Validation and Refinement Of Icy Road Forecast and Alert (IcyRoad) System Using MDT RWIS Sites

By

Principal Investigator: **Jennifer Fowler,** Director of Autonomous Aerial Systems Office, University of Montana, Jennifer.Fowler@mso.umt.edu

CO- Principal Investigator: **Steve Running,** Ph.D., Regent's Professor Emeritus, University of Montana, swr@ntsg.umt.edu

A proposal prepared for the

Montana Department of Transportation
2701 Prospect Avenue
P.O. Box 201001
Helena, MT 59620-1001

June 2020

Table of Contents

LIST OF TABLES

LIST OF FIGURES

PROBLEM STATEMENT

Significant hazards caused by snow-covered and icy roads result in fatalities and disruption of the transport of commerce. There is a need for real-time observations and weather forecasts to support timely and efficient decisions to reduce such disasters. Drivers need reliable forecasts and alerts for icy roads, in particular black ice presence, to reduce winter driving risk. State traffic and safety management need icy road forecasts to inform winter operations, public notice, snow removal resources, and school re-scheduling. For example, in the state of Montana, where snowfall and cold wind occur more than 70% of the time in winter months, car crashes induced by icy roads have been one key reason for Montana winter road accidents. Nevertheless, the ice formation mechanism, in particular black ice, is not well studied and thus not forecasted by the National Weather Service.

The Icy Road Forecast and Alert system (IcyRoad), an innovative technology developed by SpringGem Weather Information, LLC is based on numerical weather forecasts, remote sensing observations, cloud computing and data mining to provide ice information to users for any road across the US, 24 hours a day, 7 days a week, with 24-hour lead time. The University of Montana (UM) will work with SpringGem Weather Information through this project to validate and refine the IcyRoad scientific algorithm, in particular black ice algorithm, using Montana Department of Transportation (MDT) Road Weather Information System (RWIS) data and UM's drone-based ice detection technology.

BACKGROUND SUMMARY

Between 2002 and 2012, winter weather was the cause of 540,000 car collisions (10% of collisions annually), 150,000 car-related injuries and 1,900 car-related fatalities, according to the U.S. Federal Highway Administration (Harris 2018). The risk of vehicle crashes significantly increases because of the presence of winter precipitation (Black and Mote 2015, Yu et al. 2019). Icy road fatalities account for 3.6 times more deaths than all other weather hazards combined (Zebra 2020). The Montana Highway Patrol saw a 10% increase in crashes from October 2017 to March 2018. That increase was attributed to an increase in icy road conditions that winter (Graham 2018). On November 6, 2019, 102 car crashes statewide were reported to the Montana Highway Patrol with ice present for over 16 hours, on average, more than 6 crashes per hour. Icy roads start to occur from late September and normally end in April in Montana. How to forecast icy roads and effectively inform the public are the two key concerns for Montana Department of Transportation (MDT) operations team (McBroom, personal communication 2020). Hazards associated with winter weather affect public transportation and commerce, since ice or snow can lead to slower speeds, reduced reliability, denser traffic congestion, and more accidents (ARC 2014, Koetse and Rietveld 2009, Kashfi and Bunker, 2015). Accurate icy road forecasts and alerts are highly desired.

Although using electrically conductive concrete for route deicing is becoming a new approach (Shishegaran et al. 2020), before such technology has matured and is widely implemented, forecasting ice status on roads and thus alerting drivers and traffic managers is the most effective solution to reduce winter ice-induced risk.

The IcyRoad forecast has been developed as shown at https://sg-weather.com/weather/ (Figure 1)

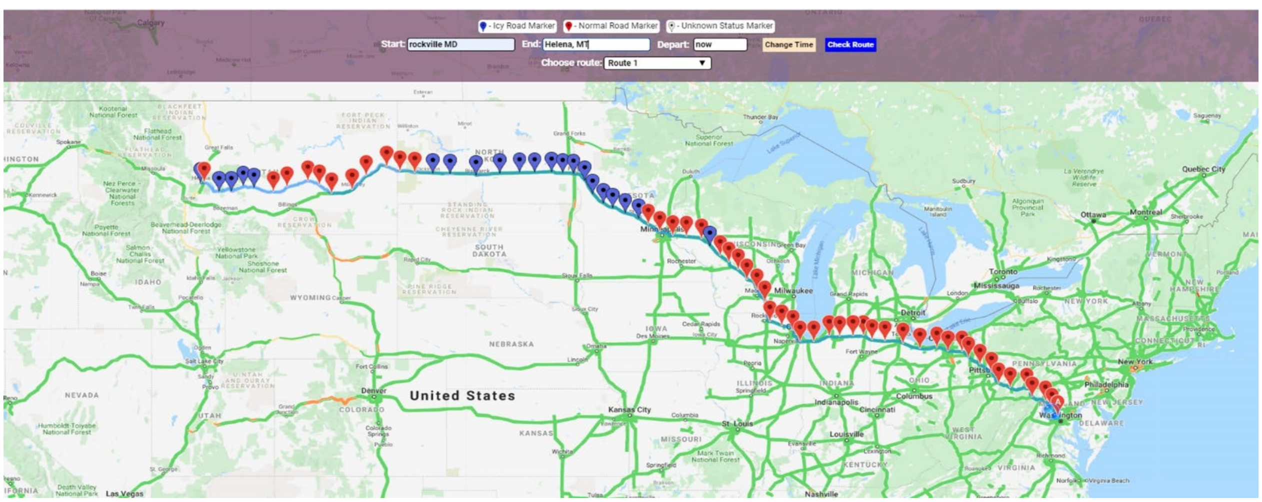

Figure 1: Current IcyRoad web app interface and forecast. The web app can be found at https://sgweather.com/weather/. This is a free community service to provide users, in particular long-distance drivers, with an icy road forecast at a 24-hour lead time, 24/7, in 5 seconds after the user inserts a query. The blue marker is for an icy road, and the red marker indicates a clear road. The starting and ending destination, city, address, or zip code, can be input by writing or by voice. The departure time can also be changed to see the forecast within the next 24 hours. A mobile app is also available with more functions including operational highway camera information.

together with value-added highway camera information http://www.sgweatherinfo.com/traffic. IcyRoad combines weather forecasts provided by the commercial sector, Weather Research and Forecasting model (WRF) with road-scheme enhancement by Jin (SpringGem Weather Information, Zhang et al. 2019), commercial cloud computing, data visualization and mining, and remote sensing technology to forecast road ice conditions for any road across the US in 5 seconds. This existing IcyRoad algorithm has been tested during the winter months(October 2018-March 2019, October 2019-present) over Montana, Wisconsin, Maine, Vermont, New York, Maryland, and Georgia. A greater than 70% accuracy has been reached as compared to RWIS data. In addition, industry users including a long-distance truck shipping company (ofoexpress.gov), NOAA national weather service, and individuals tested the IcyRoad algorithm with feedback collected for further improvement.

Water and sub-freezing surface temperatures[1] are the two key parameters for ice forming on roads. In addition, wind is the third important parameter which reduces surface temperature. Therefore, winter storms with heavy snow, including freezing rain, in general lead to icy roads. In addition to the winter storms, our Icy Road forecast refinement will consider black ice. Black ice[2] is a thin layer of transparent ice formed on the road surface. Three mechanisms are responsible for black ice formation: (1) Freezing of pooled rain water and (2) freezing of condensed water from the air outlying the ground. Rain can be in liquid form during daytime hours but freeze overnight as the temperatures decrease (Chapman et al. 2008, Call 2010, Bouilloud et al. 2009). In very humid locations, water vapor can condense onto road surfaces in sub-freezing temperatures creating icy road conditions (Riehm et al., 2012). Alternatively, (3) snow accumulated on roads can melt and then re-freeze when the temperature drops (e.g., old-snow-re-freeze). All three cases can form black ice in moments without snowfall.

Besides the weather conditions, road texture and geographic conditions affect ice formation as well. For example, road shoulders, with even a slight slope, can form ice much more easily when temperature and water conditions are optimal due to the micro-scale turbulences near the ground. Ground measurements from Road Weather Information System (RWIS, Ewin and Al-Kaisy, 2017, Johnson and Shepherd 2018) have been analyzed for implementation into black ice forecasts.

While previous development was funded by the private sector and the National Science Foundation, validation and refinement of the Icy Road Forecast and Alert System is aligned with public transportation needs in Montana. To accelerate the IcyRoad forecast readiness for operational implementation at the state-level in the department of transportation in Montana

[1] There are two kinds of land surface temperatures: 2-meter air temperature and land surface skin temperature. Two-meter air temperature is the one generally used in the transportation sector, which is measured by a weather station with a thermometer in a Stephen shelter built 1.5 - 2 meters above the ground. Skin temperature, a radiometric temperature by definition, is measured via remote sensing from thermal infrared emission as a function of ground temperature. Road surface temperature measured by RWIS is close to skin temperature. Dr. Jin has been studying skin temperature mechanisms and modeling this variable related to physical processes since her graduate study (Jin and Dickinson 1999, 2000, Jin et al. 2005a, b, Jin and Shepherd 2008, Jin 2012, Jin et al. 2014, etc see papers in https://www.atmos.umd.edu/~mjin/Publication.html). Skin temperature is the one variable that actually determines the ice formation on the road. Skin and 2-meter air temperature have high correlation due to surface boundary-layer processes.

[2] Black ice is a vague concept in scientific literature. In our research, we define black ice as "Ice formed using other water resources not related to precipitation". Namely, water that is used to form ice is from atmospheric water vapor condensation in saturation or due to high soil moisture. Thus, black ice can form from snow-induced ice and old-snow-re-freeze mechanisms and this information will be used to simulate black ice in the WRF/land-surface model.

(MDT), we plan to improve the current IcyRoad forecast accuracy by implementing a black ice forecast component and validate the system using Montana Road Weather Information Systems (RWIS) sites, Unmanned Aerial System (UAS) hyperspectral camera data, and on-site visual inspection.

Current Scientific Results:

(1) The developed IcyRoad forecast algorithm has encouraging accuracy. Ground measurements from Road Weather Information Systems (RWIS) have been used to validate IcyRoad hourly forecasts across Montana during November and December 2019. On average, there is a greater than 75% accuracy of IcyRoad forecasts on an hourly and monthly basis. This is considering most of the 73 Montana RWIS sites. Nevertheless, in a few sites the accuracy is below 60%, and further research suggests that black ice is not well forecasted. In addition, some uncertainties may be due to a chemically wet surface.

(2) A novel finding from our previous research (Figure 2) is that the road surfaces are generally warmer than the 2-meter air temperature, by 1 °F - 10 °F, partly due to anthropogenic heat flux from traffic and partly due to the modified physical properties of the paved materials (e.g. albedo, thermal emittance, thermal conductivity, specific heat, and surface roughness). This is in contrast to other studies that are the basis of the way land-surface is simulated in the WRF model. In the model, at night the land surface is colder than the 2-meter air temperature due to radiative cooling, "It is common for a road to become colder than the surrounding air on clear nights and this often leads to formation of black ice or hoar-frost" (Riehm 2012). Although, experience by MDT is more complex in that the surface temperature is colder than ambient temperature after sunrise and warmer than ambient temperature after sunset. Part of the validation work with the RWIS data in this project will further the investigation of these observations and inform simulation of road temperature in the IcyRoad algorithm.

As a starting point for this project better simulating road surface skin temperature is a priority. Based on our previous findings, the road surface energy budget differs from any other land surface and is balanced by downward longwave radiation, upward surface-emitted longwave radiation, up-ward sensible heat flux from surface to atmosphere (i.e., which is in opposite direction from normal vegetative/bare-soil land surfaces), and upward ground heat flux (e.g., from soil layers to surface), assuming the latent heat flux is negligible for the water covered roads. The road temperature, in particular roads in non-urban regions not represented in WRF/land surface model, cannot be well simulated and thus forecasted. Therefore, we developed a new road energy scheme to better simulate road temperature (Gohil and Jin 2018) and plan to implement this scheme into the Weather Research and Forecast Model (WRF)/land-surface model (e.g., Noah model) forecast for better road surface skin temperature forecasting. Again, validating the IcyRoad algorithm against RWIS data is a key step to better simulate road temperature and thus road ice status.

Figure 2 displays data involving black ice. The Road surface switched from wet to icy, back and forth during January 13-14, 2018 (i.e., Figure 2, the 700-1000 time steps on x-axis). This was so-called black ice since there was no precipitation during these two days. Another key message is that the ice formation is not simply determined by road surface temperature. For example, at midnight of January 13 and January 14, 2018, the road temperatures minimized below 20 °F but the road was "Dry". The road became icy during the early morning when road temperatures were close to 32 °F, suggesting condensation of water from air or re-freeze of old snow.

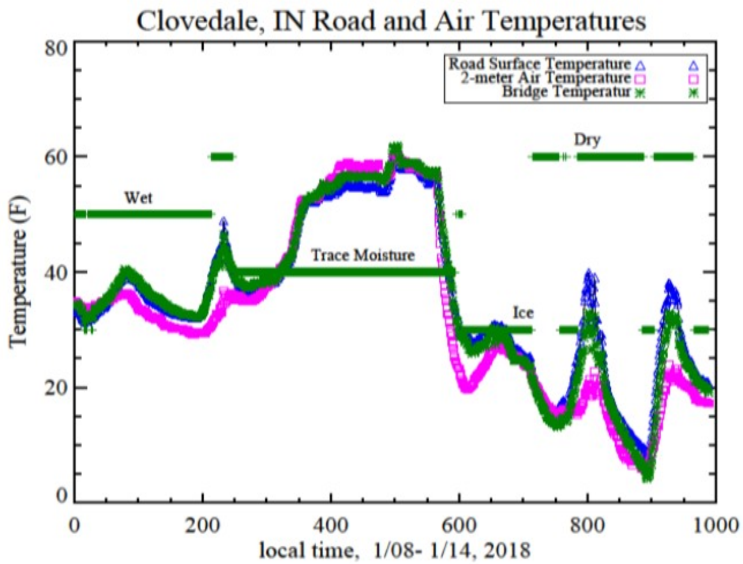

Figure 2:RWIS ground observations for Clovedale, IN during January 8-14, 2018. Data is available at https://rwis.indot.in.gov/. "Dry", "Wet" "Trace Moisture" and "Ice" are road surface conditions recorded by RWIS sensor.

Black ice mechanisms are the most challenging process and more observations are needed to understand black ice forming meteorological conditions, locations, and time in order to forecast it well. Since the road ice observations, RWIS sites, are located only in limited areas along roads, more observations between RWIS sites are needed. Studies have been done using additional sensors such as near infrared cameras (0.9 - 2.3μm) with evidence of possible black ice detection although wet and black ice surfaces had similar sensor responses and new technologies were recommended to improve detection accuracy (Jonsson et al., 2015). New technologies are definitely needed in this project to validate IcyRoad forecasts since visible cameras and RWIS data cannot discern the difference between wet and black ice surfaces. <u>We therefore propose a novel drone-based remote sensing technology to detect black ice via hyperspectral camera launched on an unmanned aerial vehicle (UAV).</u> This new detection approach will help us to improve physical modeling of black ice which has been ignored in the existing WRF/land-surface model and to subsequently validate the black ice forecast component in the The Icy Road Forecast and Alert system through camera and on-site observations. There is evidence of hyperspectral cameras with visible and near infrared capabilities (0.4 – 1 μm) being used to identify road defects (Abdellatif et al., 2019) but no one has yet attempted to distinguish road surface conditions using hyperspectral cameras. This project will have access to a hyperspectral camera capable of distinguishing 281 spectral bands at 2.1 nm resolution. As a result, an increase of accuracy for IcyRoad forecasts is expected. The algorithm has been developed by SpringGem Weather Information and this project is to conduct data validation and field experiments to validate and refine the technologies.

BENEFITS AND BUSINESS CASE

Icy roads, in particular black ice, have been a long-standing issue in Montana winter safety. For example, 102 car crashes on November 6, 2019 alone (https://mtstandard.com/news/state-and-regional/crashesreported-to-montana-highway-patrol-over--hour-period/article_2449dec7-0dcf-5559-905eb048193c4ead.html), is an example of the need to accurately forecast black ice formation. The real-world cost associated with icy roads in general is over $1 billion US wide each year (USDOT, annual report). In 2012 Mats Riehm found in his PhD thesis the, "While the cost of winter road maintenance amounts to about 10 billion US dollars worldwide each year, the savings due to the reduction of accidents and maintained road availability may be even larger. A study performed in the UK concluded that there is an eight-fold return on every one unit of currency spent on winter road maintenance (Thornes, 2000)." Thus, the public as well as state and local transportation managers will benefit from this research.

Potential benefits:

1. Improved service: A novel icy road forecast and alert system (IcyRoad) for use by MDT. A web app and mobile app are both available. IcyRoad is currently a free product. In the near future, IcyRoad will be customized and improved for commercialization. As an early user and research sponsor, MDT will have a flat discount of 50% for the IcyRoad-pro technology, after IcyRoad is mature for commercialization (i.e., IcyRoadpro).
2. Alert for drivers including MDT staff through the IcyRoad mobile app based on road segments of interest from the technical panel.
3. Cost savings for winter icy road management with strategic resource allocation based on IcyRoad forecasts.
4. Ability to accurately time road treatment to reduce icing conditions.
5. Increased safety on winter highways (e.g., by accurately forecasting icy roads and effectively informing public, accidents will be reduced).

Improving icy road awareness, in particular black ice, is the reason for initiating this project. Every driver as well as state transportation managers need icy road status and forecast information. The IcyRoad algorithm can provide such information for any road across the US, 24 hours a day, 7 days a week, with 24-hour lead time. This IcyRoad project addresses the questions of when and where icy roads occurs and will attempt to discern black ice formation. The problem of a lack of such information will remain until research is done. We propose to ultimately compare the costs associated with using current forecasting methods against use of the refined IcyRoad forecast to determine cost savings in deployment of resources for winter road maintenance from October 2020 – March 2021. Additionally, we will compare Montana Highway Patrol accident statistics over the same period to previous years to begin the process of assessing an increase in public safety due to the use of the IcyRoad forecast and Alert system. To fully understand this impact will take more years of statistical data collection and tracking of the IcyRoad system use by state. Therefore, this research should not be postponed to another year since each winter fatal accidents occur in Montana.

OBJECTIVES

The Technical Objectives of this project are to improve the capability to forecast black ice so that DOT's in general and MDT specifically can act operationally and inform the traveling public.

The validation in this project uses the following two approaches:

(a) To validate IcyRoad forecast using RWIS across Montana as well as using data from additional sensors on strategic road sections without RWIS information. Our previous results show that ice can form in various conditions (i.e. bridges, north aspects of mountains, exit and on-ramps for highways, etc.) because the low solar radiation slows the heating of the surface during the day and low sensible heat flux transported from the underlying soil layer to the road surface at night. We will compare hourly surface temperature data and icing determination from RWIS, the UAS data, visual on-site inspection with the IcyRoad forecast to identify when and where the accuracy of the forecast is acceptable, and when and where further refinement is needed.

(b) To confirm the use of UAV hyperspectral technology to detect icy road conditions and validate the IcyRoad forecast. Black ice is hard to detect from the visible bands (i.e., 0.4-0.7 µm, the wavelength of solar radiation spectrum that human eyes use for sight). Nevertheless, an ice sheet, thin or thick, has spectral reflectance (r_λ) significantly different at near infrared bands. By using the combination of visible bands and near-infrared bands (NIR), a thin ice-covered surface may be differentiated from asphalt surfaces (i.e., road surfaces). Specifically,

$$\text{Road Ice Index } \theta = (\text{NIR-RED})/(\text{NIR+RED}) \qquad (1)$$

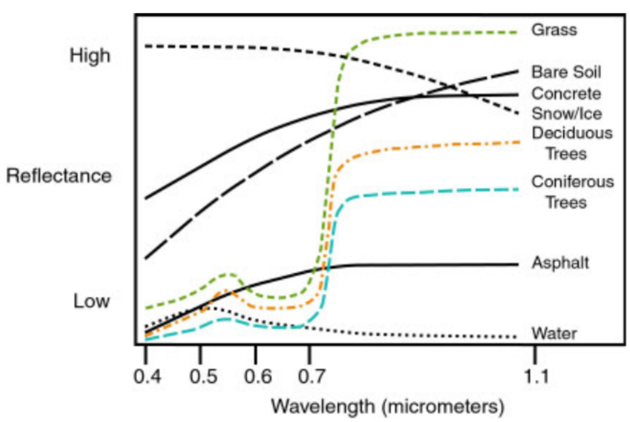

Figure 3:Spectral reflectance curve for asphalt, water, snow and vegetation.

in which RED is the radiance for the red band. The Red band is the edge of the visible band at close to 0.620 – 0.670 µm (e.g., MODIS band 1, King et al. 2004). NIR is the near-infrared region of the electromagnetic spectrum (from 0.78 µm to 2.5 µm) and we will use 0.841 – 0.876 µm (e.g., MODIS band 2) to follow NASA MODIS instrument spectral bands. For snow and ice, r_λ reduces from RED to NIR and thus θ is negative; while for asphalt surfaces, r_λ increases from RED to NIR and thus has a positive θ. As a result, icy roads can theoretically be detected using a combination of Red and NIR bands. Nevertheless, this all depends on the accuracy of the hyperspectral calibration and we may find the need to use an additional camera capable of longer bands in the NIR, such as MODIS band 6 (1.628-1.652 µm) since research showed evident spectral difference for dry, wet, snow and icy roads at this band (Hall et al. 2002, Jonsson et. al 2015).

This is the first time that drone (or UAV)-based hyperspectral camera will be used for road ice detection. It will be a challenge to distinguish between vegetation, snow covered roads, dry, and wet roads from remote sensing. Nevertheless, this process has sound theoretical basis (Figure 3) and the same technology has been used by the NASA MODIS satellite remote sensing crew to detect vegetation and ice coverage from space and from airborne platforms for more than 20 years (Hall et al. 2002, Running, MODIS science team member, personal communication, 2019). Our task is to adopt the concept, identify the most ice-sensitive bands that include black ice, and develop a quick-classifying algorithm with adequate accuracy and reasonable cost for future scale-up use. Additionally, data from the UAV and mobile vehicle-based RWIS sensors will provide more validation data on road surfaces that do not have an RWIS station.

RESEARCH PLAN

Research plan designed here is based on our previous research experience. Nevertheless, one may always find unexpected results from research and thus may need to take different research approaches.

The research plan has two major components with the principles of theories to be used outlined in the objectives and background summary section of this proposal. The first task involves scientific ice forecast algorithm refinement then validation. The refinement procedures are as follows,

(1) We will directly analyze MDT RWIS station archived observations to study black ice formation mechanisms for various spatial orographic conditions. Understanding the physical mechanisms of ice formation is critical but challenging because of the lack of appropriate observations but this challenge will start to be addressed with the UAV. Water and cold temperatures are the two necessary conditions for road ice formation. MDT RWIS site (for example, Bozeman, Butte, Billings, etc, RWIS data at http://rwis.mdt.mt.gov/) observations were used in the 2018-2019 validation and have proven extremely helpful. In this research, we will use more MDT RWIS sites to derive statistically significant conditions under which black ice forms. An online RWIS-IcyRoad system has previously been developed (https://sg-weather.com/weather_chart/) and will be used with additional RWIS sites. With this online tool and the UAV data we plan to answer the following questions:

   a) What is the threshold temperature for black ice to form? Previous research found that black ice can form below 32 °F, but sometimes can form slightly above 32 °F.
   b) Is a threshold temperature a function of elevation, nearby land cover, road type, climatic history or are there other natural and human activity factors?
   c) What is the threshold relative humidity for black ice to form?
   d) What is the statistical relation between an icy road and old snow age? Namely, to what percent, does road ice occur when old snow melts during the daytime but re-freezes when the temperature drops?
   e) To what percent does black ice occur when there is no precipitation and no old snow? Namely, how frequent is the mechanism of a water source from the outlying atmosphere necessary? What are the conditions for such a case to occur?
   f) Are there other mechanisms for black ice formation except for the three identified, namely, pooled iced rainfall water, re-freezing old snow, and ice via condensation?
   g) Compare IcyRoad forecast with RWIS road surface observations. We will integrate the scientific algorithm into the IcyRoad back-end (http://www.sgweatherinfo.com/usIcyRoads) to compare hourly icy road forecasts instantaneously with the road observations of RWIS sites across

Montana and identify algorithm accuracy and deficiencies. This step is needed because:

i. MDT RWIS data sites vary with land cover and orography which can identify where and when our algorithm has systemic deficiencies and shed light on how it can be improved.
ii. The speed of receiving the forecast and an alert is one of the key requirements for end users.
iii. Some MDT RWIS sites may have accuracy issues (Report of RWIS, Ewan and AlKaisy, 2017). If we notice some observations are not consistent with our physical understanding or with other sites, we may report to MDT staff and visit MDT RWIS sites to understand the site design, calibration, and its relationship to real road temperature and ice conditions.

(2) The second task, validation, is using a drone-based hyperspectral camera for observations of icy road conditions, in addition to on-site visual inspections. There will be two main objectives to this part;

a) First, we will develop baseline observations of spectral signatures on dry, wet, chemically wet, ice, and black ice on asphalt in a controlled environment. We will use the Montana State University Sub-zero laboratory to control temperature, humidity, and wind while setting up various scenarios on asphalt samples (i.e. snow-ice, old-snow-re-freeze, and black ice cases).
b) Following Jin's successful NSF SBIR project design, we will use the same hyperspectral camera from the subzero laboratory on an unmanned aerial vehicle to detect road ice conditions at varying altitudes when no traffic is present. Specifically, we will analyze the radiances on RED bands 0.620 – 0.670 µm (e.g., MODIS band 1), NIR bands 0.841 – 0.876 µm (e.g., MODIS band 2) and band 4 (0.545-0.565 µm) to calculate the road ice index (Eq. (1)) and identify black ice. Validation on this road ice index will be done by comparisons with the measurements from Montana sites (TBD). If we find it necessary to analyze NIR bands 1.628-1.652 µm (MODIS band 6) we will acquire short term use of a Resonon hyperspectral camera capable of these wavelengths. The UAV will also carry a temperature and relative humidity sensor on each flight.

Ongoing communication between the research team and MDT staff is critical to the success of the project. Quarterly reports, in pdf format will be emailed to the MDT champion and project manager, Doug McBroom, and Research and Project Associate, Vaneza Callejas. Such reports will be peer reviewed and follow MDT report writing requirements. These reports, as well as meeting notes, are to ensure QA/QC and ensure regular communication among PIs, MDT's Research Program staff, and Technical Panel throughout the project.

Evaluation for Validation and Refinement (Task 1)

Significant variables to be tested in the IcyRoad forecast are <u>2-meter air temperature</u> and <u>road ice status.</u>

The analytical and statistical procedures to be used are correlation coefficient, root mean square error, and absolute accuracy percentage for comparison of forecasted and observed temperature and ice status.

Experimental and testing procedures for each RWIS site involve comparison of the hourly RWIS observed 2-meter air temperature with IcyRoad hourly forecast, and comparison of the ice status for the site. Then a calculation of the correlation coefficient at a monthly scale (i.e., for each site, the data entry is 24 hours/day times 30 days/month, with removal of hours recorded if there is an RWIS sensor error or the road is chemically wet).

Evaluation criteria: Since road ice status is the key information useful for users, we will pay close attention for detecting the accuracy of the forecast with this variable. Nevertheless, surface temperature is one of the two key parameters for ice formation on the road and we will also need to validate surface temperature for future improvement. If ice status is greater than 80% accurate, this is considered acceptable at this stage. If ice status forecast accuracy is below 60%, further analysis in terms of time, duration, weather conditions, temperature forecast, and geographic conditions will be studied to understand the reasons for the low accuracy.

Controls: If at certain times a site sensor is recorded as “chemically wet”, we will remove these data samples in consultation with MDT staff from the comparison data entry since IcyRoad statistics will be biased due to human deicing activity. IcyRoad forecasts currently cannot include deicing impact. We may need to remove such data for a few continuous days since deicing salt may remain on the road surface for a few days. We will discuss this further with MDT staff. Future potential work could include adding “chemically wet” to the forecast once this project is complete.

Evaluation for UAV and the mobile vehicle-based RWIS sensors (Task 2)

Significant variables to be tested are 2-meter air temperature, relative humidity, and road ice status (using calculated calculate the road ice index (Eq. (1)) against RWIS data as well as 2-meter air temperature and road ice status against IcyRoad hourly forecast along road sections without RWIS sensors.

Statistically the procedure to be used in comparing measurements among the different sensors will be taking the average and the uncertainly in the average of the values assuming the RWIS stationary sensors as the reference value. The analytical and statistical procedures to be used for comparison of forecasted and observed temperature and derived ice status are correlation coefficient, root mean square error, and absolute accuracy percentage.

Evaluation criteria: If at least 80% of measurement averages with uncertainties overlap RWIS values then we will consider the measurements from the UAV acceptable. If ice status is greater than 70% accurate in the forecast, this is considered acceptable as well. If ice status forecast accuracy is below 70%, further analysis in terms of time, duration, weather conditions, temperature forecast, and geographic conditions will be studied to understand the reasons for the low accuracy.

Controls: If at certain times an RWIS site sensor is recorded as "chemically wet", we will remove these data samples in consultation with MDT staff from the comparison data entry for icing condition since IcyRoad statistics will be biased due to human deicing activity. We will however examine the UAV and mobile vehicle-based RWIS sensors to determine if they are able to discern a "chemically wet" surface using values from the road ice index as preliminary data towards future potential research.

IT Components and Data Management

Policies for data access and sharing: Data will be stored and shared in Box.com through the University of Montana. Box is a cloud-based storage and collaboration tool.

SpringGem has web infrastructure in place to disseminate certain research activities, http://www.sgweatherinfo.com/usIcyRoads

Policies and provisions for re-use, re-distribution, and the production of derivatives: Principal investigators and their institutions own the research data they generate. By publishing this data or otherwise releasing it to the public, investigators do not transfer data ownership but instead grant permission for others to transform and redistribute the data as necessary.

Plans for archiving: In principle, research data published in archival journals and conference proceedings is accessible in perpetuity. All other primary data made available for public distribution will be maintained for a minimum of 5 years after the end of the project or after public release, whichever is later.

UM Electronic Research Data Security Policy: Research data are created at University of Montana by faculty, staff, students, post-doctoral fellows, scholars and visiting scientists in the course of their scholarly activities and in conducting sponsored activities funded by external agencies. The Principal Investigator is responsible for ensuring that reasonable standards for data collection, retention and security are in place for all research projects.

For the purpose of this policy, "data" is defined as electronically recorded primary information regardless of form or the media on which it may be recorded. The term includes technical data, source code or algorithms developed during the course of the program, laboratory worksheets, memoranda, notes or exact copies thereof that are the result of original observation and activities of a study and are necessary for reconstructions and evaluation of the report of the study

Policy: The investigator, usually designated Principal Investigator, who bears primary responsibility for the overall conduct of the research, sponsored, or scholarly activity, is responsible for collection, management and retention of research data and providing access to it including any MDT requirements for sharing data.

Procedures: Principal Investigators should adopt an orderly system of data organization and should communicate the chosen system to all members of a research group and to the appropriate administrative person. Research data generated while individuals are pursuing research, scholarly, or sponsored activities as faulty, staff, postdoctoral fellows, scholars, students or visiting scientists must be retained by the principal investigator (PI) for a period of three years after submission of the final report on the project for which the data were collected. If the retention requirements specified in other statutes or external agency's regulations are longer, the agency requirements will apply.

When submitting a Proposal Clearance Form, the PI will assure he/she has read and agrees to adhere to UM's security guidelines.

Communication Plan

The research team will communicate with MDT staff via email, phone calls, teleconference and in person meetings on a regular basis. Please see the list of meetings and reports below for the schedule.

Meetings and Reports

Kick-off Meeting: Within 3 weeks of the project officially starting, PIs will host a kick-off meeting at the University of Montana via an online meeting format. The project kick-off meeting serves to ensure everyone involved in the research project is informed of the contractual obligations, scope of work, deliverables, project milestones, timetable, and appropriate office policies and procedures. This meeting will also provide an opportunity to clarify technical issues or concerns with the project. Meeting powerpoints, discussion notes, and minutes will be kept as a record for MDT project management use.

Implementation Meeting: Within 3 weeks before the project officially ends, PIs will facilitate discussion in person or via an online meeting format the implementation recommendations from the final report with the Technical Panel and others as appropriate. The purpose of the meeting is to review the team's implementation recommendations to determine which will be implemented as is, with changes, and which will not be implemented. The discussion will include other items, not mentioned in the project final report, to be implemented, as well as a determination of any unmet research needs. The PIs will document this discussion in the form of an implementation report, with the following sections: Introduction and Purpose, Implementation Summary, and Implementation Recommendations (includes Principal Investigator's recommendations and MDT response).

Final Presentation Meeting and Webinar: Within 1 week before the project officially ends and after review of the final report comments and integrating implementation feedback, PIs will present via an online meeting format as a webinar, the final report to the MDT technical panel, with in-depth details of the project outcomes, data sharing, improved IcyRoad forecast method, and recommendations for implementation. A powerpoint will be sent 1 weeks in advance to the project manager.

Task Reports: The research team will submit task reports by the end of the month following completion of a task.

Final Report: The research team will submit a final report draft 8 weeks before the end of the project for review by the MDT technical panel. The final report will then be presented at the final presentation webinar.

MDT AND TECHNICAL PANEL INVOLVEMENT

- We will obtain RWIS data from September 2020 - March 2021 via the publicly available online site for validating the new IcyRoad algorithm. We will consult with MDT staff for removal of "chemically wet" data samples.
- We request feedback from MDT and the TP for strategic data collection locations for UAV flights and on-site visual inspection.
- We request feedback from Technical Panel (TP) on the final report and the implementation report.
- We request feedback from MDT and the TP for future customization of the IcyRoad algorithm for operational use for MDT and the state of Montana.

PRODUCTS

Deliverables will be peer reviewed and will include:

Scientific Algorithm

- IcyRoad forecast during the project time and reduced cost access to the forecast following the project to be negotiated during the implementation meeting.
- Drone-based field and laboratory experiment measurements.
- IcyRoad and RWIS data analysis and scientific refinement scheme

Reports

- Task Reports (word and pdf formats)
- Final report cover page photo (JPG format)
- Final Report including an implementation plan (word and pdf formats)
- Implementation meeting and report (word and pdf formats only)
- Final presentation webinar (combination of powerpoint as well as word and pdf formats)

Data

- MDT will have access to all collected data stored at the University of Montana for a minimum of 5 years after the end of the project

Articles

- TRNews Research Pays Off article

IMPLEMENTATION

The research result, an improved IcyRoad algorithm, should be ready for operational implementation in the following ways:

Operational Use

1. The IcyRoad algorithm can be used, manually or automatically, for highway administration staff to inform operations for the current and next 24-hour road ice conditions for highways in Montana based on technical panel guidance for highways of interest. The management team can then arrange deicing materials, facilities, and other activities.
2. Drivers can check ice road conditions, when departing or in advance, to decide which route to take and when to depart for better road conditions.

   Part of our implementation plan is to work with MDT staff to customize the IcyRoad interface to integrate its forecast into the existing management framework for effective use in operational management and informing the public. The Implementation Section of the final report will discuss in-depth who and how to use IcyRoad by MDT and other agencies of Montana. We will have the implementation meeting before the end of the project to show the strength and limits of the IcyRoad algorithm and to discuss with MDT staff and the technical panel statewide use of the IcyRoad algorithm.

Public Alerts

3. The IcyRoad mobile app has an alert function, which can alert the user where icy roads occur. As part of this project we will re-design the alert function to give MDT staff authority to update the IcyRoad app when roads are clear. Notice for "clear" roads is not currently available.

Implementation Section of the final report will:

a) Describe the form in which the findings may be implemented, such as a mathematical model, a laboratory test procedure, or a design technique.
b) Identify who would logically be responsible for applying the research results, such as the American Association of State Highway and Transportation Officials (AASHTO), FHWA, MDT, or a particular office within MDT.
c) Identify specific standards or practices that might be affected by the research findings, such as AASHTO or MDT specifications, MDT policies and procedures, legislation, or fiscal requirements.
d) Submit IT component actions needed to integrate IcyRoad into current MDT use.
e) Describe activities necessary for successful implementation of the IcyRoad forecast.
f) Describe the criteria for judging the progress and consequences of implementation.
g) Provide an estimate of the costs of implementation.
h) Identify barriers of implementation and how these barriers might be reduced or eliminated.

As a benefit for research funding and being an early adopter, IcyRoad-pro, a customized, quality improved professional version of IcyRoad that is under development will be provided to MDT implementation use **at a flat fee discount**.

SCHEDULE

Table 1: Project Time Schedule

	Month													
Activities	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
PI and SpringGem meeting at UM or via online	▌													
Kick-off Mtg	▐													
Task 1: RWIS data analysis and algorithm refinement	■	■	■	■	■	■	■							
Task 1: algorithm validation								■	■	■	■			
Task 2: UAV laboratory baseline and data analysis	■	■	■	■	■									
Task 2: UAV and on-site visual validation						■	■	■	■	■	■			
Final Draft Report												■		
Implementation Mtg.													▌	
Final Report													■	■
Final Presentation Webinar and Recommendations														▐
TRnews Article													■	■

*The schedule also contains task reports the end of the month following completion of a task.

BUDGET

Table 2: Detailed Project Budget

Labor Expense										
Person	Role	Kick-Off Meeting	Task 1	Task 2	Total Hours	Hourly Wage Rate	Total Wage	Hourly Benefit Rate	Total Benefits	Total Cost
Fowler	PI	3		160	160	$41.54	$6912	31.5% plus $1054/mon insurance	$3864	$10,775
Running	C-PI	2	10	10	20		0			$0
UM Staff				360	360	$25	$9000	32%	$2,880	$11,880
Total:										$22,655
Direct Expense										
Subcontract SpringGem Weather										$25,900
In State Travel										$2,964
Facility Use Costs for Sub-zero Laboratory $250/day plus staffing, consultation, and training										$3,330
Expendable Supplies (UAV batteries, propellers, and gimbal)										$4,826
Total Direct Costs										$59,675
25% Indirect Costs, only first $25,000 of subawards are charged IDCs										$14,694
Total Project Costs										$74,369

Table 3: SpringGem Subcontract Budget

Labor Expense										
Person	Role	Kick-Off Meeting	Task 1	Task 2	Total Hours	Hourly Wage Rate	Total Wage	Hourly Benefit Rate	Total Benefits	Total Cost
Jin	Subcontract	5	300	100	400	$50	$20000	$9.25	$3,700	$23,700
Total:										$23,700
Direct Expense										
Travel										$2,200
Total Direct Costs										$25,900
0% Indirect Costs										$0
Total Subcontract Costs										$25,900

Table 4: Travel Budget for UM Staff

TRAVEL				
Assumptions		Number	Unit	Total
Rental Car	10 trips for data collection and meetings, 2 people	10	$100	$1000
Meals	Per diem for 2 people	7	$30.50	$427
Lodging	Bozeman June-Sept.*, 1 room, 5 nights	5	$225	$1125
Lodging	Other MT cities*, 1 room 4 nights	4	$103	$412
Total:				$2,964

*Bozeman travel is to the MSU Subzero Lab
*Other MT cities are to field sites and for MDT meetings in Helena.

Table 5: Travel Budget for SpringGem

TRAVEL				
Assumptions		Number	Unit	Total
Airfare	1 trips for 2 person to MDT	2	$350	$700
	1 trip for 1 person to UM	1	$350	$350
Hotel	1 trip for 2 person for 2 nights + 1 trip for 1 person for 2 nights	6	$100	$600
Rental Car	1 trip for UM visit – 3 day	1	$100	$100
Meals	1 trip for 2 person + 1 trip for one person	9	$50	$450
Total				$ 2,200

Table 6: Task, Meeting, and Deliverable Budget

Task, Meeting, and Deliverable Cost Break Out			
Item	Labor ($)	Travel ($)	Total
Meeting: PI and SpringGem Meeting to UM		$800	$800
Task 1	$21,627		$21,627
Task 2	$21,433	$2,497	$23,930
Meeting: Final presentation + Implementation Meeting	$1,000	$1,867	$2,867
Deliverable Final Report	$1,000		$1000
Deliverable Implementation Report	$1,000		$1000
TOTAL	$46,060	$5,164	$51,224

Table 7: State Fiscal Year Budget

Item	State Fiscal Year 2021	Total
Salaries	$15,912	$15,912
Benefits	$6,744	$6,744
In-State Travel	$2,964	$2964
Expendable Supplies	$4,826	$4,826
Facility Cost	$3,330	$3,330
Subcontractor	$25,900	$25,900
Indirect Costs	$14,694	$14,694
Total Project Costs	$74,369	$74,369

Table 8: Supplies Budget

Item	Cost
UAV Batteries $250 each and 6 total needed	$1500
Gimbal for hyperspectral camera	$2700
UAV propellers $86 each and 6 total needed	$510
Cables and wire to attach payload to platform	$116
Total Project Costs	$4826

STAFFING

Table 9: Staffing

Name of PI, Staff, and Consultant	Role of Study	Task			Percentage time vs total project hours (total time/person/total project hours)	Percentage of time Total Annual Basis (total hr/person/2080hr)
		1	2	Total		
Fowler	PI & Lead Task 2		160	160	17%	14%
Jin	Subcontractor and Lead Task 1	300	100	400	43%	19%
Running	Consultant		10	20	2%	1%
Bauer	Technical staff for Task 2		360	360	38%	17%

Background Information:

Fowler: Jennifer Fowler has extensive experience as principle investigator involving field work with continuous funding since 2006. In particular she has been working with in-situ and remote sensing platforms. UAVs have been a focus area since 2014 along with forecasting applications of the Weather Research and Forecasting (WRF) model. Fowler is a private pilot as well as an FAA certified remote pilot and has written numerous FAA certificates of authorization for the University of Montana. As a result of her work she has collaborated with federal agencies and private companies to developed and implement standard operating procedures and workflows for data collection and implementation into operations.

Jin: Dr. Jin has a Ph.D. in Atmospheric Science with minor in Management of Information System (MIS). With intensive knowledge and experience on both climate modeling and data management, Jin has had funding as a PI from NASA, NSF, DoD, and the state of Maryland on land surface weather forecast related topics. Previously a teaching faculty in San Jose, CA, Jin is now a faculty entrepreneur and has led the company to finish an NSF regional and national I-Corps training project, Maryland Innovation Initiative (MII) Phase 1 project, and NASA-related projects. Jin is also leading an NSF SBIR project on implementing weather information into the US transportation industry.

Running: Steve Running has taught at the University of Montana since 1979 and is an internationally recognized scholar in satellite-remote sensing data, global vegetation productivity, climate change and more. Dr. Running was appointed to the NASA Advisory Council Science Committee and chair of the Earth Science subcommittee within that council. Running's longstanding involvement in research led to him being a team member of the NASA Earth Observing System, a member of the National Oceanic and Atmospheric

Administration Science Advisory Board Climate Working Group, and chapter lead author for the Nobel Prize-winning 2007 Assessment of the Intergovernmental Panel on Climate Change.

Bauer: Bart Bauer has been the lead pilot for UM's Autonomous Aerial Systems Office for two years and has acquired deep experience integrating new sensors onto UAV platforms. He is an FAA certified remote pilot. He has worked closely with Fowler in developing and implementing standard operating procedures and workflows for data collection and implementation into operations. In addition to Bauer's bachelor's degree from UM, he has a certificate in Geographic Information Systems (GIS) Sciences and Technologies that gives him the knowledge, understanding and training necessary to acquire, process, analyze and properly display digital geographic data such as the data from the hyperspectral camera.

Current Commitments:

Fowler is on a split appointment between the University of Montana (.55 FTE) and Montana State University (.4 FTE). Current commitments under UM are PI for a US Forest Service Grant ending June 30th, 2020 accounting for 40% of her UM time and PI for a National Science Foundation grant ending May 31st, 2020 accounting for 1% of her time. Under this proposal Fowler will commit 14% of her UM time.

Jin is fully employed by SpringGem Weather Information. Her time includes 6 months on an NSF project, 3 months for a private-funded project, and 2.5 months for this project.

Running is Professor Emeritus of Ecosystem and Conservation Sciences with no current commitments at the University of Montana other than what is listed for this proposal of 1%.

Bauer has a .5 FTE commitment with the University of Montana in the Autonomous Aerial Systems Office. Under his UM position Bauer currently has 10% of his time committed to a project with a private company. For this proposal he will commit 17% of his time.

The level of effort proposed for principal and professional members of the research team will not be changed without written consent of MDT.

FACILITIES

SpringGem

The IcyRoad system uses an online cloud computing platform, The DigitalOcean. The DigitalOcean Cloud is a corporate-computing service (https://cloud.digitalocean.com). This Cloud Platform lets users build, deploy, and scale applications, websites, and services on the same infrastructure. It provides Big Query and Cloud Storage, among other functions. Big Query is required to interactively analyze massive datasets up to billions of rows in seconds in a fully managed system with no services to install or maintain. The service further combines the performance and scalability of Digital-Ocean Cloud with advanced security and sharing capabilities. In addition, DigitalOcean Cloud offers a web-based interface for managing user's storage, an open source command line tool and library, and advanced features resemble uploads, integration with App Engine, and international storage functionality. An online database is also provided in DigitalOcean for users to develop index tables for specific regions of road, such as bridges, north-slope of hills, and elevated terrain, so that the forecast algorithm can quickly access the needed adjustments for such locations.

Autonomous Aerial Systems Office at the University of Montana

The Autonomous Aerial Systems Office (AASO) is a fully equipped 900 square foot facility with a broad range of electronic test equipment, atmospheric measuring instrumentation, an unmanned aircraft systems (UAS) fleet and computational facilities. A variety of UAS platforms (both fixed and rotary aircraft) can be provided by this facility as well as a range of sensors. For this project we will be using the Resnon Pika L hyperspectral camera on a rotary aircraft. This office is staffed by personnel who are certified FAA remote pilots. Atmospheric instrumentation includes one GSU Graw mobile radiosonde station, four handheld mobile radiosonde stations for training, Lufft WS502 UMB surface station, and three Montana Mesonet Stations/Decagon ATMOS-41 MicroEnvironment Monitors. Additionally, this office will provide any FAA certificates of authorization or waivers for all flights and maintain operational authority for the flights.

REFERENCES

- Abdellatif, M., Peel, H., Cohn, A., Fuentes, R., 2019: Hyperspectral Imaging for Autonomous Inspection of Roads Pavement Defects, Pages 384-392 (2019 Proceedings of the 36th ISARC, Banff, Alberta, Canada)
- Associated Press Great Falls Tribune, 2018: Icy roads lead to semi crashes in western Montana, 2 killed, Retrieved from https://www.greatfallstribune.com/story/news/2018/12/19/icy-roads-lead-semi-crashes-western-montana-2-killed/2369878002/
- Atlanta Regional Commission. 2014 Transportation Factbook. Atlanta, GA: ARC, 2014. PDF.
- Black, A. W. and T. L. Mote, 2015: Characteristics of Winter-Precipitation-Related Transportation Fatalities in the United States. Weather, Climate, and Society, 7, 133-145.
- Bouilloud, Ludovic, et al. 2009: Road surface condition forecasting in France. Journal of Applied Meteorology and Climatology 48.12: 2513-2527.
- Call, David A. 2010: Changes in ice storm impacts over time: 1886-2000. Weather, Climate, and Society 2.1, 23-35.
- Chapman, L., et al, 2008: Modelling of rail surface temperatures: a preliminary study. Theoretical and Applied Climatology, 92.1-2: 121-131.
- Gohil, K and M. Jin, 2019: Validation and Improvement of WRF Building Energy Parameterization Scheme. Published in Climate 2019, 7(9), 109; https://doi.org/10.3390/cli7090109
- Graham, T, 2018: Montana Highway Patrol sees spike in winter crashes. NBC Montana Retrieved from https://nbcmontana.com/news/local/montana-highway-patrol-sees-spike-in-winter-crashes
- Ewan, L. and A. Al-Kaisy, 2017: Assessment of Montana Road Weather Information System (RWIS). A report to MDT https://www.mdt.mt.gov/research/projects/rwis.shtml
- Harris, Kelly, 2018: An analysis of Atlanta road surface temperature for improving urban transit. master thesis, supervised by J. M. Shepherd, 2018.
- Hall et al. 2002 MODIS snow map ATBD
- Jin, M. and R. E. Dickinson, 1999: Interpolation of surface radiation temperature measured from polar orbiting satellites to a diurnal cycle. Part 1: Without Clouds. Journal of Geophysical Research, 104, 2105-2116.
- Jin, M. and R. E. Dickinson 2000: A Generalized algorithm for retrieving cloudy sky skin temperature from satellite thermal infrared radiances. Journal of Geophysical Research, D22, 27,037-27,047
- Jin, M, R. E. Dickinson, and D. L. Zhang, 2005a: The footprint of urban areas on global climate as char-acterized by MODIS. J. Climate, 18, 1551-1565.
- Jin, M., J. M. Shepherd, M. D. King, 2005b: Urban aerosols and their interaction with clouds and rainfall: A case study for New York and Houston. J. Geophysical Research, 110, D10S20, doi:10.1029/2004JD005081.
- Jin, M., and J. M. Shepherd, 2008: Aerosol relationships to warm season clouds and rainfall at monthly scales over East China: Urban-land vs. ocean. J. Geophys. Res., 113, D24S90, doi:10:1029/2008JD010276.

- Jin, M. 2012: Developing an Index to Measure Urban Heat Island Effect Using Satellite Land Skin Temperature and Land Cover Observations. J. of Climate. vol 25, 6193-6201.
- Jin, M, T. Mullens, and H. Bartholomew, 2014: Evaluate CLM skin temperature and soil moisture simulation using ARM ground observation. Climate 20, 2. Paper accessible at http://www.mdpi.com/2225-1154/2/4/279
- Johnson, B., and M. Shepherd, 2018: An analysis of Atlanta road surface temperature for improving urban transit, https://www.sciencedirect.com/science/article/pii/S2212095518300853
- Jonsson, P., J. Casselgren, and B. Thörnberg, 2015: Road surface status classification using spectral analysis of NIR camera images IEEE Sensors Journal, Volume: 15 , Issue: 3, pages 1641 – 1656.
- Kashfi, Syeed Anta, and Jonathan Bunker, 2015: Adverse weather effects on bus ridership. 44.
- King, M. D., S. Platnick, P. Yang, G. T. Arnold, M. A. Gray, J. C. Riedi, S. A. Ackerman, and K. N. Liou, 2004: Remote sensing of liquid water and ice cloud optical thickness and effective radius in the arctic:
- Application of airborne multispectral MAS data. J. Atmos. Oceanic Technol., 21, 857–875.
- Koetse, Mark J., and Piet Rietveld, 2009: The impact of climate change and weather on transport: An overview of empirical findings. Transportation Research Part D: Transport and Environment 14.3: 205-221.
- Riehm, M. (2012). Measurements for winter road maintenance (PhD dissertation). Stockholm. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-105152
- Riehm, Mats, et al. "Ice formation detection on road surfaces using infrared thermometry." Cold Regions Science and Technology 83 (2012): 71-76.
- Nakajima, T., and M. D. King, 2003: Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. Part I: Theory. J. Atmos. Sci., 47, 1878-1893.
- Shishegarana, A., F. Daneshpajohb, H. Taghavizadec, and S. Mirvaladd, 2020: Developing conductive concrete containing wire rope and steel powder wastes for route deicing. Construction and Building Materials, Volume 232, 117184.
- Thornes, J., 2000: PERFORMANCE AUDIT METHOD FOR WINTER MAINTENANCE, School of Geography and Environmental Sciences, University of Birmingham, UK http://people.cs.ksu.edu/~weihe/RoadWeather/References/Thornes_1_PAM%20WinterMaintenance.pdf
- Yu, H., Z. Li, G. Zhang, and P. Liu, 2019: A latent class approach for driver injury severity analysis in highway single vehicle crash considering unobserved heterogeneity and temporal influence. Analytic Methods in Accident Research, Volume 24, Article 100110.
- Zebra Insurance, 2020: Winter Driving Statistics in 2020, https://www.thezebra.com/winter-driving-statistics/
- Zhang, D-L, Jin, M., Y, Shao, C. Dong, and D. Zhang, 2019: The Influences of Urban Building Complexes on the Ambient Winds over the Washington-Baltimore Corridor. Journal of Applied Meteorology and Climatology. https://doi.org/10.1175/JAMC-D-19-0037.1