Development of an Automated Ice Sensing System to Assist the Operators of a Cable Stayed Bridge in Making Decisions

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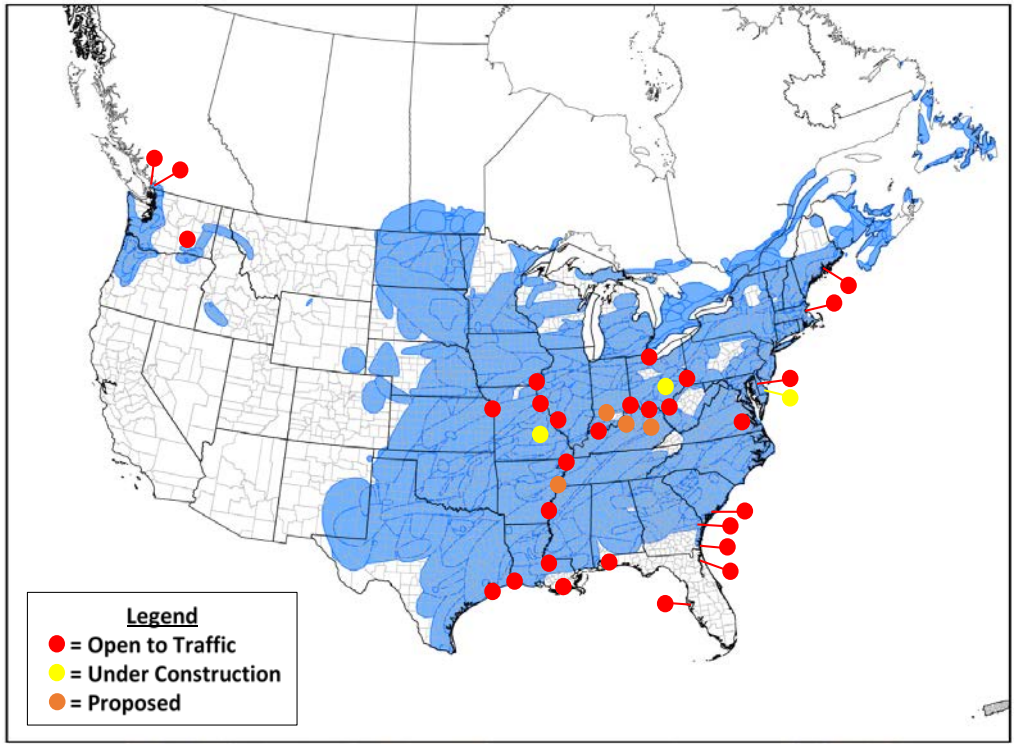
Learning Outcomes

- The overall extent of icing problems on cable stayed bridges
- Icing issues on the Veterans' Glass City Skyway Bridge in Toledo, Ohio
- Ice fall hazard mitigation strategies
- Why an administrative ice hazard mitigation strategy was selected for the VCGS
- What information do bridge operators need to help them make decisions to protect the public from ice fall hazard.
- Why were new sensors developed to monitor ice on the VGCS stays
- How can the required information be conveyed in a clear, concise and actionable manner to the bridge operators.

Ice Accumulation and Shedding

- Icing is a significant challenge that affects structures in many countries.
- Examples of structure that can be affected: Power lines, bridges, telecommunication towers, and wind turbines.
- ***Ice accumulation*** on structure can cause overloading which will affect the mechanical strength of the structure and trigger collapse.
- ***Ice shedding*** is considered as a serious issue as it affects public safety, besides economic loss.

Icing on bridges



Known cable stayed bridges in the United States and lower tier of Canada overlaid onto the damaging winter storm footprint map (1946-2014)

Veterans' Glass City Skyway (VGCS)

Weather History on VGCS

VGCS Icing Event History

Ice Event	Ice Accretion	Ice Shedding Trigger	Ice Persistence (Days)	No. of Lanes Closed	Damaged Vehicles
Dec 2007	Freezing rain, fog	Rain with temperature above freezing	2	2	Yes
Mar 2008	Snow, rain, fog	Sun with temperature above freezing	1	2	Yes
Dec 2008	Snow, fog; freezing rain, fog	Rain, gusty winds and temperatures above freezing	7	2	No
Jan 2009	Freezing rain, fog	Gusty winds, temperature above freezing	10	1	No
Feb 2011	Freezing rain, clear	Light wind, overcast, and temperature above freezing	4	All	No
Jan 2015	Freezing rain, snow	Gusty winds and overcast, remaining ice sublimated/melted following day when air temperature was above freezing	4	All	No

Weather History on VGCS

February 2011

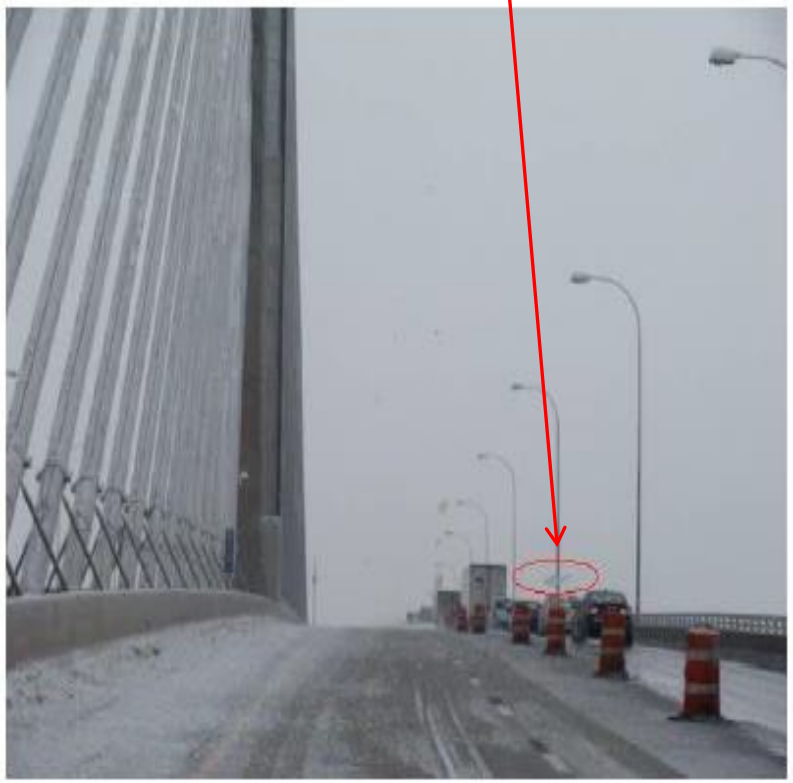
Ice accumulation pattern on VGCS stays (2011)

Ice accumulation on the east side of VGCS (2011)

Event Timeline

- **Ice accumulated on the stays on Sunday evening**
- **Nearly released Tuesday afternoon. Temp below freezing, bright sun.**
- **Finally, released Thursday am when overcast was a bit lighter and the temp went above 32°**

Large piece of ice blowing over the edge of the bridge.



Ice shed from the stays (2011)

Mitigating the icing problem

- Active and passive strategies
  - Anti/de-icing technologies
  - Active requires an operator action. Passive technology permanently in place (I.E. coating)
- Administrative strategies
  - Development of real time monitoring system (Dashboard)
  - Requires accurate information
    - Use existing regional sensors
    - Deploy off the shelf sensors on the VGCS
    - Develop of new sensors
  - Model the icing event
    - Ice accumulation modelling
    - Ice shedding modelling

Anti/de-icing technologies

- Broad investigation was conducted to review all the identified anti/de-icing technologies: heat, coating, electro-pulse, chemicals, scrapers, expanding membranes, shakers, robots, …

- Selection of the tested technologies was based on efficiency, cost, and environmental friendliness of each technique

- Three technologies selected for outdoor laboratory trials.
  - icephobic coatings
  - chemicals
  - internal heating

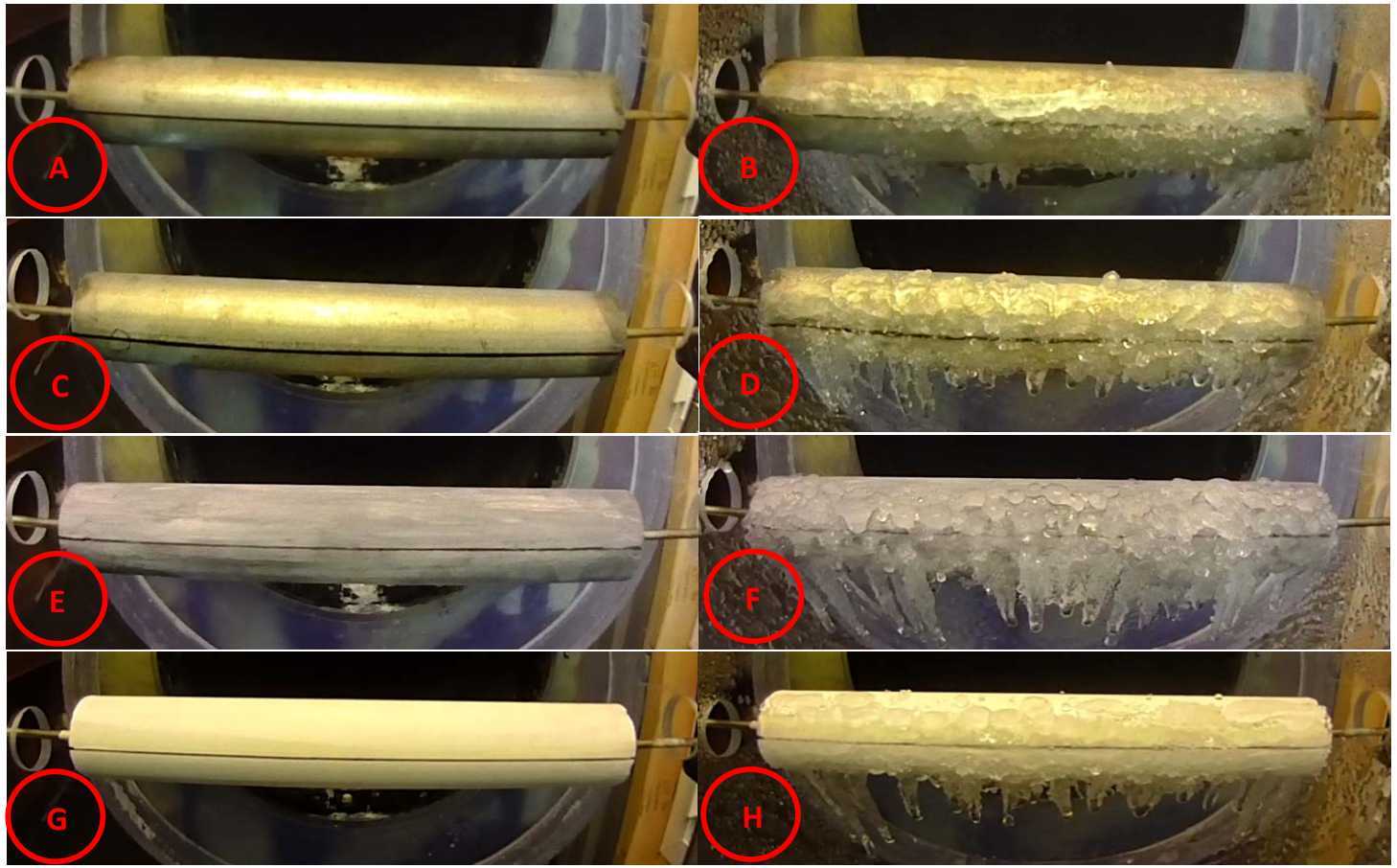
Indoor coating testing

Uncoated specimen

Coating 1: Aliphatic petroleum distillates with proprietary additives

Coating 2: Epoxy polymers, silicate mesh with new melt-point-depressants

Costing 3: Fluorocarbon polymer and aliphatic, moisture-cure, three-part polyurethane

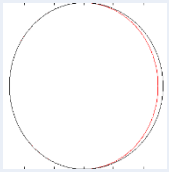
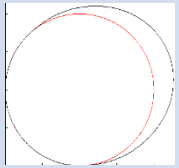


Sensor development

- Existing sensors do not capture the desired information about the state and thickness of ice on the stay cables.
- ***UT Ice presence and state sensor***: resistance based sensor used in conjunction with a thermocouple to detect whether water is present on the stay and if it is liquid or ice

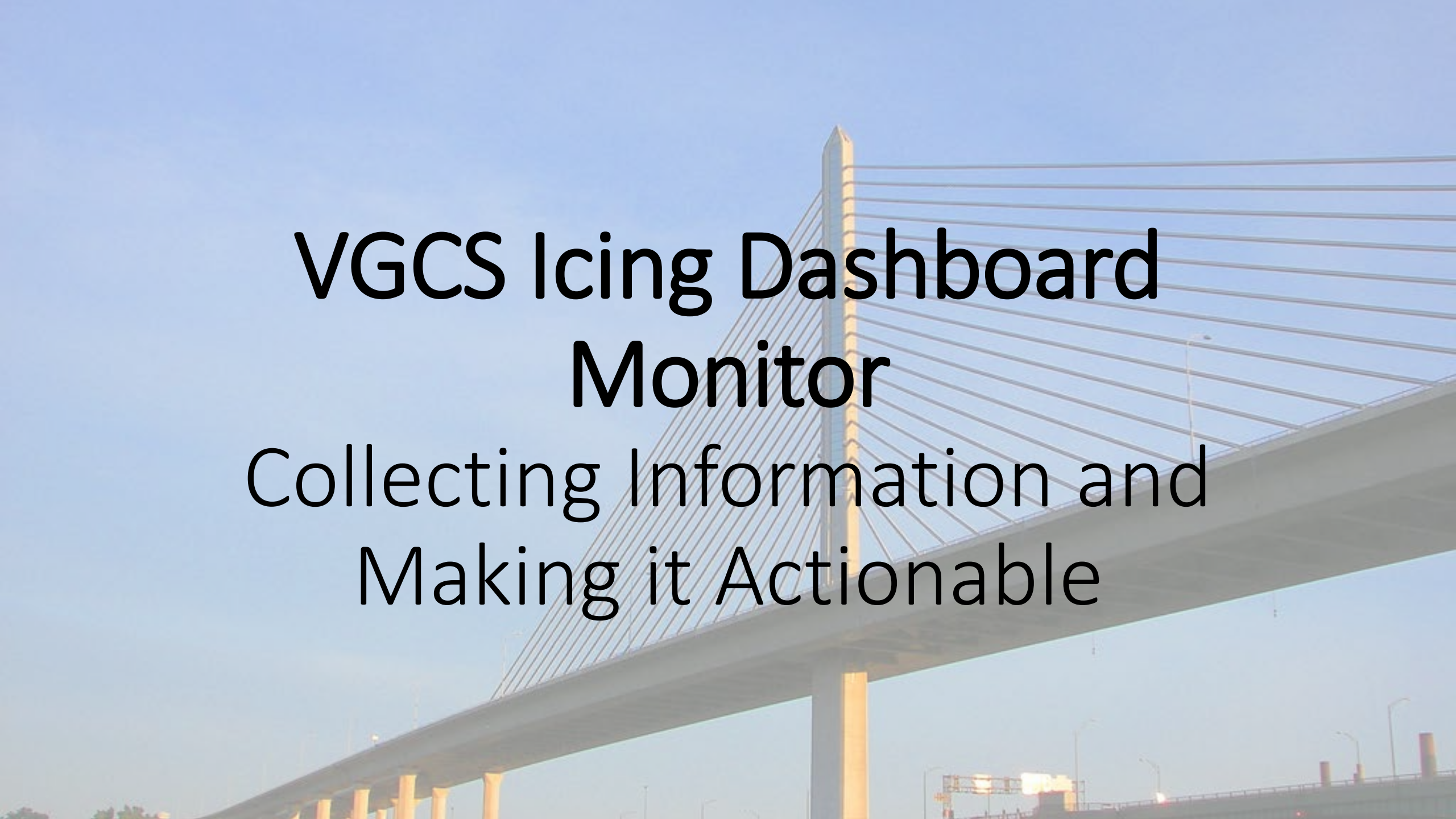
- ***UT Optical ice thickness sensor***: measures thickness of the ice on the stay with a laser and camera

Icing modelling – comparing observed to calculated behavior

Time Stamp	Ice accumulation	Max ice thickness on stay (mm)	Ice profile	Ice shedding	Duration
10/5/2015 3:10:00	no	--------	--------	No	-------
10/5/2015 4:10:00	Yes	≈ 2 mm		-------	-------
10/5/2015 5:10:00	Yes	≈ 10 mm		-------	-------
10/5/2015 6:10:00	--------	≈ 10 mm	--------	yes	≈ 4 hours
10/5/2015 7:10:00	--------	≈ 8 mm	--------	yes	≈ 3.5 hours

Summary anti/de-icing techniques tested

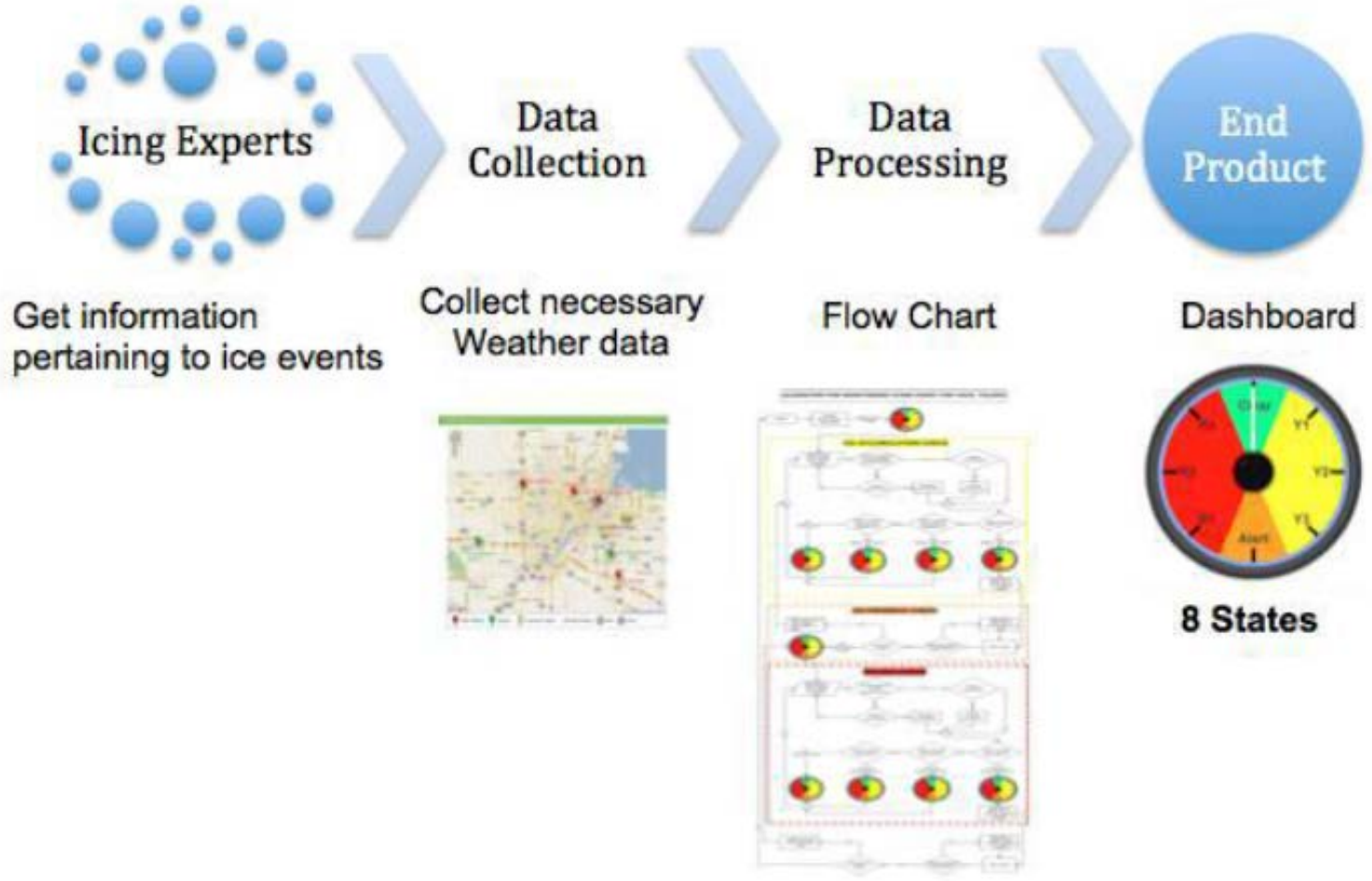
- None of the tested active or passive anti/de-icing technologies worked efficiently.
- Therefore, administrative management strategy was chosen
- Administrative management strategy includes:
  - Develop real time monitoring system(Dashboard)
  - New sensor development.
  - Model the icing event (Ice accumulation and shedding modelling)
    - Evaluating current conditions
    - Predicting future states of ice on the cable.



VGCS Icing Dashboard Monitor

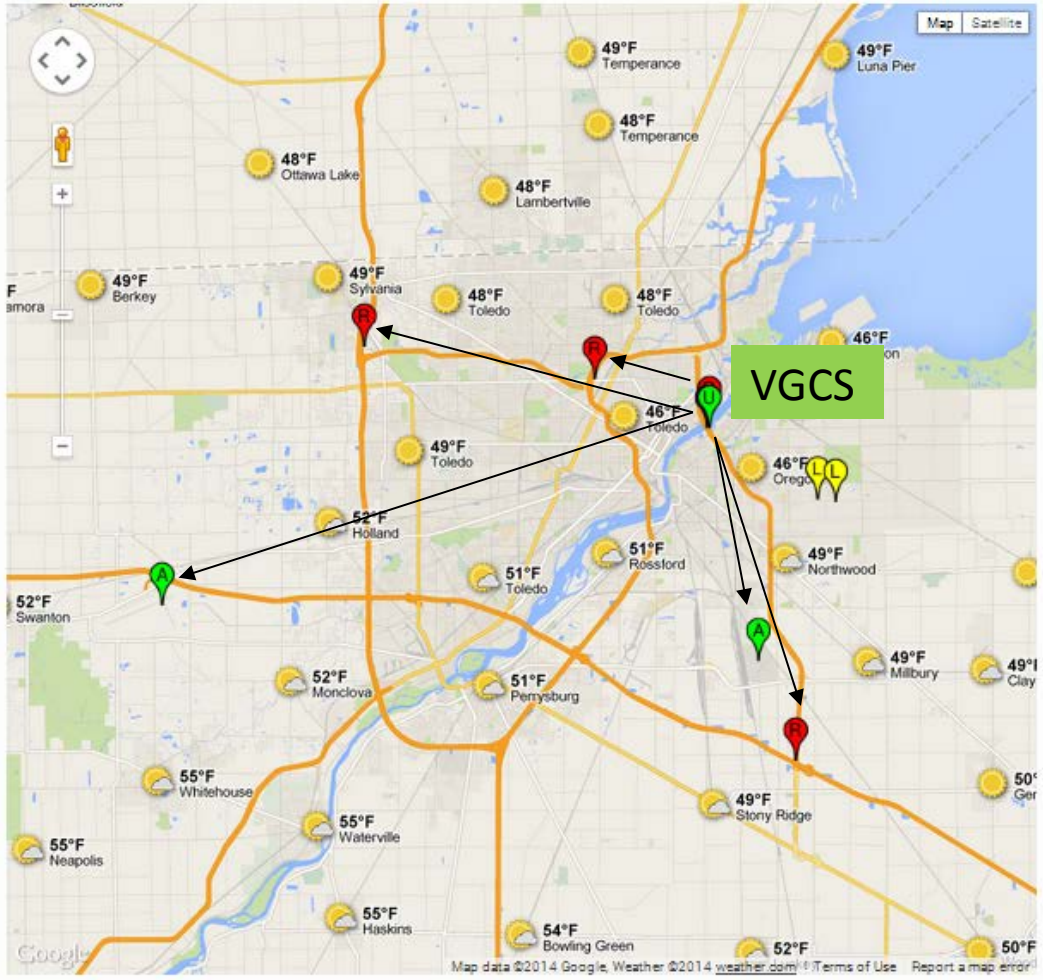
Collecting Information and Making it Actionable

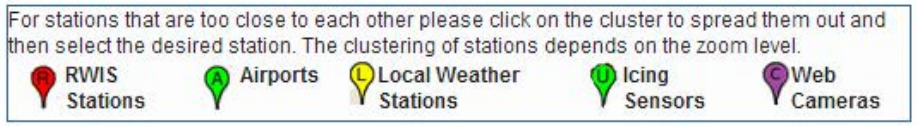
Dashboard Overview



Dashboard implemented in Jan 2011 with many upgrades and modifications over the years

Weather Stations – Data Sources





- **Two Airports**: Toledo Express Airport and Metcalf Field Airport.
- **Four RWIS stations**: 582016, 582014, 582013, 582024.
- **Bridge Sensors**

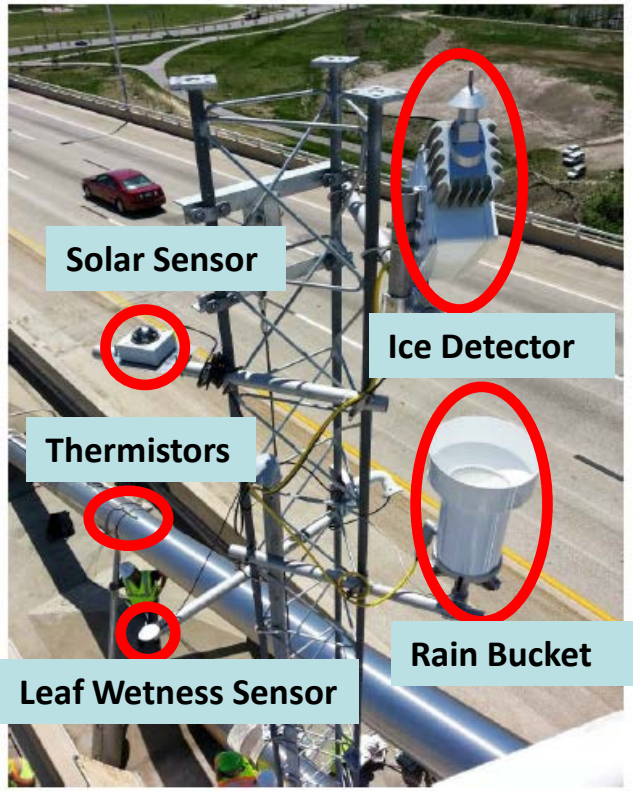
Source	Source Update Time	Collection Interval	Algorithm Run Time
RWIS	10 minutes	30 minutes	1 hour
METAR	1 hour	30 minutes	1 hour
Bridge Sensors	10 minutes	10 minutes	1 hour

Weather Stations – Data Sources

RWIS
Air Temperature
Dewpoint Temperature
Surface Temperature
Surface Condition
Relative Humidity
Average Windspeed
Wind Direction
Precipitation type*

METAR
Air Temperature
Dewpoint Temperature
Relative Humidity
Pressure
Conditions
Wind Direction
Wind Speed
Precipitation
Visibility
Event

Bridge Sensors	Values
Thermistors	Stay Temperature
Ice Detector	Ice Accumulation
	Heat Time
Leaf Wetness	Dielectric Value (LWS)
Solar Sensor	Global Radiation
	Diffused Radiation
	Sun Status
Rain Bucket	Rainfall



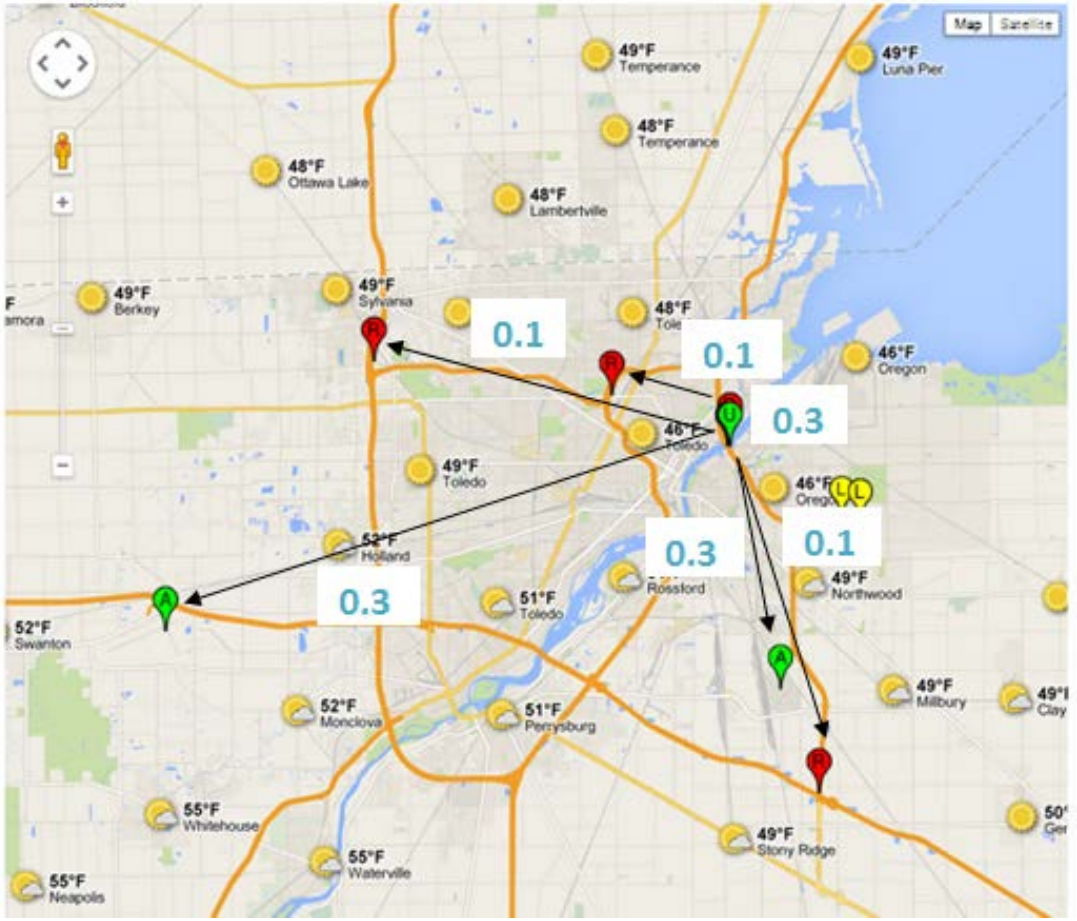
Ice Accumulation Rules

Type of Station	Ice Accumulation Check
RWIS	• Temperature less than 32° F and precipitation type: rain **OR** • Wet snow with temperature greater than 32° F
Airports	• Temperature less than 32° F and precipitation type: rain **OR** • Wet snow with temperature greater than 32° F **OR** • Fog with the temperature less than 32° F
Bridge Sensors – Leaf Wetness and Thermistors	• Wet surface **(LWS> 275 mV)** and any of the stay temperatures below 32° F.
Bridge Sensors – Ice Detector	• **Ice accumulation > 0.05 inches** recorded by the Ice detector. **OR** • **Cumulative Ice > 0.25 inches** calculated from the Ice detector.
Bridge Sensors – Rain Bucket and Thermistors	• **Precipitation > 0.1 inches/hr** recorded by rain bucket and any of the stay temperatures below 32° F.

Parameters that can be altered from the website is highlighted in red.

Station Weights
Ice Accumulation and Shedding

Weather Station	Station Type	Weight
140-IR 475 @ US 23 Split	RWIS	**0.1**
141-IR 75 @ SLM 4.9 475 Split	RWIS	**0.1**
142-I-280 @ VGCS	RWIS	**0.3**
150-I-280 @ Libbey Road	RWIS	**0.1**
Toledo Express Airport	Airport	**0.3**
Metcalf Field Airport	Airport	**0.3**
Bridge Sensors – Leaf Wetness and Thermistors	VGCS	**0.1**
Bridge Sensors – Ice Detector	VGCS	**0.3**
Bridge Sensors – Rain Bucket and Thermistors	VGCS	**0.3**
Bridge Sensors – Thermistors	VGCS	**0.3**
Bridge Sensors – Solar Sensor	VGCS	**0.3**
Alarm Threshold – 0.3		



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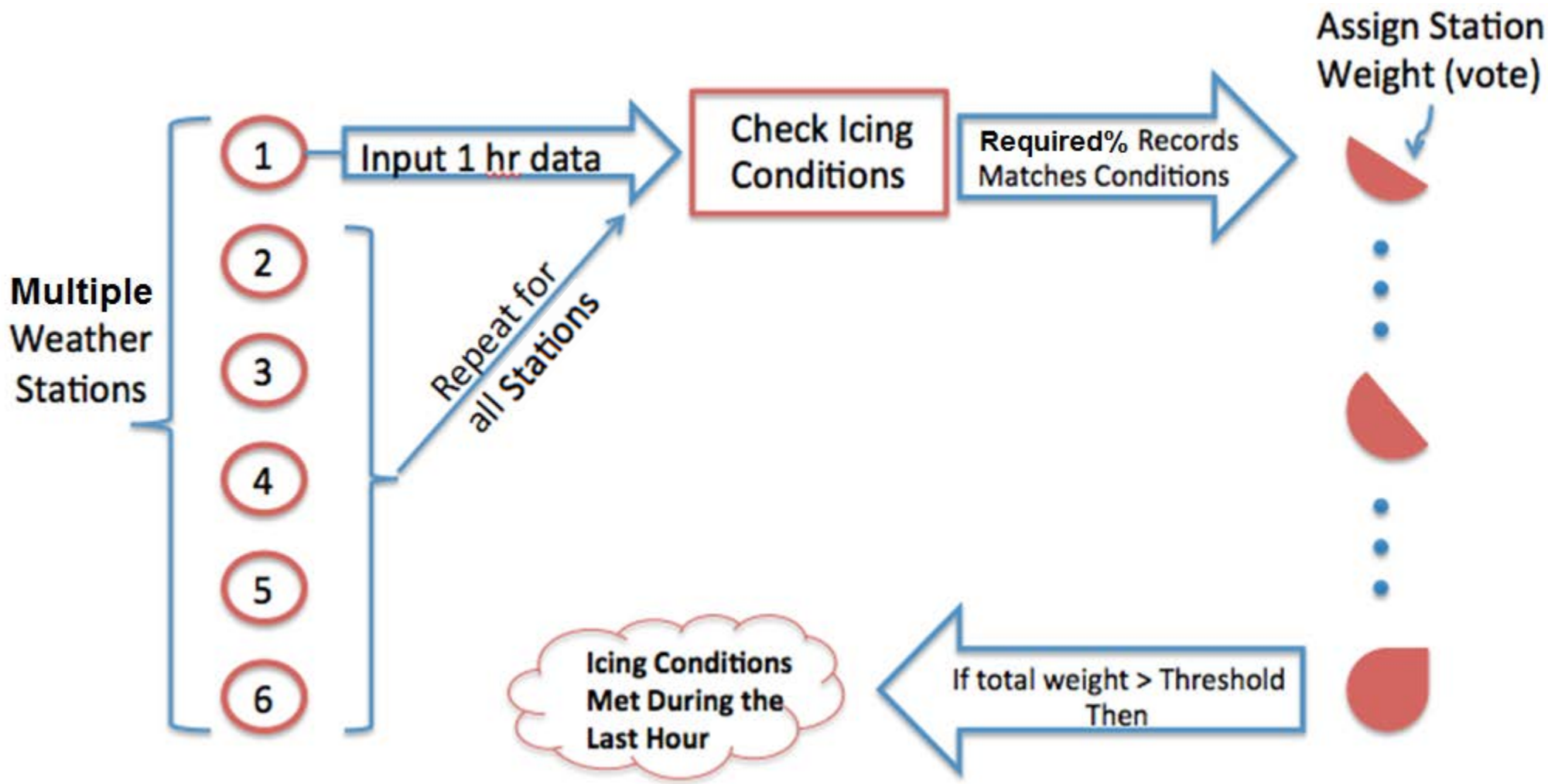
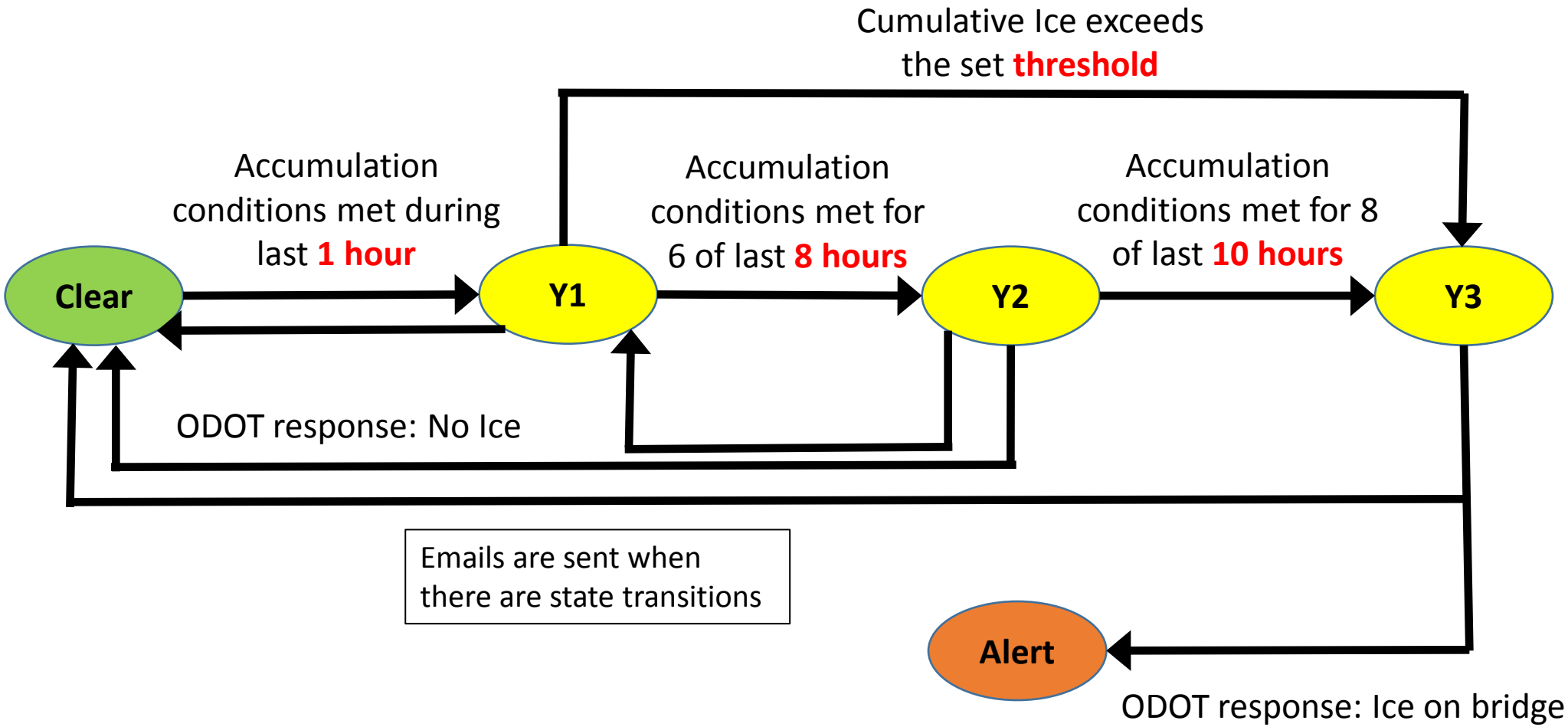
Ice Accumulation/Shedding



Emails are sent when conditions are met

Accumulation State Transitions



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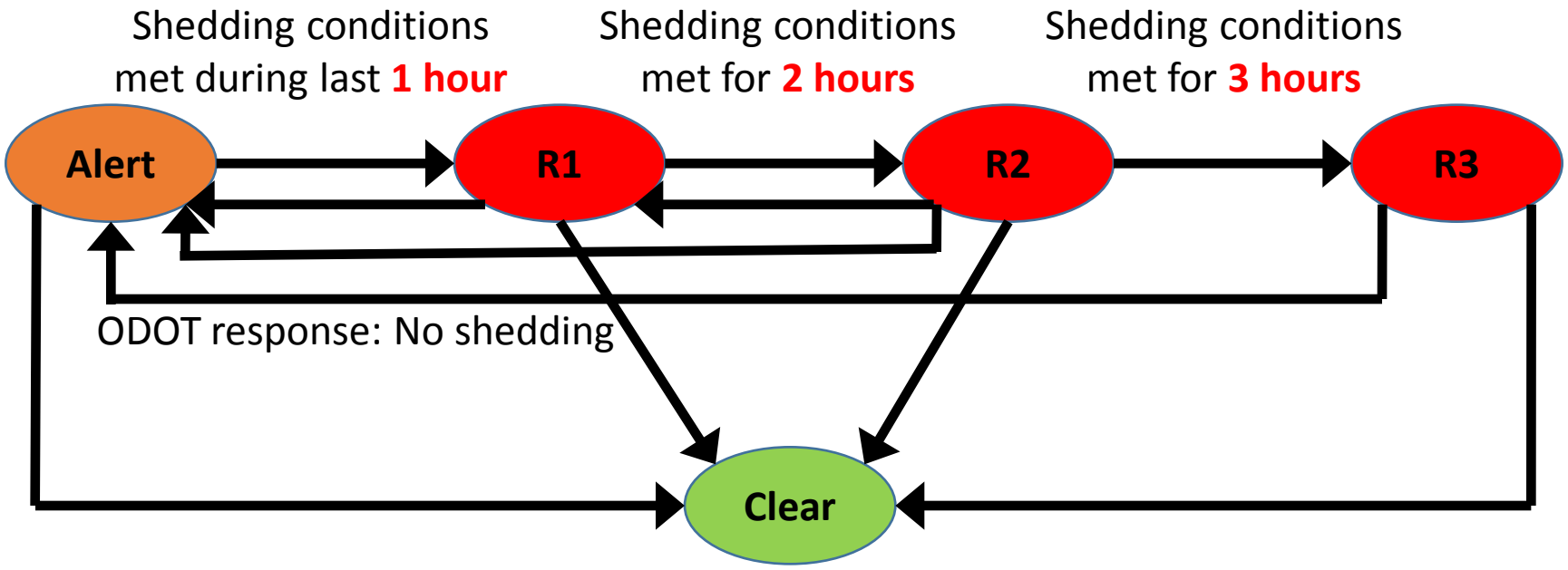
Ice Shedding Rules

Type of Station	Ice Shedding Check
RWIS	• Temperature greater than or equal to 32° F.
Airports	• Temperature greater than or equal to 32° F **OR** • Clear sky / Scattered Clouds / Partly Cloudy during day time (8am to 6pm).
Bridge Sensors – Thermistors	• Any of the stay temperatures above 32° F.
Bridge Sensors – Solar Sensor	• Solar radiation sensor reports Sunshine (i.e., Global radiation > 1.25 times Diffused radiation and Global radiation > 25 W/m^2)

Shedding State Transitions



Emails are sent when there are state transitions

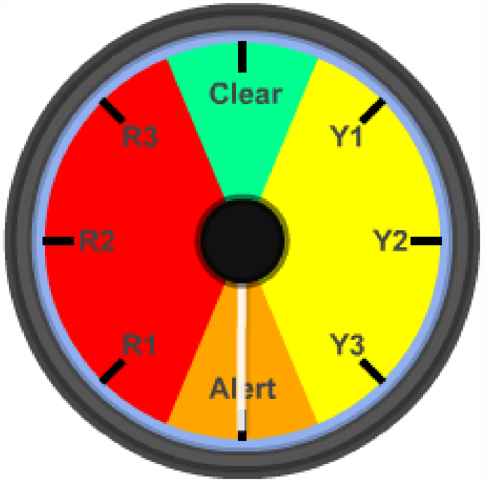
Parameters that can be altered from the website is highlighted in red.

VGCS Icing Status

Dashboard | Map (Weather Data by Location) | History | Documentation | Plotting | Algorithm Parameters

Current Stay Icing Conditions

Last Run: 2015-01-21 10:03:09



Legend

Clear	Icing conditions are not present.	Alert	Ice present, field verified.
Y1	Icing conditions met for at least 1 hour, monitoring continuing.	R1	Ice fall conditions met for at least 1 hour, monitoring continuing.
Y2	Icing possible, conditions met for past 8 hours, monitoring continuing.	R2	Ice fall possible, conditions met for past 2 hours, monitoring continuing.
Y3	Icing likely, conditions met for past 10 hours or CumulativeIce from Ice Detector >= 0.25 in. **ODOT verification required.**	R3	Ice fall likely, conditions met for past 3 hours, **ODOT verification required.**

Response

Report

This button is used for logging field reports and for responding to verification requests (Y3 & R3).

Recent Response Comments

2015-01-21 09:03:09
[Tom Powell]
Ice present on stays

See History table for all Comments

Last 48 Hours of Recorded Icing Conditions

C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	Y1	Y1	Y1	Y1	Y1	Y2

48hrs ago	24hrs ago	Recent

Learning Outcomes Summary – Part 1

- Extent of icing: Icing affects bridges in the eastern two thirds of the US as far south as Georgia and Texas and in the northwest west of the Rockies
- VGCS icing experience: Ice pieces as thick as ¾ of an inch have fallen 200 feet to the bridge deck.
- Ice fall hazard mitigation strategies includes active, passive and administrative approaches.
- An administrative ice hazard mitigation strategy was selected for the VCGS because no efficient, practical or economical active or passive strategy.

Learning Outcomes Summary – Part 2

- Key information that bridge operators need to help them make decisions to protect the public from ice fall hazard is the accumulation of ice on the stays and, if the conditions are right, for accumulated ice to shed.
- Existing sensors do not capture the desired information about the state and thickness of ice on the stay cables so new thickness and state sensors were developed.
- The required information can be conveyed in a clear, concise and actionable manner to the bridge operators is it collected directly from the bridge and presented to the operators in a clear graphic format.

Acknowledgements

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