Statistical model-based forecast of minimum and maximum temperatures at Manali

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Various types of avalanches frequent northwest Himalayan regions during winter months. Winter season over this region is frequented by westward-moving weather systems called western disturbances (WDs). These weather systems yield enormous amount of precipitation. Knowledge of minimum and maximum temperatures during winter months is very useful for assessing human and natural hazards. Models for forecasting minimum and maximum temperatures have been developed for Manali in Himanchal Pradesh, for the months of December, January and February. These models are based on statistical techniques and use surface and upper air meteorological data from 1984 to 1989. The models are also tested with independent data and the results for 1995–96 are presented. The models yield good results with independent cases providing about 88% correct forecast within ± 2°C of the observed values.

MANALI in Himachal Pradesh is located at an altitude of 2192 m and is a representative station of glaciated region during winter months from the avalanche point of view. It experiences most of its annual precipitation during winter months (December to February). Most of the winter precipitation at Manali and its neighbourhood comes in the form of solid precipitation, i.e. snow. Moreover, this region is also frequented by cold-wave conditions during winter months, that may hamper many of the outdoor activities, including public utility services and also lead to acute human discomfort and sometimes loss of human lives too. Intense low minimum temperatures may lead to ground frost conditions and sometimes to low-level inversions. Knowledge of minimum temperature is helpful in assessing cold conditions in northwest India, which will help the public/residents and defence personnel deployed at forward areas at large. Prediction of maximum temperature is useful for avalanche threat assessment and also to understand snow-melt processes taking place within the snow pack and hence sintering processes among snow crystals within snow layers, which ultimately lead to avalanche release.

In India, various authors have carried out studies on minimum and maximum temperatures[1,2]. WMO[3], Kendall and Stuart[4] and Panofsky and Brier[5] provide detailed description of various forecasting techniques based on statistical methodology, including the widely-used technique of multiple regression analysis. Klien and Hammons[6] suggested many predictors for prediction of maximum/minimum temperature. Singh and Jaipal[7], Mohan *et al.*[8], Raj[9], Charantoris and Liakatas[10], Vashisth and Pareek[11] and Gupta and Jayanti[12] have studied minimum temperature forecasts employing various techniques, including Markov chains. Attri *et al.*[13] have used multiple regression method for forecasting minimum temperature at Gangtok, in Sikkim, a hill station located close to the glaciers and snow-covered areas in northeast India. Mohanty *et al.*[14] have developed a statistical model for prediction of minimum temperature during winter and maximum temperature during summer at Delhi.

Multiple linear regression is used to develop prediction models for minimum and maximum temperatures. It works best for continuous weather elements. In meteorological applications of regression, there is usually more than one potential predictor, and the procedure is generalized to find the best overall linear-fit among all the predictors and the weather element. The output is a set of coefficients. In this study, using past historical data, an attempt has been made to develop a deterministic statistical model for forecasting minimum and maximum temperatures at Manali, 24 h in advance.

In order to obtain a reliable forecast, surface data of stations all around Manali are considered for the study. Simultaneously, upper-air meteorological variables are also considered. For developing the forecast models for predicting minimum and maximum temperatures, five-year data (1985–89) for the months of December, January and February (DJF) in Manali and neighbouring stations, have been utilized. The performance of the model was evaluated with independent data set of DJF 1995–96. Statistical technique-based model development needs a continuous set of data for a considerable period for prediction[15]. Since Manali is located in a mountainous and data-sparse region, very few data sets are available. The above-mentioned data sets are found to be continuous in the mountainous region and are therefore considered for the study.

In the formulation of the model equations for minimum and maximum temperatures, surface observations corresponding to 0830 and 1730 IST and the upper-air observations corresponding to 0530 and 1730 IST are utilized. Twenty-four hour lead-time has been chosen for issuing the forecasts. The 24 h forecast of minimum and maximum temperatures is issued at 0830 IST (0300 UTC), which is valid for the next day. All the data taken for model development are recorded before the time of issue of the forecast.

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Table 1. List of potential predictors and their notations used in the study

Predictor	Station	Time	Total
Surface			
Dry bulb (TT) and dew point (TD) temperature, saturation mixing ratio (r_s) mixing ratio (r), dew point depression (DPD), relative humidity (rh), wind direction (dd) and speed (ff) at surface, U and V components of wind dry bulb difference (ΔTT), dew point temperature difference (ΔTD), average dry bulb temperature (avTT), average dew point temperature (avTD) between Patiala and Delhi	Patiala and Delhi	00 and 12 GMT	48
Upper air			
Dry bulb (TT) and dew point (TD) temperature, saturation mixing ratio (r_s), mixing ratio (r), dew point depression (DPD), relative humidity (rh), direct wind shear (WS), speed shear (SS), U and V components of shear (Us and Vs) between various hPa levels, potential temperature difference (Δq) between various hPa levels, mean of relative humidity (rh), mean of saturation mixing ratio (r_s), mean of mixing ratio (r) between various hPa levels, dry bulb temperature (ΔTT) difference between various hPa levels, wind direction (dd) and speed (ff), U and V components of wind at hPa levels, dry bulb and dew point temperature difference (ΔTT), average dry bulb (avTT) and average dew point temperature (avTD) between Patiala and Delhi at various hPa levels	Patiala and Delhi	00 and 12 GMT	358
Surface parameters			
Maximum and minimum temperature (T_{max} and T_{min}), dry bulb temperature, wind speed and wind direction, snow surface temperature	Kanzalwan, Haddan Sonamarg, Gulmarg, Manali	03 GMT	30
Persistence			
Minimum (maximum) temperature on the previous day of forecast (T_{min-1}/T_{max-1})	Manali	03 GMT	01
Total number of predictors			437

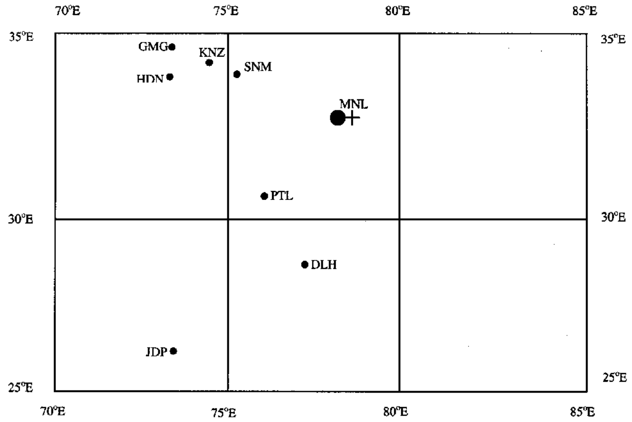

Figure 1. Location of station considered for study and data. +, Selected place of study; HDN, Haddan Taj; JDP, Jodhpur; KNZ. Kanzalwan; PTL, Patiala; GMG, Gulmarg; DLH, Delhi; SNM, Sonamarg; MNL, Manali.

Table 2. Statistics of minimum and maximum temperatures using data from 1984 to 1989

	Minimum	Maximum
Mean	0.97	13.94
Standard deviation	2.93	3.60
Highest	15.0	22.0
Lowest	–9.0	0.0
Range	24.0	22.0

During data selection in the present study, stringent standard quality control checks are implemented. In the process of checking the quality of the data, space, time and synoptic condition, consistency checks are used. The individual data gaps were filled up by using linear interpolation of the previous and subsequent observations of meteorological parameters. The data selected for the study consist of past surface and upper-air data at Manali (the location selected for the development of the model), and the surrounding stations at Patiala, Jodhpur, Delhi, Haddan, Kanzalwan, Gulmarg and Sonamarg. The geographic locations of these stations are shown in Figure 1. The list of potential predictors and their notations used in this study is given in Table 1.

To understand the variation in minimum and maximum temperatures, climatological study is carried out. This is done by establishing the nature of distribution of temperature and its relationship with the potential predictors. Developmental sample is used to establish the climatological characteristics.

The frequency distribution of minimum temperature is given in Figure 2, which indicates that it is close to the normal distribution with a slight skewness to the left. Sample statistics are given in Table 2. Average temperatures during DJF are studied and it is found that lowest minimum temperature occurs mostly around 0700 IST. There are some rare occasions when lowest

Table 3. Minimum temperature forecast model: equation, predictor and reduction of variance

24 h forecast issued at 0830 IST
Equation:

$$Y = -14.2921 + (0.31519*A1) + 0.081139*A2) + (0.329523*A3) - (0.063776*A4) - (0.027843*A5) - (0.029767*A6) - (0.109458*A7) + (0.136247*A8) + (0.017019*A9) + (0.07951*A10)$$

Sl. no.	Predictor	Time	Level	Place	Correlation	VE	CVE
A1	$T_{\min}$	0830 IST	Surface	Manali	+0.61	36.88	36.88
A2	TT	0530 IST	700 hPa	Patiala	+0.58	10.4	47.28
A3	avTT	1730 IST	Surface	Patiala and Delhi	+0.44	2.47	49.75
A4	V	0530 IST	850 hPa	Patiala	–0.17	2.05	51.80
A5	rh	1730 IST	850 hPa	Patiala	–0.19	1.76	53.56
A6	U	1730 IST	500 hPa	Delhi	–0.28	1.34	54.90
A7	Δq	0530 IST	Surface and 500 hPa	Patiala	–0.35	1.11	56.01
A8	$T_{\min-1}$	0830 IST	Surface	Manali	+0.49	1.07	57.08
A9	Us	0530 IST	300 and 500 hPa	Delhi	+0.27	0.97	58.05
A10	ΔTT	0530 IST	700 and 300 hPa	Delhi	+0.43	0.91	58.96
						MCC = 0.77	

VE, Variance explained; CVE, Cumulative variance explained; MCC, Multiple correlation coefficient.

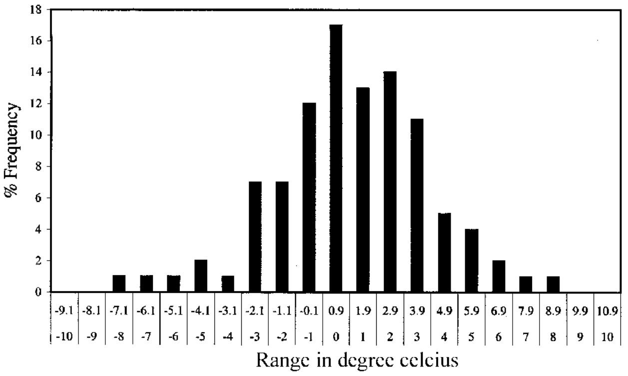

Figure 2. Frequency distribution of minimum temperature (DJF 1984–89).

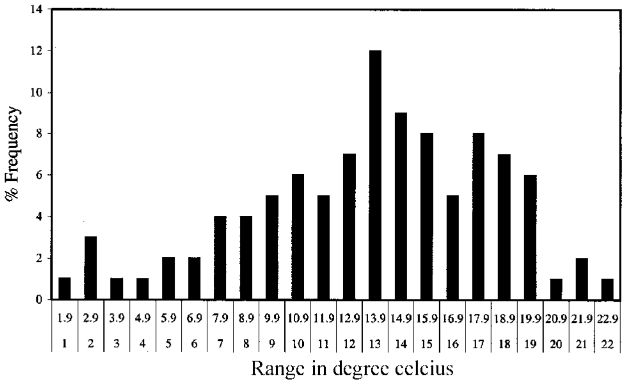

Figure 3. Frequency distribution of maximum temperature (DJF 1984–89).

minimum temperature was recorded at different times also. These were either due to strong inversion or due to clearing of an overcast sky. Correlation of minimum temperature with dry bulb temperature, U and V components of wind and relative humidity of various places during the previous 24 h are given in Table 3. These show that minimum temperature is positively correlated with dry bulb temperature and previous day's minimum temperature. Positive correlation with previous day's minimum temperature shows the persistence of minimum temperature. As shown in Table 3, minimum temperature was negatively correlated with zonal component of wind at Delhi, which indicates that higher values of minimum temperatures are associated with easterly winds (U negative), while a lower minimum temperature is associated with the westerly component of the wind (U positive). Similarly, relative humidity is negatively correlated with minimum temperature.

In most of the analysis, minimum temperatures are associated with synoptic weather systems. Arrival of the western disturbance (WD) over northwest India is significantly known on the basis of fluctuating behaviour of certain meteorological parameters. Due to passage of WD general increase in dry bulb and dew point temperature takes place, winds mainly turn from westerly to easterly to southerly, which mainly leads to general rise in minimum temperature. After the passage of the system the sky becomes clear, dry bulb and dew point temperatures decrease, winds become cold and dry and thus leading to decrease in minimum temperature.

The distribution of maximum temperature during DJF is shown in Figure 3. It is seen that maximum temperature has distribution with skewness to the left. This shift towards the left is mainly due to high values of maximum temperature, which occur during a passage of the system. The sample statistics is given in Table 2. Temperature during DJF months is examined and it is found that maximum temperature occurs between 1430 IST (0900 UTC) and 1730 IST (1200 UTC).

Table 4. Maximum temperature forecast model: equation, predictor and reduction of variance

24 h forecast issued at 0830 IST
Equation:
$Y = 5.6249 + (0.7717*A1) - (1.8383*A2) - (0.0253*A3) - (0.2508*A4) + (0.0142*A5) - (0.0938*A6) + (0.1523*A7) - (0.7189*A8) - (0.1039*A9) + (0.0028*A10)$

Sl. no.	Predictor	Time	Level	Place	Correlation	VE	CVE
A1	T_{max}	1730 IST	Surface	Manali	+0.85	71.63	71.63
A2	r	1730 IST	500 hPa	Patiala	–0.17	1.98	73.61
A3	rh	0530 IST	500 hPa	Delhi	–0.41	1.05	74.66
A4	TD	0530 IST	700 hPa	Patiala	–0.08	1.03	75.69
A5	dd	0530 IST	500 hPa	Delhi	+0.19	0.98	76.67
A6	DPD	0530 IST	850 hPa	Delhi	–0.30	0.92	77.59
A7	ΔTT	0530 IST	500 and 400 hPa	Patiala	+0.23	0.56	78.15
A8	r	0530 IST	700 hPa	Patiala	–0.02	0.52	78.67
A9	ΔTT	0530 IST	Surface and 900 hPa	Delhi	–0.33	0.49	79.16
A10	dd	1730 IST	700 hPa	Patiala	+0.03	0.48	79.64
						MCC = 0.88	

VE, Variance explained; CVE, Cumulative variance explained; MCC, Multiple correlation coefficient.

To understand the relationship between maximum temperature and other surface parameters, correlation studies were carried out with synoptic observation made during the previous 24 h. The results are presented in Table 4. The maximum temperature has positive correlation with persistence with maximum temperature and negative correlation with dew point temperature and relative humidity. Negative correlation with relative humidity mainly indicates that advection or incursion of moisture may result in cloud formation and hence reduction of maximum temperature. As far as winds are concerned, maximum temperatures are positively correlated with wind direction. Increase in westerly wind leads to increase in maximum temperature and vice versa.

Like the minimum temperature, the maximum temperature over northwest India is also associated with synoptic systems. During the passage of the WD, the dew point temperature and humidity increase and the winds at the surface and in the lower tropospheric levels become easterlies, resulting in a reduction of maximum temperature. After the passage of the WD the sky becomes clear, the winds become westerlies to northwesterlies, humidity and dew point temperature fall and hence the maximum temperature increases.

The climatological study shows that over the selected place of study, the minimum and maximum temperatures are linked with synoptic systems and the correlation studies clearly indicate the effect of movement of such weather systems across the station.

In order to provide a short-range, location-specific deterministic prediction of minimum and maximum temperatures, statistical methods are used. The relation is expressed as:

$$Y_t = f[X_0],$$

where Y_t is the estimate (forecast) of the predictand (minimum or maximum temperature) at time t and X_0 is a vector of observational data at time ‘0’ (observations are not necessarily made at time ‘0’, but must be made available at that time). A multiple regression analysis approach is used to formulate minimum and maximum temperature prediction equations separately. A total of 437 predictors consisting of surface, upper air and derived parameters are used to develop multiple regression equations (Table 1).

As a first step all the predictors are put up for screening in the forecast of minimum and maximum temperatures. Out of these potential predictors some are intercorrelated. Hence, only those predictors are identified which explain most of the variance of the predictand. Forward stepwise selection procedure is used for selecting the best potential predictors. As a result, only significant predictors are selected which contain practically all the linear predictive information of the entire set with respect to a specific predictand and satisfy a statistical significance test. Fisher’s F-test is utilized to select significant predictors at the 95% confidence level. The stepwise procedure continues by adding one predictor at a time to the model. This procedure terminates when the new predictor fails to reduce the variance at least by 0.5% or does not satisfy statistical significance at the prescribed 95% confidence level. In this procedure, ten predictors have been retained into the final multiple regression equations for prediction of minimum and maximum temperatures.

Models developed for minimum and maximum temperatures are tested with independent data set of DJF 1995–96.

Table 5. Error analysis and skill score for minimum temperature (24 h forecast)

Error range	Development data (DJF 1984–89)	Test data (DJF 1995–96)
0.0–1.0	256 (71%)	65 (71%)
1.1–2.0	61 (17%)	16 (18%)
2.1–3.0	29 (08%)	08 (09%)
3.1–4.0	03 (01%)	02 (02%)
4.1–5.0	07 (02%)	–
≥ 5.1	05 (01%)	–
Total	361 (100%)	91 (100%)
ABS	1.37	1.01
RMS	1.87	1.46
P-ABS	1.80	1.51
P-RMS	2.59	1.94
SKILL (%)	48	43
CC	0.77	0.79

ABS, Absolute error; RMS, Root mean square error; P-ABS, Absolute error assuming persistence; P-RMS, RMS error assuming persistence; SKILL, Skill score; CC, Correlation coefficient.

Table 6. Error analysis and skill score for maximum temperature (24 h forecast)

Error range	Development data (DJF 1984–89)	Test data (DJF 1995–96)
0.0–1.0	223 (62%)	58 (64%)
1.1–2.0	93 (26%)	20 (22%)
2.1–3.0	36 (10%)	12 (13%)
3.1–4.0	09 (02%)	01 (01%)
4.1–5.0	–	–
≥ 5.1	–	–
Total	361 (100%)	91 (100%)
ABS	1.36	1.32
RMS	1.68	2.37
P-ABS	1.59	1.96
P-RMS	2.0	2.70
SKILL (%)	29	23
CC	0.88	0.87

In Tables 5 and 6, the skill scores for forecast are estimated as

$$\text{Skill score} = \left[1 - \frac{\text{RMSE}_{\text{m}}^{2}}{\text{RMSE}_{\text{p}}^{2}}\right] 100\%,$$

where RMSE_{m} and RMSE_{p} stand for rmse of the model prediction and the persistence, respectively. A positive value of skill score stands for a better performance of the model over persistence, while a negative value of skill score indicates that the model does not have skill even to match the persistence. Though there are few occasions with the forecast errors of minimum/maximum temperature exceeding 3°C, the skill score given in Tables 5 and 6 clearly indicate that the developed equations have positive skill and perform better than the persistence with independent data sets.

Table 7. Persistence: change in observed minimum temperature in 24 h

Error range	Development data (DJF 1984–89)	Test data (DJF 1995–96)
0.0–1.0	165 (45.7%)	42 (46.2%)
1.1–2.0	98 (27.1%)	23 (25.3%)
2.1–3.0	39 (10.8%)	12 (13.2%)
3.1–4.0	30 (8.3%)	8 (8.8%)
4.1–5.0	15 (4.2%)	4 (4.3%)
≥ 5.1	14 (3.9%)	2 (2.2%)
Total	361 (100%)	91 (100%)

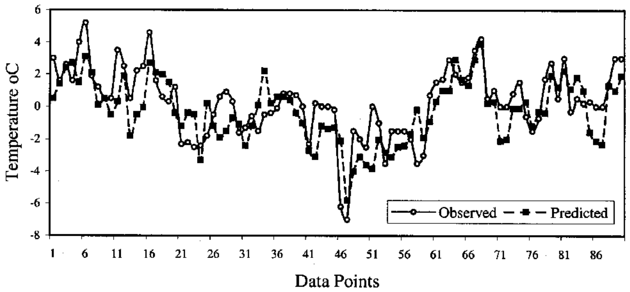

Figure 4. Observed and 24 h forecast minimum temperature for DJF 1995–96.

Twenty-four hour minimum temperature forecast along with the actual values for DJF 1995–96 are given in Figure 4. The model responds quite well to the variation of minimum temperature. Some of the extreme values of minimum temperature are not predicted quite well. The error analysis of the forecasts for both the developmental sample and the independent data sets is given in Table 5. From Figure 4 and Table 5 it is found that 71% of the forecast is correct within ± 1°C and about 98% of the forecast is within ± 3°C of the actual values with independent data set. Further, persistence of minimum temperature is studied to see its effect on model predictions and is represented in Table 7. It shows the ± 1°C, ± 2°C, …, ≥ ± 5°C absolute changes in observed minimum temperature in the next 24 h for developmental sample and the independent data sets. It is observed that there are days when absolute change in persistence of minimum temperature was more than ± 5°C. Even with a variation of this degree, the model could inherit a variable nature of this kind while making the predictions.

Large deviations between observed and predicted values are studied in detail for the independent data set. For example on 12 December 1995, minimum temperature observed was 3°C, the value of 24 h forecast was 0.3°C. Hence 24 h forecast error was 2.7°C. On analysis it is found that a weak the WD had passed just before that day. After the passage of the WD, the sky became clear and hence drop in minimum temperature had taken place. The cloud amount and type, not included as forecast elements in the equation, might have caused the large deviation. Similarly, on 15 January 1996 to 17 January 1996, the deviations between observed and forecast values are 3.6°C, 2.4°C and –3.0°C, respectively. Analysis during this period shows that a strong WD remained active over the region and gave considerable precipitation. Due to overcast sky and continued intermittent precipitation, general increase in minimum temperature is recorded. Thus the large deviation has taken place. Sometimes, weather changes which have taken place within 24 h, which is the lead time of forecast, cannot be taken care of in the model and hence they make considerable impact on model capabilities.

Similarly, all departures of more that ± 3°C were investigated. In most of the cases it was found that the rapid movement of synoptic systems are associated with precipitation, thunderstorm, etc. which passed across the station in a time-frame less than the selected range of forecast (24 h), and resulted in sudden change in certain predictors of the forecast equations which led to such large deviations. Further analysis of forecast and actual values for 1995 indicates that day-to-day minimum temperature variations are quite homogeneous in nature as indicated in root mean square error (rmse) values assuming persistence alone. Thus the performance of the forecast equation with the independent data set of 1995 is found to be better than the development sample.

Twenty-four hour maximum temperature forecast along with actual values for DJF 1995–96 are given in Figure 5. Once again, it is found that the model responds quite accurately to the actual variations in maximum temperature. The error analyses for the forecast of both dependent and independent data sets are given in Table 6. It is found that 64% forecast is correct within ± 1°C, whereas 99% forecast is correct within ± 3°C of the actual value with the independent data set. Persistence of maximum temperature is studied to see its effect on model predictions as shown in Table 8. It shows the ± 1°C, ± 2°C, …, ≥ ± 5°C absolute change in observed maximum temperature in the next 24 h for the developmental sample and the independent data set. It is observed that there are days when persistence change is more than 5°C.

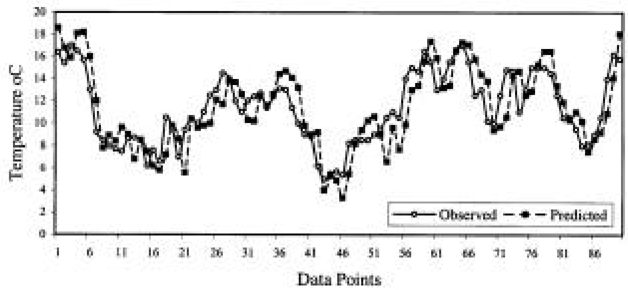

Figure 5. Observed and 24 h forecast maximum temperature for DJF 1995–96.

Table 8. Persistence: change in observed maximum temperature in 24 h

Error range	Development data (DJF 1984–89)	Test data (DJF 1995–96)
0.0–1.0	173 (48%)	45 (49.5%)
1.1–2.0	92 (25.5%)	22 (24.2%)
2.1–3.0	35 (9.7%)	9 (9.8%)
3.1–4.0	37 (10.2%)	11 (12.1%)
4.1–5.0	15 (4.1%)	2 (2.2%)
≥ 5.1	9 (2.5%)	2 (2.2%)
Total	361 (100%)	91 (100%)

As was found for minimum temperature, there are days when forecasts deviated by more than 3°C even on a timescale of 24 h. Analysis of these large errors reveals that very rapid and large but sudden changes in predictors could be responsible for the large departures. Such changes are mainly attributed to rapid movement/intensification of the synoptic systems associated with precipitation or thunderstorm, which in turn sharply change the value of certain predictors of the forecast equations. For example, on 8 December 1995, the observed maximum temperature was 13°C. The 24 h forecast for this was 16°C. Thus the 24 h forecast deviated by 3°C. Analysis of the data reveals that on that particular day, precipitation had taken place in the morning. This resulted in the actual maximum temperature being significantly lower than the forecast produced by the equation. Similarly, on 27 January 1996, observed maximum temperature is 13.2°C, whereas 24 h forecast is 9.9°C, thus the forecast deviated by 3.3°C. On investigation, it is found that rise in dry bulb temperature had taken place along with general decrease in mixing ratio at upper levels, hence resulting in forecast value being lower than the actual one. Further, on 14 February 1996, it was observed that forecast was away from the actual by 3.7°C. While investigating, it was observed that dew point depression on that particular day was high compared to both the previous and the next day. Dew point depression has a negative correlation with maximum temperature, which ultimately resulted in lowering of the actual maximum temperature.

Similarly, other cases of significant departure of forecasts are also examined that confirm the above reasoning. This indicates that large deviations are mainly associated with rapid changes in the predictors of the equation, which are within the 24 h scale. It was seen that due to significant changes in humidity and moisture increase on local basis within the observation period, maximum temperature changes are significant.

In this study minimum and maximum temperature forecast equations are developed based on multiple regression method and are tested with an independent data set. The following are the main conclusions drawn from the study.

(a) Minimum and maximum temperatures are well predicted by the forecast model equation, as in 60% of the cases the errors are within ± 1°C and about 98% of the cases are within ± 3°C, which is less than or equal to one standard deviation.

(b) Verification of the model equations indicates that in each of the cases there is definite positive skill in the forecast produced by the models over the persistence.

(c) On a few occasions, large deviations of the forecast are observed. These are mainly attributed to rapid movement of synoptic systems associated with precipitation.

In the present study, only historical data have been used to develop the statistical models. The model equations do not use the forecast parameters from Numerical Weather Prediction (NWP) models. It is possible to improve the forecast with incorporation of the NWP products. Further improvement can be achieved through incorporation of weather elements such as rain, thunderstorm, strong surface winds, etc. predicted by other methods in the present model equations. The process could reduce cases of large forecast errors of minimum/maximum temperature prediction associated with rapid movement/intensification of the synoptic systems.

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Intraspecific hybridization in *Pinus roxburghii* Sargent

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Inter-racial hybridization was performed successfully in *Pinus roxburghii* taking three different provenances, i.e. Pauri, Badiyargarh and Srinagar (locality-specific) at lower (900 m a msl) and higher (1900 m a msl) altitudes. The results revealed that cone and seed setting percentages in the selected provenances varied from 38.57 to 60.00% and 76.00 to 88.00% at the lower, and 36.00 to 58.33% and 68.00 to 84.67% at the higher altitudes, respectively. Controlled pollination resulted in enormous fertilization success, with no signs of incompatibility. Ovulate strobili remained receptive up to 5 days.

PINUS *roxburghii* Sargent in Silva N. Am. 2. 9. 1897 (Chir pine or Himalayan long-needle pine), a precious timber-resin resource, is native to the outer range and principal valleys of the Himalayas from Afghanistan to Arunachal Pradesh in north-eastern India between 450 and 2300 m altitude, where the full force of the monsoon is felt. It covers very large areas as pure forests and also with other species, particularly at its upper and lower limits. In *P. roxburghii*, natural variation is associated with the extremely diverse geographical regions in which it grows. It covers vast areas and is differentiated into many provenances and races. Each provenance is adapted to a distinct local climate, and also to altitudinal and latitudinal ranges. To exploit the natural variability, selection of desirable parents and crossing them in a desired way is a key step for any sound tree-improvement programme. However, intraspecific hybridization in chir pine has not yet been reported. Mirov[1] reported that turpentine composition of pine-species could be changed by intraspecific hybridization and its quality can be improved by breeding. In the present study an attempt was made to cross the three provenances of chir pine on lower (900 m a msl) and higher (1900 m a msl) altitudes, in order to evaluate the degree of success of racial hybridization in *P. roxburghii*.

This study was conducted during February and March 1999, when profuse flowering of female strobili occurred in the chir-pine forests of Pauri Garhwal (latitude 29°20′ to 30°15′N and longitude 78°10′ to 79°20′E) on two different altitudes, viz. Ashtavakra (900 m a msl) and Ransi (1900 m a msl), situated in the central part of western Himalaya.

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