Use of objective analysis to estimate winter temperature and precipitation at different stations over western Himalaya

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Temperature and fresh snow are essential inputs in an avalanche forecasting model. Without these parameters, prediction of avalanche occurrence for a region would be very difficult. In the complex terrain of Himalaya, nonavailability of snow and meteorological data of the remote locations during snow storms in the winter is a common occurrence. In view of this persistent problem present study estimates maximum temperature, minimum temperature, ambient temperature and precipitation intensity on different regions of Indian western Himalaya by using similar parameters of the neighbouring regions. The location at which parameters are required and its neighbouring locations should all fall in the same snow climatic zone. Initial step to estimate the parameters at a location, is to shift the parameters of neighbouring regions at a reference height corresponding to the altitude of the location at which parameters are to be estimated. The parameters at this reference height are then spatially interpolated by using Barnes objective analysis. The parameters estimated on different locations are compared with the observed one and the Root Mean Square Errors (RMSE) of the observed and estimated values of the parameters are discussed for the winters of 2007–2008.

1. Introduction

Northwest Himalayas are divided into three climatic zones – lower, middle and upper (Sharma and Ganju 2000) based on the average altitude of the mountain ranges, temperature and precipitation pattern. The snow climate of lower and middle climatic zones is similar to that of maritime and is characterized by mild temperatures and deep snow pack. The middle climatic zone has snow climate similar to that of continental snow climate and is characterized by very low temperature and shallow snow pack. The weather on various regions/road axes of Himalaya is monitored by various observatories in each of the regions. Continuous data observations at these observatories enable to predict weather as well as avalanche activities over the region on daily basis. During a severe storm because of the lack of data communication from some of the remote regions it becomes very difficult to predict weather as well as avalanche occurrence for those regions.

A few attempts are made so far over Himalaya for the prediction of weather parameters. Srinivasan *et al* (2005) predicted meteorological parameters for avalanche prediction on a 10 × 10 km resolution grid over northwest Himalaya. Though this mesoscale model gives a quantitative weather forecast, the information is not adequate to predict avalanches on a local scale since one grid point of this model covers larger area. Hence local scale avalanche/weather forecast need weather parameters on a finer resolution. Singh *et al* (2008) predicted snow and meteorological parameters for Stage II in the Pir-Panjal range of Indian Himalaya by using nearest-neighbour

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technique. This technique needs historical database and unable to capture the abrupt transition of the weather.

Meteorological parameters over complex terrain have been produced worldwide by various spatially distributed models. Liston *et al* (1999); Liston and Sturm (2002); Liston and Elder (2006) developed an intermediate complexity meteorological model (MicroMet) to produce high resolution (e.g., 30 m to 1 km horizontal grid increments) meteorological data distribution. Preliminarily undocumented and incomplete version of micromet have been used to distribute both the observed and modeled meteorological variables over complex terrain in Colorado, Wyoming, Idaho, Arctic Alaska, Svalbard, Central Norway, Greenland and Antarctica as a part of a wide variety of terrestrial modeling studies (e.g., Liston and Sturm 1998, 2002; Bruland *et al* 2004; Liston and Winther 2005).

Present study estimates temperature and precipitation intensity on various regions of Indian Himalaya by using Barnes (1973) objective analysis which is a convergent weighted averaging interpolation technique that can be used to obtain any desired amount of details in the analysis of a set of randomly spaced data. The practical limitations of the scheme are that the data distribution be reasonably uniform and that the data be accurate. The scheme is tested at various places over Indian Himalaya and compared the results with observations.

Many attempts in the past are made to improve the objective analysis scheme. The most successful attempt of doing this is a surface fitting scheme, i.e., the method of fitting a geometrical surface to the reported data and calculating the values determined by that surface at any other point of interest, specifically the grid points. The works of Dellert, Pieffer *et al* and of Penn *et al* (1963) are all based on that method. There are three major disadvantages for such methods: the calculations are complicated and require considerable time to complete; the data to which the surface is fitted are chosen in a rather artificial manner (that which produces the best results); the effect of erroneous data can be disastrous since each datum is given equal ranking in determining the shape of the surface. To cope up with this problem, a smoothing process has been recommended employing a least square fit of the surface to the data with the influence of each datum weighed according to its distance from the grid point. This weighted average method determines the value of the variable at grid points as the sum of weighted values of the individual data. The closer a data point to the grid point in question, the greater influence the datum at that point exerts. The main disadvantage of such schemes is their tendency to smooth out all small variations in the field, whether caused by data errors or actual atmospheric disturbances.

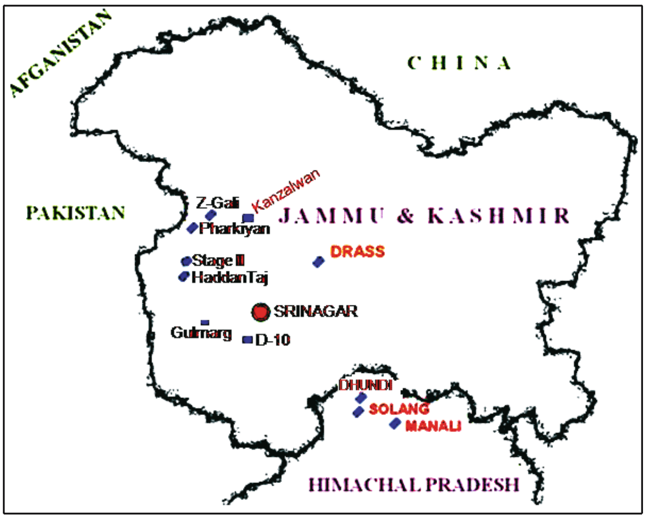

Figure 1. Study area and concerned locations.

2. Data and methodology

Database consists of a record of maximum temperature, minimum temperature, ambient temperature, fresh precipitation and duration of the precipitation for the winter 2007–2008. Precipitation intensity has been derived from fresh precipitation and its duration. The analysis involves the data recorded daily at 1730 h for the months of November, December, January, February, March, and April of the winter 2007–2008. Eleven of the observatories placed at different regions of western Himalaya are included in the analysis. The area of the study and the concerned observatories are shown in figure 1. The estimation of the parameters at a location involves the parameters of neighbouring observatories. The observatories, their altitude from mean sea level and their radius of influence are summarised in table 2.

The parameters at a location are estimated in two steps:

1) The parameters of neighbouring four observatories (except at Manali, Solang, Dhundi, and Drass where there are only two neighbouring observatories available) are brought to a reference height corresponding to the height of the location at which the parameters are to be estimated, and
2) the parameters at the reference height are then spatially interpolated to the desired location by using Barnes objective analysis.

Table 1. *Air temperature lapse rate variations for each of the months in Northern Hemisphere (Kunkel 1989), and precipitation elevation adjustment factors (Thornton et al 1997).*

	November	December	January	February	March	April
Air temperature lapse rate (°C km^{-1})	5.5	4.7	4.4	5.9	7.1	7.8
Precipitation adjustment factor (km^{-1})	0.30	0.35	0.35	0.35	0.35	0.30

2.1 *Barnes objective analysis*

The Barnes objective map analysis scheme is a computationally simple Gaussian weighted averaging technique which assigns a weight to a datum solely as a known function of distance between datum and grid point. The weight 'W' is assigned according to the distance 'd' between grid point and station as:

$$W = \exp\{-(d/R)^2\}, \tag{1}$$

where 'R' is the radius of influence.

The Barnes technique employs the method of successive corrections, applying two passes through the station data. Using the weighing function (equation 1) to assign a value to each grid point creates a first pass analysis field. During the second pass, a difference field is calculated that determines the residuals. The step by step procedure is explained below:

- An appropriate weight is chosen and an initial interpolation is performed. This is a 'first-guess' of the desired location and determined by:

$$X_g = \frac{(\sum W_i X_i)}{\sum W_i}. \tag{2}$$

- At each data point, subtract from the reported value the value obtained in the first guess analysis at that point.
- The smoothed field of difference values are determined by the interpolation of the 'first guess' values back to the original station and subtracting from the interpolated value using a correction weight parameter 'W'. Each correction step can be represented as:

$$X'_g = X_g + \frac{\sum W'_i (X_i - X_a)}{\sum W'_i}, \tag{3}$$

where,

$$W'_i = \exp\{-(d/R\beta)^2\}. \tag{4}$$

Table 2. *Altitude and radius of influence of different locations over the Himalaya.*

Locations in the northwest Himalaya	Altitude in meters (m.s.l.)	Radius of influence (km)
Manali	2192	12
Drass	3250	124
Stage II	2650	54
Haddan-Taj	3080	49
Gulmarg	2800	64
Pharkiyan	2960	32
Solang	2480	8
Dhundi	3050	12
Z-Gali	3192	49

The convergence parameter β ranges between 0 and 1. A value between 0.2 and 0.3 is generally assumed. Present study assumes a value of 0.25 for β.

The parameters (maximum temperature, minimum temperature, ambient temperature and precipitation intensity) are first estimated at a reference height using their lapse rates as discussed below:

2.2 *Temperature*

Earlier, point air temperature data were distributed spatially by using simple interpolation. While such methods work in flat terrain, they often misrepresent temperature distributions in areas having significant topographic variability. Recent studies have tried to improve the simulated temperature distributions by taking advantage of the strong temperature–elevation relationships that are known to exist. The station air temperature can be adjusted to a common level using the formula:

$$T_0 = T_{\mathrm{stn}} - \Gamma(Z_0 - Z_{\mathrm{stn}}), \tag{5}$$

where T_{stn} (°C) is the observed station air temperature at the station elevation, Z_{stn} (m); T_0 (°C) is the air temperature at the reference level, Z_0 (m) (sea level, $Z_0 = 0$); and the lapse rate Γ (°C/m), is given in table 1 and varies depending on the month of the year (Kunkel 1989).

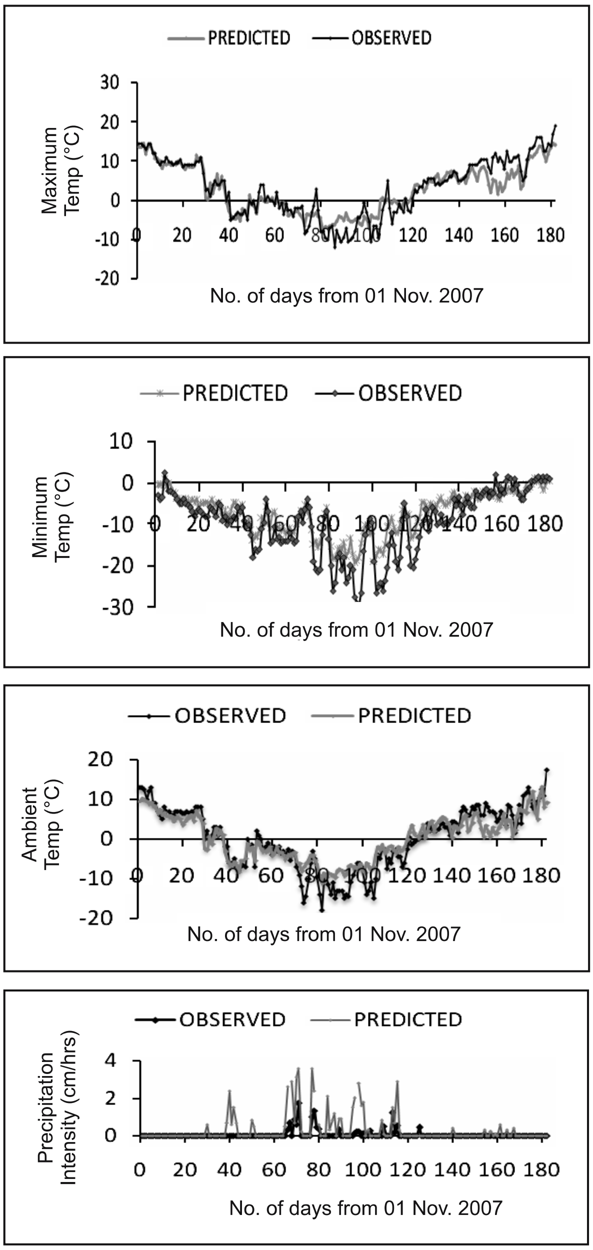

Figure 2. Observed and predicted parameters at Drass.

2.3 *Precipitation intensity*

The rate of precipitation, P, at a topographic reference surface is computed from

$$P = P_0 \left[\frac{(1+\eta(z-z_0))}{(1-\eta(z-z_0))}\right], \qquad (6)$$

where P_0 is the station precipitation, z_0 is the station elevation, and η (km^{-1}) is a factor (table 1) defined to vary seasonally (Thornton *et al* 1997).

After estimating the parameters at a reference height using above-mentioned lapse rates (equations 5 and 6) they are then spatially interpolated to the desired location by using Barnes objective analysis.

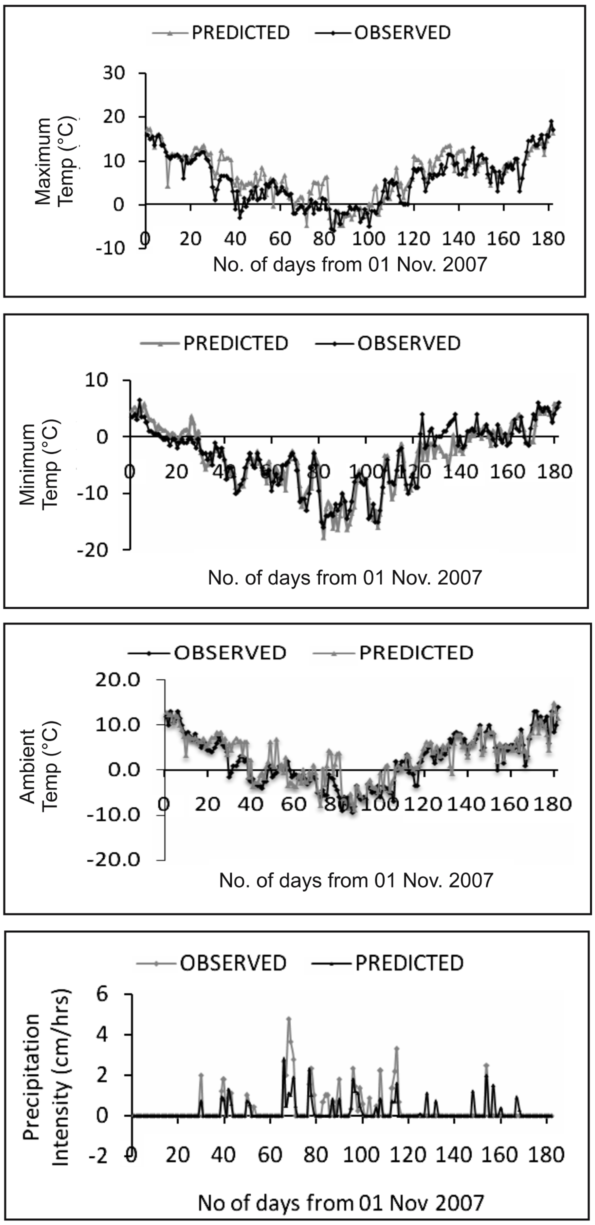

Figure 3. Observed and predicted parameters at Stage II.

3. Result and discussion

Maximum temperature, minimum temperature, ambient temperature and precipitation intensity computed for nine locations in the Himalaya have been compared with the observed one for the winter 2007–2008. The observed and predicted parameters of few of the stations (Drass, Stage II and Pharkiyan) have been plotted in figures 2, 3 and 4. The RMSE of the predicted parameters and their correlation (squared correlation) with the observed one have been summarised in table 3.

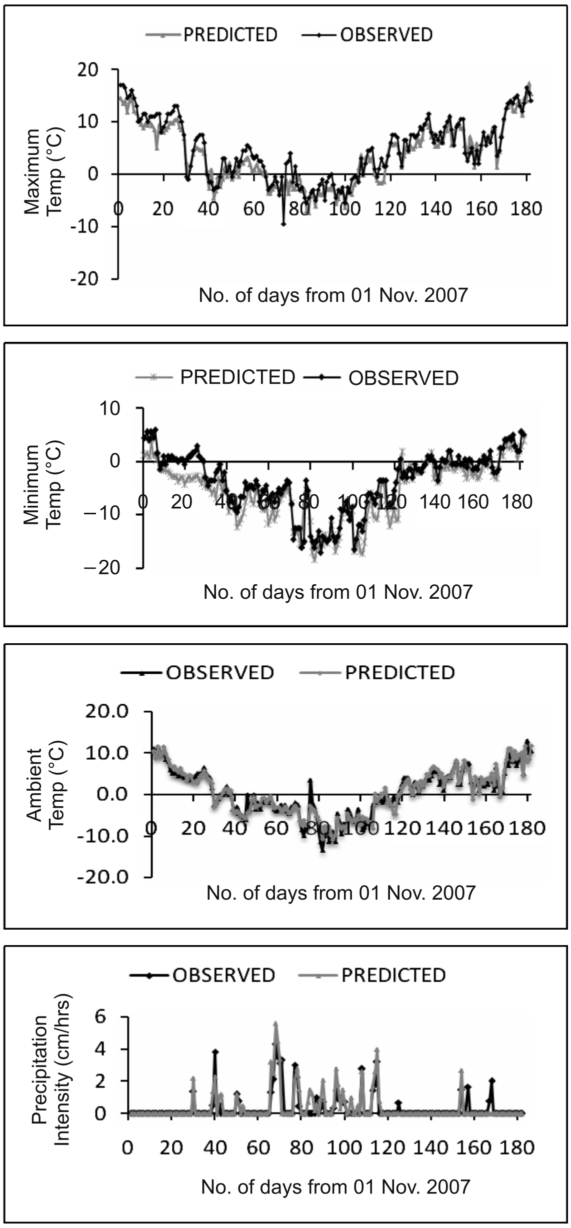

Figure 4. Observed and predicted parameters at Pharkiyan.

Predicted maximum, minimum and ambient temperatures match well with the observed ones except for few stations. This mismatch is because of the following reasons: firstly the computation of parameters at Manali, Solang and Dhundi involves the parameters of only two neighbouring stations because only two of the stations fall in their radius of influence, whereas at other stations the computation involves four neighbouring stations. Secondly, some of the stations like Drass and Z-Gali fall in a different climatic zone than their neighbouring stations. This is one of the limitations of this technique that the station concerned and its neighbouring stations should fall in the same climatic zone.

The mismatch between observed and predicted precipitation intensity at many locations is because of the complex topography and difference in orographic conditions that cause variability and time lag (precipitation may occur at one place and at the same time it may not occur at the other place) in precipitation on different locations. For e.g., whenever western disturbances hit northwest Himalaya, western region of Pir-Panjal range receives maximum precipitation and its moisture content decreases as it proceeds towards Greater Himalaya. Therefore, in the Pir-Panjal range itself, some of the stations like Haddan-Taj, Stage II, etc., receive more precipitation than others, therefore estimation of precipitation intensity at these stations with the help of neighbouring stations produce error. Moreover, the calculation of appropriate value of precipitation adjustment factor ‘η’ for Himalayas can help to achieve better accuracy in the estimation of precipitation intensity.

This study has got mainly two limitations:

1) The estimation of the parameters at a specific location is based on the simple topographic relationships, and

Table 3. *RMSE of the prediction at different locations over the Himalaya.*

Locations in the northwest Himalaya	Maximum temperature		Minimum temperature		Ambient temperature		Precipitation intensity	
	RMSE	Squared correlation	RMSE	Squared correlation	RMSE	Squared correlation	RMSE	Squared correlation
Manali	4.5	0.76	2.3	0.75	3.7	0.82	0.4	0.50
Drass	2.7	0.87	3.9	0.88	3.1	0.87	0.6	0.41
Stage II	2.9	0.80	2.1	0.86	2.6	0.80	0.5	0.51
Haddan-Taj	3.3	0.74	2.4	0.83	3.1	0.73	0.8	0.95
Gulmarg	3.2	0.71	2.5	0.83	3.4	0.70	0.7	0.39
Pharkiyan	2.0	0.92	2.6	0.88	1.5	0.93	0.5	0.26
Solang	3.2	0.74	2.9	0.76	2.1	0.85	0.5	0.23
Dhundi	3.2	0.74	2.9	0.76	2.1	0.85	0.7	0.51
Z-Gali	2.5	0.89	4.9	0.66	2.4	0.86	0.9	0.43

2) the adjustments are completely one-way, i.e., there are no feedbacks between the land and atmosphere in the calculations of the near-surface atmospheric conditions.

The land surface conditions can have a substantial impact on near-surface atmospheric properties (Pielke 2001). Thus there is scope for additional improved physical realism in this technique.

4. Conclusion

Barnes objective analysis has been used to interpolate irregularly distributed station observations to the specific locations. In addition to the station interpolations, corrections based on temperature-elevation and precipitation-elevation have been employed. This technique produce an improved temperature and precipitation distribution when the spatial scale of topographic variability is smaller than the distance between the stations. The estimation of temperature and precipitation at specific locations over Indian western Himalaya is more accurate when the location and the data of its neighbouring locations all fall in the same snow climatic zone. Using this technique wind field and solar radiation over complex topography can also be simulated and can be the scope of further work.

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