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An analogue method for simultaneous prediction of surface weather parameters at a specific location in the Western Himalaya in India

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ABSTRACT: Avalanches in the Western Himalaya cause loss of life and damage property every year. To reduce such losses avalanche forecasting is practiced. This technique requires information about various surface weather parameters at least a couple of days in advance. In view of the above requirement, an analogue method has been employed to predict maximum, minimum and ambient temperatures, average wind speed, surface pressure and relative humidity at a specific location in the Western Himalaya. Predictions for surface weather parameters 3 days in advance have been attempted using information of past synoptic situations corresponding to the current situation searched from a database through Euclidean distance. Surface weather observations of the past 16 winters (1989–1990 to 2005–2006) have been used to develop the model. The model has been tested with independent data set of 166 days of winter 2006–2007. The forecast accuracy for maximum, minimum and ambient temperature falls in the range 74.7–85.5, 64.2–81.8 and 58.5–79.9% within an error limit of 3 °C for day 1, day 2 and day 3. Forecast accuracy for prediction of average wind speed is in the range 65.7–70.9% and it is in the range 73.7–82.5% for atmospheric pressure with same error limit as temperature (with respective units) for day 1, day 2 and day 3. Accuracy for the prediction of relative humidity is in the range 58.5–69.3%, within an error limit of 20% for all three days. The root mean square error (RMSE) and mean absolute error (MAE) of each weather parameter have been computed to test the prediction error of the model. The results suggest that the analogue method holds promise for simultaneous prediction of surface weather parameters with reasonable accuracy. Predicted surface weather parameters have been used for assessing future avalanche situations with reasonable confidence. Copyright © 2008 Royal Meteorological Society

KEY WORDS weather; weather forecasting; avalanche forecasting and analogue method

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1. Introduction

Avalanche forecasting refers to the process of diagnosis and prognosis of the instability state of snow cover on a group of mountain slopes and it is one of the most cost effective mitigation techniques to reduce loss of lives in avalanche terrain. Avalanche forecasting is mainly practiced on the basis of three classes of parameters (McClung and Schaerer, 1993): Class I (instability factors), Class II (snow pack factors) and Class III (meteorological factors). These three classes are relevant to the interpretation of snow instability on different spatial scales. Whereas the Class I and Class II parameters are more reliable and useful for prediction of avalanches on a smaller scale (∼1 km), at a larger scale (∼100 km) spatial variability of snow cover dominates and restricts their usage. Therefore, the Class III parameters become more relevant for operational avalanche forecasting on a regional scale.

The Class III parameters mainly comprise snow and weather observations (e.g. fresh snow amount, snow cover depth, temperature, average wind speed and relative humidity) (McClung and Schaerer (1993)). Most of the empirical avalanche prediction models (Obled and Good, 1980; Buser *et al.*, 1985) have been developed using the Class III parameters as they are easily available on a real time basis. To assess the avalanche danger situation for a specific area and period, predicted or estimated values of Class III parameters are required.

In view of this requirement, an attempt has been made to predict surface weather parameters simultaneously at a specific location in the Western Himalaya employing an analogue method. This method searches past situations corresponding to the current weather conditions either in terms of circulation patterns observed in the past (Bergen and Harnack, 1982; Van Den Dool and Nap, 1985; Toth, 1991) or in terms of various surface weather parameters (Singh *et al.*, 2005). Past weather situations corresponding to the current situation can be used for predicting weather and its various components (Bergen and Harnack, 1982; Van Den Dool, 1989; Toth, 1991; Singh *et al.*, 2005). In this study, past similar synoptic situations are used to predict maximum, minimum and ambient temperatures, average wind speed, atmospheric pressure and

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relative humidity simultaneously at a specific location in the Western Himalaya in India.

Although the analogue method appears straightforward, it has a few disadvantages. To find good atmospheric analogues over a large area is practically impossible (Lorenz, 1969; Gutzler and Shukla, 1984). However, over a limited area (over a circle with radius of about 900 km from the target point) the method has shown considerable skill (Van Den Dool, 1989). The limited record of past weather data puts another constraint on exploring real potential of the analogue method (Toth, 1989; Van Den Dool, 1989).

The study area and data are described in Section 2. An analogue model for prediction of weather parameters is presented in Section 3. Test results on the independent data set are given in Section 4. Conclusions and Limitations are presented in Section 5.

2. Study area and data description

The aim of this study is to predict surface weather parameters simultaneously at a specific location (i.e. Dhundi (3050 m msl, Figure 1), Himachal Pradesh (HP), India, in the Pir Panjal range of the Western Himalaya, employing an analogue method for the winter (November–April) and to explore the potential of the analogue method for prediction of surface weather parameters. Surface weather parameters measured at 1200 UTC during the winter months at Dhundi have been taken for the study. The primary reason for selecting this particular area for the study is the availability of a large homogeneous database in comparison to other nearby stations in the Western Himalaya.

The past database of surface weather parameters at Dhundi was first divided into two mutually exclusive data sets: base data and test data. Base data consist of surface weather parameters of the past 16 winters (winter 1989–1990 to winter 2005–2006, excluding incomplete data of winter 2004–2005) and the test data consist of the surface weather parameters of 166 days of winter 2006–2007. The surface weather parameters used for the development of the analogue model are given in Appendix A and the surface weather parameters predicted with the help of the developed model are given in Appendix B.

3. Analogue search process and prediction scheme

The base data have been used to search past weather situations corresponding to each day of the test data and surface weather parameters recorded in those situations have been used to draw predictions for any day of the test data. The past weather situations corresponding to the current weather situation (i.e. the forecast day) were identified from the base data using a Euclidean distance (Equation (1)). The degree of deviation (quantitative measure of deviation) and tendency (direction of deviation) of a few weather parameters from their preceding situation (on

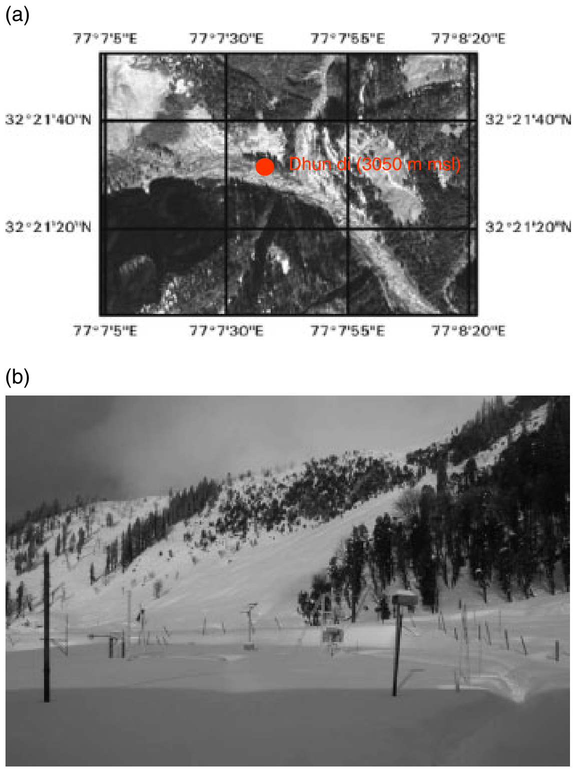

Figure 1. (a) Research station Dhundi (3050 m msl), HP (India), in the Pir Panjal range of the Western Himalaya. (b) Snow and Meteorological observatory at Dhundi. This figure is available in colour online at www.interscience.wiley.com/ma

the previous day) have also been considered as a parameter for searching for these analogue situations (Appendix A). This is because the current weather situation represented by a value of each parameter for any day does not include the degree of deviation and tendency of current weather situation from its preceding situation. This plays an important role in the future evolution of weather (e.g. a drop of atmospheric pressure is indirect evidence for approaching bad weather situation). As an example, the specific value of surface pressure on any day does not represent the degree of deviation and its tendency, because a surface pressure of 724 hPa (say) on one day may be a 2 hPa pressure drop from that of the previous day (degree of deviation 2, tendency positive) or due to increase in pressure by 3 hPa from that of the previous day (degree of deviation 3, tendency negative).

Prediction of weather parameters is largely affected by the presence or absence of seasonal snow cover in the forecast area (Namias, 1985; Walsh *et al.*, 1985; Petersen and Hoke, 1989; Wojcik and Wilks, 1992). Therefore, similar situations for any day in the test data have been searched for according to the presence or absence of seasonal snow cover at Dhundi. A schematic view of the procedure adopted for searching for analogue situations and the prediction scheme is given in Figure 2. The following Euclidean distance is used to search past situations:

$$d_{ij} = \sum_{k=1}^{p} \left\{ \left(x_{ik} - x_{jk}\right)^2 + \left(\Delta x_{ik} - \Delta x_{jk}\right)^2 \right\}^{1/2} \qquad (1)$$

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where x_{ik} is a vector of k measurements for day i ($k = 1, p$) and $\Delta x_{ik} = x_{(i-1)k} - x_{ik}$ is the deviation in the value of parameter k from its preceding situation and d_{ij} is the distance between day x_i and day x_j.

Using the above Euclidean distance as a search criterion, the 10 analogue situations (10 days with least distances) are searched from the base data. The weather situation observed after 24 and 48 h corresponding to each analogue situation are also searched from the base data (Figure 2). The analogue situations, weather situations observed after 24 and 48 h corresponding to analogue situations are utilized to predict surface weather parameters for day 1 (next 24 h), day 2 (next 48 h) and day 3 (next 72 h) respectively (Figure 2).

Observed values of surface weather parameters are retained for analogue situations, weather situations observed after 24 and 48 h of analogue situations. Surface weather parameters for day 1 are predicted using the following expression (Equation (2)) (Kruizinga and Murphy, 1983):

$$X_{p,\ day1} = \frac{\sum_{i=1}^{n} X_{i,\ day1}}{n} \tag{2}$$

$n = 10$ in present case (number of analogue situations), $X_{p,\ \mathrm{day1}}$ is the vector representing the predicted value of parameters for day 1 and $X_{i,\ \mathrm{day1}}$ is the vector representing the observed value of parameters in the ith analogue situation. Weather situations observed after 24 and 48 h of analogue situations are used to predict surface weather parameters for day 2 and day 3 using Equation (2).

4. Results and discussion

The developed analogue model is run for each day of the test data. The normal Z-test (Fleming and Nellis, 1994) has been applied to test whether the predicted mean of any parameter for the test data significantly differs from the observed mean for all three days. The normal Z-test results are in acceptance of predicted mean of all the parameters do not differ significantly from the observed mean at 5% ($Z.025 = \pm 1.96$) level of significance for all 3 days. This implies that predictions made with the analogue model are significant at 5% level of significance.

Although the normal Z-test favours predictions made with the help of the analogue model at 5% level of significance, this does not give any idea about accuracy and error associated with predictions made by the analogue model. Root mean square error (RMSE) (Mao and McNiDer, 1999; Riable *et al.*, 1999) and mean absolute error (MAE) (Abdel-aal and Elhadidy, 1995; Mao and McNiDer, 1999) are computed for all weather parameters corresponding to day 1, day 2 and day 3. These measures of prediction error are considered to compare the prediction error of the analogue model with earlier studies (Abdel-aal and Elhadidy, 1995; Mao and McNiDer, 1999; Riable *et al.*, 1999) for prediction of maximum and minimum temperature.

Statistics of observed and predicted maximum temperature along with errors is shown in Figure 3. RMSE and MAE of analogue model for prediction of maximum temperature increase with lead time (Figure 3) and predicted mean maximum temperature (test data) is lower than observed mean maximum temperature (test data) for all 3 days. Statistics of other parameters are given

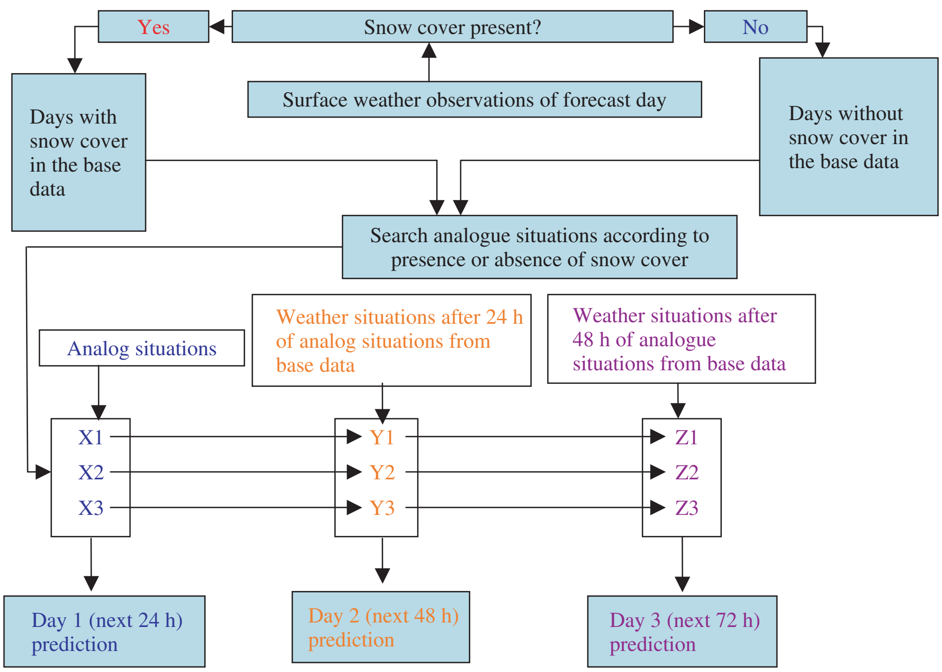

Figure 2. A schematic view of procedure followed for development of analogue model. This figure is available in colour online at www.interscience.wiley.com/ma

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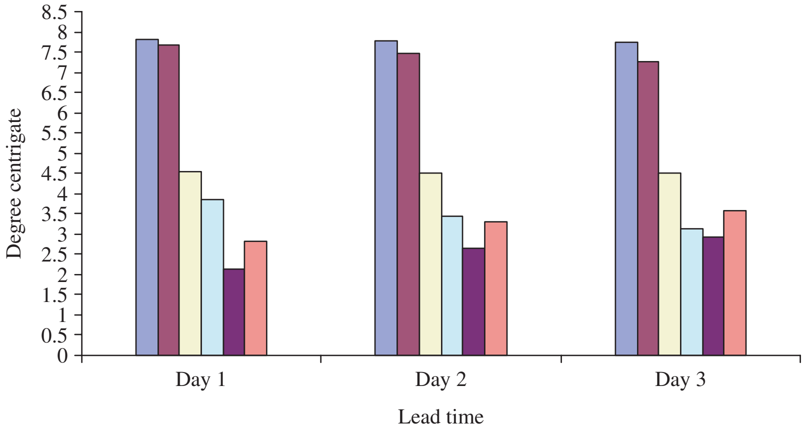

Figure 3. Statistics of observed, predicted maximum temperature and errors (RMSE, MAE) associated with simultaneous prediction of it with minimum, ambient temperature, average wind speed, surface pressure and relative humidity. Observed mean maximum temperature; Predicted mean maximum temperature; Observed standard deviation; Predicted standard deviation; Mean absolute error (MAE); Root mean square error (RMSE). This figure is available in colour online at www.interscience.wiley.com/ma

Table I. Statistics of observed and predicted surface weather parameters for test data.

Parameters	Day 1 (next 24 h)				Day 2 (next 48 h)				Day 3 (next 72 h)			
	Observed		Predicted		Observed		Predicted		Observed		Predicted	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Maximum temperature (°C)	7.82	4.53	7.68	3.85	7.78	4.51	7.48	3.45	7.75	4.51	7.26	3.12
Minimum temperature (°C)	−1.26	3.75	−1.53	3.21	−1.30	3.74	−1.53	3.16	−1.32	3.74	−1.64	3.17
Ambient temperature (°C)	3.10	4.31	2.88	3.66	3.06	4.29	2.76	3.23	3.03	4.29	2.65	2.85
Relative humidity (%)	66.54	21.13	66.21	19.22	66.56	21.19	68.46	12.23	66.50	21.25	69.37	8.60
Average wind speed (km/h)	5.72	3.31	5.84	2.70	5.74	3.32	5.91	1.75	5.75	3.32	5.72	1.52
Atmospheric pressure (hPa)	721.24	2.97	721.08	1.86	721.22	2.96	721.06	1.78	721.2	2.96	720.98	1.55

in Table I. Predicted mean minimum, ambient temperature and atmospheric pressure are also lower than the observed mean values, whereas predicted mean relative humidity and average wind speed are higher. The standard deviation of the predicted values of any parameter is less than the observed standard deviation for the test data. RMSE and MAE associated with simultaneous prediction of surface weather parameters are shown in Figure 4. Errors (RMSE, MAE) in the prediction of maximum, minimum, ambient temperature, average wind speed and atmospheric pressure are comparable, while for relative humidity errors are large (Figure 4). Significant increase in prediction error (MAE, RMSE) is not found for any parameter as the lead time increases (Figure 4).

Verification of model predictions against observations is shown in Figure 5. The model predictions have been verified with specified error limits for each parameter. At present the specified error limit chosen does not have any relevance to avalanche forecasting and is not statistically derived. Primarily, it is important to know whether the predictions made with the help of the analogue model are reasonable and comparable to earlier studies (Klein and Hammons, 1975; Abdel-aal and Elhadidy, 1995; Mao and McNiDer, 1999; Riable *et al.*, 1999). Therefore, specified error limits chosen for verification of temperature forecasts (maximum, minimum and ambient temperature) are kept the same as reported in Abdel-aal and Elhadidy (1995) to obtain an idea of the prediction accuracy of the analogue model for forecasting temperature, when it is implemented for simultaneous prediction of weather parameters. Error limits for verification of average wind speed and atmospheric pressure are also kept the same as temperature to know relative forecast accuracy for average wind speed and surface atmospheric pressure compared to temperature. For relative humidity, error limits are considered as 10 and 20%: values ≥40% are taken as large errors.

Forecast accuracy (percentage of hit) of the analogue model for the prediction of maximum, minimum and ambient temperature within an error limit of 3 °C are in the range 74.7–85.5, 64.2–81.8 and 58.5–79.9% for day 1, day 2 and day 3 respectively (Figure 5). Forecast accuracy for prediction of average wind speed is in the range 65.7–70.9% and it is in the range 73.7–82.5% for atmospheric pressure for day 1 day 2 and day 3 within an error limit of 3 with respective units (Figure 5). Accuracy for prediction for relative humidity is in the range 58.5–69.3% within an error limit of 20% for all three days. Analogue model performs slightly poor for prediction of average wind speed and surface atmospheric

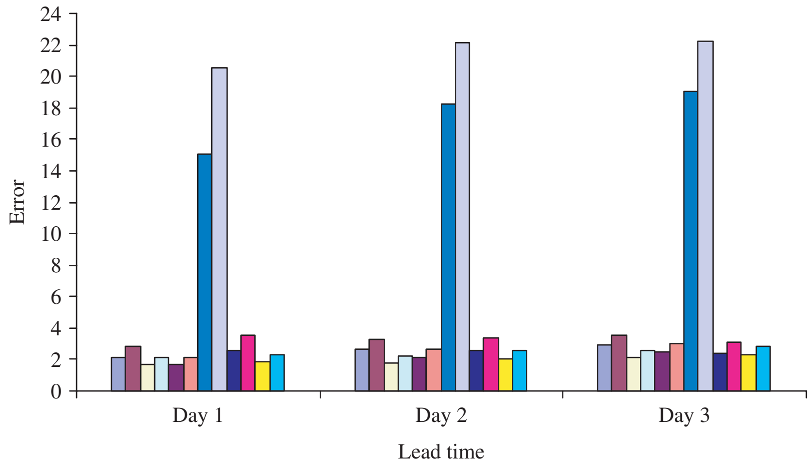

Figure 4. Errors associated with simultaneous prediction of surface weather parameters employing an analogue method at Dhundi. Maximum temperature (MAE); Maximum temperature (RMSE); Minimum temperature (MAE); Minimum temperature (RMSE); Ambient temperature (MAE); Ambient temperature (RMSE); Relative humidity (MAE); Relative humidity (RMSE); Average wind speed (MAE); Average wind speed (RMSE); Atmospheric pressure (MAE); Atmospheric pressure (RMSE). This figure is available in colour online at www.interscience.wiley.com/ma

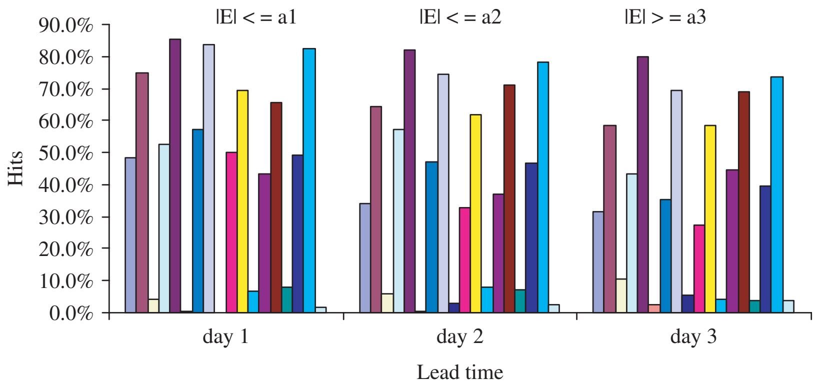

Figure 5. Verification of forecasts for simultaneous prediction of surface weather parameters at Dhundi. (E: error limit, $a1 = 1.5$, $a2 = 3.0$ and $a3 = 6.0$ for temperature, average wind speed and atmospheric pressure with respective units and $a1 = 10.0\%$, $a2 = 20.0\%$ and $a3 = 40.0\%$ for relative humidity). Maximum temperature (a1); Maximum temperature (a2); Maximum temperature (a3); Minimum temperature (a1); Minimum temperature (a2); Minimum temperature (a3); Ambient temperature (a1); Ambient temperature (a2); Ambient temperature (a3); Relative humidity (a1); Relative humidity (a2); Relative humidity (a3). This figure is available in colour online at www.interscience.wiley.com/ma

pressure relative to temperature with same error limits. More than 7.8, 7.8 and 10.4% days have not been found with large error for any parameters for all 3 days (Figure 5).

Errors (RMSE, MAE) and forecast accuracy of the analogue model for prediction of maximum or minimum temperature is found comparable to previous studies (Klein and Hammons, 1975; Abdel-aal and Elhadidy, 1995; Mao and McNiDer, 1999; Riable *et al*., 1999). However, in this study, predictions for maximum or minimum temperature are drawn simultaneously with ambient temperature, average wind speed, atmospheric pressure and relative humidity. The results suggest that analogue method may be useful tool for simultaneous prediction of weather parameters with reasonable accuracy.

5. Conclusions and limitations

In this study prediction of surface weather parameters at a specific location by employing an analogue method is considered. Reasonable accuracy is found for simultaneous prediction of surface weather parameters. In the near future, predicted weather for all three days will be included in analogue search process and model tuned according to predicted weather may provide better results.

At present, surface weather parameters predicted with the help of an analogue model are passed to expert avalanche forecasters for subjective assessment of avalanche danger. Predictions made with the help of an analogue model can be coupled with the avalanche prediction models. However, this could not be attempted mainly due to lack of predicted snow parameters.

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Avalanche prediction models can be tuned according to predicted snow and meteorological parameters by training them with same errors to partially overcome propagation of error from analogue model to avalanche prediction models. This may offer an opportunity to extend the current time range of avalanche forecast guidance, generally 1 day in advance to 2–3 days in advance.

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Appendix A

(Surface weather parameters used for development of the analogue model)

1. Maximum temperature and maximum temperature deviation in past 24 h (°C).
2. Minimum temperature and minimum temperature deviation in past 24 h (°C).
3. Ambient temperature and ambient temperature deviation in past 24 h (°C).
4. Relative humidity and relative humidity deviation in past 24 h (%).
5. Spot wind speed and spot wind speed deviation in past 24 h (km h^{-1}).
6. Average wind speed and average wind speed deviation in past 24 h (km h^{-1}).
7. Atmospheric pressure and atmospheric pressure deviation in past 24 h (hPa).
8. Fresh snowfall (cm).
9. Sun shine duration and sun shine duration deviation in past 24 h (h).

Appendix B

(Surface weather parameters predicted simultaneously at a specific location and time)

1. Maximum temperature (°C).
2. Minimum temperature (°C).
3. Ambient temperature (°C).
4. Average wind speed (km h^{-1}).
5. Relative humidity (%).
6. Surface pressure (hPa).

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