

Variations in the Swedish winter road slipperiness

A. K. Andersson¹, T. Gustavsson² & J. Bogren³

^{1,2,3} Department of Earth Sciences, Physical Geography,
Road Climate Centre, Göteborg University, SWEDEN
Email: ¹ annaa@gvc.gu.se, ² torbjorn@gvc.gu.se, ³ jorgen@gvc.gu.se

ABSTRACT

Winter indices are a well-established tool for calculating the need for winter maintenance activities in relation to the climate. In this paper, data from 654 Road Weather Information System stations in Sweden were used during the five winter seasons, 1998/1999 to 2002/2003. They were used for studying the distribution of slippery conditions throughout Sweden. The number of incidents involving slipperiness during a winter season varies according to the location in Sweden and the manner in which the slippery conditions were formed. Winter indices were used to calculate the total number of slippery conditions. This was later compared to Sweden's latitudes. It shows a good correlation between the distribution of slipperiness and Sweden latitudes, both for the total slipperiness and the different types of slipperiness. When severe hoarfrost was analysed at the regional level, a high degree of correlation between slipperiness and latitude was found.

Keywords: slipperiness, winter road, Sweden

1. INTRODUCTION

Today, winter indices are a well-established tool for calculating the need for winter maintenance activities in relation to the climate e.g. [2], [3]. The qualities of the indices have progressively increased due to the fact that Road Weather Information Systems (RWIS) have been expanding and that much research has been dedicated to this area.

A combination of parameters is used in order to calculate the occurrence of different kinds of winter road slipperiness, i.e., road icing, hoarfrost, precipitation or drifting snow. These can be used to calculate the winter indices by adding the number of occasions of slipperiness together.

Calculations based on winter indices can be used in many different types of applications, both in the form of planning winter road maintenance and in economic follow-up studies [4]. The relationship between winter indices and maintenance costs has been explored in Scotland [1].

The aim of this study is to reveal if there is a particular pattern in the spreading of slipperiness on the Swedish winter roads, both in total slipperiness and in four different classes of slipperiness. These studies are performed in two different scales, both the entire country and on the regional scale. The different slippery situations were compared to the Swedish latitudes.

2. DATA AND METHOD

2.1 Study area

Sweden is used as a study area. The Swedish Road Administration uses both districts and counties in order to subdivide the country into smaller administrative units. In total there are 7 districts (Figure 1a). The districts are not similar in size but are still useful, as they form areas of similar characteristics. These districts are used as a base for the calculations. In order to analyse the influence of local and micro-factors, one district was selected for a more detailed study, namely Region Väst in the western part of the country (Figure 1b).

2.2 Swedish climate

The climate of Scandinavia and Sweden is influenced by the proximity to the sea and the large continent in the east. This results in a varying climate depending on which of the two that has the largest influence on the air masses and the weather systems. In general, the temperature in Sweden decreases with latitude. The coldest mean annual temperature is found in the areas of the mountain range in North West.

Data from five different winter seasons, 1998 – 2003, are used in this study. Since 1988, the annual mean temperatures in Sweden have been higher than the normal reference value, with the exception of 1996. On average, the mean annual temperature was about 1.3°C higher than normal between 2000 and 2003 [5-8]. The mean temperature in January for 1961-1990 can be found in Figure 1c, which shows the typical pattern of decreasing temperatures with increasing latitude.

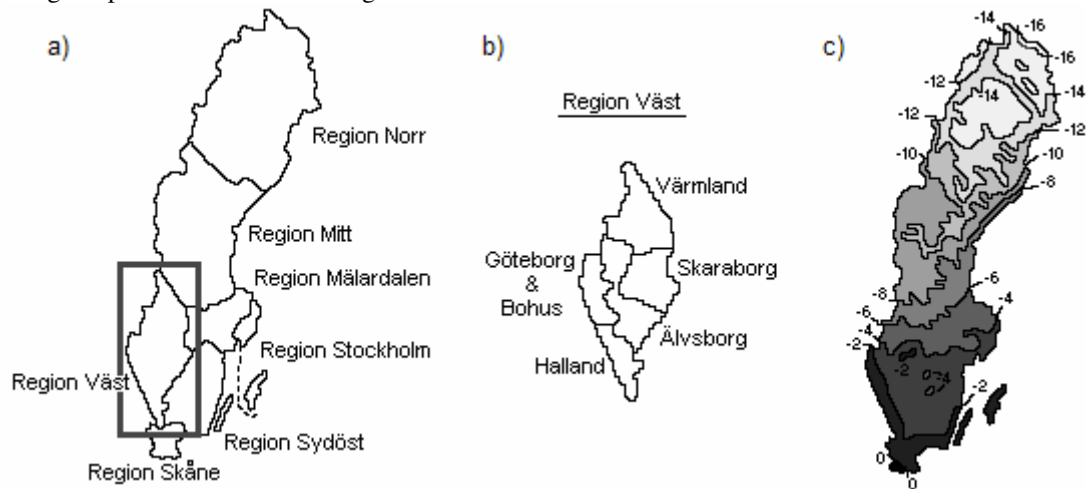


Figure 1 a) The seven districts in Sweden b) Counties in Region Väst c) Mean air temperature in January 1961-1990 redrawn from [9]

2.3 Road weather data and winter index

The data used in this study come from the field stations in the Swedish RWIS. Today, the system consists of more than 710 stations situated along the major roads in the country. The stations measure road surface temperature, air temperature, relative humidity, precipitation and wind speed. The dew point is calculated from air temperature and relative humidity. Measurements are collected every 30 minutes and stored in a database at the Swedish Road Administration for the winter months. For this study wintertime is defined as the period between October and April.

The winter index (WI) investigated in this paper consists of four different classes of slipperiness and can be written as follows:

$$WI = HR1 + HR2 + HT + HN \quad (1)$$

HR1 is moderate hoarfrost, HR2 is severe hoarfrost, HT is a moist/wet surface that freezes and HN is rain or sleet falling on a cold road. The index is increased by one each time the actual situation is registered.

2.4 Method

In total, data from 654 RWIS-stations were used for the winter seasons 98/99 – 02/03. All stations were checked for missing data. The number of stations varies between the different districts, as well as between the years. See Table 1 for the number of stations.

To compare slipperiness in the different districts and between different winters, the mean value of the number of occasions on which slippery conditions developed was calculated for each state of slipperiness and each county in Sweden for the five winters 98/99 – 02/03. There were very few days on which there was a recurrence of the same type of slipperiness, thus every occasion of slipperiness will henceforth be called one day of slipperiness.

Season	Skåne	Sydöst	Väst	Stockholm	Mälardalen	Mitt	Norr
98/99	33	52	87	26	36	107	72
99/00	35	52	88	26	37	111	72
00/01	36	53	95	30	38	118	76
01/02	36	53	95	30	38	117	76
02/03	36	53	94	31	38	117	76
Mean of stations	35	53	92	29	37	114	74

Table 1 Number of stations in use in each district

The first step in the analysis of the distribution of the pattern of slipperiness in Sweden looks at the relation with latitude. The latitude used is an estimated mean value for the region. The calculated winter index and the individual types of slipperiness are investigated for each region and each winter season.

3. RESULTS

3.1 Distribution of slipperiness – a country perspective

The mean value of the total number of incidents of slipperiness for the five studied winters is shown in Figure 2a. A clear distribution can be seen, i.e., that the total number of situations increases towards the north. There are approximately twice as many situations of slipperiness in the north in comparison to the southern parts of the country.

The results presented in Figure 2a show a very clear pattern regarding the distribution of slipperiness calculated by use of WI. One of the factors that could be the cause of this variation is a longer winter season in the north compared to the south, i.e., the gradual decrease in temperature with latitude.

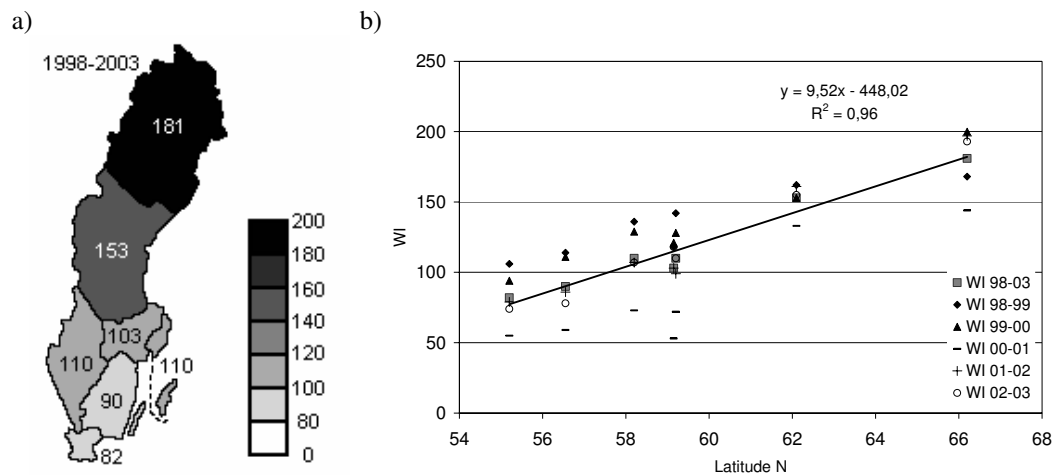


Figure 2a) Mean value of the distribution of the days with slipperiness (WI) in Sweden for the 1998-2003 period
 b) Relation between latitude and WI, the correlation is 0,96 for the 1998/2003 period

Calculating the number of slipperiness occasions (WI) as a result of variation in latitude shows that latitude can be closely correlated as an explanatory factor for the WI distribution. Figure 2b shows the relation between latitude and WI for each of the years, both separately and for the entire period.

The distribution of WI is well correlated to the latitude. Nevertheless, it is also important to consider the separate slipperiness situations which constitute the index, as well as the variation between different years.

3.2 Distribution of slipperiness in Sweden divided into seven regions

The distribution of the total number of days with slippery conditions (WI) for each winter season (see Table 2) follows the same pattern as shown in Figure 2a, WI for the years 1998-2003. In general, there are fewer days with slippery conditions in the south. Region Sydöst has had a smaller number of days with slippery conditions than Region Väst during all studied winters. Region Mälardalen varies the most during the five seasons; it varies from a mean value of 53 days in the winter season 2000/2001 to 121 days in the previous year.

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		Region Skåne	Region Sydöst	Region Väst	Region Mälardalen	Region Stockholm	Region Mitt	Region Norr
Latitude		55,2	56,55	58,2	59,15	59,2	62,1	66,2
Year								
WI	98/03	82	90	110	103	110	153	181
	98/99	106	114	136	118	142	162	168
	99/00	94	111	129	121	128	153	200
	00/01	55	59	73	53	72	133	144
	01/02	79	86	107	103	99	161	197
	02/03	74	78	107	118	110	155	193
HR1	98/03	37	44	50	51	53	68	70
	98/99	48	56	62	57	66	72	67
	99/00	42	56	56	60	59	77	64
	00/01	25	28	37	29	35	64	61
	01/02	35	42	49	53	50	74	71
	02/03	37	36	47	54	53	68	76
HR2	98/03	11	15	27	23	26	55	85
	98/99	14	18	28	24	31	64	78
	99/00	13	17	34	27	34	58	94
	00/01	6	10	13	9	16	38	58
	01/02	13	18	30	24	18	56	95
	02/03	7	13	27	32	30	62	100
HT	98/03	21	14	15	12	14	11	9
	98/99	24	17	19	15	19	12	9
	99/00	24	18	19	14	15	14	12
	00/01	12	11	11	6	10	12	9
	01/02	22	14	14	13	16	9	8
	02/03	20	12	12	13	12	9	8
HN	98/03	13	16	19	17	17	18	16
	98/99	21	23	27	22	25	15	14
	99/00	15	19	20	20	20	17	17
	00/01	12	10	12	9	11	19	16
	01/02	9	12	13	13	16	22	23
	02/03	11	16	21	19	14	16	9

Table 2 Distribution of slippery conditions according to district, both in total (WI) and separately, for the different types of conditions.

3.3 Distribution of different types of slippery conditions

When it comes to the separate classes of slipperiness, the distribution pattern differs according to type. The correlations (R^2) between latitude and slipperiness are shown in Table 3.

Season	WI	HR1	HR2	HT	HN
98/03	0.96	0.84	0.96	0.77	0.07
98/99	0.83	0.60	0.93	0.82	0.53
99/00	0.97	0.52	0.96	0.70	0.01
00/01	0.82	0.78	0.91	0.08	0.45
01/02	0.94	0.85	0.90	0.74	0.90
02/03	0.98	0.95	0.99	0.67	0.12

Table 3 Correlation (R^2) between latitude and slipperiness during the different winter seasons

3.3.1 Moderate hoarfrost (HR1)

Slipperiness of the type moderate hoarfrost (HR1) is most common in the northern part of Sweden, i.e., in Region Mitt and Region Norr. In the southern half of the country there is no clear pattern, except from a few more occasions of hoarfrost in the western part of the country. The correlation for moderate hoarfrost as a result of latitude varies from a value of $R^2=0,52$ to 0,95 which means that latitude can explain the distribution quite well.

3.3.2 Severe hoarfrost (HR2)

Severe hoarfrost (HR2) also occurs most frequently in the northern parts of Sweden. In Region Skåne and Region Sydöst the number of days with severe hoarfrost is very low. For example, in the winter of 2000/2001 there are only six days of slippery conditions in Region Skåne. The distribution pattern of severe hoarfrost differs very little between the seasons.

3.3.3 Road icing (HT)

Road icing, i.e., moist/wet roads that freeze (HT), shows a contrary pattern to that found in the class of slipperiness which is dependent on hoarfrost. The larger value is found in the southern parts of Sweden and decrease further north. The only exception is in the winter of 2000/2001, where the number of days is almost the same in the seven regions. The only deviation is in Region Mälardalen and Region Norr, where the number of days is six and nine respectively, while the other regions have 10-12 days.

For road icing the distributional pattern is quite different compared to the previous hoarfrosts and total index (WI). There is a marked change in the trend, which indicates an opposite direction, i.e., an increased number of situations towards South. There is also a larger difference between the separate seasons for this type of slipperiness.

3.3.4 Rain or sleet on a cold road (HN)

Slipperiness caused by rain or sleet on a cold road (HN) shows no specific pattern; furthermore, it shows frequent variations between the seasons. One year there is a higher number in the southern parts, while the following year, the highest values of this type is found in the northern regions. In the winter seasons 1998/1999, 1999/2000 and 2002/2003, Region Väst has the largest number of days with slipperiness caused by precipitation on a cold road.

The distribution of the slipperiness of the type “rain/sleet on a cold road” (HN) is not related to latitude.

3.4 Distribution of slipperiness – a regional perspective

The distribution of days with slipperiness (WI) follows the same pattern in Region Väst as the rest of the country. In the southern part of Region Väst there are fewer occurrences of slippery conditions than in the northern part of the county (Figure 3a).

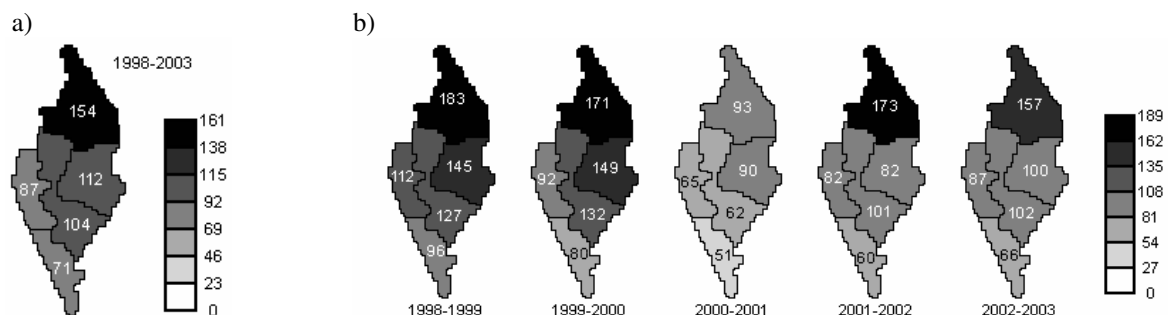


Figure 3a Mean value of the distribution of the days with slippery conditions (WI) in Region Väst 1998-2003
 b) Distribution of slipperiness in total (WI) in Region Väst

When Region Väst is studied year by year (Figure 3b), there is a larger difference between the counties. The slipperiness in Region Väst is increasing towards northeast. Halland has the lowest incidences of slippery conditions in all of the five winters that were studied and Värmland had the highest incidences.

3.5 Distribution of different types of slippery conditions in Region Väst

Slipperiness which arises on account of both moderate and severe hoarfrost appears to have the same pattern in Region Väst as in the entire country, increasing towards the north. HR1 spread to the northeast, while HR2 has a more northerly direction.

Slipperiness on account of moist/wet roads which freeze, or due to rain or sleet on a cold road has a more diffuse pattern in Region Väst. HT has a slight tendency to increase towards the east. HN has the most irregular pattern; the precipitation appears to be spread evenly over the region. There is a weak indication of an increasing degree of slipperiness towards North, when wet roads freeze to ice.

4. DISCUSSION AND CONCLUSION

Slipperiness is distributed differently in Sweden depending on the type of situation. The mean temperature gives a general picture of the total slipperiness (WD), i.e., latitudinal dependency. Slipperiness caused by severe hoarfrost tends to increase towards the north i.e., the latitude control. Moderate hoarfrost, on the other hand, is not dependent on latitudes and road icing thus tends to decrease towards the north. It appears that scale does matter. This study has showed that differences in latitude and the winter weather are the most important on a regional level. A variation in time and space of the slipperiness is also evident.

The variation in the distribution of different kinds of slippery conditions within Sweden means that the related costs vary accordingly. Results from this study give a broad picture of how slipperiness is distributed in different scales as a result of varying winter climates. It will be possible to calculate costs related to the changes needed in winter maintenance; using these results as the basis of future climate change studies could influence the distribution of slippery conditions in Sweden. In addition, it might be possible to establish the future costs of winter road related accidents and other disturbances which are costly to society.

5. REFERENCES

- [1] Cornford, D. & Thornes, J. E. (1996) A comparison between spatial winter indices and expenditure on winter road maintenance in Scotland. *Int. J. Climatol.*, **16**: 339-357.
- [2] Gustavsson, T. (1996) Test of indices for classification of winter climate. *Meteorol. Appl.*, **3**: 215-222.
- [3] Heiberg Mahle, A. & Rogstad, G. (2002) NORIKS - A Winter Index for Norwegian Conditions. *Proceedings of the 11th SIRWEC Conference, Sapporo, Japan, 2002*. Available from: <http://www.sirwec.org/conferences/sapporo2002.html> [Accessed Apr 2005].
- [4] Sherif, A. & Hassan, Y. (2004) Modelling pavement temperature for winter maintenance operations. *Can. J. Civil Eng.*, **31**: 369-378.
- [5] SMHI (2000) Väder och vatten, Väderåret 2000, SMHI, Nr 13/2000.
- [6] SMHI (2001) Väder och vatten, Väderåret 2001, SMHI, Nr 13/2001.
- [7] SMHI (2002) Väder och vatten, Väderåret 2002, SMHI, Nr 13/2002.
- [8] SMHI (2003) Väder och vatten, Väderåret 2003, SMHI, Nr 13/2003.
- [9] SMHI (2004) Medeltemperaturen 1961-1990 januari, *in swedish*. Available from: <http://www.smhi.se> [Accessed Jun 2004].