Event coordinators:

LAURYNA ŠIDLAUSKAITĖ
JUSTAS KAŽYS
JONAS KAMINSKAS

S-I-R-W-E-C

PROCEEDINGS OF THE 20TH SIRWEC CONFERENCE

Druskininkai, Lithuania (14–16th June 2022)

VILNIAUS UNIVERSITETO LEIDYKLA

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2022

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dr. Lauryna Šidlauskaitė (Kelių priežiūra, AB)
assoc. prof. dr. Justas Kažys (Institute of geosciences, Vilnius University)
Jonas Kaminskas (Kelių priežiūra, AB)

Edited by:
assoc. prof. dr. Justas Kažys (Institute of geosciences, Vilnius University)
dr. Lauryna Šidlauskaitė (Kelių priežiūra, AB)

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DEAR COLLEAGUES, WELCOME TO SIRWEC2022 CONFERENCE!

We are delighted to host *SIRWEC2022* for the first time in Druskininkai, our country Lithuania. A double occasion to celebrate, as it is 20th anniversary edition of SIRWEC conference. It is an honor to have you all: speakers, participants, sponsors, guests, entrepreneurs, specialists, and organizers here at this wonderful place in southern Lithuania.

SIRWEC – The Standing International Road Weather Commission – operates as a forum for the exchange of information relevant in the field of road meteorology. This includes management, maintenance, road safety, meteorology, environmental protection, and any other area of interest considered relevant by the Commission. SIRWEC exists to encourage meteorologists, weather forecasters, highway engineers, road masters, and others interested in the topic, to exchange ideas and make roads safer in all weather conditions.

After the first SIRWEC conference held in The Hague, Netherlands (1984), we are proud to still be making 'weather' in road mereology, and highlighting 'roadmaps' for users, maintenance specialists, and authorities. Through years roads were made safer, transport - smarter, infrastructure - more durable. However, in these changing world conditions the roles of road maintenance, equipment manufacturers, and traffic control specialists are crucial to sustainability in transport sector.

Despite all the problems and postponements world is facing, The Conference brings together all of the road weather enthusiasts and encourages them to share their new scientific discoveries, products or technologies, and any other related issue on road weather field.

The focus topics of SIRWEC2022 are:

- Road weather forecasting
- Winter road maintenance
- RWIS and other road weather sensors and equipment
- Road weather data systems – part of ITS
- Innovation and technological advancements
- Future perspectives of road meteorology and climatology

On behalf of The Organizing Committee, we wish you great presentations, new impressions, fruitful discussions, and unforgettable moments in Druskininkai.

The SIRWEC2022 Organizing Committee

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FOCUS TOPIC #1

ROAD WEATHER FORECASTING

IMPACT OF SATELLITE-DERIVED CLOUD COVER ON ROAD WEATHER FORECAST IN THE CZECH REPUBLIC

Vojtěch Bližňák [a], Petr Pešice [a], Pavel Sedlák [a], Zbyněk Sokol [a], Jindřich Šťástka [b], Martin Tomáš [c], Petr Zacharov [a]

[a] Institute of Atmospheric Physics, Czech Academy of Sciences, Boční II 1401, Prague-Spořilov, 141 00, Czech Republic

bliznak@ufa.cas.cz

[b] Czech Hydrometeorological Institute, Generála Šišky 942, Prague 4 - Libuš, 143 00, Czech Republic

[c] Czech Hydrometeorological Institute, Na Šabatce 17, Prague 4 - Komořany, 143 06, Czech Republic

Summary

The goal of the contribution is to assess an impact of extrapolated cloud cover derived from satellite observations on forecasts of road surface temperature (RST) and road surface condition (RSC) performed by the road weather model FORTE. By default, the model uses prognostic cloud cover data derived from the ALADIN NWP model and, in cases where these prognoses significantly differ from observations, the FORTE model may produce erroneous RST and/or RSC. This is supported by preliminary results, which show that the inclusion of satellite-derived cloud cover leads to more realistic RST forecasts for several selected case studies.

Introduction

Forecast of road surface temperature and conditions is crucial information for traffic safety in winter conditions. Majority of forecasting methods is based on the application of mathematical models consisting of the heat conduction equation and the energy balance equation [1][2]. The initial model conditions are usually derived from meteorological, surface and subsurface data measured at road weather stations (RWS). Prognostic data derived from a numerical weather prediction (NWP) model form boundary conditions, and they are used to forecast road surface temperatures (RST) and road surface conditions (RSC).

It should be emphasized that cloud cover is a meteorological variable that has the strongest impact on the resulting radiation fluxes into the road surface, and therefore its prediction is crucial for the correct forecast of RST and RSC. In this contribution, the effect of satellite-derived cloud cover on road weather forecasts will be assessed and compared to the standard model setup that use NWP model data only.

Model description

The Institute of Atmospheric Physics (IAP) CAS and the Czech Hydrometeorological Institute (CHMI) have developed and currently run FORTE model for a linearly continuous forecast of RST and RSC on Czech highways. The model stems from the METRo model [1] and differs mainly in detailed check of input data, and radiation fluxes, which are calculated taking into account shadowing of direct sun radiation by obstacles and the impact of sky-view factor [3]. The model uses measured data at RWS, and forecasts of the ALADIN NWP model as inputs to prepare initial and boundary conditions [2][4]. The model utilizes detailed topography (parameters of buildings, woods, orography etc.), which can influence the radiation fluxes. Calculation procedures of the FORTE model using standard (ALADIN NWP model data only) and new (ALADIN NWP model data + extrapolated Cloud Mask) schemes is shown in Fig. 1.

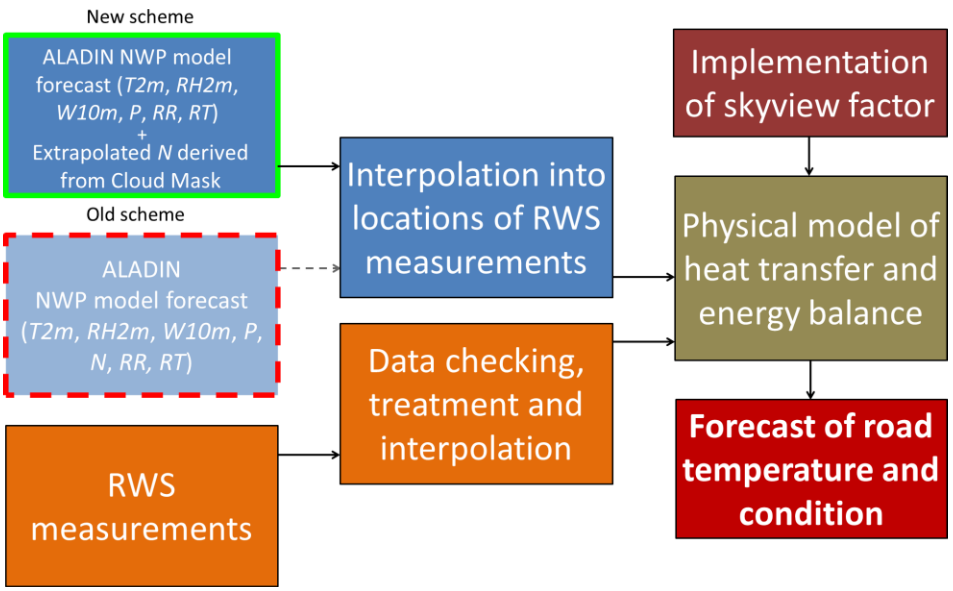

Fig. 1. Calculation scheme of road weather model FORTE. The old scheme using only NWP model forecasts is highlighted by dotted red line. The new scheme combining prognostic variables derived from ALADIN NWP model and extrapolated cloud cover (N) derived from the Cloud Mask algorithm is highlighted by full green line. T2m, RH2m, W10m, P, RR and RT stand for air temperature at 2 m, relative humidity at 2 m, wind speed at 10 m, model pressure at the model orography, accumulated precipitation and type (rain/snow), respectively.

Satellite data and extrapolation

Satellite data measured by the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) aboard the geostationary meteorological satellite Meteosat-11 of Meteosat Second Generation (MSG) is used as a source data for the estimation of cloud cover. MSG data are available every 15 minutes in 12 spectral channels ranging from visible to infrared part of the electromagnetic spectrum and its horizontal resolution is about 4 x 6 km over the Czech Republic. The assessment of whether a given grid box is cloudy or cloud-free is made using the Cloud Mask (CMa) algorithm, which is part of the NWC SAF (Satellite Application Facility on Support to Nowcasting & Very Short Range Forecasting) software provided by EUMETSAT in cooperation with national meteorological services and scientific institutions

[5]. The CMa cloud detection is performed by a multi-spectral threshold method using both operational satellite and NWP model data. The observed values in individual spectral channels and their differences are compared with thresholds, which delimit brightness temperatures/reflectance of cloud-free pixels from those that contain clouds. The total cloud cover *N* over a given grid box will be obtained as a mean value of a number of cloudy pixels from the square of a given size (square of 10 x 10 grid box centred over a considered pixel).

The estimate of cloud cover for the next minutes and hours is then calculated using the Extrapolated Imagery (EXIM) algorithm [6], which extrapolates the CMa (or other selected product) based on atmospheric motion vectors with a defined period of lead time. The prerequisite for a correct estimate is to maintain the wind speed and its direction. The prognostic variable *N* derived from the ALADIN NWP model is replaced by

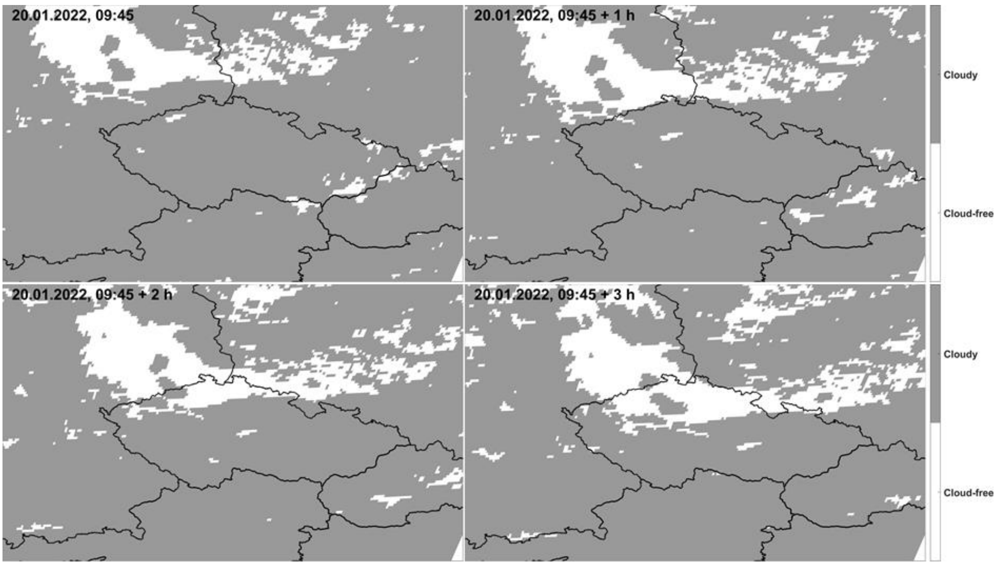

Fig. 2. Example of Cloud Mask (CMa) output for January 20, 2022, 0945 UTC (top left panel) and its extrapolation (EXIM) for the 1st (top right panel), 2nd (bottom left panel) and 3rd hour (bottom right panel). Grey and white colours display cloudy and cloud-free pixels, respectively.

extrapolated CMa at RWS locations every hour with a lead time of 3 hours (Fig. 1). For the longer lead times (3 – 6 hours), the blending with ALADIN NWP model data is applied. In this case, as the lead time increases, more weight is given to the model cloud cover forecast. An example of the CMa and EXIM outputs is shown in Fig. 2.

Verification of results

The model run with the application of extrapolated cloud cover is compared with the original run using only NWP model data. The performance of both runs is evaluated in respect to RWS measurements using statistical verification scores, such as Mean Error, Mean Absolute Error, Root Mean Square Error and/or bias. The evaluation is done for the whole winter season (i.e., from 1st November to 31st March) 2021/2022 and, in addition, selected

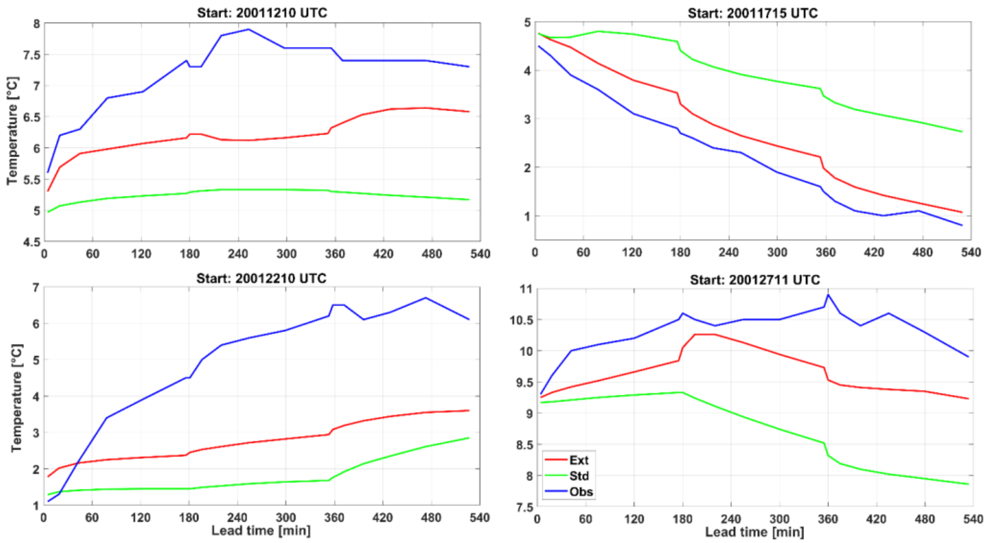

Fig. 3. Road surface temperature forecasted by FORTE model using a standard setup (Std; green line) and extrapolated Cloud Mask (Ext; red line) and measured by RWS A009 located in southern Prague. The start of the model run for the four selected case studies is given above each panel in the YYMMDDhh format and is expressed in UTC.

case studies are analysed and discussed in more detail. Example of RST forecasts for both model runs in comparison with measurements at station A009 (located on the D0 motorway south of Prague, Czech Republic) is shown in Fig. 3. Four selected case studies from January 12, 17, 22 and 27, 2020 show that inclusion of extrapolated CMa can generate RST closer to the observation for the next tens of minutes. However, such improvement is not observed in all forecasts. Possible effects, such as large differences of radiation fluxes coming from both datasets under specific weather conditions, will be discussed in the presented contribution.

Acknowledgements

This work was supported by the Technology Agency of the Czech Republic under the CK01000048 project "Forecasting system of road surface condition and temperature of the Czech highways". Road weather data was provided by Technical Administration of Roadways of the Capital of Prague and Road and Motorway Directorate of the Czech Republic. ALADIN model data was kindly provided by the Czech Hydrometeorological Institute.

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LESSONS LEARNT FROM ROUTE-BASED FORECAST VERIFICATION

Alenka Šajn Slak [a], Borut Sila [b], Samo Čarman [b]
[a] CGS Labs d.o.o., Brčičeva 13, 1000 Ljubljana, Slovenia
alenka.sajn@cgs-labs.com
[b] CGS Labs d.o.o., Brčičeva 13, 1000 Ljubljana, Slovenia

Summary

The high resolution route-based forecast is crucial for optimising preventive road measures in winter. We at CGS Labs have developed and are continuously improving our RBF model. The latest contribution to that end was the acquisition of Marwis mobile measurement sensor. The accuracy of the route-based forecast was verified using the Marwis mobile sensor on carefully selected motorway section. We drove the section in different weather conditions and times of the day and compared the measurements with the forecasted values. The results will help us understand more accurately which parameters impact the localized road temperature differences.

Introduction

Forecasting the meteorological condition of the road surface is crucial for carrying out preventive treatment. Preventive treatment uses less salt and is therefore more cost-effective and environmentally friendly. In recent years, developers of RWIS/MDSS systems have been faced with the technical challenge of how to convert point-based weather forecasts from weather station locations into a continuous (route-based weather forecast - RBF). Several papers on this topic have been presented at SIRWEC [1, 2, 3], as well as at PIARC conferences [4, 5]. In fact, the road can be very variable in terms of temperature. On a typical winter night, the temperature differences on a short stretch of road (e.g. 1 km) can vary by up to 10 °C. As a consequence, some stretches may be below the freezing point while others may not. The patterns and distribution of warm and cold sections are established and determined by local environmental factors and prevailing weather conditions. Therefore, a high-resolution RBF makes sense as it represents a step forward in optimising salting (allowing for sectional treatment) and will be of even greater value when autonomous vehicles are on the roads.

RBF has also been a subject of development at CGS Labs for many years. RBF verification is key to this. In this paper, we present the results of the verification we have carried out over the last winter.

Methods

RBF was tested on the Ljubljana - Trojane motorway section (approx. 30 km). The section of the motorway closer to Ljubljana is 13 km long and runs on flat terrain, while the other part of the selected section is more rugged and 17 km long. There are also 5 DARS road weather stations on this section of the road.

The RBF is calculated in reference points. A reference point is a geo-location on the motorway. At each reference point, a forecast of the road surface temperature is calculated every hour for 12 hours ahead. There are approximately 12,000 reference points on the entire motorway network in Slovenia. On the test section, there are 509 reference points, which are located approximately every 50 metres.

Measurements of road temperature, road condition, water film thickness and coefficient of friction were made with a contactless Marwis sensor from Lufft (OTT Hydromet). The Marwis was mounted on the rear of the vehicle at a height of 1 m from the ground, as required by the manufacturer for this model of sensor. The motorway section was driven in either one or both directions.

To make it as easy as possible to compare the Marwis measurements with the forecasts at the reference points, the measurement interval was set to 1 second and the test section was driven at speeds of up to approximately 90 km/h (25 m/s).

Quality measurements are highly dependent on the correct calibration of the sensor before each test section is measured. Following the measuring equipment manufacturer's instructions exactly means that, after cleaning the optical parts of the sensor, the calibration is carried out at a suitable temperature (or the sensor is warmed up to operating temperature), on a dry asphalt substrate comparable to that of the test section and that the calibration time is set to 60 seconds. Given the timing of the measurements (late winter/early spring), the 'AVG' (average) model was used among the pre-set models to calculate the road condition. This ensured the most reliable measurements.

The measurements were carried out in March and early April. During this time, 14 runs were carried out at different times of the day and under different weather conditions.

For the first analysis, we wanted to compare the Marwis measured mobile road temperature with our RBF road temperature model. From the data of each run, we found the closest measurement point for each reference point on the motorway. Since the time of the measurement is known (T_1), we found for the reference points the forecasts for the time T_1 calculated at T_1 - 1h, T_1 - 2h, T_1 - 3h, ... T_1 - 10h, T_1 - 11h and T_1 - 12h in the second step. An analysis of the difference between the measured temperatures and the forecasted temperatures is shown in the next section.

For the second analysis, we wanted to compare the measured mobile road temperature with the measured sensor temperatures at the five road weather stations located on the section. From the data of each run, we found the closest measurement point for each station on the motorway. For the time of the mobile measurement (T_1), we found the closest measurement in time from the station and compared the values. This analysis gave us a measure of confidence in the mobile measurements.

Results

The results of the first analysis showed that the difference between the measured temperature and the forecasted temperature increases with the forecast time difference. Interestingly, the forecasts for 1 to 3 hours ahead are quite similar. It is only when we forecast 4 hours ahead or more that the accuracy decreases and the error increases.

For forecasts 1 to 3 hours ahead is:

- The average difference is 1.5 degrees Celsius.
- Half of all forecasts have a difference of less than 2 degrees Celsius.
- For 75% of forecasts, the difference is less than 4 degrees Celsius.

The results of the second analysis can be seen in the table below and show that the mobile sensor measurements do not deviate significantly from the road weather station measurements. However, as we are only comparing two measurements against each other, there are also significant differences in some places, which should not be given too much weight as there are too many variables that affect the measurement during driving.

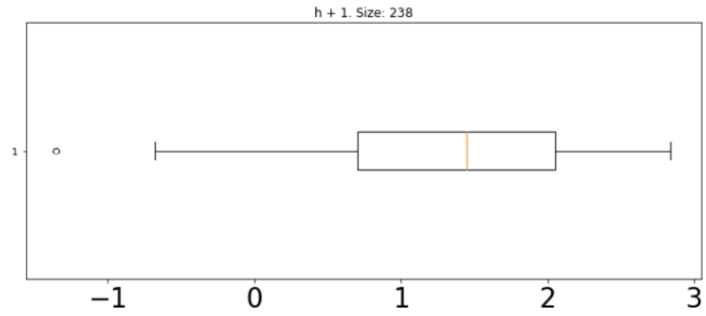

Fig. 1. Difference between the measured temperature and the predicted temperature 1 hour ahead on a flat section

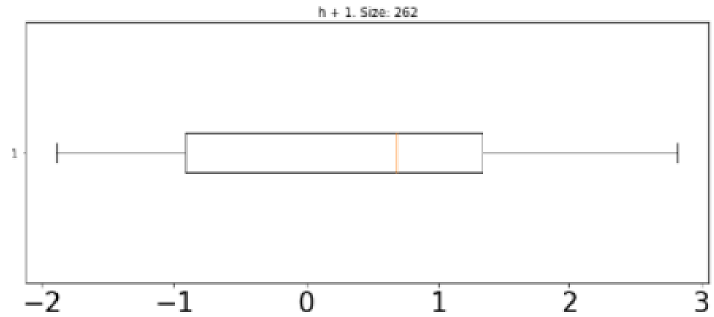

Fig. 2. Difference between the measured temperature and the predicted temperature for 1 hour ahead on a rugged stretch

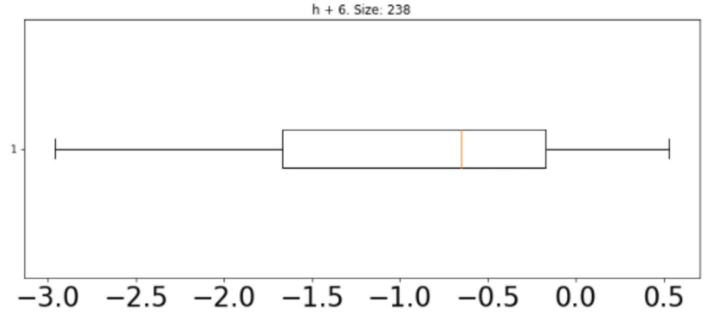

Fig. 3. Difference between the measured temperature and the predicted temperature 6 hours ahead on a flat section

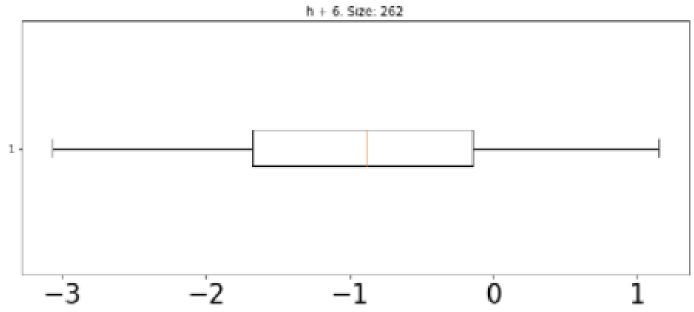

Fig. 4. Difference between the measured temperature and the predicted temperature for 6 hours ahead on a rugged stretch

Table 1. Difference in temperature measured at a road weather station and measured with a mobile meter (source for RWS measuremens DARS d.d.)

	Station 1	Station 2	Station 3	Station 4	Station 5
Drive 1	0.01	0.70	3.40	2.60	1.79
Drive 2	0.99	1.36	4.32	2.09	1.44
Drive 3	0.47	1.61	1.0	0.51	0.73
Drive 4	0.34	--	0.84	0.37	1.02
Drive 5	0.10	1.28	1.73	1.62	0.53
Drive 6	0.08	0.92	1.65	0.96	0.72
Drive 7	1.29	4.07	0.45	0.80	1.48
Drive 8	0.06	1.71	2.76	2.93	0.83
Drive 9	1.10	0.76	2.29	2.43	0.87
Drive 10	0.34	0.43	2.53	1.69	0.80
Drive 11	0.58	0.01	2.14	1.60	0.44
Drive 12	0.23	0.13	0.03	0.18	0.40
Drive 13	0.08	0.29	0.73	0.15	0.34
Drive 14	0.03	0.93	0.90	0.62	0.26

Conclusions

The mobile measurements and the analysis are a welcome insight into the state of the RBF. We have this year's forecast accuracy indicator. In the future, we will have to carry out a more detailed analysis, from which we will also be able to draw out patterns that can be used to further improve the RBF.

We assume that the forecast error is due to the second subsection, which is more rugged and has more shaded parts. Further studies are likely to show that the lowland sub-region has better prediction accuracy precisely because of its more uniform topography.

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DEVELOPING PROBABILISTIC SURFACE TRANSPORT FORECASTS AT THE MET OFFICE

Joe Eyles, Alice Lake, Hannah C.M. Susorney
Met Office, Fitzroy Road, Exeter, Devon, UK, EX1 3PB,
joe.eyles@metoffice.gov.uk, ORCID: 0000-0002-5217-4366

Summary

The Met Office is currently developing a new Surface Transport Forecasting (STF) system which makes uses of the Met Office's regional ensemble model, MOGREPS-UK, to produce probabilistic forecasts of road weather conditions. The outputs from this forecast will provide key road weather information to infrastructure decision-makers across the country. In this talk we will present initial results from our probabilistic STF system, show how these compare to a deterministic system, and give examples of how the outputs of this system can be used to aid decision-making.

Abstract

Since the 1980s, the Met Office has produced so-called Surface Transport Forecasts (STF) for the United Kingdom. The output of these forecasts are of vital importance to key infrastructure decision-makers across the country; providing accurate and timely predictions of road conditions enables gritting services to operate efficiently and effectively, reducing risk to members of the public. With the growth of the Future of Mobility (including Connected Autonomous Vehicles) sector these requirements are changing, prompting a move to modernise the Met Office's STF capability (see associated abstract Lake et al., this conference). Here, the focus is specifically on how a probabilistic STF system is being built to enable the Met

Office's new STF capabilities. This abstract starts with an outline of the current state of the deterministic STF system, followed by motivating a move to probabilistic ensemble-based forecasts. It then discusses the source of the ensemble inputs to the system, before describing the architecture of such a system, and finally reviewing the validation and verification of the new STF system.

The current operational STF system is a deterministic model. That is, for a given event (for example, whether or not there will be ice on the road surface at a particular location) it outputs only a binary "true or false"-style forecast, with no indication of how likely that particular event is to occur. Despite significant increases in forecasting capabilities over the past decades, weather such as the exact position of patchy rain showers, or the precise time a cloud will form and pass overhead, remain challenging to predict deterministically. Ensemble-based forecasting offers a solution to this problem: by producing multiple deterministic forecasts from slightly differing initial conditions (designed to all be equally likely to occur) and considering all of these forecasts in aggregate, a probabilistic view of the future can be gained. Therefore, the Met Office is currently developing a new STF system designed to make use of such ensemble forecasts in order to produce a probabilistic forecast of road state conditions (for example, dry, wet, or icy) to replace the current deterministic forecast.

The new STF system is centred on the Joint UK Land Environment System (JULES); a community model used as the land-surface component of the Met Office Unified Model (UM), but which can also be used – as the STF system does – as a stand-alone land-surface model driven by forecast output from Numerical Weather Prediction (NWP) models. In order to produce probabilistic forecasts for locations within the United Kingdom, the output from the Met Office regional ensemble model MOGREPS-UK is input to JULES. MOGREPS-UK is an 18-member ensemble model which produces hourly forecasts for the United Kingdom out to 5 days. It is generated by time-lagging over 6 hours, meaning there are three new ensemble members every hour (Fig. 1) generated from slightly differing initial conditions. The new STF system runs JULES driven by each ensemble member, which gives us a collection of 18 possible predicted road states. By combining these predictions, the probability of a given road weather condition occurring can be computed.

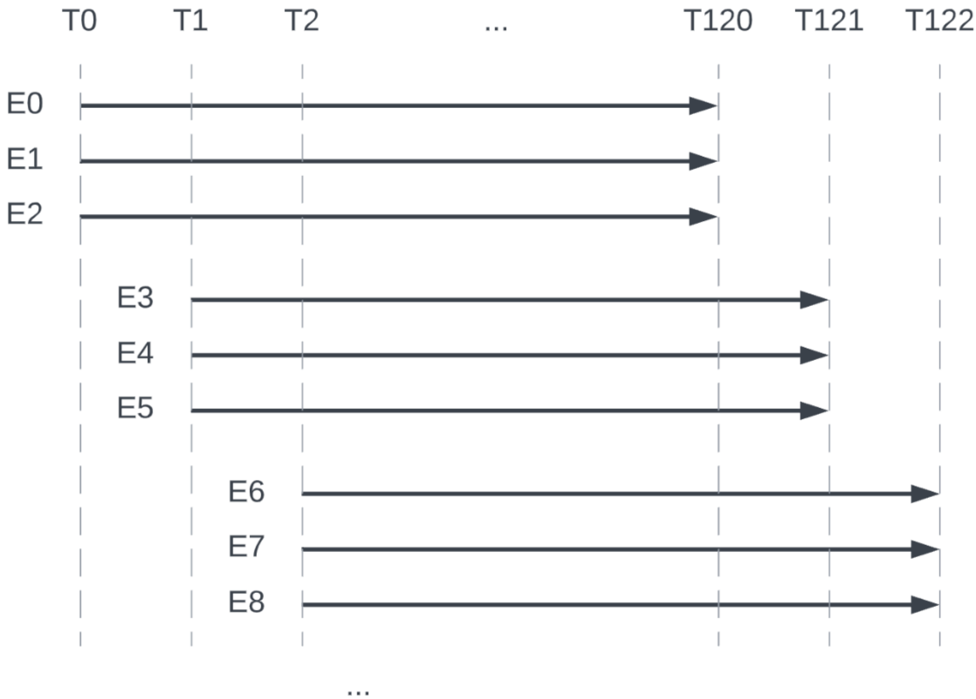

Fig. 1. Schematic diagram of MOGREPS-UK ensemble members. At each time period (here denoted T0, T1, … T122) three new ensemble members (here denoted E0, E1, E2…) are generated, and provide forecasts out for 120 hours (5 days).

The computational time of the new STF ensemble-driven system increases with the number of ensemble members. This can be mitigated by careful architectural design. In Fig. 2 we present a post-processing system (so called because the processing happens after the Met Office's main NWP model has run – in this case MOGREPS-UK), that allows much of the computation to happen in parallel. Since JULES is a physics scheme it requires initial conditions; in this example these are calculated from the previous forecasts, so this step happens before the parallel steps, at any time after the previous forecasts have run. Once the MOGREPS-UK driving data arrives, the computation splits into three parallel processes, one for each ensemble member. By introducing parallel processing here the run-time of the post-processing scheme is not significantly impacted by the increased workload. First the local effects of shading and traffic are applied to the MOGREPS-UK driving data. JULES is then run against each of the ensemble members to produce a set of initial forecasts. A machine learning bias correction step is then applied to each of the initial forecasts, yielding a set of improved forecasts. These are then considered in aggregate with the output from ensemble members at previous timesteps (since MOGREPS-UK is a lagged ensemble) to produce a probabilistic forecast.

Results from the new ensemble-driven STF system were initially compared against the same post processing steps driven by deterministic data. This has only been done in a qualitative manner, as the types of forecasts are quite different. In performing this comparison, it was found that the observed road surface temperature is generally captured within the range of road state predictions outputted by the ensemble-driven STF system, while the deterministic forecast, although accurate, can at times have a significant error. In the example in Fig. 3 the error is driven by incorrect night-time cloud cover in the deterministic NWP driving data. This error is mitigated in the ensemble driving data, since the two possible realities of cloudy or clear skies are captured in the spread of the ensemble. Accurately forecasting probabilities for nights when the sky is clear or cloudy is of particular importance, as the difference in radiative cooling can lead to a large variation in road surface temperatures. Thus, in challenging

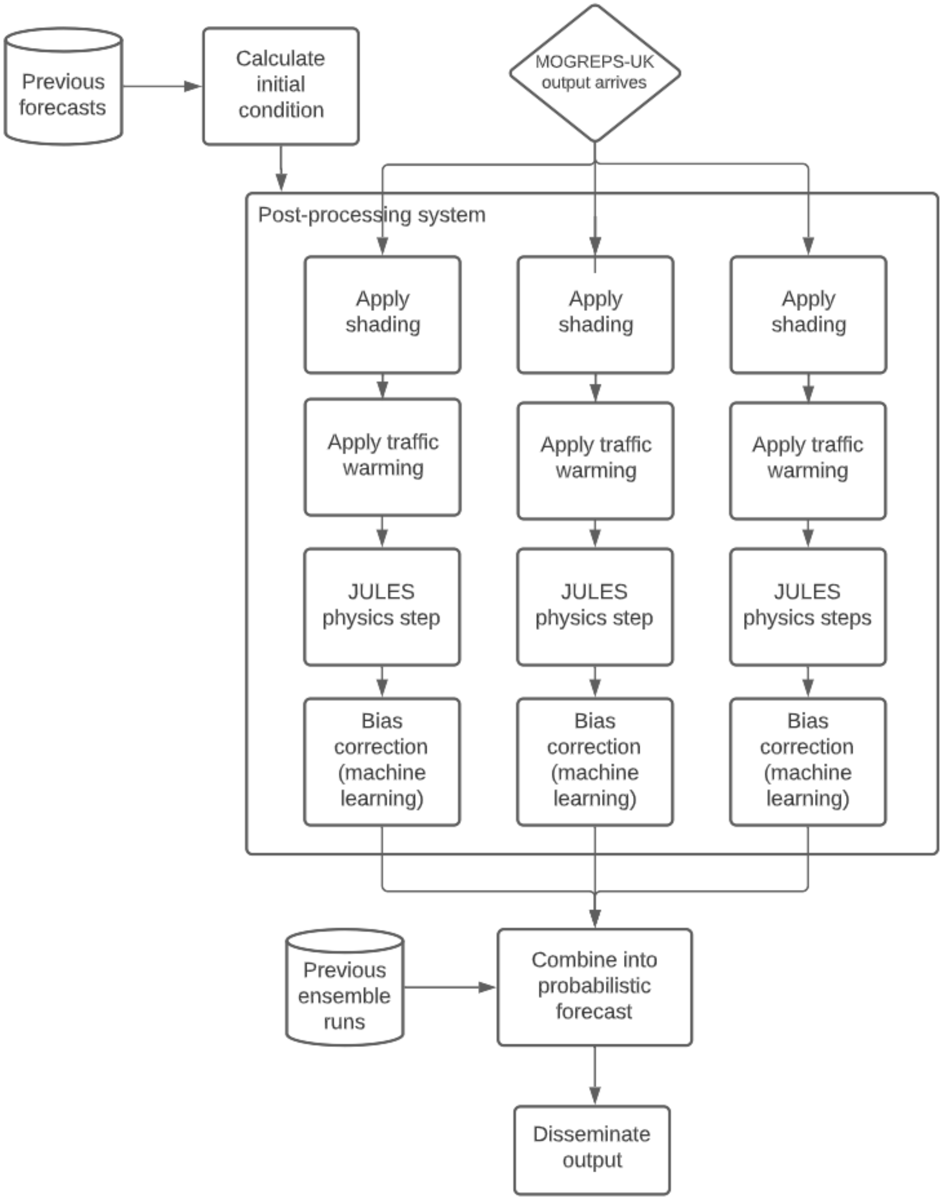

Fig. 2. Schematic of the new ensemble-driven STF system, detailing the steps required to produce a probabilistic road surface forecast. Once the MOGREPS-UK output arrives, and we have generated initial conditions from the previous forecasts, the processing splits into three parallel threads (one for each ensemble member). Each thread applies local effects, the JULES physics scheme, and bias correction. This gives three forecasts, which are combined with previous ensemble runs to create a probabilistic forecast which can then be disseminated.

meteorological conditions, for example in Fig. 3 where there is variable cloud cover, the probabilistic model allows an understanding of the uncertainty in the road state forecast in a way that the deterministic model does not.

We are currently verifying our probabilistic road surface forecasts at approximately 300 locations in the United Kingdom for which good quality road weather observation data are available between May 2019 and May 2021, using standard meteorological ensemble verification techniques, including rank histograms and reliability plots.

Future research will focus on how to best communicate a probabilistic forecast, as discussed in the advice and guidance laid out in [3]. This could include standard outputs such as RAG (Red Amber Green) statuses, updated to describe the probability of significant weather hazards such as ice on the road surface. It will also necessarily include probability- and ensemble-specific visualisations for both forecasts and verification of the current performance of the system. Carefully focussing on communication of

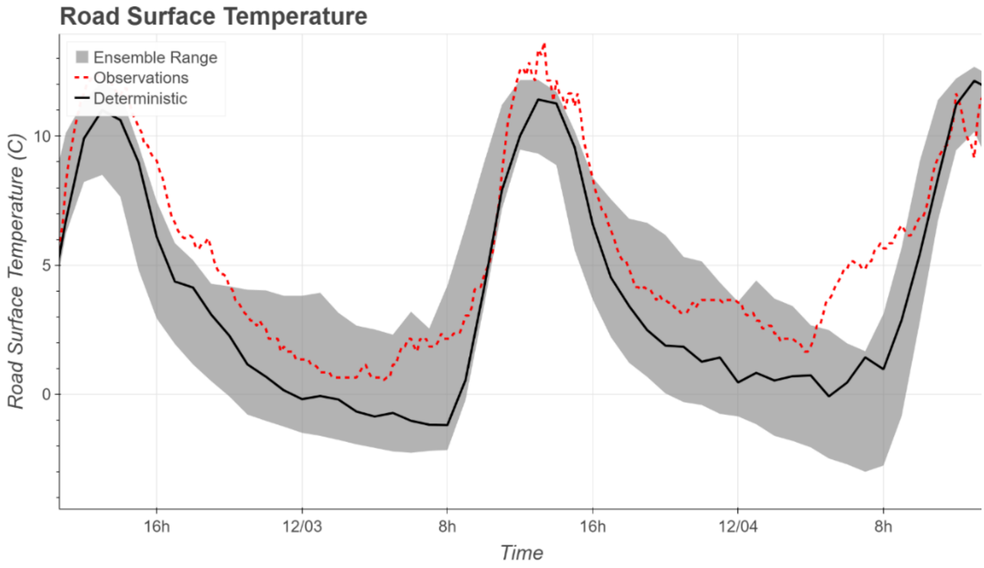

Fig. 3. An example of two marginal nights in Cornwall (United Kingdom) in 2020. The deterministic forecast predicts sub-zero temperatures, while the observations remain above zero. The range of ensemble forecasts captures both possibilities.

the forecasts ensures that end users are able to use probabilistic forecasts to enhance their decision-making.

In this talk we will present initial results from our probabilistic STF system, show how these compare to a deterministic system, and give examples of how the outputs of this system can be used to aid decision-making.

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EFFECTS OF SCREENING AND SKY VIEW FACTOR ON ROAD SURFACE TEMPERATURE FORECASTS

Virve Karsisto, Matti Horttanainen
Finnish Meteorological Institute, Erik Palménin aukio 1, 00560 Helsinki, *virve.karsisto@fmi.fi*, ORCID: 0000-0002-5212-1002

Summary

Road surroundings can affect significantly to the road surface temperature. In this study, the effects of including sky view factor and screening to the Finnish Meteorological Institute's (FMI) road weather model (RWM) are tested. According to the results, the effects vary greatly depending on the studied location. Even changing the lane can affect considerably to the road surface temperature. Shadowing increases the already negative bias in the forecasts in some cases, but at best it considerably decreases the RMSE during the day.

Introduction

Screening has a great effect on road surface temperature. During the daytime, the shadowed locations can be several degrees colder than locations exposed to the sun. On the other hand, obscured locations can remain warmer on clear nights due to the radiation emitted by the surroundings. Taking these effects into account in the road weather forecasts is an important step in making the forecasts more accurate. This can be done by determining sky view factor (SVF) and local horizon angles (LHAs) for the forecast location. The SVF means the fraction of the radiation reaching the surface from the radiation of the entire sky. The LHAs are determined as the angles between the flat surface and the visible horizon. There are two common approaches to determine these values. The first uses fish-eye photographs that give 360° view of the location [1]. The second uses digital surface models (DSM), which are height maps in raster format [2]. The DSMs include buildings and vegetation in addition to terrain features. There have been some previous studies about how the SVF and/or LHAs affect to the road surface temperature forecasts [3,4]. However, there is still need for more excessive research in different environments.

The FMI's Road weather model (RWM) has thus fare expected open road surroundings, although some experiments with SVFs and LHAs have been made. In this study, the SVFs and LHAs were included to the FMI RWM and their effect to the road surface temperature forecasts was studied. The model was run for three winter periods (2018-2019, 2019-2020, 2020-2021) with and without SVFs and LHAs and the forecast verification results of the two runs were compared. The runs without SVFs and LHAs will be called as "Reference" and the runs including them as "Test". 23 road weather stations (RWS) with the SVFs varying between 0.72 and 0.98 were included in the study.

Data and Methods

DSMs generated from the National Land Survey of Finland's (NLS) laser scanning data [5] were used to determine the SVFs and LHAs at station locations. The laser data was processed to DSM using Lastools software [6]. Fig. 1 shows an example DSM for Salo Lakiamäki station in southern Finland. There are rock cuttings at both sided of the motorway, which makes it a rather shadowed location. Fig. 2 shows the LHAs calculated for the station with Grass software [7]. The LHAs were determined for both the southern and northern lanes and the forecasts were made for them

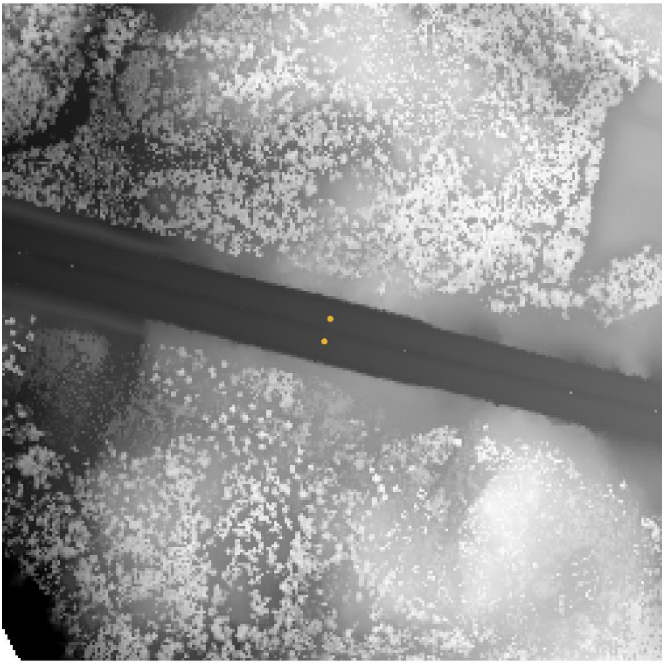

Fig. 1. The DSM determined from laser scanning data around Salo Lakiamäki RWS and the selected coordinate points for the simulations.

separately. On the southern lane the LHAs are clearly larger in the south than in the north, whereas the opposite is true for the northern lane. This causes large surface temperature differences during autumn and spring, when the northern lane is exposed to the sun but the southern lane is in shadow.

The FMI RWM is an one dimensional energy balance model which predicts surface temperature and road conditions [8]. As input, the model requires air temperature, wind speed, humidity, precipitation and incoming short and long wave radiation. Road surface temprature can be also used in the initialization. In this study, a shadowing algorithm and the SVF were added to the model. To calculate the modified radiation fluxes, direct short wave radiation and net long wave radiation were added to the input parameters. The shadowing algorithm reduces the direct solar radiation to zero when the sun elevation is lower than the LHA in the direction of the sun.

The SVF affects to the incoming diffuse short wave radiation, incoming long wave radiation and the long wave radiation emitted by the road surroundings following the equations used in the HIRLAM model [9].

The RWM runs consisted of a 48-h inititalization period where the input data was taken from the RWS observations and a 24-h forecast period where the input was taken from the MEPS (MetCoOp Ensemble Prediction System) forecast [10]. MEPS is a 3D numerical weather prediction model developed by the HIRLAM consortium. In case the the RWS had multiple surface temperature sensors, the model runs were run separately using each of their data in the initialization. The same sensor that was used in the initialization was also used in the verification. The exact coordinates of the RWS surface temperature sensors were unknown, so all the runs were done for two lanes separately. For example, if there were 2 sensors, a total number of 4

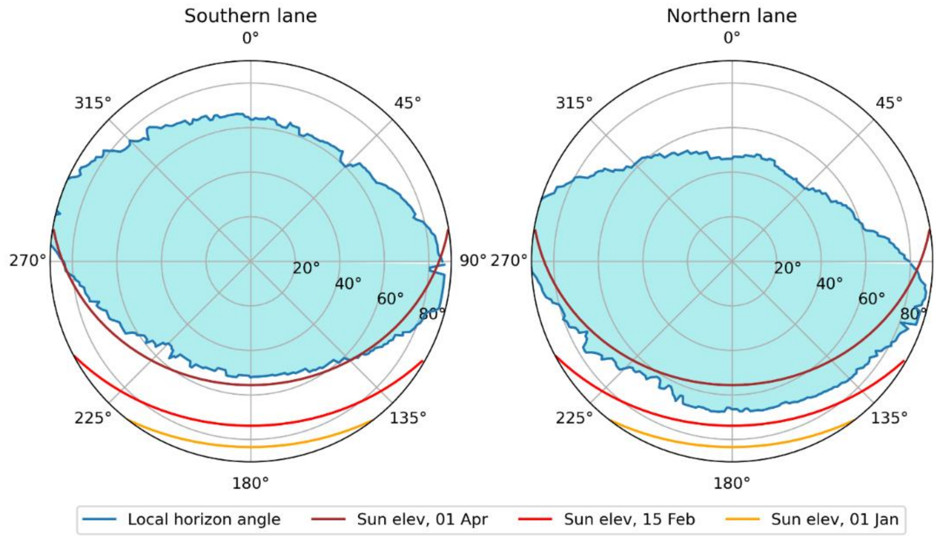

Fig. 2. The local horizon angels (blue line) at Salo Lakiamäki RWS on the southern (left figure) and the northern (right figure) lanes. The outer perimeter shows the direction so that the north is at 0°. The visible sky is shown in light blue color. Brown, red, and yellow lines show the sun elevation angels throughout days 1st April 2019, 15 February 2019, and 1st January 2019, respectively.

forecasts were made for one station. The simulations were done for three winter periods starting from October 2018 and ending to March 2021. Four forecasts with start times 03, 09, 15 and 21 UTC were done for each day.

Results

The daily behaviour of surface temperature forecast bias is clearly dependent on the lane and the sensor used in the initialization and verification (Fig. 3.). The reference simulations have warm bias during the day as they do not take screening into account. However, when the

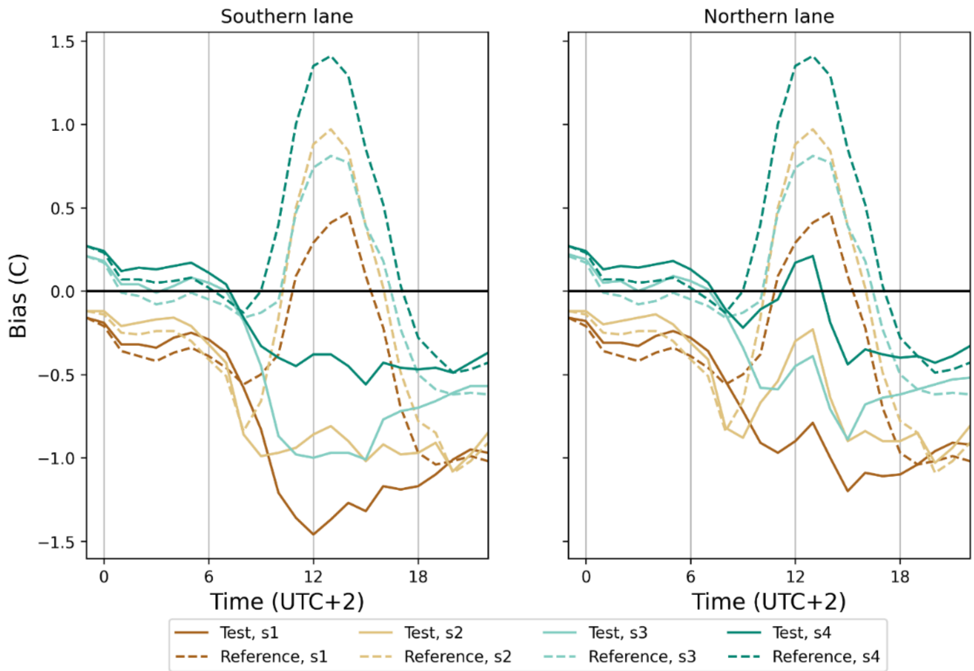

Fig. 3. Bias for Salo Lakiamäki station calculated for Octobers 2018-2020. The simulation start time was 21 UTC. The x-axis shows time of day in Finnish wintertime (UTC+2). Results for test runs are in continuous lines and for the reference runs in dashed lines. The left figure shows results for the southern lane and the right for the northern lane. Results for runs using sensor 1 are in brown, sensor 2 in light brown, sensor 3 in turquoise and sensor 4 in darker turquoise lines.

screening is taken into account the bias becomes negative for most sensors. The northern lane is warmer than the southern lane in the simulations as it is more exposed to the sun. It seems that the sensor 4 is in the most shadowed location as it has the least negative bias during the day for the test run and the most positive bias for the reference run. The sensor 1 seem to be in the most open location. During the night the radiation from the surrounding causes the test simulations to be a little warmer than the reference simulations.

The RMSE varied greatly between simulations during the day (Fig. 4). The test runs have smaller RMSE values than the reference runs except at the southern lane for the sensor 1 that was probably the most exposed to the sun. For the northern lane, the forecasts using sensors 1 and 3 have the

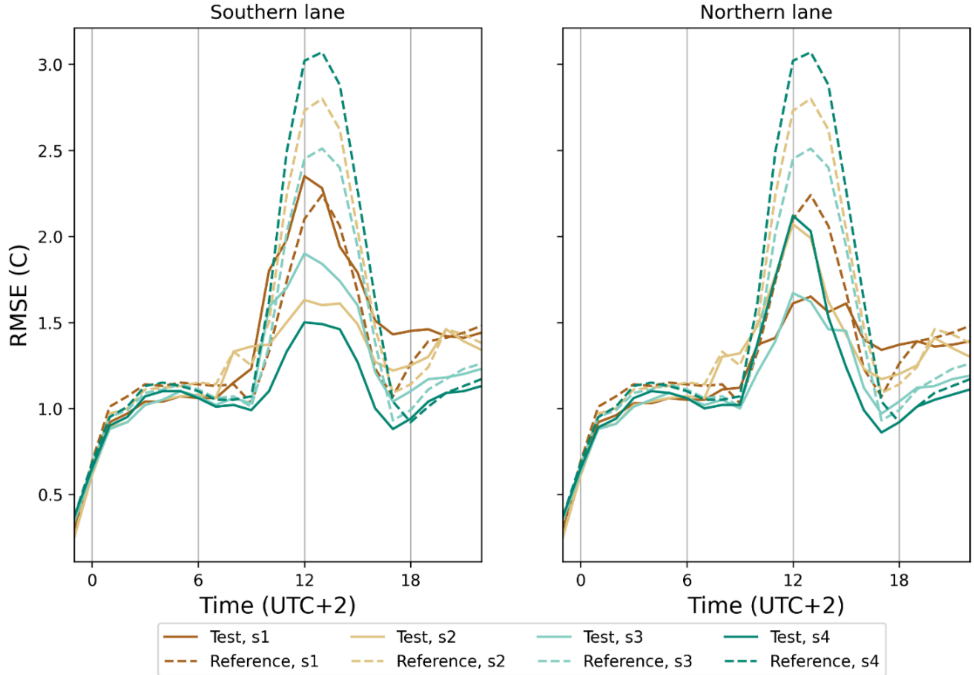

Fig. 4. Same as Figure 3 but for RMSE.

smallest RMSE values, whereas on the southern lane the forecasts for sensors 2 and 4 give the best values. However, it is still difficult to know which sensor is located on which lane as the forecast error is affected by many factors. During the night at the start of the forecast the test runs have slightly lower RMSE values. However, at the evening 17:00 local time the test simulations for sensors 1-3 have higher RMSE values than the reference simulations. At this time in the evening the bias in the reference simulation has already turned negative so the model cools too fast, but the observed temperature still matches better to the reference run than to the even colder test run.

In general, the verification results were quite dependent on the location, month and the time of the day. In October and March during the day the screening often made the already too cold forecast even colder. However, at best the shadowing algorithm decreased considerably the warm bias during the day. Only a short overview of the research results was given here, but there will be a more excessive publication about the results in the future. The data and results are available in the FMI data repository METIS [11]

Acknowledgements

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RELATION BETWEEN WEATHER AND TRAFFIC ACCIDENTS ON THE MAIN ROADS OF LITHUANIA

Justas Kažys, Aistė Jančiauskaitė
Institute of Geosciences, Vilnius University, 3 Universiteto St., 01513 Vilnius, Lithuania, *justas.kazys@gf.vu.lt*, ORCID: 0000-0003-3187-4539

Summary

Despite the significant decrease of overall number of road traffic accidents in Lithuania, weather related accidents are still remaining a challenge for road safety. The original methodology was adjusted to evaluate potential impact of adverse weather on traffic accidents frequency. The research focused on the two main roads in Lithuania during 2017-2019 period. The results proved that the frequency of the traffic accidents increase during adverse weather events and not ideal road surface conditions. The recurrence of accidents reached the highest number on icy and snowy roads.

Introduction

The Structure of the Road Network of National Significance in Lithuania contains main, national and regional roads and stretches more than 21.2 thou. km. The 50% of cargos and 97% of public transportation are using national road network. In Lithuania, in 2018 for 1 mil. inhabitants 61 fatal accidents were registered, it was 11% less than in 2017 and, even, 43% less than in 2010 [1]. However, the accidents still remain very serious problem; every year about 1.24 mil. people are killed during the crashes all over the world [2].

There are various perspectives how meteorological conditions could have the impact on roads and traffic safety [3, 4]. There are a lot of studies and methodologies dedicated to weather related traffic accidents [5, 6, 7, 8, 9, 10]. The previous research found that 20-30% of road accidents could be related to weather impact [11, 12] and the potential risk of crash on wet roads increases several times [13]. Snow has a greater effect than rain does on crash occurrence [13, 14], but the precipitation also increase the number of traffic accidents [3, 14, 15]. Moreover, the potential risk of accidents would not disappear in the future [2, 16].

The main objective of this research was to determine possible impact of adverse weather conditions on road traffic accidents by adjusting the original methodology [17] for 2 main roads in Lithuania.

Materials and methods

The main national roads A1 and ‘Via Baltica’ (sections of A1, A5, A8, A10, A17) were selected for the analysis (Fig. 1). These roads are parts of the international roads E85 and E67 passing through the territory of Lithuania. Two types of data were used: road traffic accidents and road weather (surface) conditions. All the data were provided by the Lithuanian Road Administration under The Ministry of Transport and Communications. The weather conditions data collected from the Road Weather Information System (RWIS) weather stations (WS) which were located on the selected roads: 15 WS on A1 and 7 on ‘Via Baltica’. The research covered 2017-2019 period.

The original methodology of potential adverse weather conditions impact on traffic accidents developed for Vilnius city [17] were applied and modified for state roads. Road traffic accidents could be related to road

Fig. 1. The main roads crossing Lithuanian territory: A1 (E85) from West to East and 'Via Baltica' (E67) from North to South (modified map, the base taken from eismoinfo.lt *and GDB10LT National Land Service, 2012)*

section, traffic intensity, patterns of weather season, etc., therefore, the accidents were divided: prior to the closeness to WS; prior to weather conditions into warm and cold seasons; prior to traffic intensity into weekdays and weekends. The accident rates on the road during adverse weather conditions (precipitation, wet, icy conditions, etc.) compared with the accident rates in favourable weather conditions (no precipitation, dry road surface). Overall number off traffic accidents and specified road weather (surface) conditions were calculated (Table 1). It was done by attributing every traffic accident to specific weather (surface condition) to the closest WS.

Table 1. Recurrence of road traffic accidents and road weather conditions divided into different groups of weather (surface) condition types in two main roads in Lithuania during 2017-2019 period

Type	Condition	Road traffic accidents, number (%)		Road weather conditions, number (%)	
		E85	E67	E85	E67
Road weather	No precipitation	1278 (79.1)	674 (82.4)	1822150 (88.6)	1857317 (91.0)
	Precipitation	22 (1.4)	0 (0.0)	22864 (1.1)	30731 (1.5)
	Drizzle	44 (2.7)	26 (3.2)	39797 (1.9)	36639 (1.8)
	Rain	152 (9.4)	65 (8.0)	82571 (4.0)	68278 (3.3)
	Sleet	10 (0.6)	4 (0.5)	6187 (0.3)	3955 (0.2)
	Snow	90 (5.6)	43 (5.3)	51947 (2.5)	33122 (1.6)
	Fog	9 (0.6)	3 (0.4)	21760 (1.1)	5973 (0.3)
	Mist	10 (0.6)	2 (0.2)	10638 (0.5)	6695 (0.3)
Road surface	Dry	1059 (65.6)	535 (66.3)	1377721 (67.7)	1497727 (71.0)
	Moist	215 (13.3)	139 (17.2)	427541 (21.0)	378548 (18.0)
	Wet	257 (15.9)	92 (11.4)	208597 (10.2)	206084 (9.8)
	Slushy snow	25 (1.5)	10 (1.2)	7994 (0.4)	9150 (0.4)
	Snow	33 (2.0)	16 (2.0)	8114 (0.4)	12605 (0.6)
	Ice	27 (1.7)	15 (1.9)	5464 (0.3)	4388 (0.2)

Evaluation of potential accidents risk due to adverse weather conditions

In 2017-2019 period 1713 road traffic accident registered on A1 road in which 2586 people were injured or killed. While on 'Via Baltica' road only 824 accidents there recorded (1359 people affected) in the same period. The ratio between traffic accidents and injured people is 5 percent higher on A1 road. According to police reports, the most frequent overall accident causes were collision with an animal and with other vehicle, while during adverse weather conditions were drive off the road, run on the obstacle and overturn of the vehicle. Potentially, 6 % of accidents where people were injured and 21% of technical road accidents could be related to adverse weather conditions in 2017-2019.

On every section of A1 road, the higher frequencies of potential accidents risk during wet road surface conditions were found (Fig. 2a). There were no obvious margins between road sections, seasons of the year and

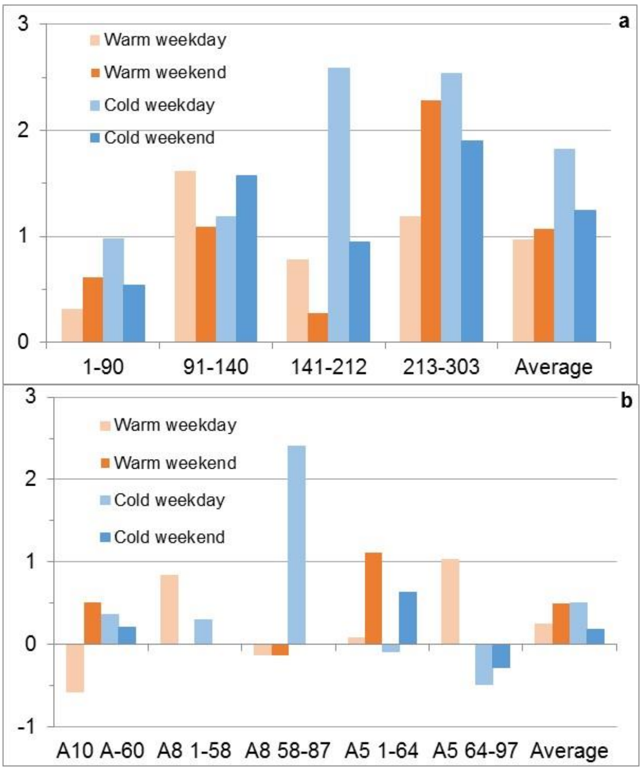

Fig. 2. The comparison (in times) of road accidents between wet road surface and dry road surface conditions on different sections (km) of the roads: a – A1 (E85); b – 'Via Baltica' (E67)

days of the week. Overall, wet conditions had smaller effect on accidents on 'Via Baltica' road sections (Fig. 2b). There were more obvious margins between road sections and high frequencies occurred during the weekdays of cold season.

Again, the fluctuations of potential impact of adverse weather conditions in different seasons and days of the week were higher on 'Via Baltica' (Fig. 3b) compared to A1 road (Fig 3a). Moist road had almost no effect on accidents, while, during the rain, the average of potential accident risk was more than doubled (in some cases almost 4 times higher) compared to 'no precipitation' conditions.

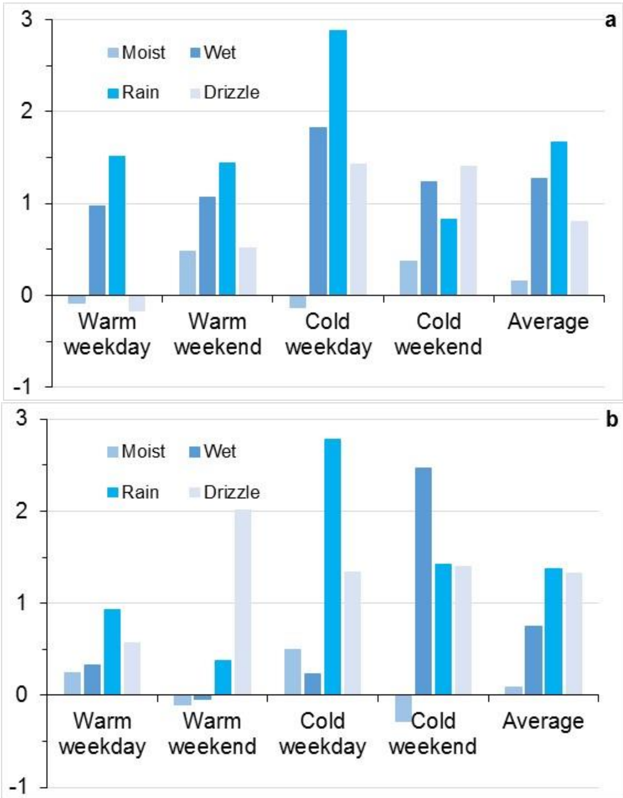

Fig. 3. The comparison (in times) of difference in seasons/ days of the week of road accidents between various road surface (weather) and dry road surface (no precipitation) conditions: a – A1 (E85); b – 'Via Baltica' (E67)

The traffic accident risk due to adverse weather conditions is higher on the A1 road comparing to 'Via Baltica' (Fig. 4), but the differences are not statistically significant. Potentially, the liquid state water (in air and on surface) formed around 1-2 times higher rates of traffic accident compared to normal conditions (Fig. 4a) Meanwhile, from 5 to 17 times higher potential of traffic accidents related to solid state water (Fig. 4b) were found.

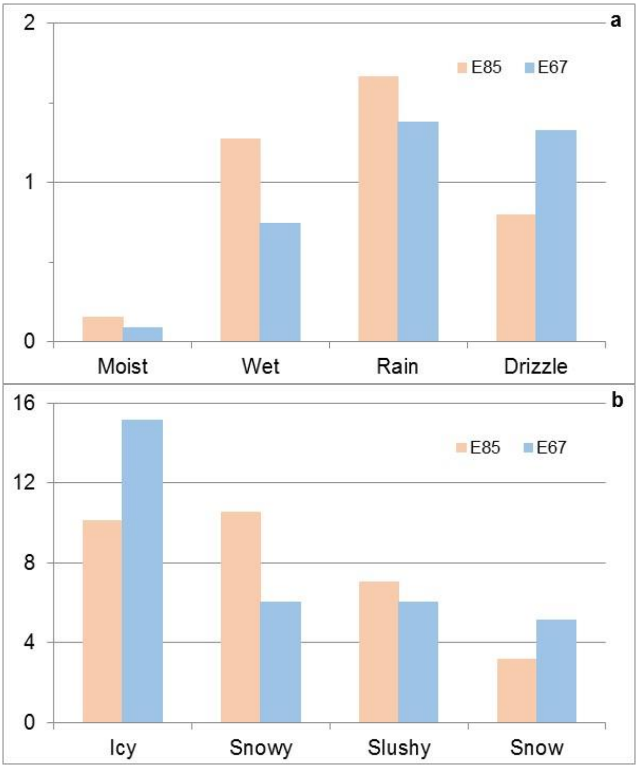

Fig. 4. The comparison (in times) of road accidents between various road surface (weather) and dry road surface (no precipitation) conditions on two main roads in Lithuania. Water state: a – liquid; b – solid

Conclusions

- On two main roads in Lithuania in 2017-2019 period the overall numbers of traffic accidents were higher during all types of precipitation and wet road surface comparing to normal ones.

Therefore, the accidents could be potentially linked to the adverse weather conditions.

- The potential impact of adverse weather conditions fluctuated in very wide range: from 9% on moist ‘Via Baltica’ road surfaces (16% – A1 road) to 15.2 times on icy ‘Via Baltica’ road surfaces (10.1 times – A1 road).
- Cold season impact on road accidents rates were higher because snow and ice had showed very high potential risk of accidents. However, the recurrence of icy and snowy conditions was not frequent (around 1% of all weather conditions).
- Now, the potential impact of all types of rains and wet road surface on road accidents were more frequent all year round, respectively 7% and 10% of all conditions, due to climate change effect (higher temperatures in cold season).

Acknowledgements

The authors are grateful to the Lithuanian Road Administration under The Ministry of Transport and Communications for providing traffic accidents and weather conditions data.

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SURFACE TRANSPORT FORECASTING AT THE MET OFFICE: LOOKING TO THE FUTURE

Alice Lake, Henry Odbert, Joe Eyles, Hannah C.M. Susorney,
Alasdair Skea
Met Office, Fitzroy Road, Exeter, Devon, EX1 3PB,
alice.lake@metoffice.gov.uk, ORCID: 0000-0002-8001-4685

Summary

The Met Office is currently developing a new Surface Transport Forecast (STF) system, centred around a community numerical land surface model called the Joint UK Land Environment System (JULES). This new system has been designed to support future user requirements, especially from the emerging Future of Mobility sector, including Connected and Autonomous Vehicles (CAVs). In this talk, we will discuss the modifications we have made to JULES to enable it to model road surfaces, as well as discussing the future capabilities this system will enable.

Abstract

For more than 35 years the Met Office has been delivering key road weather information to infrastructure decision-makers across the United Kingdom, allowing them to anticipate and react to road weather hazards and thus reduce risk to members of the public [1]. So-called surface transport forecasts are currently generated using the Met Office Road Surface Temperature (MORST) model. Originally developed in the early 2000s, MORST is a bespoke surface energy exchange and water balance scheme which takes forecast outputs from numerical weather prediction (NWP) models and evaluates the surface conditions for a list of predefined locations.

In addition to forecasting road surface temperatures, MORST also provides forecasts of road surface states: for example, whether a particular road surface will be dry, damp, wet, or icy.

Both the way road forecast data is accessed, and the specific types of forecast metrics users are interested in, are likely to significantly evolve in the coming years. Currently, the Met Office is developing a new Surface Transport Forecast (STF) system designed to accommodate these future user requirements, especially from the emerging Future of Mobility sector, including Connected and Autonomous Vehicles (CAVs). Automation of weather-related decisions by vehicles and supporting systems will drive increased demand for direct machine-to-machine communication of real time weather analysis and forecast data. The new STF post-processing architecture (described below) is designed to accommodate this evolution, with the provision to provide on-demand forecasts for new locations near-instantly via application programming interfaces (APIs).

STF has historically focused on determining the state of a road surface in order to provide decision support to winter road maintenance. Although still an important use case, with the development of CAVs the ability to accurately – and consistently – describe a broader range of weather conditions may also become equally vital to ensuring safety and efficiency on road networks. For example, road spray, rain, localised fog, and the accretion of precipitation to sensors or targets, can all degrade the performance of CAV sensors [2]. Standard CAV sensors have different and pronounced responses to a range of weather types with, for example, lidar and daytime camera performance being significantly more impacted by fog than infrared and radar (Fig. 1). Additionally, settled snow also has the potential to obscure road markings, which can impede vehicle manoeuvring when using camera systems. The Met Office aims to provide the best possible decision support to mitigate weather impacts; it is therefore important that the Met Office is able to accurately evaluate and forecast all relevant hazardous weather conditions so that the CAV ecosystem can function within its Operational Design Domain (ODD; the conditions within which CAV systems can competently and safely operate) [3].

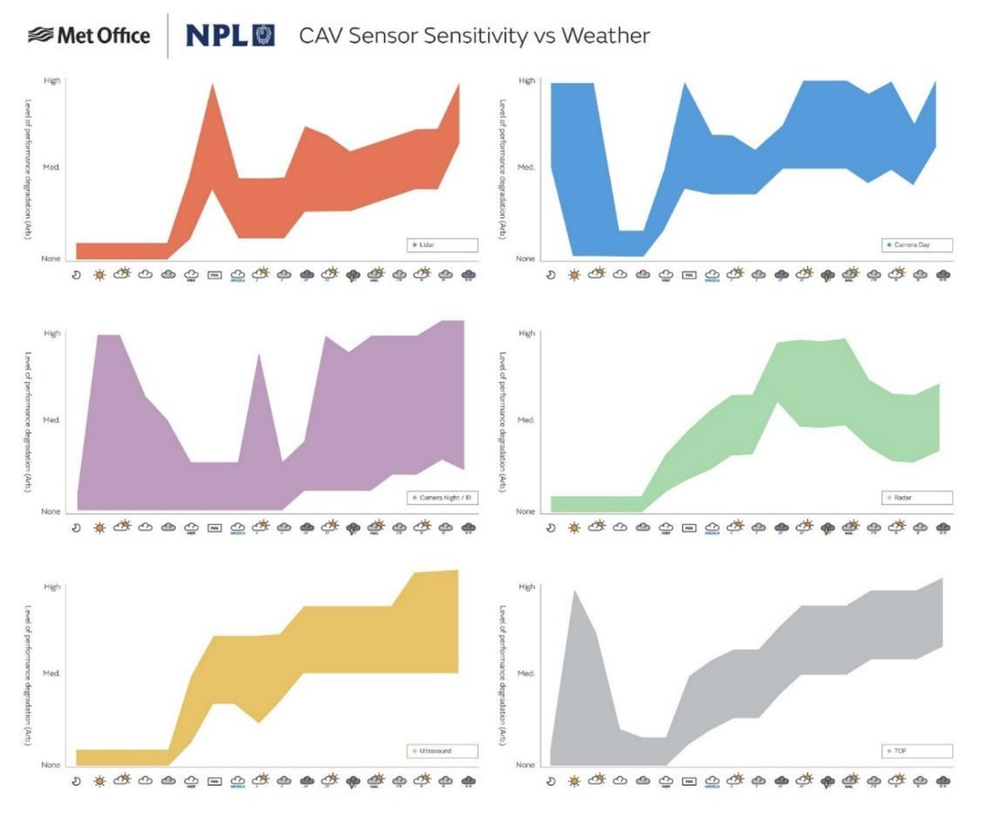

Fig. 1. Plots of sensor performance degradation (y-axis), from none to high, against various weather types (x-axis). Top left to bottom right: lidar, camera (day), camera (night, infrared), radar, ultrasound, TOF. The type of weather can have a significant impact on sensor performance, however the magnitude of the impact depends upon the sensor type. [2]

At the centre of the new STF system is a community land surface model called the Joint UK Land Environment System (JULES) [4]. JULES is the land surface model integrated into the Met Office Unified Model for coupled atmospheric weather and climate modelling, but it can also be used as a stand-alone land surface model driven by forecast output from

Numerical Weather Prediction (NWP) models. It is used in the latter mode in the STF system, since this allows site-specific (point based) forecasts. Since JULES was originally developed to describe soil-vegetation-atmosphere interactions for application to atmospheric modelling, several modifications have had to be made to the physics of the model to enable the STF system to use it for the bespoke purpose of generating site-specific forecasts of road surface temperature and road state.

These modifications are based around adjusting the properties of the surface to better represent those of a road. In its standard form, JULES recognises nine surface types: bare soil, urban, inland water, and ice, along with five types of vegetation. These nine surface types are modelled as nine different “tiles”. To allow JULES to model a road surface, a bespoke “road” tile has been developed by modifying the standard urban tile to make it impermeable; that is, water cannot penetrate from the surface to the sub-surface but it can be stored in, and evaporate from, a small store on top of the surface. Since this effectively takes away a removal mechanism for the surface water store (penetration into the subsurface), this modification led to JULES modelling more water on the road than was physically observed. To account for this a water runoff scheme has been implemented for the new JULES road tile, in which the effect of the camber of road surfaces on the surface water store is numerically modelled. Investigations have also been performed into which values should be used for physical parameters such as emissivity, albedo, and conductivity, to best represent the construction of a road surface.

The range of different applications for surface transport forecasts means that further modification of the JULES physics will be required to better represent the processes which affect the temperature and/or state of the road surface. Future developments that have been prioritised include a traffic scheme to capture the mechanical removal of water, the turbulence introduced by traffic, and the thermal influence of vehicles.

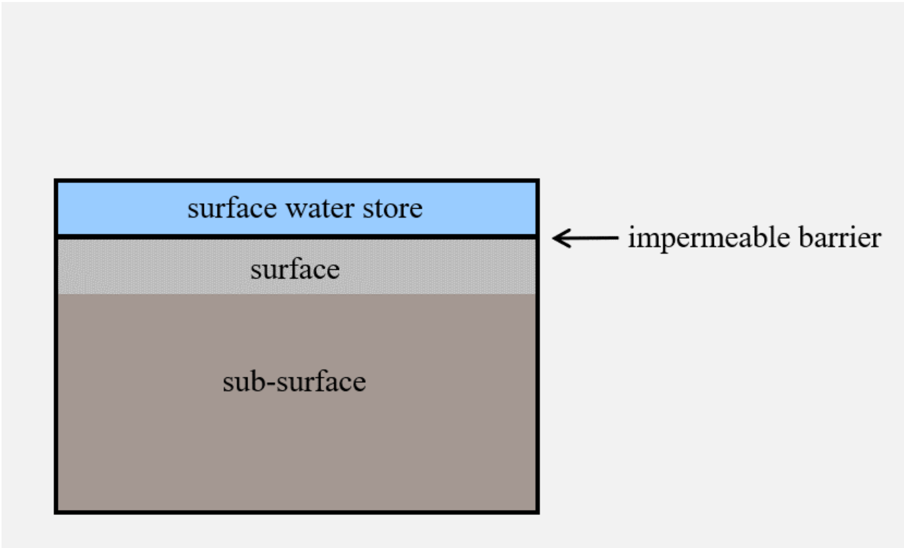

Fig. 2. Schematic diagram of a JULES "road" tile. Here the surface is a thin skin over the sub-surface, which approximates a standard road construction. The surface water store is located on top of the impermeable surface.

The preliminary verification work has involved comparisons of the JULES output to a series of representative road surface observations sites in the United Kingdom over five years of historic data, with the goal to check that the modelled road surface temperature and water surface depth (among other physical diagnostics) align with observations. It was found that the modelled road surface temperature accurately matches observations. When there is a discrepancy it tends to be attributable to errors in the driving NWP output, due to hard to model weather conditions such as patchy cloud cover, convective regimes, or the precise timing of weather fronts. Our work (not described in this abstract or talk) to build a probabilistic road surface forecast using an ensemble approach aims to resolve this issue (see associated abstract Eyles et al., this conference).

The new STF system will be capable of delivering both scheduled hourly forecasts, as well as new on-demand forecasts via an API. To do this, a cloud-based architecture is used. By building a modular system, in which steps that are common across both workflows need only be built once, the development work in building two types of services can be minimised. For example, the physics scheme JULES is required to produce both types of forecasts, and so would be shared across both types of services, however, the initial conditions are generated using different techniques across the two types of services, and thus would not be shared.

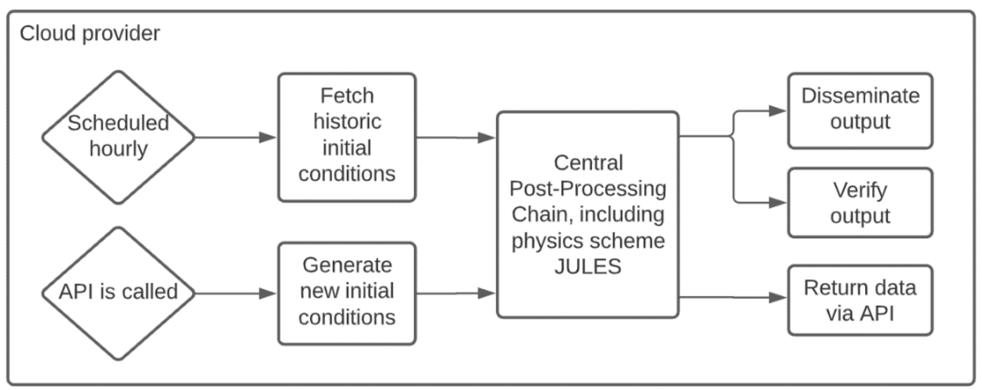

Fig. 3. High level schematic of the cloud based STF system, showing modules that are shared between the scheduled and API workflows (the central post-processing chain, described below), and the modules that are unique to each workflow (the modules that fetch or generate initial conditions).

Although the dominant step in the STF system is the land surface model JULES, there are a number of auxiliary steps that are vital to providing accurate forecasts over diverse road and traffic types. These steps, considered together, form a post-processing chain, so called because the processing happens after the Met Office's main NWP model has run. The post-processing chain contains two steps that correct the NWP output (which is used to drive JULES) for local effects. The first of these is to apply additional incoming longwave radiation to account for the impact of traffic heating. The magnitude of the additional longwave radiation depends upon on a model for traffic volume and speed. This model takes into account the type of road (including the speed limit and number of lanes), the day of the week, and the time of day. The second of these applies a shading scheme to the incoming shortwave radiation. This uses local topographic information, along with the height and angle of the sun, to set direct shortwave radiation to zero when the site is in shadow. Finally, a bias correction scheme based on machine learning is applied to the JULES output to yield a more accurate forecast.

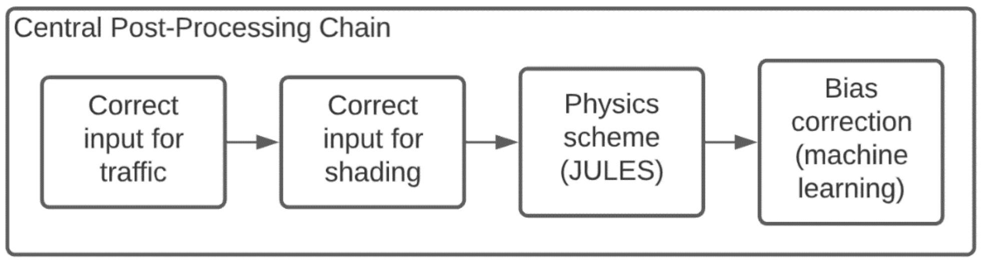

Fig. 4. Schematic of the "post-processing chain" in the new STF system. Here there are two initial steps to correct the NWP output for local effects. This corrected NWP output is then used to drive JULES. The output from JULES is then bias corrected by a machine learning scheme.

In this presentation we will discuss the motivations for the development of a new STF system at the Met Office, present some initial results from our new JULES-based STF system, and discuss the further scientific development required to enable us to provide skilful forecasts of the range of weather conditions required to ensure safety and efficiency of future road networks, with a particular focus on the requirements of the emerging CAV sector.

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IMPLEMENTATION OF A RESIDUAL SALT MODEL

Claus Petersen
Research Department., Danish Meteorological Institute, 2100 Copenhagen Lyngbyvej 100, *cp@dmi.dk*

Summary

A REsidual Salt Model (RESM) is used to estimate the need for sating. There are several use of a RESM. In case there is no salt on the road the RESM can be used to estimate the needed dose of salt to avoid slippery roads. If the road is already salted the RESM will estimate the need for additional salting. Further-more the RESM is useful to make differential salting of the road network depending on local conditions. All together the RESM is needed in a Management Decision Support System for winter maintenance. This enables dynamic salting routes as well as a planning tool for optimal timing and dose when salting the road network. In this report implementation of MOdelling Residual Salt (MORS) model at Danish Meteorological Institute (DMI) is described. The model was developed in the framework of NordFoU (nordfou.org) [1].

Introduction

In many situations it is obvious that salt has to be spread. This would be a direct consequence of the present weather such as snow fall, icy or wet roads. After the salt are spread it will often in these cases be removed very fast by run-off of water, melting water or mechanical by vehicles. Even if large amount of salt are spread it will soon be flushed away. Additional to this process traffic can splash the water away from the road. Also evaporation and condensation of dew and rime to the road can have an important role and strong wind will also enhance the process. In many other situations the salt will not disappear so fast. This could be on by-cycle lanes and in less travelled roads. Further-more in relative dry situations dominated by rime or dew in the night time the road is only exposed to little water and minor traffic. As a part of a development of Management Decision Support System for winter maintenance, models to simulate these processes have become more and more requested. Recently a RESM was implemented at DMI. The model is based on a project developed in the framework of NordFoU [1]. The detailed description of the model can be obtained from nordfou.org [1].

Model description

The details of the model is described in [1]. Here we will only outline the basic model properties. In practice the road is divided into two parts:

- Wheel tracks (Wt)
- Between wheel tracks (Bt)

In that sense the model can be seen as a two box model. The basic parameters to describe the road is

- Width of the road
- Slope of the road
- Roughness of the road

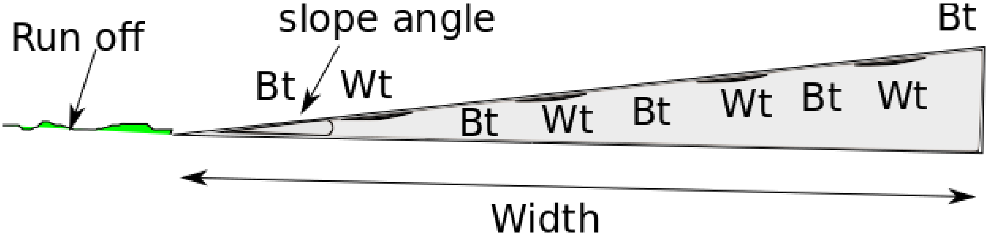

Fig 1. The road is divided into wheel tracks and between tracks and a run-off zone.

(Fig 1) shows the properties of a standard road. It does not matter how many wheel tracks the road has. This is implicit contained in the road width. The output from the model is basically four parameters

1. Salt in Wt
2. Salt in Bt
3. Water in Wt
4. Water in Bt

These four parameters should also be known as initial conditions and is obtained partly from a first guess from a previous model run and partly from reported salting. The salting data are obtained from the Danish Road Directorate (vd.dk) and contain information of the amount of salt spread, type of salt, position and time of day. If the model is cold started the four parameters are all set to 0. The model consists of an equation for each parameter. The basic forcing of the model is salting information, precipitation, wind and traffic density.

Water and salt start to run off the road when the water height reach a critical level. The run off is enhanced by precipitation, wind and traffic. Further-more there is an exchange of water and salt between wheel tracks and between tracks. In order to take dew and rime in to account evaporation and condensation on the road are also calculated.

The model run in two different modes

1. Assimilation mode
2. Forecast mode

In assimilation mode information of spread salt is inserted during the model run. Further-more radar data is used to provide precise information of precipitation. In principle also real time data of traffic density can be used but for the time being only a statistical product of traffic density is used. For wind speed and calculation of evaporation/condensation input from a Numerical Weather Prediction (NWP) model is used. In forecast mode it is assumed that salt is not spread. Also radar data is re-placed with forecasts of precipitation from a NWP model. The use of radar data is crucial as precipitation is one of the main uncertainties in the calculation of residual salt and using radar data in the assimilation mode is necessary to get good initial conditions.

Results

The RESM were initially in the framework of NordFou tested developed and tested against field experiment and at test sites. However the RESM was not brought into an operational environment. In the first implementation at DMI the goal has been to setup an operational model and do subjective verification. Does the model as expected? (Fig 2) shows salt in wheel track as a function of time under different weather conditions for a road station in Denmark where the initial condition is set to 15 g/m^2 salt on the road. In these cases the traffic density has been set to a fix value with little traffic. As expected salt is removed fastest in the light rain case. In the dry case salt is removed slowest and the rime case is in the middle. This is completely as expected. For the time being there is few good observations of residual salt and the most reliable observations are done manually often referred to the instrument as SOBO 20 measurements which are very costly in man power. It is also the experience that the variability of residual salt can be very large when measured. As precipitation is a key parameter forecasting of residual salt will depend of the quality of rain forecasts. The quality also depend of forecasts of traffic density and history of spread salt. It is well-known that the information of spread salt is uncertain. All together this will result in uncertain initial conditions. The forecast of residual salt depends also on parameters with high uncertainties in particular precipitation. For this reason radar data is used in the assimilation step of the model.

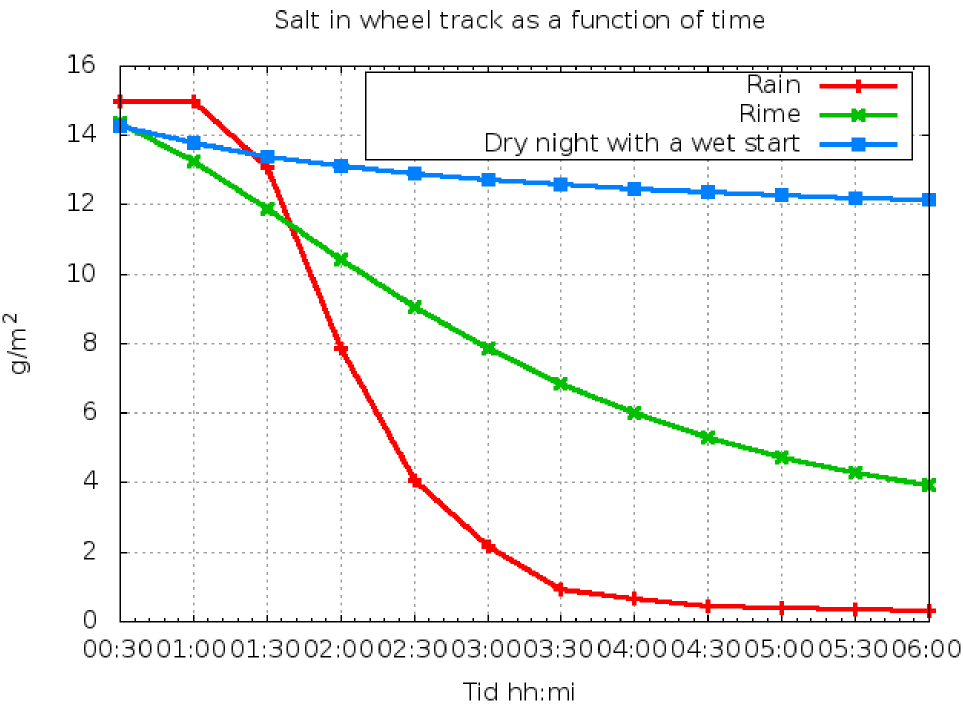

Fig. 2. Tree experiments of residual salt as function of time are shown. Initial time of the model is 00:00 UTC in Denmark and residual salt is set to 15 g/m². Output from the model is every 30 minutes.

Conclusion

The RESM has been implemented successfully. Technically the system is complex and requires input of many parameters as well as the initial state of the road. In particular the amount of spread data have large variability and this is also the case for precipitation. However if these conditions are known the model can perform good forecasts. In cases where the uncertainties are high the model can be used to estimate the potential salt loss by running the model with a pre-set value of salt as shown in the experiments in (Fig 2). It is expected that the model will be operational in 2022 and that the model quality will be subjectively verified by users of the product and also from SOBO 20 measurements when these become available,

Acknowledgements

The implementation and development of the RESM has been done in corporation with the Danish Road Directorate (vd.dk) and the model is adopted from NordFoU.

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ROAD WEATHER FORECASTING SYSTEMS IN CZECH REPUBLIC

Petr Zacharov [a], Vojtěch Bližňák [a], Josef Hanzlík [b], Petr Pešice [a], Pavel Sedlák [a], Zbyněk Sokol [a]

[a] *Institute of Atmospheric Physics, Czech Academy of Sciences, Boční II 1401, Prague-Spořilov, 141 00, Czech Republic*

bliznak@ufa.cas.cz

[b] *Czech Hydrometeorological Institute, Na Šabatce 2050/17, Prague-Komořany, 143 06, Czech Republic*

Summary

The forecast of road surface temperature is crucial for winter road maintenance and safety on frozen roads. We present results of two forecasting systems for the main Prague roads – ICEWARN and the main Czech highways – FROST. Both systems are based on the FORTe forecasting model and forecast road surface temperature and condition along a given road. Both systems use measurements from road weather stations, numerical weather prediction from ALADIN model and utilize detailed topography (parameters of buildings, woods, orography etc.), which can influence direct solar radiation. The innovation of the FROST system is the application of time-extrapolated satellite cloud measurements as a forecast of cloud cover for the first three hours.

Fig 1: Map of Central Europe with zoomed Czech Republic (Czechia). Map source: maps.google.com.

ICEWARN

Forecasting system ICEWARN produces linearly continuous forecast for the main Prague roads with winter maintenance priority. Road weather data are provided by Technical Administration of Roadways of the Capital of Prague and Road and Motorway Directorate of the Czech Republic. The roads were selected to have at least two road weather stations and data measured at stations located close to a given road were interpolated into this road (see fig. 2). The road was divided into points with measurements and points without measurements where the measured data were interpolated. The ALADIN forecasts are interpolated to each selected point on a given road.

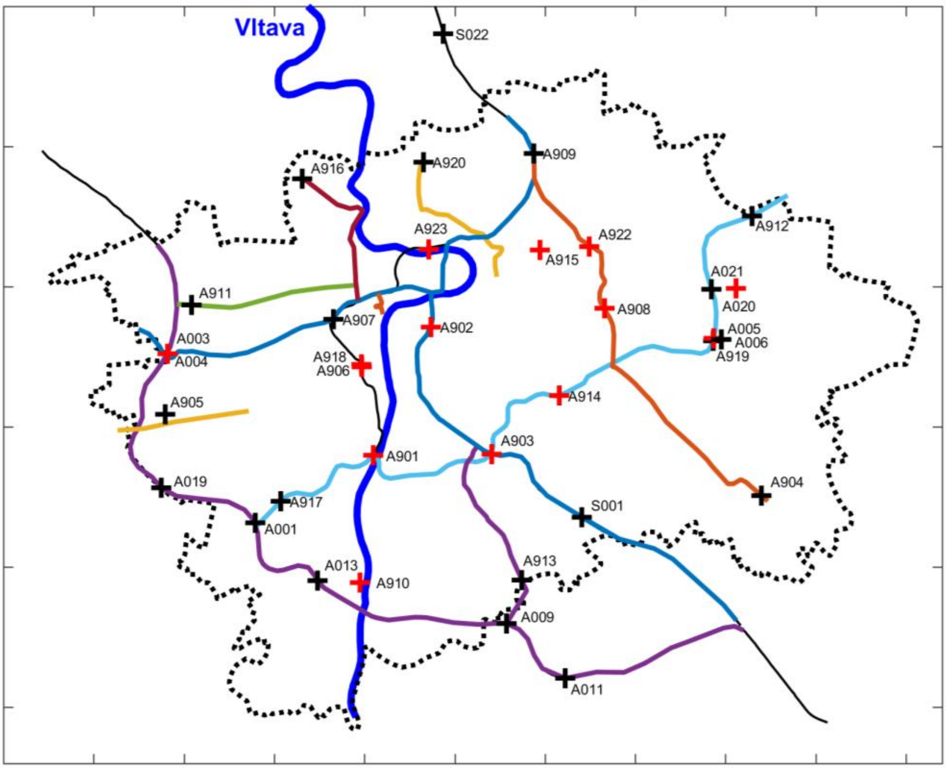

Fig 2: Selected Prague roads (colour lines, thick blue line is Vltava river) for ICEWARN computation with road weather stations marked. Red crosses represent bridges.

FROST

Forecasting system FROST is going to produce linearly continuous forecast for Czech highways. The system, which is very similar to ICEWARN, uses time extrapolated satellite cloud measurements for cloud cover forecast. When verifying the results of the ICEWARN forecasts, we found that the quality of the cloud cover forecast strongly affects the resulting road surface temperature. The ALADIN model sometimes underestimates low clouds or fog, which results in excessively high afternoon temperatures. This

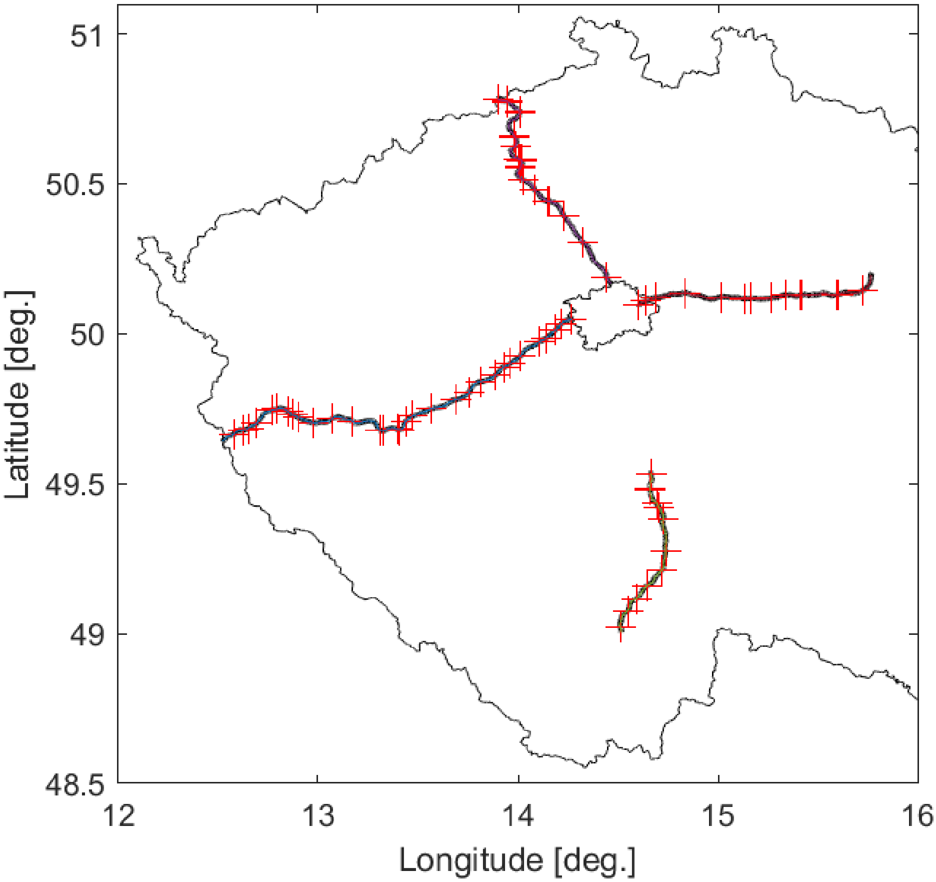

Fig 3: Selected Czech highways (black lines) for FROST computation with marked road weather stations (red crosses).

is a reason why we try to utilize the time-extrapolation of cloud cover for the first three hours of forecasts. The detailed description is in the article Bližňák et al (2022 – this issue).

Acknowledgements

This work was supported by the Technology Agency of the Czech Republic under the CK01000048 project "Forecasting system of road surface condition and temperature of the Czech highways". Road weather data was provided by Technical Administration of Roadways of the Capital of Prague and Road and Motorway Directorate of the Czech Republic. ALADIN model data was kindly provided by the Czech Hydrometeorological Institute.

FOCUS TOPIC #2

WINTER ROAD MAINTENANCE

IMPROVING WINTER SERVICE ON BICYCLE PATHS

Thorsten Cypra [a], Niklas März [a], Christian Holldorb [b], Jan Riel [b], Tim Wiesler [b]

[a] HTW Saar University of Applied Sciences, Goebenstraße 40, 66117 Saarbrücken, Germany, *thorsten.cypra@htwsaar.de*

[b] Karlsruhe University of Applied Sciences, Moltkestraße 30, 76133 Karlsruhe, Germany

Summary

Numerous municipalities have started a transformation of the transport network in recent years and decades and have been able to achieve considerable changes in the modal split within a reasonable period of time. For example, the share of cycling in Karlsruhe could be increased from 16 % in 2002 to 25 % in 2012 to currently more than 30 %. But cyclists are much more exposed to weather conditions than public transport passengers and car users, especially in winter time. Latest studies show clearly the increase of bike accidents under wintry conditions.

The Federal Ministry for Digital and Transport (BMDV), represented by the Federal Highway Research Institute (BASt), has commissioned the Saarbrücken University of Applied Sciences (htw saar) and the Karlsruhe University of Applied Sciences (HKA) with a research project on the sustainable promotion of cycling in winter through optimised winter road maintenance.

The recommendations of this ongoing research project will be based on differentiated cost-benefit analysis of different measures, which may include not only the conception and implementation of appropriate winter service treatments but also aspects of planning and design of bicycle facilities. The realisation of the recommendations and requirements of this

project will open the possibility to encourage bicycle traffic as a whole year type of transport, an important step towards a climate friendly mobility.

Winter Service on bicycle paths

According to the definitions of the Road and Transportation Research Association (FGSV) [1], winter road maintenance means "the totality of measures taken by the road authority to maintain and facilitate traffic and to ensure traffic safety in winter weather conditions". It is undisputed that the primary objective is to ensure traffic safety. In addition, maintaining the flow of traffic is of great importance. This is also reflected in the fact that mobility is nowadays an important location factor; smooth traffic is an essential prerequisite for the sustainable development of a functioning economy and society. In addition, there is an increasing demand for the roads to be operated according to the rules, but in an economic manner.

By increasing importance of the bicycle as a means of transport, it becomes more and more the focus of interest by public administration and on political level. Due to the increase in bicycle traffic, not only attention is being paid to winter road maintenance, but also to bicycle traffic infrastructure and their users. Cycling is becoming a part of everyday life in many cities, but it has become apparent that cycling is not promoted enough in winter due to various problems and influences.

There are two types of gritting materials that are used in winter maintenance on bike paths: abrasive materials or de-icing materials. In Germany in several municipalities, it is not allowed to spread de-icing materials on bike paths or walkways.

Abrasive materials mostly consist of natural materials such as sands, grits or foamed clay. With a snow layer, these materials can form a bond with the snow and ice, thus increasing the grip in winter conditions. But the disadvantages of this type of gritting is that they have little effect on icy and slippery conditions and must be removed frequently after thawing. Cyclists are complaining the use of abrasive materials on bike paths because of the sharp edged materials, which can damage the tyre and the danger of slipping in curves or in case of harder breaking.

The use of de-icing materials like salt and brine prevent slippery conditions on bicycle paths and other traffic areas in winter conditions. Chlorides such as sodium chloride (NaCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) are particularly suitable for this purpose. The most common form of application for winter service in Germany is sodium chloride because of mild climate conditions.

Salt can theoretically also be spread in dry form. However, it should be applied pre-wetted or in a completely liquid form (brine) to avoid loss during spreading, to ensure a good spreading pattern, and to optimize effectiveness. The designation of the spreading material is based on the mass ratio of dry salt to salt solution (FS 30 corresponds to 30 % salt solution, 70 % dry salt). Compared to pre-wetted salt, brine (FS 100) offers a more uniform distribution and longer lying time. Brine spreading is useful when roadway temperatures are not too low (down to approx. -6°C) and large amounts of precipitation and temperature drops are not expected. Pre-Salting can prevent snow or ice from sticking to the surface during snowfall or freezing rain. Brine is normally spreaded by special nozzle constructions or spray bars. When spreading via a spreading disc, special attention must be paid to a uniform distribution.

The question is, what kind of treatment should be recommended on bike facilities (brine, pre-wetted salt or dry salt), because the circumstances on bike paths are different compared to road conditions with car traffic and higher driven velocities.

Along with the choice and use of gritting materials, the implementation of winter maintenance on bicycle paths represents the second important component for bicycle-friendly use of bicycle facilities in winter and wintry conditions.

This winter maintenance consists of clearing the road surface and bike lanes in case of snowfall and spreading gritting materials, both preventively and immediately after clearing as an additional safety measure to avoid slippery conditions.

Due to different widths, changing surfaces, obstacles such as barriers and poles, problems often arise in the implementation of winter maintenance, especially on bike paths. For this reason, more and more so called narrow gauge vehicles are being used for winter maintenance on cycle paths. These are both smaller and more maneuverable and are therefore ideally suitable for smaller widths, narrow places and tight curves.

As a desired goal of proper winter road clearance on bicycle routes, snow removal, which mostly uncovers the trafficked area, has become

Fig. 2 – Difficult conditions on bicycle path for winter service because of infrastructure installations [picture source Cypra, 2021]

established in Germany. The aim is to remove all snow and ice from the surface of cycling routes permanently. The decisive factor for this objective is the minimization of the risk of accidents for cyclists, but also an economically, politically and environmentally justifiable clearing of these cycling routes. Due to the increasing number of cyclists and the change in mobility in many cities and municipalities, cycle paths and especially everyday cycle routes are becoming more and more important. The year-round use of bicycles is highly dependent on optimized winter road maintenance on important bicycle routes.

Depending on the height of snow, best results for snow removal is achieved by using a sweeping broom. Plows are required for significantly higher snow amounts and, in combination, can significantly improve the result of clearing a surface of snow and ice as the first clearing operation before clearing with a sweeping broom.

Fig. 3 - Narrow gauge vehicle with front sweeping broom and spreader for pre-wetted salt treatment [picture source Cypra, 2021]

Narrow gauge vehicles are more and more used nowadays in winter service on cycle paths in many cities. The vehicles differ depending on the manufacturer, brand and model in the dimensions, weight, steering or drive technology. All these small vehicles can be equipped with a front and a rear attachment. The front attachment can vary between a plow and a broom, for example, depending on the application and the amount of snow. The rear attachment is a spreader with appropriate spreading material and a distribution device such as a spreader disc, spray bar, etc.

The picture shows a narrow gauge vehicle in operation on a cycle path with a sweeper broom and a spreader for pre-wetted salt. The result of snow removal behind the winter maintenance vehicle is clearly visible. The objective of creating a cycling-friendly and generally cycling compatible surface on the cycle paths is fulfilled by the use of these narrow gauge vehicles.

Winter bicycle network in major German cities

In many major German cities, there has been an increased focus on cycling and the expansion of cycling infrastructure in recent years. Climate protection, improved ecological balance and the promotion of personal health have led to a steady increase in the number of cyclists as a percentage of total traffic. This also affects the use of cycling routes in winter. Several large German cities are joining the trend and promoting cycling all year round. This is made possible by ensuring winter road maintenance on certain bike routes. The winter bicycle network is treated with a level of service like road network. One of the challenges is, how to communicate to cyclists, that a winter bicycle network exists and which parts of the cycling facilities belongs to the winter bicycle network. One of the best ways is a visualisation on a map [3], like in Karlsruhe published in internet.

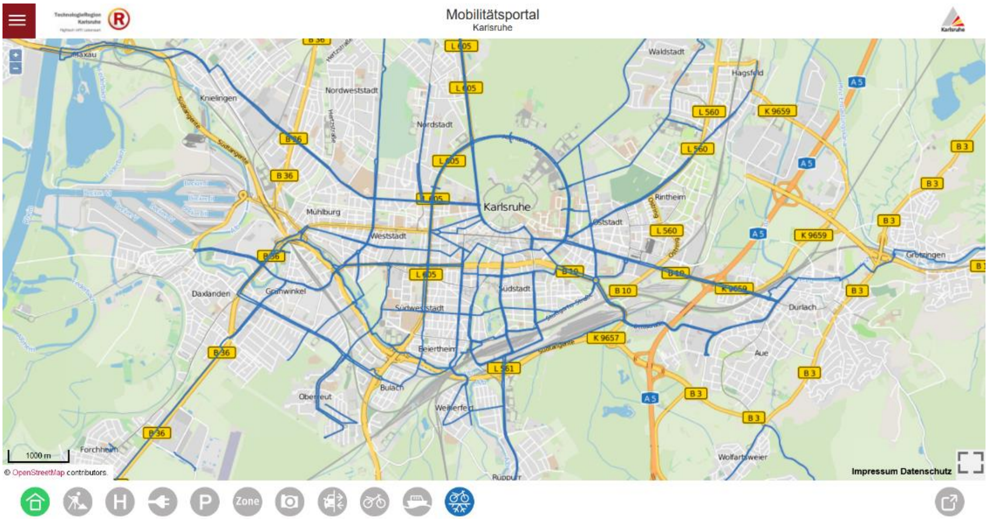

Fig. 4 - Winter bicycle network in city of Karlsruhe [3]

However, several cities and municipalities in Germany do not have a defined winter bicycle network or an appropriate communication is missing.

Studies of winter service in municipalities

The winter road maintenance on cycle paths in the three municipalities of Karlsruhe, Cologne and Munich was examined as an example. In addition to winter service practice and the clearing and gritting technology used, the system of designated cycle routes was also examined.

In order to investigate the navigability of cycle path connections on site in winter weather, several routes were cycled in each municipality. The routes were modelled on typical everyday routes and led from the suburbs or outer city districts to the city centre, mostly on alternating bicycle facilities designs and sometimes across municipal boundaries. The routes were recorded with a camera and GPS-tracking. The classified trafficability could then be compared with the winter road maintenance data. It became clear where problems lie in practice and how this affects the possibility for cyclists (see Figure 4).

Fig. 4 - Snow bulge at crossing section [picture source Wiesler, 2022]

In addition, it was possible to determine how long good passability can be guaranteed with the clearing and gritting technology used, depending on the weather. In some cases, routes were travelled several times in one day.

To analyse the optimised winter road maintenance on cycle paths, several winter road maintenance operations in the municipalities were documented. For this purpose, winter service vehicles were equipped with cameras and their operations were filmed. These video recordings provide information about problem spots and areas as well as avoidable time losses due to obstacles such as poles or excessively narrow passage widths. Recommendations for improved and optimised winter road maintenance will be developed.

Survey of cyclists from the user perspective

Within the framework of a survey with almost 3,000 participants, it was investigated, what experiences cyclists have had in winter and how they evaluate certain typically occurring road conditions of the cycling infrastructure in winter.

Especially for experienced cyclists, bad weather conditions are hardly an obstacle. On the other hand, unreliable or poorly executed winter maintenance on cycle routes can make cyclists feel considerably restricted. Particularly annoying and dangerous are snow bulges on bicycle paths.

Slippery ice is also often seen as a reason for preferring not to cycle.The majority is willing to do without a particularly large cycling network in winter as long as there are designated and reliably maintained routes that can be cycled safely in all weather conditions.

However, offers such as a dedicated winter cycle network or defect indicators are still often unknown even to experienced cyclists.

Furthermore, the aspect of route lighting plays a major role in many cyclists' sense of safety in winter.

Conclusions

Due to the existing problems and difficulties in different areas, differentiated recommendations and requirements will be developed for an optimised winter service on bicycle routes in the future. These recommendations will be evaluated and finally assessed based on a cost-benefit analysis. Based on this analysis, cities and municipalities as well as states can decide which of the proposed recommendations and requirements should be implemented.

The realisation of the recommendations and requirements of this project opens the possibility to encourage bicycle traffic as a whole year type of transport, an important step towards a climate friendly mobility.

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DIGITALISATION OF THE WINTER ROAD MAINTENANCE SUPERVISION IN FINLAND

Ossi Kortiainen [a*], Kirsti Laurila [a*], Janne Ruuskanen[a*], Le Thi [b]

[a] Transport System Services, The Finnish Transport and Communications Agency Traficom, ossi.kortiainen@traficom.fi

[b] Information and Service Management, Aalto University

Summary

In Finland, three different state offices are involved with wind road maintenance. The Finnish Transport Infrastructure Agency owns the road infrastructure and is responsible for its maintenance. The Centres for Economic Development, Transport and the Environment Office are in charge of the procurement and supervision of the road maintenance contractors. The Finnish Transport and Communication Agency Traficom both supervises road infrastructure offices and develops and elaborates the processes of the road maintenance. The Finnish road network consists of nine contract areas. Regional contractors are responsible for providing road maintenance in accordance with the service level defined by the Finnish Transport Infrastructure Agency. Moreover, the roads belong to different maintenance categories according to their level and type of use, with varying intervals for different maintenance measures, such as snow ploughing and antiskid treatment. At the moment, surveillance of the winter road maintenance is carried out by physically going to the roadside and verifying the level of snowfall and friction. This is not efficient and do not offer vast and punctual data of the level of maintenance. Traficom has digitalized the surveillance of the winter road maintenance by developing a tool that analyzes optical snowfall and friction data. Analyzed data is then compared with the service

levels to see whether the maintenance is adequate. The tool provides a way to allocate the surveillance resources timely and to use the resources more efficiently. This provides safer roads with lower costs and changes the surveillance to happen in real time. Additionally, the contractors can find out faster if the winter road maintenance actions should be carried out. Similar analysis could be used for other roads as well to make cycle paths and pavements safer cost efficiently.

USING MOBILE OBSERVATIONS TO DRIVE MAINTENANCE DECISION MAKING

Jim McCaa
Vaisala OYJ, Keilaranta 19, 02150 Espoo, Finland,
jim.mccaa@vaisala.com

Summary

Accurate measurement of road weather conditions is the foundation for both ongoing road maintenance operations and forecasting upcoming treatment requirements. Here we describe the evolving role of mobile sensing devices in providing situational awareness and forecasts for winter maintenance. Results from a study evaluating the impact of mobile observations on road weather forecasts are presented.

Road maintenance is heavily affected by weather conditions, and knowledge of current conditions combined with forecasts of anticipated conditions across the network factor in the decision making process for treatment. Forecasts used to determine likely future road conditions are impacted by direct measurements from both stationary weather stations and moving devices. Here we consider forecasts of temperature and road surface state made by numerical weather prediction models and temperature and road surface state measurements collected by Vaisala MD30 devices attached to snowplows. We focus on periods of heavy snowfall and resulting treatment activity. The mobile sensing devices collect data otherwise unavailable from stationary measurement locations, though their placement on operating plows raises some issues with representativeness of the measurements.

Body

Data from mobile sensing devices complements a traditional network of Environmental Sensing Stations (ESS) by providing more complete network coverage, albeit at less frequent intervals. Mobile device data has been used since the 1980's as a static data source for network thermography, but advances in mobile communication in the last twenty years have enabled real-time communication of vehicle data and allowed integration with maintenance decision support systems [1,2].

Use of professional-grade dedicated equipment attempts to employ vehicles as mobile Road Weather Information System (RWIS) stations. This is a different proposition from opportunistic automobile sensor data, with a smaller number of purpose-built sensors delivering higher-quality data from vehicles such as snowplows, transit buses, and service trucks. Data is typically displayed both in the vehicle for the benefit of the vehicle operator and transmitted to the cloud for centralized analysis and distribution.

To combine both data sources into a consistent network analysis, mobile sensing data is displayed in near-real-time for situational awareness and used on a regular interval to update road weather forecasts. In the absence of mobile sensor observations, the state of a road network is determined subjectively by interpolation from nearest ESS, analysis of model output, and radio communication from the field. However, geo-located mobile sensor data can be analysed more quantitatively, leading to more efficient use of materials and better planning for operations.

Here we examine a road forecasting system capable of assimilating mobile sensor observations and using them to adjust the model state through a radiative coupling process for temperature, and by direct inclusion of water layer thicknesses. The impact of the mobile sensing data can be estimated by looking at the frequency and magnitude of the adjustments made to the model when they are available.

As an example of this type of analysis, we will review the impact of a set of Vaisala MD30 sensors [3] on water layer thicknesses during a snowfall event in Fort Collins, Colorado. Table 1 is a contingency table comparing the percentages of segments of the city's road network that are measured and/or forecast to be in a dry, wet, or frozen state. Data was collected over 34 hours beginning with the onset of the snow event. The table shows that approximately 11% of the measured segment required an adjustment to the model-analysed state, primarily because the road weather model occasionally over-forecast dry conditions.

Table 1. Comparison of forecast road state and measurements (prior to forecast adjustment) during a significant snow event. Numbers reflect the percentage of the road network where the forecast and measurements agree and disagree, prior to assimilation of the measured data.

[%]	Forecast dry	Forecast wet	Forecast snow/ice
Observed dry	0	0	0
Observed wet	0.29	1.1	0.64
Observed snow/ice	7.9	2.1	88

The times during which the forecast required adjustment were not spread evenly over the duration of the event. Figure 1 plots the evolution of this and shows that most of the forecast adjustment occurred near the end of the event. Visual inspection of associated dash-cam video revealed that this was in part a result of clean-up operations being conducted by the snowplows on which the sensors are monitored.

A more detailed analysis of the event and seasonal results are included in the conference presentation. While direct display of mobile data helps operators make treatment decisions, one of the reported factors in deviating from MDSS recommendations is the difference between forecast and observed conditions [2], so harmonizing observations and forecasts through data assimilation can facilitate better uptake of MDSS recommendations. It also extends the value of mobile observations by propagating the impact of the data into network analysis over subsequent hours.

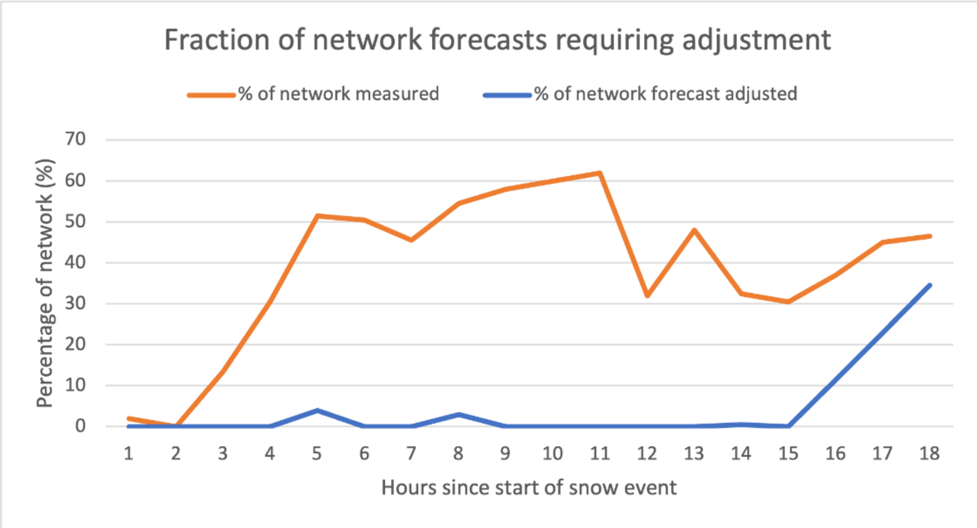

Fig. 1. Change in time since the beginning of a snow event of the fraction of the road network measured, and the fraction of the network where the forecast of the road weather model was adjusted as a result of the measurement.

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AN ADAPTED ACCUMULATED WINTER SEASON SEVERITY INDEX (AWSSI) FOR LITHUANIAN WINTER EVALUATION

Lauryna Šidlauskaitė [a], Justas Kažys [b], Silvija Pipiraitė-Januškienė [b]
[a] AB Kelių priežiūra, Savanorių pr. 321C, 50120 Kaunas, Lithuania, *lauryna.sidlauskaite@keliuprieziura.lt*, ORCID: 0000-0001-7753-2951
[b] Institute of Geosciences, Vilnius University, 3 Universiteto St., 01513 Vilnius, Lithuania

Summary

Winter severity evaluation has been a difficult task to crack for climatologists for decades. This task becomes even more burdensome once this evaluation needs to represent a certain application or task effectiveness, like winter road maintenance. Thus, the Accumulated Winter Season Severity Index (AWSSI) has been calculated in hopes to get an accurate and objective index for winter road maintenance task difficulty assessment.

After initial evaluation, it was noted, that AWSSI performed a lot better than previously used indices, thus it was decided to improve the methodology and make it a bit more suitable for Lithuanian climate, more applicable to Lithuanian RWIS network and less dependent to climate change. A several methodology changes were performed and an adaptation of AWSSI was created.

The resulting adapted AWSSI is a great tool to determine winter severity for road maintenance. It was shown that the index correlates well with performed winter road maintenance tasks and material usage. Thus, it can be used in various fields, e.g., long-term forecasts and planning, and currently is being used to determine a part of worker wages.

Introduction

It is of no surprise that winters vary significantly from season to season. Everyone who is affected by winter weather conditions in any way undeniably will try to evaluate a certain winter's severity at some point. However, opinions and memories are subjective, so an accurate and objective evaluation method has been in pursuit of many researchers for a long time, especially in winter road maintenance field. An accurate winter severity evaluation or index could be benefited from on many occasions, e.g., winter road maintenance financing adjustments, insurance evaluations, or even long-term weather forecasting for material usage planning.

Lithuania is no exception, especially when it comes to winter road maintenance. Thus, first tries at creating such an index were performed in 2015 – Lithuanian national winter road maintenance manual included a winter adversity index (WAI, in Lithuanian – "*Žiemos sunkumo indeksas"* or *ŽSI*) [1]. However, over the years WAI proved to be inaccurate and, most importantly, it did not correspond with performed winter road maintenance tasks well enough for it to be used in further evaluations.

To either increase the usefulness of WAI or replace it entirely, AB Kelių priežiūra, Lithuanian road maintenance company, financed a research study in 2020, titled "Evaluation study of winter weather conditions index" [2]. In this study, various evaluation methods were researched, including the Accumulated Winter Season Severity Index (AWSSI) [3] which is used in the USA for winter season evaluation [4]. This index is unique, because the evaluation can be performed on any day, continuously, and it uses only simple meteorological parameters and does not require special measurements or devices.

To apply AWSSI to winter road maintenance field was not a new idea – researchers at Midwestern Regional Climate Center (University of Illinois, USA) have performed enhancements and achieved greater correlations with winter road maintenance costs than the previous version [5]. The new version was called RAWSSI.

Adaptation of AWSSI to Lithuanian climate

Daily AWSSI scores are calculated based on scores assigned to temperature, snowfall, and snow depth thresholds. The daily scores are accumulated through the winter season, allowing a running total of winter severity during a season as well as a final, cumulative value characterizing the full season. Also, either daily or final scores can be compared between historical AWSSI database using quintiles, to determine the winter season severity category – from mild, to extreme.

The original methodology was simple to apply, however, presented some issues, e.g., it is calculated using meteorological station data. For the index to correlate well with road maintenance costs these stations need to be close to the roads, which usually is not the case. Also, the network of meteorological stations is a lot too sparce to be able to get an accurate index for every maintenance sub-unit. These and some other issues led to several modifications, some of which were:

- Abandon the snow depth indicator as irrelevant for winter road maintenance. Snow does not stay on the road surface for long because they are continuously cleared in accordance with existing procedures. In the USA, the modified RAWSSI index [5], which discarded the snow depth indicator, showed higher correlations with road maintenance costs. Daily precipitation accumulation when air temperature is ≤ 2 °C will be used.

- Change units of measurement: for air temperature, from Fahrenheit (°F) to Celsius (°C); for snow, from inches (in) to millimetres (mm).
- Modify the estimates of air temperature and snowfall to reflect the climatic conditions in Lithuania (Table 1).

In the winter weather conditions index study [2] four indices were calculated and had different correlations with seasonally used salt amount (Fig. 1):

- WAI, using Lithuanian meteorological station data, Pearson's correlation coefficient $r = 0.42$, however, not statistically significant (when $\alpha = 0,05$),
- AWSSI, using Lithuanian meteorological station data, $r = 0.91$, statistically significant (when $\alpha = 0,05$),
- Adapted AWSSI, or aAWSSI, using Lithuanian meteorological station data, $r = 0.89$, statistically significant (when $\alpha = 0,05$),
- aAWSSI, using Lithuanian road weather information system data, $r = 0.85$, statistically significant (when $\alpha = 0,05$).

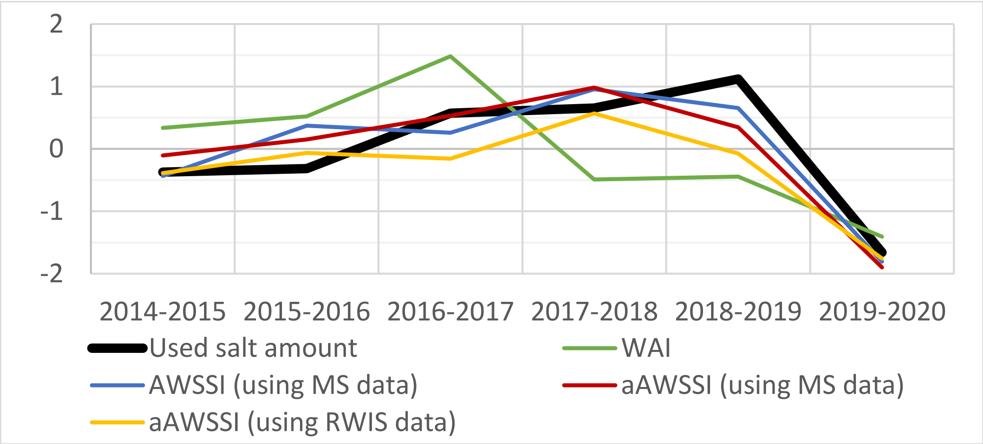

Fig. 1. The variation of various versions of AWSSI and WAI indices, and salt amount used during the winter maintenance tasks (values are standardized)

Table 1. aAWSSI score thresholds

Max. air temperature, °C			Min. air temperature, °C			Accumulated precipitation, mm (when air temp. ≤ 2°C)		
From	To	Score	From	To	Score	From	To	Score
…	-28.7	65	…	-41.7	56	0	0.2	0
-28.7	-28.2	58	-41.7	-41.5	50	0.2	0.6	1
-28.2	-27.3	51	-41.5	-41.1	44	0.6	0.8	2
-27.3	-26	44	-41.1	-40.4	38	0.8	1.3	3
-26	-23.9	38	-40.4	-39.1	33	1.3	1.8	4
-23.9	-20.5	32	-39.1	-36.2	28	1.8	2.4	5
-20.5	-15.1	26	-36.2	-29.8	23	2.4	3	6
-15.1	-9.9	19	-29.8	-21.5	19	3	3.7	7
-9.9	-7.3	15	-21.5	-16.7	16	3.7	4.5	8
-7.3	-4.5	13	-16.7	-11.4	14	4.5	5.7	9
-4.5	-2.8	11	-11.4	-8.1	12	5.7	7.5	10
-2.8	-1.5	9	-8.1	-5.8	10	7.5	9.3	12
-1.5	-0.5	8	-5.8	-4	9	9.3	13.2	14
-0.5	0.3	7	-4	-2.6	7	13.2	18.5	17
0.3	1	5	-2.6	-1.4	6	18.5	23.6	22
1	1.7	4	-1.4	-0.4	5	23.6	28.5	32
1.7	2.4	3	-0.4	0.6	4	28.5	33.3	41
2.4	2.9	2	0.6	1.1	3	33.3	38.1	51
2.9	3.4	1	1.1	1.6	2	38.1	42.7	61
3.4	3.7	1	1.6	1.8	1	42.7	47.2	71
3.7	3.8	0	1.8	1.9	0	47.2	51.8	81
						51.8	56.2	91
						56.2	60.6	92
						60.6	65	101
						65	73	111
						73	…	130

aAWSSI application to winter road maintenance activities in Lithuania

Modifications of aAWSSI allowed the methodology to be applied further and even made it possible to be implemented into IT systems. Thus, AB Kelių priežiūra automated the calculation of aAWSSI for each road maintenance sub-unit. This was done by assigning each sub-unit 3-5 RWIS stations, calculating aAWSSI daily scores for each RWIS station, and averaging those scores to receive a value for the territory of the sub-unit. This way it is easy to apply the received aAWSSI score to any other statistic of the sub-unit or to use it to influence another index.

It was found, that the new aAWSSI correlates even better: average statistically significant correlation (when $\alpha = 0{,}05$) between the index scores and monthly parameters:

- used salt amount was 0.95,
- used brine amount was 0.94,
- used fuel amount was 0.75.

Also, a small part of the variable salary component of worker wages is now determined by aAWSSI. The score is calculated monthly and compared with 10 years of historical data. If the month's score is determined to be in the lowest quintile, that means that winter conditions were very mild, and workers' wages are lessened (of that sub-unit). If the month's score is determined to be in the highest quintile, that means that winter conditions were extreme, and they receive more salary than usually.

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FOCUS TOPIC #3

RWIS AND OTHER ROAD WEATHER SENSORS AND EQUIPMENT

A COMPACT ROAD WEATHER STATION AND A MOBILE ROAD CONDITION MONITOR

Taisto Haavasoja and Pauli Nylander
Teconer Oy, Kaupintie 5, 00440 Helsinki, Finland
taisto.haavasoja@teconer.fi

Summary

Road weather stations (RWS) were introduced originally to monitor weather conditions at specific road locations comprehensively to allow forecasting of slippery driving conditions caused by adverse weather. This approach is mostly still in use, resulting in an expensive set of measured parameters. The introduction of mobile road condition measurements has further challenged the current approach of equipping fixed RWS. We report a new approach to outfitting an RWS with the most essential measurements to allow economic and timely winter maintenance as well as warning of drivers about slippery conditions. Measuring surface condition, friction, depth of contamination and temperature readings of air, surface and dew point can be done with a simple set of optical sensors, which are easy to install and cost-effective. Fixed RWS are very useful to follow short term trends in surface condition and temperature development. Mobile surface condition monitors complement the RWS information by providing surface conditions in between the stations and a more representative picture even at the station. We also report a new design of a compact mobile road condition monitor.

Introduction

Commercial fixed optical surface condition sensors were introduced nearly 20 years ago [1]. The trend has been to favour optical sensors in lieu of invasive road sensors due to challenges in installing sensors into road surface. These challenges include traffic arrangements, special tools and material as well as a demanding environment for invasive sensors, especially in areas, where studded tires are used. However, the cost of a typical fixed road weather station is still quite high, typically from 20 000 to 60 000 €. The reason is that the stations often include many meteorological measurements, which are not necessary for the main purpose of the stations.

In our approach we limit the measurements and the sensors of a fixed road weather station to a minimum. We pay attention to the importance of any measurement for the purpose of being able to initiate proper action of winter maintenance or warn a driver. For this purpose, the most essential parameters are surface condition, coefficient of friction, amount of contaminant and road surface temperature reading. Being able to make short term forecasting, dew point temperature would be helpful. For a longer forecast time ground temperature readings may be needed. All this data is available with just two sensors, one is an optical road condition monitor and the other an optical surface temperature and dew point sensor.

Information about salt concentration or amount on the road surface is often desired to be able to estimate, whether additional salt is needed to avoid slippery conditions, when a moist road surface is cooling down or there is some precipitation. Measuring salt remotely is challenging. Nevertheless, we do get information about salt by measuring optically friction, which is essentially the same as being able to observe water and ice on the surface. Since a freezing road surface does not become slippery at a fixed temperature determined by concentration, there is often time to add salt, while friction is trending to lower readings [2, 3]. When the surface temperature is not yet below 0 °C, friction does not indicate the salt concentration. However, there are simple rules to determine, whether there is enough residual salt. If it has been a long time since the last salting, the salt amount will be very low. If there is some precipitation, that will effectively dilute any practical amount of salt. We need near 0 °C about 1% concentration of NaCl to be on safe side. If we are expecting one centimetre of snow, we need about 10 g/m² of salt. That amount of residual salt will not survive under traffic for many hours.

Fixed road weather stations can follow the trend of surface condition and temperature development. However, previous research has shown that fixed RWS cannot produce surface conditions reliably in adverse weather conditions mainly due to a fairly small size of the measurement spot not being representative of the road surface [4]. Further, the distance between fixed RWS is typically tens of kilometres leaving long sections of road network not measured at all. The recent introduction of mobile road condition monitors can help with this challenge [5].

We report new developments of a compact road weather station and a compact mobile road condition monitor to tackle the challenges of road weather measurements.

A Compact Road Weather Station

The model name of the new road weather station is RWS10. It consists of two sensors, one is RCM411R Road Condition Monitor modified for remote measurements and the other RTD411 Road Surface Temperature and Dew Point sensor. The measurements of the two sensors include:

- surface condition
  - dry, moist, wet, slush, ice, snow or frost
- friction
- water and frozen layer thickness
- surface temperature
- air temperature
- dew point temperature
- atmospheric pressure

- wind speed
- ground temperature.

In addition to the sensors, there is a small cabinet containing a battery (7 Ah), a battery charger and a GSM modem for communication. The modem sends the data to a server once a minute. Figure 1 shows an RWS10 installed on a street light pole. The battery is charged overnight, while the street lights are on, and the battery takes care of the next daytime.

The data can be followed on a web map service at *roadweather.online*. Figure 2 shows the web interface of the map service. On the right side of the view there is a list of daily data and on the left a map of the station location and graphs of measured values. The data is also available through an API service or as a numeric file to be studied as a spread sheet.

Figure 1. The compact road weather station installed on a wooden street light pole. The cabinet is on the other side of the pole at the height of the traffic signs.

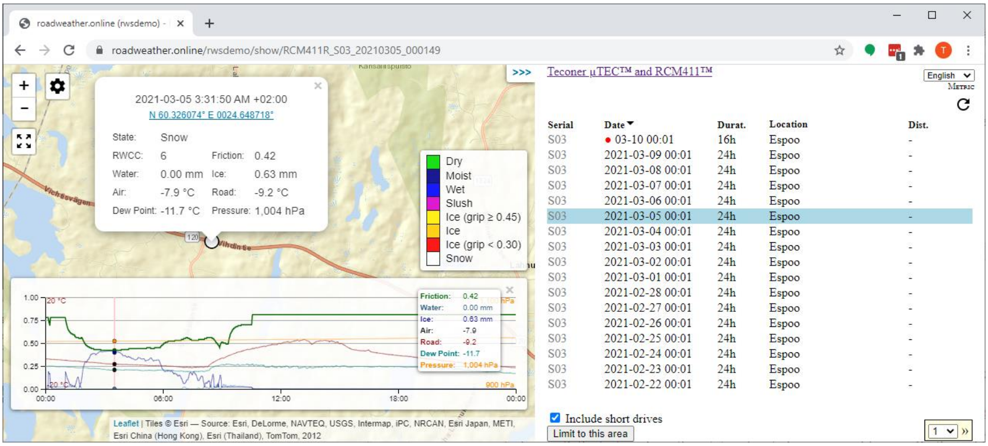

Figure 2. A web interface to the station data. A numeric window of data is available at a given time stamp. The example shows a case of light snowfall causing reduced friction before the final dry out at noon.

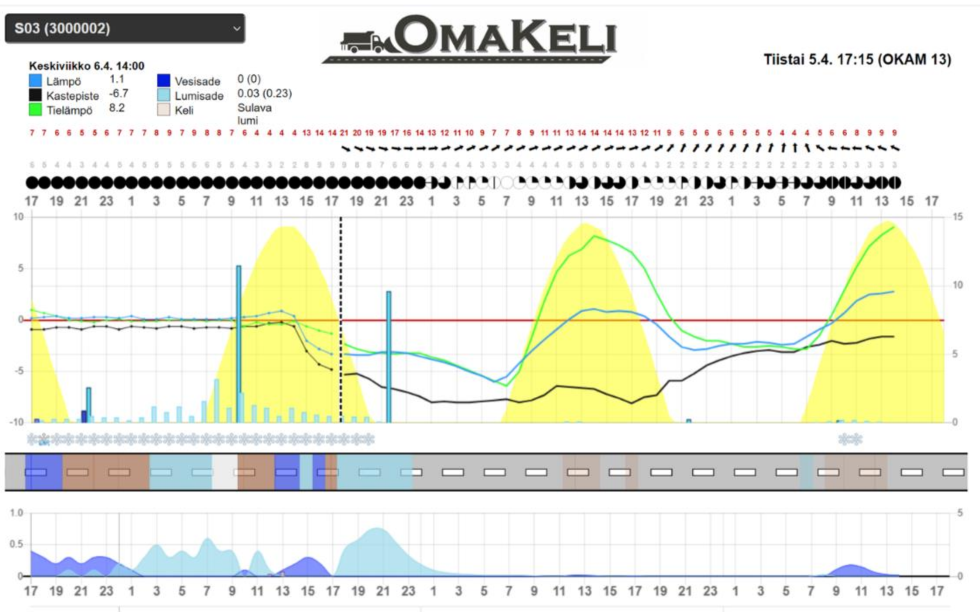

Figure 3. Omakeli road weather forecast supplied by Saaneuvos Oy. The forecasted parameters include air, dew point and surface temperature, precipitation amount of rain and snow, wind speed and direction, and road surface condition.

It is possible to generate warnings for a given weather condition at the selected station in the *roadweather.online* service. The warnings are transmitted as an SMS message to listed phone numbers. There is also available a road weather forecast service called Omakeli supplied by Saaneuvos Oy. Figure 3 shows the user interface of the Omakeli forecast.

A Compact Mobile Road Condition Monitor

Finding a suitable location in a vehicle for a mobile optical road condition monitor may be challenging. The size of the sensor should be small enough to allow installation optimally to keep the sensor window clean for extended periods. With this target in mind, we have designed a small new road condition monitor. Figure 4 shows the new sensor installed near the left mirror of the vehicle.

Figure 4. The new compact Road Condition Monitor RCM511 installed by a magnet near the left mirror.

There are a few various fixing methods for the sensor. The most straightforward way is to use a magnet for fixing the sensor on steel surfaces of the vehicle. There are also available special fixing parts to a trailer tow ball or to a screw-on tow hook in the front of a vehicle. The sensor can be powered from a cigarette lighter socket or the trailer socket.

The measurements of the sensor include surface state, friction and layer thickness of water and frozen contaminants. Air temperature, dew point and surface temperature measurements are available with an optional sensor. Figure 5 shows an Android application of a user interface to the measured data in the vehicle. The application supports taking photos or videos.

If mobile measurements are taken with buses or trucks, it may be better to use a black box cellular modem for data transmission, since then all the

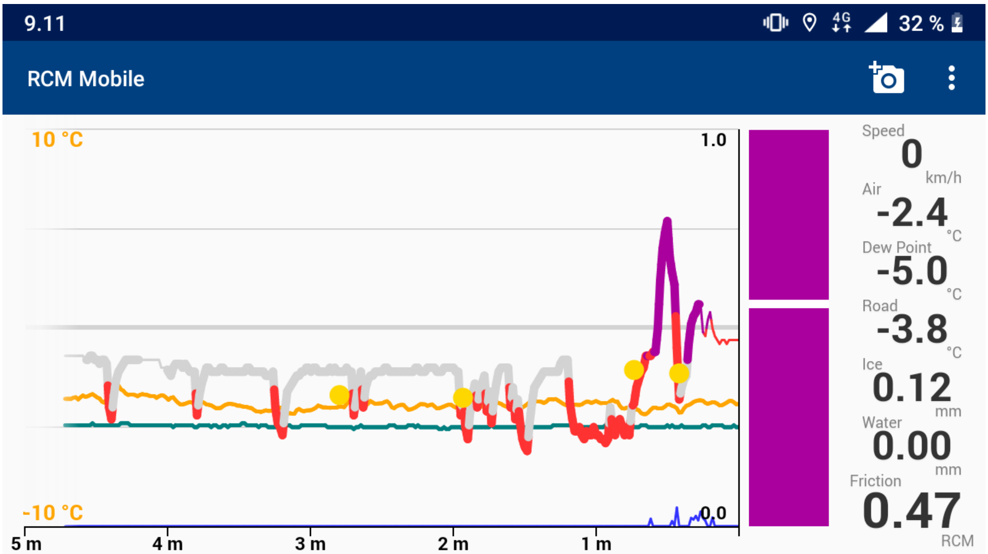

Figure 5. The user interface in the vehicle shows numerical and graphical data in an Android application. The thick line corresponds to friction and is coloured by the surface state. The yellow spots are braking friction measurements. The sensor data is transmitted to the roadweather.online cloud server for web browsing.

drivers of the vehicle do not have to know about the mobile measurement. Android turns out to be an unstable system for long periods and may require occasional intervention. When using a black box solution, it is still possible to follow the data in the vehicle with a similar Android application.

Conclusions

We have developed a compact road weather station RWS10 and a compact mobile road condition monitor RCM511 with real-time data collection and a map interface to the data. The target has been to concentrate on the most important measurements and an easy installation to keep the total cost at a minimum. Fixed road weather stations provide accurate trend information, whereas mobile measurements complement the picture by providing information in between the stations. By adding weather forecasts to the system, it is possible to build a full-service Road Weather Information System (RWIS). Furthermore, road condition measurements and weather forecasts enable calculating the required amount of salt or de-icer chemical in a given situation. This level is often called Maintenance Decision Support System (MDSS). We estimate that by using a compact approach it is possible to build an MDSS with a fractional price of a typical MDSS currently in use.

Acknowledgements

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FILLING GAPS IN REMOTE LOCATIONS WITH LOW POWER RWIS

Alex Karandreas [a], Mike Burton [b]

[a] Campbell Scientific Ltd., Fahrenheitstrasse 13, 28359 Bremen, Germany, *alex.karandreas@campbellsci.de*

[b] Campbell Scientific Canada., 14532 131 Ave NW, Edmonton, AB T5L 4X4, Canada, *mike.burton@campbellsci.ca*

Summary

Filling Road Weather Information Gaps on major roadways is nothing new. But what of the information gaps in very remote locations? To test its Gap Filling solution Campbell Scientific earned the support of the State of Alaska Department of Transportation, University of Alaska Fairbanks and the Arctic Infrastructure and Development Centre to undertake a two-year project. The first year of the project inspected the reliability of power supply, and consistent, reliable transmission of data. Sites for the first seasonal test were based on a hierarchy of need from the Alaska Department of Transportation and basic criteria including the availability of cellular communications. After a winter of use, results were extremely promising. The data was delivered consistently, ample power was provided by a small solar panel and a battery bank, and for the first time in Alaska the wildest and most remote parts of the state had Road Weather Information that increased the levels of safety on Alaska highways.

Mini-RWIS: a Gap Filling solution

Campbell Scientific's mini-RWIS (road-weather information system) is a low-cost, low-power, quick-deploy road-weather station, which complements existing RWIS networks at a fraction of the cost of a traditional RWIS station. Adding mini-RWIS stations gives a denser network of road sensors. This provides a more complete picture of the entire road and improves the reliability of road-condition forecasts.

Mini-RWIS stations typically include a datalogger, communications and power module, all installed with an enclosure, and a flexible combination of sensors and cameras according to the specific needs of the network. An example is shown in Fig. 1. The mini-RWIS stations tested and deployed in this trial featured a RM Young wind sensor, a Campbell Scientific CCFC ultra lower power field camera, an Apogee infrared surface temperature sensor designed specifically for road weather stations, and a Campbell Scientific HygroVUE5 temperature and RH sensor.

Fig. 1. mini-RWIS stations are self-sufficient, running exclusively on solar power and batteries to allow them to be placed anywhere you need them, regardless of existing infrastructure. They are easy to integrate, featuring embedded cell communication as well as NTCIP / Datex2 / Modbus compliance, making integration into an existing RWIS network simple.

Pre deployment testing at University of Alaska Fairbanks Cold Room

The meteorological, battery performance, and power data were used to analyze the operation of the mini-RWIS. In terms of the power profile, the mini-RWIS consumed the most power during communications and camera operation. Peaks in power consumption would be significantly higher by as much as 3 or 4 times when the heater for the camera lens is activated to defog/defrost the camera lens prior to taking an image of the roadway. During the first season of field testing the heater was not required.

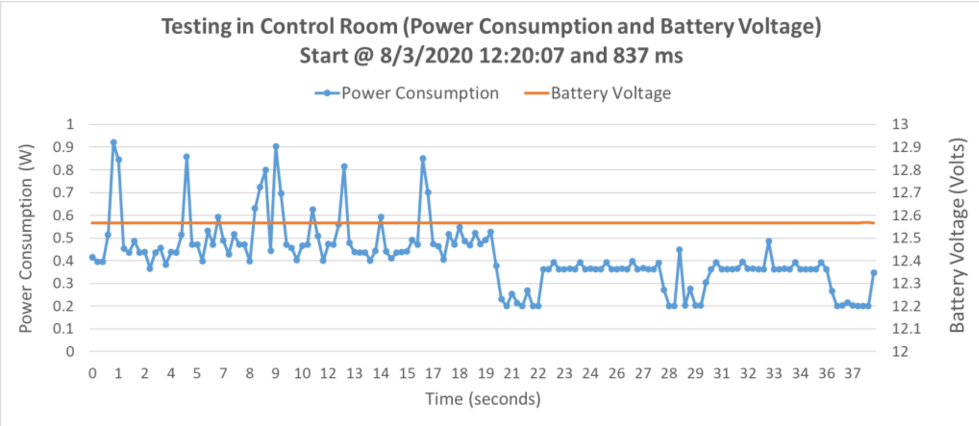

Fig. 2. Power testing in a controlled environment. Measurements show system performance with camera heaters constantly off.

Test Unit Field Deployment

Environmental data (ambient air temperature, road surface temperature, humidity, and wind speed) and operational data (average hourly, daily, and monthly power consumption, battery state of charge (SoC) and voltage, and communication link activity) were obtained from three roadside sites (Chena Hot Springs Road MP 10, Seward Highway MP 98.5, and Seward Highway MP 113.4) where the mini-RWIS systems were installed early in 2021. The air temperature, power consumption, and communications link activity were used for analysis of their operation for different periods of time ranging from late January 2021 to mid-May 2021 as shown in the following sections.

Installation and Measurements

Pictures from the deployment of the mini-RWIS system at Chena Hot Springs Road MP 10 are shown in Fig. 3. The average daily air temperature (Fig. 4), daily power consumption with air temperature (Fig. 5) and once per minute power consumption (Fig. 6), are shown for different periods from late January 2021 to mid-May 2021.

The results showed that the mini-RWIS station at Chena Hot Springs Road MP 10 was able to measure, record, and communicate the daily average air temperature, road surface temperature, humidity, wind speed & direction, while consuming on average about 1.3 watts of power. While not shown in the plots, battery SoC was maintained at or near 100% for the entire period analyzed. Peaks of about 6.5 watts were observed at hourly intervals in the once per minute power demand (see Fig. 6), which correspond to the communication link activity occurring once every hour.

Seward Highway MP 98.5 and Seward Highway MP 113.4 sites

The mini-RWIS systems deployed at the Seward Highway MP 98.5 and Seward Highway MP 113.4 sites were identical to the system described in the previous section. The measurements showed nearly identical results as for the Chena Hot Springs MP 10 mini-RWIS, confirming the results described in the previous section.

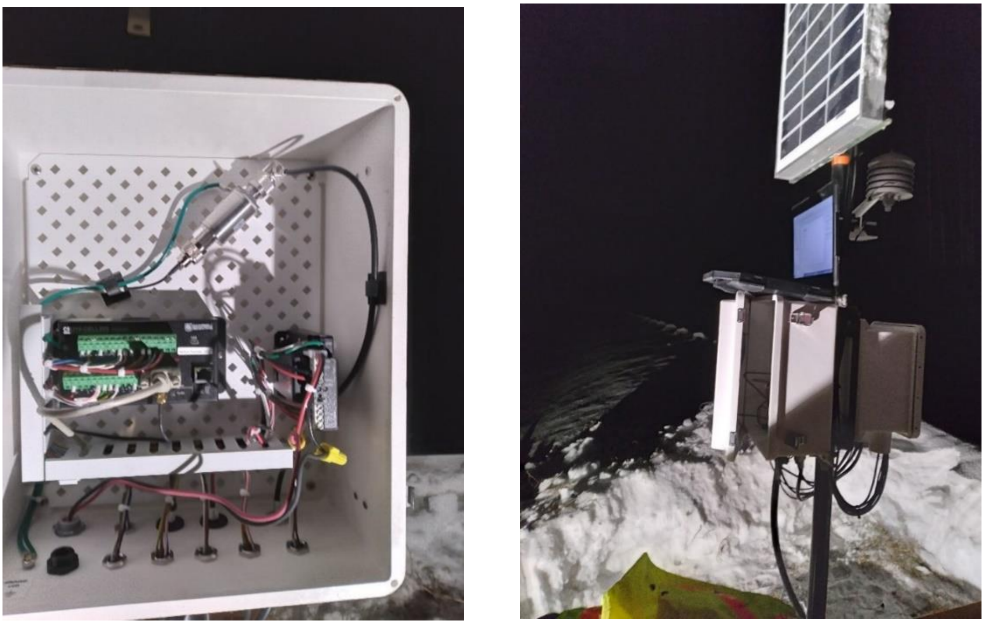

Fig. 3: Installation of mini-RWIS system at Chena Hot Springs Road MP 10 on January 21, 2021. Left: pole-mounting with solar module and weather sensors. Right: mini-RWIS data logger mounted on pole.

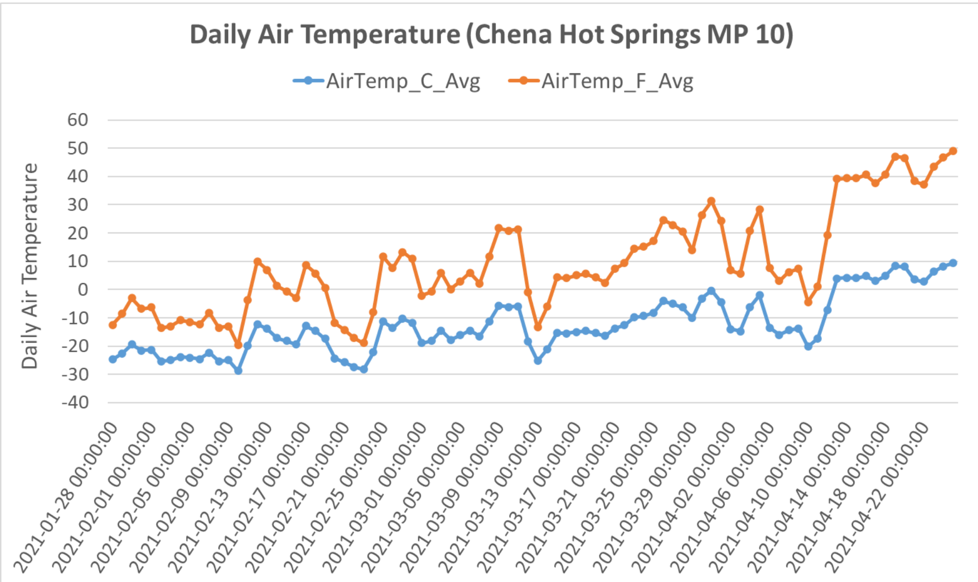

Fig. 4: Plot of daily average temperature profile (℃: blue and ℉: orange) for Chena Hot Springs Road MP 10 mini-RWIS site from January 28, 2021 to April 25, 2021.

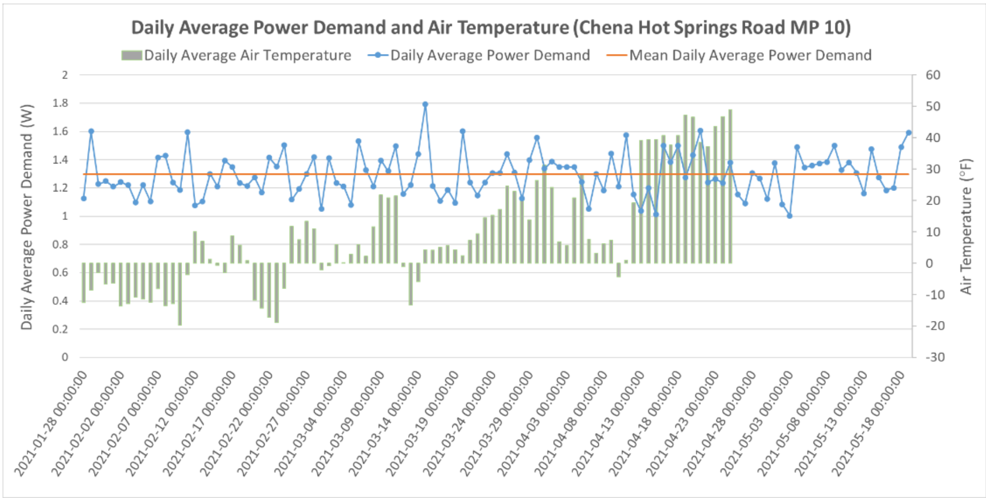

Fig. 5: Plot of daily average power consumption (blue), air temperature (green), and mean power consumption (orange) for Chena Hot Springs Road MP 10 mini-RWIS site from January 28, 2021 to May 19, 2021.

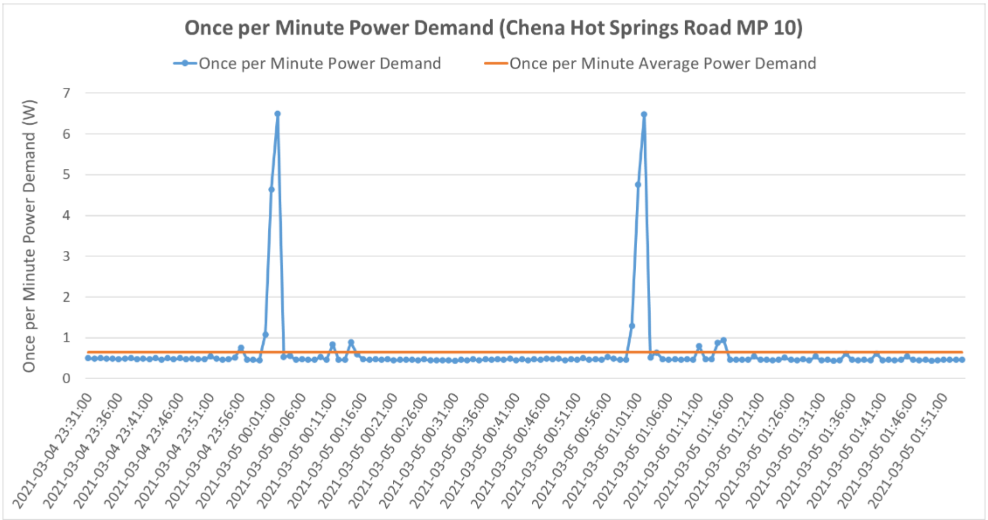

Fig. 6: Plot of once per minute power consumption (blue) and mean power consumption (orange) for Chena Hot Springs Road MP 10 mini-RWIS site from March 4, 2021 at 23:31 to March 5, 2021 at 01:54. Peaks of 6.5 W are coincident with hourly data transmission.

Summary of results and conclusions

The mini-RWIS systems have proven to be reliable throughout the initial and field testing. All three of the systems have operated through the winter of 2021 without failures. The power system has proven to be extremely robust with an estimated power reserve of nearly double the minimum required. All instrumentation has performed without problems with hoar frost or rime ice. However, there have been occasional issues with moisture on the camera lenses which degrade the images. To date, the heaters have not been employed to correct this issue since the degradation has been occasional. This may change as additional systems are installed.

An additional 5 Campbell Scientific sites were commissioned during the 2021 summer. All 8 stations performed similarly to what was experienced with the first 3 stations over the first winter of the test and a follow up report will be prepared later this year.

FOCUS TOPIC #4

ROAD WEATHER DATA SYSTEMS – PART OF ITS

WEATHER SERVICE TO SUPPORT AUTONOMOUS DRIVING IN ADVERSE WEATHER CONDITIONS

Marjo Hippi [a], Timo Sukuvaara [b], Kari Mäenpää [b], Toni Perälä [b]

[a] Finnish Meteorological Institute, Meteorological Research, P.O. BOX 503, 00560 Helsinki, Finland, marjo.hippi@fmi.fi, ORCID: 0000-0003-4750-1470

[b] Finnish Meteorological Institute, Sodankylä Arctic Space Centre, Tähteläntie 62, 99600 Sodankylä, Finland

Summary

Autonomous driving can be challenging especially in winter conditions when road surface is slippery, covered by icy or snow and visibility low due to heavy snowfall, fog or blowing snow. Also, in summertime the driving conditions can be reduced by heavy rainfall, dust, or smoke. These harsh weather and road conditions set up very important requirements for the support systems of autonomous cars. In the normal conditions autonomous cars can drive without limitations but otherwise the speed must be reduced, and the safety distances increased to ensure safety on the roads.

Finnish Meteorological Institute has developed a weather-based support system for autonomous driving. The system considers weather and road condition and makes an estimation what level of automation is possible while driving. The system is tested in the Sodankylä Arctic vehicular test track environment.

Introduction

Autonomous driving has gained a lot of interest within the recent years. With improved traffic safety and travelling convenience, it is expected to be a common part of the traffic within next 10 years. The key objective is the safety of driving, maintained in all conditions and especially in winter [1].

Autonomous driving needs very precise and real-time information about weather, road condition and other driving related information nearby (like other cars, obstacles, flooding, or other unexpected situations). Data can be collected from different sources, like (road) weather models, fixed road weather station network, weather radars and vehicle sensors. Autonomous driving is strongly dependent of several sensors (camera, LiDAR, radar) detecting the driving circumstances (obstacles, edge line etc), see Fig. 1 [2]. All these instruments have their vulnerabilities in harsh weather, especially in winter conditions [3].

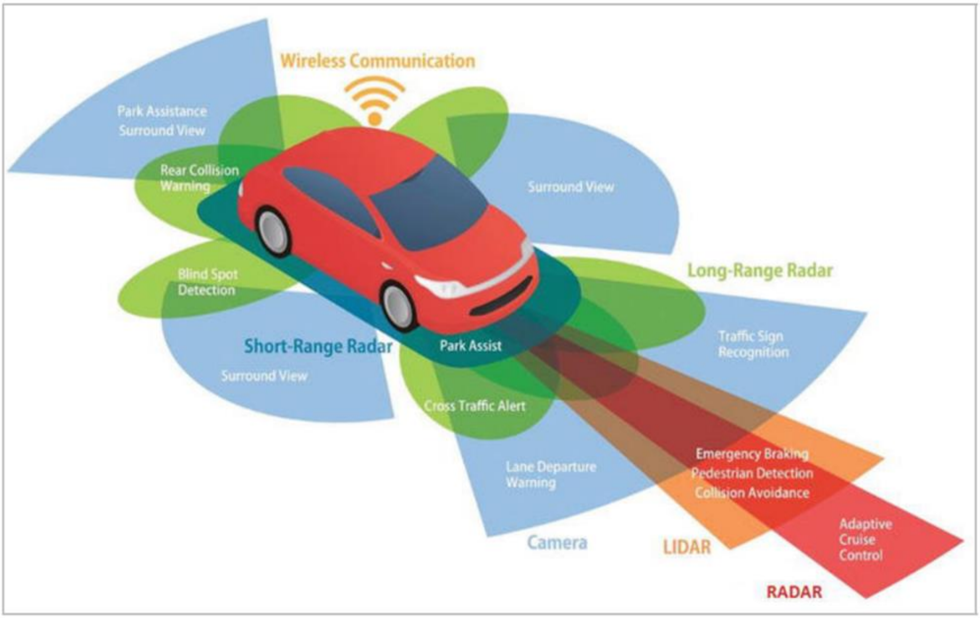

Fig. 1. Wireless communication and sensors in autonomous cars [2].

By combining the relevant weather and road condition information a weather-based autonomous driving mode system is developed to help and support autonomous driving. The driving mode system is dividing the driving conditions from perfect conditions to very poor conditions. In between there are several steps with slightly alternate driving mode depending for example snow intensity and friction. In the most challenging weather conditions, automatic driving must be stopped because the sensors guiding the driving are disturbed by for example heavy snowfall or icy road.

Arctic vehicular winter test track in Sodankylä

Finnish Meteorological Institute is testing autonomous driving in the Arctic vehicular test track in Sodankylä, Northern Finland [4]. The test track is equipped with road weather observation system network including normal road weather stations, IoT sensors measuring air temperature and humidity along with various communication systems. Also, tailored road weather services are produced to the test track, like road weather model calculations and very accurate radar precipitation observations and nowcasting. The developed weather-based autonomous driving system is tested on Sodankylä test track among other arctic autonomous driving testing.

The research work is relying on a miniature autonomous vehicle with capability to carry measurement and communication instrumentation but no passengers. The prototype vehicle is presented in the Figure 2. It has been built on miniature electrical all-terrain vehicle platform, with the size of 0.5x1.0 meter. The current configuration allows the carriage of simultaneous controlling CPUs, stereo camera, LiDAR and radar sensors, friction measuring instrument and 5G/802.11p networks support (see Table 1).

Fig. 2. FMI autonomous miniature vehicle in parallel with normal size vehicle.

Table 1. Miniature/autonomous vehicle sensors.

Device	Detection range	Object detection accuracy	Vulnerability to		
			Rain	Snow	Dark
Video camera *	>100m *	Moderate	Low	High	Low
LiDAR, Velodyne PUCK/ VLP16	>100m	Very high	Mod	Mod	Null
Vehicle radar, Continental SRR 308	>80m	High	Low	Mod	Null
GNSS RTK	∞	Null	Null	Null	Null
Friction, Vaisala MD30, Teconer RWS 431	Spot	Null	Low	Low	Null

**image resolution limited due to real-time interpretation*

Enhanced road weather service for autonomous vehicles

The scenarios envisioned for the autonomous driving are built upon the idea that autonomous vehicle is more vulnerable to the weather conditions, benefiting from more sophisticated weather information. The weather information can be collected from different sources, like weather and road weather observations including weather radar data and supplemented with observations measured by vehicles own sensors. The upcoming road weather and road condition can be forecasted by road weather model [5].

Assuming that the autonomous vehicle is possessing and operating all the instrumentation presented in the Table 1, we can compose the preliminary stepping driving mode table shown in the Table 2. Table 2 also presents weather-related explanations for different driving modes and how weather affects to the sensors. Modes 0 and 5 are straightforward; if the detected conditions are malicious or there is a detection failure, the safe driving is impossible, vehicle must either stop or autonomous driving must be switched to full manual driving. Obviously, if the vehicle's sensors themselves detect an object on the road, driving is impossible as well, but for other reasons. Mode 1 is clear as well, if the weather is fine for driving, there is no need for any adjustments.

Table 2. Concept model of weather-based stepwise autonomous driving mode.

Driving mode	Driving specifics	Road weather and driving conditions	Effect to sensors
0	Must stop	Not defined	Unknown location or other error
1	No need to adjust speed nor driving	Fair weather. Good visibility and dry surface	-
2	Anticipate braking events by lowering speed, increase safety distance	Minor rain or snow / light snowdrift / light fog. Fairly good visibility and friction.	LiDAR not detecting completely, camera detecting poorly

3	Halve the speed, increase safety distance	Moderate rain or snow / moderate snowdrift / light or dense fog. Reduced visibility or friction.	LiDAR not detecting completely, camera not detecting
4	Minimum speed, prepare to stop	Heavy rain or snow / high snowdrift / freezing rain / dense fog. Reduced visibility or friction.	LiDAR not detecting completely, camera not detecting, radar not detecting completely, ice and snow on the sensors
5	Must stop	Heavy rain or snow / moderate or long-lasting freezing rain / heavy fog. Very low visibility or friction.	LiDAR and camera not detecting, radar detecting poorly, ice and snow on the sensors

Modes 2-4 represent the stepping modes, where the detection systems (camera, LiDAR and radar) are one by one losing their capability to detect objects, finally losing the ability entirely. Driving specifics defined for these modes are the concept inherited from the autonomous miniature vehicle we are operating; each autonomous vehicle model possesses their own set of sensors, requiring slightly different countermeasures. However, when we ultimately have accurate definition of “operability” for each type of sensors, each manufacturer can tailor their driving system reactions accordingly.

The next step is to determine the local driving conditions from vehicle cameras and LiDARs. That information could be used as a supplementary material to assume the prevailing driving conditions. Reduced visibility can be detected from analysed camera data. Also, precipitation can be detected from LiDAR data, at least to some extent. Vehicle radar as such has been studied the least in this sense, but it could be used to get some information about precipitation intensity.

Acknowledgements

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WINTER TESTING TRACK ENVIRONMENT FOR THE INTELLIGENT TRAFFIC ROAD WEATHER SERVICES DEVELOPMENT

Timo Sukuvaara [a], Kari Mäenpää [a], Toni Perälä [a], Marjo Hippi [b], Aleksi Rimali [a]

[a] Arctic Space Centre, Finnish Meteorological Institute, Sodankylä, Finland

[b] Meteorological Services, Finnish Meteorological Institute, Helsinki, Finland

Summary

FMI is operating the Arctic vehicular winter testing track with advanced communication capabilities within ITS-G5 and 5G test network, along with accurate road weather data and services supported by road weather stations and on-board weather measurements. The track is located in Sodankylä, Northern Finland, where the long arctic winter period of more than half year allows road weather services development for the severe, Arctic weather conditions.

FMI is continuously studying the possibilities to improve the Arctic Road weather traffic monitoring and related safety services by innovative use of C-ITS and related methodologies. Autonomous driving, energy efficiency, green technology and drones are globally addressed as some of the future trends. 5G and other advanced communication systems are elemental part of the C-ITS, allowing autonomous vehicle services and remote control among other things.

FMI intelligent traffic road weather services research topics are all reflected into the winter testing track as well. The goal is to provide optimal

conditions for the development of advanced vehicular safety services equally for traditional, autonomous, and alternate energy vehicles, with both state-of-the-art and pioneer road weather and roadside infrastructure and communication methods for wide variety of use cases. This paper overviews the new intelligent traffic road weather service systems and technologies relevant in Arctic conditions, and their practical testing and piloting practices in the Sodankylä Arctic winter testing track.

Introduction

The Finnish Meteorological Institute (FMI) has been developing the ITS-enabled road weather services in long-term basis. In the early phase of the research work, pilot ITS-enabled on-board vehicular road weather services were tested and evaluated in the temporary test settings composed on-demand. The idea of permanent testing environment with continuous weather monitoring instrumentation and relevant ITS communication systems started to evolve. During 2017, the first permanent infrastructures were constructed into the vehicle winter testing track of Sodankylä municipality, in the vicinity of Sodankylä airport area. The test track constructed in EU ERDF Sod5G project consisted of LTE-A -based 5G-test network and two road weather stations (RWS) with integrated ITS-G5 communication systems [1].

The communication infrastructure in the test track consisted of several parallel communication entities. ITS-G5 communication was composed by wireless transceivers embedded into the RWS infrastructures and FMI vehicles, allowing the testing of both V2V and V2I communication. The 5G test network consisted of a single base station, operating in license-free 2.3 GHz band. The 5G test network has undergone upgrades and is now following the operative 3.5 GHz system. The test network has also been supplemented with support for the narrowband IoT operation.

Along with the communication, road weather services are another essential element of future driving. Autonomous vehicles are relying on the real-time knowledge of the accurate location of themselves, and co-existing traffic actors and infrastructures and all the knowledge related to their mutual safety margins. In the Sod5G test track the weather monitoring was arranged by deploying two road weather stations along with the test track. The road weather stations instrumentation consists of traditional weather monitoring parameters temperature, wind and wind direction, along with more sophisticated road surface temperature and condition, and road friction.

The test track environment has served well as demonstration platform of FMI's research activities. Among other activities, it has been served as the final demonstration platform of 5G-Safe project autonomous and cooperative vehicles 5G-enabled services [2]. However, the development of the cooperative driving and societal pursue towards the green technologies have caused the necessity for the upgrades. Test track existing infrastructure overview

The Sod5G test site is presented in Fig. 1. The main track is 1.7 km long, supplemented with several "shortcuts" for different types of surface characteristics, with additional testing routes outside the Sod5G road weather and communication testing area, altogether 11 km of test tracks. The track surface under the snow is gravel, except the part of the track

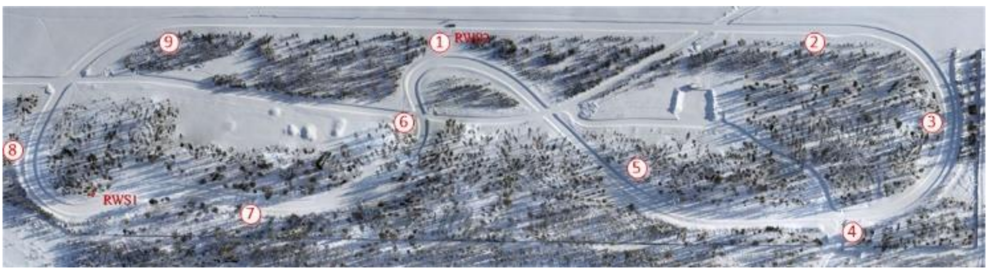

Fig. 1. Sod5G test track. The Road Weather Stations are marked as RWS1 and RWS2, IoT weather sensors as numbers 1-9.

between road weather stations which has asphalt surface and under-surface pipelining across the road.

The current communication infrastructure in the test track consists of several parallel communication entities. ITS-G5 communication based on IEEE 802.11p (IEEE Standard Association 2009 IEEE 802.11p) standard was composed by Cohda Wireless MK5 transceivers embedded into the RWS infrastructures and FMI vehicles, allowing the testing of both V2V and V2I communication. The 5G test network consists of a single LTE anchor station and two 5G stations in the 3.5 GHz band. The LTE and one of the 5G stations is located to the North of the track, just outside the area shown in Fig. 1 (North is approximately to the left-hand side of the figure). The second station 5G station is located at location 4 in the map. 5G cellular networking is expected to provide considerable improvements for the intelligent traffic, among other advances like superior bandwidth and ultra-low end-to-end delays. Reliable and efficient communication is very important aspect in autonomous driving vehicles, to assure safety and comfortability [3].

Finally, the energy efficient IoT sensor network consists of 9 Ursalink temperature and humidity sensors, operating in Digita LoRaWAN network. Sensors are periodically delivering the measurement data to the IoT network, further collected to FMI observation systems. In terms of road weather instrumentation, the Sod5G track has currently two fixed RWS, presented in the Fig. 1. RWS contain ITS-G5 communication transceivers, so they can be used as interactive roadside infrastructure in cooperative driving. IoT sensor

network temperature and humidity measurements are supplementing the RWS data, and as a result we have weather data throughout the (main) test track. The weather observation network can be supplemented with under-surface sensors in the instrument pipelines buried to the ground.

Test track services

The current infrastructure allows the testing of various services related to intelligent traffic, road weather and their advanced combining. Starting from the cooperative driving, European Commission has defined a set of so-called "day one" services of hazardous location notifications, to be standing for first set of cooperative driving services. These services are indications of 1) Slow or stationary vehicles. 2) Road works warning, 3) Weather conditions, 4) Emergency brake light, 5) Emergency vehicle approaching and 6) Other hazards [4]. These services, also known as C-ITS services, are tailored for short range ITS-G5 communication. In Sod5G test track, the ITS-G5 communication is composed with Cohda Wireless transceivers located on the RWS infrastructure and specific research vehicles. The day-one services have been successfully tested in the track.

The first set of 5G-enabled pilot road weather services contained three (plus one) different road weather services especially tailored to benefit autonomous vehicles, as presented in the Fig. 2. The autonomous vehicle can select the preferred route based on 1) weather forecast data of each route, 2) existing road weather-related alerts on the route and 3) existing safety-related alerts on the route. All these pilot services were generated by exploiting the 5G test network in real-time collection of observation data and warnings, ultimately delivered to the vehicles in near-real-time by the 5G test network. Furthermore, the V2V communication in the 5G test network and the ITS-G5 was tested with special 4) See-through -application, tailored to deliver vehicle camera data information from the front of a vehicle queue during the poor visibility conditions, allowing preparedness for unexpected anomalies in the traffic. See-through application is very sensitive to the transmission delay and possesses also juridical questions, therefore it is not

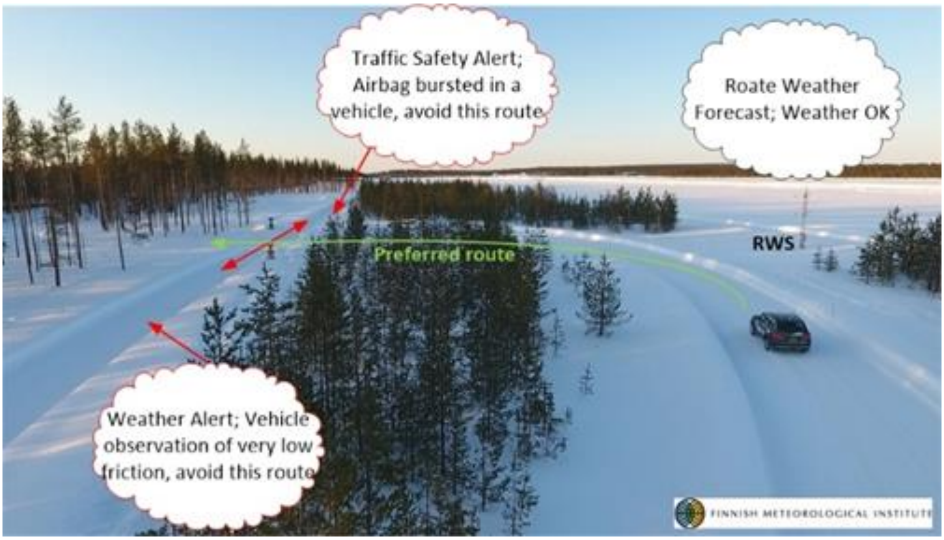

Fig.2 Pilot services exploiting 5G communication capabilities.

ready for the operational traffic environment yet. Nevertheless, the set of pilot services tailored for 5G and autonomous driving are available on the test track. Exploiting both ITS-G5 and cellular networking (4G/5G) features offers the best communication approach at hand, as long as ITS-G5, cellular or C-V2X is not clearly the superior approach [2].

Accurate road weather services for the test track are generated by combining 1) general meteorological road weather information for the area produced by FMI, 2) road weather station (RWS) measurements in the area, and 3) supplemental mobile data provided by the vehicles on the test track. Both 5G cellular networking test system and ITS-G5 vehicular networking are employed in this scenario and the experiments have been conducted with both systems. Road weather services exploiting road traffic data allow more accurate instantaneous service generation directly to different traffic and transport actors, in the very spot of observed hazardous weather condition. The target is to generate very localized warnings, furthermore leading drivers to pay more attention to “more concrete” warnings. Another aspect in the road weather service development is the tailored road weather services. The different actors demand different type of information and therefore we are fine-tuning the different contents for e.g., professional drivers, road maintenance operators, autonomous vehicles and traditional drivers [5,6,7].

Acknowledgements

This work has been supported in part by the European Regional Development Fund (ERDF), Business Finland and the EU EUREKA Celtic Plus and EU Interreg Nord programs. The authors wish to thank all our partners of the Sod5G, 5G-Safe, 5G-SAFE-PLUS, VED, EMAL and Arctic Airborne 3D projects.

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FOCUS TOPIC #5

INOVATION AND TECHNOLOGICAL ADVANCEMENTS

VEHICLE POSITION INFORMATION SYSTEM FOR ACCURATE OPERATIONAL MANAGEMENT AND OPERATIONAL SUPPORT OF SNOW AND ICE OPERATIONS

Takafumi Nagai [a], Takashi Hasegawa [b], Hideki Takahashi [a]

[a] Head Office, Central Nippon Highway Engineering Nagoya Co., Ltd., 460-0003, Nishiki 1-8-11, Naka-ku, Nagoya, Japan,

h.takahashi.a@c-nexco-hen.jp

[b] Kanazawa Branch, Central Nippon Highway Engineering Nagoya Co., Ltd., 920-0025, Eki-nishi-honchou 3-7-1, Kanazawa, Japan,

Summary

On Expressways during the winter season, Vehicle position Information System (VPIS) was developed and introduced because it is necessary to grasp the position and work of snow and ice vehicles in real time, perform appropriate snow and ice work, and secure a good road surface. VPIS is a system that automatically transmits data on snow and ice vehicles to the control room, which is used to ascertain vehicle location information, etc., and to prepare work diagrams and work inspection data. With the introduction of VPIS, snow and ice operations management personnel are able to provide accurate work instructions and operational control. In addition to facilitating the securing of good road surfaces, the time required to prepare work management documents has been reduced, and the efficiency of operations has been greatly improved.

Introduction

The Central Nippon Expressway Co., Ltd. (NEXCO Central), which is in charge of expressways in central Japan, has been working to ensure smooth traffic on expressways during heavy snowfall by strengthening the advance deployment of snow removal trucks and increasing the number of rotary snow-plows in response to the record heavy snowfall in the Kanto and Koshin regions in February 2014 [1][2]. However, this has resulted in congestion in the location information of snow removal vehicles and increased the burden of management and operation of snow removal work details, making it difficult to accurately manage snow removal work, and a formula to improve this has been sought.

To achieve this, the snow and ice operation supervisors at the snow and ice base needs to know the location and work status of the snow and ice vehicles in real time. In order to support the accurate operation and efficiency of this snow and ice operations, Central Nippon Highway Engineering Nagoya Co., Ltd. (Eng. Nagoya) has been working since 2014 on the development of Vehicle Position Information System (VPIS) to make this possible.

Development of VPIS

VPIS is a unique Eng. Nagoya system that is installed on snow and ice removal vehicles and traffic control vehicles patrolling expressways during the winter and visually displays on route maps and maps which routes and points the vehicles are traveling and working, enabling accurate work vehicle management. The VPIS system consists of on-board units (smartphones), a vehicle management server at the data center, and PCs installed at each Inter Change (IC) and snow/ice control room (SICM) for monitoring snow/ice operations (Fig.1). The system collects the location information from the GPS function installed in the on-board unit and transmits the location information and the vehicle work details entered by the on-board unit to the data center.

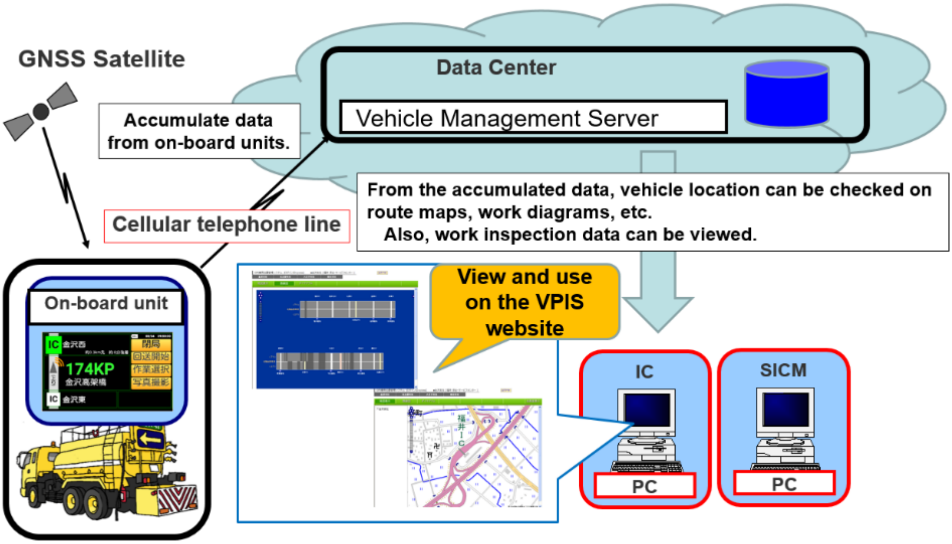


Fig. 1. Image of VPIS

The data is stored in the vehicle management server and can be checked in real time on PCs used to monitor snow and ice operations at each IC and at each SICM in NEXCO Central.

VPIS has the following four features.

The first is the use of a general-purpose Android OS smartphone as the on-board unit, which enables the use of the latest hardware performance, such as CPU, and a wide selection of smartphones from which to choose from and whose applications can be easily upgraded.

Second, because it uses cell phone lines, the communication speed is faster, more reliable, and cheaper to use.

Third, the use of a cloud system for VPIS monitoring site makes maintenance and upkeep more efficient and speeds up the response to problems.

Fourth, location information is obtained from the GPS function of the smartphone and, in tunnels, from vehicle speed pulses.

Introduction of VPIS

Installation Status

NEXCO Central manages expressways with a daily average traffic volume of 1,853,000 vehicles over 2,170 km at 24 offices in four branches [3], and the system has been installed in approximately 1,600 vehicles in the four branches combined. Figure 2 shows the percentage of vehicles with VPIS installed. VPIS has been installed in wet salt spreaders, snow removal trucks, patrol vehicles, and sign trucks, etc. VPIS is also used to support operations such as patrols and regulatory work on expressways.

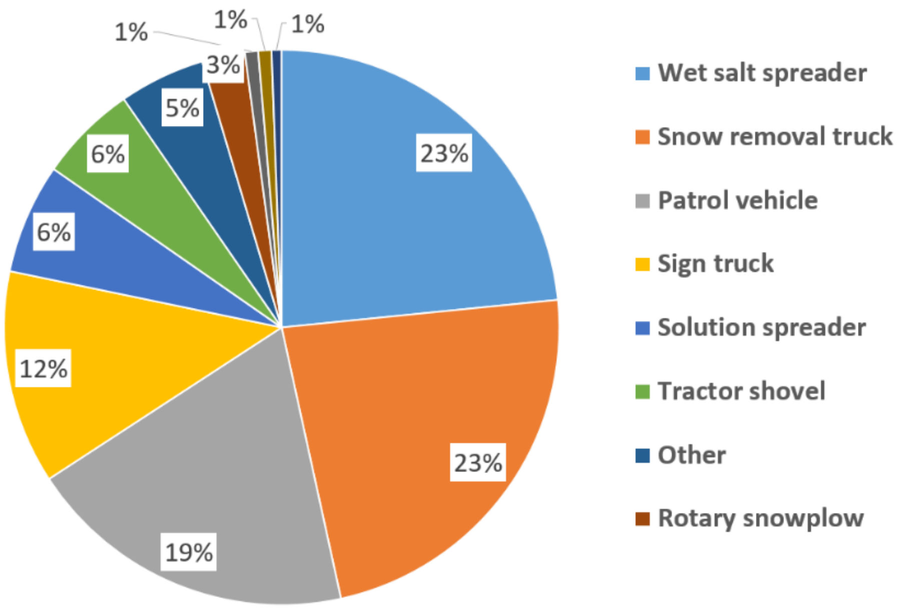


Fig. 2. Percentage of vehicles with VPIS at NEXCO Central

VPIS Operation

With VPIS, the current vehicle location information and the work selected by the operator are automatically transmitted and can be visually confirmed on the monitoring PCs at each IC and at each SICM, enabling systematic operation management. The monitoring PC can display route maps or maps and trajectories on a map.

The system also has a function to share images of road surfaces and weather conditions taken by smartphone cameras with data such as time of day, route, and kilometer post, etc. The continuous shooting function at 5-second intervals can be remotely operated from a monitoring PC in the SICM without any burden on the operator, and can be viewed as a simple video.

In addition, it can draw work diagrams and create and output work inspection documents based on data (location information, work content, etc.) stored on the server. The system can output work diagram drawings by selecting dates, areas, routes, vehicles, etc., and can save them in PDF form. It also has a real-time diagram display function, which allows users to select the route and maintenance/service center, they wish to view and display diagrams from the current time up to 24 hours before.

Improvement

After the full-scale introduction of VPIS in FY2014 and beyond, the interviews were held regularly, and the following new functions have been added so far.

In the first case, a coloring function was added to the map or route map by the section where the wet salt spreading vehicle sprayed and by the elapsed time after spraying (Fig. 3).

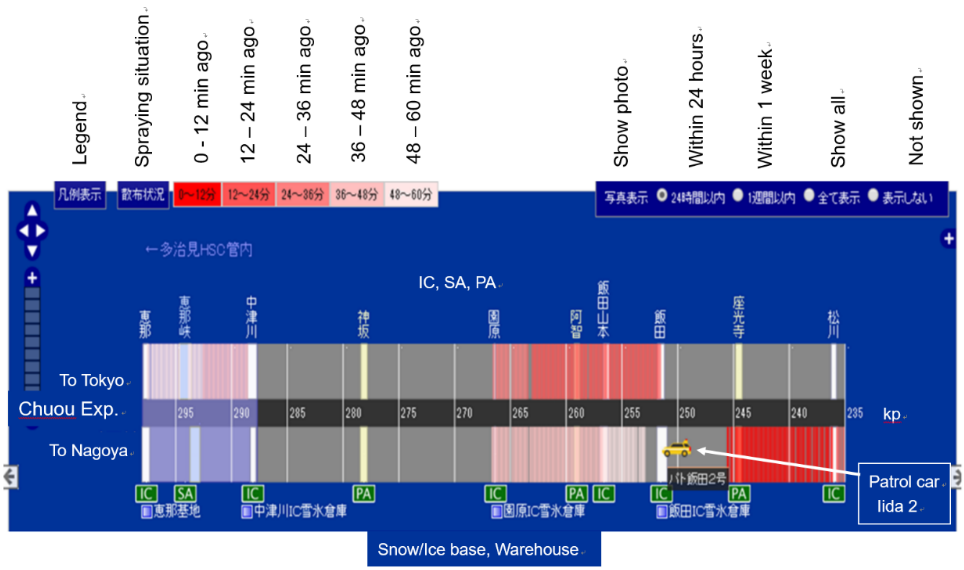


Fig. 3. Support function for monitoring spraying status

The second example is an alert support function for snow and ice operations to prevent human error. When the snowbanks in the no-throwing zone were sometimes unrecognizable due to snow accumulation, inexperienced operators had varying degrees of awareness of the hazardous areas, resulting in erroneous snow throws. This function displays a text message on the terminal screen and voice warnings when a certain kilo-meter post is reached (Fig. 4). The content of alerts, both text and audio, can be set freely, allowing the driver to inform the driver of caution and danger points, and to set alert items for individual items for each vehicle model.

The third example is a search function for photographs taken. By selecting the date, time, vehicle type and route, and kilo-meter post, a point will appear on the map, and clicking on the point will display a photo detail window. The right part of the screen displays a list of photos taken as before.

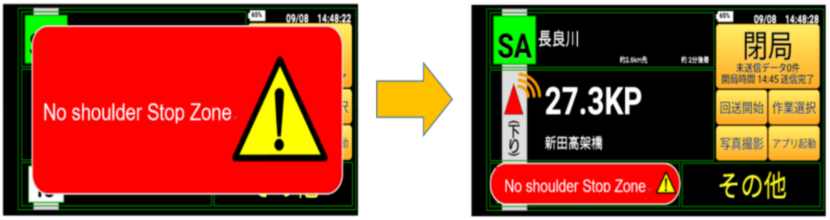
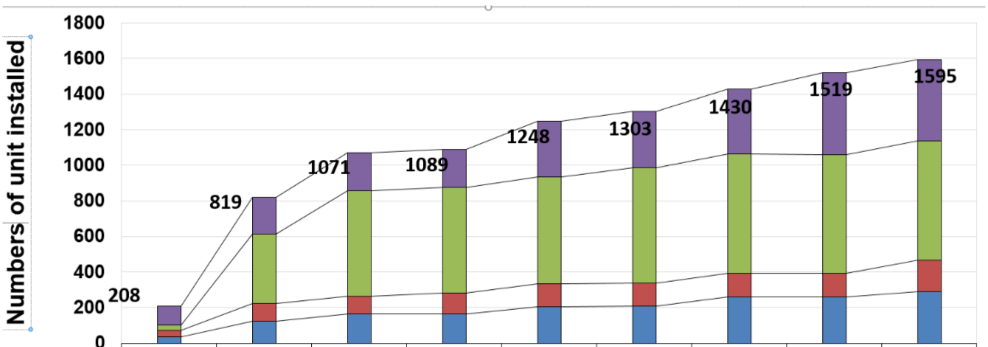


Fig. 4. Alert Screen

Effectiveness

Full-scale introduction of VPIS began in FY2014, and by the end of FY2021, VPIS had been installed in all 1,595 snow and ice vehicles and patrol vehicles in NEXCO Central business area (Fig. 5). According to interview with the person in charge of the snow and ice control room, who is the operator of VPIS, the introduction of VPIS has been evaluated as having reduced human errors, as vehicle information can now be checked visually, whereas before the introduction of VPIS, work was done by radio, which resulted in listening errors. Approximately 60 VPIS units have been installed by other expressway managing companies, and we believe that the usefulness of the functionality of VPIS has been recognized.



	FY2014	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Kanazawa	104	206	212	212	314	315	365	458	458
Nagoya	30	389	594	594	601	651	673	669	670
Hachiouji	39	98	100	118	129	129	131	130	175
Tokyo	35	126	165	165	204	208	261	262	292

Tokyo Hachiouji Nagoya Kanazawa

Fig. 5. Number of units installed VPIS

Conclusion

The VPIS system has made it possible to obtain real-time information on vehicle positions and work details during snow and ice operations, enabling accurate work instructions and operational management. This has also led to improved expressway service that satisfies drivers. Based on the operational status and the results of the interviews, we will make prompt improvements and take countermeasures for any defective events, and we also hope to realize requests for the addition of new functions.

In the future, we would like to install sensors to acquire information on road surface conditions, temperature, humidity, etc., to quantitatively check the site conditions, and to consider developing a system that can perform snow and ice operations more efficiently, such as performing snow and ice operations more suited to the conditions and identifying hazardous areas.

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CONNECTED VEHICLE DATA – REALTIME ROAD CONDITION MONITORING

Björn Zachrisson, Johan Hägg
NIRA Dynamics, Wallenbergs gata 4, 58330 Linköping, Sweden,
bjorn.zachrisson@niradynamics.se

Summary

Winter roads pose a lot of challenges. Knowing the road friction during wintertime has been the Holy Grail for road maintenance actors for a long time. Unknown low friction can cause severe single accidents as well as massive collisions as braking might be impossible due to non-existent grip.

With increased digitalization, access to road surface information in real-time is getting better and better in a cost-effective manner. This makes more efficient and sustainable winter road maintenance possible, by using better tools, based on data from a combination of fixed and mobile sensors.

Measuring road conditions

Already today, there are several options for measuring road friction during winter conditions; mounted sensors or friction wheels are the most common ones, but they share a common challenge, they do not scale. There is no way to know the status of the entire road network using dedicated special equipped vehicles. The cost to cover all roads would be too high. Without knowing the road status there is no real way to measure maintenance performance objectively, nor is it possible to know if there are hazardous roads in the network or not.

Fig. 1. Connected vehicle data is key when gaining insights on current road conditions

What NIRA has been developing for the last 20 years and more intensely the last 5 years is friction measurement using normal passenger vehicles. No hardware is added, only utilizing existing sensors and a software component for processing the existing sensor data. Through this method, any connected vehicle with the software installed can act as a sensor and the scalability is almost limitless. (Fig. 1) How can this help road owners and road operators in their day-to-day operations?

When it comes to winter maintenance operations, reliable feedback is key – not only for being able to improve prioritization and the overall efficiency of the operation, but also for contract validation when working with road maintenance suppliers.

Analyze the outcome of performed road treatments

A key aspect when working with continuous improvements is to measure and compare outcomes between different methods. Without large-

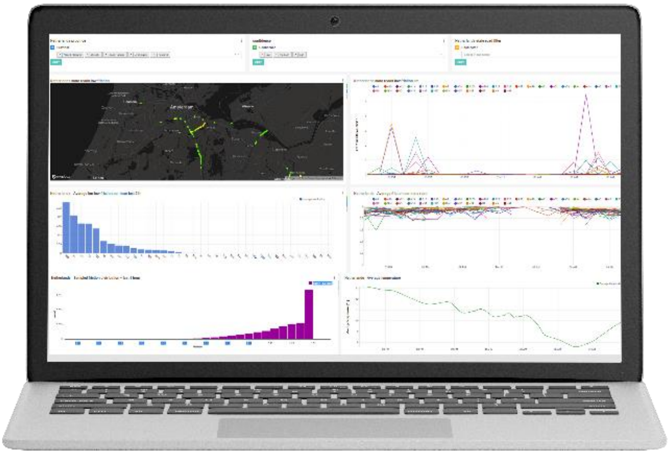

Fig. 2. Connected car data can evaluate the road network continuously, allowing objective analysis

scale data collection, however, it's not possible to work with Key Performance Indicators or to evaluate different methods and ways of working on a network level. Winter Road Insights provides the tools you need – and it's all made possible by the huge amount of friction and weather data information, collected by the vehicle fleet.

From the data, a universal KPI can be constructed, enabling effectiveness measurements of the winter road maintenance. In fact, the ability to analyze and look at events in hindsight, is what makes Winter Road Insights the first true performance evaluation system for winter maintenance and road safety.(Fig. 2)

Act instantly on slipperiness occurrence and detected road condition hazards

Car measurements does not only allow direct measurements on slippery roads in the area, it also enables preventive action by alerting citizens or instructing road maintenance to act on slippery road segments. Winter Road Insights lets operators redirect actions to certain locations to avoid accidents. What's more, the live-view enables optimization on routes and salt usage that has a potential of saving 15-20% of the winter maintenance budget.

As NIRA's friction measurements are provided in real-time, they give an active view of the actual road friction situation. (Fig. 3) This means low friction is identified no matter if it is expected or not – and should any weather forecasts turn out to be faulty, the connected cars will pickup and correct those errors immediately.

Every minute counts: if a hazardous situation can be handled 10 minutes faster, the likelihood of an accident is reduced – substantially. Normally, an accident happens 30-90 minutes after slipperiness has been detected. An alert could call for immediate action that would be required to resolve or prevent bad road conditions.

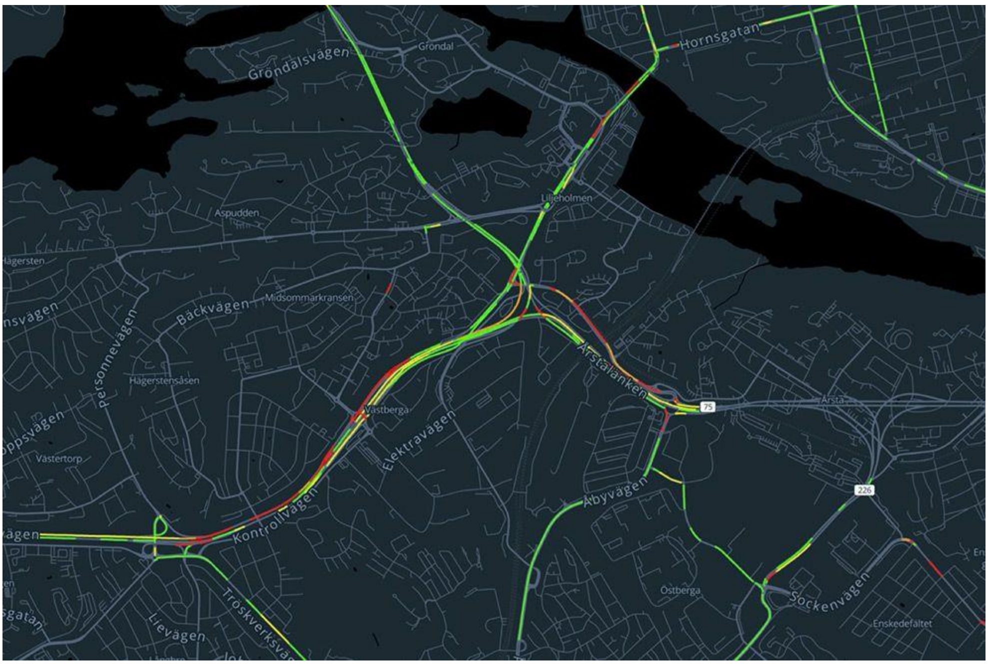

Fig. 3. Green indicates good friction; yellow is medium and red is very slippery. In this image we can see that a main highway of Sweden contains very low friction.

Making life easier for road crews

It is a fact. The situation for the road operator crew is difficult: Making the right decisions based on experience rather than objectivity, while having a huge responsibility to do what is best to maintain as safe roads as possible. Doing that while having very little access to live data from the road network.

Making the wrong calls may have severe impact on safety as well as productivity, both for the individual, but also on transportation and the society as a whole. Digitalization is changing the way of working, connected vehicles continuously monitoring the road surface conditions. New data types, applications and tools bring new possibilities for the operators to make better decisions based on objective measurements. Millions of vehicles collecting data means greater data availability than ever before.

What we have set out to do is to provide a solution that gives road operators access to real-time friction data, providing a clear picture of what the situation actually looks like. That’s on any specific stretch of any road, at any given time.

The result – Roads can be maintained in a much more efficient way, making them safer, while lowering cost and reducing environmental impact.

FOCUS TOPIC #6

FUTURE PERSPECTIVES OF ROAD METEOROLOGY AND CLIMATOLOGY

THE DECREASING IMPORTANCE OF ROAD WEATHER FORECASTS

Lee Chapman
University of Birmingham, Birmingham, B15 2TT, UK
l.chapman@bham.ac.uk, ORCID: 0000-0002-2837-8334

Summary

Road Weather Information Systems (RWIS) have seen little *rapid* fundamental change since their original implementation in the 1980's – it is often a case of evolution rather than revolution. Significant technological advances leading to a step-change are uncommon, with the adoption of geographical information systems and global positioning systems bringing arguably the first significant change in practice some twenty years later after the first generation of RWIS. However, a range of technologies now exist that have the potential to cause a paradigm shift in the way society deals with winter resilience on transport networks, signalling the end of road weather forecasts and RWIS as currently known.

Background: Road Weather Information Systems pre-2000

The original road weather forecasts were very crude with treatment decisions being made on the most basic of text forecasts [1]. For example:

"*Road surface temperatures are expected to fall below zero at 2 a.m. and ice is expected to form on most of the roads in the region.*"

This was transformed in the 1980's which saw a widespread increase in the use of Road Weather Information Systems (RWIS). The earliest from of RWIS was an *ice detection* system consisting of embedded sensors in the road to monitor road surface temperature and relay real-time road condition information back to the highway engineer. Using this approach, action could be taken if temperatures changed suddenly. However, the ice detection approach also paved the way for *ice prediction* systems which embedded the forecasting component into the system. The availability of road weather data enabled an increased level of sophistication to forecasts allowing dedicated teams of forecasters to produce 24 hour forecast graphs from simple models. These which were issued daily at noon to guide improved decision making: a midday forecast provided ample time to deploy people and vehicles, whilst complying with legal demands such as working time directives.

Advances since 2000

The system remained broadly unchanged for the next 20 years, but increased computing power meant forecasts could now be run at a scale previously impossible opening the door to high spatial resolution weather forecasts such as route-based forecasting [2]. New technologies were also starting to become embedded such as geographical information systems, global positioning systems and decision support systems meaning that treatments could be increasingly targeted and optimised [3]. It represented a step-change in RWIS for highway engineers brave enough to have confidence in the new technology. Fast forward another 20 years and it is becoming evident that a new wave of technological advances are rapidly emerging. A number of disruptive technologies are already being implemented that have the potential to radically change the way that the industry thinks about RWIS. These include:

More sophisticated sensors: Options are now far more numerous than ever with a range of vehicle mounted and in-situ non-invasive and embedded sensors now available on the market. The non-invasive market has particularly increased, offering ease of installation and measurements of surface state as well as road surface temperature.

The Internet of Things: At the other end of the scale, IoT devices provide less sophistication, but at a vastly lower cost allowing unprecedented densification of measurements [4]. The self-contained nature of the technology is attractive meaning that devices are un-reliant on mains power and are therefore 'semi-mobile' (Figure 1).

Connected & Autonomous Vehicles: The industry has long embraced the potential of collecting weather data from cars [5]. However, with the rise of the connected vehicle, opportunistic sensing provides a means to provide observations at an unparalleled scale. Forecasting solutions are already commercially available in this space taking advantage of high-resolution road condition data [6].

Artificial Intelligence (AI): AI is not new, but is enjoying a renaissance and plays a role in all three of the afore-mentioned technologies. This can take a variety of forms ranging from image processing / object recognition on sophisticated sensors to provide real-time insights of the 'big data' generated from the IoT and opportunistically sensed data from cars.

Fig. 1. The latest generation Wintersense IoT road temperature sensor.

Increasing Automation: The end of road weather forecasts?

AI is synomonous with automation and it stands to reason that a key disruption in the sector will be increasingly autonomous decision making. This is a significant topic of debate and one which is problematic. decision has to be made somewhere, by someone (or even *something* - but the responsibility still has to reside with an individual, or organisation). Hence, even if the technologies exist to automate decision making (it could be argued that this has been the case for a decade or more), the disruption is likely to take the form of a more nuanced (or even radical) approach.

For example, at a basic level, the automation of road weather forecasts is relatively simple. There is very little reason why a human weather forecaster is going to be required in the sector in the medium term – AI is already vastly more capable of producing the simple text forecasts introduced at the start of this paper. Whereas a paucity of high resolution data has limited our capabilities here previously, the IoT and opportunistic sensing means that this is no longer the case and the industry is amassing large datasets from a range of sources (e.g. [4,6]) which provide sufficient training data to fully automate the forecast process. Much of this can be readily done in the cloud, but there will be an increasing role for edge computing to deliver the processing on the sensor itself, especially when combined with federated learning approaches [7]. With this in mind, it is clear that nowcasting will play an increasingly important role in the winter road maintenance sector.

However, there is scope to take this a stage further by considering how automation may eliminate the need for weather forecasts entirely. Indeed, an increasing fleet of autonomous vehicles could render the entire RWIS ecosystem obsolete by marking a return to *ice detection*. Consider the following scenario:

1. The vehicle fleet of 2030 will have bespoke in-built sensing capabilities as standard (e.g. [6]). Given the scale, this means that deployments of in-situ sensors are no longer required.
2. Treatment vehicles will be autonomous. As unmanned vehicles, there will be no need to comply with working time directives, so no longer will decisions be required to be taken in advance.
3. Treatment will be performed on a 'just-in-time' basis. Sensor data from the autonomous vehicle fleet will be constantly relayed back to treatment vehicles meaning that sites becoming at increased risk of ice will be treated before the problem manifests (i.e. *ice detection*)
4. Actions will be stored in the cloud allowing for real-time updates on both road condition and temperature. Autonomous treatment vehicles will continue to 'patrol' the network, analysing data in real-time, keeping the roads secure as required.

Although much of this seems far-distant, the building blocks are already in place. There is a question mark on exactly when society will be ready to make the switch to autonomous vehicles, but at the time of writing, it does appear to be a case of 'when' and not 'if'. However, it is the unmanned vehicle which is pivotal to the success of the approach. It is useful to bear in mind how rapid this can be – the transition from horse-drawn carriages to motor vehicle happened in less than a decade.

Conclusion

It is counter-intuitive to think that the disruptive technologies emerging today will take the winter road maintenance sector back to *ice detection* approaches that essentially pre-date modern RWIS, but it is certainly a plausible scenario. AI will increasingly automate many aspects of the winter road maintenance sector, as has already started with road weather forecasts, but that has the potential to be only the start of a rapid journey towards an active system to manage winter road maintenance. Such active systems have been a luxury only previously afforded to high risk, high traffic areas (e.g. airport, bridge decks), but the move to autonomous vehicles affords a new paradigm – one where road weather forecasts (and indeed RWIS as currently known) are no longer required.

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