COMPARING BRIDGE AND ROAD SURFACE TEMPERATURES DURING THE WINTER SEASON IN OHIO

Seth Guidry[1], Daniel Tripp[2], Mike Baldwin[2], Andrew Rosenow[2]

[1]National Weather Center Research Experiences for Undergraduates Program
Norman, Oklahoma
[2]OU Cooperative Institute for Severe and High-Impact Weather Research and Operations and NOAA/OAR/National Severe Storms Laboratory
Norman, Oklahoma

ABSTRACT

Unfavorable road conditions due to winter weather have major impacts throughout the United States. Though transportation agencies take measures to prevent freezing precipitation from accumulating on highways, one critical challenge is knowing when road surfaces are sub-freezing. With this motivation, the National Severe Storms Laboratory (NSSL) created a probabilistic model that predicts the likelihood of sub-freezing roads within the U.S. However, one major caveat of this model is that it does not differentiate between road and bridge surfaces, and bridges are commonly known to ice before roads do. This study investigates how road and bridge surface temperatures differ throughout the 2022-2023 winter season using hourly road sensor observations from Road Weather Information System (RWIS) stations in Ohio. Air temperature readings from RWIS towers are used to compare how bridge and road surface temperatures behave in cold environments. Results suggest that roads are typically warmer than bridges when both surface temperatures are below/near freezing. Additionally, if only one surface is below freezing, it is most likely to be the bridge rather than the road. Differences between air and surface temperatures also provide some evidence that suggests surface temperatures on bridges act differently than surface temperatures on roads. However, in environments near freezing (0 deg C), both road and bridge surfaces are typically 1-3°C warmer than the air temperature. Since roads and bridges behave similarly near 0°C, this suggests that a separate model for bridges may not be necessary as these small deviations will unlikely result in significant changes to the probabilistic output of the model.

1. INTRODUCTION

Adverse road conditions cause a multitude of issues when traveling, with notable threats including congestion along major highways and billions of dollars in damages throughout the United States (Tobin et al. 2019; Walker et al. 2018). Winter weather is one of the leading causes for inclement road weather. When subfreezing road temperatures combine with accumulation of ice and snow, this leads to slippery situations for unsuspecting drivers (Handler et al. 2020). Vehicular accidents due to winter weather are responsible for more fatalities in the U.S. than any other weather-related disaster, with a yearly average fatality rate exceeding 800 between the years of 1996-2011 (Black & Mote 2015).

Transportation agencies combat these issues by implementing preventative measures such as adding salt and other deicing chemicals to impede any precipitation from freezing on highways. While these measures have merit, an important hurdle for road safety is determining when road surface temperatures drop below freezing. It's also important to understand how different road surfaces behave amid freezing environments. With this motivation, previous studies have investigated the surface temperature on roads, as well as different kinds of roads such as bridges and tunnels. (Bouilloud et al. 2009; Yun et al. 2014; Boyd and Phillips 2016).

In 2020, the National Severe Storms Laboratory (NSSL) created a model based on machine learning that gives a probabilistic nowcast of subfreezing road-surface temperatures. Known as the Probability of Subfreezing Roads (ProbSR), the model generates a probability field that indicates which areas across the United States are more likely to experience subfreezing road temperatures (Handler et al. 2020). One of the primary objectives of ProbSR is to provide accurate road weather information to help the National Weather Service communicate hazardous conditions during winter-weather events.

[11]*Corresponding author address:* Seth Guidry, OU CAPS, 120 David L. Boren Blvd, Suite 2500, Norman, Oklahoma, 73072
Email: sguidry1@cub.uca.edu

One limitation with ProbSR is that it doesn't discriminate between different kinds of roads. Given that bridges are known to freeze quicker than roads because there is no ground insulation underneath bridges, one could question if ProbSR accurately represents bridge temperatures. This study investigates the differences in how surface temperatures change between bridges and roads by using surface temperature data collected during the 2022-2023 winter season. This data is used to find defining characteristics that may add value into differentiating between bridges and roads. The goal is to use this information to determine whether a separate ProbSR model for bridges is necessary. Section 2 describes the data and methods used in this study, section 3 presents the results of the analysis, and section 4 provides the discussion and conclusions of the study.

2. DATA & METHODS

All data collected for this study comes from the Road Weather Information System (RWIS). These RWIS networks are used to collect current weather data such as air temperature, road conditions, road surface temperature, and many other environmental variables (Manfredi et al. 2008). These stations consist of a small weather tower along with one or more pavement sensors in the road. Not only does RWIS provide important road safety information, but the data collected can be used by agencies like the National Weather Service (NWS) to develop weather-related tools and execute forecast verification studies (Manfredi et al. 2008).

There are a few limitations within the RWIS data archive. For starters, not every state has RWIS networks. In fact, there are many states in the southern U.S. that do not have these stations at all. There is also an immense spatial variability within states that do have RWIS networks. For example, Handler et al. (2020) found that RWIS stations in Missouri only cover interstates 44 and 70. On the contrary, Ohio has a broad distribution of RWIS stations with many on primary, secondary, and tertiary highways within the state. For that reason, this study will focus on the Ohio RWIS network since the stations are well-dispersed throughout the state and there are comprehensive resources from the Ohio Department of Transportation that report their data.

The location of each RWIS station is identified using latitude and longitude coordinates provided through the Mesowest website. This website provides the station ID and surface temperature readings for each RWIS station located through the road weather map product. Mesowest has a large archive of past surface temperatures, and the site allows the public to view this information at any time. All data analyzed in this study spans the 2022-2023 winter season, which is defined here as October 1st, 2022 to March 31st, 2023. Furthermore, 17 RWIS stations with both road and bridge sensors were selected to provide a direct comparison for the study (Figure 1).

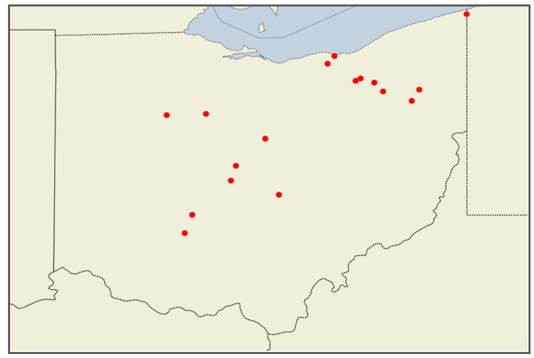

FIG 1. Map of all 17 RWIS stations used in the analysis for this study.

It is important to connect each station's data to a specific sensor's location, keeping in mind that several sensors may report to the same station. Unfortunately, the sensor's location data available from MesoWest does not include information regarding road type, and there is no simple way to identify if sensors are located on bridges. The first objective of this study focused on manually identifying sensors on bridges using multiple online resources. There is a web resource called Buckeye Traffic, which is run by the Ohio Department of Transportation. This website contains the location of each sensor associated with each station along with certain nomenclature that can help identify the road type. Sensors with descriptions such as "bridgedeck" or "bridge" provide good indicators that the sensor is located on a bridge. Using the station's location, the sensors' location and road type can be matched to the surface temperature data from MesoWest for the analysis presented in Section 3.

Once the bridge identification process is complete, the next step is to compare both the road and bridge surface temperature information throughout the entire 2022-2023 winter season. The goal is to locate certain trends within the data that differentiate between road and bridge surface temperatures. For example, looking at differences between road and bridge temperatures can show how often one surface is relatively warmer than the other. The RWIS stations also provide air temperature, wind speed, elevation, and other variables conducive to this study, and the intent is to investigate the differences in road and bridge temperatures based on the surrounding environment.

3. RESULTS

The analysis begins by comparing road and bridge surface temperatures directly by subtracting their values (road minus bridge). There are 44,252 measurements of surface temperature difference within the data set. Positive values indicate that the road surface is warmer than the bridge surface. If the values are negative, this means that the bridge is warmer than the road. Figure 2 shows the frequency of surface temperature difference values within the data set. A majority of the values are positive (lie to the right of the black line), with a mean value of 0.996540 (~1.0) deg C and a median at exactly 1.0 deg C. This indicates that during the 2022-2023 winter season in Ohio, roads are more often warmer than bridges. Though it is important to note, the largest concentration of surface temperature difference values are found between 0.0 and 2.5 deg C. These small differences suggest that bridges are most often only slightly warmer than bridges during winter time.

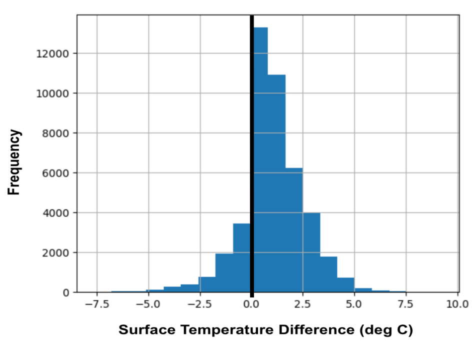

FIG 2. Histogram of the frequency of road and bridge surface temperature differences (calculated as road temperature minus bridge temperature) throughout the winter season. The black line indicates where the bridge and road surface temperatures are equal.

Both bridge and road surface temperatures are also compared directly using the scatter plot in Figure 3. A one-to-one trend line was applied to show how the values skew along the plot. When both surface temperatures are below 0 deg C, the points skew below the one-to-one trendline, which suggests that roads are more often warmer than bridges at sub-freezing temperatures. As the surface temperatures increase above 0 deg C, the points are more evenly distributed around the one-to-one line, which suggests that there is a less systematic difference between road and bridge surface temperatures.

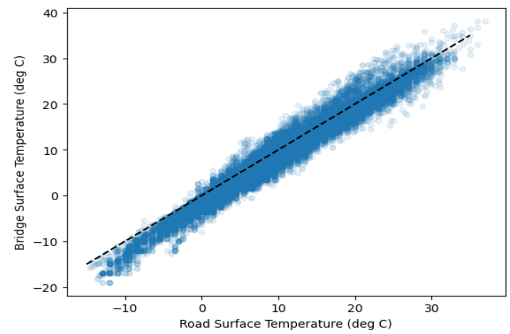

FIG 3. Scatterplot showing a comparison between road and bridge surface temperatures. The black dashed line is a one-to-one line marking where road and bridge temperatures would be equal.

Of the observations that contained both bridge and road temperature sets, this study counts the frequency in which road and/or bridge surface temperatures are above and/or below freezing as shown in the contingency table in Figure 4. The data shows a vast majority of the cases (85.7%) have both the bridge and road above freezing. However, the more interesting cases are where either or both surface temperatures are below freezing (the highlighted boxes in Figure 4). Of the 6,310 cases within these parameters, 63.0% (3,971) of the cases are where both bridge and road surfaces are below freezing, 36.7% (2,317) of the cases are where only the bridge is below freezing, and 0.3% (22) of the cases are where only the road is below freezing. Therefore, if only one surface is below freezing, it is more likely to be the bridge rather than the road, which is consistent with previous studies.

	Bridge Surface Temperature	
Road Surface Temperature	T_{sfc} < 0°C	T_{sfc} ≥ 0°C
T_{sfc} < 0°C	**3971**	**22**
T_{sfc} ≥ 0°C	**2317**	**37942**

FIG 4. Contingency table showing the frequency that road and bridge surface temperatures are above and/or below freezing. The inner box values show the frequency of conditions characterized by both road and bridge surface temperatures. The blue boxes highlight cases where either or both surface temperatures are sub-freezing.

The previous analysis is repeated while the temperature sets are categorized according to various characteristics in order to discern confounding variables that may be influencing road and bridge surface temperatures. Though the time of day and month of year impact the amount of sunlight received at a specific location, neither of these variables produced road or bridge temperature trends that differed from that of the overall distribution. Additionally, the latitude of each RWIS station is considered as a potential delimiter of underlying distributions given that stations residing farther north could be primarily associated with colder observations. The latitude, however, did not have a significant impact on the resulting temperature differences between bridges and roads. Predicted surface temperatures from the High-Resolution Rapid Refresh (HRRR) model are also examined alongside the road/bridge temperature observations, though there are not any notable differences to report. Finally, a statistical analysis of average road/bridge surface temperatures is performed to determine if skewness or kurtosis provided any information about contrasting behaviors of bridges and roads. Once again, this analysis did not find any significant trends that suggest road and bridge surface temperatures are drastically different from each other.

Finally, this study investigates how bridge and road temperatures behave separately as a function of air temperature. The boxplots in Figure 5 show the relationship between bridge/air temperature differences and air temperature. The plot in Figure 6 repeats the format of Figure 5, but for road/air temperature differences. For air temperatures falling in the range of -15–15 deg C, the medians of bridge/air temperature difference hover consistently around 2.5 deg C with very little deviation. However, for the same air temperature range, Figure 6 indicates that the medians of road/air temperature differences decrease as air temperatures increase. With an air temperature of -15 deg C, the median difference in road/air temperature lies at 5 deg C. Comparatively, at an air temperature of 15 deg C, the median road/air temperature difference drops to around 2.5 deg C, where it remains static at higher temperatures. Together, Figures 5 and 6 show different trends between road/air and bridge/air surface temperature differences.

Although air temperatures provide some insight into finding characteristics that distinguish between road and bridge temperatures, the most critical condition for significant ice accumulations is when the air temperature is near freezing (0 deg C). According to the distribution of temperature differences associated with the 0 deg C air temperature in Figures 5 and 6, the medians of both bridge/air temperature difference (2.4 deg C) and road/air temperature difference (3.0 deg C) are within a degree of each other. For ProbSR, this small difference likely has little effect on the probabilistic output. Though, this impact to ProbSR was not tested in this study and is motivation for future work. If ProbSR generated a deterministic prediction, then the difference could have a bigger impact. Therefore, despite the contrasting air temperature trends between road and bridge surface temperatures, whether or not a bridge ProbSR model is needed remains inconclusive.

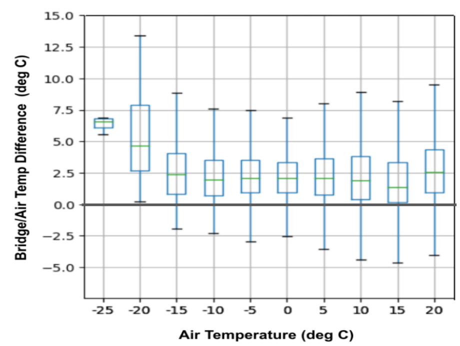

FIG 5. Boxplots showing the variance in bridge surface temperature and ambient air temperature. The differences are put into air temperature categories in intervals of 5-degree Celsius. The green lines show the medians of each category. The black line highlights where the bridge and air temperatures are equal.

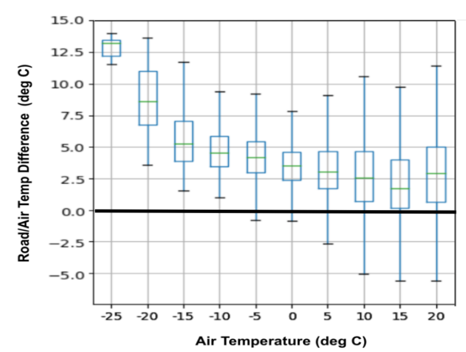

FIG 6. Boxplots showing the variance in road surface temperature and ambient air temperature. The differences are put into air temperature categories in intervals of 5-degree Celsius. The green lines show the medians of each category. The black line highlights where the road and air temperatures are equal.

4. SUMMARY & CONCLUSION

The purpose of this study was to investigate how bridge and road sensor measurements behave in below/near freezing environments. Previous studies have found that bridges can freeze before roads because bridges have an increased exposure to cold air temperatures, whereas roads have extra heat insulation from the ground. The NSSL developed ProbSR – a model that accurately and efficiently predicts if road temperatures are sub-freezing (Handler et al. 2020).

This study investigates if ProbSR accurately predicts bridge surface temperatures by collecting data from 17 RWIS stations across Ohio and making comparisons between road and bridge sensor temperature readings.

Both surface temperatures were compared by subtracting bridge surface temperatures from road surface temperatures. Results showed that when both surface temperatures are below/near freezing, the road surface is more likely to be warmer than the bridge surface. At warmer surface temperatures, there is little to no systematic difference between road and bridge surface temperatures. In addition, sensor observations were categorized by above/below freezing temperature conditions to tabulate the frequency in which one or both surfaces are below freezing. Observations showed that in the event that at least one surface is below freezing, 36.7% of these instances occur when only the bridge is below freezing, compared to only 0.3% of the cases in which only the road is below freezing.

Air temperature data from RWIS towers were also considered in the study to find contrasting trends in how bridge and road sensor data correlate with air temperature. It is important to uncover differences between road and bridge temperatures at air temperatures near freezing (-15–15 deg C) because this range provides prime conditions for freezing precipitation such as sleet and freezing rain. To accomplish this analysis, the air temperature data was subtracted from both road and bridge temperatures, and these differences were compared as a function of air temperature. Results found that in near freezing air temperatures, bridge/air temperature differences remain constant, while road/air temperature differences decrease as the air temperature increases. Though these trends might be true, when air temperatures are at freezing, the median bridge/air and road/air temperature differences are likely too small to make any notable difference in the ProbSR output.

In summary, more research is needed to make a confident decision on whether or not a separate ProbSR model for bridge surface temperatures is needed. In the future, looking at other RWIS networks around the U.S., examining data from other winter seasons, and finding more bridge sensor data may help gain further confidence in the importance of a bridge ProbSR model. In addition, other variables such as elevation, wind speed, and dew point could also point research in the right direction to find a more drastic difference in road and bridge surface temperature behaviors.

5. ACKNOWLEDGMENTS

The corresponding author would like to acknowledge Alex Marmo and Daphne LaDue for the opportunity of being a participant in the Real-World Research Experience for Undergraduates Program at the National Weather Center. The corresponding author would also like to thank Allison Brannan for assisting in writing this paper. This work was prepared by the authors with funding provided by National Science Foundation Grant No. AGS-2050267, and NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA11OAR4320072, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, NOAA, or the U.S. Department of Commerce.

6. DATA AVAILABILITY

All RWIS information in this study including latitude/longitude and surface/air temperatures was collected through the MesoWest website: https://mesowest.utah.edu/cgi-bin/droman/mesomap.cgi?state=OH&rawsflag=3 [Accessed June 1, 2023]

The nomenclature used for the bridge identification process was found through the Ohio Department of Transportation website: https://www.buckeyetraffic.org/reporting/RWIS/results.aspx [Accessed June 1, 2023]

7. REFERENCES

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, https://doi.org/10.1175/WCAS-D-14-00011.1.

Bouilloud, L., and Coauthors, 2009: Road Surface Condition Forecasting in France. *Journal of Applied Meteorology and Climatology*, 48, 2513–2527, https://doi.org/10.1175/2009JAMC1900.1.

Boyd, P., and W. Phillips, 2016: Predicting Surface Temperatures of Roads: Utilizing a Decaying Average in Forecasting. *JPUR*, 6, 9–15, https://doi.org/10.5703/1288284316160.

Handler, S. L., H. D. Reeves, and A. McGovern, 2020: Development of a Probabilistic Subfreezing Road Temperature Nowcast and Forecast Using Machine Learning. *Weather and Forecasting*, 35, 1845–1863, https://doi.org/10.1175/WAF-D-19-0159.1.

Manfredi, J., and Coauthors, 2008: *Road weather information system environmental sensor station siting guide, version 2.0*. https://rosap.ntl.bts.gov/view/dot/3290 (Accessed June 15, 2023).

Tobin, D. M., M. R. Kumjian, and A. W. Black, 2019: Characteristics of Recent Vehicle-Related Fatalities during Active Precipitation in the United States. *Weather, Climate, and Society*, 11, 935–952, https://doi.org/10.1175/WCAS-D-18-0110.1.

Walker, C. L., 2018: Developing a Winter Severity Index to Improve Safety and Mobility. 98th American Meteorological Society Annual Meeting, AMS https://ams.confex.com/ams/98Annual/webprogram/Paper325395.html (Accessed June 21, 2023).

Yun, D., J. Park, and J. Sung, 2014: MEASUREMENT OF ROAD SURFACE TEMPERATURE USING THERMAL MAPPING SYSTEM.URL: https://proceedings-andorra2014.piarc.org/content/actes/185_eng.pdf (Accessed 28 July 2023)