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Estimating grass minimum temperature and probability of ground frost at Eelde (Netherlands)

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Summary

Forecasts of ground frost have been issued for many years in The Netherlands; a practical forecasting tool, however, was not available for the forecaster on the bench. In this study a set of forecasting diagrams is given for use at Eelde airport, situated in the north-east of the country; separate diagrams are constructed for use in April/May and October/November. The probability of ground frost at Eelde can be estimated from the tables given in this paper. Given the appropriate data, similar tables could be constructed for use at other sites.

1. The data

The data used are observations of wind speed and total cloud amount at 03 UTC, state of ground at 06 UTC and minimum temperature and grass minimum temperature both observed in the period 00–06 UTC. Eelde (WMO number 06280, ICAO letter code EHGG, 35° 08′N, 06° 35′E, station height 4 m) was chosen because it is in an area where ground frost often damages crops. The observations were taken in April, May, October and November of the years 1983 to 1988 inclusive; this selection was made because in these months the most damage is done to growing fruit and potato plants (spring) and harvested sugar beet (autumn). Only the period 00–06 UTC was studied, as this is the most important part of the night for the occurrence of ground frost. Wind speed and cloud amount at 03 UTC were taken as estimates of the mean value during the second part of the period. Unfortunately the amount of low cloud only was not available, so total cloud cover was used; for the forecaster this is an advantage, because the method used in determining the screen minimum temperature (Roodenburg 1983) needs the same predictors. The total number of cases was 732; there were 76 (roughly 10%) nights with air frost and 145 (roughly 20%) nights with ground frost. These numbers are small when compared with the climatological mean for 1951–80 for days with air frost and for 1971–80 for days with ground frost (see Table I). The anomalies are probably a symptom of the relatively high mean surface temperatures in the 1980s observed in The Netherlands as well as in many other places.

2. Grass minimum depression

The parameter under examination was the grass minimum depression, rather than the actual grass minimum temperature itself. The grass minimum depression is the departure of grass minimum temperature from screen minimum temperature; it depends on wind speed, cloud amount (Steele *et al.* 1969), state and properties of the soil (Lawrence 1960), and during winter possibly also on the value of the minimum temperature (Saunders 1952).

In accordance with Steele *et al.* (1969), the grass minimum depression was determined from the data as a function of cloud amount and geostrophic wind speed. As in their study, three categories of cloudiness have been distinguished: little or no cloud (0–2 oktas), cloudy (6–8 oktas) and an intermediate category (3–5 oktas). However, instead of geostrophic wind, the actual wind speed has been used, as geostrophic wind and actual wind might be only weakly related in cases with highest probability of (ground) frost. Four wind speed categories were defined: Beaufort force 0 and 1, 2, 3, and 4 or more; amounting to a total number of 12 weather categories. The results (not shown here, see Floor 1989) were subjected to a statistical test (Student's t-test); weather categories that did not show significantly different results were taken together as one new category. This happened to be the case for weather categories with 0–2 oktas and 3–5 oktas of cloud, regardless of wind speed and for the weather categories with 6–8 oktas of cloud and wind speeds of Beaufort force 3, and 4 or more. For the situation most prone to ground frost — little or no cloud and low wind speeds — the importance of the state of the ground was examined; dry soil showed grass minimum depressions that are 1 °C lower than moist or wet soils, the difference being significant at the 0.1% level. The definitive results for the 24 months that have been investigated are shown in Table II.

3. Grass minimum depression in spring and autumn

When Table II was constructed, no distinction was made between different seasons. However, Saunders (1952) found higher values for grass minimum depression in summer than in winter (air temperatures near or slightly below 0 °C). Steele *et al.* (1969) also mention that there is evidence that grass minimum depressions on radiation nights are greater in spring and summer

Table I. Average number of days per year with air frost or ground frost at Eelde for the months and periods shown

Month	1951–80	1971–80	1983–1988	
	Air frost	Ground frost	Air frost	Ground frost
April/May	7	21	5.5	12.7
October/November	9	18	7.2	11.5
Total	16	39	12.7	24.2

Table II. Grass minimum depression (°C) at Eelde for April/May and October/November combined, for 1983–88

Oktas	Soil	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	dry	0, 1	37	3.69	1.18
	moist		50	2.67	1.35
		2	114	1.99	1.21
		3	93	1.13	0.57
		>3	34	0.86	0.44
6–8		0, 1	62	1.41	1.52
		2	102	0.83	1.04
		>2	240	0.55	0.52

than in autumn and winter. Therefore the data have been split up into April/May data and October/November data. The results show a mean value in April/May that was 0.6 °C higher than in October/November, the difference being significant at the 0.1% level. The reason for the difference probably is the continuously wet grass in the winter time, counteracting the cooling of the soil and the nearby air. Soil temperatures of Eelde are not available; values for De Bilt (WMO number 06260, 52° 06'N, 05° 11'E, station height 2 m) were looked at instead. These soil temperatures (September 1962–August 1972) are higher on average in April/May (8.7 and 13.0 °C respectively) than in October/November (11.8 and 7.1 °C respectively) (Van der Hoeven 1974); consequently the observed difference in grass minimum depression cannot be explained in this way. The seasonal difference found made necessary the construction of new Tables III and IV, like Table II but valid for April/May or for October/November only. As was the case with the construction of Table II, weather categories in Tables III and IV that did not depart significantly from another category were taken together as one new category. Distinction between dry and moist soil is not meaningful in autumn; the number of wind categories can be reduced in most cases.

4. A simple forecasting tool

From the results, given in Tables III and IV, diagrams have been constructed for use by the forecaster on the bench (Tables V and VI). Given the expected amount of cloud and the expected wind speed, the grass minimum depression can be taken from the appropriate diagram. The difference between grass minimum depressions in situations with a wind speed of Beaufort force 3 and greater than 3 with 0–6 oktas of cloud in October and November was significant, but nevertheless too small to be of practical use; therefore all cases with a Beaufort force of 2 or more have been taken together. The forecaster not only wants to obtain a spot value, but also the interval between the extreme values that have occurred in analogous weather situations; these are taken from the data set and shown in Tables VII and VIII.

5. Probability of ground frost at Eelde

The data used for the construction of the forecasting tool for grass minimum depression, consisting of Tables V to VIII, can also be used for estimating the probability of ground frost. Table IX provides the probability of ground frost for April/May, given an observed minimum temperature. A similar table, valid for October/November, is not given here but shown in Floor (1989). The table can be rewritten, taking into account the error in the forecast value of the minimum temperature. Steele *et al.* (1969) elaborate such a case for a minimum temperature forecast with a systematic error of −0.3 °C and a standard deviation of 1.89 °C. Using these values and their method, the same was done for the Eelde data; the results are shown as Table X for April/May and give more realistic values for the

Table III. Grass minimum depression (°C) at Eelde for April/May, for 1983–88

Oktas	Soil	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	dry	0, 1	26	4.03	1.09
	moist		28	2.94	1.49
		2	58	2.38	1.34
		>2	67	1.13	0.62
6–8		0, 1	33	1.83	1.64
		2	55	1.16	1.25
		>2	99	0.56	0.56
	All cases		366	1.58	1.48

Table IV. Grass minimum depression (°C) at Eelde for October/November, for 1983–88

Oktas	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	0, 1	33	2.52	1.05
	2	56	1.58	0.89
	3	40	1.06	0.46
	>3	20	0.81	0.39
6–8	0, 1	29	0.94	1.20
	>1	188	0.52	0.48
All cases		366	0.97	0.93

Table V. Forecasting diagram for grass minimum depression (°C) at Eelde for April/May

Cloud amount	Wind speed (Beaufort force) <2		2	>2
0–5 oktas	dry soil	4	2.5	1
	wet soil	3		
6–8 oktas		2	1	0.5

Table VI. Forecasting diagram for grass minimum depression (°C) at Eelde for October/November

Cloud amount	Wind speed (Beaufort force) <2	2	>2
0–5 oktas	2.5	1.5	1
6–8 oktas	1	0.5	0.5

Table VII. Extreme values of grass minimum depression (°C) at Eelde for April/May

Cloud amount		Wind speed (Beaufort force) <2	2	>2
0–5 oktas	dry soil	1.9/6.0	−1.0/5.7	0.0/4.0
	wet soil	0.8/6.0		
6–8 oktas		−0.3/5.2	−0.4/5.2	−0.2/3.7

Table VIII. Extreme values of grass minimum depression (°C) at Eelde for October/November

Cloud amount	Wind speed (Beaufort force) <2	2	>2
0–5 oktas	0.0/4.5	0.0/4.2	0.1/2.5
6–8 oktas	−0.2/5.2	−0.6/2.4	

Table IX. Probability (%) of ground frost at Eelde as a function of observed minimum temperature and weather situation

Cloud amount (*oktas*)	Beaufort force	Soil	Forecast minimum (°C) 0	1	2	3	4	5	6
0–5	<2	dry	100	100	100	88	77	35	11
		moist	100	100	79	64	38	14	7
	2		98	94	70	48	20	6	1
	>2		100	97	13	3	3	–	–
6–8	<2		100	79	42	27	18	12	–
	2		100	43	7	3	1	–	–
	>2		100	73	27	15	7	2	–

Table X. Estimated probability (%) of ground frost at Eelde as a function of forecast minimum temperature and weather situation for April/May

Cloud amount (*oktas*)	Beaufort force	Soil	Forecast minimum temperature (°C) −4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
0–5	<2	dry	100	100	>99	99	97	93	85	72	56	38	22	11	5	2
		moist	100	>99	99	96	91	82	69	53	37	23	12	6	2	1
	2		100	99	98	94	86	75	59	42	27	15	7	3	1	–
	>2		100	98	96	88	75	57	37	20	9	4	1	–	–	
6–8	<2		100	98	95	89	78	63	47	33	21	12	6	3	1	–
	2		99	97	91	80	64	44	26	13	6	2	1	–	–	
	>2		100	98	94	87	74	56	39	23	13	6	3	1		

Table XI. Estimated probability (%) of ground frost at Eelde as a function of forecast minimum temperature and weather situation for October/November

Cloud amount (*oktas*)	Beaufort force	Forecast minimum temperature (°C) −4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
0–5	<2	100	>99	98	95	89	78	62	44	28	15	7	3	1	–
	2	100	99	97	91	81	65	46	28	15	7	2	1		–
	>2	>99	98	95	88	74	56	36	19	8	3	1		–	
6–8	<2	99	97	93	83	69	50	33	19	10	5	2	1	–	
	>1	99	97	92	81	64	45	26	13	5	2	–	–		–

probability of ground frost than Table IX. Table XI contains realistic estimates for the probability of ground frost in October/November. As in Table X the values for the forecast screen minimum temperature are shown in the top line.

6. Conclusion

The grass minimum depression in spring is different from that in autumn, therefore different diagrams have been constructed for April/May and for October/November, to be used in forecasting the grass minimum depression, at Eelde, starting from the forecast screen minimum temperature and weather type. Separate diagrams show the extreme values taken by the grass minimum depression in the period examined. Using the available data and following a method described by Steele *et al.* (1969) tables are presented that give a realistic estimate for the probability of ground frost.

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