NEW ZEALAND METEOROLOGICAL SERVICE

TECHNICAL NOTE 217

FROST FORECASTING FOR CHRISTCHURCH

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Abstract

Following the work of several authors a simple empirical formula is derived for forecasting frost intensity at Christchurch Airport during the winter and spring months on clear nights with light winds.

Introduction

The occurrence of hard frosts is a matter of considerable economic importance in Canterbury. During the winter there are many frost affected operations, e.g. concrete pours, road surfacing, which can benefit from timely and accurate forecasts of expected frost intensity. During the spring months orchardists and market gardeners are particularly vulnerable and may suffer considerable financial loss from the effects of killing frosts. Most growers now have frost abatement devices such as smoke pots or sprays and many of these have alarm systems. Some spray systems operate automatically when the temperature falls below a predetermined level. However, these systems are expensive to operate and may have undesirable side effects such as branches broken from the weight of accumulated ice, so they are not brought into use indiscriminately.

It is thus desirable to be able to make a quantitative forecast of frost intensity. This investigation is concerned solely with attempting to forecast the minimum temperature on grass. For some purposes the screen minimum or the duration of frost may be more significant but these aspects have not been considered.

Frosts in coastal Canterbury occur almost without exception on nights when there is a period of clear skies with light winds. Because of the difficulty of assessing the effects of varying periods of cloud cover and wind during the night and perhaps the greater difficulty of forecasting such periods, only those nights on which "radiation" conditions prevailed for most of the night were considered. Thus the first step in forecasting frost intensity is to forecast whether "radiation" conditions will occur. This, of course, may be difficult but, as will be shown, there is a fair degree of tolerance in the definition of "radiation" conditions.

Procedure

The degree of ground frost will depend on air temperature, humidity, soil moisture and soil temperature. Lawrence (1960) tested a number of formulae containing these parameters for a site in southeast England. One of the more successful, which had the advantage of simplicity, was

$$G = 5(T+\frac{E}{2} - X' - 19)/9$$

where G is the forecast grass minimum temperature in degrees Fahrenheit,

T and E are the 3 p.m. dry bulb temperature and the dew point respectively in degrees Fahrenheit.

X' is the number (< 10) of consecutive days with less than 0.01 in. of rain.

This formula was tested for Christchurch Airport using data for the months April to October for the five years 1965 to 1969. An alternative formula for use when the 4 inch earth temperature was greater than 60 degrees F was not used since 4 inch earth temperatures at Christchurch Airport are below 60 degrees F during the period considered.

The criteria used for "radiation" nights, based on experience and a preliminary examination of the figures, were as follows:

(i) cloud amount: less than 2 oktas low cloud or middle cloud or less than 6 oktas high cloud, except for a single observation.

(ii) wind speed: less than 5 kt from E or NE, or less than 7 kt from any other direction.

The criteria were applied for the hours from sunset until one hour after sunrise.

There were 164 nights meeting these criteria. Frosts occurred on many more nights, of course, when clear skies and light winds prevailed for only part of the night.

Results

When the formula was tested using these observations it was soon found that the parameter X', i.e. the number of days since appreciable rain, was of little value and in fact led to appreciable errors. Many hard frosts occurred on nights following a cold outbreak with rain during the previous 12 hours or so. Under these conditions X' is a minimum. The conclusion drawn was that the local free draining soil acted as "dry" surface at all times.

It seemed that a simpler relation could be found. In Lawrence's article the parameter $T + \frac{E}{2}$ was shown to be generally used in other treatments. These are figures readily available at a time which allows a useful forecast to be issued.

Accordingly, the observed value of the grass minimum temperature read at 9 a.m. was plotted against $T + \frac{E}{2}$ where T and E are the values for dry bulb temperature and dew point read at 3 p.m. the previous day. In accordance with current practice, all temperatures were now expressed in degrees Celsius.

The points on the plot were scattered about the line

$$G = \tfrac{1}{3}\left(T + \frac{E}{2}\right) - c \quad \text{where c is a constant.}$$

When all data were plotted the scatter was quite large but when data for individual months were plotted the scatter was reduced and a useful result obtained. The value of c was derived as 8 for May, September and October, 9 for June and August and 10 for July. The figure for July was based on limited data.

The formula was tested against 1970-71 data on nights which fulfilled the criteria for "radiation" nights. No attempt was made to assess if such "radiation" conditions were successfully forecast. Assuming they were, the test was successful to the extent that on 39 of the 55 occasions, i.e. 71%, the forecast error was one degree C or less. On 93% of occasions the forecast error was two degrees C or less. The root mean square error was 1.43 degrees C. The frequency distribution of errors is shown in Table 1.

Table 1. Frequency distribution of errors (per cent), n=55

Error deg.C	-3	-2	-1	0	+1	+2	+3
%	4	7	18	18	35	15	4

In an attempt to characterise the few occasions when the error was as large as 3°C the hydrolapse and wind field below 900 mb were examined but no conclusions could be drawn from the widely varying and limited data available.

It is perhaps worth noting that the 3 p.m. temperatures are read at a site adjacent to the airport car park while the grass minimum temperature is read in the climatological enclosure some 400 m distant.

The application of the formula is virtually independent of weather conditions at 3 p.m. Even precipitation at that time does not affect the forecast provided a clearance takes place. However, if wind speeds are greater than 15 kt at 3 p.m. a better forecast is made using data from the first hourly observation with a wind speed below that figure. Experience showed that weather conditions before 10 p.m. do not affect the forecast except for the restraint on wind speed mentioned above. Thus it is only necessary to forecast "radiation" conditions from 10 p.m. onwards to allow the use of the formula. The presence of radiation fog at any time of the night does not affect the forecast. An airmass change after 3 p.m. does, of course, preclude the use of the formula but a useful estimate can often be made using readings from the first observation after the change.

No attempt has been made to investigate likely minimum readings when radiation criteria are met for only part of the period after 10 p.m. The formula will, however, give a value which may be modified subjectively for likely departures from the necessary conditions.

Spring frosts, which are probably the most important for orchardists, market gardeners and home gardeners, are forecast successfully. In September and October 1970 there were seven nights which met the criteria. Use of the formula gave forecasts which were one degree or less in error on five of these occasions and an error of two degrees on two occasions. On the 26 September 1970 after the passage of a frost at 3 p.m. moderate rain fell from 5 p.m. until 7 p.m. and light rain continued until 9 p.m. A rapid clearance then took place and a grass minimum temperature of -7^{o}C was read at 9 a.m. next morning. The forecast based on 3 p.m. data was -6^{o}C.

Frosts can follow warm days. On 31 July 1967 the 3 p.m. temperature at Christchurch Airport was 21^{o}C but a grass minimum of -1^{o}C was read next morning. The forecast value would have been -2^{o}C. A frost of this intensity is probably of little significance but the example illustrates the wide application of the formula.

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Conclusion

The formula

$$G = \frac{1}{3}\left(T + \frac{E}{2} \right) - c$$

where G is the forecast grass minimum (deg C)

T is the 3 p.m. dry bulb reading (deg C)

E is the 3 p.m. dew point (deg C)

c is a constant (8 for May, Sep., Oct.
9 for Jun., Aug.
10 for July)

may be used to forecast grass minimum temperatures below 0 deg C on nights when the following conditions are expected to prevail:

(i) cloud amount < 2 oktas low or medium cloud and
< 6 oktas high cloud

(ii) wind speed < 5 kt for E or NE
< 7 kt any other direction.

The forecast values are for Christchurch Airport but may be taken to represent Christchurch as a whole. There are often wide variations in frost readings throughout the city but no information from other sites is readily available except for the Botanical Gardens where frost readings are generally within a degree or two of the Airport figures.

Reference

Lawrence, E.N., 1960: Forecasting grass minimum and soil temperatures under clear skies and light winds. The Meteorological Magazine, 89: 35-42.