Raindrop Size Distribution Characteristics of Summer and Winter Season Rainfall Over North Taiwan

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Data and methodology:

JWD @ NCU, Taiwan  
(24° 58’ N, 121° 10’ E)

Joss-Waldvogel Disdrometer (JWD)

Data:
Winter (December-February) : (2002-2016, excl. 2003)

- RSD from Joss-Waldvogel disdrometer (JWD)
- JWD collocated AWS rainfall
- Z – mosaic from 6 radar from CWB
- Convective Available Potential Energy from ERA-Interim
- Storm and bright band heights from TRMM 2A23 product
- Cloud effective radii from MODIS

Fig. Geographical location of Taiwan. The red colored circle represents the location of national central university disdrometer (NCU-JWD), and the locations of radar sites are represented with blue color squares.

Fig. Scatter plot between daily accumulated rainfall of Joss–Waldvogel Disdrometer (JWD) and the collocated tipping bucket rain gauge of the automatic weather station (AWS).
Data and methodology:

The rain drop concentration \(N(D)\) (m\(^{-3}\) mm\(^{-1}\)) at an instant of time from the JWD are obtained from the following equation,

\[
N(D_i) = \sum_{j=1}^{20} \frac{n_{ij}}{A\Delta t \nu_j \Delta D_i}
\]

where

\(n_{ij}\) is the number of drops reckoned in the size bin \(i\) and velocity bin \(j\),
\(A\) (m\(^2\)) and \(\Delta t\) are the sampling area and time,
\(D_i\) (mm) is the drop diameter for the size bin \(i\) and \(\Delta D_i\) is the corresponding diameter interval (mm),
\(\nu_j\) (m/s) is the fall speed for the velocity bin \(j\).

Radar Reflectivity (dBZ)

\[
Z = \int_{0}^{\infty} N(D) D^6 dD
\]

Rain Rate (mm/h)

\[
RR = \frac{\pi}{6} \int_{0}^{\infty} N(D) D^3 \nu(D) dD
\]

Liquid Water content (kg/m\(^3\))

\[
LWC = \rho_w \frac{\pi}{6} \int_{0}^{\infty} N(D) D^3 dD
\]

Where \(N(D)\) is drop concentration, \(D\) drop diameter, \(\nu(D)\) terminal fall velocity, \(\rho_w\) is the water density.
Data and methodology:

In the present study the gamma parameters ($D_m$, $\mu$, $\Lambda$ & $N_w$) defined by Ulbrich, (1983) are used to study the RSD characteristics:

$$N(D) = N_0 D^\mu \exp(-\Lambda D)$$

$D_m$-Mass weighted mean diameter

$$D_m = \frac{M_4}{M_3}$$

$$M_n = \int_{D_{min}}^{D_{max}} D^n N(D)dD$$

$\mu$ - Shape parameter

$$\mu = \frac{(11G - 8) + \sqrt{G(G + 8)}}{2(1 - G)}$$

$$G = \frac{M_4^3}{M_3^2 M_6}$$

$\Lambda$- Slope parameter

$$\Lambda = \frac{(\mu + 4)M_3}{M_4}$$

$N_w$-Normalized intercept parameter

$$N_w = \frac{4^4}{\pi \rho_w} \left( \frac{10^3 W}{D_m^5} \right)$$


$W$- liquid water content

The normalized intercept parameter $N_w$, represents $N(D)$ when D approaches to its minimum value.

The shape parameter($\mu$) describes the breadth of the RSD concave downward ($\mu > 0$), upward ($\mu < 0$), or exponential ($\mu = 0$) shape.

The slope parameter ($\Lambda$) characterizes RSD tail extension along Drop diameter small (large) $\Lambda$ indicates an extension of the RSD tail to larger (smaller) $D$. 

The normalized intercept parameter $N_w$, represents $N(D)$ when D approaches to its minimum value.
**Results:**

Fig. Variation of mean raindrop concentration, \(N(D)\) \((\text{m}^{-3}\text{mm}^{-1})\) with drop diameter, \(D\) (mm) for summer and winter rainfall.

Fig. The probability distribution functions (PDF) of (a) rain rate, \(\log_{10} R\) (mm h\(^{-1}\)), (b) liquid water content, \(\log_{10} LWC\) (g m\(^{-3}\)), (c) mass-weighted mean diameter, \(D_m\) (mm), (d) normalized intercept parameter, \(\log_{10} N_w\) (m\(^{-3}\text{mm}^{-1}\)), (e) shape parameter, \(\mu\) (-), and (f) slope parameter, \(\Lambda\) (mm\(^{-1}\)) for summer and winter rainfall.

\[
\begin{align*}
\text{Summer (Winter)}
\end{align*}
\]

- Small size drops: \(D\) (mm) < 1 mm
- Mid size drops: \(1 \leq D\) (mm) \(\leq 3\) mm
- Large size drops: \(D\) (mm) > 3 mm
Results: RSD variation in different rain rate classes:

\[ \delta(D, R_{Ck})_{\text{summer}} = \frac{[N(D)_{\text{summer}}]_{Ck}}{([N(D)_{\text{summer}}]_{Ck} + [N(D)_{\text{winter}}]_{Ck})} \times 100 \]

\[ \delta(D, R_{Ck})_{\text{winter}} = \frac{[N(D)_{\text{winter}}]_{Ck}}{([N(D)_{\text{summer}}]_{Ck} + [N(D)_{\text{winter}}]_{Ck})} \times 100 \]

**Fig.** Average raindrop spectra for winter (blue color) and summer (red color) rainfall in six rain rate (R) classes (C1: 0.1 ≤ R < 1, C2: 1 ≤ R < 2, C3: 2 ≤ R < 5, C4: 5 ≤ R < 10, C5: 10 ≤ R < 20, C6: > 20 mm h⁻¹).

**Fig.** Variation of mass weighted mean diameter, \( D_m \) (mm) and normalized intercept parameter, \( \log_{10} N_w \) (m⁻³ mm⁻¹) in six rain rate classes of summer (red color) and winter (blue color) rainfall. The center line of the box indicates the median, and the bottom and top lines of the box indicate the 25th and 75th percentiles, respectively. The bottom and top of the dashed vertical lines indicate the 5th and 95th percentiles, respectively.
Results: Diurnal variation of RSD:

\[ \delta(D, T_h)_{\text{summer}} = \frac{[N(D)_{\text{summer}}]_h}{([N(D)_{\text{summer}}]_h + [N(D)_{\text{winter}}]_h)} \times 100 \]

\[ \delta(D, T_h)_{\text{winter}} = \frac{[N(D)_{\text{winter}}]_h}{([N(D)_{\text{summer}}]_h + [N(D)_{\text{winter}}]_h)} \times 100 \]

**Fig.** Three hourly variation of mass weighted mean diameter, $D_m$ (mm) and normalized intercept parameter, $\log_{10} N_w$ (m$^{-3}$ mm$^{-1}$) in summer (red color) and winter (blue color) rainfall. Three hourly observations represented in above plot are in local time (UTC+8 hr).
Results: Stratiform and convective RSD  *Bringi et al. [2003]*.

**Fig.** Mean raindrop concentration in stratiform and convective regimes of summer and winter rainfall.

**Z-R and μ-Λ relations:**

<table>
<thead>
<tr>
<th>Precipitation type</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratiform</td>
<td>$Z = 276.13 , R^{1.41}$</td>
<td>$Z = 127.67 , R^{1.54}$</td>
</tr>
<tr>
<td>Convective</td>
<td>$Z = 237.88 , R^{1.41}$</td>
<td>$Z = 142.94 , R^{1.52}$</td>
</tr>
<tr>
<td>Total</td>
<td>$Z = 266.42 , R^{1.38}$</td>
<td>$Z = 129.76 , R^{1.55}$</td>
</tr>
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**Fig.** Variation of normalized intercept parameter, $\log_{10}N_w (m^3 \, mm^{-1})$ with mass weighted mean diameter, $D_m$ (mm) in stratiform and convective regimes of summer and winter rainfall.

**Fig.** Scatterplots of $\mu$ versus $\Lambda$ for (a) summer and (b) winter rainfall of north Taiwan.
Discussion:

Fig. Annual variations in monthly mean of (a) Convective available potential energy (CAPE, J/kg) and (b) vertical integral water vapor (kg/m²) obtained from ERA-Interim for summer and winter seasons.

Fig. Annual variation of (a) mean storm top height, and (b) bright band height (BBH) during summer and winter seasons obtained from TRMM PR 2A23 product.

Fig. Annual variations of ground (a) temperature and (b) relative humidity over NCU.

Fig. Cloud effective radii (CER, μm) values of (a) liquid, (b) ice particles, and (c) cloud droplet number concentration (CDNC, cm⁻³) for summer and winter seasons.
Discussion:

Fig. Contoured frequency-by-altitude diagram of radar reflectivity from six ground-based radars for (a) summer, (b) winter, (c) summer convective, (d) winter convective, (e) summer stratiform, and (f) winter stratiform rainfall.
Summary:

- No. of small drops ➔ Winter > Summer
- No. of large drops ➔ Summer > Winter
- PDF distribution of RSD parameters ➔ Summer ≠ Winter
- Mass weighted mean diameter ($D_m$) ➔ Summer > Winter
- Slope ($\lambda$), shape ($\mu$), normalized intercept parameter ($N_w$) ➔ Palau > Taiwan
- Raindrop concentration ➔ convective > stratiform (in Summer & Winter)
- No. of small drops ➔ Winter > Summer (for both stratiform and convective rainfall)
- Clear variations in Z-R relations between Summer and Winter rainfall.
- Deeply extended clouds in summer (with cold rain process) and shallow clouds in winter (with warm rain process) causing RSD differences at the ground through different microphysical process.
Thanking you