SENSOR BASED ADAPTION OF TREATMENT STRATEGIES

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Topic 4. Winter service management

ABSTRACT RÉSUMÉ

With digitalisation of spreaders, recent development in wireless data transmission and road sensor technology the potential amount of data available for winter maintenance decisions grows rapidly. Thus, it becomes more and more difficult to control data quality distilling the necessary information for decision making. The research project "WinterFIT" of ASFINAG, ZAMG and Vienna University of Technology deals with issues of an optimal sensor infrastructure in order to cover large road networks with automated treatment suggestions. Based on a new holistic winter maintenance model, the integration of different types of RWIS – sensors together with extensive field measurements it was possible to achieve considerable improvements regarding decision making in winter maintenance. Combining this information from the field with the new European-wide weather nowcasting system INCA a real-time optimization of treatment strategies for the entire highway network in Austria becomes feasible. The Integrated Nowcasting Through Comprehensive Analysis (INCA) system, which has been developed at ZAMG (Central Institute for Meteorology and Geodynamics), provides improved numerical weather forecasts especially in the nowcasting range (0-6 hours ahead) on a very high resolution (1 km x 1 km). The basic idea of INCA is to complement and improve NWP direct model output using real-time observations, remote sensing data and high-resolution topographic data. The INCA system provides near-real-time analyses and forecasts for the parameters temperature, humidity, wind, precipitation amount, precipitation type, cloudiness, and global radiation. Based on the research results it was furthermore possible to build a scientific background for the selection and localization of road sensors. The paper gives an overview of the findings regarding a nowcasting and sensor based adaption of winter maintenance treatment strategies. Furthermore the necessary requirements and accuracy of weather forecasting, sensor selection and model calibration are covered as well.

KEY WORDS: RWIS – sensors, now cast, surface temperature, hoarfrost

1. INTRODUCTION AND OVERVIEW

In a previous research project for the optimization of pre-wetted salting a holistic model allowing the comprehension of winter maintenance strategies on road friction was developed at the Vienna University of Technology [1]. With this model all relevant factors like precipitation, traffic, treatment rate, road surface texture and friction are accounted for. Figure 1 provides an overview of the developed model which consists of the four modules residual salt, water film thickness, freezing point and skid resistance. Basically the applied amount of salt is reduced due to spreading losses and traffic. As a result of hoarfrost, precipitation, drying processes and road run-off the resulting water film is mixed with the residual salt and forms a brine on the road surface with decreasing concentration over time and traffic.

Depending on selected de-icing agent, brine concentration and actual road surface temperature a freezing process occurs if the road surface temperature is below the freezing point of the brine. Such freezing processes might occur despite winter maintenance but do not necessarily lead to a substantial reduction in skid resistance. Only if the road surface texture is filled with a freezing brine up to a certain extent the resulting skid resistance becomes critical for road safety. Thus, the developed holistic model allows a theoretic calculation of the resulting skid resistance for any given application rate of de-icing agents or the minimal necessary application rate to provide a given level of skid resistance at all times. An in-depth view into this winter maintenance model and its results can be found in already published or recently submitted papers [2;3;4].

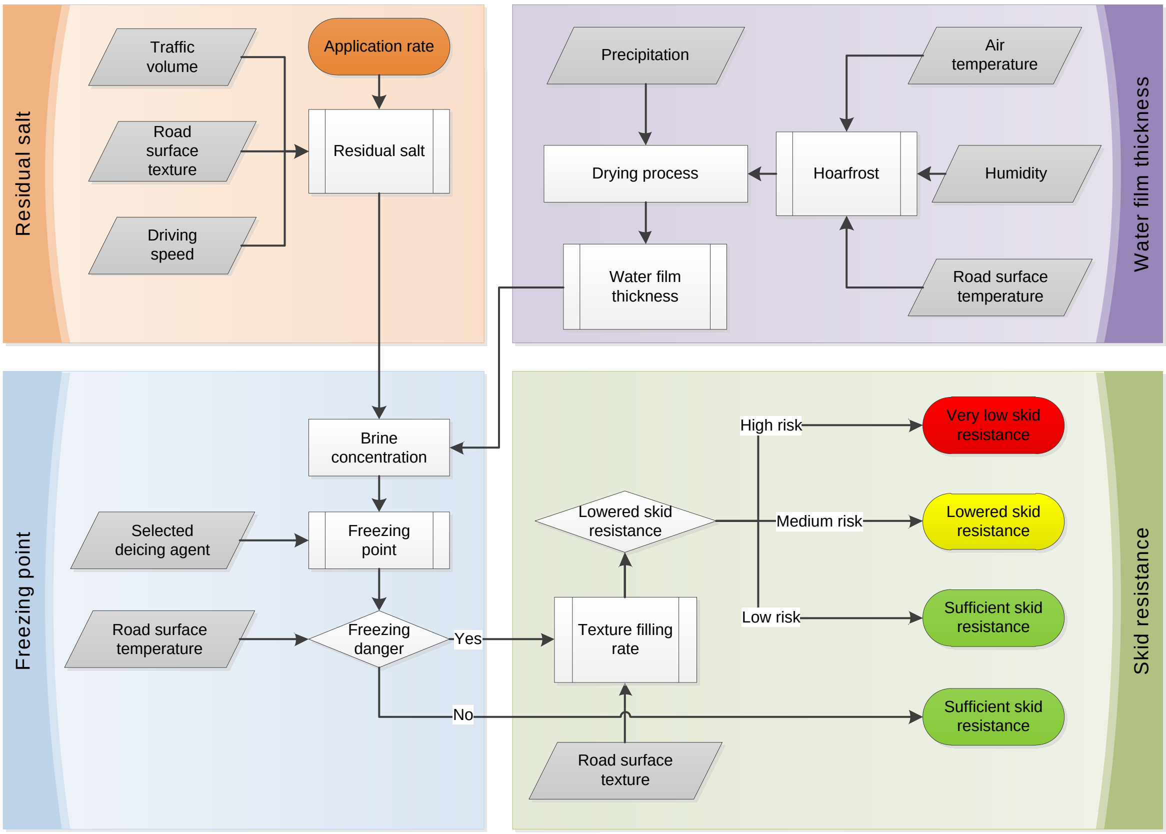

Figure 1: Winter maintenance model developed at the Vienna University of Technology

Apart from communication and practical implementation issues one of the main drawbacks of such complex holistic models for highly stochastic processes are an accurate determination of the relevant input variables and an on-going calibration based on real-time measurements. For an optimization of winter maintenance processes the Austrian highway company ASFiNAG decided to assess the potentials for an implementation of the developed model in the research project “Winterfit”. The main question in this project was the possible accuracy in the determination of optimal application rates of de-icing agents based on the existing dense network of state of the art RWIS – sensors on their road network as well as the employed weather forecasting technologies [5].

Currently the necessary model input parameter are mainly available based on periodic measurements (eg. texture, skid resistance) or real-time measurements (e.g. precipitation, air temperature, surface temperature, traffic volume) on the highway network in Austria. The winter maintenance vehicles are equipped with a GPS-based tracking system allowing a real-time monitoring of local application rates and timing. In addition the weather forecasting systems provide long and short term predictions of air and road surface temperature as well as the timing of precipitation events and precipitation rates. The long term predictions cover a time frame between 12 to 36 hours and are mainly used for scheduling and preparation of winter maintenance. The short term predictions cover a time frame between 0 to 6 hours and are used for general application strategies and application recommendations. The final decision for the actual application at specific road sections remains with the winter maintenance personnel due to their local knowledge and actual perception of the real situation.

Uncertainties in an accurate assessment of road conditions and a selection of appropriate treatment strategies as well as optimal application rates will therefore lead in most cases to higher application rates than necessary. In order to dispel such uncertainties a regular training with clear and easy to handle instructions are a must [1;6;7]. In order to improve the current standard of winter maintenance systems as well as a possible implementation of the developed winter maintenance model a validation of both RWIS – Sensor data as well as weather forecasting systems was conducted in the research project “Winterfit”.

Due to the enormous amount of data on the entire road network the efforts in the project “Winterfit” were concentrated on two highway sections with a high number of available sensors and a challenging meteorological terrain. The periodic measurements of road surface texture and skid resistance have been verified with the Griptester Mark II, laser scanning, sand patch method and a new optical device. The accuracy of RWIS – sensors for continuous measurement of road surface temperature, film thickness and residual salt have been verified with reference equipment as well.

To adapt the treatment strategies based on the sensors obviously weather information has to be considered as well. The link between road sensors and weather information in this case is a weather nowcasting tool, which uses sensor information to improve the performance of usual weather forecasts based on typical sources like weather radar and satellite images. The meteorological expertise as well as the nowcasting tool were provided by the central institute for meteorology and geodynamics in Vienna ZAMG. In order to verify the critical weather information both from common weather forecasting systems and the nowcasting tool an independent weather station was used in the project area in the winter season 2012/2013. Due to the small number of different sensor types in an restricted project area the names of sensors and weather services are not disclosed.

2. RWIS SENSORS ANALYSIS

Parameters such as road surface temperature and water film thickness tend to vary along the cross-section of a road mainly depending on traffic, gradient and condition. The surface temperature in the wheel tracks for example is up to 2°C warmer due to the friction energy and can be estimated with around +0.001°C per vehicle/lane/hour [1]. Also the water film thickness depends on how many tyres roll over the surface with each tyre transporting tiny amounts of water to or from the wheel track as central point of interest for the assessment of road conditions.

Therefore the exact position of all available sensors in the project area was determined in both GPS-coordinates and stationing with distance between sensor and edge marking. As shown in Figure. 2 most of the sensors are in an area with little tyre contact. Thus the sensors take less damage from vehicles but do not fully cover the impact of traffic on the measured parameters. Usually several sensors are combined into one measurement location (Figure 3). At one point of the project area a complete cross-section was equipped with sensors from emergency lane to the 2^{nd} lane.

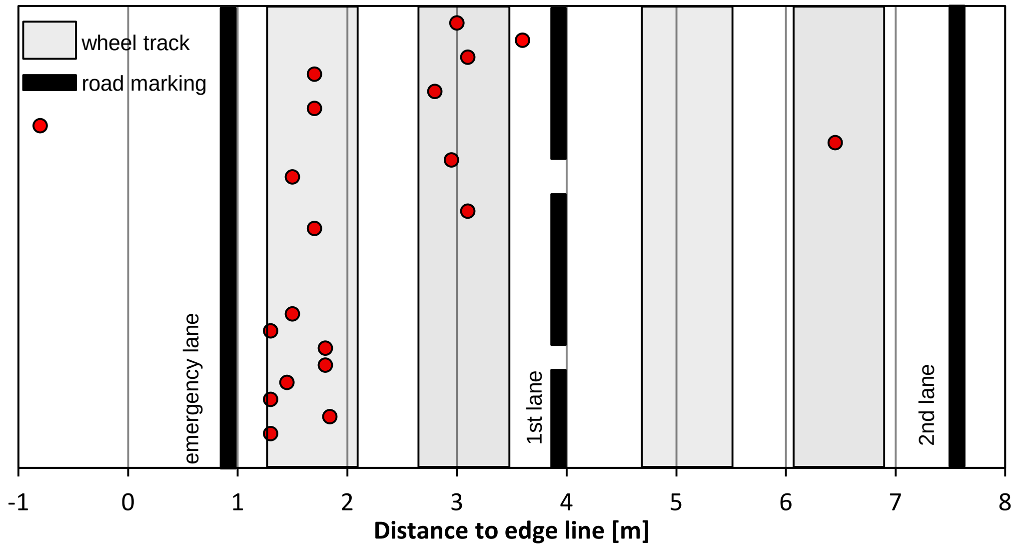

Figure 2: Placement of RWIS sensors in the project area

Based on the established location of the available sensors in the project area three specific locations were selected for additional verification measurements. Since the highway in the project area has high gradients and small curves, safety aspects had to be taken into account as well for the measurement processes. The following section of the paper provides an overview of the reference measures on road surface temperature.

2.1. Road surface temperature sensors

Road sensors for punctual pavement and pavement surface temperature measurements are essential to calibrate nowcast data from weather models with real data from the field. In contrast to embedded sensors temperature measurements with sensors on the surface face the challenge of different albedo due to the sensor material which may cause different temperature measurements compared to the pavement surface temperature. A typical layout of multiple sensors in the project area is shown in Figure 3 with 2 sensors in separate boxing and one sensor implemented in the pavement. Due to this arrangement of sensors a direct comparison of measured surface temperatures becomes feasible.

Figure 3: Typical road sensor layout in the project area

When validating the road temperature sensors with reference equipment also other kinds of surface temperature sensors were tested to check out possible measurement alternatives. Especially mobile devices promise good mobility and easy handling. Furthermore such sensors are providing a line-like temperature measurement for individual lanes at certain points in time in form of temperature profiles. By linking this temperature profiles to punctual measurements from stationary sensors it is feasible to create accurate temperature maps of the entire road network. Mounting these sensors on winter maintenance trucks would both help to choose an optimal application rate of de-icing agents [1;7] as well as to provide a regular update of these temperature profiles.

As reference equipment for road surface temperature measurements a thermometer with ±0.2°C accuracy and a matching surface probe were used. A consistent contact between the coarse road surface texture and the probe was guaranteed due to the use of thermal conductive paste. In order to avoid data lag problems with the corresponding temperature value from the sensors using the database, the actual temperature was read out at the local terminals at the same time. A stable weather situation and avoidance of shadowed areas on measurement runs provided comparable data without insolation interferences.

As mentioned before, boxed sensors tend to read out the surface temperature from the sensor which might deviate from the actual surface temperature of the pavement. The reference measurements have been done on the pavement surface in a distance of 5 cm from the edge of the sensors. To rule out local temperature peaks and minimize errors the mean of 3 measurements is used as reference temperature. Typical measurement points can be seen in the left picture in Table 1 as white dots of remaining thermal conductive paste. The technical specifications and pictures of the used measurement equipment as well as the two employed optical devices are given as well (Table 1).

The car-mounted device was both used for punctual calibration and longitudinal temperature profile measurement runs in order to validate road surface temperature forecasts. Apart from the listed measurement equipment a thermal imaging camera was employed on the first run to obtain temperature distributions for all lanes in a road section. Thermal imaging has been proved as useful to find local temperature differences in an entire area that may not be accounted for by punctual or longitudinal measurements.

Table 1: Technical specifications of the surface temperature measurement equipment

	Thermometer Testo 735-2	**Surface probe Pt100**	**Car-mounted optical device**	**IR-device**
Temperature range	-200… +800°C	-50… +400°C	-	-35… +250°C
Reaction time	-	40s	-	< 1s
Accuracy	±0.2°C	Class B	±0.3°C	±2°C / ±2%
Resolution	0.05°C		0,1°C	
				

The car-mounted optical device can be easily fitted on any maintenance vehicle due to its small dimensions of about 15 cm in length and 3 cm in diameter. Assuming a sufficient accuracy the cheap and easy to use manual IR-device may be helpful as well to check the road surface temperature if no sensors are around. As it is necessary to stop the car and get out to measure the temperature with these IR-devices their main use will be restricted to rural and local roads rather than highways with their tighter safety regulations.

The deviations of the different measurements compared to the reference equipment are given in Figure 3. The temperature value of the selected small IR-sensor is often far off with deviations from at least 1.5°C up to 5°C. The standard deviation for the IR-sensor is 2.7°C with all values below reference point as a systematic failure. Reasons for that might be found in a fixed absorption value for other materials than pavements as main focus of the device. The selected cheap IR-Sensor does not provide the necessary accuracy for an assessment of road surface temperatures and is thus unsuitable for winter maintenance.

The car-mounted optical device shows a similar tendency of underrating the surface temperature but at a considerably lower deviation. The mean deviation for this optical device is 0.59°C with the advantage of mobile measurements while driving. Furthermore, the device allows setting different absorption rates for different types of surfaces. On roads with a similar surface material or an automated correction algorithm to account for different rigid and flexible pavement surfaces the results might be even better.

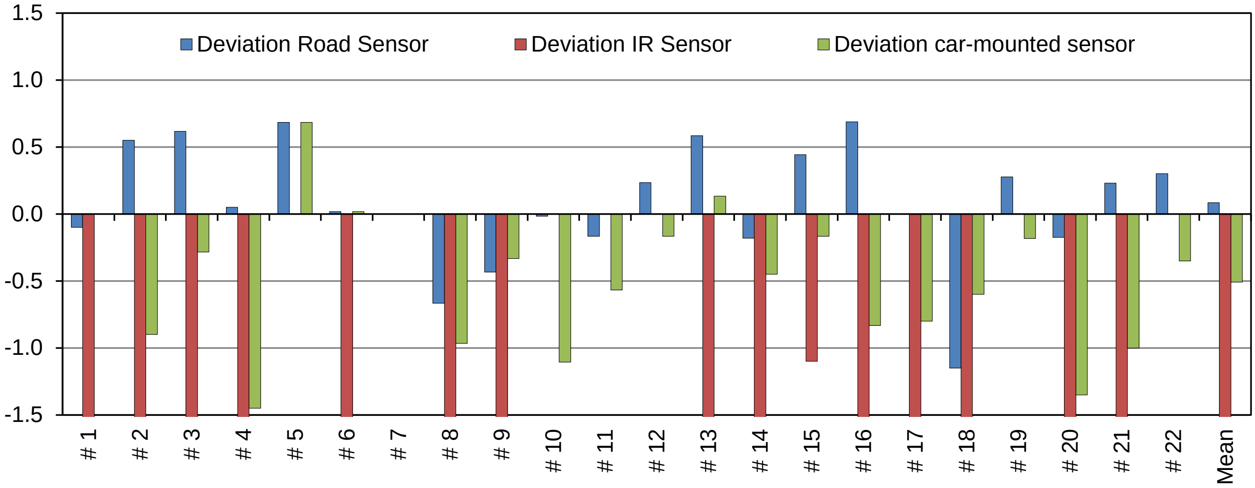

Figure 4: Deviation of tested sensor types road sensor, IR-sensor, car-mounted optical device compared to reference measurement at 22 different stations

The result of a comparison of different types of built in road surface temperature sensors is given in Figure 5 for five different sensor types. The boxplot graphic shows the mean deviation as well as the 25% and 75% quartiles in the blue box. The whiskers mark the 1.5 interquartile distance and eventual outliers. Thus 99.3% of the measurement values are to be expected within these whiskers. Apart from type B all sensor types deliver values with a mean deviation smaller than 0.5°C under field conditions. If the road sensors in the highway network of ASFiNAG are calibrated on a regular basis it can therefore be concluded that the measured road surface temperature will have a sufficient accuracy. A calibration of nowcasts as well as a use in winter maintenance based on these sensor measurement data is therefore recommended.

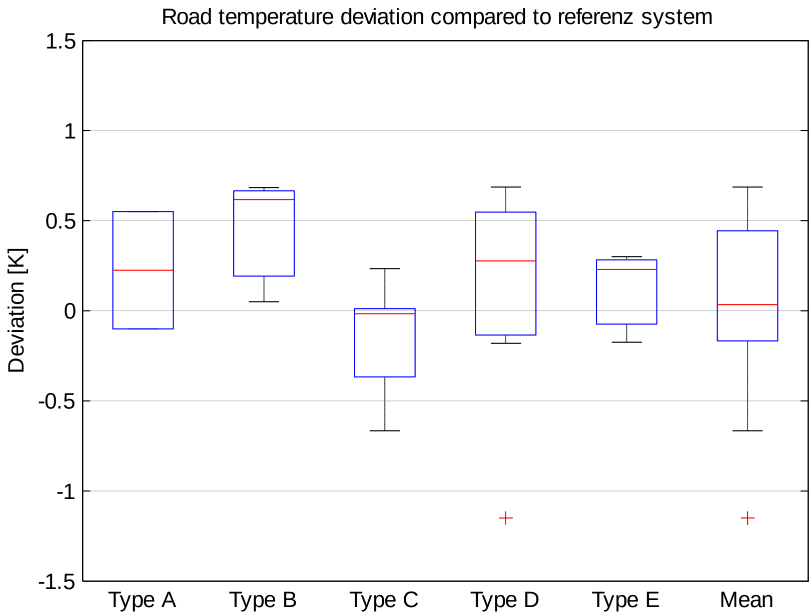

Figure 5: Histogram with fitted normal distribution and cumulative distribution function of the deviation between 2h nowcast and measured sensor values of air temperature

3. NOWCASTING WITH INCA: CHARACTERISTICS AND RECENT DEVELOPMENTS

The INCA analysis and nowcasting system is being developed primarily as a means of providing improved numerical forecast products in the nowcasting range (up to +4 h) and very short range (up to about +12 h) even though it adds value to NWP forecasts up to +48 h through the effects of downscaling and bias correction. INCA algorithmically combines station observations and remote sensing data (radar, satellite) in order to provide meteorological analysis and nowcasting fields at high temporal (5min-1h, depending on parameter) and spatial (1 km) resolution [8]. A short description of the input values and modules of the nowcasting system is given below:

3.1. NWP background

For the three-dimensional INCA analyses of temperature, humidity, and wind, NWP forecast fields provide the first guess on which corrections based on observations are superimposed. Beginning with 1st of March 2011 a new operational ALADIN configuration named ALARO5-AUSTRIA was set to operations at ZAMG, replacing the old 9.6km version ALADIN-AUSTRIA [9]. The new 4.8km version is coupled to the IFS model and uses the ALARO physics package.

3.2. Surface observations

The single most important data source for the INCA system are surface stations. ZAMG operates a network of ~250 automated weather stations (TAWES) across the country in Austria, which provide data in a high temporal resolution. In addition, a high number of data from other providers such as hydrological services, avalanche warning services etc. are used.

3.3. Radar data

The Austrian radar network is operated by the civil aviation administration (Austrocontrol). It consists of five radar stations and ZAMG operationally obtains 2-d radar data synthesized from these five locations, containing column maximum values in 14 intensity categories, at a time resolution of 5 minutes. Ground clutter has already been removed from the data.

3.4. Satellite data

The Meteosat 2nd Generation (MSG) satellite products used in INCA are ‘Cloud Type’ which consists of 17 categories, and the VIS image. Cloud type differentiates between three cloud levels (low, medium, high) as well as different degrees of opaqueness. It also diagnoses whether clouds are more likely convective or stratiform in character. The VIS image is used to downscale the infrared-based (and thus coarser resolution) cloud types during the day.

3.5. Elevation data

The 1-km topography used in INCA was obtained through bilinear interpolation from the global 30’’ elevation dataset provided by the US Geological Survey. The resolution of 30’’ of the original dataset corresponds to ~930 m in latitudinal, and ~630 m (at 48°N) in longitudinal direction.

3.6. INCA output fields air temperature, road surface temperature and precipitation

The project partners have access to INCA analyses and forecasts through a customized webportal with the main emphases of an easy access to all relevant weather and temperature information. The features of the three most important fields for winter maintenance are described in the following. The three-dimensional analysis of temperature in the INCA system starts with the ALADIN/ALARO5 forecast as a first guess. This first guess is corrected based on differences between observation and forecast at surface station locations. Since the station observations are all made in the atmospheric surface layer it is important to take the daytime temperature surplus and the nighttime temperature deficit near the surface into account in the interpretation of these differences. Thus the model 2m-temperature forecast is conceptually and computationally separated into a ‘3-d’ or model-level part, and a 2-d surface-layer contribution.

$$T_{ALA} = TL_{ALA} + DT_{ALA} \qquad (1)$$

Here, T_{ALA} is the standard model 2m-temperature output, and TL_{ALA} is the temperature at the lowest model level. The difference DT_{ALA} between the two temperatures is the temperature surplus (or deficit) in the surface layer. For this first guess, model forecasts of temperature on pressure levels are interpolated trilinearly onto the 3-d INCA grid. The analysis of road temperature in INCA is based on observations of the pavement temperatures (obtained from ASFiNAG on the A2 Südautobahn for two selected road sections at Pack and Wechsel, respectively), and air temperature at 2 m above ground. Beyond the nowcasting range, the NWP forecast of surface temperature is used (corrected for the actual terrain height based on 2-m temperature). INCA road temperature serves as a main input for INCA precipitation types on the road.

The precipitation analysis is a combination of station data interpolation including elevation effects, and radar data. It is designed to combine the strengths of both observation types, the accuracy of the point measurements and the spatial structure of the radar field. The radar can detect precipitating cells that do not hit a station. Station interpolation can provide a precipitation analysis in areas not accessible to the radar beam. Precipitation nowcasts are computed by motion vectors and finally blended with NWP precipitation fields beyond the nowcasting range.

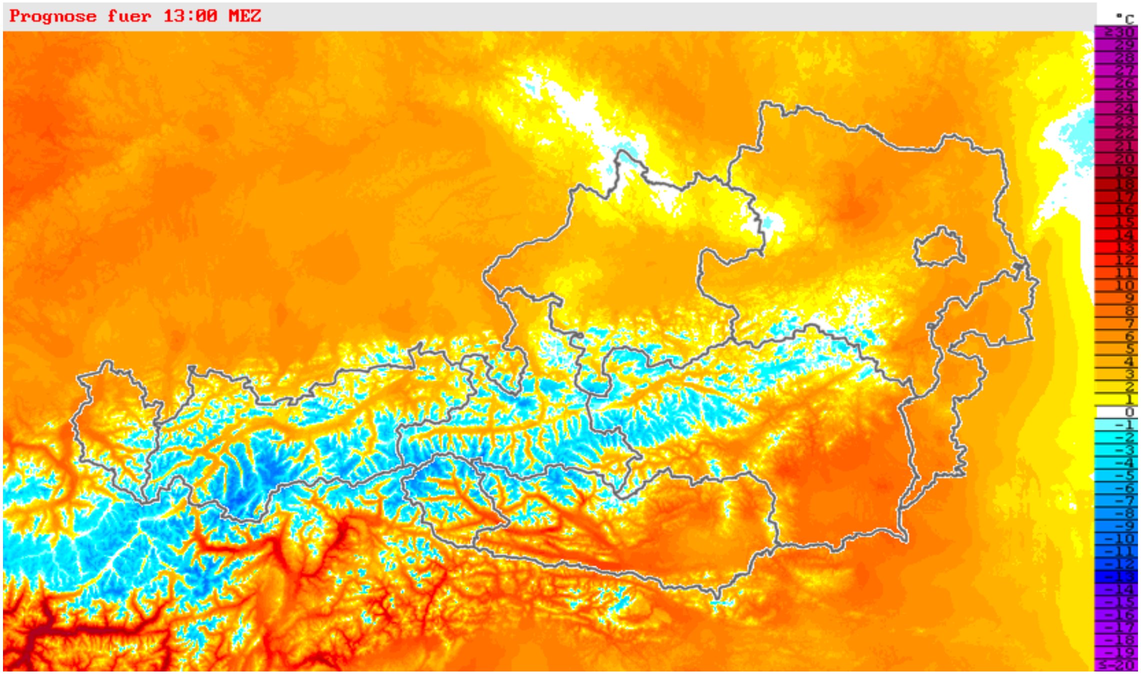

Figure 6. Example of an INCA 2m temperature nowcast for a time frame of +01h.

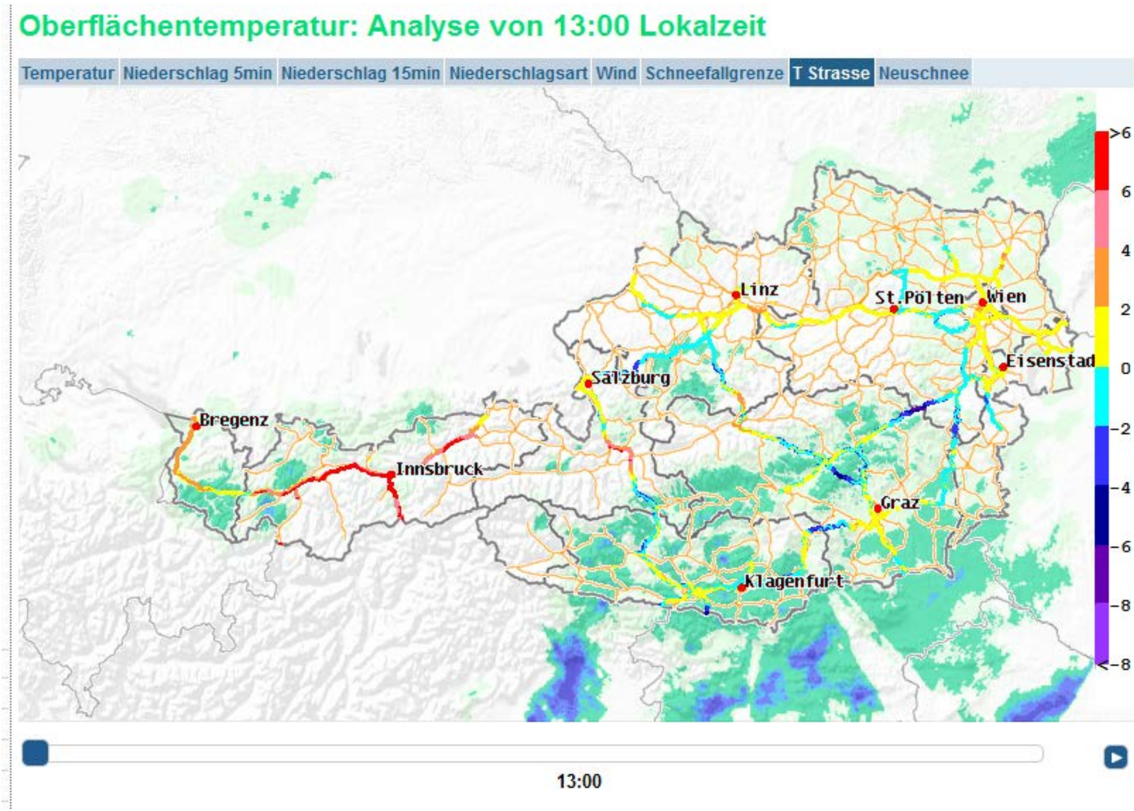

Figure 7. Precipitation and road temperature analysis at the 2013.03.25 – 1200 UTC.

In many situations, the distinction between rain and snow may not be sufficient. If rain falls into a near-surface layer of cold air, or on a surface with sub-freezing temperature, freezing rain will occur. This precipitation type is critical since it has enormous effects on transportation and may cause widespread structural damage in severe cases. In INCA the distinction between rain and snow is based on the vertical profile of the wet-bulb temperature at each grid point, derived from the 3D temperature and humidity fields. The road temperature determines the distinction between rain and freezing rain in cases of road temperature analyses and nowcasts below 0°C and is therefore crucial for winter road maintenance.

4. NOWCAST VERIFICATION

As explained before a typical nowcast only covers a time frame of a few hours into the future. Prior to this time span the principal assignment of personnel and equipment to their tasks is already completed based on medium to long-term weather forecasts for a time frame of 12 to 36 hours. With this strategic decisions at hand the added value of nowcasts lies in delivering valuable and more accurate information regarding the schedule and timing of winter maintenance activities and the selection of optimal application rates of de-icing agents. In the pilot area a 2 hour nowcast was selected as a realistic approach for covering the time span between planning and execution. In the following analysis the 2 hour nowcast information is compared with actually measured data collected from the sensors and the independent weather station in the pilot area.

The analyzed weather information from actual measurements, as well as the nowcast and a conventional weather information service cover one month of the winter season 2012/2013. With the winter season in Austria lasting for around 5 months starting from the 1st of November and ending on the 31st of March a comparison of the two meteorological services based on the provided data is not intended. The paper focusses instead on an in-depth analysis of the accuracy of the forecasts in general and the resulting possibilities and limits for an automated winter maintenance on highways in Austria.

4.1. Air temperature nowcast

In order to gather enough data 13 sensors were analyzed in the period from 1st of December 2012 to the 15th of April 2013 with the corresponding weather information from two different meteorological services. As the data of the weather prognosis is available in 1h intervals the differences between prognosis and measurement were analyzed on a daily basis for every station. Figure 8 provides an overview of the development of the 2m air temperature in a 24 hour time frame together with the average deviation from the prognosis of the weather services compared to the measured values. The temperature forecasts are able to cover the principal air temperature development and timing quite well. However, the deviations between forecasting and actual measurement of air temperature are still considerable.

Figure 9 provides an overview of the average deviation between 2h forecast and measurements on a daily basis for an entire month for one station as well as an aggregated view on all data for one month. The average air temperature of both forecasts is quite close to the measured value with service #1 being more accurate than service #2 due to the smaller deviation. Due to the central limit theorem this outcome is expected if there are no systematic failures in the prediction models. Figure 10 shows a histogram of the temperature deviations from the forecasts for one month. Again service #1 is more accurate with a standard deviation of ± 0.93 °C compared to service #2 with a standard deviation of ± 1.75 °C.

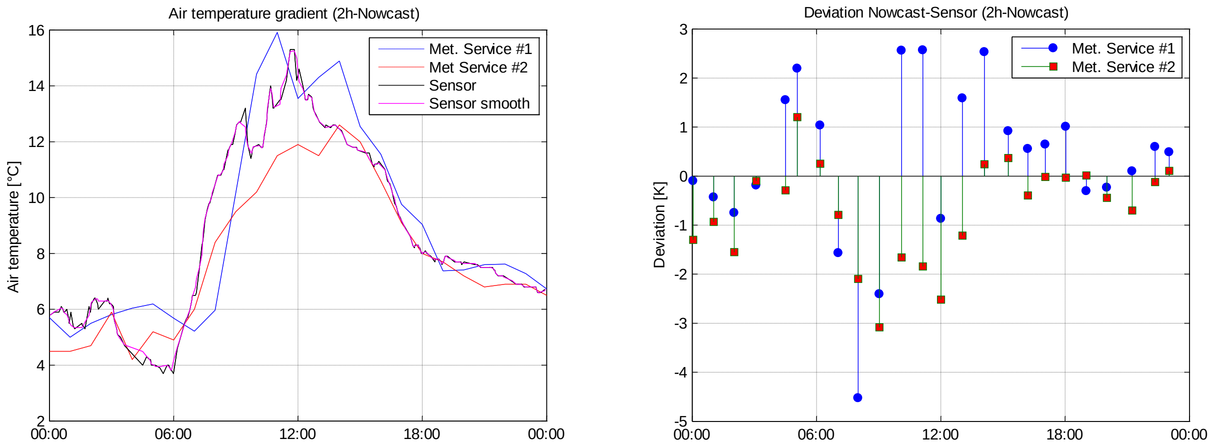

Figure 8: Comparison of air temperature forecasting from two meteorological services with actual measurements from one weather station during a time frame of 24 hours

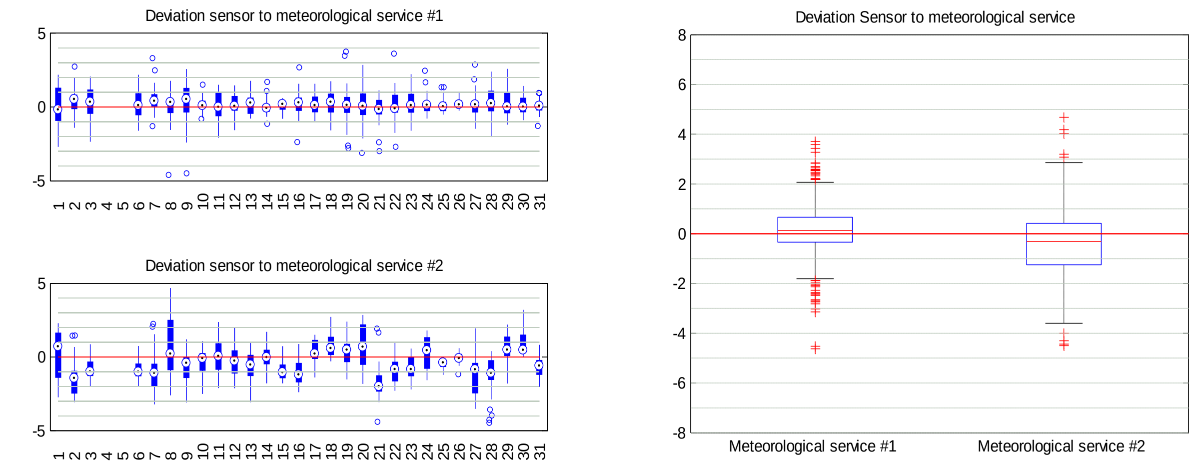

Figure 9: Boxplots of air temperature deviation between a 2h forecast from two meteorological services and actual measurements for one sensor in one month

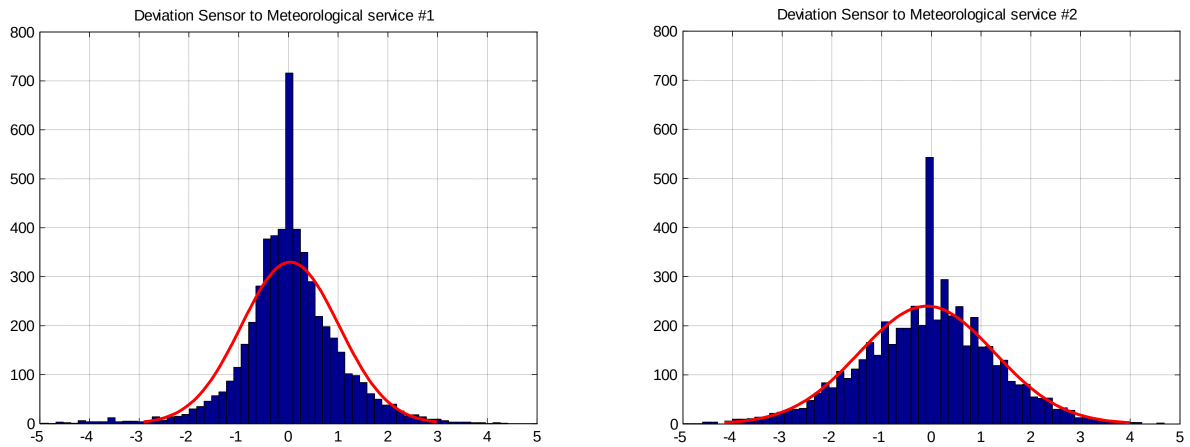

Figure 10: Histogram with fitted normal distribution and cumulative distribution function of the deviation between 2h nowcast and measured sensor values of air temperature

An accurate prediction of air temperature is crucial in winter maintenance in order to distinguish between precipitation types rain, freezing rain and snow fall .Due to the fact that local circumstances may not be accurately modelled in a weather forecast and thus punctual measurements might fail to accurately catch the air temperature distribution in the pilot area an aggregated view is given in Figure 11. The average prognosis value is for both services right on the mark without any systematic deviations in one direction. Again weather service #1 shows a considerably lower deviation with 50% of all predicted values in a range of ± 0.50 °C compared to a range of ± 0.90 °C from weather service #2. With the majority of snowfall events occurring between +2°C and -3°C deviations of more than 1°C should be avoided to achieve a reliable basis for winter maintenance decisions.

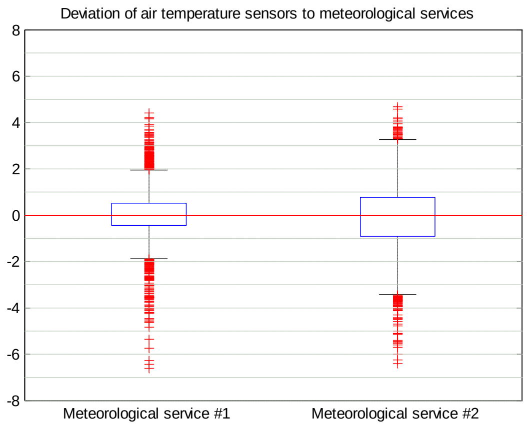

Figure 11: Boxplot of air temperature deviation between 2h nowcast of two meteorological services and measured values for all sensors in the project area and one month

4.2. Road surface temperature

For an appropriate selection of application rates a nowcast of the road surface temperatures is even more important than air temperature especially for a temperature between +2°C and -3°C. In case of snowfall the temperature of the snow on the road will gradually adapt to the road surface temperature and either melt on its own or get even colder. Thus the optimum application rate is highly correlated to road surface temperature rather than air temperature. With on-going snowfall usually available winter maintenance vehicles are on their routes and the strategic decisions are already on the level of an appropriate selection of treatment rates. Weather situations like hoarfrost or freezing fog do not immediately require all trucks on the road if a preventive treatment strategy is used. Decisions for such a preventive treatment are often based upon road temperature sensors and data from RWIS stations. As sensors are only able to deliver already measured data, necessary treatments might be too late. Therefore, a preventive treatment heavily depends on accurate road surface temperature predictions as a precondition for substantial savings in the amount of used salt and winter maintenance costs.

Even though some RWIS-Systems are capable of forecasting, a sufficient accuracy based only on the data available from RWIS-sensors or meteorological information alone is hardly feasible. Thus, in the project area both information sources were combined to achieve a higher accuracy in the prediction with the nowcast. Figure 12 provides the 2h road surface temperature forecast for the same day and station as the air temperature nowcast from figure 8. Figure 13 gives an overview of the comparison for one month and one sensor while the resulting histograms of deviations are included in Figure 14.

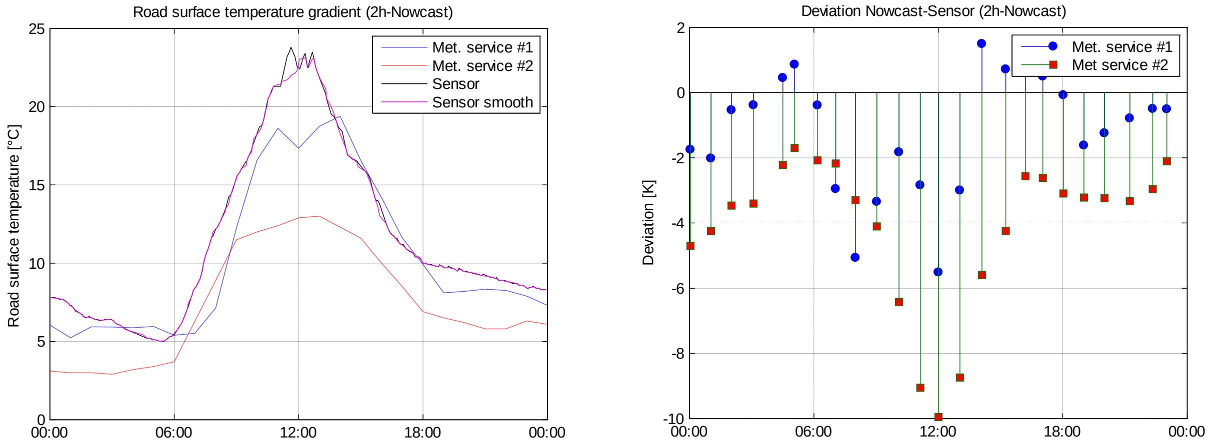

Figure 12: Road surface temperature nowcast from two meteorological services and measured values for one day on one station with the resulting deviation

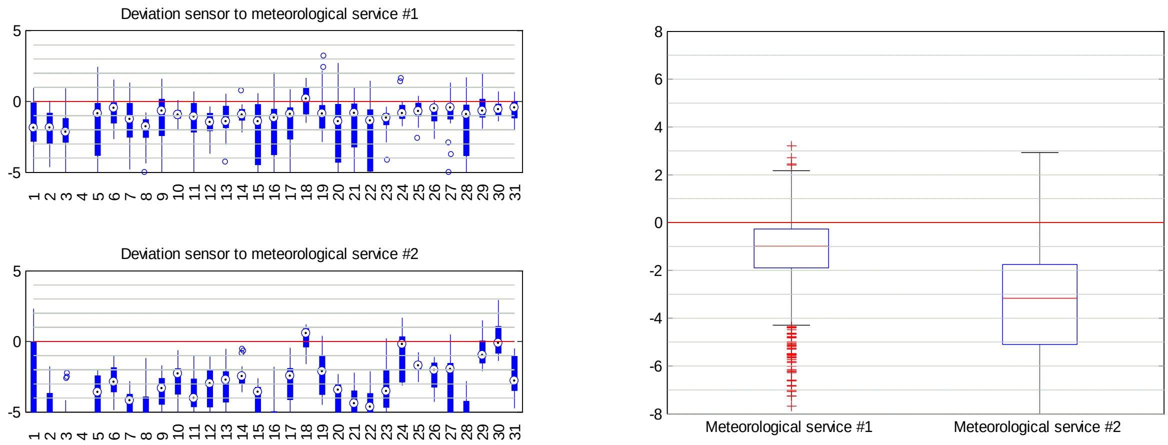

Figure 13: Boxplots of surface temperature deviation between a 2h forecast from two meteorological services and actual measurements for one sensor in one month

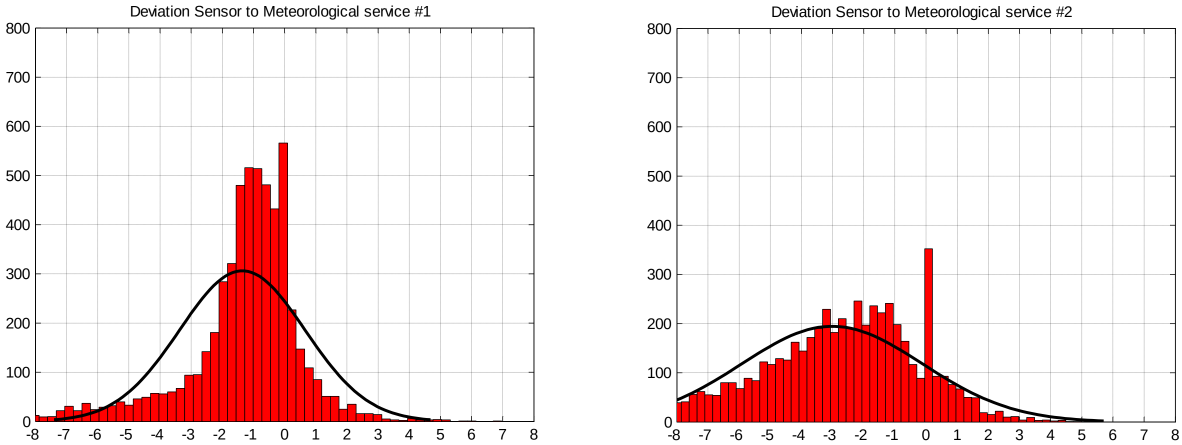

Figure 14: Histogram with fitted normal distribution and cumulative distribution function of the deviation between 2h nowcast and measured sensor values of surface temperature

The remaining absolute difference between measurement and prediction of pavement surface temperature is still very high for weather service #1 and weather service #2 with the temperature trends being somewhat in line with actual development trends. Both weather services systematically predict lower surface temperatures with an average difference of -1.0°C for weather service #1 and -3.1°C for weather service #2 (figure 13). Even if there are local areas showing a somewhat lower temperature compared to the measured actual surface temperatures in the sensor area the predictions are too far on the “safe side” leading to uneconomic high application rates. Furthermore, the resulting deviations from the predictions compared to actual measurements in Figure 14 provide sufficient evidence for further improvement potentials in the calibration of nowcast models.

For a general overview of the accuracy of nowcast models and in order to account for local deviations in road surface temperatures the predicted road surface temperatures are compared with the measurement data of all sensors in the project area. According to Figure 15 the resulting deviation for weather service #1 with an average of –1.36°C and a standard deviation of ±2.01°C is still high. Weather service #2 is even more off with an average of –3.01°C and a standard deviation of ±2.91°C. For a systematic implementation of road surface temperature predictions in winter maintenance it is therefore absolutely necessary to calibrate the analysed prediction models based on punctual measurement data from sensors as well longitudinal temperature profiles.

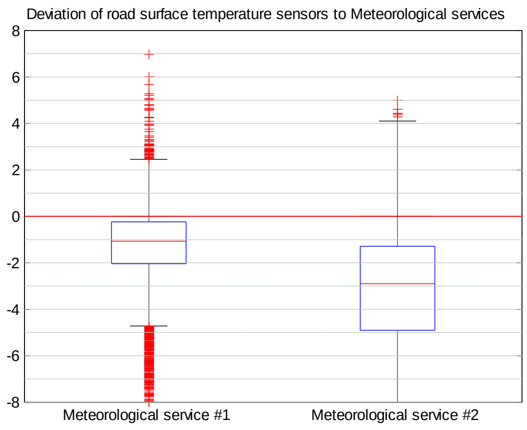

Figure 15: Boxplot of surface temperature deviation between 2h nowcast of two meteorological services and measured values for all sensors and one month

4.3. Precipitation nowcast

The forecast of precipitation type, amount and timing is also of crucial importance for an automated winter maintenance. Therefore, the predicted amount and timing of precipitation events was compared to measured values from an independent weather station in the project “Winterfit”. In Figure 16 the resulting precipitation rates and total amount of precipitation are provided based on data of two weather services and the weather station alike for one single day. For this randomly selected precipitation event weather service #1 is closer to the characteristic of the actual precipitation rates than weather service #2. The total amount of precipitation of the event in the given time frame is considerably overestimated in the predictions of weather service #1 and underestimated in the predictions of weather service #2.

The start of a precipitation event is of crucial importance for a timely deployment of winter maintenance activities in order to avoid lowered slippery road conditions and safety risks.

From the analysis of Figure 16 it is not possible to distinguish a clear beginning point in time of the precipitation event. For a comparison it is necessary to define a boundary for the total amount of precipitation that is linked to the pavement texture. If this boundary is exceeded due to a filling of the texture and a beginning freezing process a sudden drop in the resulting skid resistance is to be expected [2;3]. Theoretically there is no fixed boundary due to the range of pavement textures in the project area. For practical reasons and analysis of precipitation events a simplification with a boundary value of 0.5 mm total precipitation seems acceptable. For the given example and boundary conditions weather service #2 is closer to the start of the actual event than service #1. Figure 17 provides an overview of the analysis of all observed precipitation events from one month compared to the predictions of the two weather services. The deviation of the predictions for the total amount of precipitation is still somewhat large with an average of -0.24 mm and a standard deviation of ±4.74 mm for weather service #1 and the corresponding values of -0.39 mm and ±4.72 mm for weather service #2. The predicted start of precipitation events is even more off with an average of 1.5 hours and a standard deviation of ±4.3 hours for service #1 respectively 2.8 hours and ±4.4 hours for weather service #2.

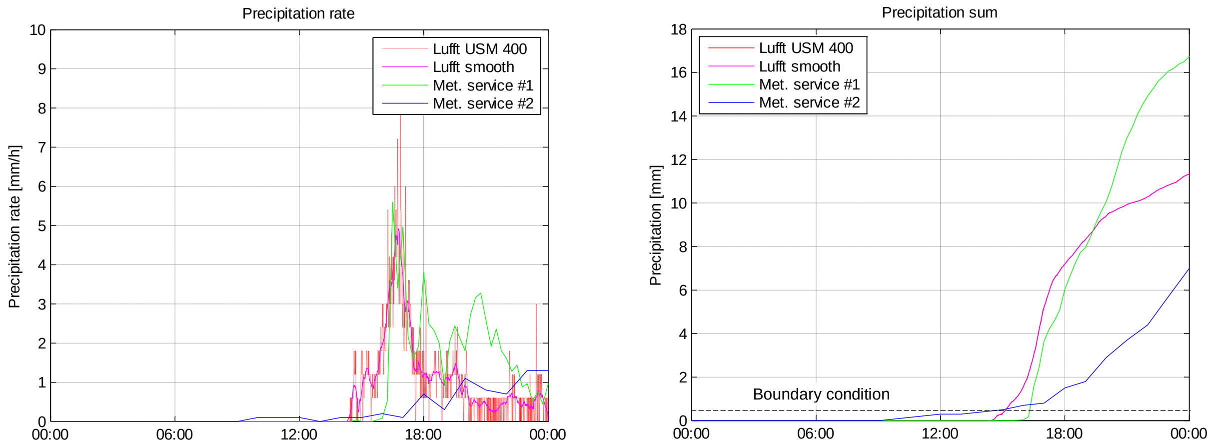

Figure 16: Nowcast of rate and total amount of precipitation from two meteorological services compared to measured values for one day on one independent weather station

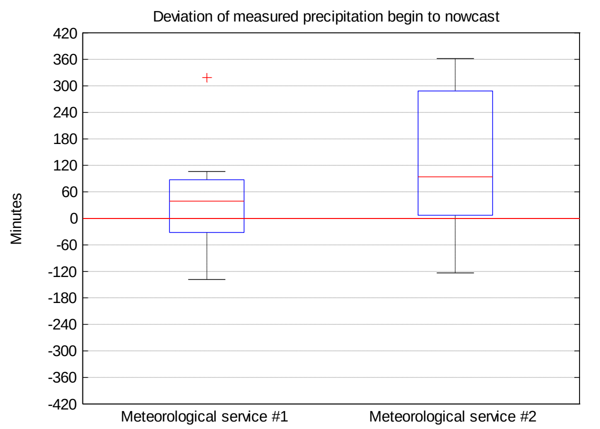

Figure 17: Boxplots of deviations from precipitation nowcast (2h) start and daily amount of precipitation and measured data from one independent weather station (n=13)

5. CONCLUSIONS AND OUTLOOK

Winter maintenance is an essential task of road authorities to provide a high accessibility and safety on the road network in Austria during winter periods. The developed holistic winter maintenance model provides a solid theoretical background for the assessment of winter maintenance strategies, measures and equipment as well as a practical implementation in guidelines and training courses. The main emphasis of the paper are the findings regarding a nowcasting and sensor based adaption of this holistic model. The resulting conclusions regarding necessary requirements and accuracy of weather forecasting, sensor selection and model calibration can be summarized as follows:

- State of the art now-casting of both air and pavement surface temperature are already feasible for the entire highway network in Austria
- The deviations from actual conditions can be reduced to a satisfactory level if the predictions are calibrated based on temperature profiles and sensor measurements
- Long – term forecasts (12 to 36 hours) of precipitation events are a good basis for strategic planning whereas short term forecasts (0 – 6 hours) are the backbone for actual maintenance decisions together with local observations of the personnel
- The quality of state of the art nowcasting of precipitation amount and timing has improved considerably and is of great value for winter maintenance decisions
- However, current prediction models still fall short as a solid base for the selection of appropriate application rates without real-time sensor measurements and the observations from experienced winter maintenance personnel
- Model based automated recommendations for application rates seem feasible on the highway network if the winter maintenance vehicles are equipped with optical sensors for pavement temperature and film thickness
- The remaining uncertainties regarding accurate input parameters for the model can be dispelled either through rigorous training or higher application rates

REFERENCES RÉFÉRENCES

1. Hoffmann M. & Nutz P. & Blab R. 2012; Optimization of pre-wetted salting; Research report (German 215 pages) published by the Federal Ministry for Transport, Innovation and Technology; Vienna; 2012
2. Hoffmann, M. & Nutz, P. & Blab, R. 2012: Dynamic modelling of winter maintenance strategies and their impact on skid resistance; Transport Research Arena TRA2012; Athen, 23. – 26. April 2012; Proceedings ELSEVIER; 2012
3. Nutz P. & Hoffmann M. 2012; „Towards real-time skid resistance forecast“; SIRWEC 2012, Helsinki, 23-25 May 2012
4. Hoffmann M. & Nutz P. & Blab R. 2014; Holistic Winter Maintenance Model; submitted paper for the XIVth International Winter Road Congress, Andorra la Vella, 4-7 February 2014
5. Hoffmann, M. & Nutz, P. & Blab R. & KANN, A. & BECK, A 2013; WINTERFIT – Requirements for the weather forecasting services and sensor integration in winter maintenance; unpublished project report for the highway and motorway operator ASFINAG; Vienna; 2013
6. Hoffmann, M. & Nutz, P. & Blab R. 2012; „New findings in winter maintenance and their implementation in Austria“; SIRWEC 2012, Helsinki, 23-25 May 2012
7. Neuhold, J. & Nutz P. & Hoffmann M. & Blab R. 2014; Innovative winter maintenance guidelines in Austria; submitted paper for the XIVth International Winter Road Congress, Andorra la Vella, 4-7 February 2014
8. Haiden, T., A. Kann, C. Wittmann , G. Pistotnik, B. Bica, and C. Gruber, 2011: The Integrated Nowcasting through Comprehensive Analysis (INCA) system and its validation over the Eastern Alpine region. *Wea. Forecasting,* **26,** 166-183, doi: 10.1175/2010WAF2222451.1.
9. Wang, Y., T. Haiden, and A. Kann, 2006: The operational limited-area modelling system at ZAMG: ALADIN-Austria, *Oesterreich. Beitr. Meteorol. Geophys*. 37: ISSN 1016–6254.