

Title: Hydrometeor Mask and Cloud Boundaries

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1.0 Data Set Overview:

Introduction

Extensive observations of cloud macro- and microphysical properties of marine boundary layer clouds were made during the Cloud System Evolution in the Trades (CSET) field campaign. Among the instruments onboard the Gulfstream-V High Performance Instrumented Airborne Platform for Environmental Research (GV-HIAPER) aircraft was the HIAPER Cloud Radar (HCR) and the High Spectral Resolution Lidar (HSRL). We have combined the data collected by the HCR and the HSRL to calculate hydrometeor masks and cloud boundaries. The dataset also has thresholded HCR Doppler spectral moments and the HSRL backscatter.

Time period covered by the data: July 1, 2015 to August 15, 2015.

Physical location of the measurement or platform: Variable based on GV altitude

Data source if applicable: None

Any web address references:

- https://www.eol.ucar.edu/field_projects/cset
- http://faculty.washington.edu/robwood2/wordpress/?page_id=639
- <http://cseteducation.weebly.com/about-cset.html>

2.0 Instrument Description:

The HCR operated at the 95 GHz frequency and reported the first three moments of Doppler spectra and linear depolarization ratio (LDR) at a 10 Hz and 20 m resolution (Vivekanandan et al., 2016) using the pulse-pair method. The HSRL operated at 532 nm wavelength, and reported the calibrated molecular, aerosol and total backscatter cross-sections, optical depth and depolarization ratio. The operating settings of the HCR and the HSRL are reported in the table below.

Operating settings of HCR and HSRL

	HCR	HSRL
Wavelength	3.2 mm	532 nm
Pulse Repetition Frequency	10 kHz	4 kHz
Number of Samples used to calculate moments or backscatter	1000	2000
Range Resolution	20 m	7.5 m
Temporal Resolution	2 Hz	2 Hz
Variables Used in this dataset	<ul style="list-style-type: none">• Signal To Noise Ratio (dB)• Radar Reflectivity,	<ul style="list-style-type: none">• Backscatter cross-section ($\text{km}^{-1} \text{Sr}^{-1}$)• Standard Deviation of

	(dBz) <ul style="list-style-type: none"> • Mean Doppler Velocity (m s^{-1}) • Doppler Spectrum Width (m s^{-1}) 	the Backscatter cross-section ($\text{km}^{-1} \text{Sr}^{-1}$) <ul style="list-style-type: none"> • Molecular Backscatter ($\text{km}^{-1} \text{Sr}^{-1}$)
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3.0 Data Collection and Processing:

Data from each instrument was averaged to a 2 Hz and 20 m time-height grid. Hydrometeor masks were generated separately for each instrument, and then the union between the separate masks was found in order to generate a combined mask for each flight leg. Basic details for each step are as follows.

1) HCR

In all cases, data from the first 22 range gates of HCR were removed as the first 12 gates were at negative ranges, and the rest had near-field effects. This resulted in a radar dead zone of 203 meters. This dead zone was chosen, after inspecting the data, in order to remove all questionable radar returns. For each flight leg, HCR reflectivity, signal-to-noise ratio (SNR), average Doppler velocity, and Doppler spectral width (as provided by the HCR team using the pulse-pair method) were averaged to a 2-Hz temporal grid. Calibration periods, intervals where the radar was not recording data, and intervals where the radar was pointing in directions other than zenith or nadir were filled with the missing value (-9999).

Using the aircraft altitude as reported in the HCR data along with the distance from the radar to the center of each range gate, each HCR quantity was then linearly interpolated to a new range grid of 20-m resolution between 140 m and 14 km. Differences in aircraft altitude reported in the HCR data and in the aircraft in situ files (GGALT) are generally within one radar range gate. The Doppler spectral moments estimated using the pulse-pair technique were previously filtered by application of a simple SNR threshold, but a significant amount of speckle noise and noise due to various other uncertainties (such as in antenna pointing angle) remained. Therefore, on a flight-by-flight basis, times where the antenna angle was apparently recorded incorrectly were set to the missing value, and combinations of reflectivity (about -30 dBz) and Doppler spectrum width ($\sim 1.2 \text{ m s}^{-1}$) thresholds were used to remove other spurious features. These thresholds were deemed sufficient as we do not expect echoes of low reflectivity that have higher spectrum width values.

2) HSRL

The HSRL backscatter data at 2 Hz and 30 m resolution was downloaded from the University of Wisconsin website (<http://hsrl.ssec.wisc.edu/>). It was then re-gridded to the same height grid as was the HCR data.

The ratio of measured particulate backscatter to mean background aerosol backscatter was calculated from the backscatter cross-section on a flight-by-flight basis. Specifically, for each flight, a significantly long period and set of cloud-free range gates were manually chosen. For each profile in the chosen period, the block of 100 samples with the lowest average backscatter was chosen in order to estimate the background aerosol backscatter for each profile. These background aerosol backscatter estimates were then averaged to produce a single estimate for the

mean background aerosol backscatter value for the entire flight leg. The particulate backscatter variable provided in the HSRL data files were divided by the estimate of mean background aerosol backscatter, and converted to decibels (dB). This ratio is reported as `ratio_bscat` in the files.

Aerosol returns were distinguished from hydrometeor returns, using a `ratio_bscat` threshold. As the returns from cirrus clouds are lower than liquid clouds, a separate threshold (with the exception of one flight) was chosen for range bins above 6 km and range bins below 6 km.

3) Hydrometeor Masks

In order to remove speckle noise, hydrometeor masks for each flight leg were generated by applying a spatio-temporal filter (Clothiaux et al., 1995) to SNR-thresholded maps of significant hydrometeor returns. The filter identifies eight pixels around the any given pixel and thresholds it if less than four pixels around it have returns. As a result, cloud elements shorter than 1.5 sec wide and 60 m tall were discarded. Given the fast moving platform, and sensitivity of the HCR, we believe this to be the most optimal filter size. Periods with either or both instruments not operational were flagged. The HCR and HSRL hydrometeor masks were then merged by finding their union. Values in the mask variable in the NetCDF file indicate whether, at a given time and range, hydrometeors were detected by neither instrument (`mask = 0`), the HCR alone (`mask = 1`), the HSRL along (`mask = 2`), or by both instruments (`mask = 3`).

4) Detection of Hydrometeor Boundaries and Cloud Base

Included in the merged hydrometeor mask files are estimates of hydrometeor boundaries, as functions of time, taken from the merged hydrometeor masks. For each profile, up to 20 hydrometeor layers were identified, based on the gaps within the elements. Hydrometeor elements with gaps less than 3 range gates were considered to be part of the same cloud and precipitation mass. The boundaries of each of the hydrometeor layer were then identified from the top and the base of the mask, and are reported. *During precipitating conditions, the value of the layer bottom refers to the lowest return, while the layer top values correspond to the cloud top heights.*

We also calculated the cloud base heights from the HSRL data when it was looking upwards. The technique used to calculate the cloud base height is similar to that used by ground-based lidars (e.g. ceilometer, MPL) and identifies the lowest maximum in the gradient of the backscatter. The reported cloud base height corresponds to the lowest cloud layer.

For calculating cloud thicknesses, we recommend using the hydrometeor layer top for the lowest layer (`layer_top` variable) and the lidar cloud base (`lidar_cloud_base` variable).

4.0 Data Format:

One NetCDF file is created for each flight. This is the fourth version of the hydrometeor masks. Previous versions of this could be obtained from the Box files hosted at Argonne National Laboratory.

The file names are as follows

RFXX_YYYYMMDD_COMBINED_HCR_HSRL_data_mask_version4.cdf

Where XX = flight number (e.g. 03, 12 etc.) from 02 to 15.

YYYY = Year (e.g. 2016).

MM = Month (e.g. 07 or 08).

DD = Day of the month (e.g. 07, 25 etc).

The header of the NetCDF file is as below.

```
netcdf RF14_20150807_COMBINED_HCR_HSRL_data_mask_version4 {  
dimensions:
```

```
    time = 50167 ;
```

```
    range = 699 ;
```

```
    layer_no = 20 ;
```

```
variables:
```

```
    double absolute_time(time) ;
```

```
        absolute_time:long_name = "seconds since 1970-1-1 0:00:00 0:00" ;
```

```
        absolute_time:units = "seconds" ;
```

```
    double range(range) ;
```

```
        range:long_name = "altitude of measurement above MSL" ;
```

```
        range:units = "meters" ;
```

```
    float lat(time) ;
```

```
        lat:long_name = "latitude" ;
```

```
        lat:units = "degrees" ;
```

```
    float lon(time) ;
```

```
        lon:long_name = "longitude" ;
```

```
        lon:units = "degrees" ;
```

```
    float alt_msl(time) ;
```

```
        alt_msl:long_name = "altitude of aircraft above mean sea level" ;
```

```
        alt_msl:units = "m" ;
```

```
    float ant_elev_angle(time) ;
```

```
        ant_elev_angle:long_name = "HCR antenna elevation angle (-90 is nadir; 90 is  
zenith)" ;
```

```
        ant_elev_angle:units = "degrees" ;
```

```
    float ant_az_angle(time) ;
```

```
        ant_az_angle:long_name = "HCR antenna azimuth angle (0 degrees is forward,  
increasing clockwise" ;
```

```
        ant_az_angle:units = "degrees" ;
```

```
    float beta(time, range) ;
```

```
        beta:long_name = "particulate backscatter from HSRL" ;
```

```
        beta:units = "per km per steradian" ;
```

```
    float beta_molecular(time, range) ;
```

```
        beta_molecular:long_name = "molecular backscatter from HSRL" ;
```

```
        beta_molecular:units = "per km per steradian" ;
```

```
    float beta_std(time, range) ;
```

```
        beta_std:long_name = "standard deviation of particulate backscatter from HSRL"
```

```
;
```

```

        beta_std:units = "per km per steradian" ;
float ratio_bscat(time, range) ;
    ratio_bscat:long_name = "ratio of measured aerosol backscatter to mean
background aerosol backscatter" ;
    ratio_bscat:comment = "derived from the variable beta_a_backscat, see
documentation for more information" ;
    ratio_bscat:units = "dB" ;
float dBZ(time, range) ;
    dBZ:long_name = "reflectivity from HCR (computed using pulse-pair method)" ;
    dBZ:units = "dBZ" ;
float vel(time, range) ;
    vel:long_name = "corrected average doppler velocity from HCR (computed using
pulse-pair method)" ;
    vel:units = "m/s" ;
float sp_width(time, range) ;
    sp_width:long_name = "Doppler spectrum width from HCR (computed using
pulse-pair method)" ;
    sp_width:units = "m/s" ;
float SNR_HCR(time, range) ;
    SNR_HCR:long_name = "SignaltoNoiseRatio estimated from HCR" ;
    SNR_HCR:units = "dB" ;
float combined_mask(time, range) ;
    combined_mask:long_name = "flagged for significant returns from HCR/HSRL" ;
    combined_mask:comment = "3x3-pixel spatio-temporal mask, following
Clothiaux et al., 1995" ;
    combined_mask:units = "unitless" ;
float hsrl_attenuation_mask(time, range) ;
    hsrl_attenuation_mask:long_name = "flagged for attenuation or missing data from
HSRL" ;
    hsrl_attenuation_mask:comment = "0 = bin good; 1 = bin attenuated; 2 = bin
missing" ;
    hsrl_attenuation_mask:units = "unitless" ;
float layer_top(layer_no, time) ;
    layer_top:long_name = "range of tops of hydrometeor layers" ;
    layer_top:units = "meters" ;
float layer_bot(layer_no, time) ;
    layer_bot:long_name = "range of bottoms of hydrometeor layers" ;
    layer_bot:units = "meters" ;
float layer_count(time) ;
    layer_count:long_name = "number of hydrometeor layers" ;
    layer_count:units = "unitless" ;
float lidar_cloud_base(time) ;
    lidar_cloud_base:long_name = "range of bottom of first cloud base when HSRL
looking up" ;
    lidar_cloud_base:units = "m" ;
float mask_flag(time) ;

```

```

        mask_flag:long_name = "0=neither instrument available;1=radar only;2=lidar
only;3=both instruments available" ;
        mask_flag:units = "unitless" ;

// global attributes:
        :Resolution = "HSRL/HCR gridded to 2 Hz, 20 m vertical resolution" ;
        :Nav\ Data\ Source = "HCR data stream (corrected altitude)" ;
}

```

5.0 Data Remarks:

PI's assessment of the data

The reported files are the fourth version of our algorithm. Although the technique used to merge the HCR and HSRL data and calculate the cloud boundaries is similar to that applied to the data collected by ground base instruments, the fast moving platform poses significant challenges. The cloud base heights are only estimated during periods when the HSRL was pointing upwards. This is by far the most significant limitation of the dataset. We are exploring new techniques to retrieve cloud base height from the Doppler spectra.

The HCR INS suffered intermittent failure at times, and hence needed to be restarted. This resulted in missing periods in the HCR data. The HSRL was calibrated a few times during the ferry legs on each flight, resulting in missing data from HSRL for ~5 min periods.

Missing data periods

The merged masks files were not produced for the RF01 and RF16. Due to technical issues with the aircraft, RF01 was cut short shortly after making the initial descent for starting the low-level sampling sequence. RF16 had a relatively long ferry flight (>2 hours) and shorter sampling at low-levels (~80 minutes).

Software compatibility

The NetCDF files were produced using Matlab, and should be readable by most of the scientific software. A sample Matlab code to read and plot the data is available from the PI.

6.0 References:

Campbell, J. R., D. L. Hlavka, E. J. Welton, C. J. Flynn, D. D. Turner, J. D. Spinhirne, V. S. Scott III, and I. H. Hwang, 2002: Full-Time, Eye-Safe Cloud and Aerosol Lidar Observation at Atmospheric Radiation Measurement Program Sites: Instruments and Data Processing. *J. Atmos. Oceanic Technol.*, **19**, 431–442, doi: 10.1175/1520-0426(2002)019<0431:FTESCA>2.0.CO;2.

Clothiaux, E. E., T. P. Ackerman, G. G. Mace, K. P. Moran, R. T. Marchand, M. A. Miller, and B. E. Martner, 2000: Objective Determination of Cloud Heights and Radar Reflectivities Using a Combination of Active Remote Sensors at the ARM CART Sites. *J. Appl. Meteor.*, **39**, 645–665, doi: 10.1175/1520-0450(2000)039<0645:ODOCHA>2.0.CO;2.

Vivekanandan, J., Tsai, P., Burghart, C., Ellis, S., Dixon, M., Loew, E. 2016. GV-HIAPER Cloud Radar (HCR) moments data, 10Hz in cfradial format, Version 1.0. UCAR/NCAR - Earth Observing Laboratory. <http://doi.org/10.5065/D6CJ8BV7>. Accessed 25 Oct 2016.