CLPX-Ground: Ground-Based Frequency Modulated Continuous Wave (FMCW) Radar, Version 1

USER GUIDE

How to Cite These Data

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

Marshall, H., G. Koh, and R. Forster. 2004. *CLPX-Ground: Ground-Based Frequency Modulated Continuous Wave (FMCW) Radar, Version 1* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/R3WIYZO7YU82. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0164

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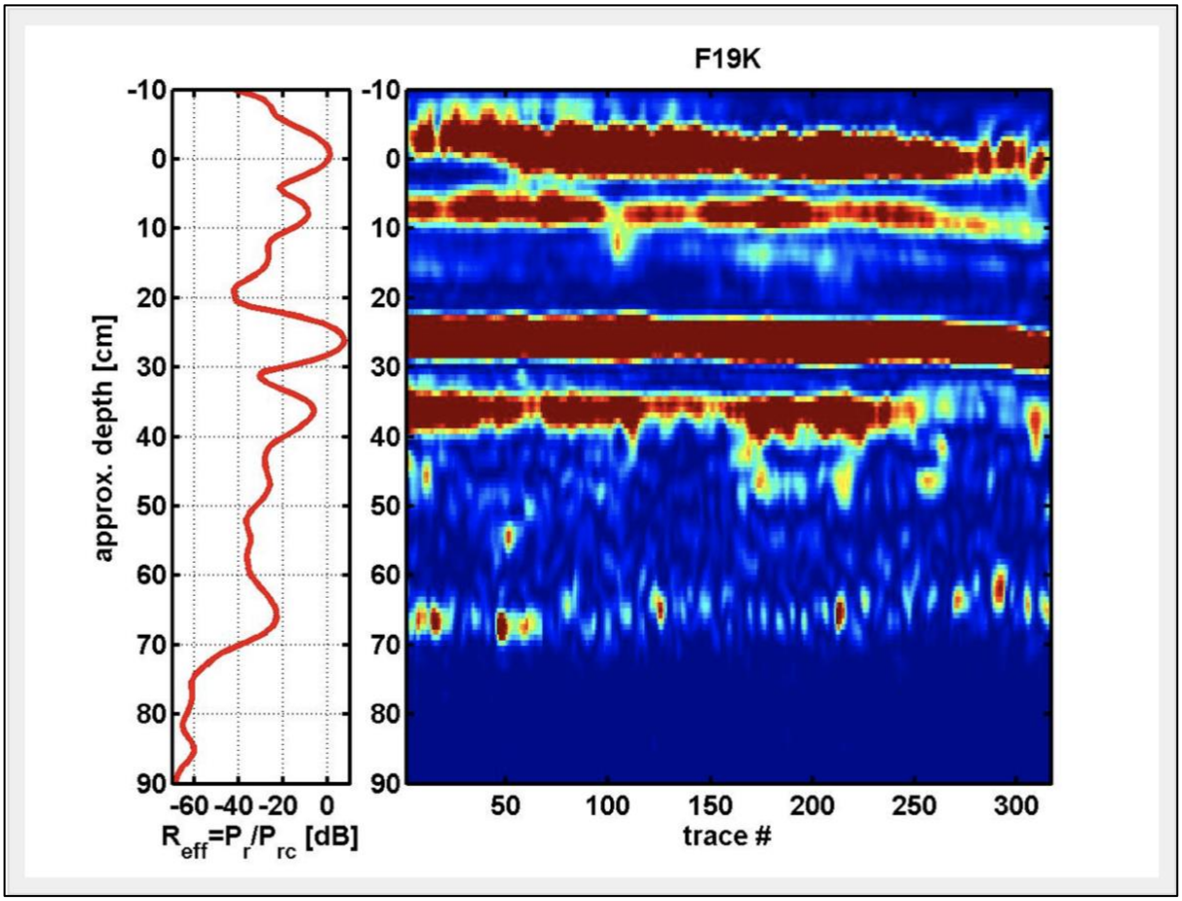
1 DATA DESCRIPTION

Nadir measurements were made at the CLPX Local Scale Observation Site (LSOS) in northern Colorado. This site is a 100 x 100 m study site within the Fraser Intensive Study Area (39.9066°N, 105.8829°W). The LSOS has flat topography with sections of uniform pine forest, sections of discontinuous pine forest, and a small clearing.

Radar data are provided as ASCII text files and JPEG images. Each measurement has three ASCII data files: one containing the approximate depth scale z, one containing the mean effective reflectivity Reff, and one containing the Power Spectral Density (PSD) data for the entire scan. The JPG files are visualizations of the ASCII data (example below), created with MATLAB scripts. The left-hand side of the image shows the effective reflectivity (Reff), plotted vs depth (z). The right-hand side is an image of the entire PSD scan, with red corresponding to large reflectivity, and blue corresponding to no reflection.



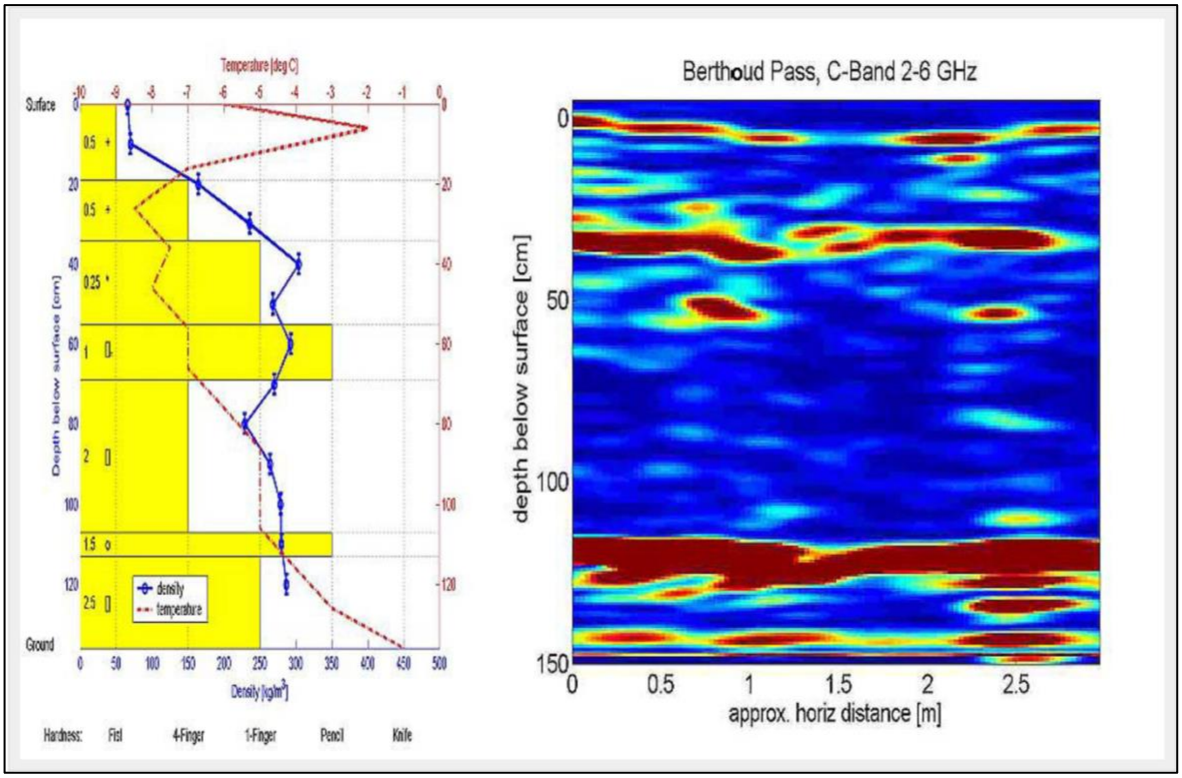
Note that no figures are provided for measurements at incidence angles greater than 15 degrees, as snow stratigraphy could not be seen because the signal was dominated by volume scattering and ground reflection.

1.1 Parameters

This data set presents frequency modulated continuous wave radar profiles (frequency differences represent various discontinuities in the snowpack). Parameters include depth (in cm), effective reflectivity (Reff, in dB), and power spectral density (PSD) for the radar scans.

1.1.1 Sample Data

The following figure shows FMCW C-Band radar data for Berthoud Pass on 22 February 2003, and the corresponding snow density and temperature data from a nearby snow pit.



Snow pit graphs are provided in the Appendix for the LSOS; Michigan Ridge, North Park; Berthoud Pass, Fraser; and Buffalo Pass, Rabbit Ears during February and March 2003.

1.2 File Information

1.2.1 Format

Each measurement has three data files: one containing the approximate depth scale (Z, in cm); one containing the mean effective reflectivity,Reff, (relative to the surface or calibration target) in [dB]; and and one containing the power spectral density (PSD) data for the entire radar scan. The first two are column vectors, and the last file is a matrix – each column corresponds to an independent measurement along the scan (approx 3 m horizontal).

1.2.2 Directory Structure

The radar data are provided as three tarred and zipped files: IOP1.tgz, IOP2.tgz, and IOP3.tgz. When uncompressed, each IOP file yields a data/ and a figures/ directory for that IOP. The data/ directory contains ASCII text files of the data. Each measurement has three data files.

Snow pit data are provided as JPEG images in the top-level directory.

1.2.3 Naming Convention

1.2.3.1 IOP1 and IOP2 Data

IOP1 and IOP2 radar files are named mddf_type.txt, where

m = month (F for February, M for March)

dd = date (two-digit date of month)

f = frequency (c, k, or x)

type = depth scale (Z, in cm), effective reflectivity (Reff, in dB), or power spectral density for the entire scan (PSD)

E.g., F19c_z.txt is the depth scale file for C-Band measurements on 19 February 2002.

For the IOP1 measurements at different incidence angles, the "type" identifier is preceeded by ‘θ’, where θ is the angle of incidence. E.g., F20c_0_z.txt is the depth scale file for C-Band measurements on 20 February 2002 at an incidence angle of 0.

1.2.3.2 IOP3 Data

Radar data files and image files for each IOP3 (February 2003) measurement are named xxxxmmdd_f_type.txt, where

xxxx = a four- or two-digit abbreviation for location:

LSOS = LSOS, Fraser

NP = Michigan Ridge, North Park

BP = Berthoud Pass, Fraser

SB = Buffalo Pass, Rabbit Ears

mm = month (F for February, M for March)

dd = date (two-digit date of month)

f = frequency (c, x, or k)

type = depth scale (Z, in cm), effective reflectivity (Reff, in dB), or power spectral density for the entire scan (PSD)

E.g., bp0222_c_Z.TXT, bp0222_c_Reff.TXT, and bp0222_c_PSD.TXT are the depth, effective reflectivity, and power spectral density files, respectively, for the C-band measurements made at Berthoud Pass on 22 February 2003.

For the measurements made at the LSOS on 20 February 2003, an additional letter follows the frequency band indicator, corresponding to measurements made in the morning (A), at midday (B), or in the afternoon (C). E.g., lsos0220_cA_Z.TXT is the depth scale file for for C-band measurements taken at the LSOS during the morning of 20 February 2003.

The following image files are plots of snow pit parameters, including snow depth, temperature, hardness, density, grain size, and type.

bp0222pit.jpg (Berthoud Pass, Fraser, 22 February 2003)

lsos0220pit.jpg (LSOS, 20 February 2003)

lsos0325pit.jpg (LSOS 25 March 2003)

lsos0328pit.jpg (LSOS, 28 March 2003)

np0221pit.jpg (Michigan Ridge, North Park, 21 February 2003)

sb0223pit.jpg (Buffalo Pass, Rabbit Ears, 23 February 2003)

The density profile is in blue in each figure (axis at bottom), temperature is in red (top axis), and hand hardness is in yellow (scale in black below density scale). The grain size and type are given on the left-hand side of the figure, with the size in mm and the type:

+ = new snow

\ = fragments

- = ice lense

[] = facets

[]* = facets turning to rounds

* = rounds

o = melt-freeze

1.3 Spatial Information

1.3.1 Coverage

Measurements were taken at the following CLPX sites:

CLPX LSOS
Michigan Ridge, North Park MSA
Berthoud Pass, Fraser MSA
Buffalo Pass, Rabbit Ears MSA

Southernmost Latitude: 39.828

Northernmost Latitude: 40.6449

Westernmost Longitude: -106.6788

Easternmost Longitude: -105.7681

The location of measurements within the LSOS study area is shown in the photo below. Measurements were made at the edge of the main clearing, approximately 50 m from the U. Tokyo GBMR-7 radiometer.

Michigan Ridge, North Park MSA

This site was extremely wind affected, with some sections containing no snow at all, and some areas with as much as 40 cm of snow cover. Because of the amount of spatial variability, even in the ~ 3 meters scanned with the radar, the investigators chose to measure a section with the most amount of snow (40 cm).

Berthoud Pass, Fraser MSA

This site was located near a parking lot just short of the summit of Berthoud Pass. Although the new snow was not disturbed, it is possible that some of the deeper layers were affected by skiers.

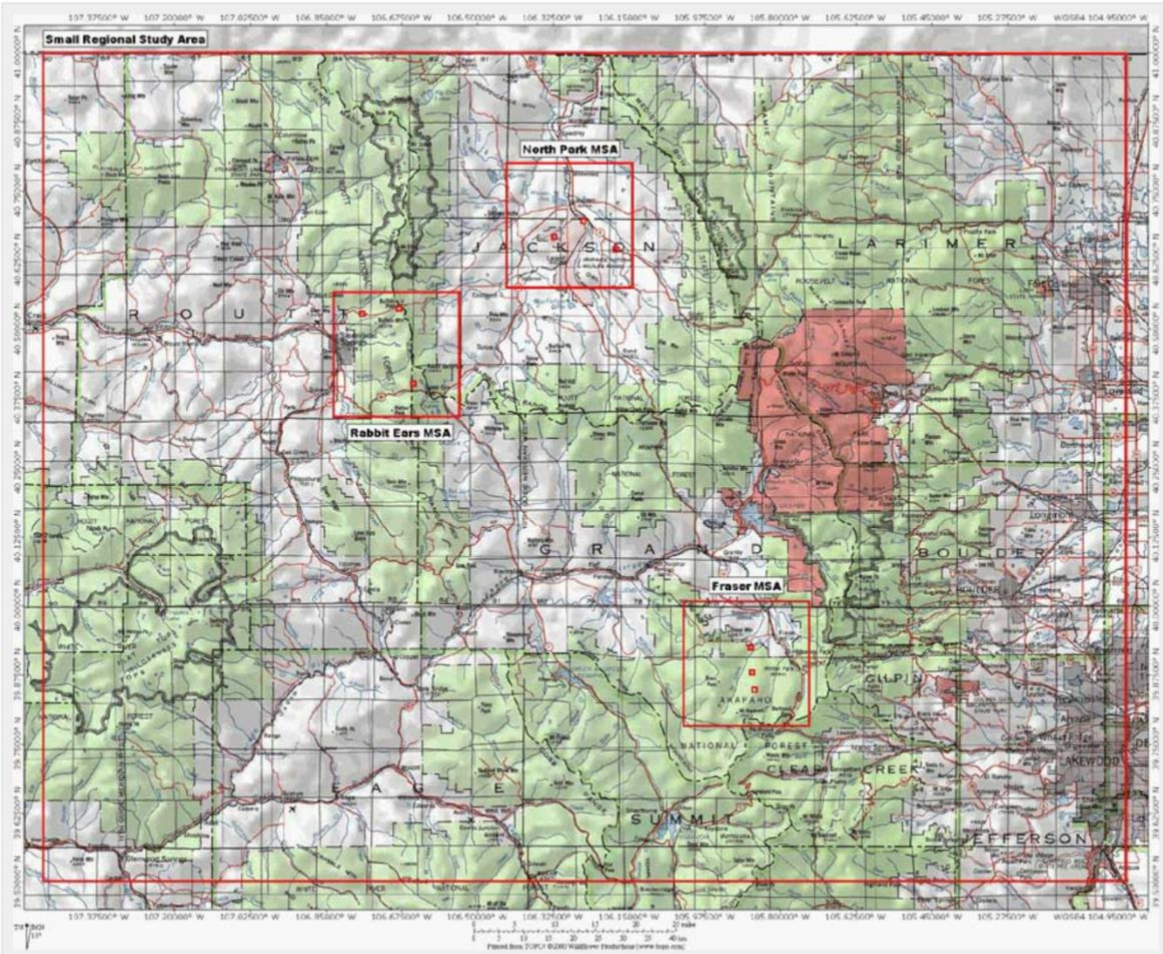
Buffalo Pass, Rabbit Ears MSA

There is a high degree of layering in all three images for Buffalo Pass. The snowpit measurements at this site showed a very homogeneous snowpack; this layering was not observed in the pit. Due to the lack of strong reflectors, the radar responded to very subtle changes not observable at the scale measured in a manual profile.

Spatial Coverage Map

The following map provides an overview of the LSOS, including the location of the FMCW radar. The snow pit locations shown on this map are those pits measured during the Snow Measurements at the LSOS.

The following is a map of the Small Regional Study Area, including the three Mesocell Study Areas (MSAs)



1.4 Temporal Information

1.4.1 Coverage

Nadir measurements were made at the LSOS at C-, X-, and Ku-Band frequencies on 19 and 21 February 2002 (IOP1), 24 and 26 March 2002 (IOP2), 19-20 February 2003 (IOP3), and 25, 28, and 29 March 2003 (IOP4). In addition, on 21 February 2002, measurements were made for each frequency range at incidence angles of 0, 15, 30, and 45 degrees.

On 19 - 23 February 2003 (IOP3), additional measurements were made at Michigan Ridge (21 February), Berthoud Pass (22 February), and Buffalo Pass (23 February).

2 DATA ACQUISITION AND PROCESSING

2.1 Acquisition

The FMCW radar was mounted at the end of a 2 m boom, attached to a motorized tripod, and scanned a 5 m section of an undisturbed snow pack. (During 2002, a survey tripod was used to manually scan the snow surface.) At the start of each radar scan, a metal calibration target was placed at the snow surface. This reference determined the reflectivity of the discontinuities in the snow pack. (Note that the measurements on 19-21 Feb 2003 were referenced to the power reflected from the snow surface, as the investigators did not have a calibration target available.)

In conjunction with the radar measurements, snow pit measurements were collected at a site near each radar location in order to correlate the radar profile with the local snow conditions. Due to local spatial variations in snowpack properties, the snowpit data in this data set are somewhat different from the comprehensive CLPX snowpit data in the ISA Snow Pit Measurements data set and the Snow Measurements at the LSOS data set. Radar correlation snow pit data are provided only in JPEG graphs of snow depth, temperature, hardness, density, grain size, and type.

2.1.1 IOP1 Data

Nadir measurements were made at C-Band (2-6 GHz), X-Band (8-12 GHz), and Ku-Band (14-18 GHz) frequencies at a single site in the LSOS, and additional measurements were made for each frequency range at incidence angles of 0, 15, 30, and 45 degrees.

Additional images in the IOP1 data directory provide a comparison of measurements at varying incidence angles at C-Band frequencies; these are the files sig_theta.jpg and sig_theta_dB.jpg in the "figures/" directory for IOP1 (with linear and dB scales, respectively). The file sig_theta 3.jpg shows peak values for the surface, ground, and an internal layer, as a function of incidence angle.

2.1.2 IOP2 Data

Nadir measurements were made at C-, X-, and Ku-Band frequencies at a single site in the LSOS.

2.1.3 IOP3 Data

Nadir measurements were made at C-, X-, and Ku-Band frequencies in the LSOS, and additional measurements were made in three different snowpacks within the Mesocell Study Areas (MSAs): Michigan Ridge in North Park MSA, Berthoud Pass in Fraser MSA, and Buffalo Pass in Rabbit Ears MSA. On 20 February 2003, three complete sets of measurements were taken at different times of the day in the LSOS, during varying snow conditions. In the morning, a melt-freeze crust was present (which had formed overnight), and there was some surface hoar deposited above this crust. The measurements made during the morning are labeled A in the filename. By mid-day, the air temperature had risen above freezing and the surface crust had melted; these mid-day measurements are labeled B. In the late afternoon, the upper surface had refrozen, producing a hard melt/freeze crust, approximately 0.5 mm thick. These late afternoon measurements are labeled C.

During IOP3, due to a tripod/boom problem discussed in the Quality Assessment section, the effective reflectivity was calculated for a representative section, not an average for the entire scan. In the JPEG files in the "figures/" directory for IOP3, this calculation is shown between the thick vertical yellow lines.

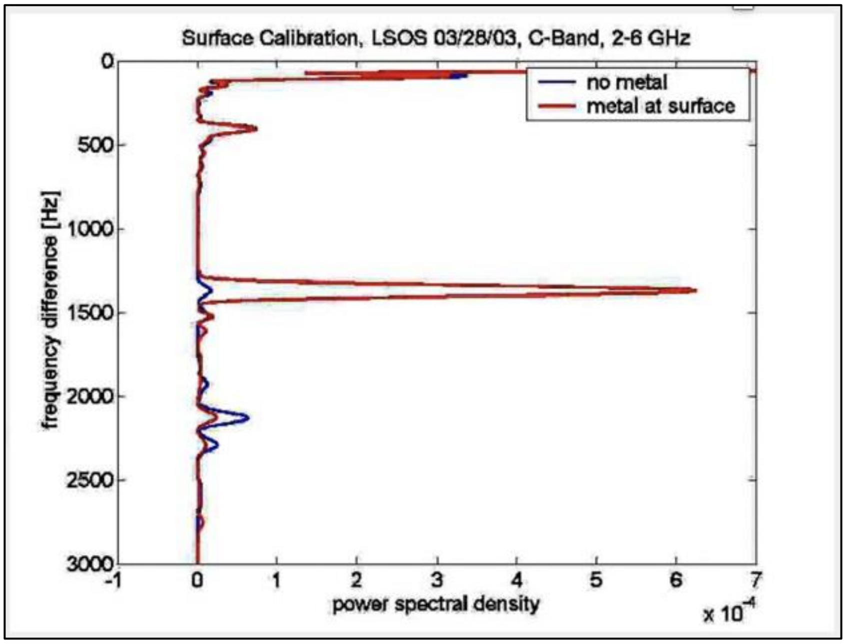
Nadir measurements were made at C-Band (2-6 GHz), X-Band (8-12 GHz), and Ku-Band (14-18 GHz) frequencies. Additional measurements were made for each frequency range at incidence angles of 0, 15, 30, and 45 degrees during IOP1 only. These measurements each spanned a period of one hour. All measurements were made with an output power of 320 mW and with a sweep time of 64 ms.

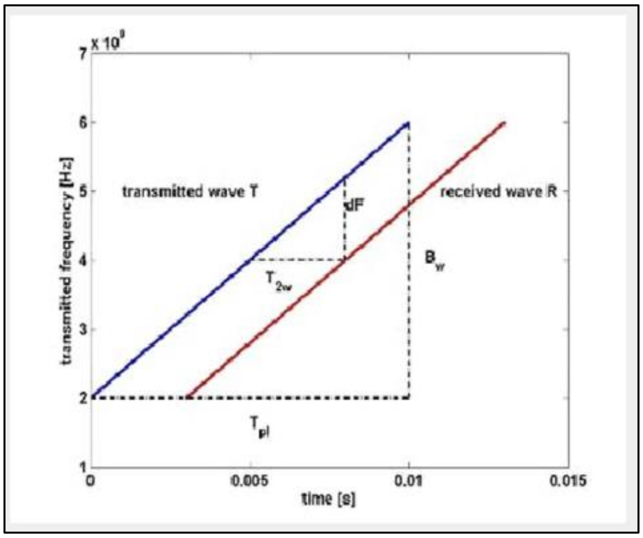
Freq Range	**Gain of Antenna**
2-6 GHz (C-Band)	12 dB
8-12 GHz (X-Band)	20 dB
14-18 GHz (Ku-Band)	23 dB

Note that, for the Ku-Band measurements at the LSOS on 20 February 2003, measurements were taken in the morning, at midday, and in the afternoon to assess the effects of melt and refreeze.

The principles of FMCW radar measurement are illustrated by the following:

1. Linear frequency chirp transmitted (T)
2. Received signal (R) “mixed” with transmitted wave before signal acquisition
3. Recorded signal contains the sum and difference frequencies from T + R
4. Frequency differences from reflectors linearly related to the distance to target.
5. The resulting power recorded at a given frequency difference is proportional to the magnitude of the electromagnetic discontinuity at that corresponding distance.





$$T_{2w} = dF\,\frac{T_{pl}}{B_w} = \frac{2d}{v_s} = \frac{2d\sqrt{\varepsilon}}{c}$$

2.2 Processing

A zero-padded, windowed Fast Fourier Transform (FFT) was then applied to the time domain data. The resulting Power Spectral Density (PSD) data was normalized using measurements from a calibration target, which also helped to locate the snow surface. An algorithm was developed which removes unwanted instrumentation-related signals, without affecting reflections caused by the snowpack.

Windowed FFT, zero-padded, normalized by DC-coupling, power from surface calibration

The entire scan from each measurement is given as a PSD matrix, with size [1024, N], where N is the number of traces in the scan. Next, from the scan the mean trace is computed and used to calculate the reflected power Pr(ω):

$$P_r(\omega) = \int_{\omega-\delta\omega}^{\omega+\delta\omega} \overline{PSD(\omega)}d\omega$$

where the window of integration (2δω) was determined from the -3 dB points of the reflection from the calibration target. Density measurements from a nearby snowpit were used to estimate the wave velocity, so that the frequency scale could be converted to an approximate depth scale. For each scan, a depth scale is given as a column vector, size [1024,1]. Finally, the effective reflectivity Reff was calculated as:

$$R_{eff}(z) = \frac{P_r(z)}{P_{rc}}$$

where Prc is the reflected power from the calibration target (or snow surface). The resulting effective reflectivity Reff, as a function of depth z is given as a column vector, size [1024,1].

Experiments were made with metal reflectors placed at different snowpack depths (see Marshall , H.P., G. Koh, and R. Forster, in press. Estimating Alpine Snowpack Properties Using FMCW Radar. Annals of Glaciology, vol. 40).

3 SOFTWARE AND TOOLS

The measurements on 19-21 February 2003 were not referenced to the reflected power from a surface calibration target, as the investigators did not have a calibration target available. These measurements are referenced to the reflection from the snow surface.

The large motorized tripod used during 2002 was not used during the 2003 measurements. A survey tripod was used instead, with a boom built by the investigators. This boom, which was not as stable as that used with the motorized tripod, was moved manually over the snow surface, so it was not possible to keep it perfectly level and at a constant height over the snow surface, although every effort was made to do so. This should be noted when comparing data from 2002 and 2003, as the layer depths appear much more consistent in 2002.

4 RELATED DATA SETS

AMSR-E/AQUA Data at NSIDC

5 CONTACTS AND ACKNOWLEDGMENTS

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6 REFERENCES

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Marshall , H.P., G. Koh, and R. Forster. In press. Estimating alpine snowpack properties using FMCW radar. *Annals of Glaciology* 40.

Marshall , H.P., G. Koh, and R. Forster. 2004. Ground-based frequency-modulated continuous wave radar measurements in wet and dry snowpacks. Colorado , USA: An Analysis and Summary of the 2002-03 NASA CLPX Data," *Hydrological Processes* 18(18): 3609-3622.

7 DOCUMENT INFORMATION

7.1 Publication Date

6 October 2003

7.2 Date Last Updated

25 March 2021

APPENDIX – SNOW PIT GRAPHS

The following figures are plots of snow pit parameters, including snow depth, temperature, hardness, density, grain size, and type.

The density profile is in blue in each figure (axis at bottom), temperature is in red (top axis), and hand hardness is in yellow (scale in black below density scale). The grain size and type are given on the left-hand side of the figure, with the size in mm and the type:

+ = new snow
\ = fragments
- = ice lense
[] = facets
[]* = facets turning to rounds
* = rounds
o = melt-freeze

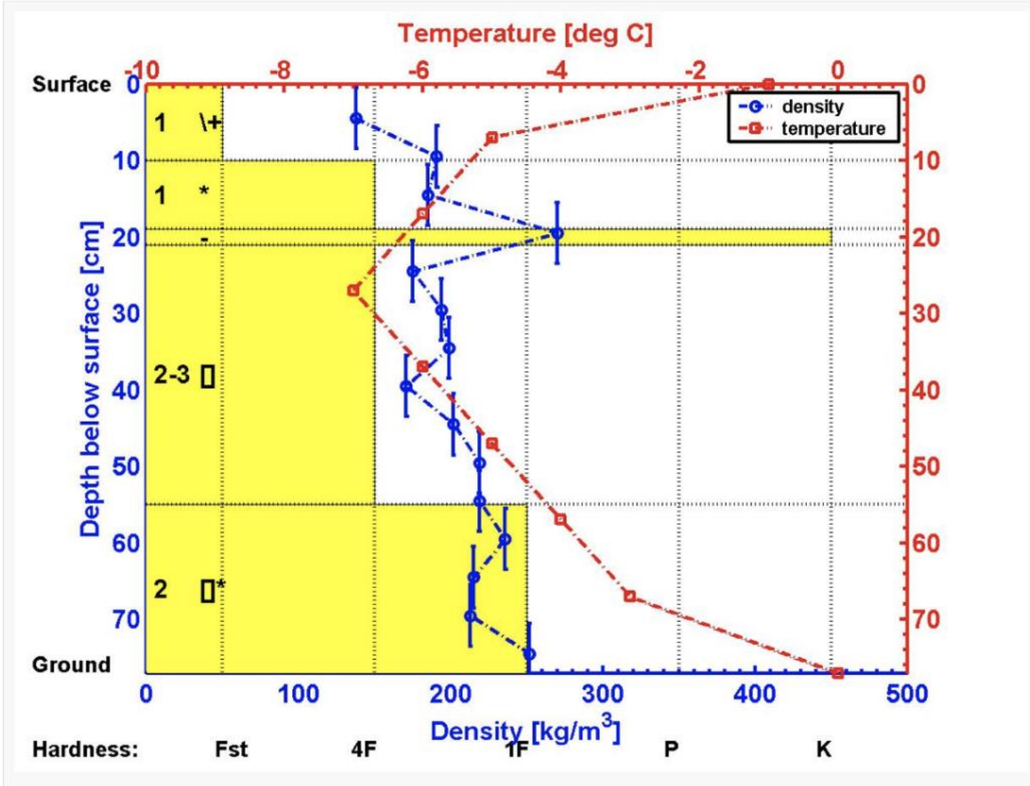

Figure A-1 Snow pit data from the LSOS on 20 February 2003.

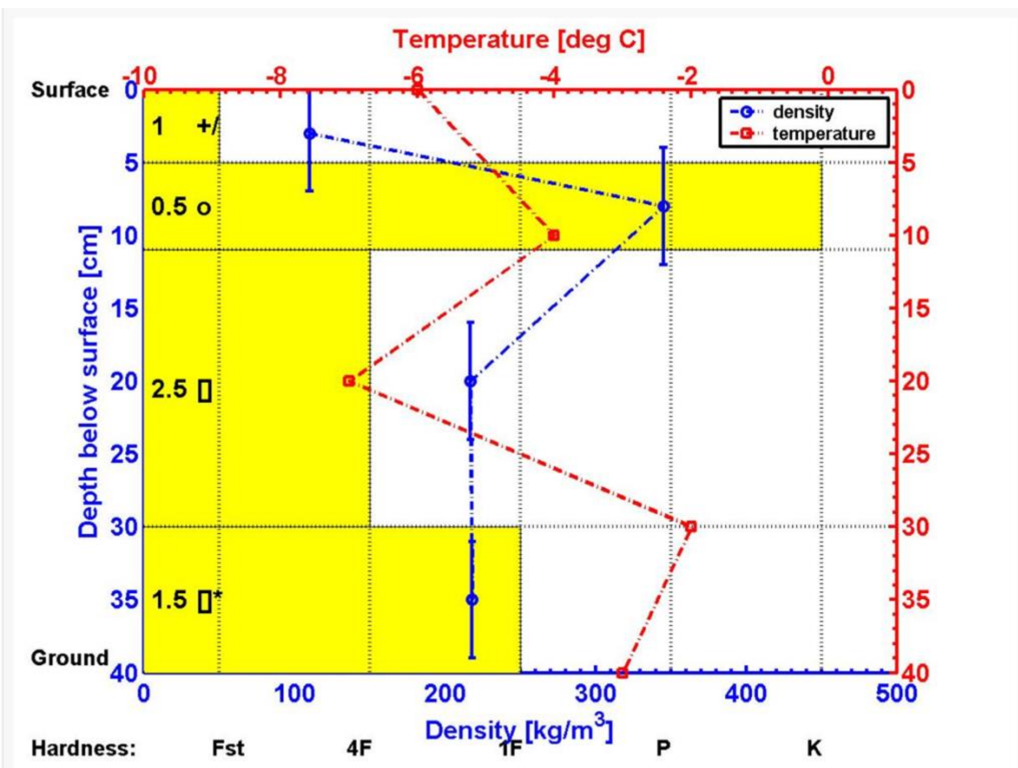

Figure A-2 Snow pit data from MIchigan Ridge, North Park MSA, on 21 February 2003.

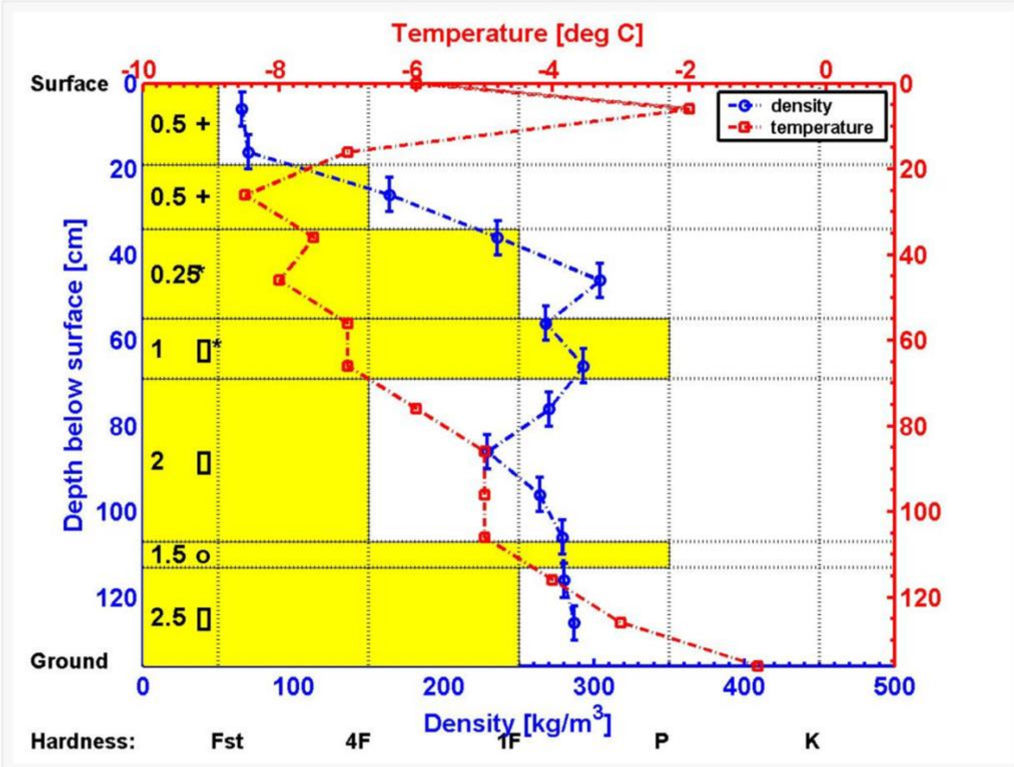

Figure A-3 Snow pit data from Berthoud Pass, Fraser MSA, on 22 February 2003.

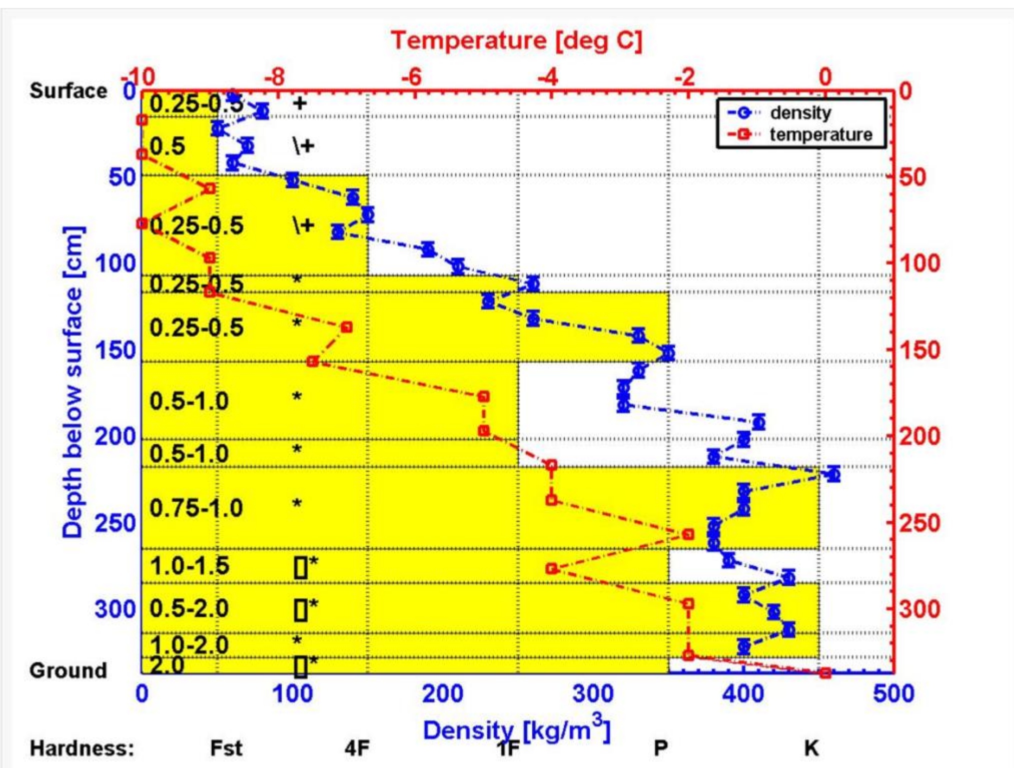

Figure A-4 Snow pit data from Buffalo Pass, Rabbit Ears MSA, on 23 February 2003.

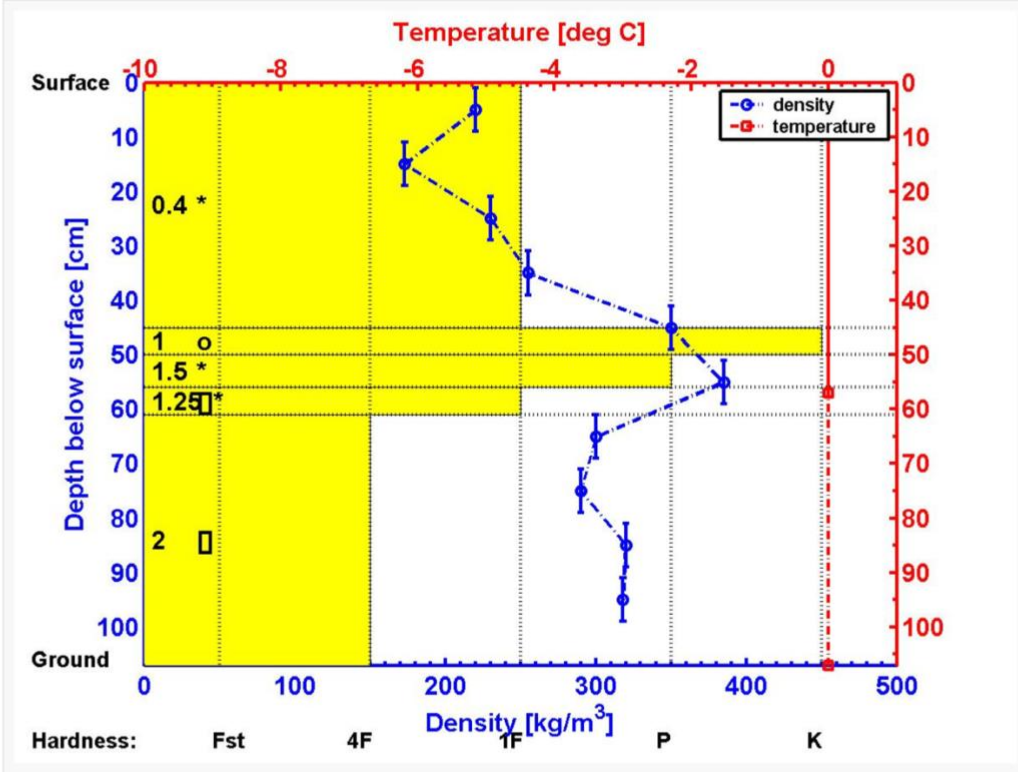

Figure A-5 Snow pit data from the LSOS on 25 March 2003.

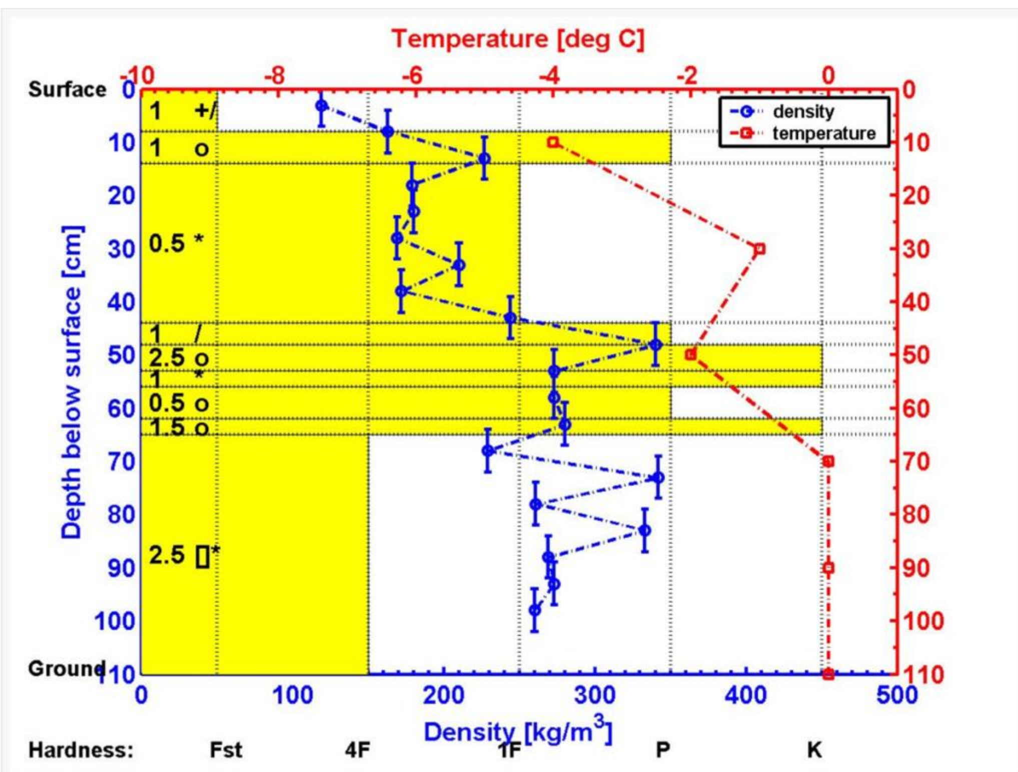

Figure A-6 Snow pit data from the LSOS on 28 March 2003.