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

2011 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

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Table of Contents

Executive Summary	**3**
Introduction	**4**
Reasons for Monitoring Climate	**4**
Project Background	**6**
Methods and Instrumentation	**6**
Activities in 2011	**8**
Collaborations and Synergistic Activities	**9**
Management Implications and Significance	**10**
Acknowledgements	**10**
References Cited	**10**
Appendix A. Air Temperature Record (2000-2011)	**12**
Appendix B. Precipitation Record (2000-2011)	**14**

Cover Photo: CRREL climate station at Johns Hopkins Inlet; this station was removed in August 2011.

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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 prior to 1999, we initiated a long-term monitoring of contemporary climate in Glacier Bay in cooperation with the National Park Service (NPS). Our climate monitoring system provides the initial decadal record of the climate across the Glacier Bay watershed. It may provide the basis for understanding the effects of global and regional changes in climate on Glacier Bay National Park and Preserve. Climate data records of sufficient length from multiple locations are necessary to calibrate Global Climate Models (GCM's) and predict how future global changes in climate will impact the environment and ecosystems of Glacier Bay. Knowledge of the likely short- and long-term responses will be important in the future for utilizing and protecting Park resources while accommodating visitors.

The complexity of the climate system in the Park is evident in the data which are now being analyzed statistically and will be furthered examined in collaboration with our colleagues. The temperature data provide the basis for calibrating tree-ring records and interpreting the paleoclimatic indices of interstadial wood sites and the climate of the past 10,000 years. Combined with other measurements, such as ablation and accumulation rates and elevation and area changes, temperature and precipitation records are critical to understanding the response of glaciers and ice sheets, as well as other physical systems to regional and global climatic change.

Two primary activities comprised our efforts in 2011. First, the entire CRREL network of twenty-four sites was removed, the first sites in June and continuing through the summer, with the final two sites being removed in September. Each site was thoroughly inspected and all equipment and materials removed. Sites had extremely minimal surface disturbance but in each case, these disturbances were remediated to appear as natural and undisturbed as possible. Secondly, we completed processing the data for the period of record and provided an Excel 2007 database of the climate records with meta-data from 2000 to 2010 in March to meet the Park's requirement to discontinue the climate monitoring and provide this documentation. This effort required re-formatting of all data to Excel 2007 and text formats, with the field downloaded date concatenated into two files for each site's precipitation and air temperature records. Each file was examined in

detail, an initial QA/QC performed, and meta-data including logger meta-files, assembled In addition to the database, additional documents, including a report assessing the efficacy of the CRREL climate network, a digital copy of all informal field notes, and several summary files and spreadsheets related to the data record and site meta-data, were provided to the Park.

Introduction

Over the last 22 years, we have conducted long-term, integrated monitoring and site-specific multidisciplinary studies of glacial, marine and terrestrial environments in Glacier Bay 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 the positions of 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 therefore to provide the baseline climatic record to which future changes in climate can be compared, and ultimately applied to understanding physical and biological changes in the Park in response to climate variability. CRREL climate sites were distributed across the Glacier Bay watershed such that regional trends may be identified and compared and correlated with temporal variations as sufficiently long records are eventually developed. These data may then allow analysis of climatic patterns, differences in weather between the East and West Arms, and impacts of short-term climatic changes that result from ENSO (El Nino/La Nina), PDO (Pacific Decadal Oscillation) and AO (Arctic Oscillation).

Reasons for Monitoring Climate

Climate is the primary driver of the physical, hydrological and biological processes of Glacier Bay's diverse marine, freshwater and terrestrial ecosystems. With the exception of historical data from Bartlett Cove and Gustavus, no systematic monitoring of the climate within the Park had been done prior to 1999, and therefore as part of our research, we initiated long-term monitoring of contemporary climate in the Glacier Bay watershed in cooperation with the Park in that year.

Without a baseline for the current climate, it is impossible to know if changes in the global climate are, or will, affect southeast Alaska climate and more specifically and importantly, the climate of Glacier Bay. The CRREL climate network is the first and only detailed monitoring of climate at a scale sufficient to monitor variability within a large,

natural and undisturbed watershed in southeast Alaska. We hope that the database will be linked to the SEAN Climate Monitoring effort so that the two most important climatic variables affecting the Park's environment and ecosystems, air temperature and precipitation, can be used to detect changes in the future. Once the record is extended another one to two decades, it could provide valuable data that do not otherwise exist within the Gulf of Alaska and North Pacific that are required to calibrate Global Climate Models (GCM's) for this region. GCM's could then be used to predict how future global and regional variability in climate will impact the environment and ecosystems of Glacier Bay. Our network was limited in the sense that additional data from higher elevation sites in glaciated areas and from the outer coast would have provided a more complete understanding of how the Park's mountainous terrain affects temperature and precipitation, and thus the accumulation or ablation of the glacial systems and their expansion or thinning and retraction over time.

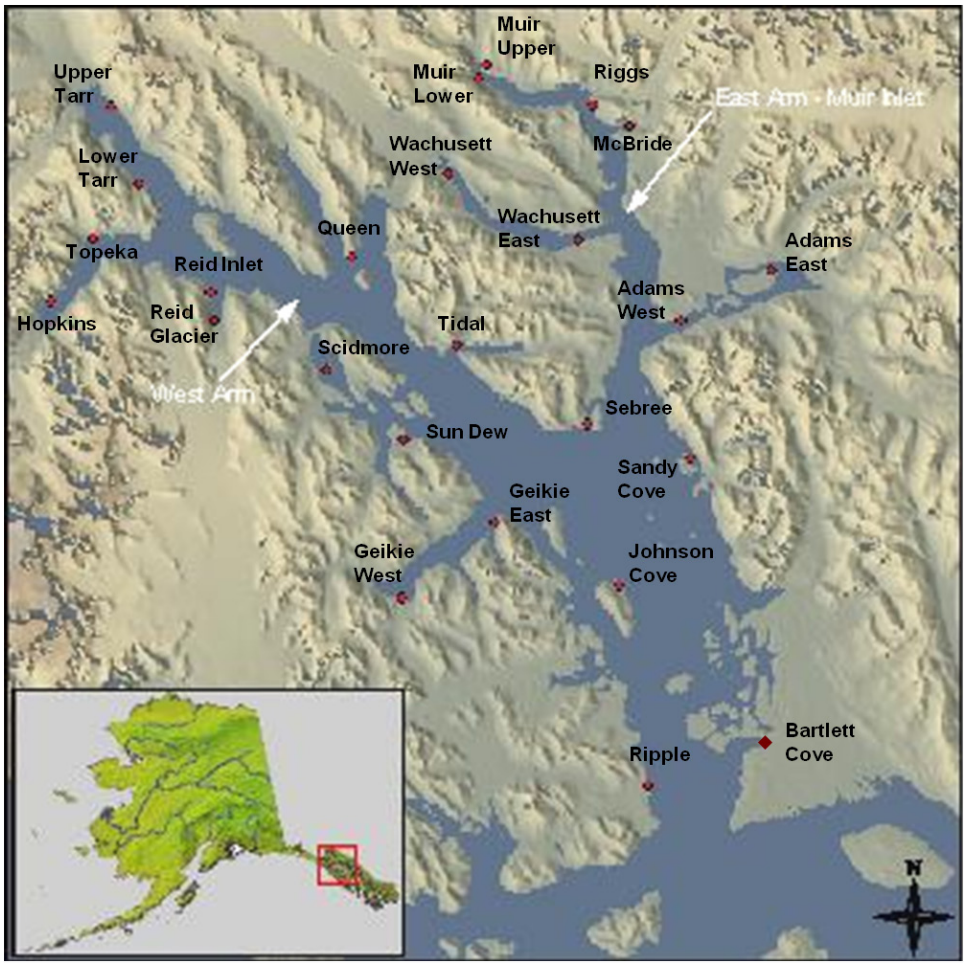

Figure 1. *CRREL climate monitoring sites were located across the Glacier Bay watershed. Bartlett Cove was established jointly by NWS, NPS and CRREL in December 2007 and located on the NPS fuel dock, with both local and satellite transmission capabilities.*

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 independent 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 primary 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 and available at the Glacier Bay web site.

The Park has determined that the entire monitoring system be removed as it lies on the edge of designated wilderness. This removal was accomplished in summer 2011, with the first sites removed in June and the remainder of the sites removed over the next three months.

Methods and Site Instrumentation
Climate sites were located along fjord margins, generally at or near sea level and generally within 100 m or less of the wilderness boundary (Figure 1). All climate sites were assigned names generally in keeping with their location in the Park. The description that follows provides information on the instrumentation and standard operating procedures used.

Each climate site had 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; the tipping bucket is the primary data source, while the digital gauge provided back-up to failed loggers or damage resulting from bears or other natural hazards (Figure 2). Temperature is measured to 0.1 ° C accuracy at a 20 minute interval using two separate thermistors that are housed within a solar radiation shield. Appendix A in Lawson *et al*. (2007) provided detailed information on each climate site.

Originally two sites (Queen, Hopkins) utilized GOES (Geostationary Operational Environmental Satellite) transmitters for year-round, near-real time data transmission including precipitation, temperature, solar radiation and wind measurements. However, the Queen site suffered massive electronic failure in 2008, while the Johns Hopkins site suffered a major avalanche in winter 2007-2008 and again in 2008-2009 that destroyed all sensors, GOES transmitter and tower. The destroyed Johns Hopkins station was removed early in August, 2010, while the entire area was returned to its natural state. After significant research and testing, we re-established the Johns Hopkins site in 2010 but it too was removed in 2011.This system (photo, cover page) had included the full suite of climate sensors with extremely low power usage requiring only 4 AA lithium ion

batteries in the data logger and an internal, sealed-cell lithium ion battery with small (~6 in^2) solar panel for a satellite modem.

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 was only used where animals were unlikely to damage rain gauges, but preferred wherever possible to reduce snow cover effects on winter season data.*

Each climate site was routinely maintained during late spring to early summer and again in early fall. We typically required five days to complete servicing, data download, repair and maintenance of all climate stations. We recorded 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 level of the rain gauges was measured and any deviation noted as this affects the volume recorded. The data loggers of each instrument were then downloaded to portable recorders, referred to as shuttles, and batteries and desiccant were replaced while clearing the memory of older data and reinitializing loggers to begin a new data collection cycle.

Any problems with data loggers or instruments were noted in our field books, and we replaced problematic loggers and broken instruments in the field with spares that we carried with us to minimize service time for each site and insure that we had fully operational equipment for the next period of monitoring. Simple repairs or download issues were addressed on board the vessel used to access the site or back in the office or lodging that night. More serious problems were repaired back at the CRREL-Hanover laboratory. Details of each instrument recorded in the field book included 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 had to be replaced, the new serial numbers and time of start-up are recorded electronically. On-board the vessel, we downloaded data files to a folder on a portable laptop computer and backed up these data on a data key.

In the office, we stored the raw data files and later transferred the data using the Onset Computer Corporation Hobo Pro or BoxCar Pro software (depending on generation of the loggers) into Excel and text format files, which included the basic meta-data on each logger, for later analysis. A copy of the raw data files was archived annually at the Park as required by our research permit. Prior to analysis of the temperature and precipitation records, we evaluated the data record from each individual instrument to ascertain if any problems existed such as an incomplete data stream or overlap of records when new loggers are installed. Problems such as clogged intakes on the rain gauges or sensors knocked from their mounts to the ground will cause the records to be incomplete but easily identifiable by absence of data. Duplicity of the rain gauges may in some cases fill gaps in the record. The raw data records were combined in a continuous time-series from which annual as well as monthly and daily information can be extracted and analyzed using standard statistical methods. QA/QC of these records was straightforward, generally removing of duplicate readings when loggers were replaced and identifying gaps in the records. Each of the individual Excel and Txt files were archived by site name.

Activities in 2011

Our primary focus the first three months of this year has been to meet the park's requirement to provide the data records of temperature and precipitation from each site in an Excel 2007 database for the period of record (2000-2010). Collaboration between CRREL and University of Birmingham made this effort possible now, rather than at the planned timeline of 2012-2013. We insured all possible data were included in the database, returning failed loggers to the manufacturer Onset Computer for their technicians to attempt data recovery.

The site-by-site data were concatenated into single file structure within Excel 2007. In addition to the Excel 2007 database and meta-data, we provided a full digital copy of all informal field notes from 2000 to 2010 on servicing of the climate network, wrote a report assessing the efficacy of the climate network, and provided several summary files and spreadsheets related to the data record and meta-data for each site. A summary bar graph showing the length of record for air temperature and precipitation for each site was provided and included in the 2010 Annual report to the Park (Lawson et al. 2010). We

have updated that bar graphs for both parameters to include the data collected during removal of the twenty-four sites in summer 2011 (Attached Appendices A, B)

From June through end of September at various times with boat support provided by the Park, we systematically removed each climate site. We restored any disturbance caused by the installations which were extremely minimal as the footprint of the instrumentation was very small. Any holes from mounting bolts in bedrock were filled with InstaCrete camouflaged with local granular rock fragments as required by the Park. We inspected every site thoroughly to insure all of our materials were removed. The loggers were returned to CRREL and data have been retrieved from them. These records are currently being processed and will be sent to the Park at a later date for addition to the database we provided that is archived on the Park's server. We are planning to develop the statistical relationships for the air temperature and precipitation records and prepare a manuscript for publication at a later date.

Collaborations and Synergistic Activities

Collaboration is underway on the effects of a major rain event on salmon habitat and spawning within the streams of Glacier Bay. Sandy Milner and Megan Klaar are using the climate record to help understand how geomorphic stream response to a November 2005 flood impacted salmon spawning and the subsequent recovery of the salmon population. Most of the climate stations within the Glacier Bay watershed recorded ~25 inches of rain in a 24 hour period, followed by several subsequent large events over the next several weeks. This event modified the stream substrate including woody debris distribution, changing the habitat and spawning cycle of salmon. The impact has lasted over 5 years.

We have been exploring collaboration with Dave Hill (Oregon State) to examine how the climatic data may provide insights into details on the freshwater flux to marine systems, a critical parameter driving water properties within the fjord estuarine environments of the Park (Etherington *et al.* 2007; Hill *et al.* 2009).

We will continue our collaboration with Brendan Moynihan for SEAN I&M climate monitoring and with research and interpretive staff to provide our expertise and knowledge of the climate, climate change and glacial response. It is our hope that the final results of the ten-year effort will provide the baseline for the long-term monitoring within the park and an understanding of the regional nature of the global climate signal in the Glacier Bay watershed.

Our field efforts during the summer of 2011 relied in part on undergraduate students from Middlebury College and Dartmouth College, high school students from Vermont. Graduate students at Birmingham and Maine assisted greatly in the database effort. We provided multiple temperature and precipitation gauges to the Gustavus School for use in science and other classes.

Management Implications and Significance

Climate change is one of the most important things affecting the world today and in the future. The decadal climate record will be essential to identifying future global and regional changes in climate in Glacier Bay. 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 hopefully feed directly into the SEAN Inventory and Monitoring Program.

Acknowledgements

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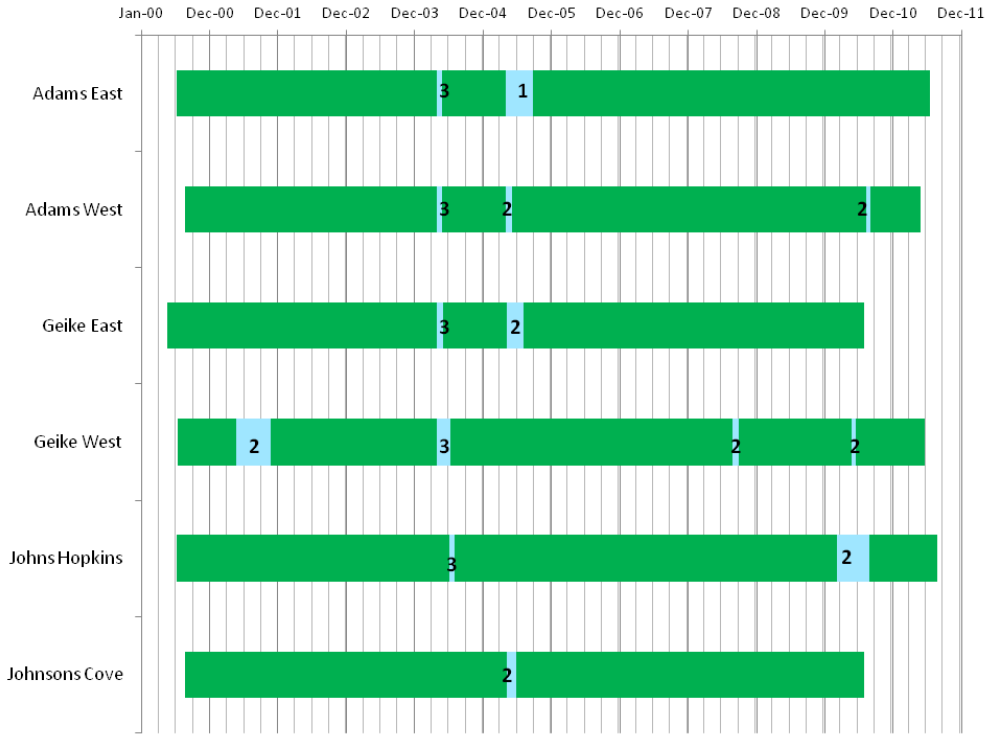
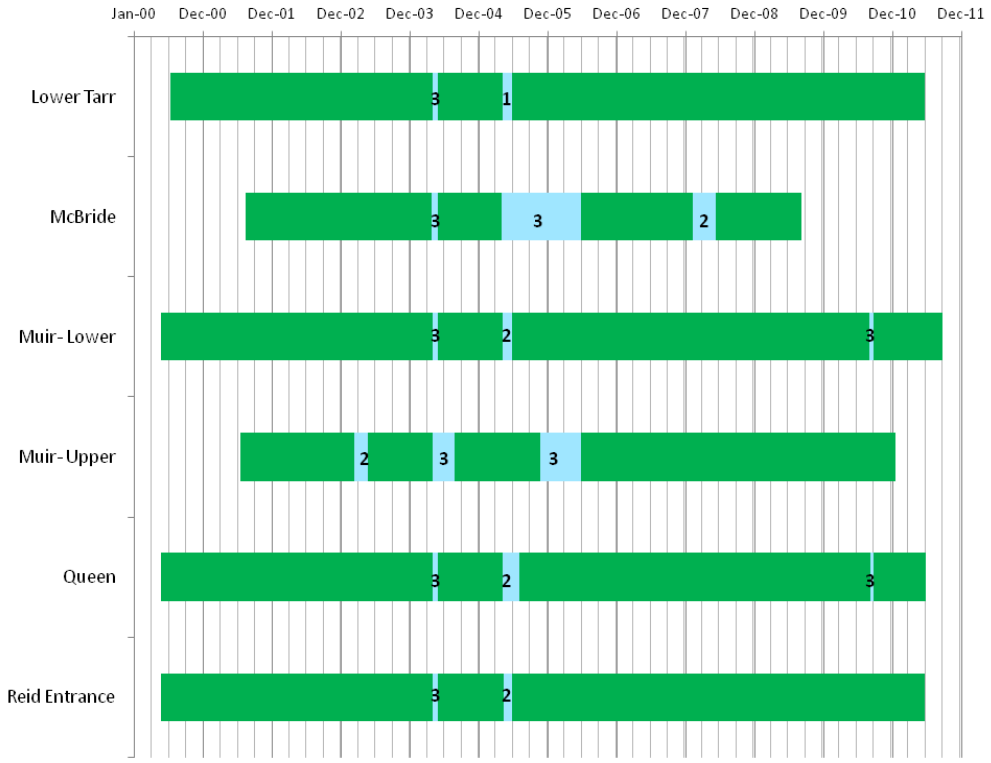
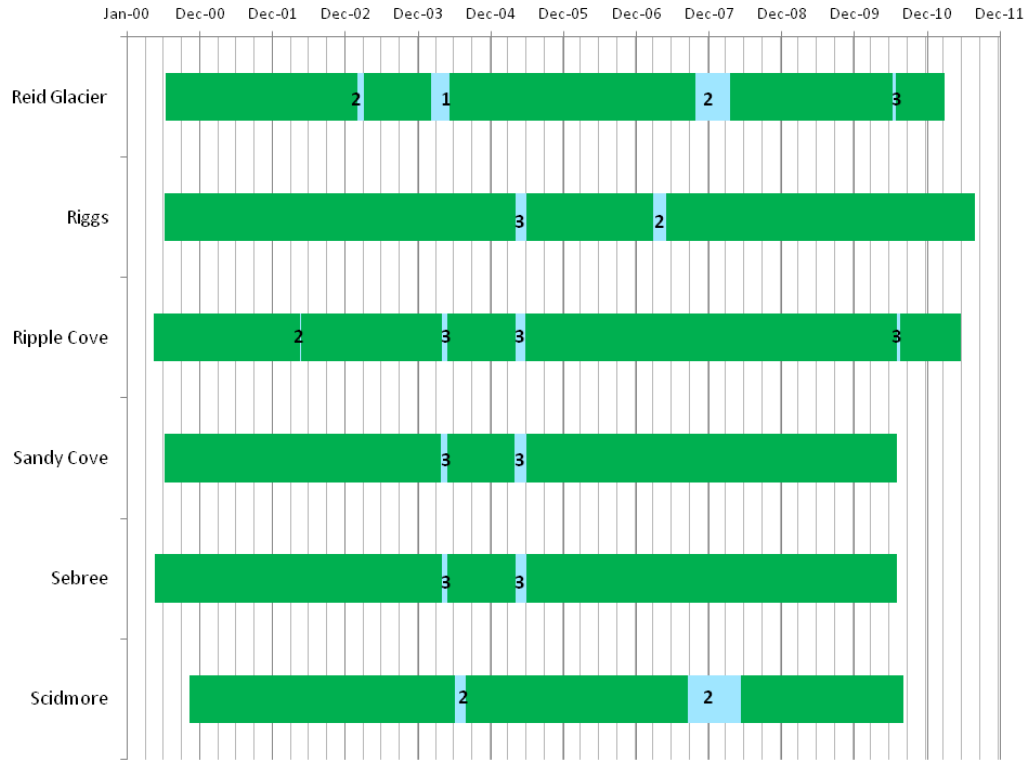
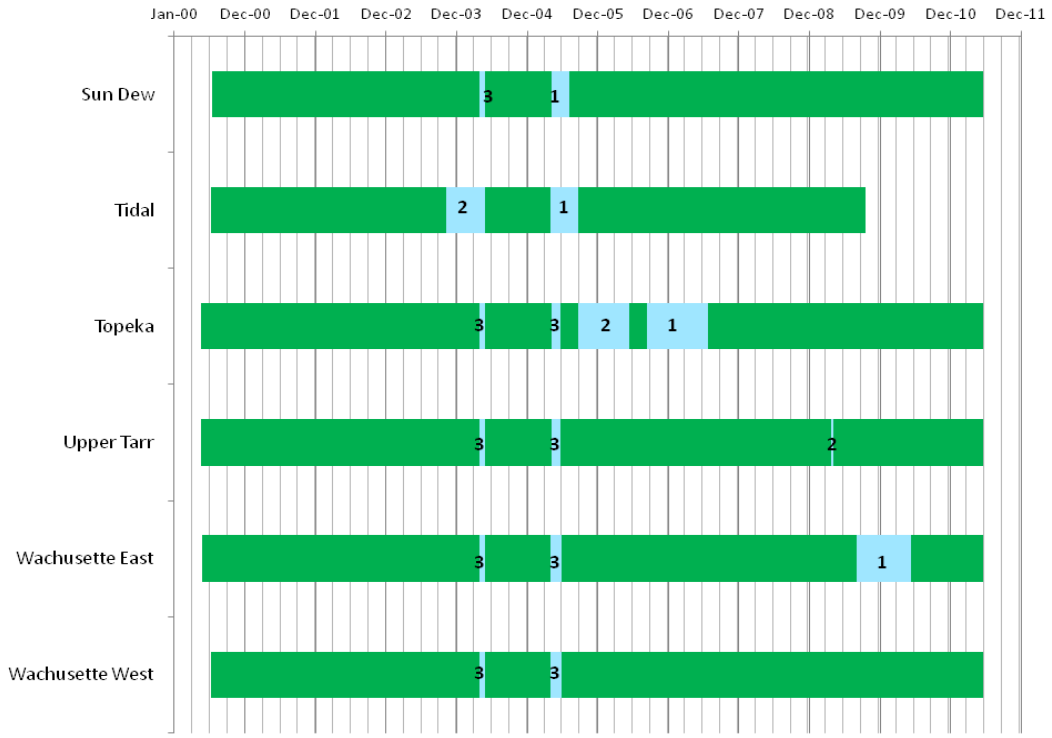
Appendix A. Air Temperature Record (2000-2011)

The bar graphs show the periods of record of air temperature at each climate site. Green indicates data available; blue are gaps in the record. The numbers refer to the footnotes which briefly explain the reason why a particular gap exists.





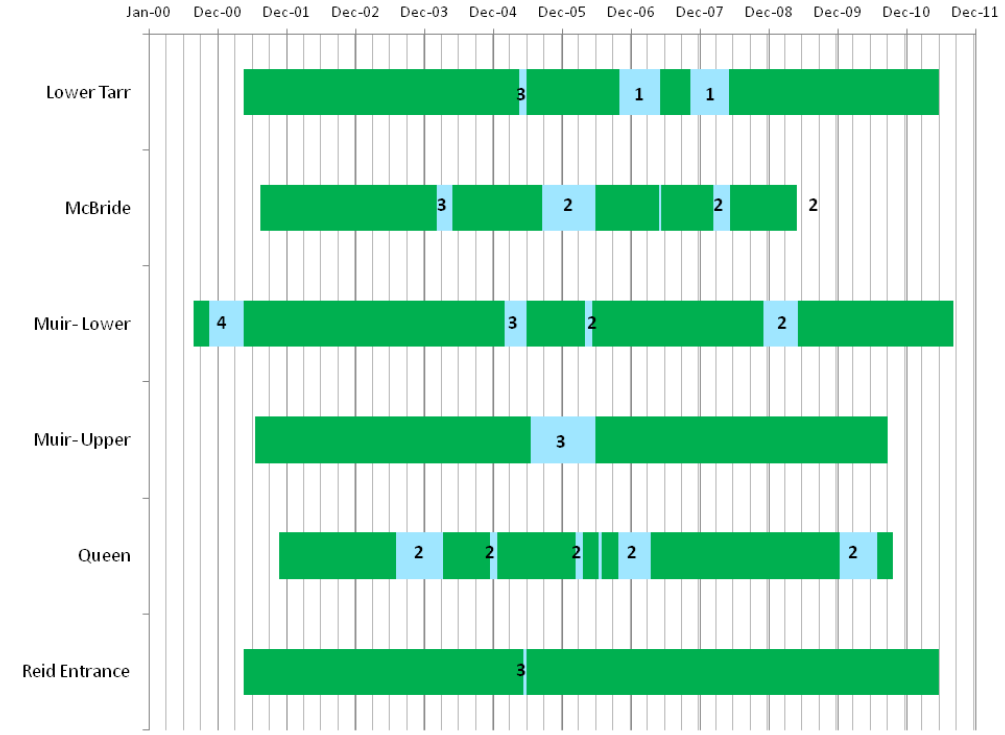


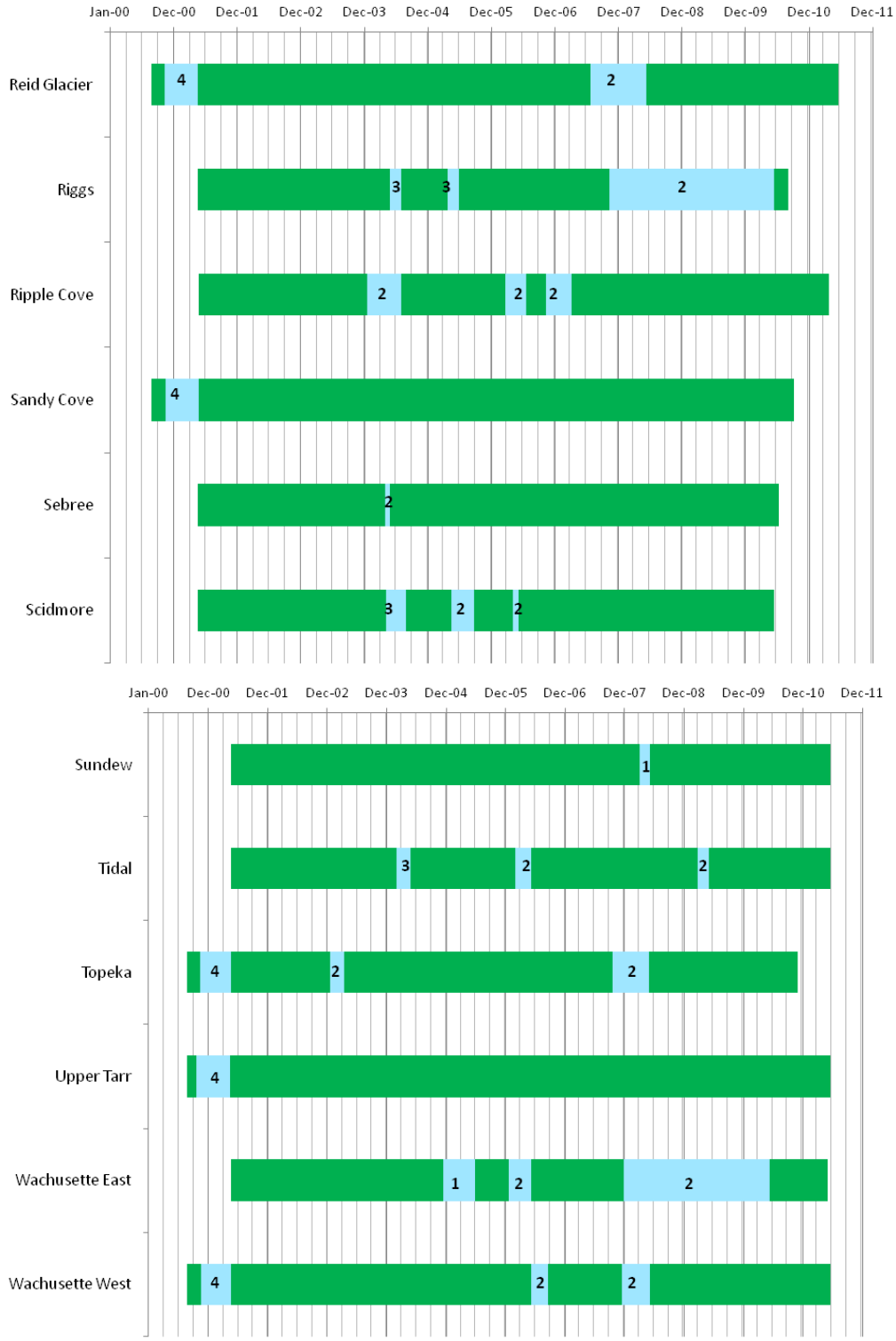


Key: Green = data available; Blue = data missing. 1 = logger/ equipment damage (bear, avalanche etc); 2 = equipment malfunction (battery, corrupt file etc); 3 = logger memory 'full', due to lack of access to climate station.

Appendix B. Precipitation Record (2000-2011)

The bar graphs show the periods of record of precipitation at each climate site. Green indicates data available; blue are periods of time without data recorded. The numbers refer to the footnotes which briefly explain the reason why a particular gap in the record exists.





Key: Green = data available; Blue = data missing. 1 = logger/ equipment damaged (bear, avalanche etc); 2 = equipment malfunction (battery, corrupt file etc); 3 = logger memory 'full', due to lack of access to climate station; 4 = precipitation gauge covered to prevent snow and ice damage- practice stopped after winter 2000- 2001.