Icing Rate Measurements Using Clear Ice Indicators™

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Abstract— **Since 2003 HoloOptics has developed an Icing Rate sensor. The sensor has evolved through several stages, prototype, beta version and today a calibrated production version. During the development several measurement campaigns was conducted. This paper gives a brief summary of measurement campaigns at Bromma airport in Stockholm, in Sourva, Sveg and Härnösand in Sweden. Measurement was also made in Tromsö and Narvik in Norway and Geutsch in Switzerland. The indications are compared with the risk for ice at each location.**

In Härnösand the effect of icing on a wind power plant was studied.

I. Nomenclature

Icing Rate	The speed of ice building up on a structure, measured in mm/h
Risk for ice	Metrological conditions on which the risk for icing building up is reasonable large.
High Risk for Ice	Metrological conditions on which the risk for icing building up is almost certain.

II. Introduction

Icing is an important problem for all structures constructed in cold regions.

HoloOptics has worked for several years on an Icing Rate Sensor. An Icing Rate senor shows the speed on which ice is built up and not the ice thickness itself. It is very fast and indicates icing many hours before icing itself becomes a problem.

During the test period several changes was made in the design of the Clear Ice Indicator. Today a calibrated production version is ready for use.

The prototype was used at Sourva. A beta version was used at Bromma airport, in Narvik, Guetsch and Tromsö.

The production version was used in Sveg, and Härnösand

The prototype and beta sensors were not calibrated. Therefore only indications it self or a relative icing rate is shown.

An ice sensor with four arms indicates ice regardless of wind direction. A sensor with only one arm is sufficient on a wind power plant, as it is always pointing upwind. Often the wind direction, which is giving ice, is well known. If so a fixed installation of a sensor with one arm is sufficient.

III. Metrology

It is common knowledge that ice is normally built up (in vertical surfaces) only if the humidity (R_h) is over 90 % and air temperature is under 0°C.[1] Periods with those conditions are called here times with risk for ice.

Unfortunately periods with conditions showing risk for ice, but without icing building up are also very common. In some places risk for icing but no ice building up, is 2- 3 times as common as periods with risk for ice <u>and</u> icing actually building up.

In this report, therefore, period with risk for icing and indications are considered as having ice building up. Indications at times with low risk for ice are probably due to heavy rain/fog or wetting snow etc.

In Narvik and Tromsö, Norway during the winter risk for icing is very common. Therefore periods with"high risk for icing" are also noted. This is defined as periods with R_h over 98 % and air temperature is under 0°C.

Figure 1 shows a typical period with light icing. The icing measured is with one sensor with probe heating (T23) and one without (T21).

The T21 (without probe heating) is indicating, as long as more than 15 µm of ice is present on the probe. It shows the length of the icing period. The T23 (with probe heating) is indicating each time the ice is 15 µm thick. Probe heating is turned on and off without time delay. This gives a typical pattern as shown in figure 4.The icing rate is calculated from

[1] On horizontal surfaces ice may occur at higher air temperature due to heat emission to a clear sky

this pattern.

The preferred types of logger are event loggers or loggers which sense the status at short intervals e.g. every three seconds. This logger makes it possible to use the number of indications per hour or 24hour to calculate the icing rate.

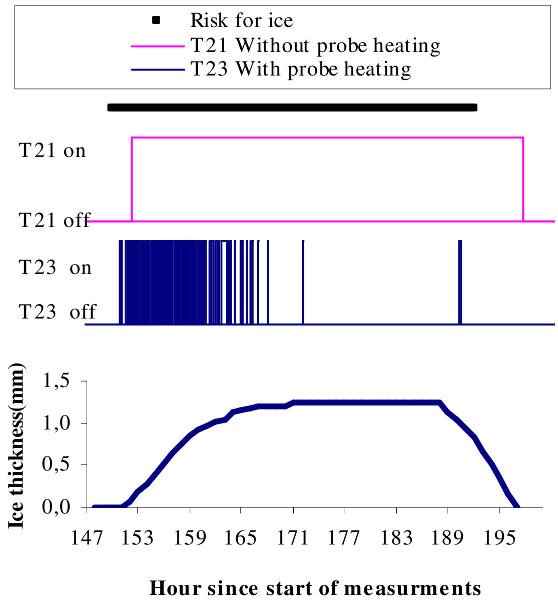

Fig 1 Example of indications and calculated ice thickness

Calibration shows that each indication equals 15 µm of ice as long as the icing rate is less than 10 mm/h.

Indication time i.e. the time it takes to melt the ice on the probe depends of many factors besides icing rate. Some factors are type of ice, air temperature, wind speed and melting power. Therefore if only indicating time is knows only relative icing rate may be calculated. That is, icing rate during different times may not be compared.

Indicating time per 10 minutes was used in Guetsch, Narvik, Aapua and Sveg.

IV. Calibrations

The production sensor with probe heating was calibrated in the VTT icing wind tunnel in Espoo, Finland. The mean droplet size was approx. 30 µm and air temperature –5°C. The wind speed was between 2 and 30 m/s. The icing rate is direct proportional against wind speed under these conditions [1][2][3].

Each calibration was run until a minimum of four indications was made, see figure 2.

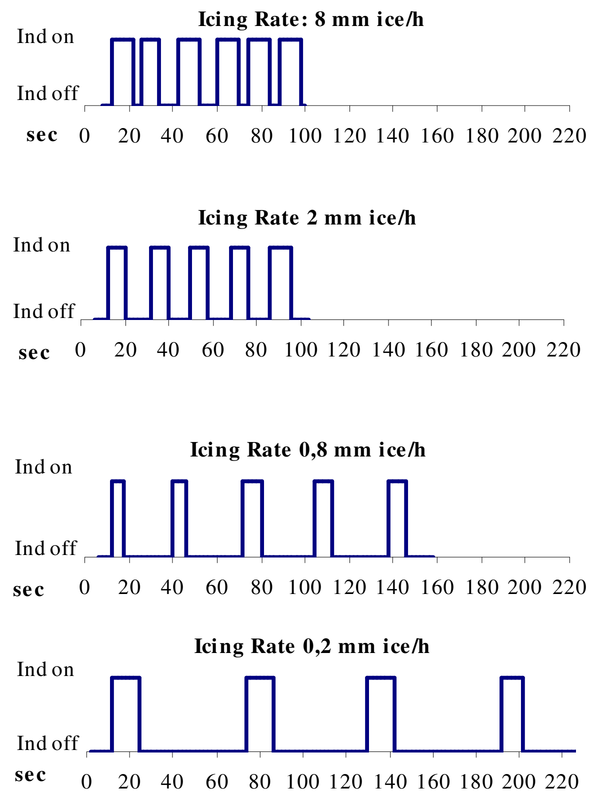

Fig 2 Calibrations run

As clearly shown the number of indications per hour is a good measurement of the icing rate, as long as the sensor is not saturated.

The calibration is confirmed by [4].

The sensor is saturated if indication is uninterrupted for more than 10 minutes. With a probe heating capacity of 5 000 W/m^2 the saturation level is approx. 10 mm ice/h.

V. CAM PAINS

1) Härnösand, Sweden

In Härnösand approx. 400 km north of Stockholm, on the shore of the Baltic Sea a sensor is installed on a wind power plant. Together with the Icing Rate Sensor the wind speed and power output from the plant was also measured. The aim was to show the effect of icing on the power output. Figure 3 and 4 shows two out of eleven periods with icing from the fall 2008 to the spring 2009. [5] [6]

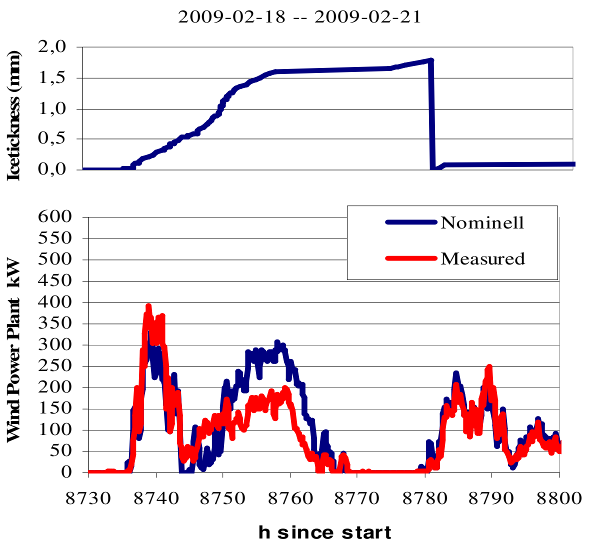

Fig 3 Härnösand Light icing on a wind power plant

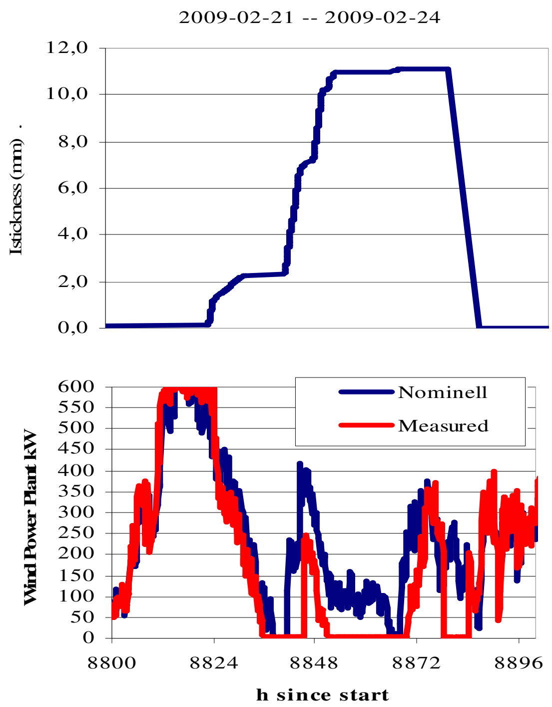

Fig 4 Härnösand Medium icing on a wind power plant

2) Sveg, Sweden

In Sveg approx. 600 km North of Stockholm in the inland several sensors was installed at different height.

The sensors were not calibrated and therefore only a relative icing rate is shown.

Two periods with icing on different levels are shown in figure 5. Measurements were made 2008/2009.

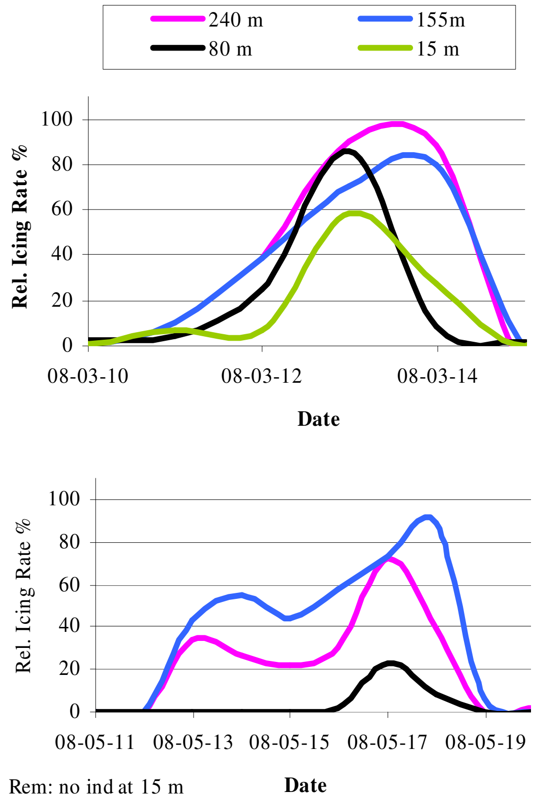

Fig 5 Sveg Two periods with icing at different height

3) Guetsch, Switzerland

In Guetsch in the Swiss Alps tests was made during the 2008/2009 seasons. The indications for 14 days are shown in figure 6.

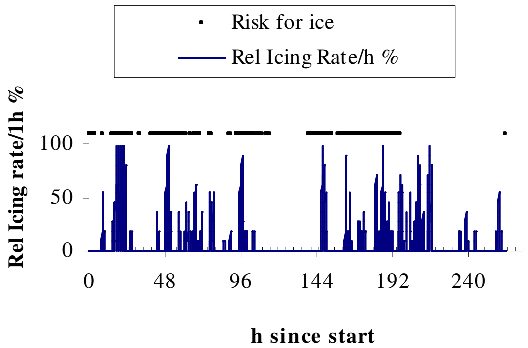

Fig 6 Guetsch 2008/2009

4) Narvik and Tromsö, Norway

In Tromsö, Norway were some beta version sensors tested during the 2004/2005 season, see figure 7. Tests were also made in the Narvik area during the 2005/2006 season, see figure 8. Risk for ice is very common.

Narvik and Tromsö are close to the North Sea 200 and 400 km north of the polar circle.

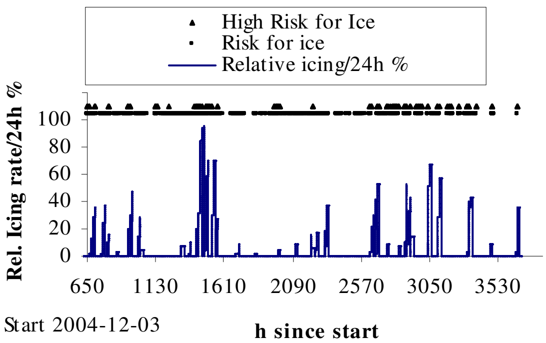

Fig 7 Tromsö 2004/2005

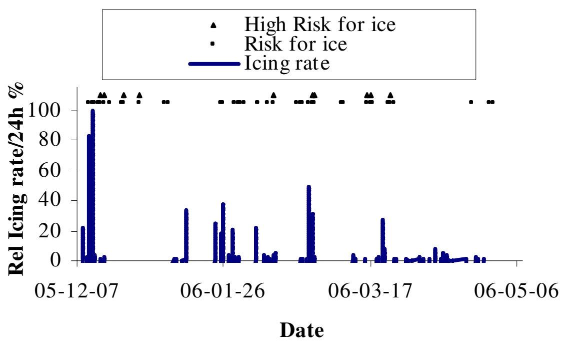

Fig 8 Narvik 2005/2006

5) Bromma Airport, Sweden

At Bromma Airport, Stockholm, Sweden was four beta version sensors tested. The sensors were installed in different directions, see figure 9. The tests were made 2004/2005.

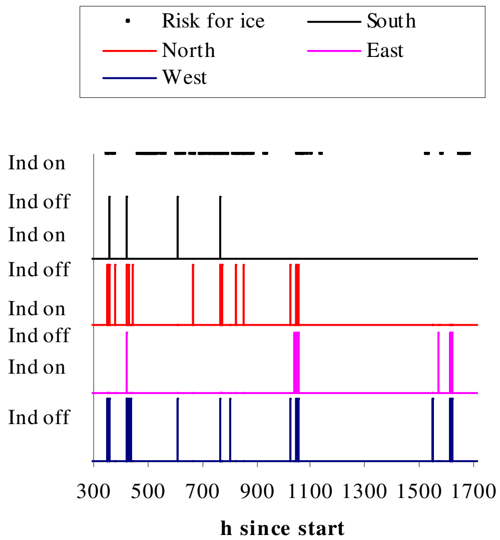

Fig 9 Indications at different directions Bromma Airport

6) Aapua and Bjelkevare, Sweden

Production sensor with probe heating was installed at a wind power farms in Aapua and Bjälkevare in Northern Sweden. Installation was made 2009.

The result is very similar to Narvik and Tromsö.

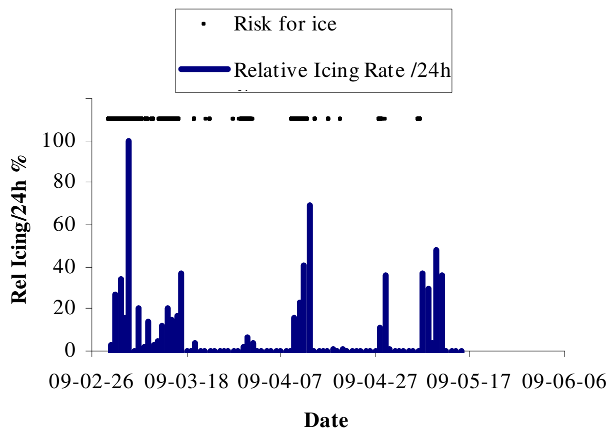

Fig 10 Aapua 2009

7) *Sourva, Sweden*

The prototype sensors were tested 2003/2004 at Sourva wind power plant in the northern Sweden inland. Sourva is approx. 100 km north of the polar circle. The effect of different types of sensors and the use of probe heating is clearly shown, see figure 11.

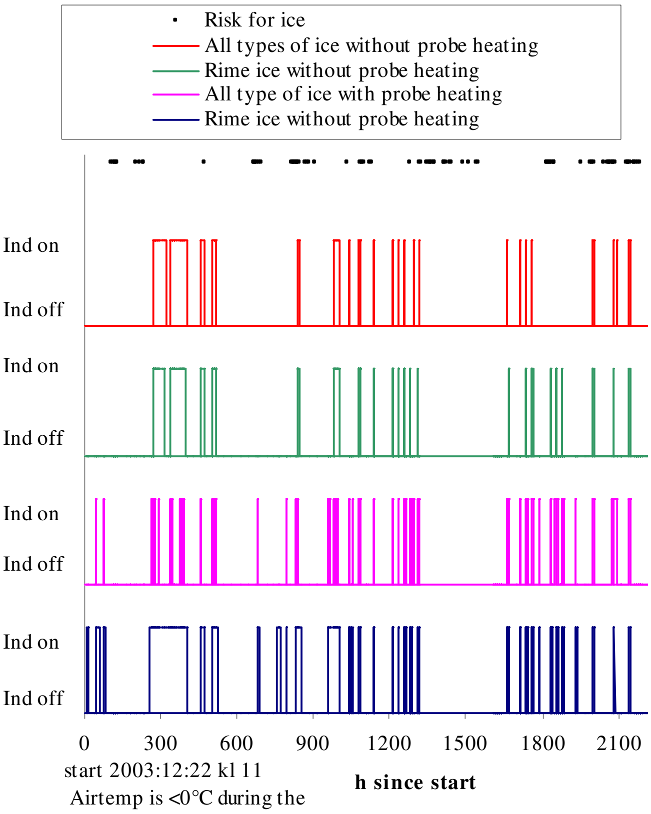

Fig 11 Sourva Different types of indicators Sourva

VI. CONCLUSIONS

Extensive testing has show Icing Rate Sensor it react fast on icing. Some 50-60 indications within a 24 hour period indicates an ice thickness of approx. 1mm. Often the senor is indication ice six to twelve hours before the ice is becoming a real hazard.

To improve the reliability the indications some temperature readings is recommended.

VII. REFERENCES

[1] Lasse Makkonen “Analysis of Rotating Multicylinder data in Measuring Cloud-Droplet-Size and Liquid Water Content” Journal of Atmospheric and Oceanic Technology vol. 9 1992

[2] An Inferred European Climatology of Icing Conditions, Including Supercooled Large Droplets, DOT/FAA/AR-05/24 Office of Aviation Research Washington DC.

[3] NASA/TM-2005-213653 Collection Efficiency and Ice Accretion Characteristics of Two Full Scale and one ¼ Scale Business Jet Horizontal Tails Colin S. Bidwell Glenn Research Center, Cleveland, Ohio Michael Papadakis Wichita State University, Wichita, Kansas.

[4] The study of HoloOptics T26 Icing Rate Sensor, Shigeo Kimura, Kanagawa Institute of Technology. Kanagawa Japan. Unpublished report.

[5] Experiences from icing at Nygårdsfjäll wind park Matthew C. Homola, Per J. Nicklasson, Per A. Sundbö Arne E. Holdo Department of computer Science, Electrical Engineering and Space Technology, Narvik University College

[6] Rime Ice Accretion and Its Effect on Airfoil Performance Michael B. Bragg, Ohio State University, Columbus, Ohio, March 1982