Registration of Observed Icing on Overhead Lines in Iceland

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Abstract — **This article describes the registration of observed icing on overhead lines in Iceland. The article provides an overview of the data sources, and how they were evaluated, as well as the observation and registration of new events, and how the data was entered into a special database (IceDat) developed for this purpose. The system of location is described along with the main features of the database. IceDat is divided in two: an icing database and a damage database. The number of records in each part in June 2019 is 3926 and 2429, respectively.**

Keywords: ***Icing, observation, registration, icing database, IceDat.***

I. Overhead lines in Iceland

Overhead lines in Iceland date back about 130 years. The first overhead line was a telephone line constructed between Reykjavík and Hafnarfjörður in 1890. In 1906, a telephone line was built from Seyðisfjörður across North Iceland to Reykjavík (614 km). This line was part of a larger project involving a submarine telegraph cable from Shetland through the Faroe Islands to Seyðisfjörður on the east coast. In 1926 the total length of telephone lines in Iceland had reached 2700 km. Fifty years later they had been transformed to underground cables.

The first transmission line of any significance in Iceland was a 45 km 66 kV line from Ljósafoss Power Plant in the Sog River to Reykjavík, built in 1935. After the Second World War, especially after 1954, the construction of a distribution line system around Iceland proceeded rapidly. This work was not finished until ca. 1980. In 1990, the distribution overhead line system was 6166 km long (Fig. 1). Now, the change to underground cables is in progress, and it will probably be completed in 2035 with ca. 9000 km of cables (Fig. 10).

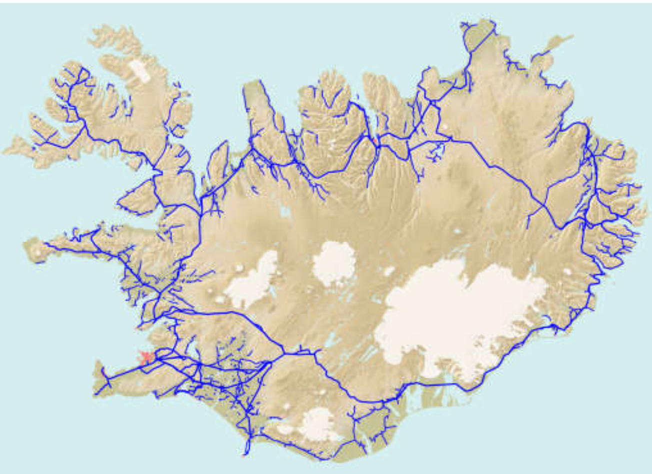

Fig. 1 Overhead lines in Iceland in 2019.

The first 220 kV transmission lines were built in 1969 from Búrfell Power Station (240 MW) to Reykjavík and an aluminium smelter in Straumsvík (Hafnarfjörður). A system of 132 kV transmission lines around the country was built in 1972 to 1984, with later additions.

II. Registration of Icing and the Icing database

In 1976 the Transmission Line Committee (Raflínunefnd) and The National Energy Authority (Orkustofnun) began the systematic recording of icing on existing overhead lines in Iceland. The reason was the preparation of a system of 132 kV transmission lines around the country. The system's mechanical design demanded accurate knowledge of the risk from icing. Before, employees of the power companies and the Icelandic Telephone Company had made occasional reports about icing hazards.

In 1977, the largest distribution company, Iceland State Electricity (RARIK), overtook the project, and in 2005 it was transferred to Landsnet. Since then, icing on transmission lines has been recorded continuously. Árni Jón Elíasson has been the project leader since 1977. Iceland is a big country and as travelling in wintertime can be difficult and time-consuming, it was initially decided to use the local staff of the power utilities all over the country. In general, they are the first to arrive at the site of overhead line failures. The traces of icing can disappear quickly, from both natural reasons and the repair process. Every effort was made to select enthusiastic individuals at each service location to carry out the registration. They could be either repair men or other members of the staff. They were trained and provided with a simple and portable kit of tools and special registration forms in their vehicles to make the observations more efficient (Fig. 2). Special reports were written for each season (from September to August). They gradually developed to include maps and photographs.

Fig. 2 A kit of simple portable tools for the observation of icing.

When new transmission lines were in preparation, a documentary search was conducted to find information about icing in the respective area. Each time it proved necessary to go through the whole document file, both old and new data, to find the icing incidents which could be of use. This was laborious, and there was always the risk of missing some necessary information. The solution developed was to make this data more accessible by entering it into a computer database. After great icing damage to lines in North Iceland in January 1991, the project began.

In the spring of 1993, work began on development of a database on icing on transmission and distribution lines owned by Icelandic State Electricity (RARIK). The development process was defined as follows: examine all available sources on icing from 1961 to 1991; gather information on the icing diameter and its distribution, along with the damage caused by icing. Then enter the information into a computer database, where it would be easy to access. The database was called »The Icing Databank« (IceDat) (*Ísingarbanki* in Icelandic). At that time, the work was considered of top priority because of massive icing damage in the previous years. Furthermore, using underground cables instead of 11 kV distribution lines was becoming more and more feasible. The database made it possible to get overviews of all icing events on specific lines and determine whether they had broken down or failed because of icing. These reports were used to prioritize which lines should be converted to underground cables. Work on this first stage of the database was completed in September 1994, and, by then, icing data from the period 1960-1993 had been entered into the database. During the following year, an agreement was reached about adding the transmission lines of the National Power Company (Landsvirkjun), The Westfjord Power Company (Orkubú Vestfjarða), and Suðurnes Regional Heating Corporation (Hitaveita Suðurnesja) to the database. Furthermore, it was decided to add available older information dating back to 1930. As a result, by May 1996, the database covered the period from 1930-1995 for the whole country.

The database was originally programmed in Oracle software, but in 1995, it was moved into Access, and the user interface concurrently changed to Windows. A new version of the interface was programmed in 2015.

III. Positioning system

An important consideration was the positioning system. The original idea was to use the Global Positioning System (GPS) or Isnet93 coordinates to locate icing events. However, as GPS digits of the angle poles of transmission lines were not available at that time, the decision was to use the existing system of transmission and distribution line-numbers and expand it so that it would encompass the entire country.

The basis used was the numerical system of Icelandic State Electricity (RARIK).

For example: Line 6-08-02-14

which means: Zone 6 (Northeast Iceland), distribution station 08 (Akureyri), line 02 from the station, branch 14.

Along each line, the position of icing is pinpointed with pole numbers. The Icing Database is connected to a database on pole numbers, and pole numbers can therefore be easily accessed. In some places, where lines and pole numbers have been changed since the icing occurred, they must be updated. For lines owned by other power companies, a similar numerical system was used.

For transmission lines of 66-220 kV, the names are according to the KKS numbering system, in the form: **SU3**, etc.

Even if GPS coordinates were not used for positioning, nothing rules out adding them to the Icing Database, and this will hopefully be done in the near future.

IV. Available sources on icing events

The first serious telephone line failure took place in Haugsöræfi in Northeast Iceland on 1 November 1906. When the repair man came to the site, he saw that a long section of the line lay on the ground, the wires in tatters, the isolators broken and the iron hooks bent down. Because there had been much disagreement about the telephone line project, the first thought that came to mind was sabotage. However, everybody soon realized that this was in fact the first known icing event. Since then, icing has been the greatest threat to overhead lines in Iceland. [7], [8].

Over time, much experience has accumulated on icing in Iceland, especially at the power companies. As the overhead line system was almost all within the range of residential areas, which are mostly close to the coast, or on mountain roads between them, little was known about the risk from icing in the uninhabited central highland and in other remote places. There it has been necessary to build special test spans for research purposes.

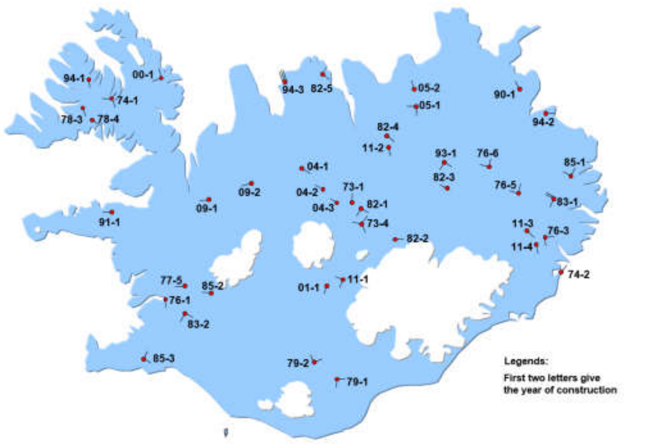

Fig. 3 Test spans in operation in Iceland 2019.

The main documental sources used in the Icing Database were as follows:

1. Yearly reports on icing since 1976.

These reports [1], [2], come close to fulfilling today's requirements for the recording of icing.

2. Damage reports from the power companies 1947-1976.

In many cases, these sources are passably good, especially after 1960, but they are not comparable to the reports after 1976. Often the diameter and even the density of icing is recorded. However, diameter often seems to be measured where it is extraordinary, it is not an average value. It was largely coincidental whether reports were made on single icing events. It depended on the severity of the event and the interest of the company director concerned.

3. Diaries of distribution stations and power stations.

These sources are very reliable, for instance, on the exact time of line failures. However, there is seldom any detailed information about the icing.

4. Articles in books and journals, old reports, etc.

These sources are both good and interesting. The Icelandic Engineering Society (Verkfræðingafélag Íslands) wrote a report in 1952 and 1953. It contains interesting maps of the main icing sites in Iceland, mainly on telephone lines.

5. Newspaper clips from the Meteorological Office

The Icelandic Meteorological Office (Veðurstofa Íslands) had a collection of newspaper clips, reaching back to 1930. Newspapers can be unreliable sources. It is therefore necessary to use them with caution. However, they often contain useful information. Sometimes the diameter of icing is reported and often the number of broken and damaged poles.

6. Information from the internet

In later years the internet has been an important source of information, both the home pages of the power companies and other sources. With digital cameras in telephones, which are always at hand, it is now easy to get and send photographs and even videos of icing on overhead lines.

In general, it is useful to interview members of maintenance teams and even farmers to get an overall picture of the risk of icing in a particular area. It is however rarely possible to rely on such interviews for details, such as dates and information about icing damages and weather conditions.

V. The Recording of Icing

The Icing database (IceDat) can be divided into two parts, first a database about icing on overhead lines (icing database) and secondly a database about icing damage on power lines (damage database). The power companies have during recent years listed all functional disturbances of the distribution network in a systematic way. However, information on icing and damages appears only partially in those records, therefore the observations in the field are very important.

The main items listed in the Icing database are following:

- Line section: Line number and pole numbers.
- Date of icing weather (from and to).
- Maximum average icing diameter (cm).
- Most prevalent average icing diameter (cm).
- Estimation method (or accuracy) for ice, four groups.
- The way of icing formation, five groups.
- The type of the icing, six groups.
- The direction of icekeel (from and to) deg. from north.
- The density of icing, if measured (from and to) g/cm^3.
- The extent of line-failures (six groups).

A more accurate description of the icing and its distribution is given in text, and other things which may be necessary or advisable to report. Finally, the sources are listed, the name of the person who brought information into the icing database and the date when it was done (Fig. 5).

Available information about the icing differs a lot, both in details and accuracy. Sometimes we have information on the density and even the pollution of icing.

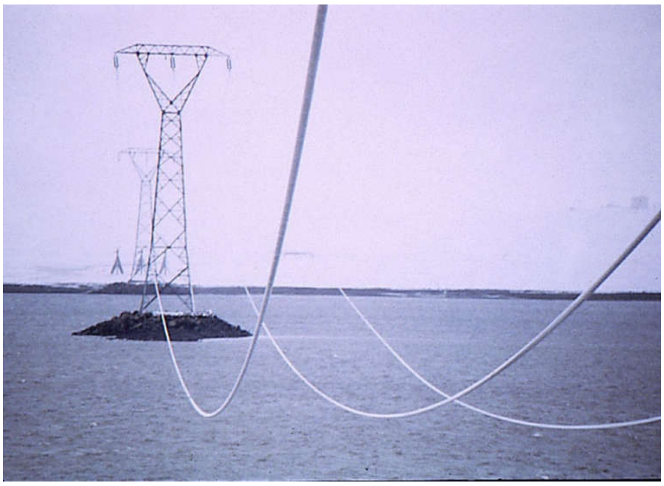

Fig. 4 Icing on 832 m span over Gilsfjörður, West-Iceland, November 23. 1992.

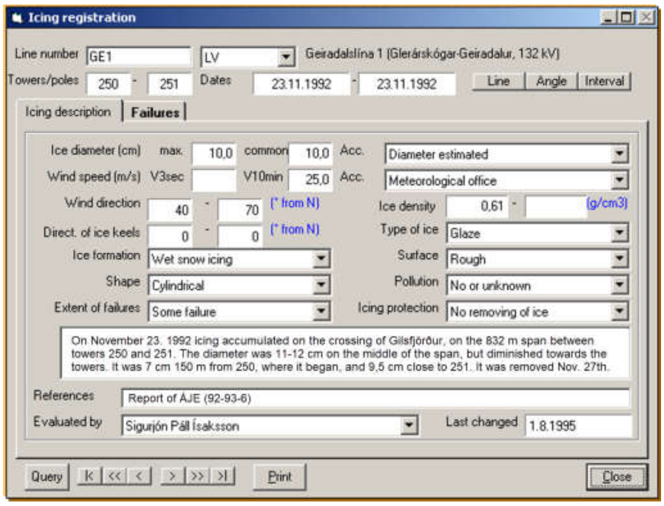

Fig. 5 The icing description window. The Gilsfjörður event.

Often the icing slides on the conductor so that the diameter is largest at the centre of each span. Average diameter is an estimated mean value which would result if the icing were distributed evenly across the span. Maximum average diameter pertains to the span of the line where the icing is thickest. Most prevalent average icing diameter is an average value for the line section being discussed. All cases where the diameter is less than 4 cm are omitted.

Fig. 6 Wet-snow icing on Mjólkárlína 1, West Iceland, 20 February 2014. The icing diameter at each line section is shown.

VI. EVALUATION AND REGISTRATION OF DATA

One of the most delicate parts of the data processing stage was the evaluation of available sources on the diameter of icing. A clear demand was made that the diameter of icing would always be recorded, whether good information was available or not. There were therefore four options for recording the accuracy of the icing diameter:

1 Diameter measured directly in a satisfactory manner.
2 Diameter estimated at the site or from an extreme example.
3 Diameter estimated with good probability.
4 The diameter is a wild guess. No information is available.

When icing diameter had to be estimated because of limited information, the extent of icing failures on the line section in question was a starting point. Former values of icing diameter in the area were also considered, or how much icing took place in the same weather in another district. Often diameter is described by comparison with some familiar object which helps to estimate the diameter in cm. Of course, we must use information of this type with caution, but the main purpose is to get an overview of the frequency of icing in particular areas and wind directions, and to include data of line failures, which is generally more reliable.

Fig. 7 Catastrophic failure in the north of Iceland, Kópaskerslína 1 (KS1) 10.09.2012.

Fig. 8 Extreme midspan-diameter in the same event, 27 cm.

If possible, wind direction at the time of accretion is estimated, but no special emphasis was on the recording of wind speed because it is accessible from the Icelandic Meteorological Office. Attempts were made to estimate the way in which icing formed, whether it was wet-snow icing, in-cloud icing, freezing rain, ice crystal condensation, or geothermal or sea breeze.

To coordinate the data, rules were written on how to estimate the sources and record the data.

In June 2019, there are 3926 records in the Icing Database.

VII. OVERHEAD LINE FAILURES

The power companies often have more information about the extent of overhead line failures, than the icing itself. For the extent of overhead line failures, there are six categories:

0 No failure.
1 Minimal failure, for instance, short circuit or flashover.
2 Some failure, for instance, bent pins, damaged stays, strained conductor.
3 Considerable failure, for instance, a broken conductor, a broken crossarm.
4 Serious failure, for instance, a broken pole, or conductors broken at many locations.
5 Very serious failure, many broken or fallen poles.

This classification is used for 11-33 kV distribution lines. Large transmission lines, such as 220 kV lines with steel towers, are classified one step higher, e.g., a broken conductor is a serious failure.

In registration of line failures, several items are evaluated and recorded. The main items are the following:

- The number of poles broken or fractured.
- The number of poles with foundation failure, where poles are reclining considerably or lie sideways.
- The number of broken crossarms.
- The number of broken conductors or earth wires.
- The extent of short circuits or flashovers (four groups).
- The exact time of the power outage.

In addition to this, a more detailed description of the failure is given in text, e.g., which poles were broken, on what spans conductors were damaged, how long it took to repair and so on.

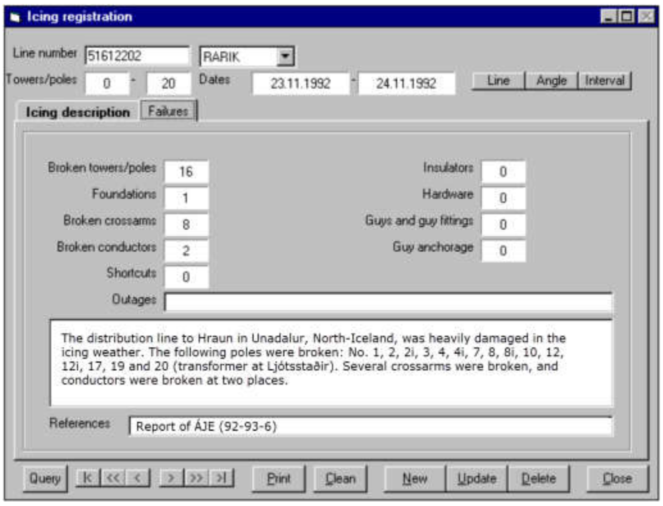

Fig. 9 The failure description window.

The available information about failures varies considerably. Usually there is a good estimate on the number of poles which broke or fell and the number of broken conductors. However, in general, information regarding the failure of isolators, hardware and stays is seldom recorded.

In June 2019, there are 2429 records in the failure database.

VIII. Further Discussion

During this work, several new ideas surfaced as to how the database could be further used or improved. Many of them were implemented directly; others are still waiting.

It is necessary to maintain the Icing Database and update it regularly with new icing events. The continuous recording of icing since 1976 has gradually provided a good overview of the main icing areas in Iceland, and the most common ice load in each area.

Weather data from the Icelandic Meteorological Office is seldom added to the icing records for older cases. However, it is generally included in recent reports as it is now easily available on the internet. When studying icing events in special areas, such information is included in connection with a computer-based meteorological study and modelling of known icing events.

Another field worth discussing is the replacement of overhead distribution lines with underground cables. This is process which began ca. 1993 and will be finished in 2035 (Fig. 10). The urgency of prioritizing the laying of underground cables around Iceland was what really necessitated the construction of the Icing Database. The rapid decrease in broken poles after 1995 shows that it has been very useful, see Fig. 13. A comparable decrease is in the number of reported icing records, see Fig. 14.

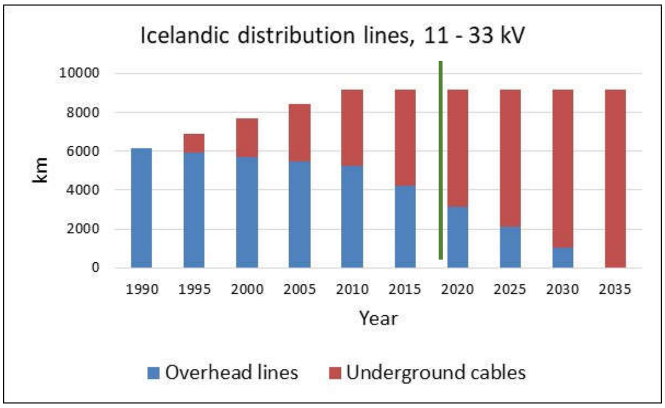

Fig. 10 The Icelandic distribution net, OH-Lines and Cables. Predicted values are on the right side of the vertical line.

Though the Icing Database is an important tool, it does not cover all icing events for Icelandic power lines. It covers most events with failures and many events without failures which are located close to inhabited areas. In remote areas, where we have strong transmission lines, there are probably many events that are not reported. This can be seen where we have load-cells with continuous recording on operating lines, e.g., on Hallormsstaðaháls, East Iceland, where incloud icing is common in the winter, see Fig. 11. Such cases are not added to the database, but are used in special studies of the area, as another source of information.

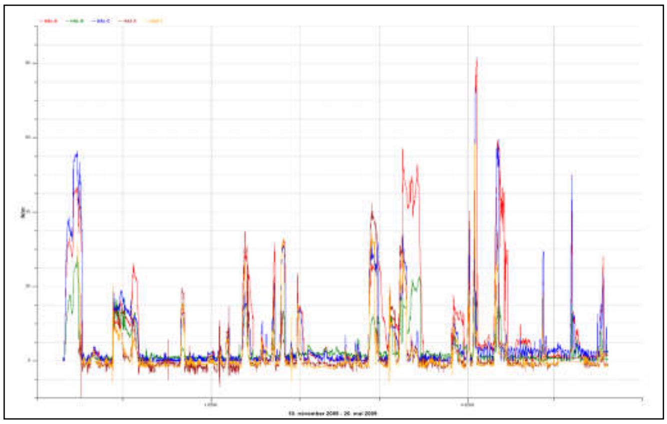

Fig. 11 Remote recording of incloud icing on Hallormsstaðaháls in the winter 2008-2009. The highest load is 80 N/m.

The Icing Database has been used mainly for the following purposes:

- Prioritization of maintenance and underground cable projects, see above.
- Evaluation and optimization of line routes for new overhead transmission lines, 132-400 kV.
- Setting the design iceload for new overhead transmission lines, 132-400 kV.
- Information on incloud icing has been used in projects for other structures, such as new telephone and radio masts in exposed locations.

In optimizing new line routes, attempt has been made to avoid dangerous areas, or go through them in a preferable direction as the danger is greatest when the lines are perpendicular to the main icing direction in the area.

In setting the design ice load for new transmission lines, it is customary to write a report with a special study of the area, where the Icing Database is one of the sources included.

In areas where there are no power lines, but may be feasible for transmission lines in the future, the power companies, especially Landsnet, have constructed a system of test spans with continuous recording of icing, see Fig. 3 and Fig. 11.

Record	Icing event		Max Ice+Wind	Max Iceload
No.	From	To	[N/m]	[N/m]
1	30.11.2005	5.12.2005	16	16
2	7.12.2006	18.12.2006	11	10
3	7.1.2007	15.1.2007	5	4
4	11.1.2008	18.1.2008	6	5
5	10.11.2008	16.11.2008	7	6
6	19.3.2010	24.3.2010	11	10
7	21.1.2012	28.1.2012	12	11
8	**10.9.2012**	**12.9.2012**	**164**	**156**
9	21.11.2012	22.11.2012	13	12
10	16.9.2013	17.9.2013	21	19
11	24.12.2013	8.1.2014	70	67

Fig. 12 Data from a load cell in mast no. 168 on Kópaskerslína 1, 66/132 kV. Event No. 8 is in the Icing Database. It was catastrophic wet snow icing, see Fig. 7 and 8. The other events are not there, but they are in most cases minimal.

IX. Conclusions

Special icing studies with computer-based meteorological modelling are progressing rapidly. However, observations in the field are the reality that the models are trying to imitate. Such field observations are indispensable for verifying the models and improving research, especially since there will always be some uncertainties in the input data which is a prerequisite for the model's results. The Icelandic power companies have maintained the Icing Database and other sources of icing-data to advance the development of computer models to make them more accurate and useful in the future.

The IceDat information is one of the most important parts of Iceland's contribution to the field measuring program, which has been published internationally. It has served as a reference database for the refinement of theoretical icing models, especially for wet snow accretion, as well as for the improvement of international standards and design codes.

The following figures (Fig. 13 to Fig. 16) show examples of data presentation from IceDat.

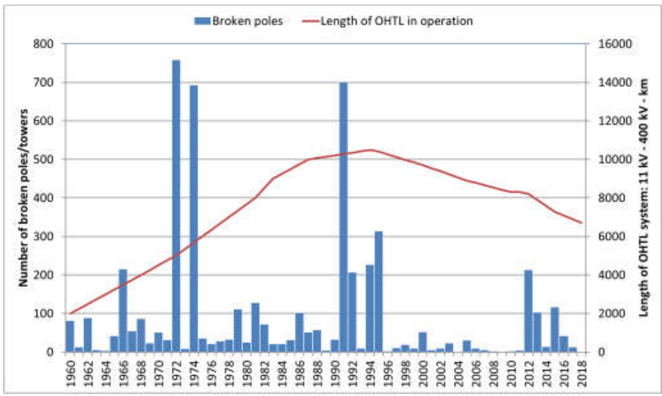

Fig. 13 Number of broken poles due to icing, registered since 1960. Note the fall after 1995; the prioritizing of the underground cables began in 1993. In 2012 and 2013, severe icing weather in the north were comparable to the weather in 1991.

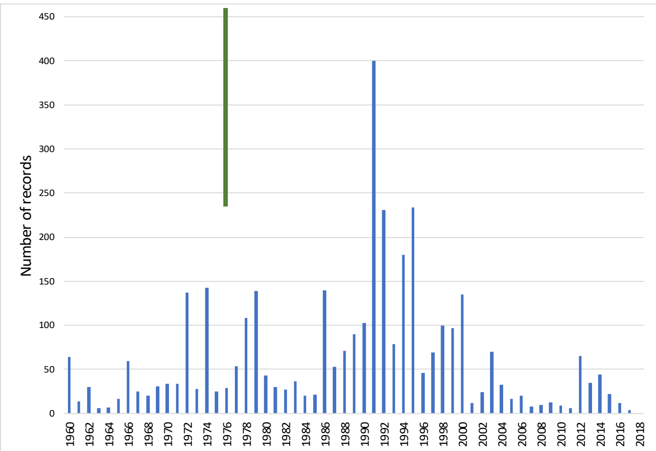

Fig. 14 The number of icing-records 1960-2018. Systematic recording of icing began in 1976, see the vertical line. Note the decrease after 1993 when the underground cable project began.

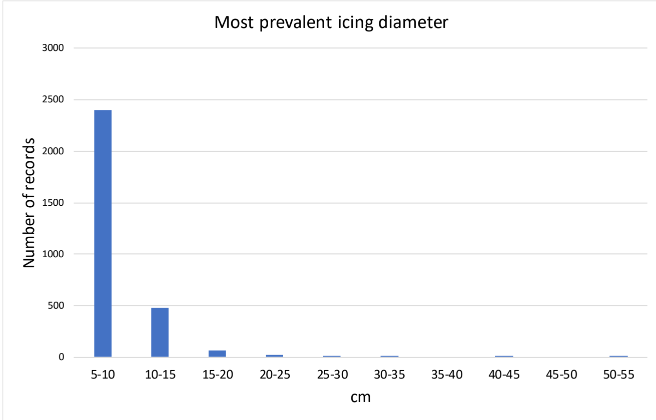

Fig. 15 Most prevalent icing diameter (measured/evaluated), number of records.

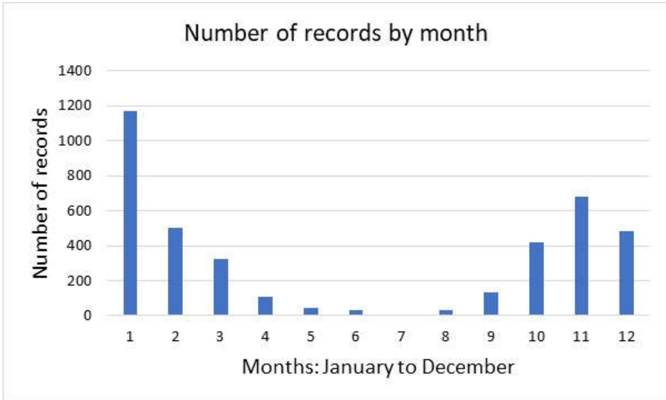

Fig. 16 Distribution of icing records during the year.

Acknowledgment

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