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Daily rainfall forecasts through a quantitative precipitation forecasting (QPF) model over Thiruvananthapuram and Madras areas for the monsoons of 1992

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सार — थिरुवनन्तपुरम और मद्रास की वर्ष 1992 की क्रमशः जून-सितम्बर तथा अक्तूबर-दिसम्बर की दैनिक वर्षा के मात्रात्मक वर्षण के पूर्वानुमान (क्यू.पी.एफ.) का प्रयास किया गया है। विशिष्ट आर्द्रता संरक्षण की संकल्पना पर आधारित क्यू.पी.एफ. के गणितीय निदर्श में आंकड़ा निवेश के रूप में केन्द्रों के संजाल के उपरितन वायु आंकड़ों का उपयोग किया गया है। दोनों केन्द्रों के लिए क्रमशः लगभग 66% तथा 72% सही पूर्वानुमान प्राप्त हुए है और अधिक सुधार की संभावना पर संक्षेप में चर्चा की गई है।

ABSTRACT. Quantitative precipitation forecasting (QPF) of daily rainfall of Thiruvananthapuram and Madras for June-September and October-December respectively for the year 1992 has been attempted. A mathematical model of QPF based on the concept of conservation of specific humidity and with upper air data of a network of stations as the data input has been employed. Nearly 66% and 72% correct forecasts were realised respectively for the two stations. Scope for further refinement has been briefly discussed.

Key words — Quantitative Precipitation Forecasting (QPF), Vertical velocity, Orography, Moisture advection, Divergence, Precipitation efficiency, Liquid Water Content (LWC), Forecast verification, Skill score.

1. Introduction

Forecasting precipitation over a region for the time scales of short/medium/long range is one of the most challenging and fascinating problems in meteorology and hydrology. Precipitation, which is a complex function of several meteorological factors, is also influenced by the topography and orography of the region and further manifests diurnal and seasonal variation. Precipitation/rainfall forecasts are generally issued by the National Meteorological Services for a fairly large area, the validity period of short range forecasts being 12-72 hours. These generally describe the likely spatial distribution of rainfall besides the chance, if any, of heavy rainfall at some locations. Forecasting the quantum of rainfall over a location or small area for the next 24 or 48 hours is also done albeit rarely for specific areas, such as catchment areas of rivers or dams. Such forecasts are popularly called Quantitative precipitation forecasts (QPF) and are extremely useful in flood management.

QPF has attracted the attention of several Indian workers. Banerji *et al.* (1967), Rao *et al.* (1970), Gupta *et al.* (1979), Lal *et al.* (1983), Upadhyay *et al.* (1986), Basu and Kamruj (1989) and Sen (1991) are some of the studies done in India. Sen (1994) provide a review of QPF models used in India. These authors have used statistical association, analogues, categories of synoptic situations, dynamical or semi-dynamical techniques and other thermodynamical inputs in their work. Pettersen (1956) and Haltiner and Martin (1957) provide a brief description of QPF theory. Georgakakos and Bras [1984 (a)] and Georgakakos and Hudlow [1984 (b)] have used QPF for hydrological forecasting.

In case of Sen (1991), QPF was based on a mathematical model formulated by incorporating physical and dynamical laws and had upper air sounding as the major data input. In this study we propose to attempt QPF with a forecast lead time of approximately 24 hours over two regions of southern peninsula during southwest and northeast monsoon seasons of 1992 by the application of the above mathematical model on QPF.

2. Basic model

In case of Sen (1991) the model was derived based on the assumption of conservation of specific

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humidity q in an air column. Thus we assume $dq/dt = 0$, which yields,

$$\frac{\partial q}{\partial t} = -\left(u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y}\right) - \omega \frac{\partial q}{\partial p} \quad (1)$$

notations having usual meaning. The liquid water content (LWC) in an air column is defined by (Byers, 1959)

$$\mathrm{LWC} = R = -1/g \int_{p_s}^{p_t} q \, \mathrm{d}p \quad (2)$$

where p_s and p_t denote the pressures at bottom and top levels of the atmosphere. Differentiating Eqn. (2) with respect to time t and substituting from Eqn. (1) we obtain,

$$\frac{\partial R}{\partial t} = \frac{1}{g} \int_{p_s}^{p_t} \left(u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y} \right) \delta p + \frac{1}{g} \int_{p_s}^{p_t} \omega \, \delta q \quad (3)$$

The right hand side of Eqn. (3) does not contain t explicitly and so can be evaluated once u, v, $\frac{\partial q}{\partial x}, \frac{\partial q}{\partial y}$ and ω are known at various levels. The first and second terms of right hand side of Eqn. (3) are known as the advection term and the vertical velocity term respectively. Once $\frac{\partial R}{\partial t}$ is derived the LWC which will be added to the atmosphere during the next 24 hrs, which we will denote by LWC24, could be computed. A forecast of precipitation over the area represented by the above parameters for 24 hrs could then be obtained by multiplying LWC24 by the so called Precipitation Efficiency (PE), a ratio that specifies how much percentage of the moisture added is precipitated.

3. Data and methodology

The objective of this paper is to employ the QPF model described in section 2 over the Thiruvananthapuram (TRV) area located in south Kerala for the southwest monsoon season of June-September 1992 and over the Madras (MDS) area located in north coastal Tamil Nadu for the northeast monsoon season of October-December 1992. It is proposed to work out a 24 hrs forecast for the cumulative rainfall during 0300-0300 UTC of two consecutive days, the forecast to be based on the 0000 UTC upper air data of the first day.

For QPF over TRV we chose a network of four upper air observatories, *viz.*, Minicoy, Thiruvananthapuram, Amini Devi and Karaikal and two rainguage stations, *viz.*, TRV and TRV Air Port. For QPF over Madras we selected Madras, Karaikal, Bangalore and Machilipatnam for upper air data and MDS and MDS AP as rain guage stations. Fig. 1 presents spatial distribution of the upper air observatory network in respect of QPF schemes for both TRV and MDS.

The upper air data, *viz.*, wind, dry bulb, dew point — temperatures and contour heights at 0000 UTC (0530 hr IST) for the four stations for QPF of TRV for the period 1 June-30 September 1992 were extracted from the daily weather charts available at the Regional Meteorological Centre, Madras. Similar data for the period 1 October-31 December 1992 at 0000 UTC were collected for the respective stations. Daily rainfall data for the stations chosen for the 24-hrs ending 0300 UTC were also extracted.

The specific humidity q was computed at each level of the atmosphere for the four stations. The terms $\frac{\partial q}{\partial x}$ and $\frac{\partial q}{\partial y}$ were evaluated by finite differencing. The advection of moisture over TRV and MDS for the appropriate periods was then computed by vertically integrating $\left(u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y}\right)$ by taking $\Delta p = 50$ hPa.

In this paper we have computed vertical velocity from the continuity equation as suggested in Hess (1959) and Holton (1979). Though the profile thus obtained may not be very accurate the alternative methods such as omega equation are beset with tedious computations besides being not very accurate in tropics. The effect of western ghats which lie approximately 80 km east of the west coast oriented in a NNW-SSE direction, in generating low level convergence upto 850 hPa, and so vertical velocity over TRV has been incorporated by an approximate method detailed below.

In Fig. 1, A, B, C, D represent Amini, Minicoy and Thiruvananthapuram and the intersection of 11°N latitude line with the west coast respectively. Approximately D is the midpoint of line joining Amini and Karaikal. The wind at D could be

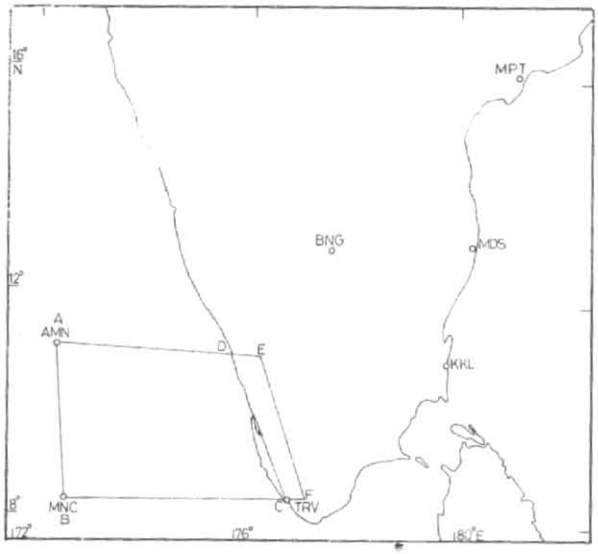


Fig. 1. Network of upper air observatories for QPF over TRV and MDS

estimated from the winds of the other stations. The divergence at a central point at the polygon ABCD could be easily computed which is the divergence as generated by the larger flow pattern. However the winds that blow from the Arabian sea have to slow down and rise as they approach the ghats. In Fig. 1. EF approximately denotes the orientation of ghats where we assume the wind is very weak. Now the divergence over DEFC could be computed which is the divergence as generated by the ghats. The divergence over TRV area was taken as the weighted mean of the above two values the weights being the areas of the respective polygons, upto 850 hPa level. Aloft this level the divergence computed over ABCD alone was used. For Madras the divergence was computed by finite differencing based on the wind observations of the four stations considered.

Once divergence is computed the vertical p-velocity ω can be obtained from the vertical integration of,

$$\frac{\partial \omega}{\partial p} = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \tag{4}$$

by taking $\omega = 0$ at 1000 hPa and $\Delta p = 50$ hPa. If necessary, $w = dz/dt$ can be computed from the relation $\omega = -g\rho w$.

Computation of LWC24 and daily rainfall forecasts

The advection and the vertical velocity terms of Eqn. (3) were computed as per the methodology described in the previous section. The sum of these terms was computed and hence LWC24 was evaluated. According to Sen (1991) PE is a complex elusive factor to determine and is not spatially constant either. Pettersen (1956) has taken that the whole of LWC24 precipitates into rain, *i.e.,* PE = 1. Rhea (1978) has reported that many computations of precipitation rates routinely set PE = 1. Haltiner and Martin (1957) suggested that only 30% of LWC24 precipitates which has been used in Sen (1991). It is likely that a PE value of 0.3 might very much underestimate heavy monsoon rainfall in tropics whereas PE value of 1.0 implies that all the moisture added is being precipitated. If the atmosphere is not fully saturated a part of LWC24 will have to expend itself in saturating the atmosphere further before condensation could take place.

Taking all the above into consideration, in this paper we have computed PE by means of a simple statistical technique. For the first 2 days of the seasons, *i.e.,* 1 & 2 June and 1 & 2 October, PE was taken as 0.3. For all subsequent days PE was computed by setting $Y = PE \times X$, where X = LWC24 and Y is the realised daily rainfall for a maximum of 7 days prior to the date of forecast. PE was then estimated by the method of least squares. A lower limit of 0.3 and a higher limit of 1.0 for the PE was kept as PE > 1 is not theoretically possible. Thus the forecast precipitation during 0300-0300 UTC of nth and (n+1)th days based on LWC24 computed from the upper air data of 0000 UTC of nth day is as under : If LWC24 is negative no rain is forecast. If positive, PE × LWC24 is the forecast rainfall amount, PE having been computed from the data of (n−1) to (n−7)th days.

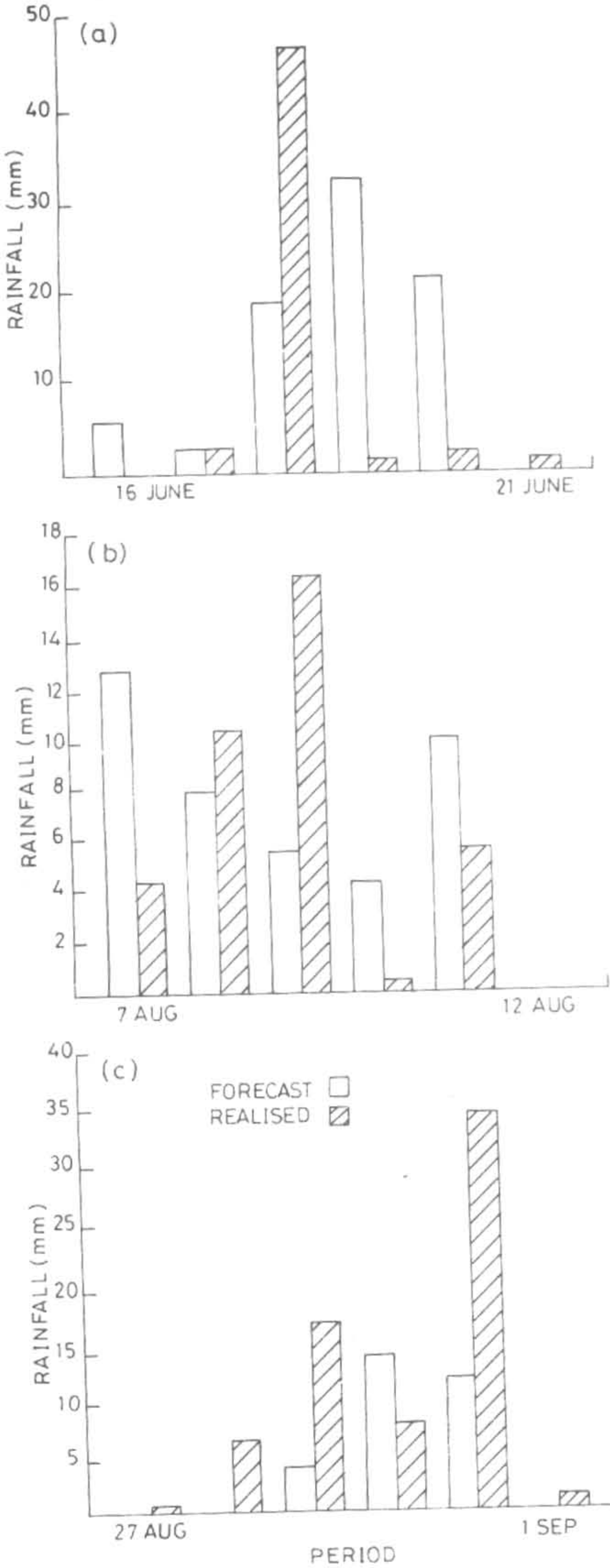
The forecast rainfall amounts for TRV and MDS areas for the respective seasons were thus obtained.

4. Results and discussion

4.1. *Performance of the QPF model*

4.1.1. *For TRV June-September 1992*

During 1992 the southwest monsoon set in over TRV on 5 June. The onset rain spell lasted upto 15 June and the next spell commenced on 17 June. During the onset spell forecasts were good on many days. Fig. 2 presents the forecast and realised rainfall for TRV for 16-21 June, 7-12 August and 27 August-3 September. The satisfactory performance of the system is seen from the figure. The forecasts were very good on 18, 19, 21, 23 June and also on all



Figs. 2 (a-c). Forecast and realised rainfall (mm) over TRV for three rain spells

TABLE 1

Performance of QPF over TRV for Jun-Sep 1992 and MDS for Oct-Dec 1992

Area		TRV Forecast		MDS Frequency-F	
		NR	R	NR	R
Realised-F	NR	50	22	48	13
	R	19	30	11	15
Total no. of fcsts		121		87	
Per. of correct fcsts		66		72	
Skill Score		0.30		0.36	
Chi square		11.08		10.95	

Fcst — Forecast, F — Frequency, NR — No Rain, R — Rain (No forecasts on Sep 30 and Dec 31. No data and so no forecasts computed during Dec 8-10)

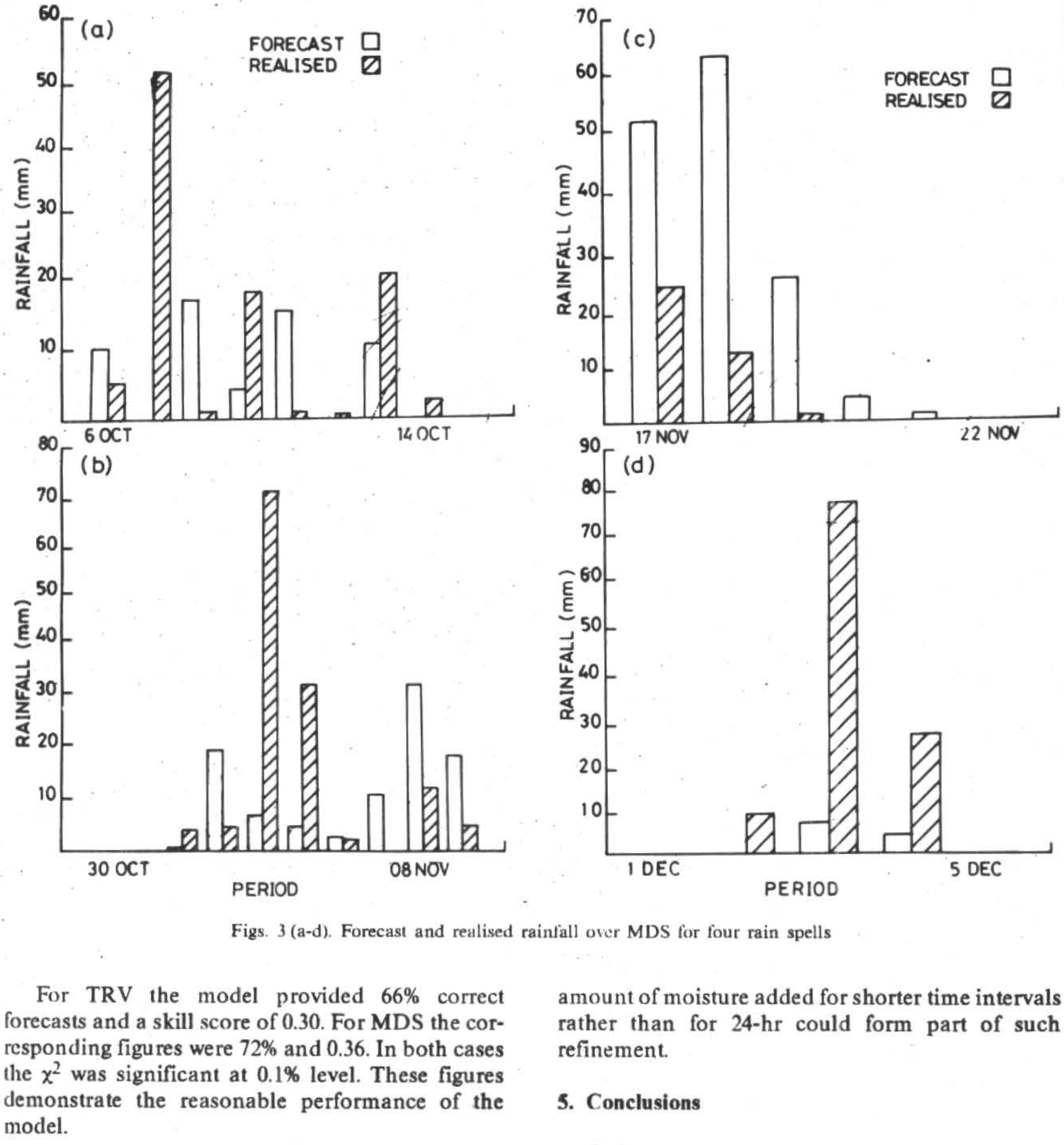
the days of 7-12 August and on 30 September. On several other days they were satisfactory though on some days they were wrong.

4.1.2. *For Madras October-December 1992*

During 1992 the northeast monsoon set in over Madras on 2 November. Fig. 3 presents the forecast and realised — rainfall during four rain spells, *viz.*, 6-14 October and 30 October-8 November, 17-22 November and 1-5 December. By and large the pre-onset rainspell during October has been predicted satisfactorily. The commencement of rains at the time of north-east monsoon onset has been predicted very well. A brief spell of rain during December has been correctly predicted in so far as occurrence despite difference in the amounts.

4.2. *Evaluation of forecasts*

To have an overall assessment of the forecasting capability of the model, the performance of the QPF models for MDS and TRV were evaluated by designating the forecast and realised-rainfall for a day as 'Rain' (R) day if the rainfall is atleast 2.5 mm and as 'No rain' (NR) day if otherwise. The forecast and realised rainfall figures were categorised as R and NR for all the days. The forecast contingency tables were constructed and hence the skill scores and χ^2 values for 'no relation' computed as defined in Panofsky and Brier (1958). Table 1 presents the details.



Figs. 3 (a-d). Forecast and realised rainfall over MDS for four rain spells

For TRV the model provided 66% correct forecasts and a skill score of 0.30. For MDS the corresponding figures were 72% and 0.36. In both cases the χ^2 was significant at 0.1% level. These figures demonstrate the reasonable performance of the model.

Though the basic model described in section 2 is quite sound in theory, its application requires incorporating several assumptions. Considering that QPF is a difficult problem, the realisation of satisfactory results and the modest success of the model could be of interest. It should be possible to obtain better results from further refinement of the model. Deriving and using a much more accurate vertical velocity profile, using PE values of better objectivity and stepwise computation of amount of moisture added for shorter time intervals rather than for 24-hr could form part of such refinement.

5. Conclusions

Daily rainfall forecasts have been computed for Thiruvananthapuram and Madras for the southwest and northeast monsoon seasons of 1992, using a QPF model based on the concept of conservation of specific humidity. The model yielded satisfactory forecasts.

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