S-I-R-W-E-C 2018

19th International Road Weather Conference

from 29th May to 1st June 2018
Smolenice, Slovakia

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Conference organised by:

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SLOVAK METEOROLOGICAL SOCIETY

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SIRWEC2018 AGENDA						
Date	From	To	Place	ID	Session name/ Presenting author	Title of the presentation
29.5.	15:30		Bratislava		Shuttle bus	
	16:00		Entrance Hall		Registration	
	19:00		Conference Hall		Welcoming Icebreaker and Sponsor Meeting Session	
30.5.	9:00		Conference Hall		Welcome and Introductions chair: Jozef Vivoda and Vladimír Rak	
	9:00	9:10			Norbert Kurilla (State secretary of Ministry of Environment of Slovakia)	Official opening of 19th Road Weather Conference
	9:10	9:20			Jozef Csaplár (Director of Forecast Department of SHMÚ)	Welcome speech
	9:20	9:40		1.1	Richard Habrovsky (Slovakia, SHMÚ)	Overview of the road weather forecasting activities at SHMÚ
	9:40		Conference Hall		Novel Approaches in Road Weather Systems (1) chair: Thorsten Cypra	
	9:40	10:00		2.1	Lee Chapman (UK, University of Birmingham)	Network design considerations for a new generation of high resolution road weather information systems
	10:00	10:20		2.2	Rhonda Kae Young (USA, Gonzaga University)	Wyoming connected vehicle pilot to manage road weather impacts
	10:20	10:40		2.3	Esben Almkvist (Sweden, Klimator)	RSI - a glimpse of the future for winter maintenance
	10:40	11:00			Coffee Break, Companies Exhibition	
	11:00		Conference Hall		Novel Approaches in Road Weather Systems (2) chair: Thorsten Cypra	
	11:00	11:20		2.4	Arto Niskanen (Finland, RoadCloud)	Fleet based road weather monitoring
	11:20	11:40		2.5	Liping Fu (Canada, University of Waterloo)	Image-based Automated Winter Road Condition Monitoring – a Deep Learning Approach
	11:40		Conference Hall		Road Weather Management and Winter Maintenance chair: Lee Chapman	
	11:40	12:00		3.1	David Konecny (Czech Republic, CROSS)	Advanced road weather and maintenance information system in the Czech Republic

Date	From	To	Place	ID	Session name/ Presenting author	Title of the presentation
	12:00	12:20		3.2	Arnaud X. Varé (Switzerland, Boschung Mecatronic)	Optimizing surface condition management
	12:20	13:50			Wednesday Lunch	
	13:50				RWIS Sensors & Equipment chair: Rhonda Young	
	13:50	14:10		4.1	Horst Badelt (Germany, Federal Highway research Institute)	Test methods for sensors of road weather stations
	14:10	14:30		4.2	Tomáš Juřík (Czech Republic, MetSense)	Innovative detection of road surface conditions in two dimensions by 2DRoad
	14:30	14:50		4.3	Janne Miettinen (Finland, Finnish Meteorological Institute)	Digitalization and road weather forecasts to help decision making for road maintenance
	14:50	15:10		4.4	Jan Szczerbiński (Switzerland, Boschung Mecatronic)	Selected weather facts on the example of a fixed automated spraying system in Pilisvörösvár (Hungary)
	15:10	15:30		4.5	Kimmo Kynnös (Finland, Vaisala)	Amount of salt versus freezing point
	15:30	15:50			Coffee Break, Companies Exhibition	
	15:50	17:30	Poster room		Poster Session chair: Jozef Csaplár	
				P.1	Erika Toivonen (Finland, Finnish Meteorological Institute)	Validation of road weather model roadsurf in fennoscandia using regional climate model data
				P.2	Zacharov Petr (Czech Republic, Czech Academy of Sciences)	ICEWARN – road weather forecasting for Prague city
				P.3	Joris Van den Bergh (Belgium, Royal Meteorological Institute Belgium)	Road weather forecasting in Belgium
				P.4	Olga Gladysheva (Russia, Voronezh State Technical University)	The winter maintenance of roads sites with snowdrift
				P.5	Hella Riede (Germany, Deutcher Wetterdienst)	FlowKar: Using high-resolution data from vehicle sensors to improve operational weather products
				P.6	Mark Vinogradov (Russia, Institute of Radar Meteorology)	Automatic anti-icing spraying system on the west high speed diameter in Saint-Petersburg
				P.7	Satoshi Omiya (Japan, Civil Engineering Research Institute for Cold Region)	Proposal of a correction coefficient for the estimation of ground snowfall amounts based on x-band multiple parameter radar precipitation data

Date	From	To	Place	ID	Session name/ Presenting author	Title of the presentation
				P.8	Peter Fabo (Slovakia, University of Zilina)	Detecting the hydrometeors based on multi-frequency passive monitoring of mobile network stations signals
				P.9	Ján Barani (Slovakia, Barani design Technologies)	Title not yet available
				P.10	Pavel Sedlák (Czech Republic, Czech Academy of Sciences)	Influence of shading and sky-view factor on road temperature forecast
	17:30	18:30			bus transport to Modra	
	18:30	21:30	Restaurant Stary Dom in Modra		Conference dinner in Stary Dom Restaurant	
	21:30	22:15			bus transport back to Smolenice	
	16:15	17:15	Library		SIRWEC Committee Meeting (Closed)	
31.5.	9:00		Conference Hall		Systems / Decision Support Systems chair: Alenka Šajn Slak	
	9:00	9:20		5.1	Samo Carman (Slovenia, CGS Labs)	MDSS in Slovenia – experiences after 2 years of operation
	9:20	9:40		5.2	Samu Karanko (Finland, Foreca)	MDSS snow accumulation percentage based on road segment maintenance requirements
	9:40	10:00		5.3	Lauryna Šidlauskaité (Lithuania, Vilnius university)	Thermal mapping in flat lowlands and undulating uplands – a comparison of results
	10:00		Conference Hall		Advances In Road Weather Forecasting (1) chair: Jörgen Bogren	
	10:00	10:20		6.1	Jan Sulan (Czech Republic, CHMI)	Operational experience with ICEWARN model (METRO-CZ) in comparison with other tools
	10:20	10:40		6.2	Henry Odbert (UK, Met Office)	Decision guidance with probabilistic road forecast
	10:40	11:00			Coffee Break, Companies Exhibition	
					Advances In Road Weather Forecasting (2) chair: Torbjörn Gustavsson	
	11:00	11:20		6.3	Karl E. Schedler (Germany, KS-Consulting)	Route based road condition forecast using mobile sensors
	11:20	11:40		6.4	Teruyuki Fukuhara (Japan, Hiroshima Institute of Technology)	A route-based forecasting model of road surface friction and snow/ice conditions

Date	From	To	Place	ID	Session name/ Presenting author	Title of the presentation
	11:40	12:00		6.5	Ingeborg Smeding (Netherlands, MeteoGroup)	Use errors in observation data to discover valuable information for road forecasting
	12:00	12:20		6.6	Andre Simon (Hungary, Hungarian Meteorological Institute)	Experimental road weather forecasting in Hungary
	12:20	12:40		6.4	Virve Karsisto (Finland, Finnish Meteorological Institute)	Verification results for road surface temperature forecasts utilizing mobile observations
	12:40	14:10			Thursday Lunch	
	14:10				Meteorological & Climatological Studies (1) chair: Henry Odbert	
	14:10	14:30		7.1	Danny Chereshnick (USA, Global Weather Corporation)	A road state climatology from the global weather corporation road weather forecasts
	14:30	14:50		7.2	Justas Kazys (Lithuania, Vilnius University)	Future climate conditions for summer roads in Lithuania
	14:50	15:10		7.3	Hirotaka Takachi (Japan, Civil Engineering Research Institute for Cold Region)	Relationship between the development of a snowdrift and snow transport rate on a road section with a cut on one side - observation in Teshikaga-cho during wintertime in FY2016 and FY2017
	15:10	15:30			Coffee Break, Companies Exhibition	
	15:30				Meteorological & Climatological Studies (1) chair: Rose Webster	
	15:30	15:50		7.4	Tae J. Kwon (Canada, University of Alberta)	A Geostatistical Approach to Classification of Topography and Climate Zones for RWIS Network Planning
	15:50	16:10		7.5	Branislav Jaros (Slovakia, Microstep-MIS)	Visibility monitoring and forecasting system for traffic safety
	16:10	16:30		7.6	Marjo Hippi (Finland, Finnish Meteorological Institute)	Visibility estimation based on camera data and weather parameters
	16:30	16:45	Conference Hall		Closing Session chair: Jozef Vivoda	
	18:00 - midnight		Garden Restaurant		Farewell party	
1.6.	9:00				Transport to Bratislava and leaving home	

Session 1 Welcome and Introductions

THE OVERVIEW OF ROAD FORECAST ACTIVITIES AT SLOVAK HYDROMETEOROLOGICAL INSTITUTE

Richard Habrovský[a], Rastislav Bujňák[a], Viktor Tarjáni[a], Jozef Vivoda[a]

[a]*Slovak Hydrometeorological Institute*
richard.habrovsky@gmail.com

The road forecasts at SHMÚ are based on the chain of operationally exploited physical and statistical models. The methodologies takes into account various time and spatial scales of meteorological phenomenon responsible for high impact weather. The forecast longer that 12h is based on products from local area model ALADIN with spatial resolution 4.5km and 63 vertical levels. Model suite is computed 4 times a day and it includes surface assimilation of local observations. The forecast up to 12h is based on nowcasting and high resolution analysis system INCA. It corrects the products of model ALADIN using all available local surface observations of temperature, humidity, wind, precipitation, cloudiness and solar radiation using statistical-empirical approach. Corrected forecasts are then used as an input to METRo model. We further postprocess road forecasts using Kalman filter in order to reduce systematic errors.

In order to compute whole forecast chain on time, we must exploit high performance computing systems. Currently we are using two cluster with 10 and 12 computing nodes based on PowerPC architecture.

Our activities related to road state forecasting (RF) started in 2012. The first operational products from model METRo were produced during winter 2012/2013 for the National Highway Company (NHC) together with the companies BOSCHUNG Mecatronic A.G., Nope a.s. and Spinet a.s. (Slovak VAISALA partner).

The RF activities started in 2006 when the first impulse was given by project INCA-CE. Further improvement was implementation of the project METRoSTAT under Eureca-Eurostars initiative. It started in 2012. We investigate solar flux blocking by the terrain using high resolution DEM. This development was made available to whole community and it was implemented into official version of model METRo.

The road forecast post processing is based in Kalman filter approach used to remove biases of the 2m temperature in locations of road weather stations.

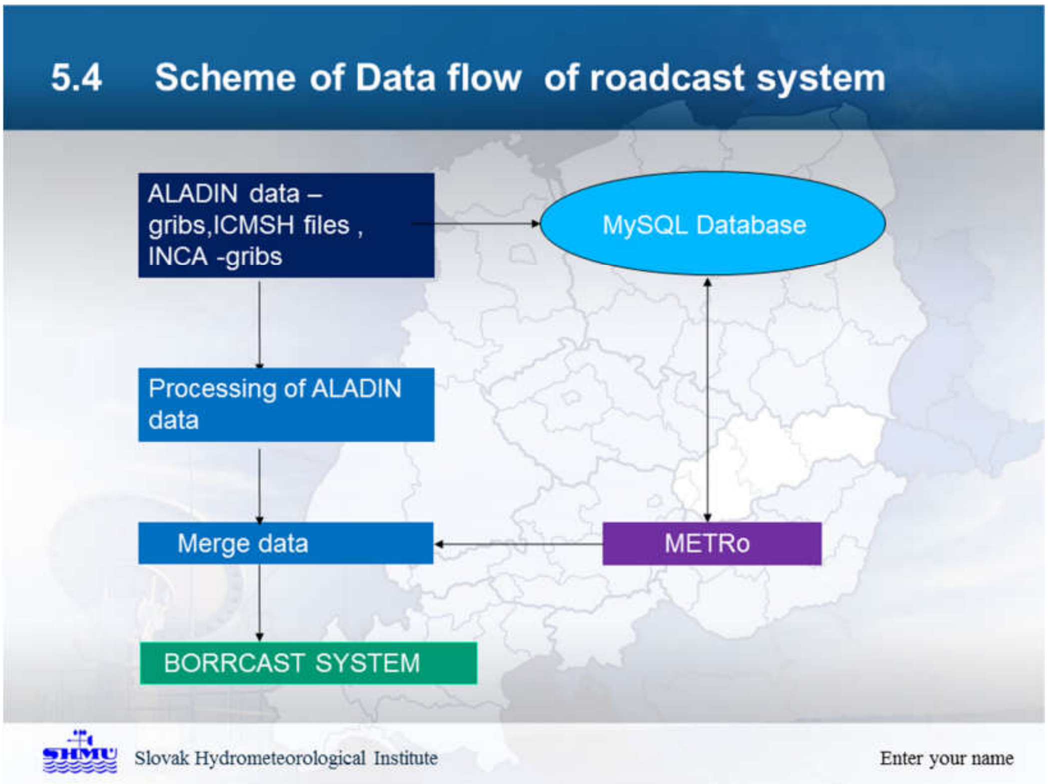

Fig. 1. Operational Expert System.

SURFEX model is currently being implemented to analyse and nowcast surface parameters (surface temperature, snow cover, deep soil temperature) that are relevant for improvement of METRo model products. We are also preparing the upgrade of high performance computing system in order to increase available CPU performance 30-40 times in order to allow assimilation of all local radar data and move to spatial resolution approx. 2.5km with 90 levels and mode to rapid update cycle mode (model ALADIN will be computed every 1-3 hours). These steps will allow us to significantly improve quality of road forecast in near future.

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1.Habrovský, R., Tarjáni, V., Bujňák, R., Vivoda, J., **2015** Application of a road weather forecast model at Slovak Hydrometeorological Institute *Meteorological Journal (Slovenský hydrometeorologický ústav)*, Vol. *18*, 9-14.

Session 2 Novel Approaches in Road Weather Systems

NETWORK DESIGN CONSIDERATIONS FOR A NEW GENERATION OF HIGH RESOLUTION ROAD WEATHER INFORMATION SYSTEMS

Lee Chapman[a], Simon J. Bell[a]

[a]*School of Geography, Earth & Environmental Science,*
University of Birmingham, Birmingham, B15 2TT, UK.
l.chapman@bham.ac.uk

Introduction

Route based forecasting (RBF) is now a standard technique used by highway authorities to make daily winter road maintenance decisions. RBF takes into account the interaction of the regional climate with the local geography to produce a high resolution forecast (e.g. 100m) of road conditions (1). The approach was motivated by the concept of selective salting, where highway engineers identify which routes need treatment on a nightly basis, or control in-route treatments by turning the spreader on or off depending on local road conditions (2). However, whilst the approach has been available for over a decade, selective salting is still not happening with practitioners nervous about making decisions based on largely unverified forecasts (3). Previous research has investigated the clustering of road stretches to better locate the limited RWIS instrumentation available, but concluded that instrumentation was too expensive to be deployed in the quantity required (4). However, technology has since moved on and via the Internet of Things, high resolution weather monitoring of road networks to complement RBF is now a reality (3). A discussion is now required to understand how best to use this new technology.

An Internet of Things Road Surface Temperature Sensor

A low-cost road surface temperature sensor has been developed at the University of Birmingham (3). The sensor is based on a thermopile, powered by lithium (or alkaline) batteries and uses the latest generation of Internet of Things communication networks. It is self-contained and simply mounts on a lighting column or gantry in minutes (Fig. 1a). The combination of technologies means that sensors can be produced and deployed at an order of magnitude cheaper than traditional alternatives that require slot cutting, external power, dataloggers, or GSM communications.

Deployment Strategies

Traditionally, the road network is subdivided into distinct climatic domains (e.g. coastal, urban, high altitude etc) each of which would receive a dedicated forecast. It was logical to then provide a means of initialisation and verification for each forecast and hence it was common (and generally affordable) to install a RWIS outstation for each domain. This strategy has remained relatively unchanged over the last 30 years and the move to high resolution RBF has not significantly changed thinking. This is surprising as the number of routes treated by highway authorities significantly outnumbers outstations leading to a paucity of observations (routes may also traverse several domains). Hence, the existing strategy is far from ideal for RBF, but outstations remain too expensive to deploy on every route (the larger local authorities in the UK can have upwards of 40 routes). Hence, an extension of existing RWIS can easily be achieved by locating low-cost sensors on routes where there is presently no instrumentation (Fig. 1b). This step could probably be achieved for most highway authorities at a cost of less than a single traditional outstation yet would in itself provide a step-change in available information.

The traditional climate domain approach also favours locating outstations in 'representative' locations (in most countries). Whilst this maximises value from the limited number of sites, the disadvantage is that information is not then available about conditions on the most problematic road sections. The low-cost approach also provides an opportunity to rethink this and design a strategy particularly suitable for use with RBF. Sensors could be placed at the COLDEST location(s) of every salting route providing a snapshot of the present worst case scenario. Locations would be identified by thermal mapping, RBF ensembles, or tacit knowledge. This step only requires a modest investment in a small number of additional sensors, but the financial benefits (especially on marginal nights) could be significant.

Whilst the one sensor per route strategy is ideally suited to maximise the benefits of RBF (i.e. treat the route or not), it would be insufficient for use in genuine selective salting practices where a much denser network would be required. Indeed, the complexity greatly increases when multi-laned roads are considered, where cross-profile differences (up to 3°C between lanes) would also need to be resolved (5). At current costs, this would be too expensive, but there is no need to saturate the entire network with sensors. Unlike traditional outstations, sensors are portable and so blanket coverage (i.e. every 100m) could be obtained on a single route at a time, moving the sensors once confidence in forecasts had been achieved.

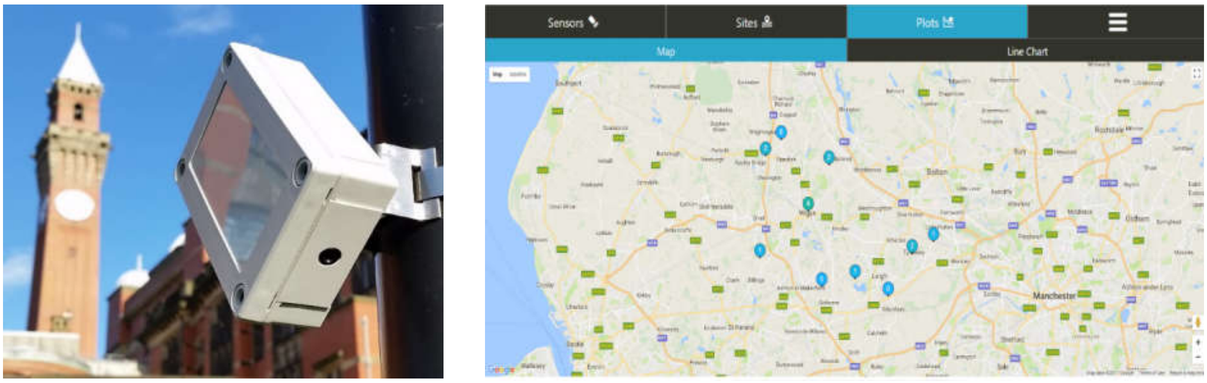

Fig 1. a) Prototype road surface temperature sensor and b) An example deployment in a UK Highway Authority. Each salting route has its own dedicated road surface temperature sensor.

Conclusions

Given the rapid emergence of low-cost sensing, there are many opportunities and options to rethink RWIS: i) Continue with traditional outstations deployed on a climate domain basis; ii) Supplement traditional outstations with representatively located sensors on a route by route basis; iii) Locate sensors at cold locations; iv) High resolution coverage (say every 100m) to also include the cross-profile. Option 3 is the recommended way forward as not only being cheap to implement, it should also provide easy returns from RBF and have the potential to reduce the number of traditional sites. However, option 4 should still be explored as costs continue to fall.

References

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Presentation 2.2

WYOMING CONNECTED VEHICLE PILOT TO MANAGE ROAD WEATHER IMPACTS

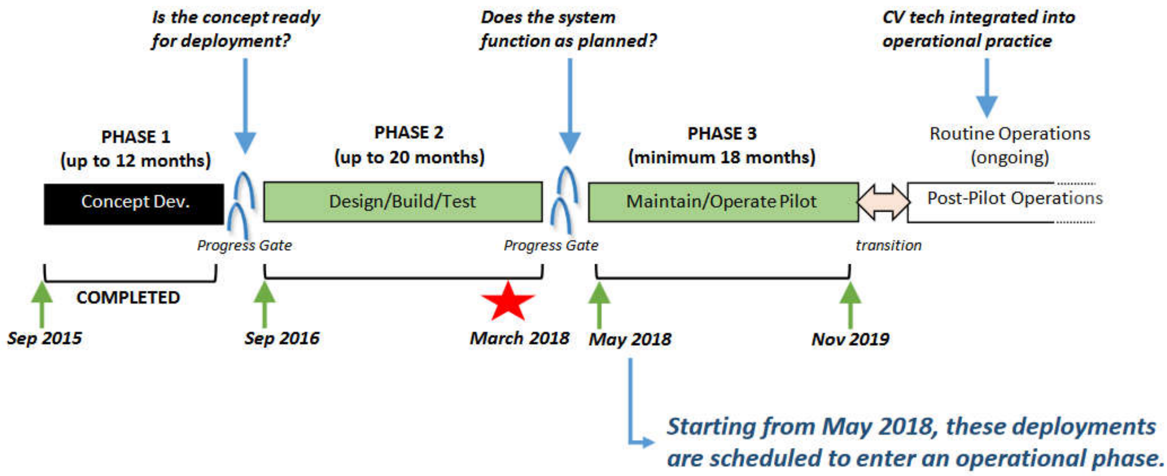
Rhonda Kae Young[a]

[a]*Civil Engineering, Gonzaga University, 502 E Boone Ave, Spokane, WA USA 99258-0026*
youngr1@gonzaga.edu

Road weather affects transportation systems by reducing traveller mobility and decreasing safety. The state of Wyoming, in the high western plains of the United States, is an area where these impacts are acutely felt. To improve safety and to decrease the frequency and duration of weather-related road closures in this region, the U S Department of Transportation (USDOT) selected the 402-mile (650 kilometre) Wyoming Interstate-80 corridor in the fall of 2015 as one of three Connected Vehicle (CV) Pilot Deployment sites. The Wyoming CV Pilot looks at the use of connected vehicle technology as a way to mitigate road weather impacts, particularly those impacts to freight vehicles that rely on the I-80 corridor to move goods between the mid-west and western coastal areas of the US.

Connected vehicle technology uses dedicated short-range communication (DSRC) to transmit data between vehicles (V2V), between vehicles and the road infrastructures (V2I), and between vehicles and mobile devices (V2X). The Wyoming pilot involves deployment of both V2V and V2I applications in approximately 400 connected vehicles that frequently travel the corridor. The project also involves back office applications to improve traveller information on current conditions. One of these new applications is in partnership with the National Center for Atmospheric Research (NCAR) to use a USDOT program called Pikalert ® to leverage Road weather information system (RWIS) and atmospheric data, weather forecasts and mobile data from connected vehicles to provide better real-time and forecasted weather conditions for travellers on the corridor. In addition to CV-equipped vehicles, the system will provide information that is expected to be more timely and accurate to all road users through existing traveller information systems such as their website, mobile phone application, and roadside signs.

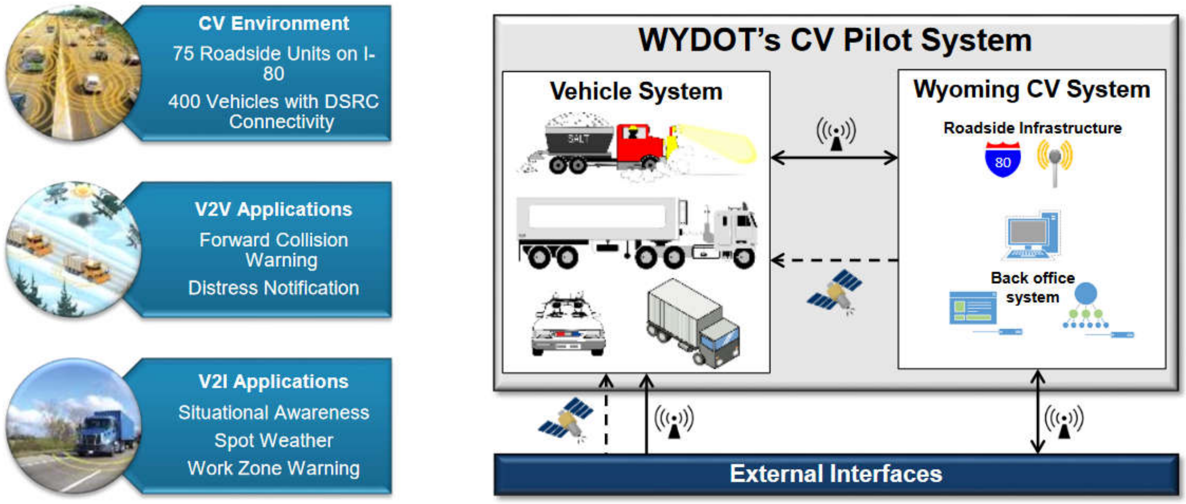
The project was selected for funding in September of 2015. The first twelve months was used on system engineering to fully develop the concept of operations and to draft a system deployment plan. The project is current wrapping up 18-months of Phase 2 with the deployment of roadside and vehicle equipment along with all the data systems to support the project. The winter of 2018-2019 will be the primary review of the system in operations.



Source: USDOT, 2015

Fig. 1. Project Timeline.

The Wyoming CV Pilot has five main connected vehicle applications. Forward Collision Warning issues an alert to drivers if there is a threat of front-end collisions with another connected vehicle in their travel lane and direction. The system does not take control of the vehicle but provides timely alerts to drivers of the impending collision. This application is a concern for snowplows and highway patrol vehicles on the corridor who may be traveling slower than other drivers. I2V Situational Awareness is an application that proves relevant road condition information including weather alerts, speed restrictions, vehicle restrictions (such as no lightweight vehicles due to severe winds), parking, incidents, and road closures. Information is broadcast from roadside units and picked up by passing vehicles but in-vehicle units display the information based on geographic location of the vehicle so that the warnings and alerts are spatially relevant to the driver. Work zone warning is the main non-winter application that provides information to vehicle approaching a work zone such as reduces speeds, lane shifts, and lane closures. Spot impact warning is an application that enables localized road condition information to be broadcast from roadside units to connected vehicles. The last application in the Wyoming CV Pilot is distress notification, which allows connected vehicles to communicate distress status that requires assistance from others. Given the remoteness of the corridor and the long distances between services, this notification is critical and can greatly speed emergency response to incidents.



Source: WYDOT, 2017

Fig. 2. Wyoming CV Pilot Components

A primary purpose of a pilot deployment project is to bridge the barriers between research applications and agency deployable technology. To meet this objective, the project has engaged in extensive project documentation and outreach. Additional information can be found on the project site at https://wydotcvp.wyoroad.info/ and on the USDOT site at https://www.its.dot.gov/pilots/.

This work was supported by the United States Department of Transportation.

References:

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RSI - A GLIMPSE OF THE FUTURE FOR WINTER MAINTENANCE

Esben Almkvist[a], Eric Zachrisson[a], Jörgen Bogren[b], Torbjörn Gustavsson[b], Peter Hagberg[a].

[a]*Klimator AB, Holtermansgatan 1A, 411 29 Göteborg, Sweden;* [b]*Department of Earth Sciences, Göteborg University, Box 460, SE 405 30 Göteborg, Sweden.*

Corresponding author: esben.almkvist@klimator.se

With self-driving cars and trucks around the corner(1), there will be challenges for winter weather forecasts to be accurate, so that the autonomous vehicles can adjust their speed and actions according to the risk of encountering low friction. The maintenance vehicles are also likely to be automated, which requires them to connect to a routing program according to the current and future weather conditions. Even with human drivers it is possible to increase the efficiency of the maintenance operations by creating optimized routes based on road condition forecasts.

In southern Sweden, RSI (Road Status Information) – a system to monitor the winter weather, plan maintenance operations and track performance – has been used by several major Swedish road maintenance organisations during the past three winters (2015-2018). In particular, during the winter 2017-2018, the south-eastern district of Blekinge was selected as a test area for automatically generated and optimized (by B&M Systemutveckling AB) salting and ploughing routes, which could be directly transmitted to the maintenance vehicles (operated by Svevia AB).

A major feature of the RSI system is the inclusion of roughly 500 connected vehicles, using in-car sensors and a software developed by Nira Dynamics AB, to perform accurate friction measurements. The connected cars can also transmit weather related data, such as air temperature and wind shield wiper information, which serves as a proxy for precipitation or wet roads.

Fig. 1 presents the features of the RSI system in the Gothenburg area during a passing snow storm. There are many warnings from the vehicles due to the snow as seen in (**a**), which is also seen in (**e**) which shows low friction. The road coverage, accumulated over an hour, is normally 80-90% during the day as seen in (**b**) and dropping to a minimum of 10-20% during the night. The performed and recommended future maintenance activity is shown in (**c**), while the residual salt amount is shown in (**d**). The default map layer is the road status, here mostly melting snow, which is shown in (**f**).

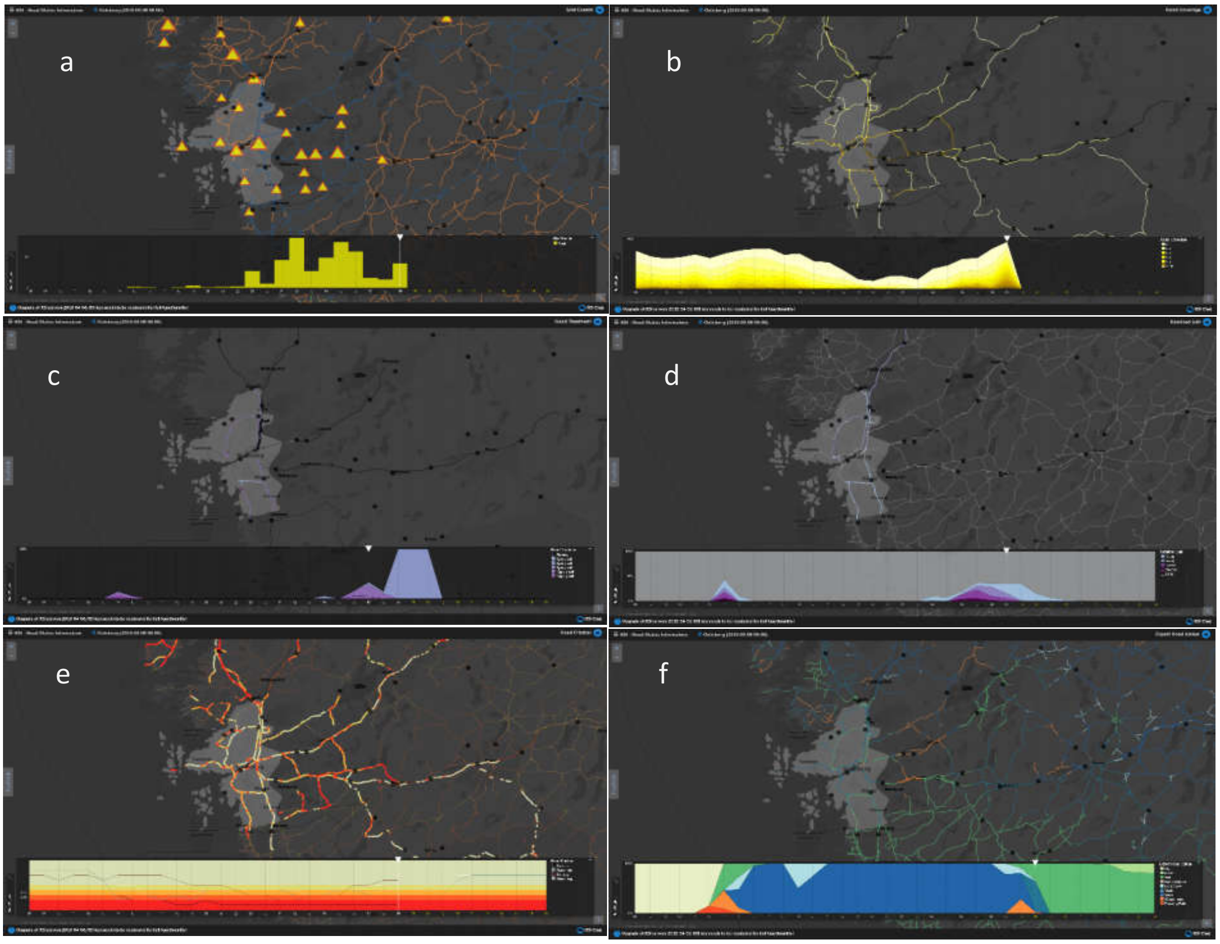

Fig. 1. The RSI application, displaying the view at 2018-03-06 09:00. The lower bar shows past and forecasted conditions in the selected maintenance region. (**a**) shows warnings when the friction drops below 0.25 µ, (**b**) shows the road coverage percentage of the connected vehicles, (**c**) shows the registered salting and ploughing activity at 07:00, (**d**) shows the residual salt amount, (**e**) shows the measured (thick lines) and modelled (thin lines) friction and (**f**) shows the road status two hours ahead at 11:00.

The forecasts in the RSI system are calculated with a typical energy balance model(2,3,4), which includes GIS data modeling(5,6,7) and recent developments of radiation calculation(8,9,10) to achieve accurate route based forecasts. The accuracy (mean absolute error) of the surface temperature 4 hour forecast for an arbitrary segment, validated by cross-validating RWIS-station data, is 0.75-0.78ºC from December to February. For the RWIS-stations more than half of them (413 out of 714) had a mean absolute error less than 0.5ºC degrees for 4 hour forecasts of surface temperature in January.

By including friction data from the vehicles it is possible to adjust several factors that are important for the friction of the roads, e.g. snow/ice amount on the roads, maintenance activities and surface temperature. Furthermore, by combining climate model and vehicle data it is possible to interpolate/extrapolate vehicle measurements to assess the road conditions on nearby roads. This was tested for distances of 10-20 km during the period 2018-03-06 to 2018-03-08 before and after two snow storms passing southern Sweden. This model was able to determine low or high friction with an accuracy of 95%. The low friction cases were correctly estimated 98% of the time, while only giving 5.5 % false warnings. Thereby it is possible to establish, with high certainty, the prevailing road conditions, which provides a basis for precise road condition forecasts and valuable information for autonomous vehicles in winter weather.

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FLEET BASED ROAD WEATHER MONITORING

Arto Niskanen[a], Ari J. Tuononen[a], Jaakko Laine[a]

[a]*RoadCloud Oy, Otakaari 5 I, 02320 Espoo, FINLAND, ari@roadcloud.fi*

Accurate wintertime road weather information is essential for road maintenance operations and for more autonomous driving functions of vehicles. Traditional static road weather stations typically provide basis for road weather monitoring. However, on-board sensors of cars have become more popular and recently wireless data transmission allows that commercial vehicles can be used as probes instead of road maintenance vehicles itself. In other words, cars are turning into mobile weather stations producing massive amount of different type of data about continuously alternating surroundings. It is not mandatory to have all the cars equipped with special instrumentation but carefully selected, highly utilised vehicles which will produce data around the clock from the road network of interest.

The data acquisition system of the fleet vehicles consists of optical road probe, 6 degree-of-freedom Inertial Measurement Unit and CAN-bus access. The position is available with GNSS and data is transmitted via cellular network to cloud where it is processed. This enables for example automatic calibration functions for the optical sensors removing the repeated need for maintenance.

The example results were mined from over 1 million kilometres of measurements in Finland and the illustrations are from the Helsinki region. Figure 1 shows how static road weather station can give dangerously misleading information about the road condition. Based on static weather station the road weather is excellent, all main roads are classified as “dry”. However, reality is the opposite, most of the city streets are icy and approximately half of the main roads are icy. The road condition at the static road weather station location was indeed “dry”, but in most of the cases only locally.

Figure 2 shows how moisture transmitted by the traffic from the lower road network can generate a very local icy road section. The image a) shows mostly moist road section (salted) near crossroad with few local icy spots and dry sections further from the crossroad. In the image b), the road is now more dry in general, but some water has been transferred from smaller road to the main road (wet road after crossroad for both driving directions). The situation in image c) shows how this water is freezing during morning rush hours. It also begins to snow which forms slippery ice layer on the road. As shown in image d), there are already some spots covered with snow. When snowing continues, the snow starts to form a layer on top of the icy road making conditions very challenging.

As a conclusion, even a dense network of static road weather stations cannot provide accurate local road condition information, and overall road weather can be estimated incorrectly. Meanwhile, mobile measurements by using highly utilised commercial vehicles is cost effective method to produce current road condition information and is undoubtedly highly valuable for nowcasting and forecasting road weather models. By utilising a fleet of measurement vehicles and cloud-based analysis, both local and large scale road weather phenomena can be observed in real-time. More extensive results are shown in the conference presentation.

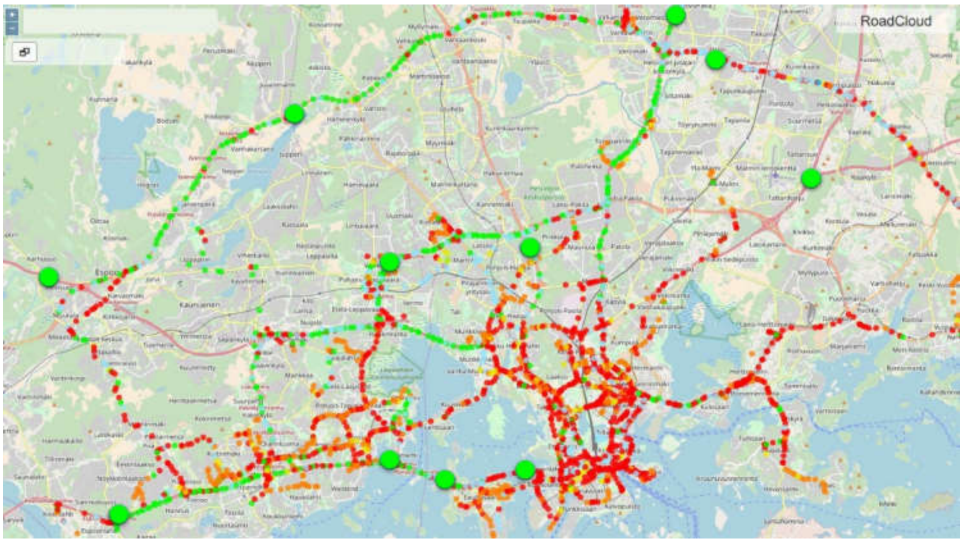

Fig. 1. Road network surface condition from mobile measurements (dry - green, light blue - moist, dark blue – wet, red – ice, snow - orange, yellow - slush) and static weather stations (larger circles) indicating dry conditions.

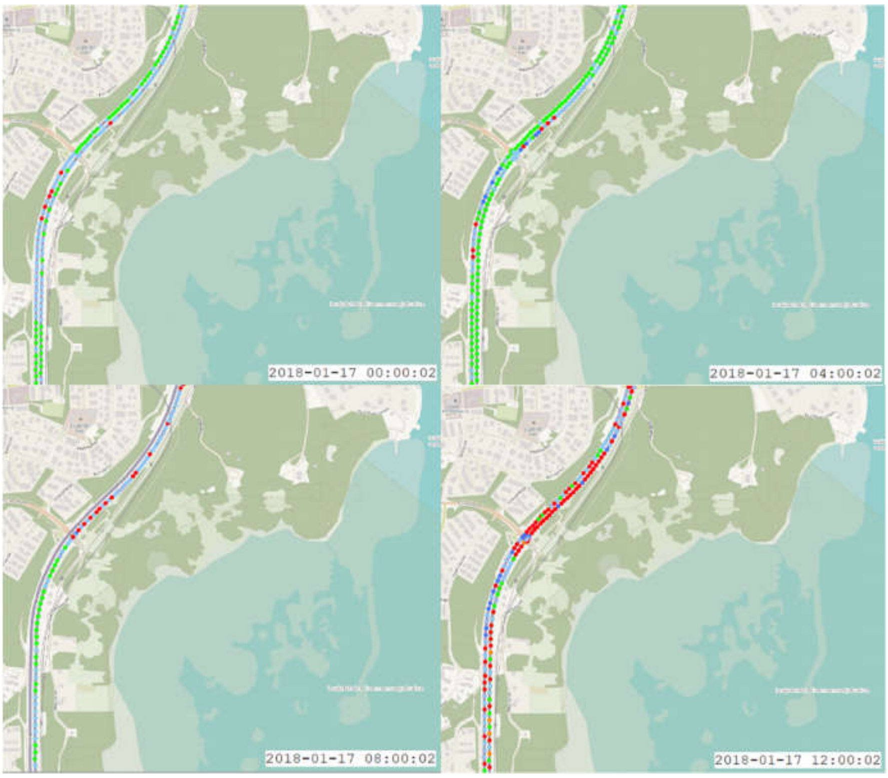

Fig. 2. Road surface condition of Ring Road 1 in Helsinki 17.1.2018 (T = -5 degC). The colours on the map indicates the current road surface condition the same way as in Figure 1.

IMAGE-BASED AUTOMATED WINTER ROAD CONDITION MONITORING – A DEEP LEARNING APPROACH

Guangyuan Pan[1], Liping Fu*[1,3], Ruifan Yu[2] and Tae J. Kwon[4]

[1]*Professor, Department of Civil & Environmental Engineering, University of Waterloo, Waterloo, ON, Canada, N2L 3G1;* lfu@uwaterloo.ca (Presenter)

[2]*David R. Cheriton School of Computer Science, University of Waterloo, Waterloo, ON, N2L 3G1, Canada*

[3]*Intelligent Transportation Systems Research Center, Wuhan University of Technology, Mailbox 125, No. 1040 Heping Road, Wuhan, Hubei 430063*

[4]*Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB., Canada*

Real-time winter road surface condition (RSC) monitoring is of critical importance for both winter road maintenance operators and the travelling public. Accurate and timely RSC information during snow events can help maintenance operators to deliver better maintenance services such as plowing and salting for reduced costs and salt usage and improved level of service. With this information, the traveling public can make more informed decision on whether or not to travel, where to go, and which highways to drive. In this research, we proposed an RSC recognition solution that can automatically generate descriptive RSC information using video images from fixed traffic/weather cameras and in-vehicle devices. The core engine behind the solution is the widely successful machine learning technique called deep neural networks (DNN). In particular, we tested the idea of applying a set of pre-trained convolutional neural networks (CNN) instead of training a CNN from scratch. Four of the most successful CNN models currently available from the industry, namely, VGG16, ResNet50, Inception-V3 and Xception, are evaluated for their potential to address the particular challenges that we face in our application – RSC classification. The pre-trained models were first customized with additional fully-connected layers of neurons for learning the specific features of the RSC images. The extended models are then trained through a fine-tuning process using a set of RSC images with sufficient representations. Lastly, the models were tested using independent images from fixed traffic and weather cameras and vehicle dashboard cameras. A case study using data from a large training/testing data set from the province of Ontario, Canada was used to demonstrate the reliability of the proposed approach.

Session 3 Road Weather Management and Winter Maintenance

ADVANCED ROAD WEATHER AND MAINTENANCE INFORMATION SYSTEM IN THE CZECH REPUBLIC

David KONECNY, Libor SUSIL, Jan SLEZAK

CROSS Zlin, Hasicska 397, Louky, Zlin, Czech Republic
konecny@cross.cz

In this paper, we would like to present the national road weather and maintenance information system used in the Czech Republic. The system is based on METIS platform with other connected services. METIS has been developed and used for supporting winter road maintenance in the Czech Republic from 2003 and nowadays it provides many useful modules for decision making as well as for maintenance management. METIS is a software product of the company CROSS Zlin, but as a national road weather information system, it integrates several data sources and services from other parties contracted by the national road authority.

This is also the main advantage of the system, that it concentrates all weather-related data and information into a single application so that the maintenance dispatcher and even maintenance manager has everything at fingertips.

The METIS platform is flexible and open to implement local specific products or integrate third-party services if it is implemented in any other country. In the past, METIS was implemented in different trials also in Sweden, Serbia, Slovakia, and Georgia.

During the years three key modules have been established to fully support the whole process of winter road maintenance. First, road weather information system. Second, maintenance decision support system. Third, maintenance information system.

Road Weather Information System (RWIS)

METIS is used as a national RWIS in the Czech Republic for more than a decade as a long-term service for the Czech national road administration. METIS is a web-based system for presenting all kinds of weather-related information to support decision making of winter maintenance personnel. Main parts are the status map, weather stations, cameras, radar and satellite pictures, text forecasts, MDSS (see below), vehicle tracking, and MIS (see below).

METIS is technology-independent which means that it can integrate data from different stations from different manufacturers. Basically, a central server is responsible for collecting and validating data from different stations or repositories and storing them in a unified format in a central database. METIS then visualizes the data, no matter if it is Vaisala, CrossMet or any other station.

In the mid-90's we have started to construct and operate road weather stations in the Czech Republic. The first technology originated from Vaisala, later on, other stations were added like domestic CrossMet or Lufft. In 2018 there are approximately 600 road weather stations from six different producers throughout the Czech Republic, all integrated into METIS.

Most recently, we are really proud of integration of an innovative meteorological camera called 2DRoad in the Czech Republic, which is the first road sensor worldwide which scans the road surface in two dimensions in an area up to 6 x 6 metres wide providing road condition and friction. This hi-tech sensor is a highly beneficial solution for road weather monitoring and supporting decision-making of maintenance personnel in an entirely new way.

METIS is available for the end users online using a standard web browser – it means from anywhere and without any special requirements. The system offers also an alerting service using SMS messages or emails in case of detection of critical road or weather conditions.

Maintenance Decision Support System (MDSS)

MDSS stands for a maintenance decision support system, which is a specialized system providing the dispatchers of winter road maintenance with the road surface forecasts and also treatment recommendations.

Road surface forecast is based on a CROSS – Klimator scientific core (SSWM model) and using ALADIN numerical weather prediction model. A scientific core allows unique spatial forecasting of road surface temperature and road condition for each 1km road stretch for next 12 hours which provides the possibility of maintenance planning and even selective maintenance. Spatial modelling is very effective mainly in case that the thermal mapping is available for the particular road stretch.

Treatment recommendations are based on road surface forecast and are focused on defined maintenance areas. The algorithm analyses the need for chemical treatment and ploughing in every maintenance area in next 12 hours, including recommended salt dosage.

The outputs of MDSS forecasts are implemented in METIS as a map-based color-coded animation of covered road stretches. Treatment recommendations are presented as a set of graphs, including meteorological diagram (meteogram).

Maintenance Information System (MIS)

MIS is an important part of the RWIS focusing on maintenance personnel and managers. METIS offers the interface for maintenance reporting (manual or automatic based on GPS data from connected vehicles), the unique system of validation and evaluation of maintenance activities in comparison to recorded weather conditions (see WMi below) and even automated invoicing tools.

In case there are maintenance vehicles tracked by any telemetric unit with GPS location (which is obligatory nowadays for all class I roads in the Czech Republic, approx. 1000 maintenance vehicles), METIS provides an extensive interface for visualization of movement and activity of those vehicles. The vehicle tracking system integrated into METIS uses the PROTANK DYNAMICS engine developed by the Czech company R ALTRA. This engine uses a standardized XML protocol for receiving the data from connected vehicles so the system is independent on the GPS system installed in the vehicle.

Based on the GPS data METIS can provide very effective reporting of maintenance performances like daily consumption of salt and kilometres of spreading and ploughing for MIS. Controlling of maintenance activities is also possible thanks to the central electronic maintenance logbook which is again obligatory for all contractors working on class I roads.

Further, the Winter Maintenance Index (WMi) is used to analyse and control the adequacy of performed maintenance. The intention is to 1) support sustainability – detect unnecessary over-reactions which mean over-pricing of maintenance, and 2) unify the standard of maintenance throughout the country using an innovative way of comparison of regional standards of winter maintenance of different contractors – in other words, we want the same level of safety, mobility, and efficiency across the country.

WMi has been developed and used in the Czech Republic since 2003 and has been nominated for Intertraffic Innovation Award in 2008. The system controls the performance of winter maintenance (kilometres of spreading and ploughing, consumption of salt, brine, and grit) on all highways and class I roads in the Czech Republic and the experience confirms that it really helps to optimize maintenance activities, maintain the quality of maintenance and keep overall costs under control.

Conclusion

In recent years, when the system is supporting the maintenance operations according to new contractual terms between the road administration and the contractors, we have very positive feedback from both sides regarding all RWIS modules. The system indeed proved itself to improve the efficiency of processes of decision making and subsequent reporting and control activities.

According to the analysis done by the Czech Ministry of Transport in 2014, the METIS system with all its modules helps to optimize the costs for winter maintenance by 26 % (cost reduction) with a higher quality of winter maintenance service.

Another Czech experience is that an important aspect of well-performed maintenance is also a special annual training of winter road maintenance dispatchers. The last period of such training was attended by 550 dispatchers from all maintenance areas working on class I roads in the Czech Republic.

All the above-stated services and activities confirm our long-term enthusiasm for road weather and broad experience in the field, which we would like to share with SIRWEC members when we get a chance.

Presentation 3.2

OPTIMIZING SURFACE CONDITION MANAGEMENT

Dr. Arnaud X. Varé

Boschung Mecatronic AG, Aéropôle 108, 1530 Payerne, Switzerland
arnaud.vare@boschung.com

The Boschung Group has a rich history of more than 70 years of activity in the field of mobile and stationary surface condition management. Electronic developments led, in the 70's, to the establishment of Boschung Mecatronic with the installation of the first ice early warning system and fixed automated thawing system.

Indeed, Boschung was the first company to design active pavement sensors to detect the freezing point temperature on the road surface. This is nowadays still the only approach that can detect the freezing temperature, in anticipation and with high precision, in order to take preventive action against the formation of ice layers (see [1]).

Fig. 1. IT-ARCTIS (left) and IT-Sens (right) pavement sensors.

The combination of several pavement probes and atmospheric sensors are offered as ice early warning stations GFS3000 and RCM500-NT. Latest developments in this field are the following: the RCD system, the multi-sensor r-weather and the non-invasive sensor r-condition.

The RCD system (Runway Contaminant Depth) is an arrangement of pavement sensors that allows the air traffic management to determine the type of contaminant and the thickness of the film on runway airport, in order to eliminate friction tests that are traditionally done by vehicles.

The r-weather is a compact atmospheric sensor combining the measuring functionalities for the most important weather parameters in one unique enclosure. It provides precipitation type, precipitation intensity, precipitation quantity, visibility, air temperature, relative humidity, barometric pressure, dew point, wind speed, wind direction. Making use of optical backscattered technologies, the instrument provides very accurate measurements.

The r-weather moreover has a unique design that reduces maintenance needs and guarantees for long-term reliability. By use of pressurized air, the optical parts can be automatically cleaned to make sure that insects, spider webs, dust, water or snowflakes are kept off the optics. For winter environments, a heating system is available, which avoids the creation of ice and moisture on the lenses.

Fig. 2. r-weather (left) and r-condition (right).

The r-condition is a sensor designed to monitor, remotely from the pavement, the road condition, the pavement temperature and detects the appearance of water, snow and ice formation. Thanks to a near infrared laser system, backscattered signals are analysed in real-time. Easily installed on a mast or an existing structure, it does not require any installation in the pavement.

Boschung Mecatronic's comprehensive solution portfolio for surface condition management is completed with Fixed Automated Spray Technology (FAST) systems, the universal vehicle control unit vpad and the management software BORRMA-web.

FAST systems are proven systems for increasing road safety and improving the flow of traffic in critical areas. They are automatically controlled by ice early warning systems. Before ice can form, they spray the road surface with de-icing chemicals in a uniform manner, using spray nozzles at the side of the road, spray discs in the road surface or by means of the innovative Micro-FAST technology. This guarantees the efficient, cost-effective and ecological spreading of the de-icing agent and reduces the risk of ice-related accidents.

The vpad (vehicle pad) is the control unit for the operation and monitoring of spreader, communal engineering systems as well as vehicle equipment. It enables the optimization of spreading interventions with the capability to setup the spreading patterns as well as to prepare the route with a navigation module. All information is recorded and transferred automatically to the data collection software BORRMA-web.

The software BORRMA-web (BOschung Road and Runway MAnagement system) collects different data from ice early warning systems, FAST systems and vehicles with vpad on a central database. The different data are shown in real-time on an interactive map, by use of a web browser or in the smartphone-based RWIS App, the latter being a necessity to ensure the mobility of the winter service operators [2].

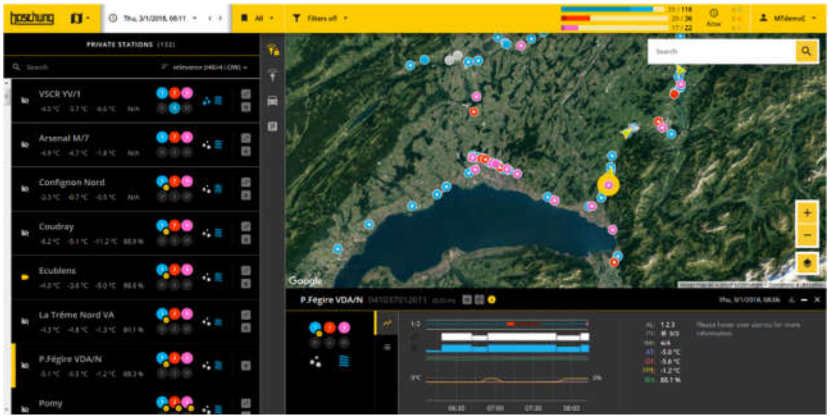

Fig. 3. BORRMA-vision.

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Session 4 RWIS Sensors & Equipment

TEST METHODS FOR SENSORS OF ROAD WEATHER STATIONS

Horst Badelt & Sandra Eimermacher

Federal Highway Research Institute, Germany, Brüderstraße 53 51427 Bergisch Gladbach

badelt@bast.de

ABSTRACT

Today, the winter service is in the conflict of goals between traffic safety, capacity conservation, cost-efficiency and environmental impact. It should not only eliminate smoothness quickly, but avoid in advance. Therefore the winter service has be active before the occurrence of a smoothness. The corresponding activities cannot be carried out by means of control trips, since the development of the relevant parameters for a smoothness development can only be inadequately observed from a moving vehicle. For this reason, the winter service personnel must obtain the necessary data on the date of origin and the further development of a possible smoothness from other sources.

Special road condition- and weather information systems are now available for this information. They are an indispensable prerequisite for an appropriate winter service to ensure high traffic safety while at the same time providing low resource consumption and low environmental impact.

The quality of the decisions depends on the quality of the predictions and their quality again on the basis of the measurement data of the road weather stations. The data quality must usually be guaranteed by the road construction authorities themselves. To assess the quality of road weather stations, various investigations have been carried out at BASt in recent years.

The correct estimation of the mentioned parameters requires necessary measurement accuracy. The European Standard EN 15518-3 8 (DIN 2011) provides corresponding requirements according to the state of the art. Appropriate procedures have been developed for the verification of the requirements. The procedures are described in a German regulation on data recording on roads (TLS, BASt 2012) and in the European pre-standard CEN/TS 15518-4 (DIN 2013).

The results are based on various investigations with sensors, among others on the test field of the BASt at the BAB A4 for road weather stations as well as experiments with sensors in the BASt laboratory.

Since the second half of 2016, various sensors have been available for assessment purposes in the BASt test field. One focus is the comparison of remote (non-contact) sensors and pavement (in build) sensors for parameters of the roadway. The remote sensors are quite new on the market. Furthermore, sensors for precipitation, air temperature, dew point and relative humidity are tested. A second focus is the verification of test results obtained in the laboratory. This is used to examine the practicability of these procedures.

All remote sensors for the road parameters and for the atmospheric parameters are mounted on masts on the edge of the road (Fig. 1). All pavement sensors are installed in the middle of the left lane.

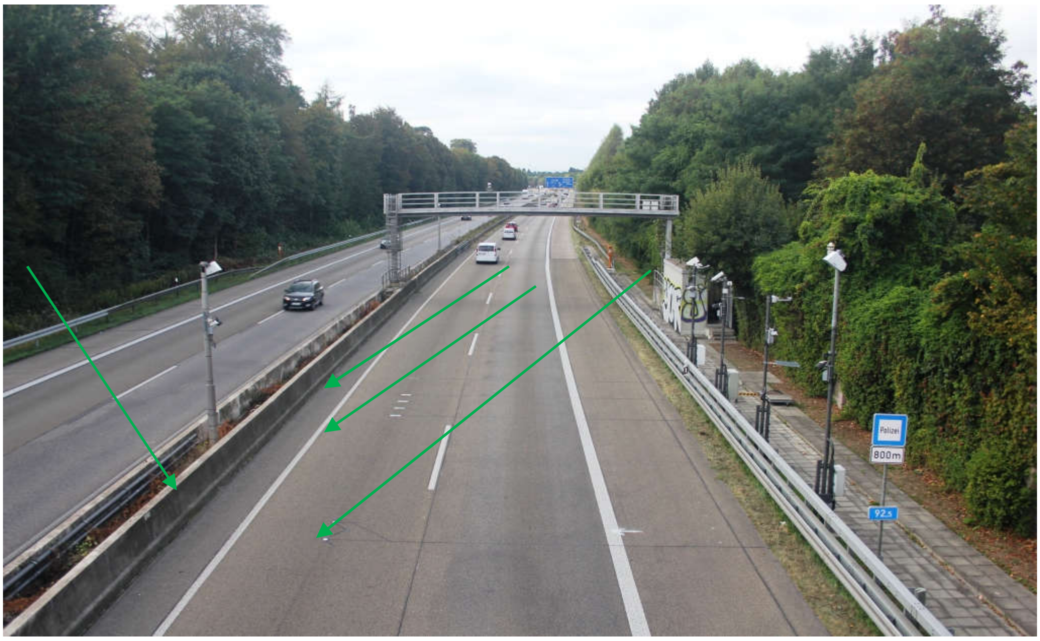

Figure 1: Test field of the BASt for road conditions and weather data (the arrows indicate the center points of the measuring surfaces of the remote sensors)

The data from all sensors on the test field are stored on a server every minute. They can be compiled using customized software. In addition to the sensor data, a photo of the five installed cameras is stored every minute. Data and photos of any time period can be viewed easily in the software. Thus, the situations can be judged qualitatively at a later stage.

With the test field data and associated laboratory tests the most diverse sensors for road weather stations could be evaluated. Different road weather sensors, but not all types of them, can measure the most important parameters (road surface temperature, dew point temperature, moisture on the roadway [yes/no] and precipitation) with a sufficient accuracy. For the decision making process the tolerances which occur must be taken into account in the measurement accuracy for the individual parameters.

Quantitative data on sensors, in particular regarding the water film thickness, freezing temperature or the precipitation intensity, show high differences in comparison tests under the same conditions. This also applies to remote sensors for the road surface temperature. Under practical conditions and partly even under laboratory conditions, it is currently difficult to test the accuracy of the sensors sufficiently. In future, corresponding developments for the sensors them self as well as for their testing under practical conditions are urgently required. Only in this way these sensors can provide further advantages in winter service decisions. They should not be used until proof of a reliable operation.

A precise control of all sensors after a new installation is necessary to ensure the desired accuracy. Continuous control is also necessary during use time. Maintenance can provide automatic plausibility checks, which can indicate possible measurement errors.

With a corresponding control and maintenance management a high reliability and accuracy of the road weather stations can be achieved. A sufficient number of staff should be available. This is the only way to ensure a high quality of the slippery forecasts which are the basis for a purpose-oriented winter service with high profitability for traffic- safety and -capacity at the lowest possible costs.

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INNOVATIVE DETECTION OF ROAD SURFACE CONDITIONS IN TWO DIMENSIONS BY 2DROAD

Jörgen BOGREN, Torbjörn GUSTAVSSON and Peter HAGBERG

MetSense AB, Box 460, SE 405 30 Göteborg, Sweden

jorgen.bogren@metsense.com

In this paper, an introduction to a new and ground-breaking road surface sensor, the first-of-its-kind in sensing the road surface for winter road maintenance in two dimensions will be presented. Traditional road sensors, either embedded or non-intrusive, detect the surface by a single spot or a small area. What separates 2DRoad (**Fig. 1**) from these traditional road sensors is a stationary meteorological camera carefully designed to increase the amount of information from a much wider area by sensing 4096 points simultaneously instead of a single spot or a small area.

Fig. 1. 2DRoad – a sensor and a spotlight.

The problem with weather and road condition is that it varies along the road (with both terrain and geographical factors) and it varies even in one location across the road profile. The first aspect is traditionally solved by locating road weather stations in representative as well as risk locations, e. g. cold spots. But still, there is one weather station per tens of kilometers. The second aspect is also hard to deal with. One can install the sensor (or focus a non-invasive sensor) to a wheel track or between wheel tracks, but the uncertainty about the road condition in different parts of the road remains.

The 2DRoad fights against the second aspect very well by scanning the whole profile of the road or a traffic lane. Based on the measuring distance, the sensor can observe an area up to 6 x 6 meters. The main purpose is to detect different road conditions. The detection principle is near-infrared spectroscopy. The 2DRoad distinguishes 7 statuses: dry, moist, wet, slush, snow, bright ice and dark ice. Another status to be fairly separated is frost and light snow. Two-dimensional overview of the road conditions provides the winter maintenance operator with completely new road surveillance capabilities, including more complex situations with various road conditions in different parts of the road such as icy wheels tracks, snow between wheels tracks or snow in the shoulder.

Based on the detected road condition combined with raw spectral data, 2DRoad calculates the friction which is more and more popular value in recent years when it comes to evaluation of the level of danger for travelers. The friction is basically calculated for each detection point but visualized in a longitudinal direction of passing traffic. One general value of friction is also available per image to represent the overall road condition.

The most important component to perfectly observe the state of the pavement is raw spectral data. The latest development focuses on the improvement of measuring the amount of water, ice, and snow on the road surface.

Further on, the sensor is equipped with a remote temperature sensor. 2DRoad measures the road surface temperature in one spot, located approximately in the center of the scanned area.

Last but not least, the sensor provides a conventional visual image which is the foundation of the user output from the meteorological camera. The classified spectral data is presented as a colored overlay over the gray-scaled visual image (**Fig. 2**) which enables clear graphic perception of a spatial distribution of different road conditions.

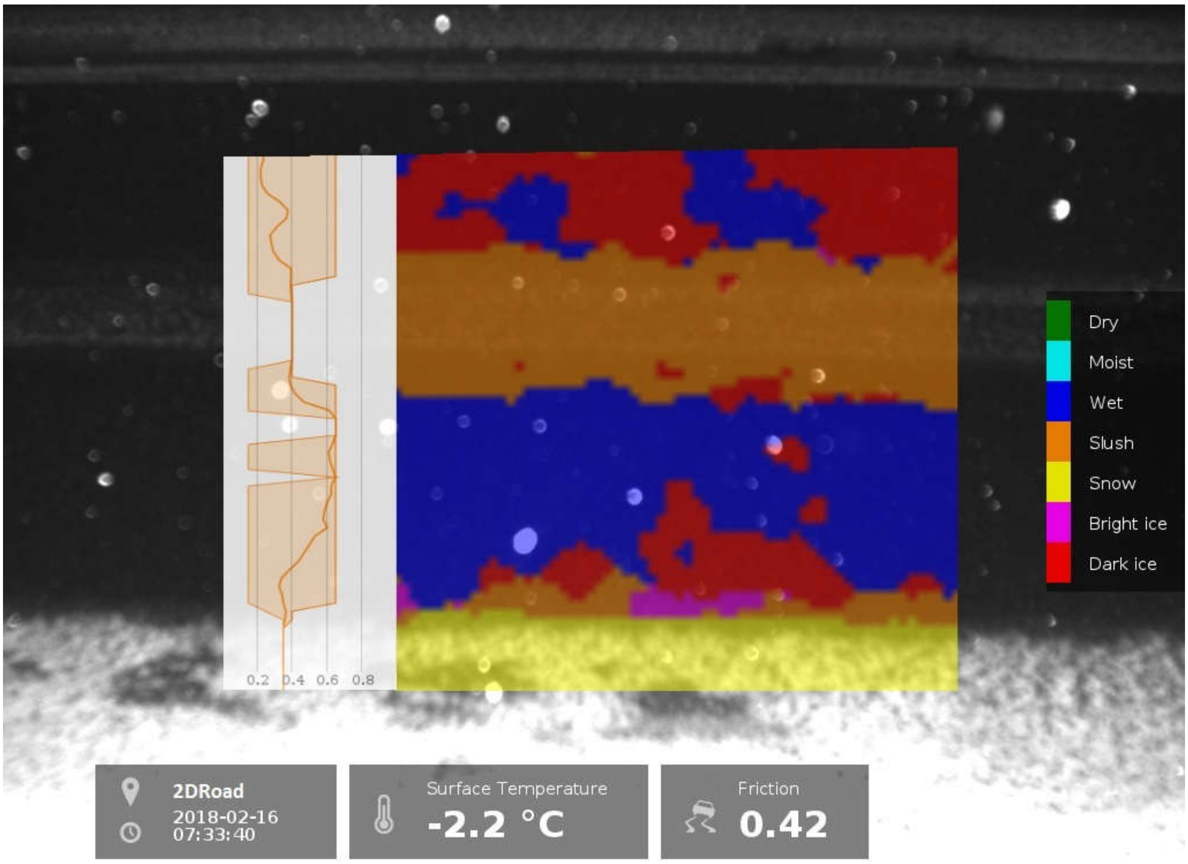

Fig. 2. 2DRoad user output.

Conclusion

The role of the winter maintenance dispatcher is to continuously judge all meteorological data and make decisions regarding maintenance management. The decision-making is not an easy field and the dispatcher has a huge responsibility. The contribution of the new meteorological camera 2DRoad is the increase of the amount and usability of information from a weather station site.

During the last five years of development and testing a ground-breaking product has been completed as a 2-dimensional sensing of the road condition, as the first on the market. Moreover, the experience from multiple testing sites confirms that the same classification algorithms are universally applicable on different sites; only a minor setup procedure during dry conditions is required to determine the local properties of the surface (1).

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DIGITALIZATION AND ROAD WEATHER FORECASTS TO HELP DECISION MAKING FOR ROAD MAINTENANCE

Janne Miettinen[a]

[a]*Customer Services, Finnish Meteorological Institute, P.O.BOX 503*
janne.miettinen@fmi.fi

Introduction

Road maintenance and its timing is critical on countries like Finland where wintery roads are present for notable part of the year. With well scheduled and controlled maintenance operations companies can cut down their costs on operations and also gain more safety on roads.

Finnish Meteorological Institute's (FMI), Road Weather Model (RWM) is been used to forecast the upcoming road conditions. One of the biggest road maintenance companies in Finland Destia has directed their maintenance operations side by side with FMI's on duty meteorologists for over 15 winters. During the ongoing 5G-SAFE project, funded by Finnish Funding Agency for Technology and Innovation (Business Finland), FMI and Destia has been improved the snowplough scheduling forecast system.

Destia among other Finnish maintenance companies is collecting their maintenance operations information in digital format. This information has been imported to FMI's RWM to make the road maintenance operation scheduling even more precise.

FMI Road Weather Model

At Finnish Meteorological Institute (FMI), Road Weather Modelling (RWM) development has been going on since the 1970's to improve the knowledge of the forthcoming road surface conditions. The present-day RWM is a one-dimensional energy balance model that can predict surface temperature and storage amounts for water, snow, ice and frost on roads. The model produces gridded (for map visualization with 10 km spatial resolution (Figure 1)) and point forecasts for any desired location with a one hour time resolution. The model can be simulated wherever Numerical Weather Prediction (NWP) data is available. The model has been operationally running since 2000 (1).

Already since the early years the RWM has been used to predict the road surface conditions for road maintenance scheduling to take action beforehand and also to bring more cost-efficiency to the operations. The output products have been in everyday use for winter time for road maintenance scheduling for over 15 years in Finland. As one of the spin-offs in R&D for RWM has been the snowplough operation scheduling forecast. It tells the user predicted time for next snow plough based on NWP model data. Lot of presumptions have been made in RWM calculation since lot of important information has been lacking e.g. time of the last snowplough.

During the latest years' one of the major development for RWM is the use of observed road surface temperature, so called coupling method (2). It is shown that using road surface temperature instead of using observed 2 m temperatures as input data for starting the model, it will make the model perform even better for the first hours. Model can still be simulated without any road weather station observations. The model has been already in the past designed that way that if real time snowplough information would be available it could be imported in to the model.

Finnish Transport Agency (FTA) nowadays demand the maintenance companies to provide their maintenance information digitally and in real-time. With use of this information we have more precise knowledge of the snow amounts that are on the road which will make scheduling forecast more precise.

Winter Road Maintenance

In Finland the FTA tenders out the road maintenance work. It also determines the limit values of snow allowed on different roads and the operation time when the snow has to be removed from the roads. The snow amount allowed on the roads depends heavily on the traffic rate.

In Finland the total cost of national winter road maintenance is around 100 M€. This update for snow plough scheduling will hopefully bring more cost efficiency to the maintenance and improve safety on winter roads.

Snowplough scheduling product development made in 5G-SAFE project

Firstly it was made possible to read the real time road maintenance operations into the RWM. Assumption was made that when snow was ploughed from a road weather station location the snow storage on that location would be decreased close to 0. To be more precise of the snow amounts on the road after last snowplough also more accurate radar observation data was implemented into the model. While knowing the maximum snow thicknesses and operation times allowed for different maintenance levels it was possible to determine the scheduling times for snowploughing.

Future development

As the project goes on we plan on implementing other observation data eg. mobile observations into the RWM as well. We have half a dozen trucks implemented with telemetry devices, friction and road temperature measuring devices made by Teconer ltd. and also on board dash cameras. The trucks are running in harsh conditions in wintertime, almost non-stop between Kevitsa Mine and Kemi harbour in Finnish Lapland. With all this information we hope to get more precise situation awareness of the road state during the winter season and this will keep on improving our RWM based services.

This work was granted by Business Finland

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WINTER SEASON 2017 / 2018 SELECTED WEATHER FACTS ON THE EXAMPLE OF A FIXED AUTOMATED SPRAYING SYSTEM IN PILISVÖRÖSVÁR (HUNGARY)

Jan Szczerbiński

Boschung Mecatronic AG, Aéropôle 108, CH-1530 Payerne, Switzerland
jan.szczerbinski@boschung.com

The climate of the Hungary can be described as typical European continental influenced climate with warm, dry summers and fairly cold winters. January is the coldest month with daytime temperatures usually around zero, but in some cases winter months can be very cold with temperatures far below zero and strong, cold north-easterly winds. Heavy snowfall or even snowstorms are also possible on some days there; the yearly average number of days with snow is less than 40 in the low-land regions of Hungary [1].
Minus temperatures, snowfalls and slipperiness of roadway are always a problem for citizens and drivers. There are specific places where, this not often winner conditions, can cause long distance traffic congestions. On of such place is tunnel under rail line in Pilisvörösvár, city placed c.a. 9 km from borders of Budapest. This ex main road to Vienna is important communication duct, also for heavy traffic. Mostly road was built as a flat without very steep inclines. But because of need of reconstruction of rail line and need of elimination railroad crossing with a barrier, small tunnel under railroad was constructed. In down part of the tunnel intersection with road lights was planned. This technical solution on one hand solved traffic problems but on other hand caused new environmental interaction between road and weather. Winter conditions on slopes became important problem for braking drivers approaching tunnel and for heavy vehicles trying to move from interchange with traffic lights.
In 2017 Boschung Mecatronic AG Fixed Automated Spray System was installed in this tunnel. Micro FAST solution, based on high pressure fine-spray installation of longitudinal profiles (pressure tubes), has built-in nozzles every 5 meters. The nozzles are fixed by means of a sealing compound in the upper layer of technical sidewalks on both sides of the road. A working pressure of 16 bars and spray duration of 40 seconds ensure the proper coverage of the surface with the equivalent of 2 grams of salt per square meter. The nozzles are equipped with two micro fine-spray holes, which dispense the thawing agent onto the road surface almost invisibly, thanks to the high degree of pulverisation. The thawing agent is then equally distributed on the carriageway surface by the traffic [2].
Pump station was placed in the chamber next to the tunnel, as well as 8 000 l calcium chloride brine tanks, 3 000 l water tanks and weather station. Installation in Pilisvörösvár was planned as c.a. 200 m long, with total 100 Micro-fast nozzles placed on both sides of the road.
Weather station has its most important role for such a system and it was equipped with two active pavement sensors (type BOSO and type ARCTIS) and with thermo-hygrometer and precipitation sensor. Role of this station is to measure air parameters, presence of precipitation and its type and road condition. Most important for successful work of the system, is active measurement of the freezing point temperature (by mean of cooling and heating) as well as constant monitoring of moisture and temperature of the roadway. Thanks to measured

data, automatic ice early warning alarms are computed in weather station to trigger spraying process. Management software stores measured data, alarms as well information about spraying in the past. Thanks to this after winter analyses of all data is available.

Description	value	unit
The air temperature has reached or dropped below 0°C	95	times
The pavement temperature has reached or dropped below 0°C	91	times
The freezing point temperature reached or dropped below pavement temperature when road was wet	45	times
Days when weather station reported weather alarms (different types)	90	days
Days with presence of precipitation (different types and durations)	55	days
Days with presence of snow precipitation	29	days
Key days of most often alarming and spraying	38	days
Brine used in total (calculated from % of tanks)	9120	liters
Spray programs triggered in total	298	times
Spray programs triggered because of weather conditions	251	times
Spray programs triggered for self-cleaning (maintenance spraying)	47	times
The average amount of liquid used for one spray (calculated from % of tanks and number of spray programs)	30,60	liters
Average time of spraying for one nozzle	40	seconds
Number of nozzles	100	pieces
Average quantity of de-icer sprayed by one nozzle	306	ml

Fig. 1. Selected weather and spraying system facts

Author would like to share with readers some facts and statistics from first operational winter of the system (**Fig. 1**). Crucial for road conditions are so called “zero crossings”, when pavement or air temperature goes below 0°C. On other hand from point of view of road maintenance real problems starts when temperature of road goes below freezing point temperature of the liquid on the surface of the road. For statistics there was chosen period from first day when air or pavement temperature reached 0°C (31.10.2017) till last such phenomenon this winter (28.03.2018). Thus all below presented statistics are given for period of 148 days.

Official commissioning of the system took place on 29.11.2018, when the first truly winter conditions appeared in Pilisvörösvár, including air temperatures below 0°C and first snow. Of course winter conditions (minus temperatures) were present also before that date but they were not dangerous for road users and they didn’t triggered spraying.

First time freezing point temperature was measured by mean of active way on 30.10.2017 and last time on 18.03.2018. What needs to be underlined, freezing point temperature from Arctis active sensor is measured according to standard EN 15518-3. According to this sensor starts measuring cycles when tow conditions are met: pavement must be moist with film thickness 0,05-0,5 mm and must be started from ≤ 4 °C of pavement surface temperature. Thanks to this, measurement is independent of the de-icing agent being used and accuracy of 0,5°C is kept [3].

This statistics can be analysed in various ways, but it must be underlined that system installed in Pilisvörösvár is truly answering to specific winter road conditions of this particular place and supports road flow and safety.

Dedicated to all those people who were involved in successful completion of this project, especially to Bapst Jonathan, Kruger Thomas, Lourenço Filipe, Mayerhofer Erich, Pammer Michael, Pásztor Zoltán, Szczerbinski András, Szczerbiński Jaś, Szczerbiński Marcin and many others.

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Presentation 4.5

AMOUNT OF SALT VERSUS FREEZING POINT

Kimmo Kynnös, Daniel Johns

Vaisala Oyj

Freezing temperature is not as useful as it appears to be at first glance for road maintenance decision making. One major challenge is that concentration of the de-icing chemical may vary very rapidly, as only a very small absolute change in the water amount of water, easily occurring by evaporation or precipitation in minutes, causes a drastic change in the freezing temperature, which is directly and strongly dependent on the concentration.

Due to this at given time viewing only freezing point, concentration or salt % maintenance people are not able to know how the road will tolerate expected change of water.

To overcome this problem the measurement of actual total amount of chemical (g/m^3) should be used instead. The total amount of the de-icing chemical present on the road per unit area do not change when absolute change of water does. Amount of the chemical clearly indicates how much residual salt is on the road and how much road surface will tolerate expected change of water.

Maintenance people also spread the salt in g/m^3 and residual salt should be measured in the same understandable unit.

Even the bigger challenge using freezing point is the measurement accuracy in real road environment. Particularly active type of freezing temperature sensor can measure freezing temperatures with high accuracy in lab conditions where measurements are not disrupted by traffic or any weather related phenomena's. In practice, it can be demonstrated that freezing point temperatures may change quite randomly even there is no obvious reason for it due to chemical treatment or concentration related changes. Principle of freezing the actual small sample of the solution is highly vulnerable for large measurement errors in true road environment.

It is almost impossible to define if reading at given time is correct or if measurement freezing cycle is disturbed by traffic or other sources of measurement error.

Total amount of chemical measurement is less sensitive for such errors as are based on continues measurement instead of freezing the sample volumes of the solution.

Session 5 Systems / Decision Support Systems

MDSS IN SLOVENIA – EXPERIENCES AFTER 2 YEARS OF OPERATION

Samo Čarman[a], Alenka Šajn Slak [a], Rok Kršmanc [a], Denis Kotnik [a], Rok Soczka Mandac [a], J. Trnkoczy [a] and Marko Korošec [b]

[a]CGS Labs d.o.o., Brnčičeva 13, SI-1000, Ljubljana, Slovenia

[b] DARS d.d., Ulica XIV. divizije 4, SI-3000, Celje, Slovenia

samo.carman@cgs-labs.com

INTRODUCTION

Road weather information system RWIS have been used to support road maintenance services in Slovenia for many years. The need for this assistance is particularly pronounced in winter time since Slovenia is located in a meteorologically diverse territory between the western Alps, northern Adriatic and Pannonian Plain. There are nearly 120 road weather stations (RWSs) altogether on Slovenian roads, situated mostly on motorways and regional roads.

Beside the RWSs data, short-term weather forecasts of high temporal and spatial resolution from INCA/ALADIN meteorological systems of National weather service ARSO are used. The INCA (Integrated Nowcasting through Comprehensive Analysis) system has been developed primarily for providing improved numerical forecast products in the nowcasting with high time resolution (30 min and 1 hour) and high spatial resolution of 1 km. The INCA analysis and nowcasting data include temperature, humidity, wind, and the amounts and types of precipitation. A widely used physical model for forecasting the road surface temperature (RST) and road condition METRo was incorporated into the road weather information system (RWIS).

Experiences of using METRo model showed that the root mean square (RMS) error for the RST predictions were generally satisfactory but could be too high at some sites, especially for the predictions around noon. Generally, to solve this problem, physical model was improved with further parameterisations of the relevant physical phenomena (anthropogenic influence, traffic influence, shadowing from the near objects, road physical characteristics) and combined with statistical techniques (i.e. regression, neural network) to improve the quality of input or output variables. Results of this development (Eurostars project METRoSTAT) were presented at SIRWEC conference in Andorra in 2014.

In winter 2015/2016 the RWIS was upgraded with additional functionalities and become a Maintenance Decision Support System (MDSS) which supports managers in making appropriate decisions. Route-based forecasts were implemented along the entire Slovenian road domain. Such road forecasts can support winter maintenance decisions with automatically treatments selection (MDSS provides time, type, amount and place of each treatment). The consultant for this module was company Klimator AB from Sweden. System is developed as a modern cloud-ready web application. The poster was presented at SIRWEC conference in Colorado in 2016.

EXPERIENCES AFTER 2 YEARS OF OPERATION

MDSS was fully operational on Slovenian motorways in last two winters. There is a picture about user's interface below to show the basic functionalities of MDSS.

Our experiences showed that route-based weather forecasts optimization is a is a process that never ends. We developed algorithms and methods to extrapolate measurements from RWSs and forecasts with emphasis on continuous validation and verification of the obtained data. Verifications of route-based forecasts were made with occasional additional measurements at predefined locations.

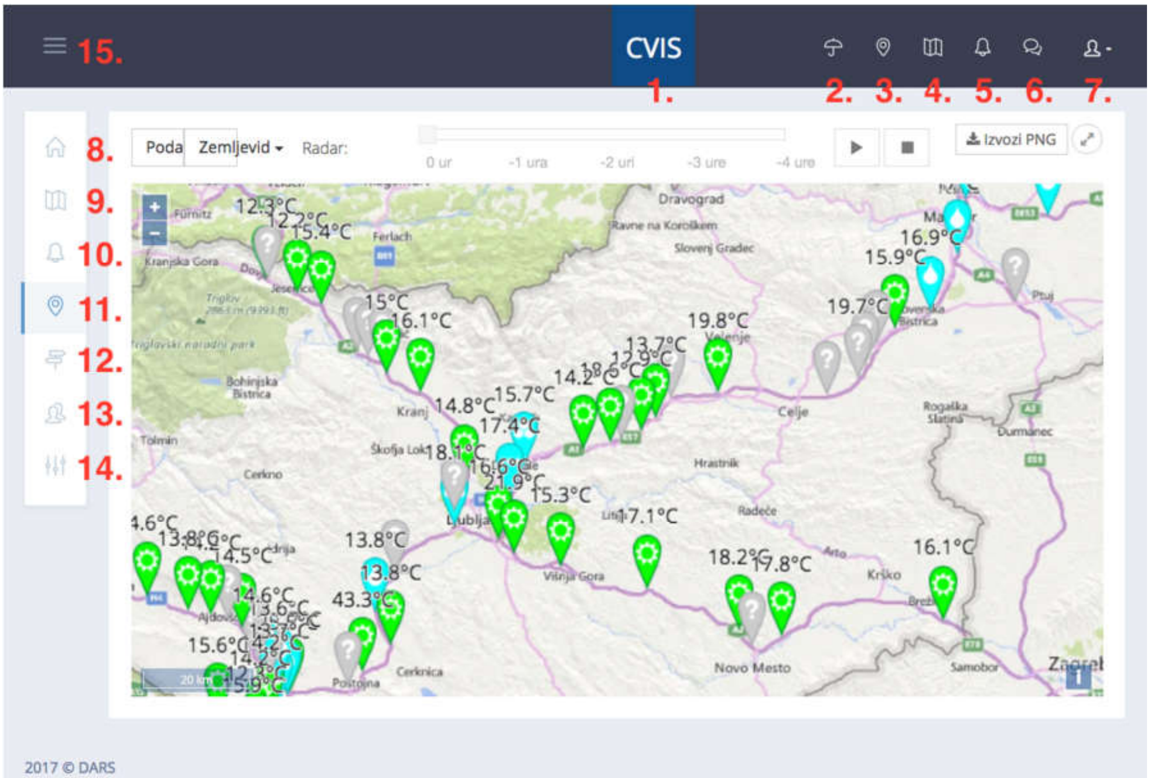

Fig. 1. MDSS user's interface: 1 connection to RWIS, 2 weather forecast in words and pictures, 3 map with RWSs, reports about measurements, 4 road forecast with actions, 5 notices of measures, 6 message notices, 7 Edit your profile, browse conversations, and sign out, 8 The MDSS entry page, 9 road forecast with actions, 10 Overview of current and archive actions and the possibility of creating a new one, 11 map with RWSs, reports

about measurements, 12 Overview of motorway bases, 13 User administration, 14 Control panel administration of applications and files, 15 Extension of the menu / navigation bar.

The implementation of the MDSS into the winter service and the education of users was also a very important task of the implementation process. Training was carried out across all motorway maintenance bases (9 locations). Winter service staff is a demanding user who expect precise and reliable weather information on the road. In order to gain more trust in MDSS from the service staff, we had needed to clearly distinguish real time RWS measurements from real time (route-based) extrapolations/predictions. Based on the feedback, proper use of words in warnings, actions, decisions etc. should be used (for example: phrase "Possibility of ice on the road" instead of "Ice on the road"). Continuous cooperation with road winter maintenance staff is the key to an effective system that is tailored to the needs of the user.

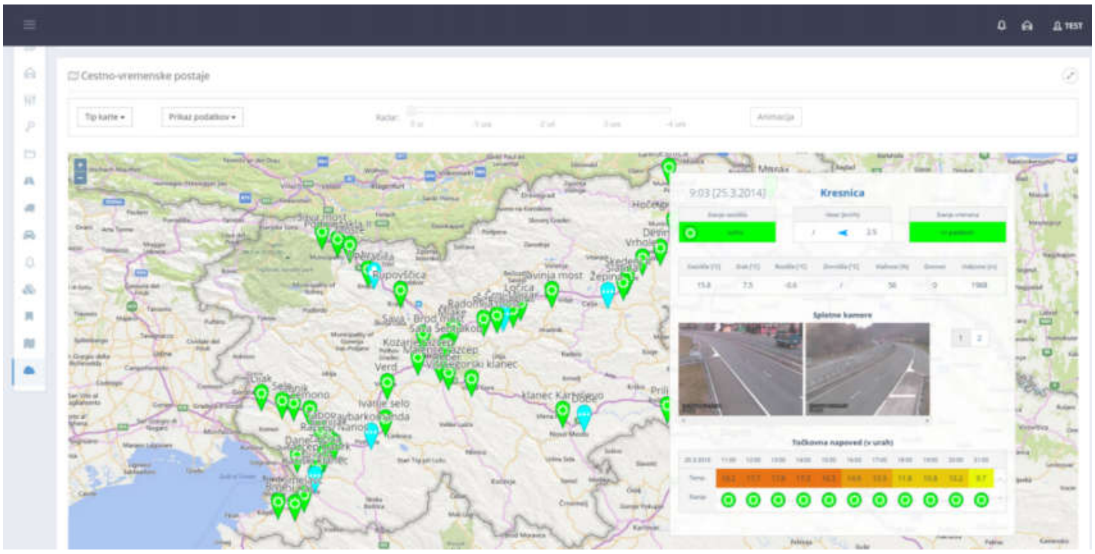

Fig. 2. Recommendation of action in MDSS.

PLANS FOR THE FUTURE

Mobile measurements of 15 new mobile sensors on winter service vehicles will be implemented into RWIS/MDSS before the next winter season. They will enable route-based weather forecast verification on one hand and dynamic route-based weather forecasts, especially on critical sections, on the other hand. Route-based weather forecast will be further optimized with additional thermal maps and machine learning.

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MDSS SNOW ACCUMULATION PERCENTAGE BASED ON ROAD SEGMENT MAINTENANCE REQUIREMENTS

Samu Karanko, Rami Honkanen
Foreca Ltd, Keilaranta 1, 02150 Espoo, Finland
samu.karanko@foreca.com

This presentation describes a decision support tool implemented in Finland for maintenance supervisors who are in charge of a large heterogeneous road network.

Snow accumulation displays have been a key element of winter maintenance decision support systems from the beginning (1). Typical presentation is a graph for a point location and/or a map that shows the spatial distribution of snow accumulation, as measured in centimetres. These suffice if the end-user is either focusing on a single ploughing route or if all the roads in the area have similar maintenance requirements. The Finnish Transport Agency contracts out winter maintenance and employs supervisors that randomly check the performance of the contractors. During a snowfall event the supervisors face a problem: where to focus surveillance during the event, in order to optimally spend their time. The problem is challenging since one supervisor is responsible for a geographically large area in which there are roads that belong to different winter maintenance road classes. The maintenance requirements per road class include the maximum snow depth allowed during the snowfall and the time after event start at which maintenance actions must begin. For example, a class I highway has a maximum snow depth of 4 cm and an action time of 3 hours while the numbers for a class III road are 10 cm and 6 hours, respectively. The variety in maintenance requirements combined with uneven distribution of snowfall makes it difficult to see where exactly the action thresholds are being triggered at any given time. The solution was to create an hourly updated service where past and future snowfall are consistently presented, not in centimetres, but as a percentage of the maximum allowed snow depth for each road segment.

To create the service, data from multiple sources had to be combined. The Finnish state-owned highway network comprises 78,000 kilometres of roads. The entire highway network was split into one kilometre segments and each segment was assigned to a winter maintenance class. If possible, each segment was additionally assigned to a ploughing route to enable per-route alerts, but this data was not available from all the contractors. The service time-line extends 12 hours into the past and 24 hours into the future. The past snowfall is based on radar and the future snowfall is obtained from an in-house manually edited snow accumulation product. The on-duty meteorologists typically use radar extrapolation for the first hours of the product. During the first 2016-2017 winter season, the service derived past snowfall from radar using a fixed reflectivity-based formula. Even though the formula has been experimentally calibrated using observed snow accumulation in weak wind situations, it was found to be too inaccurate to justify the high level of detail in the service. During the second winter season 2017-2018, a real-time calibration based on hourly precipitation measurements from the Finnish SYNOP stations was implemented. Another refinement based on the first season's experiences was related to radar clutter filtering. Clutter filtering invariably removes some real precipitation and there is a trade-off between the amount of remaining false echoes and the amount of falsely removed precipitation. It was realised that for a service which combines automatic alerts with long accumulation periods, aggressive filtering is needed. To support the service, a custom radar-based snow accumulation product was therefore created based on aggressive filtering and real-time calibration against SYNOP stations.

The user interface of the service allows navigation in time, zooming and panning, and clicking on arbitrary road segments for detailed information. The key feature of the service is a map (Fig. 1.) where the road segment colouring is based on the percentage of maximum snow depth reached. The colouring is based on a traffic light scheme: roads are green if no action is required, then turn yellow when action should have started at 50% of maximum snow depth, and then turn red when the maximum snow depth is reached. This map makes it easy for the supervisors to plan their daily route: they simply need to check where the roads turn red at any given time. To relieve the supervisors of the need to continually monitor the service, email alerts can be subscribed to, based on arbitrarily selected areas.

A separately funded independent study about the snow accumulation accuracy and about the usefulness of the service was performed during the first winter. (2) The study found the service useful for the monitoring of snow accumulation when the target area was large, but found some issues with the actual accumulations. Additionally, test users reported issues that were tracked down to false radar echoes and to the conversion of radar reflectivity to snow depth. The earlier-mentioned improvements implemented during the second winter addressed most of the concerns, and the service has been found useful.

Fig. 1. The snow accumulation percentage map display

Possible future work includes ingestion of live maintenance action data from the contractors' fleets. Such data is already available to some extent, but for this service such data should be available for the entire country. Real-time de-icing and ploughing information would make it meaningful to run a full road maintenance model with ploughing-based snow removal and residual salt modelling. Without comprehensive maintenance data it was deemed sufficient to build the service using only snowfall data. Another possible future improvement is advection-based adjustment of radar measurements (3).

This work was supported by the Finnish Transport Agency. The idea of a service where snow accumulation is presented as a percentage of the maximum allowed snow depth was presented by Pekka Rajala, ELY Centre.

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THERMAL MAPPING IN FLAT LOWLANDS AND UNDULATING UPLANDS – A COMPARISON OF RESULTS

Lauryna Šidlauskaitė[a], Jörgen Bogren[b]

[a]*Institute of Geosciences, Vilnius university, Universiteto g. 3, LT-01513 Vilnius, Lithuania,* [b]*Department of Earth Sciences, Gothenburg university, Box 100, SE-40530 Gothenburg, Sweden*
lauryna.sidlauskaite@gf.vu.lt

Regions with ice and snow are dependent on microclimate conditions of roads, since cleaning, de-icing and treating the network is financially expensive and time consuming. Thermal mapping technique was firstly introduced to road climatology as an idea in middle 1970s, but was best described and applied to research after 15–20 years (Bogren, Gustavsson 1989; Thornes 1991; Bogren, Gustavsson 1991). Since then the technique was improved and re-evaluated (Gustavsson 1999), in order to minimize the possibility of errors and increase the quality of data received using this method.

The idea for this paper arose from thermal mapping applications to Lithuanian roads, which produced inconclusive results in some research areas and raised the question whether this technique is applicable to flatlands as effectively as to uplands. While distinctive temperature anomalies can still be observed in some places (e. g. negative temperature anomalies on bridges or overpasses), otherwise, it seemed that there were no significant patterns connected to altitude as expected beforehand. In order to determine the cause for this, a comparison between different areas needed to be done, therefore a second country with reliable thermal mapping database was chosen – Czechia. In conclusion, the aim of this paper is to discuss whether thermal mapping can be as effective in lowlands as in mountainous or hilly regions, taking Czechia and Lithuania as two examples on the opposite sides.

There were several datasets used in this study. Firstly, there was thermal mapping data from Czechia collected in 2015. All chosen sections do not contain major interchanges, are about 45–50 km in length and relatively straight. The choosing of road stretches was mostly influenced by them being in a mountainous region, and the elevation changing rapidly and constantly along the route.

Secondly, there was thermal mapping data from Lithuania, which was collected during January and February of 2015. Because of differences in type of roads that were measured, the whole dataset was divided into 4 major sections with some interchanges and other similar parts of the route being omitted. These sections varied in length – from around 78 to 118 km, but were relatively straight. The altitude was not measured, therefore the required data was derived from Lithuanian georeferenced database (acronym – GDR10LT). Thus, this data does not reflect the absolute altitude of a road, but rather represents the average absolute altitude for the area around it.

For an area as mountainous as Czechia, it is expected to observe cold air pooling in some surface depressions during extreme weather conditions. The chosen routes reflected this to some degree: overall average difference between temperatures in depressions and peaks is –0.78 °C for air temperature and –0.25

°C for road surface temperature. The difference between road and air temperature is greater by 0.52 °C on average in depressions. Nevertheless, not every depression can form cold air pools since roads might not go through the lowest part of the valley. Moreover, the higher it gets, the rarer it is for road to be colder than air. This tendency is similar in both stretches of road.

Air temperature relation to altitude is uneven across the roads. In those stretches where there's a relatively steep slope, moving correlation (with a radius of 0.5 km around the segment point) drops to 0 and in some places, reverts to negative. One of the best examples of this is a stretch of road, where the lowest points in altitude are Vltava and Brzina rivers. In this example, in areas where relative altitude of the road (compared to an average with radius of 0.5 km around the road) changes considerably, moving correlation drops from strong positive to weak and even to strong negative. Conversely, in areas where relative altitude change falls within overall noise range, relation is strong and positive. This suggests, that the strength of air temperature relation to altitude is essentially dependent on whether the area is relatively flat or has an incline. While air temperature could be partially predicted by relative altitude in former areas, the latter would have lower rate of predictability.

There are differences between different routes (CZ1 and CZ2) as well. CZ1 has less variation in absolute height, with highest peaks being at the ends of the route and several larger valleys in between, but has the highest peaks and lowest depressions in both road stretches (absolute height varies between 277–547 m). Whereas CZ2 elevation varies considerably, constantly switching between peaks and depressions, but has lower absolute height (absolute height varies between 413–526 m). Using average measurement data during extreme conditions, only 6.0 % of CZ1 and 4.7 % of CZ2 had favourable conditions for cold air pooling effect to take place (where road was colder than air and moving correlation between road temperature and altitude was +0.8 or above). Moreover, the variation (amplitude) of this index on different measurements in extreme conditions is greater in CZ2 than in CZ1: 6.7 % and 1.8 % respectively. Therefore, according to this data it is expected that a relatively flat area with sudden depressions to have more predictability value than an area with more undulating and changing landscape. For example, for altitude to be a decent predictor it is necessary to have an area with smaller depressions and less frequent overall landscape shifts, rather than a constantly interchanging hills and valleys.

Both of these results suggest that roads which lie in flatlands should have a higher predictability value, that's related to the altitude. Nevertheless, data from Lithuanian thermal mapping shows quite the opposite. The best example could be LT1 road section, which was measured 4 times during extreme conditions. Correlation between temperature difference (road surface temperature minus air temperature) and altitude in that one stretch of road during different measurement events varied from –0.76 to +0.55. This suggests that cold air pooling might not take place in relation to the area being more influenced by other variables, rather than changes in altitude. Nevertheless, the before mentioned parameter for favourable conditions for cold air pooling effect to take place is similar to Czechian roads. On average, it varied from 2.3 % to 8.0 % between different road stretches in extreme conditions. Moreover, the index was lower in areas where the landscape was flatter.

In conclusion, it appears that in flat landscapes altitude has less predictability value for road surface temperature than in undulating uplands. The former areas are being more influenced by advancing air masses and general weather changes rather than local landscape. Nevertheless, there are still some cases in Lithuanian roads, for example, where road temperature consistently dropped lower than air during most of the measurement events, therefore thermal mapping is still a valid method for determining such cold spots. However, usage of these maps for road temperature forecasting is becoming questionable and somewhat inefficient, for them being quite expensive to make and having a significantly low predictability value.

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Session 6 Advances In Road Weather Forecasting

OPERATIONAL EXPERIENCE WITH ICEWARN MODEL (METRO-CZ) IN COMPARISON WITH OTHER TOOLS

Jan Sulan[1], Martin Tomáš[2]

[1]*Regional Forecasting Office, Czech Hydrometeorological Institute, Mozartova 41, 323 00 Plzeň, Czech Republic*
[2]*Central Forecasting Office, Czech Hydrometeorological Institute, Na Šabatce 17, 143 06 Praha 4 – Komořany, Czech Republic*
sulan@chmi.cz

Successful forecast of road surface temperature (RST) and conditions is crucial for winter maintenance decision support as well as for warning system of national meteorological services. Czech Hydrometeorological Institute (CHMI) has been using outputs from the **VAISALA FORECASTER** for almost 20 years (22 sites mostly around the highways, 24 hours lead time) calculated four times per day. Since the 2013/2014 winter season we have had access to the Support System for Winter Maintenance (**SSWM**) operated by CROSS Zlín and KLIMATOR company – developer of RST model (**1,2**). The outputs are in form of thermal maps and graphs calculated every hour with lead time 12 hours presented in the official Road Weather Information System (RWIS). The third source of RST forecasts is the **ICEWARN** system based on the METRo algorithm. METRo-CZ version was developed by Institute of Atmospheric Physics AS CR (**3,4**) and has been operated regularly by CHMI since winter 2014/2015 for internal use and further development with outputs adapted to the Visual Weather meteorological workstation software produced by IBL Software Engineering. Since February 2018 the graphs from METRo-CZ have become regular alternative source of RST forecasts for RWIS and serve for the purpose of nowcasting and warning in some local systems as the ICEWARN. RST is calculated for most road weather stations every hour with lead time 18 hours. All the above-mentioned RST models are supported by weather forecast from the numerical weather prediction (NWP) model ALADIN operating with horizontal resolution 4,7 km in four runs per day.

The first findings from case-studies in winter 2014/2015 revealed tendency of all RST models to be a little pessimistic with negative bias 1-2 °C for the first 6 hours and 2-4 °C for 6-12 hours lead time during nights. Maybe VAISALA FORECASTER was more successful in some cases. Models failed especially during nights with: a/ unexpected low cloudiness, b/ during warm advection c/ non-falling air temperature.

In the next seasons we focused on cases with cold advection and risk of black ice behind the cold front and warming after cold spell with potential of freezing precipitations. We found 5-6 suitable situations for each category. If the forecast of cloudiness behind cold front had been correct the models were almost perfect, if there had been more cloudiness than expected the negative bias was about 1 °C. For cases with warm advection the negative bias was usually up to 1 °C for ICEWARN and SSWM and 1-3 °C for VAISALA FORECASTER.

Conclusion from these case-studies can be that both SSWM and ICEWARN undertook positive development whereas VAISALA FORECASTER without update of the software remains behind these two RST models. During 2018 CHMI will start to operate new version of local NWP model with horizontal resolution 2,2 km which could be promise of further improvement in RST forecasting.

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DECISION GUIDANCE WITH PROBABILISTIC ROAD FORECASTS

Henry Odbert[a], James Shapland[a]

[a]*Met Office, Fitzroy Rd, Exeter, EX1 3PB, UK.*
henry.odbert@metoffice.gov.uk

The key objective of winter road treatment is to mitigate risk introduced by adverse weather conditions. In the UK and elsewhere winter road maintenance decisions are largely based on whether or not a deterministic road surface temperature forecast falls below some critical threshold. This approach has two key drawbacks: first, deterministic forecasts do not consider uncertainty or how different plausible future weather scenarios might drive different treatment decisions. Second, weather forecasts only convey information about the physical hazard (e.g., whether or not the road will be cold) and not about variations in other factors that affect risk (i.e. the likelihood of there being some loss due to the hazard). Using a hazard forecast to make a risk-based decision can therefore neglect important information, place inappropriate decision responsibility on forecast providers, or result in misinterpretation of forecast data. We present an approach to addressing these issues that combines probabilistic forecasting, and a framework for risk-based decision guidance.

Uncertainty is implicit and unavoidable in weather forecasting; the atmosphere is chaotic and our ability to understand and model its future state will always be incomplete. However, improving our knowledge of uncertainty can itself help forecasters to provide better advice to decision makers. This is particularly true for road forecasting in moderate climates, where marginal weather conditions – in which it may not be clear whether or not treatment is necessary – are common during winter months. A 'margin of error' is sometimes applied to forecast data to account for generalised uncertainty. On average, this leads to over-conservative mitigation (and associated costs) and does not reflect the reality that some forecasts are more certain than others. Alternatively, expert meteorologist interpretation of weather model data provides valuable commentary around forecast uncertainty. However, with increasing complexity and resolution of model data, numerical probabilistic forecasting becomes more attractive.

We explore the use of probabilistic data in operational road forecasting and demonstrate scenarios in which they should lead to better decision guidance. For example, Fig. 1 shows a scenario in which several key weather models forecast a minimum road surface temperature (RST, e.g. blue curve) comfortably above freezing; observed RST fell below 0°C, resulting in emergency reactive road treatment. A comparable probabilistic forecast (grey ribbon) shows wide uncertainty in the model data overnight, including the possibility of freezing RST. With this information, could the decision-maker have been better prepared?

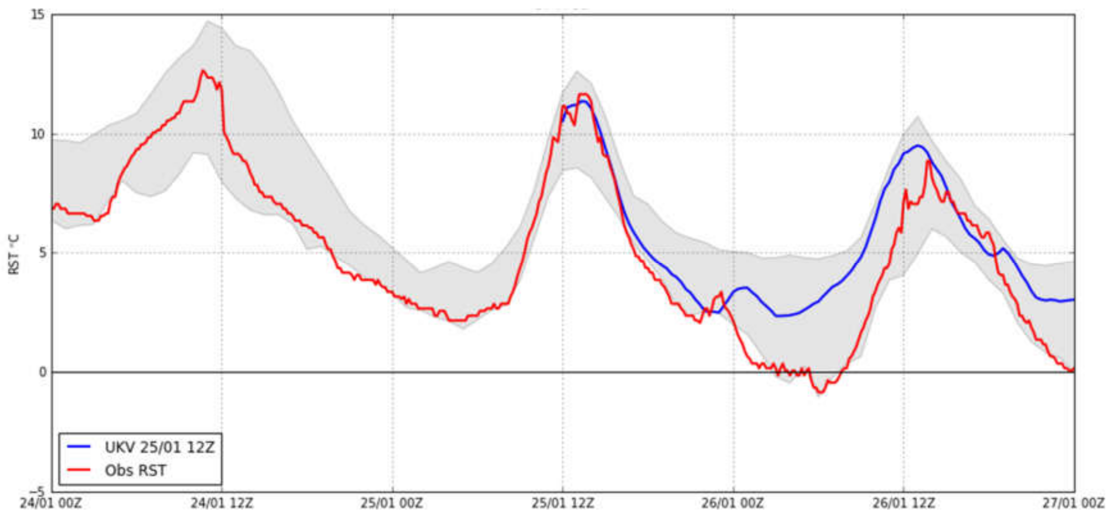

Fig. 1. Road Surface Temperature (RST) at a UK forecast location. Single model solution (blue curve) issued at 12Z on 25 January 2018, compared to observed RST (red). The range of plausible RST values, from all solutions of 4 NWP models, is shown by the grey ribbon.

A common concern with probabilistic methods is that they might introduce complexity that bloats or obfuscates the decision-making process in practice. This need not be the case. We define risk as the probability of incurring loss due to a hazard:

*Risk of loss due to hazard = Pr(hazard) * Pr(loss | hazard)* [1]

The weather forecast provides information about the hazard (e.g. ice on the road), but the *conditional* probability of loss (e.g. traffic disruption or a road incident) depends on other factors and may not be equivalent at all forecast sites. Considering hazard likelihood and conditional impact independently facilitates the use of a risk matrix approach (Fig. 2), providing support that is appropriate for risk-based decisions and straightforward to interpret.

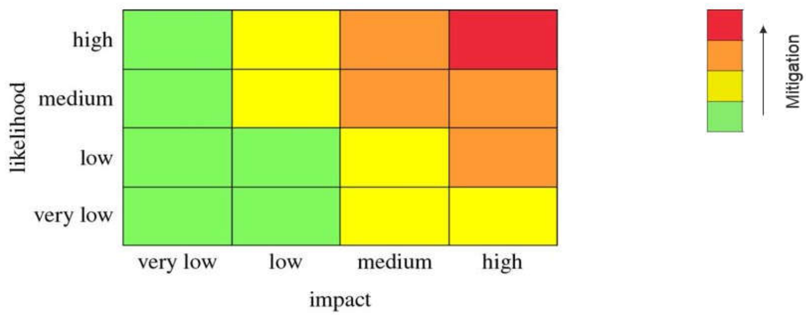

Fig. 2. Generalised risk matrix, after (1). Risk (coloured from low, green, to high, red) is the product of hazard likelihood and conditional impact. The extent of risk mitigation increases with higher risk of impact or loss.

To illustrate this concept, we report recent advances in the aviation sector: since 2014, Met Office risk-based decision support has been trialled at London Heathrow airport to modulate runway landing rates in low visibility (fog) conditions. Cost savings from reduced flight delays (at LHR, fog delays can cost €10s M per month) has resulted in the service being adopted by an increasing number of major hubs and the national air traffic service (NATS). We demonstrate how a similar risk matrix approach could be applied to winter road forecasts to guide risk-based decisions. We discuss the development of probabilistic and risk-based forecast services on a new Met Office cloud platform and considerations for integration with future technologies.

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ROUTE BASED ROAD CONDITION FORECAST USING MOBILE SENSORS

Karl E. Schedler[a], Karl G. Gutbrod[b]

[a]*KS-Consulting, Alpgaustr.22, Oberstdorf, DE,*
[b]*meteoblue AG, Clarastrasse 2, Basel, CH*
karl.schedler@ks-consulting.de

In the R&D project FE040279 "Route based sleekness prediction", methods for the more accurate prediction of winter-related sleekness were tested over 2 winters (2015/16 and 2016/17) and 3 road networks ((A-4, A-9, St2139). Therefore, new concepts were compared and tested in a 5-step process, including (1) weather models, (2) point forecasts, (3) roadway forecasts, (4) route forecasts and (5) temporal variability (gradients)
The routes A-9 (about 50 km, 380-520 m above sea level) and St-2139 (14 km, 480-901 m above sea level) have varied topography and terrain characteristics interesting for meteorological conditions. For the characterization, they are equipped with 3 resp. 1 stationary weather stations and were measured almost daily in the two winter half-years for a total of more than four hundred drives with mobile sensors (MARWIS from company Lufft) installed on maintenance trucks. The following parameters were recorded: dew point and road temperature, water film height and ice percent, as well as supporting parameters such as friction, road conditions and time-based radiation.
The measurements showed a high variability on the routes, reach within a drive differences of up to 17°C for temperatures and 2000µm for water film heights. This variability correlates little with the measurements at the stations and is not detected well by any prognosis provider.
The forecasts reached an MAE of 2.3°C for stations and a MAE of 2.1°C compared to mobile measurements on the road. For water film height, an average error of 180 µm is reached.
On the basis of the mobile measurements, standard profiles of the temperature were made by classification according to weather conditions, which allow to reduce the forecast error for temperature from 2.1°C to 1.9°C, and with the help of nowcasting to 0.6°C. A forecast for the next 12 hours should be able to achieve an error (MAE) of 1.2°C using these methods.
For the water film heights, standard road profiles of the water film height were created with mobile measurements and classification according to the amount of precipitation, which allowed to reduce the prognosis error for water film height from 190 µm to 90 µm and with nowcasting to below 50 µm. A prognosis for the next 12 hours should be able to achieve an error of less than 100µm using these methods.
The methods were developed using data from 2015/16 and tested on the journeys of 2016/17 so that an application is scientifically secured to independent journeys and other routes. It requires the creation of regular mobile measurement profiles, which are classified as standard profiles. On the basis of the experiences of 2 winters, a training of the model is likely to be possible within a winter season, during which improvements could be made to the route predictions.

The new methods represent a significant improvement in the state of the art and can be introduced into the practice within a few months using appropriate measures.

This R&D work was performed on behalf of the German Ministry of Transportation (BMVI) and the German Highway Research Institute (BASt) in Bergisch Gladbach.
We acknowledge the support of Horst Badelt and his Team from BASt as well as the support of the center of road maintenance at the North-Bavarian Highway directorate and the workgroup teams at Greding and Viechtach. .

Presentation 6.4

A ROUTE-BASED FORECASTING MODEL OF ROAD SURFACE FRICTION AND SNOW/ICE CONDITIONS

Teruyuki Fukuhara[a], Akira Saida[b], Akihiro Fujimoto[c], Masato Tanaka[d]

[a] Department of Civil Engineering, Hiroshima Research Institute of Technology, 2-1-1, Miyake, Saiki-ku, Hiroshima, Japan, [b] Civil Engineering Research Institute for Cold Region, Japan, 1-34, 1-jo 3-choume Hiragishi, Toyohira-ku, Sapporo, Japan [c] Department of Civil Engineering, University of Fukui, 3-9-1, Bunkyo, Fukui, Japan, [d] Misawa Environmental Technology Co. Ltd., 4252-2, Mukoueta, Miyoshi, Japan,

t.fukuhara.ek@it-hiroshima.ac.jp

1. Introduction

Road surface friction ⍰ is an objective parameter to express the degree of driving risk. Obtaining ⍰ over a wide area in advance is an effective way to support flexible deployments of snow removal machines and necessary to minimize salt use without reducing winter road safety.

This study aims at proposing a route-based ⍰ forecasting model (SAFFII-model)) and evaluating the model accuracy by comparing the calculated road surface temperature (*RST*) and road resistance value (Halliday Friction Number, *HFN*) with the measured ones.

2. Road weather and heat balance theory

2.1 Heat balance of snow layer

The proposed forecasting model consists of the calculations of the road weather, *RST*, ice mass fraction of snow on a road surface, snow depth and *HFN*.

The heat balance of snow layer on the road surface is given by Eq. (1).

$$(\rho c)_s \frac{\partial (T_s h_s)}{\partial t} = q_{sds} + q_{lds} - q_{lus} + q_{as} + q_{sf} - q_{le} - q_{sa} + q_{lm} - q_{if} - q_{dr} + q_{sp} - q_{st} \qquad (1)$$

where, $(\rho c)_s$: volumetric heat capacity of snow layer, T_s: snow temperature, h_s: thickness of snow layer, t: time, q_{sds}: solar radiation flux[1)] (top surface layer, TSL), q_{lds}: incoming longwave radiation flux[1)] (TSL), q_{lus}: outgoing longwave radition[1)] (TSL), q_{as}: sensible heat flux due to vehicle induced or natural wind[1)] (TSL), q_{sf}: rain/snow sensible heat flux[2)] (TSL) , q_{le}: latent heat flux due to evaporation[2)] (TSL), q_{sa}: sensible heat flux associated with splash[2)], q_{lm}: latent heat flux due to melting or freezing[2)], q_{if}: sensible heat flux due to downward movement of meltwater[3)] (except bottom snow layer, BSL), q_{dr}: sensible heat flux due to drain (BSL), q_{sp}: heat flux between snow layer and road surface[2)] (BSL), q_{st}: solar radiation flux through the snow layer [2)].

2.2 Heat balance of road surface layer

A sudden change of snow condition due to snow removal is taken account in this theory. The heat balance of the road (pavement) surface layer contacting with the snow layer is given by Eq. (2).

$$(\rho c)_p \frac{\partial T_{ps}}{\partial t} dz_{ps} = -q_{sp} + q_p + q_{st} \qquad (2)$$

where, $(\rho c)_p$: volumetric heat capacity of pavement, T_{ps}: temperature of road surface layer, dz_{ps}: thickness of road surface layer and q_p: conductive heat flux in pavement.

3. Mass and volume balance theory of snow layer

3.1 Water mass balance

The time rate of water mass M_w in the snow layer is expressed by Eq. (3).

$$\frac{\partial M_w}{\partial t} = M_{fw} + M_{lw} + M_{iw} - M_{sw} - M_{dw} - M_{saw} \qquad (3)$$

where, M_{fw}: water flux due to rainfall [2)] (TSL), M_{lw}: water flux due to phase change [2)] (TSL), M_{iw}: ice flux due to melting or freezing [2)] (>0: melting, <0: freezing), M_{sw}: melt water flux[3)] (except BSL), M_{dw}: draining water flux (BSL) and M_{saw}: water flux reduced by splash.

3.2 Ice mass balance

The time rate of ice mass M_i in the snow layer is expressed by Eq. (4).

$$\frac{\partial M_i}{\partial t} = M_{fi} + M_{li} - M_{iw} - M_{sai} \qquad (4)$$

where, M_{fi}: ice flux due to snowfall[2)] (TSL), M_{li}: sublimation flux[2)] (TSL) and M_{sai}: ice flux reduced by splash.

3.3 Air volume balance

The time rate of air volume V_a in the snow layer is expressed by Eq. (5).

$$\frac{\partial V_a}{\partial t} = V_{fa} - V_{exa} - V_{oa} - V_{saa} - V_{vca} \qquad (5)$$

where, V_{fa}: air volume flux due to snowfall[2)] (TSL), V_{exa}: air volume flux replaced by water or ice due to melting or freezing[2)], V_{oa}: air volume flux reduced by snow-melting[2)] (TSL), V_{saa}: air volume flux reduced by splash and V_{vca}: air volume flux reduced by snow condensation[2)].

3.4 Sliding resistance and snow conditions

The sliding resistance of the snow layer is expressed by the *HFN*. The *HFN* is calibrated in a range of 0 to 80~100 (min: 0-slip ratio, max: dry road surface) and may be given as a function of the thickness of ice component in the snow layer as follows:

$$HFN = HFN_w - 86.8 + 64.8(\theta_i h_s)^{-0.154} \qquad (6)$$

where, HFN_w: *HFN* on wet road surface and ϑ_i: volumetric ice content.

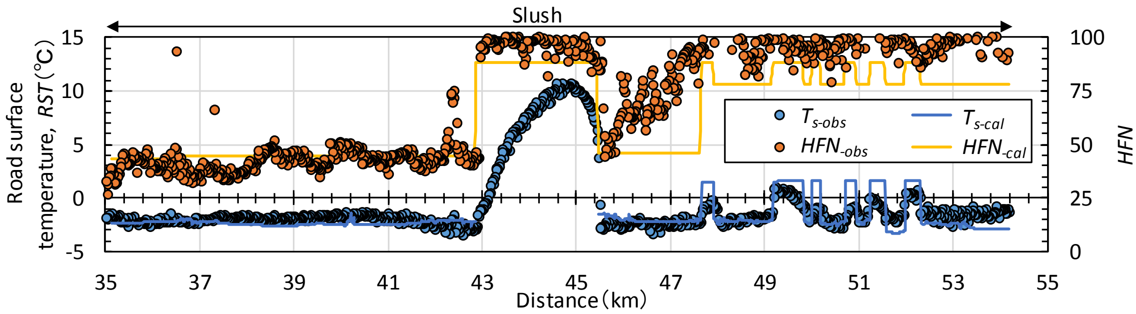
4. Thermal and *HFN* mapping

Thermal-*HFN* mapping and meteorological survey were conducted over the 12.6 km section between Santo IC and Aogaki IC on the Kasuga-Wadayama Expressway in Hyogo prefecture, Japan. The *RST* and *HFN* were measured at intervals of approximately 2m by a vehicle equipped with a continuous friction tester (CFT).

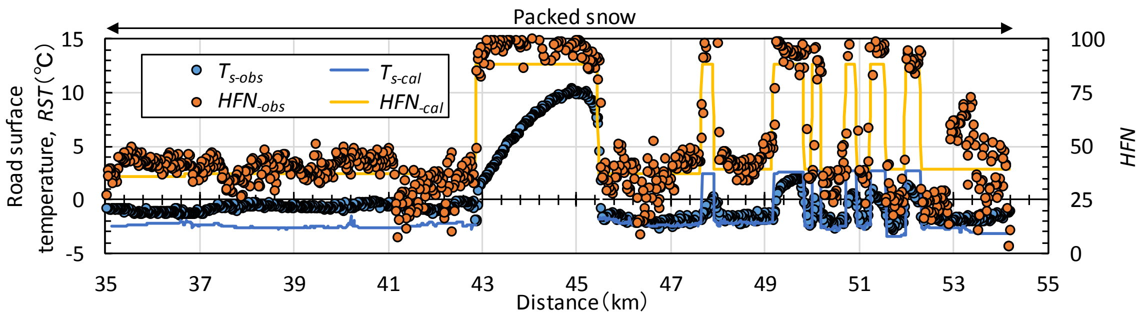
5. Results and discussions

Fig. 1 (a) and 1 (b) show the comparison of the calculated and measured spatial variations in T_s and *HFN* at 02:00 and 06:30 on January 26, 2012, respectively. These data were obtained on slush and snow packed road surfaces. The calculated T_s, $T_{s\text{-}cal}$ was in good agreement with measured T_s, $T_{s\text{-}obs}$ (•) at two different times of the day.

Spikelike fluctuations of measured *HFN*, $HFN_{\text{-}obs}$ may include mechanical errors of the CFT on random rough snow surfaces. When the contact position of the CFT on the road surface deviates from the track of the tire in front of the CFT, the calculation accuracy of HFN may become low. It is seen that the plots of $HFN_{\text{-}obs}$ (•) are scattered around the



(a) 1/26 2:00



(b) 1/26 6:30

Fig. 1. *RST* and *HFN* distribution along the route (2012)

calculated lines as a series of plots of $HFN_{\text{-}cal}$ at two different times of the day. Significant changes in $HFN_{\text{-}cal}$ can be recognized at the mouths of tunnels as well as $HFN_{\text{-}obs}$.

6. Conclusions

A route-based ? forecasting model (SAFFII-model) was proposed and the model accuracy was discussed in this paper. It is concluded that SAFFII-model could reproduce the spatial variations in the road surface temperature and Halliday Friction Number, *HFN* measured along the expressway.

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USE ERRORS IN OBSERVATION DATA TO DISCOVER VALUABLE INFORMATION FOR ROAD FORECASTING

Ingeborg Smeding[a], Jelle Wisse[a], Menno Mimpen[a]

[a]*MeteoGroup, P.O. Box 617, 6700 AP Wageningen, The Netherlands*
i.smeding@meteogroup.com

Nowadays road forecasting is mainly based on observations from traditional (road) weather stations. Although these stations provide high quality observations, the spatial resolution is often poor and local wintry conditions are not always detected. To fill these gaps, we developed a method to retrieve valuable information from consumer weather stations.

A lot of people have their own private weather station in the garden or on the balcony. Currently there are over 200.000 stations worldwide available online, providing very high information density compared to the approximately 10.000 official weather stations. Private weather stations are however often not properly installed, maintained or equipped compared to official professional weather stations, and therefore the data can be erroneous. Looking to individual stations it is hard judge the data quality, but by looking to a big number of these stations, we can even find valuable information within the errors!

We highlight two examples of valuable information which can be derived from these structural errors in consumer weather stations: night-time cloud cover and solid precipitation. Both are relevant information for road forecasting, so could be a helpful additional source of data.

Night-time cloud cover can be derived based on cooling behavior of the station. The principle is based on the fact that most consumer stations are not placed in ventilated Stevenson screens, and are therefore more sensitive to changes in long wave radiation, which indicate clear spells. We derive a machine learning model to nowcast effective cloud cover. Night-time cloud cover is crucial information for road weather forecasting, as a clear spell can bring the road surface temperature down in a very short time period and result in icy road conditions.

Solid precipitation can be derived based on the “problem” that the rain gauge of the consumer weather station stops working in case of solid precipitation, because there is ice formation or the cups are filled with snow. When this information is combined with radar or satellite images, the precipitation type can be derived. Looking to the big amount of consumer weather stations, this method can create very local precipitation type information, close to real-time.

Special thanks to Tom de Ruijter (former MeteoGroup) for doing this research.

EXPERIMENTAL ROAD WEATHER FORECASTING IN HUNGARY

André Simon[a], Zsolt Szarka[b]

[a]*Hungarian Meteorological Service, 1024 Budapest, Kitaibel Pál u. 1, Hungary*
[b]*Hungarian Public Road Nonprofit PLC, 1024 Budapest, Fényes Elek utca 7-13, Hungary*
simon.a@met.hu

In winter, cold temperature, freezing rain or blowing snow is often observed in several parts of Hungary. Currently, the Hungarian Meteorological Service (OMSZ) provides forecasts of several meteorological parameters (e.g. 2m and surface temperature, precipitation, precipitation type and probability of its occurrence) which are used for road safety and road maintenance purposes. These parameters are mostly outputs of numerical weather prediction (NWP) models, like the ECMWF or AROME. In the recent years, also experimental forecasts were prepared with use of the METRo road weather forecasting model [1], which were coupled with the ECMWF and WRF model data. The feasibility and accuracy of the road surface temperature (RST) forecasts was tested on case studies and also statistically verified.

The METRo model (version 3.2.7) was applied on 165 road weather station (RWS) data of the Hungarian Public Road. For the verification, we selected 25 days of the December 2014 with usual winter road conditions in Hungary. The NWP input data were derived from the 12 UTC ECMWF model runs (at nearly 9 km horizontal resolution). We performed 24 h forecasts starting at next day 00 UTC (this was preceded by an 8h coupling period). The results were evaluated with use of standard statistical parameters (BIAS, MAE, RMSE, POD, FAR, Random Correct, Heidke Skill Score, etc.). For case studies, the outputs were depicted with the use of the Hungarian Advanced WorKstation (HAWK), developed at OMSZ [2], which enables overlapping of road weather data with many kinds of meteorological observations and forecasts.

The results of the verification showed that the average mean absolute error (MAE) is about 1.5 °C (all stations, whole forecasting period) and the root mean square error is about 2 °C. For 94 RWS the MAE was below 1.5 °C and for 86 RWS the RMSE did not exceed 2 °C, which is not much higher compared to usual 2m temperature errors of the input ECMWF model over Hungary in wintertime. The forecast RST was mostly underestimated (mean BIAS was -0.3°C). The underestimation was typical for the morning and evening period but the RST was overestimated at noon (**Fig. 1**).

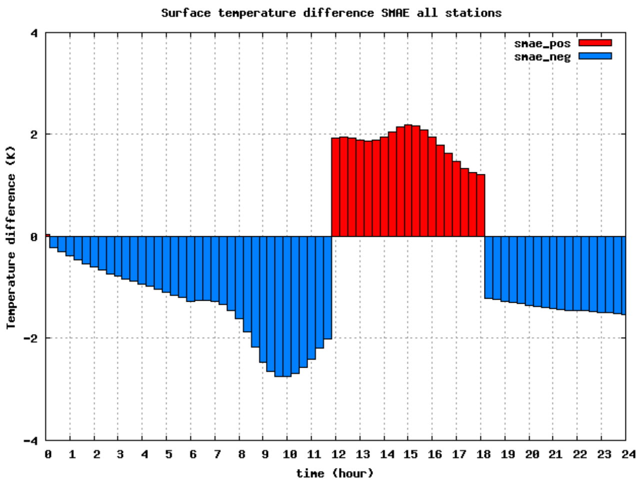

Fig. 1. Daily course of SMAE (MAE multiplied by signum of BIAS) of the road surface temperature for all verified stations and for the period of 02.12.-30.12.2014.

The case studies indicated that the spatial distribution and accuracy of the forecast RST is largely determined by the precision of the NWP forecasts of cloudiness and radiation fluxes (**Fig. 2**). The areal distribution of RST was similar to the ECMWF surface temperature field but the RST usually exhibited much higher amplitudes in its daily course. Occasionally, large errors (exceeding 6 °C) were detected, for example in a test forecast using the high-resolution (2.5 km) WRF model as input. This example demonstrated high sensitivity of the RST forecast on the NWP input precision, mainly in situations with delays or displacements of precipitation bands. Errors in the predicted 2m temperature, 10m wind etc. caused a rapid deviation of the forecast RST from the observed one. However, experiments, in which the input data were set close to observations, predicted the RST correctly. Nevertheless, there were also many examples of successful forecasting of sudden RST cooling (of 8-10 °C in 12 h) caused by cold weather outbreaks in January 2016 and March 2018. In such cases the model RST forecasts could be the most valuable for the users, while outperforming the linear extrapolation methods or persistence significantly.

A special parameter has also been developed to predict the occurrence and intensity of blowing snow. The Blowing Snow Index (BSI) was based on observations of blowing snow events in Hungary and constructed as a function of 2m temperature, wind, wind gusts, snow depth, snow density and skin (snow surface) temperature [3]. The index is calculated from the ECMWF model forecasts and it was successfully used during intense blowing snow events in March 2013 and 2018, which caused large traffic problems on the roads.

The experiences with RST or BSI forecasts showed high sensitivity of these parameters on the quality of the input NWP forecast, which would suggest application of an EPS system (e.g. ECMWF-EPS, AROME-EPS) in the future. The case studies showed that these tools can be effectively used in everyday forecasting of road weather, even in difficult conditions, but recognizing and filtering the sources of systematic errors requires experience and a good knowledge of the meteorological models and processes in the background.

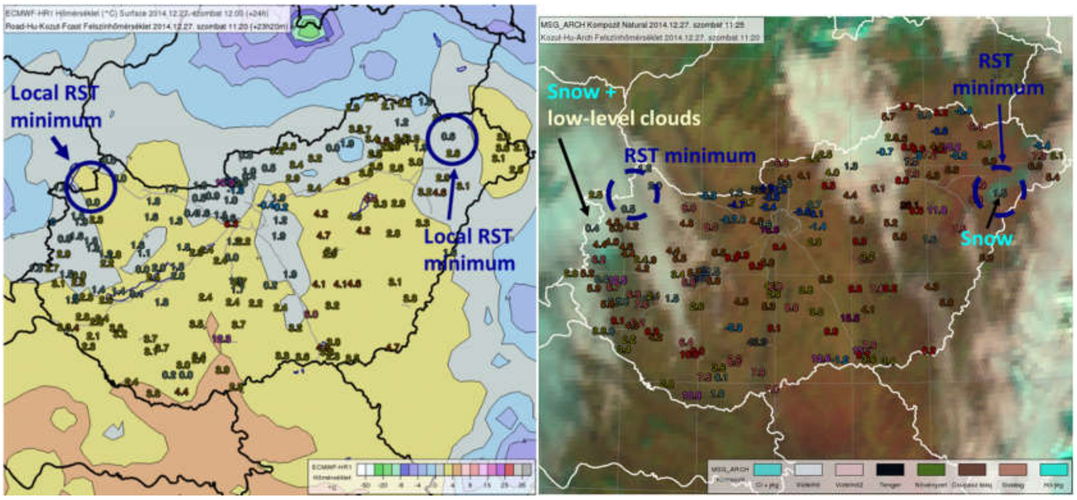

Fig. 2. Left: Forecast RST (numbers, °C) valid for the 27.12.2014 11:20 UTC and corresponding ECMWF surface temperature (color shades) forecast for the area of Hungary. Right: Observed RST (numbers) and the METEOSAT Natural Color Composite satellite image showing areas with snow (turquoise color) and low-level clouds (light blue and pink color) at 11:20 UTC.

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VERIFICATION RESULTS FOR ROAD SURFACE TEMPERATURE FORECASTS UTILIZING MOBILE OBSERVATIONS

Virve Karsisto[a], Timo Sukuvaara[a]

[a]*Finnish Meteorological Institute, P.O. BOX 503, FI-00101 Helsinki, Finland*
virve.karsisto@fmi.fi

Observations from mobile sources have great potential to improve road weather forecasts in areas with sparse road weather station (RWS) network. Precise road condition forecasts are essential for optimal planning of the road maintenance operations and keeping the roads safe for drivers. The availability of mobile road condition observations have greatly increased in recent years. For example, Teconer Oy's optical sensors (RCM411 and RTS411) [1] installed in vehicles covered globally approximately 200 000 km of roads in a month during period November 2016-March 2017. However, observations made from moving vehicles are more exposed to disturbances than measurements done at RWSs. The behaviour of the used instruments should be studied before implementing the observations to the road weather forecasting system.

In this study, Finnish Meteorological Institute's (FMI) road weather model (RWM) [2] was used to make road surface temperature hindcasts to RWS points along the motorway in southern Finland for the time period 12th October 2017- 28th February 2018. Surface temperature observations made by optical Teconer RTS411 instruments attached to vehicles were used in the model initialization and the observations from the RWSs in verification. The simulations were done with and without statistical correction terms added to the Teconer RTS411 measurements. The verification results were compared to the corresponding scores of the control run not using Teconer measurements to find out the effect of mobile observations to the simulation accuracy.

The FMI's RWM is a one dimensional heat balance model. It requires atmospheric values (e.g. air temperature) as input data and gives road surface temperature and amounts of water, ice, snow and deposit on the road as output. In this study, the model was initialized with atmospheric values obtained from data interpolated from weather stations by using kriging method [3]. Observations from road weather stations were not used in the interpolation. The forecast part of the model run used data from HARMONIE-AROME model configuration that is run four times a day (00, 06, 12 and 18 UTC).

The cases where a vehicle passed a RWS were separated from the Teconer measurements to obtain data for the simulations. The used value for road surface temperature was obtained as an average of the measurements done within 50 m radius from the station during a pass. The station points are shown in Figure 1. The statistical correction terms for Teconer RTS411 instruments were determined by comparing the observations done during previous winter period (November 2016-Apri 2017) to the RWS measurements. The correction term was determined separately for each individual Teconer instrument as the mean difference value between the RWS and Teconer observations.

Three-day RWM simulations were run for time period 12th October 2017- 28th February 2018 with 52 h initialization period and 21 h forecast period. A separate run was done for each HARMONIE forecast. The forecast phase in the RWM started 3 hours after the HARMONIE analysis time. Mobile road surface temperature observations were utilized in the RWM by using coupling method [4]. The idea of the coupling method is to adjust the radiation in the model so that the modelled road surface temperature fits to the latest observation. If there was a mobile observation available within three hours from the HARMONIE analysis time, it was included in the simulation.

Observations from the RWSs were used in the verification of the simulations. The verified value was road surface temperature. Only the simulations which utilized mobile observations were included in the calculation of the verification scores. Figure 1a shows how many such simulations there were for each station. The scores for the control run were calculated using the corresponding simulations, although those did not utilize Teconer measurements. The root mean square error (RMSE) values for the first hours in the forecast were clearly smaller for the simulations using mobile observation than for the control simulations (Figure 1b). The effect is strongest at the beginning of the forecast and decreases gradually until the end of the 21 h forecast period, where the RMSE values are rather similar. When the statistical correction terms are added to the Teconer values, the RMSE values decrease even further. They remain smaller than the RMSE values obtained with the other run using mobile observations during the first seven hours of the forecast phase.

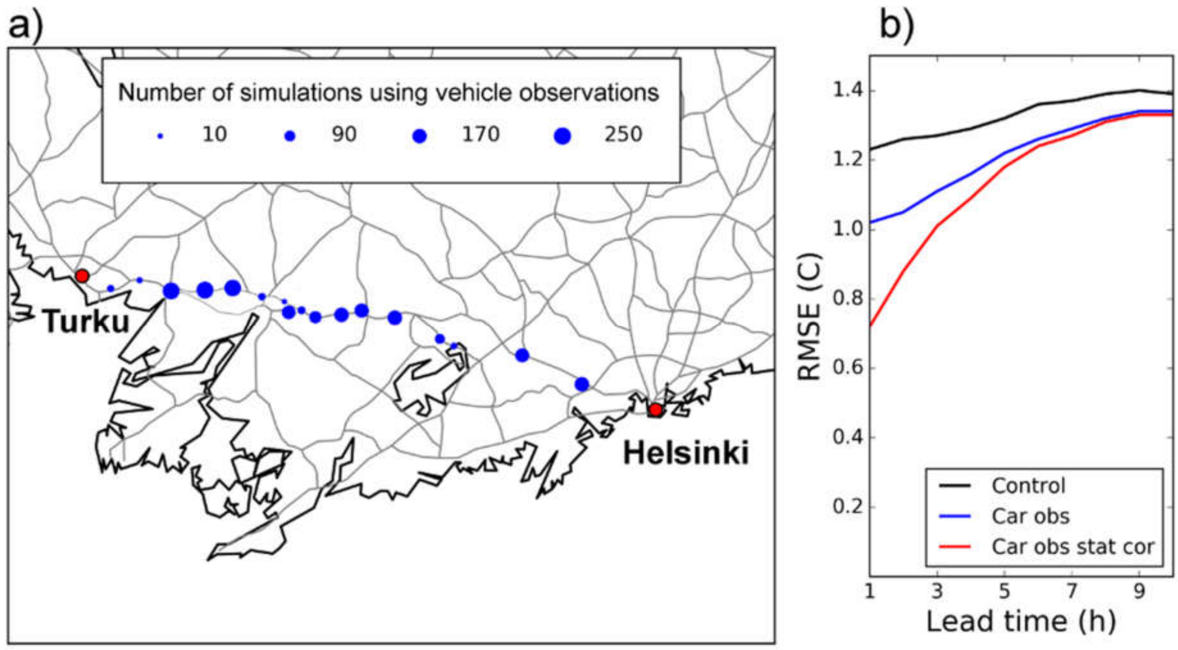

Fig. 1. Panel a) shows simulation points along the Helsinki-Turku motorway. The size of the point indicates how many simulations in that point utilized vehicle observations. Panel b) shows RMSE of surface temperature simulations as a function of forecast lead time. Black line shows results for simulation without mobile observations, blue line for simulation with mobile observations and red line for simulation with statistical corrections added to mobile observations.

As conclusion, utilizing mobile observations clearly improved the simulation accuracy. However, the simulations do not correspond well to an actual forecast case since the RWS observations were not used. Nevertheless, verifying the simulation results would have been difficult in points without RWS because of the lack of independent observations.

This work has been supported by several research projects: 5G-Safe funded by Business Finland and Intelligent Arctic trucks, Sod5G and WiRMa funded by EU regional funds and Regional Council of Lapland.

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Session 7 Meteorological & Climatological Studies

A ROAD STATE CLIMATOLOGY FROM THE GLOBAL WEATHER CORPORATION ROAD WEATHER FORECASTS

Danny Cheresnick[a], Bill Gail[a], Josh Thompson[a]

[a]*Global Weather Corporation, 3005 Sterling Circle Boulder, CO, USA 80301*

dcheresnick@globalweathercorp.com

Global Weather Corp (GWC) produces high spatial and temporal resolution road weather forecasts (referred to by the product name RoadWX), across North America, Europe, and Asia. The RoadWX forecasts combine GWC's industry leading atmospheric forecasts with our road physics models to compute road surface temperature and road state, which represent critical information for road maintenance, vehicle safety, and navigation applications.

GWC has archived RoadWX forecast data across the United States and Europe for over one year. From this archive, analyses of the monthly, seasonal, and annual tendencies of road state can be determined, as well as the relationships between different atmospheric and road parameters. Example analyses include an estimate of how often roads are: a) dry, wet, slushy, or ice/snow covered; b) contain significant amounts of water or snow/ice; c) or are in a state where the predominant precipitation type does not match the road state (i.e., snow falling onto a comparatively warm road and melting, or snow falling onto a road that would induce melting when chemically treated). The primary goal of this study is to better understand and quantify the typical occurrence of different road characteristics at all locations across Europe. Additional insight into the road state evolution and interactions between atmospheric conditions and the road surface are provided as well.

FUTURE CLIMATE CONDITIONS FOR SUMMER ROADS IN LITHUANIA

Justas Kažys[a], Lauryna Šidlauskaitė[a], Donatas Valiukas[b]

[a]*Institute of Geosciences, Vilnius University, M.K. Čiurlionio st. 21, LT-03101 Vilnius, Lithuania,* [b] *Climatology Division, Lithuanian Hydrometeorological Service, Rudnios st. 6, LT-09300 Vilnius, Lithuania*
justas.kazys@gf.vu.lt

Usually traffic safety and driving conditions were associated with winter roads. However, summer rods could very dangerous to traffic accidents because of weather conditions (1). Recent changing climate conditions already brought new challenges for summer maintenance specialists in Lithuania. In summer, at a temperature of (25–30) °C, road pavement surface heats up to (40–45) °C (2). The problem of deformation of asphalt pavement due to hot air temperature are possible. Moreover, the summer months typically bring higher numbers of traffic deaths, with July and August being considered the most dangerous months of the year to be on the roads (3)

Adverse weather conditions usually cause severe road network disruptions, no matter the location or time of the year (4). During summer, such conditions usually include high winds and intense precipitation (rain and hail), caused by some form of a storm passing through the region (local or advective). This significantly decreases the visibility and causes the drivers to slow down or even stop, moreover, flooding might occur in some areas, causing the transportation network to halt (5).

Projected climate changes will have a different impact on transport system than other sectors, thus its adaptation and mitigation strategies require special assessment of meteorological data (6). The aim of this research is to investigate what future climate conditions that influence transport system will take place in Lithuania during summers until the end of 21st century. A better understanding of what to expect will help decision and policy makers to evaluate and choose proper adaptation and mitigation strategies.

The data from eighteen meteorological stations (MS) covering 20 years period from 1986 to 2005 were used in this research (Fig. 1). The daily data included maximum air temperatures (°C), precipitation amount (mm), maximum wind speed (m/s) and atmospheric pressure (hPa) for summer (May-September). Three Global Circulation Models (GCM) were chosen for projections of future climate conditions for winter roads in Lithuania: GFDL-CM3, NorESM1-M and HadGEM2-ES. CMIP5 (Coupled Model Intercomparison Project Phase 5) project outputs (7) of daily meteorological variables were used in the research downloaded from NOAA GFDL database and World Data Center for Climate / CERA at DKRZ. GCMs daily values obtained for reference period (1986-2005), near-term (2016-2035) and long-term (2081-2100) futures. Near- and long-term projections were made using 4 RCPs (Representative Concentration Pathway): RCP2.6, RCP4.5, RCP6.0, and RCP8.5. GCMs have different grid cell distribution (Fig. 1) over Lithuania: we used 3 cells for GFDL-CM3 and NorESM1-M; 5 cells – HadGEM2-ES. The value of grid cells assimilated to nearest MS using statistical downscaling methods.

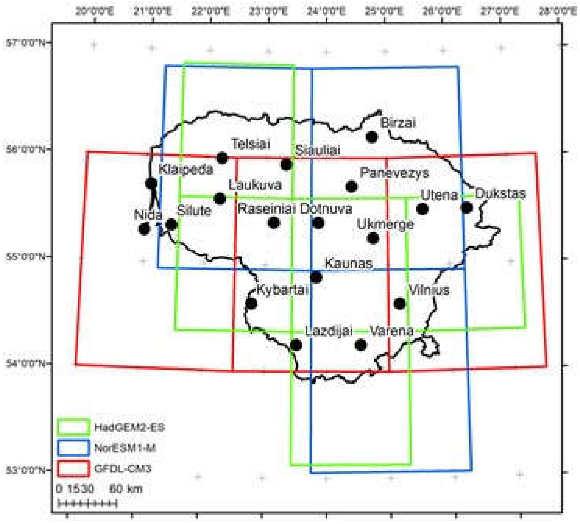

Fig. 1. Meteorological stations in the territory of Lithuania and grid cells of 3 GCMs (GFDL-CM3, NorESM1-M and HadGEM2-ES).

Three new adjusted meteorological parameters database of 21st century projections was created for every MS, which allowed us to estimate dangerous and adverse climatic conditions for summer roads in Lithuania:

- Hot Dry days (HD) – number of days per summer when maximum air temperature is >28 °C), atmospheric pressure >1018 hPa and no precipitation recorded (0.0 mm). It can be the reason for road pavement (asphalt) deformation. The rutting of asphalt could affect driving comfortability and safety, and rise the costs of roads reconstruction.
- Fine Weather days (FW) – number of days per summer when atmospheric pressure is >1018 hPa, no precipitation recorded (0.0 mm) and maximum air temperature stay between 20 and 30 °C. It could be a reason of more busy traffic on roads and more relaxation of drivers, etc. which could be a reason for traffic accidents.
- Severe Summer Weather days (SSW) – number of days per summer, when maximum air temperature is above 18 °C, maximum wind speed exceeds 10 m/s and there is at least 5 mm of precipitation. These conditions describe a situation when there's a high chance of having a front or a squall line passing through and significantly worsening driving conditions. During summers, at the second half of a hot day there's a high chance for local thunderstorms forming too, therefore, this parameter provides an insight in averaged frequency changes of such stormy days in the future.

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RELATIONSHIP BETWEEN THE DEVELOPMENT OF A SNOWDRIFT AND SNOW TRANSPORT RATE ON A ROAD SECTION WITH A CUT ON ONE SIDE – OBSERVATION IN TESHIKAGA-CHO DURING WINTERTIME IN FY2016 AND FY2017-

Hirotaka Takechi, Satoshi Omiya, Jouji Takahashi, Masaru Matsuzawa, Takanori Konaka

Civil Engineering Research Institute for Cold Region (CERI), PWRI

Hiragishi 1-3, Toyohira-ku, Sapporo, 062-8602, Hokkaido JAPAN

hiro-takechi@ceri.go.jp

1. Introduction

In recent years, stranding of vehicles in snowdrifts and other traffic hazards have been reported in relation to road sections with a cut during snowstorms. Therefore, it is important to predict the formation of snowdrifts on such cut road sections on a real-time basis and to carry out more effective wintertime road management, which involves snow removal and road closure. However, it has been unclear what kind of impact the structure of the cut road section and weather conditions have on the process of snowdrift development. This study examines the relationship between the depth of snowdrifts on a cut road section and the transport rates in order to propose a snowdrift prediction method for cut road sections.

2. Research method

The authors investigated the process of snowdrift development on a cut road section with a height of approximately 2 m and a grade of 100 % located in a suburb of Teshikaga-cho, Hokkaido Prefecture (N43°30', E144°27'). **Fig. 1** shows a photograph of the investigation spot and the position of the measurement equipment. The investigation spot has a fetch of 500 m or more, which is enough for blowing snow to accumulate on the windward side. This investigation assumes that there is a two-lane Type 3 Class 1 road on the lee side of the cut. The depths of snowdrifts on the measurement lines shown in **Fig. 1** were measured. Measurement was conducted during wintertime over two years, namely from November 20, 2016, to January 17, 2017 and from November 20, 2017, to March 30, 2018.

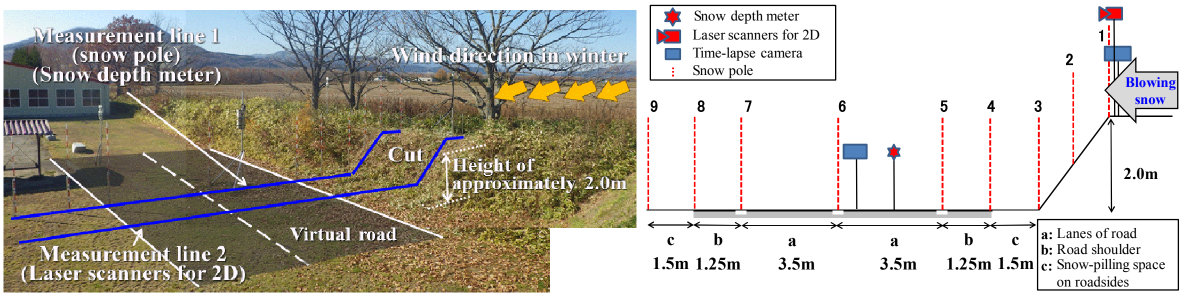

Fig. 1. Investigation spot and Measurement method

For measurement, we set nine measuring sticks (snow poles) and took photographs with a time-lapse camera every 20 minutes from 6 a.m. to 4 p.m. We also set a snow depth meter in the middle of the lanes on the windward side and measured the snow depth every hour. From November 20, 2017, we also measured the depth of snow on the road's cross-section with a laser scanner every hour.

3. Analysis method

This paper analyzses the following three periods during which blowing snow formed a snowdrift on the lanes of the virtual road where there had been almost no snowdrift before the blowing snow.

[Event I] : December 9 to 12, 2016

[Event II] : December 13 to 14, 2017

[Event III] : January 3 to 4, 2018

Since the transport of snow greatly contributes to the formation of a snowdrift, we estimated the transport rate by the following method. First, we determined whether or not there was blowing snow. If blowing snow was occurring, we estimated the snow transport rate during such event using Formula (1), which was proposed by Matsuzawa[1], et al. With reference to The Highway Snowstorm Countermeasure Manual[2] , we determined whether there was blowing snow based on Condition 1 or 2, depending on whether it was snowing or not.

$$Q = 0.005\, U_{1.2}^{4} \qquad \text{Formula (1)}$$

[Condition 1 (snowing)] : $T \le -5°C$ and $U \ge 5ms^{-1}$ or $-5°C < T < 0°C$ and $U \ge 6\ ms^{-1}$

[Condition 2 (not snowing)] : $T \le -5°C$ and $U \ge 10\ ms^{-1}$ or $-5°C < T < 0°C$ and $U \ge 11\ ms^{-1}$

Q is the snow transport rate ($gm^{-1}s^{-1}$), $U_{1.2}$ is the average wind velocity (ms^{-1}) at 1.2 m high, T is the temperature (°C), and U is the maximum instantaneous wind velocity (ms^{-1}) at 10 m high. We used observation values (ten-minute values) obtained by the AMeDAS located near the investigation spot for the calculation of transport rates. Wind velocities at individual heights were calculated according to the logarithmic law (snow surface roughness was set at 1.5×10^{-4} m).

4. Analysis results

Fig. 2 shows the relationship between the depths of snowdrifts and the accumulated snow transport rate. The results show that snowdrifts are formed earlier and the development speed as a ratio to the snow transport rate is larger on the windward side near the cut slope.

Fig. 3 shows the relationship between the depths of the snowdrift and the accumulated snow transport rate on the middle line of the lanes on the windward side for individual events. In Events I and II, the depth of the snowdrift reached 15 cm, with which it is said to be difficult to start a car, when the accumulated snow transport rate reached approximately 1000 kgm^{-1} (**Fig. 3** a)). Meanwhile, in Event III, the depth of the snowdrift reached 15 cm earlier than in Event I or II, when the accumulated transport rate reached 300-700 kgm^{-1} (**Fig. 3** b)). In Event III, a snowdrift had already been formed on the cut slope before the blowing snow started. It is considered that the difference in the accumulation of snow on the cut slope on the windward side has an impact on the development speed of snowdrifts.

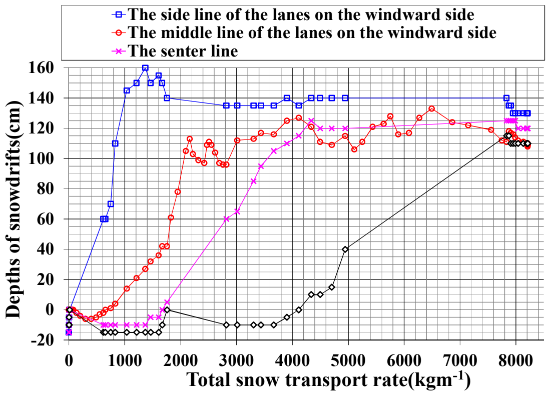

Fig. 2. Relationship between the depths of snowdrifts and accumulated snow transport rate (Event I)

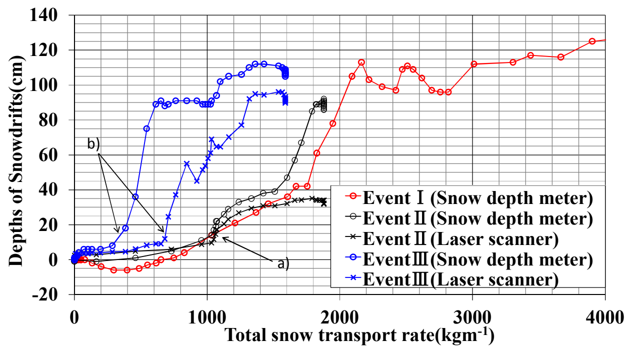

Fig. 3. Relationship between the depths of snowdrifts and accumulated snow transport rate on the middle line of the lanes on the windward side

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A GEOSTATISTICAL APPROACH TO CLASSIFICATION OF TOPOGRAPHY AND CLIMATE ZONES FOR RWIS NETWORK PLANNING

Simtia Biswas[1], Tae J. Kwon[1]* and Liping Fu[2, 3]

[1]Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB., Canada
[2]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, ON., Canada
[3]Intelligent Transportation Systems Research Center, Wuhan University of Technology, Mailbox 125, No. 1040 Heping Road, Wuhan, Hubei 430063. Email: lfu@uwaterloo.ca

Abstract

Road Weather Information System (RWIS) is a combination of advanced technologies that collect, process, disseminate road weather and condition information. This information is subsequently used by road maintenance authorities for making operative decisions for improved safety and mobility during inclement weather events. For this reason, many North American transportation agencies have invested millions of dollars to deploy RWIS stations to improve the monitoring coverage of winter road surface conditions. Currently, however, there are substantial gaps in knowledge in determining the network density (i.e., number of stations) to provide an acceptable level of coverage. To fill this gap, an investigation was done on the hypothesis that the optimal RWIS density is dependent on the spatial variability of the road weather conditions as well as its respective topographical characteristics. To test this hypothesis, geostatistical semivariogram models were developed to quantify the underlying spatial autocorrelation structures, in which the RWIS network optimization model is employed to examine the potential relationship between the density and topography. The study area combines several North American States and Provinces with varying zonal characteristics and includes regions of higher or lower elevations, fairly flat or highly varied terrain, and warm or cold regions. This study proposes that the RWIS data collected from a specific region can be used to estimate the number of stations required for another region of similar zonal characteristics. The outcome of this study can be used as a decision-making tool for RWIS network expansion planning thus maximizing the RWIS network monitoring capability using zonal classifications.

*Presenter; E-mail tjkwon@ualberta.ca

Presentation 7.5

VISIBILITY MONITORING AND FORECASTING SYSTEM FOR TRAFFIC SAFETY

Branislav Jaroš[a], Jozef Omelka[b]

MicroStep-MIS, spol. s r.o., Čavojského 1, 841 04 Bratislava, Slovak Republic
branislav.jaros@microstep-mis.com
jozef.omelka@microstep-mis.com

The interest in short-term weather warnings with higher localization accuracy has been increased recently. The significant and hazardous meteorological events jeopardise many activities of the society especially traffic.

Almost all fog events in Dubai region are of radiation origin culminating in the early morning hours of the traffic rush. Several fog events were cause of serious traffic incidents. Ghantoot incident (accident near Ghantoot, UAE with more than 200 cars involved in 2008) aroused interest of Dubai Municipality for possibilities to monitor and also forecast fog events. It resulted in cooperation with Microstep-MIS Company.

Our solution is **Visibility Monitoring and Forecasting System for Traffic Safety** (2009) in Dubai which consists of:

- 14 automated weather stations for visibility and other weather condition monitoring, majority of stations have also camera
- Climatological database UDCS/CLDB (for data collection and storage)
- Web Real-time display to monitor actual weather condition online
- Weather prediction modul
- Fog prediction modul
- Sandstorm prediction modul
- Satellite images browser

The Groundwork for **fog predictions** comes from three sources:

- Physical model outputs (3D model WRF, 1D model Pafog)
- Model based on data mining methods
- Satellite images with high frequency (5-min, 15-min)

Fig. 1. Output of the Visibility Monitoring and Forecasting System for Traffic Safety

The **sandstorm modelling system** is based on the art of 3D numerical weather prediction and model for sand dispersion. Outputs of sandstorm modelling:

- Maps of sand particles uplift and dispersion two times daily (run 0000 and 1200UTC)
- Sandstorm warning icons for whole Dubai area

Part of our Visibility Monitoring and Forecasting for Traffic Safety System in Dubai is **real time display -** tool to monitor decrease of the visibility and other measured weather parameters online in real time at all stations.

There is also possibility to analyse all measured data retrospectively, because they are all saved in **Climatological database.** There are also tools to filter, select and visualise measured data.

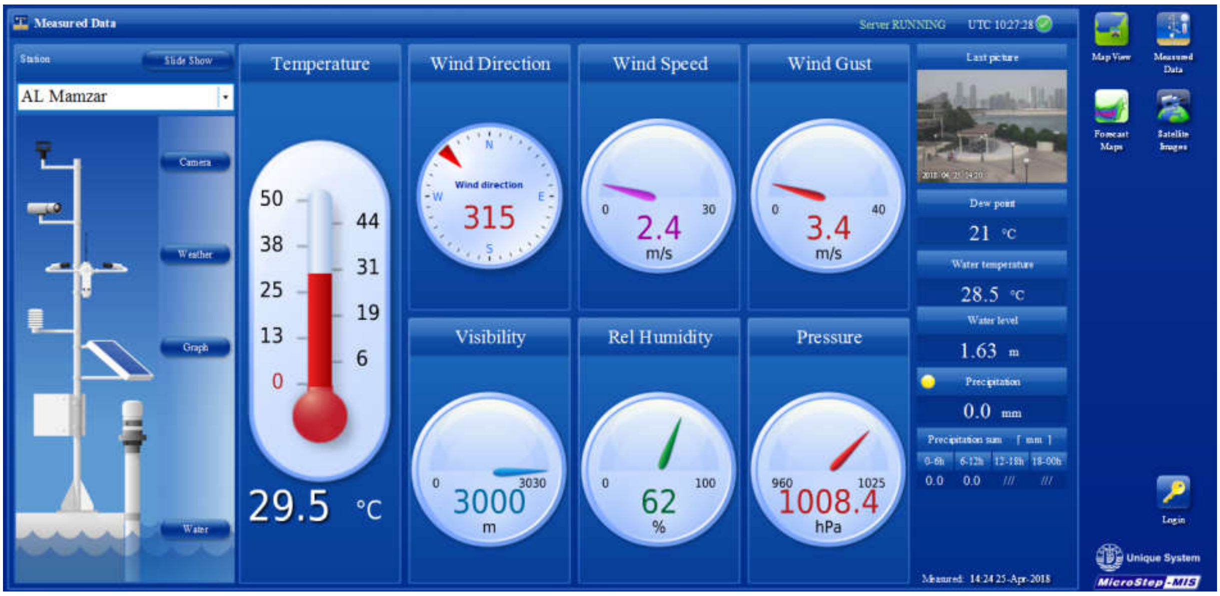

Fig. 2. Real-time display

Other strong tool to monitor fog or sandstorm development are satellite images. Our Visibility Monitoring and Forecasting System consists of **Satellite images browser** which allows to monitor situation on different satellite RGB composites online.

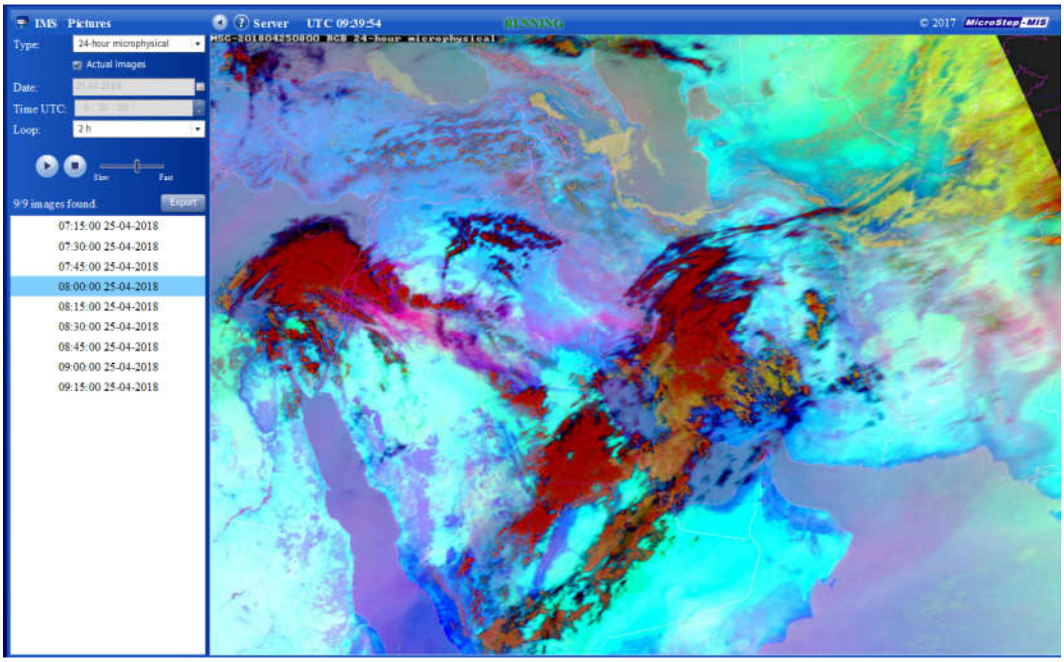

Fig. 3. Satellite images browser

Presentation 7.6

VISIBILITY ESTIMATION BASED ON CAMERA DATA AND WEATHER PARAMETERS

Marjo Hippi[a], Antti Mäkelä[b], Mika Rantonen[b]

[a]*Finnish Meteorological Institute, P.O. BOX 503, FI-00101 Helsinki, Finland,* [b]Jyväskylä University of Applied Sciences*, P.O.BOX 207 FI-40101 Jyväskylä, Finland*
marjo.hippi@fmi.fi

Background

Finnish Meteorological Institute (FMI) has studied together with Jyväskylä University of Applied Sciences (JAMK) how to estimate visibility on the roads based on camera data. Camera data can be for example a still picture from road weather camera or video data from car's dash board camera. JAMK has used neural network technology to estimate the level of visibility from camera data.

The idea is to classify the observed visibility into three classes (normal, poor and very poor) and clarify the reason for the reduced visibility (snowfall, sleet, drifting/blowing snow on the road surface). Also, weather observations has been used to identify the precipitation form (snow, sleet or rain). Fog and rain are not included in to this study. In the meteorological point of view very poor visibility means that the horizontal visibility is 1000 meters or less.

Juga et al. have studied massive wintertime pile-up cases taken place in Finland [1, 2] and low visibility has played a significant role in those cases. Low visibility and icy road surface with low friction is a challenging combination for road safety. The aim of this study is to develop an image recognition system that could be used in targeted warnings about reduced visibility which can be delivered to drivers for example via wireless networks [3].

Neural network architecture and training process

Today terms like artificial intelligence (AI), machine learning (ML), and deep learning (DL) are big topics to deal for example big data. In this study, the deep learning algorithms are used to recognize the visibility from the images. Machine and deep learning algorithms can be used to building an approximate model of some function, such as extracting visibility from an image. The models are trained with a large dataset of training examples.

The algorithm relies on a convolutional neural network which is used to predict a single scalar (visibility) from the input image. Convolutional neural networks are one of the most widely used neural network models in image recognition and other image based regression tasks [4]. The main advantage of convolution layers is the ability to detect the same features independent of location within the input image.

A dataset of images with varying levels of visibility were chosen to train the network. A small portion of this dataset extracted to be the evaluation dataset, which was used to evaluate the performance of the network.

The rest of the data was used as training data. Only the image was used as an input: no other variables were used in predicting the visibility.

Due to the limited amount of training data and to avoid overfitting, several dataset augmentation techniques are used to grow the size of the dataset. Tools such as cropping, padding, rotation, flipping, contrast adjustment and random noise are used to alter the original training image data.

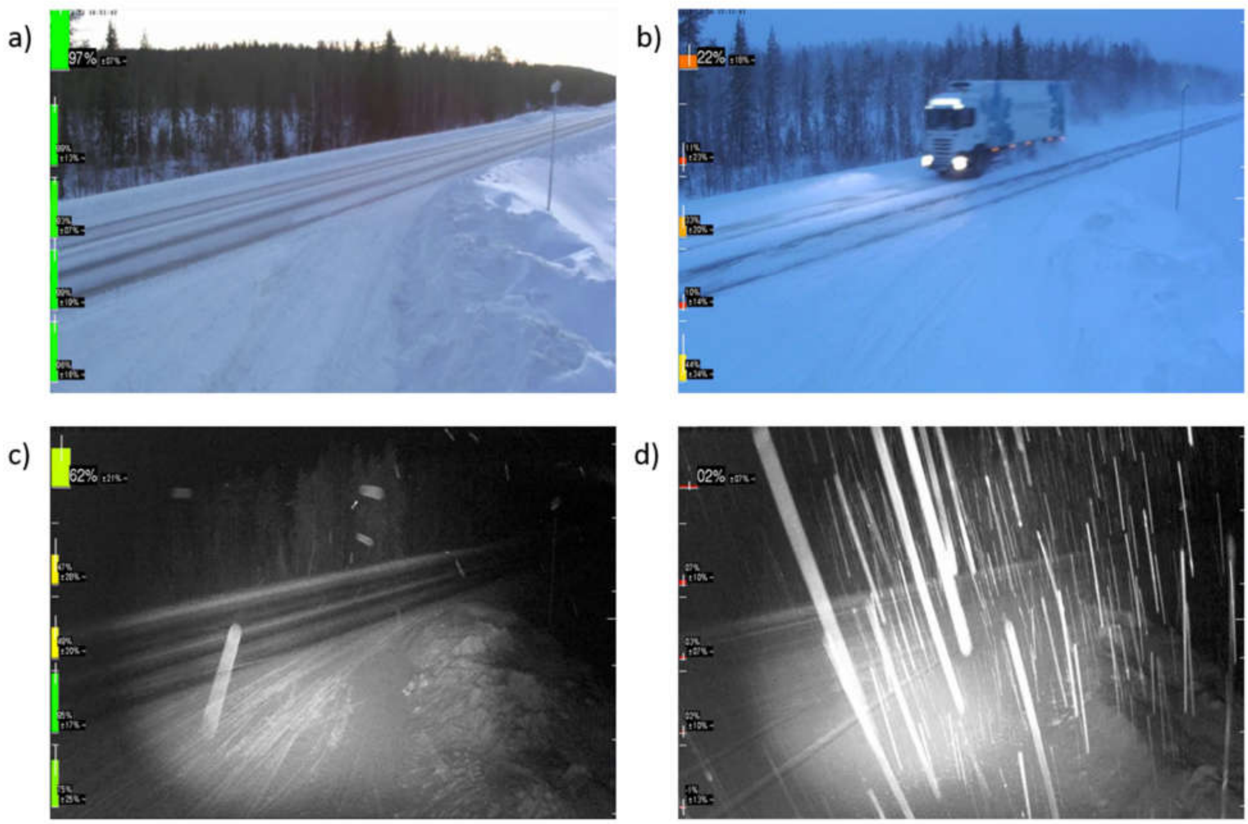

Fig. 1. *Different visibility classes based on neural network analyse of road weather camera pictures. Panel a) presents good visibility, b) very poor visibility (blowing snow), c) poor visibility (snowfall) and d) very poor visibility (snowfall).*

All of the networks were trained with Adam optimization algorithm with the suggested default settings [5]. All layers used Rectified Linear Unit, (ReLU) [6] as their activation function, other than the final fully connected layer which used no activation. The uncertainty quantifier [7] was implemented with the softplus activation function and the value for the lambda hyperparameter was chosen to be 3.25.

Results

Analysed visibilities from road weather camera picture are presented on figures 1a – 1d. Percent values on the left hand side present the relatively visibility, where 100 means good visibility and 0 very poor visibility. The percent value on top is an average of four different percent values analysed by using different neural network technique.

Acknowledgements. *This work has been supported by 5G-Safe project funded by Business Finland.*

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Poster Session

VALIDATION OF ROAD WEATHER MODEL ROADSURF IN FENNOSCANDIA USING REGIONAL CLIMATE MODEL DATA

Erika Toivonen, Joni-Pekka Pietikäinen, Marjo Hippi, Hannele Korhonen, Ari Laaksonen & Markku Kangas

Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland

erika.toivonen@fmi.fi

At northern high latitudes, road traffic sector benefits from improved local and regional climate information. These regions experience frequent winter-time snow and ice conditions, and traffic weather conditions can also change quickly with e.g. the onset of snowfall or during rapid temperature variations around the freezing point. Systematic consideration of upcoming weather events helps not only the general public in safe every-day commute but also the road maintenance authorities to attend the roads in a cost-effective manner. In Finland, Finnish Meteorological Institute (FMI) has a duty to issue warnings of hazardous traffic conditions to the general public. To support this purpose, the institute has developed a road weather model RoadSurf, which has been in operational use since 2000 (1). RoadSurf produces information on road surface temperature, friction as well as road surface classification index describing the status of the road surface (e.g. dry, snowy or partly icy) and a traffic index describing the weather-related traffic conditions (normal, difficult or very difficult) which are used when issuing road weather warnings.

The road weather conditions are expected to be altered by the ongoing anthropogenic climate change throughout the inhabited northern high latitudes as this region is strongly impacted by the Arctic amplification of climate warming. For example, winter months in Finland have warmed most rapidly (by 3-4 degrees) and this trend is projected to continue in the coming decades. In addition, precipitation is projected to increase, most strongly in the northern part of Finland in winter-time (2). The expected warmer and wetter future climate implies new challenges to road maintenance and traffic safety as precipitation events are likely to shift towards less snowfall and more frequent rain and sleet episodes. This would decrease the snowy road conditions, but at the same time increase wet road surfaces, which could lead to more frequently observed icy road conditions during the night and the morning. It is also possible that outside the summer season the events of rapid temperature change around the freezing point will become more frequent leading to increasing black ice conditions and making the roads more vulnerable to erosion.

We have combined a high-resolution regional climate model, the HIRLAM–ALADIN Regional Mesoscale Operational Numerical weather prediction In Europe (HARMONIE) Climate (HCLIM) (3), and RoadSurf to study how the future road weather will be affected in Fennoscandia by the climate change. Currently, the combined HCLIM–RoadSurf configuration has been evaluated against 25 traffic weather stations in Finland (**Fig. 1**) in terms of road weather conditions in the present-day climate. For the evaluation, HCLIM was run for the years 2002–2014 with a horizontal domain resolution of 12.5 km*12.5 km and with 65 vertical levels. The lateral boundary conditions of HCLIM were taken from ERA-Interim reanalysis, and the HCLIM data was further utilized by RoadSurf. The first results show that the HCLIM-RoadSurf modeling system is able to predict the road surface temperature with a very high accuracy. In addition, the model produces realistic road surface conditions, although it tends to predict more partly icy road conditions compared to the observations. However, the evaluation of HCLIM-RoadSurf indicates that this model configuration can be used further to estimate the effects of climate change on the road weather conditions in Fennoscandia.

Fig. 1. Locations of the road weather stations used for the model evaluation. Stars are representing stations which have also an optical sensor defining e.g. friction.

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ICEWARN – ROAD WEATHER FORECASTING FOR PRAGUE CITY

Zacharov Petr[a], Bližňák Vojtěch[a], Pešice Petr[a], Pop Lukáš[a], Sedlák Pavel[a], Sokol Zbyněk[a]

[a]*Department of Meteorology, Institute of Atmospheric Physics, Czech Academy of Sciences, Boční II 1401, Prague 14131, Czech Republic*
petas@ufa.cas.com

I. INTRODUCTION

The Institute of Atmospheric Physics (IAP) CAS, Prague, and the Czech Hydrometeorological Institute (CHMI) have developed and currently run FORTE model for Road Surface Temperature (RST) and Road Surface Condition (RSC) forecasts within the ICEWARN project. The goal of the project is to develop a method for a linearly continuous forecast of RST and RSC in Prague city. The model stems from the METRo model (METRo, Crevier and Delage, 2001) and is based on solving the energy balance and heat conduction equations. The FORTE model differs mainly in detailed check of input data (i.e., data quality control) and that radiation fluxes are calculated taking into account shadowing of direct sun radiation by obstacles along the roads. In addition, the model is run every hour in nowcasting mode, when a potential risk on roads is expected. The model uses measured data from road weather stations (RWS), and forecasts of the numerical weather prediction (NWP) model ALADIN as inputs to prepare temperature, radiation and precipitation forecasts (Sokol et al., 2014, 2017). The model utilizes detailed topography, such as parameters of buildings, woods and orography, which can influence direct solar radiation.

II. DATA DESCRIPTION

The RWS data consists of 21 RWS managed by the Technical Administration of Roadways of the Capital of Prague and about 20 RWS managed by Road and Motorway Directorate of the Czech Republic. The RWS measure mainly road surface and air temperature, often also wind speed, subsurface temperature, humidity and precipitation. Data forecasted by the NWP model ALADIN, which is operated by the CHMI, are available every 6 hours in a horizontal resolution of 4.7 km and 1-h temporal resolution. Data used for the model run include air temperature and humidity at 2 m, wind speeds at 10 m, pressure at the ground, cloud cover and accumulated precipitation and its type (rain/snow).

III. DATA FLOW

Before the model run, ALADIN data are linearly interpolated to the positions of RWS and, at the same time, the RWS data are checked by set of procedures correcting and/or eliminating erroneous measured data values. The most common errors include abrupt jumps of the temperatures, measuring only zero temperatures or switched sensors of subsurface temperatures in 5 and 30 cm depth. An overview of the data flow is shown in Fig. 1.

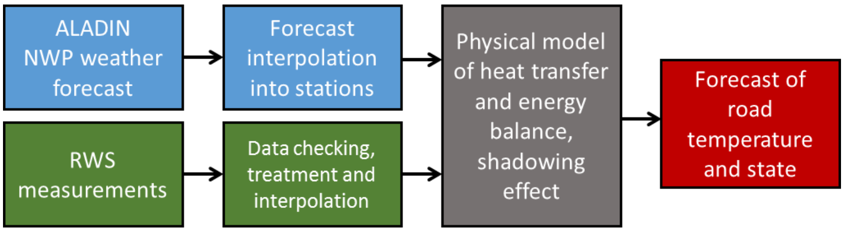

Fig. 1. Block diagram of ICEWARN forecast process.

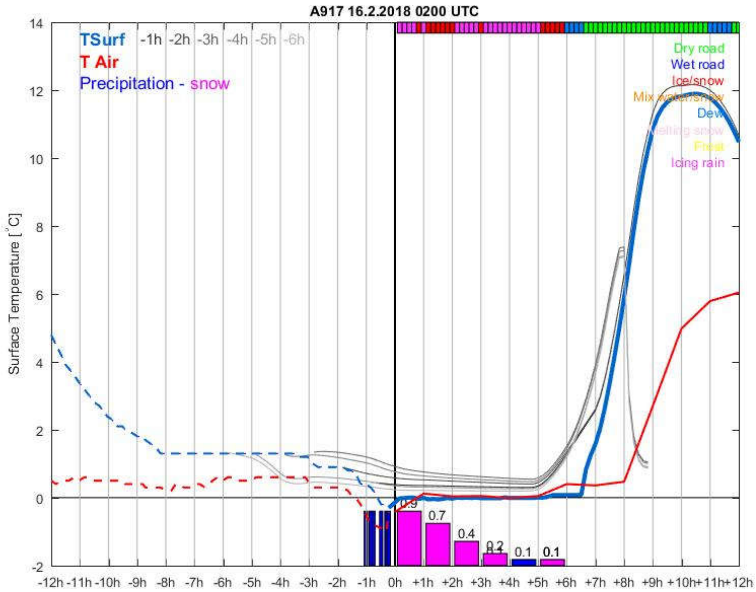

Fig. 2. Measurements (dotted lines) and forecasts (full lines) of model FORTE from 16 February 2018, 0200 UTC at the A917 RWS. Blue line depicts RST, red line shows air temperature at 2 m, and grey lines show previous model forecasts of RST so that the lighter is the colour the older is the forecast (see legend in the upper left corner). The bars on the bottom show observed (binary format, before 0h) and forecasted precipitation (total 1-h amount, after 0h) in a state given by colour (see legend in the upper right corner). The forecast of RSC is marked by small rectangles on the right top (see legend in the upper right corner).

IV. MODEL FORECASTS

An example of the model forecast from 16th February 2018, 0200 UTC at the station A917 is shown in Fig. 2. Snowfall and temperatures around 0°C caused slippery roads and transport complications in Prague. One of the goals of the presented contribution will be an objective evaluation of this event with observations on several RWS using various verification scores (i.e., bias and/or RMSE). A linear forecast of the RST and RSC will be presented as well.

V. CONCLUSIONS AND OUTLOOK

The forecasting system ICEWARN enabling a 1-h linear forecast of the RST and RSC has been successfully developed for Prague city roads and its operational run is planned in the near future. The next step is implementation and assessment of the impact of sky-view factor.

Acknowledgement:
The work was supported by the project CZ.07.1.02/0.0/0.0/16_023/0000117: Forecasting of road-surface temperature and road condition on the area of Prague in winter season provided by Operational Programme Prague – Growth Pole of the Czech Republic. 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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3. Sokol, Z., et al., 2017, Ensemble forecasts of road surface temperatures, *Atmos. Res.*, *187*, 33–41.

THE WINTER MAINTENANCE OF ROADS SITES WITH SNOWDRIFT

Tatiana Samodurova, Olga Gladysheva, Konstantin Panferov, Iurii Baklanov,

Natalia Alimova

Department of Roads and Bridges Designing, Voronezh State Technical University,

20-letiia Oktiabria, 84, Voronezh, Russia, 394006

samodurova@vgasu.vrn.ru, ov-glad@ya.ru

Designing of snow protection is necessary for winter maintenance of roads sites with possible snowdrift. The solution of these problems is especially important in Russia, which have an extended road network and different climatic conditions during the winter.

The special road climatic map was made to solve the problems of designing snow protection of roads. The special road climatic map is a map with isolines for specific territory, corresponding to the same snowbring volumes to the road. The information on the map allows to reveal the prevailing direction of snow transfer and to estimate the possibility of snowdrifts formation in separate road sections with the given road direction.

The maps set from 16 maps with the estimated snowbring volume for roads with different directions was created for each region of Russia. The maps of the distribution parameters that are used for designing snow protection were created additionally: the map with distribution of the blizzards duration, the map with distribution of the average density of the snow cover and the map with distribution of the coefficient of snow losses from melting and evaporation during thaw.

The example of map with the snowbring volume for roads towards the north (left) to the south (right) with the probability of exceeding 10% for Voronezh region is shown in Fig.1.

The map on the Fig.1 can be used for designing temporary snow protection to the left of the road for roads with direction to the north and to the right of the road for roads with direction to the south.

The snowbring volumes taken from the map allow to determine a type of snow protection, to determine the number of shields rows or nets, number of snow trenches, to determine the distance from the road. The full maps set allow to design any type of snow protection for a large area.

The maps set can be used for road winter maintenance, construction and reconstruction projects.

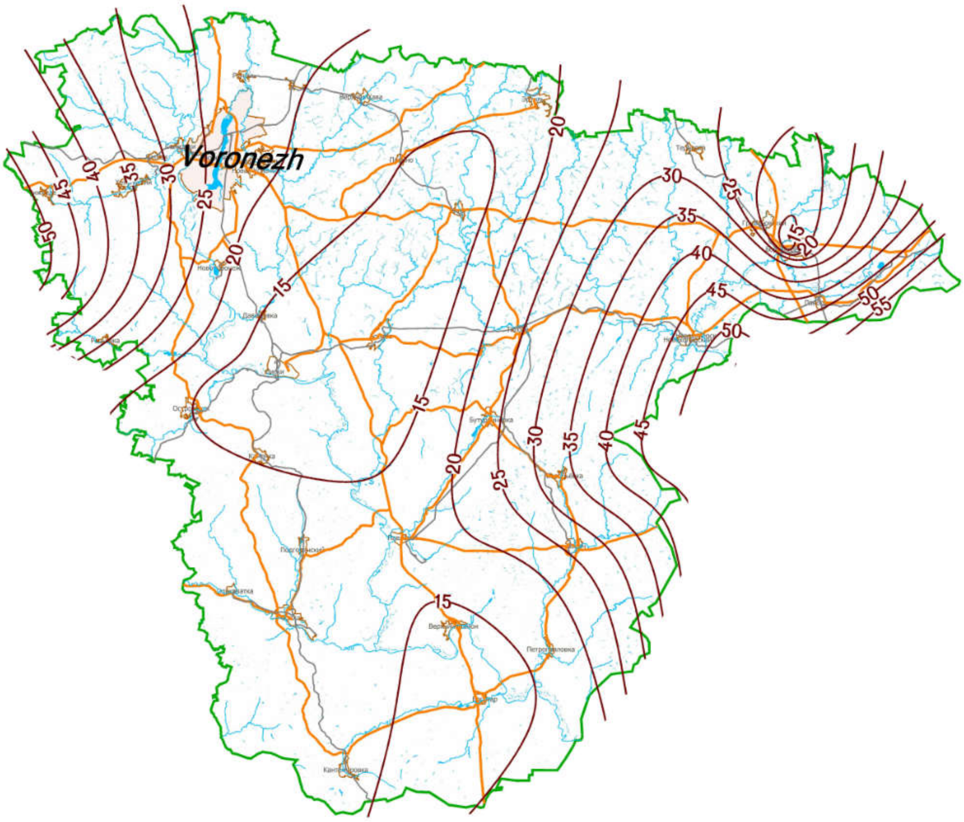

Fig. 1. The map with the snowbring volume for roads towards the north (left) to the south (right) with the probability of exceeding 10% for Voronezh region.

The maps can be represented as a set of layers for the designing of snow protection using information technology. The layers scheme is shown in Fig.2.

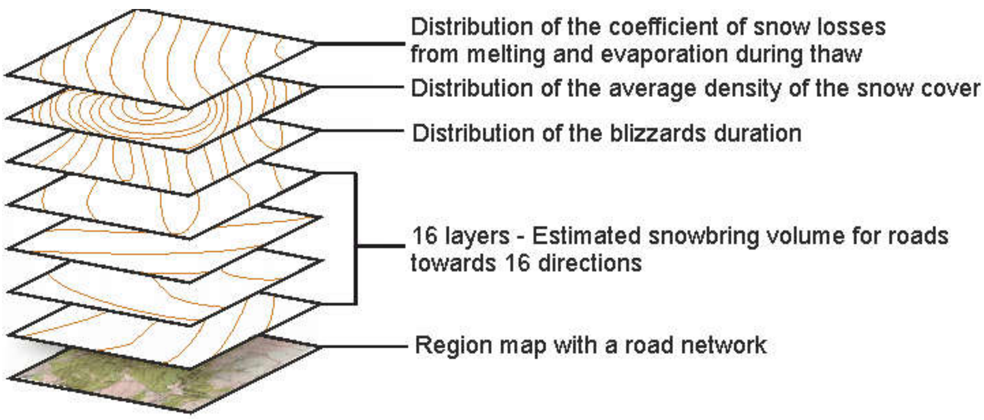

Fig. 2. The layers scheme.

The layered data organization allows the use of GIS technology for different stages of the road life cycle.

The integration of special road-climatic maps into GIS allows to automate the process of snow protection designing.

The technology of using the special road-climatic maps in the design of snow protection:

1. The location of the road section found on the map.

2. The direction of each road section (the azimuth) is determined from satellite images.

3. The selection of necessary maps (layers) with snowbring volumes and additional parameters is done in accordance with the direction of the road sites with possible snow drift.

4. The database is formed with addresses and direction of the road sites with possible snow drift, and snowbring volumes. The database can be supplemented with recommended snow protection options.

5. The variants of snow protection for the road section are selected according to the estimated snowdrift volumes using the recommendations of normative documents.

The special road climatic maps with the blizzard parameters also can be used to solve the following problems: detection of road sites with possible snow drifts; designing different variants of snow protection (forest belts, fences, etc.); planning snow removal (snow plowing); calculation of resources (equipment, anti-icing materials) for winter road maintenance.

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FLOWKAR: USING HIGH-RESOLUTION DATA FROM VEHICLE SENSORS TO IMPROVE OPERATIONAL WEATHER PRODUCTS

Hella Riede[a], Alexandros Bouras[a], Zoi Paschalidi[a], John-Walter Acevedo-Valencia[a], Thomas Kratzsch[a], Jens Nachtigall[b]

[a]*Deutscher Wetterdienst, Frankfurter Str. 135, 63067 Offenbach am Main, Germany,* [b]*AUDI AG, August-Horch-Straße, 85055 Ingolstadt, Germany*

hella.riede@dwd.de, alexandros.bouras@dwd.de

The demand for higher spatial and temporal resolution of routine weather products is rising. Among potential users is the car industry and autonomous driving community, eager to asses all possible environmental conditions necessary to gauge driving safety. On the other hand, passenger cars already generate large amounts of data, which mostly relate to the operation of the vehicles, but also include environmental data, for instance temperature, pressure, precipitation, or visibility.

To explore the mutual benefits of data exchange between passenger vehicles and weather services, Germany's National Meteorological Service (Deutscher Wetterdienst), cooperates with the German car manufacturer AUDI AG in the joint research project FloWKar (1), which started in September 2017.

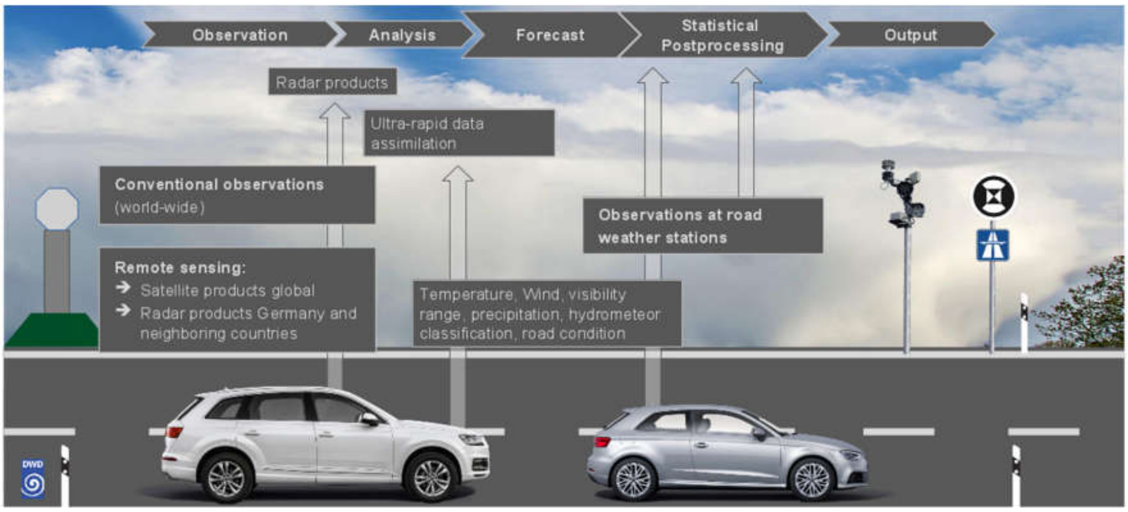

Fig. 1. Concept for using vehicle sensor data and combining it with existing data sources and meteorological methods.

For the German Meteorological Service, the goal is to assess how environmental data from millions of cars on Germany's roads can be used, in real-time and respecting data protection laws, to improve weather products, nowcasting, and weather models (**Fig. 1**).

The observations on-board passenger vehicles will fill observational gaps between weather stations and road weather stations, with a special focus on the German road network. The nowcasting of precipitation events is expected to benefit from vehicle data by providing information near the ground in high spatial and temporal resolution, where quantitative precipitation estimates as well as hydrometeor classification based on radar remote sensing alone prove difficult.

Vehicle data, such as temperature and pressure will be employed in a unique new ultra-rapid data assimilation cycle within the regional operational weather model COSMO-DE. In 5-minute time steps, vehicle data will be used to optimize model performance near the ground. This is expected to improve model predictions for mountainous and coastal areas. It will also play a role in proceeding towards higher spatial and temporal model resolution by providing the necessary observations at correspondingly high resolutions.

Model output statistics may use the additional data to optimize model output for specific locations that prove pivotal to driving safety, e.g., for extreme cold spots in the road network.

The main challenges are expected to be

- the proper assessment of the passenger vehicle sensor data quality according to weather service standards, before incorporating the data into existing operational methods
- the planning of measurement campaigns with accompanying mobile weather service equipment
- the development of suitable data models to produce reliable meteorological information by combining available sensor data
- the real-time exchange of data between commercially available vehicles and weather service with time resolution on the order of a few minutes
- and to verify the benefit for meteorological operational methods from incorporating vehicle sensor data.

This work is supported by the mFUND funding initiative of the German Federal Ministry of Transport and Digital Infrastructure.

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AUTOMATIC ANTI-ICING SPRAYING SYSTEM ON THE WEST HIGH SPEED DIAMETER IN SAINT-PETERSBURG

Mark Vinogradov[a], Tatiana Bazlova[a],
Nikolay Bocharnikov[a], Alexander Solonin[a]

[a]*Institute of Radar Meteorology (IRAM), Russia*
vms@iram.ru

The highway West High Speed Diameter (WSHD) is a complicated engineering object comprising flyovers, bridges and tunnels over more than its half-length. It consists of low and high sections and stretches over 46 km under the influence of different local climate conditions. Road surface temperature and conditions are influenced by a wide range of meteorological, geographical and road construction parameters.

The Automatic Anti-Icing Spraying System (AAISS) has been installed on the WSHD and put into operational use since 2017 to facilitate the highway capacity and safety. Installation sites are seven sections of the highway with a small radius of curvature and high-elevated bridges. The AAISS is comprised of a storage tank, a pump and delivery system. The number of spray nozzles varies from 50 to 200 depending on the length of the section. Each section has RWS, which controls air temperature and humidity, wind parameters, rainfall intensity, temperatures of road surface and at a depth of 10 cm, surface conditions including grip. The RWIS MeteoTrassa (1) collects data from RWSs and manages of the AAISS starting on the basis of algorithms with precipitation and road icing nowcasts taken into account. Doppler weather radar data enables to nowcast precipitation for two hours ahead in terms of onset and cessation of rainfall, precipitation phase, intensity, amount of rainfall for separate sections of the highway. The MeteoTrassa provides nowcasts road surface temperature and icing for each section based on a local atmospheric boundary layer numerical model. When predetermined threshold values are met, the MeteoTrassa initiates spray program automatically. Operator is also able to start spraying in manual mode. Conventional treatment strategies (e.g., plowing and salting) supplement the AAISS if slush or snow accumulates on the road.

For a year of operation the system has proved to be an effective mean of emergency slip prevention in difficult weather conditions.

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PROPOSAL OF A CORRECTION COEFFICIENT FOR THE ESTIMATION OF GROUND SNOWFALL AMOUNTS BASED ON X-BAND MULTIPLE PARAMETER RADAR PRECIPITATION DATA

Satoshi Omiya, Tetsuya Kokubu, Hiroki Matsushita, Masaru Matsuzawa

Civil Engineering Research Institute for Cold Region (CERI), PWRI

Hiragishi 1-3, Toyohira-ku, Sapporo, 062-8602, Hokkaido JAPAN

somiya@ceri.go.jp

1. Introduction

In order to carry out effective winter-time road management, which involves decision making regarding when to close roads and when to launch winter service vehicles, it is essential to accurately estimate snowfall amounts in different spots. X-band multiple parameter radars (hereinafter referred to as "X-MP") that have been established all across Japan by the Ministry of Land, Infrastructure, Transport and Tourism are widely used as an effective means to monitor concentrated heavy rains and localized downpours. Meanwhile, X-MPs still have some problems in terms of the accuracy of snowfall amount estimations. This study aims to compare publicly distributed X-MP radar precipitation data during snow against actual ground snowfall amounts and to improve the accuracy of ground snowfall amount estimations based on X-MP data.

2. Methodology

There are two X-MP stations (Ishikari Station and Kita-Hiroshima Station) near Sapporo City, Hokkaido Prefecture. This study compares and analyzes synthesized radar precipitation data obtained through X-MP observations against actual ground snowfall amounts and examines how we can improve the accuracy of snowfall amount estimations based on X-MP data. The X-MP radar precipitation data used in this analysis was downloaded from the Data Integration and Analysis System (DIAS) [1)]. Actual ground snowfall amounts were observed at CERI's Ishikari Blowing Snow Test Field (43 degrees, 12 minutes north latitude and 141 degrees, 23 minutes east longitude). This test field constantly collects weather data, including wind direction and velocity and temperature. Figure 1 shows the locations of the two X-MP stations and the Ishikari Blowing Snow Test Field. Ground snowfall amounts were measured with the Double Fence Intercomparison Reference (DFIR), a gauge recommended by the WMO [2)], and a weighing precipitation gauge (Geonor T-200B).

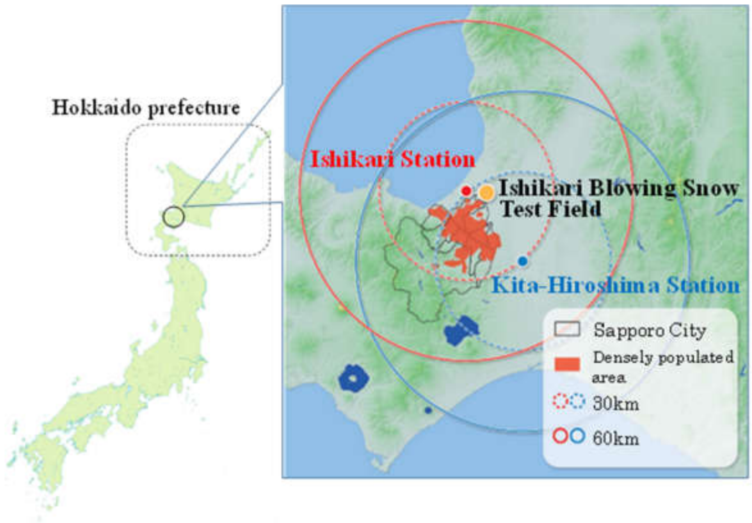

Figure 1 Locations of the two X-MP stations and Ishikari Blowing Snow Test Field

3. Data analysis

The comparison analysis used data collected during wintertime over three years (December 1 to March 31 from FY2014 to FY2016). 250-meter-mesh X-MP radar precipitation data is distributed every minute. In this analysis, ten-minute precipitations were calculated based on X-MP radar precipitations in the mesh right above the DFIR. The calculated ten-minute precipitations were compared against ten-minute ground snowfall amounts. Since this study focuses on snow, only the data collected under a zero or lower ground temperature was used. While the X-MP radar precipitation data was collected in the air, the DFIR observation data was collected on the ground. This means that comparison of this data would require us to take into account the advection effect of wind for falling snow particles and the time that snow particles take to reach the ground. Here, we only analyzed data less than 0.3 m/s, and we assumed that the time to reach the ground was ten minutes.

4. Results

Figure 2 shows the relationship between X-MP radar precipitations and ground snowfall amounts (converted into water amounts). The dashed lines in the figure are isopleths at the ratio of 1:1. These results reveal that X-MP observations at the time of snow tend to overestimate ground snowfall amounts. The solid lines in the figure show an approximation formula between X-MP observation values and ground observation values. The determination coefficient R^2 is 0.55 and RMSE is 0.06 mm, which means that this formula well explains ground snowfall amounts. In other words, the accuracy of winter-time X-MP radar precipitations can be improved by using the coefficient of 0.71 of the formula shown in the figure as a correction coefficient.

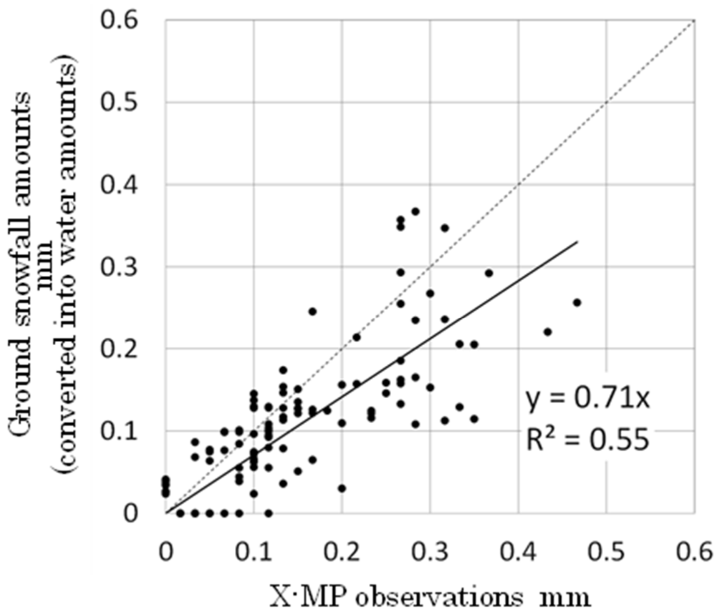

Figure 2 Relationship between X-MP observations and ground snowfall amounts

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DETECTING THE HYDROMETEORS BASED ON MULTI-FREQUENCY PASSIVE MONITORING OF MOBILE NETWORK STATIONS SIGNALS

Peter Fabo[1], Pavol Nejedlík[2], Dušan Podhorský[2], Michal Kuba[1], Anna Buchholcerová[2]

[1]*University of Žilina Research Centre, Žilina, SK,*
[2]*Earth Science Institute of SAS, Bratislava, SK*

Intensive convective phenomena show strong variability in space and time, from tenths to hundreds of meters and from tenths of seconds to minutes. Atmospheric hydrometeors interfere electromagnetic signal in atmosphere. The magnitude of the interference is relative mainly to the intensity of precipitation. This fact enables us to detect the hydrometeors by monitoring the changes of electromagnetic signal either by active broadcasting of the signal and by detecting its part reflected by the hydrometeors or by passive receipt of the signal from different broadcasters.

Despite of the massive technical advancement in measurement of meteorological parameters and phenomenon in situ, for example by installing the automatic weather stations including the modern pluviographs, disdrometers, by completing optimal automated network and meteorological radars, there is relatively little effort in Europe being put into the use of data based on the evaluation of attenuation and signal drop-out on the telecommunication lines for hydrometeors detection.

The use of the methods of multi-frequency passive monitoring of the anthropogenic sources of electromagnetic energy around 1 GHz by means of which we can measure the parameters of attenuation and dropout of electromagnetic signal with the time resolution of 100m and space resolution a few seconds can enable to detect the hydrometeors in the peplosphere. Besides this fact the relation between the attenuation/signal drop-out and precipitation intensity shows lower sparsity and is closer to linear in contrast to highly non-linear relation between the precipitation intensity and reflected signal broadcasted by meteorological radar (Leijnse et al., 2007). It appears that the information derived by this method can not be obtained by other available methods and may supplement the information about precipitation field in concrete space.

Presented paper will discussed the possibilities of application of the method in the field of precipitation detection, fog and extraordinary phenomena.

Based on the utility model of the receiver system to measure parameters of multispectral electromagnetic smog there was measured and evaluated data about the time of occurrence, intensity and space distribution of hydrometeors in meso and micrometeorological space in the boundary layer of the troposphere. The processing and evaluation of the received signal disturbances is done on the original physical-mathematic aparatus for Kalman filters.

The frequencies used are below those used so far for the detection of hydrometeors. It is enabled by an innovative way of retrieving the data from the radio signals by modification of Kalman filter.

Electronic equipment uses synchronized receivers to receive signals from mobile base stations with directional antennas in GSM mobile downlink frequency range (920-960 MHz). The shift of signal received by the antenas refers the composition of the atmosphere in between the broadcaster and the antenas. The signal change reflects to different phenomenon differently and further to the precipitation or general hydrometeors there are detected more impacts on the signal (air pressure change, turbulence, air flow…). Nevertheless, the signal reacts mostly on the precipitation and also the intensity of the precipitation close to the ground can be derived from this data (see fig. 1).

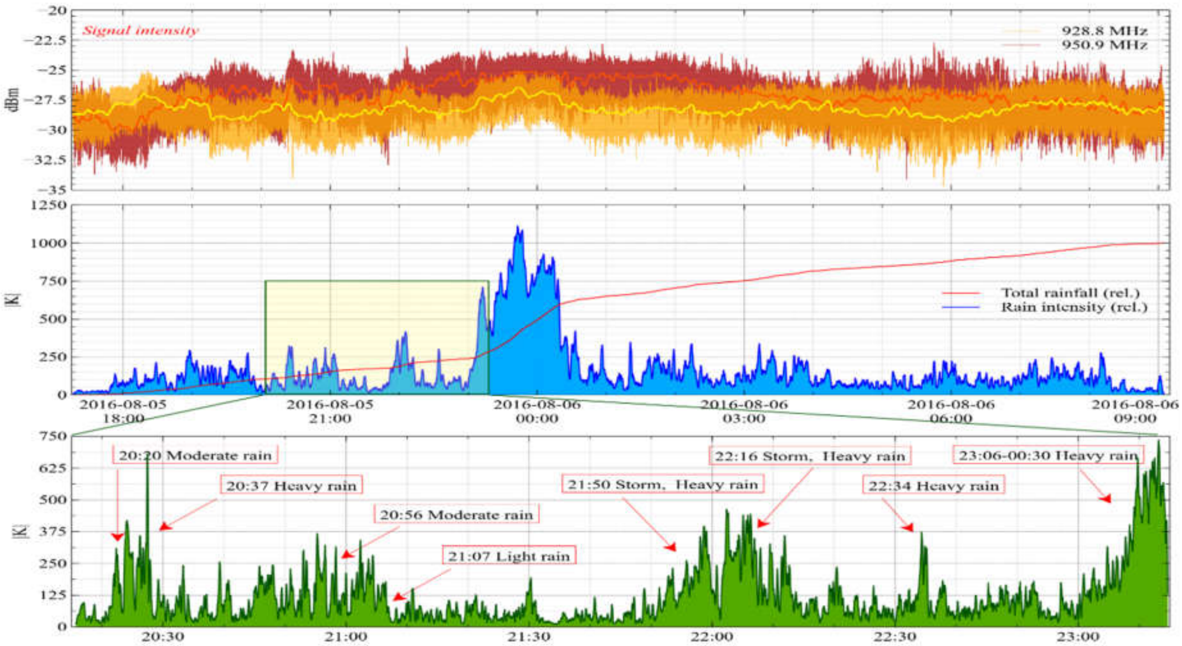

Fig. 1 The impact of atmospheric hydromemeteors (precipitation) on the electromagnetic signal.

The equipment for the detection of hydrometeors in the boundary layer close to the ground is under the development and was not calibrated towards the in situ measurements so far. Nevertheless, the measurements showed us the possibility to detect the presence of hydrometeors in the atmosphere with high space resolution in real time. This opens its use in many branches including the various types of ground transport as the space of transport lines in many countries is well covered by the respective signal.

Acknowledgement: this work was supported by the VEGA grant 2/0015/18.

Reference:

Leijnse, H., Uijlenhoet, R., Stricke, J.N.M, 2007, Rainfall measurement using radio links from cellular communication networks. https://doi.org/10.1029/2006WR005631.

INFLUENCE OF SHADING AND SKY-VIEW FACTOR ON ROAD TEMPERATURE FORECAST

Pavel Sedlák[a], Vojtěch Bližňák[a], Petr Pešice[a], Lukáš Pop[a], Zbyněk Sokol[a], Petr Zacharov[a]

[a]*Department of Meteorology, Institute of Atmospheric Physics, Czech Academy of Sciences, Boční II 1401, 14131 Prague 4, Czech Republic*
sedlak@ufa.cas.cz

VI. INTRODUCTION

Within the ICEWARN project, the Institute of Atmospheric Physics of CAS, Prague, and the Czech Hydrometeorological Institute currently collaborate in developing and application of the FORTE model for a linearly continuous road weather forecast in the city of Prague (1). The model stems from the METRo model (2), the initial modifications being described in (3). The ensemble method (4) is not applied in the current project ICEWARN. In cities, the impact of obstacles on the modification of radiation fluxes, and consequently on the road temperature, is of a particular importance. The modification includes shading the direct shortwave radiation and the sky view restriction. Our present contribution is focused on implementing and testing a parametrization of these effects in the FORTE model.

VII. METHODS AND MODEL TESTS

Radiation fluxes on the road surface are modified by the surrounding topography, buildings or trees. We prepared a detailed pre-calculated dataset where for individual points along the road, sky-view factors are stored as well as zenith angles of the upper edge of obstacles in a fine azimuthal resolution.

In the computation of modified radiation fluxes in the FORTE model, at each time step the decision whether shading of the direct shortwave radiation occurs is based on a comparison of the Sun zenith angle with the stored obstacle information for the corresponding azimuth. For the sky-view effect on the longwave and the diffuse shortwave radiation, we adopted a simple parametrization according to Müller and Scherer (5). Four model versions are tested:

I. no modification of radiation fluxes applied
II. only shading of direct shortwave radiation included
III. shading + sky-view effect after (5)
IV. shading + sky-view effect after (5) but omitted reflection of shortwave radiation

Model results are evaluated against the road temperature measurements.

VIII. RESULTS

When evaluating the model results for a winter period as a whole, shading effects were found for none of the locations of road weather stations (RWS) in Prague. That was why we decided to test the model against the RWS in the NW part of the Czech Republic. An example of the root mean square error (RMSE) of the road surface temperature for 3 winter months is shown in **Fig. 1**.

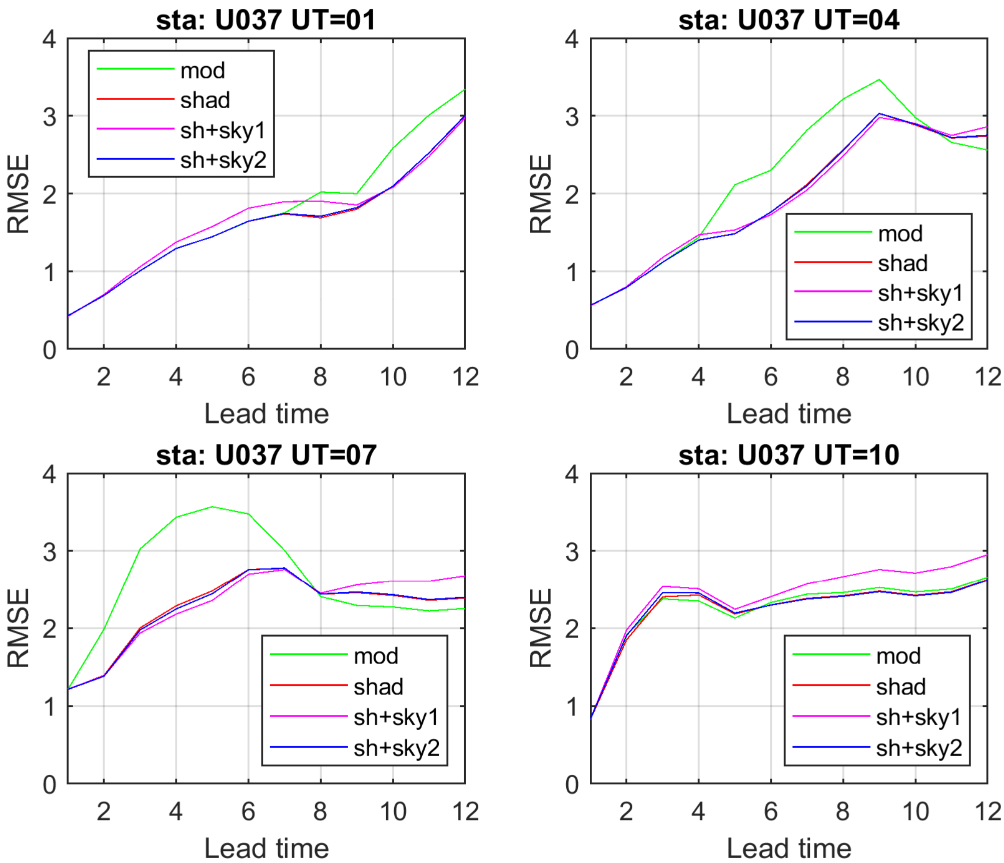

Fig. 1. Root mean square errors (RMSE, in degrees) of the road surface temperature forecast for the RWS U037, which is exposed to shading. The RMSE values were calculated for the whole period January-March 2017. They are plotted in dependence on the lead time up to 12 hours for the forecasts started at 01, 04, 07 and 10 UTC. The coloured lines correspond to the results of model version I (green line), II (red line), III (magenta line), and IV (blue line).

IX. DISCUSSION

It is evident from **Fig. 1** that including the shading effect on the direct shortwave radiation lowers the RMSE of the road surface temperature during the daylight period even if no data selection with respect to cloudiness is applied. There are only minor differences among the other model versions. The plots indicate that including the reflection of shortwave radiation (model version III), as suggested in (5) for mesoscale models, is not suitable for our purpose. Apart from the effect of modified radiation fluxes, a positive impact of starting the model run every hour in the nowcasting mode (3) is apparent when the RMSE for a certain hour is compared with the RMSE for the same hour in the run started earlier.

Acknowledgements:

The work was supported by the project CZ.07.1.02/0.0/0.0/16_023/0000117 "Forecasting of road-surface temperature and road condition on the area of Prague in winter season", provided by Operational Programme

Prague – Growth Pole of the Czech Republic, and by the project CZ.2.16/3.1.00/24512, provided by Operational Programme Prague Competitiveness. Road weather data was provided by Technical Administration of Roadways of the Capital of Prague and by Road and Motorway Directorate of the Czech Republic. ALADIN model data was kindly provided by the Czech Hydrometeorological Institute.

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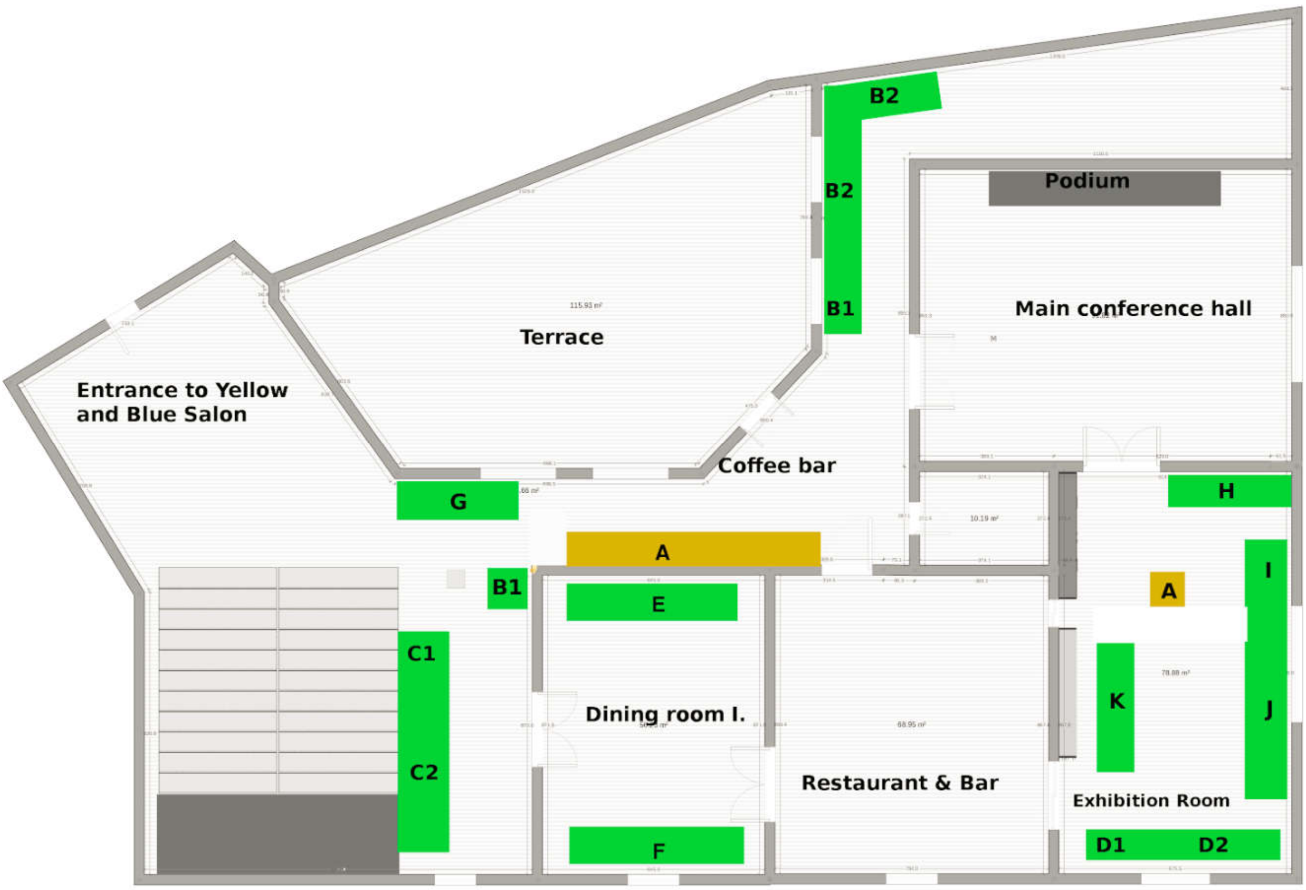
NOTES:



B2
B2
B1
Podium
Main conference hall
Terrace
Entrance to Yellow
and Blue Salon
Coffee bar
G
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A
B1
E
C1
K
J
Dining room I.
C2
Restaurant & Bar
Exhibition Room
D1
D2
F

What is SIRWEC?

The Standing International Road Weather Commission (SIRWEC) operates as a forum for the exchange of information relevant to 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 seeks to identify those areas where increased and/or new research and development may yield improvements in practices, techniques, systems and methodologies.

SIRWEC exists to encourage meteorologists, weather forecasters, highway engineers, road masters and others, who are interested in road weather problems, to exchange ideas to make our roads safer to drive on in all weather conditions.

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