W00462

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service

DESCRIPTIVE REPORT

Type of Survey:	Navigable Area
Registry Number:	W00462

LOCALITY

State(s):	Alaska
General Locality:	Icy Bay
Sub-locality:	Taan Fjord

2016

CHIEF OF PARTY
P. J. Haeussler

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

REGISTRY NUMBER:

HYDROGRAPHIC TITLE SHEET

W00462

INSTRUCTIONS: The Hydrographic Sheet should be accompanied by this form, filled in as completely as possible, when the sheet is forwarded to the Office.

State(s):	**Alaska**
General Locality:	**Icy Bay**
Sub-Locality:	**Taan Fjord**
Scale:	**40000**
Dates of Survey:	**05/01/2016 to 09/01/2016**
Instructions Dated:	**N/A**
Project Number:	**ESD-PHB-18**
Field Unit:	**US Geological Survey**
Chief of Party:	**P. J. Haeussler**
Soundings by:	**Teledyne RESON SeaBat T50-P (MBES)** **Teledyne Odom Hydrographic MB2 (MBES)**
Imagery by:	**N/A**
Verification by:	**Pacific Hydrographic Branch**
Soundings Acquired in:	**meters at Mean Lower Low Water**

Remarks:

Any revisions to the Descriptive Report (DR) applied during office processing are shown in red italic text. The DR is maintained as a field unit product, therefore all information and recommendations within this report are considered preliminary unless otherwise noted. The final disposition of survey data is represented in the NOAA nautical chart products. All pertinent records for this survey are archived at the National Centers for Environmental Information (NCEI) and can be retrieved via https://www.ncei.noaa.gov/. Products created during office processing were generated in WGS84 UTM 7N, MLLW. All references to other horizontal or vertical datums in this report are applicable to the processed hydrographic data provided by the field unit.

DESCRIPTIVE REPORT MEMO

November 16, 2021

MEMORANDUM FOR: Pacific Hydrographic Branch

FROM: Report prepared by PHB on behalf of field unit
P. J. Haeussler
Principal Investigator, U.S. Geological Survey

SUBJECT: Submission of Survey W00462

This survey was conducted by USGS to investigate a landslide that occurred in Taan Fiord, Alaska, on 17 October 2015 and caused a tsunami.

Survey products were generated by the hydrographic branch.

All soundings were reduced to Mean Lower Low Water using Constant Separation. The horizontal datum for this project is World Geodetic System (WGS) 1984. The projection used for this project is Universal Transverse Mercator (UTM) Zone 7.

Data acquisition and processing information is included in the attached report and at the link below.

All data were reviewed for DTONs and none were identified in this survey.

U.S. Geological Survey acquired the data outlined in this report. Data are available at https://doi.org/10.1029/2018JF004608. Additional documentation from the data provider may be attached to this report.

This survey does meet charting specifications and is adequate to supersede prior data.

Journal of Geophysical Research – Earth Surface

Supporting Information for

Submarine Deposition of a Subaerial Landslide in Taan Fiord, Alaska

P. J. Haeussler[1], S. P. S. Gulick[2], N. McCall[2] , M. Walton[3], R. Reece[4], C. Larsen[5], D. H. Shugar[6], M. Geertsema[7], J. Venditti[8] and K. Labay[1]

[1]U.S. Geological Survey, 4210 University Dr., Anchorage, AK 99508

[2]Institute for Geophysics and Department of Geological Sciences, University of Texas at Austin, Austin, TX

[3]U.S. Geological Survey, Santa Cruz, CA 95064

[4]Texas A&M University, Waco, TX

[5]University of Alaska, Fairbanks

[6]University of Washington, Tacoma

[7]British Columbia Ministry of Forests, Lands and Natural Resource Operations, Canada

[8]Simon Fraser University, Burnaby, British Columbia, Canada

Introduction

This Supporting Information describes how a combined topography and bathymetry DEM was produced for Taan Fiord, Alaska, utilizing several bathymetry and topography datasets collected in the spring and summer of 2016. The document describes details of data acquisition of each dataset, and the steps made in producing the combined DEM. The Supporting Information also describes details of seismic data acquisition, and tsunami runup and flow-direction mapping from imagery. The Supporting Information also provides the digital topographic, bathymetry, tsunami runup, and tsunami flow direction data.

Supporting Information S1.

Bathymetry data collection and processing.

A Reson SeaBat T50-P multibeam system was used aboard the R/V *Alaskan Gyre* and is capable of a 190 to 420 kHz sweep and up to 7 times the water depth and swath width. We generally employed a 200 kHz acquisition frequency and at least a 30 μs pulse length due to the deeper water bottom in the fjord setting. The multibeam unit was mounted on a custom pole on the port side of the lab on the '*Gyre'* and coupled to an Applanix POS MV GPS system. The POS MV system blends Global Navigation Satellite System (GNSS) data with angular rate and acceleration data from an inertial measurement unit (IMU) and heading data from a GNSS Azimuth Measurement System (GAMS) to obtain highly accurate positioning information. A CastAway brand Conductivity-Temperature-Depth (CTD) profiler was used to obtain sound velocity profile (SVP) information, generally at least once per day during multibeam acquisition in deeper area(s) of the day's surveyed locations. Multibeam bathymetry data were initially loaded into Teledyne's PDS interpretation software; data were further processed using Caris software following the cruise. A surface gridded to 1m resolution was used. Manual swath and subset editing was performed to eliminate noise after applying the sound velocity profile and corrections for tide and roll.

Seafloor bathymetry was also surveyed from a Teledyne Oceanscience ZBoat, an Unmanned Surface Vessel (USV *Jökull*), equipped with a Teledyne Odom MB2 multibeam echo sounder (MBES). The USV's multibeam system was coupled to an SBG Ekinox-D Inertial Measurement System and Trimble R10 real-time kinematic (RTK) Global Navigation Satellite System, which provided +/-0.08 m in horizontal and vertical accuracy. The MB2 MBES is a 200-400 kHz system, which measures water depth across a swath up to 140° perpendicular to the vessel direction, though we restricted the swath width to <~100°. Sonar data were collected and later processed using HYPACK/HYSWEEP and MBMAX. Corrections for water column sound velocity variations were made using an AML Oceanographic MinosX sound velocity profiler once per day (in afternoon) by means of an inflatable kayak.

Tidal Corrections

For tidal corrections, it is simplest to compare to Mean Sea Level (MSL). Two HOBO brand water level data loggers (www.onsetcomp.com) were deployed from 6 June 2016 to 8 August 2016 and produced a time series of depths for the duration. Both gauges were checked on and redeployed in approximately the same location on 3 August 2016. We calculated the mean of the time series before and after the movement, which differed by 39.8 cm. As the time series between 3 and 8 August is much shorter than that from 6 June to 3 August, we then adjusted the later time series upward. This adjustment added some uncertainty, but it seemed the only way to get a longer time series that included the time period in which we were collecting the multibeam data. The mean of the time series from 6 June to 3 August differs from the mean of all the data from 6 June to 8 August (including the adjusted data) by 3 cm, which is ~1/3 the errors in depth from our multibeam systems. We then compared the Mean Sea Level (MSL) and phase of the time series to the Yakutat tide gauge (station 9453220), which has been operating since 1940 (station information can be found here: https://tidesandcurrents.noaa.gov/stationhome.html?id=9453220#info). We find the tides are exactly in phase in both locations, but that MSL is 23 cm higher at Yakutat. Given the high topography near Taan Fiord, and assuming crustal compensation, it is reasonable to expect that MSL is higher in Taan than at Yakutat. We then used an adjusted time series of Yakutat tides to fill in the tidal variation at Taan, for the time period when the water level loggers were not deployed. NOAA provides these data for the Yakutat tide gauge relative to ellipsoids and geoids (see: https://tidesandcurrents.noaa.gov/datums.html?id=9453220):

0 m Local MSL (2007-2011 tidal epoch)
= 1.402 m relative to NAVD88(Geoid12B)
= 7.312 m relative to NAD83(2011) epoch 2010.0 ellipsoid
= 7.539 m relative to ITRF2008 epoch 2005.0 ellipsoid

And thus the Taan tide gauge data can be related to the ellipsoid or geoid, even though the Taan tide gauges were not surveyed.

Topography

A comprehensive LiDAR dataset was collected for Taan Fiord on 29 May 2016. There were no surveyed ground control points in Taan Fiord as the data were collected. Data were provided with elevation values in ellipsoid heights. These values were then converted to orthometric heights in the NAVD88(Geoid12B) vertical datum. To move the data relative to local MSL, we adjusted the LiDAR data downward 23 cm (difference between Taan tide gauge and Yakutat tide gauge) plus 1.402 m (from the table above). This value of 1.632 m was applied to the LiDAR.

The LiDAR system is owned by the University of Alaska Fairbanks (UAF) and is based on a Riegl LMS-Q240i Pulsed Scanning Altimeter. This 904 nm wavelength laser records (at 10,000 Hz) a swath of surface elevations roughly 550 m wide from 500 m AGL over snow and ice with a density of one point per square meter. This laser scanner is Class 1 eye safe, allowing for unregulated use over populated areas. Aircraft orientation is measured by a GPS aided solid state Inertial Measurement Unit (IMU) from Oxford Technical Solutions. This IMU provides pitch and roll at 100 Hz, with accuracy of 0.05 degrees, and heading accurate to 0.1 degrees. Three integrated GPS receivers significantly mitigate attitude drift with this IMU.

The UAF system is designed to keep everything as compact and complete as possible in a single package. Cabling and connections to the rest of the aircraft are kept to an absolute minimum: Only power-in (12 VDC, 8 amps) and three GPS antenna cables are needed. This approach significantly reduces installation time and the potential for minor installation errors. Pilot and Instrument Operator display information (height above ground, swath coverage over planned flightlines, data quality, recording on/off) is output via ethernet. Data rate of the in-flight recordings are on the order of 0.5 Gb/hr. Total system weight is approximately 22 kg (50 lbs).

Aircraft positioning was performed by a Trimble R7 dual frequency GPS unit, using a calibrated Sensor Systems L1/L2 aircraft antenna, and recording at 5 Hz. Up to an additional seven Trimble R7 systems are available for associated ground control of the aircraft unit. Kinematic post processing of the GPS data was done in two steps. Initially a high precision solution was performed using the Track module of the Globk/Gamit package, incorporating precise orbits from Jet Propulsion Laboratory (JPL). This high precision solution is then blended with the raw IMU data using Oxford Technical Solutions' RTpostprocess software, which improves both the accuracy of the IMU attitude measurement and corrects for periods of weak GPS satellite geometry such as during turns where an aircraft wing may block some satellites.

Multiple calibration-validation missions have compared surface elevations recorded by this system to those of independent surveys, with overlapping data points numbering in the tens of thousands. The overall system accuracy is 8 cm. Survey flights were carefully planned to establish multiple GPS base stations close to the glaciers surveyed in order to ensure the most accurate and tightest coupling of the swath data into global reference systems.

The digital photogrammetry system consists of a calibrated digital SLR camera and an intervalometer/event marker. The camera is a Nikon D800 with 36 MP resolution. Using a Zeiss 28mm lens, the field of view almost exactly overlies the LiDAR swath. At the typical survey height above ground of 500 meters, the frames are 550 m wide with a resolution of better than 10 cm per pixel. This resolution is two orders of magnitude higher than the LiDAR point density. The intervalometer/event marker, designed and built by Cirrius Digital Systems (John Arvesen), allows the shutter actuation of the camera to be precisely timestamped and correlated with the GPS-IMU for exact geo-referencing of each image.

The photogrammetry system generates an independent Digital Elevation Model (DEM) of the terrain it is imaging. The imagery can achieve a large degree of forward overlap between frames (70-80%). This large degree of overlap makes the use of multi-view photogrametric method particularly effective. By analyzing all images overlapping a given region simultaneously, a much higher quality DEM is produced than with stereo processing alone. We use a SfM (structure from motion) software package (Agisoft Photoscan) to produce high-resolution DEMs from the imagery. The method combines advanced image-matching techniques with precision GPS-IMU data to produce an elevation model with exceptionally high horizontal resolution. The UAF team and methods has been successful at producing high resolution DEMs from DMS imagery collected over nearly 50 projects across Alaska, California, Oregon and Utah since 2012. Direct comparison with simultaneously acquired LiDAR DEMs have been used to calibrate and validate these photo derived DEMs, and in general the agreement is on the order of 10 cm or better in all three dimensions.

Sea level was digitized at a scale of 1:300-500 from the aerial photographs taken by the digital photogrammetry system. Data collection lasted approximately 3 hours, and thus sea level would have changed during this time period. For the west side shoreline, photographs were taken from 20:30 to 21:15 UTC time, and for the east side shoreline from 22:30 to 23:30 UTC. For the west side, this corresponds to an average of -1.29 ±0.06 m relative to MSL (tide range during the photos was from about -1.45m to -1.57m). For the east side, the average tide was -1.04 ±0.08 m relative to MSL (tide range during the photos was from about -1.41 to -1.12 m). The MSL for the entire interval is: -1.15 m, which we use as the mean tide stage for the orthophotos, relative to MSL. This shoreline is thus not perfect, but is the best we could come up with, and better than a shoreline from satellite imagery.

We then compared the ~ -1.15m MSL elevation of the shoreline relative to the adjusted LiDAR elevations. The LiDAR data were consistently 1-2 m above this shoreline value where the LiDAR data cross the inferred shoreline value. We could not find reasonable way to get the data to reconcile. We merely applied a smoothing function to get the data to resolve at the digitized shoreline.

For combining the datasets, we also use the NOAA multibeam survey in Icy Bay as well as our own. That survey is relative to MLLW, so given the Yakutat tide gauge corrections, we lowered the NOAA survey data 1.61 m to get it to a MSL datum, but then add 23 cm (1.38 m adjustment)

Combined Topography and Bathymetry

We produced a combined bathymetry and topography dataset using four separate datasets as input. The elevations in each of the datasets were adjusted to make them relative to MSL. Overlaps between the datasets, or areas that extended beyond the final area of interest (AOI), were clipped prior to combining them. Topography was provided by the LiDAR dataset. Areas of the LiDAR that extended past the digitized shoreline were removed. The largest area of bathymetry in Taan Fiord proper came from the *Alaskan Gyre* dataset. Shallower areas at the head of the fiord between this dataset and the shoreline were filled by the *Jökull* data. At the mouth of the fjord NOAA multibeam survey H11994 was used (Fig. 4 in paper). These datasets, together with the shoreline and AOI, were combined into a GIS terrain dataset. The final 1 m resolution combined topography and bathymetry DEM was created from this dataset using a natural neighbors interpolation to fill the gaps between the LiDAR and bathymetry datasets.

Supporting Information S2.

Seismic Data Acquisition

The seismic data were collected in a joint effort between the U.S. Geological Survey (USGS), the University of Texas Institute for Geophysics (UTIG), and Texas A&M University (TAMU); a suite of high-resolution multi-channel seismic (MCS) data and multibeam bathymetry were collected in Icy Bay and Taan Fiord. The seismic system utilized TAMU's DuraSpark sparker source along with a dual-streamer system including UTIG's 24-channel, ~72 m active length streamer and TAMU's 24-channel, 150 m active length streamer. Over 450 line-km of MCS data collected in Taan Fjord and Icy Bay.

For a sound source, we utilized TAMU's sparker, a Dura-Spark 240, which is manufactured by Applied Acoustics (www.appliedacoustics.com). The sparker contains 240 negative-pulse sparker tips and an operational bandwidth of 300 Hz to 1.2 kHz. During our survey, the dominant frequency was ~600 Hz. The sparker was run using a power source in conjunction with a custom "shot box" firing controller that allowed for shots every 2 seconds throughout the survey. The sparker was grounded to the water by dragging a piece of rebar connected to the grounding wire.

The UTIG seismic receiver is a Beam Systems, Inc.® (Pearland, TX), 100 m (~72 m active), 24-channel, oil-filled, analog cable. 72 hydrophones (Teledyne Model T-2) are grouped three to a channel, with group spacing at 3.125 m. The cable is 1.6 inch in diameter and gel-filled (Isopar M fluid). Nominal tow depth is 1 m or less. The cable was deployed directly from the wooden shipping reel by hand. During active acquisition aboard the *Alaskan Gyre*, a custom wooden A-frame was built for the streamer reel, which was kept on top of the fish hold, and the cable was deployed from the wooden shipping reel by hand. The streamer was always deployed from the starboard side.

The TAMU seismic receiver streamer was used in conjunction with the UTIG streamer to increase offsets, improve signal-to-noise ratios, create redundancy in the data, and to examine differences in data quality between the two receiver systems. The TAMU streamer, a solid streamer manufactured by Geometrics (www.geometrics.com), has 24 channels spaced at 6.25 m for a total active length of ~144 m. Each channel has 4 hydrophones, a custom configuration different than the usual 3, to improve the signal to noise ratio. During acquisition on the *Alaskan Gyre*, the TAMU streamer was stored on the port side of the main deck outside and deployed by hand from the port side. During the double, extra-long streamer configuration, the TAMU streamer was towed behind the UTIG streamer using a longer tow line. The TAMU streamer was always towed from the port side, and the UTIG streamer always towed from the starboard side regardless of the streamer configuration.

Geode seismic recorders were used with both the UTIG and the TAMU streamers. For each streamer, analog signals from the streamer cable were digitized and recorded using a single Geometrics® Geode 24-channel seismic recorder, and accompanying Geometrics® SGOS software running on a laptop. Each Geode was powered by an external 12-volt car battery. Data were stored on disk in SEG-D format. For this experiment, we used a record length of 0.5 seconds.

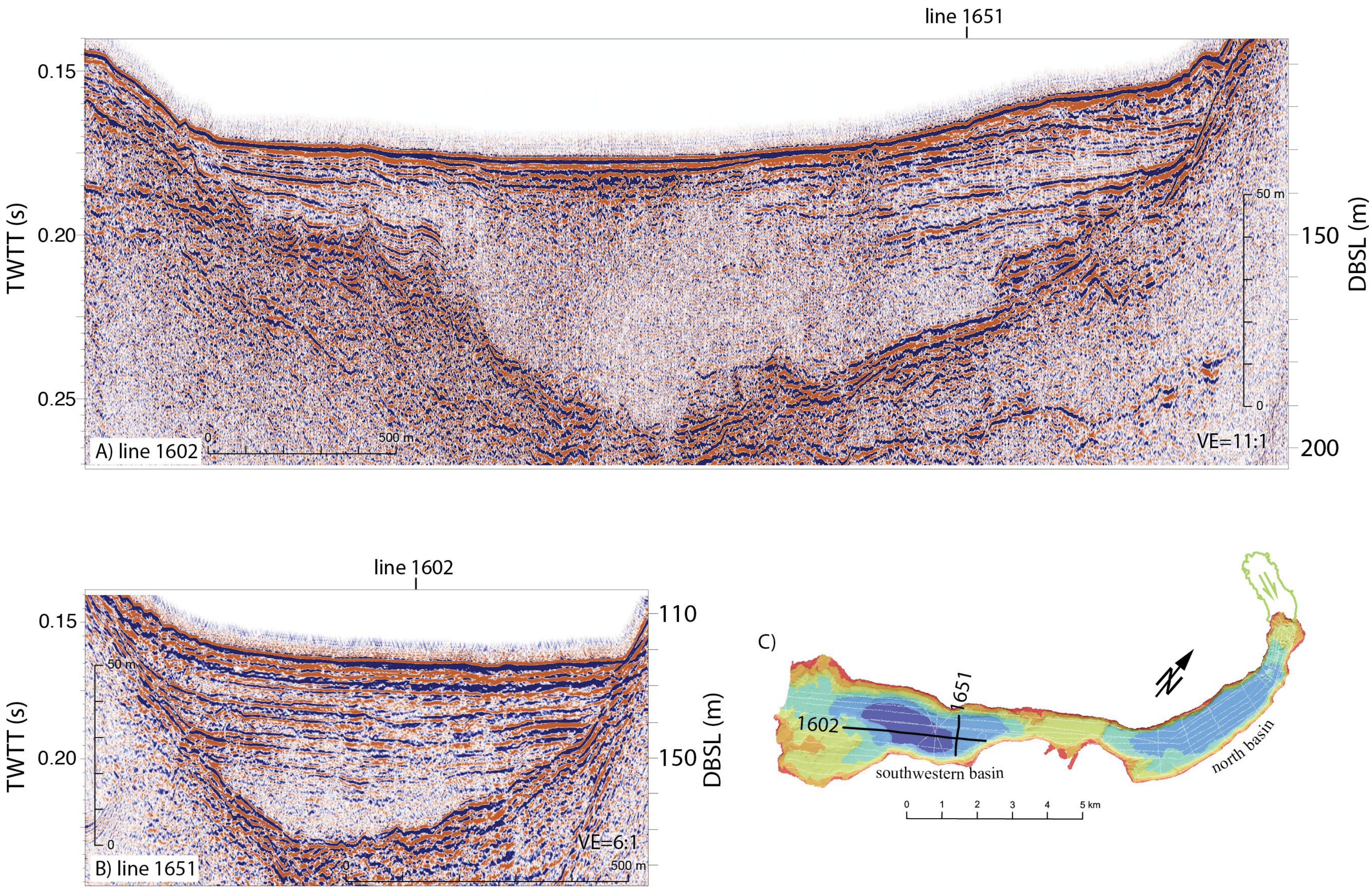
line 1651
TWTT (s)
0.15
0.20
0.25
DBSL (m)
150
200
50 m
0
A) line 1602
0
500 m
VE=11:1
line 1602
TWTT (s)
0.15
0.20
DBSL (m)
110
150
50 m
0
B) line 1651
0
500 m
VE=6:1
C)
1602
1651
southwestern basin
north basin
0 1 2 3 4 5 km

Figure S2.1. An overview of the uninterpreted data from the southwestern basin of Taan Fiord. This figure is the same as Figure 10 in the main manuscript, but with no interpretation or units assigned.

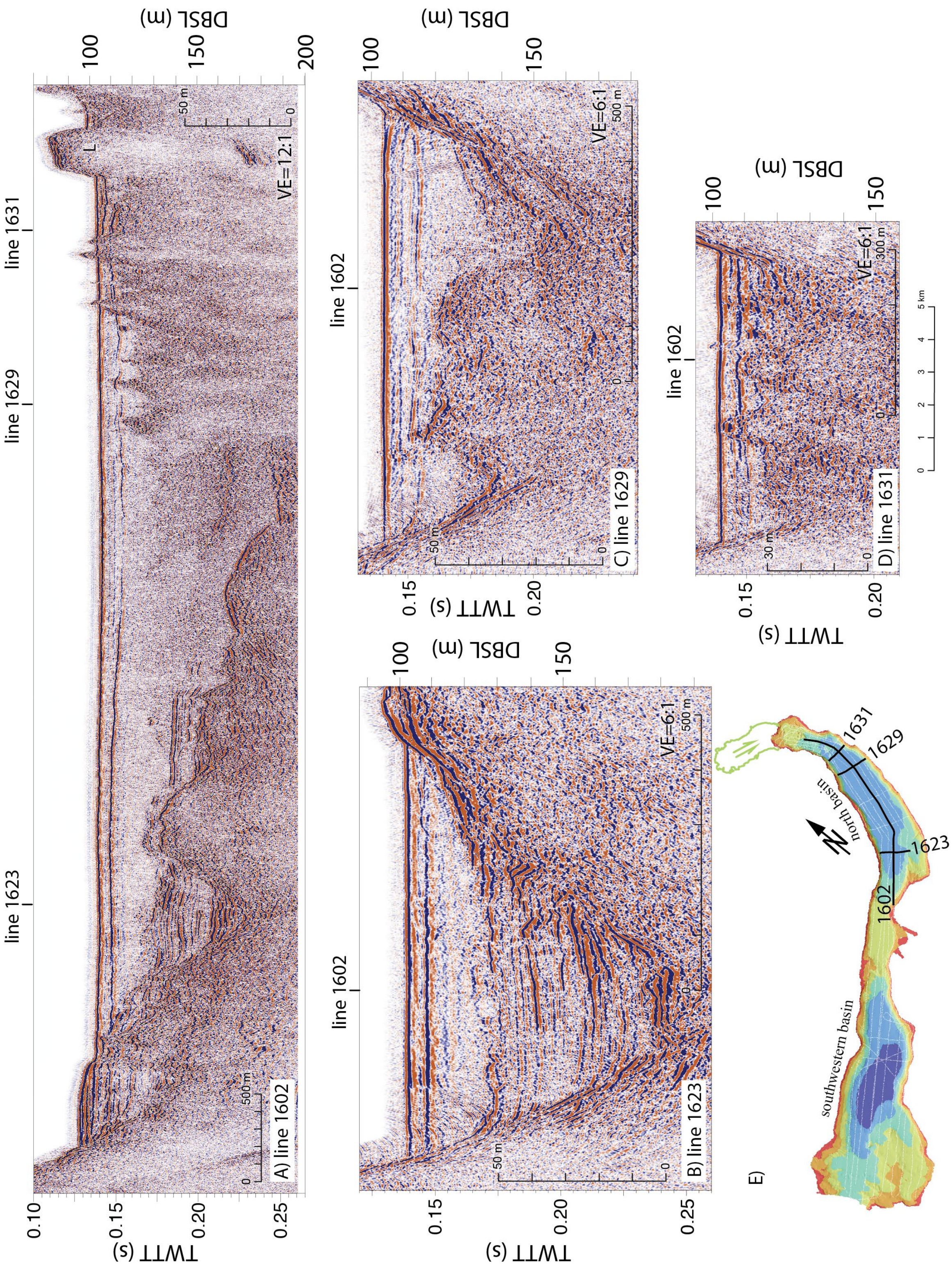

Figure S2.2. An overview of the uninterpreted data from the northern basin of Taan Fiord. This figure is the same as Figure 11 in the main manuscript, but with no interpretation or units assigned.

Supporting Information S3.

Estimate of Volume of Subaerial Landslide Material Remaining in the Slide Scar

To estimate the volume of material remaining in the slide scar, we inferred an approximate geometry for the base of the landslide from drawing nine cross sections across the slide spaced 100 m apart. These cross sections are shown in Figure S3. This method provides an additional volume of 18.0 million m^3. To estimate the error in this number we also drew reasonable cross-sectional profiles with the base of the landslide as shallow and deep as plausible, and then calculated the volumes. This provides error estimates of +2.4/-3.6 million m^3.

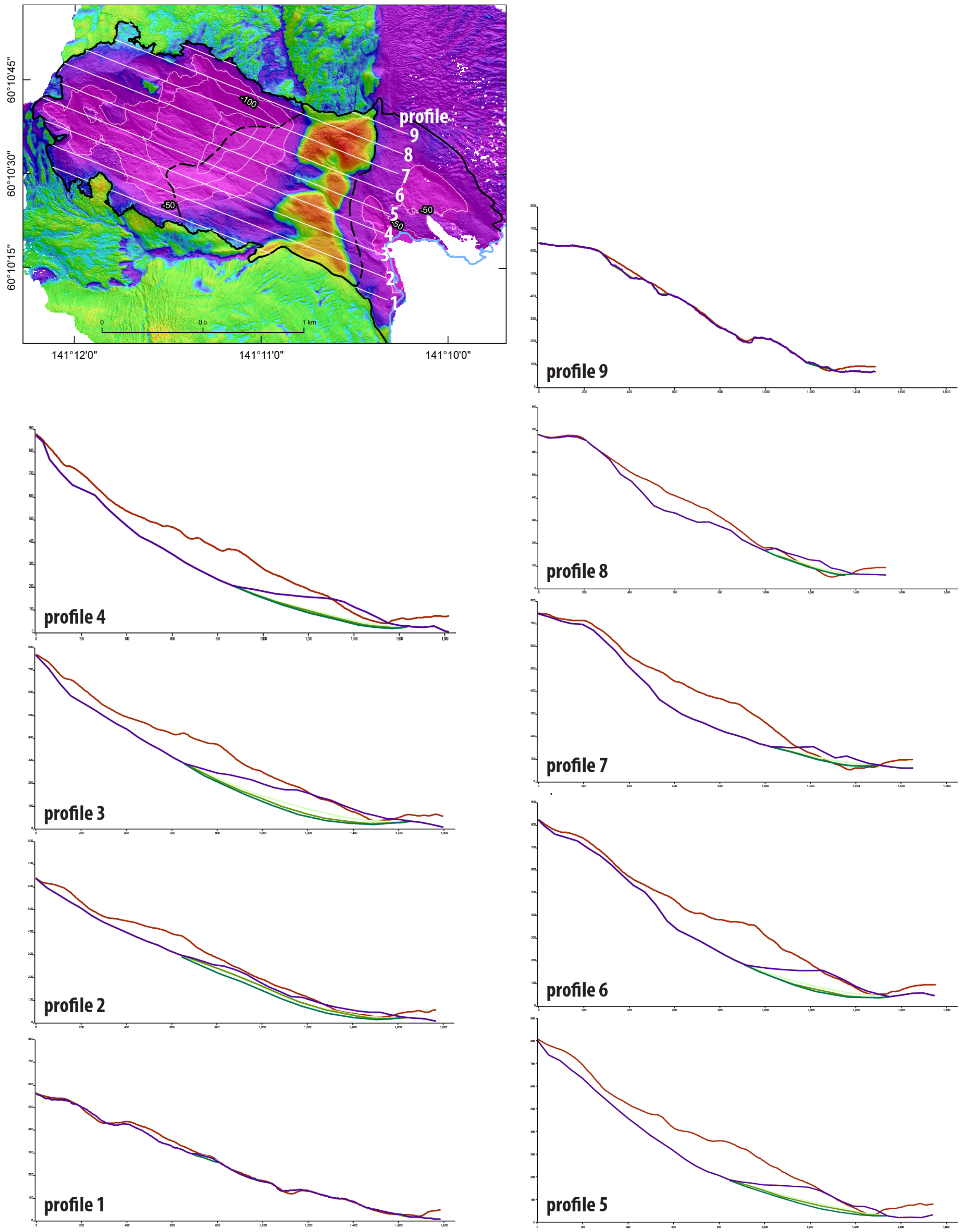

Figure S3. Nine cross sections through the subaerial landslide showing pre- and post-landslide surfaces from DEMs. The inferred base of landslide is shown by the middle green line. The green lines above and below the middle green line show our estimates for how shallow or deep a plausible base-of-slide surface may lie. These lines are used to estimate our error in the volume of this part of the landslide deposit. Figure 6 in the main paper is the same, but just showing one cross section.

Supporting Information S4.

Tsunami Runup and Flow Direction Mapping

Tsunami runup elevations and flow direction mapping was accomplished using imagery acquired for digital photogrammetry. As described in Supporting Information S1, the digital photogrammetry system consists of a calibrated digital SLR camera and an intervalometer/event marker. The camera is a Nikon D800 with 36 MP resolution. Using a Zeiss 28mm lens, the field of view almost exactly overlies the LiDAR swath. At the typical survey height above ground of 500 meters, the frames are 550-m wide with a resolution of better than 10 cm per pixel. This resolution is two orders of magnitude higher than the LiDAR point density. The intervalometer/event marker, designed and built by Cirrius Digital Systems (John Arvesen), allows the shutter actuation of the camera to be precisely timestamped and correlated with the GPS-IMU for exact geo-referencing of each image. We then imported the georeferenced images into ArcMAP brand GIS.

For tsunami runup mapping, we examined the georeferenced images in ArcGIS. We placed the tsunami runup line as the upper limit of either where vegetation was completely removed, or as the upper limit of undisturbed vegetation (see Figure S3). As it was common to observe trees, which were mostly alders, that had been swept and toppled by the tsunami, near the upper limit, the contrast between these disturbed trees and undisturbed trees was mapped as the limit of tsunami inundation. It is possible that the tsunami locally ran higher, and did not produce an observable impact on the vegetation. Ground-based surveys could do a better job of examining this issue, but our map is based only on the aircraft-acquired images.

For tsunami flow-direction mapping, we used the georeferenced images, and plotted vectors where toppled, but still rooted trees (again, dominantly alders), were swept over in the direction of water flow (see Figure S4). Obviously the flow direction from the trees does not necessarily reflect the strongest or dominant flow direction in the tsunami, but often the last direction of water flow. Thus, many flow directions are downhill or obliquely downhill and downfjord.

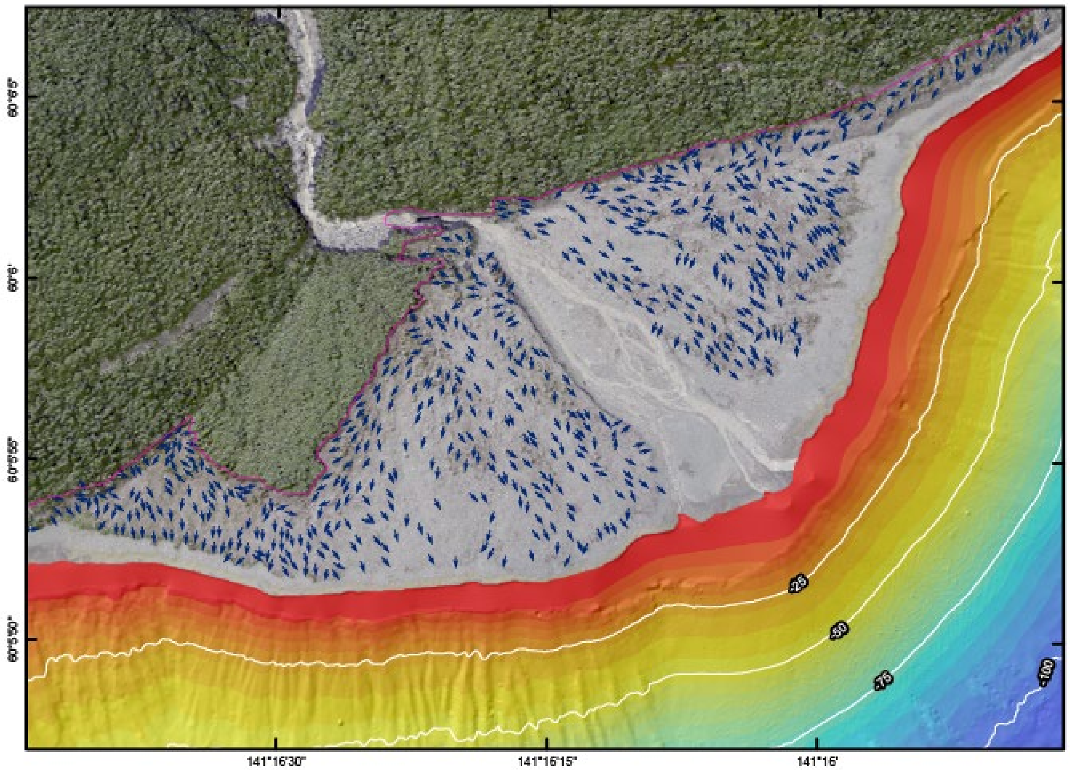

Figure S4. Example of tsunami runup and flow direction mapping. The pink line shows the tsunami runup line from the georeferenced imagery. We could be confident in the runup limit as individual trees can be identified. The blue arrows show the flow direction based on the drag of trees, dominantly alders, into the direction of water flow. Map area is on the northwest side of the 1983 glacier location.

Data Set S1. Zip file containing a 1-m DEM in GeoTiff format of combined topography and bathymetry of Taan Fiord. The projection is UTM zone 7, the datum is WGS84.

Data Set S2. Zip file containing a 1-m DEM in XYZ format of combined topography and bathymetry of Taan Fiord. The projection is UTM zone 7, the datum is WGS84.

Data Set S3. Zip file containing the following three files: (A) tsunami runup height – certain, (B) tsunami runup height – inferred, and (C) tsunami flow directions. All three files are in .csv, (i.e. comma separated) format. For the tsunami runup height files, the format is: longitude, latitude, height in meters. For the tsunami flow direction file, the format is: longitude, latitude, and bearing of the flow direction. The datum for all files is WGS84.

Data Set S4. Zip file containing the following ArcGIS shape files: (A) tsunami runup height – certain, (B) tsunami runup height – inferred, and (C) tsunami flow directions. The projection is UTM zone 7, the datum is WGS84.

APPROVAL PAGE

W00462

Data meet or exceed current specifications as certified by the OCS survey acceptance review process. Descriptive Report and survey data except where noted are adequate to supersede prior surveys and nautical charts in the common area.

The following products will be sent to NCEI for archive

- Descriptive Report
- Collection of Bathymetric Attributed Grids (BAGs)
- GeoPDF of survey products

The survey evaluation and verification has been conducted according current OCS Specifications, and the survey has been approved for dissemination and usage of updating NOAA's suite of nautical charts.

MILLER.JAMES.JEFFREY.1399283295
2022.02.15 19:00:57
-08'00'

Approved:___________________________________

James Miller
Chief, Pacific Hydrographic Branch