JPL D-101481

MSPI

Multiangle SpectroPolarimetric Imager

AirMSPI Level 2 Cloud Droplet Size and Cloud Optical Depth Product Quality Statement: ORACLES Campaign

Gerard van Harten, Feng Xu, David J. Diner (PI), James L. McDuffie, Irina N. Tkatcheva, Michael J. Garay, Abigail M. Nastan
Corresponding author: David.J.Diner@jpl.nasa.gov

Jet Propulsion Laboratory
California Institute of Technology

17 January 2018

Campaign	
Name	ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS)
Dates	28 July - 6 October 2016
Locations	California (US), Georgia (US), Walvis Bay (Namibia), South Atlantic Ocean off the coast of Namibia and Angola.
ER-2 #809 remote sensing instruments	AirMSPI, HSRL-2, SSFR, RSP, eMAS, APS
Publications	http://doi.org/10.5194/amt-6-2007-2013

AirMSPI Overview of Data Processing to Level 2	
Data	http://doi.org/10.5067/AIRCRAFT/ORACLES/CLOUD/AirMSPI
Data Delivery Version	V001
PGE Software Version	v1.01
Level 1 (L1) Data	http://doi.org/10.5067/AIRCRAFT/ORACLES/RADIANCE/AirMSPI
L1 Data Delivery Version	V006

JPL D-101481

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)

AirMSPI Level 2 Cloud Droplet Size and Cloud Optical Depth Product Quality Statement: ORACLES Campaign

APPROVALS:

David J. Diner

AirMSPI Principal Investigator

Approval signatures are on file with the AirMSPI Project.
To determine the latest released version of this document, consult the AirMSPI website (http://airbornescience.jpl.nasa.gov/instruments/airmspi/).

Jet Propulsion Laboratory
California Institute of Technology

Document Change Log

Revision	Date	Affected Portions and Description
Original release	17 January 2018	

Which Product Versions Does this Document Cover?

Product Filename Prefix	Version Number in Filename	Brief Description
AirMSPI_ER2_CLOUD_DROPLET	V001	L2 ellipsoid-projected georegistered liquid water cloud droplet size and cloud optical depth

TABLE OF CONTENTS

1 INTRODUCTION

The purpose of this document is to describe the data quality of the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) Level 2 cloud products specifically for the ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) field campaign. ORACLES took place in Jul-Oct 2016, including preceding check flights over the US and transit flights to and from Walvisbay, Namibia. The science flights were performed over the southeast Atlantic Ocean off the coast of Namibia and Angola from the National Aeronautics and Space Administration (NASA) ER-2 high-altitude research aircraft.

1.1 AirMSPI L2 Cloud Products

The AirMSPI Level 2 (L2) liquid water cloud products contain a droplet size distribution (DSD), parametrized by an effective radius (r_{eff}) and effective variance (v_{eff}) of a gamma size distribution, as well as a spatially resolved cloud optical depth (COD) at 470, 660 and 865 nm. These L2 products are derived from L1B2 radiometric and polarimetric data taken in the instrument's continuous sweep mode with 25 m spatial sampling. Along with the L2 products, their retrieval uncertainties are reported, as propagated from the relevant uncertainties in the radiometric (systematic calibration uncertainty) and polarimetric (random measurement uncertainty) data. Files are distributed in NetCDF4 format.

1.2 AirMSPI Data Processing and Distribution

The MISR Science Computing Facility (SCF) at the Jet Propulsion Laboratory (JPL) supports the development of AirMSPI science algorithms and software, instrument calibration and performance assessment, and also provides quality assessment and data validation services with respect to AirMSPI Science Data Processing (SDP). The MISR SCF is used to perform the standard processing of the AirMSPI data. After AirMSPI data processing is complete, the standard output products are archived and made available to users via the Langley Research Center (LaRC) Atmospheric Science Data Center (ASDC) client services. See https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table.

1.3 Controlling Documents

1) Cloud Droplet Size and Cloud Optical Depth Retrieval Algorithm Theoretical Basis, JPL D-100521, January 2018

1.4 Related Documents

1) AirMSPI Data Quality Statement: ORACLES Campaign, JPL D-100522, June 2017
2) Data Product Specification for the AirMSPI Level 1B2 Products V006, JPL D-100523 rev C, June 2017
3) User Guide for the AirMSPI Level 1B2 Products, JPL D-78962, April 2014 (or latest version).

2 DATA APPLICABILITY AND LIMITATIONS

2.1 Liquid water clouds over ocean

The applicability of these L2 products is limited to liquid water clouds over an ocean surface. The presence of e.g. ice clouds or land surface may contaminate the L2 products (see Section 2.5).

2.2 Cloud mask

Only cloudy pixels in L1 AirMSPI imagery are used for the L2 cloud retrievals. The identification of cloudy pixels utilizes the radiometric contrast at 660 nm between clouds and an ocean background. Land surface, often significantly brighter than ocean, may be misinterpreted for a cloud. Care was taken to filter out products containing land surface.

Each L2 file contains the cloud mask that was used to perform the corresponding cloud retrievals. To check the validity of a specific cloud mask, the user is referred to the corresponding L1 data products, including JPEG quicklook imagery, which reside alongside the L2 data.

2.3 Retrieval Quality Indicator

Each L2 file reports a Retrieval Quality Indicator (RQI) for the droplet size distribution retrieval. The definitions are as follows:

RQI=1: Successful retrieval, meaning that (a) both effective radius and variance are within their bounds, and (b) the Chi-square fitting error is smaller than the criterion value.

RQI=2: (a) is violated: effective radius and / or variance are / is not within bounds.

RQI=3: (b) is violated: Chi-square fitting error is larger than criterion value.

RQI=4: Retrieval did not converge within maximum number of iterations.

RQI=5: Retrieval not performed: not enough data.

Caution should be applied when using data with RQI≠1. Droplet size distribution parameters r_{eff} and v_{eff} are reported regardless of the RQI value. Cloud optical depth (COD) is only reported if RQI=1, i.e. if the droplet size distribution was successfully retrieved.

Even if RQI=1, the user may want to check the validity of the droplet size distribution retrieval. For example, even though the number of data points was large enough to perform a retrieval, it may still be sparse or sampling only part of the polarized cloudbow fringe pattern. To this end, the observed phase function and the best fitting model are reported in the L2 files.

The distribution of RQI values for the ORACLES field campaign is shown in Figure 1. 828 out of 1002 files contain successful retrievals of droplet size distribution and cloud optical depth, whereas the remaining 17% have RQI≠1.

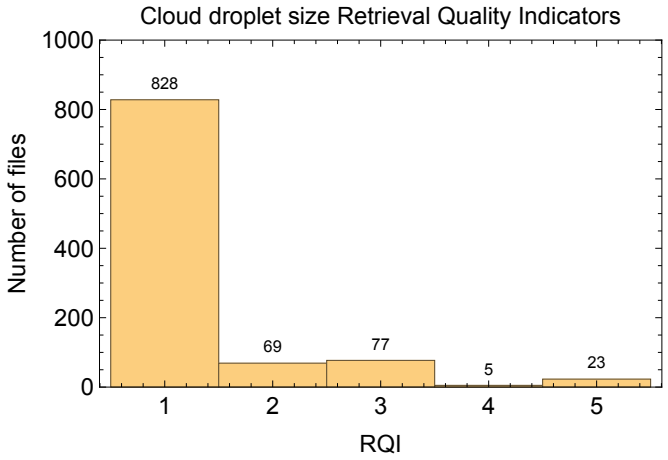

Figure 1: RQI distribution for the ORACLES field campaign

2.4 Cloud droplet size distribution spatial resolution

For each L2 file, a single, image-wide cloud droplet size distribution is retrieved, described by one r_{eff} and one v_{eff}. However, these values are reported as spatially resolved images, in preparation for future spatially resolved retrievals.

The cloud DSD is retrieved from the cloudy pixels within the cloudbow region with scattering angles within 135-160°. This region typically spans an area of 200-500 km^2, depending on viewing geometry and the number of cloudy pixels. For the interpretation of the droplet size parameters, it is important to note that v_{eff} has dependence on the size of the cloudbow area, because it describes the larger-scale spatial cloud heterogeneity in addition to small-scale droplet size variability; r_{eff} has no intrinsic scale dependence.

2.5 Errors due to scene contents

A variety of scene contents can cause errors in the cloud optical depth product, for example:

- Land surface, visible next to the cloud, mistakenly classified as cloud by the cloud mask.
- Thin clouds, transmitting light from the underlying surface.
- Ice cloud above the liquid water cloud, or next to the liquid water cloud but classified as cloud.
- Aerosols above the cloud.
- 3D radiative effects including radiative smoothing, sub-pixel cloud inhomogeneity.
- Vertical heterogeneity of cloud droplet size distribution.

Any pixels outside the actual liquid water cloud which are mistakenly classified as cloud will report a non-physical cloud optical depth, but these will not affect the COD retrievals for the actual cloudy pixels. On the other hand, thin clouds, ice clouds above the liquid water cloud, aerosols above the cloud, and 3D effects in broken clouds alter the observed reflectance, which is used to retrieve COD. The uncertainty due to 3D effects for flat clouds, typically observed during the ORACLES campaign, is on the order of 20%, as explained in Cornet et al (2017). Xu et al (2017) show that the error due to aerosols, specifically for the absorbing aerosol loadings observed during the ORACLES campaign, is an underestimate of COD of about 15%.

None of the aforementioned scene contents have a significant effect on the droplet size distribution parameters r_{eff} and v_{eff}. This retrieval is robust (in contrast to the Nakajima-King method which uses total reflectance) thanks to the utilization of a characteristic fringe pattern in the polarized reflectance around the cloudbow scattering angles, which originates from an interference effect in liquid water cloud droplets only. The DSD is derived from the shape of the polarized reflectance in terms of the angular location, the width and the contrast of the fringes (see Fig. 2). Offsets and linear gradients in the polarized reflectance, caused by e.g. polarimetric calibration errors or aerosols and atmosphere above the cloud, are accounted for in the cloudbow fits. Pixels with outlying polarized reflectance values, e.g. due to surface contributions in open cloud structures, can degrade the fringe-fit quality. However, for the scenes acquired during the ORACLES campaign, only a small fraction of the pixels are outliers after applying the cloud mask, thus causing no significant errors in the DSD.

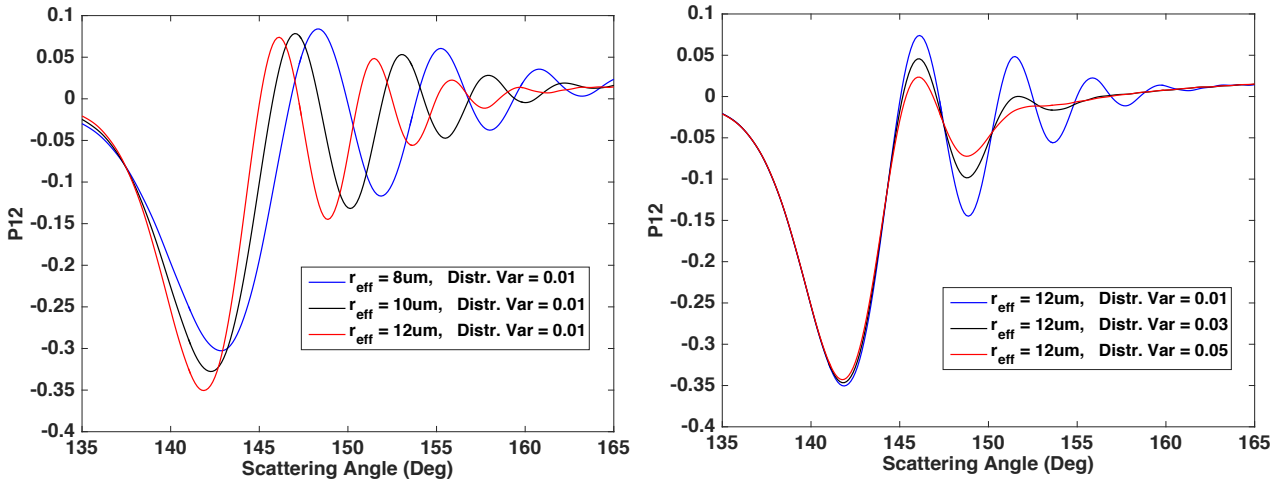

Figure 2: Polarized reflectance pattern at cloudbow scattering angles, calculated using Mie theory. The dependence of the fringes' locations, widths, and contrast forms the basis of the droplet size distribution retrieval from polarized reflectance. The different curves show the effect of gamma size distributions with different effective radii (left) and different effective variances

3 REFERENCES

Diner, D.J., F. Xu, M.J. Garay, J.V. Martonchik, B.E. Rheingans, S. Geier, A. Davis, B.R. Hancock, V.M. Jovanovic, M.A. Bull, K. Capraro, R.A. Chipman, and S.C. McClain. The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI): a new tool for aerosol and cloud remote sensing. *Atmos. Meas. Tech*. **6**, 2007-2025 (2013).

Jovanovic, V.M., M. Bull, D.J. Diner, S. Geier, and B. Rheingans. Automated data production for a novel Airborne Multiangle SpectroPolarimetric Imager (AirMSPI). *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, **XXXIX-B1**, 33-38 (2012).

Cornet, C., L. C. Labonnote, F. Szczap, L. Deaconu, F. Waquet, F. Parol, C. Vanbauce, F. Thieuleux, and J. Riédi. Cloud heterogeneity effects on cloud and aerosol above cloud properties retrieved from simulated total and polarized reflectances. *Atmos. Meas. Tech. Discuss.*, https://doi.org/10.5194/amt-2017-413, in review (2017).

Xu, F., G. van Harten, D. J. Diner, A. B. Davis, F. C. Seidel, B. Rheingans, M. Tosca, M. D. Alexandrov, B. Cairns, R. A. Ferrare, S. P. Burton, M. A. Fenn, C. A. Hostetler, R. Wood, and J. Redemann. Coupled Retrieval of Liquid Water Cloud and Aerosol Above Cloud Properties using the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI). *Journal of Geophysical Research*, in review (2017).

4 APPENDIX A

Acronym List:

AirMSPI	Airborne Multiangle SpectroPolarimetric Imager
ASDC	Atmospheric Science Data Center
COD	Cloud Optical Depth
DSD	Droplet Size Distribution
JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center (NASA)
MISR	Multi-angle Imaging SpectroRadiometer
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
ORACLES	ObseRvations of Aerosols above CLouds and their intEractionS
RQI	Radiometric Quality Indicator
SCF	Science Computing Facility
SDP	Science Data Processing