AIR HARP

Airborne Hyper-Angular Rainbow Polarimeter

AirHARP Data Quality Statement and User's Guide: ACEPOL Campaign

J. Vanderlei Martins (PI), Brent A. McBride, Henrique M. J. Barbosa, Xiaoguang Xu, Anin Puthukkudy, Noah Sienkiewicz, Roberto Fernandez-Borda, Lorraine Remer

Earth and Space Institute, University of Maryland Baltimore County, Baltimore, MD 21250

Corresponding author: mcbride1@umbc.edu

Campaign

Name	ACEPOL (Aerosol Characterization from Polarimeter and LIDAR)
Dates	19 October – 9 November 2017
Locations	California, Pacific Ocean, Arizona, Nevada, New Mexico, Utah
ER-2 #806 Remote Sensing	AirHARP, AirMSPI, CPL, HSRL-2, RSP, AirSPEX

AirHARP Overview of Data Calibration and Processing to Level 1B

Data Delivery Version	**V002**
Non-Linear Correction	13 June 2018
Radiopolarimetric Calibration	13 June 2018 (Radiometric), 31 January 2018 (Polarimetric)
Spectral Calibration	13 June 2018
Flatfield De-Striping	20 February 2019
Geo/Attitude Correction	20 February 2019
Quality Assurance	20 February 2019
Topographical Correction	16 July 2019

TABLE OF CONTENTS

1   INTRODUCTION and AirHARP L1B PRODUCTS

The Airborne Hyper-Angular Rainbow Polarimeter (AirHARP) instrument, designed and developed by the Laboratory for Aerosol and Cloud Optics (LACO) at the University of Maryland, Baltimore County (UMBC), participated in the Aerosol Characterization from Polarimeter and LIDAR (ACEPOL) field campaign over the Western United States and the Pacific Ocean from 19 October to 9 November 2017. AirHARP joined three other polarimeters and two LiDAR instruments on-board the National Aeronautics and Space Administration (NASA) Armstrong Flight Research Center (AFRC) ER-2 high-altitude research aircraft. This document details the Level 1B processing and data quality of AirHARP datasets during this campaign.

AirHARP observed cloud, aerosol, land, and ocean scenes using radiometric and polarimetric techniques during the ACEPOL field campaign. Using wide field-of-view, polarized information from three co-aligned detectors, AirHARP sampled Earth scenes in four channels (unique viewing angles) simultaneously: 440 (20), 550 (20), 670 (60), and 870 (20) nm. All wavelengths and angles are polarization-capable, producing Stokes parameters for total radiance (I) and electric-field-oriented, or *polarized*, radiance (horizontal over vertical - Q, 45° over 135° - U) in L1B processing. AirHARP measurements are gridded to 2000 pixels per geolocated degree on Earth's surface, corresponding to 55m pixel resolution at nadir. The pixel resolution grows as a function of viewing zenith angle off-nadir. All files are formatted with the HDF5 designation.

2   INSTRUMENT BASELINE CALIBRATION

2.1   Calibration Summary

The instrument baseline calibration (IBC) was performed once before (24 July 2017) and twice after the ACEPOL field campaign, (31 January and 13 June 2018) using a 1.01m integrating sphere source at NASA Goddard Space Flight Center (GSFC) Radiometric Calibration Facility. The sphere is NIST-traceable, radiometrically calibrated every year, and produces uniform output to a level of 0.25% over the entire sphere aperture (Cooper, private communication).

AirHARP image background correction is performed using an experimental relationship between dark reference counts and detector temperature derived from the counts in the last 180 pixels of the detector row that are masked from the light path. This method can be used with or without shutter actuation, and is done by using the above relationship to scale a template dark frame taken in the lab, for each sensor. The remaining calibrations take advantage of the AirHARP telecentric optical train: calibration coefficients derived at nadir transfer to the entire FOV with assistance from flatfield images. This is called the *nadir-spread technique* and allows for efficient calibrations in the field and lab while maintaining off-nadir measurement accuracy (McBride et al. 2018). The flatfields are made by illuminating the entire AirHARP FOV with a homogenous source, such as an integrating sphere, to capture relative pixel behavior. Finally, non-linear correction is performed on each detector individually by exposing the instrument to a tunable light source capable of spanning the full detector well.

Incident light arrives at the three AirHARP detectors through an optimized Phillips prism. Prism coatings and glass angles send excesses of S- and P-polarization to three prism output ports. Before reaching the detector, this light first passes through a sheet polarizer, oriented such that each sensor is uniquely sensitive to 0, 45, or 90° linearly polarized light over the entire focal plane array. Lab-generated polarization and co-aligned detector counts are used to derive the *characteristic matrix* (Borda et al. 2009), a mathematical

object that translates detector readings to normalized Stokes parameters (Q/I, U/I). A typical polarization calibration involves a wire-grid polarizer on a mechanized rotational stage at the aperture of an integrating sphere (DOP < 0.005). The polarizer is rotated perpendicular to the AirHARP optical axis at incremental angles. The polarizer is tilted 10° off-axis to avoid back reflection and the rotational stage is tunable within 0.001°. AirHARP laboratory DOLP uncertainty is estimated at 0.005 for all channels. Characteristic matrix coefficients are derived using the nadir-spread technique.

AirHARP observes the same GSFC sphere aperture, with no external polarizer, for radiometric calibration. Prior calibrations (24 July 2018 and 31 January 2018) illuminated the entire AirHARP FOV, but stray light and cross-talk considerations suggested a reduced aperture; radiometric calibration on 13 June 2018 restricted the sphere light core to the 20° viewing angle in the AirHARP image plane. AirHARP observed the sphere at incremental light levels, and an external Avantes spectrometer monitored the sphere output and spectral response at each level. After background and non-linear correction, the characteristic matrix is applied to the AirHARP sphere observations. The normalized Stokes intensity (I) is juxtaposed with the calibrated radiance levels of the sphere to produce a radiometric gain factor for each wavelength. The radiometric gain factor is derived using the nadir-spread technique. AirHARP radiometric uncertainty is estimated conservatively at 0.05 for all channels.

AirHARP does not have in-flight calibration mechanisms and must rely on laboratory and vicarious calibrations in-flight to adjust measurement quality. As such, it is difficult to estimate the in-flight stability of the AirHARP radiance and polarization measurements. Instruments, like AirMSPI, with in-flight calibration ability can be used to vicariously judge the in-flight stability and adjust AirHARP measurements for co-incident scenes during the ACEPOL campaign. Future iterations of the HARP concept, such as HARP2 on the Plankton-Aerosol-Cloud-ocean Ecosystem (PACE) spacecraft, will include an on-board diffuser calibrator specifically for this purpose.

2.2   Improvements to Calibration in Later L1B Version Releases

With stray light and cross-talk considerations in account, a full FOV *polarizer dome* mechanism is under development for full FOV polarimetric calibration of the AirHARP sensor. This object considers the ray trace of all incident light on the AirHARP front lens such that generated polarization does not alter its state entering the system. The nadir-spread calibration with a flat, wire-grid polarizer has geometrical limitations that invalidate coefficients derived far from the axis shared by the polarizer normal and a position on the AirHARP front lens (Kliger et al. 1992). Theoretically, with a full FOV calibration, flatfield and polarization calibration can be done simultaneously and is equivalent to the nadir-spread calibration. Any internal changes to the instrument are calibrated out in one operation as opposed to two with the nadir-spread method. Current investigation is underway with preliminary results slated for an upcoming paper (McBride et al. 2020, in preparation).

3   SPECTRAL CALIBRATION

Spectral calibration of AirHARP was also performed at the NASA GSFC Radiometric Calibration facility, using a continuous scanning monochromatic Ekspla laser system fed into a 20cm integrating sphere. The Ekspla system scans wavelengths at a 5 cm^{-1} maximum linewidth, scanning step of 0.1nm, and total available range from 210 to 2100 nm. An external Avantes spectrometer monitored the sphere output of each Ekspla wavelength. Co-aligned counts from the three detectors applied to the characteristic matrix produces a Stokes intensity (I) for each AirHARP wavelength.

Spectral response functions found via super-Gaussian fitting of the Stokes intensity in the four AirHARP wavelengths, after smoothing for laser noise variation and total-band spectrometer correction, are presented in Table 1 and Figure 1. The effective bandwidth and center wavelength derived from super-Gaussian (order

5) first and second moments. The reported solar irradiance (F_0) is the equivalent square-band response using the American Society for Testing and Materials Standard Extraterrestrial Spectrum Reference E-490 (ASTM E-490) Air Mass Zero solar irradiance spectrum. Stokes parameters, I, Q, and U reported in the AirHARP HDF files may be reduced to reflectance, from radiance units, by multiplying by a factor of $\pi/F_0(\lambda)$. The AirHARP spectral response function is not currently included in the L1B data product. This information will be included ancillary to the HDF5 files at a later date.

In all three sensors, the AirHARP instrument rejects out-of-band illumination to a $< 10^{-5}$ level relative to peak normalization. Wavelength selection in AirHARP is done via stripe filter overlaid on microlens CCD detectors; interpixel cross-talk and stray light under the filters drives $< 10^{-2}$ order in-band leakage from other wavelengths.

Table 1. *Total-band effective center wavelength, bandwidth, and total-band weighted solar irradiance F_0*

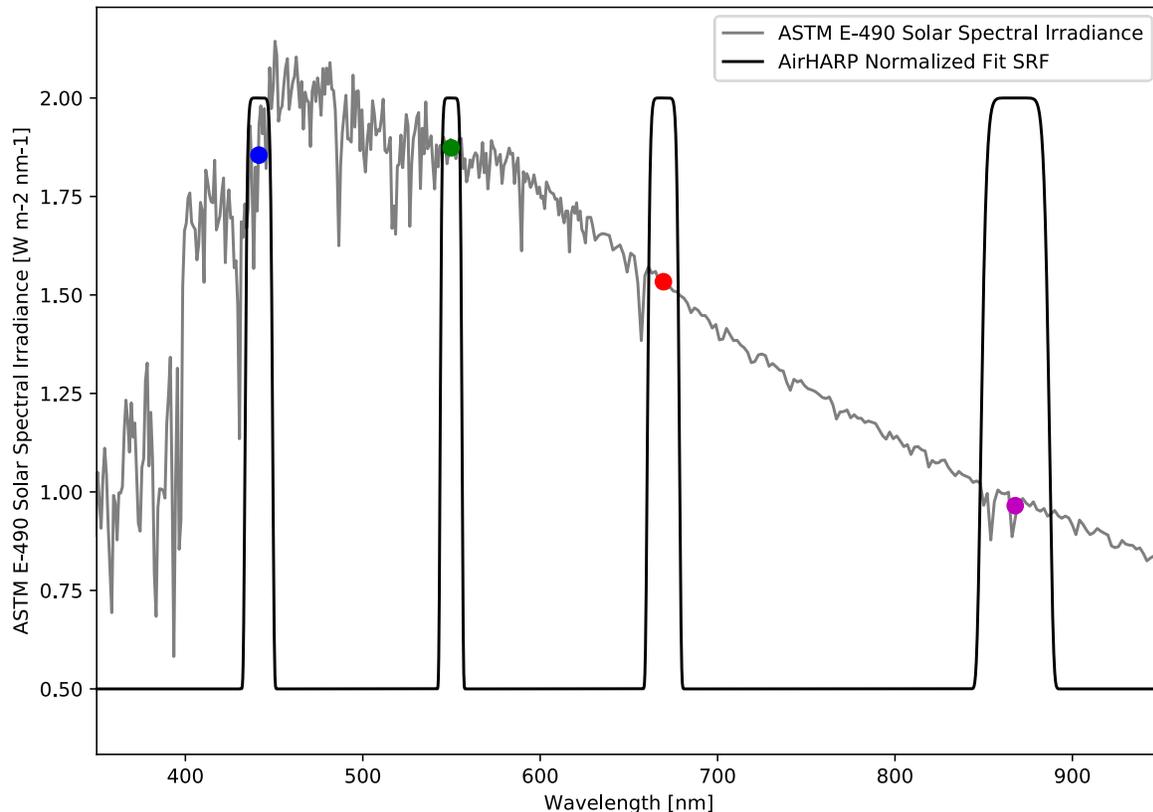| Channel Name	Center Wavelength (nm)	Effective Bandwidth (nm)	Solar Irradiance (F_0) (W m^{-2} nm^{-1})
Blue	441.4	15.7	1.855
Green	549.8	12.4	1.873
Red	669.4	18.1	1.534
Near-InfraRed (NIR)	867.8	38.7	0.965

Figure 1. *Solar spectral irradiance function from ASTM E-490 dataset overlaid with AirHARP normalized fit spectral response function, scaled by 1.5 and offset by 0.5 for visual effect. Colored in-band dots represent the integrated solar irradiance (F_0) for each wavelength used for reflectance conversion.*

4 GEORECTIFICATION, CO-REGISTRATION, AND POLARIZATION AXIS

Geolocation and co-registration of AirHARP data involves ancillary data, including f-theta distortion tables for front lens pixel projections, magnification, and inertial monitoring unit (IMU) and instrument mounting statistics from the science flights. All data included in the HDF is projected onto the same Universal Transverse Mercator (UTM) projection grid, at 2000 pixels per degree. In Version 001 and onward, geo-location of the AirHARP L1B data incorporates the flight yaw angle information reported by the ER-2 IMU and the roll and pitch angle data recorded by a commercial VectorNAV IMU unit mounted on the AirHARP doghouse enclosure when both IMU data are available. This combination of flight navigation data improved the co-location and registration of AirHARP data between different scan angles. However, when the AirHARP IMU data were not reported (i.e., for the flight on October 26, 2017), only ER-2 IMU data is used and is adjusted with an offset angle to each of the roll and pitch angles.

Geolocation of AirHARP images are determined by projecting the detector optical pointing vectors to the Earth ellipsoid as defined by the Geodetic Reference System 1980 (GRS80). Terrain of the land surface are taken into account though a topographical correction algorithm starting in the Version 002. By making use of the USGS Shuttle Radar Topography Mission (SRTM) 1 Arc-Second (30 m spatial resolution) digital elevation map (DEM) data, the algorithm iteratively updates the geolocation and searches the matched surface elevation for each AirHARP pixel. The algorithm was deigned to be able to accurately estimate surface elevation in an efficient manner in order to address AirHARP's high data volume rate. Overall, the uncertainty in geolocation of AirHARP pixels is found better than 55 meters at nadir, which can be incurred from the error in sensor attitude and from the residuals in topographical correction.

Band-to-band relative co-registration and detector co-alignment can also affect the geospatial accuracy. All pushbrooms are geolocated to a geographical sector of interest. Data gaps due to pitch modulation of the ER-2 aircraft in-flight affects far-forward or aft angles more strongly than nadir due to the extended ground projections and limited pixel allocation for those angles. This limitation is discussed in more detail in Section 5.2 below.

To match convention for instrument and model data products, AirHARP L1B Stokes parameters Q and U are reported with respect to the local view meridian plane of each pixel (i.e. the plane containing the target pixel, AirHARP detector, and the local zenith). Current AirHARP L1B processing includes a rotation that transforms the scan axis reference plane of the Stokes parameters to this view meridian plane. Uncertainty in this rotation angle (or in the orientation of the scan axis plane of reference) is smaller than 1.0°: an empirical estimate of the misalignment of the AirHARP scan axis to the ER-2 heading direction.

5 KNOWN DATA QUALITY ISSUES UNDER INVESTIGATION

5.1 Flatfield optical interference

Proper flatfield measurements for each AirHARP sensor are performed in the laboratory using either the GSFC sphere, a 0.5m SphereOptics integrating sphere or 16.4cm integrating hemisphere at the UMBC LACO facility. AirHARP responds differently to each sphere due to narrow bandwidths in the four HARP channels and the unique spectral responses of each source; the flatfields that best represent the flight conditions are used for L1B processing. Preliminary inter-comparisons with RSP and AirMSPI show the global flatfield is successfully spreading the RPC across the FOV and yielding comparable results for the evaluated cases.

AirHARP flatfield images reveal shallow, concentric artifacts when observing a homogenous source, and light linear fringes also appear superimposed on the images aligned with the axis of each detector polarizer.

These features modulate the detector counts by no more than 2% and are robust; a proper flatfield measurement corrects for these features at room temperature. In flight, internal temperatures reach 0° on the instrument busbar (close to the optical train), compared to 23°C in lab. The AirHARP Stokes parameter pushbrooms from ACEPOL data, processed with the lab flatfield, still show interference fringes, suggesting that the lab flatfield does not completely account for temperature-dependent changes to the optical train during flights. This issue could be solved through two approaches: (1) application of a temperature-dependent model for our optical interference, and (2) mid- or post-processing correction for extraneous fringing. While the former is an effort in progress, the latter option is found successful in removing fringes in DOLP pushbrooms after processing for a significant improvement in data quality, shown in Figure 2.

This issue does not affect our calibration coefficients derived using the nadir-spread technique; the flatfields are normalized to the same nadir locations used in calibration activities. The extraneous fringes created in field data processing only contribute to the accuracy of the AirHARP field measurement.

In Version 001, flatfield residuals are identified for each AirHARP detector to correct the extraneous optical fringes appearing on the pushbroom images for Q, U, and DOLP before gridding, in routine outside the general L1 processing structure. One set of flatfield residuals are obtained for each flight and applied to all AirHARP data acquired during that flight. With such a correction, optical fringes are significantly removed (see Figure 2), but are not totally gone for some scan angles. De-striping is applied to all polarization data in the HDF5 files, and considered default for further version releases.

In-flight flatfield calibration is proposed for future AirHARP deployments; this operation is already planned for the HARP-2 platform on the PACE mission: a field-stop diffuser combined with frequent solar calibration will counter and correct for any similar optical interference. Currently, flatfield optical interference is the largest contributor to the AirHARP error budget, and the overall contribution to DOLP and reflectance uncertainty is under study.
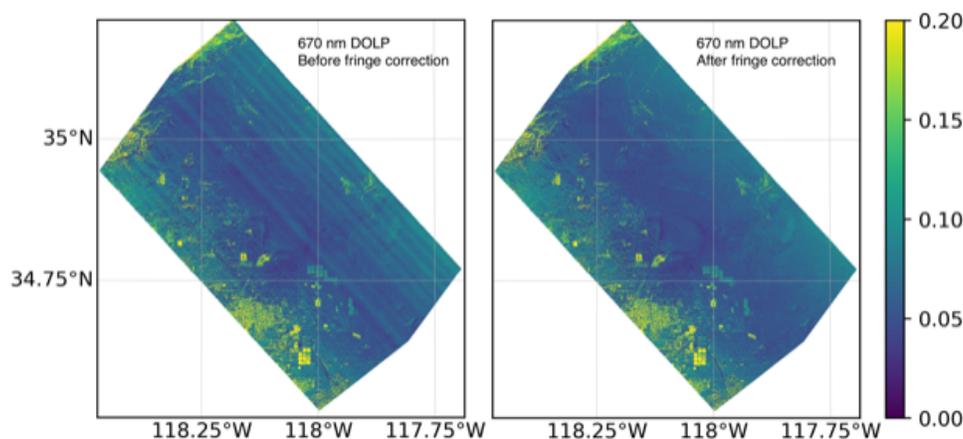

Figure 2. *Nadir gridded 670nm DOLP pushbroom sector during an ACEPOL science flight over the Rosamond Dry Lake on October 25, 2017. Note the stable linear fringes in the Version 001 L1B processed image (left) that are removed in a robust post-processing correction (right) after masking scene variability and defect sectors.*

5.2   ER-2 pitch surfing and data gaps

As a wide FOV instrument, angles further from nadir see elongated pixel projections on the ground, relative to the aircraft altitude. The L1B pushbroom processing for each angle requires that there are enough pixels per viewing angle such that two consecutive images will stitch together or overlap and form a continuous

pushbroom. The AirHARP data compression algorithm takes the nominal aircraft altitude and velocity into account when selecting how many pixels are appropriate for continuous overlap, at each viewing angle. For much of the campaign, the ER-2 aircraft performed Mach-hold, which stabilizes velocity at the expense of altitude. In turbulent regions of the atmosphere, this forces the plane to see-saw along the axis of the wings, or *pitch-surfing*, to maintain constant velocity. Pitch-surfing overextends the projection of far-forward/aft angles and leads to data gaps during pushbroom processing. This issue affects mainly the AirHARP Images collected during 19 – 27 October 2017. Data acquired on and after 1 November 2018 was taken with an expanded AirHARP data compression algorithm, mitigating the data gap issue.

5.3   Quality assurance

Defect pixels are masked with fill value in the data processing, including hot pixels, pixels with low flatfield quality, point contaminations on the detectors, and lens condensation. Defect pixel maps, identified for each of the three AirHARP detectors, are averages of over 2000 selected images acquired during the ACEPOL campaign. In some legs (such as images taken on 23 October 2017), lens condensation affects pixels from nadir to $+20^\circ$ in scan angle, resulting in a blurring effect that not only degrades the spatial resolution of the sectors, but biases the total intensity and polarization measurement in this area. This feature is considered defective; further study of the lens condensation may upgrade these regions in future releases, pending validation with other co-incident instruments. Currently, a preliminary quality flag (QFlag) is also saved in the AirHARP L1B HDF file for each scan angle and spectral band, which simply uses 0 and 1 to indicate 'bad' and 'good', respectively. Future version releases will include a hierarchy based on the quality of geolocation, calibration, and/or vicarious metrics.

6   REFERENCES

Borda, R.F., E. Waluschka, S. Pellicori, J. V. Martins, L. Ramos-Izquierdo, J.D. Cieslak, P. Thompson (2009), Evaluation of the polarization properties of a Phillips-type prism for the construction of imaging polarimeters. *Polarization Science and Remote Sensing IV.* Proc. of SPIE. **7461**, 1-13. doi:10.1117/12.829080

Kliger, D. S., J. W. Lewis, and C. E. Randall (1990), *Polarized Light in Optics and Spectroscopy.* Academic Press, 27-58.

McBride, B.A., J. V. Martins, H. M. J. Barbosa, R. F. Borda, J. Cieslak (2020), in preparation.

McBride, B. A., J.V. Martins, H. M. J. Barbosa, R. F. Borda, O. Hasekamp, M. Smit, J. Reitjens, G. van Harten, D. Diner, B. Cairns, A. Wasilewski, and L. Remer, 2018: Validations of AirHARP calibration with coincident observations from RSP, AirMSPI, and SPEX polarimeters during ACEPOL field campaign. *American Geophysical Union, Fall Meeting 2018,* Washington, D.C., 10-14 December 2018.

Xu, X., and J. Wang (2019), UNL-VRTM, A Testbed for Aerosol Remote Sensing: Model Developments and Applications, in *Springer Series in Light Scattering Volume 4*, edited by A. Kokhanovsky, pp. 1-69, Springer International Publishing, Cham

APPENDIX A. HDF USERS GUIDE

AirHARP L1B products are in HDF5 format. The AirHARP HDF skeleton can be externally viewed using free software like HDFView (https://support.hdfgroup.org/products/java/hdfview/). An example reader is provided in the Appendix C of this document. The filenames are in the required ICARTT format on the NASA ACEPOL data archive (https://www-air.larc.nasa.gov/missions/acepol/index.html) .

File names for the AirHARP L1B data are defined as follows:

ACEPOL-AIRHARP-L1B_ER2_YYYYMMDDhhmmss_R[x].h5

Where the fields are described as follows:
YYYY: four-digit year
MM: two-digit month
DD: two-digit day
hh: two-digit UTC hour
mm: two-digit minute
ss: two-digit second
R: revision number of data

The HDF is comprised of four internal master folders: **Coordinates, blue, green, nir, red**. The Coordinates folder includes the gridded Latitude and Longitude matrices for the dataset. All information included in this HDF can be projected and displayed using these two coordinate matrices. The Latitude and Longitude files themselves include *attributes*, as shown in Figure 3, in a screenshot from HDFview.

Latitude and Longitude coordinate datasets are in floating-point format with a 2D shape of along-track x cross-track (1756 × 966 for this file). Fill value ("_Fillvalue") is assigned to regions of no data. Longitude includes different values with the same structure.
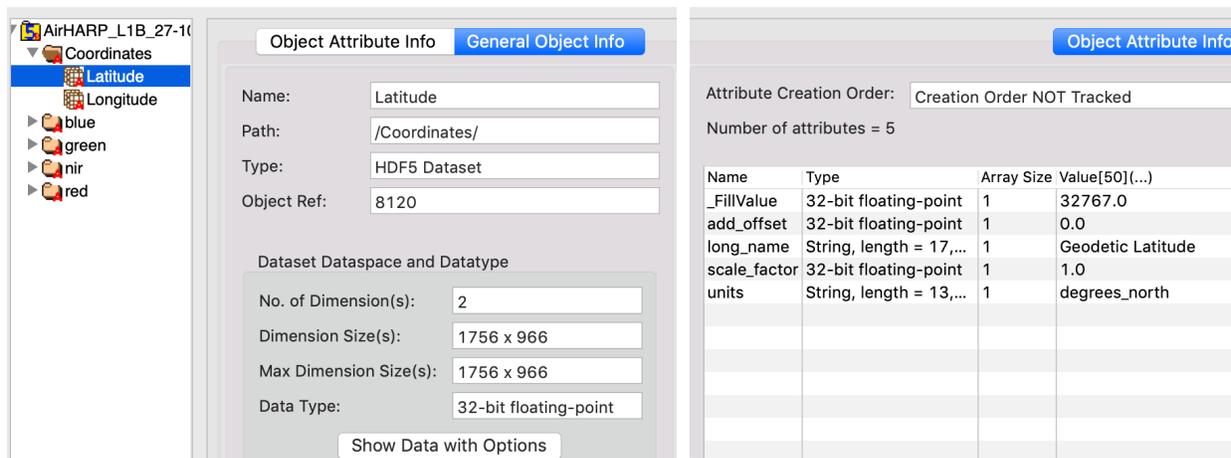

Figure 3. *AirHARP L1B HDF file structure, with Latitude dataset selected. Note the attributes listed in right table of the image, corresponding with the Latitude variable.*
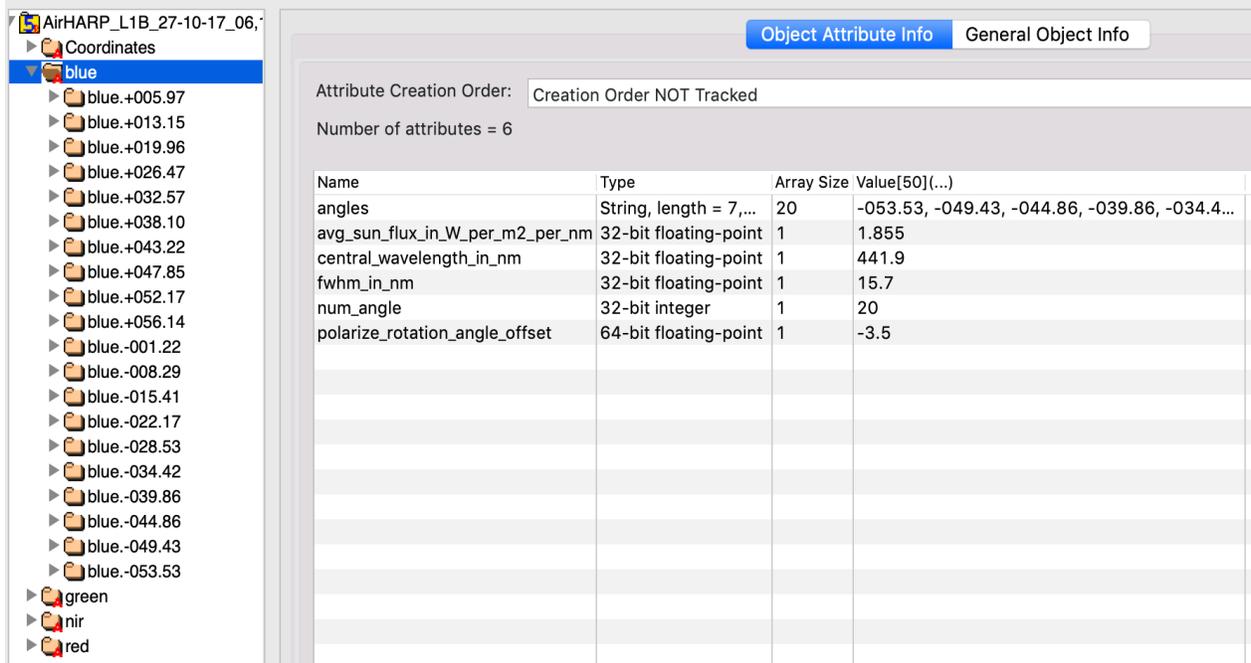
Figure 4. *AirHARP L1B HDF file structure, with blue internal master folder selected. Note the attributes listed in the right table of the image, corresponding with the blue wavelength.*

The other four internal master data folders include the polarization and viewing geometry information for each wavelength and viewing angle. Figure 4 outlines the structure of the blue folder, as an example. Inside the blue internal master folder, there are 20 unique data folders, corresponding to the 20 blue global viewing angles in the detector. The angle given in the filename corresponds to the nominal scan angle. It should be noted that it does not represent the viewing zenith angle for the entire image. Plus (+) and minus (-) characters before the angle signify the observation is toward the top of the detector (forward, +) or toward the bottom of the detector (aft, -).

Similarly, green and nir internal master folders have the same amount of data as the blue master folder, as they sample 20 global viewing angle locations in the detector. The red internal master folder contains 3x as much information due to observations at 60 unique detector viewing angles. Note the nominal viewing angles for the blue wavelength are unique and will not be shared with green, nir, or red because they reference unique rows of detector pixels; the same goes for the view angles for other wavelengths.

Note in the attributes for the blue in the gray box of Figure 4, the equivalent square-band extraterrestrial solar irradiance (avg_sun_flux_in_W_per_m2_per_nm, W m^{-2} nm^{-1}), spectral bandwidth (fwhm_in_nm), global viewing angle number density in the detector (num_angle), view angle values (angles), and center wavelength (wavelength, nm). All other fields are for internal checking. Green, nir, and red internal master folders all have different values but similar structure to their attributes.

Figure 5 examines the internal structure of the blue scan angle sub-folder (blue.+005.97). Inside each sub-folder, the gridded and calibrated polarization fields are included (see Figure 5): the degree of linear polarization (DOLP), the radiances as characterized by the first three Stokes-vector parameters (I, Q, and U), and the quality assurance flag (QFlag), as well as the information on the solar zenith (solzen), solar azimuth (solaz), viewing zenith (zen), and viewing azimuth (az) gridded fields.

Figure 5 (left). *AirHARP L1B HDF file structure, with the I measurement at the unique viewing angle +5.97° for the blue wavelength. Note the attributes listed in the right table of the image, corresponding with this measurement matches the structure seen in Figure 3.*

All data fields in the AirHARP HDF are optimized to minimize total HDF file size; all float32 data values are scaled and offset to maximize the resolution of their int16 packaged format. These **scale_factor and add_offset** parameters are included as attributes in Figure 3 and are such for all files in the HDF. Equation 1 defines how these are applied:

$$\text{DATA}_{\text{float32}} = \text{DATA}_{\text{int16}} \times \text{scale}_{\text{factor}} + \text{add}_{\text{offset}}. \tag{1}$$

All AirHARP data files in the HDF require scaling and offset before science use.

APPENDIX B. MANIPULATION OF POLARIZATION PARAMETERS

The AirHARP/ACEPOL Level-1 products provide the first three parameters (I, Q, and U) of the Stokes vector. I is the total radiance, and the polarized radiance can be calculated by $I_p = \sqrt{Q^2 + U^2}$. Also provided is the degree of linear polarization (DOLP) as defined by

$$\text{DOLP} = \frac{I_p}{I} = \frac{\sqrt{Q^2 + U^2}}{I}. \tag{2}$$

The reported Stokes vector in the HDF file is with respect to the reference frame defined by the local view meridian plane, i.e., the plane containing the viewing direction and the local zenith. Under this reference frame, the angle of polarization (χ) can be calculated by

$$\chi = \frac{1}{2}\arctan\left(\frac{U}{Q}\right), \quad \text{with } \chi = \chi + \frac{\pi}{2} \text{ if } Q < 0. \tag{3}$$

One can convert the Stokes vector from the view meridian plane to the scattering plane (the plane containing the sun beam and view direction). While I and DOLP remain unchanged for such conversion, Q and U (as denoted with primes in the scattering plane) are transformed by rotating through an angle σ via (see Xu and Wang, 2019 for details)

$$Q' = Q \cos 2\alpha + U \sin 2\alpha; \quad U' = -Q \sin 2\alpha + U \cos 2\alpha, \tag{4}$$

where the rotation angle σ is related to the solar zenith θ_0, view zenith θ, and relative azimuth angle ϕ by

$$\tan \alpha = \frac{\sin \phi}{\frac{\sin\theta\cos\theta_0}{\sin\theta_0} - \cos\theta \cos\phi}. \tag{5}$$

APPENDIX C. PYTHON SCRIPT TO READ AirHARP L1B HDF

Below is an example Python 3 script to read "DOLP" from the V002 AirHARP Level 1B data product.

```python
"""
    This script contains a group of functions that read geolcation and a
    variable of generated AirHARP L1B HDF5 data products.
    (xxu, 4/26/2019; xxu@umbc.edu)
"""

#-----------------------------------------------------------------------#
# Utility functions:
#-----------------------------------------------------------------------#

######
def _apply_scale_and_offset(dataset_array,scale,offset,missnum):
    """
    Function to rectify airHARP dataset values after applying scale and offsets
    """
    import numpy as np

    miss_index = (dataset_array==int(missnum))
    dataset_array = dataset_array.astype(np.float32)
    dataset_array[miss_index] = np.nan

    return (dataset_array*scale) + offset

# function to get scale, missing value, and offsets for airHARP data
def _scale_offset_missnum(dset_attr,key):
    """
    Function to get scale, missing value, or offsets for airHARP data
    """
    import numpy as np

    return np.float([v for k,v in (dset_attr.items()) if k == key][0])

#-----------------------------------------------------------------------#
# Main:
#-----------------------------------------------------------------------#
if __name__ == "__main__":

    #-- required python modules
    import numpy as np
    import h5py

    #-- specify the AirHARP Level-1B hdf filename, the band, and angle index
    airharp_hdf = '/mnt/SSD_860EVO/hippruns/v1.4/' \
                + 'ACEPOL-AIRHARP-L1B_ER2_20171025175722_R2.h5'

    #-- specify the variable name, bandname, and angle index to be grabbed
    # variable names can be "I", "Q", 'U', "DOLP", "zen", etc.
    grab_var    = 'DOLP'

    # band name is from ['green', 'red', 'nir', 'blue']
    grab_band   = 'red'
```

```
# index for the selected band, can be 0–19 for green, nir, and blue bands,
# and 0–59 for red band.
grab_angle  = 29

#-- h5py engages the file
f = h5py.File(airharp_hdf,'r')

#-- get grids, note that coordinate variables are not scaled in hdf
dset_lons  = f.get('/Coordinates' ).get('Longitude')
dset_lats  = f.get('/Coordinates' ).get('Latitude')
lons       = np.array(dset_lons)
lats       = np.array(dset_lats)

#-- retrieve angle name for specified band and angle index
grp_band   = f.get( grab_band )
angle_set  = np.array( grp_band.attrs['angles'] ).astype(str)
angle_name = grab_band + '.' + angle_set[grab_angle]

#-- engage with the angle group in hdf, and grab the dataset
grp_angle  = grp_band.get( angle_name )
dset       = grp_angle.get( grab_var )

#-- apply scale, offset, and fillvalue
data       = _apply_scale_and_offset(
                np.array(dset),
                _scale_offset_missnum(dset.attrs, "scale_factor" ),
                _scale_offset_missnum(dset.attrs, "add_offset"   ),
                _scale_offset_missnum(dset.attrs, "_FillValue"   ) )

#-- close the hdf file
f.close()

#-- screen print ...
print("The following variables have been read:" )
print(" -lons with size: {:d}x{:d}".format(lons.shape[0],lons.shape[1]) )
print(" -lats with size: {:d}x{:d}".format(lats.shape[0], lats.shape[1]) )
print(" -{:} with size: {:d}x{:d}".format(grab_var, data.shape[0], data.shape[1]))
```