Investigation of Drizzling Virga Depth below Marine Stratocumulus Clouds Using Ground-Based Remote Sensing Observations
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1. Motivation
Stratocumulus clouds are common in tropical and subtropical oceans and play a critical role in the Earth’s hydrological cycle and energy balance. Drizzle drops are frequently observed in marine stratocumulus clouds and play a crucial role in cloud lifetime, sub-cloud scavenging, and evaporative cooling below cloud base. Understanding where drizzle exists in the sub-cloud layer, which depends on drizzle virga depth, can help us better understand where below-cloud scavenging and evaporative cooling and moisturizing occur. Two related questions are:
1. What is the drizzling fraction for marine stratocumulus clouds?
2. What controls the drizzle virga depth?

2. Data
• Data were collected between Oct. 6, 2015 and Nov. 23, 2016 at the Eastern North Atlantic.
• Ka-band cloud radar and ceilometer were used to get cloud thickness (Hc) and drizzle virga depth (Hv). The vertical resolutions of the radar and lidar are 30 m and 15 m respectively.
• Single layer stratocumulus clouds are manually chosen from days having boundary layer dry

3. Marine stratocumulus clouds are frequently drizzling
An example of a drizzling cloud:

Fig. 1. Time series of radar reflectivity of a marine stratocumulus cloud at the ENA site on March 4, 2016. The black line is the cloud base as detected by the ceilometer. Drizzle virga exist when the lowest radar range gate with detected signal is at least three range gates below cloud base, but also above surface.

Fig. 2. Drizzling fraction as a function of radar reflectivity threshold at three range gates below cloud base. 83% of our cloud profiles are drizzling in a 42 days dataset of stratocumulus clouds.

Fig. 3. Relative occurrence of cloud base height for all the selected stratocumulus clouds in this study at the ENA site. The subset bounded by vertical dashed lines centered at the maximum relative occurrence of cloud base height, consisting of five radar range gates (852±75 m), is used for our statistical analysis.

Fig. 4. The relative occurrences of cloud thickness (solid line) and drizzle virga thickness (dashed line) for the subset data in Fig. 3

4. Deriving a Minimalist Model

In cloud, Kostinski (2008):

\[ \rho_v \rho_L \approx \rho_d V_c p_0 \Delta T \]

Droplet volume fraction: \( f = \frac{V_c}{V} = 0.4 \times 10^{-6} H_c \)

Continuous collection: \( 4\pi^2 \frac{d r}{d z} = \pi^2 f dz \)

Derivation below cloud base:

\[ \frac{d r}{d z} = \frac{d r}{d z} \frac{V_c}{V} = G_s(z) \]

Assume \( V(r) \tau \) and \( s(z) = k(z-z_o) \):

\[ r_c \propto G_s H_c \]

Derived relationship: \( H_v \propto H_c^{3/2} \)

5. Results

Is \( r_c \propto H_c^2 \)?

Is \( H_v \propto H_c^{3} \)?

Fig. 5. (left) Median volume diameter of drizzle (D0) retrieved at 90 m (three range gates) below cloud base versus cloud thickness. The color represents the occurrence frequency per range bin normalized horizontally, and the black line is the best 2nd-order power law fit. Panel on the right shows the relative occurrence of different D0. (right) Drizzle virga thickness versus cloud thickness. The color represents the horizontally normalized occurrences, and the black line is the best 3rd-order power law fit. Panel on the right shows the relative occurrence of different drizzle virga depths.

Fig. 6. Results for the relatively humid (left) and dry (right) subsets. White lines are the best fitted lines for all data.

6. Take home messages
• Marine stratocumulus clouds are frequently drizzling.
• We derive \( H_v \propto H_c^{3/2} \) that shows good agreement with independent observations.

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