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AN OPERATIONAL MEDIUM RANGE LOCAL WEATHER FORECASTING SYSTEM DEVELOPED IN INDIA

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ABSTRACT

A forecasting system for objective medium range location specific forecasts of surface weather elements was evolved at the National Centre for Medium Range Weather Forecasting (NCMRWF). The basic information used for this is the output from a general circulation model (GCM). The two essential components of the system are statistical interpretation (SI) forecast and direct model output (DMO) forecast. These are explained in brief. The SI forecast is obtained by using dynamical-statistical methods like model output statistics (MOS) and the perfect prog method (PPM) in which prediction of upper air circulation from a GCM around the location of interest is used. The DMO forecast is obtained from the prediction of surface weather elements from the GCM. The procedure for preparation of final forecast by using these two components and prevailing synoptic conditions is also explained. This is essentially a man–machine-mix approach. Finally, an evaluation of the forecast skill for the 1996 monsoon and some of the future plans are presented. Copyright © 2000 Royal Meteorological Society.

KEY WORDS: local weather forecasting; India; medium range; general circulation model

1. INTRODUCTION

Surface weather elements like cloud amount, rainfall, maximum temperature, minimum temperature, wind speed and wind direction play an important role in agriculture and other economic activities in India. Historically, the weather forecast in India was mainly issued in qualitative terms with the help of conventional methods using satellite data and synoptic information about the location of interest. As these forecasts are subjective and cannot be used for risk assessment in quantitative terms, the work of developing an objective medium range local weather forecasting system was begun for the first time in India at NCMRWF. An R-40 general circulation model (GCM) with a resolution of 2.5×2.5 was installed for this purpose in 1989. Later on, a T-80 GCM with a higher resolution of 1.5×1.5 was made operational in 1993.

An objective forecast is a forecast which does not depend on the subjective judgement of the person issuing it. Strictly speaking, an objective forecasting system is one which can produce one and only one forecast from a specific set of data. The objective forecast for the above surface parameters is directly obtained from the GCM operational at NCMRWF and is called the direct model output (DMO) forecast. As this forecast has some drawbacks, a second type of objective forecast is obtained by using the dynamical-statistical methods. In this, a forecast for upper air circulation from the GCM is used and is termed the SI forecast. Then, the final local weather forecast for these parameters is obtained by using information from these two types of objective forecasts and the prevailing synoptic situation around the location of interest. Although the process of the preparation of the final local weather forecast is a man–machine-mix approach, the final forecast is issued as definite quantitative values and hence one can

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say, partially, that the final local weather forecast issued from NCMRWF is objective. The final forecast was issued from NCMRWF on 23 March 1991; since then the procedure has evolved over the years. In the present paper, the local weather forecasting system based upon the T-80 model and using statistical interpretation (SI) of the NWP model output is presented. This forecasting system is currently being used for issuing the operational local weather forecast to various agro-advisory service (AAS) units.

In the subsequent sections the different steps involved in the operational local weather forecasting system is presented and in order to assess the skill of the system, the verification results for the 1996 monsoon are also described.

Section 2 describes the first approach in which the forecast of the important surface weather elements is directly obtained from the NWP model and is called the DMO. In the second approach, discussed in Section 3, the forecast for the surface weather elements is obtained by SI of the NWP model output. SI forecast is obtained only for three parameters, viz. maximum temperature, minimum temperature and rainfall during monsoon and winter seasons. Section 4 discusses in detail the man–machine-mix approach used for preparation of the final local weather forecast to be disseminated to field units, hereafter referred to as the final forecast. Section 5 describes the evaluation of the forecast and conclusions and future plans are given in Section 6.

2. DMO FORECAST

The forecast values for different surface and upper air weather elements can be obtained at the 256×128 Gaussian grids of the T-80 model. The longitudinal distance between any two grid points is 1.40625° while the latitudinal distance varies from 1.38847 to 1.40021°. Forecast values are available at each time step which is 15 min. Hence, for a particular day, 96 forecast values are obtained and the model is run for 5 days starting from 00 GMT initial conditions. Fifteen stations during monsoon season and five stations during winter season (Figure 1) are considered for obtaining different types of forecasts and finally, the local weather forecast.

2.1. Model output

From 256×128 Gaussian grids of the T-80 model, an Indian window of size (25×25) covering India is considered, starting from 38.52° latitude and 66.09° longitude to 4.90° latitude and 99.84° longitude. The model output is then obtained at each time step at these 625 grid points for the following six surface weather elements: (i) surface pressure (mb); (ii) rainfall rate (mm/s); (iii) zonal wind component (at 10 ft or 3.048 m) (m/s); (iv) meridional wind component (at 10 ft or 3.048 m) (m/s); (v) temperature (at 4.5 ft or 1.3716 m) (°C); (vi) specific humidity (g/g).

2.2. Nearest grid and interpolated forecast values

As the forecasts are obtained at Gaussian grids and not at a particular location, the simplest way to get a forecast at a specific location is to use the interpolated value from the four grid points surrounding it. But if the location is very near to a grid point, then the forecast at that grid point can also be taken as the forecast for the location. In order to decide as to which forecast among the two should be given more weighting for a location, it is necessary to know the distance of the location from the four grid points surrounding it. If the distance of the location from the nearest grid is less than one-fourth of the diagonal distance between any two grid points, then more importance is given to the nearest grid forecast values otherwise the interpolated value is considered (Figure 2).

2.3. DMO forecast

DMO forecast values of both types, i.e. nearest grid and interpolated, for each location of interest are obtained. A four-day forecast for the following parameters is obtained by using forecast values at each

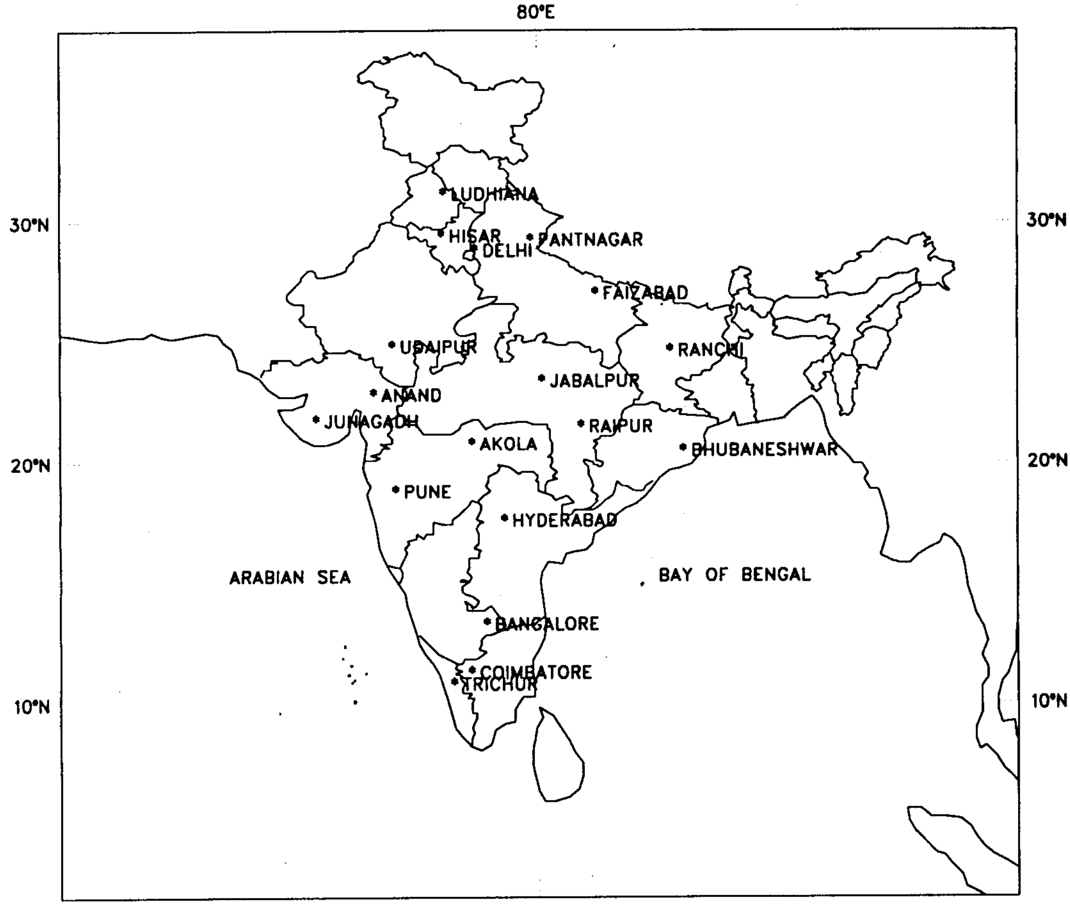

Figure 1. Map of India showing the stations considered in the study

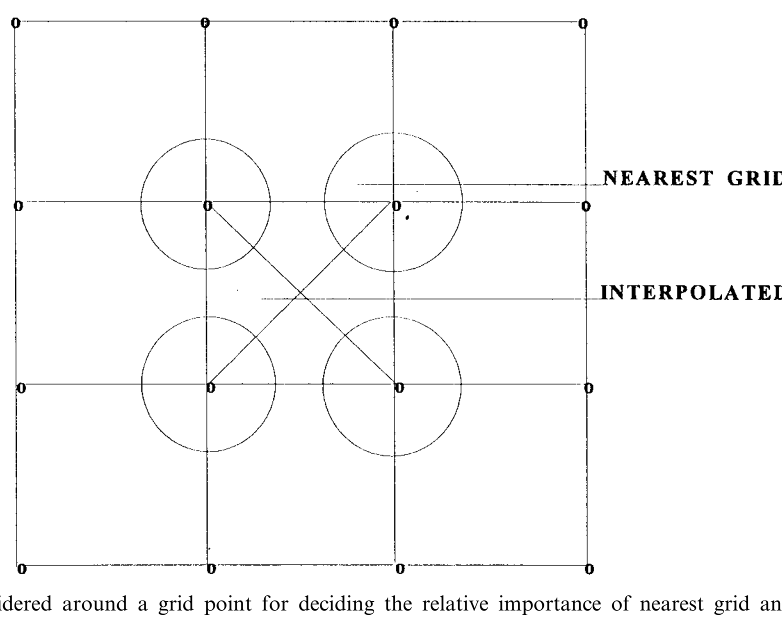

Figure 2. Area considered around a grid point for deciding the relative importance of nearest grid and the interpolated DMO forecast values for a particular location

time step of 15 min: (i) average mean sea level pressure (MSLP); (ii) cloud amount (morning and evening); (iii) rainfall (24 h accumulated); (iv) maximum temperature; (v) minimum temperature; (vi) average wind speed; (vii) predominant wind direction; (viii) maximum relative humidity; (ix) minimum relative humidity.

Here, the validity of the forecast values for a particular day is for the subsequent 24 h starting from 03 GMT (08:30 h) of that day. As at NCMRWF the T-80 model is run only for 5 days based on 00 GMT analysis, hence only the 24, 48, 72 and 96 h forecasts are obtained. For maximum and minimum temperatures the trends from 24 to 48, 48 to 72 and 72 to 96 are also obtained. In order to have the correct assessment of the predominant wind direction, the wind direction for a particular day is divided into eight classes and the frequency of each class is obtained. The forecast values are shown in the first two columns of the forecasting table (Table II) prepared for each statistic.

2.4. Bias free DMO forecast

For getting bias free DMO forecasts during any season, the forecast and observed values of the predictand during the recent one or two seasons are considered and correction factors are obtained by a trial and error method so that the skill of the forecast is maximized. The same correction factors are used while obtaining the bias free DMO forecast during the current season. During the present study, correction factors are calculated based upon the monsoon season (June–September) of 1994 and 1995 and the winter season (December–February) of 1993–1994 and 1994–1995. The same correction factors are used for obtaining bias free forecasts during the 1996 monsoon and winter 1995–1996, which is used for the evaluation of the forecast skill.

2.4.1. Bias free rainfall forecast. For rainfall the optimal threshold value is set so as to maximize the skill score. The optimal threshold value means that if the forecasted rainfall amount is less than the threshold then the forecasted value is taken as zero, otherwise it is taken as the forecasted rainfall amount. After deciding about the rainy or non-rainy days, a regression is fitted based upon the last one or two seasons in order to correct the rainfall amounts.

2.4.2. Bias free temperature forecast. For temperature, the bias is removed on the mean error, thereby keeping the original temperature trends unchanged. The mean error (ME) is calculated as follows:

$$\mathrm{ME} = \bar{f} - \bar{x},$$

where $\bar{f}$ is the mean of forecasted values and $\bar{x}$ is the mean of observed values during the previous seasons. This value of ME is added to the forecasted values in order to get the bias free forecast during the current season. This method is followed for both maximum and minimum temperature.

3. SI FORECAST

3.1. SI approach

Surface weather elements like rainfall, maximum temperature and minimum temperature are highly dependent on local topographic and environmental conditions. As in NWP models and particularly in GCM it is very difficult to include each and every aspect of these local conditions at all the locations, the DMO forecast obtained from NWP models may have problems. But upper air circulation at a specific location is not so dependent on local conditions and can be obtained from the analysis or forecast of a GCM easily. Moreover, uncertainties involved in the relationships between the circulation and surface weather can be formally expressed by a suitable statistical relation for a particular location. Hence, a statistical relation developed between upper air circulation around the location of interest and observed values of the surface weather element at the location, by using carefully chosen predictors and suitable statistical techniques, will account for the effect of these local conditions. This indicates that the SI forecast so obtained will have better skill as compared to the DMO forecast. Basically two methods are used for the SI forecast. These are the perfect prog method (PPM) (Klien *et al.*, 1959) and the model output statistics (MOS) (Glahn and Lowry, 1972).

In the PPM approach, a statistical relation is derived that relates large sample of observed surface elements (predictands) to concurrent observed surface and upper air reports, i.e. analysis (predictors). In order to get a forecast for the appropriate valid time, values of the predictors obtained from NWP models are substituted in the relation developed. This approach assumes that the model forecasts are 'perfect'. Hence, this approach has the disadvantage that it does not account for systematic biases and errors of the model. This problem can be solved by using the unbiased model forecast, which can be obtained just on the basis of model analysis and forecast data for the last 1 or 2 months. A major advantage of this method is that stable forecasting relations can be derived from a long period of record. Its forecast improves as the NWP model forecast is improved.

In the MOS approach, a statistical relation is developed using the observed surface weather elements (predictands) and the NWP model forecasts for upper air circulation variables (predictors). As such, a separate MOS relation is developed for a particular day forecast. To make operational forecasts, MOS relations are usually applied to the same dynamical model that provided the developmental sample. It has the advantage that MOS relations account for some of the biases and systematic errors found in the NWP model. A disadvantage of this technique is that the model output data are required for a sufficiently longer period so as to derive a stable relation. Hence, it cannot be applied immediately when a new NWP model is made operational. Also, if the NWP model undergoes a major change, the MOS relations will have to be developed again.

3.2. Data

In order to cover all types of variability for a season, at least 5–6 years of data are required (Carter, 1986). As sufficient data are not available from the NWP model operational at NCMRWF, the PPM models are developed for 15 stations during the monsoon season and five stations during the winter season by using 6 years (1985–1990) of analysis data obtained from the ECMWF. The data used are at a 2.5×2.5 latitude–longitude grid. The period of the monsoon season is taken as June–August or June–September depending upon the location of the station and for the winter season it is taken as December–February.

Predictands chosen for development of the PPM models are the observed values of quantitative precipitation (QP), probability of precipitation (PoP), maximum temperature and minimum temperature. Due to high variability in the distribution of rainfall values the model is developed by taking the cube root of QP. PoP values are obtained from the observed rainfall values as 1 for a rain case and 0 for a no rain case.

Forty-seven meteorological parameters are chosen as a possible set of predictors (Table I), these include basic analysis fields such as geopotential height, temperature, u-component and v-component of wind, vertical velocity and relative humidity at 1000, 850, 700 and 500 hPa. Besides these fields, many other derived weather parameters obtained by using the known meteorological relations are also considered. These derived parameters include vorticity, advection of vorticity, temperature gradient, advection of temperature, advection of temperature gradient, thickness, MSLP, 1000–500 hPa, precipitable water (PPW), saturation deficit (SD) and rate of change of moist static energy (RMSE).

Rainfall reported at 03 GMT on a particular day is the accumulated rain in the past 24 h. Similarly, maximum and minimum temperatures recorded at 03 GMT on a particular day pertains to the past 24 h. On the other hand the predictor values are available only at 00 GMT and 12 GMT. Keeping the above facts in mind, the reference times at which the predictors are to be considered for different predictands are: (i) 00 GMT of the same day for minimum temperature; (ii) 12 GMT of the previous day for maximum temperature; (iii) 00 GMT of the same day, 12 GMT of the previous day and average of the two for rainfall (QP and PoP).

A 'day' in this case is the calendar date on which the 24-h rainfall is reported (Figure 3). This means that there are 47 predictors each for maximum and minimum temperatures and 141 (47×3) predictors for rainfall.

Table I. Meteorological parameters considered as possible predictors

Serial no.	Parameter	Level (hPa)
1	Mean relative humidity	1000–500
2–5	Relative humidity	1000
		850
		700
		500
6–9	Temperature	1000
		850
		700
		500
10–13	Zonal wind component	1000
		850
		700
		500
14–17	Meridional wind component	1000
		850
		700
		500
18–21	Vertical velocity	1000
		850
		700
		500
22–25	Geopotential	1000
		850
		700
		500
26	Saturation deficit	1000–500
27	Precipitable water	1000–500
28	MSLP	—
29–30	Temperature gradient	850–700
		700–500
31–32	Advection of temperature gradient	850–700
		700–500
33–36	Advection of temperature	1000
		850
		700
		500
37–40	Vorticity	1000
		850
		700
		500
41–44	Advection of vorticity	1000
		850
		700
		500
45	Thickness	850–500
46	Horizontal water vapour flux div.	1000–500
47	Rate of change of moist static energy	1000–500

3.3. Forecast equations

Development of forecast equations involves two major steps. The first step is the interpolation of predictor fields to the station location and the second step is the development of multiple regression equations through a screening procedure. Since the predictors are available at a regular ($2.5° \times 2.5°$) grid and the stations are located irregularly, the predictor field ought to be interpolated to the station location.

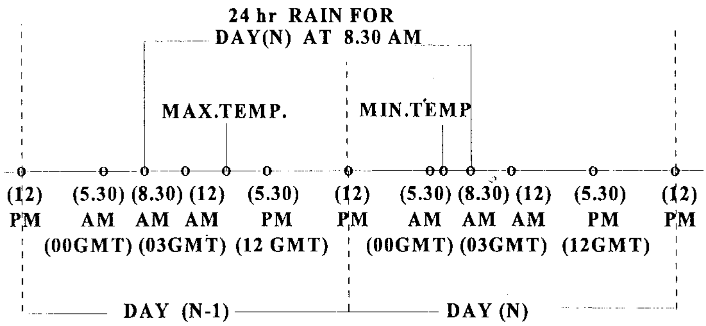

Figure 3. Reference time for predictors

3.3.1. Predictor's value at the station location. The value of a particular predictor at a station is obtained by using the values of that predictor at the nine grids surrounding the station (Figure 4) (Woodcock, 1984). This is achieved by employing canonical correlation (Rousseau, 1982). In this technique the first canonical variate, which is the best linear combination of the values of a predictor at the nine grid points that has maximum correlation with the predictand, is taken as the value of a particular predictor at the station. These canonical variates are found for each of the predictors to give a new set of potential predictors.

3.3.2. Predictors selected. Predictors that explain most of the variance are selected from the set of all potential predictors by using a stepwise selection procedure. In this procedure, selection of predictors is terminated if the new candidate predictor contributes less than a critical value to the percentage of variance explained by the predictors already selected (Tapp *et al.*, 1986). In order to have a significant percentage of variance explained by the predictors selected and to have less noise in the predictions, this critical value is taken as 1.0% for maximum/minimum temperature and PoP and 0.5% for QP (Kumar and Maini, 1993, 1996).

Generally two to three variables are selected for prediction of maximum temperature in which the 1000–500 hPa saturation deficit and 850 hPa temperature are the most important predictors. In the case of minimum temperature three to seven variables are selected and the 850 hPa temperature and 850–500 hPa thickness are generally selected. Five to ten variables are selected for PoP and five to fourteen variables are selected for QP. The mean relative humidity and the 850 hPa meridional wind component play an important role in case of both PoP and QP. The 850 hPa vorticity is also an important variable in the prediction of QP. An almost similar trend is noticed in the variables selected as predictors both for the monsoon and winter seasons.

These selected predictors are then used for developing the PPM models. Simple linear regression equations of the form (1) are obtained relating one predictand to the set of selected predictors:

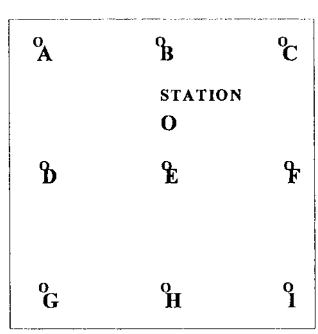

Figure 4. The grids considered around a station for canonical variates

$$Y = a_0 + a_1X_1 + a_2X_2 + \cdots + a_nX_n, \tag{1}$$

where a_is are the multiple regression coefficients and X_is are the values of the predictors at the station. Here Y provides the predicted value of predictand for a given set of predictors. These equations are developed for each season for a given station.

3.4. SI forecast

For obtaining the SI forecast from these PPM models, the post-processed output at the same resolution, i.e. (2.5×2.5), from the NWP model operational at NCMRWF is used. Earlier, the R-40 model with a resolution of (2.5×2.5) was operational at the centre (Kumar and Maini, 1996). Later in 1993, the T-80 model with higher resolution was made operational. Hence, the post-processed output of the T-80 model is used here.

The SI forecast for 24, 48, 72 and 96 h is obtained for maximum and minimum temperature, QP and PoP by substituting the X_is in Equation (1) by the respective forecast values from the operational NWP model output.

Hence

$$Y_{24} = a_0 + \sum_{I=1}^{n} a_iX_i, \tag{2}$$

where n is the number of selected predictors. Similarly Y_{48}, Y_{72} and Y_{96} are also obtained.

3.5. Bias free SI forecast

As the PPM model equations are developed based upon ECMWF analysis and SI forecast is obtained using the T-80 model forecast, the forecasts so generated have an inherent bias. For getting a bias free SI forecast during any season, the forecasted and observed values of the predictand during the recent one or two seasons are considered and correction factors are obtained by the trial and error method so that the skill of the forecast is maximized. The same correction factors are used while obtaining the SI forecast on an operational basis during the current season. Data used for SI forecast bias correction are for the monsoon season (June–September) of 1994 and 1995 and the winter season (December–February) of 1993–1994 and 1994–1995. The same correction factors are used for obtaining bias free forecast during the 1996 monsoon and winter 1995–1996.

3.5.1. Rainfall forecast bias. For QP, the optimal threshold value is set so as to maximize the skill score. The optimal threshold value implies that if the rainfall amount is less than the threshold then QP is taken as zero otherwise it is taken as the forecasted value. After deciding about the rainy or non-rainy days, a regression is fitted based upon the last one or two seasons in order to correct the QP amounts. For PoP a constant factor is added to the forecasted probability, so that skill scores for PoP and also for the yes/no forecast derived from it, get maximized. The yes/no forecast from probability is derived by using the criterion that if PoP is less than 0.5 then it is considered as a no rain case otherwise it is considered as a rain case.

As the forecasting system for PoP and the yes/no forecast has been found to have desirable skill (Kumar *et al*., 1999), for obtaining the SI rainfall forecast, the forecast obtained from QP equations has been modified by giving more weight to the PoP forecast, while deciding the rainy or non-rainy days. Hence, if the PoP is greater than or equal to 0.5 and QP is zero, the forecasted rainfall value of QP is set to 0.1 and if PoP is less than 0.5 and QP is not zero, then the forecasted rainfall value of QP is set to zero (Tapp *et al*., 1986). If the PoP is greater than or equal to 0.5 and QP is some positive quantity, then the forecasted rainfall value is equal to the forecasted value of QP.

3.5.2. Temperature forecast bias. In the case of temperature forecasts, bias is removed based on mean error, which is calculated by using the previous seasons data. This is done so that original temperature trends remain unchanged. The ME is calculated as follows:

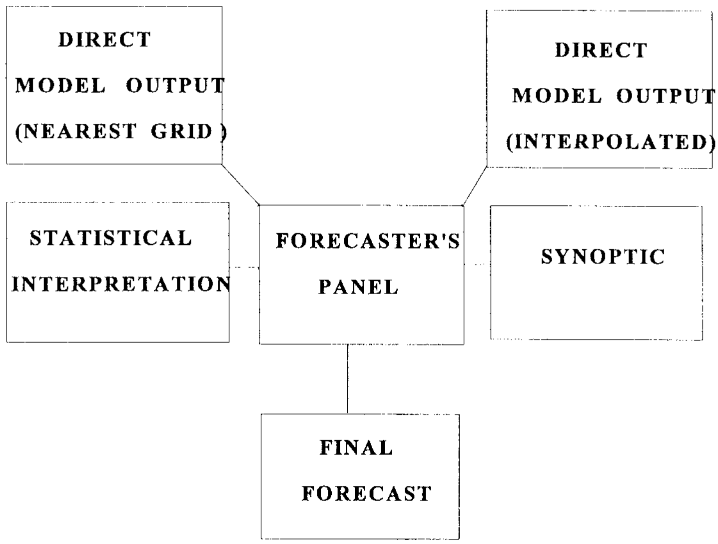

Figure 5. An integrated scheme for preparation of local weather forecast (man–machine-mix approach)

$$ME = \bar{f} - \bar{x},$$

where $\bar{f}$ is the mean of the forecasted values and $\bar{x}$ is the mean of the observed values during the previous season. This value of ME is added to the forecasted temperature values in order to get bias free forecasts during the current season. This method is followed both for the maximum and minimum temperature.

4. FINAL FORECAST

The forecasting system for preparation of the final forecast is essentially a man–machine-mix approach (Figure 5). It has the following important constituent forecasts: (i) DMO (nearest grid); (ii) DMO (interpolated); (iii) SI.

The forecasters panel studies all these objective forecasts and depending upon the current synoptic situation, the forecast is given for different weather parameters for a particular location.

For this purpose a table is designed, as mentioned earlier, which is produced along with the operational run of the NWP model at NCMRWF. This table is location specific and the first three columns contain the three types of objective forecasts. The fourth column is left blank in order to give comments about the synoptic situation by the synoptician and in the fifth column the final forecast is given by the forecasters panel. As PPM models are developed for monsoon and winter seasons only, the SI forecast is used in forecasting the maximum and minimum temperature and the rainfall during the monsoon and winter season only. Trends in maximum and minimum temperature values are also obtained for DMO and SI. The final forecast is prepared for the next 3 days by using the 48, 72 and 96 h forecasts obtained from the NWP model, as is clear from the sample table (Table II).

At present, the final forecast is being prepared for the following weather elements for the next 3 days at 24 h intervals starting at 08:30 h: (i) average cloud amount (okta); (ii) accumulated rainfall (mm); (iii) average wind speed (km/h); (iv) predominant wind direction (°); (v) maximum temperature trend (°C); (vi) minimum temperature trend (°C).

Maximum and minimum temperature forecasts are derived by adding the trends to the base value, i.e. today's temperature. This is done at the user's end.

Table II. Forecast table

Serial no.	Weather parameters	DMO (interpolated). Altitude: 44 m				DMO (nearest grid point)[a]: 28.72°N, 77.34°E. Altitude: 19 m				SI				Synoptic			Final		
		15 Aug 24 h	16 Aug 48 h	17 Aug 72 h	18 Aug 96 h	15 Aug 24 h	16 Aug 48 h	17 Aug 72 h	18 Aug 96 h	15 Aug 24 h	16 Aug 48 h	17Aug 72 h	18 Aug 96 h	16 Aug 24 h	17 Aug 48 h	18 Aug 72 h	16 Aug 24 h	17 Aug 48 h	18 Aug 72 h
1	MSLP (hPa)	1002	1002	1002	1001	1002	1002	1002	1001										
2	Cloud cover (okta)																		
	E	7	1	5	3	7	1	5	3								6	6	8
	M	4	2	5	3	4	2	5	3										
3	Probability of precipitation									0.81	0.80	0.77	0.72						
	Precipitation (mm)	2.4	11.1	11.9	25.6	1.2	11.6	13.3	27.2	1.1	1.7	1.2	2.0				10	15	20
	PPM equation precipitation									1.1	1.7	1.2	2.0						
4	Wind speed (km/h)	6	7	7	8	6	7	7	8								5	5	6
5	Wind direction (°)	128	157	201	214	124	157	201	210								250	250	240
6	Maximum temperature (°C)	32.0	32.9	31.5	32.8	31.7	32.7	31.3	32.5	30.7	31.0	31.2	31.3				1	−1	1
			0.9	−1.4	1.3		1.0	−1.4	1.2		0.3	0.2	0.1						
7	Minimum temperature (°C)	25.5	25.5	25.4	25.1	25.3	25.4	25.3	25.0	24.5	24.1	25.4	25.8				0	0	0
			0.0	−0.1	−0.3		0.1	−0.1	−0.3		−0.4	1.3	0.4						
8	Relative humidity maximum (%)	98	97	100	100	98	97	100	100										
9	Relative humidity minimum (%)	67	63	70	70	68	64	71	71										
10	Wind direction frequency																		
	0–45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										
	45–90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										
	90–135	55.2	7.3	0.0	0.0	59.4	7.3	0.0	0.0										
	135–180	44.8	89.6	18.7	0.0	40.6	92.7	19.8	0.0										
	180–225	0.0	3.1	69.8	59.0	0.0	0.0	68.7	65.6										
	225–270	0.0	0.0	11.5	40.6	0.0	0.0	11.5	34.4										
	270–315	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										
	315–360	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										

Station: Delhi; position code: NG; coordinates: 28.58°N, 77.20°E; altitude (model topography): 19 m; altitude: 229 m; distance from nearest grid: 22.00 km; date: 16 August 1996; time: 03 GMT; based upon 00 GMT analysis for 15 August 1996.

[a] More weight to be given as compared with other type of DMO.

5. EVALUATION OF THE FORECAST

For the evaluation of the forecast skill different skill scores are calculated for the bias free DMO and SI forecasts and also for the final forecast. This study is carried out for 15 stations during the 1996 monsoon and five stations during winter 1995–1996.

For the rainfall forecast the ratio score and Hanssen and Kuiper's (HK) score are calculated for a 2×2 contingency table between the forecast and observed rain situations, the ratio and HK scores are defined as follows:

Forecasted	Observed	
	Rain	No rain
Rain	YY	NY
No Rain	YN	NN

$$\text{HK score} = \frac{YY*NN - YN*NY}{(YY + YN)*(NY + NN)},$$

$$\text{Ratio score} = (YY + NN)/(YY + YN + NY + NN).$$

The ratio score describes the success rate of the correct forecast, where as the HK score describes the ability to discriminate between rainy and non-rainy days. The value of the HK score varies from '-1' to '$+1$'. If the forecasts are incorrect, that is $YY = NN = 0$, then the HK score equals -1. If forecasts are perfect, that is $YN = NY = 0$, then the HK score equals $+1$. Correlation (CORR) and root mean square error (RMSE) is calculated for the maximum and minimum temperature.

Table III. (a) Skill scores for rainfall, winter (December–February) 1995–1996; (b) skill scores for maximum temperature, winter (December–February) 1995–1996; (c) skill scores for minimum temperature, winter (December–February) 1995–1996

Station	SI		DMO		Final	
	Ratio	HK	Ratio	HK	Ratio	HK
(a)						
Delhi	82	0.55	87	0.22	90	0.25
Ludhiana	69	0.56	77	0.31	78	0.16
Hisar	78	0.58	90	0.33	97	—
Bhubaneshwar	77	0.28	92	0.45	95	—
Raipur	80	0.47	83	0.51	99	0.99
(b)	CORR	RMSE	CORR	RMSE	CORR	RMSE
Delhi	0.65	2.37	0.57	2.90	0.55	2.50
Ludhiana	0.61	2.15	0.50	2.56	0.37	2.60
Hisar	0.76	2.07	0.64	2.39	0.54	2.29
Bhubaneshwar	0.77	1.43	0.79	1.72	0.67	1.77
Raipur	0.58	2.08	0.65	2.22	0.66	1.91
(c)						
Delhi	0.43	2.68	0.65	2.47	0.74	2.09
Ludhiana	0.52	3.10	0.53	3.43	0.57	2.99
Hisar	0.41	3.74	0.43	2.81	0.27	3.85
Bhubaneshwar	0.65	2.27	0.61	2.77	0.59	2.75
Raipur	0.60	2.50	0.58	2.70	0.60	2.46

Table IV. (a) Skill scores for rainfall, monsoon (June–August) 1996; (b) skill scores for maximum temperature, monsoon (June–August) 1996; (c) skill scores for minimum temperature, monsoon (June–August) 1996

Station	SI		DMO		Final	
	Ratio	HK	Ratio	HK	Ratio	HK
(a)						
Akola	67	0.26	61	0.27	58	0.27
Anand	68	0.32	56	0.16	65	0.36
Bangalore[a]	61	0.24	53	0.08	55	0.12
Coimbatore[a]	57	0.33	48	0.20	63	0.23
Delhi	67	0.36	72	0.44	59	0.21
Faizabad	59	0.21	56	0.22	64	0.37
Hyderabad[a]	59	0.16	50	0.07	55	0.17
Jabalpur	64	0.29	56	0.11	72	0.40
Junagadh	61	0.34	58	−0.16	78	0.48
Ludhiana	65	0.34	70	0.36	58	0.22
Pantnagar	79	0.57	76	0.43	74	0.41
Pune[a]	69	0.11	55	0.07	68	0.15
Ranchi[a]	57	0.14	50	0.00	52	0.05
Trichur[a]	75	0.46	63	0.15	75	0.30
Udaipur	67	0.25	53	0.08	59	0.21
(b)	CORR	RMSE	CORR	RMSE	CORR	RMSE
Akola	0.84	2.33	0.76	2.78	0.83	2.32
Anand	0.78	2.63	0.81	2.48	0.77	2.69
Bangalore[a]	0.65	1.65	0.59	2.31	0.64	1.92
Coimbatore[a]	0.70	1.63	0.74	1.87	0.52	2.42
Delhi	0.62	3.08	0.63	3.39	0.68	2.84
Faizabad	0.71	2.92	0.77	3.07	0.77	2.65
Hyderabad[a]	0.76	2.35	0.71	2.91	0.77	2.65
Jabalpur	0.89	2.44	0.89	2.54	0.89	2.49
Junagadh	0.70	2.41	0.69	2.31	0.72	2.27
Ludhiana	0.42	3.50	0.50	3.51	0.48	3.29
Pantnagar	0.38	3.20	0.46	3.19	0.54	2.98
Pune[a]	0.82	1.87	0.84	1.79	0.80	1.97
Ranchi[a]	0.50	2.17	0.56	2.16	0.60	2.06
Trichur[a]	0.64	1.80	0.67	1.68	0.62	1.82
Udaipur	0.80	2.69	0.84	2.56	0.83	2.53
(c)						
Akola	0.67	1.29	0.46	1.61	0.63	1.38
Anand	0.52	1.49	0.50	1.69	0.45	1.74
Bangalore[a]	0.65	0.88	0.57	0.94	0.47	0.95
Coimbatore[a]	0.37	1.31	0.26	1.28	0.25	1.45
Delhi	0.26	2.36	0.14	2.62	0.21	2.34
Faizabad	0.62	1.87	0.56	1.80	0.68	1.70
Hyderabad[a]	0.34	2.18	0.40	2.13	0.35	2.12
Jabalpur	0.81	1.26	0.57	1.97	0.76	1.42
Junagadh	0.53	1.16	0.63	1.14	0.48	1.39
Ludhiana	0.41	2.27	0.23	3.22	0.25	2.71
Pantnagar	0.14	2.58	0.40	2.43	0.37	2.26
Pune[a]	0.74	1.01	0.74	1.05	0.73	1.05
Ranchi[a]	0.50	2.17	0.27	1.50	0.40	1.35
Trichur[a]	0.50	1.03	0.51	1.01	0.44	1.09
Udaipur	0.55	2.34	0.54	2.48	0.54	2.40

[a] The monsoon season for the stations is June–September.

Skill scores of the comparative study conducted during winter 1995–1996 are shown in Table III(a), (b) and (c) and for the 1996 monsoon scores are shown in Table IV(a), (b) and (c). The study reveals that the skill of the SI and final forecasts is better than the DMO forecast for most of the stations during the monsoon season and for more than half of the stations during the winter season. This indicates that the SI and final forecast improves upon the DMO forecast.

It can also be noted that the skill of the SI forecast is comparable to that of the final forecast for most of the stations and even better for more than half of the stations. The graphical representation of the scores is given in Figures 6 and 7, which also shows that the skill of the SI forecast is comparable and even better in many stations as compared with the final forecast and the SI and final forecast is a definite improvement over the DMO forecast for most of the stations.

Evaluation of the SI and final forecast prepared over the period of the past 4 or 5 years, has shown that the skill of the forecast is considerably good. For rainfall, the ratio score varies from 55% to 80% and the HK score varies from 0.1 to 0.6 during the monsoon season and in the winter season ratio score varies from 60% to 90% and the HK score from 0.2 to 0.6. Similarly, correlation of the order of 0.3 to 0.7 for the minimum temperature and 0.5 to 0.8 for the maximum temperature is attained.

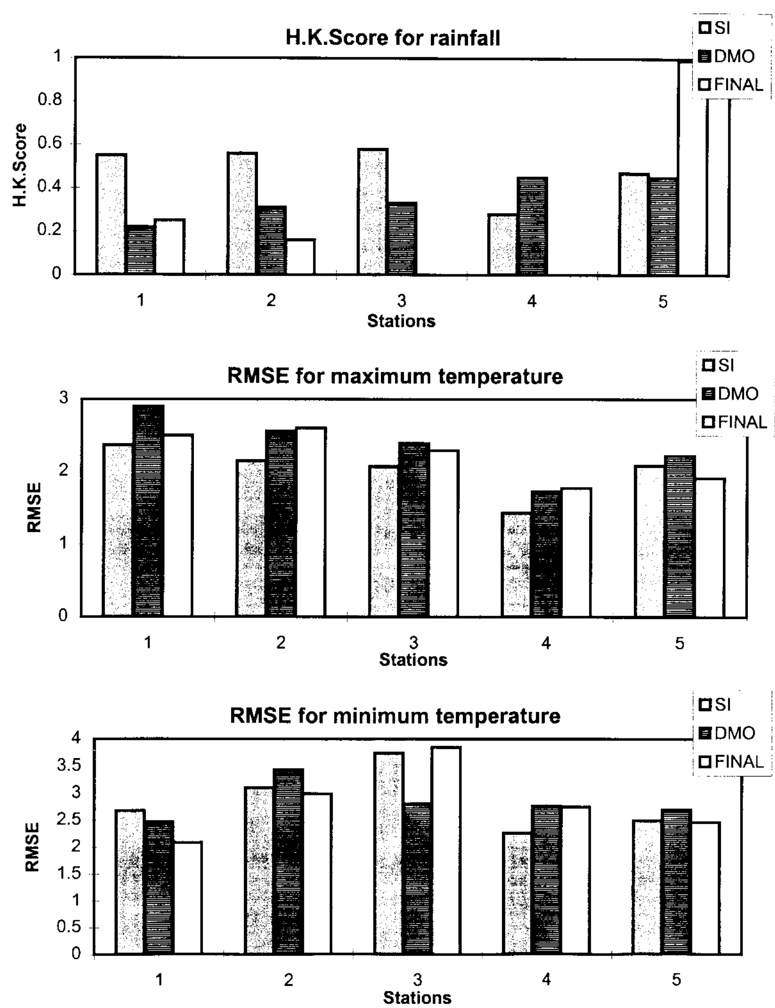

Figure 6. Skill scores during winter 1995–1996 for the stations, viz. 1. Delhi, 2. Ludhiana, 3. Hisar, 4. Bhubaneshwar, 5. Raipur

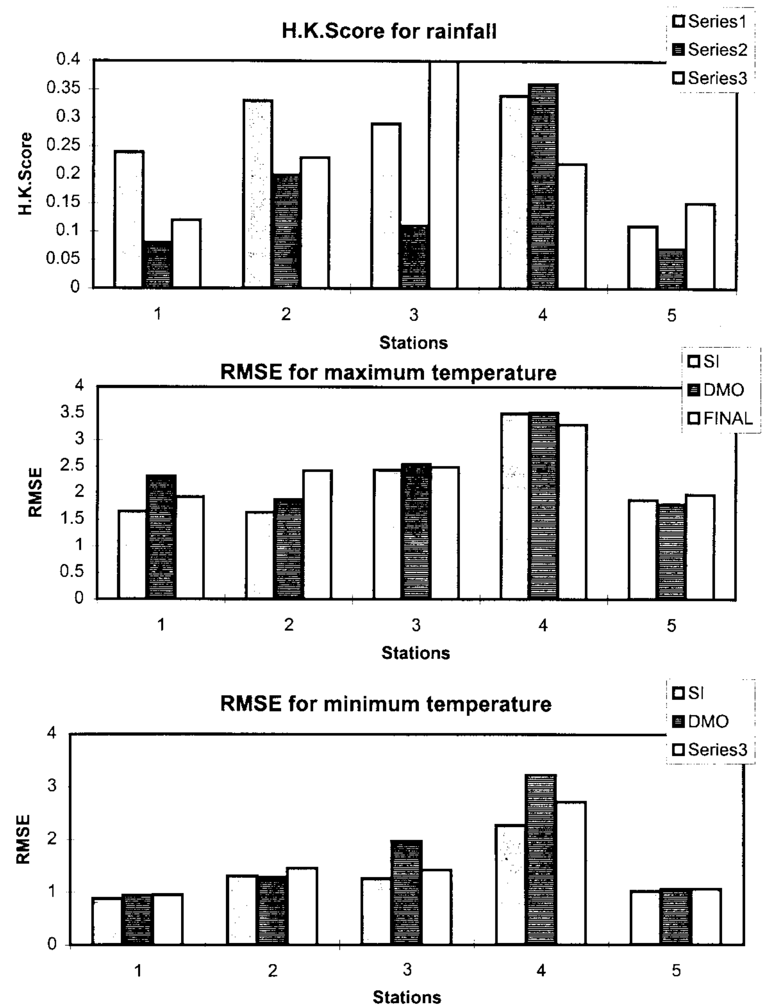

Figure 7. Skill scores during the 1996 monsoon for the stations, viz. 1. Bangalore, 2. Coimbatore, 3. Jabalpur, 4. Ludhiana, 5. Pune

6. CONCLUSIONS AND FUTURE PLANS

Evaluation studies on the skill of the DMO and the SI forecast over the period of the past 4 to 5 years have shown that the skill of the SI and final forecasts have definitely improved upon the DMO forecast and the skill of the SI forecast is comparable for most of the stations and even better for more than half of the stations as compared with the final forecast. But still, full confidence is not there in the SI forecast system, so in order to consider all variability and unusual weather cases, the man–machine-mix approach for issuing the final operational weather forecast is still being followed.

Hence, efforts will be made in order to improve upon the DMO and the SI forecast so that the final forecast is improved. And if the skill of the SI forecast is improved up to the level that it could be issued as a final forecast with full confidence, then it may be developed as a fully automatic operational weather forecasting system. An expert system using both type of forecasts, viz. DMO and SI, may be developed, in which both types of forecasts are combined as per their skill in order to have better skill, as each type of forecast has a skill to contribute, which may be further used as an automatic operational weather forecasting system.

For improvement of the DMO forecast, efforts will be made to improve the operational NWP model and the regional model. A better approach and more suitable data will be considered for improvement in the SI forecast. Better statistical techniques will also be tried in order to improve the SI forecast. A more appropriate method for getting a bias free forecast will be developed by using the Kalman filter and neural network techniques.

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