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Shallow Cumulus (SHALLOWCUMULUS) Value-Added Product Report

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ARM

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Acronyms and Abbreviations

AERI	atmospheric emitted radiance interferometer
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remotely Sensed Cloud Locations
BL	boundary layer
DOE	U.S. Department of Energy
G-1	Gulfstream-1 aircraft
GCM	global climate model
GOES	Geostationary Operational Environmental Satellites
HI-SCALE	Holistic Interactions of Shallow Clouds, Aerosols, and Land-Ecosystems
KAZR	Ka-Band ARM Zenith Radar
LASSO	LES ARM Symbiotic Simulation and Observation
LES	large-eddy simulation
LWP	liquid water path
MCS	mesoscale convective system
MPL	micropulse lidar
SGP	Southern Great Plains
SNR	signal-to-noise ratio
TSI	total sky imager
UTC	Coordinated Universal Time
VAP	value-added product

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1.0 Introduction

Periods of shallow cumulus clouds are identified automatically at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) observatory in order to help determine times of interest for Large-Eddy Simulation (LES) and Observation (LASSO) modeling efforts. This value-added data product (VAP) uses input from the Cloud Type (CLDTYPE) VAP (with cloud types determined from Active Remotely Sensed Cloud Locations [ARSCL] VAP cloud boundaries), the ceilometer, and the total sky imager (TSI). The data set uses an hourly temporal resolution and only classifies events as shallow cumulus when low clouds are detected for at least 1.5 hours and meet specified criteria for cloud occurrence and cloud fraction. In addition to time periods that contain just shallow cumulus, cases with overlying cirrus and a number of transitional cases (transitions to/from cirrus, stratus, and altocumulus/altostratus) are also identified.

2.0 Input Data

Three input datastreams are used in the VAP as listed below.

2.1 Cloud Type (CLDTYPE)

sgpcldtype.C1.c1.YYYYMMDD.hhmmss.nc

2.2 Total Sky Imager (TSI)

sgptsiskycoverC1.b1.YYYYMMDD.hhmmss.cdf

2.3 Ceilometer

sgpceilC1.b1. YYYYMMDD.hhmmss.nc

3.0 Algorithm and Methodology

The process and criteria for identifying shallow cumulus events are given in Figure 1. The algorithm was developed to match manually identified shallow cumulus cases from previous studies (Berg and Kassiano 2008; Zhang and Klein 2013). A paper describing the algorithm and validation against those data sets is in progress (Kyo-Sun Lim et al. “Long-term cloud type retrieval using a combination of active remote sensors and a total sky imager at the ARM SGP site,” in progress). The algorithm was then tested and adjusted based on cases that were manually identified by the LASSO team in 2015 and 2016 as described in Appendix B.

The CLDTYPE VAP provides cloud classification input for the initial step of identifying time periods of low clouds on a given day. The VAP’s criteria for a low-cloud-only period allows at most two detections (at 1-minute time resolution) of other cloud types. This prevents exclusion of cases with small amounts of

false cloud layer detections due to radar or lidar noise. Additionally, the VAP identifies periods with low clouds and overlying cirrus and again permits at most two detections of any other cloud type.

A potential event is selected for further evaluation if the duration of low clouds in a period is longer than 1.5 hour and contains at least two detections (at 1-minute resolution) of low cloud.

Concurrent cloud fraction measurements from the TSI and ceilometer then screen the potential events further. The TSI cloud fraction must be greater than 0.5% and less than 80% and the ceilometer cloud fraction must be greater than zero. The TSI cloud fraction helps to distinguish between shallow cumulus and a broken stratus deck or when convectively produced shallow cumulus also experiences lifting (stratocumulus).

Time periods that have met all of the criteria at this point are now identified as events. Two events will be combined if they are separated by less than 2.5 hours and the time between them either contains only cirrus or the total number of other cloud type detections is at most two.

Finally, the five hours prior to and subsequent to an identified event are inspected for transitional status. If more than two hours of another cloud type is found within the five hours prior to the event, the event is identified as transitional. These cases are listed in Table 1 and are defined as events transitioning to shallow cumulus. Likewise, if more than two hours of another cloud type is found within the five hours subsequent to the shallow cumulus event, the case is identified as transitioning from shallow cumulus (see Table 2). The event is labeled with the dominant cloud type that the shallow cumulus is transitioning to or from. Only stratus, cirrus, and altocumulus transitional cases are currently included. The transitional cases were defined to give context for the meteorological state, but users should note that these transitional state classifications are preliminary and may not be a reliable indicator of meteorology. Sensitivity test results from varying the 5-hour transitional status window are provided in Appendix A. Currently, we recommend using both shallow cumulus and transitional cases in statistical studies of shallow cumulus occurrence.

4.0 Output Data

4.1 Daily File

This VAP produces daily files identifying shallow cumulus events and shallow cumulus transitional events in 1-hour time blocks. The seven event categories (shcu, st_shcu, shcu_st, ci_shcu, shcu_ci, ac_shcu, and shcu_ac) are represented as distinct field variables and are flagged with either ‘0’ for event not detected or ‘1’ for event detected in each of the 24 1-hour time blocks. The event category shcu has an additional flag, ‘2’, for shallow cumulus events detected with overlying cirrus.

If no event is identified within a given hour, flags in the field shcu_test_criteria describe which test or test criteria failed and/or if required input data was not available. This field consist of nine flags in a bit- packed integer format.

Hourly average cloud fractions for the TSI and ceilometer are given in cloud_fraction_tsi and cloud_fraction_ceil when this input data is available.

Two additional fields available in the daily file include major_cloud_type and max_cloud_type. These fields are used to evaluate time periods for possible shallow cumulus events and represent the dominant cloud type and the maximum cloud type detected in each 1-hour time block. Cloud types are identified in the Cloud type VAP as 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 the Cloud Type Classification VAP technical report.

Each daily output file follows the convention:

SSSshallowcumulusXX.c1.YYYYMMDD.hhmmss.nc

where: SSS = the location of the instrument (nsa, sgp, twp, pye, etc.)
shallowcumulus = 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
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
calendar = gregorian
standard_name = time

time_bounds(time, bound): double
long_name = Time cell bounds
bound_offsets = -1800.,1800.

flag_shcu(time)*;
long_name = Flag for single-layer fair weather shallow cumulus cloud

units = unitless
description = Indicates if shallow cumulus cloud is detected
flag_method = integer
flag_0_description = Shallow cumulus cloud not detected
flag_1_description = Only shallow cumulus cloud is detected
flag_2_description = Shallow cumulus cloud detected with cirrus
flag_values = 0,1,2
flag_meanings = shallow_cumulus_not_detected shallow_cumulus_detected shallow_cumulus_detected_with_cirrus

flag_st_shcu(time):int*
long_name = Flag for transition from stratus to shallow cumulus clouds
units = unitless
description = Indicates if stratus to shallow cumulus transition detected
flag_method = integer
flag_0_description = Transition from stratus to shallow cumulus not detected
flag_1_description = Transition from stratus to shallow cumulus detected
flag_values = 0,1
flag_meanings = Transition_from_stratus_to_shallow_cumulus_not_detected Transition_from_stratus_to_shallow_cumulus_detected

flag_shcu_st(time):int*
long_name = Flag for transition from shallow cumulus to stratus cloud
units = unitless
description = Indicates if shallow cumulus to stratus transition detected
flag_method = integer
flag_0_description = Transition from shallow cumulus to stratus not detected
flag_1_description = Transition from shallow cumulus to stratus detected
flag_values = 0,1
flag_meanings = Transition_from_shallow_cumulus_to_stratus_not_detected Transition_from_shallow_cumulus_to_stratus_detected

flag_ci_shcu(time):int*
long_name = Flag for transition from cirrus to shallow cumulus cloud
units = unitless
description = Indicates if cirrus to shallow cumulus transition detected
flag_method = integer
flag_0_description = Transition from cirrus to shallow cumulus not detected
flag_1_description = Transition from cirrus to shallow cumulus detected
flag_values = 0,1
flag_meanings = Transition_from_cirrus_to_shallow_cumulus_not_detected Transition_from_cirrus_to_shallow_cumulus_detected

flag_ci_shcu_1(time):int*
long_name = Flag for transition from cirrus to shallow cumulus cloud
units = unitless
description = Indicates if cirrus to shallow cumulus transition detected
flag_method = integer
flag_0_description = Transition from cirrus to shallow cumulus not detected
flag_1_description = Transition from cirrus to shallow cumulus detected
flag_values = 0,1
flag_meanings = Transition_from_cirrus_to_shallow_cumulus_not_detected
Transition_from_cirrus_to_shallow_cumulus_detected

flag_shcu_ci(time):int*
long_name = Flag for transition from shallow cumulus to cirrus cloud
units = unitless
description = Indicates if shallow cumulus to cirrus transition detected
flag_method = integer
flag_0_description = Transition from shallow cumulus to cirrus not detected
flag_1_description = Transition from shallow cumulus to cirrus detected
flag_values = 0,1
flag_meanings = Transition_from_shallow_cumulus_to_cirrus_not_detected
Transition_from_shallow_cumulus_to_cirrus_detected

flag_ac_shcu(time):int*
long_name = Flag for transition from autocumulus or autostratus to shallow cumulus cloud
units = unitless
description = Indicates if autocumulus/autostratus to shallow cumulus transition detected
flag_method = integer
flag_0_description = Transition from autocumulus/autostratus to shallow cumulus not detected
flag_1_description = Transition from autocumulus/autostratus to shallow cumulus detected
flag_values = 0,1
flag_meanings = Transition from autocumulus/autostratus to shallow cumulus not detected
Transition from autocumulus/autostratus to shallow cumulus_detected

flag_shcu_ac(time):int*
long_name = Flag for transition from shallow cumulus to autocumulus or autostratus cloud
units = unitless
description = Indicates if shallow cumulus to autocumulus/autostratus transition detected
flag_method = integer
flag_0_description = Transition from shallow cumulus to autocumulus/autostratus not detected
flag_1_description = Transition from shallow cumulus to autocumulus/autostratus detected
flag_values = 0,1

flag_meanings = Transition from shallow cumulus to autocumulus/autostratus not detected
Transition from shallow cumulus to autocumulus/autostratus detected

shcu_test_criteria(time): bit
long_name = Individual shallow cumulus tests
units = unitless
description = Tests applied to determine shallow cumulus cloud events, a value of 0 means none of the following tests applies
bit_1_description = tsi not available during the current hour
bit_2_description = ceilometer not available during the current hour
bit_3_description = cldtype VAP does not detect any cloud
bit_4_description = frequency of low clouds during the current hour <= num_low
bit_5_description = cloud_fraction_tsi <= tsi_cldfra1 during the current hour
bit_6_description = cloud_fraction_ceil <= c_cldfra1 during the current hour
bit_7_description = cloud_fraction_tsi >= tsi_cldfra2 during the current hour
bit_8_description = 1 < max_cloud_type < 7 during the current hour
bit_9_descrition = cloudtype data not available due to missing input
flag_mask = 1,2,4,8,16,32,64,128,256
flag_meanings = tsi_not_available_during_the_current_hour
ceilometer_not_available_during_the_current_hour
cldtype_VAP_does_not_detect_any_cloud
frequency_of_low_clouds_during_the_current_hour_<=_num_low
cloud_fraction_tsi<=tsi_cldfra1_during_the_current_hour
cloud_fraction_ceil<=c_cldfra1_during_the_current_hour
1_<_max_cloud_type_<_7_during_the_current_hour
cloudtype_data_not_available_due_to_missing_input

float cloud_fraction_tsi(time);
long_name = Opaque cloud fraction from tsiskycover averaged hourly
units = %
missing_value = -9999.f
cell_methods = time: mean

float cloud_fraction_ceil(time);
long_name = Cloud fraction from ceilometer averaged hourly
units = %
missing_value = -9999.f
cell_methods = time: mean

float major_cloud_type(time);
long_name = Major cloud type during the hour
units = unitless
missing_value = -9999.f

float max_cloud_type(time);
    long_name = Maximum cloud type during the hour
    units = unitless
    missing_value = -9999.f

float lat;
    long_name = North latitude
    units = degree_N
    valid_min = -90.f
    valid_max = 90.f
    standard_name = latitude

float lon;
    long_name = East longitude
    units = degree_E
    valid_min = -180.f
    valid_max = 180.f
    standard_name = longitude

float alt;
    long_name = Altitude above mean sea level
    units = m
    standard_name = altitude

    command_line
    Conventions = ARM-1.2
    process_version =
    dod_version =
    input_datastreams =
    site_id =
    platform_id =
    facility_id =
    data_level =
    location_description =
    thresholds =
    datastream =
    doi = 10.5439/1392569
    history =

4.2 Monthly Summary Files

In addition to daily files, monthly files are also produced identifying days when one or more shallow cumulus and/or transitional events have been detected. The VAP permits up to four detected events per day; however, more than one or two events on the same day is unusual.

The event type (either shcu or one of six transitional cases mentioned previously) is found in the field shallowcumulus_event. This field is multi-dimensional with four potential events for each calendar days in a given month. The format is bit-packed integer values, where each bit either indicates event type or a value of '0' indicates no cloud event is detected.

The field shallowcumulus_events_test provides information on when a potential case failed test criteria. This field follows the same multi-dimensional and bit-packed integer format. If the bit for a given potential event on a given calendar day is '0', then no event was detected according to test criteria. All other bits values identify what criteria the potential event failed.

Each monthly summary file follows the convention:

SSSshcusummaryXX.c1.YYYYMMDD.hhmmss.nc

where: SSS = the location of the instrument (nsa, sgp, twp, pye, etc.)
shcusummary = The name of this VAP output file
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
event = 4
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_bounds(time, bound):double
long_name = Time cell bounds
bound_offsets:double = 0, 86400

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

shallowcumulus_event(time, event):int*
   long_name = Shallow cumulus event detected
   units = unitless
   missing_value:int = -9999
   flag_masks:int = 1, 2, 4, 8, 16, 32, 64
   flag_meanings = Shallow_cumulus_detected
Transition_from_stratus_to_shallow_cumulus_clouds
Transition_from_shallow_cumulus_clouds_to_stratus
Transition_from_cirrus_to_shallow_cumulus_clouds
Transition_from_shallow_cumulus_clouds_to_cirrus
Transition_from_altocumulus_or_altostratus_to_shallow_cumulus_clouds
Transition_from_shallow_cumulus_clouds_to_altocumulus_or_altostratus
   flag_method = bit
   description = This field contains bit-packed integer values, where each bit indicates the shallow cumulus event detected. A value of 0 indicates no cloud event detected.
   bit_1_description = Shallow cumulus detected
   bit_2_description = Transition from stratus to shallow cumulus clouds
   bit_3_description = Transition from shallow cumulus clouds to stratus
   bit_4_description = Transition from cirrus to shallow cumulus clouds
   bit_5_description = Transition from shallow cumulus clouds to cirrus
   bit_6_description = Transition from altocumulus or altostratus to shallow cumulus clouds
   bit_7_description = Transition from shallow cumulus clouds to altocumulus or altostratus

shallowcumulus_event_tests(time, event):int
   long_name = Shallow cumulus event tests
   units = unitless
   flag_masks:int = 1, 2, 4, 8
   flag_meanings = Event_detected_with_overlying_cirrus
Event_not_detected_no_low_clouds_found
Event_not_detected_due_to_short_duration_of_low_clouds
Event_not_detected_no_input_found
   flag_method = bit
   description = This field contains bit-packed integer values, where each bit indicates why the event is detected or not detected. A value of 0 means shallow cumulus cloud event detected.
   bit_1_description = Event detected with overlying cirrus

bit_2_description = Event not detected, no low clouds found
bit_3_description = Event not detected due to short duration of low clouds
bit_4_description = Event not detected, no input found

start_hour(time, event):int
long_name = Starting hour when event is detected
units
missing_value:int = -9999

end_hour(time, event):int
long_name = Ending hour when event is detected
units
missing_value:int = -9999

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
input_datastreams
site_id
platform_id
facility_id
data_level
location_description

datastream
doi = 10.5439/1392581
history

5.0 Example Plots

Monthly quicklooks are generated by the shallowcumulus VAP as shown in Figure 2 below. This figure shows the quicklook for May of 2017 at the Sothern Great Plains Central Facility (sgpC1).

The top plot shows the day and start and end hours of the identified events that meet the criteria.

The bottom plot shows event status for up to four periods (potential events) of low clouds that may have been evaluated on a given day. These events are color coded (1) red, (2) blue, (3) green, and (4) cyan. Events that meet the criteria are flagged 0 (low clouds only) or 1 (low clouds and overlying cirrus). Periods of low clouds that are identified but do not meet the duration requirement are flagged 3. Periods of low clouds that may be an event but criteria is undetermined due to missing inputs are flagged 4. Flag 2 indicates when there is no detection (if event 1) or no additional detection (if event 2 or greater) of low clouds to evaluate for potential shallow cumulus events.

6.0 Summary

The HSALLOWCUMULUS VAP is being run at the Southern Great Plains (SGP) Central Facility (C1) during the summer season – May through September time period – when occurrence of this cloud type is highest. The VAP was evaluated on 2015 and 2016 data (Appendix B) and became operational for 2017 (Appendix C). A 9-year (2000-2009) data set has been run to compare with manually determined Shallow Cumulus (Berg and Kassianov 2008; Zhang and Klein 2013). This comparison will be described in a journal article that is currently being written (Lim et al. 2018, in progress).

7.0 References

Berg, LK, and EI Kassianov. 2008. "Temporal variability of fair-weather cumulus statistics at the ACRF SGP site." *Journal of Climate* 21: 3344-3358, doi:10.1175/2007JCLI2266.1.

Yunyan, Z, and SA Klein. 2013. "Factors controlling the vertical extent of fair-weather shallow cumulus clouds over land: Investigation of diurnal-cycle observations collected at the ARM Southern Great Plains site." *Journal of the Atmospheric Sciences* 70(4): 1297-1315, doi:10.1175/JAS-D-12-0131.1.

Flynn, D, Y Shi, K Lim, and L Riihimaki. 2017. Cloud Type Classification (cldtype) Value-Added Product. ARM Research Facility. U.S. Department of Energy. DOE/SC-ARM-TR-200.

Appendix A

Transitional Status Results with Varying Window

To assess the impact of the size (duration) of the window used to determine transitional status, the Shallow Cumulus VAP was run with window lengths varying between 1 and 4 hours on SGP data between the months of May and August, 2015 and 2016. The results are provided in the two table below. Each table lists an event's date, start and end time (UTC), and the classification type (either ShCu or one of six transitional types) for a given window length. There were 32 events identified in this data set and they were sorted according to the change in the transitional types with response to a change in the window length. Classification types are shown in red when there is a change in the transitional type in response to an increase in the window length.

Of the 32 events identified, 17 changed transitional type status when the window was increased from 1 to 2 hours (see Table 3). Increasing the window to 3 or 4 hours for these cases did not lead to any further changes. The next 15 events (see Table 4) change if the window is increased from 2 hours to 3 or 4 hours. These results indicate that transitional classification is highly variable and dependent on the length of time used to evaluate the status prior to and subsequent to a shallow cumulus event. The classification is, however, useful to identify dominant cloud type in the near time vicinity of events and to suggest factors influencing the presence and development of shallow cumulus clouds.

Appendix B

Notes on Selected 20015 and 2016 Results

The Shallow Cumulus VAP was developed to support the interests for Large-Eddy Simulation (LES) and Observation (LASSO) modeling efforts. The VAP was initially developed to match manually identified shallow cumulus events from Berg and Kassianov (2008) and Zhang and Klein (2013). We then tested the VAP using shallow cumulus cases determined manually by the LASSO team in 2015 and 2016. Table 5 contains a list of all shallow cumulus events detected by the final version of the VAP during 2015 and 2016, along with notes provided by the LASSO team for those periods as a guide for the type of events that we were soliciting. The final cases chosen by LASSO are labeled as Decision-Priority. In 2015, only a small number of cases were chosen (labeled yes in the table). In 2016, the LASSO team ranked those cases as high (A), medium (B), or low (C) priority. The A list of notes from two individual LASSO team members are shown in columns labeled LASSO Notes 1 and LASSO Notes 2, and the notes on final decision by the LASSO team are shown in column LASSO Notes 3.

The first column of the table (VAP Notes) shows notes and comments from sensitivity tests we ran to test the ability of changing different algorithm settings. Different versions of the algorithm were evaluated with the goal of successfully identifying all of the events LASSO considered high priority. Included in the evaluation was assessing criteria in 30-minute time blocks rather than 60-minute blocks and varying the TSI cloud-fraction criteria between 70% and 80%. Additionally, allowing shallow cumulus events with overlying cirrus was also considered to include priority cases LASSO had selected. The final version of the algorithm only misses one high-priority LASSO case (August 26, 2015), though it includes cases that are likely false positives.

Appendix C

Notes on 2017 Selected Results

The first operational run of the Shallow Cumulus Results was 2017 on May through August for SGP. Notes on the identified cases are provided in Table 6.

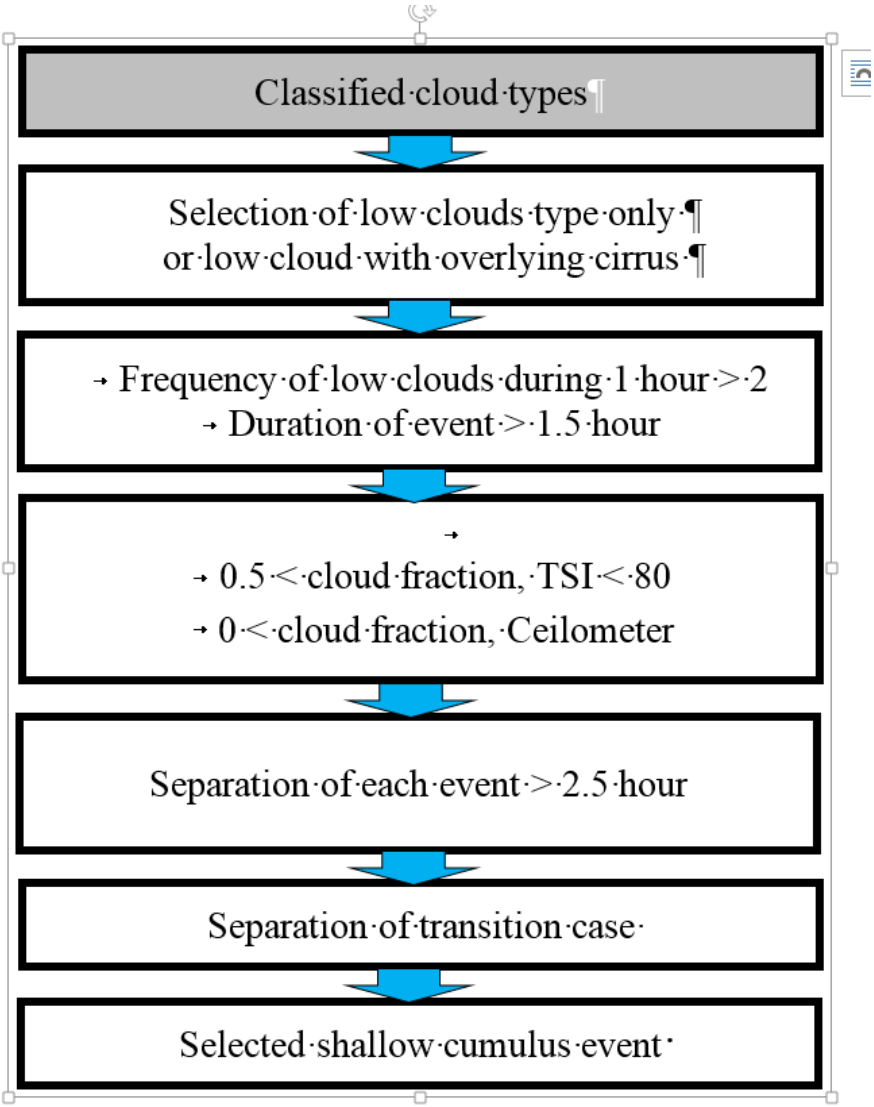

Figure 1. Shallow cumulus event processing and criteria.

Table 1. Shallow cumulus transitional "to" cases.

Event label	Transitional Cloud Type
1. st_shcu	Stratus
2. ci_shcu	Cirrus
3. ac_shcu	Altocumulus

Table 2. Shallow cumulus transitional "from" cases.

`Event label	Transitional Cloud Type
1. shcu_st	Stratus
2. shcu_ci	Cirrus
3. shcu_ac	Altocumulus

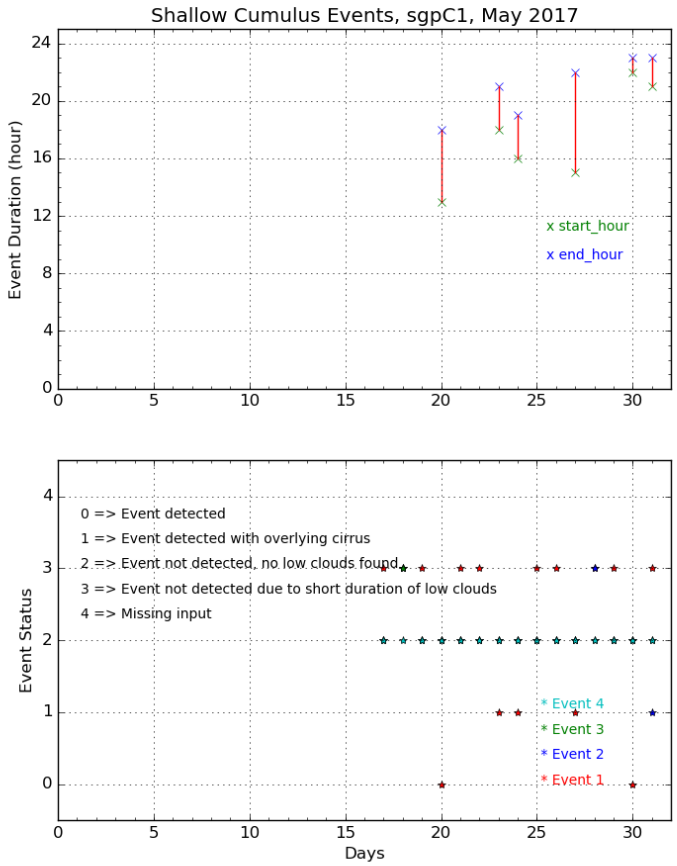

Figure 2. Example quicklook plots.

Table 3. Transitional status with varying window. Cases 1-17 with transitional cloud type change from 1-hour to 2-hour window only.

Case #	Date	start UTC	end UTC	#hrs	Type	#hrs	Type
1	20150605	21	23	1	ShCu	2	CiCs_ShCu
2	20150607	22	23	1	ShCu	2	AcAs_ShCu
3	20150627	16	21	1	ShCu	2	ShCu_AcAs
4	20150804	22	23	1	ShCu	2	St_ShCu
5	20160518	20	23	1	ShCu	2	AcAs_ShCu
6	20160611	15	16	1	ShCu	2	ShCu_AcAs
7	20160616	19	23	1	ShCu	2	AcAs_ShCu
8	20160702	22	23	1	ShCu	2	CiCs_ShCu
9	20160703	20	23	1	ShCu	2	St_ShCu
10	20160704	15	23	1	ShCu	2	St_ShCu
11	20160712	13	18	1	ShCu	2	ShCu_AcAs
12	20160727	16	18	1	ShCu	2	AcAs_ShCu
13	20160809	19	20	1	ShCu	2	CiCs_ShCu
14	20160828	14	17	1	ShCu	2	CiCs_ShCu
15	20150824	19	21	1	ShCu_Ci	2	CiCs_ShCu
16	20160509	17	20	1	ShCu_Ci	2	St_ShCu
17	20160819	20	22	1	ShCu_Ci	2	ShCu

Table 4. Transitional status with varying window. Cases 18-32 with transitional cloud type change if the window is increased from 2 hours to 3 or 4 hours.

Case #	Date	start UTC	end UTC	#hrs	Type	#hrs	Type	#hrs	Type	#hrs	Type
18	20160619	13	19	1	ShCu	2	ShCu	3	ShCu_AcAs	4	ShCu_AcAs
19	20160629	22	23	1	ShCu	2	ShCu	3	CiCs_ShCu	4	CiCs_ShCu
20	20160823	20	22	1	ShCu_Ci	2	ShCu_Ci	3	CiCs_ShCu	4	CiCs_ShCu
21	20150613	21	23	1	CiCs_ShCu	2	CiCs_ShCu	3	CiCs_ShCu	4	St_ShCu
22	20150709	22	23	1	CiCs_ShCu	2	CiCs_ShCu	3	CiCs_ShCu	4	St_ShCu
23	20160520	11	13	1	ShCu_St	2	ShCu_St	3	ShCu_St	4	St_ShCu
24	20160524	11	14	1	ShCu_St	2	ShCu_St	3	ShCu_St	4	St_ShCu
25	20160525	11	20	1	ShCu	2	ShCu	3	ShCu	4	CiCs_ShCu
26	20160715	14	23	1	ShCu	2	ShCu	3	ShCu	4	CiCs_ShCu
27	20160820	13	16	1	ShCu	2	ShCu	3	ShCu	4	ShCu_Ci
28	20160820	19	22	1	ShCu	2	ShCu	3	ShCu	4	ShCu_AcAs
29	20150823	19	22	1	ShCu	2	AcAs_ShCu	3	St_ShCu	4	St_ShCu
30	20160521	11	15	1	ShCu	2	ShCu_AcAs	3	ShCu_St	4	ShCu_St
31	20160626	16	18	1	ShCu	2	ShCu_Ci	3	CiCs_ShCu	4	CiCs_ShCu
32	20160819	12	18	1	ShCu	2	ShCu_Ci	3	CiCs_ShCu	4	CiCs_ShCu

Table 5. VAP and LASSO notes and days of interest for 2015 and 2016.

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
Cirrus layer not consistently detected due to MPL SNR		20150601			
		20150602			
Excluded by VAP unless ci layer allowed	Yes	20150603	Cu with thin Ci	ShCu form a little late around 19:00, wispy Ci	
		20150604			
	Yes	20150606	Cu. No higher cloud.	Classic ShCu case	
Short-duration-cirrus	Yes	20150607		Different type of multi-layer that could be compared with Ci-Cu overlap, fair amount of mid-level cloud	
		20150608			
	Yes	20150609	Cu. No higher cloud.	Classic ShCu case	
Low CF 5-20%		20150610			
		20150613			
Detected by 30-min VAP		20150615			
		20150621			
		20150622			
Significant aerosol structure		20150624			
Detected by 30-min VAP,		20150625			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
Significant aerosol structure					
		20150626			
	Yes	20150627	Cu. Almost no high cloud (a spider at the bottom of the TSI view but no overlap with sky)	High clouds gone by time ShCu start	
		20150703			
		20150705			
		20150706			
		20150709			
		20150710			
		20150722			
Detected by 30-min VAP, questionable radar layer below MPL layer		20150729			
Detected by 30-min VAP, some possible false cloud detection		20150731			
Sparse clouds and short duration	Yes	20150801	Nice Cu mediocris under Ci; few bird drops on TSI in low elevation	Fair amount of Ci throughout day, but lots of ShCu too; possible system to S	
MPL misses clouds 13-14UTC due to instrument condensation attenuation		20150802			
		20150803			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20150804			
		20150805			
		20150817			
MPL cloud mask missing some clouds		20150821			
		20150822			
		20150823			
Detected by 60-min VAP only, sparse clouds, possible misidentification of aerosol as clouds		20150824			
High CF, detected if CF threshold adjusted		20150825			
**This case not detected by VAP due to short duration of low clouds	Yes	20150826	Cu w/occasional Ac (1330-14,16, 0030 UTC)	Ac in morning approach en masse implying synoptic forcing. ShCu form late in day around 19:30. Sampled by Steve S's photos.	
	Yes	20150829	Cu under clear sky. Flat Cu (forced?)	Change in wind direction implies synoptic forcing of clouds	
Detected by 30-min VAP	Yes	20150831	Scattered small Cu under clear sky	Very low CF, could be challenging to replicate	
		20160502			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20160503		Heavy cirrus, but has some ShCu in afternoon, but low-level CF is very small	
		20160509			
		20160511	SGP on W edge of partial cloudy band. MCS to S in afternoon, SGP in quiet pocket.	ShCu but with very low cloud fraction	
		20160514			
		20160515			
	B	20160518	Patchy cloud to N and E, deeper organized cloud to S, on edge, mixed in 300-km region. Good case to test pre-existing cloud issues.	A period of overcast in morning but nice ShCu almost all day	Agreed. Adding note on thick CI until 15 UTC
		20160519			
High CF, detected if CF threshold adjusted		20160520		Fully overcast almost all day, some high CF ShCu in afternoon	Agreed: Could be an interesting St breakup case
High CF, detected if CF threshold adjusted		20160521		Mixed Cu clouds, not sure about elevation and cloud heights, mostly high CF	No: Is a case of residual layer plus BL cloud -- impossibly complicated
		20160522			
Detected by 30-min VAP		20160523	Rains on and off all day, mostly overcast	NFNBML	
		20160524			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
High CF, detected if CF threshold adjusted		20160525		Rains in morning and then clouds break up to clear; possible transition case	
Short duration		20160529			
	C	20160530	On rear side of a squall line, possibly cold-air outbreak scenario? Good case to test forcing-scale sensitivity.	Morning starts overcast but then clears to nice ShCu; clouds at initialization time	
		20160601			
Excluded by VAP unless ci layer allowed, false radar cloud tops		20160603	Post frontal ShCu	Lots of cirrus, but has OK ShCu, late in day gets more complicated, wind shear evident; possible Ci heat shield	Secondary because of CI
		20160604	Very low CF of ShCu and a period of AlCu		
	A	20160610	Pretty uniform and clean case with just some leftover Ci from day before	Morning Ci and then classic ShCu in afternoon	OK now: TSI BL CF looks v low. Need AERIoe LWP to decide.
	A	20160611	Nice uniform ShCu field over SGP much of the day. Organized convection on S OK border that sends cold pool toward central and W OK.	Clear morning with classic ShCu in afternoon	

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20160612		Clear morning with very low CF ShCu late in afternoon	No: shcu only around for 1 h
Excluded by VAP unless ci layer allowed, false radar cloud tops		20160613	Widespread ShCu but complications for forcing from organized Cu		Maybe: Post-frontal shcu after storm (GCMs have problems with them). Similar to 6/14 but the rain is later in the day.
	C	20160614	Strip of patchy clouds that seems tied to a synoptic situation, but obvious diurnal cycle impact as well.	Rain in morning that clears and then classic ShCu in afternoon	Yes. Note: KAZR out after 17 UTC
		20160616		Occasional mid-level with some low-level Cu, low CF in most cases	No: CF too low
Short duration		20160617			
		20160618			
Some false radar cloud tops	A	20160619	Pretty uniform patchy clouds in OK and KS.	ShCu that may be a bit deeper	
	C	20160620	Pretty uniform patchy clouds in OK and KS. Interesting splotchy breakup in afternoon. MCS to N.	Good afternoon ShCu	Agreed. Need to check the LWP, though; no sounding at 12 UTC
		20160621			
		20160622			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
Short duration		20160624			
	B	20160625	OK has nice patchy clouds. Squall line to W and convection to S in TX, but probably not a problem.	Good afternoon ShCu	Agreed. Need to check the LWP, though
Detected by 30-min VAP		20160626		Shallow-to-deep transition	Yes: shallow-to-deep
Non-cirrus clouds at 16UTC split event into two		20160628	Transition to deep occurs mostly to north of SGP and propagates to S across SGP	Good ShCu much of day, rains a tad, clears again, and then deep in late day	Maybe
Detected by 30 min VAP		20160629	ShCu are not widespread. Too small-scale and short lived.	Late afternoon ShCu is good, but lots of upper synoptic-looking cloud in morning that delays ShCu	Maybe: LWP could be low
Detected by 30 min VAP		20160630		Interesting in that the ShCu forms from descending cloud deck	No: Not linked to the BL (descent must be advective)
		20160702	Pretty complicated. Two MCSs develop in KS and strong convection to SW. Patchy clouds form in between. Would be a difficult case.	Fair amount of Ci, but get afternoon ShCu. Changed mind after seeing GOES animation.	No: The precip at 12 UTC plus the MCSs suggest synoptical influences that would mess up the forcings.
		20160703			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
False radar tops		20160704	Patchy clouds form in pocket to E of deeper clouds. Clear to W. Forcing would be a highly mixed regime. ShCu advect E with system.	Low CF ShCu in afternoon	Maybe: I think the low CF kills it, unless we want something the models should get low CF for…
Detected by 60-min VAP only, 13-15 UTC high CF, but 15-18 okay		20160712	Small region of patchy clouds. Highly influenced by gravity waves. Diurnal cycle influence is hard to discern.	Pretty heavy CF but is cumuliform and develops over day. Might be sensitive to scale of forcing due to small region of ShCu.	Maybe (gravity wave issue) and note KAZR out for part of day.
False radar tops		20160713	Very small region of patchy clouds, but appears diurnal cycle driven after a line of convection passes in morning. Get a good case of shallow-to-deep transition just to E of SGP at end of day.	AlCu in morning and then classic ShCu in afternoon. Transition environment (forms to N or E of SGP).	Yes/secondary
Aerosol misidentified as cloud		20160715	Patchy clouds along N OK border that get overridden by an MCS late in the afternoon. Mixed forcing conditions.	Some Ci and maybe AlCu, mostly classic ShCu	Maybe: I think the low CF kills it, unless we want something the models should get low CF for…
	C	20160716	SGP on dividing line between clear (to W) and patch clouds (to E). Might be a tough case – likely forcing-scale dependent.	Morning Ci then afternoon ShCu	Agreed

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20160718	Partial clouds form across SGP region as sun advances. Deep convection to E and clear to W.	Get ShCu but forms a bit later in day	I guess so, but the CF is quite low
Detected by 30 min VAP	B	20160719	Nice widespread partial cloudiness in OK. KS more clear. Looks like a good case.	Ci with underlying ShCu building during day	Agreed
Missing MPL data	C	20160720	Nice uniform partial clouds over SGP region. Good case.	Classic ShCu day; linked to LCL	I guess so, but the CF is quite low
		20160721			
		20160724		Has ShCu but later in day	Agreed. Note that the CF is quite low
Excluded by VAP unless ci layer allowed		20160726		Probably synoptic, pretty complicated	Yes: It seems that the low clouds are BL linked. At least I think this should be a secondary.
		20160727	Partial clouds form from diurnal cycle but get swamped by lots of surrounding deep convection. Appears to mainly be air-mass thunderstorms, so could be a good case to attempt for shallow-to-deep transition.	Most of day is ShCu, some higher clouds occasionally	Yes/primary. Besides the funny cloud ending at 15 UTC it looks like a very good day.

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20160728	Shallow-to-deep transition in area. Cold pool comes across SGP area.	Ci, then classic ShCu that later transitions to rainy deep	Yes/secondary
		20160729			
Detected by 30-min VAP		20160809			
Detected by 60-min VAP only, sparse clouds and low CF		20160810		Probably synoptic, ShCu for part of day, but at higher levels, more clouds to east	
Detected by 60-min VAP only, some of cloud tops high		20160811			
False radar tops		20160812			Maybe: Post-frontal after 18 UTC
		20160816		Very low CF ShCu	
Half of event high CF but second half ok	A	20160818	System to S. Probably sensitive to forcing scale.	Mostly classic ShCu with high CF	Yes/primary
Detected by 30-min VAP	C	20160819		Decent ShCu and Ci. Primary or secondary – complicated forcing.	Yes, probably primary
False radar tops		20160820			
False radar tops		20160823			
Detected by 30-min VAP		20160824			

VAP Notes	Decision-Priority	Date	LASSO Notes1	LASSO Notes2	LASSO Notes3
		20160825		Maybe, for lower end of CF. MPL out for part of the period.	
False radar tops		20160826			
Sparse clouds and low CF		20160828			
	B	20160830	Deep-to-shallow transition case. Looks like a lot of air-mass thunderstorms.	G-1 flew 2 flights for HI-SCALE. Jerome likes this day based on initial impressions.	Yes/primary. Classic shcu (maybe one of the most classic of this set).
		20160831	Shallow-to-deep transition that forms much more deep than prior day.		Maybe. Shcu, then precip, then shcu

Table 6. Notes on 2017 selected results.

	Type	Date	Start (UTC)	End (UTC)	Comment
1	tsi missing	20170504	17	22	
2	tsi missing	20170509	9	13	meets VAP criteria?
3	tsi missing	20170509	18	22	
4	tsi missing	20170516	20	22	meets VAP criteria?
5	tsi missing	20170517	16	19	
1	CiCs_ShCu	20170520	12	17	intermittent high CF
2	CiCs_ShCu	20170523	18	20	
3	ShCu	20170524	15	18	radar doesn't see boundary layer clouds
4	ShCu_Ci	20170527	14	21	
5	ShCu	20170530	21	22	radar suggests low cloud base?
6	CiCs_ShCu	20170531	20	22	radar suggests low cloud base?
7	CiCs_ShCu	20170601	17	20	

	Type	Date	Start (UTC)	End (UTC)	Comment
8	ShCu_St	20170602	11	12	insect clutter
9	CiCs_ShCu	20170605	16	23	insect clutter excludes 14-16 UTC
10	CiCs_ShCu	20170606	17	19	
11	CiCs_ShCu	20170609	14	23	
12	St_ShCu	20170610	16	17	
13	ShCu	20170612	20	22	insect clutter, radar suggests low cloud boundary
14	ShCu	20170613	20	23	
15	ShCu	20170614	14	23	insect clutter
16	ShCu	20170615	0	1	
17	CiCs_ShCu	20170626	16	23	
18	CiCs_ShCu	20170627	11	12	
19	CiCs_ShCu	20170627	16	23	
20	AcAs_ShCu	20170629	14	21	insect clutter excludes 22-23 UTC
21	St_ShCu	20170630	17	19	insect clutter
22	ShCu	20170701	22	23	
23	CiCs_ShCu	20170704	20	22	
24	ShCu	20170706	19	21	radar and lidar disagree, insect clutter above 3.5 km 20-21.5 UTC?
25	ShCu	20170709	19	23	insect clutter?
26	ShCu	20170711	11	15	
27	ShCu_Ci	20170712	18	22	insect clutter
28	ShCu_Ci	20170716	0	1	
29	CiCs_ShCu	20170716	13	21	insect clutter, precip?,cld pts above 3.5 km at 16-17 UTC,
30	ShCu	20170717	16	23	
31	ShCu	20170718	16	20	
32	ShCu	20170719	17	22	
33	ShCu	20170720	18	22	
34	ShCu	20170721	12	13	
35	ShCu	20170721	18	23	
36	CiCs_ShCu	20170724	20	22	
37	ShCu	20170725	17	23	
38	St_ShCu	20170728	20	23	insect clutter, 19-20 UTC high CF
39	ShCu_Ci	20170729	0	1	insect clutter in layer above 3km?
40	St_ShCu	20170801	19	22	insect clutter

	Type	Date	Start (UTC)	End (UTC)	Comment
41	ShCu_Ci	20170802	0	1	
42	ShCu	20170802	12	22	MPL instrument issue, insect clutter
43	ShCu	20170803	16	20	
44	St_ShCu	20170804	15	16	
45	CiCs_ShCu	20170805	17	19	

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