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MWRRET Value-Added Product: The Retrieval of Liquid Water Path and Precipitable Water Vapor from Microwave Radiometer (MWR) Datasets

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Abstract

This report provides a short description of the Atmospheric Radiation Measurement (ARM) microwave radiometer (MWR) RETrievel (MWRRET) Value-Added Product (VAP) algorithm. This algorithm utilizes complimentary physical and statistical retrieval methods and applies brightness temperature offsets to reduce spurious liquid water path (LWP) bias in clear skies resulting in significantly improved precipitable water vapor (PWV) and LWP retrievals. We present a general overview of the technique, input parameters, output products, and describe data quality checks. A more complete discussion of the theory and results is given in Turner et al. (2007b).

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1. Introduction

The Atmospheric Radiation Measurement (ARM) Program deploys microwave radiometers (MWR) that observe downwelling radiation at 23.8 and 31.4 GHz to each of its data gathering sites. Retrievals of precipitable water vapor (PWV) and liquid water path (LWP), crucial elements in building a better understanding of radiative transfer in the atmosphere and clouds, are generated from a retrieval algorithm that resides on the MWR instrument computers. These instrument-based retrieval algorithms use a statistical methodology based on site-dependent monthly retrieval coefficients (Liljegren and Lesht 1996). While very fast, this inversion approach can have large errors if atmospheric conditions are significantly different from the conditions captured in the retrieval coefficients, the retrieval coefficients are site-specific and cannot be applied to other locations, and the method does not address the systematic clear-sky biases in the retrieved LWP (Turner et al. 2004). The MWR RETrieval (MWRRET) Value-Added Product (VAP) was developed to address the inherent short-falls in the original (orig) statistical retrieval algorithm that resides on the MWR. It does this through the use of complementary physical and statistical retrieval methods and the application of brightness temperature offsets. While too computationally intensive to use to process all MWR data samples, the physical retrieval algorithm (phys) produces the most accurate retrievals possible when the atmospheric temperature profile and an estimate of the distribution of water vapor and liquid water are known. For general processing, the statistical retrieval method (stat2) should be used. The stat2 algorithm utilizes more information than the 'orig' algorithm resulting in improved accuracy and, through the use of surface meteorological data, allows the retrieval to be site independent if the initial dataset used to develop the statistical relationship includes a range of atmospheric state conditions observed in different locations.

The details of this algorithm have been published in Turner et al. (2007b). We refer the readers to this article for more detailed information about the algorithm applied in this VAP.

2. Input Data

The input data required by this VAP include observed brightness temperatures, PWV and LWP retrievals produced by the 'orig' algorithm residing on the MWR instrument, and surface meteorology observations. The actual datastream from which the surface met data is extracted is a function of the site and facility that is being processed. Appendix A, Table A.1, lists the datastreams and correlating input and quality check fields that are required to run the MWRRET VAP. Optional inputs such as reflectivity, cloud base height, and vertical profiles of atmospheric conditions are presented in Appendix A, Table A.2. While the VAP will run without the SONDE profiles, they should be used when available. The specific sonde platform used as input is selected based on data availability. If more than one sonde platform is available for a given day, the input is chosen based on a prioritized list with 'wnpn.b1' the first choice, followed by 'wrpn.a1', 'wrpn.b1', 'wnpn.a1', and 'wrpr.a1'. Whether or not to use the cloud base height from the Belfort laser ceilometer (BLC), Vaisala ceilometer (VCEIL), or active remote sensing of cloud locations (ARSCL) as input is specified at the command line and is left to the VAP operator's discretion.

3. Output Data

The primary data products of the MWRRET VAP are best estimates of the PWV and LWP values. When run in real time on the ARM production system, the best estimates are equal to the retrievals produced by the stat2 statistical retrieval algorithm. As part of the yearly reprocessing discussed in the following section on annual reprocessing to determine brightness temperature offsets, the best estimates are updated to represent an optimized blend of both the stat2(statistical) and phys(physical) retrieval methods. In addition to the best estimate values, the PWV and LWP values for the orig, stat2, and phys methods are included in the output as are supporting surface meteorological and MWR input data used in their calculations. Global attributes read from the MWR input file are propagated to the output and new attributes are defined for the static T_b offset bias values and, if so, when these offsets were created. A complete list of all the output fields and a brief description of each is given in Appendix B.

One file is created for each day named with the following convention:

XXXmwrret1liljclouFF.c1.YYYYMMDD.hhmmss

where:

XXX = the location of the instrument (nsa, sgp, twp, pye, etc.)
mwrret1liljclou = identifies that this is Turner’s version 1 MWRRET VAP
FF = facility (e.g., C1)
YYYYMMDD = year, month, and day
hhmmss = hour, minute, second

The VAP generates a quicklook output file within which three plots are presented: (1) MWR brightness temperature values including data quality status, (2) PWV calculated by the 'orig', 'stat2', and 'phys' retrieval methods, and (3) LWP calculated by the 'orig', 'stat2', and 'phys' retrieval methods. Two versions of this quicklook product are created. One with a standard fixed y-axis for each of the plots, and another with a dynamically resized y-axis to automatically adjust for periods with relatively flat brightness temperature and retrieval values. The output file for the standard and dynamically resized quicklooks use the following naming convention: XXXmwrret1liljclouC1.YYYYMMDD.png XXXmwrret1liljclouC1.YYYYMMDD.dynamic.png

4. Brightness Temperature Offsets

Offsets to brightness temperature can be applied to both the 23.8-GHz and 31.4-GHz channels. The 23.8-GHz offsets, which reduce bias in the retrieved PWV, are determined once per year for each site and facility and as such are referred to as 'static' offsets. When running in real time on the ARM production system, static T_b offsets are not applied. At the end of each year, the data from the year are post-analyzed and the appropriate static offset value at 23.8 GHz is determined. The T_b offset configuration file is updated with the value of newly determined static offsets and the data is reprocessed to apply the offsets.

As previously discussed, small biases in the retrieved LWP (from +/- 5 to 30 g/m2) can be retrieved from the MWR in clear sky scenes when the LWP should be zero (within the retrieval uncertainty). These LWP biases, which can exist for long periods of time, result in significant error in radiative transfer calculations (e.g., Turner et al. 2007a). To reduce the size of the LWP biases, the VAP also can be configured to subtract small offsets from the observed brightness temperature at 31.4 GHz so that, statistically, a LWP of zero in clear skies is obtained. To capture the impact of calibration changes over time, these 'variable' offsets are computed directly from the data for a specified number of cases, which are kept in a rolling database of offsets stored in the T_b offset configuration file. The VAP computes the mean value from the middle two quartiles of the offset data to determine the value to subtract from the observation. This offset is added to the rolling database, and the oldest offset value is removed to maintain a fixed number of points in the rolling database. The variable offset is applied only to the 31.4-GHz channel. More details on the T_b offsets are given in Turner et al. 2007b.

5. Data Quality Testing

All quality flags associated with the input fields are propagated to the output. Additional quality tests, developed by Jim Liljegren, are applied to the MWR brightness temperatures to identify periods where these values experience sudden abnormal instantaneous changes in their values. These additional brightness temperature tests relate to instrument health as determined by examination of available data. Tests applied include identification of thermal stabilization issues, detection of spikes, and invalid optical depths. Quality control (QC) tests also were developed for the non-best estimate PWV and LWP fields calculated by the VAP.

6. Examples

Figure 1 shows the standard quicklook product for March 14, 2000. For this day, the VAP was run with the option of performing physical retrievals only at the samples that correspond to the sonde launch. Using command line options the MWRRET VAP allows the user to specify whether and how to perform the physical retrievals for a given day. Possible scenarios include running the physical retrieval for each sample in the day, for every nth sample, for 30 minutes after each sonde launch, or only for samples that correspond to a sonde launch. While difficult to see the single phys_retrieval sample indicated in blue at each launch, it is inherent in the plot that the physical retrieval was run because the 'pwv_phys', 'lwp_phys', 'sonde_launch' are defined in the PWV and LWP legends and the sonde launch times are indicated in the PWV plot.

In Figure 2, the dynamically sized version of March 14, 2000, the blue line representing the physical retrieval sample value is evident just above the stat2 and orig values at the time correlating to the last sonde launch of the day.

Figure 3 illustrates how the data quality test results are folded into the brightness temperature plot. The qc instrument health tests that failed, 'warm up' and 'over heat' are indicated at the right of the plot, with the affected samples marked with corresponding color bars. It is also a day with relatively flat brightness temperatures and retrievals.

Figure 4 is the companion dynamically sized plot for the same day. For this day, the physical retrievals were run for a 30-minute set of samples immediately following the sonde launch.

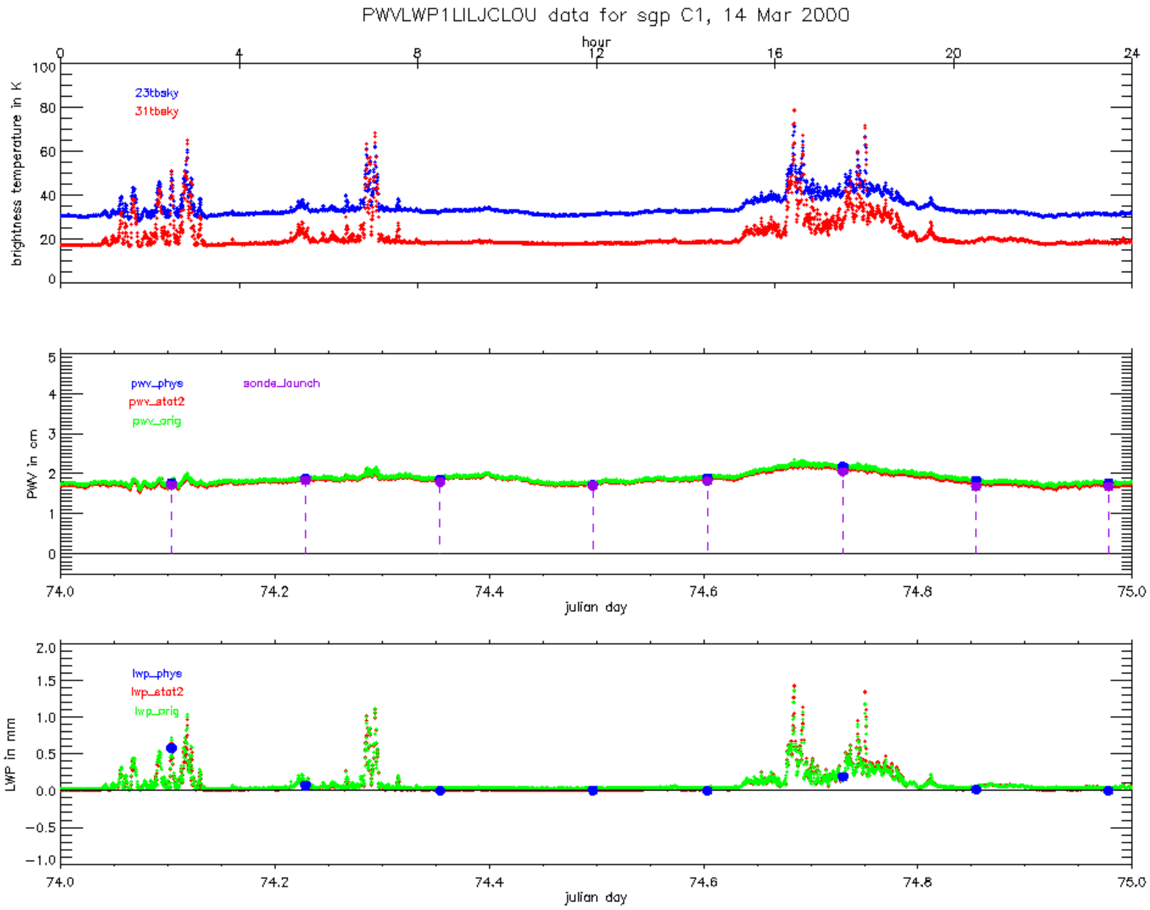

Figure 1: Quicklook image using standard y-axis ranges where the physical retrievals are performed only for samples corresponding to the sonde launch times.

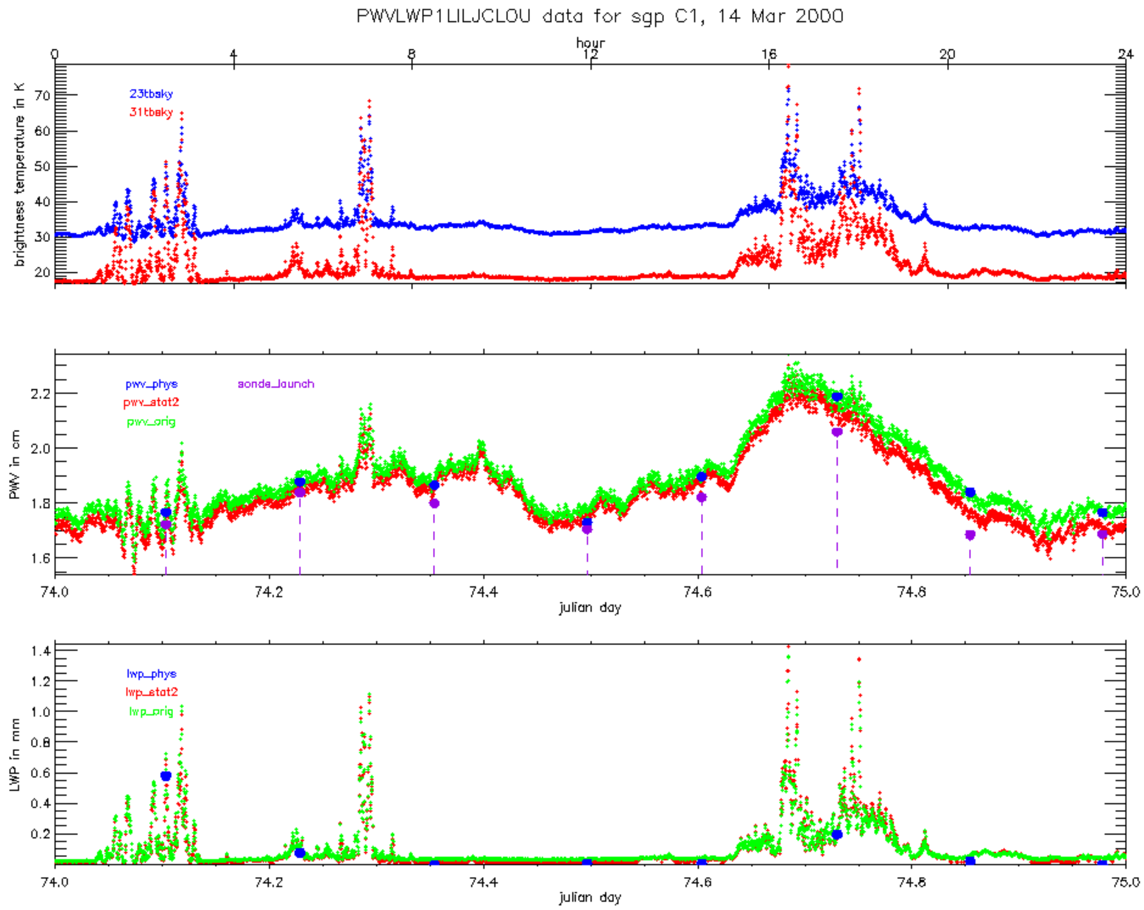

Figure 2: Quicklook image using dynamically sized y-axis where the physical retrievals are performed only for samples corresponding to the sonde launch times.

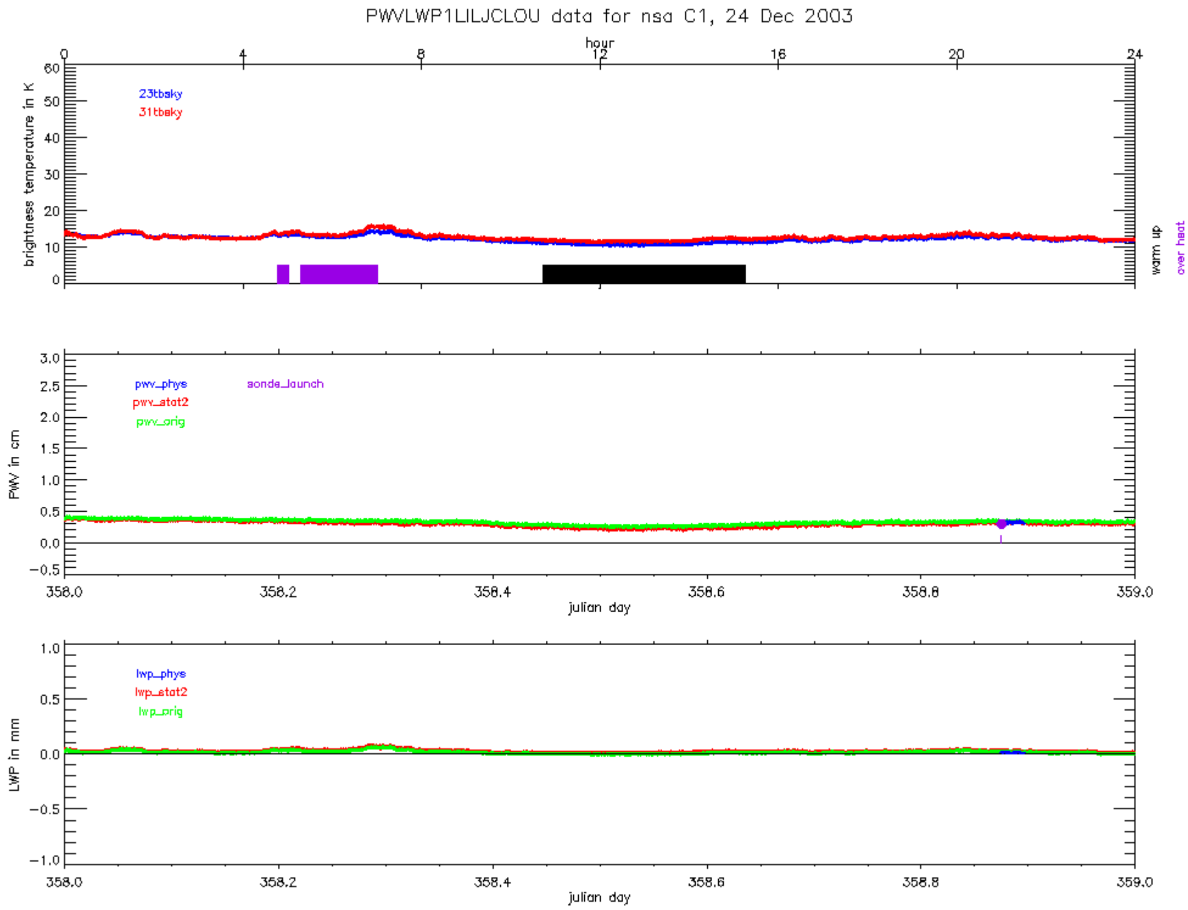

Figure 3: Quicklook image using standard y-axis ranges where the physical retrievals are performed for a 30-minute period following the sonde launch times.

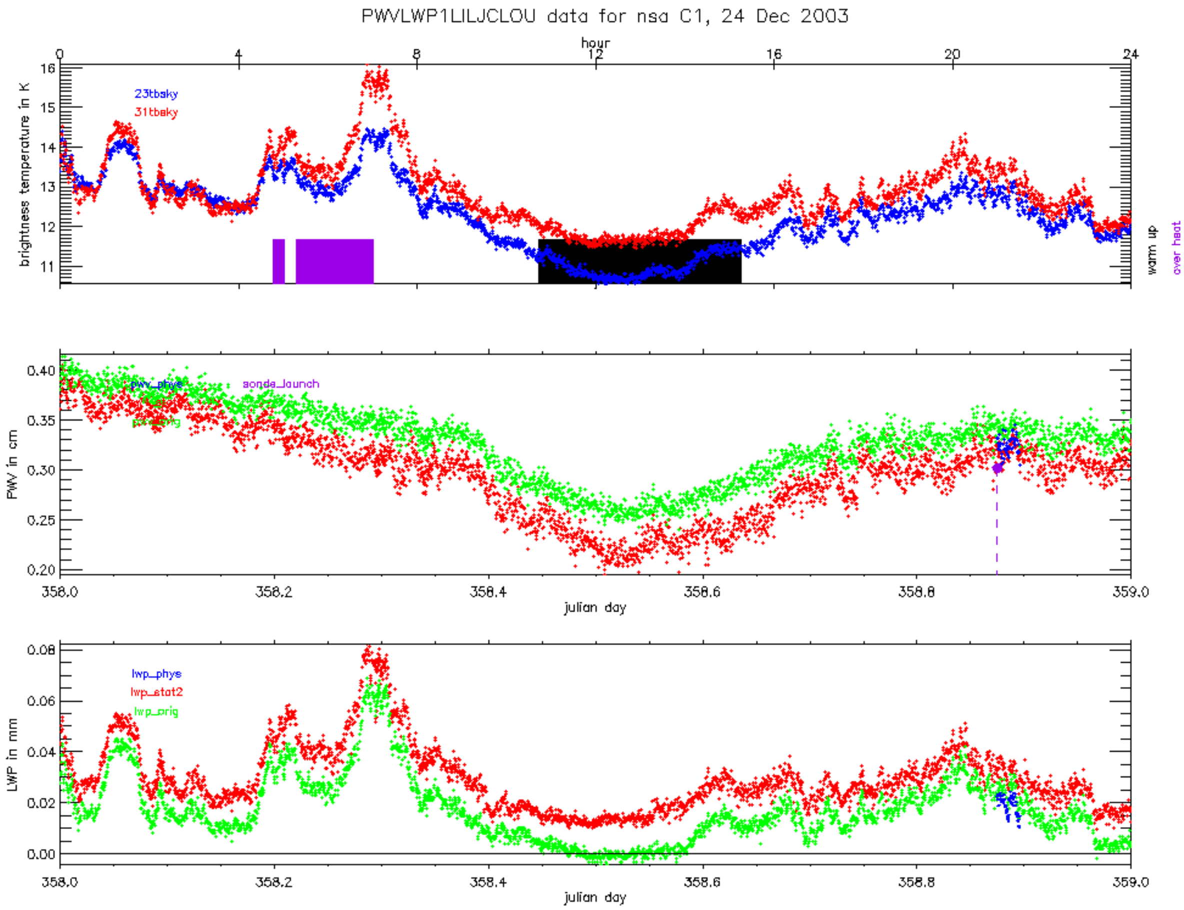

Figure 4: Quicklook image using dynamically sized y-axis where the physical retrievals are performed for a 30-minute period following the sonde launch times.

7. Conclusions

Measurements of both cloud properties and radiative fluxes are needed to improve global climate models (GCMs) and subsequently their prediction of future climates. Accurate measurements of PWV and LWP values support these goals through validating radiative transfer models, specifying atmospheric and cloud properties, and increasing the understanding of the first aerosol indirect effect. By providing two improved retrieval methods and applying brightness temperature offsets to reduce spurious LWP bias in clear skies, the MWRRET algorithm provides significantly better retrievals of PWV and LWP from the ARM 2-channel microwave radiometers compared to the original retrieval method included in the ARM MWR ingest data product.

8. References

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Appendix A: Input Data

Table A.1 lists the input datastreams and fields required to run the MWRRET VAP.
Talbe A.2 lists the input datastreams and fields that are optional inputs to the MWRRET VAP.

Table A.1: Required input files and variables.

Datastream	Variable Name	Variable Long Name	Units
XXXmwrlosFF.b1 XXX is all sites	tbsky23	23.8 GHz sky brightness temperature	K
	tbsky31	31.4 GHz sky brightness temperature	K
	vap	Total water vapor along LOS path	cm
	liq	Total liquid water along LOS path	cm
	sky23	23.8 GHz sky signal	counts
	sky31	31.4 GHz sky signal	counts
	teflon_window_correction_coef_23	global attribute - no long name	unitless
	teflon_window_correction_coef_31	global attribute - no long name	unitless
	mean_atmos_radiating_temp_23	global attribute - no long name	unitless
	mean_atmos_radiaing_temp_31	global attribute - no long name	unitless
	cosmic_background_temperature	global attribute - no long name	unitless
	vapor_retrieval_coefficient_0	global attribute - no long name	unitless
	vapor_retrieval_coefficient_0	global attribute - no long name	unitless
	vapor_retrieval_coefficient_1	global attribute - no long name	unitless
	liquid_retrieval_coefficient_0	global attribute - no long name	unitless
	liquid_retrieval_coefficient_1	global attribute - no long name	unitless
	liquid_retrieval_coefficient_2	global attribute - no long name	unitless
XXXmwrlosFF.b1 XXX is not a parsl site	bb23	23.8 GHz Blackbody signal	counts
	bb31	31.4 GHz Blackbody signa	counts
	bbn23	23.8 GHz blackbody+noise injection signal	counts
	bbn31	31.4 GHz blackbody+noise injection signal	counts
	tkbb	Blackbody kinetic temperature	K
	tkxc	Mixer kinetic (physical) temperature	K
	tnd_nom23	Noise injection temp at nominal temperature at 23.8 GHz	K
	tnd_nom31	Noise injection temp at nominal temperature at 31.4 GHz	K
	tc23	Temperature correction coefficient at 23.8 GHz	K/K

Table A.1: Required input files and variables (cont.).

Datastream	Variable Name	Variable Long Name	Units
XXXmwrlosFF.b1 XXX is not a parsl site (cont.)	tc31	Temperature correction coefficient at 31.4 GHz	K/K
	qc_tbsky23	Quality check results on field: 23.8 GHz sky brightness temperature	unitless
	qc_tbsky31	Quality check results on field: 31.4 GHz sky brightness temperature	unitless
	qc_vap	Quality check results on field: Total water vapor along LOS path	unitless
	qc_liq	Quality check results on field: Total liquid water along LOS path	unitless
XXX1twrmwrFF.c1 XXX is sgp FF is C1 or E13	pres_02	Barometric pressure at 2 m	mb
	temp_02	Temperature at 2 m	degC
	vap_pres_02m	Vapor pressure at 2 m	mb
	rh_02	Relative humidity at 2 m	%
XXXthwapsFF.b1 where XXX is sgp FF is not C1 or E13	pres	Pressure	hPa
	temp	Temperature	C
	vap_res	Vapor Pressure	kPa
	rh	Relative Humidity	%
	qc_press	Quality check results on field: Pressure	unitless
	qc_temp	Quality check results on field: Temperature	unitless
	qc_vap_pres	Quality check results on field: Vapor Pressure	unitless
	qc_rh	Quality check results on field: Vapor Pressure	unitless
XXXsmet60sFF.b1 XXX is twp or pye and not a parsl site	atmos_pressure	Pressure	
	temp_mean	Temperature	
	vappress_mean	Vapor Pressure	
	relh_mean	Relative Humidity	
	qc_atmos_pressure	Quality check results on field: Pressure	unitless
	qc_temp_mean	Quality check results on field: Temperature	unitless
	qc_relh_mean	Quality check results on field: Vapor Pressure	unitless

Table A.1: Required input files and variables (cont.).

Datastream	Variable Name	Variable Long Name	Units
XXXmettwr4hFF.b1 **XXX is nsa** **FF is C1**	AtmPress	Atmospheric Pressure	kPa
	T2M_AVG	2m Average Temperature	C
	VP2M_AVG	2m Average Calculated Vapor Pressure	kPa
	RH2M_AVG	2m Average Relative Humidity	%
	qc_AtmPress	Quality check results on field: Atmospheric Pressure	unitless
	qc_T2M_AVG	Quality check results on field: 2m Average Temperature	unitless
	qc_VP2M_AVG	Quality check results on field: 2m Average Calculated Vapor Pressure	unitless
	qc_RH2M_AVG	Quality check results on field: 2m Average Relative Humidity	unitless
XXXmettwr2hFF.b1 **XXX is nsa** **FF is C2**	AtmPress	Atmospheric Pressure	kPa
	T2m_AVG	2m Average Temperature	C
	VP2m_AVG	2m Average Calculated Vapor Pressure	kPa
	RH2m_AVG	2m Average Relative Humidity	%
	qc_AtmPress	Quality check results on field: Atmospheric Pressure	unitless
	qc_T2m_AVG	Quality check results on field: 2m Average Temperature	unitless
	qc_PV2m_AVG	Quality check results on field: 2m Average Calculated Vapor Pressure	unitless
	qc_RH2m_AVG	Quality check results on field: 2m Average Relative Humidity	unitless
XXXmettwrFF.b1 **XXX is a parsl site**	pressure	Surface atmospheric pressure	hectoPascals (milibars)
	temperature	Surface atmospheric dry bulb temperature	degrees Celcius
	rh	Surface atmospheric relative humidity	Percent

Table A.2: Optional input files and variables.

Datastream	Variable Name	Variable Long Name	Units
XXXsonde<type>FF.b1	alt	altitude	meters above Mean Sea Level
	pres	Pressure	hPa
	tdry	Dry Bulb Temperature	C
	rh	Relative Humidity\	%
XXXarscl1clothFF.c1	CloudBaseBestEstimate	Cloud Base Height Best Estimate	m AGL
	Heights	Height of Measured Value	m AGL
	ReflectivityBestEstimate	MCR Best Estimate of Hydrometeor Reflectivity	dBZ (X100)
XXXvceil25kFF.a1 **XXXvceil25kFF.b1**	first_cbh	Lowest cloud base height detected	m
	detection_status	Detection status.	unitless
XXXblcFF.a1	cloud1	Base height of lowest cloud detected by threshold algorithm	m above ground level

The names of the input datastreams have the format:

XXX<plat>FF.<level>.YYYYMMDD.hhmmss

Where:

XXX = the locations of the instrument (nsa, sgp, twp, pye, etc.)
<plat> = the main instrument name
FF = facility (e.g., C1)
<level> = data level, can be a1
YYYYMMDD = year, month, and day
hhmmss = hour, minute, second

Appendix B: Output Data

Table B.1 lists the fields found in the MWRRET output NetCDF files.

Table B.1: Output variables.

Fieldname	Description	Units
base_time	Base Time in Epoch	seconds since 1970/01/01 00:00:00
time_offset	Time offset from base_time	seconds since base_time
time	Time offset from midnight	seconds since midnight
hour	Hour of the day	UTC
level_height	Level height	km AGL
be_pwv	Precipitable water vapor best-estimate value	cm
be_lwp	Liquid water path best-estimate value	g/m^2
cloud_base_height	Cloud base height	km AGL
surface_temp	Surface temperature	K
qc_surface_temp	Quality check results on field: Surface temperature	unitless
surface_vapor_pres	Surface vapor pressure	kPa
qc_surface_vapor_pres	Quality check results on field: Surface vapor pressure	unitless
surface_pres	Surface pressure	kPa
qc_surface_pres	Quality check results on field: Surface pressure	unitless
surface_rh	Surface relative humidity	%
qc_surface_rh	Quality check results on field: Surface relative humidity"	unitless
tbsky23	Sky brightness temperature at 23.8 GHz	K
qc_tbsky23	Quality check results on field: Sky brightness temperature at 23.8 GHz	unitless
tbsky31	Sky brightness temperature at 31.4 GHz	K
qc_tbsky31	Quality check results on field: Sky brightness temperature at 31.4 GHz	unitless
orig_pwv	Total water vapor along LOS path	cm
qc_orig_pwv	Quality check results on field: Total water vapor along LOS path	unitless
orig_lwp	Total liquid water along LOS path	g/m^2
qc_orig_lwp	Quality check results on field: Total liquid water along LOS path"	unitless
tbsky23_nobias	Sky brightness temperature at 23.8 GHz, with the bias removed	K

Table B.1: Output variables (cont.).

Fieldname	Description	Units
tbsky31_nobias	Sky brightness temperature at 31.4 GHz, with the bias removed	K
stat2_pwv	Precipitable water vapor retrieved using predicted mean radiating temperatures and retrieval coefficients	cm
stat2_pwv_uncertainty	1-sigma uncertainty in precipitable water vapor retrieved using the stat2 approach	cm
qc_stat2_pwv	Quality check results on field: Precipitable water vapor retrieved using predicted mean radiating temperatures and retrieval coefficients	unitless
stat2_lwp	Cloud liquid water path retrieved using predicted mean radiating temperatures and retrieval coefficients	g/m^2
stat2_lwp_uncertainty	1-sigma uncertainty in cloud liquid water path retrieved using the stat2 approach	g/m^2
qc_stat2_lwp	Quality check results on field: Cloud liquid water path retrieved using predicted mean radiating temperatures and retrieval coefficients	unitless
stat2_tliq_flag	Status flag associated with stat2 retrievals	unitless
tbsky23_calculated	Calculated sky brightness temperature at 23.8 GHz	K
tbsky31_calculated	Calculated sky brightness temperature at 31.4 GHz	K
phys_pwv	Precipitable water vapor retrieved using a physical/iterative approach	cm
qc_phys_lwp	Quality check results on field: Precipitable water vapor retrieved using a physical/iterative approach	unitless
phys_lwp	Cloud liquid water path retrieved using a physical/iterative approach	g/m^2
qc_phys_lwp	Quality check results on field: Cloud liquid water path retrieved using a physical/iterative approach	unitless
phys_pwv_uncertainty	1-sigma uncertainty in precipitable water vapor retrieved using a physical/iterative approach	cm
phys_lwp_uncertainty	1-sigma uncertainty in cloud liquid water path retrieved using a physical/iterative approach	g/m^2
phys_niter	Number of iterations needed by the physical retrieval for convergence	counts
phys_rms	Root mean square difference between the computed and observed brightness temperatures for the last iteration	K
phys_converge	Convergence value for the physical retrieval	arbitrary
sonde_times	Flag indicating when the sonde launches occurred	unitless

Table B.1: Output variables (cont.).

Fieldname	Description	Units
sonde_pwv	Precipitable water vapor integrated from the radiosonde profile	cm
mean_pwv_mwr	Ensemble average for MWR vapor in window centered upon current sample	cm
sdev_pwv_mwr	Standard deviation of ensemble average for MWR vapor	cm
num_pwv_mwr	Size of MWR ensemble for mean_pwv_mwr field	unitless
mean_lwp_mwr	Ensemble average for MWR liquid in window centered upon current sample	g/m^2
sdev_lwp_mwr	Standard deviation of ensemble average for MWR liq	g/m^2
num_lwp_mwr	Size of MWR ensemble for mean_lwp_mwr field	unitless
mean_tbsky23_mwr	Ensemble average for MWR 23.8 GHz sky brightness temperature in window centered upon current sample	K
sdev_tbsky23_mwr	Standard deviation for ensemble average for MWR 23.8 GHz sky brightness temperature	K
num_tbsky23_mwr	Size of MWR ensemble for mean_tbsky23_mwr field	unitless
mean_tbsky31_mwr	Ensemble average for MWR 31.4 GHz sky brightness temperature in window centered upon current sample	K
sdev_tbsky31_mwr	Standard deviation for ensemble average for MWR 31.4 GHz sky brightness temperature	K
num_tbsky31_mwr	Size of MWR ensemble for mean_tbsky23_mwr field	unitless
vbias_yyyymmdd	Variable bias date	YYYYMMDD [UTC]
vbias_hour	Variable bias hour	hour [UTC]
vbias_23	Variable bias offset at 23.8 GHz	K
vbias_31	Variable bias offset at 31.4 GHz	K
lat	north latitude	degrees
lon	east longitude	degrees
alt	altitude	altitude