P3.34 MELTING MODELS FOR CHARACTERIZNG WINTER PRECIPITATION PARTICLE SIZE DISTRIBUTION

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1. INTRODUCTION

Mixed phases of hydrometeors including ice and snow play important roles in winter precipitation microphysics and corresponding processes such as accretion/breakup, deposition/sublimation and precipitation in all seasons (Rauber et al. 2000). Understanding and effectively representing ice microphysics are required in developing accurate and efficient parameterization schemes for numerical weather prediction (NWP).

Ice and snow particle size distributions (PSDs) and rain and cloud drop size distributions (DSDs) are an essential part of bulk microphysics (BMP) parameterization schemes commonly used in NWP model. Given that rain DSDs are much more frequently measured as the surface using distrometers, melting models that link up snow PSDs and rain DSDs can be very valuable for understanding ice processes, and for comparing and verification surface and elevated microphysical measurements. Although melting models (Straka 2009: Chapter 11) exist in the context of BMP parameterizations, a simple model for directly interpreting observations is generally not available.

In this work, two simple melting models are developed to investigate how a snow PSD is related to a rain DSD when snowflakes are completely melted to raindrops. Using the melting models, snow PSDs are converted to rain DSDs to explore possible relations with the measured DSDs during the rain period.

2. MELTING MODELS

For the data used in this study, rain DSDs and snow PSDs are measured by a ground-based 2D video disdrometer (2DVD) which records two images of each particle (Brandes et al. 2007; Zhang et al. 2011). The recorded particles in a given time interval are then sorted into different size bins to form a size distribution. The PSD can be found using the following:

$$N(D) = \frac{N_T(D)}{Av(D)T\Delta D}, \qquad (1)$$

where $N_T(D)$ is the total number of drops per bin, D the particle equivolume diameter, ΔD the bin size, A the collection area, $v(D)$ the average drop velocity per bin, and T the collection time.

It can also be useful to fit the measured PSD data to an analytical PSD. Following Ulbrich (1983), a gamma distribution can be used in fitting the data, in

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D) \qquad (2)$$

where N_0 is a number concentration parameter, μ a shape parameter, and Λ a slope parameter.

We developed simple melting models and applied to the PSD data of frozen precipitation measured by the 2DVD disdrometer. Power-law relationships are used for the density of frozen precipitation, as well as the velocity of rain. Both models assume that the mass of a single particle will be conserved. One model assumes that the total number of drops will be conserved, and thus, the total liquid water content will be conserved. As a result, this model will be referred to as the 'mass conservation' (MC) model. The other assumes that the number flux of the distribution will be conserved, and is thus known as the 'flux conservation' (FC) model. They are formulated as follows.

Since the mass of a particle will be conserved, we have

$$\rho_s D_s^3 = \rho_r D_r^3, \qquad (3)$$

assuming that $\rho_s = aD^{-b}$ and $\rho_r = 1$, rearranging gives,

$$D_s = a^{-\frac{1}{3-b}} D_r^{\frac{3}{3-b}}, \qquad (4a)$$

$$D_r = a^{\frac{1}{3}} D_s^{\frac{3-b}{3}}. \qquad (4b)$$

Differentiating (4a) with respect to D_r, we arrive at the following,

$$\frac{dD_s}{dD_r} = \frac{3}{3-b} a^{-\frac{1}{3-b}} D_r^{\frac{b}{3-b}}. \qquad (5)$$

a) MASS CONSERVATION MODEL

In the mass conservation model, the total liquid water content of a distribution is conserved, as the mass of a particle and the total number of particles will be conserved,

$$N_r(D_r)dD_r = N_s(D_s)dD_s. \qquad (6)$$

Rearranging leads to

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$$N_r(D_r) = N_s(D_s)\frac{dD_s}{dD_r}. \quad (7)$$

Substituting (4a) and (5) into (7), we arrive at

$$N_r(D_r) = N_s(D_s)\frac{3}{3-b}a^{-\frac{1}{3-b}}D_r^{\frac{b}{3-b}}. \quad (8)$$

After melting, the uniform bin size set by the disdrometer no longer applies, and a new bin size must be calculated. Rearranging (5), and using ΔD_s = 0.2 mm,

$$\Delta D_r = \frac{3-b}{15}a^{\frac{1}{3-b}}D_r^{\frac{-b}{3-b}}, \quad (9)$$

where ΔD_r and D_r are in mm.

2) FLUX CONSERVATION MODEL

The other model, the "flux conservation" model, also assumes that the mass of a particle is conserved. However, this model assumes that the number flux instead of the total number of particles is conserved. Unlike the mass conservation model, the water content will not be conserved, but rather the snow water equivalent and rain rates should be equal. The DSD found from the original frozen PSD can be found in a similar manner to the MC model, but since

$$N_r(D_r)v_r(D_r)dD_r = N_s(D_s)v_s(D_s)dD_s, \quad (10)$$

rearrangement gives

$$N_r(D_r) = N_s(D_s)\frac{v_s(D_s)}{v_r(D_r)}\frac{dD_s}{dD_r}. \quad (11)$$

We assume a power-law relationship, $v_s = \alpha e D_s^g$, for snow velocity where α is the velocity adjustment to density, and also assume a power-law relation for rain velocity, $v_r = cD_r^d$. Inserting the power law relationships, and again substituting (4a) and (5) into (11) gives

$$N_r(D_r) = N_s(D_s)\frac{3e\alpha}{c(3-b)}a^{-\frac{g+1}{3-b}}D_r^{\frac{3g+b}{3-b}-d}. \quad (12)$$

The new bin sizes are found as in (9).

3. CONVERSION OF SNOW PSDS TO RAIN DSDS

Figure 1 shows an example of four snow PSDs and their melted DSDs using both the MC and FC models. They were selected from the periods of heaviest snow from the 30 November 2006-27 January 2007 snow events in central Oklahoma to ensure that the measured distributions have sufficient numbers of particles. The PSDs and DSDs are also fitted to a gamma distribution (Ulbrich, 1983) with a moment estimator using the second, forth and sixth moments and are shown as curves. It is seen that they fit the gamma distribution well. The detailed fitting procedure and performance have been examined in Cao and Zhang (2009).

As expected, the measured snow PSDs have long tails – containing a few large flakes, and applying the melting models shortens the tails. The shortening of the distributions' tails are seen in all four panels, consistent with previous observations (Steward et al. 1984). This is because the large snowflakes have lower density, and hence shrink more in size when they melt. The melting effect on the distribution of very small drops is also apparent that increases the number concentration of small drops. The MC model yields more increase in small drop number concentration than the FC model in which the increase in number concentration is offset by reduction caused by large fall velocities of raindrops. While measured snow PSDs are closer to exponential distribution or concave gamma distribution, the melted rain DSDs have more of a convex shape – similar to the observed rain DSDs for stratiform and weak convection in warm season as reported in previous papers (Brandes et al. 2006; Cao and Zhang 2009).

To further understand the variation of precipitation microphysics for a winter storm containing both liquid and ice phases, the measured rain DSDs and snow PSDs are shown in Fig. 2a for the 30 November 2006 event. Also shown are melted DSDs using the MC and FC melting models for the dry snow period (1600—2400 UTC) in Figs. 2c and 2d. Both melting models yield rain DSDs similar to observed DSDs in an earlier period (0000—0900 UTC). As noted earlier, both models tend to shorten the long tails and create distributions with higher numbers of small drops than observed because snowflakes melt and decrease in size. In looking at the DSDs for the two periods, the models yield more compact distributions than the observed rain DSDs. The maximum diameters of the resulting DSDs from snow are not larger than 3 mm, which is consistent with previous in-situ observations that 5-11 mm diameter snowflakes melt to 1.1-2.6 mm raindrops (Stewart et al. 1984). The model rain rates (snow-water equivalent) are lower than the measured rain rates at the earlier time. Although a quantitative comparison is difficult, when looking at times with similar rain rates, the size of the maximal diameters are much more similar.

Table 1: Comparison of Microphysical Parameters between Rain and Snow

Variables	Rain	Snow: MC	Snow: FC
<N_T>, # m^{-3}	90.2	410.1	284.2
<W>, g m^{-3},	0.050	0.061	0.040
<D_0>, mm	1.06	0.79	0.75
<Z>, dBZ	20.6	17.8	17.3
<Z_{DR}>, dB	0.467	0.315	0.342

To quantitatively compare the two melting models, microphysical parameters including the mean values for number concentration (N_T), water content (W), median volume diameter (D_0), reflectivity factor (Z) and differential reflectivity (Z_{DR}) are calculated for melting-model-derived DSDs from snow and for measured rain (Table 1). Although there are some differences, the results are close to each other and indicate the similarity of the winter precipitation microphysics between rain and snow periods, especially for the median volume diameter and radar reflectivity.

4. SUMMARY AND CONCLUSIONS

Two melting models were developed and applied to periods of frozen precipitation, and the results compared to periods of rain during an episode of mixed precipitation types. Applying the melting models to measured snow PSDs yields rain DSDs that are similar to those recorded during the rain periods for the same precipitation event. The distributions' tails are shorten, and the number of small drops are increased because the large snowflakes become small drops. Compared with the rain period DSDs, melted snow DSDs consistently have more small drops and occasionally have more large drops. The median volume diameter in melted snow DSDs is smaller than that in rain period DSDs as well as reflectivity and differential reflectivity. Both melting models yield the similar results, but the Flux Conservation model yields less unmber concentration than the Mass Conservation model.

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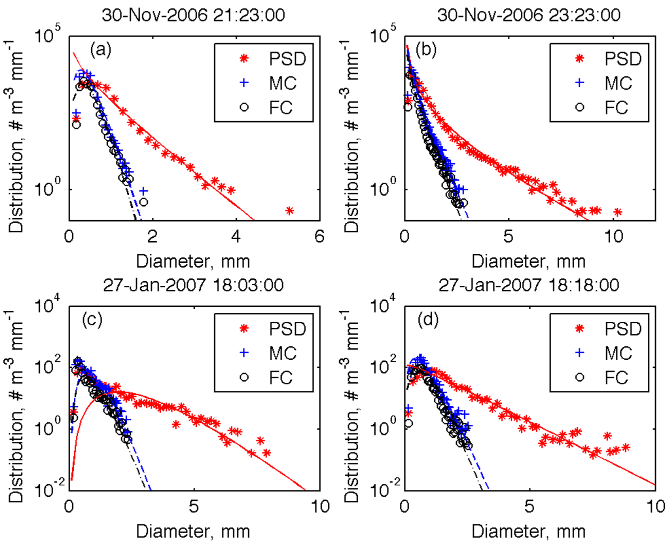

Figure 1: Examples of the melting model applications to a measured snow PSD from November 30, 2006 (a and b) and January 27, 2007 (c and d). Solid lines and asterisks denote the measured snow PSD; dash-dot lines and crosses, the Mass Conservation Model; dotted lines and circles, the Flux Conservation Model

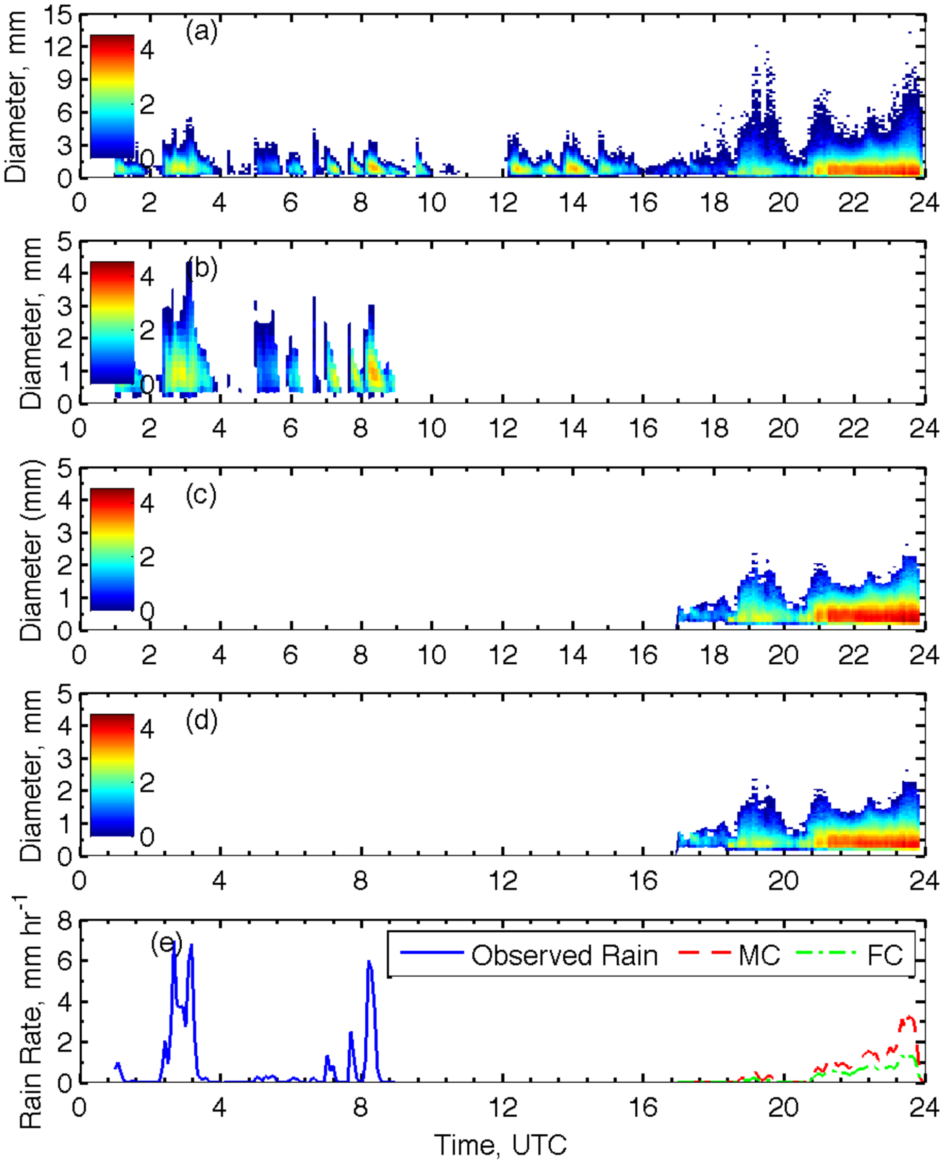

Figure 2: Raindrop size distributions (DSD) and snow PSDs as well as the converted rain DSDs for the November 30, 2006 event: a) observed rain DSDs and snow PSDs, b) observed rain DSDs, c) the Mass Conservation model, and d) the Number Flux Conservation model. Also shown is e) rain rate.