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Cloud Type Classification (cldtype) Value-Added Product

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Acronyms and Abbreviations

AGL	above ground level
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remotely Sensed Cloud Location
DOE	U.S. Department of Energy
hr	hour
KAZR	Ka-band ARM Zenith Radar
km	kilometer
LASSO	Large-Eddy Simulation ARM Symbiotic Simulation and Observation
m	meter
MET	Surface Meteorological System
mm	millimeter
MPL	micro pulse lidar
NSA	North Slope of Alaska
QC	quality control
SGP	Southern Great Plains
TWP	Tropical Western Pacific
VAP	value-added product

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1.0 Introduction

The Cloud Type (cldtype) value-added product (VAP) provides an automated cloud type classification based on macrophysical quantities derived from vertically pointing lidar and radar. Up to 10 layers of clouds are classified into seven cloud types based on predetermined and site-specific thresholds of cloud top, base and thickness. Examples of thresholds for selected U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility sites are provided in Tables 1 and 2. Inputs for the cldtype VAP include lidar and radar cloud boundaries obtained from the Active Remotely Sensed Cloud Location (ARSCL) and Surface Meteorological Systems (MET) data. Rain rates from MET are used to determine when radar signal attenuation precludes accurate cloud detection. Temporal resolution and vertical resolution for cldtype are 1 minute and 30 m respectively and match the resolution of ARSCL. The cldtype classification is an initial step for further categorization of clouds. It was developed for use by the Shallow Cumulus VAP to identify potential periods of interest to the LASSO model and is intended to find clouds of interest for a variety of users.

Table 1. Cloud-type definition over the ARM Southern Great Plains (SGP) site.

`Cloud type	Cloud base	Cloud top	Cloud thickness
1. Low clouds	< 3.5 km	< 3.5 km	< 3.5 km
2. Congestus	< 3.5 km	3.5 - 6. 5 km	≥ 1.5 km
3. Deep convection	< 3.5 km	> 6.5 km	≥ 1.5 km
4. Altocumulus	3.5 - 6. 5 km	3.5 - 6. 5 km	< 1.5 km
5. Altostratus	3.5 - 6. 5 km	3.5 - 6. 5 km	≥ 1.5 km
6. Cirrostratus/Anvil	3.5 - 6. 5 km	> 6.5 km	≥ 1.5 km
7. Cirrus	> 6.5 km	> 6.5 km	No restriction

Table 2. Cloud-type definition over the ARM Tropical Western Pacific (TWP) site.

`Cloud type	Cloud base	Cloud top	Cloud thickness
1. Low clouds	< 4 km	< 4 km	< 4 km
2. Congestus	< 4 km	4 - 8 km	≥ 1.5 km
3. Deep convection	< 4 km	> 8 km	≥ 1.5 km
4. Altocumulus	4 - 8 km	4 - 8 km	< 1.5 km
5. Altostratus	4 - 8 km	4 - 8 km	≥ 1.5 km
6. Cirrostratus/Anvil	4 - 8 km	> 8 km	≥ 1.5 km
7. Cirrus	> 8 km	> 8 km	No restriction

2.0 Input Data

2.1 Active Remotely Sensed Cloud Location (ARSCL)

SSSarscl1clothXX.c1.YYYYMMDD.hhmmss.cdf

SSSarsclkazr1kolliasXX.c1.YYYYMMDD.hhmmss.nc

2.2 Surface Meteorological Systems (MET)

SSSmetXX.b1.YYYYMMDD.hhmmss.cdf

where: SSS = the location of the instrument (nsa, sgp, twp, pye, etc.)
XX = facility (e.g. C1, E13, …)
YYYYMMDD = year, month, day
hhmmss = hour, minute, second

3.0 Algorithm and Methodology

The primary input for cloud classification in the cldtype VAP is cloud boundaries from the ARSCL data product. ARSCL merges lidar and radar cloud tops and bases to produce a single composite of clouds, a cloud mask, at 1-minute time resolution and 30-m vertical resolution. The combination of lidar and radar retrievals provides complementary capabilities. While the lidar detects low- and most mid/high-level clouds, it can be limited by strong optical attenuation if a cloud layer has a high concentration of hydrometeors. Radar, on the other hand, can be effective at detecting mid/high clouds through the low lidar-attenuating layers but fails to detect cloud layers with small particles to which the lidar is more sensitive. Sensitivity studies at SGP suggest that 27% of clouds detected by lidar below a height of 3.5 km are not detected by radar. To insure all clouds are included, if lidar cloud boundaries at this level or below are available but not found in the ARSCL cloud mask, the boundaries are added in a preliminary step in the cldtype VAP.

Cloud top, cloud base, and thickness of the cloud layers are calculated from the ARSCL data product. Prior to cloud classification, cloud layers are screened based on a minimum required thickness and a minimum separation between layers. In the first step, cloud layer with thickness less than or equal to 120 m are removed. In the second step, adjacent clouds layers that are separated by 120 m or less are merged into a single cloud layer. These filtering steps are included to reduce noise.

Each identified layer (up to 10 layers) is then assigned one of seven cloud types (1. Low clouds, 2. Congestus, 3. Deep Convection, 4. Altocumulus, 5. Altostratus, 6. Cirrostratus/Anvil, 7. Cirrus) on the basis of the top height, base height, and layer thickness, using the thresholds described in Tables 1 or 2 depending on the site. These thresholds were chosen based on studies in the literature (Burleyson et. al 2015, McFarlane et. al 2013).

Time periods with rain rates greater than 1 mm hr^{-1} are identified when the radar signal may become significantly attenuated. These time periods are not included in classification due to potential cloud-top underestimation or failure to detect some high-level clouds. The qc fields contain information about what input data was available and quicklook plots show ARSCL radar reflectivity, the ARSCL cloud base best estimate from ceilometer and micro pulse lidar, the cloud type, and rain rates.

4.0 Output Data

This VAP produces one-minute cloud type classifications. One file is created each day named with the following convention:

SSScldtypeXX.c1.YYYYMMDD.hhmmss.nc

where: SSS = the location of the instrument (nsa, sgp, twp, pye, etc.)
cldtype = The name of this VAP
XX = facility (e.g. C1, E13, …)
YYYYMMDD = year, month, day
hhmmss = hour, minute, second

Here is the netcdf header of the output file:
time = UNLIMITED
height = 0
layer = 10
bound = 2

base_time():int
string
long_name = Base time in Epoch
units = seconds since 1970-1-1 0:00:00 0:00
ancillary_variables = time_offset

time_offset(time):double
long_name = Time offset from base_time
units
ancillary_variables = base_time

time(time):double
long_name = Time offset from midnight
units
bounds = time_bounds

time_bounds(time, bound):double
long_name = Time cell bounds
bound_offsets:double = -30, 30

height(height):float
long_name = Height above ground level
units = m
standard_name = height

layer(layer):int
long_name = Cloud layer number
units = unitless

cloudtype(time, layer):int*
long_name = Cloud type

units = unitless
ancillary_variables = qc_cloudtype
missing_value:int = -9999
flag_values:int = 1, 2, 3, 4, 5, 6, 7
flag_meanings = low_cloud congestus deep_convection altocumulus altostratus cirrostratus/anvil cirrus

qc_cloudtype(time, layer):int
long_name = Quality check results on field: Cloud type
units = unitless
description = This field contains bit-packed integer values, where each bit represents a QC test on the data. Non-zero bits indicate the QC condition given in the description for those bits; a value of 0 (no bits set) indicates the data has not failed any QC tests.
flag_method = bit
bit_1_description = Cloud layer cannot be determined
bit_1_assessment = Bad
bit_2_description = MMCR not available
bit_2_assessment = Indeterminate
bit_3_description = MMCR clutter detected
bit_3_assessment = Indeterminate
bit_4_description = MPL not available
bit_4_assessment = Indeterminate
bit_5_description = MPL beam blocked or attenuated
bit_5_assessment = Indeterminate
bit_6_description = Precipitation data not available
bit_6_assessment = Indeterminate
bit_7_description = Precipitation > th_precip
bit_7_assessment = Bad

cloud_base_best_estimate(time):float*
long_name = Cloud base best estimate, based on ceilometer and micropulse lidar
units = m
missing_value:float = -9999
valid_range:float = 0, 25000
flag_values:float = -2, -1
flag_meanings = possible_clear_sky clear_sky
comment = -2. Possible clear sky (No MPL observations available, ceilometer obscured, but no cloud detected), -1. Clear sky, >= 0. Valid cloud base height

cloud_layer_top_height(time, layer):float*
long_name = Top height (AGL) of hydrometeor layers for up to 10 layers, based on combined radar and micropulse lidar observations
units = m
ancillary_variables = qc_cloud_layer_top_height
missing_value:float = -9999
description = The cloud top height is derived from ARSCL product. Layers are combined if they are less than cdepth apart (see global attribute for the value of cdepth)

qc_cloud_layer_top_height(time, layer):int
long_name = Quality check results on field: Top height (AGL) of hydrometeor layers for up to 10 layers, based on combined radar and micropulse lidar observations
units = unitless

description = This field contains bit packed integer values, where each bit represents a QC test on the data. Non-zero bits indicate the QC condition given in the description for those bits; a value of 0 (no bits set) indicates the data has not failed any QC tests.
flag_method = bit
bit_1_description = Data value not available in input file, data value set to -9999 in output file.
bit_1_assessment = Bad
bit_2_description = Minimum cloud thickness < cdepth
bit_2_assessment = Bad
bit_3_description = MMCR not available
bit_3_assessment = Indeterminate
bit_4_description = MMCR clutter detected
bit_4_assessment = Indeterminate
bit_5_description = MPL not available
bit_5_assessment = Indeterminate
bit_6_description = MPL beam blocked or attenuated
bit_6_assessment = Indeterminate
bit_7_description = Precipitation data not available
bit_7_assessment = Indeterminate
bit_8_description = Precipitation > th_prec
bit_8_assessment = Bad

cloudtop_instrument(time, layer):int
long_name = Instrument that detected layer top height
units = unitless
flag_values:int = 0, 1, 2, 3, 4, 5
flag_meanings = cloud_top_determined_from_MMCR_(best_situation) 1st_cloud_layer_top_detected_by_MPL 2nd_cloud_layer_top_detected_by_MPL 3rd_cloud_layer_top_detected_by_MPL 4th_cloud_layer_top_detected_by_MPL 5th_cloud_layer_top_detected_by_MPL
description = Indicates which instrument was able to detect cloud top height. Lower numbers indicate higher reliability.
comment = This flag is only set when arscl1cloth.c1 datastream is available. The values are set to -9999 otherwise
missing_value:int = -9999

cloud_source_flag(time, height):short
long_name = Instrument source flag for cloud (hydrometeor) detections
units = unitless
flag_values:short = 0, 1, 2, 3, 4, 5, 6
flag_meanings = no_detection_due_to_missing_radar_and_micropulse_lidar_data clear_according_to_radar_and_lidar cloud_detected_by_radar_and_lidar cloud_detected_by_radar_only cloud_detected_by_lidar_only cloud_detected_by_radar_but_lidar_data_missing cloud_detected_by_lidar_but_radar_data_missing
comment = This flag is only set when arsclkazr1kollias.c1 datastream is available. The values are set to -9999 otherwise
missing_value:short = -9999

cloud_layer_base_height(time, layer):float*
long_name = Cloud base height (AGL) for up to 10 layers
units = m
ancillary_variables = qc_cloud_layer_base_height

missing_value:float = -9999
description = The cloud base height is derived from ARSCL product. Layers are combined if they are less than cdepth apart (see global attribute for the value of cdepth)

qc_cloud_layer_base_height(time, layer):int
long_name = Quality check results on field: Cloud base height (AGL) for up to 10 layers
units = unitless
description = This field contains bit-packed integer values, where each bit represents a QC test on the data. Non-zero bits indicate the QC condition given in the description for those bits; a value of 0 (no bits set) indicates the data has not failed any QC tests.
flag_method = bit
bit_1_description = Data value not available in input file, data value set to -9999 in output file.
bit_1_assessment = Bad
bit_2_description = Minimum cloud thickness < cdepth
bit_2_assessment = Bad
bit_3_description = MMCR not available
bit_3_assessment = Indeterminate
bit_4_description = MMCR clutter detected
bit_4_assessment = Indeterminate
bit_5_description = MPL not available
bit_5_assessment = Indeterminate
bit_6_description = MPL beam blocked or attenuated
bit_6_assessment = Indeterminate
bit_7_description = Precipitation data not available
bit_7_assessment = Indeterminate
bit_8_description = Precipitation > th_prec
bit_8_assessment = Bad

precipitation(time):float
long_name = Mean precipitation rate
units = mm/min
ancillary_variables = qc_precipitation source_precipitation
valid_min:float = 0
valid_max:float = 10
missing_value:float = -9999

source_precipitation(time):int
long_name = Source for field: Mean precipitation rate
units = unitless
description = This field contains integer values that should be interpreted as listed. A value of 0 represents no source available.
flag_method = integer
flag_0_description = No source available
flag_1_description

qc_precipitation(time):int
long_name = Quality check results on field: Mean precipitation rate
units = unitless
description = This field contains bit-packed integer values, where each bit represents a QC test on the data. Non-zero bits indicate the QC condition given in the description for those bits; a value of 0 (no bits set) indicates the data has not failed any QC tests.

flag_method = bit
bit_1_description = Value is equal to missing_value
bit_1_assessment = Bad
bit_2_description = Value is less than the valid_min
bit_2_assessment = Bad
bit_3_description = Value is greater than the valid_max
bit_3_assessment = Bad

reflectivity(time, height):float
long_name = Best estimate reflectivity from ARSCL product
units = dBZ
ancillary_variables = qc_reflectivity
valid_min:float = -90
valid_max:float = 50
missing_value:float = -9999

qc_reflectivity(time, height):int
long_name = Quality check results on field: Best estimate reflectivity from ARSCL product
units = unitless
description = This field contains bit-packed integer values, where each bit represents a QC test on the data. Non-zero bits indicate the QC condition given in the description for those bits; a value of 0 (no bits set) indicates the data has not failed any QC tests.
flag_method = bit
bit_1_description = Data value not available in input file, data value has been set to missing_value
bit_1_assessment = Bad
bit_2_description = Value is less than the valid_min
bit_2_assessment = Bad
bit_3_description = Value is greater than the valid_max
bit_3_assessment = Bad

lat():float
long_name = North latitude
units = degree_N
valid_min:float = -90
valid_max:float = 90
standard_name = latitude

lon():float
long_name = East longitude
units = degree_E
valid_min:float = -180
valid_max:float = 180
standard_name = longitude

alt():float
long_name = Altitude above mean sea level
units = m
standard_name = altitude

command_line
Conventions = ARM-1.2

process_version
dod_version
site_id
facility_id
platform_id
location_description
th_1:float
th_1_comment = Threshold height (m) between low and middle clouds
th_2:float
th_2_comment = Threshold height (m) between middle and high clouds
th_depth1:float
th_depth1_comment = Cloud thickness threshold (m)
th_depth2:float
th_depth2_comment = Low cloud thickness threshold (m)
cdepth:float
cdepth_comment = Minimum cloud thickness (m)
th_prec:float
th_prec_comment = Precipitation threshold (mm)
datastream
data_level
input_datastreams
doi
history

5.0 Example Plots

Daily quicklooks are generated by the cldtype VAP as shown in the figure below. This figure shows the quicklooks for 20120501 at the Southern Great Plains central facility (sgpC1).

The top plot shows the Ka-band radar reflectivity from the ARSCL data set, showing the cloud_base_best_estimate (based on ceilometer and MPL) superimposed on the plot as black +.

The plot in the middle shows the cloud type classifications as functions of time and height.

The bottom plot is the precipitation (mm/min) on this day obtained from the MET datastream.

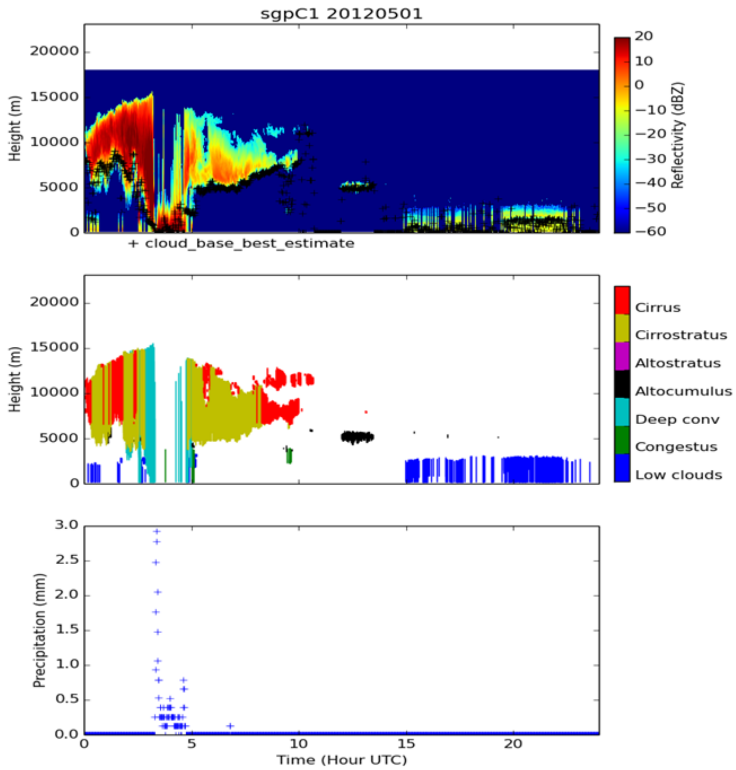

Figure 1. Example of (a) time-height evolution of radar reflectivity from the Ka-band ARM Zenith Radar (KAZR) in the color scale and cloud-base best estimate, retrieved using micro pulse lidar (MPL) and ceilometer (black +), (b) classified cloud types, and (c) 1-minute total precipitation at the ARM SGP C1 site on May 1, 2012.

6.0 Summary

The cldtype VAP is currently being run at the Southern Great Plains (SGP) Central Facility (C1), and Tropical Western Pacific (TWP) sites (C1, C2, and C3). In the future, we may also run the cldtype VAP at the North Slope of Alaska (NSA) Barrow site (C1), and ARM Mobile Facility (AMF) sites where ARSCL data are available, however, this may take some work to define meaningful cloud boundary thresholds for cloud types at these sites. The quicklooks can be found here:

http://www.dmf.arm.gov/ql.php

7.0 References

Burleyson, CD, CN Long, and JM Comstock. 2015. "Quantifying diurnal cloud radiative effects by cloud type in the Tropical Western Pacific." *Journal of Applied Meteorology and Climatology* 54(6): 1297-1312, doi:10.1175/jamc-d-14-0288.1.

McFarlane, SA, CN Long, and J Flaherty. 2013. "A climatology of surface cloud radiative effects at the ARM Tropical Western Pacific sites." *Journal of Applied Meteorology and Climatology* 52(4): 996-1013, doi:10.1175/jamc-d-12-0189.1.

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