Below Cloud Drizzle Properties During the CSET Campaign

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1. Introduction

The Cloud System Evolution in the Trades (CSET) campaign was conducted in July-August 2015 for studying processes related to the transition from stratocumulus to cumulus cloud fields in the Northeast Pacific (Albrecht et al. 2019). One of the mechanisms responsible for this transition is precipitation, and hence the data collected during the campaign were used to retrieve profiles of precipitation properties below the cloud base. Onboard the Gulfstream-V High-performance Instrumented Airborne Platform for Environmental Research (GV-HIAPER) were the HIAPER Cloud Radar (HCR) and the High Spectral Resolution Lidar (HSRL). The retrieval technique proposed by O'Connor et al. (2005), with minor modifications, was applied to the revised data from HCR and HSRL for retrieving drizzle properties. Briefly described below are the data, and retrieval technique followed by the description of the data created. More details can be found in Schwartz et al. (2019) and in Sarkar et al. (2020).

2. Attenuation Correction and Retrieval Technique

The second version of the HCR (https://data.eol.ucar.edu/dataset/487.002) and the HSRL (https://doi.org/10.5065/D63N21JR) data are used for the retrievals, as both the instruments went through improved calibration and noise-filtering after their first release. The data were combined on a uniform 0.5 second temporal and 20 m vertical geo-referenced grid before applying the retrieval technique. As the retrieval needs data from both the HCR and the HSRL, and the HSRL suffers from complete extinction due to cloud droplets, the retrievals were only performed for surface legs when both the instruments were pointing upwards.

The HCR reflectivity is corrected for gaseous attenuation following the procedure given in Fairall et al. (2018). Thermodynamic data from the aircraft in situ probes and from dropsondes were combined on a uniform 2-degree longitudinal and 100 m vertical grid. These data were used to calculate the attenuation due to Oxygen (γ_o) and water vapor (γ_w) using the following equations

$$\gamma_o = \left[2 \times 10^{-4} r_t^{15}(1 - 1.2 \times 10^{-5} f^{15}) + \frac{4}{(f-63)^2 + 1.5 r_p^2 r_t^2} + \frac{0.28 r_t^2}{(f-118.75)^2 + 2.84 r_p^2 r_t^2}\right] f^2 r_p^2 r_t^2 \times 10^{-3}$$

$$\gamma_w = \left[3.27 \times 10^{-2} r_t + 1.67 \times 10^{-3} \frac{\rho r_t^7}{r_p} + 7.7 \times 10^{-4} f^{0.5} + \frac{3.79}{(f-22.235)^2 + 9.81 r_p^2 r_t} + \frac{11.73 r_t}{(f-183.31)^2 + 11.85 r_p^2 r_t} + \frac{4.01 r_t}{(f-325.153)^2 + 10.44 r_p^2 r_t}\right] f^2 \rho r_p r_t \times 10^{-4}$$

Where f is frequency in Gigahertz, p is pressure in hectopascal, t is temperature in degree Celsius, $r_p = p/1013$, $r_t = 288/(273 + t)$ and ρ is water vapor density in grams per cubic meter.

The retrieval technique assumes drizzle particles to have a three parameter (D_0, μ, N_w) normalized gamma drop size distribution (DSD) as described below.

$$n(d) = N_w f(\mu) \left(\frac{d}{D_0}\right)^{\mu} \exp\left[\frac{-(3.67 + \mu)d}{D_0}\right]$$

$$f(\mu) = \frac{6}{3.67^4} \frac{(3.67 + \mu)^{4+\mu}}{\Gamma(\mu + 4)}$$

The radar reflectivity (Z) corresponds to the sixth moment of the DSD, while the lidar backscatter (β) corresponds to the second moment of the DSD; hence the ratio of the two quantities is proportional to the fourth moment, accounting for the lidar ratio (S) and the Mie-to-Rayleigh backscatter ratio (γ').

$$\frac{Z}{\beta} = \frac{2}{\pi} \frac{\Gamma(7 + \mu)}{\Gamma(3 + \mu)} \frac{S(D_0, \mu)\gamma'(D_0, \mu)}{(3.67 + \mu)^4} {D_0}^4 \quad (1)$$

In addition, the width of the Doppler spectrum as recorded by the cloud radar can be also expressed as a function of (D_0, μ) after accounting for the beam broadening due to turbulence and aircraft motion. Additional details regarding this are mentioned in Schwartz et al. (2019).

$$\sigma_D{}^2 = \frac{a^2 {D_0}^2 (\mu + 7)}{(3.67 + \mu)^2} \quad (2)$$

As radar reflectivity, lidar backscatter and spectrum width are measured, equations (1) and (2) can be solved iteratively for (D_0, μ). The retrieval assumes a diameter-fall velocity relationship as reported by Gossard et al. (1990) with constants $a = 4.1667 \times 10^{-3}\ s^{-1}$ and $b = -0.0833\ m\ s^{-1}$. Further, the drizzle normalized number concentration (N_w), drizzle total number (N_t), drizzle liquid water content (LWC), and rain rate or drizzle liquid water flux (LWF) are also calculated using the equations below. The density of water (ρ_l) is assumed to be 1000 $kg\ m^{-3}$.

$$N_w = \gamma' \times Z \times \frac{(3.67 + \mu)^{7+\mu}}{f \times {D_0}^7 \times \Gamma(7 + \mu)}$$

$$N_t = \frac{N_w \times f \times D_0 \times \Gamma(\mu + 1)}{(3.67 + \mu)^{2+\mu}}$$

$$LWC = \frac{\pi \rho_l N_w}{(3.67)^4} {D_0}^4$$

$$LWF = \left[\frac{\pi}{6} \frac{N_w f {D_0}^4 \Gamma(\mu + 4)}{(3.67 + \mu)^{\mu+4}}\right] \left[\frac{a \times D_0(\mu + 4)}{3.67 + \mu} + b\right]$$

3. Dataset Description

One file for each flight is produced in the Network Common Data Format (NetCDF). In addition to the retrieved drizzle properties, the input variables are also included in the files. The retrievals are made only for surface legs that lasted about 10 minutes each, with each flight having 3 to 4 surface legs. Hence, the retrieved drizzle variables are empty for the rest of the grid cells. An example of the file header is given below. Further documentation and the retrieval codes are available from the corresponding author.

```
dimensions:
	time = 51394 ;
	height = 601 ;
variables:
	double time(time) ;
		time:long_name = "seconds since 1970-1-1" ;
		time:units = "seconds" ;
	double gv_alt(time) ;
		gv_alt:long_name = "GV Altitude" ;
		gv_alt:units = "meter" ;
	double height(height) ;
		height:long_name = "Height" ;
		height:units = "meter" ;
	double dbz(time, height) ;
		dbz:long_name = "radar reflectivity" ;
		dbz:units = "dBz" ;
	double mean_Doppler(time, height) ;
		mean_Doppler:long_name = "HCR Mean Doppler velocity" ;
		mean_Doppler:units = "m/s" ;
	double width(time, height) ;
		width:long_name = "spectrum width" ;
		width:units = "m/s" ;
	double beta(time, height) ;
		beta:long_name = "HSRL Backscatter" ;
		beta:units = "1/(m*sr)" ;
	double dm(time, height) ;
		dm:long_name = "Modal Diameter" ;
		dm:units = "meter" ;
	double mu(time, height) ;
		mu:long_name = "Shape Parameter" ;
		mu:units = "unitless" ;
	double nw(time, height) ;
		nw:long_name = "Normalized Number Concentration" ;
		nw:units = "m^{-4}" ;
	double nt(time, height) ;
		nt:long_name = "Drizzle Number Concentration" ;
		nt:units = "m^{-3}" ;
	double gamma_p(time, height) ;
		gamma_p:long_name = "Mie-to-Rayleigh Ratio" ;
		gamma_p:units = "unitless" ;
	double lidar_ratio(time, height) ;
		lidar_ratio:long_name = "Lidar Ratio" ;
		lidar_ratio:units = "Sr" ;
	double rain_rate(time, height) ;
		rain_rate:long_name = "Rain Rate" ;
```

```
                rain_rate:units = "m/s" ;
        double lwc(time, height) ;
                lwc:long_name = "Liquid Water Content" ;
                lwc:units = "kg/m^3" ;
}
```

4. References

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