SnowEx 2021 SWE Report

Little Cottonwood Canyon Site, CO

Survey Date: March 18, 2021

Airborne Snow Observatories, Inc. is a public benefit corporation with a mission to provide high-quality, timely, and accurate snow measurement, modeling, and runoff forecasts to empower the world's water managers to make the best possible use of our planet's precious water.

Historical data and reports can be found at:
data.airbornesnowobservatories.com

Survey Date: March 18, 2021
Report Delivery Date: November 10, 2023

Full site SWE: 20.7 ± 0.6 TAF

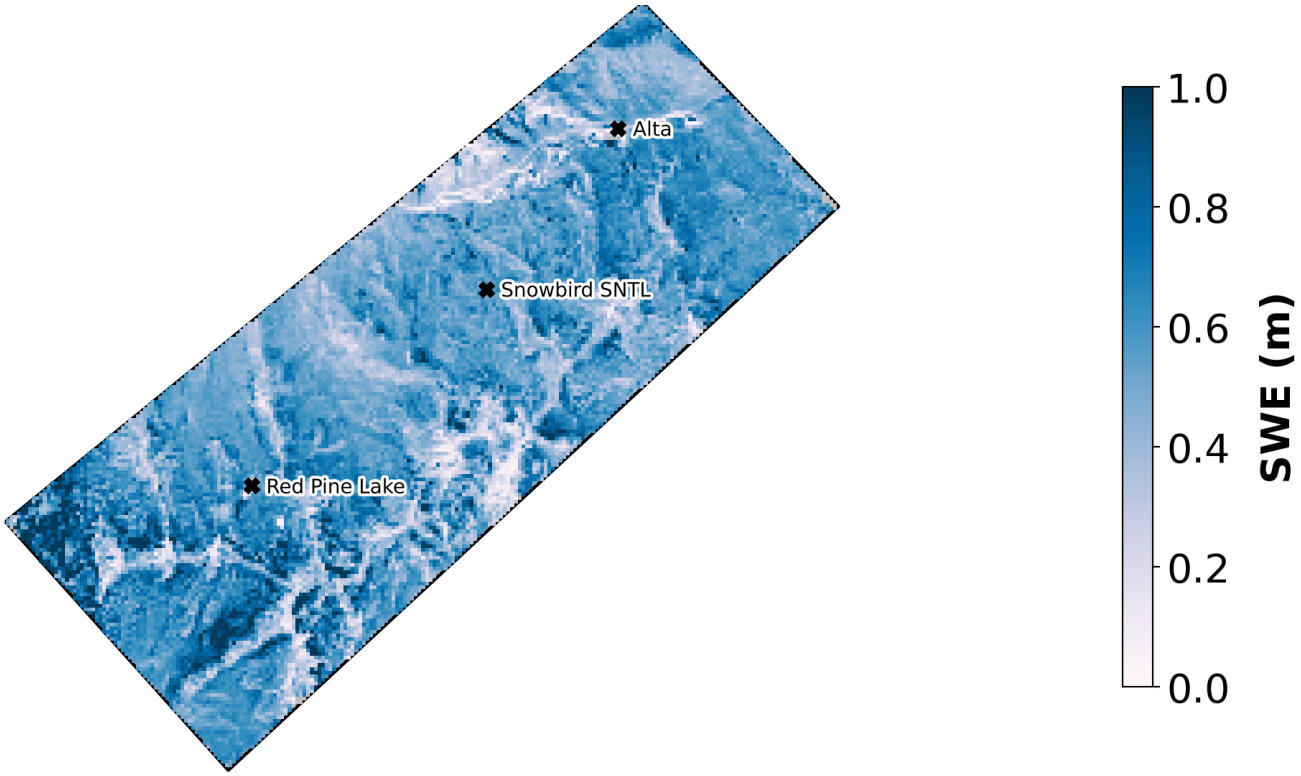


Figure 1. Spatial distribution of SWE depth (m).

Table 1. Estimated SWE volume (TAF) for the Little Cottonwood Canyon site.

Site	Estimated SWE (TAF) March 18
Full Site	20.7
Uncertainty range	*20.1 - 21.3*

2.

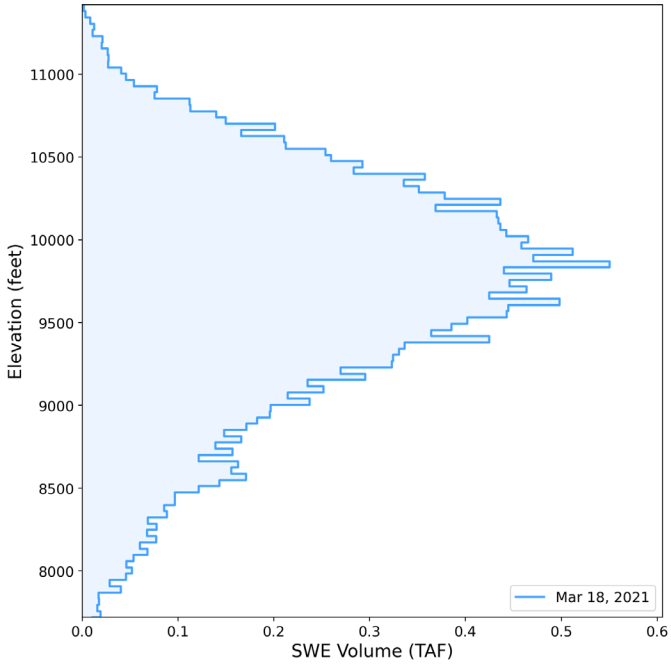


Figure 2. Distribution of SWE volume (TAF) across elevations for the March 18 survey. See Figure 7 for more descriptive plots.

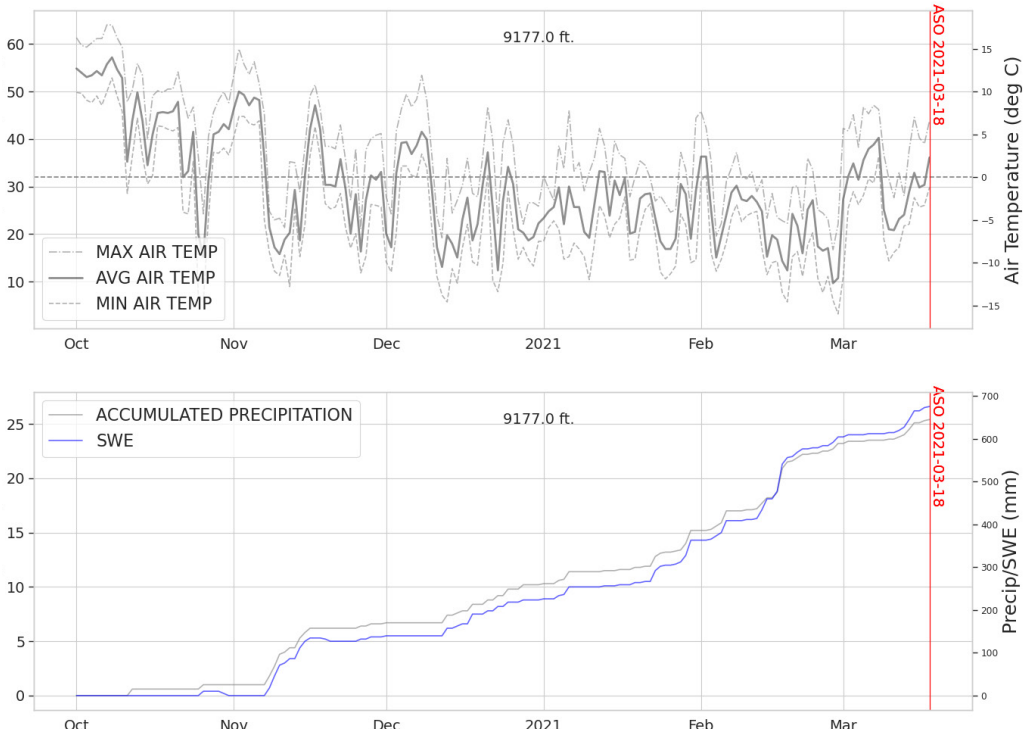


Figure 3. Daily meteorological conditions at Snowbird (SNTL 766) (elevation 9177 ft). Note: the raw daily data shown has been downloaded directly from NRCS and has not been quality checked. There may be noise or incorrect data present. Precipitation data will only be shown if the featured station records it, and the air temperature plot shows daily max, mean, and min values. ASO surveys are marked with red vertical lines.

Summary of background conditions

- The 2021 snow season in the Little Cottonwood Canyon site began slightly late compared to the median SWE series, with sparse snowfall events commencing in early to mid-November 2020.
- A series of storms between November 7th and 16th boosted the snowpack slightly above the 30-year median, though it was followed by a dry spell spanning from mid-November to mid-December. The new year brought regular snowfall events until the SnowEx flight was conducted on March 18th, 2021.

Evaluation of ASO snow depth measurements

Point-to-point comparison of in-situ snow depth with ASO 3 m resolution snow depth* is shown in **Table 2**. These depth comparisons are at stations for which we are very confident in 1) the location, and 2) the depth data that is being reported at the time of the ASO survey. Because we are directly comparing a point to a 3 m pixel in our data, we need to be certain that the station location is accurate to within 1.5 m. For reference, GPS data is usually only accurate to within 5 m, but we are often able to hone in on locations using Google Earth and other means, thereby enabling these comparisons. For these reasons, specific sites might not be included in the comparison. Please contact the ASO team to converge on accurate and precise coordinates and/or investigate data quality issues for any sites of interest.

At this known and trusted station location in Little Cottonwood, the snow depth difference was 5 cm; however, only one location was available for comparison. SnowEx in-situ measurements in Little Cottonwood were conducted on March 18th, 2021 on the day of the airborne survey. The standard deviation of biases determined in the relative registration step indicates a snow depth uncertainty of 1.4 cm.

Table 2. Comparison of ASO and snow pillow snow depths. Note: ASO long-term depth uncertainty is ± 5 cm.

Site ID	Elevation (ft)	Date	Site Depth (cm)	ASO Depth (cm)	Depth Difference (cm)
Snowbird SNOTEL	2777	2021-03-18	183	188	5

*Note: Snow-free, planar surfaces, common between the snow-on and snow-off datasets, are used to co- register the elevation datasets throughout the site. This relative registration process ensures that in areas without snow, we measure a snow depth of 0, and enforces snow depth accuracy throughout the site. At 3 m resolution, the standard deviation of snow depth distribution was 0.006 m, unbiased. At 50 m resolution, the snow depth uncertainty based on a rigorous bare surface evaluation is less than 1 cm.

The airborne lidar data for this survey were collected by a third-party contractor using parameters different from conventional ASO surveys. During the time of survey, March 18th, 2021, the target area at Little Cottonwood was almost completely snow covered with limited bare surfaces to use for the standard ASO relative registration procedure, which is designed to ensure homogenous snow depth accuracies throughout the domain. The relatively narrow road following Little Cottonwood Canyon along the NW corner of the site and servicing the base areas of Alta and Snowbird ski areas was the only target available for the relative registration of snow-off and snow-on elevation data sets, and as such we do not have relative registration control across the full target area. Though geographically constrained spatial distribution of registration control may be typical for more conventional topographic lidar surveys, for snow depth mapping it makes reliable assessment of the snow depth accuracy more difficult. We expect that this may introduce uncertainties into the snow depth values on the order of several cm.

The SnowEx field campaigns collected snow pit profiles of depth, density, and SWE within each field site. The field measurements were not specifically designed for assessment of lidar snow depth retrievals. Several sources of uncertainty make these pit data unsuitable for lidar snow depth comparison while remaining valuable for the site-wide snow density estimation. Pits were sampled in the days before and/or after the flight acquisition, which due to ongoing compaction will result in different depths from that at the time of the flight. Georegistration of the snow pits is uncertain (especially in forested areas), often placing the measurement location in the wrong 3m pixel. The precise location within the pit of the depth measurement is unknown, as is the contribution of fine-scale surface undulations to the ruler placement and depth measurement. Disturbance of the snow from pit digging and refilling can also contribute to (sometimes large) differences in depth from the airborne measurement where the pit measurements were conducted prior to the lidar flight. As such, we direct data users to the post-registration histogram of residual biases at bare targets to indicate the uncertainty in snow depth throughout the domain, and to the SNOTEL depth comparisons as a secondary confirmation of the snow depth accuracies.

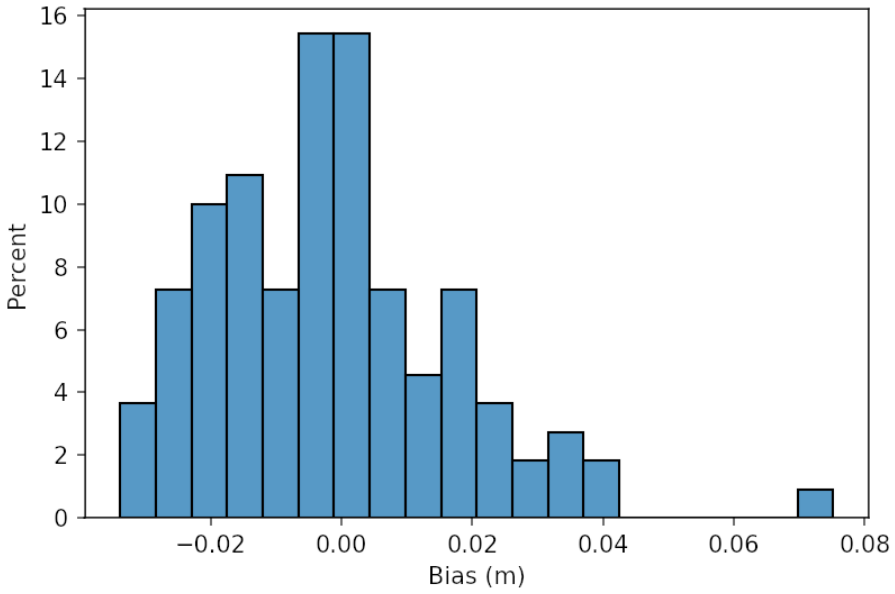


Figure 4. Histogram of residual biases after relative registration of the snow-off and snow-free elevation data sets. The median bias is 0.0 m and the standard deviation is 0.014 m.

In-situ measurements

Field collections

- ASO field team did not conduct field work coincident with this survey.
- SnowEx field teams conducted fieldwork on March 18th coincident with the airborne survey.
- The mean snow density from a 2.66 m snow pit at 10200 ft elevation near the Alta Collins weather station was 337 kg/m³.
- The mean snow density from a 1.87 m snow pit at 8700 ft elevation near Atwater SNOTEL was 396 kg/m³.
- Coincidental snow pits were excavated by SnowEx field teams at Alta Collins and Atwater locations. Given the much lower depths in the ASO data at these locations (up to 1.5 m lower than reported at the pit location), we suspect that the snow pits were excavated or partially excavated before the plane flew over these locations. As such, we have omitted these snow depth comparisons from Table 2.

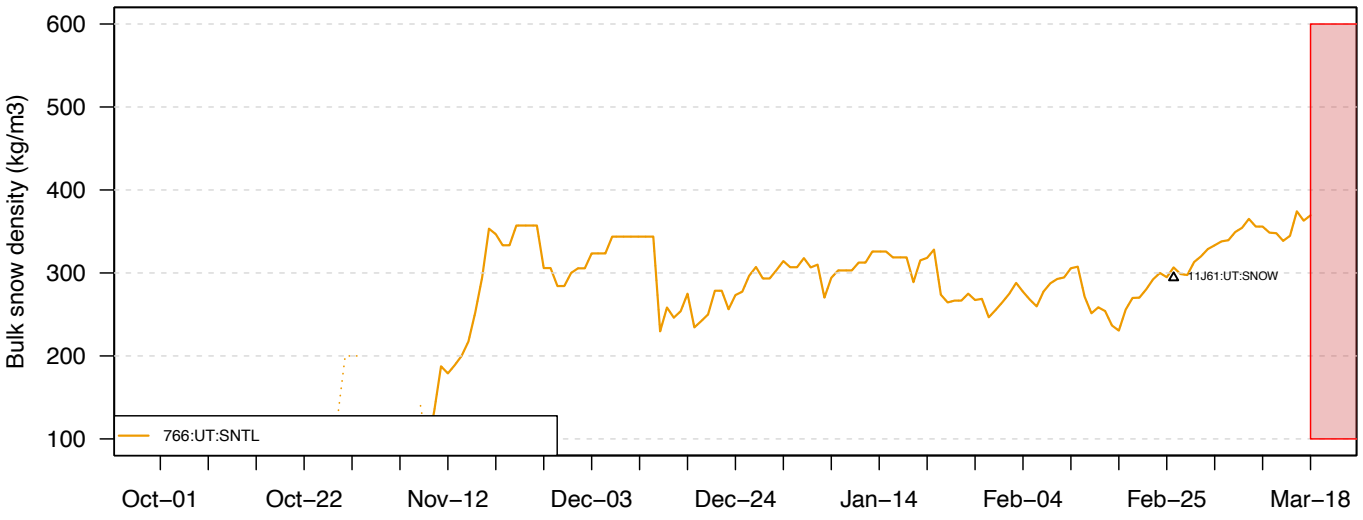


Figure 5. Daily snow density timeseries at Snowbird SNOTEL. Red represents the airborne survey date. (Data source: NRCS).

Sensor measurements

- The snow density reported from the Snowbird SNOTEL site on March 18th was 369 kg/m³.

Snow course measurements

- The March snow course measurements were not available for this airborne survey at the time of processing.

Density evaluation

- The in-situ measurements span a range of values between 337 - 396 kg/m³, and suggest a spatially varying density map where density is inversely correlated with elevation. The in-situ measurements were sampled coincidently with the airborne survey and are weighted heavily in our evaluation. There is some remaining uncertainty in snow density for elevations below 8500 ft and snow depths less than 1.5 m.
- To address this uncertainty in bulk snow density, we have generated two snow density scenarios. In Scenario H, we increased the density map globally by 3% - towards a value of 337 kg/m³. In Scenario L, we decreased the density map globally by 3% - towards a value of 314 kg/m³.

- The resulting full site SWE outcomes for these scenarios were 21.3 TAF and 21.3 TAF respectively, and suggest that the site SWE is sensitive to uncertainty in the snow density in the order of 3% of the total site SWE (as dictated by the scenarios). These scenarios span beyond the full range of the in-situ measurements and should be interpreted as guidance on sensitivity to snow density rather than equally probable SWE outcomes. We have factored uncertainty based on these outcomes into the values reported on the front page of this report.

Table 3. Snow density scenarios and SWE volume estimates. The ASO density is used in calculating the reported SWE. The other density scenarios are computed to evaluate the density sensitivity and to help determine the uncertainty in the reported SWE values.

Scenario	Spatial-mean density (kg/m³)	SWE (TAF)	Description
ASO	327	20.7	ASO depths
Scenario L	317	20.1	Decreased density map globally by 3% + ASO depths
Scenario H	337	21.3	Increased density map globally by 3% + ASO depths

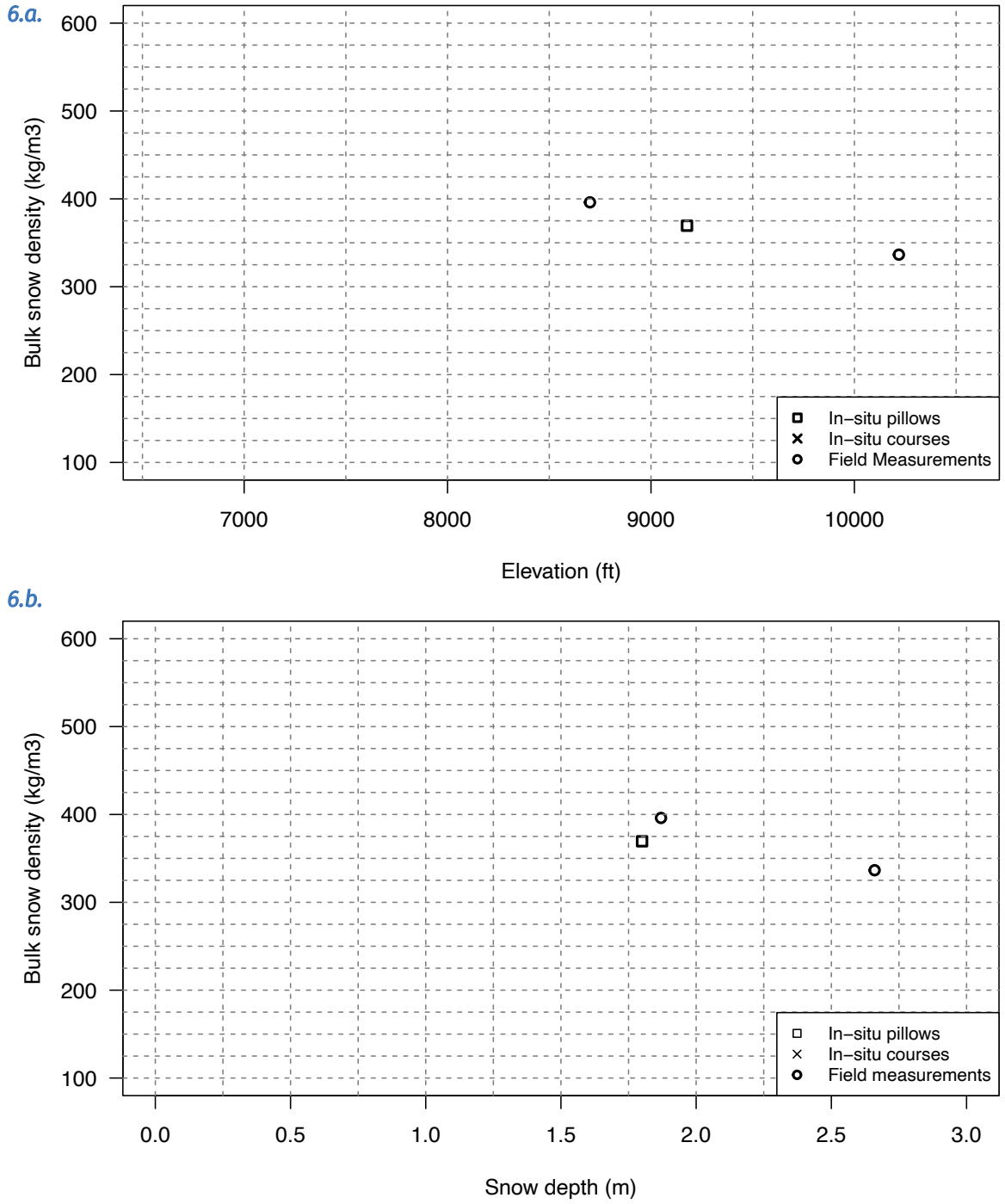
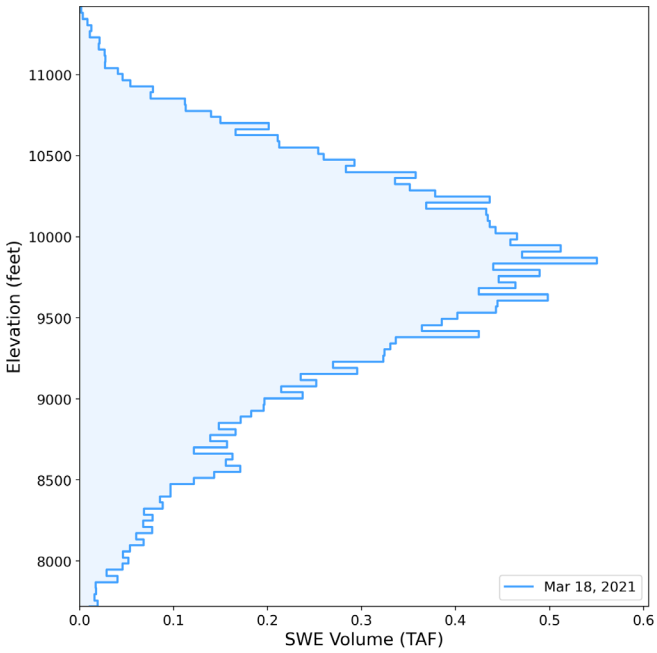


Figure 6. Observed bulk snow density (kg/m³) by a. elevation (ft) and b. snow depth (m). The horizontal axes on these plots span the elevation and snow depth ranges across the full Little Cottonwood Canyon target area.

Additional data / remarks

- Please refer to the text files included in the data package for SWE volume per elevation band and other summary statistics.

7.a.



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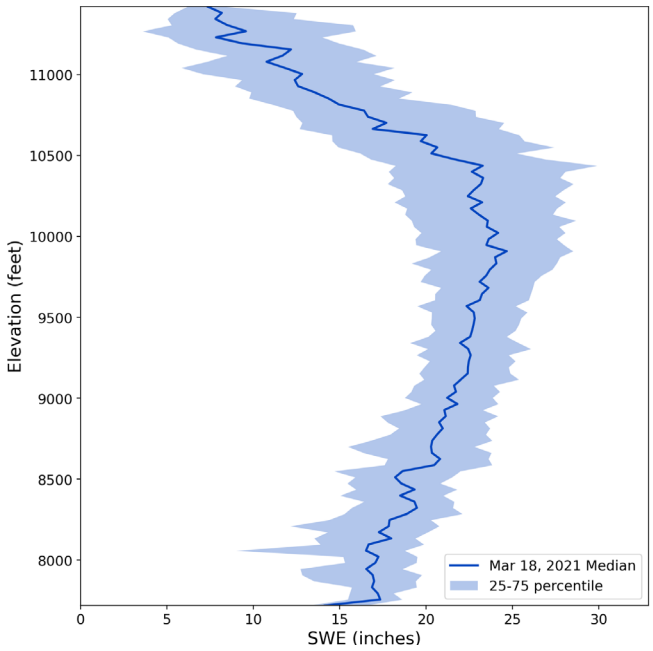

Figure 7. Difference plots of SWE volume (TAF) and depth (in) across elevations. 7.a. Distribution of SWE volume (TAF) across elevations. 7.b. Distribution of SWE depth (in) across elevations; solid lines represent median SWE depth (in), lighter color bands represent the 25th to 75th percentiles.