Snowfall Rate Estimation Based On Disdrometer During ICE-POP

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Abstract

Accurate estimation of snowfall rate and ice water content (IWC) during snow storms is crucial. These estimates will have a direct impact on the hydrological and atmospheric models. The density of snow plays a very important role in estimating the snowfall rate and IWC. In this paper, the density of snow is investigated for a huge snowstorm event during the International Collaborative Experiment held during the PyeongChang 2018 Olympics and Paralympic winter games (ICE-POP 2018). The density is calculated using the terminal velocities and diameters of the snow particles measured by disdrometer. The effect of snow density on the snowfall rate and IWC is studied using the density derived using the disdrometer measurements. The snowfall rate and IWC values obtained using the disdrometer measurements is compared with the results estimated with different density-size relationships (ρ_s-D) reported in the literature and their results are discussed.

***Index Terms*—** Density, disdrometer, snowfall rate, IWC

1 Introduction

The snowfall rate and ice water content (IWC) are used as an input in hydrological and weather prediction models. Since the output of these models make a huge impact, it is necessary to determine the accurate estimates of snowfall rate and IWC. The density of snow plays a major role in the estimation of these parameters. Unlike the density of raindrops, the density of snow is not a constant and depends on many factors, including snow types and climatological location. Because of this the estimation of snowfall rate and IWC gets complex.

In the literature, there are size-density relationships from which density of snow can be obtained [1][2][3]. But these relationships are derived using various datasets and report only the mean values. These relationships may not fit for the events captured during International Collaborative Experiment held during the PyeongChang 2018 Olympics and Paralympic winter games (ICE-POP 2018) campaign.

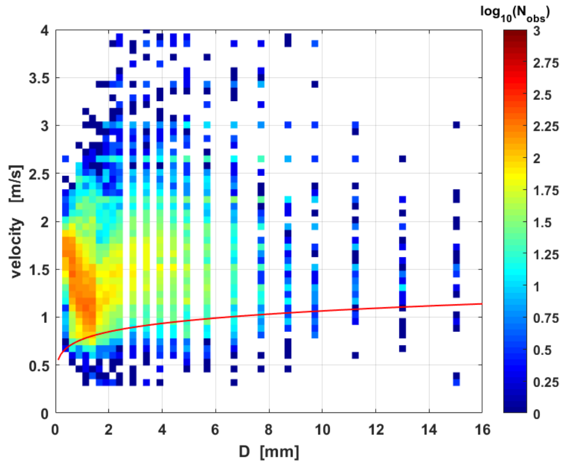

Figure 1. Plot of diameter versus velocity for data from 28th of February 2018. The red line is empirical terminal velocity of snow from Brandes et al. (2007).

Although density of snow could not be directly measured by disdrometer, this paper uses the terminal velocity and diameter measured by disdrometer to indirectly get an idea of the density of snow from which snowfall rate and IWC are estimated. Details about the ICEPOP equipment deployment can be found in ICEPOP experiment document [4]. Data from the disdrometer deployed in YongPyong Cloud physics Observatory (YPO) is considered in this study.

2 Methodology and preliminary results

The method for estimating the approximate snow density using the disdrometer measurements is discussed in this section. Ignoring the buoyancy, pressure gradient, and inertial forces, when gravitational force equals the drag force, the hydrometeor falls relative to the air at its terminal fall speed [5].

The density can be approximated using velocity and diameter, this can be obtained by using the disdrometer measurements and the equation below [5].

$$\rho_s = \frac{3\rho v^2 C_D}{4gD} \quad (3)$$

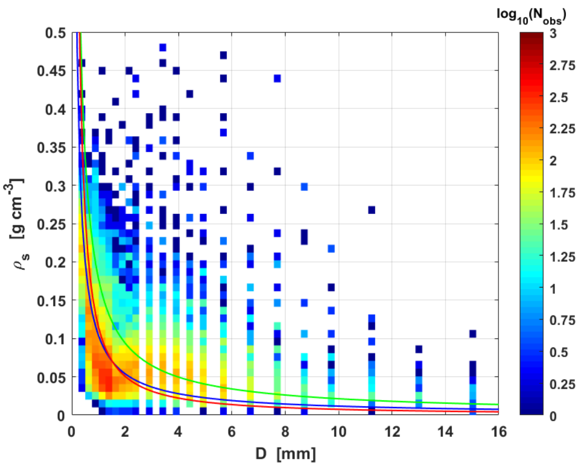

Figure 2. Plot of diameter versus density derived from disdrometer measurements. The solid lines indicate the three ρ_s - D relations from literature. Green line is from Brandes et al. (2007). Blue line is from Heymsfield et al. (2004). Red line is from Huang et al. (2010).

Figure 1 shows the plot of diameter versus velocity for disdrometer data taken on 28th February 2018. It can be seen from the figure that the empirical terminal velocity of snow from Brandes et al. (2007) does not fit well for the disdrometer measurements.

Figure 2 shows the plot of diameter versus density derived using disdrometer data and equation (3). The data considered here is from 28th February 2018. The ρ_s - D relations from literature is also plotted with solid lines of different colors. It can be seen from the figure that the density retrieval is a challenge.

Once the particle size distribution and density of snow are known, some physical parameters such as total number concentration (N_T), median mass diameter D_0, liquid water equivalent snowfall rate R_s, and IWC can be computed. The total number concentration of snowflakes is a useful quantity and this is given using the equation below.

$$N_T = \int_0^\infty N(D)dD \quad (4)$$

Where, N(D) is drop size distribution in $m^{-3}mm^{-1}$. Figure 3 shows the total number concentration during this day for the snow event. The range of values extend from 0 to 8500 m^{-3}.

The median mass diameter (D_0) can be expressed using the equation below.

$$\int_0^{D_0} D^3 N(D)dD = \int_{D_0}^\infty D^3 N(D)dD \quad (5)$$

From equation (5), we can say that total mass for drops of diameter less than D_0 is equal to the total mass for drops of diameter equal to or larger than D_0. The mean mass di-

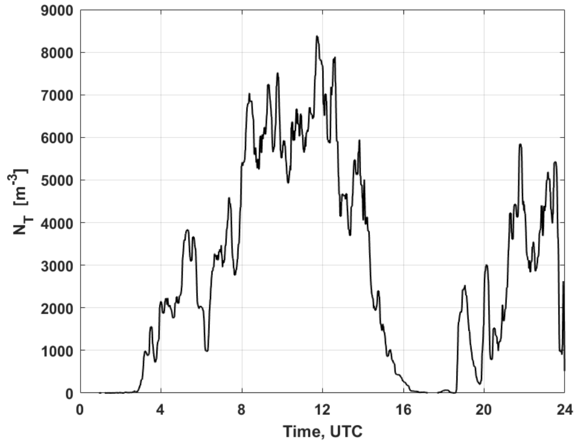

Figure 3. Total number concentration on 28 February 2018.

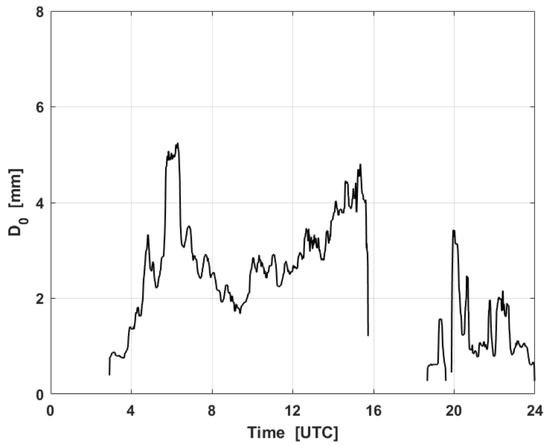

Figure 4. Median mass diameter on 28 February 2018.

ameter plot for 28th February 2018 is shown in figure 4. The median mass diameter during this event varied between from 0 to 6mm.

The liquid water equivalent snowfall rate (Rs) in mmh^{-1} is defined using the equation below.

$$R_s = 6\pi \times 10^{-4} \int_0^{D_{max}} \rho_s D^3 v(D) N(D)dD \quad (6)$$

The IWC in g m^{-3} is defined using the equation below.

$$IWC = \frac{\pi}{6} \times 10^{-4} \int_0^{D_{max}} \rho_s D^3 N(D)dD \quad (7)$$

From equations (6) and (7), it can be seen that snowfall rate and ice water content has relationship with the density of snow.
Figure 5 and Figure 6 illustrate the comparison of snowfall rate and IWC between the density calculated from

disdrometer measured fall speed and empirical ρ_s - D relations. From these figures it can be seen that when Rs and IWC values are large, they are more consistent with the results using density from Brandes et al. (2007). But when IWC values are low, they are more consistent with the results using density from Heymsfield et al. (2004) and Huang et al. (2010).

Figure 7 shows the results of accumulation using three ρ_s - D relations and gauge. It is clear that accumulation agrees well with gauge after calculating density from measured fall speed and diameters. Using relation from Brandes et al. (2007) overestimates accumulation and Using relation from Heymsfield et al. (2004) and Huang et al. (2010) underestimate accumulations.

3 Summary

Accurate estimates of snowfall rate and ice water content (IWC) are challenging. The density of snow has a major effect on snowfall rate and IWC. The density of the snow varies during different snow storm events and it is difficult to fit with a simple empirical ρ_s - D relation. An approximate density estimate derived using terminal velocity and diameter from disdrometer is used to estimate snowfall rate and IWC. The results of snowfall rate and IWC using data from a disdrometer are studied to compare against single parameter estimation methods.

4 Acknowledgements

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5 References

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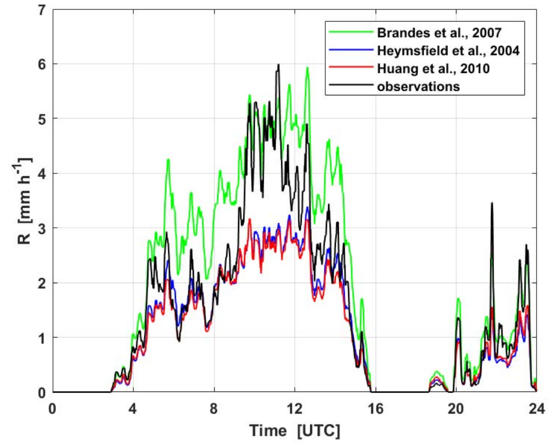

Figure 5. Snowfall rate using density calculated from disdrometer and three different ρ_s - D relations.

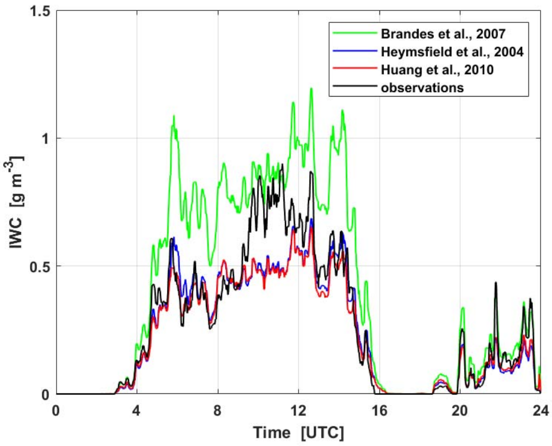

Figure 6. IWC using density calculated from disdrometer and three different ρ_s - D relations.

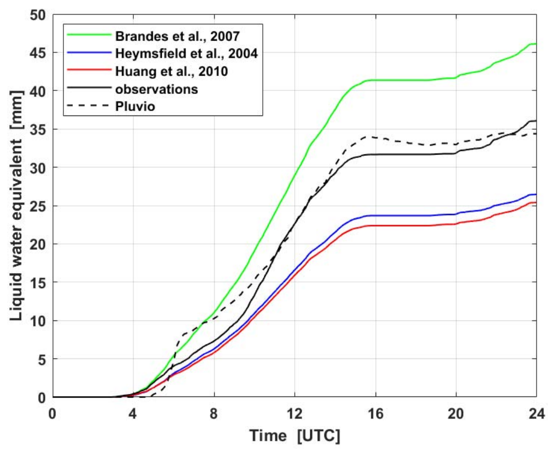

Figure 7. Comparison of accumulations at YPO site using ρ_s- D relations and gauge.