ICESat/ICESat-2 Traverse: Monthly GPS Surface Elevation Data at Summit Station, Greenland, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Hawley, R. L., Pickell, D. J., McConnell, J. R., Neumann, T. A., Felikson, D., & Dorsi, S. W. (2026). *ICESat/ICESat-2 Traverse: Monthly GPS Surface Elevation Data at Summit Station, Greenland* (IS2TGPSSS, Version 1). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/UNBV80EA7YBW [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IS2TGPSSS

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Summary

This is a data set of monthly Global Positioning System (GPS) surface elevation and position data gathered along a defined survey transect to the west of Summit Station, Greenland. The data transect is aligned with ICESat and ICESat-2 reference ground tracks (RGTs) to support ground comparison efforts.

1.2 File Information

1.2.1 Format

The raw data are available as Receiver Independent Exchange (RINEX) 2.11 format and processed data are available as comma-separated values (`.csv`). A metadata (`.txt`) file, providing RINEX file details for calculating surface elevation, is also included (see Section 2.2, Eq. 1).

RINEX is a data interchange format for raw satellite navigation system data and must be processed using precise point positioning (PPP) or real-time kinematic (RTK) platforms to derive latitude, longitude, and elevation. Summit Station base station data are freely available at Earthscope (UNAVCO Community, 2017).

1.2.2 File Contents

1.2.2.1 RINEX

Screenshots and descriptions of the RINEX file header and observation data block are provided below.

1.2.2.1.1 RINEX Header

```
1     2.11           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
2  teqc  2019Feb25                       20250317 13:56:39UTCPGM / RUN BY / DATE
3  OSX ker:10.11.6|Core i5|gcc 4.3 -m64|OSX ker:10.10+|=+     COMMENT
4  BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION      COMMENT
5  93850850                                                   MARKER NAME
6  0850                                                       MARKER NUMBER
7  -Unknown-           -Unknown-                              OBSERVER / AGENCY
8  0220379385          TRIMBLE R7          2.26               REC # / TYPE / VERS
9  -Unknown-           TRM39105.00     NONE                   ANT # / TYPE
10   1496387.1235 -1192329.9787  6067392.9837                 APPROX POSITION XYZ
11         0.0460        0.0000        0.0000                 ANTENNA: DELTA H/E/N
12      1     1                                               WAVELENGTH FACT L1/2
13      6    L1    L2    C1    P2    S1    S2                 # / TYPES OF OBSERV
14     14                                                     LEAP SECONDS
15   SNR is mapped to RINEX snr flag value [0-9]              COMMENT
16    L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                COMMENT
17    2008     3    25    17    47   26.0000000     GPS       TIME OF FIRST OBS
18                                                           END OF HEADER
```

Figure 1. Example RINEX file header.

The header section contains metadata related to the station and equipment. Header line descriptions corresponding to the example file (Figure 1) are provided below (adapted from Janssen, 2024):

Line 1: RINEX version (2.11) and statement that this is an observation file with GPS data
Line 2: Program used to generate the RINEX file and date/time it was run
Line 3: Comments, i.e., operating system information
Line 4: Comments, i.e., status of anti-spoofing (A/S)
Line 5: Marker name
Line 6: Marker number
Line 7: Observer and agency (unknown)
Line 8: Receiver serial number, receiver type, and firmware version
Line 9: Antenna serial number (the same as the receiver serial number for integrated antennas) and antenna type using the International GNSS Service (IGS) naming convention.
Line 10: Approximate site position in WGS84 Cartesian coordinates (X, Y, Z)
Line 11: Antenna height (measured vertically between ground mark and Antenna Reference Point, ARP) and any horizontal offset from the mark (i.e., small horizontal eccentricities of the ARP to the marker, which are typically zero for all but some scientific applications)
Line 12: Wavelength factor for the L1 and L2 frequencies
Line 13: Number and types of observations; i.e., L1 (carrier phase measurement), L2 (carrier phase measurement), C1 (L1 pseudorange measurement), P2 (L2 pseudorange measurement), S1 (L1 signal strength), and S2 (L2 signal strength)
Line 14: Number of leap seconds between GPS time and UTC, i.e., 14.
Lines 15–16: Comments, i.e., signal-to-noise ratio (SNR) flag description

Line 17: Time of first observation epoch; i.e., 17:47:26 hours GPS time on 25 March 2008.
Line 18: End of RINEX header indicator

1.2.2.1.2 RINEX Data Block

```
19  08  3 25 17 47 26.0000000  0  4G21G24G25G08
20    -107630.37558    -50692.52056  22355632.2894   22355629.2974        49.0004
21         37.2504
22     -11892.27758    -10981.06656  21783386.2974   21783384.5864        48.2504
23         39.2504
24      51320.81657     24352.04755  23955855.6174   23955853.4964        43.7504
25         32.5004
26     -86502.18458    -41130.64156  21819403.8834   21819401.6054        49.0004
27         39.2504
```

Figure 2. Example RINEX observation data block.

The observation block contains the actual data (Figure 2). Line descriptions corresponding to the example file are provided below (adapted from Janssen, 2024):

Line 19: Date and time of the observation epoch (receiver time of the received signals) in the format of two-digit year, month, day, hours, minutes, seconds (in this example, 25 March 2008 at 17:47:26 hours); epoch flag (0 = OK, 1 = power failure between current and previous epoch, 2+ = special event), the number of satellites in the current epoch (i.e., 4), followed by the system identifier (G = GPS) and the 2-digit satellite number
Lines 20–21: Observations recorded for the first satellite listed (i.e., G21). In this example, six types of observations were recorded (i.e., L1, L2, C1, P2, S1, and S2).
Lines 22–27: Observations recorded for other satellites in this epoch (i.e., G24, G25, and G08).

1.2.2.2 CSV

The CSV position files are intended for users who prefer pre-processed data (see Section 2.3.2). These files contain the following fields:

- `latitude_decimal_degree`: epoch latitude in (decimal degrees)
- `longitude_decimal_degree`: epoch longitude (decimal degrees)
- `antenna_hae_m`: epoch height above the ellipsoid (m)
- `decimal_hour`: fractional hour measurement to nearest hundred-thousandths in UTC
- `day_of_year`: day of year
- `year`: year
- `rcvr_clk_ns`: calculated/estimated time bias between the GPS receiver clock and the worldwide GPS clock (ns)
- `NSV`: number of satellites in view (quality metric)
- `GDOP`: geometric dilution of precision (quality metric)
- `SDLAT_95`: standard deviation (95%) of estimated latitude (precision metric)
- `SDLON_95`: standard deviation (95%) of estimated longitude (precision metric)
- `SDHGT_95`: standard deviation (95%) of estimated height (precision metric)

1.2.2.3 TXT

Track depth measurements are taken at the start and end points of the survey. These data are recorded in `IS2TGPSSS_TraverseMetadata_v01.txt` with the following fields:

- `Associated RINEX File`
- `Date`
- `Survey Start Time (UTC)`
- `Survey End Time (UTC)`
- `Start Track Depth (cm)`
- `End Track Depth (cm)`
- `ARP to Sled Base (m)`
- `Notes`

In the early years of the ground traverse, the track depth measurement and antenna height measurement protocols were not standardized, as noted in the text file.

1.2.3 Naming Convention

The RINEX 2.11 file naming convention is `XXXXDDDS.YYo`; for data distribution, three additional variables were added (Table 1):

`IS2TGPSSS_XXXXDDDS_nn.YYo.v01`

Examples:
`IS2TGPSSS_ICE12120_12.15o.v01`
`IS2TGPSSS_ICE13500.12o.v01`

Table 1. RINEX File Naming Convention

Variable	Description
`IS2TGPSSS`	ICESat/ICESat-2 Traverse: Monthly GPS Surface Elevation Data at Summit Station, Greenland data set
`XXXX`	Four-character site name (i.e., ICE1)
`DDD`	Day of year (i.e., 001 to 365, or 366 during a leap year)
`S`	Session identifier (i.e., 0 to 9, or A to X indicating the first observation epoch's hour of the day with A = 0 hours and X = 23 hours)
`nn`	One- or two-digit number of files for years with multiple files; this variable is not present when the year has a single file
`YY`	Two-digit year (i.e., 24 for the year 2024)
`o`	Observation file
`v01`	Data set version 1

The CSV files utilize a similar file naming convention:

```
IS2TGPSSS_XXXXDDDS_nn.YYYY_v01.csv
```

Examples:

```
IS2TGPSSS_ICE13260_2.2012_v01.csv
IS2TGPSSS_ICE13270.2007_v01.csv
```

Table 2. CSV File Naming Convention

Variable	Description
IS2TGPSSS	ICESat/ICESat-2 Traverse: Monthly GPS Surface Elevation Data at Summit Station, Greenland data set
XXXX	Four-character site name (i.e., ICE1)
DDD	Day of year (i.e., 001 to 365, or 366 during a leap year)
S	Session identifier (i.e., 0 to 9, or A to X indicating the first observation epoch's hour of the day with A = 0 hours and X = 23 hours)
nn	One- or two-digit number of files for years with multiple files; this variable is not present when the year has a single file
YYYY	Four-digit year
v01	Data set version 1

1.3 Spatial Information

1.3.1 Coverage

15 km survey transect to the west of Summit Station, Greenland

Northernmost latitude: 72.648222º N
Southernmost latitude: 72.578616º N
Easternmost longitude: 38.474193º W
Westernmost longitude: 38.585667º W

1.3.2 Resolution

N/A

1.3.3 Geolocation

1.3.3.1 RINEX

N/A

1.3.3.2 CSV

Latitude, longitude, and antenna ellipsoidal heights are output in the ITRF reference frame in the epoch of the data, relative to the GRS80 ellipsoid (EPSG 7019).

1.4 Temporal Information

1.4.1 Coverage

24 August 2006 to 2 April 2025

1.4.2 Resolution

Monthly

Every three months, the survey is conducted twice that month to include ICESat-2 RGT 879 and RGT 749.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

This data represents one of the longest records of consistent surface elevation measurements made in the dry snow zone in Greenland. The roving surface elevation and position data have been used to study ice dynamics (e.g., Hawley et al., 2020), validate and assess campaign biases of ICESat (Siegfried et al., 2011), and assess Operation IceBridge altimetry data in preparation for ICESat-2 (Brunt et al., 2017).

2.2 Acquisition

The survey is conducted from a sled towed behind a snowmobile (Figure 3). A Trimble R7 is configured with a Trimble Zephyr Geodetic Antenna mounted atop the sled at a height of 1.797 m above the sled bottom. During the start and end of the survey, the sled sinkage into the snow is measured; these values may be averaged together to correct for the sled sinkage component of the elevation estimate. Surface elevation can be calculated as:

$$\texttt{surface elevation} = \texttt{antenna\_hae\_m} - 1.797\ \texttt{m} + \texttt{Ztrack} \quad \text{(Eq. 1)}$$

where `antenna_hae_m` is the antenna ellipsoidal height and `Ztrack` is the track depth.

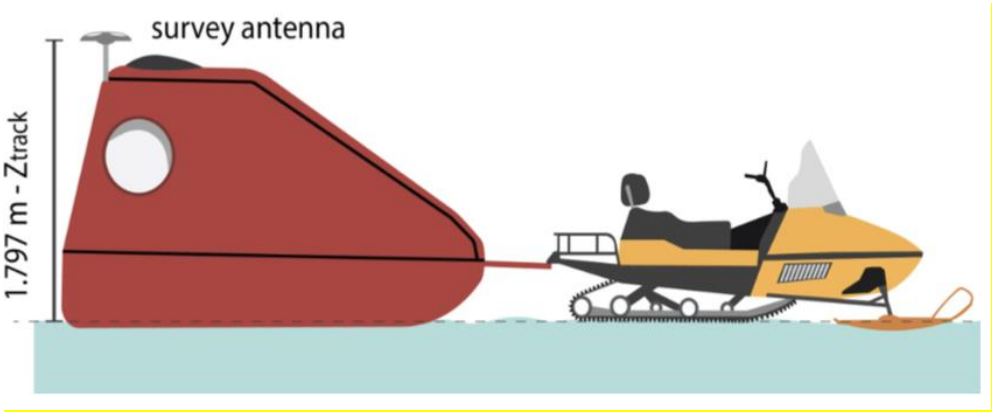

Figure 3. Survey vehicle setup

During the survey (between the start and end markers), the route is driven at approximately 5 m/s, with occasional stops to measure bamboo stakes and take breaks (Figure 4). In 2016, the original traverse route was augmented with an extension at the northern terminus to better capture the ICESat-2 orbital pattern and increase the sampling coverage.

The timing of the survey is intended to coincide with the overflight of the ICESat-2 (and previously ICESat) missions. During inclement weather, the survey can take place several days before or after the actual overflight. Given the 91-day repeat cycle of these missions, the survey also occurs each month without overflights to maintain a monthly record. After the launch of ICESat-2, the survey frequency increased to accommodate a second overflight path, defined by RGT 879, which is a descending orbit. Thus, every three months, the survey is conducted twice that month to include RGT 879 and RGT 749. Due to the spacing of the ICESat-2 six-beam configuration, only the inner two beams (2L and 2R) intersect with the route (Figure 4).

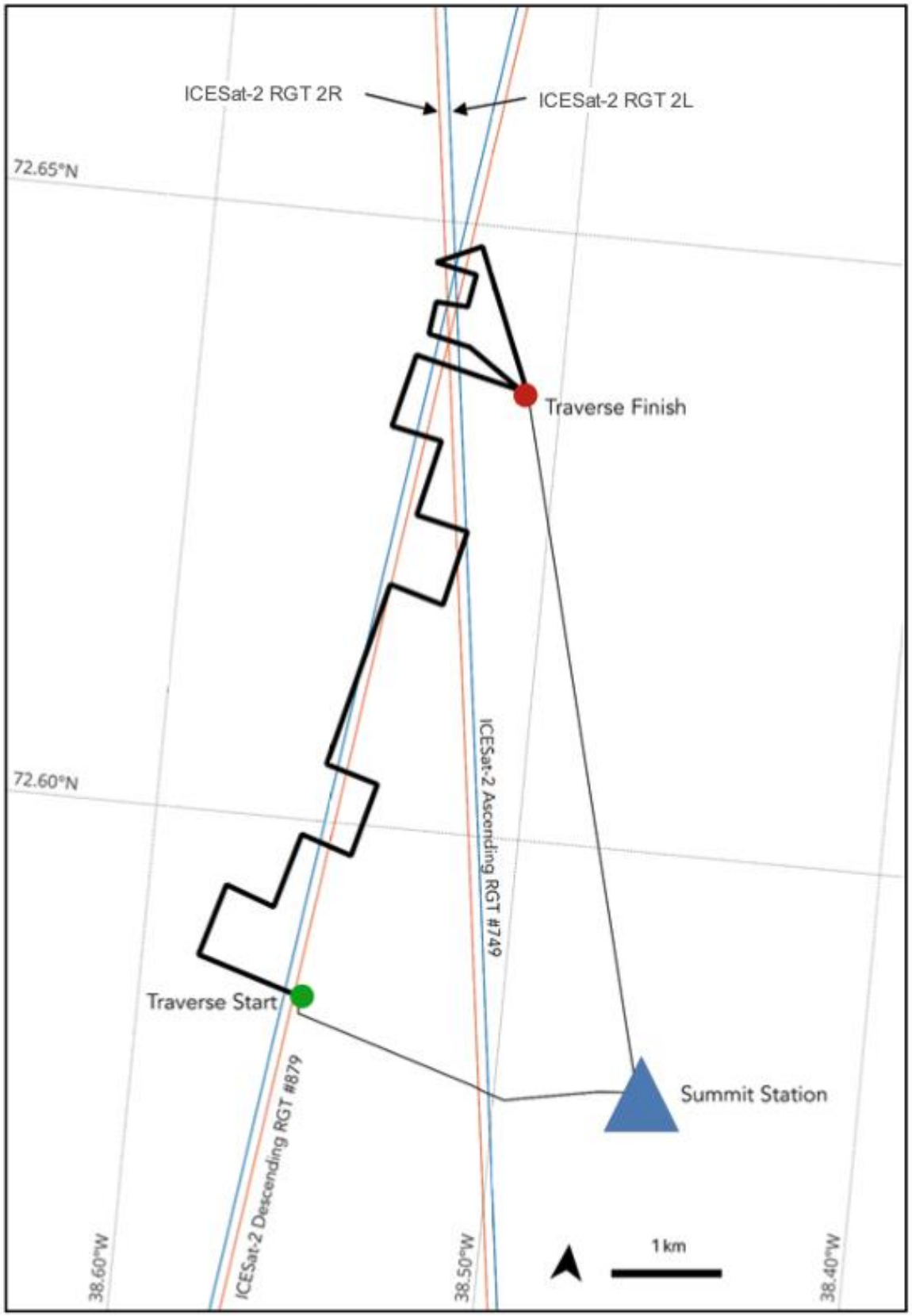

Figure 4. Map of ground traverse route and two ICESat-2 RGTs.

2.3 Processing

2.3.1 RINEX

The proprietary Trimble files (`.T01`) were converted to `.dat` format using Trimble Business Center; then, the `.dat` files were converted to RINEX using Earthscope's TEQC software package. The main file includes GPS L1 and L2 pseudoranges, carrier phases, and signal strength (carrier-to-noise density ratio), which are the standard observations needed to process the RINEX file into a position file with the user's platform of choice. The Trimble R7 is configured with a 1 Hz measurement rate, a 10-degree elevation mask, and a 20 Position Dilution of Precision (PDOP) mask.

Prior to June 2010, the receiver logged data at a 2-second measurement rate.

2.3.2 CSV

The CSV files are processed using precise point positioning (PPP) via the Natural Resources Canada tool CSRS-PPP. All standard processing parameters are used, including a 7.5-degree elevation mask, kinematic processing, ocean tidal loading (OTL) corrections, precise final satellite ephemeris, fixed ambiguities, and antenna phase center corrections.

No corrections are applied to the ellipsoidal height to account for the antenna height above the snow surface.

3 VERSION HISTORY

Table 3. Version History Summary

Version	Date	Description of Changes
1.0	19 Feb 2026	Initial release

4 REFERENCES

Brunt, K. M., Hawley, R. L., Lutz, E. R., Studinger, M., Sonntag, J. G., Hofton, M. A., Andrews, L. C., & Neumann, T. A. (2017). Assessment of NASA airborne laser altimetry data using ground-based GPS data near Summit Station, Greenland. *The Cryosphere*, **11**, 681–692. https://doi.org/10.5194/tc-11-681-2017

Hawley, R. L., Neumann, T. A., Stevens, C. M., Brunt, K. M., & Sutterly, T. C. (2020). Greenland Ice Sheet elevation change: Direct observation of process and attribution at Summit. *Geophysical Research Letters*, **47**, e2020GL088864. https://doi.org/10.1029/2020GL088864

Janssen, V. (2024). Understanding the RINEX Format. Proceedings of the 27th Association of Public Authority Surveyors Conference (APAS2024) Canberra, Australian Capital Territory, Australia, 18-20 March 2024.

Siegfried, M. R., Hawley, R. L., & Burkhart, J. F. (2011). High-resolution ground-based GPS measurements show intercampaign bias in ICESateElevation data near Summit, Greenland. *IEEE Transactions on Geoscience and Remote Sensing*, **49**(9), 3393–3400. https://doi.org/10.1109/TGRS.2011.2127483

UNAVCO Community (2017). Greenland GNSS Network - SMM3-SummitCampGNSS__GAGE Facility operated by EarthScope Consortium [Data set]. https://doi.org/10.7283/T5FX7878

5 DOCUMENT INFORMATION

5.1 Publication Date

February 2026

5.2 Date Last Updated

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