

## New Approach to Road Weather: Measuring Slipperiness

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### ABSTRACT

In this paper we present results of field testing a new road surface condition sensor based on optical spectroscopy and short distance remote sensing. Since the sensor can provide amount of water, ice and white ice independently of each other, we tested also the feasibility to model directly slipperiness caused by winter weather on road surfaces. We turned out that it is possible to obtain a fair correlation between actually measured and modeled friction values in typical winter weather conditions. The field testing included also a remote infrared surface temperature sensor. Impact of the technology on road weather information systems is discussed.

**Keywords:** ice detection, slipperiness, friction, grip

### 1. INTRODUCTION

The purpose of the testing was to evaluate the performance of two new remote optical sensors, one is called Vaisala Remote Road Surface State Sensor DSC111 and the other Vaisala Remote Road Surface Temperature Sensor DST111. These sensors are remote in the sense that they can be installed on any post by the road side or a gantry across the road. Thus installation is fully non-invasive, i.e. there is no need to install anything on the road surface.

DSC111 is based on active transmission of infrared light beam on the road surface and detection of the backscattered signal at selected wavelengths. Most of the backscattered light has traversed through a possible surface layer of water or ice. By proper selection of wavelength it is possible to observe absorption of water and ice practically independently of each other. Since white ice, i.e. snow or hoar frost, reflect light much better than black ice, these two main types of ice can be distinguished as well. The observed absorption signal is readily transformable to water layer, to ice layer or to snow/frost amount in millimeters of water equivalent. With this information it is straightforward to determine the surface state as dry, moist, wet, icy, snowy/frosty or slushy. It turned out that we can go even one step further and model the apparent reduction of the friction coefficient due to ice and water on a road surface.

DST111 is based on measuring long wave infrared radiation between the detector of the instrument and a selected location on the road surface. If this radiation is in balance, then the temperature of the detector and the road surface are equal whereas a non-balance can be calibrated to a known temperature difference. However, this method applied as such measures the apparent radiation temperature, which can be offset by many degrees due to reflection of long wave infrared radiation at the road surface. In DST111 these reflection induced errors are minimised by properly selecting the range of wavelengths in use. The accuracy of DST111 is estimated to be 0.3 °C in typical icing conditions.

Field testing of these sensors was carried out during the winter season 2004-2005. Main results of the testing are reported in the following chapters with some discussion of possible new applications.

### 2. TEST ARRANGEMENTS

The most comprehensive testing was carried out in the highway VT6 in Utti near Kouvola in south-eastern Finland during Nov 19<sup>th</sup> 2004 and Mar 20<sup>th</sup> 2005. The surface condition sensor DSC111 was aimed at the right wheel track of

the lane going from east to west on this two lane road. Fig. 1 shows a photograph of DCS111 installed on a wooden pole mast in the Utti test station. The testing in Utti included human observations of the road surface state and occasional measurements of friction by lock braking a vehicle equipped with a decelerometer. The remote road surface temperature sensor DST111 was included in the test starting in February 2005.



Fig. 1. DCS111 installed on a wooden pole mast in the Utti test location.

The other test locations, three in Finland and two in the UK, were set up for the purpose to follow up the performance of determining the surface state by DSC111 in different environmental locations.

### 3. TEST RESULTS: SURFACE STATE

Determination of road surface state with DSC111 is based on measuring layer thicknesses of water and black ice as well as the amount of white ice. The nominal sensitivity of DSC111 is 10  $\mu\text{m}$  of water or ice, but in practice the condition from a dry surface to a moist state can be observed already at a few microns of water layer. At a water layer thickness of about 30 to 50  $\mu\text{m}$  there is enough water to leave a clear mark in the wheel track when a car has just passed. This amount of water is a suitable limit for a moist to wet surface state. An icy state is reached when there is an observable layer of ice and it starts to reduce the friction coefficient. Typically this reduction starts at ice layers of about 30  $\mu\text{m}$  [1], but it depends strongly on road surface structure, amount of salt, and type of tire. There is experimental evidence that it can start at clearly lower thicknesses [2]. Thus it is essential to be able to detect fairly thin layers of ice, at least around 10  $\mu\text{m}$ .

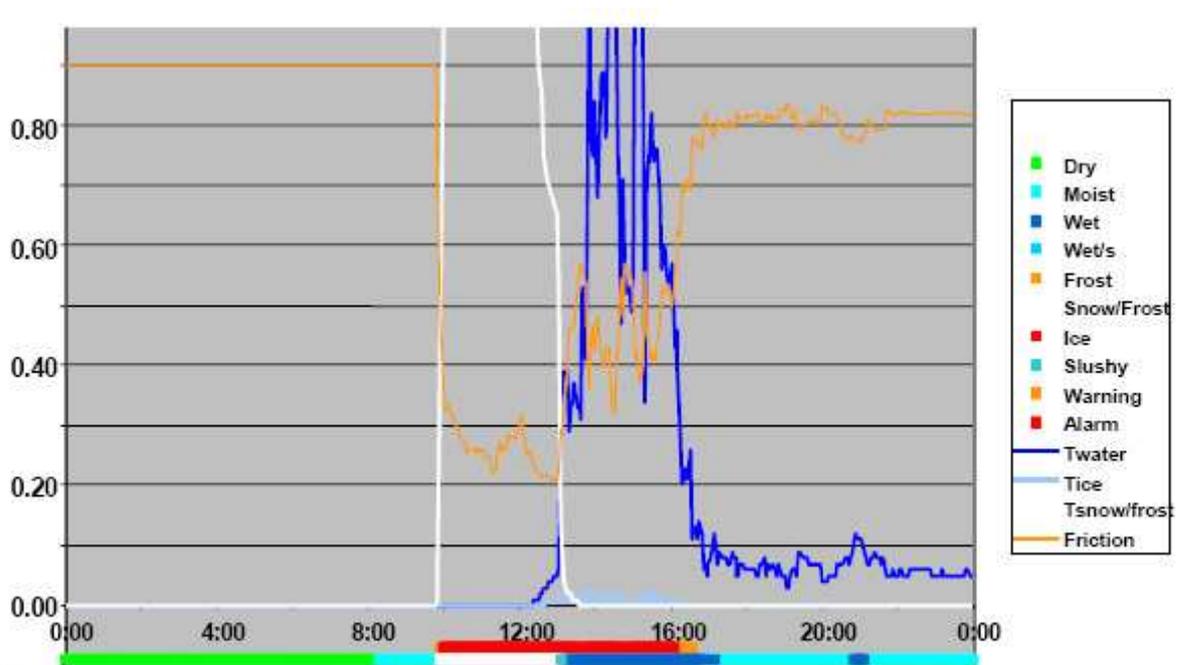


Fig. 2. An example graph of the behavior of surface state in the Salo location measured by DSC111 in 04.12.2004. The x-axis is the time (h) and the y-axis is either water (Twater, blue), ice (Tice, light blue), snow/frost (Tsnow/frost, white) amount in millimeters or the modeled friction (brown) reading. On the negative y-axis there are two colored bar codes, the lower is the surface state and the upper the warning state.

In Fig. 2 there is an example of a snow episode in one test location. At around 8:00 the surface state changes from a dry to a moist condition due to some light snow fall, which melts on the surface. At 09:50 a heavy snow fall begins. The intensity is so high that the snow cannot melt anymore and the snow amount starts to increase rapidly and the state changes to snowy. The modeled friction reading drops consequently reaching a value 0.3 or less quite fast. Consequently, a warning and soon an alarm are set on. This situation lasts to afternoon until at around 13:00 the snow starts to melt rapidly due to recent salting. While the snow is changing to slush and finally to water the modeled friction value increases to a level of moderate grip. After 17:00 there is only some water left on the surface and no reason to warn about slipperiness.

The field testing in the Utti location includes altogether 293 human observations of the surface state. These observations were done by experienced observers who did not have access to the DSC111 output at the time of the observation. Out of all the observations 90.1 % agreed with the DSC111 output and in 95.9 % of the cases DSC111 was showing the same or worse surface state. In the Salo location the overall agreement was 91.9 % out of 74 observations.

The percentages of agreement are surprisingly good. We have to take into account that the scatter between two observers, who made observations very close in time, is on the order of 10 %. Also some of the cases, when DSC111 was showing a better surface condition than the observer, may have been caused by the fact that the aiming of DSC111 turned out to be somewhat out of wheel track towards the middle of the lane. In certain weather conditions, e.g. light snow fall at low temperatures, the surface becomes slippery on the wheel tracks only and between the wheel tracks it may stay practically dry.

#### 4. FRICTION MEASUREMENTS

A number of actual friction measurements were carried out at the Utti location. The friction was measured by a commercial decelerometer by applying brakes to lock the wheels for a while. In Fig. 3 the results are compared against the modeled friction value of DSC111 called "grip". The data has been taken in various types of slippery conditions including icy, snowy and frosty surfaces at surface temperatures ranging from -10 to 0 °C during 12.01.-18.03.2005.

Since the model has amount of water, ice and snow/frost as input parameters, the effect of various types of ice on the apparent friction can be taken into account. For example, a slushy surface condition can have a reasonably high

friction value although the amount of ice is fairly high. In the contrary, a very thin layer of ice can have a dramatic drop of friction especially if the ice is hard and does not contain salt. If there is salt, then ice will build up as a fragile structure with pores filled with salty solution and again friction may stay comparably high. This is the actual reason why nominally dilute solutions are effective in preventing slippery roads.

The RMS difference of the measured and modeled friction values is only 0.07 in friction units. We should take into account that this result is obtained without using surface temperature as a model parameter nor measuring it at all while detecting the surface state. Naturally, more elaborate models could improve the result to some extent.

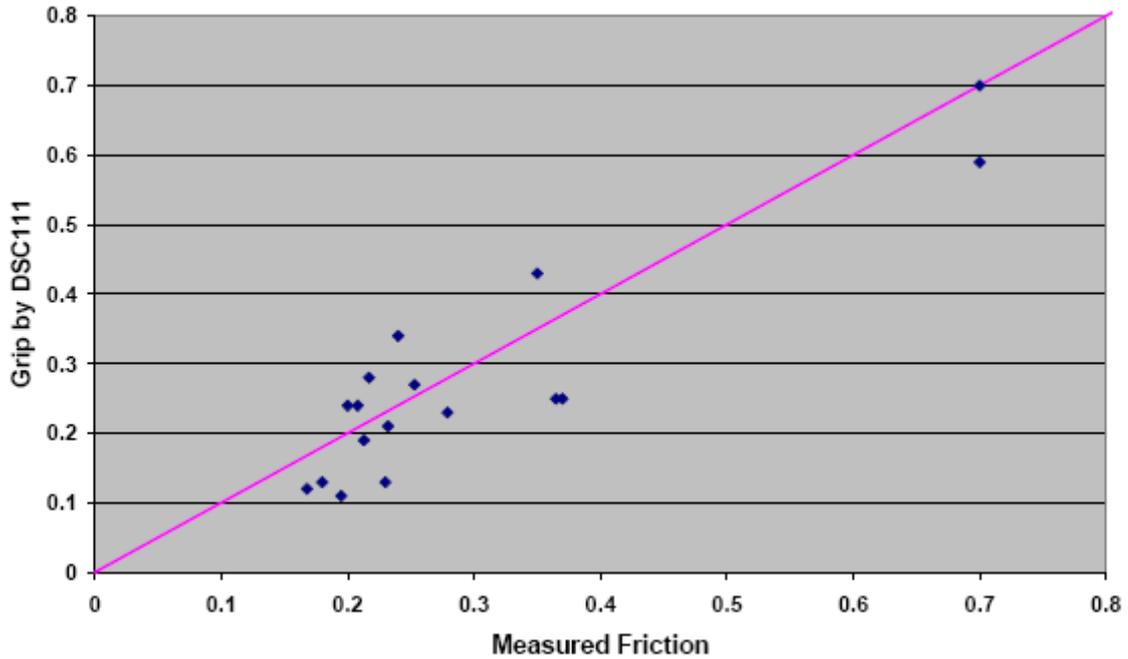


Fig. 3. The modeled grip readings of DSC111 as a function of actual measured friction. The RMS difference is 0.07 units.

#### 4. DISCUSSION

There are many thousands of road weather stations mainly in the northern hemisphere. These stations have been installed in the first place to help winter maintenance to take proper action at right time to keep up safety on the roads and save costs of winter maintenance. For deciding the right action and time one needs to have a forecast of weather as well. If we ask what the most essential information of the weather station for making the right decision is, we tend to say, e.g., road surface temperature and depression of freezing point. The first would help to understand where we are going and the latter whether there will be ice formation. It turns out that since the amount of ice alone does not make road surfaces slippery, it is more important to know which kind of ice it is and whether it reduces the friction.

We define the apparent friction as if a vehicle had a friction reading of 0.80 in lock braking on a dry surface. Naturally some vehicles could have higher or lower actual readings depending on a number parameters like type of tyres, roughness and type of road surface, gritting, speed, temperature and many others. Our assumption here is that despite these factors the relative reduction of friction due to ice is not a strong function of these parameters, i.e. presence of ice is relatively more important than the other factors in describing the level of slipperiness. Practical evidence, e.g. accident statistics on icy roads, supports this assumption. Anyway, friction will be studied further in the coming seasons.

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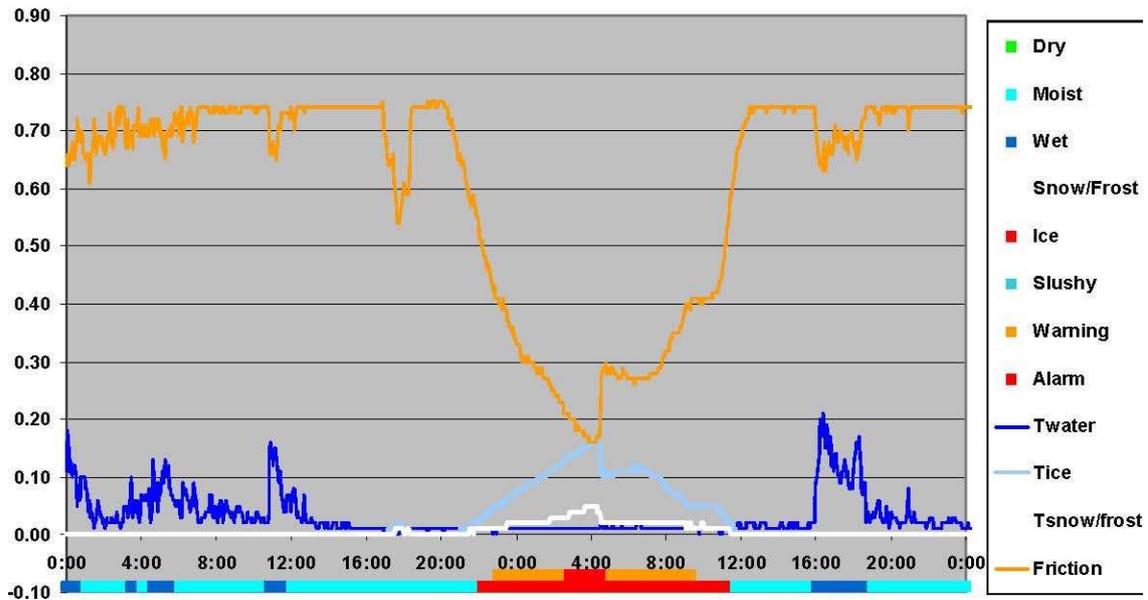


Fig. 4. Hoar frost formation in Utti overnight 11.-12.01.2005. The x-axis is the time and the y-axis is either the amount in millimeters or the grip by DSC111. Observe the dramatic hoar frost (white line) and ice (light blue line) formation starting around 21:00 in 11.01.2005 and the consequential drop of the grip (light brown line).

To show the importance of being able to follow friction values in real time we show one more example case in Fig. 4 in Utti in 11.-12.01.2005. On the 11th of January the road surface was moist and wet due to light showers until at around 18:00 there is some buildup of ice and frost with a dramatic reduction of friction. This was due to surface temperature dropping half a degree below zero with a moist and lightly salted surface. After a while the surface temperature increases and ice melts off until at around 21:00 ice buildup starts again with continuously dropping modeled friction reading. Observe that since 21:00 there was a nonzero value of water, ice, and hoar frost at the same time until noon next day. The dew point was much higher than the surface temperature, which caused the continuous buildup of ice and hoar frost. The reason not to detect just hoar frost in this case is that the traffic transforms the hoar frost to black ice.

The essential point in the case of Fig. 4 is that the road was salted only after 4:00 in the morning although it could have been treated about six hours earlier. The cost of treatment would have been the same, but the road had not been slippery over night.

The sensitivity of DSC111 to detect ice and reduced friction is high enough to improve current and open up some new applications for this technology. So far we have noted at least the following areas:

- more accurate decision making tool for winter maintenance
- automatic launching of management actions
- direct control of message signs
- weather adaptable speed limit systems
- quality controlling of maintenance work
- direct information to the drivers
- maintenance of walkways, garage slopes, tunnel entrances
- automatic deicer spraying systems.

Currently available automatic deicer spraying systems are typically built on detecting depression of freezing point and comparing that to measured surface temperature. Technically this logic can work safely assuming those parameters are measured correctly. However, the actual needed amount of deicer is fundamentally less than what the depression of freezing point indicates. A control logic based on determining the friction could save a lot of chemicals and costs, since the deicer tanks would not need so frequent filling up.

There is a simple physical explanation why salt or other deicers can effectively increase apparent friction on road surfaces although there may be a comparable amount of ice present. When ice starts to build up on a road surface with salty solution, the ice crystals reject salt and thus the solution around the ice crystals will become more concentrated. This increase in concentration stops further buildup of ice if the surface temperature is not lowering

any further. In addition, ice formation releases heat to the surface reducing the speed of icing even though the weather is cooling. In practice, our experience during the test period was that while ice buildup starts, there seems to be enough time to apply more salt or deicer before the surface is too slippery.

## 5. CONCLUSION

We have carried out a comprehensive field testing of two new remote road sensors intended for determining surface state and surface temperature in a non-invasive manner. The installation and service will be remarkably easier when compared to traditional sensors installed flush in the road surface.

The detection threshold of any kind of ice is small enough to enable a direct measure of slipperiness with the surface state sensor. This capability of measuring slipperiness in the form of a modeled friction reading will open up a new approach to road weather applications. Ice alone does not make a road surface slippery. Thus the relevant question is not what the surface state is but whether the surface is slippery.

## 6. REFERENCES

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