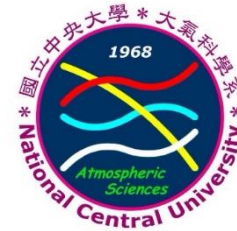


An investigation on microphysical characteristics of heavy rainfall events over Taiwan



Jayalakshmi Janapati¹, Balaji Kumar Seela¹, Pay-Liam Lin^{1,2,3*}, Everette Joseph^{4,5}, Chian-Yi Liu⁶, and M. Venkatrami Reddy⁷

¹Institute of Atmospheric Physics, Department of Atmospheric Sciences, National Central University, Zhongli District, Taoyuan City 320317, Taiwan

²Earthquake-Disaster and Risk Evaluation and Management Center, National Central University, Zhongli District, Taoyuan City 320317, Taiwan

³Research Center for Hazard Mitigation and Prevention, National Central University, Zhongli District, Taoyuan City 320317, Taiwan

⁴Atmospheric Sciences Research Center, University at Albany, State University of New York, Albany, NY USA

⁵National Center for Atmospheric Research, Boulder, CO, USA

⁶Research Centre for Environmental Changes, Academia Sinica, Taipei, Taiwan

⁷National Centre for Medium Range Weather Forecasting, Earth System Science Organization, Ministry of Earth Sciences, Noida, India

Introduction

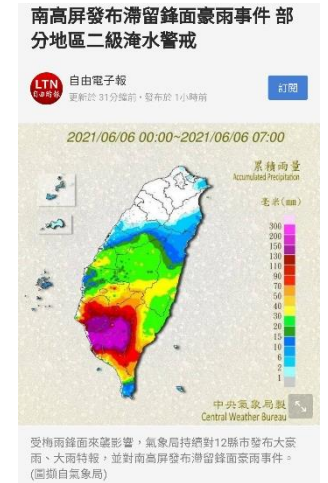
Extreme Rain events in Taiwan

Normal day



Dahu Park, Taipei, Taiwan

Extreme rainy: June 4, 2021



August 07, 2021



Maolin District, Kaohsiung.



Yusui River bridge, Kaohsiung's Taoyuan District.



Sansia District, New Taipei City.



Yunlin County.

Introduction

Normal day

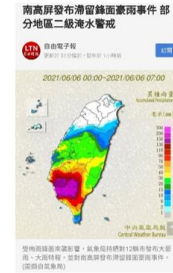


Dahu Park, Taipei, Taiwan

Extreme rainy: June 4, 2021



Taipei, Taiwan



GPM DPR: global precipitation measurement mission dual-frequency precipitation radar

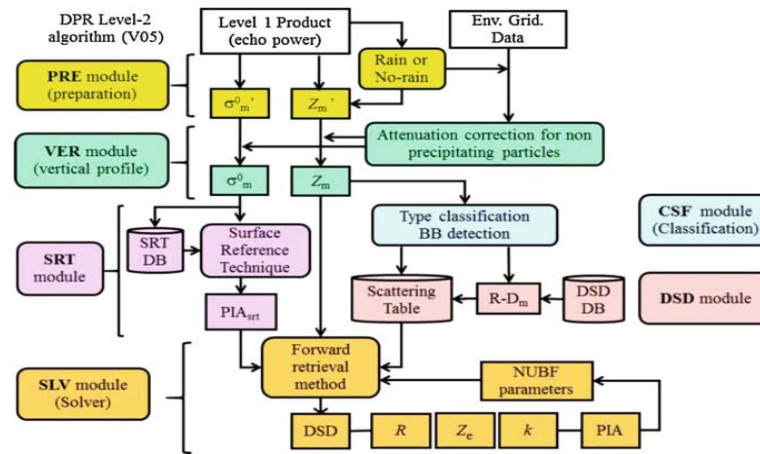
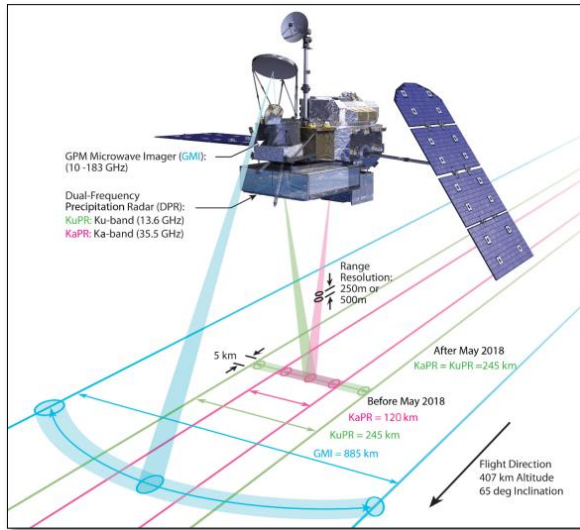
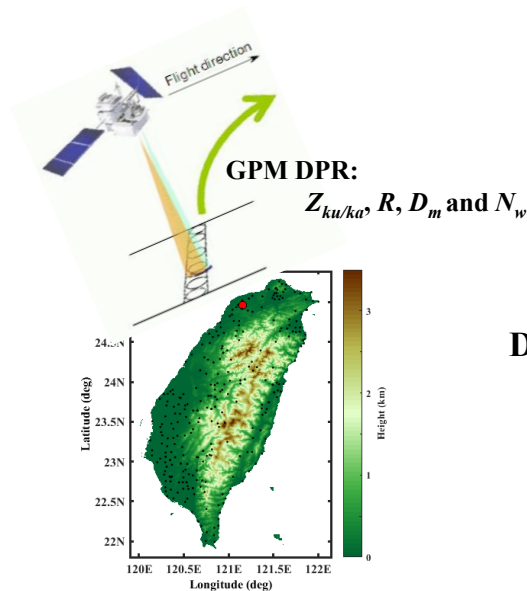
 $R \text{ (mm h}^{-1}\text{)}$ $Z_{ku/Ka}$ (dBZ) D_m (mm)
$$\text{dBN}_w (\text{m}^{-1} \text{ mm}^{-1})$$

Fig.: GPM DPR algorithm

System	KuPR	KaPR
Swath Width	245 kilometers (km)	245 kilometers (km) as of May 2018 (previously 120km)
Range Resolution	250 meters (m)	250/500 meters (m)
Spatial Resolution	5 km (Nadir)	5 km (Nadir)
Beam Width	0.71 degrees	0.71 degrees
Transmitter	128 Solid State Amplifiers	128 Solid State Amplifiers
Peak Transmit Power	1013 Watts (W)	146 Watts (W)
Pulse Repetition Freq. (In nominal operations mode)	4100 to 4400 Hertz	4100 to 4400 Hertz
Pulse Width	two 1.667 microseconds (μ s) pulses	two 1.667 microseconds (μ s) pulses in matched beams two 3.234 microseconds (μ s) pulses in interlaced scans
Beam Number	49	49 (25 in matched beams and 24 in interlaced scans)



2014-2023

Daily rainfall accumulation (RA) classification

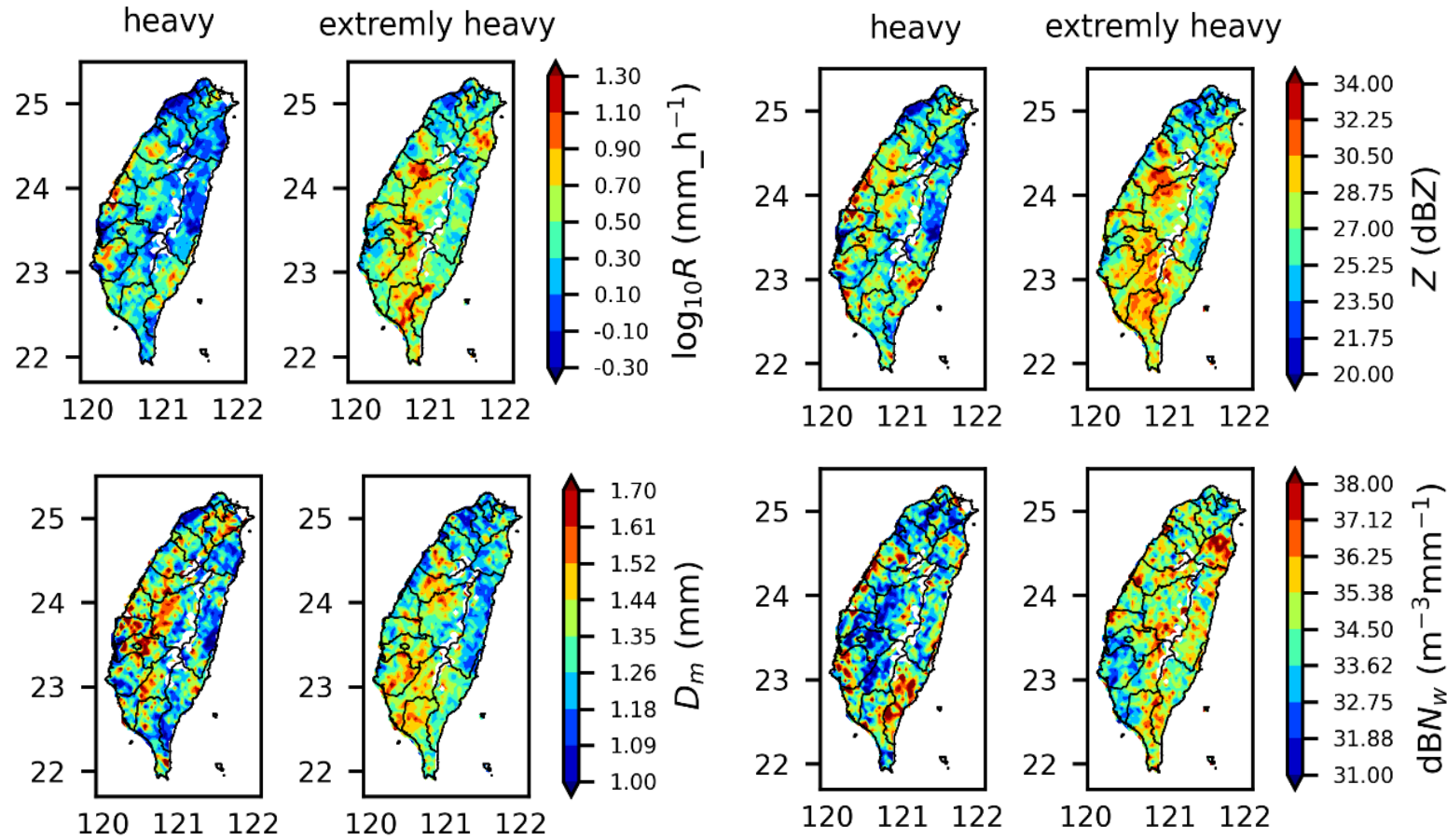
Heavy rainy days:

daily RA: 50-130 mm, hourly $R > 15 \text{ mmh}^{-1}$

Extremely heavy rainy days:

daily RA > 130 mm, hourly $R > 15 \text{ mm h}^{-1}$

Results & Discussion



Higher rainfall rates and radar reflectivity in

Heavy: Central and southeastern Taiwan

Extremely heavy: South, central, and northeastern Taiwan.

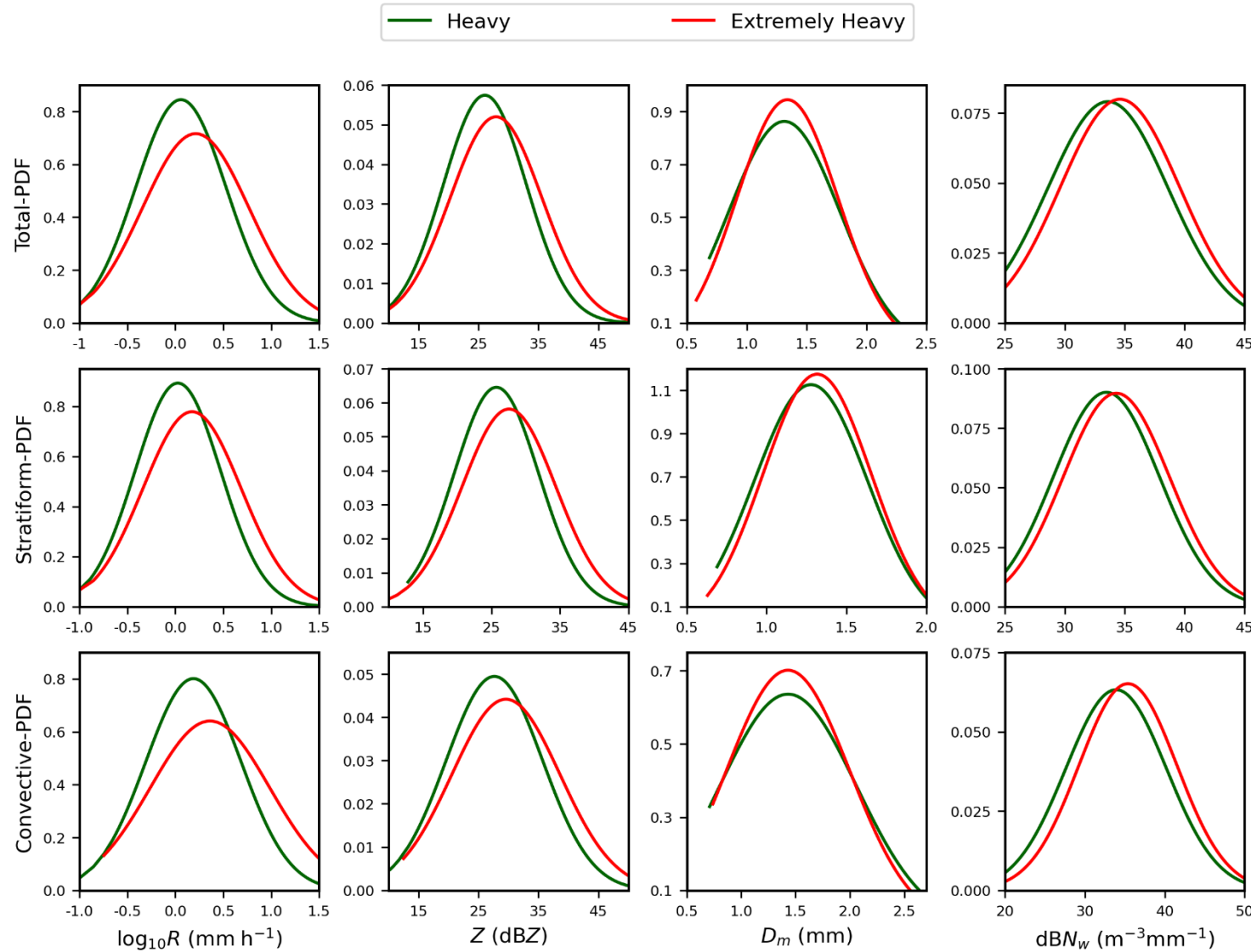
More large drops in

Heavy: Central Taiwan

Extremely heavy: South and central Taiwan.

Fig. Spatial distribution near-surface (2 km) $\log_{10}R$, (R in mm h^{-1}), Z (dBZ), D_m (mm), and dBN_w ($10\log_{10}N_w$, N_w in $\text{m}^{-3} \text{mm}^{-1}$).

Results & Discussion

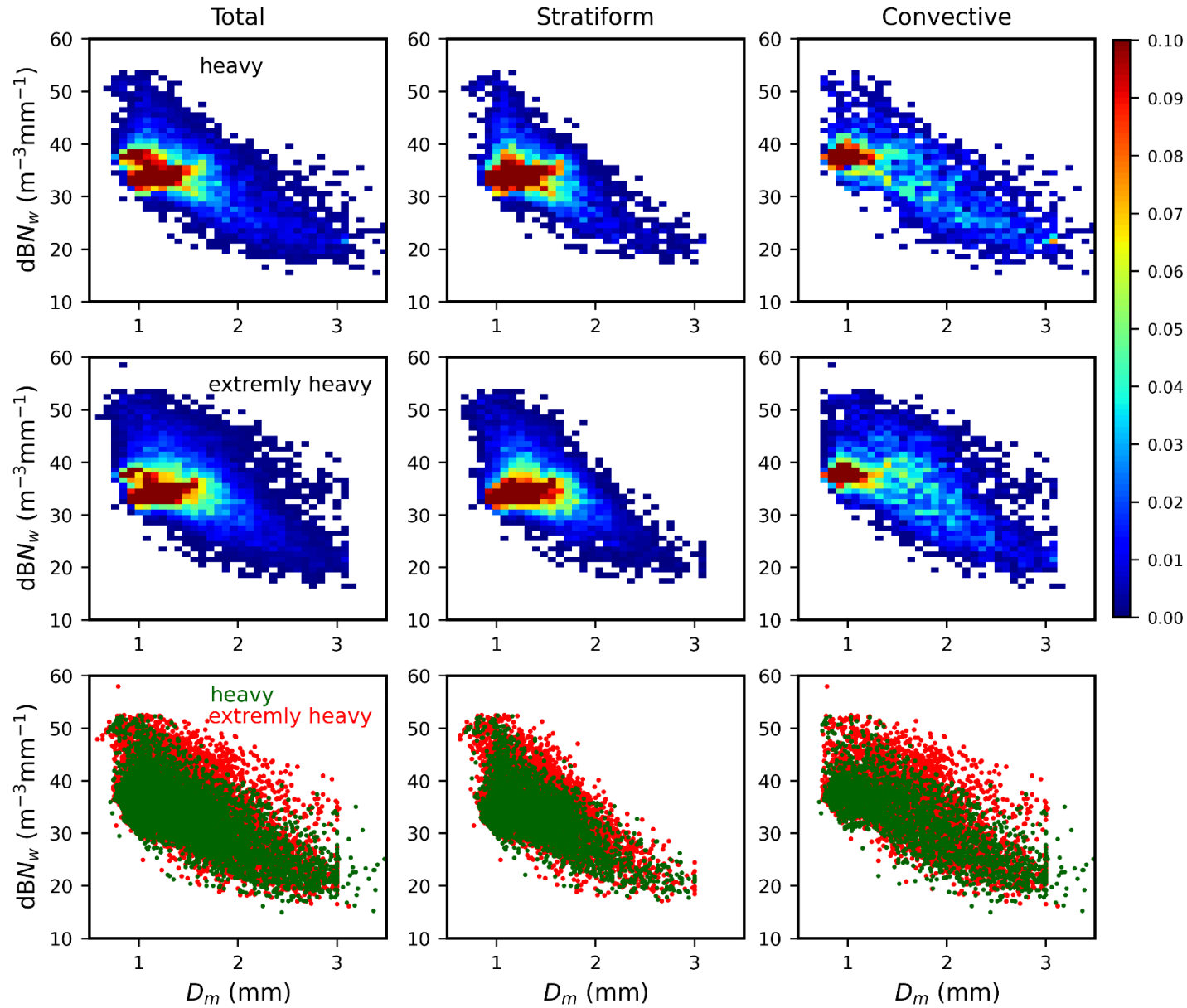


For $\log_{10}R > 0.5$ and $Z > 30$ dBZ, PDFs of extremely heavy > heavy

Despite of feeble variability in D_m , the dBN_w values > 35 show higher PDF in extremely heavy rainy days.

Fig. Probability density function (PDF) of near-surface (2 km) rainfall rate (R , mm h⁻¹) (first column), radar reflectivity (Z , dBZ), mass-weighted mean diameter (D_m , mm), and normalized intercept parameter (dBN_w : $10\log_{10}N_w$, N_w in m⁻³ mm⁻¹).

Results & Discussion



Irrespective of precipitation type with the increase of D_m , dBN_w show a decreasing tendency for heavy as well as extremely heavy rainy days.

Moreover, extremely heavy rainy days show wider D_m - dBN_w distributions than the heavy rainy days.

Fig. Two dimensional histogram between the near-surface (2 km) mass-weighted mean diameter (D_m , mm) and normalized intercept parameter (dBN_w : $10\log_{10}N_w$, N_w in $m^{-3}mm^{-1}$).

CFAD: Total rainfall

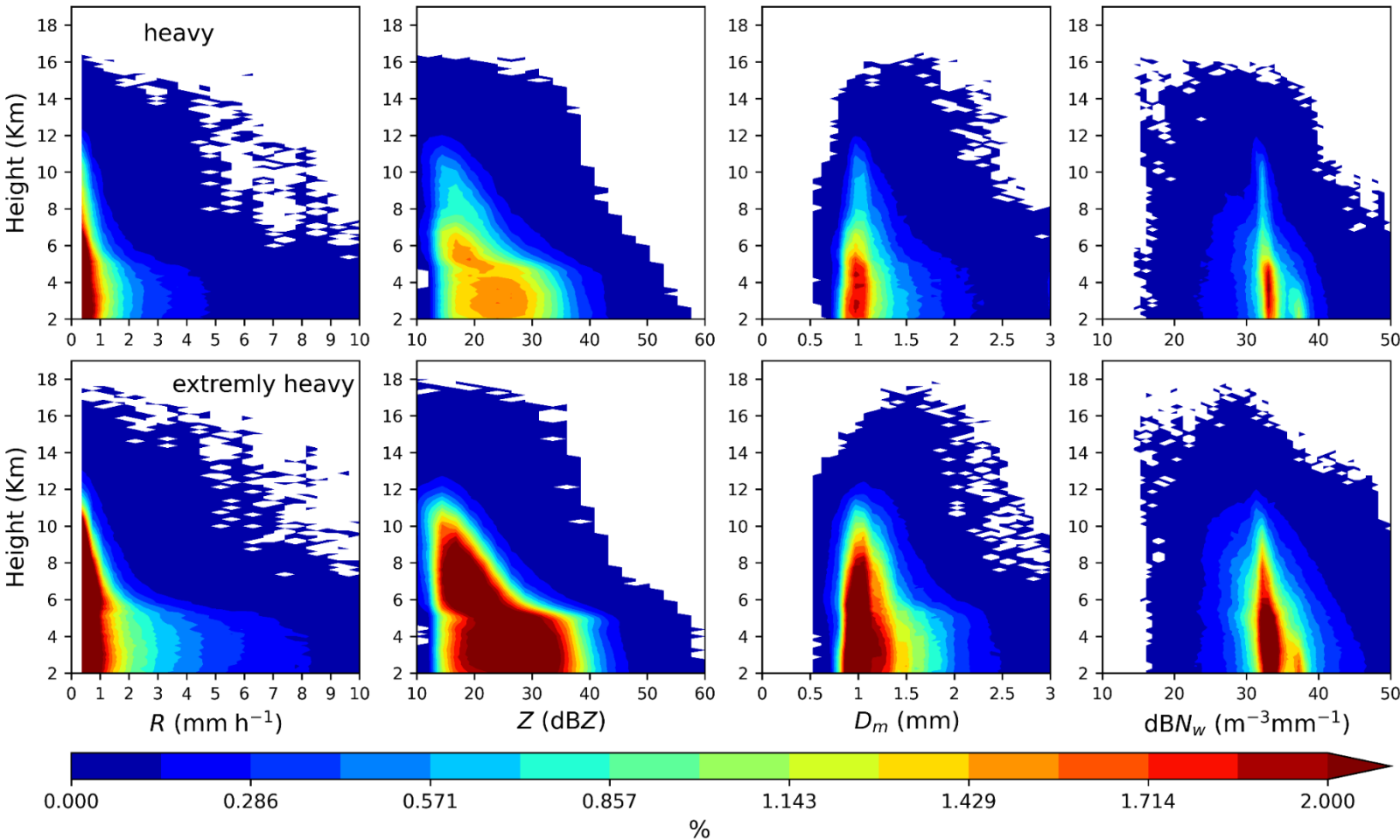


Fig. Contour frequency by altitude diagram (CFAD) of R (mm h^{-1}), Z (dBZ), D_m (mm) dBN_w ($10\log_{10}N_w$, N_w in $\text{m}^{-3} \text{mm}^{-1}$) for **total rainfall**.

The echo tops of extremely heavy rainy days are slight higher ($>16 \text{ km}$) than the heavy rainy days ($\leq 16 \text{ km}$).

At 6-12 km, R and Z show nearly identical occurrence frequencies between heavy and extremely heavy rainy days.

However, in the warm rain region, i.e., below 5 km altitude, a rapid increase in R and Z values can be seen in extremely heavy rainy days than the heavy rainy days.

Higher percentage of raindrops with $D_m > 1.5 \text{ mm}$ and $dBN_w > 35$ can be seen in the warm rain regions of extremely heavy days over the heavy rainy days.

CFAD: Stratiform rainfall

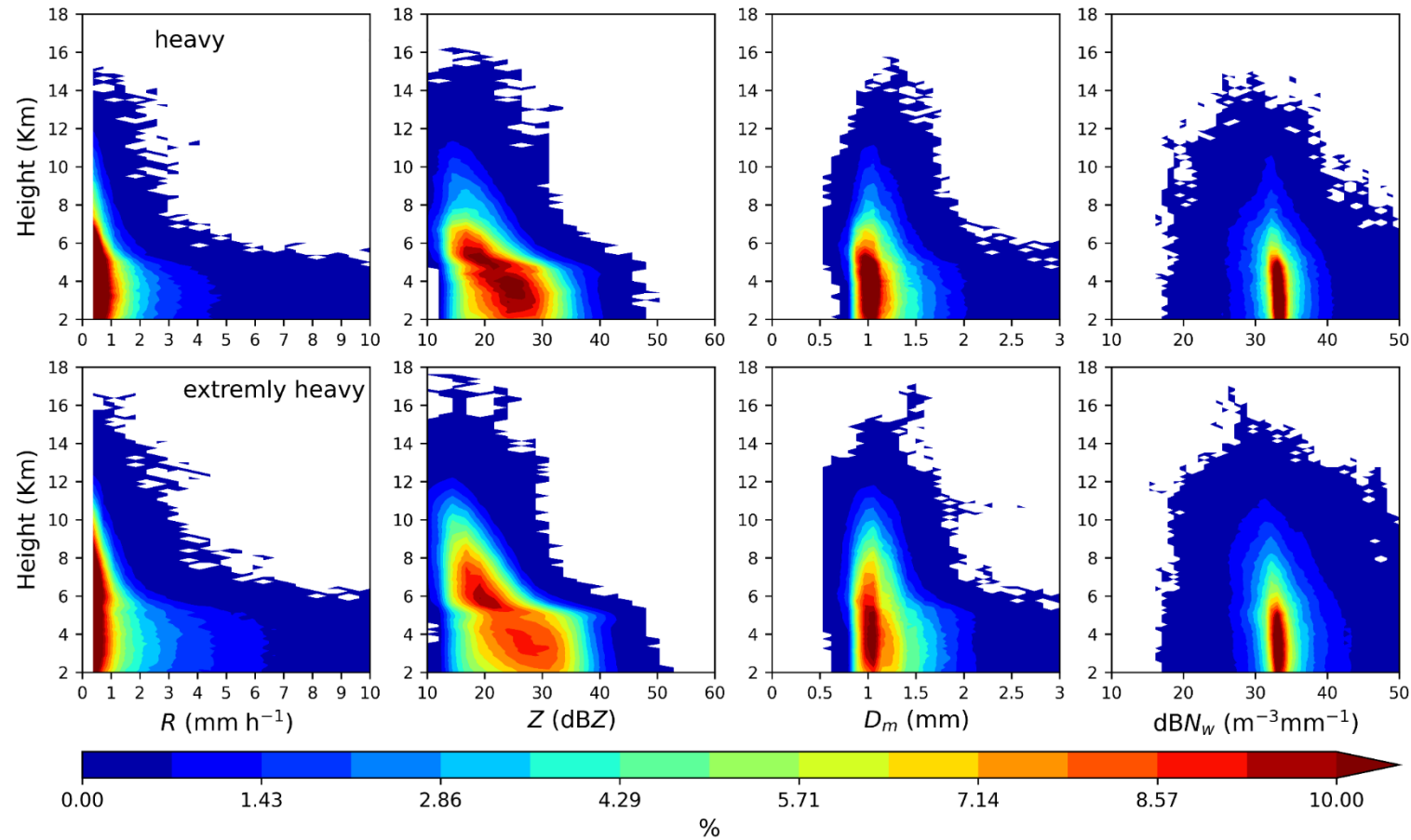


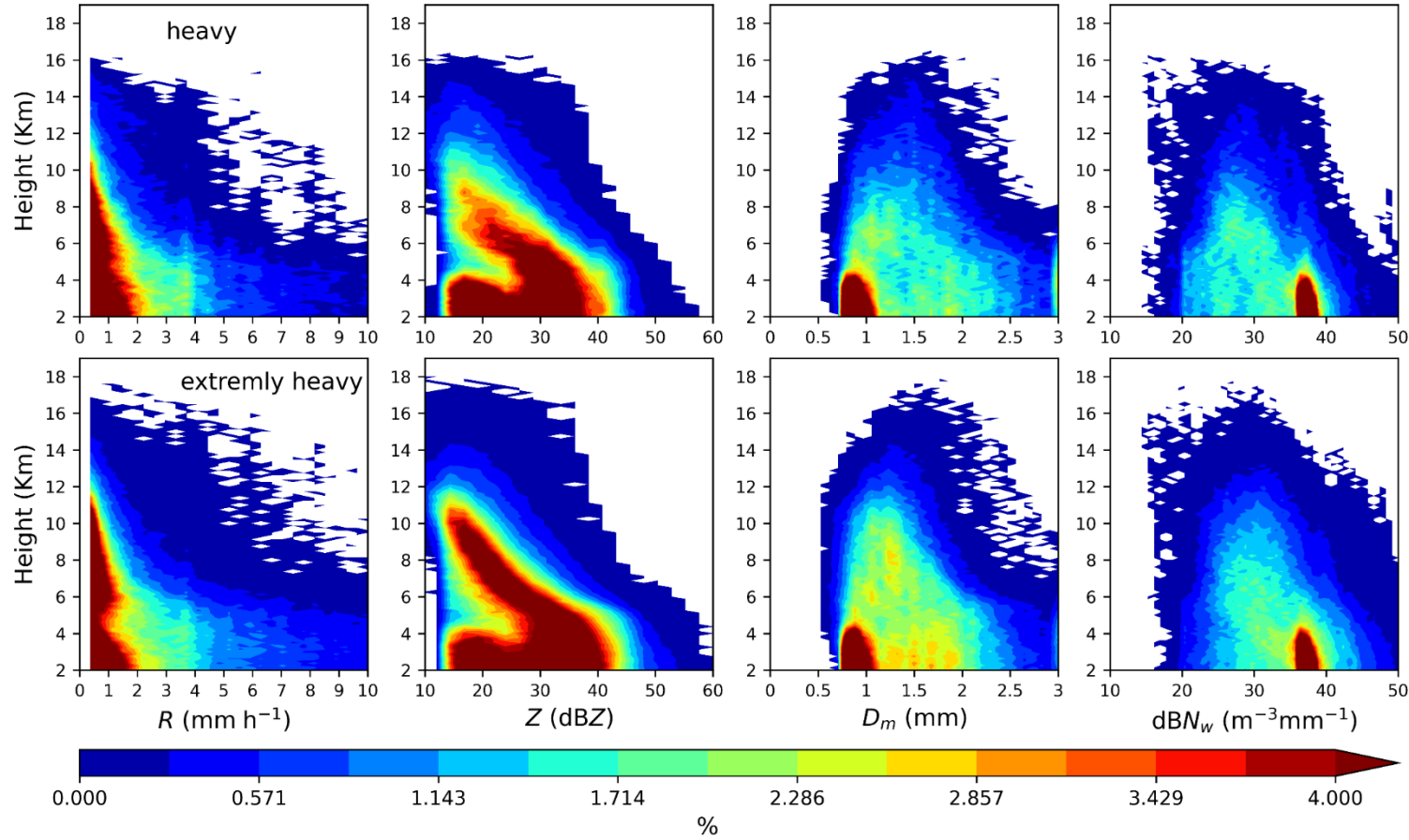
Fig. Contour frequency by altitude diagram (CFAD) of R (mm h^{-1}), Z (dBZ), D_m (mm) dBZ_w ($10\log_{10}N_w$, N_w in $\text{m}^{-3} \text{mm}^{-1}$) for *stratiform rainfall* .

The CFADs of stratiform precipitation show identical characteristics to that of the total precipitation.

The occur frequency of precipitation rate and radar reflectivity values is greater in the warm rain regions of extremely heavy rainy days over heavy rainy days.

Also, we can see the raindrops with $D_m > 1.5 \text{ mm}$ and $\text{dBZ}_w > 35$ in extremely heavy rainy days exhibit higher frequency than heavy rainy days.

CFAD: Convective rainfall



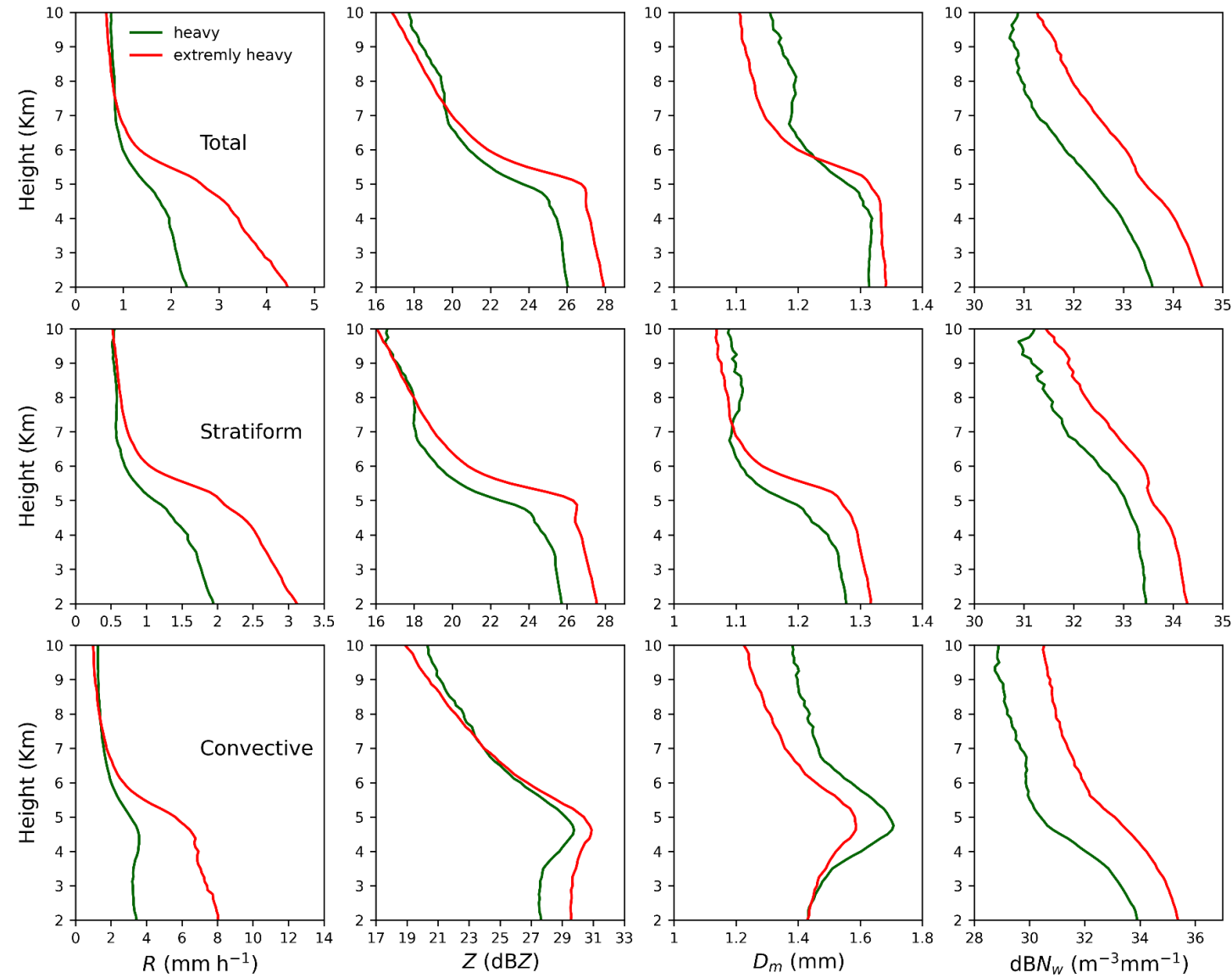
Cold rain regions (> 6 km) of heavy rainy days showed higher occurrence frequency of R , Z , D_m and dBN_w values.

However, such higher occurrence frequencies in the warm rain regions can be seen in extremely heavy rainy days.

This clearly indicates that higher rainfall amounts produced in the extremely heavy rainy days is chiefly contributed from warm rain processes.

Fig. Contour frequency by altitude diagram (CFAD) of R (mm h⁻¹), Z (dBZ), D_m (mm) dBN_w ($10\log_{10}N_w$, N_w in m⁻³ mm⁻¹) for *convective rainfall*.

Results & Discussion

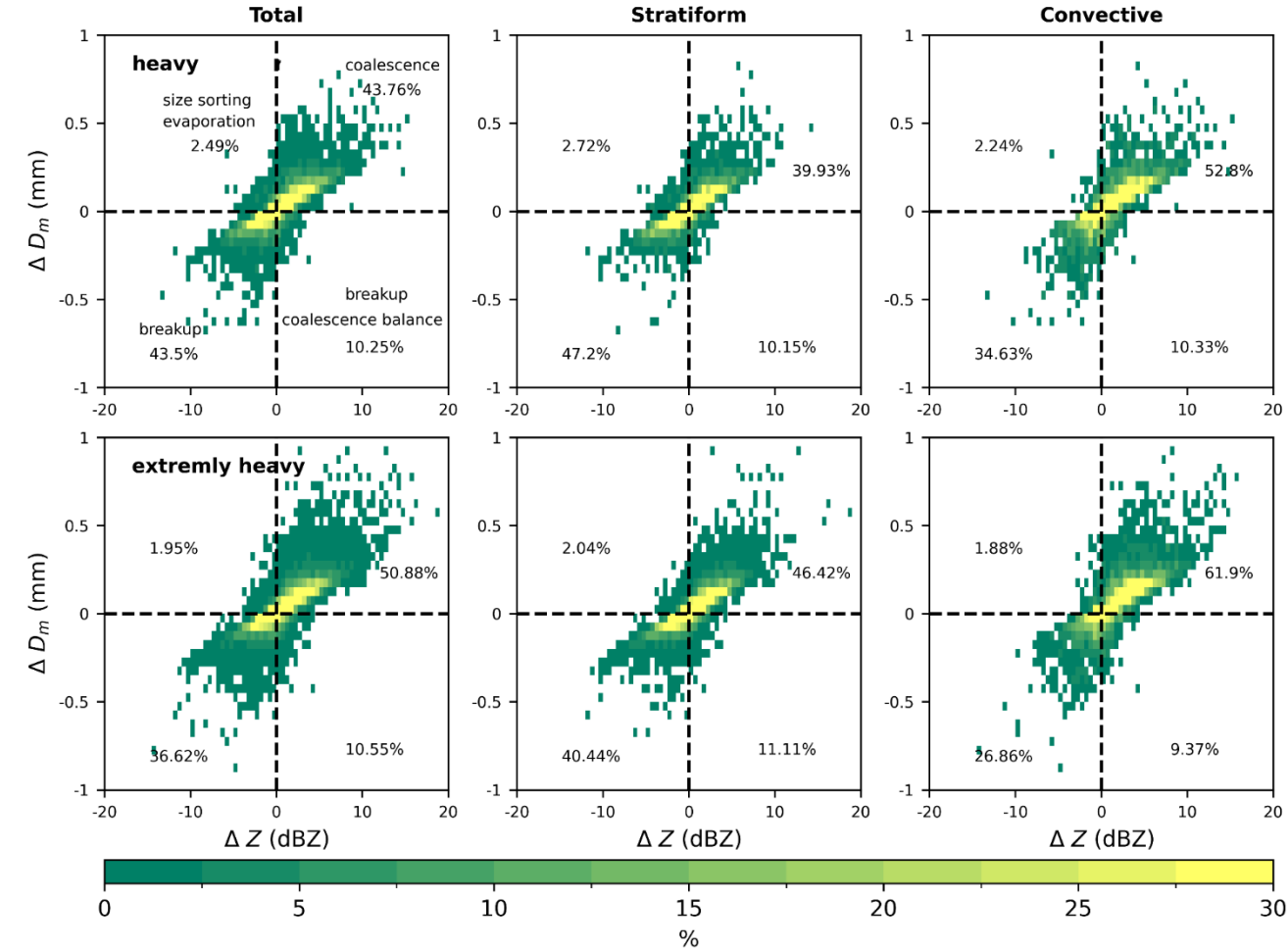


For three types of precipitations, the rain parameters (R , Z , D_m , and dBN_w) exhibit higher values in extremely heavy rainy days than heavy rainy days.

However, in the convective precipitation, the D_m values are nearly identical at 2km.

Fig. Mean profiles of R (mm h⁻¹), Z (dBZ), D_m (mm), dBN_w ($10\log_{10}N_w$, N_w in m⁻³ mm⁻¹).

Results & Discussion



To further understand the possible warm rain processes between heavy and extremely heavy rainy days, changes in D_m and Z values between 2km and 3 km height levels ($\Delta D_m = (D_m)_{2\text{ km}} - (D_m)_{3\text{ km}}$ and $\Delta Z = (Z)_{2\text{ km}} - (Z)_{3\text{ km}}$) are plotted.

Based on positive and negative values of ΔD_m and ΔZ , the ΔD_m - ΔZ scatter plots are segregated into four quadrants and they indicate different warm rain processes.

Top left quadrant indicates : Size sorting and evaporation process

Top right quadrant indicates : collision-coalescence process.

Bottom left quadrant indicates : breakup process

Bottom right quadrant indicates: breakup coalescence balance.

Fig. Probability density distributions of mass-weighted mean diameter and radar reflectivity in the 1 km layer depth ($\Delta D_m = (D_m)_{2\text{ km}} - (D_m)_{3\text{ km}}$ and $\Delta Z = (Z)_{2\text{ km}} - (Z)_{3\text{ km}}$) in the warm rain regions .

Results & Discussion

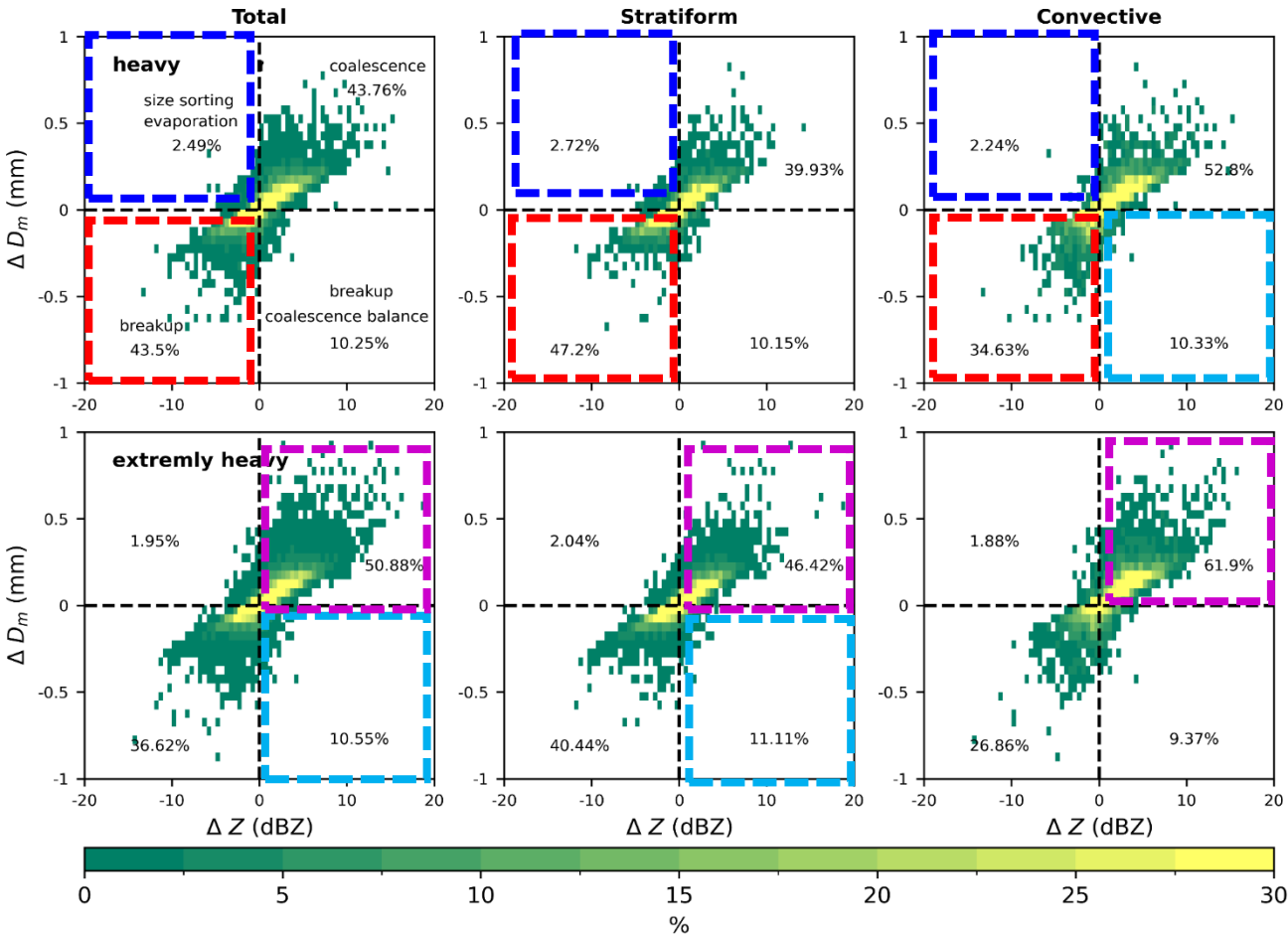


Fig. Probability density distributions of mass-weighted mean diameter and radar reflectivity in the 1 km layer depth ($\Delta D_m = (D_m)_{2 \text{ km}} - (D_m)_{3 \text{ km}}$ and $\Delta Z = (Z)_{2 \text{ km}} - (Z)_{3 \text{ km}}$) in the warm rain regions .

Total precipitation:

heavy rain : size sorting, evaporation and breakup

extremely heavy rain : collision-coalescence and breakup coalescence balance.

Stratiform precipitation :

heavy rain: size sorting, evaporation and breakup

extremely heavy rain : collision-coalescence and breakup coalescence balance .

Convective precipitation:

heavy rain: size sorting, evaporation, breakup, and breakup-coalescence balance

extremely heavy rain : are dominated with collision-coalescence process.

Conclusions

- extremely heavy rainy days showed higher rainfall rates over central and southern Taiwan.
- Large size raindrops → extremely heavy rainy days > heavy rainy days
- Small drops concentration in stratiform → Heavy rainy days > Extremely heavy rainy days
- The echo top heights → Extremely heavy rainy days > heavy rainy days.
- Warm rain processes:
 - Size sorting-evaporation processes: heavy rainy days
 - Breakup process : heavy rainy days
 - collision-coalescence processes: extremely heavy rainy days
 - Collision-coalescence and breakup balance : heavy rainy days (convective)
extremely heavy rainy days (total and stratiform)
- Extremely heavy rainy days : Dominant Collision-coalescence and breakup coalescence balance
- Heavy rainy days : Predominant breakup and size sorting evaporation process

Thank you for listening !!