Rainfall probabilities and amounts associated with monsoon depressions over India

R. H. Kripalani and S. V. Singh
Indian Institute of Tropical Meteorology, Pune
(Received 29 February 1984)

ABSTRACT. Composite charts of distribution of probabilities of 24-hr rainfall amounts \( \geq 2.5 \) mm and \( \geq 65 \) mm and the average 24-hr rainfall amounts over India are determined for various geographical locations of the depressions by using daily rainfall data of 220 stations for a 16-year period. The composite charts of rainfall probabilities are used to issue forecasts of probability of rain at 12 stations during five independent years. These forecasts when evaluated by a proper quadratic score showed skill score of 10%.

1. Introduction

It is well known that even during the period of established monsoon the day-to-day circulation and the associated rainfall distribution undergoes dramatic change from little rainfall to abundance of rainfall over India. As the large scale rainfall distribution over the country is mainly controlled by the synoptic systems, the forecaster formulates the forecast of the expected areal coverage of rainfall over various parts of the country from the empirical knowledge and some dynamical principles including the formation, intensification, decay and movement of the circulation systems and the associated rainfall distribution. In this formulation he is guided by the published literature on the above mentioned synoptic climatological aspect of the monsoon circulation and rainfall and his own past experience about the behaviour of circulation systems. It is desirable that the knowledge about the rainfall distribution around various synoptic systems is objectified and is made available to the forecaster in the form compatible with his mode of expression of forecasts. The most suitable way, in which rainfall distribution around or due to circulation systems over larger parts of the country can be presented is compositing. Apart from their obvious use as an aid in operational forecasting, it is believed that such composite charts shall be useful for (i) extending the enquiries into the physical mechanism responsible for particular type of distribution of rainfall and (ii) verification of results of medium range prediction or simulation of circulation and weather fields by numerical models. The similar synoptic systems needed for compositing can be identified either by comparing the entire distribution of some meteorological field(s) over the region of interest or by comparing location and other features of some prominent circulation systems. The latter approach is followed in the present study. Since the monsoon depressions are one of the most important rain producing agencies and they undergo somewhat orderly movement over the Indian region during the monsoon season, the study is confined to these synoptic systems only.

1.1. An overview of past studies

Pisharoty and Asnani (1957) were the first to present a composite picture of heavy rainfall (\( \geq 6.5 \) cm in 24-hr) distribution based on rainfall data for 4 monsoon depressions. They found that the heavy rainfall occurs upto 1000 km ahead of the depression centre and upto 400 km to the left of depression track. Raghavan (1967) studied the spatial distribution of percentage deficiency in the monthly rainfall of July and August caused by the absence of monsoon depressions. Mooley (1973) studied the spatial distributions of mean 24-hr rainfall within 500 km of the 24-hr mean positions of the depressions centred around 87 deg. E, 80 deg. E and 75 deg. E longitudes. He noted that the maximum rainfall is
located about 150 km ahead of the 24-hr mean centre of the depression or about 300 km from the centre of the depression at the beginning of the 24-hr period for which rainfall has been considered and between 50 and 150 km to the left of the track of depression. He further pointed out that the heavy rainfall extends only upto 250 km south and upto 500-600 km ahead of the depression position at the beginning of the 24-hr period. Further, from the analysis of average rain per depression day, standard deviation of depression rain and the contribution of depression rain to the total rain for the three-longitude sector, he established that the mean rainfall per depression day in the left sector of depression increases westward, Dhar and Mhaiskar (1973), after composing the rainfall distribution around 10 depressions crossing the Orissa coast, found that the heavy rainfall occurs over a strip with its boundaries 40 to 120 km south of the track of depression. Recently Chowdhary and Gaikwad (1983) have also arrived at similar conclusions about the distribution of 24-hr rainfall around the depression by using data of 540 rainfall stations and 27 depression cases.

1.2. Scope of the present study

All studies mentioned above have identified the areas receiving heavy rainfall with respect to the location of monsoon depressions by analysing the spatial distribution of the maximum mean and heavy rainfall during the 24-hr period. No composite charts for the probability of occurrence of rainfall or heavy rainfall have been presented. Thus, although the hitherto published composite charts guide the forecaster to delineate the areas expected to receive heavy rainfall, there is no guidance available about the probability of occurrence of rain over the area affected by the depression. Most of the previous studies have considered the rainfall occurrence within 500 km of the daily mean position of the depressions. It has been pointed out by some workers (e.g., Mukherjee and Shyamala 1978) that the influence of depressions in causing rainfall extends beyond 500 km. Thus it seems to be necessary that the climatic characteristics of the rainfall over the whole country is studied for the cases of depressions. Further no study seems to have verified the utility of the composite rainfall charts in actual forecasting. The principal objective of the present study is to present the composite charts of the distribution of probability of rainfall $\geq 2.5$ mm and $\geq 65$ mm during the peak monsoon months (i.e., July and August) such that they provide probabilistic guidance to the forecasters for the occasions when a depression is present over the country. The utility of these composites is verified on independent sample by using proper scores.

2. Data

Daily rainfall data of 220 stations (Fig. 1) evenly distributed over India were collected for July and August for 16 years (1958 to 1973) from the India Meteorological Department. The rainfall data of 12 of these stations were extended by 5 years, i.e., upto 1978, to create an independent sample needed for the verification of the utility of the rainfall composite charts. Locations of depressions (or deep depressions) at 03 GMT were taken from the India Meteorological Department (IMD) publication "Tracks of storms and depressions" (IMD 1979).

3. Methodology

At first the frequencies of occurrence of depressions during the sixteen years period are determined for each of the twenty-two 2.5° Lat./Long. blocks (Fig. 2). For determining the composite picture of rainfall due to the depressions, a computerised moving grid method similar to that of Jorgensen (1963) is adopted. The centre of a 14° Lat./20° Long. rectangular grid of mesh size 1° Lat./Long. is assumed to be placed (in the computer memory) on the centre of the depression, located within a particular geographical block (see Fig. 2), with the x-axis of the grid oriented along the latitude circle. Rainfall stations falling in each of the 280 $(14 \times 20)$, $1^\circ \times 1^\circ$ Long. squares of the grid are identified and the occurrence of the three types of rain events, viz., rain $\geq 2.5$ mm, $\geq 10$ mm and $\geq 65$ mm and the actual rain amount during the 24-hour period are noted and stored squarewise in the computer memory along with the number of stations which fell in each square. All these rainfall parameters, viz., (i) number of occurrences of rain events defined for the three different thresholds, (ii) actual rainfall amount and (iii) the number of stations falling in each square, are accumulated over all the depression cases for which the depression centres lay in a particular geographical block. The probabilities of occurrence of rain events (for each of three thresholds) are then determined for each square by dividing the number of accumulated rain events by the accumulated number of stations which fell in the particular square. Likewise the average 24-hr rain amount in each square is determined by dividing the accumulated rain amounts by the accumulated number of stations which fell in the particular square. The above types of composites (henceforth to be referred as moving grid composites) are prepared for each of the 22 geographical blocks.

Since the above moving grid could not capture the distinct effects (e.g., Mukherjee and Shyamala 1978) of the depressions in producing rain, we determined the similar rainfall statistics for each of the 220 rainfall stations by considering the days when the depression centre lay in a particular geographical block. This type of compositing (to be referred below as station composites) was also done for all 22 geographical blocks. A total of about 100 composite charts of different types are prepared but only a few composites, which are based on sufficient number of depression cases are presented and discussed in section 4 below. The climatic probabilities of occurrence of rainfall at stations in each month (needed below) are determined by using the same 16 years (1958-1973) of data.

The choice of the three types of rain events is governed by the following consideration. A day is officially considered as rainy day (heavy rainfall day) by the India Meteorological Department if the 24-hr rainfall on the day equals or exceeds 2.5 mm (65 mm). The official forecasts predict the likely occurrence of rain events equalling or exceeding these two thresholds.
In the discussion which follows the terms probability of occurrence of rainy days (heavy rainfall days) will refer to the above amounts respectively and the composite charts will be presented for these two types of rain events only. In general the average rainfall per day during the peak monsoon months (i.e., July and August) over the major parts of the country is near 1 cm. Hence this additional threshold was also considered in the present study. The composite charts for this threshold are not presented as this threshold does not form a component in the official forecasts. We have, however, used the composites corresponding to this threshold for verifying the utility of the composites in issuing the forecasts on independent sample.

4. Results and discussion

The probabilities of rain days and heavy rain days and the average rain amount recorded during the 24-hr periods are presented in Figs. 3(a, b & c) respectively for selected six blocks only which lie along the main track of the depressions (Dhar and Ghose 1972) and have sufficient frequencies of depression cases. The probability of rain days exceeds 0.8 ahead of the depression, over an area varying from 3 to 5 deg. Lat. width and 5 to 10 deg. Long. in length (1 deg. Long. ≈ 100 km) depending on the geographical positions of the depression. Over half of this area the probability of rain exceeds 0.9 when the depressions are centered to the east of 80 deg. E longitude. The probability of rain day is found to be more than the climatic probability over the area lying ahead of the depression up to the westernmost boundary of the country. Far north and south of the depression track the probability of rainy days is less than the climatic probability (e.g., see Fig. 4). Thus the depressions do not enhance the probability of occurrence of rainy days over the whole country but reorganise the rain occurrence of a particular manner (see also Raghavan 1967). This reorganisation (enhancement or reduction) of rain probability is more extensive when the depressions lie between 80 deg. longitude and the east coast (e.g., see the diagram corresponding to square 4 in Fig. 3a). The probability of rainy days increases over Rajasthan, Gujarat, west coast and adjoining Peninsula as soon as the depression crosses 85 deg. E longitude thus supporting the results of Mukherjee and Shyamala (Loc. cit.). The increase in probability of rainy days over the west Rajasthan is not, however, more than 0.2 unless the depression reaches near 80 deg. E. The probability of rainy days is found to increase in the rear of the northeast quadrant when the depression crosses the 82.5 deg. E longitude supporting Raghavan’s (Loc. cit.) results.

The probability of heavy rainfall exceeds 0.2 over an area of about 2-3 deg. wide and 5-6 deg. long lying to the south or more specifically southwest sector of depression. As the depressions move west of 80 deg. E the extent of isopleth of probability 0.2 or 0.3 decreases but the probability of heavy rainfall in isolated areas becomes quite high. Probability of heavy rainfall over Gujarat and north Konkan increases significantly as the depressions reach near 80 deg. E (see also Abbi et al. 1970).

The averages 24-hr rainfall exceeds 2 cm over a rectangular belt 3-4 deg. wide and 7 to 10 deg. long. Over an inner core, the average rainfall exceeds 4 cm. This core of higher rainfall is more extensive when the depressions lay in blocks 7, 8 and 12. There is evidence of an anchored zone of heavier rainfall near 80 deg. E as observed by Bedekar and Banerjee (1967) when the depression lies in the squares 5, 7 and 8.

The composite charts for the probability of rainfall can directly be used as guidance for issuance of forecasts of expected areal coverage of rainfall over the sub-divisions. It may be remembered that the simple average of probabilities of rainy days over the stations in a geographical area is equal to the expected areal coverage of rainfall in the area. Thus the given probabilities of rainy days for the individual stations or 1 deg. × 1 deg. grid squares can be easily transferred into the expected areal coverage of the rainfall over any geographical region, say a meteorological subdivision. Likewise composite charts for the probability of heavy rain days and the average expected rain amount can be used as guidance for issuing the forecasts of respective aspects of rainfall over any geographical region.

5. Application of forecasting

5.1. The skill of forecasts

The probabilities of rain (≥ 2.5 mm and ≥ 10 mm) in 24-hr periods determined above are used to issue the forecasts of rain occurrence over 12 stations on 76 depression days during the 5 years (1974-78) of independent period. The results of forecasts in terms of probability score are given in Table 1. The probability score (PS) is given by: \[ \text{PS} = \frac{1}{n} \sum_{i=1}^{n} (P_i - \delta)^2 \], where \( P_i \) is the forecast probability of rainy day and \( \delta \) is 1 if the rain event occurs and 0 if the rain event does not occur.
Figs. 3 (a-c). Probabilities (× 100) of 24-hr rainfall: (a) rainfall (≥ 2.5 mm), (b) heavy rainfall (≥ 65 mm) and (c) Average rain distribution (in mm) in 24-hr period for various geographical locations of depressions in association with depressions located in various geographical areas. The first number on the right top corner represents the serial number of the blocks, while the number following represents the frequencies of occurrence of depressions in the particular block. The average positions of the depressions in the block at the beginning of the 24-hr period is shown by a solid circle and at the end of the 24-hr period is shown by arrowhead.
RANKED PROBABILITIES AND AMOUNTS IN DEPRESSIONS

Fig. 4. Difference between probability of rainy days (≥2.5 mm) associated with depression minus the climatic probability, in percentage for the depression's location in block 7.

### TABLE 1

<p>| Probability score for climatology and forecasts and skill scores in percentage for two thresholds, viz., 2.5 mm and 10 mm of rainfall. The probability scores are rounded up to 2 decimal places and skill scores expressed in percentage are rounded up to integer number. Total number of forecasts is 76. |</p>
<table>
<thead>
<tr>
<th>Probability score</th>
<th>Skill score</th>
<th>Probability score</th>
<th>Skill score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clim. F/C</td>
<td></td>
<td>Clim. F/C</td>
<td></td>
</tr>
<tr>
<td>Rainfall ≥2.5 mm</td>
<td>26</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>04</td>
<td>04</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
</tbody>
</table>

and n is the number of forecasts. The probability score shall be 0 if the forecasts are perfect and 1 if they are complete failures. Thus the lower probability scores go with more skillful forecasts. The probability scores (Murphy and Epstein 1967) for the forecasts based on climatic probability are also given in the same table. The skill-score in percentage are determined as

\[
\text{Skill-score} = \frac{\text{PS (Climatology)} - \text{PS (Forecasts)}}{\text{PS (Climatology)}} \times 100
\]

The skill-score of the forecasts are about 10% and are relatively higher for Jharsaguda, Purnea and Ahmedabad. However, the skill-scores are negative for Bombay, Mangalore and Aurangabad.

5.2. Reliability of forecasts

The forecasts are said to be reliable (Murphy and Epstein, Loc. cit.) if on verification, for all the cases for which a particular value of probability of rainfall \((P_i)\) is forecast, the relative frequency \((f_i)\) of occurrence of rainfall approximates the value \(P_i\), i.e., \(f_i \approx P_i\). We have verified the relative frequency of occurrence of rainfall for five classes of \(P_i\), with central values, .1, .3, .5, .7 and .9. After verification for individual stations, the verification sample (76) was found to be too small. Hence the relative frequencies of rainfall occurrence, corresponding to particular class of forecast probability are averaged over all the 12 stations and presented in Table 2.

The \(P_i\) and \(f_i\) match reasonably well except for the last class \((P_i = .9)\) for the 10 mm case for which the number of observations is too small. Thus, the forecasts produced by using the above composite charts are reliable and there is no overpredicting or underpredicting of the probability of rainy days.

6. Conclusion

The probability of occurrence of 24-hr rainfall ≥2.5 mm exceeds 0.8 over an area lying ahead of the depression and varying in extent from 3 to 5 deg. Lat. width and 5 to 10 deg. Long. In length, depending on the geographical position of the depression at the start of the 24-hr period. Likewise the probability of heavy rainfall exceeds 0.2 over an area about 2-3 deg. wide and 5-6 deg. long lying to the left of the depression track (Fig. 3b). The average rain exceeds 2 cm over
a rectangular belt 3-4 deg. wide and 7-10 deg. long lying to the left of the depression track (Fig. 3c). Reliable forecasts of rainfall point probabilities or expected areal coverage can be made, for the occasions when a depression is present over the Indian region, by using the above probabilities of rainfall associated with depressions. The skill score of the forecasts is expected to be about 10%.

This paper has dealt with statistics of rainfall in association with monsoon depressions. Distribution of rainfall has been explained on physical and dynamical considerations by many workers (e.g., Rajamani and Rao 1981) and hence no explanation has been put forward here.

Acknowledgements

The authors are extremely grateful to the Director, Indian Institute of Tropical Meteorology, Pune for the facilities provided and to Shri D. R. Sikka, F. A. Sc., Head, Forecasting Research Division for guidance. They are also grateful to the Deputy Director General of Meteorology (Climatology) for supplying the rainfall data. Thanks are also due to Miss C. P. Ghosh and Mrs. Sathy Nair for typing the manuscript.

References


Dhar, O.N. and Mhaiskar, P.R., 1973, 'Areal and point distribution of rainfall associated with depressions/storms on the day of crossing the east coast of India', Indian J. Met. Geophys., 24, pp. 271-278.


