REAL-TIME CORRECTIONS AND INFORMATION PROCESSING IN MAINTENANCE DECISION SUPPORT SYSTEMS

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ABSTRACT RÉSUMÉ

Two very basic questions reside at the heart of winter service. The first question is “when should I spread anti-freezing treatments on the road?” The second is “when should I spread again?” The particularities of the road environment (extensive work area, variable traffic, etc…) make answering these questions with certainty a difficult task in a very high stakes-game: miscalculations may result in accidents, traffic collapse and intense pressures on administrations.

Two main tools are relied upon to design effective responses: weather prediction and weather monitoring. Although great strides have been made in both these areas, we are still faced with significant limitations. For instance, high-definition predictions are often costly and focus on “atmospheric” conditions, rather than on actual road impact. And monitoring of both weather and state-of-the-road is complicated by problems such as heterogeneous hardware and software standards, communications in remote locations and applicability of measurements to segments that cannot be consistently controlled. This is especially relevant when it comes to salt and de-icer detection, where spot-specific measures can often be misleading of general road conditions.

Winter maintenance decision support systems are, arguably, the most interesting technological development in the field. Systems such as MDSS or WSMS allow winter service managers to plan better responses by integrating multiple flows of information, processing data (weather prediction, Road Weather Information Systems, fleet position…) and generating treatment suggestions. More recently, they have also begun to intake information with which to continuously verify, re-evaluate and correct predictions.

However, reliance on immobile technology severely impairs the capacity of weather systems to achieve full potential. An MDSS may reliably calculate the effect that 20gr/m2 of NaCl will have during a snow event, but has little way of knowing if that is the actual amount on the road. The system may very accurately calculate and verify road conditions in a spot where a weather station is posted, but has no way of doing so in remote locations, making us rely on unverifiable projections.

Mobile and on-board monitoring technology is the only feasible answer to fill in those gaps, and advances in optical and laser-based monitoring technology (temperature, road surface and even salinity) are making that possible. The Spanish Ministry of Public Works (Ministerio de Fomento) is in the process of conducting a pilot experience in using this technology to feed information into MDSS, in order to observe if performance was improved to a point that was cost-effective.

1. INTRODUCTION

Winter Maintenance Decision Support Systems operate by ingesting and processing numerical prediction models, "interpreting" the impact of atmospheric weather predictions on the actual state of the road, and emitting treatment recommendations that will suffice to achieve the "transitability" or quality standard that the administration wishes to achieve for a particular road

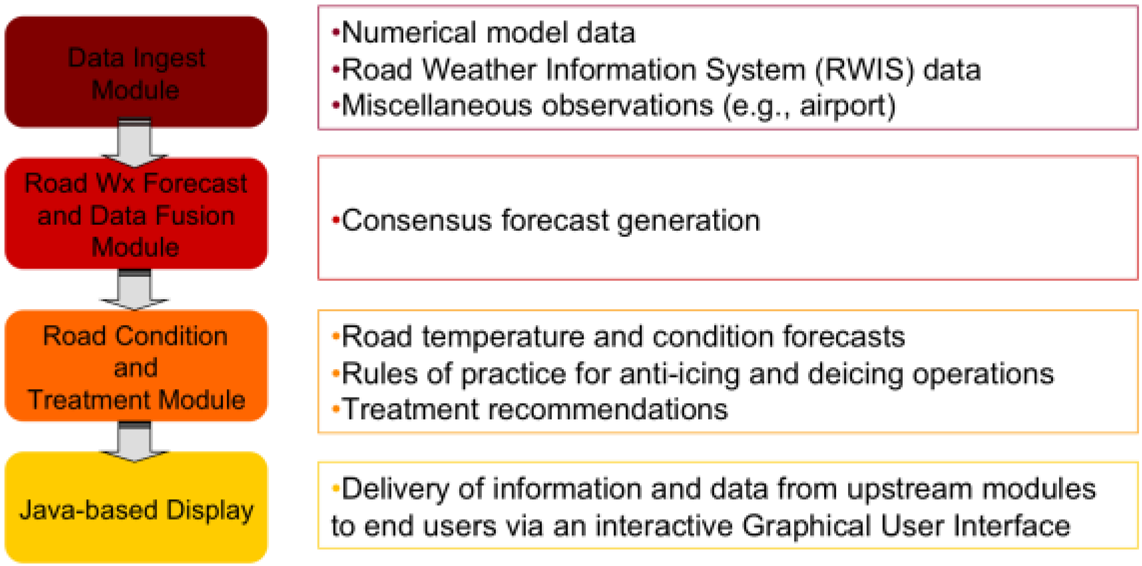

Figure 1: MDSS data processing scheme

In other words, a first forecast (weather) generates another, different forecast (road condition) that generates a further forecast (amount of de-icer needed to reach the desired condition. In order for this processing of data to arrive at a useful and reliable result (ie. the recommendation to spread a certain amount of anti-icer or de-icer in a specific stretch of road at a specific time with security), every forecast in the model must be verified and, if at all possible, verified in real time to avoid errors.

The Fomento MDSS pilot project, conducted on the A1 motorway in Madrid during the winters of 2010 and 2011, allowed the Ministry to implement and verify a series of atmospheric or weather prediction models, and to introduce real-time corrections in order to have the most accurate weather prediction before arriving at road condition predictions and treatment recommendations. Once this first step in the process is quality assured, the logical next step is to perform the same process in the subsequent predictions in the process: road condition and necessary de-icing and anti-icing equipment.

This paper describes the results of the weather model validation models employed, the reasons why real-time corrections in multi-model weather prediction drastically improved results, and describes the scope of the second phase of the Ministry’s project, which intends to apply the same philosophy to arrive at accurate road weather prediction and, therefore, safer and more precise treatment recommendations.

2. ATMOSPHERIC/WEATHER PREDICTION

Local weather forecast is one of the most challenging problems in operational meteorology from both a scientific and socioeconomic standpoint. Downscaling methods work by post processing the outputs of global atmospheric numerical models (for instance, the ECMWF or the GFS models) using regional atmospheric models adapted to the region of interest (in this work a 100x100 km domain covering the region under study). In this work we use the WRF-UC Iberia 9km simulations done with the open-source WRF (Weather Research and Forecast) model developed by NCAR and by the Meteorology group in University of Cantabria (in particular WRF-ARW 3.1.1 version). In order to simulate this final domain with a 9km resolution, we run two nested grids at 27 and 9 km, for a small North-Atlantic region and the Iberian Peninsular domains shown below. For each run, a total of 108 hours are simulated daily, from 12 UTC of day+0 to 00 UTC of day+4. The projection used is a Lambert Conformal conic projection. The results are obtained daily for a 9km grid covering the region under study (see figure 3); moreover, a linear interpolation of the results to the local position of the meteorological station is also produced in order to provide the prediction of the air conditions corresponding to the location of the meteorological station.
Figure 3 shows the meteogram, showing the ensemble of five physical parameterizations of the model used for the study and comparing the results with those obtained from the HIRLAM 16km model from AEMET (see http://www.meteo.unican.es/localForecast for more details).

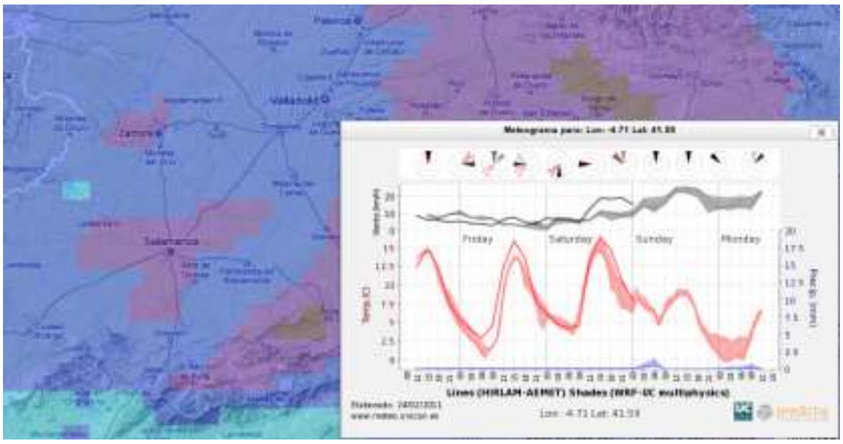

Figure 2 – Regional meteogram

3. WEATHER FORECAST PERFORMANCE

The Road Weather Forecast System (RWFS) is tasked with ingesting reformatted meteorological data (observations, models, statistical data, climate data, etc.) and producing meteorological forecasts at user-defined forecast sites and forecast lead times. The forecast variables output by the RWFS are used by the Road Condition and Treatment Module (RCTM) to calculate the road surface temperature and to calculate a recommended treatment plan. In order to achieve this goal, the RWFS generates independent forecasts from each of the data sources using a variety of forecasting techniques.

A single consensus forecast from the set of individual forecasts is provided for each user-defined forecast site or district (e.g., plow route and zone) based on a processing method that takes into account the recent skill of each forecast module and the current accuracy of each of the predictions.

The RWFS is designed to optimize itself using available site observations along or near the routes (e.g., RWIS, METARS). The forecast modules that perform the best are given more weight over time. In addition, Dynamic Model Output Statistics (DMOS) are calculated weekly using observations and model output. The DMOS process is used to remove model biases.
The system and the java-based display (Figure) were customized for two roads (Autovia A-1 and Carretera Nacional N-320) north of Madrid.

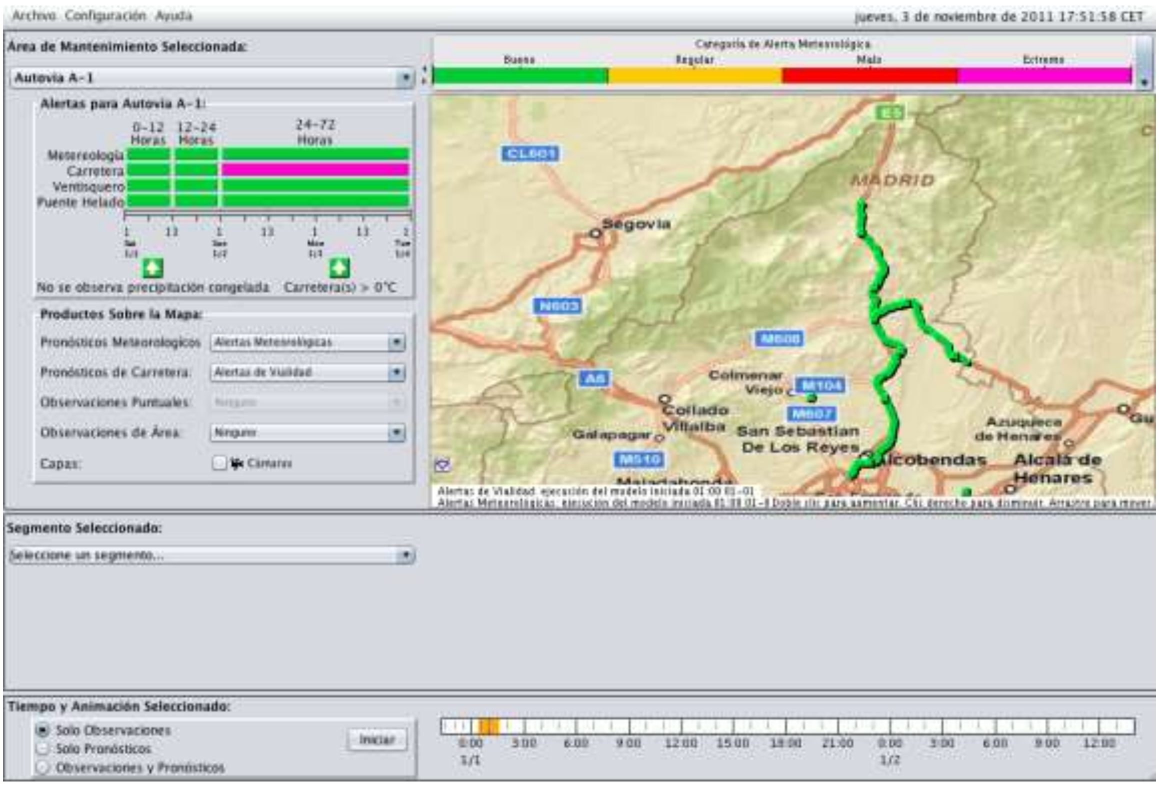

Figure 3. Customized MDSS display

3.1. Data Sources: Weather Observations

The following weather observation data sources were used for verification and analysis:

- Maintenance contractor RWIS
- Spanish Traffic Authority RWIS
- Spanish METAR
- Weather satellite
- Weather radar

3.2. Data Sources: Weather Models

The following weather models were used in the forecast generation and were analyzed in this study:

GFS – US National Oceanic and Atmospheric Administration (NOAA)
WRF – University of Cantabria in Santander, Spain

5 separate parameterizations of the WRF forecast were provided by UNICAN. However, only one (PH2) was used in the initial generation of the consensus forecast. A separate analysis of the five parameterizations was also conducted and will be included in this report. The following table (Table 2) provides a listing of the components for each of the five WRF parameterizations (PH1 – PH5) that were provided:

Table 1. A listing of the five WRF model runs and the components that make up the different parameterizations

	Microphysics	Cumulus	LW Radiation	SW Radiation	Surface Layer	PBL	Surface
PH1	WSM 5-class scheme	Kain-Fritsch	RRTM scheme	Dudhia scheme	Monin-Obukhov scheme	YSU scheme	Unified Noah
PH2	Ferrier (new ETA)	Kain-Fritsch	RRTM scheme	Dudhia scheme	Monin-Obukhov scheme	Mellor-Yamada-Janjic (ETA)	Unified Noah
PH3	WSM 5-class scheme	Kain-Fritsch	RRTM scheme	Dudhia scheme	Monin-Obukhov scheme	Mellor-Yamada-Janjic (ETA)	Unified Noah
PH4	WSM 5-class scheme	Kain-Fritsch	RRTM scheme	Dudhia scheme	Pleim-Xiu	Asymmetric Convective Model 2	Unified Noah
PH5	WSM 5-class scheme	Grell-Devenyi	RRTM scheme	Dudhia scheme	Pleim-Xiu	Asymmetric Convective Model 2	Unified Noah

3.3 Overall Performance Results

In this section, performance results are described for the 2011 field demonstration for specific components of the MDSS. Bulk statistics based on the weighted average root mean square error (RMSE), median absolute error (MAE) and bias (forecast minus observation) are calculated. 83 fixed non-RWIS sites and 4 RWIS sites were used for verification.

The weighted average RMSE is calculated in the following manner: for each lead-time, RMSE is calculated for each site and then weighted based on the total number of valid errors for that site. The RMSE values (for each site) are then summed over all sites and divided by the sum of the errors for each site.

The MAE is calculated by taking the absolute value of the difference between the forecast and the observation), which is the absolute value of the bias calculation.

3.4 RWFS Forecast Modules

The RWFS was configured to utilize and integrate two different forecast modules for the winter 2011 demonstration. Numerical Models that were ingested into the RWFS included the Global Forecast System (GFS; formerly called the Aviation Model by the NWS) and the UNICAN WRF.

The RWFS integration process independently optimized the forecasts based on recent skill at each prediction site for each parameter and forecast lead time. Forecast modules with the most skill get more weight in the RWFS integration process that generates the consensus forecast. More information on the RWFS can be found in the MDSS Technical Description (see Table 1 for reference information).

The RWFS also applied a Forward Error Correction (FEC) scheme, which is used to ensure that the forecasts produced by the RWFS more accurately reflect the current conditions in the near term. The forecasts valid at the current time are forced to match the available observations. Then, in the first several forecast hours, the forecast time series is forced to trend toward and blend seamlessly into the RWFS consensus forecast.

3.5 Overall Performance of the Road Weather Forecast System

3.5.1 *Performance Assessment of Meteorological Variables*

The RWFS consensus forecast was compared to the forecasts from the individual models included in the ensemble in order to discern whether the RWFS statistical post processing methods and techniques added value (e.g., increased skill).

3.5.2. *Error Analysis*

Bulk statistics were computed for the two individual models described in section 8.1 and the RWFS final consensus forecast for three meteorological variables (air temperature, dew point temperature and wind speed). The results are based on average RMSE and bias per lead time (out to 48 hours for WRF and 96 hours for GFS) of forecasts initiated at 1200 UTC for the entire season (15 January 2011 to 30 April 2011). As previously mentioned, and as will be the case for all the statistics in this section, the results are based on 83 sites in Spain.

For all three variables, the RWFS performed well with the consensus forecasts having lower RMSE values compared to the individual forecast module components for all lead times (Figs. 3-5). Forward Error Correction (FEC), which is applied to all the verifiable variables (variables that have corresponding observations), reduces the RMSE within the first six hours.

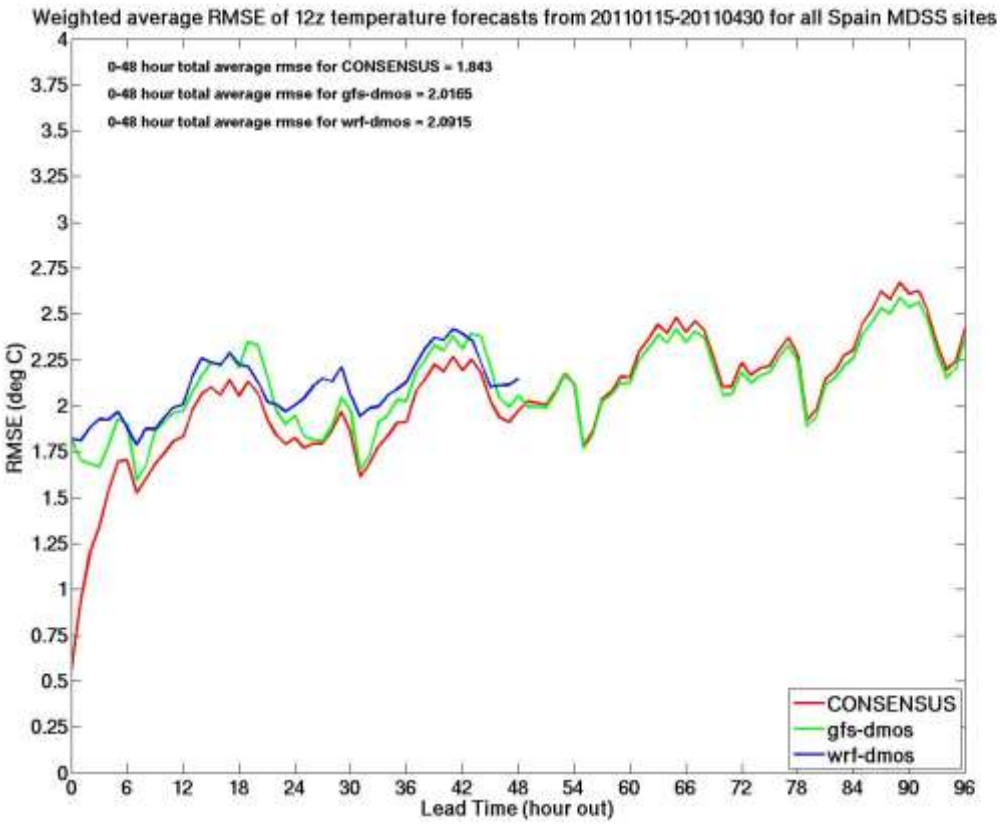

Figure 4. Weighted average air temperature RMSE computed from the 12 UTC forecasts for the entire demonstration season (15 January 2011 to 30 April 2011). The consensus forecast (red line) and the individual forecast module components for the Spanish sites are shown.

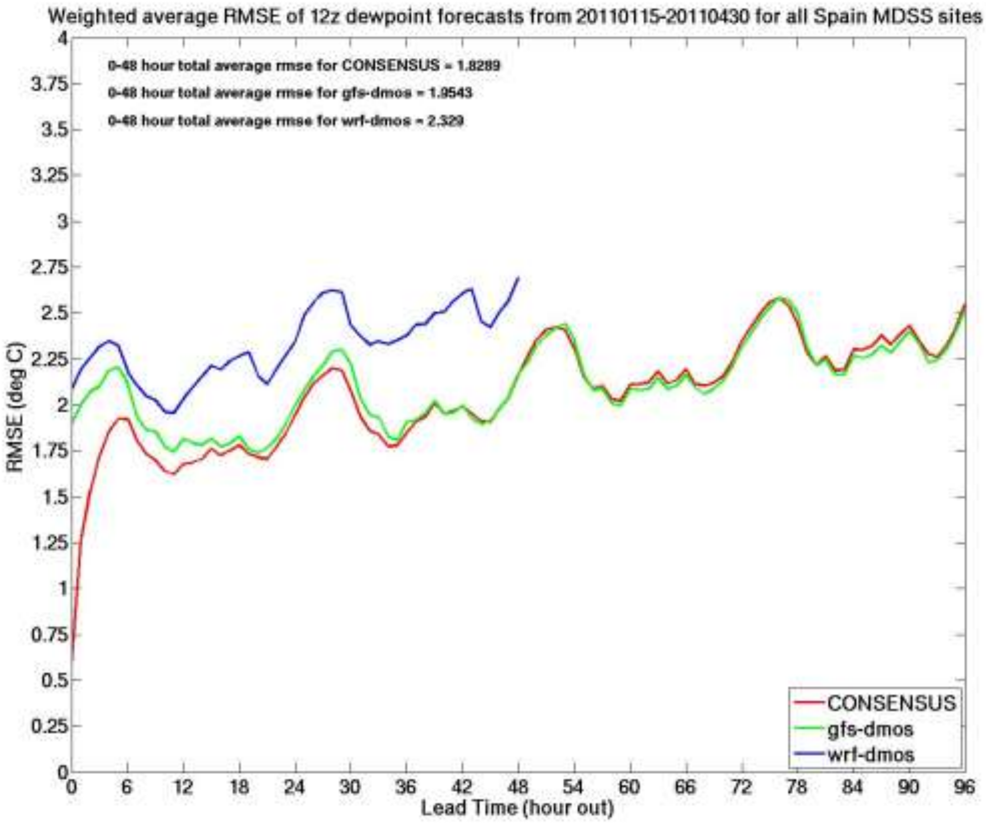

Figure 5. Weighted average dew point temperature RMSE computed from the 12 UTC forecasts for the entire demonstration season (15 January 2011 to 30 April 2011). The consensus forecast (red line) and the individual forecast module components for the Spanish sites are shown.

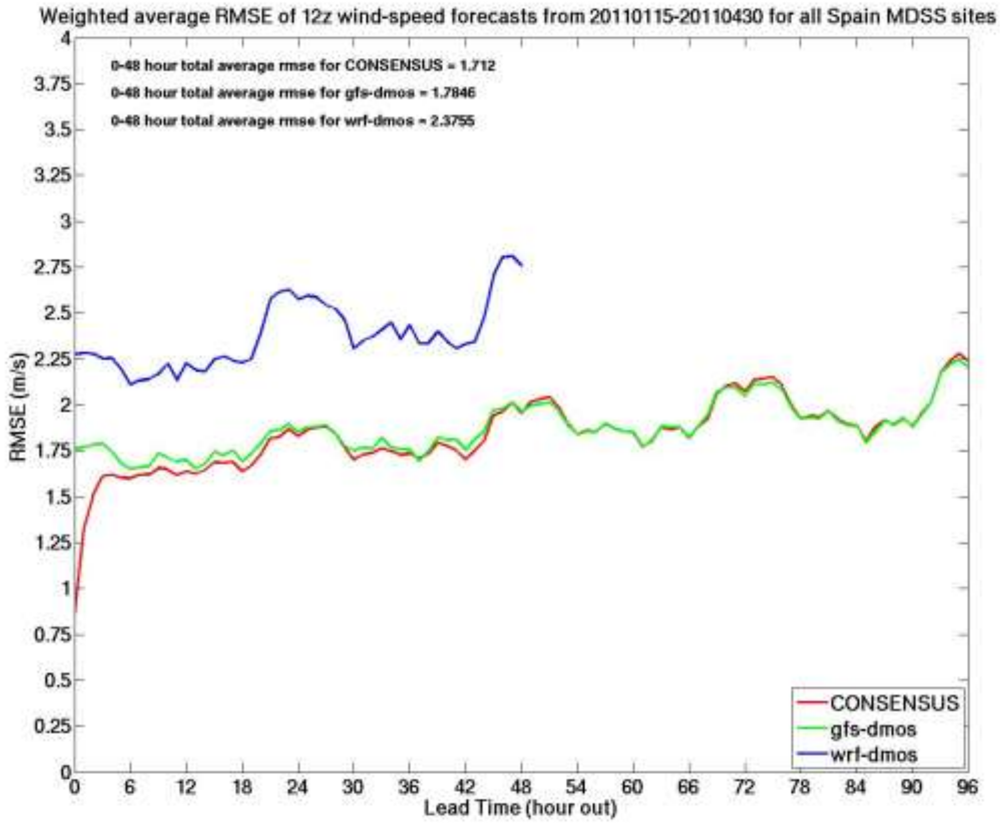

Figure 6. Weighted average wind speed RMSE computed from the 12 UTC forecasts for the entire demonstration season (15 January 2011 to 30 April 2011). The consensus forecast (black line) and the individual forecast module components for the Spanish sites are shown.

3.5.3 *Results Summary*: The statistical methods and techniques utilized by the RWFS do improve the predictions on average for all verifiable parameters. It is clear from the analyses that no single model performs better for all parameters; therefore, a blend of weather models will provide better results.

It also becomes apparent that real time correction, allowing the system to favour the model that is displaying the best performance at any specific time drastically reduces uncertainty and results in more accurate prediction.

4. NEW PILOT/ FUTURE RESEARCH

Given the outstanding results of automated real-time verification and correction of atmospheric weather prediction, it became evident that a similar process applied to road weather or road condition prediction would allow decision makers to further fine-tune their anti-icing and de-icing treatments, providing users with a more comfortable and safe infrastructure, while also opening the door to reduced maintenance costs. The Ministry of Public Works 2nd pilot project therefore intends to introduce a whole set of verification and supervision equipment that will not only be used to assess performance of the model, but will also correct predictions (weather/ road and necessary de-icers) continuously.

Given the extensive area covered by the road, the potentially heterogenous nature of different road stretches (proximity or not to water, altitude, exposition to wind and/or sun…), the amount of verification spots along a route would be too large to be economically feasible. This is especially the case when it comes to road salinity measurements, where spot detectors, normally conductivity based, relay information about an area that is too small to be safely considered representative of the entire road.

For these reasons, the Ministry has decided to make a firm commitment to mobile sensor technology which, attached to maintenance or supervision vehicles that continuously patrol the road, will relay information about the complete road, rather than a specific location.

4.1. Satellite temperature supervision

After observing the use of infrared satellites in agricultural endeavours, The Ministry is exploring the possibility and reliability of using high-definition infra-red and other satellite imaging to identify the temperature of the air and road along extensive areas, as well as relative humidity. This technology is currently being used by winemakers in the region of La Rioja to come to decisions regarding the ideal moment in which to collect the grapes, based on the heat exhibited by areas over periods of time and dryness (see Figure). This technology would have the benefit of being able to supervise complete roads or even networks, but may not have the precision, neither spatial or in temperature, to be of use to fine tune predictions in the environment of 0ºC, where even fractions of a degree may hold the key to ice formation.

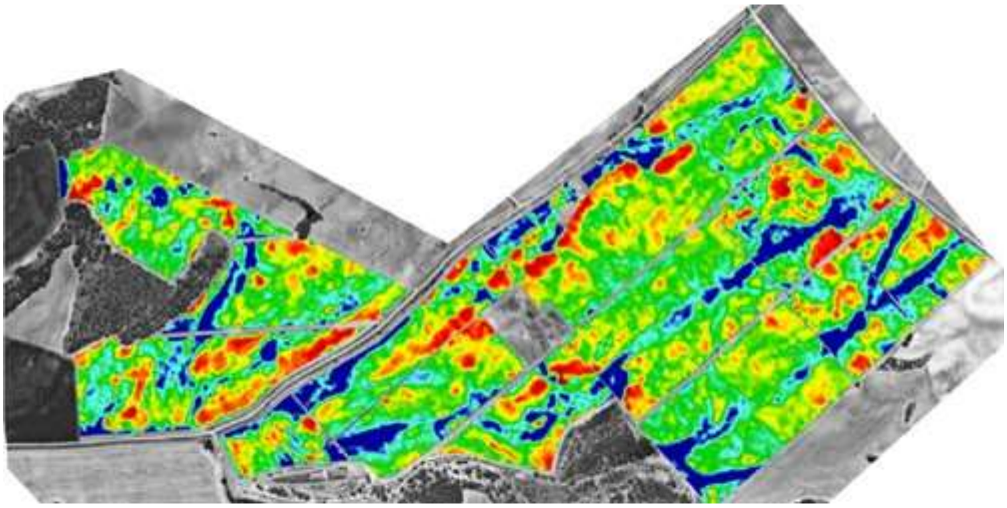

Figure 7. Satellite temperature mapping of a vineyard

4.2 Mobile Weather and Road Temperature Supervision

The second avenue for improvement would therefore come from increased verification and correction capacity of the weather prediction model in real time. In other words, an increased access to meteorological and road temperature data in the areas “between” RWIS. In this respect, the deployment of mobile weather stations and super vision vehicles whose data automatically corrects biases in the prediction would greatly improve its reliability. Mobile weather stations are commonplace in the market, and sufficiently low-cost to be a good option to relay air temperature, road temperature and dew point information to the system. The challenge is therefore only related to developing the software that will feed this information to the system in a fashion that is fixed to its geolocation, and ensuring that the corrections to predictions will be applied on a spot-by-spot (or, possibly, homogenous road section), and not to the entirety of the roads included in the system.

Figure 8. Vaisala Surface Patrol HD

4.3 Mobile Road Surface Condition Sensors

Current technological advances may allow us to evaluate road condition predictions and verify our predictions with highly replicable, high-quality data. “manual” or even spot observations of road condition do not allow us to gather sufficient or sufficiently precise data to evaluate road surface prediction across a whole network. In contrast, optical sensors may not only gather a large amount of internally consistent data along long stretches of road providing us with an ideal verification tool that will increase confidence in the system.

Additionally, mobile surface condition detection technology, linked to GPS data, would allow us to correct road condition predictions in real time along the whole length of the road, and generate alerts when and if recommended treatments have proved insufficient.

Vaisala Condition Patrol DSP310

Teconer Road Condition Monitor RCM411

Figure 9: Road condition sensors

4.4 Non-contact friction measurements

Due to the need for continuous measurements during adverse weather events, the use of contact friction technology for supervision has been discarded. However, once again, optical sensors could be an elegant solution. After a short period comparing optical sensors to contact friction measurer (slip-wheel or fix-slip), said sensors could be employed to establish road usability, to evaluate system performance, and to correct system miscalculations regarding treatments.

Road eye SD, from Sten Löfving Optical sensors

IceSight-RW, from Innovative Dynamics Inc.

Figure 10: non-contact friction sensors

4.5 Mobile salinity detection

Mobile salinity detection, although not yet a very advanced technology, would allow for two crucial aspects to be verified and fine-tuned. The first is the verification that system guidelines are being followed (ie. the system recommends 20 gr. NaCl/ m^2 and the spreaders actually spread that amount), and secondly that salt permanence is conforming to system expectations.

Feeding salinity information into the system would, once again, allow for real-time re-calculation of treatment needs, if more anti icer has, for instance, been removed from the road by snow and rain that was expected.

Figure 11. Yamada-Giken mobile salinity sensor

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