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DOE/SC-ARM-TR-190

ARM Cloud Radar Simulator Package for Global Climate Models Value-Added Product

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Revision 1

September 2017

ARM
CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

ACME	Accelerated Climate Modeling for Energy
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remotely Sensed Cloud Locations
CFAD	radar reflectivity-height histogram
CFMIP	Cloud Feedback Model Intercomparison Project
COSP	CFMIP Observation Simulator Package
D	dimension
dBZ	decibels relative to Z
DOE	U.S. Department of Energy
GCM	global climate model
GHz	gigahertz
km	kilometer
LST	local standard time
m	meter
netcdf	Network Common Data Form file format
ROF	relative occurrence frequency
SGP	Southern Great Plains
TWP	Tropical Western Pacific
VAP	value-added product

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1.0 Introduction

It has been challenging to directly compare U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility ground-based cloud radar measurements with climate model output because of limitations or features of the observing processes and the spatial gap between model and the single-point measurements. To facilitate the use of ARM radar data in numerical models, an ARM cloud radar simulator was developed to converts model data into pseudo-ARM cloud radar observations that mimic the instrument view of a narrow atmospheric column (as compared to a large global climate model [GCM] grid-cell), thus allowing meaningful comparison between model output and ARM cloud observations.

The ARM cloud radar simulator value-added product (VAP) was developed based on the CloudSat simulator contained in the community satellite simulator package, the Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package (COSP) (Bodas-Salcedo et al., 2011), which has been widely used in climate model evaluation with satellite data (Klein et al., 2013, Zhang et al., 2010). The essential part of the CloudSat simulator is the QuickBeam radar simulator that is used to produce CloudSat-like radar reflectivity, but is capable of simulating reflectivity for other radars (Marchand et al., 2009; Haynes et al., 2007). Adapting QuickBeam to the ARM cloud radar simulator within COSP required two primary changes: one was to set the frequency to 35 GHz for the ARM Ka-band cloud radar, as opposed to 94 GHz used for the CloudSat W-band radar, and the second was to invert the view from the ground to space so as to attenuate the beam correctly. In addition, the ARM cloud radar simulator uses a finer vertical resolution (100 m compared to 500 m for CloudSat) to resolve the more detailed structure of clouds captured by the ARM radars.

The ARM simulator has been developed following the COSP workflow (Figure 1) and using the capabilities available in COSP wherever possible. The ARM simulator is written in Fortran 90, just as is the COSP. It is incorporated into COSP to facilitate use by the climate modeling community. In order to evaluate simulator output, the observational counterpart of the simulator output, radar reflectivity-height histograms (CFAD) is also generated from the ARM observations.

This report includes an overview of the ARM cloud radar simulator VAP and the required simulator-oriented ARM radar data product (radarCFAD) for validating simulator output, as well as a user guide for operating the ARM radar simulator VAP.

2.0 ARM Cloud Radar Simulator

2.1 Flowchart

As shown in Figure 1, the ARM simulator follows the COSP flowchart and includes three steps: 1) generating a subgrid-scale distribution of cloud and precipitation; 2) simulating radar signals; and 3) calculating statistical summaries from the subgrid-scale distribution of simulated signals.

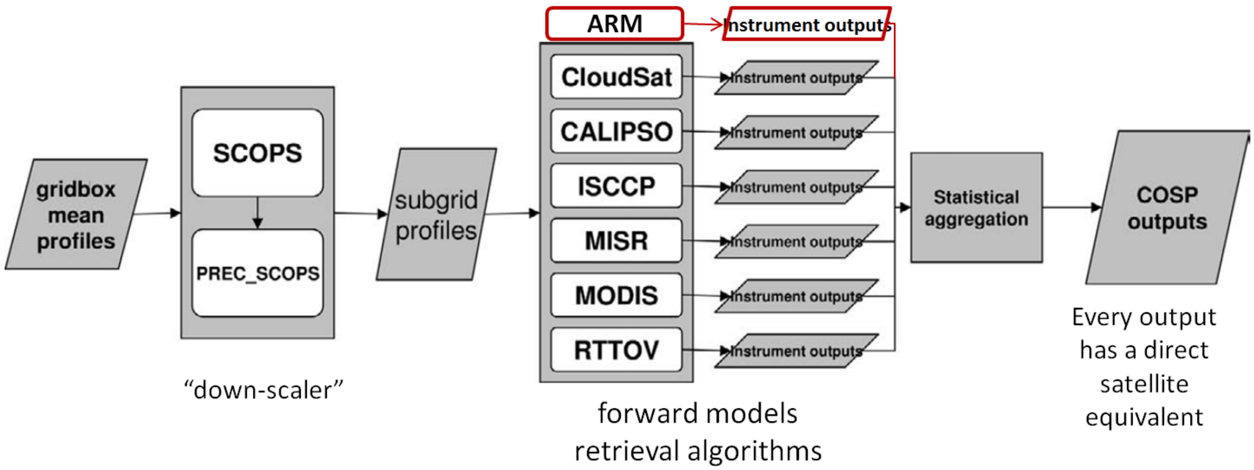

Figure 1. Flowchart of ARM simulator, modified from the COSP flowchart from Bodas-Salcedo et al. (2011).

2.2 Radar Simulator with Instrument Limitations

When calculating profiles of radar reflectivity based on model hydrometeor occurrence, the ARM simulator takes into consideration the minimum sensitivity of the ARM radar, as well as the saturation of the radar receiver. Simulated reflectivity values below the radar sensitivity (modeled as equation 1 below) are eliminated from the occurrence calculations because the ARM cloud radar would not be able to detect them, whereas values above dBZ_max (modeled as equation 2 below) are set to dBZ_max as it represents the saturation limiting value which would be measured:

$$dBZ\_min(h) = -50 + 20 \times log_{10} h \quad (1)$$

$$dBZ\_max(h) = 20 + 20 \times log_{10} h \quad (2)$$

where h is height in kilometers. While the radar hardware and operational parameters have undergone many changes over the years, the sensitivity of the ARM radars nominally exceeds this threshold; and these same thresholds are used in the simulator and when processing the observations.

3.0 Radar CFAD Data Product

3.1 Radar CFAD

The measurement-based CFADs, required for validating ARM cloud radar simulator output, were generated from the ARM value-added cloud product called ARSCL (Active Remotely-Sensed Cloud Locations) with quality controls and only include clouds detected by cloud radar. The reflectivity-height data were produced for every hour with the vertical resolution of 100 m to capture both the diurnal variability and detailed vertical structures of clouds. The decibels relative to Z (dBZ) values are binned by each 5 dBZ in the range of -50 dBZ to 25 dBZ. The daily and monthly mean data can be easily calculated from the hourly data. Figure 2 provides an example of how the measured radar reflectivity is shown in CFAD.

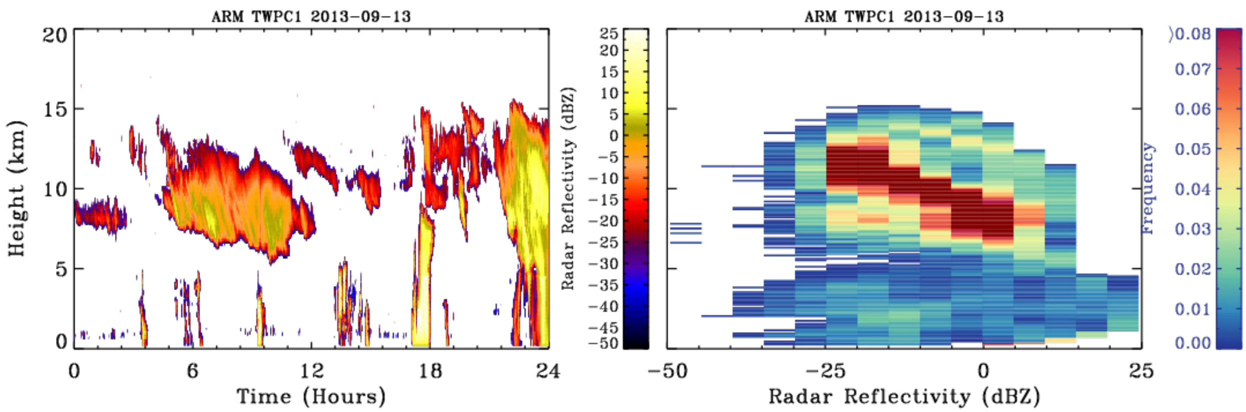

Figure 2. Measured radar reflectivity (left) and the calculated radar CFAD (right) at the Tropical Western Pacific (TWP) Manus Island (Papua New Guinea) site on September 13, 2013.

3.2 Clutter Issue

For the ground-based ARM radar, insect clutter is a big issue for signals detected at lower levels, typically below 3 km. This is particularly true at the ARM Southern Great Plains (SGP) site during the summertime (Luke et., 2008). To address this issue, we produced two sets of ARM CFAD data based on the data quality flags “qc_ReflectivityClutterFlag=1” and “qc_ReflectivityClutterFlag=1 or 2”, respectively, contained in the ARSCL data product. A flag value of 1 indicates that the algorithm used to produce the ARSCL data did not find evidence of clutter contaminating the hydrometeor, while a flag value of 2 indicates the presence of a potential (unknown) mixture of hydrometeors and clutter. Therefore, histograms built using “qc_ReflectivityClutterFlag = 1 and 2” may overestimate cloud amount because clutter may be identified as cloud, whereas those based on “qc_ReflectivityClutterFlag = 1” may underestimate cloud amount because some hydrometeors potentially contaminated by clutter were not incorporated into the histograms. The two sets of ARM CFAD data products provide upper and lower bounds for the ARM observations by considering potential impacts of insect clutter on the data. Figure 3 indicates that large differences (~15%) are seen in non-precipitating low clouds between the two data products.

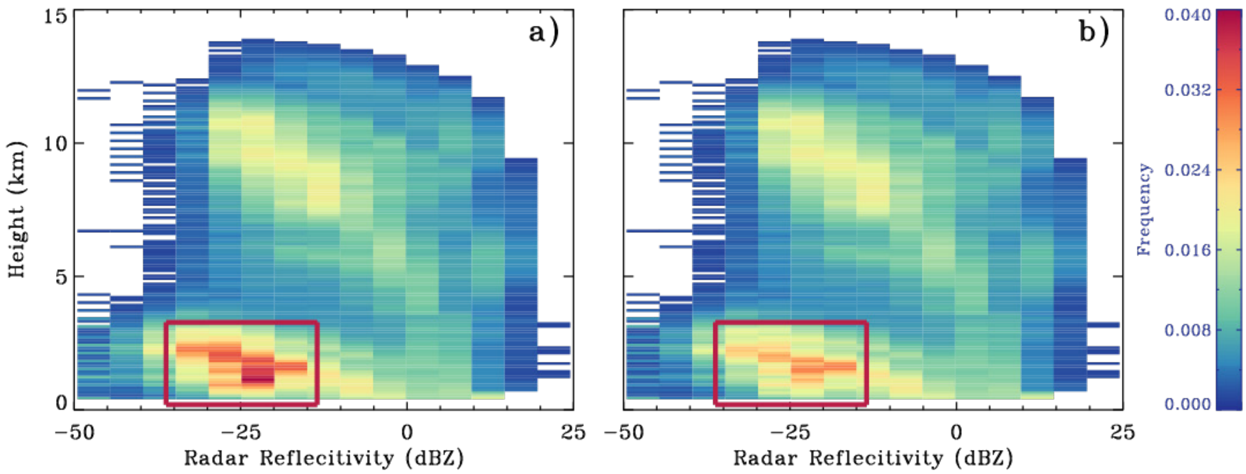

Figure 3. Monthly-mean ARM observation-based CFADs at the ARM SGP site for May 2009. a) qc_ReflectivityClutterFlag equal to 1 and 2, b) qc_ReflectivityClutterFlag equal to 1.

3.3 Monthly Statistics

The monthly statistics were also generated from the hourly radar CFAD data. The monthly data files include monthly-mean joint histogram of reflectivity-height data and occurrence frequency of non-precipitating clouds/precipitating hydrometeor. The reflectivity-height data were produced at the original vertical resolution and 5-dBZ bins. The occurrence frequency of non-precipitating clouds/precipitating hydrometeor were at hourly temporal resolution with vertical resolution of 100 m to capture both the diurnal variability and detailed vertical structures of clouds. The details for calculating occurrence frequency of non-precipitating and precipitating hydrometeors are shown in section 4.4.

4.0 User Guide

4.1 Obtain ARM Radar Simulator

Currently, we have implemented the ARM radar simulator into the latest version of COSP (version 2.0), which involves fundamental reorganization to the COSP version 1 infrastructure for easily adding new simulators. The COSP 2.0 with the ARM simulator has been released as a branch in the COSP repository https://github.com/CFMIP/ COSPv2.0/tree/impArmSim so that the users can get both COSP and the ARM radar simulator in one package.

To run the ARM simulator, the user needs to run COSP by tuning on the option for the ARM simulator. The user interaction with COSP is done via namelists, which is located in file cosp_input_nl.txt. The configuration variables are given in Table 1.

Table 1. COSP_INPUT namelist set-up for the ARM radar simulator.

	Configuration variable	Default value

ARM_RADAR_FREQ	ARM Radar Frequency (GHz)	35.0
ARM_SURFACE_RADAR	ARM radar position surface=1, spaceborne=0	1

With QuickBeam, the user can define the distribution, phase, and mass-diameter relationship for each hydrometeor type. The calculations of the radar signal strength are based on the profiles of nine hydrometeor types that are defined in cosp_constants.F90:

I_LSCLIQ = 1 (large-scale cloud liquid)
I_LSCICE = 2 (large-scale cloud ice)
I_LSRAIN = 3 (large-scale rain)
I_LSSNOW = 4 (large-scale snow)
I_CVCLIQ = 5 (convective cloud liquid)
I_CVCICE = 6 (convective cloud ice)
I_CVRAIN = 7 (convective rain)
I_CVSNOW = 8 (convective snow)
I_LSGRPL = 9 (large-scale cloud graupel)

Modeled profiles of the mixing ratios and optional effective radius/number concentration of each hydrometeor type (liquid, ice, rain, and snow) are supplied separately, and all hydrometeors are treated as spheres whose densities vary with particle diameter in a way specified by the user. The radar simulator calculates the radar reflectivity by selecting the appropriate size distribution for the model from the options contained within Quickbeam. The built-in distributions include modified gamma, exponential, power law, monodisperse, and lognormal. QuickBeam accounts for attenuation by atmospheric gases and hydrometeors.

Although the COSP can be applied to both online and offline runs, we recommend that users run the ARM simulator offline to save computational costs. This will require climate modeling centers to output all of the model variables necessary to run the simulator at these ARM sites as described in the following section.

4.2 Input

The model outputs required to run the ARM radar simulator are listed in Table 2 and also marked as bold in the COSP input file listed in the Appendix.

Table 2. The model output required to run the ARM radar simulator.

Variable	long_name	unit
height	height_in_full_levels	m
height_half	height_in_half_levels	m
T_abs	air_temperature	K
qv	specific_humidity	kg/kg
rh	relative_humidity_liquid_water	%
pfull	p_in_full_levels	Pa
phalf	p_in_half_levels	Pa
mr_lsliq	mixing_ratio_large_scale_cloud_liquid	kg/kg

mr_lsice	mixing_ratio_large_scale_cloud_ice	kg/kg
mr_ccliq	mixing_ratio_convective_cloud_liquid	kg/kg
mr_ccice	mixing_ratio_convective_cloud_ice	kg/kg
fl_lsrain	flux_large_scale_cloud_rain	kg m^-2 s^-1
fl_lssnow	flux_large_scale_cloud_snow	kg m^-2 s^-1
fl_lsgrpl	flux_large_scale_cloud_graupel	kg m^-2 s^-1
fl_ccrain	flux_convective_cloud_rain	kg m^-2 s^-1
fl_ccsnow	flux_convective_cloud_snow	kg m^-2 s^-1
tca	total_cloud_amount	0-1
cca	convective_cloud_amount	0-1
Reff	hydrometeor_effective_radius	m

Note that the ARM cloud radar simulator can automatically handle and run satisfactorily if the model does not have all the variables—for example, effective radius or flux of graupel.

4.3 Output

The namelist of output variables is in the file cosp_output_nl.txt. The logical flags that control the output variables of the ARM radar simulator are shown in Table 3.

Table 3. COSP_OUTPUT namelist for the ARM radar simulator.

	Flag for ARM simulator output	**Default value**
Larmcfaddbze35	ARM radar reflectivity CFAD	True
Larmdbz35	ARM radar reflectivity (attenuation-corrected)	true

These two variables, ARM radar reflectivity CFAD and ARM radar reflectivity (attenuation-corrected), are the general output of the ARM radar simulator.

4.4 Application in Climate Model Evaluation

The seasonal/annual-mean radar CFAD are the primary diagnostics used for model evaluation. In addition to the simple CFAD comparison, more information can be derived from the ARM continuous observations. Different from the CloudSat observations, one unique feature of ARM cloud observations with high temporal resolution is that it allows examination of detailed cloud vertical structures over the diurnal cycle, which is one fundamental mode of climate variability that most current climate models have difficulty capturing. As a demonstration, we applied the simulator to the DOE Accelerated Climate Modeling for Energy atmosphere model version 0 (ACME v0). The ARM simulator was run offline with input files from ACME day 2 hindcasts for the period from May to August 2009 at SGP.

Figure 4 illustrates the observed and model-based diurnal cycles of hydrometeors averaged over the four-month period. The hydrometeors with reflectivity less than -20 dBZ are typically small and will be considered as non-precipitating clouds. For non-precipitating clouds, the model fails to capture the occurrence of shallow cumulus clouds that grow atop the daytime boundary layer (compare Figures 4a and 4b). For precipitating hydrometeors, estimated by the occurrence of reflectivities larger than -20 dBZ, the model significantly overestimates clouds at all levels. Finally, modeled precipitating clouds peaked in the afternoon around 4 PM LST (Figure 4d), in contrast to the corresponding peak in the observations near midnight (Figure 4c). The nighttime peak in observed precipitation at SGP is due largely to the impact of organized mesoscale convective systems, which most current climate models have difficulty capturing.

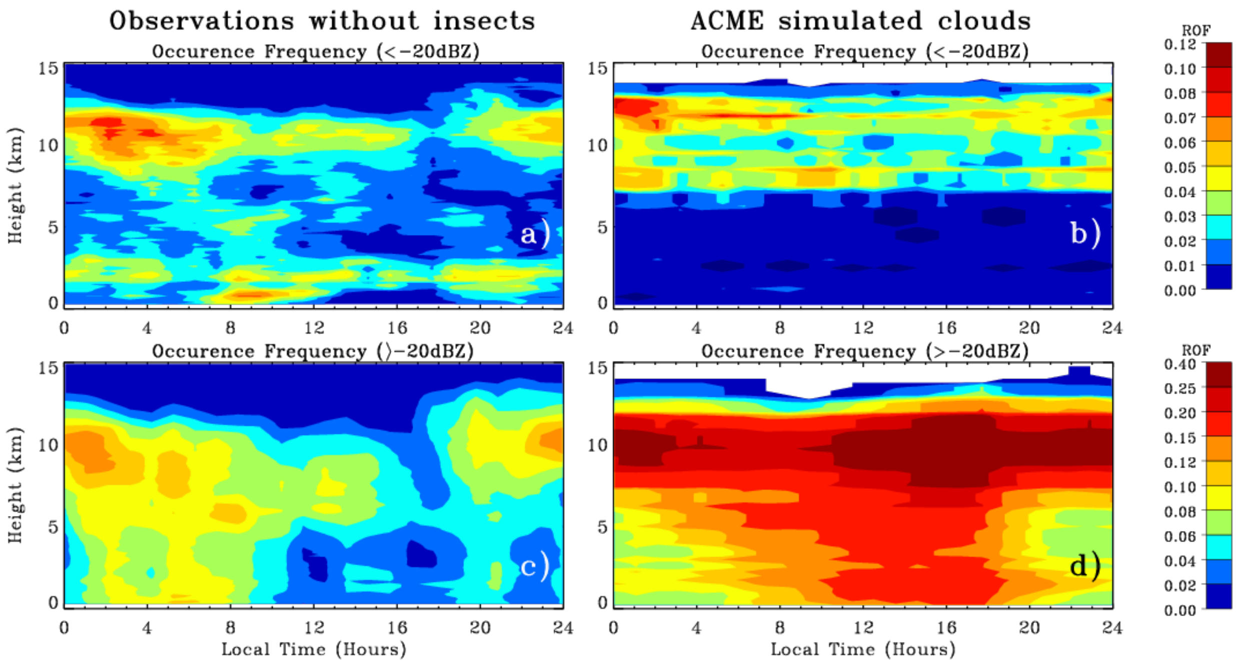

Figure 4. Observed (a and c) and modeled (b and d) diurnal cycles of clouds during the summer months (i.e., May, June, July, and August) of 2009. a) and b) are the relative occurrence frequencies (ROFs) of non-precipitating clouds and c) and d) are the ROFs of precipitating clouds.

5.0 References

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Marchand, RJ, J Haynes, GG Mace, T Ackerman, and G Stephens. 2009. "A comparison of simulated cloud radar output from the multiscale modeling framework global climate model with CloudSat cloud radar observations." *Journal of Geophysical Research – Atmospheres* 114(D8): doi:10.1029/2008JD009790.

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Appendix A

Structure of the COSP Input File

The Common Data Language structure of the COSP input NETCDF file in 1D mode:

```
netcdf cosp_input_um {
dimensions:
        point = 1236 ;
        level = 50 ;
        hydro = 9 ;
variables:
        short year(point) ;
         year:long_name = "year" ;
         year:_FillValue = -32767s ;
         year:units = "yr" ;
        byte month(point) ;
         month:long_name = "month" ;
         month:_FillValue = -127b ;
        byte day(point) ;
         day:long_name = "day" ;
         day:_FillValue = -127b ;
         day:units = "day" ;
        byte hour(point) ;
         hour:long_name = "hour" ;
         hour:_FillValue = -127b ;
         hour:units = "hr" ;
        byte minute(point) ;
         minute:long_name = "minute" ;
         minute:_FillValue = -127b ;
         minute:units = "min" ;
        float second(point) ;
         second:long_name = "second" ;
         second:_FillValue = -1.e+30f ;
         second:units = "s" ;
        float t(point) ;
         t:long_name = "t" ;
         t:_FillValue = -1.e+30f ;
```

t:units = "min" ;
float tUM(point) ;
tUM:long_name = "tUM" ;
tUM:_FillValue = -1.e+30f ;
tUM:units = "min" ;
float lst(point) ;
lst:long_name = "lst" ;
lst:_FillValue = -1.e+30f ;
lst:units = "h" ;
float lon(point) ;
lon:long_name = "longitude" ;
lon:_FillValue = -1.e+30f ;
lon:units = "degree_east" ;
float lat(point) ;
lat:long_name = "latitude" ;
lat:_FillValue = -1.e+30f ;
lat:units = "degree_north" ;
float landmask(point) ;
landmask:long_name = "landmask" ;
landmask:_FillValue = -1.e+30f ;
landmask:units = "1" ;
float orography(point) ;
orography:long_name = "orography" ;
orography:_FillValue = -1.e+30f ;
orography:units = "m" ;
float psfc(point) ;
psfc:long_name = "surface_pressure" ;
psfc:_FillValue = -1.e+30f ;
psfc:units = "Pa" ;
float **height**(level, point) ;
height:long_name = "height_in_full_levels" ;
height:_FillValue = -1.e+30f ;
height:units = "m" ;
float **height_half**(level, point) ;
height_half:long_name = "height_in_half_levels" ;
height_half:_FillValue = -1.e+30f ;
height_half:units = "m" ;
float **T_abs**(level, point) ;
T_abs:long_name = "air_temperature" ;
T_abs:_FillValue = -1.e+30f ;
T_abs:units = "K" ;
float **qv**(level, point) ;
qv:long_name = "specific_humidity" ;
qv:_FillValue = -1.e+30f ;
qv:units = "kg/kg" ;
float **rh**(level, point) ;

```
  rh:long_name = "relative_humidity_liquid_water" ;
  rh:_FillValue = -1.e+30f ;
  rh:units = "%" ;
 float pfull(level, point) ;
  pfull:long_name = "p_in_full_levels" ;
  pfull:_FillValue = -1.e+30f ;
  pfull:units = "Pa" ;
 float phalf(level, point) ;
  phalf:long_name = "p_in_half_levels" ;
  phalf:_FillValue = -1.e+30f ;
  phalf:units = "Pa" ;
 float mr_lsliq(level, point) ;
  mr_lsliq:long_name = "mixing_ratio_large_scale_cloud_liquid" ;
  mr_lsliq:_FillValue = -1.e+30f ;
  mr_lsliq:units = "kg/kg" ;
 float mr_lsice(level, point) ;
  mr_lsice:long_name = "mixing_ratio_large_scale_cloud_ice" ;
  mr_lsice:_FillValue = -1.e+30f ;
  mr_lsice:units = "kg/kg" ;
 float mr_ccliq(level, point) ;
  mr_ccliq:long_name = "mixing_ratio_convective_cloud_liquid" ;
  mr_ccliq:_FillValue = -1.e+30f ;
  mr_ccliq:units = "kg/kg" ;
 float mr_ccice(level, point) ;
  mr_ccice:long_name = "mixing_ratio_convective_cloud_ice" ;
  mr_ccice:_FillValue = -1.e+30f ;
  mr_ccice:units = "kg/kg" ;
 float fl_lsrain(level, point) ;
  fl_lsrain:long_name = "flux_large_scale_cloud_rain" ;
  fl_lsrain:_FillValue = -1.e+30f ;
  fl_lsrain:units = "kg m^-2 s^-1" ;
 float fl_lssnow(level, point) ;
  fl_lssnow:long_name = "flux_large_scale_cloud_snow" ;
  fl_lssnow:_FillValue = -1.e+30f ;
  fl_lssnow:units = "kg m^-2 s^-1" ;
 float fl_lsgrpl(level, point) ;
  fl_lsgrpl:long_name = "flux_large_scale_cloud_graupel" ;
  fl_lsgrpl:_FillValue = -1.e+30f ;
  fl_lsgrpl:units = "kg m^-2 s^-1" ;
 float fl_ccrain(level, point) ;
  fl_ccrain:long_name = "flux_convective_cloud_rain" ;
  fl_ccrain:_FillValue = -1.e+30f ;
  fl_ccrain:units = "kg m^-2 s^-1" ;
 float fl_ccsnow(level, point) ;
  fl_ccsnow:long_name = "flux_convective_cloud_snow" ;
  fl_ccsnow:_FillValue = -1.e+30f ;
```

```
 fl_ccsnow:units = "kg m^-2 s^-1" ;
float tca(level, point) ;
 tca:long_name = "total_cloud_amount" ;
 tca:_FillValue = -1.e+30f ;
 tca:units = "0-1" ;
float cca(level, point) ;
 cca:long_name = "convective_cloud_amount" ;
 cca:_FillValue = -1.e+30f ;
 cca:units = "0-1" ;
float Reff(hydro, level, point) ;
 Reff:long_name = "hydrometeor_effective_radius" ;
 Reff:_FillValue = -1.e+30f ;
 Reff:units = "m" ;
float dtau_s(level, point) ;
 dtau_s:long_name = "Optical depth of stratiform cloud at 0.67 micron" ;
 dtau_s:_FillValue = -1.e+30f ;
 dtau_s:units = "1" ;
float dtau_c(level, point) ;
 dtau_c:long_name = "Optical depth of convective cloud at 0.67 micron" ;
 dtau_c:_FillValue = -1.e+30f ;
 dtau_c:units = "1" ;
float dem_s(level, point) ;
 dem_s:long_name = "Longwave emissivity of stratiform cloud at 10.5 micron" ;
 dem_s:_FillValue = -1.e+30f ;
 dem_s:units = "1" ;
float dem_c(level, point) ;
 dem_c:long_name = "Longwave emissivity of convective cloud at 10.5 micron" ;
 dem_c:_FillValue = -1.e+30f ;
 dem_c:units = "1" ;
float skt(point) ;
 skt:long_name = "Skin temperature" ;
 skt:_FillValue = -1.e+30f ;
 skt:units = "K" ;
float sunlit(point) ;
 sunlit:long_name = "Day points" ;
 sunlit:_FillValue = -1.e+30f ;
 sunlit:units = "1" ;
float u_wind(point) ;
 u_wind:long_name = "eastward_wind" ;
 u_wind:_FillValue = -1.e+30f ;
 u_wind:units = "m s-1" ;
float v_wind(point) ;
 v_wind:long_name = "northward_wind" ;
 v_wind:_FillValue = -1.e+30f ;
 v_wind:units = "m s-1" ;
float mr_ozone(level, point) ;
```

```
        mr_ozone:long_name = "mass_fraction_of_ozone_in_air" ;
        mr_ozone:_FillValue = -1.e+30f ;
        mr_ozone:units = "kg/kg" ;
       float emsfc_lw ;
        emsfc_lw:long_name = "Surface emissivity at 10.5 micron (fraction)" ;
        emsfc_lw:_FillValue = -1.e+30f ;
        emsfc_lw:units = "1" ;

// global attributes:
        :title = "COSP inputs UKMO N320L50" ;
        :Conventions = "CF-1.0" ;
        :description = "" ;
        :history = "Mon Dec 20 13:01:16 2010: ncatted -a units,qv,m,c,kg/kg
cosp_input_um.nc" ;
}
```

The Common Data Language structure of the COSP input NETCDF file in 2D mode:

```
netcdf cosp_input_um_2d {
dimensions:
        lon = 17 ;
        lat = 9 ;
        level = 38 ;
        bnds = 2 ;
        hydro = 9 ;
variables:
        float lon(lon) ;
                lon:axis = "X" ;
                lon:units = "degrees_east" ;
                lon:long_name = "longitude" ;
                lon:bounds = "lon_bnds" ;
        float lat(lat) ;
                lat:axis = "Y" ;
                lat:units = "degrees_north" ;
                lat:long_name = "latitude" ;
                lat:bounds = "lat_bnds" ;
        float lon_bnds(lon, bnds) ;
        float lat_bnds(lat, bnds) ;
        float height(level, lat, lon) ;
                height:units = "m" ;
                height:long_name = "height_in_full_levels" ;
                height:FillValue = -1.e+30f ;
        float pfull(level, lat, lon) ;
                pfull:units = "Pa" ;
```

```
        pfull:long_name = "p_in_full_levels" ;
        pfull:FillValue = -1.e+30f ;
float phalf(level, lat, lon) ;
        phalf:units = "Pa" ;
        phalf:long_name = "p_in_half_levels" ;
        phalf:FillValue = -1.e+30f ;
float T_abs(level, lat, lon) ;
        T_abs:units = "K" ;
        T_abs:long_name = "air_temperature" ;
        T_abs:FillValue = -1.e+30f ;
float qv(level, lat, lon) ;
        qv:units = "kg/kg" ;
        qv:long_name = "specific_humidity" ;
        qv:FillValue = -1.e+30f ;
float rh(level, lat, lon) ;
        rh:units = "%" ;
        rh:long_name = "relative_humidity" ;
        rh:FillValue = -1.e+30f ;
float tca(level, lat, lon) ;
        tca:units = "1" ;
        tca:long_name = "total_cloud_amount" ;
        tca:FillValue = -1.e+30f ;
float cca(level, lat, lon) ;
        cca:units = "1" ;
        cca:long_name = "convective_cloud_amount" ;
        cca:FillValue = -1.e+30f ;
float mr_lsliq(level, lat, lon) ;
        mr_lsliq:units = "kg/kg" ;
        mr_lsliq:long_name = "mixing_ratio_large_scale_cloud_liquid" ;
        mr_lsliq:FillValue = -1.e+30f ;
float mr_lsice(level, lat, lon) ;
        mr_lsice:units = "kg/kg" ;
        mr_lsice:long_name = "mixing_ratio_large_scale_cloud_ice" ;
        mr_lsice:FillValue = -1.e+30f ;
float mr_ccliq(level, lat, lon) ;
        mr_ccliq:units = "kg/kg" ;
        mr_ccliq:long_name = "mixing_ratio_convective_cloud_liquid" ;
        mr_ccliq:FillValue = -1.e+30f ;
float mr_ccice(level, lat, lon) ;
        mr_ccice:units = "kg/kg" ;
        mr_ccice:long_name = "mixing_ratio_convective_cloud_ice" ;
        mr_ccice:FillValue = -1.e+30f ;
float fl_lsrain(level, lat, lon) ;
        fl_lsrain:units = "kg m^-2 s^-1" ;
        fl_lsrain:long_name = "flux_large_scale_cloud_rain" ;
        fl_lsrain:FillValue = -1.e+30f ;
```

```
float fl_lssnow(level, lat, lon) ;
        fl_lssnow:units = "kg m^-2 s^-1" ;
        fl_lssnow:long_name = "flux_large_scale_cloud_snow" ;
        fl_lssnow:FillValue = -1.e+30f ;
float fl_lsgrpl(level, lat, lon) ;
        fl_lsgrpl:units = "kg m^-2 s^-1" ;
        fl_lsgrpl:long_name = "flux_large_scale_cloud_graupel" ;
        fl_lsgrpl:FillValue = -1.e+30f ;
float fl_ccrain(level, lat, lon) ;
        fl_ccrain:units = "kg m^-2 s^-1" ;
        fl_ccrain:long_name = "flux_convective_cloud_rain" ;
        fl_ccrain:FillValue = -1.e+30f ;
float fl_ccsnow(level, lat, lon) ;
        fl_ccsnow:units = "kg m^-2 s^-1" ;
        fl_ccsnow:long_name = "flux_convective_cloud_snow" ;
        fl_ccsnow:FillValue = -1.e+30f ;
float orography(lat, lon) ;
        orography:units = "m" ;
        orography:long_name = "orography" ;
        orography:FillValue = -1.e+30f ;
float landmask(lat, lon) ;
        landmask:units = "1" ;
        landmask:long_name = "land_mask" ;
        landmask:FillValue = -1.e+30f ;
float height_half(level, lat, lon) ;
        height_half:units = "m" ;
        height_half:long_name = "height_in_half_levels" ;
        height_half:FillValue = -1.e+30f ;
float psfc(lat, lon) ;
        psfc:units = "Pa" ;
        psfc:long_name = "surface_pressure" ;
        psfc:FillValue = -1.e+30f ;
float Reff(hydro, level, lat, lon) ;
        Reff:units = "m" ;
        Reff:long_name = "hydrometeor_effective_radius" ;
        Reff:FillValue = -1.e+30f ;
float dtau_s(level, lat, lon) ;
        dtau_s:units = "1" ;
        dtau_s:long_name = "Optical depth of stratiform cloud at 0.67 micron" ;
        dtau_s:FillValue = -1.e+30f ;
float dtau_c(level, lat, lon) ;
        dtau_c:units = "1" ;
        dtau_c:long_name = "Optical depth of convective cloud at 0.67 micro" ;
        dtau_c:FillValue = -1.e+30f ;
float dem_s(level, lat, lon) ;
        dem_s:units = "1" ;
```

```
                dem_s:long_name = "Longwave emissivity of stratiform cloud at 10.5 micron" ;
                dem_s:FillValue = -1.e+30f ;
        float dem_c(level, lat, lon) ;
                dem_c:units = "1" ;
                dem_c:long_name = "Longwave emissivity of convective cloud at 10.5 micron" ;
                dem_c:FillValue = -1.e+30f ;
        float skt(lat, lon) ;
                skt:units = "K" ;
                skt:long_name = "Skin temperature" ;
                skt:FillValue = -1.e+30f ;
        float sunlit(lat, lon) ;
                sunlit:units = "1" ;
                sunlit:long_name = "Day points" ;
                sunlit:FillValue = -1.e+30f ;
        float emsfc_lw ;
                emsfc_lw:units = "1" ;
                emsfc_lw:long_name = "Surface emissivity at 10.5 micron (fraction)" ;
                emsfc_lw:FillValue = -1.e+30f ;
        float mr_ozone(level, lat, lon) ;
                mr_ozone:units = "kg/kg" ;
                mr_ozone:long_name = "mass_fraction_of_ozone_in_air" ;
                mr_ozone:FillValue = -1.e+30f ;
        float u_wind(lat, lon) ;
                u_wind:units = "m s-1" ;
                u_wind:long_name = "eastward_wind" ;
                u_wind:FillValue = -1.e+30f ;
        float v_wind(lat, lon) ;
                v_wind:units = "m s-1" ;
                v_wind:long_name = "northward_wind" ;
                v_wind:FillValue = -1.e+30f ;
```

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