Climate Monitoring in Glacier Bay National Park and Preserve: Capturing Climate Change Indicators

2008 Annual Report

Studies Conducted As Part of Research Project:
Long-term tidewater and terrestrial glacier dynamics, glacier hydrology, and Holocene and historic glacier activity and climate change in Glacier Bay National Park and Preserve

Daniel E. Lawson [1, 2]
David C. Finnegan [1]
[1] CRREL, 72 Lyme Road, Hanover, NH 03755
[2] Geography and Earth Sciences Departments, Dartmouth College, Hanover, NH 03755

Table of Contents

Climate Monitoring In
Glacier Bay National Park and Preserve:
Capturing Climate Change Indicators

2008 Annual Report

Studies Conducted As Part of Research Project:
Long-term tidewater and terrestrial glacier dynamics, glacier hydrology, and Holocene and historic glacier activity and climate change in Glacier Bay National Park and Preserve

Daniel E. Lawson [1, 2] and David C. Finnegan [1]
[1] CRREL, 72 Lyme Road, Hanover, NH 03755
[2] Geography and Earth Sciences Departments, Dartmouth College, Hanover, NH 03755

Executive Summary
Climate is the primary driver of the physical, hydrological and biological processes of Glacier Bay's diverse ecosystems. Because few data on the climate of the Park existed and no systematic monitoring of the climate had been performed previously, we initiated a long-term monitoring of contemporary climate in Glacier Bay in cooperation with the National Park Service (NPS) in 1999. Our climate monitoring is providing data necessary to understand the effects of global changes in climate on Glacier Bay and to calibrate Global Climate Models (GCM's) for southeast Alaska, thus enabling them to be used to predict how future global changes in climate will impact the environment and ecosystems of Glacier Bay. Knowledge of such likely responses in the short- and long-term will be important considerations to management for utilizing and protecting Park resources while accommodating visitors in the future.

Currently, twenty-five climate sites measuring a minimum of air temperature and precipitation are active. In addition, we are evaluating upgrades for the near real-time GOES satellite systems at Johns Hopkins and Queen, as part of our efforts to improve performance and reliability, with the goal of establishing multiple remote sites that can be monitored by park staff and researchers via a World Wide Web site established and maintained by CRREL. We are currently collaborating with Brendan Moynihan (NPS) to utilize our climate sites as part of the SEAN I&M Program on climate monitoring in Glacier Bay. We conducted field visits to our sites and discussions about how to integrate the two monitoring efforts, upgrade existing CRREL sites for full suite of climate parameters, and add higher elevation sites to supplement and compliment CRREL sea level sites. We also have had discussions with Brendan and Tom Ainsworth (NWS) about adding a site at Lone Island for full parameter monitoring as part of the SEAN-CRREL network and provide essential real-time weather data for NWS forecasting. In addition, we are working with Lewis Sharman to develop staff capabilities to assist in the bi-annual system maintenance and data acquisition. The idea is to provide

better coverage at possibly reduced costs and timing in keeping with boat access closure dates.

A primary focus this past year has been in the development, testing and analysis of data collection and transmission instrumentation for upgrading the climate sites to improve capabilities and access to real-time data of multiple types. These include the use of Iridium satellite phones for transmitting data and images, a potentially powerful means of moving large datasets while providing communication to and from the data platform. We have also been testing climate sensors and power systems at our field site on Haenke Island near Hubbard Glacier. This site provides extreme conditions including wind (>150 mph), freezing rain and icing conditions, and minimal solar radiation, allowing a useful test of the most recent developments in wind generators. A key element of this effort is to maintain or reduce the data platform footprint for wilderness deployment and at the same time provide enhanced data transmission capabilities and low power usage for remote areas.

In addition to long term monitoring of the climate, we have established the climate sites to foster research, supporting our studies as well as those of other researchers in the park and eventually providing near real time data to the Park Rangers and interpretive staff. All but one of our climate sites is located near sea level in elevation and therefore allows us a direct comparison of the measurements necessary to define the source of variability from site-to-site, a key factor in attempting to understand where and how weather may vary between inlets and the lower bay for example. The data also provide the basis for calibrating tree-ring records and interpreting the paleoclimatic indices of interstadial wood sites for our ongoing research on the climate of the past 10,000 years (Lawson and Wiles 2008). Combined with other measurements such as ablation and accumulation rates, these data are critical to understanding how glaciers and other physical systems are responding to regional and global changes in climate. We are collaborating with other researchers conducting analyses of fresh water runoff, stream dynamics and salmon response to extreme hydrologic events.

The current length of record remains too short to evaluate the source and significance of longer trends in the variability at annual and decadal scales, but it is approaching that needed to analyzing seasonal trends over the period of record and thus assessing sub-regional changes within the Glacier Bay watershed. Once sufficient in length, we will be able to evaluate whether longer historical records from climate stations such as Juneau or Sitka are representative of Glacier Bay during those times when no historical data exit for the Park.

With our primary focus on instrumentation improvements, we limited our activities to service and maintenance of the climate sites, visiting sites in May-June and September, the latter with Brendan Moynihan. Data were downloaded and all systems were operating with the exception of the Johns Hopkins GOES site, which was totally destroyed by avalanches last winter, and the Queen site where we were unable to revive the GOES transmitter. However both sites have backup systems for temperature and precipitation in place, so the climate record will not be affected. Working with Craig

Smith, Chief Resource Management, Cherry Payne, Superintendent, and Lewis Sharman, Ecologist, we began evaluating climate site locations for best placement with minimal wilderness impact physically and visually. We sought a better site for the Skidmore Island location immediately outside the Hugh Miller wilderness area but did not locate anything suitable for moving the station; we will continue the search in 2009. We are also planning to move the Adams East site to a more accessible location in upper Adams Inlet, as well as Johns Hopkins out of the avalanche paths. Other sites which are being heavily overgrown beyond capability to maintain open air and sky as required for acquiring good data, will need some movement to avoid such conditions and maintain their useful climate record.

Long-term monitoring is essential to understanding the current and future trends in climate of the Park. Expansion of the network to the outer coast and higher elevation sites would provide a more complete record and fill the critical data gap that exists on the climate of the upper accumulation areas of the glacial systems. As global climate continues to warm, the monitoring will provide a glimpse into how the Glacier Bay watershed is being impacted and provide the data needed by researchers investigating biological and physical system adjustments to such changes. The database will be important to calibrating Global Climate Models for the Glacier Bay and southeast Alaska region, so that improved predictions of future changes in climate can be made. Such knowledge may be important to management in determining strategies for a park under the stress of climate change.

Introduction

Over the last 16 years, we have conducted long-term, integrated monitoring and site-specific multidisciplinary studies of glacial, marine and terrestrial environments to improve our understanding of the physical processes and their interactions with regional and global systems. Understanding climatic change and the resulting environmental and ecosystem responses are critical to the Park's adaptive management scheme for utilizing and protecting its resources and accommodating visitors in the future. Our research investigates the processes that control physical conditions and ultimately ecosystem biodiversity along marine and terrestrial glacier margins. Sedimentologic, climatic, oceanographic and glaciohydraulic studies of glacier dynamics improve the state of knowledge of tidewater and terrestrial glacier systems. Although sediment dynamics appear to control glacier margins in fjords over the short-term, climate affects longer-term trends in tidewater glacier activity but data to investigate the role of climate in tidewater glacier dynamics have been lacking.

Thus, climatic data are a critical component in most of our research, as well as in numerous other investigations of the marine, terrestrial and freshwater environments and ecosystems within the Park. Having a detailed, high resolution record of the air temperature and precipitation is necessary to define the daily, seasonal, annual and decadal controls on the biological and physical processes operating within each ecosystem. An important aspect of the monitoring is to provide the baseline climatic data to which future changes in climate can be compared, and ultimately applied to understanding ecosystem and other changes in the Park. CRREL climate sites are distributed across the Glacier Bay watershed such that regional trends can be identified and compared and correlated with temporal variations as sufficiently long records are developed. These data will allow us to analyze storm patterns in the Park, assess differences in weather between the East and West Arms, and evaluate impacts of short-term climatic changes. For our paleoclimate investigations, we are using these data to calibrate tree-ring records, and as the record lengthens, examine the spatial and seasonal variability that may affect how the tree-ring record is interpreted (Lawson and Wiles 2008).

Project Background

We began establishing test sites for monitoring climate within Glacier Bay in 1999. We identified the lack of any climatic data within Glacier Bay as a significant gap in knowledge about a very important and basic driver of the physical and biological systems within the Park, a sentiment echoed by many Park staff and researchers alike. Although specific funding for climate monitoring could not be secured, it was an obvious data gap that we have tried to fill by establishing the current network of climate sites. We initially established the network to monitor air temperature and precipitation, two climatic indicators that are applicable to many physical and biological research projects The sequence of events in developing the current deployment of 24 climate sites is detailed in the 2006 Annual Report (Lawson et al 2006a) to which the reader is referred..

We are continuing to improve and upgrade the climate sites with significant effort in our lab and at field test sites to identify wilderness-ready systems and sensors. Our primary goal is to develop systems that have low power usage, a remote near real time capability for data transmission, minimal repair requirements and multiple sensors to monitor the full suite of meteorological parameters. We have identified barometric pressure, solar radiation and wind speed and direction sensors to meet these requirements and are continuing to evaluate satellite systems for data transmission. We are also very mindful of reducing the footprint of systems in wilderness areas. In addition to increasing the suite of parameters measured, it is critical to establish higher elevation sites at several or more locations across the Glacier Bay watershed. Such sites were not initially established due to requirements for remote access and unknown reliability of instrumentation for long-term deployment of battery power systems. The use of GOES, meteor burst, satellite phones and other technologies as well as various wind generators for power may be a viable means for higher elevation sites requiring only one servicing trip annually.

Methods and Site Instrumentation

Climate sites are located along fjord margins, generally at or near sea level (Figure 1). The description that follows provides information on our the instrumentation and standard operating procedures

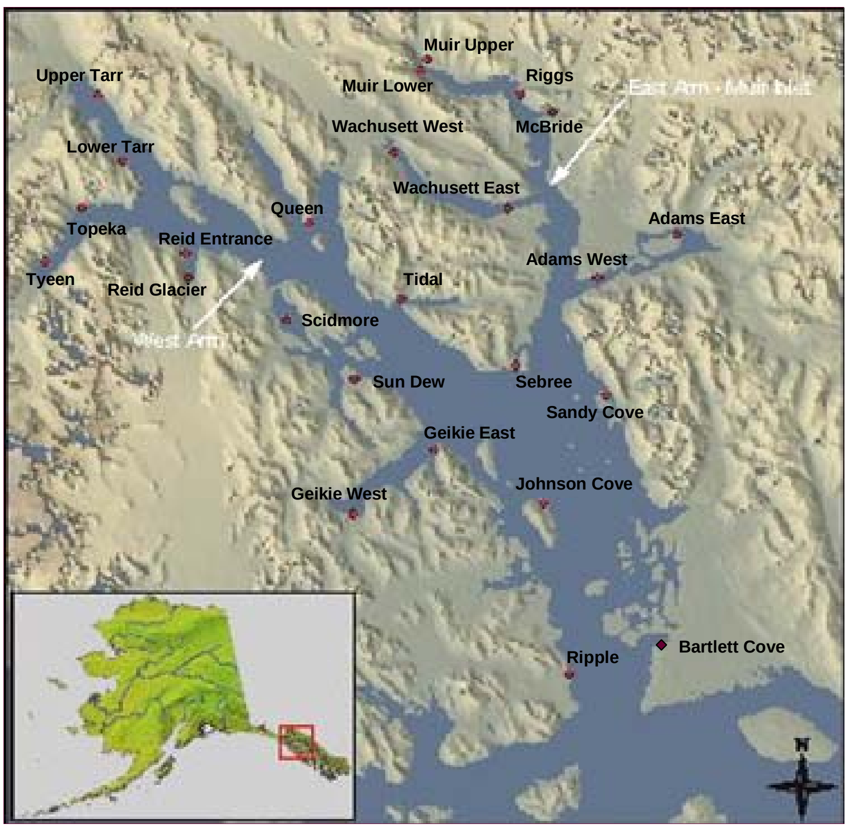


Figure 1. CRREL climate monitoring sites located within the Glacier Bay watershed. Bartlett Cove is a new site established jointly by NWS, NPS and CRREL in December 2007 and located on the NPS fuel dock, with both local and satellite transmission capabilities.

Each climate site has a minimum of two rain gauges (for redundancy), a dual temperature sensor, and a bulk precipitation collector for heavy isotope analysis (Lawson *et al* 2004; Finnegan *et al* 2007). The rain gauges (Onset RG-2 Tipping Bucket; Peet Electronic) record rainfall to Hobo event data loggers in 0.01 inch increments (Figure 2). Temperature is measured to 0.1 ° C accuracy at a 20 minute interval using two separate

Figure 2. Typical climate sites. Upper left photo shows white solar radiation shield housing temperature sensors and a tipping bucket rain gauge installed on 1-meter tall post at Muir Glacier. Photo on lower right shows the tipping bucket and electronic rain gauges in steel housings as mounted on the ground at the Riggs site. A post can only be used where animals are unlikely to damage rain gauges, but preferred to reduce snow cover effects early in the winter season.

thermistors that are housed within a solar radiation shield (Figure 2). Snow gauges previously used at three sites are being upgraded and will be returned to active use in 2009. As part of this effort, we have been laboratory testing of systems that have better resolution and smaller footprint than the previous tower based snow gauges. Appendix A in Lawson et al. (2006) provides detailed information on each climate site.

We have two sites (Queen Inlet, Tyeen) utilizing GOES (Geostationary Operational Environmental Satellite) transmitters for year-round, near-real time data transmission including precipitation, temperature, solar radiation and wind measurements. However, the site at Johns Hopkins suffered a major avalanche in winter 2007-2008 that destroyed all sensors, GOES transmitter and tower, and is currently out of service. We are moving the base for the climate tower to a location we think is out of the path of avalanches. We installed a new temperature sensor and tipping bucket rain gauge at this location to maintain the climate record and will be checking on its condition this coming summer before installing a new system. In addition, the Campbell GOES transmitter at the Queen site stopped functioning and all attempts to repair it in the field this past summer failed. Once funds are available, a new transmitter will be purchased an installed. This site has a ground based system as back up and thus no data have been lost and monitoring continues.

When operating, the GOES transmission system collects and transmits data at regularly timed hourly interval. Transmitted data are decoded at a central receiving station located at the New England District Corp of Engineers Reservoir Control Center in Concord, MA. These data are quality checked and then pushed to a central database server at CRREL where the information is disseminated via the World Wide Web. The site address is: https://rsgis.crrel.usace.army.mil/ltir/GBweb/GBindex.

We plan additional satellite transmitters as funds allow to reduce the need for costly site visits especially in areas where access may be limited by vessel restrictions and to provide data in near real time to park managers, staff and researchers. We are currently developing and testing new systems for transmitting larger amounts of data, including digital images via Iridium satellite phones. Testing of various components was one of our major tasks in 2008 and we will be evaluating the system at a field test site in 2009. This system is ultimately expandable to include new instruments as research needs arise, and allows for collaboration with other researchers who likewise may benefit from near real-time data transmission.

Each climate site is routinely maintained during late spring or early summer and again in late summer or early fall. Typically we require 5 days to complete servicing, download, repair and maintenance of the 24 field sites. We record the condition of the site in a field book upon arriving, sometimes photographing more serious problems such as animal or natural destruction of instruments and mounting equipment. The levelness of the rain gauges is measured and any deviation noted as this affects the volume recorded. The data loggers of each instrument are then downloaded to portable recorders, and batteries and desiccant are replaced while clearing the memory of older data and reinitializing loggers to begin a new data collection cycle.

Figure 3. GOES site in Queen Inlet. GOES satellite transmission system transmits hourly data on precipitation and air temperature, while storing all data on a Campbell data logger located within the grey box. We are currently working on new systems to replace this unit and that at the Johns Hopkins which was completely destroyed by avalanches.

Any problems with data loggers or instruments are noted in our field books, and we replace problematic loggers and broken instruments in the field with spares that we carry with us to minimize the time required to service each site and insure that we have fully operational equipment for the next period of monitoring. Simple repairs or download issues are addressed on board the vessel used to access the site or back in the office or lodging that night. More serious problems are repaired back at the CRREL Hanover laboratory. Details of each instrument recorded in the field book include condition and operation of the data loggers and any problems noted that may have affected the operation and recording of data (for example leaves or spiders in the rain gauge orifice). If data loggers or entire instruments must be replaced, the new serial numbers and time of start up are recorded. Bulk water samples are collected in 60 ml, air-tight Nalgene bottles and assigned sample numbers recorded in the notes for the particular site. On-board the vessel, we download all data files to a folder on a portable laptop computer and back-up these data on a data key.

Data files are archived on CRREL server and backed up daily in Hanover, as well as on our office computers for processing and analyses. Prior to analysis of the temperature and precipitation records, we evaluate the data record from each individual instrument to ascertain if any problems exist. Such things as gaps in data or spurious data points must be identified and removed from the data set. In addition, any situation or problems in the field that were noted in our field books must be taken into account. Such things as clogged intakes on the rain gauges or sensors knocked from their mounts to the ground will either cause records to be incomplete or result in partly correct records with certain sections that must be deleted. In the case of rain gauges, we have two gauges and we can use the two records to delineate the latter problem. This is commonly a tedious and lengthy job for the over 96 instrument records taken during each download period. Once problems in the data sets are corrected, records are combined to develop a continuous time-series from which annual as well as monthly and daily information can be extracted and analyzed using standard statistical methods.

Current Activities

In 2008, we continued to service and acquire data from all sites across the park in May and September, with the data now on servers at CRREL and being processed to add to the existing record for the park. Our primary effort this past year has been in evaluating and developing new capabilities and instrumentation for near real time data transmission while testing new sensors, power systems and related data platforms. We continue to process and analyze data as well.

Although we now have approximately seven years of data from most of the twenty-four sites, the length of record remains generally too short to permit analysis of the trends in seasonal and annual variability in climate and attempting to interpret its significance. The data from the climate sites do provide some preliminary indication of sub-regional variability within the Glacier Bay watershed and observations on the range in values for air temperature and precipitation over the course of a year. The entire database for all sites for the period is posted at the web site listed earlier and updated annually to Bill Eichenlaub by DVD for archiving on the Glacier Bay server.

Due to very limited funding in 2008 and extensive data processing efforts the previous year, we chose to focus much of our funds and energy on developing and testing climate system components so that upgrades of the climate network might provide more reliable data collection and transmission and flexibility of operations in wilderness conditions.. In particular we have been working to develop systems that can transmit large data volumes as well as allow remote communication to query instrumentation or to modify data collection parameters. One system that was lab tested is now at Hubbard Glacier near Yakutat and embodies new wind generators for power under cloudy and dark lighting. This charging system has provided continuous power without interruption through winters 2007 and current winter of 2008. This is important for application in Glacier Bay as power is usually lost during winter for some period of time at both the Johns Hopkins and Queen Inlet sites. Sensors for multiple parameters are supported by this hybrid wind – solar battery system. We have sought to keep costs low so that multiple systems may be deployed at our other existing sites, funding permitting.

In addition, our ability to tackle new systems has greatly benefited from other research efforts at CRREL funded under The Flood and Coastal Storm Damage Reduction program for the USACE, for which CRREL is developing, testing and implementing new remote data collection communication technologies. These technologies are intended to be small in their overall footprint, autonomous and low power for long term and easy setup in remote locations that lack direct communication links. The data generated by these systems are simultaneously being integrated into the Corps Water Management

System (CWMS) database structure for ease of data collection and analysis. By utilizing the CWMS backbone, we are assured a seamless implementation of the new technologies.

In addition, we have begun implementing Iridium Short Burst Data modems. These modems are small packet type modems that provide 2-way data transmission up to 190 bytes each and unlimited number of packets, while being very limited in power consumption. By implementing this technology, we are able to reduce our overall footprint at each climate monitoring site by well over a third through the reduction in size and quantity of power sources, modem/transmitter and antennas. We are in final testing with field deployments at climate monitoring sites in the high Andes of Peru, portable flood monitoring systems throughout the Midwest and the remote climate site at Haenke Island.

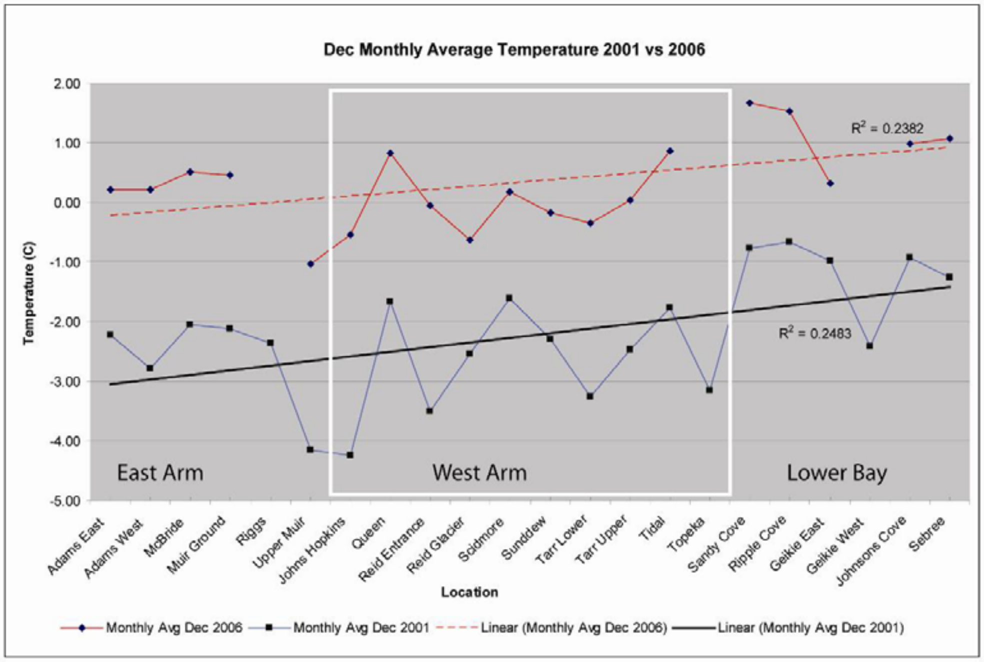
Analyses show that the trends in precipitation data are still inconsistent. Precipitation during the period of record of 2001 to 2008 did not have spatial trends that were consistent monthly or year to year. Rainfall amounts generally are low during the months of May through August, and highest in the months of October to December. For the period of record, rainfall has actually dominated over snowfall during these latter months, and snow is only prevalent as precipitation during the months of January and February, and less often in March, with temperatures generally near the freezing mark most of the time. Very cold periods with minimal temperatures at zero or below are rare events, usually short in duration, a week or less, sometimes lasting only a day or two before warming.

Large rain events typically occur in October through November, sometimes into December. A particularly important event that altered the landscape and modified stream hydrology and thereby their ecosystem, occurred in late November, 2005, with average rainfall amounts across the watershed of 20 to 28 inches in a 24 hour period. Extreme erosion of gullies and steep slopes of fjord walls brought large quantities of sediment into alluvial fans and adjacent fjords (Figure 4). Stream bank erosion coupled with flood removal of nearly all wood within the channel had major impact on salmon spawning (Milner, pers. comm.., 2008). Our data for this event and others provide the only climatic record for understanding such major changes in riparian and other habitats. We are currently collaborating with Sandy Milner in investigating the effects of this storm and other rain events on salmon populations of streams within the park.

Figure 4. Gully eroded by a significant rain event in November of 2005; precipitation totals across the park varied but averaged 20 to 28 inches in a 24 hour period. Similar large changes occurred in gullies and streams across the Park. The effects of this storm on river hydrology and geomorphology on salmon spawning are currently being investigated.

In general, annual rainfall (excluding snowfall amounts) generally exceeds 70 inches to over 120 inches. Snowfall adds significantly to the amounts of precipitation with between 60 and 80 inches water equivalent measured at the Johns Hopkins, Muir and Geikie sites. Precipitation values exhibit the orographic effect of the Fairweather Range, with lowest values within Johns Hopkins Inlet in particular as well as Tarr Inlet, in contrast to mid-bay and the East Arm where average precipitation totals are higher monthly and generally as a total amount during any given storm. We are continuing to process the precipitation data and extrapolate trends in precipitation, with 2007 to 2008 data in process. Inconsistent data acquisition during the early years of our monitoring continues to complicate interpreting this record. More recently, the instrumentation has been more reliable and with less disturbance by wildlife that has resulted in more complete records for the last 4 years.

We are now seeking a college student to begin the important task of evaluating the climate across the Park as part of their thesis. This will provide further detailed data analysis while allowing us to focus on improving the climate monitoring capabilities. A primary objective of the thesis will be to understand what the data indicate in terms of their temporal and spatial differences on a site-by-site and subregional basis, and considering daily, weekly, monthly and annual variability. An example of the types of analyses that are possible for the records of temperature on an annual basis is exhibited in Figure 5.



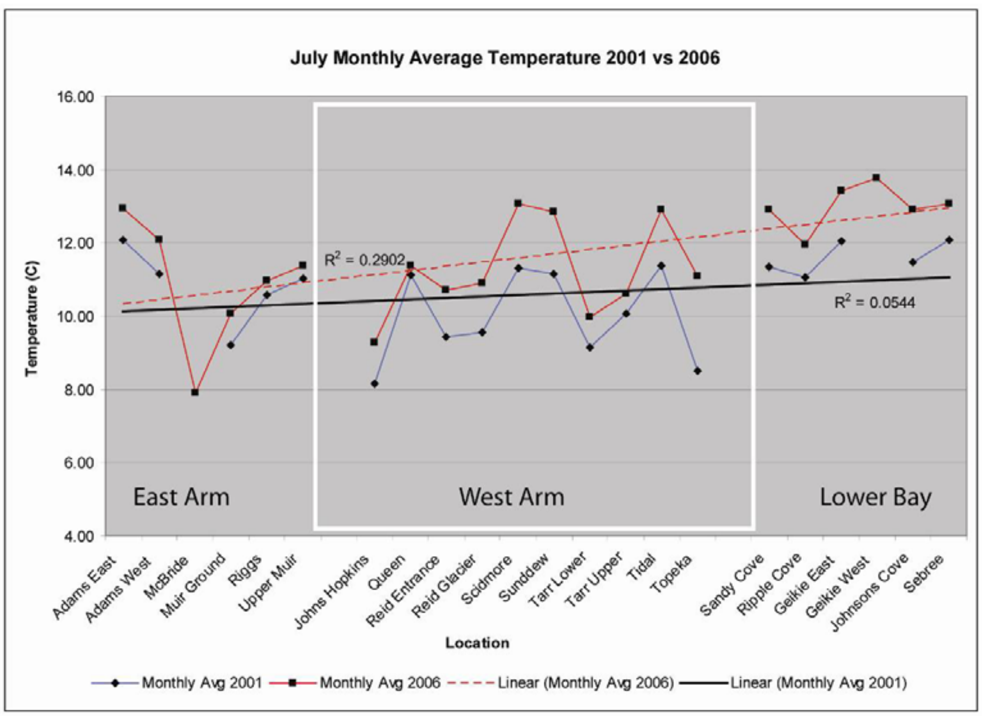


Figure 5. Graphs of the monthly average temperatures by site across the Glacier Bay watershed. The upper plot is of average December or winter temperatures by site, comparing the years of 2001 and 2006. The lower plot shows the mean July or summer temperatures by site for the years 2001 and 2006.

which shows how winter (December) and summer (July) average temperatures varied by site for the years 2001 and 2006. Overall, annual temperatures in 2001 were colder at the majority of sites than in 2006. The graphs suggest that this difference is due to colder winter temperatures (3 ºC), with summer temperatures nearly equal (1ºC) each year at each site. Similar variability is apparent other years of record and including this past summer when temperatures were generally cooler during summer than all previous years of record, with maximums much less than normal. The one factor which observation suggests is important is the large percentage and lengthy duration of cloud cover such as during summer 2008, suggesting the need to examine solar radiation at climate sites. Other apparent trends in data will be examined as well, such as colder temperatures and drier conditions in the upper West Arm than in the East Arm and lower Bay. Looking at each site individually, the coldest sites in the East and West Arms are located nearer the active glacier margins at the heads of fjords.

Collaborators and Synergistic Activities

We are collaborating with Brendan Moynihan to utilize our climate monitoring network as part of the NPS SEAN I&M climate monitoring program. Discussions and a field visit in September 2008 led to a draft plan for using existing sites, installing potentially two new sites within the bay, one in conjunction with Tom Ainsworth (NWS, Juneau), and upgrading certain CRREL stations, including Upper Muir, with additional sensors and satellite transmission of data. We are hoping to have the Iridium interface tested and electronic chips produced for deployment at one or more sites this upcoming field season as part of this collaboration.

In addition, we are working on collaborating with the Park to involve staff in annual servicing and maintenance of the climate sites. This would potentially allow greater coverage during open waters outside closed seasons, while possibly reducing costs to do so. Lewis Sharman accompanied us in the field in May and September to visit each site and learn about the procedures and some of the typical problems encountered and how to solve them on site, while he provide able assistance and discussion during the field work.

Our field work during the summer of 2008 relied in part on undergraduate students from The College of Wooster and Dartmouth College, high school students from Vermont and significant assistance from Park volunteers in the downloading of data loggers and servicing of the instruments, as well as the able assistance and collaboration with Lewis Sharman as part of our joint efforts to utilize Park staff to help in downloading data and servicing the climate sites each year.

We are collaborating with Dave Hill (Penn State) to enhance his oceanographic model for the freshwater flux based on the precipitation data across the park, and to provide our discharge data at tidewater glacier margins to supplement his efforts this next summer. We are also collaborating with Sandy Milner to examine the effects of the November 2005 storm on salmon streams within the park, attempting to understand what the short and long term effects may be from the drastic alteration of stream hydrology.

Continuing Work and Products
We plan to visit each climate site over two, 5-day periods in the spring and fall of 2009, and each year thereafter until systems are fully automated. These visits are necessary to insure that a complete record of the air temperature and precipitation from each site is acquired, barring any problems over which we have no control. Two maintenance trips are essential to insure as continuous a record as possible, given the many random problems we have encountered particularly from animals and a field evaluation we conducted in 2008 showing that it improved the likelihood of uninterrupted measurements. In addition, we are evaluating all sites because of the continuing expansion of vegetation in and around the instruments; this affect's both precipitation and temperature data, producing errors in collection if not cleared. We will continue with field testing of new systems and sensors and testing at the Haenke Island site with the objective of future deployment of these systems within the park. We will be updating the archival database through Bill Eichenlaub for the NPS Glacier Bay server. Our climate data are available for use by other researchers and park staff, but we ask that requests be made directly to us to insure no duplication of effort and that the most up-to-date and quality checked processed data are utilized. We will also be updating and improving the CRREL Glacier Bay web site.

Our goal is to produce continuous records for precipitation and temperature at monthly and annual intervals that is fully quality checked and therefore useable by others. We will continue our collaborations with Brendan Moynihan for SEAN I&M climate monitoring and with Lewis Sharman and other park staff for developing capabilities for NPS staff to assist in the climate monitoring. As measurements continue to be acquired annually, the length of record necessary to discern and analyze long-term trends versus short-term variability inherent in natural systems will lengthen and enable analyses of such questions as whether changes in climate globally are having an effect on the climate of Glacier Bay. Given the climatically sensitive nature of southeast Alaska, the temperature trends may ultimately show that decadal events and cycles (e.g. El Nino and the longer Pacific Decadal and Arctic Oscillations) that are known to influence the North Pacific region, are also important to understanding the Park's climate over shorter time periods and such changes are known to have major effects on marine population dynamics.

Management Implications and Significance
Climate change is one of the most important things affecting the world today and in the future. The long-term climatic data that we are now collecting will be essential to understanding how global and regional changes in climate are affecting Glacier Bay and in predicting how such changes will impact the Park's ecosystems. Such changes may cause significant changes in marine, terrestrial and freshwater ecosystems in the park, significant impacts that Park management may need to consider mitigating. Climate is the essential driver controlling physical and biological processes and environments and the feedbacks among them. The CRREL climate network is a first step toward meeting the goal of long-term monitoring and will feed directly into the SEAN Inventory and Monitoring Program. By upgrading the existing sites for additional sensors for wind, solar and barometric pressure and for satellite transmission with web access to the data, a

full suite of climatic data will be available in near real time for use by park management, rangers, naturalists and interpreters as well as researchers and other agencies, particularly the NWS. Our extremely limited understanding of the climate in the Park and such basic knowledge as storm tracks and prevailing winds will be met by our enhanced climate network as the collaborations with NWS and NPS come to fruition. Emergency situations such as accidents involving cruise ships would benefit from having real time information on local meteorological conditions within the fjords.

Acknowledgements
This project has been funded in part by the US Army Cold Regions Research and Engineering Lab, the National Science Foundation, Rockefeller Center for Public Policy and Social Sciences and the Institute of Arctic Studies at Dartmouth College, and private donations. We are extremely grateful to the current and past staff and management of Glacier Bay National Park and Preserve for their logistical support, assistance and encouragement. We particularly would like to thank Cherry Payne, Superintendent, Craig Smith, Chief Resource Management, and Lewis Sharman, Ecologist, for their permission and encouragement to conduct the research, and in providing the continuing support of their staff and vessels, housing, office space and other facilities. We thank Justin Smith for his excellent vessel support and interest in insuring that the climate site maintenance and data acquisition are accomplished efficiently and safely.

References

Finnegan, D.F., Lawson, D.E. and Kopczynski, S.E. 2007. Assessing contemporary and Holocene glacial and glacial-marine environments. *in* Piatt, J.F., and Gende, S.M., eds., Proceedings of the Fourth Glacier Bay Science Symposium: U.S. Geological Survey Scientific Investigations Report 2007-5047, p. 42 – 45.

Lawson, D.E., Finnegan, D. C., Kopczynski, S. and Bigl, S., 2004. Long-term studies of tidewater and terrestrial dynamics, glacier hydrology and Holocene and historic climate activity, Glacier Bay National Park and Preserve, Southeast Alaska. Annual Report; Prepared for Glacier Bay National Park and Preserve, Gustavus, AK (March).

Lawson, D.E., Finnegan, D.C. and Wiles, G. 2006a. Climate Monitoring: Glacier Bay National Park and Preserve. 2006 Annual Report. Prepared for Glacier Bay National Park and Preserve, Gustavus, AK

Lawson, D.E. and Wiles, G., 2008. Paleoclimate of the Last 10,000 Years, Glacier Bay National Park and Preserve: Progress Understanding Climate Change in Southeast Alaska. Annual Report, Glacier Bay National Park and Preserve, Gustavus, AK.