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Development and Demonstration of a Freezing Drizzle Algorithm for Roadway Environmental Sensing Systems

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Aurora Project 2007-04

Final Report
October 2012

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16. Abstract

The primary goal of this project is to demonstrate the accuracy and utility of a freezing drizzle algorithm that can be implemented on roadway environmental sensing systems (ESSs).

The types of problems related to the occurrence of freezing precipitation range from simple traffic delays to major accidents that involve fatalities. Freezing drizzle can also lead to economic impacts in communities with lost work hours, vehicular damage, and downed power lines.

There are means for transportation agencies to perform preventive and reactive treatments to roadways, but freezing drizzle can be difficult to forecast accurately or even detect as weather radar and surface observation networks poorly observe these conditions. The detection of freezing precipitation is problematic and requires special instrumentation and analysis.

The Federal Aviation Administration (FAA) development of aircraft anti-icing and deicing technologies has led to the development of a freezing drizzle algorithm that utilizes air temperature data and a specialized sensor capable of detecting ice accretion. However, at present, roadway ESSs are not capable of reporting freezing drizzle.

This study investigates the use of the methods developed for the FAA and the National Weather Service (NWS) within a roadway environment to detect the occurrence of freezing drizzle using a combination of icing detection equipment and available ESS sensors.

The work performed in this study incorporated the algorithm developed initially and further modified for work with the FAA for aircraft icing. The freezing drizzle algorithm developed for the FAA was applied using data from standard roadway ESSs.

The work performed in this study lays the foundation for addressing the central question of interest to winter maintenance professionals as to whether it is possible to use roadside freezing precipitation detection (e.g., icing detection) sensors to determine the occurrence of pavement icing during freezing precipitation events and the rates at which this occurs.

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DEVELOPMENT AND DEMONSTRATION OF A FREEZING DRIZZLE ALGORITHM FOR ROADWAY ENVIRONMENTAL SENSING SYSTEMS

Final Report
October 2012

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

Freezing drizzle is a weather phenomenon that can occur during the cool season of the year at most temperate locations. The occurrence of freezing drizzle may result in significant loss of property and present a significant safety hazard for all forms of surface mobility. The National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) defines freezing drizzle (NWS Glossary 2009) as, "a drizzle that falls as a liquid but freezes into glaze or rime upon contact with the cold ground or surface structures."

The NWS issues a Freezing Drizzle Advisory when freezing rain or freezing drizzle is forecast but a significant accumulation is not expected. However, even small amounts of freezing rain or freezing drizzle may cause significant travel problems (pedestrian and vehicular), which are the most common problems associated with freezing drizzle events.

The primary goal of this project is to demonstrate the accuracy and utility of a freezing drizzle algorithm (which also detects freezing rain) that can be implemented on roadway environmental sensing systems (ESSs).

BACKGROUND

Media reports provide anecdotal information on the various types of problems related to the occurrence of freezing precipitation. The types of problems range from simple traffic delays to major accidents that involve fatalities.

A freezing drizzle event in southwest Michigan on December 29, 2011 formed areas of glaze ice on bridges, overpasses, and ramps, which led to several single and multiple car accidents (Zimney 2011). A January 10, 2011 freezing drizzle event in north Texas produced dozens of accidents and stretched the Texas Department of Transportation (TxDOT) resources to the limit to clear the roads. (Vega et al. 2011) An event on January 23, 2012 affected parts of North Dakota, South Dakota, Minnesota, Wisconsin, and Iowa, producing hazardous roads, numerous weather and traffic advisories, interstate closures, and more than 70 reported accidents (Associated Press 2012).

It is important to note that the impact of freezing drizzle is not limited to observed conditions, as forecasts of these conditions can result in impacts owing to the safety considerations of travel during these events. An example of this occurred on February 13, 2012 where a freezing drizzle forecast led to school cancellations in Sedalia, Missouri due to potentially hazardous traveling situations (Satnan 2012).

There are means for transportation agencies to perform preventive and reactive treatments to the roadway, but freezing drizzle can be difficult to forecast accurately or even detect given weather radar and surface observation networks poorly observe these conditions.

An event on January 20, 2012 highlighted the Missouri DOT (MoDOT) preparations prior to a freezing precipitation event. MoDOT used a salt brine mixture to pre-treat roads and bridges in advance of a freezing precipitation storm. The efforts were summarized by a comment from the St. Louis County Department of Highways and Traffic public information manager to show their thought process for the event: "We'd rather pre-treat with salt and not have the expected storm arrive than to not salt and find ourselves contending with very difficult ice conditions" (Gosling 2012).

For a January 23, 2012 event in the Washington DC area, the Office of Personnel Management (OPM) issued a delay opening Federal offices based on a 7 p.m. freezing drizzle forecast for the following morning. In a Washington Post article describing the event, the OPM decision was questioned as to the timing of the decision as well as the severity of the freezing drizzle event (Stillman 2012).

In noting the weather prediction difficulties, LaDue (2011) gives an example of the difficulty of forecasting freezing drizzle events by analyzing a storm that occurred on December 19, 2011. In this event, unforecasted freezing drizzle preceded a winter storm in Colorado. The Colorado DOT (CDOT) did not pre-treat the roads for the freezing drizzle that led to icy conditions where as many as 30 vehicles slid off I-70, resulting in two fatalities. In his analysis, LaDue notes that several models failed to predict the freezing drizzle and the WSR-88D radar network did not detect it.

Freezing drizzle can also lead to economic impacts in communities with lost work hours, vehicular damage, and downed power lines. An example of the economic impacts is found in a study by Cortinas et al. (2004) in which they describe the impacts of a 1998 ice storm that affected people in four states and two Canadian provinces. The report attributes to the storm 44 fatalities and damage estimates of 3 billion US dollars (USD) in Canada and 1.4 billion USD in the US. Ice buildup on power lines and tree limbs that broke and fell onto power lines led to the loss of electricity to about 1.5 million people. Ice buildup also led to the collapse of broadcast and two-way communication towers that disrupted phone services to customers.

This study also noted a report that stated the storm had an impact on 25 million acres of forest in the US and Canada. This damage had an impact on animal habitats as well as to forest-related industries. According to the report, logging and hauling industries were disrupted for a week or more and the maple syrup industry had more than 10 million USD in losses. This 1998 storm represents an extreme example of the impact of freezing precipitation storms.

Detection

The detection of freezing precipitation is problematic and requires special instrumentation and analysis. The small size and supercooled nature of the water drops result in low backscatter cross sections that make detection by remote sensing (such as weather radar) extremely difficult. Even surface-based observations are limited in their reporting of freezing drizzle.

The NWS Automated Surface Observing Systems (ASOS) and the Federal Aviation Administration (FAA) Automated Weather Observing System (AWOS) report freezing rain, but not freezing drizzle. Given the significance of aircraft icing, the FAA development of aircraft anti-icing and deicing technologies has led to the development of a freezing drizzle algorithm that utilizes air temperature data and a specialized sensor capable of detecting ice accretion.

The algorithm, initially developed by Science Applications Corporation (Ramsay 1999) and refined by the National Center for Atmospheric Research (NCAR), has been demonstrated successfully at the Denver International Airport. The presentation of freezing drizzle alerts to the airlines has since resulted in the successful avoidance of engine damage due to the ingestion of ice (Rasmussen 2005).

However, at present, roadway ESSs are not capable of reporting freezing drizzle. This study investigates the use of the methods developed for the FAA and NWS within a roadway environment to detect the occurrence of freezing drizzle using a combination of icing detection equipment and available ESS sensors.

METHODOLOGY

The work performed in this study incorporated the algorithm initially developed by Ramsay and further modified by NCAR in support of their work with the FAA for aircraft icing. It used the same sensor technology developed for the NWS for the detection of ice accretion using the raw vibration frequency of a Rosemount freezing rain sensor (the Rosemount Aerospace Corporation Model 872C2). The freezing drizzle algorithm developed for the FAA was applied using data from standard roadway ESSs.

Rosemount Freezing Rain Sensor

The Rosemount sensor (now produced by BF Goodrich after their acquisition of Rosemount) is a device (Figure 1) for relating frequency change of a vibrating rod to the amount of ice accretion that has occurred. (The specification of the sensor is provided in Appendix A.)

Figure 1. Rosemount 872C2 icing detector

The sensor uses a one-inch rod that is driven mechanically at a vibration frequency of 40 kHz. As ice accumulates on the rod, the added mass reduces the mechanical vibration. Circuitry in the system records the frequency changes and provides an interface to external data logging devices. Once the frequency reduces to a pre-set minimum due to ice accretion, a heating cycle is triggered to shed the ice from the vibrating rod. This permits a continuation of the ice accretion measurements.

The rate of accretion can be used to differentiate between freezing rain or freezing drizzle and that of frost. Examples of frequency change versus time from a study performed by Raytheon for the NWS (1999) show that similar profiles can exist for freezing rain and freezing drizzle with a distinctively different profile for frost. However, owing to the possibility of similar accretion rates for freezing rain and freezing drizzle, where the difference between drizzle and rain is distinguished by droplet size, the Rosemount sensor cannot alone distinguish between these two phenomena.

The NWS uses another sensor, the Light Emitting Diode Weather Identifier (LEDWI), to distinguish between freezing rain and freezing drizzle by using precipitation detection by the LEDWI to trigger a report of freezing rain.

Data Collection

A Rosemount freezing drizzle sensor (model 872C2) was acquired and installed at the University of North Dakota (UND) Road Weather Field Research Facility (RWFRF). The RWFRF is a road weather observation facility located adjacent to Interstate 29 in northeast North Dakota about 34 kilometers (21 miles) south of Grand Forks, North Dakota and UND.

The RWFRF has an extensive suite of atmospheric, pavement, and sub-pavement sensors that continuously collect data supporting surface transportation weather research at UND. The

Rosemount sensor was attached to a vertical pole (Figure 2) with data and power connections extending to the RWFRF's data collection facility 20 meters to the south.

Figure 2. The Rosemount Aerospace Corporation Model 872C2 icing detector mounted on a temporary structure

Vibration frequency data from the Rosemount sensor, output at 1/60 Hz, were captured by a computer interfaced to the sensor. One-minute air temperature data from a RWFRF temperature sensor co-located with the Rosemount sensor were integrated to produce the principal study data.

These data were used to drive the freezing drizzle algorithm developed originally by Ramsay and modified by NCAR. The output from the algorithm included freezing drizzle occurrence, freezing drizzle intensity, and freezing rain intensity (Figure 3). The intensity values were based on accretion rates.

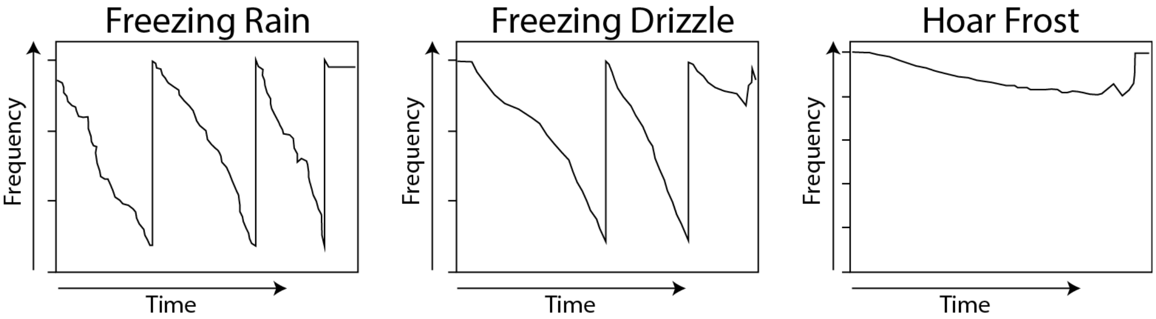

Figure 3. Response signature of frequency over time due to ice accretion on Rosemount ice detection sensor (adapted from Ramsay 1999)

The data collection and algorithm execution were performed during 2008-2009 and 2009-2010 winters, defined as November 1 through March 31. This period encompasses the typical climatological range of freezing drizzle events in eastern North Dakota, though the number and intensity of events, as well as their distribution throughout the winter, varies considerably from year to year.

Data collected during the project were reduced using software developed during the project that permitted the assimilation of additional observed precipitation from sensors at the RWFRF.

Quantitative validation and analysis of the data were performed to include standard contingency table metrics (probability of detection, false alarm ratio, accuracy, bias, threat score, etc.) for yes/no detection, with contingency table events defined as follows:

- Hits defined as events detected by the Rosemount sensor and verified either by other sensors at the UND RWFRF and/or by NWS observations at Grand Forks and/or Fargo International airports. Reported precipitation rates from other observations were also used in an attempt to discriminate between freezing rain and freezing drizzle.
- Misses defined as events where the Rosemount sensor fails to detect freezing drizzle, but other observations at the UND RWFRF and/or NWS clearly indicate freezing precipitation. Discrimination between freezing rain/drizzle as well as aggregation/separation of statistics were done as described above.
- False Alarms defined as events where the Rosemount sensor indicates freezing drizzle, but where there are no verifying observations of freezing precipitation (rain or drizzle) at either the UND RWFRF or NWS stations.

Data Collection and Analysis

The data collection process yielded 29 events of either freezing rain or freezing drizzle over the two winters (12 months of total data collection) (Table 1).

Of these 29 events, six involved freezing rain and 23 involved freezing drizzle. Several of these events were associated with the same storm system and were the result of evolving intensity of precipitation events. The duration of the events ranged from one minute to 1,036 minutes as determined from the Rosemount icing sensor data, which collected data each minute during the study periods.

Table 1. Freezing rain and freezing drizzle events observed during November through March 2008 to 2010

Date	Type	Duration (minutes)
November 7, 2008	Freezing Drizzle	657
November 7, 2008	Freezing Rain	40
November 8, 2008	Freezing Drizzle	46
December 26, 2008	Freezing Drizzle	325
December 27, 2008	Freezing Drizzle	23
January 12, 2009	Freezing Drizzle	132
January 22, 2009	Freezing Drizzle	14
January 23, 2009	Freezing Drizzle	139
February 9, 2009	Freezing Drizzle	121
February 9, 2009	Freezing Rain	52
February 11, 2009	Freezing Rain	149
March 25, 2009	Freezing Drizzle	126
October 14, 2009	Freezing Rain	431
December 1, 2009	Freezing Drizzle	47
December 1, 2009	Freezing Rain	1
December 27, 2009	Freezing Drizzle	50
December 27, 2009	Freezing Drizzle	5
January 14, 2010	Freezing Drizzle	116
January 18, 2010	Freezing Drizzle	1036
January 22, 2010	Freezing Drizzle	13
January 22, 2010	Freezing Rain	151
February 4, 2010	Freezing Drizzle	28
February 5, 2010	Freezing Drizzle	81
February 18, 2010	Freezing Drizzle	18
February 28, 2010	Freezing Drizzle	15
March 2, 2010	Freezing Drizzle	166
March 4, 2010	Freezing Drizzle	1
March 6, 2010	Freezing Drizzle	209
March 24, 2010	Freezing Drizzle	15

In addition to denoting freezing rain and freezing drizzle, the algorithm indicated the presence of frost (or situations where ice accretion occurred at very low rates). The presence of either freezing rain or freezing drizzle was found to represent only a short time period aggregated over the two winter study periods (Table 2).

This result was expected and is consistent with a continental climate. The occurrence of “moderate” freezing drizzle was found to be the dominant intensity of freezing drizzle reports, which was something of a surprise.

Table 2. Distribution of icing events during the period of study

Data Collection by Event	Minutes Collected	Percentage of Total
Total Data Samples	524,754	100%
Frost	505	0.10%
Freezing Rain	443	0.08%
Freezing Drizzle	1,577	0.30%
Light Freezing Drizzle	385	0.07%
Moderate Freezing Drizzle	883	0.17%
Heavy Freezing Drizzle	309	0.06%

The determination of "accuracy" of freezing drizzle was proposed to be assessed through use of contingency tables comparing the occurrences with external precipitation sensors. Three observation types were incorporated in the assessment, including instrumentation at the RWFRF and hourly airport observations from the NWS.

The former included a Lufft R2S radar-based precipitation sensor and two Geonor weighing rain gauges. The NWS observations were from hourly meteorological aerodrome reports (METAR) taken from the ASOS at the Grand Forks International Airport. While the former instrumentation was located within 100 meters of the Rosemount icing detector, the Grand Forks International Airport is located about 35 kilometers from the RWFRF.

The reduction of icing detector data used protocols developed according to the algorithm mentioned previously. This algorithm (Table 3) is designed to determine the occurrence of freezing precipitation based on a combination of frequency changes in the probe, air temperatures, and the present weather conditions from a local observation. However, the lack of a present weather sensor at the RWFRF, such as an LEDWI used within ASOS observations, presented a significant limitation in processing of icing sensor data. Thus, resulting reports from the processing discriminated only between "frost" and "freezing drizzle."

The further reduction to identify freezing rain events was done using temperature of the icing report as a discriminator where samples at temperatures greater than 0° C were classified as freezing rain. It is understood that this method has flaws and a more appropriate method was needed in the study.

Table 3. Icing algorithm as developed for the NWS and modified by NCAR (Rasmussen et al. 2006)

Ice Detector	LEDWI Present Wx Type	Temp	Visibility	Sky Cover	Present Weather Reported
Accretion Frequency < 39,967 Hz and 15 min Accretion Rate >13 Hz in 15 min	RA,UP	<2.8 C (<37°F)	Any	Any	FZRA
	SN	Any	Any	Any	SN
Accretion Frequency < 39,967 Hz and 15 min Accretion Rate >6 Hz in 15 min	No Precip	≤ 0 C (<32°F)	Any	OVC	FZDZ
				Not OVC	None
Accretion Frequency < 39,967 Hz	No Precip	≤ 0 C (<32°F)	≥ 7 miles	CLR or SCT	FROST

RESULTS

Contingency tables were constructed from the data comparisons between the icing detector and the various external observations of (freezing) precipitation. Tables 4 through 7 are aggregates of various contingency table metrics across the entire data as compared to the individual external observations. Individual tables were constructed for each month, whether or not events occurred.

Table 4. Contingency table of predicted freezing drizzle versus observed from R2S sensor

R2S		Observed	
		Yes	No
Predicted	Yes	4	756
	No	3410	218719

Table 5. Contingency table of predicted freezing drizzle versus observed from South Geonor sensor of Geonor pair

Geonor (South Gauge)		Observed	
		Yes	No
Predicted	Yes	140	624
	No	16138	186531

Table 6. Contingency table of predicted freezing drizzle versus observed from North Geonor sensor of Geonor pair

Geonor (North Gauge)		Observed	
		Yes	No
Predicted	Yes	131	633
	No	15922	186747

Table 7. Contingency table of predicted freezing drizzle versus observed from Grand Forks METAR observation

Grand Forks Airport (METAR)		Observed	
		Yes	No
Predicted	Yes	10	46
	No	72	7923

Table 8 provides a summary of metrics from the contingency tables.

Table 8. Metrics for specific verification measures from the contingency table data

	Percent Correct	Probability of Detection	False Alarm	Threat Score
R2S	0.98	0.001	0.945	0.001
Geonor (So)	0.92	0.009	0.817	0.008
Geonor (No)	0.92	0.008	0.829	0.008
METAR	0.99	0.122	0.821	0.078

Clearly, the results suggest that considerable disagreement existed between the observed conditions of the icing detector and the external observations (low probability of detection and high false alarm rates). The first response would be to consider the predictability of the icing events to be low. However, the results show more the inability of the external observations to serve as reliable evaluators of icing conditions.

Except for the METAR observations, which are not likely a good independent evaluator due to distance and independence in ASOS and Rosemount methods of detection, the sensors at the RWFRF are not directly designed to support icing detection. Furthermore, given the discriminator for freezing drizzle involves identifying periods where icing occurs without presence of precipitation, the fact that no precipitation is occurring the majority of the time when the icing detector is reporting icing is expected.

CONCLUSIONS

After review of the research conducted given the intent of the research, it is not clear that the approved design of the project was appropriate to meet the objectives of the Aurora program, which was to better understand how to detect the presence of pavement icing conditions due to freezing precipitation.

The accuracy of the Rosemount icing detector had already been investigated in various US and International studies and the sensor, or a variant of the sensor, had already been selected for operational use within government systems, both in the US and Canada. Hence, the credibility of the sensor to detect freezing precipitation was already established at the time the reported research was performed.

The work performed did reinforce the previous findings that a freezing precipitation detector (i.e., the Rosemount 872C2) does provide the capability of detecting icing conditions when coupled with an appropriate algorithm for corresponding the sensor observations to observed temperatures and precipitation events.

However, the central issue related to the appropriateness of the icing detector when used in a roadway environment to detect pavement-icing rates was not explicitly addressed in the research conducted. Only the fact that freezing precipitation was being observed in the vicinity of the roadway was investigated in the research conducted.

It can be concluded from the work performed that the sensor and algorithm used in this study do provide meaningful information with regards to freezing precipitation occurrence and detection.

Furthermore, when the freezing precipitation sensor is installed with other precipitation and temperature-detecting devices, such as those found within a typical environmental sensor station configuration, it is possible to observe freezing precipitation within certain constraints. However, this work does not answer the question as to the corresponding rate by which (or if) ice accretion on roadways will occur, as no pavement condition information or pavement observations were incorporated in the study.

RECOMMENDATIONS

The work performed in this study does lay the foundation for addressing the central question of interest to winter maintenance professionals as to whether it is possible to use roadside freezing precipitation detection (e.g., icing detection) sensors to determine the occurrence of pavement icing during freezing precipitation events and the rates at which this occurs. However, to answer this question, it is necessary to relate the occurrence of freezing precipitation to the state of the pavement directly.

This will require extending the work performed in this study to include in situ measurement of pavement conditions during freezing rain events. These pavement conditions should include information as to the pavement/sub-pavement temperature, extent of residual chemical on the pavement, winter maintenance actions performed, and traffic volume present during the freezing precipitation event.

Completion of this proposed research will provide valuable information that links the occurrence of freezing precipitation to the state of the road, making it possible to apply the observation of freezing precipitation better to winter maintenance decision-making.

It is further recommended that research studies be performed to understand the impact of the observed freezing precipitation, as it relates to observed pavement conditions, to the performance of pavement condition prediction models. This will extend further the decision support capabilities of observed freezing precipitation monitoring.

REFERENCES

Associated Press. "Freezing rain, snow cause crashes, school delays." LaCrosseTribune.com. January 23, 2012. Accessed June 18, 2012. http://lacrossetribune.com/news/local/freezing-rain-snow-cause-crashes-school-delays/article_67916e66-456e-11e1-a050-001871e3ce6c.html

Cortinas, J. V., Jr., B. C. Bernstein, C. C. Robbins, and J. W. Strapp. "An Analysis of Freezing Rain, Freezing Drizzle, and Ice Pellets across the United States and Canada: 1976-1990." *Weather and Forecasting*. 19 (2004): 377-390.

Gosling, K., "St. Louis-area road crews pre-treat for potential freezing drizzle." KSDK.com [St. Louis]. January 20, 2012. Accessed June 25, 2012. http://www.ksdk.com/news/article/298385/3/St-Louis-area-road-crews-pre-treat-for-potential-freezing-drizzle

Ladue, J. "Freezing drizzle with an all snow sounding?" December 20, 2011. Accessed August 15, 2012. http://jimladueview.blogspot.com/2011/12/freezing-drizzle-with-all-snow-sounding.html

National Weather Service. June 25, 2009. National Weather Service Glossary. Accessed June 25, 2012. http://www.weather.gov/glossary/index.php?letter=f

Ramsay, A. *Freezing Drizzle Algorithm Development*. 1999: National Weather Service Final Report. (W/OSO14x1).

Rasmussen, R., C. Wade, A. Ramsay, D. Fleming, T. Lisi, R. Moore, M. Kjolleberg, and K. Morten. 2004: A New Ground Deicing Hazard Associated with Freezing Drizzle Ingestion by Jet Engines during Taxi. 11th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Hyannis, MA.

Satnan, B. "Freezing drizzle forecast forces school cancellation." SedaliaDemocrat.com. February 13, 2012. Accessed June 19, 2012. http://www.sedaliademocrat.com/articles/school-41011-freezing-drizzle.html

Stillman, D. "Was OPM delay for freezing drizzle the right call?" The Washington Post. January 23, 2012. Accessed June 18, 2012. http://www.washingtonpost.com/blogs/capital-weather-gang/post/was-opm-delay-for-freezing-drizzle-the-right-call/2012/01/23/gIQA3fS9KQ_blog.html

Vega, C., D. Schechter, G. Fields, and M. Owens. "Freezing drizzle leads to dozens of wrecks across N. Texas." WFAA.com [Dallas/Fort Worth]. January 10, 2011. Accessed June 18, 2012. http://www.wfaa.com/news/local/Freezing-drizzle-leads-to-dozens-of-wrecks-across-N-Texas-113205124.html

Zimney, J. "What A Mess! Freezing drizzle causes dangerous driving conditions." News/Talk 95.3 MNC. December 29, 2011. Accessed June 25, 2012. http://michiananewschannel.com/Admin/ArticleViewPage/tabid/66/ArticleId/7556/What-A-Mess-Freezing-drizzle-causes-dangerous-driving-conditions.aspx

APPENDIX A. ROSEMOUNT SENSOR SPECIFICATIONS

The following is a summary of specifications of the sensor used in the research described within this report. Information on sensor specifications was taken from a Goodrich freezing rain sensor specification (No. 4085). Goodrich is the current manufacturer of the former Rosemount 872C2 sensor.

Description

The sensor is designed to measure the intensity and duration of ice storms. Ice accumulations as low as 0.13 mm (0.005 inches) are detected.

Specifications

Ice Signal Output Range:	Mass equivalent between 0.5 mm and 2.5 mm (0.020 and 0.10 inches)
Output Formats:	RS-232 (9600, 2400, 300 baud) Customized interface software per customer
Input Power Requirements:	115 Volts
Power Consumption:	5 Watts in ice sensing mode 350 Watts in deicing mode
Electrical Connections:	Conduit Fiber optic Current loop or customer-specified connector
Sensor Mounting:	Optional mounting pole available

/documents/rwis_web_guide.pdf