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# Development of mobile optical remote road condition monitoring in Finland

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## ABSTRACT

Mobile observing methods of wintertime road conditions have been developed in Finland for the past six years. Key results from several measurement projects are presented, showing the local variability of snow, ice, water, temperature and slipperiness on the road surface in great detail. In addition, it is discussed how mobile and fixed road weather observations and high-resolution road condition models are combined in an optimal way for snow removal and slipperiness control.

**Keywords:** road conditions, mobile measurements, optical remote sensing, winter road maintenance

## 1 INTRODUCTION

Finland is a long country (between 60 – 70 degrees North) with large variations from the Southern coastal areas to Northern Lapland especially in the wintertime (Fig. 1). Sub-freezing temperatures and slippery winter conditions are common approximately 3-4 months in the South and up to 6-8 months in the North. Thus it is essential to have high quality and reliable winter road maintenance systems and services for all operators and citizens in urban and rural areas. These are organised and responsibility of public sector road administrators, but most of the maintenance operations and forecasting activities are outsourced to private sector companies. Foreca Ltd is a private weather service company that has been providing nationwide road weather services since 1998. With its R&D subsidiary Foreca Consulting Ltd it has been actively involved in the development of road weather systems and models for the past 14 years, and has devoted special interest in development of mobile on-the-road observing methods since 2006.

The emergence of Global Navigation Satellite Systems (GNSS) during the past decade has provided a new platform to observe atmospheric conditions from mobile sources (such as specially equipped or ordinary cars on the roads) with unprecedented spatial accuracy. Whereas fixed road weather stations are typically 100 km apart at best, observations from moving vehicles with position tracking can be performed with about 100 m resolution. However, combining and analysing data coming from these two very different sources is not a trivial task.

Simultaneously with the development of navigational aids, in Finland there has been innovative development of optical remote road condition monitoring sensors by Vaisala Inc. and Teconer Ltd. In the following, key results from several national and European research projects are presented to give a summary of the developments in Finland, and to give some ideas of what could be the optimal and most cost-efficient combination of different measuring systems. It is also vital to understand the real nature of variability of local risks to drivers due to sudden ice and slipperiness that can be revealed by combining mobile and fixed observations into a hybrid monitoring system.

## 2 MOBILE OBSERVING OF ROAD CONDITIONS

Traditionally road conditions have been observed visually by road managers driving along the roads. Friction has been measured by various methods based on wheels or braking tests. Project ColdSpots (2005-2007) was the start of more comprehensive mobile road condition observing in Finland. The project was initiated after a very serious road accident that was caused by slipperiness due to a very small scale super-cooled rain shower. Project was co-funded by the Ministry of Transport and Communications in Finland, Finnish Road Administration, and

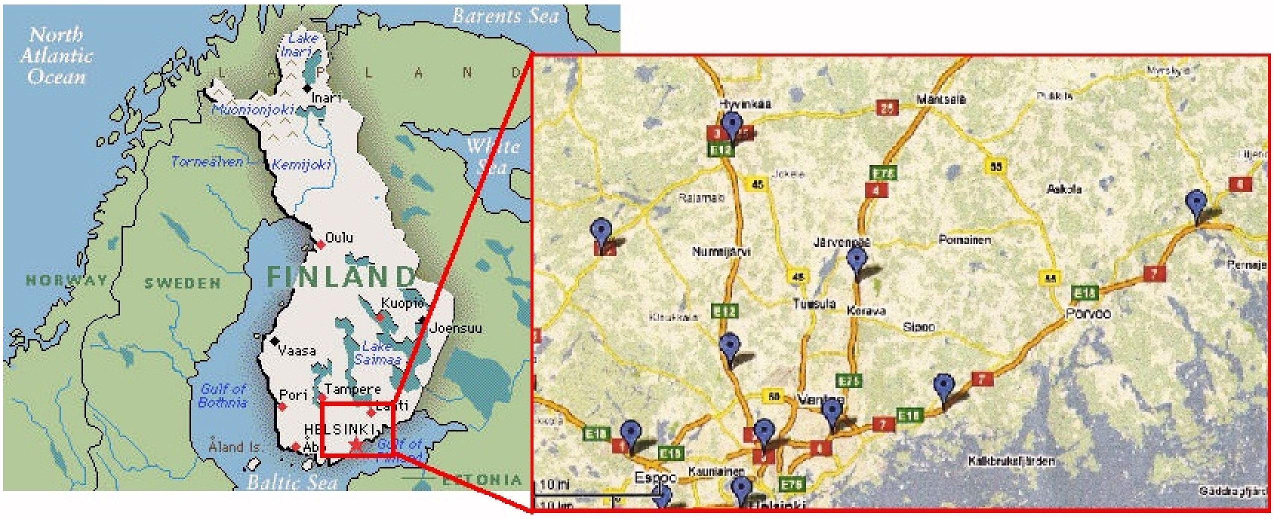


Figure 1. Main study area in Southern Finland. Blue bubbles are fixed road weather stations with optical remote sensors near Helsinki capital area.

the consortium of three public and private partners: Foreca Ltd, Destia (formerly Finnish Road Enterprise) and Finnish Meteorological Institute.

The objective was to improve the conventional weather and road condition forecast models by establishing and utilizing a novelty database containing detailed local information on problematic road sections in Finland. Before this project, a lot of information was available in various databases, such as registers of road structure and traffic accidents, map information, road maintenance feedback and quality control data, but not in the reach of the developers of weather forecast models.

ColdSpots started in 2005 with analysing and database forming phase, where a test set of some fifty most problematic locations were selected based on the information of the accidents occurred due to freezing and on the knowledge of the local road maintenance experts [1]. In the second phase 2006-2007, this additional and more accurate information of ColdSpots locations were implemented in the road condition models. The new system was verified with pilot studies by applying state-of-the-art verification methodologies [2].

Detailed mobile observations of road surface state started in 2006 and results were used in verifications and model development. This was the first time when optical remote sensors (Vaisala DSC111 and DST111) designed for fixed road stations were mounted on a car (Fig. 2a) [3] [4]. Instruments measure the amount of snow, ice and water on the road surface, air and road surface temperature and air moisture, and friction derived from the measured values. Observations were received every 5 seconds corresponding to some 100 m resolution along the road. The observing car was equipped with a GPS receiver measuring the car position every second, and a laptop that collected measuring data using a Bluetooth connection to the instruments.

The very first field tests immediately revealed the great potential of mobile observations. Observing instruments reacted rapidly to visible changes on the road surface conditions. Variability between fixed stations was in some cases surprisingly large. Some examples of the first observations are shown in Chapter 3.

The only major problem with the first installation was the accumulation of dirt and slush droplets on instrument lenses, thus degrading gradually the quality of the measurements. To avoid this, the second installation was mounted on top of the car (Fig. 2b). This was used during the next measurement campaign for project ROADIDEA. Optical remote sensors were identical to those during ColdSpots, but wireless Bluetooth was replaced by cables to avoid any breaks in data connection.

ROADIDEA (2007-2010) was a cooperative R&D project co-funded by the European Commission under the 7$^{th}$ Community Framework Programme for Research and Technological Development. Its objective was to study the potential of the European transport service sector for innovations, analysing available data sources, revealing existing problems and bottlenecks, and developing better methods and models to be utilized in service platforms. These are capable of providing new, innovative transport services for various transport user groups. Project had fourteen partners from eight European countries, i.e. Finland, Sweden, the Netherlands, Germany, Italy, Slovenia, Croatia and Hungary. More information and public reports are available from http://www.roadidea.eu .

a) b)

Figure 2. a) The first installation in 2006 using optical remote sensors Vaisala DSC111 and DST111 behind the observing vehicle. b) The second installation on top of the car during ROADIDEA project in 2007-2010.

Mobile observations were continued during ROADIDEA to gain more information of the variability of road conditions and the local effects of maintenance operations to slipperiness. The collected data was used to develop a new friction model and slipperiness warning service with a pilot name “Pulp Friction”. The initial service idea went through the complete development cycle and reached a level of first pilot version of the service with user tests. Demonstration is shown in Fig. 3 and on the ROADIDEA web site. See also Fig. 8 of Chapter 3.

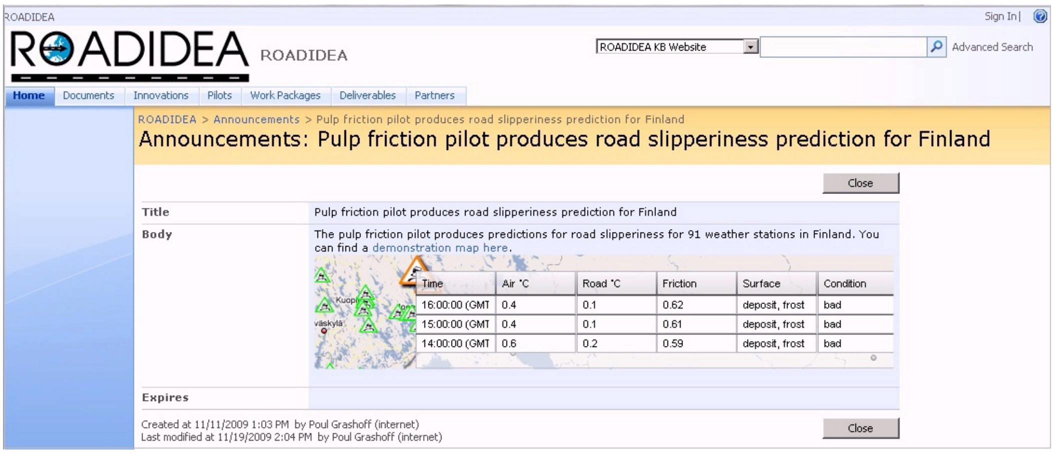


Figure 3. ROADIDEA pilot service “Pulp Friction” in http://www.roadidea.eu .

Research on hybrid observing systems continued with the European project GalileoCast involving Foreca Consulting Ltd and two European SME companies in Iceland and France. Objective was to innovate new GNSS enabled services and in particular, study the feasibility of the Galileo satellite system for road weather services. Some results are presented in Chapter 4.

Foreca’s research in this area is now continuing in several new projects, one of which is a European ERA-NET Road project “Mobi-Roma: Mobile Observation Methods for Road Maintenance Assessments” (see http://www.eranetroad.org ). Project started in September 2011 and has three other partners from Sweden and Germany. Data collected from the CAN-BUS within the car is used to measure the quality of the road surface (roughness, cracks, holes) and strength of the road bed. For winter road condition assessments, a new optical remote sensor RCM411 developed by Teconer Ltd will be used [5]. It is based on a similar technology as the earlier observing system, but due to its smaller size and closeness to the road surface, the system is very user-friendly and gives accurate measurements on the road surface conditions. Data is delivered via Bluetooth to a Nokia smart phone that stores the data every second (Fig. 4). The first test drives have shown that RCM411 measures the levels of water, ice and snow on the road very accurately.

Figure 4. Most recent installation in 2011-2012 using Teconer RCM411.

## 3 VARIABILITY OF ROAD CONDITIONS

Figure 5 presents two analysis products (air temperature and surface friction) from Foreca's national road weather service. One can see the scale of variability that can be resolved at best from the fixed observations network of the Finnish RWIS. The network has some 500 stations of which about 100 are equipped with optical remote sensors. Analyses of this scale give a good overview of the situation, but cannot reveal any local details.

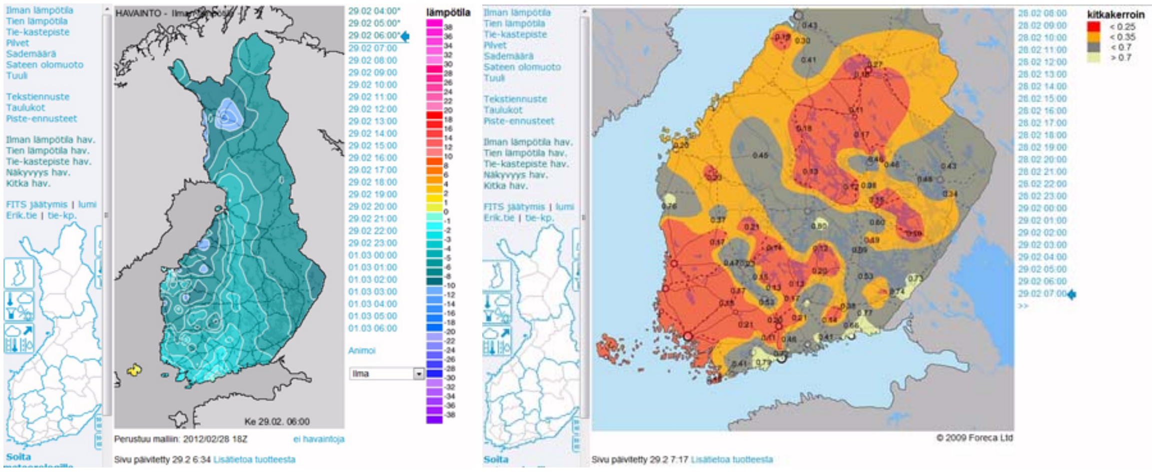


Figure 5. a) Example of the variability of temperature after a cold night as resolved with RWIS data. b) Variability of friction as resolved with optical remote sensors DSC111. Orange and red colours indicate slipperiness (friction below 0.35 and 0.25 respectively).

The actual and often large local variability of road conditions can be revealed only with detailed mobile measurements. Figures 6 and 7 represent two illustrative cases from the first ColdSpots field tests. On the highest panel, road surface temperature measured by DST111 is shown as red curve, values from the car's sensor by circles and from the fixed road weather stations by asterisks. In Figure 6 the previous night had been very cold and calm, and thus the pooling of cold air into valleys caused plenty on variability in temperature. In station data this variability cannot be resolved, even though this particular test road had exceptionally dense station network.

The middle panels show the measured value of ice (red), snow (blue) and water (green) in millimetres behind the car. The sensors were tilted in such a way to measure the values from the car's wheel path. High values of snow correspond to places where the car has been either standing on a bus stop or by the high-way on the snowy bank. Due to the very cold temperatures there is no water on the surface, and the ice sheet is causing the friction to be very low at places (the lower panel) and even dangerously low below value of 0.2. This case was on example of a very risky situation when the weather generally was clear and sunny and drivers do not see or feel the risks due to local slipperiness caused by the ice sheet on the road surface.

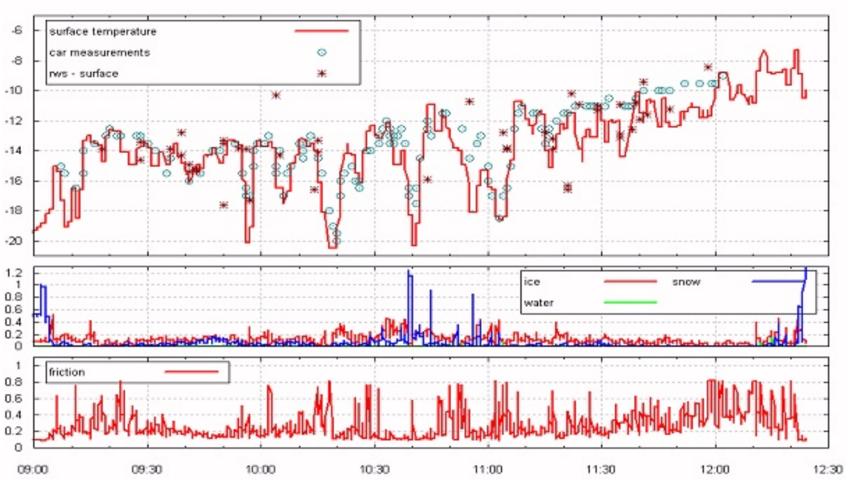


Figure 6. Variability of road conditions on a very cold day [6].

The second case in Figure 7 is a milder day when salting has been used to reduce slipperiness. On the left hand side, the drive has started from Helsinki city area, where streets have been covered (as is often the case) with some snow. The highways are better maintained and the amount of snow is less. However, there is again a thin sheet of ice on the road in the morning hours reducing the friction down to dangerous levels at certain stretches of the road. The road maintenance has observed this and salted the road, and thus while driving back there is a water level on the surface due to the salting. Friction has improved to a reasonably good level, even though there are still some dangerously slippery spots on the road. Again, the values measured from the road weather stations do not reveal any of this local variability that can cause a risk for drivers.

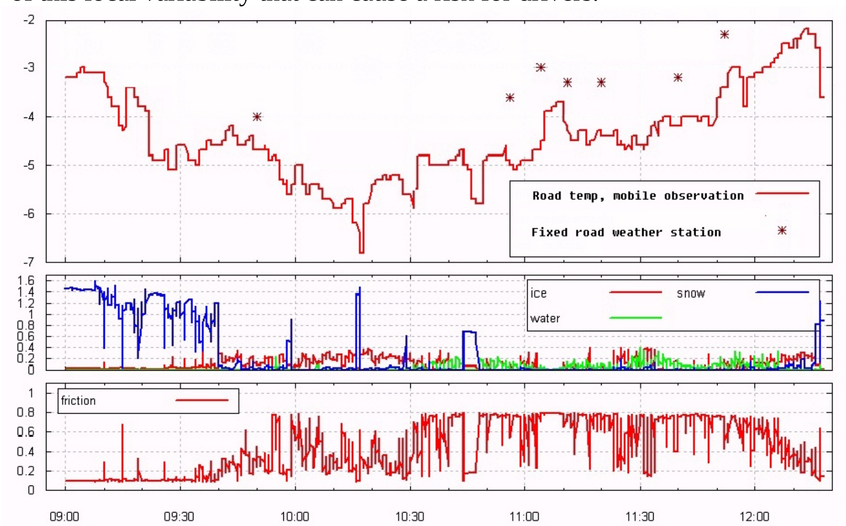


Figure 7. Example of a mild day with snow, ice and water on the road [6].

In Figure 8, two cases from ROADIDEA measurements are shown. Only values of friction are shown in this case. The first case a) on the upper panel was an extremely slippery evening in a snowfall, and during the first drive friction was varying between 0.1-0.2 because no salting had been done yet (the red curve). One person was killed in an accident due to slipperiness near the measuring area. The second drive through the same road was done after the salting had been just performed, and the effect is clearly visible (green curve). A third drive half an hour later gives even somewhat better (higher) friction, as the salt has had time to melt the ice on the road.

The second drive on the lower panel b) started through an area filled with super-cooled fog. Friction was at places very low but there was large local variability inside the fog area. After coming out of the cloud, the friction was maximum corresponding to a dry road. The photograph in the back of Fig. 8 shows how the instruments had been completely covered with frost after the fog drive.


Figure 8. Effects of a) salting and b) super-cooled fog on local variability of friction [7]

## 4 DEVELOPMENT OF HYBRID OBSERVING SYSTEMS

Next step has been to study what is the best way to combine observations coming from fixed stations and mobile sources. What kind of a combination would be optimal to reveal the critical aspects of road conditions and most cost-effectively? The field tests provided a sample of mobile observations, which were compared to the output from the fixed stations of RWIS, which is analysed every 30 minutes.

In the European project GalileoCast [8], the combination of the optimal set of fixed and mobile measurements was studied. Most important feature of different kind of observation systems is their detection capability (DC) of meteorological phenomena that can cause slipperiness or other risks to drivers. Generally, these phenomena can be classified according to their size in synoptic scale (100 km), meso-scale (10 km) and micro scale (1 km) features. Each of these have a typical life time (24 h, 6 h and 1 h, respectively) causing a swath of reduced friction while passing over the area. In addition, local topographic effects cause spots that are prone to slipperiness. In the following Table 1 the detection capability of fixed, mobile and hybrid (fixed and mobile combined) observing networks are compared. The fixed network corresponds to that of presently in Finland, which has an area of 300.000 $km^2$. The hypothetical mobile system consists of 10 units that measure 250 km long road 4 times per day. Spatial resolution is superb, but the system has poor temporal resolution compared to the fixed system. Hybrid system contains both good features and gives the best detection capability [9]. With the coming Galileo system, measuring accuracy will again increase. One can even analyse from which lane the observations have been taken.

Table 1. Estimates of the detection capability (DC) of present fixed road weather station network in Finland, a hypothetical mobile system of 10 units and a hybrid system combining both data sources. Source: GalileoCast Final Report.

| **Observing system** | **Fixed** | **Mobile** | **Hybrid** |
|---|---|---|---|
| Measurement units | Equipped masts | Equipped cars with GNSS | Both masts and cars |
| Total units | 80 | 10 | 90 |
| Spatial resolution | 60 km | 100 m | 60 km & 100 m |
| Temporal resolution | 30 min | 3 sec | 30 min & 3 sec |
| Observations / day | 3840 | 172800 | 176640 |
| DC synoptic 100 km | 100 % | 100 % | 100% |
| DC meso-scale 10 km | 40 % | 15 % | 55 % |
| DC micro-scale 1 km | 1 % | 5 % | 6 % |
| DC topographic effects | No | Yes | Yes |
| DC lanes, GPS | No | No | No |
| DC lanes, Galileo | No | Yes | Yes |

## 5 CONCLUSIONS

The field tests of mobile road condition measurements in Finland have been conducted for the past six years, revealing the small-scale variability that cannot be resolved with fixed network data. This variability consists of different scales starting from few centimeters (e.g. in and outside wheel paths), few meters (e.g. road structure, bus stops) to hundreds of meters (local topographic effects). Some of these may come unexpectedly to drivers leading to accidents. However, there are also large differences in variability depending on the weather type. As expected, variability is largest in cases of strong inversions after clear and calm nights. There are also cases quite often when local variability is negligible and can be resolved with the fixed network just as well.

Results indicate that the optimal hybrid observing network – where resolvability is maximised and costs minimised – could be achieved by complementing the fixed network with a reasonable number of routine mobile observing drives that are targeted to risky weather situations, and cover the road stretches that are known for their large local variability or unusually high risk for slipperiness and accidents.

Mobile observations provide also good reference data to test and verify road condition models in very fine scale. Further, better filtering methods to downscale atmospheric model output can be developed to reach and depict – from end user perspective – the most critical local road surface scale phenomena.

In Finland, the development of mobile road condition measurement systems continues in several research projects. More data is required in particular to analyse the total variability of conditions over the different parts of the road system, and for the development of better friction and road condition models.

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