SETUP AND TEST OF A SIMPLE MODEL FOR PREDICTION OF LATE FROST EVENTS OVER COMPLEX TERRAIN

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Abstract: A simple algorithm for prediction of spring frost is presented along with results form its application to reproduce observed temperature minima at 24 meteorological stations in Trentino (Italy). The method is based on the model proposed by Reuter (1947, 1951) where the cooling process is assumed proportional to the square root of time after sunset by means of a decay coefficient. Data recorded during the periods March-May 2003 and 2004 have been used to determine an optimal value of the decay coefficient embedded in the algorithm. The value for this coefficient is obtained through a multiple linear regression which involves meteorological variables as wind speed, air temperature and relative humidity. The performance of the method is satisfactory in reproducing the time evolution of the process. For most of the stations the method provide a satisfactory tool for issuing a frost alert within 1.5°C of tolerance.

Keywords - *Frost prediction, nocturnal stable boundary layer (NBL), Adige River Valley, Non Valley*

1. INTRODUCTION AND ALGORITHM DESCRIPTION

Frost is a relevant damage factor for many species of crops. In this work we study the meteorological phenomenon determined by the cooling of air temperature at ground below the water freezing point. Under the assumption that nocturnal ground cooling occurs in still air, under clear sky and relatively low water vapour pressure, frost events are mainly determined by radiative cooling.

Many attempts have been made to reproduce by means of suitable models the decay of temperature at night in connection with various local factors. One theoretical approach was proposed by Reuter (1947, 1951) assuming initial conditions typical for radiation frost events, as outlined above. In order to correctly model the radiative cooling process, the correct thermal balance has to include the soil and its interaction with the atmosphere. An energy flux from the air above the ground toward the surface must balance the radiative energy loss from the surface. The model shows that the decrease in surface air temperature is proportional to the square root of time, thus yielding

$$\Delta T_{noct} = D\sqrt{\Delta t} \qquad (1)$$

where ΔT_{noct} is the nocturnal cooling at the ground surface and Δt is the time elapsed after sunset. The decay coefficient D is given by

$$D = \frac{2}{\sqrt{\pi}} \frac{E + \gamma_g k_g + (\gamma_a - \gamma_d) c_p K\rho}{\sqrt{k_g \rho_g c_g} + c_p \sqrt{K\rho^2}} \qquad (2)$$

where E is the outgoing long-wave radiation flux, γ_a the air temperature gradient at sunset, K and ρ_a the eddy diffusivity and air density respectively, k_g the soil heat conductivity, ρ_g the soil density, c_g the soil specific heat and γ_d the vertical temperature gradient in the terrain.

The choice of this algorithm is mainly motivated by the fact that it is relatively easy to apply and requires a limited amount of input parameters. These features are particularly appreciable whenever resources for weather monitoring are essentially limited to standard weather stations, whose data are usually stored as hourly averaged values. In fact, the algorithm is based on the assumption that the cooling process makes ground temperature decay with time, but the decay coefficient is not easy to determine.

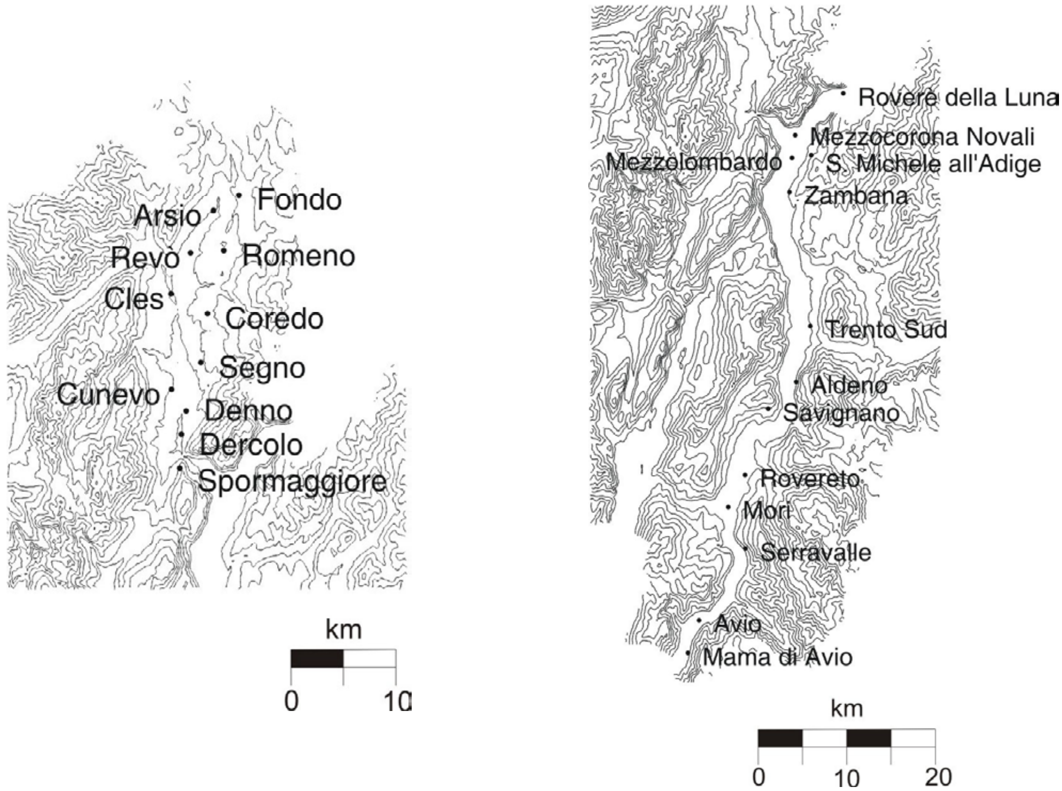

Figure 1: Topographical maps of the Non Valley (left) and Adige River Valley (right) along with the locations of the meteorological stations considered in this work.

2. MULTIPLE LINEAR REGRESSION METHOD

In the present work 24 weather stations (Figure 1) have been identified in two valleys of Trentino (Italy), namely the Adige River Valley and the Non Valley nearby, as a basis for monitoring the main meteorological variables related to the cooling process, such as wind velocity, air temperature and humidity. Data collected at these stations have been first used to test the applicability and overall performance of the forecasting algorithm.

First the ability of Reuter's model (1947, 1951) of forecasting the nocturnal cooling has been tested. For each night, D has been chosen as the coefficient that minimizes the mean square difference over the whole nocturnal cycle. The determination coefficient R^2 is always greater than 0.9358 (Table 1), thus suggesting the overall good performance of the method.

The decay coefficient D can be calculated from Eq. (2) only when all of the physical parameters entering therein are available. Notice that part of the above coefficients describe atmospheric conditions (E, γ_a and K), while another part depends on soil properties (k_g, ρ_g and c_g) and thermal state (γ_d). The values of coefficients in the first set can be more easily evaluated on the basis of observations routinely performed by weather services. On the contrary the latter set requires a detailed determination of local soil properties as well as their heterogeneity in space and variability in time (e.g. soil water content): this is hardly available on a routinely and continuous basis.

Considering terrain complexity, many authors have proposed method to estimate the spatial variation of air temperature close to the ground with respect to that measured at a weather station nearby based on some relationship with other meteorological variables (see for example Bootsma, 1976). A similar approach can be used in the estimation of the decay coefficient by seeking for a rather simple relationship between the decay coefficient and related meteorological variables by means of a multiple linear regression on a suitable dataset.

In the present work a reasonable value for D is estimated through a multiple linear regression based on meteorological data. As a consequence of physical reasoning, the following set of variables, generally available from standard weather stations, has been chosen: minimum and maximum air temperature values recorded after midnight of the day before (T_{min}, T_{max}), diurnal excursion between maximum and minimum temperature (ΔT_{obs}), wind speed (V_{min}, V_{max}) and relative humidity (RH_{min}, RH_{max}).

For each cycle of nocturnal cooling available from the database, the value of D that best fits Equation (1) to the observed temperatures has been evaluated. Then the statistical correlation of evaluated values of D with each of the above meteorological variables recorded at the corresponding days has been evaluated by means of a linear regression. This procedure allowed to single out those variables which mainly contribute to the cooling process and to simplify the subsequent multiple linear regression analysis.

Table 1: Determination of the correlation coefficient R^2 between observed and predicted air temperature

Station	Height m a.s.l.	Multiple linear regression	Mean square regression
Adige River Valley			
Aldeno	180	0.8473	0.9451
Avio	137	0.9201	0.9747
Mama di Avio	124	0.8618	0.9589
Mezzocorona Novali	216	0.9032	0.9746
Mezzolombardo	204	0.8423	0.9584
Mori	190	0.9225	0.9816
Roverè della Luna	715	0.8468	0.9469
Rovereto	912	0.8674	0.9665
San Michele all'Adige	205	0.8481	0.9472
Savignano	677	0.9264	0.9854
Serravalle	150	0.8820	0.9673
Trento Sud	185	0.8804	0.9650
Zambana	200	0.8233	0.9358
Non Valley			
Arsio	797	0.9356	0.9865
Cles	652	0.9220	0.9841
Coredo	787	0.9408	0.9850
Cunevo	558	0.9047	0.9714
Denno	321	0.8809	0.9687
Dercolo	410	0.9163	0.9739
Fondo	907	0.9351	0.9866
Revò	715	0.9148	0.9855
Romeno	912	0.9272	0.9849
Segno	525	0.9201	0.9858
Spormaggiore	548	0.9285	0.9813

Further exploring the relationship with single meteorological variables, the relative humidity registered at 16:00 displays a rather good correlation. The value at 16:00 has been chosen because during the investigated season all stations display between 15:00 and 16:00 the maximum temperature and hence starting at this time it is possible to forecast the cooling process well in advance with respect to the sunset. In accordance with the assumptions of calm wind implied in model proposed by Reuter (1947, 1951) appreciate no correlation between D and wind speed.

Following these considerations, the multiple linear regression has been applied taking into account only the diurnal temperature difference ΔT_{obs} along with the relative humidity measured at 16:00 $RH_{16:00}$, thus giving

$$D = a_0 + a_1 \Delta T_{obs} + a_2 RH_{16:00} \tag{3}$$

3. APPLICATION OF THE METHOD AND RESULTS

The data used to test the method cover 184 days in the period between March-May 2003 and 2004 at 1 hour acquisition interval. The temperature data analysis has been limited to the nocturnal phase starting at local sunset time. Recalling here that the model of Reuter needs the air temperature at sunset as the initial condition, this has been evaluated by means of interpolation between the two nearest hourly data. An example of the reliability of the proposed method is given in Fig. 2: one week of measured and forecasted data are reported for Fondo. The overall performance of the method is reported in Table 1 by means of the correlation coefficient R2: values are generally lower with respect to those obtained by mean square regression, but it is important to notice that the proposed method allows to forecast dangerous conditions well in advance.

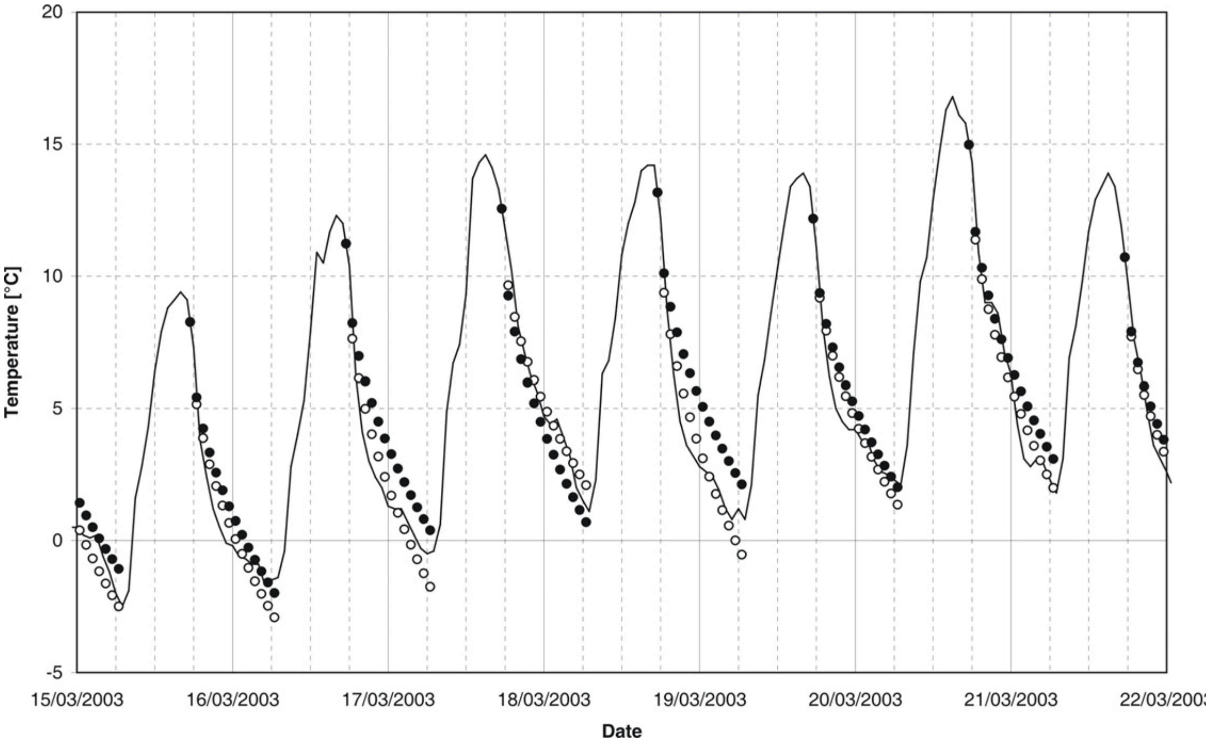

Figure 2: Simulated and observed temperature series at the station of Fondo (Non Valley): solid line correspond to observed air temperature, filled circles represent the air temperature where the decay coefficient D is evaluated with the multiple linear regression while open circles refer to the air temperature where the mean square difference is minor.

4. CONCLUSIONS

The results obtained in this work from the application of Reuter's model (1947, 1951) along with a simple method for estimating the decay coefficient D using standard meteorological observations are very encouraging. The data analysis showed a good correlation between decay coefficient D, diurnal air temperature excursion and relative humidity measured at 16:00. The overall accuracy obtained is better than 1.5 °C for the minimum temperatures for most of the stations.

From a practical point of view, the key factor for frost damage is the temperature of the vegetation tissues; future developments will not only involve the implementation of more physically based models, but also the investigation of the plant behaviour at different developing stages in relation to low temperatures.

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