A citizen science freezing rain tree

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Abstract— **Freezing rain shows significant spatial variation. During a weather event with freezing rain, the precipitation may vary among freezing rain, ice pellets, snow, and rain. The rate of precipitation, wind speed, and temperature may also vary with time. Because of the spatial scale, many of these variations are not captured at weather stations. In the United States, citizen scientists in the Community Collaborative Rain Hail and Snow Network (CoCoRaHS), measure precipitation and snow depth to spatially augment the measurements made at weather stations. Similarly, in the mPING network, citizen scientists report on precipitation type using a cell phone app. A simple freezing rain tree from which volunteers collect and measure accreted ice could augment these networks. The ice load on a cylinder from freezing rain is best described in terms of the equivalent radial ice thickness, which is independent of cylinder diameter. The equivalent radial ice thickness is the thickness the ice on the cylinder would have if the actual accretion was molded into a uniformly thick layer around the cylinder. A freezing rain tree for measuring the equivalent radial thickness consists of a vertical post with removable horizontal dowels in drilled holes at 45° angles around the post and a vertical dowel in a hole drilled in the post top. This tree is augmented by an inexpensive but accurate battery-powered electronic balance (e.g. AWS-1KG) with a capacity of 1000 g and a precision of 0.1 g. To make a measurement during a freezing rain event, an iced dowel is removed and the mass of the ice plus dowel is measured and recorded. The iced dowel can be replaced in the tree for further measurements as freezing rain continues to fall, or as the ice melts after freezing rain ends. The assembly of the freezing rain tree needs to ensure that the iced dowels can be readily removed. Dowels should protrude from the back of the post and the section in the post covered with petroleum jelly. That allows the volunteer to twist the dowel loose and push it partially out of the post. The loosened dowel may then be removed, the bare section grasped with pliers, and carried to the electronic balance to measure the total ice plus dowel mass. The ice mass m_{ICE} (g) from this measurement is calculated by subtracting the mass of the dowel from the total mass. The equivalent radial ice thickness t (cm) is then calculated from m_{ICE} using the dowel diameter D_C (cm), the ice covered length of dowel L_{ICE} (cm) and the density of ice ρ=0.9 g cm^{-3}:**

$$t = -\frac{D_C}{2} + \sqrt{\frac{{D_C}^2}{4} + \frac{m_{ICE}}{\pi \rho L_{ICE}}}$$

A network of citizen scientists making these measurements, which can be done even in locations with no power because of the freezing rain, would add valuable information to the national weather station network.

Keywords— ***freezing rain, citizen scientist, ice mass, equivalent radial thickness, icicles***

I. INTRODUCTION

We are interested in ice accretion from freezing rain on cylinders, which roughly represent branches on trees and wires, cables, and conductors of power, internet/cable, and phone lines. Ice accretions of 0.6 cm and larger can cause branches and even entire trees to fall on power distribution lines, knocking out power to the local area. In the absence of trees, the weight of ice and the wind blowing on the wires and cables of distribution lines can also cause them to fail. Power transmission lines are designed for ice and wind-on-ice loads and are constructed in right-of-ways that are cleared of trees for some distance on both sides of the lines. They, however, still fail in significant ice storms from ice and wind, perhaps associated with previous damage to the conductors, shield wires, insulator strings, and support structures as an exacerbating factor. Ice also accretes on the structural components and guys of tall lattice communication towers. They are also designed for ice loads but also may fail under significant ice and wind-on-ice loads.

A. Freezing Rain

Freezing rain consists of supercooled rain drops, which originate as snow that melts when it falls into a layer of warm air and then supercools as it falls through a layer of air with temperature $T_a \leq 0$ºC at the earth's surface. As the thicknesses and temperatures of the warm and cold air layers change, the precipitation type may vary among freezing rain, ice pellets, snow, and rain. Mixed precipitation types, including freezing rain and ice pellets or freezing rain and snow, also occur.

Automated Surface Observing Systems (ASOS) were installed at most of the first-order weather stations in the U.S. in the 1990s, replacing human observers. At the relatively few ASOS stations that still have observers, all these precipitation varieties continue to be reported. Most stations, however, are fully automatic, with no observer contribution to the METARs (aviation routine weather report) that are generated from the weather observations. At fully automatic stations, ice pellets are not reported at all and in mixed precipitation only a single precipitation type is reported for the hour. Because snow is higher in the precipitation hierarchy (snow, freezing rain, rain), in mixed snow and freezing rain, only snow is reported. In the regions between weather stations, the precipitation type may differ from that in the METAR, both because of the METAR constraints and because of real differences in the weather.

B. Simple Flux Model

A simple flux model for ice accretion on a horizontal cylinder in freezing rain assumes that the falling, wind-blown

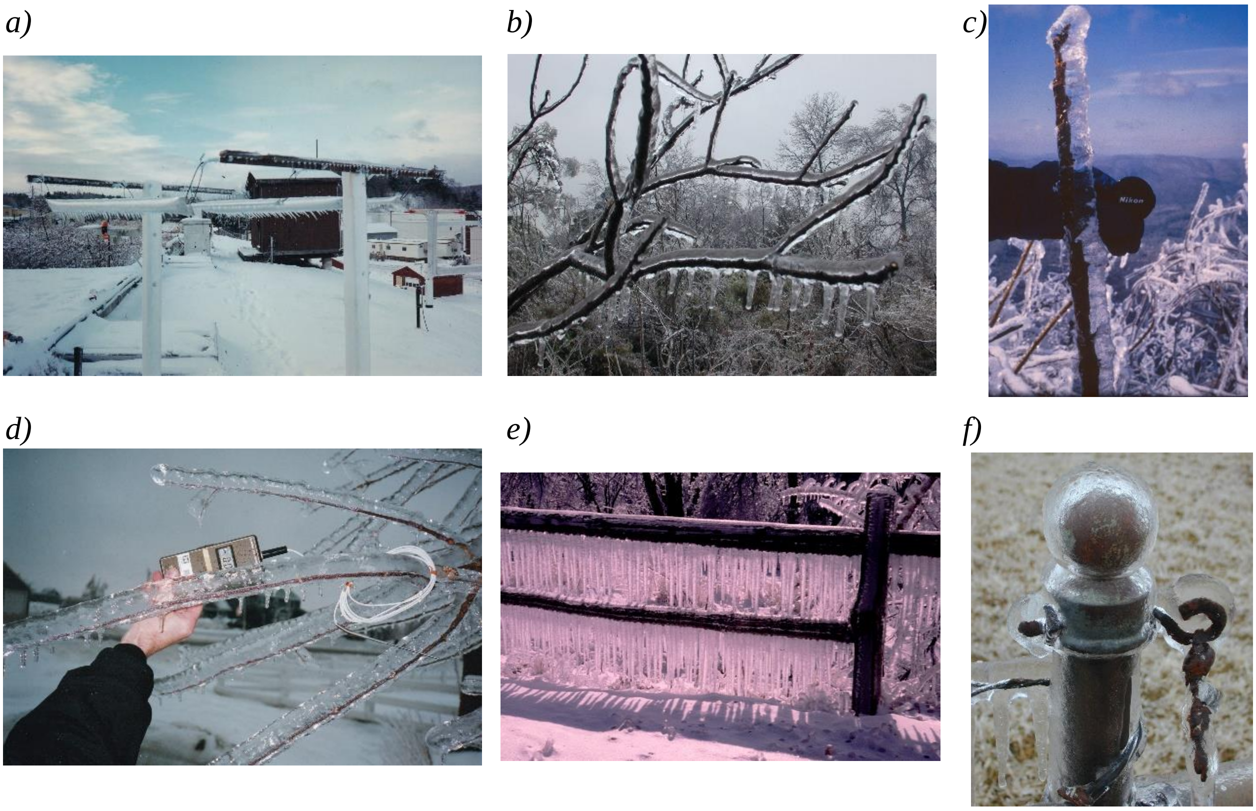

Fig. 1 Examples of CRREL ice accretion observations: a) New Hampshire 28 Feb 1995 (photo K. Jones), b) Arkansas 27 Dec 2000 (photo K. Claffey), c) North Carolina 2 Feb 1996 (photo N. Mulherin), d) New York 8 Jan 1998 (photo N. Mulherin), e) North Carolina 4 Feb 1996 (photo K. Jones), and f) Texas 13 Dec 2000 (photo K. Claffey).

rain drops that are swept out by the cylinder diameter D_C freeze in a uniformly thick layer around the cylinder circumference πD_C. The thickness of this layer t is the equivalent radial thickness and is independent of the cylinder diameter. The ice layer on small and large cylinders will have the same thickness in the same freezing rain conditions, but the weight of ice on a large cylinder will be greater than on a small one. Vertical cylinders sweep out the wind-blown drops, so the equivalent radial ice thickness depends linearly on wind speed: no ice if there is no wind.

Real life is more complicated than this idealization, with the ice accretion shape on a particular cylinder depending on how fast the impinging water freezes in the local weather conditions. The ice may freeze with a uniform thickness around and along a horizontal cylinder, but it also may freeze as a crescent on upper windward side, as a variably thick layer with small icicles, or as a relatively thin layer with substantial icicles. Icicles form as initially unfrozen water begins to drip off. On vertical cylinders the impinging wind-blown rain drops may flow some distance before freezing, perhaps resulting in a larger ice thickness near the bottom of the cylinder than near the top. A few photos of ice accretions from a number of freezing rain storms that CRREL (Cold Regions Research and Engineering Laboratory) personnel documented are collected in Fig. 1. Three of the photos, Fig. 1a, of ice on cylinders at the CRREL weather station [1], and Figs. 1b and e, show accretions in which icicles are a significant portion of the ice mass. This is common. Convective and evaporative cooling are the primary contributors to freezing the impinging freezing rain drops so the rate the water freezes depends on the rain rate, air and dewpoint temperatures, and wind speed. Fig. 1d shows an accretion with most of the impinging water frozen on top of the twigs, with only a small fraction ultimately freezing as icicles. Fig. 1c shows a typical ice accretion on a vertical element: the wind-blown drops froze on the windward side of the branch. Fig. 1f shows an accretion that closely conforms to the underlying ball and hook shape, but still with icicles on the horizontal chain to the left of the post.

It is difficult to measure maximum dimensions of these shapes and estimate the thickness the ice would have if it were spread uniformly thickly around and along the cylinder. But by measuring the mass of accreted ice m_{ICE} along with the length of the accretion L_{ICE} along the cylinder and diameter of the cylinder we can calculate the equivalent radial ice thickness. The ice mass m_{ICE} with uniform thickness t is

$$m_{ICE} = \pi \rho L_{ICE}(D_C t + t^2), \tag{1}$$

where ρ=0.9 g cm^{-3} is the density of glaze ice. If m_{ICE} is measured, we can calculate the thickness the ice would have if the actual accretion was molded in a uniformly thick layer:

$$t = -\frac{D_C}{2} + \sqrt{\frac{{D_C}^2}{4} + \frac{m_{ICE}}{\pi \rho L_{ICE}}}\,. \tag{2}$$

We can use this formula with a simple freezing rain tree and an inexpensive electronic balance to calculate the equivalent radial ice thickness.

C. Citizen Science Networks

In 1974 Hydro-Quebec began their Passive Ice Measurement (PIM) network of volunteer ice accretion observers [2], [3], with most observers in southern Quebec, which is the region of Quebec most prone to freezing rain. In each volunteer's yard, Hydro-Quebec installed a 1.5 m tall structure that included four horizontal cylinders oriented north, east, south, and west, two with diameter D_C=12 mm and two with D_C=25 mm. Volunteers use dial calipers to measure the maximum dimension D_{PIM} of each ice-covered cylinder and also sketch the ice accretion shape. If the ice is the same thickness all the way around the circumference and along the length of the cylinder, the equivalent radial thickness t would be $0.5(D_{PIM} - D_C)$. Hydro-Quebec suggests using an empirical calibration $0.7(D_{PIM} - D_C)$ to estimate t [4]. The derivation of this factor is not explained. I assume that the volunteers are instructed to not include icicles in their measurement and that the 0.7 factor is intended to include the contribution of any icicles to the equivalent radial thickness. The PIM program continued to at least the winter of 1994-1995 [4].

There are currently two newer networks that help to fill in gaps between the ASOS stations in the U.S., the Community Collaborative Rain Hail and Snow Network (CoCoRaHS) and meteorological Phenomena Identification Near the Ground (mPING).

CoCoRaHS (https://www.cocorahs.org) with slogan "Every drop counts" began in 1996 at Colorado State University and included all 50 U.S. states by 2013 [5]. CoCoRaHS is supported by the National Science Foundation, National Weather Service, Bureau of Land Management and many local organizations. Canada joined CoCoRaHS in 2012. The thousands of volunteers who staff this network report daily precipitation every morning. They may also measure snow depth and snow water equivalent as well as ice from freezing rain. The volunteers who choose to report on freezing rain measure ice accretions either on a convenient nearby object or on a horizontal 20-in. (51 cm) long, ¾ inch (1.9 cm) diameter horizontal dowel installed specifically for that purpose. They use calipers to measure the vertical and horizontal ice+dowel thicknesses at three points along the dowel and report the values in 0.1 in. (0.25 cm) increments. CoCORaHS personnel calculate the average ice thickness at that location from these six values.

The mPING network (https://mping.nssl.noaa.gov/) is more recent. The National Severe Storms Laboratory (NSSL) at the University of Oklahoma (UO) created the mPING app for the U.S. in 2012 [6]. Volunteers download the app to their phone or tablet and use it to report rain, snow, freezing rain, hail, tornadoes, fog, floods, and dust storms. Those reports are immediately archived at UO and displayed on a map that is available to everyone. The data is used by NSSL to improve precipitation type forecasts [7], [8]. The app went international in 2016 and now includes precipitation type lists in 11 languages, including Greek, French, Polish Chinese, Spanish, and Estonian.

II. METHODS

A. Freezing Rain Tree

The CoCoRaHS dowel can be incorporated into a freezing rain tree for measuring ice accretion at various angles to the wind. Four dowels installed in a vertical 2x2 post (with dimensions 3.5 by 3.5 cm) can be arranged so that the dowels are perpendicular to the wind in 45° increments. In this freezing rain tree construction information I am using the lumber and hardware dimensions that are available in the U.S., with approximate dimensions in metric units following in parentheses. Two dowels are installed in two flat, perpendicular sides of the 2x2 (0° and 90°), and the other two are installed at the corners, at 135° and 225°. These angles are a convenient way of describing the dowel orientations relative to each other, rather than relative to north. However, volunteers who also have a weather station with an anemometer could record the angle of the 0° dowel relative to north. With this arrangement one of the dowels is never more than 22.5° from perpendicular to the wind direction. So that the ice-covered dowels can be weighed, they are installed in slightly oversize holes drilled all the way through the post. Oversize 9/16 in. (1.4 cm) holes for ½ inch (1.3 cm) diameter dowels are easier to drill, and remove less wood from the support post, than 13/16 in. (2.1 cm) holes for ¾ in. (1.9 cm) diameter dowels. To reduce wind interference, adjacent dowels should be offset vertically from each other, by, say, 8 cm. A vertical dowel mounted in a ~2 cm deep hole drilled in the top of the post adds information on the horizontal flux of the precipitation due to the wind. The angles between the dowels and their locations relative to the top of the 2x2 post are shown in Fig. 2.

a)
b)

Fig. 2 Post with dowels installed a) top view of post showing horizontal dowel angles and the hole for vertical dowel, b) side view of post showing vertical separation of dowels.

Use a 9/16 in. (1.4 cm) spade bit to drill the diagonal holes first, at 4 and 12 cm from the top of the post. Using a utility knife, slightly flatten the corner of the post where the hole will be to make it easier to drill on the diagonal. If those drilled holes have reasonably accurate orientations at 90° to each other and 45° to the flat sides, then drill the holes in the flat sides of the post at 20 and 28 cm from the top. If not, saw off the misdrilled short section of the post and try again. Ultimately the post is installed in the ground so that the dowels are at an accessible height for the volunteer, with the top of the post between, say, 1.5 and 1.9 m above ground. A pole installed in a ~30 to 40 cm deep hole with the dirt backfilled and packed down is probably sufficient to support the freezing rain tree under eccentric ice and wind-on-ice loads, giving a total post length between 1.8 and 2.3 m. The standard length of a 2x2 is 8 ft (2.4 m). Each dowel should extend about 1 cm from the back of the post to make it easy to grab with pliers to loosen and remove for measuring the mass.

To keep the dowels in place in the post, I use pieces of plastic cut from plastic containers (e.g. for dairy, lettuce greens, soda, eggs, etc.) with a hole punched in the middle and cuts out to the diameter of the dowel. The intention is to make it possible to slide the plastic piece on to the dowel but have it tight enough that it stays in place. The plastic pieces are placed on the dowel both in front of and behind the post (Fig. 3). The section of the dowel in the post is coated with a thin layer of petroleum jelly so it does not freeze to the post.

a)

b)

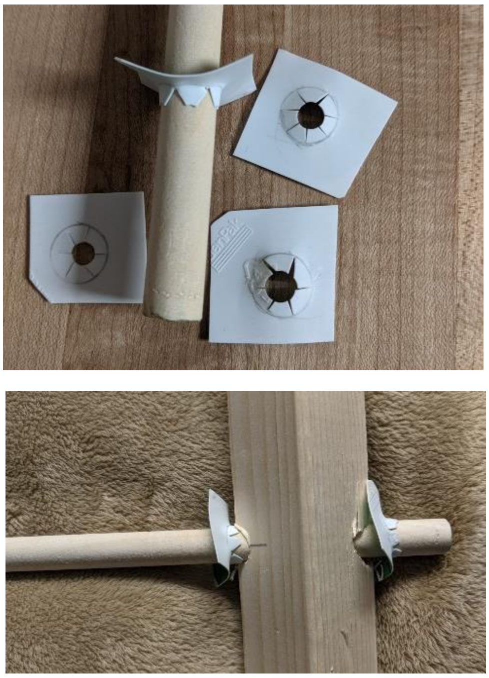

Fig. 3 Dowel installation details a) plastic pieces for dowels and b) dowel inserted into post diagonal, secured by plastic pieces.

A common dowel length in the U.S. is 4 ft (1.2 m), so three dowels make the necessary five freezing rain tree branches, each 2 ft (0.6 m) long, with one extra for backup. The final useful length of a branch ~53-58 cm, from the front plastic piece out to the end, will depend if it is used on a diagonal or flat side of the post, or is the vertical dowel

B. Electronic Balance

The ice-covered dowels are weighed using an AWS electronic balance, powered by two included AAA batteries, which is both inexpensive and relatively accurate. The AWS-1KG has a maximum capacity of 1000 g, with a precision of 0.1 g and can be calibrated with a 500 g mass. That maximum capacity can handle equivalent radial ice thickness up to about 2 cm on the freezing rain tree dowels (Fig. 4). Freezing rain storms generating this much ice are rare, with a mean recurrence interval of more than 50 years in most of the United States [9]. The small, low profile balance works well for measuring the mass of an ice covered dowel if the

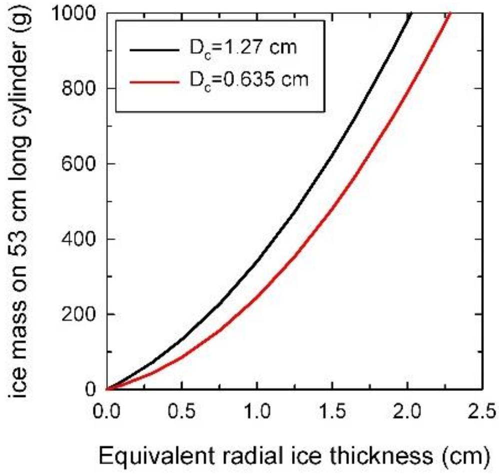

Fig. 4 Ice mass vs equivalent radial thickness for L_{ICE}=53 cm for two cylinder diameters.

weighing platform is adapted to the task. This is done with a few layers of bubble wrap cut to fit the surface of the weighing platform (Fig. 5), with a long piece of cardboard on top of the bubble wrap to support the ice-covered dowel. This structure, which is tared before the dowel is placed on it, keeps the iced dowel evenly supported on the platform with the readout visible. The ice length on the dowel L_{ICE} is recorded along with the mass of the dowel+petroleum jelly+ice m_{TOT}. To calculate m_{ICE} and then t (Eq. 2), the mass of the bare dowel+petroleum jelly m_C (is subtracted from m_{TOT}. Measurements of m_{TOT}, m_C, and L_{ICE} are shown in Fig. 6.

Fig. 5 Electronic balance with bubble wrap platform. This supports the cardboard piece that the iced dowel rests on.

C. Cost

The material and construction costs for the freezing rain tree are approximately (US$):

AWS-1KG	$21
2x2 by 8 ft lumber	$ 4
½ in. by 48 in. dowel (3)	$ 7
9/16 in. spade bit	$ 6
Total	**$38**

This assumes that the volunteer already has available an electric drill, hand saw, spade, pliers, utility knife, bubble wrap, and petroleum jelly.

a)

b)

c)

Fig. 6 Bare and iced dowel measurements a) mass of iced dowel is 304.6 g, b) mass of bare dowel with petroleum jelly is 32.9 g, c) length of ice on dowel is 56 cm.

III. Discussion

A. Test

I built a freezing rain tree and tested the experimental process by spraying water on one dowel in subfreezing temperatures to create an iced dowel with an accretion similar to that from freezing rain. Before retrieving the dowel, I turned on the digital balance on the kitchen table, added the bubble-wrap+cardboard platform and tared it. At the freezing rain tree, I used pliers to crush the ice on the short back end of the dowel, rotate the dowel to loosen it from the post, push it ~1 cm through the post, and grab the bare section of the dowel. Carrying the iced dowel into the house, I placed it on the platform on the balance and recorded the mass m_{TOT}, then moved it to the table and measured the iced length L_{ICE}. The ice mass m_{ICE} is then the difference between m_{TOT} and m_C. The equivalent radial ice thickness t = 0.82 cm is calculated using Eq. 2. These data are recorded in the 13 March entry in Table I. The next day, 14 March, I monitored the ice on the dowel as it melted under sunny skies in above freezing temperatures, measuring the partially melted accretion at 1130. At 1700, as I was carrying the dowel, the ice fell off into the snow, breaking into three pieces. I gathered the pieces up and measured the mass, without the dowel. The melting measurements are the 2nd and 3rd entries in Table I.

B. Options

In addition to measuring the ice on the dowel that is most nearly perpendicular to the wind, citizen scientists can make a number of other interesting measurements. The side of the vertical dowel with ice on it helps to identify the horizontal dowel with axis closest to perpendicular to the wind, as well as providing the equivalent radial ice thickness on vertical structural components. Measuring the ice mass on that dowel as well as on all four of the horizontal dowels provides information on the contribution of wind to the amount of ice accreted on cylinders with varied orientations. Volunteers may also choose to monitor the duration of the ice accretion, tracking the ice as it melts or simply noting when a particular dowel is bare, along with the associated weather conditions. This information would help modellers relying on weather data better estimate the persistence of ice accretions in a variety of air temperature, sky cover, and wind conditions.

IV. Conclusions

Measuring the mass of accreted ice on a freezing rain tree with removable branches using a small electronic balance is easy to do. The equipment required is inexpensive and the tree is easy to build even for moderately handy citizen scientists. Once built, the tree can be easily installed in the winter and disassembled and stored for the summer. The measured mass of ice on the dowels provides accurate equivalent radial ice thicknesses. This is in contrast to the measurements of the ice plus cylinder thicknesses on the PIM and the single dowel suggested for CoCoRaHS. Ideally, the citizen-scientist making these measurements of ice accretion in freezing rain would also join the CoCoRaHS and mPING networks to report precipitation type and amount.

Acknowledgment

I thank Nathan Mulherin and Keran Claffey who were fellow members of the CRREL team that deployed to freezing rain events across the U.S. to measure ice accretions and document the associated damage. They took most of the ice accretions photographs on these trips. The images in Fig. 1 are a representative sample.

TABLE I. Freezing rain tree data: March 2022 test

Date time	Dowel orientation	D_C cm	m_C g	L_{ICE} cm	m_{TOT} g	m_{ICE} g	t cm	comments
13 Mar 22 1100	0°	1.27	32.9	56	304.6	271.7	0.82	Ice created by spraying water on dowel 3/12-13; $-8 \leq T_a \leq -2$°C
14 Mar 22 1130	0°	1.27	32.9	56	240.8	207.9	0.68	Sunny, 2.5°C
14 Mar 22 1700	0°	1.27	0	56	114.4	114.4	0.43	Sunny, 6.3°C; ice fell off dowel, collected pieces and measured mass

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