Rate of Ice accumulation During Ice Storms

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Abstract—**The rate of glaze ice accumulation during ice storms is an important parameter for the design of mechanical and electrical deicing devices. Rates of ice accumulation are a function of the rate of precipitation, wind speed and direction, and air temperature. These rates can be obtained from accumulation models based on meteorological data from airports or alternatively from site specific direct observations. In this paper, the historical database of Hydro-Quebec has been used to compute accumulation rates at several stations across Quebec. The observed rates were adjusted to account for the predominant wind direction during each storm relative to the ice collector. The accumulations were converted to represent the average ice on a 30 mm diameter conductor at 30 m above ground with a span of 300 m. The results indicate that despite significant spatial variations in the expected severity of ice storms as a function of location, the distribution function for rates of accumulation are fairly similar and can be assumed to be independent of location. The results are given for a line that is perpendicular to dominant winds.**

I. INTRODUCTION

The objective of this paper is to estimate the distribution of the rate of glaze ice accumulation on conductors in southern Quebec. This information is critical for the design of mechanical and electrical deicing devices. The rate of glaze ice accumulation is the result of a complex process that depends on numerous meteorological and physical factors that are often not well documented and difficult to integrate in a numerical simulation. For these reasons, the analysis presented in this paper is based on direct observations of ice accumulation collected on passive icemeters. The stations that were selected for the analysis are those located at the Quebec, Montreal and St-Hubert airports.

II. PREVIOUS STUDIES

Laflamme (2002) analyzed the climatology of freezing rain in the region of Lévis and the accumulation of glaze ice of various segments of electric transmission lines. This was the first study to describe the circulation of humid air that generates glaze precipitation in the region surrounding Quebec City.

McComber (2002) analyzed glaze ice accumulation on passive icemeters and electric transmission lines at the experimental site of Mont Bélair to develop correlations between ice accumulations on the passive icemeter and conductors of a transmission line. He demonstrated that both accumulations on standardized cylinders as well as on flat surfaces of the icemeeter were good predictors of ice accumulation on transmission lines.

III. DATABASE OF GLAZE ACCUMULATION

The electric transmission line network of Hydro-Quebec covers a very large territory and atmospheric icing hazards are quite variable as a function of location. The areas most exposed to ice storms are located in the southern part of the province and in particular in the valley of the St-Laurent River which is also the most densely populated part of the province. A network of passive icemeters was deployed through the province in the middle of the Seventies in order to document the incidence of glaze ice. The icemeters were often installed at the site of existing meteorological and climatological stations.

The icemeter comprises four cylinders of 10 mm in diameter arranged in a square configuration (oriented North, South, East and West), four cylinders of 25 mm in diameter similarly arranged, and finally four vertical surfaces plus one horizontal.

The database comprises observations at over 140 stations over a period of more than 25 years. Measurements were taken manually at intervals of three to twelve hours during periods of glaze ice depending on the accessibility of the site and the availability of the observers. This paper presents results from the analysis of the three passive icemeters located at the airports of Quebec, Montreal and St-Hubert.

The data was processed such that each glaze ice event is numbered in a chronological sequence. Each event consists of the time series of ice accumulations on each of the eight cylinders and of the five surfaces of the icemeter.

For the purpose of the study, only the accumulations on the 25 mm cylinders were analyzed. The observations were corrected to account for the water content of the glaze ice as evidenced by the presence or absence of icicles. The corrected observations are representative of accumulations on a 30 mm diameter conductor at an elevation of 30 m above ground on a line with a 300 m span.

IV. ANALYSIS OF GLAZE ICE ACCUMULATION

Table 1 is a summary of the data for the three stations. Each site experiences on average of 4 icing events per year and the severity and duration of the events are quite variable.

A. Analysis Method

Three methods were used for the analysis of the rate of glaze ice accumulation. The first method consists in calculating the average rate of ice accumulation using data only from the most exposed cylinder for each time period of each ice event. The objective is to obtain an estimate of the rate of ice accumulation for a line that is almost perpendicular to the dominant winds. The second method consists in calculating the average rate of accumulation during only the period of maximum ice accumulation during each storm and provides a very conservative estimate of ice accumulation rates since these high rates are never sustained during the full length of the storms. The third method consists in calculating the average accumulation for a 12 hour period using data only from the most exposed cylinder. This last method is thought to be the most useful for deicing strategies since the time scale is representative of the time required to implement deicing strategies during field operations.

TABLE I

SUMMARY OF ICE STORM DATA FOR EACH STATION

Name of Station	Number of years of observation	Number of icing events	Number of readings
Québec	26	92	334
Montréal	28	106	368
St-Hubert	27	88	368

B. Results and Discussion

The detailed results of the analysis are presented only for the station of Montreal (Figures 1 to 3) since the results are similar for the other two stations. The figures are histograms of the rate of ice accumulation for each of the three methods of calculation

(1) Results for the First Method

The results using this first method indicate that the greatest number of observations is for an average accumulation rate between 0 et 0.5 mm/hr with 75.1%, 85.5% and 95.8% of all observations for Québec, Montréal, and St Hubert respectively (Figure 1). For the three stations the percentages fall to 14.2%, 8% and 1.8% respectively for average rates of accumulations between 0.5 and 1 mm/hr. The percentages of observations for accumulation rates higher than 1.0 mm/hr are 10.7%, 6.5% and 2.4%, for Québec, Montréal and St-Hubert respectively.

(2) Results for the Second Method

The results using the second method indicate that the average hourly rate of accumulation is between 0 and 0.5 mm/hr in 65.6%, 81.9% et 69.2% of the storms for Québec, Montréal and St-Hubert respectively. The second most frequent interval is for accumulation rate between 0.5 an 1 mm/hr and corresponds to 17.2%, 9.7% and 23.5% of the storms. Finally, accumulation rates larger than 1.0 mm/hr correspond to 17.1%, 8.4% and 7.3% of the storms for Québec, Montréal and St Hubert respectively (Figure 2).

(3) Results for the Third Method

The results of the analysis with the third method provide accumulation rates over 12-hour periods. The percentages of periods with accumulation rates between 0 and 0.5 m/hr are 79.4%, 84.7% et 79.5% for Québec, Montréal and St Hubert respectively (Figure 3).

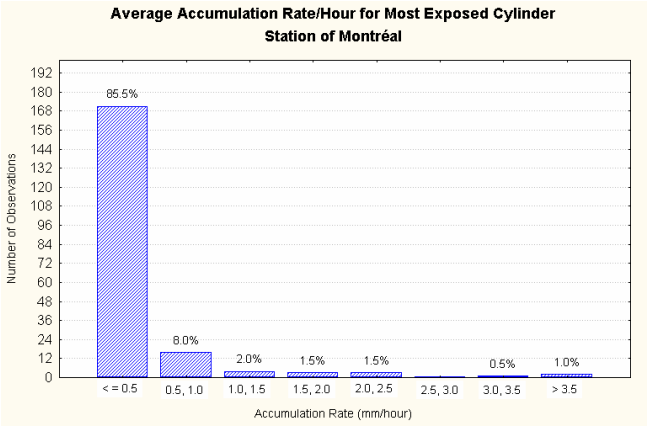

Fig. 1. Histogram using first method of calculation for Montreal station

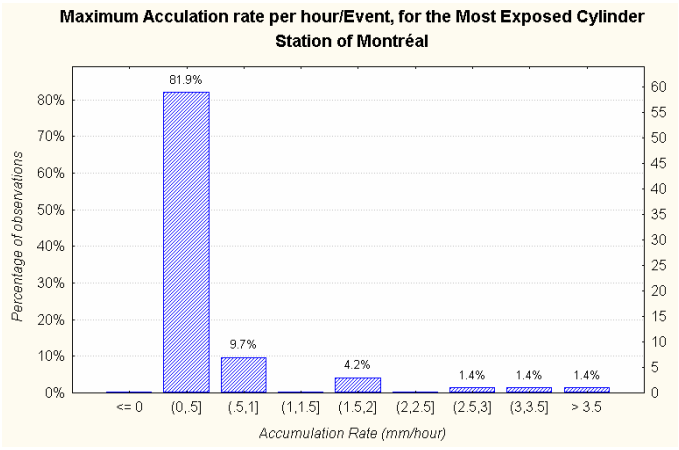

Fig. 2. Histogram using second method of calculation for Montreal station

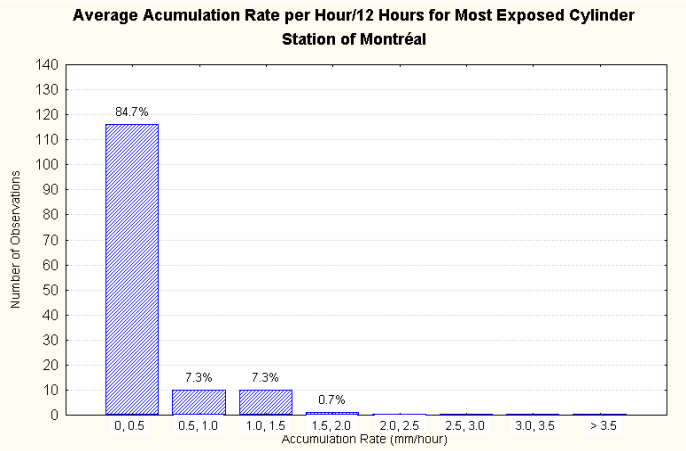

Fig. 3. Histogram using third method of calculation for Montreal station

(4) Results for Combined Stations,

The results of the analysis of the rate of ice accumulation for the three stations of Quebec, Montreal and St-Hubert were first compared and it was determined that the samples could be considered to be homogeneous. The results for the combined stations were compiled for the three procedures described above. Using the first method, the hourly rate of ice accumulation between 0 and 0.5 mm/hr represents 85.4% of the observations while rates between 0.5 and 1 mm/hr and greater than 1 mm/hr represent 8% and less than 8% of the observations respectively. (Figure 4).

Using the second method, the maximum average hourly accumulation rate per event is between 0 and 0.5 mm/hr in 72.5% of the cases and between 0.5 and 1 mm/hr in 16.7% of the cases. The number of observations decreases significantly for rates higher than 1.0 mm/hr.

When hourly accumulation rates are computed over 12 hour periods (third method), 81.4% of the observations correspond to a rate between 0 and 0.5 mm/hr followed by 11.7% for a rate between 0.5 and 1 mm/hr (Fig. 6). As with the first and second methods, the percentage of observations decreases significantly for rates higher than 1 mm.

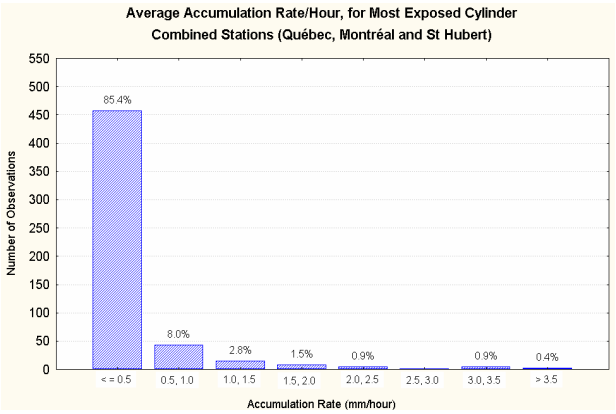

Fig. 4. Histogram using first calculation method for combined stations

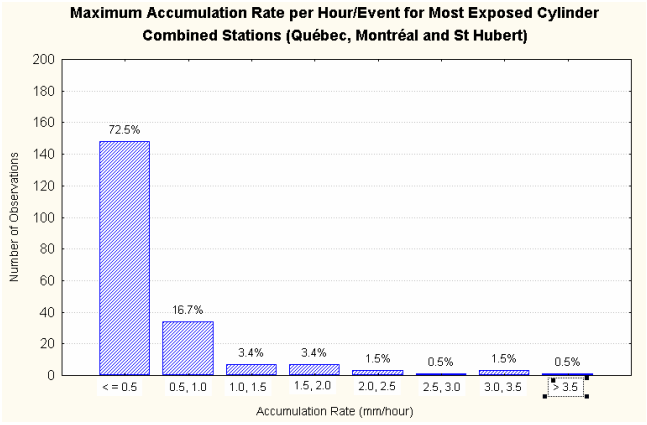

Fig. 5. Histogram using second calculation method for combined stations

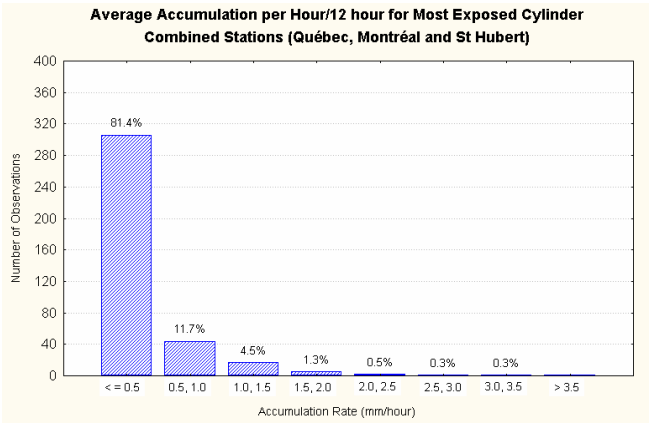

Fig. 6. Histogram using third calculation method for combined stations

(5) Accumulation Rate higher than 1.0 mm/hour

Table 2 presents the percentages of accumulation rates higher than 1.0 mm/h calculated with the three methods, for the three stations under study and for the three combined stations.

TABLE 2
PERCENTAGE OF ACCUMULATION RATE > 1.0 MM/HOUR

Station/ Method	Quebec	Montreal	St-Hubert	Combined stations
First Method	10.7%	6.5%	2.4%	6.5%
Second Method	17.1%	8.4%	7.3%	10.8%
Third Method	6.6%	8.0%	6.2%	6.9%

The results show that the second method provides the highest proportion of accumulation rates greater than 1 mm/hr. This is expected since the second method considers only the maximum rate of accumulation for each of the icing events.

C. Discussion

The results show that for the three stations of Quebec, Montreal and St Hubert the highest number of observations corresponds to an average accumulation rate between 0 and

0.5 mm/hr followed by rates ranging between 0.5 and 1 mm/hr using all three methods of calculation. The results for the three combined stations are similar to those for individual stations and show that the greatest number of observations corresponds to an average maximum rate per hour of 1 mm .

It can be concluded from this analysis that after 12 hours or more of ice storm, the average accumulation rate does not exceed 1.0 mm for more than 90% of the observations as shown on figure 3 for Montreal and figures 4 to 6 for the combined stations.

In theory, the rate of ice accumulation on a transmission line is a function of wind speed and direction. This was investigated by analyzing the rate of ice accumulation as a function of wind speed for each station (Figures 7, 8 and 9). Figure 10 shows the same relationship but for total accumulations greater than 4 mm for the station of Montreal.

The accumulation rate increases in general, according to wind speed as shown in Figures 8 and 9 for the stations of Quebec and St Hubert. In the case of the station of Montreal (Figure 7), this effect is less pronounced except for wind speeds between 10 and 20 km/hour It should be noted that the largest historical ice accumulations occurred during the Ice Storm of January 1998. The total duration of the event was long and consequently the average accumulation rate per hour is lower than for the 3 cases mentioned previously.

The same conclusions apply to the relationship between rate of ice accumulation and wind speed for total accumulations greater than 4 mm for the three stations under study. Figure 10 shows the tendency for the station of Montreal.

It can be noted that most accumulation rates are in the interval of 0 to 1 mm independently of wind speed.

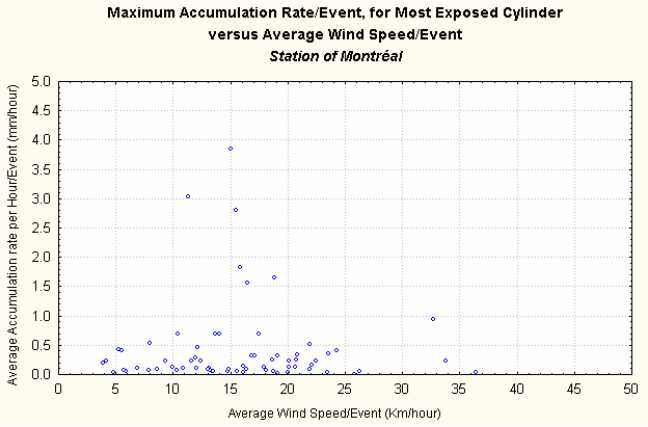

Fig. 7. Accumulation rate versus wind speed for the station of Montreal

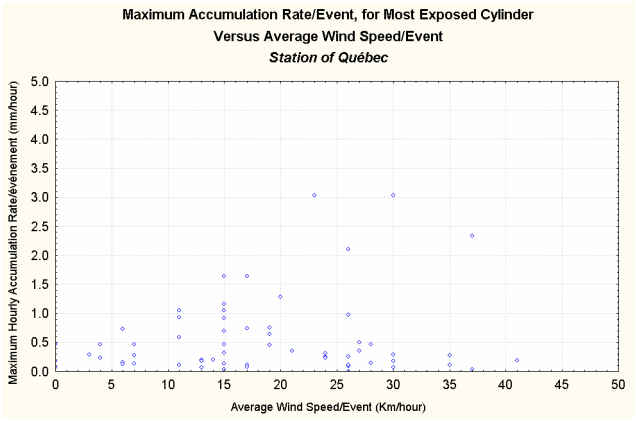

Fig. 8. Accumulation rate versus wind speed for the station of Quebec

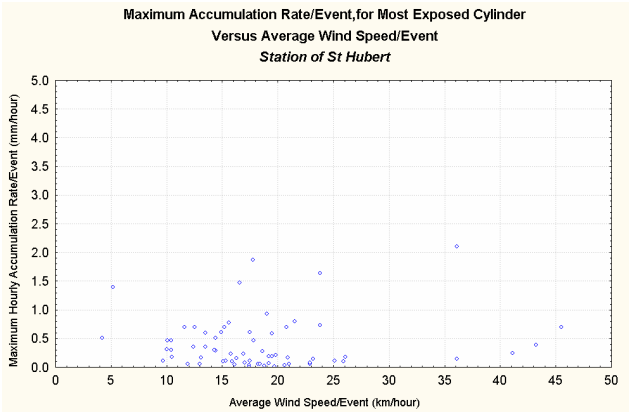

Fig. 9. Accumulation rate versus wind speed for the station of St Hubert

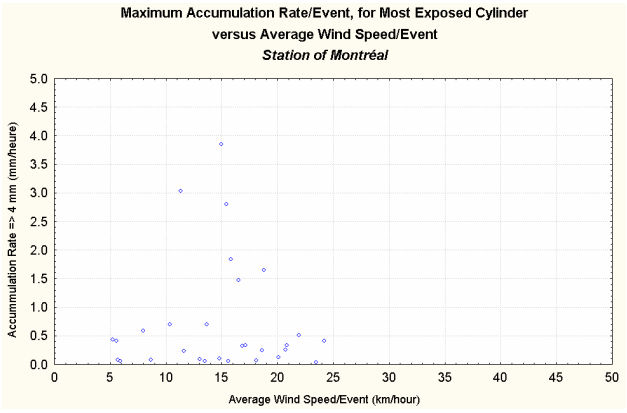

Fig. 10. Accumulation rate versus wind speed for the station of Montreal (total accumulation ≥ 4 mm)

V. CONCLUSION

The data on glaze ice accumulation for the three stations of Quebec, Montreal and St Hubert were analyzed in order to estimate the rate of ice accumulation on conductors. The results obtained for the three stations using three analysis methods show that the average hourly rate of ice accumulation is 1.0 mm/hr . The analysis indicates that observations from several sites can sometimes be combined in order to obtain

better estimates of the distribution of hourly rates of ice accumulation. These rates are highly variable and should be computed in relation to a standard time period. High accumulation rates have been observed but usually these are not sustained over long periods of time. For deicing strategies, average accumulation rates over 12-hour periods seem appropriate; however, analyses should also be performed for other time intervals to appreciate the variability in the rates of ice accumulation over time. Finally, accumulation rates do not appear to be highly correlated with average wind speed for maximum hourly accumulation rates.

VI. REFERENCES

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