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## AirMOSS: L1 S-0 Polarimetric Data from AirMOSS P-band SAR, Walnut Gulch, 2012-2015

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Documentation Revision Date: 2018-04-13

Data Set Version: 1

### Summary

This data set provides level 1 (L1) polarimetric radar backscattering coefficient ( $\sigma_0$ ), multilook complex, polarimetrically calibrated, and georeferenced data products from the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) radar instrument collected over the Walnut Gulch site in Arizona. The AirMOSS radar is a P-band (UHF) fully polarimetric synthetic aperture radar (SAR) currently operating in the 420-440 MHz band designed to measure root-zone soil moisture (RZSM) and is flown on a NASA Gulfstream-III aircraft. Flight campaigns took place at least biannually from 2012 to 2015 at 10 study sites across North America. The acquired L1 P-band radar backscatter data will be used to retrieve the RZSM at the study sites. Subsequent analyses will investigate both seasonal and inter-annual variability in soil moisture and the relationships to carbon fluxes and their associated uncertainties on a continental scale.

This data set provides all of the L1 products derived for flight campaigns at Walnut Gulch. The L1 products were derived for each data take (acquisition) of the AirMOSS radar instrument, where one data take is one flight line over a site. There were usually 4 data takes performed on a visit to a site (on some occasions as few as one or as many as six were taken). There is a separate directory for each data take containing 40 individual derived data products. Note that data are provided at two resolutions, 0.5 arcseconds (about 15 meters) and 3.0 arcseconds (about 90 meters), and the resolution is denoted in each file name.

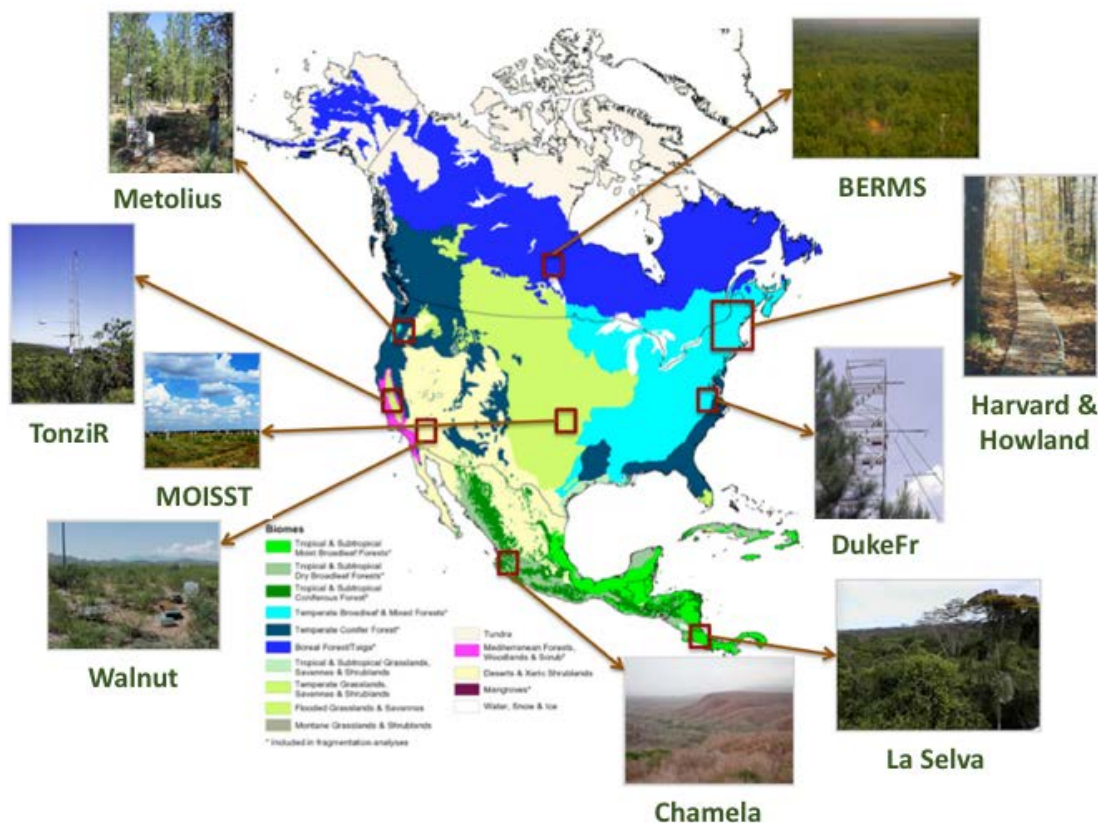


Figure 1: AirMOSS flights during 2012-2015 provided repeated measurements of soil moisture in nine different North American biomes.

## Citation

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## 1. Data Set Overview

This data set provides level 1 (L1) polarimetric radar backscattering coefficient ( $\sigma_0$ ), multilook complex, polarimetrically calibrated, and georeferenced data products from the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) radar instrument. The AirMOSS radar is a P-band (UHF) fully polarimetric synthetic aperture radar (SAR) currently operating in the 420-440 MHz band designed to measure root-zone soil moisture (RZSM) and is flown on a NASA Gulfstream-III aircraft. Flight campaigns took place at least biannually from 2012 to 2015 at 10 study sites across North America. The acquired L1 P-band radar backscatter data will be used to retrieve the RZSM at the study sites.

**Project:** Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)

The goal of NASA's Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) investigation is to provide high-resolution observations of root-zone soil moisture over regions representative of the major North American climatic habitats (biomes), quantify the impact of variations in soil moisture on the estimation of regional carbon fluxes, and extrapolate the reduced-uncertainty estimates of regional carbon fluxes to the continental scale of North America.

- The AirMOSS campaign used an airborne ultra-high frequency synthetic aperture radar flown on a Gulfstream-III aircraft to derive estimates of soil

moisture down to approximately 1.2 meters.

- Extensive ground, tower, and aircraft in-situ measurements were collected to validate root-zone soil measurements and carbon flux model estimates.

The AirMOSS soil measurements can be used to better understand carbon fluxes and their associated uncertainties on a continental scale. Additionally, AirMOSS data provide a direct means for validating root-zone soil measurement algorithms from the Soil Moisture Active & Passive (SMAP) mission and assessing the impact of fine-scale heterogeneities in its coarse-resolution products.

#### Related Data:

Numerous data products were generated based on these Level 1 data. A full list of AirMOSS data products is available at: <https://airmoss.ornl.gov/dataproducts.html>.

## 2. Data Characteristics

**Spatial Coverage:** Walnut Gulch site in Arizona

**Spatial Resolution:** Data are provided at two different resolutions: 0.5 arcseconds (about 15 meters) and 3.0 arcseconds (about 90 meters).

**Temporal Coverage:** Periodic flights occurred over the Walnut Gulch site in Arizona from September 2012 – September 2015.

**Temporal Resolution:** Each flight campaign represents a single day. Most sites had at least three campaigns per year.

**Study Area** (coordinates in decimal degrees)

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Walnut Gulch, Arizona	-111.24	-109.48	32.07	31.58

#### Data File Information

There are 3388 data files in 84 directories provided with this data set. Each directory corresponds to an AirMOSS flight campaign and contains approximately 40 individual files.

**Table 1.** AirMOSS L1 Sigma-0 directory naming format. Example directory name: DukeFr\_04533\_13122\_003\_130713\_PL09043020\_XX\_03

Name element	Example value	Description
Site name	<i>DukeFr</i>	One of the ten AirMOSS sites (see Table 3).
Flight line ID	<i>04533</i>	Flight line is based on aircraft orientation. There may be multiple flights on different dates that followed the same flight line.
Flight ID	<i>13122</i>	The first 2 digits are the last 2 digits of the year and the next 3 digits are a numeric counter chosen to ensure uniqueness of the flight ID.
Data take counter	<i>003</i>	See File Naming Convention table
Flight date	<i>130713</i>	UTC date at start of flight (yymmdd)
Radar codes	<i>PL09043020</i>	See File Naming Convention table
Crosstalk		

removal status	XX	See File Naming Convention table
Version number	03	Incremental version number

**Table 2.** List of data product files in each directory. See Section 5 below for details.

File extension	Number of files per flight data take directory	Description
.ann	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	Annotation files contain metadata for this product, including filenames, file dimensions, grid coordinates, and radar processing parameters.
.grd	12 files, 6 for the 0.5 arcsecond grid spacing and 6 for 3.0 arcsecond.	Georeferenced data (GRD) files are generated by projecting the (slant range) SLC data to ground range using the backward projection method.
.h5	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	The HDF5 files contain copies of the ground-range product layers described above, specifically the Georeferenced data (.grd), Digital Elevation Map (.hgt), Terrain slope (.slope), and Incidence angle (.inc).
.hgt	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	Digital elevation map files contain the terrain height values that were used to produce the GRD data in the same geographic coordinates as those files.
.inc	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	The incidence angle files contain the local incidence angle at each point in the GRD files.
.jpg	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	Browse thumbnails in .jpg format produced from the .png files.
.kmz	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	The KMZ files contain the GRD data rendered as color images. The KMZ files are compressed Keyhole Markup Language files for display in Google Earth.
.mlc	12 files, 6 for the 0.5 arcsecond grid spacing and 6 for 3.0 arcsecond.	Multi-looked complex (MLC) cross products.
.png	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	The PNG files contain the images from the KMZ files in PNG file format.
.slope	2 files, one for the 0.5 arcsecond grid spacing and one for 3.0 arcsecond.	The terrain slope files contain the derivatives of the DEM files in the East and North direction.

## File naming convention

The names of the annotation, digital elevation map, terrain slope, incidence angle, KMZ, PNG, and HDF5 files have the format:

`ssssss_LLLLL_FFFFF_CCC_YYMMDD_PL090fffww_gg_XX_vv.ext`

where:

Name element	Description
ssssss	6-character sitename assigned to the site where data was acquired.
LLLLL	5-character flight line ID, where the first 3 characters are the aircraft heading in integer degrees, range 000-359; and the last 2 characters are an alphanumeric counter chosen to ensure uniqueness of the flight line ID.
FFFFF	5-digit flight ID, where the first 2 digits are the last 2 digits of the year of the AirMOSS flight and the next 3 digits a numeric counter chosen to ensure uniqueness of the flight ID.
CCC	3-digit data take counter for this flight. The allowed characters for this field are digits 0-9. A first digit of 0 indicates that the data take was collected in automatic mode, while a first digit of 1 indicates that it was collected in manual mode. Usually, the data take counter starts at 000 for the first science data take of a flight and increments by 1 for each successive science data take. Since the radar system may reinitialize the counter if a system reset occurs during flight, the data take counter may not be unique for a flight.
YYMMDD	UTC date at the start of the data take, with <i>YY</i> being the last two digits of the year, <i>MM</i> the month of the year (01-12), and <i>DD</i> the day of the month (01-31)
P	Radar band, 1 character; fixed value of <i>P</i> for P-band for AirMOSS
L	1 character indicating whether radar is <i>Left-looking</i> or <i>Right-looking</i> relative to direction of flight; fixed value of <i>L</i> for AirMOSS.
090	Squint angle in integer degrees; fixed value of <i>090</i> for AirMOSS
fff	3-digit chirp center frequency in integer MHz, with allowed values in (280, 440). All standard AirMOSS science data products have this field set to <i>430</i> .
ww	2-digit chirp bandwidth in integer MHz, with allowed values in [06, 80]. All standard AirMOSS science data products have this field set to <i>20</i> .
gg	2-digit grid spacing in integer units of 0.1 arcseconds ("). The allowed values are <i>05</i> for 0.5" and <i>30</i> for 3.0".
XX	2-character crosstalk removal status. The allowed values are <i>CX</i> when crosstalk has been removed and <i>XX</i> when crosstalk has not been removed. All standard AirMOSS science data products have this field set to <i>XX</i> .
vv	2-digit product version number starting at <i>01</i> . The version number is incremented by 1 when a product is redelivered.
ext	File suffix indicating the product data type. The allowed values are given in Table 2.

The names of the multi-looked complex cross products and georeferenced data files have the format

sssss\_LLLLL\_FFFFF\_CCC\_YYMMDD\_PL090ffvw\_ggpppp\_XX\_vv.ext

All elements are the same as above except for the addition of the following:

*pppp* 4-character abbreviation for the cross product. The abbreviation is formed from the subscripts of the two factors of each cross product read from left to right. For example, the abbreviation for the second cross product,  $S_{HH}S^*_{HV}$ , is *HHHV*. The allowed values for this field are thus *HHHH*, *HHHV*, *HHVV*, *HVHV*, *HVVV*, and *VVVV*.

### 3. Application and Derivation

The Level 1 Sigma-0 data generated by the AirMOSS radar instrument were used to generate other, higher-level, AirMOSS data products including the Level 2/3 Root Zone Soil Moisture estimates for each AirMOSS flight (Chapin et al, 2012).

### 4. Quality Assessment

These Level 1 data are provided with no QA information. Extensive quality checks were performed on the higher-level products derived from this data.

### 5. Data Acquisition, Materials, and Methods

The goal of the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) investigation is to provide high-resolution observations of root-zone soil moisture over regions representative of the major North American climatic habitats (biomes), quantify the impact of variations in soil moisture on the estimation of regional carbon fluxes, and extrapolate the reduced-uncertainty estimates of regional carbon fluxes to the continental scale of North America.

#### AirMOSS Flights

These Level 1 data are one set of products generated by the AirMOSS campaign.

For AirMOSS, NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) was flown on a Gulfstream-III aircraft, making frequent flights over ten sites (given in Table 3) in 9 different biomes of North America over the course of four years.

**Table 3.** AirMOSS sites

Site name	North latitude	South latitude	East longitude	West longitude	Fluxnet Site ID	Description
BermsP	54.125	53.501	-103.626	-107.125	CA-Ojp & CA-Oas	BERMS (Boreal Ecosystem Research and Monitoring Sites), Saskatchewan, Canada. Landcover: Mixed boreal forest. Elevation: 518m.
Chamel	20.326	19.316	-104.22	-105.29	MX-Cha	Chamela Biological Station, Jalisco, Mexico. Landcover: Seasonally dry tropical forest. Elevation: 58m.
DukeFr	36.368	35.437	-78.694	-79.849	US-Dk1, US-Dk2, US-Dk3	Duke Forest site, North Carolina, USA. Landcover: Mature oak-hickory dominated hardwood forest. Elevation: 169m.
Harvrd	43.376	42.293	-71.839	-72.389	US-Ha1 & US-Ha2	Harvard Forest site, Massachusetts, USA. Landcover: Temperate deciduous forest. Elevation: 353m.
Howlnd	45.778	44.669	-68.336	-69.086	US-Ho1, US-Ho2, US-Ho3	Howland Forest site, Maine, USA. Landcover: boreal - northern hardwood transitional forest. Elevation 72m.
LaSelv	10.878	9.92	-83.519	-84.57	CR-Lse	La Selva Biological Station, Costa Rica. Landcover: tropical rain forest. Elevation 93m.
Metoli	45.242	43.38	-120.363	-123.283	US-Me1 to US-Me6	Metolius site, Oregon, USA. Landcover: evergreen needleleaf forest. Elevation 1237m.

Oklaho or Moisst	36.880	35.775	-96.824	-98.996	US-ARM	The Marena, Oklahoma In Situ Sensor Testbed (MOISST) is located in Oklahoma, USA. Landcover: temperate grasslands, crops. Elevation: 312m.
TonziR	38.625	37.501	-120.001	-121.25	US-Ton	Tonzi Ranch site, California, USA. Landcover: oak savanna and grazed grassland. Elevation 170m.
Walnut	32.125	31.501	-109.376	-111.5	US-Wkg & US-Whs	Walnut Gulch site, Arizona, USA. Landcover: warm season C4 grassland with a few shrubs. Elevation 1524m.

Beginning in September 2012, the AirMOSS instrument flew 215 flight campaigns. A summary of flight campaigns by year and site is found in Table 4. Typically, the aircraft made repeat visits to sites in the same region in a single week and then proceeded to another region. Most sites had at least three campaigns per year. The Harvard and Howland forest sites were flown together in a single day. In 2012, Chamela, La Selva, and Tonzi were not surveyed.

**Table 4.** Summary of AirMOSS flight campaigns.

	Site									
Year	BermsP	Chamel	DukeFr	Harvrd	Howlnd	LaSelv	Metoli	Oklaho	TonziR	Walnut
2012	3	0	3	3	3	0	4	3	0	3
2013	6	3	9	9	9	6	7	8	5	6
2014	7	3	10	9	9	3	9	9	6	5
2015	9	2	5	5	5	3	9	6	5	6
<b>Total</b>	25	8	27	26	26	12	29	26	16	20

A complete list of AirMOSS flights can be found at: <https://airmoss.ornl.gov/flights.html>.

### AirMOSS Level 1 Sigma-0 Radar Data Products

The AirMOSS aircraft carried an ultra-high frequency synthetic aperture radar that has the capability to penetrate through substantial vegetation canopies and soil to depths down to approximately 1.2 meters (see <https://airmoss.ornl.gov/documentation.html>).

A Level-1 S0 ("sigma-0") polarimetric product consists of the following set of files that are generated from a single data take (data collection or acquisition) of the AirMOSS radar instrument.

Several of the file descriptions below specify dependencies upon the number of chirp waveforms used for a data take. While the AirMOSS radar is capable of using one, two, or three chirp waveforms during a single data take, all AirMOSS data takes that were acquired for standard science data processing were collected using a single chirp waveform having a center frequency of 430 MHz and a (10-dB) bandwidth of 20 MHz.

Many of the AirMOSS Level-1 S0 product layers are the same as the ones produced for the L-band UAVSAR airborne radar polarimetric products. Much of the material in this section has been adapted from the online UAVSAR product documentation at: <http://uavsar.jpl.nasa.gov/science/documents/polsar-format.html>.

#### 1. Annotation Files

The annotation files contain the metadata for this product, including filenames, file dimensions, grid coordinates, and radar processing parameters. The annotation files do not conform to any of the standard metadata file formats but use a simple "keyword = value" ASCII text file format, with a maximum of one keyword per line. Each line is terminated by a carriage return (newline). Unit specifications, if present, are placed within a single pair of parentheses to the left of the equals sign. At least one space should separate the right parenthesis of the unit specification and the equals sign.

Most of the Level-1 S0 product layers are output at grid spacings of 0.5" (arcseconds, about 15 meters) and 3.0" (about 90 meters). Two annotation files

are generated for each chirp waveform used during the data take, one for the 0.5" files and the other for the 3.0" files.

## 2. Single-Look Complex (SLC) Data

*Because of the large data volume and low demand for this layer, the SLC data is not provided here.*

The Single-Look Complex (SLC) files contain the scattering matrix measurements  $S_{HH}$ ,  $S_{HV}$ ,  $S_{VH}$ , and  $S_{VV}$ , corresponding to the four possible combinations of the transmit and receive polarizations. Each file contains the data for a single transmit/receive combination. One set of four SLC files is produced for each chirp waveform used during the data take. Radiometric calibration is performed on this data.

The following keywords in the annotation file can be used to determine the geographic location of the SLC files:

set_plat	Peg latitude
set_plon	Peg longitude
set_phdg	Peg heading
slc_mag.row_addr	Along-track offset to upper left pixel
slc_mag.col_addr	Cross-track offset to upper left pixel

## 3. Multi-Looked Complex (MLC) Cross Products

The multi-looked complex (MLC) cross products are generated by first calculating the following six cross products from each set of four SLC files:

$$\begin{aligned} S_{HH}S_{HH}^* \\ S_{HH}S_{HV}^* \\ S_{HH}S_{VV}^* \\ S_{HV}^*S_{HV} \\ S_{HV}^*S_{VV} \\ S_{VV}S_{VV}^* \end{aligned}$$

where  $S_{HV}^*$  is the symmetrized cross-polarization, defined as

$$S_{HV}^* = 0.5(S_{HV} + mS_{VH} e^{i\phi})$$

$$m = \text{cross-polarization magnitude correction} = \sqrt{\sum S_{HV}^2 / \sum S_{VH}^2}$$

$$\phi = \text{cross-polarization phase correction} = \text{phase}(\sum S_{HV}S_{VH}^*)$$

and where each summation has been performed over all samples in the respective SLC file(s).

Each cross product is then multi-looked (averaged) in both the range and the azimuth dimensions. The cross products are output at grid spacings of approximately 0.5" and 3.0", with separate files written for each combination of cross product and grid spacing. Twelve MLC files are thus produced for each chirp waveform used during the data take.

Each MLC file is a pure binary file with a fixed record length, no header or trailer records, and no prefix or suffix data within each record. The six files produced for a given chirp waveform and grid spacing have the same record length. For the  $S_{HH}S_{HH}^*$ ,  $S_{HV}S_{HV}^*$ , and  $S_{VV}S_{VV}^*$  cross products, each sample within a record is a 4-byte real single-precision floating-point number with little-endian byte ordering and units of linear, not dB, radar power. For the  $S_{HH}S_{HV}^*$ ,  $S_{HH}S_{VV}^*$ , and  $S_{HV}S_{VV}^*$  cross products, each sample within a record is an 8-byte complex single-precision floating-point number with little-endian byte ordering and units of linear, not dB, radar power. The projection of the data is the natural slant range projection. Samples within a record are ordered by increasing range. Records are ordered by increasing azimuth.

The following keywords in the annotation file can be used to determine the geographic location of the MLC files:

set_plat	Peg latitude
set_plon	Peg longitude
set_phdg	Peg heading
mlc_mag.row_addr	Along-track offset to upper left pixel
mlc_mag.col_addr	Cross-track offset to upper left pixel

The following keywords in the annotation file give the number of looks used to generate the MLC files:

Number of Range Looks in MLC

Number of Azimuth Looks in MLC

## 4. Georeferenced Data (GRD)

The georeferenced data (GRD) files are generated by projecting the (slant range) SLC data to ground range using the backward projection method. An



equiangular grid is defined with latitude and longitude boundaries that cover the entire slant range image. For each point on the ground range grid, the corresponding location is calculated within the SLC image. The data value closest to this location is assigned to the point on the ground range grid. One GRD file is produced for each of the six cross product formats defined for the MLC files.

Each GRD file has the same sample data type (complex or real) as that of the corresponding MLC cross product. Each sample has units of linear, not dB, radar power. Samples within a record are ordered by increasing longitude (i.e., west to east). Records within a file are ordered by descending latitude (i.e., north to south).

The following keywords in the annotation file can be used to determine the geographic location of the GRD files:

grd\_mag.set\_rows    Number of records in GRD file  
 grd\_mag.set\_cols    Number of samples per record  
 grd\_mag.row\_mult    GRD Latitude Pixel Spacing  
 grd\_mag.col\_mult    GRD Longitude Pixel Spacing  
 grd\_mag.row\_addr    Center Latitude of Upper Left Pixel of Image  
 grd\_mag.col\_addr    Center Longitude of Upper Left Pixel of Image

## 5. Digital Elevation Map (DEM)

The Digital Elevation Map (DEM) files contain the terrain height values that were used to produce the GRD data in the same geographic coordinates as those files. Two DEM files are generated for each chirp waveform used during the data take, one at 0.5" grid spacing and the other at 3.0" grid spacing. Each sample within a file is a 4-byte real single-precision floating-point number with little-endian byte ordering and units of meters. Each DEM file is co-registered to the GRD files having the same grid spacing.

The following keywords in the annotation file provide information about the source DEM used for processing:

DEM Used in Ground Projection

DEM Datum

DEM Source

DEM Original Pixel Spacing

## 6. Terrain Slope

The terrain slope files contain the derivatives of the DEM files in the East and North direction. Two terrain slope files are generated for each chirp waveform used during the data take, one at 0.5" grid spacing and the other at 3.0" grid spacing. Each sample within a file consists of two values, the first of which is the terrain slope in the east direction and the second value the slope in the north direction. Each slope value is a unitless 4-byte real single-precision floating-point number with little-endian byte ordering. Each terrain slope file is co-registered to the GRD files having the same grid spacing.

## 7. Incidence Angle

The incidence angle files contain the local incidence angle at each point in the GRD files.

In the figure below, the local incidence angle  $\theta_i$  is the angle between the surface normal  $\hat{n}$  and the radar line of sight  $\hat{l}$ , specifically

$$\theta_i = \cos^{-1}(-\hat{n} \cdot \hat{l})$$

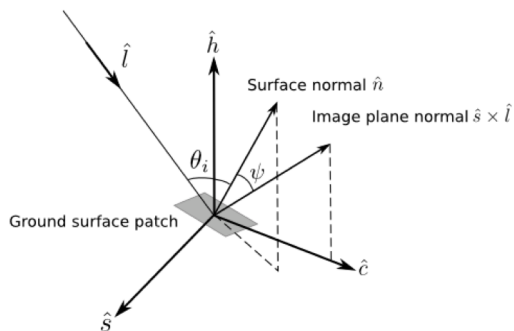


Figure 2: Geometry for calculation of local incidence angle

Two incidence angle files are generated for each chirp waveform used during the data take, one at 0.5" grid spacing and the other at 3.0" grid spacing. Each sample is a 4-byte real single-precision floating-point number with little-endian byte ordering and units of radians. Each incidence angle file is co-registered to the GRD files having the same grid spacing.

## 8. KMZ Files

The KMZ files contain the GRD data rendered as color images. The KMZ files are compressed Keyhole Markup Language files. These files can be

displayed in Google Earth. The images use the following color mappings:

Red =  $S_{HH}S_{HH}^*$

Green =  $S_{HV}S_{HV}^*$

Blue =  $S_{VV}S_{VV}^*$

Note that the color scaling of an image depends upon the dynamic range of the particular source dataset; no absolute color scale exists for the KMZ imagery.

Two KMZ files are generated for each chirp waveform used during the data take, one at 0.5" grid spacing and the other at 3.0" grid spacing.

### 9. PNG Files

The PNG files contain the images from the KMZ files in PNG file format. Two PNG files are generated for each chirp waveform used during the data take, one at 0.5" grid spacing and the other at 3.0" grid spacing.

### 10. HDF5 Files

The HDF5 files contain copies of the ground-range product layers described above, specifically the Georeferenced data, Digital Elevation Map, Terrain slope, and Incidence angle.

Two HDF5 files are generated for each chirp waveform used during the data take, one containing the 0.5" grid spacing files and the other the 3.0" grid spacing files.

## 6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

[AirMOSS: L1 S-0 Polarimetric Data from AirMOSS P-band SAR, Walnut Gulch, 2012-2015](#)

Contact for Data Center Access Information:

- E-mail: [uso@daac.ornl.gov](mailto:uso@daac.ornl.gov)
- Telephone: +1 (865) 241-3952

## 7. References

E. Chapin, A. Chau, J. Chen, B. Heavey, S. Hensley, Y. Lou, R. Machuzak, and M. Moghaddam. 2012. AirMOSS: An Airborne P-band SAR to measure root-zone soil moisture, *2012 IEEE Radar Conference*, Atlanta, GA, 2012, pp. 0693-0698. doi: 10.1109/RADAR.2012.6212227



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