this can actually cause problems in locating stations for maintenance unless GPS assistance is used.

Consideration was given in this evaluation to whether the climate of GAAR or NOAT could be monitored sufficiently well to meet the goals of the I&M Program, by means of a set of stations located just outside the periphery of the park unit, or through remote sensing means from above (satellites) or the side (eg, radar). Recalling earlier analogies, is it possible to determine sufficiently well what is happening with weather and climate within either West Virginia or the Navajo Nation, using only stations around the state or reservation boundary? Here, "sufficiency" consists of the following: the ability to reconstruct the spatial variability of climate inside the park unit, the ability to distinguish differing elevation effects, or the ability to track slow and sometimes subtle changes in climate associated with changes in ecological communities, or in near-surface soil conditions, in wind patterns, in the diurnal cycles of weather (temperature in particular), in the occurrence of extreme events (wind bursts, heat or cold spells, heavy precipitation) that lead to physical or biological disturbances, or in the ability to retrospectively identify changes in climate behavior that led to ecological changes noted after the fact rather than at the time of their occurrence. A network should be able to provide these things. A wide consensus of climatologists would conclude that this is not really possible to accomplish within acceptable error limits using only "edge" measurements. Climate knowledge about the interior of West Virginia cannot be determined well enough from outside the state boundary to provide answers to such questions, and thus requires localized observations from within that state.

5.4 Interpretive needs

National parks have a significant interpretive mission. Climate has always been an element in that interpretation, and climate change is rapidly being incorporated into that mission. The interpretation messages can address climate itself, or the relation of climate to other ecological communities and physical processes in a given park. For this important purpose, there is almost no substitute for in situ station-based measurement. The public has ample experience with and acceptance of weather and climate information, is imbued with this from frequent exposure to such information from many sources each day, and can relate to such information more readily than to proxy or remote sensing measurements. It therefore does not seem unreasonable to suggest that the public simply expects that such information is available for each national park unit of any significance, including those of ARCN. Experience at WRCC with other parks leads to an expectation that there will be wide interest in access to ARCN data via internet from many sources.

5.5 Station data archival and access

Though not specifically highlighted in the proposal, data from all stations in the proposed ARCN climate network will be rapidly ingested into the archives of the NOAA Western Regional Climate Center in Reno. The entire hourly record will be available, along with a variety of applications that can help users visualize or summarize data, or download for their own use. A web page will be prepared to facilitate station selection, similar to those that are now available for many other national parks, for the interagency RAWS program, and for many other observing networks in the western states including Alaska. Station documentation and photos ("metadata") will also be available for every station. Metadata are very helpful, even crucial, in the proper interpretation of climate station records for many applications.

6. Comments on specific suggested sites

Sousanes (2009) describes each of the proposed sites and provides photo documentation from actual visits via helicopter or plane, or from aerial flybys. A more complete set of photos was also examined from a Powerpoint presentation. In the ensuing text, brief comments are provided for each potential site.

A blanket comment can be made that pertains to nearly all prospective locations. Most would score extremely high on objective scoring systems used for the NOAA Climate Reference Network and the Modernized Historical Climatology Network (report authors are performing these surveys for the western US). The ARCN region offers an abundance of ideal exposures for all but snow-related measurements. This exception applies to all exposures described below as "excellent." Most are windswept, and gauge undercatch of frozen precipitation during the winter would lead to unreliable data in those months. At inland locations typically 50-70 percent of the annual precipitation falls during the warm season as rain, and the tipping bucket gauges should function adequately in those months. The inclusion of ultrasonic snow depth sensors provides useful information about winter precipitation, snowfall and snow depth.

In each park unit, an approximate priority for particular sites is suggested, in terms of useful climate knowledge likely to be acquired. Among the five ARCN park units, GAAR is the both the largest and the least well sampled and thus most in need of monitoring. The much smaller CAKR also has no current stations within its borders. Large areas in NOAT and KOVA are without measurements as well.

<u>BELA</u>

The strategy to add interior stations is well-founded, as is the north-south transect. The Serpentine and Midnight Mountain sites are a logical pair, at respective elevations of 518 and 2267 ft (158 and 691 meters), separated by 5 mi (8 km). The exact Serpentine site is near but out of sight of the airstrip. Exposures are excellent.

The (2009) Devil Mountain Lake site appears very good. Plants are slightly taller here, so perhaps soils are more moist than other locations. Climate warming is expected to dry soils in summer, so this may be a good location to watch for that effect. Exposures are excellent.

At Ella Creek, there do appear to be small patches of vegetation that would be somewhat preferable to pure rock ground cover, to prevent excess heating on clear calm summer days. Climate change may lead to more vegetation in presently rocky areas. Exposures are excellent.

The higher elevation site at Midnight Mountain is most preferable by virtue of its central location, followed by the site at Ella Creek, each because of their elevation. Serpentine would be the next choice, especially to complete the high-low elevation pair (with Midnight) proposed for this area. Devil Mountain Lake would be fourth. The first one or two stations should be at higher elevations, with a lowland station as the third or fourth choice.

CAKR

The inland-elevated strategy makes sense to align with that for the other park units, and complements existing sites at Kivalina and the Red Dog Mine. The Mount Noak 2009 site (809 ft, 247 meters) is better than the top of Mount Noak (1946 ft, 593 meters) for the exposure-related reasons given in the proposal. This location is close to the coast, and as sea ice recedes will likely be exposed to stronger storms during the “shoulder” seasons around winter. Icing may be more common with the proximity to the ocean than at inland park units of ARCN. A temperature sensor attached to or near the Mt Noak summit repeater could act as a supplement to obtain a vertical gradient. Rabbit Creek site looks very good. Exposures are excellent at both sites.

The Noak 2 (2009) site appears to deserve the highest priority, followed by the site at Rabbit Creek. A limited observational setup at the summit of Mount Noak (just for temperature) would be a next priority, followed by the site at Igarich if resources permitted.

NOAT

The upland strategy with sites on both sides of the river is good for this park unit, especially since existing sites are at lower elevations. The proposed number (4) is about right to capture the major gradients of climate from north to south and east to west. Spacing averages about 70 mi (110 km), or approximately the equivalent of one degree of latitude.

The Asik-low site takes advantage of an existing (10 meter / 33 ft) tower called Stottlemeyer. There is existing instrumentation which may be refurbished at some time, but new instrumentation for consistency with other network sites is recommended. The site is potentially subject to seasonal flooding events; therefore instrumention and enclosures should not be mounted too close to the surface. The Asik pair spans a 277 ft to 1329 ft (84 to 405 meters) elevation range, an adequate elevation gradient to capture climate above and below tree line. The inversion is sometimes quite shallow. Some brush maintenance may be needed to avoid encroachment. Trees appear far enough away to avoid serious blockage, but also appear close enough to provide some shielding for precipitation measurements. The Asik-high site is very good and has excellent exposure.

The Kugururok site for 2009 (on a knob at 1028 ft / 313 meters) is better than the 2008 site at 2038 ft / 621 meters. There is no danger from flooding and exposure is excellent.

The Sisiak site at 1823 ft (556 meters) is very representative of a wide area, and looks really excellent. Conditions appear quite uniform for some distance from the location.

Kaluich Creek at 2486 ft (758 meters) also is very representative of a wide area, and is a long way from any other site. Willow and alder are below but in the vicinity, and may march upward with climate change, so this could be a good location to monitor tree line and climate together. Tree line position could be photographed with each maintenance visit. In fact, a complete set of photos should be obtained with every maintenance visit to all stations, to document systematic local changes in vegetation.

Imelyak at 3569 ft (1088 meters) is fairly high and from the photos and maps represents a wide area, probably at least 50 miles (80 km), which is good because it is a long ways to the nearest proposed stations (50, 70, 100 mi / 70, 110, 160 km). The site has really excellent exposure. This location seems like a very good location to represent potential climatic variability across the Noatak-Kobuk divide. This site helps provide an upper end to bracket an elevation range among the five ARCN units.

Howard Pass 2009 site at 2109 ft (643 ft) is likewise far from any other proposed site, and has excellent exposure. With the relatively wide expanse of this broad valley, the site is representative of large sections of northwest NOAT. The late Quaternary history of Howard Pass has been described by Oswald et al. (1999). Park staff performing the site reconnaissance had previously received cultural resource site training, noted the presence of archeological evidence during their field visits, and specifically chose sites without any noticeable archaeological features. This would likely be confirmed by prior to installation. In any case there are many nearby alternative candidate sites.

Of the locations suggested for NOAT, Imelyak has high priority because of its elevation and also distance to other existing or proposed stations. Next would be Kaluich Creek for similar reasons, followed by the Howard Pass site as a northerly location and potential migration corridor. The Asik pair is attractive for the reasons given and would be next, followed by Kugururok and then Sisiak. All appear to be excellent exposures. The RAWS station would be improved by addition of a snow depth sensor.

KOVA

The rationale given for a tree line setting appears well justified. As noted, the valleys are already represented. A station or two somewhere in the ARCN network that is deliberately placed a short distance above the present tree line, and below a future projected tree line, would be extremely useful in understanding and interpreting the encroachment of trees up the slope with future warming. The stations must be emplaced before this upward “migration” begins. The remainder of the rationale given in the proposal for other sites is quite sound.

The Salmon River site at 1262 feet (385 meters) is among the lower sites suggested in the three contiguous park units, but is still above the tree line, visible below the site in the photos. Is there evidence that ecotonal shifts have begun in the vicinity in the past decade or two? This climate-biota consideration is very relevant to the reasons why there is a need to establish such a network, and to do so before change starts to be seen. The site has excellent exposure. The site at nearby Nikok Creek is higher (1861 ft / 567 meters), also has excellent exposure, and is a good backup site.

In KOVA the site at Salmon deserves high priority, followed by that at Nikok. The alternate site at Old Man would be the next priority

GAAR

Considering the size of GAAR, the area represents an immense data void. The rationale for an approximately east-west transect is sound. The stations are not especially close and the area represented by each site is very large. In light of all the other considerations for GAAR, the suggested deployment of four stations is a good compromise, sufficient to illuminate broad patterns within the park unit, but showing a respectful deference to the minimalist approach arising from wilderness considerations. Stations on land bordering GAAR are generally at lower elevations. Therefore the emphasis on higher locations, with their greater spatial representation, is justified. Also, GAAR is generally higher than the other 4 units of ARCN, and the elevations are correspondingly higher. The sites were not visited directly, but photographed by close-in aerial flybys.

The site above Chimney Lake at 3200 ft (975 meters) looks good, and can be reached by two types of craft, float planes (with hike) and helicopters. Exposure is very good. This site can adequately represent the eastern quarter of the park. Several sites are along the Haul Road to the east about 60 miles (100 km), reducing the need for a more eastern location in the park close to the border. For deployment, is the hike very far? Can equipment be left by helicopter, or must it be carried up the hill?

Pamichtuk Lake at 2000 ft (610 meters) is a very good site and has excellent exposure. A one-time stress test of hauling equipment up the hill from the lake is ok if not too far. Subsequent visits for maintenance will likely not require much to be carried. The location of this site within GAAR fits well in the context of the locations of the other suggested sites.

Killik Pass at 3000 feet (914 meters) also has an excellent exposure and from the photos seems representative of a large area. It is presumed that the site is not in the middle of the pass to avoid migration routes of animals (including perhaps the occasional human visitor), and for aesthetic reasons (to keep the station from being too prominent). It is worth noting that wind patterns in the vicinity of passes are somewhat steered by the topography and have less regional representation. However, these local topographic controls can lead to just a few preferred wind directions, and these can be helpful in establishing which of several wind regimes (e.g., up or down this drainage or that drainage?). It seems better to steer away from perpetually wet tundra to something just slightly drier. There are many questions relating to herd migratory patterns, and a station in this area could help shed light on this important topic.

At Ram Creek at 3000 feet (914 meters) the general regional setting consists of a topographically complicated area with steep and rugged relief in most directions from the suggested site. However near the proposed location itself, there are several km of less complex terrain, and the actual site suggested does have excellent exposure. The comment in the proposal about this site being a good location to track vegetation migration is worth noting

In GAAR, the northerly site at Killik seemed to offer the greatest likelihood for providing new and unique climate data and information. Chimney Lake would be next, and helps fill in the eastern half of the park unit. These two sites would be followed by Ram Creek and Pamichtuk Lake would be next on a priority basis.

<u>Alternative sites</u>

Most of these sites were deemed somewhat less acceptable in the proposal by NPS personnel, but nonetheless would likely still be adequate for most purposes. The site at Ear Mountain is a bit close to the coast, where other existing stations and records can already be found. The Noak Mountain (summit) site is a bit steep, but a role as a limited supplemental site for temperature would be fine. Igarich is somewhat rocky, but specific locations could potentially be found. The Tasaychek Lagoon site at elevation 2 ft (0.6 meters) is a candidate for drowning or storm surge, too low, too vulnerable to too much hazard and risk. Kugururok 2008 is adequate with excellent exposure, as is Imikneyak. The Old Man site is the highest (by some margin) of all the ARCN candidate stations

(4551 ft / 1387 meters) and would definitely help bracket the elevation range. It's near the upper limit of where one might want to place a station. The site will be windy, and there appears to be very little vegetation. The site is already disturbed. Wind fetch is excellent and representative of a wide area. Agiak Lake has blockage issues for signal transmission and battery charging, and probably not a serious candidate.

7. Conclusion

The proposed suite of ARCN climate monitoring sites is a result of a careful and considered process that anticipates many of the issues and comments that will be faced further in the sequence of steps to eventual deployment. There was considerable consultation with local, regional and national experts throughout the process. The proposal has benefited greatly from related and precursor activities, advice, and documentation of the past few years. Wilderness issues appear to have met the recommendations of the newly published Framework Report. The proposal is in capable hands and is ready to move on to the next phase in the sequence.

It should be noted that the 17 stations have already been purchased and have been in a testing mode at the Fairbanks Airport, and have been operating over the winter of 2009-2010, in very close proximity to each other. This itself can tell us many interesting things about inter-station differences and microscale climate differences. Such a testing period is very helpful in identifying simple problems that are frustrating to learn about once a site has been deployed and left for winter. This is mentioned as indicative of the care and thoughtfulness that has gone into planning this ARCN climate monitoring effort.

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