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Macquarie Island Cloud and Radiation Experiment (MICRE) Field Campaign Report

R Marchand

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ARM

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R Marchand, University of Washington
Principal Investigator

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Executive Summary

The U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility, the Australian Antarctic Division (AAD), and the Australian Bureau of Meteorology (BOM) collaborated in deploying a variety of ground instrumentation to Macquarie Island between March 2016 and March 2018. Macquarie Island is located at 54.5° S, 158.9° E and is well situated for studying clouds over the Southern Ocean. The primary objective of the March 2016 to March 2018 deployment, hereafter the Macquarie Island Cloud and Radiation Experiment (MICRE), was to collect observations of surface radiation, cloud, precipitation, and aerosol properties.

This report describes the instruments deployed and data sets collected, along with a summary of key data quality issues and information on some value-added products that are being developed to assist scientists in using the data.

Acronyms and Abbreviations

AAD	Australian Antarctic Division
ARM	Atmospheric Radiation Measurement
BOM	Australian Bureau of Meteorology
CAPRICORN	Clouds, Aerosols, Precipitation, Radiation, and Atmospheric Composition over the Southern Ocean
CCN	cloud condensation nuclei particle counter
CPC	condensation particle counter
CPP VAP	Cloud and Precipitation Parameters Value-Added Product
DQPR	Data Quality Problem Report
DQR	Data Quality Report
EP VAP	Environmental Parameters Value-Added Product
GMT	Greenwich Mean Time
GNDRAD	ground radiometers on stand for upwelling radiation
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory Model
INP	ice nucleating particle
LCL	lifting condensation level
LTS	lower tropospheric stability
LW	longwave
LWP	liquid water path
MARCUS	Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean
MCAO	marine cold air outbreak
MFRSR	multi-filter rotating shadowband radiometer
MICRE	Macquarie Island Cloud and Radiation Experiment
MWR	microwave radiometer
MWRRET	microwave radiometer retrievals
NetCDF	Network Common Data Form
PC	primary contact
PF	polar front
PIRAT	Parsivel Improved Rate and Type
PWV	precipitable water vapor
SKYRAD	sky radiometers on stand for downwelling radiation
S/N	signal-to-noise ratio
SO	Southern Ocean
SOCRATES	Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study
SST	sea surface temperature
SW	shortwave
UTC	Coordinated Universal Time
VAP	value-added product

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1.0 Introduction

Clouds over the Southern Ocean (SO) differ from those over the Northern Hemisphere oceans, with low-altitude supercool clouds being more ubiquitous over the SO (Mace et al. 2009, 2010; Huang et al. 2016). Global climate model simulations (Trenberth and Fasullo 2010) and reanalysis products (Naud et al. 2014) struggle to represent these clouds, and in recent years, a lack of low cloud over the Southern Ocean, primarily in the cold sector of cyclonic systems, has been found to result in large radiative errors in both climate models and reanalysis (Williams et al. 2013, Naud et al. 2014, Bodas-Salcedo et al. 2014, 2016; Kay et al 2016). These cloud radiative errors result in significant errors in the surface energy budget and excess heat uptake by the ocean surface (Sallée et al. 2013, Schneider and Reusch 2016), and are of profound importance to global climate, including influencing the position of the Southern Hemisphere midlatitude jet, the Intertropical Convergence Zone position, cross-hemispheric energy transports (Ceppi et al. 2012, 2013; Hwang and Frierson 2013, Kay et al 2016), and even SO cloud feedbacks and global climate sensitivity (Gettelman et al 2019b, Bodas-Salcedo et al. 2019). In addition, the remoteness of the SO from anthropogenic and natural continental aerosol sources makes the SO a unique venue to improve our understanding of cloud aerosol interactions, and the role of marine biogenic aerosols and their precursors. Despite the importance and the challenge of simulating cloud and aerosol effects over the SO, there have been only sparse and infrequent observations in this region. Observations are sorely needed to improve process-level understanding of atmospheric processes, and their representations in models.

In response to the need for additional measurements of surface radiative fluxes, as well as cloud, precipitation, and aerosol properties over the Southern Ocean, the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility, the Australian Antarctic Division (AAD), and the Australian Bureau of Meteorology (BOM) collaborated in deploying a variety of ground instrumentation to Macquarie Island between March 2016 and March 2018. Macquarie Island is located at 54.5° S, 158.9° E and has a small research station operated by the AAD that is staffed year-round, in part by the BOM. The station supports a variety of research activities and includes a long history of surface weather and radiosonde observations (Hande et al. 2012, Wang et al. 2015).

The primary objective of the March 2016 to March 2018 deployment, hereafter the Macquarie Island Cloud and Radiation Experiment (MICRE), was to collect observations of surface radiation, cloud, precipitation, and aerosol properties. These could then be used evaluate satellite data sets, improve knowledge of diurnal and seasonal variations in cloud and aerosol properties (especially as pertains to the vertical structure of boundary-layer clouds, precipitation, and the pervasive supercool liquid clouds that occupy this region), and eventually enable more detailed modeling studies that will improve model representations of key aerosol, cloud, and precipitation processes.

MICRE is part of a set of coordinated Southern Ocean experiments. Specifically, these are the aircraft-based Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES) and ship-based Measurements of Aerosols Radiation and Clouds over the Southern Ocean (MARCUS) and Australian-funded Clouds, Aerosols, Precipitation, Radiation, and Atmospheric Composition over the Southern Ocean (CAPRICORN) II projects. MICRE's key contribution to this collection of experiments derives from its longer duration, which provides a longer sampling interval for the evaluation of satellite data and a seasonal and diurnal context from which to understand the aircraft- and ship-based observations.

2.0 Instrumentation

Instruments deployed during MICRE (by BOM, AAD, ARM, and some additional individual investigators) are listed in Table 1. In short, the observational data include (i) observations of passive surface radiation (solar, longwave, microwave), (ii) precipitation rain rates, types and particle size from a precipitation disdrometer (iii) cloud radar reflectivity and Doppler velocity, along with ceilometer and lidar backscatter (including depolarization) that provide information on cloud occurrence, cloud-base height, cloud and precipitation particle size and phase, and (iv) surface measurements of total aerosol number concentration, cloud condensation number concentration, and ice nucleating particle (INP) number concentration from contributors Ruhi Humphries and Paul DeMott.

Data from all ARM instruments are available through the ARM Data Center. Data from non-ARM instruments, as well as many derived fields from the Principal Investigator (Dr. Marchand) and contributing investigators at BOM and AAD, will eventually be available through the ARM Data Center as principal investigator value-added-products (VAPs). As of the date of this report, these VAP data are still being developed. Developmental versions of these data are publicly available to interested users on Dr. Marchand's web site. Details on the VAP contents are given in Section 4.

Table 1. MICRE instruments. Dates listed for each instrument denote periods for which high-quality data are generally available, though all instruments have occasional "drop-outs" where data is missing or of poor quality for a few hours or days. "PC" denotes the primary contact for non-ARM instruments. "ARM" denotes the name of the ARM datastream (which can be used to quickly find these data in the ARM Data Center).

MICRE instrumentation	Data availability	References/notes
94 GHz cloud radar (BASTA)	20160402 − 20170317 (First year only)	Delanoë et al. 2016 Mace and Protat 2018 PC: Alain Protat (BOM)
AAD **polarization lidar**	20160407 − 20161127 20170401 − 20180313	See note 1 PC: Simon Alexander (AAD)
Vaisala **ceilometer** ARM	20160402 − 20161214 20170222 − 20180313	Vaisala Model CT25K Münkel et al. 2007 ARM: mcqceilS1.b1
U. Canterbury	20160402 − 20180313	PC: Adrian McDonald (UC)
Microwave radiometers: ARM **3 channel** ARM **2 channel**	20160402 − 20160613 20161228 − 20180313	Cadeddu et al. 2013 See note 2
ARM **disdrometer** (OTT Parsivel2)	20160402 − 20180313 (see note 3)	Angulo-Martínez et al. 2018 ARM: mcqpars2S1.b1
Broadband Shortwave (SW) and longwave (LW) fluxes (SKYRAD, GNDRAD)	20160403 − 20180313 (LW see notes 4, 5)	Andreas et al. 2018 ARM: mcqskyrad60sS1.b1, mcqgndrad60sS1.b1
CIMEL sun photometer	20160403 − 20180311	Holben et al. 1998 ARM: mcqcsphot
Multi-filter rotating shadowband radiometer (MFRSR)	Failed (see note 6) 20160321 − 20160810 20160915 − 20180313	ARM: mcqmfrsrS1

Other data		
Surface INP filter samples	2nd year only	Two-week samples DeMott et al. 2018
Surface condensation particle counter (CPC) and cloud condensation nuclei particle counter (CCN)	Both years Both years	PC: Ruhi Humphries Twice per day, 0 and 12 UTC
BOM radiosondes	Both years	PC: Simon Alexander (AAD)
AAD surface meteorological instruments		

Table notes:
1: The AAD-lidar failed in fall of 2016. The instrument was fixed and redeployed in Spring 2017. Calibration issues (primarily with depolarization) remain and are under study.
2: LWP and PWV retrieved via physical-iterative technique (Marchand et al. 2003) is included in the CPP VAP (Section 4). Raw brightness temperatures are in ARM Data Center but be aware of some unusual interference noise with these data (Section 3). For 3-channel microwave radiometer (MWR), these raw data are only instrument-level files (not NetCDF). Current plans are for the ARM standard MWRRET retrieval to be run on the 2-channel data.
3: For unknown reasons the Parsivel reset to a previous output mode starting on 20161031 that was incompatible with the ARM ingest. This caused bad/corrupt data in several fields, most notably the precipitation rate, liquid water content, total number of particles, and weather codes (DQR D170524.7 / DPQR 6227). In general the Parsivel vendor's algorithm did not work well during MICRE and additional processing was undertaken by Marchand and Tansey (see Section 4).
4: Upwelling and downwelling LW fluxes are biased or bad from start of experiment until 20060815. Upwelling LW is suspect for several more weeks until 20160908, but downwelling is fine after 20060815.
5: Two radiometers for broadband LW were deployed. Their measurements agree well except in two time windows, where radiometer 2 has a value 2% lower than radiometer 1 and appears to be incorrect.
6: MFRSR collected data for much of the experiment, but the rotating shadow band was not initially aligned well and the rotating band eventually failed completely. Narrowband radiances during cloudy period might be used but the data are uncalibrated because of the inability to carry out a Langley analysis. Use with great caution.

3.0   Overview of ARM Instrument Data Quality

Much of the ARM instrumentation was operational by April 4, 2016. All of the instruments, however, suffered some difficulties or down time during the experiment, and several instruments had to be replaced during the fall or spring resupply voyages. Users of the instrument-level data are advised to read associated ARM instrument data quality reports. A variety of key issues are noted at the bottom of Table 1. In this section, we discuss further some additional issues related to the MWR and Parsivel disdrometer.

Passive microwave radiometer

The MWR data record is perhaps the most problematic of the ARM data sets. A 2-channel and a 3-channel radiometer was deployed to Macquarie Island. The 2-channel failed on arrival. The 3-channel worked initially, but it also failed on June 13, 2016. A second 2-channel instrument was deployed as part of the November 2016 resupply. Problems with the power supply stability (ground faults) resulted in

limited data collection by the replacement until December 28, 2016. Once these problems were solved, the instrument worked admirably until the end of the deployment in March 2018.

All MWR measurements suffered from interference from an unknown source that caused periodic spikes in the measurements at all frequencies (23, 30, and 89 GHz). An example is shown below in Figure 1. While the spikes are obvious during periods with little cloud water (e.g., on the right half of the figure in the top panel), they are difficult to see during periods with significant variation in cloud water (i.e., on the right half). However, the spikes are regularly spaced, and PI Marchand developed a filter to remove the spikes from retrievals for cloud liquid water path and precipitable water vapor.
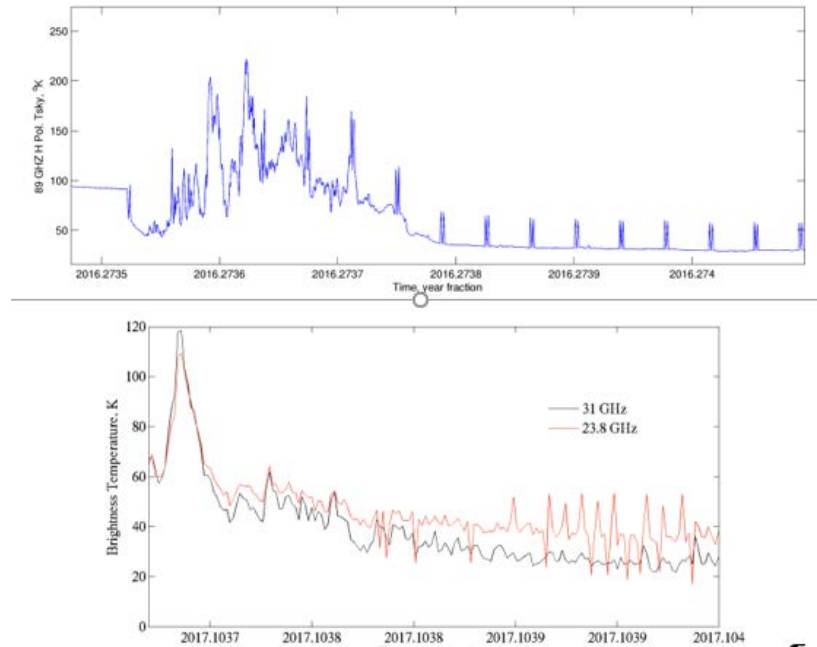

Figure 1.   Example of noise spikes in 3-channel 89 GHz (top) and 2-channel data (bottom).

Parsivel laser disdrometer

The Parsivel disdrometer did not function particularly well during MICRE. The data were found to have considerable wind-driven artifacts and did not perform well during periods with solid (ice) or mixed-phase precipitation. It appears that the manufacturer's algorithms treat all precipitation as liquid phase. In addition, for unknown reasons the Parsivel reset to an unexpected output mode on 20161031 that was incompatible with the ARM data logger configuration. This resulted in bad/corrupt data in several fields, which was not noticed at the time. Most notably this included the precipitation rate, liquid water content, total number of particles, and weather codes (which contain information on the precipitation type).

Consequently, considerable effort has been devoted by University of Washington graduate student, Emily Tansey, in developing an improved algorithm called "Parsivel Improved Rate and Type" or PIRAT. The algorithm is undergoing final development work now and publication of results is expected in the next few months. The PIRAT data are included in the value-added products described below.

4.0   Value-Added Products

Under support from the ASR program and as part of the MARCUS and MICRE campaigns, an Environmental Parameters Value-Added Product (EP VAP) as well as a Cloud and Precipitation Parameters Value-Added Product (CPP VAP) is being generated. The purpose of this value-added data set is to advance scientific studies associated with the MARCUS and MICRE campaigns, as well as to provide a vehicle to ensure that non-ARM data sets are data quality controlled and archived by ARM.

Work on these VAPS is not complete. In particular, for the CPP VAP the plan is to include cloud-base and sub-cloud precipitation phase (liquid versus ice) based on lidar-depolarization measurements, and potentially daytime cloud microphysics based on microwave radiometer and broadband SW fluxes. We hope to have the depolarization-based phase soon. For the EP VAP, the plan is to include some aerosol fields, which are not yet in place. For MICRE this will include only surface CCN and condensation nuclei counts. These data were received by the PI only in the past month and have not yet been quality controlled.

The next two subsections list the contents of each VAP (as they stand presently). When completed, these VAP products will be placed in the ARM Data Center, but for now developmental versions are available via PI Marchand's website at the link below. This site also contains documentation describing the contents (and retrieval techniques) in greater detail.

https://atmos.uw.edu/~roj/nobackup/MARCUS_and_MICRE/

4.1   CPP VAP

The contents of the VAP are listed in Table 2. The data are organized by DATA_SOURCE (defined as an instrument or retrieval) where the data source is in capital letters and the associated variables are in small letters. For example, the data file contains the variable "RADAR_time_gmt", which is the time of day (in GMT hours) associated with all the RADAR variables. Many but not all of the variables are tied to the radar time-grid.

Please note that most of the DATA_SOURCE categories have a data_quality field. This is a bit-packed variable, where a value of 0 means "no known problems or concerns" and all other values mean there is a potential problem or concern. The file metadata explains each bit in the data_quality field. Additional details on the retrievals are given in the online documentation.

Table 2.   Contents of CP VAP file. Units and other metadata are included in the NetCDF file.

Data source	Variables	Notes:
RADAR Radar measurements	time_gmt data_quality_flag height reflectivity_masked mean_Doppler_velocity	Radar data have been processed to remove coupling artifacts and clutter.
RADAR_LIDAR_BOUNDARIES	time_gmt data_qualtity_flag n_layers (number of layers)	Time sampling matches radar (~12s) when

Data source	Variables	Notes:
Boundaries from combination of radar, ARM ceilometer, and UC ceilometer	layer_type (radar only, lidar only, both) layer_radar_base layer_radar_top layer_median_lidar_base n_ceilometer_columns n_ceilometer_columns_obscured	radar was running, otherwise 60s. Lidar boundaries are smoothed to 1-minute scale.
ZV_PRECIP_RETRIEVAL Near-surface precipitation based on radar reflectivity (Z) and mean Doppler velocity (V)	time_gmt near_surface_data_quality_flag near_surface_max_reflectivity near_surface_max_precip_rate near_surface_max_precip_effective_radius	Near-surface mean 250 to 500 m above the surface but also below cloud base. Retrieval is not undertaken when cloud base is below 350m (see quality flag).
MWR_RETRIEVAL Retrieval uses radiosondes profiles and radar-lidar-boundaries, in addition to MWR brightness temperatures	time_gmt data_quality_flag liquid_water_path (LWP) precipitable_water_vapor (PWV) hours_to_sonde n_layers tb23 (measured value) tb31 (measured value) calculated_tb23 (retrieved value) calculated_tb31 (retrieved value)	Based on an iterative technique that tries to adjust LWP and PWV so forward calculated value of brightness temperatures (tb) matches observed values.
Z_LWP_CLOUD_RETRIEVAL Retrieved cloud microphysics for ***non-precipitation*** liquid clouds ONLY	time_gmt data_quality_flag droplet_number_concentration column_effective_radius (LWC-weighted)	
SURFACE_MET Automated surface meteorological station data	time_gmt temperature pressure relative_humidity wind_speed wind_direction accumulated_rainfall	Accumulated_rainfall is based on tipping bucket, since the start of the UTC day.
PARSIVEL Parsivel surface disdrometer VENDOR retrievals (not recommended)	time_gmt vendor_precip_rate vendor_precip_effective_radius	Neither the Parsivel's measurements nor vendor's retrievals are optimal for Macquarie. We will likely remove these data in future versions.
PARSIVEL_PIRAT Parsivel Improved Rate and Type (PIRAT) retrieval	time_gmt (fixed five-minute grid) precip_type_best precip_type_metrics precip_rate_best precip_rate_by_type precip_effective_radius bin_particle_size bin_velocity spectrum_raw spectrum_corrected	Temporal sampling rate is reduced to 5 minutes to improve S/N and includes various corrections (see Section 2). Data include raw and corrected drop size-velocity spectra.

Data source	Variables	Notes:
SURF_RAD Surface broadband shortwave and longwave fluxes	time_gmt shortwave_down_total shortwave_down_direct shortwave_down_diffuse shortwave_up_total longwave_down longwave_up	

4.2 EP VAP

This products merges measurements and derived products obtained from ARM and other sources. The files contain the quantities listed below, at the location on the *Aurora Australis* research vessel (during MARCUS) or at Macquarie Island at 10-min resolution. A more detailed description of the file contents is provided in the online documentation.

Environmental Parameters VAP parameters:

1. Basic time and location information

2. Local meteorological conditions including:

   sea surface temperature (SST), lower tropospheric stability (LTS), marine cold air outbreak (MCAO) index, inversion height, and lifting condensation level (LCL).

3. Location relative to the oceanic polar front (PF), center of the closest cyclone, and nearest warm fronts and cold fronts

4. Location of air parcels 72 hours prior to their arrival at/above the ship computed using the HYSPLIT back trajectory model

5. Aerosol properties (*to be determine; still under construction but will include condensation nuclei and CCN*)

6. Cloud and precipitation properties, including:

   Cloud base/top height, and cloud base/top temperature (precipitation fields are not included yet).

7. Coincident cloud properties retrieved from the Himawari-8 satellite including:

   cloud fraction, cloud base/top height, cloud top temperature, cloud top pressure, liquid water path, optical depth, cloud effective radius, cloud droplet number concentration.

5.0   References

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