SnowEx17 Cloud Absorption Radiometer BRDF, Version 1

USER GUIDE

How to Cite These Data

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

Gatebe, C. K. and R. Poudyal. 2018. SnowEx17 Cloud Absorption Radiometer BRDF, Version 1. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/VH3F5ZPLH3PM [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX17_CAR

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

NOTE: This data set contains radiance measurements for the entire filghts, a related data set processed to only include bidirectional reflectance distribution (BRDF) circles, is available here. That data set is only available during aircraft circular orbits and file size is muach smaller. Generally, quicklook images can help the user determine on what days and locations data were collected.

1.1 Parameters

The airborne Cloud Absorption Radiometer (CAR) is a multi-wavelength scanning radiometer that measures radiance in fourteen spectral bands (See Table 1). The CAR unique viewing geometry, rotating the scan mirror 360° in a plane perpendicular to the direction of flight and data collection through a 190° aperture, makes it most suitable for measuring surface bidirectional reflectance-distribution (BRDF).

Table 1. CAR Instrument Spectral Bands

Bands 1-8 (sampled simultaneously)	Bands 9-14 (sampled individually)
339 nm	1557 nm
380 nm	1638 nm
474 nm	1723 nm
687 nm	2094 nm
870 nm	2188 nm
1030 nm	2323 nm
1229 nm	-
1266 nm	-

Note: At each point in time nine of the fourteen spectral bands are sampled simultaneously. Band 1-8 are measured continuously together, plus one out of the remaining six bands (bands 9-14). This last channel can either cycle through bands 9-14 at a set interval, or lock onto one band and sample it continuously. This results in missing data for the not sampled bands. Each band's spectral range and spectral response function are also provided within the data. For more details on the CAR instrument and sampling options see the NASA CAR readme file on the technical reference tab on the data set landing page.

1.2 Format

Data files are formatted as NetCDF4/HDF5 (.nc). Each data file also has an associated XML file which includes additional metadata.

NetCDF is a set of software libraries and self-describing, machine-independent data formats that are specifically designed to help create, access, and share array-oriented scientific data sets. Note that NetCDF-4 is not a file format. It is a convention for storing data as HDF using the NetCDF data model. For more information, visit the HDF Group's HDF5 Home Page and Unidata's NetCDF Documentation website.

1.3 File and Directory Structure

Five flights (one per day) were flown during February, 2017. Each .nc file contains the CAR measurements for the day indicated in the file name. All five flights obtained measurements at the Grand Mesa (GM) study site; two flights additionally acquired data for Senator Beck (SB) Basin (see Table 2 and Figure 1).

Table 2. Sites Visited by Date

Date	Site
02/16/17	GM, SB
02/18/17	GM
02/20/17	GM
02/21/17	GM
02/22/17	GM, SB

Figure 1 shows the flight line for 16 February, 2017. During this flight, CAR measurements were acquired at both the Grand Mesa and Senator Beck study sites.

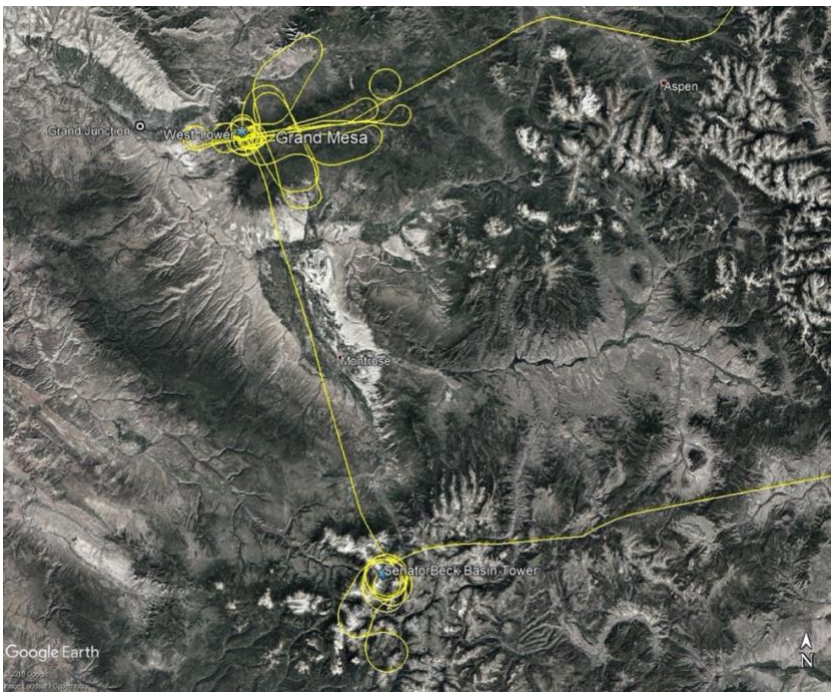

Figure 1. CAR flight line for 02/16/17.

1.3.1 Variables

Data files contain radiance values, spectral ranges, and spectral response functions in separate variables for each of the 14 bands observed by the CAR instrument. Additional variables are provided that specify aircraft position and orientation, plus CAR viewing angles and solar angles and irradiance. Consult tables 3 and 4 for variable names and descriptions.

Table 3. CAR Spectral Variables

Variable Name	Description	Data Type
SRF_[λ]nm	Spectral response function for central wavelength λ	32-bit floating point
SpectralRange_[λ]nm	Spectral range for central wavelength λ	32-bit floating point
radiance_[λ]nm	Radiance ($W/m_2 \cdot sr$) for central wavelength λ	32-bit floating point
CentralWaveLength	Array containing central wavelengths	32-bit floating point

Table 4. Aircraft/Instrument Variables

Variable Name	Description	Data Type
AircraftAltitude	Aircraft altitude, meters above mean sea level	32-bit floating point
AircraftHeading	Aircraft heading, degrees relative to local geodetic north	32-bit floating point
AircraftLatitude	Aircraft latitude, degrees	32-bit floating point
AircraftLongitude	Aircraft longitude, degrees	32-bit floating point
AircraftPitch	Aircraft pitch, degrees relative to local sky-Earth normal	32-bit floating point
CAR_Viewing_Angles	CAR viewing angles, 0 to 180° in half-degree increments	32-bit floating point
CoordinatedUniversalTime	Time (UTC) for each aircraft position measurement	32-bit floating point
Date	Data acquisition date and time (UTC), YYYYMMDDhhmmss.s	String
Scan_Start_Angle	Scan start angle, degrees relative to local sky-Earth normal	32-bit floating point
Scans	Scan line count from start of data acquisition	32-bit floating point
SolarAzimuthAngle	Solar azimuth angle, degrees relative to local geodetic north	32-bit floating point
SolarIrradiance	Solar spectral irradiance (W/m^2)	32-bit floating point
SolarZenithAngle	Solar zenith angle, degrees relative to local sky-Earth normal	32-bit floating point

Variable Name	Description	Data Type
Time	Seconds since 00:00:00.0, day of data acquisition	64-bit floating point
ViewingAzimuthAngle	CAR pixel viewing azimuth angle, degrees relative to local geodetic north	32-bit floating point
ViewingZenithAngle	CAR pixel viewing zenith angle, degrees relative to local sky-Earth normal	32-bit floating point

Note: Data files also contain a NetCDF dimension scale corresponding to each spectral response function variable. When viewing the data files in software packages that use the HDF API (for example, HDFView), these arrays will be displayed as additional variables named "SRF_[λ]nm_dim," where λ represents the central wavelength. Software packages like Panoply that use the NetCDF API do not display NetCDF dimension scales.

1.4 File Naming Convention

Data files utilize the following naming convention:

```
SnowEx17_car_p3c_[YYYYMMDD]_R1_[nnnn]_Level1C_[YYYYMMDD].[ext]
```

Table 5. File Naming Convention

Variable	Description
SnowEx17	SnowEx 2017 field season
car	Instrument code, car = Cloud Absorption Radiometer
p3c	Aircraft code, p3c = Naval Research Lab NP-3C Orion research aircraft
YYYYMMDD	Year, month, day of data acquisition
R1	Data revision number
nnnn	Four-digit unique flight number based on historic CAR data records
Level1C	NASA data processing level (1C)*
YYYYMMDD	Date data were processed or last updated
ext	File format. Value = .nc (NetCDF4/HDF5) or .xml

*Level 1C modified for CAR data from EOSDIS data processing levels as described in NASA CAR | Data Overview: "In Level-1C processing, georeferencing parameters are applied to Level 1B data for each scan line. Each scan line contains 361 pixels (representing a 180° field of regard). CAR data [are] expanded into 14, two-dimensional arrays and engineering data [are] excluded. Global attributes are kept to a minimum."

Example file:

```
SnowEx17_car_p3c_20170216_R1_2063_Level1C_20171031.nc
```

1.5 File Size

Data files are typically between 0.5 GB - 1.0 GB. XML files are <10 KB. The complete set of NetCDF files (5) is approximately 3.2 GB.

1.6 Spatial Coverage

Overall spatial coverage:

Northernmost Latitude: 40.243618° N
Southernmost Latitude 37.653967° N
Westernmost Longitude: 108.448729° W
Easternmost Longitude: 104.459534° W

Complete BRDF data for this mission were only collected during circular orbits in the vicinity of the meteorological stations within the Grand Mesa or Senator Beck Basin study sites (listed in Table 6) during favorable cloud free conditions. At all other times CAR radiance measurement data were acquired in limited azimuthal directions. Note: Complete BRDF data are only acquired through all the 360 azimuthal directions when an aircraft flight path is circular). The circular orbits were flown at an aircraft roll angle of about 20° and with a diameter of about 3km (~0.03°lat/lon) surrounding the meteorological stations.

Table 6. Meteorological Stations Latitudes/Longitudes

Station Name	Latitude, Longitude
Skyway	39.05074° N, 108.06143°W
LSOS	39.05225°N, 108.09792°W
West Tower	39.03388°N, 108.21399°W
Eastern Tower	39.10374°N, 107.88448°W
Middle Tower	39.03954°N, 107.94174°W
Senator Beck Basin	37.90689°N, 107.72628°W

1.6.1 Spatial Resolution

Spatial resolution varies with altitude. At a height of 600 m above the surface, the resolution at nadir is about 10 m.

1.6.2 Projection and Grid Description

Aircraft latitudes and longitudes are provided for each flight. Latitude/longitude pairs correspond to nadir pixels in CAR scans.

1.7 Temporal Information

Data are available for the following days:

- 16 February, 2017
- 18 February, 2017
- 20 February, 2017
- 21 February, 2017
- 22 February, 2017

1.7.1 Temporal Resolution

Varies.

2 SOFTWARE AND TOOLS

2.1 Software and Tools

NetCDF4/HDF5 data files can be accessed using software packages that read either NetCDF4 or HDF5, such as Panoply and HDFView.

3 DATA ACQUISITION AND PROCESSING

3.1 Data Acquisition Methods

During SnowEx 2017, the CAR instrument was flown aboard a Naval Research Lab (NRL) P-3 Orion research aircraft over the Grand Mesa and Senator Beck Basin study sites. To measure the BRDF of the surface–atmosphere system, the aircraft banked at a roll angle of about 20° and flew roughly 3 km diameter circles (assuming an altitude of 600 m above the ground) for approximately 2 minutes. Multiple circular orbits were acquired over selected surfaces and at different altitudes.

The CAR scan mirror rotates 360° in a plane perpendicular to the direction of flight and collects data (60 MB/hr) through a 190° aperture that allows the instrument to observe the earth-atmosphere scene around the starboard horizon from local zenith to nadir. Data are acquired at high angular (1°) and spatial resolution (>10 m at nadir, assuming 600 m altitude). During operations, CAR is stabilized by an independent system (the CAR Autonomous Navigation System) that corrects the sensor in real time with respect to aircraft roll, using inputs from a precision navigation sensor. This stabilization ensures that the resulting data and imagery are clear and require little or no post-processing to correct for aircraft motion. Radiometric calibration of the CAR is performed at NASA Goddard Space Flight Center.

3.2 Derivation Techniques and Algorithms

CAR radiance data can be converted to reflectance following the van de Hulst formulation:

$$R_\lambda(\theta, \theta_0, \Phi) = \pi I_\lambda(\theta, \theta_0, \Phi)/ \mu_0 \cdot F_\lambda$$

where:

I_λ is measured reflected or scattered intensity (radiance);
θ, $\theta 0$ are the viewing and incident zenith angles, respectively;
Φ is the azimuthal angle between the viewing and incident light directions;
μ_0 is the $\cos\theta_0$;
F_λ is the solar flux density (irradiance) incident on the top of the atmosphere, assuming mean-earth distance;
The viewing directions range from 0–180°;
The relative azimuth angles range from 0-360°, where 0° or 360° or 180° coincide with the solar principal plane.

To convert the reflectance data to BRDF, multiply $R_\lambda (\theta, \theta_0, \Phi)$ by π, as defined by Nicodemus et al. (1977).

3.2.1 Processing Steps

- In Level-1C processing, georeferencing parameters are applied to Level 1B data for each scan line.
- Each scan line contains 361 pixels (representing a 180° field of regard).
- CAR data are expanded into 14 two- dimensional arrays and engineering data is excluded.

4 REFERENCES AND RELATED PUBLICATIONS

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van de Hulst, N. C. 1980. Multiple Light Scattering, Tables, Formulas, and Applications, Vol. 1, Academic Press, San Diego, CA.

4.1 Related Data Collections

CAR SnowEx17 BRDF Measurements L1 V2
SnowEx at NSIDC

4.2 Related Websites

NASA Cloud Absorption Radiometer (CAR)
NASA Cloud Absorption Radiometer Bibliography
NASA Cloud Absorption Radiometer (CAR) Data Readme File
SnowEx CAR Quicklook Images

5 CONTACTS AND ACKNOWLEDGMENTS

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6 DOCUMENT INFORMATION

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