CHAPTER VIII

SUMMARY OF THE RESULTS
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The study of rain drop size distribution (DSD) and rain integrals is the focal theme of the thesis. Data from an impact type Disdrometer installed at four different locations for differing periods, from a Micro Rain Radar (MRR) and a conventional rain gauge have been used in the study. The results from this study have been described and discussed in the earlier chapters. Here a summary of the results are presented.

8.1. EVALUATION OF AN EMPIRICAL MODEL FOR THE VARIATION OF DSD WITH RAIN RATE

The one-minute DSD data has been sorted according to rain rate. Then the data is grouped into different rain rate windows. This DSD data for each rain rate group is averaged. It has been found that the DSD data for this region is represented by the lognormal distribution better than the Gamma and Marshal-Palmer distributions. Therefore for each of the rain rate group, the lognormal distribution is fitted and the constants are evaluated. Then the variation of these constants with rain rate was obtained. Using this, an empirical model to describe the variation of DSD with rain rate has been obtained. This empirical model has been tested using the actual measurements and found to be a good representation. The data used for testing was not included in the derivation of the model.

The lognormal distribution is given by

\[ N(D) = \frac{\exp(A)}{D} \exp \left\{ -0.5 \left[ \frac{\ln(D) - B}{C} \right]^2 \right\} \] (8.1)

The variation of parameter A with rain rate is

\[ A = A_0 + A_1 R + A_2 \ln R \] (8.2)

and that of B is given by

\[ B = B_0 + B_1 R + B_2 \ln R \] (8.3)

and C is found to be a constant.

Replacing these expressions in the above equation (8.1) we get the empirical model.
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\[ N(D) = \frac{\exp(A_0 + A_1 R + A_2 \ln R)}{D} \exp \left\{ -0.5 \left[ \frac{(\ln D - (B_0 + B_1 R + B_2 \ln R))}{C} \right]^2 \right\} \]  \hspace{1cm} (8.4)

where \( D \) is the drop diameter, \( N(D) \) is the number of drops per cubic meter per unit diameter interval, and \( A_i, B_i \) and \( C \) are fit parameters.

The following table gives the constants for all the stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Season</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVM*</td>
<td></td>
<td>\begin{array}{ccccccc} A_0 &amp; A_1 &amp; A_2 &amp; B_0 &amp; B_1 &amp; B_2 &amp; C \ 0.930 &amp; 0.013 &amp; 0.489 &amp; 0.286 &amp; 0.005 &amp; 0.152 &amp; 0.370 \ 0.318 &amp; 0.005 &amp; 0.308 &amp; 0.404 &amp; 0.001 &amp; 0.216 &amp; 0.383 \ 0.968 &amp; 0.008 &amp; 0.409 &amp; 0.321 &amp; 0.002 &amp; 0.192 &amp; 0.386 \end{array}</td>
</tr>
<tr>
<td>Kochi</td>
<td></td>
<td>\begin{array}{ccccccc} A_0 &amp; A_1 &amp; A_2 &amp; B_0 &amp; B_1 &amp; B_2 &amp; C \ 0.850 &amp; 0.014 &amp; 0.327 &amp; 0.362 &amp; 0.002 &amp; 0.310 &amp; 0.388 \ 0.080 &amp; 0.003 &amp; 0.297 &amp; 0.416 &amp; 0.001 &amp; 0.178 &amp; 0.416 \end{array}</td>
</tr>
<tr>
<td>SHAR</td>
<td>ASO*</td>
<td>\begin{array}{ccccccc} A_0 &amp; A_1 &amp; A_2 &amp; B_0 &amp; B_1 &amp; B_2 &amp; C \ 0.268 &amp; 0.005 &amp; 0.558 &amp; 0.713 &amp; 0.005 &amp; 0.079 &amp; 0.532 \ 0.960 &amp; 0.008 &amp; 0.115 &amp; 0.547 &amp; 0.002 &amp; 0.280 &amp; 0.368 \end{array}</td>
</tr>
<tr>
<td>Munnar</td>
<td></td>
<td>\begin{array}{ccccccc} A_0 &amp; A_1 &amp; A_2 &amp; B_0 &amp; B_1 &amp; B_2 &amp; C \end{array}</td>
</tr>
</tbody>
</table>

\textbf{Table VIII.I. Parameters of the empirical model corresponding to each season at all the stations. (\* August, September and October, + Thiruvananthapuram).}

The rain rate measurements are available at a number of places, while DSD measurements are very less. Therefore this model could be used to derive DSD from rain rate alone. To make the model rigorously applicable and truly valid, measurements of DSD at more locations could be done and with this data, model can be updated.

\textbf{8.2. RAIN RATE CHARACTERISTICS}

The one-minute rain rate data from the Disrometer available from three stations, viz., Thiruvananthapuram, Kochi and Munnar has been used to study the characteristics of rain rate. The salient features of the results are given here.

- Around 90 % of the time, the rain rate is below 5 mm/h, except at Thiruvananthapuram where it is around 65%. This indicates that stratiform clouds are more prevalent in these stations compared to cumuliform.
- The most interesting aspect was the apparently lower presence of cumuliform clouds during July 2002 at Kochi, which possibly contributed to the deficiency in rainfall.
The rain rate temporal cumulative distribution could be fitted with a Weibull distribution function of the form

$$y = 1 - \exp \left( 1 - \left( \frac{x}{\lambda} \right)^k \right)$$  \hspace{1cm} (8.5)

The $k$ is the shape parameter and $\lambda$ is the scale parameter. It is found that the shape parameter is more or less the same at all stations during the southwest monsoon period.

• The value of shape parameter ($k$) of the weibull distribution fit to the temporal cumulative distribution remains more or less same for each station during the southwest monsoon period.

• Rainfall is present only for less than 10% of the time (or about 4300 minutes) even during a rainy month like June or July. This indicates that rainfall could be actually present for lesser duration.

8.3. DSD CHARACTERISTICS

Using the lognormal distribution, three physically significant parameters viz. Total number of drops (N_T), Geometric mean diameter (D_g) and Standard geometric deviation ($\sigma$) have been derived. Their variation with rain rates are presented here.

• The standard geometric deviation of drop size is constant for all rain rates at all the stations.

• Geometric mean diameter increases exponentially with rain rate at all the stations. This indicates heavier rainfall usually has more larger drops.

• Total number of drops increases exponentially with rain rate at Kochi and SHAR. However, at Thiruvananthapuram and Munnar, the total number of drops starts decreasing or remaining constant after a certain rain rate. This shows intense rainfall at these stations may not have the same increase in larger sized drops like in the other two stations.
8.4. VARIATION OF DSD DURING THE COURSE OF A RAINSPELL

The variation of the DSD during the course of a rain event lasting over 2½ minutes with an average rain rate of 2.028 mm/h has been studied. It is seen that:

- At the beginning of the rainfall event, the smaller drops are more in number compared to larger drops.
- During the course of the event, the number of smaller drops is seen to decrease while that of larger drops seen to increase showing the possibility of coalescence.
- Decrease in smaller drops without the corresponding increase in larger drops showing the possibility of evaporation.
- The movement of rain patches downward is also seen during the course of the event.

8.5. RADAR REFLECTIVITY AND RAIN RATE (Z-R)

The variation of radar reflectivity with rain rate has been derived using the MRR data. The stratiform and convective clouds could be distinguished from the presence of Bright band or otherwise, from the MRR data.

The results from the study are given below.

- The Z-R relations (of the form $Z=AR^b$) derived is given in the table VIII.II.

<table>
<thead>
<tr>
<th>Rain type</th>
<th>Stratiform</th>
<th>Convective</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A$</td>
<td>$b$</td>
</tr>
<tr>
<td>Pre-monsoon</td>
<td>496</td>
<td>1.26</td>
</tr>
<tr>
<td>Southwest monsoon</td>
<td>334</td>
<td>1.36</td>
</tr>
</tbody>
</table>

*Table VIII.II. The parameters $A$ and $b$ of the Z-R relation for different rain type during different seasons.*

- The values of $A$ and $B$ are seen to decrease with height except for southwest stratiform where they are found to be constant with height.
8.6. COMPARISON OF SATELLITE DATA WITH GROUND-BASED MEASUREMENTS

The rain rate data from the Disdrometer, MRR, Manual rain gauge and the TRMM are compared both for the simultaneous detection and for the amplitude of the magnitude.

• 77% of the total events could be detected together by the TRMM and Disdrometer sensors.

• TRMM rainfall agrees well with the Manual rain gauge, Disdrometer and MRR rainfall, when monthly accumulation is taken (Correlation coefficient is > 0.9). The same comparison for daily accumulated rainfall gives a correlation coefficient of around 0.6. For 3-hourly rainfall, the comparison gives a value of around 0.4.

• Magnitude of Root Mean Square Error (RMSE) has no dependence on the magnitude of rainfall accumulation.

• Munnar shows a better correlation compared to other stations. This could be attributed to the “coastal-grid effect”, as the other three stations are coastal stations. This could be due to the land and ocean back-ground emissivity within the same grid box in the scenario of satellite measurements.

• The number of events detected by single sensor only is being significant indicates that the rainfall may not be uniform even over a small grid size of 0.25º X 0.25º.

• Hence to evaluate the ‘ground truth’ in a detailed way, it would be better to deploy more instruments within a single grid of 0.25º X 0.25º.

In short, the major results pertain to the development and testing of an empirical model to represent the variation of DSD with rain rate in the tropics. The evaluation of the vertical profiles of Z-R relations for our region is another important result of this study. The correlation between satellite measured rainfall and ground-based measurements has brought out a broad agreement between them. However the need to have a closer look at the satellite retrieval is required. The
behaviour of the intensity of rain fall or rain rate at tropical stations and the possible
effect of orography on DSD has been also brought out.

8.7. SCOPE OF FUTURE WORK

The empirical model developed in this study could be updated with more
data and from other locations. Using the collocated MRR for classification of rain
into stratiform and convective origin on the basis of radar bright band signature,
DSD model could be derived separately for stratiform and for convective rain. The
shape and scale parameters of the weibull-distribution fitted to the cumulative rain
rate distributions could be explored during different monsoon seasons to understand
the spatial variability in rainfall and even the prevalence of stratiform and
convective clouds. More Disdrometers could be deployed within a single TRMM
grid to get a better resolution and comparison with satellite data. This will
ultimately help in evaluating the ground truth accurately. The DSD data could be
collected from more west coast stations and high altitude stations in the western
ghat and comparison could be done between those coastal and high altitude stations
in the same latitude for getting more evidence for the orographic effect on rain DSD.
The behaviour of DSD with altitude using the micro rain radar data would throw
some light on the possible effects of the atmospheric medium on rain processes
itself.