ROAD PAVEMENT TEMPERATURES AND THEIR IMPACT ON TRAVEL DURING SNOW STORMS

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1. INTRODUCTION

The National Weather Service issues a variety of products such as snow advisories and heavy snow warnings to raise awareness of upcoming public impact events. Except for instances of blowing snow, the issuance of these products is totally based on snowfall amount. For example, for parts of Montana a heavy snow warning is issued if at least 15 cm of snow is expected in a 12-hour period, with a snow advisory issued for lesser amounts. Generally, the greater the snowfall the higher the impact to the public will be, but there are situations where additional factors can modify the effects of a given storm. One of these factors is often wind, and this is typically well addressed by NWS forecasts and warnings (e.g. Blizzard Warnings, Snow and Blowing Snow Advisories). Another modifying factor is the road pavement temperatures, which can amplify or minimize the impact snowfall has on traveling conditions.

In recent years, the state's Departments of Transportation (DOT) have deployed roadside weather sensors to assist their operations, which are often provided on the Internet for real-time use. These DOT sensors measure various aspects of the road surface itself, in addition to air temperature, dew point, and wind. At some sites, this may be no more than a sensor that measures the temperature of the pavement surface. Other sites may have more sophisticated equipment that can measure road moisture state (i.e. dry, wet, icy, etc) and sub-surface temperature, in addition to pavement temperature. While forecasters often make use of "standard" observations from the DOT (e.g. air temperature, dew point, and wind), the road surface sensors typically receive less attention from NWS forecasters.

NWS meteorologists have used basic knowledge of pavement temperatures in the past and provided forecast detail such as "snow accumulation mainly on grassy surfaces." This was typically employed during fall or spring events when the sun angle is high and relatively warm ground (including road) temperatures would melt any snowfall. By doing this, the forecasters were attempting to downplay the public impact of the snowfall. However, there are instances where the road temperatures can actually heighten the impact that a snowfall event has on the traveling public. Such events are often not incorporated into NWS forecasts and warnings.

To gain a better understanding on how road temperatures play a role on travel during snow events, light snowfall events from fall 2006 through winter 2007 in Billings, MT, in Eastern Washington, and North Idaho were analyzed. The analysis focused on snow events with 5 to 10 cm of snow falling in 12 to 24 hours, with snowfall rates generally less than 1 cm h⁻¹. This was done so that the study would focus on events that typically receive less attention than larger snowstorms and are often considered to have a lower impact. In addition, only snowfall events in which the snow started on a day or night and continued to at least midnight that night were considered. The snow events also had to start on a Sunday, Monday, Tuesday, Wednesday, or Thursday day or night. This way, the impact a nighttime snow has on the week day morning commute could be analyzed. This paper will present accident statistics for cases matching the aforementioned criteria. Four light snowfall events will also be presented to describe the specific impacts on travel for each event.

2. DATA AND ANALYSIS

Accident statistics for Billings MT, a metro area with a population around 100,000, were acquired from the Montana State Highway Safety Bureau. Since there is more than a 90 day lag in the availability

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Table 1. Billings, MT accident reports for (a) entire month of January 2007 and (b) the period of 9-13 January 2007.

Table 1A. 1-31 January 2007 Billings, MT Accidents Reports								
Time (LT)	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
0600	0	0	0	1	0	2	2	
0700	4	3	1	2	5	3	1	
0800	1	2	0	4	3	2	0	
0900	2	0	1	0	8	1	0	
Total	7	5	2	7	16	8	3	

Table 1B. 9-13 January 2007 Billings, MT Accidents Reports							
Time (LT)	Tue Jan 09	Wed Jan 10	Thu Jan 11	Fri Jan 12	Sat Jan 13		
0600	0	0	0	0	0		
0700	0	0	0	5	2		
0800	0	0	0	2	0		
0900	1	1	0	1	1		
Total	1	1	0	8	3		

of the data, only snow events from October 2006 through January 2007 could be considered at the time this paper was written. Accident statistics for the Coeur d'Alene, ID area were obtained from the Idaho Transportation Department. Since the October 2006 to January 2007 statistics were not yet available, data from October 2005 to January 2006 were used for the long-term averages.

These statistics consist of the total number of accidents for each month and each day of the week and sorted by hour. In addition, the total number of accidents by day and hour were acquired for the individual events. An example of this data for 0600 through 0900 Local Time (LT) is provided in Tables 1A and 1B. Βv gathering data in both ways, the total number of accidents occurring during a snow event was known as well as how the number of accidents during a snow event relates to that particular day of the week and In addition accidents statistics for month. the morning rush commute (defined here as 0600 to 1000 LT) could be known and allow the study to focus on times of heaviest traffic.

The snowfall events were identified and analyzed through a few surface observations in Billings, MT including the METAR at the Billings Logan International

Airport (KBIL) and Montana Department of Transportation sensor on Interstate 90 near the Yellowstone Bridge (MYRB). KBIL along with NWS WSR-88D radar was used to identify the snow events including snow rates in addition to air temperature, wind, MYRB provided and dew point. temperature, wind, dew point, and precipitation data as well. However, MYRB also provided sub-surface temperature along with surface road temperatures for the eastbound lanes on Yellowstone Bridge and also westbound lanes a few hundred feet east of Yellowstone Bridge. Maps of Billings including the location of these observation sensors are provided in Figs. 1 and 2.

3. SURFACE FLUX CONSIDERATIONS

An attempt to consider effects of road temperature on a snowfall event requires a basic understanding of the general energy budget that affects pavement temperature. Previous studies focused on aspects such as accumulation of ice on bridges (Suzuki, et al. 2007) as well as overall heat balance equations (Jansson, et al. 2006) for road surfaces. The Finnish (personal Meteorological Institute communication) has been conducting sophisticated research into а onedimensional Road Weather Model, which



Fig 1. Map of Billings, MT area showing the location of the roadside sensor (MYRB) used in this study. The location of the Billings ASOS (KBIL) and National Weather Service Office, where surface observations are also taken, are also shown.



Fig 2. Map of Yellowstone Bridge and location of atmospheric and road sensors.

accounts for atmospheric and sub-surface forcing on the pavement temperature. While the complexity of these studies is likely beyond what operational weather forecasters can be expected to account for, there are still some basic concepts that most forecasters will already be familiar with.

The most obvious forcing for pavement temperature are incoming short-wave solar radiation and outgoing long-wave radiation. During the day, the pavement receives short-wave solar radiation, which varies depending on the angle (i.e., time of day, year, and latitude) as well as cloud cover. Long-wave radiation back to the atmosphere is unable to offset the incoming short-wave energy during the middle of the day, and as a result the pavement warms. This warming can be rather significant during the winter, as the case studies will show. At the same time, there are heat fluxes that vary depending on the temperature difference between the air, the pavement, and the sub-The heat flux will be surface ground. directed from warm to cold. Thus, while the road is warming during the day, it will transfer sensible heat to the air and ground if they are cooler than the pavement. At night, the process is often reversed. The continuation of long-wave radiation and absence of solar radiation results in a cooling of the pavement. If the air or ground is warmer than the pavement, the heat fluxes reverse to warm the road. An additional and potentially important factor is the latent heat flux. As precipitation accumulates on the road surface, heat from the pavement is required to melt snow or to evaporate rain. This also results in loss of heat and cooling of the road surface.

These processes are well understood by operational weather forecasters and can be accounted for in the decision-making process. Additional effects such as traffic patterns or road treatments are beyond the scope of the operational forecaster and won't be considered.

4. ACCIDENT STATISTICS

Six Billings, MT light snow events meeting the criteria defined above were identified. These snow events were divided into three types based on road temperature tendencies; Type 1) Snow falls while road surface temperature remain at or above 0°C (hereafter referred to as All-Above), Type 2) Snow falls while road surface temperatures remain below 0°C (All-Below), and Type 3) Snow falls as road temperatures fall from above 0°C to below 0°C (Above-To-Below). Three Above-To-Below snowfall events, two All-Below events and one All-Above event were observed.

The number of accidents reported during the morning rush, is sharply higher in Above-To-Below events compared to All-Above and All-Below events, as can be seen in Table 2. In two of the Above-To-Below cases, nearly 25% of all weekday morning rush hour commutes for the month occurred on that one day. Meanwhile, the accident percentages for All-Above and All-Below events were similar to the average number of accidents for any given weekday in the While the number of cases is month. limited, this small data set suggests that Above-To-Below snowfall events may have a significant impact on travel while the others may not.

Bilings, MT Snow Events meeting criteria for analysis						
Morning	Approximate	Approximate	Snow	Road Temp.	% of 6-10AM	
Commuter	Snow Staring	Snow Ending	Fall	Tendency	weekday accidents	
Impact Date	Hour	Hour	(cm)	Туре	for month	
17 October 2006	1500 LT 16 October	1400 LT 17 October	10.16	All-Above	5%	
30 October 2006	1300 LT 29 October	0700 LT 30 October	5.08	Above-To-Below	24%	
10 November 2006	1700 LT 29 November	0400 LT 10 November	10.16	All-Below	0%	
28 November 2006	1400 LT 27 November	0600 LT 28 November	10.16	All-Below	6%	
29 December 2006	0900 LT 29 December	0000 LT 29 December	10.16	Above-To-Below	16%	
11January 2007	1700 LT 10 January	0900 LT 11January	10.16	Above-To-Below	27%	

 Table 2. Light snow events where road temperatures dropped from above freezing to below freezing during the event. Events are from Billings, MT during the winter of October 2006 - January 2007.

5. SPECIFIC CASES

5.1 Case 1 - 17 October 2006 and 30 October 2006

Two snow fall events meeting the defined criteria for analysis occurred in October 2006; 1) 17 October 2006 where 9.1 cm of snow fell and 2) 30 October 2006 where 5.6 cm of snow fell. Since these events occurred just two weeks apart with similar sun angles and road temperatures at the event onset, yet drastically different accidents statistics were reported for the morning rush, it is worth comparing these two events (Table 2).

In the first event, the precipitation started as rain on the morning of 16 October 2007, transitioned to a mixture of rain and snow early in the afternoon, and then turned to all snow by mid-afternoon (Fig. 3). The snow persisted overnight and until early afternoon the next day. It is important to note that this encompassed the morning traffic rush on 17 October. Around 5 cm of snow was reported by 0700 UTC 17 October 2007 (midnight LT) with half of that snow likely falling when air temperatures were around 0°C. An additional 4 cm of snow fell through the early morning hours when air temperatures fell to around -1°C.

In the 30 October event, the 5 cm of snow fell in a 6 hour time period from 0000 to 0600 LT (Fig. 4). The precipitation started as snow with air temperatures around 0°C, but fell below -5°C when the snow ended at the onset of the morning traffic rush. This left the bulk of the morning rush free from snowfall. While air temperatures between the two events were not drastically different, the road temperature tendency was noticeably different.

In the 17 October case, MYRB road and air temperatures were 9 to 9.5°C when the rain started around 0700 LT. Because of a moderately high sun angle, MYRB road temperatures warmed 1°C through late morning despite the rain and cooler air temperatures. Air and road temperatures then dropped to 1.1 °C and 3 °C respectively by 1800 LT in response to a cold front. The air temperatures fell to -1.7°C 0600 LT on 17 October, but sensible heat flux up to the pavement from the sub-surface helped

Fig 3. Temperatures from the Air, Road, and Sub-Surface sensors at Yellowstone Bridge 16-17 October 2006. Shading indicates precipitation in the form of rain (green) and snow (blue).

Fig 4. As in Fig. 3 except for 29-30 October 2006.

keep the pavement at the west bound sensor just above freezing. The MYRB road temperatures remained just above freezing through the morning commuter rush, except for a 30 minute window from 0545 to 0615 LT and a 15 minute window from 0815 to 0830 LT on the east bound bridge (Fig. 2).

This allowed for untreated road surfaces to remain primarily wet with ice possible on bridges and overpasses.

On 29 October, MYRB air road temperatures were near 22°C and 27 °C at 1400 LT prior to a strong cold front passage. As cooler air ushered in behind the cold front, air temperatures dropped to 0 °C around 0030 LT 29 October when snow began to fall. MYRB road temperatures at this time were 2.5°C on the east bound bridge, but 4.5 °C on the west bound sensor just east of the bridge. This difference is likely a result of heat flux up from the sub surface to the west bound lanes that is bridge. absent the The on road temperatures remained above freezing until around 0300 LT at the east bound bridge sensor and until 0430 LT at the west bound sensor, allowing for 3 to 4 hours of melting on the road surface. By 0600 LT, near the start of the commuter traffic, east and west bound sensors were -3.8 °C and -1.1 °C respectively. As a result, the snow that melted on the road re-froze on untreated roads prior to the morning rush.

Another potentially important factor preventing ice from forming on 17 October 2006 may be related to the amount of liquid that fell between the two cases. 20.8 mm of liquid was reported at KBIL on 16-17 October 2006 while only 3.3 mm of liquid was reported on 30 October 2006. Because a relatively high amount of liquid was introduced to the road surface and numerous puddles likely formed, more energy would need to be released in the cooling process due to the high specific heat of water, thus slowing the cooling. It is also possible the release of latent heat as ice formation initiated also helped prevent temperatures from dropping below 0°C on 17 October 2006. This may explain why road temperatures fell to 0°C and hovered for several hours on that day. Also worth noting is the small period of time when road temperatures hovered near 0°C on 30 October 2006. Perhaps, because there was less liquid introduced to the road surface on 29-30 October 2006, ice was able to form quicker.

5.2 Case 2 - 28 November 2006

On 27 November 2006 a cold air mass was in place with maximum air temperatures around -6°C. The cold air mass had been in place since 25 November and as a result the sub-surface temperature at MYRB was a cold -0.5°C. With this event occurring near the winter solstice, solar heating only warmed westbound lanes at MYRB to -1.4°C and eastbound bridge lanes to -2.7°C at the time of peak sun angle (Fig. 5). Thus, snow that falls in this regime would not be able to melt and refreeze on untreated road surfaces, regardless of the time of day.

A light snow started around 1600 LT on 27 November 2006 and continued until around 0700 LT on 28 November 2006 (Fig. 5). A total of 10 cm of snow fell during this event. The snow to liquid ratio was around 30 to 1, which made for a very light snow that could be blown off the main part of the road and to the shoulders by traffic. This is especially true of faster moving traffic such as on a major highway or interstate.

The number of accidents during the morning rush on 28 November 2006 was typical of any given weekday (Table 2). Just six percent of the morning rush accidents for the month occurred on this day, which is just slightly above the average of four to five percent for weekdays in November 2006.

Snow started to fall in the late afternoon when road surface temperatures are typically near peak values and above freezing due to solar heating. Yet this case is somewhat rare since on this day the road temperatures remained below freezing. A comparison of westbound pavement temperatures with eastbound bridge temperatures shows the eastbound bridge lanes did not warm as much as the westbound lanes. This is likely because the

Fig 5. As in Fig. 4 except for 27-28 November 2006.

eastbound bridge lanes were radiating heat from both above and below. Meanwhile, the subsurface was adding heat to the pavement in the westbound lanes. However, the amount of energy was not enough to over come the -6 to -8° C air temperatures and warm the pavement to above freezing. As a result, this event resulted in primarily snow packed roads. Had this event occurred in the beginning of November, when solar heating was stronger and sub-surface temperatures likely warmer, this may have been an Above-To-Below snow event with more accidents rather than an All-Below event.

5.3 Case 3 - 29 January 2007

In the week prior to this event, the weather was dry with above freezing davtime temperatures. This resulted in clear and dry roads for commuters. Due to the time of year though, 10 cm ground temperatures were only 0.5°C. On 29 January, the skies in Coeur d'Alene area were dominated by low overcast all day. Light snow began around 1330 LT and continued for about 5 hours, persisting through the evening commute. Air temperatures throughout the day ranged from -4.4 to -1.7°C.

Figure 6 shows the location of 3 road sensors in the Coeur d'Alene, ID area. All sensors show that despite the dense overcast cloud cover and the sub-freezing air temperatures, the incoming solar radiation was able to warm the pavement temperatures to slightly above freezing by 1300 As the snowfall event began, LT (Fig. 7). pavement temperatures cooled below freezing. In part this cooling was likely due to the normal diurnal cycle. Road temperatures on the day before and after this event also recorded a maximum temperature at 1300 LT. But latent heat flux due to melting the snow was likely in part responsible for the 1 to 1.5°C drop between 1300 and 1400 LT. As the pavement cooled below freezing, the snowfall, which initially melted, froze to the road surface. The total snowfall for the event was only 4.6 cm, which did not even warrant the issuance of a snow advisory according to local criteria.

Analysis of accident statistics for this event illustrates the impact it had on the evening commute. The average number of accidents in the area (excluding weekends) from December 2005 to January 2006 was 8.1. On 29 January 2007, more than 19 accidents occurred, which is similar to much heavier snowfall events.

Fig 6. Map of the Coeur d'Alene, ID area showing the location of the three Department of Transportation weather sensors. Also shown is the location of the Coeur d'Alene airport AWOS observation.

Fig 7. 28-29 January 2007 air and road temperatures from Pleasant View, ID road sensor along with road temperatures from Veterans Bridge, ID and Liberty Lake, WA road sensors. Interpolated values, because of missing data, is plotted in a thinner line. Blue Shading indicates snow fall.

The critical factor is the timing of the snowfall event. If this event had occurred during the night or morning hours, pavement temperatures would have been sub-freezing and no initial melting would have occurred. If the air or ground temperatures had been considerably colder, it is likely that the solar radiation would have been unable to warm the pavement above the freezing mark.

5. SUMMARY

Separate analyses of snow events in Billings, MT, across eastern Washington, and north Idaho indicate that the type of event plays a large role in traffic accidents. In all locations, snow events that started with road temperatures above freezing and then fell below freezing while the snow fell had the highest number of accidents; two to four times more than an average day. Meanwhile, events with pavement temperatures that remained above freezing or below freezing had a lower number of accidents, which was comparable to a normal day without snowfall. Thus, it seems the formation of ice can be a more important factor impacting traffic than the amount of snow for light snow events. It also appears that while wet or snow-packed roads create less than ideal traveling conditions, these conditions do not make travel so hazardous that there is a sharp increase in the number of accidents reported such as on the icy roads created during Above_To_Below events.

Initial investigations, not specifically mentioned in this paper, indicate perhaps that mid-winter snow events without strong cold frontal passages which start around peak solar heating may produce the most widespread and least difficult to forecast Above-To-Below events (e.g. 29 January 2007). This is partly because the time of peak solar heating in mid-winter would most commonly produce above freezing road temperatures with below freezing air In these situations, road temperatures. temperatures could be anticipated by simply analyzing air and road temperature trends from previous days and even weeks. Another scenario that may be less difficult to forecast are fall or spring, night time events with a strong cold front passage resulting in significantly below freezing air temperatures (e.g., 30 October 2007). freezing prior to a strong frontal passage. However, soon after frontal passage, air and road temperatures would be quick to drop below freezing; leaving a short window in which post-frontal snow could melt on contact with the pavement. Onset of snow events late in the afternoon or early evening could make it even harder to anticipate since road temperatures would already be falling in response to sunset, creating an even shorter period in which road temperatures could be above freezing when the snow starts. Cold sub-surface temperatures in mid winter would further aid the rapid drop of road surface temperatures.

The number of cases analyzed thus far is limited and certainly more events will need to be considered in order to gain a better understanding the impact different types of snow events have on travel. In addition, more cases will allow for a development of a climatology of the different type of snow events, so that the most common scenarios that result in the three types of snow events could be known. This information will also help improve the ability to recognize and anticipate the higher impact events that are more easily forecast. This is a major goal of this project since many forecasters have not specifically attempted to forecast the impact of snow has on travel.

It is important to note that the results of this study will likely not describe all high impact light snow events. This study purposefully looked at

multiple locations with a fairly high frequency of snow events to see if there would be a difference in the type of events. As demonstrated, there was not a difference in the impact on travel for Above-To-Below events versus All-Above or All-Below. However, there was a difference in the weather regime in which the Above-To-Below events most commonly occurred. For example, in eastern Washington and north Idaho many Above-To-Below events were associated with daytime snow events with slowly falling temperatures while around Billings greater prefrontal warming resulted in a similar number of nighttime and daytime Above To Below events. Other locations may experience a different type of snow event that also has a significant impact on travel. One such example may be light snow events that fall in a one or two hour period of time with above freezing road temperatures. The snow rates in these instances may be able to overcome melting of snow, leaving the road surface covered with a wet and very slick snow. Clearly, further studies will need to be conducted to better understand the variety of high impact snow events that can occur so that meteorologists can better identify and forecast true high impact events.

6. REFERENCES

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