IRWIN

Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios

Final Report

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Executive summary

The main objective of IRWIN is to develop an improved winter road index capable of assessing the implications of climate change in various weather parameters and also related road maintenance actions.

Climate change scenarios have so far been calculated based on ordinary meteorological data, which have large limitations in respect to resolution. The idea of IRWIN is to combine the best traditionally made climate scenarios with the much more accurate spatial data from field stations in the Road Weather Information systems (RWIS) installed in most northern hemisphere countries.

This Final Report presents first briefly the results of the two inception reports: state-of-the-art of climate models and winter index formulation, the data collection and database formation phase of the project. The objective was to develop a novel database of possible future road condition scenarios by combining archived historical RWIS data with widely accepted climate change scenarios. Observations from the Swedish and Finnish RWIS stations were collected from national Road Administrations from as long time span as has been archived with homogeneous contents and quality. The target was to get 10 years of observations of air and surface road temperature, moisture, wind speed, rainfall amount and precipitation type.

The data collection phase of IRWIN revealed that there is enough archived RWIS data in Sweden and Finland to perform the planned winter index development. Ten years of observations were collected from 50 road weather stations in Sweden and 49 stations in Finland. Observations in each country were divided into three regions with distinctive climatic characters. Extensive processing had to be performed first to create a high-quality database with corrected and uniform observations. The Finnish and Swedish data were reformatted to similar data format. Maintenance activities from the regions of interest were collected as well, to be used in winter index calculations.

Once a good quality observational database was completed, the climate downscaling task was started to establish the climate database. Weather classes were developed to select the historical analogue days matching the future days.

The final phase of the project developed a winter index technique to evaluate temporal and spatial variations of some weather parameters and corresponding winter maintenance needs. The results showed that temperature would increase most in the northern areas in Sweden and Finland. Same areas will experience a larger amount of events when there is a shift from plus to minus degrees, and therefore need more maintenance due to slipperiness caused by this shift. Only the region in southwestern Sweden will in the future have fewer days when temperature shifts from plus to minus degrees due to a warmer climate in that area.

The future will bring more rainy days on a cold surface in the north due to the milder climate and more rainy days in the north instead of precipitation falling as snow. The northern areas will also experience more slipperiness due to frost days when the surface temperature is low and the dew point is larger than the surface temperature. These frost days will occur less frequently in the future in the more southerly areas, due to fewer days with minus degrees. Higher temperatures will also result in precipitation falling as rain instead of snow, which can be seen as a large decrease of ploughing events indices.

The need for maintenance operations will change in the different regions as the climate changes. A warmer climate can both mean more needs for salting due to more slippery roads but at the same time less ploughing events when precipitation falls as rain instead of snow.

The index developed in this study has shown to be a useful tool for future maintenance operations. It can give valuable information to stakeholders as to where and when measures need to be taken. Possibilities were also investigated of using road weather data from other ERA-NET countries to perform similar calculations. Similar assessments could be done relatively easily if enough road weather information was archived and available. Taken into account the seriousness of climate change and its implications, it is highly recommended that Road Owners if not yet do so, start operational archival and quality control of all road weather observations in their countries. Standardisation of data formats is also recommended.

Table of contents

List of Tables

List of Figures

1 Introduction

“ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” is a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) are United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Federal Ministry of Transport, Innovation and Technology (BMVIT), Austria, Federal Ministry of Transport, Building and Urban Affairs (BMVBS), Germany, Ministry of Transport, Danish Road Directorate (DRD), Denmark, Centre for Studies and Research in Public Works (CEDEX), Spain, Finnish Road Administration (Finnra), Finland, National Roads Authority (NRA), Ireland, Directorate of Public Works and Water Management (RWS), the Netherlands, Norwegian Public Roads Administration (NPRA), Norway, General Directorate of National Roads and Motorways (GDDKiA), Poland, Swedish Road Administration (SRA), Sweden, and Department for Transport, Highways Agency (HA), the United Kingdom.

IRWIN is one of the research and development projects initiated by ERA-NET ROAD in 2008. The main objective of IRWIN is to develop an improved winter road index capable of assessing the implications of climate change in various weather parameters and also related costs and benefits of winter road maintenance actions.

Climate change scenarios have so far usually been calculated based on ordinary meteorological data, which have large limitations in respect to resolution. The idea of IRWIN is to combine the best traditionally made climate scenarios with the much more accurate spatial data observed by field stations in the Road Weather Information systems (RWIS). These are installed in most northern hemisphere countries being susceptible to wintertime weather hazards to road traffic.

IRWIN started on 1st November 2008. The First Inception Report was delivered to ERA-NET ROAD in January 2009, presenting the IRWIN Work Plan in more detail, state-of-the-art of Global Climate Models (GCM), winter indexes and recent studies on climate impact on road network (IRWIN 2009a).

The Second Inception Report was delivered on 1st June 2009 (IRWIN 2009b). Report describes the data collection and database formation phase of the project. The objective was to develop a novel database of possible future road condition scenarios by combining archived historical RWIS data with widely accepted climate change scenarios. Observations from the Swedish and Finnish RWIS stations were collected from national Road Administrations from as long time span as has been archived with homogeneous contents and quality. The target was to get 10 years of observations of air and surface road temperature, moisture, wind speed, rainfall amount and precipitation type.

After the initial data collection phase, the raw archived observational data had to be processed into regular interval time series. The Finnish and Swedish data were reformatted to similar data format. Once a good quality observational database was completed, the climate downscaling task was started to establish the climate database. Weather classes were developed to select the historical analogue days matching the future days.

The final phase of the project developed a winter index technique to evaluate such phenomena as the spatial variations of winter maintenance needs as well as the cost/benefit of various winter maintenance strategies. Possibilities were investigated of using road weather data from other ERA-NET countries to perform similar calculations.

Target user groups of IRWIN results are the road owners and administrations in ERA-NET countries and the European Union. In addition to this Final Report which is available to key users, results will be presented in transport forums, reviewed scientific papers and conferences in 2009 and 2010.

In this report, the next two Chapters 2 and 3 summarise briefly the key findings of earlier Inception reports (IRWIN 2009a, IRWIN 2009b). Chapter 2 gives a short summary of the state-of-the-art of climate models and winter indexes. Chapter 3 summarises the data collection phase and the formation of IRWIN database.

Chapter 4 presents the final project results. Climate of the studied areas in Sweden and Finland and climate scenarios for those areas are presented, followed by results of downscaling using RWIS data. The calculated IRWIN index is presented with an example of its use in assessing winter maintenance needs. Chapter 5 presents the evaluation of quality of data, user benefits and analyses the possibilities to extend IRWIN index to other areas in Sweden and Finland, and even further to other ERA-NET countries. Conclusions and references are the two last Chapters of this report.

2 State-of-Art

2.1 Climate Models and scenarios

Global climate models (GCMs) represent the atmosphere-land-ocean system as a three-dimensional grid in a computer program, which encodes well-established basic laws of physics, fluid motion, and chemistry. By repeating the calculations many times, the evolution of global climate change can be investigated.

GCMs cannot be used to determine what weather phenomena will occur at a given time and place in the future, but they can be used to estimate the effect of changed conditions, and in particular, changes in greenhouse gasses in the atmosphere. GCM outputs can be used to answer questions such as – what is the average change, at a particular place, over a period of time?

Approximately twenty GCMs have been developed by research groups around the world. These are able to reproduce many observed features of recent and past climate changes, and there is considerable confidence that they provide credible estimates of future global temperature change at continental and larger scales. All GCMs show global temperatures will increase as greenhouse-gas concentrations increase. Model inter-comparisons have shown, however, that the level of temperature increase is different among different models.

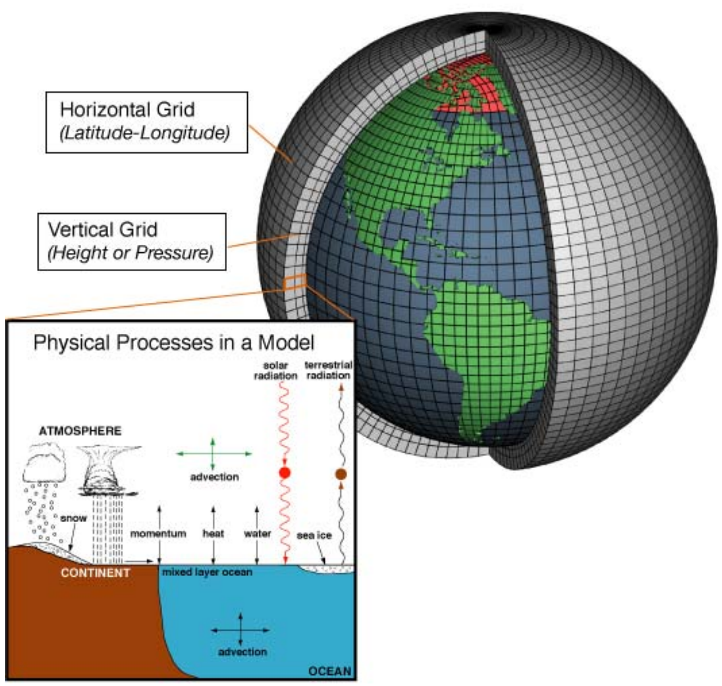

Figure 1: Global Climate model schematic. Source: http://celebrating200years.noaa.gov/breakthroughs/climate_model/modeling_schematic.html

Neither GCMs nor regional climate models (RCMs) are sufficiently accurate or detailed to allow road weather conditions to be simulated directly. Instead, road-weather time-series must be derived from GCM or RCM outputs using statistical relationships between large-scale atmospheric patterns (which GCMs simulate well) and the observed road weather, a process known as *empirical statistical downscaling*. The relationships between the large-scale atmosphere and the road weather must be determined by analyzing historical atmospheric patterns and road weather time-series. A simple statistical downscaling technique, which can and has been confidently be applied for this project is the *analogue model*. This method involves iterating over each day in the GCM future scenario, and for each day finding the day in the historical record for which the large-scale atmospheric patterns match most closely. The future road-weather for each future day is taken to be the historical road-weather on the most closely matched historical day.

As is impossible to know how much greenhouse gas our civilization will produce in the future, most GCM simulations use hypothetical *emissions scenarios* from the Special Report on Emissions Scenarios (SRES) report prepared by the Intergovernmental Panel on Climate Change (IPCC). The scenarios most commonly used in climate modeling are used, from the lowest B1 to highest A2. Scenario A1B represents a balance across all energy sources.

IRWIN analysis will use the same GCM outputs which were used to support the IPCC 4th Assessment Report (AR4), so the project results will be compatible with the scientific conclusions from that report.

Figure 2 shows the average projected temperature increase, calculated using all GCMs considered in AR4, under the SRES A1B scenario. The models generally project higher warming over land than over the oceans, with the exception of the Arctic where very large temperature increases are projected.

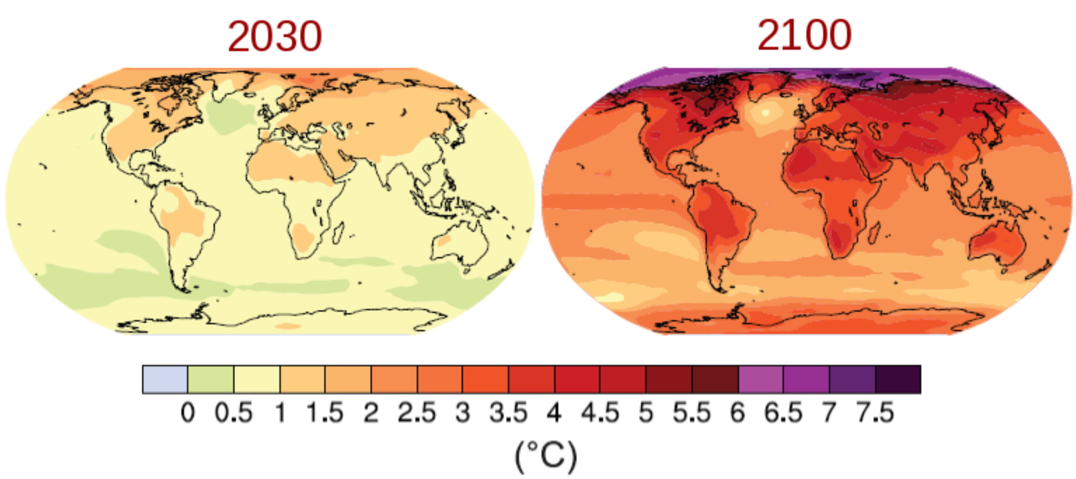

Figure 2: Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999, showing multi-model average projections for the A1B SRES scenario averaged over the decades 2020– 2029 (left) and 2090–2099 (right). [From IPCC 2007:WG1 -AR4 Figure SPM.6]

The effects of climate change on road networks are a matter of great concern to road owners, as many decisions especially on investments in the infrastructure may have implications over decades. A change in the impacts may cause a need to change road structures. Improvements of drainage, erosion control and raising the road surface levels may be needed. Other adaptation and proactive measures are control of design criteria and improvement of current roads to assure the service level. Services for road users may need changes as well, in order to deliver appropriate warnings and other valid information through the most efficient channels.

A feature common to all climate scenarios is that the changes will be most dramatic near the poles and during the winter, due to the positive feed back effects of the shrinking snow and ice coverage. According to Saarelainen and Makkonen (2007), some of the most probable and prominent changes in the Finnish climate affecting the road maintenance will be:

- Mean annual temperature will rise by 3-5 ^{o}C.
- Maximum temperatures will rise by 5 ^{o}C in summer and 10 ^{o}C in winter.
- Annual rainfall amount will increase by 15 %.
- Risks for heavy rainfall showers and flash flooding will increase. The probability of very heavy showers will increase by 25%, and by 50% in certain areas.
- Though snowfall amounts will decrease in southern parts of the country, the number of traffic disturbances due to heavy snowfall will increase.
- The total amount of freezing and melting cycles will decrease in southern parts of the country but will increase further north.
- Even though there are no indications that destructive storms will increase, trees will fall more easily during wintertime storms. The reason is because the layer of thawing will be thinner in the future.
- It will be more and more difficult to maintain the present ice roads.

2.2 Winter indexes

Winter indexes describe the main characteristics of the road climate in an area and relate to the amount of maintenance activity needed. Index calculations can show the severity of winter in a specific area by comparing different climate parameters, or compare the climate between different years or seasons. Winter indices can be utilized for several applications and needs, e.g. to calculate the cost effectiveness of winter maintenance system in general, to perform more detailed cost/benefit calculations, to assess the cost effectiveness of an already existing warning system, or to calculate maintenance costs for a specific area.

With IRWIN index the objective of development and key application has been somewhat different, relating to the rapidly progressing climate change and urgent needs to get new tools for strategic decision-making. Using IRWIN, it should be possible to calculate the present need for maintenance activities but also the need for activities that can be predicted to occur based on climate scenarios. Linking index calculations to maintenance costs allows making of cost/benefit analyses today but also in the future.

The factors that need to be taken into account when developing a Road related Winter Index are:

- *Ice*. It is common to use temperature falls from positive to negative degrees to indicate the risk of ice formation and the need for salting operations.
- *Precipitation* in the form of snow or water. Types include direct snowfall, with air temperatures below 0^{o}C, melting snow, or drifting snow when the snowfall occurs with strong winds. Rain, especially intense rain, may influence road safety by decreasing visibility and by causing aquaplaning. Super cooled rainwater or rains preceded by cold weather are hazardous as well since they may cause ice on the roads.
- *Wind*. Strong winds may force vehicles off the roads or in unwanted directions. Fallen trees or flying materials such as tree branches or litter may be troublesome to drivers. Winds may also create road blocks from drifting snow.

3 Data collection and data base

3.1 RWIS data

From the total number of about 760 RWIS stations in Sweden, 50 were selected for the IRWIN analysis from three different areas in Sweden: southwestern region with 24 stations around Gothenburg, 12 stations in the east around Stockholm and 14 stations in northeast around Sundsvall. These three areas represent three different types of climate in Sweden. The southwestern region was the test area for this project, and these stations were used to establish methods to be used, and to develop routines for quality assurance etc.

The stations in the three different areas are spatially distributed over an area of approximately 10.000 – 20.000 km^2. The topography varies within the regions as does the closeness to the sea or larger water bodies, openness, and vegetation cover. The station locations also represent various local climates within the areas, which makes it possible to analyse variation due to this factor in respect of maintenance needs.

The RWIS stations in Sweden are adminsitered by the Swedish National Road Administration. The data used for this project include: precipitation type and amount, surface and air temperature, wind speed and direction and dew point (calculated from humidity), for the winter period (November-to-March), 1998 to 2008.

The Finnish Road Administration (FinnRA) has been developing the national road weather observing network since the 1970's. Archived observations exist from 1997 onwards. Today the network consists of some 500 stations covering also Lapland, the northernmost parts of the country. However, existing road weather stations in Lapland do not have long enough measuring time series, and that is why the climatic regions had to be selected more south compared to what was originally intended. Altogether 49 stations were selected from three climatic regions:

- The southwestern corner of Finland is the warmest, having most winter road maintenance problems related to temperatures around 0 degrees and risk for slipperiness.
- The southeastern corner of the country has more continental climate due to the effect of the large Eurasian continent in the east. The coastal region has similar problems as in the southwest, but inland the wintertime average temperature is several degrees lower compared to the southwestern region.
- The northeastern area has typical continental climate with lower average temperature and higher snowfall amounts. Snow removal is the largest road maintenance concern during winter.

See Chapter 4.1.1 and Figure 4 for the map of study area and selected RWIS stations.

3.2 Maintenance data

In Sweden the road network is divided into 5 classes depending on the traffic on the roads. Motorways are class 1 roads and the most important in regard of maintenance. Basically they should always have summer road conditions. Class 5 roads are smaller roads with almost no traffic, and the criteria for these roads are lower.

For future improvements of the road maintenance a connection will be made between the historical maintenance data and the RWIS station´s climate data. Existing maintenance data includes for example which road stretch has been salted or ploughed, the date and time when the measure has been done, and how much salt has been used.

In Finland, the quality requirements for winter road maintenance were revised recently. As in Sweden, the road network has been divided into five classes. Finland is divided into 82 winter road maintenance areas. Data from maintenance areas corresponding to the selected IRWIN stations, 22 areas altogether, were collected to separate files from FinnRA's AURA-database. The monthly usage of salt was available from 2003 onwards. All maintenance actions were collected to a specific file containing information on ploughing of snow and slush, liquid salting, point and line salting, and other maintenance actions such as removal or packed ice or friction observation.

3.3 The IRWIN database

The IRWIN database is stored as a compressed directory tree. The layout of the IRWIN database is shown In Figure 3 on the next page. The data files are arranged under the top-level directories SWEDEN and FINLAND, then by dataset (historical or scenario), and finally by region. The same folder layout is used for the historical and scenario directories.

The IRWIN database, including both the error-corrected RWIS data and downscaled simulations, will be made publicly available from the University of Gothenburg via http://rcg.gvc.gu.se/data/IRWIN/index.html

Data file format is described in detail in the Second Inception Report (IRWIN 2009b).

- Sweden.zip
    - README.txt
    - HISTORICAL
      (error-corrected and patched data files)
        - Gothenburg
        - Stockholm
        - Sundsvall
    - mpi_echam5
      (simulations covering 1961-2100)
    - ncar_ccsm3_0
      (simulations covering 1961-2100)
- Finland.zip
    - README.txt
    - HISTORICAL
        - NE
        - SE
        - SW
    - mpi_echam5
      (simulations covering 1961-2100)

Figure 3. Layout of the IRWIN database.

4 Final results

4.1 Climate of the studied areas

Historical observations were analyzed to understand how the actual climates in the study areas were, to see the natural variations in climate both within and between the six different regions (Fig. 4) and to be able to compare the observed values to the future modeled changes. Data from the 1st of October to the 31st of March, 1997 to 2008 were studied, and it was on this historical data that the modeled future scenarios were done. In chapter 4.1.2 future scenario changes are presented.

4.1.1 Past climate

a) Temperature

The mean historical observed road and air temperatures showed that the temperature decreases in a northeasterly direction, following the expected trend caused by less short wave radiation towards the north and a larger influence from continentality towards the east. As an example mean road temperature in S1 region in southern Sweden from 1st of November to 31st of March during the ten year period was 0.63˚C and in the F3 region in north eastern Finland the mean road temperature was -5.5˚C. See Table 1 below for more values.

There is also a local variability in the temperatures within the regions, and this is mainly due to the positions of the road weather stations, in respect of their local climate environments. Some stations are positioned in valleys or on bridges where the climate is colder, while other stations are situated in more flat and open areas, normally referred to as the influence from local and microclimate factors.

Table 1. Mean road and air temperature per region from the 1st of October to the 31st of March, 1997 to 2008.

Area	Road T (˚C)	Air T (˚C)
S1	0.63	0.78
S2	-0.44	-0.24
S3	-4.52	-4.10
F1	-2.38	-2.39
F2	-4.05	-4.29
F3	-5.50	-5.50

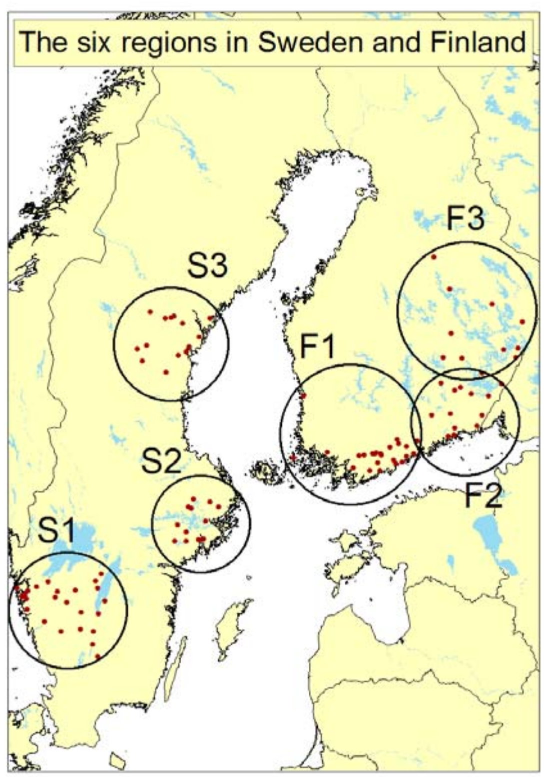

Figure 4 The six regions and the stations in Sweden and Finland.

The examined areas show a great joint variability both regarding air and surface temperatures. The natural climate variations in the two countries are therefore covered by these six defined regions, and they can give valuable information on the climate changes to come both locally and on a regional scale.

b) Precipitation

The precipitation pattern, in the winter season from 1997 to 2008, shows that the regions in Finland have generally higher precipitation than the regions in Sweden. F2 and F3 in northern Finland have more snow while S1 in southwestern Sweden has more rain. As expected the colder regions have more snow than rain compared to the more southerly regions. The area with the highest total precipitation during the winter season from 1997 to 2008 was F2 (Table 2).

Table 2. Precipitation as snow, rain and combined total amount. Values are expressed as the total amount per season.

Area	Snow (mm/season)	Rain (mm/season)	Total precipitation (mm/season)
S1	95.65	151.19	246.84
S2	99.95	60.68	160.63
S3	158.79	21.16	179.94
F1	183.04	95.02	278.06
F2	254.71	81.20	335.91
F3	262.38	43.41	305.79

Precipitation extremes showed that the areas in Finland have much more extreme precipitation than Sweden, and especially area F2 in southeastern Finland (Table 3). This large difference in precipitation between the two countries might however be caused by the different precipitation measuring techniques used in the two countries.

Area S1 in southwestern Sweden was the area with the most extreme precipitation events in Sweden, which is line with what can be expected due to its more exposed position towards the west and therefore more influenced by the low pressure systems.

Table 3. Extreme precipitation expressed as mean number of events (30 minutes) per area and season.

Area	Precipitation 1-3mm	Precipitation 3-6mm	Precipitation 6-9mm	Precipitation >9mm
S1	36.31	1.99	0.20	0.03
S2	12.08	0.43	0.06	0.00
S3	9.66	0.18	0.01	0.00
F1	40.40	3.91	0.34	0.20
F2	46.83	5.46	0.67	0.23
F3	37.90	3.00	0.29	0.20

There is also a spatial difference of the mean precipitations over time. All three areas in Sweden show different patterns of when the precipitation extremes occur. Especially the really extreme precipitations show large spatial deviations.

The S1 area in southwestern Sweden was chosen to illustrate the local variability and spatial scatter within one region (Figure 5). In the maps below it is shown that the coastal stations have more precipitation extremes than the inland ones. The station in bright blue in the top two maps is positioned on "Tjörnbron", a bridge in the archipelago, which has shown very high precipitation values before.

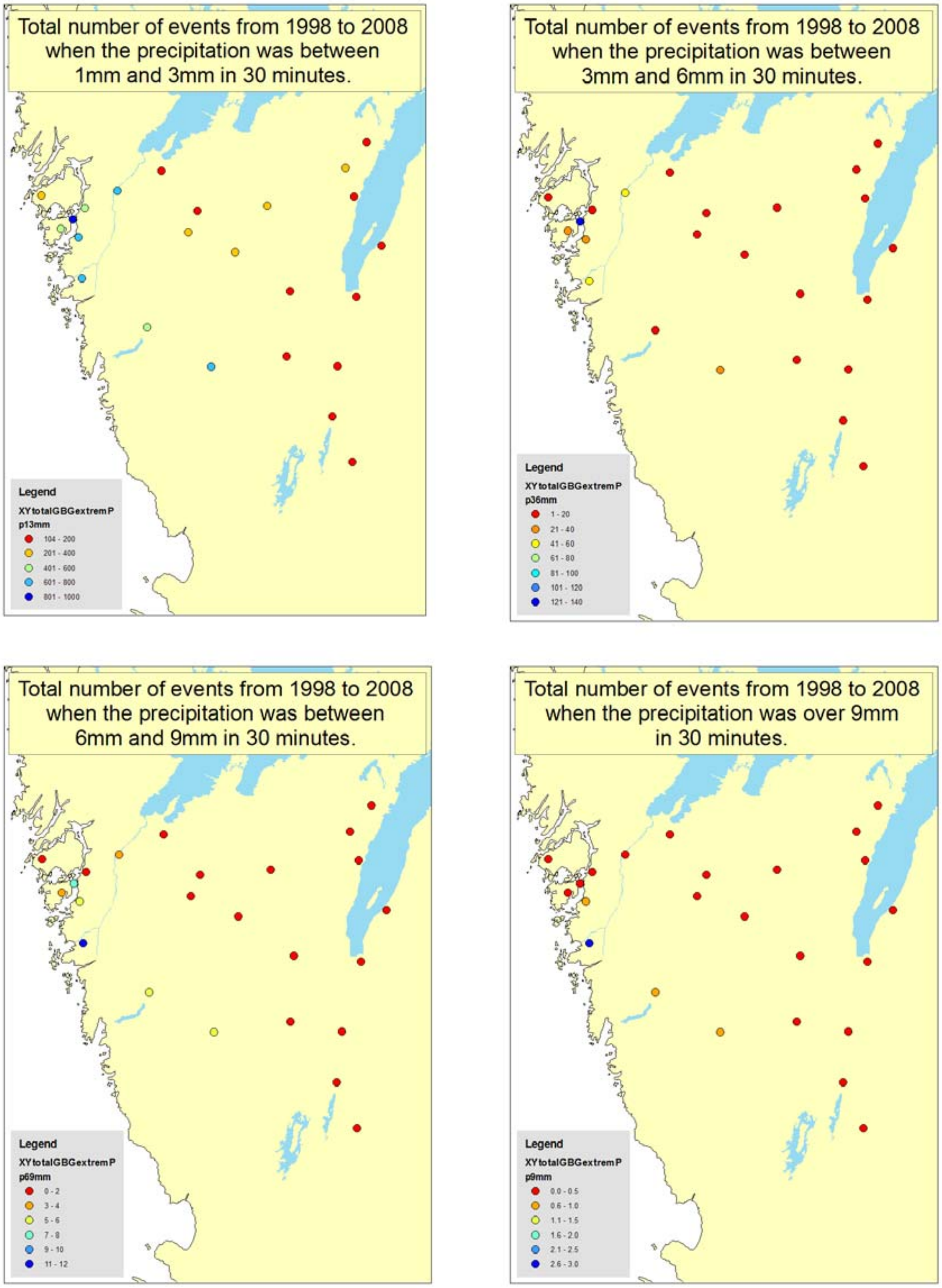

Figure 5. Local variability of extreme precipitation during the winter season 1997 to 2008. Values are total number of extreme events (30 minutes) during the ten-year period.

c) Wind

The historical observations of the wind speed show that it decreases towards the north east. S3 in northern Sweden was the area with the lowest values. The highest wind speed was found in the southwestern Sweden, the S1 region, both for mean maximum wind speeds and mean winds (Table 4).

Table 4. Mean max and mean wind speeds per region during
the ten year historical period.

Area	Mean max wind (m/s)	Mean wind (m/s)
S1	5.28	2.69
S2	4.51	2.27
S3	3.22	1.31
F1	4.33	1.82
F2	3.85	1.63
F3	3.59	1.51

Table 5 shows the wind extremes and the seasonal mean number of events per area from 1997 to 2008. The S1 area in southern Sweden is most exposed for extreme high winds, and the F3 area in northern Finland the least. Values were derived from the maximum winds recorded by the stations.

Table 5. Wind extremes expressed as mean number of events (30 minutes) per area and season.

Area	Wind 10-15m/s	Wind 15-20m/s	Wind 20-25m/s	Wind 25-30m/s	Wind >30m/s
S1	641.35	93.45	11.23	1.44	0.17
S2	361.58	25.08	1.49	0.12	0.00
S3	147.51	14.97	0.81	0.02	0.00
F1	301.30	23.73	1.37	0.11	0.00
F2	193.43	7.92	0.20	0.00	0.00
F3	79.16	0.94	0.03	0.00	0.00

The spatial scatter of wind speeds within one region shows that the coastal areas generally experiences higher winds than the inland areas (Figure 6). Otherwise the scatter is quite well spread, due to the different positioning of the stations in the landscape.

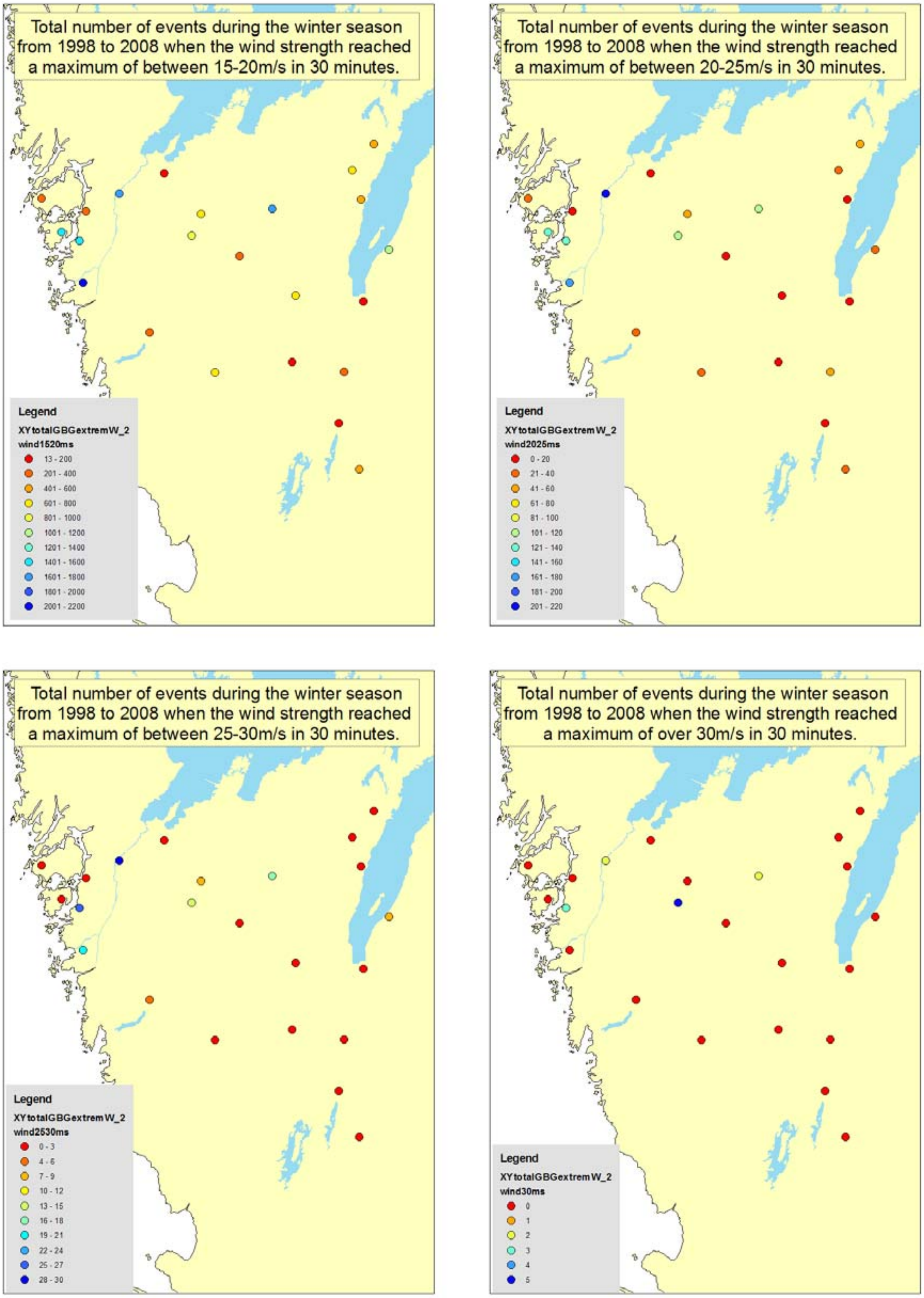

Figure 6. The maps illustrate the total number of events when a certain wind speed was reached in a 30 minute interval. Station 1407 on the bridge "Tjörnbron" in the archipelago was removed because of the extremely high wind values.

4.1.2 Climate scenarios

In this study the change in climate was calculated as the average temperature, precipitation or wind speed during the winter period (1st of November to the 31st of March) from 2025 to 2055 minus the average from the same months from 1980 to 2010. Two models were used, the "ECHAM5" and the "CCSM3". See chapter 4.2 for more information on the models and scenario calculations.

a) Temperature

Both air and road temperature will increase in the future according to the Echam and NCAR scenarios. The highest temperature rise will be in the north in the F3 region, and the smallest in south in the S1 area (Table 6).

The NCAR model and the Echam model show more or less the same result, although the NCAR shows higher temperature increases in general. The NCAR model also shows a more easterly gradient in temperature increase. Finland, according to the NCAR model, will have a higher temperature increase calculated as percentage when compared to Sweden than Finland according to the Echam model. In Echam it seems as if the northerly gradient is stronger than the easterly.

Previous studies from Källström (2009) shows that winter temperature increase based on ECHAM4 scenario A4 in Finland will be as large as 6°C from the normal period 1961 – 1990 to the future 1970 -2100. For Sweden the same figure is about 5°C temperature increase.

Table 6. Mean road and air temperature changes according to the ECHAM and the NCAR models.

	ECHAM		NCAR	
Area	**Road T (˚C)**	**Air T (˚C)**	**Road T (˚C)**	**Air T (˚C)**
S1	0.89	1.03	1.06	1.21
S2	1.07	1.28	1.22	1.44
S3	1.19	1.58	1.38	1.86
F1	1.18	1.31	1.95	2.14
F2	1.20	1.37	2.11	2.41
F3	1.27	1.44	2.22	2.57

b) Precipitation

According to the Echam model the precipitation as snow will decrease in all areas in the future, most in S2 around the Stockholm area in Sweden. Rain will increase in all regions but most on the west coasts (S1 and F1). The overall precipitation change maps show that the S3 and S2 areas in northern Sweden will have the least precipitation increase (almost none at all) in the future when both snow and rain is taken into consideration. In S1 in southern Sweden the precipitation will increase the most of all six areas (Table 7).

Table 7. Precipitation changes according to the ECHAM model. Values show the mean annual change from historical values to the future.

ECHAM

Area	Snow change (mm)	Rain change (mm)	P. change (mm)
S1	-8.92	38.45	29.52
S2	-20.75	23.05	2.30
S3	-10.11	10.73	0.62
F1	-8.33	28.95	20.62
F2	-4.80	26.19	21.39
F3	-4.21	20.98	16.77

The NCAR model shows in line with the Echam model that snowfall will decrease in all areas in the future, most in southern Sweden in the S1 region, in northern Sweden in the S3 region and in F1 (southwestern Finland), although the decrease is larger than for the Echam model. Rain will increase most in F2 (southeastern Finland) and S1 (southwestern Sweden) and as with the Echam model not so much in S3 (northern Sweden). The futures total precipitation pattern is quite similar to the Echam model. In S2 and S3 however, the seasonal total averaged precipitation will decrease when compared to the present climate. Instead of S1 as in the Echam model, S2 will experience the largest precipitation increase (Table 8).

Table 8. Precipitation changes according to the NCAR model. Values show the seasonal total averaged over 30 years from the past to the future.

NCAR

Area	Snow change (mm)	Rain change (mm)	P. change (mm)
S1	-37.66	60.02	22.35
S2	-32.19	18.82	-13.37
S3	-38.89	10.68	-28.21
F1	-37.20	47.36	10.16
F2	-27.64	61.32	33.68
F3	-25.92	37.90	11.98

Källström (2009) showed that there will be more precipitation extremes in the future, and that precipitation during the winter months will increase more than during summer. In the maps below (Figure 7) extreme precipitation changes is plotted from the first thirty-year period (1980 to 2010) to the last thirty-year period (2025 to 2055) in Southern Sweden (the S1 region). The western areas will experience more extreme precipitation in the future compared to today. The changes for the inland and more easterly stations are not as large, although an increase is expected for most areas.

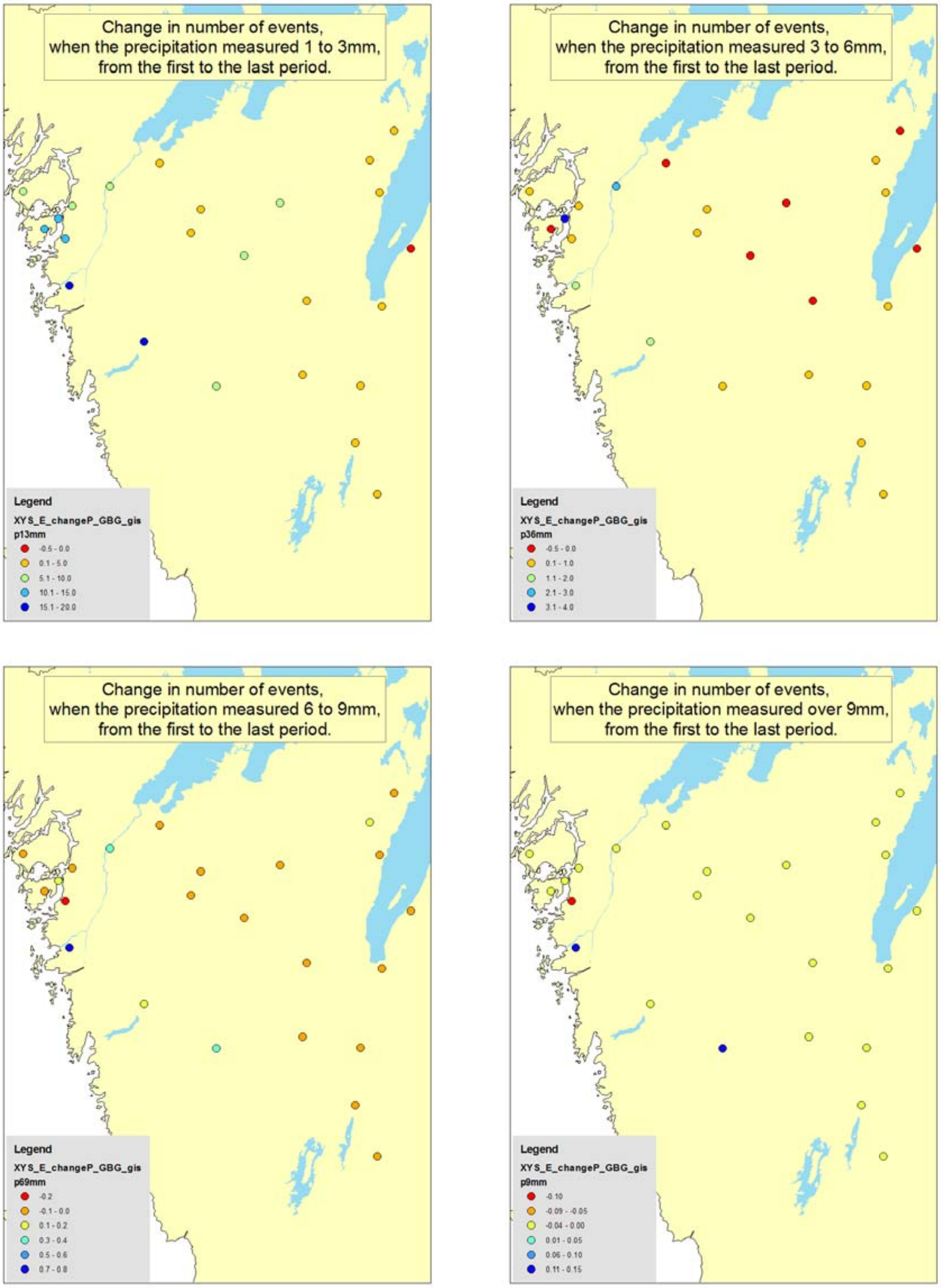

Figure 7. Extreme precipitation changes in mean number of events (30 minute periods) from the historical to the future period in S1 region.

c) Wind

The wind change patterns from present climate to future climate do not vary much from region to region. According to the Echam model the maximum wind speeds will increase most in the north in S3 and F3. The NCAR model shows different results with higher maximum wind speeds in F3, S1 and S2. The S3 region which in the Echam model shows quite high wind speed changes for the future shows opposite results in the NCAR model.

Table 9. Mean wind changes according to the ECHAM and NCAR models.

	Echam		NCAR	
Area	**max wind (m/s)**	**mean wind (m/s)**	**max wind (m/s)**	**mean wind (m/s)**
S1	0.14	0.08	0.27	0.12
S2	0.15	0.07	0.28	0.14
S3	0.17	0.07	0.15	0.06
F1	0.11	0.04	0.12	0.03
F2	0.11	0.04	0.22	0.09
F3	0.18	0.08	0.34	0.15

Figure 8 shows the changes in extreme wind events from the historical to the future period in southwestern Sweden in the S1 region. Results show that extreme wind events will generally increase here in the future. Some areas however will experience fewer wind extremes in the future. These stations are marked in red in the figures below.

In a recent analysis by Wern and Bärring (2009) it was shown the winds in Sweden have not increased during the last decade. The variability is larger than the change but a small decrease in the potential wind energy was recorded especially in the northern parts of the country. The local variability as it is scattered today due to the different positioning of the stations will probably be preserved in the future but certain areas might experience a larger increase of extremes than others. This can be seen when comparing the future changes (Figure 8) to the historical observations (Figure 6).

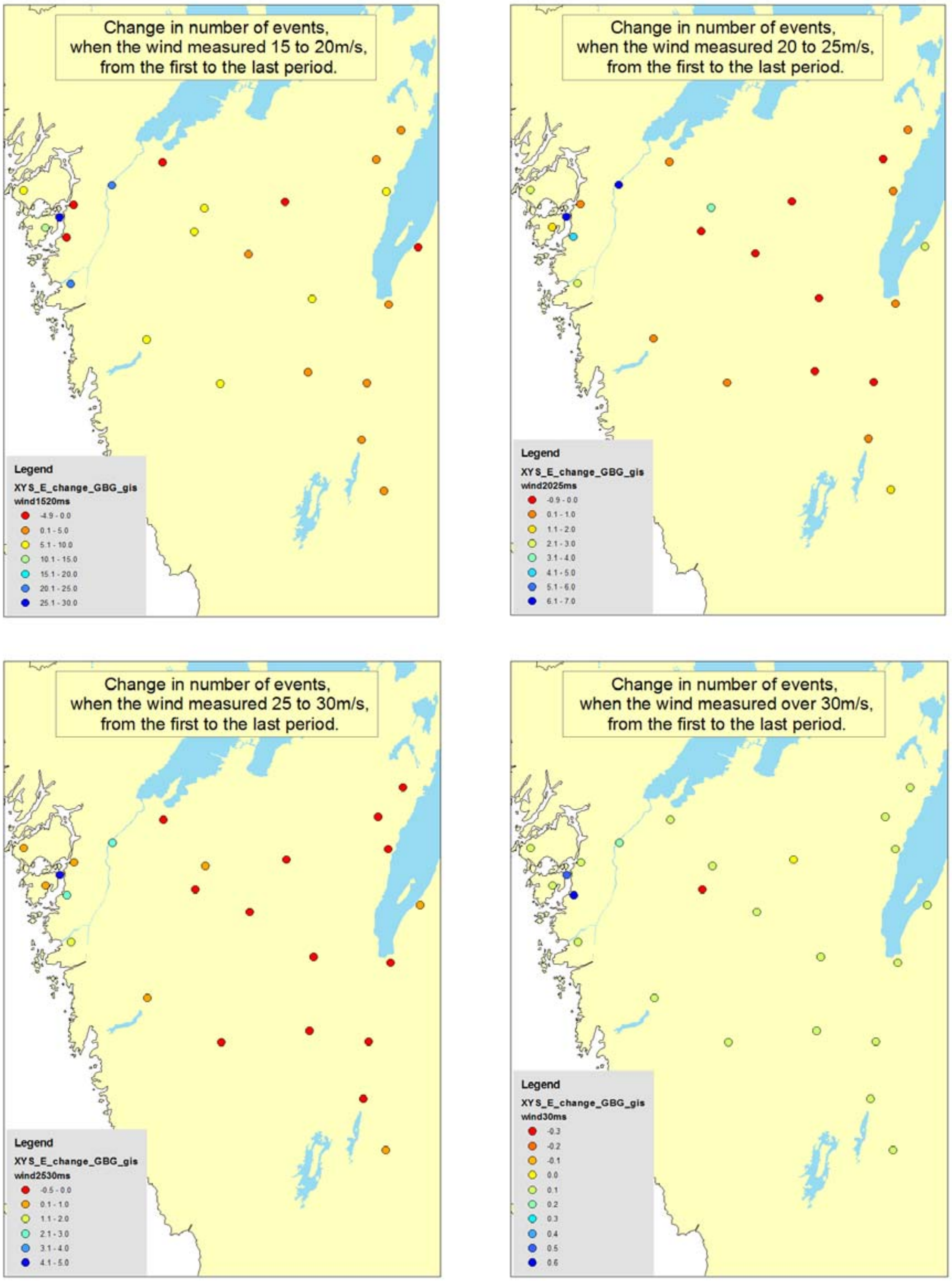

Figure 8. Changes in number of wind extremes from historical period to the future period. Values are mean number of events (30 minute periods).

4.2 Downscaling with RWIS data

This study used the outputs from two General Circulation Models (GCMs), the Community Climate System Model, version 3.0 (CCSM3), and the ECHAM5/MPI-OM model (ECHAM5). Data were downloaded from the WCRP CMIP3 multi-model database. We used SRES A1B emission-scenario runs, which we consider mid-range emissions-scenarios in-terms-of 21st Century global warming.

GCMs simulate the climate at a large scale, and road weather climate cannot be extracted from GCM outputs. Firstly, GCMs do not have all the appropriate variables: the do not have road surface temperature, for example. Secondly, the resolution is too course. GCMs have spatial resolutions of 1-200km and most modeling groups provide only daily or monthly outputs. Thus, GCMs only indicate the general weather conditions in a region. Thirdly, GCMs are far from perfect, and GCM climatologies are always biased, i.e. temperatures might be systematically too warm or too cold by several degrees, and there are nearly always too many days with precipitation when compared to observations. An example GCM temperature time-series, for the SW Finland location, is shown in Figure 9.

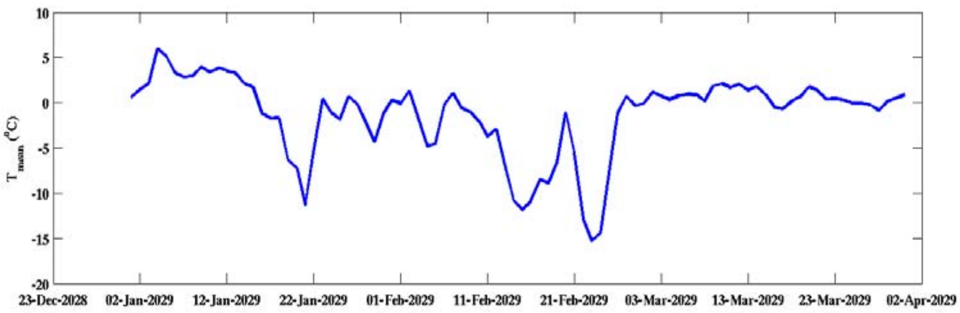

Figure 9. Mean daily air temperature for the SW Finland location, from the CCSM3 GCM.

To overcome these problems, realistic climate scenarios are often derived by using the large-scale atmospheric patterns from GCM outputs (which GCMs simulate well) and combining these with historical weather observations. This process is called statistical downscaling.

We used a historical re-sampling algorithm to generate statistically-downscaled climate time-series. This technique involves iterating over each day in the GCM scenario, and for each day finding a day in the historical record for which the large-scale atmospheric situations match closely. A 30-minute weather time-series for each future day is constructed using the historical weather from the matched historical days. In this way, warmer days from the historical sequence are used to represent the climate of the future.

We calculated three properties for each day, for both historical days and for days from the GCM simulations. These properties were then used to find analogue days. The properties were:

1. The Lamb-Jenkinson weather class (Lamb, 1950; Jenkinson and Collins, 1977). The large-scale atmospheric situation – roughly speaking, whether a high or low pressure system dominates, or whether a particular wind direction is the dominant weather feature – was classified using an adaption of Chen (2000). This algorithm uses geostrophic winds and cyclonicity derived from NCEP/NCAR reanalysis project (Kalnay *et al*., 1996) daily-average sea-level pressure to assign daily circulatory regimes to one of 27 classes.

2. An “average regional temperature”. This factor takes into account that daily weather cannot be described simply by the pressure and winds. Daily-average temperature at 2m height from the nearest model grid cell was used as average regional temperature. NCEP/NCAR reanalysis data was used for the historical days, and the normalized GCM temperature for the GCM scenarios. Normalization of the GCM temperature time-series was required to remove the bias between the GCM and NCEP/NCAR reanalysis temperatures. Thus, the GCM temperatures were normalized to the NCEP/NCAR reanalysis temperatures, independently for each season and circulation class, using data from the period 1983-2000 (the overlap between the observations and the GCM *Climate of the 20th Century* simulations).
3. The clear-sky solar radiation. This criteria was used to restrict the seasonal range over which an analogue could be selected. We do not expect that future mid-winter days will have the same road temperature as current late-seasons (March) days, even if the regional air temperatures are the same. This is because solar heating of the road surface is irrelevant at mid-winter, but it becomes important towards the end of winter. Greenhouse warming will not change this.

Using these criteria, a historical day was selected as an analogue for each future day. Historical days were selected independently for each station. A historical day was considered a candidate analogue for a future day if:

1. the two days had the same (or adjacent[1]) circulation classes;
2. the two days had average regional temperatures within 5°C;
3. the two days had clear-sky solar radiation within 2MJ/m^2/day or 25%. Essentially these criteria meant that analogues for winter months with low clear-sky solar radiation matched any day from any other winter month with low solar radiation, but that days in late February or March matched only days within a two-week window.
4. the mismatch between station air temperature at 2400 hours on the *previously* selected day and 0000 hours on the candidate day was <2°C, and the mismatch in dew-point <3°C. These criteria ensured that the downscaled temperature and dew-point time-series were realistically continuous.

With these criteria, there existed at least one candidate analogue day for 65% of GCM scenario days. If no candidate analogue was found for a GCM day then restriction (1) was removed, allowing analogues to be found for over 95% of days. Further relaxation of criteria allowed historical analogues to be found for all scenario days. If more than one candidate was round, then a particular day was selected to be the analogue using the differences in average regional temperature (GCM vs. NCEP), and the station air temperature and dewpoint mismatches.

The final result is realistic RWIS climate scenarios. A short section of the downscaled time-series for a SW Finland station is shown in Figure 10. The temperature profile shows the same basic pattern as the GCM time-series from Figure 9, with cold spells around 21-Jan, 14 Feb and 23 Feb, but there is much more realistic detail. And, of course, the downscaled time-series also contains data for road temperature, wind and precipitation.

[1] eg. North-West or North-East flow classes are adjacent to the North flow class.

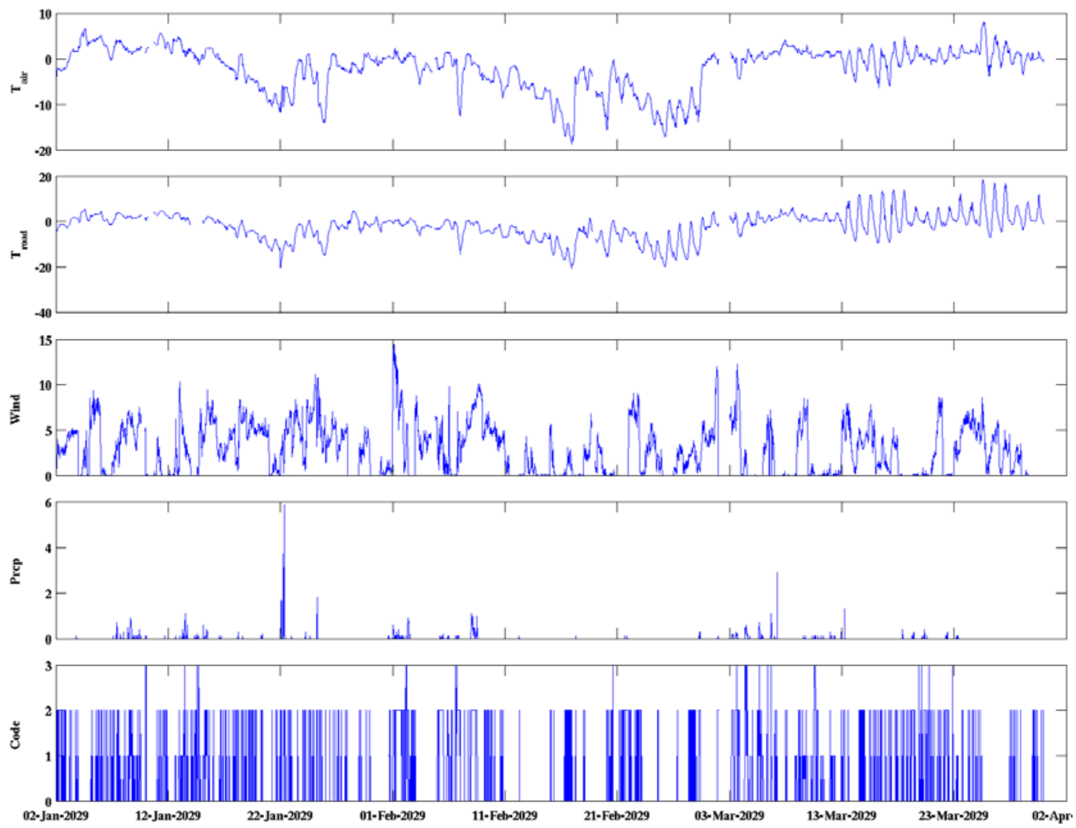

Figure 10. A short section of the downscaled data for Helsinki station (1002) for year 2029, based on the CCSM3 model. The very discontinuous wind data are caused by residual discontinuities in the input data for this station – the observed wind data is quite different year-to-year, presumably a result of sensor changes.

Statistical downscaling by selecting historical analogues has a number of limitations. Most obviously, the analogue technique cannot generate days with more extreme climate than those observed historically. In particular, with the SRES A1B scenario we expect days with higher temperatures than occur in the historical record, but we do not see this in our scenarios. Instead, the downscaled scenarios show an increased *number* of days with temperatures that are high (but not unprecedented) by current standards. We had originally intended to overcome this issue by including historical data from October and April (i.e. outside the IRWIN "winter"), but most Swedish RWIS stations do not operate at these times.

We investigated whether we "ran out" of suitable analogues towards 2100, and found we did not. We calculated the bias in the average regional temperatures for the selected days – if the temperatures of the analogues were consistently much lower than the GCM days, then this indicates the method has failed. We found the bias was small, even to 2100. This suggests that the natural variability in the 10-year RWIS record contains sufficient natural variability to support analogue reconstructs even through to 2100.

A second issue with the downscaling algorithm is that it assumes that the relationships between the regional atmospheric situation and the RWIS records continue to hold in the future. This assumption is present in some form in every statistical downscaling study, and is almost unavoidable when scenarios are required that realistically represent local weather time-series.

4.3 IRWIN index

The indices were calculated to be able to study the potential change in need of maintenance activities such as ploughing and salting in the future. They were calculated using the ECHAM5 model. Periods of 4 hours were selected to present an “event”. These events were then calculated to see the change in numbers of events from the historical period (1980 - 2010), to the future period (2025 - 2055) (Tables 10-11).

The indices were calculated as follows:

Index 1	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was between -3 to +1°C Wind velocity was between 0-7 m/s
Index 2	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was between -3 to + 1°C Wind velocity was between 7-14 m/s
Index 3	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was between -3 to + 1°C Wind velocity was more than 14 m/s
Index 4	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was less than -3°C Wind velocity was between 0-7 m/s
Index 5	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was less than -3°C Wind velocity was between 7-14 m/s
Index 6	Number of events when the amount of snow was more than 1mm during 4 hours Temperature was less than -3°C Wind velocity was more than 14 m/s
Index 7	Number of events when it was or had been raining and the surface temperature was less than 0,5°C
Index 8	Number of events when the surface temperature was between -6°C and 0°C during 4 hours and the dew point was larger than the surface temperature
Index 9	Number of events when the surface temperature shifts from +1°C to -1°C

Index 1, 2 and 3 shows the number of occasions when snow has accumulated for 4 hours with a temperature between -3˚C to +1˚C. The wind varies in the different indices and we have seen before that the low wind occasions dominate (figs. 14-17). These events with low wind values (index1) are quite frequent in all regions although most frequent in the S2 region in eastern Sweden and least frequent in S3 (northern Sweden) and F1 (southwestern Finland). Index2, with stronger winds are most frequent in the S1 region, but also in S2. Index3 with wind values over 14m/s shows very high values at one station in S1 area in southeastern Sweden. This station is however positioned on a bridge in the archipelago. Index 1 shows a positive change (in the more northerly regions) for the future, which means more events when these conditions will occur. As for index 2 and 3 these events will not be as frequent in the future as they were historically (table 10).

Index4, 5 and 6 shows the number of occasions when snow has accumulated for 4 hours, the temperature is less than -3˚C and the wind varies as in the first three indices. Also here the low wind occasions are dominating. As a matter of fact there are close to no events at all with the criteria in index 6, when temperature is below -3˚C and the wind is more than 14m/s. The only case is station 1002 in the archipelago in southwestern Finland, which has strong wind values. The high negative change (-50%) from historical to future values are due to the one event in the past and then no events at all in the future. Happenings like this are likely to make the changes look larger than they are in reality. Index 4 shows more occasions in S3 in northern Sweden and in F3 in northern Finland, which might be due to the lower temperatures up there. For the future however the more southern areas will experience less events of index 4 which might be a result of the change in temperatures. Index 5 does not show the same trend. The highest values were obtained in S1 and S2 in southern and eastern Sweden, which might be due to the more seaside station positions, which has stronger winds. These areas however show a quite large decrease in these events for the future. In northern Sweden and southwestern Finland ploughing events due to this type of weather will increase (Table 10).

Index 7, 8 and 9 are salting indices. Index 7 shows the number of events when it is raining on a cold surface, and the results shows that this occurs most often in the F2 and F3 (north and northeastern Finland), while S1 in southern Sweden has the least number of events of this kind. Index 8 shows when salting is needed due to frost, and here there is a clear trend with more cases the further north we come. Index 9 shows the number of events when temperature shifts from plus to minus degrees and therefore causing slipperiness. There is a clear trend that southern areas experience this shift more often. This is due to the colder weather in the north. Temperature does not reach plus degrees in the winter as often as it does further south. Only the region in southern Sweden shows a decrease in the future in frost events caused by this temperature shift and the other areas shows an increase. The same trend has been observed before when Källström (2009) used the ECHAM4 model to make the same predictions. The number of events increased in north and decreased further south as a response to the warming in the future (Table 11).

Table 10. Percent change in ploughing indices from historical to future period. Based on the Echam model.

Seasonal mean events change per area

Area	% change Index 1	% change Index 2	% change Index 3	% change Index 4	% change Index 5	% change Index 6
S1	-3.0%	1.2%	-48.0%	-27.1%	-9.5%	0%
S2	-5.8%	-12.2%	-20.0%	-34.2%	-25.5%	0%
S3	20.3%	1.8%	0%	-16.6%	11.1%	0%
F1	-2.7%	-0.3%	-50.0%	-18.0%	31.9%	-50.0%
F2	5.9%	-16.7%	0%	-15.6%	-11.6%	0%
F3	13.2%	-26.7%	0%	-13.1%	-9.1%	0%

Table 11. Percent change in salting indices from historical to future period. Based on the Echam model.

Seasonal mean events change per area

Area	% change Index 7	% change Index 8	% change Index 9
S1	-2%	-2%	-2%
S2	-7%	2%	5%
S3	15%	16%	23%
F1	-5%	3%	6%
F2	12%	10%	16%
F3	13%	11%	18%

Furthermore the precipitation values have been subdivided into three groups depending on the amount of precipitation per 4-hour period. This division has been done in order to show how the need for ploughing will change in the future compared to the present situation.

Normally more precipitation requires more actions from the maintenance personnel and therefore this division into three groups (table 12).

A. Number of events when the snow amount reaches 1-3mm
B. Number of events when the snow amount reaches 3-5mm
C. Number of events when the snow amount reaches over 5mm

For A one ploughing event can be enough but with B and C the need for more ploughing events will increase.

Below are the calculated changes in events when there was a certain amount of snow falling within a 4 hour period. Almost all areas will have a decrease of snow events in the future, and region S2 will experience a large decrease. The F2 and F3 regions will however have an increase in snow events by 3 to 5mm and more than 5 mm (Table 12). These results seem to be fairly consistent with the scenario changes calculated before in chapter 4.1.2.

Table 12. Percent change in snow events from historical to future period. Based on the Echam model.

Seasonal mean events change per area

	Change snow 1-3mm	Change snow 3-5mm	Change snow >5mm
S1	-8.90%	-8.28%	-7.53%
S2	-15.38%	-17.42%	-15.03%
S3	-3.06%	-4.20%	-8.46%
F1	-4.85%	-2.76%	-0.60%
F2	-4.35%	-1.71%	2.48%
F3	-0.62%	0.45%	1.90%

4.4 Maintenance needs

An example of how to use the index calculations above is to multiply the length of the roads with the number of times ploughing was needed each winter season to get the total road length which has to be ploughed each season (Table 13).

Changes in the index calculations from past to the present climate showed that for index 1, in the past in the S1 region according to Echam model, 51970 km of road was ploughed per season. In the future the same area would only need to plough 50209 km of road. This indicates a decrease of 1761 km. There was generally a decrease in maintenance needs in the future calculated for all the indices. Index 3 and 6 however showed no values not in the past or in the future, which means no roads in this area had to be maintained due to very high wind speeds. See Table 13 for more values on the other indices. Only region S1 was analyzed here as an example of how the index calculations can be used to follow the development in the future and the needs to come.

Table 13. Kilometers of road in the S1 region which according to the 9 different indices had to be "maintained" in the past, for the future and the change from past to the future according to the Echam model scenario. Calculations are based on the maps below.

Kilometers of main roads in S1 region which need maintenance

	km 1980-2010	km 2025-2055	km change
Index1	51970	50209	-1761
Index2	4775	4569	-207
Index3	0	0	0
Index4	20603	14875	-5728
Index5	2062	1814	-248
Index6	0	0	0
Index7	14002	13693	-309
Index8	144543	141814	-2730
Index9	96934	94765	-2169

Figures 11 a-b presents examples of indices 1 and 4 and show the change in how often ploughing events according to these two indices will be needed in the future. Only the larger and most trafficked roads (class 1 and 2) were taken into consideration.

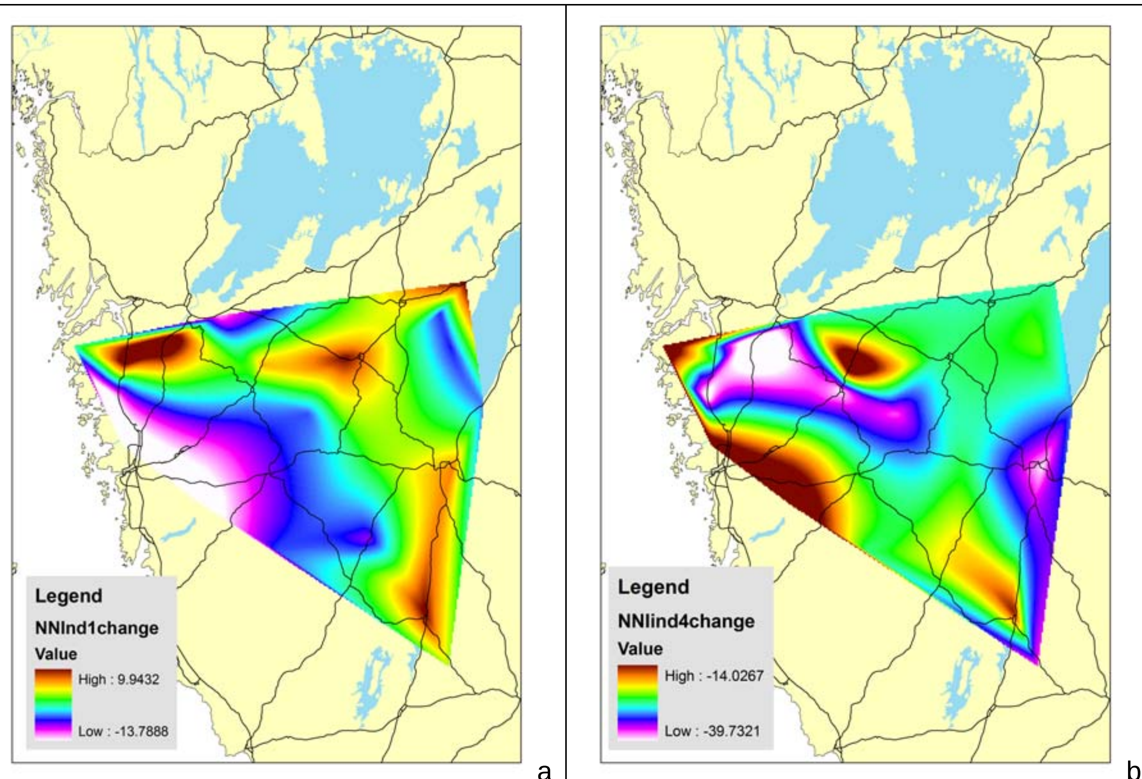

Figure 11. Maps show the percentage change of how often ploughing will be needed in the future compared to the past in the S1 region. Figure a shows index 1. Figure b shows index 4. Positive values indicate increase and negative values decrease.

5 Evaluation of results

5.1 Quality of data

The data collection phase of IRWIN revealed that there was enough archived RWIS data in Sweden and Finland to perform the planned winter index development. The required minimum samples of ten years of observations were collected from 50 road weather stations in Sweden and 49 stations in Finland. Observations in each country were available from three regions with distinctively differing climatic characters, allowing localised climate comparisons. Maintenance actions from the regions of interest were available as well, and were used in the final winter index calculations.

General weather observations are quality controlled and corrected before their archival into climate database, whereas archived road weather observations are not ready as such for further analysis. This is because there is no regular quality control and correction routine of observations before saving those into the archived databases. Thus in IRWIN project, a major effort was the quality control and correction of the raw RWIS data before those could be used for reliable climate analysis. The following multi-step processing was necessary to compile a high-quality database:

- Sometimes the data from the stations was missing or irregularly spaced, i.e. not every half hour as was desired. To make homogenous time series for all stations for the selected periods, the data was adjusted to nearest half hour. With the Swedish data, observations that were further than 15 minutes from the nominal time has been replaced marked as missing.
- All times were corrected to CET wintertime.
- In the Swedish data, the rain sensor often recorded rain values a factor 10 too high during transition from rain to snow or vice versa. If these values were tagged as suspicious they were adjusted appropriately.
- For the Swedish and Finnish data, snow and sleet depths were converted to mm-water-equivalent by dividing by 10.
- Extreme precipitation amount values were validated by comparing those to nearby weather stations. Suspicious data was marked as missing.
- Temperature, dew point and precipitation values, which differed significantly from the values measured in the previous and next half hours were marked as missing.
- Where air- and surface-temperature records for the same station and half-hour were incompatible, they were both marked as missing.
- Where average-wind-speed and maximum-wind-gust records for the same station and half-hour were incompatible, they were both marked as missing.
- To further validate the Swedish RWIS data, precipitation data from SMHI were downloaded and crosschecked with the RWIS. A general conclusion from this comparison was that the SMHI stations measure a somewhat larger precipitation than the RWIS stations. This could be due to different measuring techniques and instruments.

After these tedious but necessary quality control steps, the resulting IRWIN observational database resulted in a set of reliable and unbiased observations. It provides a valuable source for further studies in local road climatology.

The climate database was constructed using well-established and documented downscaling methods, applied on two widely used and acknowledged global climate models CCSM3 and

ECHAM5. Thus the IRWIN climate database can be considered as reliable as it is possible in today's climate research.

5.2 User benefits

Winter indexes are not very often used operationally nowadays in road maintenance activities. One reason may be the earlier convention to use more coarse general weather information as the basis for index calculations.

Using a more accurate index such as IRWIN, many benefits are expected:

- Better representation of weather and climate of the road network gives better linkage between weather and maintenance needs
- IRWIN index provides better understanding of local weather variations
- IRWIN is a user-friendly tool when assessing the impact of climate change on maintenance needs
- IRWIN index provides better coverage of extreme events, such has heavy snowfall or strong winds
- After assessing the potential change of maintenance needs and actions compared to present, it is straightforward to assess the monetary implications to road owners in the changing future climate.

IRWIN index calculation can be considered also as a service for road owners. A structured self-evaluation of such a service has been performed using ITS service assessment framework developed within the R&D Programme on Real-Time Transport Information AINO, and managed by the Ministry of Transport and Communications Finland. The framework is based on the national guidelines of evaluation of ITS projects from 2002.

Details and the evaluation template are available from www.evaserve.fi. Evaserve is a meta-tool for evaluation and development of information services which can be used by service developers and evaluation experts. Evaserve has been designed for evaluation of information services in the fields of transport and logistics, but it is suitable also for other information services. The tool has been used in the R&D projects focused on meteorological information services in Finland and other countries. Evaserve has been developed by VTT Technical Research Centre of Finland.

ITS service assessment sheet for IRWIN can be found as and Annex in the end of this report. Parts that are relevant to IRWIN have been filled. These are:

- Background and objectives
- Service content and dissemination channels
- Service provision concept
- Costs, resourcing needs and financing
- Potential market and users
- Relationship to other activities
- Impacts on travel, transport system efficiency, special groups, safety, environment and community structure
- Impacts on transport system development and management
- Usefulness, innovation and economic efficiency
- Technical performance and qualtiy assurance

- Accessibility and user centered design
- Opportunities and threats
- Impact mechanisms and targets

5.3 Extending IRWIN in other areas and countries

It is important to know if IRWIN type of index can be used in other areas and countries. The calculations performed for this study are applicable only for the selected six areas represented by the sample of about one hundred RWIS stations. To extend the results to even nearby areas such as Lapland is not feasible, as the climate if very different there. Calculations should be repeated there when long enough time-series are available.

In order to know if similar calculations can be made in other ERA-NET ROAD countries, it was necessary to know if archived road weather observations exist and if the databases are from long enough period. Germany, Ireland, Netherlands, Poland, and Spain, and replied to a short questionnaire asking about the availability and extent of archived RWIS data. Summary is shown in Table 14. Questions were:

Q1 Are there any archived road weather observations in your country and since when?

Q2 If yes, how many stations have archived observations

Q3 Who is responsible for maintaining the data archive?

Q4 In which format is data archived? Can you send a short

Q5 What is the availability and conditions of use of data for similar studies like IRWIN?

Table 14. Availability of archived RWIS data in other countries

Country	Q1	Q2	Q3	Q4	Q5
Germany	German Weather Service DWD archives	Most stations (over 600) for more than 5 years	DWD	Information from DWD	Information from DWD
Ireland	Since ca. 2000	54	National Roads Authority and Met Eireann	CSV and XML	Available for use on a non-commercial basis
Netherlands	Since 1990	Around 320 stations	Dutch Ministry of Transport, Rijkswaterstaat, Centre for Data and ICT	XML	Freely available in raw XML
Poland	About 15 years ago	In 2000: about 100 stations. Totally about 400 stations	Company "TRAX elektronik", cooperating with GDDKiA	Information from the company	Possible for research studies
Spain	Since ten years ago. More info coming each year	Not known	General Directore for Traffic of Spain. Each provincial delegation responsible for its archive	Each provincial delegation decides the format, e.g. Valencia uses Oracle	Permission usually given if asked

It can be seen even from this small sample, that there are countries with enough data for IRWIN type of climate studies using RWIS, and countries where the usage of data, even though some of it is archived, may be very difficult due to problems in availability or differing data formats. Taken into account the seriousness of climate change and its implications, it is highly recommended that Road Owners if not yet do so, start operational archival and quality control of all road weather observations in their countries. Standardisation of data formats is also recommended.

6 Conclusions

IRWIN project was successful in collecting large enough database from the Swedish and Finnish road weather information systems and their archived observations. The quality-controlled database was useful for reliable climate downscaling operations, which were utilising well-established global climate models. Maintenance actions were also collected from the six climatologically different study areas for winter index calculations.

The results showed that according to well-established climate models, temperature increase would be largest in the northern areas in Sweden and Finland in coming decades. Same areas will experience a larger amount of events when there is a shift from plus to minus degrees (index 9), and therefore these areas need more maintenance due to slipperiness caused by this shift. Only the region in southwestern Sweden will in the future have fewer days when temperature shifts from plus to minus degrees due to a warmer climate of that area.

The future will bring more rainy days on a cold surface in the north due to the milder climate and more rainy days in the north instead of precipitation falling as snow. The northern areas will also experience more slipperiness due to frost days when the surface temperature is low and the dew point is larger than the surface temperature. These frost days will occur less frequent in the future in the more southerly areas, due to fewer days with minus degrees.

Higher temperatures will also result in precipitation falling as rain instead of snow, which can be seen as a large decrease of ploughing events (index 1 to 6). Index 1 showed a positive change in the more northerly regions but indices with higher winds showed a decrease in almost all regions. Historically, regions S1 and S2 had more events of index 5 which might be caused by the higher winds in these areas. These two regions however show a quite large decrease in these events in the future. Northern Sweden and southwestern Finland, which have moderate winds today, will in the future experience an increase in index 5.

The need for maintenance operations will change in the different regions as the climate changes. A warmer climate can both mean more needs for salting due to more slippery roads but at the same time less ploughing events when precipitation falls as rain instead of snow.

The index developed in this study has shown to be a useful tool for future maintenance operations. It can give valuable information to stakeholders as to where and when measures need to be taken. Similar assessments could be done relatively easily in other countries too, if enough road weather information was archived and available. Taken into account the seriousness of climate change and its implications, it is highly recommended that Road Owners if not yet do so, start operational archival and quality control of all road weather observations in their countries.

7 Sources

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Annex: ITS service assessment sheet for IRWIN

ITS service assessment sheet

page 1/4

NAME OF PROJECT/SERVICE IRWIN winter index

ASSESSMENT INFORMATION Dec 2009 Pirkko Saarikivi/Foreca Consulting Ltd Final evaluation

SERVICE DESCRIPTION

BACKRGOUND AND OBJECTIVES

- What is the user need behind the service and the problem to be solved with the service?

Planning and evaluating costs and effectiveness of road maintenance today and in the future in various climate change scenarios.

- What is the development trend and severity of the background problem (e.g. the current and future number of accidents, incidents or delays, and their effect on the society)?

Global climate change is progressing with worrying speed. Implications to road infrastructure and maintenance may be severe, in particular in northern latitudes. The whole society will be affected, causing further indirect effects to the entire transport system.

- What are the objectives of the service?

To provide the road owners and decision makers a practical tool, IRWIN winter index, in order to assess accrately the effects of climate change to road network. The tool can be used for many time scales from present to future road climatologies.

SERVICE CONTENT AND DISSEMINATION CHANNELS

- What kind of information or control does the service produce?

Climatological frequencies of such weather events that cause maintenance actions, ploughing and salting

- Via which channels can users access the service?

Index calculations are performed by experts on request using local RWIS observations

- Can the service be tailored to fit user's needs?

Yes. This report presents a typical set of indices, but limits and parameters can be selected otherwise if needed.

- How will the service content and dissemination channels change when new technology solutions are developed and taken into use?

In most cases indices are calculated once per year, after the winter season. Thus dissemination channels may be selected as seen best from end users. Service contect may develop along with observational techniques. One example is optical friction and road conditions measurements, which could be used as input when long enough time series are available.

SERVICE PROVISION CONCEPT

- How is service provision organised?

Index calculations are run by expert organisations who can deal with RWIS data and climate models.

- Which are the responsibilities of the organisations involved?

Organisation responsible of maintaining RWIS provides observations with best possible quality. Calculating organisation provides data quality procedures, climate models and downscaling operations, analysis and dissemination of results.

- How are the service ownership and host issues solved?

At the moment IRWIN data bases using Finnish and Swedish RWIS data are hosted by University of Gothenburg. Further archival and ownership issues must be discussed and decided if data would be used in further studies. Raw data is archived in national road administrations. Climate models are in IPCC servers.

- How are the maintenance and liability issues solved?

Not yet, as there has been no discussion yet on further use of IRWIN databases.

- Which data bases and technology solutions are the service provision and user access built upon?

Custom format, described in detail in 2nd Inception Report.

COSTS, RESOURCE NEEDS AND FINANCING

- What investments, annual maintenance and operational costs as well as fees does the service require in total and from the public sector as a purchaser/supporter?

Archical of RWIS observations are most important. Operational quality checking would be beneficial but not necessary.

- What organisations finance the service and in which manner and proportions?

Annual index calculations are financed by the users.

- What is the potential for wider commercial exploitation of the service?

Countries with wintertime road maintenance problems, in norhtern latitudes and in mountaineous areas.

- How is the service to be marketed or promoted, and have the marketing costs been considered in the calculations?

Planning has not proceed this far.

- Which personnel resource needs are required from the purchaser or public sector?

Nothing outside the normal maintenance of RWIS, unless a regular quality control of archived data is added to normal routines.

POTENTIAL MARKET AND USERS

- Which and how large are the potential primary customers of the service (e.g. number of users of the transport system part targeted by the service)?

Limited, as this is a special service targeted to the decision makers of road owners.

- Which is the estimated number of persons, companies or transportations using the service (e.g. estimated number of service subscribers) and how is the estimate calculated?

Only few per country (see previous).

RELATIONSHIPS TO OTHER ACTIVITIES

- Description of how the service is related to other projects and services?

Good practices in RWIS observations archival help other studies on local road network.

- Does the service enable new or more efficient operations, and what is the economic significance of such operations?

Local winter index give support in short and long term planning of maintenance operations and road network. Economic significance can be very large, if wrong decisions e.g. in infrastructure can be avoided in the rapidly changing climate.

ITS service assessment sheet

page 2/4

NAME OF PROJECT/SERVICE IRWIN winter index

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DESCRIPTION OF IMPACT INFORMATION

IMPACTS ON TRAVEL

- How does the service affect the number, time and modal choice of journeys and their costs?

Service has mainly indirect effects to transport system operability, see analysis on the right. It is diffult to estimate in detailed level the effects to journeys.

IMPACTS ON TRANSPORT SYSTEM EFFICIENCY

- How does the service affect route choices, journey times, congestion and traffic flow?

Impact is positive. Better planned winter road maintenance reduces congestions, and delays. Infrastructure which has been planned and measured using best estimates of changing local climate, ensures the most effective and fluent transport.

- How does the service affect incident occurrence, incident impacts and possibilities for incident management?

Well planned and effective winter maintenance reduces also number of accidents.

IMPACTS ON SPECIAL GROUPS

- How does the service affect the travel and other possibilities of specific user groups, such as the elderly and disabled?

Well managed winter maintenance helps all tranport users, elderly and disabled as well.

- How does the service affect the business possibilities and welfare of some types of enterprises?

Effective and flawless transport is a necessity for all economic activities of the society. Thus better winter maintenance helps to achieve this target.

IMPACTS ON SAFETY, ENVIRONMENT AND COMMUNITY STRUCTURE

- How does the service affect traffic safety, security, environment, landscape, cityscape and community structure?

Indirect impacts through better managed wintertime tranpsort system affect positively on traffic safety. Reduced congestion has positive impact on environment and community structure.

IMPACTS ON TRANSPORT SYSTEM DEVELOPMENT AND MANAGEMENT, OTHER IMPACTS?

- How does the service affect e.g. the needs to build and improve transport infrastructure?

This tool is also intended to help in decision making on future investments in transport infrastructure and thus it may have very large impacts.

- How does the service affect transport infrastructure maintenance and operational costs?

Better planning in local scale helps optimising the costs.

- How does the service affect public transport operational costs?

More fluent overall tranport system will reduce also public transport operational costs.

- What other impacts does the service have?

Decision makers gain better understanding of climate change, future scenarios and local effects

SERVICE IMPACT ASSESSMENT PLAN

- How can and will the impacts of the service be studied and monitored?

Regular user surveys are recommended.

- What assessment methods can and will be applied?

User surveys can include both qualitative and quantitative assessments of service impacts

ITS service assessment sheet

page 3/4

NAME OF PROJECT/SERVICE IRWIN winter index

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SERVICE ASSESSMENT

USEFULNESS, INNOVATION AND ECONOMIC EFFICIENCY

- What new or more efficient operations does the service enable? More efficient winter maintenance
- What relevant information does the service produce? Local effects of climate change on road network
- What is the added value or operations due to the service? Better knowledge of future climate on road network for planning
- What are the innovative aspects in service provision? RWIS data is used in climate downscaling allowing much better local resolution
- Are there experiences from similar services or technology applications from elsewhere? Not as accurate
- How does the service cater for fulfilment of transport or other policy objectives? Better adaptation to climate change
- Which are the social benefits that can be expressed in monetary terms in relation to investment and maintenance costs (if estimation is possible)? Less congestion and accidents
- Which are the total costs and fees for the service life cycle against the number of user groups, users or use occasions? NA
- Which are the prerequisites for the business profitability of the service? Sensitivity to central assumptions made?

TECHNICAL PERFORMANCE AND QUALITY ASSURANCE

- How reliably does the service functions (as estimated or measured)? Comprehensive quality control procedures and well-known climate models ensure best possible results
- Correctness of the information provided by the service (as estimated or studied)? See above, best reliability available today
- How is the quality of the service ensured and/or monitored? Climate models used must be from well-established and reliable sources. Qulaity control of RWIS observations must include procedures described in this report.
- How is user feedback utilised in the further development of the service? Fine-tuning of the winter index classes and parameters can be performed utilising user feedback.

ACCESSIBILITY AND USER CENTERED DESIGN

- How many users can use the service? Not limited in any way.
- What is the estimated number of users of service? Decision makers mainly, not many.
- What kind of human machnice interfaces (HMI) exist (observability, comprehensibility, ways of presentation of information, effect on user workload etc.)? Does not require any special HMI
- Which skills, investments or actions does the use of the service (e.g. getting access to information) require from the user? Basic understanding of some weather parameters and winter maintenance actions
- How have user requirements been considered in design of human machine interaction? Has use context been considered (in vehicle/at home/etc.)? Has the HMI been tested? NA
- Have the needs of special groups been considered? NA
- Has the users' willingness to pay been investigated? Not yet
- Are there user instructions and support services? In operational service: are necessary and must be provided

OPPORTUNITIES AND THREATS

- Do similar services exist? Only using general weather data
- Is service financing settled? No
- Is the service compatible to existing system architectures (standard solutions, open interfaces, generic platforms..) Yes
- Is service continuity (maintenance, development) settled? No
- Have the key organisations in the service value network been identified and involved? Yes
- Have legal issues (privacy, data security, etc.) been solved? Are new or modified regulations required? In some cases access to observational data may be problematic
- Can the service be organised via competitive tendering? Yes
- Can the service be extended with regard to content or user groups (service integration, e.g. with tourism, entertainment)? NA
- Can the service be expanded and exported? For other climate impact studies, yes
- What threats exist with regard to service comprehensibility, adaptability and usability? Users must understand some basics of climate change scenarios
- Are all raw data available in electronic form? Yes

IMPACT MECHANISMS AND TARGETS

Target of impacts

Impact mechanims	Service level and performance of transport system	Costs of transport system	Prerequisitives for businesses	Traffic safety	Other, specify?
Change in transport infrastructure or vehicle fleet investments	x	x		x	
Improved public transport incident management or route choice	x	x		x	
More efficient public transport operation	x	x		x	
More efficient use of transport infrastructure	x	x		x	
More efficient transport network incident management	x	x		x	
Improved dirver and vehicle support					
Promotion of non-motorised transports					
Improved logistic chains and deliveries	x				
Improved service provision prerequisites and tendering	x		x		
Promotion of standardised and generic solutions			x		
Development and piloting of innovative solutions			x		
Other, specify?					