Videographic and GPS Techniques for Monitoring Active Glacial Surge: Bering Glacier, Alaska

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Table of Contents:

List of Figures:

(figures located at end of text)

Figure 13: This shows a single frame of video imagery of Muller Narrows captured on January 3, 1994. The glacier is seen consuming the land mass from the north/west. The cross and arrow indicate the principal point and the northerly direction of flight. Basic photogrammetry is used to scale displacements from the principal point to the glacier front and convert them to map scale for plotting.

Figure 14: This shows an uncontrolled photo-mosaic of Weeping Peat Island created by capturing and printing several overlapping frames of video imagery and pasting them together visually. Images were acquired on January 3, 1994 with a Canon A1 digital video camera, full wide angle, at ~5000' AGL. The individual frames were captured using a VIP frame grabber with an image size of 640 x 480 pixels. Approximate ground coverage for each frame is 945m x 1260m with an approximate ground resolution of 10-15m. The image contrast and brightness were enhanced in Easy Image and printed on a HP LaserJet 4 at 300 DPI. The long, x, axis of the video frame is aligned with the direction of flight. This minimizes the number of images required to mosaic a flight line, while at the same time it sacrifices the extent of coverage perpendicular to the flight line.

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ABSTRACT: Aerial videography in combination with GPS were used to monitor the active surge of Alaska's Bering Glacier. The large aerial extent of the study area and the unpredictable weather in coastal Alaska required innovative techniques to be used in order to successfully monitor the surge environment. A portable aerial videographic system which mounts in a variety of small aircraft was developed to allow detailed mapping of the glacier's terminus under a variety of conditions. This system is georeferenced with GPS tracking of the aircraft, as well as GPS ground truthing and rectification of imagery and mapping products. This allowed precise mapping in a region with no established survey network. Video imagery is encoded with GPS time to allow precise location of individual frames of video imagery allowing mapping accuracies of approximately 20 meters. Long distance differential correction of the GPS data improved the accuracies to close to 10 meters. Additional work with time-lapse videography allowed detailed analysis of small sections of the terminus to be studied over longer time periods.

Introduction:

Aerial videography, in its many forms, is rapidly becoming an important tool in the field of geography. It has been used for diverse applications ranging from crop maturation studies, to right of way mapping, to ground truthing of other data sources when compiling GIS data layers or creating thematic maps (Anderson 1993). One application in which videography is particularly well suited is in monitoring time sequence events. This is by no means limited to events with consistent change. Many of the characteristics of videography make it well-suited for capturing and analyzing events ranging from large-scale, rapidly changing events such as natural disasters, to small-scale slowly changing processes over longer time spans. Its portability, low-cost, and accessibility to scientists make it a practical alternative to conventional photography.

Videography is successfully being used to monitor spatial and temporal changes resulting from the most recent surge of the Bering Glacier, Alaska (figure 1). The Bering Glacier is the largest glacier in North America with an area of 5,500 square kilometers. It originates in the Bagley Icefield in the Chugach Mountains and flows approximately 50 kilometers as an 8-kilometer wide valley glacier before spreading out on the Gulf of Alaska coastal plain as a large piedmont lobe with a 70 kilometer terminus. From source to terminus the total length is in excess of 200 kilometers.

Special attention has been directed towards the eastern piedmont lobe of the glacier where the glacier is advancing over a series of islands in the ice-marginal lake environment. Before the current surge, this area has been the site of five summers of intense study by the Bering Research Group (BeRG) as the glacier was receding from the region. It is being used as a modern analog of the ice-age glaciers that fashioned much of the landscape of central New York and the Puget Sound area of the Pacific Northwest. On June 3, 1993, BeRG scientists observed that a kinematic wave was spreading from the trunk of the Bering Glacier indicating that an incipient surge was in progress (Muller et al., 1993).

Between November 1993 and November 1994, 5 separate monitoring flights were conducted to map the position of the glacier's 70 km terminus. On each videographic mission, the flight path of the aircraft is recorded using a roving Global Positioning

System (GPS) receiver in the aircraft. Positional information is later differentially corrected at Oregon State University (OSU) using Base Station files collected by the OSU Trimble Pathfinder Base Station. Individual frames of video imagery are captured using a digital frame-grabber, enhanced with common image processing techniques to improve overall image quality for visual interpretation, and printed on a laser printer. Overlapping images are captured to allow stereoscopic viewing of selected features and for creating uncontrolled photo-mosaics. Individual frames of imagery can be rectified to ground coordinates and overlaid on base maps of the area allowing direct digitizing of features from the imagery for inclusion in the base map. The resulting data allows detailed mapping of the position of the glacier front in relation to distinctive landmarks on the ground and to the principal point of the images using conventional photogrammetric techniques. From the final maps, estimates of surge velocities, motion vectors, and magnitude across the glacier front can be calculated from the terminus position at the initiation of the current surge.

The digital video camera used for the aerial imagery is programmable and is easily set up to perform time-lapse videography. When located on the ground facing the advancing glacier terminus, hours of slow dynamic processes are conveniently condensed into several minutes, making often imperceptible changes in the environment dramatically clear. This technique is useful for studying subtle geomorphic processes at the glacier surge front.

The following details the efforts of scientists from Oregon State University, acting as part of the Bering Research Group (BeRG), to monitor the surge of the Bering Glacier using digital videography, the Global Positioning System, and conventional panchromatic imagery.

Techniques:

The BeRG scientists have integrated many techniques in order to successfully monitor the Bering Glacier. Due to the unpredictability of the weather in the Gulf of Alaska and persistent cloud cover, relying on conventional aerial photography or satellite imagery is impractical. Also, planning conventional aerial photographic runs proves extremely risky, as the cost of a failed flight due to low cloud cover or otherwise poor visibility is high. To avoid these problems, a combination of video imagery and conventional 70 mm panchromatic photography geopositioned with GPS was employed using a Cessna 185 or DeHaviland Beaver aircraft for the photo platform. The combination is low-cost and reliable, essential requirements for this type of research.

Base Map and Ground Control-

The pre-surge terminus and surroundings are well documented by long-term BeRG scientists' research on geomorphic processes in recessional glacier environments. A detailed base map was compiled from an uncontrolled photo-mosaic showing the position of the glacier in July 1993, just prior to the latest surge (Figure 2)(Post, 1993). This map was digitized in UTM coordinates using AutoCad and all subsequent mapping was done in relation to this map. AutoCad was chosen in order to facilitate automated digital input of GPS data defining the flight lines of the aircraft, as well as GPS positioned ground control, photo stations and study points (figure 3). The UTM system uses Cartesian coordinates and meter units making it a convenient reference system to work with for calculating surge rates and measuring displacements.

Due to the lack of a fixed ground control network which is tied into established geodetic markers, a local network of identifiable control points was located using conventional triangulation and a borrowed L1/L2, P-code (Precision) GPS receiver during an earlier summer field season (Appendix I). Several of these points have been destroyed by the advancing glacier and additional control points away from the surge front were added during the June 1994 field camp. It is important that the control points be identifiable on the aerial imagery to allow for scaling and rectification of the imagery to the base map. GPS provided accurate location of control points and fixing of the floating network.

Digital Video-

Digital video marks a significant step forward in video technology. As a result, it is becoming a increasingly useful tool for documenting and updating spatial information in areas prone to rapid change (Greene, 1988). Conventional video imagery is limited for use in most scientific applications due to reduced image quality (Faig and Shih, 1988) caused by the original video sensors and the noise inherent in analog electrical signals (figure 4)(Luther 1989). Digital video replaces the analog technology designed for television in the 1950's with modern solid-state electronics. The new sensors, commonly charge-coupled devices (CCD's), and binary recording systems are more rugged and stable than the vacuum-tube sensors and noisy analog recorders of their predecessors. Binary recording of the video signal does not eliminate the noise in the signal, rather it only allows discrete values to be represented in the signal. If the signal is above the threshold it has one value, if below it has another (figure 4)(Luther 1989). This effectively eliminates the effects of noise on image degradation.

The benefits of digital video over conventional photography are many (Mausel et. all, 1992). For instance, there are no processing costs associated with video imagery and image quality can be reviewed during acquisition. Photographs require developing and printing in order to assess image quality. In the worst case, the photo run may need to be completely re-flown due to poor image quality or failure to acquire images of the correct area. A small monitor connected to the video camera allows in-flight viewing of the imagery as it is being collected, as well as review of the video after the run to determine if another pass is needed. This eliminates the high cost of flying an entirely new run. Videography also allows the continuous collection of images across the entire image swath. This guarantees the 60% overlap required for stereo viewing and allows individual scenes to be selected in order to highlight particular features when they are most visible. Finally, the need for expensive and time consuming image scanners to digitize the photographs or negatives is eliminated.

For all of these reasons, video imagery was selected as the primary image acquisition tool for monitoring the Bering surge.

Conventional Photography-

Conventional photographic techniques were utilized for three major purposes during the early stages of the Bering Glacier surge. High resolution vertical aerial photographs were taken over several study areas to document the glacier's position and the geomorphic processes occurring in these areas. These photographs were taken with a Hasselblad 70 mm medium format camera using Kodak Aerographic Panchromatic film. Stereo photogrammetric techniques applied to overlapping stereo pairs helped identify areas of active geomorphic processes for study during the field season and to monitor and document processes when access to the glacier was difficult or impossible.

Secondly, oblique aerial photographs were taken from various positions to assess changes in areas of the glacier not directly imaged with video or conventional vertical photographs. These images helped supplement knowledge of the area and were crucial for monitoring the changes in large scale features on the glacier. The patterns in crevasses and medial moraines in the main trunk glacier and the piedmont lobes are easily monitored with this oblique photography.

Finally, many ground photo-stations were located around the terminus of the glacier to document the progress of the glacier over time. Photo-stations and the direction of photography were designated with stone cairns and efforts were made to take consecutive images from a station with the same focal length lens to ease interpretation of sequenced images. Several stations used to monitor the recession of the glacier over previous field seasons have been consumed by the recent surge, necessitating the development of new photo-stations. The new stations were geolocated with GPS to facilitate returning to the stations should they also be overrun by the current surge. This is crucial for comparison of topography from the previous recession and the topography resulting from this surge.

In order to save processing costs, only the images of interest were printed. From these, uncontrolled photo-mosaics have been created to piece together the configuration of the terminus. The prints are useful for locating access routes to areas of interest while performing ground studies. They are also serve as a detailed, permanent record of the conditions present at the time of the photograph.

In the latest imaging missions, use of the Hasselblad 70mm photography has been eliminated. Confidence has grown in the utility and reliability of the vertical videographic techniques making the use of conventional vertical aerial photography obsolete for all but the most detailed imagery needs. Casual comparisons of the quality of both the videographic and photographic images only shows a marginal gain in mapping precision which is made unnecessary by the dynamic nature of the glacier. Countless frames of oblique 35mm slides as well as oblique videography fill the need for permanent records of the surge environment.

Camera Mounting-

During the past several years a special camera mounting system has been developed by scientists at OSU which is adaptable to a wide variety of situations. The resulting video and conventional camera set-up is portable, versatile and low cost--ideally suited for use on the Bering Glacier.

Both the video and 70mm cameras mount side-by-side on a combination shipping case/mounting bracket (figure 5) which can be located in the belly hole of a DeHaviland Beaver aircraft or housed in a custom nacelle, a small fiberglass insert which replaces the baggage door in most Cessna 170, 172 or 185 aircraft (figures 6 and 7). All of these aircraft are common in Alaska, and in rental fleets throughout the world. A small black and white monitor is attached to the video camera to allow active monitoring of the area being imaged and to assure proper operation of the camera. This monitor is crucial to help the pilot stay centered over the irregular line of the terminus of the glacier while flying. An additional system which utilizes a small, forward looking camera and a separate black and white monitor proved enormously helpful for the pilot to anticipate turns while following a winding path such as a glacier terminus or stream. The system has been used successfully in environments ranging from coastal Oregon to Bangladesh (Rosenfeld, 1994).

GPS-

As mentioned earlier, the track of each videographic mission is recorded using a portable GPS receiver. Throughout the study, a Trimble Pathfinder Plus has been used. The Pathfinder is a eight channel, L1 band, C/A code receiver with a the ability to store several hours of data at a 5 second collection interval. An external antenna is mounted on the dash of the aircraft. This arrangement provides adequate visibility to the satellites in most situations. Occasionally, on northward headings, the high wing of the aircraft interferes with satellite tracking, causing sporadic breaks in position logging. On each visit, the scientists fly the length of the of the terminus following the path of the glacier's calving front where the glacier terminates in water and the ice land contact elsewhere. The receiver logs the position of the aircraft every 5 seconds. The resulting data file is later used to plot the location of the aircraft relative to glacier. The receiver can locate the aircraft position to within approximately 100 feet. This data can then be correlated to the video imagery using either manual interpolation methods or direct correlation of the GPS and video time codes (discussed in the next section).

The accuracy of the GPS data can be improved through "differential correction." Differential correction uses data collected simultaneously by a second GPS receiver stationed at a known location to remove most of the clock and atmospheric errors inherent in GPS which degrade the position calculations made by the receiver. Various attempts have been made to differentially correct the GPS data collected from the Bering Glacier. Differential correction requires simultaneous tracking of a common set of satellites by both the base and roving receivers. Earlier efforts to use a base station located 80 miles west of the Bering Glacier in Cordova, Alaska proved ineffective. High hills to the south of Cordova effectively blocked tracking of satellites by the base station which were visible and tracked on the glacier. As a result, the two receivers lacked a common set of satellites and the data was not differentially correctable.

Beginning with the November 21, 1993 reconaissance, the GPS data has been differentially corrected using the Oregon State University, Department of Geosciences base station (Trimble Community Base Station). Using this system, nearly 70 percent of the GPS positions were correctable. Ultimately, the success of differential correction is dependent on the geometric configuration of the satellite constellation and the distance between the base and roving receivers. Relying on long-distance differential correction is not recommended. The utility of GPS correction decreases as distance increases between the base and roving receivers. Trimble recommends a maximum of 300 miles between receivers (Trimble 1992). Currently, due to the lack of an established geodetic network at the glacier, the accuracy of the corrected positions in this study is not known. Test calculations to precisely positioned landmarks do indicate a slight improvement in accuracy using the corrected data. Fortunately, for the surge velocities of the Bering Glacier the loss of accuracy using undifferentially corrected data is negligible. Future flights will make use of a survey service in Anchorage, 220 miles west of the study area, for differential correction base station files.

Integrating GPS and Video-

Accurate coordination of the video imagery with the GPS derived flight lines is necessary to precisely geolocate individual frames of imagery for mapping. This is accomplished with an auxiliary time code generator which takes the time code from the GPS receiver, converts it to SMPTE (Society for Motion Picture and Television Engineers) time code and records it directly on one of the unused audio tracks of the video (figure 8). The SMPTE time code can then be output in real time or during video playback and overlaid on the video image. The GPS receiver logs camera position and the precise time the data was taken. This position/time log can be printed out. During analysis, individual frames of imagery with the SMPTE time code can be correlated precisely with the GPS time and position in the log. With a differentially corrected GPS file and compensation for antenna offset from the camera the potential accuracy for mapping is less than five meters. Additional equipment such as a laser profiler and a two-axis vertical gyroscope, which correct for the difference in aircraft position and the nadir of imagery caused by inconsistencies in the attitude of the aircraft and the height above ground level, can improve the potential accuracy to 2 to 3 meters (Wanless 1992). Wanless (1992) describes a Digital Video Geographic (DVG) system which incorporates these elements. Currently such systems are not readily available and their costs are prohibitive for all but the most precise studies. These estimates are for flight altitudes of approximately 3000 feet above ground level. Mapping accuracy will decrease as altitude above ground level increases. Below this altitude, the ability to follow winding paths and keep the terminus within the frame of the image becomes difficult.

To date, this technique has not been implemented on the Bering Glacier. Its utility has been tested on several studies in Oregon including habitat mapping in mountainous terrain, soil studies and highway corridor mapping in the Willamette Valley using a Horita GPS1 time code generator. The GPS1 resets its internal clock to GPS time taken from a GPS receiver, then dedicates itself to creating a Genlocked SMPTE time code. A Genlocked code assures that each second of video imagery (60 frames) is precisely coordinated with the SMPTE time code. Thus, each frame of imagery has a unique Hour, Minute, Second and Frame code. While this precision is not always needed when GPS positions are only being logged every 1 to 5 seconds, as the precision of GPS positioning increases, it may be helpful.

Regardless, the ability to precisely locate features of interest from large, fairly homogeneous areas is extremely helpful. These can then be located on the ground by entering the coordinates in a portable GPS receiver as a waypoint and navigating to that waypoint. The time and money saved in processing and analysis can be significant.

Time-Lapse Videography:

A separate application of videography was tested during the June 1994 field camp. A series of "time-lapse" videography experiments were conducted to monitor small scale geomorphic processes occurring at the glacial terminus. The same digital video camera used for the aerial imagery is enclosed in a weather proof housing and mounted on a small platform (figure 9). Power to the camera is supplied by a 12 volt deep-cycle marine battery which is charged as needed with a small portable generator in base camp. The camera is programmed to take 1 1/2 seconds of imagery at designated intervals, 30 seconds, 1 minute, or 2 minutes, then placed with an oblique view near the glacier terminus. Every six hours, the camera is reprogrammed to avoid automatic shutdown. At the 2 minute collection interval, playback at normal speed effectively condensed six hours of glacial motion into 4 1/2 minutes. This was carried out at four different locations (Figure 10) representative of different surge-front environments: 1) saturated soils on a topographic high, 2) dry soils at a topographic low containing a sheering ice block, 3) saturated soils with standing water at a topographic low, and 4) mixed soils at a topographic high.

The results of the fourth experiment were the most interesting. Here scale markers were incorporated into the image and several markers were attached to the sole of the glacier where it had sheered up off the ground using eye-bolts and survey tape (figures 11a and b). From these markers, fairly accurate rates of motion can be calculated. From the scale markers, approximately 130 cm of motion were documented over a 13 hr period. These rates are consistent with rates acquired from a manual measurement site approximately 20 meters west.

In areas of rapid surge, greater than five meters per day, a six hour time-sequence image can relate a great deal about the dynamics of a glacier front. Longer occupations with greater time intervals between consecutive images would be more helpful where the rates are slower. The large scale of the resulting images allows detailed viewing of subtle and intricate geomorphic processes such as low-angle basal thrusting of ice blocks. Another advantage of the videography in this type of application is that it is a simple process to capture individual frames of the video imagery and manipulate them digitally for viewing and analysis.

Difficulties with this technique stem from the power supply and the short time periods between reprogramming. For long occupations of a site, more than a couple of days, it would be more convenient to be able to leave the entire set up in place and not have to recharge the batteries or reprogram the camera. These tasks take valuable time away from performing other duties. Ultimately, the ability to leave the camera for several weeks would be desirable. The life of the power supply could be extended by using a more sophisticated camera which can be programmed to shut down between images. Also, better power supplies could be used such as hooking up several batteries in parallel or attaching solar panel battery chargers to the system. Each of these solutions warrant further investigation in order to be able to make full use of this technique.

Aerial Mapping of the Glacier Front-

The GPS flight line positions are exported from the GPS software and converted to UTM coordinates in DXB format for import into AutoCad. A special program was written in "C" to do the conversion to UTM coordinates and create the DXB file. Since the study area lies in UTM zones 6 and 7, with the majority of the piedmont lobe contained in zone 7, all positions were output relative to grid zone 7 coordinates.

Several techniques are being used to map the position of the terminus from the video images. The dynamic nature of the glacier front, the variety of terminal environments, the scale and quality of the imagery (determined mostly by weather conditions) and the variable scale of mapping products needed required a variety of manual and digital techniques to be applied. The video imagery proved extremely adaptable to the variety of environments encountered in the study. The final plotting of sequential surge fronts depended on the variables mentioned above.

Where the glacier terminates in water, defining the actual edge of the glacier as opposed to the calved debris floating in the lake is difficult (figure 12). Also the lack of identifiable landmarks makes precisely positioning the terminus difficult. In this environment, the GPS defined flight path of the photo run is used to define the front. Every effort is made during the flight to stay centered over the terminus as distinguished from the glacial debris. Rough displacements of the terminus from the flight line can scaled from the images by calculating the scale of the image from features of known size on the ground, then calculating the distance along the flight line from known landmarks by interpolating the time between known features. This is a tedious task and, for this study, the added mapping accuracy does not justify the added effort. The fact that the greatest rates of motion are located where the terminus is located in water works to the scientists' advantage. Surge rates of up to 30 meters per day make a 50 to 100 meter error in mapping precision acceptable as this is only 2 to 4 days of motion. Errors in positioning of the ice front, therefore, tend to be averaged out over the 1 to 2 month return interval between mapping runs.

Another more precise technique utilizes simple photogrammetry performed on individual video images to calculate the displacement of the glacier front from the principal point of the video image (figure 13). This requires knowledge of several variables: image scale, geographic location of the principal point of the image, and direction of flight. Since the elevation of the aircraft above the surface is known by subtracting the ground elevation of the imaged area from the aircraft elevation, both determined from GPS data, the scale of the video image can be accurately calculated.

Also, since the video camera is positioned as close to vertical as possible, the location of the principal point is assumed to be the position of the aircraft. No corrections were made for the displacement of the antenna from the camera within the aircraft or the pitch and roll of the aircraft which introduce errors in the location of the principal point. The flight direction is loosely defined as the line of tangency to the GPS determined track of the flight line at the time the image was acquired. Image distances between the principal point, or ground control points, and the glacier front, as well as direction from flight line, are converted to map scale and plotted in reference to the plotted flight line on the base map. Similar techniques have been used to monitor ice freeze-up in the Tanana River, Alaska (George, et. all, 1988).

This process works well for plotting the glacier front and features where the glacier is terminating on land. The presence of identifiable landmarks and their location in relation to the glacier front prove extremely important for making sense of the constantly changing environment. Again the errors introduced in the assumptions adopted with this technique are balanced out by the dynamic nature of the surge. For more detailed mapping, additional measures for constraining the attitude of the aircraft and its influence on the location of the principal point would have to be adopted to ensure the required precision. For our requirements, the apparent accuracies of 10 to 20 meters are more than adequate.

The most conventional technique uses a zoom transfer scope to transfer the location of the glacier front to the base map. Uncontrolled photo-mosaics are constructed to produce a more extensive view of the configuration of the glacier front (figure 14). Individual overlapping frames of video imagery are cut and pasted together visually. Low flight altitudes make this technique cumbersome by requiring a great number of images to be processed. Not only is this expensive in terms of digital data storage requirements, more images translates to lower accuracy in the geometric characteristics of the final mosaic. A TV monitor can be used in place of the photomosaic in the zoom transfer scope. With this technique, the video is played back through the monitor and paused to allow transfer of the desired features to the base map. The video is then advanced to display the next section of terminus and the next set of features are transferred. As long as there are identifiable features in the image to allow the base map to be oriented quickly and easily, long swaths of video imagery can be quickly mapped.

Problems and Continued Work:

On June 15, 1994 a controlled experiment was conducted to assess both the accuracy of the videographic techniques and the resolutions achievable from videography taken at differing elevations above ground level. Successive passes over the eastern piedmont lobe of the Bering Glacier were flown at 9000', 7000', 5000', and 3000' above ground level. Each of the passes were georeferenced with GPS. Special effort was made to keep the terminus centered in the video field while imaging Weeping Peat Island. The field camp, located on the southern tip of the island, allowed easy access to the glacier front from the ground. Several hours after the aerial data collection, the glacier terminus on Weeping Peat Island was walked and the location of an approximately 1 km section was ground truthed with GPS. Attempts to process the data have failed due to two major unforseeable problems. First, a poor satellite constellation made tracking sporadic while ground truthing. The terminus of the glacier effectively blocked any satellites to the north while walking close to the terminus making the ground truth file broken and difficult to analyze. The second major problem came with attempts plot the ground truthed terminus on the base map of Weeping Peat Island. Here plotted positions were displaced as much as 200 meters away from the locations plotted from previously positioned GPS control points. This is well outside the standard uncorrected GPS positional errors. Thus, either the entire control network was positioned incorrectly, or the ground truth file was giving false locations. A possible source of the displacement could be attributed to a process known as "multi-tracking" in which the signals are received both directly from the satellite and after being reflected off a flat object, such as the glacier front. If this is the case, the aerial videographic techniques are potentially much more accurate than ground based GPS measurements.

The spatial and spectral resolution of the video imagery is well suited for identifying all but the most subtle glacial features and structures such as crevasse patterns, sheering zones, and debris band patterns. Stereo pairs of video images are successfully being used to identify active bulges on the glacial surface thought to result from the passage of a kinematic surge wave. These stereo pairs are printed and viewed with a stereoscope in the laboratory. A recent acquisition allows the images to be displayed side by side on a pen-based laptop computer (Rosenfeld, et all, 1994). With this technique, actual images from previous expeditions can be compared to current conditions while in the field, thus helping one to identify areas of interest and allow decisions to be made regarding setting research priorities. For minimally funded experiments or for situations in which one must guarantee the greatest potential for success these techniques are extremely helpful.

Conclusions:

The use of simple tools has helped in monitoring the current Bering Glacier surge. By combining the strong points of videography, GPS and conventional photography, scientists have been able to adapt to the varying conditions present in coastal Alaska and successfully document the surge of the largest glacier on the continent, in terms of length and area. By developing a modular system, it is possible to configure it to nearly any situation encountered. This is important not only at the Bering Glacier, but in performing cost-effective, quality surveys in a plethora of natural and man-made environments.

By combining GPS positions and time codes with the video imagery, the mapping accuracies improve dramatically. Other possibilities for increasing the analysis potential of the video imagery include using stereographic computer monitors to view stereo pairs. Certain UNIX workstations now have built in capabilities allowing capture, enhancement and viewing of video images. These allow use of the full resolution of the captured video image. Most PC based video capture boards capture a 640 x 480 pixel image, thus cutting the resolution of the original image in half. The full resolution images are rapidly approaching the quality of most photography.

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APPENDIX I: Bering Glacier GPS Locations:

Date	Title	Lat. N60 +	Long. W143 +	Elev. Feet	Elev. Meters	UTM (7V) M. East	UTM (7V) M. North	Instru-ment
20June92	Tent at Base Camp	11'50.5"	13'14.3"	64	20	376888	66752?	1
20June92	Shore Rock	11'47.6"	13'21.8"	33	10	376769	66751?	1
20June92	Gull Rock	11'52.4"	13'39.6"	59	18	376501	66753?	1
20June92	Mess Area	11'50.4"	13'16.0"	59	18	376862	66752?	1
21June92	East Bluff 1	11'25.4"	11'59.6"	103	31	378027	66744?	1
21June92	East Bluff 2	11'35.0"	11'59.4"	152	46	378025	66747?	1
21June92	Bath Rock	11'46.7"	12'17.9"	75	23	377752	66751?	1
21June92	Interlaken	12'37.9"	12'54.4"	34	10	377243	66767?	1
22June92	S. Debris Band	13'03.9"	13'00.0"	7	2	377185	66775?	1
23June92	Confusion Pt.	11'57.4"	10'21.5"	23	7	379555	66753?	1
25June92	Brown Chip	14'20.0"	15'52.3"	302	92	374615	66799?	1
25June92	Traverse Start	14'26.0"	15'55.9"	302	92	374565	66801?	1
25June92	Lunch Rock	14'53.8"	14'30.7"	594	181	375905	66809?	1
25June92	Near '91 Trav. End	15'14.7"	13'51.7"	423	129	376526	66815?	1
25June92	Ice Beyond Trav. End	15'29.4"	13'24.9"	518	158	376953	66820?	1
26June92	Arrowhead North	10'35.9"	17'04.8"	92	28	373259	66730?	1
28June92	Willow	13'20.9"	09'58.7"	75	23	379991	66779?	1
28June92	Camp Bay Canal	13'26.3"	10'50.6"	10	3	379198	66781?	1
28June92	Basin 210	12'42.9"	10'39.6"	10	3	379323	66767?	1
28June92	Tsivat Traps	12'05.8"	10'56.2"	10	3	379030	66756?	1
29June92	Ice Margin	12'47.6"	12'45.4"	7	2	377392	66770?	1
29June92	Interlaken Shore Rock	12'44.1"	12'59.4"	10	3	377174	66769?	1
30June92	East End Traverse	13'04.3"	12'59.3"	7	2	377195	66775?	1
30June92	West End Traverse	12'54.5"	13'46.5"	108	33	376460	66772?	1
30June92	Debris Band Top	12'53.9"	13'45.6"	138	42	376473	667723	1
30June92	Peat Falls Island	11'54.4"	14'42.6"	171	52	375533	667542	1
30June92	Grand Canyon	11'52.2"	14'55.1"	108	33	375338	667536	1
30June92	Lower Grand Canyon	11'51.3"	15'08.0"	49	15	375138	667534	1
30June92	Photo Rock	11'52.4"	15'30.3"	33	10	374796	667538	1
30June92	Post Pile	12'16.0"	16'31.6"	328	100	373877	667614	1
30June92	Green Slab	12'18.1"	16'08.3"	226	69	374238	667620	1
1July92	Analog Area; Sta. A	12'24.4"	12'22.7"	95	29	377717	667627	1
2July92	Analog Area; Sta. B	11'58.7"	13'11.6"	95	29	376938	667550	1
3July92	Bentwood	10'51.3"	13'07.4"	82	25	376933	667342	1
3July92	Breakout	11'08.7"	14'03.3	62	19	376090	667398	1
16June94	Video #1	N/A	N/A	N/A	N/A	377619	6675586	2
16June94	Video #2	N/A	N/A	N/A	N/A	377131	6675411	2
16June94	Riverhead Rock (PP)	N/A	N/A	N/A	N/A	377113	6675265	2
16June94	Split Pond Rock	N/A	N/A	N/A	N/A	377628	6675273	2
16June94	Mossy Rock	N/A	N/A	N/A	N/A	377647	6674678	2
17June94	Brink	N/A	N/A	N/A	N/A	378132	6674479	2
17June94	Black Rock	N/A	N/A	N/A	N/A	378129	6674464	2
17June94	Slick Rock	N/A	N/A	N/A	N/A	378228	6674496	2
17June94	Cleft Rock	N/A	N/A	N/A	N/A	378418	6674469	2
17June94	West Point Rock	N/A	N/A	N/A	N/A	378515	6674247	2
17June94	Ice Collapse Sink	N/A	N/A	N/A	N/A	378805	6674121	2
17June94	Ice Collapse Basin	N/A	N/A	N/A	N/A	378987	6673894	2
18June94	Video #4 E. Bentwood	N/A	N/A	N/A	N/A	376079	6674027	2
18June94	E. Bentwood (PP)	N/A	N/A	N/A	N/A	376142	6673998	2
18June94	Congo Rock	N/A	N/A	N/A	N/A	376595	6673629	2
18June94	Gouged Rock	N/A	N/A	N/A	N/A	376364	6673168	2
18June94	Bentwood Narrows	N/A	N/A	N/A	N/A	374546	6672750	2
18June94	Black Rock	N/A	N/A	N/A	N/A	375919	6672962	2
19June94	Tsiu Outlet	N/A	N/A	N/A	N/A	377354	6672824	2
19June94	Grn. Schist (Ts. Out.)	N/A	N/A	N/A	N/A	377262	6672896	2

Instrument: 1) Trimble Prototype PLGR; 2) Trimble Pathfinder Plus.

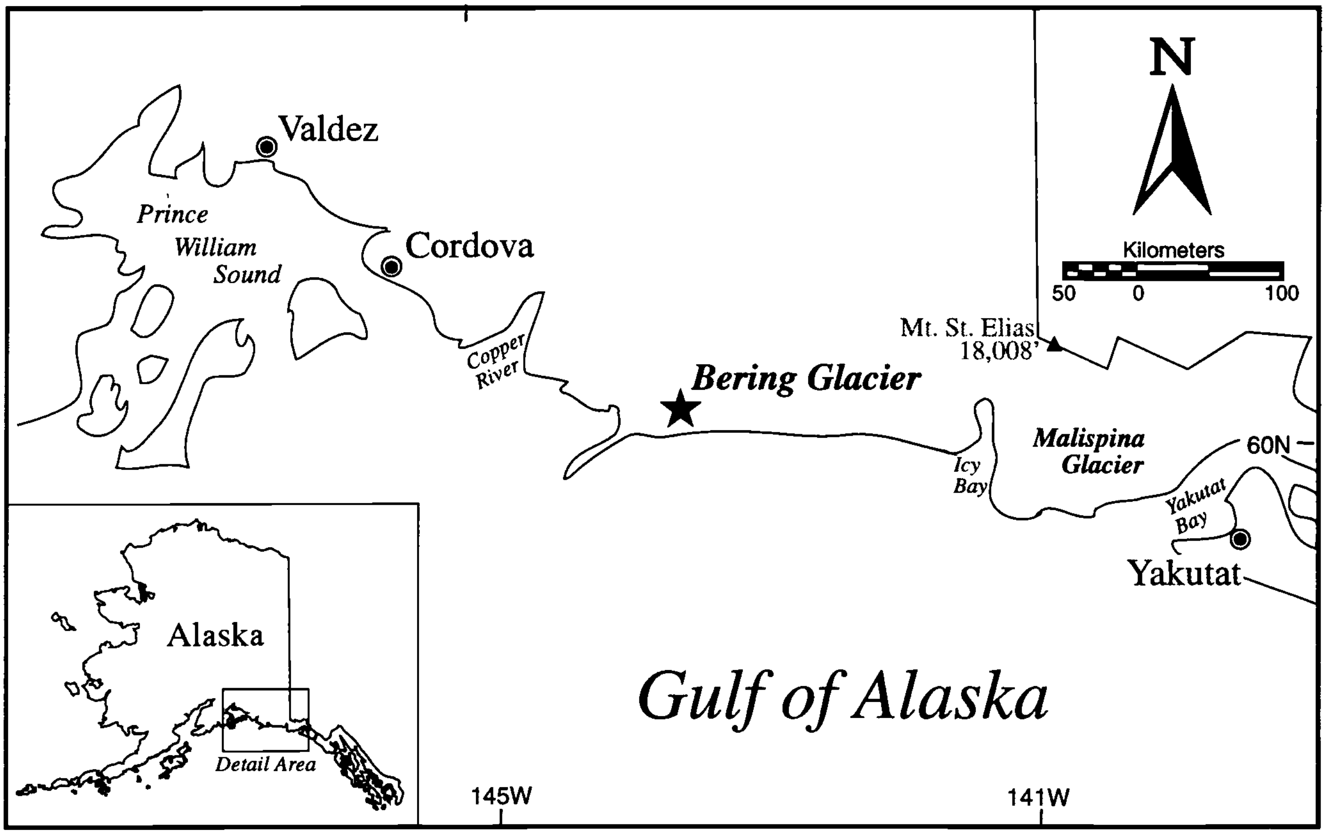


Figure 1: Bering Glacier and the south east Alaskan coast.

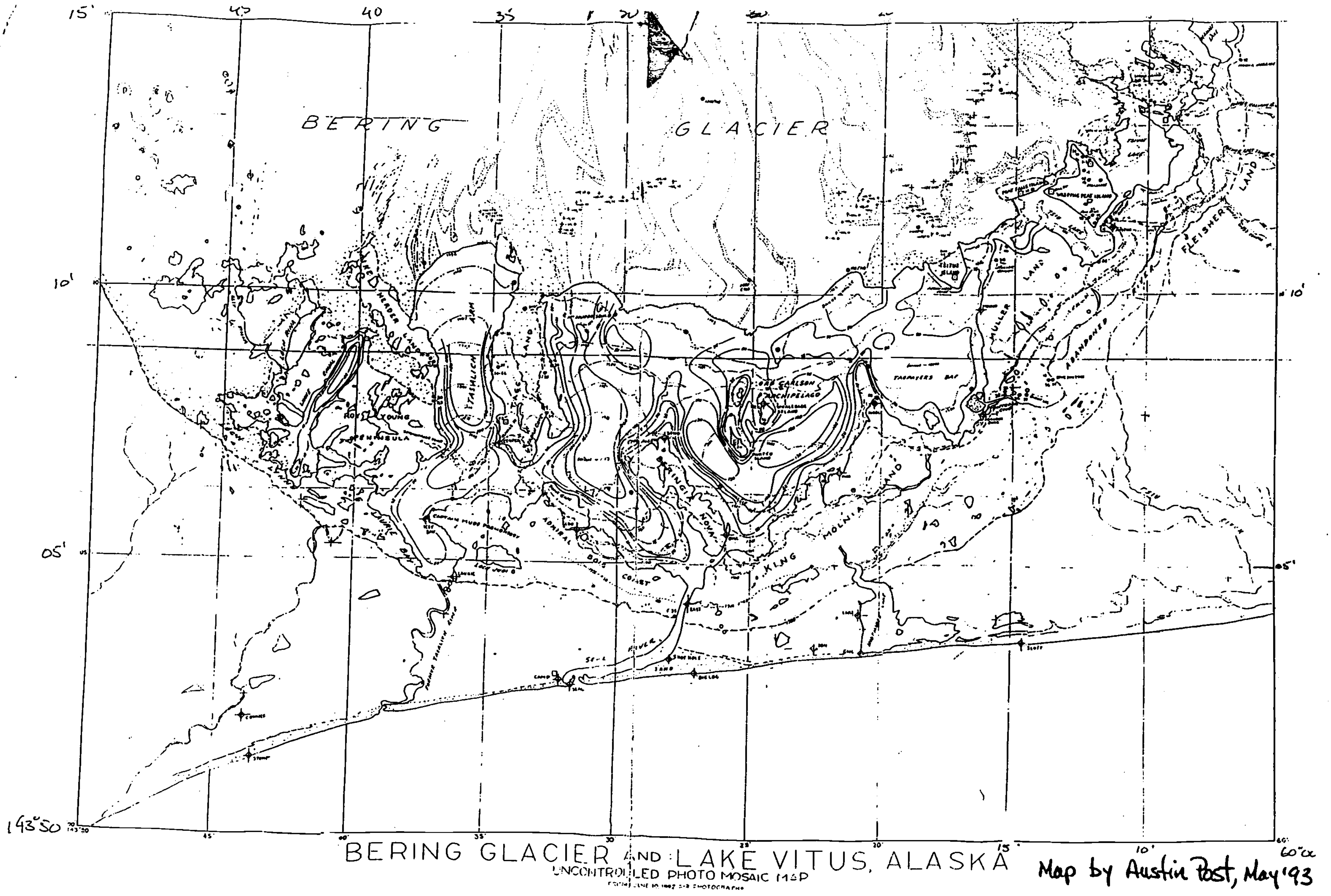


Figure 2: Bering Glacier base map showing the piedmont area and the June 10, 1992 terminus (Post 1993).

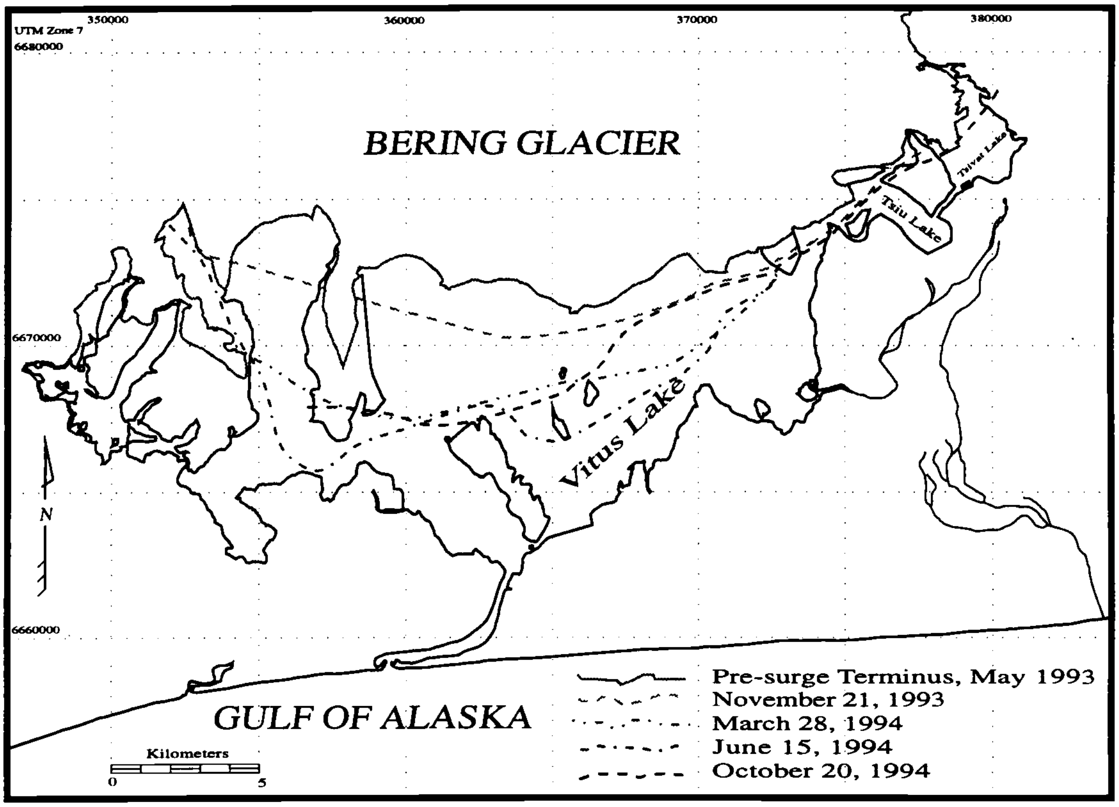


Figure 3: Flight lines of video acquisition flights.

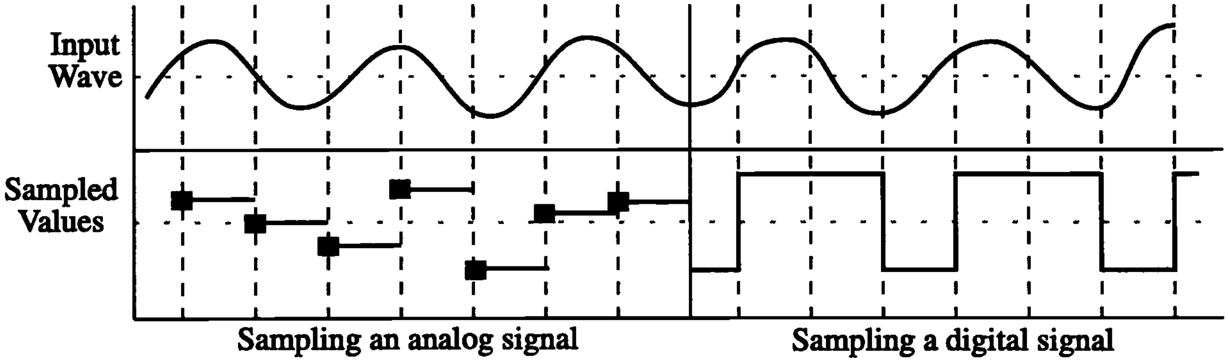


Figure 4: Digital versus analog video signals. Digital video recording allows discrete values to be recorded. (Adapted from Luther, 1989)

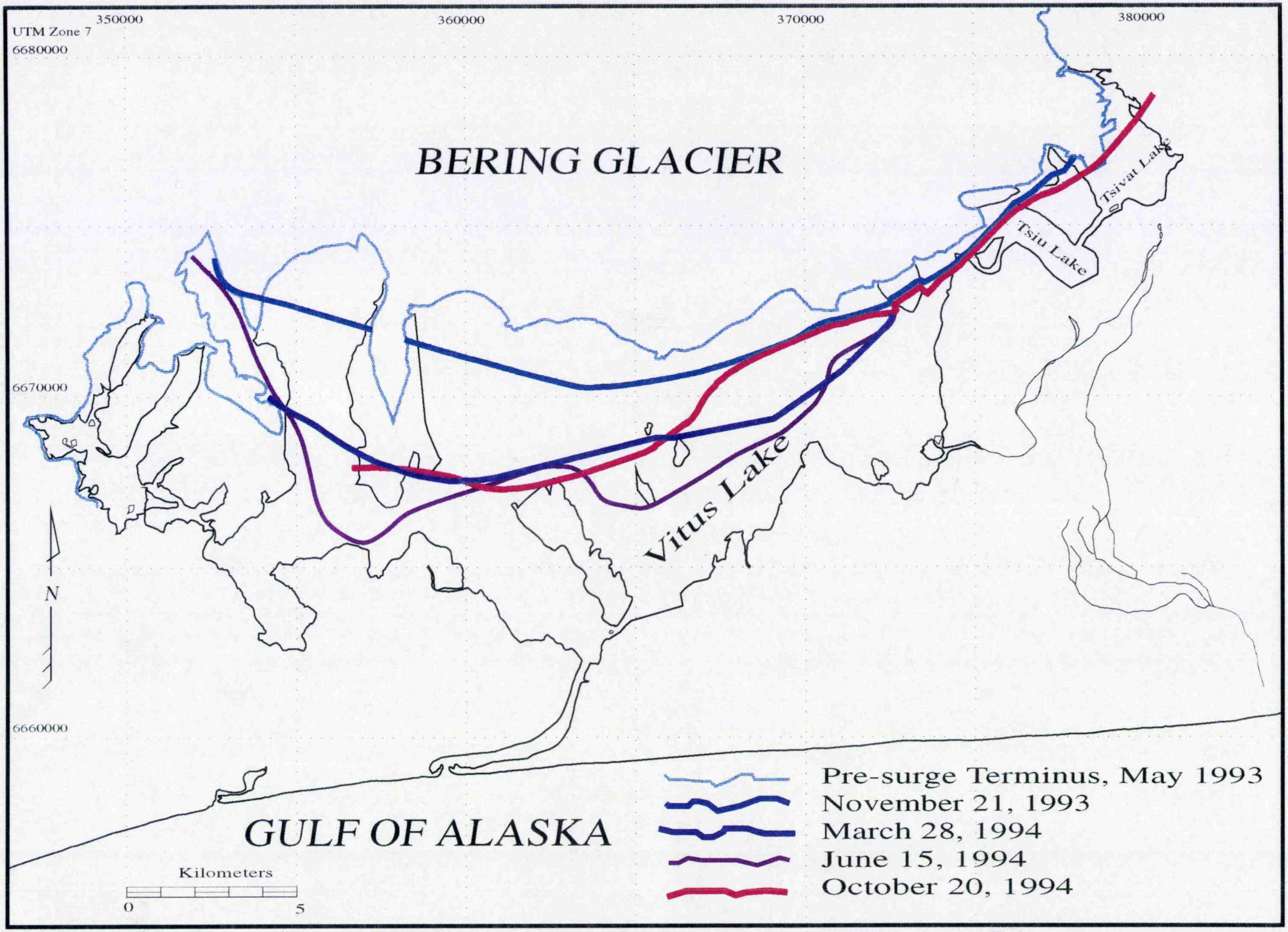


Figure 3: Digital base map as digitized from figure 2 showing the GPS determined flight paths of the video acquisition flights. The flight line closely approximates the location of the surge front.

Figure 5: The camera set-up is compact, versatile, and cost efficient. The Canon A1 Hi8 digital video camera, left, can be controlled remotely and is monitored with an external monitor (not shown). The Hasselblad 70mm camera is used to collect high resolution panchromatic images of areas of geomorphic interest.

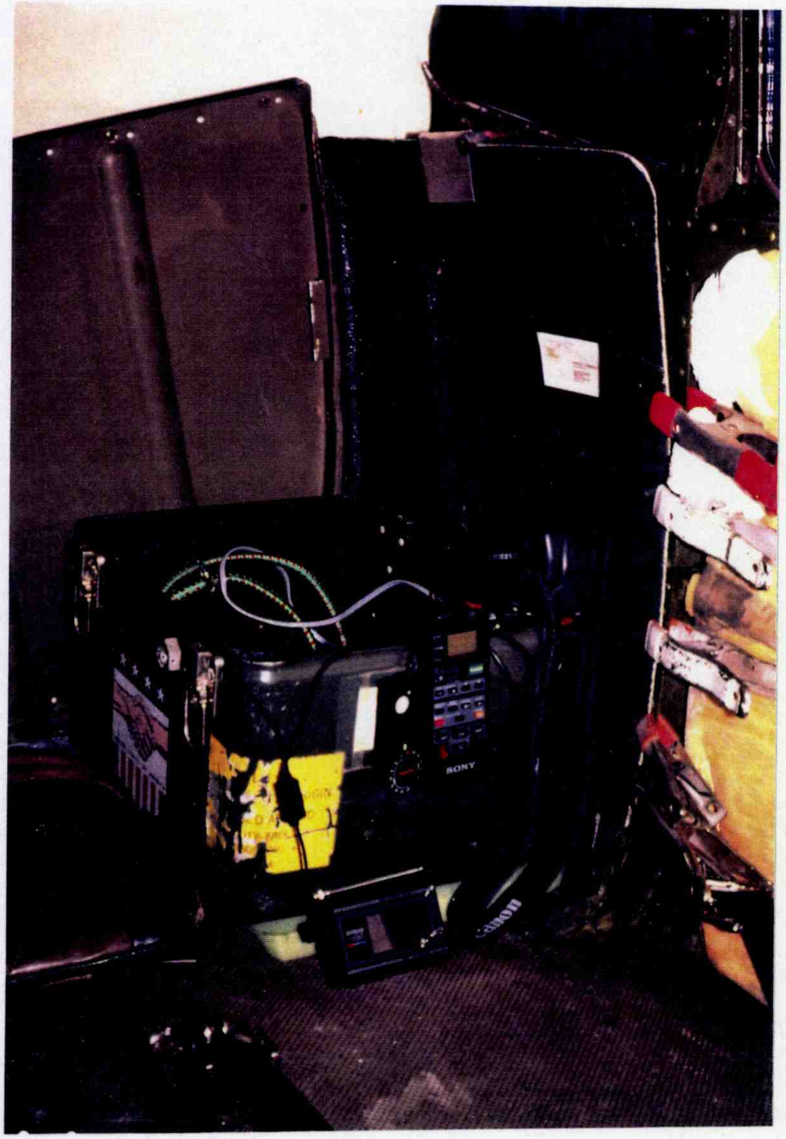


Figure 6: Camera and fiberglass nacelle installed in a Cessna 182 aircraft. The 70mm (left) and video (right) remote controls hang from the camera mount. A color LCD monitor is seen in front of the box.

[redacted]

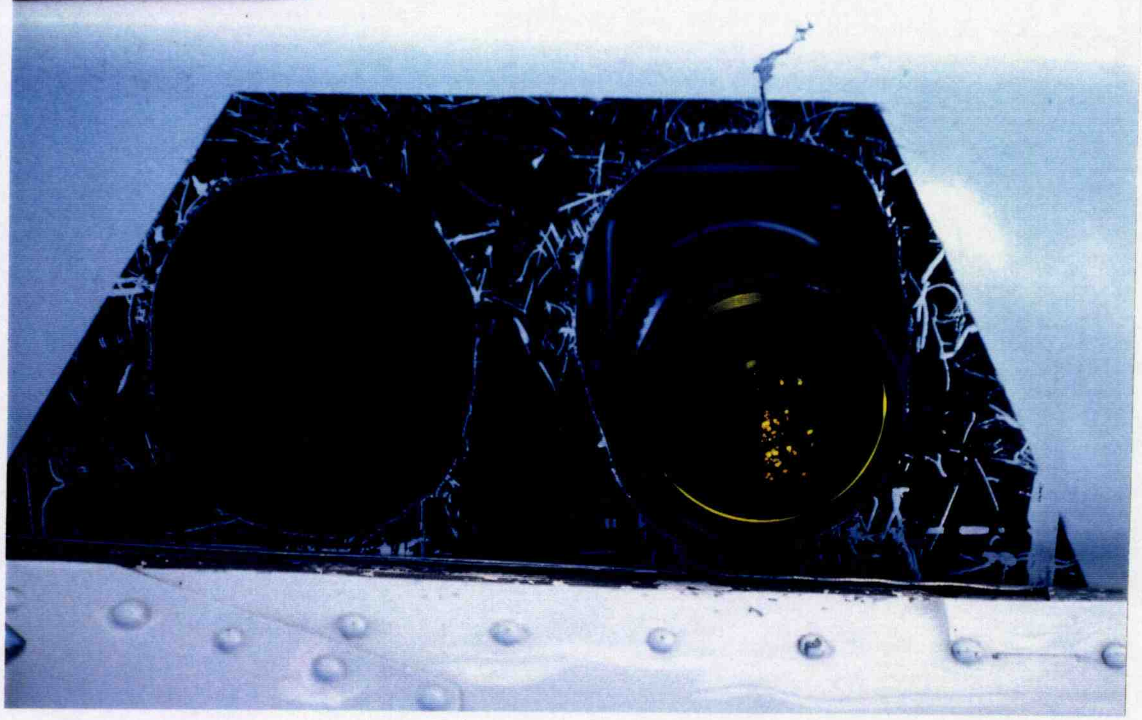


Figure 7: Camera view ports are located in the bottom of the nacelle. A minus blue filter is seen on the 70mm camera (right).

Creating the Time Code

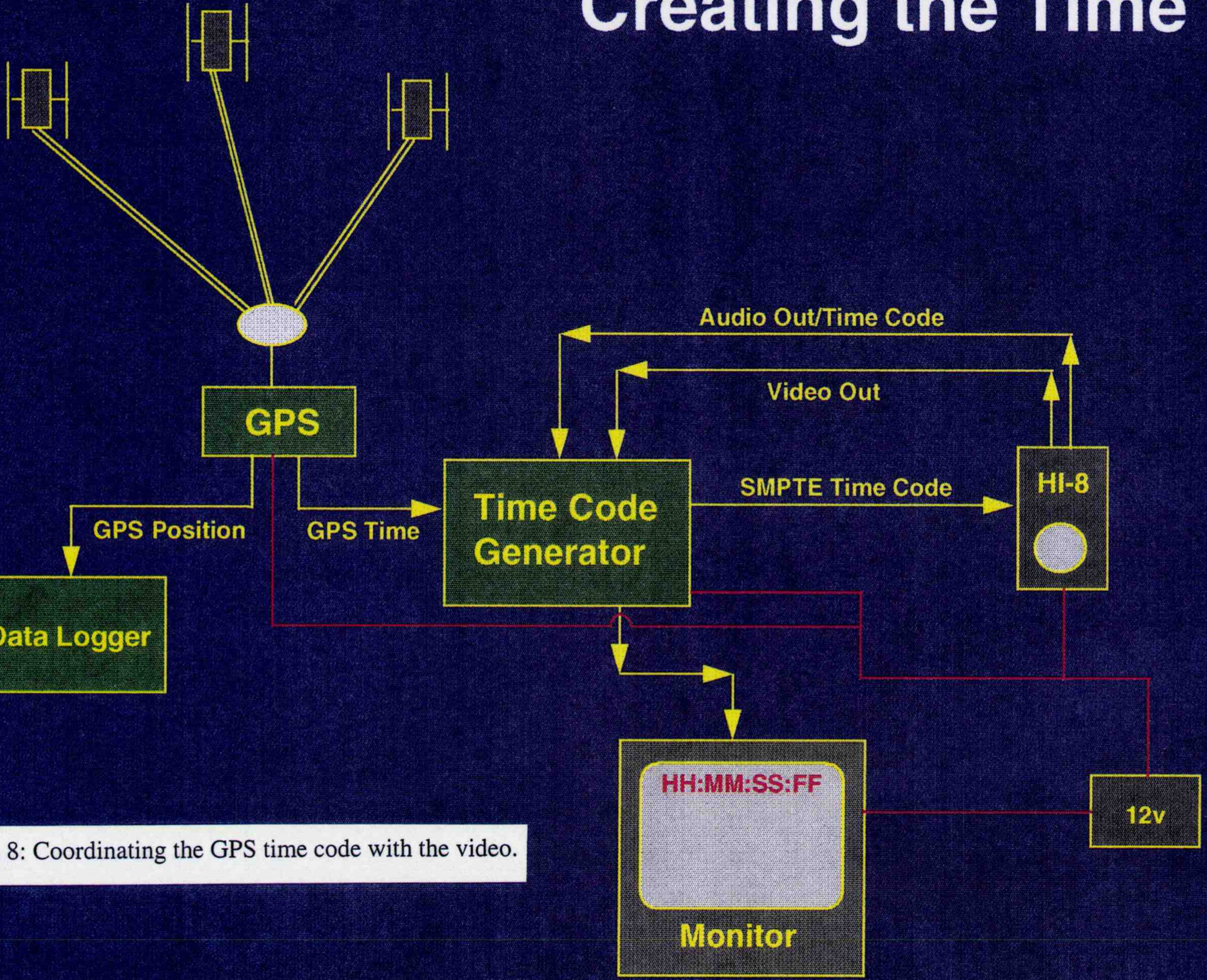


Figure 8: Coordinating the GPS time code with the video.

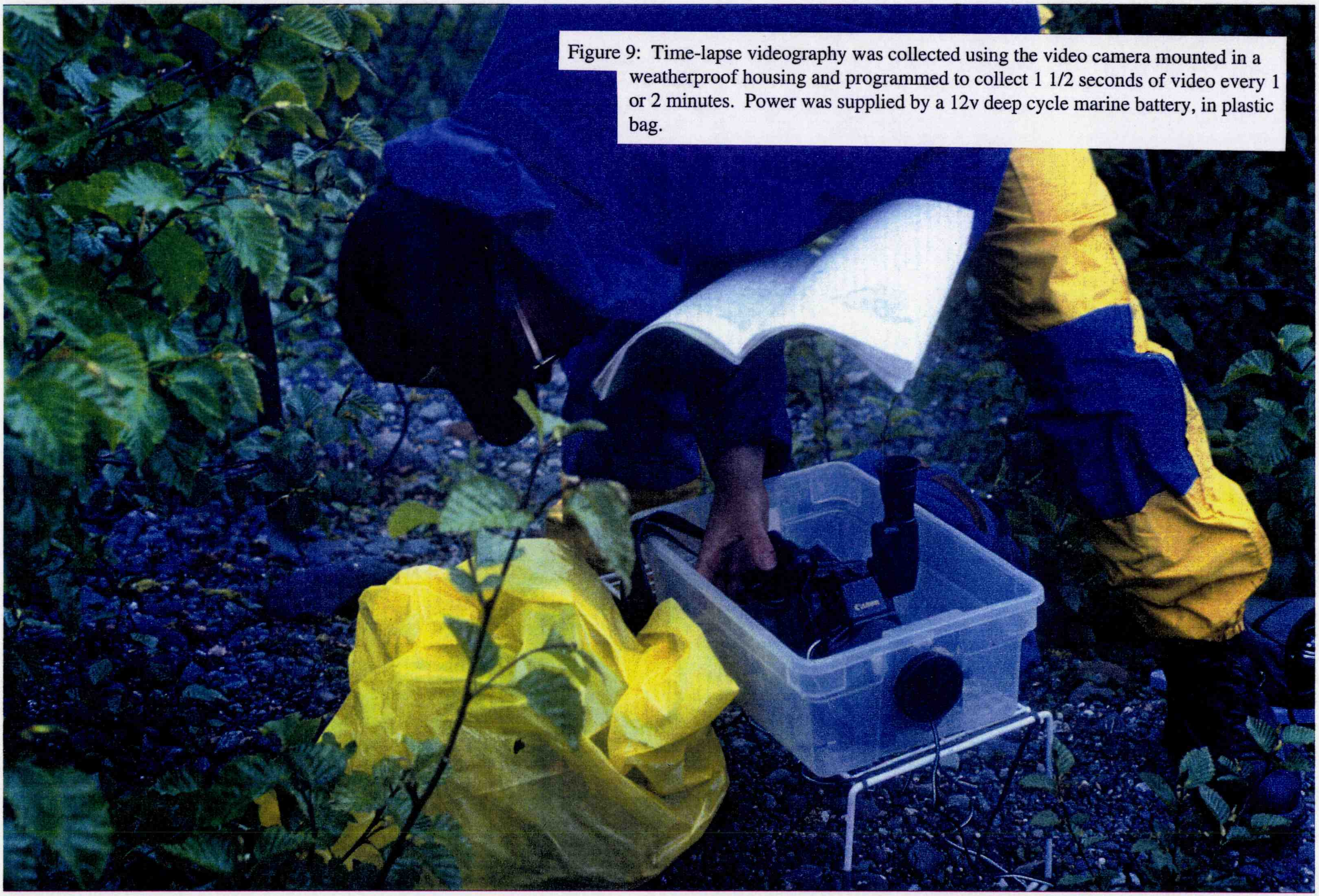


Figure 9: Time-lapse videography was collected using the video camera mounted in a weatherproof housing and programmed to collect 1 1/2 seconds of video every 1 or 2 minutes. Power was supplied by a 12v deep cycle marine battery, in plastic bag.

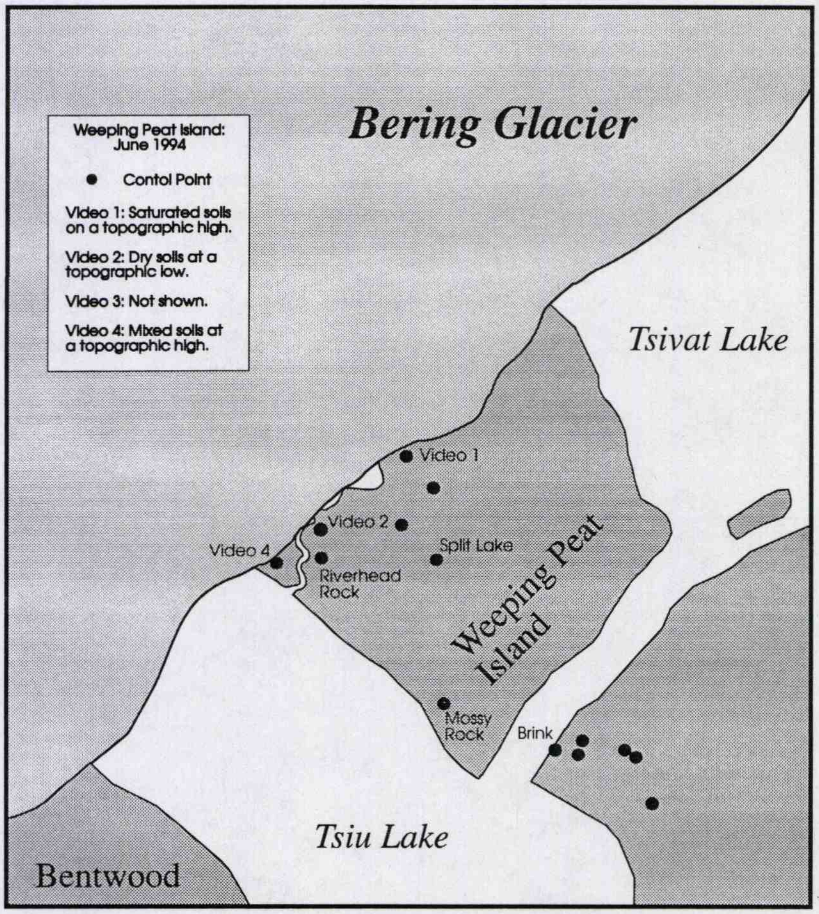
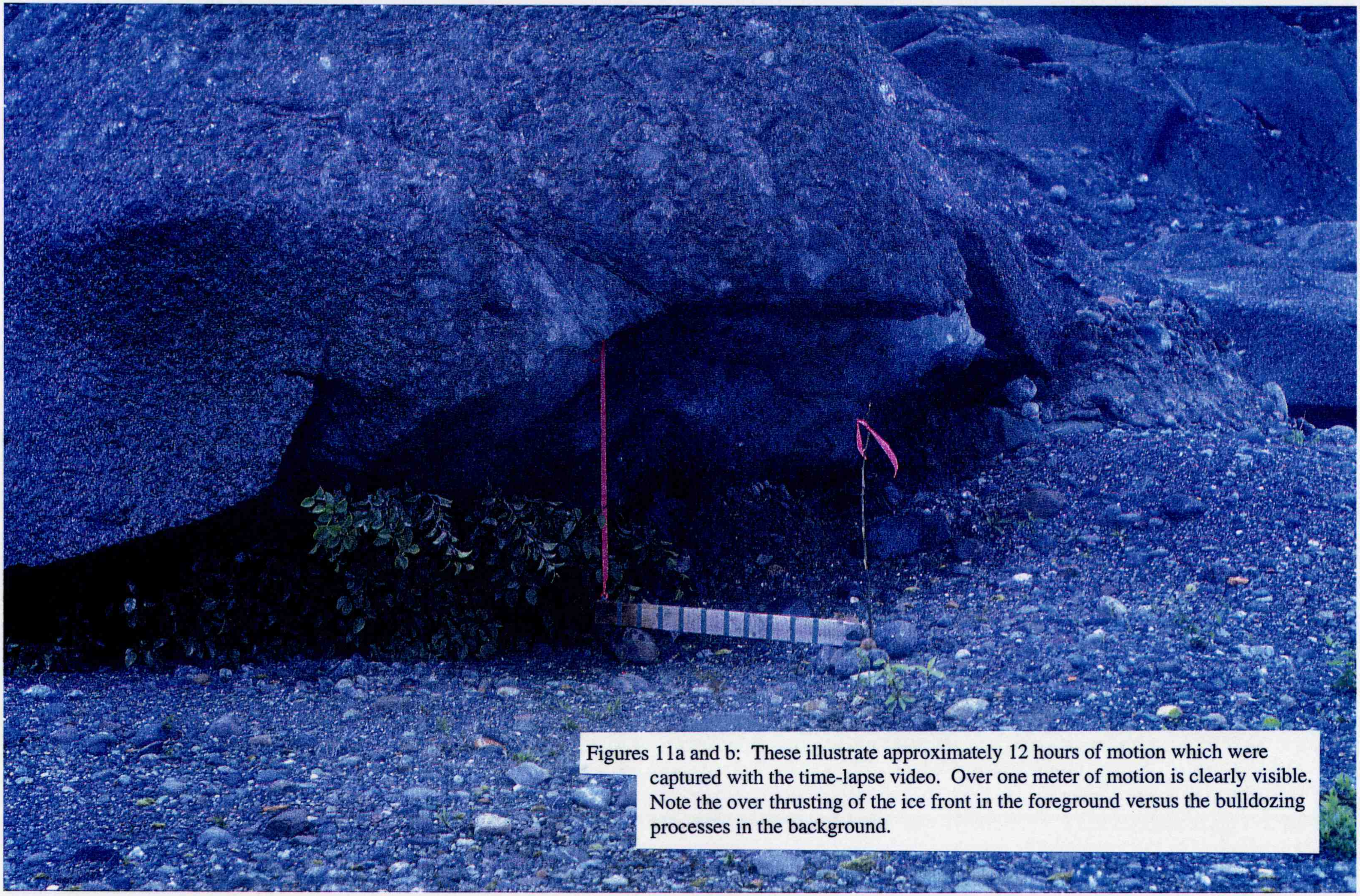


Figure 10: Locations of time lapse videography.



Figures 11a and b: These illustrate approximately 12 hours of motion which were captured with the time-lapse video. Over one meter of motion is clearly visible. Note the over thrusting of the ice front in the foreground versus the bulldozing processes in the background.

Figure 12: Looking west across Lake Vitus on January 3, 1994, the terminus is often indistinguishable from the calved debris in the water.

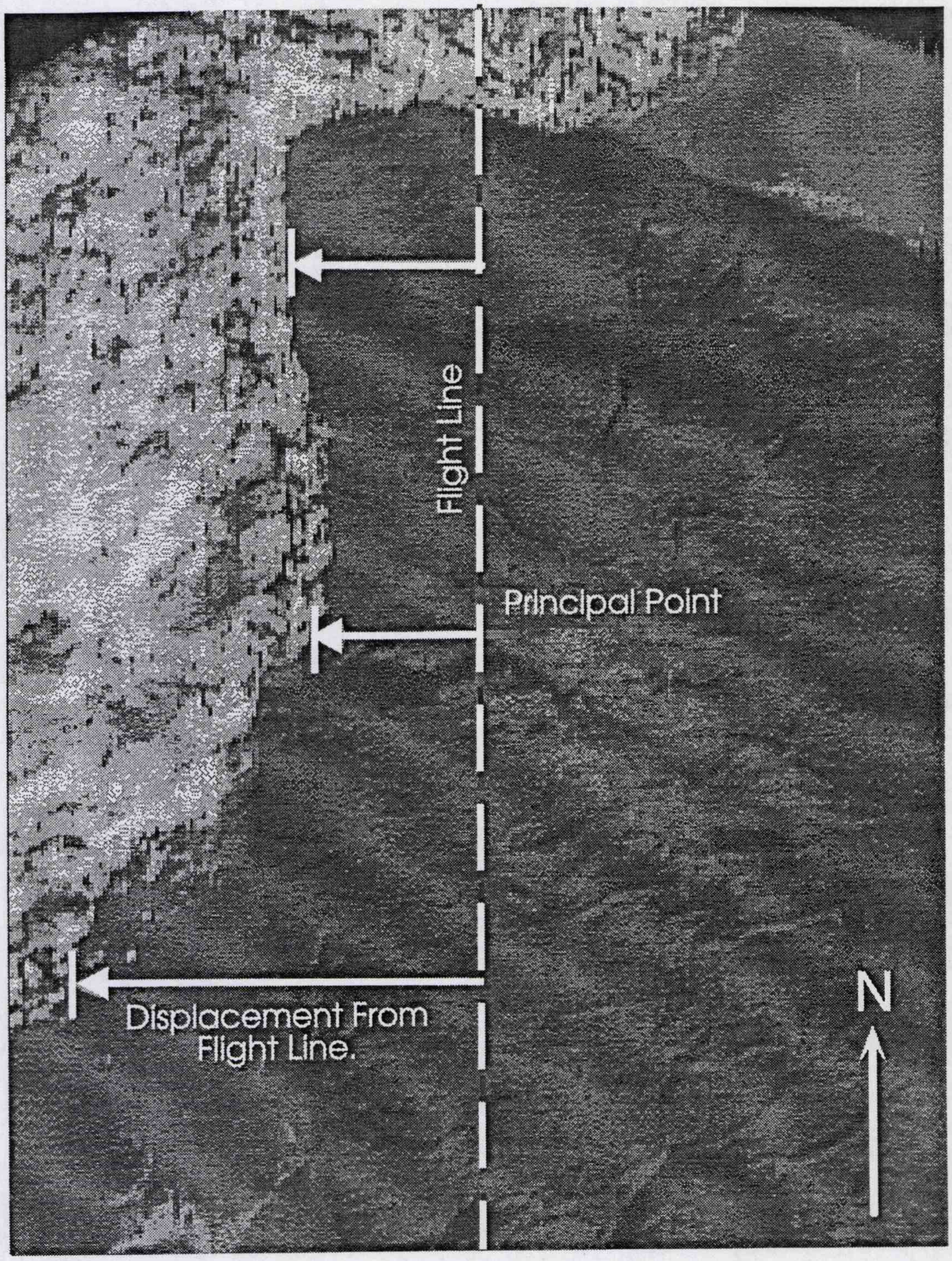


Figure 13: This shows a single frame of video imagery of Muller Narrows captured on January 3, 1994. The glacier is seen consuming the land mass from the north/west. The cross and arrow indicate the principal point and the northerly direction of flight. Basic photogrammetry is used to scale displacements from the principal point to the glacier front and convert them to map scale for plotting.

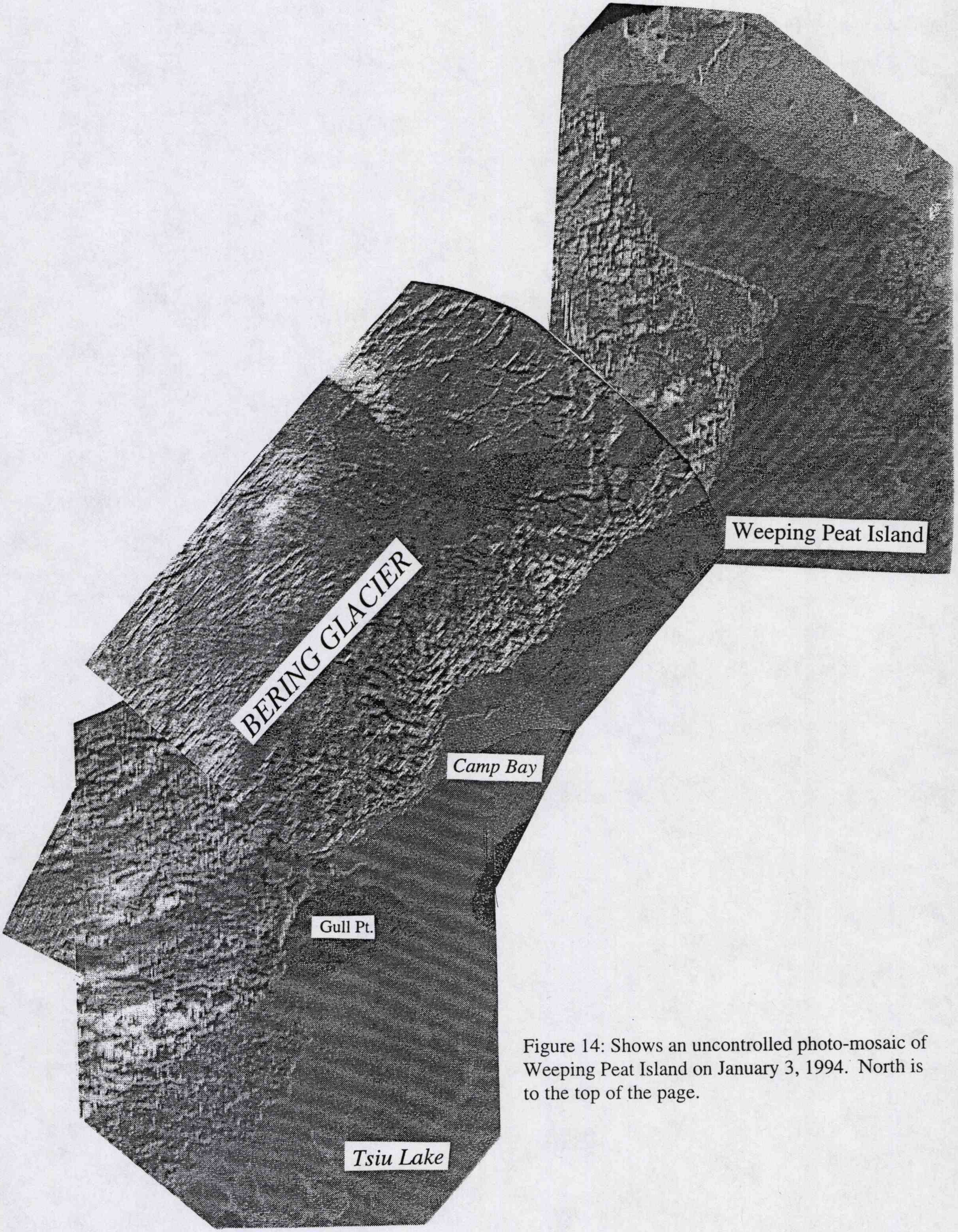


Figure 14: Shows an uncontrolled photo-mosaic of Weeping Peat Island on January 3, 1994. North is to the top of the page.