Modified soil surface temperature forecasting method for automated data collection systems

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Abstract. There are presents a developed method for predicting temperature of soil surface for next 24 hours with using data of air temperatures at height of 2 meters. The proposed method is a modification of the Mikhaelvsky method, recognized in agrometeorology when predicting radiation freezes. Only dry-bulb thermometer temperature data and relative air humidity are available for application in automated systems. We have therefore obtained formulas for the calculation of dry thermometer temperature. A separate study was to test the simplified formula for calculating saturated vapour pressure above water in the temperature range 0-60 °C. The study showed the complete correspondence of the saturated vapour pressure above water value calculated by different methods in the range 0-60°C. The relative error in the given temperature range is not exceed 0.35%. Thanks to obtained equations, the value of dry-bulb thermometer temperature for the first decade of May 2020 was calculated. The temperature and humidity of the air were measured by the automatic station every hour, and the value dry-bulb thermometer temperature were obtained from psychrometric tables. The absolute error in the calculation of value dry-bulb thermometer according to the proposed formulas do not exceed 1°C in the temperature range 0-16°C.

1 Introduction

Accurate frost forecasting can potentially reduce frost damage because it provides growers with the opportunity to prepare for frost events. Snyder et al. (1987) and Kalma et al (1992) divided the heat-transfer processes associated with this phenomenon in two categories: advective and radiative [1, 2]. Advective frost occurs due to the incursion of cold air mass over the continent and occurs either during the day or the night. Frosts due to radiative loss occur during clear, windless nights with a thermal inversion and the predominance of a high pressure centre. In some situations, a combination of these two categories may also occur [3].

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Predicting when the temperature falls to a critical value is important for starting active frost protection methods. Starting and stopping protection at the proper temperature is important because it avoids losses resulting from starting too late and it saves energy by reducing the operation time of the various methods [4].

Growers within the same general climatic and topographical conditions often find differences in frost damage that seem unexplainable. Possible explanations include differences in soil type, ground cover, soil water content and ice-nucleating bacteria concentrations. The variety of soils hydro-physical properties, heat and moisture transfer in the aeration zone and their effect on water content in the soil are shown in works [5-8].

Owing to the large impact that frosts have upon the agriculture, numerous scientific studies have centred on addressing the damage caused by this phenomenon to: coffee [9], peaches [10], sugar cane [11], corn [12], beans [13], apples [14], vines [15] and canola [16], among other crops. Minimizing frost damage can be done by taking preventive measures (passive protection) or by acting during the frost [4]. The main frost prevention techniques used are: (1) artificial fog or covering the crops to avoid infrared radiation loss, (2) direct heating of the air, (3) forced ventilation to avoid low-level temperature inversion and (4) sprinkling [4]. Knowledge of atmospheric conditions favourable for frost, along with the techniques used to minimize its damage, are of low utility if one does not have accurate weather predictions [3]. Thus, frost-alert systems have been developed/tested based on predictions of numerical models [17] and neural networks [18]. The paper presents a developed method for predicting the minimum temperature of the soil surface based on the collected meteorological data at a height of 2 meter to use the method in automated meteorological systems.

2 Methods

The proposed method is a modification of the Mikhalevsky method [19], recognized in agrometeorology when predicting radiation freezes. Expected minimum air temperature was calculated using formula (1):

$$t_{air} = t' - (t - t')C$$

and the minimal temperature on soil surface using formula (2):

$$t_{soil} = t' - (t - t')2C$$

where $t$ is air temperature by dry-bulb thermometer, °C; $t'$ is the air temperature by wet-bulb temperature, °C; $C$ is the table value coefficient depending on relative humidity of air.

Only dry thermometer temperature data, relative air humidity and atmospheric pressure ($P$) are available for application in automated systems. We have therefore obtained formulas for the calculation of $t'$. The formulas for calculating saturated water vapour pressure ($E$) and partial pressure ($e$) are known [20]:

$$E = 6.112 \exp \left[ \frac{17.62t}{(243.12 + t)} \right]$$

$$e = \frac{fE}{100}$$

$$e = E_w - AP(t - t')$$

From here we get:
where \( A = 0.0007947 \, ^\circ\text{C}^{-1} \) - psychrometric constant; \( W(x) \) Lambert’s dual function (W-function of Lambert), with an approximate solution calculated using formula (7) [21]:

\[
W(x) = \begin{cases} 
0.665 \cdot (1 + 0.0195 \cdot \ln (x + 1)) \cdot \ln (x + 1) + 0.04 & 0 < x \leq 500 \\
\ln (x - 4) - \left( 1 - \frac{1}{\ln x} \right) \ln \ln x & x > 500
\end{cases}
\]

(7)

Also, we have obtained correlation between coefficient \( C \) and relative humidity \( f \) (The survey was conducted held over 13-hours period):

\[
C = 6.1576f^3 - 3.612f^2 + 2.581f + 0.00667
\]

(9)

### 3 Results and Discussion

A separate study was carried out to test a simplified formula (3) for calculating the vapor pressure \( E_w \) over water in the temperature range 0-60 \(^\circ\text{C} \) (fig.1-2.) instead of the more cumbersome formula recommended by the World Meteorological Organization (WMO) [22].

![Fig. 1. Correlation field between the pressure of saturated vapour above water according to WMO formula: \( E_w \) (WMO) and the same value calculated using simplified formula (3): \( E_w(M) \)](image)

The figure 1 shows the complete correspondence of the \( E_w \) (saturated water vapor pressure) value calculated by different methods in the range 0-60°C. The relative error in the given temperature range is not exceed 0.35% (fig.2).
Fig. 2. Relationship of the relative error (E) of the $E_w$ formula calculation (3) to temperature $T$.

Thanks to obtained equations, the value of $t'$ for the first decade of May 2020 was calculated (fig.3). The temperature and humidity of the air were measured by the automatic station every hour, and the $t'$ value was obtained from psychrometric tables [23].

Fig. 3. Dynamics of $t'$ values calculated according to the proposed formulas (calc) and obtained from tables (tab).
Figures 3 and 4 show that the \( t' \) calculated values are overestimated in comparison with the tabulated ones. The absolute error in calculating the \( t' \) value according to the proposed formulas does not exceed 1 °C in the temperature range 0-16 °C.

4 Conclusions

The application of proposed method in gradient masts will make it possible to determine the evapotranspiration value not only by aerodynamic and energy balance method which are based on the Bowen’s equation. It also allows to predict radiation ground freezes, which depend heavily on the microclimate. Such complements will help performing the synoptic prediction of advective ground frost.

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