C41A-0058

# Near Realtime Monitoring of Tidewater Glacier Advance and Retreat: Hubbard Glacier, Southeast Alaska.


*US Army Corp of Engineers*
*Cold Regions Research & Engineering Lab*
*Remote Sensing and GIS Center of Expertise*
*Hanover, New Hampshire*

[1]David C. Finnegan, [1]Daniel E. Lawson, [2]Greg Hanlon and [3]George Kalli
David.Finnegan@erdc.usace.army.mil

[1]*Cold Regions Research and Engineering Lab, Hanover, NH 03755 USA*
[2] *US Army Corp of Engineers, New England District, Concord, MA 01742 USA*
[3] *US Army Corp of Engineers, Alaska District, Anchorage, AK 99506 USA*

**US Army Corps of Engineers**
*Alaska District - Anchorage, AK*
*New England District - Concord, MA*


## Background

Tidewater glaciers advance and retreat as part of the well-documented tidewater glacier cycle (Post, 1975; Meier and Post, 1987; Post and Motyka, 1995) while exhibiting seasonal changes that are not yet well understood. Quantitative data on factors that influence tidewater glacier activity are often difficult to capture. The accurate collection of such data is a key to better understanding the annual and seasonal dynamics of tidewater glaciers. With this in mind, we are examining the activity of Hubbard Glacier at its terminus, using automated high-resolution ranging measurements and local meteorologic conditions to obtain quantitative data in near real-time.

Hubbard Glacier, near Yakutat, Alaska, is the largest non-polar tidewater glacier in the world and the largest tidewater glacier in North America. It encompasses an area of ~3500 km$^2$, flowing 120 km from the flanks of Mt. Logan (5959 m a.s.l.) in the Wrangell - St. Elias Mountains (Canada) to sea level where its terminus widens to ~11.5 km and discharges into Disenchantment Bay and Russell Fiord (Figure 1). In contrast to most glaciers in Southeast Alaska, Hubbard Glacier continues to advance and thicken. The high accumulation area ratio (0.95) of Hubbard Glacier suggests that it will continue to advance for hundreds of years, barring any significant changes in climate altering its Equilibrium Line Altitude (ELA). Thus our data are providing a unique, high-resolution (4 times daily) look at a rapidly advancing ice margin. We are monitoring ice margin motion along a section of the terminus near Gilbert Point (Figure 1). Gilbert Point is the location where ice dams were previously formed by Hubbard Glacier (1986, 2002), blocking the entrance to Russell Fiord east of Gilbert Point, and forming a 63 km long ice dammed lake. During both closure events, the dams failed and generated two of the largest outburst floods recorded in historic times. Understanding the dynamics of the ice margin here is critical to understanding how ice dams are created and the potential for a permanent closure of Russell Fiord by Hubbard Glacier.

A permanent closure of Russell Fiord would have significant environmental and economic impacts to the downstream community of Yakutat. If an ice dam remained stable and the water level reaches an elevation of 40 m above sea level, waters from Russell Lake will flow through a gap in an end moraine at the southern end of the fiord into the Situk River. The Situk River supports one of the most productive commercial and sport fisheries in southeast Alaska, this flooding could destroy the fishery thereby damaging the local economy as well as the infrastructure in Yakutat.



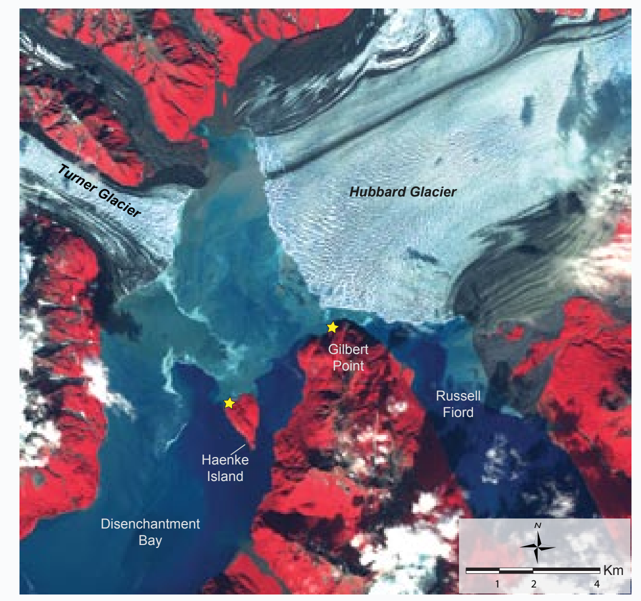


**Figure 1**
Location of the Hubbard Glacier in Southeast Alaska (upper left). Hubbard Glacier flows south from the Wrangell St Elias Mountains and discharges into Disenchantment Bay and the entrance to Russell Fiord (right). The upper yellow star locates the laser monitoring station at Gilbert Point; the star on Haenke Island locates the climate site and GOES transmitter. The 1 m/pixel RGB false color composite image was acquired by Digital Globe's Quickbird satellite September 18, 2007.

***Bottom left***
Water level view of the Hubbard Glacier terminus near Gilbert Point and the ice terminus monitoring location. The ice face is ~100m high.

## Monitoring Locations & Equipment

Two monitoring locations were installed in late September of 2006. One at Gilbert Point to monitor terminus motion and potential ice dam formation between Disenchantment Bay and Russell Fiord, and a second site on Haenke Island (also locally known as Egg Island) in Disenchantment Bay, ~3.2 km from Gilbert Point (see figure 1), to serve as a communication repeater and a full climate station to record meteorological conditions.

Each site utilizes numerous commercial, off-the-shelf components to reduce the complexity in system design, build-time and maintenance (Table 1). Given the location and data acquisition requirements, electronic circuit boards, programming interfaces and physical infrastructure that were designed in-house were needed to integrate and control the laser ranging unit at Gilbert Point.

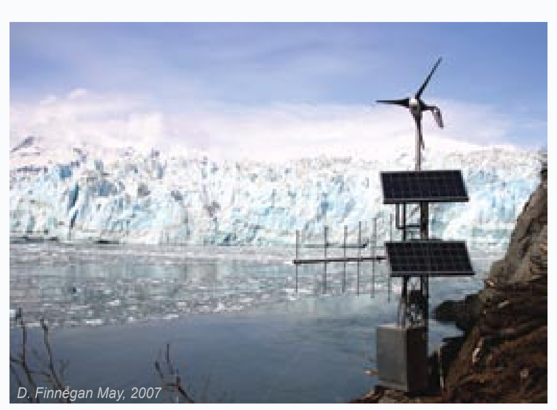



**Figure 2**
***Left*** - Ice terminus monitoring system, positioned ~50 m above sea level along the western shore of Gilbert Point.

***Right*** - Haenke Island meteorological monitoring station and radio/GOES satellite repeater.

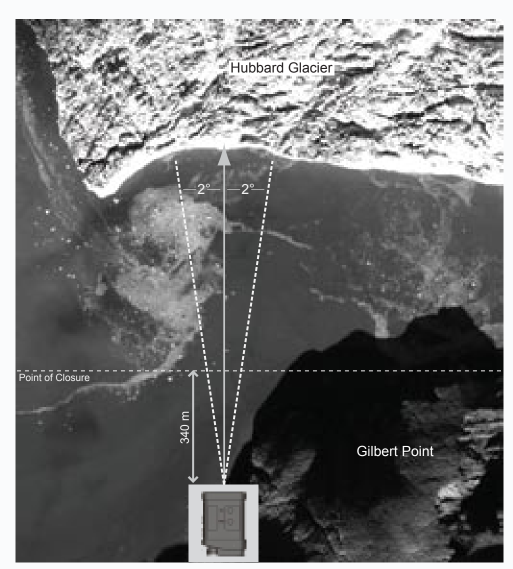


**Figure 3**
Plan view schematic of the Gilbert Point laser ranging station overlaid on a Quickbird panchromatic image (0.6 m/pixel) acquired on September 18, 2007.

| Gilbert Point | Haenke Island |
|---|---|
| ***Communications*** | |
| Integra-TR VHF Radio | Integra-TR VHF Radio<br>Sutron GOES Transmitter |
| ***Sensors/Data Storage*** | |
| Riegl FG21 LaserTape<br>CSI Disgital Camera<br>Sutron Xpert Data Logger | Sutron Temperature Sensor<br>WindSonic Anemometer<br>MetOne Rain Gauge<br>Barometric Pressure Gauge<br>Solar Radiation<br>Sutron Xpert Data Logger |
| ***Power Source*** | |
| 2-50 Watt Solar Panels<br>AirX 400 Watt Wind Turbine<br>3-120 AH Gel Cell Batteries | |

**Table 1**
Equipment and instrumentation at Gilbert Point and Haenke Island meteorological station

### *Data Acquisition/Dissemination*

The primary objective of the monitoring sites is to measure movement of the tidewater ice margin and link the motion data to simultaneously collected meteorological data and eventually to other measurements planned for the marine environment near Gilbert Point and Hubbard Glacier itself. The distance to the tidewater glacier terminus from Gilbert Point is obtained by a long-range (1.5 km) high-precision (10 cm), laser rangefinder operating in the near-infrared spectrum (0.9 µm). We measure distances once every six hours along a 4-degree scanned section of the ice face (Figure 3). Approximately 20 discrete samples are returned during each measurement cycle and then averaged. Concurrently, a digital image is acquired from a camera co-located with the laser (Figure 5). Ranging data are then transferred via radio modem to a repeater location on Haenke Island where they are combined with meteorological measurements acquired every 15-minutes. The combined data set are transmitted hourly via the Geostationary Operational Environmental Satellite (GOES) to a Corps of Engineers Oracle-based time series relational database in New England. Data are then reviewed for quality, rate of change errors and missing data before further analysis and public dissemination. Information is available to the public and the scientific community via the Web at www.GlacierResearch.com (Figure 4).

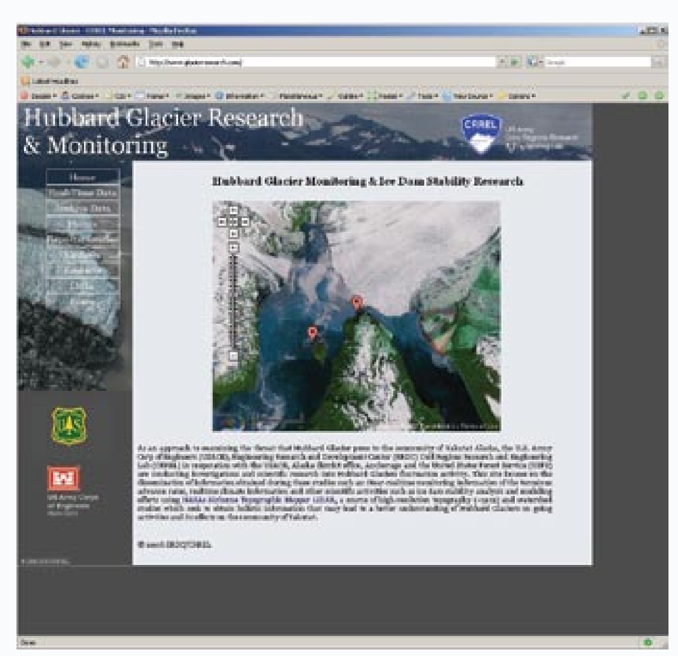


**Figure 4**
Ice margin range and climate data are available in near-real time through an interactive database driven website www.GlacierResearch.com. In addition, we provide project information, updates, recent photography, archived data and references on Hubbard Glacier research.


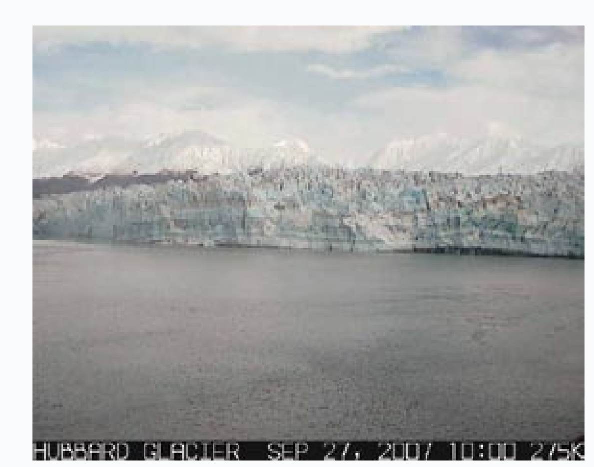


**Figure 5**
Digital images acquired at Gilbert Point using an automated camera. Each image was obtained at exactly the same position, time and settings on differing dates. Image at left shows the Hubbard terminus at it's maximum advance position (467 m). Image at right shows the ice terminus late in its seasonal retreat (732 m).

## Discussion

Although less than a year in length, the record of ice margin advance and retreat from the range data at Gilbert Point provide us a unique opportunity to observe the changes that the Hubbard Glacier terminus undergoes during daily and seasonal cycles. When coupled to digital images acquired daily and high-resolution temporal meteorological records from Haenke Island, we can speculate on what the variability in these data may indicate about tidewater glacier dynamics.

Our range data show a distinct seasonality to the advance and retreat of the ice margin (Figure 6). Ice advance began prior to March 2007, ending June 14, 2007 with a rapid, large loss of ice of ~70 meters depth in less than 48 hours and continuing retreat through October. The glacier margin advanced about 280 m in 98 days at an average of 2.85 m day$^{-1}$; recession after June 14 has moved the terminus back beyond its position in early March. Ritchie et al (in press) examined imagery of the last 15 years and found the magnitude of seasonal changes across the entire terminus ranged from as high as 500 meters to less than 200 meters. Trabant *et al* (2003) also observed that seasonally variable surface rates of ice flow as high as 12 meters per day occurred during the spring advance, but ice flow rates decreased by several meters per day later in the season.

The daily rates of ice margin advance and retreat were highly variable (Figure 6), with advance rates ranging from ~ 3 to 7 m day$^{-1}$ while recession took place at rates ranging from ~1 to 6 m day$^{-1}$ (Table 2). The range data clearly show that the daily advance tended to be fastest early in the year, during late winter, slowing in May through June until a sudden loss of ~ 70 m ice took place June 15 – 16, 2007. Recession then began at a rather modest pace through the end of August, with short periods of more rapid daily ice loss (Table 2). Daily retreat averages were several meters per day higher through early September, when rates increased to ~ 5 m

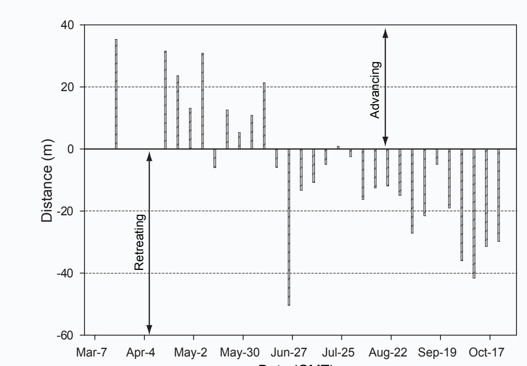


**Figure 7**
Total weekly change in ice margin position relative to Gilbert Point monitoring station (0m)

| *Start date* | *End date* | *Change (m)* | *Terminus Change (meters day $^{-1}$)* |
|---|---|---|---|
| Mar-10-07 | Apr-08-07 | 137 | 4.5 |
| Apr-09-07 | Apr-17-07 | 32 | 4.0 |
| Apr-18-07 | Apr-22-07 | 37.5 | 7.5 |
| Apr-23-07 | May-02-07 | 43 | 4.8 |
| May-03-07 | May-09-07 | 0 | 0 |
| May-10-07 | May-16-07 | 19 | 3.1 |
| May-17-07 | May-26-07 | 3 | 0.3 |
| May-27-07 | May-30-07 | 19.7 | 4.9 |
| Jun-01-07 | Jun-13-07 | 39 | 3.9 |
| Jun-14-07 | Jun-16-07 | -71.4 | -35.7 |
| Jun-17-07 | Jul-09-07 | -42.2 | -1.9 |
| Jul-10-07 | Jul-30-07 | -8.0 | -0.4 |
| Jul-31-07 | Aug-03-07 | -25 | -6.3 |
| Aug-04-07 | Aug-10-07 | 0 | 0 |
| Aug-11-07 | Aug-25-07 | -31 | -2.2 |
| Aug-26-07 | Sep-07-07 | -50 | -3.8 |
| Sep-08-07 | Sep-24-07 | -32 | -1.8 |
| Sep-25-07 | Oct-22-07 | -144 | -5.1 |

**Table 2**
Terminus change rates for distinct periods of ice marginal activity

The climate record from Haenke Island offers no obvious direct causal relationship between air temperature, precipitation, incoming solar radiation or other parameters, and the weekly or daily variability in ice margin movement at Gilbert Point (Figure 6,7,8). But if we consider the data on a seasonal basis, including the limited number of our range data from fall of 2006 and observed past behavior by Trabant *et al* (1991, 2003), there is a distinct inverse relationship between seasonal variations in rainfall and advance or recession. Rainfall quantities are largest in September through December when ice flow is decreasing and the ice margin is receding, whereas advance is initiated in winter and gains momentum into spring when precipitation is low and mostly snow.

It is tempting to speculate that this inverse relationship may reflect the seasonal evolution of the drainage system and water storage at the bed (Kamb *et al* 1994; Van der Veen 1999). During late fall and early winter, when presumably the subglacial drainage system is less developed, storage of meteoric water may raise the water pressure at the bed and cause a progressive increase in the sliding rate that propagates from upglacier to the terminus. The increasing meltwater flux in May and June, when average air temperature and incoming solar radiation increase, leads to coincidental expansion of the drainage system to accommodate the higher discharge, lowering water pressures and decreasing sliding rates when ablation is highest (Röthlisberger and Lang 1987).

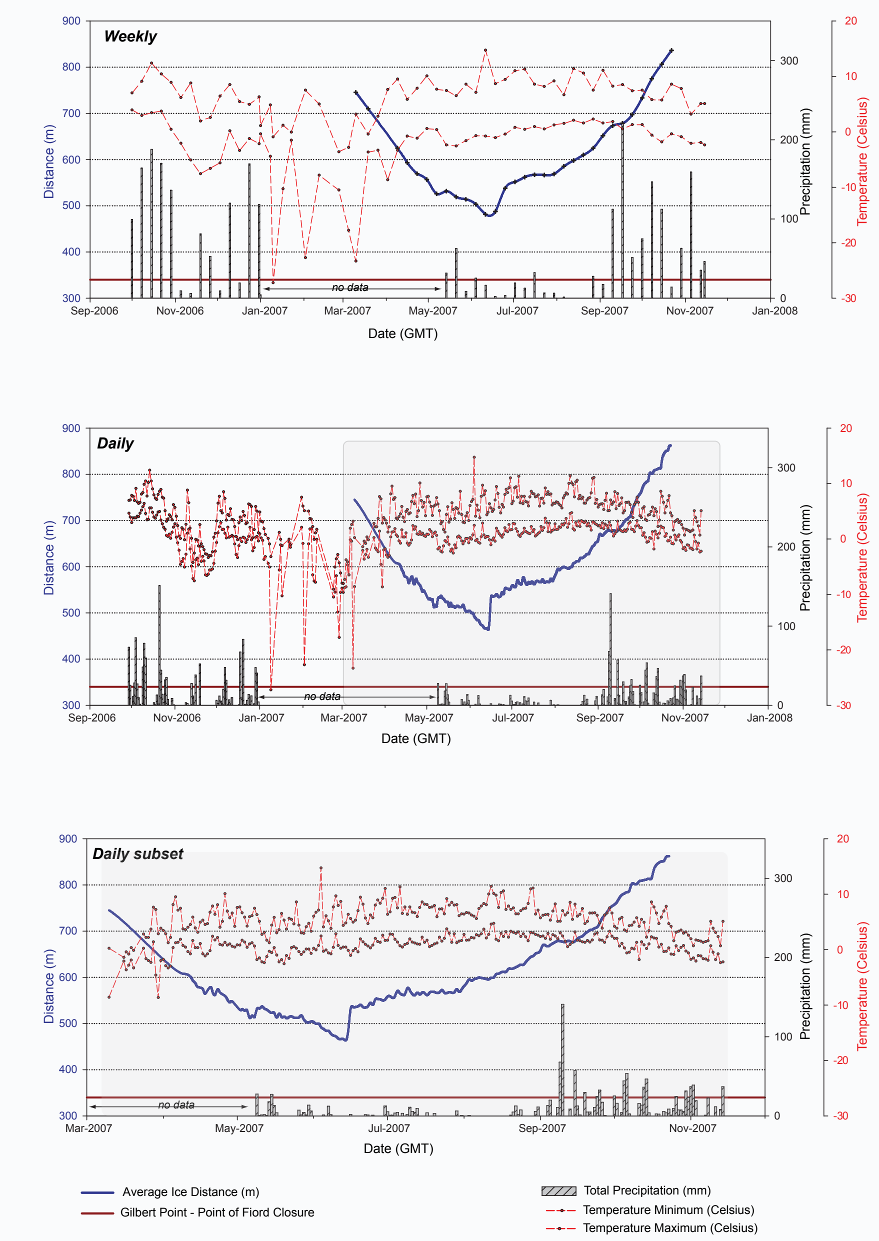


**Figure 6**
Average weekly (top) and daily (middle & bottom) rates of ice margin advance and retreat alongside averages of air temperature and daily total precipitation. Range measurements are relative to the distance from the Gilbert Point monitoring location (*see figure 3*). **The Haenke Island precipitation gauge was frozen from ~January to May**

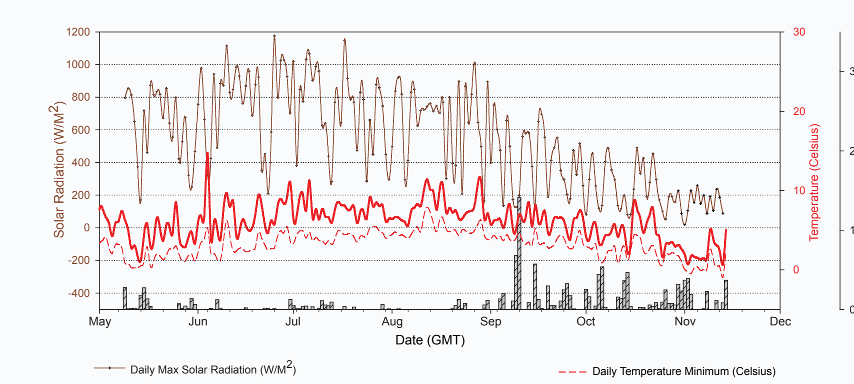


**Figure 8**
Daily climate record from Haenke Island for the period May through November 2007.

## Future Work

We plan to continue operating the monitoring sites at Hubbard Glacier for the foreseeable future. We continue to learn from technical and field problems as they occur and based on the experiences gained, plan to deploy a second, more robust version of the monitoring system for the 2008 season. We also plan further investigations of the glacier and its bed using geophysical methods and the ice marginal marine environment using in situ measurements and geophysics. These studies will provide the essential boundary conditions necessary to understand Hubbard Glacier dynamics and ultimately the mechanics of potential ice dam formation and stability at Gilbert Point.


**Acknowledgements**
Support for this project is funded in part by the Alaska District, Army Corps of Engineers, Anchorage, AK; US Forest Service, Tongass National Forest; New England District, Army Corps of Engineers, Concord MA and Headquarters, US Army Corps of Engineers. We would also like to thank Roman Motyka and Martin Truffer for insightful conversation and data cooperation, Captain Mark Sappington, Pat Fitzgerald, David Williams, Chris Williams, Dan Stenstream, Paul Marinelli, John and Fran Latham and the personnel at the Yakutat Ranger District office for their continuing support and assistance.